A Survey of Geoduck Abundance at the Moore Islands, Central Coast, British Columbia, 1998

J. Babuin, G. Dovey, C.M. Hand, D. Bureau, W. Hajas, and I. Murfitt

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
Nanaimo, British Columbia
V9T 6N7

2006

Canadian Manuscript Report of Fisheries and Aquatic Sciences 2739

Fisheries and Oceans Canada   Pêches et Océans Canada

Canada

Canadian Manuscript Report of Fisheries and Aquatic Sciences

Manuscript reports contain scientific and technical information that contributes to existing knowledge but which deals with national or regional problems. Distribution is restricted to institutions or individuals located in particular regions of Canada. However, no restriction is placed on subject matter, and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Manuscript reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1-900 in this series were issued as Manuscript Reports (Biological Series) of the Biological Board of Canada, and subsequent to 1937 when the name of the Board was changed by Act of Parliament, as Manuscript Reports (Biological Series) of the Fisheries Research Board of Canada. Numbers 1426 - 1550 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Manuscript Reports. The current series name was changed with report number 1551.

Manuscript reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport manuscrit canadien des sciences halieutiques et aquatiques

Les rapports manuscrits contiennent des renseignements scientifiques et techniques ques qui constituent une contribution aux connaissances actuelles, mais qui traitent de problèmes nationaux ou régionaux. La distribution en est limitée aux organismes et aux personnes de régions particulières du Canada. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports manuscrits peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports manuscrits sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annual des publications scientifiques et techniques du Ministère.

Les numéros 1 à 900 de cette série ont été publiés à titre de manuscrits (série biologique) de l'Office de biologie du Canada, et après le changement de la désignation de cet organisme par décret du Parlement, en 1937, ont été classés comme manuscrits (série biologique) de l'Office des recherches sur les pêcheries du Canada. Les numéros 901 à 1425 ont été publiés à titre de rapports manuscrits de l'Office des recherches sur les pêcheries du Canada. Les numéros 1426 à 1550 sont parus à titre de rapports manuscrits du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 1551.

Les rapports manuscrits sont produits a l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Manuscript Report of
Fisheries and Aquatic Sciences 2739

2006

A SURVEY OF GEODUCK ABUNDANCE AT THE MOORE ISLANDS, CENTRAL COAST, BRITISH COLUMBIA, 1998

by

J. Babuin[1], G. Dovey[1], C.M. Hand, D. Bureau, W. Hajas, and I. Murfitt

Fisheries and Oceans, Canada
Science Branch, Pacific Region
Pacific Biological Station
Nanaimo, British Columbia
V9T 6N7

[1]Underwater Harvesters Association
P.O. Box 39005, 3695 W. 10th Ave.
Vancouver, B.C. V6R 4P1

Cat. No. Fs 97-4/2739E ISSN 0706-6473

Correct citation for this publication:

Babuin, J., Dovey, G., Hand, C.M., Bureau, D., Hajas, W., and Murfitt, I. 2006. A survey of geoduck abundance at the Moore Islands, Central Coast, British Columbia, 1998. Can. Manuscr. Rep. Fish. Aquat. Sci. 2739: v + 29 p.

TABLE OF CONTENTS

ABSTRACT

Babuin, J., Dovey, G., Hand, C.M., Bureau, D., Hajas, W., and Murfitt, I. 2006. A survey of geoduck abundance at the Moore Islands, Central Coast, British Columbia, 1998. Can. Manuscr. Rep. Fish. Aquat. Sci. 2739: v + 29 p.

A survey of a portion of the geoduck (*Panopea abrupta)* habitat at the Moore Islands, on the central coast of British Columbia, was conducted by the Underwater Harvesters Association and Fisheries and Oceans Canada in 1998. The objectives of the survey were to estimate geoduck density in commercial beds, confirm or revise area estimates for surveyed beds, and to collect biological samples. The Moore Islands were selected for surveying in order to collect baseline data from a virgin area. At the time of the survey in 1998, the beds had been only lightly fished, with landings of 19 metric tonnes and estimated removals of 0.02 geoducks/m^2.

This survey covered 86 ha of seabed. Mean geoduck density ranged from 1.18 to 10.21/m^2 over four survey sites. Mean overall density of geoducks at the Moore Islands was estimated to be 4.65/m^2 (95% CB: 3.70-5.71), which is the highest overall survey density to date from modern surveys in British Columbia. Digitized bed area increased from 49 to 64 ha for the surveyed beds at the Moore Islands. Mean age of the geoducks sampled at the Moore Islands was 64 and ranged from 8 to 125 years.

RÉSUMÉ

Babuin, J., Dovey, G., Hand, C.M., Bureau, D., Hajas, W., and Murfitt, I. 2006. A survey of geoduck abundance at the Moore Islands, Central Coast, British Columbia, 1998. Can. Manuscr. Rep. Fish. Aquat. Sci. 2739: v + 29 p.

En 1998, l'Underwater Harvesters Association et Pêches et Océans Canada ont effectué un relevé d'une partie de la population de panope (*Panopea abrupta*) des îles Moores, situées sur la côte centrale de la Colombie-Britannique. Ce relevé avait comme objectifs d'évaluer la densité des panopes dans les bancs exploités commercialement, de confirmer ou de réviser les estimations de la superficie des bancs étudiés et de prélever des échantillons biologiques. L'obtention de données de base sur un secteur vierge est à l'origine du choix des îles Moores. Au moment du relevé en 1998, les bancs n'étaient encore que peu exploités; seulement 19 tonnes avaient été pêchées, soit un estimé de 0,02 panope prélevée/m^2.

Le relevé a couvert une superficie de 86 ha du fond marin. La densité moyenne des panopes allait de 1,18 à 10,21 individus/m^2 pour les quatre sites du relevé, alors que la densité moyenne globale était estimée à 4,65/m^2 (l'intervalle de confiance à 95 % se situait de 3,70 à 5,71). Cette densité est la plus élevée qui ait été estimée jusqu'à maintenant parmi les relevés récents effectués en Colombie-Britannique. La superficie numérisée des bancs est passée de 49 à 64 ha pour les bancs étudiés aux îles Moore. L'âge des panopes échantillonnées allait de 8 à 125 ans, alors que l'âge moyen se situait à 64 ans.

1. INTRODUCTION

Geoduck clams (*Panopea abrupta* (Conrad 1849)) have been commercially harvested in British Columbia (BC) since 1976. Fishermen target concentrations of clams found in beds of soft substrate and, to date, an estimated 24,000 hectares of geoduck beds have been harvested throughout the BC Coast. The $33.6 million (CAD) fishery (2004) is among the highest valued in BC (M. James, www.geoduck.org, personal communication) and is managed with individual vessel quotas, area quotas and scheduled openings. The fishery and biology of geoduck clams is summarized by Hand and Bureau (2006).

Quotas for the fishery are determined from estimates of virgin biomass and an annual harvest rate of 1% (Hand and Bureau 2006). Transect surveys provide the density information needed to calculate biomass, as well as a verification of the area of the beds. Hand and Bureau (2006) provide a review of the survey results used to establish density estimates in BC.

Fisheries and Oceans Canada (DFO) and the Underwater Harvesters Association (UHA) have collaborated on geoduck surveys in BC since the early 1990s. This paper details the results of the Moore Islands survey completed in 1998. The objectives of the survey were to estimate geoduck density in commercial beds, confirm or revise area estimates for surveyed beds and collect biological samples to measure life history parameters in the survey area.

2. METHODS

2.1 DESCRIPTION OF STUDY AREA

In 1996, 1999 and 2002 a total of 101 metric tonnes of geoducks were harvested from the Moore Islands geoduck management area (GMA). The survey at the Moore Islands covered a portion of the beds within this GMA, from which total landings of 84 metric tonnes have been landed to date (Fig.1 and Table 1). At the time of the survey in 1998, the beds had been only lightly fished, with landings of 19 tonnes and estimated removals of 0.02 geoducks/m^2 (Table 1). The Moore Islands were selected for surveying to collect baseline data from a virgin area.

In 1996, an exploratory quota of 25,000 kg was set and harvesters were instructed to follow the 'new bed protocol', whereby the on-grounds monitor directed each vessel to move outside the radius of the diver's hose length (average 75 m) after harvesting approximately 900 kg. The new bed protocol was developed in order to encourage the fleet to spread out effort and help establish bed boundaries. In 1999, quotas for the Moore Islands GMA were estimated with a density of 1.57/m^2, which was the average density from surveys completed in Statistical Area 6 in 1996. The quota for 2002 (45,360 kg) was based on preliminary survey density estimates from this study. The

50,378 kg quota for the Moore Islands GMA in 2005 was, also based on a preliminary density estimate (4.34/m^2) from this survey.

2.2 FIELD METHODS

2.2.1 Dive Survey Design

The location of known geoduck beds, as reported by fishermen in their harvest logs and from extensive on-grounds monitor notes, was used in the design phase of this survey to establish the general area of survey coverage. Transect locations were assigned *a priori*, in order to reduce possible bias under field conditions. Survey protocol followed the Survey Type 1 methodology outlined in Campbell *et al.* (1998a) at the Moore Islands. This is a two-stage design where transect locations were systematically determined at the first stage and a census of secondary sampling units, or quadrats, was taken at the second stage. A line of best fit was first drawn parallel to geoduck beds selected for surveying. Next, an initial transect, drawn perpendicular to the line of best fit, was drawn from 3m to 18m depth (corrected to chart datum). The start point for the initial transect was randomly selected from within 100 m of one end of the line of best fit. Additional transects were then spaced 150m apart across the entire bed perpendicular to the line of best fit. Some transects were also drawn outside of the boundaries of existing beds to confirm or revise existing bed area. Type 1 survey designs may be treated as a random sample of the geoduck population because it is unlikely that fluctuations in geoduck density will match the widely separated spacing of transects (Goodwin and Pease 1991, Campbell *et al.* 1998a). Type 1 surveys with evenly spaced transects are particularly useful in relatively new areas where harvesting has not yet delineated the specific boundaries of the commercial beds.

