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Evaluation of the Southeastern Alaska Geoduck *(Panopea Abrupta)* Stock Assessment Methodologies

by

Christopher Siddon

March 2007

Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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ABSTRACT

The geoduck (*Panopea abrupta*) fishery in southeastern Alaska has grown dramatically over the last two decades, yet little is know about geoduck ecology. This lack of information inhibits the use of alternative methods to increase the precision of the Guideline Harvest Level (GHL). The GHL is a product of biomass estimates and harvest rate, both of which can significantly affect overall harvest. The low precision in abundance estimates has fostered concern from commercial fishermen that the GHL is too conservative. The current southeastern Alaska stock assessments is critiqued and recommendations on short- and long-term improvements provided.

A combination of stock assessment comparisons and fieldwork were utilized to evaluate the southeastern Alaska geoduck methodologies. The stock assessments from Washington, British Columbia, and Alaska were evaluated and compared. This comparison focused on transect methods, show factors, and harvest rates. The fieldwork component evaluated the merits of an alternative sampling design and examined differences between commercial, management and university divers' ability to locate and count geoducks.

The survey method used by Alaska Department of Fish and Game is statistically sound, straightforward and logistically simple. Although this method provides an unbiased estimate of abundance, it does not allow for comparisons of geoduck density among sites, nor does it allow for use of auxiliary data or stratification. In addition, annual harvest rates are not based on data specific to Alaska and the data for show factor estimates are minimal (and highly variable).

Four main areas should be focused on for improving the scientific rigor of the Alaskan geoduck fishery: 1) Modification of current transect methods to improve precision, 2) Accurate mapping of geoduck areas, 3) Increased precision of show factor estimates, and 4) Collection of biological data to produce an annual harvest rate specific to southeastern Alaska.

Key words: Geoduck, *Panopea abrupta*, Alaska, stock assessment, sampling

INTRODUCTION

The geoduck (*Panopea abrupta*) fishery has grown dramatically over the last two decades in southeastern Alaska, yet relatively little is know about geoduck biology and ecology. This lack of information inhibits the use of more sophisticated methods to increase the accuracy and precision of Guideline Harvest Limits (GHL). The relatively low precision in abundance estimates has fostered concern from the commercial fishing industry that the GHL is too conservative. However, the GHL is a combination of abundance estimates and the annual harvest rates (based on population dynamics data); each should be periodically re-evaluated to incorporate new information and to set research priorities, which aim to maximize sustainable harvest.

Total geoduck catch has increased nearly four times since the start of the fishery, and the average price per pound jumped from $0.20 in 1986 to $3.00/lb in 2004, with a projection of $5.00/lb for 2005. In addition, the shift to shipping live geoducks starting in 2000 led to a 250% jump in price over the past 3 seasons (ADF&G, unpublished data). The rapid growth of the fishery will impose greater pressure on management to estimate precise harvest limits, which are sustainable while maximizing yield to the industry. Improvement in stock assessment, recovery rates of exploited beds, and understanding the effects of fishing on geoduck habitat all hinge on having solid biological data to make management decisions.

Although geoducks are sedentary and long-lived animals (up to 130 years; Bradbury and Tagart 2000), relatively little is known about their ecology (especially in Alaskan waters) and thus accurately estimating their total population abundance and understanding their population dynamics is extremely challenging. In general, geoducks are distributed between Alaska to Mexico (Anderson 1971), from the intertidal to over 110 m depth (Jamison et al. 1984), and typically in muddy to sandy habitats (Goodwin and Pease 1991). Growth rates are slow (5–7 years to harvestable size) and can vary significantly among locations (Hoffman et al. 2000). The reproductive biology and the importance of natural predators to geoduck populations are poorly understood and add to the difficulty in managing stocks.

