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Results of surveys of intertidal razor clams (*Siliqua patula*) on beaches near Massett, Haida Gwaii and recommendations on fishery management

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Abstract

Intertidal razor clam populations and biomass on beaches near Massett, Haida Gwaii were estimated using a three stage sampling design stratified by beach section for the period 1994 to 2000. The 2000 razor clam population on 18.8 km of beach accessible to the commercial fishery was estimated by the ratio method to be 36.3 x 10^6 (CV 17%) clams $\geq$ 4 mm, 22.3 x 10^6 (CV 8.5%) clams $\geq$ 20 mm, and 10.5 x 10^6 (CV 8%) clams $\geq$ 90 mm). Estimates using the inflation method in 2000 were similar, at 36.4 x 10^6 (CV 14%) clams $\geq$ 4 mm, 22.9 x 10^6 (CV 7%) clams $\geq$ 20 mm and 12.5 x 10^6 (CV 6%) clams $\geq$ 90 mm. The two methods varied considerably in some years mainly due to assumptions about average transect length (and the area of the beach). The inflation method estimate provides a lower bound since it is based on the number of clams found on a transect. Also it was independent of transect length, which varied between years. The 2000 biomass of clams > 90 mm at the time of the survey was estimated to be 1699 t (SE 157 t). Age-at-maturity studies showed that razor clams do not start to mature until they reach 80 mm, 50% are mature at 87 mm and all are mature at 97 mm. The surveys show that the biomass was at a historic high in 2000 and that a large number of two year old clams were in the population, most of which will recruit to the fishery in 2001.

Résumé

Pour la période 1994-2000, nous avons estimé la taille et la biomasse des populations intertidales de couteau sur les plages près de Massett, Haïda Gwaii, à l'aide d'un plan d'échantillonnage en trois étapes stratifié en coupes de plage. Selon la méthode des quotients, la taille de la population en 2000 sur 18,8 km de plage accessibles aux pêcheurs commerciaux se chiffrait à 36,3 x 10^6 (c.v. 17 %) couteaux $\geq$ 4 mm, 22,3 x 10^6 (c.v. 8.5 %) couteaux $\geq$ 20 mm et 10,5 x 10^6 (c.v. 8 %) couteaux $\geq$ 90 mm). Les estimations pour 2000 reposant sur la méthode d'extension étaient semblables, soit 36,4 x 10^6 (c.v. 14 %) couteaux $\geq$ 4 mm, 22,9 x 10^6 (c.v. 7 %) couteaux $\geq$ 20 mm et 12,5 x 10^6 (c.v. 6 %) couteaux $\geq$ 90 mm. Les résultats obtenus selon les deux méthodes variaient fortement pour certaines années, en grande partie à cause des hypothèses relatives à la longueur moyenne des transects (et la superficie de la plage). L'estimation obtenue de la méthode d'extension donne une limite inférieure du fait qu'elle repose sur le nombre de couteaux récoltés dans un transect et qu'elle est indépendante de la longueur de celui-ci, qui variait d'une année à l'autre. Nous avons estimé que la biomasse de couteaux > 90 mm au moment de la réalisation du relevé en 2000 se chiffrait à 1 699 t (e.-t. 157 t). Les études sur l'âge à la maturité ont révélé que les couteaux ne commencent à montrer des signes de maturité qu'à 80 mm, 50 % étant matures à 87 mm et 100 % à 97 mm. Les relevés indiquent que la biomasse avait atteint un pic historique en 2000 et que la population comprenait un grand nombre de couteaux de deux ans, dont la plupart seront recrutés à la pêche en 2001.

Introduction

This paper presents the results of surveys of razor clams on beaches near Massett, Haida Gwaii from 1994 to 2000. Beaches near Massett, Haida Gwaii have significant populations of razor clams that have supported a major commercial fishery since 1922 and a small but important non-commercial fishery. Commercial landings over this period have fluctuated widely depending on market demand, fishing effort and fluctuations in populations (Fig. 1, Table 1). The commercial fishery had record landings in 2000 and because of concerns about possible overexploitation of the stock the fishery was closed in September. Following a preliminary analysis of the survey data, the fishery was reopened in February 2001 with an arbitrary annual catch ceiling of 235.8 tonnes (520,000 pounds) and monthly catch limits to pace the fishery. There have been several assessments of razor clam populations in the past that have covered one or two year periods (Bourne 1969; Jones et al. 1998). This paper presents information collected over a seven year period and provides information about trends in abundance, biomass and recruitment in the fishery.

Background and Literature Review

Razor clams are found on surf-swept sandy beaches from Pismo Beach, California to the Aleutian Islands in Alaska (Weymouth and McMillin 1930). There are eight major concentrations sufficient to support fisheries, one in Oregon (Hirschhorn 1962), one in Washington (Tegelberg 1964), two in British Columbia (Bourne 1969) and four in Alaska (Nickerson 1975). The major stocks in British Columbia are located at beaches near Massett in Haida Gwaii with a smaller population at Long Beach on the west coast of Vancouver Island (Bourne 1969).

Razor clams are characterized by a long siphon, a prominent muscular foot and brittle elongated valves. Razor clams can burrow at rates exceeding 20 cm per minute and are found up to 25 cm in the sand that makes harvesting a challenge for an inexperienced clam digger. Adults left on the surface of the beach will quickly reburrow. Lateral movement of adults is believed to be small, although juvenile clams have been found to move because of substrate instability (Nickerson 1975). Juvenile clams burrow to a lesser depth and may be washed out and moved because of scouring of the substrate. Although there have been numerous studies of intertidal populations, little is known about subtidal populations in the vicinity of major razor clam beaches (Bourne 1969).

Adult razor clams reach shell lengths up to 160 mm and ages of 18 years. Growth rates vary with latitude with northern populations generally growing slower but reaching a greater age and maximum size (Weymouth and McMillin 1930). Northern populations can be aged by annual winter growth checks, although interpretation depends on ability to identify all the checks (Bourne and Quayle 1970; Nickerson 1975). Survival of intertidal razor clams is likely affected by availability of food, predators and natural occurrences such as storms or disease. Predators on larger clams include gulls, ducks, crabs and a few fish species.

Razor clams have separate sexes and are broadcast spawners. Age and size of sexual maturity varies with latitude, but most clams are sexually mature at 2 to 4 years of age and 97 to 103 mm in length (Weymouth et al. 1925). Time of spawning varies with location, but generally occurs from April to September, occurring later at northern latitudes. Spawning can be influenced by temperature, upwelling, tidal cycles, currents, food availability and gonad maturity.

The life history follows a common bivalve pattern of release of gametes into the surrounding water, fertilization, development as a free-swimming pelagic larvae, settlement to the bottom as "spat" and finally development as a sedentary organism. Larval period was estimated to be about 8 weeks in Washington (Weymouth et al. 1925). By the time of settlement, larvae can be widely distributed from the point of origin by currents and tides. In laboratory culture at 16.5 C, metamorphosis took place about 20-25 days after fertilization at a shell length of about 300 microns in length. After three months, juveniles reached a mean shell length of 5 mm (Breese and Robinson 1981). Bourne followed the growth of zero age clams by beach screening over 12 months and found that clams 2 to 6 mm in July, reached 4 to 10 mm in September, 12 to 14 mm the following May and 18 to 20 mm the following June (Bourne and Quayle 1970). Relatively little is known about environmental factors contributing to survival of razor clams during the vulnerable larval and early juvenile stage of their life history.

Intertidal populations have been estimated using a variety of techniques including mark-recapture, tagging and, more recently, hydraulic core sampling. Bourne (1969) estimated density of clams at North Beach using: (1) repeated digging of 7 transects on three beaches near Massett in 1966; (2) repeated counts of shows in the transects; and (3) tagging and recapture by repeated digging. Repeated digging resulted in recovery of 15 to 25% of tagged clams. The Washington Department of Fisheries conducts regular assessments of razor clam beaches using: (1) mark recapture; and (2) stratified random digs (Ayres and Simons 1988). Eighteen areas on 4 major beaches are sampled in the spring and a reduced number are sampled in the fall. Stratified random digs provide an indication of density and size composition. Plots are re-dug a minimum of two times until at least 20% of the marks are recovered. Szarzi (1991) estimated razor clam densities at Cook Inlet Alaska beaches using hydraulic core sampling and a two stage sampling design by beach and distance from a gravel line. Although sampling was carried out on randomly selected transects as part of a three stage design, a two stage design which ignored the variability between transects was adopted for the final analysis.

Hydraulic sampling was selected for the present study because of the advantages of providing an unbiased sample of the population and ease of sampling. Digging by hand is selective for larger clams and screening of sand to obtain small clams is quite laborious.

Management practices in British Columbia, Washington and Alaska vary with the type and intensity of the fishery. Commercial and recreational razor clam fisheries at North Beach are open year round except for the occasional marine toxin (PSP or ASP) closures. The commercial fishery is currently managed by a 90 mm size limit. As well, in 2000, an arbitrary catch ceiling of 235.8 t (520,000 pounds) was introduced. Recreational clam diggers are limited to a daily catch of 75 clams and a possession limit of 150 clams. There is no recreational size limit. Recreational fisheries on Washington beaches are managed by a fixed season (usually 1-2 days) and a daily bag limit of 15 clams with no size limit (Doug Simons, Washington Department of Fisheries, Pers. Comm.). There is no size limit in the commercial or recreational fishery. Size limits in commercial fisheries in Washington were eliminated in the 1960s after high wastage of undersize clams was found. Alaska currently has a major commercial and recreational fisheries near Cook Inlet (Alaska Department of Fish and Game, Pers. Comm.). There are currently no size limits or quota in the Alaska fishery.

The Haida Gwaii razor clam fishery is co-managed by the Council of the Haida Nation and Fisheries and Oceans Canada (Jones and Garza 1998). The details of the management arrangement are described in the Razor Clam Subagreement, an agreement negotiated through DFO's Aboriginal Fisheries Strategy in 1994. The agreement was renewed with minor changes in 1998 and 1999 and the current agreement extends to March 31, 2003. Two joint Haida/DFO committees are responsible for implementing and monitoring the agreement. The Joint Shellfish Technical Committee is responsible for developing and recommending an annual management plan to a Cooperative Management Group, assessing sustainable harvest levels in the fishery, and monitoring, surveying and enforcing the fishery. The Haida fishery is managed through a Communal Licence and the CHN issues designations to Haida participants. DFO issues licences to six individuals to participate in the fishery. Licences are personal and non-transferable and were limited in 1995. Under the Communal Licence, CHN is responsible for collecting and compiling fish slip data and collection of samples for marine toxin monitoring. The number of Haida participants under the Communal Licence is not limited.

Haida Gwaii razor clam landings, effort and value from 1994 to 2000 are shown in Table 1 and Figure 2. The number of licences and Haida participants in the fishery during this period is shown in Table 2.

Methods

Hydraulic Sampling and Survey Methods

From 1994 to 2000, razor clam populations in three beach sections were sampled using a three stage design, generally following the methods described in Jones et al. (1998).

The three main beaches near Massett are commonly called North Beach, South Beach and Agate Beach. The three sections of the beach sampled, referred to as North-1, South-1, and South-2 are 7.2 km, 4.6 km and 6.75 km in length, respectively (Figure 3). Beach sections were selected based on clam density, beach accessibility and use as reported by commercial clam diggers. North-1 is the main focus of the commercial razor clam fishery. South-1 is occasionally dug commercially, but clam densities are lower and the distribution is spottier. South-2 is rarely dug. Agate Beach is rarely dug commercially because truck access is very difficult. Generally, sampled beaches have gentle slopes from the driftwood line, with 60 to 75 m of beach exposed per 1 m of elevation. North-1 is a uniform sand beach. South-1 and South-2 are mainly sand beaches interspersed with pockets of gravel. South-2 is more gravelly than South-1. The coarser beach material at South-1 and South-2 beaches are said by commercial diggers to make digging and retrieving clams more difficult. Most diggers won't fish North Beach beyond about 7.3 km, because vehicles tend to get stuck in the soft substrate. However in 2000 there was considerable effort and landings beyond this point and this area is being included for surveys in 2001.

The intertidal razor clam population was estimated using a three stage sampling design that was stratified by beach area. Transects, elevations (on the transect) and core samples (conducted at each elevation) were the primary, secondary and tertiary sampling units, respectively. Transects were sampled during tides less than 1.0 m in height at the locations and dates shown (Table 3). Commercial diggers generally only dig when tides are less than 1.2 m (4.0 feet). Representative samples of the population were collected by hydraulic sampling of sand cores with a 0.5 m^2 sampling tube. For example, in 1994, 14 transects in 3 beach areas were surveyed and samples were collected at 99 beach elevations. A total of 533 cores were sampled and 4,569 clams of all sizes were captured.

