Age, Size Structure and Growth Parameters of Geoducks (*Panopea abrupta*, Conrad 1849) from Seven Locations in British Columbia Sampled in 2001 and 2002

D. Bureau, W. Hajas, C.M. Hand and G. Dovey

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

2003

Canadian Technical Report of Fisheries and Aquatic Sciences 2494

Fisheries and Oceans   Pêches et Océans

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. 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.

Technical 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 - 456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457 - 714 were issued as Department of the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical 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 technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais que ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. 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 scences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques 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 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques 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 925.

Les rapports techniques sont produits à l'échelon regional, 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 Technical Report of

Fisheries and Aquatic Sciences 2494

2003

AGE, SIZE STRUCTURE AND GROWTH PARAMETERS OF GEODUCKS (*Panopea abrupta*, CONRAD 1849) FROM SEVEN LOCATIONS IN BRITISH COLUMBIA SAMPLED IN 2001 AND 2002

by

D. Bureau, W. Hajas, C.M. Hand and G. Dovey[1]

Fisheries and Oceans Canada

Science Branch, Pacific Region

Pacific Biological Station

Nanaimo, British Columbia

V9T 6N7

[1]Underwater Harvesters Association,
PO Box 39005, W 10th Ave,
Vancouver, BC, V6R 4P1

Cat. No. Fs 97-6/2494E ISSN 0706-6457

Correct citation for this publication:

Bureau D., W. Hajas, C.M. Hand and G. Dovey. 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.

ABSTRACT

Bureau D., W. Hajas, C.M. Hand and G. Dovey. 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.

Geoducks samples were collected from seven locations in British Columbia in 2001 and 2002. Total weight, shell length and shell weight were measured and shells were aged. Summary statistics, age frequency distributions and growth curves are presented for each sample location. Relationships for shell length/age, total weight/shell length, total weight/age and shell weight/age were calculated for all samples.

Age frequency distributions showed strong recruitment events between 1992 and 1994. Results of growth models indicated fast growth in the first 10 to 20 years of life, followed by a long period with virtually no growth, except for a slow thickening of the shell with age. Growth rates and maximum size attained by geoduck populations varied between sample locations.

RÉSUMÉ

Bureau D., W. Hajas, C.M. Hand and G. Dovey. 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.

Nous avons prélevé en 2001 et 2002 des échantillons de panopes à sept stations en Colombie-Britannique. Nous avons mesuré le poids total, la longueur de la coquille et son poids, et nous avons déterminé l'âge des coquilles. Pour chaque station d'échantillonnage, nous présentons des statistiques sommaires, les distributions des fréquences d'âge et les courbes de croissance. Nous avons calculé pour tous les échantillons les relations longueur de la coquille/âge, poids total/longueur de la coquille, poids total/âge et poids de la coquille/âge.

Les distributions des fréquences d'âge font ressortir des épisodes de fort recrutement entre 1992 et 1994. Les résultats des modèles de croissance révèlent une croissance rapide pendant les 10 à 20 premières années de la vie, suivie par une longue période de croissance pratiquement nulle, à part un lent épaississement de la coquille avec le temps. Les taux de croissance et la taille maximale atteinte par les populations de panopes variaient d'une station d'échantillonnage à l'autre.

INTRODUCTION

Geoducks (*Panopea abrupta*, Conrad 1849) are large bivalves found in soft substrates in depths ranging from the intertidal zone to greater than 100 m (Jamison *et al.* 1984). They range from Alaska to the Gulf of California in the Northeast Pacific (Quayle 1960, Coan *et al.* 2000). A dive fishery for geoducks started in British Columbia (BC) in 1976 and has grown to be the most valuable fishery for any species in the province, with a value of $43.8 million in 2001. Harvest by dive is focused in beds between 3 - 20 m depth, and harvesters prefer to fish populations in substrate mixtures of sand and crushed shell over combinations of shell fragments and gravel.

The geoduck fishery is managed on a precautionary, sustainable yield basis with annual harvest quotas calculated as one percent of the estimated virgin biomass (Hand and Bureau 2000). The one percent exploitation rate is within the range of 0.75% to 2% suggested by age-structured yield modelling (Breen 1982). Values of input parameters for mortality and recruitment were estimated from a limited number of biological samples that were collected from Southern coastal areas (Breen and Shields 1983), where early harvesting was concentrated. Since the early 1980's, the proportion of the coast-wide geoduck harvest that occurs in the North Coast has steadily increased. Several authors stressed the importance of collecting biological samples over a broader geographical range in order to provide estimates of growth, mortality and recruitment rates in all areas fished and thus address uncertainties in stock assessment (Harbo *et al.* 1983, Campbell and Rajwani 1998, Orensanz *et al.* 2000, Bradbury and Tagart 2000). A broad-scale geoduck sampling and ageing program was initiated in BC in 1993, and is ongoing. Bureau *et al.* (2002) reported on age, size structure and growth parameters of geoducks from 34 locations throughout the BC coast that were sampled between 1993 and 2000. Orensanz *et al.* (in prep) reviewed recent recruitment trends in BC geoduck populations from the published literature.

The present manuscript is a sequel of the report by Bureau *et al.* (2002) and reports on new biological data obtained in 2001 and 2002. Age and size distributions and growth parameters of geoducks from seven locations in BC are presented. In 2001 and 2002, three samples were collected from the West Coast of Vancouver Island, three from the Inside Waters and one from the Queen Charlotte Islands.

Further analyses of the samples collected from un-harvested geoduck beds will lead to new estimates of natural mortality rate. Additional analyses of all sample data will be conducted to investigate the effects of geoduck density, fishing history and habitat characteristics (current, exposure and substrate) on growth and recruitment rates of geoducks. Results of these investigations will be published in future documents.

METHODS

Field and laboratory methods used in this study were identical to those used in Bureau *et al.* (2002) and are only summarized here. Analytical methods and growth models used were also identical to Bureau *et al.* (2002) and are detailed below.

SURVEY SITES AND FIELD METHODS

Biological samples were collected at seven locations along the coast of BC in 2001-2002 (Figure 1, Appendix 1). Survey sites included a variety of fishing histories and management histories (Table 1) (Hand *et al.* 1998a, 1998b, 1998c; Harbo *et al.* 1992, 1993, 1995). The sample from South Round Island was collected from an un-surveyed virgin bed while the others were collected during biomass surveys on previously harvested beds.

Surveys conducted in 2001 and 2002 used a stratified random design, where geoduck beds were treated as strata and transects were randomly placed within them. Survey locations were based on harvest log maps, submitted by harvesters, that identified locations of commercial harvest. In 2002, substrate mapping, using QTC-View, an acoustical remote-sensing tool, was used before the surveys to help define the extent of beds. Transects were assigned by Department of Fisheries and Oceans (DFO) personnel onto charts *a priori*, in order to reduce possible bias that might be encountered under field conditions. Secondary sampling units on transects consisted of 2x5 m quadrats surveyed systematically along the transects. Information collected at each quadrat included the number of geoducks observed, depth, substrate type, and dominant algal species. Field survey methods are described in detail in Hand and Dovey (1999, 2000) and Dovey and Hand (in prep).

Biological samples were generally collected on the last day of each survey. The South Round Island sample location was not surveyed for density. The sample from Rolling Roadstead was collected in 2002 but the area was surveyed in 2001. Approximately 150 clams were collected at each of three sub-sample sites within each survey area, for a total of 450 clams collected per survey. Experienced commercial geoduck harvesters collected all samples. In 2001-2002, the majority of sampling locations were selected by randomly choosing from eligible surveyed transects. A transect was considered eligible if it contained a 100m section with enough geoducks to comprise a sub-sample. At each sample location, divers attempted to sample the entire depth range surveyed and to sample non-selectively from the entire size range of geoducks. Geoducks less than 3 to 4 years old are likely under-represented in the samples because their small siphon shows are hard to detect. Extremely small geoducks that are associated with adults often pop up when the adult is harvested, and these are collected. Divers used standard geoduck commercial fishing gear, i.e., surface supplied air (hookah) and a "stinger" (high-pressure water jet), to harvest the geoducks. The sampled geoducks were placed into dive bags (juveniles kept in a separate small bag), brought to the surface, and tagged. The tagging technique involved drying the shells with a jet of air and gluing a plastic tag with a unique identification number using cyanoacrylate gel glue. Samples were then transported live to licensed processing plants.

LABORATORY MEASUREMENTS

Morphometric Measurements

After the geoduck samples arrived at the processing plant, morphometric measurements were obtained by staff of Archipelago Marine Research Ltd. Draining time prior to weighing varied from several hours to two days, depending on shipping time from the harvest location. Total wet weight was obtained and shell length and width were measured using callipers while the animal was still in the shell. The geoducks were processed for body meat and the empty shells sent to the Pacific Biological Station for further processing. Shells were cleaned, dried, weighed and separated into individual valves prior to being measured again for length and width using callipers. Where a significant portion of a shell was broken, the shell weight was obtained by multiplying the weight of the intact valve by two. In cases where both shells were broken, the shell weight was not recorded. Shell length and width measured at the Pacific Biological Station were used for the analyses conducted in this paper.

Shell Ageing

Geoduck ageing was conducted using a validated technique, following methods presented in Shaul and Goodwin (1982). The left valve of each geoduck was cut through the umbo using a water-cooled diamond blade rotary saw. If the left valve was damaged or lost, the right valve was used. The cut surfaces were dry polished using 400 and 600-grit wet/dry diamond sandpaper mounted on rotating disks. The polished surface was then etched by applying a few drops of 1% hydrochloric acid solution for approximately one minute to reveal the annular rings, after which it was rinsed with distilled water. A peel of the etched surface was then made by applying a few drops of acetone and taking an impression of the annular rings on acetyl cellulose film (acetate). Each peel was then projected through a microscope and the number of annual growth rings counted and recorded. Shell preparation and age validation procedures are discussed in greater detail in Shaul and Goodwin (1982) and Noakes and Campbell (1992).

ANALYTICAL METHODS

Shell Length - Age Relationship

The relationship between geoduck shell length and age was described using the von Bertalanffy, or LVB, growth model (von Bertalanffy 1938, in Quinn and Deriso 1999) (Equation 1).

$$L(t) = L_{\infty}[1 - e^{-\kappa(t-t_0)}] + \varepsilon_1 \qquad \text{Equation 1}$$

Where:

- L is length at age t
- L_{∞} is the mean length of very old geoducks
- κ is a shape constant (Brody growth parameter)

- t_0 is a phase-variable
- $\varepsilon_1 \sim N(0, \sigma_1^2)$ is a normal variate

Initially, values for the independent parameters of Equation 1 were fitted simultaneously using maximum likelihood methods (Bain and Engelhardt 1991). For samples with many young geoducks, the fitted value of t_0 was between –1 and +1. However, in samples where there were few young geoducks, the fitted-values of t_0 were too large (positive or negative) to be credible. The parameter t_0 was therefore set to zero for all the samples data sets, in order to fit the curves through the origin, and L_∞, κ and σ_1 estimated again.

