Age, Size Structure and Growth Parameters of Geoducks (*Panopea abrupta*, Conrad 1849) from 34 Locations in British Columbia Sampled Between 1993 and 2000

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AGE, SIZE STRUCTURE AND GROWTH PARAMETERS OF GEODUCKS (*Panopea abrupta*, CONRAD 1849) FROM 34 LOCATIONS IN BRITISH COLUMBIA SAMPLED BETWEEN 1993 AND 2000

by

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ABSTRACT

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.

Samples of geoduck clams (*Panopea abrupta*, Conrad 1849) were collected from 34 locations throughout BC between 1993 and 2000. Clams were measured for total weight, shell length, shell weight and were aged. Summary statistics, age-frequency distributions and growth curves are presented by survey location and by geographic area. Relationships for shell length – age, total weight – shell length, total weight – age and shell weight – age were calculated for all 34 samples and eight geographic areas.

Geoducks from Southern BC were generally smaller, younger and grew faster than geoducks from Northern BC. Possible causes for the smaller size and younger age in Southern BC are: 1- removal by the fishery of large old clams in Southern beds, 2- higher recruitment rates in Southern BC, or 3- pre-existing differences between Southern and Northern BC. Recent recruitment events were noted in several geoduck populations throughout BC and over a range of harvest histories. Variability in growth rates between and within regions suggests that the use of a single exploitation rate in the management of the BC geoduck fishery should be reviewed.

RÉSUMÉ

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.

Des échantillons de panopes (*Panopea abrupta*, Conrad 1849) ont été récoltés à 34 sites en Colombie-Britannique, de 1993 à 2000. On a mesuré le poids total, la longueur de la coquille, le poids de la coquille et l'âge. Pour chaque site et chaque région, les auteurs présentent des statistiques sommaires, des distributions de fréquences des âges et des courbes de croissance. Pour les 34 échantillons et les 8 régions, on a calculé des rapports entre la longueur de la coquille et l'âge, le poids total et la longueur de la coquille, le poids total et l'âge, et le poids de la coquille et l'âge.

En général, les panopes du Sud de la Colombie-Britannique étaient plus petites et plus jeunes que celles du Nord de la province, et la croissance de ces dernières était plus lente. Parmi les causes possibles de la taille plus petite et du plus jeune âge des individus vivant dans le Sud, on note : 1- la récolte de grosses panopes âgées dans les pêcheries des bancs du Sud, 2- des taux de recrutement plus élevés dans le Sud de la province ou 3- des différences préexistantes entre le Sud et le Nord de la Colombie-Britannique. Récemment, on a remarqué des recrutements dans plusieurs populations de panopes en Colombie-Britannique dans un éventail de profils antérieurs de récolte. La variation des taux de croissance inter- et intrarégionale indique qu'il faudrait réviser le taux d'exploitation unique pour la gestion des pêcheries de panopes dans cette province.

1. INTRODUCTION

The geoduck clam (*Panopea abrupta*, Conrad, 1849) is a large subtidal bivalve with a wide distribution that extends from Alaska to the Gulf of California in the Northeast Pacific (Quayle 1960). Geoducks are found in soft substrates (including mud, sand, silt and gravel), in water depths ranging from the intertidal to greater than 110 metres (Jamison *et al.* 1984). Geoduck harvesters prefer fishing in softer substrates like sand or mud and generally do not target geoducks found in harder gravel or shell-packed substrates. As well, harvest is focused on the stocks between 3 m and 20 m depth. Geoducks at greater depths, in hard substrate or in otherwise inaccessible areas occupy a form of refugia (Campbell *et al.* 1998a).

The geoduck fishery started in 1976 in British Columbia (BC) and has come to represent a valuable source of export for the province, with a 1999 fishery value of $33 million (Hand and Bureau 2000). The geoduck fishery is managed on a precautionary, sustainable yield basis with annual harvest quotas calculated as one percent of the estimated virgin biomass. The exploitation rate is a conservative choice 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 harvesting was concentrated in the first five years of the fishery. Since the early 1980's, the proportion of the coast-wide geoduck harvest that occurs in the North Coast has steadily increased.

Harbo *et al.* (1983) noted the need to estimate mortality rates of geoducks from more locations in BC. Campbell and Rajwani (1998) also noted the need for geoduck age samples to provide an indication of current recruitment levels. Orensanz *et al.* (2000) noted the urgent need for an extensive geoduck ageing program, with a broad geographic coverage, to address the uncertainties in stock assessment and to reduce risk in the management of the geoduck fishery. Bradbury and Tagart (2000) identified the direct estimation of mortality rates and recruitment of geoducks as research priorities.

Biological samples of geoducks have been collected during surveys, conducted throughout BC from 1993 to 2000, as part of the broader survey objectives of determining geoduck density, distribution and population structure. The goal of this paper is to present the results of analyses to determine age and size distributions, growth rates and morphometric characteristics of geoducks from 34 locations in BC, totalling 14,210 geoducks. Differences in morphometric and age parameters between regions of BC were investigated by dividing the coast in eight geographic areas. Geographic area boundaries were based on broad management divisions, but further defined by oceanographic characteristics. Smaller scale differences in morphometric and age parameters were investigated by comparing sub-samples from within individual samples.

Further analysis of the sample data will lead to estimates of mortality, growth and recruitment characteristics for populations subjected to a range of exploitation rates. These will be presented in following reports where the parameter estimates for the purposes of yield modelling will be discussed.

2. METHODS

2.1. SURVEY SITES AND FIELD METHODS

Biological samples were collected during geoduck density surveys at 34 locations along the coast of BC between 1993 and 2000 (Figures 1 and 2, Appendix 1). The survey sites included a variety of fishing histories and management histories (Table 1 and Table 2) (Hand *et al.* 1998a, 1998b, 1998c; Harbo *et al.* 1992, 1993, 1995).

Survey design followed one of four survey types described in Campbell *et al.* (1998b) (Appendix 1). Early surveys (1993 through 1995) used a systematic transect placement with a random starting point protocol, where transects were spaced at regular intervals over large expanses of coastline, regardless of substrate type. Surveys conducted from 1996 to 2000 used a stratified random design, where geoduck beds were treated as strata and transects randomly placed within them. Survey locations for the latter surveys were based on harvest log maps, submitted by harvesters, that identified the locations of commercial harvest. A few large geoduck beds have been surveyed by placing transects within randomly selected grid squares that were over-laid on the bed.

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 algae species. Field survey methods are described in detail in Hand and Dovey (1999, 2000) and Dovey and Hand (in prep).

Biological samples were collected on the last day of each survey. Approximately 500 clams were collected from a single site within the surveyed beds in 1993, 1994 and on four of the six surveys in 1995. In an effort to obtain a more representative sample, the protocol was modified for two of the 1995 surveys wherein five sub-samples of approximately 100 clams each were collected from within the surveyed beds. In 1996, sub-samples of approximately 150 clams were collected from three or four sites within the surveyed beds. Following a review of optimal sample sizes (Campbell and Rajwani 1998), the number of clams per subsample was reduced to 100 for samples collected in 1997 through early 2000. The protocol was modified again in September 2000 to again collect 150 clams per sub-sample site. Sample size was increased to account for losses due to shell breakage, tag loss and damage to soft body parts during sample collection, shipping and processing, and to provide a more representative sample for statistical analysis. Campbell and Rajwani (1998) suggested collecting approximately 10% more geoducks than the desired sample size to compensate for this loss.

Experienced commercial geoduck harvesters collected all samples. Prior to 1997, the majority of sampling locations were selected by choosing a randomly placed transect with suitable density, substrate and exposure. Suitable transect characteristics were analogous to a good commercial harvest location. From 1997 to 2000, the majority of sampling locations were selected by randomly choosing from eligible surveyed transects. A transect was considered eligible if it contained a 100 m 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. Divers used standard geoduck fishing commercial 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, brought to the surface, and labelled with a unique identification number. Samples were then transported live to licensed processing plants.

2.2. LABORATORY MEASUREMENTS

2.2.1. 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 again measured 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, with the exception of the samples collected during the 1995 Duncan Island and Goletas Channel surveys. For these, shell dimensions measured at the processing plants were used because shell measurements were not obtained at the Pacific Biological Station.

2.2.2. Shell Ageing

Geoduck ageing methods followed those 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 polished dry 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).

2.3. ANALYTICAL METHODS

Statistical analyses were completed using the statistics program, S-Plus 4.5 (Mathsoft 1997).

2.3.1. 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.

2.3.2. 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:

$$\log(W) = \log(\alpha) + \beta * \log(L) + \varepsilon_2$$ Equation 3

Originally α and β were estimated as independent variables. However, a consistent relationship was observed between the estimated values of α and β (Figure 3), which is described by:

$$\log(\beta) = 0.5140 - 0.07231 * \log(\alpha)$$ Equation 4

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.

2.3.3. 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:

$$W = \alpha * (L_\infty * (1 - e^{-\kappa(t-t_0)}) + \varepsilon_1)^\beta * e^{\varepsilon_2}$$ 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 (e.g. individual survey data set or groupings of data over a geographic area). The 0.025 and 0.975 quantiles of the resample-means were used as 95% confidence bounds.

2.3.4. Shell Weight - Age Relationship

The shell weight – age relationships were first investigated using a model similar to that used in calculating the total weight – age relationships (Equation 5). The model was rejected, however, because it predicted shell weight would reach an asymptote, while data showed that shell weight continued to increase with age. An allometric model was therefore 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 better 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.

2.3.5. Geographic Area Effects

The geoducks beds that are fished throughout the BC coast span a wide range of physical and oceanographic conditions and have experienced a variety of management regimes (Hand and Bureau 2000, Hand *et al.* 1998a, 1998b) and fishing histories (Table 1 and Table 2). Potential differences in growth parameters and morphometrics between regions, were investigated by first separating the data into geographic areas. Eight geographic areas were defined, based on differing fishery management history and/or oceanographic features. These include: Central Coast, North Coast, East and West Coasts of the Queen Charlotte Islands (QCI-East & QCI-West), West Coast of Vancouver Island (WCVI), Area 24, Area 12 and Georgia Basin (Figures 1 and 2). In the geoduck fishery management plan, Northern BC is divided into three fishery rotation areas, each area being fished once every three years: Central Coast, North Coast and the Queen Charlotte Islands. For our purposes, the Queen Charlotte Islands were further divided into East and West, since the west coast is more exposed to weather and has been fished for fewer years (Table 2). Statistical Area 24, around Tofino, was separated from the rest of the WCVI because Area 24 has been fished annually, while rotational fisheries were in effect for the rest of the WCVI. The waters on the inside of Vancouver Island were broken down into Statistical Area 12 and Georgia Basin because they were managed differently (Hand and Bureau 2000, Hand *et al.* 1998a) and are subject different oceanographic conditions.

Survey samples were compared between geographic areas using a two-stage bootstrapping approach (Davison and Hinkley 1997). The following procedure, to generate the means and 95% confidence bounds of age, total weight, shell length and shell weight, was repeated one thousand times for each geographic area:

1. Survey data sets were re-sampled with replacement, where the size of each re-sample was equal to the number of survey data sets in the geographic area.
2. For each re-sampled data set, individual geoducks were re-sampled, with replacement, where the size of the re-sample was equal to the size of the original survey sample.
3. Averages were calculated for the re-sampled geoducks in the re-sampled survey. For any given calculation, some geoducks were used more than once and others were not used.

One thousand averages were thus generated for each geographic area. The 0.025 and 0.975 quantiles of the averages were used as the upper and lower 95% confidence bounds on the mean.

With this method, survey samples with more geoducks were weighted more heavily in the estimates of the means. Confidence bounds reflect the uncertainty that occurs when just a few surveys data sets wield disproportionate influence.

The same sets of 1,000 averages were used to establish confidence levels for differences in mean age, total weight, shell length and shell weight between geographic areas. Averages from one geographic area were compared against the averages from another area on a one-to-one basis. The fraction of times that the average from one geographic area was greater than the average from another was used as the confidence level that the mean from the first geographic area was greater than the mean from the second.

The same re-sampling that was used to establish confidence bounds on the means was also used to estimate confidence bounds on the parameters of the growth equations. Each time the geoducks were re-sampled, the model parameters were re-estimated.

2.3.6. Variability Within Geographic Areas

Analyses were also completed to determine if there was variability within geographic areas. Analysis of variance (ANOVA) was used to compare three sources of variability for age, total weight, shell length and shell weight: 1- variability between geographic areas, 2- variability between samples in the same geographic area; and 3- variability between geoducks in the same sample. Survey data sets were weighted according to the number of sampled geoducks. Sub-samples were not considered in the analysis of variability within geographic areas.

2.3.7. Sub-Sample Analysis

Variations in age and morphometric parameters of geoducks may also occur on a small spatial scale due to differences from bed to bed or within a bed. For surveys where sub-samples were collected from different locations within a survey area, comparisons of mean age, total weight, shell length and shell weight between sub-samples were made to determine the variability of geoduck age and morphometric parameters on a small spatial scale. There were 22 surveys where sub-samples were collected. In these, there was an average of 3.2 sub-samples per biosample and 116 geoducks per sub-sample.

ANOVA was used to evaluate three sources of variability in the age of the geoducks: 1- variability between biosamples, 2- variability between sub-samples of the same biosamples; and 3- variability between geoducks in the same sub-sample. Geographic areas were not considered in this analysis.

A modelling exercise was also performed to predict how the sub-samples affected the estimated mean age, length and weight for a biosample. If a survey is balanced (same number of geoducks in each sub-sample), the standard error (SE) of the mean of a given parameter is:

$$SE = \sqrt{\frac{\sigma^2_{sub}}{Number\_Subsamples} + \frac{MS(error)}{Number\_Animals}} \qquad \text{Equation 8}$$

Where:

- σ^2_{sub} was the estimated variance between sub-samples of the biosample.
- MS (error) was the estimated variance between geoducks in the same sub-sample.
- Number_Subsamples was the number of sub-samples in the biosample.
- Number_Animals was the number of geoducks in the biosample (combined sub-samples).

Equation 8 showed that if the number of geoducks remained constant, then the estimated mean would be more accurate if more sub-samples per survey were taken. The existing data were used to estimate σ^2_{sub} and MS(error) in order to predict how the number of sub-samples affected estimates of SE.

Each of the existing biosamples was treated as an unbalanced two-stage sampling design. The first stage was the sub-sample and the second was geoducks within the sub-sample. The data from all the applicable surveys were pooled together to get a larger sample size and better estimates of variability. The result was an unbalanced set of data.

The surveys were unbalanced and the expected sum of squares for a sub-sample (*SSQ*(*sub*)) lead to the following approximation:

$$E(SSQ(sub)) = E(\sum_{survey}\sum_{subsample} n_{sub}(y_{sub} - y_{survey})^2)$$

Which can be approximated as:

$$\sigma^2_{sub} \sim \frac{SSQ(sub) - MS(error) * (Total\_Number\_of\_SubSamples)}{Total\_Number\_of\_Animals} \qquad \text{Equation 9}$$

Where:

- n_{sub} was the number of animals in a sub-sample
- y_{sub} was the mean value of a given parameter for a sub-sample
- y_{survey} was the mean value for a biosample

For age: $\sigma^2_{sub} \sim \frac{488982 - 879 * 68}{7883} = 54.5$

For total weight: $\sigma_{sub}{}^2 = 18771$

For shell length: $\sigma_{sub}{}^2 = 37.0$

Values of $\sigma_{sub}{}^2$ and MS(Error) estimated from available data were then input into Equation 8 and the values of number of sub-samples and total number of animals in a sample were changed to model their effect on the standard error.

3. RESULTS

3.1. AGE

A total of 12,848 geoducks could be aged out of the 14,210 that were collected, representing a 9.6% loss. Sample loss was due mostly to shell breakage during transport and/or processing, or to the loss of identification tags from shells.

Plots of age frequency distributions of survey data sets are shown in Figure 4. The oldest age recorded was 168 years from a geoduck from Tasu Sound, on the West Coast of the Queen Charlotte Islands (QCI-West, 2000). The youngest age recorded was 1 year, found at Hakai Pass

(Central Coast, 1998) and Comox (Georgia Basin, 1993). Mean age ranged from 14.5 years at Round Island (Georgia Basin, 2000) to 72.2 years at Hippa Island (QCI-West, 2000) (Table 3).

Overall, mean age of clams from Northern BC was higher than mean age of clams from Southern BC. Three of the six highest mean ages were from QCI-West (Hippa Island = 72.2 yrs, Tasu Sound = 54.2 yrs, Gowgaia Bay = 51.7 yrs). The second, third and fourth highest mean ages were from the North Coast: West Aristazabal Island at 65.9 years, Moore Islands at 63.8 years and Principe Channel at 54.8 years. No sample from Northern BC had a mean age less than 30 years, whereas 50% of the samples from Southern BC had mean ages less than 30 years (Table 3). All samples from the Tofino region, Area 24 (Table 3) had a mean age under 30 years.

Many samples showed large proportions of young geoducks (Table 4, Figure 4). For seven of the 34 samples, more than 50% of geoducks were ≤20 years, six of which were in Southern BC. Three of the seven samples had more than 50% of geoducks aged ≤10 years. The site with the highest proportion of young clams was Round Island (2000) which had 78.0% of clams aged ≤10 years. The Otter Pass sample was the only sample from Northern BC that showed more than 50% of clams ≤20 years. For several samples, there was an under-representation of geoducks younger than 20 years old. The Selwyn/Dana/Logan Inlets sample showed the lowest proportion of young clams, only 2.5% of geoducks were ≤20 years.

Year-class-strengths calculated for each sample and averaged by geographic area (Figure 5) showed an increase in recruitment between 1980 and the 1990's for most regions, most notably in Southern BC. The apparent drop in recruitment in the late 1990's was most likely an artefact caused by under-sampling of 1 to 5 year old clams, whose siphons may be too small to notice by divers harvesting the samples. Also, since samples were collected from several years during the 1990's, not all years are fully represented in all samples, especially for the late 1990's.

Only three samples, all in Northern BC, had more than 10% of clams older than 100 years (Table 4). Hippa Island (QCI-West) had the highest proportion of old clams, where 27.1% of geoducks were older than 100 years. Six samples showed no clams older than 100 years, three of which were from the Tofino area (Area 24). The others were in QCI-East and Price Island in the Central Coast.

When data were pooled by geographic area, QCI-West showed the highest mean age at 60.4 years, while the lowest mean age of 26.6 years was shared by Area 24 and the Georgia Basin (Table 5, Figure 6). Mean age in QCI-East, 42.6 years, was about 17 years lower than on the QCI-West. Mean age on WCVI (39.0) was about 12 years older than in Area 24.

ANOVA indicated that the mean age of geoducks was significantly different between both survey and geographic area (Table 6). Mean age was significantly higher in QCI-West than all other geographic areas except the North Coast (Table 7). All areas had significantly higher mean ages than Area 24 and the Georgia Basin.

3.2. TOTAL WEIGHT

Plots of total weight frequency distributions by year and survey location are shown in Figure 7. The heaviest clam sampled was 2,768 g at Gowgaia Bay (2000). Mean total weight ranged from 658.4 g at Seaforth Channel (Central Coast, 1995) to 1509.9 g at Gowgaia Bay (QCI-West, 2000) (Table 3). Although Seaforth Channel had the lowest mean total weight, the 1993 Comox sample showed the lowest mean shell length and shell weight, however no total weights were obtained from the sample (Table 3).

Mean weights tended to be higher for Northern BC than for Southern BC. Only three out of 20 samples in Northern BC had a mean total weight less than 800 g while seven out of 13 samples in Southern BC had a mean total weight less than 800 g.

-Cumulative percent frequencies of total weight showed that in the majority of samples, most clams were ≤1,500 g (Table 8). Only four samples showed more than 20% of clams to be >1,500 g: Gowgaia Bay (49.0%), Elbow Bank (47.6%), Burnaby Island (39.8%) and Hakai Pass (29.2%). The Thormanby Island sample was the only one to contain no geoducks heavier than 1,500 g.

ANOVA indicated that the mean total weight of geoducks was significantly different between both survey and geographic area (Table 6). Data pooled by geographic area showed that the highest mean total weight, 1,112.6 g, was found in Area 24 (Table 5, Figure 8) which had the lowest mean age. The lowest mean weight, 800.5 g, was found on the WCVI followed closely by the Georgia Basin at 819.4 g. The mean total weight in Area 24 was much higher than in the WCVI area, despite the fact that mean age of clams in Area 24 was younger.

Mean total weight was significantly greater in QCI-West, QCI-East and Area 12 than in WCVI and Georgia Basin (Table 7). Mean total weight was significantly greater in the Central Coast than in WCVI. Mean total weight was also significantly greater in QCI-East and Area 12 than in the North Coast. Although Area 24 had the highest mean total weight estimated, the mean total weight for Area 24 was not significantly different than that of other geographic areas due to its wide confidence bounds.

3.3. SHELL LENGTH

Mean shell length ranged from 120.5 mm at Comox (Georgia Basin, 1993) to 169.2 mm at Elbow Bank (Area 24, 1994) (Table 3). Elbow Bank had the second highest mean total weight. Gowgaia Bay (QCI-West, 2000), which had the largest mean total weight, had the second largest mean length at 164.6 mm and the largest clam found in the samples at 205 mm. As observed for the total weight, shell length of geoducks from Northern BC tended to be higher than that of geoducks from Southern BC. Mean shell length was larger than 140 mm in 11 of 20 samples from Northern BC while only three of 14 samples from Southern BC had a mean shell length larger than 140 mm.

ANOVA indicated that the mean shell length of geoducks was significantly different between both survey and geographic area (Table 6). Data pooled by geographic area showed that the highest mean shell length, 151.9 mm, was found in Area 24 (Table 5) followed by the four Northern BC geographic areas. The lowest mean shell length, 128.9 mm, was found in the Georgia Basin.

Shell length was significantly greater in QCI-East than all other areas except QCI-West, Area 24 and Area 12 (Table 7). All areas except WCVI had significantly larger shell length than the Georgia Basin. Mean shell length in QCI-West, QCI-East, Area 24 and Area 12 was higher than in WCVI.

3.4. SHELL WEIGHT

Mean shell weight ranged from 53.1 g at Comox (Georgia Basin, 1993) to 302.0 g at Gowgaia Bay (QCI-West, 2000). Elbow Bank (Area 24, 1994) had the second highest shell weight at 270.6 g (Table 3). The heaviest shell, 761 g, was found in the West Aristazabal Island sample (North Coast, 1996). Mean shell weight was generally higher in Northern BC than in Southern BC. Mean shell weight was greater than 150 g for 17 of 20 samples in Northern BC while only half (seven of 14) samples in Southern BC had a mean shell weight above 150 g.

ANOVA showed that the mean shell weight of geoducks was significantly different between both survey and geographic area (Table 6). Data pooled by geographic area showed that the QCI-West and QCI-East had the highest mean shell weights at 223.8 g and 222.3g, while the Georgia Basin had the lowest mean shell weight at 108.5 g (Table 5).

All areas had a significantly higher mean shell weight than the Georgia Basin (Table 7). Mean shell weight in QCI-East was higher than that in the Central Coast, WCVI, Area 12 and the Georgia Basin. Mean shell weight at QCI-West, QCI-East, Central Coast and Area 12 was greater than in WCVI.

3.5. SHELL LENGTH – AGE RELATIONSHIP

Analyses of the shell length and age data, using the LVB growth model (Equation 1), showed that growth of geoducks in all survey sites was rapid in the first 10 years, followed by an extended period of slower growth (Figure 9). Variation in growth parameters between sample locations was noted (Table 9). The asymptotic length (L_∞) ranged from 127.7 mm at Seaforth Channel (Central Coast, 1995) to 169.7 mm at Elbow Bank (Area 24, 1997). There were no clear trends in L_∞ values between regions.

The Brody growth parameter (k) ranged from 0.1429 at Tasu Sound (QCI-West, 2000) to 0.4917 at Millar Channel (Area 24, 1997). Geoducks from Tasu Sound were therefore the slowest growing in terms of length, while those from Millar Channel were the fastest growing. Geoducks from Gowgaia Bay had the second highest L_∞ value but a low k value, indicating that geoducks reached a large maximum size but at a slow rate. WCVI and Area 24 showed some of the fastest growth on the BC coast, with six of the highest eight k values from those regions. Area 24 alone had three of the four highest k values. Only Barkley Sound on the WCVI had a relatively low k value. Generally, growth tended to be faster in Southern BC than in Northern BC. Estimated k values were higher than 0.2500 for 12 of 14 samples in Southern BC while only four of 20 samples in Northern BC showed k values above 0.2500. Surprisingly, the second largest k value (0.4318) was for Cumshewa Inlet (QCI-East, 1997). Geoducks sampled from Seaforth Channel had the second lowest growth rate and the lowest L_∞.

Pooling data by geographic area showed the highest L_∞ in Area 24 (161.0 m) while the lowest value (135.2 mm) was from the surrounding waters of WCVI (Table 10, Figure 10). L_∞ in QCI-East and QCI-West were very similar and relatively high (QCI-East=147.5 mm and QCI-West=147.1 mm), however, geoducks from QCI-East grew faster than those from QCI-West. Growth rates were highest for WCVI, followed by Area 24. WCVI was therefore characterised by fast-growing clams that reached a small maximum size whereas Area 24 clams also grew fast but attained a large maximum size.

The L_∞ at QCI-East, Area 24 and Area 12 was significantly higher than values in the Central Coast, WCVI and Georgia Basin (Table 11). L_∞ was also significantly higher in Area 24 than on the North Coast. QCI-West had a significantly lower k value than all other areas on the coast. Area 24 had a significantly higher k than that of all areas except WCVI and QCI-East. The k value for WCVI was significantly greater than all other areas except Area 24, QCI-East and Georgia Basin. The k value for the Georgia Basin was significantly higher than that of QCI-West, North Coast and Central Coast.

3.6. TOTAL WEIGHT – SHELL LENGTH RELATIONSHIP

As mentioned previously, estimation of parameters of the allometric growth model (Equation 2, Figure 11) revealed a relationship between estimated values of α and β such that values of β decreased as α increased (Equation 4, Table 9, Figure 3). Given this relationship, the higher the intercept in the linear growth relationship, $\log(\alpha)$ in Equation 3, the lower the slope β. Growth curves from the sample data presented here ranged between two extremes. At one extreme, growth (weight gain per length increment) was initially slow, followed by a rapid increase of weight with length later in life (e.g. Hakai Passage 1998, Central Coast, Figure 11, Table 9). At the other extreme, the initial growth rate was high (steep initial slope) but the growth rate was more gradual over the remainder of the animal's life (e.g. Burnaby Island 1994, QCI-East, Figure 11, Table 9).

Unlike the Length – Age relationship, there were no clear trends in model parameter values for specific geographic regions for the Weight – Length relationship. However, there were differences between Northern and Southern BC. In Northern BC, 11 of 20 α values were greater than 0.004000 while only five of 13 α values in Southern BC were greater than 0.004000. Conversely, eight of 13 β values in Southern BC were greater than 2.500 while only nine of 20 β values in Northern BC were greater than 2.500. In other words, Northern BC tended to have a higher initial growth rate while Southern BC tended to have a slow initial growth followed by a rapid increase in weight gain per length increment.

Once data were pooled by geographic area, a relationship between α and β was still present. Area 24 had the lowest α and largest β while Area 12 had the largest α and lowest β (Table 10, Figure 12). Furthermore, when pooled by geographic area, the data showed a weak trend between α and the Brody growth coefficient k of the LVB growth model. Values of α decreased with increasing k so that the initial growth rate was faster in those geographic areas where overall growth, in terms of length vs. age, was slow. Conversely, geographic areas where overall growth (length vs. age) was fast were characterised by slow initial weight gain per length increment. In other words, in areas where growth (length vs. age) was fast, clams were light for their shell length while in areas where growth (length vs. age) was slow, clams were relatively heavier for their shell size. The differences mentioned above apply mainly to young clams, as curves with high α - low β and those with low α - high β tend to converge as clams increase in size.

Values of β were significantly larger in Area 24 than in all other areas except WCVI (Table 11). Values of β for WCVI and the Georgia Basin were significantly larger than that of Area 12. Since α and β values are inversely related, the opposite applies to α values. Values of α were significantly larger than that of Area 24 for all areas except WCVI. The α value for Area 12 was also significantly higher than that in WCVI and the Georgia Basin.

3.7. TOTAL WEIGHT - AGE RELATIONSHIP

Plots of Total Weight – Age relationships showed considerable variability between survey locations in both the growth rate and the maximum weight attained (Figure 13, Table 9). Each plot was fitted with the combined allometric total weight-shell length model and the LVB length-age model (Equation 5). Growth in total body weight was rapid in the first 10 to 20 years and then stabilised. Variability in growth rates was demonstrated by the range of slopes seen in the first 20 years on the graphs. Graphs with a steeper initial slope (e.g., Elbow Bank 1994, Figure 13) showed faster growth than those with lower initial slopes (e.g., Tasu Sound 2000, Figure 13). Variability in maximum total weight was demonstrated by differences in the level of the asymptotes on the graphs (Figure 13) and TW_∞ values (Table 9). The highest predicted mean total weight was 1,563.5 g, for Gowgaia Bay (QCI-West, 2000) and the lowest predicted mean total weight was 680.8 g for Seaforth Channel (Central Coast, 1995). TW_∞ was directly related to L_∞ (Table 9). TW_∞ values varied within geographic areas but tended to be greater in Northern BC than in Southern BC. In Northern BC, TW_∞ was higher than 900 g for 15 of 20 samples while in Southern BC only seven of 13 samples had a TW_∞ greater than 900 g.

As for the Shell Length – Age relationships, the samples from Area 24 showed some of the fastest growth rates in terms of Total Weight – Age (Figure 13).

When data were pooled by geographic area, the highest TW_∞ calculated, 1,268.3 g, was for Area 24 (Table 10, Figure 14). The lowest TW_∞ calculated, 805.3 g, was for WCVI. Geoducks from Area 24 grew faster and to a larger size than those from WCVI. The TW_∞ was about the same for QCI-East and QCI-West (1,059.2 g and 1,042.2 g respectively), however, the growth rate was faster on QCI-East so the maximum size was reached at a younger age.

The TW_∞ values for QCI-East, Area 24 and Area 12 were significantly larger than those in the North Coast, WCVI and Georgia Basin (Table 11).

3.8. SHELL WEIGHT - AGE RELATIONSHIP

An allometric model was used to fit the shell weight to the age data for each survey and geographical area (Table 12 and Table 13, Figure 15). The model provided a good fit to the data for geoducks above 5 years of age. For geoducks under 5 years, the model tended to overestimate the shell weight for a given age. The over-estimation of shell weight of clams less than 5 years was best seen in the Georgia Basin data (Figure 16) where most of the clams under 5 years of age were found.

Estimates of γ and δ on a by-survey basis indicated that δ tended to decrease as γ increased (Table 12), that is, as the intercept (γ) on the log(Shell Weight)-log(Age) graphs increased, the slope (δ) decreased. Estimates of γ and δ varied within and between geographic areas. There were no clear trends in γ and δ between Southern and Northern BC. However, six of seven samples from the Georgia Basin and Area 12 showed a δ value greater than 0.600 while only seven of 20 samples from Northern BC and no samples from the WCVI and Area 24 had δ values greater than 0.600. Elbow Bank (1994) had the highest γ and lowest δ while Comox (1993) and Seaforth Channel (1995) shared the lowest γ and the highest δ.

The same trend for δ to decrease with increasing γ was present in the by-geographic area estimates (Table 13). The trend had exceptions, most notably Area 24 which had both a high γ and δ meaning that shell weight in Area 24 was generally high for any given age compared to the other geographic areas. Values of γ were significantly higher in Area 24 than in the North Coast, Central Coast, Area 12 and Georgia Basin (Table 14). Values of γ were also significantly higher on WCVI than in the Central Coast, Area 12 and Georgia Basin (Table 14). Values of γ in QCI-East were higher than in the Central Coast and Area 12. Values of δ were higher in the Central Coast than in the QCI-East and West and WCVI. Values of δ in Area 12 were significantly higher than in the QCI-West and WCVI.

