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REPORT ON RESEARCH FINDINGS RELATED TO SUBTIDAL GEODUCK AQUACULTURE

Prepared for
Washington State Department of Natural Resources

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March 31, 2004

INTRODUCTION

In 1970, a subtidal fishery on wild stocks of geoduck clams (*Panopea abrupta*, Conrad 1849) was initiated in Washington State. The fishery has since evolved to be highly lucrative both to the citizens of the State of Washington, and to fishers due to market demand from Asia. Natural recovery of fished areas to pre-exploitation levels has been slow, ranging between 11 and 73 years (2001 Final Supplemental EIS, Appendix 2), possibly owing to both the low natural mortality (M=0.023, Bradbury and Tagart 2000) and low recruitment rates in this long-lived clam. In 1982 Washington Department of Fisheries (WDF, now Washington Department of Fish and Wildlife, WDFW) expanded a geoduck hatchery program to accelerate recovery of fished beds via subtidal seeding.

Attempts at juvenile geoduck broadcast seeding onto subtidal fished beds are numerous, but resulted in no documented successes. One trial included the blanket distribution of 25,830 juveniles (mean length 15.9 mm) from the surface along each of three 46 m transects set at 6.7, 9.4, and 12.8 m Mean Lower Low Water (MLLW). Another trial included the high density distribution of 10,000 juveniles released from the surface at each of 14 buoyed sites located at 4.4, 9.1, and 11.9 m MLLW in a 32 m grid. In this trial, dispersion and burial rates were measured 34-155 min after release. Two of these buoyed sites were subsampled two years later to gauge planting success. Five one m^3 quadrats were excavated, but no geoducks were recovered (unpublished data). An associated concurrent experiment examined the burial rates of juvenile geoducks by counting the number of broadcast seeded juveniles in replicate patches that had buried themselves at 5 min intervals over a one hour period. Approximately 50% of juveniles were buried 20-60 minutes after seeding (Fig. 1, Don Rothaus, WDFW, unpublished data). Notes from the various broadcast seeding trials suggest that the generally poor success of the broadcast planting methods were likely a result of intense predation. Alternatively, low seed quality and inability to reach burial refugia may have precluded predator avoidance.

In 1991, WDF pioneered predator exclusion for geoduck seed on intertidal plantings at four sites in Puget Sound using PVC tubes with plastic netting. Concomitant subtidal planting trials of alternative predator exclusion devices were also initiated by WDF. These subtidal trials achieved some successes, and are the primary subject of this report. Briefly, four subtidal plots between 5.6 and 7.6 m MLLW were seeded with juvenile geoducks with mean shell length of 16.8 mm during late 1991 and 1992. The treatment groups were planted in groups of three paper mache tubes, with the control groups planted directly on the substrate (no tube). While the100% gravel and 100% mud substrate sites experienced high mortalities, the mean survivorship of 19.4% from sites with 100% sand and 50% sand / 50% mud substrates are indicative of the potential success of subtidal planting.

MATERIALS AND METHODS

Geoduck seed were produced at the WDF Pt. Whitney Shellfish Lab in Brinnon, Washington in 1992. Subsamples of 100 juveniles from each site were measured for shell length (overall mean length 16.8 mm, Table 1). Three 9 x 9 m and one 8 x 9 m trial plots at approximately -7 m MLLW water depth were each planted with an equal number of treatment and control groups in 1 m^2 grids. Substrate composition varied among sites, from 100% mud to 100% pea gravel (Table 2). Each treatment group (gang) consisted of three connected paper mache truncated cones (tubes): 3.5 cm top and 5.6 cm base diameters and 20.3 cm tall. Treatment groups were planted with three juvenile geoducks per tube, yielding a total of nine juveniles per treatment group. Using SCUBA, divers buried the tubes in a vertical orientation leaving approximately 2 cm of the narrow end exposed above the substrate. To test for orientation effects on survivorship or growth, gangs were placed at 90° alternating orientations (parallel either to rows or columns) throughout the grid. The control groups received no paper mache tubes; groups of nine juvenile geoducks were planted at the same depth, density, and orientations as the treatments but were placed directly in the substrate. A 2 m wide buffer between treatment and control zones received no treatment.

Each site was revisited approximately one month after initial planting (Table 2) to visually monitor site status and make any notations on obvious predation and presence of juvenile geoduck siphons in individual tubes and control areas. After approximately one year, the sites were quantitatively evaluated. For each sample, approximately 0.0625 m^3 of substrate was removed in a 0.5 x 0.25 x 0.5 m (LxWxD) swath using a venturi dredge equipped with 0.6 and 1.3 cm mesh screens to collect surviving geoducks. Differences between terminal valve length and the last growth check on the valve, assumed to be the shell length at planting, were used as a proxy for growth.

In addition to geoducks, benthic macrofauna recovered in each sample were also quantified, including other species of infaunal clams, gastropods, and crustaceans (Table 3). Also recorded was the presence of various worms and other organic material, such as shell, woody debris, macroalgae, and leaf litter.

Statistical analyses

The factors investigated in this pilot study included tubes, sites, tube set orientation, edge effects on survival and growth, and density (survivorship) effect on growth.