Total Weight – Shell Length Relationship

An allometric growth model (Equation 2) (Quinn and Deriso 1999) was used to describe the relationship between total weight and shell length:

$$W = \alpha L^{\beta} * e^{\varepsilon_2} \qquad \text{Equation 2}$$

Where:
- W is the total weight of a geoduck
- L is the shell length of a geoduck
- α and β are parameters
- $\varepsilon_2 \sim N(0, \sigma_2^2)$ is a normal variate

By taking the natural log of Equation 2, the linear relationship was:

$$\log(W) = \log(\alpha) + \beta * \log(L) + \varepsilon_2 \qquad \text{Equation 3}$$

Originally α and β were estimated as independent variables. However, Bureau *et al.* (2002) observed a consistent relationship between the estimated values of α and β (Figure 2), which was described by:

$$\log(\beta) = 0.5140 - 0.07231 * \log(\alpha) \qquad \text{Equation 4}$$

The values of α and β obtained from 2001-2002 data fit the relationship described by Bureau *et al.* (2002) (Figure 2). Therefore, for consistency and more comparable results, the same relationship between α and β (Equation 4) was used in analyses of 2001-2002 data.

Since β was a function of α, Equations 3 and 4 were combined to give a weight-length relationship with one less site-specific parameter value to estimate. For each sample data set, maximum likelihood methods were used to simultaneously estimate values for α and σ_2 Equation 2 indicates that, for a given length, the weight was assigned a lognormal distribution, therefore the estimated mean weight was larger than the weight that would be estimated if variability was ignored ($\varepsilon_2 = 0$). Both upper and lower 95% confidence bounds were determined for the fitted total weight - shell length data.

Total Weight - Age Relationship

Combining the equations for the shell length – age relationship (Equation 1) and the total weight – shell length relationship (Equation 2), the equation for the total weight-age relationship was:

$$W = \alpha * (L_\infty * (1 - e^{-\kappa(t-t_0)}) + \varepsilon_1)^\beta * e^{\varepsilon_2} \qquad \text{Equation 5}$$

- $\varepsilon_1 \sim N(0, \sigma_1^2)$ is a normal variate
- $\varepsilon_2 \sim N(0, \sigma_2^2)$ is a normal variate

As mentioned previously, t_0 was set to zero and β was treated as a function of α. Maximum likelihood estimates were used to simultaneously estimate five model parameters. Two of the model parameters, σ_1 and σ_2, were used to describe variability.

Mean weight for a given age was calculated from 10,000 combinations of ε_1 and ε_2, representing equally probable ranges of values. First, 100 values of both ε_1 and ε_2 were generated corresponding to cumulative probabilities of 0.005, 0.015, 0.025,... 0.995. A value of W was then calculated for each of the 10,000 combinations of ε_1 and ε_2. The mean value of W approximates the average of the 10,000 values.

Bootstrapping was used to produce 95% confidence bounds for the mean weight. The 10,000 weight estimates were re-sampled with replacement 1,000 times and the mean calculated for each re-sample. Each re-sample was of size N, the size of the original sample over which the parameters were being estimated. The 0.025 and 0.975 quantiles of the resample-means were used as 95% confidence bounds.

Shell Weight - Age Relationship

As in Bureau *et al.* (2002), an allometric model was chosen to describe the shell weight – age relationship:

$$SW = \gamma(Age)^\delta * e^{\varepsilon_3} \qquad \text{Equation 6}$$

Where:

- SW is the shell weight of a geoduck
- Age is the age of a geoduck
- γ and δ are parameters
- $\varepsilon_3 \sim N(0, \sigma_3^2)$ is a normal variate

By taking the natural log of Equation 6, the linear relationship was:

$$\log(SW) = \log(\gamma) + \delta * \log(Age) + \varepsilon_3 \qquad \text{Equation 7}$$

The allometric model offered a good fit to the data as the model kept increasing with age and did not reach an asymptote over the domain of the data. Bootstrapping was used to estimate confidence bounds of the parameters.

RESULTS

AGE

A total of 3,059 geoducks could be aged out of the 3,082 collected in 2001-2002, representing a 0.75% loss. Losses were attributable to shell breakage during transport and/or processing, or to the loss of identification tags from the shells.

The oldest recorded age in the 2001-2002 samples was 145 years (Table 2) at Parry Pass in the Queen Charlotte Islands while the youngest was 2 years at S Round Island. Mean age ranged between 19.6 at Marina Island and 54.0 at NE Barkley Sound.

Age frequency distributions showed prominent modes of younger age-classes in all samples except Parry Pass (Figure 3). Four out of the seven samples contained more than 50% of clams ≤20 years old (Table 3). Only two samples had fewer than 11% geoducks ≤20 years old: Parry Pass and NE Barkley Sound. The proportion of geoducks >100 years old was less than 5% for all samples.

WEIGHT AND SIZE DISTRIBUTIONS

Mean total weight of 2001-2002 samples ranged from 599.6 g at Winter Harbour to 1,111.3 g at Marina Island which had the lowest age (Table 2). The heaviest geoduck sampled was 2,579 g at Rolling Roadstead. Between 83 to 100% of geoducks were ≤1,500 g (Table 4, Figure 4).

Mean shell length ranged from 119.4 mm at S Round Island to 150.7 mm at Marina Island (Table 2). The largest geoducks found were 193 mm at Rolling Roadstead and Marina Island.

Mean shell weight ranged from 102.8 g at Winter Harbour to 233.9 g at Parry Pass which also had the heaviest shell sampled (686 g) (Table 2).

GROWTH

The von Bertalanffy growth model for shell length – age relationships indicated rapid growth in the first 10 years of life, followed by a long period of slower growth (Figure 5). Values of model parameters varied between sample locations (Table 5). Asymptotic length (L_∞) ranged from 127.0 mm, at S Round Island, to 163.2 mm, at Rolling Roadstead, and values of the Brody growth coefficient (k) ranged from 0.1562 at Parry Pass, to 0.2593 at Marina Island. Of the samples collected in 2001-2002, geoducks from Marina Island were the fastest growing while those from Parry Pass were the slowest growing.

The relationship found between α and β values of the allometric total weight – shell length relationship (Figure 2) (see Methods section) indicated that, as the intercept of the linear growth model (log(α) Equation 3) increased, the slope of the relationship, β, decreased (Table 5). Total weight – shell length growth patterns therefore ranged between samples from fast initial growth (weight gain) that changed little as the shell increased in length (e.g. S Round Island), to slow initial growth followed by an accelerated rate of weight gain as the shell gets larger (e.g. Rolling Roadstead) (Figure 6).

Total weight – age relationships showed variability in both growth rate and maximum size attained between samples (Table 5, Figure 7). As with shell length, Marina Island showed the fastest growth of the 2001-2002 samples. Rolling Roadstead showed the largest estimated asymptotic weight (TW_∞) at 1301.6 g while Winter Harbour had the lowest at 702.1 g. Growth in weight was rapid during the first 10 years of life, slowed down between 10 and 20 years and geoducks generally reached asymptotic weight by age 20 (Figure 7).

Log-transformed plots of the allometric shell weight – age relationships (Figure 8) showed a good model fit for geoducks older than 5 years. For geoducks younger than 5 years, the model overestimated shell weight. Model parameters showed variability between sample locations (Table 6).

DISCUSSION

This paper is the second to discuss age, size distributions, and growth parameters of geoduck samples that were collected in BC in the last 10 years. Bureau *et al.* (2002) presented similar analyses on 34 geoduck biological samples collected in BC between 1993 and 2000. In addition to individual sample analyses, Bureau *et al.* (2002) also analyzed data by geographical areas. For the present paper, geographical area analyses were not performed as the number of samples involved was considered too small.

AGE

A total of 3,059 geoducks were aged in 2001-2002, bringing the total number of geoducks aged in BC since 1993 to 15,907. Sample loss was much lower for samples collected in 2001 and 2002 (0.75%) than for the samples collected between 1993 and 2000 (9.6%) (Bureau *et al.* 2002). The lower sample loss can be attributed to improved tag retention resulting from the new practice of drying shells with an air jet instead of a towel. Also, in 2002, juveniles with fragile shells were kept in separate cages on the boat and sent directly to the Pacific Biological Station for processing, in order to avoid breakage that results from transport and handling of the shells at processing plants in Vancouver. In the past, some juveniles sent to the plants were crushed, so that shell loss may have been higher for juveniles than for older clams. This bias in shell breakage may have led to an under-representation of young clams in earlier samples. Sending the juveniles directly to the Pacific Biological Station should provide a better representation of young geoducks in the samples.

Mean ages observed in the current study (19.6 to 54.0 years) are within the range of earlier BC samples (14.5 to 72.2 years) (Bureau *et al.* 2002). Mean age at Parry Pass 2002 (48.0) was lower than that of samples from the West coast of the QCI (51.7 to 72.2 years) but within the range of mean ages found on the East coast of the QCI (31.0 to 49.7 years) (Bureau *et al.* 2002). Mean age of samples collected from the Inside Waters was within the range reported for that region (Bureau *et al.* 2002). The sample from NE Barkley Sound had the highest mean age (54.0 years) of all samples reported to date for the West Coast of Vancouver Island.

Comparison of re-sampled locations

Four samples collected in 2001-2002 can be compared to earlier samples collected in the same or nearby locale.

The Winter Harbour area was surveyed in 1996 and again in 2002, due to growing concerns related to sea otter predation on geoducks in the area. Sub-samples collected at Winter Harbour in 2002 were taken from the same locations as the 1996 samples. Mean age decreased from 49.0 years in 1996 (Bureau *et al.* 2002) to 33.1 years in 2002. Two mechanisms may explain the drop in mean age: removal of older geoducks from the population or recruitment of young geoducks to the population. If the age frequency distribution is expressed in absolute terms (geoducks per m^2 for a given age group) by normalizing the distribution by the overall density estimate, geoduck densities for a given age group can be compared between years. The biological sample is assumed to be representative of geoducks counted in the density survey. Plots of density of geoducks of various age groups (Figure 9) show that density of young geoducks, especially 6 to 12 years, has increased between 1996 and 2002. Density of adult geoducks showed either a slight decrease, no change or even slight increase between 1996 and 2002, depending on the age group. The increase in density of adults of some age groups was unexpected and suggests that sampling errors associated with spatial variability occurred. Although attempts were made in 2002 to sample the same locations as in 1996, the harvest locations were not marked and the samples may have been collected from slightly different areas. Therefore, it appears that recruitment was the main cause of the decrease in mean age at Winter Harbour.

Mean age in a market sample from Rolling Roadstead, in 1981, was 35.2 years (Harbo *et al.* 1983) and decreased to 20.0 years in 2002. Density at Rolling Roadstead in 1984 was 0.89 geoducks per m^2 (unpublished data) and decreased to 0.30 geoducks per m^2 in 2002 (Appendix 1). We applied the 1984 density data to the 1981 age frequencies, assuming that density was the same in 1981, to calculate the density of geoducks of different age groups. The same was done with 2002 density and age data. Density of geoducks ≤10 years increased from 0.035 in 1981 to 0.155 geoducks per m^2 in 2002 while density of geoducks >10 years decreased from 0.855 in 1981 to 0.145 geoducks per m^2 in 2002. Two factors therefore acted to decrease the mean age at Rolling Roadstead: recruitment and removal of old clams from the population by the fishery and/or sea otters. Between 1982 and 2002, 1,145,856 kg of geoducks (63% of total landings for the bed) were harvested at Rolling Roadstead.