The equipment used was similar to that described by Szarzi (1991). A galvanized steel sampling ring (0.79 m diameter, 0.5 m^2 in area), was drilled throughout with 3 mm holes to allow easy drainage of water. Four additional oval holes (60 mm long covered with 5 mm wire mesh) were located near the top of the ring to allow further drainage. The sampling ring was forced into the sand to a depth of about 0.5 m. Seawater was pumped using a 4.0 HP Honda pump (Model GX-120) and injected into the sand using a wand (a steel pipe, 1.5 m in length, 38 mm in diameter) attached to the pump by a 51 mm diameter hose about 45 m in length. Upwelling water liquified the sand, dislodging the razor clams. Razor clams were captured by straining the upwelling mixure with a coarse mesh (5 mm) dipnet followed by a fine mesh (< 1 mm) dipnet.

Generally the procedure requires about 3 to 5 minutes per sample with a five person crew. One person acted as a tender for the pump intake, one person worked the wand that fluidized the sand, two others strained the mixture and one person supervised field activities and surveyed the beach elevations, providing assistance wherever necessary. Sampling continued until approximately one minute after the last clam was captured. At that time, all clams in the sample area were thought to be captured. A few broken clams were noted, likely due to pressure from the wand as it was inserted. Razor clams from each sample were put into separate labeled bags. Length of individual clams was measured using calipers to the nearest mm after field sampling was completed. The wet weight of individual clams was measured using an Ohaus electronic balance. The length of all clams was measured but not all clams were weighed. Where clams were measured but not weighed, the wet weight was estimated using a length-weight regression. A small amount of breakage from handling clams in sample bags was recorded which occurred mostly for small clams e.g.in 1994 broken clams averaged 2.5% of each sample of which 1.9% were <20 mm shell length.

In 1994, transects were randomly selected in each beach section from a subset of transects 100 m apart. This was the accuracy of the truck odometer used to locate the transect. In subsequent years, the length of the beach was divided by the proposed maximum number of transects (e.g. 7.2 km/6 = 1.2 km) and a transect in the first section of beach was randomly selected (e.g. 0.3 km). In this example subsequent transects would then be systematically placed 1.2 km apart. Transects in each beach section were randomly selected for surveying and located by driving a fixed distance from an access point. Just before sampling, each transect was laid out perpendicular to the beach using rebar marked with flagging tape. One transect was sampled per tide. Depending on daylight, sampling generally began 2 - 3 hours before the low tide and continued until approximately three hours after the low tide.

Beach elevations sampled within a transect were located systematically along the transect, with sampling starting at the surfline at the time of arrival. Distance between sampled elevations was generally 15 m (except in 1994 when the distance ranged from 10 to 25 m depending on number of core samples at each elevation and the rate of subsidence (or approach) of the tide). Each beach elevation was flagged with a metal rebar stake during sampling. For each transect, 4 to 16 beach elevations were sampled depending on the low tide level and time available.

At each beach elevation, the survey crew completed 3 core samples (except in 1994 when 3 to 9 core samples were taken). The sampling strategy after 1994 was changed to complete more elevations with fewer core samples per elevation as a means of improving the precision of estimates. Core samples were situated parallel to the surfline within about 7 m of the transect line with approximately the same number on each side of the transect line. Core samples were approximately 1.5 m apart to avoid anyone falling into the depression created in the sand from the previous core. If the tide was falling rapidly, then the survey crew moved to the next lower beach elevation and completed sampling at higher beach elevations on the rising tide.

Elevation was measured using a surveyor's level (Pentax Model AL.-240) and rod, using the tidewater level as the reference elevation. At a recorded time near low tide, a profile of the beach and the tidewater elevation relative to the sampled beach elevations was determined using the level and rod. Tidewater elevation above chart datum at the time of sampling was calculated using time and procedures described in Canadian Tide and Current Tables. For the purposes of the calculation, Bella Bella was the reference port and Wiah Point was the secondary port. There was a small random error in estimation of tidewater elevation because of ocean swells. Generally, tidewater elevation was estimated to be within $\pm$ 0.1 m of the true value.

Abundance and Biomass Estimates

The estimates of the abundance and biomass were obtained using methods described in Babineau (2000). The analysis consists of two steps for each size class at each beach in each year.

Step 1. Estimate the total number of clams or biomass of clams in a 0.5 m wide strip along the transect.

The total number (or biomass) of clams along a .5 m strip along the transect was estimated using an area-under-the-curve approach. The mean density at each sampling point along the transect is computed using the average of the samples taken at that distance. Then these points are joined by straight lines, and the area under the curve is computed by summing the trapezoids formed by the sampling points and the mean densities, i.e. to estimate the total number

$$\hat{T}_i = \frac{\sum_{j=1}^{n_i - 1} \left(\overline{Y}_{ij} + \overline{Y}_{i,j+1}\right) b_j}{2}$$

where

$\hat{T}_i$ is the estimated transect total,

$\overline{Y}_{ij}$ is the sample mean of the counts in transect i at sampling point j

b_j is the distance along the transect between the j^{th} and $j+1^{st}$ sampling points.

The beach above the highest sampling point and below the lowest sampling point are given a density of zero. [Note that in Babineau (2000), the curve was extrapolated down to zero above the highest elevation of the beach. Hence our results differ slight from those presented in her thesis.].

Step 2. Estimate the total number and biomass of clams on the beach.

Once the estimates of the total number of clams along the 0.5 m strip on the transect are found, the estimated density over the entire beach was calculated using both the ratio and inflation method.

Density in the ratio method is calculated as the ratio of the total clams in all transects to the total area of the transects. This is then multiplied by the beach area to estimate the total clams on the beach, i.e. to estimate the total number

$$\hat{N}_{ratio} = A \frac{\sum_{i=1}^{n} \hat{T}_i}{.5 \sum_{i=1}^{n} L_i}$$

where

A is the area of the beach section,

L_i is the length of transect i.

The precision of the estimates is determined using a Taylor series expansion as outlined in Babineau (2000, Equation 2.15).

$$\hat{\text{v}}\text{ar}\left(\hat{N}_{ratio}\right)=4A^2\left(\frac{(1-f)\sum_{i=1}^{n}\left(\hat{T}_i-\frac{\sum\hat{T}_i}{\sum L_i}L_i\right)^2}{n\hat{\bar{L}}^2(n-1)}+\frac{\sum_{i=1}^{n}\hat{\text{v}}\text{ar}\left(\hat{T}_i\right)}{\left(\sum L_i\right)^2}\right)$$

where

n is the number of transects sampled on the beach

N is the number of possible transects on the surveyed beach having a width of approximately 0.5 m (e.g. length of the beach in m x 2)

$\hat{\bar{L}}$ is the sample mean of the transect lengths

f = n/N

In the inflation method the number of clams is estimated for each beach section as the average density of clams in a transect multiplied by an inflation factor, the number of possible transects on the beach (two times the length of the beach since each transect was assumed to be 0.5 m wide).

$$\hat{N}_{\text{inf}}=N\frac{\sum_{i=1}^{n}\hat{T}_i}{n}$$

where parameters are defined above.

Again the precision of the estimates is calculated as outlined in Babineau (2000, Equation 2.24).

$$\hat{\text{v}}\text{ar}\left(\hat{N}_{\text{inf}}\right)=N^2\left(\frac{s_T^2(1-f)}{n}+\frac{1}{n^2}\sum_{i=1}^{n}\hat{\text{v}}\text{ar}\left(\hat{T}_i\right)\right)$$

A similar calculation is performed to estimate the biomass density over the beach and the total biomass for clams $\geq$ 90 mm. Biomass was calculated using only the inflation method.

The weight of all clams in a core sample was calculated as the total of the weight of individual clams. If the length of a clam was available but not the weight, then it was estimated using a length-weight regression from 1994 sampling for clams > 20 mm (n=1406) (Jones et al. 1998):

$$\log_{10} W = 3.3058 \log_{10} L - 4.7813$$

where

W is the weight in grams,

L is the length in mm.

Length Frequency distributions

Length-frequency distributions of the population were constructed for all years by pooling samples from all transects and core samples (except 1994 when only transects sampled early in the season, March-May, were used) (Figure 4). As well a random commercial catch sample was collected by sampling and measuring clams from individual diggers on the beach. In 2000 this was done on five occasions during the fishery (April 10, May 2, May 4, June 19, August 13).

2000 Year-Class Abundance

Abundance of razor clams in 2000 by year-class was calculated using an age-length key (Gulland and Rosenberg 1992; Kutkuhn 1963). This technique uses an age sample and the size frequency distribution from a larger sample of the population to calculate the proportion of clams in each age-class. The number of clams of each age is then the product of the proportion and number of clams in the population.

The pooled length frequency distribution for each year was assumed to be representative of the overall population. A random sample of shells from 2000 was selected for aging using a target number of 10 or more clams for each 5 mm size class. Clams selected for aging were primarily from two transects (one NB and one SB) that had the largest number and size range of shells and supplementing this with large and small clams from additional transects to reach the target number.
The proportion of age j clams in the population was estimated using Equation (1) from Kutkuhn (1963):
Where

$$p_{j(st)} = \sum_{i-1}^{L} p_i p_{ij}$$

p_i is the proportion of clams in the *i*th length strata

p_{ij} is the proportion of age j clams in the *i*th length strata in the age sample

The variance in the estimate of the proportion of clams of age *j* was calculated using equation 2 from Kutkuhn

$$\mathrm{var}\left(p_{j(st)}\right) = \frac{n}{n-1} \sum_{i=1}^{L} \left[p_i^{\,2} \quad \frac{p_{ij} q_{it}}{m_i} + \frac{p_i \left(p_{ij} - p_{j(st)}\right) \quad ^2}{n} \right]$$

Where

n is the number in the length sample

m is the number in the age sample

m_i is the number of clams falling into the *j*th age group

The SE of the number of clams of each age was calculated using using Goodman's formula (Goodman 1960) which assumes that the two multiplicands are independent.

Size at Maturity

In 1995, razor clam gonads were examined to determine the sex and stage of maturity of individual clams. Razor clams from North Beach were sampled between June 12 and 17 and razor clams from South Beach were examined between July 12 and 14. During biosampling, the foot of individual razor clams was removed and uniquely identified and examined within 2 to 4 hours. A smear of the gonad section was taken from the heel (the posterior edge of the foot) and placed on a slide for examination under a compound light microscope. Samples were classified as male (M - presence of spermatozoa), female (F - presence of oocytes) or unknown (U - no visible presence of gametes) depending on the presence of living generative cells. The stage of maturity was determined qualitatively according to whether or not gametes were visible in the sample. The stage of maturity of each individual was classified as either mature (M - gametes fully mature and abundant), developing (I2 - gamete structure visible but few mature cells), immature (I1 - no visible gamete structure) or undetermined (U - moving egg-sized amoeboid cells in gonad section) based on observations of gametes in the samples.

Results

Transect sampling

The sampling dates and location of transects is shown in Table 3. Distances on North beach section were measured east from Tow Hill. Distances on South-1 and South-2 beach sections were measured in a westerly direction. North-1 beach area was consistently sampled in all years. Sampling effort on South-1 and South-2 beach areas was variable, particularly on South-2 where there was no sampling in 1995 and only one transect in1997.

There were some variations in transect sampling that will be important later in comparing the results of the two methods (Figure 5). Note that the average length of transects varied from year to year. Variation may be due to changes in the sampling procedures so that upper elevations were not sampled completely, or in some cases, discontinuing sampling due to not finding clams at upper elevations. Note also that sampling on South-2 beach section in 1994 and 1996 took place during higher tides which would contribute to lower density and biomass estimates in those years.

