A Survey of Geoduck Populations in the Elbow Bank and Yellow Bank Area of Clayoquot Sound, West Vancouver Island, in 1994 and 1995

C. M. Hand and G. Dovey

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
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V9R 5K6

1999

Canadian Manuscript Report of Fisheries and Aquatic Sciences 2479

Fisheries and Oceans Canada
Science

Pêches et Océans Canada
Sciences

Canada

Canadian Manuscript Report of Fisheries and Aquatic Sciences

Rapport manuscrit canadien des sciences halieutiques et aquatiques

Canadian Manuscript Report of

Fisheries and Aquatic Sciences 2479

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by

C. M. Hand and G. Dovey[1]

Fisheries and Oceans Canada

Science Branch, Pacific Region

Pacific Biological Station

Nanaimo, British Columbia

V9R 5K6

[1] Underwater Harvesters Association
Box 2715
Ladysmith, British Columbia
V0R 2E0

Cat. No. Fs 97-4/2479E ISSN 0706-6473

Correct citation for this publication:

Hand, C. M. and G. Dovey. 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.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Hand, C. M. and G. Dovey. 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.

A survey of geoduck (*Panopea abrupta)* stocks in a portion of Clayoquot Sound, on the west coast of Vancouver Island, was conducted by the Underwater Harvesters Association and Fisheries and Oceans Canada in Sept. and Oct. of 1994 and Sept. and Oct. of 1995. The purpose of these surveys was to estimate the density of geoducks in known beds, establish and verify the boundaries of the beds and determine the age and weight distribution of the population from samples of geoducks collected. Virgin density was also calculated by reconstructing it from the survey density, the density of geoducks removed by the fishery and the density of recruited geoducks. Survey results are considered in the process of quota calculations for the geoduck fishery on the west coast of Vancouver Island.

A total of 48 randomly-placed transects were completed over 392 hectares on Elbow Bank, Yellow Bank, Morfee and Dunlap Islands and north Epper Pass. The average density was estimated to be 1.5 geoducks/m^2 on Elbow Bank, 2.5/m^2 on Yellow Bank, 1.7/m^2 on Morfee/Dunlap and 1.1/m^2 on north Epper Pass. The density of geoducks removed ranged from 0.1/m^2 to 1.1/m^2 and averaged 0.5/m^2 over all four beds. The density of new recruits, determined from biological samples collected from Elbow Bank and Yellow Bank, ranged from 0.2/m^2 to 0.8/m^2 and averaged 0.5/m^2. Estimates of reconstructed virgin geoduck densities are 2.3/m^2 for both Elbow Bank and Yellow Bank, 1.3/m^2 for Morfee/Dunlap and 1.2/m^2 for Epper Pass, with an overall average of 1.87/m^2. This is a 34% increase over previous estimates.

Results of the survey indicate that the geoduck bed on Yellow Bank and the bed on Morfee/Dunlap are, in effect, one continuous bed. As a result, the original estimate of the area of geoduck beds in the survey area, based on harvest logs, increased by 40% from 272 ha to 383 ha.

The total biomass of geoducks in the survey area and the back-calculated biomass of the virgin population were both estimated to be 15.9 million pounds, compared to 9.2 Mlb from previous estimates of density, area and mean weight. Survey results suggest that these heavily harvested beds could support continued harvests.

RÉSUMÉ

Hand, C. M. and G. Dovey. 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.

Des relevés des stocks de panope (*Panopea abrupta*) ont été menés en septembre et octobre 1994 et 1995 dans une portion de la baie Clayoquot, sur la côte ouest de l'île de Vancouver, par l'Underwater Harvesters Association et le ministère des Pêches et des Océans. Les relevés avaient pour but d'estimer la densité des panopes dans les gisements connus, d'établir et de vérifier les limites des gisements et de déterminer la distribution par âge et par poids de la population à partir des échantillons prélevés. La densité du stock vierge a également été reconstituée à partir de la densité tirée des relevés, de la densité des panopes prélevées par la pêche et de la densité des panopes recrutées. Les résultats de ces relevés sont considérés dans le mode de calcul des quotas de la pêche à la panope sur la côte ouest de l'île de Vancouver.

L'échantillonnage a eu lieu sur un total de 48 transects établis au hasard dans une zone de 392 hectares sur le banc Elbow, le banc Yellow, les îles Morfee et Dunlap et le nord de la passe Epper. On a estimé la densité moyenne à 1,5 panope/m^2 sur le banc Elbow, 2,5/m^2 sur le banc Yellow, 1,7/m^2 aux îles Morfee et Dunlap et 1,1/m^2 dans le nord de la passe Epper. La densité des panopes prélevées allait de 0,1/m^2 à 1,1/m^2, et elle était en moyenne de 0,5/m^2 sur l'ensemble des quatre gisements. La densité de nouvelles recrues, calculée à partir d'échantillons biologiques recueillis au banc Elbow et au banc Yellow, allait de 0,2/m^2 à 0,8/m^2, et elle était en moyenne de 0,5/m^2. Les estimations des densités du stock vierge seraient de 2,3/m^2 pour le banc Elbow et le banc Yellow, 1,3/m^2 pour les îles Morfee et Dunlap, et 1,2/m^2 pour la passe Epper, soit une moyenne globale de 1,87/m^2, ce qui représente une augmentation de 34 % par rapport aux estimations précédentes.

Les résultats des relevés indiquent que le gisement du banc Yellow et celui des îles Morfee et Dunlap constituent en fait un seul gisement. En conséquence, l'estimation initiale de la superficie des gisements de panope dans la zone d'étude, à partir des journaux de pêche, a augmenté de 40 %, passant de 272 ha à 383 ha.

La biomasse totale de panope de la zone couverte, et la biomasse de la population vierge obtenue par rétrocalcul, ont été toutes deux estimées à 15,9 millions de livres, contre 9,2 millions de livres dans les estimations antérieures d'après la densité, la superficie et le poids moyen. Les résultats des relevés permettent donc de penser que ces gisements déjà fortement exploités pourraient continuer à être pêchés.

1.0 INTRODUCTION

Geoduck clams (*Panopea abrupta (*Conrad, 1849)) have been harvested commercially in British Columbia (BC) since 1976. The fishery and biology are summarized by Hand *et al.* (1998). Geoducks are managed under an Individual Vessel Quota system where the coastwide annual quota is divided equally amoung licence holders. Annual quotas for each geoduck bed are calculated as a product of the estimated virgin biomass and a fixed exploitation rate of 1% (Hand *et al.* 1998). Estimates of virgin biomass are calculated from estimates of the area of geoduck clam beds, the estimated virgin density and the estimated mean weight per individual.

This method of quota calculation depends on accurate estimates of virgin biomass which, in turn, depends on reliable estimates of geoduck density and bed area (Sloan 1985). A variety of methods are currently being used, or investigated, to improve estimates of bed area. These methods include structured observer fishing, interviews with fishers and on-grounds observers, hydroacoustic technology and transect surveys, with the latter also providing the only reliable source of density information.

Initial estimates of geoduck density were based on large-scale surveys in Washington State (Goodwin 1978) and British Columbia (Table 8 in Harbo *et al.* 1992), small-scale field studies in BC (Breen and Shields 1983, Harbo and Adkins unpublished data, summarized in Table 13 in Harbo *et al.* 1992) and consultations with fishers. The density estimates varied with geographical area, and initially ranged from 1.0 geoducks/m^2 to 5.0/m^2, coastwide. Areas on the west coast of Vancouver Island were assumed to have an estimated 2.0/m^2, double that of the Strait of Georgia. With the results of surveys conducted by the Canadian Department of Fisheries and Oceans (DFO) in 1992 and 1993 in the Strait of Georgia (Campbell *et al.* 1995a, 1995b), densities were reduced to 0.45/m^2 to 0.7/m^2 for Inside Waters (waters east of Vancouver Island) and 1.4/m^2 for the west coast.

Biomass surveys since 1994 have been joint ventures between the geoduck Underwater Harvesters Association (UHA), First Nations groups and DFO. From 1994 to 1998, 28 surveys have been completed throughout all areas of the BC coast. The objectives of these surveys were to obtain density estimates for geoduck clams and horse clams (*Tresus spp.)* in known beds and to establish the boundaries, and thereby the area, of these beds.

The Elbow and Yellow Bank area was selected for survey in response to concerns about overharvesting. A survey was scheduled for September 1994, but only five of the proposed 48 transects were completed, all of them on Elbow Bank. The survey was rescheduled and met with more success in 1995 when 43 transects were completed, five of which overlapped transects done the previous year. Additional survey activity on Yellow Bank was scheduled for 1997, however only one random transect was completed. These surveys, the first to be done on the west coast of Vancouver Island, were conducted by UHA divers, DFO, and contract biologists. This report will present the results for geoducks only; horse clam density and distribution will be reported elsewhere.

Biological samples of geoducks were obtained for age and weight composition, and to assess recruitment. A reconstructed virgin density was calculated by adding the density of geoducks removed by the fishery to the survey density estimates and subtracting the estimated density of geoducks that recruited to the population since the fishery began. The latter quantity was calculated as a product of the survey density and the proportion of geoducks from the biological sample that were between the ages of 5, the youngest age that would be counted in a survey, and 18, the years elapsed since the fishery began.

Information on density and age structure from this survey is compared to results from small-scale studies conducted in 1981 on Elbow Bank (Breen and Shields 1983; Harbo *et al.* 1983).

1.1 Description of Study Area

The survey concentrated on known geoduck and horse clam beds at Elbow and Yellow Banks, Dunlap and Morfee Islands and portions of Epper Passage in Clayoquot Sound, Statistical Area 24-6 and 24-7 (Fig. 1). The beds included in the survey were easily accessible from the west coast community of Tofino. The geoduck fishery began on the west coast of Vancouver Island in 1978, and Elbow Bank was amoung the first beds to be discovered. Over 19 years of fishing (1978-1996), 2,465 tonnes (5.4 million pounds) of geoducks have been harvested from the study area (Table 1). Landings from these beds account for over 20% of the total from Area 24. Area 24 is unique in that it continues to be fished annually whereas the rest of the coast is fished on a three-year rotation. It has supported more fishing than any other Area on the B.C. coast.

Beds located on Elbow and Yellow Banks were closed in 1994 and 1995 for conservation. The management decision for closure was based on the accepted practice of closing fisheries when biomasses was estimated to be less than 50% of the unfished biomass (Harbo *et al.* 1994, 1995). In 1996, Elbow Bank remained closed, while a quota of 37,498 lb (30,000 plus 7,498) was transferred to Yellow Bank from two other areas within Area 24. This was justified by favourable preliminary survey results. In 1997, Yellow Bank was allocated 8,086 lb of quota (15,584 minus 7,498), based on unpublished density estimates from this survey and, in 1998, it was allocated the full calculated 15,584 lb of quota (Hand *et al.* 1998).