Mean age at Marina Island decreased from 36.7 years in 1992 (southern bed, unpublished data), to 19.6 years in 2002 (northern bed). Since only 16,125 kg of geoducks (5% of total landings) were harvested at the northern Marina Island bed between 1992 and 1994 (after which the bed was not fished), removal of old clams from the population by the fishery is unlikely to be the cause of the decrease in mean age. Another explanation for the decrease in mean age would be increased recruitment. Density at Marina Island in 1992 was 0.23 geoducks per m^2 (Campbell *et al.* 1996) while density in 2002 was 0.32 geoducks per m^2. Combining densities with age frequency distributions showed that recruitment was indeed the main cause of the decrease in mean age at Marina Island. Density of geoducks ≤20 years tripled from 0.075 in 1992 to 0.224 geoducks per m^2 in 2002, while density of geoducks >20 years decreased slightly from 0.155 in 1992 to 0.096 geoducks per m^2 in 2002.

A sample collected from the commercial bed at Round Island in 2000 showed the lowest mean age recorded for BC, at 14.5 years, and highest proportion of geoducks ≤10 years at 78% (Bureau *et al.* 2002). A new bed was discovered less than 1 km south of the documented Round Island bed, and slightly deeper, through bottom substrate mapping work. This new bed, named South Round Island in this paper, had no reported landings and is believed to be a un-harvested bed. A sample was collected off the South Round Island bed in 2002 to compare it to the 2000 Round Island sample and evaluate the effects of harvest on age frequency distributions. Mean age at South Round Island was 40.6 years and only 17.4% of geoducks were ≤10 years. The age composition between the two samples was therefore different. The Round Island bed was harvested heavily between 1979 and 1994, after which the bed was closed to fishing. The low proportion of old clams at Round Island suggests that the fishery removed most old clams from the population. The low abundance of adults at Round Island could be partly responsible for the strong recruitment peak seen at Round Island 2000. The recruitment peak observed at South Round Island 2002 was not as strong as that observed at Round Island 2000, however, this may be an artifact of the near-absence of older geoducks in the Round Island 2000 sample. No density data are available for South Round Island so a comparison of recruit density cannot be made. A decrease in the proportion of older clams was similarly shown in areas with a time-series of samples, presented in Bureau *et al.* (2002).

Recruitment

Early studies of geoduck age samples concluded that recruitment rates were low (Breen and Shields 1983, Fyfe 1984, Goodwin and Shaul 1984, Harbo *et al.* 1983, Noakes and Campbell 1992, Sloan and Robinson 1984). A review of published geoduck age data available in 2000 suggested that recruitment decreased over the last 60 years, long before the fishery started and hence was due to other causes than harvesting (Orensanz *et al.* 2000). Recent geoduck age data

(1993-2002) shows a reversal in recruitment trends of geoducks in BC (Bureau *et al.* 2002, Orensanz *et al.* in prep).

Although a high proportion of young clams in a sample could merely reflect the absence of older clams, many samples were dominated by geoducks ≤20 years old. The Winter Harbour, Rolling Roadstead, Marina Island and Boatswain Bank samples had more than 50% of geoducks ≤20 years old and over 25% of geoducks ≤10 years old. Harvest on these beds started at least 17 years before sample collections occurred. Therefore, most geoducks ≤20 years in the samples have recruited to the beds after the start of the fishery. These results support the findings of Bureau *et al.* (2002) who noted strong recruitment in some geoduck beds with long harvest histories, and suggested that harvesting may not have a negative effect on recruitment as proposed by Goodwin and Shaul (1984).

All samples from Southern BC collected in 2001-2002 showed a recruitment event around 1992 to 1994. A strong recruitment pulse also occurred in many parts of the BC coast in 1988 (Bureau *et al.* 2002) suggesting that geoduck recruitment is sporadic, as indicated in other studies (Fyfe 1984, Goodwin and Shaul 1984, Bureau *et al.* 2002, Orensanz *et al.* in prep). Recruitment of another species of geoduck from New Zealand (*P. zelandica*) was also found to be variable (Breen *et al.* 1991). Perhaps more importantly, these results suggest that conditions that are favorable to geoduck larval survival and settlement may be widespread. Orensanz *et al.* (in prep) back-calculated relative recruitment from the age frequency distributions presented in Bureau *et al.* (2002) and concluded that the data were strongly suggestive of long-term trends in recruitment, coherent on a very large geographic scale. Moderate to strong El Niño events occurred in 1987, 1992 and 1994 (Ware 1995). The appearance of strong geoduck recruitment during or soon after El Niño events suggests that large scale climatic patterns, such as El Niño, may have an effect on geoduck recruitment. A strong El Niño event also occurred in 1997-1998. The 1997-1998 year-classes should appear in geoduck age samples collected in 2003 and 2004 and it should prove interesting to further investigate the possible links between geoduck recruitment and El Niño events.

WEIGHT AND SIZE DISTRIBUTIONS

Mean total weights were within the range reported earlier for BC (Bureau *et al.* 2002) except for the Winter Harbour sample which had the lowest total weight reported to date (599.6 g). Marina Island had the highest mean weight (1111.3 g) and shell length (150.7 mm) of the 2001-2002 samples despite the fact that it had the lowest mean age, suggesting that Marina Island may be a productive area. Mean weight at Rolling Roadstead and Winter Harbour decreased since they were last sampled. Possible causes for the decrease in mean weight, as for mean age, are recruitment or removal of larger and older clams over time by the fishery.

Mean shell length values for the 2001-2002 samples were within the range reported for BC (Bureau *et al.* 2002) except for the Winter Harbour (119.9 mm) and South Round Island (119.4 mm) samples which showed lower mean shell lengths than previously recorded. Substrate at South Round Island consisted of a soft layer of sand from 30-60 cm thick with a harder layer of shell/rock below. Many clams were deformed, small and showed evidence of growing between hard objects which may partially explain the low mean size at South Round Island. Mean shell weight was within the range reported for BC by Bureau *et al.* (2002).

Several authors have found differences in mean weight and/or shell length of geoducks between sample locations or regions (Goodwin 1976, Goodwin and Pease 1991, Bureau *et al.* 2002). Evidence of variability in mean geoduck sizes between locations was also evident in the 2001-2002 samples from BC.

GROWTH

The observed pattern of geoduck early rapid growth to near maximum size followed by a long period of minimal growth was similar to observations reported in the literature (Andersen 1971, Goodwin 1976, Breen and Shields 1983, Harbo *et al.* 1983, Goodwin and Shaul 1984, Noakes and Campbell 1992, Hoffman *et al.* 2000, Bureau *et al.* 2002). All growth parameters estimated for 2001-2002 data were within the range obtained by Bureau *et al.* (2002) for 1993-2000 data, except for L_∞ at S Round Island which was the lowest estimated to date for BC at 127.0 mm. The sample from Rolling Roadstead had the highest L_∞ recorded for the West Coast of Vancouver Island (excluding Area 24) (Bureau *et al.* 2002). As noted by Bureau *et al.* (2002) there was no relationship between growth rate (k) and maximum size reached (L_∞). Both fast and slow growing geoducks can attain large (e.g., Marina Island and Parry Pass respectively) or small maximum sizes (e.g., Boatswain Bank and S Round Island respectively).

Growth rates were variable between sample locations, even within a geographical region, as observed in other studies (Harbo *et al.* 1983, Goodwin and Shaul 1984, Noakes 1992, Hoffman *et al.* 2000, Bureau *et al.* 2002). For Inside Waters, Marina Island had the highest L_∞ and TW_∞ recorded in the region to date while S Round Island had the lowest L_∞ and k values. A variety of factors have been suggested to explain differences in growth and mean size of geoducks, such as: exposure (Breen and Shields 1983), substrate type (Goodwin and Pease 1991), primary productivity (Goodwin and Pease 1987), temperature (Noakes and Campbell 1992), current (Goodwin and Pease 1987, Hoffmann *et al.* 2000) and possibly geoduck population density (Bureau *et al.* 2002).

Values of α and β, of the allometric total weight – shell length models, are inversely related so that as the intercept (log (α)) of the log transformed allometric model (Equation 3) increases, the slope (β) decreases. This translates in different growth rates (weight gain per length increment) in early life, but the differences in weight-at-length diminish later in life as the different relationships tend to converge. The converging point of the total weight – shell length relationships was computed for each pair of locations sampled in 2001-2002. The converging point of total weight – shell length relationships for each pair of locations was greater than L_∞ at those locations, therefore, differences in weight-at-length will remain present between samples. Locations with a greater α will have a higher total weight for a given shell length.

Geoduck shell weight, unlike shell length or total geoduck weight, keeps increasing slowly with age through a thickening of the shell over time (Harbo *et al.* 1983, Goodwin and Shaul 1984, Sloan and Robinson 1984, Bureau *et al.* 2002). The allometric growth model for the shell weight – age relationships fitted data well for geoducks over 5 years of age, suggesting that model parameters predict the shell thickening period of shell growth better than the early period of shell length increase.

CONCLUSIONS

Geoduck age samples collected in 2001-2002 showed prominent modes of younger clams, similar to samples collected in the 1990's for other areas of the BC coast (Bureau *et al.* 2002). The trend of increasing recruitment during the last 20 years (Orensanz *et al.* in prep) therefore appears to be continuing. Possible links between strong geoduck recruitment and El Niño events requires further study.

Data from the 2001-2002 samples further showed the potential for the fishery to remove old geoducks from the population while some data showed recruitment events can decrease mean age and weight in a population. The collection of more samples from areas that have been sampled in the past would be valuable to help determine the effects of harvesting and recruitment on geoduck age frequency distributions.

New data again showed differences in growth rates of geoducks between sample locations. As proposed by Bureau *et al.* (2002) the appropriateness of using a single exploitation rate in management of the geoduck fishery, given variations in growth rates between areas, should be reviewed.

Although a considerable volume of geoduck age data has been collected in BC in the last 10 years, few samples have come from virgin, un-harvested, beds. Between 1993 and 2002, only 4 samples (out of 41 samples collected) have come from virgin beds (Tasu Sound, Moore Island and Principe Channel in Northern BC and S Round Island in Southern BC). Age frequency distributions from un-fished populations are required to calculate natural mortality rates. Estimation of natural mortality rates of geoducks has been identified as a research priority by Bradbury and Tagart (2000) and Harbo *et al.* (1983) because mortality rate is the parameter that has the most influence on yield modeling (Bradbury and Tagart 2000). Therefore, collection of biological samples of geoducks from virgin populations throughout the BC coast should be a priority, especially considering that unfished populations are increasingly rare. Collection of geoduck age samples from virgin beds has been scheduled for the 2003 field season.

Further analyses of data presented in this paper and that of Bureau *et al.* (2002) will be conducted to investigate effects of geoduck density, fishing history, substrate, exposure and current on geoduck growth and recruitment.

ACKNOWLEDGEMENTS

We would like to thank the Underwater Harvesters' Association for their ongoing participation and financial support in geoduck research activities in British Columbia. The Haida Fisheries Program participated in one survey. Bill Thompson cut and polished the shells and

Jeanine Bond aged the geoducks. Georg Jorgensen provided database support. Neil Bourne reviewed the manuscript.

ERRATA

The following errors were found in Bureau *et al.* (2002):

The end of the last sentence on p. 16 is missing. The sentence should read: "This suggests that differences in mean age between Northern and Southern BC may have been present before the fishery and that other factors can play a part in building the population age structure."

