# Invertebrate Working Papers Reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1996 

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# Canadian Technical Report of Fisheries and Aquatic Sciences 2221 

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## Canadian Technical Report of Fisheries and Aquatic Sciences

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INVERTEBRATE WORKING PAPERS REVIEWED BY THE PACIFIC STOCK ASSESSMENT REVIEW COMMITTEE (PSARC) IN 1996
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#### Abstract

Gillespie, G.E., and L.C. Walthers [eds.]. 1998. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee in 1996. Can. Tech. Rep. Fish. Aquat. Sci. 2221: 340 p.

Working Papers prepared in 1996 by Fisheries and Oceans Canada staff and reviewed by the Pacific Stock Assessment Review Committee (PSARC) are presented. These documents form the basis of biological advice given to managers for the development of fishing plans for 1997. Topics included: a framework for developing scientific advice for data-limited invertebrate fisheries; evaluation of survey methods and biological sampling requirements for geoducks (Panopea abrupta); quota options for the 1997 and 1998 geoduck fisheries; assessment of prawn (Pandalus platyceros) stocks in Statistical Area 12; assessment of inshore shrimp fisheries; studies of euphausiid populations in Jervis Inlet and Barkley Sound; quota recommendations for the 1996/97 green sea urchin (Strongylocentrotus droebachiensis) fisheries; and advice for management of the sea cucumber (Parastichopus californicus) fishery.


## RESUME

Gillespie, G.E., and L.C. Walthers [eds.]. 1998. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee in 1996. Can. Tech. Rep. Fish. Aquat. Sci. 2221: 340 p.

Les documents de travail préparés en 1996 par le personnel de Pêches et Océans Canada et révisés par le Comité d'examen de l'évaluation des stocks du Pacifique (CEESP) sont présentés ici. Ces documents constituent la base des avis biologiques donnés aux gestionnaires pour l'élaboration des plans de pêche de 1997. Y sont traités les sujets suivants : un cadre de travail pour l'élaboration d'un avis scientifique sur les pêches d'invertébrés pour lesquels on dispose de peu de données; l'évaluation des méthodes de relevés et des exigences en matière d'échantillonnage des panopes (Panopea abrupta); les options pour l'établissement des quotas de pêche à la panope en 1997 et 1998; l'évaluation des stocks de crevette tachetée (Pandalus platyceros) dans le secteur statistique 12; l'évaluation des pêches côtières des crevettes; les études des populations d'euphausiacés dans le bras Jervis et la baie Barkley; les recommandations de quotas pour la pêche à l'oursin vert (Strongylocentrotus droebachiensis) en 1996 et 1997; et un avis pour la gestion de la pêche de l'holothurie (Parastichopus californicus).

## INTRODUCTION

The Invertebrate Working Papers contained in this document were prepared by staff of the Stock Assessment Division of Science Branch; North Coast, South Coast and Fraser River Divisions of Operations Branch, Fisheries and Oceans Canada and other collaborators. The Working Papers were assigned reviewers by the Subcommittee Chair, and written comments were provided to the authors prior to the Subcommittee meeting. Assessments and advice to managers were then reviewed by the Invertebrate Subcommittee of the Pacific Stock Assessment Review Committee (PSARC) as a whole, which included representatives from Science Branch, Operations Branch, Program, Planning and Economics Branch, and the B.C. Provincial Government. The Subcomittee must reach consensus on any recommendation before it is submitted to the PSARC Steering Committee. Subcommittee recommendations were reviewed by the Regional Management Executive Committee, then used by the Shellfish Working Group to formulate management plans for industry review.

PSARC Working Papers document the scientific basis for fisheries management advice in the Pacific Region. As such, they provide one component of the stock assessment process and are not intended as comprehensive treatments of stock management.

The Invertebrate Subcommitte met twice in Nanaimo in 1996: April 1-3 and September 9-13. These meetings addressed advice and recommendations for management of invertebrate fisheries in British Columbia in 1997 and identified concerns and future research needs. An overview of British Columbia invertebrate fisheries, summaries of the Working Papers, reviewers comments and Invertebrate Subcommittee discussions are included in the 1996 PSARC annual report (Rice et al. 1997). Commercial fishery updates for 1996 have been collected and presented elsewhere.

This report is part of a series which document Working Papers which have been reviewed and accepted by the Invertebrate Subcommittee. Previous reports include Waddell et al. (1998a, b), Hand and Waddell (1996), Thomas (1990, 1992), Harbo and Jamieson (1987), Jamieson (1984, 1985) and Bernard (1981). This report presents 5 Working Papers from the spring meeting and 5 Working Papers from the fall meeting.

## REFERENCES

Bernard, F.R. [ed.]. 1982. Assessment of invertebrate stocks off the west coast of Canada (1981). Can. Tech. Rep. Fish. Aquat. Sci. 1074: 39 p.

Hand, C.M., and B.J. Waddell [eds.]. 1996. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1993 and 1994. Can. Tech. Rep. Fish. Aquat. Sci. 2089: 303 p.

Harbo, R.M., and G.S. Jamieson [eds.]. 1987. Status of invertebrate fisheries off the Pacific coast of Canada (1985/86). Can. Tech. Rep. Fish. Aquat. Sci. 1576: 158 p.

Jamieson, G.S. [ed.]. 1984. 1982 shellfish management advice, Pacific Region. Can. Manuscr. Rep. Fish. Aquat. Sci. 1774: 71 p.

Jamieson, G.S. [ed.]. 1985. 1983 and 1984 invertebrate managment management advice, Pacific Region. Can. Manuscr. Rep. Fish. Aquat. Sci. 1848: 107 p.

Rice, J.C., B.M. Leaman, S. Farlinger, L. Richards, R.J. Beamish, B. Holtby, and G. Thomas [eds.]. 1997. Pacific Stock Assessment Review Committee (PSARC) annual report for 1996. Can. Manuscr. Rep. Fish. Aquat. Sci. 2447: 289 p.

Thomas, G. [ed.]. 1990. Shellfish stock assesssments for the west coast of Canada in 1990 as reviewed by the Pacific Stock Assessment Review Committee (PSARC). Can. Manuscr. Rep. Fish. Aquat. Sci. 2099: 307 p.

Thomas, G. [ed.]. 1992. Shellfish stock assessments for the west coast of Canada in 1991 as reviewed by the Pacific Stock Assessment Review Committee (PSARC). Can. Manuscr. Rep. Fish. Aquat. Sci. 2169: 287 p.

Waddell, B.J., G.E. Gillespie, and L.C. Walthers [eds.]. 1998a. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 1. Bivalves. Can. Tech. Rep. Fish. Aquat. Sci. 2214: 437 p.

Waddell, B.J., G.E. Gillespie and, L.C. Walthers [eds.]. 1998b. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 2. Echinoderms. Can. Tech. Rep. Fish. Aquat. Sci. 2215: 169 p.

# Framework for Providing Scientific Advice for the Management of Data-Limited Invertebrate Fisheries 

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Editors' note: Because this paper has been revised and submitted for publication elsewhere, only a summary is included here. For more information, please contact the author.


#### Abstract

Perry, R.I. 1998. Framework for providing scientific advice for the management of data-limited invertebrate fisheries. p. 3. In: G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1996. Can. Tech. Rep. Fish. Aquat. Sci. 2221.


A framework is developed for the provision of scientific advice to support the management of new and developing (i.e., data-limited) invertebrate fisheries. The framework explicitly endorses the precautionary approach to fisheries management and research. Information on the abundance, distribution, and productivity of the target species is identified as the key scientific requirement for development of precautionary management strategies. Three "phases" are proposed to obtain this information: (a) Phase (0) "collection of existing information", consisting of a search for available formal (and anecdotal) information on the target species (and similar species) and application of a "meta-analysis"; (b) Phase (1) "fishing for information", consisting of surveys to obtain essential information that is insufficient or lacking in the Phase ( 0 ) analysis, and which must be based on a formal statistical sampling design; and (c) Phase (2) "fishing for commerce" which consists of closely monitored fishing operations to increase the information base available, to refine the results from Phase (1) activities, and to probe the stock's response to fishing. The roles and importance of modelling, uncertainty, additional biological studies, and the establishment of no-fishing reference areas are also recognised. Throughout this framework, strong interaction and collaboration among science, management, and stakeholder activities is crucial to the provision of scientific advice for precautionary fishery management.

# EVALUATION OF SOME SURVEY METHODS FOR GEODUCKS 

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#### Abstract

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


Four survey methods to estimate geoduck density and biomass with the appropriate parametric and bootstrap analytical techniques are described. For all survey types, the primary sampling unit is a transect (or cluster of secondary sampling units of $10 \mathrm{~m}^{2}$ quadrats), the placement of which depends on the survey type: (1) systematic, (2) two-stage grid (3) three-stage or (4) two-stage. Example data sets analysed for survey types 1,3 and 4 provide similar density estimates. However survey types 3 and 4 are more efficient in terms of area covered per time period than survey 1 . Optimizing sampling design for a two-stage survey was also examined. Survey type 4, with randomly placed transects and sampling every second or third quadrat, is logistically easier to implement for field crew than survey type 1 or 3 .

## INTRODUCTION

The bivalve geoduck clam, Panopea abrupta (Conrad, 1849) (Pelecypoda: Hiatellidae), has been commercially exploited in British Columbia (B.C.) since 1976. The total landed value of geoducks has increased steadily since the inception of the fishery to about $\$ 42.2$ million Cdn in 1995, despite recent decreases in landed weight (Hand et al. 1998b). The geoduck fishery has been largely managed by annual quotas set for geoduck management areas (GMA) (Harbo et al. 1995; Hand et al. 1998b). Quotas are calculated as a product of original biomass and a sustainable harvest rate. The original biomass is calculated from estimates of pristine density, estimated mean individual geoduck weight and estimates of geoduck-bearing area (e.g., Campbell et al. 1998c).

Since estimates of geoduck density are an important component of quota derivation and because of the uncertainty of geoduck stock status, there has been considerable interest in conducting extensive surveys of geoduck beds throughout B.C. Initial dive surveys for geoducks were conducted in the late 1970's by the Province of B.C. (Cox and Charman 1979), however these were designed to examine the distribution of geoducks along the coast rather than measure density or abundance. There have been numerous small-scale studies and surveys (e.g. Breen and Shields 1983; Harbo and Adkins, unpublished manuscript) that have produced more realistic estimates of commercial density, however survey methods were different and results were not comparable. Up to and including 1993, quotas were calculated with density estimates from survey results from Puget

Sound which were modified in a relative way for different areas according to information from fishers. More recently, Campbell et al. (1996a, 1996b, 1998) and Hand et al. (1998a) describe several surveys of geoduck density which formed the first measured estimates of geoduck density for B.C. waters. Additional surveys are being conducted throughout B.C. by representatives of the Underwater Harvesters Association (UHA) and Aboriginal groups, with a contract biologist participating in all surveys to provide continuity and quality control. Survey methods and analytical techniques are continuing to evolve in an attempt to account for differing physical features of the areas that geoducks inhabit (e.g. large beds over comparatively even slope, narrow beds on steep slopes or small pockets) and to make surveys more efficient.

The objectives of this paper are to document recent developments for improvements to field survey methods and the analytical techniques used to estimate current geoduck densities and biomass in B.C. Four methods for surveying geoducks and the associated analytical techniques are examined and optimal sample sizes suggested.

## SURVEY METHODS

In this section we describe the rationale for the choice of survey sample designs and the procedures for collecting the geoduck density and associated data.

## Choice of Area to be Surveyed

Logistics will not allow every geoduck bed in B.C. to be surveyed. Thus, present survey objectives are to obtain density estimates of geoducks from representative beds within each geographic region, including the North, Central and South Coasts of B.C. Suggestions from the UHA and Aboriginal groups are compiled and considered in light of geographic location, year of next scheduled harvest in the three-year rotation (Hand et al. 1998b) and fishing history. After selection, protocols are designed for each survey wherein the individual geoduck bed characteristics are considered. In most cases, additional bottom area adjacent to the reported harvest beds are included to overlap the local distribution of the geoduck population and to obtain information from possible new geoduck beds.

## SAMPLE DESIGNS

After an area has been identified for surveying, DFO personnel assign transect locations on charts $a$ priori, to reduce possible bias under field conditions. The number, spacing and positioning of transects on the charts depends on the survey type, the area to be covered, estimated time required per transect (which can vary with slope and substrate type) and total dive time available for the survey. Initially, the number of transects per survey ( $n$ ) is crudely estimated as $n=T / t$, where $T$ is the total number of effective hours available during a survey and $t$ is the estimated average time (h) required to complete a transect.

Four survey methods have been developed to measure geoduck density (Fig. 1). In all methods, the primary sampling unit is a "transect", made up of a cluster or variable number of secondary
sampling units. The secondary sampling unit is a $10 \mathrm{~m}^{2}$ quadrat comprised of two $5 \mathrm{~m}^{2}(1 \times 5 \mathrm{~m})$ quadrats located on each side of the transect line.

## Survey Type 1 -Systematic

Transects are systematically placed perpendicular to shore along a geoduck bed (Fig. 1a). The position of the first transect is randomly chosen as follows. A straight line is placed on the chart parallel to shore. One of 10 subdivisions of a 100 m section at one end of the line on the bed is randomly chosen (from a random numbers table) for the position of the first transect and subsequent transects are spaced 100 m apart for small ( $<50 \mathrm{ha}$ ) or narrow ( $<60 \mathrm{~m}$ wide) beds to 300 m apart for large ( $>100 \mathrm{ha}$ ) beds. Geoduck counts are made within all consecutive quadrats along a transect (Fig. 1a). This survey type has been used for all but one geoduck survey in B.C. to date.

## Survey Type 2 - Two-Stage Grid

A grid is placed over a chart of the area to be surveyed and a number of equal-sized squares are randomly selected (Fig. 1a). In each of the selected squares, a transect is randomly placed in a 0 18.3 m water depth range and all geoducks in consecutive quadrats along the transect counted. This type of survey may be useful in areas characterised by numbers of beds around small islands, but has not been used on geoducks to date.

## Survey Type 3 - Three-Stage Sampling

A straight line is placed on the chart parallel to shore and the position of transects along the line is randomly selected (Fig. 1a). The transect is sectioned into blocks that can accommodate q quadrats per block, e.g. a block would be 20 m long for 4 quadrats (i.e., $5 \mathrm{~m} /$ quadrat length). Geoducks are counted in one quadrat randomly located in one of the q possible quadrats in each block. The block size should be constant for all transects within a given bed. This survey type was implemented for the first time on a survey of Yellow Bank on the west coast of Vancouver Island during 1995 (A. Campbell, unpublished data) and is being considered as a replacement to survey type 1.

## Survey Type 4 -Two-Stage Sampling

A straight line is placed on the chart parallel to shore and the positions of transects along the line are randomly selected (Fig. 1b). The transect rope is marked every 5 m interval ( $5 \mathrm{~m} /$ quadrat length). A random starting point along the first q (e.g., 2-4) lengths of the transect is chosen. Thereafter every $q^{\text {th }}$ (e.g. every 2 nd or 3 rd or every 4 th) quadrat along a transect is sampled. If the bed width is on average narrow ( $e . g .<200 \mathrm{~m}$ ) every 2 nd quadrat could be sampled. If the bed width is on average wide (e.g. 200-1,000 m) every 3rd quadrat could be sampled. If the bed width is on average very wide ( $e . g .>1,000 \mathrm{~m}$ ) every 4 th quadrat could be sampled. Although survey type 4 has not been tried before this survey type should be considered as a replacement to survey type 1 .

## Data Collection

## Number Per Transect Estimation

In the field, a lead-core polypropylene transect line is placed approximately perpendicular to the shoreline from the intertidal to about $18.3 \mathrm{~m}(60 \mathrm{ft})$ datum depth. The final start and end positions of the transects are determined in the field with a Global Positioning System (GPS) (accuracy $\pm 30$ m ), Loran C system and by taking visual bearings on land features. Two SCUBA divers work together, one on either side of the transect, to record the number of geoduck siphon shows and probable shows within one measured meter of the line (using a meter stick) for every 5 m section. Shows are geoduck siphons clearly visible at or above the substrate. Probable shows, i.e., dimples in the substrate, are counted as a geoduck if the siphon retracts in response to probing. The divers agree beforehand who should record any geoducks bisected by the transect line. Shows touched by the end of the metre stick are included in the counts. Divers also record, for the whole transect, the approximate average percent of geoduck necks extending greater than 1 to 2 cm above the substrate surface as a general impression after swimming each transect.

## Bed Area

The surveyed bed area was measured by digitising the perimeter bounded by the extreme transects in each distinct locale and within the depth range covered by the divers. Measurements, using a computer driven digitizing tablet, were repeated at least three times to obtain an estimated mean and estimated standard error. The bed area surveyed could also be calculated by summing the area of all possible 2 m width sample units determined from the dive operations. Since there is no detailed a priori knowledge of the distribution of geoducks within the survey area, the length of transects not sampled is assumed to be equal to the nearest sampled transect.

## Depth and Substrate Type

The depth, substrate type and dominant algae are recorded for each quadrat during the survey. The percent slope of the bottom, general exposure, water visibility and start and end times are recorded for each transect. Depths at each quadrat are corrected to chart datum (metres below estimated mean lower low water) using predicted tide heights from the closest port and by assuming that all quadrats took equally long to survey. General exposure of coastline to currents and storms is also noted.

## Diver Calibration

Dive teams are made up of commercial divers, personnel from various Aboriginal groups and contract biologist-divers. The teams of SCUBA divers usually work on separate transects. To ensure consistent results between teams, divers make underwater counts of geoducks along the same 'calibration' line. This is repeated several times during the survey to maintain a record of the accuracy of each diver's counts compared to the other divers. Analysis of variance is used to determine if there are differences between diver counts. If there are no differences the data collected
by different divers are combined for density estimation. However, if there are differences in counts between divers then estimated mean densities and associated statistics are analysed separately.

## Show Factors

Individual geoduck siphons are not consistently visible throughout the day, season or year due to physical and/or biological effects (Goodwin 1973, 1977; Cox and Charman 1979; Turner and Cox 1981; Fyfe 1984). Consequently, area (bed) specific and time specific show factor data are required to correct the density counts to account for the fraction of the population not visible at the time of observation. This is accomplished by establishing 3 to 4 show factor plots within the survey situated to represent varying levels of exposure, to have sufficient numbers of individuals to observe in areas that are centrally located for ease of access. Plots each measuring 10 m by 2 m are established prior to the survey and visible geoduck siphon "shows" are recorded daily. A flag is placed beside each geoduck when first observed, any new shows that appear during the observation period are flagged while flags not associated with a show are noted. The proportion of geoducks showing on any given day is then determined by dividing the number showing on that day by the total cumulative number of geoducks flagged. Permanent markers are left to indicate the location of the show plots to allow repeated examination of shows for a number of years.

## Biological Sample

A sample of geoducks of all sizes are randomly collected from an area within a bed, if possible, to determine biological characteristics of the population such as the meat weight, size distribution, age composition, and mortality rates (Campbell and Rajwani 1996).

## ANALYTICAL METHODS

Initial general descriptive analyses are conducted to determine the interrelationships between density, depth and substrate. Histograms of geoduck counts per quadrat and plots of density along a transect are produced to examine how the distributions are characterised. Graphical summaries of these data help to reveal trends or anomalies. ANOVA comparisons of geoduck counts are conducted to determine if there are differences between divers and the density data are combined or kept separate accordingly.

To assist with quota determination for the geoduck fishery the surveys are used to generate three important estimated means, associated standard errors and approximate $95 \%$ confidence intervals of (i) density, (ii) total population numbers and (iii) total biomass of geoducks from each bed. A Microsoft QuickBasic program was developed to calculate: estimated mean and estimated standard error of the density estimates based on classical sampling methods (Thompson 1992); distribution free estimated mean and confidence limits of density; population size and biomass estimates using bootstrap techniques (Efron and Tibshirani 1993). A glossary of the variable names in the following formulae is shown in Table 1.

## Show Factor Proportions

Estimates of the total number of geoducks per show factor plot using the flagging method are based on the following assumptions: (1) All geoducks in the plot area show their necks and are flagged during the period of the survey; (2) No mortality of geoducks occurs during the survey. Mortality of geoducks over a short period (1-3 weeks) is unknown but probably minimal. Fyfe (1984) adjusted for mortality rates of the total flagged geoducks over a long period of a year; and (3) Geoducks do not change the position of their necks to outside the plot boundaries during the survey. The extent to which geoducks may change the neck position relative their shell position is unknown but is believed to be minimal. Geoducks generally have their necks, bodies and shells in a vertical position. There may be exceptions where geoducks have to bend their necks around barriers such as rock or dead shell debris to reach the substrate surface.

The daily proportion of geoducks showing (SPi) in an area is calculated as,

$$
\begin{equation*}
S P_{i}=\frac{X_{i}}{\sum_{i} T_{i}} \tag{1}
\end{equation*}
$$

where $i=1,2, \ldots, \mathrm{n}$ index days, $X_{i}$ is the number of observed shows in the plot on day $i$ and $T_{i}$ is the number of previously unobserved shows on day $i$. The estimated mean and estimated standard error are calculated from replicate plots on the same day as long as they are considered representative of the same general area. Where only one show plot is available, an approximate estimated standard error of the estimated mean proportion (Cochran 1977) of the show factor $S E\left(S P_{i}\right)$ can be calculated as,

$$
\begin{equation*}
S E\left(S P_{i}\right)=\sqrt{\frac{\left(S P_{i}\left(1-S P_{i}\right)\right)}{\sum_{i} T_{i}}} \tag{2}
\end{equation*}
$$

## Density Estimates

The methods of calculation for the estimated mean density, the estimated standard error and approximate $95 \%$ confidence intervals of the density depend upon the following four types of survey.

## Survey Type 1: Transects are Systematic with Consecutive Quadrats.

The sample fraction will be small in most surveys so that the samples are assumed to be taken with replacement. Fluctuations in geoduck density are unlikely to match the widely separated spacing of the transects (Goodwin and Pease 1991; Campbell et al. 1996 a), thus the systematic survey type may be treated as a random sample of the population.

## Classical Method 1

The estimated mean density, $d$, and the estimated standard error of the estimated mean, $S E(d)$, are calculated as follows:

$$
\begin{equation*}
d=\frac{\sum_{i} g_{i}}{\sum_{i} a_{i}} \tag{3}
\end{equation*}
$$

and,

$$
\begin{equation*}
S E(d)=\sqrt{1-\frac{n}{N}}\left(\sqrt{\frac{\sum_{i}\left(g_{i}-d a_{i}\right)^{2}}{n(n-1) a^{2}}}\right) \tag{4}
\end{equation*}
$$

where $g_{i}$ is defined as,

$$
\begin{equation*}
g_{i}=\frac{b_{i}}{S P_{i}} \tag{5}
\end{equation*}
$$

where for each $i^{\text {th }}$ transect, $b_{i}$ is the number of geoducks observed, $g_{i}$ is the number of geoducks adjusted for the show factor, $S P_{i}$ is the estimated mean proportion of geoducks showing for transect $i, a_{i}$ is the area of transect surveyed in square metres, $a$ is the estimated mean transect area for all transects, $n$ is the number of transects sampled and $N$ is the total population of possible transects. For estimating $S E(d)$, although the show factor proportion can change for each transect, $S P i$ is assumed to be known exactly, rather than being a random variable. Where no adjustment for show factor is made then $S P_{i}=1$. An approximate $95 \%$ confidence interval can be computed as $d \pm 2 S E(d)$.

## Bootstrap Procedure 1

The first bootstrap procedure, for surveys of type one, uses the following method. For each of the $n$ times the observed transects are randomly resampled with replacement, a number of geoducks is assigned to $b_{k}$. Normally, $n$ should be set as the observed sample size of the survey. When we are correcting for the show factor, $b_{k}$ is modified by a show factor proportion, and a random component. The formula is:

$$
\begin{equation*}
g_{k}=\frac{b_{k}}{h_{k}} \tag{6}
\end{equation*}
$$

where for each bootstrapped transect $(k), b_{k}$ is the number of geoducks observed, $g_{k}$ is the number of geoducks adjusted for the show factor, and $h_{k}$ is a show factor proportion (between 0 and 1)
calculated by adjusting the estimated mean show factor $\left(S P_{k}\right)$ by the estimated standard error of the mean show factor $S E\left(S P_{k}\right)$ and a random number from a standard normal population $(z)$ after the Box Muller method (Press et al. 1986) using a log odds transformation calculated as follows:

$$
\begin{equation*}
h_{k}=\frac{1}{(1+\exp (-y))} \tag{7}
\end{equation*}
$$

where,

$$
\begin{equation*}
y=\ln \left(\frac{S P_{k}}{\left(1-S P_{k}\right)}\right)+\frac{\left(S E\left(S P_{k}\right)\right)}{\left(S P_{k}\left(1-S P_{k}\right)\right) z} \tag{8}
\end{equation*}
$$

When not correcting for show factor, $b_{k}$ is simply equal to the number of geoducks in a randomly selected transect $k, g_{k}$, in which case $h_{k}$ and $S P_{k}$ are each set to 1 and the log odds calculation is bypassed.

All the $n g_{k}$ 's are added, as are the corresponding areas for the resampled transects. The total number of geoducks is then divided by the total area to obtain an estimated mean density $\delta_{\mathrm{r}}$. The process is repeated $m(e . g .,=1000)$ times to obtain the $m$ estimated mean densities: $\delta_{1}, \delta_{2}, \ldots, \delta_{\mathrm{m}}$. The densities are then sorted, and the $95 \%$ confidence interval is calculated by removing the top and bottom $2.5 \%$ of the ranked densities (Efron and Tibshirani 1993), and reporting the first and last remaining density. The bootstrap overall estimated mean is calculated by summing $\delta_{1}, \delta_{2}$, $\ldots, \delta_{\mathrm{m}}$ and dividing by $m$.

## Survey type 2: Two-Stage Samples

Stage 1 , randomly select grids with replacement; Stage 2 , randomly place 1 transect per grid.

## Classical Method 2

The estimated mean density, $d$, and the estimated standard error of the estimated mean, $S E(d)$, are calculated as follows:

$$
\begin{equation*}
d=\frac{1}{n} \sum_{i} \frac{g_{i}}{a_{i}} \tag{9}
\end{equation*}
$$

and

$$
\begin{equation*}
S E(d)=\sqrt{1-\frac{n}{N}}\left(\sqrt{\frac{\sum_{i}\left(d_{i}-d\right)^{2}}{n(n-1)}}\right) \tag{10}
\end{equation*}
$$

where $d_{i}$ is defined as

$$
\begin{equation*}
d_{i}=\frac{g_{i}}{a_{i}} \tag{11}
\end{equation*}
$$

and

$$
\begin{equation*}
g_{i}=\frac{b_{i}}{S P_{i}} \tag{12}
\end{equation*}
$$

Equations 11 and 12 underestimate the estimated standard error because there is no estimate of the second stage variability available. For estimating $S E(d)$, although the show factor proportion can change for each transect, $S P_{i}$ is assumed to be known exactly, rather than being a random variable. Where no adjustment for show factor is made then $S P_{i}=1$. An approximate $95 \%$ confidence interval can be computed as $d \pm 2 \operatorname{SE}(d)$.

## Bootstrap Procedure 2

In the second bootstrap procedure, used with surveys of type 2, we generate $m$ estimated mean densities $\delta_{1}, \delta_{2}, \ldots, \delta_{\mathrm{m}}$. Each $\delta_{\mathrm{i}}$ is calculated by randomly resampling with replacement $n$ times from the original transect data. Normally $n$ is set as the observed number of transects per bed survey. For each of the $n$ times the original data are resampled, a density $D_{k}$ is calculated. When correcting for show factor, $\mathrm{D}_{\mathrm{k}}$ is equal to a randomly selected transect density which has been modified by the show factor and a random component. The formula is:

$$
\begin{equation*}
D_{k}=\frac{b_{k}}{a_{k} h_{k}} \tag{13}
\end{equation*}
$$

where for each bootstrapped transect $(k), b_{k}$ is the number of geoducks observed, $a_{k}$ is the transect area, and $h_{k}$ is a show factor proportion (between 0 and 1) calculated by adjusting the estimated mean show factor $\left(S P_{k}\right)$ by the estimated standard error of the mean show factor $S E\left(S P_{k}\right)$ and a random number from a standard normal population (z) after the Box Muller method (Press et al. 1986) using a log odds transformation calculated as in equations 7 and 8.

When not correcting for show factor, $h_{k}$ is simply made 1 .
The $n \mathrm{D}_{\mathrm{k}}$ 's are added together and divided by $n$ to arrive at a bootstrapped mean density $\delta_{\mathrm{i}}$. The process is repeated $m(e . g .,=1000)$ times to obtain the $m$ estimated mean densities: $\delta_{1}, \delta_{2}, \ldots, \delta_{m}$. The densities are then sorted, and the $95 \%$ confidence interval is calculated by removing the top and bottom $2.5 \%$ of the ranked densities (Efron and Tibshirani 1993), and reporting the first and last remaining density. The bootstrap overall estimated mean is calculated by summing $\delta_{1}, \delta_{2}$, $\ldots, \delta_{\mathrm{m}}$ and dividing by $m$.

## Survey type 3: Three-Stage Sample

Stage 1, randomly select transects; Stage 2, all blocks chosen; Stage 3, one out of every $q$ quadrats within each block randomly chosen for measurement. The transect selection is assumed to be with replacement since the total number and area of transects sampled per bed is small (e.g. $<1 \%$ ) compared to the overall bed area.

## Classical Method 3

The estimated mean density, $d$, and the estimated standard error of the estimated mean, $S E(d)$, are calculated as follows:

$$
\begin{equation*}
d=\frac{\sum_{i} g_{i}}{\sum_{i} a_{i}} \tag{14}
\end{equation*}
$$

and

$$
\begin{equation*}
S E(d)=\sqrt{1-\frac{n}{N}}\left(\sqrt{\frac{(n) \sum_{i}\left(g_{i}-d a_{i}\right)^{2}}{(n-1)\left(\sum_{i} a_{i}\right)^{2}}}\right) \tag{15}
\end{equation*}
$$

where

$$
\begin{equation*}
g_{i}=\frac{b_{i}}{S P_{i}} \tag{16}
\end{equation*}
$$

For estimating $S E(d)$, although the show factor proportion can change for each transect, $S P_{i}$ is assumed to be known exactly, rather than being a random variable. Where no adjustment for show factor is made then $S P_{i}=1$. Note there is no estimate for the third stage variability. An approximate $95 \%$ confidence interval can be computed as $d \pm 2$ SE ( $d$ ).

## Bootstrap Procedure 3

The bootstrap procedure 3, used to mimic survey types 3 and 4, should be considered the so called "naive" bootstrap (Rao and Wu 1988). The procedure randomly samples a transect and then randomly selects quadrats within each transect. Consequently, an additional expanded data file is required that includes data identifying each block of quadrats and transect and the number of geoducks observed per quadrat/block/transect (Appendix 1, 2). This bootstrap procedure is
similar to the bootstrap procedure 1 , except for some minor changes in calculating $b_{k}$, the number of observed geoducks per transect. For each of the $n$ times we resample, a transect is randomly selected from the available transects, a number of blocks ( $u$ ) are randomly selected with replacement from the total number of blocks $(U)$ available in this transect, the number of geoducks sampled (multiplied by $q$ quadrats in a block) are then summed for the transect. The same procedure for applying a show factor and associated variance is used as described for bootstrap procedure 1 .

## Survey Type 4: Two-Stage

Stage 1, randomly select transects; Stage 2, random start within first $q$ quadrats and subsequent one out of every $q$ quadrats chosen systematically along a transect ( $q=2,3$ or 4 depending on transect length). The sample fraction will be small in most surveys so that the first stage samples are assumed to be taken with replacement.

## Classical Method 4

The estimated mean density and estimated standard error of the estimated mean are calculated as follows:

$$
\begin{equation*}
d=\frac{\sum_{i} g_{i}}{\sum_{i} a_{i}} \tag{17}
\end{equation*}
$$

and

$$
\begin{equation*}
S E(d)=\sqrt{1-\frac{n}{N}}\left(\sqrt{\frac{(n) \sum_{i}\left(g_{i}-d a_{i}\right)^{2}}{(n-1)\left(\sum_{i} a_{i}\right)^{2}}}\right) \tag{18}
\end{equation*}
$$

where

$$
\begin{equation*}
g_{i}=\frac{b_{i}}{S P_{i}} \tag{19}
\end{equation*}
$$

For estimating $S E(d)$, although the show factor proportion can change for each transect, $S P_{i}$ is assumed to be known exactly, rather than being a random variable. Where no adjustment for show factor is made then $S P_{i}=1$. An approximate $95 \%$ confidence interval can be computed as $d \pm 2 S E(d)$.

## Population Number and Biomass Estimates - Bootstrap Procedure

The population numbers and biomass are calculated from any of the above three different bootstrap procedures to generate distribution free estimates of density. For each $\mathcal{D}_{\mathrm{i}}$ calculated $m$ (e.g., $=1000$ ) times, a corresponding population number $\left(P_{i}\right)$ and biomass $\left(B_{i}\right)$ are calculated:

$$
\begin{equation*}
P_{i}=\delta_{i}(L+S E(L) z) \tag{20}
\end{equation*}
$$

and

$$
\begin{equation*}
B_{i}=P_{i}(W+S E(W) z) \tag{21}
\end{equation*}
$$

where $L$ is the size of the bed in square metres, $S E(L)$ is the estimated standard error of the size of the bed, $W$ is the estimated mean weight of a geoduck in kilograms, $S E(W)$ is the estimated standard error of the weight of a geoduck and $z$ is a random number from a standard normal population calculated by the Box Muller method (Press et al. 1986). In both bootstrap equations 20 and 21 the variability in the bed area estimates and mean weight estimates can be included in precision of the estimates. If $S E(L)$ and or $S E(W)$ are unknown either can be set to zero.

The confidence intervals for the population and the biomass are calculated in the same fashion as the density confidence intervals; the $B_{i}$ 's and $P_{i}$ 's, are ranked and the appropriate elements chosen, i.e., the $95 \%$ confidence interval is calculated by removing the top and bottom $2.5 \%$ of the ranked densities (Efron and Tibshirani 1993), and reporting the first and last remaining values. The bootstrap overall estimated mean population number or biomass is calculated by summing all the $B_{i}$ 's or $P_{i}$ 's and dividing by $m$.

## EXAMPLE DATA SETS

Data from four surveys on geoducks conducted around Vancouver Island during 1993-94 were used in this paper to provide examples in the analyses. The logistics, including bed size and time taken to conduct survey, are summarized in Table 2. Data were available for analysis for survey types 1,3 and 4 . No data for survey type 2 was available for analysis.

## Comparison of Survey Types 1, 3 and 4.

In order to test the program, actual data from two different surveys types completed in the same area were used. A survey type 1 and a survey type 3 were conducted over the same general area on southern Elbow Bank (near Tofino, west coast of Vancouver Island) during 1994 and 1995, respectively (Table 2 and Appendix 1, 2 unpublished data). The classical and bootstrap estimates of the estimated mean geoduck density and $95 \% \mathrm{CI}$ were similar between the two survey types (Table 3).

The S. Elbow Bank 1994 data (Appendix 1 and 3) were modified to test the output for survey type 4. Transects were assumed to be randomly placed and the total number of geoduck per
transect were counted either every quadrat, every 2 nd quadrat, 3rd quadrat or 4th quadrat (Table 4). Since a random starting point for each transect was chosen, the estimated means can vary especially if $q=4$ (every 4th quadrat). Consequently 10 sets of data (from the five transects) were extracted with random starting points for the 4th quadrat example. Although only one set of results is shown for each combination of q's there were no differences between each set and using all quadrats in estimated mean density, population number or biomass (Table 4).

## Changing Parameters in the Bootstrap Program

Differences in precision between the bootstrap confidence intervals and "classical" $S E$ (Table 3, 4) were caused by introducing variability in the estimates of show factor, bed area and mean weight in the bootstrap. The bootstrap program was tested by varying various parameters using the S. Elbow Bank 1995 survey type 3 data.

The value of $n$ should always be set at the same number of transects actually sampled per bed to provide reasonably realistic confidence intervals. Indeed, the bootstrap procedure requires $n$ to be used, except in bias correction efforts (Rao and Wu 1988 ) or survey planning purposes. The estimates of the estimated mean and confidence intervals of the densities remained approximately constant when changing $m$ at various levels from 50 , to 10,000 . We recommend $m$ be set at 1,000 or 2,000 for most runs to reduce variability in estimating the end points of the confidence interval and for economy of computation time.

Increasing standard error of the estimated mean bed size and estimated mean weight did not change the estimated mean estimates of population size and biomass (Fig. 2, 3), as was expected since the added random normal variate had an expectation of zero. However, increasing error about the estimated mean bed size and weight caused the confidence intervals to widened considerably especially when the standard error of the estimated means was greater than $5 \%$ of the mean (Fig. 2, 3). This suggests that caution should be used in estimating geoduck biomass when the standard error estimates are greater than $5 \%$ of the bed size or geoduck weight estimated means.

Increasing the standard error $\left(S E\left(S P_{i}\right)\right)$ of the mean show factor proportion $\left(S P_{i}\right)$ caused the mean density and confidence intervals to increase only when $S E\left(S P_{i}\right)$ was $\geq 8 \%$ of $S P_{i}$, especially when $S P_{i}$ was high (e.g., $>0.80$ ). This suggests that $S E\left(S P_{i}\right)$ should not be used in the bootstrap (i.e., set $S E\left(S P_{i}\right)$ to zero) if $S E\left(S P_{i}\right)$ exceeds $8 \%$ of $S P_{i}$, especially if $S P_{i}$ is large (e.g., $S P_{i}=0.95$ and $\left.S E\left(S P_{i}\right)=0.07\right)$.

## OPTIMIZING SAMPLING DESIGN FOR GEODUCK DENSITY SURVEYS

The optimal sampling analysis of geoduck densities for a particular bed can be viewed as a twostage design (Cochran 1977). In this design, transects are randomly placed across a bed, perpendicular to the shoreline and a random number of quadrats/transect are examined. The number of transects that are sampled is dependent on the size and shape of the bed. For example, if a bed is known to be narrow and perpendicular to the shoreline, then it seems reasonable that more transects should be placed and fewer quadrats examined within each selected transect than
for a large bed. Since the number of quadrats that are examined in a particular transect is dependent on the length of the transect, the two-stage design can be viewed as being an unbalanced design with an unequal number of quadrats within each transect.

Due to limited resources, in time or funding, often surveying all possible transects and all quadrats within a transect is not possible to obtain the geoduck density for a particular bed. An optimal survey design must be developed to yield the most precise estimate of the geoduck density of a given bed.

The objective of the following analysis is to determine optimal two-stage survey designs for geoduck densities obtained from two different beds. The bed from Goletas is narrow and long with short transects surveyed and the bed from Sandy Island, Comox is a large bed with long transects surveyed (Table 2).

## Analytical Methods

For a two-stage sampling design, the mean geoduck density for a particular bed is found to be (Cochran 1977, section 10.3):

$$
\begin{equation*}
\overline{\bar{y}}=\frac{1}{n} \sum_{i=1}^{n} \bar{y}_{i}, \tag{22}
\end{equation*}
$$

and the mean density for the $i^{\text {th }}$ transect is of the bed is:

$$
\begin{equation*}
\bar{y}_{i}=\sum_{i=1}^{m_{i}} \frac{y_{i j}}{m_{i}} \tag{23}
\end{equation*}
$$

where $y_{i j}$ is the geoduck density for the $j^{\text {th }}$ quadrat in the $i^{\text {th }}$ transect, $m_{i}$ is the number of quadrats examined in the $i^{\text {th }}$ transect, and $n$ is the number of transects randomly sampled from $N$ possible transects in the bed.

If the $n$ transects and $m_{i}$ quadrats within each transect are selected by simple random sampling, then $\overline{\bar{y}}$ is an unbiased estimate of $\overline{\bar{Y}}$, the mean density of geoducks in the bed, with variance:

$$
\begin{equation*}
V(\overline{\bar{y}})=\left(1-\frac{n}{N}\right) \frac{S_{1}^{2}}{n}+\left(1-\frac{\bar{m}}{\bar{M}}\right) \frac{S_{2}^{2}}{n \bar{m}} \tag{24}
\end{equation*}
$$

where $N$ is the total number of transects available for sampling within the bed, $\overline{\mathrm{M}}$ is the mean number of all quadrats available for examination within each of the $n$ transects, and $\overline{\mathrm{m}}$ is the mean number of quadrats examined in the $n$ transects. The variance among transects is:

$$
\begin{equation*}
S_{1}^{2}=\sum_{i=1}^{N} \frac{\left(\bar{Y}_{i}-\overline{\bar{Y}}\right)^{2}}{N-1} \tag{24}
\end{equation*}
$$

and the variance among quadrats within transects is:

$$
\begin{equation*}
S_{2}^{2}=\sum_{i=1}^{N} \sum_{j=1}^{M} \frac{\left(y_{i j}-\overline{Y_{i}}\right)^{2}}{N-1} \tag{25}
\end{equation*}
$$

An unbiased estimate of $V(\overline{\bar{y}})$ from the sample is:

$$
\begin{equation*}
V(\overline{\bar{y}})=\left(1-f_{1}\right) \frac{s_{1}^{2}}{n}+f_{1}\left(1-f_{2}\right) \frac{s_{2}^{2}}{n \bar{m}} \tag{26}
\end{equation*}
$$

where

$$
\begin{equation*}
f_{1}=\frac{n}{N} \text { and } f_{2}=\frac{\bar{m}}{\bar{M}} \tag{27}
\end{equation*}
$$

and $\mathrm{s}_{1}^{2}$ and $\mathrm{s}_{2}^{2}$ are the sample analogues of $\mathrm{S}_{1}^{2}$ and $\mathrm{S}_{2}^{2}$.
An optimal sampling design for a two-stage sampling procedure is dependent on the allocation of available resources between each stage; as well as, the variability at each stage. By assuming a linear relationship between costs for each stage and the number of quadrats and transects selected, a cost equation of the following format can be assumed to be appropriate:

$$
\begin{equation*}
C=c_{1} n+c_{2} n \bar{m} \tag{28}
\end{equation*}
$$

In this equation, $C$ is the total survey cost, $\mathrm{c}_{1}$ is the cost to establish a transect and $\mathrm{c}_{2}$ is the cost to examine a quadrat. If the costs are in time units, then $c_{2}$ could be composed of time to travel between quadrats and time to examine and record information for a quadrat.

Optimal values of $\overline{\mathrm{m}}$ and $n$ are the set of values that minimize the true variance of the estimator, $\mathrm{V}(\overline{\mathrm{y}})$, for a fixed survey cost, $C$; or minimize the cost for a fixed variance. Proceeding from Cochran (1977), the optimal values are:

$$
\begin{equation*}
\bar{m}_{o p t}=\sqrt{\left(\frac{c_{1}}{c_{2}}\right)\left(\frac{S_{2}^{2}}{S_{1}^{2}}\right)} \tag{29}
\end{equation*}
$$

and,

$$
\begin{equation*}
n=\frac{C}{c_{1}+c_{2} \bar{m}_{o p t}} \tag{30}
\end{equation*}
$$

Notice that $\bar{m}_{\text {opt }}$ is a function of the individual costs and variances for each stage, and not dependent on the total survey cost. For a fixed cost per transect, $\mathrm{c}_{1}$, and fixed variance ratio, $\mathrm{S}_{2}^{2} / \mathrm{S}_{1}^{2}$, if the cost per quadrat, $\mathrm{c}_{2}$, is increased, then there is a decrease in the optimal number of quadrats, $\overline{\mathrm{m}}_{\mathrm{opt}}$, that should be sampled within each selected transect.

The survey costs used to determine optimal allocation of resources are derived from information based on surveys of similar types conducted in previous years; these can be thought of as being fixed or known values. The optimal values are also dependent on how well the estimated variances, $s_{1}^{2}$ and $s_{2}^{2}$, represent their population analogues. For example, if the variance ratio, $\mathrm{s}_{2}^{2} / \mathrm{s}_{1}^{2}$, is observed to increase then this in an indication that there is more variability between quadrats within transects then between transects and thus more quadrats should be examined within fewer transects.

The optimal number of quadrats ( $\overline{\mathrm{m}}_{\text {opt }}$ ) refers to the average number of quadrats that should be examined in each of the $n$ randomly selected transects. If the total number of quadrats within each of the $n$ selected transects is known $\left(\mathrm{M}_{\mathrm{i}}\right)$, then it is possible to determine the optimal number of quadrats that should be examined in the $\mathrm{i}^{\text {th }}$ transect in the sample:

$$
\begin{equation*}
m_{i, o p t}=\frac{\bar{m}_{o p t}}{\frac{1}{n} \sum_{i=1}^{n} M_{i}} M_{i} \tag{31}
\end{equation*}
$$

## Results of Analysis of Example data

Goletas geoduck bed had a narrow bed along to the shoreline with 77 transects surveyed with an average of 12.7 quadrats/transect (min 5, max 26) (Table 2). In contrast, Sandy Island, Comox, had a large bed with 15 transects surveyed with an average 107.9 quadrats/transect (min 77, max 190).

For each quadrat examined within a selected transect, a count of the number of geoducks was obtained; a quadrat has been defined as a $10 \mathrm{~m}^{2}$ area on the transect line. The density for a given quadrat is then equal to the number of geoducks observed in the quadrat divided by 10.

Summary statistics for geoduck density indicate the estimated mean geoduck density at Goletas Channel was greater than at Comox (Table 5). The variance ratio ( $\mathrm{s}_{1}^{2} / \mathrm{s}_{2}^{2}$ ) was greater at Comox indicating that the samples from Comox showed more variability in density among quadrats within a transect than among transects than at Goletas.

Optimal values of the number of quadrats and transects for various costs are listed in Tables 6 and 7. In these tables, costs are given in terms of the amount of time required to perform a task; either, time to establish a transect $\left(c_{1}\right)$ or time to examine a quadrat $\left(c_{2}\right)$. Currently, resources permit approximately 8 days ( $=8$ hours/day $=3,840$ minutes) for the examination of a bed. The narrow Goletas bed has quite a few transects and not as many quadrats per transect since the transect lines are not long ( $<500 \mathrm{~m}$ ). The time spent examining a quadrat within a transect and travel time between quadrats ranged from 1 to 3 minutes. The time to establish and swim a transect can range from 20 to 40 minutes. Values for the optimal numbers listed in Table 6, indicate that fewer quadrats within a transect should be examined and many more transects should be sampled than was surveyed. This could be due to the close values obtained for the between and within variances, $s_{1}^{2}$ and $s_{2}^{2}$.

In contrast, the large Comox bed required longer transects ( $>500 \mathrm{~m}$ ), which resulted in many more quadrats per transect being examined. Less time was spent per quadrat within a transect ( 0.5 minutes) and more time to establish and swim per transect ( 100 to 150 minutes) for the Comox bed compared to the Goletas bed. The values in Table 7 indicate that, on average, fewer $(<50)$ quadrats/transect need be examined as compared to the 107 that were examined per transect for the Comox survey.

For both of these beds, notice that for a fixed cost per transect $\left(c_{1}\right)$, increasing the cost per quadrat $\left(c_{2}\right)$ results in a decrease in the number of quadrats that should be examined (Table 6,7 ).

Figure 4 is a graphical representation of how the variance estimate, $V(\overline{\overline{\mathrm{y}}})$, is affected by the number of quadrats examined per transect $(\mathrm{m})$ for various costs ( $c_{1}$ and $c_{2}$ ). For each curve, the variance estimates have been standardized by their respective optimal variance estimates (the variance estimate for the optimal values of $m$ and $n$ for the given cost combination). The optimal values of m , for the listed cost combinations, are the minimum point of their respective cost curves. Notice that an increase in $c_{1}$ for a fixed value of $c_{2}$ causes a shift to the right to a higher value of $m$; more quadrats should be examined within each transect.

Figure 5 is a graphical representation of the effect of varying the variance ratio, $\mathrm{S}_{2}^{2} / \mathrm{S}_{1}^{2}$, on the variance estimate, $V(\overline{\overline{\mathrm{y}}})$, given fixed cost values. For both plots of Goletas and Comox, the solid lines represent the variance ratios obtained from the sample data. Notice that a decrease in the variance ratio indicates that less quadrats should be examined; there is less variability within transects than between.

The optimal sampling design is dependent on the allocation of available resources between each stage of the sampling procedure. For both types of beds, more transects should be sampled with fewer quadrats/transect should be examined. The number of transects that should be sampled is dependent on the total allocation of time for the examination of a bed.

The optimal sample design suggested that the number of transects should be increased by 20 to $30 \%$ and that the number of quadrats per transect could be reduced to a half or third of that used in these surveys (e.g., every second or third quadrat per transect).

## DISCUSSION

## Show Factors

Estimates of the total geoduck population in a show factor plot may be underestimated resulting in an underestimate of geoduck density for the whole area surveyed. The scale of this underestimate is likely to be small if the survey is conducted during April to September when shows are expected to be highest (Goodwin 1973, 1977; Cox and Charman 1979; Turner and Cox 1981; Fyfe 1984). Shows are highest when the local water currents are not excessive and there is no mechanical disturbance of the bottom (Goodwin 1977), e.g., the proportion of geoduck shows was reduced after a storm in an exposed area (Campbell et al.1996b). Clearly, surveys should be conducted when geoduck shows are most likely to be high: i.e., during seasonal periods of April-September, low tidal exchange periods and reasonably calm periods in exposed areas (avoid periods soon after storms).

We recognise that there may be problems with estimating geoduck percentage show and further research is required. Sources of error need to be defined. The number of show factor plots required to best represent the survey area in relation to the limited time and logistics requires consideration. Behaviour of geoducks due to local physical disturbances and physiological effects needs to be better understood to help with planning of when and where surveys are conducted and to schedule daily counts in the show factor plots. Factors affecting the seasonal and diurnal changes in the proportion of geoducks showing in different areas and alternative efficient methods of determining the total geoduck population in small areas need to be examined.

## Geoduck Distribution by Depth

The present survey are depth limited to about 20 m datum which is similar to the geoduck fishery at present. However, geoduck beds may extend deeper than this lower depth limit (Jamison et al. 1984). Different survey methodologies may have to be developed or modified should significant exploitation of geoducks occur at deeper water levels.

## Choice of Survey Type

Kronlund et al.(1998) suggested that systematic sampling designs should be avoided. We agree based on survey sampling theory. Consequently this paper recommends using randomly selected primary units (transects or cluster of sampling units) for future geoduck surveys such in survey types 2,3 or 4.

For surveying geoduck beds in an archipelago of small islands survey type 2 may be useful. However, there are no data to evaluate this survey design at present.

Not all secondary units (quadrats) along a transect need to be sampled to estimate within transect density. Reduction in the number of secondary units measured along a transect will reduce the effort and time required to sample a transect and allow more transects to be sampled during a survey. Survey type 3 provides similar density estimates of geoducks, but is more efficient in terms of area covered in a shorter time period than survey 1 (Table 2,3 ). No third stage variance can be computed in survey type 3 which therefore offers no advantage over a 2 stage design such as survey type 4. Logistic simplicity, especially underwater, requires that all randomization procedures are made prior to diving. Survey type 4 is logistically easier to implement for field crews than survey type 1 or 3 .

We recommend survey type 4 should be adopted with primary sampling units (transects or clusters of sampling units) randomly spaced within beds and with systematically placed secondary units (quadrats) for future geoduck surveys. For at least two of the surveys analyzed, the optimal sample design suggested that the number of transects should be increased by 20 to $30 \%$ and that the number of quadrats per transect could be reduced to a half or third of that used in these surveys (e.g., every second or third quadrat per transect).

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## REFERENCES

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

Breen, P.A. and T.L. Shields. 1983. Age and size structure in five populations of geoduck clams, Panope generosa, in British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1169.

Burger, L., E. Rome, A. Campbell, R. Harbo, J. Wasilewski and D. Stewart. 1998. Analysis of landed weight information for geoduck clams (Panopea abrupta) in British Columbia, 19811995. pp. 365-375. In: B.J. Waddell, G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 1. Bivalves. Can. Tech. Rep. Fish. Aquat. Sci. 2214.

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

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

Campbell, A. and K.N. Rajwani. 1998. Optimal sample sizes for geoduck biosamples. pp. 4369. In: G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Committee (PSARC) in 1996. Can. Tech. Rep. Fish. Aquat. Sci. 2221.

Campbell, A., B. Clapp, C. Hand, R. Harbo, K. Hobbs, J. Hume and G. Scharf. 1998. A survey of geoduck population density in Goletas Channel, 1994. pp. 319-348. In: B.J. Waddell, G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 1. Bivalves. Can. Tech. Rep. Fish. Aquat. Sci. 2214.

Cochran, W.G. 1977. Sampling Techniques. 3rd ed., John Wiley \& Sons, Inc. New York. 428 p.
Cox, R.K. and E.M. Charman. 1979. A survey of abundance and distribution (1977) of the geoduck clam, Panope generosa, in Queen Charlotte, Johnstone and Georgia Straits, British Columbia. Marine Resources Branch Fisheries Development Report 16: 122 p.

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

Fyfe, D.A. 1984. The effect of conspecific association on growth and dispersion of the geoduck clam, Panope generosa. M. Sc. thesis. Simon Fraser University, Burnaby, B.C.: 110 p.

Goodwin, C.L. 1973. Subtidal geoducks of Puget Sound, Washington. Wash. Dept. Fish. Tech. Rep. 13: 64 p.

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

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

Goodwin, C.L. and W. Shaul. 1984. Age, recruitment and growth of the geoduck clam (Panope generosa, Gould) in Puget Sound, Washington. Progress Report No. 215 State of Washington, Dept. of Fisheries: 29 p.

Hand, C.M., A. Campbell, L. Lee and G. Martel. 1998a. A survey of geoduck stocks on north Burnaby Island, Queen Charlotte Islands, July 7-18, 1994. pp. 349-364. In: B.J. Waddell, G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 1. Bivalves. Can. Tech. Rep. Fish. Aquat. Sci. 2214.

Hand, C.M., K. Hobbs, R. Harbo and G.A. Thomas. 1998b. Quota options and recommendations for the 1996 geoduck clam fishery. pp. 377-437. In: B.J. Waddell, G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 1. Bivalves. Can. Tech. Rep. Fish. Aquat. Sci. 2214.

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

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

Jamison, D., R. Heggen, and J. Lukes. 1984. Underwater video in a regional benthos survey. Proc. Pac. Cong. on Mar. Tech. Mar. Tech. Soc. Honolulu, Hawaii.

Kronlund, A.R., G.E. Gillespie and G.D Heritage. 1998. Survey methodology for intertidal bivalves. pp. 127-243. In: B.J. Waddell, G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 1. Bivalves. Can. Tech. Rep. Fish. Aquat. Sci. 2214.

Press, W.H., B.P. Flannery, S.A Teukolsky and W.T. Vetterling. 1986. Numerical Recipes. The Art of Scientific Computing. Cambridge Univ. Press. 818 p.

Rao, J.N.K. and C.F.J. Wu. 1988. Resampling inference with complex survey data. J. Amer. Statistical Assoc. 83 (401): 231-241.

Thompson, S.K. 1992. Sampling. John Wiley and Sons, Inc. New York. 343 p.
Turner, K.C. and R.K. Cox. 1981. Seasonal reproductive cycle and show factor variation of the geoduck clam, Panope generosa, (Gould) in British Columbia. J. Shellfish Res. 1: 125.

Table 1. List of variables used in equations for analyzing geoduck survey data.

| Variable | Definition |
| :---: | :---: |
| a | mean transect area ( $\mathrm{m}^{2}$ ) |
| $\mathrm{a}_{\mathrm{i}}$ | area of the $i^{\text {th }}$ transect ( $\mathrm{m}^{2}$ ) |
| $\mathrm{B}_{\mathrm{i}}$ | mean estimated population biomass (kg) for the $i^{\text {th }}$ bootstrap |
| $\mathrm{b}_{\mathrm{i}}$ | number of observed geoducks in the $i^{\text {th }}$ transect |
| C | total cost of the survey (minutes) |
| $\mathrm{c}_{1}$ | cost of establishing a transect (minutes) |
| $\mathrm{c}_{2}$ | cost of examining a quadrat (minutes) |
| d | estimated mean density of geoducks in bed (number $/ \mathrm{m}^{2}$ ) |
| $\mathrm{d}_{\mathrm{i}}$ | density for the $i^{\text {th }}$ transect (number $/ \mathrm{m}^{2}$ ) |
| $\mathrm{D}_{\mathrm{k}}$ | density estimate for each $k^{\text {th }}$ transect for bootstrap procedure 2 |
| $\delta_{\text {m }}$ | mean bootstrapped densities for $m$ number of bootstraps |
| $\mathrm{h}_{\mathrm{k}}$ | retransformed log odds show factor proportion between 0 and 1 |
| L | bed size in square metres |
| m | number of bootstraps (usually 1000) |
| $\mathrm{m}_{\mathrm{i}}$ | number of quadrats examined in the $i$ thenst |
| $\overline{\mathrm{m}}$ | mean number of quadrats examined in $n$ transects, $\bar{m}=\sum_{i=1}^{n} m_{i} / n$ |
| n | number of transects sampled |
| N | total population number of possible transects samples in a bed |
| $\mathrm{P}_{\mathrm{i}}$ | mean estimated population numbers from the ith bootstrap |
| q | number for every qth (e.g., 2 nd, 3rd or 4th) quadrat or block surveys 3 or 4 |
| $S_{1}^{2}$ | estimated variance due to among transect variation |
| $\mathrm{S}_{2}^{2}$ | estimated variance due to among quadrat variation within a transect |
| SE (d) | estimated standard error of the mean density |
| SE(L) | estimated standard error of the bed size |
| $\mathrm{SE}\left(\mathrm{SP}_{\mathrm{i}}\right)$ | estimated standard error of the mean show factor |
| SE(W) | estimated standard error of the mean weight (kg) |
| SPi | estimated mean daily proportion of geoducks showing on day $i$ |
| $\mathrm{T}_{\mathrm{i}}$ | number of previously unobserved show on day $i$ |
| $\mathrm{v}(\overline{\overline{\mathrm{y}}})$ | estimate variance of $\overline{\overline{\mathrm{y}}}$ |
| $\mathrm{X}_{\mathrm{i}}$ | number of observed shows in a plot on day $i$ |
| $y_{i j}$ | density of the $j^{\text {dh }}$ quadrat in the $i^{\text {th }}$ transect |
| $\bar{y}_{i}$ | mean density of the $i^{\text {th }}$ transect |
| $\overline{\bar{y}}$ | mean density for the bed |

Table 2. Summary details of surveys for geoducks at Sandy Island (Campbell et al. 1998b) and Goletas Channel (Campbell et al. 1998c) and the southern portion of Elbow Bank during 1994 and 1995 (unpublished data). values in brackets are for total area ( $\mathrm{m}^{2}$ ) in transects or minutes that include all quadrats where geoducks were not counted.

| Details | SandyIsland1993 Survey | Goletas Southern Elbow Bank |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  |  | $1994$ <br> Survey | 1994 Survey | 1995 Survey |
| Dates | 11-29 June | 31-21 Sep. | 27 Sep.-1 Oct. | 14-18 Sep. |
| Survey days | 8 | 9 | 4 | 3 |
| Survey type | 1 | 1 | 1 | 3 |
| Approx. bed area (ha) | 304.7 | 161.3 | 64.85 | 64.85 |
| No. of transects | 15 | 77 | 5 | 8 |
| Transect length (m) mean | 539.7 | 63.7 | 277 | 20 |
| min | 385 | 25 | 210 | 180 |
| max | 950 | 130 | 340 | 380 |
| Quadrat size (m) | $5 \times 2$ | $5 \times 2$ | $5 \times 2$ | $5 \times 2$ |
| Block length (m) | 5 | 5 | 5 | 20 |
| No. possible quadrats/block | 1 | 1 | 1 | 4 |
| No. quadrats surveyed/block | 1 | 1 | 1 | 1 |
| Total possible quadrats | 1,619 | 981 | 277 | 400 |
| Total quadrats surveyed | 1,619 | 981 | 277 | 100 |
| Total area ( $\mathrm{m}^{2}$ ) in transects surveyed | 16,190 | 9,810 | 2,770 | 1,000 (4,000) |
| Mean quadrats surveyed/transect | 107.9 | 12.7 | 55.4 | 12.5 |
| Mean area ( $\mathrm{m}^{2}$ ) surveyed/transect | 1,079 | 127 | 554 | 125 |
| Square metres surveyed/ha | 53.1 | 60.8 | 42.7 | 15.4 (61.7) |
| Percent area surveyed/total bed area | 0.531 | 0.608 | 0.427 | 0.154 (0.617) |
| No. transects/ha | 0.049 | 0.477 | 0.077 | 0.125 |
| Total dive time (minutes) | 824 | 1,246 | 442 | 430 |
| Mean minutes/transect | 54.9 | 16.2 | 88.4 | 53.75 |
| Mean area ( $\mathrm{m}^{2}$ ) surveyed/minute | 19.65 | 7.87 | 6.27 | 2.33 (9.30) |
| Mean minutes/quadrat surveyed | 0.51 | 1.27 | 1.59 | 4.30 (1.08) |

Table 3. Comparison of geoduck density (number $/ \mathrm{m}^{2}$ ), population number and total biomass (kg) estimates (adjusted and not adjusted for show factor) from the same area on southern Elbow Bank, near Tofino, using survey type 1 during 1994 and survey type 3 during 1995. Estimated mean weight was $1.483 \mathrm{~kg} \pm 0.017 \mathrm{SE}$ and estimated bed area was $648500 \mathrm{~m}^{2} \pm 6485 S E$. number of bootstraps, $\mathrm{m}=1,000 . \mathrm{CI}=95 \%$ confidence interval

| Details | Elbow Bank | (1994) | Elbow Bank | (1995) |
| :---: | :---: | :---: | :---: | :---: |
| Adjustment for show factor | no | yes | no | yes |
| Classical density estimate |  |  |  |  |
| mean | 0.464 | 0.514 | 0.469 | 0.582 |
| SE | 0.084 | 0.093 | 0.050 | 0.060 |
| Bootstrap estimates |  |  |  |  |
| Density, mean | 0.463 | 0.516 | 0.465 | 0.590 |
| lower CI | 0.316 | 0.337 | 0.348 | 0.441 |
| upper CI | 0.604 | 0.667 | 0.581 | 0.727 |
| Population number, mean | 300,096 | 334,419 | 301,656 | 382,417 |
| lower CI | 202,792 | 219,440 | 227,682 | 287,327 |
| upper CI | 389,902 | 432,493 | 376,997 | 472,384 |
| Total Biomass, mean | 445,090 | 495,769 | 447,301 | 566,940 |
| lower CI | 299,932 | 325,915 | 332,887 | 424,564 |
| upper CI | 576,603 | 643,798 | 558,634 | 700,897 |

Table 4. Comparison of geoduck density (number $/ \mathrm{m}^{2}$ ), population number and total biomass (kg) estimates (adjusted for show factor) using different alternating quadrats per transect for a survey type 4 analyses from data on southern Elbow Bank 1994 survey Estimated mean weight was $1.483 \mathrm{~kg} \pm 0.017 S E$ and estimated bed area was $648,500 \mathrm{~m}^{2} \pm 6,485 S E$, number of bootstraps, $\mathrm{m}=1,000 . \mathrm{CI}=95 \%$ confidence interval. To simulate a survey type 4 a random quadrat within each transect was chosen from the first q quadrats and every succesive qth quadrat was then selected. The values given are examples only since there could be slightly different values for different random starts especially for every third ( $q=3$ ) or fourth ( $q=4$ ) quadrat per transect survey.

| Details | All Quadrats | $q=2$ | $\mathrm{q}=3$ | $\mathrm{q}=4$ |
| :---: | :---: | :---: | :---: | :---: |
| Classical density estimate mean | 0.514 | 0.509 | 0.485 | 0.507 |
| SE | 0.093 | 0.095 | 0.083 | 0.111 |
| Bootstrap estimates |  |  |  |  |
| Density, mean | 0.516 | 0.502 | 0.482 | 0.500 |
| lower CI | 0.337 | 0.314 | 0.311 | 0.274 |
| upper CI | 0.667 | 0.668 | 0.646 | 0.707 |
| Population number, mean | 334,419 | 325,661 | 312,525 | 323,899 |
| lower CI | 219440 | 204,614 | 200,724 | 178,938 |
| upper CI | 432,493 | 433,203 | 421,261 | 461,493 |
| Total Biomass, mean | 495,769 | 482,988 | 463,276 | 480,272 |
| lower CI | 325,915 | 304,812 | 296,482 | 263,091 |
| upper CI | 643,798 | 641,666 | 621,518 | 685,902 |

Table 5. Summary statistics of geoduck densities from Goletas Channel and from Sandy Island, Comox.

|  | Goletas Channel | Comox |
| :--- | :---: | :---: |
| n | 77 | 15 |
| Number of quadrats/transect | 13 | 107 |
| $\quad$ mean | 5 | 77 |
| $\quad$ min | 26 | 190 |
| max | 0.987 | 0.322 |
| Mean density for bed, $\overline{\bar{y}}$ | 0.018 | 0.002 |
| $\mathrm{v}(\overline{\overline{\mathrm{y}}})$ | 0.133 | 0.040 |
| $\mathrm{se}(\overline{\overline{\mathrm{y}}})$ | 1.223 | 0.023 |
| $\mathrm{~s}_{1}^{2}$ | 1.783 | 0.144 |
| $\mathrm{~s}_{2}^{2}$ | 1.457 | 6.241 |
| $\mathrm{~s}_{2}^{2} / \mathrm{s}_{1}^{2}$ |  |  |

Table 6. Optimal sampling design for a two-stage design for geoduck densities from Goletas Channel for various cost estimates ( $1=$ cost to establish a transect, $2=$ cost to examine a quadrat in a transect). $\overline{\mathrm{m}}_{\mathrm{opt}}=$ optimum mean number of quadrats, $\mathrm{n}=$ optimal number of transects.

| Cost (in minutes) |  |  | Cost ratio | Optimal values |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| C | 1 | 2 | $\mathrm{c}_{1} / \mathrm{c}_{2}$ | $\overline{\mathrm{m}}_{\text {opt }}$ | n |
| 2,880 | 20 | 1 | 20.0 | 5 | 113 |
| ( 6 days $=48$ hours) | 20 | 2 | 10.0 | 4 | 104 |
|  | 20 | 3 | 6.7 | -3 | 98 |
|  | 30 | 1 | 30.0 | 7 | 79 |
|  | 30 | 2 | 15.0 | 5 | 73 |
|  | 30 | 3 | 10.0 | 4 | 70 |
|  | 40 | 1 | 40.0 | 8 | 61 |
|  | 40 | 2 | 20.0 | 5 | 57 |
|  | 40 | 3 | 13.3 | 5 | 54 |
| 3,840 | 20 | 1 | 20.0 | 5 | 151 |
| ( 8 days $=64$ hours) | 20 | 2 | 10.0 | 4 | 139 |
|  | 20 | 3 | 6.7 | 3 | 131 |
|  | 30 | 1 | 30.0 | 7 | 105 |
|  | 30 | 2 | 15.0 | 5 | 98 |
|  | 30 | 3 | 10.0 | 4 | 93 |
|  | 40 | 1 | 40.0 | 8 | 81 |
|  | 40 | 2 | 20.0 | 5 | 76 |
|  | 40 | 3 | 13.3 | 4 | 72 |
| 4,800 | 20 | 1 | 20.0 | 5 | 189 |
| ( 10 days $=80$ hours) | 20 | 2 | 10.0 | 4 | 174 |
|  | 20 | 3 | 6.7 | 3 | 164 |
|  | 30 | 1 | 30.0 | 7 | 131 |
|  | 30 | 2 | 15.0 | 5 | 122 |
|  | 30 | 3 | 10.0 | 4 | 116 |
|  | 40 | 1 | 40.0 | 8 | 101 |
|  | 40 | 2 | 20.0 | 5 | 95 |
|  | 40 | 3 | 13.3 | 4 | 90 |

Table 7. Optimal sampling design for a two-stage design for geoduck densities from near Sandy Island, Comox, for various cost estimates ( $1=$ cost to establish a transect, $2=$ cost to examine a quadrat in a transect). $\overline{\mathrm{m}}_{\mathrm{opt}}=$ optimum mean number of quadrats, $\mathrm{n}=$ optimal number of transects.

| Cost (in minutes) |  |  | Cost ratio | Optimal values |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| C | 1 | 2 | $\mathrm{c}_{1} / \mathrm{c}_{2}$ | $\overline{\mathrm{m}}_{\text {opt }}$ | n |
| 2,880 | 100 | 0.5 | 200.0 | 35 | 24 |
|  | 100 | 1.0 | 100.0 | 25 | 23 |
|  | 100 | 1.5 | 66.7 | 20 | 22 |
|  | 150 | 0.5 | 300.0 | 43 | 17 |
|  | 150 | 1.0 | 150.0 | 31 | 16 |
|  | 150 | 1.5 | 100.0 | 25 | 15 |
|  | 200 | 0.5 | 400.0 | 50 | 13 |
|  | 200 | 1.0 | 200.0 | 35 | 12 |
|  | 200 | 1.5 | 133.3 | 29 | 12 |
| 3,840 | 100 | 0.5 | 200.0 | 35 | 33 |
|  | 100 | 1.0 | 100.0 | 25 | 31 |
|  | 100 | 1.5 | 66.7 | 20 | 29 |
|  | 150 | 0.5 | 300.0 | 43 | 22 |
|  | 150 | 1.0 | 150.0 | 31 | 21 |
|  | 150 | 1.5 | 100.0 | 25 | 20 |
|  | 200 | 0.5 | 400.0 | 50 | 17 |
|  | 200 | 1.0 | 200.0 | 35 | 16 |
|  | 200 | 1.5 | 133.3 | 29 | 16 |
| 4,800 | 100 | 0.5 | 200.0 | 35 | 41 |
|  | 100 | 1.0 | 100.0 | 25 | 38 |
|  | 100 | 1.5 | 66.7 | 20 | 37 |
|  | 150 | 0.5 | 300.0 | 43 | 28 |
|  | 150 | 1.0 | 150.0 | 31 | 27 |
|  | 150 | 1.5 | 100.0 | 25 | 26 |
|  | 200 | 0.5 | 400.0 | 50 | 21 |
|  | 200 | 1.0 | 200.0 | 35 | 20 |
|  | 200 | 1.5 | 133.3 | 29 | 20 |

Survey Type 1 - Systematic


Transect - conseculive quadrats


Transect - consecutive quadrats


Fig. 1a. Schematic diagrams to indicate spacing of transects and quadrats in transects for three survey types to estimate geoduck density. For survey types 1 and 3 outer borders are approximate bed boundaries and horizontal lines in beds are lines to estimate random placement on chart of first transect (subsequently even spacing ( 100 or 300 m ) of transects) of survey type 1 and all transects in survey type 3 . For survey type 2 a grid is placed over a chart with random choice of grid square and placement of a transect in $0-18.3 \mathrm{~m}$ water depth range per square.


Transect - systematic quadrats every second, third or fourth quadrat alter lirst quadrat. randomly chosen in first two, three or four quadrats, respectively, on transect.

Fig. 1b. Schematic diagram to indicate spacing of transects (primary units) and quadrats (secondary units) in transects for survey type 4 to estimate geoduck density. Outer borders are approximate bed boundaries and horizontal lines in beds are lines to estimate random placement on chart of all transects. Quadrats are placed with a random start within first q quadrats and subsequently one out of every q quadrats chosen systematically along a transect. ( $q=2,3$ or 4 depending on transect length).


Fig. 2. The effect of varying the estimated standard error (as a \%) of the bed area in the bootstrap estimation of estimated mean and $95 \%$ confidence intervals of geoduck total numbers (adjusted for show factor) in the southern portion of Elbow Bank 1995 using survey method 3. Approximate bed area $=64.85$ ha, $n=8, m=1000$.


Fig. 3. The effect of varying the estimated standard error (as a \%) of the estimated mean weight of a geoduck in the bootstrap estimation of estimated mean and $95 \%$ confidence intervals of geoduck biomass (tonnes) (adjusted for show factor) in the southern portion of Elbow Bank 1995 using survey method 3. Approximate bed area $=64.85$ ha ( $0.65 S E$ ), estimated mean geoduck weight $=1.483 \mathrm{~kg}(0.017 \mathrm{SE}), \mathrm{n}=8, \mathrm{~m}=1000$.


Fig. 4. Variance estimates, $V(\overline{\bar{y}}) / V\left(\overline{\bar{y}}_{\text {opt }}\right)$, for various values of $\bar{m}$ (mean number of quadrats/transect /bed) for geoduck density surveys from Goletas and Comox.


Fig. 5. Variance estimates, $V(\overline{\overline{\mathrm{y}}}) / \mathrm{V}\left(\overline{\overline{\mathrm{y}}}_{\text {opt }}\right)$, for various values of $\overline{\mathrm{m}}$ (mean number of quadrats/transect /bed) for geoduck density surveys from Goletas and Comox given various variance ratios, $S_{2}^{2} / S_{1}^{2}$, and fixed survey costs. Goletas: $C=3,840, c_{1}=30, c_{2}=2$; Comox: $C$ $=3,840, \mathrm{c}_{1}=200, \mathrm{c}_{2}=0.5$.

Appendix 1. Geoduck numbers, transect area $\left(\mathrm{m}^{2}\right)$ and show factor data from the same general area of southern Elbow Bank, near Tofino, using survey type 1 during 1994 and survey type 3 during 1995. N.B. for survey type 1 all geoducks were counted in the whole area of each transect, whereas for survey type 3, although geoducks were counted in only one quarter of each transect the whole area for each transect is shown

|  |  | Show factor |  |
| :---: | :---: | :---: | :---: |
| Total Geoducks | Transect Area | Mean | SD |
| S. Elbow Bank | 1994 Survey type 1 |  |  |
| 226 | 420 | 0.803 | 0.051 |
| 335 | 680 | 0.842 | 0.045 |
| 187 | 530 | 0.974 | 0.019 |
| 96 | 500 | 0.974 | 0.019 |
| 440 | 640 | 0.974 | 0.019 |
|  |  |  |  |
| S. Elbow Bank 1995 Survey type 3 |  |  |  |
| 42 | 400 | 0.778 | 0.052 |
| 25 | 400 | 0.778 | 0.052 |
| 58 | 560 | 0.778 | 0.052 |
| 101 | 760 | 0.822 | 0.051 |
| 81 | 520 | 0.822 | 0.051 |
| 58 | 400 | 0.822 | 0.051 |
| 88 | 600 | 0.800 | 0.061 |
| 16 | 360 | 0.822 | 0.051 |

Appendix 2. Geoduck numbers per $10 \mathrm{~m}^{2}$ quadrat for each block of 20 m per transect from the southern portion of Elbow Bank 1995 survey. These data were used in bootstrap procedure 3 along with the data in Appendix 1.

| Transect number | Block number | No. of geoducks per quadrat | Transect number | $\begin{gathered} \text { Block } \\ \text { number } \end{gathered}$ | No. of geoducks per quadrat | Transect number | Block number | No. of geoducks per quadrat |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 1 | 1 | 4 | 1 | 3 | 6 | 3 | 13 |
| 1 | 2 | 5 | 4 | 2 | 0 | 6 | 4 | 6 |
| 1 | 3 | 5 | 4 | 3 | 2 | 6 | 5 | 9 |
| 1 | 4 | 12 | 4 | 4 | 1 | 6 | 6 | 5 |
| 1 | 5 | 5 | 4 | 5 | 3 | 6 | 7 | 3 |
| 1 | 6 | 4 | 4 | 6 | 4 | 6 | 8 | 0 |
| 1 | 7 | 0 | 4 | 7 | 0 | 6 | 9 | 3 |
| 1 | 8 | 0 | 4 | 8 | 1 | 6 | 10 | 3 |
| 1 | 9 | 3 | 4 | 9 | 2 | 16 | 1 | 12 |
| 1 | 10 | 7 | 4 | 10 | 8 | 16 | 2 | 7 |
| 2 | 1 | 3 | 4 | 11 | 12 | 16 | 3 | 2 |
| 2 | 2 | 3 | 4 | 12 | 7 | 16 | 4 | 4 |
| 2 | 3 | 3 | 4 | 13 | 16 | 16 | 5 | 3 |
| 2 | 4 | 1 | 4 | 14 | 15 | 16 | 6 | 2 |
| 2 | 5 | 1 | 4 | 15 | 8 | 16 | 7 | 2 |
| 2 | 6 | 3 | 4 | 16 | 4 | 16 | 8 | 12 |
| 2 | 7 | 3 | 4 | 17 | 10 | 16 | 9 | 7 |
| 2 | 8 | 2 | 4 | 18 | 4 | 16 | 10 | 17 |
| 2 | 9 | 1 | 4 | 19 | 1 | 16 | 11 | 5 |
| 2 | 10 | 5 | 5 | 1 | 10 | 16 | 12 | 10 |
| 3 | 1 | 6 | 5 | 2 | 13 | 16 | 13 | 3 |
| 3 | 2 | 5 | 5 | 3 | 10 | 16 | 14 | 1 |
| 3 | 3 | 0 | 5 | 4 | 10 | 16 | 15 | 1 |
| 3 | 4 | 1 | 5 | 5 | 12 | 51 | 1 | 0 |
| 3 | 5 | 5 | 5 | 6 | 4 | 51 | 2 | 4 |
| 3 | 6 | 2 | 5 | 7 | 2 | 51 | 3 | 3 |
| 3 | 7 | 7 | 5 | 8 | 4 | 51 | 4 | 0 |
| 3 | 8 | 8 | 5 | 9 | 6 | 51 | 5 | 4 |
| 3 | 9 | 2 | 5 | 10 | 7 | 51 | 6 | 0 |
| 3 | 10 | 5 | 5 | 11 | 3 | 51 | 7 | 3 |
| 3 | 11 | 3 | 5 | 12 | 0 | 51 | 8 | 2 |
| 3 | 12 | 2 | 5 | 13 | 0 | 51 | 9 | 0 |
| 3 | 13 | 4 | 6 | 1 | 10 |  |  |  |
| 3 | 14 | 8 | 6 | 2 | 6 |  |  |  |

Appendix 3. Geoduck numbers per $10 \mathrm{~m}^{2}$ quadrat for each quadrat per transect from the southern portion of Elbow Bank 1994 survey. These data were used to estimate densities for different quadrat combinations in survey method 4 along with the data in Appendix 1.

| Transect number | Quadrat number | No. of geoducks per quadrat | Transect number | Quadrat number | No. of geoducks per quadrat | Transect number | Quadrat number | No. of geoducks per quadrat |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 1 | 0 | 2 | 7 | 13 | 2 | 55 | 2 |
| 1 | 2 | 0 | 2 | 8 | 13 | 2 | 56 |  |
| 1 | 3 | 0 | 2 | 9 | 13 | 2 | 57 | 1 |
| 1 | 4 | 3 | 2 | 10 | 7 | 2 | 58 | 2 |
| 1 | 5 | 15 | 2 | 11 | 9 | 2 | 59 | 2 |
| 1 | 6 | 9 | 2 | 12 | 11 | 2 | 60 | 3 |
| 1 | 7 | 0 | 2 | 13 | 12 | 2 | 61 | 0 |
| 1 | 8 | 9 | 2 | 14 | 14 | 2 | 62 | 0 |
| 1 | 9 | 8 | 2 | 15 | 10 | 2 | 63 | 3 |
| 1 | 10 | 10 | 2 | 16 | 6 | 2 | 64 | 2 |
| 1 | 11 | 8 | 2 | 17 | 1 | 2 | 65 | 3 |
| 1 | 12 | 7 | 2 | 18 | 6 | 2 | 66 | 4 |
| 1 | 13 | 4 | 2 | 19 | 11 | 2 | 67 | 8 |
| 1 | 14 | 3 | 2 | 20 | 12 | 2 | 68 | 11 |
| 1 | 15 | 1 | 2 | 21 | 13 | 3 | 1 | 7 |
| 1 | 16 | 6 | 2 | 22 | 6 | 3 | 2 | 9 |
| 1 | 17 | 5 | 2 | 23 | 2 | 3 | 3 | 10 |
| 1 | 18 | 0 | 2 | 24 | 6 | 3 | 4 | 10 |
| 1 | 19 | 6 | 2 | 25 | 10 | 3 | 5 | 6 |
| 1 | 20 | 5 | 2 | 26 | 2 | 3 | 6 | 7 |
| 1 | 21 | 6 | 2 | 27 | 2 | 3 | 7 | 5 |
| 1 | 22 | 5 | 2 | 28 | 7 | 3 | 8 | 7 |
| 1 | 23 | 4 | 2 | 29 | 7 | 3 | 9 | 3 |
| 1 | 24 | 7 | 2 | 30 | 5 | 3 | 10 | 2 |
| 1 | 25 | 4 | 2 | 31 | 3 | 3 | 11 | 2 |
| 1 | 26 | 3 | 2 | 32 | 3 | 3 | 12 | 0 |
| 1 | 27 | 4 | 2 | 33 | 1 | 3 | 13 | 3 |
| 1 | 28 | 5 | 2 | 34 | 1 | 3 | 14 | 2 |
| 1 | 29 | 5 | 2 | 35 | 3 | 3 | 15 | 2 |
| 1 | 30 | 3 | 2 | 36 | 2 | 3 | 16 | 1 |
| 1 | 31 | 13 | 2 | 37 | 2 | 3 | 17 | 0 |
| 1 | 32 | 6 | 2 | 38 | 2 | 3 | 18 | 3 |
| 1 | 33 | 6 | 2 | 39 | 0 | 3 | 19 | 5 |
| 1 | 34 | 6 | 2 | 40 | 0 | 3 | 20 | 3 |
| 1 | 35 | 5 | 2 | 41 | 1 | 3 | 21 | 3 |
| 1 | 36 | 6 | 2 | 42 | 0 | 3 | 22 | 1 |
| 1 | 37 | 6 | 2 | 43 | 2 | 3 | 23 | 6 |
| 1 | 38 | 4 | 2 | 44 | 1 | 3 | 24 | 2 |
| 1 | 39 | 7 | 2 | 45 | 1 | 3 | 25 | 0 |
| 1 | 40 | 5 | 2 | 46 | 2 | 3 | 26 | 1 |
| 1 | 41 | 12 | 2 | 47 | 2 | 3 | 27 | 2 |
| 1 | 42 | 5 | 2 | 48 | 3 | 3 | 28 | 0 |
| 2 | 1 | 0 | 2 | 49 | 10 | 3 | 29 | 0 |
| 2 | 2 | 1 | 2 | 50 | 5 | 3 | 30 | 1 |
| 2 | 3 | 0 | 2 | 51 | 5 | 3 | 31 | 0 |
| 2 | 4 | 5 | 2 | 52 | 3 | 3 | 32 | 0 |
| 2 | 5 | 11 | 2 | 53 | 13 | 3 | 33 | 0 |
| 2 | 6 | 5 | 2 | 54 | 8 | 3 | 34 | 0 |

Appendix 3 (cont.)

| Transect number | Quadrat number | No. of geoducks per quadrat | Transect number | Quadrat number | No. of geoducks per quadrat | Transect number | Quadrat number | No. of geoducks per quadrat |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 3 | 35 | 0 | 4 | 35 | 0 | 5 | 38 | 11 |
| 3 | 36 | 0 | 4 | 36 | 0 | 5 | 39 | 6 |
| 3 | 37 | 0 | 4 | 37 | 0 | 5 | 40 | 11 |
| 3 | 38 | 3 | 4 | 38 | 3 | 5 | 41 | 8 |
| 3 | 39 | 1 | 4 | 39 | 0 | 5 | 42 | 14 |
| 3 | 40 | 2 | 4 | 40 | 1 | 5 | 43 | 11 |
| 3 | 41 | 5 | 4 | 41 | 2 | 5 | 44 | 12 |
| 3 | 42 | 3 | 4 | 42 | 1 | 5 | 45 | 9 |
| 3 | 43 | 2 | 4 | 43 | 1 | 5 | 46 | 5 |
| 3 | 44 | 3 | 4 | 44 | 1 | 5 | 47 | 6 |
| 3 | 45 | 5 | 4 | 45 | 1 | 5 | 48 | 9 |
| 3 | 46 | 6 | 4 | 46 | 0 | 5 | 49 | 21 |
| 3 | 47 | 11 | 4 | 47 | 1 | 5 | 50 | 12 |
| 3 | 48 | 11 | 4 | 48 | 2 | 5 | 51 | 16 |
| 3 | 49 | 6 | 4 | 49 | 5 | 5 | 52 | 8 |
| 3 | 50 | 3 | 4 | 50 | 3 | 5 | 53 | 8 |
| 3 | 51 | 8 | 5 | 1 | 5 | 5 | 54 | 12 |
| 3 | 52 | 5 | 5 | 2 | 6 | 5 | 55 | 16 |
| 3 | 53 | 10 | 5 | 3 | 2 | 5 | 56 | 14 |
| 4 | 1 | 4 | 5 | 4 | 4 | 5 | 57 | 6 |
| 4 | 2 | 2 | 5 | 5 | 3 | 5 | 58 | 9 |
| 4 | 3 | 4 | 5 | 6 | 2 | 5 | 59 | 6 |
| 4 | 4 | 6 | 5 | 7 | 6 | 5 | 60 | 5 |
| 4 | 5 | 4 | 5 | 8 | 5 | 5 | 61 | 15 |
| 4 | 6 | 4 | 5 | 9 | 3 | 5 | 62 | 6 |
| 4 | 7 | 4 | 5 | 10 | 2 | 5 | 63 | 7 |
| 4 | 8 | 1 | 5 | 11 | 4 | 5 | 64 | 11 |
| 4 | 9 | 2 | 5 | 12 | 3 |  |  |  |
| 4 | 10 | 1 | 5 | 13 | 4 |  |  |  |
| 4 | 11 | 3 | 5 | 14 | 4 |  |  |  |
| 4 | 12 | 1 | 5 | 15 | 5 |  |  |  |
| 4 | 13 | 3 | 5 | 16 | 1 |  |  |  |
| 4 | 14 | 1 | 5 | 17 | 2 |  |  |  |
| 4 | 15 | 0 | 5 | 18 | 5 |  |  |  |
| 4 | 16 | 2 | 5 | 19 | 4 |  |  |  |
| 4 | 17 | 0 | 5 | 20 | 4 |  |  |  |
| 4 | 18 | 0 | 5 | 21 | 4 |  |  |  |
| 4 | 19 | 1 | 5 | 22 | 4 |  |  |  |
| 4 | 20 | 1 | 5 | 23 | 6 |  |  |  |
| 4 | 21 | 0 | 5 | 24 | 4 |  |  |  |
| 4 | 22 | 2 | 5 | 25 | 7 |  |  |  |
| 4 | 23 | 4 | 5 | 26 | 2 |  |  |  |
| 4 | 24 | 3 | 5 | 27 | 2 |  |  |  |
| 4 | 25 | 2 | 5 | 28 | 9 |  |  |  |
| 4 | 26 | 1 | 5 | 29 | 4 |  |  |  |
| 4 | 27 | 2 | 5 | 30 | 3 |  |  |  |
| 4 | 28 | 3 | 5 | 31 | 4 |  |  |  |
| 4 | 29 | 3 | 5 | 32 | 7 |  |  |  |
| 4 | 30 | 2 | 5 | 33 | 3 |  |  |  |
| 4 | 31 | 3 | 5 | 34 | 5 |  |  |  |
| 4 | 32 | 2 | 5 | 35 | 9 |  |  |  |
| 4 | 33 | 3 | 5 | 36 | 8 |  |  |  |
| 4 | 34 | 1 | 5 | 37 | 11 |  |  |  |

# OPTIMAL SAMPLE SIZES FOR GEODUCK BIOSAMPLES 

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#### Abstract

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Sampling for mean weight, mean age or age structure of geoduck populations during field surveys was considered as a three-stage sampling problem. Optimum allocation of sampling resources (in terms of time) was obtained by minimizing the variance of the variable of interest for a fixed total time cost. Example data of biosamples collected from five geoduck beds located throughout British Columbia were used in the optimizing survey design analyses. These optimal designs were found to be sensitive to costs as well as estimated variances. For each optimal design considered, the amount of time (cost) to process a geoduck for age was greater than for a weight measurement. More geoducks were required for mean age compared to mean weight estimates because of the higher variability in ages compared to weights of geoduck. The most reasonable sample requirement depended on the objective variable to measure and the amount of time required for obtaining the samples. For mean weights about 20 geoducks per site within a bed with 1 site per bed from 3 to 4 beds could be sampled per survey day (Total $\cong 80$ geoducks). For both mean weight and age about 60 geoducks per site within a bed, with 1 site per bed from 2 to 4 beds could be sampled (Total $\cong 240$ geoducks). For age structure analyses about 100 geoducks per site within a bed, with 2 sites per bed and 2 beds (range $1-4$ beds) could be sampled per survey (Total $\cong 400$ geoducks). An additional approximate $10 \%$ of geoducks should be added to the sample size due to damage to soft body parts and shell breakage during sample collection, transportation and processing.