For each site, survivorship and growth values were resampled 10000 times with replacement to obtain bootstrapped means. Confidence limits (95%) were computed using the Bias Corrected and accelerated method (BC_a) of Efron and Tibshirani (1993), using the statistical software package S-PLUS 2000 (ver. 2, ©1999, Mathsoft, Inc).

RESULTS

Inspection

After less than one month, Site C (100% pea gravel) had numerous unbroken juvenile geoduck valves, a signature characteristic of shrimp predation, both within and adjacent to the planting site. Overall survivorship of juvenile geoduck at Site C was zero after 10 days and the site was excluded from further analyses.

The remaining sites (A, B, and D) appeared in good condition on the first visit. Paper mache tubes had retained their shape, and geoduck siphons or their depressions in the substrate were visible in many cases. Presence of a few predators was noted, but predation did not appear problematic (except, as noted above, at Site C). Site B had not been fully planted initially due to low numbers of available geoduck seed; planting at Site B was completed during the subsequent inspection work.

After one year, cone condition varied greatly between sites. In some cases, the binding agent had dissolved but the paper fibers were intact. In other cases, anaerobic decomposition had progressed, and the only remains of the tubes were black detritus. In the sandier substrates, many of the tubes were recognizable and in earlier stages of decay. At Site A, juvenile geoducks were occasionally found below the sampled depth (0.5 m). As a consequence of these depths, some juvenile geoducks at Site A may have been missed by the sampling method.

Survivorship

Sites A, B, and D achieved 18, 1, and 21 percent survivorship in the treatment groups, respectively, compared to 1, 0, and 2 percent survivorship in the respective control groups. Variation in the treatment groups was high: after one year, survivorship per treatment group of three tubes (nine geoducks) ranged from zero to six geoducks (0%-67%), whereas survivorship in the control groups was consistently low and did not exceed one individual (11%) per set of nine geoducks.

A clear effect of tubes on survivorship was observed only at sites A and D ($P < 0.0001$). The effect of treatment site on survival was significant with Site B included ($P < 0.0001$), but nonsignifcant between Sites A and D (Fig 2). Comparing just Sites A and D, neither tube set orientation nor edge effects (Fig 2) were significant.

Growth

At all three sites (A,B,D), mean valve length at T=1 was greater than the mean check length estimate of length assumed to represent T=0 ($P<0.001$). Significant differences were also observed between the growth check mean and the mean of the subsampled valve lengths at T=0 ($P<0.001$) at all three sites (Table 1).

The effect of treatment site on growth rate was significant ($P<0.0001$, Fig 3) and appeared to be correlated with survivorship (R square 0.97) although the relationship was not significant (Fig. 4).

Other fauna

At Site A, the overall mean density of bivalves (excluding geoducks) was 4.2 clams/sample (0.0625 m^3) in the treatment zone and 2.9 clams/sample in the control zone (Table 4). Clam densities did not differ between treatment and control zones (T-test; $P>0.05$). The four most frequently occurring species were *Thracia trapezoides*, followed by *Macoma secta / Thracia* sp. (the clams were recorded together due to difficulties distinguishing between the two species), *Macoma secta*, *Solen sicarius*, and *Thracia beringi* (Table 4). In addition to bivalves, moon snails (*Polinices lewisii*) were recovered from samples taken in the treatment zone (n=2) and in the control zone (n=3), as well as one red rock crab (*Cancer productus*) in the control zone. Unidentified tube worms, polychaetes, and other worms were noted in 68% of samples from Site A.

At Site B, there was a significant difference in non-geoduck clam abundance between the two zones (T-test, $P<0.001$). The mean density of non-geoduck bivalves was higher in the treatment zone (10.4 clams/sample) than in the control zone (7.6 clams/sample, Table 4). *Macoma nasuta* exhibited the highest densities (8.8 and 6.6 clams/sample in treatment and control zones, respectively), followed by *Lucina annulata* (1.6 and 0.8 clams/sample in treatment and control zones, respectively). One *Cancer gracilis* as well as four *Crangon* sp. were recovered from the control zone. Polychaetes or other worms were rarely noted, occurring in only 3% of the samples within the experimental array. Woody debris and/or shell (principally oyster shell) were present in 71% of samples from Site B.

At Site D, the mean density of non-geoduck bivalves did not differ between the treatment (1.1 clams/sample) and control zones (1.4 clams/sample) (P>0.05, Table 4) with *Macoma incongrua* the most prevalent species. Two *Cancer gracilis* and one *C. magister* were recovered from the control plot. Burrowing ghost shrimp *Neotrypaea californiensis* (formerly *Callianassa californiensis*) were present in 78% of samples from Site D, with similar mean densities of 1.2 shrimp/sample in the treatment zone and 2.1 shrimp/sample in the control zone (P>0.05). Divers also noted the presence of nereid poychaetes, tube worms, and/or shell hash (*Macoma* shell) in 71% of samples taken in the treatment zone but in only 6% of samples from the control zone.