Table 17: For the 1981 Rolling Roadstead sample, the Total Weight and the Shell Length data were reversed.

REFERENCES

Andersen, A.M. 1971. Spawning, growth, and spatial distribution of the geoduck clam, *Panope generosa* Gould, in Hood Canal, Washington. PhD Diss. U. of Washington, 133 p.

Bain, L.J., and M. Engelhardt. 1991. Introduction to Probability and Mathematical Statistics. 2nd Edition. Duxbury Press. Belmont. 644 p.

von Bertalanffy, L. 1938. A quantitative theory of organic growth (Inquiries on growth laws II). Human Biol. 10: 181-213.

Bradbury, A., and J.V. Tagart. 2000. Modeling geoduck, *Panopea abrupta* (Conrad, 1849) population dynamics. II. Natural mortality and equilibrium yield. J. Shellfish Res. 19: 63-70.

Breen, P.A. 1982. Geoducks, p. 14-16. *In*: Bernard, F.R. [ed.]. Assessment of invertebrate stocks off the West Coast of Canada (1981). Can. Tech. Rep. Fish. Aquat. Sci. 1074.

Breen, P.A., and T.L. Shields. 1983. Age and size structure in five populations of geoduc clams (*Panope generosa*) in British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1169: 62 p.

Breen, P.A., C. Gabriel and T. Tyson. 1991. Preliminary estimates of age, mortality, growth, and reproduction in the hiatellid clam *Panopea zelandica* in New Zealand. New Zealand J. Mar. Freshwater Res. 25: 231-237.

Bureau, D., W. Hajas, N.W. Surry, C.M. Hand, G. Dovey and A. Campbell. 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.

Campbell, A., and K.N. Rajwani. 1998. Optimal sample sizes for geoduck biosamples, p. 43-69. *In*: G.E. Gillespie 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., R. Harbo and S. Heizer. 1996. 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.

Coan, E.V., P.V. Scott and F.R. Bernard. 2000. Bivalve seashells of western North America. Marine Bivalve Mollusks from Arctic Alaska to Baja California. Santa Barbara Museum of Natural History Monographs 2. 764 p.

Dovey G., and C.M. Hand. In prep. A survey of geoduck populations at three locations on the West side of the Queen Charlotte Islands in 1999: 1. West Skidegate Channel and Buck Channel, 2. Englefield Bay, 3. Gowgaia Bay. Can. Manuscr. Rep. Fish. Aquat. Sci. ####: ## p.

Fyfe, D.A. 1984. The effect of conspecific association on growth and dispersion of the geoduck clam (*Panope generosa*). M.Sc. Thesis, Simon Fraser U. 109 p.

Goodwin, L. 1976. Observations on spawning and growth of subtidal geoducks (*Panope generosa*, Gould). Proc. Natl. Shellfish. Assoc. 65: 49-58.

Goodwin, L., and B. Pease. 1987. The distribution of geoduck (*Panope abrupta*) size, density, and quality in relation to habitat characteristics such as geographic area, water depth, sediment type, and associated flora and fauna in Puget Sound, Washington. Wash. Dept. Fish. Tech. Rep. 102: 44 p.

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

Goodwin, L., and W. Shaul. 1984. Age, recruitment and growth of the geoduck clam (*Panope generosa*, Gould) in Puget Sound, Washington. Wash. State Dept. Fish. Prog. Rep. 215: 30 p.

Hand, C.M., and D. Bureau. 2000. Quota options for the geoduck clam (*Panopea abrupta*) fishery in British Columbia for 2001 and 2002. Can. Stock Assessment Secretariat Res. Doc. 2000/163: 53 p.

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

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

Hand, C.M., B.G. Vaughan and S. Heizer. 1998a. Quota options and recommendations for the 1999 and 2000 geoduck clam fisheries. Can. Stock Assessment Secretariat Res. Doc. 98/146: 52 p.

Hand, C.M., K. Marcus, S. Heizer and R. Harbo. 1998b. Quota options and recommendations for the 1997 and 1998 geoduck clam fisheries, p. 71-159. *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.

Hand C.M., K. Hobbs, R. Harbo and G. Thomas. 1998c. Quota options and recommendations for the 1996 geoduck clam fishery, p. 375-434. *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 1. Bivalves. Can. Tech. Rep. Fish. Aquat. Sci. 2214.

Harbo, R., G. Thomas and K. Hobbs. 1993. Quotas for the 1992 – 1993 geoduck clam fisheries. Can. Manuscr. Rep. Fish. Aquat. Sci. 2179: 201 p.

Harbo, R., G. Thomas and K. Hobbs. 1995. Quota options and recommendations for the 1995 geoduck clam fishery. Can. Manuscr. Rep. Fish. Aquat. Sci. 2302: 141 p.

Harbo, R.M., B.E. Adkins, P.A. Breen and K.L. Hobbs. 1983. Age and size in market samples of geoduc clams (*Panope generosa*). Can. Manuscr. Rep. Fish. Aquat. Sci. 1714: 77 p.

Harbo, R., S. Farlinger, K. Hobbs and G. Thomas. 1992. A review of quota management in the geoduck clam fishery in British Columbia, 1976 to 1990, and quota options for the 1991 fishery. Can. Manuscr. Rep. Fish. Aquat. Sci. 2178: 135 p.

Hoffmann, A., A. Bradbury and C.L. Goodwin. 2000. Modeling geoduck, *Panopea abrupta* (Conrad, 1849) population dynamics. I. Growth. J. Shellfish Res. 19: 57-62.

Jamison, D., R. Heggen and J. Lukes. 1984. Underwater video in a regional benthos survey. Proc. Pacific congress on marine technology, Honolulu, Hawaii, April 24-27, 1984.

Noakes, D.J. 1992. On growth and mortality of geoduck clams (*Panope abrupta*), p. 22-34. *In*: Thomas, G.A. [Ed.]. Shellfish stock assessment for the West coast of Canada in 1991 as reviewed by the Pacific Stock Assessment Review Committee (PSARC). Can. Manuscr. Rep. Fish. Aquat. Sci. 2169.

Noakes, D.J., and A. Campbell. 1992. Use of geoduck clams to indicate changes in the marine environment of Ladysmith Harbour, British Columbia. Environmetrics. 3(1): 81-97.

Orensanz, J.M., R. Hilborn and A.M. Parma. 2000. Harvesting Methuselah's clams- Is the geoduck fishery sustainable, or just apparently so? Can. Stock Assessment Secretariat Res. Doc. 2000/175: 68 p.

Orensanz, J.M., C. Hand, A.M. Parma, J. Valero and R. Hilborn. In prep. Precaution in the harvest of Methuselah's clams – the difficulty of getting timely feedback from slow-pace dynamics. Can. J. Fish. Aquat. Sci. ##: ###-###.

Quayle, D.B. 1960. The intertidal bivalves of British Columbia. Handbook No. 17, B.C. Provincial Museum, Victoria. 104 p.

Quinn II, T.J., and R.B. Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press. New York. 542 p.

Shaul, W., and L. Goodwin. 1982. Geoduck (*Panopea generosa*: Bivalvia) age determined by internal growth lines in the shell. Can. J. Fish. Aquat. Sci. 39: 632-636.

Sloan, N.A., and S.M.C. Robinson. 1984. Age and gonad development in the geoduck clam *Panope abrupta* (Conrad) from southern British Columbia, Canada. J. Shellfish Res. 4(2): 131-137.

Ware, D.M. 1995. A century and a half of change in the climate of the NE Pacific. Fish. Oceanogr. 4(4): 267-277.

Table 1: Summary of geoduck fishing history statistics for each location where age samples were collected in BC in 2001 and 2002.

Year	Location	# of Beds	# of Samples	Year First Harvested	Bed Area (ha)	Total Landing (kg)	kg/m^2 Harvested Average	kg/m^2 Harvested Range	Total Effort (h)	min/m^2 Fishing Effort Average	min/m^2 Fishing Effort Range
Queen Charlotte Islands											
2002	Parry Pass, QCI	1	3	1987	49.5	137,325	0.277	-	727	0.088	-
West Coast Vancouver Island											
2002	Winter Harbour	3	3	1985	60.5	287,646	0.475	0.148 - 1.029	1,538	0.153	0.051 - 0.320
2002	Rolling Roadstead	1	5	1980	122.2	1,823,899	1.492	-	10,260	0.504	-
2002	NE Barkley Sound	3	3	1982	41.5	273,267	0.658	0.239 - 1.297	1,506	0.218	0.067 - 0.481
Inside Waters											
2002	Marina Island	1	2	1978	81.1	302,073	0.373	-	2,356	0.174	-
2002	S Round Island	N/A	3	N/A	0.0	0	0.000	-	0	0.000	-
2001	Boatswain Bank	1	3	1980	50.6	41,442	0.082	-	235	0.028	-

Table 2: Summary statistics of age, total weight, shell length and shell weight for geoduck samples collected in BC in 2001 and 2002. Sub-sample sizes are approximate.

Year	SurveyTitle	# and Size of Sub-Samples	n	Age (years) Mean (Range)	Age S.D.	Age n	Total Weight (g) Mean (Range)	Total Weight S.D.	Total Weight n	Length (mm) Mean (Range)	Length S.D.	Length n	Shell Weight (g) Mean (Range)	Shell Weight S.D.	Shell Weight n
Queen Charlotte Islands															
2002	Parry Passage	3 * 150	441	48.0 (6-145)	22.4	440	1020.4 (101-2140)	305.3	441	143.1 (70-184)	16.0	441	233.9 (12-686)	87.8	440
West Coast Vancouver Island															
2002	Winter Harbour	3 * 150	496	33.1 (5-135)	29.8	495	599.6 (82-1498)	243.4	496	119.9 (74-165)	15.4	494	102.8 (11-416)	69.3	482
2002	Rolling Roadstead	5 * 40 to 200**	421	20.0 (3-115)	19.8	418	950.5 (29-2579)	409.9	418	144.7 (34-193)	23.2	421	176.8 (3-530)	105.8	397
2002	NE Barkley Sound	3 * 150	502	54.0 (3-120)	22.7	501	802.9 (6-1499)	207.0	502	131.9 (30-164)	12.3	502	144.5 (1-393)	49.9	495
Inside Waters															
2002	Marina Island	2 * 150	308	19.6 (3-100)	13.6	304	1111.3 (12-1930)	369.6	308	150.7 (43-193)	19.6	308	172.8 (2-403)	71.4	287
2002	South Round Island	3 * 150	464	40.6 (2-115)	25.3	460	740.4 (10-1790)	300.2	463	119.4 (35-176)	19.5	458	158.8 (1-441)	82.8	452
2001	Boatswain Bank	3 * 150	450	38.1 (4-137)	34.4	441	667.8 (170-1568)	285.0	449	125.4 (69-170)	17.2	450	141.8 (23-430)	80.8	409

**: Harvested from 5 locations due to poor shows. The boat had to be moved to new locations to find good shows.

Table 3: Cumulative percent age frequency of geoducks from seven locations sampled in BC in 2001 and 2002.