## INTRODUCTION

The fishery for the bivalve geoduck clam, Panopea abrupta, is managed by setting quotas for management areas throughout British Columbia (B.C.) (Harbo et al. 1995). Calculating quotas requires information on geoduck biomass (density, mean individual weights and bed areas) and sustainable harvest rates (i.e., recruitment rates) from individual geoduck beds. Recruitment of geoduck clams is not well understood and is generally considered to be low (0.75-2.0\% of estimated virgin biomass) (Breen 1982; Breen and Shields 1983; Harbo et al. 1983; Goodwin and Shaul 1984). Obtaining samples of age composition from representative populations is considered important in providing an indication of current recruitment levels of geoducks throughout B.C. Although survey
methodology for estimating geoduck density and bed areas has been developed (Campbell et al. 1998), detailed descriptions of optimal sampling schemes for obtaining biological samples (i.e., mean weight and age composition characteristics) from geoduck populations in the corresponding areas surveyed has been lacking. Density estimates can be made relatively efficient by counting the number of geoducks showing their necks above the substrate surface. However, biological samples are time consuming because geoducks have to be dug from the substrate and brought back to the laboratory for analysis. The amount of effort allocated to obtaining a biological sample is often low (i.e., one day) compared to the overall density survey (i.e., 10-14 days). In addition, the number of geoducks that can be aged is limited by budget constraints.

The problem is how to allocate limited resources to sampling a representative number of geoducks. The process of sampling geoducks to determine a particular variable within transects, (sites) at various beds, can be analyzed by a three-stage sampling design (Cochran 1977). In this design, beds are termed "primary units," sites within beds "secondary units", and individual geoducks "elements" or "tertiary units." One of the objectives of optimal survey designs is to define a survey which yields the most precise estimate at a fixed total survey cost or at a minimum variance. Once these optimal sample sizes have been determined, the total number of geoducks in the sample and the total processing cost for this sample can be calculated.

The objective of this paper is to determine preliminary optimal survey designs for three variables from a geoduck population: (1) mean individual weight, (2) mean age, and (3) age structure.

## METHODS

## Mean Measures (Weight and Age)

The objective of this analysis is to estimate the value of some feature (i.e., a mean weight or age) of geoducks, to derive an optimal sampling procedure, and to calculate the cost of processing the optimal sample. Processing refers to the time taken to mark each geoduck with a unique identification number, and weigh and age it.

To calculate the mean measure of geoducks and estimated variance, equations for a threestage design were obtained from Cochran (1977, section 10.8).

From a sample of $n$ beds, if $m$ sites are examined within each bed and $k$ geoducks are collected and measures taken, then let $y_{i j u}$ represent the measure of the $u^{\text {th }}$ geoduck obtained from the $j^{\text {th }}$ site of the $i^{\text {th }}$ bed (Table 1). The mean measure of geoducks in the $j^{\text {th }}$ site of the $i^{\text {th }}$ bed is then found to be:

$$
\begin{equation*}
\overline{\mathrm{y}}_{\mathrm{ij}}=\frac{1}{\mathrm{k}} \sum_{\mathrm{u}=1}^{\mathrm{k}} \mathrm{y}_{\mathrm{iju}}, \tag{1}
\end{equation*}
$$

and the mean measure of geoducks in the $i^{\text {th }}$ bed is:

$$
\begin{equation*}
\overline{\overline{\mathrm{y}}}_{\mathrm{i}}=\frac{1}{\mathrm{~m}} \sum_{\mathrm{j}=1}^{\mathrm{m}} \overline{\mathrm{y}}_{\mathrm{ij}} . \tag{2}
\end{equation*}
$$

Lastly, the mean measure of geoducks in the sample is:

$$
\begin{equation*}
\overline{\overline{\mathrm{y}}}=\frac{1}{\mathrm{n}} \sum_{\mathrm{i}=1}^{\mathrm{n}} \overline{\overline{\mathrm{y}}}_{\mathrm{i}} \tag{3}
\end{equation*}
$$

If the $n$ beds, $m$ sites within beds, and $k$ geoducks are selected by simple random sampling, then $\overline{\overline{\mathrm{y}}}$ is an unbiased estimate of $\overline{\overline{\mathrm{Y}}}$, the mean measure of geoducks in the population, with variance:

$$
\begin{equation*}
V(\overline{\overline{\bar{y}}})=\left(1-\frac{\mathrm{n}}{\mathrm{~N}}\right) \frac{\mathrm{S}_{1}^{2}}{\mathrm{n}}+\left(1-\frac{\mathrm{m}}{\mathrm{M}}\right) \frac{\mathrm{S}_{2}^{2}}{\mathrm{~nm}}+\left(1-\frac{\mathrm{k}}{\mathrm{~K}}\right) \frac{\mathrm{S}_{3}^{2}}{\mathrm{nmk}} \tag{4}
\end{equation*}
$$

where $N, M$ and $K$ are the population analogues of $n, m$ and $k$. In this equation, the variance due to among bed variation is:

$$
\begin{equation*}
S_{1}^{2}=\frac{\sum_{i=1}^{N}\left(\overline{\bar{Y}}_{i}-\overline{\bar{Y}}\right)^{2}}{N-1} \tag{5}
\end{equation*}
$$

the variance due to among site variation within beds is:

$$
\begin{equation*}
S_{2}^{2}=\frac{\sum_{i=1}^{N} \sum_{j=1}^{M}\left(\bar{Y}_{i j}-\overline{\bar{Y}}_{i}\right)^{2}}{N(M-1)}=\frac{1}{N} \sum_{i=1}^{N} S_{2 i}^{2} \tag{6}
\end{equation*}
$$

and the variance due to among geoduck variation within sites and beds is:

$$
\begin{equation*}
S_{3}^{2}=\frac{1}{N M(K-1)} \sum_{i=1}^{N} \sum_{j=1}^{M} \sum_{u=1}^{K}\left(y_{i j u}-\overline{Y_{i j}}\right)^{2}=\frac{1}{N M} \sum_{i=1}^{N} \sum_{\mathrm{j}=1}^{\mathrm{M}} \mathrm{~S}_{3 \mathrm{ij}}^{2} . \tag{7}
\end{equation*}
$$

An unbiased estimate of $V(\overline{\overline{\mathrm{y}}})$ from the sample is:

$$
\begin{equation*}
v(\overline{\overline{\bar{y}}})=\left(1-f_{1}\right) \frac{s_{1}^{2}}{n}+f_{1}\left(1-f_{2}\right) \frac{s_{2}^{2}}{n m}+f_{1} f_{2}\left(1-f_{3}\right) \frac{s_{3}^{2}}{n m k} \tag{8}
\end{equation*}
$$

where:

$$
\mathrm{f}_{1}=\frac{\mathrm{n}}{\mathrm{~N}}, \quad \mathrm{f}_{2}=\frac{\mathrm{m}}{\mathrm{M}}, \quad \mathrm{f}_{3}=\frac{\mathrm{k}}{\mathrm{~K}},
$$

and $\mathrm{s}_{1}^{2}, \mathrm{~s}_{2}^{2}$, and $\mathrm{s}_{3}^{2}$ are the sample analogues of $\mathrm{S}_{1}^{2}, \mathrm{~S}_{2}^{2}$, and $\mathrm{S}_{3}^{2}$.
The total cost of the survey (harvest) can be expressed as a linear function of the costs per individual stage:

$$
\begin{equation*}
\mathrm{C}=\mathrm{c}_{1} \mathrm{n}+\mathrm{c}_{2} \mathrm{~nm}+\mathrm{c}_{3} \mathrm{nmk} \tag{9}
\end{equation*}
$$

where $C$ is the total cost of the harvest, $c_{1}$ is the cost of moving between beds, $c_{2}$ is the cost of moving between sites within a bed, and $c_{3}$ is the cost of collecting a geoduck.

Optimal values of $k, m$ and $n$ are the set of values that minimize the true variance of the estimator, $V(\overline{\overline{\mathrm{y}}})$, for a fixed cost or minimize the cost for a fixed variance. Proceeding from Cochran, these values are found to be:

$$
\begin{align*}
& \mathrm{k}_{\mathrm{opt}}=\sqrt{\left(\frac{\mathrm{c}_{2}}{\mathrm{c}_{3}}\right)\left(\frac{\mathrm{S}_{3}^{2}}{\mathrm{~S}_{2}^{2}}\right)}  \tag{10}\\
& \mathrm{m}_{\mathrm{opt}}=\sqrt{\left(\frac{\mathrm{c}_{1}}{\mathrm{c}_{2}}\right)\left(\frac{\mathrm{S}_{2}^{2}}{\mathrm{~S}_{1}^{2}}\right)} \tag{11}
\end{align*}
$$

and:

$$
\begin{equation*}
\mathrm{n}_{\mathrm{opt}}=\frac{\mathrm{C}}{\mathrm{c}_{1}+\left(\mathrm{c}_{2}+\mathrm{c}_{3} \mathrm{k}_{\mathrm{opt}}\right) \mathrm{m}_{\mathrm{opt}}} \tag{12}
\end{equation*}
$$

Notice that $k_{\text {opt }}$ and $m_{\text {opt }}$ are functions of the individual costs and variances and not of the total cost of the harvest; whereas, the optimal number of beds ( $n_{\text {opt }}$ ) is dependent on the total cost

From the optimal values, the total number of geoducks that should be harvested can be expressed as:

$$
\begin{equation*}
\text { Total_Geoducks }=\mathrm{k}_{\mathrm{opt}} \mathrm{~m}_{\mathrm{opt}} \mathrm{n}_{\mathrm{opt}} \tag{13}
\end{equation*}
$$

If the cost of marking and weighing a geoduck ( $\mathrm{c}_{4}$ ) and the cost of aging a geoduck ( $\mathrm{c}_{5}$ ) are known values, then the cost for processing the optimal set for mean weight only is :

$$
\begin{align*}
\text { Processing_Cost } & =\mathrm{c}_{4} \times \text { Total_Geoducks } \\
& =\mathrm{c}_{4} \mathrm{k}_{\mathrm{opt}} \mathrm{~m}_{\mathrm{opt}} \mathrm{n}_{\mathrm{opt}} \tag{14}
\end{align*}
$$

and for mean weights and ages the cost is:

$$
\begin{equation*}
\text { Processing_Cost }=\left(c_{4}+c_{5}\right) \times \text { Total_Geoducks } . \tag{15}
\end{equation*}
$$

## Age Structure

The objective of the age structure analysis is to estimate the proportion of geoducks in each of the age-classes from 4 to 12 years ( y ) based on all of the geoducks in the sample with ages identified. Since age-classes are never uniformly distributed in a population, the optimal design for one age group will likely not be optimal for another (Schweigert and Sibert 1983). In addition, given processing costs, it is possible to calculate the cost of processing the optimal sample of each age-class. Processing refers to the time taken to mark each geoduck with a unique identification number, as well as, weighing and aging it.

For a specified age-class, to calculate the proportion of geoducks at each stage and respective estimated variance, equations for a three-stage design were derived from a two-stage design, based on Cochran (1977, section 10.5).

From a sample of n beds, if m sites are examined within each bed and k geoducks are collected and ages determined, then let $\mathrm{a}_{\varepsilon \mathrm{jju}}=1$ if geoduck iju is of age $\ell$, and 0 otherwise. The mean proportion of geoducks at age $\ell$ in the $j^{\text {th }}$ site of the $i^{\text {th }}$ bed is:

$$
\begin{equation*}
\mathrm{p}_{\ell \mathrm{ij}}=\frac{1}{\mathrm{k}} \sum_{\mathrm{u}=1}^{\mathrm{k}} \mathrm{a}_{\ell \mathrm{iju}}, \tag{16}
\end{equation*}
$$

and the mean proportion of geoducks at age $\ell$ in the $i^{\text {th }}$ bed is:

$$
\begin{equation*}
\mathrm{p}_{\ell \mathrm{i}}=\frac{1}{\mathrm{~m}} \sum_{\mathrm{j}=1}^{\mathrm{m}} \mathrm{p}_{\ell \mathrm{ij}} \tag{17}
\end{equation*}
$$

Lastly, the mean proportion of geoducks at age $\ell$ in the sample is:

$$
\begin{equation*}
\mathrm{p}_{\ell}=\frac{1}{\mathrm{n}} \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{p}_{\ell \mathrm{i}} . \tag{18}
\end{equation*}
$$

If the $n$ beds, $m$ sites within beds, and $k$ geoducks are selected by simple random sampling, then $\mathrm{p}_{\ell}$ is an unbiased estimate of $\mathrm{P}_{\ell}$, the mean proportion of geoducks in ageclass $\ell$ in the population, with variance:

$$
\begin{equation*}
V\left(p_{\ell}\right)=\left(1-\frac{n}{N}\right) \frac{S_{1}^{2}}{n}+\left(1-\frac{m}{M}\right) \frac{S_{2}^{2}}{n m}+\left(1-\frac{k}{K}\right) \frac{S_{3}^{2}}{n m k} \tag{19}
\end{equation*}
$$

where $N, M$ and $K$ are the population analogues of $n, m$ and $k$. In this equation, the variance due to among bed variation is:

$$
\begin{equation*}
S_{1}^{2}=\frac{\sum_{\mathrm{i}=1}^{\mathrm{N}}\left(\mathrm{P}_{\ell \mathrm{i}}-\mathrm{P}_{\ell}\right)^{2}}{\mathrm{~N}-1}, \tag{20}
\end{equation*}
$$

the variance due to among site variation within beds is:

$$
\begin{equation*}
S_{2}^{2}=\frac{\sum_{\mathrm{i}=1}^{\mathrm{N}} \sum_{\mathrm{j}=1}^{\mathrm{M}}\left(\mathrm{P}_{\ell \mathrm{ij}}-\mathrm{P}_{\ell \mathrm{i}}\right)^{2}}{\mathrm{~N}(\mathrm{M}-1)}=\frac{1}{\mathrm{~N}} \sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{~S}_{2 \mathrm{i}}^{2} \tag{21}
\end{equation*}
$$

and the variance due to among geoduck variation within sites and beds is:

$$
\begin{equation*}
S_{3}^{2}=\frac{K}{N M(K-1)} \sum_{i=1}^{N} \sum_{\mathrm{j}=1}^{M} \mathrm{P}_{\ell \mathrm{ij}}\left(1-\mathrm{P}_{\ell \mathrm{ij}}\right)=\frac{\mathrm{K}}{N M} \sum_{\mathrm{i}=1}^{\mathrm{N}} \sum_{\mathrm{j}=1}^{\mathrm{M}} \mathrm{~S}_{3 \mathrm{ij}}^{2} . \tag{22}
\end{equation*}
$$

An unbiased estimate of $\mathrm{V}\left(\mathrm{p}_{\ell}\right)$ from the sample is similar in format to equation (8):

$$
\begin{equation*}
\mathrm{v}\left(\mathrm{p}_{\ell}\right)=\left(1-\mathrm{f}_{1}\right) \frac{\mathrm{s}_{1}^{2}}{\mathrm{n}}+\mathrm{f}_{1}\left(1-\mathrm{f}_{2}\right) \frac{\mathrm{s}_{2}^{2}}{\mathrm{~nm}}+\mathrm{f}_{1} \mathrm{f}_{2}\left(1-\mathrm{f}_{3}\right) \frac{\mathrm{s}_{3}^{2}}{n m k} \tag{23}
\end{equation*}
$$

where:

$$
\mathrm{f}_{1}=\frac{\mathrm{n}}{\mathrm{~N}}, \quad \mathrm{f}_{2}=\frac{\mathrm{m}}{\mathrm{M}}, \quad \mathrm{f}_{3}=\frac{\mathrm{k}}{\mathrm{~K}},
$$

and $\mathrm{s}_{1}^{2}, \mathrm{~s}_{2}^{2}$, and $\mathrm{s}_{3}^{2}$ are the sample analogues of $\mathrm{S}_{1}^{2}, \mathrm{~S}_{2}^{2}$, and $\mathrm{S}_{3}^{2}$.

The total cost of the survey (harvest) can be expressed as a linear function of the costs per individual stage as in equation 9. Optimal values of $k, m$ and $n$, for age-class $\ell$, are the set of values that minimize the true variance of the estimator, $\mathrm{V}\left(\mathrm{p}_{\ell}\right)$, for a fixed cost (or vice-versa) as in equations 10 to 12 . Given these optimal values, the total number of geoducks in the optimal set can be calculated from equation 13. If the cost of marking
and weighing a geoduck ( $\mathrm{c}_{4}$ ) and the cost of aging a geoduck ( $\mathrm{c}_{5}$ ) are known values, then the cost for processing the optimal set for age-class $\ell$ can be calculated from equations 14 and 15.

## Example Data

Five biosamples were used as examples in the analyses (Table 2). The biosamples represent geoducks collected from five beds throughout B.C. For beds 2, 3, 4 and 5, only one site (about $100 \mathrm{~m}^{2}$ per site) per bed was used to collect approximately 500 geoducks. Bed 1 was sampled from five randomly placed sites from which approximately 105 geoducks per site were obtained. Each geoduck was given a unique identification number written with a pencil on the shell. The total wet weight of each geoduck was recorded usually at the processing plant, about $24-48 \mathrm{~h}$ after collection. Some geoduck samples, especially those kept more than 24 h prior to processing, were stored in running sea water to keep them from drying out. Geoduck shells were aged according to Shaul and Goodwin (1982); the method is briefly described as follows. One valve of the geoduck shell was cut with a thin diamond saw. The cross-sections of the valve hinges were polished with 180 and 600 grit diamond flat wheels. The clean polished shells were then etched with $1 \% \mathrm{HCL}$ for 1-2 min., washed with distilled water, dried, treated with acetone and lastly, a thin acetylcellulose film was applied to the polished surface. The cellulose peels were magnified and the number of annual growth rings for each geoduck was recorded. Not all geoducks collected could be aged because some geoducks and/or shells were damaged during the harvest, transportation or processing.

The equations derived in Methods are for a balanced design, in the sense that each bed contains an equal number of sites and the same number of geoducks be collected from each site. To satisfy this requirement, the data for each bed (assumed to be about 100 ha ) were modified to created a balanced design. The mean weight data were divided into 80 geoducks per site with 5 sites per bed. The mean age and age structure data were divided into 96 geoducks per site with 4 sites per bed. Data for bed 1 (Kitasu Bay), which were collected from 5 sites, were truncated within each site to the required number of geoducks; for the age data, site 1 contained 38 observations, and therefore, site 1 was ignored in the age analysis. Data for the remaining beds, 2 through 5 , was sequentially divided into sites. Consider for example, weight data for bed 2, geoducks 1 to 80 were identified as being from site 1 , geoducks 81 to 160 were identified as being from site 2 , etc. Grouping geoducks into sites was possible under the assumption that geoducks were selected randomly for marking and analysis. Table 3 contains summary statistics for these modified data.

A range of cost estimates (in minutes) for each sampling stage (equation 9) obtained from sampling the five beds (Table 1) were used to reflect logistic conditions; e.g., varying distances between beds, between sites within a bed, and geoduck densities and substrate types. Total cost of the survey (harvest) was set to 1 or 2 days (assuming $8 \mathrm{~h} / \mathrm{d}$ ) which restricted the total number of beds recommended for sampling in the overall analysis.

Mean processing costs for estimating weights and ages of geoduck were 0.70 and 15 minutes, respectively (Table 1).

## RESULTS

## Changing Cost and Variance Ratios

Changing cost and variance ratios for fixed variances, if the ratio of $c_{2}$ to $c_{3}\left(c_{2} / c_{3}\right)$ increases, implies collecting more geoducks from each site is cheaper than to examine more sites. If the ratio of $c_{1}$ to $c_{2}\left(c_{1} / c_{2}\right)$ increases, for fixed variances, then to move between sites in a bed is cheaper than between beds, implying that more sites in a bed should be examined.

Where the variances vary between beds at fixed costs, then the optimal values will be dependent on the variance ratios. For example, if the ratio of $S_{3}^{2}$ to $S_{2}^{2}\left(S_{3}^{2} / S_{2}^{2}\right)$ increases, then this implies that there is more variability between geoducks than between sites and thus more geoducks should be examined within each site. Also, if the ratio of $S_{2}^{2}$ to $S_{1}^{2}$ is observed to increase, then more sites within beds should be examined since there is more variability between sites than beds.

Figure 1 provides a graphical representation of the effect of various combinations of cost ratio and variance ratio on the optimal variable ( $k_{\text {opt }}$ or $m_{\text {opt }}$ ). For example, if the optimal variable of interest is $k_{\text {opt }}$ then cost ratio refers to values of $c_{2} / c_{3}$ and variance ratio refers to values of $S_{3}^{2} / S_{2}^{2}$. Notice for a fixed cost ratio, an increase in the variance ratio caused an increase in the optimal value.

## Mean Measures (Weight and Age)

Using the three-stage sampling design equations, the mean weight and age of the geoducks from the five beds were calculated (Table 4). The largest variation was observed to be among geoducks within sites $\left(\mathrm{S}_{3}^{2}\right)$. The large variance ratio $\mathrm{S}_{3}^{2} / \mathrm{S}_{2}^{2}$ indicated that there was more variability within sites than between sites. Also, the small ratio $S_{2}^{2} / S_{1}^{2}$ indicated that there was more variability between beds than between sites in a bed. Both of these variance ratios indicated that more geoducks should be collected from fewer sites within each bed, and more beds should be examined. The variance ratios for age were much larger than for weight because of the larger variability in ages than in weights of geoducks. These results were supported by the following sensitivity analyses of the variance components.

For various cost values, it is possible to calculate the optimal allocation of resources between the number of geoducks that should be obtained from a site in a bed $(k)$, the number of sites in a bed to randomly examine $(m)$ and the number of beds that should be sampled ( $n$ ). Table 5 lists optimal values for $k, m$ and $n$ given various cost values, as
identified in Table 1, for determining the mean weight and age of geoducks. The value of $c_{2}$ was fixed ( $=30$ minutes); whereas, $c_{1}$ and $c_{3}$ were varied to obtain various cost ratio combinations ( $c_{1} / c_{2}, c_{2} / c_{3}$ ) to observe their effect on the optimal values. If $c_{1}$ was fixed at some value, in addition to $c_{2}$, then an increase in $c_{3}$ caused a decrease in $k$ and no change in $n$. If $c_{3}$ and $c_{2}$ were held constant, increasing $c_{1}$ resulted in a decrease in $n$ but $k$ remained unchanged. Lastly, if $c_{1}$ and $c_{3}$ were fixed, an increase in $c_{2}$ would cause an increase in $k$ and a decrease in $m$.

For the given survey cost values in Table 5, the optimum number of geoducks that should be harvested to determine mean weight was found to be less than to determine mean age. This was due to the larger variance values obtained for the age data than for the weight data.

Figure 2 provides a graphical representation of the effect of varying costs on the variance of $\overline{\overline{\mathrm{y}}}$. The optimal values for each cost combination $\left(c_{1}, c_{2}, c_{3}\right)$ are at the lowest point of their respective curves. When $c_{1}$ and $c_{2}$ were fixed, an increase in $c_{3}$ caused the $c_{2} / c_{3}$ to decrease and the curve to shift towards the right so that the minimum point was at a higher value of $k$ for both the weight and age data (Fig. 2).

Consider the effect on the optimal allocation of resources if survey costs are fixed and variances for each stage ( $S_{1}^{2}, S_{2}^{2}$, and $S_{3}^{2}$ ) are varied. The optimal sampling design was not only dependent on the survey costs but also on how good the estimated variances represented the population variances. Table 6 lists optimal sampling values for various combinations of variance ratios $\left(\mathrm{S}_{2}^{2} / \mathrm{S}_{1}^{2}\right.$ and $\left.\mathrm{S}_{3}^{2} / \mathrm{S}_{2}^{2}\right)$ and fixed cost values. If the value of $S_{2}^{2} / S_{1}^{2}$ was constant and $S_{3}^{2} / S_{2}^{2}$ was increased, then the optimal number of geoducks per site per bed ( $k$ ) increased, but the number of sites per bed ( $m$ ) did not change (Table 6). If $S_{2}^{2} / S_{1}^{2}$ increased and $S_{3}^{2} / S_{2}^{2}$ remained constant, then there was no apparent change in $m$ for small changes in the variance ratio; but a noticeable change in $m$ when there was a large increase in the variance ratio for both weight and age data.

Figure 3 provides a graphical representation of the effect of varying the variance ratio $S_{3}^{2} / S_{2}^{2}$ on the variance estimate of $\overline{\overline{\mathrm{y}}}$ for the weight and age data with the ratio $S_{2}^{2} / S_{1}^{2}$ and survey costs kept constant. Notice that by increasing $S_{3}^{2} / S_{2}^{2}$, the curves shifted to the right so that the minimum points were at a higher value of $k$ indicating the location of the optimum value of $k$ for each given variance ratio.

Once the optimal sampling design was determined, the total number of geoducks that should be sampled could be calculated (equation 13) for various harvest cost values (Table 5) and for various variance ratios (Table 6). Given the processing costs for weighing and aging ( $\mathrm{c}_{4}$ and $\mathrm{c}_{5}$ ) (Table 1) the time required to process geoducks to determine weight alone (equation 14) or weight and age (equation 15) were calculated (Table 5, 6). Consider for example the following cost equation for the harvesting process
(equation 9) $960=60 \mathrm{n}+30 \mathrm{~nm}+0.75 \mathrm{nmk}$. If the variable of interest was mean age, then the optimal design (Table 5 b) would be to collect 47 geoducks from 1 site in each of 7 beds. A total of 329 geoducks ( $k \times m \times n$ ) would be collected in 960 minutes ( $=16$ hours $=2$ days) and a processing time of 86.1 hours $(=329(0.7+15) / 60)$ would be required for weighing and aging. Whereas, if the variable of interest was weight, then for this survey cost combination, 15 geoducks should be collected from 1 site in each of 9 beds. This would result in a total of 135 geoducks being collected in 16 hours and require 1.6 hours (equation 14 in hours) for determining the weight of each geoduck.

## Age Structure

For each age-class from 4 to 12 years, the number of geoducks within each site of a bed were identified from the age data and proportions and variance components calculated for each bed (Table 7, 8). The largest proportion of geoducks in this sample appeared to be in age-class 6 and the lowest in age-class 4. The largest variation was between geoducks $\left(S_{3}^{2}\right)$. The ratio $S_{3}^{2} / S_{2}^{2}$ was large for all age-classes indicating that there was more variability between geoducks within a site than between sites.

Given survey costs, the optimal allocation of resources could be calculated between each stage of a three-stage sampling design. Optimal values of $k$ and $m$ differed for the various age-class and cost combinations (Table 9). For a given age-class, by fixing $c_{1}$ and $c_{2}$ and increasing $\mathrm{c}_{3}, k$ decreased but $m$ was not affected. If $\mathrm{c}_{1}$ and $\mathrm{c}_{3}$ were held constant, and $\mathrm{c}_{2}$ was increased, then $k$ increased and $m$ decreased. Lastly, if $c_{2}$ and $c_{3}$ were held constant and $c_{1}$ was increased, then $k$ remained unchanged and $m$ increased (Table 9).

Figure 4 provides a graphical representation of the location of the optimal number of geoducks to collect from a site in a bed ( $k$ ) for each age-class. The survey cost was kept the same for all age-classes. Optimal values of $k$ were identified by the minimum point on the curve for each age-class. Note that around the optimal point the curves were relatively flat; an indication of the values of $k$. that could be used without having a significant effect on the variance estimate (Fig. 4).

After determining the optimal sampling design for a given age-class, the total number of geoducks was calculated from equation 13 (Table 9). From previous experience, marking and weighing a geoduck ( $\mathrm{c}_{4}$ ) could take 0.7 minutes and aging ( $\mathrm{c}_{5}$ ) can take 15 minutes per geoduck. Using these values, the processing time for the optimal set of each age-class was determined from equation 15. Consider for example, the following cost equation for the harvesting process: $480=60 n+30 n m+0.5 n m k$ (equation 9). For age-class 4 , the optimal design was to collect 107 geoducks from 1 site in each of 2 beds giving a total of 214 geoducks which would require 56 hours for the aging process.

## DISCUSSION

Three-stage optimal sampling designs were identified for a variety of cost estimates for mean weight and mean age and various age-classes. These optimal designs were sensitive to sampling costs as well as estimated variances for each stage of the sampling stage. Although costs used in this analysis reflected the range in current practice there was some uncertainty in their exact values since each survey could be logistically different. Estimating variance components for each sampling stage was important in defining an optimal survey design since the optimal allocation of resources was also dependent on how well the estimated variances represented the population variances. More geoduck were required for determining mean age compared to the number required for determining mean weight due to the higher variability in ages than weights of geoduck (Table 2). As well, the cost of aging was considerably greater than the cost of determining the weight of a geoduck. The optimal designs differed between the various age-classes analyzed in the age-structure analysis emphasizing the importance in determining the exact age that should be used in recruitment studies.

Different survey conditions and objectives will require specific sampling regimes and sample sizes. However, the following general strategy from these analyses seems to emerge as a reasonable "rule of thumb" summary for geoduck biosamples, based on the representative cost values considered and one day of sampling. Assuming the objective is to obtain representative samples from the density survey area of only geoduck mean weight, about 20 geoduck (range 15-26 geoduck/site/bed) from 1 site per bed with 3 to 4 beds sampled per survey day should be obtained (Total $\cong 80$ geoduck) (Table 5a, Fig. 2). For both mean weight and age, about 60 geoduck (range 47-83 geoduck/site/bed) from 1 site within each of 2 to 4 beds sampled should be obtained (Total $\cong 240$ geoduck) (Table $5 b$, Fig. 2). For age-structure analysis of geoduck, about 100 geoducks (range 41-152 geoduck/site/bed) from 2 sites / bed (range 1 to 4 sites / bed) and 2 beds (range 1 to 4 beds) should be obtained (Total $\cong 400$ geoducks) (Table 9a). This analysis would provide some indication of variability in age composition within and between beds. Clearly, given the high cost of aging geoducks, the objective of the analysis and the amount of funds available will be important in influencing the extent of the biosample program.

An additional approximate $10 \%$ should be added to the estimated sample size to account for loss of geoducks due to factors such as damage to soft body parts and shell breakage during the collection, transportation and age processing phases.

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## REFERENCES

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

Breen, P.A. and T.L. Shields. 1983. Age and size structure in five populations of geoduck clams, Panope generosa, in British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1169.

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

Cochran, W. G. 1977. Sampling Techniques. John Wiley \& Sons, Inc. New York. 428 p.

Goodwin, C.L. and W. Shaul. 1984. Age, recruitment and growth of the geoduck clam (Panope generosa, Gould) in Puget Sound, Washington. Prog. Rep. No. 215, State of Washington, Dept. of Fisheries: 29 p.

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

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

Schweigert, J.F., and J.R. Sibert. 1983. Optimizing survey design for determining age structure of fish stocks: an example from British Columbia Pacific herring. Can. J. Fish. Aquat. Sci. 40: 588-597.

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

Table 1. List of variables and cost values used in equations to determine optimal sample sizes for geoduck mean weights, mean age and age structure.

| Variable | Definition |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| n | number of beds in sample |  |  |  |
| m | number of sites examined in a bed |  |  |  |
| k | number of geoducks collected from a site in a bed |  |  |  |
| $\overline{\overline{\mathrm{y}}}$ | mean measure (weight or age) of geoducks |  |  |  |
| $\mathrm{v}(\overline{\overline{\mathrm{y}}})$ | estimated variance of $\overline{\overline{\mathrm{y}}}$ |  |  |  |
| $\bar{y}_{i j}$ | mean measure (weight or age) of geoducks in the $\mathrm{j}^{\text {th }}$ site of the $\mathrm{i}^{\text {th }}$ bed |  |  |  |
| $\overline{\bar{y}}_{i}$ | mean measure (weight or age) of geoducks in the $\mathrm{i}^{\text {th }}$ bed |  |  |  |
| $\mathrm{p}_{\ell}$ | mean proportion of geoducks at age $\ell$ |  |  |  |
| $\mathrm{v}\left(\mathrm{p}_{\ell}\right)$ | estimated variance of $\mathrm{p}_{\ell}$ |  |  |  |
| $\mathrm{p}_{\ell \mathrm{i}}$ | mean proportion of geoducks at age $\ell$ in the $\mathrm{j}^{\text {th }}$ site of the $\mathrm{i}^{\text {th }}$ bed |  |  |  |
| $\mathrm{p}_{\text {fij }}$ | mean proportion of geoducks at age $\ell$ in the $\mathrm{i}^{\text {th }}$ bed |  |  |  |
| $\mathrm{S}_{1}^{2}$ | variance due to among bed variation |  |  |  |
| $\mathrm{S}_{2}^{2}$ | variance due to among site variation within beds |  |  |  |
| $\mathrm{S}_{3}^{2}$ | variance due to among geoduck variation within sites and beds |  |  |  |
|  |  | Cost Values (minutes) |  |  |
| C | total cost of the survey (harvest) | 480 | 960 |  |
| $\mathrm{c}_{1}$ | cost of moving between beds | 60 | 120 | 180 |
| $\mathrm{c}_{2}$ | cost of moving between sites in a bed | 30 |  |  |
| $\mathrm{c}_{3}$ | cost of collecting a geoduck | 0.25 | 0.50 | 0.75 |
| $\mathrm{c}_{4}$ | cost of marking and weighing a geoduck | 0.70 |  |  |
| $\mathrm{c}_{5}$ | cost of aging a geoduck | 15 |  |  |

Table 2. Summary statistics from original data of mean weight and age of geoducks from differents beds. Samples taken from five sites at bed one and from one site for beds two to five.

| Location |  |  | Total Weight (kg) |  |  | Age (years) |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Bed | Year | Site | mean | SE | k | mean | SE | k |
| 1. Kitasu Bay | 1995 | 1 | 1.24 | 0.04 | 105 | 37.7 | 3.91 | 38 |
|  |  | 2 | 1.21 | 0.05 | 104 | 45.2 | 2.82 | 99 |
|  |  | 3 | 0.86 | 0.02 | 105 | 45.4 | 2.13 | 100 |
|  |  | 4 | 1.44 | 0.04 | 105 | 45.3 | 2.27 | 98 |
|  |  | 5 | 0.96 | 0.03 | 105 | 43.4 | 1.86 | 99 |
|  | All Sites |  | 1.14 | 0.02 | 524 | 44.2 | 1.10 | 434 |
| 2. Juan Perez | 1995 |  | 0.91 | 0.02 | 507 | 42.7 | 1.52 | 385 |
| 3. Elbow Bank | 1994 |  | 1.48 | 0.02 | 433 | 28.8 | 0.63 | 405 |
| 4. West Higgins | 1995 |  | 0.92 | 0.01 | 525 | 42.8 | 0.70 | 474 |
| 5. Berry Island | 1995 |  | 0.66 | 0.01 | 482 | 48.59 | 1.05 | 458 |

Table 3. Summary statistics from modified data of geoduck mean weight and age for each site within a bed. These values were used for the optimization process. For mean weight, each bed was sequentially divided into 5 sites with 80 observations (k) per site. Whereas, for mean age, each bed was sequentially divided into 4 sites with 96 observations (k) per site. Site 1 for Kitasu Bay was omitted from the mean age analysis.

| Location |  |  | Total Weight (kg) |  |  | Age (years) |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Bed | Year | Site | $\begin{gathered} \text { mean } \\ \left(\overline{\mathrm{y}}_{\mathrm{ij}}\right) \end{gathered}$ | estimated variance $\left(\mathrm{s}_{3 \mathrm{ij}}^{2}\right)$ | k | mean $\left(y_{i j}\right)$ | estimated variance $\left(\mathrm{s}_{3 \mathrm{ij}}^{2}\right)$ | k |
| 1. Kitasu Bay | 1995 | 1 | 1.23 | 0.161 | 80 | - | - | - |
|  |  | 2 | 1.21 | 0.170 | 80 | 44.2 | 781.0 | 96 |
|  |  | 3 | 0.85 | 0.054 | 80 | 45.6 | 458.0 | 96 |
|  |  | 4 | 1.44 | 0.185 | 80 | 45.7 | 510.8 | 96 |
|  |  | 5 | 0.95 | 0.076 | 80 | 42.8 | 327.4 | 96 |
| 2. Juan Perez | 1995 | 1 | 0.87 | 0.084 | 80 | 39.8 | 700.3 | 96 |
|  |  | 2 | 0.83 | 0.162 | 80 | 44.2 | 907.3 | 96 |
|  |  | 3 | 0.97 | 0.115 | 80 | 41.1 | 1,029.8 | 96 |
|  |  | 4 | 0.86 | 0.098 | 80 | 46.2 | 940.8 | 96 |
|  |  | 5 | 0.91 | 0.123 | 80 |  |  |  |
| 3. Elbow Bank | 1994 | 1 | 1.55 | 0.140 | 80 | 32.3 | 193.7 | 96 |
|  |  | 2 | 1.49 | 0.132 | 80 | 27.8 | 211.6 | 96 |
|  |  | 3 | 1.40 | 0.129 | 80 | 26.8 | 108.7 | 96 |
|  |  | 4 | 1.50 | 0.127 | 80 | 28.2 | 99.9 | 96 |
|  |  | 5 | 1.54 | 0.132 | 80 |  |  |  |
| 4. W. Higgins | 1995 | $1$ | 1.06 | 0.081 | 80 | 47.1 | 182.6 | 96 |
|  |  | 2 | 1.05 | 0.082 | 80 | 41.6 | 303.2 | 96 |
|  |  | 3 | 0.85 | 0.072 | 80 | 40.5 | 240.8 | 96 |
|  |  | 4 | 0.83 | 0.054 | 80 | 42.6 | 192.6 | 96 |
|  |  | 5 | 0.83 | 0.056 | 80 |  |  |  |
| 5. Berry Island | 1995 | 1 | 0.72 | 0.056 | 80 | 50.0 | 488.2 | 96 |
|  |  | 2 | 0.78 | 0.052 | 80 | 55.4 | 612.5 | 96 |
|  |  | 3 | 0.61 | 0.024 | 80 | 49.9 | 472.2 | 96 |
|  |  | 4 | 0.71 | $0.050$ | 80 | 45.9 | 365.2 | 96 |
|  |  | 5 | 0.61 | 0.032 | 80 |  |  |  |

Table 4. Mean weight and age of geoducks, and estimated variance components for all five beds as calculated for a three-stage design.

|  | Total Weight $(\mathrm{kg})$ | Age (years) |
| :---: | :---: | :---: |
| $\overline{\overline{\bar{y}}}$ | 1.03 | 41.9 |
| $\mathrm{v}(\overline{\overline{\mathrm{y}}})$ | 0.020 | 13.2 |
| $\mathrm{~s}_{1}^{2}$ | 0.094 | 62.8 |
| $\mathrm{~s}_{2}^{2}$ | 0.016 | 7.9 |
| $\mathrm{~s}_{3}^{2}$ | 0.098 | 456.3 |
| $\mathrm{~s}_{2}^{2} / \mathrm{s}_{1}^{2}$ | 0.17 | 0.13 |
| $\mathrm{~s}_{3}^{2} / \mathrm{s}_{2}^{2}$ | 6.03 | 57.56 |

Table 5a. Optimal sampling design for a three-stage design for Total Weight data of geoducks given various cost estimates $(1=$ cost
to move between beds, $2=$ cost to move between sites in a bed, $3=$ cost of collecting a geoduck $)$. Total cost for processing also
calculated. $\mathrm{k}_{\mathrm{opt}}=$ optimum number of geoducks to collect, $\mathrm{m}_{\text {opt }}=$ optimum number of sites, $\mathrm{n}_{\text {opt }}=$ optimum number of beds

| Cost (minutes) |  |  |  | Cost ratios |  | Optimal values |  |  | Total Geoducks | $\begin{gathered} \text { Processing } \\ \text { Cost } \\ \text { (hours) } \\ \hline \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| C <br> (Harvest) | 1 | 2 | 3 | $c_{1} / c_{2}$ | $\mathrm{c}_{2} / \mathrm{c}_{3}$ | $\mathrm{k}_{\text {opt }}$ | $\mathrm{m}_{\text {opt }}$ | $\mathrm{n}_{\text {opt }}$ |  |  |
| $\begin{gathered} 480 \\ (1 \mathrm{~d}=8 \mathrm{~h}) \end{gathered}$ | 60 | 30 | 0.25 | 2 | 120 | 26 | , | 4 | 104 | 1.2 |
|  |  | 30 | 0.5 | 2 | 60 | 19 | 1 | 4 | 76 | 0.9 |
|  |  | 30 | 0.75 | 2 | 40 | 15 | 1 | 4 | 60 | 0.7 |
|  | 120 | 30 | 0.25 | 4 | 120 | 26 | 1 | 3 | 78 | 0.9 |
|  |  | 30 | 0.5 | 4 | 60 | 19 | 1 | 3 | 57 | 0.7 |
|  |  | 30 | 0.75 | 4 | 40 | 15 | 1 | 2 | 30 | 0.4 |
|  | 180 | 30 | 0.25 | 6 | 120 | 26 | 1 | 2 | 52 | 0.6 |
|  |  | 30 | 0.5 | 6 | 60 | 19 | 1 | 2 | 38 | 0.4 |
|  |  | 30 | 0.75 | 6 | 40 | 15 | 1 | 2 | 30 | 0.4 |
| $\begin{gathered} 960 \\ (2 \mathrm{~d}=16 \mathrm{~h}) \end{gathered}$ | 60 | 30 | 0.25 | 2 | 120 | 26 | 1 | 9 | 234 | 2.7 |
|  |  | 30 | 0.5 | 2 | 60 | 19 | 1 | 9 | 171 | 2.0 |
|  |  | 30 | 0.75 | 2 | 40 | 15 | 1 | 9 | 135 | 1.6 |
|  | 120 | 30 | 0.25 | 4 | 120 | 26 | 1 | 6 | 156 | 1.8 |
|  |  | 30 | 0.5 | 4 | 60 | 19 | 1 | 6 | 114 | 1.3 |
|  |  | 30 | 0.75 | 4 | 40 | 15 | 1 | 5 | 75 | 0.9 |
|  | 180 | 30 | 0.25 | 6 | 120 | 26 | 1 | 4 | . 104 | 1.2 |
|  |  | 30 | 0.5 | 6 | 60 | 19 | 1 | 4 | 76 | 0.9 |
|  |  | 30 | 0.75 | 6 | 40 | 15 | 1 | 4 | 60 | 0.7 |

Table 5b. Optimal sampling design for a three-stage design for Age data of geoducks given various cost estimates ( $1=$ cost to move between beds, $2=$ cost to move between sites in a bed, $3=$ cost of collecting a geoduck). Total cost for processing also calculated. $\mathrm{k}_{\mathrm{opt}}=$ optimum number of geoducks to collect, $\mathrm{m}_{\mathrm{opt}}=$ optimum number of sites, $\mathrm{n}_{\mathrm{opt}}=$ optimum number of beds.

| Cost (minutes) |  |  |  | Cost ratios |  | Optimal values |  |  | Total Geoducks | Processing Cost (hours) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\begin{gathered} \mathrm{C} \\ \text { (Harvest) } \end{gathered}$ | 1 | 2 | 3 | $c_{1} / c_{2}$ | $c_{2} / c_{3}$ | $\mathrm{k}_{\text {opt }}$ | $\mathrm{m}_{\text {opt }}$ | $\mathrm{n}_{\text {opt }}$ |  |  |
| 480 | 60 | 30 | 0.25 | 2 | 120 | 83 | 1 | 4 | 332 | 86.9 |
| ( $1 \mathrm{~d}=8 \mathrm{~h}$ ) | 60 | 30 | 0.5 | 2 | 60 | 58 | 1 | 4 | 232 | 60.7 |
|  | 60 | 30 | 0.75 | 2 | 40 | 47 | 1 | 3 | 141 | 36.9 |
|  | 120 | 30 | 0.25 | 4 | 120 | 83 | 1 | 2 | 166 | 43.4 |
|  | 120 | 30 | 0.5 | 4 | 60 | 58 | 1 | 2 | 116 | 30.4 |
|  | 120 | 30 | 0.75 | 4 | 40 | 47 | 1 | 2 | 94 | 24.6 |
|  | 180 | 30 | 0.25 | 6 | 120 | 83 | 1 | 2 | 166 | 43.4 |
|  | 180 | 30 | 0.5 | 6 | 60 | 58 | 1 | 2 | 116 | 30.4 |
|  | 180 | 30 | 0.75 | 6 | 40 | 47 | 1 | 1 | 47 | 12.3 |
| 960 | 60 | 30 | 0.25 | 2 | 120 | 83 | 1 | 8 | 664 | 173.7 |
| $(2 \mathrm{~d}=16 \mathrm{~h})$ | 60 | 30 | 0.5 | 2 | 60 | 58 | 1 | 8 | 464 | 121.4 |
|  | 60 | 30 | 0.75 | 2 | 40 | 47 | 1 | 7 | 329 | 86.1 |
|  | 120 | 30 | 0.25 | 4 | 120 | 83 | 1 | 5 | 415 | 108.6 |
|  | 120 | 30 | 0.5 | 4 | 60 | 58 | 1 | 5 | 290 | 75.9 |
|  | 120 | 30 | 0.75 | 4 | 40 | 47 | 1 | 5 | 235 | 61.5 |
|  | 180 | 30 | 0.25 | 6 | 120 | 83 | , | 4 | 332 | 86.9 |
|  | 180 | 30 | 0.5 | 6 | 60 | 58 |  | 4 | 232 | 60.7 |
|  | 180 | 30 | 0.75 | 6 | 40 | 47 | 1 | 3 | 141 | 36.9 |

Table 6a. Optimal sampling design for three-stage design for total weight data of geoducks given various variance ratios $\left(\mathrm{S}_{2}^{2} / \mathrm{S}_{1}^{2}=\right.$ variance among sites/variance among beds, $\quad S_{3}^{2} / S_{2}^{2}=$ variance among geoducks/variance among sites) for fixed cost values (C $\left.=960, c_{1}=60, c_{2}=30, c_{3}=0.50\right) . \mathrm{k}_{\mathrm{opt}}=$ optimum number of geoducks to collect, $\mathrm{m}_{\text {opt }}=$ optimum number of sites, $\mathrm{n}_{\text {opt }}=$ optimum number of beds.

| Variance ratios |  | Optimal values |  |  | Total Geoducks | Processing Cost (hours) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{S}_{2}^{2} / \mathrm{S}_{1}^{2}$ | $\mathrm{S}_{3}^{2} / \mathrm{S}_{2}^{2}$ | $\mathrm{k}_{\mathrm{opt}}$ | $\mathrm{m}_{\text {opt }}$ | $\mathrm{n}_{\text {opt }}$ |  |  |
| 0.01 | 1 | 7 | 1 | 10 | 70 | 0.8 |
|  | 6 | 19 | 1 | 9 | 171 | 2.0 |
|  | 12 | 26 | 1 | 9 | 234 | 2.7 |
|  | 24 | 37 | 1 | 8 | 296 | 3.5 |
| 0.17 | 1 | 7 | 1 | 10 | 70 | 0.8 |
|  | 6 | 19 | 1 | 9 | 171 | 2.0 |
|  | 12 | 26 | 1 | 9 | 234 | 2.7 |
|  | 24 | 37 | 1 | 8 | 296 | 3.5 |
| 0.50 | 1 | 7 | 1 | 10 | 70 | 0.8 |
|  | 6 | 19 | 1 | 9 | 171 | 2.0 |
|  | 12 | 26 | 1 | 9 | 234 | 2.7 |
|  | 24 | 37 | 1 | 8 | 296 | 3.5 |
| 1.00 | 1 | 7 | 1 | 10 | 70 | 0.8 |
|  | 6 | 19 | 1 | 9 | 171 | 2.0 |
|  | 12 | 26 | $1$ | 9 | 234 | 2.7 |
|  | 24 | 37 | 1 | 8 | 296 | 3.5 |
| 5.00 | 1 | 7 | 3 | 6 | 126 | 1.5 |
|  | 6 | 19 | 3 | 5 | 285 | 3.3 |
|  | 12 | 26 | 3 | 5 | 390 | 4.6 |
|  | 24 | 37 | 3 | 4 | 444 | 5.2 |

Table 6b. Optimal sampling design for three-stage design for age data of geoducks given various variance ratios $\left(S_{2}^{2} / S_{1}^{2}=\right.$ variance among sites/variance among beds, $S_{3}^{2} / S_{2}^{2}=$ variance among geoducks/variance among sites) for fixed cost values ( $C=960, c_{1}=60$, $\mathrm{c}_{2}=30, \mathrm{c}_{3}=0.50$ ). $\mathrm{k}_{\mathrm{opt}}=$ optimum number of geoducks to collect, $\mathrm{m}_{\mathrm{opt}}=$ optimum number of sites, $\mathrm{n}_{\mathrm{opt}}=$ optimum number of beds.

| Variance ratios |  | Optimal values |  | $\mathrm{n}_{\text {opt }}$ | Total Geoducks | Processing <br> Cost (hours) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{S}_{2}^{2} / \mathrm{S}_{1}^{2}$ | $\mathrm{S}_{3}^{2} / \mathrm{S}_{2}^{2}$ | $\mathrm{k}_{\text {opt }}$ | $\mathrm{m}_{\text {opt }}$ |  |  |  |
| 0.01 | 40 | 48 | 1 | 8 | 384 | 100.5 |
|  | 57 | 58 | 1 | 8 | 464 | 121.4 |
|  | 80 | 69 | 1 | 7 | 483 | 126.4 |
|  | 100 | 77 | 1 | 7 | 539 | 141.0 |
| 0.13 | 40 | 48 | 1 | 8 | 384 | 100.5 |
|  | 57 | 58 | 1 | 8 | 464 | 121.4 |
|  | 80 | 69 | 1 | 7 | 483 | 126.4 |
|  | 100 | 77 | 1 | 7 | 539 | 141.0 |
| 1.00 | 40 | 48 | 1 | 8 | 384 | 100.5 |
|  | 57 | 58 | 1 | 8 | 464 | 121.4 |
|  | 80 | 69 | 1 | 7 | 483 | 126.4 |
|  | 100 | 77 | 1 | 7 | 539 | 141.0 |
| 5.00 | 40 | 48 | 3 | 4 | 576 | 150.7 |
|  | 57 | 58 | 3 | 4 | 696 | 182.1 |
|  | 80 | 69 | 3 | 3 | 621 | 162.5 |
|  | 100 | 77 | 3 | 3 | 693 | 181.3 |
| 10.00 | 40 | 48 | 4 | 3 | 576 | 150.7 |
|  | 57 | 58 | 4 | 3 | 696 | 182.1 |
|  | 80 | 69 | 4 | 3 | 828 | 216.7 |
|  | 100 | 77 | 4 | 2 | 616 | 161.2 |

Table 7. Proportion $\left(\times 10^{-4}\right)$ of geoducks in each age-class for each bed ( $\mathrm{P}_{\mathrm{f}}$ ), in a three-stage sampling design, where 4 sites are examined in each bed and 96 geoducks are harvested from each site.

|  | Age $(\ell=)$ |  |  |  |  |  |  |  |  |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| Bed | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1. Kitasu Bay | 0.0 | 0.0 | 0.0 | 104.2 | 182.3 | 52.1 | 130.2 | 130.2 | 130.2 |
| 2. Juan Perez | 78.1 | 130.2 | $1,302.0$ | 442.7 | 208.3 | 26.0 | 78.1 | 182.2 | 208.3 |
| 3. Elbow Bank | 26.0 | 52.1 | 52.1 | 52.1 | 130.2 | 26.0 | 78.1 | 156.3 | 234.4 |
| 4. West Higgins | 0.0 | 0.0 | 0.0 | 0.0 | 26.0 | 78.1 | 78.1 | 52.1 | 52.1 |
| 5. Berry Island | 0.0 | 0.0 | 0.0 | 26.0 | 0.0 | 26.0 | 0.0 | 52.1 | 130.2 |

Table 8. Proportion $\left(\times 10^{-4}\right)$ of geoducks $\left(p_{\ell}\right)$ in each age-class and estimated variance components for all five beds in a three-stage
design. $v\left(p_{\ell}\right)=$ estimated variance of $p_{\ell} ; \quad s_{1}^{2}=$ variance between beds; $s_{2}^{2}=$ variance between sites/bed; $s_{3}^{2}=$ variance between
geoducks/site/bed.

|  | Age $(\ell=)$ |  |  |  |  |  |  |  |  |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
|  | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| $\mathrm{p}_{\ell}{ }^{*}$ | 20.83 | 36.46 | 270.83 | 125.00 | 109.38 | 41.67 | 72.92 | 114.58 | 151.04 |
| $\left.\mathrm{v}^{*} \mathrm{p}_{\ell}\right)$ | 4.45 | 5.87 | 16.21 | 9.43 | 7.54 | 4.82 | 5.71 | 7.16 | 7.37 |
| $\mathrm{~s}_{1}^{2} *$ | 0.12 | 0.33 | 33.28 | 3.30 | 0.86 | 0.05 | 0.22 | 0.36 | 0.52 |
| $\mathrm{~s}_{2}^{2} *$ | 0.11 | 0.71 | 2.60 | 1.34 | 1.90 | 0.43 | 0.51 | 2.64 | 2.26 |
| $\mathrm{~s}_{3}^{2}$ | 20.83 | 35.91 | 237.39 | 121.05 | 107.18 | 41.56 | 72.59 | 112.17 | 148.19 |
| $\mathrm{~s}_{2}^{2} / \mathrm{s}_{1}^{2}$ | 0.94 | 2.17 | 0.08 | 0.41 | 2.20 | 8.00 | 2.33 | 7.35 | 4.33 |
| $\mathrm{~s}_{3}^{2} / \mathrm{s}_{2}^{2}$ | 192.00 | 50.92 | 91.16 | 90.46 | 56.45 | 95.75 | 143.35 | 42.48 | 65.55 |

Table 9a. Optimal sampling design for a three-stage design for each age-class given various cost estimates ( $1=$ cost to move between beds, $2=$ cost to move between sites in a bed, $3=$ cost of collecting a geoduck). Total cost for processing also calculated. $\mathrm{k}_{\mathrm{opt}}=$
optimum number of geoducks to collect, $\mathrm{m}_{\text {opt }}=$ optimum number of sites, $\mathrm{n}_{\text {opt }}=$ optimum number of beds. $\mathrm{C}($ Harvest Cost $)=480$, $c_{1}=60$

| Cost | (min) | Cost ratio |  |  | Age ( $\ell=$ ) |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2 | 3 | $\overline{c_{1} / c_{2}}$ | $c_{2} / c_{3}$ |  | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 30 | 0.25 | 2 | 120 | $\mathrm{k}_{\text {opt }}$ | 152 | 78 | 104 | 104 | 82 | 107 | 131 | 71 | 89 |
|  |  |  |  | $\mathrm{m}_{\text {opt }}$ | 1 | 2 | 1 | 1 | 2 | 3 | 2 | 4 | 3 |
|  |  |  |  | $\mathrm{n}_{\text {opt }}$ | 3 | 3 | 4 | 4 | 3 | 2 | 3 | 2 | 2 |
|  |  |  |  | Total_Geoducks | 456 | 468 | 416 | 416 | 492 | 642 | 786 | 568 | 534 |
|  |  |  |  | Processing_Cost (hrs) | 119.3 | 122.5 | 108.9 | 108.9 | 128.7 | 168.0 | 205.7 | 148.9 | 139.7 |
| 30 | 0.5 | 2 | 60 | $\mathrm{k}_{\text {opt }}$ | 107 | 55 | 74 | 74 | 58 | 76 | 93 | 51 | 63 |
|  |  |  |  | $\mathrm{m}_{\text {opt }}$ | 1 | 2 | 1 | 1 | 2 | 4 | 2 | 4 | 3 |
|  |  |  |  | $\mathrm{n}_{\text {opt }}$ | 2 | 3 | 4 | 4 | 3 | 2 | 2 | 2 | 2 |
|  |  |  |  | Total_Geoducks | 214 | 330 | 296 | 296 | 348 | 608 | 372 | 408 | 378 |
|  |  |  |  | Processing_Cost | 56.0 | 86.4 | 77.5 | 77.5 | 91.1 | 159.1 | 97.3 | 106.8 | 98.9 |
| 30 | 0.75 | 2 | 40 | $\mathrm{k}_{\text {opt }}$ | 88 | 45 | 60 | 60 | 48 | 62 | 76 | 41 | 51 |
|  |  |  |  | $\mathrm{m}_{\text {opt }}$ | 1 | 2 | 1 | 1 | 2 | 4 | 2 | 4 | 3 |
|  |  |  |  | $\mathrm{n}_{\text {opt }}$ | 3 | 3 | 4 | 4 | 2 | 1 | 2 | 2 | 2 |
|  |  |  |  | Total_Geoducks | 264 | 270 | 240 | 240 | 192 | 248 | 304 | 328 | 306 |
|  |  |  |  | Processing_Cost | 69.1 | 70.7 | 62.8 | 62.8 | 50.2 | 64.9 | 79.5 | 85.8 | 80.1 |




Cost Ratio

Fig. 1. The effect of various combinations of cost ratio (e.g., $\mathrm{c}_{2} / \mathrm{c}_{3}$ or $\mathrm{c}_{1} / \mathrm{c}_{2}$ ) and variance ratio $\left(S_{3}^{2} / S_{2}^{2}\right.$ or $S_{2}^{2} / S_{1}^{2}$ ) on the optimal variable (for geoducks, $\mathrm{k}_{\mathrm{opt}}$ or sites, $\mathrm{m}_{\mathrm{opt}}$, respectively).

Total Weight


Age


Fig. 2. Variance estimates, $V(\overline{\overline{\bar{y}}}) / V\left(\overline{\overline{\mathrm{y}}}_{\text {opt }}\right)$, for various values of $k$ (number of geoducks to collect from a site) for geoduck mean weight and age given various cost value combinations (e.g., $\mathrm{c}_{1}=60 \mathrm{~min}$ for moving between beds, $\mathrm{c}_{2}=30 \mathrm{~min}$ for moving between sites within a bed, and $\mathrm{c}_{3}=0.75 \mathrm{~min}$ for collecting a geoduck).


Fig. 3. Variance estimates, $V(\overline{\overline{\bar{y}}}) / V\left(\overline{\overline{\mathrm{y}}}_{\text {opt }}\right)$, for various values of $k$ (number of geoducks to collect from a site) for geoduck mean weight and age given various variance ratios for $S_{3}^{2} / S_{2}^{2}$, a fixed value of $S_{2}^{2} / S_{1}^{2}(=0.2)$. Survey costs also fixed $\left(C=960, c_{1}=60, c_{2}=\right.$ $30, \mathrm{c}_{3}=0.75$ ).


Fig. 4. Variance estimates, $V(\overline{\overline{\bar{y}}}) / V\left(\overline{\overline{\mathrm{y}}}_{\text {opt }}\right)$, for various values of k (number of geoducks to collect from a site) for each age class from 4 to 12 given the following survey costs: $C$ $=960 \mathrm{~min}$ (total survey cost), $\mathrm{c}_{1}=90 \mathrm{~min}$ (cost to move between beds), $\mathrm{c}_{2}=45 \mathrm{~min}$ (cost to move between sites) and $c_{3}=0.75 \mathrm{~min}$ (cost of collecting a geoduck)

# QUOTA OPTIONS AND RECOMMENDATIONS FOR THE 1997 AND 1998 GEODUCK CLAM FISHERIES 

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#### Abstract

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Geoduck (Panopea abrupta, Conrad 1849) stocks were examined and quota options presented for the north coast, west coast of Vancouver Island, and waters inside Vancouver Island for 1997 and 1998. The assessment methodology is unchanged from previous assessments, where the area of geoduck habitat reported by fishers, estimated geoduck densities and mean geoduck weights form the basis of biomass estimates, and an estimated sustainable harvest rate is applied to derive quota options.


In response to a request by fishers for more stable quotas, data were compiled for two of the three rotational areas and equal quota options are presented for the 1997 and 1998 fisheries. Changes in biomass and quota calculations include updated geoduck density estimates from survey data, updated estimates of mean geoduck weight from commercial market samples, and new estimates of harvest areas from geoduck beds. The approach initiated in 1994 of reducing quotas where overharvesting had occurred, according to stock status relative to a 50 -year cycle, was continued coastwide, as was the correction of landings reported on harvest logs with sales slip or port validator information. A range of quota options are presented, based on the uncertainty around mean geoduck densities from survey data, the variance around mean geoduck weights and the uncertainty around geoduck bed area.

For the 1997 fishery, recommended low, medium and high quota options are $2,495,024 \mathrm{lb}$., $3,943,936 \mathrm{lb}$. and $5,756,833 \mathrm{lb}$. Quota options for the 1998 fishery are $2,007,614 \mathrm{lb} ., 3,387,548 \mathrm{lb}$. and $5,174,590 \mathrm{lb}$.

## INTRODUCTION

The geoduck clam (Panopea abrupta, Conrad 1849) fishery began in 1976 in British Columbia and has grown to be the major invertebrate fishery in value, at $\$ 42.5$ million dollars in 1995, and fourth in landings, next to shrimp, red sea urchins and crab. The fishery has been described by Cox (1979), Harbo and Peacock (1983), Harbo et al. (1986, 1992, 1993, 1994, 1995), Farlinger and Bates (1985) and Farlinger and Thomas (1988).

A fixed-exploitation rate strategy is currently used to manage the B.C. geoduck clam fishery. For each geoduck bed, virgin biomass is estimated from the bed area, an estimated mean density and a mean weight per individual. The annual allowable harvest is calculated as the product of the virgin biomass and a target harvest rate. To date, quota options have been calculated on a yearly basis, however the Underwater Harvesters Association (UHA) have requested quota projections for longer than one year to reassure the market concerns stemming from the downward trend in quotas since 1987. The objectives of this assessment are to update the historical fishery information with data from the 1994 and 1995 seasons, present estimates of geoduck density from fishery-independent surveys and mean geoduck weight from market samples and provide quota options by Geoduck Management Area (GMA) for the 1997 and 1998 fishing rotations.

## Geoduck Biology

Geoducks are distributed from Alaska to the Gulf of California (Quale 1970), however commercial fisheries exist only in northern Washington State, throughout British Columbia and in Alaska. Geoducks are large burrowing clams found between the intertidal and approximately 210 m (Jamison et al. 1984), with an average landed weight of approximately one kilogram. Individuals can be aged from growth rings using a validated procedure (Shaul and Goodwin 1982). They are among the longest-lived animals in the world, often reaching ages in excess of 100 years and with a maximum recorded age of 146 years (Breen and Shields 1983, Harbo et al. 1983). Geoducks grow rapidly in the initial 10 to 15 years, after which time the growth in shell length ceases while total weight increases at a slow rate through a thickening of the shell and an increase in meat weight (Harbo et al. 1983; Goodwin and Shaul 1984; Sloan and Robinson 1984). Estimates of natural mortality rate in British Columbia populations range from 0.01 to <0.05 (Breen and Shields 1983; Harbo et al. 1983; Sloan and Robinson 1984; Noakes and Campbell 1992). Geoducks begin to recruit to the fishery at age 4 and are fully recruited at 12 years (Harbo et al. 1983).

Adult geoducks have separate sexes. Ripe gonads are found in clams ranging from 7 to 107 years old, suggesting that individuals may be capable of reproducing over a century. Spawning occurs annually, mostly from June to July in association with increases in seawater temperature (Sloan and Robinson 1984). Larval stages have been described from hatchery programs. Females release from 7 to 10 -million eggs which are fertilized and develop in the water column until settlement on the bottom within 40 to 50 days (Goodwin et al. 1979; Goodwin and Shaul 1984). The settled post-larvae are active crawlers and can travel along the bottom aided by a byssal thread parachute. At a shell length of approximately 2 mm , they begin to burrow into the substrate; the depth occupied is related to shell length and siphon length. At settlement and for the first two years, juvenile geoducks are vulnerable to number of predators, including snails, sea stars, crabs (Cancer spp), shrimp and fishes (Goodwin and Pease 1989). Fast growing clams can bury to a refuge of 60 cm or more in two years. The end of the burrowing stage coincides with the beginning of annual reproductive activity at 7 to 8 years for males and females, respectively (Sloan and Robinson 1984).

Despite the large reproductive output of $P$. abrupta over extended periods of time, juveniles are scarce and recruitment is low, although age-frequencies do show periodic peaks of abundance in
juvenile settlement (unpublished data; Breen and Shields 1983; Goodwin and Shaul 1983). Laboratory experiments indicate that geoduck embryos have relatively narrow salinity and temperature tolerance limits (Goodwin 1973).

## FISHERY BACKGROUND AND SUMMARY OF MANAGEMENT

The fishery started in the inside waters of Vancouver Island in 1976, spread to Clayoquot Sound on the west coast of Vancouver Island the following year, and to the north coast in 1980 (Table 1, Fig. 1). Annual landings and value increased steadily from 1976 to 1987 when landings peaked at 5,735 tonnes ( t ). Landed values continued to increase, despite a decrease in landings, and reached an all-time high of $\$ 42.5 \mathrm{M}$ in 1995. Cumulative landings to the end of 1995 are 60,105 t. Summaries of landings by statistical area for the south and north coasts, respectively, are presented in Table 2 and Table 3; $70 \%$ of the landings have come from the South Coast ( $25 \%$ from Inside Waters and $45 \%$ from the west coast of Vancouver Island) and $30 \%$ from the North Coast.

Quota management and licence limitation are the main strategies used to regulate the geoduck industry. Minimum size limits can not be applied to this fishery because, once removed, geoducks are not capable of reburying into the substrate. Breen (1982) recommended target harvest rates to calculate quotas for the geoduck fishery but stressed that these quotas would depend on accurate estimates of virgin biomass. Jamieson (1986) reviewed the geoduck management approach and the problems with invertebrate fishery management in general and Sloan (1985) discussed the feasibility of improving biomass estimation.

For the first three years of the fishery (1976-1978) there were no restrictions imposed on the fishery. A licence moratorium and regional quotas were introduced in 1979. A fleet reduction was implemented in 1980 and a separate quota was given for the west coast of Vancouver Island and Inside Waters. In 1981, minimum landing criteria further reduced the fleet size to 55 eligible licences and the North Coast quota was split into QCI (Queen Charlotte Islands), Prince Rupert, and the Central Coast. Harvest logbook data, mandatory since 1977, were first used in quota calculation in 1984. Quota options for 1991, 1992 and 1993, 1994, 1995 and 1996 are presented in Harbo et al. $(1992,1993,1994,1995)$ and Hand et al. $(1996)$. Most quotas set were within the large ranges of potential stock and annual yield options. Some exploratory quotas were also set. Table 5 summarizes the annual quotas for north and south coast districts from 1979 to 1996.

Individual Vessel Quotas (I.V.Q.'s) were introduced in 1989 and all landings since then have been monitored at designated landing ports by contracted port observers. Also in 1989, a three year rotational area fishery was implemented, where each of the three geographic regions of the coast (North Coast, West Coast and Inside Waters) were divided into three portions with roughly equal geoduck harvest area, based on historical quotas and landings. Each of these subunits were fished at three times the annual quota, once every three years. Rotational fisheries were implemented primarily for management reasons, to reduce the annual number of delivery ports for validation of quotas. The rotational fishery also allowed for a more thorough examination of fishery areas, since only one third of the coast needed to be processed. The exception to
rotational fisheries is Area 24, Clayoquot Sound, which is fished annually. A breakdown of the areas included in each of the rotations since 1989 is shown in Table 4.

In an effort to reduce redundancy in data collection and improve data accuracy and timeliness, a pilot harvest-data collection project was initiated in 1995 for Inside Waters where port monitors collected the harvest information from fishers at the time of landing rather than have the data recorded on harvest logs and mailed in by the fishers. The program proved successful and was expanded to the rest of the coast for the 1996 fishery. The dock-side catch monitoring program now in place is very effective and landing information is currently accurate. The total fishing mortality, however, could be higher by an unknown amount through the härvest and discarding of poor quality geoducks. The Asian market for live geoducks favours geoducks which are light in colour, free of blemishes, of good siphon length and unbroken. The market quality of geoducks varies from bed to bed and may be related to age or substrate characteristics (R. Harbo, DFO, pers. comm.). Though it is felt that highgrading is not as prevalent as it once was (J. Austin, UHA, pers. comm) and the groupings of beds into Geoduck Management Areas are being adjusted to reduce the market pressure to discard, the total catch is likely underestimated.

As the fishery developed, the number of Geoduck Management Areas was increased in order to spread out fishing effort, find new fishing grounds and to reduce the potential for local overharvesting. For the 1989 to 1991 rotation, there were 75 GMA's defined, each with a separate quota. This increased to 170 GMA's for the 1992 to 1994 rotation and to 233 for the 1995 to 1997 rotation (Table 5).

## STOCK BIOMASS AND QUOTA CALCULATIONS

Calculations of virgin stock biomass use current estimates of the area of known geoduck-bearing habitat, estimates of virgin geoduck density and estimates of mean geoduck weight. Annual sustainable quotas are calculated at $1 \%$ of this biomass estimate. Associated with each of these components are various levels of uncertainty. These are discussed in detail in the following sections.

## GeOduck Biomass

## Area of Geoduck Habitat

Estimates of geoduck bed areas are obtained from charts and harvest logs provided by fishers. Bed information is transcribed from the harvest charts to a set of reference nautical charts and assigned a unique (within PFM Area and Subarea) ID number. Bed polygons are constrained to lie between 10 and 60 feet depth; stocks deeper than 60 ft are not considered as part of the exploitable biomass due to the technical limitations of working at that depth, while stocks shallower than 10 feet are restricted to protect eelgrass beds. The beds were initially measured planometrically on a computer-driven digitizing tablet with Gap1 software. Harbo et al. (1986) first published estimates of the area of beds that were harvested between 1978 and 1984. Estimates were revised each year as additional harvest beds were identified. In 1995, all of the harvest location information to date was re-digitized using COMPUGRID, a raster-based geo-
spatial program, and new area estimates were obtained. The new beds or bed expansions to be fished in 1997 and 1998 were similarly digitized and added to the database.

Inaccuracies in the estimates of bed area can arise from several sources: from errors by fishers in recording the actual harvest location, in transcribing the fishers information onto the reference charts, from digitizing measurement error and from the inherent bias involved in defining the boundary of a geoduck bed. Data accuracy is further affected by the accuracy and scale of the reference nautical chart.

The method of determining area described above is likely to give a generous estimate of the size of the beds, since all of the area between the 60 ft ( 10 fathoms or 20 m , depending on the chart) and 10 ft depth contours within a harvest locale is included in the bed polygon. Surveys have shown that geoducks have a patchy distribution, largely related to the distribution of substrate types (Campbell et al. 1995, 1996a; Hand et al. 1995) and that not all of the measured area within a defined bed has harvestable densities.

Overestimation of area in some geoduck beds was suspected when the density of geoducks removed from commercial beds is examined. Following a series of meetings with fishers held prior to the 1995 fishery, the following criteria were defined to decrease the area in suspiciously large beds which had not supported the expected production Harbo et al. (1993):

- beds with no reported landings were not considered (0 hectares)
- beds with cumulative landings $<5000 \mathrm{lb}$. were assigned an area of 1 ha
- beds with cumulative landings $>5000$ but $<10,000 \mathrm{lb}$. were assigned an area of 2 ha
- beds with cumulative landings $>10,000$ but $<20,000 \mathrm{lb}$. were assigned an area of 5 ha
- beds with cumulative landings $>20,000$ but $<50,000 \mathrm{lb}$. were assigned an area of 25 ha

Some of these 'problem' beds have been resolved with bed verification programs using on-board observers and through geoduck surveys. Geoduck surveys have shown that geoduck bed areas can be both overestimated and underestimated (Table 7) and a preliminary examination of observer fishing to date has also indicated that the actual geoduck bed may be larger or smaller than recorded. Until a more quantitative examination of these data can be undertaken, an arbitrary error range of plus or minus $10 \%$ of the measured bed area is used to express the uncertainty in this parameter estimate.

The total extent of geoduck habitat is not known as yet since new beds are still being discovered. Also, deep water stocks of geoducks are known to exist through surveys, reports of fishers and the literature (Jamison et al. 1984). The technology exists to fish these stocks, however little is known of the densities, productivity or reproductive contribution of these stocks and they are currently not included as part of the fishable biomass.

All of the updated bed area estimates for the 1997 and 1998 fisheries were examined and validated prior to use. In most cases, the new estimate was accepted, but many beds were reassigned the arbitrary area assigned to them according to the above criteria because of
continued low landings. Geoduck beds falling within a contaminated, temporary or permanent closure were excluded (Table 6).

## Average Densities

In past assessments, estimates of geoduck density have been based on surveys where available and on information from fishers. Initial surveys were discussed by Harbo et al. (1986, 1992). Large-scale surveys in Washington State produced estimates of geoduck density of $0.86 / \mathrm{m}^{2}$ over 13,678 ha (Goodwin 1978). Exploratory surveys by Cox and Charman (1980) suggested low densities of geoducks in British Columbia of 0.002 to 0.21 geoducks $/ \mathrm{m}^{2}$ ov̈er large areas ( $>100$ ha). However, unpublished data from later surveys in 1980 and 1991 of areas on the west coast of Vancouver Island and the north coast indicate higher densities ranging to as high as 9.8 geoducks $/ \mathrm{m}^{2}$. Assessments from 1990 to 1993 have used average densities ranging from 0.45 to 5.0 geoducks $/ \mathrm{m}^{2}$, depending on the area.

Joint surveys by the geoduck industry (Underwater Harvesters Association), aboriginal groups and the Department of Fisheries and Oceans have been undertaken in recent years using a standardized survey design. Survey protocols and analyses followed the methodology described in Campbell et al. (1998). Results of these have been used in assessments since 1993 (for the 1994 fishery). To date, 12 surveys have been conducted coastwide, the results of 9 of which are used to calculate quotas for the 1997 and 1998 fisheries (Table 7). Estimates of virgin density were obtained by adding the density removed by the fishery to the current density from survey results.

In the analyses, all of the data collected from within a known geoduck bed, as drawn on the reference chart, were included in calculating mean geoduck density. In some early surveys, however, where protocols had specified the placement of transects in places where harvesting had not been reported, observations from these sites were excluded if they clearly did not fall on geoduck habitat. The design of surveys beginning in 1996 is stratified at the first stage by known geoduck beds and, if an exploratory component of the survey is included in areas outside recorded beds, these data can be analyzed separately and excluded if deemed to be non-geoduck habitat.

The accuracy of survey results for density estimation is affected by the behaviour of geoducks of retracting their siphons, so as to be invisible at times (Goodwin 1977). While surveys attempt to correct for this with 'show factor plots', there is some likelihood that a complete census is not obtained and therefore densities may be underestimated.

The area and density estimated for a bed are highly inter-related. Data from all surveys were highly skewed, illustrating the contagious distribution of geoducks. Bed areas are not abrupt and defined beds may include many non-productive areas. The density estimates calculated from all of the data within a defined bed are lower than what a fisher would see while harvesting, however since the bed areas used to derive quotas include these low productivity patches, these lower densities are appropriate. Bootstrapped $95 \%$ confidence limits are used to express the uncertainty in density estimates. Results of all survey analyses will be documented elsewhere.

## i) Inside Waters

A mean density of 1 geoduck $/ \mathrm{m}^{2}$ was used to derive quotas for 1991 to 1993. In 1994, a value of $0.7 / \mathrm{m}^{2}$ was used, based on 1992 survey data from Marina Island (Campbell et al. 1996a). For the 1995 fishery, additional 1993 survey data from Comox Bar (Campbell et al. 1996b) was used and densities were reduced to 0.45 geoducks $/ \mathrm{m}^{2}$ for beds larger than 75 ha. Area 12 was treated separately and assigned higher densities of 1 and 2 geoducks $/ \mathrm{m}^{2}$, based on reports from fishers and the high level of removals from these beds (Table 8).

Two surveys have been conducted in Area 12, in Goletas Channel in 1994 and Duncan Island area in 1995, which yielded similar virgin density estimates of 1.8 and 1.33 geoducks $/ \mathrm{m}^{2}$ (Table 7). An average of these estimates was used to calculate virgin biomass and quota options for the surveyed beds for the 1998 fishery only (Table 8). Beds in the remainder of Area 12 were assigned the same density as Inside Waters at $0.7 / \mathrm{m}^{2}$ (see below).

There are no additional survey data available for southern Inside Waters. Densities estimated from the Marina Island and Comox Bar surveys still form the basis of quota calculations for southern Inside Waters with the exception of the Oyster Bay area. A 75 ha threshold for a change in density from 0.45 and 0.7 geoducks $/ \mathrm{m}^{2}$ originated with the Marina Island survey, in that one bed in the study area was 74 ha and had a density of $0.73 / \mathrm{m}^{2}$, while the other bed was of 310 ha and had a density of $0.48 / \mathrm{m}^{2}$. The low density for large harvest areas was corroborated by the Comox Bar survey where the 433 ha bed had a density of $0.45 / \mathrm{m}^{2}$. The large uncertainty in these results is in the cut-off point for density change, ranging from 74 ha to 310 ha . For the assessment for the 1996 fishery, three threshold points for low, medium and high range quota options of 75 ha, 200 ha and 300 ha were used (Hand et al. 1996). Specifically, for the low range option, quotas for beds less than 75 ha were calculated using a density of 0.7 geoduck $/ \mathrm{m}^{2}$ and for beds greater than 75 ha , a density of 0.45 geoduck $/ \mathrm{m}^{2}$ was used. Similarly, for the medium range, beds less than 200 ha were assigned a density of $0.7 / \mathrm{m}^{2}$ and beds greater than 200 ha were assigned a density of $0.45 / \mathrm{m}^{2}$. For the high range option, the change in density occurred at 300 ha. Thus, if there are no beds larger than 200 ha in a given management area, the medium and high range options would be equal. This approach was continued in this assessment for the 1997 and 1998 fisheries.

## ii) West Coast of Vancouver Island

A mean density of 2 geoduck $/ \mathrm{m}^{2}$ was used to derive quotas for 1991 to 1993 , based on the advice from fishers that densities on the west coast were twice that or more than stocks in Inside Waters. In 1994 and 1995, the density was reduced to $1.4 / \mathrm{m}^{2}$, double that of the new estimate of densities in Inside Waters (Table 8). In 1995, a survey conducted in the Elbow/Yellow Bank area indicated higher virgin densities of 2.4 geoducks $/ \mathrm{m}^{2}$ (2.1-2.8 $95 \%$ C.I.). Since these estimates are considerably higher than $1.4 / \mathrm{m}^{2}$, they were only applied to the general area in which the survey was conducted. There are no other modern survey data from the west coast of Vancouver Island that are available and therefore we continue to use a single density estimate of $1.4 / \mathrm{m}^{2}$ to calculate quotas for 1997 and 1998 for the remainder of the west coast areas (Table 8).

## iii) North Coast

Fishers have reported the greatest densities of geoducks in the north coast (Harbo et al. 1986). For the 1991 fishery, some areas were assigned densities of 5 geoducks $/ \mathrm{m}^{2}$. Following preliminary surveys of known beds in the north coast in 1991 (Farlinger and Thomas 1991), there was concern that beds were not as large as indicated on charts and may have lower densities than previously thought. As a result, the highest densities used for quota calculations for 1992 to 1995 was 3.5 geoducks $/ \mathrm{m}^{2}$ (Table 8).

In 1994, a survey was conducted in south Juan Perez Sound in the Queen Charlotte Islands (Hand et al. 1995). Results from this indicated that the mean virgin geoduck density in the area of commercial harvesting is $1.8 / \mathrm{m}^{2}$ with a $95 \%$ confidence interval of 1.3 to $2.5 / \mathrm{m}^{2}$. A survey was conducted in north Juan Perez Sound in 1995 which yielded virgin density estimates of 1.4 ( $95 \%$ CI: 1.1-1.9) (Table 7). An average of these sets of values was used to calculate quotas for the Queen Charlotte Islands for the 1997 fishery in the north coast (Table 8).

One survey was completed in the Central Coast in 1994. Mean virgin density from the McMullin Group (Area 7) of 1.7 geoducks $/ \mathrm{m}^{2}$ ( $95 \% \mathrm{CI}: 1.2-2.3$ ) was used to calculate quota options for the 1998 fishery (Table 7, 8).

## Average geoduck weight

Up to and including 1995, an average fresh weight of 1.065 kg ( 2.348 lb ) was used for all areas of the coast based on limited sampling of geoducks collected from four sites on the West Coast and one site on the North coast and one site from Inside Waters in 1981-1982 (Harbo et al. 1983). This estimate was revised for the 1996 fishery using data from additional and extensive sampling in all three licence areas of the coast and spanning the period 1981 to 1995 (Burger et al. 1998). Different average weights for each region were used, based on the data collected from the areas where fishing occurred in 1996 (Hand et al. 1996). For the 1997 and 1998 fisheries, additional new data was included in the data set and mean weights were calculated on a finer geographic scale (Table 9). Where data were not available from a statistical area, means of adjacent areas were used. The upper and lower $95 \%$ confidence limits were used to express the uncertainty in this parameter in computing the quota options.