DISCUSSION

The results of this study demonstrate the potential for subtidal geoduck aquaculture, and highlight the need for further experimental work to examine planting and growout methods that result in improved seed performance. Survivorship varied greatly among sites, from 0-21%. A significant difference in growth rate was detected among sites. While not statistically significant, there appeared to be a positive correlation between survival and growth. Survivorship-growth correlations have not been tested in intertidal studies of geoduck clams. In this subtidal study, mean annual growth varied between 20.33 and 43.54 mm which is within the range previously reported byAndersen (1971) and Goodwin (1976). Average growth rates at Sites A and D appear greater than those modelled by Von Bertalanffy parameters estimated by either Andersen (1971) or Hoffmann *et al.* (2000) (Fig. 5). Average growth in the present study was calculated as the difference between size at T=1 and an estimate of size at T=0 via growth check measurements at T=1. At all three sites, mean size at T=0, based on a random sample, and the estimated size at T=0 of the survivors were significantly different (P<0.001 at all three sites). The most plausible explanation for the difference is that growth check measurements are biased upward. The alternate explanation, attributing the difference to survival bias of larger seed, is less likely since the 95% confidence limits for the growth check and original measurements do not overlap. Thus, the estimates of size at T=0 would result in underestimate growth. In either case, the growth values for sites A and D appear to be greater than values from previous work and highlight the need for further investigation of subtidal growth.

The utility of narrow top predator exclusion as used in this trial is not clear. It was thought that the narrow (3.5 cm) top openings of the tubes used in this study would exclude predation by *Cancer sp.* and Asteroidea predators, whereas current intertidal aquaculture methods use tubes with 8 to 10 cm diameters which necessitate the use of netting. Given the higher survivorship in the tube planted zones, the tubes clearly afforded some protection. Although the lack of predator exclusion netting precludes any direct comparison with intertidal geoduck tube planting, these preliminary results warrant a planting trial comparing intertidal and subtidal growth and survivorship.

While survivorship (approximately 20%) was acceptable and appears promising, it was not optimal in this trial. There are a number of possible explanations for the low subtidal tube survivorship relative to current intertidal tube planting practices. First, the seed used was produced in the relative infancy of geoduck aquaculture, so seed quality may have been lower than currently produced seed. However, survivorship at the four concomitant intertidal plantings of juveniles during the same period was 20%-70% (mean 40%) after one year (Beattie, 1992), suggesting reasons other than seed quality for the low survivorship. Second, the seed used in the present trial averaged 16.7 mm shell length, much larger at planting than the 5-7 mm seed used in current intertidal geoduck aquaculture. Survivorship is positively correlated with size, providing larger seed an advantage over smaller seed. On the other hand, digging speed is negatively correlated with size. In the search for an optimal method, the aquaculture industry may move toward planting seed in the 8-10 mm range (J.P. Davis, Baywater Inc., personal communcation). Current intertidal seeding practices result in approximately 75% survivorship, assuming good seed quality (J.P. Davis, pers. com). A third explanation for the lower survivorship in this study than with current intertidal practices is that planting season, tube length, diameter, and spacing in the subtidal planting trials all differ from current intertidal practices, and there may have been negative effects of the paper mache tubes on geoduck growth and survivorship. Fourth, predator exclusion netting was not used in these trials. Beattie (1992) investigated the effects of predator exclusion netting in intertidal geoduck planting, and found significantly higher survivorship in netted tubes. Fifth, subtidal seed are continuously exposed to predation; intertidal seed may experience some reprieve during low tide. Finally, site characteristics such as primary productivity, depth, temperature, salinity, current flow, sediment type, etc. are likely important factors in survivorship. Whether the larger shell length, seed quality, planting methodology, or sites used in the trial adversely affected survivorship merits further investigation.

This study sheds some light on the suitability of substrate type for tube planting. Adult geoducks are seldom found at high densities in 100% mud substrates, an observation supported by the high mortalities at Site B (REF). Wild geoducks are found in 100% pea gravel substrates, but the highest geoduck densities generally occur in 100% sand and mixed sand with other substrates. This generalization is supported by the greater survivorship at Sites A and D.

Benthic species composition varied among the three subtidal sites. Infaunal bivalves co-occurred with planted geoducks, but sites differed with respect to species composition and number of species present (Table 4). Burrowing ghost shrimp were present in samples taken at Site D but not at Sites A or B. The effect of burrowing shrimp on geoduck seed survival and growth has not been examined as far as we know, but studies have shown that the disturbance resulting from the shrimps' burrowing and feeding activities in some cases can, in some cases, restrict community composition to species that are able to withstand the perpetual bioturbation and sediment turnover (Posey et al. 1991; Dumbauld et al. 2002). At the sites A and D where geoduck seed exhibited the highest survival, unidentified tube worms, nereid polychaetes, and other worms were prevalent in the treatment zones. Chaetopterid polychaetes have been positively correlated with geoducks in other studies and may provide a settlement cue for settling geoduck larvae (Goodwin and Pease 1987). Moon snails and cancrid crabs, also present in venturi samples, have been shown to prey on geoduck seed (Beattie and Blake 1989).

An important question that should be addressed in subsequent subtidal and intertidal geoduck seeding experiments is how do planted geoducks affect species diversity and abundance of other benthic organisms? The data that were collected in this experiment are valuable and highlight interesting differences among sites but cannot be used to answer this particular question since no benthic samples were collected in treatment and control zones prior to outplanting geoduck seed. Any differences that exist between treatment and control zones may have existed prior to seeding. Also, given the potential for subtidal geoduck culture, it would be beneficial to conduct further studies that examine the spatial and temporal distributions of geoduck predators and how best to protect seed from predation.