In the field, transect location was determined using geographical references on the shoreline, Global Positioning System (GPS) data and depth sounder readings. Lead-core transects were laid perpendicular to depth contours from 3 to 18m (10 to 60 feet) depth (uncorrected for tide height in the field). Transects were terminated at submerged reefs of less than 3m depth or valleys deeper than 18m and continued on the other side with a new transect number. Final start and end positions of each transect were recorded with GPS, which in 1998, was accurate to within 100 m horizontally 95% of the time (R. Silberhorn, Canadian Coast Guard, personal communication). Exposure to weather and tidal currents was recorded for each transect using DFO exposure codes.

The lead-core transect lines were marked every 5m to define the end of each quadrat (secondary sampling unit). Two SCUBA divers worked together, one on either side of the transect, and counted geoduck shows within one metre (using a metre stick) of each side of the transect, each diver thus surveying half of the 10m^2 quadrat. Every 2nd, 3rd or 4th quadrat was surveyed, depending on the length of the transect (<200 m every 2nd, 200-400 m every 3rd, >400 m every 4th). A show is either an observed geoduck siphon or a dimple left in the substrate by a retracted siphon. Dimples were counted if the siphon retracted in response to probing and if the appearance of the dimple, the feel of the siphon and the manner of the retracting siphon were consistent with characteristics of a geoduck, as determined by an experienced survey diver. For each surveyed quadrat, divers also recorded the number horse clams (*Tresus nuttallii* and/or *T. capax*), depth, substrate type and algal cover. No attempt was made to differentiate between the two species of horse clams. The data from either side of each quadrat were pooled and, thus, one data record was the number of geoducks, the number of horse clams and the auxiliary data for each 10m^2 quadrat. Neck exposure, which is the percentage geoduck necks extending greater than 1 – 2cm above the substrate surface, was estimated for each transect as an indicator of how difficult it was to recognize shows.

2.2.2 Show Factor Plots

Individual geoduck siphons are sometimes withdrawn, without trace, below the surface of the substrate due to physical and/or biological effects (Goodwin 1977), such as wind and sea conditions (Campbell et al. 1996a, 2004). The fraction of geoduck siphons and/or dimples that are readily visible to divers is the show factor.

The show factor was estimated by monitoring the same 10 x 2m plots every day through the duration of the survey. Two show factor plot locations were selected at the Moore Islands to be representative of the substrate, depth and exposure encountered during the survey. Each day, the number of shows was recorded and flags were placed beside geoducks showing for the first time. The show factor for any given day was determined by dividing the number of shows by the total number of geoducks flagged during the survey.

2.2.3 Biological Samples

Three sub-samples of approximately 100 geoducks each were collected on the last day of the survey at Moore Islands. Details of sample collection methods, data collected and sample processing are described in Bureau et al. (2002, 2003). Briefly, geoducks were individually tagged in the field and then sent to a processing plant in Vancouver where total individual weight and market quality was recorded before the geoducks were processed for meat. The shells were then sent to the Pacific Biological Station where they were individually measured and weighed and later prepared for age determination. Methods for age determination are described in Bureau et al. (2002, 2003).

2.3 ANALYTICAL METHODS

2.3.1 Diver Comparisons

Divers participating in the surveys rotated partners in the field to allow a comparison of their detection abilities. The number of geoducks counted by diver-left was compared to the number counted by diver-right for each quadrat in which both individuals were paired in the field. Significance values were calculated by testing against the null hypothesis that the counts were equal for each diver. In the event of large, significant biases, a correction could be applied to the data relative to the lower proportion of geoducks counted by a particular diver(s). None of the dive team totals were significantly different ($p>0.05$ for all comparisons). No corrections were applied.

2.3.2 Depth Correction and Analysis

Observed depths were converted to depth below chart datum by subtracting tidal height, using tidal prediction data from the closest Canadian Hydrographic Service harmonic station at McKenney Island.

In order to compare the mean density of geoducks for four depth ranges (0-5 m, 5-10 m, 10-15 m, >15 m), a non-parametric approach known as bootstrapping was used (Efron and Tibshirani 1993). Parametric tests are not appropriate since the frequency distribution of geoduck counts is not normal (Fig. 2). For each depth range, the number of geoducks per quadrat was resampled (with replacement) from the recorded values. The resampling was repeated 1000 times and the average number of geoducks (*Avg*) in the g^{th} depth range (D_g) and the r^{th} resampling was computed:

$$Avg(D_g,r) \qquad (1)$$

As a further step:

$$diff(D_g,D_h,r) = Avg(D_g,r) - Avg(D_h,r) \qquad (2)$$

was also calculated for each resampling, where D_g was the first depth range and D_h was the second depth range. The confidence level that the mean from D_g was greater than the mean from D_h was the fraction of times that $diff(D_g,D_h,r)$ was greater than zero. For example, if the density in D_g was greater than the density in D_h in 600 of the 1000 resamplings, the confidence level would be 0.6.

2.3.3 Post-stratification and Data Exclusion

Survey sites were defined by the general location and area of geoduck beds as they were recorded on DFO charts at the time of the survey; independent knowledge of habitat was not available. This sometimes resulted in data being recorded from substrates not suitable for geoducks. Survey data was post-stratified to measure the density of geoducks in revised commercial bed area. Transects that were clearly outside of commercial harvest areas were excluded from the data set for the calculation of overall density. Independent information from logbooks and detailed reports from the north coast on-grounds monitor supplemented survey data in order to revise the location of commercial harvest. The remaining transects within a site were sometimes combined into larger sites if they represented a more or less continuous geoduck bed and/or a DFO bed code entity. This is why the survey site numbers at the Moore Islands are not continuous (Sites 1, 7, 8 & 10) (Fig. 1).

2.3.4 Show Factor Proportions

The proportion of geoducks showing on day *i* (SP_i) in any given area was calculated as

$$SP_i = \frac{X_i}{T} \qquad (3)$$

where X_i is the number of geoduck shows in the plot in day *i* and *T* is the sum of all shows observed in the plot over the duration of the survey, which is assumed to be a full census of geoducks in the plot.

Density data were corrected for show factor using data from the nearest show factor plot(s) on the same day a transect was surveyed.

2.3.5 Area Estimation

Estimates of area were calculated using two different methods. The first method calculates the commercial bed area from digitized polygons drawn on DFO reference charts, using geographical information systems (GIS) software. The polygons are based on geo-referenced fishing information provided by fishermen on harvest logs as a condition of license. Polygons representing the geoduck beds are continually being revised as part of the on-going process of updating and improving the geoduck spatial database with new information. In this report, the revised bed area is defined as the digitized polygons that have been updated with survey data and the latest fishery logbook and on-grounds monitor reports.

The second method of area estimation calculates the area surveyed, which is the sum of the area of all possible transects, as the product of the mean transect length and the length of the site, as measured from the appropriate nautical chart.

2.3.6 Survey Density, Number of Geoducks, and Biomass Calculations

Analytical procedures were based on Campbell *et al.* (1998a). Number of geoducks for each quadrat (g_j) were adjusted for the proportion of geoducks not showing on the day the transect was completed by:

$$g_j = \frac{q_j}{SP_i} \qquad (4)$$

where q_j is the number of observed geoducks in each quadrat *j* and SP_i is the mean proportion of geoducks showing on the day that the data were collected.

The density of geoducks in each transect (d_t) was calculated as:

$$d_t = \frac{\sum_j g_j}{\sum_j a_j} \tag{5}$$

where $\sum_j a_j$ represents the total area of the surveyed quadrats in transect t.
Site densities are a weighted mean of transect densities:

$$d_{site} = \frac{\sum_t d_t * L_t}{\sum_t L_t} \tag{6}$$

where L_t is the length of the tth transect. By weighting the estimate by transect length, the longer transects will have more influence on the estimated site density. It is expected that this approach will result in more accurate results than if all transects were weighted equally.

Because the distribution of the density data is not normal (Fig. 2), non-parametric confidence intervals for the mean geoduck density at each site were calculated using bootstrap techniques (Efron and Tibshirani 1993). The procedure randomly samples *n* transects with replacement from the *n* surveyed transects. The process was repeated 1000 times to obtain 1000 estimated mean densities: d^*_1, d^*_2, ...d^*_{1000} . Bootstrap 95% confidence intervals were then constructed using bias corrected and accelerated (BCa) methodology (Hollander and Wolfe 1999). The BCa methodology adjusts the results for bias and skewness, as estimated from d^*_1, d^*_2, ...d^*_{1000} .

For each of the 1000 calculated d^*_{site}'s, a total number of geoducks (N_{site}) and biomass (B_{site}) are calculated as:

$$N_{site} = d_{site}(A + se(A)z_A) \tag{7}$$

and

$$B_{site} = N_{site}(w + se(w)z_w) \tag{8}$$

where *A* is the estimated size of the bed in square metres, *se(A)* is the standard error of the size estimate, *w* is the estimated mean weight of a geoduck in kilograms, *se(w)* is the standard error of the weight estimate and z_A and z_w are random numbers from a standard normal population. Therefore, $(A + se(A)z_A)$ is a randomized value of area and

$(w + se(w)z_w)$ is a randomized value of mean weight. The confidence intervals for the total number of geoducks (*N*) and the biomass (*B*) are calculated as for density (BCa methodology). The precision of the mean density and biomass estimates, expressed as a percentage, were obtained by averaging the intervals of the asymmetrical bootstrapped 95% confidence bounds and dividing by the mean. Mean estimated geoduck abundance (*N* & *B*) for each site and the entire survey combined, was calculated using the estimated values of area and mean weight in equations 7 and 8 (*z*-values set to zero).

Mean weights were estimated from 1996, 1999 and 2002 (2005 values have yet to be processed) logbook data where both the number of geoducks landed and landed weight were provided. Refer to Hand and Bureau (2006) for a more detailed description of mean weight estimates.

2.3.7 Calculation of Virgin Density

The yield model that produced the harvest rate options from which 1% was chosen (Breen 1982) was based on simulations of virgin biomass. Virgin density for the surveyed beds was back-calculated by adding the density of geoducks removed by the fishery prior to the survey to the estimated survey density. This method assumes that natural mortality and recruitment rates are in balance.

Reported landings for each surveyed bed were obtained from the logbook database and converted to number of animals using mean weight estimates from logbook records (1996-2002). Density removed was calculated by dividing the number of geoducks harvested over the revised digitized bed area estimate. Biomass removed (kg/m^2) was also estimated in order to estimate virgin biomass over just the survey area.