An approximate 5\% water loss occurs over the time between harvesting and processing (Archipelago Marine Research, unpublished data). Since many of the samples used for determining mean weights were collected at processing plants, these weights may be slightly underestimated.

## Harvest Rates

Recruitment of geoduck clams is generally considered to be very low. The effect of fishing on recruitment is not known, although some evidence (Goodwin and Shaul, 1984) indicates that there may be a relationship between adult and juvenile abundance such that juveniles are less
abundant in harvested areas. Conversely, there have been recent reports from commercial fishers of high proportions of juveniles in some beds that have been heavily fished in the past. This is substantiated by some aged biological samples taken during surveys (unpublished data).

Breen (1982) estimated that quotas should be kept within 0.75 to $2.0 \%$ of the virgin biomass, depending on the stock-recruitment relationship, to achieve an equilibrium population of $50 \% \mathrm{~B}_{0}$. The negative recruitment effects of fishing noted by Goodwin and Shaul (1984) suggested using the lower end of the estimate. Results from a study in British Columbia in 1989 (Noakes and Campbell 1992) confirmed the low productivity and also suggested that the range was reasonable. Shaul and Goodwin (unpublished manuscript) suggested that $2 \% \mathrm{~B}_{0}$ was an appropriate harvest rate for Washington geoducks.

More recent PSARC working papers (Breen 1992, Campbell and Dorociez 1992) produced agestructured models and examined sustainable fishing patterns for geoduck populations in B.C. Breen suggested that the current $1 \%$ level was conservative while Campbell and Dorociez suggested that exploitation rates near $0.5 \%$ were more appropriate except where recruitment was shown to be higher, in which case $2 \%$ of the original biomass could be considered.

All of the available information indicates that geoduck productivity is low. Research projects are nearing completion that were designed to examine recruitment characteristics of geoduck populations and evaluate the sustainability of the harvest rate. Three study areas, one on the west coast and two in inside waters, have been set up to determine growth and mortality rates, to determine the rate of natural and enhanced recruitment and to monitor the effects of harvest on recruitment. These studies are in their fifth to sixth years and results should be available for use in stock assessments within a couple of years. Pending the results of these long-term research projects, we continue to use the $1 \%$ harvest rate for calculating the 1997 and 1998 quota options.

## Quota Calculations

The original or unfished biomass, $\mathrm{B}_{0}(\mathrm{lb})$ for each geoduck bed is calculated as:

$$
\begin{equation*}
B_{0}=A D_{0} \bar{W} \tag{1}
\end{equation*}
$$

where $A$ is the area ( $\mathrm{m}^{2}$ ) of the geoduck bed, $D_{0}$ is the estimated virgin density $\left(\# / \mathrm{m}^{2}\right)$, and $\bar{W}$ is the mean geoduck weight (lb). Upper and lower $95 \%$ confidence limits around the virgin density and mean geoduck weight estimates and the upper and lower estimates of bed area ( $\pm 10 \%$ ) are used to calculate the upper and lower ranges of biomass estimates.

The 3-year rotational quota options $(\mathrm{Q})$ are calculated as:

$$
\begin{equation*}
Q=3\left(0.01 B_{0}\right) \tag{2}
\end{equation*}
$$

for each estimate of $\mathrm{B}_{0}$.

Beginning in 1995, an amortization program was incorporated into quota calculations for South Coast areas, based on an arbitrary management goal of maintaining a population size of at least $50 \% \mathrm{~B}_{0}$ (Harbo et al. 1995). As the estimates of geoduck biomass have improved through surveys and market sampling, it became apparent that quotas for many beds had been set too high and overexploitation may have occurred. This situation would also arise in quota areas where certain beds are closer to port, better known by fishers, more protected from exposure or of higher quality product. To compensate for this overage, calculated quotas by bed were reduced by the ratio of the number years of quota left in a 50 -year cycle to the actual number of years left to fish in the 50 years since the fishery began in any given bed. Beds that had greater than $50 \%$ of the estimated stock removed were closed, pending surveys and further evaluations. Amortization was applied to South Coast fishing areas in 1995 and extended to North Coast areas for the 1996 fishery (Hand et al. 1996). It is continued for the 1997 and 1998 quota calculations.

To produce the amortization factors for each bed, the years of quota fished $\left(\mathrm{Y}_{\mathrm{F}}\right)$ is calculated as:

$$
\begin{equation*}
Y_{F}=\left(\frac{L}{0.01\left(B_{0}\right)}\right) \tag{3}
\end{equation*}
$$

where $L$ is the cumulative landings ( lb ) by bed. The number of years of quota remaining in a 50 year cycle, $Y_{Q}$, is then $50-Y_{F}$. The number of actual years remaining in the 50 -year cycle $\left(Y_{R}\right)$ is 50 minus the number of years elapsed since the fishery began in any given bed. The amortization factor (AF) is then:

$$
\begin{equation*}
A F=\frac{Y_{Q}}{Y_{R}} \tag{4}
\end{equation*}
$$

The reduced 3-year quota for each of the low, medium and high options is simply the calculated quota $(\mathrm{Q})$ times the amortization factor (AF).

Reported logbook landings have, especially in the early years of the fishery, been under-reported. To correct for this, reported landings by bed are factored by the ratio of fishslip landings (19761988) or validated landings (1989-1995) to logbook landings, summed over statistical area.

The estimated original (virgin) stock, reported and adjusted landings and recommended low, medium and high quota options, by management area, are shown in Table 10 for the 1987 fishery and Table 11 for the 1988 fishery. These are summarized by region and compared to the quotas and geoduck areas from the last rotation for each region (Table 12).

## 1997 AND 1998 QUOTA OPTIONS AND RECOMMENDATIONS

Recommended coastwide quotas for 1997 are:

Low Range - $\quad 2,495,024 \mathrm{lb}$
Medium Range - 3,943,936 lb
High Range - $\quad 5,756,833 \mathrm{lb}$
Recommended coastwide quotas for 1998 are:
Low Range - $\quad 2,007,614 \mathrm{lb}$
Medium Range - 3,387,548 lb
High Range - $\quad 5,174,590 \mathrm{lb}$

In comparison to the 1994 quota of $4,950,000 \mathrm{lb}$, the last time that the 1997 management areas were fished, the recommended low, medium and high quota options are $50 \%$ less, $20 \%$ less and $16 \%$ more, respectively. The 1998 quotas options are $57 \%$ less, $27 \%$ less and $12 \%$ greater than the 1995 quota of $4,621,200 \mathrm{lb}$.

## DISCUSSION AND RECOMMENDATIONS

The quota calculation process makes use of all available data, applied in as fine a geographic scale as possible, using database software (Appendix 1). Harvest information is accurate, complete and received in a timely fashion, and market sample data, observer data and survey data continue to be collected.

The parameter estimates used in the quota calculations are all associated with varying degrees of uncertainty. Estimates of average geoduck weight are probably the best determined component and it's variation has the least effect on quotas. Geoduck density estimates are improving through extensive survey efforts, and analysis of new survey data will further increase our confidence in the estimates. The interpretation of survey results for density estimation over all harvest areas involves balancing the inter-relationship of density and area. In theory, if a geoduck bed is surveyed in an unbiased manner, the calculated biomass for that bed should be reasonably accurate. In applying densities from surveyed beds to unsurveyed beds, however, one must proceed cautiously to ensure that the unsurveyed bed areas represent similar density characteristics as the area surveyed. The approach taken to applying survey results to unsurveyed beds is conservative in that lower densities are assumed and applied until field studies indicate otherwise.

Estimates of geoduck bed area are sensitive to human subjectivity, interpretation of fishers information and to variable imprecision of nautical charts. Arbitrary reductions in bed area based on landing history is used to deal with perceived overestimates on a gross level. Through time, 'problem' beds are being fished under observation to resolve bed area uncertainties, while survey results are being used to calibrate fisher's information. Work planning in the future includes a systematic review and evaluation of all charted bed polygons using data from other sources, including surveys, monitored fishing, on-grounds observers and substrate mapping.

The recommended annual exploitation rate of $1 \%$ of virgin biomass is at the conservative end of the recommended range of $0.5 \%-2 \%$. Recommendations resulting from more recent modeling exercises are contradictory and do not provide a strong indication that the value should be a changed. Research on recruitment and productivity is nearing completion which will provide the data required to address this area of uncertainty. Previous examinations of sustainable exploitation rates have used parameters taken from studies in Washington State and southern British Columbia. Since the north coast fishery now accounts for the majority of landings, efforts should be made to incorporate biological data from the northern regions. In particular, natural mortality rate has a major effect on productivity and emphasis should be placed on collecting biological data from unexploited areas in the north coast, while they still exist.

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## REFERENCES

Andersen, A.M., Jr. 1971. Spawning, growth and spatial distribution of the geoduck clam, Panope generosa (Gould) in Hood Canal, Washington. Ph.D. Thesis. University of Washington, Seattle. 133 pp.

Breen, P.A. 1982. Geoducks. pp. 14 -16 In: F.R. Bernard [ed.]. Assessment of invertebrate stocks off the west coast of Canada (1981). Can. Tech. Rep. Fish. Aquat. Sci. 1074: iv + 39 p.

Breen, P.A. 1992. Sustainable fishing patterns for geoduck clam (Panopea abrupta) populations in British Columbia. PSARC Working paper 193-10. Summarized In: J.R. Irvine, R .D. Stanley, D. McKone, S. M. McKinnell, B. M. Leaman and V. Haist [eds.]. 1993. Pacific Stock Assessment Review Committee (PSARC) annual report for 1992. Can. Manuscr. Rep. Fish. Aquat. Sci. 2196: 199 p.

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

Burger, L., E. Rome, A. Campbell, R. Harbo, P. Thuringer, J. Wasilewski and D. Stewart. 1998. Analysis of landed weight information for geoduck clams (Panope abrupta) in British Columbia, 1981-1995. p. 365-375. In: B.J. Waddell, G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 1. Bivalves. Can. Tech. Rep. Fish. Aquat. Sci. 2214.

Campbell, A. and J. Dorociez. 1992. Yield and risk analysis for the geoduck fishery in two areas of southern British Columbia. PSARC Working Paper I93-2. Summarized In: J.R. Irvine, R.D. Stanley, D. McKone, S.M. McKinnell, B.M. Leaman and V. Haist [eds.]. 1993. Pacific Stock Assessment Review Committee (PSARC) annual report for 1992. Can. Manuscr. Rep. Fish. Aquat. Sci. 2196: 199 p.

Campbell, A., B. Clapp, C. Hand, R. Harbo, K. Hobbs, J. Hume, and G. Scharf. 1998. Survey of geoduck population density in Goletas Channel, 1994. pp. 319-348. In: B.J. Waddell, G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1996. Pärt 1. Bivalves. Can. Tech. Rep. Fish. Aquat. Sci. 2214.

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

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

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

Cox, R.K. 1979. The geoduck clam, Panope generosa: some general information on distribution, life history, harvesting, marketing and management in British Columbia. Marine Resource Branch, Ministry of the Environment, Fisheries Management Report No. 15: 25 p.

Cox, R.K. and E.M. Charman. 1980. A survey of abundance and distribution (1977) of the geoduck clam Panope generosa in Queen Charlotte, Johnstone and Georgia Straits, British Columbia. Marine Resources Branch Fisheries Development Report 16: 122 p.

Farlinger, S. and K.T. Bates. 1985. Review of shellfish fisheries in northern British Columbia to 1984. Can. Manuscr. Rep. Fish Aquat. Sci. 1841: 35 p.

Farlinger, S. and G.A. Thomas. 1988. Review of shellfish fisheries in northern British Columbia 1985 and 1986. Can. Manuscr. Rep. Fish Aquat. Sci 1988: 38 p.

Farlinger, S. and G.A. Thomas. 1991. Results of a preliminary survey of geoduck beds in the North Coast. Summarized In: J.R. Irvine, A. D. Anderson, V. Haist, B. M. Leaman, S. M. McKinnel, R. D. Stanley, and G. Thomas (eds). 1992. Pacific Stock Assessment

Review Committee (PSARC) Annual Report for 1991. Can. Manuscr. Rep. Fish. Aquat. Sci. 2159: 201 p.

Goodwin, L. 1973. Effects of salinity and temperature on embryos of the geoduck clam (Panope generosa). Proc. Nat. Shellfish Assoc. 63: 93-96.

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

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

Goodwin, L. and B. Pease. 1989. Species profiles: life histories and environmental requirements of coastal fish and invertebrates (Pacific Northwest)--Pacific geoduck clam. U.S. Fish. Wild. Serv. Biol. Rep. 82 (11.120). U.S. Army Corps of Engineers, TR EL-82-4: 14 p.

Goodwin, L., W. Shaul and C. Budd. 1979. Larval development of the geoduck clam (Panope generosa Gould). Proc. Nat. Shellfish. Assoc. 69: 73-76.

Goodwin, L. and W. Shaul. 1984. Age, recruitment and growth of the geoduck clam (Panope generosa Gould) in Puget Sound, Washington. Progress Report No. 215 State of Washington, Dept. of Fisheries: 29 p.

Hand, C.M., A. Campbell, L. Lee and G. Martel. 1998. A survey of geoduck stocks on north Burnaby Island, Queen Charlotte Islands, July 7-18, 1994. pp. 349-364. In: B.J. Waddell, G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessement Review Committee in 1995. Part 1. Bivalves. Can. Tech. Rep. Fish. Aquat. Sci. 2214.

Hand, C.M., K. Hobbs, R. Harbo and G.A. Thomas. 1998. Quota options and recommendations for the 1996 geoduck clam fishery. pp. 377-437. In: B.J. Waddell, G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessement Review Committee in 1995. Part 1. Bivalves. Can. Tech. Rep. Fish. Aquat. Sci. 2214.

Harbo, R.M., B.E. Adkins, P.A. Breen and K.L. Hobbs. 1983. Age and size in market samples of geoduck clams (Panope generosa) Can. Manuscr. Rep. Fish. Aquat. Sci. 1714: iii +78 p.

Harbo, R.M. and S.D. Peacock.. 1983. The commercial geoduck clam fishery in British Columbia, 1976 to 1981. Can. Manuscr. Rep. Fish. Aquat. Sci. 1712: vii +40 p.

Harbo, R.M., C. Hand and B.E. Adkins. 1986. The commercial geoduck clam fishery in British Columbia 1981 to 1984. Can. Manuscr. Rep. Fish. Aquat. Sci. 1873: 59 p.

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

Harbo, R.M., G. Thomas and K. Hobbs. 1993. Quotas for the 1992-1993 geoduck clam fisheries. Can. Manuscr. Rep. Fish. Aquat. Sci. 2179: 209 p.

Harbo, R.M., G. Thomas and K. Hobbs. 1994. Quota options and recommendations for the 1994 geoduck clam fishery. Can. Manuscr. Rep. Fish. Aquat. Sci. 2228: x + 115 p.

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

Jamieson, G.S. 1986. A perspective on invertebrate fisheries management - the British Columbia experience. pp. 57-74. In G.S. Jamieson and N. Bourne [eds.]. North Pacific workshop on stock assessment and management of invertebrates. Can. Spec. Publ. Fish. Aquat. Sci. 92.

Jamison, D., R. Heggen and J. Lukes. 1984. Underwater video in a regional benthos survey. Presented at Pacific Congress on Marine Technology, Honolulu, Hawaii. April 24-27, 1984.

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

Quale, D.B. 1970. Intertidal bivalves of British Columbia. Handbook No. 17, B.C. Provincial Museum, Victoria, B.C.: 104 p.

Shaul, W. and L. Goodwin. 1982. Geoduck (Panope generosa: Bivalvia) age as determined by internal growth lines in the shell. Can. J. Fish. Aquat. Sci. 29: 632-636.

Sloan, N.A. 1985. Feasibility of improving geoduck stock assessment: history of the problem, recommended methods and their costs. pp. 57-67. In: G.S. Jamieson [ed.]. 1983 and 1984 Invertebrate Management Advice, Pacific Region. Can. Manuscr. Rep. Fish. Aquat. Sci. 1848.

Sloan, N.A. and S.M.C. Robinson. 1984. Age and gonad development in the geoduck clam, Panope abrupta (Conrad) from southern British Columbia, Canada, J. Shellfish Res.(4): 131-137.
Table 1. Number of licences issued, number of vessels fished, landings and landed values of geoduck clams in British Columbia, as reported on sales slips (1976 to 1988), and on validation logs (1989 to 1995).

| Year | Licences Issued | VesselswithLandings | Total Landings |  | Total Value ${ }^{1}$ | Mean Price ${ }^{2}$ |  | Price Range ${ }^{2}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | (lb) | (t) | \$10-3 | (\$.1b) | (\$.kg) | (\$.1b) | (\$-kg) |
| 1976 | 7 | 5 | 97,002 | 44 | N/A | N/A | N/A | N/A | N/A |
| 1977 | 30 | 14 | 540,898 | 245 | 89 | 0.17 | 0.37 | N/A | N/A |
| 1978 | 54 | 27 | 2,239,950 | 1,016 | 569 | 0.25 | 0.55 | 0.15-0.35 | 0.33-0.77 |
| 1979 | 101 | 72 | 5,429,886 | 2,463 | 1,669 | 0.31 | 0.68 | 0.13-0.40 | 0.29-0.88 |
| 1980 | 95 | 63 | 6,186,067 | 2,806 | 2,299 | 0.37 | 0.82 | 0.30-0.48 | 0.66-1.06 |
| 1981 | 52 | 49 | 5,961,405 | 2,704 | 2,162 | 0.36 | 0.79 | 0.32-0.70 | 0.71-1.54 |
| 1982 | 52 | 53 | 6,910,800 | 3,135 | 2,814 | 0.40 | 0.89 | 0.22-0.46 | $0.44 \cdot 1.01$ |
| 1983 | 54 | 53 | 5,810,913 | 2,636 | 1,804 | 0.31 | 0.68 | 0.00-0.60 | 0.00-1.32 |
| 1984 | 54 | 44 | 7,678,465 | 3,483 | 2,937 | 0.38 | 0.84 | 0.00-0.95 | 0.00-2.09 |
| 1985 | 55 | 52 | 11,838,624 | 5,370 | 4,599 | 0.40 | 0.89 | 0.00-1.00 | 0.00-2.20 |
| 1986 | 55 | 55 | 11,035,396 | 5,006 | 4,605 | 0.39 | 0.86 | 0.00-0.85 | 0.00-1.87 |
| 1987 | 55 | 56 | 12,643,298 | 5,735 | 6,184 | 0.49 | 1.08 | 0.00-1.05 | 0.00-2.31 |
| 1988 | 55 | 56 | 10,068,830 | 4,567 | 9,807 | 0.97 | 2.14 | 0.03-1.88 | 0.07-4.14 |
| 1989 | 55 | 47 | 8,784.247 | 3.985 | 12,571 | 1.43 | 3.15 | 0.25-1.75 | 0.55-3.85 |
| 1990 | 55 | 46 | 8,722,366 | 3,956 | 10,581 | 1.21 | 2.67 | 0.14-2.27 | 0.31-5.00 |
| 1991 | 55 | 47 | 7,346,864 | 3,333 | 9,659 | 1.29 | 2.84 | 0.58-2.55 | 1.27-5.62 |
| 1992 | 55 | 45 | 6,313,748 | 2,864 | 16,237 | 2.56 | 5.64 | 1.60-5.01 | 3.53-11.04 |
| 1993 | 55 | 44 | 5,365,420 | 2,434 | 26,994 | 4.99 | 11.00 | 1.00-9.38 | 2.20-20.68 |
| 1994 | 55 | 45 | 4,908,523 | 2,226 | 33,552 | 6.87 | 15.15 | 1.20-9.00 | 2.66-19.84 |
| 1995 | 55 | 43 | 4,624,330 | 2,098 | 42,518 | 9.36 | 20.63 | 3.50-15.00 | 7.72-33.07 |

[^0]Table 2. Summary of geoduck landings (tonnes) by South Coast Management Area, as reported on sales slips (1976 to 1988) and on validation logs (1989 to 1995). A three year rotation of areas was initiated in 1989, with the exception of area 24.

| Year | SOUTH COAST MANAGEMENT AREAS |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | $\begin{array}{r} \text { Annual } \\ \text { Landings } \\ \hline \end{array}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | East Coast Vancouver Island |  |  |  |  |  |  |  |  |  |  | West Coast Vancouver Island |  |  |  |  |  |  |  |
|  | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 28 | 29 | 20 | 21 | 23 | 24 | 25 | 26 |  |  |
| 1976 |  |  |  | 10 |  |  | 8 |  | 26 |  |  |  |  |  |  |  |  |  | 44 |
| 1977 |  |  | 14 | 9 | 77 |  | 137 | 2 |  |  |  |  |  | 6 |  |  |  |  | 245 |
| 1978 |  |  | 8 | 261 | 321 | 3 | 24 | 19 | 136 |  |  | 1 | 3 | 2 | 236 | 2 |  |  | 1016 |
| 1979 |  | 24 | 160 | 276 | 263 | 148 | 209 | 3 | 159 |  |  |  |  | 153 | 950 | 87 | 22 | 9 | 2463 |
| 1980 |  |  | 97 | 215 | 17 | 301 | 225 | 34 | 91 |  |  | 5 |  | 288 | 841 | 321 | 303 |  | 2738 |
| 1981 |  |  | 41 | 180 | 29 | 70 | 155 | 44 | 28 |  |  | 8 |  | 187 | 819 | 473 | 156 | 6 | 2195 |
| 1982 |  | 83 | 14 | 144 | 33 | 103 | 17 | 1 | 14 |  |  | 14 |  | 174 | 1218 | 366 | 726 |  | 2907 |
| 1983 |  | 16 | 29 | 340 | 29 | 42 | 13 | 2 | 10 |  |  |  |  | 84 | 1066 | 215 | 287 | 1 | 2134 |
| 1984 | 8 | 302 | 150 | 285 | 54 | 129 | 128 | 1 | 118 |  |  |  |  | 219 | 628 | 442 | 443 | 2 | 2909 |
| 1985 | 13 | 490 | 81 | 172 | 42 | 38 | 137 | 4 | 78 |  |  | 0 |  | 227 | 730 | 599 | 272 | 1050 | 3934 |
| 1986 | 21 | 212 | 148 | 200 | 137 | 117 | 136 | 13 | 124 |  | 11 | 96 |  | 231 | 803 | 450 | 226 | 388 | 3313 |
| 1987 |  | 275 | 112 | 286 | 98 | 159 | 265 | 103 | 50 |  | 100 | 40 |  | 247 | 661 | 552 | 398 | 241 | 3587 |
| 1988 | 62 | 290 | 51 | 191 | 59 | 95 | 110 | 2 | 116 | 1 | 17 | 49 |  | 192 | 633 | 187 | 206 | 279 | 2541 |
| 1989 | 5 | 662 | 203 |  |  |  |  |  |  |  |  |  |  | 538 | 633 |  |  | 345 | 2386 |
| 1990 |  |  |  | 605 |  | 258 |  |  |  |  |  |  |  |  | 540 |  | 614 | 343 | 2360 |
| 1991 |  |  |  |  | 258 |  | 181 | 37 | 244 |  | 14 | 1 |  |  | 416 | 702 | 153 |  | 2006 |
| 1992 |  | 256 | 78 | 291 |  |  |  |  |  |  |  |  |  | 255 | 479 |  |  | 306 | 1665 |
| 1993 |  |  |  | 349 |  | 182 |  |  |  |  |  |  |  |  | 497 |  | 220 | 124 | 1371 |
| 1994 |  |  |  |  | 181 |  | 134 | 20 | 64 |  | 10 |  |  |  | 232 | 496 |  |  | 1137 |
| 1995 | 6 | 80 | 54 | 286 |  |  |  |  |  |  |  |  |  | 129 | 188 |  |  | 210 | 953 |
| $\begin{array}{r} 1976 \text { to } \\ 1995 \end{array}$ | 116 | 2690 | 1240 | 4100 | 1598 | 1645 | 1879 | 284 | 1258 | 1 | 152 | 214 | 3 | 2932 | 11569 | 4892 | 4025 | 3304 | 41904 |

Inside Waters Total: 14,964 West Coast Total: 26,940
Table 3. Summary of geoduck landings (tonnes) by North Coast Management Area, as reported on sales slips (1980 to 1988), and on validation logs (1989 to 1995). A three year rotation of areas was initiated in 1989.

| Year | NORTH COAST MANAGEMENT AREA |  |  |  |  |  |  |  |  |  |  | Annual Landings |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1 | 2 E | 2W | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |  |
| 1980 |  | 31 |  |  | 4 |  |  |  |  | 28 | 5 | 68 |
| 1981 |  | 11 |  |  |  | 84 | 6 | 370 | 18 |  | 20 | 509 |
| 1982 |  |  |  |  |  |  |  | 227 |  |  |  | 227 |
| 1983 |  |  |  |  |  |  |  | 202 | 299 |  |  | 501 |
| 1984 |  | 4 |  | 3 |  | 214 | 8 | 109 | 183 | 54 |  | 575 |
| 1985 |  | 341 | 213 |  |  | 291 | 60 | 494 | 37 |  |  | 1436 |
| 1986 | 7 | 254 | 325 | 120 | 125 | 323 | 24 | 392 | 2 | 103 | 17 | 1692 |
| 1987 | 137 | 391 | 179 | 134 | 95 | 287 | 484 | 222 | 91 | 11 | 117 | 2148 |
| 1988 | 119 | 462 | 45 | 77 | 150 | 191 | 423 | 309 | 250 |  |  | 2026 |
| 1989 |  |  |  |  |  |  | 149 | 1269 | 40 |  | 142 | 1600 |
| 1990 |  |  |  | 77 | 356 | 441 | 721 |  |  |  |  | 1596 |
| 1991 | 91 | 848 | 388 |  |  |  |  |  |  |  |  | 1327 |
| 1992 |  |  |  |  |  |  | 202 | 853 | 83 | 23 | 39 | 1199 |
| 1993 |  |  |  | 37 | 170 | 411 | 445 |  |  |  |  | 1063 |
| 1994 | 48 | 684 | 359 |  |  |  |  |  |  |  |  | 1091 |
| 1995 |  |  |  |  |  |  | 218 | 736 | 121 | 30 | 40 | 1145 |
| $\begin{gathered} 1976 \text { to } \\ 1995 \end{gathered}$ | 402 | 3025 | 1509 | 448 | 900 | 2242 | 2739 | 5183 | 1124 | 248 | 380 | 18201 |

Table 4. Summary of rotation areas and geoduck quotas (b) for 1989 to 1996 and proposed fishing areas for the 1997 and 1998 rotations.

| Inside Waters |  |  | $\begin{gathered} \hline \text { West Coast } \\ \text { V.I. } \\ \hline \end{gathered}$ |  | North Coast |  | Annual | $\frac{\text { Annual }}{\text { I.V.Q. }}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Year | Areas | Quota | Areas | Quota | Areas | Quota | Quota |  |
| First Rotation (1989-90-91) |  |  |  |  |  |  |  |  |
| 1989 | 11,12,13 | 1,920,000 | 23,24,27A | 3,360,000 | lower 6, 7 to 10 | 3,520,000 | 8,800,000 | 160,000 |
| 1990 | 14,16 | 1,920,000 | 24,26,27H,271 | 3,360,000 | 3,4,5,upper 6 | 3,520,000 | 8,800,000 | 160,000 |
| 1991 | $\begin{aligned} & 15,17,18, \\ & 19,29-5, \end{aligned}$ | 1,620,000 | $\begin{aligned} & 20,24,25,26 \mathrm{~B} 1 \\ & 26 \mathrm{~B} 2,26 \mathrm{C} \end{aligned}$ | 2,835,000 | 1,2E,2W | 2,970,000 | 7,425,000 | 135,000 |
| Second Rotation (1992-1993-1994) |  |  |  |  |  |  |  |  |
| 1992 | $\begin{aligned} & \text { 12,13,14A, } \\ & \text { 14B,14C } \end{aligned}$ | 1,377,000 | 23,24A, 24A2, <br> 24A3,24B,24B2 <br> 24B3,27A,27B, <br> 27D,27E,27F, <br> 27G,27H,27I | 2,295,000 | lower 6, 7 to 10 | 2,639,250 | 6,311,250 | 114,750 |
| 1993 | 14D,14E,16 | 1,170,000 | 24A,24A2,24A3, 24B,24B2,2484, 26A,26B2, 26D,27H | 1,852,500 | 3,4,5,upper 6 | 2,340,000 | 5,362,500 | 97,500 |
| 1994 | $\begin{aligned} & \text { 15A, 15B, 15C } \\ & \text { 15D,15E,15F, } \\ & \text { 15G,17A,17B, } \\ & \text { 18A,18B,19A, } \\ & \text { 19B,19C,29-4 } \\ & \text { 29-5 } \end{aligned}$ | 900,000 | $\begin{aligned} & \text { 24A } 2,24 \mathrm{~A} 3,24 \mathrm{~A} 4,2 \\ & \text { 4A5 } \\ & \text { 24A6,24B1,24B2,24B } \\ & \text { 24B4,25A,25B, } \\ & \text { 25C,25D } \end{aligned}$ | $1,620,000$ <br> 3, | 1,2E,2W | 2,430,000 | 4,950,000 | 90,000 |

Table 4. (cont.)

Table 5 a. Summary of annual quotas ( $100^{3} \mathrm{lb}$.) and the number of quota management areas (brackets) from 1979 to 1996 in the geoduck clam fishery.

|  | South Coast |  |  |  |  |  | North Coast |  |  |  |  |  |  |  | $\begin{gathered} \hline \text { Coast } \\ \text { Total } \\ \hline \text { (lb) } \end{gathered}$ | $\begin{aligned} & \text { Total } \\ & \text { Quota } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Inside |  | est Coast |  |  |  |  |  | Prince |  |  |  |  |  |  |  |
| Year | Waters |  | V.I. |  | Subtotal |  | QCI |  | Rupert |  | Central |  | Subtotal |  |  | Units |
| 1979 | NA |  | NA |  | 4,500.0 | (1) | NA |  | NA | NA | NA | NA | 3,500.0 | (1) | 8,000.0 | (2) |
| 1980 | 1,700.0 | (5) | 2,800.0 | (3) | 4,500.0 | (8) | NA |  | NA | NA | NA | NA | 3,500.0 | (1) | 8,000.0 | (9) |
| 1981 | 876.0 | (7) | 3,125.0 | (3) | 4,001.0 | (10) | 600.0 | (3) | 575.0 | (3) | 950.0 | (5) | 2,175.0 | (11) | 6,176.0 | (21) |
| 1982 |  |  |  |  | oastwide q | ta set | -. |  |  |  |  |  |  |  | 6,500.0 | (1) |
| 1983 | 1,000.0 | (1) | 3,500.0 | (1) | 4,500.0 | (2) | 650.0 | (1) | 350.0 | (1) | 1,000.0 | (1) | 2,000.0 | (3) | 6,500.0 | (5) |
| 1984 | 1,500.0 | (6) | 3,100.0 | (6) | 4,600.0 | (12) | 650.0 | (2) | 350.0 | (1) | 1,000.0 | (1) | 2,000.0 | (3) | 6,600.0 | (15) |
| 1985 | 1,650.0 | (10) | 2,900.0 | (9) | 4,550.0 | (19) | 650.0 | (3) | 500.0 | (1) | 850.0 | (1) | 2,000.0 | (4) | 6,550.0 | (23) |
| 1986 | 2,025.0 | (11) | 3,500.0 | (11) | 5,525.0 | (22) | 1,350.0 | (5) | 850.0 | (3) | 1,050.0 | (3) | 3,250.0 | (11) | 8,775.0 | (33) |
| 1987 | 1,850.0 | (13) | 3,950.0 | (14) | 5,800.0 | (27) | 1,235.0 | (6) | 800.0 | (3) | 1,510.0 | (7) | 3,545.0 | (16) | 9,345.0 | (43) |
| 1988 | 1,750.0 | (11) | 3,350.0 | (16) | 5,100.0 | (27) | 950.0 | (5) | 800.0 | (1) | 1,725.0 | (8) | 3,475.0 | (16) | 8,575.0 | (43) |
| 1989 | 1,920.0 | (4) | 3,360.0 | (5) | 5,280.0 | (9) | closed |  | closed |  | 3,520.0 | (7) | 3,520.0 | (7) | 8,800.0 | (16) |
| 1990 | 1,920.0 | (5) | 3,360.0 | (8) | 5,280.0 | (13) | closed |  | 3,520.0 | (5) | closed |  | 3,520.0 | (5) | 8,800.0 | (18) |
| 1991 | 1,620.0 | (10) | 2,835.0 | (12) | 4,455.0 | (22) | 2,970.0 | (19) | closed |  | closed |  | 2,970.0 |  | 7,425.0 | (41) |
| 1992 | 1,377.0 | (16) | 2,295.0 | (21) | 3,672.0 | (37) | closed |  | closed |  | 2,639.3 | (24) | 2,639.3 | (24) | 6,311.3 | (61) |
| 1993 | 1,117.0 | (7) | 1,852.5 | (13) | 3,022.5 | (20) | closed |  | 2,340.0 | (27) | closed |  | 2,340.0 | (27) | 5,362.5 | (47) |
| 1994 | 900.0 | (15) | 1620.0 | (15) | 2,520.0 | (30) | 2,430.0 | (32) | closed |  | closed |  | 2,430.0 | (32) | 4,950.0 | (62) |
| 1995 | 924.3 | (16) | 1,176.0 | (25) | 2,100.8 | (41) | closed |  | closed |  | 2,520.9 | (38) | 2,520.9 | (38) | 4,621.7 | (79) |
| 1996 | 959.2 | (10) | 811.6 | (16) | 1,770.8 | (26) | closed |  | 2,287.3 | (43) | closed |  | 2,287.3 | (43) | 4,058.2 | (69) |

Table 5b. Summary of annual quotas (tonnes) and the number of quota management areas (brackets) from 1979 to 1996 in the geoduck clam fishery.

() * number of subquotas specified for areas or portions of areas.
Table 6. Area (ha) and standing stock of geoduck beds or portions of beds in areas under contaminated, temporary or permanent closure to 1997. Standing stock is calculated using updated mean weights by Statistical Area.

| $\begin{gathered} \text { Stat } \\ \text { Area } \end{gathered}$ | $\begin{array}{r} \text { Sub } \\ \text { Area } \end{array}$ | $\begin{aligned} & \text { Bed } \\ & \text { Code Description } \end{aligned}$ | Fishing Area (Ha) | Est. Ha Closed | Est.Density $\left(\# / \mathrm{m}^{2}\right)$ | Standing <br> Stock (lb) | Reason for Closure | Closure Number |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| INSIDE WATERS |  |  |  |  |  |  |  |  |
| 12 | 16 | 202 Hardy Bay | 9 | 9 | 1.7 | 360,032 | Contaminated | 12.1 |
| 12 | 16 | 301 Beaver Harbour | 43 | 43 | 1.7 | 1,907,679 | Contaminated | 12.3 |
| 12 | 16 | 404 E Thomas Pt - airport | 12 | 12 | 1.7 | 506,651 | First Nations |  |
| 13 | 1 | 2101 Mittlenatch Island | 12 | 12 | 0.7 | 193,222 | Marine Park |  |
| 13 | 3 | 401 Gowland Harbour | 5 | 5 | 0.7 | 73,787 | Marine Park |  |
| 13 | 3 | 402 Gowland Island | 4 | 4 | 0.7 | 58,154 | Marine Park |  |
| 13 | 15 | 1201 Mansons Landing | 16 | 16 | 1.7 | 250,750 | Contaminated | 13.A |
| 14 | 4 | 5301 Qualicum Beach (portion) | 181 | 91 | 0.45 | 1,407,283 | Contaminated | 14.6 |
| 14 | 8 | 4 beds Baynes Sound | 73 | 73 | 0.7 | 1,157,099 | Contam. risk |  |
| 14 | 10 | 4601 Comox Bar (portion) | 831 | 300 | 0.45 | 3,010,500 | Contaminated | 14.1 |
| 14 | 11 | 4705 Union Pt. | 16 | 16 | 0.7 | 247,056 | Contam. risk | 14.1 |
| 15 | 21 | 701 Westview to Grief Pt | 63 | 63 | 0.7 | 971,898 | Contaminated | 15.1 |
| 16 | 21 | 1501 Gillies Bay (portion) | 66 | 9 | 0.7 | 128,876 | Contaminated | 16.4/16.11 |
| 17 | 6 17 | 7102 Boulder Point | 27 | 2 | 0.7 | 31,174 | Contaminated | 17.1 |
| 17 | 17 | 6201 E. Mudge Island | 77 | 77 | 0.45 | 902,605 | DFO Research |  |
| 17 | 17 | 105 Cordero Point | 4 | 4 | 0.7 | 41,938 | MPA |  |
| 19 | 8 | 0201 Towner/Patricia Bay | 88 | 88 | 0.45 | 1,103,276 | Contaminated |  |
| 19 | 8 | 0202 Coles Bay | 11 | 11 | 0.7 | 139,859 | Contaminated | $19.6$ |
|  |  | Total Inside Waters |  | 835 |  | 12,491,839 |  |  |
| WEST COAST |  |  |  |  |  |  |  |  |
| 23 | 4 | 2301 S. Flemming | 5 | 5 | 1.4 | 168,618 | Bamfield Research |  |
| 23 | 5 | 2102 Marble Cove | 1 | 1 | 1.4 | 33,724 | Bamfield Research |  |
| 23 | 5 | 2302 NW Flemming | 2 | 2 | 1.4 | 67,447 | Bamfield Research |  |
| 23 | 5 | 2303 NW Flemming | 11 | 11 | 1.4 | 381,752 | Bamfield Research |  |
| 23 | 8 | 1201 S. Brabant-N. Peacock Ch. | 5 | 5 | 1.4 | 182,108 | Pacific Rim Park Reserve |  |
| 23 | 8 | 1701 NE Clarke Is. | 5 | 5 | 1.4 | 168,618 | Pacific Rim Park Reserve |  |
| 23 | 8 | 1702 E . Turret Is. | 4 | 4 | 1.4 | 121,405 | Pacific Rim Park Reserve |  |
| 24 | 1 | 2101 Hesquiat Harbour | 1 | 1 | 1.4 | 33,724 | First Nations |  |
| 24 | 6 | 0605 Whitesand Cove | 42 | 42 | 1.4 | 1,435,993 | Marine Park |  |
| 24 | 6 | 1202 S. Robert Point | 7 | 7 | 1.4 | 248,381 | DFO Research |  |
| 24 | 6 | 1203 Dunlap Is. | 22 | 15 | 1.4 | 508,200 | DFO Research |  |
| 24 | 6 | 0806 Ahous Bay | 13 | 13 | 1.4 | 440,440 | Whale Sanctuary |  |
| 26 | 7 | 0501 N. | 33 | 33 | 1.4 | 1,111,530 | Sea Otter Reserve |  |
| 26 | 7 | 0502 Battle Bay - NW Bunsby Is. | 8 | 8 | 1.4 | 258,153 | Sea Otter Reserve |  |
| 26 | 7 | 0503 West of Battle Bay | 5 | 5 | 1.4 | 164,523 | Sea Otter Reserve |  |
| 26 | 7 | 0504 SW of Theodore Pt. | 6 | 6 | 1.4 | 188,599 | Sea Otter Reserve |  |
| 26 | 7 | 0505 N.Acous Pen.- Cuttle Is. Total West Coast | 29 | 29 192 | 1.4 | $\begin{array}{r} 956,371 \\ 6,469.586 \end{array}$ | Sea Otter Reserve |  |

Table 6. (cont.)

| $\begin{array}{r} \text { Stat } \\ \text { Area } \end{array}$ | $\begin{array}{r} \text { Sub } \\ \text { Area } \end{array}$ | Bed <br> Code Description | $\begin{array}{r} \text { Fishing } \\ \text { Area (Ha) } \end{array}$ | $\begin{aligned} & \text { Est. Ha } \\ & \text { Closed } \end{aligned}$ | $\begin{gathered} \text { Est.Density } \\ \left(\# / \mathrm{m}^{2}\right) \end{gathered}$ | Standing Stock (Ib) | Reason for Closure | Closure Number |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| NORTH COAST |  |  |  | 95 | 1.6 | 4,349,385 | First Nations |  |
| 2 | 1 | 2801 Skidigate Mission | 43 | 43 | 1.6 | 1,988,814 | Contaminated |  |
| 2 | ${ }^{1}$ | 2803 Shingle Bay | 20 | 20 | 1.6 | 910,166 | Marine Park |  |
| 2 | 13/16 | 401/402 Dolomite Narrows |  | 2 | 2.3 | 117,300 | Contaminated | 7.8 |
| 7 |  | Total North Coast |  | 160 |  | 117,300 |  |  |
|  |  | Total Coastwide |  | 1187 |  | 19,078,725 |  |  |

Table 7. Summary of results from the geoduck surveys used to determine quotas for the 1997 and 1998 fisheries. 'Density removed' is the number of geoducks harvested over the area surveyed.

| Location |  | Statistical <br> Area |  | Bed Area (ha) |  |  |  | Survey Density |  | Density Removed | Reference |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\overline{\substack{\text { Logboo } \\ k^{1}}}$ |  | Survey ${ }^{2}$ | Redrawn ${ }^{3}$ | L95\% | Mean | U95\% |  |  |
| North Coast | Griffith Harbour |  | 5 | 95 | 182.4 | 192.1 | 168.1 | 2.50 | 2.90 | 4.10 | 0.53 | in prep |
| QCI | Burnaby Island | 2 | 94 | 112.0 | 155.1 | 124.7 | 0.94 | 1.45 | 2.19 | 0.36 | Hand et al. 1996 |
|  | Hotspring Island | 2 | 95 | 110.7 | 116.7 | 84.0 | 0.90 | 1.30 | 1.80 | 0.12 | in prep |
| Central Coast | McMullin Group | 7 | 94 | 61.8 | 94.8 | na | 0.80 | 1.30 | 1.90 | 0.42 | in prep |
| West Coast | Elbow/Yellow Bank | 24 | 95 | 272.2 | na | 359.4 | 1.49 | 1.85 | 2.21 | 0.58 | in prep |
| Inside Waters | Marina Island | 13 | 92 | 74.3 | 84.2 | na | - | 0.27 | - | 0.46 | Campbell et al. 1996a |
|  | Comox Bar/Sandy Isl. | 14 | 93 | 433.0 | 304.7 | na | - | 0.31 | - | 0.13 | Campbell et al. 1996 b |
|  | S Goletas Channel | 12 | 94 | 64.0 | 161.3 | na | 0.96 | 1.28 | 1.66 | 0.52 | Campbell et al. 1995 |
|  | Duncan Island | 12 | 95 | 67.4 | 112 | na | 0.75 | 0.98 | 1.25 | 0.35 | in prep |

${ }_{2}$ Logbook bed area is as measured off the reference chart.
${ }^{2}$ Survey area is the area covered by the transect survey
${ }^{3}$ Redrawn area is the area of commercial harvest, redrawn using the survey results to obtain a more accurate estimate of the extent of geoduck habitat.
Table 8. Summary of geoduck densities $\left(\# / \mathrm{m}^{2}\right)$, by region, used to calculate quotas from 1991 to present. All Statistical Areas within each region shared the same value of density, except where noted.

| REGION |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Fishery | Queen Charlotte Islands |  |  | Prince Rupert |  |  | Central Coast |  |  | West Coast Van. Is. |  |  |  | Inside Waters |  |  |  |
|  | low | med. | high | low | med. | high | low | med. | high | Areas | low | med. | high | Areas | low | med. | high |
| 1991 | - | 3.5,5.0 | - | - | - | - | - | - | - | All | - | 2.0 | - | All | - | 1.0 | - |
| 1992 | - | - | - | - | - | - | - | 3.5, 5.0 | - | All | - | 2.0 | - | All | - | 1.0 | - |
| 1993 | - | - | - | - | 3.5 | - | - | - | - | All | - | 2.0 | - | All | - | 1.0 | - |
| 1994 | - | 1.0,3.0,3.5 | - | - | - | - | - | - | - | All | - | 1.4 | - | All | - | 0.7 | - |
| 1995 | - | - | - | - | - | - | - | 3.5 | - | All | - | 1.4 | - | 12 | - | 1.0,2.0 | - |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | 13-19,29 | - | 0.45,0.7 | - |
| 1996 | - | - | - | 1.3 | 1.8 | 2.5 | - | - | - | All | - | 1.4 | - | 12 | 1.5 | 1.8 | 2.2 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | 13-19,29 | - | 0.45,0.7 | - |
| 1997 | 1.2 | 1.6 | 2.2 | - | - | - | - | - | - | All | - | 1.4 | - | All | - | 0.45,0.7 | - |
| 1998 | - | - | - | - | - | - | 1.2 | 1.7 | 2.3 | Yellow | 2.1 | 2.4 | 2.8 | ptn. 12 | 1.4 | 1.7 | 1.95 |
|  |  |  |  |  |  |  |  |  |  | Bank |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | Remainder | - | 1.4 | - | Remainder | - | 0.45,0.7 | - |

Table 9. Summary of mean individual geoduck weight (lb), from market samples, used to convert estimates of geoduck density from numbers to weight, by statistical area and fishery year.

|  | Year |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Stat | 1995 | 1996 | 1997/1998 |  |  |
| Area |  |  | Mean | $95 \%$ C.I |  |
| $1^{1}$ | - | - | 2.862 | 2.832 | 2.891 |
| 2 | - | - | 2.862 | 2.832 | 2.891 |
| 3 | - | 2.765 | - | - | - |
| 4 | - | 2.765 | - | - | - |
| 5 | - | 2.765 | 2.683 | 2.643 | 2.723 |
| 6 | 2.348 | 2.765 | 2.848 | 2.780 | 2.916 |
| 7 | 2.348 | - | 2.550 | 2.513 | 2.586 |
| $8^{2}$ | 2.348 | - | 2.550 | 2.513 | 2.586 |
| $9^{2}$ | 2.348 | - | 2.550 | 2.513 | 2.586 |
| $10^{2}$ | 2.348 | - | 2.550 | 2.513 | 2.586 |
| $11^{3}$ | - | - | 2.308 | 2.270 | 2.522 |
| $12^{3}$ | 2.348 | 2.396 | 2.308 | 2.270 | 2.522 |
| $13^{4}$ | 2.348 | - | 2.233 | 2.206 | 2.262 |
| 14 | 2.348 | 2.227 | 2.233 | 2.206 | 2.262 |
| 15 | - | - | 2.200 | 2.157 | 2.243 |
| 16 | - | 2.227 | - | - | - |
| 17 | - | - | 1.664 | 1.599 | 1.730 |
| 18 | - | - | 1.797 | 1.732 | 1.862 |
| $19^{5}$ | - | - | 1.797 | 1.732 | 1.862 |
| $29^{5}$ | - | - | 1.797 | 1.732 | 1.862 |
| 23 | 2.348 | - | 2.409 | 2.357 | 2.461 |
| 24 | 2.348 | 2.474 | 2.424 | 2.383 | 2.465 |
| 25 | - | - | 2.569 | 2.492 | 2.646 |
| 26 | - | 2.474 | - | - | - |
| 27 | 2.348 | - | 2.388 | 2.346 | 2.431 |
| 1 |  |  |  |  |  |

${ }_{2}^{1}$ value from Area 2 market sample
${ }_{2}^{2}$ values from Area 7 market sample
${ }_{4}^{3}$ values from Area 12 biological sample
${ }_{5}^{4}$ value from Area 14 market sample
${ }^{5}$ values from Area 18 market sample
Table 10a. Estimates of geoduck bed area, original stock, total removals and recommended low, medium and high quota options, by geoduck management area (GMA), for the 1997 Inside Waters fishery.

| GMA | $\begin{gathered} \hline \text { \# } \\ \text { Beds } \end{gathered}$ | $\frac{\text { Bed Area }}{\text { (ha) }}$ | Estimated Original Stock (lb) |  |  | Reported Landings | Adjusted Landings | Quota Options (lb) |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | low | med | high |  |  | low | med | high |
| 13A | 6 | 85 | 1,185,163 | 1,333,167 | 1,485,158 | 177,535 | 203,855 | 27,598 | 32,306 | 37,385 |
| 13B | 2 | 0 | 4,897,413 | 5,508,380 | 6,135,809 | 1,735,850 | 2,144,455 | 0 | 0 | 0 |
| 13 C | 6 | 174 | 1,842,824 | 2,719,485 | 3,029,528 | 489,341 | 567,118 | 25,193 | 63,919 | 76,860 |
| 13D | 9 | 64 | 887,204 | 997,999 | 1,111,779 | 133,360 | 153,906 | 21,576 | 25,329 | 29,169 |
| 15A | 1 | 134 | 1,174,197 | 2,070,057 | 2,321,657 | 333,697 | 392,951 | 17,650 | 58,371 | 69,650 |
| 15B | 1 | 193 | 1,688,279 | 2,976,361 | 3,338,116 | 93,466 | 107,825 | 50,648 | 89,291 | 100,143 |
| 15 C 1 | 2 | 120 | 1,239,566 | 1,852,027 | 2,077,127 | 186,345 | 208,27 | 34,882 | 54,079 | 61,683 |
| 15 C 2 | 1 | 165 | 1,440,409 | 2,539,377 | 2,848,019 | 382,513 | 453,954 | 24,205 | 74,158 | 85,441 90,802 |
| 15D | 17 | 201 | 2,736,261 | 3,101,082 | 3,477,996 | 513,941 | 594,783 | 65,893 | 7,100 | 80,802 5,465 |
| 15E | 2 | 19 | 257,594 | 291,939 | 327,422 | 71,030 | 89,042 | 2,873 | 4,148 | 5,465 |
| 15F | 1 | 59 | 512,510 | 903,533 | 1,013,350 | 117,568 | 143,476 | 9,951 | 27,106 | 30,401 |
| 15 G | 3 | 91 | 806,205 | 1,395,641 | 1,565,271 | 169,801 | 210,347 | 17,312 | 41,085 | 46,178 |
| 15H | 1 | 79 | 693,129 | 1,221,956 | 1,370,475 | 44,726 | 46,068 | 19,598 | 36,659 | 41,114 |
| 15 I | 1 | 107 | 931,392 | 1,642,003 | 1,841,576 | 167,806 | 191,873 | 24,893 | 49,260 | 55,247 |
| 18A | 1 | 46 | 498,423 | 574,580 | 654,857 | 85,589 | 96,411 | 13,097 | 16,361 |  |
| 18B | 11 | 48 | 511,516 | 589,674 | 672,060 | 195,031 | 232,992 | 4,514 | 6,929 | 9,493 |
| 19A | 2 | 0 | 1,078,510 | 1,243,135 | 1,416,893 | 60,906 | 78,569 | 0 | 0 |  |
| 19B | 4 | 485 | 3,538,247 | 4,078,512 | 4,648,753 | 1,703,416 | 2,088,756 | 0 | 56 | 23,352 |
| 19C | 8 | 196 | 2,136,846 | 2,463,127 | 2,807,512 | 561,065 | 653,691 | 30,797 | 43,244 | 56,381 |
| Total | 79 | 2,266 | 28,055,690 | 37,502,035 | 42,143,358 | 7,222,986 | 8,658,347 | 390,679 | 700,401 | 838,409 |

Table 10b. Estimates of geoduck bed area, original stock, total removals and recommended low, medium and high quota options, by geoduck management area (GMA), for the 1997 West Coast fishery.

| GMA | $\begin{gathered} \# \# \\ \text { Beds } \end{gathered}$ | Bed Area | Estimated Original Stock (lb) |  |  | Reported <br> Landings | Adjusted <br> Landings | Quota Options (lb) |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | (ha) | low | med | high |  |  | low | med | high |
| 24A2a | 1 | 130 | 3,909,758 | 4,419,276 | 4,943,967 | 1,405,500 | 1,659,515 | 8,687 | 16,180 | 23,896 |
| 24A2b | 3 | 63 | 1,876,828 | 2,121,415 | 2,373,286 | 248,950 | 297,049 | 17,171 | 20,360 | 23,626 |
| 24A3 | 2 | 46 | 1,383,305 | 1,563,577 | 1,749,217 | 274,769 | 325,911 | 10,352 | 12,856 | 15,434 |
| 24A4 | 9 | 211 | 6,345,552 | 7,172,502 | 8,024,077 | 1,010,163 | 1,210,937 | 47,636 | 56,862 | 66,364 |
| 24A5 | 2 | 118 | 3,527,908 | 3,987,664 | 4,461,110 | 650,440 | 796,336 | 25,412 | 31,799 | 38,375 |
| 24A6a | 3 | 97 | 4,260,088 | 5,464,570 | 7,081,899 | 1,659,245 | 1,954,821 | 4,867 | 21,596 | 44,059 |
| 24A6b | 3 | 112 | 3,356,196 | 3,793,574 | 4,243.976 | 2,283,495 | 2,740,142 | 5,465 | 6,640 | 7,803 |
| 24B | 11 | 525 | 15,769,918 | 17,825,048 | 19,941,376 | 6,472,091 | 7,680,795 | 39,003 | 54,150 | 77,760 |
| 24B2 | 2 | 354 | 10,632,957 | 12,018,640 | 13,445,586 | 2,487,341 | 2,949,374 | 70,923 | 91,712 | 113,120 |
| 24B3 | 3 | 179 | 5,378,319 | 6,079,219 | 6,800,991 | 2,237,242 | 2,661,775 | 18,016 | 22,087 | 26,279 |
| 24B4 | 3 | 202 | 6,074,775 | 6,866,437 | 7,681,673 | 1,203,767 | 1,441,959 | 42,572 | 53,317 | 64,382 |
| 24 Cl | 8 | 99 | 2,976,748 | 3,364,677 | 3,764,157 | 637,310 | 764,491 | 18,950 | 22,180 | 26,370 |
| 24 C 2 | 3 | 24 | 718,070 | 811,648 | 908,014 | 104,388 | 129,310 | 4,936 | 5,951 | 6,997 |
| 24D | 19 | 94 | 2,829,051 | 3,197,732 | 3,577,391 | 490,319 | 591.517 | 18,538 | 22,434 | 26,452 |
| 24D1 | 3 | 35 | 1,057,892 | 1,195,756 | 1,337,726 | 34,866 | 43,234 | 10,050 | 11,476 | 12,946 |
| 25A | 17 | 516 | 16,187,434 | 18,539,370 | 21,002,804 | 4,971,154 | 6,006,362 | 155,279 | 250,811 | 350,808 |
| 25B | 5 | 595 | 18,680,611 | 21,394,791 | 24,237,641 | 2,667,152 | 3,076,361 | 477,526 | 581,159 | 689,704 |
| 25 C | 2 | 54 | 1,704,403 | 1,952,043 | 2,211,422 | 667,115 | 822,189 | 2,389 | 13,252 | 24,631 |
| 25D | 23 | 177 | 5,564,116 | 6,372,549 | 7,219,307 | 1,232,156 | 1,503,277 | 89,067 | 117,602 | 147,426 |
|  | 122 | 3,632 | 112,233,929 | 128,140,489 | 145,005,620 | 30,737,463 | 36,655,354 | 1,066,839 | 1,412,425 | 1,786,431 |


Table 10c. (cont.)

| GMA | $\begin{gathered} \# \\ \text { Beds } \end{gathered}$ | $\frac{\text { Bed Area }}{\text { (ha) }}$ | Estimated Original Stock (lb) |  |  | ReportedLandings | Adjusted Landings | Quota Options (lb) |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | low | med | high |  |  | low | med | high |
| (cont.) |  |  |  |  |  |  |  |  |  |  |
| QCD10 | 6 | 45 | 1,376,366 | 2,060,235 | 3,148,181 | 128,052 | 161,728 | 37,253 | 60,009 | 94,445 |
| QCDII | 4 | 5 | 167,611 | 250,891 | 383,379 | 57,406 | 59,702 | 3,381 | 5,781 | 9,600 |
| QCEI | 5 | 80 | 2,452,990 | 3,671,968 | 5,610,759 | 363,258 | 496,622 | 50,277 | 92,604 | 158,765 |
| QCE2 | 2 | 53 | 1,607,596 | 2,406,467 | 3,677,076 | 271,264 | 282,115 | 34,023 | 60,073 | 101,506 |
| QCF1 | 8 | 41 | 1,255,858 | 1,879,850 | 2,872,541 | 223,294 | 246,737 | 26,836 | 46,154 | 77,553 |
| QCF2 | 6 | 67 | 2,053,538 | 3,073,871 | 4,697,087 | 447,762 | 528,213 | 38,183 | 71,653 | 126,836 |
| QCF3 | 5 | 24 | 721,828 | 1,080,479 | 1,651,046 | 148,831 | 159,139 | 15,852 | 24,903 | 41,573 |
| QCF4 | 4 | 21 | 643,528 | 963,274 | 1,471,950 | 38,799 | 48,037 | 17,971 | 27,670 | 43,100 |
| QCF5 | 12 | 149 | 4,559,748 | 6,825,330 | 10,429,575 | 1,233,628 | 1,546,469 | 50,087 | 129,487 | 258,375 |
| QCF6 | 6 | 61 | 1,877,975 | 2,811,076 | 4,295,519 | 135,029 | 160,657 | 37,211 | 60,002 | 96,253 |
| QCF7 | 4 | 31 | 937,152 | 1,402,791 | 2,143,562 | 113,354 | 140,643 | 23,669 | 40,123 | 63,556 |
| QCF8 | 1 | 23 | 718,157 | 1,074,985 | 1,642,651 | 443,929 | 525,806 | 0 | 876 | 22,164 |
|  | 187 | 1,674 | 51,194,705 | 76,631,874 | 117,098,356 | 9,468,725 | 11,491,895 | 1,037,506 | 1,831,110 | 3,131,993 |

Table 1la. Estimates of geoduck bed area, original stock, total removals and recommended low, medium and high quota options, by geoduck management area (GMA), for the 1998 Inside Waters fishery.

| GMA | $\begin{gathered} \hline \# \\ \text { Beds } \end{gathered}$ | $\frac{\text { Bed Area }}{\text { (ha) }}$ | Estimated Original Stock (lb) |  |  | Reported <br> Landings | Adjusted Landings | Quota Options (lb) |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | low | med | high |  |  | low | med | high |
| 12A | 17 | 105 | 2,569,191 | 3,553,599 | 4,636,091 | 1,026,066 | 1,140,566 | 20,900 | 48,621 | 84,367 |
| 12B2 | 4 | 44 | 1,265,149 | 1,801,787 | 2,393,097 | 358,377 | 387,650 | 15,823 | 33,034 | 52,005 |
| 12B3 | 9 | 90 | 2,568,047 | 3,657,335 | 4,857,597 | 1,818,615 | 2,196,864 | 4,011 | 11,068 | 25,343 |
| 12 C | 8 | 59 | 1,102,716 | 1,420,961 | 1,768,498 | 215,369 | 242,387 | 12,495 | 16,717 | 21,604 |
| 12 D | 7 | 166 | 2,374,157 | 2,784,519 | 3,224,195 | 584,551 | 704,959 | 36,627 | 51,975 | 68,192 |
| 12 E | 1 | 31 | 440,400 | 516,521 | 598,080 | 327,600 | 369,380 | 0 | 0 | 0 |
| 12 F | 3 | 7 | 94,943 | 111,354 | 128,937 | 26,542 | 33,368 | 864 | 1,366 | 1,904 |
| 12G | 13 | 34 | 482,724 | 566,161 | 655,558 | 16,733 | 20,098 | 13,523 | 16,044 | 18,744 |
| 13 E | 5 | 6 | 83,384 | 93,797 | 104,491 | 19,069 | 23,952 | 2,476 | 2,790 | 3,112 |
| 14A1 | 3 | 508 | 4,540,967 | 6,048,547 | 6,736,552 | 1,438,271 | 1,577,856 | 74,231 | 132,811 | 163,724 |
| 14A2 | 4 | 255 | 2,795,544 | 3,981,048 | 4,433,880 | 404,666 | 511,228 | 63,747 | 116,615 | 130,611 |
| 14 B | 3 | 808 | 7,338,278 | 8,256,619 | 9,195,786 | 2,767,191 | 3,411,333 | 43,127 | 72,351 | 108,102 |
| 14 C | 10 | 143 | 1,827,418 | 2,234,141 | 2,488,268 | 396,954 | 486,313 | 38,401 | 52,215 | 61,060 |
| 17A1 | 1 | 91 | 586,202 | 1,054,515 | 1,205,474 | 154,028 | 172,677 | 10,322 | 30,393 | 36,164 |
| 17A2 | 1 | 69 | 696,293 | 805,215 | 920,486 | 165,047 | 197,909 | 13,658 | 18,609 | 23,849 |
| 17A3 | 1 | 41 | 413,827 | 478,562 | 547,071 | 75,310 | 94,163 | 9,664 | 12,439 | 15,375 |
| 17B | 55 | 493 | 4,408,616 | 5,769,775 | 6,595,752 | 2,600,954 | 3,216,533 | 21,413 | 57,508 | 80,159 |
| 29 | 4 | 83 | 909,556 | 1,048,439 | 1,195,027 | 346,843 | 435,101 | 2,162 | 6,830 | 11,758 |
| Total | 149 | 3,032 | 34,497,412 | 44,182,896 | 51,684,841 | 12,742,186 | 15,222,338 | 383,443 | 681,385 | 906,072 |

Table 11b. Estimates of geoduck bed area, original stock, total removals and recommended low, medium and high quota options, by geoduck management area (GMA), for the 1998 West Coast fishery.

| GMA | $\begin{gathered} \# \\ \text { Beds } \end{gathered}$ | $\begin{gathered} \text { Bed Area } \\ \hline \text { (ha) } \end{gathered}$ | Estimated Original Stock (lb) |  |  | Reported <br> Landings | Adjusted <br> Landings | Quota Options (lb) |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | low | med | high |  |  | low | med | high |
| 23A | 8 | 149 | 4,439,171 | 5,041,012 | 5,664,177 | 1,699,788 | 2,018,954 | 31,234 | 54,495 | 80,449 |
| 23 B | 7 | 44 | 1,299,559 | 1,475,747 | 1,658,177 | 405,329 | 488,233 | 11,589 | 17,662 | 25,046 |
| 23BG | 7 | 33 | 989,518 | 1,123,672 | 1,262,579 | 163,760 | 203,062 | 17,859 | 21,966 | 26,218 |
| 23 C | 10 | 128 | 3,802,457 | 4,317,977 | 4,851,760 | 1,133,254 | 1,341,772 | 43,402 | 65,043 | 87.451 |
| 23D | 22 | 197 | 5,861,082 | 6,655,700 | 7,478,470 | 1,194,871 | 1,384,900 | 121,800 | 146,944 | 176,770 |
| 23E | 14 | 107 | 3,171,684 | 3,601,686 | 4,046,922 | 1,120,089 | 1,329,261 | 30,973 | 42,247 | 54.846 |
| 24A2a | 1 | 130 | 3,909,758 | 4,419,276 | 4,943,967 | 1,405,500 | 1,659,515 | 8,687 | 16,180 | 23,896 |
| 24A2b | 3 | 63 | 1,876,828 | 2,121,415 | 2,373,286 | 248,950 | 297,049 | 17,171 | 20,360 | 23,626 |
| 24A3 | 2 | 46 | 1,383,305 | 1,563,577 | 1,749,217 | 274,769 | 325,911 | 10,352 | 12,856 | 15,434 |
| 24A4 | 9 | 211 | 6,345,552 | 7,172,502 | 8,024,077 | 1,010,163 | 1,210,937 | 47,636 | 56,862 | 66,364 |
| 24AS | 2 | 118 | 3,527,908 | 3,987,664 | 4,461,110 | 650,440 | 796,336 | 25,412 | 31,799 | 38,375 |
| 24A6a | 3 | 97 | 4,260,088 | 5,464,570 | 7,081,899 | 1,659,245 | 1,954,821 | 4,867 | 21,596 | 44,059 |
| 24A6b | 3 | 112 | 3,356,196 | 3,793,574 | 4,243,976 | 2,283,495 | 2,740,142 | 5,465 | 6,640 | 7,803 |
| 24B | 11 | 525 | 15,769,918 | 17,825,048 | 19,941,376 | 6,472,091 | 7,680,795 | 39,003 | 54,150 | 77,760 |
| 24B2 | 2 | 354 | 10,632,957 | 12,018,640 | 13,445,586 | 2,487,341 | 2,949,374 | 70,923 | 91,712 | 113,120 |
| 24B3 | 3 | 179 | 5,378,319 | 6,079,219 | 6,800,991 | 2,237,242 | 2,661,775 | 18,016 | 22,087 | 26,279 |
| 24B4 | 3 | 202 | 6,074,775 | 6,866,437 | 7,681,673 | 1,203,767 | 1,441,959 | 42,572 | 53,317 | 64,382 |
| 24 Cl | 8 | 99 | 2,976,748 | 3,364,677 | 3,764,157 | 641,279 | 768,738 | 18,950 | 22,180 | 26,370 |
| 24 C 2 | 3 | 24 | 718,070 | 811,648 | 908,014 | 104,388 | 129,310 | 4,936 | 5,951 | 6,997 |
| 24D | 19 | 94 | 2,829,051 | 3,197,732 | 3,577,391 | 490,319 | 591,517 | 18,538 | 22,434 | 26.452 |
| 24D1 | 3 | 35 | 1,057,892 | 1,195,756 | 1,337,726 | 34,866 | 43,234 | 10,050 | 11,476 | 12,946 |
| 27A | 7 | 115 | 3,406,325 | 3,852,029 | 4,314,308 | 596,420 | 691,324 | 74,914 | 91,456 | 108,614 |
| 27B | 4 | 46 | 1,352,598 | 1,529,580 | 1,713,144 | 164,881 | 187,061 | 37,528 | 44,104 | 50,792 |
| 27 C | 3 | 149 | 4,393,580 | 4,968,462 | 5,564,724 | 1,522,635 | 1,781,198 | 41,416 | 56,952 | 77,226 |
| 27D | 3 | 52 | 1,534,679 | 1,735,485 | 1,943,760 | 197,626 | 226,729 | 41,035 | 48,653 | 56,554 |
| 27E | 1 | 127 | 3,762,209 | 4,254,480 | 4,765,057 | 361,214 | 403,381 | 105,552 | 123,133 | 141,368 |
| 27F | 2 | 17 | 490,672 | 554,874 | 621,464 | 189,036 | 229,754 | 1,024 | 3,159 | 5,373 |
| 27G | 1 | 5 | 147,793 | 167,131 | 187,205 | 14,050 | 15,034 | 3,604 | 4,196 | 4,810 |
| 27 H | 9 | 220 | 6,509,970 | 7,361,774 | 8,245,255 | 1,648,646 | 1,923,056 | 106,442 | 131,259 | 158,807 |
| 27I | 15 | 118 | 3,500,912 | 3,958,993 | 4,434,108 | 1,242,877 | 1,448,673 | 42,685 | 56,483 | 70,793 |
| Total | 188 | 3,798 | 114,759,573 | 130,480,339 | 147,085,557 | 32,858,331 | 38,923,805 | 1,053,636 | 1,357,353 | 1,698,978 |

Table 11c. Estimates of geoduck bed area, original stock, total removals and recommended low, medium and high quota options, by

| GMA | $\begin{gathered} \hline \# \\ \text { Beds } \\ \hline \end{gathered}$ | $\frac{\text { Bed Area }}{\text { (ha) }}$ | Estimated Original Stock ( l ) |  |  | ReportedLandings | $\begin{aligned} & \hline \text { Adjusted } \\ & \text { Landings } \end{aligned}$ | Quota Options (lb) |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | low | med | high |  |  | low | med | high |
| CCAIa | 2 | 31 | 833,907 | 1,331,590 | 2,009,877 | 437,446 | 561,411 | 93 | 8,545 | 37,117 |
| CCAlb | 4 | 21 | 560,281 | 894,662 | 1,350,386 | 203,496 | 211,636 | 8,831 | 15,165 | 28,638 |
| CCA2 | 4 | 26 | 703,609 | 1,123,529 | 1,695,834 | 319,189 | 365,450 | 1,367 | 13,562 | 33,602 |
| CCA3 | 7 | 14 | 371,350 | 592,974 | 895,024 | 183,124 | 197,361 | 2,254 | 7,019 | 15,826 |
| CCA4 | 3 | 5 | 132,470 | 211,529 | 319,277 | 68,356 | 79,327 | 1,575 | 2,725 | 5,021 |
| CCA5a | 2 | 17 | 453,871 | 724,746 | 1,093,918 | 136,657 | 160,997 | 4,390 | 13,773 | 26,561 |
| CCASb | 9 | 95 | 2,570,128 | 4,104,004 | 6,194,505 | 514,166 | 579,535 | 53,200 | 102,411 | 168,706 |
| CCA6 | 2 | 54 | 1,478,882 | 2,361,492 | 3,564,392 | 894,175 | 987,927 | 1,250 | 13,602 | 57,251 |
| CCA7 | 2 | 7 | 178,074 | 284,350 | 429,193 | 17,518 | 18,219 | 4,405 | 7,709 | 12,197 |
| CCA8 | 2 | 47 | 1,275,835 | 2,037,264 | 3,075,008 | 95,828 | 99,661 | 37,440 | 61,118 | 92,250 |
| CCA9 | 6 | 34 | 924,030 | 1,475,499 | 2,227,091 | 624,170 | 735,665 | 5,603 | 13,228 | 30,489 |
| CCBla | 2 | 7 | 196,533 | 313,825 | 473,682 | 29,062 | 30,224 | 4,438 | 8,262 | 13,475 |
| CCB1b | 3 | 11 | 304,029 | 485,476 | 732,768 | 83,125 | 104,702 | 3,771 | 9,152 | 17,347 |
| CCB2a | 1 | 36 | 990,265 | 1,581,264 | 2,386,729 | 324,766 | 385,804 | 8,200 | 30,362 | 60,567 |
| CCB2b | 1 | 2 | 54,291 | 86,692 | 130,851 | 6,380 | 6,635 | 1,256 | 2,248 | 3,599 |
| CCB3 | 9 | 29 | 796,989 | 1,272,640 | 1,920,898 | 238,782 | 248,333 | 9,591 | 24,825 | 46,107 |
| CCB4 | 3 | 6 | 162,872 | 260,076 | 392,554 | 23,145 | 25,617 | 4,074 | 7,228 | 11,216 |
| CCB5 | 1 | 63 | 1,712,333 | 2,734,269 | 4,127,053 | 978,043 | 1,266,490 | 0 | 8,627 | 68,317 |
| CCB6 | 1 |  | 115,097 | 183,787 | 277,405 | 72,096 | 74,980 | 0 | 1,103 | 4,156 |
| CCB7a | 2 | 3 | 90,123 | 143,909 | 217,213 | 63,755 | 75,241 | 531 | 1,265 | 2,265 |
| CCB7b | 1 | 17 | 458,215 | 731,681 | 1,104,386 | 98,666 | 102,613 | 8,825 | 18,365 | 31,366 |
| CCB8 |  | 3 | 78,179 | 124,837 | 188,426 | 33,172 | 34,499 | 423 | 1,019 | 2,614 |
| CCC1 | 8 | 31 | 844,765 | 1,348,268 | 2,036,048 | 329,011 | 405,474 | 10,600 | 19,534 | 40,891 |
| CCC2 | 10 | 64 | 1,729,706 | 2,761,802 | 4,168,926 | 558,355 | 649,958 | 20,397 | 53,350 | 104,550 |
| ССС3a | 4 | 86 | 2,347,536 | 3,746,729 | 5,658,014 | 726,592 | 918,146 | 19,950 | 75,987 | 152,533 |
| CCC3b | 2 | 6 | 162,872 | 259,949 | 392,554 | 16,066 | 22,492 | 3,742 | 6,819 | 11,022 |
| CCC4 | 5 | 11 | 311,629 | 497,369 | 751,087 | 33,562 | 34,904 | 6,621 | 11,871 | 19,011 |
| CCC5 | 7 | 58 | 1,571,177 | 2,507,639 | 3,786,839 | 185,010 | 228,702 | 42,357 | 71,105 | 110,375 |
| CCC6 |  | 5 | 143,328 | 228,755 | 345,448 | 1,400 | 1,456 | 4,291 | 6,863 | 10,363 |
| CCC7 | 2 | 18 | 494,047 | 788,511 | 1,190,748 | 465,804 | 505,550 | 5,104 | 10,242 | 17,037 |
| CCC8 | 4 | 34 | 913,172 | 1,457,446 | 2,200,920 | 255,618 | 327,820 | 9,203 | 28,949 | 54,712 |
| CCC9 | 5 | 20 | 547,252 | 873,428 | 1,318,982 | 110,842 | 144,548 | 8,851 | 19,023 | 33,073 |
| CCDIa | 4 | 96 | 2,734,370 | 4,409,559 | 6,719,465 | 330,780 | 360,506 | 74,080 | 129,464 | 201,520 |
| CCDIb | 3 | 23 | 701,305 | 1,130,954 | 1,723,394 | 79,128 | 82,293 | 16,949 | 30,502 | 49,180 |

Table 11c. (cont.)

| GMA | $\begin{gathered} \# \\ \text { Beds } \end{gathered}$ | $\begin{gathered} \hline \text { Bed Area } \\ \hline \text { (ha) } \end{gathered}$ | Estimated Original Stock (lb) |  |  | Reported <br> Landings | Adjusted <br> Landings | Quota Options (lb) |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | low | med | high |  |  | low | med | high |
| (cont.) |  |  |  |  |  |  |  |  |  |  |
| CCD2 | 11 | 44 | 1,318,550 | 2,126,349 | 3,240,217 | 581,487 | 668,992 | 18,579 | 41,910 | 74,409 |
| CCD3 | 5 | 28 | 837,003 | 1,349,787 | 2,056,859 | 75,209 | 80,024 | 22,303 | 38,674 | 60,138 |
| CCD 4 | 3 | 131 | 2,984,150 | 4,812,365 | 7,333,277 | 1,053,154 | 1,387,809 | 22,391 | 92,076 | 188,164 |
| CCD5 | 4 | 30 | 802,178 | 1,293,626 | 1,971,279 | 89,262 | 92,832 | 21,266 | 37,057 | 57,742 |
| CCD6 | 1 | 16 | 475,543 | 766,880 | 1,168,603 | 95,372 | 99,187 | 9,038 | 18,538 | 31,638 |
| CCD7 | 1 | 12 | 345,849 | 557,731 | 849,893 | 164,551 | 173,593 | 0 | 7,703 | 18,392 |
| CCD8a | 1 | 26 | 697,094 | 1,113,126 | 1,680,132 | 229,339 | 238,513 | 7,176 | 20,742 | 39,232 |
| CCD8b | 1 | 24 | 647,147 | 1,033,370 | 1,559,749 | 536,179 | 557,626 | 0 | 0 | 15,506 |
| CCD9a | 1 | 16 | 446,271 | 712,609 | 1,075,598 | 37,599 | 50,566 | 11,505 | 20,383 | 32,268 |
| CCD9b | 2 | 28 | 765,501 | 1,222,358 | 1,845,005 | 133,214 | 138,543 | 15,891 | 30,756 | 51,016 |
| CCA10a | 8 | 182 | 4,930,693 | 7,873,376 | 11,883,923 | 1,870,871 | 2,361,914 | 33,541 | 139,144 | 291,222 |
| CCAIOb | 3 | 50 | 1,347,498 | 2,151,698 | 3,247,731 | 827,585 | 1,090,935 | 1,080 | 20,397 | 58,091 |
| CCA10c | 4 | 26 | 694,983 | 1,109,659 | 1,674,779 | 125,602 | 149,227 | 14,201 | 23,234 | 37,498 |
| CCAll | 7 | 23 | 612,401 | 977,887 | 1,476,004 | 138,268 | 153,806 | 9,903 | 23,176 | 41,265 |
| Total | 156 | 1,339 | 36,261,805 | 58,058,706 | 87,879,505 | 11,532,651 | 13,521,862 | 511,810 | 1,142,859 | 2,141,462 |

Table 12. Summary of geoduck quota options for consideration in the 1997 and 1998 fisheries, compared to quotas from the last area rotation.



Fig. 1. Geoduck quotas $(\mathrm{t})$, landings $(\mathrm{t})$, and value $\left(\$ \mathrm{x} 10^{6}\right)$ by region and year.

Appendix 1. Flow chart of the quota calculation process, listing each MS Access query (single border) and table (double border) involved and the order of calculation performed. An 'M' indicates that the query is part of a macro, designed to automate the process.


## APPENDIX 2. FISHING HISTORIES AND DOCUMENTATION OF MANAGMENT DECISIONS FOR GEODUCK MANAGEMENT AREAS IN INSIDE WATERS.

## Area 11 - Fishing History

Area 11 was first opened for exploratory fishing 1981, in combination with Area 12. No landings were reported from Area 11, however, until 1984. An exploratory fishery with no quota continued to open annually, from 1985 until 1989 , when a separate quota of $75,000 \mathrm{lb}$. ( 34 t ) was set. After this, the area opened often in conjunction with an exploratory fishery in the mainland inlets of Area 12. The quota could not be achieved by fishers in 1989 and was combined in-season with the mainland inlets (Area 12) quota. The greatest annual landings of 62 t were recorded in 1988. There are few documented small beds in Subarea 11-2, totaling 39 ha . of reported fishing area. Access to this isolated area is also more difficult than most Inside Waters areas. In the 1992 quota assessment (Harbo et al. 1993), it was estimated that 28 years of quota had been harvested if the original density had been 1 geoduck $/ \mathrm{m}^{2}$. In the 1992 rotation, fishers supported closure of this area and recommended periodic rotations. Closure has continued, and has been implemented for the 1998 rotation, until further evaluation is carried out.

## Area 12 - Fishing History

Area 12 has proved to be a very productive geoduck fishing area since the first landings were recorded in 1979. Harbo et al. (1993) describe the history of the fishery and quotas. There were minor landings in 1982 and 1983 and major fisheries began in 1984. By the end of 1993, 2610 t had been landed, at that time a quantity second only to Area 14 landings ( 3465 t) in Inside Waters.

There was concern that most of the fishing activity in recent years had occurred in beds in Goletas Channel near Port Hardy. As a consequence beds in the Goletas Channel area were closed and effort was directed in 1992 to the south of Hardy Bay and around Malcolm Island.

Fishers interviewed had no knowledge of geoduck beds in Subareas 12-1 to 12-5. A bed in Subarea 12-1 was reported in the past, but no landings were reported on logs to support it.

Although the number of reported beds has increased, some of the large beds (at False Head and in Trinity Bay) were suspected of being overestimated in size and were remeasured in 1994. The total area was estimated at 448 ha for open beds compared to the 1992 estimate of 893 ha.

Joint surveys were undertaken by the Underwater Harvesters Association (G licence holders) and the Kwakiutl Territories Fisheries Commission (KTFC) at Trinity Bay in June, 1994, in Goletas Channel in September, 1994 and in the Duncan Island area in May 1995. As well, ongrounds observers were present in the Mainland Inlets in 1995, and in 1996, portions of Upper Goletas Channel and Bates Passage were fished with an ongrounds observer to document bed size and to monitor exploratory fishing.

Fishers have reported that, although beds are long and narrow, densities are higher in Area 12 than in other areas of the south coast. The survey, undertaken in Goletas Channel in 1994 (Campbell et al. 1995), of beds 0201 to 0205 found that densities were $1.8 / \mathrm{m}^{2}$, less than the 2 to 2.5 geoducks $/ \mathrm{m}^{2}$ previously used in quota calculations, but the area in which geoducks occurred was greater than that reported on logs. The survey conducted around Duncan and Balaclava Islands yielded virgin density estimates of $1.3 / \mathrm{m}^{2}$ (Hand and Dovey, in prep).

Due both to preliminary survey results and reports of more productive beds in GMAs $12-\mathrm{A}$ and 12-B, higher densities ( 2 geoducks $/ \mathrm{m}^{2}$ ) were used for calculating 1995 quotas, while 1 geoduck $/ \mathrm{m}^{2}$ (unchanged from 1992) was used for the balance of GMAs $12-\mathrm{C}$ to 12 -G. GMA 12B (Goletas Channel) remained closed in 1995. Fishers continued to request fishing opportunities in portions of GMA 12-B, in upper Goletas Channel, and as a result, a portion of GMA 12-B was opened for harvest in 1996 (re-designated as GMA 12-B2). In addition, Subarea 12-12 was opened for exploratory fishing opportunities (re-designated as GMA 12-B1) with an ongrounds observer to document new beds.

The calculations for 1997 and 1998 quota options have been based on densities of 1.7 geoducks $/ \mathrm{m}^{2}$ for surveyed beds in Goletas Channel and Duncan Island. Densities of 0.7 geoducks $/ \mathrm{m}^{2}$ were used in all other GMAs in Area 12. Mean geoduck weights of 2.308 lb were used in quota calculations.

## Area 12 - Management Decisions for 1998 by Geoduck Management Area

## GMA 12-A: NORTHERN ISLANDS - SUBAREAS 12-10 TO 12-13.

GMA 12-A, the islands northeast of Port Hardy, (Subareas 12-10,-11 and -13), is scheduled to be fished in 1998. One bed was deleted (as there were no harvest charts) in the 1996 quota assessment to yield a total of 17 beds with an area of 105 ha (from data complete to 1995). Calculations were previously done using 18 beds with an area of 102 ha.

This area was heavily fished in 1989 with high removals calculated in the quota assessment for 1995. Harbo et al. (1995), report up to 1.99 geoducks $/ \mathrm{m}^{2}$ in one small bed of 1 ha in one season. Harvest logs reported $1,003,654 \mathrm{lb}$ over the equivalent of 11 years fishing. These landings are equivalent to 28 years of quota at $47,940 \mathrm{lb} /$ year to 1994 ( $1 \%$ harvest rate @ 2 geoduck $/ \mathrm{m}^{2}$ over 102 ha ).

The fishers suggested that there may be exploratory fishing opportunities in the area of Bates Passage and Vansittart Island (Subarea 12-12). It was initially recommended that there be no fishery for this area in 1992. However, a management decision was made to allow a $100,000 \mathrm{lb}$ fishery for 1992 based on the advice of the fishers that this area had substantial stocks. The 1992 fishery took place in Subarea 12-11 at previously fished beds. No new beds were identified.

In 1995, a reduced 3 year quota for GMA 12-A was set at $80,121 \mathrm{lb}$ based on the remaining 39 years of a 50 year cycle. It was recommended that Subarea 12-11 remain closed, however, based
on preliminary survey reports, densities suggested that this recommendation not be followed, and the area was open to fishing in 1995.

In 1996, Subarea 12-12 was removed from GMA 12-A and redesignated to GMA 12-B1 to provide exploratory fishing opportunities. No beds had been identified in Subarea 12-12 prior to 1996.

In 1998, bed closures will be in effect at Cardigan Rocks (bed 2001), Gordon/Doyle Islands (bed 108) and East Christie Pass (bed 101) and will be fished with an observer to ensure boundary compliance.

Recommended quota options for the 1998 fishery in the remainder of GMA 12-A range from $20,900 \mathrm{lb}$ to $84,367 \mathrm{lb}$ and the quota was set at the mid-range option of $48,621 \mathrm{lb}$.

## GMA 12-B: Goletas Channel - Subarea 12-15 and a portion of Subarea 12-16.

Based on fishing data to 1993, GMA 12-B had 13 beds reported with a total of 116 ha. Remeasuring of beds using 1995 fishing data resulted in a revised area of 201 ha which was used for the 1996 quota assessment.

GMA 12B, comprised of portions of Subareas 12-15 and a portion of 12-16 has been closed to the commercial fishery since 1989, when it was determined that a number of beds in Goletas Channel had been over fished. At an estimated original density of 2 geoducks $/ \mathrm{m}^{2}$ over 116 ha , $53 \%$ of the stock has been landed. To support the level of fishing over the past 11 years at a $1 \%$ harvest rate, an original density of 9.6 geoducks $/ \mathrm{m}^{2}$ would be required (Harbo et al. 1995). Four beds, \# 201, 203, 204, and 205 (with an aggregate area of 56.3 ha in 1996) in Subarea 12-16, have adjusted landings of over 1.7 M lb during the period 1984 to 1989.

## GMA 12-B1: Bate Passage - Subarea 12-12.

Subarea 12-12 was open as a portion of GMA 12A in 1995, but no landings were reported. Although no beds were documented in harvest logs, historic reports from fishers indicated that there might be stocks in the Bate Passage/Shadwell Passage area. Subarea 12-12 was redesignated as GMA 12-B1 for an exploratory opening in 1996, with a quota of $154,655 \mathrm{lb}$, based on the calculated quota for the original GMA 12-B. Subarea 12-16 was to be a fallback area if the set quota could not be taken. An observer was present on the grounds to document fishing activity. The quota was landed within GMA 12-B1, however the data has not yet been analysed.

