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Assessment Framework for Sea Cucumber (*Parastichopus californicus*) in British Columbia

Cadre d'évaluation pour le concombre de mer (*Parastichopus californicus*) en Colombie-Britannique

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ABSTRACT

The Pacific sea cucumber (*Parastichopus californicus*) fishery in British Columbia has been undergoing a rigorous period of data collection, analysis and review since 1995, with the objective of developing a biologically-based stock assessment program and risk-averse fishery management. Here we describe how sea cucumber stocks were historically assessed and document how current assessments are carried out. Methods and protocols for estimating sea cucumber densities for both surveyed and unsurveyed areas of the coast, and for calculating mean weight estimates, are described. Procedures for measuring and calculating shoreline length are described, along with conventions for applying baseline densities to differing classes of shoreline exposure. The precision and accuracy of density estimates is presented, with a comparison of the accuracy of two different methods of calculating density; linear and spatial. The new harvest rates, modelled from the results of the long term Experimental Fishing Areas (EFA) data are reviewed, as well as the recommended Limit Reference Point of 50% B_o. Reserves, or no-take areas, are discussed in detail especially in regards to the sea cucumber fishery and to future development of a network of reserves throughout the British Columbia coast. Research and stock assessment needs are listed, including defining the priority for future surveys, determining the optimal sample size for density estimation, developing methods to include error in shoreline length and cucumber weight estimates into biomass calculations and investigating recruitment and re-colonization dynamics. Finally, recommendations to fishery managers are made regarding the fisheries in low-density areas fisheries in non-productive areas.

RÉSUMÉ

Depuis 1995, la pêche du concombre de mer du Pacifique (*Parastichopus californicus*) a fait l'objet d'une période rigoureuse de collecte de données pour fins d'analyses et d'examens. Ces exercices avaient comme objectif d'établir un programme d'évaluation des stocks fondé sur des bases biologiques et une gestion sans risques de la pêche. Dans le présent document, nous décrivons comment les stocks de concombre de mer ont été évalués dans le passé et comment les évaluations sont maintenant effectuées. Les méthodes et les protocoles pour estimer les densités du concombre de mer dans les zones relevées et non relevées de la côte et pour calculer les estimations moyennes de poids sont décrits. Les procédures pour mesurer et calculer la longueur du rivage sont décrites, ainsi que les conventions utilisées pour appliquer les densités de référence afin de différencier les classes d'exposition au rivage sont décrites. La précision et l'exactitude des estimations de la densité sont présentées et l'exactitude des deux méthodes de calcul, linéaire et spatial, est comparée. Les nouveaux taux de récolte, fixés à partir des résultats des données à long terme des zones de pêche expérimentale (ZPE), sont examinés, tout comme le niveau de référence limite recommandé de 50 % B_o. Les réserves ou zones interdites à la récolte, sont décrites en détail, surtout en ce qui concerne la pêche du concombre de mer et le développement futur d'un réseau de réserves tout le long du littoral de la Colombie-Britannique. Les besoins en matière de recherche et d'évaluation des stocks sont mentionnés, notamment la définition de la priorité en ce qui concerne les prochains relevés, l'établissement de la taille maximale de l'échantillonnage pour l'estimation de la densité et l'élaboration de méthodes afin d'inclure les erreurs dans les estimations de la longueur moyenne du rivage et du poids moyen des concombres de mer dans les calculs de la biomasse et l'étude des dynamiques en matière de recrutement et de recolonisation. Enfin, des recommandations sont faites aux gestionnaires des pêches en ce qui concerne la pêche dans les zones de faible densité dans les zones non productives.

1 INTRODUCTION

The giant red sea cucumber (*Parastichopus californicus*) fishery in British Columbia (BC) has undergone a rigorous period of data collection, analysis and information review since 1995, with the objective of developing a biologically-based stock assessment program and risk-averse fishery management. The first stock assessment and quota options paper was undertaken in 1995, utilizing a surplus production model (Phillips and Boutillier 1998). In the course of conducting this assessment, gaps in knowledge of the species' biology were identified and shortcomings of the fishery-dependent data became clear. Phillips and Boutillier (1998) identified the need for a change in approach for the BC sea cucumber fishery and laid the groundwork for a more comprehensive, Phase 0 (Perry et al 1999) review in 1996 (Boutillier et al 1998). The review paper concluded that the fishery was not providing the information necessary for stock assessments and evaluation of the impacts of the commercial fishery on sea cucumber populations. Accordingly, it was recommended that the fishery henceforth be conducted in a manner that would provide the necessary data. Thus, in 1997, Phase 1 of the sea cucumber fishery began (Hand and Rogers 1999), wherein the area open to commercial harvest was restricted to a static 25% of the coast, 50% of the coast was closed to harvest, and the remaining 25% of the coast was set aside for fishery experiments. Since only a small fraction of the 25% allocated for research was used, the closed area, in reality, encompassed almost 75% of the coast. A survey program was initiated in areas open to commercial harvest (termed 'Open Surveys') and Experimental Fishery Areas (EFA) were initiated in four select locations in BC.

After the anticipated 10-year period of the Phase 1 fishing regime, the data collected from open surveys, experimental fisheries and biological sampling were analyzed and the results and recommendations presented to the Invertebrate Subcommittee of the Pacific Science Advice Review Committee (PSARC) in 2007 (Hand et al. 2008). The recommendation to allow expansion of the commercial fishery beyond the geographically-restricted area of 25% of the shoreline and re-open areas that were historically harvested, using BC-based exploitation rates, was endorsed. The sea cucumber fishery then entered Phase 2, 'fishing for commerce' (Perry et al 1999).

This document describes the methodology and data sources used to estimate sea cucumber biomass from estimates of shoreline length, density and weight, and describes the rules for applying these estimates to surveyed and unsurveyed areas for quota calculation purposes. The precision and accuracy of biomass estimates are reviewed. In addition, a review of recommended harvest rates, limit reference point and upper stock reference point are presented. We also discuss no-take reserves and make recommendations for research priorities.

2 BIOMASS CALCULATION

In 1997, arbitrary annual quotas for the BC sea cucumber fishery were replaced with a calculated annual Total Allowable Catch (TAC) based on the best available data on density and animal weight (Hand and Rogers 1999). In order to estimate the total biomass of sea cucumbers in a given area, three pieces of information are required: the linear density (number of sea cucumbers per metre of shoreline, c/m-sh), the average animal weight and the length of shoreline. Biomass is estimated, at the Pacific Fisheries Management Area Subarea (Subarea) level, as the product of these three parameters;

estimates for each of these are thus required for each Subarea that is open to commercial harvest. At present, only the density parameter is estimated with error, and the 90% lower confidence bound (LCB) on mean estimated density is used to derive conservative estimates of biomass. The adoption of linear estimates of density over spatial estimates, in 1997, followed the approach used in Alaska (Woodby et al. 1993) because sea cucumber populations do not exist in discreet beds but, rather, are ubiquitous over most of the shallow seabed. As well, no spatial estimates of sea cucumber populations were available due to the lack of accurate bathymetric data.

The following equation is used to estimate the biomass for a Subarea:

$$\text{Biomass}_{(\text{Subarea})} = \text{density}_{(\text{Subarea})} * \text{mean weight}_{(\text{Subarea})} * \text{shoreline length}_{(\text{Subarea})}$$

The TAC is then calculated as:

$$\text{TAC} = \text{biomass}_{(\text{Subarea})} * \text{harvest rate}_{(\text{Subarea})}$$

2.1 ESTIMATING BIOMASS DENSITY IN SURVEYED AREAS

Several fishery-independent dive surveys are conducted in select locations every year. They are collaborative efforts between Fisheries and Oceans Canada (DFO), responsible for the survey design and data-collection protocols, and the Pacific Sea Cucumber Harvesters Association (PSCHA) who provides vessels and divers.