Logistically, geoduck surveys require the use of SCUBA and are thus limited to collecting data on 45–60 minute increments, under typically strenuous conditions. Another difficulty with surveying subtidal organisms is that even if there is a strong association with certain habitat types, there is no accurate way to know if survey methods will cross habitats prior to conducting the survey, nor can we accurately map the proportion of each habitat type in order to stratify the sampling design ahead of time. New technology is emerging for fine-scale mapping using acoustics and may reduce this source of error in the future (Legendre et al. 2002; Murfitt and Hand 2004). In addition, the broad distribution of geoducks makes estimating abundance very difficult. For example, in southeast Alaska their distribution spans 100's of kilometers (Pritchett 2003) and only little is known about how variable geoduck abundance is over scales of meters let alone hundreds of kilometers. This in combination with the difficulty in sampling means that either a wide range of sites are surveyed with low precision, or few sites with greater precision. In addition, geoduck density is known to fluctuate with latitude, water depth, substrate (Goodwin and Pease 1991), yet this information has not been utilized to improve stock assessments.

The GHL is a product of stock assessment, population dynamics of the species, and policy decisions. Improvements to GHL are generally achieved through increased understanding of the ecology of the organisms and/or through more efficient sampling designs. Significant improvements to the GHL thus require unbiased and precise sampling designs, and better understanding of basic ecology. Improving the precision of biomass estimates is the most direct approach for producing significant changes in the GHL.

Biological stock assessment of any species requires estimates of species density, biomass, and the area over which the total is to be calculated along with their corresponding variances (Thompson 2002; Thompson 2004). The typical goal in stock assessment is to produce an unbiased estimate and to minimize its variance (and thus maximize precision) to make well-founded management decisions. Typical sampling designs are known to produce unbiased estimators, therefore stock assessment generally focuses on minimizing variance. Total variation of estimates is a function of natural variation of species distributions and the survey design. These are not independent as survey designs can be adapted to increased knowledge of natural variation in species that can lead to increased precision. Conversely, well-designed sampling can increase our understanding of the natural variation in the target population. Thus, sampling designs should be statistically sound and provide useful information on natural variation in animal abundance that can be incorporated into subsequent surveys.

Natural variation in species density occurs over a broad range of spatial and temporal scales, and is the result of both abiotic (e.g., temperature, substrate, hydrodynamics) and biotic (e.g., predation, competition, harvest) factors. Understanding the importance of such factors and at which scales they operate can be utilized to significantly reduce variance estimates. This reduction can come through either reducing the overall area (e.g., by eliminating areas where density is zero), stratifying sampling methodology to minimize within-stratum variation, incorporating auxiliary data, and sampling adaptively (Thompson and Seber 1996; Thompson 2002).

Well-designed sampling aims at producing an unbiased and efficient method to estimate total abundance of a population of a given area. The two general ways in which sampling designs can reduce variance are to increase the proportion of the area that gets sampled, and to sample in such a way as to incorporate natural variation. Increasing the proportion of sampled area can happen from increasing the sample size or reducing the total area (number of total possible samples). Increasing sample size is often infeasible due to logistical or financial constraints. Only if a more efficient method for collecting samples is adopted is this possible. Reducing the total area in which abundance estimates are extrapolated requires a better knowledge of the species' habitat requirements and accurate method for calculating areas. Although decreasing total area size could reduce variance estimates it will also reduce the total estimated abundance and may bias estimates of non-sampled areas if done incorrectly. Knowledge of natural patterns in species distributions can be incorporated into sampling designs to reduce parameter variance. For example, if a species density changes with depth, then utilizing a stratified sampling design (with different depths as strata) could significantly reduce parameter variance.

The show factor is another parameter used in calculating the GHL that can have substantial impact on the biomass estimate. Since not all geoducks are visible to divers, the show factor (proportion of geoducks counted versus the actual number present) adjusts geoduck counts into total number of geoducks present. The show factor is a percentage and small changes in the show factor can translate into relatively large changes in the total biomass estimates. Thus having a solid understanding on show factors and how they vary spatially is essential to accurately determining the total geoduck biomass.

Similar to show factors, small changes in the annual harvest rates have the potential to modify the GHL dramatically, and thus should be as accurate and precise as possible. Again, this warrants solid biological data to optimize the balance between commercial harvest and long-term population stability.