3.9. SUB-SAMPLE ANALYSIS

ANOVA indicated that there were significant differences in age, total weight, shell length and shell weight between both the samples and sub-samples (Table 15).

Analyses to determine if taking sub-samples was advantageous showed that the standard error around the estimated means could be decreased by increasing the total number of geoducks sampled or, by increasing the number of sub-samples in the biosample (Table 16). There were however, diminishing-returns effects to increasing the number of sub-samples, i.e., each additional sub-sample gave less benefit than the previous one.

4. DISCUSSION

This examination of geoduck age data is the largest of its kind in the literature. Seven studies of geoduck age-structure from BC and Washington (WA) have previously been published, in which a total of 7,251 geoducks were aged (Table 1 in Orensanz *et al.* 2000). Four studies provided parameter estimates of the LVB growth model from a total of 21 sites in BC and WA (Andersen 1971, Hoffmann *et al.* 2000, Noakes 1992, Noakes and Campbell 1992). The current study included 12,848 geoducks from 34 locations in BC. LVB growth parameters were estimated for all locations sampled.

4.1. AGE

The estimated maximum age of geoducks in BC has increased from 146 years (Harbo *et al.* 1983) to 168 years. Mean ages from the current study span a wider range (14.5 years to 72.2 years) than previous studies (Goodwin and Shaul 1984, Harbo *et al.* 1983, Breen and Shields 1983, Fyfe 1984, Noakes and Campbell 1992) (Table 17), which is likely a function of the larger number of samples considered, the more extensive geographic range of these samples and the longer fishing history of at least some of the sample locations.

There is strong evidence that the commercial fishery acts to remove the older age-classes that have accumulated in a population over time. The proportion of samples comprised of older clams and the mean age was generally higher in Northern BC than in Southern BC; Southern BC beds have been fished longer (Table 2). Area 24 and the Georgia Basin, the two geographic areas with the lowest proportion of older clams, have longer fishing histories than the rest of BC, and QCI-West, with the highest mean age, is the region that has been fished the least. Thormanby Island is one site in Georgia Basin where fishing pressure has been very low due to the poor quality of the geoducks; the sample there showed a higher proportion of older clams than other areas in the Georgia Basin. Further evidence of the effect of harvest on populations is the decrease in mean age in locations where previous estimates are available. A sample collected from Comox Bar in the Georgia Basin in 1981 had a mean age of 46.1 years, while the sample collected in 1993 had a mean age of only 19.2 years (Table 3 and Table 17). Similarly, two sample locations on the West Coast of Vancouver Island, Kyuquot and Elbow Bank, showed decreases in mean age of 18.8 years and 5.8 years, respectively, over periods of 17 and 13 years.

Some sites in Northern BC, however, show low proportions of older clams, despite relatively light fishing pressure. Furthermore, samples collected from virgin beds in Northern BC (Tasu Sound, Principe Channel and Moore Is.) had mean ages within the range of Northern BC samples from fished areas. Possible impacts of the fishery on age-structure in Northern BC beds were therefore not evident at this time. The Northern BC samples from virgin beds (Table 3) are the most comparable to the early 1980's Southern BC research samples (Table 17). Comparing samples from virgin beds from Northern and Southern BC shows that mean age tended to be higher in Northern BC. This suggests that differences in mean age between Northern and

Differences in mean age between samples are due also to varying proportions of younger clams. While recognising that high proportions of young clams in a sample could merely be a result of the absence of older clams, many samples display what appears to be evidence of strong recent recruitment. Over half of the geoducks in the samples from Comox (1993 and 1998), Round Island, Kyuquot, Millar Channel, Yellow Bank and Otter Pass are younger than 20 years old. These animals would have recruited to their respective populations since the beds began to be commercially exploited. Year-class-strength graphs also showed increased recruitment since 1980. Estimated densities of newly recruited geoducks in the area of sample collection (from Table 4 and Appendix 1) are significant in comparison to the estimated virgin densities from the same bed:

		Recruit Age	Recruit Density	Virgin Density	
Area	Year	Cut-off	geoducks/m^2	geoducks/m^2	Source
Comox	1993	10	0.30	0.45	Hand and Bureau 2000
	1998	10	0.15	0.45	Hand and Bureau 2000
Round Island	2000	10	0.30	0.99	Unpublished data
Millar Channel	1997	10	0.82	1.96	Hand and Bureau 2000
Yellow Bank	1997	10	0.41	3.05	Hand and Bureau 2000
Otter Pass	1996	20	2.20	2.68	Hand and Bureau 2000

The Round Island bed was closed after the 1994 fishing season due to its heavy harvest history and, in 2000, 26.7% of geoducks were ≤5 years and thus had recruited to the bed after it was closed to fishing. All these beds are popular fishing locations with relatively long harvest histories. This suggests that harvest activity does not have the negative effect on recruitment that was suggested by Goodwin and Shaul (1984) and may even enhance it, provided there is a source of larvae. Geoduck larvae can spend up to 6 weeks in the water column (Goodwin *et al.* 1979) so recruitment to heavily harvested beds may come from other populations.

Past studies have largely concluded that geoduck recruitment rates were low (Breen and Shields 1983, Fyfe 1984, Godwin and Shaul 1984, Harbo *et al.* 1983, Noakes and Campbell 1992, Sloan and Robinson 1984), although it was acknowledged that it may be partly explained by sampling bias. The review of the published studies to 2000 conducted by Orensanz *et al.* (2000) further suggested that recruitment has been decreasing over the last 60 years, many years before the fishery and hence due to other forces. The results presented here indicate that many geoduck populations along the BC coast have experienced relatively good recruitment events in recent years in beds over a range of harvest histories.

Of particular note is the strong appearance of the 1988 year-class in samples throughout the coast in both lightly fished and heavily fished populations. This synchrony of recruitment over large areas of the BC coast would imply that periodic conditions favourable to larval settlement and survival are widespread. In most of the age frequencies examined, the appearance of prominent modes suggests that recruitment is not consistent from year to year, but rather undergoes periodic pulses.

4.2. WEIGHT AND SIZE DISTRIBUTIONS

Overall, samples from Northern BC contained higher proportions of heavier animals, which is likely linked to the wider age-distribution discussed earlier. The distributions of total weight can be quite variable within geographic regions; Gowgaia Bay has a very wide distribution while Hippa Island has a relatively tight distribution of total animal weights, despite the wide range in ages found at Hippa.

There was a high degree of variability in the size of animals between regions of the coast and, generally, geoducks from Northern BC tended to be larger than those from Southern BC, with the exception of Area 24. As well, large differences existed between samples within some geographic regions. For instance, the mean weight of animals from Gowgaia Bay is approximately twice that of clams from Hippa Island just to the north on QCI-West, but approximately the same as Elbow Bank in Area 24. Comox Bar in Georgia Basin and Seaforth Channel in the Central Coast have the smallest clams on the coast. There is especially high variability of total weight within Area 24. Elbow Bank geoducks were close to the largest and heaviest on the coast while Millar Channel and Yellow Bank animals, less than nine km away, were similar to the average size for the rest of the West Coast of Vancouver Island. Breen and Shields (1983) found similar results in their study of geoduck populations from BC, where their sample from Elbow Bank had the highest and second highest mean length and weight, respectively, of five sites investigated. Harbo *et al.* (1983) also reported similar results in a study of 10 commercial geoduck samples where the two highest mean lengths were from Elbow Bank and another bed in Area 24.

Goodwin (1976) found differences in mean shell length of geoduck samples from 24 locations in Puget Sound, WA. Goodwin and Pease (1991) also found differences in mean total weight and shell length of geoducks between four geographic areas in Puget Sound which, though following a decreasing trend with increasing latitude, they attribute to different local conditions.

Mean geoduck weights, estimated from commercial harvest log data, showed little trend with geographical area. Geoducks harvested from QCI-East were the heaviest (1,292 g) followed by Area 12 (1,158 g), QCI-West, North Coast, Central Coast, Area 24, Georgia Basin and the West Coast of Vancouver Island (1,054 g) (Hand and Bureau 2000, QCI unpublished data).

Geoducks from the Georgia Basin were generally smaller than geoducks from other areas on the coast. A study of geoduck market samples, collected between 1981 and 1995, found that geoducks from the Inside Waters of Vancouver Island were smaller than geoducks from the West Coast of Vancouver and geoducks harvested from the North Coast were the largest (Burger *et al.* 1998). However, no published studies have followed trends in market weights of geoducks over time for BC. Such studies would help determine to what extent the lower geoduck sizes observed in the Georgia Basin are a result of the fishery.

4.3. GROWTH

Growth was similar to that reported in other studies (Andersen 1971, Goodwin 1976, Breen and Shields 1983, Harbo *et al.* 1983, Goodwin and Shaul 1984, Noakes and Campbell 1992, Hoffman *et al.* 2000). Geoducks shell length and total weight increases rapidly from settlement to 10 years, growth may continue at a considerably slower rate for the next 10 years and ceases thereafter except for a gradual thickening of the shell. Rapid growth in early life allows geoducks to attain sufficient size and thus a refuge depth in the sea floor that is safe from predators. The end of rapid growth and burrowing coincides with the beginning of annual reproductive activity (Sloan and Robinson 1984).

Growth rates varied considerably between locations, as observed in previous studies (Harbo *et al.* 1983, Goodwin and Shaul 1984, Noakes 1992, Hoffmann *et al.* 2000). Overall, growth rates tended to be higher in Southern BC than in Northern BC, although there were many exceptions. Growth in 11 sites in Puget Sound (Hoffmann *et al.* 2000) had a similar range of asymptotic length as BC data, but lower k values. This may indicate faster growth in BC or it may be due to differences in methodologies. Their study used measurements of inter-annular growth increments for individual clams from the acetate peels of the shell sections.

There was little relationship between the growth rate and the maximum size reached. Both fast-growing and slow-growing clams can reach large sizes (e.g. Elbow Bank and Gowgaia Bay, respectively), and fast and slow-growing clams can plateau at small sizes (e.g. Winter Harbour, Seaforth Channel). Apparently, the factors responsible for fast growth are not the same as those that control the maximum size reached.

Differences in growth rate between locations may be caused by a variety of factors. Breen and Shields (1983) found a relationship between mean size of the population and its exposure to surge, where the smallest clams were found at the area of highest exposure. In our study, growth rates were lower in populations on the QCI-West, where exposure to ocean swell is generally higher, than on the more protected QCI-East, although there was no such relationship with the maximum size reached (which were highly variable). High wave activity from storms can result in geoducks retracting their necks below the substrate surface (Campbell *et al.* 1996, 1998c, Hand *et al.* 1998d), which in turn reduces the feeding time. Growth would logically be lower under such conditions.

Although Goodwin and Pease (1991) found no relationship between mean geoduck size and density, our results suggest that geoducks from very dense populations may be smaller than those in less dense populations. In the QCI-West, geoducks sampled from Hippa Island with an average density of $3.43/m^2$ were small compared to those from Gowgaia Bay with and average density of only $0.75/m^2$, although their growth rates were similar. Similarly, the clams from Millar Channel and Elbow Bank had fast growth rates, but were much smaller in the former location where densities were approximately three times higher. Dundas Island is another example where a relative fast growth rate is associated with small animal sizes and high densities.

Goodwin and Pease (1991) found a link between sediment type and mean geoduck length, where clams were larger in sand and sand/mud, than in mud or pea gravel. They also found higher densities in sand than in mud or gravel. Likely, the mechanisms are inter-related, in that local water currents determine both particle size in soft sediments and the amount of planktonic material that flows past the clams' inhalent siphon. Goodwin and Pease (1987) suggested that growth and final size were dependent on local primary productivity of phytoplankton and volume of food-bearing currents. Hoffmann *et al.* (2000) found growth to be greatest in sites that are subject to intermediate tidal flow. As well, changes in mean annual temperature could be associated with shifts in annual geoduck growth (Noakes and Campbell 1992).

The relationship found between α and β values of the allometric growth model implies that geoducks from different locations experienced different growth patterns. The growth patterns ranged from fast initial growth, in terms of weight gain per length increment, with a growth rate that increased little with size, to slow initial growth with a pronounced increase in growth rate with size. For geoducks in the former case, body weight increased at a relatively constant rate and the rate did not increase much with size. For geoducks in the latter case, at first, body weight increased slowly as the shell grew, producing "skinny" clams with long shells, followed by a period of rapid increase in body weight. With data pooled by geographic area, Area 24, WCVI and the Georgia Basin showed the three lowest initial growth rates α and three the largest β values. These regions also exhibited some of the fastest growth rates in the length – age relationships (high k values). A trend for β to increase with k was also present in the by-survey analyses although with many exceptions. Geoducks whose growth in shell length (vs. age) was fast therefore gained relatively little weight per length increment until a time where the rate of weight gain increased greatly. If burying depth is related to shell length then investing more energy in shell growth may allow geoducks to attain a depth refuge from predators earlier in life than geoducks with slow shell growth. Geoducks with fast initial shell growth could therefore be expected to invest less energy in weight gain until such time as the depth refuge is reached and shell growth starts to slow.

Visual examination of data often showed that shell weight was the variable that had the closest relationship with age. Unlike shell length or total weight which reach an asymptote, shell weight continues to increase with age due to the shell's thickening rather than growth in length (Harbo *et al.* 1983, Goodwin and Shaul 1984, Sloan and Robinson 1984). A linear model of the log-transformed data fitted the data well for geoducks above 5 years of age (Figures 15 and 16). Despite the fit, variability in estimates of γ and δ, both within and between geographic areas, suggests that shell weight may be of little use as a predictor of age, unless applied only on a small spatial scale. Fyfe (1984) arrived at the same conclusion when describing shell-thickness-index to age relationships for three sites in the Tofino area.

The results showed that differences in mean age, total weight, shell length and shell weight were sometimes present between sub-samples of a given survey location. The use of sub-samples is thus warranted to get a better representation of mean age, weight and length of geoducks from a general area. The analyses showed that increasing the number of sub-samples taken on a survey may be desirable since it decreased the standard error of mean age, weight and length estimates. However, logistical considerations in the field would probably prevent taking more than five sub-samples per area due to the time required to change sampling locations (retrieve diver hoses and boat anchor, move boat to new location and re-deploy diver hoses). Furthermore, since there are diminishing returns to increasing the number of sub-samples collected, taking more than five sub-samples per survey would provide little additional benefit considering the time costs associated. Campbell and Rajwani (1998) recommended taking two samples of 100 geoducks from two sites within a bed, at two beds, for a total of 400 geoducks. The current practice of taking samples of 150 geoducks from three sites (total 450 clams) within a survey area is probably adequate as a compromise between optimal sampling and logistical considerations.

4.4. CONCLUSIONS

- Geoducks from Southern BC tended to be younger and smaller than geoducks from Northern BC. Possible causes for these differences are: 1) removal of old, large clams from Southern BC beds with a longer fishing history; 2) different growth patterns in different regions; or 3) more recruitment in Southern BC. Early Southern BC data suggests that mean age and size have decreased in at least some areas and supports the hypothesis that the fishery has removed old age classes from some populations. Some data support the second hypothesis in that, generally, growth was faster and maximum size smaller in Southern BC so that the maximum size was attained at a younger age than in Northern BC. Also, data from virgin beds indicated higher mean age in Northern BC samples suggesting differences in mean age between Southern and Northern BC may have been present before the fishery. Hypothesis-3 was also supported as data suggested higher recruitment in Southern BC. Therefore, the cause of the younger mean ages and smaller sizes observed in Southern BC is probably a combination of all three factors.

Geoduck market weight data should be re-analysed to look at trends in landed weights over time for different regions of the coast to determine the effect of the fishery on landed weights for different regions. Re-survey of certain sites may also help separate random effects from the effects of harvest on mean size and age of geoducks.

The Tofino area (Area 24) was the region of the coast that showed the fastest growth in terms of length – age, the highest mean length, total weight and lowest mean age. Area 24 therefore appears to be the most productive area on the BC coast. Area 24 is characterised by large shallow sandy banks and high tidal currents, which may be conducive to high productivity. Further analyses of existing data should be conducted to determine the effects of geoduck density, substrate, current regime, exposure and depth on the growth parameters estimated in the current study.

Significant differences in growth rates between and within regions of the BC coast were shown. The use of a single exploitation rate applied to the BC coast in the management of the fishery may therefore be inappropriate. Hoffmann *et al.* (2000) had similar results in Washington State and suggested that managers use the lowest k value (conservative approach) for a region or that a study with a sampling plan designed to yield unbiased regional estimators be conducted.

Data presented here did not show obvious negative effects of geoduck harvesting on recruitment of geoducks to fished beds. However, harvesting appears to remove larger and older geoducks from the population, which may impact the reproductive output of the population. Ongoing sampling of geoducks for age determination should be continued to monitor trends in recruitment.

A recent review has suggested that an extensive geoduck ageing program with broad geographic coverage was needed to reduce risks and uncertainties in the management of geoduck fisheries (Orensanz *et al.* 2000). The current study is a first step in the analysis of geoduck age data from BC. Mortality rates and recruitment mechanisms have been identified as research priorities for geoducks because the mortality rate is the parameter with the most influence on yield modelling (Bradbury and Tagart 2000). Harbo *et al.* (1983) also identified the need for mortality rate estimates based on a wide sample of geoduck populations. These topics will be the focus of further analyses performed on the data presented in the current paper and are to be published in future reports.

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Table 1: Summary of geoduck fishing history statistics for each location where age samples were collected.

Year	Location	# of Beds	# of Samples	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
Northern British Columbia										
Queen Charlotte Islands West										
2000	Gowgaia Bay	3	3	28.5	25,511	0.078	0.01-0.19	115	0.021	0.01-0.05
2000	Hippa Island	3	3	42.4	226,831	0.609	0.43-0.83	1,192	0.195	0.13-0.24
2000	Tasu Sound	3	3	na	6,070			28		
Queen Charlotte Islands East										
1994	Burnaby Island	1	1	10.9	64,427	0.594	-	265	·0.147	-
1995	Hotspring Island	1	1	4.7	27,091	0.577	-	125	0.160	-
1996	Houston Stewart Ch.	3	3	42.5	434,321	0.915	0.66-1.25	1,416	0.156	0.08-0.27
1997	Cumshewa Inlet	3	6	229.5	337,801	0.165	0.09-0.31	1,833	0.052	0.03-0.09
1998	Selwyn/Dana/Logan	3	3	27.4	30,550	0.107	0.01-0.19	156	0.032	0.004-0.06
North Coast										
1996	Otter Pass	3	3	62.2	365,113	0.471	0.32-0.76	1,719	0.128	0.07-0.22
1996	W. Aristazabal Island	3	3	40.3	248,206	0.569	0.34-0.72	1,122	0.150	0.09-0.21
1997	Principe Channel	3	3	21.1	43,318	0.171	0.10-0.27	197	0.049	0.04-0.07
1998	Dundas Island	2	3	46.7	230,423	0.505	0.39-0.64	931	0.127	0.08-0.17
1998	Moore Islands	2	3	22.4	31,554	0.141	0.00-0.16	123	0.022	0.00-0.36
Central Coast										
1993	W. Price Island	1	1	29.4	144,227	0.490	-	616	0.126	-
1995	Kitasu Bay	4	5	30.8	31,980	0.104	-	128	0.025	-
1995	W. Higgins Pass	1	1	23.4	334,902	1.432	-	1,474	0.378	-
1995	Seaforth Channel	1	1	8.8	10,800	0.122	-	49	0.033	-
1996	S. Bardswell/Prince	3	3	37.0	102,970	0.439	0.30-0.95	419	0.107	0.02-0.23
1997	Anderson/Laredo	3	3	54.0	204,644	0.364	0.15-0.06	1,026	0.110	0.01-0.16
1998	Hakai Passage	3	3	98.0	556,906	0.523	0.41-0.59	2,654	0.145	0.10-0.17
Southern British Columbia										
Area 24										
1994	Elbow Bank	1	1	86.9	981,952	1.130	-	7,265	0.502	-
1997	Millar Channel	1	3	367.2	1,010,264	0.275	-	6,607	0.108	-
1997	Yellow Bank	1	3	121.8	834,023	0.685	-	6,396	0.315	-
West Coast of Vancouver Island										
1996	Winter Harbour	4	4	104.6	591,816	0.654	0.15-1.03	3,101	0.205	0.05-0.32
1998	Kyuquot	1	3	177.2	2,230,057	1.258	-	12,619	0.427	-
2000	Barkley Sound	3	3	151.2	775,466	0.395	0.26-0.09	5,443	0.160	0.10-0.23
2000	Nootka Sound	3	3	24.7	162,054	0.568	0.27-0.73	876	0.195	0.12-0.25
Area 12										
1995	Goletas Channel	3	5	37.9	299,568	0.783	0.64-0.91	1,144	0.209	0.14-0.28
1995	Duncan Island	1	1	6.7	60,055	0.902	-	332	0.299	-
Georgia Basin										
1996	Oyster River	1	3	1324.4	652,062	0.049	-	4,073	0.018	-
1998	Comox 1998	1	6	1277.8	1,228,830	0.096	-	9,409	0.044	-
1999	Thormanby Island	1	3	284.5	63,453	0.022	-	419	0.009	-
2000	Round Island	1	3	12.7	110,956	0.875	-	781	0.369	-

Table 2: Summary of geoduck fishing history statistics by geographic area.

Geographic Area	Area (Ha)	Total Landing (kg)	% of Coastal Landings	Mean kg/m^2 Harvested	Total Effort (h)	Mean Fishing Effort (min/m^2)	Years Fished
Northern British Columbia							
QCI-West	655.3	2,199,053	3.3	0.336	9,634	0.088	8
QCI-East	1904.4	4,379,212	6.6	0.230	19,232	0.061	11
North Coast	1870.5	6,939,369	10.5	0.371	31,751	0.102	12
Central Coast	1729.6	9,255,776	14.0	0.535	41,814	0.145	13
Southern British Columbia							
Area 24	2847.7	12,103,604	18.3	0.425	82,759	0.174	23
West Coast	3866.4	15,798,633	23.9	0.409	91,247	0.142	22
Area 12	820.4	2,623,360	4.0	0.320	14,249	0.104	12
Georgia Basin	11181.8	12,746,827	19.3	0.114	93,743	0.050	23
Total for BC Coast	24875.9	66,045,834	100.0	0.266	384,428	0.093	23

Table 3. Summary statistics of age and total wet weight for geoduck samples collected between 1993 and 2000. Sub-sample sizes are approximate.

Year	Location	# and size of sub-samples	n	Age (yrs) Mean (range)	S.D.	n	Total Weight (g) Mean (Range)	S.D.	n
Northern British Columbia									
Queen Charlotte Islands West									
2000	Gowgaia Bay	3*100	288	51.7 (5-133)	27.0	270	1509.9 (380-2768)	464.7	288
2000	Hippa Island	3*150	445	72.2 (5-160)	37.3	432	770.7 (222-1549)	221.1	442
2000	Tasu Sound*	3*150	456	54.2 (3-168)	31.3	446	1049.6 (94-2304)	376.4	456
Queen Charlotte Islands East									
1994	Burnaby Island	1*500	485	44.8 (5-138)	17.3	431	1421.4 (58-2737)	368.2	485
1995	Hotspring Island	1*500	512	42.7 (4-145)	29.9	385	907.1 (9-2321)	347.9	507
1996	Houston Stewart Ch.	3*150	480	49.7 (3-120)	27.1	453	915.1 (107-1876)	290.9	478
1997	Cumshewa Inlet	6*100	600	31.0 (3-95)	22.4	480	1101.4 (105-2357)	350.1	600
1998	Selwyn/Dana/Logan	3*100	331	46.6 (4-100)	18.1	321	981.2 (158-1891)	254.7	331
North Coast									
1996	Otter Pass	3*150	454	30.4 (4-126)	24.1	427	850.1 (168-2085)	385.7	451
1996	W. Aristazabal Island	3*150	435	65.9 (4-139)	28.0	395	1019.4 (220-2053)	304.0	435
1997	Principe Channel*	3*100	303	54.8 (8-160)	29.5	298	852.9 (261-1528)	226.4	303
1998	Dundas Island	3*100	314	43.0 (5-132)	21.8	306	758.4 (231-1903)	259.0	314
1998	Moore Islands*	3*100	311	63.8 (8-128)	32.7	290	1005.3 (281-1750)	244.5	311
Central Coast									
1993	Price Island	1*500	500	39.0 (4-100)	20.9	455	960.0 (121-2022)	343.6	463
1995	Kitasu Bay	5*100	525	44.2 (6-114)	22.9	434	1141.9 (185-2710)	414.7	522
1995	W. Higgins Pass	1*500	525	42.8 (8-101)	15.1	474	922.8 (255-1900)	281.5	525
1995	Seaforth Channel	1*500	493	48.4 (5-126)	22.5	460	658.4 (66-1524)	225.4	479
1996	S. Bardswell/Prince	3 *150	448	44.3 (5-120)	21.3	427	858.4 (101-1979)	299.0	445
1997	Anderson/Laredo	3 *100	300	43.1 (6-140)	29.0	293	893.9 (231-1983)	335.3	299
1998	Hakai Passage	3 *100	308	38.5 (1-116)	25.9	292	1201.3 (6-2668)	517.9	308
Southern British Columbia									
Area 24									
1994	Elbow Bank	1*450	433	28.8 (4-93)	12.6	405	1490.1 (530-2590)	363.2	422
1997	Millar Channel	3*100	302	24.6 (2-96)	22.2	277	738.7 (33-1646)	334.6	301
1997	Yellow Bank	3*100	298	24.8 (2-95)	20.4	186	954.6 (91-1876)	396.8	296
West Coast of Vancouver Island									
1996	Winter Harbour	4*150	620	49.0 (4-160)	31.9	580	773.0 (14-2038)	290.6	617
1998	Kyuquot	3*100	314	19.2 (3-120)	20.7	304	727.6 (100-1871)	328.0	314
2000	Barkley Sound	3*100	304	36.3 (4-114)	23.5	301	964.4 (183-1997)	348.6	304
2000	Nootka Sound	3*100	318	42.2 (4-162)	26.9	311	769.1 (147-1675)	299.7	318
Area 12									
1995	Goletas Channel	5*100	490	40.6 (3-113)	22.7	447	1048.8 (108-2158)	365.4	483
1995	Duncan Island	1*500	507	40.9 (3-112)	24.4	468	942.1 (132-2062)	328.9	500
Georgia Basin									
1993	Comox 1993	1*500	503	19.2 (1-117)	18.3	440	N/A	N/A	0
1996	Oyster River	3*200	606	31.6 (2-120)	21.9	466	936.8 (14-2284)	359.8	598
1998	Comox 1998	6*50	312	21.5 (2-120)	22.6	289	779.5 (66-2001)	361.8	311
1999	Thormanby Island	3*100	327	48.7(5-126)	21.2	283	741.1 (232-1492)	222.7	327
2000	Round Island	3*100	363	14.5 (2-117)	19.8	322	730.7 (28-2182)	364.0	363

*: Virgin beds

Table 3 (continued): Summary statistics of shell length and shell weight for geoduck samples collected between 1993 and 2000. Sub-sample sizes are approximate.

Year	Location	# and size of sub-samples	n	Length (mm) Mean (Range)	S.D.	n	Shell weight (g) Mean (Range)	S.D.	n
Northern British Columbia									
Queen Charlotte Islands West									
2000	Gowgaia Bay	3*100	288	164.6 (115-205)	17.6	288	302.0 (47-675)	122.2	276
2000	Hippa Island	3*150	445	133.6 (93-171)	12.5	445	177.2 (23-419)	75.1	441
2000	Tasu Sound*	3*150	456	143.8 (65-195)	18.0	456	221.6 (21-628)	107.3	454
Queen Charlotte Islands East									
1994	Burnaby Island	1*500	485	158.5 (67-195)	15.2	467	260.5 (7-517)	81.5	464
1995	Hotspring Island	1*500	512	141.3 (38-202)	16.9	512	188.8 (27-542)	96.8	391
1996	Houston Stewart Ch.	3*150	480	141.4 (79-185)	16.0	480	242.6 (18-718)	102.4	472
1997	Cumshewa Inlet	6*100	600	146.9 (65-193)	17.2	600	214.6 (15-490)	84.3	572
1998	Selwyn/Dana/Logan	3*100	331	138.2 (86-175)	13.0	331	192.4 (76-476)	67.3	324
North Coast									
1996	Otter Pass	3*150	454	134.2 (80-178)	19.2	453	143.8 (22-474)	86.5	428
1996	W. Aristazabal Island	3*150	435	146.6 (84-185)	13.4	435	251.2 (38-761)	88.5	427
1997	Principe Channel*	3*100	303	134.2 (88-170)	12.1	303	171.4 (40-443)	66.0	295
1998	Dundas Island	3*100	314	128.2 (91-165)	14.5	314	138.1 (26-375)	60.4	304
1998	Moore Islands*	3*100	311	142.6 (104-180)	11.4	311	233.2 (58-574)	84.2	299
Central Coast									
1993	Price Island	1*500	500	141.2 (81-181)	16.8	498	193.0 (19-454)	84.8	498
1995	Kitasu Bay	5*100	525	144.5 (85-185)	16.9	497	227.4 (21-565)	96.9	496
1995	W. Higgins Pass	1*500	525	134.5 (97-194)	13.1	525	173.1 (35-539)	69.7	478
1995	Seaforth Channel	1*500	493	124.7 (58-168)	14.2	485	137.7 (7-422)	63.7	466
1996	S. Bardswell/Prince	3 *150	448	134.1 (86-175)	13.7	448	188.4 (22-532)	81.3	444
1997	Anderson/Laredo	3 *100	300	138.7 (92-175)	16.6	300	189.8 (23-522)	104.0	298
1998	Hakai Passage	3 *100	308	148.6 (34-195)	23.6	308	217.7 (1-559)	112.6	287
Southern British Columbia									
Area 24									
1994	Elbow Bank	1*450	433	169.2 (125-201)	13.2	417	270.6 (48-644)	74.2	413
1997	Millar Channel	3*100	302	132.8 (50-180)	20.1	302	141.4 (2-359)	81.7	283
1997	Yellow Bank	3*100	298	147.0 (73-186)	21.1	298	182.1 (11-510)	97.5	275
West Coast of Vancouver Island									
1996	Winter Harbour	4*150	620	126.6 (37-180)	16.9	617	151.7 (13-585)	75.7	588
1998	Kyuquot	3*100	314	132.1 (70-190)	19.7	314	118.5 (13-399)	66.7	301
2000	Barkley Sound	3*100	304	142.5 (87-185)	17.2	304	200.4 (22-617)	101.8	296
2000	Nootka Sound	3*100	318	132.5 (78-176)	15.5	318	150.6 (13-416)	66.8	316
Area 12									
1995	Goletas Channel	5*100	490	142.3 (72-180)	17.3	490	202.9 (10-500)	89.4	460
1995	Duncan Island	1*500	507	138.5 (74-191)	15.8	504	170.6 (10-510)	81.5	455
Georgia Basin									
1993	Comox 1993	1*500	503	120.5 (25-167)	25.8	481	53.1 (1-347)	42.5	477
1996	Oyster River	3*200	606	137.6 (41-182)	20.4	602	141.0 (8-387)	59.8	373
1998	Comox 1998	6*50	312	128.0 (57-178)	21.2	312	126.1 (4-474)	82.6	272
1999	Thormanby Island	3*100	327	127.4 (94-160)	12.5	327	143.4 (25-423)	58.6	312
2000	Round Island	3*100	363	127.6 (50-171)	21.3	363	104.1 (11-476)	78.7	327

*: Virgin beds

Table 4: Cumulative percent age frequency of geoducks from 34 surveys from 1993 to 2000.