The planting trials were designed to allow the eventual mechanization of subtidal planting, if success could be demonstrated. A planting device could be developed to automate the distribution and burial of the tubes. The use of paper mache tubes, with some design refinements, potentially mitigates the necessity of tube removal and retrieval. At all sites the paper mache decomposed to some extent during the trial. A biodegradable cotton or jute mesh/screen for predator exclusion might bring survivorship in subtidal plants in line with intertidal survivorship. The timing of tube decomposition and the effects of paper mache tubes on geoducks and the benthic community structure have not been investigated, but owing to the relative success of this project merit further investigations and modifications of this method.

FOLLOW - UP

An additional subtidal planting trial in Dabob Bay near Camp Discovery was initiated in September and October of 1994. This trial differed significantly from the first trial. Tubes were filled with sand and seeded in the hatchery, and racks of seeded tubes were staged at the dive site prior to planting. A total of 4,500 juvenile geoducks (mean valve length 12 mm) were planted in rectilinear cardboard columns (tubes) measuring 5 x 5 x 30.5 cm. These tubes were open at the ends along the long axis. The tubes were pre-filled with sand and five juvenile geoducks. Three 50 m transect lines set parallel to shore were established 20 meters apart. Six tubes, 0.4 m apart, were placed every meter in centered rows perpendicular to each transect line. Thus, a total of 900 tubes were planted (300 per transect line).

In the same period and locale, 1500 juvenile geoduck were planted under each of four 10 x 3.33 m sheets of 1.3 cm mesh. The edges of the nets were buried 30 cm to prevent predator ingress, and the nets were float-suspended 30 cm from the substrate.

The site was revisited 1.5 years later (April, 1996) for a quick assessment. For the tube plantings, geoducks from four randomly chosen tubes were measured for length and weight. Of the original twenty 12mm geoducks planted in these tubes, thirteen survived (65% survival). The average length and weight were 37.8 mm (34.1-41.3) and 12.2 g (9.4-15.2), respectively. Three mortalities were also found with valve lengths of 24, 32, and 36 mm. For the netted sites, nets were cut along their perimeter and removed to prevent fouling, under the assumption that surviving geoducks were buried deep enough to avoid predation. The buried sections of netting were left *in situ* to mark the boundaries of the plantings. The Dabob Bay-Camp Discovery site has neither been revisited nor assessed since 1996.

In the Camp Discovery study, time logs were kept to track hours spent preparing, seeding, and planting the tubes. These logs are quite comprehensive, and comprise hatchery personnel taping tubes, filling tubes with sand, and pre-seeding; dive personnel loading, unloading, and tending the boat; diver suitup and dress down, gear wash, cylinder fills, and logged dive times. Including startup inefficiencies, it took approximately 107 hours to prep, seed, and plant 746 tubes or 3,730 geoduck seed. This rate of 7 tubes/hour increases to 9 tubes/hour when startup and equipment failure data are excluded.

SUMMARY

A subtidal planting trial of juvenile geoducks, conducted during 1992, produced some compelling results, including ~20% survivorship in biodegradable tubes, in the absence of predator exclusion netting. Growth was significantly different between sites and may have been correlated with survivorship; growth in the two best sites appears to exceed expectations from the Von Bertelannfy growth models. A second subtidal planting trial initiated in 1994 has not yet been fully evaluated. Based on preliminary data from a very small sample of the 1994 tube plant trial, survivorship was ~ 65% and average growth was ~25.8 mm over 1.5 years.

RECOMMENDATIONS FOR FUTURE STUDIES

1. Conduct a full survey of the Dabob Bay/Camp Discovery trial to fully evaluate 10 year survival and growth in the square tube geoduck planting method.
2. Investigate survivorship, growth, and digging ability of different size seed to arrive at optimal planting sizes for intertidal and subtidal aquaculture.
3. Explore the use of substrate type and/or tube worm characteristics to identify portential pilot study sites.
4. Evaluate different types of predator exclusion devices (PVC, degradable tubes, netting, etc.) at selected study sites.
5. Determine how planting and harvesting geoducks affects species diversity and abundances of other benthic organisms.

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Table 1. Valve lengths (mm) for subtidal plants of *Panopea abrupta* juveniles at four sites with 95% BCa confidence intervals (brackets).

Site	Final check	T=0	T=1 year	Growth
Long Spit (A)	19.8 (18.9-20.7)	17.2 (16.3-18.4)	57.6 (53.7-59.9)	37.2 (32.7-39.6)
Quilcene (B)	17.3 (16.7-18.0)	15.9 (15.2-16.5)	37.7 (36.3-40.0)	20.3 (19.3-22.0)
Pt. Whitney (C)	N/A	18.8 (16.8-20.8)	N/A	N/A
Carr Inlet (D)	19.2 (18.4-19.8)	17.0 (16.3-17.7)	62.6 (61.1-64.4)	43.6 (41.9-49.9)

Table 2. Site characteristics for subtidal planting trials of juvenile geoduck, *Panopea abrupta*.