2.0 METHODS

2.1 Field Methods

Dive Survey Design

Survey protocols follow the methodology outlined in Campbell *et al.* (1998b). The study area encompassed known geoduck harvest locations, according to logbook information from fishers. Transect locations were assigned by DFO personnel onto charts *a priori* and provided to the survey crews, to reduce possible bias under field conditions. In 1994, the survey followed a two-stage design. Transect locations were assigned systematically along a reference line drawn through the bed at the first stage, and a complete census of the quadrats within the transects was taken at the second stage. Transects were spaced 300 m apart. In 1995, a three-stage sampling design was used. Transects positions were randomly selected at the first stage, a complete census of blocks (multiples of 4 quadrats) taken at the second stage and random selection of a single quadrat within each block at the third stage. The method used in 1995 reduced the time required for each transect, thereby increasing the number of transects that could be completed.

In the field, lead core transect lines were laid perpendicular to depth contours and approximately parallel to each other (Figs. 2 and 3). They extended from 10 ft to 50 ft gauge depth in 1994 and to 60 ft gauge depth in 1995. The shallow depth limit conforms to the minimum depth below chart datum to which the commercial fishery is restricted. Gauge depths were converted to tide height below chart datum using tidal predictions from the harmonic station at Tofino. Corrected depths were, on average, about 7 ft shallower than gauge depths.

The location of the first transect in each study area was determined using references on the shoreline, Global Positioning System (GPS) readings and depth sounder readings. Thereafter, transect location was determined by measuring the predetermined distance between each transect with a loggers hip chain. If a transect ran over a reef of less than 10 feet diving depth, it was terminated and continued on the other side. This occurred in 1995 for transect 4 on Elbow Bank and transects 26 and 27 on Yellow Bank (Fig. 3). Final start and end positions of the transects were recorded with GPS, accurate to within 30 m.

Underwater, two SCUBA divers worked together, one on either side of the transect, and counted all geoduck shows (visible siphons) and dimples (indentations left in the substrate by retracted siphons) within 1 m of each side of the transect. Dimples were counted if the siphon retracted further in response to probing. Divers also recorded the number of horse clams, the depth, substrate type, algal cover and the percentage geoduck necks extending greater than 1-2 cm above the substrate surface. Data was recorded at the end of each 5-m quadrat.

Since geoduck shows can be cryptic, calibration dives were conducted to compare and quantify the detection abilities of the survey divers on one test transect. All survey divers repeated the calibration transect several times during the survey. The possibility of diver's mis-identifying other bivalve species as geoducks is considered low because all participants were either experienced commercial fishers or experienced geoduck surveyors.

Show Factor Plots

Individual geoduck siphons are sometimes withdrawn below the surface of the substrate due to physical and/or biological effects (Goodwin 1977, Turner and Cox 1981) and are not readily visible to divers. Show factor plots, described in Campbell *et al.* (1998b), were established prior to the surveys to estimate the percentage of geoducks showing on each day of observations. The plots were placed in areas with relatively high abundance of geoducks to optimize the precision of the observations, and were situated to attempt to represent the typical substrate and exposure covered by the survey area. In 1994, one plot was located on north Elbow Bank and one on south Elbow Bank (Fig. 2). In 1995, two plots were again located on north and south Elbow Bank and one on Yellow Bank (Fig. 3). These show factor plots were monitored daily and were removed at the end of the survey.

Geoduck Biosamples

Biological samples were collected to determine the size and age characteristics of the geoduck population within the survey area. In the 1994 survey, a sample of 433 geoducks was collected, with no intentional bias towards size, from a single site on Elbow Bank at an average depth of 35 feet (Fig. 2). During the sampling, survey crews on the surface marked each geoduck with a unique number on the right and left valve of the shell. The geoducks were sent to a registered geoduck processing plant where individual total wet weight and shell length were recorded. All shells were cleaned, packaged and sent to the Pacific Biological Station for ageing. In 1997, three sub-samples of 100 geoducks each were collected from randomly selected locations within the Yellow Bank bed, following the recommendations of Campbell *et al.* (1998c) for optimal sample size. A 100 m transect line was laid at each harvest site and was surveyed before the sample was collected. Divers harvested the geoducks within one metre of either side of the full 100 m length of each transect line. The geoducks were again sent to a processing plant where, in addition to the weight and length data, market quality data were also recorded. These quality grades are based on colour, where grades 1 and 2 are white or light coloured and always acceptable to the market, grade 3 is less preferred but usually accepted and grade 4 is usually rejected. Due to a numbering problem, only 13 shells from site H#2 could be aged.

2.2 Laboratory Methods

Method for Ageing Geoduck Shells

Individual geoducks can be aged from growth rings using a validated procedure (Shaul and Goodwin 1982). One of the two geoduck valves are cut perpendicular to the hinge with a thin diamond saw and polished. The surface is etched with hydrochloric acid, treated with acetone and a thin acetylcellulose film is applied, which produces an imprint of the rings of the shell on the cellulose peel. The peels are magnified using a projector and the number of annual growth rings and distance between annuli measured and recorded.

2.3 Analytical Methods

Data Treatment

As an alternative check on the comparability of individual diver counts, transects that were completed by the same pair of divers were grouped, and the number of geoducks counted on each side of the transect line tested against the null hypothesis that the counts are equal. In the event of large biases, a correction would be applied to the data.

This survey was also designed to measure the abundance of horseclams (*Tresus spp*), whose vertical distribution overlaps that of geoduck but extends into shallower water. Since the geoduck fishery is restricted to depths of greater than 10 ft below chart datum, all observations that were shallower than this depth were excluded from the data sets used to calculate geoduck density and bed area. (These excluded data can be seen in Fig. 8.) In doing so, there were two transects (25 and 28), that were broken into two parts because of a shallow middle section (Fig. 3). The excluded portion is indicated by a dotted line on the figure, and the transect that continues on the other side of the bank is renumbered with a decimal 1.

Show Factor Proportions

Analytical procedures for calculating show factor proportions follow Campbell *et al.* (1998b). The proportion of geoducks showing on day *i* (SP_i) in any given area is calculated as

$$SP_i = X_i / \sum_i T_i \tag{1}$$

where X_i is the number of geoduck shows in the plot in day *i* and T_i is the number of previously unobserved shows on day *i*, the sum of which is the total number of enumerated geoducks in the plot. Since SP_i is binomially distributed, the standard error of the estimate ($se(SP_i)$) is approximated as

$$se(SP_i) = \sqrt{\frac{(SP_i(1 - SP_i))}{\sum T_i}} \tag{2}$$

The observed number of geoducks in each surveyed quadrat in the survey was divided by the proportion showing on the same day from the nearest show plot. Yellow Bank, north Epper Pass and Morfee/Dunlap data were corrected with the show factor plot on Yellow Bank. Elbow Bank data were corrected with the closest of the two show factor plots on Elbow Bank. If a transect was completed over two days, the show factors were averaged over the two days.

Area Estimates

Several methods were used to estimate the area of the surveyed geoduck beds. Initial estimates of commercial bed area were based on chart information from fishers that accompany the harvest log reports. DFO personnel transcribed the location of fishing onto reference charts. The resulting polygons were digitized and the area calculated using Geographic Information System software. This information was used in the design phase of the survey to establish the extent of the geoduck bed within which transect locations were randomly or systematically placed. Bed boundaries were redrawn with new information from the survey, and revised estimates of bed area obtained.

The area surveyed was calculated as the sum of the area of all possible transects. Since transect length is only known for those transects surveyed, the lengths of transects that were not surveyed was assumed to be equal to the length of the nearest sampled transect. Thus, the area surveyed (A), in hectares, for each geoduck bed *j* is

$$\mathrm{A_j} = \sum_{i=1}^{n} \mathrm{L}_i(\mathrm{W1}_i + \mathrm{W2}_i) \tag{3}$$

where n is the number of sampled transects in geoduck bed *j*, L_i is the length (m) of the i[th] transect, and $W1_i$ and $W2_i$ are the distances (m) on either side of transect *i*, equidistant to its adjacent transect. For instance, if transect 2 is 100 m from transect 1 and 150 m from transect 3, $W1_2$ would be 50 m and $W2_2$ would be 75 m. Areas were calculated using all observations (that is, including shallow depth) and using the data set where observations less than 10 feet chart datum were removed.

Geoduck Density Estimates

Survey Density

Geoduck counts are adjusted for the proportion of geoducks not showing, by:

$$g_i = b_i \,/\, SP_i \qquad (4)$$

where, for each transect *i*, b_i is the total count of geoducks observed and SP_i is the mean proportion of geoducks showing.

Parametric estimates of the mean density for each bed *j* (d_j) is calculated as the ratio of the sum of adjusted geoduck counts over bed *j* and the sum of transect areas as:

$$d_j = \frac{\sum_{i=1}^{n} q(g_i)}{\sum_{i=1}^{n} a_i} \qquad (5)$$

where *q* is the sampling interval along each transect (in this case, 4) and a_i is the total area of transect *i* in square metres. This ratio estimator of the mean density assumes a straight-line relationship between the estimation variable (number of geoducks) and the auxiliary variable (transect area) (Fig. 4). Area can be viewed as an auxiliary variable, which enables the calculation of the population mean when the total survey area can only be approximated. Use of the ratio estimator reduces the variance of the estimate of mean density due to unequal transect lengths by weighting the transect counts appropriately, according to their length.

Since the distribution of the density data is skewed (Fig. 5), non-parametric confidence intervals for the mean geoduck density were calculated using bootstrap techniques (Efron and Tibshirani 1993). This procedure is referred to as the "naive" bootstrap because the method is generally expected to be biased when applied to complex survey designs, particularly in the case of ratio estimators (Rao and Wu 1988). The procedure randomly samples n transects, with replacement, from the n sampled transects. For each *i-th* selected transect, a number of blocks (u) from the U sampled blocks is randomly selected, with replacement, and the total number of geoducks sampled is multiplied by q (=4) to produce b^*_i.

This count is adjusted by the show factor proportion (SP_i). To include a random component in the proportion, a random sample (j_i) is taken from a binomial distribution with assumed parameters $p = SP_i$ and $n = \sum_i T_i$. This value is then divided by $\sum_i T_i$ to create a proportion $SP_i = j_i / \sum_i T_i$, thus ensuring that the show factor proportion will be between 0 and 1. The corrected geoduck count for the i-th selected transect ($g*_i$) is calculated by:

$$g*_i = \frac{b*_i}{SP_i} \tag{6}$$

The n $g*_i$'s are added, as are the corresponding areas for the resampled transects, and the mean density d_j* calculated as in equation (5). The process was repeated 1000 times to obtain 1000 estimated mean densities: $d*_1, d*_2, \ldots, d*_{1000}$. Bootstrap 95% confidence intervals were then constructed using the percentile method. The 1000 bootstrap estimates of the mean were sorted and the $1000(0.025)^{th}$ value and $1000(1\text{-}0.025)^{th}$ value were used as the bounds of the 95% confidence interval.