Year Survey	Cumulative % frequency of geoducks ≤10 yrs	≤20 yrs	≤40 yrs	≤60 yrs	≤80 yrs	≤100 yrs	≤120 yrs	≤140 yrs	≤160 yrs	≤180 yrs
Northern British Columbia										
Queen Charlotte Islands West										
2000 Gowgaia bay	4.8	17.4	28.1	71.5	86.3	93.3	98.9	100.0		
2000 Tasu Sound	2.7	14.3	37.7	62.8	79.8	89.7	98.4	99.3	99.8	100.0
2000 Hippa Island	3.5	9.0	22.2	42.1	59.5	72.9	88.7	97.5	100.0	
Queen Charlotte Islands East										
1994 Burnaby Island	2.1	4.6	39.4	86.1	97.2	98.8	99.5	100.0		
1995 Hotspring Island	22.9	30.4	45.7	73.5	87.8	96.6	99.0	99.7	100.0	
1996 Houston Stewart Channel	7.1	17.2	39.5	69.1	84.3	96.2	100.0			
1997 Cumshewa Inlet	26.9	43.3	67.3	87.7	98.5	100.0				
1998 Selwyn/Dana/Logan Inlets	0.3	2.5	36.4	81.9	94.7	100.0				
North Coast										
1996 Otter Pass	28.8	52.7	60.7	91.1	97.2	99.3	99.8	100.0		
1996 West Aristazabal Is	4.6	8.9	17.0	41.5	65.3	91.1	99.0	100.0		
1997 Principe Channel	4.4	18.1	26.2	66.8	84.9	94.3	97.0	98.3	100.0	
1998 Dundas Island	8.5	13.7	52.9	87.9	94.1	97.7	99.3	100.0		
1998 Moore Islands	8.6	16.9	24.8	47.9	64.5	87.9	99.3	100.0		
Central Coast										
1993 Price Island	11.4	27.5	46.8	87.3	96.9	100.0				
1995 Kitasu Bay	4.8	17.5	44.5	79.5	92.4	98.4	100.0			
1995 West Higgins Pass	1.9	6.5	44.7	89.2	97.9	99.8	100.0			
1995 Seaforth Channel	2.8	11.3	32.8	76.5	90.0	97.8	99.8	100.0		
1996 S. Bardswell/Prince	1.4	10.5	44.3	84.3	93.9	98.4	100.0			
1997 Anderson/Laredo	18.8	33.4	50.9	68.6	88.7	98.6	99.7	100.0		
1998 Hakai Passage	15.8	32.9	52.4	85.6	91.8	98.3	100.0			
Southern British Columbia										
Area 24										
1994 Elbow Bank	4.4	23.5	86.7	97.8	99.3	100.0				
1997 Millar Channel	45.1	54.9	75.1	93.9	98.9	100.0				
1997 Yellow Bank	40.3	51.1	80.6	95.7	98.9	100.0				
West Coast of Vancouver Island										
1996 Winter Harbour	17.4	25.3	43.3	65.2	86.4	94.5	97.2	98.6	100.0	
1998 Kyuquot	54.9	69.4	86.5	95.4	97.7	99.3	100.0			
2000 Barkley Sound	24.6	32.9	57.8	86.0	96.3	99.0	100.0			
2000 Nootka Sound	10.6	27.3	48.2	80.1	90.4	96.5	99.0	99.7	99.7	100.0
Area 12										
1995 Duncan Island	24.8	28.2	36.5	84.2	95.7	99.8	100.0			
1995 Goletas Channel	16.3	23.3	47.4	84.6	96.0	99.1	100.0			
Georgia Basin										
1993 Comox 1993	50.7	66.4	85.7	96.1	99.5	99.8	100.0			
1996 Oyster River	12.0	42.1	71.0	89.1	96.6	99.6	100.0			
1998 Comox 1998	48.4	67.1	84.1	92.4	96.9	99.3	100.0			
1999 Thormanby Island	3.5	9.2	34.6	72.4	92.6	98.6	99.6	100.0		
2000 Round Island	78.0	86.3	87.9	92.5	99.1	99.7	100.0			

Table 5: Mean, lower and upper confidence bounds for age, total weight, shell length and shell weight of geoducks per geographic area.

Geographic Area	Age (years)			Total Weight (grams)			Shell Length (mm)			Shell Weight (grams)		
	Lower 95% Confidence Bound	Estimated Mean	Upper 95% Confidence Bound	Lower 95% Confidence Bound	Estimated Mean	Upper 95% Confidence Bound	Lower 95% Confidence Bound	Estimated Mean	Upper 95% Confidence Bound	Lower 95% Confidence Bound	Estimated Value	Upper 95% Confidence Bound
QCI-West	51.6	60.4	71.2	773.7	1057.4	1496.5	133.8	145.0	164.3	178.8	223.8	296.2
QCI-East	36.1	42.6	47.9	927.2	1071.3	1257.7	140.1	145.6	152.2	198.7	222.3	246.2
North Coast	37.3	50.7	63.1	811.8	901.9	988.1	131.7	137.6	143.4	145.9	188.9	231.4
Central Coast	40.5	43.1	45.6	819.6	940.4	1059.8	131.9	137.4	142.5	167.1	188.2	209.1
Area 24	23.6	26.6	28.7	739.8	1112.6	1488.3	132.9	151.9	169.0	141.3	207.9	269.8
West Coast	24.3	39.0	47.4	740.1	800.5	904.0	127.6	132.0	139.5	131.8	154.4	182.8
Area 12	39.3	40.8	42.3	930.5	994.5	1063.0	137.9	140.3	142.9	167.6	186.8	206.1
Georgia Basin	17.8	26.6	36.2	729.0	819.4	905.2	123.3	128.9	134.8	75.6	108.5	138.1

Table 6: Analysis of Variance (ANOVA) for effect of survey and geographic area on geoduck mean age, total weight, shell length and shell weight.

Variable	Source of Varibility	Degrees of Freedom	Sum of Squares (SSQ)	Mean Sum of Squares (MS)	F-value	p-value
Age	Geographic Area	7	1168942	166992	276.80	0.000
	Survey	26	976379	37553	62.25	0.000
	Within Survey	12814	7730601	603		
	Total	12847	9875922			
Total Weight	Geographic Area	7	144030232	20575747	182.61	0.000
	Survey	25	421911030	16876441	149.78	0.000
	Within Survey	13563	1528187752	112673		
	Total	13595	2094129014			
Shell Length	Geographic Area	7	618739	88391	302.64	0.000
	Survey	26	900933	34651	118.64	0.000
	Within Survey	14071	4109702	292		
	Total	14104	5629373			
Shell Weight	Geographic Area	7	17140105	2448586	351.40	0.000
	Survey	26	17233264	662818	95.12	0.000
	Within Survey	13228	92173089	6968		
	Total	13261	126546457			

Table 7: Confidence levels that mean values for each variable are different between geographic areas. Values represent the confidence level that the geographic area in the column has a higher mean than the area in the row. Values ≥ 0.95 are significantly different and are indicated in bold print.

Variable	Geographic Area	QCI West	QCI East	North Coast	Central Coast	Area 24	West Coast	Area 12	Georgia Basin
Mean Age	QCI-West		0.00	0.15	0.00	0.00	0.00	0.00	0.00
	QCI-East	**1.00**		0.86	0.53	0.00	0.25	0.28	0.01
	North Coast	0.85	0.14		0.13	0.00	0.07	0.08	0.00
	Central Coast	**1.00**	0.47	0.87		0.00	0.21	0.06	0.00
	Area 24	**1.00**	**1.00**	**1.00**	**1.00**		**0.95**	**1.00**	0.52
	West Coast	**1.00**	0.75	0.93	0.79	0.05		0.64	0.09
	Area 12	**1.00**	0.73	0.92	0.94	0.00	0.36		0.01
	Georgia Basin	**1.00**	**0.99**	**1.00**	**1.00**	0.49	0.91	**0.99**	
Mean Total Weight	QCI-West		0.51	0.15	0.24	0.55	0.04	0.35	0.05
	QCI-East	0.49		0.02	0.11	0.57	0.00	0.21	0.00
	North Coast	0.85	**0.98**		0.69	0.78	0.06	**0.95**	0.10
	Central Coast	0.76	0.89	0.32		0.76	0.05	0.76	0.07
	Area 24	0.45	0.43	0.22	0.25		0.08	0.28	0.10
	West Coast	**0.96**	**1.00**	0.94	**0.95**	0.92		**1.00**	0.56
	Area 12	0.65	0.79	0.05	0.24	0.72	0.00		0.00
	Georgia Basin	**0.95**	**1.00**	0.90	0.93	0.90	0.44	**1.00**	
Mean Shell Length	QCI-West		0.53	0.13	0.13	0.70	0.03	0.23	0.00
	QCI-East	0.47		0.02	0.02	0.71	0.00	0.06	0.00
	North Coast	0.87	**0.98**		0.51	0.91	0.13	0.81	0.02
	Central Coast	0.87	**0.99**	0.49		0.90	0.13	0.82	0.02
	Area 24	0.30	0.29	0.09	0.10		0.03	0.16	0.00
	West Coast	**0.97**	**1.00**	0.87	0.87	**0.97**		**0.98**	0.22
	Area 12	0.77	0.94	0.19	0.19	0.84	0.02		0.00
	Georgia Basin	**1.00**	**1.00**	**0.98**	**0.98**	**1.00**	0.78	**1.00**	
Mean Shell Weight	QCI-West		0.49	0.13	0.08	0.34	0.00	0.07	0.00
	QCI-East	0.51		0.07	0.02	0.33	0.00	0.01	0.00
	North Coast	0.87	0.93		0.51	0.67	0.10	0.49	0.00
	Central Coast	0.92	**0.98**	0.49		0.71	0.04	0.46	0.00
	Area 24	0.66	0.67	0.33	0.29		0.10	0.29	0.00
	West Coast	**1.00**	**1.00**	0.90	**0.97**	0.90		**0.96**	0.02
	Area 12	0.93	**0.99**	0.51	0.54	0.71	0.04		0.00
	Georgia Basin	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**0.98**	**1.00**	

Table 8: Cumulative percent frequency of total weight of geoducks, from 34 surveys from 1993 to 2000.

Year	Survey	Cumulative % frequency of geoducks					
		≤500 g	≤1000 g	≤1500 g	≤2000 g	≤2500 g	≤3000 g
Northern British Columbia							
Queen Charlotte Islands West							
2000	Gowgaia Bay	0.7	14.2	51.0	83.7	98.6	100.0
2000	Tasu Sound	4.6	48.2	87.5	98.7	100.0	
2000	Hippa Island	10.9	85.5	99.8	100.0		
Queen Charlotte Islands East							
1994	Burnaby Island	1.9	9.5	60.2	94.6	99.8	100.0
1995	Hotspring Island	15.6	61.5	95.9	99.6	100.0	
1996	Houston Stewart Channel	6.3	61.9	96.4	100.0		
1997	Cumshewa Inlet	3.3	42.8	88.0	98.8	100.0	
1998	Selwyn/Dana/Logan Inlets	1.2	55.0	96.7	100.0		
North Coast							
1996	Otter Pass	22.6	62.5	95.6	99.6	100.0	
1996	West Aristazabal Is	2.3	50.3	92.0	99.8	100.0	
1997	Principe Channel	7.3	76.2	99.7	100.0		
1998	Dundas Island	17.2	84.1	99.0	100.0		
1998	Moore Islands	1.0	53.1	97.1	100.0		
Central Coast							
1993	Price Island	8.4	54.4	93.5	99.8	100.0	
1995	Kitasu Bay	4.0	41.0	80.7	97.3	99.4	100.0
1995	West Higgins Pass	3.8	67.8	96.2	100.0		
1995	Seaforth Channel	23.2	93.1	99.8	100.0		
1996	S. Bardswell/Prince	7.6	70.3	96.4	100.0		
1997	Anderson/Laredo	16.7	60.5	96.7	100.0		
1998	Hakai Passage	9.1	37.7	70.8	93.8	99.7	100.0
Southern British Columbia							
Area 24							
1994	Elbow Bank	0.0	9.2	52.4	91.5	99.5	100.0
1997	Millar Channel	25.6	78.7	97.7	100.0		
1997	Yellow Bank	13.2	53.7	90.9	100.0		
West Coast of Vancouver Island							
1996	Winter Harbour	14.3	80.2	98.1	99.8	100.0	
1998	Kyuquot	25.2	79.9	98.1	100.0		
2000	Barkley Sound	9.9	52.3	94.4	100.0		
2000	Nootka Sound	18.2	77.0	97.8	100.0		
Area 12							
1995	Duncan Island	10.0	53.4	96.2	99.6	100.0	
1995	Goletas Channel	5.4	44.5	87.4	99.0	100.0	
Georgia Basin							
1993	Comox 1993	N/A	N/A	N/A	N/A	N/A	N/A
1996	Oyster River	9.2	56.7	94.1	99.5	100.0	
1998	Comox 1998	24.4	72.0	96.8	99.7	100.0	
1999	Thormanby Island	13.1	87.5	100.0			
2000	Round Island	30.0	77.7	96.7	99.7	100.0	

Table 9: Parameter estimates for the Total Weight – Age relationship from geoduck samples collected on surveys between 1993 and 2000. 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	
Survey	L_∞ (mm)	k	$sigma_1$	n	α	β	$sigma_2$	n	Mean TW_∞ (g)	n
Northern British Columbia										
Queen Charlotte Islands West										
2000 Gowgaia Bay	168.4	0.1767	15.29	270	0.008542	2.359	0.2125	288	1563.5	270
2000 Hippa Island	134.7	0.1908	11.87	432	0.002301	2.594	0.2124	442	786.0	430
2000 Tasu Sound	147.8	0.1429	15.15	446	0.005613	2.432	0.2250	456	1088.8	446
Queen Charlotte Islands East										
1994 Burnaby Island	159.7	0.2467	11.11	418	0.011107	2.315	0.2077	467	1430.0	418
1995 Hotspring Island	147.4	0.2890	12.31	385	0.000334	2.982	0.2305	507	1006.4	382
1996 Houston Stewart Ch.	143.9	0.2552	13.56	453	0.002150	2.607	0.2057	478	927.0	451
1997 Cumshewa Inlet	145.9	0.4318	15.92	480	0.006330	2.411	0.2087	600	1068.1	480
1998 Selwyn/Dana/Logan In.	139.1	0.1778	12.51	321	0.008507	2.360	0.1701	331	986.4	321
North Coast										
1996 Otter Pass	146.3	0.2232	11.43	426	0.000177	3.123	0.2167	451	1047.1	424
1996 West Aristazabal Island	147.9	0.2841	12.63	395	0.003259	2.530	0.2073	435	1027.5	395
1997 Principe Channel	135.4	0.2338	11.66	298	0.005215	2.445	0.1852	303	864.2	298
1998 Dundas Island	129.7	0.3104	13.58	306	0.004196	2.484	0.1827	314	754.9	306
1998 Moore Islands	143.9	0.2738	10.48	290	0.006157	2.416	0.1921	311	1025.9	290
Central Coast										
1993 Price Island	145.0	0.2389	14.04	454	0.003178	2.534	0.2153	461	976.5	423
1995 Kitasu Bay	145.6	0.2310	15.13	430	0.009442	2.342	0.2138	494	1126.8	427
1995 West Higgins Pass	136.1	0.1560	12.57	474	0.008014	2.370	0.2018	525	933.6	474
1995 Seaforth Channel	127.7	0.1478	11.39	455	0.002156	2.606	0.2116	478	680.8	448
1996 S Bardswell/Prince Gr.	135.2	0.1979	13.45	427	0.004594	2.468	0.2172	445	852.5	424
1997 Anderson/Laredo	145.5	0.1832	12.03	293	0.002134	2.608	0.2126	299	956.4	292
1998 Hakai Passage	155.1	0.2436	17.35	292	0.000146	3.167	0.1962	308	1287.2	292
Southern British Columbia										
Area 24										
1994 Elbow Bank	169.7	0.4206	12.94	400	0.005190	2.446	0.1620	406	1494.8	389
1997 Millar Channel	142.0	0.4917	14.62	277	0.000468	2.911	0.2506	301	888.5	277
1997 Yellow Bank	157.9	0.4225	11.19	186	0.000613	2.854	0.2285	296	1185.1	184
West Coast of Vancouver Island										
1996 Winter Harbour	129.3	0.3203	14.25	580	0.004869	2.457	0.2343	617	772.7	580
1998 Kyuquot	140.1	0.4194	16.24	304	0.000483	2.904	0.2010	314	842.9	304
2000 Barkley Sound	149.1	0.2509	13.16	301	0.002839	2.555	0.2160	304	1038.1	301
2000 Nootka Sound	133.5	0.3989	15.08	311	0.001540	2.671	0.2226	318	748.8	311
Area 12										
1995 Duncan Island	144.3	0.3111	11.65	468	0.004578	2.468	0.2327	500	1003.7	465
1995 Goletas Channel	146.7	0.2625	14.09	447	0.006481	2.407	0.2016	483	1084.1	443
Georgia Basin										
1993 Comox 1993	137.6	0.2622	12.65	422	N/A	N/A	N/A	0	N/A	0
1996 Oyster River	145.4	0.2472	11.59	464	0.002423	2.584	0.2399	598	968.6	462
1998 Comox 1998	139.2	0.3249	15.54	289	0.003205	2.533	0.2380	311	885.9	288
1999 Thormanby Island	128.5	0.2263	11.85	283	0.004272	2.481	0.1934	327	741.8	283
2000 Round Island	149.2	0.2891	12.73	322	0.001225	2.715	0.2160	363	1000.7	322

Table 10: Parameter estimates for the Total Weight – Age relationships of geoducks, by geographic area. Mean TW_∞ is the estimated mean asymptotic total weight from the combined growth model.

	Von Bertalanffy (Length-Age)				Allometric (Total Weight-Length)				Combined	
Geographic Area	L_∞ (mm)	k	$sigma_1$	n	α	β	$sigma_2$	n	Mean TW_∞ (g)	n
QCI-West	147.1	0.1794	18.91	1148	0.004244	2.482	0.2249	1186	1042.2	1146
QCI-East	147.4	0.3189	15.12	2057	0.004610	2.467	0.2286	2383	1059.2	2052
North Coast	141.0	0.2525	13.73	1715	0.003753	2.504	0.2105	1814	923.8	1713
Central Coast	139.3	0.2457	16.25	2825	0.004531	2.470	0.2275	3010	919.0	2780
Area 24	161.0	0.3698	16.79	863	0.000475	2.908	0.2133	1003	1268.3	850
WCVI	135.2	0.3980	16.38	1496	0.002584	2.572	0.2341	1553	805.3	1496
Area 12	145.5	0.2904	12.99	915	0.005439	2.438	0.2190	983	1042.3	908
Georgia Basin	138.7	0.3087	14.40	1780	0.002718	2.563	0.2282	1599	862.4	1355

Table 11: Confidence levels that model parameters are different between geographic areas. Values represent the confidence level that the geographic area in the column has a higher mean than the area in the row. Values ≥ 0.95 are significantly different and are shown in bold print.

Parameter	Geographic Area	QCI West	QCI East	North Coast	Central Coast	Area 24	West Coast	Area 12	Georgia Basin
L_∞	QCI-West		0.51	0.21	0.15	0.83	0.08	0.39	0.12
	QCI-East	0.49		0.06	0.04	0.88	0.03	0.31	0.03
	North Coast	0.80	0.94		0.38	**0.98**	0.18	0.92	0.33
	Central Coast	0.85	**0.96**	0.63		**0.99**	0.24	**0.97**	0.43
	Area 24	0.17	0.12	0.02	0.01		0.02	0.07	0.01
	West Coast	0.92	**0.97**	0.82	0.76	**0.98**		**0.97**	0.68
	Area 12	0.61	0.69	0.08	0.04	0.94	0.03		0.02
	Georgia Basin	0.88	**0.97**	0.67	0.57	**0.99**	0.32	**0.99**	
k	QCI-West		**1.00**	**0.99**	**0.95**	**1.00**	**1.00**	**1.00**	**1.00**
	QCI-East	0.00		0.10	0.06	0.89	0.78	0.30	0.45
	North Coast	0.01	0.90		0.29	**1.00**	**0.99**	0.90	**0.95**
	Central Coast	0.05	0.94	0.71		**1.00**	**0.99**	0.94	**0.97**
	Area 24	0.00	0.11	0.00	0.00		0.44	0.00	0.05
	West Coast	0.00	0.22	0.01	0.01	0.57		0.05	0.16
	Area 12	0.00	0.70	0.10	0.06	**1.00**	**0.95**		0.72
	Georgia Basin	0.00	0.55	0.05	0.04	**0.95**	0.84	0.29	
σ_1	QCI-West		0.20	0.06	0.28	0.22	0.31	0.05	0.10
	QCI-East	0.80		0.13	0.79	0.57	0.90	0.06	0.24
	North Coast	0.94	0.87		**0.95**	0.78	**0.98**	0.36	0.72
	Central Coast	0.72	0.21	0.05		0.41	0.52	0.02	0.09
	Area 24	0.78	0.43	0.22	0.59		0.56	0.16	0.33
	West Coast	0.69	0.10	0.02	0.48	0.44		0.00	0.02
	Area 12	**0.95**	0.94	0.65	**0.98**	0.85	**1.00**		0.84
	Georgia Basin	0.90	0.76	0.28	0.91	0.67	**0.98**	0.16	
α	QCI-West		0.55	0.35	0.52	0.00	0.14	0.74	0.12
	QCI-East	0.45		0.30	0.43	0.05	0.14	0.65	0.12
	North Coast	0.65	0.70		0.70	0.00	0.16	0.94	0.15
	Central Coast	0.48	0.57	0.30		0.00	0.09	0.78	0.07
	Area 24	**1.00**	**0.95**	**1.00**	**1.00**		0.78	**1.00**	**0.97**
	West Coast	0.86	0.86	0.84	0.91	0.22		**0.99**	0.56
	Area 12	0.26	0.35	0.06	0.22	0.00	0.01		0.00
	Georgia Basin	0.88	0.88	0.85	0.93	0.03	0.44	**1.00**	
β	QCI-West		0.45	0.65	0.48	**1.00**	0.86	0.26	0.88
	QCI-East	0.55		0.70	0.57	**0.95**	0.86	0.35	0.88
	North Coast	0.35	0.30		0.30	**1.00**	0.84	0.06	0.85
	Central Coast	0.52	0.43	0.70		**1.00**	0.91	0.22	0.93
	Area 24	0.00	0.05	0.00	0.00		0.22	0.00	0.03
	West Coast	0.14	0.14	0.16	0.09	0.78		0.01	0.44
	Area 12	0.74	0.65	0.94	0.78	**1.00**	**0.99**		**1.00**
	Georgia Basin	0.12	0.12	0.15	0.07	**0.97**	0.56	0.00	
σ_2	QCI-West		0.56	0.17	0.66	0.36	0.69	0.40	0.64
	QCI-East	0.44		0.19	0.54	0.35	0.60	0.37	0.55
	North Coast	0.83	0.81		0.90	0.58	0.87	0.71	0.85
	Central Coast	0.34	0.46	0.11		0.29	0.59	0.29	0.52
	Area 24	0.64	0.65	0.42	0.71		0.70	0.56	0.67
	West Coast	0.31	0.40	0.14	0.41	0.30		0.27	0.42
	Area 12	0.60	0.63	0.29	0.71	0.44	0.73		0.70
	Georgia Basin	0.36	0.45	0.15	0.49	0.33	0.58	0.30	
TW_∞	QCI-West		0.50	0.21	0.21	0.77	0.07	0.44	0.10
	QCI-East	0.50		0.04	0.09	0.81	0.01	0.41	0.01
	North Coast	0.79	**0.96**		0.53	**0.95**	0.13	**0.99**	0.22
	Central Coast	0.79	0.91	0.47		0.94	0.14	0.94	0.23
	Area 24	0.23	0.19	0.05	0.06		0.02	0.17	0.02
	West Coast	0.93	**0.99**	0.87	0.86	**0.98**		**0.99**	0.69
	Area 12	0.56	0.59	0.01	0.06	0.83	0.01		0.00
	Georgia Basin	0.90	**0.99**	0.78	0.77	**0.98**	0.31	**1.00**	

Table 12: Parameter estimates for Shell Weight – Age relationships of geoduck samples collected on surveys between 1993 and 2000.

Survey	γ	δ	$sigma_3$	n
Northern British Columbia				
Queen Charlotte Islands West				
2000 Gowgaia Bay	33.58	0.5525	0.3099	262
2000 Hippa Island	14.34	0.5882	0.2389	429
2000 Tasu Sound	21.19	0.5838	0.3326	444
Queen Charlotte Islands East				
1994 Burnaby Island	34.04	0.5367	0.2113	415
1995 Hotspring Island	19.76	0.6095	0.2465	376
1996 Houston Stewart Ch.	27.58	0.5603	0.2775	449
1997 Cumshewa Inlet	43.99	0.4633	0.2473	468
1998 Selwyn/Dana/Logan Inlets	23.88	0.5386	0.2585	318
North Coast				
1996 Otter Pass	12.95	0.7202	0.2856	416
1996 West Aristazabal Island	36.02	0.4653	0.2496	393
1997 Principe Channel	24.54	0.4866	0.2477	292
1998 Dundas Island	18.31	0.5325	0.3138	303
1998 Moore Islands	37.21	0.4485	0.2087	290
Central Coast				
1993 Price Island	26.05	0.5458	0.3442	453
1995 Kitasu Bay	25.66	0.5729	0.2609	429
1995 West Higgins Pass	10.66	0.7352	0.2431	467
1995 Seaforth Channel	5.77	0.8135	0.2795	453
1996 S Bardswell/Prince Group	18.73	0.6036	0.2919	425
1997 Anderson/Laredo	11.45	0.7461	0.2705	291
1998 Hakai Passage	13.84	0.7588	0.4446	279
Southern British Columbia				
Area 24				
1994 Elbow Bank	75.28	0.3800	0.2174	399
1997 Millar Channel	24.73	0.5706	0.3477	270
1997 Yellow Bank	33.31	0.5600	0.2855	186
West Coast of Vancouver Island				
1996 Winter Harbour	21.36	0.5040	0.3179	567
1998 Kyuquot	25.92	0.5310	0.4427	300
2000 Barkley Sound	24.87	0.5835	0.3216	294
2000 Nootka Sound	34.40	0.3919	0.3697	309
Area 12				
1995 Duncan Island	18.33	0.6100	0.2588	450
1995 Goletas Channel	21.01	0.6140	0.3168	440
Georgia Basin				
1993 Comox 1993	5.01	0.8037	0.4952	419
1996 Oyster River	25.39	0.4988	0.2850	362
1998 Comox 1998	18.01	0.6404	0.4621	271
1999 Thormanby Island	12.61	0.6166	0.3103	279
2000 Round Island	17.28	0.7030	0.4161	313

Table 13: Parameter estimates for the Shell Weight – Age relationships of geoducks by geographic area.

Geographic Area	γ	δ	$sigma_3$	n
QCI-West	27.25	0.5036	0.3993	1135
QCI-East	31.55	0.5212	0.2919	2026
North Coast	18.49	0.5936	0.3140	1694
Central Coast	16.74	0.6343	0.3717	2797
Area 24	29.38	0.6094	0.3549	855
WCVI	28.39	0.4646	0.3944	1470
Area 12	19.42	0.6148	0.2984	890
Georgia Basin	13.14	0.6448	0.5564	1644

Table 14: Confidence levels that model parameters for the Shell Weight – Age relationships are different between geographic areas. Values represent the confidence level that the geographic area in the column has a higher mean than the area in the row. Values ≥ 0.95 are significantly different and are indicated in bold print.

Parameter	Geographic Area	QCI West	QCI East	North Coast	Central Coast	Area 24	West Coast	Area 12	Georgia Basin
γ	QCI-West		0.72	0.17	0.06	0.77	0.66	0.11	0.14
	QCI-East	0.28		0.06	0.01	0.50	0.33	0.02	0.06
	North Coast	0.84	0.94		0.26	**0.95**	0.92	0.57	0.30
	Central Coast	0.94	**0.99**	0.74		**1.00**	**1.00**	0.82	0.41
	Area 24	0.23	0.50	0.05	0.00		0.30	0.00	0.01
	West Coast	0.34	0.67	0.08	0.00	0.71		0.00	0.03
	Area 12	0.90	**0.98**	0.43	0.19	**1.00**	**1.00**		0.34
	Georgia Basin	0.86	0.94	0.70	0.59	**0.99**	**0.97**	0.66	
δ	QCI-West		0.49	0.79	**0.98**	0.81	0.21	**0.98**	0.78
	QCI-East	0.52		0.79	**0.96**	0.79	0.25	0.94	0.81
	North Coast	0.21	0.21		0.83	0.50	0.06	0.73	0.66
	Central Coast	0.02	0.05	0.17		0.14	0.01	0.27	0.49
	Area 24	0.19	0.21	0.50	0.87		0.07	0.76	0.67
	West Coast	0.79	0.75	0.94	**0.99**	0.93		**1.00**	0.92
	Area 12	0.02	0.07	0.28	0.73	0.24	0.00		0.60
	Georgia Basin	0.22	0.19	0.34	0.51	0.33	0.08	0.40	
$sigma_3$	QCI-West		0.05	0.08	0.45	0.28	0.64	0.06	0.90
	QCI-East	**0.96**		0.82	**0.99**	0.79	**1.00**	0.67	**1.00**
	North Coast	0.93	0.18		0.92	0.71	**0.99**	0.35	**1.00**
	Central Coast	0.55	0.02	0.08		0.29	0.71	0.05	0.91
	Area 24	0.72	0.22	0.30	0.71		0.89	0.25	**0.96**
	West Coast	0.36	0.00	0.01	0.29	0.11		0.00	0.86
	Area 12	0.94	0.33	0.65	**0.95**	0.75	**1.00**		**1.00**
	Georgia Basin	0.10	0.00	0.00	0.09	0.04	0.14	0.00	

Table 15: Analysis of Variance (ANOVA) for effect of sample and sub-sample on geoduck mean age, total weight, shell length and shell weight.

Variable	Source of Variability	Degrees of Freedom	Sum of Squares (SSQ)	Mean Sum of Squares (MSE)	F-value	p-value
Age	Sample	21	1609863	76660	124.15	0.000
	Sub-sample	46	488982	10630	17.21	0.000
	Error	7815	4825679	617		
	Total	7882	6924524	879		
Total Weight	Sample	21	265834439	12658783	130.46	0.000
	Sub-sample	46	172378311	3667624	37.80	0.000
	Error	7815	831957652	97033		
	Total	7882	1270170403	146976		
Shell Length	Sample	21	618617	29458	111.64	0.000
	Sub-sample	46	345576	7353	27.87	0.000
	Error	7815	2260208	264		
	Total	7882	3224401	373		
Shell Weight	Sample	21	17030057	810955	121.48	0.000
	Sub-sample	47	7657374	162923	24.41	0.000
	Error	8052	53752774	6676	1.00	
	Total	8120	78440205	9660	1.45	

Table 16: Effect of total sample size and number of sub-samples taken on the Standard Error of age, total weight and shell length of geoducks.

Total Number of Animals	Number of SubSamples	Standard Error of Mean		
		Age	Total Weight	Shell Length
450	1	7.51	138.19	6.15
450	3	4.48	81.14	3.63
450	5	3.58	63.88	2.87
450	10	2.72	46.94	2.13
450	100	1.58	22.68	1.10
450	450	1.44	19.19	0.96
100	1	7.95	142.27	6.39
100	3	5.19	87.90	4.01
100	5	4.44	72.28	3.34
100	10	3.77	57.85	2.73
100	100	3.05	40.71	2.03
50	1	8.49	147.34	6.67
50	3	5.98	95.90	4.45
50	5	5.33	81.82	3.86
50	10	4.80	69.40	3.34

Table 17: Review of published data on geoduck age, total weight, shell length, von Bertalanffy shell length – age growth parameters and allometric total weight – shell length growth parameters. Values are means, with ranges in brackets, or range of sample means in square brackets.