						Dates	
Location (Site)	**Substrate type**	**Area (m^2)**	**Depth (m MLLW)**	**Triplet Tubes**	**Control**	**Plant**	**Sample**
Long Spit (A)	100% Sand	81	7.6	36	36	12/16/91	12/20/92-1/5/93
Quilcene Bay (B)	100% Mud	88	7.6	36	36	1/6/92*	1/6/93-2/2/93
Point Whitney (C)	>50% pea gravel <25%mud <25% sand	81	5.8	36	36	12/20/91 12/27/91	N/A
Carr Inlet (D)	50% sand 50% mud	72	7.2	32	32	1/29/92	2/8/93-2/10/93

Table 3. A list of species and their common names found during benthic sampling of subtidal geoduck outplants.

Species Name	**Common Name**
Thracia beringi	Pacific Thracia
Thracia trapezoides	--
Macoma secta	Sand Clam
Macoma nasuta	Bent-nose Clam
Macoma incongrua	Incongruous Clam
Macoma inconspicua	Inconspicuous Clam
Solen sicarius	Western Jackknife Clam
Spisula falcata	Hooked Surf Clam
Compsomyax subdiaphina	--
Yoldia ensifera	Yoldia Clam
Tellina buttoni	Button Tellina
Saxidomus giganteus	Butter Clam
Protothaca tenerima	Thin-shelled Littleneck
Clinocardium nutalli	Nutal’s Cockle
Cryptomya californica	California Soft-shelled Clam
Lucina annulata	Western Ringed Lucina
Polinices lewisii	Moon Snail
Cancer gracilis	Graceful Crab
Cancer productus	Red Rock Crab
Cancer magister	Dungeness Crab
Crangon sp.	--
Neotrypaea californiensis	Ghost Shrimp

Table 4. Mean densities and standard deviations of benthic invertebrate species recovered from venturi sampling (0.25 m^3) taken in treatment and control zones at three sites (Long Spit, Quilcene Bay, and Carr Inlet) in Puget Sound, Washington.

Species	**Long Spit**				**Quilcene Bay**				**Carr Inlet**			
	Treated		**Control**		**Treated**		**Control**		**Treated**		**Control**	
Infaunal Bivalves	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Thracia beringi	0.28	1.00	0.11	0.67	0	0	0	0	0	0	0	0
Thracia trapezoides	1.39	1.87	1.31	1.86	0	0	0	0	0	0	0.03	0.18
Macoma secta / Thracia sp.	1.17	2.17	0.86	1.66	0	0	0	0	0.03	0.18	0.03	0.18
Macoma secta	0.44	0.84	0.22	0.48	0	0	0	0	0	0	0	0
Macoma nasusta	0.06	0.23	0.06	0.23	8.75	3.05	6.62	2.92	0	0	0	0
Macoma incongrua	0.14	0.35	0.08	0.28	0	0	0.05	0.23	0.74	0.86	0.66	0.83
Macoma inconspicua	0	0	0	0	0	0	0.03	0.16	0	0	0	0
Solen sicarius	0.28	0.57	0.17	0.38	0	0	0	0	0.16	0.37	0.16	0.45
Spisula falcata	0.03	0.17	0.03	0.17	0	0	0	0	0	0	0	0
Compsomyax subdiaphina	0	0	0	0	0	0	0.03	0.16	0	0	0	0
Yoldia ensifera	0.06	0.23	0	0	0	0	0	0	0	0	0	0
Tellina buttoni	0.06	0.23	0.06	0.23	0	0	0	0	0.10	0.30	0.34	0.6
Saxidomus giganteus	0.08	0.28	0	0	0	0	0	0	0	0	0	0
Protothaca tenerima	0.03	0.17	0	0	0	0	0	0	0	0	0.09	0.39
Clinocardium nutalli	0.03	0.17	0	0	0	0	0	0	0.03	0.18	0.06	0.25
Cryptomya californica	0	0	0	0	0.06	0.23	0.03	0.16	0	0	0	0
Lucina annulata	0.14	0.42	0.03	0.17	1.56	1.27	0.84	0.87	0	0	0.03	0.18
Total Bivalves	4.17	2.61	2.92	2.16	10.36	3.20	7.59	3.05	1.06	1.06	1.41	1.27
Gastropods												
Polinices lewisii	0.06	0.23	0.08	0.28	0	0	0	0	0.06	0.25	0	0
Crustaceans												
Cancer gracilis	0	0	0	0	0	0	0.03	0.16	0.03	0.18	0.06	0.25
Cancer productus	0	0	0.03	0.17	0	0	0	0	0	0	0	0
Cancer magister	0	0	0	0	0	0	0	0	0	0	0.03	0.18
Crangon sp.	0	0	0	0	0	0	0.11	0.31	0	0	0.03	0.18
Neotrypaea californiensis	0	0	0	0	0	0	0	0	1.16	0.90	2.09	1.87