Virgin Density

Population levels fluctuate with natural and fishing mortality, and with recruitment. Estimates of recruitment were calculated from the age compositions of the biological samples collected from Elbow Bank and Yellow Bank. These were examined to determine the proportion (Pr) of the sample between the ages of 5 (the youngest age at which geoducks are detectable by divers) and 18 (the number of elapsed years since the fishery began) (Fig. 6). The proportions in Epper Pass and Morfee/Dunlap were estimated from the age composition at Yellow Bank, which was considered to be more representative due to its proximity. The survey density (d_j) for each survey area j is multiplied by Pr to obtain the density recruited, Dr_j.

$$Dr_j = Pr \times d_j \tag{7}$$

The density of geoducks removed by the fishery is calculated from harvest log data and estimates of bed area. The weight of geoduck landings were converted to numbers landed using mean weights determined from the harvest log records where number landed is reported. The density removed from each geoduck bed (Dh_j) is calculated by

$$Dh_j = \frac{C_j}{A_j} \tag{8}$$

where C_j is the total number of geoducks landed from each bed, j, as reported on harvest logs (Table 1) and A_j is the area (m^2) of the bed. For estimates of area, the surveyed area (deeper than 10 feet chart datum) was used, to be consistent with the area over which survey density was calculated.

Virgin density (Dv_j) for each bed is calculated as

$$Dv_j = d_j - Dr_j + Dh_j \tag{9}$$

where Dr_j is the density of geoducks that have recruited to geoduck bed *j* since the fishery began, and Dh_j is the density of geoducks removed by the fishery in each geoduck bed. We made no corrections for natural mortality, which is considered to be very low (Noakes 1992), and therefore virgin density may be underestimated.

3.0 RESULTS

Transect details are summarized in Appendix Tables 1 and 2. A total of 48 transects were completed on the Elbow Bank, Yellow Bank, Epper Pass and Morfee/Dunlap beds in 1994 and 1995 (Fig. 2 and Fig. 3). The single transect completed on Yellow Bank in 1997 is not presented. Transects varied in length between 95 m and 1080 m over mixed substrates of sand, shell and mud. The slope of all of the survey sites was gentle, ranging from 1.2 to 15.2 degrees.

The data from the diver calibration transects were not used to test for bias in the diver's counts because the source of inconsistencies in geoduck counts between divers could not be determined. There was no consistency within either the left side or the right side counts. Even counts by the same diver on the same side of the transect were quite different. The table below illustrates this problem. Same-day inconsistencies could have resulted from geoducks retracting their necks in response to the physical disturbance created by the first diver surveying the calibration line. Inconsistencies over many days may be from disruption resulting from differing oceanographic conditions

Date	Left Side			Right Side		
	Diver	Total	Range[1]	Diver	Total	Range[1]
Sept. 16	A	11	2-5	B	13	0-5
Sept. 17	C	16	1-6	A	10	1-5
Sept. 18	B	14	2-5	C	15	2-5
Sept. 19	C	27	4-10	D	18	1-6

[1] over 20 1-m^2 quadrats

Results of t-tests between diver pairs on survey transects indicated that two of the diver-combinations were significantly different in geoduck counts between the left and right sides of the transect ($p<0.05$). These are the diver combinations '2 : 4' and '1: 3' shown in Figure 7. These biases do not appear large and corrections for under-counting were not made.

3.1 Estimates of geoduck bed area

The original estimate of the area of geoduck beds surveyed, based on logbooks, totalled 272 ha (Table 2). This estimate was increased by 40% to 383 ha when the survey results were used to redraw the beds. The increase was due to extensions of the beds on Yellow Bank and Morfee/Dunlap. Since there was such a large increase, especially on Morfee/Dunlap where it increased from 32 ha to 107 ha, the original logbooks were re-examined to verify that the original bed size had been accurately transcribed. Through this exercise, logbook charts were found which indicated some fishing activities had occurred beyond the boundary of the original polygon. In addition, consultation with divers experienced in the area verified that the bed extended well towards, if not all the way, to Yellow Bank and suggested that fishing effort was low in this section of the bed because of high tidal currents. Since the geoduck population clearly extends well to the northeast of Morfee Island, as indicated by transects 39 to 42 (Table 5), the increased bed area was accepted and used in calculations for geoduck biomass.

The area covered by the survey was 392 ha for all observations and 358 ha for the data set where observations less than 10 feet chart datum were excluded. This latter estimate, slightly less than the revised digitised area estimate of 383 ha, was used to compute density removed by the fishery, to be consistent with the area over which the survey density estimates were calculated.

3.2 Fishery removals

The fishery has been heaviest on Elbow Bank where a total of 2.6 million lb have been removed, followed by Yellow Bank (1.9 M lb) Epper Pass (0.7M lb) and Morfee/Dunlap (0.2M lb) (Table 1). The density of geoducks removed by the fishery (over the surveyed area deeper than 10 feet) varies between 0.1/m^2 for Morfee/Dunlap and 1.06/m^2 for Elbow Bank, with the average over all areas of 0.54/m^2 (Table 2). Density removed is a function of landings and area, both of which vary considerable between beds. The low density removed from Morfee/Dunlap is due to the relatively large area over which the landings were averaged, in contrast to Elbow Bank where ten times the landings were taken from approximately the same area.

3.3 Distribution in relation to substrate and depth

The survey data lacked the contrast in both substrate type and general exposure to demonstrate any relationship with geoduck density. All substrates throughout the survey area were observed to be either sand or mixtures of sand, shell and mud (Appendix Tables 1 and 2). It must be noted that these observations are of the surface only, and therefore any unsuitable substrate type lying beneath the surface that may have influenced the geoduck distribution would go undetected. The general exposure was consistently noted as being of strong tidal flow (code 5 in Appendix Tables) and therefore could not be related to differences in density.

Geoduck densities increased with increasing depth in all areas except Elbow Bank (Fig. 8). This relationship is consistent with the results of many other geoduck surveys (e.g. Campbell *et al.* 1995a, 1995b, 1998a). Only eight of the 48 transects extended to 60 ft below chart datum (Table 5), the depth to which geoduck bed area is measured for quota calculations.

3.4 Size and age structure

Information on the size and age structure of geoduck populations was obtained from Elbow Bank in 1994 and Yellow Bank in 1997 (Fig. 6). Geoducks were significantly older on Elbow Bank (mean 28.7 yr, std=12.6 yr) compared to Yellow Bank (mean=24.8 yr, std=20.5 yr) (Wilcoxon rank sum test, p<0.01). Geoducks from Elbow Bank were also a significantly heavier than those sampled from Yellow Bank (Wilcoxon rank sum test, p=<0.01). The age-frequency distribution from Yellow Bank shows a large mode at ages less than 10 years, which suggests that recruitment in the five years prior to the sample date may be significant.

The proportion of geoducks ('Pr' in equation 8) that were between the ages of 5 and 18 was 0.20 in the Elbow Bank sample and 0.31 in the Yellow Bank sample. These values were used to estimate the recruit densities for each of the four beds surveyed, as described earlier. It is interesting to note that the same age range constituted 0.17 of the research sample collected from Elbow Bank in 1981 (Fig. 11 in Breen and Shields 1983). Market quality information was collected from the Yellow Bank sample only. Grades 1 and 2 comprised 33% and 31% of the total sample, respectively, while the less-preferred grades 3 and 4 were 22% and 14%, respectively.

Mean age and weight from the biosamples are presented in Table 3. Statistics obtained from Elbow Bank samples collected in 1981 (Breen and Shields 1983, Harbo *et al.* 1983) are also presented for comparison. It should be noted that the 1981 market sample was, by definition, comprised of only marketable clams whereas both the 1991 study plot sample and the 1994 biosample were not selected for size. The mean age estimate of 28.7 yr from the Elbow Bank sample collected in 1994 is very similar to the age of 28.3 yr obtained from a market sample from Elbow Bank, 13 years earlier in 1981. Despite the similarity in mean age and age composition between the years, the mean geoduck weight from the 1994 Elbow Bank sample was considerable larger than the 1981 market sample (1.48 kg compared 1.01 kg) and to mean weights derived from fishery data (1.08 kg, Table 1).

3.5 Show factors

The two show factor plots in 1994 were monitored over a period of 8 days and the three show plots in 1995 were monitored over a total period of 29 days (Table 4). The proportion of geoducks showing on days when transects were completed was generally high, ranging from 71% to 100%. This is expected during the summer months when storm activity is minimal (Goodwin 1977). The shows were lower on Elbow Bank than Yellow Bank, which is likely due to a higher tidal current on Elbow Bank, as noted in comments on the dive forms and anecdotal information.

3.6 Stock densities and dispersion

Individual transect densities are shown in Table 5. Survey densities, for depths greater than 10 ft. chart datum, were highest at Yellow Bank (2.5/m^2), followed by Morfee/Dunlap (1.7/m^2), Elbow Bank (1.5/m^2) and Epper Pass (1.1/m^2) (Table 5). Densities increased from south to north on Elbow Bank, increased from north to south on Epper Pass and were fairly consistent within Yellow Bank. Densities were variable but without trend on the Morfee/Dunlap bed (Table 5). The trend in density may be related to tidal current, at least on Elbow Bank where the southern end experiences much greater tidal action than the north end. Densities were slightly higher when data less than 10 feet chart datum were excluded from the analysis.

The reconstructed virgin densities for both Yellow Bank and Elbow Bank were 2.3/m^2, even though the survey densities differed by 1 geoduck/m^2 (Table 6). The high density of geoducks removed from Elbow Bank (1.1/m^2) and the high density of recruits on Yellow Bank (0.8/m^2) account for the difference. The virgin density for Morfee/Dunlap (1.3/m^2) and Epper Pass (1.2/m^2) are also similar, with the low density removed from Morfee/Dunlap playing a significant role. The reconstructed virgin densities from Morfee/Dunlap and Yellow Bank are actually less than the survey density. The ratio of survey density to virgin density ranges from 0.66 for Elbow Bank to 1.33 for Morfee/Dunlap. Overall, survey density is 97% of estimated virgin levels.

3.7 Estimates of biomass

The virgin biomass as calculated with previous estimates of bed area, virgin geoduck density and mean individual weight was compared to the virgin biomass as calculated using the results of the survey (Table 7). Estimates of biomass on Elbow Bank and Yellow Bank increased because of a higher estimated mean density for both beds and, for Yellow Bank, a larger estimated area. The four-fold increase in biomass estimates on Morfee/Dunlap is primarily due to an increase in estimated bed size while and the Epper Pass biomass was lower because of a decreased estimated density. Overall, the virgin biomass is estimated to be 73% greater than what had previously been calculated for stock assessment purposes.