Sampling Year	Location	Sample Type	Age (years)	Total Weight (g)	Shell Length (mm)	von Bertalanffy Length-Age Growth Parameters: k	von Bertalanffy Length-Age Growth Parameters: L_∞ (mm)	Allomeric Weight-Length Growth Parameters: α	Allomeric Weight-Length Growth Parameters: β	Study
British Columbia										
1980-90	7 sites in BC	Research & Market				0.215 (0.198-0.245)				Noakes 1992
Northern British Columbia										
Central Coast										
1981	Spider Anchorage	Market	60.9 (12-118)	972.8 (150-1643)	144.6 (90-175)	0.198**				Harbo et al 1983
Southern British Columbia										
Area 24										
1981	Elbow Bank	Market	28.3 (4-69)	1076.4 (182-1902)	159.9 (95-192)					Harbo et al 1983
1981	Elbow Bank	Research*	34.6 (5-84)	1219.1 (326-2156)	165.5 (103-210)					Data from Breen & Shields 1983
1981	Ritchie Bay	Research*	40.0 (4-101)							Data from Fig. 9 in Fyfe 1984
1991	Ritchie Bay	Research	35.8							Campbell & Noakes 1993
1981	Shot Island	Market	29.5 (10-60)	1187.4 (756-1876)	162.4 (141-187)					Harbo et al 1983
1982	Blunden Island	Market	57.4 (11-117)	1126.1 (260-1830)	148.9 (118-173)					Harbo et al 1983
West Coast Vancouver Island										
1981	Kyuquot	Market	39.3 (5-146)	1242.3 (225-2198)	154.5 (119-195)	0.213**				Harbo et al 1983
1982	Kyuquot	Market	41.4 (8-126)	1044.4 (361-2116)	146.1 (104-190)					Harbo et al 1983
1981	Rolling Roadstead	Market	35.2 (7-99)	153.7 (102-194)	1165.2 (247-2054)	0.219**				Harbo et al 1983
1980	Bamfield***	Research*	42.1 (1-144)	685.7 (2-1365)	136.2 (17-183)	0.203**				Data from Breen 1982 and Breen & Shields 1983
1981	Bamfield***	Research*	45.0 (9-120)	737.5 (211-1417)	139.8 (96-175)					Data from Breen & Shields 1983
Georgia Basin										
1981	Sidney	Research*	41.6 (10-84)	940.0 (354-1483)	151.1 (110-180)					Data from Breen & Shields 1983
1981	Crofton	Market	36.2 (8-73)	754.9 (94-1607)	137.1 (99-173)	0.245**				Harbo et al 1983
1980	Ladysmith***	Research*	53.0 (6-102)	845.9 (111-1645)	144.2 (81-176)	0.219				Data from Noakes & Campbell 1992
1981	Ladysmith***	Research*	40.3 (7-89)	1404.7 (493-2263)	165.6 (122-196)					Data from Breen & Shields 1983
1981	Comox	Research*	46.1 (14-102)	936.4 (501-1345)	156.3 (123-190)					Data from Breen & Shields 1983
1982-83	Nanaimo	Research	31.4 (4-107)	802.9						Sloan & Robinson 1984
1990	Gabriola Is.	Research	40.9			0.229**				Campbell & Noakes 1993
Washington State										
1967-70	2 sites in Hood Canal	Research				0.15	225	0.266	3.064	Andersen 1971
1973-85	Puget Sound	Research		882.4	135.6					Goodwin & Pease 1991
1979-82	11 sites in Washington	Research			[120-168]	(0.1131-0.2353)	(130-173)			Hoffmann et al 2000
N/A	24 sites in Washington	N/A			143.8 [123.8-171.3]			0.00037	2.97281	Goodwin 1976
1979-82	14 sites in Washington	Research	[28-57]							Goodwin & Shaul 1984
1979-82	2 sites in Hood Canal and 1 site in South Sound	Research						(0.00002275-0.00009069)	(3.2416-3.5242)	Goodwin & Shaul 1984

* Sample data from original publications were reviewed and parameter estimates re-calculated.

** From Noakes 1992. Note that for some locations it is unclear if the estimate is for the 1980, 1981 or 1982 data set, or if data sets were combined.

*** Virgin bed

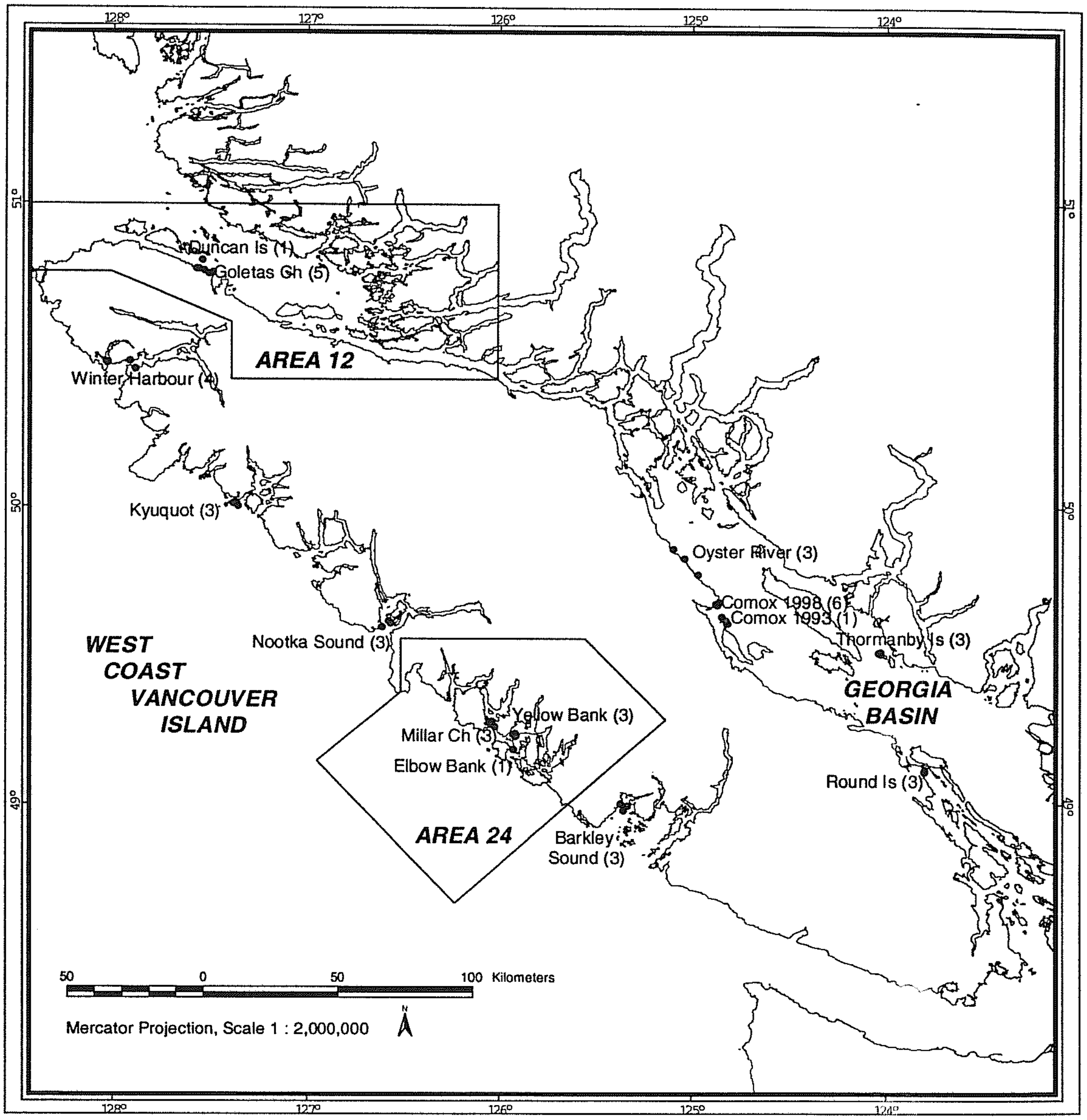


Figure 1: Map of Southern BC showing the locations of sample collections and number of sub-samples collected at each location (in brackets). Geographic areas used in analyses are denoted in bold capital letters.

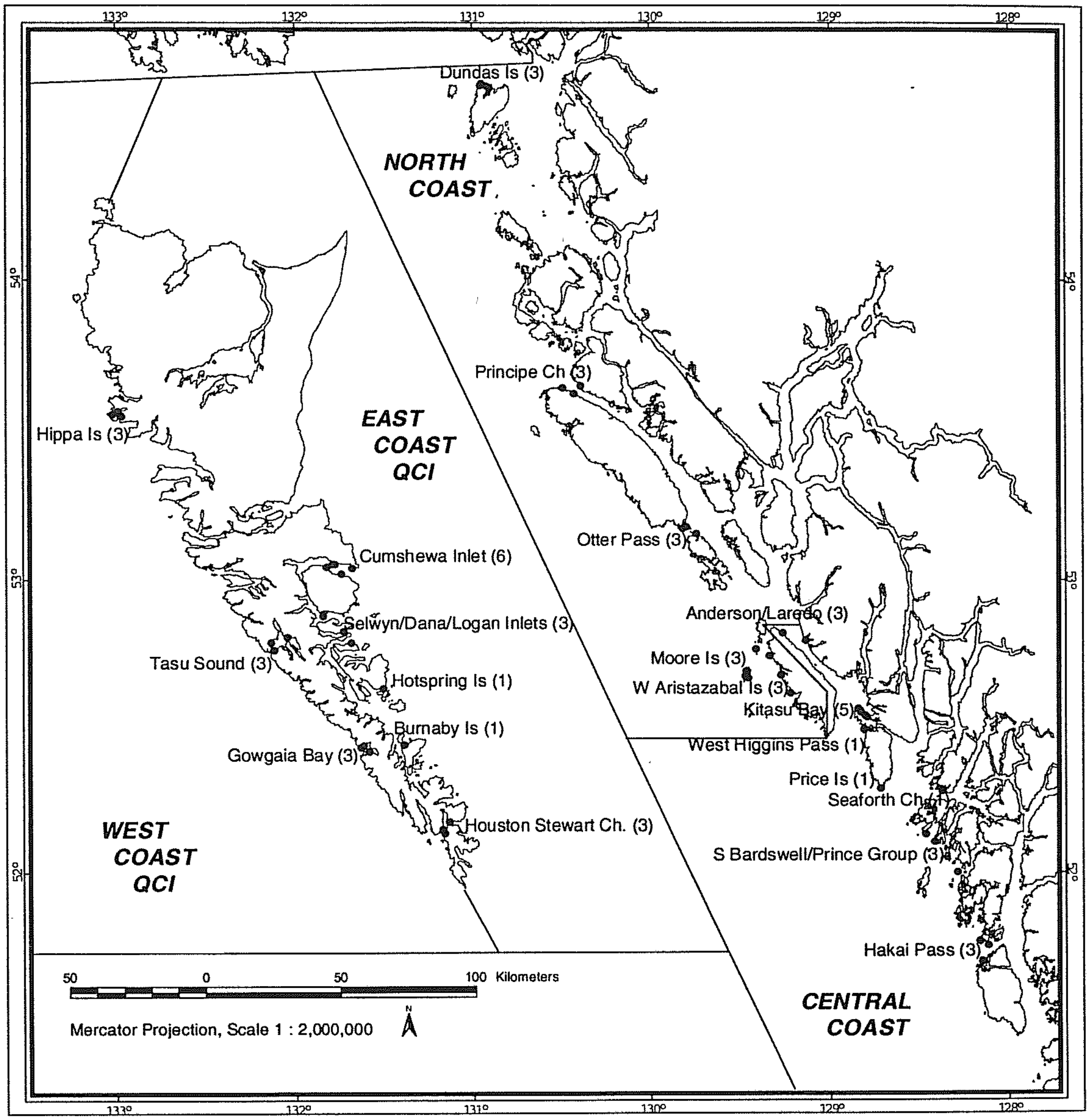


Figure 2: Map of Northern BC showing the locations of sample collections and number of sub-samples collected at each location (in brackets). Geographic areas used in analyses are denoted in bold capital letters. QCI = Queen Charlotte Islands.

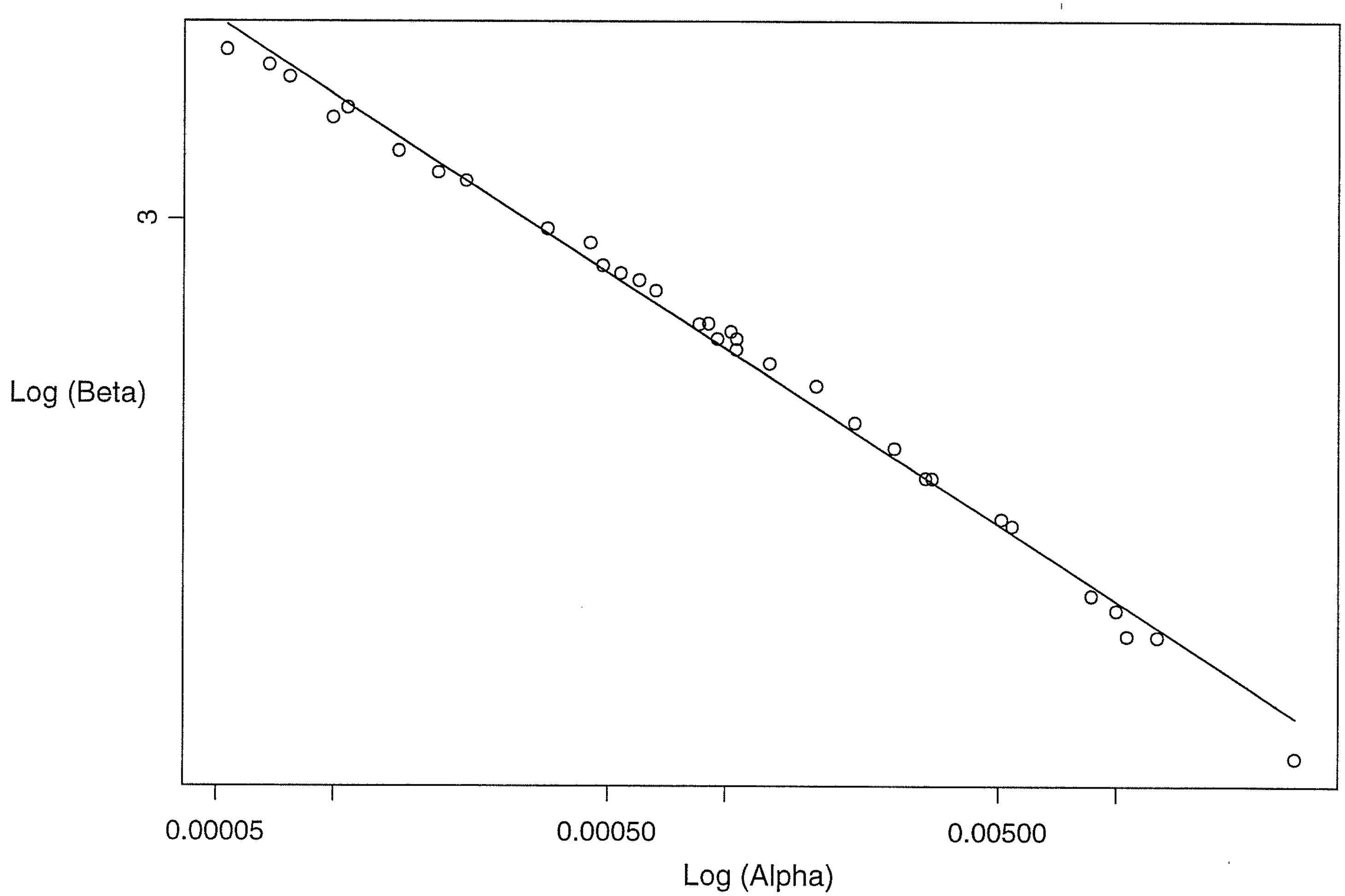


Figure 3: Relationship between log(α) and log(β) values calculated from geoduck shell length – total weight allometric functions from samples from 34 locations in BC. Values of α and β were calculated for each sample with a least squares regression.

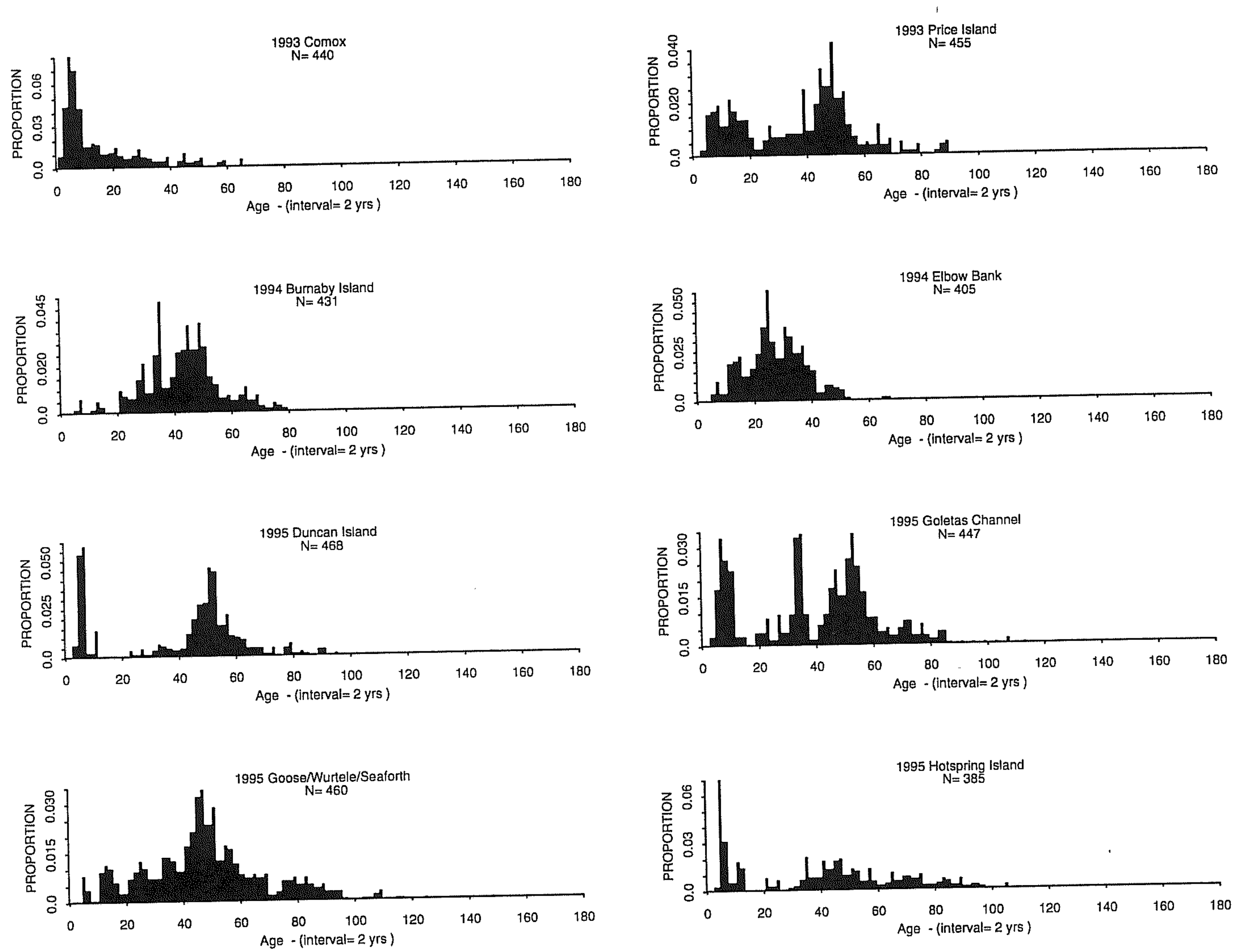


Figure 4: Age frequency distributions of geoducks collected on surveys from 1993 to 2000, sorted by year.

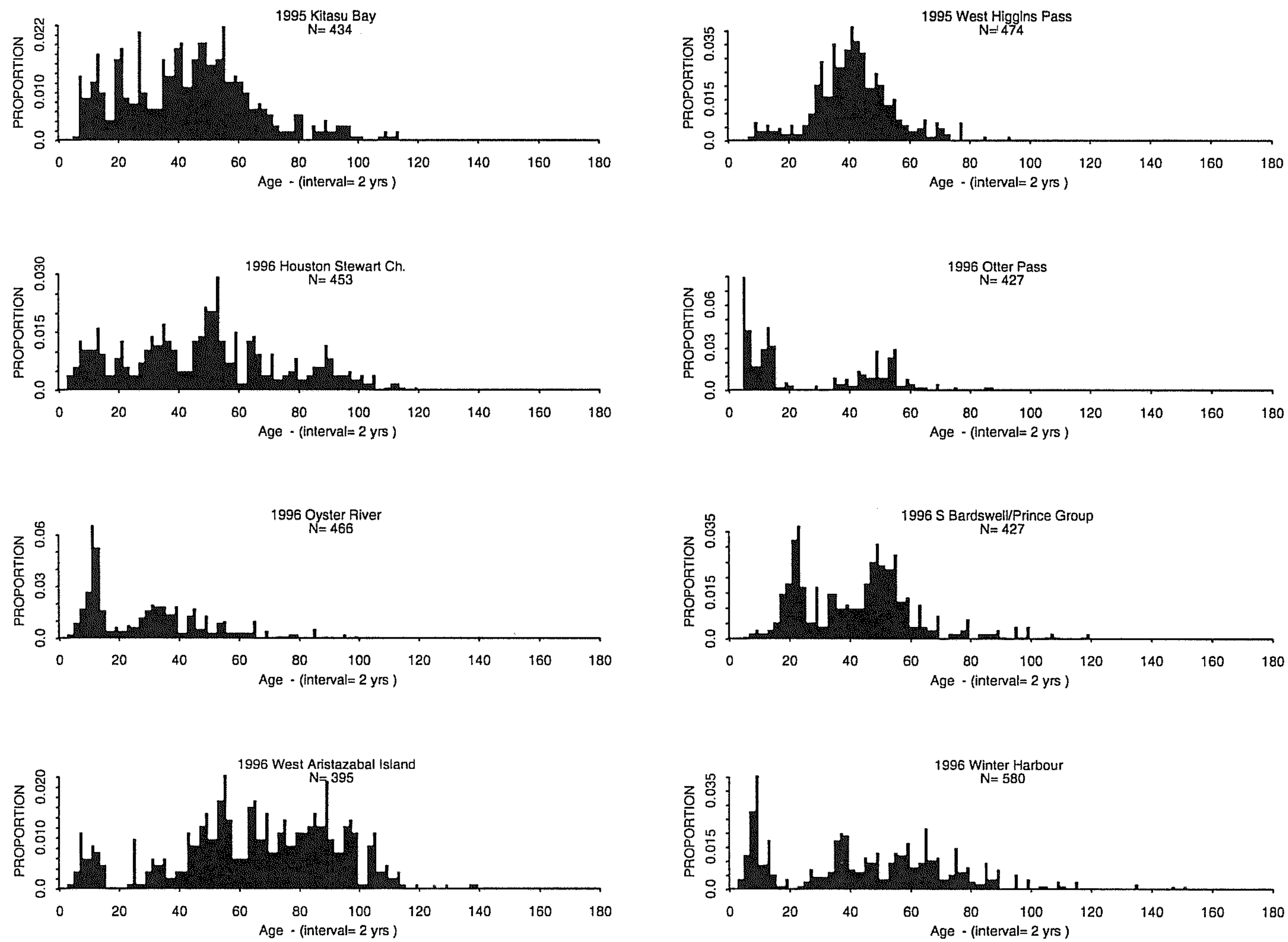
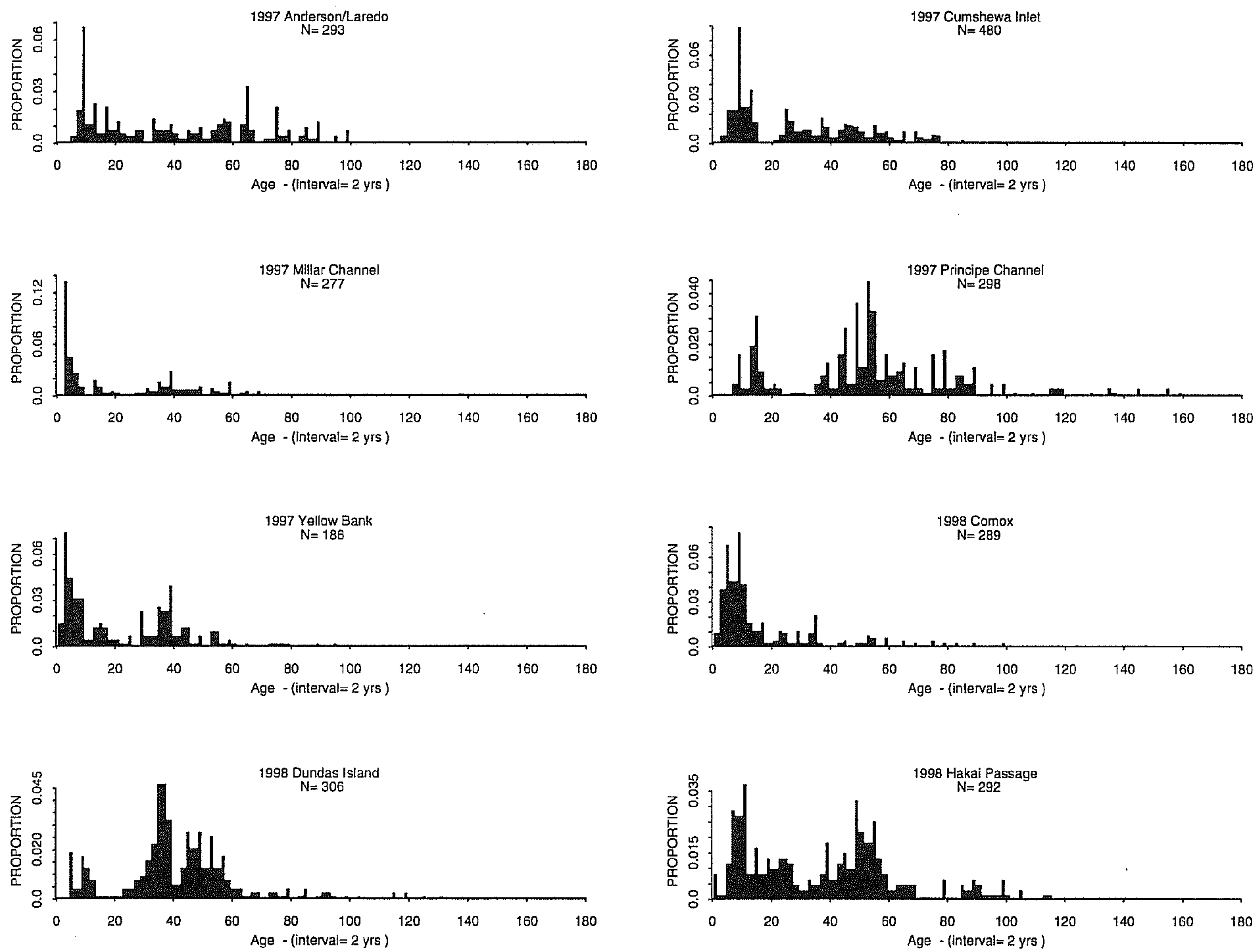


Figure 4 (continued)



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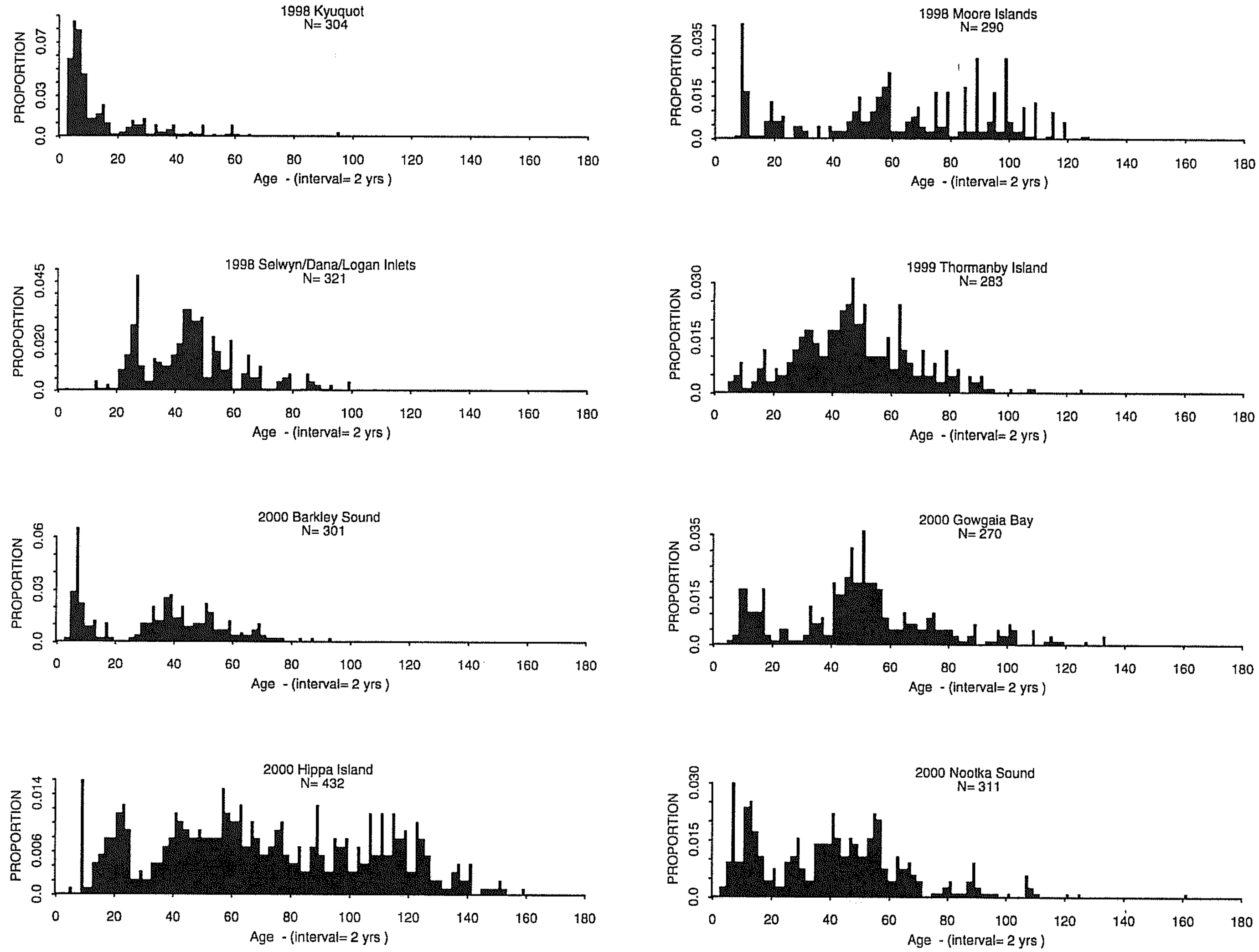

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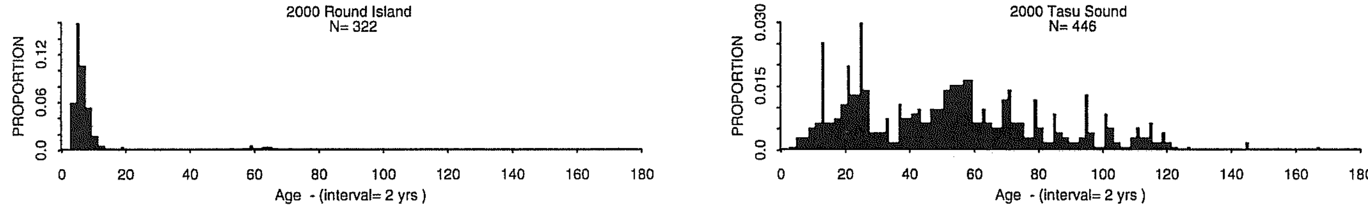

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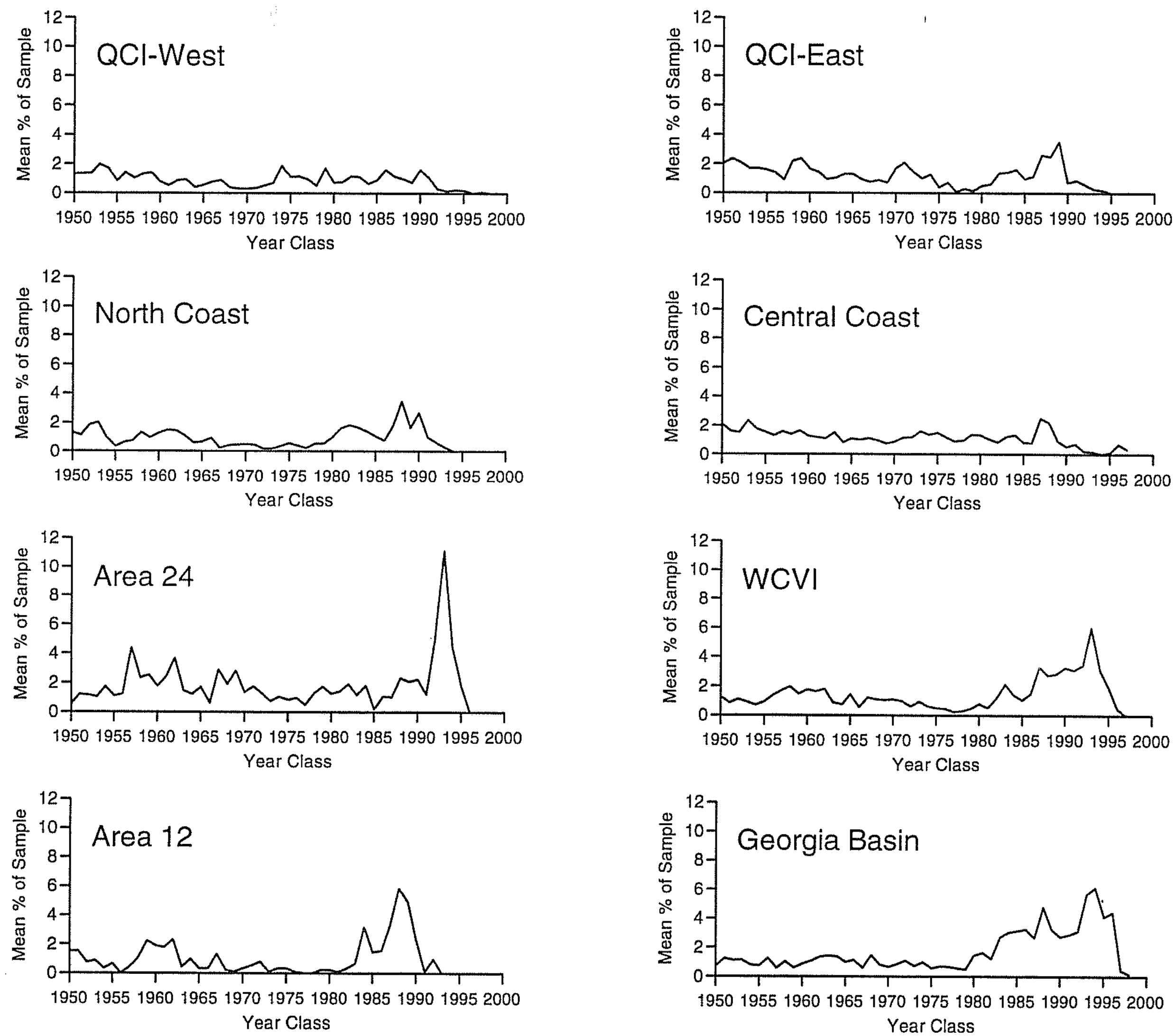


Figure 5: Relative strength of year-classes from 1950 to 2000 in geoduck age samples combined by geographic area.