2.1.1 Linear Density Estimates

Since 1997, fisheries-independent dive surveys have been conducted in areas open to commercial harvest. Surveys are developed to establish area-specific density estimates of *P. californicus* and to assess the impact of annual harvesting on the populations through periodic re-surveys. Surveys are conducted by SCUBA divers at randomly determined transect locations within each selected survey area. The number of sea cucumbers, depth and the dominant substrate and algae are recorded at 5 m intervals along a 4 m wide swath from 18 m gauge depth to the water's edge. Transects are treated as the primary sampling unit. The mean linear density by Subarea is calculated as the sum of the sea cucumbers counted for all transects in the Subarea divided by the total width of all transects (4 x the number of transects). A complete description of density survey methodologies and density calculation methods are documented in Campagna and Hand (2004). Survey data are archived in a relational database housed by the shellfish data unit at the Pacific Biological Station. Data are analyzed using a custom program ('Cuke Analysis'; W. Hajas, DFO) which computes mean linear density and bootstrapped confidence intervals for a given survey, by Subarea. Each bootstrap computation involves 1000 iterations of re-sampling from the population of transect densities in a Subarea or strata (a seed of 756 was used for all bootstrap runs from 2008 to present) and the confidence intervals are derived from these iterations using the quantile method (e.g. the 90% confidence bounds are given by the 50th lowest and 50th highest value of the 1000 estimates of density). As a precautionary measure, the lower 90% confidence bound of the estimated mean density is used to calculate biomass for the surveyed Subarea.

Six locations, encompassing 23 of the 96 Subareas that were open to commercial harvest during Phase 1 of the fishery (Area 7, Fitz Hugh Sound, Trutch, Gil/Gribbell, Area 12 Inlets, and Tofino; Figure 1), were surveyed on a four-year re-survey cycle between 1997 and 2007 (Hand et al. 2008). A time-series of density data was thus collected, which allowed for monitoring of trends in sea cucumber density and weight and an evaluation of harvest impact over a 10-year period (Table 1).

In order to guide decisions on where to locate future surveys, a ranking system was developed, based on harvest intensity (kg harvested per km of shoreline), to identify the Subareas where landings have been high relative to their shoreline length (Table 2). There were 96 Subareas open for fishing between 1997 and 2007. Mean annual landings for all eleven years and for the four most recent years of available data (2004 to 2007) were calculated for each Subarea by dividing total landings for each period by the number of years that the Subarea was targeted during the respective period (not all open Subareas were fished every year). The mean annual landings were divided by the shoreline length to obtain mean landings per km of shoreline, by Subarea, for each of the two periods. Subareas were ranked within each period and an overall rank of harvest intensity for each Subarea was calculated using the following formula:

$$\text{Final Rank} = [((\text{Rank 1997-2007}) / (\text{years harvested 1997-2007})) +$$

$$(((\text{Rank 2004-2007}) * 2) / (\text{years harvested 2004-2007}))] / 3$$

This ranking system gives more weight to recent harvests by making the Rank 2004-2007 account for 2/3 of the final rank, and also promotes those Subareas which have been targeted more often by dividing each period-rank by the number of years harvested. Sixty-four Subareas, totalling 6003 km of shoreline, have been harvested but never surveyed, 6 of which (totalling 599 km of shoreline) were harvested every year between 1997 and 2007 (Table 2). Biomass estimates in these Subareas are based on extrapolated baseline density estimates (see Section 2.2.1). These unsurveyed Subareas are a high priority for up-coming surveys. Seven of the ten Subareas with the highest harvest intensity have also never been surveyed. These Subareas (7-22, 7-24, 5-5, 5-4, 5-12, 7-12 and 5-15) are small (total 272 km), but commercially important, and are high priority areas for future surveys. At the other end of the spectrum, nine Subareas (320 km of shoreline) remained un-harvested after 11 years of being open to the fishery. It is recommended these areas be closed as they only serve to inflate the TAC for other Subareas in the same Quota Management Area.

2.1.2 <u>Mean Weight Estimates</u>

Three sources of sea cucumber sample data are available to estimate mean individual weight. Biological samples are a collection of animals taken from randomly selected transects during density-surveys, and are hereafter referred to as ‘biosamples’. Samples of animals collected from permanent locations established throughout the coast, independent of density-surveys, are referred to as ‘bio-transects’. Lastly, market samples are animals selected from the harvest; these data are no longer collected as they are considered not representative of populations (Humble et al. 2008) and are used only in the absence of the biological samples.

Biosamples

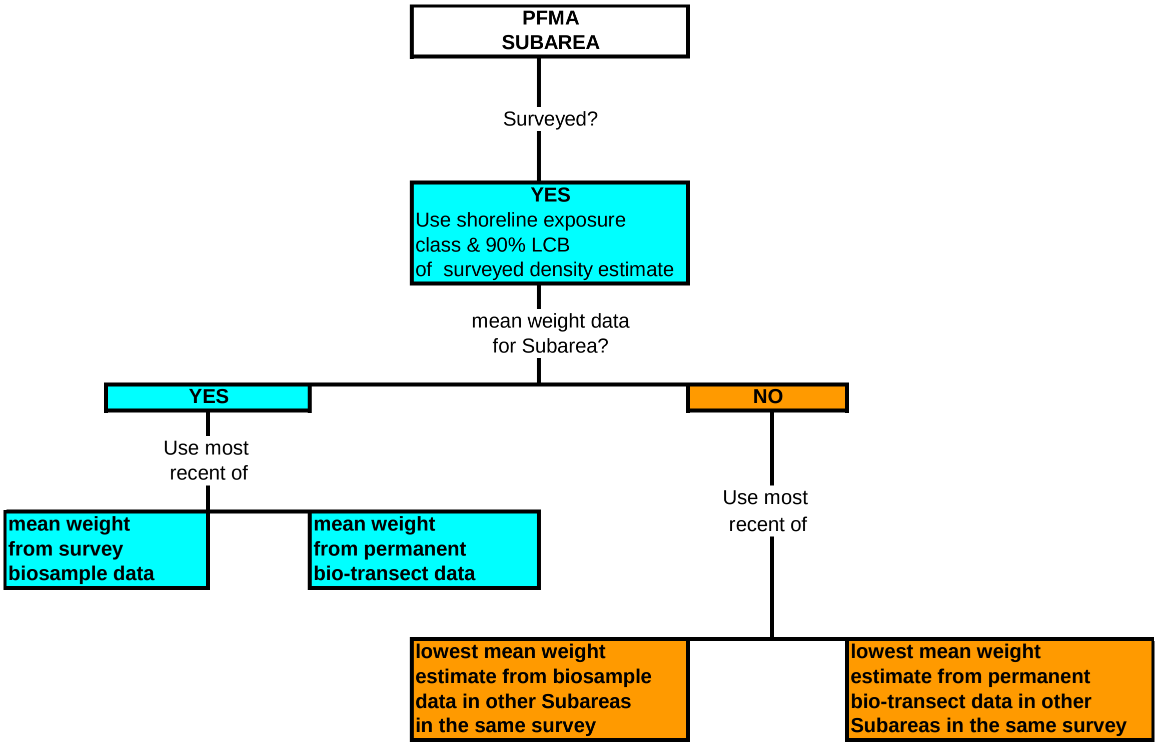
For each density-survey, between three and ten transects are randomly selected from all transects in the survey area and a sample consisting of the first “n” sea cucumbers encountered on each selected transect, regardless of size, is collected. The initial target sample-size was n = 50 animals, however recent analysis for the optimal size and number of biosamples has shown that between-transect variability in mean weight accounts for most of the variability. Consequently, in 2008, the number of animals collected was reduced to n = 25 and the number of transects increased to one for every 10 transects surveyed. Depending on the particular survey, a biosample may not be collected from all Subareas covered by the survey. Once collected, each sea cucumber is split and drained of internal organs and fluid, and individually weighed. Mean weight is calculated for each biosample and the weight estimate for the Subarea is the mean of all mean biosample weights located in that Subarea. Currently, no estimate of error is calculated for the mean weight parameter. If no biosamples are collected from a surveyed Subarea (and no bio-transects; see below), then the lowest weight estimate of all the other Subareas included in the survey area is used.