A combination of stock assessment comparisons and fieldwork were utilized to evaluate the southeastern Alaska geoduck methodologies. The stock assessments from Washington, British Columbia, and southeastern Alaska were evaluated and compared. The comparison among regions focused on transect methods, show factor estimates, and harvest rate estimates. The fieldwork evaluated potential merits of an alternative sampling design and examined differences among commercial, management, and university divers' ability to locate and count geoducks.

METHODS

The assessment of the current survey methods for geoducks in Alaska consisted of a comparison among surveys of Washington, British Columbia, and Alaska, a critique of the Alaskan design in detail, and preliminary field work to assess the potential benefits of alternative survey designs along with testing the ability of science and commercial divers in locating and counting geoducks.

The comparison of survey methodologies consisted of obtaining the survey methodologies from each region (Bradbury et al. 2000; Hand and Bureau 2004; Pritchett 2003), published manuscripts with supporting information, and interviews with the Alaska Department of Fish and Game (ADF&G; Marc Pritchett and Zac Hoyt) and British Columbia (Grant Dovey). The comparison and critiques focused on the total biomass, bed area, show factor, and annual harvest rate estimates.

Fieldwork was conducted as part of a cooperative effort among the ADF&G, University of Alaska Fairbanks (UAF), West 123° resource consulting (BC), and Southeast Alaska Regional Dive Fisheries Association (SARDFA). During the last day of this cruise an alternative survey method was implemented at Port Mayoral (N 133° 27.0', W 55° 23.5'), which allowed the examination of a stratification scheme and to evaluate the efficiency of university, management, and commercial divers ability to locate and count geoducks.

The survey design consisted of separating the eastern side of Port Mayoral into three subsites (North end, Third area, and Fifth area) and three depth strata (7–10, 12–15, and 17–20m depth). Four replicate 2 X 10m band transects were taken at each subsite/depth combination with a minimum of 10m between each transect in a similar fashion to the methods from other regions. Three divers (Grant Dovey, Brian Mattson, and Chris Siddon) rotated through three dives (one dive in each subsite) and counted geoducks in a 1m band along each transect. The geoduck density was analyzed as a two-way ANOVA with subsite (three levels: North end, Third area, and Fifth area) and depth (three levels: 10, 15, and 20m) designated as fixed factors. The mean geoduck density, standard deviation (SD), and coefficient of variation (CV) were calculated without any stratification, stratified by subsite only, and stratified by subsite and depth to examine the potential benefits of stratified sampling. Diver's ability in counting geoducks was compared using a paired t-test for each combination of divers since the 1 meter wide transects each diver counted were not independent.

RESULTS

The stock assessment survey techniques between Washington, British Columbia, and Alaska are quite similar, yet they have substantial differences in how the data is used to calculate total geoduck biomass (Table 1). All biomass estimates are a product of the number of geoducks counted on transects scaled by the proportion that are counted (show factor), the area of the bed surveyed, and the weight of geoducks. Geoduck weights are relatively uniform, are calculated adequately in all three regions, and have little influence on the precision of biomass estimates; geoduck weights will not be discussed further. Transect methods to estimate geoduck density, area estimates, and show factors for each region will be compared and critiqued. In addition, the data used to produce a sustainable harvest rate in each of the three regions was examined.

TRANSECT METHODS

All surveys are based on counting geoducks in a 2m band transect of variable lengths perpendicular from shore. The transects start in relatively shallow water and end at approximately 20m depth. Thus the number of transects (WA and BC) or the length of a transect (AK) varies as a function of the slope of the substratum. All visible geoducks are counted and a show factor is used to correct for the ones not visible (see Show Factor below).