3.8 Replicated transects

The density estimates from transects 1 to 5 on southern Elbow Bank in 1994 can be compared to those of transects 1 to 4 and 16 in 1995 (Figs. 2 and 3, Table 5). This area had similar densities of 0.50/m^2 in 1994 and 0.55/m^2 in 1995 (Table 5). There were no fishery removals on Elbow Bank between these two periods (Table 1), and since natural mortality and recruitment would be negligible over that period, the data should be comparable. In November of 1981, a study plot was set up and surveyed (Breen and Shields 1983). The density from that study, which lay in the area between transects 10 and 11 (Figs. 2 and 3), was 1.46/m^2, compared to an average of 1.30/m^2 for transects 10 and 11. These estimates agree closely, given that twelve years of commercial harvest has removed 1,093,827 lb between 1981 and 1995 from Elbow Bank (Table 1) and that some level of recruitment and natural mortality occurred in the intervening 14 years.

4.0 DISCUSSION

Our estimate of mean overall virgin density of 1.87/m^2 is approximately 34% greater than the estimate of 1.4/m^2, previously assumed for beds on the west coast of Vancouver Island. The virgin density estimates from both Elbow Bank and Yellow Bank were 65% greater than previously assumed. The 73% increase in estimated virgin biomass is accounted for partially from this increase and partially from a 40% increase in the total size of geoduck bed area.

Every parameter estimate used in calculating virgin density, including survey density, recruit density and the density of geoducks removed, is associated with varying uncertainty. Survey densities are fairly well determined, with upper and lower confidence limits within 20% of the mean. The accuracy of the estimates, for southern Elbow Bank at least, are verified by the five replicated transects that were completed over two years. The proportion of geoducks showing during the survey was relatively high, however geoduck shows may vary during the day due to tidal currents. Since show plots are monitored only once per day, the proportion applied to the observed data may not be accurate. The overall effect of this is not known. Show factor plots were likely monitored over too short a period to have completely census the total population of geoducks within them, resulting in an overestimate of proportion showing and therefore an underestimate of survey density.

The proportion of the surveyed population that has recruited since the fishery began was derived from one sample collected from the south end of Elbow Bank and two sub-samples collected from different locations on Yellow Bank. It is unknown how representative the Elbow Bank sample is of the entire bed, however the age composition is similar to a sample collected 15 years earlier toward the north end of the bed. The density of recruits on Yellow Bank was determined from randomly located subsamples and may be considered more representative of the population on that bank. Nothing is known of the age-distribution of geoducks on either Morfee/Dunlap or Epper beds, though they are assumed to be more similar to Yellow Bank than Elbow Bank because of the proximity of the sites. Assuming the higher density of recruits for Epper and Morfee/Dunlap, by using the Yellow Bank sample, results in a lower estimate of virgin density than if the Elbow Bank biological sample were used.

The estimates of geoduck density removed from the surveyed beds are derived from harvest log records of catch. These records were not corrected for under-reporting in years previous to the introduction of the IQ program in 1989 (after which all landings were validated and considered reasonably accurate). The removals are therefore probably underestimated, resulting in an underestimated density removed and an underestimated virgin density and biomass.

One factor in the reconstruction of virgin biomass that was not considered is natural mortality. By not including this source of removal from the population, the virgin density and biomass are, again, underestimated.

The original estimates of bed area (from harvest logs) along Epper Pass and on Elbow Bank appear to have been reasonably estimated. The original Yellow Bank and Morfee/Dunlap beds were similarly verified, but survey results showed that these beds extended towards each other to form one large geoduck bed. This resulted in an increase in overall area by 111 ha. A re-examination of the original harvest log charts did show limited fishing in this intermediate ground. There is not the data to determine whether the ground is unsuitable or whether, as some fishers comment, tidal currents reduce fishing opportunities there.

The market quality data that were collected from the Yellow Bank research sample in 1997 suggests that approximately 14% of the population are unacceptable to the market at the present time. Fishers actively seek to avoid lower quality product at the request of geoduck buyers. In a market sample collected during the 1996 fishery on Yellow Bank, only 5% of the fished product were of the lowest quality. This may be a consideration for fishery managers when setting the quotas.

The density of geoducks increased with depth in most of the areas surveyed. Since the majority of transects did not extend to 60 ft datum, it seems likely that the density of geoducks over the area available for harvest may be underestimated. These surveys reveal nothing about the density of geoducks at depths greater than 60 ft. The increase in density with depth suggests that there may be significant stocks below the practical diving depths of commercial fishers. Whether these stocks provide a source of larval recruits to the shallower fished stocks is unknown.

The ratio of survey density to virgin density for all beds combined is estimated to be 0.97 (Table 6). In other words, the average current density is estimated to be similar to pre-fishery levels. The estimates of density recruited and density removed, for all beds combined, are similar at 0.48/m^2 (0.38-0.60) and 0.54/m^2, respectively. The relationship between density recruited and density removed varies among the beds, from Elbow Bank where the density removed is much greater than the density recruited, to Morfee/Dunlap where the reverse is true. In beds where the recruit-density is higher than the removed-density, estimates of reconstructed virgin density are actually lower than estimates of current densities. An inflated virgin estimate would result from underestimated proportion recruited if, perhaps, the smallest animals were under-sampled. The good showing of young clams in the Yellow Bank sample shows, at least, that small individuals can be captured by the sampling gear.

These survey results allow some examination of the effects of harvest on a heavily exploited geoduck population. This is particularly so for Elbow Bank where biological and market sample data, and survey data are available from 1981. The similarity of mean age and weight from Elbow Bank between 1981 to 1995 suggests that the population age structure may not have been greatly affected by the 14-year fishery. Surprisingly, the mean weight of the 1994 sample was considerably larger than the mean weight from 1981, especially in light of the fact that it was not selected for size. The sample location for the 1994 biological sample was at the extreme south end of Elbow Bank, where the currents are generally high. The field personnel collecting the sample remarked upon the large size of the clams. The location of the 1981 market sample is not known. It is possible that different oceanographic conditions within Elbow Bank create sub-populations with different growth regimes. There is no measure of the original age/weight structure of the population on Elbow Bank since four years of intensive fishing had already occurred on Elbow Bank by 1981. The decrease in mean weight in the first three years of the fishery from 2.67 lb to 2.36 lb (Table 1) may reflect a real change in population structure but, thereafter, the trend in mean weight is without direction. The density of geoducks from a research plot in 1981 (Fig. 2) of 1.46 geoduck/m^2 (Breen and Shields 1983) compares reasonably well with the densities obtained in 1995 from transects 10 and 11 (Fig. 3, Table 5) of 1.41 and 1.27/m^2.

These survey results suggest that previously assumed densities of 1.4 geoducks/m^2 for the west coast of Vancouver Island are not unreasonable, at least in the beds covered by this survey. It may be an underestimate for the 'bank' type of bed, like Yellow and Elbow Banks, or an overestimate for the type of bed that occurs along shorelines, like Epper Pass. The applicability of these survey results to other areas on the west coast is unknown. Additional information on the density of other beds is needed to determine how variable density estimates are between beds.

ACKNOWLEDGEMENTS

We wish to thank divers Les Tulloch, Greg Sorensen, Lutz Zilliken, Terry Keith, Doug Mousseau, Dave Thomas, Kelly Tull, Darren Matilpi and Diego Llamazares for collecting the transect and show factor data, Jim Brown and Henning Anderson for boat tending, Laurie Sorensen for overseeing the field operations in 1994, Kathy Southey and Jennifer Nash for ageing the samples of geoducks and Joseph Wasilewski for providing the biological sample weights and market grades. We are grateful for the comments and suggestions provided by Rob Kronlund and Rick Harbo.

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Table 1. Annual landings as reported on harvest logs (lb), mean geoduck weight (lb/geoduck) and the number of geoduck clams landed by geoduck bed, 1978 to 1996. Estimates of mean weight are from harvest log records in which number landed is reported. Total landings are given for each geoduck bed, along with the adjusted total, which is corrected for under-reporting. Adjustment factors of 1.24 and 1.07 were used for 1978 - 1988 and 1989 - 1996, respectively, based on the ratio of sales slips or validated landings to harvest log landings, on a Statistical Area basis.

	Yellow Bank bedcodes:1004, 1005			Morfee/Dunlop bedcodes:1002,1203			North Epper Pass bedcode:1003			Elbow Bank bedcode:1204			All Areas		
Year	lb	Mean wt	#	lb	Mean wt	#	lb	Mean wt	#	lb	Mean wt	#	lb	Mean wt	#
1978	0	-	0	0		0	0		0	398,091	2.67	149,098	398,091	2.67	149149,098
1979	0	-	0	9,653	2.26	4,271	0		0	642,551	2.48	259,093	652,204	2.47	263,364
1980	159,014	2.09	76,083	7,084	2.14	3,310	21,932	2.80	7,833	41,131	2.21	18,611	229,161	2.17	105,838
1981	252,045	2.34	107,712	293	2.27	129	113,310	2.37	47,810	134,729	2.36	57,089	500,377	2.35	212,739
1982	59,557	2.07	28,771	0		0	20,966	2.16	9,706	14,025	2.05	6,841	94,548	2.08	45,319
1983	64,370	1.9	33,879	0		0	6,565	2.13	3,082	3,243	1.95	1,663	74,178	2	38,624
1984	217,966	2.01	108,441	62,862	2.16	29,103	56,651	2.22	25,518	71,537	2.28	31,376	409,016	2.1	194,438
1985	77,784	1.97	39,484	22,737	1.91	11,904	97,394	2.20	44,270	59,997	2.11	28,435	257,912	2.08	124,093
1986	39,726	2.17	18,307	0		0	89,334	2.33	38,341	18,208	2.71	6,719	147,268	2.32	63,367
1987	48,862	2.03	24,070	0		0	78,780	2.22	35,486	39,804	2.24	17,770	167,446	2.15	77,326
1988	89,960	2.17	41,456	7,154	2.45	2,920	20,653	1.85	11,164	258,692	2.52	102,656	376,459	2.41	158,196
1989	16,754	2.04	8,213	57,500	2.72	21,140	8,253	1.43	5,771	71,975	2.34	30,759	154,482	2.34	65,882
1990	163,333	2.47	66,127	3,163	2.63	1,203	17,906	2.38	7,524	90,679	2.72	33,338	275,081	2.55	108,191
1991	68,419	2.79	24,523	3,690	2.49	1,482	19,468		0	25,943	2.31	11,231	117,520	2.63	37,236
1992	222,977	2.37	94,083	8,383	2.85	2,941	15,264		0	25,127	2.49	10,091	271,751	2.4	107,116
1993	117,660	2.25	52,293	0		0	20,831	2.83	7,361	269,079	2.64	101,924	407,570	2.56	161,578
1994	0	-	0	4,449	1.93	2,305	16,332	2.46	6,639	0		0	20,781	2.27	8,944
1995	0	-	0	1,484	3.1	479	0		0	0		0	1,484	3.1	479
Total	1,598,427	2.19	723,442	188,452	2.41	81,187	603,639	2.26	250,506	2,164,811	2.38	866,692	4,555,329	2.37	1,921,827
Adjusted	1,919,564		872,758	220,306		95,706	692,079		304,984	2,602,289		1,043,495	5,434,238		2,316,943

Table 2. Total landings (1978 to 1996), estimated bed area (ha) and estimated density of geoducks removed, by survey site.