Permanent bio-transects

Research results from Experimental Fishery Areas (EFAs) indicate that mean sea cucumber weight can change from year to year and that large-scale changes can occur within a four year period (Hand et al. 2008). In order to obtain up-to-date, location-specific data on animal size, permanent transects were established in 2006 from which samples of sea cucumbers are collected. These permanent ‘bio-transects’ are marked at the deep and shallow ends with concrete blocks and joined with ground line. Bio-transects are surveyed by two divers, who collect every sea cucumber encountered within 2 meters of the line. Since the number of sea cucumbers harvested from these bio-transects is small compared to the total harvest from the local fisheries, and because two to three years will elapse between sampling, it is felt that subsequent year’s density and weight estimates will not be impacted by this small-scale removal. This approach also allows for an estimate of density which may be useful in un-surveyed areas as a first look at potential densities in the Subarea. Collections are done within two weeks of the fishery opening, by commercial harvesters already located in the area in readiness for the opening. The collected animals are split longitudinally and internal organs removed, then bagged and tagged with the bio-transect number. The sea cucumbers are weighed individually by a dock-side validator or a biologist. Mean weight for each bio-transect is calculated; no estimate of error is currently calculated. Since these samples are collected immediately prior to the opening of the fishery, the data are not available for biomass estimation until the following year. Similar to the rule used to apply results from biosamples, if there is more than one bio-transect in a Subarea, then the weight estimate used to calculate biomass is the mean of all mean bio-transect weights in the Subarea. If no bio-transect data are available from the surveyed Subarea (and no biosamples) then the lowest mean weight estimate of all Subareas in a survey is used. If two data sources are available for a Subarea, the most recently-collected data are used.

The number of bio-transect locations throughout the coast is rapidly increasing as new bio-transects are established in harvested areas that lack survey data. As the fishery evolves into a coastwide rotational fishery, careful planning is required to determine the optimal number of bio-transects, and to select, set-up and schedule surveys at these locations in order to best utilize the data.

The flow chart, below, summarizes the decision criteria used to select the most appropriate estimate of sea cucumber weight for a given Subarea (the full flow chart is in Appendix 2). Future work on mean weight estimation will include computing the error in mean weight estimates, to be incorporated into the range of biomass estimates that are provided to resource managers for quota setting.



2.1.3 <u>Priorities for future survey work</u>

As stated above, future survey work should concentrate on Subareas that have been harvested for the last 11 years but have not yet been surveyed, and on surveying new areas of coastline (i.e. Subareas that were closed during Phase 1 of the fishery) that are being considered for fishery expansion prior to re-opening. For Subareas that are open and still require survey work, priority should be given to those with the highest harvest intensity (Table 2). Subareas where bio-transect results indicate low densities should also be short-listed for surveying, as the overall population density within that Subarea may prove to be lower than extrapolated baseline density estimates. It is therefore expected that the need to estimate the biomass of sea cucumber populations without specific survey data for the Subarea in question will decline. Lastly, it may become desirable to focus survey effort on particular habitat types, as this would allow for a better analysis of habitat preferences and a better understanding of the ecological requirements of the species.

2.2 ESTIMATING BIOMASS DENSITY IN UNSURVEYED AREAS

As described in Section 2.1, biomass estimates are the product of linear density (c/m-sh), mean weight (kg) and shoreline length (m) estimates. In the absence of survey or sample data for a Subarea, linear density and mean weight must be extrapolated from data collected in other Subareas.

2.2.1 Linear Density Estimates

2.2.1.1 The First Baseline Density Estimate (1997)

In 1997, no surveys of sea cucumbers had yet been conducted in British Columbia. However, some surveys of *P. californicus* had been conducted in Alaska and Washington, USA (Larson et al. 1995, Bradbury et al. 1998) and linear densities had been calculated for use in their commercial fisheries. Using a precautionary approach, the lowest of all the lower 90% confidence bounds of mean linear density from Alaska (Larson et al. 1995) was used as the baseline linear density estimate for BC. Thus, linear density of 2.5 c/m-sh was applied to all Subareas in BC starting in 1997 (Boutillier et al. 1998). This baseline density was used for biomass calculation until surveys of coastal BC could be completed and analyzed to provide more locally-appropriate densities.

2.2.1.2 The Second Baseline Density Estimate (2003)

An extensive survey program was initiated in 1998, following recommendations of Boutillier et al. (1998) to collect fishery-independent data that would form the basis of stock assessments of *P. californicus* populations in British Columbia. From 1998 to 2002, in collaboration with the Pacific Sea Cucumber Harvester's Association (PSCHA) and coastal First Nations, seven dive transect surveys were conducted in six locations within the commercially-open fishery areas, comprising over 30% of the then-open shoreline (Figure 1). In 2003, linear densities were calculated for a total of 23 Subareas from the so-called 'open' survey data (Campagna and Hand 2004) to derive BC-based baseline density estimates. In the analysis, some Subareas were pooled due to low sample size, while other Subareas were excluded as they were deemed poor sea cucumber habitat of low commercial potential. The resulting analysis generated 15 bootstrapped 90% LCBs, the lowest of which was 5.08 c/m-sh. It was then recommended that the baseline linear density estimate of 2.5 c/m-sh be replaced by a new baseline density estimate of 5.08 c/m-sh. This density estimate was applied to all un-surveyed areas of the coast with a few exceptions: areas identified as being over-fished or areas comprised of marginal sea cucumber habitat (extreme exposure to ocean surf or complete lack of tidal current) were assigned the original baseline density estimate of 2.5 c/m-sh (Campagna and Hand, 2004). The new baseline density was considered precautionary because 5.08 c/m-sh represented the lowest of all 90% LCBs of estimated mean density from the surveys conducted to date. The density change, combined with updated mean weight estimates and shoreline lengths, resulted in a 20% increase in the annual quota from 424 t to 520 t in 2003.

2.2.1.3 The Third Baseline Density Estimates (2008)

In 2008, with 10 years of accumulated survey results and new information on shoreline energy characteristics (Hand et al. 2008), a new extrapolation protocol was adopted. Un-surveyed Subareas were assigned a precautionary linear density value that was based on exposure class (discussed in Section 2.3) and on Management Region (Figure 2).

Management Region

Five geographically-distinct regions are defined by DFO for use in quota calculations and licence distribution in the sea cucumber fishery: East Coast Vancouver Island (ECVI), West Coast Vancouver Island (WCVI), Central Coast (CC), North Coast (NC), and Queen Charlotte Islands/Haida Gwaii (HG) (Figure 2). Sea cucumber harvesting and density surveys are currently being conducted in all Regions except HG which was closed in 1996 as a temporary response to higher costs associated with fishing and transporting sea cucumbers from that region and for safety reasons (Hand and Rogers, 1999).