Figure Legends

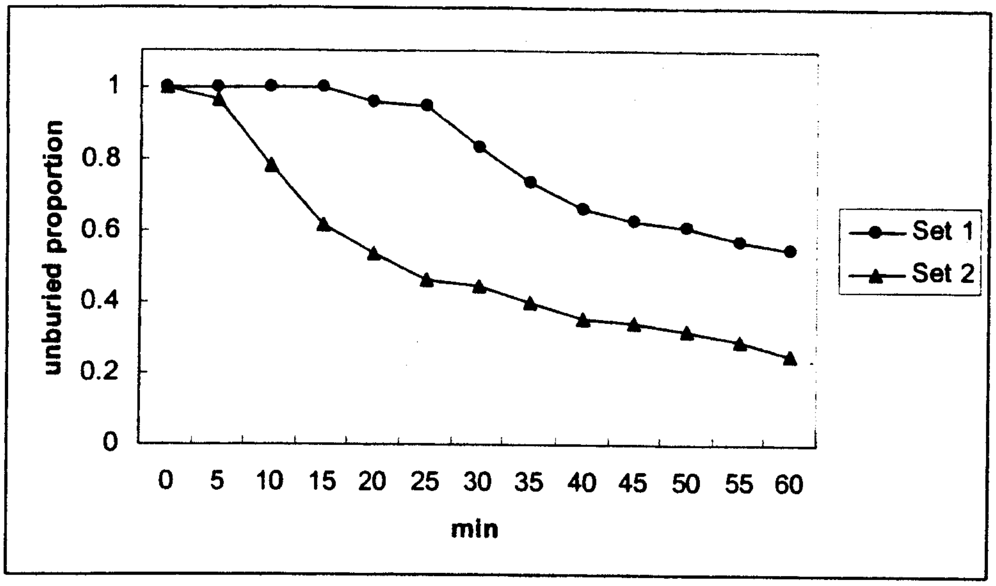
Figure 1. Mean proportion of unburied juvenile geoduck (*Panopea abrupta*) over one hour at five minute intervals for Sets 1 (●) and 2 (▲).

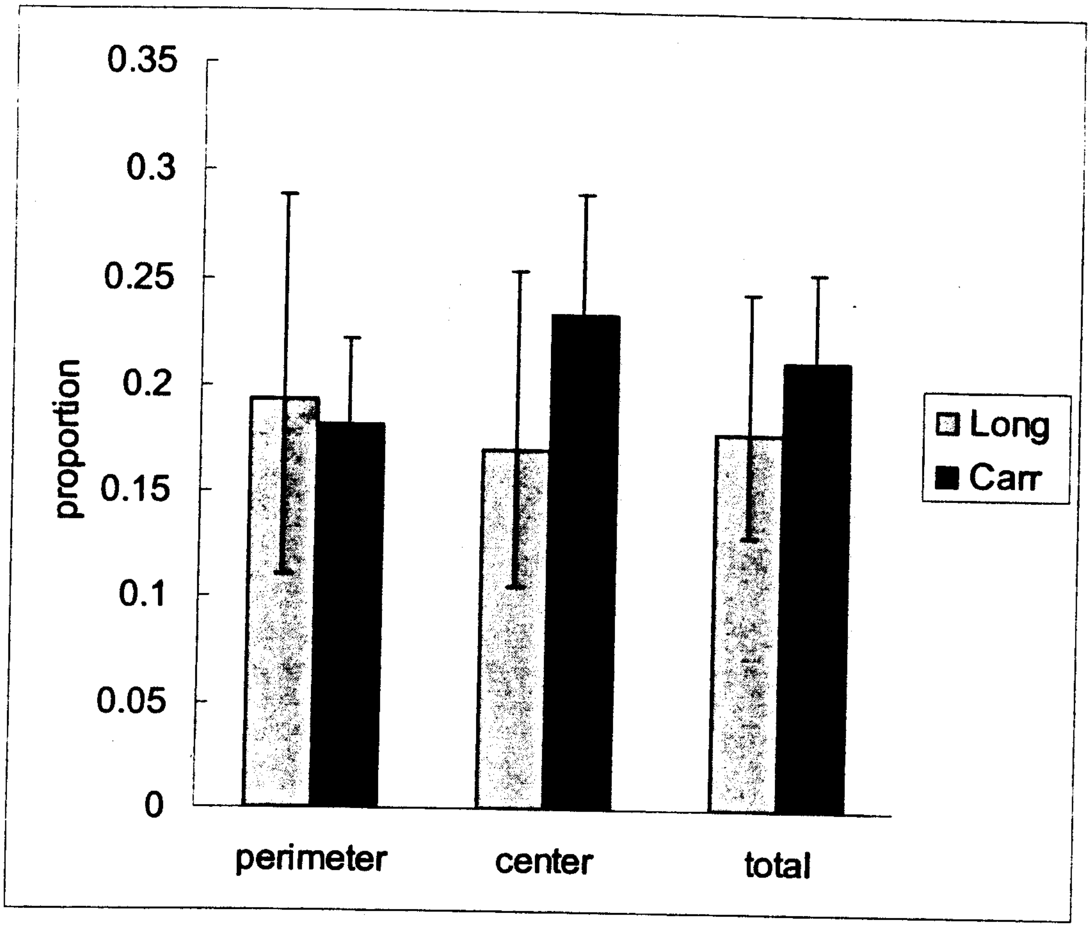
Figure 2. Mean subtidal juvenile geoduck (*Panopea abrupta*) survivorship after one year at two sites, ± 95% BC_a confidence intervals.