See the 1998 closure recommendations for GMA 12-B2 below.

## GMA 12-B2: Northern Goletas - a portion of Subarea 12-15.

In 1996, a portion of GMA 12B (a portion of Subarea 12-15 and Subarea 12-12) was proposed for an exploratory fishery. A portion of Subarea 12-15 south of Jepther Point reopened for
harvest, and was designated as GMA 12-B2 in the 1996 management plan. A quota of $55,739 \mathrm{lb}$ was assigned, which represented a portion of the calculated quota for the original GMA 12-B. Subarea 12-16 was to be a fallback area if the set quota could not be taken in the exploratory openings. The quota was, however, landed within GMA 12-B2. Bed \#0101 south of Godkin Point remained closed. An observer was present on the grounds to document fishing activity. Data from this exploratory fishery have not yet been analyzed.

The quota recommendations for the 1998 fishery have been calculated using the 1996 GMAs 12 B1 and 12-B2 combined as 12-B2, and having 4 beds and an area of 44 ha identified prior to 1996 fishery data analyses. The quota options range from a low of $15,823 \mathrm{lb}$ to a high of 52,005 lb. As these areas were fished in 1996, managers recommended closure for the 1998 rotation. No quota was assigned to GMA 12-B2 for 1998.

## GMA 12-B3: Southern Goletas - a portion of Subarea 12-16.

GMA 12-B-3 is newly designated for 1998, and is comprised of beds in the Goletas Channel portion of Subarea 12-16. There are 9 beds reported with a total of 90 ha. These beds have remained closed since 1989. The 1996 analyses, using survey densities of 1.7 geoducks $/ \mathrm{m}^{2}$ and increased bed area, indicates that some beds could reopen.

In 1998, there will be bed closures at a bed west of Frankham Point (bed 203) Meir Point (bed 204) and the Masterman Islands (bed 210).

Quota options for 1998 range from a low of $4,011 \mathrm{lb}$ to a high of $25,343 \mathrm{lb}$. The 1998 quota was set at the mid-range option of $11,068 \mathrm{lb}$.

## GMA 12-C: False Head - a portion of Subareas 12-16 and 12-17.

This area contains 8 beds measured at 38 ha (1994) in the assessment for 1995 quotas. During the assessment for 1998 quotas, and based on fishing data complete to 1995 , there were 8 beds measured at 59 ha. Increased bed area was identified during the 1995 fishery.

Beds in Subarea 12-17 (False Head to Singletree Point) had been measured at 178 ha of reported fishing area, with low landings. This was remeasured at 29 ha , for the 1994 assessment, based on the area of fishing reported on harvest logs in 1992.

Beds previously described in Beaver Harbour are in a contaminated closure. A small bed (13 ha) in the vicinity of the airport fronts an Indian Reserve at Thomas Point and is closed.

A separate quota was first set for GMA 12-C in 1992. Fishers felt that the concentrations were probably not as good as in Goletas Channel beds. In 1995, the 3 year rotational quota was calculated using 1.0 geoduck $/ \mathrm{m}^{2}$ and set at $9,952 \mathrm{lb}$.

Increases in the 1998 calculated quotas are a result of increased bed area and using a mean weight of 2.308 lb and a density of 0.7 geoducks $/ \mathrm{m}^{2}$. The recommended quotas for 1998 range
from a low of $12,495 \mathrm{lb}$ to a high of $21,604 \mathrm{lb}$. The 1998 quota was set at the mid-range option of $16,717 \mathrm{lb}$.

## GMA 12-D: Malcolm Island/Black Bluff - a portion of Subarea 12-8.

GMA 12-D was comprised of 7 beds measuring 158 ha in the assessment for 1995 quotas. Using fishing data complete to 1995, there are 7 beds with an increased bed area of 166 ha.

Beds in GMA 12-D had landings of $400,000 \mathrm{lb}$ in the 1985 season, but there was very little fishing in these beds in 1989. Fishers expressed concerns about the exposure to weather and accessibility. They were uncertain about stock in this area and advised that the measured beds may be too large. Several small beds were scaled down in size by landing criteria for 1995 and rescaled for 1998 calculations.

The 1995 calculated quota of $88,415 \mathrm{lb}$ was reduced to 57,539 allow a $30,000 \mathrm{lb}$ exploratory fishery in GMA 12G (Mainland Inlets). In season, the GMA 12-D quota was increased to 68,127 lb when $10,588 \mathrm{lb}$ could not be taken in GMA 12-G.

The quota options recommended for 1998 range from a low of $36,627 \mathrm{lb}$ to a high of $68,192 \mathrm{lb}$. The mid-range quota of $52,994 \mathrm{lb}$ was assigned in 1998 , but $30,000 \mathrm{lb}$ of this quota was transferred to GMA 12-E, at the request of fishers, leaving an assigned quota for 1998 of 22,994 lb. (Actually, this was an error: The mid-range quota was $51,975 \mathrm{lb}$, and the assigned quota should have been $21,975 \mathrm{lb}$.) It is recommended that GMA 12-D be fished with an observer, in 2001, to verify bed size and geoduck densities.

## GMA 12-E: Trinity Bay - Portions of Subareas 12-6 and 12-8.

For the 1995 quota assessment GMA 12-E had 1 bed measuring 26 ha. Bed remeasuring increased the area slightly to 31 ha during the assessment for 1998 quotas.

A very large exposed bed in Trinity Bay was reported on harvest logs in 1985 and the productive area for geoducks was likely over-estimated. The bed was remeasured according to harvest locations reported in the 1992 fishery. A preliminary bed area and geoduck density survey was undertaken in June, 1994 and considered in the assessment for the 1995 fishery.

The 1992 set quota was $201,000 \mathrm{lb}$, only slightly less than the calculated quota of $210,000 \mathrm{lb}$ (Harbo et al. 1993), which was based on the 300 ha originally identified. Based on the new bed area estimates in 1995, >50\% of the available stock in the 26 ha bed has been harvested: $51 \%$ using adjusted landings and assuming a density of 1.4 geoducks $/ \mathrm{m}^{2}$ or $71 \%$ if the original densities were 1 geoduck $/ \mathrm{m}^{2}$. A closure was recommended in 1995 pending further assessment.

Continued closure was recommended for 1998, with an estimated $50 \%$ of the available stock harvested. Fishers believed that beds in this GMA could withstand harvest while those in GMA $12-\mathrm{D}$ were less able to, and requested that $30,000 \mathrm{lb}$ be transferred from GMA 12-D to GMA

12E. The quota for 1998 was set at $30,000 \mathrm{lb}$, to be fished with an observer to verify bed size and geoduck densities.

## GMA 12-F: Malcolm Island East and south - portions of Subareas 12-5, -6 and -18.

GMA 12-F had 2 reported beds measuring 6 ha for the 1995 quota assessment. During the 1995 fishery one additional bed was reported, for a total of 3 beds and 6.6 ha .

The 1992 quota was $9,000 \mathrm{lb}$; (Harbo et al. 1993). Only $7,581 \mathrm{lb}$ were landed and validated in the 1992 fishery. The 1995 quota was set at $3,275 \mathrm{lb}$ based on a density of 1 geoduck $/ \mathrm{m}^{2}$.

Quota options recommended for the 1998 fishery, based on 0.7 geoducks $/ \mathrm{m}^{2}$ range from a low of 864 lb to a high of $1,904 \mathrm{lb}$. The 1998 quota was set at 0 to equalize coastwide quotas.

## GMA 12-G: Mainland Inlets - Subareas 12-7,12-27 to 12-48.

During the 1995 quota assessment, only 1 bed measuring 2 ha had been identified in the mainland inlets of Area 12. Additional beds had been identified in the past (a total of 10 ha ), but landings were not reported on logbooks (Hopetown Pass; Kenneth Pass; Turnbull Cove; Kinnard Island). In 1992, the advisory committee commented that surveying had found little stock in Wells Passage area, however in 1994 fishers recommended an exploratory fishery for 12-G in Wells Pass and Blackfish Sound areas.

The 1995 calculated quota was $1,120 \mathrm{lb}$. To accommodate an exploratory fishery, $28,876 \mathrm{lb}$ was transferred from Area 12-D to $12-\mathrm{G}$, for a total three year rotational quota of $30,000 \mathrm{lb}$. GMA 12 -D was designated the 'fall-back' area if the quota could not be taken in GMA 12-G.

An ongrounds observer was required to document the 1995 exploratory fishing activities. Twelve new beds were identified for a new total of 13 beds and 34 ha of fishing area. In preliminary logbook analyses, only 4 beds totalling 21.6 ha had significant landings, which may be due in part to the ongrounds observer urging fishers to cover as much area as possible scouting for new beds. The quota of $30,000 \mathrm{lb}$ was not landed. Fishers were only able to land $19,412 \mathrm{lb}$ using the exploratory protocol. The remaining $10,588 \mathrm{lb}$ were transferred in season to GMA 12-D.

The quota recommendations for 1998 range from a low of $13,523 \mathrm{lb}$ to a high of $18,744 \mathrm{lb}$ based on 0.7 geoducks $/ \mathrm{m}^{2}$ and 34 ha of bed area. The 1998 quota was set at the mid-range option of $16,044 \mathrm{lb}$.

## Area 13 - Fishing History

Area 13 has been fished consistently since 1977, the start of the geoduck fishery in B.C. Harbo et al. (1994) describe the fishery and quotas.

Beds at Marina Island supported $71 \%$ of Area 13 landings to 1992. A survey undertaken in 1992 at Marina Island estimated the area of the fishing grounds from 5 to 20 m depth to be 310 ha with an original density of 0.475 geoducks $/ \mathrm{m}^{2}$. The northern bed, with an area of 74 ha and which was surveyed intensively, was estimated to have an original density of 0.727 geoducks $/ \mathrm{m}^{2}$.

In Area 13, one bed and a portion of a second bed were permanently closed due to fecal contamination. Bed 1201 at Manson's Landing, remeasured to 16 ha, is closed. A portion of bed 202 at Willow Point is within a contaminated closure. The entire bed measures 94 ha, but an estimated 31 ha are within the closure. There is also a seasonal closure at Drew Harbour (May 1 to September 30) due to potential contamination from recreational boating activities.

## Area 13 - Management Decisions for 1997 and 1998 by Geoduck Management Area

## GMA 13-A: SE Quadra to Whiterock Pass - Subareas 13-12 to -14.

In the 1994 quota assessment, GMA 13-A was comprised of 7 beds with an area of 80 ha . In the assessment for 1997 quotas, one bed was moved to GMA 13-C and the remaining beds were rescaled according to landings for a total of 6 beds measuring 85.3 ha.

In 1992, a 3 year quota of 117,000 was calculated for GMA 13-A based on 1991 bed measurements of 164 ha. Fishers felt that this quota was too large and that bed area was likely overestimated. Bed areas from Francisco Point to Rebecca Spit and the bed near Whiterock Pass were reduced based on a formula of density of removals (Harbo et al. 1993). A quota of 40,000 lb was set for 1992 , based on an area estimate of 60 ha and a calculated quota of $42,300 \mathrm{lb}$.

For the 1995 quota calculations, some of the beds which had area reductions in 1992 were increased using landings criteria, so that the bed areas for GMA 13-A totalled 80 ha. Using a density of 0.7 geoducks $/ \mathrm{m}^{2}$ the quota was set at the calculated amount of $44,089 \mathrm{lb}$.

The 1997 quota options ranged form a low of 27,598 to a high of $37,385 \mathrm{lb}$. The quota was set at the medium option of $32,306 \mathrm{lb}$.

## GMA 13-B: Marina Island - a portion of Subarea 13-15.

GMA 13-B is comprised of 2 beds measuring 279 ha. The two beds surrounding Marina Island have been heavily fished and account for $71 \%$ of all landings reported for Area 13. Marina Island was closed in 1992 due to overharvesting concerns and a survey was undertaken (Campbell et al. 1996a). Adjusted landings total $2,144,455 \mathrm{lb}$ in the assessment for 1997 quotas. Greater than $50 \%$ of the original biomass has been harvested. Continued closure is recommended for 1997.

## GMA 13-C: S.W. Cortes Island - portions of Subareas 13-14, -15 and -1.

In the assessment for 1995 quotas, GMA 13-C was comprised of 5 beds measuring 160 ha. For the 1997 quota assessment there were 6 beds measuring 174 ha considered for GMA 13-C.

Historically, beds in this area were not as heavily fished as those near Marina Island. There are contaminated closures in effect on beds at Manson's Landing. In 1992, a quota of $112,000 \mathrm{lb}$ was set based on 1 geoduck $/ \mathrm{m}^{2}$.

In 1995, beds larger than 75 hectares were assumed to have lower densities of geoduck. One bed of 132 ha was assumed to have a density of 0.45 geoducks $/ \mathrm{m}^{2}$ and 4 beds with a total of 38 ha were assumed to have densities of 0.7 geoducks $/ \mathrm{m}^{2}$. The 1995 set quota was $43,357 \mathrm{lb}$.

Recommendations for the 1997 quota ranged from a low of $25,193 \mathrm{lb}$ to a high of $76,860 \mathrm{lb}$. The 1997 quota was set at $43,357 \mathrm{lb}$, equal to the 1995 quota.

## GMA 13-D: N.W. Cortes Island - Subareas 13-16 and 13-17.

In the 1995 quota assessment, GMA 13-D had 9 reported beds measuring 52 ha . For the 1997 quota assessment, 9 beds had a total area of 64 ha , as scale factors according to landings were adjusted after the 1995 fishery.

Fishers have reported small beds with hard digging (mud) and spotty concentrations.
The highest annual landings for this location was $41,000 \mathrm{lb}$ in 1979. The 1992 quota set was $20,000 \mathrm{lb}$ and all the landings ( $20,634 \mathrm{lb}$ ) were taken from one site in Plunder Pass. The 1995 quota was set at $27,453 \mathrm{lb}$.

The recommended quota options for 1997 range from a low of 21,576 to a high of $29,169 \mathrm{lb}$. The 1997 quota was set at the medium option of $25,329 \mathrm{lb}$.

## GMA 13-E: Remainder of Area 13 - Other Subareas 13-1, 13-2, 13-4.

In the 1995 quota assessment, GMA 13-E had 3 beds measuring 7 ha. The assessment for 1997/98 quotas shows 5 beds measuring 6 ha.

There are small beds identified in the Boulder Point to Willow Point area which fishers have indicated as too rocky to be suitable fishing area. A large bed had been identified at Cape Mudge, with no landings on logs, but no one in the advisory committee had experience there. Beds in Gowland Harbour (Subarea 13-4) were closed in-season as they fall within the Discovery Passage Dive Closure area. A new bed was identified at Wilby Shoals in the 1995 fishery.

Mitlenatch Island (in Subarea 13-1) may have stock, but fishing to date has only identified beds in Subarea 15-03 near the island. Mitlenatch Is. is proposed to be included in a Marine Protected Area in the future.

A quota of $8,000 \mathrm{lb}$ was set for GMA 13-E in 1992 (Harbo et al. 1993). Fishers were unable to find suitable fishing area. This quota was transferred in-season to Area 14-C.

The quota for 1995 for GMA $13-\mathrm{E}$ was $3,545 \mathrm{lb}$.
Fishers maintain that there may still be fishing area along the Vancouver Island shore and at Wilby Shoals. They requested that GMA 13-E could be fished in the 1998 rotation, rather than the 1997 rotation when GMA 14-A2 is fished, with a landing port at Campbell River.

The recommended quota options for GMA 13-E in 1998 range from a low of $2,476 \mathrm{lb}$ to a high of $3,112 \mathrm{lb}$. The mid-range quota of $2,790 \mathrm{lb}$ was assigned in 1998 .

## area 14 - Fishing History

Area 14 has been fished since 1976. The area of commercial fishing ground was assumed to be very large and estimated at over 2000 ha in 1978. After 1989, the sizes of some of the very large beds were suspected to be overestimated. A survey undertaken in 1993, at Comox Bar, found a mean density of 0.300 geoducks $/ \mathrm{m}^{2}$ over the 305 ha surveyed, This is similar to the results of the Marina Island survey.

The large bed at Comox Bar, between the 5 and 20 m depth intervals, was remeasured, after the survey, on a new metric chart to exclude a large contaminated area. The bed was again remeasured in 1995 to 527 ha.

## Area 14 - Management Decisions by Geoduck Management Area

## GMA 14-A: Cape Lazo to Shelter Point - Subarea 14-13.

In the 1997/98 quota assessment, this area has been divided into GMA 14-A1 and GMA 14-A2, in order to distribute fishing effort more evenly between the beds in the northern and southern portions of Subarea 14-13. In the assessment for 1995 quotas, GMA 14-A had 6 reported beds measuring 1151 ha (1994).

The northern portion of this area, from the vicinity of Oyster River north to Shelter Point, was fished from 1978 to 1982 and in 1984. Landings were not made again in Subarea 14-13 until 1987, when a separate opening was set for Subarea 14-13. Except for a small landing from Oyster Bay ( 5108 lb ) in 1988, the focus for the fishery has been beds at the southern end of Subarea 14-13 (which has become GMA 14-A), with product landed at Comox.

The southern portion, from south of Oyster River to Cape Lazo was fished 2 years (1978 and 1979) and was not fished again until a separate quotas were set for Subarea 14-13 for 1987, 1988 and 1990. Substantial landings came from this southern portion in 1990; amounting to $346,160 \mathrm{lb}$ on logs (approx. $77 \%$ of the 1990 Area 14 quota).

GMA 14-A is a large exposed area with relatively long distances to landing ports at either Comox or Campbell River. From Cape Lazo to Shelter Point is approximately 12 nautical miles ( 22 km ). The bottom is mostly sand and due to the exposure of the shore to winds and wave action, the shows of geoducks are reported as poor in winter.

The historical quotas for this area have been between $100,000 \mathrm{lb}$ and $200,000 \mathrm{lb}$ annually. A three year rotational quota of $412,000 \mathrm{lb}$ was set for 1992 (-93-94) far less than the calculated quota option (Harbo et al. 1993). GMA 14-A had the largest measured bed area and the largest quota of all the geoduck management areas in the inside waters and it was felt that the size of the beds, especially in the northern portion, were possibly overestimated. Fishers advise that there are clams all along the shoreline although densities are sometimes spotty. A survey was recommended. A limited survey was undertaken in 1995, which resulted in a reduction in bed area to 763 ha for Subarea 14-13.

## GMA 14-A1: Williams Beach bluffs to Cape Lazo - southern portion of Subarea 14-13.

In the assessment for 1998 quotas, the former GMA 14-A was divided into two fishing areas. GMA 14-A1 has a total of 3 large beds measuring 508 ha,. Beds were redrawn and remeasured to exclude rocky portions and the size of beds reduced form 826 ha to 508 ha..

The recommended quota options for 1998 range from a low of $74,231 \mathrm{lb}$ to a high of $163,724 \mathrm{lb}$. The mid-range option of $132,811 \mathrm{lb}$ was assigned in 1998.

## GMA 14-A2: Williams Beach to Shelter Point - northern portion of Subarea 14-13.

In the assessment for 1998 quotas, the former GMA 14-A was divided into two fishing areas. The new GMA 14-A2 is comprised of 4 beds measuring 255 ha. In past years, this area contained the largest bed in Inside Waters and was assigned the largest quota. Beds were redrawn and remeasured according to survey and observer fishing data collected in the 1995 fishery resulting in a reduction from 525 ha to 255 ha for the 1998 assessment.

The observer fishery found no geoducks from Oyster Bay to Shelter Point. In other beds, densities were estimated by fishers at $0.15 / \mathrm{m}^{2}$ to $0.27 / \mathrm{m}^{2}$.

A landing port at Campbell River in 1998, for GMA 14-A2, may encourage fishers to concentrate more fully on the beds in the northern portion of Subarea 14-13.

The recommended quota options for 1998 range from a low of $63,747 \mathrm{lb}$ to a high of $130,611 \mathrm{lb}$. The mid-range option of $116,617 \mathrm{lb}$ was assigned in 1998. This was an error in transcription: The mid-range quota should actually have been $116,615 \mathrm{lb}$.

GMA 14-B: Comox Bar - portions of Subareas 14-7, 14-9 and 14-10.
In the 1995 assessment, GMA 14-B had 3 beds measuring 893 ha. For the 1997/98 quota assessment, as a result of remeasuring, the 3 beds measured 808 ha.

The bed at Comox Bar (4601) is partially under closure for sewage contamination. This large bed was originally assigned 769 ha and represented $18 \%$ of the bed area in Area 14 in the 1990 estimates. The bed, as charted from harvest logs, runs from Cape Lazo to the navigation bell
buoy (P54) and then along the eastern shore of Denman Island. This bed was surveyed in 1993 and remeasured in 1994 to a total of 612 ha of open fishable area ( $17 \%$ of open area in Area 14 calculated in 1994). Fishers advise that the most productive areas to the north of Comox Bar now fall within the contaminated closure (which measured approximately 350 ha in 1994). The open bed is most productive from Palliser Rock off Sandy Island, south-east along the eastern shore of Denman Island. The northern portion of the bed near Cape Lazo, northeast of the contaminated closure was remeasured at 179 ha. The total estimated open bed area for bed 4601 is 527 ha for 1997/98 quota calculations.

There are large beds in the vicinity of Komas Bluff and Lambert Channel (coded as bed 4901) which were formerly 417 ha , and were remeasured to 256 ha in 1991. This measurement was also used in the 1997/98 assessment. Bed 4902 at the south-east end of Denman Island (Lambert Channel) has been scaled with landings criteria to 25 ha.

A precautionary quota of $200,000 \mathrm{lb}$ was set for 1992 in GMA $14-\mathrm{B}$, less than the calculated option (using a density of 1 geoduck $/ \mathrm{m}^{2}$ ) of $263,000 \mathrm{lb}$ (Table 3.14, Harbo et al. 1994).

In the assessment for 1995 quotas, using a density of 0.45 geoducks $/ \mathrm{m}^{2}$ for beds over 80 ha, the quota was reduced to $189,702 \mathrm{lb}$.

In the assessment for 1998 quotas, a density of 0.45 geoducks $/ \mathrm{m}^{2}$ was once again used for large beds. Based on market sample data, the mean geoduck weight was reduced to 2.206 lb from 2.348 lb in previous assessments, resulting in reduced original biomass estimates and an increased amortization factor.

In 1998, the fishery will be restricted to bed 4901 at Komas Bluff which will be fished with an observer to verify the bed size.

The recommended quota options for 1998 range from a low of $43,127 \mathrm{lb}$ to a high of $108,102 \mathrm{lb}$. The mid-range quota of $72,344 \mathrm{lb}$ was assigned for 1998 . This was an error, probably in transcription: The mid-range quota should actually have been $72,351 \mathrm{lb}$.

## GMA 14-C: Baynes Sound - Subareas 14-11, 14-15 and 14-8.

The bed area used in the 1991 assessment was 193 ha. Based on fisher's recommendations, the 1992 quota was set initially at $20,000 \mathrm{lb}$, considerably less than the calculated quota of 145,000 lb. The GMA 13-E quota of $8,000 \mathrm{lb}$ was transferred in-season to GMA 14 -C for a total 1992 quota of $28,556 \mathrm{lb}$.

In the 1995 assessment, GMA 14-C had 6 beds measuring 169 ha after 5 beds had been removed due to sewage contamination ( 89 ha @ 0.7 geoducks $/ \mathrm{m}^{2}$; 80 ha @ 0.45 geoducks $/ \mathrm{m}^{2}$. The estimate of 169 ha was suspected to be too large based on past fishing in Baynes Sound. There are several new contamination closures proposed for this area that may affect the availability of geoducks. The 1995 quota was $78,862 \mathrm{lb}$, reduced to balance the number of inside water quotas to 11 .

In the 1997/98 quota assessment, a total of 12 beds have been recorded for GMA 14-C. Two beds have been deleted from quota calculations due to no harvest log landings. Managers did not consider, in the assessment, the 5 beds seaward of the sewage contamination areas. The remaining 5 beds had an area of 143 ha.

The recommended quota options for 1998 , based on 5 beds and 143 ha, range from a low of 38,401 to a high of 61,060 . The mid-range quota of 52,215 was assigned for 1998 and the area was divided into 3 quota blocks to distribute fishing effort.

## Area 15 - Fishing History

Landings of geoducks are recorded since 1977 in Area 15 and peaked at 321 t in 1978. In 1980, a separate quota of $500,000 \mathrm{lb}$. ( 227 t .) was set for Areas 15 and 16 combined. Landings appeared to decline sharply in 1980 in Area 15 and to have increased in Area 16. This may, however, only reflect the suspected inaccuracy of catch reporting between these two areas in the early years of the fishery. Quotas were decreased in 1981 to $40,000 \mathrm{lb}$. in Area 15 and increased again to 400,000 in 1984 in combination with Area 16. A separate quota of $225,000 \mathrm{lb}$. (102 t.) was set for Area 15 in 1985, but only 42 t were landed. In 1986, the quota of $200,000 \mathrm{lb}$. ( 91 t ) was exceeded by 46 t . The 200,000 lb. quota was maintained annually through 1987 and 1988 (Harbo et al. 1992).

In the assessment for 1991 quotas, 19 beds and 855 ha. were considered, reduced from the 21 beds and 1074 ha. previously reported. Two beds with small landings were removed from the assessment. The large bed at south Savary Island was reported to be over-estimated in size and was factored by removals, which reduced the estimated area from 244 ha. to 25 ha. Area 15 was divided into four GMAs (15-A to 15-D) to distribute fishing effort throughout the area, and a quota of $569,089 \mathrm{lb}$. ( 258 t .) set for 1991.

The assessment for 1994 quotas considered 26 beds and 804 ha. GMA 15-D was further divided into $15-\mathrm{E}, 15-\mathrm{F}$ and $15-\mathrm{G}$ to distribute effort to beds in Malaspina Inlet and on the eastern and southern shores of Cortes Island. Large beds at Harwood Island were closed due to concerns that the bed size was over-estimated and potentially over-harvested. The total quota for Area 15 was reduced to $398,400 \mathrm{lb}$. in 1994.

In the assessment for 1997 quotas, additional GMA's were added (15-C1 and 15-C2 at Hernando Island) in order to further direct effort to the large bed on the west coast of Hernando Island. GMAs $15-\mathrm{H}$ and 15-I were added to allow observer documented fishing at Harwood Island beds in 1997. Purge fishing was permitted on aquaculture lease sites at Savary Island. The total Area 15 quota was 493,718 lb. in 1997.

## Area 15 - Management Decisions by Geoduck Management Area

## GMA 15-A: North Coast of Savary Island - portion of Subarea 15-2.

In the 1994 assessment, 1 bed was measured at 124 ha (1992). In the assessment for 1997 quotas, that bed was remeasured to 134.4 ha.

A separate quota for this GMA was first set in 1991 at $87,000 \mathrm{lb}(29,000 \mathrm{lb}$ annually) for the north coast of Savary Island (124 ha) to limit fishing at this site. It had been fished most years, with harvests of 20,000 to $50,000 \mathrm{lb}$ annually.

In 1994 the calculated quota was $61,150 \mathrm{lb}$. Fishers recommended shifting quota to the southern shore of Savary Island which was done. The quota on the south shore was set at $12,300 \mathrm{lb}$ for 1994 , which was then shifted to the north shore.

An aquaculture lease has been granted to FAN Seafoods for a portion of the bed. Purge fishing was undertaken in 1996 and 1997 (and will continue in subsequent years) in order to remove wild stock prior to seeding. Landings in 1996 were $34,068 \mathrm{lb}$, and in 1997 were $21,843 \mathrm{lb}$ (total 1997 landings were $67,562 \mathrm{lb}$ ). It was proposed to continue to fish as much of the $15-\mathrm{A}$ quota as possible from within the lease boundaries in 1997. If fishers were unable to land the quota from within the lease site they could move to other portions of the bed. In 1998, when the GMA is not open, quota taken during purging from the lease site will be deducted from other nearby GMAs.

The recommended quota options for 1997 ranged from a low of $17,650 \mathrm{lb}$ to a high of $69,650 \mathrm{lb}$. The quota was set at the medium option of $58,371 \mathrm{lb}$.

## GMA 15-B: South Coast of Savary Island. - portion of Subarea 15-2.

For the 1994 assessment, 1 bed was considered with an area of 25 ha (1992). The bed, which had previously been much larger, was scaled according to landings criteria. In the 1997 quota assessment, the bed area used is 193 ha, it's measured size.

A separate quota for this GMA of $17,625 \mathrm{lb}$ was first set in 1991 for the bed south of Savary Island. Although a very large bed had been identified on harvest logs, there were few landings reported, so the quota was assigned based on an estimated 25 ha . The quota was landed with no problem. The low quota, however, allowed little opportunity for exploration of the bed.

In 1994, fishers believed that the bed was larger than 25 ha and requested that the calculated quotas for the north and south shore beds of Savary Island be reversed to encourage further exploration of the southern bed. The 1994 quota was set at $61,000 \mathrm{lb}$.

An aquaculture lease has been granted to FAN Seafoods for a portion of the southern bed. Purge fishing was undertaken in 1996 and 1997 (and will continue in subsequent years) in order to remove wild stock prior to seeding. Landings from the purge sites in 1996 were $56,674 \mathrm{lb}$, and in 1997 were $105,502 \mathrm{lb}$ (total 1997 landings from GMA 15B were $190,213 \mathrm{lb}$.). It was proposed to
continue to fish as much of the GMA 15-B quota as possible from within the lease boundaries in 1997. If fishers were unable to land the quota from within the lease site they could move to other portions of the bed. . In 1998, when the GMA is not open, quota taken during purging from the lease site will be deducted from other nearby GMAs.

The recommended quota options for GMA $15-\mathrm{B}$ in 1997 range from a low of $50,648 \mathrm{lb}$ to a high of $100,143 \mathrm{lb}$. The quota was set at the medium option of $89,291 \mathrm{lb}$.

GMA 15-C1: Hernando Island, west and south - portions of Subareas 15-2 and 15-3.

In the 1994 assessment, GMA 15-C included 2 beds on the west side of Hernando with a scaled and estimated area of 61 ha. In the 1997 assessment, this GMA has been renamed to $15-\mathrm{Cl}$ and has 2 beds with a measured area of 120 ha .

Bed 403 on the west coast of Hernando Island was measured at 80 ha but had supported only minor landings. In 1991, a separate quota of $74,730 \mathrm{lb}$ was set for the west coast of Hernando Island to determine if stocks were present and to spread fishing effort throughout Management Area 15. Landings of $74,271 \mathrm{lb}$ were made.

The quota for GMA 15-C was set at the calculated amount of $30,100 \mathrm{lb}$ in 1994.
In the 1997 assessment, the full area of 120 ha has been considered for the beds on the west coast. The recommended quota options ranged from a low of $34,882 \mathrm{lb}$ to a high of $61,683 \mathrm{lb}$. The quota was set at the medium option of $54,079 \mathrm{lb}$.

GMA 15-C2: Hernando Island, east coast - portion of Subarea 15-3.
GMA 15-C2 is a new GMA for 1997. The one very large bed ( 165 ha ) was fished with GMA 15-D in the 1991 and 1994 fisheries. Most of the 1994 landings came from bed 401 on the east coast of Hernando Island ( $47 \%$ of landings reported on logs).

Although total adjusted landings of $453,954 \mathrm{lb}$ have been reported from this bed, bed size may be overestimated. An ongrounds observer was recommended for a portion of the fishery to document the extent of the bed.

The recommended quota options for 1997 ranged from a low of $24,205 \mathrm{lb}$ to a high of $85,441 \mathrm{lb}$. The quota was set at $55,679 \mathrm{lb}$. The medium option was reduced by $21,269 \mathrm{lb}$ to equalize inside licenses to 9 , and another 2790 lb was transferred from GMA 13-E so that GMA 13-E could be fished in 1998.

## GMA 15-D: the Balance of Area 15 - portions of Subareas 15-1 and 15-2.

A reduced quota of $389,785 \mathrm{lb}$ was set in 1991 to balance inside waters individual quotas, and because of heavy harvesting concerns.

In the 1994 quota assessment, GMA 15-D had three areas subdivided off into separate GMAs (15E, $15-\mathrm{F}$ and $15-\mathrm{G}$ ), and beds in the vicinity of Harwood Island were closed. This left GMA 15 D with a balance of 17 beds (including 2 small beds found during the 1994 fishery), measuring an estimated 419 ha , and with a quota of $207,000 \mathrm{lb}$.

In the 1997 assessment, the quota for GMA 15-D was further reduced; Harwood Island beds were separated into GMAs $15-\mathrm{H}$ and $15-\mathrm{I}$, each with separate quotas assigned. The recommended quota options for GMA 15-D ranged from a low of $65,893 \mathrm{lb}$ to a high of $90,802 \mathrm{lb}$. The quota was set at $78,040 \mathrm{lb}$.

## GMA 15-E: Malaspina, Theodosia and Okeover Inlets - Subarea 15-4.

In the assessment for 1994 quotas, the new GMA 15-E contained 2 reported beds, with an estimated 14 ha of fishing area (1992). The 1997/98 assessment has 2 beds measuring 19 ha. A separate quota of $10,000 \mathrm{lb}$ was set for GMA $15-\mathrm{E}$ in 1994, as no fishing had been reported in the inlets since 1988.

In the 1997 assessment, quotas were reduced due to the 50 year amortization factor. The quota recommendations for 1997 range from a low of $2,873 \mathrm{lb}$ to a high of $5,465 \mathrm{lb}$. The quota was set at the medium option of $4,148 \mathrm{lb}$.

## GMA 15-F: Cortes Island/Redonda Islands: - Subarea 15-5.

The 1994 quota assessment considered 1 bed, with 62 ha estimated (1992). This area of Cortes Island had not been fished since 1983, so a separate quota of $30,000 \mathrm{lb}$ was set in 1994 to direct fishing effort into this area.For the 1997 assessment, the bed was re-drawn and remeasured to 59 ha, but was still suspected of being over estimated in size.

Recommended quota options for 1997 ranged from a low of $9,951 \mathrm{lb}$ to a high of $30,401 \mathrm{lb}$. The quota was set at 27,106 , with the requirement for an ongrounds observer to document bed size.

## GMA 15-G: South Cortes/Twin Islands - portion of Subarea 15-3.

A new GMA in the 1994 assessment, 15-G was comprised of 2 beds estimated at 99 ha (1992). In the 1997 assessment 3 beds are remeasured at 91 ha.

Beds in this area on the east side of Cortes Is. had minor landings reported in 1991 ( 6084 lb .). A separate quota of $48,000 \mathrm{lb}$ was set in 1994. Quota options for 1997 ranged from a low of 17,312 lb to a high of $46,178 \mathrm{lb}$. The quota was set at the medium option of $41,085 \mathrm{lb}$.

GMA 15-H: West coast Harwood Island - portion of Subarea 15-2.
A newly designated for 1997, GMA 15-H has one bed of 79 ha.

Due to overharvesting concerns, all of Harwood Island was closed in the 1994 rotation. Adjusted landings of only $46,068 \mathrm{lb}$ have been reported from this large bed as the fishery has been more focused on beds on the east side of the island.

The recommended quota options for 1997 ranged from a low of $19,598 \mathrm{lb}$ to a high of $41,114 \mathrm{lb}$. The medium option quota of $36,659 \mathrm{lb}$ was set, with a requirement for an ongrounds observer to monitor fishing and document bed size.

## GMA 15-I: West coast Harwood Island, portion of Subarea 15-2.

A newly designated area for 1997, GMA 15-I has 1 bed measured at 107 ha .
Due to overharvesting concerns, all of Harwood Island was closed in the 1994 rotation. Adjusted landings of $191,873 \mathrm{lb}$ have been reported from this bed and there have been concerns that the bed size may be overestimated.

The recommended quota options for 1997 ranged from a low of $24,893 \mathrm{lb}$ to a high of 55,247 lb . The medium quota option of $49,260 \mathrm{lb}$ was set, with a requirement for an ongrounds observer to monitor fishing and document bed size.

## Area 17 - Fishing History

The geoduck fishery has been active in Area 17 since the first recorded landings in 1976. In the early 1980s, quotas were set in combination with other 'inside' areas and, in 1985, Area 17 was separated from the rest and assigned a quota of $100,000 \mathrm{lb}$. ( 45 t ). In 1986, the quota was increased to $200,000 \mathrm{lb}$. $(91 \mathrm{t}$ ) and was maintained at this annual amount through 1988. The quota applied to Areas 17 and Subareas 29-4 and 29-5.

In the assessment for 1991, quotas, 35 beds and a reduced estimate of 636 ha were considered. A research area of 82 ha (bed 6201) at Gabriola Island was removed from the estimated bed area. Bed 6201 had been very productive in the fishery, with reported landings in excess of $300,000 \mathrm{lb}$. in six years of harvesting. However, fishers regarded the quality of geoducks at this site to be poor. Six beds ( 47 ha ) with low landings were removed from the quota calculations.

In 1991, Area 17 was divided in two GMAs - GMA 17-A, from Neck Point to Nanoose Bay, and GMA 17-B - the balance of Area 17. Subareas 29-4 and -5 were also assigned a separate quota. The total three year rotational quota for Areas 17, 29-4 and 29-5 was set at $431,085 \mathrm{lb}$. (196 t).

In 1994, the portion of GMA 17-A in Subarea 17-18, (from Blunden Point to Neck Point) was closed to distribute effort to other beds and encourage exploration. The east shore of Kuper Island, in GMA 17-B, was closed to distribute effort. The total three year rotational quota for Areas 17, 29-4 and 29-5 was $316,904 \mathrm{lb}$. ( 144 t ), a decrease, from 1991, due to bed closures and the use of a reduced density estimate in quota calculations.

## Area 17 - Management Decisions by Geoduck Management Area

## GMA 17-A: Nanoose Bay to Neck Point - Subareas 17-18, 17-19, 17-20.

In the 1994 assessment, GMA 17-A was comprised of 3 beds measuring 160 ha (1993). In the 1997/98 assessment, has been divided into 3 separate GMAs; 17-A1, 17-A2 and 17-A3.

In 1991, a separate quota of $108,000 \mathrm{lb}$ was set for GMA 17-A (Nanoose Bay to Neck Point shoreline) to spread fishing effort over Area 17. To simplify the boundaries, Subareas 17-18 to 17 20 inclusive were opened for fishing. The fleet, however, concentrated their efforts in Subareas 1718 and 17-19 and did not fish 17-20.

In 1994, a portion of Subarea 17-18 from Blunden Point to Neck Point was closed to encourage fishing effort on other beds in GMA 17-A. The quota set in 1994 was $78,904 \mathrm{lb}$.

## GMA 17-A1: Icarus Point/Lantzville shore - Subarea 17-18.

A new designation for 1998, GMA 17-A1 has 1 bed measured at 91 ha. This bed was heavily harvested in 1991 and closed in 1994. Adjusted landings are estimated at $172,677 \mathrm{lb}$.

The recommended quota options for 1998 range from a low of $10,322 \mathrm{lb}$ to a high of $36,164 \mathrm{lb}$. The mid-range quota of $30,393 \mathrm{lb}$ was assigned in 1998.

## GMA 17-A2: Nanoose Bay to Blunden Pt - Subarea 17-19.

A new designation for 1998, GMA 17-A2 has 1 bed measured at 69 ha. Historic landings are the greatest of the three beds which comprised GMA 17-A, and have been adjusted to $197,909 \mathrm{lb}$.

The recommended quota options for 1998 range from a low of $13,658 \mathrm{lb}$ to a high of $23,849 \mathrm{lb}$. The mid-range quota of 18,609 was assigned in 1998.

## GMA 17-A3: Nanoose Bay - Subarea 17-20.

A new designation for 1998, GMA 17-A3 has 1 bed measured at 41 ha. There are concerns that the bed area is overestimated. Historic landings are less than the other beds which comprised GMA 17-A, and are adjusted to $94,163 \mathrm{lb}$. The bed was fished until 1985 and not again until 1994.

The recommended quota options for 1998 range from a low of $9,664 \mathrm{lb}$ to a high of $15,375 \mathrm{lb}$. The mid-range quota of $12,439 \mathrm{lb}$ was assigned in 1998 , and will be fished with an observer to verify bed size.

## GMA 17-B: Balance of Area 17 - Subareas 17-1-3, -15-17 and -21.

In the 1994 quota assessment, GMA 17-B was comprised of 47 beds measuring an estimated 446 ha (1992). The 1997/98 assessment included 51 beds measuring 493 ha.

The quota set in 1991 for GMA 17 -B was $293,085 \mathrm{lb}$. Due to overharvesting concerns, a large bed on the east shore of Kuper Island was closed in 1994 to direct effort to other portions of Area 17. The 1994 quota was set at $216,000 \mathrm{lb}$.

In the 1997/98 assessment, 15 of 51 beds, measuring 164 ha have been fished to greater than $50 \%$ of the original biomass and should be excluded from further harvest. Beds in GMA 17-B have been heavily harvested, especially in the early years of the fishery, with an adjusting landings estimate of 3.2 million pounds fished to the end of 1994. The mean weight of geoducks from Area 17 market samples is 1.599 lb , significantly less than the standard mean weight of 2.348 lb used in past quota assessments.

In 1998, there will be a number of bed closures. As a consequence, GMA 17-B will be subdivided into 'quota blocks' with quota assigned to each block calculated according to the open beds in each block. The GMA will be fished with an observer to ensure boundary compliance.

Recommended quota options for 1998 range from a low of $21,413 \mathrm{lb}$ to a high of $80,159 \mathrm{lb}$. The mid-range quota of $57,508 \mathrm{lb}$ was assigned in 1998. An ongrounds observer will be required for the duration of the fishery to monitor bed closures.

## area 18 - Fishing History

Quotas were set in combination with other inside areas and/or Area 17 until 1986, when a separate quota of $100,000 \mathrm{lb}$. ( 45 t ) was set for Area 18. Only 13 t were landed. In 1987, portions of Area 18 (GMA 18-A - Subareas 18-3, $-4,-6$ to -8 and -10) were combined with Area 19 for a total quota of $150,000 \mathrm{lb}$. ( 68 t ). GMA 18-B was assigned the remaining Subareas ( $18-1$, $-2,-5,-9$ and -11 ) as an exploratory fishery with no quota. In a six week summer opening 86 t were landed. All of Area 18 remained closed in 1988.

In the assessment for 1991 quotas, one large bed at Boatswain Bank, with a history of small landings, was assigned a separate three year rotational quota of ( $33,000 \mathrm{lb}$.) as GMA $18-\mathrm{A}$. The quota was landed in 5 days. The balance of Area 18 became GMA 18-B, with a three year rotational quota of $48,000 \mathrm{lb}$. The fishery was focused in exposed areas late in the year, and experienced difficulty landing the quota.

In 1994, the calculated quotas were reduced by using a density of 0.7 geoduck $/ \mathrm{m}^{2}$. The total quota for Area 18 beds in 1994 was $44,000 \mathrm{lb}$.

## Area 18 - Management Decisions by Geoduck Management Area.

## GMA 18-A: Boatswain Bank - Portion of Subarea 18-7.

GMA 18-A is comprised of one large bed, 45 ha estimated in the 1994 assessment, and remeasured to 46 ha in the 1997/98 assessment.

A separate quota of $33,725 \mathrm{lb}$ was set in 1991 for Boatswain Bank to assess the stock in this large bed which was reported in harvest $\log$ data but had few landings recorded. The quota was landed within a few days.

Based on a density of 0.7 geoduck $/ \mathrm{m}^{2}$, the 1994 quota was set at $22,000 \mathrm{lb}$.
The recommended quota options for 1997 ranged form a low of $13,097 \mathrm{lb}$ to a high of $19,646 \mathrm{lb}$. The mid-range option of $16,361 \mathrm{lb}$ was assigned in 1997.

GMA 18-B: The balance of Area 18 - Subareas 1-6, a portion of 7 and 9-11.
In the 1994 assessment, GMA 18-B was comprised of 10 beds with a total area of 44 ha. The 1997/98 assessment includes 11 beds measuring 48 ha.

The 1991 quota for the balance of Area 18 was $48,000 \mathrm{lb}$. Most of the product was landed at Sturdies Bay in 1991 in late October and November, and was not an optimum time of the year to fish this area. The three year quota set for 1994 was $22,000 \mathrm{lb}$.

In the 1997/98 assessment, a reduced mean weight of 1.733 lb calculated from market samples resulted in a reduced estimate of original biomass. Two beds have been harvested to greater than $50 \%$ of original biomass and should remain closed, while several other beds have increased amortization factors.

The recommended quota options for 1997 ranged for a low of 4,514 to a high of $9,493 \mathrm{lb}$. The quota was set at the medium option of $6,929 \mathrm{lb}$.

## area 19 - Fishing History

The fishing area in Area 19 was reduced in 1994 to exclude beds in Saanich Inlet that now fall under contaminated closures. Contaminated closures along the shoreline of Saanich Peninsula should be reviewed with consideration of extending the closure to close subtidal regions in the vicinity of the sewage outfalls.

Concerns have been expressed in the past few years about the level of harvest form a number of large beds in the vicinity of James Island, where a separate reduced quota was first set in 1994.

In the 1997/98 assessment, original biomass estimates are reduced as a result of a smaller mean geoduck weight of 1.797 lb calculated from market sample data.

## area 19 - Management Decisions by Geoduck Management Area.

## GMA 19-A: Saanich Inlet - Subareas 19-7 to 19-12.

In the 1994 assessment, GMA 19-A was comprised of 2 beds with an estimated area of 101 ha (1992). The beds are under contaminated closures. No landings have been reported since 1981.

## GMA 19-B: - James Island - a portion of Subarea 19-5.

In the 1994 assessment, GMA 19-B was comprised of 5 beds measuring 509 ha (1992). In the 1997/98 assessment, 4 beds were considered with a total of 485 ha.

GMA 19-B had the second highest landings in Inside Waters up to 1992. A reduction in fishing effort was recommended for 1994 , and the quota was set at $55,696 \mathrm{lb}$ to balance Inside waters I.Qs.

At the low range quota option in the 1997/98 assessment, all 4 beds are estimated to have harvest amounts greater the $50 \%$ of the original biomass. At the mid-range option, one bed has a three year quota of 56 lb . At the high range option, the calculated quota is $23,352 \mathrm{lb}$. Closure was recommended for 1997 and no quota was set for 19-B.

## GMA 19-C: The Balance of Area 19 - Subareas 19-3, -4, a portion of -5 and -6.

In the 1994 assessment, GMA 19-C was comprised of 7 beds, 172 ha estimated (1992). In the 1997/98 assessment 8 beds were remeasured to 196 ha.

This was a new GMA in 1994, designed to spread effort from James Island. The recommended quota for 1994 was $85,000 \mathrm{lb}$.

In the 1997/98 assessment, there is a small portion of a bed at Cordova Bay within a contaminated closure. Open beds are in the vicinity of Sidney Island, the Vancouver Island shore of Saanich Peninsula, Bazan Bay (with a bed closure at Cordova Spit) and Island View Beach area. There are continued concerns about subtidal water quality and increased contamination closures.

The recommended 1997 quota options ranged from a low of $30,797 \mathrm{lb}$ to a high of $56,381 \mathrm{lb}$. The 1997 quota was set at $30,000 \mathrm{lb}$ (reduced from 43,244 due to contamination concerns) with sampling requirements to assess contamination levels in geoducks.

## area 29 - Fishing History

Portions of Subarea 29-1 have been historically fished with portions of Area 16. Subarea 29-5 has been historically fished in conjunction with beds in Area 17. A portion of a large heavily fished bed in the vicinity of Gabriola Pass falls within the boundaries of a proposed Marine Protected Area.

## Area 29 - Management Decisions by Geoduck Management Area

GMA 29: Outside Valdes and Galiano Islands - Subareas 29-4 and 29-5.
In the 1994 assessment, GMA 29-4 and 29-5 was comprised of 4 beds with a scaled area of 45 ha.(1992). In the 1997/98 assessment, 4 beds were remeasured at 83 ha.

Three sites were charted in Subarea 29-5: Kendrick Island and two locations along the N.E. coast of Valdes Island. There were concerns that the area might be overestimated. Subarea 29-4 has one bed of 23 ha recorded. The 1994 quota was set at $22,000 \mathrm{lb}$ with fishers intending to further explore the outside shores of Valdes and Galiano Islands. Logbook information from 1994 indicated larger bed areas for the Valdez Is./Galiano Is. beds and resulted in larger measured areas being used for the 1998 assessment.

In the 1997/98 assessment, using a reduced mean weight, one bed (106) has been harvested in excess of $50 \%$ of the original biomass and the other three have increased amortization factors.

The recommended quota options for 1998 range from a low of $2,162 \mathrm{lb}$ to a high of $11,758 \mathrm{lb}$. The mid-range quota of $6,830 \mathrm{lb}$ was assigned in 1998.

## APPENDIX 3. FISHING HISTORIES AND DOCUMENTATION OF MANAGMENT DECISIONS FOR GEODUCK MANAGEMENT AREAS ON THE WEST COAST OF VANCOUVER ISLAND.

## Area 23 - Fishing History

The fishery in Area 23 began in 1977. Initial quotas were first set in 1980 at 500,000 lb. (227 t). This quota included Areas 20 and 21. The quota fluctuated around 400,000 to $525,000 \mathrm{lb}$ through the mid-1980's. In 1989, at the start the I.Q. program, a three year rotational quota of $1,200,000 \mathrm{lb}$ was set, divided into two geoduck management areas (23-A - Bamfield and 23-B Ucluelet). In the fall of 1991, due to fishers inability to fish because of poor weather conditions, remaining quota from Area 27 was transferred to Area 23. A change in PSP regulations late in 1991 caused this fishery to be postponed and the remaining quota was transferred to Area 26. In 1992, the Area 23 quota was set at $435,000 \mathrm{lb}$ and Area 23 was divided into five geoduck management areas (GMAs 23-A to 23-E) with separate quotas assigned to distribute fishing effort.

In the 1995-96-97 rotation, the Area 23 quota was further reduced to $284,472 \mathrm{lb}$, when an amortisation factor for past excessive harvest was introduced in quota calculations and lower mean densities were used for the west coast of Vancouver Island. Many beds were assigned lower quotas as a result (Harbo et al. 1995).

Stocks of geoducks are present in the Broken Islands Group (Barkley Sound) and are closed to harvest as part of the Pacific Rim National Park reserve. Preliminary surveys were carried out in this area in 1978. An estimated 2653 ha of geoduck habitat were identified with an estimated biomass of 5476 t (Harbo et al. 1986). A large research area closure near Bamfield Marine Station also contains geoduck beds.

## Area 23 - Management Decisions for 1998 by Geoduck Management Area

GMA 23-A: Maggie River - portions of Subareas 23-9,23-10 and 23-11.
In the assessment for 1995 quotas, GMA 23-A was comprised of 6 beds measuring 157 ha. This was a reduction from 171 ha in 1992. In the 1997/98 assessment, the are 8 beds measuring 149 ha.

The 1992 quota set was $240,000 \mathrm{lb}$. In 1995, six beds were assessed with high rates of removals ( 1.4 geoducks $/ \mathrm{m}^{2}$ in a 2 ha bed and 0.43 geoducks $/ \mathrm{m}^{2}$ removed over 110 ha ). This compared to estimated removals of 0.46 geoducks $/ \mathrm{m}^{2}$ on a 74.3 ha bed at north Marina Island (which was deemed to be an example of high removal rates, and the area was closed.) As a consequence of this high rate of removal, the three year quota for 1995 was set at the calculated amount of $56,148 \mathrm{lb}$.

An ongrounds observer was dedicated, in 1995, to monitor fishing at an 18 ha site in NE Newcombe Channel (bed 401) where no landings had been recorded since 1980. Fishers could
not locate a geoduck bed in this area, and bed 401 has been deleted from quota calculations for 1998. Beds at NE Francis Island (bed 402), Forbes Island (bed 502) and Roland Island (bed 505) have all been harvested to greater than $50 \%$ of original biomass and are closed. Bed 402 is also within a contaminated closure. In the 1998 assessment, the large bed (501) at Maggie River supports most of the quota. The area of this bed may be overestimated and will be fished with an observer, in 1998, to verify the bed area.

The recommended quota options for 1998 for GMA 23-A range from a low of $31,234 \mathrm{lb}$ to a high of $80,449 \mathrm{lb}$, with a number of bed closures. The low-range quota of $31,234 \mathrm{lb}$ was assigned in 1998.

## GMA 23-B: Toquart Bay/Pipestem Inlet - portion of Subarea 23-10.

In the assessment for 1995 quotas, GMA 23-B was comprised of 7 beds measuring 39 ha. In the 1997/98 assessment there are 7 beds measuring 44 ha.

Until 1992, the majority of landings $(340,565 \mathrm{lb})$ had come from bed 601 on the west shore of Toquart Bay, north of the Indian Reserve. The 1992 quota set was $15,000 \mathrm{lb}$ based on a reduced area (by exclusion of bed 601) of 10 ha. The bed closure was set at bed 601 to distribute harvesting to other beds. Bed 601 re-opened in 1995. Fishing at a reduced harvest rate for the balance of a 50 year fishery was recommended and the 1995 quota was set at 19,004 lb.

The recommended quota options for 1998 range from a low of $11,589 \mathrm{lb}$ to a high of $25,046 \mathrm{lb}$. The mid-range quota of $17,662 \mathrm{lb}$ was assigned in 1998.

GMA 23-C: Mayne Bay/Stopper, Bryant and Curwen Islands - portions of Subareas 23-9, 23-10.
In the assessment for 1995 quotas, GMA 23 -C was comprised of 9 beds measuring 124 ha. In the 1996/97 assessment, there are 10 beds measuring 128 ha .

This area has been heavily fished in the past. The 1995 assessment stated that $31 \%$ of the original stock has been harvested in 16 years (Harbo et al. 1995), with an average estimated removal rate of 0.43 geoducks $/ \mathrm{m} 2$ for all beds in GMA 23-C.

A management decision was made in 1992 to allow for a $35,000 \mathrm{lb}$ quota with a provision for adding $130,000 \mathrm{lb}$ if the fleet could not attain the quota in GMA 27-G ('Exploratory'). The Mayne Bay area was harvested for $166,118 \mathrm{lb}$ in 1992. The 1995 quota was set at the calculated amount of 69,263 lb.

The recommended quota options for 1998 range from a low of $43,402 \mathrm{lb}$ to a high of $87,451 \mathrm{lb}$. The mid-range quota of $65,042 \mathrm{lb}$ was assigned in 1998.

## GMA 23-D: Pinkerton Islands - portions of Subareas 23-6 and 23-8.

In the assessment for 1995 quotas, GMA 23-D was comprised of a total of 22 beds measuring 182 ha ( 16 beds measured 114 ha in 1992, excluding Alma Russell Islands). In the 1997/98 quota assessment, there are 22 beds measuring 197 ha.

A closure was set in 1992 for the Alma Russell Islands. The calculated quota option of 162,000 lb for GMA 23-D was based on the reduced area of 114 ha. A more conservative quota of $145,000 \mathrm{lb}$ was set for 1992.

In the assessment for 1995 quotas, approximately $52 \%$ of the reported landings on logs had come from the Alma Russell Islands (beds 2701, 2702 and 2703), where the 3 beds measured at 51 ha. This bed area was included in the quota calculations. Continued closure was initially recommended for 1995 to spread effort into other beds, but this did not occur. There was ongoing concern about the level of past harvest from Alma Russell Islands as well as the increased risk of contaminated closures on geoduck habitat due to float homes in the area. The 1995 quota was set at the reduced rate of $118,643 \mathrm{lb}$, adjusted to close beds at Lyall Pt. and Equis Beach.

The boundary of GMA 23-D was adjusted, in 1998, so as to close beds at Equis Beach (bed 1101) and at Lyall Pt. (bed 1103).

In 1998, a bed in the vicinity of Robinson Is. (bed 2701) will be fished with an observer to verify the size of this bed.

The recommended quota options for 1998 range from a low of $121,800 \mathrm{lb}$ to a high of 176,770 lb . A quota of $104,008 \mathrm{lb}$ was assigned, in 1998, somewhat below the low-range option of $121,800 \mathrm{lb}$, to equalize quotas between the three coastal regions.

## GMA 23-E: Chain Group - portions of Subareas 23-4, 23-5, 23-6.

In the assessment for 1995 quotas, GMA 23-E was comprised of 14 beds measuring 90 ha. In the assessment for 1997/98 quotas, there are 14 beds measuring 107 ha.

The 1995 assessment showed high removals at some locations: $1.65 \mathrm{~g} / \mathrm{m}^{2}$ over $5 \mathrm{ha} ; 1.09 \mathrm{~g} / \mathrm{m}^{2}$ over $6 \mathrm{ha} ; 0.51 \mathrm{~g} / \mathrm{m}^{2}$ over 13 ha . (Harbo et al. 1995). The fishery was closed in 1992 due to over harvesting concerns (Harbo et al. 1993). Based on the area identified ( 90 ha ) and landings adjusted for missing catch on logs, $991,169 \mathrm{lb}$, or $40 \%$ of the original stock, had been harvested from this area. In 1995, the quota was set at the calculated amount of $21,422 \mathrm{lb}$ using the 50 year amortisation factor so as to continue fishing but at a reduced rate. Beds at Stud Is. (bed 2108), Weld Is. (bed 2109) and on the W. side of Diplock Is. (bed 2112) in GMA 23-E were closed, in 1998, and the area was fished with an observer to ensure compliance with boundaries

The recommended quota options for 1998 range from a low of $30,973 \mathrm{lb}$ to a high of $54,846 \mathrm{lb}$. The mid-range quota of $42,247 \mathrm{lb}$ was assigned in 1998.

## Area 24 - Fishing History

Area 24 has supported more fishing than any other area on the coast. The area was divided into two geoduck management areas ("Inside" - GMA 24-A and "Outside" - GMA 24-B) in 1984 in order to protect herring spawning grounds. The inside areas were portions of Area 24 that traditionally supported herring spawn or herring fisheries and were closed to geoduck fishing from mid February to mid April. Both GMAs 24-A and 24-B have been subdivided a number of times since 1984 in order to either encourage exploration of unfished areas in the earlier years of the fishery or, in later years, to distribute effort and protect heavily harvested areas.

In 1985, an exploratory area (GMA 24-C) called "Exposed" was set to promote exploratory fishing in more exposed portions of Area 24 that could not be fished until summer months. Traditionally, all quotas had been reached early in the year so that the more exposed areas were not fished or explored. In 1986, another management area was designated (GMA 24-D) called "Inlets" to promote further exploration in the inlets where there was great interest in locating salmon fish farms.

Since 1989, with the introduction of the three year rotational fishery, Area 24 has continued to be the exception with an annual fishery. This was initially set since there was a processing plant located in Tofino, many fishers lived in Tofino and the economy of Tofino benefited from the annual fishery. All geoducks are now shipped out live from Area 24 to plants in Vancouver.

The total landings from 18 years of fishing (1978 to 1995 inclusive) are estimated to be $11,569 \mathrm{t}$ ( 25.5 million lb). Approximately $19 \%$ of the Area 24 catch was missing from logbook bed analyses. Logbook reports from the early years of the fishery were missing the greatest amount of catch reported by bed. The bed landing estimates have been adjusted to reflect this difference by factors of 1.24 prior to 1989 and 1.07 from 1989 to 1995.

The recommended annual quota for Area 24 in 1995 was $414,251 \mathrm{lb}$. The increase to $527,240 \mathrm{lb}$, in 1996, was largely a result of using increased average weights in the assessments for the west coast ( $1.065 \mathrm{~kg} /$ geoduck in 1995 compared to $1.122 \mathrm{~kg} /$ geoduck in 1996). Harvest log landing and bed data for the 1996 quota assessment was complete to the end of 1993.

For the 1997 fishery, further adjustments were made to the boundaries of Geoduck Management Areas. GMA 24-A2 was divided into GMAs 24-A2a and 24-A2b. GMA 24-A6 was divided into GMAs 24-A6a and 24-A6b. The large bed in GMA 24-B2 was divided, with one half to be fished in 1997 and the other half in 1998.

A number of beds were remeasured with adjusted boundaries in 1996, based on harvester information, surveys and observer fishing, for a total of 78 beds with an area of 2290 ha in Area 24. A density of 1.4 geoducks $/ \mathrm{m}^{2}$ and a mean weight of $2.424 \mathrm{lb} /$ geoduck was used for all beds in Area 24 with the exception of beds at Yellow Bank, where a density of 2.2 geoducks $/ \mathrm{m}^{2}$ was
used based on preliminary survey results from the fall of 1995 (in prep.). The quota in 1997 was set at $357,137 \mathrm{lb}$. Quota options for 1998 range from a low of $342,578 \mathrm{lb}$ to a high of $573,863 \mathrm{lb}$.

## Area 24 - Management Decisions for 1997 and 1998 by Geoduck Management Area

## GMA 24-A1: Inside - a portion of Subarea 24-6 and Subareas 24-7 and 24-9.

This Geoduck Management Area designation is no longer used. The area has been divided into seven separate management units - GMAs 24-A2a, -A2b, -A3, -A4,-A5, -A6a, and -A6b.

This was traditionally the major fishing area in the "inside" areas, a portion of Subarea 24-6, Subarea 24-7 and Subarea 24-9. Major grounds are Elbow Bank, Maurus Channel and Yellow Bank.

Fishers supported the recommendation that Elbow Bank and Yellow Bank (GMA 24-A6) be closed for the 1994 and 1995 seasons and effort shifted to other areas, with new quotas in 1994 for Lemmens Inlet (GMA 24-A5) and Epper Pass-Morfee-Dunlap (GMA 24-A4). A survey was undertaken at Yellow Bank in the fall of 1995. In 1996, the Yellow Bank portion of GMA 24A6 re-opened with a $30,000 \mathrm{lb}$ quota and experimental fishing with an on-board observer. For 1997 and 1998 a further division of GMA 24-A6 into GMAs 24-A6a and 24-A6b has been recommended. The Elbow Bank portion remains closed, with limited fishing opportunities proposed at Yellow Bank (GMA 24-A6a) and on the east side of Marus Channel (GMA 24-A6b).

## GMA 24-A2: Yarksis/Wickaninish - portion of Subarea 24-8.

The single recommended quota option for 1996 was $73,112 \mathrm{lb}$. In the analysis for 1997 quotas, GMA 24-A2 was split into GMAs 24-A2a (Yarksis) and 24-A2b (East Father Charles Channel) in order to distribute fishing effort more evenly over the four beds reported in this area.

## GMA 24-A2a: Yarksis - portion of Subarea 24-8.

This new GMA for 1997, in the northern portion of Subarea 24-8, has one bed (1302), measuring 130.2 ha. The greatest portion of landings to date from GMA 24-A2 have come from this bed.

Quota options for 1997 and 1998 ranged from a low of $8,687 \mathrm{lb}$ to a high of $23,896 \mathrm{lb}$. The 1997 and 1998 quotas were set at the mid-range option of $16,180 \mathrm{lb}$.

## GMA 24-A2b: East Father Charles Channel - portion of Subarea 24-8.

This is a new GMA for 1997 in the southern portion of Subarea 24-8. This GMA has three beds ( $1403,1303,1301$ ) measuring 62.5 ha. Bed 1301 was suspected of being too large. After consultation with fishers, this bed was redrawn to exclude much of the shallow unproductive area, and assigned a new area of 35 ha . The area of bed 1403 has been scaled by landings criteria to 5 ha.

Quota options for 1997 and 1998 ranged from a low of $17,171 \mathrm{lb}$ to a high of $23,626 \mathrm{lb}$. The 1997 and 1998 quotas were set at the mid-range option of $20,360 \mathrm{lb}$.

GMA 24-A3: Tonquin/Echachis - portion of Subarea 24-8.
GMA 24-A3 is comprised of the southern portion of Subarea 24-8, with one bed measuring 46 ha. The westerly boundary of GMA 24-A3 was adjusted slightly for the 1996 fishery to accommodate the new GMA $24-\mathrm{C} 2$, but did not result in any changes to the number of beds or hectares of reported fishing area in GMA 24-A3. The recommended quota option for the 1996 fishery was $41,462 \mathrm{lb}$. However, $30,000 \mathrm{lb}$ were transferred to Yellow Bank to support exploratory fishing, leaving $11,462 \mathrm{lb}$ to be fished in GMA Area 24-A3.

Harvesters have continued to recommended a reduction in quota for this GMA, stating that the beds are both difficult to fish due to exposure and that there is little productive ground. One bed (1402) was eliminated from the assessment for 1997 quotas as its' existence is suspect. Bed 1401 was remeasured again, during the assessment for 1997 quotas, and reduced to 46 ha .

Recommended annual quota options ranged from a low of $10,352 \mathrm{lb}$, mid range at $12,856 \mathrm{lb}$ to a high of $15,434 \mathrm{lb}$. However, harvesters recommended that GMA 24-A3 remain closed in 1997 and 1998, in order to balance I.Q.s in the three coastal regions.

GMA 24-A4: Epper Pass/Dunlap Island - portions of Subareas 24-6 and 24-7.
GMA 24-A4 is comprised of waters in the vicinity of Epper Pass and Dunlap Island (portions of Subareas 24-6 and 24-7) with 9 beds totalling 211.4 ha in 1996. Measured areas have changed often: In 1994, 9 beds measured 122 ha. In 1995, 9 beds measured 118 ha.

During the assessment for 1997 quotas, two beds within the research closure at Richie Bay were removed from calculations. Bed 1002 was remeasured with increased area documented in the 1995 survey at Yellow Bank (Hand, DFO, pers.comm.). One small new bed (1102) was added from the 1996 fishery.

GMA 24-A4 was separated from GMA 24-A1 in 1994. This area has been heavily fished: Total cumulative removals to 1994 were estimated at 0.41 geoducks $/ \mathrm{m}^{2}$ (Hand et al. 1996). The 1994 recommended quota was $40,000 \mathrm{lb}$, approximately equal to the calculated option (Harbo et al. 1994). The calculated and set quota for 1995 was $22,410 \mathrm{lb}$. The recommended quota set for 1996 was $26,896 \mathrm{lb}$.

Annual quota options for 1997 and 1998 ranged from a low of $47,636 \mathrm{lb}$ to a high of $66,364 \mathrm{lb}$. The 1997 quota was set at the mid range option of $56,862 \mathrm{lb}$. In 1998, the bed at the S. end of Morfee Is. (bed 903) was closed. The 1998 quota was set at $56,841 \mathrm{lb}$. The 21 lb reduction from 1997 was part of the reduction needed to account for the $97 / 98$ switch of Lemmens Inlet, Sydney Inlet and Epper/Dunlap quotas for Coomes Bank quota (see GMA 24-B2 below).

GMA 24-A5: Lemmens Inlet - Subarea 24-9.
GMA 24-A5 is comprised of the waters of Subarea 24-9 (Lemmens Inlet) with 2 beds totalling 118 ha (1996). One bed of 3 ha (1603) was deleted from the analyses for 1997 quotas due to there being no landing history recorded on logs.

GMA 24-A5 was separated from GMA 24-A1 in 1994. These beds had not been fished from 1989 to 1994 due to "poor" quality relative to other beds in Area 24.

The calculated and set quota for 1995 was $27,722 \mathrm{lb}$. For the 1996 analyses, bed 1602 , which had been scaled by landing criteria, reverted to the measured area of 28.7 ha. The recommended quota option set for 1996 was $39,014 \mathrm{lb}$.

Annual quota options for 1997 and 1998 ranged from a low of $25,412 \mathrm{lb}$ to a high of $38,375 \mathrm{lb}$. The 1997 quota was set at the mid-range option of $31,799 \mathrm{lb}$ with a requirement for both a market sample and an ongrounds observer to document beds. The 1998 quota for Lemmens Inlet was reassigned to 1997 so that the 1997 quota from Coomes Bank, which could not be taken in 1997, could be taken in 1998. No quota was assigned to Lemmens Inlet in 1998.

## GMA 24-A6: Elbow Bank/Yellow Bank - portions of Subareas 24-6 and 24-7.

In the assessment for 1996 quotas, the Yellow Bank and Elbow Bank GMA had 7 beds measuring a total of 204 ha (1995).

This GMA was a new designation for 1994, and was separated from GMA 24-A1. The bed areas for Elbow Bank and Yellow Bank were remeasured in 1993. With the elimination of shallow grounds, the bed areas were reduced; Elbow Bank from 268 ha to 90 ha and Yellow Bank from 137 ha to 58 ha.

Harbo et al. (1994) estimated that 41 and 58 years of quota have been landed at Yellow Bank and Elbow Bank, respectively. Further analyses in 1994 indicated that $72 \%$ of original stock had been harvested from GMA 24-A6 collectively and that removal rates were 1.00 geoducks $/ \mathrm{m}^{2}$ (Harbo et al. 1995).

A closure was recommended in 1994. A continued closure was recommended for 1995. A survey on Yellow Bank was conducted in the fall of 1995. Assessment in 1996 using increased mean weights for west coast geoducks determined that $69 \%$ of estimated original geoduck stocks had been harvested from beds in this GMA in 18 years of fishing, and that removals were 0.96 geoducks $/ \mathrm{m}^{2}$.

Stock assessment surveys were undertaken at both Elbow Bank and Yellow Bank in the 1995 fishing season.

Although a continued closure was recommended for 1996, a management decision was made, based on favourable preliminary survey results, to transfer quota ( $30,000 \mathrm{lb}$ ) from GMA 24 -A3 to
allow for an experimental fishery at Yellow Bank with an ongrounds observer. Late in the fall of 1996, fishers were unable to land the quota assigned to GMA $24-\mathrm{C} 2$, so $7,498 \mathrm{lb}$ were transferred to Yellow Bank, to be deducted from the 1997 quota.

Elbow Bank was remeasured during the 1997 assessment to 88.5 ha, with calculations showing greater than $50 \%$ of the original biomass has been harvested. This area was divided into two new geoduck management areas, in 1997, in order to fish beds on the east side of Maurus Channel (GMA 24-A6b) and at Yellow Bank (24-A6a).

## GMA 24-A6a: Yellow Bank - portion of Subarea 24-7.

GMA 24-A6a, new in 1997, is comprised of 2 beds measuring 97.3 ha, an increase from 58 ha used since 1993. Former bed \#1005 was combined with \#1004 as a single large bed.

Annual quota options for 1997 and 1998 ranged from a low of $4,867 \mathrm{lb}$ to a high of $44,059 \mathrm{lb}$. The mid-range option of $21,596 \mathrm{lb}$ was calculated with the mid-range estimates of bed area, mean weight and the mid-range survey density of 2.8 geoducks $/ \mathrm{m}^{2}$. Survey from 1995 data still require additional assessment, and this may influence future quota calculations.

A management decision was made to set quotas based on the low range density estimate of 2.2 geoducks $/ \mathrm{m}^{2}$ (but still using mid range estimates of bed area and mean weight) until the data analyses are complete for Yellow Bank (bed \#1004). The 1997 quota was set at $15,584 \mathrm{lb}$., however the removal of $7,498 \mathrm{lb}$. fished in late 1996 left a remaining quota for 1997 of $8,086 \mathrm{lb}$. The 1998 quota was set at the mid-range amount of $15,584 \mathrm{lb}$.

## GMA 24-A6b: East Maurus Channel - portion of Subarea 24-6.

GMA 24-A6b, new in 1997, is comprised of a total 3 beds measuring 112 ha. However, the large bed on Elbow Bank remains closed due to harvest estimated at greater than $50 \%$ of original biomass, calculated using a density of 1.4 geoducks $/ \mathrm{m}^{2}$. Survey data from 1995 still require further evaluation.

Annual quota options for the beds on the east side of Maurus Channel ranged from a low of $5,465 \mathrm{lb}$ to a high of $7,803 \mathrm{lb}$. The 1997 and 1998 quotas were set at the mid-range option of 6,640 lb.

## GMA 24-B1: Outside - portion Subarea of 24-6.

In the assessments for 1996 and 1997 quotas, GMA 24-B1 was comprised of 10 beds measured at 565 ha (1995). Bed 801 was remeasured and bed 706 was scaled by landings criteria for the 1997 quota calculation.

In the analyses for 1994 quotas, all beds were included. However, some beds were scaled down with landing criteria (Harbo et al. 1993) or remeasured. For 1996 quotas, all beds were remeasured. Bed \#704 at Hobbs Islet reverted from a scaled area of 10 ha to the measured area
of 30.28 ha . The area of bed \#701 was maintained at the previous measured area of 101 ha, as it was suspected that the new measurements had encompassed some unsuitable shallow areas. One bed with minor landings (806) remained scaled at 1 ha. Bed 705 was deleted from the biomass estimate for 1997/98 quotas. This bed is recorded in very shallow ground, unlikely to be acceptable geoduck habitat and has no landings recorded since 1986.

The recommended quota for 1994 was $125,000 \mathrm{lb}$, reduced from $185,095 \mathrm{lb}$ to compensate for high landings in past years. Based on 1.4 geoducks $/ \mathrm{m}^{2}, 34$ years of quota had been landed (Harbo et al. 1994). Analyses leading to 1995 quotas indicated that $39 \%$ of available stock had been harvested in 16 years of fishing. Removals were estimated at 0.55 geoducks $/ \mathrm{m}^{2}$. The quota was set at $58,412 \mathrm{lb}$.

Analyses for 1996 quotas also estimated that $39 \%$ of available stock has been harvested. However, the increased mean weights used for the west coast resulted in a slight increase in the calculated quota. The 1996 quota was set at $66,728 \mathrm{lb}$.

In the 1997 analyses, a new estimate of adjusted landings was used to estimate the harvest over past years not reported on harvest logs, with landings amortised over a 50 year fishery. As a result, a number of beds in GMA 24-B1 have estimated harvests greater than $50 \%$ of the original biomass and are closed.

Annual quota options for 1997 and 1998 ranged from a low of $39,003 \mathrm{lb}$ to a high of $77,760 \mathrm{lb}$. The 1997 and 1998 quotas were set at the mid-range option of $54,150 \mathrm{lb}$ with large bed closures in the vicinity of Shot and Shag Islands. An ongrounds observer was required to monitor harvest of the remaining beds and to ensure boundary compliance.

## GMA 24-B2: Coomes Bank - portion of Subarea 24-6.

In the assessment for 1996 and for 1997 quotas, GMA 24-B2 was comprised of 2 beds with an area of 354 ha (1995).

One large bed (\#901), measured at 322 ha (1995), supported a fishery in excess of 1.9 million lb adjusted landings ( 886 t ) to the end of 1993.

In order to spread fishing effort over the GMA 24-B "outside" area, an annual quota has been assigned to this bed since 1991. The annual quota using 1.4 geoducks $/ \mathrm{m}^{2}$ over 339 ha was calculated at $111,452 \mathrm{lb}$ (Harbo et al. 1994). The recommended quota for 1994 was $100,000 \mathrm{lb}$. For 1995 quotas, an estimated $20 \%$ of original stock had been harvested over 16 years of fishing. Removals were estimated at 0.27 geoducks $/ \mathrm{m}^{2}$. The quota for 1995 was $99,515 \mathrm{lb}$ (Harbo et al. 1995). In 1996, area boundaries were rationalised to include beds on the south side of Calmus Passage, resulting in a slight increase in available hectares of fishing area and a quota of 104,943 lb.

Fishers have expressed concerns in the past over the available stock in GMA 24-B2 and the difficulties of fishing due to strong tides and poor shows. The annual quota options for 1997 and

1998 ranged from a low of $70,923 \mathrm{lb}$ to a high of $113,120 \mathrm{lb}$. In order to address concerns that the bed size may be overestimated (bed \#901-322 ha) or that the bed has been overharvested, roughly half the calculated annual quota ( $54,000 \mathrm{lb}$ ) was assigned to the eastern half of bed \#901 in 1997 and the other (western) portion of the quota ( $37,712 \mathrm{lb}$ ) to the other half of the bed which was to be harvested in 1998. Bed \#902 would serve as a fallback area if the quota could not be attained. Fishing in 1997 and 1998 was to be directed by an ongrounds observer to test out the size and relative productivity of the bed. This did not occur in 1997 as the bed could not be fished until too late due to PSP and weather related problems. In 1998, 91,712 lb are assigned to GMA 24-B2. The quota will be divided in half $(45,856 \mathrm{lb})$ and each half will be taken, separately, and with an observer to verify bed size.

## GMA 24-B3: Ahousat - portions of Subareas 24-4 and 24-6.

In the assessment for 1996 quotas, GMA 24-B3 was comprised of 2 open beds measuring 263 ha. These beds were remeasured in the assessment for 1997/98 quotas to 179 ha.

A separate annual quota was first set in 1991 to spread fishing effort throughout Area 24. A bed at Whitesand Cove (\#605) has been closed as a grey whale sanctuary and was removed from area calculations (Harbo et al. 1994).

GMA 24-B3 was closed in 1993. A reduced quota of $50,000 \mathrm{lb}$ was recommended for 1994 in compensation for heavy fishing. Analysis for 1995 quotas indicated that $26 \%$ of original stock has been harvested in 16 years of fishery and removals were estimated at 0.36 geoducks $/ \mathrm{m}^{2}$. The quota was set at $54,963 \mathrm{lb}$ in 1995. In 1996 quota calculations, the large bed \#601 near Ahousat was suspected being overestimated as to size. Therefore, an estimated area of 191 ha was used for the combination of this bed and former bed \#602, which was amalgamated with bed \#601. Further remeasurement of these beds was recommended. The 1996 quota was set at 70,202 lb .

In the assessment for 1997/98 quotas, beds near Ahousat were redrawn on an updated chart with advice from fishers and remeasured to a total of 179 ha.

The 1997 quota options ranged from a low of $18,016 \mathrm{lb}$ to a high of $26,279 \mathrm{lb}$. The 1997 and 1998 quotas were set at the mid-range option of $22,087 \mathrm{lb}$, to be fished with an ongrounds observer to verify bed size.

## GMA 24-B4: Russell Channel - portion of Subarea 24-6.

In the assessment for 1996 quotas, GMA 24-B4 was comprised of 3 beds measuring an estimated 203 ha (1995). In the 1997/98 assessment, bed area was rounded to 202 ha.

Fishers were unable to attain the $75,000 \mathrm{lb}$ quota in Area 20 during the summer of 1991. The remaining quota from Area 20 of $72,129 \mathrm{lb}$ was assigned to the newly designated GMA 24-B4 in the fall of 1991. Area 24-B4 was closed in 1992 and opened in 1993 with a quota of $180,000 \mathrm{lb}$ (Harbo et al. 1994).

The quota recommended for 1994 was $50,000 \mathrm{lb}$, less than the annual calculated quota of 60,493 lb. For 1995 quota calculations, an estimated $22 \%$ of original stock had been harvested in 13 years of fishing, with estimated removals of 0.36 geoducks $/ \mathrm{m}^{2}$. The reduced annual quota for 1995 was $46,421 \mathrm{lb}$ (Harbo et al. 1995).

In 1996, area boundaries of GMA 24-B4 were adjusted slightly to better describe the fishing area. This resulted in the inclusion of 2 additional beds (\#607 and \#501) to the west of Kutcous Island that were previously part of the $24-\mathrm{B} 1$ quota. The quota was set at $58,377 \mathrm{lb}$.

In the 1997/98 assessment, annual quota options range from a low of $42,572 \mathrm{lb}$ to a high of $64,382 \mathrm{lb}$. The 1997 and 1998 quotas were set at the mid-range option of $53,317 \mathrm{lb}$.

## GMA 24-Cl: Sydney Inlet - Subarea 24-2.

A new GMA in 1996, GMA 24-C1 was comprised of 11 beds measuring 100 ha. Two beds at Hesquiat Harbour were removed from calculations leaving 9 beds for consideration. In the 1997/98 assessment, these 11 beds measured 99 ha.

The original GMA 24-C was divided into GMAs 24-C1 (Sydney Inlet) and 24-C2 (Exposed areas), in 1996, to distribute fishing effort to the lightly harvested exposed beds.

Sydney Inlet was first added to GMA 24-C in 1985 and, with the exception of a closure in 1988, was fished annually until 1990. Fishers expressed concerns about low densities of geoducks and recommended closure from 1991 through 1994. Quota calculations for 1995 indicated that $19 \%$ of the original stock had been harvested in 10 years of fishing. Removals were estimated at 0.27 geoducks $/ \mathrm{m}^{2}$. In 1995, fishers requested an opportunity for an exploratory fishery once again. A quota of $30,000 \mathrm{lb}$ was set, transferred from GMA 24-A3. The quota was landed from Sydney Inlet beds without problem. During 1995, before the opening of GMA 24-C, (Hesquiat Harbour Subarea 24-1) beds were closed in consideration of First Nations concerns. The 1996 quota was set at $25,132 \mathrm{lb}$.

In the 1997/98 assessment, a large bed (\#301) in the vicinity of Sharpe Point has been harvested to greater than $50 \%$ of original biomass and was closed. Annual quota options for 1997 and 1998 , in the remaining beds, ranged from a low of $18,950 \mathrm{lb}$ to a high of $26,370 \mathrm{lb}$. The 1997 quota was set at the mid-range option of $22,180 \mathrm{lb}$. The 1998 quota was reassigned to 1997 so that the 1997 quota from Coomes Bank could be taken in 1998. No quota was assigned to Sydney Inlet in 1998.

## GMA 24-C2: Exposed - portions of Subareas 24-8 and 124-3.

New in 1996, GMA 24-C2 was comprised of 3 beds measuring 24 ha (1995). Beds and hectares were the same in the assessment for 1997/98 quotas.

Beds in the exposed areas were fished for greater than $100,000 \mathrm{lb}$ in the years 1985,1986 , and 1990. Fishers reported that there are very small fishing areas and they were only able to land 770
lb in 1990 from the 11 ha bed at the La Croix Group. Beds in the vicinity of Ahous Point and south have not been fished since 1986. Closure was recommended in Harbo et al. (1993).

In 1996, these three beds were separated from GMA 24-C and assigned a separate quota. If this quota could not be achieved, it should be removed from future quota calculations. Opportunity to fish in GMA 24-C2 was left until too late in the 1996 season. Poor weather conditions required that the 1996 quota of $7,498 \mathrm{lb}$ be transferred to Yellow Bank, and that amount was deducted from the 1997 Yellow Bank quota.

Quota options were once again calculated 1997 and 1998 for GMA 24-C2 and ranged from a low of $4,936 \mathrm{lb}$ to a high of $6,997 \mathrm{lb}$. Fishers chose to leave this area closed for 1997 and 1998 in order to equalise 1997 and 1998 coastwide I.Q.s.

## GMA 24-D: Inlets - Subareas 23-3, 24-5, 24-10, 24-12, 24-13 and 24-14.

New boundaries were determined for GMA 24-D in the assessment for 1996 quotas, leaving a total of 19 beds measuring 97 ha (1995).

The "Inlet" areas were fished between 1984 and 1990, for logbook landings of $490,319 \mathrm{lb}$, adjusted for misreporting in logbooks to $591,517 \mathrm{lb}$. Fishers have expressed concern that, generally, these areas have been overfished and that they should remain closed until further evaluation. The fishery has been closed in the inlets since 1991. Analyses for 1995 quotas indicated that $20 \%$ or more of original stock had been harvested in 9 years of fishing, with removals estimated at 0.28 geoducks $/ \mathrm{m}^{2}$ (Harbo et al. 1995).

In consultation during 1996 quota assessments, fishers requested that a small quota be allotted for a portion of Subarea 24-11. As a result, a new quota area was designated for 1996; GMA 24-D1 (Indian Islands), while the remainder of GMA 24-D remained closed.

Recommended quota options in the 1997/98 assessment ranged from a low of $18,538 \mathrm{lb}$ to a high of $26,452 \mathrm{lb}$. The closure was continued in 24-D in 1997 and 1998.

## GMA 24-D1: Indian Islands - portion of Subarea 24-11.

GMA 24-D1 was a new designation in 1996, comprised of 3 beds with a total area of 35 ha in the 1996 and the 1997/98 quota assessments.

Three beds in the vicinity of Indian Island have been harvested for a total of $34,866 \mathrm{lb}$, adjusted for misrepresenting to $40,689 \mathrm{lb}$ in 1986 and 1987. A portion of bed \#2002 falls within the Pacific Rim Park closure and was excluded from the quota calculation. A quota of $13,876 \mathrm{lb}$ was set in 1996, with $13,811 \mathrm{lb}$ landed.

In the 1997/98 assessment, quota options ranged from a low of $10,050 \mathrm{lb}$ to a high of $12,946 \mathrm{lb}$. The 1997 and 1998 quotas were set at the mid-range option of $11,476 \mathrm{lb}$.