In 2008, all open survey data collected from 1998 to 2007 were re-analysed at the Subarea or the Analysis Area level. Analysis Areas were created by merging data from Subareas with low sample size (fewer than 10 transects) that share similar habitat and oceanographic characteristics. Transects from each Analysis Area, whether consisting of a single Subarea or several, were bootstrapped to obtain a 90% LCB, using 1000 iterations and a random seed of 756. There were notable differences in linear density estimates across Regions (Table 1). The highest densities were observed on the North Coast and Central Coast, where the minimum value of the 90% LCBs was 6.0 c/m-sh, a value higher than the previous baseline density estimate of 5.08 c/m-sh. The lowest density estimates were observed in the WCVI and the ECVI where the minimum of the 90% LCBs were 1.9 c/m-sh and 4.1 c/m-sh, respectively; both less than the estimate of 5.08c/m-sh. In order to maintain a precautionary approach in the management of the sea cucumber fishery, Regional density estimates were assigned to un-surveyed Subareas equal to the lowest of 90% LCBs of all density surveys conducted within that Region.

Following the PSARC Invertebrate Subcommittee acceptance of the recommendation to expand the sea cucumber fishery to other areas along the BC coast (Hand et al. 2008), density surveys were conducted in new Subareas identified for reopening for the 2008 fishery. These areas had not been harvested or surveyed within the previous 11 years, and included Subareas in Pacific Fisheries Management Area (PFMA) 9 (Rivers Inlet) and 10 (Smiths Inlet) on the Central Coast (CC), and PFMA 12 and 13 on the East Coast of Vancouver Island (ECVI). The mean density for Analysis Areas ranged from 2.0 to 15.9 c/m-sh (Table 3). In PFMA 9, the lowest 90% LCB of mean density was 2.7 c/m-sh (Subareas 3, 4, 5 and 6), while in PFMA 10 the lowest 90% LCB was 2.0 c/m-sh (Subareas 3, 4 and 5); both lower than the NC/CC regional density baseline estimate of 6.0 c/m-sh (Table 3). Similarly in PFMA 13 the lowest 90% LCB of density was 0.4 c/m-sh (for Subarea 11), a value considerably lower than the ECVI regional density estimate of 4.1 c/m-sh (Table 3). Surveying of new Subareas continued in 2009, with additional Subareas in PFMA 12, as well as several Subareas in PFMA 4 and PFMA Subarea 3-1. The 90% LCBs of mean density for Analysis Areas ranged from 1.7 to 14.4 c/m-sh (Table 3).

The conclusion from these new survey results was that sea cucumber density varies considerably and that all Management Regions could have low or high densities. However, the Regional baseline density estimates that were applied to unsurveyed areas were not altered with the new results. Firstly, some of these new areas were not considered to be representative of commercial-quality habitat for sea cucumbers, and secondly, because a decrease in Regional baseline density by as much as 90% would lead to large and unrealistic quota reductions. These results did, however, prompt a review of the use of Regional densities as a baseline for extrapolation to unsurveyed areas. Since density apparently can't be predicted based on geographical location, the decision was made to discontinue the approach of using baseline density estimates in unsurveyed areas and to survey all new areas prior to re-opening. Existing unsurveyed, yet open, areas would be targeted for surveying as described in Section 2.1.1.

The survey and subsequent harvest in some of the new areas, notably PFMAs 9 and 10, also led to an examination of spatial allocation of harvest effort relative to population concentrations. Of the 7 Subareas in PFMA 9 that were opened post-survey, 6 were not harvested. Of the 9 Subareas in PFMA 10 that were surveyed and opened, 6 were not harvested. Not surprisingly, harvest effort was concentrated in the locations of highest density. It has been observed that some areas where the overall density is low are characterized by a patchy distribution of animals, such that some locations within it have high densities (DFO, unpublished data). In these cases, there is concern that the few aggregations that exist may be depleted by harvest and that reproductive output may be reduced over time. It is assumed that commercial harvesting will continue to be focussed on the aggregations and, therefore, fishery managers may want to consider not opening Subareas where 90% LCB density estimates are less than 2.50 c/m-sh and, further, to phase out currently-open areas of low density. Further analysis of the relationship between the degree of clumping and density should be carried out.

2.2.2 Mean Weight Estimates

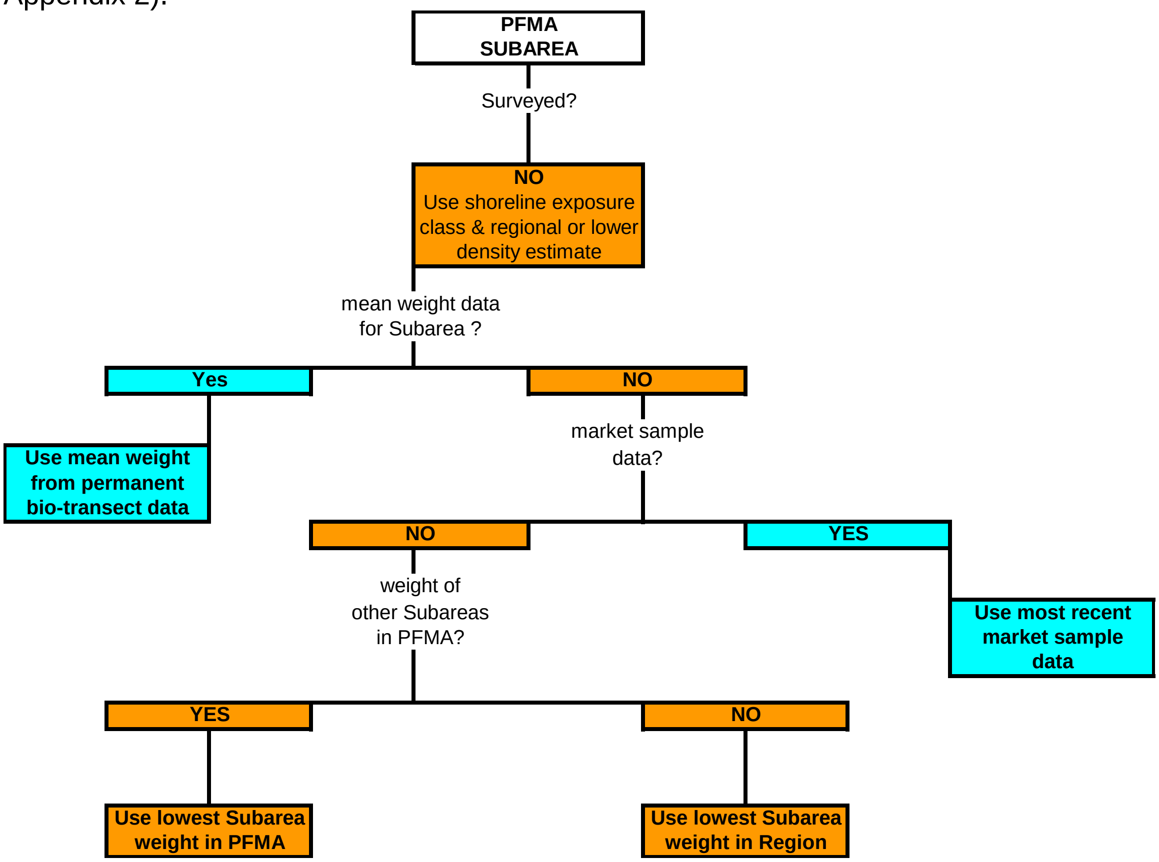
In 1995, 160 samples of harvested sea cucumbers (termed "market samples") were collected and weighed during the BC sea cucumber fishery and the resulting mean weight of 263 g was applied to populations coastwide (Rome and Clarke, unpublished manuscript). In 1997, with the implementation of the phased approach to the development of the fishery, a more intensive market sampling protocol was initiated (Campagna and Hand 2004). Dockside validators randomly selected approximately 25 animals per sample from the landed product and weighed each sample to the nearest 50 grams. The number of samples taken from each landing depended on how busy the validator was at the time. Average animal weight was obtained by dividing the total weight of the sample by the number of animals in the sample. Dockside validators sampled commercial landings from 81 Subareas from 1997 to 2001 and the mean weights obtained during those five years were incorporated into quota calculations for the 2002 and 2003 fisheries.