In Washington, locations along the shore are chosen at 300m intervals. The number of intervals depends on the size of the geoduck bed. At each interval, a variable number of 2m X 45m transects are done until the target depth is reached. For example, if the distance from 5.5m to 21m depth is 45m only one transect is done; if the distance is 450m then 10 transects are done. The total sample size (n_T) for the Washington method is the number of the transects within a given interval, summed over all intervals:

$$n_T \sum_{i=1}^{k} n_i \ ,$$

where n_i is the number of transects done on interval *i*, and *k* is the number of intervals in a given geoduck bed. Overall geoduck density (D) and its variance (s^2) are calculated according to a simple random sampling design:

$$D = \frac{1}{n_T} \sum_{i=1}^{n_T} d_i$$

$$s^2 = \frac{1}{n_T - 1} \sum_{i=1}^{n_T} \left(d_i - D\right)^2$$

where d_i is the density of geoducks (no./m^2) on transect *i*.

This method is flawed. The transects conducted at a given interval are not independent of one another and therefore cannot be considered true replicates. This is a classic example of "pseudoreplication" (Hurlbert 1984) and can lead to severe bias of biomass estimates. In addition, since the sample size is grossly overstated this design could significantly underestimate its variance (i.e. its precision would be overstated). The biomass estimates and their variances for this method should be calculated as a two-phase sampling design (see below and Thompson 2002 for detailed explanation of two-phase sampling).

The area estimates used to scale geoduck density to total number of geoducks within a given bed is done with DGPS coordinates taken at the corners of a bed and the area calculated using ArcGIS software. Onshore and offshore points are determined by depth limits (5.5 and 21m) and the side boundaries determined (and modified if necessary) by *in situ* verification of appropriate habitat. The accuracy of the area estimate can be influenced by the accuracy of the GPS and measurement error (i.e., including non geoduck habitat). Non-geoduck habitat within a bed is not quantified and may overestimate the true bed area. The precision of this method is relatively high and like the precision of geoduck weight will have little direct influence on the overall precision of total geoduck biomass. However, more accurate descriptions of bed areas will allow the reduction of the number of transects done in a low density bed and those transects could be added to higher density areas and increase the precision due to a larger sample size in those areas.

In British Columbia, the survey is based on a two-phase sampling design. In the primary phase, transects are placed perpendicular to shore at randomly determined points. Within each transect, geoducks are counted on a variable number of 2m X 5m quadrats (secondary phase) depending on the transect length. The mean number of geoducks per transect is calculated by summing the total number of geoducks counted in each quadrat and divided by the total area of the quadrats surveyed for each transect. This provides an unbiased estimate of the geoduck density over the entire bed. However, they do not count every possible 2m X 5m quadrat for each transect and are therefore estimating the within transect density. In so doing the correct calculation for the variance should include a term for between transects and a second term for the variance within a given transect. They assume that the within transect variance is zero, and thus are underestimating the overall variance of geoduck density. This error though relatively minor will be more pronounced on longer transects where a smaller proportion of quadrats is sampled.

Area estimates for British Columbia are made from a combination of logbook data from fishermen, GIS mapping, and the use of acoustic mapping techniques (Murfitt and Hand 2004).

The utilization of many different data sources allows restructuring and recalculating bed areas as new information is gained. Again, the removal of non-commercial geoduck habitat allows more focused effort when conducting transect surveys.

In Alaska, the geoduck survey is based on a systematic sampling design utilizing a 2m wide band transect of variable length within known geoduck sites. Transects are spaced approximately every 100m along the shoreline and the number of geoducks along each transect are counted down to 17m depth. Average number of geoducks per transect is calculated and multiplied by the total length of shoreline surveyed to estimate total geoduck abundance. Estimates are based on simple random sampling, which have been shown to be adequate for systematic sampling designs (Thompson 2002). The method used for Alaska is unbiased, straightforward, and logistically simple to implement.

The area of geoduck beds is not estimated per se, rather the length of shoreline in which transects were conducted is estimated by a straight line drawn onto an electronic chart. It does not take into account the width of the bed, the irregularity of the shoreline, the presence or absence of suitable habitat, nor the accuracy of the charts. However, there is no variance associated with this measurement so it does not directly affect the precision of the biomass estimate, rather it can only bias (positively or negatively) the biomass estimate itself. The measurement of the shoreline is only used to estimate how many possible transects could be done at a given site, therefore the bias from this method is relatively small.