## Area 25 - Fishing History

Landings from Area 25 were first reported in 1978. In 1980, a separate quota of $600,000 \mathrm{lb}$. was set for the combined Areas 25, 26 and 27. Landings from Area 25 made up $11.5 \%$ of the coastwide total and $18 \%$ of the west coast areas in 1980 (Harbo and Peacock, 1983). In 1981 a quota of 499 t was set for Areas 25, 26 and 27 combined. Area 25 was second in west coast landings to Area 24 and supported $17.5 \%$ of the coastwide landings. In 1982 there were no area quotas set, just a coastwide TAC. $37 \%$ of the coastwide landings came from Areas 24, 25 and 26. In 1983 the west coast fishery was primarily focused in Area 24 due to management actions, however increased again in Area 25 in 1984, when the overall west coast quotas were increased and for the first time a separate quota of $800,000 \mathrm{lb}$. ( 363 t ) was set for Area 25. The first closures were implemented in 1984 in Area 25 to protect herring spawn (Harbo et al. 1986).

A quota set of $800,000 \mathrm{lb}$. ( 363 t ) was set for Area 25 in 1985 and was exceeded by 236 t , with reported fish slip landings of 599 t .. The quota remained at $800,000 \mathrm{lb}$. through 1987 , when Area 25 was divided into GMA's 25-A (Nootka - Esperanza) and 25-B (Nuchatlitz).

A re-evaluation of logbook areas and densities used in quota calculations resulted in a quota reduction of $200,000 \mathrm{lb}$. in 1988 to 400,000 for GMA $25-\mathrm{A}$ and $200,000 \mathrm{lb}$. for GMA $25-\mathrm{B}$, which remained closed due to large quota overages incurred in 1987.

For 1991 and 1994 fisheries, Area 25 was divided into four quota areas to distribute fishing effort. A three year rotational quota was set at $1,570,000 \mathrm{lb}$. in 1991 and $1,157,913 \mathrm{lb}$. in 1994 with the closure of GMA 25-C.

## Area 25 - Management Decisions for 1997 by Geoduck Management Area

## GMA 25-A: Esperanza Inlet/Port Eliza - Subareas 25-9, 25-11, 25-12 and a portion of 25-13.

In the assessment for 1994 quotas, GMA 25-A was comprised of 10 beds measuring 442 ha (1992). (Harbo et al. 1994 reports 5 beds in error). In the assessment for 1997 quotas, 17 beds measured 516 ha.

Beds at Rolling Roadstead and Double Island have been subjected to heavy fishing pressure since 1980. Adjusted landings from Rolling Roadstead are estimated at about 4.6 million lb up to the end of the 1994 fishery. Beds in GMA 25-A may have higher densities than others. A survey in 1978 (Cox, pers. comm.) estimated 2.04 geoducks $/ \mathrm{m}^{2}$ over 426.7 ha.

In the assessment for 1994 quotas, five beds with low landings were scaled by landings criteria. New beds were found in both the 1991 and 1994 fisheries. The 1991 quota was set at $560,000 \mathrm{lb}$ and reduced to $431,000 \mathrm{lb}$ in 1994 in an attempt to compensate for the years of quota landed compared to years of actual fishing. An estimated 21 to 30 years of quota had been landed up to and including 1991, in 12 years of fishing .

In the 1997 assessment, quota options ranged from $155,279 \mathrm{lb}$ to a high of $350,808 \mathrm{lb}$. The quota was initially calculated at the medium range of $250,811 \mathrm{lb}$. Quotas in GMAs 25-A and 25-B were both adjusted (reduced) to allow for an even number of I.Qs on the west coast. The quota was set at $221,945 \mathrm{lb}$.

## GMA 25-B: Nuchatlitz - a portion of Subarea 25-13 and 25-14.

In the 1994 quota assessment, GMA 25-B had 4 beds measuring an estimated 586 ha. In the assessment for 1997/98 quotas this GMA had 5 beds measuring 595 ha.

Until a separate quota was assigned to this GMA in 1991, this large area had only been fished for three years in the past, 1984, 1985 and 1987. The services of a fish packer are required to make fishing this area viable due to navigation difficulties and the distance to a landing port. The 1991 quota was set at $785,000 \mathrm{lb}$. The 1994 quota was reduced to $578,000 \mathrm{lb}$, based on an original density estimate reduced from 2 to 1.4 geoduck $/ \mathrm{m}^{2}$.

In the 1997 assessment, quota options ranged from a low of $477,526 \mathrm{lb}$ to a high of $689,704 \mathrm{lb}$. The medium range option, for 1997 , of 581,159 was reduced by $59,196 \mathrm{lb}$ to $513,806 \mathrm{lb}$ in order to equalise west coast I.Q.s.

## GMA 25-C: Rosa Harbour - portion of Subarea 25-13.

In the assessment for 1991 quotas, GMA 25-C had 2 beds which measured an estimated 69 ha (1989 data). For 1994 quota calculations, one bed was scaled with landings criteria. These two beds totalled 58 ha. In the assessment for 1997 quotas, the 2 beds were remeasured at 54 ha.

This is a small GMA with one bed fished heavily, the other bed with very minor landings to date. An estimated 22 to 31 years of quota were landed up to and including 1991, when the quota was set at $100,000 \mathrm{lb}$. A closure was recommended for 1994.

In the assessment for the 1997 fishery, recommended quota options ranged from a low of 2,389 lb to a high of $24,631 \mathrm{lb}$. The 1997 quota was set at $13,252 \mathrm{lb}$, with the requirement for an observer to verify the existence of a bed with a history of minor landings (bed 104 at Nuchatlitz Reef).

## GMA 25-D: Nootka Sound - Subareas 25-3 to 25-8 and 25-15.

In the 1994 quota assessment, GMA 25-D was comprised of 23 beds measuring 146 ha. In the assessment for 1997/98 quotas, 23 beds measured 177 ha.

This area is characterized by many small beds. In the 1994 assessment, 14 beds with minor landings were scaled according to landings criteria. The quota was set at $100,000 \mathrm{lb}$ in 1991 based on 7 beds and 81 ha.. In 1994 the quota was again set at $100,000 \mathrm{lb}$ after consultation with fishers, which was less than the calculated quota option for that year of $144,000 \mathrm{lb}$.

In the assessment for 1997 , quota options ranged from a low of $89,067 \mathrm{lb}$ to a high of $147,426 \mathrm{lb}$. The 1997 quota was set at $117,602 \mathrm{lb}$.

## Area 26 - Fishing History

Area 26 beds will be re-assessed in 1998 for a fishery in the 1999 rotation.

## Area 27 - Fishing History

Only minor landings were reported from Area 27 ( $<10 \mathrm{t}$ ) until 1985 when the fishery landed 1050 t. Up to and including 1984, the quota for Area 27 was combined with Area 26, or sometimes with Areas 25 and 26, where most of the past effort had been directed.

In 1985, separate quotas were assigned to Area 27, and the area was divided into GMA 27-A (Inlet Subareas 27-7 to 27-11) and GMA 27-B (Exposed, 27-1 to 27-6) which was an exploratory fishery with no quota. GMA 27-B included protected waters in Subarea 27-2 (Winter Harbour and Forward Inlet). The fishery landed 953 t from this area before the last portion of GMA 27-B was closed on Aug. 30,1985.

In 1986, Area 27 was divided into three portions, GMA 27-A (Subareas 27-2, 27-3, 27-7 to 2711), GMA 27-B (Subareas 27-4 to 27-6-Klaskino and Klaskish Inlets); and an exposed section described in-season from north of Kains Light to Cape Scott (a portion of Subarea 27-2, Subarea 27-1 and Cape Scott to Cape Sutil (Subarea 12-14).

In 1988, the division of Area 27 remained the same, but a $300,000 \mathrm{lb}$ quota was set for GMA 27A (Inside) and a $300,000 \mathrm{lb}$ quota for $27-\mathrm{B}$ (Outside-Inlets). No quota was set for GMA 27-C (North Exposed area). Landings of 130 t were recorded for $27-\mathrm{C}$ in 1988.

In 1989, a three year rotational quota of $760,000 \mathrm{lb}$ was set for GMA 27-A (Subareas 27-2, 27-3 and 27-7 to 27-11 inclusive). GMA 27-B (Klaskino and Klaskish Inlets) was scheduled to be fished in 1990 and GMA 27-C in 1991. The fishery in GMA 27-C North was delayed to 1992 for convenience of the fishers.

In 1992, Area 27 was divided into eight quota units, GMAs 27-A to 27-H to distribute effort and protect beds that had been heavily harvested in the past. The total three year rotational quota was set at $676,378 \mathrm{lb}(307 \mathrm{t})$ based on a density of 2 geoducks $/ \mathrm{m}^{2}$ and 770 ha of identified fishing area. The fishery was complicated by several closures for PSP. As a result, 273,622 lb of quota was moved from GMA 27-H (Klaskino Inlet) late in the season to portions of Area 24 (GMAs 24-A, 24-B2 and 24-B3). An exploratory quota was set in GMA 27-G, (exposed portions of 27-1 and 27-2), but fishers were unable to locate stock and the quota was moved to Area 23 (Harbo et al. 1993).

In 1995, the total calculated quota for Area 27 was decreased by $29 \%$ to $477,698 \mathrm{lb}$ for the three year period 1995-96-97.

## Area 27 - Management Decisions for 1998 by Geoduck Management Area

## GMA 27-A: Quatsino Sound - Subarea 27-7.

In the assessment for 1995 quotas, GMA 27-A was comprised of 7 beds measured at 112 ha . In the assessment for 1997/98 quotas, 7 beds measured 115 ha.

This area has been fished since 1985 with high removals at two of the four beds on the north shore (Nordstom Cove and Bedwell Island). In 1992, the fishery was restricted to the south shore only of Subarea 27-7, with a quota of $100,000 \mathrm{lb}$ (Harbo et al. 1993). There was concern that contaminated areas needed to be identified.

In the analysis for 1995 quotas, several beds were scaled by landings criteria. Analyses based on a 50 year fishery showed that $17 \%$ of original stock had been harvested in 10 years of fishing (using all beds) up to and including 1992. Removals were estimated at 0.24 geoduck $/ \mathrm{m}^{2}$ (Harbo et al. 1995). The 1995 quota was set at the calculated amount of $91,230 \mathrm{lb}$.

Quota options in the 1998 assessment ranged from a low of $74,914 \mathrm{lb}$ to a high of $108,614 \mathrm{lb}$. The mid-range quota of $91,456 \mathrm{lb}$ was assigned in 1998.

## GMA 27-B: Cliffe Point to Lawn Point - a portion of Subarea 27-2.

In the assessment for 1995 quotas, GMA 27-B was comprised of 3 beds measuring 40 ha (1994). In the 1997/98 assessment, there are a total of 4 beds reported with a measured area of 46 ha.

GMA 27-B is an exposed portion of the coast with hard packed bottom and is likely difficult to fish, especially for small vessels. The 1992 quota was $50,000 \mathrm{lb}$ and most was landed from Gooding Cove. Analyses for 1995 quotas, based on a 50 year fishery, showed that $12 \%$ of original stock was harvested in 10 years of fishing. Removals were estimated at 0.16 geoducks $/ \mathrm{m}^{2}$. The 1995 quota was set at the calculated amount of $37,784 \mathrm{lb}$.

Quota options for the 1998 fishery range from a low of $37,528 \mathrm{lb}$ to a high of $50,792 \mathrm{lb}$. The mid-range quota of $44,104 \mathrm{lb}$ was assigned in 1998.

## GMA 27-C: Forward Inlet - Subarea 27-3.

In the assessment for 1995 quotas, GMA 27-C was comprised of 3 beds measuring 126 ha. In the 1997/98 quota assessment, 3 beds measured 149 ha.

This area has been fished heavily since 1983, with landings of at least 573 t reported up to 1992. Fishers have taken 31 years of quota assuming a harvest rate of $1 \%$ and an average density of 1.4 geoducks $/ \mathrm{m}^{2}$. Bed removals were as high as 0.74 geoducks $/ \mathrm{m}^{2}$ over 6 ha. Fishers reported large numbers of small "juvenile" clams. The fishery was closed in 1992, pending reassessment (Harbo et al. 1993).

Analyses for 1995 quotas, based on a 50 year fishery, estimated that $39 \%$ of original stock had been harvested in 10 years of fishing. Removals were estimated at 0.55 geoducks $/ \mathrm{m}^{2}$ (Harbo et al. 1995). The quota for 1995 was $34,035 \mathrm{lb}$. A survey was conducted in Forward Harbour in 1996 (Hand, in prep.).

A bed closure is required in the vicinity of Mathews Island, where greater than $50 \%$ of the original biomass has been harvested. An ongrounds observer is recommended to monitor fishing this bed closure

Quota options for the 1998 fishery range from a low of $41,416 \mathrm{lb}$ to a high of $77,226 \mathrm{lb}$. The increase in calculated quotas is due to increased bed area. The mid-range quota of $56,952 \mathrm{lb}$ was assigned in 1998.

## GMA 27-D: Kains Island - portion of Subarea 27-2.

In the assessment for 1995 quotas, GMA 27-D was comprised of 2 beds measuring 46 ha. In the assessment for 1997/98 quotas, there are 3 beds measuring 52 ha.

A separate quota was set for 2 beds in this area in 1992, which had supported a modest fishery in the past. Fishers reported low densities and believe they will be having to fish in deeper areas. The 1992 quota was set at $70,000 \mathrm{lb}$ and landed without problem. Analyses for 1995 quotas, based on a 50 year fishery, showed that $14 \%$ of original stock had been harvested in 10 years of fishing. Removals were estimated at 0.20 geoducks $/ \mathrm{m}^{2}$ (Harbo et al. 1995). The 1995 quota was set at the calculated amount of $40,286 \mathrm{lb}$.

Quota options for the 1998 fishery range from a low of $41,035 \mathrm{lb}$ to a high of $56,554 \mathrm{lb}$. The mid-range quota of $48,653 \mathrm{lb}$ was assigned in 1998.

## GMA 27-E: San Josef Bay - portion of Subarea 27-2.

In the assessment for 1995 quotas, 1 bed was reported which measured 110 ha. In the 1997/98 assessment this one bed was remeasured to 127 ha .

There was relatively minor fishing reported from a large measured area, estimated at $262,681 \mathrm{lb}$ landed in two fishing years, 1988 and 1992. A separate quota of $175,000 \mathrm{lb}$ was set for San Josef Bay 1992. This was set higher than the quota option (Harbo et al. 1993) to balance the west coast quotas and meet the management decision to reduce quotas by $15 \%$ in both 1992 and 1993.

Analyses for 1995 quotas, based on a 50 year fishery, showed that $10 \%$ of original stock has been harvested in the 7 years since this area was first fished. Removals were estimated at 0.14 geoducks $/ \mathrm{m}^{2}$. The quota for 1995 was $101,763 \mathrm{lb}$.

Quota options for 1998 range from a low of $105,552 \mathrm{lb}$ to a high of $141,368 \mathrm{lb}$. An ongrounds observer fishery is recommended to document bed size during the next fishery in GMA 27-E. The area was not opened, in 1998, in order to equalize quotas coastwide.

## GMA 27-F: Sea Otter Cove - portion of Subarea 27-2.

In the assessment for 1995 quotas, GMA 27-F had one reported bed measuring 14 ha. In the 1997/98 quota assessment, 1 bed measured 17 ha.

This area was fished for 14 days in 1988, and fishers advised that there may be more stock at this site than first identified. Analyses for 1992 quotas estimated 23 years of quota (@ 2 geoducks $/ \mathrm{m}^{2}$ ) had been taken over the 14 ha then charted from harvest logs. This area should have been closed in 1992. However, to balance the 1992-1993 quotas, a quiota of $50,000 \mathrm{lb}$ was set (Harbo et al. 1993).

Analyses for 1995 quotas, based on a 50 year fishery, showed that $55 \%$ of original stock had been harvested in 7 years of fishing history. Removals were estimated at 0.77 geoducks $/ \mathrm{m}^{2}$ which exceeded the criterion of keeping harvesting to less than $50 \%$ of the original stock. The area was closed in 1995.

The quota options for 1998 indicate that a small fishery could be considered. Options range from a low of $1,024 \mathrm{lb}$ to a high of $5,373 \mathrm{lb}$. The area was not opened, in 1998 , in order to equalize quotas coastwide.

## GMA 27-G: Exploratory - portion of Subarea 27-1, 27-2, Scott Is.(Subarea 111)

In the 1997/98 quota assessment, GMA 27-G was comprised of one bed at Scott Islands which had a measured area of 48.88 ha, scaled by landing criteria to 5 ha.

Fishers recommended an exploratory fishery in 1992, from north of Kains Islet to Cape Scott, for $130,000 \mathrm{lb}$. A decision to include Restless Bight was made in-season, in July 1992, when the quota for Cliffe Point to Lawn Point (GMA 27-B) was reached, but no fishing had taken place in Restless Bight. No landings were made in GMA 27-G in 1992 and the quota was moved to the designated fallback area, GMA 23-C.

In 1995, an exploratory fishery in the Scott Islands was proposed. The minimum set quota of $14,377 \mathrm{lb}$ balanced the number of licences on the west coast of Vancouver Island for 1995.

The quota was landed with no problem. However, prior to the quota assessment 1997/98, the Scott Islands area was proposed as a Marine Protected Area (MPA). If accepted as an MPA, the area may be closed to future geoduck fishing. Quota options, based on 5 ha of fishing area, ranged from a low of $3,604 \mathrm{lb}$. to a high of $4,810 \mathrm{lb}$. The area was not opened, in 1998, in deference to the concerns about it's future as an MPA and to equalize quotas coastwide.

GMA 27-H: Klaskino Inlet - Subarea 27-5.
In the assessment for 1995 quotas, GMA $27-\mathrm{H}$ was comprised of 9 beds measuring 223 ha (1994). In the 1997/98 assessment, 9 beds measured 220 ha.

Beds in Klaskino Inlet were first fished in 1985 as part of an exploratory fishery. Over the 10 year period 1985-1994, estimated landings of $1,381,744 \mathrm{lb}(627 \mathrm{t})$ were reported on logs.

The 1992 quota was set at $340,000 \mathrm{lb}$, greater than the calculated quota option of $318,000 \mathrm{lb}$, in order to equalise I.Q.s on the west coast. Due to PSP closures in the fall of 1992 , only $66,378 \mathrm{lb}$ of quota was landed. The remaining $275,000 \mathrm{lb}$ of quota was deferred to the 1993 fishery. (Harbo et al. 1993).

Some beds with minor landings were reduced in area using landing criteria in the assessment for 1995 quotas. Analyses for 1995 quotas, based on a 50 year fishery, estimated that $24 \%$ of original stock had been harvested in 10 years. Removals were estimated at 0.34 geoducks $/ \mathrm{m}^{2}$ (Harbo et al. 1995). The calculated and set quota for 1995 was $142,133 \mathrm{lb}$, with a requirement for an ongrounds observer to verify a large bed with very little harvest history reported at Side Bay.

In the assessment for 1997/98 quotas, the 28 ha bed at Side Bay was reduced to 2.4 ha based on observer fishing in 1995. Beds at Mocino Pt. (bed 404) and Anchorage Is. (bed 405) are estimated to have greater than $50 \%$ removals and will be closed in 1998, with an ongrounds observer to monitor fishing in the remainder of the beds. The quota options for GMA 27-H in 1998 range from a low of $106,442 \mathrm{lb}$ to a high of $158,807 \mathrm{lb}$. The mid-range quota of $131,259 \mathrm{lb}$ was assigned in 1998.

## GMA 27-I: Klaskish Inlet - Subarea 27-6.

In the assessment for 1995 quotas, GMA 27-I was comprised of 15 beds measuring 107 ha. In the 1997/98 quota assessment, 15 beds measured 118 ha.

Until 1992, this area was fished in combination with Klaskino Inlet (GMA 27-H). In 1985, 194,950 lb were recorded on logs from beds in Klaskish Inlet and in 1990, 376,773 lb.

In 6 seasons, over a 10 year period to 1992, a small 6 ha bed at mouth of Klaskish Basin had recorded landings of $247,898 \mathrm{lb}$, a removal of 2.17 geoducks $/ \mathrm{m}^{2}$. In a 3 ha bed, there were recorded landings of $119,487 \mathrm{lb}$ or 2.09 geoducks $/ \mathrm{m}^{2}$ removed.

This area should have been closed in 1992. However a management decision was made to reduce the 1992 and 1993 coastwide quotas by $15 \%$ each year and a fishery quota of $165,000 \mathrm{lb}$ was set for GMA 27-I, based on 13 beds with an area of 101 ha. At the quota options for 1992, an estimated 22 years of quota had been taken (Harbo et al. 1993).

The high removal rate suggests that there may be high densities in this area. An estimated original density of 6.14 geoducks $/ \mathrm{m}^{2}$ over 107 ha would be required to support the fishing to 1995. Analyses for 1995 quotas, based on a 50 year fishery, and a density of 1.4 geoducks $/ \mathrm{m}^{2}$ estimated that $44 \%$ of original stock had been harvested in 10 years. Removals were estimated at
0.61 geoducks $/ \mathrm{m}^{2}$ (Harbo et al. 1995). The quota was set at the calculated amount of $16,130 \mathrm{lb}$ in 1995.

The assessment for 1998 quota options range from a low of $42,685 \mathrm{lb}$ to a high of $70,793 \mathrm{lb}$. Beds E. of Orchard Pt. (bed 504), Klaskish Basin mouth (bed 506) and on the S. side of Klaskish Inlet (bed 512) are estimated to have been harvested to greater than $50 \%$ of original biomass and will be closed, with an ongrounds observer to monitor fishing in the remainder of the beds. The mid-range quota of $99,035 \mathrm{lb}$ was assigned in 1998.

## APPENDIX 4. FISHING HISTORIES AND DOCUMENTATION OF MANAGEMENT DECISIONS FOR GEODUCK MANAGEMENT AREAS IN THE QUEEN CHARLOTTE ISLANDS FOR 1997.

Adjusted quotas by GMA in the North Coast were derived through a review process undertaken by Doug Stewart, the North Coast On Grounds Monitor (OGM) and Shane Neifer, the North Coast species coordinator. Initial recommended quotas (Calc. Quota) were calculated from bed areas, density, mean weight and amortization factors while the adjusted quota (Adj. Quota) was derived through advice from the on-grounds monitor, based on his observations during the fishery. Density used was 1.6 geoducks $/ \mathrm{m}^{2}$, based on surveys in the Queen Charlotte Islands.

A1: Skidegate Inlet: All of Subarea 2-1.
Bed codes: $\quad 2801,2802,2803,2804,2805,2806,2810$.
Area (ha): 28
Calc. Quota (lb): 36,999
Adj. Quota (lb): $\quad 31,874$
Comments: Half of bed 2801 and all of beds 2803, 2804, 2805 and 2806 are inside the sanitary closure area. Bed 2803 has no bed table information attached. There is construction work on a Marina in the location of this bed so a search for it will be requested. Only used quota from bed 2802.

A2: Cumshewa Inlet East: That portion of Subarea 2-3 east of a line running from McCoy Cove light to Girard Point and northwest of a line running from Girard Point east to $53^{\circ} 00^{\prime} \mathrm{N}$ lat, $131^{\circ} 38^{\prime} \mathrm{W}$ long, then southerly to $52^{\circ} 57.9^{\prime} \mathrm{N}$ lat, $131^{\circ} 35.7^{\prime} \mathrm{W}$ long.
Beds: 103,2501.
Area (ha): 54.2
Calc. Quota (lb): 51,214
Adj. Quota (lb): $\quad 55,000$
Comments: About 45,000 lbs was removed off these beds in the last cycle. Quotas in this range appear realistic.

A3: Cumshewa Inlet West: That portion of Subarea 2-3 west of a line running from McCoy Cove light to Girard Point.
Beds:
101, 102, 104, 105, 106, 107.
Area (ha): $\quad 122.6$
Calc. Quota (lb): 166,774
Adj. Quota (lb): 197,284
Comments: The calculated quota for bed 102 was $169,049 \mathrm{lbs}$. There appears to be some discrepancies in the measurement of bed 102 so 'gap ha' were used and the quota re-adjusted to 45,325 . Although this bed is large it usually gets little effort on it as the colour of the ducks appears to be not as good as those found in adjacent beds. The OGM feels that the adjusted quota expressed above is more realistic for this area.

A4: Skedans: That portion of Subarea 2-3 south and west of a line running from Girard Point east to $53^{\circ} 00^{\prime} \mathrm{N}$ lat., $131^{\circ} 38^{\prime} \mathrm{W}$ long., then southerly to $52^{\circ} 57.9^{\prime} \mathrm{N}$ lat., $131^{\circ} 35.7^{\prime} \mathrm{W}$ long; and
that portion of Subarea 2-7 north of a line running from a point at $52^{\circ} 55.4^{\prime} \mathrm{N}$ lat, $131^{\circ} 37^{\prime} \mathrm{W}$ long true east to the surfline.
Beds: 2203, 2204, 108.
Area (ha): $\quad 9.5$
Calc. Quota (lb): 9,585
Adj. Quota (lb): 23,384
Comments: It was felt that quotas in beds 108 and 2203 could be increased as they weren't fished last cycle. It also appears that bed 2203 may be larger than expressed and 10 K was arbitrarily added to it for harvest even though it is ' 0 ' rated.

A5: Limestone Islands: That portion of Subarea 2-7 south of a line running from a point at $52^{\circ} 55.4^{\prime} \mathrm{N}$ lat, $131^{\circ} 37^{\prime} \mathrm{W}$ long true east to the surfline.
Beds: 2201, 2202.
Area (ha): $\quad 39.9$
Calc. Quota (lb): 53,328
Adj. Quota (lb): $\quad 54,177$
Comments: Substantially, no changes.
A6: Selwyn Inlet East: That portion of Subarea 2-6 north of a line running from Alford Point on Moresby Island, then true east to Talunkwan Island and east of $131^{\circ} 45^{\prime} \mathrm{W}$ long.
Beds:
2203, 2206, 2208, 2211.
Area (ha): $\quad 17.1$
Calc. Quota (lb): 20,112
Adj. Quota (lb): 23,762
Comments: Selwyn Inlet was split east and west to force fishers to move between the different beds more. Duck colour is consistent but of different grades so by splitting these areas market competition to harvest only the best beds is removed. Adjusted quota is substantially the same.

A7: Selwyn Inlet West: That portion of Subarea 2-6 north of a line running from Alford Point on Moresby Island, then true east to Talunkwan Island and west of $131^{\circ} 45^{\prime} \mathrm{W}$ long.
Beds: 2207, 2209.

Area (ha): $\quad 2.7$
Calc. Quota (lb): 2,848
Adj. Quota (lb): $\quad 20,000$
Comments: About 18 K was harvested off these two beds last cycle, with no difficulty. There is more area to harvest. 20 K appears a more realistic quota for this area.

A8: Dana Inlet: That portion of Subarea 2-6 south of a line running from Alford Point on Moresby Island, then true east to Talunkwan Island.
Beds:
2205, 2210.
Area (ha): $\quad 3.6$
Calc. Quota (lb): 3,731
Adj. Quota (lb): $\quad 20,000$

Comments: The OGM feels that the beds are larger than reported. 18 K was harvested here last cycle. This adjusted quota of 20 K could be as high as 25 K . There is potential for growth in this area.

A9: Tanu Island North: That portion of Subarea 2-8 north of a line running true west from Stalkungi Point to Moresby Island, running true east from Klue Point on Tanu Island to Kunga Island, and true east from the northeastern point of Kunga Island to the surfline.
Beds: 2603, 2605, 2606, 2609, 2610, 2613.
Area (ha): $\quad 32.7$
Calc. Quota (lb): 43,048
Adj. Quota (lb): $\quad 63,152$
Comments: The difference between calculated and adjusted and quotas lies in a significant increase allocated to bed 2606. OGM has received reports that there are high densities in this bed.

A10: Tanu Island South: That portion of Subarea 2-8 south of a line running true west from Stalkungi Point to Moresby Island, running true east from Klue Point on Tanu Island to Kunga Island, and true east from the northeastern point of Kunga Island to the surf line, and all of Subarea 2-9.
Beds: $\quad 2601,2602,2604,2611,2612,2607,2608$.
Area (ha): $\quad 28.3$
Calc. Quota (lb): $\quad 28,546$
Adj. Quota (lb): 39,762
Comments: Quota was added to beds 2601 and 2604. There were good harvest rates from these beds last cycle and the bed sizes may be underestimated.

F1: Upper Juan Perez: That portion of Subarea 2-11 north of a line running from Andrew Point on Ramsay Island to Sedgwick Point on Lyell Island.
Beds:
2101, 2104, 2106, 2107, 2109, 2401, 2402, 2403.
Area (ha): 41.1
Calc. Quota (lb): 46,155
Adj. Quota (lb): 48,654
Comments: Although bed 2402 is ' 0 ' rated, the Paul Anthony (John Palychuk) found good quantities of ducks last rotation and $10-15 \mathrm{~K}$ was harvested then. 2500 lbs has been added for this rotation.

F2: North Marco Island: Those portions of Subareas 2-11 and 2-12 south of a line running from Andrew Point on Ramsay Island to Sedgwick Point on Lyell Island, and north of a line running from $52^{\circ} 31.6^{\prime} \mathrm{N}$ lat., $131^{\circ} 25^{\prime} \mathrm{W}$ long. and $52^{\circ} 34.35^{\prime} \mathrm{N}$ lat., $131^{\circ} 36.1 \mathrm{~W}$ long., and northwest of a line running from Werner Point on Moresby Island to Crombie Point on Ramsay Island.
Beds: $\quad 2102,2103,2105,2108,2301,2302$.
Area (ha): 67.1
Calc. Quota (lb): 71,653
Adj. Quota (lb): 78,289

Comments: Quotas were increased in beds 2301 and 2302 on the advise of the OGM.
F3: South Marco Island: Those portions of Subareas 2-11 and 2-12 south of a line running from $52^{\circ} 31.6^{\prime} \mathrm{N}$ lat., $131^{\circ} 25^{\prime} \mathrm{W}$ long. and $52^{\circ} 34.35^{\prime} \mathrm{N}$ lat., $131^{\circ} 36.1 \mathrm{~W}$ long., and northwest of a line running from Werner Point on Moresby Island to Crombie Point on Ramsay Island.
Beds: 301, 2001, 2002, 2003, 2004.
Area (ha): 23.6
Calc. Quota (lb): 24,903
Adj. Quota (lb): 24,903
Comments: Accept quota as calculated.
F4: Werner Bay: That portion of Subarea 2-12 west of a line from Werner Point to Newberry Point.
Beds: 302, 303, 304, 305.
Area (ha): $\quad 21.1$
Calc. Quota (lb): 27,671
Adj. Quota (lb): $\quad 27,670$
Comments: Accept quota as calculated. Quota evaluation was originally done by OGM and Shane Neifer when beds 303 and 305 were scaled. This run is using measured beds and these two beds have received about 4 K each extra.

F5: Lower Juan Perez: That portion of Subarea 2-12 south of a line running from Werner Point on Moresby Island to Crombie Point on Ramsay Island and east of a line running from Werner Point on Moresby Island to Newberry Point on Moresby Island; and a portion of Subarea 2-13 east of a line running $328^{\circ}$ True through the northwest tip of Section Island.
Beds:
201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212.
Area (ha):
147.2

Calc. Quota (lb): 129,468
Adj. Quota (lb): 129,487
Comments: Bed 206 is on the chart but not in the bed calculations, need to find out why. Accept quota as calculated.

F6: Poole Inlet: That portion of Subarea 2-14 north of a line running true east from Poole Point to the surfline.
Beds: $\quad 504,505,507, \underline{508}, 515, \underline{516}$.
Area (ha): 46.1
Calc. Quota (lb): 60,002
Adj. Quota (lb): 70,953
Comments: Quota was reduced in bed 505. Quota was increased in bed 515 and 516. Again, beds 508 and 516 are on the bed chart but not in the bed tables so have no bed area or quota attached, need to find out why.

F7: North Skincuttle Inlet: That portion of Subarea 2-14 south of a line true east from Poole Point to the surfline and north of a line from Ikeda Point true east to the surfline; and the portion of Subarea 2-15 north of a line running from Huston Point to Deluge Point.

Beds: $\quad$ 502, 503, 506, 509.
Area (ha): $\quad 30.6$
Calc. Quota (lb): 40,123
Adj. Quota (lb): 40,123
Comments: Accept quota as calculated.
F8: South Skincuttle Inlet: That portion of Subarea 2-15 south of a line running from Huston Point to Deluge Point.
Beds: 501.
Area (ha): 23.5
Calc. Quota (lb): 876
Adj. Quota (lb): 20,000
Comments: Last rotation 51 K was removed in three days. It is felt that the measured bed area of this bed is not accurate. There has been landings of over 500 K reported from this bed over time but the OGM feels it is still healthy and could conservatively be harvested to 25 K .

B1: Collison Bay: That portion of Subarea 2-14 south of a line running from Ikeda Point true east to the surfline.
Beds: $\quad 2902,2903,2910$.
Area (ha): 20.0
Calc. Quota (lb): 25,384
Adj. Quota (lb): 29,168
Comments: Quota was increased in bed 2910 by about 3K. The OGM feels that this bed has more potential and warrants the increase in quota.

B2: Carpenter Bay West: That portion of Subarea 2-17 west of a line running from Ingraham Point true north.
Beds: 2902, 2903, 2904, 2906, 2907, 2908, 2915.
Area (ha): 48.7
Calc. Quota (lb): $\quad 55,245$
Adj. Quota (lb): 68,465
Comments: A lot of these beds were new beds last cycle so quota was increased in beds 2902, 2908, and 2915 to reflect their potential for increased harvest.

B3: Carpenter Bay East: That portion of Subarea 2-17 east of a line running from Ingraham Point true north, and a portion of Subarea 2-18 north of a line running true east from Koya Point.
Beds:
2901, 2905, 2903.
Area (ha): $\quad 28.0$
Calc. Quota (lb): 33,934
Adj. Quota (lb): 33,934
Comments: Accept quota as calculated.
B4: Upper East Houston - Stewart Channel: That portion of Subarea 2-18 south of a line running true east from Koya Point, and north of a line running from Catherine Point to the southern tip of Ross Island then true east to the surfline.

Beds: $\quad 608,702,705,713,720$.
Area (ha): $\quad 36.5$
Calc. Quota (lb): 34,872
Adj. Quota (lb): $\quad 40,659$
Comments: Quotas were slightly increased in beds 713 and 720.

B5: Lower East Houston - Stewart Channel: That portion of Subarea 2-18 south a line running from Catherine Point to the southern tip of Ross Island then true east to the surfline and north of a line running from Orion Point true east to the surfline.
Beds: $\quad 703,704,711,714$.
Area (ha): $\quad 34.0$
Calc. Quota (lb): 20,059
Adj. Quota (lb): 34,080
Comments: Quota was increased in bed 703. Although this bed has had substantial landings over time it still appears to be healthy. Calculated quota was just under 16 K and was increased to 30 K on the advise of the OGM. Last cycle 69 K was removed without difficulty.

B6: Keeweenah Bay: That portion of Subarea 2-18 south of a line running from Orion Point on Kunghit Island true east to the surfline, and east of a line running true north from Jenkins Point on Kunghit Island.
Beds:
701.

Area (ha): $\quad 16.7$
Calc. Quota (lb): $\quad 18,147$
Adj. Quota (lb): 10,000
Comments: Quota was reduced in this area on advice of OGM. 7,800 lbs was removed last cycle from this bed

B7: Heater Harbour: That portion of Subarea 2-18 south of a line running from Orion Point on Kunghit Island true east to the surfline, and west of a line running true north from Jenkins Point on Kunghit Island.
Beds:
$710,712,715,716,717$.
Area (ha):
12.8

Calc. Quota (lb): $\quad 15,075$
Adj. Quota (lb): $\quad 55,260$
Comments: It was felt by the OGM that bed area information for beds 715, 716 and 717 were incomplete. Quotas were increased on these beds.

B8: Inner Luxana Bay: That portion of Subarea 2-19 north of a line running from $52^{\circ} 03.3^{\prime} \mathrm{N}$ lat, $131^{\circ} 03.9^{\prime} \mathrm{W}$ long to $52^{\circ} 03.1^{\prime} \mathrm{N}$ lat, $131^{\circ} 01.9^{\prime} \mathrm{W}$ long.
Beds: 801, 804.
Area (ha): $\quad 50.0$
Calc. Quota (lb): $\quad 68,260$
Adj. Quota (lb): $\quad 50,872$

Comments: Although we accepted the calculated quotas, this area was one area where we could reduce catch if we needed to as a way to even out quotas coastwide. Quota was reduced to facilitate that process.

B9: Outer Luxana Bay: That portion of Subarea 2-19 south of a line running true east from Annis Point and east of a line running from $52^{\circ} 03.3^{\prime} \mathrm{N}$ lat, $131^{\circ} 03.9^{\prime} \mathrm{W}$ long to $52^{\circ} 03.1^{\prime} \mathrm{N}$ lat, $131^{\circ} 01.9^{\prime} \mathrm{W}$ long.
Beds: 802, 803.
Area (ha): $\quad 30.0$
Calc. Quota (lb): $\quad 35,875$
Adj. Quota (lb): $\quad 35,875$
Comments: Calculated quotas were accepted.
B10: Howe Bay: That portion of Subarea 2-19 south of line running true east from Annis Point.
Beds: 901.
Area (ha): $\quad 20.0$
Calc. Quota (lb): $\quad 20,120$
Adj. Quota (lb): $\quad 10,000$
Comments: Quota was reduced. Only 2,600 lbs was removed from this bed last cycle.
C1: West Houston - Stewart Channel (Moresby): That portion of Subarea 2-31 that is in the vicinity of the Moresby Island shore north of a line running from Cape Fanny true east to Kunghit Island.
Beds: 603,606.
Area (ha): 11.5
Calc. Quota (lb): 74
Adj. Quota (lb): 10,000
Comments: It was recommended that these beds not be fished. Last cycle only bed 603 was fished and 14 K was removed with little problem. The OGM advised a small quota of 10 K should be applied to this area.

C2: West Houston - Stewart Channel (Kunghit): That portion of Subarea 2-31 that is in the vicinity of the Kunghit Island shoreline south of a line running from Cape Fanny true east to Kunghit Island, and east of a line running from Cape Fanny on Moresby Island to Barber Point on Kunghit Island.
Beds: $\quad 601,602,610,620$.
Area (ha): 74.8
Calc. Quota (lb): $\quad 56,296$
Adj. Quota (lb): 76,296
Comments: The calculated quota was accepted for all beds except for bed 602. This bed was ' 0 ' rated yet last cycle 82 K was removed with little effort. 20 K was allocated to this bed.

C3: Gordon Island: That portion of Subarea 2-31 that is in the vicinity of Gordon Island.
Beds: 609.
Area (ha): 25.6

Calc. Quota (lb): 28,356
Adj. Quota (lb): 28,356
Comments: Calculated quotas were accepted.
C4: Louscoone Inlet: All of Subareas 2-32, 2-33, and 2-34, and the portion of Subarea 2-31 west of a line running from Cape Fanny on Moresby Island to Barber Point on Kunghit Island.
Beds: 604, 605, 607, 609.
Area (ha): $\quad 46.0$
Calc. Quota (lb): $\quad 55,477$
Adj. Quota (lb): 63,114
Comments: Quotas were increased slightly on beds 604 and 605. Harvest on these beds last cycle were higher than quotas which are assigned to them this cycle.

C5: Flamingo Inlet: All of Subareas 2-35, 2-36, and 2-37.
Beds: $\quad 1001,1002,1003,1004$.
Area (ha): $\quad 7.5$
Calc. Quota (lb): 7,852
Adj. Quota (lb): $\quad 20,000$
Comments: The OGM felt that the area contained within these 4 beds could handle a harvest in the 20 to 25 K range.

C6: Gowgaia Bay: All of Subareas 2-38 to 2-41.
Beds: 1101, 1102, 1103, 1104, 1105.
Area (ha): 8.7
Calc. Quota (lb): 9,591
Adj. Quota (lb): 75,000
Comments: Most of these beds were recorded for the first time last cycle. The OGM feels that the area has a lot of potential and would be a good area to add quota to relieve pressure from other areas.

D1: South Englefield Bay: All of Subareas 2-49, 2-53 to 2-60.
Beds:
1302, 1304, 1305.
Area (ha): $\quad 8.4$
Calc. Quota (lb): 8,891
Adj. Quota (lb): 30,000
Comments: Engelfield Bay was split north and south this cycle to spread effort over more area. The OGM felt that a harvest between 50 and 60 K for both areas would be acceptable. Last cycle about 100 K came from both areas.

D2: North Englefield Bay: All of Subareas 2-50, 2-51, and 2-52.
Beds: 1301, 1303.
Area (ha): $\quad 8.6$
Calc. Quota (lb): 2,340
Adj. Quota (lb): $\quad 15,000$

Comments: Englefield Bay was split north and south this cycle to spread effort over more area. The OGM felt that a harvest between 50 and 60 K for both areas would be acceptable. Last cycle about 100 K came from both areas.

D3: Buck Channel: All of Subarea 2-63.
Beds: 6301,6302.
Area (ha): $\quad 3.0$
Calc. Quota (lb): 3,562
Adj. Quota (lb): 20,000
Comments: These beds are relatively new and the OGM feels that recorded area of the beds is not accurate and that they can sustain a larger quota than calculated.

D4: West Skidegate Channel: All of Subareas 2-64 to 2-68.
Beds: $\quad 1801,6401,6402,6601,6602,6603,6604$.
Area (ha): $\quad 17.4$
Calc. Quota (lb): 21,052
Adj. Quota (lb): 21,052
Comments: Calculated quotas were accepted.
D5: Kano Inlet: All of Subareas 2-69, 2-70, and 2-71.
Beds: 1401, 1402.
Area (ha): 52.5
Calc. Quota (lb): 84,332
Adj. Quota (lb): 63,570
Comments: Quota was reduced in bed 1401 by approx. 20K. The OGM felt that 70K was too much for that bed.

D6: Shields Bay: All of Subareas 2-73 to 2-77.
Beds: 1501, 1506.
Area (ha): $\quad 7.0$
Calc. Quota (lb): 37,219
Adj. Quota (lb): 37,219
Comments: Calculated quotas were accepted.
D7: Rennel Sound: All of Subareas 2-72, 2-78, 2-80, and 2-81.
Beds: 8001.
Area (ha): $\quad 5.0$
Calc. Quota (lb): 6,172
Adj. Quota (lb): $\quad 10,000$
Comments: Quota was increased slightly as bed is fairly new.

D8: Seal Inlet: All of Subareas 2-79, 2-82, 2-83, and 2-84.
Beds: $\quad 1502,1505,1506$.
Area (ha): 29.6

Calc. Quota (lb): $\quad 40,600$
Adj. Quota (lb): 40,600
Comments: Calculated quotas were accepted.
D9: Hippa Island: All of Subareas 2-85, 2-86, and 2-87.
Beds: $\quad 1601,1602,1603,1604,1605,1606,1607$.
Area (ha): 79.7
Calc. Quota (lb): 80,966
Adj. Quota (lb): 80,966
Comments: Calculated quotas were accepted.
D10: Port Chanal: All of Subareas 2-88 to 2-91.
Beds: $\quad 1701,1702,1703,1704,1705,1706$.
Area (ha): 42.8
Calc. Quota (lb): $\quad 60,009$
Adj. Quota (lb): 60,009
Comments: Calculated quotas were accepted.
D11: Port Louis: All of Subareas 2-92 to 2-100.
Beds: 9301, 9302, 9303, 9401.
Area (ha): 5.5
Calc. Quota (lb): 5,781
Adj. Quota (lb): $\quad 20,000$
Comments: Many of these beds are newly recorded and the areas are felt to be inaccurate.
The OGM felt that a quota of 20K was more appropriate for the area.

E1: Parry Pass: All of Subareas 1-2 and 1-7.
Beds: 101, 102, 103, 104, 105.
Area (ha): 80.2
Calc. Quota (lb): $\quad 92,604$
Adj. Quota (lb): 20,000
Comments: The quota was reduced in this area to 20 K which reflects what was removed last cycle. It is felt that a quota in the 90 K range is not warranted for this area at this time.

E2: Virago Sound: All of Subarea 1-3.
Beds: 301, 302.
Area (ha): $\quad 52.6$
Calc. Quota (lb): 60,073
Adj. Quota (lb): 60,073
Comments: Calculated quotas were accepted.

# Assessment of the Area 12 Prawn Fishery in Relation to Declines in Annual Catch 

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#### Abstract

Boutillier, J.A. 1998. Assessment of the Area 12 prawn fishery in relation to declines in annual catch. p. 161-185. In: G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1996. Can. Tech. Rep. Fish. Aquat. Sci. 2221.

This paper was produced in response to managers' concerns about declining catches in the Area 12 prawn fishery. Historically this area has been the largest prawn producing area on the coast. Managers were concerned and wanted a review conducted to establish if these declines were caused by the fishery. The analysis was carried out using data from the logbook program, the spawner monitoring program, and historical fishery notices. The logbook data was analyzed to produce a standardized CPUE which was modeled for the area. As a result of this analysis it was found that CPUE trends were similar to catch trends with the exception that the degree of declines were smaller for CPUE and the fact that CPUE showed some recovery in 1995. The analysis of the spawner index data showed two potential problems with the managment of the area that compromise biological objectives. These management problems include: early openings prior to complete egg hatch and delays in closing the fishery which allow substantial catches to occur after the biological reference point for closures has been reached.


## INTRODUCTION

## Objectives

This paper was prepared at the request of the South Coast Managers for an assessment of the Area 12 prawn fishery. Since 1992 the area has undergone large declines in catch. This assessment was intended to examine why this decline in catch occurred, identify the factors which may have contributed to these declines and determine what if anything could be done about them.

To undertake this assessment there were a number of questions that were addressed:

1) Were the declines in catch a reflection of the declines in abundance of prawns in the area or were they a reflection of changes in the fishery?
2) Were the trends similar in all areas?
3) What factors may have lead to the declines?
4) Is there anything that managers can do to avoid these declines in the future?

## Biological Management Objectives

The fishery is presently managed to meet two biological objectives: to prevent growth overfishing and to prevent recruitment overfishing.

Growth overfishing is controlled through a combination of size-limits and manipulation of the opening times. For Area 12, only the size limit ( 30.0 mm carapace length (CL) ) has been implemented. Boutillier (1984) recommended this coast-wide size limit based on a mean CL of a prawn when it turns 2 years of age. It was noted by Boutillier (1985) that a coast-wide size limit can not take into account variations in growth rates between areas and between years.

Since 1979 , recruitment over-fishing for the commercial prawn fishery is managed using an inseason index of female spawners per standard trap hauled. This management system for the prawn fishery in British Columbia, as pointed out by Boutillier, (unpublished manuscript, 1996) was developed based on the assumption of a spawner/recruit relationship. The management system is similar in principle to the salmon escapement targets used in the management of the B.C. Salmon fishery. The present spawner index targets were based on empirical data collected from a series of assessment cruises carried out in the early to mid-1970's in Area 12, the largest prawn producing area on the coast. The target spawner index was set at a biological reference point (BRP) of 1 female spawner per trap in March (the month of egg hatching) using a Pardiac trap soaked for 24 hours. This BRP level was established by taking the mean number of female spawners/trap in March from survey areas with consistently good production over the period of the surveys. Spawner indices for the months prior to the March hatching period were extrapolated using the natural mortality estimates for the area at that time.

The assumption in developing this management strategy was that historically the area produced harvestable quantities of prawns at this spawner index and would continue to do so if this level were maintained. There are a number of short-comings to management decisions based on this assumption. The first was that the index was based on measurement of effort that either had to remain constant or could be standardised. Since methods of fishing are constantly changing this led to a number of experiments on effort standardisation, and finally to a modification of the escapement targets based on the numbers that relate to more recent fishing technology (Boutillier, unpublished manuscript). The second shortcoming was that the spawner index needs to be based on stock/recruitment productivity relationship but due to insufficient detailed data the present system is only based on empirical evidence. This lack of rigour will not allow the management of the areas to be tuned to a measure of maximum potential in terms of a spawner/recruit relationship while taking into account the variation caused by environmental factors.

The history of the use of this management strategy was reviewed and critiqued by Boutillier (1996). The paper gives the history of the development and use of this management strategy and tests the stock/recruitment assumptions associated with the original spawner index. This was
achieved by developing a spawner/recruit relationship using data collected in the Howe Sound experimental fishery and comparing the productivity from the present management spawner BRP to the spawner index at the point of peak productivity from the model. The results of the analysis indicated that for Howe Sound, peak production would be achieved if the BRP spawner index were increased by a factor of three. The resulting recommendation from the paper was to initiate a systematically documented process of increasing the BRP criteria for closures in a variety of fisheries. The increases could be timed with strong cohorts so the impact on the fishery is minimal. Because of the short life span of prawns and the time it takes for recruitment to the fishery, an evaluation of the response could be evident in the fishery within 2 to 3 years. However to date this strategy has not been applied except as an experimental management strategy in Howe Sound where the BRP spawner index has been increased by $50 \%$ for 1995 .

In addition to closures made as a result of reaching a BRP, all areas are closed during the winter. This coast-wide closure was implemented in 1985 because of the inability to monitor the fishery in the winter months.

## METHODS

## available Data

In this analysis, data was used from three sources: logbooks, inseason spawner assessments, and historical opening and closure notices for the years 1984-1995.

## Logbook Data

The logbook information provided a number of critical pieces of information including: total catch; changes in fishing patterns and methods; the incorporation of these changes in fishing patterns and methods, if appropriate, into the calculation of standardized effort; and trends in standardized catch per unit effort (CPUE) as a reflection of population trends by year and area.

## In-season Spawner Assessments

This data is comprised of a commercial sampling bridge log recorded during sampling for spawner index and some length frequency data. Only the analysis of the commercial sampling bridge $\log$ data will be discussed in this paper. The inconsistency with which the length frequency data was collected made it impossible to use the data to determine cohort strength and various year class contributions to the fisheries. Analysis of the commercial sampling bridge log data provided information on: spawner index associated with the closure of the area; sex composition of the catch; and date when the biological reference point for a closure was observed.

## Historical Fisheries Notices

This data comprises of official opening and closure dates for the fishery in the area. It also provides information on the rationale for the management actions taken.

## ANALYTICAL METHODS

## Logbook Data

## Total Catch

Total catch from the fishery was calculated from all $\log$ entries. Estimates were made for the entire area as well as specific management areas. For the purposes of this analysis, Area 12 was divided into 4 management areas based on the pattern of closures used in the 1995 fishery. The four management areas were composed of: the Outside areas - Subareas 1-21; Knight Inlet areas Subareas 22-34; Tribune Channel and associated areas - Subareas 35-38; and Kingcome Inlet and associated areas - Subareas $39-48$. It was also possible to investigate the data for changes in fishing patterns such as reduced soak times and more double hauling of gear in a single day.

## Standardized CPUE

For the purposes of calculating standardized effort, logbook records which indicated problems with the fishing process (such as: gear fell off edge; gear pulled; etc.), were eliminated from the analysis. The effort was initially standardized by gear type using weighting scales documented by Boutillier (unpublished manuscript). Subsequently this data was analyzed using the Generalized Linear Model (GLM) of Nelder and Mead (1975) approach as outlined in Hilbourn and Walters (1992). This analysis was conducted to determine if soak time should be included in effort standardization process and if it was included, what were the appropriate weighting factors to be used to standardize effort. The actual analysis was conducted using the GLIM statistical package developed by the Royal Statistical Society. The data was modeled two ways: the first was with soak-time alone and the second was with soak-time and year combined, as seen in equation 1 below.

$$
\begin{equation*}
\log \left(U_{t i}\right)=\log \left(U_{11}\right)+\log \left(\alpha_{t}\right)+\log \left(\delta_{t}\right)+\varepsilon_{t i} \tag{1}
\end{equation*}
$$

Where $U_{t i}$ is the catch rate for $t$ th year for the $i$ th soak-time; $U_{I I}$ is the catch rate in the 1 st year and the 1 st soak-time; $\alpha_{t}$ is the $t$ th year; and $\delta_{\mathrm{I}}$ is the $i$ th soak-time. There are 12 years being tested (1984-1995) and 7 soak times (1-6 hours, 7-12 hours, 13-18 hours, 19-24 hours, 25-30 hours, 31-36 hours, 37-120 hours).

From this initial analysis the effort was then standardized to include a soak-time component and the resulting CPUE data was then fit to the GLM model with area, time and area/time in combination, where area was one of the four management areas mentioned above. There were three models fit to the data: the first was with area alone the second was with year alone, and the third was with area and year as outlined in equation 2 below.

$$
\begin{equation*}
\log \left(U_{t i}\right)=\log \left(U_{11}\right)+\log \left(\alpha_{t}\right)+\log \left(\beta_{l}\right)+\varepsilon_{t i} \tag{2}
\end{equation*}
$$

Where $U_{t i}$ is the catch rate for $t$ th year and the $i$ th area; $U_{l l}$ is the catch rate in the 1st year and the 1 st area; $\alpha_{\mathrm{t}}$ is the $t$ th year; and $\beta_{\mathrm{I}}$ is the $i$ th area.

## Spawner Index

This data was collected through an onboard monitoring system in which the total catch from random traps were sampled for number of prawns by sex category. Sex categories were: " 0 " immature, " 1 " mature male, " 2 " immature female, " 3 " mature female, " 4 " berried female, and " 5 " spent female.

## Historical Openings and Closures

Historic openings and closures dates for the area were compiled along with documented rationale for each closure.

## RESULTS

## Logbook Data

## Total Catch

The historical trends from Area 12 can be seen in Fig. 1. It is evident that there was a substantial increase in catch from the area in the early 1990's followed by a declining catch trend since 1992. It is also evident from Fig. 1 that the catch trends for the entire area were not the same as the catch trends when the area was divided into management areas. In particular the catch in Kingcome area has been increasing and may have been at historically high levels in 1995 (this is not possible to tell with absolute certainty as there is a component of the log data with unknown sub-areas which varies between years).

## Changes in Fishing Patterns and Methods

With the introduction of the trap limits for the prawn fishery in 1995, there was an awareness that fishers might change their fishing methods. In particular, it was speculated that there would be a substantial increase in pulling gear more than once a day. Figure 2 shows the proportions of traps pulled using different soak times in each year. In 1995 with the restriction in the number of traps per vessel, there was an increase in utilization of all categories of shorter ( $<19 \mathrm{hr}$ ) soaktimes. The use of these short soak times, however, had also been seen in 1985 and 1986.

Industry is constantly changing its fishing methods to become more effective. If CPUE is to be used as an index of abundance, it is important to keep track of these changing fishing methods and incorporate changes in effective effort into standardized effort calculations. This is especially true with the implimentation of trap limit restrictions, because fishers will be looking at improving fishing practices such as type of traps run and soak times to increase their overall competitiveness.

In addition the fisheries are becoming more intensive which has resulted in much shorter fishing periods. Figure 3 shows the substantial reduction in time it takes to achieve the catch. It is apparent that in 1995, $70-80 \%$ of the catch from the area is achieved in 2 months of fishing while historically it took 5-6 months to achieve smaller catches.

It has been documented by Boutillier (1996) that changes in the timing of the fishery result in marked changes to the catch composition. Factors such as availability of recruiting $1+$ animals, average size/weight of individuals in a cohort etc., all come into play when comparing differences between fisheries in the different seasons. To sort out this kind of information however requires data on the size and age of animals in the catch at the different times of the year. This information is only available through analysis of biological samples (at minimum length frequency data). Unfortunately, there were no biological samples taken from the fishery to evaluate any changes in catch composition over time.

## Standardizing CPUE

The results of the Soak and Year + Soak GLM analyses are shown respectively in Tables 1 and 2. To determine if the Soak model sufficiently described the data, the results from the two models (Soak and Year + Soak) were compared using a Chi-squared test of the difference between the scaled deviance and degrees of freedom (d.f.) as explained by Healy (1988). The difference between the models ( 0.641 for 11 d.f.) was insignificant. Therefore, the results of the Soak model were used to estimate differences in CPUE for various soak times. Interpretation of these results show that catch efficiency from soak times $>19$ hours were $13-17 \%$ higher than $1-6$ hour soaks, while the $7-12$ hour soak is $5 \%$ less efficient than the $1-6$ hour soaks and the 13-18 hour soaks were $7 \%$ more efficient than the 1-6 hour soaks. As a result of this analysis, the CPUE was recalculated for standard trap and soak times using the weighting factor for each of the soak-time categories. This new CPUE was analyzed to see if there was an area component to the trends observed.

## Standardized CPUE Trends by Year and Area

For the analysis of CPUE (standardized by trap and soak time) by area and year, the model was run three times: year alone, area alone, area and year in combination without an interaction term. The results of these analyses are seen in Tables 3-5.

Again using the Chi-squared test of the differences between the scaled deviance and degrees of freedom for the various models and comparing the results to the chi-square table from Zar (1984), it was found that the differences seen between the single factor models and the two factor model were insignificant (difference between the year and year+area model was deviance $=0.332$ and d.f. $=3$ and between the area and year+area model was deviance $=1.735$ and d.f. $=11$ ).

Looking at the results of the area model, it can be seen that the inside areas were between 22$31 \%$ higher than the CPUE for the outside area.

The results of the year model shows a decline in CPUE since 1992 similar to the trend seen in the modeling of the catch over the same period. However, compared to 1992, these declines in CPUE were in the magnitude of $21 \%, 23 \%$, and $19 \%$ for 1993,1994 , and 1995 respectively as compared to the $33 \%, 38 \%$, and $40 \%$ declines in total catch for 1993, 1994 and 1995 (Fig. 1). In addition the CPUE trends are similar to but not exactly the same as the trends seen in total catch. 1995 is still showing a declining trend in total catch but it is showing an increase in annual standardized CPUE (albeit these are preliminary figures).

Using CPUE (standardized by trap and soak-time) the trends in the annual catch rates for the 4 management areas and the total area can be seen in Fig. 3.

The trends in all the management areas seem to parallel each other with the exception of the outside area in 1995 which is showing a continued decline while the other areas seem to be rebounding. When we look at the fishing patterns for the outside management areas in Fig. 5, there appears to be a slight delay in the timing of the fishery in 1995, with most of the catch being taken in the first three months of the year rather then the first two months.

However when the data is further analyzed by sub-areas, it is apparent that there has been a major shift in effort into areas that have not traditionally been fished. Figure 6 shows the outside area catches in the 1980's came from sub-areas $9-13$ but this has changed radically in recent years with the fleet moving into the southern Johnston Strait area. In the 1990's this probably took place as result of large fleets leaving the Knight Inlet management area when it was closed for the season.

## Inseason Spawner Assessments and Historical Openings and Closures

Review of spawner index data and historical openings and closures shows a varied history of sampling and closures for the area. With the exception of 1995, however, the area has consistently opened on April 1 (in 1995 it was opened on April 19 due to a delay in licencing renewals).

Historically the threshold to implement a closure from the female spawner index sampling was the point when the monthly spawner BRP was less than or equal to the upper $75 \%$ confidence level (U75CL) of the sample mean of female spawners. This standard was not always adhered to and other confidence levels e.g. $80 \%$ and $95 \%$ were used intermittently. Once that point was reached the area was to be closed to fishing until after the females had undergone spawning and the eggs had hatched from their pleopods.

The sex of the animals used in the calculation of the female spawner index varied depending on the time of year. Prawns are protandic hermaphrodites. They start their lives as males, go through a transition phase and generally function as females in the last (4th) year of their lives. The actual component of the stock that is used in the female spawner index can be composed of some of the larger males, transitions and unberried females (sexes 1,2 , and 3 ) in the spring; by summer it is usually only the transitions and unberried females (sexes 2 and 3); by fall it is
composed of unberried females and berried females (sexes 3 and 4); and finally by winter it is only berried and hatched females (sexes 4 and 5).

Past practices for determining the composition of animals for inclusion in the spawner index generally followed the process outlined above with the exception of spring sampling which did not include the male component of the stock into their spawner calculation. These prawns would undergo sex reversal later that year and finally function as spawning females. This component was not included, as this required ageing of the male component of the sample using a length frequency analysis. Since length frequencies were rarely collected this analysis was not conducted.

The historical data shows the area was not always closed using a sampling BRP index. In many cases, closures were based on other criteria including: comments from fishermen in the area; part of a larger area closure; or part of a coast-wide closure.

The following sections outline the management history of Area 12 and the criteria used to make closure decisions. Sampling results for closures implemented on a BRP criteria are summarized by the four management areas in Appendix Table 1.

## 1984

There was one sample taken from the area in September from the inlet portion of the area, the low sampling index resulted in the inlet portions of the area being closed on October 1, while the outside area remained open until January $3 / 85$, when it was closed as part of the winter coastwide closure.

## 1985

Sampling was conducted in the inlet portion of the area in April, July, October, and December. In none of these samples were indices below the BRP. The entire area remained open until January 16/86, when it was closed as part of the winter coast-wide closure.

1986
Sampling was conducted in the inlet portion of the area in April, May, September, and November/December. The November/December sampling caused the total area to be closed on December 16 .

1987

Sampling was conducted in the inlet portion of the area in April, May, June and October. The index sampling resulted in a portion of Knight Inlet being closed on June 15 and the remainder of the area being closed on October 16.

Sampling was conducted in the inlet portion of the area in April, October and November. The sampling resulted in one sub-area in Knight Inlet being closed on December 1 while the remainder of the area closed December 31 as part of the winter coast-wide closure of the area.

1989
Sampling was conducted in the inlet portion of the area in May and November. The sampling resulted in portions of the Knight and Tribune areas being closed on May 22, with the remainder of the area being closed on November 20.

1990

Sampling was conducted in the inlet portion of the area in April, July and October/November. The sampling resulted in this portion of the area being closed November 9, while the outside area was closed on December 15, as part of the winter coast-wide closure.

1991
Sampling was conducted April, June and October in the inlet portion of the area. Sampling in the area resulted in portions of the Knight and Tribune areas being closed on July 13, the remainder of the inlet areas being closed on November 6 and the outside portion of the area being closed on December 18 as part of the winter coast-wide closure.

1992

Sampling was conducted in the inlet portion of the area in May and July. Sampling resulted in most of the inlet areas being shut down on July 25, while the remaining areas where shut down on October 31 as a result of concerns expressed by the industry.

Sampling was conducted in the inlet portion of the area in May. Sampling resulted in most of Kingcome and Tribune and two sub-areas of Knight being closed on May 30, while remaining portions of Knight, Tribune and Kingcome and portions of outside areas where closed July 15 as a result of concerns expressed by industry, and the remainder of the area was closed on November 21 as part of the winter coast-wide closure.

Sampling was conducted in the inlet portion of the area in May. Closures occurred on July 31 and October 5 in the inlet portion of the area, as a result of concerns expressed by the industry. The outside portion of the area was closed on November 18, as part of the winter coast-wide closure.

Sampling was conducted in the inlet portion of the area in May, June and July and in the outside portion of the area in October. Sampling resulted in the Knight area being closed June 4, most of Kingcome being closed July 12, the remainder of Kingcome and Tribune closed August 16 and the outside portion being closed October 30.

As mentioned above, prior to 1995, the area was consistently opened on April 1, as this was thought to be the time of year when hatching was complete and the spawning females no longer contributed to the recruitment of the area. In reviewing the spawner index data it became evident that there are still berried females in the area in April and May. Figure 7, shows the proportion of berried females to spent females at various times in these months. In general there appears to be a trend towards complete hatching by the end of May, although there does seem to be some between year differences, which are probably a function of temperature. The data at this point are purely qualitative. That is, they do not tell us the relative abundance of year " $t-1$ " berried spawners lost to the fishery when it opened on April 1 in year " t " or the relative abundance of those animals which successfully completed hatching and contributed to the overall recruitment in the area.

The next thing that was obvious from looking at the history of the closures, was that it took 2 to 4 weeks between the time sampling was completed, to the time the area actually closed to fishing activity. This response time can have a significant impact on catch. In Fig. 8, a comparison of the total catch up to the time sampling was completed with the catch taken during the time period from the end of the trip to the actual closure date. This comparison showed that increases in catches of $>30 \%$ can and have occurred, after the time the area has been identified as requiring closure.

## DISCUSSION

The discussion will center around answering the four questions that were posed at the beginning of the paper.

## Were the declines in catch a reflection of the declines in abundance of prawns in THE AREA OR WERE THEY A REFLECTION OF CHANGES IN THE MANAGEMENT OF THE FISHERY?

The analysis, in trends in catch rates, substantiate that there was an overall decline in prawn stocks in Area 12 since 1992. The declines are not, however, as severe as the overall catch declines would indicate. There does appear to be an increase in CPUE to $0.73 \mathrm{~kg} / \mathrm{stnd}$ trap ( 24 hr soak) in 1995, which is very close to the 12 year average CPUE of 0.74 .

## Were the trends similar in all areas?

The trends in the catch rates by area generally parallel each other, with the exception of recent years in the outside area. The outside area CPUE's continued to decline. However, this decline
may not may not reflect a change in population size as much as a shift in effort to southerly outside subareas from the traditional, and apparently more productive, northerly outside subareas. This shift may be a result of boats finishing off a trip on the way south, after inlet areas are closed.

## What factors may have led to the declines?

To determine what abiotic and biotic factors are contributing to the population dynamics of a stock the right types, quality and quantity of data must be collected. The data sources that were available for this assessment and for addressing this question were of varying degrees of usefulness. The logbooks proved to be extremely useful for analyzing variation in fishing patterns and it was possible to utilize this information to standardize the effective effort in the area and get a more realistic reflection of the population trends. However, as pointed out in the results, there were changes in fishing patterns concerning the timing and duration of the fishery which will confound the interpretation of the results if we do not break the data down by age class and size of the animals. The inconsistency with which the length frequency data was collected along with the missing spawner index information at the time of closures, made it impossible to undertake an analysis to distinguish between the biotic (spawner/recruit and growth) factors and other abiotic (environmental) factors which were driving the CPUE and catch trends. To utilize length frequency data and determine the age composition of the catch, the data must be collected in a systematic manner which allows for analysis of the catch at least at the beginning and end of the fishing season. The catch composition by age, and size of animals changes rapidly throughout the year and a single sample in the year makes extrapolation of this data to the entire catch a questionable exercise. Estimating population parameters and modeling population dynamics, such as area specific spawner recruit relationships, is an impossible task without age structured data and estimates of the spawner escapement index.

## IS THERE ANYTHING MANAGERS CAN DO TO AVOID THESE DECLINES IN THE FUTURE?

In spite of being unable to confirm the factors causing the fluctuations in catch and CPUE, it was possible to identify a number of practices which may compromise the biological objectives outlined for the management of this fishery.

It is evident that fishing methods and patterns have changed over time. It is important to keep track of these shifts in effort so the measurement of the critical BRP is not compromised by an inability to standardize effective effort.

The opening of the fishery in April does not afford sufficient protection of the spawners so that they complete egg hatch. This situation would be equivalent to allowing salmon to escape to a river to meet its escapement target, leave the fish to ripen in the river and then hold a wide open fishery for them prior to them laying their eggs.

It takes too long to implement a closure once the BRP closure index has been identified. With the intensity that some of these areas are now being fished, significant catches can be taken out of the area in the 2-4 weeks that it takes to close the area. It has been difficult to find the resources to
manage the areas in a timely manner in the past, however, this has improved significantly in 1995 with the industry funded observer program.

## RECOMMENDATIONS

A system should be developed to insure consistent biological samples can be obtained at critical periods throughout the fishery. Investigation of a program using volunteer fishermen to collect biological samples for later analysis should be piloted.

The logbook system, is important in identifying changes in fishing methods and patterns which may result in changes in effective effort. Consultations should be held with industry to insure they are aware of the importance of this information and to insure they have an opportunity to give input into the design of the program, especially with regard to the data they feel are critical measures of changing fishing methods.

Every effort should be made to delay the opening of the fishery until hatching is complete. Collection of information on the prevalence of berried and hatched females during the early portions of the fishery will be critical to setting realistic opening dates for this and other areas. There will be area and annual differences in the timing of egg hatch.

Efforts should be made by stock assessment and managers to shorten the length of time it takes to implement a closure once a problem has been identified. The FAO (1995) stance on biological reference points (BRP), urges that management action be proactive in response to reaching a biological reference point (BRP) rather than being reactive.

Managers should be aware that the lower reaches of Johnston Strait may require more specific attention than has been received in the past. These southern areas do not appear to be able to withstand much fishing pressure and are showing continual declining trends in relative abundance of prawns.

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## REFERENCES

Boutillier, J.A. 1984. Prawn - minimum size limit. p. 11-24. In: G.S. Jamieson [ed.]. 1982 shellfish management advice, Pacific Region. Can. Manuscr. Rep. Fish. Aquat. Sci. 1774.

Boutillier, J.A. 1985. Effect of variability in growth rates on minimum size restrictions for prawns (Pandalus platyceros). p. 15-20. In: G.S. Jamieson [ed.]. 1983 and 1984 invertebrate management advice, Pacific Region. Can. Manuscr. Rep. Fish. Aquat. Sci. 1848.

Boutillier, J.A. Unpublished manuscript. Standardization of effort in the prawn fishery as it relates to biological sampling and escapement management. PSARC Working Paper I8805.

Boutillier, J.A. 1996. Review of experimental prawn fishing in Howe Sound, 1993. p. 28-45. In: C.M. Hand and B.J. Waddell [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1993 and 1994. Can. Manuscr. Rep. Fish. Aquat. Sci. 2089.

FAO. 1995. Precautionary approach to fisheries. Part 1: Guidelines on the precautionary approach to capture fisheries and species introductions. Elaborated by the Technical Consultation on the Precautionary Approach to Capture Fisheries (Including Species Introductions). Lysekil, Sweden, 6-13 June 1995 (A scientific meeting organized by the Government of Sweden in cooperation with FAO). FAO Fisheries Technical Paper. No.350, Part 1. Rome, FAO. 1995. 47p.

Healy, M.J.R. 1988. GLIM: An Introduction. Clarendon Press, Oxford. 130 p.
Hilborn, R. and C.J. Walters. 1992. Quantitative Fish Stock Assessment: Choice, Dynamics and Uncertainty. Chapman and Hall, New York. 570 p.

Nelder, J.A. and R. Mead. 1975. A simplex method for function minimization. Comput. J. 7: 308-313.

Zar, J. H. 1984. Biostatistical Analysis. Prentice-Hall, Inc., Toronto. 718 p.

Table 1. GLIM model results with Year/Soak Data (Model Fit $=$ Soak). Scaled deviance $=1.074$ and d.f. $=77$.

| Parameter | Ln Value | Value | CPUE |
| :---: | :---: | :---: | :---: |
| Constant | -1.059 | 0.35 | 0.35 |
| Soak (7-12) | -0.044 | 0.96 | 0.33 |
| Soak (13-18) | 0.065 | 1.07 | 0.37 |
| Soak (19-24) | 0.149 | 1.16 | 0.40 |
| Soak (25-30) | 0.164 | 1.18 | 0.41 |
| Soak (31-36) | 0.149 | 1.16 | $\ddots$ |
| Soak (37-120) | 0.118 | 1.13 | 0.40 |

Table 2. GLIM model results with Year/Soak Data (Model Fit $=$ Soak + Year $)$. Scaled deviance $=$ 0.433 and d.f. $=66$.

| Parameter | Ln Value | Value | CPUE |
| :---: | :---: | :---: | :---: |
| Constant | -1.016 | 0.36 | 0.36 |
| 1985 | 0.214 | 1.24 | 0.45 |
| 1986 | -0.044 | 0.96 | 0.35 |
| 1987 | -0.341 | 0.71 | 0.26 |
| 1988 | -0.164 | 0.85 | 0.31 |
| 1989 | -0.24 | 0.79 | 0.28 |
| 1990 | 0.021 | 1.02 | 0.37 |
| 1991 | -0.037 | 0.96 | 0.35 |
| 1992 | 0.129 | 1.14 | 0.41 |
| 1993 | -0.083 | 0.92 | 0.33 |
| 1994 | -0.083 | 0.92 | 0.33 |
| 1995 | -0.018 | 0.98 | 0.36 |
| Soak (7-12) | -0.044 | 0.96 | 0.35 |
| Soak (13-18) | 0.065 | 1.07 | 0.39 |
| Soak (19-24) | 0.149 | 1.16 | 0.42 |
| Soak (25-30) | 0.164 | 1.18 | 0.43 |
| Soak (31-36) | 0.149 | 1.16 | 0.42 |
| Soak (37-120) | 0.118 | 1.13 | 0.41 |

Table 3. GLIM model results with Year/Area Data (Model Fit $=$ Year). Scaled deviance $=1.901$ and d.f. $=36$.

| Parameter | Ln Value | Value | CPUE |
| :---: | :---: | :---: | :---: |
| constant | -0.688 | 0.50 | 0.50 |
| 1985 | 0.826 | 2.28 | 1.15 |
| 1986 | 0.417 | 1.52 | 0.76 |
| 1987 | -0.005 | 1.00 | 0.50 |
| 1988 | 0.288 | 1.33 | 0.67 |
| 1989 | 0.169 | 1.18 | 0.59 |
| 1990 | 0.44 | 1.55 | 0.78 |
| 1991 | 0.36 | 1.43 | 0.72 |
| 1992 | 0.555 | 1.74 | 0.87 |
| 1993 | 0.313 | 1.37 | 0.68 |
| 1994 | 0.288 | 1.33 | 0.67 |
| 1995 | 0.349 | 1.42 | 0.71 |

Table 4. GLIM model results with Year/Area Data $($ Model Fit $=$ Area $)$. Scaled deviance $=3.304$ and d.f. $=44$.

| Parameter | Ln value | Value | CPUE |
| :--- | :--- | :--- | :--- |
| Constant | -0.503 | 0.60 | 0.60 |
| Area(2) | 0.207 | 1.23 | 0.74 |
| Area(3) | 0.196 | 1.22 | 0.74 |
| Area(4) | 0.27 | 1.31 | 0.79 |

Table 5. GLIM model results with Year/Area Data (Model Fit $=$ Year+Area). Scaled deviance $=$ 1.569 and d.f. $=33$.

| Parameter | Ln Value | Value | CPUE |
| :---: | :---: | :---: | :---: |
| Constant | -0.862 | 0.42 | 0.42 |
| Area(2) | 0.207 | 1.23 | 0.52 |
| Area(3) | 0.196 | 1.22 | 0.51 |
| Area(4) | 0.27 | 1.31 | 0.55 |
| 1985 | 0.826 | 2.28 | 0.96 |
| 1986 | 0.417 | 1.52 | 0.64 |
| 1987 | -0.005 | 1.00 | 0.42 |
| 1988 | 0.288 | 1.33 | 0.56 |
| 1989 | 0.169 | 1.18 | 0.50 |
| 1990 | 0.44 | 1.55 | 0.66 |
| 1991 | 0.36 | 1.43 | 0.60 |
| 1992 | 0.555 | 1.74 | 0.74 |
| 1993 | 0.313 | 1.37 | 0.58 |
| 1994 | 0.288 | 1.33 | 0.56 |
| 1995 | 0.349 | 1.42 | 0.60 |




Fig. 1. Catch from Area 12 proportioned by management areas.


Fig. 2. Proportion of traps pulled after varying soak times.


Fig. 3. Proportion of catch by month for Area 12.


Fig. 4. CPUE standarized by trap type and soak-time by Year and Management Area.


Fig. 5. Proportion of catch taken in each month for the Outside Management Areas (Sub-Areas 1-21).

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Fig. 6. Catches from Area 12 Outside Management Area, by year and sub-area.


Fig. 7. Proportion of previous year spawners that were still berried and those that had completed hatching.


Fig. 8. Catch before and after sampling trip and prior to actual closure.

# Assessing the Inshore Shrimp Fisheries: Data Status, Model Requirements and Problems 

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#### Abstract

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Managers expressed concern about increased effort in the small inshore shrimp trawl fisheries. In response to this concern an analysis of all the available data from landing slip, logbooks and biological sampling from these fisheries was conducted with particular attention to some of the historically largest and oldest fisheries (Management Areas 4, 14, 17 and 28/29). The intention of the analysis was to address the following questions:

1) Is there any evidence that the inshore stocks of shrimp are being subject to increased fishing pressure?
2) Are there any indications that stocks are being put at risk with these increased pressures?
3) What are the options for controlling the fishery in a manner that assures sustainability?

The paper points out the complexity of the problem of a fishery that now targets six different species of shrimp which occupy different habitats, have different live history strategies and occupy at times, quite isolated, unique areas. The responses to the above questions are:

1) yes, effort in the fishery has increased, but that the nature of the fishery has also changed with the targeting of isolated populations of low quantity, high quality, high valued species;
2) yes, there is a high likelihood that the fishery can have large impacts on stocks and in some cases may already have; and
3) there are a number of options for developing a management system for these fisheries, that would insure sustainability.

The recommendations for these fisheries include: implementing an active management program and improving the information gathering systems.

## INTRODUCTION

## Request For Advice

Managers, in charge of inshore shrimp trawl fisheries, requested this assessment document be prepared because of a major shift in effort in the shrimp trawl fishery. It was recognized that this shift in effort was occurring at a time when the shrimp trawl fishery did not have any control mechanisms in place to insure conservation and sustainable development.

The increase in effort in this trawl fishery was a function of a number of variables. Low expectations in the salmon fishery and management changes to groundfish fishery resulted in activation of shrimp trawl licenses that had been previously dormant. New fishing technologies in the trawl industry also made the industry more efficient.

## Objectives

The objectives of this paper are to answer the questions below and develop a framework for the active assessment and management of inshore shrimp fisheries. The questions that need answering are:

1) Is there any evidence that the inshore stocks of shrimp are being subject to increased fishing pressure?
2) Are there any indications that stocks are being put at risk with these increased pressures?
3) What are the options for managing the fishery in a manner that assures sustainability?

## Methods

We addressed these questions by:

1) Providing a summary of the fishery with respect to management practices, historic trends in participation, effort and catch;
2) Reviewing the biological considerations that are relevant to stock assessment and management;
3) Analysing harvest logbook and biological data to look for trends in populations in select fisheries;
4) Presenting theoretical models for the management of inshore stocks, including the limitations and data requirements of each model.

## GENERAL BIOLOGY

The inshore shrimp trawl fishery in British Columbia targets six species of shrimp which belong to the family Pandalidae. Butler (1980) and Butler and Boutillier (1983) give detailed and general accounts, respectively, of the biology of these animals.

## Reproductive Strategy

Pandalid shrimp in general undergo a change of sex in mid-life. Individuals function initially as males then undergo a sexual transformation and become functional females in the final year or two of their lives, a condition known as protandic hermaphrodism. The time spent in each stage varies by species and by location (Berkeley, 1930). Although this is the general pattern, individuals of some species bypass the male phase of their life cycle completely and function only as females. These individuals are known as primary females. Butler (1964) identified primary females in northern pink shrimp (Pandalus borealis eous), smooth pink shrimp ( $P$. jordani), humpback shrimp ( $P$. hypsinotus) and coonstripe shrimp ( $P$. danae). Even though he did not identify sidestripe shrimp (Pandalopsis dispar) as having primary females, he does show one case of shrimp going through transition at a size which he would normally ascribe to the male phase.

Spawning occurs in late autumn or early winter. The females carry developing eggs on their pleopods (swimmerets) until they hatch in the spring. The timing of these events varies by species and by area. This is critical information in establishing when to re-open a fishery if it was closed to prevent recruitment overfishing. Boutillier (1998) points out the problem with an early opening in the prawn ( $P$. platyceros) fishery after it has been closed for six to eight months to protect the breeding females.

Upon hatching, shrimp larvae remain in the plankton for up to three months before settling to the bottom as juveniles. Berkeley (1930) describes the post-embryonic development for five of the commercial species. The stages of development and their distribution varies considerably between species. P. danae seems to spend most of its larval development in the area of hatching, while species like $P$. platyceros and $P$. hypsinotus spend the first two stages near the site of hatching and then tend to disappear but juveniles are generally found in comparatively shallow water. The time spent as larval stages can also vary between species. For example, prawn larvae are much more developed and undergo fewer moults to settlement stage than do pink shrimp and would, therefore, spend less time in the plankton community.

Hannah (1993) developed a recruitment index for $P$. jordani which he then showed to be strongly correlated with changes in sea level at the time of larval release, thus suggesting for this population that early larval transport plays a major role in determining year class survival. However, even after accounting for this environmental influence, he was still unable to develop a stock-recruitment relationship for this population. This correlation between recruitment success and early larval transport may account for some of the highly fluctuating situations in B.C. waters like the offshore fisheries in Management Area 124 where between year estimates of populations of $P$. jordani, have fluctuated from 23 to 13,000 tonnes.

In contrast, however, the smaller inshore fisheries appear to have quite long, stable histories. In some areas like those around Vancouver, trawl fisheries have been going on since before the first world war (T.H. Butler, pers. comm.). In these areas, the larvae are probably not subjected to the same variations in larval transport both from a geographic perspective as well as species differences with respect to larval location and development. Larvae in some inshore areas, such as Howe Sound, show very small scale entrainment patterns. This is evident where areas in close proximity produce two separate population of distinct species of pink shrimp, $P$. jordani and $P$. borealis eous. Areas of high larval containment would enhance the likelihood of a strong stock recruitment relationship and, thus, raise greater concerns about the likelihood of recruitment overfishing. Boutillier (1996) developed a Ricker density dependant stock recruitment relationship for $P$. platyceros in this same area.

## AgE AND GROWTH

The age of recruitment to a fishery depends on the species and the gear used. In the trap fishery for $P$. platyceros the industry has modified their gear to allow for optimal growth and the age of first recruitment is age $2+$. In the trawl fishery for $P$. jordani off the west coast of Vancouver Island shrimp are fully recruited to the fishery at age $2+$, but partial recruitment can occur at as early as 9 months of age. The age of recruitment can change as a result of variations in growth patterns which can result in between area differences or density dependence of growth within an area. Species such as Pandalopsis dispar, which have much greater growth rates, are commonly mixed in with pink shrimp catches at half the age of the pink shrimp. Hannah and Jones (1991) pointed out that Oregon has undergone a major shift to a younger age of recruitment due to fishery induced changes to growth patterns. The age of recruitment is important when trying to determine the effects of fishing activities on various segments of the stock such as the calculation of instantaneous fishing mortality " $F$ ".

Shrimp must shed their exoskeleton to grow. As a result of this, there are no permanent body structures retained making the use of conventional ring counting ageing techniques impossible. For shrimp, a modal analysis of length data that incorporates sex and maturity condition is used to estimate age. Sex and maturity condition information are important factors in the analysis because males and females have different growth patterns. The male portion of the population will continue to grow and moult throughout the year while the females will cease moulting during the period that they are carrying eggs. Similarly, the abundance of females can not be extrapolated from the age/size composition alone because some animals can skip the males phase completely. Without taking the extra step of collecting biological information on the sex of the animals, determining the proportion of potential egg bearing spawners for a spawner recruit relationships is difficult if not impossible. Four is the maximum age for most of B.C.'s species of commercial shrimp, although most probably live to age 3 .

## Habitats, Behavior and Migration

In the assessment process, shrimp habitat, behavior and migration are important criteria when interpreting data. Species can vary in their preferred habitats from rocky to green mud and sand. Species also differ in the ecological niche they occupy from a benthic or pelagic environment. $P$.
danae, $P$. hypsinotus and $P$. platyceros are basically benthic dwellers; $P$. borealis eous and $P$. jordani are both benthic and pelagic with preferences depending on diurnal cycles; while Pandalopsis dispar is probably mostly pelagic.

Shrimps may undergo diurnal migrations. For species such as $P$. jordani and $P$. borealis eous, this means that they rise off the bottom at night and will not be as available to bottom trawl gear. For species such as $P$. platyceros, this may mean a migration into shallower water. An analysis of CPUE data to track population trends must incorporate correction factors that account for variations by location, gear, species, time of day and season.

Tagging studies of $P$. platyceros showed that adult prawns do not move any great distances (Boutillier 1996). However, repeat surveys of pink shrimp on the grounds of the west coast of Vancouver Island have shown quite substantial changes in the distribution of pink shrimp throughout the year (Boutillier et al. 1978a,b). Butler (1964) described different growth rates for three stocks of sidestripes in close proximity (Howe Sound, Burrard Inlet and Indian Arm) which would indicate very limited movement between areas for these animals.

Hilborn and Walters (1992) describe a number of distribution profiles for animals. From these profiles, the pink shrimp appear to best be characterized as diffusive stocks that show a constant density model of behavior. This means that abundance of animals at any one location will depend on abundance elsewhere, and that the animals maintain a reasonably constant density by adjusting the area covered. This type of tendency is evident in survey results of the offshore shrimp stocks in high and low abundance years (Boutillier et al. 1976 and Boutillier et al. 1982). Hannah (1995) confirmed this type of distribution profile for $P$. jordani off Oregon, where he found a strong linear relationship between catch and area. The residuals of this regression did, however, indicate that it might be non-linear with the area expanding less rapidly at large stock sizes. This kind of understanding of an animal's behavior is critical when interpreting CPUE data.