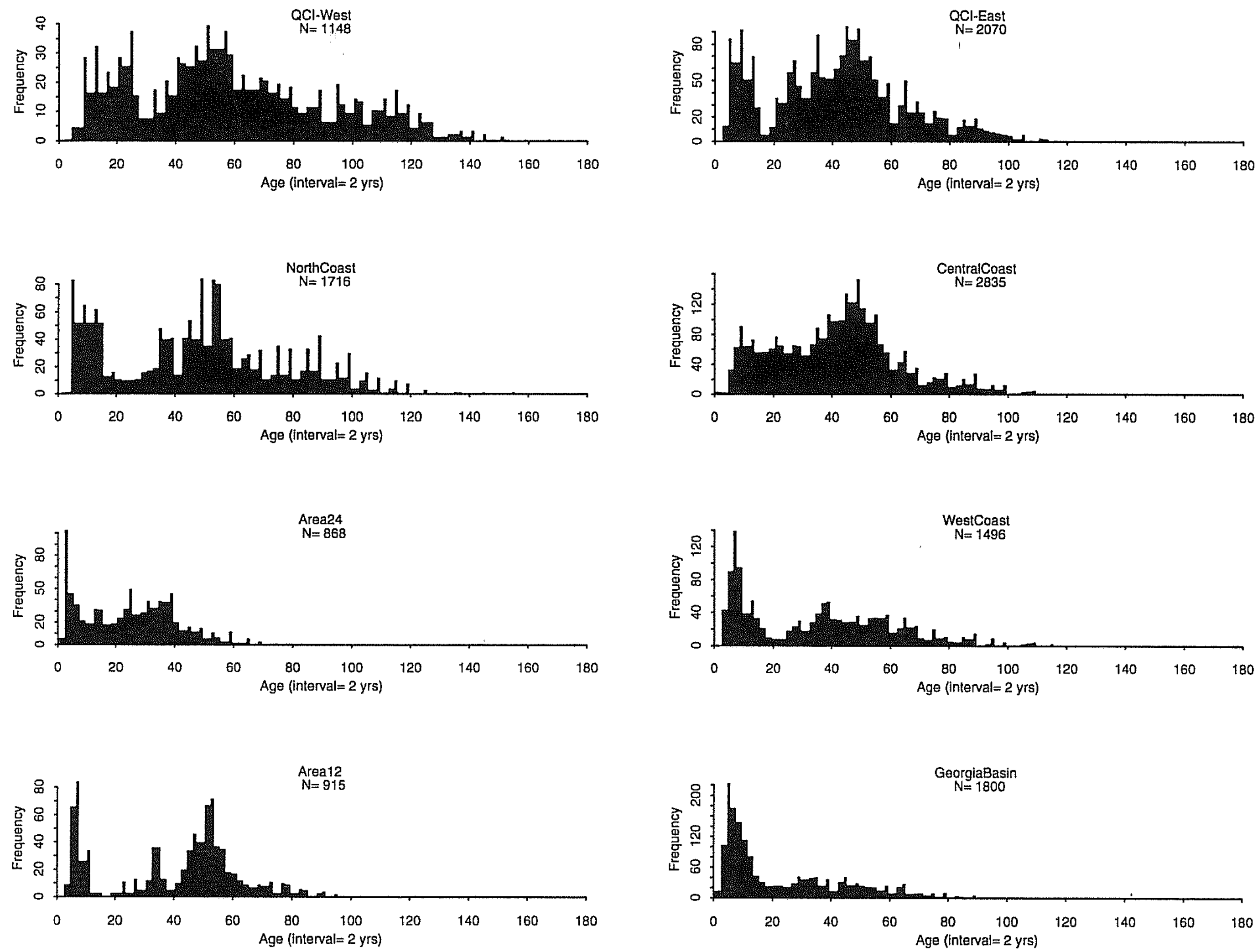


Figure 6: Age frequency distribution by geographic area for geoduck samples collected from 1993 to 2000.

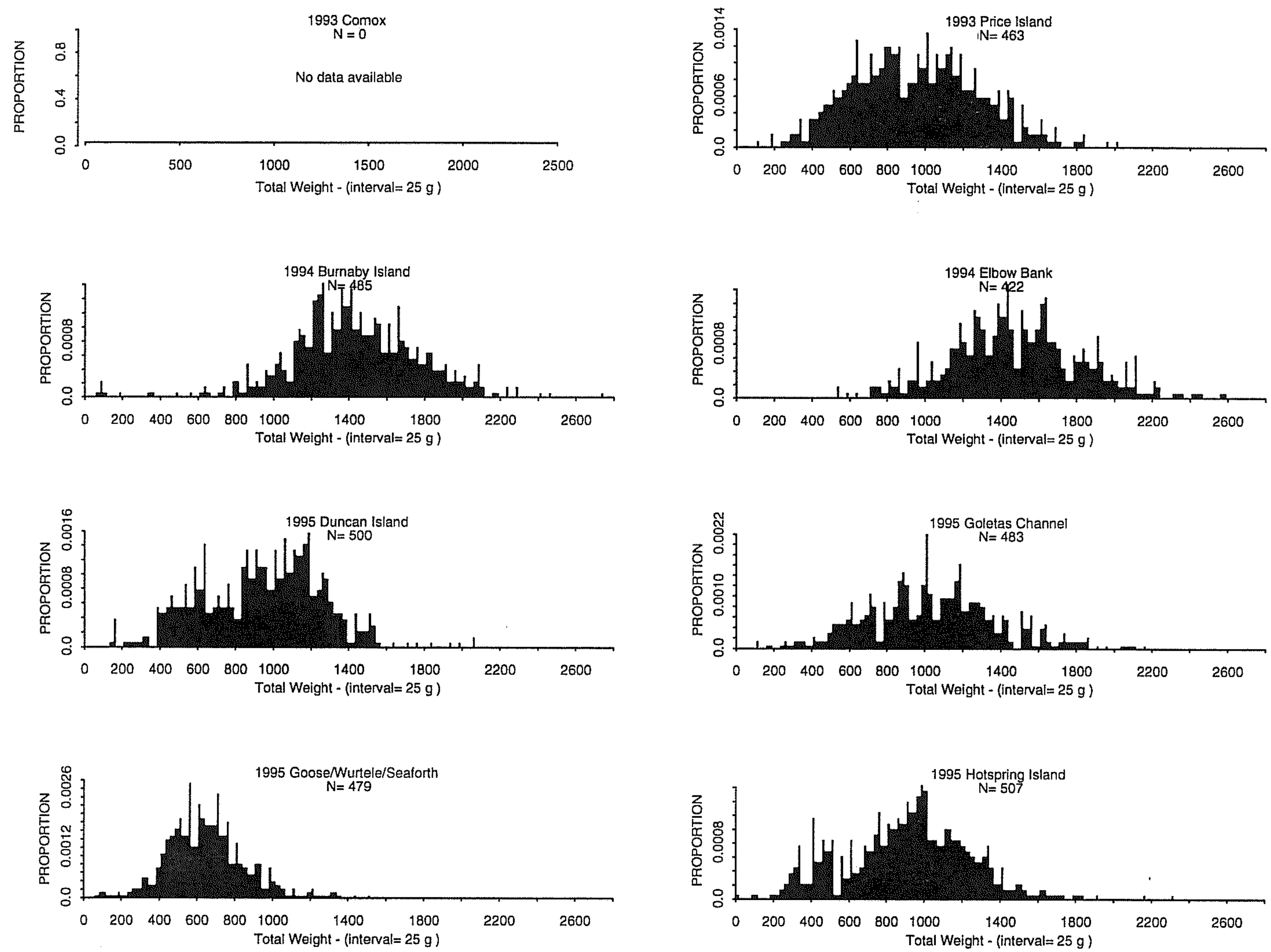


Figure 7: Total weight frequency distributions of geoducks collected on surveys from 1993 to 2000, sorted by year.

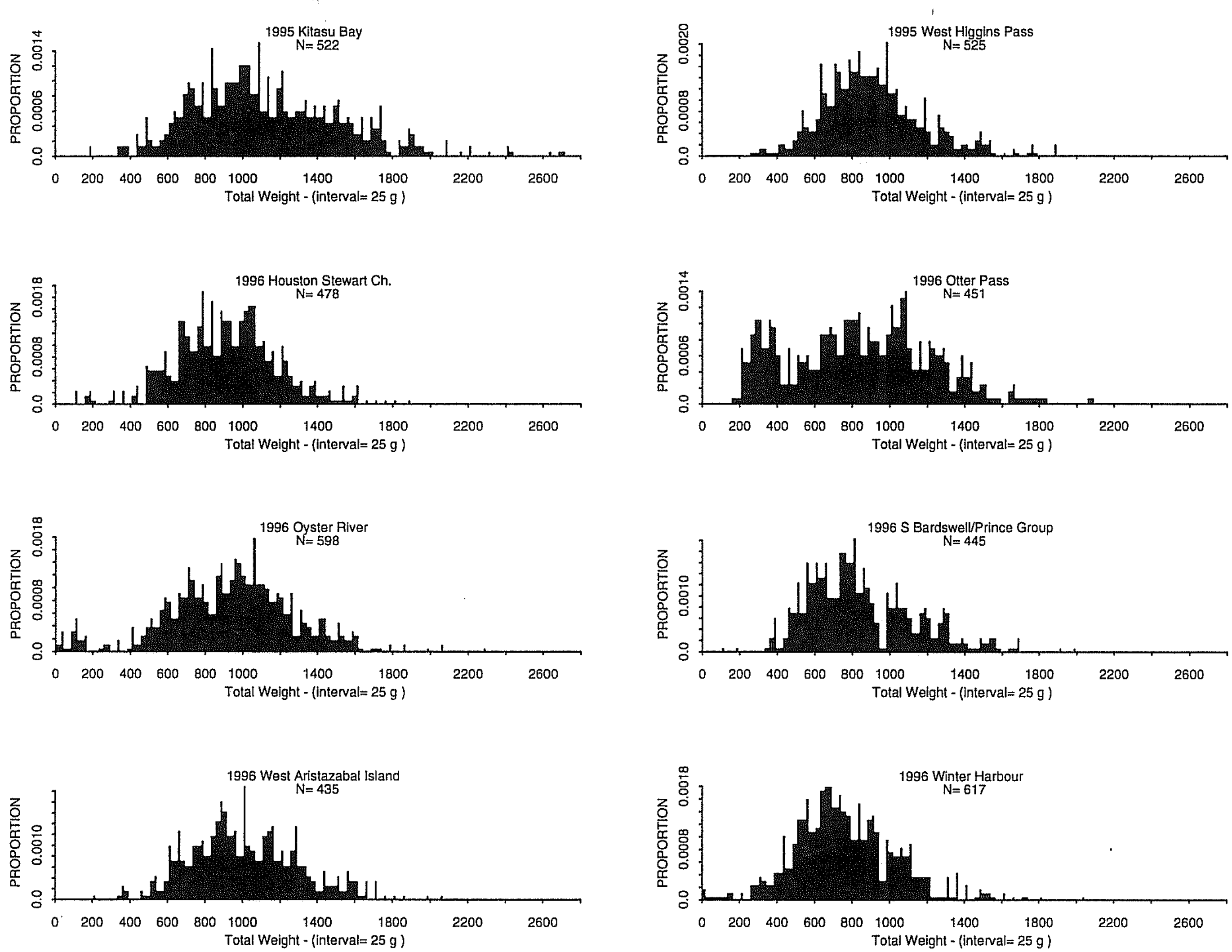
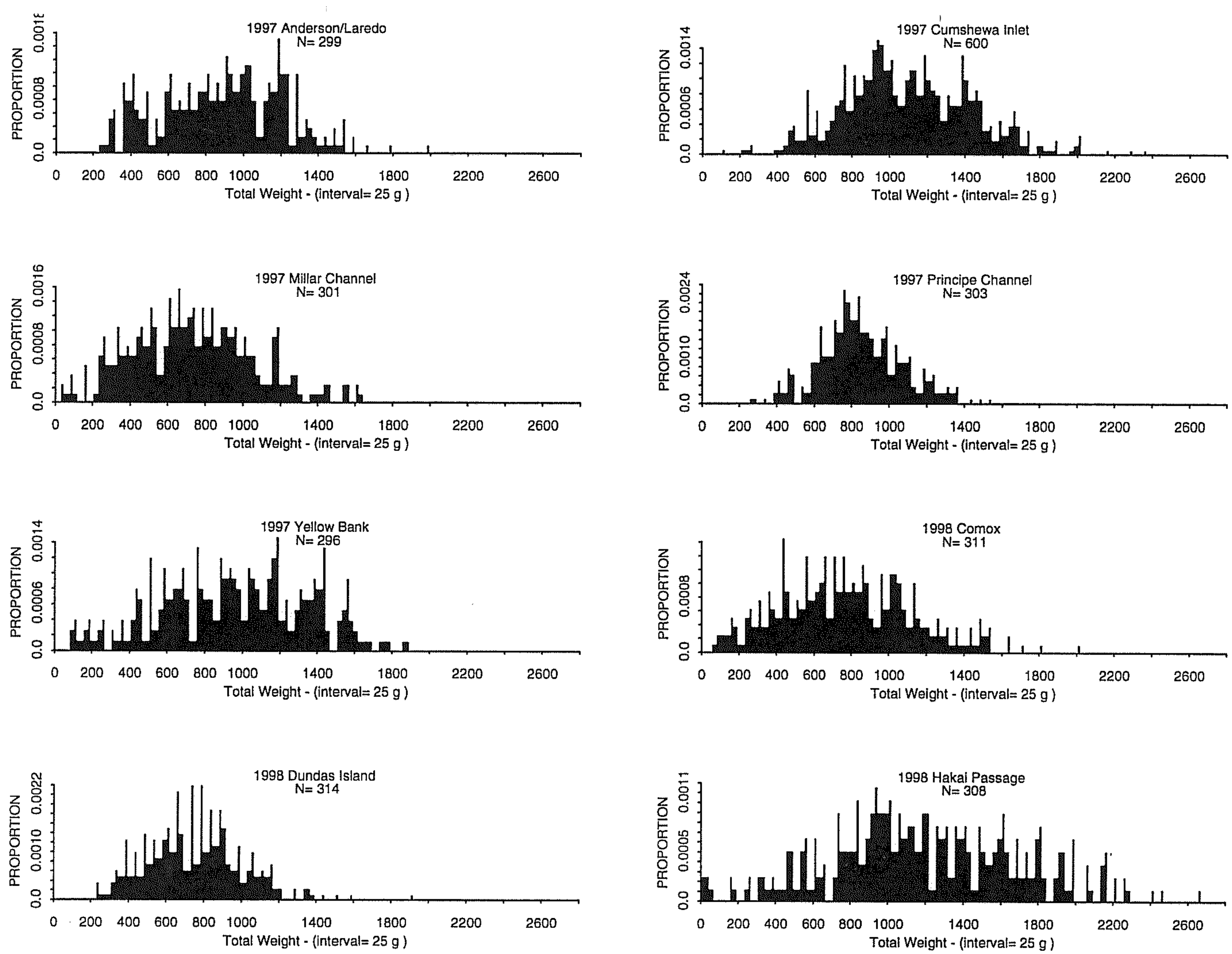


Figure 7 (continued)



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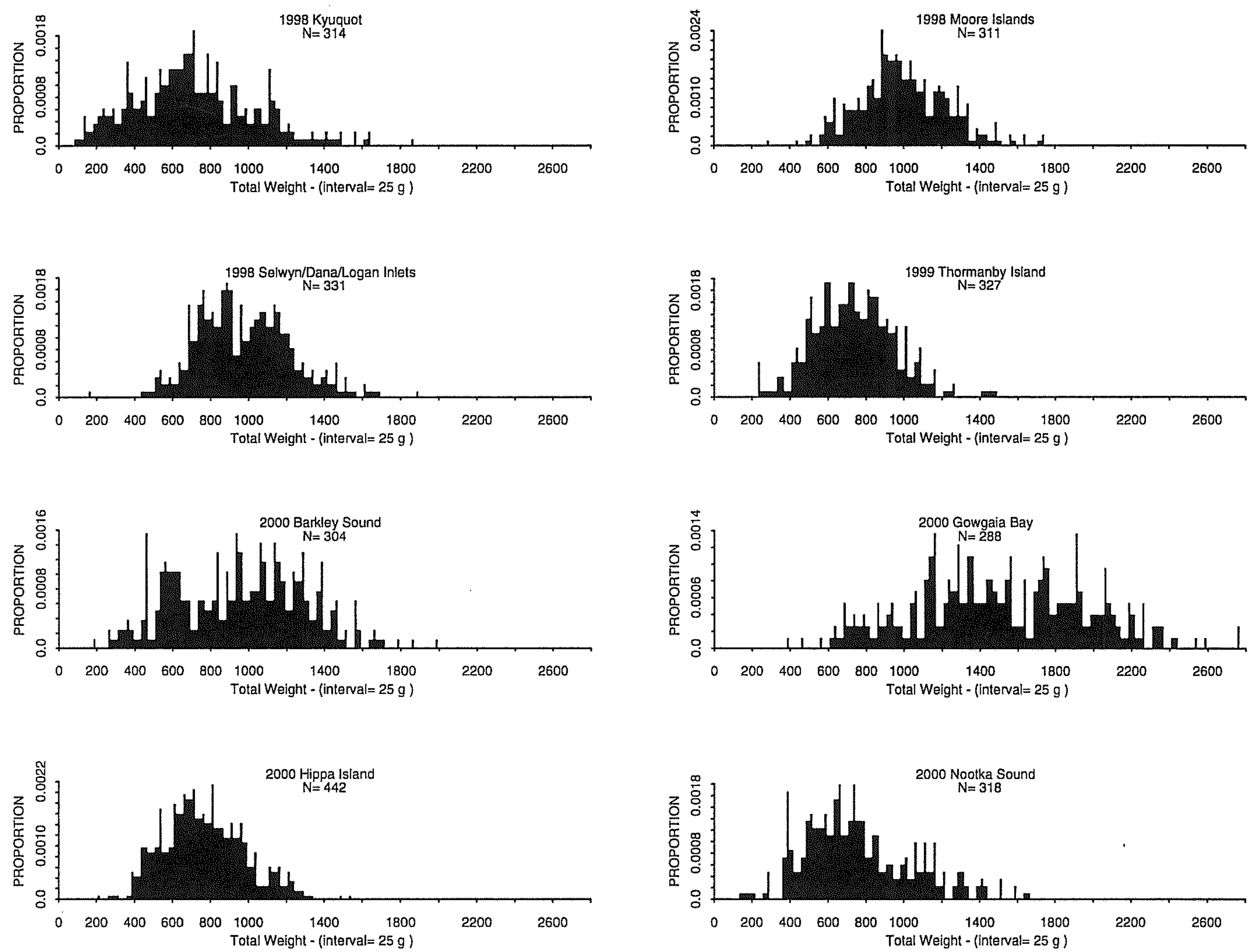

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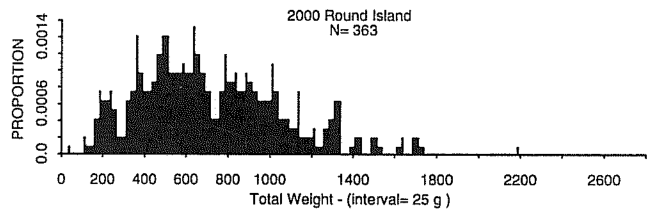

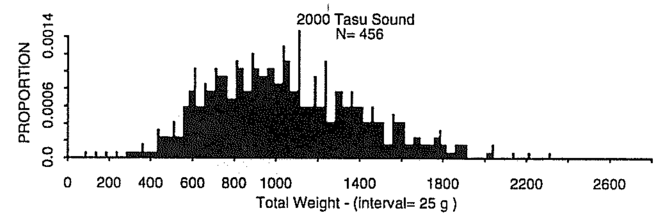

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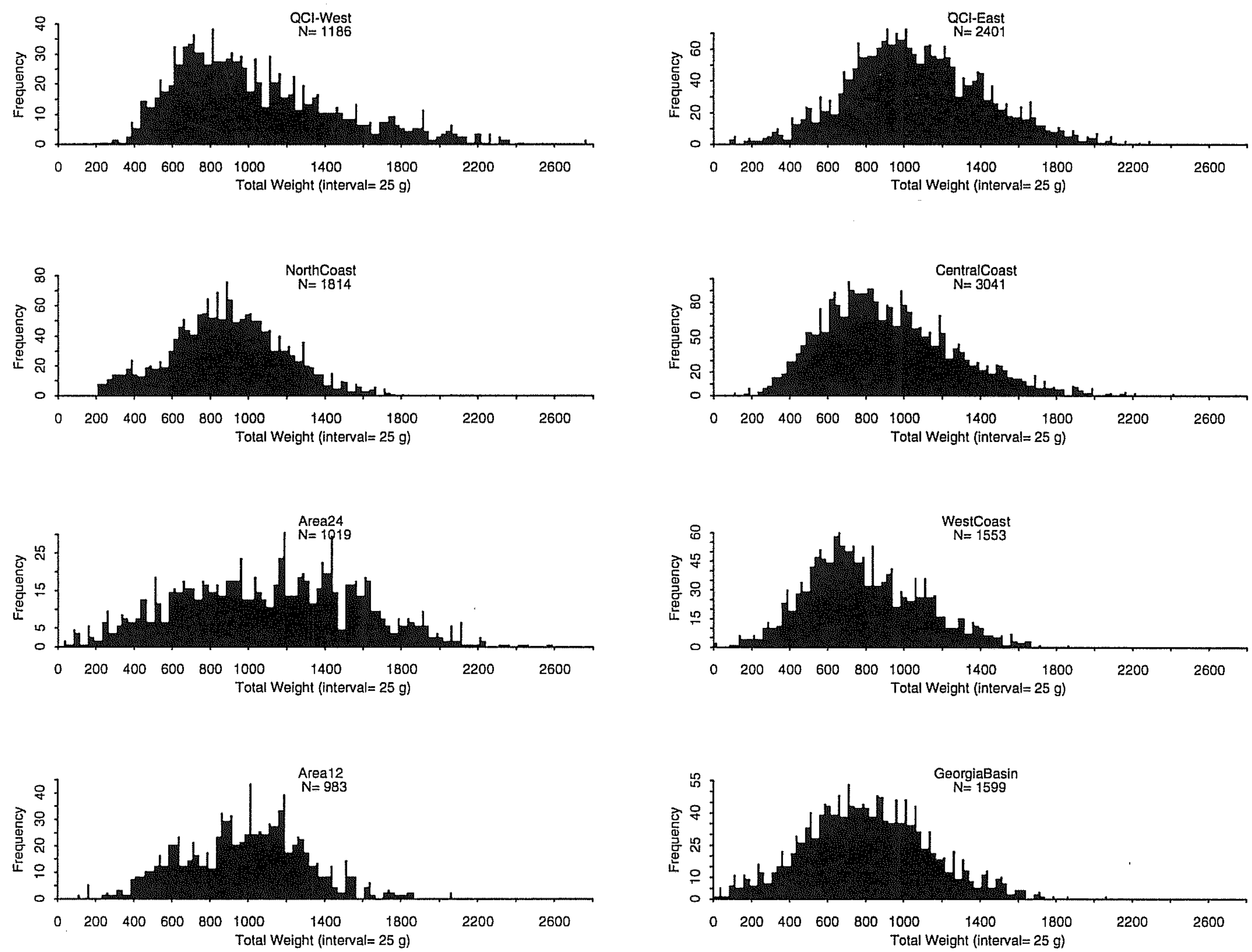


Figure 8: Total weight frequency distribution by geographic area for geoduck samples collected from 1993 to 2000.

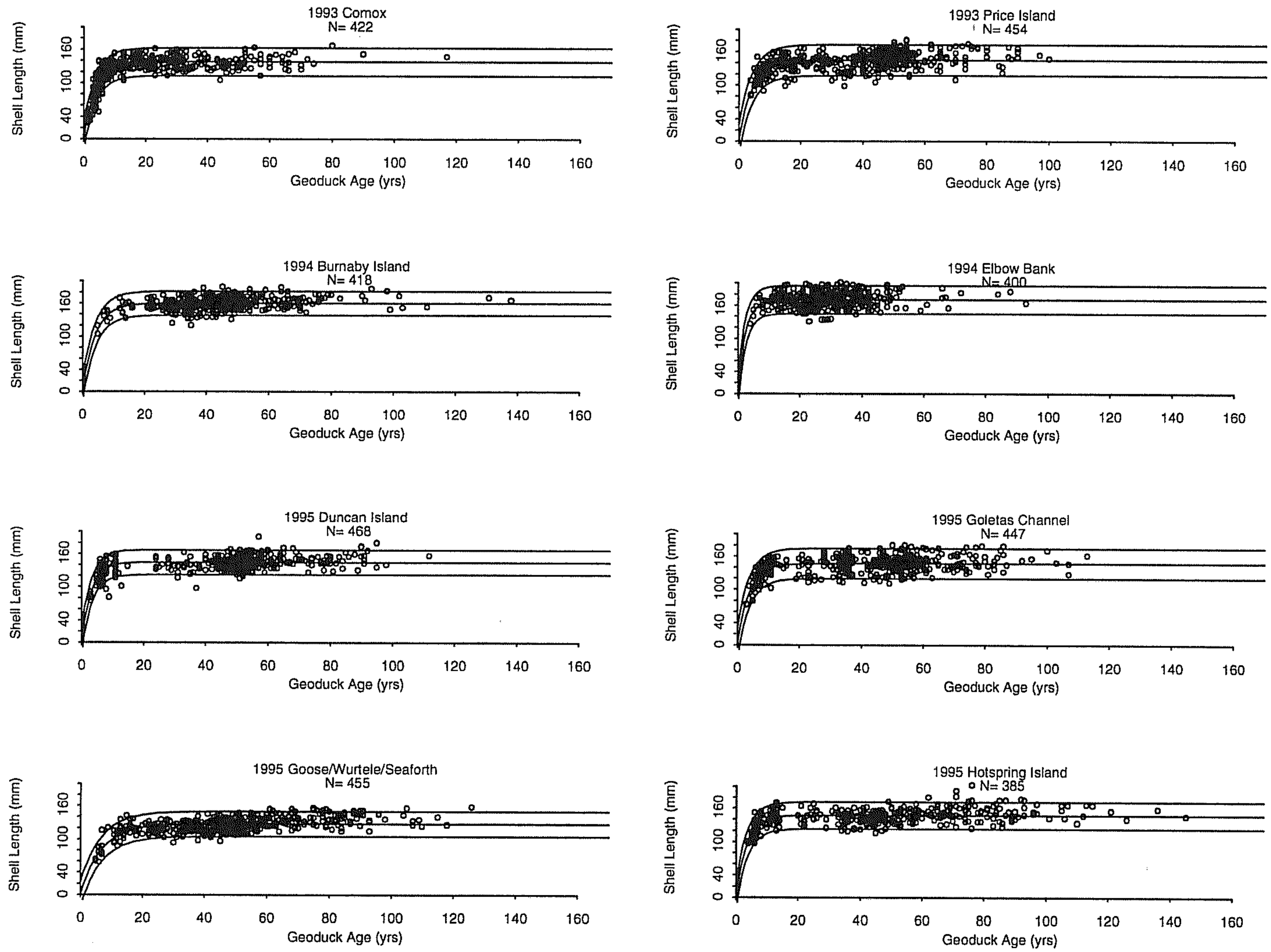


Figure 9: Shell length vs. age for geoduck samples from 1993 to 2000, by year. Upper and lower lines are 95% confidence bounds.