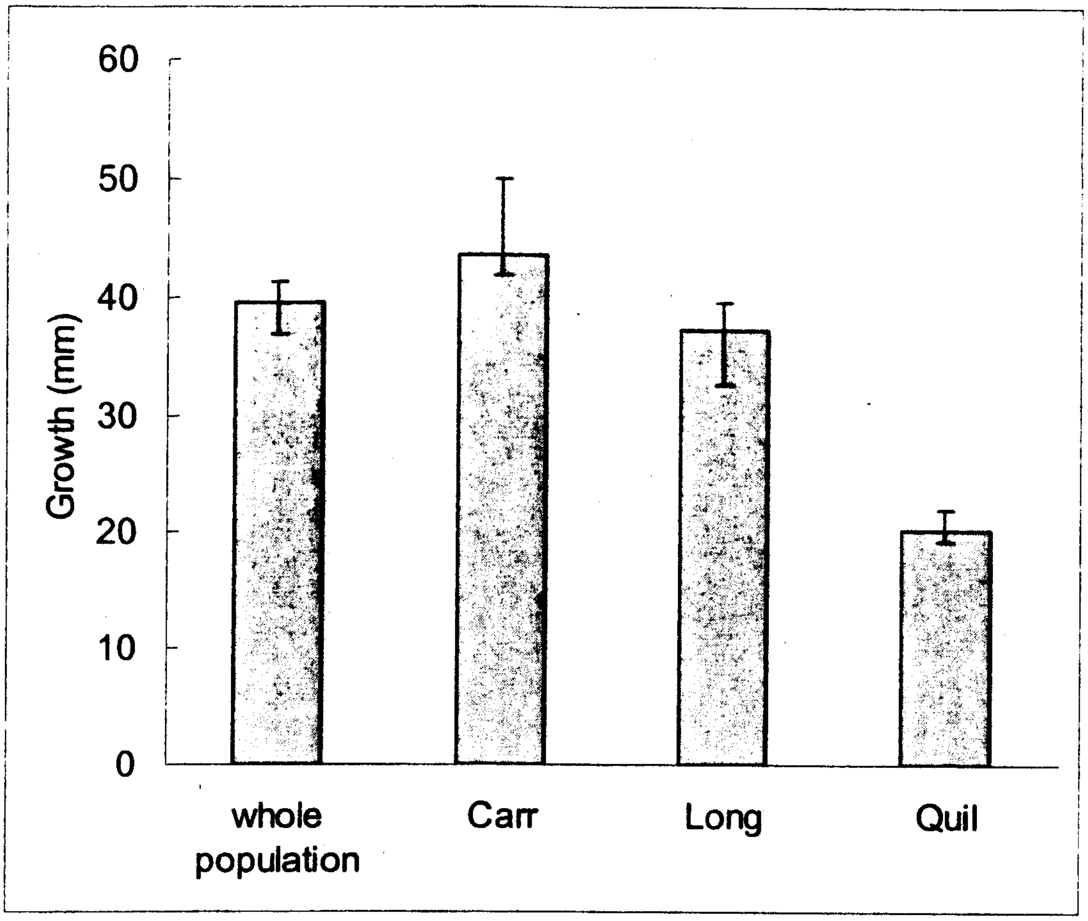
Figure 3. Mean subtidal juvenile geoduck (*Panopea abrupta*) growth during first year at three sites, ± 95% BC_a confidence intervals.