Survey Site	Landings[1]	Mean Wt.	Landings[2]	Bed Area (ha)				Density Removed (#/m^2)			
				Digitized		Surveyed		Digitized		Surveyed	
	(lb)	(lb)	(#)	Logbook	New[3]	All Data	>10'	Logbook	New[3]	All Data	>10'
Elbow Bank	2,164,811	2.38	**866,692**	88.5	88.5	91.7	**81.7**	0.98	0.98	0.95	**1.06**
Yellow Bank	1,598,427	2.19	**723,442**	83.2	119.6	143.5	**126.2**	0.87	0.60	0.50	**0.57**
Morfee/Dunlop Is.	188,452	2.41	**81,187**	32.4	106.9	83.1	**83.1**	0.25	0.08	0.10	**0.10**
North Epper Pass	603,639	2.26	**250,506**	68.1	68.1	74.1	**66.5**	0.37	0.37	0.34	**0.38**
	4,555,329	2.31	1,921,827	272.2	383.1	392.4	**357.5**	0.71	0.50	0.49	**0.54**

[1] As reported on harvest logs.

[2] Pounds converted to numbers using mean weights from harvest logs where number landed was recorded

[3] Beds were redrawn using results from the survey.

Table 3. Mean age and weight of geoducks sampled from Elbow Bank in 1981 and 1994 and Yellow Bank in 1997.

Sample	Number Sampled	Mean Age (yr)	Mean Weight (kg)
Elbow Bank			
Study Plot, 1981	316	34.8	1.19
Market Sample, 1981	223	28.3	1.01
Biological Sample, 1994	433	28.7	1.48
Yellow Bank			
Bio. Sub-sample H1, 1997	100	20.8	1.02
Bio. Sub-sample H2, 1997	100	na	0.95
Bio. Sub-sample H3, 1997	97	27.8	0.91

Table 4a. Summary of daily show factor data by plot on Elbow Bank, 1994.

DATE	PLOT				Average
	N. Elbow B. SH#2		S. Elbow B. SH#1		
	%	n	%	n	
940926	66.0	33	80.8	21	71.1
940927	80.0	40	80.8	21	80.3
940928	92.0	46	69.2	18	84.2
940929	90.0	45	84.6	22	88.2
940930	98.0	49	96.2	25	97.4
941001	100.0	50	92.3	24	97.4
941002	92.0	46	100	26	94.7
941003	94.0	47	88.5	23	92.1
Total	89.0	50	86.6	26	

Table 4b. Summary of daily show factor data by plot, Elbow and Yellow Banks, 1995.

DATE	PLOT						Average
	S. Elbow B. SH#1		N. Elbow B. SH#2		Yellow B. SH#3		
	%	n	%	n	%	n	
950907					94.4	51	94.4
950908	73.3	33	76.2	32			74.7
950914	77.8	35	78.6	33	100.0	54	86.5
950915	82.2	37	81.0	34			81.6
950916	71.1	32	69.0	29			70.1
950917	66.7	30	83.3	35	100.0	54	84.4
950918	80.0	36	73.8	31			77.0
950919			88.1	37	100.0	54	94.8
950920					98.1	53	98.1
950921					98.1	53	98.1
950922					100.0	54	100.0
951002					92.6	50	92.6
951003	88.9	40			96.3	52	92.9
951004	93.3	42			96.3	52	94.9
951005	93.3	42			100.0	54	97.0
Total	80.7	45	78.6	42	97.8	54	89.2

Table 5. Depth range, transect length, show factor and geoduck numbers and density, by bed and transect, from surveys conducted in the Elbow/Yellow Bank area, west coast of Vancouver Island, Sept 1994, Sept.-Oct. 1995 and May 1997. Results are shown for all data and for data where observations less than 10 feet were excluded (>10' datum).

Transect	Depth (ft)[1]		Transect Length (m)		Show	# of Geoducks [2]		Geoducks/m^2	
	min	max	all data	>10' datum	Factor	all data	>10' datum	all data	>10'datum
ELBOW BANK									
1994									
1	14	54	210	210	0.80	281	281	0.67	0.67
2	6	53	340	310	0.84	398	372	0.59	0.60
3	12	51	265	265	0.97	192	192	0.36	0.36
4	12	51	250	250	0.97	99	99	0.20	0.20
5	20	55	320	320	0.97	452	452	0.71	0.71
Combined						1422	1395	0.50	0.51
1995									
1	17	66	200	200	0.78	54	54	0.54	0.54
2	15	47	200	200	0.78	32	32	0.32	0.32
3	8	51	280	250	0.78	68	59	0.52	0.49
16	7	53	290	280	0.80	110	110	0.73	0.73
4	2	58	380	355	0.82	123	122	0.65	0.68
4.1	0	2	170	-	0.82	19	0	0.24	0.00
5	3	66	250	180	0.82	99	86	0.76	0.96
6	3	59	200	125	0.82	71	63	0.71	0.90
7	1	59	190	95	0.71	86	75	0.95	1.49
8	1	66	100	65	0.71	60	38	1.21	1.27
9	2	54	100	45	0.71	53	15	1.07	0.77
10	8	61	95	85	0.71	66	56	1.32	1.41
11	8	68	215	170	0.71	139	139	1.27	1.27
12	13	56	645	645	0.83	545	545	1.65	1.65
13	12	58	575	575	0.83	414	414	1.38	1.38
14	13	57	495	495	0.74	726	726	2.91	2.91
15	13	59	435	435	0.74	736	736	3.34	3.34
Combined						3402	3271	1.40	1.51
YELLOW BANK									
1995									
22	26	52	500	500	1.00	577	577	2.40	2.40
23	18	62	735	735	1.00	1106	1106	2.99	2.99
24	12	53	755	755	0.98	1039	1039	2.66	2.66
25	11	51	1045	380	0.98	1410	448	2.71	2.24
25.1			-	535	0.98	-	869	-	3.34
26	11	32	495	495	0.98	600	600	2.40	2.40
26.1	0	55	225	225	0.98	192	192	1.48	1.60
27	11	29	550	550	0.98	580	580	2.07	2.07
27.1	4	38	175	75	0.98	87	81	0.97	2.03
28	7	63	1080	575	0.98	949	656	1.79	2.34
28.1				210	0.98	-	217	-	1.97
Combined						6800	6626	2.16	2.37

Table 5 (cont'd.)

Transect	Depth (ft)[1]		Transect Length (m)		Show	# of Geoducks [2]		Geoducks/m²	
	min	max	all data	>10' datum	Factor	all data	>10' datum	all data	>10'datum
EPPER PASS									
30	0	57	150	70	1.00	64	59	0.91	1.97
31	3	51	250	200	1.00	105	104	0.88	1.04
32	5	52	250	210	1.00	111	107	0.93	1.07
33	5	51	250	195	1.00	98	92	0.82	1.02
34	6	55	500	485	1.00	178	177	0.71	0.74
35	2	54	550	515	0.93	232	222	0.83	0.86
36	5	59	435	425	0.93	309	309	1.40	1.40
37	6	53	250	245	0.93	176	176	1.35	1.35
38	0	57	100	65	0.93	108	110	1.66	2.52
Combined						1381	1356	1.00	1.11
MORFEE/DUNLAP									
39	32	56	415	415	0.96	395	395	1.88	1.88
40	20	56	755	755	0.96	503	503	1.32	1.32
41	20	59	965	965	0.96	814	814	1.70	1.70
42	18	38	405	405	0.98	160	160	0.84	0.84
43	36	58	195	195	1.00	141	141	1.41	1.41
44	5	60	65	65	1.00	37	37	1.23	1.23
45	33	51	465	465	1.00	559	559	2.43	2.43
46	43	56	145	145	1.00	273	273	3.41	3.41
Combined						3052	2881	1.69	1.69

[1] Corrected to chart datum.
[2] Corrected for show factor.

Table 6. Mean survey density, recruit density, removed density and reconstructed virgin density (#/m^2) estimates of geoducks from all data collected and from data where observations less than 10 feet were excluded, by survey area. C.I. = 95% confidence interval estimated using the bootstrap.

	Elbow Bank	Yellow Bank	Morfee/ Dunlap	N. Epper Pass	All Areas
a) ALL DATA					
Number of Transects	17	9	9	9	44
Mean Survey Density	1.40	2.33	1.60	1.00	1.66
95% C.I.	0.90 - 1.90	1.96-2.68	1.20 - 2.10	0.80 - 1.30	1.20 - 2.19
b) OBSERVATIONS GREATER THAN 10 FEET DEPTH					
Number of Transects	16	11	8	9	44
Mean Survey Density	1.51	2.51	1.73	1.11	1.82
95% C.I.	0.92 - 2.12	2.20 - 2.80	1.31 - 2.18	0.85 - 1.48	1.49 - 2.16
Mean Recruit Density[1]	0.30	0.77	0.53	0.34	0.48
95% C.I.	0.18 - 0.42	0.67 - 0.86	0.40 - 0.67	0.26 - 0.45	0.38 - 0.60
Mean Density Removed[2]	1.06	0.57	0.10	0.38	0.54
Mean Virgin Density	2.27	2.31	1.30	1.15	1.87
95% C.I.	1.80 - 2.76	2.10 - 2.52	1.00 - 1.61	0.96 - 1.40	1.65 - 2.10
Ratio Dc/Dv[3]	0.66	1.08	1.33	0.97	0.97

[1] Calculated as the product of survey density and the proportion recruited (Pr). Elbow Bank = 19.75%; Yellow Bank and other areas = 30.6%.
[2] Calculated as total reported landings in numbers, by survey area, over the area surveyed greater than 10 feet depth (Table 2).
[3] Dc = current (survey) density; Dv = virgin density.

Table 7. Comparison of virgin geoduck biomass, by bed, as calculated from A) previous estimates of bed area (ha), mean wt (lb) and density (#/m^2) and B) estimates of area, mean weight and mean geoduck density resulting from survey.