The bed area estimates used to calculate removals were larger than the survey area estimates. Geoduck beds may be comprised of many polygons, and the survey protocol does not always include every polygon within a bed. However, landings are assigned per DFO bed code, not individual polygons. Density removed may be overestimated if un-surveyed polygons are not accounted for. Virgin biomass may also be overestimated if removals for un-surveyed polygons are added to the biomass estimate calculated for the survey area.

3. RESULTS

3.1 GENERAL

Two pairs of divers worked from one vessel for 9 days in the Moore Islands. Forty one transects were completed in four survey sites, covering 86 ha of area, and two show factor plots were surveyed (Tables 2 & 3, Figures 3 to 5). Sampling intensity ranged from 3.70 to 5.31 quadrats/hectare (Table 2). Three additional “harvest” transects (HT1 to HT3) were surveyed and a biological sample was collected adjacent to each on the last day of the survey (Table 2, Figures 3 to 5).

Show factor data indicated that 95 – 100% of geoducks were showing in the two plots (excluding day 1 at 88%) (Table 2). Both show plots had high densities of geoducks (plot 1: 15.3/m^2, plot 2: 6.6/m^2). Data from both plots were combined and used to correct all survey transects.

3.2 POST-STRATIFICATION OF DATA AND GEODUCK BED AREA

Six of the 41 transects were excluded from the analysis to estimate density over the revised geoduck bed. Three of these six (transects 21, 32 & 37) had unsuitable substrate (cobble, boulder and/or bedrock) with non-commercial densities (0.00 – 0.03 geoducks/m^2, Table 2). The most dominant substrate code on transects 31 and 33 was soft, but the habitat was too muddy for commercial harvest (Table 2). Transect 45 was excluded because it had unsuitable substrate (cobble, boulders and bedrock) for commercial harvest, despite the relatively high geoduck density (3.57/m^2, Table 2).

The beds surveyed in the Moore Islands had been fished for just one year (1996) prior to the 1998 survey (Table 1) and the beds were not fully explored. At that time, the digitised estimate of bed polygons in the survey area was 49 ha (Table 4). The geoduck beds were re-mapped using all available information, including these survey results, commercial harvest reports from 1996 to 2002 and on-grounds monitor comments. The revised area of harvestable geoduck habitat increased 31%, from 49ha to 64 ha.

The total area surveyed (sum of the area of all possible transects) was 86 ha. The area surveyed decreased to 79 ha when transects that fell outside of the revised digitized bed area (6 of 41) were excluded (Table 3). The 15 ha difference between overall surveyed and digitized area can largely be accounted for by the difference between the survey and digitized area estimates for Site 1. Transects 17 to 20 were laid over ground that appeared on the depth sounder image to be potential bed. However, large sections of these transects were ultimately excluded from the bed polygons that represent the fishable area because they were found to be of unsuitable substrate.

3.3 DENSITY IN RELATION TO DEPTH AND SUBSTRATE

At the Moore Islands, transects were limited to 18m (60 ft) diving depth. With varying tide heights between transects, the minimum and maximum depths ranged from -1 to 10 m and 5 to 18 m, respectively (Table 2).

Mean geoduck density increased with depth to 12 m where density levelled off (Fig. 6). Confidence levels that the deeper adjacent depth range had more geoducks were 1.0 for the two shallowest comparisons. Thus, we are 100% confident that there were higher densities in the 10m-15m depth range than in the 5m-10m depth range, and higher densities in the 5m-10m than the 0m-5m depth ranges. There was no significant density trend below 15 m, where data were limited.

For each quadrat, divers recorded the two most prevalent substrate types encountered out of nine possible substrate codes (bedrock, boulders, cobble, gravel, pea gravel, sand, shell, mud and wood debris). The substrate type for each quadrat was then reduced into one of three categories representing hardness: hard, mixed and soft. As expected, the highest densities were found in soft substrate, while mixed soft/hard substrate yielded lower densities and no geoducks were counted in hard substrate (Fig. 7). Sixty two percent of the quadrats sampled in the Moore Islands were coded 3, soft.

3.4 DENSITY AND BIOMASS ESTIMATES

Transects averaged 156 m in length, and individual transect density ranged from 0 to 16.2 geoducks/m^2 (Table 2). High densities of geoducks were encountered in the Moore Islands, with 14 of 41 survey transects having densities greater than 5/m^2 (Table 2).

Transects were grouped into sites that correspond to commercial beds, as defined by DFO (Tables 2 and 3, Fig. 1). The overall mean density estimate over the entire survey area at the Moore Islands was 4.32 geoducks/m^2 (95% CB: 3.40-5.30/m^2) and the range of density estimates over the four survey sites was 0.98 – 10.21/m^2 (Table 3). The overall density estimate increased slightly to 4.65/m^2 when transects were excluded, but the precision was unchanged (95% CB ±22% of the mean for both estimates). Individual site confidence bounds were less precise, ranging from ±33 to 62% of the means (Table 3). The overall density estimate for the revised digitized area of 5.04/m^2 was higher than the estimate for the revised survey area, even though the same transects were analyzed, because of the increased influence of the high-density Site 10 in the area weighting.

The survey biomass estimate over the revised digitized area (3,735 tonnes) was 4.3 times the pre-survey biomass estimate of 873 tonnes and the precision of the estimate increased from ±40% to ±27% (Tables 4 & 5). Confidence bounds for survey biomass estimates had similar precision as the density estimates (±24 to 27% of the combined means). Removals by the limited fishery before the survey (0.02 geoducks/m^2) were very low (Table 1), and therefore estimates of virgin biomass were similar to estimates of biomass at the time of the survey (Table 4).

3.5 BIOLOGICAL SAMPLES

Mean age of geoducks at Moore Islands, by sub-sample, ranged from 52.0 years to 74.2 years (Table 5). Sub-sample mean weight ranged from 986.8 g to 1020.7 g. Shell length ranged from 141.5 mm to 144.2 mm and shell weight ranged from 226.7 g to 241.7 g. The sub-sample with the highest mean age (H2, Site 8) had the highest mean shell length and weight but the lowest mean total weight and poor quality.

Age frequency distributions (Figure 8) varied between sub-sample locations (Figures 3 to 5). Sub-sample H1 (Site 1) and H2 (Site 8) had roughly similar age frequency distributions, both having strong modes at ages 10 and 11, although Sub-sample H1 had a mode around age 54 to 60 years which was lacking in Sub-sample H2. Sub-sample H3 (Site 10) lacked the strong mode of the youngest age classes and had fewer geoducks in the oldest age classes. Also, Sub-sample H3 had a mode between 18 to 24 years which was not present in the other two sites.

3.6 HORSE CLAMS

Horse clams were encountered on 27 of 41 surveyed transects in densities ranging from 0.01 – 0.49/m^2. Site 10 had the highest horse clam densities (0.33/m^2) followed by Site 1 (0.13/m^2). The two remaining sites had densities < 0.1/m^2.

4. DISCUSSION

4.1 GENERAL

The estimated biomass of geoduck stocks in the beds surveyed at the Moore Islands increased more than four times as a result of higher estimated survey density and increased bed area. The density estimate used to calculate quotas increased from the previous estimate of 1.57/m^2, which was an extrapolation from other north coast surveys (estimated in 2001) to 5.04/m^2. The large increase in the area estimate reflects the lack of information about the size and extent of geoduck beds in the Moore Islands prior to the 1998 survey due to the limited prior fishing activity.

To date, the Moore Islands have been fished in three rotations and 2.2% of the estimated virgin biomass, calculated with the revised digitized area estimate, has been harvested from surveyed geoduck beds. This is less than the current target harvest rate of 1% virgin biomass per year, given that each of the three rotations equates to three years harvest (3% per rotation, 9% overall).

Two other North/Central Coast survey locations that have been analyzed to date had similarly short fishing histories prior to surveying. East Prescott Island, surveyed in 2004, and Principe Channel, surveyed in 1997, had harvest removal densities of 0.02 and 0.03/m^2, respectively. Principe Channel and Prescott Island had mean density estimates over the revised survey area of 2.39/m^2 and 2.61/m^2, respectively, approximately half that of the Moore Islands (Dovey et al. 2006a, 2006b).

For 2005, the north coast geoduck fleet recommended a 50.4 tonne quota for the Moore Islands (GMA PRA14, IFMP Geoduck and Horse Clam, 2005, www.pac.dfo-mpo.gc.ca) and landed 51.5 tonnes (preliminary logbook data), which was well below the 160 tonne mean calculated quota. Comments from the fleet and the on-grounds monitor confirm high densities in the Moore Islands, but a lower quota is recommended in order to avoid harvesting high numbers of poor quality geoducks (short, dark siphons). Harvesters comment that geoduck quality varies throughout the Moore Islands, as was reflected in the biological samples, and that fishing concentrates on the high quality geoducks.

Growth parameters for the Moore Islands samples (all sub-samples combined) were estimated by Bureau et al. (2002). Of 41 surveys where age samples were collected, Moore Islands had the third highest mean age of 63.8 years (Bureau et al. 2002, 2003). The relatively high mean age at Moore Islands compared to other sampled areas is probably reflective of the relatively unfished state of the beds at Moore Islands. Interestingly, the size frequency distributions showed a peak of recruitment about 10 years before the sample was collected, or 8 years before the Moore Islands were fished for the first time, suggesting that even virgin populations can periodically receive strong recruitment pulses.

The low mean total weight associated with Sub-sample H2 is likely associated with the 'poor' geoduck quality at this location, in that a high proportion of the geoducks had short siphons (termed "bullets"). This site also had the highest mean age. Differences in mean age, mean weight and age frequency distributions of geoducks have been found to occur on various spatial scales (Bureau et al. 2002, 2003). Data presented here for Moore Islands show that variations in those parameters are also present on small spatial scales (the farthest distance between samples at Moore Islands was only 2.8 km), and that they can occur in virgin populations.