## BACKGROUND MATERIAL AND METHODOLOGY

## Review of B.C. Inshore Shrimp Fisheries

For the purposes of this paper, the summary of the fishery will mainly concentrate on four fisheries: Area 4, Area 14, Area 17, and Area 28/29 combined (Fig 1). Discussion, however, will include trends and results from other areas where applicable. The in-depth analysis included only areas with historically consistent and large catches. The one exception to these selection criteria was the fishery in Area 23. Even though the fishery has a long and productive history, data quality problems have excluded the area from the analysis. In particular, the inshore Barkley Sound fishery catches could not be separated from the Area 123 outside shrimp fishery catches. Parasite markers show that these inshore and offshore fisheries are exploiting quite separate populations of shrimp. The data used will be a combination of landing-slip data, which is available from these fisheries since the 1950's, and logbook data, which is available from these fisheries since 1987.

## Biological Considerations

The inshore shrimp trawl fisheries are generally multi-species fisheries which historically targeted primarily on three species of shrimp: Pandalus jordani (smooth pink); P. borealis eous (northern pink); and Pandalopsis dispar (sidestripe). There was also sporadic targeting on P. platyceros (prawn), however, a prawn by-catch limit was implemented in 1990 (Adkins and Fulton 1990). The degree of targeting on $P$. danae (coonstripe shrimp) and $P$. hypsinotus (humpback) has varied historically but generally the level has been low through the 70 's, 80 's and early 90 's. The degree to which a fishery is a single-species verses multi-species fishery varies considerably between geographic areas and gear used.

## ANALYSIS OF Logbook and Biological Data

## Logbook Data

Data from the mandatory logbook program for these inshore fisheries goes back to 1987. The analysis of logbook data provided estimates of biomass and exploitation rates. For the purposes of this analysis, the data was separated by species, area, season and gear type.

Separation of catch rates by species grouping provided catch rates for sidestripe and pink shrimp ( $P$. jordani and $P$. borealis eous) and total catch for all other species. Separation by species was necessary so that catch per unit effort (CPUE) of one species did not mask trends on a different species. An example of the type of problem that could arise if total catch was used to determine CPUE occurred in Area 4 where for many years pink shrimp were discarded at sea and not documented, then as a market developed and they were retained thus increasing the CPUE substantially. This was a particular problem in Area 4, which had a very limited market for pink shrimp in most years. It was not possible to calculate catch rates for other species because of inconsistent and incorrect reporting. Industry, at a number of meetings and during at sea sampling, indicated difficulties in separating catch by species especially for coonstripe and humpback shrimps as it appears that fishermen were either unwilling or unable to identify their catches by species. Only in 1996 have they made an effort to more accurately report their catch.

## Effort Standardization

A paired t-test and Wilcox non-parametric test were used to look for significant differences in catch rates by gear types fished in the same area, on the same day, for the same species grouping. The analyses by area ran comparisons of catch rates of all gear types against the most common gear used. The $40-49$ foot beam trawl " 4 P " was the most commonly used gear in all the inshore shrimp fisheries.

## Biomass Dynamic Model

The CPUE data by species and by area were fit to a modified Schaefer biomass dynamic model (production model) using both the Walters and Hilborn (1976) difference equation and the Pella and Tomlinson (1969) observation error/time-series fitting method.

The Walters and Hilborn (1976) difference equation is:

$$
\begin{equation*}
\frac{U_{t+1}}{U_{t}}=r-\left(\frac{r}{k q}\right) U_{t}-q E_{t}+1 \tag{1}
\end{equation*}
$$

The model states that the 'rate of change of biomass' = 'intrinsic growth rate' minus 'density dependent reduction in growth rate' minus 'exploitation rate'. $U$ (CPUE in year $t$ and $t+1$ ) and $E$ (effort in year $t$ ) are the independent variables. The calculated parameters of the regression are $r$ (intrinsic growth rate), $-r / k q$ and $-q$ (catchability coefficient).

The Pella and Tomlinson time-series fittings take the initial estimate of the stock size at the beginning of the data series and then predicts the whole time-series of the data set. It involves estimating the normal parameters of the Schaefer model, $r, k$, and $q$, plus the starting biomass ( $B_{0}$ ) using non-linear parameter estimation procedures. The measure of goodness of fit is minimization the squared deviations between observed and predicted CPUE.

## Biological Sampling

Biological samples were collected on an opportunistic basis by fisheries officers and observers when sampling commercial vessels. All samples were processed for sex and carapace length. Although the time series of biological sampling data for any single management area was insufficient to undertake an age structured modeling of a particular fishery, comparisons of age, sex and size information from individual samples between areas provided some insights on the apparent differences between areas.

## RESULTS

## Overview of the Fishery

## Management Practices

A valid "S" licence is required to commercially harvest shrimp by trawl gear. Limited entry was introduced in 1979 and the fishery currently has 249 valid licenses. At the present time, B.C. inshore shrimp trawl fisheries are not actively managed with the exception of a five pound prawn by-catch allowance, which is permitted when the prawn-by-trap fisheries are open. The fishery is open year round with no restrictions on gear or harvest. Fishers are required to submit monthly harvest logs detailing catch, effort and fishing location and to submit landing slips within 7 days of landing product.

## Historical Trends in Participation, Effort and Catch

Inshore fisheries are mainly conducted with smaller ( $<15 \mathrm{~m}$ ) trawl vessels that fish beam type trawls. In 1995, 183 vessels submitted logbooks with catches of pinks and/or sidestripes. Catch, effort and trends in species composition of the catch are presented for the four fishing areas (Areas 4, 14, 17 and 28/29) assessed in this review (Table 1).

## Area 4:

Chatham Sound is mainly a small boat, beam trawl fishery. The catch from the fishery (Fig. 1) peaked in the 1960's, averaging 99 t/year, and declined in the 70's and 80's with average annual catches of 19 t and 17 t respectively. The fishery is undergoing a resurgence in the 1990's similar to that in the 1960's. In 1995, 25 vessels landed 160 t , one of the highest recorded landings from the area.

The average catch composition since 1987 by species has been $51 \%$ pinks and $49 \%$ sidestripes with the catch of other shrimp species at $<1 \%$. Figures 2 and 3 show that the unstandardized logbook CPUE's, for pinks and sidestripes respectively, are at recorded highs for the area. The average CPUE for pinks and sidestripes is .77 and $.54 \mathrm{lb} / \mathrm{min}$., respectively.

Since 1987, the "4P" trawl has been the most consistently used gear. With respect to the total effort expended in the area, the use of the " 4 P " trawl varied from $28 \%$ to $88 \%$ for pink shrimp and $33 \%$ to 93\% for sidestripes (Figs. 4 and 5, respectively). The "4S" trawl was used extensively in 1987 while the " 5 P " trawl was used in 1988, 1989 and 1995. The use of otter trawls has been evident from 1989 to 1994 with the use of a variety of sizes of flat, semi-balloon and high-rise trawls.

## Area 14:

Comox has generally been a local small boat beam trawl fishery which underwent a significant increase in landings since 1990 that peaked in 1993 and subsequently declined (Fig. 1). In 1995, 23 vessels landed 32 t . This was well below the 131 t peak landing taken from the area in 1965.

The catch from 1987-1995 has been made up of $91 \%$ pinks, $8 \%$ sidestripe, and $1 \%$ humpbacks and prawns combined. It is evident in Figure 2 that logbook CPUE for pink shrimp, which averaged $0.96 \mathrm{lb} / \mathrm{min}$., has declined steadily since 1992. The average unstandardized CPUE for sidestripe shrimp is $0.13 \mathrm{lb} / \mathrm{min}$., and CPUE was at all time recorded low in 1995 (Fig. 3).

Since 1987, the main trawl type in the area was again the "4P" beam trawl with use varying from $31-96 \%$ for pinks (Fig. 4) and 12-97\% for sidestripes (Fig. 5). In 1987, the 40-49 foot sled trawl " 4 S " was the dominant gear used. Use of the $50-59$ foot " 5 P " pole trawl has been increasing since 1991. In 1995 the use of otter trawls has increased. In that year, $17 \%$ of the pink shrimp and $26 \%$ of the sidestripe catch was taken using a variety of otter trawls.

## Area 17:

Stuart Channel has a small-boat beam trawl fishery composed of a local fleet and a transient fleet from Steveston and Vancouver. In 1995, 16 vessels landed 17 t , which is well below the peak catch of 327 t in 1957. The fishery in the 50's and 60's had reported catches in excess of 100 t while catches in the 1970's, 80's and 90's are consistently below 50 t , with the exception of the mid 80 's where catches fluctuated between 50 and 100 t (Fig. 1).

The catch over the period 1987-1995 has be made up of $73 \%$ pinks, $19 \%$ sidestripes and $8 \%$ prawns. The rather high percentage of prawns in this fishery indicates that the fishery had been targeting on this less available, more valuable shrimp. A look at the 1994 and 1995 data from logbooks, shows a reported catch of prawns of $1 \%$ or less. It is evident in Fig. 2 that the logbook unstandardized CPUE for pink shrimp, which averaged $0.42 \mathrm{lb} / \mathrm{min}$., has declined steadily since 1992, although there has been a slight increase in 1995. However, as in Area 14, the 1995 unstandardized CPUE for sidestripe shrimp, which averaged $0.14 \mathrm{lb} / \mathrm{min}$. (Fig. 3), is at an all time low for the recorded history of the area.

On average, the most frequently used trawl type in Area 17 is again the " 4 P " trawl with the use varying from $28-88 \%$ for pinks (Fig. 4) and $56-90 \%$ for sidestripes (Fig. 5). The second most frequently used gear used was the " 3 S " trawl in all years except 1992. The " 4 S " trawl was popular in 1987 through 1989, and again in 1994 and 1995. Since 1992, the "5P" and "3P" trawls were also used extensively.

## Area 28/29:

Howe Sound and Vancouver/Sechelt area has a small-boat beam trawl fishery which seems to have a catch record similar in many respects to Area 17 . In the 50's and early 60's the catches were substantially higher than they have been since that time. For example, the average annual catch up to 1963 was 295 t . However, the average catch dropped by more then $50 \%$ since that time. In 1995, 46 vessels reported landing 145 t of shrimp (Fig. 1).

In the combined Area 28/29, the catch was made up of $84 \%$ pinks and $16 \%$ sidestripes, with less than $1 \%$ incidental other species. Average unstandardized CPUE for pinks since 1987 was 0.78 and $0.32 \mathrm{lb} / \mathrm{min}$. (Fig. 2) for Areas 28 and 29, respectively. CPUE for pinks peaked in both areas in 1988 and 1992 and has since declined, although 1995 showed a slight increase. The 1995 trend in sidestripe CPUE (Fig. 3) is not as obvious, with Area 28 recording a high CPUE and Area 29 the second lowest CPUE recorded since 1987. Since 1987, overall average unstandardized CPUE for sidestripes was 0.12 and $0.11 \mathrm{lb} / \mathrm{min}$. for Areas 28 and 29, respectively. Boutillier (1994) pointed out that Area 29 was the major sidestripe producing area of the combined fisheries. Historically, landings in Area 28 have only been $1 / 4$ to $1 / 2$ of those in Area 29. In 1995, however, Area 28 recorded peak production and landings of sidestripes, which exceeded those in Area 29 for the first time in recorded history. How much of this is due to population trends in the respective areas and how much is due to reporting discrepancies is hard to determine at this time.

The trends in gear used is similar to the previous areas discussed, with the most common gear being the " 4 P " trawl. $65-99 \%$ of the effort directed towards pinks (Fig. 4) and $54-99 \%$ of the effort directed towards sidestripes (Fig. 5) used the "4P" trawl. Early use of the " $4 \mathrm{~S} "$ in 1987 was followed by switch to " 5 P " and "3P" gears in more recent years. There was some use of a variety of otter trawls in Area 29 but this has been fairly minimal with catches taken using these gear types amounting to $<1 \%$ of the total catch.

## Other areas:

Analysis of logbook data showed that effort in other areas has been expanding along with the trends seen in the four major production areas. Figures 6 and 7 show increases in effort in 1995 for all major geographic areas (North Coast, South Coast, West Coast Vancouver Island, and Offshore areas) for pinks and sidestripe shrimp. Table 2 shows an increase in catches of humpback and coonstripe shrimp. This is particularly evident in 1996 preliminary catch data. Again, how much is due to changes in the fishery and how much is due to better reporting late in 1996 is hard to quantify. If anything, however, it probably underestimates increased targeting on these two species of shrimp, since most of the catch is from newer areas in which fishermen have admitted to not reporting catch-by-species accurately.

## Review of Biological Considerations

A distinction is made between inshore and offshore fisheries for a variety of reasons:

1) Some inshore fisheries have a long and relatively stable history, with some fisheries being in existence since the early 1900 's. The offshore fisheries have a much briefer, more erratic history, with the fishery starting in the early 1970's.
2) The inshore fisheries do not undergo the same degree of fluctuation, and the localized nature of some stocks (such as those described above for Howe Sound) tend to indicate containment of larvae and, therefore, a likelihood of a strong stock-recruit relationship.
3) Inshore fisheries tend to be mixed-species fisheries, harvesting at least 5 different species of shrimp, while the offshore fisheries generally harvest only pink shrimp ( $P$. jordani).

## Analysis of Existing Logbook and Biological Data

## Effort Standardization

The results of the effort standardization exercise produced significant ( $\mathrm{P}<0.05$ ) but often conflicting differences depending on the species or area being tested.

For Area 4, there were a number of significant $(\mathrm{P}<0.05)$ differences found in paired T-test and Wilcox non-parametric comparisons of CPUE by gear. For both pinks and sidestripes, the larger " 5 P " trawl had higher catch rates than the " 4 P ". For sidestripes, this was again the story for the larger 130-150 foot high-rise otter trawl in comparison to the " 4 P " beam trawl. There were,
however, significant differences also observed in which the small " $3 S$ " beam trawl outperformed the larger " 4 P " for sidestripes and the smaller " 4 P " out performing the $70-90$ foot flat trawl for pink shrimp.

Area 14 results of paired T-tests and Wilcox non-parametric tests of data by day revealed that there were significant differences between the CPUE of major gear-types for pink shrimp, but not sidestripe shrimp. In the case of pink shrimp, mean catch rate was higher for " 4 P " gear than both other gear types, even though the " 5 P " is a larger net.

In Area 17, the results of paired T-tests and Wilcox non-parametric test of CPUE by day for the various gear types indicated that there are significant differences between CPUE of " 4 P " vs. " 3 S " and "4P" vs. "5P" gear types. However, unlike the results from Area 14, the larger nets had larger CPUE's, which is intuitively more acceptable.

Paired T-tests and Wilcox non-parametric tests of paired observations by day in Area 28/29 combined found that there were significant differences between the gear types. However, the results were inconsistent; for example, the smaller " 3 P " nets had higher catch rates for pinks than the larger " 4 P " net. For the larger " 5 P " net, lower catch rates for pinks were reported than for the " 4 P " trawl in Area 28, but not Area 29, while the catch rate for sidestripes was consistently significantly higher for the " 5 P " trawl in both areas.

Since the results of effort standardization analysis did not produce consistent results, all further analyses were conducted using unstandardized CPUE.

## Biomass Dynamic Models

Using Hilborn and Walters' regression to fit unstandardized annual CPUE for each species grouping to the Schaefer model produced, for most part, unusable results. That is, results generally produced negative values of $q$ (catchability coefficient) and/or negative values of $k$ (estimated unfished biomass). The Pella and Tomlinson time-series fit of the data appears to give more usable initial results (Table 3), however, many of the results do not explain the data very well.

Boutillier (1994) fit Leslie models to data from all shrimp years minus the first 3 months of each year. These first three months were generally periods of small effort and increasing CPUE's. The increase in CPUE in the spring under these low fishing effort conditions is probably a function of growth of all non-berried animals and recruitment of juveniles. When realistic results for the Leslie model were found for the various areas, the estimated populations sizes were very close to the actual catches, especially in the later years. There were a number of reasons cited for this, including that the data does not take into account factors such as growth, recruitment, and natural mortality. The way the analysis was conducted it was not possible to take into account any seasonal shifts in effort from high volume-low priced pink shrimp to low volume-high priced sidestripe shrimp.

## Biological Data

We are just beginning to accumulate information from biological sampling of these trawl fisheries. Most of the data to date has been obtained from on-board sampling as part of the 1996 by-catch study, fishery independent survey results, and sporadic commercial sampling by charter and patrol vessels in Areas 28/29, 123 and 23.

While limited in scope, the evaluation of the biological data consisted of comparisons of size, age and sexual condition of sidestripe shrimp from: (a) a relatively unfished area with high CPUE (Area 10); (b) a heavily fished area with high CPUE (Area 4); and (c) a heavily fished area with low CPUE (Area 28/29 combined) (Figs. 8, 9 and 10, respectively). The most interesting feature of these histograms is that Area $28 / 29$ is missing the age group 2 males, which show up as primary females. That is, most of the age 2 shrimp are bypassing the male phase and going directly through transition to females. This population characteristic is absent for the other two areas with high CPUE's and is rare for sidestripes in general.

## DISCUSSION = ANSWERING THE QUESTIONS

## 1) IS THERE ANY EVIDENCE THAT THE INSHORE STOCKS OF SHRIMP ARE SUBJECT TO INCREASED FISHING PRESSURE?

The results confirm that inshore shrimp fisheries have been undergoing increased fishing pressure. This increased pressure is evident as an overall increase in unstandardized fishing effort (Figs. 6 and 7), and in an increased use of larger more efficient otter trawls. It is also evident that the fishery is changing from targeting mainly on pink shrimps and sidestripes and is now also targeting on isolated pockets of humpback and coonstripe shrimp.

## 2) ARe there any indications that stocks are being put at risk with these increased PRESSURES?

## Historical Data

The answer to this question varies by the area and species of concern. Interesting trends occur in the historic catches from the areas with pink shrimp production. There appears to have been much higher production regimes in the early 1950's and 1960's, declining production in the 1970's and 1980's and increasing production in the 1990's. This increase in the 1990's is evident in Areas 4 and 14, where fishing pressure was low or non-existent in the 1970's and 80's. The increase in the 1990's however is not as evident in Areas $28 / 29$ and 17 where there has been a steady fishery.

There are two possible explanations for this difference between the areas, either:

1) Fishing pressure in Areas $28 / 29$ and 17 was so high in the 1970's and 80's (the supposed poor production period) that the stocks were depressed to such low levels that they could not respond to the good production period in the 1990's; or
2) The patterns were totally due to differences in fishing effort over this period.

There has been a shift to species which will support a fishery with lower catches because of their higher value. An increased demand for high quality shrimp made fishing in areas of lower concentrations still profitable at a much lower CPUE, cited by Hilborn and Walters (1992) as a classic situation which could lead to severe overexploitation and stock collapse. We have also seen a shift to the exploitation of populations which are restricted to confined smaller areas. Winters and Wheeler (1985) point out that populations in small areas are more efficiently exploited per unit of fishing effort than populations fished with proportionally comparable effort in a larger area.

## CPUE Analysis

When analyzing CPUE data, factors such as the relationship between distributional area and abundance of the animals (Winters and Wheeler 1985; Hannah 1995) and communication and cooperation between fishermen compromise the effectiveness of CPUE as an index of abundance because they lead to hyperstability of CPUE. Hyperstability is a situation where CPUE remains high while the population abundance declines. This is described by Hilborn and Walters (1992) as one of the best and worst features of a fishery. For the fishermen, it means not suffering decreases in CPUE as abundance changes, but for the assessment biologist, it means that stock will have gone through drastic declines before it is detectable from CPUE data. Winters and Wheeler (1985) reviewed the problems associated with the use of CPUE for stock abundance estimation due to the interaction of stock area and catchability coefficient. They pointed out that even when CPUE is measured with the utmost precision, and the relationship between abundance and distributional area can be accounted for in the model, commercial data will still be biased.

Keeping these points in mind, it appears that Area 4 is relatively healthy at the present time, with historically good levels of CPUE for both sidestripes and pink shrimp. South Coast inshore areas all seem to be showing relatively low or declining levels of unstandardized CPUE for sidestripes and, in some cases, pink shrimp.

## Biological Samples

Analysis of sidestripe shrimp biological sample data supports this view. In Area 4, age class structure of the population seems to be similar to the lightly exploited stocks in Area 10. However, in Area $28 / 29$ combined, the population of sidestripes is exhibiting a compensatory response by producing primary females.

Butler (1964) speculated that primary females occur when shrimp stocks are under the stresses of adverse environmental conditions, and that the occurrence of primary females is a mechanism to increase the reproductive potential of the population.

Charnov et al. (1978) hypothesized that if the proportion of primary females ( $y$ variable) is plotted against the ratio of older breeders to primary females ( $x$ variable) than a negative relationship is expected for small $x$ values and no relation for large $x$ values. That is, when the ratio of older animals to younger animals is low, likelihood of primary females is high. Charnov (1982)
extensively reviewed sex allocation in shrimp populations and found, in most cases, trends which appeared to support stable sex ratio and a lack of older breeding male shrimp when there were primary females. He noted that increased production of primary females in P. borealis eous fisheries occurred after heavy fishing pressure. However, he did discuss some contradictory evidence from Oregon for a $P$. jordani stock, where there were abundant primary females at the same time as some older functioning males. In this case, the time of sex reversal seemed to be influenced by age and size distribution of the population.

Hannah and Jones (1991) report on fishery induced changes of increased growth rates and younger age structure of $P$. jordani stocks off Oregon. With the shift in age structure to younger shrimps came a dramatic increase in primary females in the fishery. This fishery originally exploited three year classes of animals, but now an intensive fishery targets almost exclusively on age group 1+ shrimp, which are composed of nearly $50 \%$ primary females. They state that the ability to accelerate sex change and growth rates makes these animals very resistant to overharvest. They do, however, also state that, at some level of exploitation, the ability of these animals to accelerated sex change and density-dependent growth will not prevent declines in larval release and declining recruitment, even though there has not been a stock recruit relationship demonstrated for the area. They believe that they have not reached a level of exploitation in the Oregon offshore shrimp fishery that would affect recruitment, and use strong year classes passing through the fishery from 1986-1988 as a justification for this point of view. The USA Pacific Fishery Management Council for California, Oregon and Washington (1981) however, does identify both increases in percentage of age-1 shrimp and percentage of primary females as potential indicators of overharvest in pink shrimp fisheries.

## 3) What are the options for controlling the fishery in a manner that assures SUSTAINABILITY?

Pandalid shrimp fisheries, for other gear types and target species and/or in other areas of the world for the same gear types and species, have been actively managed in a variety of ways for a variety of reasons. In B.C., concerns of recruitment overfishing in the prawn trap fishery have led to a management system which sets constant spawner escape targets (Boutillier, 1996). In the same fishery, size limit restrictions and escape modifications for various trap types have been instituted to address growth overfishing problems (Boutillier 1984). Trawl fisheries for pandalid shrimp in other parts of the world have been restricted at times by quotas, seasonal spawning period closures, size count restrictions, and active $100 \%$ observer coverage. These management actions have been undertaken to address various recruitment and growth overfishing concerns. These actions have been documented in many places and the actions have met with varying degrees of success. However, it must be stated that the B.C. inshore trawl fishery is unique in its complexity of species, habitats and life history strategies, and the data available to evaluate these fisheries is totally inadequate.

Considering that DFO has a mandate to develop risk averse management, it is appropriate to review the FAO (1995) guidelines on the precautionary approach to capture fisheries and species introductions. Under a precautionary approach, there is a recognition that there are uncertainties in
fisheries systems and yet there is a desire to harvest in spite of this incomplete knowledge. The eight points that they advise must be considered by managers are:

1) "consideration of the needs of future generations and avoidance of changes that are not potentially reversible;
2) prior identification of undesirable outcomes and of measures that will avoid them or correct them promptly;
3) that any necessary corrective measures are initiated without delay, and that they should achieve their purpose promptly, on a time-scale not exceeding two or three decades;
4) that where the likely impact of resource use is uncertain, priority should be given to conserving the productive capacity of the resource;
5) that harvesting and processing capacity should be commensurate with estimated sustainable levels of resource, and that increases in capacity should be further contained when resource productivity is highly uncertain;
6) all fishing activities must have prior management authorization and be subject to periodic review;
7) an established legal and institutional framework for fishery management, within which management plans that implement the above points are instituted for each fishery; and
8) an appropriate placement of the burden of proof by adhering to the requirements above."

Managers have a number of options for controlling fisheries, including common harvest strategies such as: constant catch quota, constant harvest rate, and fixed escapement strategies. Constant harvest rate and fixed escapement can also be used in conjunction with a critical threshold management policy. For example, under this scenario harvesting occurs at a constant harvest rate, but ceases when a population drops below a critical low level.

No matter which strategy is chosen there will always be questions that have to be addressed so that appropriate levels set and the efficacy of the management action can be evaluated. For example;

| Constant Quota | $\rightarrow$ What should the quota be? |
| :--- | :--- | :--- |
| Fixed Harvest Rate | $\rightarrow$ What is the appropriate harvest rate? |
|  | $\rightarrow$ What is the biomass to which to apply the harvest rate? |
| Fixed Escapement | $\rightarrow$ What is the appropriate escapement level? |
| Critical Threshold | $\rightarrow$ How is the escapement measured? |
|  | $\rightarrow$ What should the critical threshold level be? |
|  |  |

Any one of these options may meet the fisheries management objectives, but they each will require a framework for development and evaluation.

## Framework

The purpose of this section is to conceptually develop some of these strategies.

## Critical Thresholds

Critical thresholds are in use in a number of fisheries, such as the B.C. herring fishery. Conceptually, a threshold limit is based on a percentage of the average size of stock in an unfished stage. Pearse and Walters (1992) suggest an appropriate critical threshold could be one third the size of the stock in an unfished state. They recognize that having a critical threshold is for the management of the conservation goals of a public resource and that the stock at this size is below peak production potential. They, however, suggest leaving the choice for a more conservative limit up to the stake-holders.

Once a critical threshold percentage is established, how do we translate it into an index that can be used by managers and assessment biologists for management of the fishery? Since many of these populations have been exploited over a period much longer then any historic records, one option that we have to determine appropriate indices of virgin biomass is to extrapolate indices from newly fished areas to these areas. If we consider CPUE as an index of relative abundance, then by looking at CPUE of relatively new fisheries, we can extrapolate this value as an appropriate index level for a virgin stock for areas with a long history of fishing. Annual catch rates for sidestripes in new fishing areas in the north coast range from 0.35 to $1.30 \mathrm{lb} / \mathrm{min}$. Area 4 has been a major sidestripe producing area and it has had an average catch rate of 0.54 since 1987. If an arbitrary level, such as the running average CPUE for Area 4 , were used as a index of $B_{0}$ for sidestripe producing areas, then the threshold cut-off point would be approximately 0.18 pounds per minute. If this threshold were applied to the southern areas evaluated in this study, they would be closed to sidestripe fishing.

Applying a similar exercise to pink shrimp revealed that CPUE's from newly fished areas ranged from 0.30 to 2.00 . Area 14 , which is mainly a pink shrimp producing area, has not historically received as much fishing pressure as other southern areas. If we were to use the running average of CPUE for pinks for Area 14 as an index, it would be $0.96 \mathrm{lb} / \mathrm{min}$. and the threshold level would be $0.32 \mathrm{lb} / \mathrm{min}$. All the areas reviewed in this paper exceed this level except Area 29, which was at the threshold level.

Another method of estimating an index of abundance (CPUE) at the unfished stage is to use the results of the Schaefer model, fit using the Pella and Tomlinson time-series estimation procedure, where CPUE at $B_{0}$ is $q B_{0}$. In this case, the estimates CPUE at $B_{0}$, for Areas 4,14,17 and 28/29 are respectively: $1.75,3.61,0.56$, and 0.67 for pink shrimp and $1.14,0.15,0.14$, and 0.29 for sidestripes. Using this scenario, theoretical cutoff points could be established for each specific area.

Determining which method to use would depend on the weight of the reliability that you place on the estimation procedure.

## Setting Quotas

Quotas are usually set using models which try to take the catch while maintaining the stock size at a level where peak growth is obtained. This quota or MSY has been estimated to be at a level of " $X M B_{0}$ ", where " $X$ " is a scaling factor (commonly used scaling factors include: 0.2 (Garcia et al. 1989), 0.4 (Caddy 1987) and 0.5 (Gulland 1971)), " $M$ " is an instantaneous mortality rate, and " $B_{0}$ " is the unfished biomass.

Using Hoenig's (1983) method to calculate $M$ :

$$
\begin{equation*}
\ln (M)=1.44-0.982 \ln \left(t_{\max }\right) \tag{2}
\end{equation*}
$$

then $M$ equals 1.08 if the maximum age of 4 is used for shrimp in B.C. The estimated exploitation rates calculated, for $0.2,0.4$ and 0.5 scaling factors would be $0.22,0.44$ and 0.54 respectively. The problem now, in calculating the quota, is estimating $B_{0}$ and determining where the present stock is in comparison to the unfished biomass. If, for instance, the biomass is above the estimated MSY biomass level, then the population could be reduced with catches at or above MSY and the population would be expected to more than compensate for overall reduction. If, however, the biomass was below the MSY biomass level then the expected quota would be below the MSY level. If the quota were equal to surplus production at the current low biomass level, then the population would, theoretically, remain constant at this less productive level. However, if the quota were below the surplus production level of the current biomass, then the population would, theoretically, be in a position to rebuild to a more productive level.

Another method that could be used to calculate quotas and to estimate exploitation rates at MSY for these various species groupings is to use the results of Schaefer model, as fitted by the Pella and Tomlinson time-series estimation procedure. For the Schaefer model, the rate of exploitation at MSY is equal to " $r / 2$ " where " $r$ " is the intrinsic growth rate. The estimates of this exploitation rate at MSY for the different areas varied between 0.05 and 0.40 for pink shrimp and 0.12 and 0.44 for sidestripes. The 0.2 and 0.4 scaling factors recommended by Garcia et al. (1989) and Caddy (1987) produced estimates within the range of the Schaefer model estimates.

The problem of how to estimate current biomass still remains. As has been discussed previously, reliance on CPUE data is fraught with problems. Winters and Wheeler (1985) concluded that "emphasis should be placed on research vessel survey data collected in a standard manner and covering the distributional area of the stock". Historically, this type of survey has been conducted using a systematic grid pattern which provides not only density estimates of the shrimp but also a good definition of the boundaries of shrimp biomass by continuing to survey along the grid line until shrimp are no longer found in the catches. These types of surveys are possible in areas where shrimp occupy a portion of a large uninterrupted trawlable areas. If, however, the survey is in an area with very restricted areas of trawlable bottom, then survey design will have to be modified to
allow for measurement of shrimp density in small untrawlable pocket areas in close proximity to the trawlable grounds.

If fishery-independent survey estimates are not available, then a fishery-dependent CPUE index would have to be established at the beginning of the fishery, and a monitoring system put in place to watch for fixed rate decline in CPUE. This latter method would be difficult considering the likelihood of hyperstability of the CPUE index for shrimp, as discussed earlier. It may be possible to get around some of the problems with CPUE by incorporating information on the area swept and the exact location of the fishing activity. To do this, fishery-dependent data has to be sufficiently geo-referenced and better information on the gear used must be collected.

## Fitted Escapement Targets

Fixed escapement targets are dependent on a stock-recruitment relationship where an index of spawners is set and the fishery closes once that level is reached. In the case of prawns, the index is set as CPUE of female spawning prawns for a standard trap hauled, and the commercial fishery is then monitored in-season to measure the index. Shrimp trawl fisheries have insufficient data from which to develop a stock-recruitment relationship and the problems discussed previously with CPUE would make measuring an index on individual tow basis difficult to interpret precisely.

## RECOMMENDATIONS

1) The increased effort in fisheries for distinctive species of shrimp in small, isolated areas has the potential to have significant impacts on the stocks of these inshore shrimp populations. To meet DFO conservation and sustainable fisheries goals, a much more active management system is recommended for these fisheries.
2) To undertake active management of these fisheries, there must be data available to monitor the interplay between the fishery and the stock dynamics. This means monitoring various levels of exploitation against such factors as: stock abundance, growth rates, primary female production rates, egg production, and mortality rates (including natural and fishing mortalities). There must also be an infrastructure in place to collect this data. Without a data collection infrastructure, the fisheries should not proceed. With industry co-operation, a few simple and relatively inexpensive improvements to databases could be easily implemented. A data collection framework to meet these data needs would include improvements such as:
a) From the logbooks, the CPUE data used in Leslie depletion estimates provide often unusable results. If we are going to continue to try to use this fishery-dependant data, we are going to have to start insisting on more precise location information. It would be preferable to have it geo-referenced using latitude and longitude co-ordinates of the start, stop or middle of the tow along with the distance trawled. In addition, better information on the exact type of gear being used will be essential.
b) Fishery-independent surveys would provide the most useful and meaningful series of data. There is an opportunity here for industry to work with DFO to undertake annual
pre-fishery synoptic surveys of the major fishing areas. This type of survey should cover the entire fishing area and would take only a few days to complete. Fishers would help work up the survey results and would participate in discussions on how to proceed with that year's fishery. Similar procedures have been implemented in some small, Australian shrimp fisheries (C.J. Walters, University of British Columbia, pers. comm.).
c) Over the entire period of the fishery, it is necessary to conduct consistent biological sampling. Having the data collected on an ad hoc basis will not provide us with the information necessary to monitor population responses to the fishery.

## REFERENCES

Adkins B. and J. Fulton. 1990. Prawn trap fishery (Fishery Update). pp. 213-219. In: G.A. Thomas [ed.]. Shellfish stock assessment for the west coast of Canada in 1990 as reviewed by the Pacific Stock Assessment Review Committee (PSARC). Can. Manuscr. Rep. Fish. Aquat. Sci. 2099.

Berkeley, A.A. 1930. The post-embryonic development of the common pandalids of British Columbia. Contr. Can. Bio. Fish. 6.

Boutillier, J.A. 1979. Shrimp population survey, west coast of Vancouver Island, September 1978. Fish. and Marine Serv. Data Rept. 145: 55 p.

Boutillier, J.A. 1982. G.B. REED shrimp cruise 82-S-1, May 6-20, 1982 west coast of Vancouver Island and Queen Charlotte Sound. Can. Data Rep. Fish. Aquat. Sci. 383: iii + 56 p.

Boutillier, J.A. 1984. Prawn - minimum size limit. pp. 11-24. In: G.S. Jamieson [ed.]. 1982 shellfish management advice, Pacific Region. Can. Manuscr. Rep. Fish. Aquat. Sci. 1774.

Boutillier J.A. 1996. Review of experimental prawn fishing in Howe Sound, 1993. pp. 28-45. In: C.M. Hand and B.J. Waddell [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1993 and 1994. Can. Tech. Rep. Fish. Aquat. Sci. 2089.

Boutillier J.A. 1998. Assessment of the Area 12 prawn fishery in relation to declines in annual catch. pp. 161-185. In: G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1996. Can. Tech. Rep. Fish. Aquat. Sci. 2221.

Boutillier, J.A., J.R.Carmichael and T.H.Butler. 1978. Shrimp population survey, west coast of Vancouver Island, May 1978. Fish. and Marine Serv. Data Rep. 100: 84 p.

Boutillier, J.A., A.N. Yates and T.H. Butler. 1976. G.B. REED shrimp cruise 76-S-1, May 3-19, 1976. Fish. and Marine Serv. Data Rep. 13: 46 p.

Butler, T.H. 1964. Growth, reproduction, and distribution of pandalid shrimps in British Columbia. J. Fish. Res. Bd. Canada, 21(6): 1403-1452.

Butler, T.H. 1980. Shrimps of the Pacific coast of Canada. Can. Bull. Fish. Aquat. Sci. 202: 280 p.
Butler T.H. and J.A. Boutillier. 1983. Selected shrimps of British Columbia. Underwater World Fact Sheet. Communications Dir., DFO, Ottawa.

Caddy, J.F. 1986. Stock assessment in data-limited situations -- The experience in tropical fisheries and its possible relevance to evaluation of invertebrate resources. pp. 379-392. In. G.S. Jamieson and N. Bourne [eds.]. North Pacific workshop on stock assessment and management of invertebrates. Can. Spec. Publ. Fish. Aquat. Sci. 92.

FAO. 1995. Precautionary approach to fisheries. Part 1: Guidelines on the precautionary approach to capture fisheries and species introductions. Elaborated by the Technical Consultation on the Precautionary Approach to Capture Fisheries (Including Species Introductions). Lysekil, Sweden, 6-13 June 1995 (A scientific meeting organised by the Government of Sweden in co-operation with FAO). FAO Fisheries Technical Paper 350, Part 1. Rome, FAO. 1995.52 p.

Garcia, S., P. Sparre and J. Csirke. 1989. Estimating surplus production and maximum sustainable yield from biomass data when catch and effort time series are not available. Fish. Res. 8: 13-23.

Gulland J.A. 1971. The Fish Resources of the Ocean. Fishing News (Books), West Byfleet. 255 p.

Hannah, R.W. 1993. Influence of environmental variation and spawning stock levels on recruitment of ocean shrimp (Pandalus jordani). Can. J. Fish. Aquat. Sci. 50: 612-622.

Hannah, R.W. 1995. Variation in geographic stock area, catchability, and natural mortality of ocean shrimp (Pandalus jordani): some new evidence for a trophic interaction with Pacific hake (Merluccius productus). Can. J. Fish. Aquat. Sci. 52: 1018-1029.

Hannah, R.W. and S.A. Jones. 1991. Fishery induced changes in the population structure of pink shrimp (Pandalus jordani). Fishery Bull. (U.S.) 89: 41-51.

Hilborn, R. and C.J. Walters. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics, and Uncertainty. Chapman and Hall, New York.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bull. (U.S.) 82: 898-903.

Pacific Fishery Management Council. 1981. Discussion draft fishery management plan for the pin shrimp fishery off Washington, Oregon, and California. Pac. Fish. Manage. Counc., Portland, OR. 169 p.

Pearse. P.H. and C.J. Walters. 1992. Harvesting regulation under quota management systems for ocean fisheries: decision making in the face of natural variability, weak information, risk and conflicting incentives. Mar. Policy 16: 167-182.

Pella, J.J. and P.K. Tomlinson. 1969. A generalized stock production model. Bull. Inter-Am. Trop. Tuna Comm. 13: 419-496.

Walters, C.J. and R. Hilborn. 1976. Adaptive control of fishing systems. J. Fish. Res. Board Can. 33: 145-159.

Winters G.H., and J.P. Wheeler. 1985. Interaction between stock area, stock abundance, and catchability coefficient. Can. J. Fish. Aquat. Sci. 42: 989-998.

Table 1. Historic summary of shrimp fisheries in Pacific Fishery Management Areas 4, 14, 17 and 28/29.

| CATCH AND EFFORT | Area 4 | Area 14 | Area 17 | Area 28/29 |
| :---: | :---: | :---: | :---: | :---: |
| Peak catches <br> [year (tonnes)] (Fig. 1) | $\begin{aligned} & 1963,1995 \\ & (160 \mathrm{t}) \end{aligned}$ | $\begin{aligned} & 1965 \\ & (131 \mathrm{t}) \end{aligned}$ | $\begin{aligned} & 1957 \\ & (327 \mathrm{t}) \end{aligned}$ | $\begin{aligned} & 1957 \\ & (443 \mathrm{t}) \end{aligned}$ |
| Recent trends in catch | increasing | declining | declining | low but stable |
| 1995 [vessels / (tonnes)] | 25/(160 t) | 23/(32 t) | 16/(17 t) | 46/(145 t) |
| CATCH BY SPECIES |  |  |  |  |
| Catch composition 1987-1995 [\%Pinks/ \%Sides / \%Other] | 51\% pinks $49 \%$ sides $<1 \%$ other | $91 \%$ pinks $8 \%$ sides $1 \%$ other | 73\% pinks $19 \%$ sides 8\% prawns | 84\% pinks $16 \%$ sides $<1 \%$ other |
| Ave. CPUE 1987-95 <br> (lbs/min) <br> Pinks/Sides <br> (Fig. 2 \& 3) | $\begin{aligned} & \hline 0.77 \text { pinks } \\ & 0.54 \text { sides } \end{aligned}$ | $\begin{aligned} & \hline 0.96 \text { pinks } \\ & 0.13 \text { sides } \end{aligned}$ | 0.42 pinks <br> 0.14 sides | 0.48 pinks <br> 0.12 sides |
| GEAR |  |  |  |  |
| Main gear used (Fig. 4 \& 5) | "4P" | "4P" | " 4 P " | "4P" |
| Other gear trends | Increased use of otter trawls from 1989-1994 | Substantial increase in use of otter trawls in 1995 | Mainly beam trawls | Mainly beam trawls |

Table 2. Total catch by shrimp species by year for all areas except the West Coast of Vancouver Island offshore areas. Note: Pinks are combined $P$. jordani and $P$. borealis eous.

| Year | Total Pinks | Total Sidestripe | Total Prawn | Total Humpback | Total Coonstripe |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 1987 | 396,467 | 72,591 | 10,415 | 6,503 | 0 |
| 1988 | 421,253 | 87,830 | 14,041 | 4,446 | 0 |
| 1989 | 355,904 | 95,167 | 14,119 | 4,590 | 0 |
| 1990 | 480,455 | 158,866 | 5,855 | 5,495 | 0 |
| 1991 | 617,215 | 168,566 | 9,167 | 4,269 | 0 |
| 1992 | 899,902 | 154,264 | 3,484 | 2,736 | 0 |
| 1993 | 608,857 | 165,488 | 6,626 | 6,281 | 0 |
| 1994 | 804,565 | 181,236 | 1,911 | 1,159 | 0 |
| 1995 | $3,456,594$ | 328,332 | 3,682 | 6,436 | 0 |
| 1996 | $7,298,375$ | 348,475 | 1,617 | 64,637 | 2,194 |

Table 3. Results of the Schaefer model fit using the Pella and Tomlinson time-series estimation routine.

| Species | Area | $q$ | $r$ | $b(1987)$ | $K$ | $R$ fit |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Pinks | 4 | $1.50 \times 10^{-6}$ | 0.304 | 355,680 | $1,170,002$ | 0.868 |
|  | 14 | $6.41 \times 10^{-6}$ | 0.096 | 54,064 | 563,166 | 0.791 |
|  | 17 | $3.88 \times 10^{-7}$ | 0.528 | 757,399 | $1,434,468$ | 0.728 |
|  | $28 / 29$ | $8.98 \times 10^{-8}$ | 0.800 | $6,005,060$ | $7,506,325$ | 0.515 |
| Sidestripes | 4 | $1.73 \times 10^{-7}$ | 0.248 | $1,632,778$ | $6,583,782$ | 0.983 |
|  | 14 | $4.69 \times 10^{-8}$ | 0.872 | $2,833,826$ | $3,249,800$ | 0.931 |
|  | 17 | $1.20 \times 10^{-6}$ | 0.584 | 141,141 | 241,680 | 0.144 |
|  | $28 / 29$ | $1.95 \times 10^{-8}$ | 0.512 | $4,972,974$ | $9,712,840$ | 0.624 |



Fig. 1. Reported landings of mixed shrimp catches by trawl from landing slips.


Fig. 2. Average annual unstandardized CPUE (lbs/minute) for mixed pink shrimp catches from shrimp trawl logbooks.


Fig. 3. Average annual unstandardized CPUE (lbs/minute) for sidestripe shrimp catches from shrimp trawl logbooks.


Fig. 4. Percent of total effort, by area and year, in which the " 4 P " trawl was used to fish pink shrimp.


Fig. 5. Percent of total effort, by area and year, in which the " 4 P " trawl was used to fish sidestripe shrimp.


Fig. 6. Total unstandardized effort (minutes) directed at pink shrimp.


Fig. 7. Total unstandardized effort (minutes) directed at sidestripe shrimp.


Fig. 8. Carapace length frequencies of sidestripe shrimp from Area 10, taken in May 1996.


Fig. 9. Carapace length frequencies of sidestripe shrimp from Area 4, taken in July 1996.


Fig. 10. Carapace length frequencies of sidestripe shrimp from Areas 28/29, taken in June 1996.

# Comparison of Repeat Acoustic Surveys of the Euphausiid Stock in Jervis Inlet, British Columbia: 1990-1996 

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Editors' note: Because this paper has been revised and submitted for publication elsewhere, only a summary is presented here. For further information, please contact the authors.


#### Abstract

Mackas, D.L., S.J. Romaine, M.C. Macauly and D.J. Saxby. 1998. Comparison of repeat acoustic surveys of the euphausiid stock in Jervis Inlet, British Columbia: 1990-1996. p. 219-220. In: G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1996. Can. Tech. Rep. Fish. Aquat. Sci. 2221.

Management of euphausiid and other Strait of Georgia fisheries requires better information about seasonal and interannual variability of euphausiid stock size and the within-time-period statistical reliability of these stock size estimates. To provide this, we conducted repeated euphausiid surveys in Jervis Inlet over the past five years: twice per year (Oct-Nov and Jan-Feb) in most years since November 1991; and monthly June 1994 - June 1995. Underway echosounding gave spatially detailed measurements along zig-zag transect lines. Net tows (mostly discussed previously, Mackas and Moore 1994) provided species identification and size-frequency distributions.


The steps in our analysis were:

1. Generate snapshot "maps" of euphausiid biomass density within Jervis Inlet by averaging/interpolation of data from the closely-spaced acoustic transect lines making up individual survey grids.
2. Integrate these biomass density estimates over the inlet area, giving time series estimates of total stock size that track seasonal and year-to-year changes in stock biomass and distribution.
3. Compare observed changes in stock biomass vs. removals by the commercial fishery.
4. Evaluate statistical consistency of the stock size estimates through within-time-period comparison of replicated survey grids, and alternate data collection and analysis methodologies.

Overall, we believe our within-time-period stock size estimates are reliable to about factor of 2.5 . We partition the uncertainty as follows:

1. Within-time-period-repeated complete survey grids done with the same echosounder and the same data processing method agreed on average to $\pm 25-30 \%$. Partial surveys agree to about factor of 1.65 .
2. For replicate surveys done with two different echosounders (operating at 104 and 200 kHz from different ships), along-line correlation was $r^{2}=0.74$. Total biomass estimates from the 200 kHz averaged $27 \%$ greater.
3. Alternate data processing methods (subarea block averages vs. kriging with and without forcing to zero biomass density along the inlet shoreline) showed similar spatial and seasonal patterns. Block averages were higher (about $15 \%$ ) than kriging with shoreline zero-forcing but we believe that kriging is more conservative and robust with respect to aliased patchiness.
4. Conversion from acoustic return to biomass was the largest single source of uncertainty. Estimates based on alternate calibration models differed by factors of up to 3 for individual time periods, typical variation was about factor of 2.

Total stock estimates ranged from a minimum of $<1,000$ tonnes (Feb. 93) to a maximum of $>10,000$ tonnes (April 95). Both seasonal and interannual components of variation were large (310 fold). In most years, acoustically-estimated stock biomass declined during the winter. Timing of the decline is coincident with the fishing season. But the magnitude of the winter decline ( $3,000-6,000$ tonnes) is much greater than the removal by the fishery ( $<500$ tonnes). We therefore attribute most of it to seasonal variation in the balance between growth and natural mortality. We conclude that present harvest levels are a small fraction of present stock size.

# A Study of the Population Biology and Productivity of Euphausiids (Thysanoessa spinifera, Euphausia pacifica) in Barkley Sound and its Implications for the Management of Commercial Krill Fishing. 

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#### Abstract

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The population biology and productivity of the euphausiids Thysanoessa spinifera and Euphausia pacifica were monitored in Barkley Sound from 1991 through 1995. There were significant ocean warmings in 1992 (El Nino Southern Oscillation, ENSO) and 1993. Results indicate substantial changes. T. spinifera abundance, biomass and productivity declined continuously and, in 1995, were $10 \%$ of the pre-ENSO level. For E. pacifica, abundance, biomass and productivity increased in 1992 and declined to $10 \%$ of the 1991 level in 1995. Because of the complexity of euphausiid biology, any consideration of changing quotas should be based on the following. First, there should be studies of euphausiid predators to determine the annual ration of euphausiids. As for the current quota, managers would decide what proportion of that ration could be available to a fishery. Second, the productivity of exploited euphausiid populations should be monitored to ensure that it is not dangerously low.

## INTRODUCTION

Euphausiids are often an abundant and conspicuous component of marine macrozooplankton, where they can play a significant role in the flow of energy and matter in pelagic food webs (Mauchline 1980). Numerous studies describe the key role that euphausiids play in specific marine ecosystems. Pillar et al. (1992) describe a continuous presence of large quantities in the Benguela ecosystem and the importance of euphausiids to zooplanktivourous fish there. They suggest that euphausiids possess several characteristics which contribute to their importance to the Benguela upwelling system. Euphausiids there are omnivorous and consequently can adapt to fluctuations in food availability. They are accessible to predators through the year because they are larger, and live longer than mesoplankton and aggregate. Mauchline and Fisher (1969) state that euphausiids are amongst the most abundant planktonic groups in the sub-arctic and boreal seas of the northeast Atlantic Ocean. Astthorsson (1990) comments on their importance as food for commercially exploited fish species there. Kulka and Corey (1978) list studies which
show that euphausiids are important prey for fish, bird and mammals in the northwest Atlantic and eastern Arctic. Euphausiids are also important to coastal marine ecosystems in the Pacific. Brodeur and Pearcy (1992) monitored fish diets in the coastal upwelling zone of Oregon and Washington (USA) over four summers. They found that euphausiids (Euphausia pacifica, Thysanoessa spinifera) dominated as prey in strong upwelling years. These species account for $88 \%, 100 \%$ and $56 \%$ of the annual summer ration for Pacific hake (Merluccius productus), Pacific herring (Clupea pallasi) and spiny dogfish (Squalus acanthias) respectively for La Perouse Bank, a productive, coastal upwelling area off the west coast of Vancouver Island, Canada (D. M. Ware, DFO, Nanaimo, pers. comm.). Ponomareva (1963) describes euphausiids as important prey for planktivorous fish and whales in the northwestern Pacific. Kock and Shimadzu (1994) state that within the five major groups of Antarctic high level consumers (seals, seabirds, cephalopods, fish and baleen whales), most species rely on krill ( $E$. superba) as their diet at least in summer and during their breeding season. They warned that krill consumption estimates are biased because of uncertainty in estimates of predator abundance and consumption rates. Nevertheless, the integral importance of krill to the Southern Ocean is widely accepted.

Numerous studies have examined the biology of a variety of euphausiid species. Examinations of growth range from the synoptic investigations of Einarsson (1945) for northern Atlantic species and Ponomareva (1963) for northwestern Pacific euphausiids to detailed laboratory investigations of larval growth in E. superba (Poleck and Denys 1982). In general, mid-and high latitude species show seasonal growth which coincides with the onset of primary productivity (Hollingshead and Corey 1974). Growth rates are inversely related to body size (Pillar et al. 1992; Ross 1982) and positively related to temperature (Mauchline and Fisher 1969). Controversy about over-winter shrinkage (Ikeda and Dixon 1982) continues and most discussion pertains to E. superba. Very few studies have examined mortality. A number (Kulka and Corey 1978, Bollens et al. 1992) describe length frequency distributions and how they change seasonally. Most work relating to numbers of animals over time has been in terms of longevity. Mauchline and Fisher (1969) present estimates of life span for a number of species. McClatchie et al. (1991) is the only one which specifically addresses mortality. Lindley (1978, 1980, 1982) made preliminary mortality estimates when he calculated production for North Atlantic euphausiids assuming that mortality is a linear function of time. Brinton (1976) and Heath (1977) referred to survival curves for E. pacifica and a number of other studies comment on the reduction in numbers of animals with age. Many investigators have examined the reproductive biology of euphausiids. Most ecological work has concentrated on describing variations in larval abundance and trying to relate these to various oceanographic characteristics, such as currents and localised productivity. Some studies have described the characteristics of the parents, mostly as the proportion that are mature. This is generally described as males bearing spermatophores and females which have been fertilised or are gravid. In some instances the proportion of animals with secondary sexual characteristics developed are described as well. Spawnings are loosely defined based on egg and larval abundances. Mauchline and Fisher (1969) provide the only data on the gonad growth cycle. Siegel and Loeb (1995) is the only report which addresses recruitment variability.

The implicit or explicit goal of all this work is to describe production characteristics and causes for variation in productivity. There are few estimates for production. Lindley (1978, 1980 and
1982) estimated production, biomass and P:B ratios for Thysanoessa longicaudata, Meganyctiphanes norvegica, Nyctiphanes couchi, T. inermis and T. raschii. He used plankton samples collected by ships of opportunity in the North Atlantic. Lindley warned of the effect of sampling bias on his estimates. Mauchline (1985) presented production estimates for nine species in the Rockall Trough. Berkes (1977) calculated production and biomass of T. raschii in the Gulf of St. Lawrence. Heath (1977) estimated production for E. pacifica in the Strait of Georgia, Canada. Lavaneigos (1995) estimated the production of N. simplex in Baja California. Production estimates for euphausiids from the southern hemisphere consist of those for Euphausia lucens (Stuart and Pillar 1988) and N. australis (Ritz and Hosie 1982). Ross and Quentin (1988) summarize estimates for E. superba, all of which are made indirectly (e.g., based on predator consumption rates).

Unfortunately, the biology of krill makes them a difficult animal to study and therefore to estimate production. A questionable assumption made is that the same population is being studied over time. It has been accepted that euphausiid distributions are influenced by ocean currents but there has been no alternative but to accept the one population assumption. All work implicitly or explicitly acknowledges the existence of more than one cohort at any time. However, very few studies (Brinton 1976; Heath 1977) attempt to segregate cohorts in their analyses. All production studies have explicitly or implicitly assumed that mortality is a linear function of time. Assuming that mortality is linear over any period longer than one day would underestimate it. Therefore production, based on more than daily estimates, would be overestimated. Finally, Lindley (1982) eludes to making incorrect assumptions of growth trajectories. Production estimates would be biased substantially by incorrect growth trajectories.

The aim of this report is to summarize my study of the influence of interannual variations in sea temperature on the growth, mortality and reproduction and ultimately the productivity of Thysanoessa spinifera and Euphausia pacifica in Barkley Sound. The impetus for the work is the importance that euphausiids have for transferring energy through the coastal upwelling ecosystem off Vancouver Island (Tanasichuk et al. 1991). The project began in 1991 and sampled through consecutive ENSO's in 1992 and 1993. I present results through March 1996. I also discuss the implications this work has for commercial krill fisheries.

## MATERIALS AND METHODS

I have been sampling euphausiids in Barkley Sound since March 1991 (Fig. 1). I chose Barkley Sound because it can be sampled conveniently using a small boat virtually all through the year, and it is next to the La Perouse Bank area. This is important because the results of this work could compliment a study of the effects of ocean climate variation on fish production that the DFO began along the lower west coast of Vancouver Island in 1985. Summers (1993) provides reasons for accepting that euphausiid samples in the Sound describe euphausiids in the La Perouse Project study area.

I collected animals during 38 cruises. There are 4 sampling stations which collectively reflect the bathymetric and circulation characteristics of the Sound. Cruises were made nine times annually between March 1991 and 1994 to define accurately the seasonal growth, reproduction and
mortality patterns. Since then, I collected samples five times a year to monitor interannual variations.

Samples were collected at night using obliquely towed bongo nets which traveled to within 10 meters of the bottom. A sub-sample of adult-sized ( $>10 \mathrm{~mm}$ total length) from one cod-end was preserved for surplus energy analyses when the hepatopancreas and gonad were weighed. The entire sample from the other cod-end was preserved. This sample was size-fractionated using 250,500 and $1700 \mu \mathrm{~m}$ sieves to separate adults and sub-adults. All adult-sized animals were identified to species, counted and measured. Individuals from sub-samples were weighed, sexed and their maturity described (immature - no secondary sexual characters; male - petasma and with or without spermatophores; female - thelycum and unfertilized or fertilized). Samples of sub-adults were split using a Folsom splitter. The goal was to have 50 calyptopes and furcillia in the split to be analysed. Eggs and nauplii were counted and measured. Calyptopis and furcillia larva were identified to species, stage, counted and measured. Larvae were identified using the descriptions presented by Boden (1950) for E. pacifica and the key developed in our laboratory using the larval descriptions of T. spinifera that Summers (1993) presented.

I defined cohorts using assumed growth and mortality trajectories. The assumptions for growth were that animals from one cohort could not be longer than animals from an earlier cohort at any time and that there were no large increases in length over winter. For the mortality trajectories, I assumed that the number of animals in a cohort decreased over time. The cohort assignments began with information extracted from the larval abundance and size data. Ross (1981) and Summers (1993) provide development times to various larval stages for E. pacifica and $T$. spinifera respectively. By knowing the larval stage, I estimated the birthdate and ultimately developed frequency histograms of birthdates for all sub-adults in a given sample. These histograms then defined cohorts of larvae as a function of development stage and sampling time. This then determined how many cohorts occurred in a given year. Estimates of mean length and abundance over time were then used to begin developing cohort-specific growth and mortality trajectories (Fig. 2a). Adult ( $>10 \mathrm{~mm}$ ) length frequency distributions were segregated subjectively. Figure 2 b shows an example of this. To date, there is no objective method for segregating multimodal distributions. My procedure is very similar to that described by Bollens et al. (1992). Distributions are determined subjectively and their uniqueness is tested using measures of dispersion ( 3 x the standard deviation of the mean for Bollens et al. (1992) and 2 x the standard deviation of the mean for this study). I then linked larval and adult trajectories using the assumptions for growth and mortality over time (Fig. 2c). (I concluded that my success in developing cohort-specific growth and mortality trends suggests two possibilities. First, Barkley Sound euphausiids are discrete populations. Second, they are, as Summers (1993) suggested, part of the lower west coast Vancouver Island populations. Therefore in- and out- migration have little effect on the biological characteristics of the animals collected in Barkley Sound. At a minimum, the animals I sampled appear to have been exposed to the same conditions which affect growth and mortality). Finally, I estimated weighted mean length and mass and abundance for each species, cohort and cruise combination. Means were weighted by volume of water filtered at each station. Mean mass for animals $<10 \mathrm{~mm}$ was estimated from length-mass relationships developed for each species and cruise combination.

I described abundance as number of animals per square meter. The volume of water filtered was measured with a flowmeter. Abundance for each cruise, species and cohort combination was estimated as (no. animals $\mathrm{x} \mathrm{m}^{-3}$ filtered) x wire out because I assumed that euphausiids were collected during the descent and ascent of the net. Abundances can be converted to per $\mathrm{m}^{3}$ considering that an average of 110 m of wire was deployed for each tow.

I did not calculate measures of dispersion for abundance estimates. They would be biased because the four sampling locations were not replicates. Results of analyses of variance showed that mean abundances for T. spinifera and E. pacifica adults were significantly different ( $\mathrm{p}=0.02$ and $<0.0001$ respectively) between sampling sites over the time series. LOWESS smoothed adult abundances (Fig. 3) showed that time trends were similar between stations. Therefore, although changes in abundance over time were comparable, mean abundances over the study were from different distributions and estimates of dispersion would be inappropriate. I used mean estimates of abundance to describe the overall abundance of euphausiids throughout the study area.

Nonlinear estimation procedures in SYSTAT (1992) were used to calculate parameter estimates for the summer growth in length and mass and the mortality functions. Growth functions were estimated for animals of the year only because no cohorts survived two complete growth seasons. I tested logistic and von Bertalanffy functions. I used the Simplex estimation procedure and input the initial size and used sizes in January to adequately asymptotic size for the growth year. For the cohort-specific mortality functions, I fit abundance at time data to exponential and hyperbolic functions. I chose the function which best described the change in numbers with time based on the function which had smaller residuals. The values input were initial abundance starting slope values of 0.1 and -0.1 for the hyperbolic and exponential functions respectively.

Daily production was calculated using daily mean wet weight and abundance estimates and the information Jerde and Lasker (1966) provide on moult weight and frequency for T. spinifera and E. pacifica. Daily production for each cohort was calculated as abundance times the growth increment. Abundance on each day was estimated from cohort-specific natural mortality functions. I assumed that changes in mean weight every day between sampling intervals were exponential. Jerde and Lasker (1966) reported that both species studied moulted about every five days. Moults represented 10.9 and $11.7 \%$ of the dry body weight for E. pacifica and T. spinifera respectively. Parsons et al. (1984) reported that North Pacific euphausiids are $80 \%$ water. Therefore, moult production calculated for every fifth day as biomass ( mg wet weight $\mathrm{x} \mathrm{m}^{-2}$ ) x $0.20 \times 0.109$ or 0.117 . I defined total production as net production plus moult production. I did not segregate egg production associated with reproduction because I could not describe overwinter ovarian growth nor was the intensity of spawns well defined. In addition, no work has shown whether euphausiid ovaries grow again in summer after eggs have been released.

Sea surface temperature data came from Amphitrite Point. This is a lighthouse station located 20 n . m. west of the study area.

## RESULTS

## Sea Temperatures Over The Study Period

Figure 4 shows the sea temperature anomalies at Amphitrite Point. There were large positive anomalies in 1992 and 1993 and large negative anomalies during the winters of 1993-1994 and 1994-1995. I used mean monthly sea temperatures to calculate mean sea temperatures over winter (November-February), and during the early (March-June) and late (July-October) portions of the potential growth period. The following table shows that winter sea temperatures $\left({ }^{\circ} \mathrm{C}\right)$ were high during the 1991-1992 and 1995-1996. Early summer sea temperatures were high in 1992 and 1993 but were uniform during the late summer.

| Year | Nov-Feb | Mar-Jun | July-Oct |
| :---: | :---: | :---: | :---: |
| $1990-91$ | 8.6 | 10.1 | 12.8 |
| $1991-92$ | 9.2 | 11.5 | 13.2 |
| $1992-93$ | 8.2 | 10.9 | 13.0 |
| $1993-94$ | 8.4 | 10.3 | 12.8 |
| $1994-95$ | 8.2 | 10.4 | 13.0 |
| $1995-96$ | 9.2 | . | . |

## Summer Growth

Figures 5 through 8 show the summer growth trajectories for length and mass for E. pacifica and T. spinifera respectively. For both species, growth begins in March or April and ends in September or October. In all cases, the logistic function described growth better than the von Bertalanffy function did.

I found that sea temperatures influenced growth rates in length and mass for both species. The daily instantaneous growth rates are defined as $\mathrm{dS} / \mathrm{dT}=\mathrm{k} \mathrm{S}_{\mathrm{t}}\left(\mathrm{S}_{\mathrm{inf}}-\mathrm{S}_{\mathrm{t}}\right)$. Since growth rates include a function of the size component which is likely independent of year, that is $S_{t}\left(S_{i n f}-S_{t}\right)$, I decided to test for temperature and size effects on $k$, the rate function constant. This would approximate an analysis of covariance of growth rate trajectories. Results of multiple regression analysis showed that sea temperature over the cohort-specific growth period and initial length described a significant amount of the variation for the rate constants for growth in length. I found that the regression parameter estimates did not differ between species and estimated a pooled regression. The equation was:

$$
\begin{gather*}
K_{1}=0.012\left(\ln \left(T_{a}\right)\right)-0.00062\left(\ln \left(L_{0}\right)\right)-0.0028  \tag{1}\\
\left(\mathrm{R}^{2}=0.68, \mathrm{p}<0.0001, \mathrm{n}=23\right)
\end{gather*}
$$

where $K_{1}$ is the growth rate constant in length, $T_{a}$ is the mean $\operatorname{SST}$ over the growth period and $L_{0}$ is initial length. Figure 9 shows the scatterplot of the points and the surface the regression defined.

Growth in mass for T. spinifera was also influenced by sea temperature and initial size. The regression equation was:

$$
\begin{gather*}
K_{m}=0.022\left(\ln \left(T_{a}\right)\right)-0.00038\left(\ln \left(M_{0}\right)\right)-0.053  \tag{2}\\
\left(\mathrm{R}^{2}=0.49, \mathrm{p}=0.03, \mathrm{n}=11\right)
\end{gather*}
$$

where $K_{m}$ is the growth constant for mass and $M_{0}$ is the initial size. The data and surface defined by the regression are shown in Fig. 10. Growth in mass for E. pacifica was influenced by sea temperature only. The regression equation was:

$$
\begin{align*}
& K_{m}=0.054(\ln (T))-0.013  \tag{3}\\
& \left(\mathrm{R}^{2}=0.049, \mathrm{p}=0.01, \mathrm{n}=10\right)
\end{align*}
$$

Figure 11 is a scatterplot showing the relationship between the growth rate in mass constant for E. pacifica and mean SST over the growth period. Results of one-way analyses of variance showed that the growth constants for length, and in mass for each species, did not differ significantly ( $\mathrm{p}=0.56,0.70$ and 0.71 respectively) between years.

## MORTALITY, LONGEVITY AND LIFESPAN

Mortality functions are given in Table 1. Mortality was either a hyperbolic or exponential function of time. Exponential functions dominated in 1992 and 1993.

## Abundance Variations

Figure 12 illustrates how adult and sub-adult abundance varied over the study period. Both species showed increases in adult abundance arising from high subadult abundances later in 1992. T. spinifera declined to levels which were lower than those for 1991 and have remained low since. Subadults were scarce in 1993 and 1994 but showed a large increase in 1995, which did not result in an increase in adults. In contrast, E. pacifica abundance was relatively high in 1993, again apparently as a consequence of high sub-adult abundance but declined continuously since. There has not been any substantial peak in subadult abundance since 1993.

Table 2 presents mean annual abundance estimates for T. spinifera and E. pacifica. Mean adult abundance for T. spinifera declined continuously since 1991. In 1995, it was $5 \%$ of the preENSO level. E. pacifica abundance increased in 1992. It declined subsequently and in 1995 was $19 \%$ of the pre-ENSO level and $6 \%$ of the 1992 peak. The proportion adults as T. spinifera declined from 0.76 in 1991 to 0.24 in 1993 and was 0.44 in 1995. Total adult euphausiid abundance increased in 1992 and declined over the next three years. In 1995, it was $7 \%$ of the 1992 peak and $8 \%$ of the amount in 1991. Changes in larval abundance reflected adult abundance until 1995. Then there was a large increase in T. spinifera larvae when adult abundances remained low. T. spinifera larvae dominated in 1991 and 1995.

## Reproductive Potential

I integrated information on sex ratios, size-at-maturity and percentage fertilized to estimates of reproductive potential as female parental abundance and biomass. To clarify, I multiplied the abundance of each cohort at each sampling by the sex ratio, percent mature based on the maturity ogives, and percent fertilised or gravid. I summed over cohorts to calculate the abundance of female parents. I estimated biomass by multiplying abundance by mean wet mass for each cohort, sampling date combination. There are large interannual differences in the abundance and biomass of female parents, as well as differences between species (Fig. 13). The following table presents mean annual abundances and biomasses for each species and the sums.

|  | T. spinifera |  | E. pacifica |  | Combined |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Year | Abundance | Biomass | Abundance | Biomass | Abundance | Biomass |
| 91 | 17 | 2506 | 14 | 1197 | 31 | 3703 |
| 92 | 20 | 2502 | 18 | 644 | 38 | 3146 |
| 93 | 2 | 139 | 11 | 488 | 13 | 624 |
| 94 | 4 | 546 | 1 | 1 | 5 | 547 |
| 95 | 3 | 587 | 1 | 30 | 4 | 616 |

After 1992, T. spinifera female and abundance dropped and has remained low. Abundance in 1995 was $85 \%$ lower than the mean for 1991 and 1992 while biomass was $77 \%$ lower. $E$. pacifica abundance was relatively stable over 1991-1993. In 1995, it was $7 \%$ of the mean abundance for 1991-1993. Biomass was $2 \%$ of the 1991 peak. For both species, abundance and biomass in 1995 were 87 and $83 \%$ lower respectively than in 1991.

## Number and Timing of Spawnings

Figures 14 and 15 present the number and timing of spawnings for T. spinifera and E. pacifica respectively. T. spinifera spawnings occurred mainly between March and September. Spawning times for E. pacifica were similar. Number of spawnings per year may have dropped slightly since 1991.

## Stock-Recruit Relationships

Relationships between female parental and recruit abundance are illustrated in Fig. 16. Neither species shows an obvious relationship. T. spinifera appears capable of generating stronger recruitments from low parental abundances.

## Biomass Changes

Figure 17 shows the changes in sub-adult and adult biomasses over the study period. Both species show large changes but the timing and magnitude differ. Adult T. spinifera biomass was highest in 1991 and showed a peak in 1992, apparently reflecting growth of the relatively strong cohort produced in 1992. Subsequent peaks in sub-adult biomass were not followed by increases
in adult biomass. Annual mean biomass of adults fell continuously since 1991 and in 1995 was $10 \%$ of the pre-ENSO level (Table 3). Larval biomass peaked in 1992 and in 1995 was $36 \%$ of the 1991 level and $30 \%$ of that for 1992. E. pacifica biomass has fallen since the peak levels in 1992. Adult biomass increased by $168 \%$ in 1992 but is now $14 \%$ of the 1991 biomass. Larval biomass was $583 \%$ higher in 1992 than in 1991 but is now at 1991 levels. Total adult euphausiid biomass in 1995 was $11 \%$ of the 1991 level.

## Production and P:B Ratios

Trends in daily total production are shown in Fig. 18. They are similar to those for biomass in that T. spinifera productivity has been very low since 1993 and $E$. pacifica production peaked in 1992 and has returned to low levels.

Table 4 gives annual total production estimates and P:B ratios. Annual production of T. spinifera adults has been at relatively low levels since 1993 and in 1995 was $10 \%$ of the 1991 value. Subadult production peaked in 1992 and is $6 \%$ of the 1991 level and is $5 \%$ of the 1992 peak. P:B ratios fluctuated and the weighted $\mathrm{P}: \mathrm{B}$ 's ranged from 2.0 to 6.8 , reflecting the proportion of production accounted for by the sub-adults. For E. pacifica, adult production has fluctuated and is currently $14 \%$ of the 1991 amount. Sub-adult production showed a large increase in 1992 and in 1995 was comparable to 1991 but $4 \%$ of the 1992 peak. P:B ratios changed as well. As for $T$. spinifera, weighted $\mathrm{P}: \mathrm{B}$ ratios were influenced by the relative abundance of sub-adults.

## DISCUSSION

The results of this study show that the production of euphausiids in Barkley Sound has fluctuated substantially as a consequence of the 1992 and 1993 ENSO's and is currently at a very low level. The decline in production is not due to changes in growth. For $T$. spinifera, it is a consequence of the loss of the adult component of the population (in other words reproductive potential) due to intense fish predation and to a continuum of recruitment failures. E. pacifica productivity is low now but it varied differently than that for T. spinifera during the study. The increase in its biomass and productivity in 1992 suggests the removal of a competitive or predatory effect of $T$. spinifera. Gradual reductions in abundance and biomass also appear to be a consequence of a loss of reproductive potential and progressively poorer recruitments.

An important point to consider is how these populations would recover. I found no obvious relationship between parental abundance and recruitment. There must be one and I suggest that the high variation is due to intervening effects. Ultimately then, a low parental biomass would be as likely as a high one to produce a strong recruitment. Therefore, it appears that there may be some change in the ocean environment which has reduced the possibility of a successful recruitment. During the 1996 Laperouse fisheries survey, I found that herring are now feeding on late furcillia. This may partially explain recruitment failure. Pacific hake migrate from California every summer to feed mainly on euphausiid adults along the west coast of Vancouver Island. Ware and McFarlane (1995) reported a strong positive relationship between sea temperature and Pacific hake abundance. Lower sea temperatures would therefore result in a lower hake biomass and a reduction in predation on adult euphausiids.

The changes in euphausiid productivity I found could have major implications for energy flow through the upwelling ecosystem along the west coast of Vancouver Island, if, in fact, my observations in Barkley Sound reflect what is happening offshore. Total production includes the biomass of moults produced and is relevant to whole ecosystem considerations. Lasker (1964, cited in Lasker 1966) suggests that moults form a substantial portion of detritus. Stuart (1986, cited in Stuart and Pillar 1988) found that moults are rapidly colonized by numerous ciliates and bacteria and thus may "either represent a substantial food resource for other organisms in the form of detritus or they may be rapidly decomposed and thereby play an important role in nutrient regeneration". I found that moulting accounted for an average of $28 \%$ of the total annual production by both species. I estimated that moults represented between 2.1 and 5.8 times of the mean annual biomass dry weight. This agrees with estimates made by Stuart and Pillar (1988) and Hosie and Ritz (1983) and Lasker (1966). Lasker (1966) estimated that E. pacifica produces a dry weight of faeces equal to its dry body weight every 50 days and euphausid biomass in Barkley Sound is very low now. The point to consider is what happens to nutrient recycling within an ecosystem when total productivity and the contribution of faeces and detritus drops dramatically. Cursory examination of the archive of samples from this study does not suggest that there has been a shift in species dominance to copepods, chaetognaths or gelatinous zooplankton. Herring biomass in the La Perouse Bank area has been low and hake appear to have moved away from the general area as well. Consequently, the Barkley Sound area, and possibly the lower west coast of Vancouver Island may be in a state of low energy.

The reduction of euphausiid productivity and biomass would also have major impacts on predator prey relationships among fish species along the lower west coast of Vancouver Island. Ware and McFarlane (1995) described how hake predation on herring is affected by interannual variations in sea temperature with euphausiid biomass variations being ultimately responsible. Briefly, a larger hake biomass would occur off the lower west coast of Vancouver Island in warmer years. They would remove a larger euphausiid biomass. Consequently, this would force herring off preferred feeding areas on the banks and increase their vulnerability to hake.

This study has implications for the management of commercial krill fisheries. It shows first how variable euphausiid productivity can be, and that these variations, at least for adults, are a consequence of predation, as exerted by commercially important fish species. Second, it shows that these populations are complex, and consequently difficult to study. This suggests then, that studies of euphausiid population biology for the sake of developing management strategies for krill fishing would have to be detailed and long term. Because euphausiids tend to be important prey items for commercially important fish species, interactions with higher trophic levels would have to be considered as well. I suggest that the Shellfish PSARC sub-committee consider a different approach, if it chooses to entertain changing the krill quota. It is based on what Heath (1977) described as the position of DFO. The quota of 500 tonnes was set as "the amount which is less than one-tenth of one percent of the annual food requirement of all fishes in the Strait of Georgia, according to scientists". Annual krill quotas could be set based on such a trophic considerations. Annual estimates of fish biomass in the Strait and diet studies would be used to estimate the annual ration of euphausiids. This work would have to be coupled with on-going monitoring of the euphausiid population(s) to ensure that production levels are not dangerously
low. Probably the greatest difficulty would be the public perception of overexploiting an animal which is generally perceived as a crucial link in energy flow in marine systems, which it is.

## REFERENCES

Astthorsson, A. 1990. Ecology of the euphausiids Thysanoessa raschii, T. inermis and Meganyctiphanes norvegica in the Isafjord-deep, northwest Iceland. Mar. Biol. 107:147157.

Berkes, F. 1977. Production of the euphausiid crustacean Thysanoessa raschii in the Gulf of St. Lawrence. J. Fish. Res. Board Can. 34: 443-446.

Boden, B.P. 1950. The post-naupliar stages of the crustacean Euphausia pacifica. Trans. Amer. Micro. Soc. 69: 373-386.

Bollens, S.M., B.W. Frost and T.S. Lin. 1992. Recruitment, growth and diel vertical migrations of Euphausia pacifica in a temperate fjord. Mar. Biol. 114: 219-228.

Brodeur, R.D. and W.G. Pearcy. 1992. Effects of environmental variability on trophic interactions and food web structure in a pelagic upwelling ecosystem. Mar. Ecol. Prog. Ser. 84: 101119.

Einarsson, H. 1945. Euphausiacea I. North Atlantic species. Dana Rep. 27: 1-185.
Heath, W.A. 1977. The ecology and harvesting of euphausiids in the Strait of Georgia. Ph.D. Thesis. Univ. British Columbia, Vancouver, British Columbia.

Hollinshead, K.W. and S. Corey. 1974. Aspects of the life history of Meganyctiphanes norvegica (M. Sars), Crustacea (Euphausiacea) in Passamaquoddy Bay. Can. J. Zool. 52: 495-505.

Hosie, G.W. and D.A. Ritz. 1983. Contribution of moulting and eggs to secondary production of Nyctiphanes australis (Crustacea:Euphausiacea). Mar. Biol. 77: 215-220.

Ikeda, T. and P. Dixon. 1982. Body shrinkage as a possible over-wintering mechanism of Antarctic krill, Euphausia superba DANA. J. Exp. Mar. Biol. 62: 143-151.

Jerde, C.W. and R. Lasker. 1966. Molting of euphausiid shrimps: shipboard observations. Limno. Oceano. 11: 120-124.

Kock, K.-H. and Y.Shimadzu. 1994. Trophic relationships and trends in population size and reproductive parameters in Antarctic high-level predators. p.287-312. In: S. Z. El-Sayed. [ed.]. Southern Ocean Ecology: the BIOMASS Perspective. University Press, Cambridge.

Kulka, D.W. and S. Corey. 1978. The life history of Thysanoessa inermis (Kroyer) in the Bay of Fundy. Can. J. Zool. 56: 492-506.

Lasker, R. 1966. Feeding, growth, respiration and carbon utilization of a euphausiid crustacean. J. Fish. Res. Board. Can. 23: 1291-1317.

Mauchline, J. and L.R. Fisher. 1969. The biology of euphausiids. Adv. Mar. Biol. 7: 1-454.
Mauchline, J. 1980. The biology of mysids and euphausiids. Adv. Mar. Biol. 18: 1-680.

McClatchie, S., S. Rakusa-Suszczewski and K. Filcek. 1991. Seasonal growth and mortality of Euphausia superba in Admirality Bay, South Shetland Islands, Antarctica. ICES J. Mar. Sci. 48: 335-342.

Lavaniegos, B.E. 1995. Production of the euphausiid Nyctiphanes simplex in Vizcaino Bay, Western Baja California. J. Crust. Biol. 15: 444-453.

Lindley, J.A. 1978. Population dynamics and production of euphausiids. I. Thysanoessa longicaudata in the North Atlantic Ocean. Mar. Biol. 46: 121-130.

Lindley, J.A. 1980. Population dynamics and production of euphausiids. II. Thysanoessa inermis and T. raschii in the North Sea and American coastal waters. Mar. Biol. 59: 225-233.

Lindley, J.A. 1982. Population dynamics and production of euphausiids. III. Meganyctiphanes norvegica and Nyctiphanes couchi in the North Atlantic Ocean and the North Sea. Mar. Biol. 66: 37-46.

Mauchline, J. 1985. Growth and production of Euphausiacea (Crustacea) in the Rockall Trough. Mar. Biol. 90: 19-26.

Parsons, T.R., Y. Maita and C.L Malli. 1984. A Manual of Chemical and Biological Methods for Seawater Analysis. Pergammon Press, Toronto. 173pp.

Pillar, S.C., V. Stuart, M. Barange and M.J. Gibbons. 1992. Community structure and trophic ecology of euphausiids in the Benguela ecosystem. p. 393-409. In: Payne, A. L., K. H. Mann and R. Hilborn [eds.]. Benguela Trophic Functioning. S. Afr. J. Mar. Sci. 12.

Poleck, T.P. and C.J. Denys. 1982. Effects of temperature on the moulting, growth and maturation of Antarctic krill Euphausia superba (Crustacea:Euphausiacea) under laboratory conditions. Mar. Biol. 70: 255-265.

Ponomareva, L.A. 1966. Euphausiids of the North Pacific, their distribution and ecology. Dokl. Akad. Nauk, SSSR. 142 pp. Israel Programme for Scientific Translation, Jerusalem.

Ritz, D.A. and G.W. Hosie. 1982. Production of the euphausiid Nyctiphanes australis in Storm Bay, south-eastern Tasmania. Mar. Biol. 68: 103-108.

Ross, R.M. 1981. Laboratory culture and development of Euphausia pacifica. Limno. Oceano. 26: 235-246.

Ross, R.M. 1982. Energetics of Euphausia pacifica. I. Effects of body carbon and nitrogen and temperature on measured and predicted production. Mar. Biol. 68: 1-13.

Ross, R.M. and L.B. Quentin. 1988. Euphausia superba: a critical review of estimates of annual production. Comp. Biochem. Physio. 90B: 499-505.

Siegel, V. and V. Loeb. 1995. Recruitment of Antarctic krill Euphausia superba and possible causes of variability. Mar. Ecol. Prog. Ser. 123: 45-56.

Stuart, V. and S.C. Pillar. 1988. Growth and production of Euphausia lucens in the southern Benguela current. J. Plank. Res. 10: 1099-1112.

Summers, P.L. 1993. Life history, growth and ageing of Thysanoessa spinifera. M.Sc. Thesis. University of Victoria, Victoria, British Columbia. 210 p.

SYSTAT. 1992. SYSTAT for Windows: Statistics. Version 5 edition. SYSTAT, Inc., Evanston IL. 750 pp .

Tanasichuk, R.W., D.M. Ware, W. Shaw and G.A. McFarlane. 1991. Variation in the diet, daily ration and feeding periodicity of Pacific hake (Merluccius productus) and spiny dogfish (Squalus acanthias) off the lower west coast of Vancouver Island. Can. J. Fish. Aquat. Sci. 48: 2118-2128.

Ware, D.M. and G.A. McFarlane. 1995. Climate-induced changes in Pacific hake (Merluccius productus) abundance and pelagic community interactions in the Vancouver Island upwelling system, p. 509-521. In: R.J. Beamish [ed.]. Climate change and northern fish populations. Can. Spec. Publ. Fish. Aquat. Sci. 121.