After a review of market sample data collected from 1997 to 2003 (Humble et al. 2008), the PSARC sub-committee accepted the recommendation to discontinue the collection of market sample data because the program failed to provide spatially-explicit data that would allow an evaluation of fishery effects on population size structure. The variability in animal size over short distances, the variable size selection by harvesters and the uncertainty in the exact sample location of market samples precluded inter-year comparisons. However, market samples represent the only data on sea cucumber mean weight in many un-surveyed Subareas and therefore the estimates from market sample data, some dating back to 1995, are still being applied to unsurveyed areas.

Bio-transects are now being used in several Subareas to estimate the mean weight of sea cucumbers, as described in Section 2.1.2. Unsurveyed areas represent a top priority for new bio-transect locations, since our information on mean weight from these areas is at best 6 years old (last market sample year 2003). In contrast, mean weight information in surveyed areas is at most 4 years old, given the 4 year cycle used for these surveys.

In unsurveyed Subareas, where no bio-transect or biosample data exist, the lowest mean sea cucumber weight from the other Subareas in the same PFMA is used for biomass calculations. If no Subareas in a PFMA have mean weight data and no market sample data exists, then the lowest weight estimate calculated for a Subarea in the same region is used. This precautionary extrapolation will hopefully be replaced by data as more surveys are conducted and more bio-transects are installed.

The flow chart (below) summarizes the decision criteria used to select the most appropriate estimate of animal weight for the Subarea (the full flow chart can be seen in Appendix 2).



It is expected that the need to attribute a sea cucumber weight estimate to a Subarea lacking sample data will gradually diminish as more bio-transects are set-up along the coast. New bio-transect locations are installed each year, concentrating first on un-surveyed Subareas. This will provide mean weight data and also some density data to aid in assessing which un-surveyed areas should be made a priority for up-coming surveys.

2.3 SHORELINE LENGTH

For each Subarea that is open to commercial harvest, an estimate of shoreline length is required in order to compute total biomass from biomass density estimates, whether areas are surveyed or unsurveyed. Analyses were conducted in 1996 to provide a measure of shoreline length based on zero chart datum (defined by Canadian Hydrographic Service (CHS) as either Lower Low Water, Large Tide or Lowest Normal Tide and is stated in the title of each chart). Shoreline length was estimated, at the Subarea level, by applying a raster-based GIS program (Compugrid; G. Langford; version 7.x; 1980's) at 20m cell resolution (Boutillier et al. 1998). Although vector-based GIS software and more accurate basemaps have become available since that time, the original measurements are still used for biomass calculations because they are more precautionary. Shorelines measured using ArcGIS were longer by approximately 10%, due to the different spatial models and a presumably more accurate measuring algorithm. Applying ArcGIS to the newer Canadian Hydrographic Service (CHS) charts resulted in further increases in length estimates, likely because the shoreline is more accurately depicted. Since using higher shoreline length estimates would result in an increase in estimated biomass and higher quota options, a decision to adopt new basemaps and measurement tools is deferred until spatial data becomes available that are at least as representative of subtidal zone as the current dataset. The concern is not so much the accuracy of shoreline measurements, but how well the subtidal habitat is indexed by shoreline length estimates. A seamless isobath of 10m would represent the fishing zone better than the zero chart datum. Indeed, if an accurate measure of subtidal habitat between 0m and 20m becomes available, that would likely be the best estimator to use in conjunction with spatial estimate of density.

A biophysical shore-zone mapping system, developed by the provincial government of British Columbia, classified the BC coast into six distinct categories based on exposure, as follows: very protected, protected, semi-protected, semi-exposed, exposed and very exposed (Searing and Frith 1997, see also Hand et al. 2008 for a description of exposure classes and the shore-zone database). An analysis of sea cucumber survey densities and fishing effort by exposure class revealed lower mean densities and little fishing effort on exposed and very exposed shoreline (Hand et al. 2008). This led to the recommendation that areas of high exposure, low productivity or unfishable shoreline be eliminated from estimates of fishable biomass. Consequently, beginning in 2008, shoreline classified as Very Exposed received a density value of 0 c/m-sh and Exposed and Semi-exposed shoreline was assigned the original baseline density estimate of 2.5 c/m-sh. The remaining shoreline in the Subarea was then assigned either a surveyed density or a Regional density (discussed above). (In 2009, it was recognized that semi-exposed shoreline should have been considered as fishable shoreline, and densities were re-assigned accordingly.) During surveys, non-navigable stretches of shoreline and hazardous-diving stretches of shoreline are noted, measured and deducted from the fishable shoreline in the Subarea.

Future work on shoreline length will include the development of an estimate of the error in shoreline length measurements in order to better express the range of uncertainty in biomass estimates.

2.4 ACCURACY OF BIOMASS ESTIMATES

Data are available to evaluate the accuracy of estimates of biomass. In 1997, intensive sea cucumber surveys were conducted to evaluate the accuracy of biomass estimates derived from survey transects (Campagna and Hand 1999). Sea cucumber populations within defined geographic areas were surveyed with both randomly and systematically selected transects and then immediately harvested, with every effort being made to remove 100% of the individuals. The total removals, therefore, provide an estimate of actual population size which can be compared to the biomass estimate from transect sampling.

Those survey data are further analyzed in this paper to compare two different methods for estimating biomass: linear and spatial. High resolution bathymetry was recently captured for the Gulf Islands study area, providing an opportunity to evaluate the two methods of calculating biomass. The linear method is as previously described, while the spatial method uses density defined as numbers of cucumbers per square metre of sea floor (c/m^2). Linear density has been the standard in quota calculations for the sea cucumber fishery because coastwide data of shoreline length is readily available. It allows for simple adjustments to estimates of fishable biomass because shoreline can easily be removed as reserves and closures are implemented. The linear method, however, does not incorporate the actual amount of seafloor surveyed and therefore may be less biologically significant. Thus, using estimates of shoreline length and spatial area, along with mean sea cucumber weight, biomass can be calculated for each method and compared to the actual population size.

Until recently, estimates of seafloor area have been very inaccurate, but, as more high resolution single and multibeam bathymetry data become available, biomass calculations based on spatial density and seafloor area have become more attainable. The objective of this re-analysis of the intensive survey and harvest data is to evaluate the accuracy of the linear and spatial methods of density and biomass estimation in order to provide guidance on which one might be more appropriate for use in the stock assessment of sea cucumbers.

2.4.1 <u>Linear versus Spatial Estimates of Biomass</u>

The linear method of calculating transect-density (dl_t) involves dividing the total number of sea cucumbers observed on a transect (δ), by the width of the transect (4 m).

$$dl_t = \delta / 4$$

A linear density is calculated for each transect surveyed, and all the transects in a given area are then bootstrapped to obtain confidence intervals (see Section 2.1.1). Various estimates of sea cucumber density from this distribution are then multiplied by the mean weight of sea cucumbers in the area and the shoreline length of the area, producing a distribution of biomass estimates for the area.

To calculate spatial density for a transect (ds_t), the total number of sea cucumbers observed on a transect (δ) is divided by the product of the length (l_t) and width (4 m) of the transect.

$$ds_t = \delta / (l_t * 4)$$

The transect spatial densities are then bootstrapped and selected estimates from the resulting distribution of spatial density estimates are multiplied by the total area (m^2) of seafloor between 0 and 15 m chart datum and the mean weight of sea cucumbers in the area to obtain an estimated biomass of the sea cucumber population.