	Cumulative % Frequency of Geoducks								
Year Survey	≤10 yrs	≤20 yrs	≤40 yrs	≤60 yrs	≤80 yrs	≤100 yrs	≤120 yrs	≤140 yrs	≤160 yrs
Queen Charlotte Islands									
2002 Parry Passage	2.3	8.0	38.9	80.9	90.5	95.9	99.1	99.8	100.0
West Coast Vancouver Island									
2002 Winter Harbour	42.2	54.5	61.4	79.4	91.3	97.8	99.4	100.0	
2002 Rolling Roadstead	51.7	70.3	84.9	92.6	98.6	99.8	100.0		
2002 NE Barkley Sound	5.0	10.8	22.8	62.5	89.4	97.4	100.0		
Inside Waters									
2002 Marina Island	25.7	70.1	93.4	96.7	99.3	100.0			
2002 South Round Island	17.4	30.7	48.3	74.6	94.8	99.6	100.0		
2001 Boatswain Bank	44.0	53.1	58.0	71.2	84.1	95.2	99.5	100.0	

Table 4: Cumulative percent frequency of total weight of geoducks from seven locations sampled in BC in 2001 and 2002.

	Cumulative % Frequency of Geoducks					
Year Survey	≤500 g	≤1000 g	≤1500 g	≤2000 g	≤2500 g	≤3000 g
Queen Charlotte Islands						
2002 Parry Passage	3.6	52.8	94.3	99.5	100.0	
West Coast Vancouver Island						
2002 Winter Harbour	38.3	94.8	100.0			
2002 Rolling Roadstead	11.7	57.7	90.7	99.0	99.8	100.0
2002 NE Barkley Sound	5.8	84.9	100.0			
Inside Waters						
2002 Marina Island	6.2	35.1	83.4	100.0		
2002 South Round Island	22.7	79.9	99.6	100.0		
2001 Boatswain Bank	31.6	85.5	99.3	100.0		

Table 5: Parameter estimates for Length – Age, Total Weight – Length and Total Weight – Age (combined model) relationships from geoduck samples collected in 2001 and 2002. Mean TW_∞ is the estimated mean asymptotic total weight estimated from the combined growth model.

	Von Bertalanffy (Length-Age)				Allometric (Total Weight-Length)				Combined Model	
Year Survey	L_∞ (mm)	k	$sigma_1$	n	α	β	$sigma_2$	n	Mean TW_∞ (g)	n
Queen Charlotte Islands										
2002 Parry Passage	145.6	0.1562	13.47	440	0.005420	2.438	0.1898	441	1052.6	440
West Coast Vancouver Island										
2002 Winter Harbour	129.1	0.2298	11.72	494	0.001812	2.639	0.2101	494	702.1	494
2002 Rolling Roadstead	163.2	0.2180	12.78	418	0.000803	2.799	0.2055	418	1301.6	415
2002 NE Barkley Sound	133.3	0.2374	10.67	501	0.003982	2.493	0.1900	502	813.8	501
Inside Waters										
2002 Marina Island	158.0	0.2593	15.50	304	0.002482	2.580	0.2144	308	1218.5	304
2002 South Round Island	127.0	0.1759	13.82	457	0.007992	2.371	0.2597	457	819.2	456
2001 Boatswain Bank	134.2	0.2420	14.27	441	0.001550	2.669	0.2161	449	778.3	440

Table 6: Parameter estimates for Shell Weight – Age relationship of geoduck samples collected in BC in 2001 and 2002.

Year Survey	γ	δ	$sigma_3$	n
Queen Charlotte Islands				
2002 Parry Passage	12.04	0.7678	0.2303	439
West Coast Vancouver Island				
2002 Winter Harbour	11.05	0.6514	0.2960	482
2002 Rolling Roadstead	20.20	0.7348	0.3326	396
2002 NE Barkley Sound	15.76	0.5544	0.3224	495
Inside Waters				
2002 Marina Island	21.62	0.6973	0.3640	287
2002 South Round Island	8.81	0.7826	0.4367	452
2001 Boatswain Bank	21.38	0.5373	0.2525	407

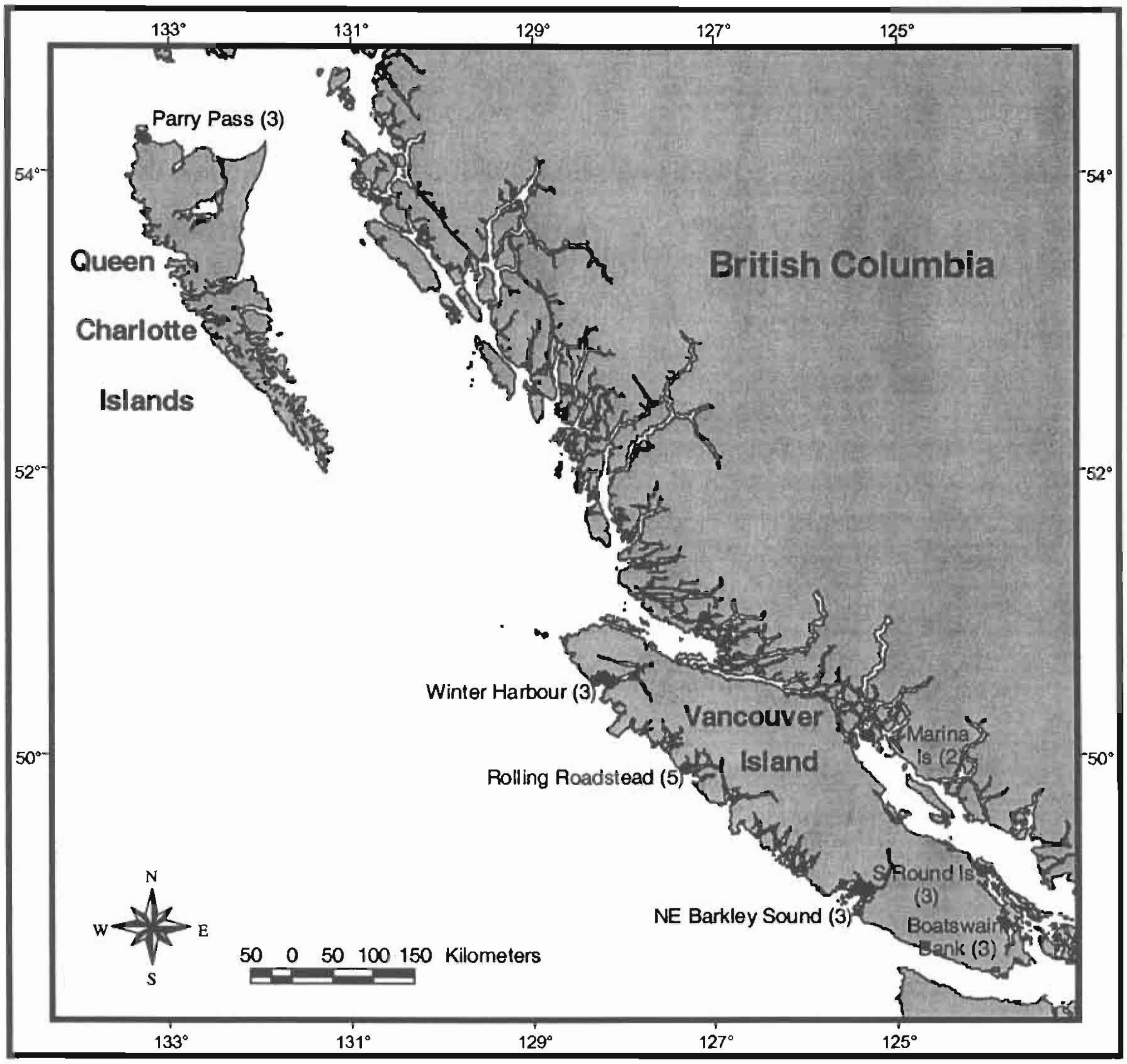

Figure 1: Map of BC showing the locations of geoduck biological sample collections and the number of sub-samples collected at each location (in brackets) in 2001 and 2002.

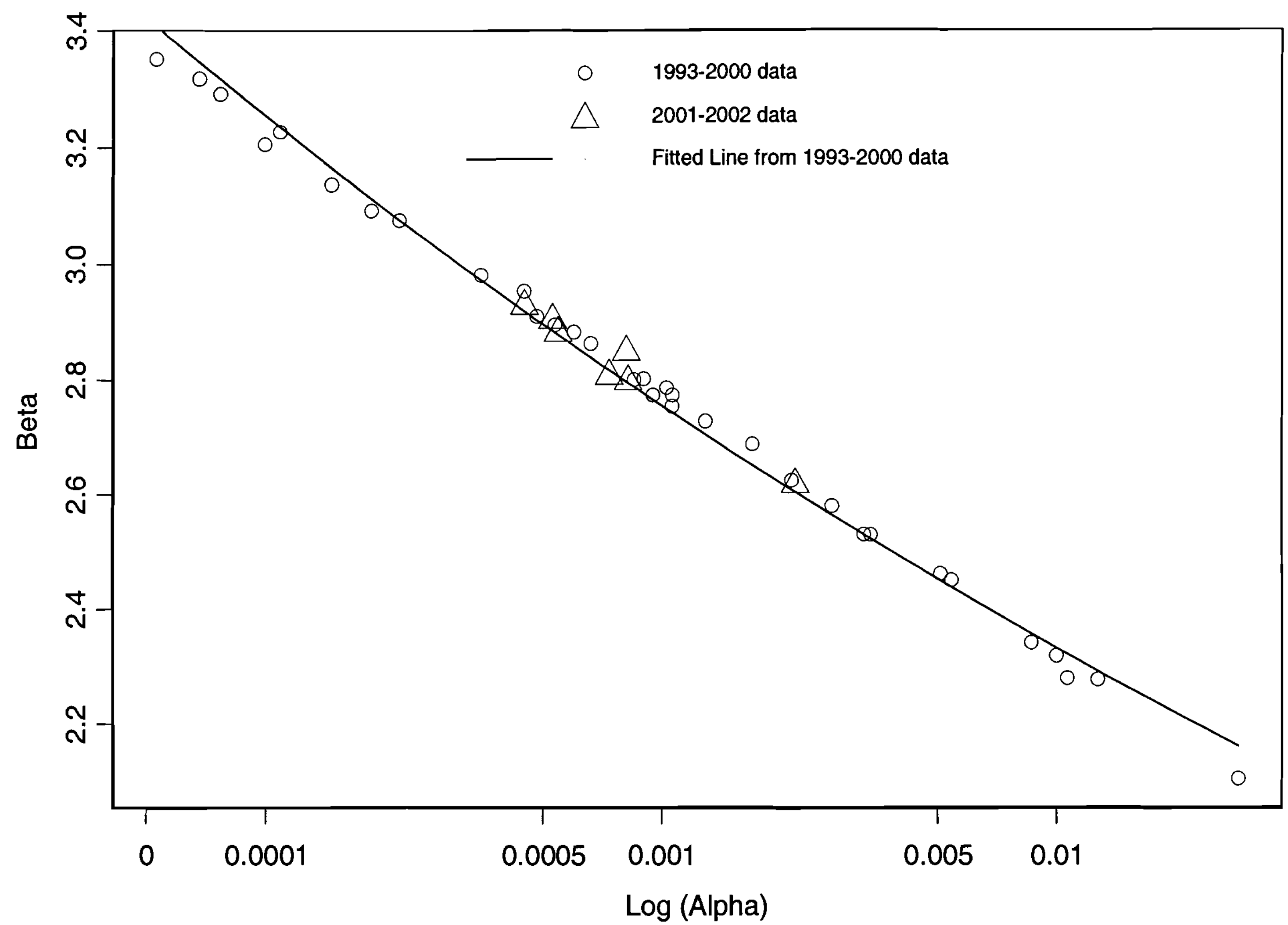

Figure 2: Relationship between log(α) and β values calculated from geoduck shell length – total weight allometric functions of samples from 34 locations sampled between 1993 and 2000 (circles) and 7 locations sampled in 2001-2002 (triangles) in BC.