Table. 1. Life span, longevity and mortality rate parameter estimates. a - intercept. b-daily instantaneous mortality rate. A negative slope identifies an exponential mortality function. c$\mathrm{n}<3$ and function not calculated. d - cohort not sampled through life-span.

|  |  | Longevity | Mortality function |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Cohort | Life-span | (days) | a | b | $\mathrm{R}^{2}$ | p |
|  |  |  | T. spinifera |  |  |  |
| $\mathrm{A}^{\mathrm{c}, \mathrm{d}}$ | ?- Jun91 |  |  |  |  |  |
| $\mathrm{B}^{\mathrm{d}}$ | ?-Feb92 |  | 85 | -0.008566 | 0.52 | 0.05 |
| C | May91-May92 | 370 | 0.0002014 | 0.0001943 | 1.00 | 0.001 |
| D | Jun91-Aug92 | 433 | 4972 | -0.001332 | 0.76 | 0.001 |
| E | Jul91-Aug92 | 400 | 0.0001488 | 0.000061 | 1.00 | 0.001 |
| F | Sep91-Feb93 | 548 | 0.004693 | 0.0001545 | 0.96 | 0.001 |
| $\mathrm{G}^{\mathrm{c}}$ | Oct91 |  |  |  |  |  |
| H | Mar92-Jun93 | 441 | 8408 | -0.04471 | 1.00 | 0.001 |
| I | Jul92-Jun93 | 411 | 24341 | -0.03084 | 1.00 | 0.001 |
| J | Aug92-May94 | 630 | 11946 | -0.05985 | 1.00 | 0.001 |
| $\mathrm{~K}^{\mathrm{c}}$ | Sep92-Oct92 |  |  |  |  |  |
| L | May93-May94 | 351 | 0.02779 | 0.0004216 | 0.80 | 0.01 |
| M | Jun93-Aug94 | 421 | 5151 | -0.05175 | 1.00 | 0.001 |
| N | Jun93-Jan95 | 523 | 0.0003384 | 0.0003069 | 1.00 | 0.001 |
| $\mathrm{O}^{\mathrm{c}}$ | Sep93-Oct93 |  |  |  |  |  |
| P | Feb94-Mar95 | 399 | 0.09406 | 0.0001738 | 0.24 | 0.10 |
| Q | Jun94-Jun95 | 366 | 0.0005074 | 0.001729 | 1.00 | 0.001 |
| R | Jun94-Aug95 | 361 | 0.0002268 | 0.0003991 | 1.00 | 0.001 |
| S | Oct94-Jan96 | 456 | 134 | -0.009563 | 1.00 | 0.001 |
| T | Mar95-Jan96 | 295 | 0.004138 | 0.009453 | 1.00 | 0.001 |
| $\mathrm{U}^{\mathrm{d}}$ | Mar95- |  | 0.00001308 | 0.0008241 | 1.00 | 0.001 |
| $\mathrm{~V}^{\mathrm{d}}$ | Aug95- |  | 0.0001602 | 0.0004887 | 1.00 | 0.001 |
| $\mathrm{~W}^{\mathrm{c}}$ | Oct95-Jan96 |  |  |  |  |  |

Table 1. (cont.)

| Cohort | Life-span | Longevity (days) | Mortality function |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | a | b | $\mathrm{R}^{2}$ | p |
|  |  |  | E. pacifica |  |  |  |
| $\mathrm{A}^{\mathrm{c}, \mathrm{d}}$ | ? - Jul91 |  | 202 | -0.04705 | 1.00 | 0.001 |
| $\mathrm{B}^{\mathrm{c}, \mathrm{d}}$ | ? - Aug91 |  | 24 | -0.01179 | 0.37 | 0.25 |
| $\mathrm{C}^{\mathrm{c}, \mathrm{d}}$ | ? - Jan92 |  | 0.002599 | 0.002007 | 0.99 | 0.001 |
| $\mathrm{D}^{\mathrm{c}, \mathrm{d}}$ | ? -Jan92 |  | 0.0009197 | 0.0006418 | 0.97 | 0.001 |
| E | May91-Aug92 | 421 | 163 | -0.0014 | 0.06 | 0.05 |
| F | Ju191-Jan92 | 232 | 0.0001944 | 0.0001337 | 1.00 | 0.001 |
| $\mathrm{G}^{\text {c }}$ | Aug91-Oct91 |  |  |  |  |  |
| $\mathrm{H}^{\text {c }}$ | Oct91 |  |  |  |  |  |
| I | Mar92-Oct92 | 208 | 0.003743 | 0.0001371 | 0.34 | 0.05 |
| J | Mar92-Aug92 | 208 | 4210 | -0.04328 | 0.99 | 0.001 |
| K | Jul92-Aug93 | 411 | 12161 | -0.01545 | 0.96 | 0.001 |
| $L^{\text {c }}$ | Aug92-Sep92 |  |  |  |  |  |
| $\mathrm{M}^{\text {c }}$ | Sep92 |  |  |  |  |  |
| $\mathrm{N}^{\mathrm{c}}$ | Sep92-Oct92 |  |  |  |  |  |
| $\mathrm{O}^{\text {c }}$ | May93-Jun93 |  |  |  |  |  |
| P | Jun93-Aug94 | 421 | 6264 | -0.03139 | 0.96 | 0.001 |
| Q | Jun93-Oct93 | 119 | 1796 | -0.01416 | 0.61 | 0.25 |
| $\mathrm{R}^{\text {c }}$ | Aug93-Sep93 |  |  |  |  |  |
| S | Aug93-Jun95 | 679 | 5609 | -0.03406 | 0.99 | 0.001 |
| $\mathrm{T}^{\text {c }}$ | Oct93 |  |  |  |  |  |
| U | Feb94-Oct94 | 238 | 37 | -0.003796 | 0.85 | 0.02 |
| V | Jun94-Aug95 | 413 | 0.0006837 | 0.0002311 | 0.98 | 0.001 |
| $\mathrm{W}^{\text {c }}$ | Aug94 |  |  |  |  |  |
| $\mathrm{X}^{\text {c }}$ | Oct94 |  |  |  |  |  |
| Y | Mar95-Oct95 | 210 | 0.005654 | 0.0006358 | 1.00 | 0.001 |
| $\mathrm{Z}^{\text {d }}$ | Mar95- ? |  | 0.003416 | 0.0004673 | 0.95 | 0.005 |
| $1^{\text {d }}$ | Jun95-? |  | 0.0001179 | 0.0001435 | 1.00 | 0.001 |
| $2^{\text {c,d }}$ | Aug95 |  |  |  |  |  |
| $3{ }^{\text {d }}$ | Oct95-? |  | 980 | -0.03102 | 0.99 | 0.001 |
| $4^{\text {c,d }}$ | Mar96 |  |  |  |  |  |

Table 2. Annual (March-February) mean abundance estimates (no. $/ \mathrm{m}^{2}$ ) for T. spinifera and $E$. pacifica, 1991-1996.

| Year | T. spinifera | E. pacifica | Total abundance | \% T. spinifera |
| :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |
| 1991 | 642 | $\frac{\text { Adults }}{208}$ |  |  |
| 1992 | 316 | 682 | 850 | 0.76 |
| 1993 | 134 | 427 | 998 | 0.32 |
| 1994 | 64 | 18 | 561 | 0.24 |
| 1995 | 31 | 39 | 82 | 0.78 |
|  |  | $\underline{\text { Subadults }}$ | 70 | 0.44 |
| 1991 | 2,641 | 1,044 | 3,685 |  |
| 1992 | 6,166 | 5,291 | 11,457 | 0.72 |
| 1993 | 1,554 | 3,010 | 4,564 | 0.54 |
| 1994 | 1,312 | 1,360 | 2,672 | 0.34 |
| 1995 | 16,620 | 2,824 | 19,444 | 0.49 |
|  |  |  |  | 0.86 |

Table 3. Annual mean biomass ( mg wet weight $\mathrm{x} \mathrm{m}^{-2}$ ) for euphausiids from Barkley Sound.

| Year | T. spinifera | E. pacifica | Total biomass |  |
| :---: | :---: | :---: | :---: | :---: |
|  |  | Adults |  |  |
| 1991 | 21,092 |  | 6,514 | 27,606 |
| 1992 | 9,456 |  | 10,993 | 20,449 |
| 1993 | 5,613 |  | 7,569 | 13,182 |
| 1994 | 1,936 |  | 324 | 2,260 |
| 1995 | 2,058 |  | 919 | 2,977 |
|  |  | Subadults |  |  |
| 1991 | 1,064 |  | 252 | 1,316 |
| 1992 | 1,263 |  | 1,469 | 2,732 |
| 1993 | 128 |  | 1,112 | 1,240 |
| 1994 | 377 | 128 | 505 |  |
| 1995 | 378 |  | 262 | 640 |

Table 4. Annual total production ( $\mathrm{P}, \mathrm{mg}$ wet weight $\mathrm{x}^{-2} \mathrm{x}^{-1}$ ) and $\mathrm{P}: \mathrm{B}$ ratios. Total production included moult production. The weighted $\mathrm{P}: \mathrm{B}$ is the mean weighted by abundance of adults and subadults.

| Year | Sub-adult |  | Adult |  | Weighted |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | P | $\mathrm{P}: \mathrm{B}$ | P | P:B | $\mathrm{P}: \mathrm{B}$ |
| T. spinifera |  |  |  |  |  |
| 1991 | 36,398 | 34.2 | 58,812 | 2.8 | 4.3 |
| 1992 | 47,006 | 37.2 | 26,280 | 2.8 | 6.8 |
| 1993 | 7,705 | 9.8 | 19,272 | 2.8 | 3.5 |
| 1994 | 1,671 | 13.0 | 9,821 | 1.7 | 2.0 |
| 1995 | 2,199 | 5.8 | 5,711 | 2.9 | 3.4 |
| E. pacifica |  |  |  |  |  |
| 1991 | 2,463 | 9.8 | 15,790 | 2.4 | 2.7 |
| 1992 | 62,738 | 42.7 | 29,234 | 2.7 | 7.4 |
| 1993 | 25,505 | 22.9 | 17,791 | 2.4 | 5.0 |
| 1994 | 942 | 7.3 | 1,045 | 3.2 | 4.4 |
| 1995 | 2,471 | 9.4 | 2,242 | 2.4 | 4.0 |

Table 5. Annual mean abundance (no. $/ \mathrm{m}^{2}$ ) and biomass (mg wet weight $/ \mathrm{m}^{2}$ ) of fertilized females.

|  | T. spinifera |  | E. pacifica |  | Combined |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Year | Abundance | Biomass | Abundance | Biomass | Abundance | Biomass |
| 91 | 17 | 2,506 | 14 | 1,197 | 31 | 3,703 |
| 92 | 20 | 2,502 | 18 | 644 | 38 | 3,146 |
| 93 | 2 | 139 | 11 | 488 | 13 | 624 |
| 94 | 4 | 546 | 1 | 1 | 5 | 547 |
| 95 | 3 | 587 | 1 | 30 | 4 | 616 |



Fig. 1. Sampling locations in Barkley Sound. C - Coaster Channel, S - Swale Rock, R Robber's Pass, M - MacKenzie Anchorage.


Fig. 2a. Cohort-specific spawning periods and larval ( $<10 \mathrm{~mm}$ ) length and abundance. Days are after Jan. 1, 1991. Error bars are 95\% confidence intervals for mean length.


Fig. 2b. Decomposition of adult length frequency distributions. Shading distinguishes distributions and does not imply a relationship between samplings.


Fig. 2c. Assignment of adult ( $>10 \mathrm{~mm}$ ) length and abundance distributions to cohorts. Days are after Jan. 1, 1991. Error bars are $95 \%$ confidence intervals for mean length.


Fig. 3. Loess smoothed abundance trends for adult E. pacifica (A) and T. spinifera (B). 1 Robber's Passage, 2 - MacKenzie Anchorage, 3 - Coaster Channel, 4 - Swale Rock.


Fig. 4. Sea temperature anomalies for Amphitrite Point.


Fig. 5. Mean total length by cohort for T. spinifera. Error bars are $95 \%$ confidence intervals.


Fig. 6. Mean total mass by cohort for T. spinifera. Error bars are $95 \%$ confidence intervals.


Fig. 7. Mean total length by cohort for E. pacifica. Error bars are $95 \%$ confidence intervals.


Fig. 8. Mean total mass by cohort for $E$. pacifica. Error bars are $95 \%$ confidence intervals.


Fig. 9. Regression of growth rate constant in length for $T$. spinifera and $E$. pacifica against $\ln \left(\mathrm{L}_{0}\right)$ (initial size) and $\ln ($ mean SST) over the cohort-specific growth period. Plotting symbol is growth year.


Fig. 10. Regression of growth rate constant in mass for T. spinifera against $\ln \left(\mathrm{M}_{0}\right)$ (initial size) and $\ln$ (mean SST) over the cohort-specific growth period. Plotting symbol is growth year.


Fig. 11. Plot of growth rate constant in mass for E. pacifica against $\ln$ (mean SST) over the cohort-specific growth period. Plotting symbol is growth year.


Fig. 12. Abundance estimates (no. $/ \mathrm{m}^{2}$ ) for T. spinifera (-) and E. pacifica (---).


Fig. 13. Abundance (no. $/ \mathrm{m}^{2}$ ) and biomass estimates ( mg wet weight $/ \mathrm{m}^{2}$ ) for T. spinifera (-) and E. pacifica (---) fertilized females.


Fig. 14. Timing and duration of spawns for T. spinifera.


Fig. 15. Timing and duration of spawns for E. pacifica.


Fig. 16. Female parental and female recruit spawner progeny abundance (no. $/ \mathrm{m}^{2}$ ) for $T$. spinifera (A) and E. pacifica (B).


Fig. 17. Biomass estimates (mg wet weight/m2) for T. spinifera (-) and E. pacifica (---).


Fig. 18. Total daily production estimates (mg wet weight/m2/day) for T. spinifera (一) and $E$. pacifica (---).

# STOCK ASSESSMENT AND QUOTA RECOMMENDATIONS FOR 1996/97 FOR THE GREEN SEA URCHIN FISHERY IN BRITISH COLUMBIA 

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#### Abstract

Perry, R.I. and B.J. Waddell. 1998. Stock assessment and quota recommendations for 1996/97 for the green sea urchin fishery in British Columbia. p. 261-307. In: G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1996. Can. Tech. Rep. Fish. Aquat. Sci. 2221.


The fishery for green sea urchins (Strongylocentrotus droebachiensis) on the British Columbia coast developed rapidly from 1987 to 1991, and peaked in 1992 with landings of 1042 t . Declining landings and catch per unit of effort followed and management restrictions were implemented in 1992. In 1995, coastwide landings were 159.3 t , with South Coast landings of 153 t , slightly below the quota of 173.4 t . The principal Pacific Fishery Management Areas for green sea urchins are 12, 13 (Queen Charlotte and Johnstone Straits) and 18, 19, 20 (Gulf Islands - Juan de Fuca Strait). Harvest logbook information was examined, and required extensive editing. Median catch per unit of effort (CPUE) was calculated from the harvest logbook data to attempt to provide a robust index of potential changes in stock size. Analyses were conducted on a fishing season basis (1 October of year $i$ to 31 March of year $i+1$ ); key results are also presented on a calendar year basis for comparison. In general the comparison was good, with the fishing season data providing slightly better results. Biomass dynamic models were developed for coastwide, South Coast - inside waters northern region (PFMA 12,13) and South Coast - inside waters southern region (PFMA 17-20,28). Precautionary reductions of $30-50 \%$ from the estimated MSY are recommended as the total allowable catch to account for uncertainties in the input CPUE data and weaknesses in the dynamic production models. Recommended yield options for the South Coast range from 175-244 t, very similar to those proposed for the 1995-1996 fishing season. Yield options for the North Coast range from 9.5-13.3 $t$, but are based on very little data. Three fishery-independent surveys were conducted in a core fishing area; the estimates of MSY from these surveys for PFMA 12,13 is similar (within $13 \%$ ) to the MSY estimated by the dynamic production model. Results from a single exploratory fishing operation to the west coast of Vancouver Island are presented for information. Recommendations are provided on improvements to the harvest logbook process and database, quotas by management area, and provision of fishery-independent and biological information.

## INTRODUCTION

The fishery for green sea urchins, Strongylocentrotus droebachiensis, is a relatively new fishery in British Columbia, with commercial harvesting beginning in 1987. Until 1995, all data were derived from the fishery, and consisted of fish slip information upon sale of the catch and harvest logbook
information on catch, effort, and locations and depths fished. In the 1995-1996 fishing season, three small fishery-independent surveys were conducted of a key fishing location; in addition, an exploratory survey protocol was developed to provide scientific information about green sea urchins outside of the usual core fishing areas. Green sea urchins were managed with few limitations until 1991, when licence limitation was introduced to control record high effort and catches, followed by quota limitations in 1994.

Previous stock assessments have been conducted by Harbo and Hobbs (1996) and Perry et al. (1998). This latter assessment recommended changing the analysis from a calendar year to a fishing season (October-March) basis, to reflect the actual time of the fishery. The objectives of the current assessment are:

1) to provide an analysis of the green sea urchin fishery in British Columbia by comparing information on fishing season and calendar year bases, and by updating the historical fish slip and harvest logbook information with data from the October 1995 - March 1996 fishing season;
2) to update the biomass dynamic production model of Perry et al. (1998) with data on a fishing season basis, including the 1995-1996 fishery, and to provide recommendations for harvest yields;
3) to present results from the fishery-independent surveys and the exploratory fishing activity, and to compare these with estimates from the biomass dynamic model.

## BIOLOGY AND FISHERY BACKGROUND

The distribution and biology of green sea urchins in B.C. is summarized by Harbo and Hobbs (1996), but is generally poorly known. Green sea urchins on the Pacific coast of North America range from Alaska to northern Washington State. They occur intertidally to depths of $>140 \mathrm{~m}$. They can reach a maximum test diameter of $>100 \mathrm{~mm}$, and in Alaska spawn at about $46-50 \mathrm{~mm}$. In B.C., the spawning period generally occurs during February - March. Green urchin growth rates vary considerably depending on food availability, with rates of $1 \mathrm{~cm} / \mathrm{yr}$ recorded for the Strait of Georgia (Foreman and Lindstrom 1974) and slightly $>1 \mathrm{~cm} / \mathrm{yr}$ in Alaska (Munk 1992). Under foodlimited conditions, growth rates may be as low as $1-2 \mathrm{~mm} / \mathrm{yr}$ (Himmelman 1986). Green sea urchins appear to be more mobile than red sea urchins, and unpredictable (in space and time) aggregations are common. They may undertake deep-shallow migrations.

In the assessment conducted in 1995, Perry et al. (1998) recommended separating green sea urchin populations on the B.C. coast into four broad "stocks", rather than assuming they represent a single continuous population. This present assessment follows this recommendation of four stocks [B.C. North Coast (Pacific Fishery Management Areas 1-10); South Coast - inside waters northern component (PFMA 11-16); South Coast - inside waters southern component (PFMA 17-20, 28, 29); and the west coast of Vancouver Island] (Fig. 1). We justify this on the basis of the expected duration of the planktonic larval stages ( $1-2$ months at prevailing winter-spring temperatures of 6$10^{\circ} \mathrm{C}$; e.g. Hart and Scheibling 1988), and the general circulation of B.C. inside waters. Thomson (1981) indicates the northern Strait of Georgia has a weak circulation (except for the strong tidal
currents near Seymour Narrows) with a possible counter-clockwise pattern; this should separate the two components of the South Coast - inside waters. Thomson (1994) cites the results of estimates of the winter flushing time for the Strait of Georgia as 3-6 months, sufficiently longer than the expected larval duration of green urchins. However, there may be greater exchange of larvae between the South Coast - inside waters southern component and the west coast of Vancouver Island.

There are major fisheries for green sea urchins on the Atlantic coasts of Canada and the United States. In 1994, landings were 20,861 tin Maine and 2,323 t in Maritime Canada (S. Robinson, DFO, St. Andrews, N.B., pers. comm.). A fishery also takes place in the inside waters of Washington State, managed by licence limitation, a limit of one diver in the water, $2 \mathrm{~d} / \mathrm{wk}$ openings and an annual quota of 272 t (Harbo and Hobbs 1996).

The fishery in B.C. developed rapidly, with landings reaching a peak of 1042 t and a landed value of 4.4 million dollars in 1992, followed by a sharp decline. It is conducted by divers, and is principally a roe fishery whose product is landed and shipped live to the Japanese market. Highest market prices occur around Christmas. As a result, the fishery for green sea urchins is conducted during winter. It is managed with a 55 mm test diameter size limit, licence limitations, and in 1995 with area quotas, individual quotas, and area closures. Management actions since the inception of the fishery are summarized in Table 1. Submission of fish slips and harvest logbooks are conditions of licence. In 1995, the licence year was changed to expire in summer ( 31 May 1996). The fishery is conducted by SCUBA divers using small vessels due to the patchy distribution of the resource. Recently, the fishery has expanded to more remote locations with the addition of packer vessels (Harbo and Hobbs 1996). Fishers report that their fishing practices have changed as a result of quota restrictions and market demands for high quality roe, i.e. they now spend more time searching for high quality roe. The North Coast fishery in particular appears to suffer from poor roe yields and quality (Harbo and Hobbs 1996). However, some fishers on the South Coast indicate that despite the increased search time they continue to fish the same grounds with catches similar to previous years.

## METHODS

All analyses in this current assessment are presented on a "fishing season" basis, defined as 1 June of year $i$ to 31 May of year $i+1$; in practice for the recent years of the fishery this reduces to 1 October of year $i$ to 31 March of year $i+1$. A "fishing season" is denoted by the year fishing started, i.e. year $i$, so that the 1995 fishing season includes 1 October 1995 to 31 March 1996. For comparison with previous assessments, in which data were presented on a calendar year basis, the key tables and analyses from the current assessment are presented on a calendar year basis in Appendix 1.

Basic information on landings ( $L$ ) and landed values are derived from fish slip information as collected by the Catch and Effort Unit of the Biological Data and Analysis Division (DFO, Vancouver). Fish slip data from 1994, 1995, and 1996 (January-February) have been thoroughly edited, and discrepancies between fish slip and harvest logbook information have been resolved. Note that fish slip data are preliminary and incomplete for the 1995-1996 fishing season. Since
catches in the harvest logbooks prior to 1994 do not represent $100 \%$ of the landings (see below) total effort ( $\mathrm{E}_{\mathrm{T} i}$, in diver hours) in year $i$ was estimated as landings divided by the catch per unit of effort ( U ) from the harvest logbook database, i.e.:

$$
\begin{equation*}
E_{T_{i}}=\frac{L_{i}}{U_{i}} . \tag{1}
\end{equation*}
$$

Calculation of U is described below. For 1994 and 1995, landings (L) were derived from the edited harvest logbook database.

Detailed information on catch, effort, depth and locations fished for all years (1987-1995) are provided in the fishers' harvest logbooks, completion of which is a condition of licence. Perry et al. (1998) calculated catch per unit of effort (U) as the sum of all catches in the harvest logbook database divided by the sum of all effort from this database,

$$
\begin{equation*}
U_{1 i}=\frac{\sum_{j} c_{i j}}{\sum_{j} e_{i j}} \tag{2}
\end{equation*}
$$

with $c_{i j}$ and $e_{i j}$ representing the catch (c) and effort (e) for year $i$ from harvest logbook records $(j)$ with non-zero entries for both catch and effort. However, extensive editing of the harvest logbook database has been done over the past year, to the extent that catch per unit of effort can be calculated for individual harvest logbook records. This allowed us to calculate and compare other indices for catch per unit of effort, including the mean ( $\mathrm{U}_{2 i}$ ), standard deviation ( $\mathrm{s}_{i}$ ), and standard error of the mean ( $\mathrm{se}_{i}$ ) from individual records:

$$
\begin{equation*}
U_{2 i}=\frac{1}{n_{i}} \sum_{j}\left(\frac{c_{i j}}{e_{i j}}\right) \tag{3}
\end{equation*}
$$

(with non-zero entries for $e_{i j}$ ) where $n_{i}$ represents the number of records in year $i$, and the median ( $\mathrm{U}_{\mathrm{M} i}$ ) of individual records:

$$
\begin{equation*}
U_{M i}=\operatorname{median}_{i}\left(\frac{c_{i j}}{e_{i j}}\right) . \tag{4}
\end{equation*}
$$

The standard error of the median ( $\mathrm{se}_{\mathrm{M} i}$ ) was calculated as $1.2533 * \mathrm{Se}_{i}$, with $\mathrm{se}_{i}$ the standard error of $\mathrm{U}_{2 i}$. For reasons discussed in Results, the median catch per unit of effort ( $\mathrm{U}_{\mathrm{M} i}$, equation 4) was chosen as the appropriate measure, and is subsequently used in all calculations requiring catch per unit of effort (U).

Changes in the range of depths fished may be useful as additional information on the status of the stocks (for example if fishers must consistently go deeper to find harvestable concentrations of urchins). We calculated mean minimum and maximum depths fished from the harvest logbook
data, excluding zero values for either depths (and excluding the average depth values occasionally provided by fishers).

## Biomass Dynamic Model

Development of a biomass dynamic production model followed the approaches outlined in Schnute (1977), Polovina (1989) and Hilborn and Walters (1992). The following is adopted from Polovina (1989). Schnute (1977) developed a linear approximation to the dynamic Schaefer production model as

$$
\begin{equation*}
\ln \left(\frac{U_{i}}{U_{i-1}}\right)=r-q \frac{\left(E_{i-1}+E_{i}\right)}{2}-\left(\frac{r}{q k}\right) \frac{\left(U_{i-1}+U_{i}\right)}{2} . \tag{5}
\end{equation*}
$$

with $\mathrm{U}_{i}$ the catch per unit of effort for year $i$ (here using $\mathrm{U}_{\mathrm{M} i}$ ), $\mathrm{E}_{i}$ the effort for year $i$ (using $\mathrm{E}_{\mathrm{T} i}$ ), r the intrinsic rate of population increase of biomass, $q$ the catchability coefficient, and $k$ the unexploited biomass. This equation can be represented as a regression of the form

$$
\begin{equation*}
Y_{i}=\alpha+\beta X_{i}+\gamma Z_{i}+\varepsilon_{i} \tag{6}
\end{equation*}
$$

with

$$
\begin{aligned}
Y_{i} & =\ln \left(\frac{U_{i}}{U_{i-1}}\right) \\
X_{i} & =\frac{\left(E_{i-1}+E_{i}\right)}{2} \\
Z_{i} & =\frac{\left(U_{i-1}+U_{i}\right)}{2}
\end{aligned}
$$

and $\varepsilon_{i}$ a lognormal error term. The parameters $\alpha, \beta, \gamma$ are then equal to $r,-q$, and $-r /(q k)$, respectively. Solutions to this regression equation were calculated using S-Plus.

Once $r, q$, and $k$ are known, the catch in year $i+1$ can be estimated as:

$$
\begin{equation*}
C_{i+1}=\left(\left(\frac{q k}{r}\right) E_{i+1}\right) \ln \left[1+\left(\frac{\left(r-q E_{i}\right)}{r-q E_{i+1}}\right)\left(\frac{\exp \left(r-q E_{i+1}\right)-1}{1-\exp \left(-\left(r-q E_{i}\right)\right)}\right)\left(1-\exp \left(\frac{-r C_{i}}{q k E_{i}}\right)\right)\right] \tag{7}
\end{equation*}
$$

and the traditional Schaefer model under equilibrium conditions is represented as:

$$
\begin{equation*}
C_{i}=q k E_{i}\left(1-\left(\frac{q}{r}\right) E_{i}\right) . \tag{8}
\end{equation*}
$$

Hilborn and Walters (1992) provide the following summary of management parameters once the parameters of the Schaefer model have been determined:

```
Maximum surplus yield (MSY)
stock size for MSY
rate of exploitation at MSY
effort required to achieve MSY
```

$\square$
k/2
$r k / 4$
$r / 2$
$r / 2 q$

The variance of the production model results was estimated following Schnute (1977). An unbiased estimate of the variance $\left(\sigma^{2}\right)$ is determined by:

$$
\begin{equation*}
\hat{\sigma}^{2}=\frac{1}{N-3} S_{1}(\hat{r}, \hat{k}, \hat{q}) \tag{9}
\end{equation*}
$$

with,

$$
\begin{equation*}
S_{1}(r, k, q)=\sum_{n=1}^{N}\left(Y_{n}-r+q X_{n}+\frac{r}{q k} Z_{n}\right)^{2} \tag{10}
\end{equation*}
$$

and,

$$
S_{1}(\hat{r}, \hat{k}, \hat{q})=\text { minimum } .
$$

The $95 \%$ confidence interval can then be estimated as:

$$
\begin{equation*}
C I_{0.95}=3 \hat{\sigma}^{2} F_{0.05}(3, N-3) \tag{11}
\end{equation*}
$$

with eight degrees of freedom this is equal to $3 * \hat{\sigma}^{2} * 5.41$. The upper $95 \%$ confidence limit is calculated as:

$$
\begin{equation*}
C_{u p p e r}=\left(\frac{r}{2 q}+C I_{0.95}\right)\left(\frac{q k}{2}+C I_{0.95}\right) \tag{12}
\end{equation*}
$$

and similarly for the lower $95 \%$ confidence limit ( $\mathrm{C}_{\text {lower }}$ ) with subtracting $\mathrm{Cl}_{0.95}$. Schnute (1977) also provides a "failure index" (I) to monitor the performance of the model:

$$
\begin{equation*}
I=\frac{S_{1}(\hat{r}, \hat{k}, \hat{q})}{S_{Y}} \tag{13}
\end{equation*}
$$

where,

$$
S_{Y}=\left[Y_{n}-\left(\frac{1}{N} \sum_{n=1}^{N} Y_{n}\right)\right]^{2}
$$

Values close to zero indicate the model works well and that the fishery is the predominate factor influencing annual stock variations.

The 1995-1996 fishing plan restricted fishing in the South Coast to the traditional core fishing areas (PFMA 12,13; 17-20, 28). In the current assessment, the biomass dynamic production model was calculated using data for all years but only from these core fishing areas. Historically these core areas have contributed $>90 \%$ to the coastwide landings of green sea urchins in B.C.

## Fishery-Independent Surveys

Scientific surveys were conducted to obtain biological and population information on green sea urchins in B.C. independent of the commercial fishery. These were small localized surveys designed to provide experience with the techniques and protocols, to develop working relationships with industry and native fishery interests, and to provide biological information from a part of the core fishing area. A detailed report of the first set of surveys is available (Waddell et al. 1997).

The locations of the surveys were in PFMA 12, Subarea 18, in eastern Queen Charlotte Strait. Three surveys were conducted: two in October 1995 [Survey 1 targeted red sea urchins, but also recorded data for green sea urchins (survey organized and conducted by Dr. Alan Campbell, Pacific Biological Station, Nanaimo, B.C.); Survey 2 targeted green sea urchins in the Stephenson Islets ( $50^{\circ} 34.5^{\prime} \mathrm{N}, 126^{\circ} 49.5^{\prime} \mathrm{W}$ )], and a repeat of Survey 2 conducted in March 1996 (Survey 3). Stephenson Islets was identified by the fishing industry as a key, first-choice location for harvesting of green urchins.

The transect-quadrat technique was used, with transects randomly selected prior to the survey. Quadrats ( $1 \mathrm{~m}^{2}$ ) were sampled along the transects by divers, working from deep to shallow. Green urchins were counted and test diameters measured on all surveys; subsamples were collected for measurements of weight and gonad condition in the March 1996 survey. Survey 1 was conducted from 11-16 October 1995, and examined 48 transects at 12 sites in PFMA 12-18, including three sites (10 transects) in the Stephenson Islets. Survey 2 was conducted on 18 October 1995, consisting of 11 transects in the Stephenson Islets, and Survey 3 repeated Survey 2 on 28 March 1996, with the exclusion of one transect. Once an estimate of biomass is derived from a survey, a maximum sustainable yield (MSY) can be estimated using Gulland's (1971) formula:

$$
\begin{equation*}
M S Y=x M B_{0} \tag{14}
\end{equation*}
$$

in which $B_{0}$ represents the biomass estimate, $M$ is the instantaneous natural mortality rate, and $x$ is a scaling factor that Sparre et al. (1989) recommend should equal 0.2 . The natural mortality
rate for green sea urchins can be estimated using Hoenig's (1983) regression of lifespan ( $T_{m}$ ) against total mortality ( $Z$ ):

$$
\begin{equation*}
\ln (Z)=1.23-0.832 \ln \left(T_{m}\right) \tag{15}
\end{equation*}
$$

with the assumption that $Z=M$ in the absence of fishing.

## Exploratory Fishing Protocol

An exploratory fishing protocol was developed to begin to provide information on green sea urchin aggregations and abundances in areas outside of the normal core fishing locations. This protocol was developed in active collaboration with the fishing industry, and did not become fully operational until late January 1996. The green sea urchin exploratory fishing protocol is presented in Appendix 2. Briefly, exploratory fishing was to be conducted by licensed industry vessels, which were allowed to sell their catch in the normal manner. For the South Coast, the catches were considered to be additional to the established quota since the protocol was not available for areas open to fishing in the 1995-1996 fishing season. Each vessel was required to have a DFO authorized observer on-board at all times while fishing, to make detailed observations of the fishery and to ensure that the exploratory protocol was followed. This protocol required prior identification by the fisher of the proposed fishing "sites", defined to have an area of $1 \mathrm{nmi}^{2}$. For any site, the maximum time for divers to be in the water was 16 diver hrs. Once this limit was reached, fishing in the current site was to cease. The intent of this regulation was to broadly limit effort on any particular aggregation of urchins, while still allowing for information on catch per unit of effort.

## RESULTS

## General Trends

The history of this fishery has been one of a boom developmental period from 1988 to 1991, peak landings in 1992, followed by declining landings, declining catch per unit of effort (CPUE), and the imposition of management restrictions (Table 2, Fig. 2). Landings in 1994 and 1995 fishing seasons were limited by quotas (e.g. Table 1). Landings by Pacific Fishery Management Area by fishing season are presented in Table 3, and illustrate the significance of the core fishing areas PFMA 12, 13, 18, 19. Note that fishing in the South Coast in the 1995 fishing season was restricted to these four core areas plus Areas 17, 20, 28 (Table 1). Since fish slip data are incomplete for the 1995-1996 fishing season, landings by month and PFM Area are presented in Table 4 from validation logs completed by the Port validators as a requirement of the Individual Quota system. It illustrates the focus of effort in PFMA 12, shifting to PFMA 13 towards the end of the season (February 1996). The total landings (from validation logs, Table 4a) for the 1995 South Coast fishing season of 153 t was slightly below the allowable quota of 173 t (Table 1), possibly because of poor prices being offered for the product around Christmas (the normal peak price period). Landings on the North Coast in 1995 of 4 t (Table 4b) were well below the quota of 90.7 t . Comparison of landings reported from fish slips versus harvest logbooks shows excellent logbook returns over the past 5 years (Table 5); the return rate of $121 \%$ in 1995 is due to the incomplete fish slip data.

## Catch per Unit of Effort

Values of catch per unit of effort calculated from individual harvest logbook records ( $\mathrm{U}_{2 i}$, eq. 3) showed many high outliers in every fishing season (Fig. 3). Some of these outliers may be real, considering the patchy distribution of green urchins and the varying skills of the fishers. However, some of these also undoubtedly result from errors in the harvest logbooks, for example, when the same number of hours fished is entered for every dive over several days of fishing. To try and reduce these errors and the influence of these outliers, we calculated the median catch per unit of effort $\left(\mathrm{U}_{\mathrm{Mi}}\right)$ as a robust estimate, and compared its values and trend with the aggregate estimate $\mathrm{U}_{1 i}$ and the mean estimate $\mathrm{U}_{2 i}$ (Fig. 4). In every fishing season, the median $\mathrm{U}_{\mathrm{Mi}}$ provided the lowest estimate of catch per unit of effort, whereas the aggregate $\mathrm{U}_{1 i}$ provided the highest estimate; the trends were similar amongst all three estimates. Standard deviations about the mean $\mathrm{U}_{2 i}$ were large; and included the estimates $\mathrm{U}_{1 i}$ and $\mathrm{U}_{\mathrm{M} i}$ in all cases. Standard errors about the mean or median were much smaller (e.g. Fig. 5), considering the large number of logbook records available. The median $\mathrm{U}_{\mathrm{M} i}$ and its standard error were chosen as a robust estimator of catch per unit of effort.

The median catch per unit of effort shows a declining trend with fishing season until 1993 in all major regions except the South Coast - inside waters southern region (PFMA 17-20, 28), in which the minimum occurred in 1992, and an increase in recent years (Fig. 3). The standard errors about the medians are small, except for the North Coast (Fig. 5d), which had few data available.

There has been a tendency in recent years towards an increasing range of depths fished, with an increase in the mean maximum depths fished for coastwide, northern and southern South Coast inside waters (Fig. 6). This is consistent with anecdotal reports from fishers about having to fish deeper for green urchins in recent years (since 1992).

## Biomass Dynamic Model

Biomass dynamic production models were calculated for the three geographic regions with adequate data: coastwide, South Coast - inside waters northern region (PFMA 12, 13), and South Coast - inside waters southern region (PFMA 17-20, 28). Landings ( $\mathrm{L}_{i}$ ) versus total effort ( $\mathrm{E}_{\mathrm{T} i}$ ) on a fishing season basis for all three regions showed increasing yield with increasing effort from 1987 to 1992 (1990 in PFMA 17-20, 28) but when effort was reduced, landings were lower than during the previous period of the developing fishery (Fig. 7). Calculation of the regression (eq. 6) separately for each of these regions produced meaningful parameter estimates in all cases (Table 6). This is in contrast to the results of Perry et al. (1998), who obtained meaningful estimates only for the South Coast - inside waters northern region, although the data were on a calendar year basis and included PFMA 11-16. Probability values for the models ranged from 0.059 to 0.077 , and explained from $64 \%$ to $68 \%$ of the variation. The coastwide MSY estimate is 511 t ; it is 228 t for PFMA 12, 13 and 100 t for PFMA 17-20, 28 (Table 6). The estimated MSY for the South Coast inside waters northern region is similar ( $89 \%$ ) to that estimated for the same region (but including more areas, i.e. PFMA 11-16) by Perry et al.(1998), and with $77 \%$ of the estimated effort at MSY.

However, the unexploited stock size ( $k$ ) in Table 6 for this region is only $46 \%$ of that calculated by Perry et al. (1998). Evidently the virgin biomass is poorly estimated by the present model, as such a large difference is unlikely to be due solely to changes in the definition of fishing year and the areas included in the model. Model fits of landings versus effort ( $\mathrm{E}_{\mathrm{T} i}$ ) using eq. 7 for each region are presented in Fig. 7. The traditional Schaefer model under equilibrium conditions for the two South Coast - inside regions using the calculated parameters and eq. 8 are presented in Fig. 8.

Estimated $95 \%$ confidence intervals about the sustainable catch are quite narrow (Table 6). The largest intervals are placed on the MSY estimates for PFMA 12 and 13, and the "failure index" ( $I$ ) suggests this is also the model with the poorest fit. The failure index for the other two models is in the middle of the expected range, suggesting that fishery and environmental processes have about similar importance to the population dynamics.

In new fisheries, data in the earliest years are often poorly collected and poorly representative of the stock in time and space, yet these may have high leverage in production models. The production model for the South Coast - inside waters northern component was re-calculated with the data for 1987-1988 excluded. Model performance was poorer ( $\mathrm{r}^{2}=0.60, \mathrm{p}=-0.158$ ) than when these data were included (Table 6), but resulted in an MSY estimate of 222 t , within the $95 \%$ confidence limits about the MSY estimated when all data were included (Table 6).

## Fishery-independent Surveys

The distribution of green sea urchin test diameters was similar between Surveys 1 and 2 (both in October 1995), but different from Survey 3 (March 1996) (Fig. 9). Analyses of these size frequencies using the approach of Schnute and Fournier (1980) and the assumption of Gaussian distributions were consistent with three modes for the October 1995 surveys and the March 1996 survey (although the middle modes were small and relatively insignificant in all three surveys) (Table 7). The modes are very similar and within one standard deviation between the two October surveys, and suggest that green urchins in the Stephenson Islets region are representative of the size distribution broadly throughout PFMA 12 Subarea 18. The shift in the mean of the smallest mode in the Stephenson Islets region from 34 mm in October 1995 to 44 mm in March 1996 ( 5 months) is most readily explained as growth by these smaller animals, since the difference of 10 mm is possible within the growth rates observed for green urchins in B.C. and Alaska.

Estimates of the densities of green urchins in PFMA 12 Subarea 18 and in Stephenson Islets confirms the importance of the latter region as a local "hot spot" (Table 8). The difference between the density estimates from Survey 1 (Stephenson Islets) and Survey 2 is likely a result of Survey 1 targeting on red sea urchins, with green sea urchins being recorded incidentally and therefore some green urchins may have been missed. The area sampled during Surveys 2 and 3 was $21,300 \mathrm{~m}^{2}$. Assuming an average weight of $122.5 \mathrm{~g}(0.27 \mathrm{lb}$.) for a legal size green urchin as collected by the fishery (calculated from the harvest logbook database), the biomass of green urchins $\geq 55 \mathrm{~mm}$ test diameter was 3.7 t in Survey 2 and 2.8 t during Survey 3. This represents a net decrease of 0.9 t between 18 October 1995 and 28 March 1996 from the Stephenson Islets region, although it does not take account of migration into (or out of) the survey area nor of growth into the legal-sized population. The area of green urchin fishing beds for PFMA 12 Subarea 18 as identified on harvest
logbooks is $350 * 10^{4} \mathrm{~m}^{2}$. If the densities of legal size green urchins at Stephenson Islets is assumed to represent the densities throughout PFMA 12 Subarea 18, the biomass of legal green urchins is estimated as $\left(350 * 10^{4} \mathrm{~m}^{2} * 1.45\right.$ urchins $\left./ \mathrm{m}^{2} * 122.5 \mathrm{~g} / \mathrm{urchin} \Rightarrow\right) 621 \mathrm{t}$ in October 1995. However, Table 7 indicates urchin densities at Stephenson Islets are not representative of PFMA 12 Subarea 18. The appropriate density to use for this larger region is 0.20 legal urchins $/ \mathrm{m}^{2}$ (from Survey 1, Table 8). Using this density provides an estimate of 86 t of legal size green urchins in PFMA 12 Subarea 18 in October 1995. Assuming further that this density ( 0.2 urchins $/ \mathrm{m}^{2}$ ) is representative throughout all of PFMA 12 and 13, with a fishing bed area of $9.119 * 10^{7} \mathrm{~m}^{2}$ (from the harvest logbook database), the legal-sized biomass of green urchins is estimated as $\left(9.119 * 10^{7} \mathrm{~m}^{2} * 0.20\right.$ urchins $/ \mathrm{m}^{2} * 122.5 \mathrm{~g} /$ urchin $\left.=\right) 2234 \mathrm{t}$. This estimate is $95 \%$ of the (unexploited) legal size biomass estimated by the production model of Perry et al. (1998), but is $208 \%$ of the (unexploited) biomass estimated for this region in the present assessment (Table 6).

An MSY from these survey biomass estimates can be calculated using Gulland's (1971) formula (eq. 14) and Hoenig's (1983) regression of mortality rate from lifespan (eq. 15). Assuming a natural lifespan for green sea urchins of $7-10$ years (Hart and Scheibling 1988), the mortality rate is $0.50-$ 0.68 . Taking an average value of 0.58 for M and $\mathrm{B}_{0}$ as 2234 t from Survey 1 , the MSY is calculated as 260 t , which is $14 \%$ larger than the current production model estimate for PFMA 12 and 13 (Table 6). The similarity of these two independent estimates of MSY for this area is encouraging.

## Exploratory Fishing

Only one fishing expedition took place under the exploratory fishing protocol. This was due to the late start to the exploratory fishing program (late January 1996), and the poor quality of green urchin roe encountered during fishing (both males and females showed signs of spawning). This trip took place from 16-18 February 1996, and examined six general sites off the west coast of Vancouver Island (PFMA 24 Subarea 6). On the first day, 10 dives were conducted before mechanical difficulties stopped the harvesting, for a total of 1.82 diver hours of which only 0.7 diver hours were actually spent harvesting (the rest was considered "survey" time). For the entire trip, the total weight harvested was only 0.18 t and the total effort was 3.22 diver hours for a catch per unit of effort of $55.9 \mathrm{~kg} /($ diver hour). This is similar to the South Coast - inside waters in 1995 (Fig. 5), although it was clear that much of the time in the exploratory fishing consisted of short dives looking for adequate aggregations of potentially high roe quality green urchins. A subsample of 74 urchins had a mean ( $\pm 1$ standard deviation) test diameter of $72 \pm 7 \mathrm{~mm}$.

All the catch that was landed came from two small islands in PFMA 24-6. Eight dives were conducted at this location, of which five landed product (Table 9). If these successive dives are treated as a depletion experiment (e.g. Hilborn and Walters 1992, Chapter 12), and dive 5 is excluded assuming that its short dive time represents a repeat dive on the same "hot spot", then the legal size biomass can be estimated by regression of catch per unit of effort against the cumulative catch (Table 9). This regression is significant $\left[\mathrm{r}^{2}=0.98, \mathrm{p}=0.012, \mathrm{a}=309.16\right.$ (standard error $=22.51$ ) and $b=-1.58(\mathrm{se}=0.18)]$ and estimates a biomass at zero catch per unit of effort of approximately 200 kg . A rough estimate of the area harvested at this site is $0.05 \mathrm{~km}^{2}$. Therefore $200 \mathrm{~kg} / 0.05 \mathrm{~km}^{2}$ equals $4 \mathrm{~g} / \mathrm{m}^{2}$ which is (assuming an average weight of 122.5 g per legal sized urchin) 0.03 urchins $/ \mathrm{m}^{2}$. This is about $1 / 6$ th the average density sampled for PFMA 12 Subarea 18 by Survey 1
(Table 8). If dive 5 is included in the analysis, the regression is not significantly different from zero ( $\mathrm{p}=0.13$ ).

## Yield Recommendations

The dynamic production model produced estimates of the maximum sustainable yield (MSY) for coastwide, and South Coast - inside waters northern and southern regions (Table 6). These results are used to provide recommendations of yield options by Pacific Fishery Management Area (Table 9). MSY estimates using the coastwide production model are assigned to each management area on the basis of the proportion that area contributed to aggregate landings (on a fishing season basis) from 1988 to 1995 (Table 4). MSY estimates for the South Coast - inside waters northern region were used for PFMA 12 and 13, and assigned on the basis of their proportional catch (Table 4) as $65 \%: 35 \%$, respectively. MSY estimates for South Coast - inside waters southern region were used for PFMA 17-20, 28, and assigned on a percentage basis of 5.7:40.5:35.2:15.7:2.9, respectively. Mace (1988) recommends allowable catches within a range of $0.6-0.9$ of MSY as a cautionary reduction for deterministic production models (such as developed here), since the deterministic MSY is not usually sustainable in a stochastic environment. Garcia et al. (1989) recommend maximum target yields of $1 / 2$ to $2 / 3$ of the estimated MSY, to account for the broad assumptions of surplus production models. These assumptions include deterministic biological processes, the fishery acting on a single stock with stable size distribution, and that catchability is not density dependent; many of these are not likely to be true for green sea urchins in B.C. Considering the uncertainties in harvest logbook information, the general problems with use of catch per unit of effort as an abundance index, and the problems with equilibrium production models in situations which are not likely to be in equilibrium, we recommend allowable catches be set at $50-70 \%$ of the estimated MSY. These reductions are presented in Table 9 as $0.5 * \mathrm{MSY}$ and $0.7 * \mathrm{MSY}$ for each management area. The range in recommended total yield for the South Coast region is 174.6-243.6 t.

## DISCUSSION

## Harvest Logbooks

Data from the harvest logbooks had numerous errors, which have been extensively edited where possible. Diver minutes were often not entered or were roughly estimated (e.g. pages of harvest logs, representing many days of diving, would have the same value entered for effort). It is also not known how effort was measured, e.g., only the time divers were actually collecting sea urchins, or the full time they were in the water. Effort was likely being recorded in different ways and we recommend that the divers (not just the licence holders) be fully informed that diver minutes are to be recorded as the time from when divers reach bottom to when they leave the bottom for the surface.

Location data also had problems, mostly involving missing information. Over the period 1987 to 1994, location data were missing for $0.3 \%$ of the management areas, $5 \%$ of the subareas, and $38 \%$ of the beds. This was mainly because fishers did not provide sufficient charts or information as to where they fished, despite this being a requirement. Occasionally the subareas and beds were
recorded or coded incorrectly. This improved in the 1995-1996 fishing season, with no missing information for areas and subareas, and only $7.4 \%$ of bed information missing. However, this does not mean that the area and subarea are always correct. The individual area totals do not agree between the validation logs and the harvest logbooks, even though the information should be identical. The fishers give the validators their harvest logs in sealed envelopes, which are sent directly to Fisheries and Oceans Canada. The validator is not allowed to check the validation log against the harvest logbook entries. We believe the fishers are entering different area and subarea information on the validation and harvest logbooks in some cases. In addition, validation logs only provide one entry for the location information per day, whereas the fishers often fish in several locations during one day. The validation company has suggested that one form be used for both the harvest logbook information and the validation of catch, with sufficient space to allow several entries per day.

This year we checked the individual harvest logbook entries for 1994, 1995 and 1996 against individual sales slip entries. We found that both logbook and sale slip entries were missing, meaning that both databases underestimated the actual total catch. We also checked the individual harvest logbook entries for 1995-1996 against the validation logs. We have resolved some of the 1994 problems in the harvest logbook and the sales slip databases, but this process is not complete. The sales slip database is not complete for 1995 and 1996, so we could not reconcile differences with the harvest logbook database. However, we have reconciled differences between the validation log database and the harvest logbook database for 1995-1996. These harvest logbook data are therefore final, and the 1994 data are close to being final. We did not have time to reconcile the data for previous years. Data for 1987 to 1993 will have to be reconciled with the sales slip data on an individual entry basis. The sales slip data for these years have been considered by the Statistics Unit as "final" and have been "rolled-up" by month, making them impossible to use for checking missing harvest logbook data. Archived files of sales slip data will need to be retrieved and checked against the harvest logbook data to find missing entries for both the sales slip and harvest logbooks.

## Calendar Year Comparison

Appendix 1 details the key data and calculations on a calendar year basis and using $\mathrm{U}_{1 i}$ as the catch per unit of effort index, for comparison with previous assessments and with the changes (fishing season basis, median CPUE) in the present assessment. The recent trend in CPUE is similar on calendar or fishing season bases, with an increase in 1994 and 1995. Estimates of the MSY coastwide and for the South Coast - inside waters northern component on fishing season and calendar year bases are within $5 \%$ of each other. In general, the results are quite similar between the two analyses, and there has been no loss of performance in moving to a fishing season basis and in the use of the median CPUE; in fact, there appears to be an increase in performance as the production model for the South Coast - inside waters southern component was not adequate on a calendar year basis.

## Catch per Unit of Effort

To the extent that catch per unit of effort can be considered as an index of the abundance of green sea urchins, the upturn in CPUE in recent years is encouraging. This upturn occurs in coastwide and

South Coast - inside waters northern and southern components, and is consistent across all three measures of CPUE and in both fishing season and calendar year analyses. Present levels of CPUE are similar to predicted equilibrium CPUE ( $q k / 2$, Table 6; Schnute 1977) for coastwide and South Coast northern components, and somewhat below predicted equilibrium CPUE for South Coast southern waters. This upturn has coincided with drastically lower quotas and the introduction of the individual quota system into this fishery (on a voluntary basis in 1994 and a regulatory basis in 1995-1996), which presumably have helped stabilize declining catch rates. Fishers report that these management changes in the fishery have caused them to alter their style of fishing. They now spend more time looking for animals which are likely to have high quality roe (i.e. increased search time). This provides further uncertainty to the use of catch per unit of effort as an-index time series of abundance, so that the results of the biomass dynamic model (based in part on the CPUE data) must be treated very cautiously.

## Biomass Dynamic Model

Dynamic production model calculations on a fishing season basis produced acceptable results for coastwide, and South Coast - inside waters northern and southern regions. Estimated MSY for the South Coast - northern region was slightly lower than that estimated by Perry et al. (1998), although the latter estimate was for a larger region (PFMA 11-16). The value of $r$, the intrinsic rate of increase of the population biomass, calculated from the biomass dynamic model seems rather high.
However, green urchins in Alaska appear to be capable of relatively rapid growth, with test diameters increasing between $25 \%-200 \%$ per year over the first 4 years of life (Munk 1992). Actual population growth rates will depend on food availability, temperature, predators, recruitment, etc. Considering the warmer temperatures of southern B.C. waters, green urchins in this area could have similar rapid rates to those in Alaska, if other conditions are equal. This needs further investigation (including recruitment) to confirm the ability of this stock to sustain itself under fishing pressure.

Although few results are available, the similarity of MSY estimates from PFMA 12 and 13 between the production model and the fishery-independent surveys is encouraging. These surveys should be continued and expanded to cover more than the traditional "hot" fishing locations. These surveys are also very important for assessing the sub-legal sized population, which does not appear in the fishery. Examination of green urchin recruitment trends would be useful to provide advance knowledge of important shifts in population size structure.

Yield options for the North Coast (and the west coast of Vancouver Island) are almost arbitrary, considering the poor knowledge of green urchin populations in these areas. It is unknown whether this poor knowledge reflects an absence of green sea urchins in these areas, or the distances to landing sites (considering that the product is shipped live) and difficulties of fishing in exposed areas. Although only one exploratory fishing trip took place using the protocol in Appendix 2 and the data were sparse, it did demonstrate the utility of these types of activities for providing information on green urchin stocks in unexploited locations. Rapid and broad-scale surveys are needed to identify aggregations of green urchins in these unexploited areas and to make initial estimates of the exploitable biomass. With the recent decisions by PSARC to promote surveys as
the preferred method to explore unfished areas for new and developing fisheries (Perry 1998), the exploratory fishing protocol presented in Appendix 2 will need to be modified somewhat.

We feel cautiously optimistic with this assessment of green urchins on the B.C. coast. The downward trend in CPUE appears to have been arrested, and there is general consistency in MSY estimates among the 1995 assessment (Perry et al. 1998), production model calculations in the present assessment, and fishery-independent surveys. We express general satisfaction with the 1995-1996 fishing plan (i.e. quotas on the core fishing areas with other areas open for surveys) and encourage relatively few changes to this basic plan.

## SUMMARY OF RECOMMENDATIONS

1) Improvements to the harvest logbook database
a) standardization of recording effort, i.e., as the time from when the divers reach bottom to when they leave bottom for the surface;
b) improvements in recording fishing location;
c) combination of validation and harvest logs into a single form with space for multiple entries per day.
2) Fishing season versus calendar year comparison

Results were similar between analyses conducted on a fishing season (e.g. October of year $i$ to March of year $i+1$ ) or a calendar year basis; the fishing season basis produced better results. Analyses should continue on a fishing season basis, and use the median catch per unit of effort as a robust index of catch rate trends.
3) Yield Options

Considering the uncertainties in the input data and the production model, caution is urged in the management of this species. Yield options for the 1996-1997 fishing season by management area should be conservative, and maintained below the estimated MSY. The South Coast total ranges from 175 to 244 t . These ranges are very similar to those proposed for the 1995-1996 fishing season. Yield options for the North Coast are provided in the range of 10 to 14 t , although few data are available on the status of stocks in the North Coast or on the west coast of Vancouver Island.
4) Fishery-independent and biological information

Analyses of green sea urchin data collected during directed surveys and during surveys for red urchins produce useful biomass and yield estimates for comparison with fisherydependent data. They should continue and be expanded to locations in addition to local "hot spots". Biological data on the catch by the fishery would also be useful, especially in collaboration with industry. Information on green urchin larval biology and recruitment is needed to identify recruitment pulses and changes in the size structure of the population. Rapid and broad-scale survey methods are needed to assess green urchin distributions and stocks in lightly or unexploited areas.

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## REFERENCES

Foreman, R.E. and S.C. Lindstrom. 1974. Urchin survey report. Rep. Fish. Res. Bd., Pacific Biol. Stn. 1973: 1-59.

Garcia, S., P. Sparre, and J. Csirke. 1989. Estimating surplus production and maximum sustainable yield from biomass data when catch and effort time series are not available. Fisheries Res. 8: 13-23.

Gulland, J.A. 1971. Science and fishery management. J. Cons. int. Explor. Mer 33: 471-477.
Harbo, R. and K. Hobbs. 1996. Precautionary quotas in the 1994 and 1995 green sea urchin fisheries in British Columbia. pp. 207-230. In: C.M. Hand and B.J. Waddell [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1993 and 1994. Can. Tech. Rep. Fish. Aquat. Sci. 2089.

Hart, M.W. and R.E. Scheibling. 1988. Heat waves, baby booms and the destruction of kelp beds by sea urchins. Mar. Biol. 99: 167-176.

Hilborn R, and C.J. Walters. 1992. Quantitative Fisheries Stock Assessment. Chapman and Hall. New York.

Himmelman, J.H. 1986. Population ecology of green sea urchins on rocky barrens. Mar. Ecol. Progr. Ser. 33: 295-306.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. (U.S.) 81: 898-903.

Mace, P. 1988. The relevance of MSY and other biological reference points to stock assessment in New Zealand. New Zealand Fisheries Assessment Res. Doc. 88/30: 41p.

Munk, J.E. 1992. Reproduction and growth of green urchins Strongylocentrotus droebachiensis (Muller) near Kodiak, Alaska. J. Shellfish Res. 11: 245-254.

Perry, R. I. 1998. A framework for providing scientific advice for the management of new and developing invertebrate fisheries. p. 3. In: G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1996. Can. Tech. Rep. Fish. Aquat. Sci. 2221. [Abstract only].

Perry, R.I., B.J. Waddell, A. Campbell and K. Hobbs. 1998. Review of fishery-dependent data and quota recommendations for 1995/96 for the green sea urchin fishery in British Columbia. pp. 111-145. In: B.J. Waddell, G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 2. Echinoderms. Can. Tech. Rep. Fish. Aquat. Sci. 2215.

Polovina, J.J. 1989. A system of simultaneous dynamic production and forecast models for multispecies or multiarea applications. Can. J. Fish. Aquat. Sci. 46: 961-963.

Schnute, J. 1977. Improved estimates from the Schaefer production model: theoretical considerations. J. Fish. Res. Bd. Canada 34: 583-603.

Schnute, J. and D. Fournier. 1980. A new approach to length-frequency analysis: growth structure. Can. J. Fish. Aquat. Sci. 37: 1337-1351.

Sparre, P., E. Ursin and S.C. Venema. 1989. Introduction to tropical fish stock assessment. Part 1. Manual. FAO Fish. Tech. Pap. 306/1: 337 p.

Thomson, R.E. 1981. Oceanography of the British Columbia coast. Can. Spec. Publ. Fish. Aquat. Sci. 56: 291p.

Thomson, R.E. 1994. Physical oceanography of the Strait of Georgia - Puget Sound - Juan de Fuca Strait system. pp. 36-98. In: R.C.H. Wilson, R.J. Beamish, F. Aitkens and J. Bell [eds]. Review of the Marine Environment and Biota of the Strait of Georgia, Puget Sound and Juan de Fuca Strait. Can. Tech. Rep. Fish. Aquat. Sci. 1948.

Waddell, B.J., R.I. Perry, G. Scharf and G. Ross. 1997. Surveys on green sea urchin (Strongylocentrotus droebachiensis) populations in Queen Charlotte Strait, British Columbia, October 1995 and March 1996. Can. Tech. Rep. Fish. Aquat. Sci. 2143: 36 p.

Table 1. Summary of management actions in the green sea urchin fishery, 1987 to 1996.

| Year |  |
| :--- | :--- |
| 1987 | Scientific permits were issued, July 22 to December 31 , to fishing vessels for harvest by diving. |
| Logbooks were issued with permits to collect data on stock abundance and distribution. |  |
| Permits were limited to the inside waters of Vancouver Island, Areas 12 to 19,28 and 29. |  |
| Some minor area closures for parks or study areas were in effect as for most dive fisheries. |  |
| A precautionary minimum size limit of 40 mm was set as a condition of the permit. |  |
| Sales slip data did not have a separate species code, so green and red sea urchin landings are mixed. As a result, landings have |  |
| been estimated from logbook returns and hails from processors. |  |
| Effort was restricted by limiting the season to the months of traditional peak market demand for seà urchins, Oct.-Dec. and Jan.- |  |
| Feb. Nineteen vessels reported landings. |  |
| Permits were issued for the period Jan. 16 to Feb. 28. |  |
| Sales data for green sea urchins was recorded with a separate species code. |  |
| A conservative closure was set, Jan. 16 to Feb. 28 in subareas $13-1$ to $13-3$ due to the intensive fishery in a small area. |  |
| A Z category (Z-A) licence for green sea urchins was introduced for the fall fishery which opened Oct. 1. |  |

Table 2. Green sea urchin landings (tonnes) and effort for British Columbia, by fishing season (Oct. to Mar.), 1986/1987 to 1995/1996, as reported on sales slips and harvest logbooks. Missing number of licences is due to this table being on a Fishing Season basis; numbers of licences for each calendar year are presented in Appendix Table A2.

| Season | Licence Type |  | $\begin{gathered} \text { Vessels } \\ \text { with } \\ \text { Landings } \\ \hline \end{gathered}$ | Fishing Days | Average Fishing Days/ Vessel | $\begin{gathered} \text { Landings } \\ (t) \\ \hline \end{gathered}$ | Landed Value (\$). 103 | Whole Landed Value (\$/t) | Mean CPUE <br> (1/vessel day) | $\begin{gathered} \text { Mean CPUE } \\ \text { ( } \mathrm{kg} /^{\text {diver hr) }}{ }^{5} \\ \hline \end{gathered}$ | Total Diver Hou rs ${ }^{6}$ | Average Hr/Diver Day ${ }^{7}$ | Total \# Divers | Average $\mathrm{Hr} /$ Vessel Day ${ }^{5}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\begin{aligned} & 86 / 87^{1} \\ & 86 / 87^{2} \end{aligned}$ | Permit ${ }^{4}$ |  | 2 | 4 | 2 | $\begin{gathered} n / a \\ 2 \end{gathered}$ | n/a | $n / \mathrm{a}$ | 0.5 | 169 | 14 | $n / \mathrm{a}$ | $1^{++}$ | 3.38 |
| $\begin{aligned} & 87 / 88^{1} \\ & 87 / 88^{2} \end{aligned}$ | Z |  | 29 | 290 | 10 | 212 207 | 240 | n/a | 0.71 | 170 | 1,216 | 2.96 | $51^{+4}$ | 4.57 |
| $\begin{aligned} & 88 / 89^{1} \\ & 88 / 89^{2} \end{aligned}$ | Z |  | 63 | 688 | 10.9 | 475 378 | 664 | n/a | 0.55 | 156 | 2,418 | 2.84 | $120^{++}$ | 4.67 |
| $\begin{aligned} & 89 / 90^{1} \\ & 89 / 90^{2} \end{aligned}$ | Z |  | 93 | 1095 | 11.8 | 642 484 | 1,104 | 1,719 | 0.44 | 131 | 3,691 | 2.47 | $175^{+}$ | 3.79 |
| $\begin{aligned} & 90 / 91^{1} \\ & 90 / 91^{2} \end{aligned}$ | Z |  | 51 | 923 | 18.1 | 455 353 | 977 | 2,147 | 0.38 | 107 | 3,310 | 2.7 | $109^{+}$ | 4.25 |
| $\begin{aligned} & 91 / 92^{1} \\ & 91 / 92^{2} \end{aligned}$ | Z |  | 44 | 1508 | 34.3 | 783 749 | 2,535 | 3,237 | 0.5 | 100 | 7,483 | 2.87 | 156 | 5.69 |
| $\begin{aligned} & 92 / 93^{1} \\ & 92 / 93^{2} \end{aligned}$ | Z |  | 53 | 1987 | 37.5 | 978 954 | 4,531 | 4,633 | 0.48 | 81 | 11,835 | 3.1 | $204{ }^{++}$ | 6.77 |
| $\begin{aligned} & 93 / 94^{1} \\ & 93 / 94^{2} \end{aligned}$ | 2 |  | 52 | 1267 | 24.4 | 576 533 | 3,134 | 5,440 | 0.42 | 69 | 7,667 | 2.94 | $189^{+}$ | 7.39 |
| $\begin{aligned} & 94 / 95^{1} \\ & 94 / 95^{2} \end{aligned}$ | Z |  | 42 | 673 | 16 | 224 | 1,602 | 7,153 | 0.33 | 70 | 3,161 | 2.73 | $103^{+4}$ | 5.23 |
| $\begin{aligned} & 95 / 96^{10} \\ & 95 / 96^{2} \\ & 95 / 96^{3} \end{aligned}$ | Z | 49 | $\begin{aligned} & 36 \\ & 39 \\ & 39 \end{aligned}$ | $\begin{aligned} & 597 \\ & 500 \\ & 547 \end{aligned}$ | $\begin{gathered} 16.6 \\ 12.8 \\ 14 \\ \hline \end{gathered}$ | $\begin{aligned} & 129 \\ & 157 \\ & 157 \end{aligned}$ | 888 | 6,883 | $\begin{aligned} & 0.22 \\ & 0.31 \\ & 0.29 \end{aligned}$ | 72 | 2,185 | 2.85 | $90^{+4}$ | 4.78 |
| ```from sales slip data from harvest logbooks from validation logs scientific permits were issued to 38 vessels for fall 1987 to spring 1988 fishery. 1987 landings and fishing days are from harvest logs as green sea urchins were not separated from reds on sales slips until mid-1998. Note a vessel can hold more than one licence. preliminary data. excludes records with missing fishing hours (effort) incomplete records of fishing hours (effort) for all years excludes records with missing diver identification possibly one or two more (due to sales slips with no CFV #, or missing diver codes) probably several more (due to missing diver codes)``` |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

Table 3a. Summary of green sea urchin landings (tonnes) by management area for the South Coast by fishing season (Oct. to Mar.),
1988/1989 to 1995/1996, as reported on sales slips ("preliminary data for 1993/1994 to 1995/1996; 1995/1996 data are from validation

| PACIFIC FISHERY MANAGEMENT AREAS |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| East Coast Vancouver Island |  |  |  |  |  |  |  |  |  |  |  | West Coast Vancouver Island Landings |  |  |  |  |  |  |  |
| Season | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 28 | 29 | 20 | 21 | 23 | 24 | 25 | 26 | 27 | Annual |
| 888189 | 2.8 | 93 | 171.8 | 17 | 7.4 | 0.3 | 15.4 | 53.8 | 74.5 | 15 | 9.8 | 1.5 |  | 2.5 | 9.5 |  |  |  | 474.3 |
| $89 / 90$ |  | 327.9 | 129.8 | 5.6 |  |  | 36.1 | 87.6 | 23.8 | 1.8 | 0.5 | 2.1 |  | 0.4 | 1.8 |  |  | 12.6 | 630 |
| 90/91 | 0.9 | 105.4 | 159.4 |  |  | 0.1 |  | 121.9 | 51.1 | 4 |  | 15.7 |  |  |  |  |  |  | 452.5 |
| 91/92 | 1 | 388.4 | 203.5 | 3.1 | 1.3 | 4.1 | 1 | 43 | 50.5 | 4.3 | 18.6 | 61.4 | 0.3 |  | 0.4 |  |  | 2 | 782.6 |
| 9293 | 43.4 | 645.4 | 189.6 |  |  | 1.9 |  | 18.9 | 36.2 | 1.7 | 2.6 | 36.2 |  |  |  |  |  |  | 975.9 |
| 93/94* | 1.5 | 250.9 | 102.1 | 0.9 | 1 |  | 0.8 | 28.3 | 60.7 | 0.4 | 1 | 16.2 | 3.8 |  | 0.4 | 0.4 |  |  | 468.2 |
| 94/95* | 2.3 | 93.8 | 56.5 | 1.1 |  | 0.3 |  | 16 | 16.4 |  | 0.1 | 9.4 |  |  |  |  |  |  | 195.4 |
| 95/96* |  | 61.9 | 53.8 |  |  |  | 0.4 | 13 | 18 |  |  | 5.7 |  |  | 0.2 |  |  |  | 153 |
| $\begin{gathered} \text { Total } \\ 88 / \text { tog to } \\ 95 / 96 \end{gathered}$ | 51.9 | 1966.7 | 1060.5 | 27.7 | 9.7 | 6.7 | 53.8 | 381.6 | 331.2 | 27.2 | 32.4 | 148.2 | 4.1 | 2.9 | 12.3 | 0.4 | 0 | 14.6 | 4131.9 |
| $\begin{gathered} \% \text { of } \\ \text { wosst } \\ \text { wide toalal } \end{gathered}$ | 1.2 | 45.8 | 24.7 | 0.6 | 0.2 | 0.2 | 1.3 | 8.9 | 7.7 | 0.6 | 1 | 3.5 | 0.1 | 0.1 | 0.3 | $\therefore 0.01$ | 0 | 0.4 | 95.4 |

Table 3b. Summary of green sea urchin landings (tonnes) by management area for the North Coast by fishing season (October to March),

Table 4b. Summary of green sea urchin landings (tonnes) by North Coast management areas and month for the 1995/1996 fishing season
(preliminary), as reported on validation logs.

Table 5. Green sea urchin landings reported on sales slips compared to harvest logbook records, by fishing season (October to March), 1986/1987 to 1995/1996.

|  | Sales <br> Slips <br> $(\mathrm{t})$ | Sales <br> Slips <br> $(\mathrm{lb})$ | Harvest <br> Logbooks <br> $(\mathrm{lb})$ | Logbook <br> Returns |
| :--- | ---: | ---: | ---: | ---: |
| $86 / 87$ | $\mathrm{n} / \mathrm{a}$ | $\mathrm{n} / \mathrm{a}$ | 5,220 | $\mathrm{n} / \mathrm{a}$ |
| $87 / 88$ | 212 | 467,460 | 456,952 | $97.80 \%$ |
| $88 / 89$ | 476 | $1,048,531$ | 832,625 | $79.40 \%$ |
| $89 / 90$ | 642 | $1,416,203$ | $1,067,996$ | $75.40 \%$ |
| $90 / 91$ | 455 | $1,003,330$ | 778,926 | $77.60 \%$ |
| $91 / 92$ | 783 | $1,726,356$ | $1,650,855$ | $95.60 \%$ |
| $92 / 93$ | 978 | $2,156,154$ | $2,103,210$ | $97.50 \%$ |
| $93 / 94$ | 576 | $1,269,091$ | $1,174,527$ | $92.60 \%$ |
| $94 / 95$ | 224 | 493,432 | 487,590 | $98.80 \%$ |
| $95 / 96$ | 129 | 285,112 | 346,831 | $121.70 \%$ |

Note: the above data assumes that all sales slips have been submitted annually, which may not always be the case. Sales slips landings for 1987 and 1988 are actually logs combined with a best guess from sales slips, as there was not a separate species code assigned to green sea urchins until the fall fishery in 1988.

Licence limitation was announced in 1989 for the 1991 fishery. Licence eligibility was based on landings from two of the three years 1987, 1998, and 1989. Fishers who knew they would not meet the landing criteria to get a limited licence were not inclined to submit harvest logbooks at the end of 1989 or in 1990, as they knew they could not renew their licence.

Sales slip data are preliminary for 1993/1994 to 1995/1996 (the majority of the 1996 sales slip data have not been entered into the system).

|  | Regression Parameters |  |  |  | Management Parameters |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\alpha$ | $\beta$ | $\gamma$ | $\begin{gathered} \hline \text { Model } \\ \left(r^{\prime}\right) \\ \hline \end{gathered}$ |  | $\underset{(\text { diver } h r)^{-1}}{q}$ | $\begin{aligned} & \begin{array}{c} k \\ (i) \\ \hline \end{array} \\ & \hline \end{aligned}$ | $\begin{gathered} \hline \text { MSY } \\ \text { (t) } \end{gathered}$ | $\begin{aligned} & \text { effort at MSY } \\ & \text { (diver hr) } \end{aligned}$ | $\begin{gathered} 95 \% \\ \mathrm{CI} \\ \hline \end{gathered}$ | $\begin{gathered} \text { Lower } \\ \text { MSY Limit } \end{gathered}$ | $\begin{aligned} & \text { Upper MSY } \\ & \text { Limit } \end{aligned}$ | I |
| Coastwide | $\begin{aligned} & \hline 0.754 \\ & (0.268) \end{aligned}$ | $\begin{aligned} & -3.98^{*} 10^{-3} \\ & (0.00001) \end{aligned}$ | $\begin{gathered} -0.0070 \\ (0.0025) \end{gathered}$ | 0.68 | 0.754 | $3.98 * 10^{-5}$ | 2715 | 511 | 9463 | 0.26 | 509 | 514 | 0.32 |
| p-level | 0.037 | 0.032 | 0.715 | 0.059 |  |  |  |  |  |  |  |  |  |
| South -inside Northern region (PFMA 12,13) | $\begin{gathered} 0.848 \\ (0.313) \end{gathered}$ | $\begin{aligned} & -0.0001 \\ & (0.00002) \end{aligned}$ | $\begin{aligned} & -0.0079 \\ & (0.0027 \end{aligned}$ | 0.67 | 0.848 | 0.0001 | 1073 | 228 | 4240 | 1.99 | 219 | 236 | 1.29 |
| p-level | 0.042 | 0.050 | 0.035 | 0.065 |  |  |  |  |  |  |  |  |  |
| South - inside Southern region (PFMA 17 $20,28)$ | $\begin{gathered} 0.744 \\ (0.291) \end{gathered}$ | $\begin{gathered} -0.0003 \\ (0.0001) \end{gathered}$ | $\begin{aligned} & -0.0046 \\ & (0.0025) \end{aligned}$ | 0.64 | 0.744 | 0.0003 | 540 | 100 | 1239 | 0.46 | 99 | 101 | 0.40 |
| p-cevel | 0.051 | 0.039 | 0.121 | 0.077 |  |  |  |  |  |  |  |  |  |

Table 7. Green sea urchin test diameter size frequency analysis from fishery-independent surveys conducted in PFMA 12 Subarea 18.

|  | Minimum value <br> of the objective <br> function | frequency <br> mode | mean <br> $(\mathrm{mm})$ | standard <br> deviation <br> $(\mathrm{mm})$ | proportion <br> of <br> population |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |
| Survey 1 | 86.77 | 1 | 28 | 9.4 | 0.56 |
| (October 1995) |  | 2 | 55 | 0.1 | $\ldots$ |
|  |  | 3 | 58 | 8.7 | 0.05 |
| Survey 2 |  |  |  |  | 0.39 |
| (October 1995) | 44.85 | 1 | 34 | 9.8 | 0.45 |
|  |  | 2 | 48 | 0.3 | 0.03 |
| Survey 3 |  | 3 | 60 | 6.5 | 0.52 |
| (March 1996) | 115.2 | 1 | 44 | 13.1 | 0.65 |
|  |  | 2 | 46 | 0.4 | 0.03 |
|  |  | 3 | 57 | 5.0 | 0.32 |

Table 8. Estimates of green sea urchin densities from fishery-independent surveys conducted in PFMA 12 Subarea 18 in October 1995 and March 1996.

|  | Number of <br> Quadrats | Total number of <br> green urchins | Density (number m ${ }^{-2}$ ) <br> All sizes | Legal size |
| :--- | :---: | :---: | :---: | :---: |
| Survey 1 <br> 11-16 Oct. 1995 <br> (PFMA 12-18) | 1,525 | 992 | 0.65 | 0.20 |
| Survey 1 <br> $11-16$ Oct. 1995 <br> (Stephenson Islets) | 276 | 481 |  |  |
| Survey 2 <br> 18 Oct. 1995 <br> (Stephenson Islets) |  |  | 1.74 | 0.57 |
| Survey 3 <br> 28 March 1996 <br> (Stephenson Islets) | 386 | 1,265 | 3.25 | 1.45 |

Table 9b. Calculations of quota recommendations for green sea urchins in North Coast management areas. The ranges of quotas recommended for the 1996-1997 fishing season are in boldface in the second and third rows.

|  | PACIFIC FISHERY MANAGEMENT AREA |  |  |  |  |  |  |  |  |  | Total |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | North Coast |  |  |  |  |  |  |  |  |  |  |
|  | 1 | 2E | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |  |
| MSY (t) | 1.5 | 0 | 0 | 14.8 | 0 | 1.0 | 0 | 0 | 1.5 | 0 | 18.8 |
| Precautionary reduction 0.7 * MSY | 1.1 | 0 | 0 | 10.4 | 0 | 0.7 | 0 | 0 | 1.1 | 0 | 13.3 |
| Precautionary reduction $0.5 * \mathrm{MSY}$ | 0.8 | 0 | 0 | 7.4 | 0 | 0.5 | 0 | 0 | 0.8 | 0 | 9.5 |



Fig. 1. Pacific Fishery Management Areas for the South Coast of British Columbia, with green sea urchin regions.


Fig. 2. Landings (from sales slip data), landed value and derived total effort ( $\mathrm{E}_{\mathrm{T} i}$; text equation 1) for the green urchin fishery in B.C. Data on the basis of a fishing season (October of year $i$ to March of year $i+1$ ).


Fig. 3. Box and whisker plot of coast-wide catch per unit effort (CPUE; $U_{2 i}$, text equation 3) from harvest logbook data on a fishing season basis. Vertical lines represent outliers.


Fig. 4. Coast-wide catch per unit effort (CPUE) versus fishing season, for different measures of CPUE: $\mathrm{U}_{1 i}$ (dotted line and diamonds), $\mathrm{U}_{2 i}$ (solid line and circles), $\mathrm{U}_{\mathrm{M} i}$ (dashed line and triangles). Vertical bars represent $\pm$ one standard deviation about $\mathrm{U}_{2 \mathrm{i}}$. See text for definitions of these CPUE measures.


Fig. 5. Median catch per unit effort (CPUE) $\pm 1$ standard error on a fishing season basis for four regions: (a) coastwide; (b) South Coast - inside waters northern component (PFMA 12,13); (c) South Coast - inside waters southern component (PFMA 17-20,28); and (d) North Coast (PFMA $<11$ ).


Fig. 5. (cont.)

(D) SOUTH COAST -- INSIDE WATERS, NORTH



Fig. 6. Mean minimum (hatched) and mean maximum (solid) depths fished for coastwide (a), northern region of South coast - inside waters (b) and southern region of South Coast - inside waters (c). Data are from harvest logbooks.


Fig. 7. Landings versus total effort ( $\mathrm{E}_{\mathrm{T} i}$ ) (solid line), and predicted values form the dynamic production model (crosses with dotted line) for (a) coastwide; (b) South Coast - inside waters northern component (PFMA 12,13); and (c) South Coast - inside waters southern component (PFMA 17-20,28). Model parameters are presented in Table 6.


Fig. 8. Predicted Schaefer model (text equation 8) for the dynamic production model results for the South Coast inside waters northern component (circles and dashed line) and the South Coast inside waters southern component (stars and dotted line).


Fig. 9. Test diameter frequency distribution of green sea urchins measured during fisheryindependent surveys in PFMA 12 Subarea 18 in (a) 11-16 October 1995; (b) 18 October 1995; and (c) 28 March 1996. The latter two surveys were conducted at Stephenson Islets only, within PFMA 12-18.

## APPENDIX 1. KEY ANALYSES ON A CALENDAR YEAR BASIS

Analyses in this appendix were conducted on a calendar year basis (excluding data for JanuaryFebruary 1996) and used the aggregate measure $\mathrm{U}_{1 i}$ (eq. 2) for catch per unit of effort, for comparisons with previous assessments. General fisheries data indicate the recent low landings (constrained by quotas) and the low effort on a coastwide basis (Appendix Table 1). Catch per unit of effort $\left(\mathrm{U}_{1 i}\right)$ shows an upward trend coastwide in 1995 (Appendix Table 1). This is reflected in the catch per unit of effort for the South coast - inside waters northern and southern components (Appendix Fig. 1). Landings by calendar year for each Pacific Fishery Management Area are presented in Appendix Table 2. Biomass dynamic production calculations produced adequate results (p-values close to 0.05 ) for the coast-wide and South coast - inside waters northern component models (Appendix Table 3). Estimates for k, MSY, and effort at MSY for the latter region are within $80 \%$ of the values estimated by Perry et al. (1998), although note that the current assessment included PFMA 12 and 13 only, whereas Perry et al. (1998) included PFMA 11-16. The model for the South coast - inside waters southern component was considered too poor ( $\mathrm{p}=0.258$ ) to estimate the management parameters.

## APPENDIX 2. GREEN SEA URCHIN EXPLORATORY FISHING PROTOCOL

Scientific Licence Applications are now being accepted for exploratory fishing of green sea urchins. The purpose of exploratory fishing is to obtain information about green sea urchins outside of the usual fishing areas (i.e. in areas currently closed to the commercial fishery). Information will be gained on potential fishing areas and bed sizes, and will provide an index of the unexploited stock catch rates (note that this is not the same as the densities of all-sized urchins), and some limited biological information such as size composition of the (legal-sized) catch, average weight of legalsize urchins, and some indication of roe quality of legal-size urchins.

The Exploratory Fishing Protocol to obtain the above information is as follows:

1) Only vessels with valid 1995/96 green urchin fishing licenses are eligible to apply for Scientific Licences for Exploratory Fishing of green sea urchins. Scientific Licence applications must be submitted and approved by DFO for exploratory fishing prior to going out.
2) Applications may be made for fishing only in the following Management Areas: $1,2,5,6,7,8$, $9,10,11,14,15,16,21,22,23,24,25,26,27$, and 29 . Exploratory fishing is NOT available in those Pacific Fisheries Management Areas designated as open to fishing in the 1995/96 Management Plan for green sea urchins.
3) Arrangements must be made prior to application for an Observer with proper DFO-approved training to agree to be on board and collect the required data during the exploratory fishing expedition. The application would identify the Observer and Observer's Company (acceptable to DFO ), and the approximate time (days) and locations of the exploratory fishing expedition. The actual dates and sites fished, and the catch and biological data, etc., are to be returned to DFO by the Observer upon completion of the exploratory fishing expedition.
4) All costs (e.g. of the Observer and subsequent data entry of information) are to be met by the fisher/licence holder.
5) A fishing "site" is defined to have a 1 square nautical mile area. These sites must be identified on Canadian Hydrographic Charts (or photocopies of a section(s) of Canadian Hydrographic Charts) with scales of 1:40,000 (or the closest scales available to 1:40,000) by the applicant and submitted to DFO with the Scientific Licence Application form. DFO may refuse permission for certain fishing sites, or alter these sites to better reflect the local geography. Upon licence approval, photocopies of the chart(s) with these approved fishing sites will be attached to the licence and will also be provided to the Observer. The Observer will use the chart(s) to record actual dive spots and beds within the sites, and will return them to DFO by the Observer upon completion of the exploratory fishing expedition.
6) For any given site, a maximum of 1 boat with a maximum of 2 divers is permitted. The boat must have a DFO-approved Observer on board at all times once the fishing commences and until the product in landed. The maximum fishing time for a vessel in any one site is 8 hours. All time in the water by a diver is to be recorded by the Observer as fishing time - i.e. if
someone is in the water in a particular site, that is considered as "fishing" in that site and the above restrictions and the duties of the Observer apply. Once the fishing time limit for a site has been reached, fishing at that site must cease. Exploratory fishing could then move to another fishing site. Note: the fishing time limit in any site is cumulative, and not necessarily contiguous (i.e. fishing could be conducted in several sites over several days, as long as the total time in any one site does not exceed 8 hours). However, divers are restricted to one site per dive (i.e. the divers must come to the surface, place their catch on board the vessel, and report all pertinent dive information to the Observer before moving into another site).
7) The usual "Hail in/Hail out" requirements for daily fishing activities pertaiin.
8) Once a particular site has been fished, it will be close to all fishing for the remainder of the licence year.
9) The usual 55 mm test diameter size limit applies to all fishing.
10) Catch must be validated upon landing in the usual manner.
11) Duties of the Observer. Observers will require training as to the specific objectives of the exploratory fishing protocol, and the appropriate data requirements. The Observers will ensure that the exploratory fishing regulations are followed (specifically with respect to limiting fishing at any one site and moving to another site). In addition, the Observers will record for each site information on: fishing times for each diver; actual time spent harvesting; weight of catch for each dive; the dive and bed locations (marked on the site chart); maximum depth fished; bottom substrate and vegetation type; the number of urchins in every fifth cage and the weight of that cage; and test diameters of randomly selected urchins (for a total of about 200 urchins per "location". Additionally, the Observer will randomly select 2 urchins per cage and record roe colour and gonad size.

Observers (or the contracting company) will provide copies of the data (including the approved 'site' charts) to DFO within 5 working days upon completion of the exploratory fishing expedition, and the data in electronic format within one month of completion of the exploratory fishing expedition.
Appendix Table 1. Green sea urchin landings (tonnes) and effort for British Columbia, by calendar year, 1987 to 1996, as reported on fish
slips and harvest logbooks.

| Year | Licence Type | $\begin{aligned} & \text { \# of } \\ & \text { Licences } \\ & \text { Issued } \end{aligned}$ |  | Fishing Days | Average Fishing Days/ Vessel | Landings $(t)$ | Landed Value (\$). 103 | Whole Landed Value (\$/t) | Mean CPUE <br> ( $/$ vessel day) | Mean CPUE $(\mathrm{kg})$ $\text { diver } h r)^{3}$ | Total Diver Hours ${ }^{6}$ | Average Hr/Diver Day ${ }^{7}$ | Total <br> \# <br> Divers | Average $\mathrm{Hr} /$ Vessel Day ${ }^{5}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $1987{ }^{1}$ | Permit ${ }^{\text {a }}$ | 38 | 20 | 248 | 12.4 | 120 | 127 | 1058 | 0.48 |  |  |  |  |  |
| $1987{ }^{2}$ |  |  | 22 | 175 | 8 | 126 |  |  | 0.72 | 170 | 689 | 2.96 | $28^{++}$ | 4.2 |
| $1988{ }^{1}$ | Z | 89 | 68 | 690 | 10.1 | 444 | 584 | 1315 |  |  |  |  |  |  |
| $1988{ }^{2}$ |  |  | 62 | 634 | 10.2 | 378 |  |  | $0.6$ | 120 | 2,540 | 2.9 | $122^{+4}$ | 4.81 |
| $1989{ }^{\text {1 }}$ | Z | 191 | $110^{+}$ | 1394 | 12.7 | 611 | 1020 | 1669 | 0.44 |  |  |  |  |  |
| $1989{ }^{\text {² }}$ |  |  | 96 | 930 | 9.7 | 428 |  |  | 0.46 | 119 | 2,945 | 2.56 | $152^{++}$ | 3.91 |
| $1990^{1}$ | Z | 155 | $90^{+}$ | 1352 | 15 | 475 | 939 | 1977 | 0.35 |  |  |  |  |  |
| $1990^{2 *}$ |  |  | 65 | 1029 | 15.8 | 384 |  |  | 0.37 | 93 | 3,568 | 2.55 | $158{ }^{+}$ | 3.92 |
| $1991{ }^{1}$ | Z | 47 | $47^{+}$ | 1348 | 28.7 | 607 | 1796 | 2957 | 0.45 |  |  |  |  |  |
| $1991^{2 *}$ |  |  | $42^{+}$ | 12.3 | 28.9 | 558 |  |  | 0.46 | 85 | 5,654 | 2.86 | $131^{+}$ | 5.36 |
| $1992{ }^{1}$ | Z | 49 | $49^{+}$ | 2096 | 42.8 | 1042 | 4427 | 4246 | 0.5 |  |  |  |  |  |
| 1992 ${ }^{\text {2* }}$ |  |  | 49 | 1998 | 40.8 |  |  |  | 0.51 | 75 | 11,538 | 3.03 | 198 | 6.66 |
| $1993{ }^{\text { }}$ | Z | 49 | $53^{+}$ | 1631 | 30.8 | 714 | 3777 | 5290 | 0.44 |  |  |  |  |  |
| $1993{ }^{2 *}$ |  |  | 52 | 1503 | 28.9 | 663 |  |  | 0.44 | 61 | 9,083 | 2.99 | $211^{++}$ | 7.15 |
| $1994{ }^{1 *}$ | Z | 49 | $46^{+}$ | 969 | 21.1 | 332 | 2122 | 6392 |  |  |  |  |  |  |
| $1994{ }^{2}$ |  |  | 47 | 951 | 20.2 | 328 |  |  | $0.35$ | 59 | 4,771 | 2.82 | $149^{++}$ | 5.77 |
| $1995{ }^{10}$ | Z | 49 | 30 | 326 | 10.9 | 76 | 567 | 7455 | 0.23 |  |  |  |  |  |
| $1995{ }^{2}$ |  |  | 33 | 269 | 8.2 | 88 |  |  | 0.33 | 73 | 1,102 | 2.67 | $69^{++}$ |  |
| $1995{ }^{3}$ |  |  | 33 | 291 | 8.8 | 87 |  |  | 0.3 | 7 | 1,102 | 2.67 | 69 | 4.53 |
| $1996{ }^{10}$ | Z | 49 | 23 | 271 | 11.8 | 53 | 321 | 6027 | 0.2 |  |  |  |  |  |
| $1996{ }^{2}$ |  |  | 28 | 231 | 8.3 | 69 |  |  | 0.3 | 59 | 1,083 | 3.06 | 55*+ |  |
| $1996{ }^{3}$ |  |  | 28 | 256 | 9.1 | 70 |  |  | 0.27 |  | 1,083 | 3.06 | 55 | 5.06 |

[^1]scientific permits were issued to 38 vessels for fall 1987 to spring 1988 fishery. 1987 landings and fishing days are from harvest logbooks as green sea urchins were not separated from reds on sales slips until mid-1998.
preliminary data. Also note that 1996 only includes data for Jan to May preliminary data. Also note that 1996 only includes data for Jan. to May.
excludes records with missing fishing hours (effort)
incomplete records of fishing hours (effort) for all years

+ possibly one or two more (due to sales slips with no CFV \#, or missing diver codes)
probably several more (due to missing diver codes)
Appendix Table 2a. Summary of green sea urchin landings (t) by Management Area for the South Coast, 1987 to 1994, as reported on
sales slips ("preliminary data for 1994).