2.4.1.1 Survey and Analytical Methods

With input from commercial fishermen, based on their personal knowledge of the area, three small sites were selected for the intensive survey and depletion study; a low density site (PFMA 17-16), a medium density site (PFMA 17-16) and a high density site (PFMA 29-05) (Figures 3, 4 and 5). Each site had a 200 m straight line measured at the shallow and deep ends. The site boundaries were then marked with concrete blocks and floats (Campagna and Hand 1999). A total of 9 or 10 transects were surveyed per site following standard survey protocols (see Section 2.1.1, and Campagna and Hand 2004). Immediately following the survey, each site was thoroughly harvested so as to obtain a second estimate of density and mean weight. Animals were hand picked by divers, put into mesh bags and, on board the boat, emptied into a tote. There they were split longitudinally with a knife and placed into plastic lined cages. All animals were counted, and once at the dock, the cages were weighed, providing a mean split weight estimate for the sea cucumbers at each site (Campagna and Hand 1999).

Single-beam acoustic surveys using Quester Tangent QTCView technology were conducted in the three sites in February, 2009, to obtain detailed bathymetry of the survey areas. For this study, we used the vector-based low water shoreline, developed by the Canadian Hydrographic Service (CHS) and released in 2008, for both the linear and spatial biomass calculations. This linework is considered the most accurate representation of low water shoreline currently available and is more appropriate for this comparative analysis than estimates of area and shoreline length obtained from the raster model described in Section 2.3. For the spatial density calculations, the area of sea floor within each site was defined using the CHS low water shoreline as the upper depth boundary, the 15 m depth contour from Quester Tangent survey data as the lower depth boundary, three 200 m lines created in ArcGIS to provide sizing guidance for polygon creation and plot-boundary latitude and longitude data archived in the sea cucumber database. Polygons were constructed and the area measured for each of the three areas locations using ArcGIS 9.3. The shoreline segments of the polygons were measured using ArcGIS 9.3 software to obtain the shoreline length for use in linear calculations.

Confidence intervals around the mean estimates were created via bootstrapping, using the custom in-house program Cuke Analysis. The mean and lower confidence bounds of the bootstrapped transect density were used to estimate population and biomass estimates.

Linear estimates of population size *(P_{lin})* were calculated from

$$P_{lin} = dl * L_{shoreline}$$

where *dl* is an estimate of linear density and $L_{shoreline}$ is the shoreline length of the site. Spatial estimates of population size (P_{spat}) were calculated from

$$P_{spat} = ds \ * A_{polygon}$$

where *ds* is an estimate of spatial density and $A_{polygon}$ is the spatial area of the site. Biomass was then calculated by multiplying the population estimates by the mean weight of sea cucumbers in the area.

2.4.1.2 Results

Harvest

A total of 936 sea cucumbers (355 kg) were harvested from the low density site, 6149 (1,839 kg) from the medium density site, and 14,329 sea cucumbers (3,441 kg) from the high density site (Table 4).

Mean weight

The mean weight of sea cucumbers harvested from the low, medium, and high density sites was 0.379 kg, 0.299 kg, and 0.240 kg, respectively. As sea cucumber density increased, mean weight decreased.

Linear density estimates

The shoreline length measured 212 m, 208 m and 202 m for low, medium and high density sites, respectively. The estimated mean density from transects was 4.30 c/m-sh (n=10) in the low density site, 24.35 c/m-sh (n=10) in the medium density site and 65.47 c/m-sh (n=9) in the high density site (Table 4).

*Comparing biomass from **linear** density estimates and total harvest*

Population size and biomass, as calculated from the mean estimate of linear density, was 912 individuals and 345.5 kg in the low-density site, which was less than the harvested population by 2.6% (Table 4). More sea cucumbers were harvested than were estimated to be present in the site from linear density estimates. Computed estimates for the medium-density site were 5,065 individuals and 1,514.4 kg, less than the harvested amount by 17.6%. Estimates calculated for the high-density site were 13,225 individuals and 3,174.0 kg, less than harvested amounts by 7.7%. When estimates from the lower confidence bounds are compared, the difference increases (Table 4).

Spatial density estimates

The area of sea floor between 0 and 15 m in each site was 56,722 m^2, 26,368 m^2 and 50,635 m^2 for the low, medium and high-density sites, respectively. The mean spatial density calculated from bootstrapping survey results was 0.0200, 0.2353, and 0.2991 c/m^2 for the low, medium and high density sites, respectively (Table 4). Note that the difference in spatial density between the medium and high density sites was less than it was for the linear estimates because the medium-density site had a steeper slope and was therefore smaller in area.

*Comparing biomass from **spatial** density estimates and total harvest*

Population size and biomass, as calculated from the mean estimate of spatial density, was 1,134 individuals and 430.0 kg in the low-density site, higher than the amount harvested by 21.2%. Estimates for the medium-density site were 6,203 individuals and 1854.8 kg, higher than harvested amounts by 0.9%. Estimates for the high-density site were 14,329 individuals and 3634.9 kg, higher than the harvest amounts by 5.7% (Table 4). When using the lower 90%, 95%, or 99% confidence bounds of the mean density, population and biomass estimates were less than harvested amounts (Table 4).

2.4.1.3 Discussion

Based on this study, spatial estimates of sea cucumber abundance appear to be closer to the true population abundance (with true populations determined by harvesting, and assuming 100% harvest in the study plots) than the linear estimates of sea cucumber abundance. Mean population abundance derived from spatial density was within 6% of the true population for the medium and high-density sites. The larger (+21.2%) difference observed in the low density site is likely due to lower precision at low densities. Abundance estimates based on spatial density (supposing accurate estimates of seabed area are available) are more meaningful because they are based on measurements of the actual sea floor. Comparisons of spatial density estimates between locations are less influenced by coastline shape. In contrast, linear density estimates are highly affected by the subtidal bathymetry. Sections of shoreline with steeper slopes in the subtidal have less surface area between the sea edge and 20m (the practical limit to diving) than sections with gentler slopes. While the linear density may be very different between these types of habitat, the spatial density could be quite similar. This is also true for areas with concave shorelines (i.e. bays) or areas containing near-shore islands; linear estimates in these areas may over-estimate population size because the measure of shoreline is high relative to the actual subtidal habitat. Conversely, linear density calculations for convex shorelines (i.e. headlands) could result in an under-estimate of population size because shoreline length is small relative to the subtidal habitat. Spatial density calculations do not have this inherent error.

Despite these arguments for spatial density, there are several advantages in continuing to use linear density in calculating population size and biomass for British Columbian populations. Shoreline length estimates are readily available, whereas very few areas of the coast have hi-resolution bathymetry in water shallower than 30 m, a requirement for using the spatial methodology. That in itself is an unavoidable barrier. In addition, making adjustments to the shoreline estimates, such as removing shoreline segments for reserve sites, closures, hazards, etc., is easier using linear methods. The Canadian Hydrographic Service maintain accurate low water and high water shoreline shape files and is currently attempting to complete their coverage of BC waters using multibeam surveys. However, it will be many years before near-shore (0-60m) bathymetric data are available.

Overall, spatial estimates of biomass are more accurate, but have a tendency to slightly over-estimate the actual biomass at the mean level. Linear estimates consistently underestimated the biomass, even at the mean level. By necessity, linear methods must continue to be used for production biomass estimates in British Columbia.

2.5 PRECISION OF BIOMASS ESTIMATES

The precision of density estimates (ratio of the difference between the mean estimate and the lower 90% confidence bound, to the mean) from the surveys conducted between 1998 and 2007 varies between 55% and 10% (Table 1). Seven of the 21 analysis areas had a precision of 20% or less in all years surveyed, 15 had a precision of 30% or less in all years surveyed (Table 1). The greatest variability is associated with low sample size (number of transects) and low density. An analysis of existing survey data should be conducted to determine the optimal sample size of transects to cover an area. If further data are needed, intensive surveys may be required. In particular, the optimal number transects per kilometre of shoreline to survey in order to yield acceptable precision for both low density and high density populations is desirable.