Show Factor

Show factor experiments in Washington and British Columbia have been conducted over many years (Goodwin 1977; Bradbury et al. 2000; Campbell et al. 2004). Show factor is calculated as the ratio of number of geoducks counted to the number actually present in a defined area:

$$Showfactor = \frac{Counted}{Total}.$$

Show factor experiments generally utilize a similar methodology, where divers count and flag geoducks in a designated area, then repeat the census until no new geoducks are encountered (generally over a week time period). Results from Washington showed a strong seasonal change in geoduck show factor ranging from 0 (Dec.–Feb.) to over 100% in the early summer (Goodwin 1977). More recent studies (Bradbury et al. 2000) examined show factors at twelve sites throughout Washington. Mean maximum show factors were 73% in March decreasing to a low of 43% in October. Yearly variation also occurred with a 25% increase in show factors between 1986 and 1992.

The most current published data from British Columbia (Campbell et al. 2004) consistently found show factors from two sites to average greater than 90% with the lower 95% confidence intervals not to fall below 80%. At one site the mean show factor exceeded 95% ± 2 (95% CI) over 6 years.

Results from show factor experiments at three sites in Alaska (two near Ketchikan and one near Sitka; Pritchett et al. 1999) suggest that on average, divers count 83% of all the geoducks present. Although this is on par with estimates from Washington (75%; Bradbury et al. 2000) and British Columbia (~90%; Campbell et al. 2004), the 95% confidence interval is large (68 – 98%). With such large commercial harvests, the relative uncertainty of the show factor could have a dramatic effect on determining guideline harvest levels.

HARVEST RATE

The harvest rate for Washington State is set at 2.7% of the total biomass estimate per year. This value stems from an equilibrium yield model, which incorporates mortality, maturity, growth, and recruitment data from geoducks throughout Washington (Bradbury and Tagart 2000; Bradbury et al. 2000; Hoffman et al. 2000). Although this is a relatively simple model of geoduck population dynamics, it provides quantitative evidence of a sustainable harvest rate.

Similarly, British Columbia used an equilibrium yield model and determined that a harvest rate of 0.75 – 2% of the virgin biomass per year would maximize harvest at a sustainable level (Breen 1992). Again, this model was based on mortality, maturity, growth, and recruitment data, from geoducks within their commercial fishing regions. New, more detailed data from BC has shown significant differences in the biological parameters (i.e., mortality, growth, and recruitment) among sites. With this new information they are planning to set site-specific harvest rates (higher in some areas, lower in others) to more accurately manage the fishery (G. Dovey personal communication).

Currently, the harvest rate for geoducks in Alaska is set at 2% per year (Larson and Minicucci 1997; Pritchett 2003). This rate was set based on Washington and British Columbia data, as there is currently no published data on the required biological parameters for geoducks in southeastern Alaska.

FIELD RESULTS

Results from the alternative sampling design showed that geoduck density changes significantly among sites and depths (Figure 1). Post hoc comparisons showed that there were significantly more geoducks at the South end than the Third area and at the 15m depth strata than the other two depths (p-values < 0.05). If all the data are pooled (n = 34), the mean geoduck density was 8.1m^{-2} ± 15.3 (SD). However, if the data is stratified by subsite the mean geoduck density is 8.3m^{-2} ± 8.3 and when stratified by both subsite and depth the mean equals 7.7m^{-2} ± 3.8. This corresponded to CVs of 32%, 30%, and 25% for the pooled, subsite, and subsite by depth regimes. This shows a marginal improvement for stratifying on subsite and a more substantial improvement when depth was considered. It should be noted that little improvement would be expected by stratifying on subsite alone unless it corresponded to some biological gradient that affects geoduck density (e.g. salinity). Stratification does provide new information on the distribution of geoducks, which can be used in subsequent surveys to allocate transects optimally (i.e., place more transects in areas of high variability) to further increase the precision of the estimate. For example, the highest density of geoducks is found between 15 – 20 m depth at the South end subsite and at 15m within the Third area (Figure 1). The variance is also highest in these areas, so subsequent surveys could allocate more transects to them and reduce the number of transects in the other areas. In addition, the low density of geoducks in the Fifth area (0.063m^{-2} ± 0.1; Figure 1) would warrant the removal of this 100m length of shoreline from subsequent surveys and allocating those transects elsewhere.