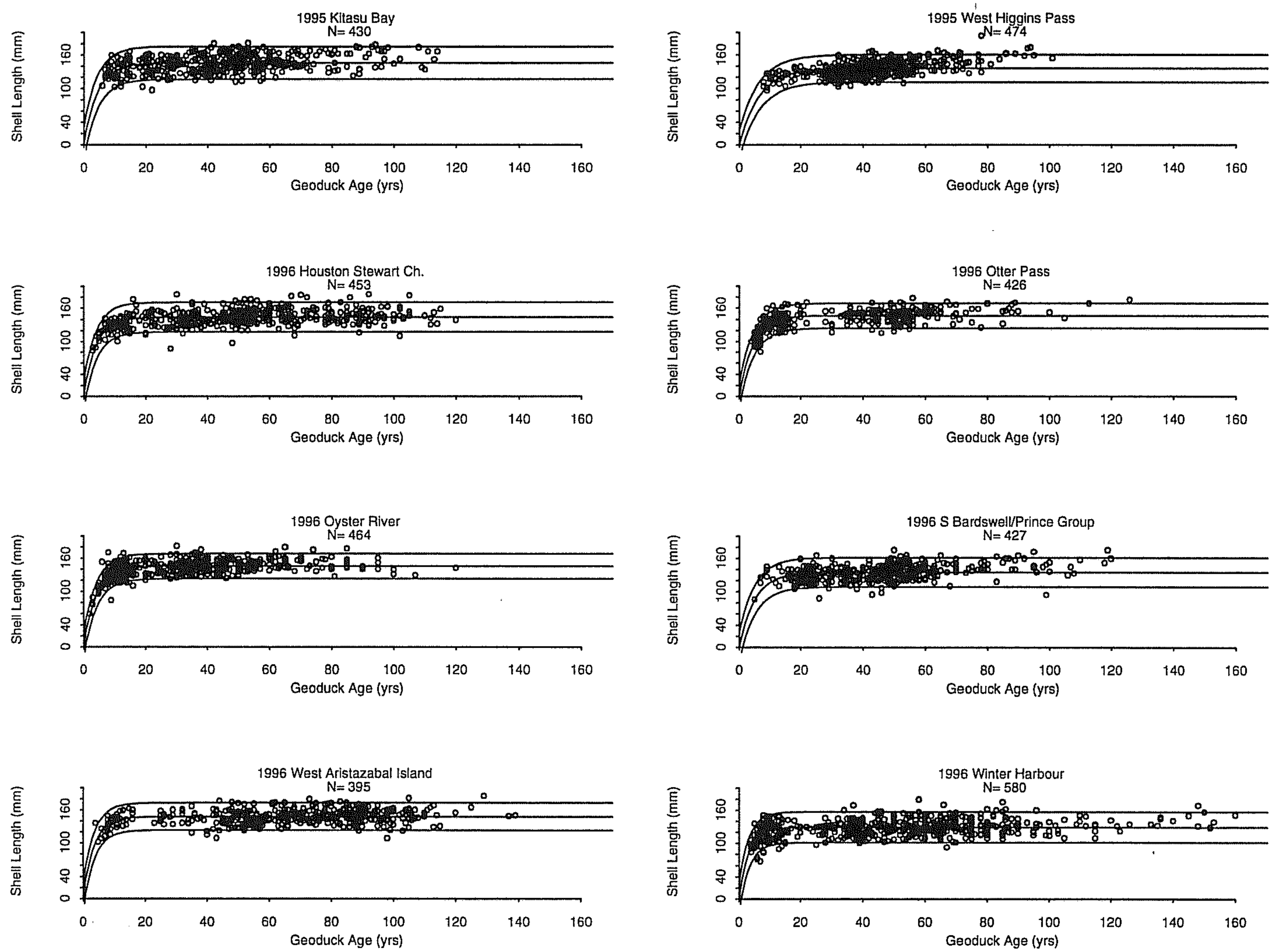


Figure 9 (continued)

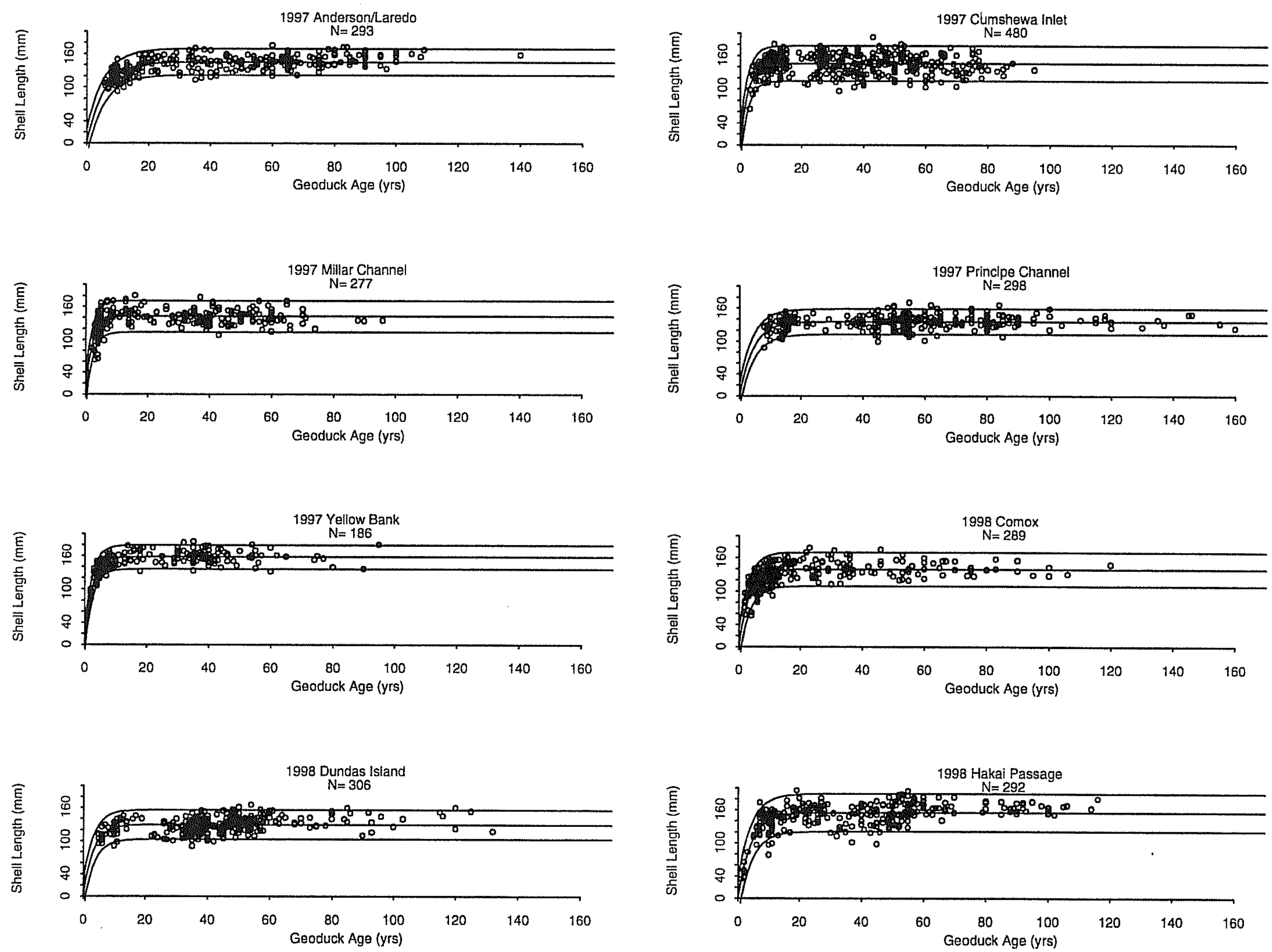


Figure 9 (continued)

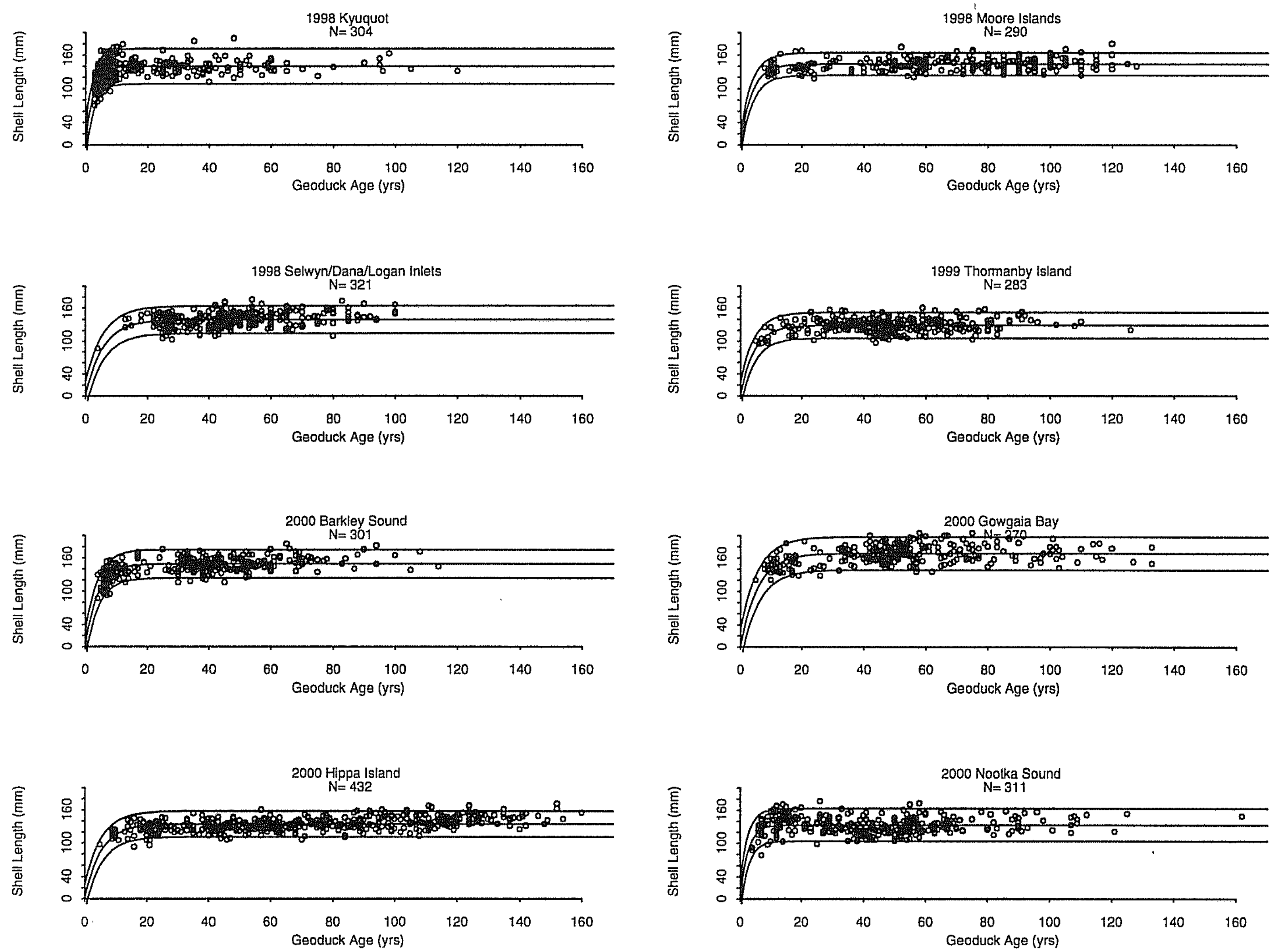


Figure 9 (continued)

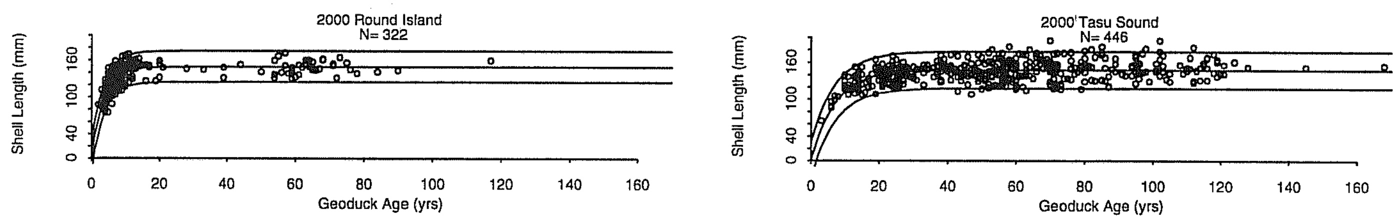


Figure 9 (continued)

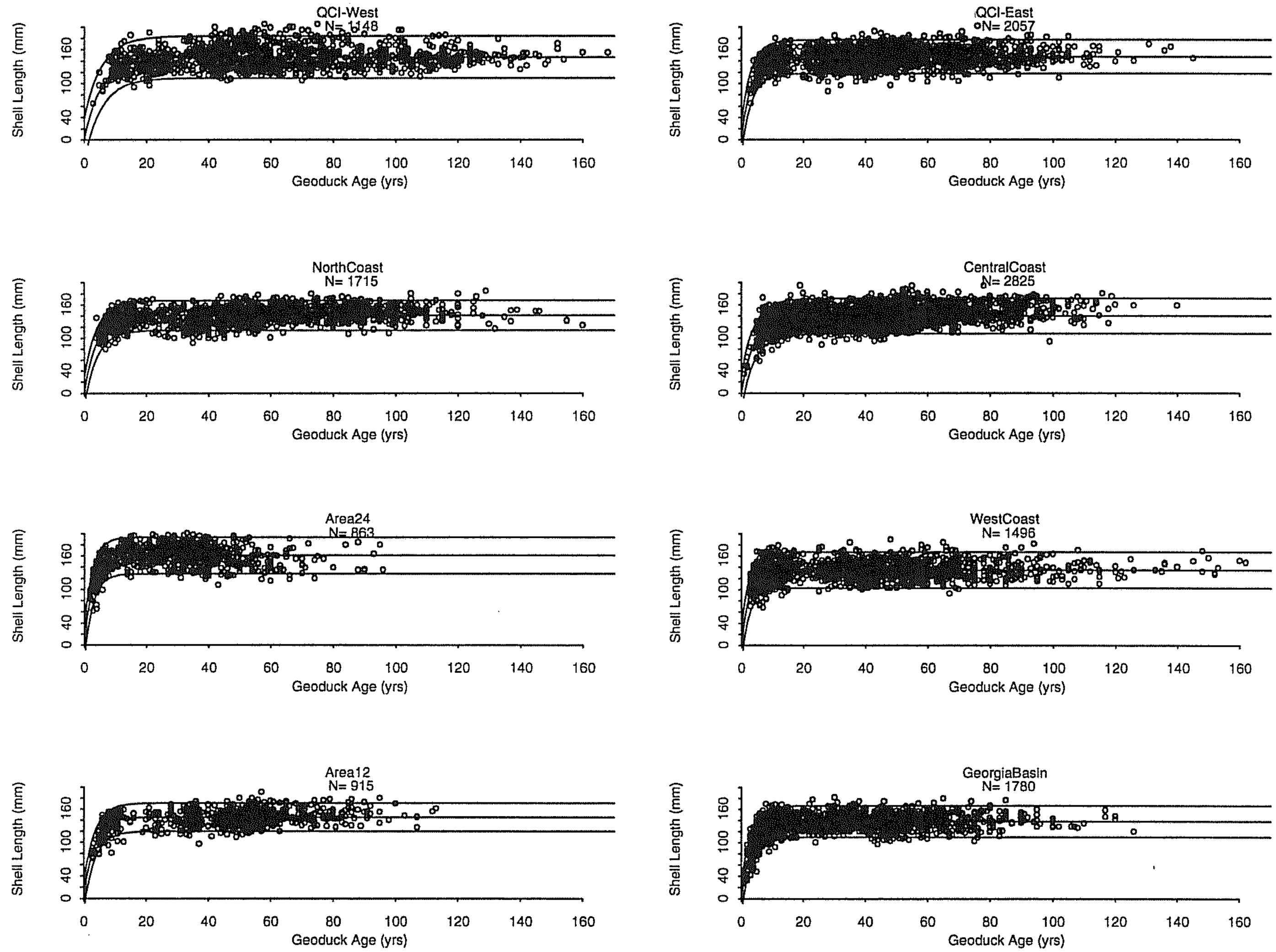


Figure 10: Shell length – age relationship, by geographic area, for geoduck samples collected from 1993 to 2000. Upper and lower lines are 95% confidence bounds.

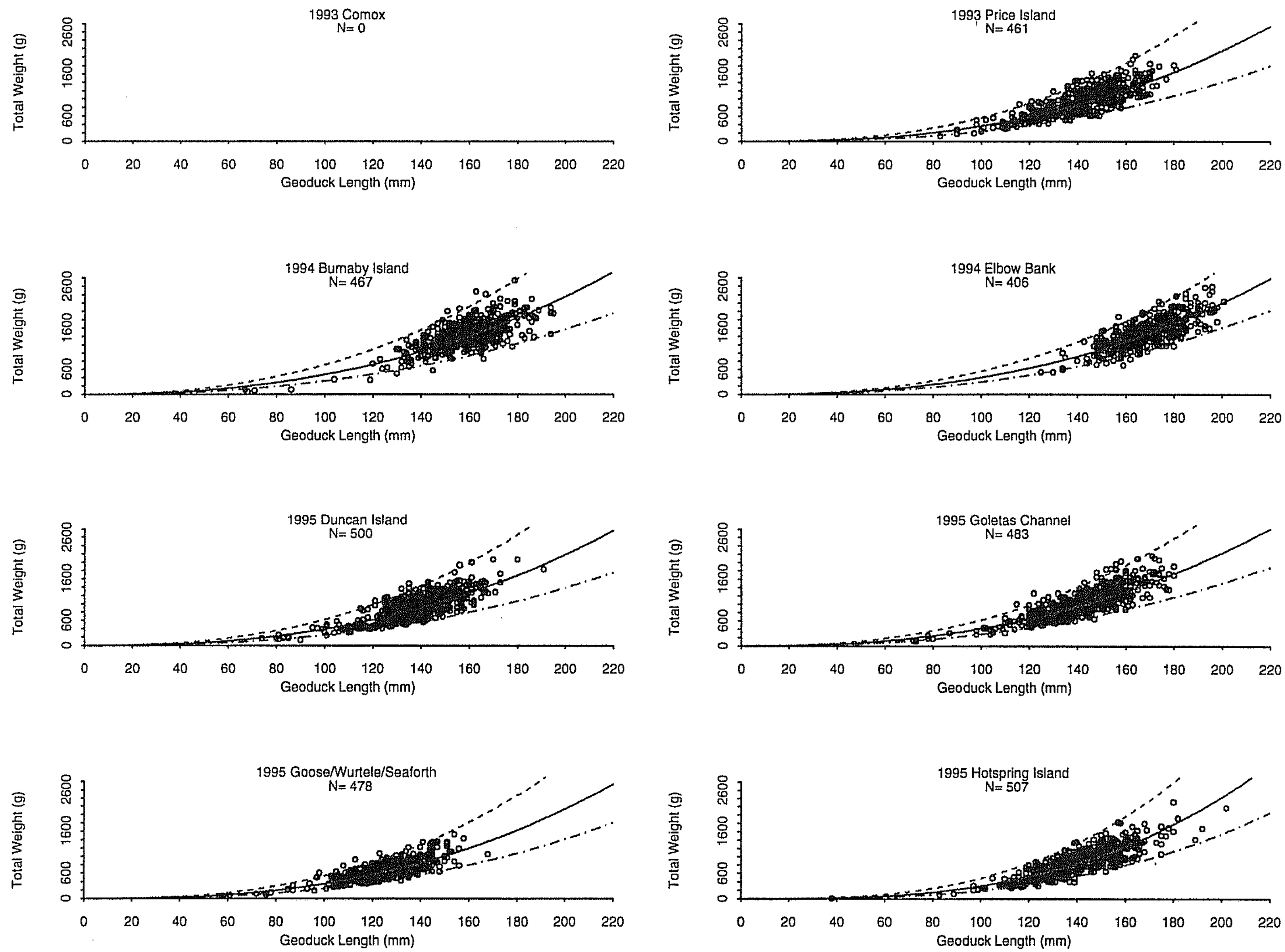


Figure 11: Total weight vs. shell length for geoduck samples from 1993 to 2000, sorted by year. Dashed lines are the 95% confidence bounds.

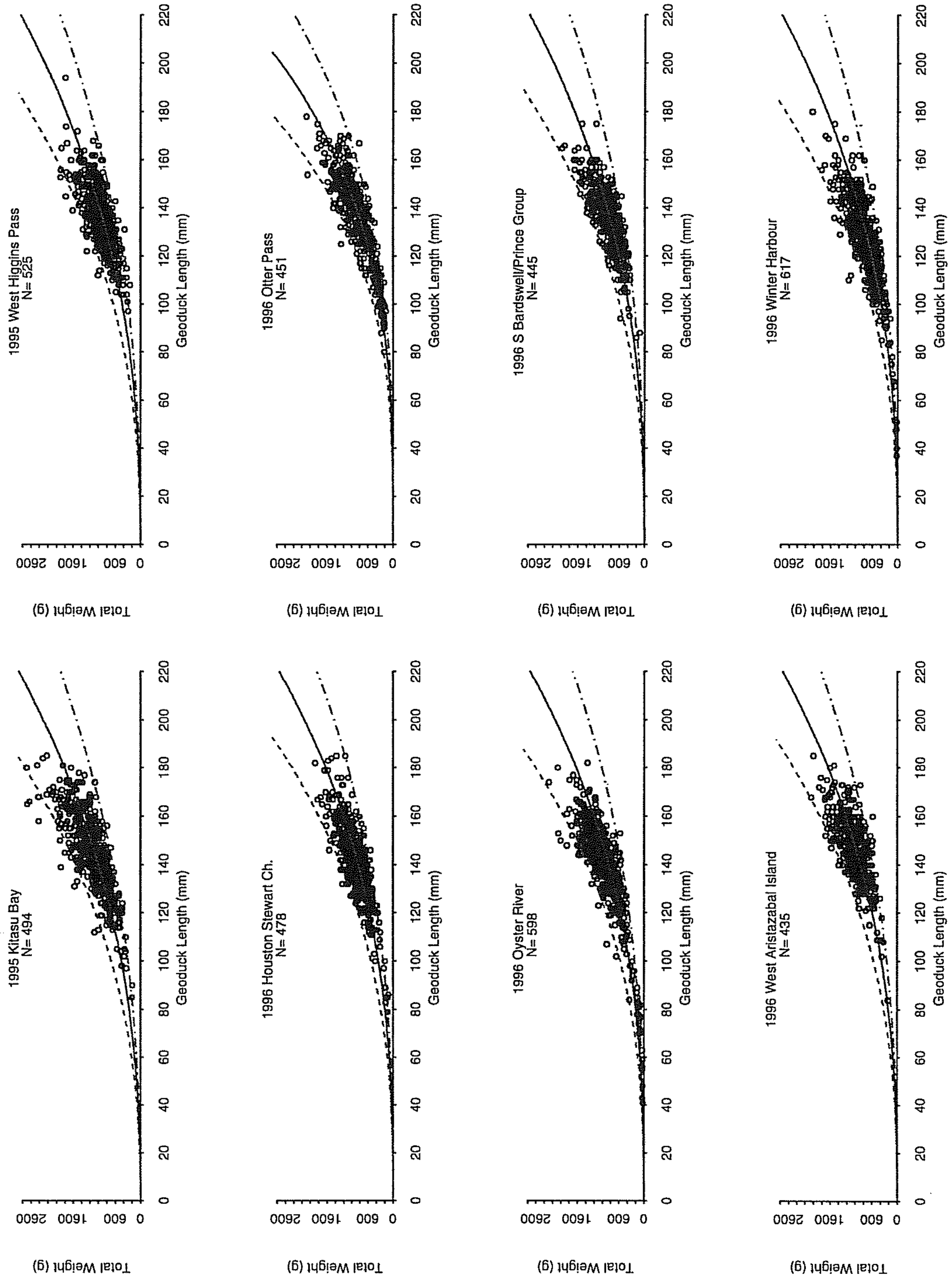


Figure 11 (continued)

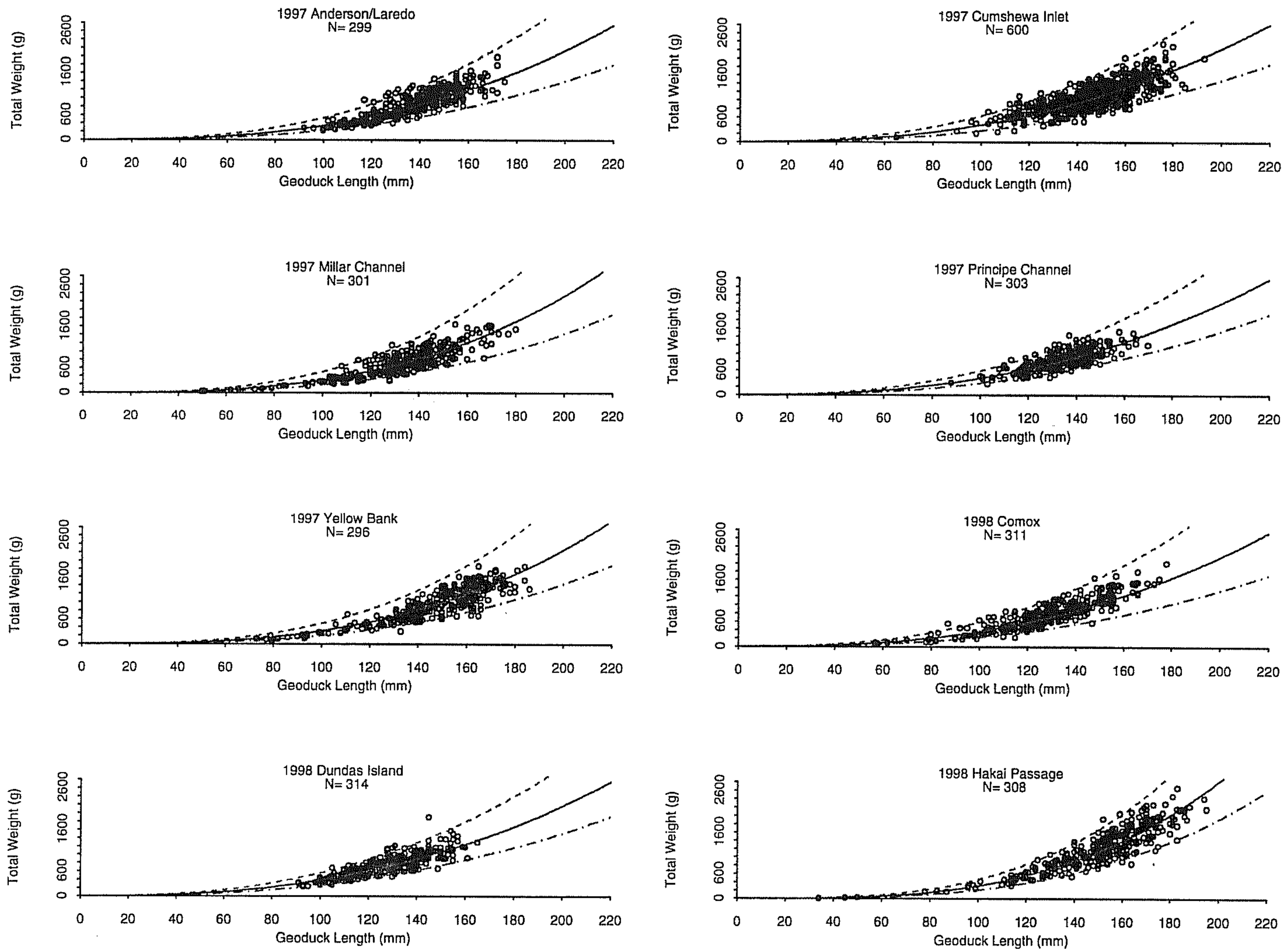


Figure 11 (continued)

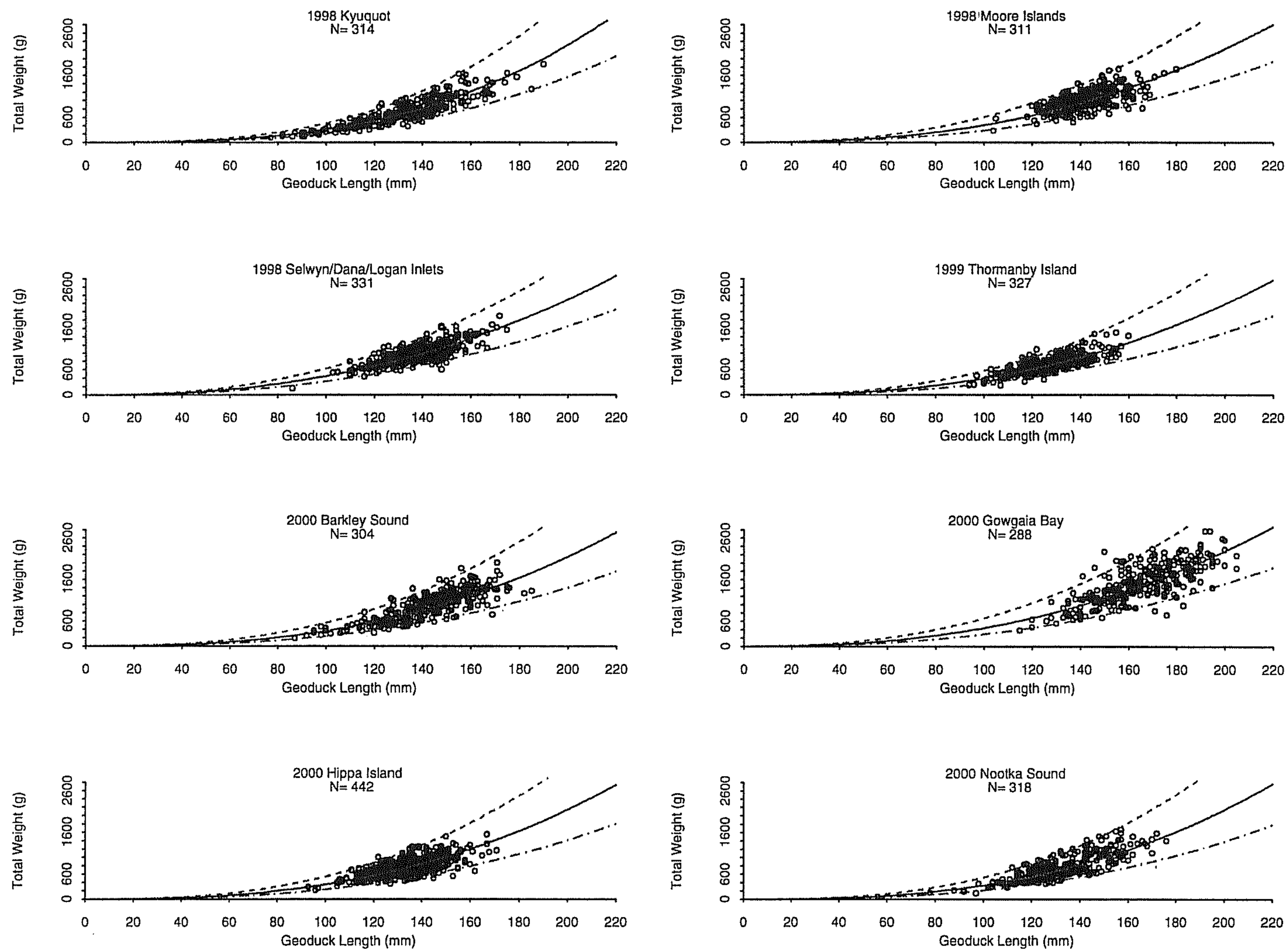
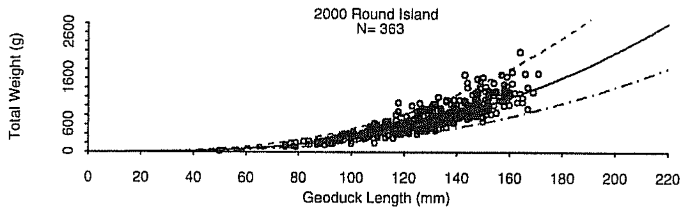


Figure 11 (continued)



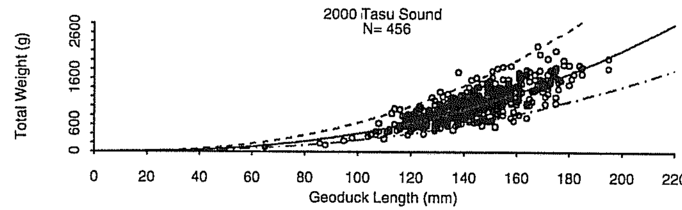


Figure 11 (continued)

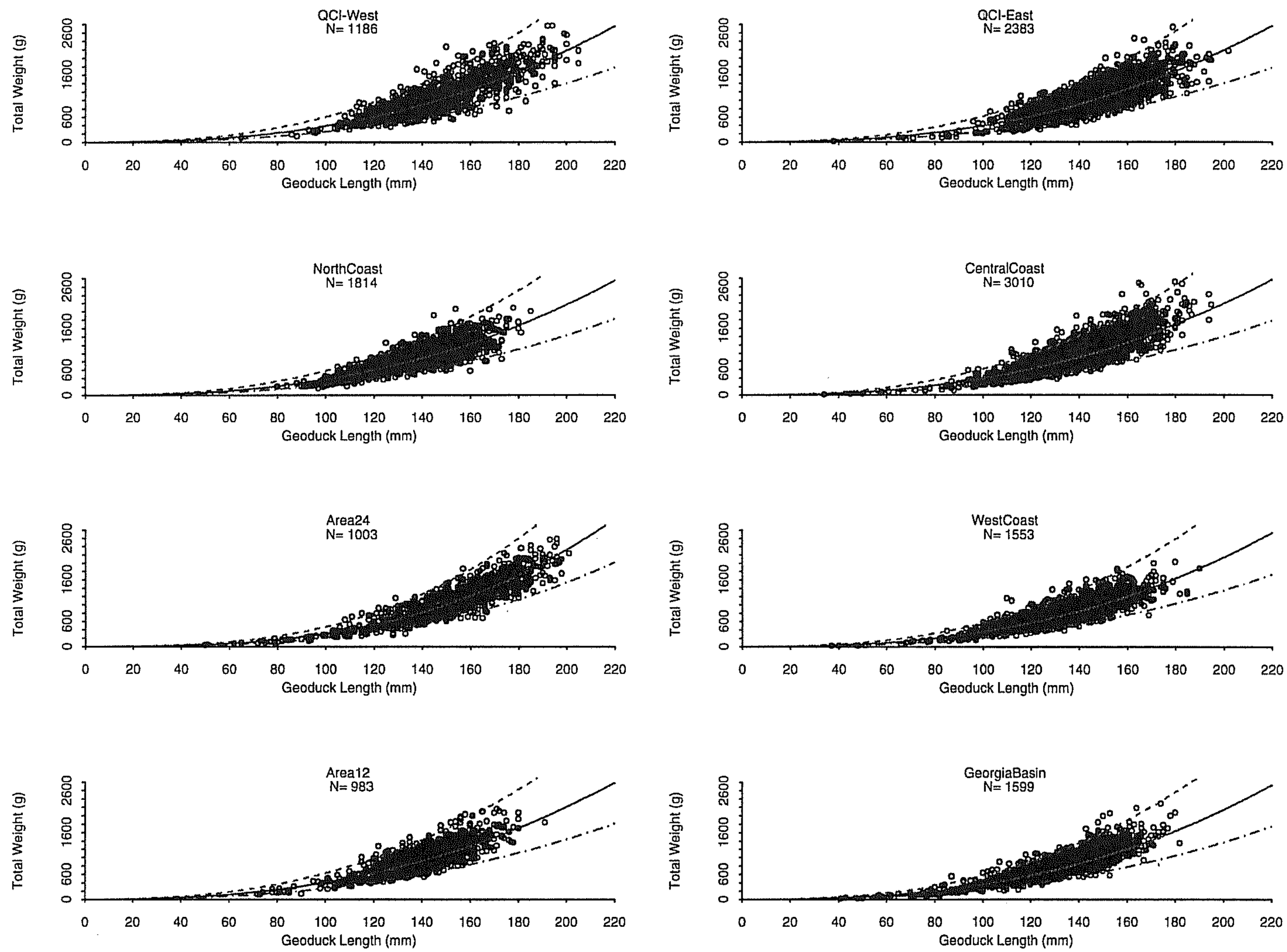


Figure 12: Total weight – length relationship, by geographic area, for geoduck biological samples collected from 1993 to 2000. Dashed lines are the 95% confidence bounds.