Geoduck harvesters have often stated that densities increase with depth, and previous survey reports from southern BC and the Queen Charlotte Islands confirm this trend up to 10 to 15 m datum (Campbell et al. 1996a, 1996b, 1998b; Hand and Dovey 1999, 2000; Dovey et al. 2006a, 2006b). The Moore Island survey also confirms this trend. Harvesting may contribute to this trend since the length of time that a diver may safely work underwater decreases with depth and divers may concentrate on geoducks at shallower depths in order to increase bottom time. However, the lack of significant fishing activity at the Moore Islands and at Principe Channel (Dovey et al. 2006a) before surveying indicates that there is a natural trend of increasing density with depth. Survey crews now dive to 18 m chart datum, instead of 18 m uncorrected tide height, in order to ensure that the full range of currently harvested geoduck densities are surveyed. Maximum survey depth could also be increased, or remote sensing techniques employed, if landings from the fleet indicate divers are working below 18 m in the future.

Field crews suspect that survey density estimates are conservative for a number of reasons, including water visibility, algal cover, show factors and diver limitations. Surveys are conducted in the summer when shows are expected to be high. Show factors from this survey were consistently high (overall mean 97%). However, visibility often deteriorates and layers of algae can cover all or portions of the transect lines. As a result, even the most experienced diver will not see every geoduck show.

Hand and Bureau (2006) reviewed show factor data and suggested that, since survey show factors are fairly consistent, survey protocols should abandon show plots. They further recommended that an analysis of extensive existing data should be completed in order to derive standard show factors applicable to sections of the BC coast. Washington Department of Fish and Wildlife uses a fixed show factor in the absence of an established show plot (75%, Bradbury et al. 2000), as does Alaska Department of Fish and Game (80%, Hoyt and Pritchett 2006) and a recent New Zealand geoduck (*Panopea zelandica*) assessment corrected density data with a fixed show factor of 91.4% (Gribben et al. 2004).

Prior to 1998, two to four show plots were routinely installed on surveys, which utilized about 25% of survey time. Some past surveys have been influenced by wind and weather, resulting in decreased show proportions for a short duration (Campbell et al. 1996a, 2004). Since 1999, survey protocols have included only one show factor plot per survey location, situated in a relatively exposed location in case of a storm event, or no show factor plot, in which case existing show factor data from the vicinity of the survey was used to correct the data.

Ideally, survey transects are placed on commercial geoduck beds only, thereby eliminating the need to post-stratify transects. This approach relies on the spatial accuracy of the fishing locations on the DFO reference charts. Detailed on-grounds observer notes and in-field adjustments to the survey protocol supplement the survey design in order to produce the best estimate of densities in commercial harvest locations. Even so, 6 of the 41 transects (15%) in this survey were omitted from the analysis because they were placed on non-commercial ground.

Geoduck beds are often patchy and even the post-stratified dataset was variable, with 95% confidence bounds of the overall mean density calculated for the revised digitized area ±27% of the mean. To reduce variability caused from placing portions of transects on non-commercial ground, remote sensing technology has been used for most surveys since 2000 to categorize the substrate of the top layer of seabed and to determine the distribution of suitable geoduck habitat (Murfitt and Hand 2004, Hand and Bureau 2006). This technology has become an invaluable tool for determining the spatial extent of geoduck beds relatively quickly, which allows a better definition of the target population prior to surveying. A further reduction of variability may be achieved by stratifying within transects using independently-collected substrate mapping and logbook data, in order to exclude from analysis segments of transects with unsuitable substrate and low densities. Survey analysis to date has only excluded entire transects that do not fall on revised bed area. Some transects, such as those in Site 1 at the Moore Islands, extend beyond the revised bed area. As a result, the transects used to calculate density for this bed included quadrats that were too exposed and had low, non-commercial densities of geoducks, which led to wide confidence bounds. At the Moore Islands 72 of the 424 surveyed quadrats (17%) had hard substrate (category 1) with estimated geoduck density of $0.004/m^2$.

Estimates of virgin geoduck density for individual beds in the North and Central Coast quota regions, excluding the Moore Islands, currently range from 0.59 to $4.91/m^2$, with a mean of $2.09/m^2$ in the North and $2.13/m^2$ in the Central Coast (unpublished data). The mean estimate of virgin density in the Moore Islands of 5.06 geoducks/m^2 (driven largely by Site 10 with a mean density of $10.21/m^2$) is representative of the upper end of geoduck beds in the North and Central Coasts. In quota calculations, density estimates for unsurveyed beds are currently obtained by extrapolating from nearby surveyed beds, if available, or from beds within the same GMA, Statistical Sub-area or Statistical Area.

An examination of survey results and biological sampling has suggested that the assumption of proximal similarity in geoduck density is often invalid (Hand and Bureau 2006) and the variability in density between sites in this survey supports the suggestion. For example, the exposed survey sites on West Moore Islands had higher densities (4.40 – 10.21/m^2) than the site that was located in a protected, shallow channel between the two islets (1.18/m2), suggesting that exposure and depth may influence density. Hand and Bureau (2006) recommend that density estimates be extrapolated on the basis of qualitative characteristics that relate to bed productivity or carrying capacity, such as substrate, exposure, current and recruitment patterns. Information from surveys, biological sampling, harvest logbooks, on-grounds monitors and comments from commercial harvesters can all be incorporated into this system.

4.2 HORSE CLAMS

Horse clam density estimates collected in 2000 on Comox Bar in the Strait of Georgia (unpublished data), prior to the start of the only directed horse clam fishery in BC, were 0.29/m^2 over approximately 60 ha. Only a small amount of the Moore Islands survey area (Site 10: 0.33/m^2, 7.15 ha) (Fig. 4) had commercial horse clam potential.

5. ACKNOWLEDGEMENTS

We are indebted to Doug Stewart, the lead on-grounds monitor, for his knowledge and detailed notes, which we used to fine tune survey protocol design. We wish to thank the crew of the geoduck fishing vessel *Lionsgate*; skipper Tom Lindberg, commercial divers Ken Brewer and Reg Glasco. In addition we appreciate the hard work and suggestions from consultant biologist Lynn Lee. Miriam O took the time to review this manuscript.

6. REFERENCES

Bradbury, A., Sizemore, B., Rotaus, D., and Ulrick, M. 2000. Stock assessment of subtidal geoduck clams (*Panopea abrupta*) in Washington. Marine Resources Unit, Fish Management Division, Fish Program, Washington Department Fish and Wildlife. 52 p.

Breen, P.A. 1982. Geoducks, p. 14-15. *In*: Bernard, F.R. [ed.]. Assessment of invertebrate stocks off the west coast of Canada (1981). Can. Tech. Rep. Fish. Aquat. Sci. 1074.

Bureau, D., Hajas, W., Surry, N.W., Hand, C.M., Dovey, G., and Campbell, A. 2002. Age size structure and growth parameters of geoducks (*Panopea abrupta*, Conrad 1849) from 34 locations in British Columbia sampled between 1993 and 2000. Can. Tech. Rep. Fish. Aquat. Sci. 2413: 84 p.

Bureau, D., Hajas, W., Hand, C.M., and Dovey, G. 2003. Age, size structure and growth parameters of geoducks (*Panopea abrupta*, Conrad 1849) from seven locations in British Columbia sampled in 2001 and 2002. Can. Tech. Rep. Fish. Aquat. Sci. 2494: 29 p.

Campbell, A., Harbo, R., and Heizer, S. 1996a. A survey of geoduck population density near Sandy Island, Comox, 1993, p. 132-156. *In*: Hand, C.M. and B.J. Waddell [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1993 and 1994. Can. Tech. Rep. Fish. Aquat. Sci. 2089.

Campbell, A., Harbo, R., and Heizer, S. 1996b. A survey of geoduck population density at Marina Island, 1992, p. 157-203. *In*: Hand, C.M and B.J. Waddell [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1993 and 1994. Can. Tech. Rep. Fish. Aquat. Sci. 2089

Campbell, A., Hand, C.M., Paltiel, C., Rajwani, K.N., and Schwarz, C.J. 1998a. Evaluation of some survey methods for geoducks, p. 5- 42. *In*: Gillespie, G.E. and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1996. Can. Tech. Rep. Fish. Aquat. Sci. 2221.

Campbell, A., Clapp, B., Hand, C.M., Harbo, R., Hobbs, K., Hume, J., and Scharf,G . 1998b. Survey of geoduck population density in Goletas Channel, 1994, p. 319-343. *In:* Waddell, B.J., G.E. Gillespie and L.C. Walthers. [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part I. Bivalves. Can. Tech. Rep. Fish. Aquat. Sci. 2214.

Campbell, A., Yeung, C.W., Dovey, G, and Zhang, Z. 2004. Population biology of the Pacific geoduck clam, *Panopea abrupta*, in experimental plots, Southern British Columbia, Canada. J. Shellfish Res. 23: 661-673.

Dovey, G., Babuin, J., Bureau, D., Hajas, W., Hand, C.M., and Murfitt, I. 2006a. Geoduck population surveys in the Rupert quota region of British Columbia between 1996 and 1998: 1. Dundas Island 1998 2. Principe Channel 1997 3. Otter Passage 1996. Can. Manuscr. Rep. Fish. Aquat. Sci. In press.

Dovey, G., Hand, C.M., Bureau, D., Murfitt, I., and Hajas, W. 2006b. A survey of geoduck populations at East Prescott Island, British Columbia, 2004. Geoduck Survey Bulletin [online], 2004-1: 14p. http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/shellfish/geoduck/Surveys/surveys.htm

Efron, B., and Tibshirani, R.J. 1993. An introduction to the bootstrap. Chapman and Hall, New York. 436 p.

Goodwin, L. 1977. The effects of season on visual and photographic assessment of subtidal geoduck clam (*Panope generosa* Gould) populations. Veliger 20(2):155-158.

Goodwin, L., and Pease, B.C. 1991. Geoduck, *Panopea abrupta* (Conrad, 1849), size, density, and quality as related to various environmental parameters in Puget Sound, Washington. J. Shellfish Res. 10(1): 65-77.

Gribben, P.E., Helson, J., and Millar, R. 2004. Population abundance estimates of the New Zealand geoduck clam, *Panopea zelandica*, using North American methodology: is the technology transferable? J. Shellfish Res. 23: 683-691.

Hand, C.M., and Bureau, D. 2006. Geoduck stock assessment framework in British Columbia. Can. Stock Assessment Secretariat Research Document. In press.

Hand, C.M., and Dovey, G. 1999. A survey of geoduck populations in the Elbow Bank and Yellow Bank area of Clayoquot Sound, West Vancouver Island, in 1994 and 1995. Can. Manuscr. Rep. Fish. Aquat. Sci. 2479: 33 p.