A)

Geoduck Bed	Area (ha)	Mean wt.[1] (lb)	Density (#/m^2)	Virgin Biomass (lb)
Elbow Bank	88.5	2.42	1.4	3,003,336
Yellow Bank	83.2	2.42	1.4	2,823,475
Morfee/Dunlop	32.4	2.42	1.4	1,099,526
N. Epper Pass	68.1	2.42	1.4	2,311,042
All Areas; Sum				9,237,379
All Areas; Average	272.2	2.42	1.4	9,222,136

B)

Geoduck Bed	Area (ha)	Mean wt.[2] (lb)	Mean Virgin Density (#/m^2)	Mean Virgin Biomass (lb)
Elbow Bank	88.5	2.38	2.27	4,781,701
Yellow Bank	119.6	2.19	2.31	6,057,930
Morfee/Dunlop	106.9	2.41	1.30	3,339,035
N. Epper Pass	68.1	2.26	1.15	1,768,397
All Areas; Sum				15,947,063
All Areas; Average	383.1	2.37	1.87	16,978,609

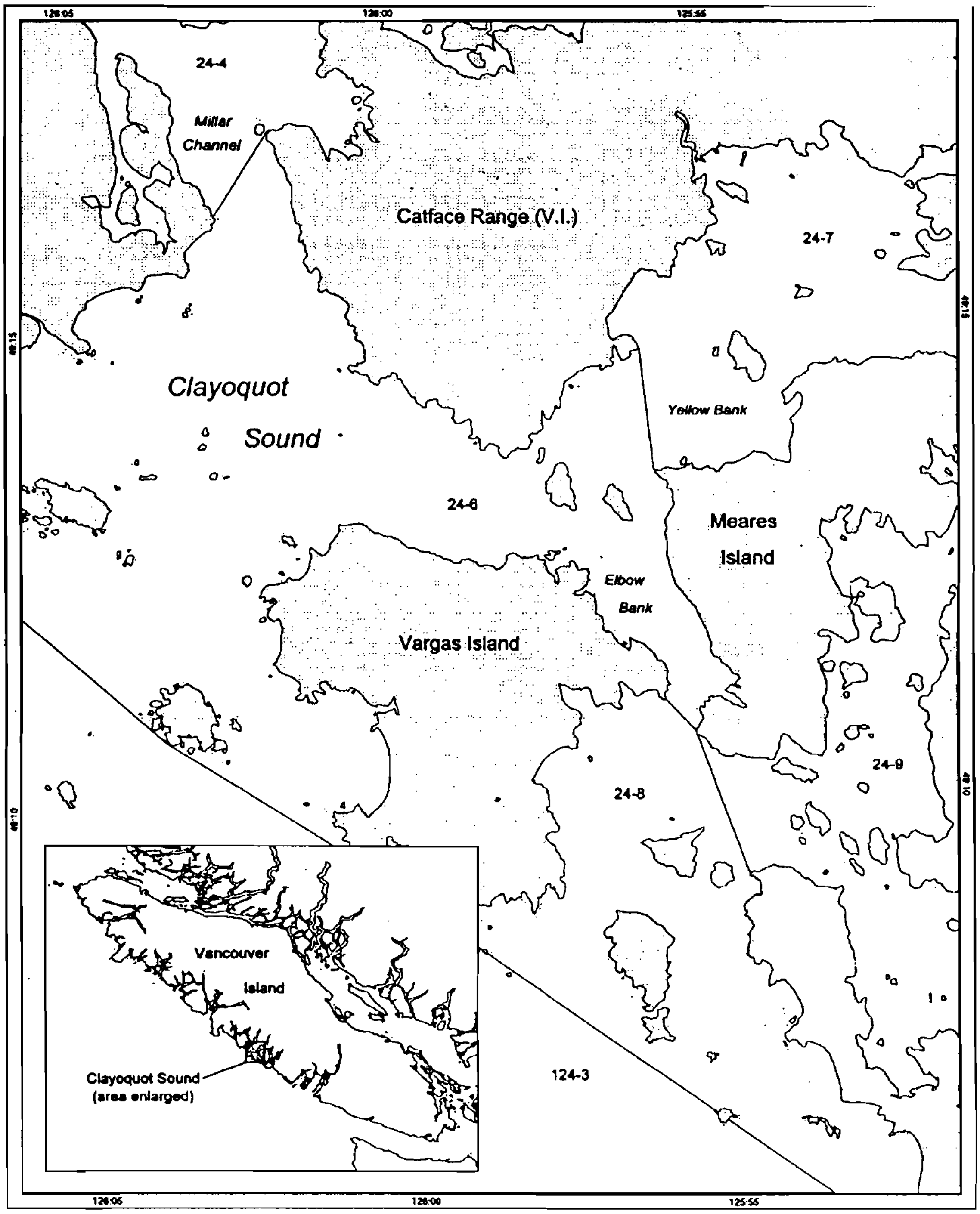

Figure 1. Location of Clayoquot Sound on the west coast of Vancouver Island showing Statistical Areas and Subareas and the location of Elbow Bank and Yellow Bank.

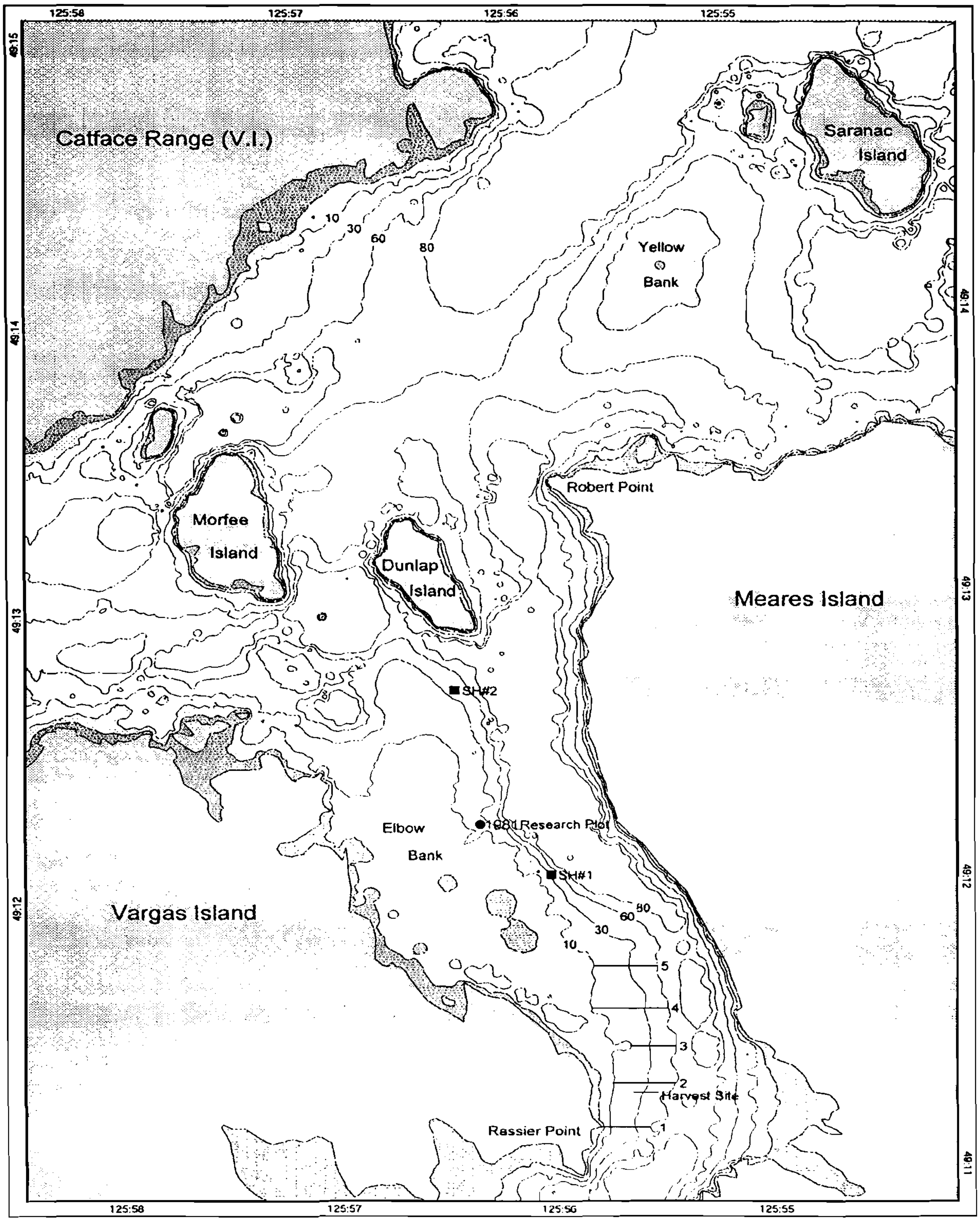

Figure 2. Location of transects, show factor sites (SH) and biological sample harvest site for the survey conducted on Elbow Bank in September and October, 1994. Depth contours are in feet.

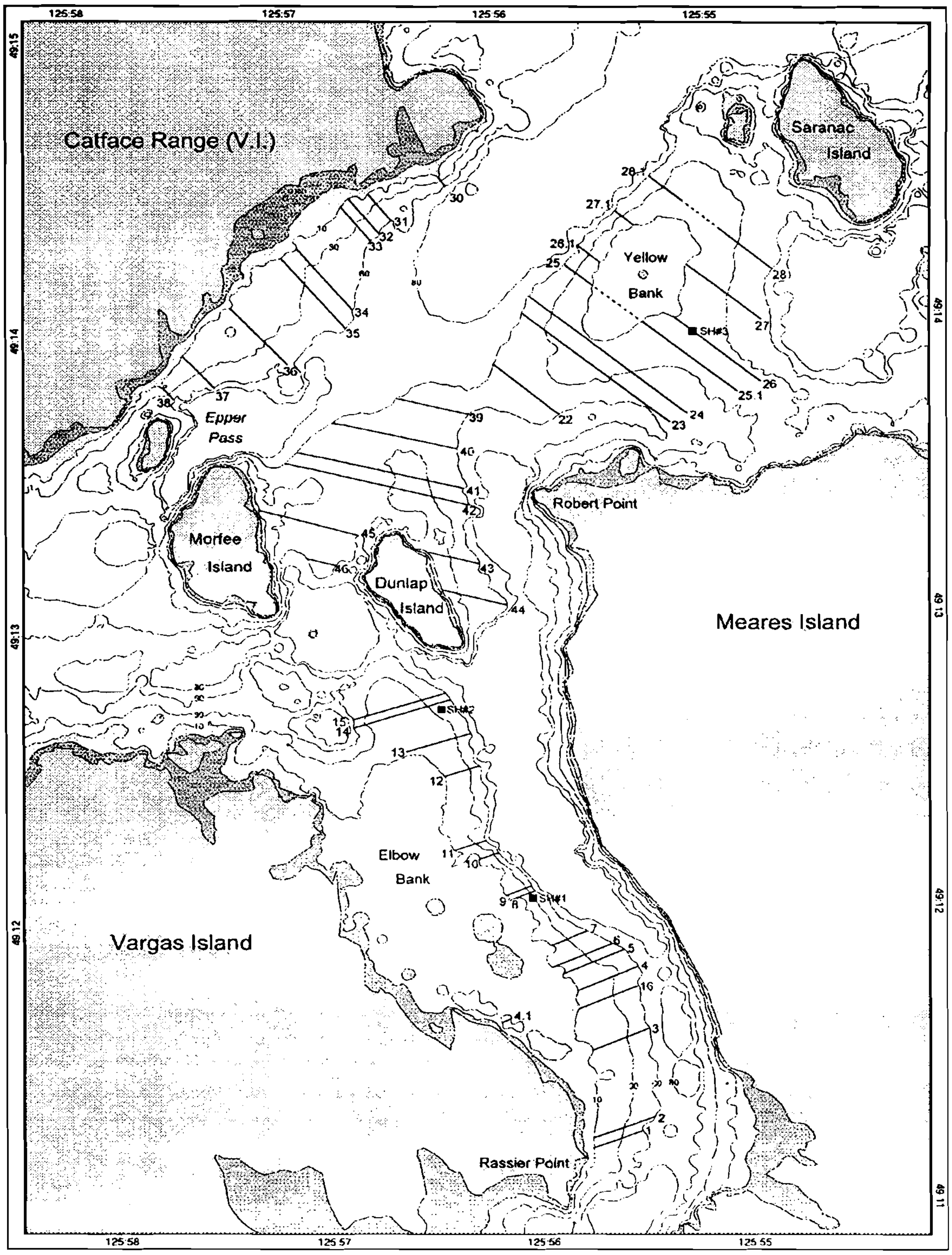

Figure 3. Location of transects and show factor sites (SH) for the survey conducted on Elbow Bank, Yellow Bank, Morfee/Dunlap and north Epper Pass in September and October, 1995. The location of the harvest sites (H) for the biological samples on Yellow Bank in 1997 are also indicated.