Abundance

Estimates of the total number of clams for the surveyed beach sections by size fraction (4 mm+, 20 mm+ and 90 mm+ and year are shown in Tables 4 and 5 for the ratio and inflation methods, respectively. The preceding size fractions refer to all clams $\geq$ 4 mm, $\geq$ 20 mm and $\geq$ 90 mm, respectively). Harvestable clams (90 mm+ clams) on North-1 show an increasing trend over the past two years and a peak in 2000. On South-1 there is no apparent trend in the number of harvestable clams. Estimates of harvestable clams on South-2 have been more variable which may be due in part the small number of transects (one transect in 1998 and two in most other years). The total number of harvestable clams on the three beach sections in 2000 was 10.5×10^6 (SE 0.8×10^6) using the ratio method and 12.5×10^6 (SE 1.0×10^6) using the inflation method. This estimate does not include the beach section west of North-1 where there were reportedly significant landings in 2000. A comparison of the ratio and inflation method estimates for clams

$\geq$ 20 mm shell length is shown in Figure 6. It shows that the ratio method estimate exceeds the inflation method in most years. The beach area assumes a constant beach width (or transect length) consisting of 150 m on North beach and 90 m on South-1 and South-2. When transect lengths are less than average length then the ratio method will extrapolate the average transect density over a fixed area which will most likely increase the overall abundance estimate. This may compensate for under-sampling in some years and be a better estimate in those years. Since the inflation method uses the actual transect length then it provides a minimum estimate of abundance (and biomass).

Figure 7 compares the abundance of clams by size fraction for the three surveyed beach sections. Figure 8 shows the relative density of clams for each beach section expressed in number of clams per meter of beach.

Clams less than 20 mm are mostly yearlings although some young of the year may be sampled in transects later in the year. Clams in this age group have been most abundant on North-1, particularly in 1994 and 1999 (Table 4, Figure 7). In 1994 there were significant numbers of clams in this age group on all three beaches. A particularly large number was also seen on North-1 in 1999 but this event was not observed on South-1 or South-2.

Clams in the 20 mm to 90 mm size range are 1 to 3 years of age that will recruit to the fishery in 1 to 2 years (See Figures 7 and 8). Potential recruits in this size range were relatively constant on North-1 and, using the ratio method results, ranged from 4.5×10^6 (in 1999) to 11.8×10^6 (in 1995) with an average of 8.6×10^6 (~1200 clams/m of beach based on 7.3 km). The average number of recruits on South-1 has been lower and less consistent (~400 clams/m of beach based on 4.6 km) and were lowest in 1999 and 2000. Potential recruits on South-2 have been much lower and more sporadic than the other two beaches (~50 clams/m of beach based on 6.75 km) although based on fewer transects.

Density of harvestable clams was greatest on North beach, followed by South-1 and South-2 (Figure 8). Also, density of harvestable clams on North-1 has had an increasing trend from 1995 to 2000.

Biomass

B_{survey}, the survey estimate of biomass of harvestable clams (SL $\geq$ 90 mm), follows a similar trend as abundance on the three beach sections (Table 6, Figure 8). South-2 was not surveyed in 1995 so the actual biomass may be slightly higher. On North-1, biomass was relatively constant from 1994 to 1998 and has increased significantly over the past two years. On South-1, biomass has fluctuated considerably. It should be noted that B_{survey} for all three beach sections is at a peak for the seven years of sampling. The 2000 survey biomass (B_{survey}) is estimated to be 1699 t (SE 157 t).

Length Frequency Distributions

Length-frequency distributions of clams from transects for different years generally showed similar trends to those discussed above under abundance (Figure 4). Figure 11 shows the length-frequency distribution of the commercial catch in 2000. Mean length of the 2000 catch sample (n=559) was 124.1 mm (SD 10.3 mm) compared to the mean length of clams > 90 mm in the population sample (n=927) of 124.1 mm (SD 14.0 mm).

Abundance by Age (2000)

Table 7 shows the age-length key constructed for 2000 and the calculation of the number of clams in each age class. First, the proportion of clams in each age class is calculated from the age-length key and the proportion of clams in each length class. Then the estimated number of clams in each age class is calculated as the product of the proportion in each age class and the population ($22.3 \times 10^6 \pm 1.9 \times 10^6$ using the ratio method results). The large number of pre-recruits in 2000 appears to consist mainly of Age 2 clams. The number of clams in the 20 mm to 90 mm size range was also calculated. This shows that approximately 68% of Age 3 clams were recruited in 2000 and 100% of Age 4 clams.

Fishing Mortality

Annual fishing mortality (F) was estimated after adjusting the survey biomass, B_{survey} to include catch up to the mean date of each survey. B_{survey} was calculated by adding the biomass for the three beach sections from Table 6. The mean survey date was the average date considering all transects for that year and ranged from May 26 to July 5. The adjusted catch, C_{adj}, was the catch up to the mean survey date estimated from Table 1 assuming that catch on each day of the month was equal. The sum of B_{survey} and C_{adj} provides an estimate of B_0, the biomass at the beginning of the year. Then F was estimated as C divided by B_0. F was found to range from 0.064 to 0.20 with an average of 0.125 (Table 8). The estimate of B_0 includes recruitment from the previous year but does not account for mortality and growth up to the mean survey date. Despite the record catch in 2000, fishing mortality was 0.12 and close to the average for the seven year period (0.129).

Size at Maturity

The stage of maturity was assessed for 531 razor clams with sizes ranging from 50 mm to 155 mm (Figure 10). Of these, 355 were classified as mature (M), 22 as developing (I2), 136 as immature (I1) and 8 as uncertain (U). No razor clams were mature at 80 mm SL, 50% were mature at 87 mm and all were mature at about 97 mm SL (Figure 3). This confirms that the commercial size limit of 90 mm protects very little of the spawning biomass of clams.

Discussion

Fishing effort was estimated based on the number of digger-days on fish slips (Table 1). However there is not a clear relationship between commercial landings and fishing effort (Figure 2). While fishing effort based on sales slip data increased sharply in 1997 there was only a modest increase in landings. Similarly landings in 2000 increased sharply with little change in effort. The number of Haida designations increased in 2000 along with fishing effort (Table 2). But it is known that some people who receive designation cards do not fish or may fish for only a short while. Landings are slightly underestimated since they do not include the recreational or Haida food fishery, both of which are believed to be small compared to the commercial fishery. Non-commercial catch was surveyed in 1994 and estimated to be less than 31,000 clams (3.1 tons based on 110 g/clam) (Jones et al. 1998).

The three beach sections were found to display significant differences in razor clam abundance and biomass that may be accounted for by different recruitment patterns. North-1 has been the main contributor to the commercial fishery and this is due to greater densities and biomass of harvestable clams compared to the other beaches. North-1 also appears to be more productive than other beach sections in terms of the relative density of pre-recruits and yearlings consistent with Bourne (1979).

Two estimates of razor clam abundance were generated from the same data using ratio and inflation estimators. The inflation estimator is based on the actual length of transects and so may be considered a conservative estimate of the actual abundance. The ratio estimator uses a fixed estimate of the area of each beach section to expand an "average" density estimate from transects. The main cause of variation between the ratio and inflation methods was due to a change in survey methods in some years that resulted in transects that were, on average, shorter or longer than usual in a particular year. The shorter transects resulted in a less complete count of clams and an underestimate of abundance and biomass. Similarly the length of transects on South-2 beach increased in 1999 and 2000 which would increase the inflation method estimate relative to the ratio method. In this case the inflation estimate provides the best estimate since it is a "minimum" estimate.

Several other population and biomass estimates were available using alternate methods with the same data. Babineau (2000) was the first to investigate several methods including the ratio and inflation methods used here and a smoothing spline estimator where a smooth curve is fit through the means rather than using a straight line interpolation and reported the results for North Beach clams (4 mm+). She found that the three methods gave very similar results. She also compared the results to a method developed by Schwarz et al. (1998) (reported in Jones et al. (1998)) where they partitioned the beaches into three strata based upon elevations above chart datum and estimated the total in each stratum using a mixed linear model. Again, results were similar. The ratio and inflation estimator were relied on in the present analysis because they are simpler and can be easily programmed in an Excel spreadsheet.

Schwarz et al (1995) (as summarized in Jones et al 1998) estimated the population on the surveyed beaches in 1994 to be 42 x 10^6 (SE 34%) clams $\geq$ 4 mm, 16.3 x 10^6 (SE 16%) clams $\geq$ 20 mm, and 5.82 x 10^6 (SE 21%) clams $\geq$90 mm length. His estimates were obtained by dividing each beach section into three levels (< 1 m, 1 to 2 m, and > 2 m elevation) and multiplying the mean density by the area of the beach calculated for each level. Estimates using the ratio method were 45.0 x 10^6, 18.3 x 10^6 and 7.2 x 10^6 clams (Table 4) which are 7%, 12% and 24% higher. Estimates using the inflation method 37.3 x 10^6, 15.2 x 10^6 and 6.0 x 10^6 clams (Table 5) were near or slightly lower than the estimate using three beach levels. The 1994 biomass estimate using the inflation method (Table 6) is 613 t which is very close to the biomass using three beach levels of 636 t (Jones et al. 1998).

In some years transects were not a random sample from the beach but were taken systematically along the beach. Due to this, estimated precisions of the population estimates are likely overestimates of the true precision because densities on transects that are very close together (e.g. within a few meters) are likely to be positively correlated. Because of the length of the beach and the wide spacing of the transects that occurs in most samples, even if allocated completely at random, this is likely not too much of a problem. Estimates of numbers are still unbiased.

We previously estimated M to be 0.27 and F_{MSY} to be 118 tonnes based on the 1994 biomass of 624 tonnes (which would correspond to an F of 0.16) (Jones et al. 1998). The estimate assumed equilibrium conditions and uses a single value of biomass and catch. A minimum estimate of biomass at the end of 2000 is 1,639 t corresponding to $B_{survey,\ 2000}$, less catch after the mean survey date ($C - C_{adj}$), assuming that growth and mortality balance each other. A large recruitment of 3 year old clams is expected in 2001. The current 2001 catch ceiling of 235.8 t corresponds to 14% of the biomass at the end of 2000 not allowing for recruitment.

The age-at-maturity results for North Beach are consistent with studies in other areas (Weymouth et al. 1925). Razor clams at North Beach were found to mature between 80 and 97 mm. Studies at Cordova and Swikshak in Alaska found that 50% were mature at 105 mm and 99.1 mm, respectively, while in Washington, all clams spawn as two year olds at about 103 mm. This confirms that the 90 mm size limit does not protect much of the spawning population. The basis for the current size limit has not been investigated. However Quayle and Bourne (1972) reported that the size limit in the late 1960s was similar (3 ½ inches). It may have been established as a means of keeping small clams off the processing line during the time when clams were processed for food. This emphasizes the importance of other measures such as quotas to meet this need.

An increase in the minimum size limit has been discussed with diggers as an alternative or complementary measure to a quota. But there are concerns that a larger size limit may increase discards and mortality due to breakage. Also a digger's efficiency would be reduced by the proportion of discards in the 90 to 100 mm size range. The impact of an increase from 90 mm to 110 mm on a digger's efficiency can be roughly estimated. Catch in 2000 was selective for larger clams but no information was available about rates of discard of smaller clams. Catch in 1994 had a similar size distribution with 1.5% sublegals (Jones et al. 1998). If the size limit were raised to 110 mm, Figure 4 shows that discard rates (clams in the 90-110 size range compared to those in the 90 mm+ size range) could be as high as 30 or 40% in some years e.g. 1996 or 1998). As well, it has been observed by the primary author that breakage of clams can be significant and depends on a diggers' experience (from trials that harvested razor clams for a live market). If an increased size limit were to be considered, further analysis should be conducted to establish a biological basis based on reproductive potential and discard rates should be assessed.

The numbers of Age 2 and 3 clams, some of which will survive and recruit in the next one to two years, are estimated to be 8.97×10^6 (SE 0.81×10^6) and 2.23×10^6 (SE 0.28×10^6). As well, approximately 68% of Age 3 and 100% of Age 4 clams were recruited in 2000. This is comparable to the estimate for 1994 of 82% of Age 3 and 100% of Age 4 clams as recruited to the fishery (Jones et al. 1998). Age samples are available from earlier years but have not been analyzed. Once completed, this should provide information on survival and recruitment over time.

The size-at-maturity assessments were consistent but not detailed. Numbers of oocytes or sperm were not counted. In general, gonads classed as mature were smears with close to 100% gamete cover and those classed as I2 had a few gametes visible scattered throughout the slide. In all cases, the same section and approximate amount of gonad material was smeared onto the slide so the maturity estimates are comparative.

There are a number of factors that would tend to make quotas based on the surveyed biomass conservative. There are known to be unexploited subtidal populations of razor clams that contribute to recruitment on North Beach and vice versa. While the magnitude is unknown, this provides insurance if there ever were a collapse of stock in the intertidal area. There have been a number of self-limiting factors in the fishery. The most important are tides and daylight hours that restrict full access to lower levels of the beach, where clam densities are greatest. Weather and strong northwest winds can further reduce the fishing season. On the other hand there appears to be a renewed market for razor clam for the food market with slightly higher prices and interest in maintaining a year-round fishery.