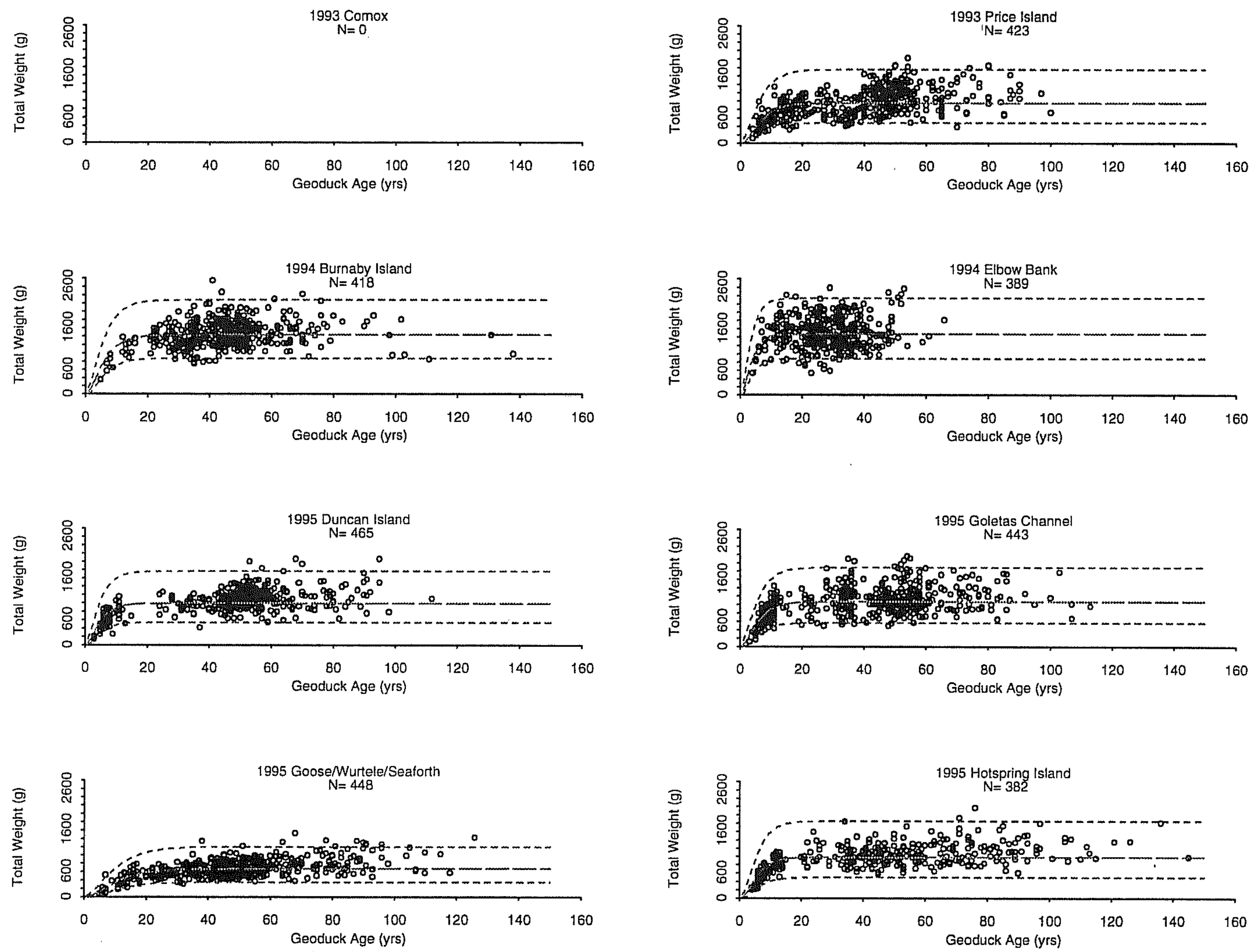


Figure 13: Total weight vs. age for geoduck samples collected from 1993 to 2000, sorted by year. Dashed lines are 95% confidence bounds.

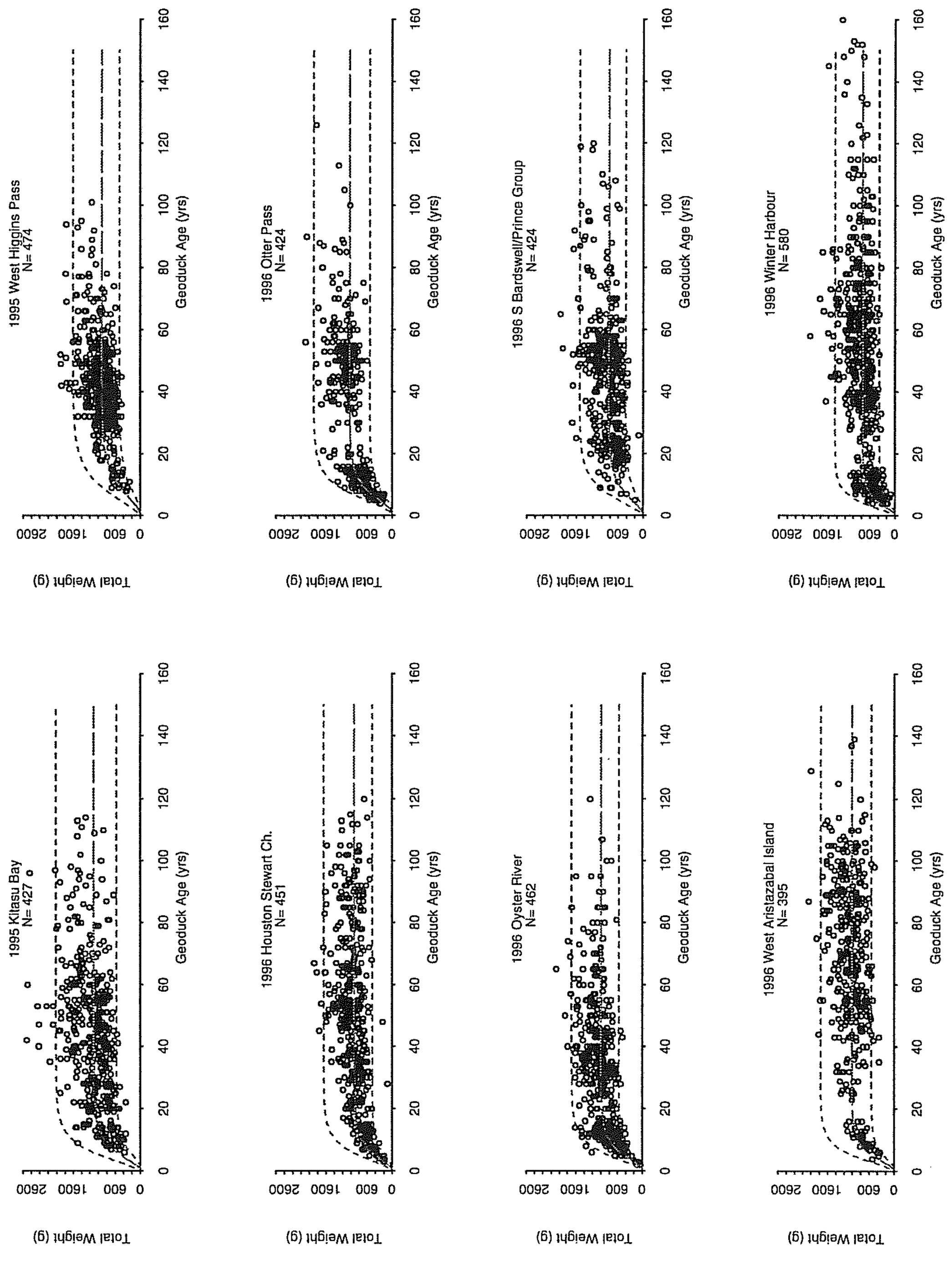


Figure 13 (continued)

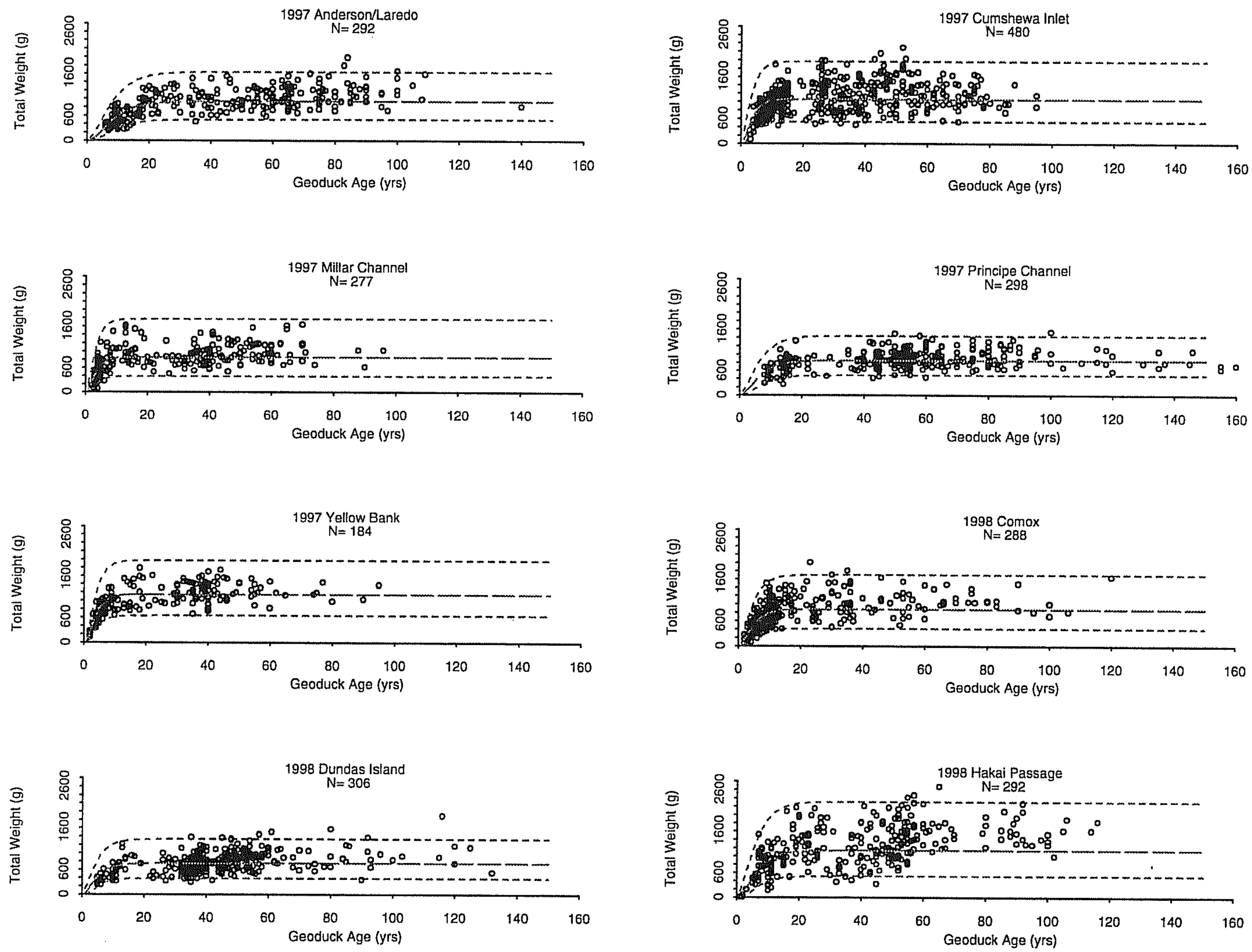


Figure 13 (continued)

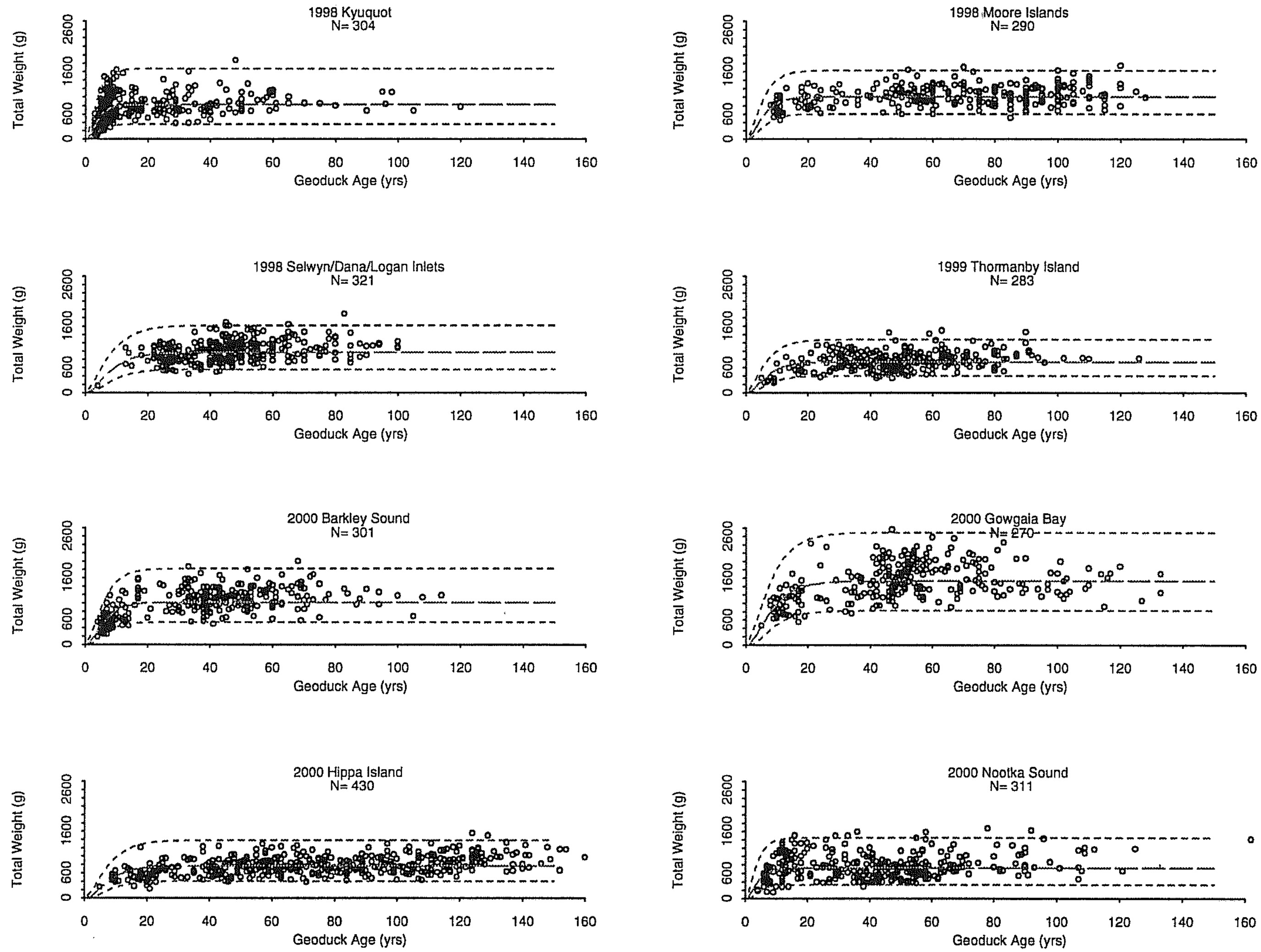
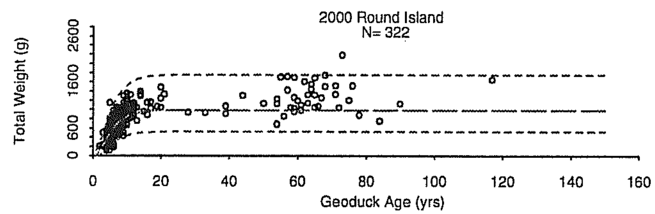


Figure 13 (continued)



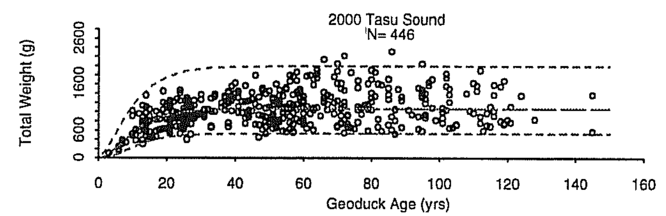


Figure 13 (continued)

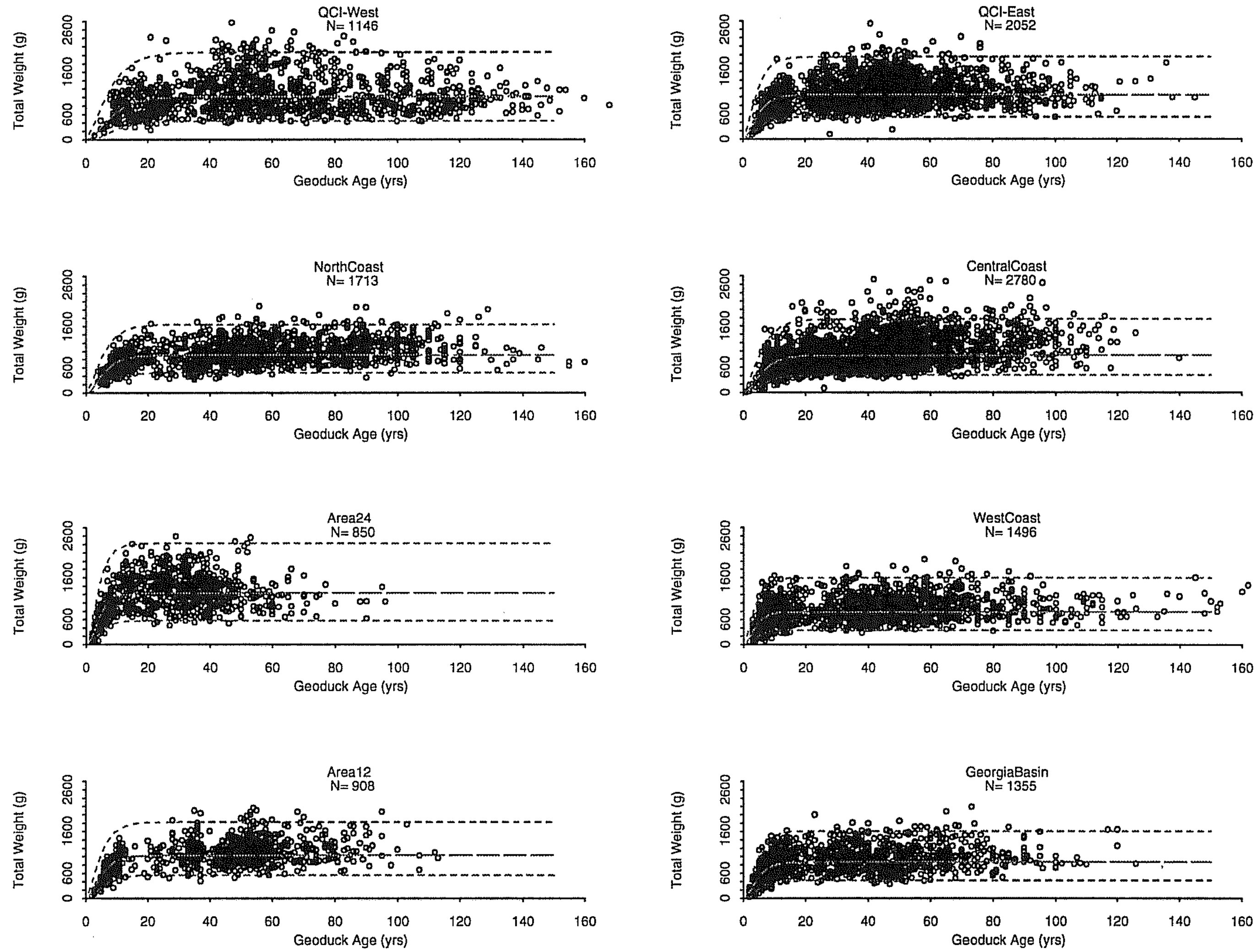


Figure 14: Total weight – age relationship, by geographic area, for geoduck biological samples collected from 1993 to 2000. Dashed lines are the 95% confidence bounds.

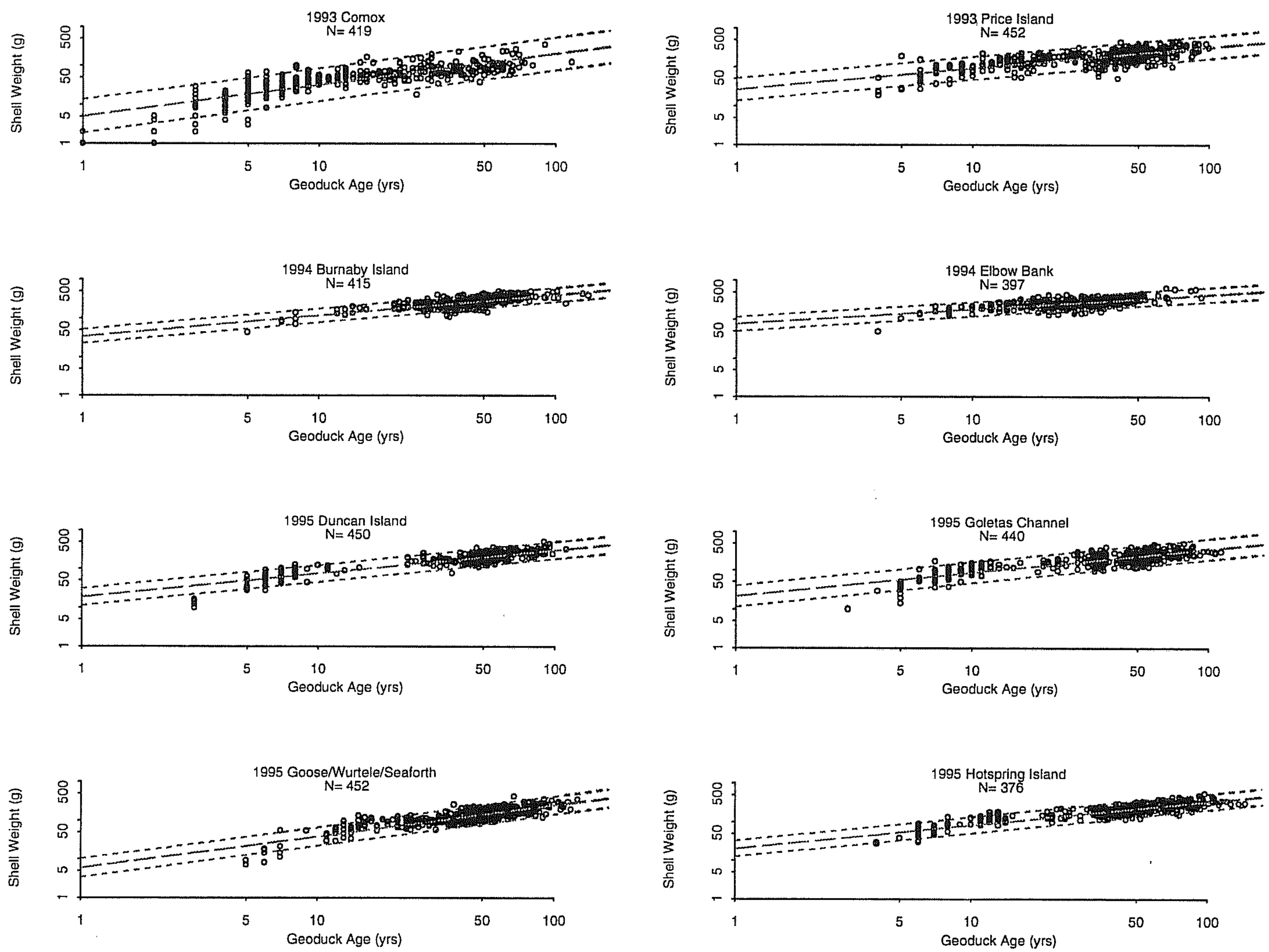


Figure 15: Shell weight vs. age for geoduck samples collected from 1993 to 2000, sorted by year. Dashed lines are the 95% confidence bounds.

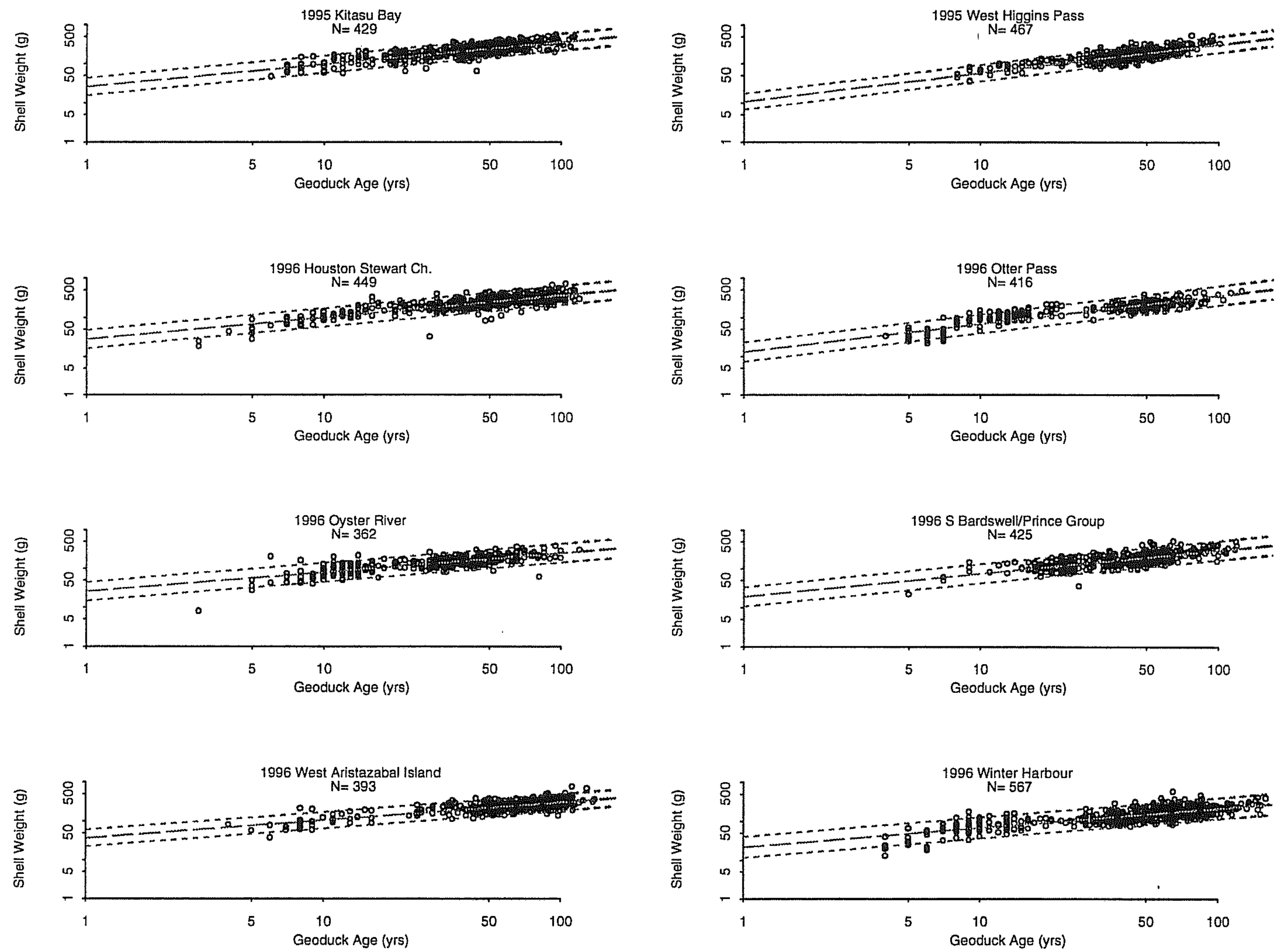


Figure 15 (continued)