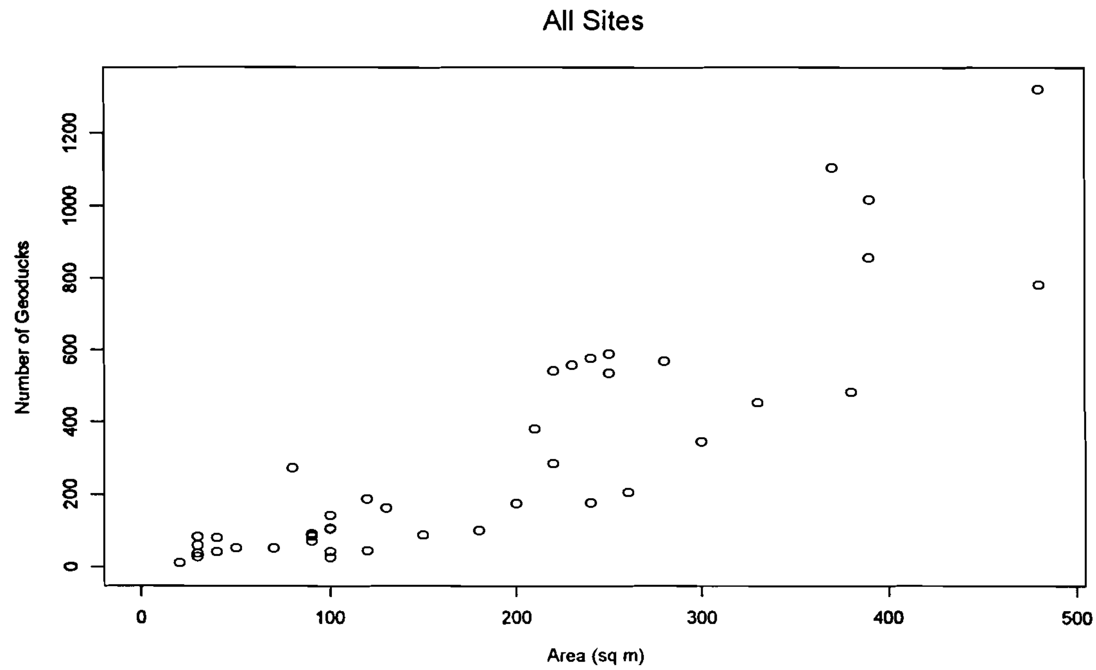

Figure 4. Relationship between transect area and number of geoducks.

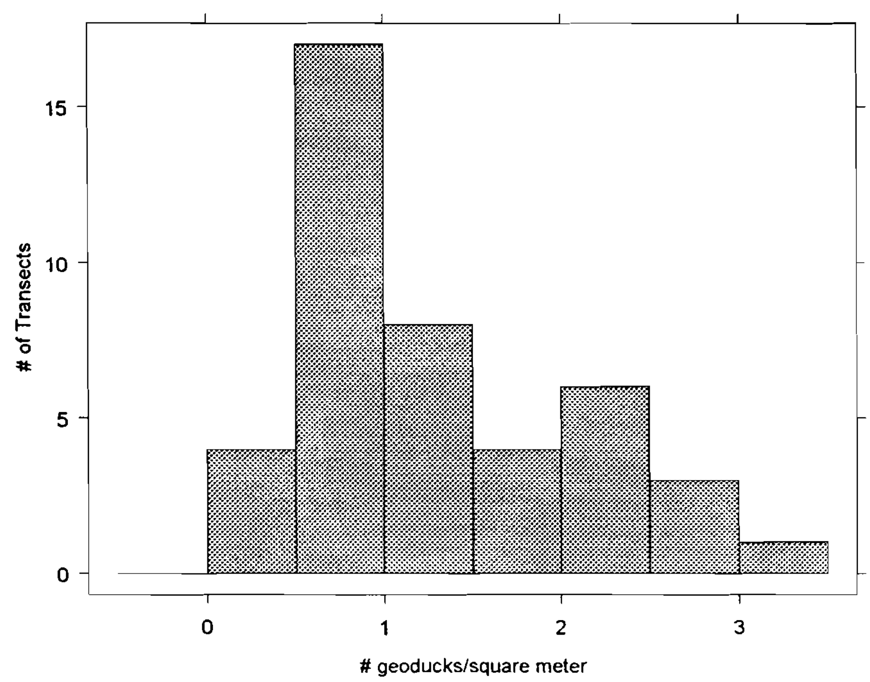

Figure 5. Histogram of observed density of geoducks (number/10m^2 quadrat), by transect.

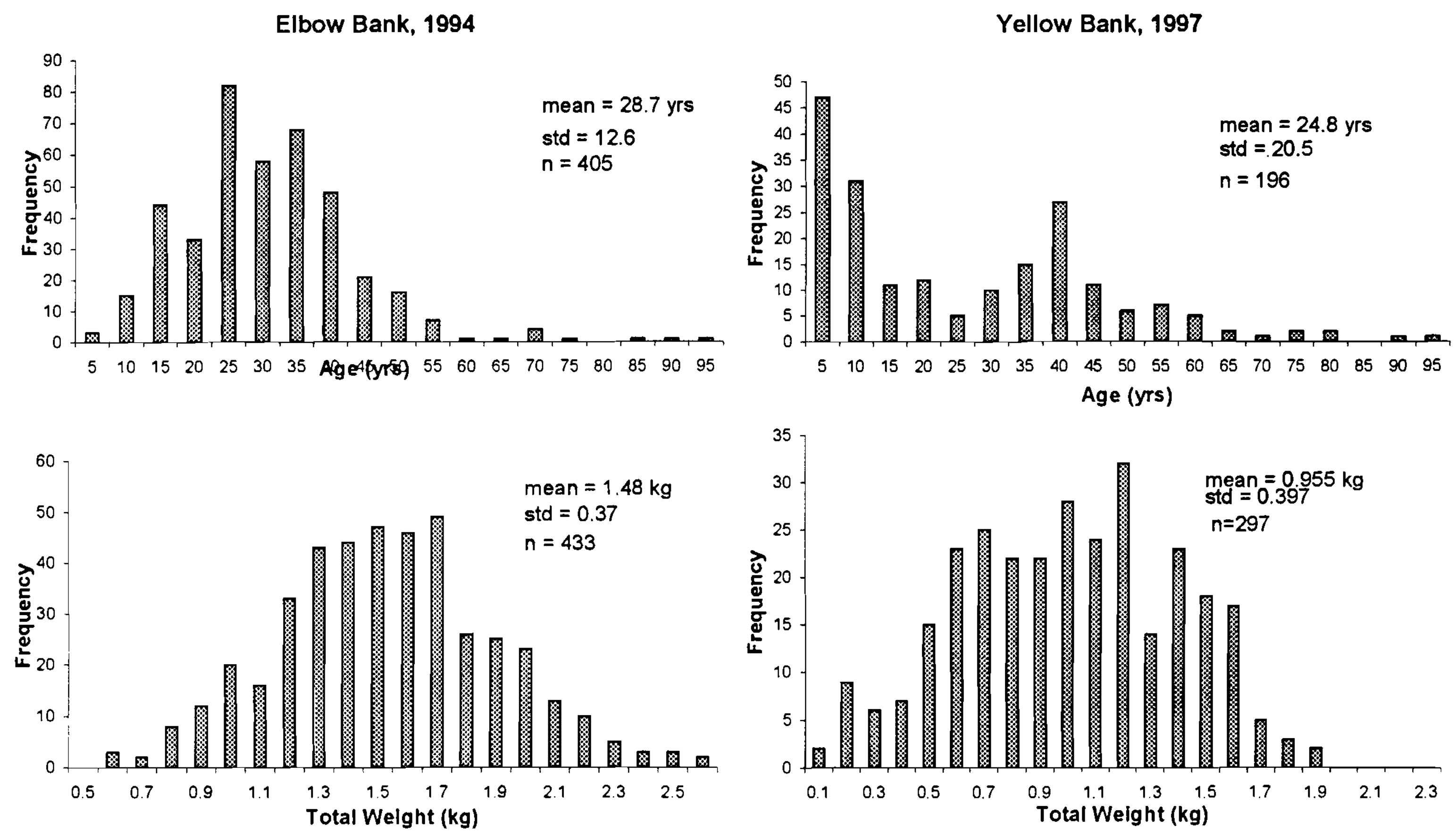

Figure 6. Histograms of geoduck age (years) and weight (kg) from Elbow Bank in 1994 and Yellow Bank in 1997.

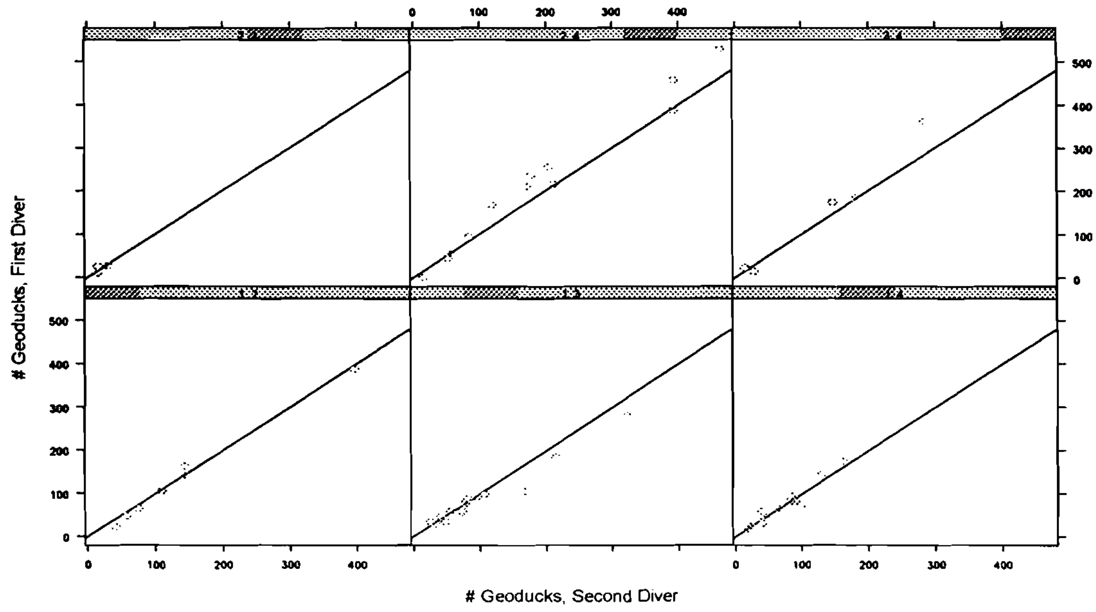

Figure 7. Plot of geoduck counts on the left side of the transect against counts on the right side of the transect, by diver pair. Each point corresponds to one transect.