The comparison among divers showed no significant difference among any diver combinations (all p-values > 0.18) and the average difference between counts was less than 2 geoducks (Figure 2). This suggests that geoduck densities are very similar from one side of the transect to the other and that the difference in locating and counting them is minimal.

RECOMMENDATIONS

The survey method used by ADF&G is statistically sound, straightforward and logistically easy to implement. Although this method provides an unbiased estimate of abundance, it does not allow for comparisons of geoduck density among sites (due to different lengths of transects), nor does it allow for use of auxiliary data or stratification. The only way to increase precision for this method is to increase the sample size, which is logistically difficult. In addition, annual harvest rates are not based on data specific to southeast Alaska and the data for show factor estimates are minimal (and highly variable).

There are four main areas that should be focused on for improving the scientific rigor of the Alaskan geoduck fishery: 1) Increased precision of stock assessment methods, 2) Accurate mapping of high density geoduck areas, 3) Increased precision of show factor estimate, and 4) Collection of biological data to produce an annual harvest rate that is specific to southeastern Alaska.

Although there is nothing mathematically incorrect with the current methodology, there is little way to improve the precision of the estimate. Collection of data on an area (m^2) basis rather than per meter of shoreline will allow for comparisons among sites, a better estimation of bed area, a way to allocate a fixed number of transects in an optimal fashion, and allow a more direct way to utilize auxiliary data (e.g. substrate type, depth) to help reduce the variability in biomass estimates. This recommendation should be a relatively straightforward change as it only requires a slight modification to the current design. It will no doubt reduce the sample size (i.e., number of transects) slightly, but the potential gain in precision both for the current year's survey, and for subsequent surveys is significant. The change to an area-based method will also allow a way to utilize auxiliary data to further help reduce variation. For example, if data (e.g., geoduck counts, substrate type, depth) are recorded on 5m increments along the total length of a transect it can be directly utilized to post-stratify results. Since geoduck density is well known to vary as a function of substrate type (Goodwin and Pease 1991) and depth (Goodwin and Pease 1991, this study) and if this auxiliary data can be directly incorporated into the biomass estimates through stratification the precision of the biomass estimates will increase. In addition, alternative sampling designs such as multistage and adaptive sampling should be tested as potential alternatives to the current design. Multi-stage designs such as done in Port Mayoral have the potential to increase the rate of gaining new information regarding geoduck distributions, but must be compared quantitatively to current methods to assess its efficacy before being implemented. The current designs from all three regions have issues and a continued effort to improve upon them especially as new techniques emerge should be promoted. There are many ways to modify transect methods, however the most important step is to collect data in a manner that allows it to be utilized in subsequent surveys. This allows improvements (e.g., reallocation of transects, modification of bed areas) to continue as more information on geoduck ecology is incorporated and thus increasing the precision of the biomass estimates.

The second recommendation is to improve geoduck bed area estimates. This recommendation is tied to the first in that improved area estimates will allow transects to be focused in areas of high variability thus increasing the precision of biomass estimates. Improving area estimates should be modeled after British Columbia by utilizing a variety of sources including logbooks and habitat mapping data. Alternative sampling designs can also be utilized to improve area estimates if the appropriate data (e.g., substrate type, depth) are collected at a finer resolution along transects.

The third recommendation is to obtain a more accurate estimate of geoduck show factors at multiple sites. At minimum, a number of well-replicated show factor experiments with similar designs to Washington and British Colombia should be conducted throughout southeastern Alaska. Geoduck behavior is likely to vary spatially due to such factors as exposure, substrate type, or the presence of predators. This variation could lead to site and/or regional differences in the geoduck show factor. Since the show factor is simply a constant multiplied by the biomass estimate it has the potential to have a marked effect on the overall biomass estimate. Thus the more accurate the show factor, the more accurate the overall biomass estimate will be. In addition, alternative methods (e.g., excavation, mechanical disturbance) should be investigated to test the efficacy of the typical multiple census method. Since the multiple census method usually occurs over a one week time period there is a possibility that some proportion of geoducks remain dormant (and therefore undetected) for longer time periods.