3 ESTABLISHING A HARVEST RATE

Since 1997, the annual total allowable catch (TAC) has been calculated using an exploitation rate of 4.2% of the estimated biomass of the population. This conservative harvest rate was taken from work conducted on the same species in Washington State (Alex Bradbury, Washington Department of Fish and Game, unpublished document) because of the lack of local data on productivity of *P. californicus* populations.

A key product of the 10-year time series of data obtained from four experimental fisheries areas (EFA) during the Phase 1 fishery (Hand et al. 2008) was estimates of maximum sustainable harvest rate (MSHR). A latent productivity model was developed to represent the dynamics of a sea cucumber stock and used to estimate the latent productivity, or the rate at which the biomass will increase if there is no harvest. The MSHR corresponds to the maximum of the latent productivity. The one-percentile of the MSHR ranged from 0.035 to 0.103 of virgin biomass per year over the four EFAs. In other words, there is 99% confidence that the maximum sustainable harvest rate is greater than those values in each of the areas. The low value of 0.035 corresponded to the Laredo Inlet EFA, which is a fjord-type habitat of low biomass density, and characterized by fishermen as being unproductive for sea cucumbers and unlikely targeted for harvesting. Hand et al. (2008) recommended an annual harvest rate of 6.7% for all areas except those that have low productivity. It was further recommended that coastal areas of low density and productivity should not be considered for commercial harvest. This recommendation was supported by Humble et al. (2008) who found, in simulation modelling, that sea cucumber populations that had low numerical recovery (increase in density) would require more than 5 years between harvesting to maintain a spawning biomass greater than 25% of unfished levels.

For surveyed Subareas, the suitability of the recommended 6.7% harvest rate can be empirically assessed by comparing measured estimates of biomass density to those in the productive EFAs. However, further analysis is needed to provide firm threshold density or biomass levels that would guide resource management decisions on opening new fishery areas. Minimum thresholds for either opening an area or using 6.7% harvest rate would likely be expressed as spatial density, which would remove the effect of differing subtidal slopes between areas. In the meanwhile, results from modelling the experimental fishery data suggest that a 6.7% harvest rate is sustainable in locations where biomass densities are higher than 1.5 kg/metre of shoreline or 0.02 kg/metre-squared (Figure 20 in Hand et al. 2008)

The assumption that productivity is determined entirely from factors internal to each experimental site is a key assumption of the model, and, if violated, could lead to an overestimation of harvest rates. Although sea cucumbers are low-mobility animals, there is no data to suggest that net vertical or horizontal migration into a site would not have an effect on model results. This is a knowledge gap that needs to be addressed. To that end, initial work has been conducted and further work is being planned to survey sea cucumbers over their entire depth range, using Remote Operated Vehicle (ROV) technology. In conjunction with this research, experimental depletion of a small area of adult sea cucumbers from shallow water will be conducted while monitoring shallow and deep-water population trends pre and post-harvest. ROV-derived density estimates still need to be calibrated to SCUBA observations and work will progress to accomplish this. A sea cucumber tagging program, using injected fluorescent elastomer tags, has been initiated and will, if successful, contribute to these efforts.

4 ESTABLISHING A LIMIT REFERENCE POINT

An additional output of the latent productivity model was estimates of limit reference points; delineations between the Cautious and Critical stock status zones (DFO 2006). The model incorporated a minimum relative biomass value ($x_{truncate}$), expressed as a fraction of the virgin biomass, because the experimental data in each EFA did not span the entire range of relative biomass possible (Hand et al 2008). In other words, none of the populations in the experimentally-harvested sites was depleted to extremely low levels and, therefore, there were no data to indicate how the system would behave when the hypothetical biomass became lower than the lowest end of the range of experimental data. In the model, if the biomass fell below the value of $x_{truncate}$, the population is forced to crash. Modelled values of $x_{truncate}$ were used as a basis to establish a limit reference point (LRP). Hand et al (2008) suggested that a conservative LRP of 50% of B_0 (biomass in the un-harvested state) be adopted for the sea cucumber fishery, pending further evaluation of results from the on-going experimental fisheries. This value is more precautionary than the 99 percentile on $x_{truncate}$ for three of the four EFAs (the exception being Laredo; Table 14 in Hand et al. 2008).

If the biomass of sea cucumbers in a Subarea falls below 50% of B_0, the area would be closed to harvest. Re-opening the Subarea would require that the population have recovered to at least 50% B_0, as determined from survey data. This LRP has been implemented in the Trutch Subarea (6-9) where the most recent of three surveys found that the density estimate (90% LCB) dropped from 8.8 c/m-sh in 2001 to 3.1 c/m-sh in 2009; a 64% decrease. The Trutch survey time-series shows the importance of continued monitoring of open Subareas to determine the status of the sea cucumber populations and whether the LRP has been reached. It should be noted that the abundance decreases that occurred in all other surveyed areas during Phase 1 annual fisheries were in the range of 10% to 23%.

5 ESTABLISHING NO-TAKE RESERVES

5.1 PURPOSE AND UTILITY OF RESERVES

Marine protected areas, or no-take reserves, have become a popular tool for the conservation of ecosystems and for fishery management of individual or groups of species. No-take reserves have been shown to have many beneficial effects on populations of marine species, including increases in recruitment, abundance, individual animal size and overall biomass (Barrett et al. 2007, Tetreault and Ambrose 2007, Harmelin-Vivien et al. 2008, Lester and Halpern 2008). Increases in recruitment and abundance within reserve boundaries may in turn lead to increases outside the reserve through larval dispersal and spillover effects, where animals spread out beyond the reserve boundaries into adjacent areas (Jamieson 2000, Roberts et al. 2001, Russ et al. 2004, Alcala et al. 2005, Francini-Filho and Moura 2008, Harmelin-Vivien et al. 2008). A significant additional benefit of reserves is a source of assessment data that can be compared to areas where fishing has occurred (Schroeter et al. 2001, Francini-Filho and Moura 2008). Fishery-independent data collected in reserves provides the means to monitor natural trends in population abundance and to compare trends between fished and unfished areas for improved stock assessment.

For fishery management purposes, reserves are created to protect a portion of the population as a safeguard against overfishing, to provide a source of recruitment, and to increase production in adjacent populations through spillover effects. To achieve these objectives, the appropriate sizes, number and locations of reserves need to be determined, which requires a knowledge of daily, seasonal or annual movement patterns of the species. Information on size or age at maturity allows for a better understanding of the timing of larval/juvenile recruitment to populations both inside and outside the reserve. As more life cycle parameters are considered in the reserve creation process, the probability that reserves will achieve their intended purpose will increase.

The many benefits of reserves do not come without cost. The initial reaction from harvesters may be negative, since the closure will be viewed as a direct loss of access to harvestable biomass. There is a cost to creating and maintaining reserves, as effort must be spent on monitoring and management. Researchers wanting to quantify the changes occurring in a reserve need to devote efforts to surveying both reserve and adjacent populations. Rigorous, well designed experiments are required to fully appreciate the benefits of reserves on the included and surrounding populations (Willis et al. 2003). This is especially true for invertebrate species for which quality studies are particularly lacking. Enforcement can become increasingly demanding and complex as more types of uses and states of protection are included. Resource managers will also need to keep track of reserve locations, made more complicated if different species have different reserve areas.