Hand, C.M., and Dovey, G. 2000. A survey of geoduck populations in the Griffith Harbour area, North Banks Island, in August 1995. Can. Manuscr. Rep. Fish. Aquat. Sci. 2541: 20 p.

Hollander, M., and Wolfe, D.A. 1999. Nonparmetric statistical methods. John Wiley and Sons, New York. 787 p.

Hoyt, Z., and Pritchett, M. 2006. Geoduck clam stock assessment surveys and fishery management for the 2003/2004 season. Regional Information Report, Alaska Department of Fish and Game. In press.

Murfitt, I., and Hand, C.M. 2004. Acoustical substrate classification for the improved estimation of geoduck clam abundance and distribution, p. 289-300. *In*: Nishida, T., P.J. Kailola and C.E. Hollingworth [eds]. 2004. GIS/spatial analyses in fishery and aquatic sciences (Vol. 2). Fishery-aquatic GIS research group, Saitama, Japan.

Table 1. Geoduck landings and estimates of density removed from the commercial bed area surveyed at the Moore Islands in 1998. Removals were calculated with mean weight estimates from logbook records (1996-2002), and the revised digitized bed area estimate.

Survey Location	Year	Landings (kg)	Number Landed	Digitized Bed Area (ha)[1]	Density Removed (#/m^2)	Biomass Removed (kg/m^2)
Prior to Survey	1996	18,854	16,715	70.68	0.02	0.03
Post Survey	1999	32,568	28,873	70.68	0.04	0.05
	2002	32,358	28,686	70.68	0.04	0.05
	Total	83,781	74,274	70.68	0.11	0.12

[1]The digitized bed area reported in this table is larger than the digitized area covered by the survey. Landings are assigned per bed code, which may be comprised of multiple polygons. Survey protocol did not cover all polygons for all beds surveyed.

Table 2. Summary of transect information for the 1998 Moore Islands survey. Density values are corrected by the show factor and presented for quadrats ≥ 3 m.

Site	Transect	Date	Depth (m)		Length (m)		Num Quads	Density	Proportion	Site	Water	Neck	Substrate[3]	Omit	Comment[4]
			Min	Max	Total	≥3m	≥3m	(#/m^2)	Showing	Exp.[1]	Vis (ft)	Exp.[2]		Transect	
1	1	13-Aug-98	6.7	17.7	125	125	13	0.57	0.961	7	35	5	1		split transect, shallow portion was T101
1	2	13-Aug-98	4.4	16.9	175	175	18	3.80	0.961	7	35	5	2		
1	3	13-Aug-98	4.8	15.3	165	195	17	3.60	0.961	7	35	5	2		
1	4	14-Aug-98	7.5	15.9	65	65	7	4.50	0.990	7	30	0	2		
1	11	15-Aug-98	8.4	15.6	95	95	7	12.82	0.985	5	30	25	3		
1	12	15-Aug-98	0.5	14.9	155	140	10	8.44	0.985	5	30	25	3		
1	13	15-Aug-98	3.4	16.6	185	185	10	4.91	0.985	5	30	5	3		
1	14	15-Aug-98	10.4	16.3	95	95	7	5.64	0.985	5	30	0	3		
1	16	14-Aug-98	1.2	15.7	65	45	3	11.07	0.990	7	30	5	1		
1	17	14-Aug-98	6.7	13.8	245	245	13	2.40	0.990	7	30	5	2		
1	18	14-Aug-98	9.1	13.7	165	165	9	6.56	0.990	7	30	5	3		
1	19	14-Aug-98	7.1	15.9	285	285	15	4.92	0.990	7	30	50	3		
1	20	15-Aug-98	9.1	15.8	245	245	13	0.23	0.985	7	30	0	3		
1	21	15-Aug-98	4.8	17.3	185	185	10	0.03	0.985	7	30	0	2	Y	off revised bed
1	101	14-Aug-98	0.1	10.1	65	35	4	0.00	0.990	7	30	NA	1		shallow portion of T1
1	HT1	19-Aug-98	8.2	13.1	95	95	10	9.32	0.991	5	30	20	3	Y	harvest
		Site Sampling Intensity (#quadrats/ha): 4.83													
7	28	18-Aug-98	2.9	4.5	110	110	8	0.65	0.995	5	30	0	2		
7	29	19-Aug-98	1.1	7.6	110	110	5	1.11	0.993	5	30	0	2		
7	30	19-Aug-98	2.4	9.5	125	125	9	0.12	0.993	5	30	0	3		
7	31	19-Aug-98	0.5	5.1	65	65	4	0.00	0.993	5	25	NA	3	Y	off revised bed
7	32	19-Aug-98	-0.8	6.8	50	50	3	0.00	0.993	5	25	NA	2	Y	off revised bed
7	33	17-Aug-98	0.7	7.1	65	65	4	0.05	0.995	5	25	0	3	Y	off revised bed
7	34	18-Aug-98	1.4	6.2	155	155	3	0.93	0.995	5	25	5	2		
7	35	13-Aug-98	-0.5	7.0	145	145	4	1.27	0.961	5	35	5	2		
7	36	16-Aug-98	0.9	9.6	170	170	8	2.55	0.983	5	30	5	2		
		Site Sampling Intensity (#quadrats/ha): 3.70													

Table 2 continued

Site	Transect	Date	Depth (m)		Length (m)		Num Quads	Density	Proportion	Site	Water	Neck	Substrate[3]	Omit	Comment[4]
			Min	Max	Total	≥3m	≥3m	(#/m^2)	Showing	Exp.[1]	Vis (ft)	Exp.[2]		Transect	
8	37	17-Aug-98	3.1	15.6	45	45	11	0.03	0.995	7	30	0	1	Y	off revised bed
8	38	17-Aug-98	3.3	17.1	145	145	8	7.25	0.995	7	30	30	2		
8	39	17-Aug-98	4.8	15.8	165	165	9	6.60	0.995	7	30	10	3		
8	40	17-Aug-98	0.1	14.8	125	125	6	6.33	0.995	7	30	20	3		
8	41	17-Aug-98	0.9	15.0	145	145	7	4.34	0.995	7	30	20	2		
8	42	16-Aug-98	3.4	16.8	205	205	11	6.56	0.983	7	30	20	3		
8	43	13-Aug-98	8.4	16.5	165	165	9	3.26	0.961	7	35	5	3		
8	44	12-Aug-98	1.9	15.4	235	235	23	0.47	0.885	7	30	5	3		
8	45	12-Aug-98	-0.6	15.7	85	85	5	3.57	0.885	7	30	5	2	Y	off revised bed
8	51	17-Aug-98	4.5	15.9	165	165	9	8.64	0.995	7	30	20	3		
8	52	18-Aug-98	1.6	16.4	225	225	11	6.92	0.995	7	30	25	2		
8	53	18-Aug-98	1.9	13.3	285	285	13	2.64	0.995	5	30	5	3		
8	54	18-Aug-98	1.0	12.5	285	285	12	4.93	0.995	5	30	5	3		
8	55	18-Aug-98	1.3	14.4	145	145	7	0.42	0.995	5	30	5	3		
8	HT2	19-Aug-98	10.9	13.7	95	95	10	0.98	0.991	7	30	5	3	Y	harvest
		Site Sampling Intensity (#quadrats/ha): 4.23													
10	48	16-Aug-98	2.1	15.0	200	200	13	16.24	0.983	5	30	10	3		
10	49	16-Aug-98	5.0	14.7	170	170	12	5.09	0.983	5	30	5	2		
10	50	16-Aug-98	5.6	16.4	185	185	13	8.85	0.983	5	30	30	1		
10	HT3	19-Aug-98	2.7	13.3	105	95	10	9.03	0.991	5	30	25	3	Y	harvest
		Site Sampling Intensity (#quadrats/ha): 5.31													

[1]Site exposure: 0 = extreme shelter, 2 = well sheltered, 3 = occasional current, 4 = moderate exposure, 5 = strong tide flow, 6 = high tide surge only, 7 = ground swell normal, 8 = high exposure
[2]Neck exposure is the percentage of geoducks with siphons extending above the surface of the substrate and is a measure of siphon visibility
[3]Substrate lists the most dominant substrate code on the transect, as follows: 1 = hard – one or mixture of: bedrock and boulder. 2 = mixed – cobble and/or gravel, or combinations of codes 1, 2 or 3. 3 = soft – one or more mixtures of: pea gravel, sand, shell or mud.
[4]Off revised bed: transect no longer falls on a bed. Following the survey the bed was re-digitised.
[4]Harvest: harvest transects were selected from survey transect locations, therefore they are not included in the analysis.

Table 3. Summary of density and biomass estimates with associated bootstrapped confidence bounds for the Moore Islands 1998 survey. Survey densities were corrected with show factor data from plots 1 and 2 combined, and are presented for quadrats ≥ 3 m depth. Results are presented for all data and for the post-stratified dataset. Mean weight estimates were calculated from logbook records (1996-2002).