Biomass at the end of 2000 was estimated to 1639 t (C.L. 1953 and 1325 t). A harvest rate of 12.3% would give a range of harvest of 163 to 240 t. This harvest rate is approximately 2/3 of the 1994 estimate of F_{MSY} (18.5% based on an exploitable biomass of 636 t and landings of 118 t) and 41% of estimated annual mortality, M. This estimate does not include recruitment which is expected to be much better than average in 2001.

Recommendations

We make the following recommendations concerning the 2001 management plan and future surveys and data analysis:

1. The current catch limit of 235.8 t would appear to be in the upper range of potential harvest based on the biomass at the end of the year and not accounting for recruitment. However the proposed rate of harvest is not unreasonable given that biomass is at an historic high and recruitment for 2001 is expected to be well above average. Also there were some landings from outside the survey area that would tend to overestimate historic fishing mortality and underestimate available biomass.

2. Surveys using hydraulic sampling should be continued as a tool for monitoring razor clam abundance and biomass that are important for estimating future quotas. Alternative approaches should be investigated in consultation with fishers and local processors such as a fixed quota that could be applied over a period of several years and a constant harvest rate approach.

3. A biologically-based size limit is a possible alternative to quotas as a means for managing the fishery. However, size limits may not be necessary if a quota management system is in place. A disadvantage of a size limit would be that discards would likely increase and mortalities would need to be monitored. There is currently no information about the rate of discard and mortality using the 90 mm size limit. If an increased size limit were to be considered, further analysis should be conducted to establish a biological basis based on reproductive potential and discard rates should be assessed.

4. The ability to estimate numbers of clams at age is promising as a tool for estimating recruitment. Age analysis of clams from 1996 to 1999 should be completed and recruitment forecasting methods investigated.

5. The 2001 management plan provided for monitoring of landings and effort by beach section and surveys of North beach east of the surveyed section. These efforts should be continued as a means to avoid possible overexploitation of individual beaches.

6. The current minimum size limit allows most clams to reach maturity before becoming available to the fishery but may not provide an opportunity for them to spawn. It may also serve other purposes such as keeping small clams off the processing lines. As described earlier, size limits are not currently used for commercial fisheries in Alaska and Washington and were found to result in high wastage of undersize clams in Washington. With the introduction of quotas as a conservation measure DFO and CHN may want to consider removing size limits from the current management plan.

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Table 1. Razor clam landings, effort and value, 1994 to 2000.

Year	Month	# days fished	Effort digger-days	Landings Pounds	Landings kg	Value
1994	January			-	-	
	February			441	200	
	March			10,293	4,668	
	April			441	200	
	May			67,461	30,595	
	June			56,879	25,705	
	July			-	-	
	August			-	-	
	September			-	-	
	October			4,850	2,200	
	November			-	-	
	December			-	-	
	Total			232,365	105,380	
1995	January	-	-	-	-	-
	February	-	-	-	-	-
	March	2	33	2,373	1,076	$1,898.00
	April	5	463	23,159	55,854	$98,527.00
	May	4	362	87,339	39,610	$69,871.00
	June	3	183	47,907	21,727	$38,326.00
	July	5	154	20,401	9,252	$16,321.00
	August	3	44	6,991	3,171	$5,593.00
	September	1	7	358	162	$286.00
	October	-	-	-	-	-
	November	-	-	-	-	-
	December	-	-	-	-	-
	Total	23	1,246	288,528	130,852	$230,822.00
1996	January	-	-	-	-	-
	February	-	-	-	-	-
	March	-	-	-	-	-
	April	3	65	8,507	3,858	$6,806.00
	May	4	261	43,517	19,736	$34,814.00
	June	5	473	75,548	34,262	$60,438.00
	July	2	144	38,189	17,319	$35,169.00
	August	-	-	-	-	-
	September	-	-	-	-	-
	October	-	-	-	-	-
	November	-	-	-	-	-
	December	-	-	-	-	-
	Total	14	943	165,761	75,175	$137,226.00
1997	January	-	-	-	-	-
	February	-	-	-	-	-
	March	13	121	9,353	4,242	$7,796.00
	April	17	620	61,983	28,110	$49,586.00
	May	19	898	81,514	36,968	$66,697.00
	June	19	610	45,290	20,540	$36,620.00
	July	15	310	18,101	8,209	$15,840.00
	August	8	87	7,203	3,267	$7,119.00

	September	7	148	8,372	3,797	$8,372.00
	October	3	24	2,231	1,012	$2,231.00
	November	7	110	5,779	2,621	$5,779.00
	December	-	-	-	-	-
	Total	108	2,928	239,826	108,764	$200,040.00
1998	January	2	8	324	147	$324.00
	February	10	55	2,920	1,324	$2,920.00
	March	15	428	19,938	9,042	$20,677.00
	April	14	255	20,348	9,228	$19,673.00
	May	-	-	-	-	-
	June	10	50	7,060	3,202	$6,393.00
	July	8	-	34,116	15,472	$26,610.00
	August	4	-	2,157	978	$1,682.00
	September	-	-	-	-	-
	October	-	-	-	-	-
	November	2	21	1,076	488	$1,101.00
	December	-	-	-	-	-
	Total	65	817	87,938	39,881	$79,381.00
1999	January	-	-	-	-	-
	February	-	-	-	-	-
	March	10	65	12,277	5,580	$12,119.00
	April	6	177	28,425	12,920	$22,967.00
	May	20	414	42,497	19,317	$3,012.00
	June	20	493	58,302	26,501	$40,811.00
	July	1	20	3,598	1,635	$3,439.00
	August	14	98	7,454	3,388	$6,546.00
	September	12	90	9,376	4,262	$1,897.00
	October	9	48	5,473	2,488	$5,301.00
	November	8	28	1,635	743	$1,516.00
	December	4	21	2,804	1,275	$1,664.00
	Total	104	1454	171,841	78,109	$127,272.00
2000 *	January	4	8	1,927	876	$1,734.00
	February	11	27	7,220	3,282	$6,550.00
	March	19	129	32,080	14,582	$27,689.00
	April	23	344	110,204	50,093	$89,956.00
	May	23	299	95,148	43,249	$87,063.00
	June	23	498	142,830	64,923	$132,200.00
	July	20	317	86,254	39,479	$79,971.00
	August	14	150	45,209	20,550	$39,876.00
	September	-	-	-	-	-
	October	-	-	-	-	-
	November	-	-	-	-	-
	December	-	-	-	-	-
	Total	137	1772	521,472	237,033	$465,038.00

Data for 1994 was collected by DFO. Data from 1995-2000 was collected by Haida Fisheries Program. Effort in digger-days is compiled from sales slips and assumes each sales slip is for one day fishing.

* The fishery closed for the season on September 7, 2000.

Table 2. Licences and Designations in the Haida Gwaii Razor clam fishery, 1995 - 2000.

Year	Number of Commercial Licences	Number of Haida Designations
1995	6	214
1996	6	143
1997	6	150
1998	6	94
1999	6	155
2000	6	269

Source: Number of licences was provided by DFO licencing branch. Number of designations was provided by the Haida Fisheries Program.

Table 3. Date and location of beach transects, 1994-2000

Year	Beach Section					
	North		South1		South2	
	Date	Location (km)	Date	Location (km)	Date	Location (km)
1994	July 26	1.3	April 29	0.4	Aug. 10	1.7
	March 28	2.5	April 27	0.8	Aug. 8	3.0
	April 26	2.7	Aug. 9	1.4	July 25	4.4
	April 28	4.0	May 27	3.6		
	March 29	4.8				
	May 24	4.9				
	May 25	5.5				
	May 28	7.6				
1995	June 15	0.6	July 13	0.8		
	June 16	1.8	Aug. 11	2.0		
	July 11	3.0	July 14	3.2		
	June 12	4.3	July 12	4.4		
	June 17	5.4				
	June 14	6.6				
	Aug. 10	7.2				
1996	June 1	0.9	July 1	0.3	Aug. 29	0.6
	June 5	2.0	July 4	0.6	July 5	2.6
	June 2	3.1	June 30	1.5		
	June 3	4.2	July 2	3.9		
	May 7	5.3				
	June 4	6.4				
1997	Aug. 21	0.3	June 5	2.1	June 6	0.6
	May 8	1.4	July 21	3.3	Aug. 19	2.6
	July 20	2.5			July 22	3.6
	May 6	4.7				
	May 7	5.8				
	May 9	6.9				
1998	June 25	0.4	May 28	0.8	June 26	2.7
	Apr. 29	1.4	May 26	2.4		
	May 25	2.4	May 27	3.4		
	June 24	4.0				
	Apr. 27	5.2				
	Apr. 28	6.4				
1999	May 16	1.4	June 16	1.0	June 15	0.6
	May 15	2.5	May 17	2.1	July 12	1.6
	Aug. 12	3.0				
	Aug 11	3.6				
	July 15	4.7				
	July 14	5.8				
2000	June 4	1.1	July 4	0.6	July 30	0.9
	July 2	2.2	Aug. 1	1.7	Aug. 2	2.4
	June 3	3.3	June 2	2.2		
	July 31	4.4	June 5	3.9		
	July 1	5.5				
	July 3	6.6				

Table 4. Razor clam population estimate by size class using ratio method, 1994-2000

Dots (.) indicate no samples taken or no estimate of precision could be determined because only a single transect was taken.

Size Class, Shell Length ≥	Year	Beach Section								
		North-1			South-1			South-2		
		No. of transects	No. of clams x 10^6	SE	No. of transects	No. of clams x 10^6	SE	No. of transects	No. of clams x 10^6	SE
4 mm+	1994	8	36.4	7.8	4	6.2	2.7	3	2.4	1.1
	1995	7	19.0	1.7	4	4.9	0.5	.	.	.
	1996	6	21.8	2.2	4	4.7	0.7	2	2.1	0.8
	1997	6	18.8	2.4	2	2.6	1.8	3	1.5	1.0
	1998	6	15.6	1.6	3	3.4	1.2	1	0.5	.
	1999	6	62.5	24.6	2	3.1	1.8	2	1.9	0.3
	2000	6	29.1	6.1	4	3.8	1.4	2	3.4	0.3
20 mm+	1994	8	14.2	1.2	4	3.5	0.5	3	0.6	0.2
	1995	7	15.5	1.4	4	4.8	0.5	.	.	.
	1996	6	14.0	1.6	4	4.7	0.9	2	2.1	0.8
	1997	6	14.8	2.3	2	2.6	1.8	3	1.5	1.0
	1998	6	14.8	1.4	3	3.4	1.2	1	0.5	.
	1999	6	11.0	1.4	2	3.1	1.8	2	1.9	0.3
	2000	6	15.9	1.7	4	3.1	0.8	2	3.3	0.3
90 mm+	1994	8	5.3	0.7	4	1.6	0.4	3	0.3	0.1
	1995	7	3.7	0.6	4	1.8	0.4	.	.	.
	1996	6	4.6	0.5	4	2.3	0.6	2	1.7	0.6
	1997	6	5.7	1.2	2	0.8	0.5	3	0.8	0.8
	1998	6	6.6	0.8	3	1.5	0.4	1	0.5	.
	1999	6	6.5	0.8	2	2.2	1.4	2	1.7	0.2
	2000	6	7.5	0.6	4	1.9	0.5	2	2.4	0.3

N.B.
Size categories are clams with shell length (SL) ≥ 4 mm (4 mm+), SL ≥ 20 mm (20 mm+) and SL ≥ 90 mm (90 mm+).
Clams of SL ≥ 90 mm are fully available to the commercial fishery. Clams recruit to the fishery at 3 to 4 years of age.
Clams of SL ≥ 20 mm include clams 20 to 90 mm SL that recruit to the fishery in 1-2 years (these clams are 1-3 years of age).
Clams of SL ≥ 4 mm include clams 4 to 20 mm SL that recruit to the fishery in 2-3 years (these clams are 0-1 years of age).

Table 5. Razor clam population estimate by size class using inflation method, 1994-2000

Dots (.) indicate no samples taken or no estimate of precision could be determined because only a single transect was taken.