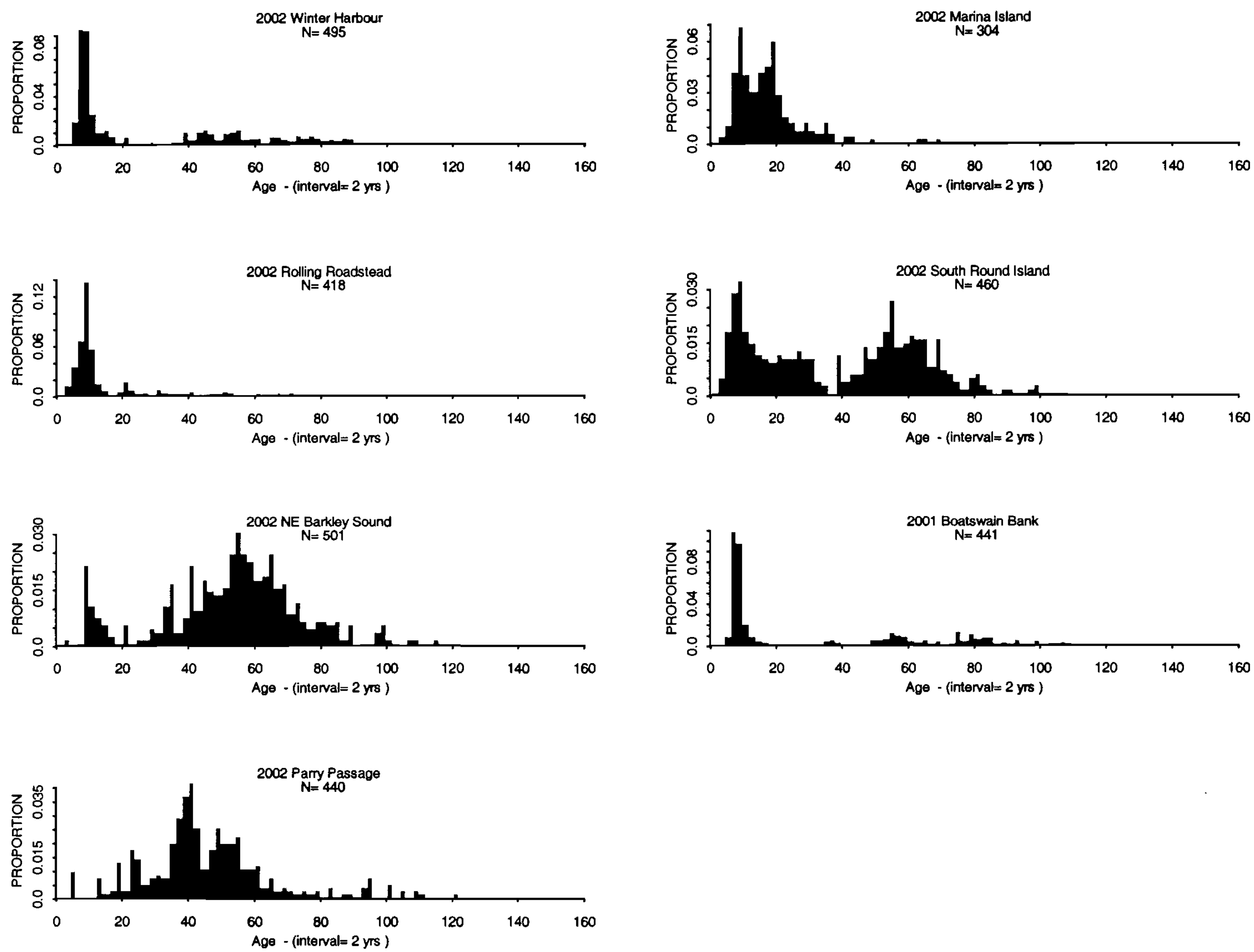

Figure 3: Age frequency distributions of geoduck samples collected in BC in 2001 and 2002.

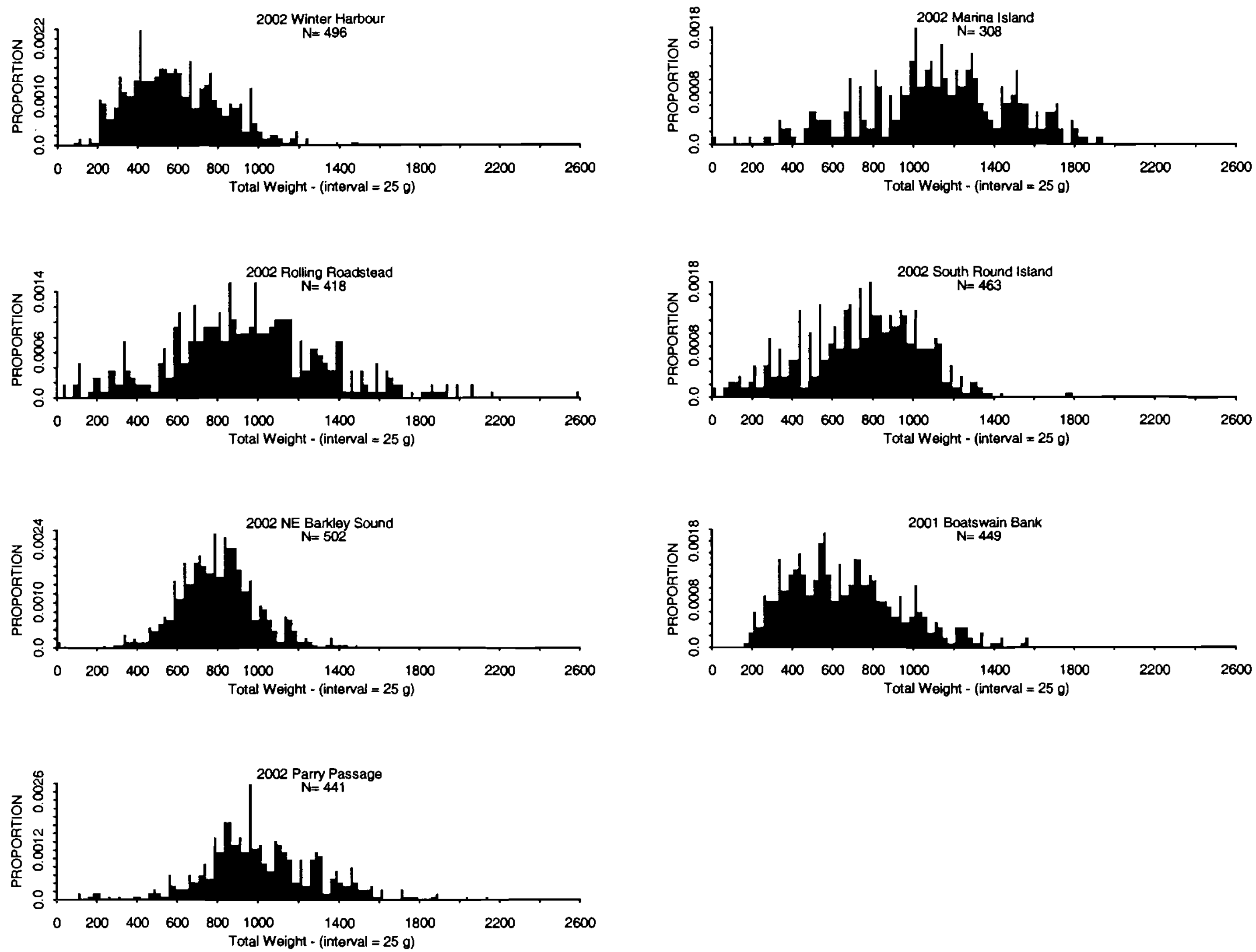

Figure 4: Total weight frequency distributions of geoduck samples collected in BC in 2001 and 2002.

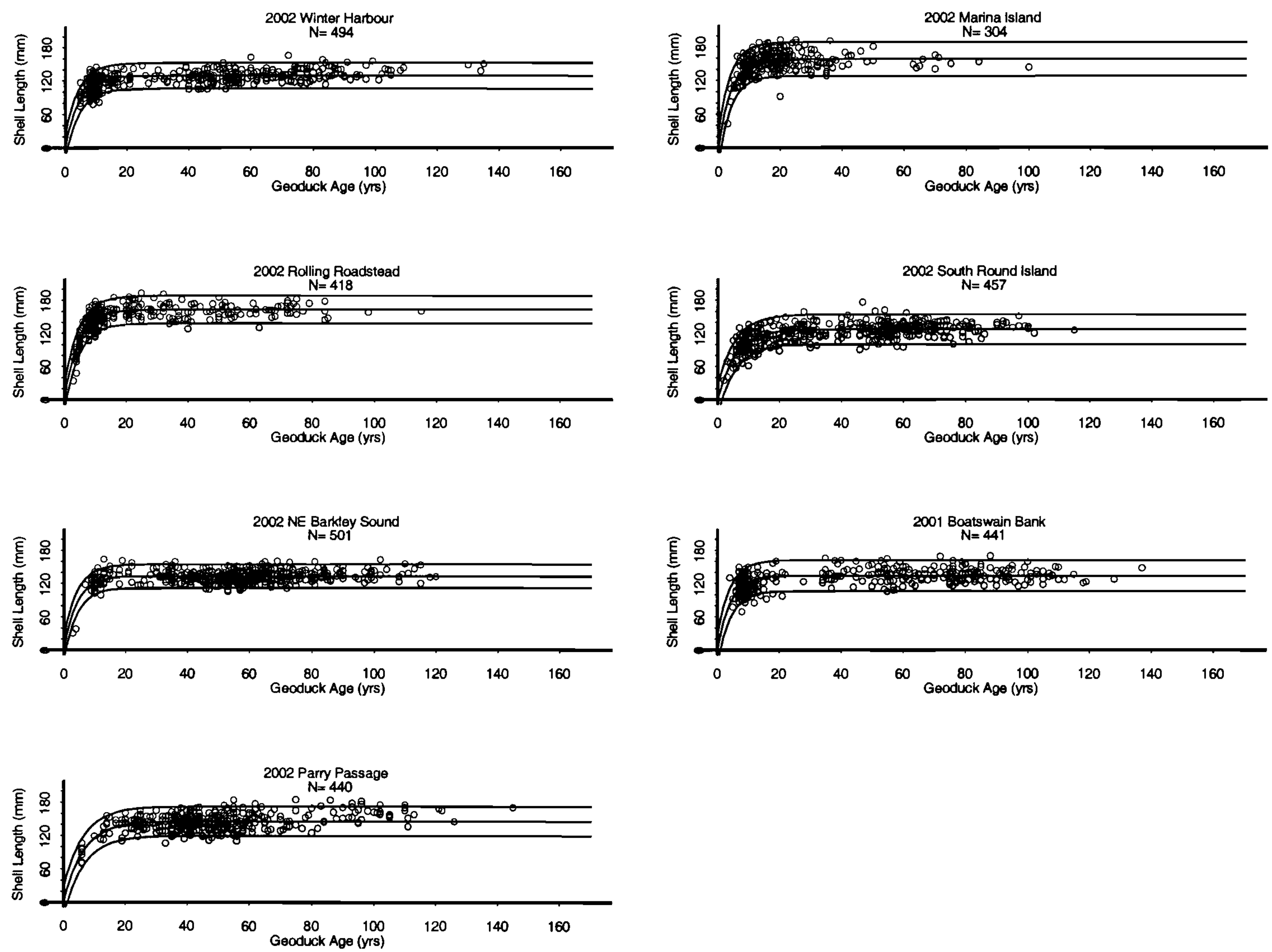

Figure 5: Shell length vs. age for geoduck samples in BC from 2001 and 2002. Upper and lower lines are 95% confidence bounds.