Survey Site	Bed Code(s)	Number of Transects	Show Plots Used	Survey Density Estimate (geoducks/m^2)		Precision[2] (±%)	Mean Weight (kg)	Biomass Density (kg/m^2)	Survey Area (ha)	Survey Biomass (metric tonnes)		Precision[2] (±%)
				Mean	(95% CB)					Mean	(95% CB)	
Moore Islands, total survey area and all transects												
1	106-02-02, -14, -15	15	1 & 2	4.05	(2.29 - 5.45)	39	1.119	4.53	32.27	1,462	(791 - 2,058)	44
7	106-02-01, -17	9	1 & 2	0.98	(0.44 - 1.85)	72	1.067	1.05	12.98	136	(58 - 254)	72
8	106-02-03	14	1 & 2	4.63	(2.90 - 5.87)	32	1.164	5.39	33.31	1,795	(1,085 - 2,416)	38
10	106-02-06	3	1 & 2	10.21	(5.09 - 13.78)	43	1.161	11.85	7.15	847	(403 - 1,263)	51
Combined[1]		**41**		**4.32**	**(3.40 - 5.30)**	**22**		**4.95**	**85.71**	**4,240**	**(3,320 - 5,314)**	**24**
Moore Islands, revised survey area and associated transects												
1	106-02-02, -14, -15	14	1 & 2	4.40	(2.71 - 5.76)	38	1.119	4.92	29.43	1,450	(858 - 2,056)	42
7	106-02-01, -17	6	1 & 2	1.18	(0.64 - 2.10)	62	1.067	1.26	10.40	131	(67 - 238)	66
8	106-02-03	12	1 & 2	4.75	(2.88 - 5.98)	33	1.164	5.53	32.51	1,798	(1,053 - 2,409)	38
10	106-02-06	3	1 & 2	10.21	(5.09 - 13.78)	43	1.161	11.86	7.15	847	(399 - 1,260)	51
Combined[1]		**35**		**4.65**	**(3.70 - 5.71)**	**22**		**5.31**	**79.48**	**4,226**	**(3,314 - 5,268)**	**24**
Moore Islands, revised digitized area and associated transects												
1	106-02-02, -14, -15	14	1 & 2	4.40	(2.71 - 5.76)	38	1.119	4.93	16.43	809	(474 - 1,109)	39
7	106-02-01, -17	6	1 & 2	1.18	(0.64 - 2.10)	62	1.067	1.26	8.09	102	(52 - 185)	65
8	106-02-03	12	1 & 2	4.75	(2.89 - 5.98)	33	1.164	5.53	30.29	1,677	(985 - 2,246)	38
10	106-02-06	3	1 & 2	10.21	(5.09 - 13.78)	43	1.161	11.85	9.68	1,147	(540 - 1,706)	51
Combined[1]		**35**		**5.04**	**(3.99 - 6.28)**	**23**		**5.79**	**64.49**	**3,735**	**(2,876 - 4,855)**	**27**

[1]Values are weighted by estimated site area.
[2]Averaged asymmetrical bootstrapped confidence bounds ±% of the mean.

Table 4. Comparison of mean biomass estimates for the 1998 Moore Islands geoduck survey. The density and area estimates presented are from the post-stratified data (transects that were off the revised bed area were omitted from analysis). Virgin density was calculated by adding the removals prior to the survey (Table 1) and virgin biomass was estimated by adding the biomass removed over the survey area (Table 1).

	Area (ha)	Density (geoducks/m^2)	Biomass (metric tonnes)
Pre-survey digitized bed area and pre-survey assumed[1] virgin density estimate	49.30	1.57	873 (548-1,242)[2]
Revised survey area and survey density estimate	79.48	4.65	4,226
Revised survey area and virgin density estimate	79.48	4.67	4,243
Revised digitized area and survey density estimate	64.49	5.04	3,735
Revised digitized area and virgin density estimate	64.49	5.06	3,752

[1]In the absence of survey data, density estimates are extrapolated from other surveyed beds in the Region.
[2] Values in brackets are estimated 95% confidence bounds, using fractional error method described in Hand and Bureau 2006.

Table 5. Summary data for biological samples collected from the Moore Islands in 1998.

Sub-Sample Location	Sample Site	Survey Site	Latitude	Longitude	n	Age (years) Mean	Age (years) Min	Age (years) Max	Mean Total Weight (g)	Mean Shell Length (mm)	Mean Shell Weight (g)	Mean Quality[1]
Moore Islands	H1	1	52 40.81	129 25.82	110	65.2	8	128	1020.7	141.8	226.7	1.4
Moore Islands	H2	8	52 39.35	129 25.13	101	74.2	9	125	986.8	144.2	241.7	2.5
Moore Islands	H3	10	52 39.92	129 26.04	100	52.0	9	120	1007.0	141.5	232.1	1.7
	Combined				311	63.8	8	128	1004.8	142.5	233.5	

[1]Mean Quality: A scale from 1 (good, cream colour and long siphon) to 4 (poor, dark colour and short siphon), which quantifies market desirability.

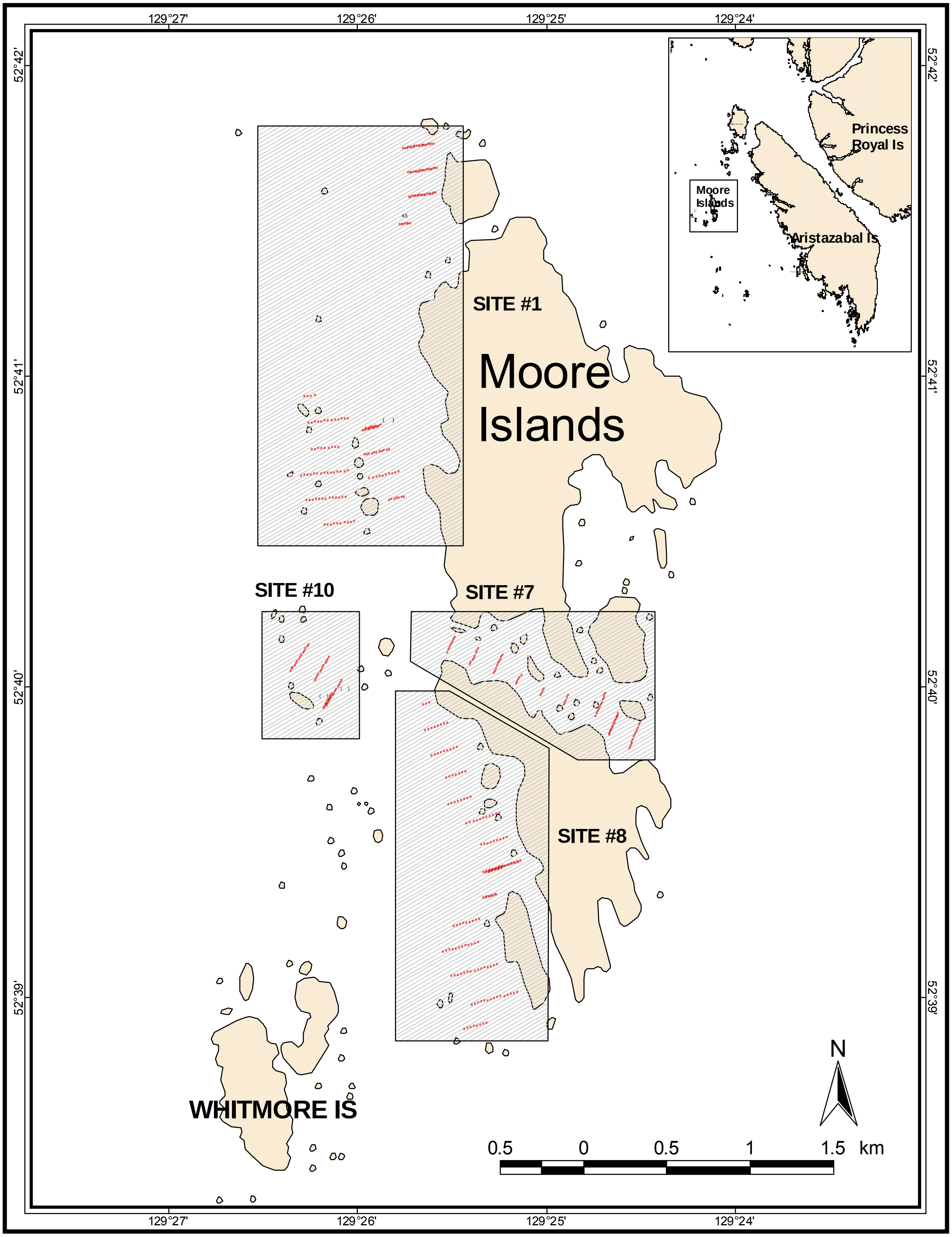


Figure 1. Moore Islands geoduck survey site locations, central coast, BC, 1998.

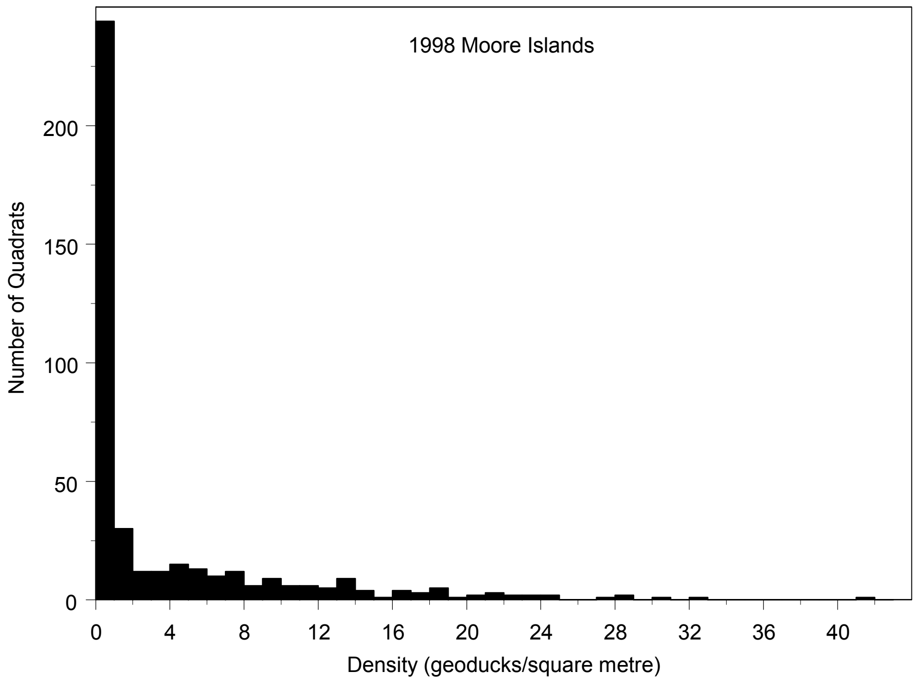


Figure 2. Frequency distribution of geoduck density from the quadrats surveyed at the Moore Islands in 1998.