Size Class, Shell Length ≥	Year	Beach Section								
		North-1			South-1			South-2		
		No. of transects	No. of clams x 10^6	SE	No. of transects	No. of clams x 10^6	SE	No. of transects	No. of clams x 10^6	SE
4 mm+	1994	8	28.8	6.0	4	5.9	2.8	3	2.6	1.7
	1995	7	15.3	1.5	4	4.6	0.5	.	.	.
	1996	6	13.6	1.6	4	3.7	0.4	2	2.2	0.6
	1997	6	9.6	1.4	2	1.8	1.0	3	1.6	0.9
	1998	6	11.1	1.0	3	2.2	1.1	1	0.5	.
	1999	6	51.6	21.0	2	2.9	1.7	2	2.7	0.9
	2000	6	27.3	4.7	4	3.9	1.6	2	5.2	0.5
20 mm+	1994	8	11.2	1.4	4	3.3	0.5	3	0.7	0.4
	1995	7	12.4	1.7	4	4.5	0.5	.	.	.
	1996	6	8.8	0.9	4	3.7	0.4	2	2.2	0.6
	1997	6	7.6	1.3	2	1.8	0.9	3	1.6	0.9
	1998	6	10.6	1.1	3	2.2	1.1	1	0.5	.
	1999	6	9.0	0.9	2	2.9	1.7	2	2.7	0.9
	2000	6	14.9	1.1	4	3.1	0.9	2	4.9	0.5
90 mm+	1994	8	4.2	0.7	4	1.5	0.4	3	0.3	0.1
	1995	7	3.0	0.5	4	1.7	0.3	.	.	.
	1996	6	2.9	0.4	4	1.8	0.4	2	1.7	0.5
	1997	6	2.9	0.7	2	0.5	0.3	3	0.9	0.8
	1998	6	4.7	0.7	3	1.0	0.4	1	0.4	.
	1999	6	5.4	0.6	2	2.1	1.3	2	2.4	0.6
	2000	6	7.0	0.7	4	1.9	0.6	2	3.6	0.4

N.B.
Size categories are clams with shell length (SL) ≥ 4 mm (4 mm+), SL ≥ 20 mm (20 mm+) and SL ≥ 90 mm (90 mm+).
Clams of SL ≥ 90 mm are fully available to the commercial fishery. Clams recruit to the fishery at 3 to 4 years of age.
Clams of SL ≥ 20 mm include clams 20 to 90 mm SL that recruit to the fishery in 1-2 years (these clams are 1-3 years of age).
Clams of SL ≥ 4 mm include clams 4 to 20 mm SL that recruit to the fishery in 2-3 years (these clams are 0-1 years of age).

Table 6. Razor clam exploitable biomass using inflation method, 1994-2000

Size Class, Shell Length ≥	Year	Beach Section								
		North-1			South-1			South-2		
		No. of transects	Biomass t	SE	No. of transects	Biomass t	SE	No. of transects	Biomass t	SE
90mm+	1994	8	434	80	4	152	40	3	27	12
	1995	7	362	61	4	172	40	.	.	.
	1996	6	300	42	4	159	34	2	142	34
	1997	6	384	78	2	62	31	3	101	90
	1998	6	499	87	3	94	45	1	38	.
	1999	6	660	63	2	244	159	2	254	99
	2000	6	982	121	4	260	87	2	457	50

Table 7. 2000 Age-Length Key and Number of Clams by Age.

(1) Age length key

Number of clams by age in each length class:
N.B. Length class 20 is 20-24 mm

Length class mm	Age in years 1	2	3	4	5	6	7	8	9	10	Total
20	2	0	0	0	0	0	0	0	0	0	2
25	4	0	0	0	0	0	0	0	0	0	4
30	2	8	0	0	0	0	0	0	0	0	10
35	1	11	0	0	0	0	0	0	0	0	12
40	0	12	0	0	0	0	0	0	0	0	12
45	0	11	0	0	0	0	0	0	0	0	11
50	0	12	0	0	0	0	0	0	0	0	12
55	0	11	0	0	0	0	0	0	0	0	11
60	0	12	0	0	0	0	0	0	0	0	12
65	0	7	0	0	0	0	0	0	0	0	7
70	0	4	0	0	0	0	0	0	0	0	4
75	0	1	4	0	0	0	0	0	0	0	5
80	0	4	10	0	0	0	0	0	0	0	14
85	0	0	9	0	0	0	0	0	0	0	9
90	0	0	14	0	0	0	0	0	0	0	14
95	0	0	11	1	0	0	0	0	0	0	12
100	0	0	10	2	0	0	0	0	0	0	12
105	0	0	4	5	0	0	0	0	0	0	9
110	0	0	2	8	1	0	0	0	0	0	11
115	0	0	0	3	8	2	0	0	0	0	13
120	0	0	0	0	7	4	0	0	0	0	11
125	0	0	0	0	0	8	1	1	0	0	10
130	0	0	0	0	1	2	6	1	0	0	10
135	0	0	0	0	0	2	1	9	2	2	16
140	0	0	0	0	0	0	3	4	2	2	11
145	0	0	0	0	0	0	2	1	3	3	9
150	0	0	0	0	0	0	1	0	2	2	5
155	0	0	0	0	0	0	0	0	0	**1**	**1**
160	0	0	0	0	0	0	0	0	0	**1**	**1**
										Made up values	

(2) The length distribution

Length	Count	% Freq
20	0	0.0000
25	14	0.0082
30	28	0.0164
35	83	0.0485
40	112	0.0655
45	150	0.0877
50	98	0.0573
55	79	0.0462
60	55	0.0321
65	53	0.0310
70	33	0.0193
75	22	0.0129
80	20	0.0117
85	23	0.0134
90	21	0.0123
95	33	0.0193
100	46	0.0269
105	43	0.0251
110	41	0.0240
115	46	0.0269
120	83	0.0485
125	131	0.0766
130	172	0.1005
135	151	0.0883
140	87	0.0508
145	60	0.0351
150	18	0.0105
155	7	0.0041
160	2	0.0012
	1711	1.0000

(3) Total clams on the beach

Total Clams	est (M)	se (M)
	22.3	1.9

Table 7. (cont.)

Table 7. 2000 Age-Length Key and Number of Clams by Age (cont.)

(4) Estimate the proportion of clams in each age class from each length class.

Length class mm	Age in years 1	2	3	4	5	6	7	8	9	10
20	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30	0.200	0.800	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
35	0.083	0.917	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
45	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
55	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
65	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
70	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
75	0.000	0.200	0.800	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80	0.000	0.286	0.714	0.000	0.000	0.000	0.000	0.000	0.000	0.000
85	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
90	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
95	0.000	0.000	0.917	0.083	0.000	0.000	0.000	0.000	0.000	0.000
100	0.000	0.000	0.833	0.167	0.000	0.000	0.000	0.000	0.000	0.000
105	0.000	0.000	0.444	0.556	0.000	0.000	0.000	0.000	0.000	0.000
110	0.000	0.000	0.182	0.727	0.091	0.000	0.000	0.000	0.000	0.000
115	0.000	0.000	0.000	0.231	0.615	0.154	0.000	0.000	0.000	0.000
120	0.000	0.000	0.000	0.000	0.636	0.364	0.000	0.000	0.000	0.000
125	0.000	0.000	0.000	0.000	0.000	0.800	0.100	0.100	0.000	0.000
130	0.000	0.000	0.000	0.000	0.100	0.200	0.600	0.100	0.000	0.000
135	0.000	0.000	0.000	0.000	0.000	0.125	0.063	0.563	0.125	0.125
140	0.000	0.000	0.000	0.000	0.000	0.000	0.273	0.364	0.182	0.182
145	0.000	0.000	0.000	0.000	0.000	0.000	0.222	0.111	0.333	0.333
150	0.000	0.000	0.000	0.000	0.000	0.000	0.200	0.000	0.400	0.400
155	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
160	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

(5) Overall proportion and estimated standard error SE is found using equation (2) from kutkuhn

											Check
Overall	0.01550	0.40245	0.09996	0.04368	0.05965	0.11416	0.09725	0.08974	0.03617	0.04143	1.00000
var pt 1	0.00002	0.00003	0.00004	0.00005	0.00016	0.00037	0.00040	0.00033	0.00012	0.00012	first term of eqn 2
var pt ii	0.00001	0.00013	0.00004	0.00001	0.00002	0.00003	0.00002	0.00002	0.00000	0.00001	second term of eqn 2
se	0.00495	0.01268	0.00918	0.00778	0.01319	0.01984	0.02043	0.01866	0.01132	0.01145	overall SE

(6) Estimated number of clams in each age class. Goodman's (1961, JASA) formula used to estimate SE

											Check
Clams (M)	0.35	8.97	2.23	0.97	1.33	2.55	2.17	2.00	0.81	0.92	22.3
se	0.11	0.81	0.28	0.19	0.31	0.49	0.49	0.45	0.26	0.27	

(7) Proportion and estimated number of clams between 20 and 90 mm

Prop.	0.01550	0.40245	0.03208	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Clams (M)	0.35	8.97	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(8) Proportion of age 3 clams recruited 0.679

Table 8. Catch and fishing mortality

Year	B_{survey}	SE	Catch, C	Mean survey	$C_{adjusted}$	Bo	F
	t	t	t	date	t	t	t
1994	613	90	105	2-Jun	37	650	0.162
1995	534+	73	131	5-Jul	120	654+	0.200
1996	601	64	75	20-Jun	46	647	0.113
1997	547	80	109	21-Jun	84	631	0.173
1998	631	98+	40	26-May	20	651	0.064
1999	1158	198	78	26-Jun	64	1222	0.064
2000	1699	157	237	2-Jul	177	1876	0.126

(.) Dots indicate no samples taken or no estimate of precision could be determined because only a single transect was taken.

\+ Indicates a minimum estimate due to no estimate of South-2 biomass in 1995 and of South-2 SE in 1998.