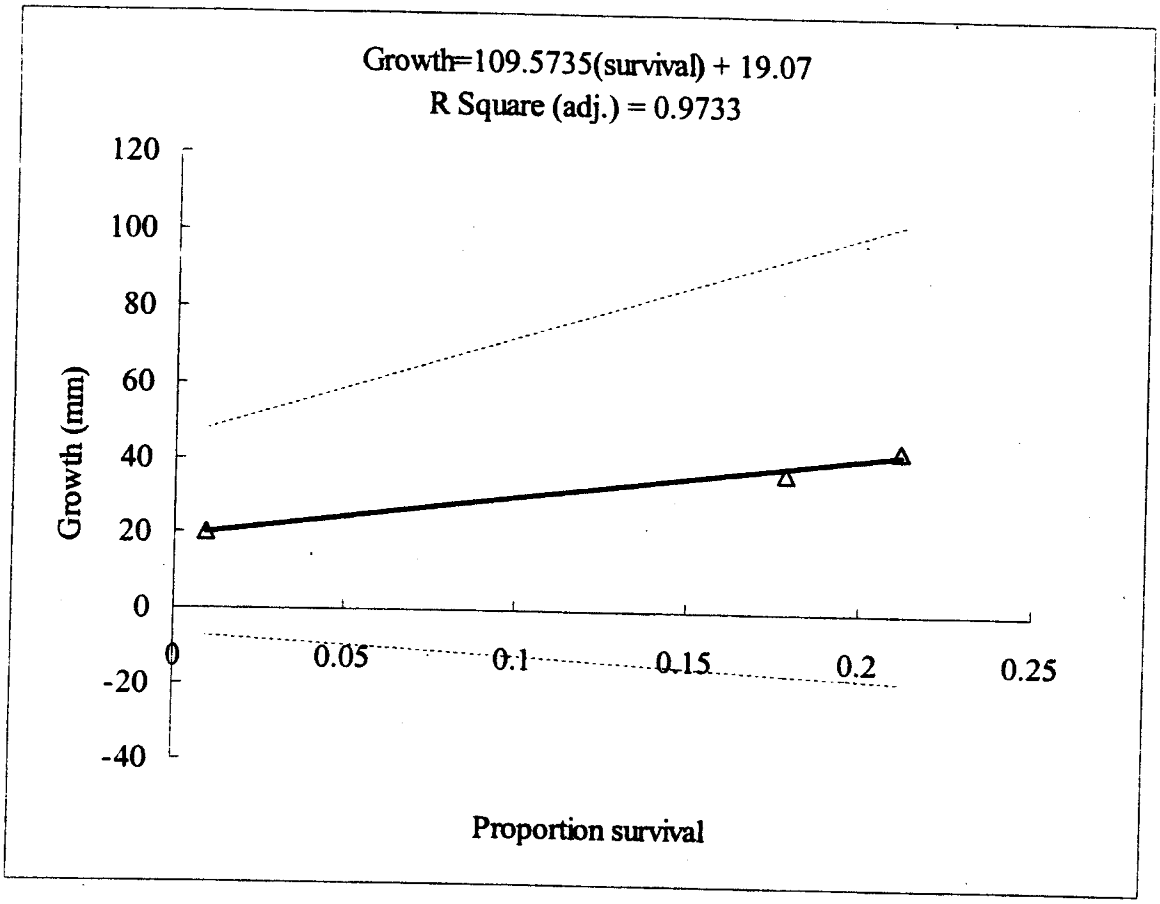
Figure 4. Regression of growth on proportion survivorship of juvenile geoduck (*Panopea abrupta*) after one year at three sites. Dotted lines indicate 95% CI for regression variables.

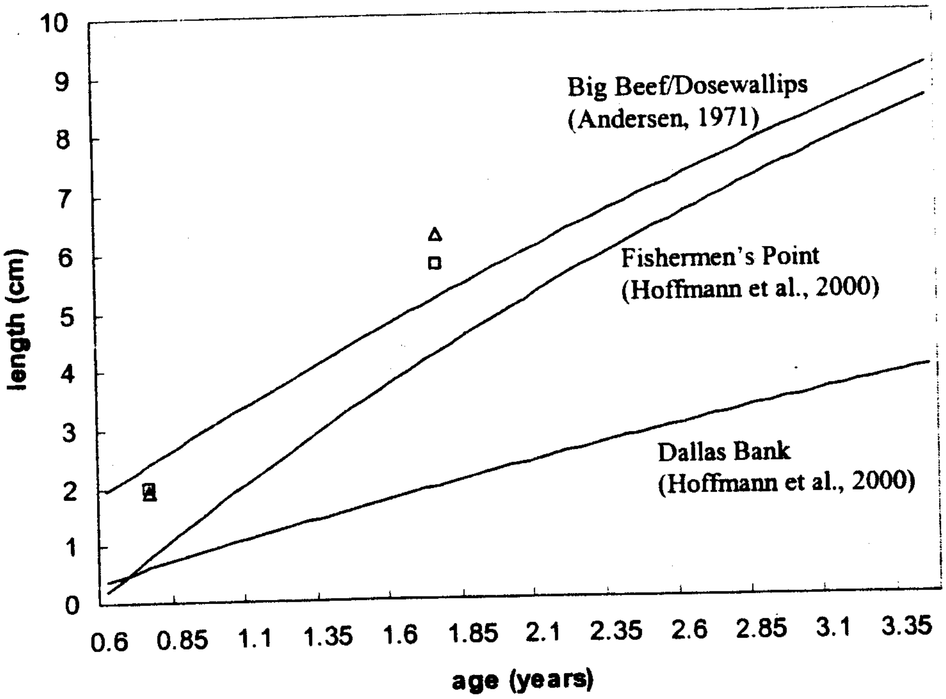
Figure 5. Juvenile geoduck (*Panopea abrupta*) growth values for Sites A (Δ) and B (□) plotted against three von Bertalannfy growth curves for geoduck growth using constants in Andersen, 1971 and Hoffmann et al., 2000.


unburied proportion
1
0.8
0.6
0.4
0.2
0
0 5 10 15 20 25 30 35 40 45 50 55 60
min
Set 1
Set 2


0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
proportion
perimeter
center
total
Long
Carr


60
50
40
30
20
10
0
Growth (mm)
whole population
Carr
Long
Quil


Growth=109.5735(survival) + 19.07
R Square (adj.) = 0.9733
120
100
80
60
40
20
0
-20
-40
Growth (mm)
0
0.05
0.1
0.15
0.2
0.25
Proportion survival


10
9
8
7
6
5
4
3
2
1
0
length (cm)
0.6
0.85
1.1
1.35
1.6
1.85
2.1
2.35
2.6
2.85
3.1
3.35
age (years)
Big Beef/Dosewallips
(Andersen, 1971)
Fishermen's Point
(Hoffmann et al., 2000)
Dallas Bank
(Hoffmann et al., 2000)