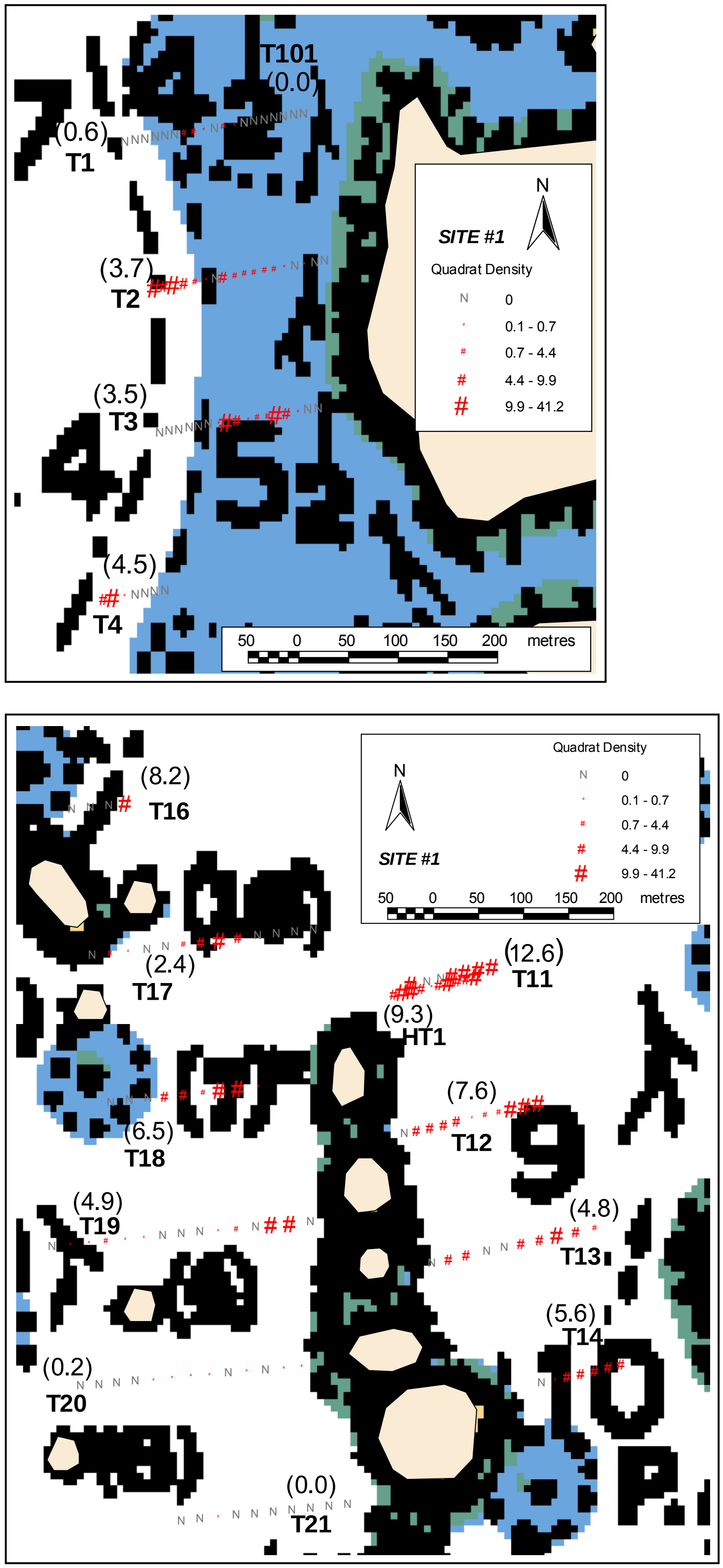
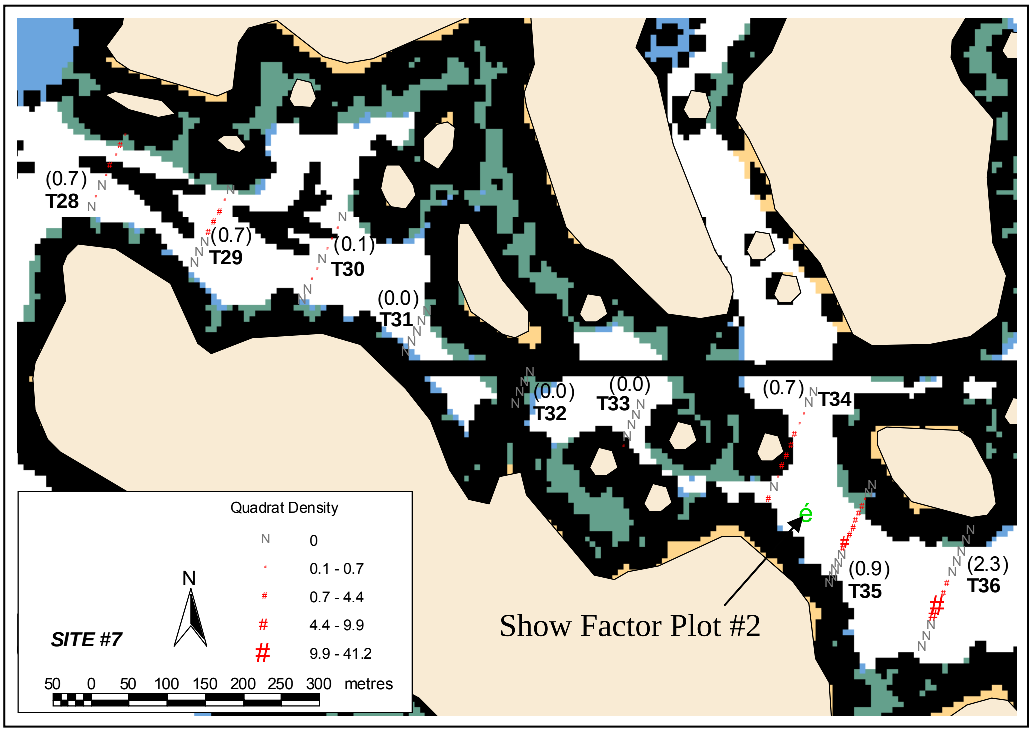


Figure 3. Transects and harvest location (HT1) for survey Site 1 at the Moore Islands (1998) showing quadrat density and overall density (in brackets) of geoducks (#/m^2).



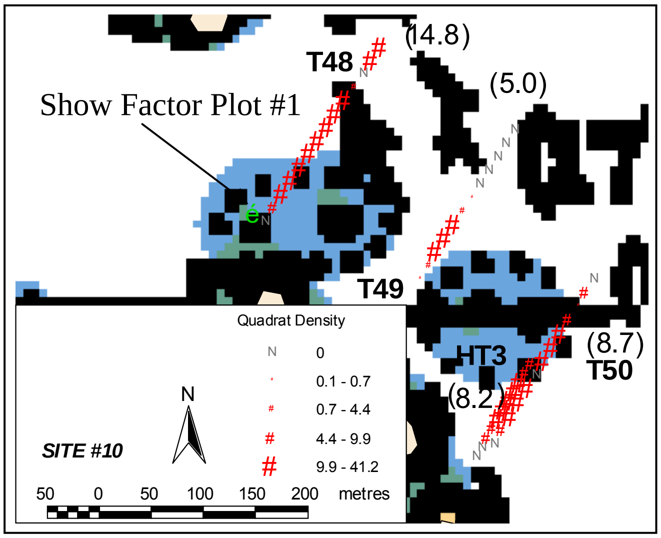


Figure 4. Transects, show plot and harvest location (HT3) for survey Sites 7 and 10 at the Moore Islands (1998) showing quadrat density and overall density (in brackets) of geoducks (#/m^2).

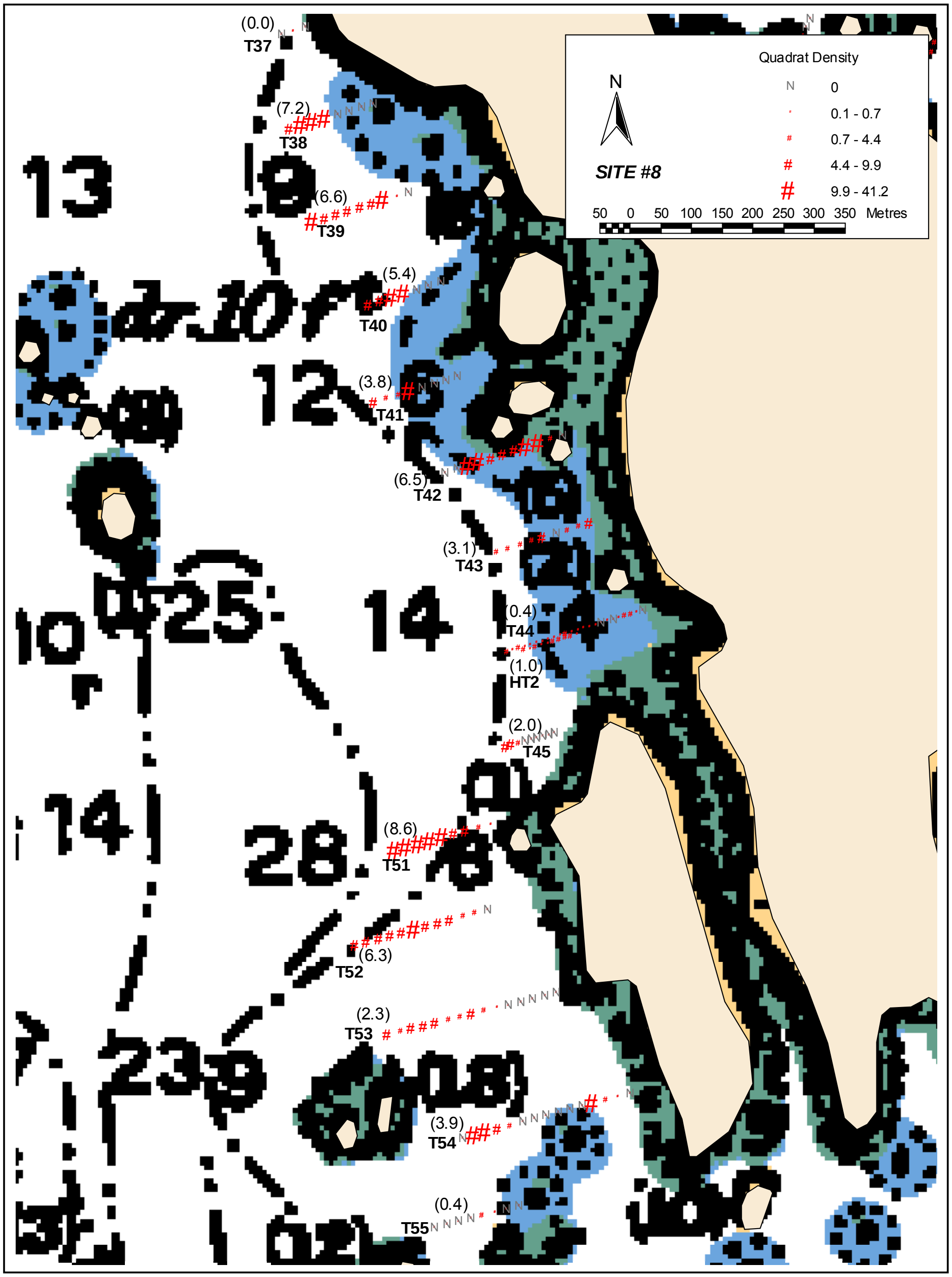


Figure 5. Transects and harvest location (HT2) for survey Site 8 at the Moore Islands (1998) showing quadrat density and overall density (in brackets) of geoducks (#/m^2).