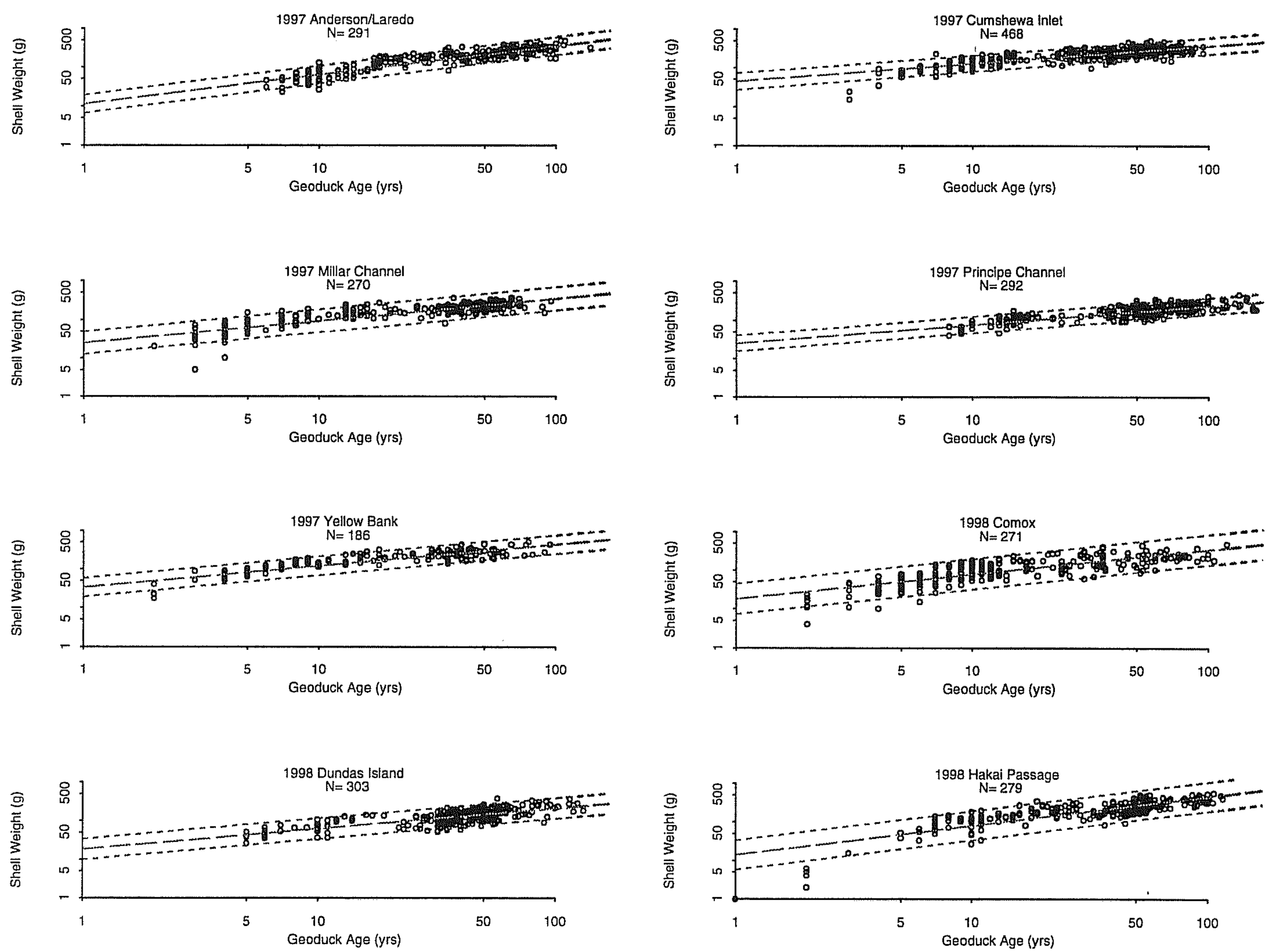


Figure 15 (continued)

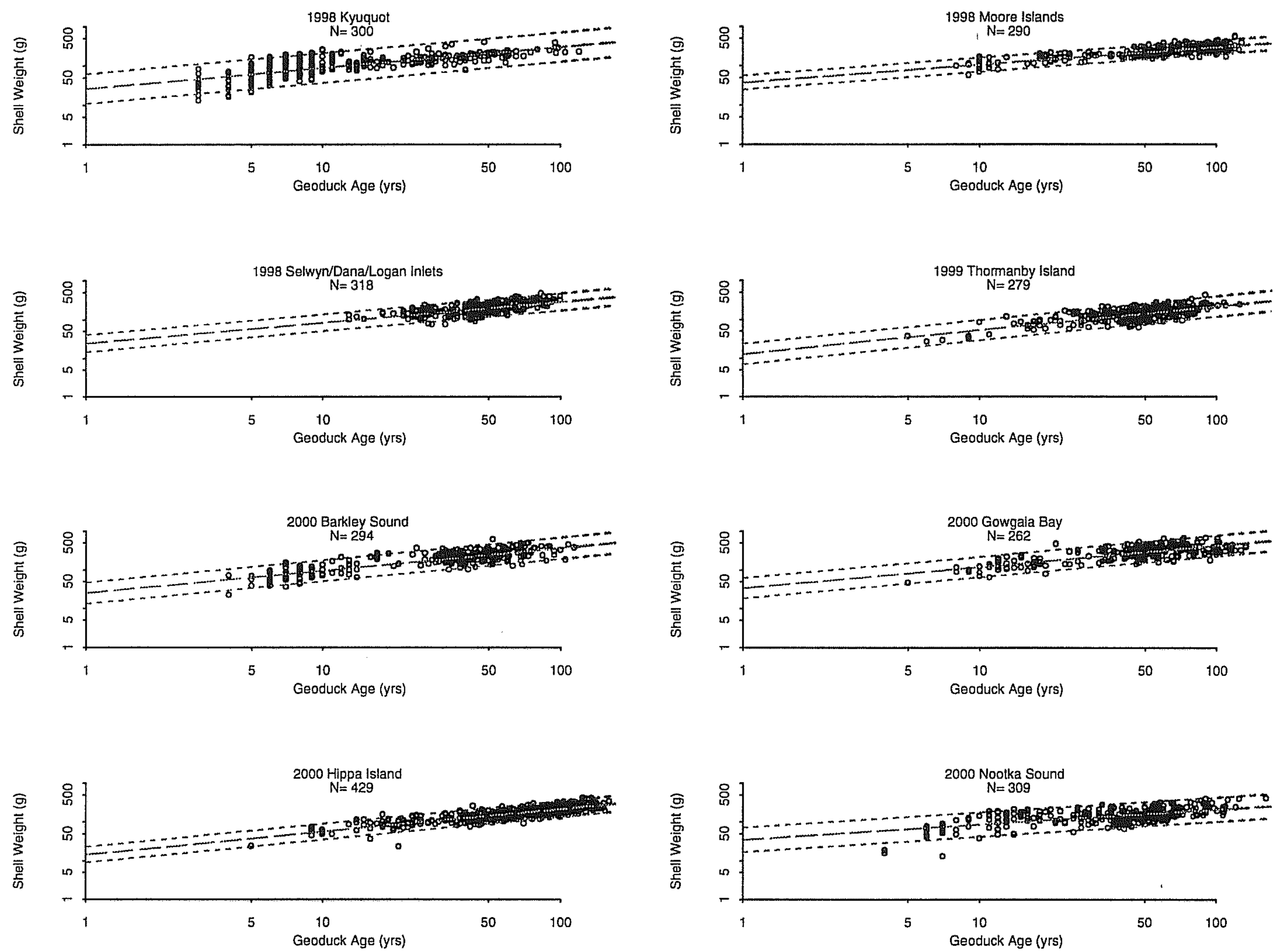


Figure 15 (continued)

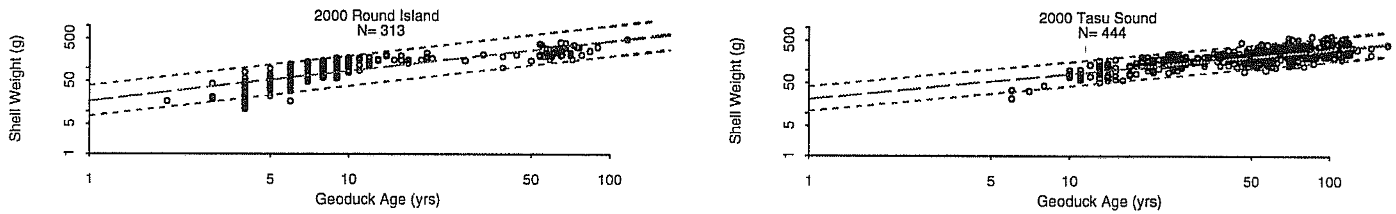


Figure 15 (continued)

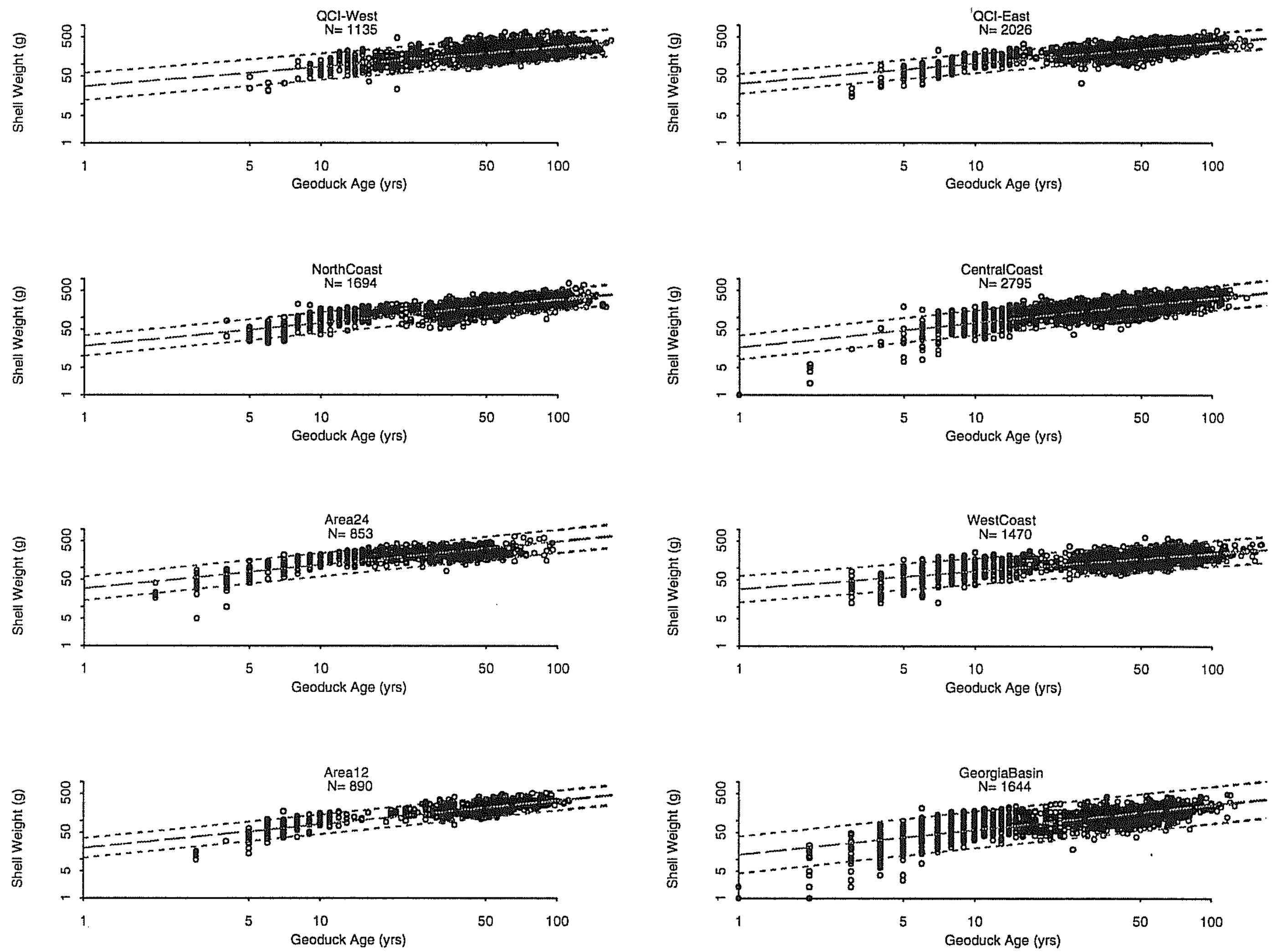


Figure 16: Shell weight – age relationship, by geographic area, for geoduck biological samples collected from 1993 to 2000. Dashed lines are the 95% confidence bounds.

APPENDIX 1: Summary of geoduck sample collection from 1993 to 2000, including date, location, depth, substrate, and mean geoduck density (with confidence bounds) estimated from harvest transects or survey areas.

Survey Title	Sub-Sample Location	Sample Site	Harvest Date	Number Geoducks Aged[1]	Stat. Area	Latitude	Longitude	Substrate[2]	Average Depth[3] (m)	Density (# geoducks/m^2) Mean	Confidence Interval L90	H90	L95	H95	Density Source	Survey Design[4]
1993																
Price Island																
	West Price Island	Tr 3	10-Sep-93	457	7-31	52° 16.670	128° 40.920	Sh/S		0.98			0.51	1.58	survey site 1	1
Comox																
	Palliser Rock	H1	17/25-Sep-93	440	14-10	49° 37.476	124° 49.611	S	11.8	0.59					harvest plot	1
1994																
Burnaby Island																
	North Section Cove		18-Dec-94	467	2-13	52° 25.700	131° 21.240	S/PGr	14.3*	2.27					survey site 6	1
Elbow Bank																
	Elbow Bank, H1	H1	29-Sep-94	417	24-6	49° 11.290	125° 55.691	S	3.4	0.51					survey site 1	1
1995																
Hotspring Island																
	Faraday Pass, Juan Perez Sound, H2	H2	10-Aug-95	391	2-11	52° 37.300	131° 28.090	S/C	6.4	2.16	1.86	2.53	1.77	2.60	transect H2	1
West Higgins Pass																
	West Higgins Pass		20-Feb-95	480	6-16	52° 28.900	128° 46.410	Sh/S	9.1*	1.93			0.81	3.28	survey sites 7, 8 & 9	1
Kitasu Bay																
	Kitasoo Bay - 1	1	07-Feb-95	489	6-18	52° 33.252	128° 48.331	S/Gr		3.47			2.50	4.45	survey site 10	1
	Kitasoo Bay - 2	2	07-Feb-95		6-18	52° 32.800	128° 47.770	S		3.47			2.50	4.45	survey site 10	1
	Kitasoo Bay - 3	3	07-Feb-95		6-18	52° 32.490	128° 47.360	S/C		3.47			2.50	4.45	survey site 10	1
	Kitasoo Bay - 4	4	07-Feb-95		6-18	52° 31.860	128° 46.190	PGr		3.47			2.50	4.45	survey site 10	1
	Kitasoo Bay - 5	5	07-Feb-95		6-18	52° 31.358	128° 45.391	S		3.47			2.50	4.45	survey site 10	1
Goose/Wurtele/Seaforth																
	Berry Inlet, H19	H19	20-Jul-95	483	7-8	52° 16.110	128° 20.300	Sh/S/Gr	9.5	4.07	1.25	7.39	1.00	7.71	protocol area 19	1
Duncan Island																
	Duncan Island, H1	H1	09-Jun-95	504	12-11	50° 48.966	127° 32.682	Sh	14.1	1.09	0.85	1.34	0.81	1.41	transect H1	1
Goletas Channel																
	Goletas Channel, GA	GA	09-Jun-95	490	12-16	50° 47.280	127° 34.490	Sh	9.3	1.44			0.82	2.33	survey site 2	1
	Goletas Channel, GB	GB	09-Jun-95		12-16	50° 47.130	127° 33.640	Sh	16.4	1.44			0.82	2.33	survey site 2	1
	Goletas Channel, GC	GC	09-Jun-95		12-16	50° 46.790	127° 32.060	Sh	13.0	1.43			0.67	2.47	survey site 3	1
	Goletas Channel, GD	GD	09-Jun-95		12-16	50° 46.320	127° 30.520	Sh	15.8	1.43			0.67	2.47	survey site 3	1
	Goletas Channel, GE	GE	09-Jun-95		12-16	50° 46.380	127° 29.460	Sh	12.8	0.61			0.30	0.93	survey site 4	1
1996																
Houston Stewart Ch.																
	W Kunghit, H2	H2	19-Jun-96	472	2-31	52° 07.550	131° 07.560	S/C	11.4	13.07	11.95	14.15	11.63	14.32	transect H2	4
	S Catherine Pt., H3	H3	19-Jun-96		2-31	52° 08.200	131° 08.500	S	10.2	13.93	12.45	15.37	12.12	15.58	transect H3	4
	Raspberry Cove, H6	H6	19-Jun-96		2-18	52° 09.910	131° 05.950	S/Sh/Gr	8.9	3.08	2.38	3.73	2.28	3.84	transect H6	4

Appendix 1 (cont'd)

Survey Title	Sub-Sample Location	Sample Site	Harvest Date	Number Geoducks Aged[1]	Stat. Area	Latitude	Longitude	Substrate[2]	Average Depth[3] (m)	Density (# geoducks/m^2) Mean	Confidence Interval L90	H90	L95	H95	Density Source	Survey Design[4]
Otter Pass																
	Otter Pass, H30	H30	25-Aug-96	431	6-9	53° 07.550	129° 51.330	Sh	6.3	7.06	5.70	8.49	5.44	8.78	transect H30	4
	Otter Pass, H34	H34	25-Aug-96		6-9	53° 09.700	129° 47.050	S	8.4	2.84	2.10	3.59	1.94	3.73	transect H34	4
	Otter Pass, H104	H104	25-Aug-96		6-9	53° 08.790	129° 42.400	S	8.5	2.62	1.63	3.58	1.44	3.77	transect H104	4
West Aristazabal Island																
	Clifford Bay, H4	H4	02-Jul-96	425	6-13	52° 36.380	129° 10.990	S	13.6	0.89	0.68	1.10	0.65	1.13	transect H4	4
	Kettle Inlet, H7	H7	02-Jul-96		6-13	52° 40.090	129° 14.300	Sh/S	10.5	1.78	1.48	2.09	1.43	2.17	transect H7	4
	Borrowman Bay, H12	H12	02-Jul-96		6-13	52° 43.940	129° 18.040	S/Sh	12.3	3.98	2.81	5.14	2.64	5.42	transect H12	4
South Bardswell/Prince Group																
	Houghton Is., H5	H5	20-Jul-96	440	7-19	52° 07.320	128° 25.820	Sh/C	9.9	4.26	3.76	4.75	3.66	4.84	transect H5	4
	South Louise Ch., H10	H10	20-Jul-96		7-18	52° 05.660	128° 23.030	S/Sh	9.8	13.64	10.98	16.27	10.52	16.81	transect H10	4
	Prince Grp., H17	H17	20-Jul-96		7-25	51° 59.390	128° 15.220	Sh/S	14.7	16.53	14.07	18.94	13.61	19.22	transect H17	4
Oyster River																
	Elma Bay, H4	H4	20-Sep-96	414	14-13	49° 51.800	125° 05.900	S/M	11.7	0.12	0.08	0.16	0.07	0.17	survey site 3	4
	S Miracle Beach, H14	H14	20-Sep-96		14-13	49° 49.900	125° 02.300	S	9.5	0.11	0.08	0.13	0.08	0.14	survey site 4	4
	S Kitty Coleman, H29	H29	20-Sep-96		14-13	49° 46.700	124° 58.000	S	11.3	0.08	0.04	0.12	0.04	0.13	survey site 6	4
Winter Harbour																
	Matthews Island, H2	H2	07-Aug-96	569	27-3	50° 28.770	128° 02.160	S/M/C	12.5	1.31	0.93	1.83	0.87	1.90	transect H2	4
	Hunt Islets, H5	H5	07-Aug-96		27-3	50° 28.520	128° 01.800	S	10.1	2.33	1.59	3.07	1.47	3.19	transect H5	4
	Nordstrom Cove, H13	H13	07-Aug-96		27-7	50° 29.060	127° 55.200	S/Sh	11.8	3.56	2.07	5.22	1.82	5.63	transect H13	4
	Koskimo Bay, H17	H17	07-Aug-96		27-7	50° 27.470	127° 53.230	S/Sh/M	11.1	4.13	3.45	4.83	3.30	4.94	transect H17	4
1997																
Cumshewa Inlet																
	Kitson Point, H2A	H2A	19-Jun-97	570	2-3	53° 01.980	131° 47.310	S/M	7.7	0.25	0.13	0.39	0.12	0.43	protocol area 2A	4
	E Mathers Creek, H2B	H2B	19-Jun-97		2-3	53° 00.580	131° 42.340	S/Sh/M	9.0	0.44	0.27	0.60	0.25	0.64	protocal area 2B	4
	Kingui Island, H1A	H1A	19-Jun-97		2-3	53° 01.730	131° 38.920	S	8.0	0.43	0.18	0.71	0.15	0.79	protocol area 1	4
	Kingui Island, H1B	H1B	19-Jun-97		2-3	53° 01.680	131° 38.660	S/Sh/C	9.9	0.43	0.18	0.71	0.15	0.79	protocol area 1	4
	McLellan Island, H3B	H3B	19-Jun-97		2-3	53° 02.560	131° 44.500	Sh/S/C	10.9	0.85	0.61	1.12	0.57	1.21	protocol area 3B	4
	McLellan Island, H3A	H3A	19-Jun-97		2-3	53° 02.620	131° 45.400	M/PGr/Gr	10.7	0.70	0.38	1.05	0.34	1.12	protocol area 3A	4
Principe Channel																
	Keswar In., H4	H4	02-Jul-97	294	5-13	53° 38.480	130° 21.330	S/Sh/M	8.0	0.61			0.28	0.93	protocol area 4	4
	N Keyarka Cove, H1C	H1C	02-Jul-97		5-13	53° 36.920	130° 23.420	S/C/PGr	9.8	2.51			1.62	3.30	protocol area 1C	4
	S Deadman It., H1B	H1B	02-Jul-97		5-13	53° 38.080	130° 27.230	S/M/C	8.7	2.66			2.01	3.56	protocol area 1B	4
Anderson/Laredo																
	Anderson Is., H1	H1	19-Jul-97	298	6-13	52° 45.250	129° 22.630	Sh/S	11.7	1.19	0.28	2.36	0.21	2.55	protocol area 4	4
	N Baker Pt., H2	H2	19-Jul-97		6-11	52° 48.540	129° 13.570	S/Sh/C	11.6	1.66	1.15	2.39	1.06	2.53	protocol area 9b	4
	Commando In., H3	H3	19-Jul-97		6-14	52° 47.120	129° 06.060	S/Sh	7.9	3.76	0.05	7.76	0.02	8.55	protocol area 13	4
Millar Channel																
	Clifford Pt., Millar Ch., H5	H5	21-May-97	277	24-4	49° 16.930	126° 02.500	S	9.9	2.44	2.00	2.86	1.87	2.92	transect H5	2
	Yates Pt., Millar Ch., H6	H6	21-May-97		24-4	49° 16.470	126° 02.740	S/Sh	9.0	2.46	1.89	3.07	1.74	3.15	transect H6	2
	Catface, Millar Ch., H4	H4	21-May-97		24-6	49° 15.940	126° 01.550	S/Sh	12.3	0.55	0.26	0.87	0.22	0.94	transect H4	4
Yellow Bank																
	NW Yellow Bank, H2	H2	22-May-97	185	24-7	49° 14.300	125° 55.750	S/Sh	15.3	0.95	0.57	1.37	0.49	1.46	transect H2	4
	N Yellow Bank, H1	H1	22-May-97		24-7	49° 14.530	125° 55.000	S	5.1	0.95	0.57	1.40	0.53	1.46	transect H1	4
	SE Yellow Bank, H3	H3	22-May-97		24-7	49° 13.910	125° 55.020	S/Sh	8.2	1.18	0.95	1.40	0.91	1.44	transect H3	4

Appendix 1 (cont'd)

Survey Title	Sub-Sample Location	Sample Site	Harvest Date	Number Geoducks Aged[1]	Stat. Area	Latitude	Longitude	Substrate[2]	Average Depth[3] (m)	Density (# geoducks/m^2) Mean	Confidence Interval L90	H90	L95	H95	Density Source	Survey Design[4]
1998																
Selwyn/Dana/Logan Inlets																
	Selwyn Inlet	H1	16-Jun-98	323	2-6	52° 52.160	131° 48.640	S/Sh/Gr	9.8	3.92	3.21	4.54	3.10	4.68	transect H1	4
	Dana Inlet	H5	16-Jun-98		2-6	52° 48.940	131° 41.750	S	14.2	2.13	1.70	2.55	1.59	2.67	transects H2, H3	4
	Logan Inlet	H4	16-Jun-98		2-8	52° 46.680	131° 39.170	S/Sh	9.7	2.31	1.90	2.74	1.83	2.84	transect H4	4
Dundas Island																
	North Dundas, H1	H1	07-Aug-98	305	3-1	54° 37.530	130° 55.220	Sh/S	11.1	4.09	2.61	5.72	2.37	5.92	transect H1	4
	North Dundas, H2	H2	07-Aug-98		3-1	54° 37.820	130° 54.760	Sh/S	8.9	8.17	6.21	10.07	5.88	10.37	transect H2	4
	Goose Bay, H3	H3	07-Aug-98		3-1	54° 37.370	130° 53.100	S/Sh	8.4	2.09	1.24	3.02	1.09	3.21	transect H3	4
Hakai Pass																
	West Stirling	H2	08-Jul-98	288	7-27	51° 45.160	128° 07.900	Sh/S	5.0	1.21	0.56	2.04	0.43	2.19	transect H2	4
	Choked Pass	H1	08-Jul-98		8-2	51° 40.760	128° 07.020	S/Sh	10.7	4.96	4.04	5.83	3.87	6.03	transect H1	4
	Breaker Group	H3	08-Jul-98		8-2	51° 44.120	128° 04.960	Sh	10.9	17.97	13.62	22.77	12.64	23.84	transect H3	4
Moore Islands																
	Moores, H1	H1	20-Aug-98	299	106-2	52° 40.810	129° 25.820	Sh/S	12.8	9.38	7.54	11.26	7.35	11.58	transect H1	1
	Moores, H2	H2	20-Aug-98		106-2	52° 39.350	129° 25.130	S	11.1	0.98	0.77	1.23	0.72	1.26	transect H2	1
	Moores, H3	H3	20-Aug-98		106-2	52° 39.920	129° 26.040	Sh/S/C	13.0	8.27	6.43	10.07	5.88	10.46	transect H3	1
Comox																
	Palliser Rock, H6D	H6D	30-Sep-98	274	14-10	49° 36.829	124° 48.919	S	15.0	0.34	0.27	0.42	0.25	0.44	survey site 2	4
	Palliser Rock, H7M	H7M	30-Sep-98		14-10	49° 37.069	124° 49.339	S/Sh	10.3	0.34	0.27	0.42	0.25	0.44	survey site 2	4
	White Spit, H12S	H12S	30-Sep-98		14-10	49° 38.200	124° 50.780	PGr/S/C	4.4	0.34	0.27	0.42	0.25	0.44	survey site 2	4
	Balmoral Beach, H5D	H5D	30-Sep-98		14-11	49° 41.060	124° 51.690	S	10.7	0.26	0.12	0.42	0.10	0.45	survey site 1	4
	Balmoral Beach, H1S	H1S	30-Sep-98		14-11	49° 40.759	124° 52.339	S	5.9	0.26	0.12	0.42	0.10	0.45	survey site 1	4
	Balmoral Beach, H2M	H2M	30-Sep-98		14-11	49° 40.520	124° 52.259	S/PGr	8.4	0.26	0.12	0.42	0.10	0.45	survey site 1	4
Kyuquot																
	N Sobry Isl.	H21	18-Sep-98	299	26-6	50° 00.840	127° 22.860	S	3.4	2.96	2.13	3.87	2.01	4.06	transect H21	1
	E Sobry Isl.	H24	18-Sep-98		26-6	50° 00.760	127° 22.300	S/Sh	12.6	2.39	2.03	2.83	1.96	2.96	transect H24	1
	Nicolaye Ch.	H37	18-Sep-98		26-6	50° 00.170	127° 21.250	S	16.4	7.56	6.15	9.04	5.94	9.32	transect H37	1
1999																
Thormanby Island																
	N. Thormanby Is., H1	H1	30-May-99	312	16-2	49° 30.679	124° 01.739	S/B	9.8	0.40	0.27	0.54	0.24	0.56	transect H1	2
	N. Thormanby Is., H2	H2	30-May-99		16-2	49° 31.020	124° 01.529	S/M	11.4	1.41	1.16	1.68	1.11	1.73	transect H2	2
	N. Thormanby Is., H3	H3	30-May-99		16-2	49° 30.940	124° 02.279	S	7.8	1.09	0.90	1.28	0.85	1.31	transect H3	2
2000																
Gowgaia Bay																
	Nangwai Bay, H1	H1	16-Jun-00	270	2-38	52° 25.165	131° 35.907	Sh/S	13.1*	1.36	1.05	1.79	1.01	1.87	protocol area 12	4
	Goski Bay, H2	H2	16-Jun-00		2-40	52° 25.477	131° 34.921	S	12.2*	0.65	0.51	0.81	0.50	0.84	survey site 8	4
	Soulsby Cove, H3	H3	16-Jun-00		2-39	52° 24.380	131° 33.020	S/M	13.1*	0.23	0.11	0.37	0.10	0.40	survey site 4	4
Tasu Sound																
	Two Mountain Bay, H1	H1	29-Sep-00	446	2-45	52° 47.802	132° 00.606	S/Sh	12.2*							4
	East Tasu Narrows, H2	H2	29-Sep-00		2-42	52° 44.978	132° 05.101	S	12.8*							4
	Lomgon Bay, H3	H3	29-Sep-00		2-42	52° 46.580	132° 06.080	S	12.8*							4

Appendix 1 (cont'd)

Survey Title	Sub-Sample Location	Sample Site	Harvest Date	Number Geoducks Aged[1]	Stat. Area	Latitude	Longitude	Substrate[2]	Average Depth[3] (m)	Density (# geoducks/m²) Mean	Confidence Interval L90	H90	L95	H95	Density Source	Survey Design[4]
Hippa Island																
	Nesto Inlet	H1	31-Oct-00	432	2-87	53° 33.150	132° 57.310	S	15.2*	4.98			3.36	7.83	survey site 8	4
	Hippa Pass	H2	31-Oct-00		2-87	53° 32.360	132° 55.900	Sh	12.2*	2.31			0.88	4.33	survey site 12	4
	Hippa Island	H3	31-Oct-00		2-87	53° 32.700	132° 59.050	Sh	12.8*	2.99			1.85	4.49	survey site 1	4
Round Island																
	Round Is., H1	H1	09-May-00	322	17-16	49° 06.915	123° 48.042	S	12.0	0.38	0.25	0.52	0.23	0.55	Survey Site 1	1
	Round Is., H2	H2	09-May-00		17-16	49° 06.800	123° 48.042	S	14.9	0.38	0.25	0.52	0.23	0.55	Survey Site 1	1
	Round Is., H3	H3	09-May-00		17-16	49° 06.722	123° 47.996	S	14.5	0.38	0.25	0.52	0.23	0.55	Survey Site 1	1
Barkley Sound																
	N Maggie R., H11	H11	03-Jun-00	301	23-10	49° 00.160	125° 21.970	M	13.5	1.43	0.97	1.98	0.90	2.11	transect H11	1
	S Stopper Is., H28	H28	03-Jun-00		23-10	48° 58.850	125° 21.140	S/M	10.4	0.95	0.59	1.34	0.54	1.44	transect H28	4
	N Stopper Is., H32	H32	03-Jun-00		23-10	48° 59.720	125° 19.920	S/Gr	7.3	0.73	0.46	1.02	0.40	1.10	transect H32	4
Nootka Sound																
	Pantoja Is., H1	H1	02-Sep-00	311	25-6	49° 36.872	126° 34.208	S/Sh	15.2	0.50	0.25	0.80	0.21	0.87	survey site 6	4
	N Friendly Cove, H2	H2	02-Sep-00		25-6	49° 36.019	126° 36.870	S/Sh	13.9	1.32	0.67	2.11	0.57	2.35	survey site 10	4
	Clotchman Isl., H3	H3	02-Sep-00		25-6	49° 37.189	126° 34.790	S/Sh	10.9	0.27	0.10	0.48	0.08	0.53	survey site 7	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] Average Depth: depths with an asterisk are not corrected for tide height

[4] Survey Design:

1 Systematic: Transects are systematically placed along the shore in the area to be surveyed. The first transect is randomly placed, and subsequent transects placed at a predetermined distance (distance varies depending on bed size). Geoduck counts may be recorded within all consecutive quadrats along each transect, or 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.

2 Two-Stage Grid: A grid made up of a number of equal-sized squares is placed over a chart in the area to be surveyed and a number of squares are randomly selected for surveying. A transect(s) is placed in each of the selected squares and the quadrats sampled as in survey design 1.

3 Three-Stage Sampling: Transects are randomly placed along the shore in the area to be surveyed. Each transect is sectioned into blocks that can accommodate q quadrats per block, e.g. a block would be 20 m long for 4 quadrats (5 m quadrat length). Geoducks are counted in one quadrat randomly located in one of the q possible quadrats in each block. The block size remains constant for all transects within a given bed.

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.