The fourth recommendation is for the initiation of a quantitative population model (e.g., equilibrium yield) for geoducks specific to southeastern Alaska. Although geoduck populations in Alaska probably share similar characteristics to those found in Washington and British Columbia there is no way to know without the appropriate data. British Columbia has also recognized that the population dynamics of geoducks can be significantly different from site to site within a region and are beginning to incorporate this new information. With the vast range of geoduck habitat in southeastern Alaska it is reasonable to assume that such variation occurs here as well. This is a longer-term goal than the others, but not any less important in its potential impact on the fishery. Again, small changes in the annual harvest level (in either direction) can have large effects on the Guideline Harvest Levels.

The southeastern Alaska stock assessment methods for geoducks is statistically sound, but has significant room for both short- and long-term improvements. A continued cooperation between ADF&G and SARDFA along with periodic reviews such as this will help promote a continued effort to improve the scientific rigor, harvest levels, and long-term sustainability of the resource.

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TABLE AND FIGURES

Table 1.–Comparison of methodologies used for geoduck biomass estimation in three regions (Washington, British Columbia, and southeastern Alaska).

	Washington	**British Columbia**	**Alaska**
Transect layout	Perp. to shore	Perp. to shore	Perp. to shore
Depth range	18–70 ft. (5.5–21m)	3–18 m	0–17 m
Sampling method	Systematic	Two-phase	Systematic
Transect size	6ft. X 150ft. (~2m X 45m)	2m X variable length (primary), 2m X 5m (secondary)	2m X variable length
Sample sizes	Incorrectly determined (see text)	1 / 100 m of shoreline (primary), variable (secondary)	1 / 100m of shoreline
Geoduck density	No. / m^2	No. / m^2	No. / linear m of shoreline
Bed area calculation	GPS/GIS	GIS, acoustic maps, Log books	Shoreline length (estimated)