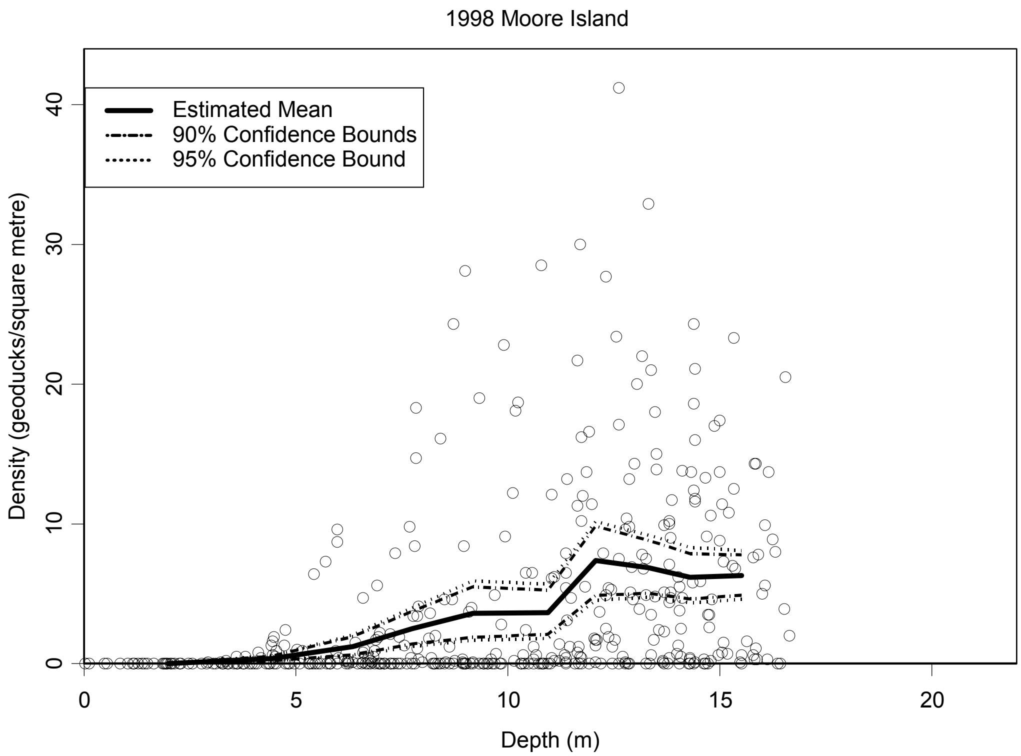


Figure 6. Geoduck density versus depth (corrected for tide height) with the estimated mean geoduck density and associated bootstrapped confidence intervals from the quadrats surveyed at the Moore Islands in 1998.

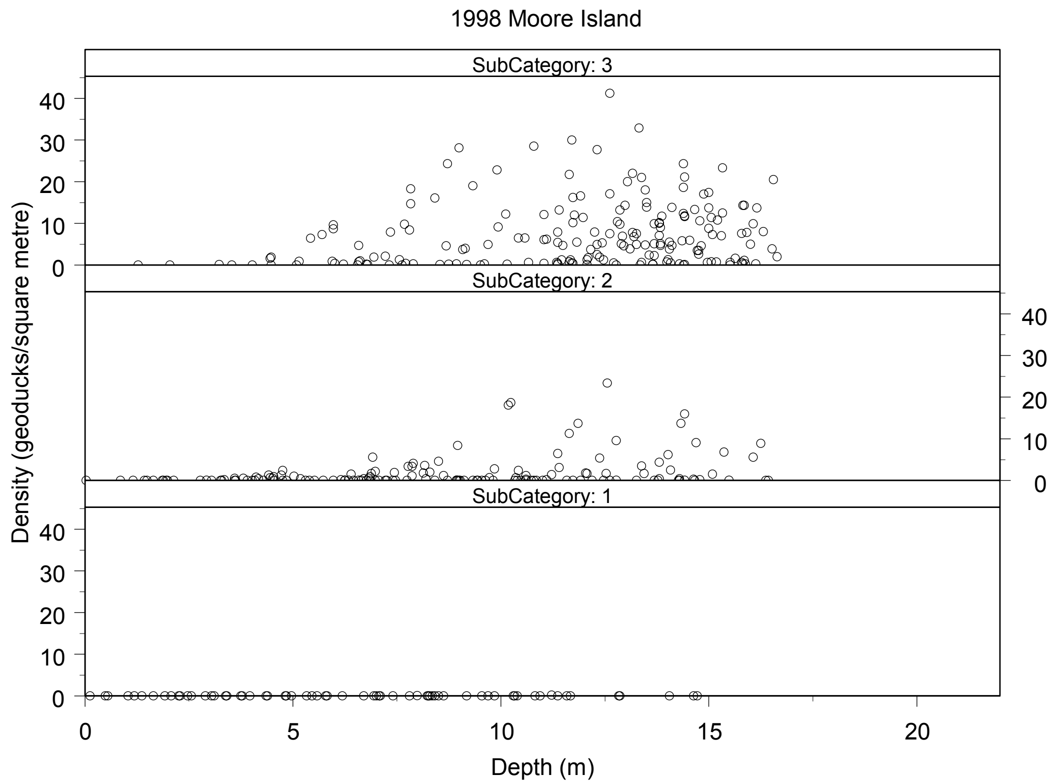


Figure 7. Geoduck density versus depth for each substrate category at the Moore Islands in 1998.
1 = hard: one or more mixtures of bedrock and boulder
2 = mixed: cobble and / or gravel or combinations of codes 1, 2 or 3
3 = soft: one or more mixtures of pea gravel, sand, shell, mud

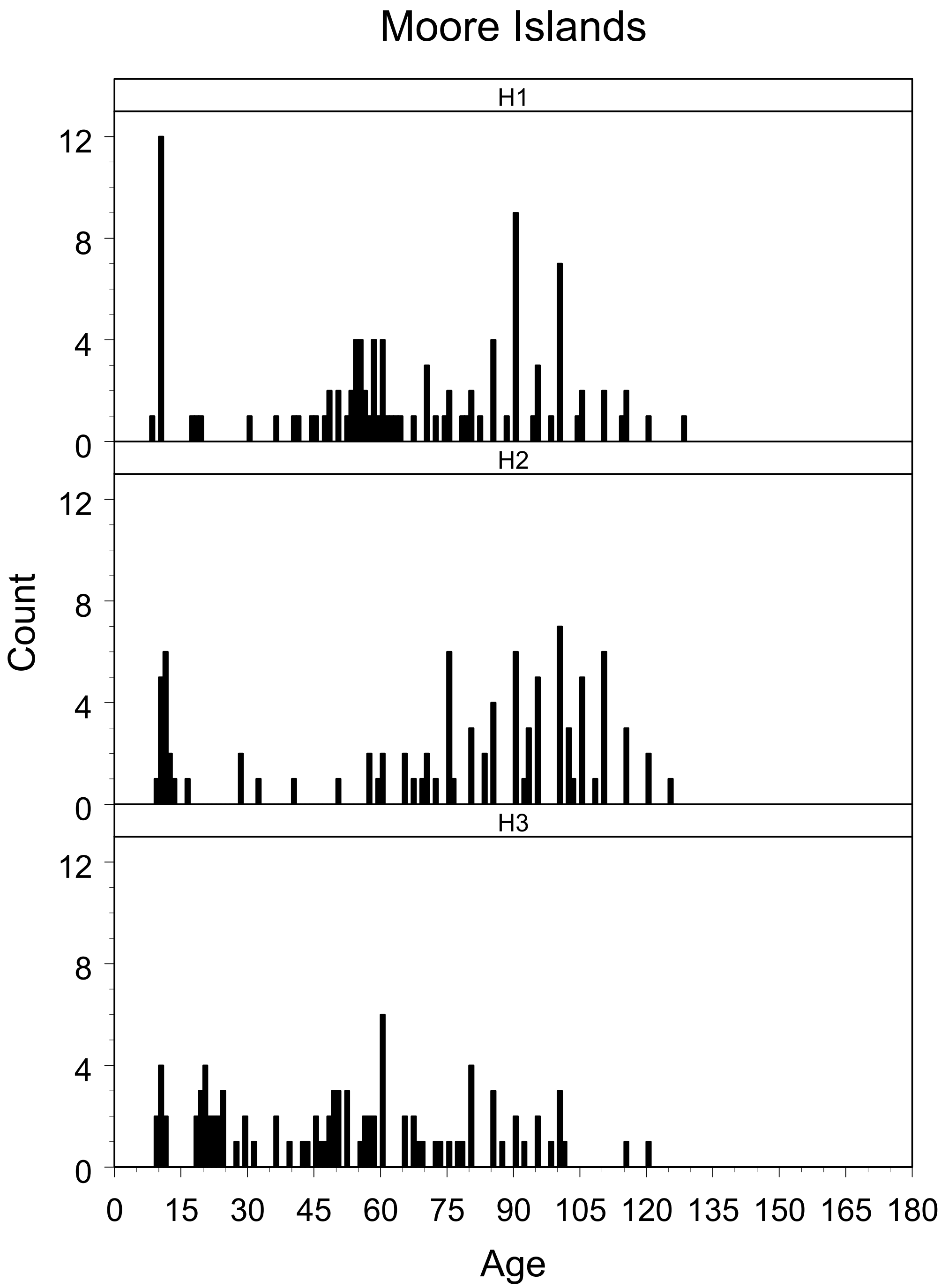


Figure 8. Age frequency of geoducks, by sub-sample location, for samples collected at the Moore Islands, 1998.