Figure 1. Haida Gwaii razor clam landings, 1923-2000

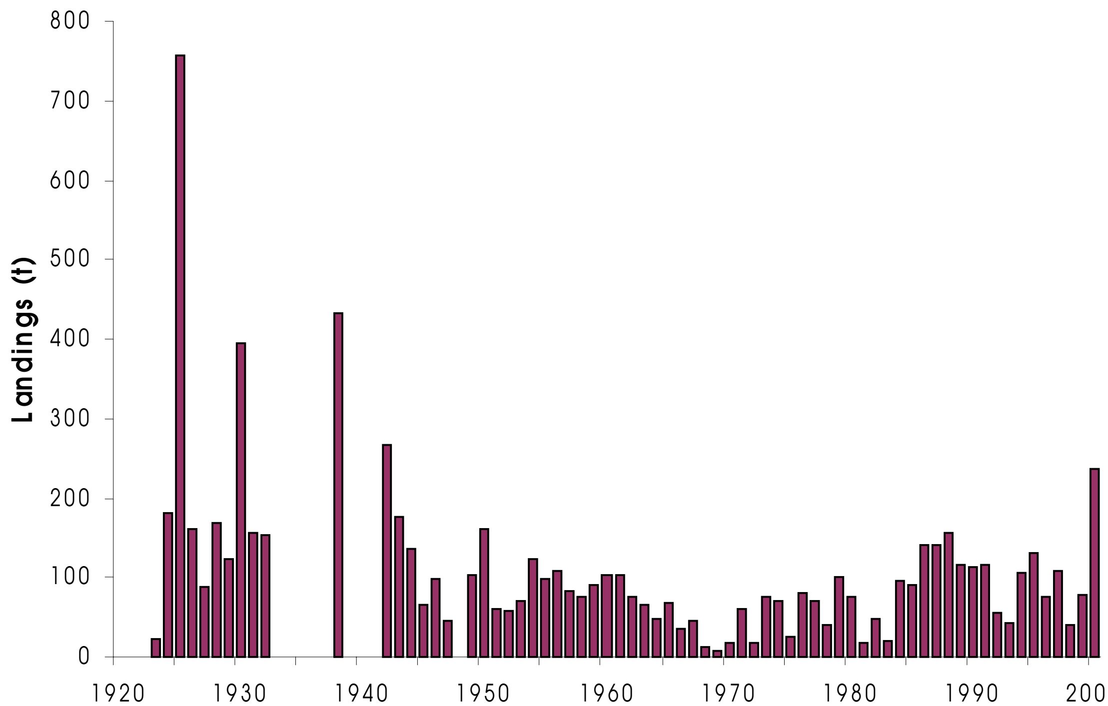


Figure 2. Razor clam landings, effort, value and CPUE, 1994-2000

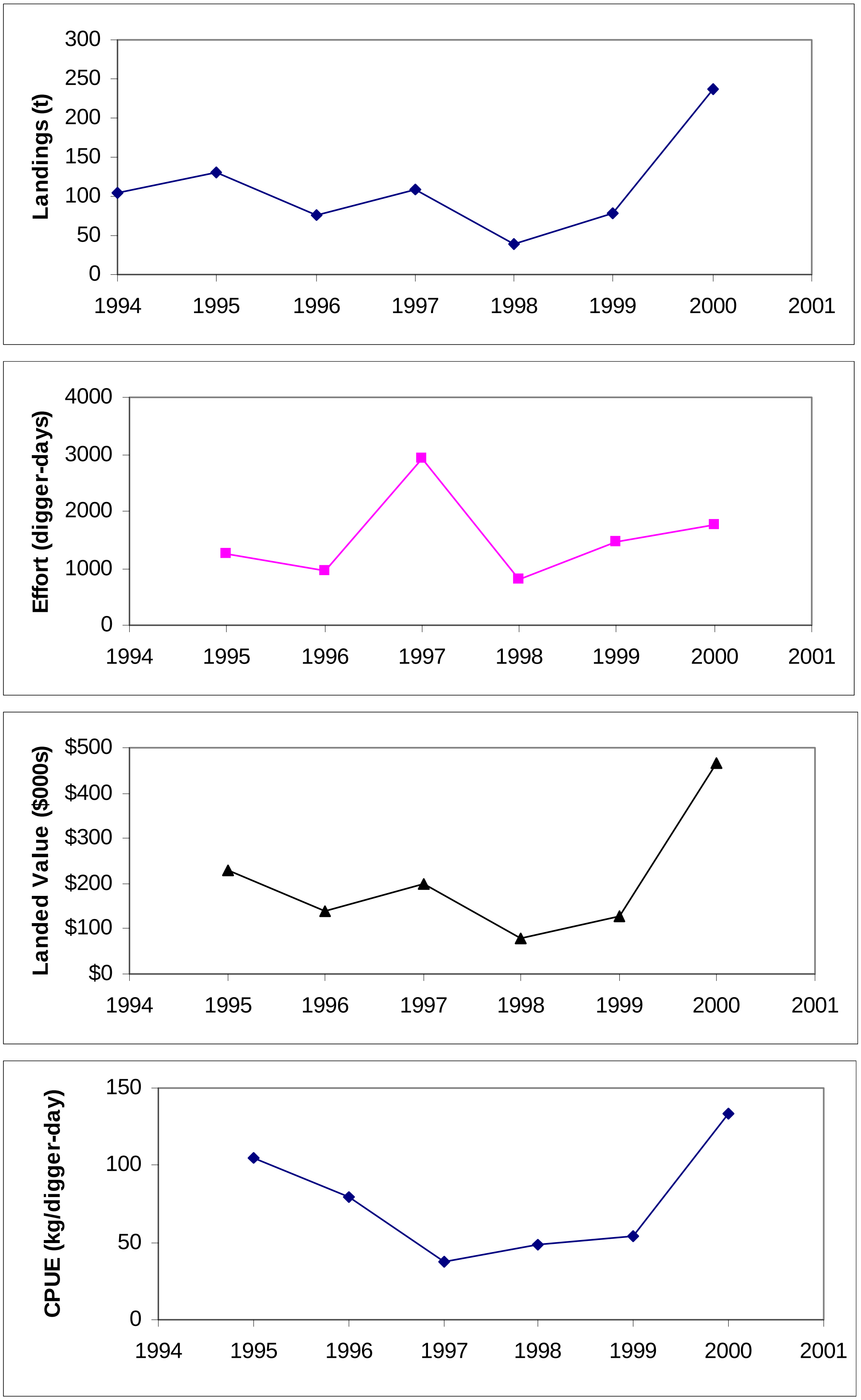


Figure 3. Map showing Haida Gwaii razor clam beaches

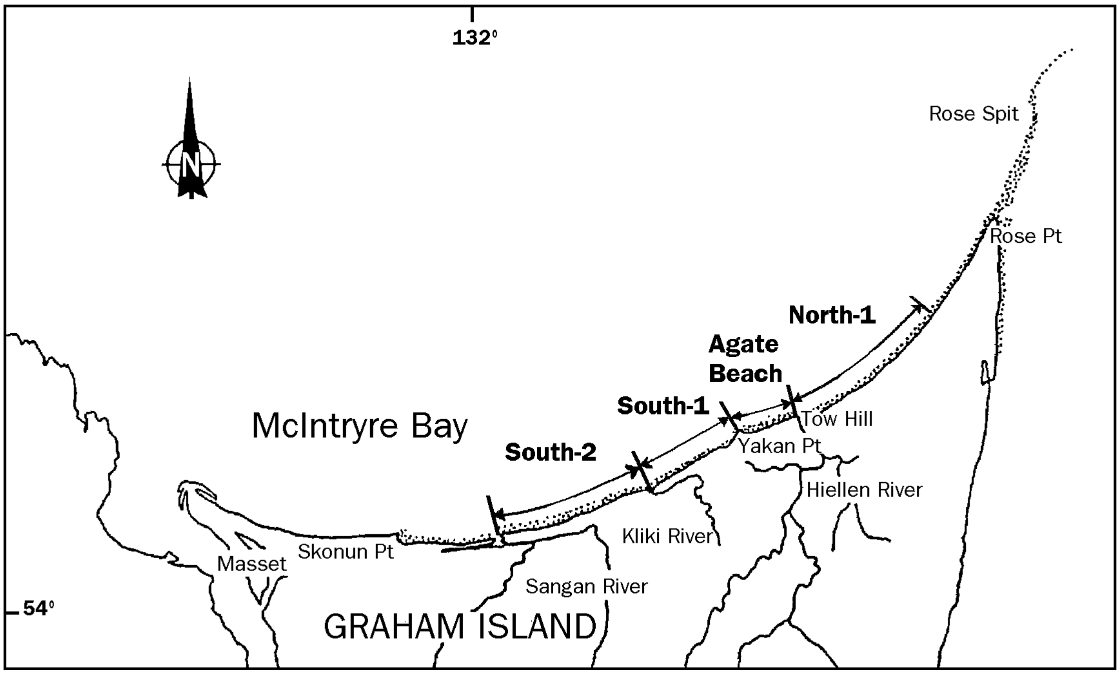


Figure 4. Razor clam length frequency distributions, 1994-2000
(clams < 20 mm not included)

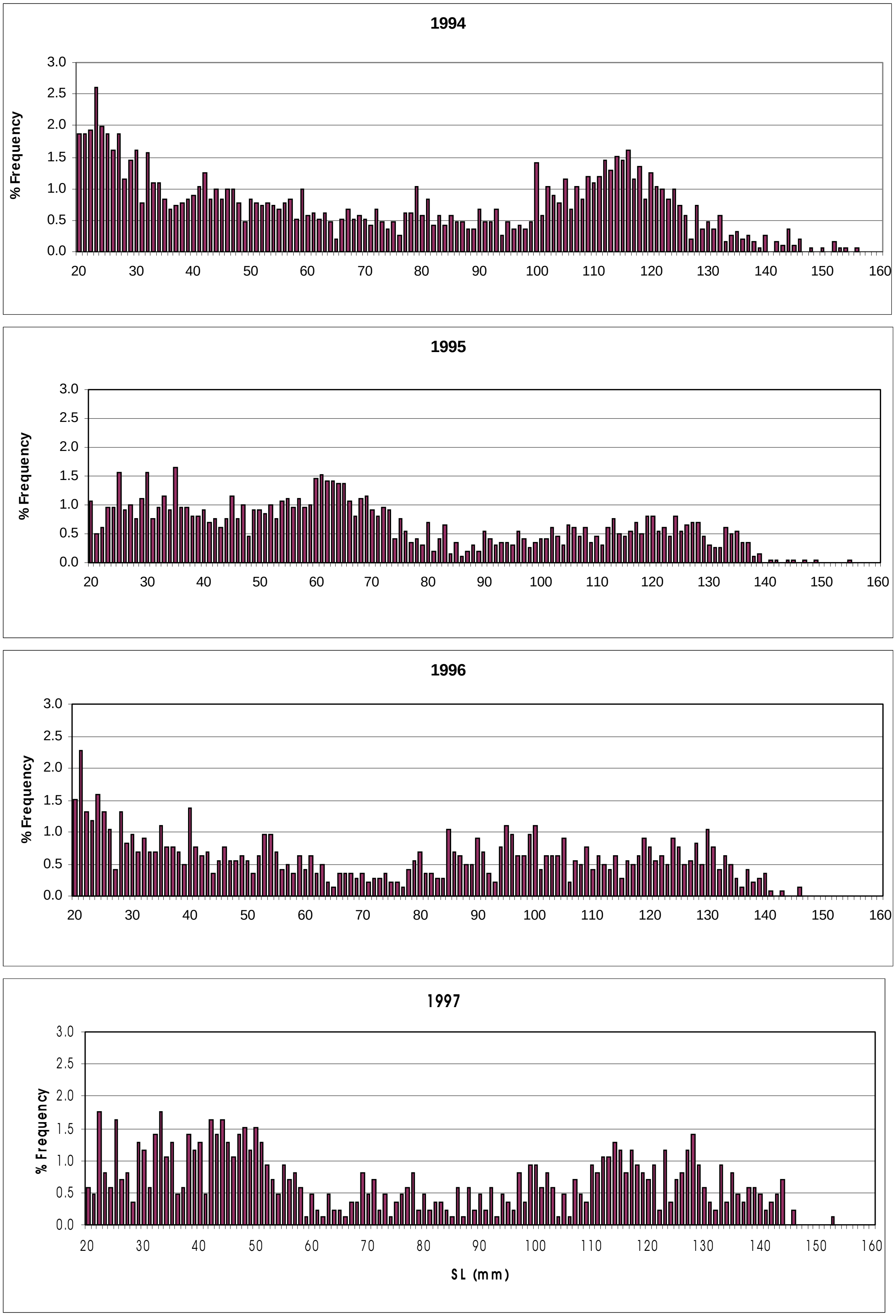
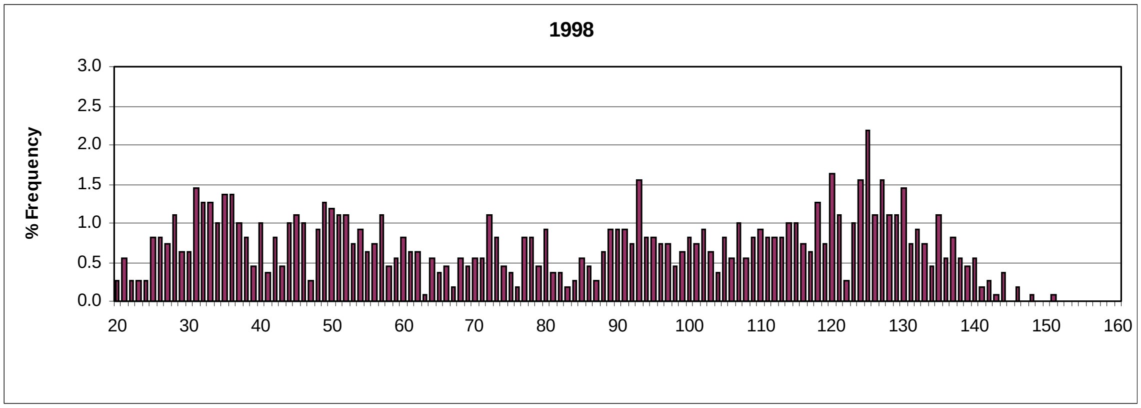
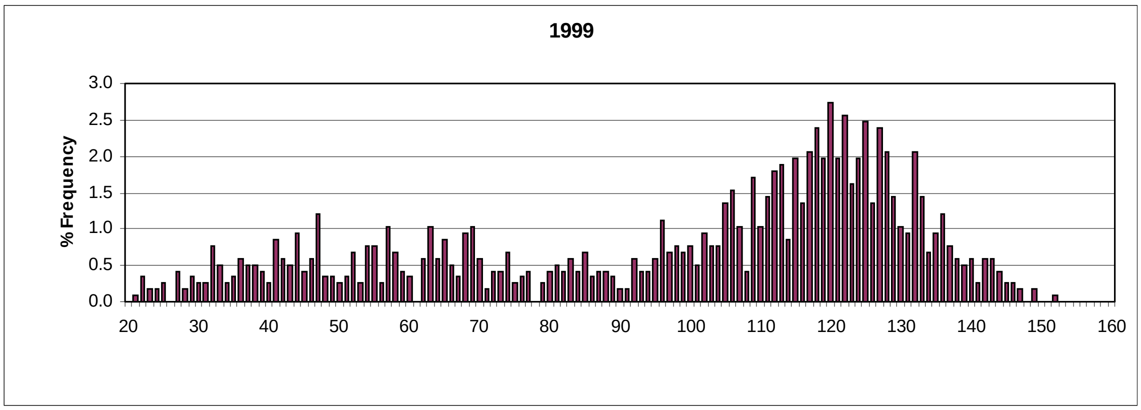


Figure 4 (cont.)