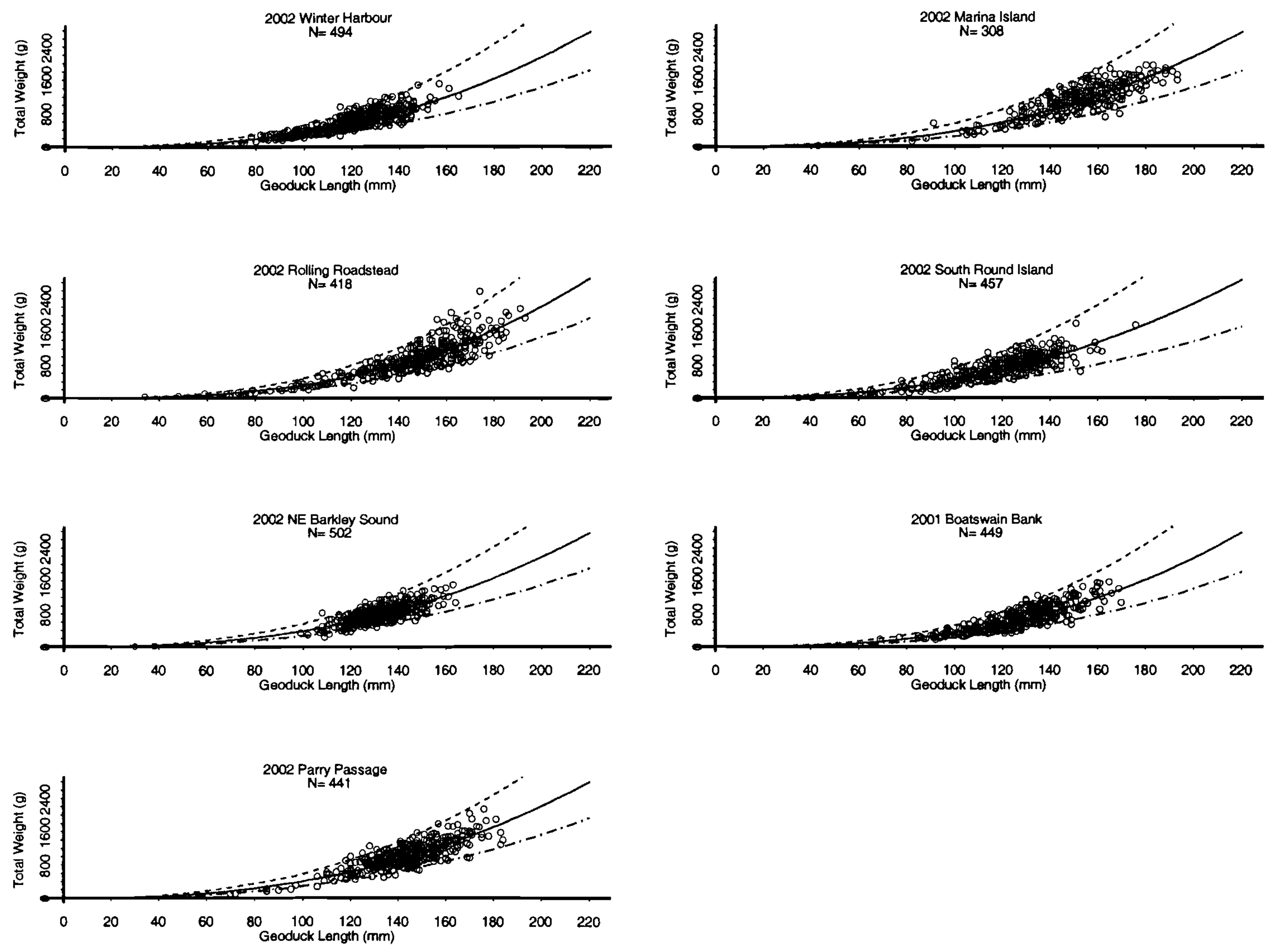

Figure 6: Total weight vs. shell length for geoduck samples in BC from 2001 and 2002. Dashed lines are the 95% confidence bounds.

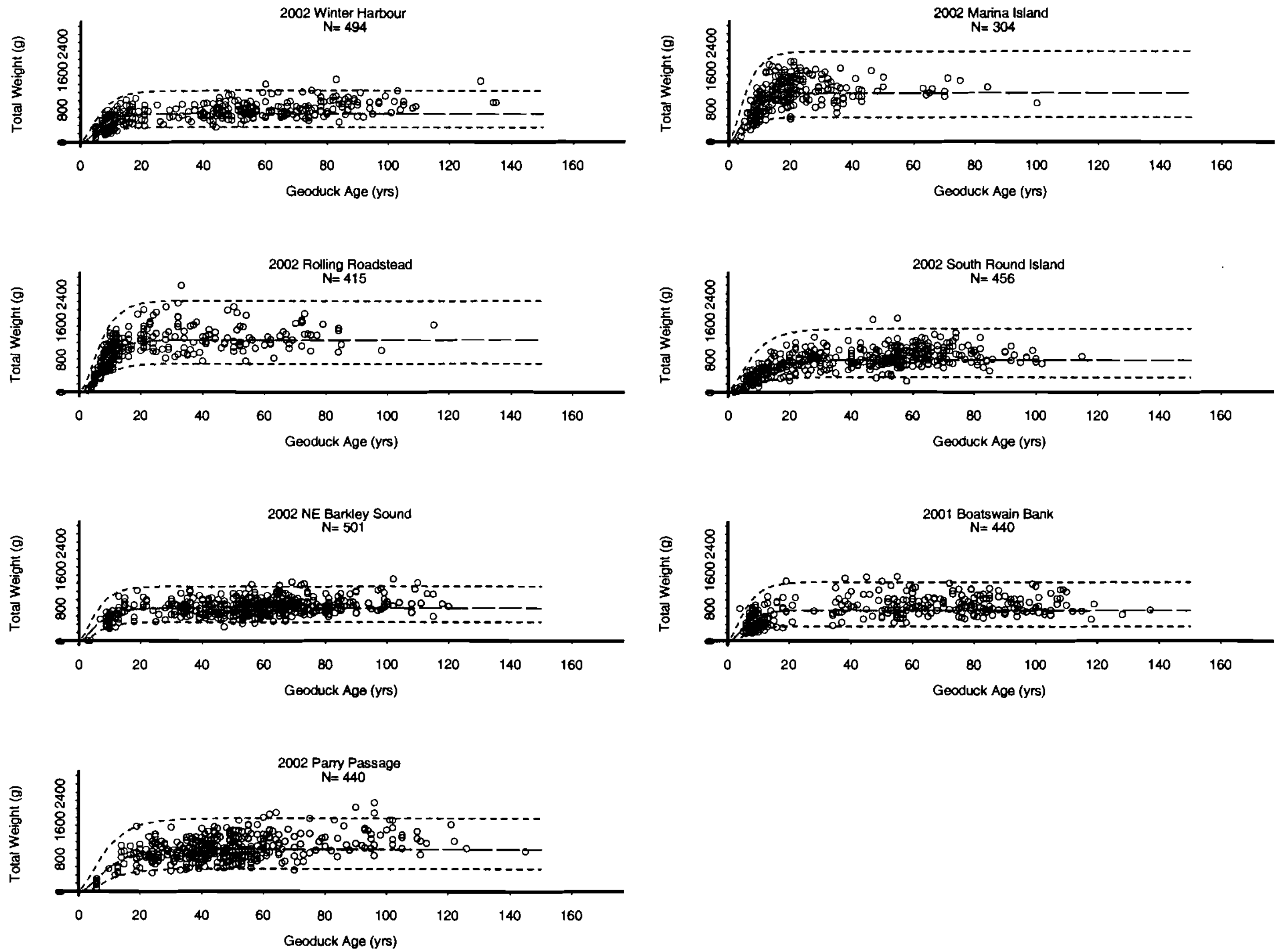

Figure 7: Total weight vs. age of geoducks samples in BC from 2001 and 2002. Dashed lines are 95% confidence bounds.

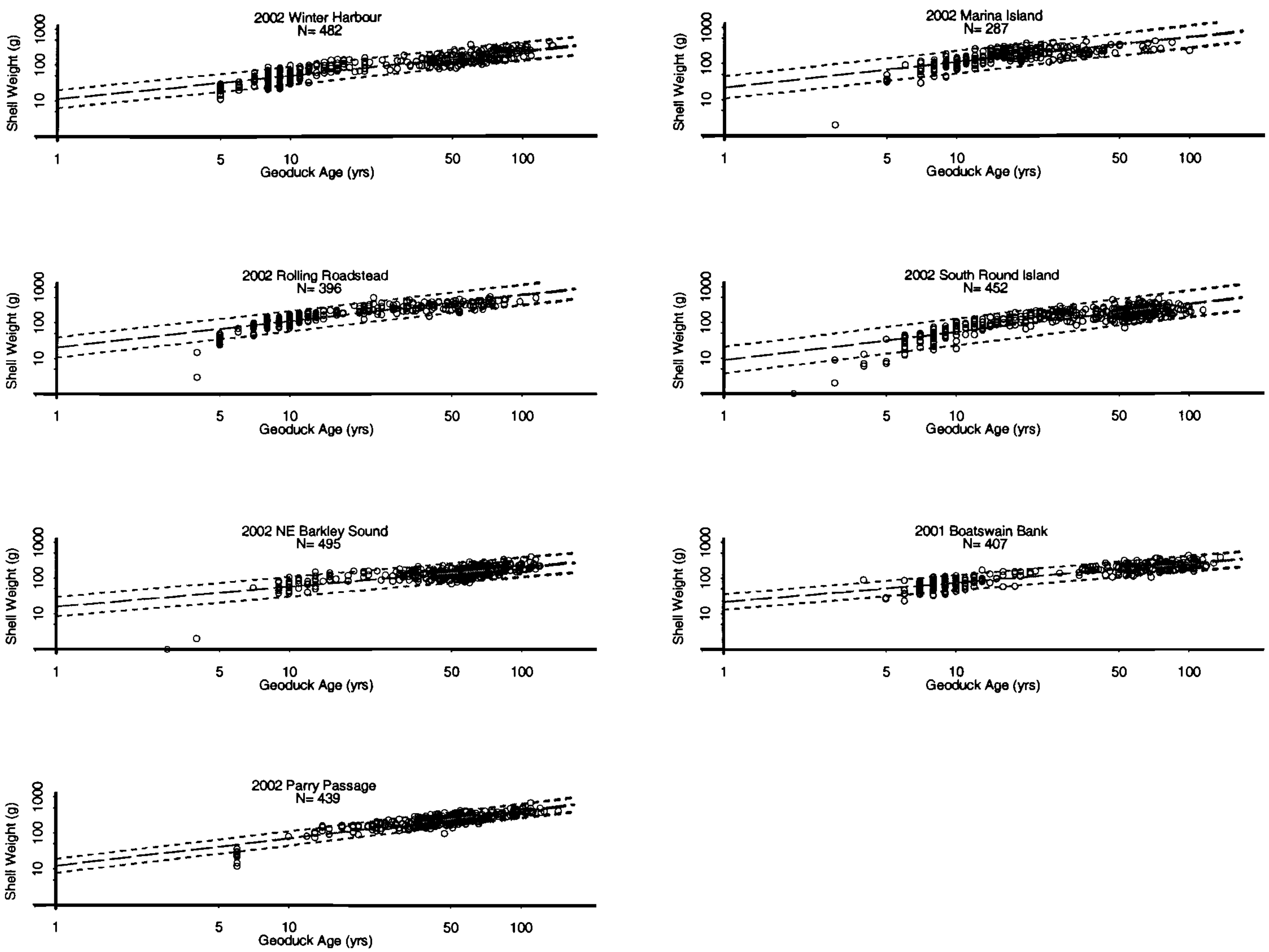

Figure 8: Shell weight vs. age for geoduck samples collected in BC in 2001 and 2002. Dashed lines are 95% confidence bounds.