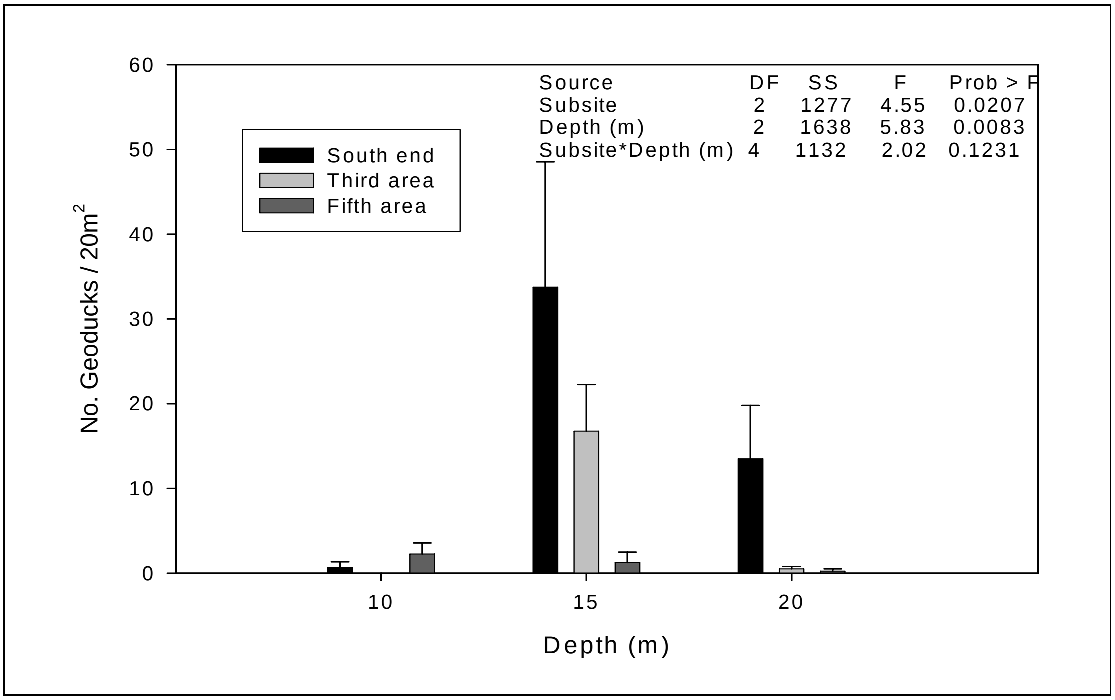

Figure 1.–Mean (± SE) geoduck (*Panopea abrupta*) density at three subsites within Port Mayoral at 10, 15, and 20m depth intervals. Two-way ANOVA shows a significant site and depth effect and no interaction.

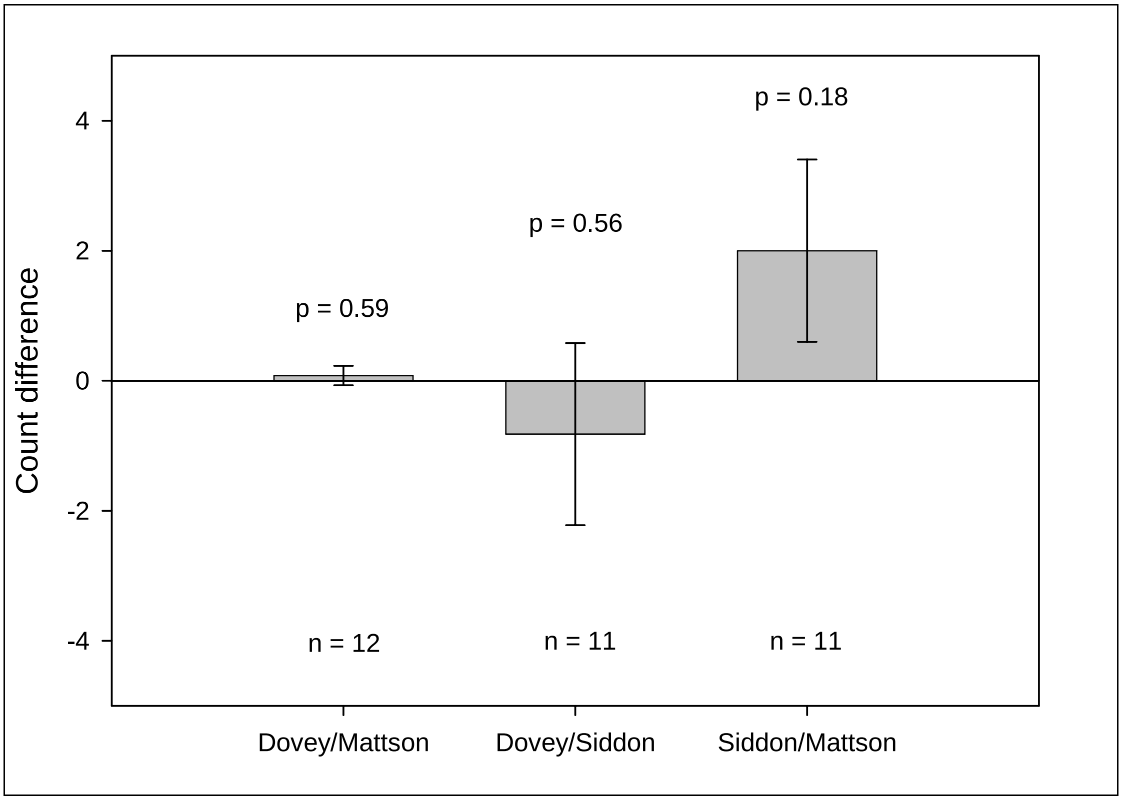

Figure 2.–Mean (±SE) difference of counting geoducks among divers at Port Mayoral. If values are positive the first person listed counted more geoducks, if negative the second person counted more geoducks. P-values are based on paired t-tests for each pair of divers (sample sizes are 12, 11, and 11).