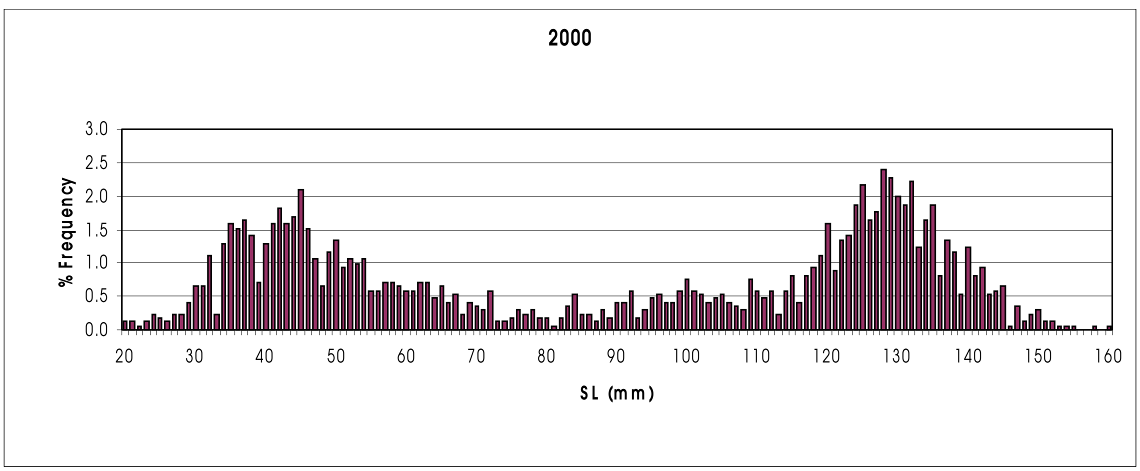
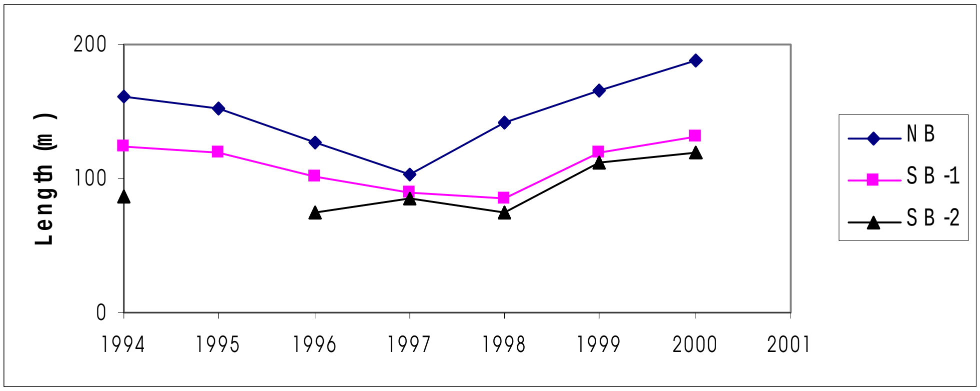
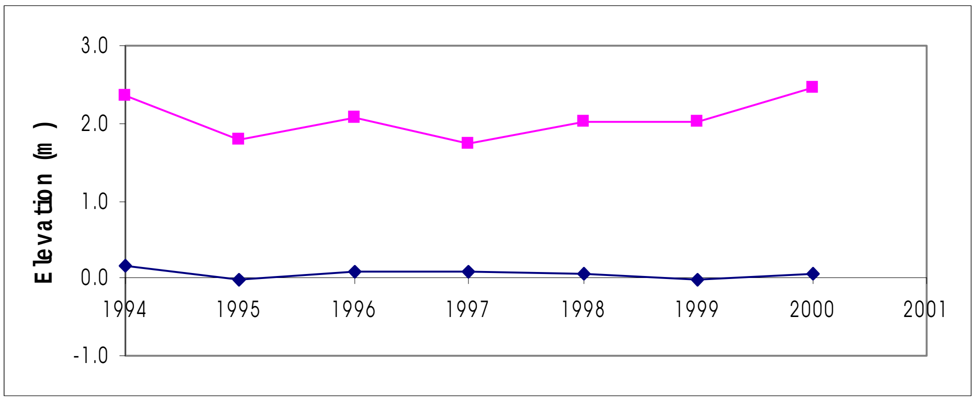


Figure 5. Comparison of average transect length and starting and ending elevations by beach section

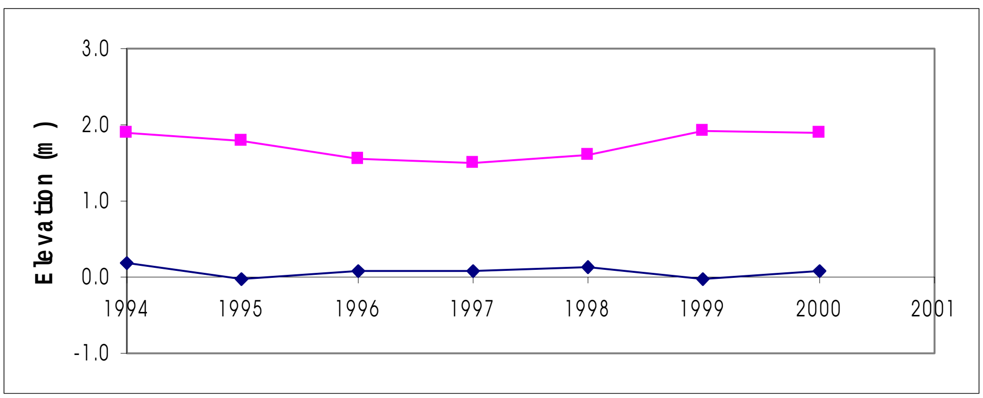
a)



b) North-1



c) South-1



d) South-2

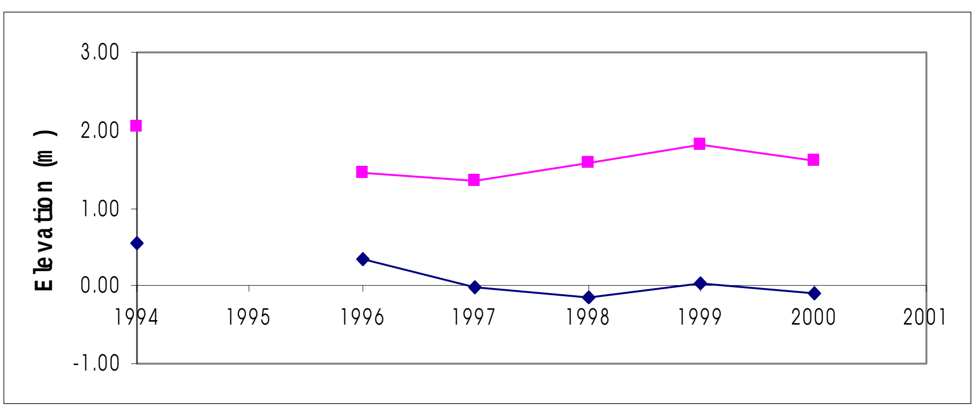
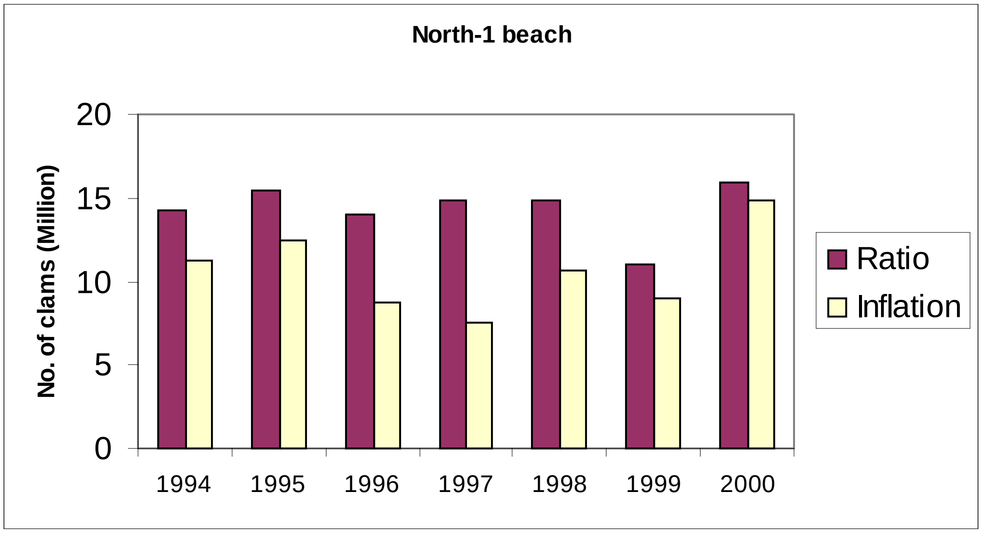
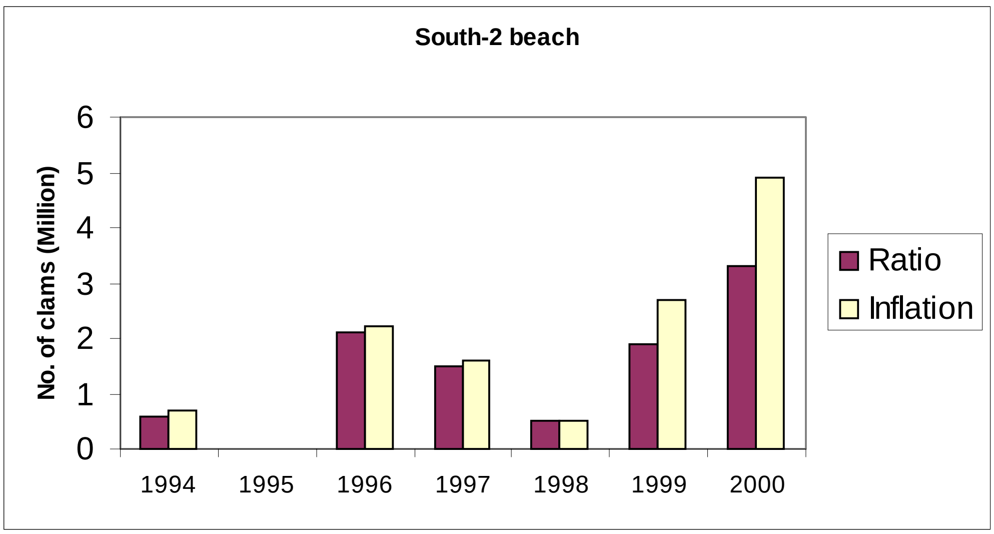


Figure 6. Comparison of ratio and inflation method to calculate abundance of 20 mm+ clams