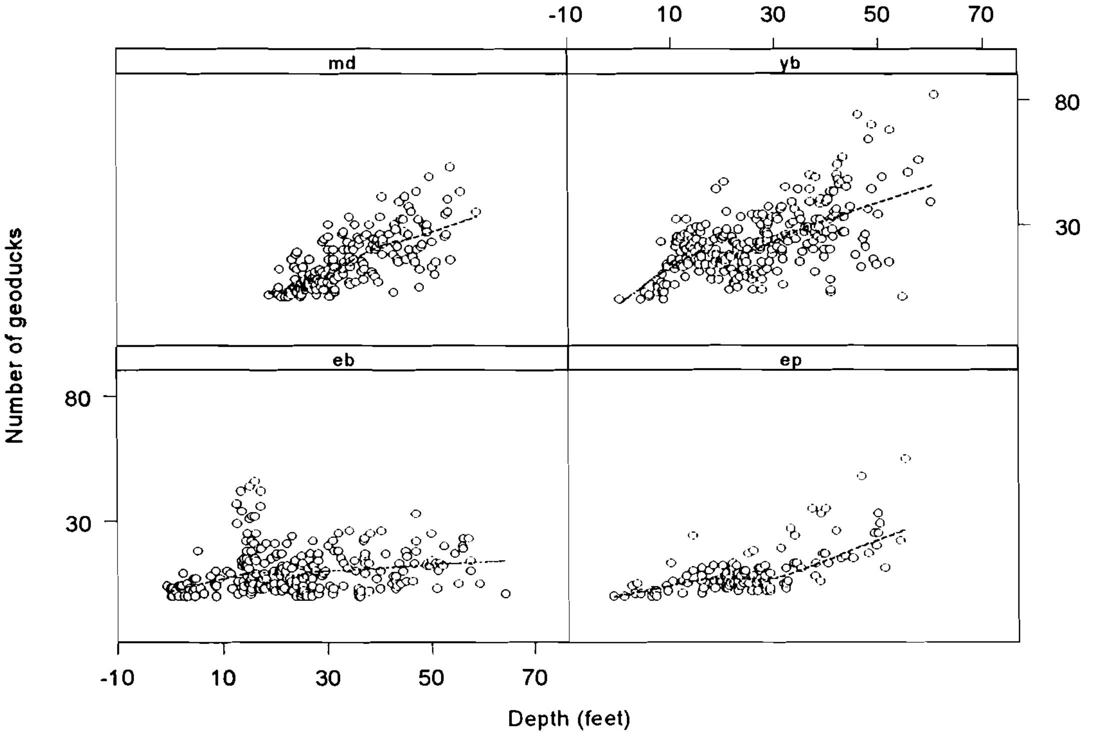

Figure 8. Number of geoducks counted per $10m^2$ quadrat plotted against depth (feet below chart datum) by bed, where 'eb' is Elbow Bank, 'ep' is Epper Pass, 'md' is Morfee/Dunlap and 'yb' is Yellow Bank. Loess smooths of the trend are shown.

Appendix Table 1. Summary of transect statistics for the dive survey at Elbow Bank, 1994. Depths are corrected to chart datum.

Transect	Date	Time (PDT)		Depth (m)		Number of	Transect	Ave. Slope	Exposure	Vis.	Neck	Geoducks	Substrate
		Start	End	Min	Max	Quadrats	Length (m)	(degrees)	of site[1]	(ft)	Exposure[2]	Counted	
1	940927	12:53	14:00	4.30	15.68	42	210	5.8	5	15	71	226	S
2	940928	13:45	14:58	1.85	16.25	68	340	2.5	5	20	50	335	S
2	940929	11:05	12:20			completed in two days				20	20		
3	940930	12:57	15:47	3.63	15.48	53	265	3.1	5	10	50	187	S/Sh
4	941001	11:50	13:14	3.59	15.61	50	250	3.2	5	10	0	96	S
5	941001	15:14	17:04	6.00	16.82	64	320	2.9	5	17	50	440	S

Appendix Table 2. Summary of transect statistics for the dive survey at Elbow Bank, Yellow Bank, North Epper Pass and Morfee/Dunlap Islands, 1995. Depths are correct to chart datum.

Transect	Date	Time (PDT)		Depth (m)		No. of Quadrats		Transect	Ave. Slope	Exposure	Vis.	Neck	Geoducks	Substrate
		Start	End	Min	Max	Total	Sampled	Length	(degrees)	of site[1]	(ft)	Exposure[2]	Counted	
Elbow Bank														
1	14-Sep	11:23	12:15	5.1	20.2	40	10	200	4.4	5	15	5	42	S/Sh
2	14-Sep	12:32	13:21	4.6	14.4	40	10	200	2.8	5	15	5	25	S/Sh
3	14-Sep	15:20	16:16	2.4	15.7	56	14	280	3.0	5	15	10	58	S/Sh
16	18-Sep	16:28	17:22	2.1	16.0	58	15	290	3.2	5	10	50	88	S/Sh
4	15-Sep	11:00	12:00	0.6	17.7	76	19	380	3.8	5	15	5	101	S/Sh
4.1	15-Sep	12:09	13:10	-0.2	0.5	34	8	170	1.5	5	15	20	16	Sand
5	15-Sep	14:20	15:10	0.8	20.0	50	13	250	4.6	5	15	5	81	S/Sh
6	15-Sep	15:30	16:18	0.8	18.1	40	10	200	5.3	5	15	5	58	Sand
7	16-Sep	10:40	11:30	0.4	18.0	38	9	190	5.7	5	10	5	61	S/Sh/M
8	16-Sep	12:20	12:40	0.4	20.0	20	5	100	11.4	5	12	5	43	S/M
9	16-Sep	12:50	13:12	0.7	16.6	20	5	100	9.4	5	12	5	38	S/Sh
10	16-Sep	14:00	14:20	2.6	18.5	19	5	95	10.0	5	10	5	47	S/Sh
11	16-Sep	14:30	15:15	2.3	20.8	43	11	215	5.3	5	15	5	99	S/Sh
12	17-Sep	9:58	12:22	4.1	17.1	129	33	645	2.8	5	15	20	454	S/M
13	17-Sep	13:26	15:15	3.6	17.5	115	30	575	3.6	5	12	50	345	S/M
14	18-Sep	9:55	12:15	3.8	17.4	99	25	495	3.1	5	10	50	536	M/S
15	18-Sep	13:14	15:00	4.0	18.0	87	22	435	4.0	5	10	30	543	S/M
Yellow Bank														
22	19-Sep	10:33	12:33	8.0	15.8	100	24	500	4.0	5	10	30	577	S/Sh/M
23	19-Sep	13:35	15:15	5.6	18.8	147	37	735	2.8	5	15	30	1106	S/M
24	20-Sep	9:05	10:40	3.8	16.2	151	39	755	2.6	5	10	40	1019	S/Sh/M
25	20-Sep	12:05	13:55	2.5	15.4	209	52	1045	2.1	5	10	25	1639	S/M
26a	20-Sep	15:10	15:40	8.4	9.6	99	25	495	1.8	5	10	30	589	S/M
26b	21-Sep	9:25	11:00	3.4	9.8		(completed in two days)			5	10	30		S/M
26.1	21-Sep	10:40	11:20	3.3	16.6	45	13	225	4.1	5	10	40	188	S/M/Sh
27	21-Sep	11:33	12:44	3.4	8.7	110	28	550	1.2	5	10	60	569	S/M
27.1	21-Sep	12:55	13:35	1.2	11.7	35	9	175	3.7	5	15	10	85	S/M
28	21-Sep	14:13	15:50	2.2	19.2	216	53	1080	2.0	5	10	30	931	M/S

Appendix Table 2 (cont'd)

Transect	Date	Time (PDT)		Depth (m)		Number of quadrats		Transect	Ave. Slope	Exposure	Vis.	Neck	Geoducks	Substrate
		Start	End	Min	Max	Total	Sampled	Length	(degrees)	of site[1]	(lb)	Exposure[2]	Counted	
North Epper Pass														
30	22-Sep	10:33	10:52	-0.1	17.4	30	7	150	6.8	5	10	30	64	M/S
31	22-Sep	11:30	12:00	0.9	15.6	50	12	250	3.4	5	10	20	105	M/S
32	22-Sep	12:20	12:49	1.6	15.9	50	12	250	3.3	5	5	20	111	S/M
33	22-Sep	13:04	13:35	1.5	15.4	50	12	250	3.2	5	15	10	98	S/M
34	22-Sep	13:55	15:30	1.7	16.8	100	25	500	2.6	5	15	15	178	S/M
35	2-Oct	10:30	12:10	0.7	16.4	110	28	550	2.3	5	15	20	215	S/M
36	2-Oct	13:00	14:00	1.5	17.9	87	22	435	2.8	5	15	10	286	S/Sh
37	2-Oct	14:35	15:15	1.9	16.1	50	13	250	4.5	5	15	15	163	Sand
38	2-Oct	15:25	15:45	-0.4	17.4	20	5	100	10.3	5	15	20	83	S/Sh
Morfee/Dunlap Is.														
39	3-Oct	10:56	12:03	9.8	17.1	83	21	415	2.2	5	15	15	380	S/M
40	3-Oct	12:42	15:10	6.0	17.0	151	38	755	2.7	5	15	30	484	S/Sh
41	4-Oct	9:38	11:03	8.7	16.9	193	48	965	1.9	5	20	20	774	S/M/Sh
41	4-Oct	12:13	13:33	6.1	18.0		(completed in two dives)			5	15	15		S/M/Sh
42a[3]	4-Oct	14:55	15:50	5.5	11.4	81	20	405	3.2	5	15	15	176	S/M/Sh
42b	5-Oct	9:48	10:40	5.9	11.8	81	21	405	2.8	5	15	5	148	S/M/Sh
43	5-Oct	14:50	15:21	11.0	17.8	39	10	195	4.1	5	15	15	141	S/Sh
44	5-Oct	14:15	14:35	1.4	18.4	13	3	65	15.2	5	15	15	37	Sh/S
45	5-Oct	12:11	13:25	10.1	15.6	93	23	465	1.7	5	15	10	559	S/M
46	5-Oct	16:35	17:00	13.0	17.0	29	8	145	3.5	5	15	15	273	S/M/Sh