Appendix Table 2b. Summary of green sea urchin landings (t) by Management Area for the North Coast, 1987 to 1994, as reported on sales slips $\left(^{*}=\right.$ preliminary data for 1994)

| Year | PACIFIC FISHERY MANAGEMENT AREAS |  |  |  |  |  |  |  |  |  | Annual Landings |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1 | 2 E | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |  |
| 1987 |  |  |  |  |  |  |  |  |  |  | 0 |
| 1988 |  | 0.4 |  |  |  |  |  |  |  | 0.4 | 1 |
| 1989 | 12.3 |  |  |  |  | 0.7 |  |  |  |  | 13 |
| 1990 |  |  |  |  |  |  |  |  |  |  | 0 |
| 1991 | 0.4 |  |  |  |  | 3 |  |  |  |  | 3 |
| 1992 |  |  |  |  |  |  |  |  | 1.7 |  | 2 |
| 1993 |  |  |  | 71 | 1 | 4 |  |  | 9 | 0.1 | 85 |
| 1994* |  |  |  | 48 |  |  |  |  | 0.9 |  | 49 |
| $\begin{gathered} 1987 \text { to } \\ 1994 \end{gathered}$ | 13 | 0 | 0 | 119 | 1 | 7 | 0 | 0 | 12 | 1 | 153 |

Appendix Table 3. Dynamic production model estimates for the parameters $\alpha, \beta, \gamma$ and their standard errors (in brackets) for the regression of equation 6 , on a calendar year basis and using $\mathrm{U}_{1 i}$ as the CPUE estimate. Regression coefficients ( $\mathrm{r}^{2}$ ), probability levels ( p -values), and calculation from these parameters of the values of $\mathrm{r}, \mathrm{q}$, and k are as described in the text. Management parameters MSY (maximum sustainable yield) and effort at MSY are calculated as described in the text.

|  | Regression Parameters |  |  |  |  |  | Management Parameters |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\alpha$ | $\beta$ | $\gamma$ | Model ( $r^{2}$ ) | $\begin{gathered} \mathbf{r} \\ (\mathrm{yr})^{-1} \end{gathered}$ | $\begin{gathered} \mathrm{q} \\ (\text { diver } \mathrm{hr})^{-1} \end{gathered}$ | k <br> (t) | $\begin{gathered} \text { MSY } \\ \ldots(t) \\ \hline \end{gathered}$ | effort at MSY <br> (diver hr ) |
| Coastwide | $\begin{gathered} 0.772 \\ (0.304) \end{gathered}$ | $\begin{aligned} & -0.00005 \\ & (0.00002) \end{aligned}$ | $\begin{gathered} -0.0051 \\ (0.0019) \end{gathered}$ | 0.62 | 0.772 | 0.00005 | 2804 | 524 | 7218 |
| p-level | 0.052 | 0.054 | 0.044 | 0.088 |  |  |  |  |  |
| South -inside Northern region (PFMA 12,13 ) | $\begin{gathered} 0.821 \\ (0.280) \end{gathered}$ | $\begin{aligned} & -0.00008 \\ & (0.00003) \end{aligned}$ | $\begin{aligned} & -0.0054 \\ & (0.0016) \end{aligned}$ | 0.71 | 0.821 | 0.00008 | 1874 | 220 | 5065 |
| p-level | 0.033 | 0.044 | 0.020 | 0.047 |  |  |  |  |  |
| Soth - inside <br> Southern region (PFMA 17-20,28) | $\begin{gathered} 0.864 \\ (0.531) \end{gathered}$ | $\begin{aligned} & -0.0005 \\ & (0.0002) \end{aligned}$ | $\begin{aligned} & -0.003 \\ & (0.003) \end{aligned}$ | 0.42 |  |  |  |  |  |
| p-level | 0.165 | 0.119 | 0.315 | 0.258 |  |  |  |  |  |



Appendix Fig. 1. Catch per unit effort ( $\mathrm{U}_{1 \mathrm{i}}$, text equation 2) on a calendar year basis for the South Coast - inside waters northern component (PFMA 12,13) (circles and solid line) and South Coast inside waters southern component (PFMA 17-20,28) (diamonds and dotted lne).

# Scientific Advice for Management of the Sea Cucumber (Parastichopus californicus) Fishery in British Columbia 

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#### Abstract

Boutillier, J.A., A. Campbell, R. Harbo and S. Neifer. 1998. Scientific advice for management of the sea cucumber (Parastichopus californicus) fishery in British Columbia. p. 309340. In: G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1996. Can. Tech. Rep. Fish. Aquat. Sci. 2221.


The present fishery on giant red sea cucumber (Parastichopus californicus) populations in British Columbia is not providing the necessary information to allow assessment and evaluation of the impacts (if any) that exploitation is having on these stocks and their ecosystems. Continuation of this situation may seriously hamper the conservation and sustainable exploitation of this species. This paper suggests a theoretical management approach based on all known published information on P. californicus. Estimates of initial biomass are derived by measuring shoreline lengths, applying a conservative estimate (previously estimated in Alaska) of sea cucumber density per meter of shoreline and calculating the biomass using fishery related measures of local mean weights of sea cucumbers. Several theoretical exploitation rates (7.4\%, $6.4 \%, 4.2 \%$ ) are presented and the estimates of quotas using the most conservative level (i.e. $4.2 \%$ ) are discussed in relation to development of an action plan for the fishery within the present IVQ system.

The next Phase of a management approach for this fishery would be to conduct the fishery in a manner which allows testing of the validity of theoretical management assumptions. This would include collection of fishery-dependent and fishery-independent data to test and refine initial theoretical model parameters and associated uncertainties. The program could include:

1) Identifying and establishing non-contiguous commercial fishing areas which are to be fished on an annual basis at a conservative sustainable level (quotas should be based on the smallest spatial scale practical, i.e., the statistical subarea level). Using the most conservative density and exploitation estimates, the actual area required to be fished and maintain the overall arbitrary quota at it's present level is only $25 \%$ of the total B.C. coastline. There should be no change in the present quota until there is sufficient information to indicate if theoretical parameter estimates are too high or too low.
2) Identifying and establishing experimental management areas (EMA) where different exploitation levels are applied on an annual basis.
3) Identifying and establishing closed reference areas to act as "controls" to compare population dynamic responses with fished areas and determine their potential as refugia for brood stock protection.
4) Identifying test fishing assessment areas. These areas would be about 100 m of shoreline randomly placed within a statistical subarea. The number of test fishing sites would depend on the size of the subarea and the estimated between-site variances. Sea cucumbers from each site would be counted, weighted, sampled for sexual maturity, removed and sold to pay for test fishing and sample collection. Optimal size, number and placement of test fishery assessment areas will need to be determined after some preliminary data is collected which provides estimates of expected variances of cucumber density. Initial information could be collected prior to the 1996 fishery, if a voluntary transect assessment program can be arranged.
5) Conduct annual fishery-independent surveys to determine biomass in identified areas for:
a) modifying quota calculations, i.e., improving estimates of cucumber density; and
b) evaluating effects of various exploitation rates in the EMAs, including zero exploitation reference areas.

## INTRODUCTION

## Problem

At present, the fishery in British Columbia (B.C.) on giant red sea cucumber (Parastichopus californicus) populations is not providing the necessary information to allow assessment and evaluation of the impacts that exploitation is having on the stocks and their ecosystems. This means that it is not possible to answer the fundamental questions that every fishery poses and which need to be addressed to insure conservation of the species and sustainability of the industry.

This PSARC paper was prepared at the request of managers to discuss options for a data collection system that would allow assessment of $P$. californicus populations and provide the information necessary to address fundamental questions of conservation and sustainability of a sea cucumber fishery in B.C.

## Background

In absence of biological data, the fishery for giant red sea cucumber in B.C. has historically been managed using arbitrary quotas, license limitations and restrictions on opening times. In 1995, the Individual Quota (IQ) system was introduced, as a more acceptable means of controlling the fishery. In the fall of 1995, the first review of catch data was undertaken by Phillips and

Boutillier (1998) and presented with a series of recommendations which were subsequently accepted by PSARC. Those recommendations were:

1) The assessment database needed to be redesigned and corrected where possible. The collection of new data should be concentrated on obtaining good information on: effort (diver ID and dive time), location (bed code information from maps) and counts of catch. Weight data should be treated with caution. Information on changing growth rates within an area would have to be collected through a biological port sampling program.
2) Quota management should be on a much finer scale than the large areas use historically (i.e. Central Coast, West Coast Vancouver Island, etc.). Until it is known what constitutes a stock (in terms of recruitment overfishing), managing on a small spatial scale would be safest option. A statistical area should be the largest quota area.
3) One management objective should be to manage the fishery in a manner which will provide data that can be used to evaluate impacts of the fishery. With the lack of biological information about sea cucumbers, use of biomass dynamic models will be the only tool available to evaluate the stock status. For this kind of model to work properly, there must be consistent fisheries data without gaps created by 2-3 year rotational fishery management strategies.
4) Biological data on this species will be hard to come by. In addition to the wild fishery as a source of this data, it is appropriate to review data from other new ventures, such as aquaculture outgrowing experiments. Data reporting should be a condition of aquaculture venture permits in the same way that the logbook catch and effort data is a requirement applied to the commercial fishery.
5) Fisheries and Oceans Canada (DFO) and Industry must work together to collect the most useful data possible for management of this fishery. If fishers continue to supply incorrect or incomplete data then it will be necessary to withhold licensing approval until accurate and timely data are provided.

The response to these recommendations within DFO has been:

1) A catch validation/port sampling program for the IQ fishery is now collecting information on mean weight and product form of the landed catch. A summary of the first year's information are presented by Rome and Clarke (unpublished manuscript). Correction of bed area and landing form data is ongoing.
2) Quotas options for statistical subareas have been provided to managers in preparation for the 1996 fishing year.
3) To date the recommendation of fixed fishing areas for consistent CPUE measurements has not been acted upon. Managers concerns regarding implications of this recommendation and how it would fit into overall management of the fishery are discussed in this paper.
4) Reports are being provided by aquaculture ventures as a condition of B.C. Science Council grants, but these reports provide little or no biological information.
5) DFO has set up a research committee with industry and aboriginal participation. The purpose of this research committee is to clearly define biological questions facing the industry, share information and develop approaches to address priority questions. Timeliness of logbook information is still a problem. In 1996, industry will be supplying this information through a port validation program at the time of landing.

## Approach to Addressing the Problem

The objectives of this paper are:

1) to discuss information and options available to DFO and stakeholders in context of the framework outlined by Perry (1998); and
2) to recommend options to resolve problems as stated above.

Perry (1998) outlined a process for dealing with new and developing invertebrate fisheries where data was limited or non-existent by using a three phase approach: Phase (0): Collection of existing information; Phase (1): Fishing for information and; Phase (3): Fishing for commerce.

## PHASE 0

The following information was summarized from a literature review conducted by Phillips and Boutillier (1998) and results of discussions at the first DFO/Stakeholder Sea Cucumber Research Committee meeting, in summer 1996.

## BASIC BIOLOGICAL INFORMATION

## Size of Population (Current; Virgin)

There is limited information about current or virgin biomass of sea cucumber populations on the B.C. coast. Since the inception of the fishery, only mandatory logbook information has been collected in a systematic way. The only fishery independent survey information available is from a survey conducted in the Kitasoo Territory, Central Coast B.C. during 1993-1994 (Campbell and Cripps, in prep.).

To obtain estimates of current abundance, there are generally two approaches used:

1) fishery-dependent data from which estimates of abundance are obtained through modeling catch and catch per unit effort; or
2) fishery-independent survey data that either provide absolute estimates of abundance or relative estimates of abundance, which, when combined with total removals, give estimates of pre-fishery abundance.

These techniques have been utilized to varying degrees of success for the giant red cucumber in at least four programs: B.C. fishery logbook analysis (Phillips and Boutillier 1998); a sea cucumber survey performed in the Kitasoo Territory (Campbell and Cripps, in prep.); Washington State biomass surveys; and Washington State logbooks (Bradbury et al., in press).

Biomass estimates and quotas were calculated for the B.C. fishery from logbook information by Phillips and Boutillier (1998). The estimates, however, were qualified and were not used because of a number of known problems with logbook and area calculations which included:

1) Some very obvious fishing bed area calculation problems. For example Area 17 has reported landings of cucumbers but since the locations of the fishing activity was not provided by the fishers, the bed size is reported as zero hectares (ha).
2) Heizer and Thomas (1997) suggested that some fishers stock-piled sea cucumbers prior to the fishery, to get a larger share of the fixed quota. This activity would bias the CPUE upward and make population estimates too high.
3) Occasionally, sea cucumbers are reported to form dense aggregates that are readily available to the dive fishery. Interviews with fishers indicate that areas of high sea cucumber abundance are scouted during other fisheries and areas of highest concentration are then exploited during the sea cucumber fishery. This unaccounted-for search time, and the fact that fishers seldom go back to the same areas, keeps CPUE high for a long period of time. This, in turn, will lead to an overestimation of maximum sustained yield (MSY) and biomass. Management over a very large area and progressive mining of the stocks leads to a condition known as hyperstability of the CPUE. A thorough discussion of this condition and it's implications is presented by Hilborn and Walters (1992).

Biomass estimates of known cucumber beds have been calculated using fishery-independent transect dive surveys in the Central Coast of B.C. Four areas were looked at using transect surveys. Mean cucumbers/m of coastline varied from 9.8 to 19.0 (Campbell and Cripps, in prep.). This was in the range of the S.E. Alaskan estimates (Larson et al. 1995).

Washington State (Bradbury et al., in press) also has a series of biomass estimation procedures using diver transects, video transects, and logbook analysis. Fishing seasons were long enough in some areas and in some years that a Leslie depletion model could be fit to logbook data to estimate the initial biomass in the area. In the video and diver transect surveys the density of animals (i.e. cucumbers $/ \mathrm{m}^{2}$ ) was multiplied by the total area of the type of strata (i.e. soft vs. hard and shallow ( $<60$ feet) vs. deep ( $>60$ feet and $<120$ feet)). These densities were either multiplied by the estimated area to give an absolute abundance estimate, or pre- and post-fishery surveys were compared to total removals to estimate total biomass.

In terms of estimation of virgin biomass, the only program measuring relative densities of virgin biomass of sea cucumbers is a series of biomass surveys that the Alaska Department of Fish and Game (ADF\&G) are conducting prior to any fishery taking place (Larson et al. 1995). The surveys consist of transects run at 4 km intervals perpendicular to shore, to a depth of 18 m . The resulting estimate of number of cucumbers $/ \mathrm{m}$ of coastline is then multiplied by coastline length of the harvest area to yield a biomass estimate. The lower $90 \%$ confidence limit (CL) of the density estimate is used for calculation of the estimated virgin biomass. Larson et al. (1995) summarized the 1993 surveys of S.E. Alaska in which fifteen separate fishery areas were surveyed. Estimates of mean number of cucumbers $/ \mathrm{m}$ of coastline from these surveys ranged from 3.5 to 20.2 with an average of 9.7 , while the lower $90 \%$ CL ranged from. 2.5 to 13.5 with an average of 7.1.

## Distribution: Space and Time

Information on the distribution of sea cucumbers was compiled from the literature (Phillips and Boutillier 1998) and through anecdotal comments from members of the research committee. Information discussed from these two sources included: geographic extent; aggregated or solitary; extent of patchiness; annual and seasonal migrations; mobility; and availability.

1) Geographic extent: P. californicus is generally considered ubiquitous. This sea cucumber is a holothurian echinoderm found subtidally to at least 90 m . This species is known to range from California to Alaska (Sloan 1986).
2) Aggregated or solitary: According to members of the research committee, $P$. californicus can be either solitary or aggregated.
3) Extent of patchiness. Some concentrations can be fairly extensive, although the exact size of these patches has not been documented.
4) Annual and seasonal migrations: Little is known about migratory patterns of this sea cucumber, and there appears to be some differences in opinion on this matter. Bradbury (Washington Dept. of Fish and Wildlife, pers. comm.) noted seasonal differences in the abundance indices from some of fishery independent surveys. Whether this is due to migration between areas or between depths is unknown. Fankboner (Simon Fraser University, pers. comm.) has conducted a number of similar studies on this species, but has not observed this phenomenon. Generally, the research committee felt that there may be seasonal differences in distribution but that these were very area specific. The research committee provided anecdotal information on areas that were fished in one year and showed little or no immigration the following year, and on areas that appeared to have good immigration between years. There was also a belief that some areas exhibit annual migration into shallow water during spawning season.
5) Mobility: Sea cucumbers are generally not very mobile. Locomotion along the bottom is achieved by body contractions with the aid of tube feet. Swimming behavior has been observed (Cameron and Fankboner 1989) where non-directional undulatory movement
produced by rapid contractions of longitudinal muscles causes the animal to rise into the water column. This is probably a predator avoidance response. There are no confirmed reports of this method being used to travel, although sustained swimming assisted by tide could in theory result in fairly rapid transportation.
6) Availability: If visibility is good and algal cover sparse, the research committee felt that virtually all cucumbers are removed from a given location in one pass. Most individuals in a fishable population are about the same size and there is little or no size selection occurring during the fishing process. Juveniles do not seem to occupy the same habitats as adults.

All these attributes tend to increase the likelihood of localized overfishing. Since there is no information on stock structure and dynamics, there is danger that what might be perceived as localized overfishing may in fact be systematic recruitment overfishing of discrete stocks.

## Preferred Habitats

Sea cucumbers are benthic detritus feeders tending to favor cobble, sand or mud bottoms with relatively low current velocities.

## Reproductive Characteristics

Spawning occurs from late spring through the summer. Gametes are released into the water and fertilization occurs externally. The resulting gastrula develops within several days into a feeding auricularia larva, which remains planktonic between 65 and 125 days (McEuen 1987). This protracted larval stage presumably optimizes dispersion to favorable habitats, and may decrease the probability of small, discrete stocks. The pelagic larval stage is followed by a brief transitional stage, the doliolaria, and finally benthic settlement of the juvenile stage, the pentactual larva.

The benthic pentactual larva, although morphologically similar to the adult, is approximately 0.25 mm long. It consists of a body with one tube foot (pedicle) and 5 buccal tentacles (Cameron and Fankboner 1986). After one year of growth, juveniles attain a size between 5 and 15 mm . At the end of 2 years they are between 4 and 10 cm in length. Juveniles less than 1 year old or 1 cm in length are rarely observed in adult habitats and are seldom encountered by divers (Cameron and Fankboner 1986).

## Productivity Characteristics (Growth, Natural Mortality and Size/Age)

Most information on the productivity of $P$. californicus populations is speculative. This is due mainly to the impossibility of aging and the difficulties of measuring, individuals in the conventional sense. In addition, P. californicus has some interesting and unusual biological characteristics which confound procedures for estimating biological productivity parameters.
P. californicus undergo annual fluctuations in body mass due to their tendency to resorb visceral organs during the winter and regenerate them throughout the spring and summer. They are also
known to eviscerate internal organs as a defensive tactic. Skin thickness reportedly varies throughout the year, becoming thicker during the winter months.

Because cucumbers cannot be aged, information on age at sexual maturity is circumstantial. Likewise, the age structure of an adult population cannot be determined although all individuals tend to be the same size at a given location. Growth rates, derived from settlement of larvae on mussel culture strings near Tofino, have enabled assignment of ages through modal analysis of length frequency data of juvenile sea cucumbers, to a maximum of 3 years (P. Fankboner, Simon Fraser University, pers. comm.). However, age determinations of individuals after 3 years have not been successful due to lack of contrast in the length frequency data and the lack of tag retention over long periods of time (A. Bradbury, Washington Dept. of Fish and Wildlife; P. Fankboner, Simon Fraser University; pers. comm.). Age of recruitment to the fishery is unknown, although since only 3 year classes can be distinguished, the animals probably enter the fishery in their 4th year. This may vary considerably throughout the geographic range of the species. Until we have data that distinguishes between year classes, and documents where these year classes are distributed, there is no way of knowing for sure. Mortality rate, longevity and maximum age are all unknown. The only published material on maximum age for P. californicus in B.C. waters was a communication from Fankboner, cited in Imamura and Kruse (1990), estimating maximum age to be 12 years. The Alaskan surplus production model assumes a maximum age of 14 years (Woodby et al. 1993).

Aging and tagging sea cucumbers has proven to be very difficult, therefore the estimate of natural mortality rate ( $M$ ) used in Alaska and British Columbia comes from Hoenig's (1983) relationship between the logarithms of maximum age and instantaneous mortality rates:

$$
\begin{equation*}
\ln (M)=1.44-0.982 \ln \left(t_{\max }\right) \tag{1}
\end{equation*}
$$

where $t_{\max }$ is the maximum age in years. Using $t_{\max }=12$, this gives an estimate of natural mortality for sea cucumbers in British Columbia of 0.37 . Caution should be exercised when using this estimate of $M$ because of the great uncertainty surrounding the maximum age of these animals.

## Theoretical Management Quota Estimation

From the preceding discussion, it is evident that there are clearly a number of unknowns that need to be addressed before we can begin to understand the dynamics of sea cucumber population response to various levels of exploitation. However, there is enough information available to prepare a conservative approach to the management of this fishery. From conservative estimates of virgin biomass and exploitation rate, we can prepare a baseline (reference) quota. With this quota, we are then able to propose a framework for collection of needed data within the Phase 1 component of the fishery.

## Estimating Virgin Biomass

An estimate of virgin biomass ( $B_{0}$ ) can be obtained by multiplying an estimated coastwide virgin density $\left(D_{o}\right)$ by the estimated length of shoreline $(S)$ to be harvested.

The estimated shoreline length, expressed in meters ( m ), is used rather than some calculated bed area from the logbooks because incomplete logbook data makes bed area calculations unreliable (only a few logbooks provided sufficient bed area information). The shoreline method is also easier to extrapolate from charts than bed area estimates. This is because of the difficulty of trying to define preferred habitat or bed for sea cucumbers. As discussed previously, sea cucumbers occupy various substrate types, and commercial depth ranges are difficult to determine from charts. This is particularly true in steep sloped areas, such as fjords, where depth contours are not well defined on charts.

## Density Estimation

As an initial step, we have adopted density estimates from surveys of the same species over large areas in close proximity to B.C. In this case, the only large scale survey information available on P. californicus virgin densities is from S.E. Alaska. The Alaskans conducted a series of eleven independent surveys over large areas throughout S.E. Alaska. They calculated virgin biomass by multiplying total shoreline length of the surveyed area by the lower $90 \% \mathrm{CL}$ of the density estimate (Woodby et al. 1993). To estimate virgin biomass in B.C. waters, we must first decide on an appropriate low-risk measure of virgin density. There are a number of options from the Alaskan survey results that may be considered appropriate, however, each option would have varying degrees of risk associated with it. Examples of two such options are:

The minimum of all lower $90 \%$ CL estimates from all surveys was 2.5 cucumbers $/ \mathrm{m}$ of shoreline. If this value were used in Alaska, it would reduce the biomass used in all but $8 \%$ of the areas surveyed. For B.C. waters this estimate would probably be the most risk averse.

The mean of all lower $90 \%$ CL estimates from all surveys was 7.1 cucumbers $/ \mathrm{m}$ of shoreline. If this value had been used in Alaska, their biomass estimates would have been higher in $77 \%$ of the areas. This value is also higher than the average number of cucumbers found in $46 \%$ of the areas surveyed. In a worst-case scenario, this would have produced a biomass estimate 2.8 times greater than the biomass estimate used in their precautionary approach.

In the present paper, we adopt option 1 as the most conservative approach, and use 2.5 sea cucumbers per meter of shoreline as an initial virgin density estimate for calculating quotas. This value is lower than the lowest $95 \%$ CL estimate ( 8 cucumbers $/ \mathrm{m}$ of shoreline) found in the Central Coast surveys (Campbell and Cripps, in prep.), however those surveys were conducted in a much smaller area where cucumbers were known to be abundant.

## Shoreline Length Estimation

Shoreline length measurements were calculated from a CompuGrid (1996) seamless GIS basemap of the B.C. coastline digitized in 1994. Calculations were conducted by statistical area, subarea and bed code. As this was a raster basemap, the following procedure was involved:

1) Select the coordinates for the area of interest and raster an image at the desired resolution:
2) Use the edge algorithm to place a boundary on the shoreline;
3) Count the number of cells (using the crosstab tool and a file of statistical subareas) that make up the shoreline;
4) Multiply the number of cells by the cell resolution of 20 m and a factor of 0.84 to correct for the overestimation inherent in the edge algorithm.

Caution should be used in interpreting estimated shoreline lengths since the values may differ depending on the scale of the digitized charts and the different scales used in the cell resolution. A fine resolution of 20 m could inflate the shoreline estimate by $1-8 \%$ compared to using a 100 m cell resolution depending on the complexity of the shoreline.

## Estimating Exploitation and Natural Mortality Rates

A theoretical production or conservative exploitation rate estimate for P. californicus was obtained from the literature for regions close to the proposed fishing areas. Again there were a number of options that could be considered.

Washington State suggests an exploitation rate of $4.2 \%$ of the unfished population. This estimate is calculated from a Schaeffer model (see Model Selection below) using one fishing area that had a relatively good data series.

Alaska suggests an exploitation rate of $6.4 \%$ of the unfished population. This is calculated using a Gulland model (see Model Selection below), where $X=0.2$ and $M$, the natural mortality ( 0.32 ), was calculated using Hoenig's model assuming that the maximum age was 14 years and $B_{0}$ is calculated from their survey results.

The third option, outlined in Phillips and Boutillier (1998), used the model described in Alaska (see 2 above) but assumed a maximum age of 12 years. In this instance the exploitation rate would be $7.4 \%$.

We use only the most conservative (4.2\%) estimate of exploitation in the quota calculations in Table 1.

## Quota Calculations

Theoretical quotas (Table 1) were calculated as:

$$
\begin{equation*}
\text { Quota }=E\left(D_{0}\right)\left(S_{i}\right)\left(W_{i}\right) \tag{2}
\end{equation*}
$$

where $E$ is the selected exploitation rate ( $4.2 \%$ ), $D_{0}$ is the virgin density (which for this exercise is the minimum lower $90 \% \mathrm{CL}$ of estimated virgin density from Alaskan surveys, i.e., $D_{0}=2.5$ cucumbers $/ \mathrm{m}$ ), $S_{i}$ is the length of shoreline for statistical area $i$, and $W_{i}$ is the average split weight conversion factor for statistical area $i$ (from Rome and Clarke's unpublished review of the 1995 B.C. sea cucumber fishery).

## PHASE 1

The objective of Phase 1 is to conduct the fishery in a manner which either proves or disproves the theoretical management system. That is, a framework must be in place to collect data which allows for the testing and refinement of the hypothetical management system and associated uncertainties. The main factors to be considered, evaluated and refined in the Phase 1 implementation are: improvement of estimates of abundance; testing the appropriateness of exploitation rates; and examining the suitability of alternative production models.

## Present IQ System and Proposed Theoretical Management System

Implementation of a Phase 1 fishery that provides useful fishery-dependent data, but is minimally disruptive to present industry, would require: continued use of the present IQ system; continued use of the present arbitrary quota; and establishment of static commercial fishing areas to be fished on an annual basis. If the present arbitrary quotas were taken from relatively the same proportion and mix of major areas (i.e. Central Coast, Queen Charlotte Islands, etc.) that has been fished historically, then under the proposed theoretical management system, the total area of coast that would be fished, using the most conservative density and exploitation estimates, would include no more than $25 \%$ of the total calculated B.C. shoreline ( $30,673 \mathrm{~km}$ ). The quota would remain unchanged in these areas until data from the Phase 1 fishery indicate otherwise.

## Calculation of $\mathbf{B}_{\mathbf{0}}$

The present calculation of virgin biomass is based on the assumption that the estimated mean density over the entire coastline is 2.5 cucumbers $/ \mathrm{m}$ of coastline. There are several ways to verify or improve on this initial density estimate.

## Fishery-Independent Transect Surveys

Conduct annual fishery-independent surveys to determine biomass in identified areas through:

1) Large scale "broad-brush" transect surveys: These would be conducted for each identified Statistical Subarea to provide index biomass estimates. Ideally these surveys should be conducted before and after fishing to allow for depletion estimates of biomass for the area. If conducted in the same manner as Alaska Department of Fish and Game then this survey would consist of 2 m wide transects run perpendicular to shore to a depth of 18 m ( 20 m depth in B.C.), using a random starting point along the shoreline to be fished. From the random starting point, a systematic survey is then conducted at 20 and $4,000 \mathrm{~m}$ intervals over the entire length of the survey area.
2) Intensive transect surveys to estimate absolute biomass: These should be conducted in special areas such as those fished under experimental management protocols and "reference non-fishing" control areas. These intensive surveys are similar to the broad-brush surveys except that the number of transects would be greater and they would be located randomly in the areas. This increased precision is required to detect differences between areas fished with exploitation rates which differ by as little as $4 \%$.

## Test Fisheries

This protocol is similar to the transect surveys with the exception that transect width would be much larger, e.g., 100 m of shoreline, and the animals would be removed and sold to pay for the costs of the survey. Test fishery sampling areas would be located randomly within a Statistical Subarea. Fishers conducting the test fishery will be requested to remove all sea cucumbers from the test area. The optimal size, number, and placement of these "test fishery" sampling areas would have to be determined through variance estimates of transect surveys and discussions with fishers on logistic costs of sampling. Transect surveys may be conducted prior to the 1996 fishery by volunteer fishers, which would provide some initial variance estimates.

There would be advantages and disadvantages with the test fishery protocol. Elliott (1979) reviewed the dimensions of the sampling unit and summarized the advantages to small sampling units as follows: "(1) more small units can be taken for the same amount of labor in dealing with the catch; (2) as a sample of many small units has more degrees of freedom than a sample of a few large units, the statistical error is reduced; and (3) since many small units cover a wider range of the habitat than a few large units, the catch of the small units is more representative." It was also noted, however, that when using the smaller unit there is proportionally greater sampling error. All of the reasons cited above for using the smaller sampling unit are based on the assumption that you can get more samples with the smaller sampling unit. This may in fact not be true. Because we are depending on voluntary labor for the fishery-independent survey, the resources available to sample 2 m transects may be much smaller than are available for a test fishery, which generate funds to offset survey costs. In addition, the funds produced from the test fishery would not only go to pay for the expenses incurred by the fishers, but also other logistic support costs (e.g., equipment, data processing, independent observers, etc.). Landings from the test fishery would, however, be taken from the annual quota for that Area.

## Combination

Another procedure worth considering is a combination of the above two protocols. A transecttype survey would be conducted along the borders of the test fishing sample area prior to the removal of cucumbers. In this way, two independent biomass estimates could be obtained and compared.

## Testing Assumptions Regarding Aggregation

One critical area of investigation is the ability of cucumbers to re-colonize an area after it has been fished out. A simple removal/resampling experiment needs to be incorporated into the design of the surveys. This could be a specific objective in a test fishery scenario, where a number of sites fished out in one year would be revisited in subsequent years to determine recovery rates.

## Calculation of Appropriate Exploitation Rates

The three exploitation rates described above are based on either: (1) a Gulland model with $X=$ 0.2 and $M$ a function of assumed maximum age; or (2) a surplus production model estimate of $M S Y$ for a population of sea cucumbers in Washington State. There are a number of ways of improving these theoretical estimates. Most of the effort would be directed either at improving the estimates of natural mortality or gathering information on population responses to various exploitation rates.

## Testing Exploitation Rates

Response of exploited populations to different exploitation rates would be evaluated under an adaptive management system. Critical to this scenario is an evaluation framework which will require accurate information on population production characteristics. An adaptive management scheme would include areas that are not exploited, as well as areas exploited at a range of rates above and below the theoretically conservative (4.2\%) exploitation level.

Pearse and Walters (1992) discuss reconciling quota management and risk management. As one of the first steps, they recommend a minimum stock size should be set that insures the protection of the public interest in the resource. They suggest that an appropriate level for this minimum stock size is one-third of the virgin stock size. They recognize that this recommended minimum stock size does not guarantee against stock collapse and that the stock is likely well below the most productive stock size. It is, however, within the range of thresholds used in other fisheries (e.g., the B.C. Herring fishery, which has a conservation threshold of $25 \%$ ).

## Establishing Experimental Management Areas

Identifying and establishing experimental management areas (EMA's) would require that:

1) they be selected from, and representative of, all major historical fishing areas;
2) they be good sea cucumber production areas; and
3) they are managed on as small a spatial scale as logistically possible.

The information necessary for selection of good areas can be derived from logbooks, industry and managers. The maximum spatial scale used should be a Statistical Subarea.

Areas closed to fishing, which will act as "controls" within the EMA's, should have the following characteristics:

1) they should have good commercial abundance of cucumbers;
2) they should be selected from areas that have not been harvested; and
3) they should be in close proximity to the experimentally fished areas.

There should be at least three statistical subareas (i.e., replicate areas) from each large geographic area chosen for experimental fisheries.

## Experimental Design

Each EMA would be fished following a pre-determined experimental design, and would be managed in this manner for approximately 5 years after the first recruits from the experimental protocol enter the fishery (i.e., approximately 4 years after the EMAs are established). The experimental design would be based on three replicates of three exploitation levels and a control in each of three or four large district areas (e.g., Inside South Coast, West Coast Vancouver Island, Central Coast, etc.), giving a total of 36-48 areas being evaluated annually.

## Model Selection

The theoretical production reference points are derived from two of many models used to relate population response to exploitation. For instance, when using a surplus production model, the assumption is that population grows according to a logistic formula or a sigmoidal shaped curve with slowest growth rates at the low and high population levels and the fastest at moderate population levels.
$M S Y$ can be calculated from either the Schaeffer model:

$$
\begin{equation*}
M S Y=\frac{r k}{4} \tag{3}
\end{equation*}
$$

where $r$ is the intrinsic growth rate and $k$ is the unfished equilibrium stock size; or the Gulland model:

$$
\begin{equation*}
M S Y=X M B_{0} \tag{4}
\end{equation*}
$$

where $B_{0}$ is the virgin biomass, $M$ is the natural mortality rate and $X$ is a scaling factor which has been estimated to be 0.5 (Gulland 1971) or 0.4 (Caddy 1986). In general it is felt that 0.5 will overestimate MSY in most cases and it has been suggested by Garcia et al. (1989) that in data limited situations that the target catch should be $1 / 2$ to $2 / 3$ of the estimated MSY. This would depend on whether the stock is considered lightly exploited or heavily exploited. Woodby et al. (1993) used this suggestion and set $X=0.2$ ( $1 / 2$ of 0.4 ) for newly developing fisheries on sea cucumber stocks in Alaska.

Industry is interested in the production capability of a population where enhancement activities are carried out after fishing activities. This kind of "take and put" scenario was proposed by industry as a possible alternative to the classic "take only" scenario that most fisheries are based on. Any proposed model will require good formulation of questions to be addressed and evaluation of the outcomes to see if expectations are met.

A Phase 1 fishery would be a longterm commitment, which would require, in this case, a minimum of 9-10 years to evaluate initial theoretical biomass estimates and population responses to various exploitation rates.

## Other Research Topics

In addition to testing theoretical model parameters, there are a number of other basic biological information needs to be addressed during collection of survey and EMA data:

1) Development of estimated growth rates, mortality rates and longevity of cucumbers in several representative areas;
2) Description of seasonal movement patterns;
3) Density and biomass surveys of deep ( $>20 \mathrm{~m}$ ) water sea cucumber stocks by mechanical device such as a ROV (remotely controlled underwater vehicle);
4) Description of annual, seasonal and regional recruitment patterns using experimental collectors or commercial oyster farms;
5) Evaluation of stock enhancement techniques such as:
a) Relocation of recruits from (i) collectors (e.g., Oyster farms) or (ii) areas of high abundance to low abundance:
b) Induced fission constriction to study effects on different sizes and rate of growth of fissiparous products: or
c) Hatchery rearing.
6) Definition of stock structure using electrophoretic or genetic markers.

## PHASE 2

This phase of the fishery is termed by Perry (1998) "fishing for commerce". At this juncture of the fishery, the experimental management scenarios will have been evaluated and the most appropriate management regime chosen and implemented. It is important to remember that even in this phase there will still be a requirement for continued monitoring of both fishery and stocks. Fisheries change over time, as do the abiotic and biotic factors affecting populations, and it will be necessary to have an information system in place to document these changes. Fishery-related data will be required through logbooks and an on-boat and or dockside observer program. These programs will combine to provide information on CPUE trends, areas fished, mean split weights/area, and diver efficiency. Other programs will have to be designed to evaluate and monitor environmental changes, impacts on substrate types, population responses to biotic factors such as predators, and factors such as value and type of product which may influence harvest strategies.

## RECOMMENDATIONS

1) Implement the most conservative fixed exploitation management strategy for the sea cucumber fishery in B.C. waters.
2) Keep the present management system of IQ's and adapt the present quotas over an area that would sustain it according to conservative estimates of fixed exploitation as defined in the theoretical Phase 0 management plan. This would require developing an annual quota for an appropriately sized area. The size of the area would depend on size of animals in the areas chosen, the density estimate used and the exploitation rate selected.
3) Divide quotas into as small a spatial scale as logistically possible (e.g., statistical subareas).
4) Do not allow expansion of the fishery until there is appropriate data collected for B.C. waters to determine the impact of the present fishery.
5) Develop, with industry, a cost neutral way of obtaining reliable data for Phase 1 evaluation of the fishery.
6) Address other research initiatives where logistically possible, and implement in a cost neutral fashion.

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## REFERENCES

Bradbury, A., W.A. Palsson and R.E. Pacunski. 1998. Stock assessment of sea cucumbers, Parastichopus californicus, in Washington State. pp. 441-446. In: R. Mooi and M. Telford [eds.]. Proceedings of 9th International Echinoderm Conference, San Francisco, Ca., August 5-9, 1996.

Caddy, J.F. 1986. Stock assessment in data-limited situations - The experience in tropical fisheries and its possible relevance to evaluation of invertebrate resources. pp. 379-392. In: G.S. Jamieson and N. Bourne [eds.]. North Pacific workshop on stock assessment and management of invertebrates. Can. Spec. Publ. Fish. Aquat. Sci. 92.

Cameron, J.L. and P.V. Fankboner. 1986. Reproductive biology of the commercial sea cucumber Parasticopus californicus (Stimpson) (Echinodermata: Holothuroidea). I. Reproductive periodicity and spawning behavior. Can. J. Zool. 64: 168-175.

Cameron, J.L. and P.V. Fankboner. 1989. Reproductive biology of the commercial sea cucumber Parasticopus californicus (Stimpson) (Echinodermata: Holothuroidea). II. Observations on the ecology of development, recruitment and juvenile life stage. J. Exp. Mar. Biol. Ecol. 127: 43-67.

CompuGrid. 1996. Spatial Analysis Toolkit Reference Manual. Version 7.1. Geo-Spatial Systems Ltd., Nanaimo, B.C. Canada, V9T 4K4.

Campbell, A. and K. Cripps. In prep. Survey of sea cucumber populations in the central coast of British Columbia during 1993-94. Can. Manuscr. Rep. Fish. Aquat. Sci.

Garcia, S., P. Sparre and J. Csirke. 1989. Estimating surplus production and maximum sustainable yield from biomass data when catch and effort time series are not available. Fish. Res. 8. 13-23.

Gulland J.A. 1971. The Fish Resources of the Ocean. Fishing News (Books), West Byfleet, 255 p.

Heizer, S. and G. Thomas. 1997. Sea cucumber (Parastichopus californicus) dive fishery. pp. 116-131. In: R. Harbo and K. Hobbs [eds.]. Pacific commercial fishery updates for invertebrate resources (1994). Can. Man. Rep. Fish. Aquat. Sci. 2369.

Hilborn R. and C. Walters. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics, and Uncertainty. Chapman and Hall, New York.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bull. (U.S.) 82:898-903.

Imamura, K and G. Kruse. 1990. Management of the red sea cucumber in Southeast Alaska: Biology, historical significance in Pacific coast fisheries, and regional harvest rate
determinations. Regional Information Report 1J90-31, Alaska Dept. of Fish and Game, Juneau.

Larson, R., T. Minicucci and D. Woodby. 1995. Southeast Alaska sea cucumber research report, 1993. Regional Information Report Series No. 1J95-04, Alaska Department of Fish and Game.

McEuen, F.S. 1987. Phylum Echinodermata: Class Holothuroidea. pp. 574-596. In: M. Strathmann [ed.]. Reproductive Biology and Development of Marine Invertebrates of the Northern Pacific Coast. University Washington Press. Seattle, WA.

Pearse, P.H. and C. J. Walters. 1992. Harvesting regulation under quota management systems for ocean fisheries. pp. 167-192. In: Marine Policy, May 1992. Butterworth-Heinemann Ltd.

Perry, R.I. 1998. A framework for providing scientific advice for the management of new and developing invertebrate fisheries. p. 3. In: G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1996. Can. Tech. Rep. Fish. Aquat. Sci. 2221.

Phillips, A.C. and J.A. Boutillier. 1998. Stock assessment and quota options for the sea cucumber fishery. pp. 147-169. In: B.J. Waddell, G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 2. Echinoderms. Can. Tech. Rep. Fish. Aquat. Sci. 2215.

Rome E. and J. Clarke. Unpublished manuscript. A review of the 1995 Sea Cucumber Fishery.
Sloan, N.A. 1986. World jellyfish and tunicate fisheries and the Northeast Pacific echinoderm fishery. pp. 23-33. In: G.S. Jamieson and N. Bourne [eds.]. North Pacific workshop on stock assessment and management of invertebrates. Can. Spec. Publ. Fish. Aquat. Sci. 92.

Walters, C.J., and R. Hilborn. 1976. Adaptive control of fishing systems. J. Fish. Res. Bd. Can. 33: 145-159.

Woodby, DA, G.H. Kruse and R.C. Larson. 1993. A conservative application of a surplus production model to the sea cucumber fishery in Southeast Alaska. pp. 191-202. In: G. Kruse, D.M. Egger, R.J. Marasco, C. Pautzke and T. J. Quinn II [eds.]. Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations. Alaska Sea Grant College Program Rep. 93-02. Univ. of Alaska, Fairbanks.

Table 1. Theoretical quota calculations for Parastichopus californicus by PMFC Subarea.

| $\begin{gathered} \hline \text { Statistical } \\ \text { Area } \\ \hline \end{gathered}$ | Statistical Subarea | Shoreline <br> Length (m) | Average Wt (gms) | $\begin{aligned} & \hline 4.2 \% \text { Quota } \\ & \text { (tonnes) } \\ & \hline \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: |
| 1 | 1 | 82,740 | 327 | 2.8 |
| 1 | 2 | 40,438 | 327 | 1.4 |
| 1 | 3 | 49,241 | 327 | 1.7 |
| 1 | 4 | 31,618 | 327 | 1.1 |
| 1 | 5 | 52,601 | 327 | 1.8 |
| 1 | 6 | 367,786 | 327 | 12.6 |
| 1 | 7 | 28,123 | 327 | 1.0 |
| 2 | 1 | 241,080 | 327 | 8.3 |
| 2 | 2 | 30,240 | 327 | 1.0 |
| 2 | 3 | 56,162 | 327 | 1.9 |
| 2 | 4 | 34,121 | 327 | 1.2 |
| 2 | 5 | 23,520 | 327 | 0.8 |
| 2 | 6 | 134,702 | 327 | 4.6 |
| 2 | 7 | 52,853 | 327 | 1.8 |
| 2 | 8 | 109,570 | 327 | 3.8 |
| 2 | 9 | 27,905 | 327 | 1.0 |
| 2 | 10 | 111,586 | 327 | 3.8 |
| 2 | 11 | 209,009 | 327 | 7.2 |
| 2 | 12 | 74,138 | 327 | 2.5 |
| 2 | 13 | 62,076 | 327 | 2.1 |
| 2 | 14 | 59,556 | 327 | 2.0 |
| 2 | 15 | 72,677 | 327 | 2.5 |
| 2 | 16 | 24,377 | 327 | 0.8 |
| 2 | 17 | 49,056 | 327 | 1.7 |
| 2 | 18 | 75,869 | 327 | 2.6 |
| 2 | 19 | 54,264 | 327 | 1.9 |
| 2 | 31 | 104,395 | 327 | 3.6 |
| 2 | 32 | 17,438 | 327 | 0.6 |
| 2 | 33 | 9,206 | 327 | 0.3 |
| 2 | 34 | 10,819 | 327 | 0.4 |
| 2 | 35 | 19,018 | 327 | 0.7 |
| 2 | 36 | 17,976 | 327 | 0.6 |
| 2 | 37 | 8,148 | 327 | 0.3 |
| 2 | 38 | 211,882 | 327 | 7.3 |
| 2 | 39 | 8,165 | 327 | 0.3 |
| 2 | 40 | 2,806 | 327 | 0.1 |
| 2 | 41 | 7,913 | 327 | 0.3 |
| 2 | 42 | 16,514 | 327 | 0.6 |
| 2 | 43 | 8,148 | 327 | 0.3 |
| 2 | 44 | 14,129 | 327 | 0.5 |
| 2 | 45 | 18,043 | 327 | 0.6 |
| 2 | 46 | 24,058 | 327 | 0.8 |
| 2 | 47 | 21,840 | 327 | 0.7 |

Table 1. (cont.)

| Statistical Area | Statistical Subarea | Shoreline Length (m) | Average <br> Wt (gms) | $\begin{aligned} & \hline 4.2 \% \text { Quota } \\ & \text { (tomnes) } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: |
| 2 | 48 | 8,568 | 327 | 0.3 |
| 2 | 49 | 43,680 | 327 | 1.5 |
| 2 | 50 | 29,316 | 327 | 1.0 |
| 2 | 51 | 5,460 | 327 | 0.2 |
| 2 | 52 | 14,482 | 327 | 0.5 |
| 2 | 53 | 18,497 | 327 | 0.6 |
| 2 | 54 | 10,466 | 327 | 0.4 |
| 2 | 55 | 8,131 | 327 | 0.3 |
| 2 | 56 | 17,942 | 327 | 0.6 |
| 2 | 57 | 9,996 | 327 | 0.3 |
| 2 | 58 | 14,969 | 327 | 0.5 |
| 2 | 59 | 15,926 | 327 | 0.5 |
| 2 | 60 | 17,976 | 327 | 0.6 |
| 2 | 61 | 20,698 | 327 | 0.7 |
| 2 | 62 | 39,648 | 327 | 1.4 |
| 2 | 63 | 42,336 | 327 | 1.5 |
| 2 | 64 | 14,213 | 327 | 0.5 |
| 2 | 65 | 24,461 | 327 | 0.8 |
| 2 | 66 | 13,894 | 327 | 0.5 |
| 2 | 67 | 27,518 | 327 | 0.9 |
| 2 | 68 | 49,711 | 327 | 1.7 |
| 2 | 69 | 17,136 | 327 | 0.6 |
| 2 | 70 | 18,077 | 327 | 0.6 |
| 2 | 71 | 12,835 | 327 | 0.4 |
| 2 | 72 | 1,310 | 327 | 0.0 |
| 2 | 73 | 2,705 | 327 | 0.1 |
| 2 | 74 | 1,865 | 327 | 0.1 |
| 2 | 75 | 32,693 | 327 | 1.1 |
| 2 | 76 | 19,505 | 327 | 0.7 |
| 2 | 77 | 26,242 | 327 | 0.9 |
| 2 | 78 | 11,626 | 327 | 0.4 |
| 2 | 79 | 13,558 | 327 | 0.5 |
| 2 | 80 | 7,526 | 327 | 0.3 |
| 2 | 81 | 6,787 | 327 | 0.2 |
| 2 | 82 | 16,750 | 327 | 0.6 |
| 2 | 83 | 5,040 | 327 | 0.2 |
| 2 | 84 | 4,603 | 327 | 0.2 |
| 2 | 85 | 21,202 | 327 | 0.7 |
| 2 | 86 | 8,820 | 327 | 0.3 |
| 2 | 87 | 21,941 | 327 | 0.8 |
| 2 | 88 | 38,069 | 327 | 1.3 |
| 2 | 89 | 15,758 | 327 | 0.5 |
| 2 | 90 | 18,900 | 327 | 0.6 |

Table 1. (cont.)

| $\begin{gathered} \hline \text { Statistical } \\ \text { Area } \\ \hline \end{gathered}$ | Statistical Subarea | Shoreline Length (m) | Average Wt (gms) | $\begin{gathered} \text { 4.2\% Quota } \\ \text { (tonnes) } \\ \hline \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: |
| 2 | 91 | 10,517 | 327 | 0.4 |
| 2 | 92 | 6,686 | 327 | 0.2 |
| 2 | 93 | 9,374 | 327 | 0.3 |
| 2 | 94 | 3,511 | 327 | 0.1 |
| 2 | 95 | 7,274 | 327 | 0.2 |
| 2 | 96 | 3,562 | 327 | 0.1 |
| 2 | 97 | 7,610 | 327 | 0.3 |
| 2 | 98 | 12,096 | 327 | 0.4 |
| 2 | 99 | 4,116 | 327 | 0.1 |
| 2 | 100 | 2,587 | 327 | 0.1 |
| 3 | 1 | 160,860 | 263 | 4.4 |
| 3 | 2 | 11,626 | 263 | 0.3 |
| 3 | 3 | 42,588 | 263 | 1.2 |
| 3 | 4 | 41,261 | 263 | 1.1 |
| 3 | 5 | 4,099 | 263 | 0.1 |
| 3 | 6 | 160,205 | 263 | 4.4 |
| 3 | 7 | 109,922 | 263 | 3.0 |
| 3 | 8 | 46,150 | 263 | 1.3 |
| 3 | 9 | 23,386 | 263 | 0.6 |
| 3 | 10 | 67,822 | 263 | 1.9 |
| 3 | 11 | 78,053 | 263 | 2.2 |
| 3 | 12 | 59,875 | 263 | 1.7 |
| 3 | 13 | 27,451 | 263 | 0.8 |
| 3 | 14 | 251,261 | 263 | 6.9 |
| 3 | 15 | 65,302 | 263 | 1.8 |
| 3 | 16 | 36,490 | 263 | 1.0 |
| 3 | 17 | 22,949 | 263 | 0.6 |
| 3 | 18 | 10,349 | 263 | 0.3 |
| 4 | 1 | 290,002 | 263 | 8.0 |
| 4 | 2 | 244,658 | 263 | 6.8 |
| 4 | 3 | 30,811 | 263 | 0.9 |
| 4 | 4 | 13,440 | 263 | 0.4 |
| 4 | 5 | 135,341 | 263 | 3.7 |
| 4 | 6 | 4,519 | 263 | 0.1 |
| 4 | 7 | 5,090 | 263 | 0.1 |
| 4 | 8 | 10,735 | 263 | 0.3 |
| 4 | 9 | 160,692 | 263 | 4.4 |
| 4 | 10 | 102,732 | 263 | 2.8 |
| 4 | 11 | 75,415 | 263 | 2.1 |
| 4 | 12 | 254,755 | 263 | 7.0 |
| 4 | 13 | 59,388 | 263 | 1.6 |
| 4 | 14 | 3,108 | 263 | 0.1 |
| 4 | 15 | 45,612 | 263 | 1.3 |

Table 1. (cont.)

| $\begin{gathered} \hline \text { Statistical } \\ \text { Area } \\ \hline \end{gathered}$ | Statistical Subarea | Shoreline Length (m) | Average Wt (gms) | $\begin{gathered} \text { 4.2\% Quota } \\ \text { (tonnes) } \\ \hline \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: |
| 5 | 1 | 38,338 | 263 | 1.1 |
| 5 | 2 | 48,317 | 263 | 1.3 |
| 5 | 3 | 74,222 | 263 | 2.0 |
| 5 | 4 | 56,750 | 263 | 1.6 |
| 5 | 5 | 13,339 | 263 | 0.4 |
| 5 | 6 | 8,047 | 263 | 0.2 |
| 5 | 7 | 19,690 | 263 | 0.5 |
| 5 | 8 | 14,347 | 263 | 0.4 |
| 5 | 9 | 61,135 | 263 | 1.7 |
| 5 | 10 | 187,706 | 263 | 5.2 |
| 5 | 11 | 25,334 | 263 | 0.7 |
| 5 | 12 | 43,579 | 263 | 1.2 |
| 5 | 13 | 116,105 | 263 | 3.2 |
| 5 | 14 | 89,880 | 263 | 2.5 |
| 5 | 15 | 21,907 | 263 | 0.6 |
| 5 | 16 | 199,080 | 263 | 5.5 |
| 5 | 17 | 173,645 | 263 | 4.8 |
| 5 | 18 | 25,838 | 263 | 0.7 |
| 5 | 19 | 58,279 | 263 | 1.6 |
| 5 | 20 | 129,797 | 263 | 3.6 |
| 5 | 21 | 72,895 | 263 | 2.0 |
| 5 | 22 | 139,171 | 263 | 3.8 |
| 5 | 23 | 188,278 | 263 | 5.2 |
| 5 | 24 | 114,946 | 263 | 3.2 |
| 6 | 1 | 514,954 | 263 | 14.2 |
| 6 | 2 | 130,822 | 263 | 3.6 |
| 6 | 3 | 141,540 | 263 | 3.9 |
| 6 | 4 | 273,185 | 263 | 7.5 |
| 6 | 5 | 203,683 | 263 | 5.6 |
| 6 | 6 | 86,906 | 263 | 2.4 |
| 6 | 7 | 28,829 | 263 | 0.8 |
| 6 | 8 | 43,210 | 263 | 1.2 |
| 6 | 9 | 367,366 | 263 | 10.1 |
| 6 | 10 | 192,662 | 263 | 5.3 |
| 6 | 11 | 11,206 | 263 | 0.3 |
| 6 | 12 | 106,882 | 263 | 3.0 |
| 6 | 13 | 312,144 | 263 | 8.6 |
| 6 | 14 | 60,413 | 263 | 1.7 |
| 6 | 15 | 39,866 | 263 | 1.1 |
| 6 | 16 | 110,225 | 263 | 3.0 |
| 6 | 17 | 44,033 | 263 | 1.2 |
| 6 | 18 | 49,207 | 263 | 1.4 |
| 6 | 19 | 207,715 | 263 | 5.7 |

Table 1. (cont.)

| Statistical Area | Statistical Subarea | Shoreline <br> Length ( m ) | Average Wt (gms) | $\begin{gathered} \text { 4.2\% Quota } \\ \text { (tonnes) } \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: |
| 6 | 20 | 190,142 | 263 | 5.3 |
| 6 | 21 | 19,387 | 263 | 0.5 |
| 6 | 22 | 14,885 | 263 | 0.4 |
| 6 | 23 | 25,049 | 263 | 0.7 |
| 6 | 24 | 17,623 | 263 | 0.5 |
| 6 | 25 | 72,324 | 263 | 2.0 |
| 6 | 26 | 16,212 | 263 | 0.4 |
| 6 | 27 | 6,871 | 263 | 0.2 |
| 6 | 28 | 22,411 | 263 | 0.6 |
| 7 | 1 | 16,783 | 263 | 0.5 |
| 7 | 2 | 6,518 | 263 | 0.2 |
| 7 | 3 | 122,270 | 263 | 3.4 |
| 7 | 4 | 67,452 | 263 | 1.9 |
| 7 | 5 | 58,985 | 263 | 1.6 |
| 7 | 6 | 106,142 | 263 | 2.9 |
| 7 | 7 | 54,314 | 263 | 1.5 |
| 7 | 8 | 9,240 | 263 | 0.3 |
| 7 | 9 | 281,014 | 263 | 7.8 |
| 7 | 10 | 46,721 | 263 | 1.3 |
| 7 | 11 | 56,851 | 263 | 1.6 |
| 7 | 12 | 83,194 | 263 | 2.3 |
| 7 | 13 | 62,899 | 263 | 1.7 |
| 7 | 14 | 208,790 | 263 | 5.8 |
| 7 | 15 | 136,080 | 263 | 3.8 |
| 7 | 16 | 85,260 | 263 | 2.4 |
| 7 | 17 | 219,038 | 263 | 6.0 |
| 7 | 18 | 197,450 | 263 | 5.5 |
| 7 | 19 | 32,978 | 263 | 0.9 |
| 7 | 20 | 28,997 | 263 | 0.8 |
| 7 | 21 | 67,721 | 263 | 1.9 |
| 7 | 22 | 12,818 | 263 | 0.4 |
| 7 | 23 | 192,461 | 263 | 5.3 |
| 7 | 24 | 40,858 | 263 | 1.1 |
| 7 | 25 | 279,082 | 263 | 7.7 |
| 7 | 26 | 17,825 | 263 | 0.5 |
| 7 | 27 | 201,113 | 263 | 5.6 |
| 7 | 28 | 109,570 | 263 | 3.0 |
| 7 | 29 | 43,898 | 263 | 1.2 |
| 7 | 30 | 37,330 | 263 | 1.0 |
| 7 | 31 | 75,180 | 263 | 2.1 |
| 7 | 32 | 76,289 | 263 | 2.1 |
| 8 | 1 | 49,644 | 263 | 1.4 |
| 8 | 2 | 90,821 | 263 | 2.5 |

Table 1. (cont.)

| $\begin{gathered} \hline \text { Statistical } \\ \text { Area } \\ \hline \end{gathered}$ | Statistical Subarea | Shoreline <br> Length (m) | Average Wt (gms) | $\begin{gathered} \text { 4.2\% Quota } \\ \text { (tonnes) } \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: |
| 8 | 3 | 19,740 | 263 | 0.5 |
| 8 | 4 | 221,071 | 263 | 6.1 |
| 8 | 5 | 43,176 | 263 | 1.2 |
| 8 | 6 | 21,958 | 263 | 0.6 |
| 8 | 7 | 193,973 | 263 | 5.4 |
| 8 | 8 | 84,118 | 263 | 2.3 |
| 8 | 9 | 102,312 | 263 | 2.8 |
| 8 | 10 | 32,206 | 263 | 0.9 |
| 8 | 11 | 58,699 | 263 | 1.6 |
| 8 | 12 | 123,161 | 263 | 3.4 |
| 8 | 13 | 102,934 | 263 | 2.8 |
| 8 | 14 | 70,056 | 263 | 1.9 |
| 8 | 15 | 88,217 | 263 | 2.4 |
| 8 | 16 | 71,753 | 263 | 2.0 |
| 9 | 1 | 59,590 | 263 | 1.6 |
| 9 | 2 | 198,979 | 263 | 5.5 |
| 9 | 3 | 21,521 | 263 | 0.6 |
| 9 | 4 | 32,928 | 263 | 0.9 |
| 9 | 5 | 15,086 | 263 | 0.4 |
| 9 | 6 | 36,826 | 263 | 1.0 |
| 9 | 7 | 20,462 | 263 | 0.6 |
| 9 | 8 | 29,400 | 263 | 0.8 |
| 9 | 9 | 32,693 | 263 | 0.9 |
| 9 | 10 | 79,078 | 263 | 2.2 |
| 9 | 11 | 82,589 | 263 | 2.3 |
| 9 | 12 | 188,177 | 263 | 5.2 |
| 10 | 1 | 56,314 | 263 | 1.6 |
| 10 | 2 | 48,451 | 263 | 1.3 |
| 10 | 3 | 33,785 | 263 | 0.9 |
| 10 | 4 | 58,934 | 263 | 1.6 |
| 10 | 5 | 28,560 | 263 | 0.8 |
| 10 | 6 | 37,918 | 263 | 1.0 |
| 10 | 7 | 58,498 | 263 | 1.6 |
| 10 | 8 | 9,089 | 263 | 0.3 |
| 10 | 9 | 19,337 | 263 | 0.5 |
| 10 | 10 | 44,218 | 263 | 1.2 |
| 10 | 11 | 39,379 | 263 | 1.1 |
| 10 | 12 | 81,900 | 263 | 2.3 |
| 11 | 1 | 17,069 | 263 | 0.5 |
| 11 | 2 | 209,311 | 263 | 5.8 |
| 11 | 3 | 143,254 | 263 | 4.0 |
| 11 | 4 | 92,215 | 263 | 2.5 |
| 11 | 5 | 63,773 | 263 | 1.8 |

Table 1. (cont.)

| Statistical Area | Statistical Subarea | Shoreline Length ( m ) | Average Wt (gms) | 4.2\% Quota (tonnes) |
| :---: | :---: | :---: | :---: | :---: |
| 11 | 6 | 46,217 | 263 | 1.3 |
| 11 | 7 | 34,910 | 263 | 1.0 |
| 11 | 8 | 57,204 | 263 | 1.6 |
| 11 | 9 | 71,232 | 263 | 2.0 |
| 11 | 10 | 81,631 | 263 | 2.3 |
| 12 | 1 | 37,111 | 318 | 1.2 |
| 12 | 2 | 39,581 | 318 | 1.3 |
| 12 | 3 | 72,710 | 318 | 2.4 |
| 12 | 4 | 14,011 | 318 | 0.5 |
| 12 | 5 | 53,693 | 318 | 1.8 |
| 12 | 6 | 153,955 | 318 | 5.1 |
| 12 | 7 | 65,201 | 318 | 2.2 |
| 12 | 8 | 16,649 | 318 | 0.6 |
| 12 | 9 | 1,915 | 318 | 0.1 |
| 12 | 10 | 924 | 318 | 0.0 |
| 12 | 11 | 103,454 | 318 | 3.5 |
| 12 | 12 | 46,116 | 318 | 1.5 |
| 12 | 13 | 195,754 | 318 | 6.5 |
| 12 | 14 | 35,347 | 318 | 1.2 |
| 12 | 15 | 73,332 | 318 | 2.4 |
| 12 | 16 | 84,017 | 318 | 2.8 |
| 12 | 17 | 13,961 | 318 | 0.5 |
| 12 | 18 | 71,551 | 318 | 2.4 |
| 12 | 19 | 34,793 | 318 | 1.2 |
| 12 | 20 | 9,274 | 318 | 0.3 |
| 12 | 21 | 10,198 | 318 | 0.3 |
| 12 | 22 | 36,574 | 318 | 1.2 |
| 12 | 23 | 41,244 | 318 | 1.4 |
| 12 | 24 | 3,360 | 318 | 0.1 |
| 12 | 25 | 26,426 | 318 | 0.9 |
| 12 | 26 | 258,502 | 318 | 8.6 |
| 12 | 27 | 59,842 | 318 | 2.0 |
| 12 | 28 | 9,878 | 318 | 0.3 |
| 12 | 29 | 14,918 | 318 | 0.5 |
| 12 | 30 | 40,622 | 318 | 1.4 |
| 12 | 31 | 23,940 | 318 | 0.8 |
| 12 | 32 | 16,464 | 318 | 0.5 |
| 12 | 33 | 16,346 | 318 | 0.5 |
| 12 | 34 | 28,610 | 318 | 1.0 |
| 12 | 35 | 118,138 | 318 | 3.9 |
| 12 | 36 | 17,002 | 318 | 0.6 |
| 12 | 37 | 11,844 | 318 | 0.4 |
| 12 | 38 | 25,385 | 318 | 0.8 |

Table 1. (cont.)

| $\begin{gathered} \hline \text { Statistical } \\ \text { Area } \\ \hline \end{gathered}$ | Statistical Subarea | Shoreline <br> Length (m) | Average <br> Wt (gms) | 4.2\% Quota (tonnes) |
| :---: | :---: | :---: | :---: | :---: |
| 12 | 39 | 313,438 | 318 | 10.5 |
| 12 | 40 | 132,031 | 318 | 4.4 |
| 12 | 41 | 251,177 | 318 | 8.4 |
| 12 | 42 | 132,602 | 318 | 4.4 |
| 12 | 43 | 32,642 | 318 | 1.1 |
| 12 | 44 | 118 | 318 | 0.0 |
| 12 | 45 | 52,668 | 318 | 1.8 |
| 12 | 46 | 7,325 | 318 | 0.2 |
| 12 | 47 | 17,590 | 318 | 0.6 |
| 12 | 48 | 7,308 | 318 | 0.2 |
| 13 | 1 | 7,644 | 318 | 0.3 |
| 13 | 2 | 8,467 | 318 | 0.3 |
| 13 | 3 | 71,971 | 318 | 2.4 |
| 13 | 4 | 4,402 | 318 | 0.1 |
| 13 | 5 | 13,390 | 318 | 0.4 |
| 13 | 6 | 15,154 | 318 | 0.5 |
| 13 | 7 | 21,286 | 318 | 0.7 |
| 13 | 8 | 4,032 | 318 | 0.1 |
| 13 | 9 | 17,623 | 318 | 0.6 |
| 13 | 10 | 35,767 | 318 | 1.2 |
| 13 | 11 | 29,971 | 318 | 1.0 |
| 13 | 12 | 107,587 | 318 | 3.6 |
| 13 | 13 | 31,433 | 318 | 1.0 |
| 13 | 14 | 16,666 | 318 | 0.6 |
| 13 | 15 | 52,466 | 318 | 1.8 |
| 13 | 16 | 65,688 | 318 | 2.2 |
| 13 | 17 | 64,126 | 318 | 2.1 |
| 13 | 18 | 37,649 | 318 | 1.3 |
| 13 | 19 | 42,118 | 318 | 1.4 |
| 13 | 20 | 26,393 | 318 | 0.9 |
| 13 | 21 | 58,111 | 318 | 1.9 |
| 13 | 22 | 94,567 | 318 | 3.2 |
| 13 | 23 | 70,930 | 318 | 2.4 |
| 13 | 24 | 23,302 | 318 | 0.8 |
| 13 | 25 | 41,311 | 318 | 1.4 |
| 13 | 26 | 59,270 | 318 | 2.0 |
| 13 | 27 | 8,484 | 318 | 0.3 |
| 13 | 28 | 44,554 | 318 | 1.5 |
| 13 | 29 | 10,601 | 318 | 0.4 |
| 13 | 30 | 12,197 | 318 | 0.4 |
| 13 | 31 | 13,490 | 318 | 0.5 |
| 13 | 32 | 29,803 | 318 | 1.0 |
| 13 | 33 | 14,381 | 318 | 0.5 |

Table 1. (cont.)

| $\begin{gathered} \hline \text { Statistical } \\ \text { Area } \\ \hline \end{gathered}$ | Statistical Subarea | Shoreline Length (m) | Average Wt (gms) | $\begin{gathered} 4.2 \% \text { Quota } \\ \text { (tonnes) } \\ \hline \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: |
| 13 | 34 | 15,288 | 318 | 0.5 |
| 13 | 35 | 19,925 | 318 | 0.7 |
| 13 | 36 | 21,017 | 318 | 0.7 |
| 13 | 37 | 20,462 | 318 | 0.7 |
| 13 | 38 | 9,677 | 318 | 0.3 |
| 13 | 39 | 20,261 | 318 | 0.7 |
| 13 | 40 | 10,366 | 318 | 0.3 |
| 13 | 41 | 27,468 | 318 | 0.9 |
| 13 | 42 | 34,558 | 318 | 1.2 |
| 13 | 43 | 46,822 | 318 | 1.6 |
| 14 | 1 | 27,720 | 318 | 0.9 |
| 14 | 2 | 370 | 318 | 0.0 |
| 14 | 3 | 55,289 | 318 | 1.8 |
| 14 | 4 | 17,724 | 318 | 0.6 |
| 14 | 5 | 20,664 | 318 | 0.7 |
| 14 | 6 | 185 | 318 | 0.0 |
| 14 | 7 | 35,095 | 318 | 1.2 |
| 14 | 8 | 44,402 | 318 | 1.5 |
| 14 | 9 | 17,976 | 318 | 0.6 |
| 14 | 10 | 15,926 | 318 | 0.5 |
| 14 | 11 | 22,999 | 318 | 0.8 |
| 14 | 12 | 806 | 318 | 0.0 |
| 14 | 13 | 46,402 | 318 | 1.5 |
| 14 | 14 | 5,662 | 318 | 0.2 |
| 14 | 15 | 11,071 | 318 | 0.4 |
| 15 | 1 | 73,853 | 318 | 2.5 |
| 15 | 2 | 73,382 | 318 | 2.5 |
| 15 | 3 | 80,993 | 318 | 2.7 |
| 15 | 4 | 81,026 | 318 | 2.7 |
| 15 | 5 | 326,122 | 318 | 10.9 |
| 15 | 6 | 85,882 | 318 | 2.9 |
| 16 | 1 | 59,825 | 318 | 2.0 |
| 16 | 2 | 25,099 | 318 | 0.8 |
| 16 | 3 | 3,965 | 318 | 0.1 |
| 16 | 4 | 22,226 | 318 | 0.7 |
| 16 | 5 | 23,587 | 318 | 0.8 |
| 16 | 6 | 46,015 | 318 | 1.5 |
| 16 | 7 | 43,932 | 318 | 1.5 |
| 16 | 8 | 32,374 | 318 | 1.1 |
| 16 | 9 | 21,235 | 318 | 0.7 |
| 16 | 10 | 36,204 | 318 | 1.2 |
| 16 | 11 | 59,892 | 318 | 2.0 |
| 16 | 12 | 53,525 | 318 | 1.8 |

Table 1. (cont.)

| $\begin{gathered} \hline \text { Statistical } \\ \text { Area } \\ \hline \end{gathered}$ | Statistical Subarea | Shoreline Length ( m ) | Average Wt (gms) | $\begin{aligned} & \text { 4.2\% Quota } \\ & \text { (tonnes) } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: |
| 16 | 13 | 79,464 | 318 | 2.7 |
| 16 | 14 | 27,804 | 318 | 0.9 |
| 16 | 15 | 61,874 | 318 | 2.1 |
| 16 | 16 | 40,958 | 318 | 1.4 |
| 16 | 17 | 27,098 | 318 | 0.9 |
| 16 | 18 | 39,228 | 318 | 1.3 |
| 16 | 19 | 66,158 | 318 | 2.2 |
| 16 | 20 | 11,441 | 318 | 0.4 |
| 16 | 21 | 69,266 | 318 | 2.3 |
| 16 | 22 | 11,323 | 318 | 0.4 |
| 17 | 1 | 13,070 | 318 | 0.4 |
| 17 | 2 | 76,003 | 318 | 2.5 |
| 17 | 3 | 19,471 | 318 | 0.7 |
| 17 | 4 | 30,962 | 318 | 1.0 |
| 17 | 5 | 23,906 | 318 | 0.8 |
| 17 | 6 | 38,102 | 318 | 1.3 |
| 17 | 7 | 24,209 | 318 | 0.8 |
| 17 | 8 | 27,031 | 318 | 0.9 |
| 17 | 9 | 27,350 | 318 | 0.9 |
| 17 | 10 | 33,886 | 318 | 1.1 |
| 17 | 11 | 5,158 | 318 | 0.2 |
| 17 | 12 | 24,662 | 318 | 0.8 |
| 17 | 13 | 20,194 | 318 | 0.7 |
| 17 | 14 | 14,146 | 318 | 0.5 |
| 17 | 15 | 1,865 | 318 | 0.1 |
| 17 | 16 | 34,608 | 318 | 1.2 |
| 17 | 17 | 32,273 | 318 | 1.1 |
| 17 | 18 | 31,870 | 318 | 1.1 |
| 17 | 19 | 7,627 | 318 | 0.3 |
| 17 | 20 | 7,896 | 318 | 0.3 |
| 17 | 21 | 2,722 | 318 | 0.1 |
| 18 | 1 | 26,712 | 318 | 0.9 |
| 18 | 2 | 29,753 | 318 | 1.0 |
| 18 | 3 | 63,034 | 318 | 2.1 |
| 18 | 4 | 49,106 | 318 | 1.6 |
| 18 | 5 | 82,606 | 318 | 2.8 |
| 18 | 6 | 57,103 | 318 | 1.9 |
| 18 | 7 | 48,653 | 318 | 1.6 |
| 18 | 8 | 16,145 | 318 | 0.5 |
| 18 | 9 | 1,663 | 318 | 0.1 |
| 18 | 10 | 16,598 | 318 | 0.6 |
| 18 | 11 | 25,116 | 318 | 0.8 |
| 19 | 1 | 24,746 | 318 | 0.8 |

Table 1. (cont.)

| $\begin{gathered} \hline \text { Statistical } \\ \text { Area } \\ \hline \end{gathered}$ | Statistical Subarea | Shoreline <br> Length (m) | Average Wt (gms) | 4.2\% Quota (tonnes) |
| :---: | :---: | :---: | :---: | :---: |
| 19 | 2 | 10,046 | 318 | 0.3 |
| 19 | 3 | 35,196 | 318 | 1.2 |
| 19 | 4 | 48,754 | 318 | 1.6 |
| 19 | 5 | 114,442 | 318 | 3.8 |
| 19 | 6 | 1,932 | 318 | 0.1 |
| 19 | 7 | 9,425 | 318 | 0.3 |
| 19 | 8 | 27,989 | 318 | 0.9 |
| 19 | 9 | 7,493 | 318 | 0.3 |
| 19 | 10 | 4,301 | 318 | 0.1 |
| 19 | 11 | 10,954 | 318 | 0.4 |
| 19 | 12 | 3,713 | 318 | 0.1 |
| 20 | 1 | 20,882 | 322 | 0.7 |
| 20 | 2 | 11,525 | 322 | 0.4 |
| 20 | 3 | 15,473 | 322 | 0.5 |
| 20 | 4 | 34,927 | 322 | 1.2 |
| 20 | 5 | 53,575 | 322 | 1.8 |
| 20 | 6 | 22,546 | 322 | 0.8 |
| 20 | 7 | 16,195 | 322 | 0.5 |
| 21 | 0 | 38,254 | 322 | 1.3 |
| 22 | 0 | 1,042 | 322 | 0.0 |
| 23 | 1 | 55,860 | 322 | 1.9 |
| 23 | 2 | 38,707 | 322 | 1.3 |
| 23 | 3 | 45,091 | 322 | 1.5 |
| 23 | 4 | 66,461 | 322 | 2.2 |
| 23 | 5 | 37,397 | 322 | 1.3 |
| 23 | 6 | 107,150 | 322 | 3.6 |
| 23 | 7 | 61,538 | 322 | 2.1 |
| 23 | 8 | 195,199 | 322 | 6.6 |
| 23 | 9 | 17,002 | 322 | 0.6 |
| 23 | 10 | 63,252 | 322 | 2.1 |
| 23 | 11 | 49,123 | 322 | 1.7 |
| 24 | 1 | 26,141 | 322 | 0.9 |
| 24 | 2 | 125,966 | 322 | 4.3 |
| 24 | 3 | 27,115 | 322 | 0.9 |
| 24 | 4 | 53,441 | 322 | 1.8 |
| 24 | 5 | 55,978 | 322 | 1.9 |
| 24 | 6 | 100,716 | 322 | 3.4 |
| 24 | 7 | 75,029 | 322 | 2.5 |
| 24 | 8 | 49,459 | 322 | 1.7 |
| 24 | 9 | 93,509 | 322 | 3.2 |
| 24 | 10 | 53,441 | 322 | 1.8 |
| 24 | 11 | 31,802 | 322 | 1.1 |
| 24 | 12 | 91,997 | 322 | 3.1 |

Table 1. (cont.)

| Statistical Area | Statistical Subarea | Shoreline Length ( m ) | Average Wt (gms) | 4.2\% Quota (tonnes) |
| :---: | :---: | :---: | :---: | :---: |
| 24 | 13 | 22,445 | 322 | 0.8 |
| 24 | 14 | 29,215 | 322 | 1.0 |
| 25 | 1 | 44,822 | 322 | 1.5 |
| 25 | 2 | 19,790 | 322 | 0.7 |
| 25 | 3 | 40,018 | 322 | 1.4 |
| 25 | 4 | 64,277 | 322 | 2.2 |
| 25 | 5 | 33,701 | 322 | 1.1 |
| 25 | 6 | 111,602 | 322 | 3.8 |
| 25 | 7 | 19,807 | 322 | 0.7 |
| 25 | 8 | 57,842 | 322 | 2.0 |
| 25 | 9 | 47,040 | 322 | 1.6 |
| 25 | 10 | 22,310 | 322 | 0.8 |
| 25 | 11 | 46,368 | 322 | 1.6 |
| 25 | 12 | 32,390 | 322 | 1.1 |
| 25 | 13 | 144,026 | 322 | 4.9 |
| 25 | 14 | 51,324 | 322 | 1.7 |
| 25 | 15 | 18,850 | 322 | 0.6 |
| 25 | 16 | 8,316 | 322 | 0.3 |
| 26 | 1 | 92,282 | 322 | 3.1 |
| 26 | 2 | 63,974 | 322 | 2.2 |
| 26 | 3 | 24,444 | 322 | 0.8 |
| 26 | 4 | 52,618 | 322 | 1.8 |
| 26 | 5 | 65,050 | 322 | 2.2 |
| 26 | 6 | 80,388 | 322 | 2.7 |
| 26 | 7 | 92,568 | 322 | 3.1 |
| 26 | 8 | 31,315 | 322 | 1.1 |
| 26 | 9 | 26,746 | 322 | 0.9 |
| 26 | 10 | 61,169 | 322 | 2.1 |
| 26 | 11 | 13,978 | 322 | 0.5 |
| 27 | 1 | 62,765 | 322 | 2.1 |
| 27 | 2 | 85,445 | 322 | 2.9 |
| 27 | 3 | 52,718 | 322 | 1.8 |
| 27 | 4 | 18,362 | 322 | 0.6 |
| 27 | 5 | 67,435 | 322 | 2.3 |
| 27 | 6 | 52,399 | 322 | 1.8 |
| 27 | 7 | 99,658 | 322 | 3.4 |
| 27 | 8 | 67,402 | 322 | 2.3 |
| 27 | 9 | 21,689 | 322 | 0.7 |
| 27 | 10 | 23,789 | 322 | 0.8 |
| 27 | 11 | 83,446 | 322 | 2.8 |
| 28 | 1 | 81,564 | 318 | 2.7 |
| 28 | 2 | 68,342 | 318 | 2.3 |
| 28 | 3 | 41,462 | 318 | 1.4 |

Table 1. (cont.)

| $\begin{gathered} \hline \text { Statistical } \\ \text { Area } \\ \hline \end{gathered}$ | Statistical Subarea | Shoreline <br> Length (m) | Average Wt (gms) | $\begin{aligned} & \text { 4.2\% Quota } \\ & \text { (tonnes) } \\ & \hline \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: |
| 28 | 4 | 21,605 | 318 | 0.7 |
| 28 | 5 | 40,236 | 318 | 1.3 |
| 28 | 6 | 8,719 | 318 | 0.3 |
| 28 | 7 | 7,342 | 318 | 0.2 |
| 28 | 8 | 15,422 | 318 | 0.5 |
| 28 | 9 | 5,208 | 318 | 0.2 |
| 28 | 10 | 33,012 | 318 | 1.1 |
| 28 | 11 | 34,188 | 318 | 1.1 |
| 28 | 12 | 38,909 | 318 | 1.3 |
| 28 | 13 | 12,953 | 318 | 0.4 |
| 28 | 14 | 2,066 | 318 | 0.1 |
| 29 | 1 | 35,045 | 318 | 1.2 |
| 29 | 2 | 6,653 | 318 | 0.2 |
| 29 | 3 | 8,333 | 318 | 0.3 |
| 29 | 4 | 14,734 | 318 | 0.5 |
| 29 | 5 | 50,719 | 318 | 1.7 |
| 29 | 6 | 2,789 | 318 | 0.1 |
| 29 | 7 | 19,186 | 318 | 0.6 |
| 29 | 8 | 34,692 | 318 | 1.2 |
| 29 | 9 | 59,018 | 318 | 2.0 |
| 29 | 10 | 33,281 | 318 | 1.1 |
| 29 | 11 | 14,918 | 318 | 0.5 |
| 29 | 12 | 63,672 | 318 | 2.1 |
| 29 | 13 | 68,225 | 318 | 2.3 |
| 29 | 14 | 45,024 | 318 | 1.5 |
| 29 | 15 | 56,280 | 318 | 1.9 |
| 29 | 16 | 74,861 | 318 | 2.5 |
| 29 | 17 | 12,432 | 318 | 0.4 |
| 101 | 1 | 6,115 | 327 | 0.2 |
| 101 | 2 | 6,384 | 327 | 0.2 |
| 101 | 6 | 7,174 | 327 | 0.2 |
| 101 | 7 | 4,385 | 327 | 0.2 |
| 101 | 10 | 15,053 | 327 | 0.5 |
| 102 | 1 | 75,953 | 327 | 2.6 |
| 102 | 2 | 4,620 | 327 | 0.2 |
| 102 | 3 | 1,982 | 327 | 0.1 |
| 105 | 1 | 14,582 | 263 | 0.4 |
| 105 | 2 | 2,587 | 263 | 0.1 |
| 106 | 1 | 3,326 | 263 | 0.1 |
| 106 | 2 | 98,549 | 263 | 2.7 |
| 107 | 3 | 1,663 | 263 | 0.0 |
| 108 | 1 | 2,822 | 263 | 0.1 |
| 109 | 0 | 504 | 263 | 0.0 |

Table 1. (cont.)

| Statistical <br> Area | Statistical <br> Subarea | Shoreline <br> Length $(\mathbf{m})$ | Average <br> Wt (gms) | 4.2\% Quota <br> (tonnes) |
| :---: | :---: | :---: | :---: | :---: |
| 111 | 0 | 44,570 | 263 | 1.2 |
| 121 | 1 | 1,193 | 322 | 0.0 |
| 121 | 2 | 588 | 322 | 0.0 |
| 123 | 1 | 28,896 | 322 | 1.0 |
| 123 | 3 | 6,283 | 322 | 0.2 |
| 123 | 5 | 2,176 | 322 | 0.7 |
| 123 | 6 | 454 | 322 | 0.7 |
| 124 | 1 | 3,830 | 322 | 0.0 |
| 124 | 3 | 58,884 | 322 | 0.1 |
| 124 | 4 | 286 | 322 | 2.0 |
| 125 | 1 | 47,208 | 322 | 0.0 |
| 125 | 2 | 8,182 | 322 | 1.6 |
| 125 | 3 | 29,988 | 322 | 0.3 |
| 125 | 5 | 2,671 | 322 | 1.0 |
| 126 | 1 | 27,670 | 322 | 0.1 |
| 126 | 4 | 3,864 | 322 | 0.9 |
| 127 | 1 | 2,638 | 322 | 0.1 |
| 127 | 2 | 17 | 322 | 0.1 |
| 127 | 3 | 14,263 | 322 | 0.0 |
| 127 | 4 | 10,651 | 322 | 0.5 |
| 130 | 3 | 6,871 | 263 | 0.4 |
| 142 | 1 | 18,312 | 327 | 0.2 |
| 142 | 2 | 19,169 | 327 | 0.6 |


[^0]:    $\begin{array}{lrrr}\text { Total: } & 132,507,032 & 60,105 & 191,650 \\ \begin{array}{l}\text { TPrice ranges taken from market reports and sales slips. } \\ 2\end{array} & & \end{array}$
    ${ }^{2}$ Price paid to commercial fishermen

[^1]:    from sales slip data
    from harvest logbooks
    fram validation logs