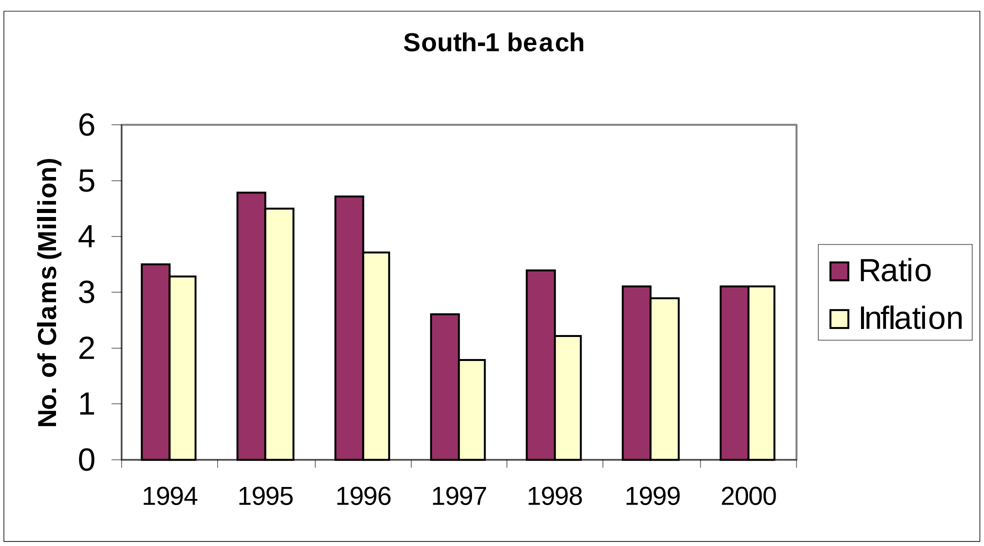


Figure 7. Razor clam population trends (ratio method) 1994-2000

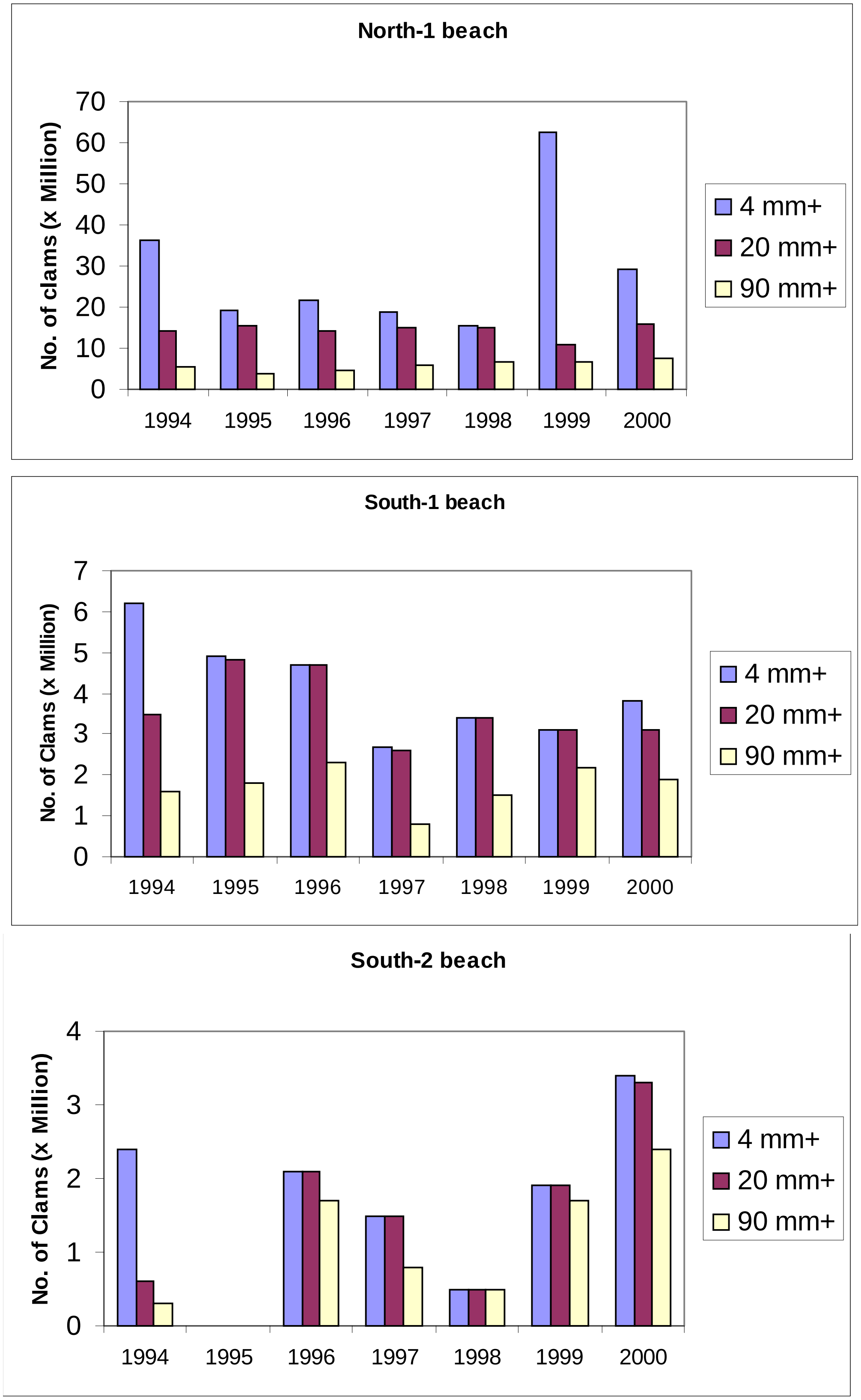


Figure 8. Density of yearlings, pre-recruits and 90 mm+ clams by beach 1994-2000

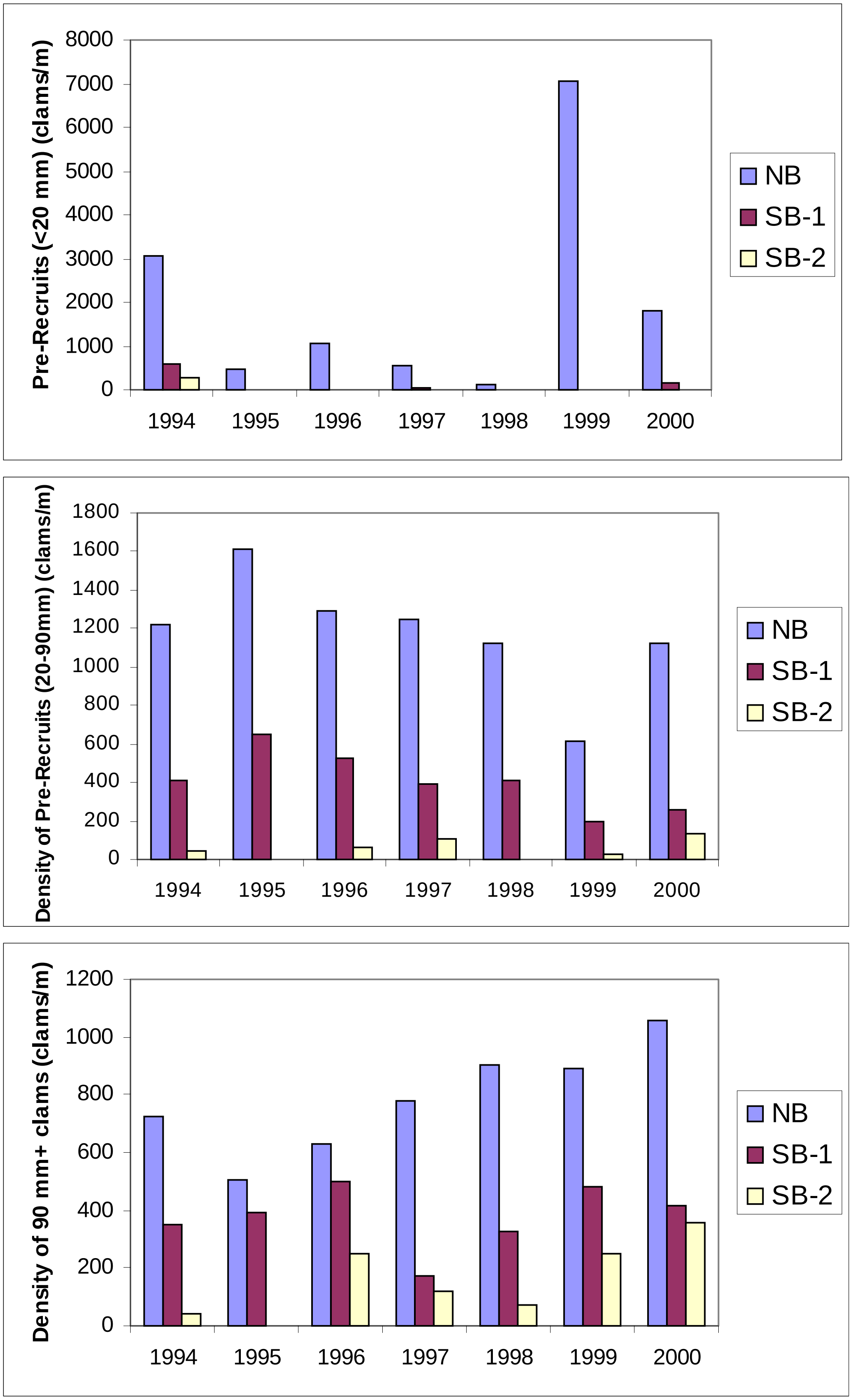


Figure 9. Razor clam biomass by beach section (inflation method)

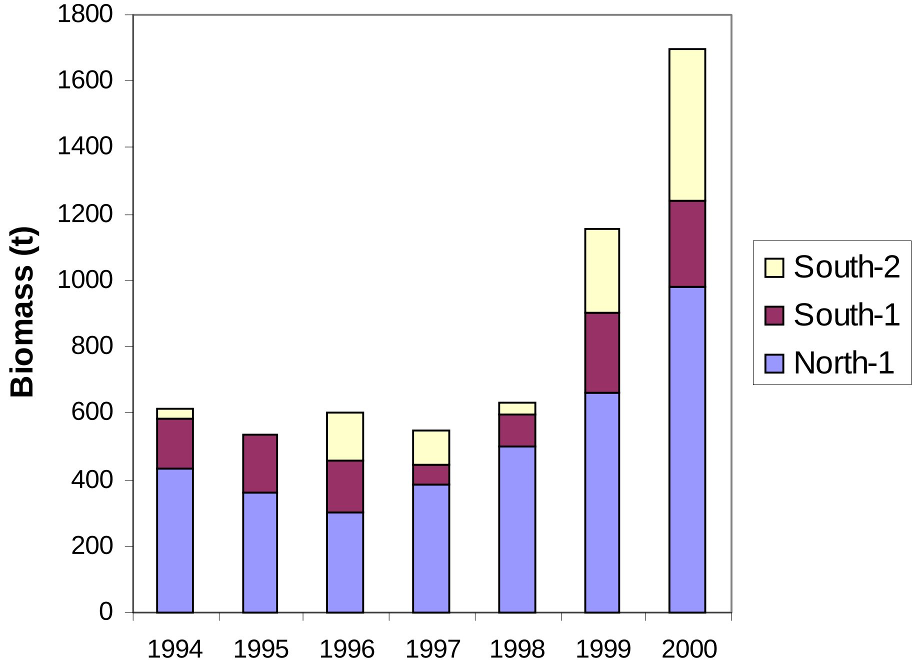


Figure 10. Size at maturity of Haida Gwaii razor clams

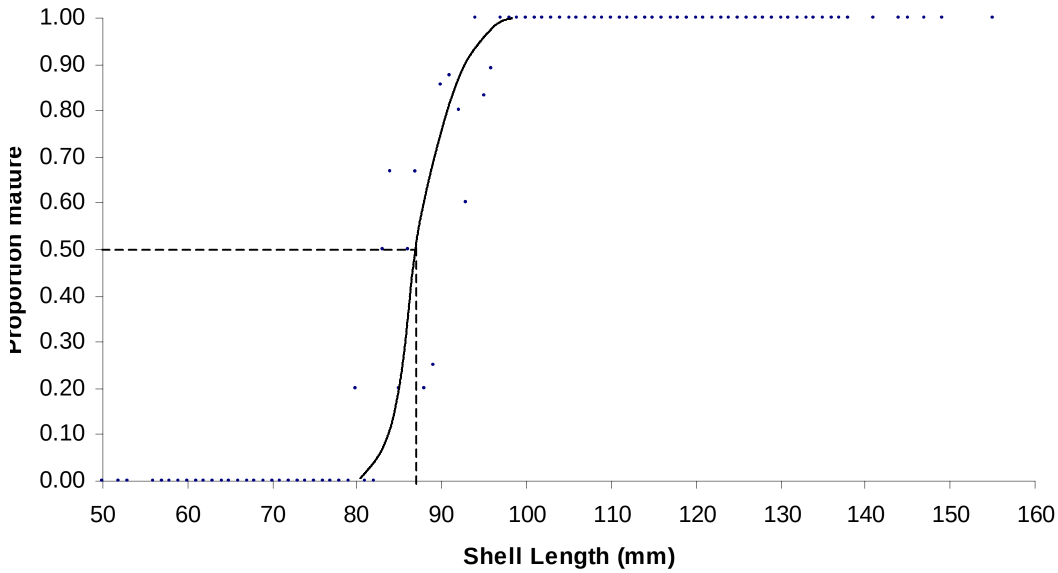


Figure 11. Size-frequency distribution of the commercial catch, 2000