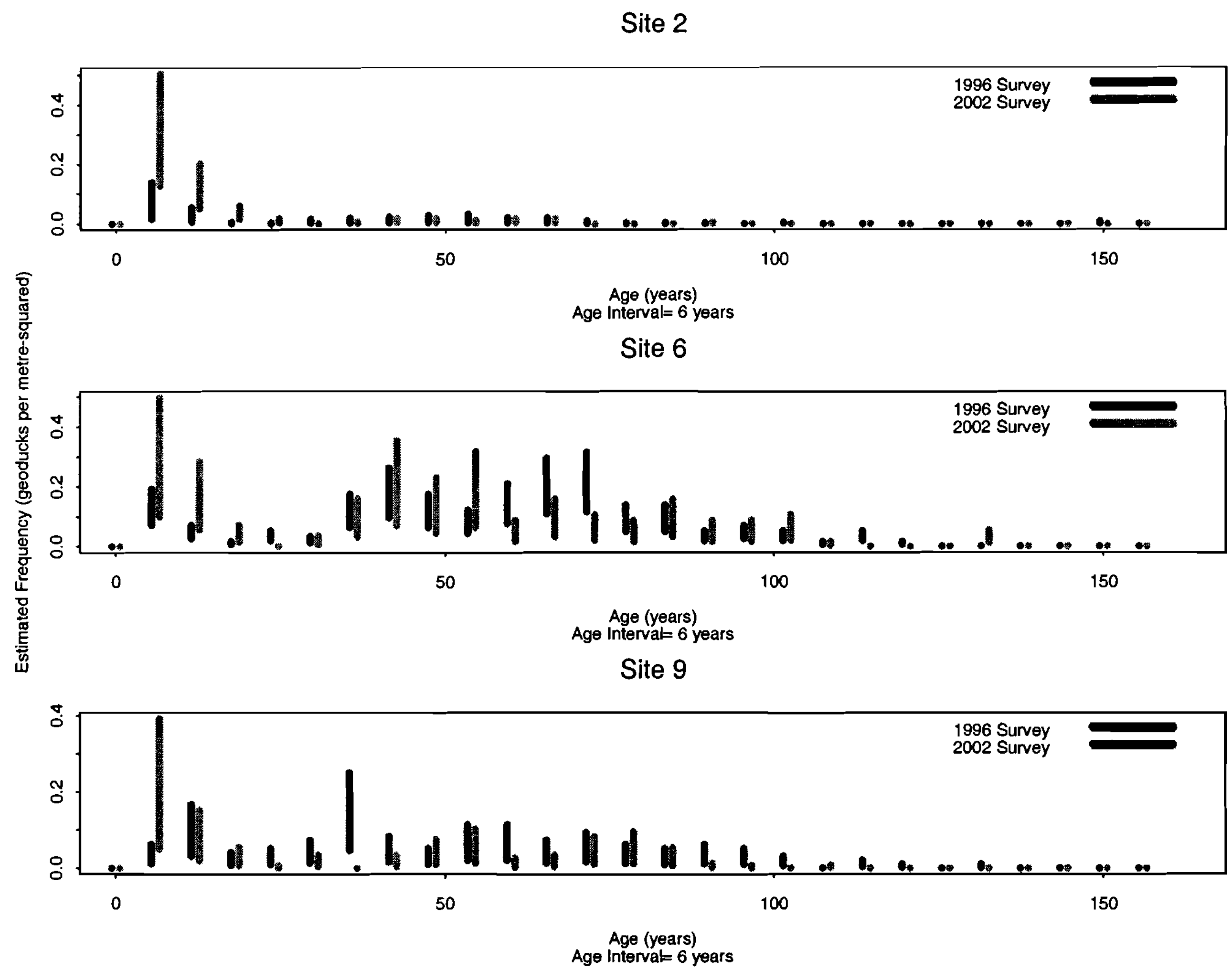

Figure 9: Density of geoducks of various age groups at the three Winter Harbour sub-sample sites in 1996 and 2002. Upper and lower bounds of vertical bars represent the upper and lower 95% confidence bounds of mean site density multiplied by the proportion of geoducks in each age group. Age groups include 6 year classes each.

Appendix 1: Summary of geoduck sample collections in BC in 2001 and 2002. Mean geoduck densities are estimated from harvest transects or survey sites and are not corrected to virgin densities.

Survey Title	Sub-Sample Location	Sample Site	Harvest Date	Number Geoducks Aged[1]	Stat. Area	Latitude	Longitude	Substrate[2]	Average Depth (m)	Density (# geoducks/m^2) Mean	Confidence Interval L90	H90	L95	H95	Density Source	Survey Design[3]
2001																
Boatswain Bank																
	Boatswain, H1	H1	27-Aug-01	441	18-07	48° 42.777	123° 32.486	S/Sh	12.71	1.19	0.89	1.50	0.84	1.55	survey site 1	4
	Boatswain, H2	H2	27-Aug-01		18-07	48° 42.584	123° 32.521	S/Sh/M	11.25	1.19	0.89	1.50	0.84	1.55	survey site 1	4
	Boatswain, H3	H3	27-Aug-01		18-07	48° 42.410	123° 32.472	S/Sh/M	12.80	1.19	0.89	1.50	0.84	1.55	survey site 1	4
2002																
Parry Passage																
	Meares Point	1002	18-Aug-02	440	01-02	54° 11.139	133° 01.208	S/PGr/C	12.68	0.80	0.61	1.03	0.58	1.07	survey site 3	4
	N Marchand Reef	1003	18-Aug-02		01-02	54° 10.937	133° 00.977	Gr/C/S	7.35	0.80	0.61	1.03	0.58	1.07	survey site 3	4
	Bruin Bay	1005	18-Aug-02		01-02	54° 10.099	132° 58.787	C/Gr/B	12.92	0.80	0.61	1.03	0.58	1.07	survey site 3	4
Marina Island, 2002																
	NE Marina	1001	12-Jun-02	304	13-15	50° 04.494	125° 01.842	S/B	7.64	0.31	0.20	0.44	0.19	0.46	survey site 3	4
	NW Marina	1002	12-Jun-02		13-15	50° 05.225	125° 03.858	S/B/Gr	9.76	0.39	0.24	0.53	0.22	0.55	survey site 2	4
South Round Island																
	S Round Island, H1001	H1001	19-Sep-02	460	17-04	49° 06.366	123° 47.571	S	14.48	NS[4]	NS[4]	NS[4]	NS[4]	NS[4]	NS[4]	NS[4]
	S Round Island, H1002	H1002	19-Sep-02		17-04	49° 06.178	123° 47.722	S/M/Sh	12.47	NS[4]	NS[4]	NS[4]	NS[4]	NS[4]	NS[4]	NS[4]
	S Round Island, H1003	H1003	19-Sep-02		17-04	49° 06.295	123° 47.733	S/C	9.97	NS[4]	NS[4]	NS[4]	NS[4]	NS[4]	NS[4]	NS[4]
Winter Harbour, 2002																
	Nordstrom Cove	1013	25-Sep-02	495	27-07	50° 29.047	127° 55.217	S/Sh/PGr	10.00	1.75	0.98	3.08	0.89	3.47	transect H1013	4
	Hunt Islets	1005	25-Sep-02		27-03	50° 28.523	128° 01.831	Sh/S	12.00	0.54	0.22	0.73	0.15	0.77	transect H1005	4
	Koskimo Bay	1017	25-Sep-02		27-07	50° 27.502	127° 53.257	S/M	16.00	0.69	0.32	1.15	0.30	1.22	transect H1017	4
Rolling Roadstead																
	Roadstead, 1004	1004	31-May-02	418	25-13	49° 50.930	127° 02.609	S	8.85	0.30	0.22	0.41	0.21	0.43	site 2, 2001 survey	4
	Roadstead, 1005	1005	31-May-02		25-13	49° 50.770	127° 02.020	S/M	8.87	0.30	0.22	0.41	0.21	0.43	site 2, 2001 survey	4
	Roadstead, 1006	1006	31-May-02		25-13	49° 50.768	127° 02.190	S/M	10.06	0.30	0.22	0.41	0.21	0.43	site 2, 2001 survey	4
	Roadstead, 1007	1007	31-May-02		25-13	49° 50.820	127° 02.172	S	9.43	0.30	0.22	0.41	0.21	0.43	site 2, 2001 survey	4
	Roadstead, 1008	1008	31-May-02		25-13	49° 50.950	127° 02.920	Gr/S	7.47	0.30	0.22	0.41	0.21	0.43	site 2, 2001 survey	4
NE Barkley Sound																
	Stud Islets	H1001	04-Oct-02	501	23-05	48° 56.471	125° 05.631	S/Sh	11.95	1.88	1.30	2.52	1.25	2.65	survey site 5	4
	Vernon Bay	H1002	04-Oct-02		23-06	48° 59.735	125° 08.062	S/PGr	10.39	0.84	0.52	1.31	0.46	1.47	survey site 1	4
	Alma Russell Is.	H1003	04-Oct-02		23-06	48° 57.761	125° 11.414	S/Sh	11.12	0.93	0.56	1.29	0.50	1.37	survey site 8	4

[1] Number of geoducks aged reported on a per-survey basis only, numbers were not broken down to the sub-sample level

[2] Substrate: B= Boulders (>30cm), C= Cobble (10-30cm), Gr= Gravel (2-10cm), PGr= Pea Gravel (4mm-2cm), S= Sand, Sh= Shell, M=Mud

[3] Survey Design: 4 = Two-Stage Sampling: Transects are randomly placed along the shore in the area to be surveyed. After sampling quadrat number 1, every qth (e.g. every 2nd, 3rd or every 4th) quadrat along a transect is sampled. The interval between sampled quadrats may vary within a given bed or site

[4] Site not surveyed for density