5.2 RESERVES FOR PARASTICHOPUS CALIFORNICUS

Between 1997 and 2008, during the Phase 1 fishery, 75% of the BC coast was closed to commercial harvesting of sea cucumbers (Hand et al. 2008). The re-opening areas of coastline, approved by the Invertebrate Subcommittee of the Pacific Science Advice Review Committee in 2007, is an opportune time to create a network of no-take reserves throughout the BC coast. For *P. californicus*, determining the size, location and monitoring requirements of reserves is challenging because information on adult movement patterns, ages at key life cycle stages, reproductive output and success and larval distribution patterns is limited.

The amount of adult spillover of adult sea cucumbers into adjacent harvest zones may only benefit the immediate neighbourhood of the reserve, as *P. californicus* are estimated to have an average daily displacement of between 3.9 m and 4.6 m per day (da Silva et al. 1986; Cieciel 2004) and an observed maximum displacement of 20.2 m in 24 hours (Cieciel 2004). However, the annual movement and migration patterns of *P. californicus* are not known and it is possible that spillover effects may be greater, especially if a high-to-low density gradient was to develop between reserve and non-reserve areas.

Larval spillover is much more likely to benefit adjacent areas because the planktonic larval stages of *P. californicus* are between 51 and 125 days (Strathmann 1978; Cameron and Fankboner 1989). The distance of drift from the site of fertilization could be large, depending on the speed and direction of tidal currents. Tidal current modeling may provide a better understanding of larval dispersal patterns and identify source and sink populations, although the complexity and the spatial and temporal variability of ocean currents makes their identification difficult and highly uncertain.

Reserves would also provide valuable stock assessment information. By monitoring natural population trends and comparing to trends in harvested areas through regular surveying, harvest effects can be better incorporated into management plans. Non-impacted populations were used by Hand et al. (2008) to compare survey data from unharvested areas to adjacent areas with varying levels of harvest pressure. Having baseline data on density, size and biomass would allow for time-series analysis and may make it possible to develop correlations and predictions about the effects of natural phenomena such as climate change, El Niño/La Niña events and long-term recruitment trends in the absence of fishing.

5.3 RESERVE REQUIREMENTS

Since *P. californicus* have limited mobility, the size of an individual reserve need not be very large to encompass an adult population or a segment of the population. However, because larval settlement may occur far from the site of fertilisation, small reserves may not be self-sustaining and may instead rely on breeding populations outside of the reserve boundaries to supply recruits. It is not known whether source-sink population dynamics are important to sea cucumber populations, however modeling of *P. californicus* larval dispersal patterns would aid in decisions on the size and location of reserve sites.

Reserve boundaries need to be easily defined in fishery management plans and easily recognized by fishermen in the field in order to minimize the risk of accidental poaching. For monitoring purposes, the size of a reserve should be small enough to permit surveying in 1-2 days, or approximately 15-35 transects. For statistical purposes, the number of transects per meter of shoreline should be similar to adjacent harvested areas, to allow for meaningful comparisons, and the reserve should contain at least 10 transects to allow for confident use of bootstrapping techniques.

The reserves themselves must be representative of adjacent open areas. General habitat similarities should also be taken into account. Although nearshore habitat classification is currently not available, at least some cartographic features should be used to make sure reserve areas represent the surrounding harvested areas. For instance, if the surrounding area has many small islands, the reserve should contain small islands.

Overall, we currently do not have sufficient knowledge of *P. californicus* biology to set a goal for the amount of shoreline that should be categorized as no-take reserves. However, as new coastline is being surveyed and reviewed for potential opening, we recommend striving for 20 percent of the harvestable shoreline to be categorized as sea cucumber no-take reserves. This is a precautionary arbitrary number that is commonly used in the literature. This target should be modified as more information becomes available to guide decisions on the optimal reserve network design, or if the goals and reasoning for no-take reserves changes. At present, we are proceeding to designate portions of surveyed areas as no-take reserves, the size and location of which largely being determined by density being representative of surrounding areas, ease of defining in the management plan to foster compliance, general location relative to harvested populations to maximize the likelihood that larvae will disperse there and manageable size for ongoing monitoring.

There would be merit in attempting to protect more than one species in the same no-take zone and overlap reserve locations as much as possible given different habitat requirements. In general, no-take reserves need to be carefully planned to achieve maximum benefits. It may be difficult to demonstrate the beneficial effects of harvest refugia on surrounding sea cucumber populations. Given that estimates of sea cucumber stock size and productivity are uncertain and until more is known on recruitment mechanisms, it would seem advisable to preserve a network of areas since they could be important and, at the very least, will provide valuable stock assessment information.

6 GENERAL DISCUSSION

The sea cucumber fishery has undergone dramatic changes since it was initially reviewed in 1995 (Phillips and Boutillier 1998) and in 1996 (Boutillier et al. 1998). Biomass estimation has evolved from being based on unpublished density data from Alaska and estimates of bed area from logbook reports. Harvest rates were initially derived from the mortality rate-based Gulland model, and then based on unpublished analyses from Washington State. There are still significant gaps in our knowledge of growth rates, recruitment, age structure and natural mortality for this species, although research is currently underway to examine the growth rates of juvenile *P. californicus* and seasonal trends in adult sea cucumber weight and migration patterns following depletion harvest. Research over the last 12 years has led to a large accumulation of data on the density and mean weight of *P. californicus* populations and an increase in knowledge on harvest impacts, making the BC sea cucumber fishery one of, if not the most, data-rich sea cucumber fishery in North America.

There are numerous protocols and decision rules in place that ensure the fishery is precautionary. The recommended target harvest rate is the lower one percentile of estimates, therefore we are 99% certain that the true MSY is higher. Biomass is estimated using the lower 90% confidence bound on linear density estimates, which may underestimate the density even at the mean level. Shoreline length estimates continue to be based on the ArcGIS ‘cucland’ shapefile, even though more up to date ArcGIS shapefiles are available, because it is more precautionary. Areas that are being contemplated for opening to the fishery will first be surveyed and have quota options based on surveyed biomass rather than on extrapolated density estimates. There is a growing system of no-take reserves being created throughout the BC coast; these reserves protect a portion of the adult population as a hedge against stock assessment uncertainty, provide a source of larvae to surrounding areas and allow a comparison of abundance trends between fished and unfished areas. Finally, only the shallow portion of sea cucumber populations is assessed and exploited, leaving the deep-water stocks, which are known to exist but are not quantified, as a potentially additional spawning reserve.

Many improvements have been made in the science and assessment of the sea cucumber fishery in BC. Assessment and research methods continue to improve and adapt to the best available techniques in order to ensure the continued sustainability and success of the BC sea cucumber fishery.

7 RECOMMENDATIONS

1. Future survey work should focus on Subareas that have been harvested for the last 12 years but have never been surveyed, on new areas of coastline being considered for fishery expansion, and in index areas with existing time-series of data.
2. Areas that remain unharvested after being open since 1997 should be closed, as they only serve to inflate the TAC for other Subareas in the same Quota Management Area.
3. Subareas where the lower 90% CB of the density estimate is less than 2.5 sc/m-sh should not be open to commercial harvest.
4. Determine the optimal number of bio-transects, and select, set-up and schedule surveys at these locations in order to best utilize the data.
5. Analyze existing survey data to determine the optimal number of transects required for adequate precision of density estimates.
6. Investigate the timing and process of sea cucumber re-colonization of depleted areas. This includes studying migration from adjacent areas and vertical migration from deep water populations to shallow waters.
7. Investigate *P. californicus* larval production and distribution in coastal BC waters, including areas of source and sinks for regional populations.
8. Develop methodology to estimate error in mean weight and shoreline length estimates in order to incorporate all sources of variability in the biomass estimates.

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Table 1. Mean and lower 90% confidence bound of estimated sea cucumber density (number per metre of shoreline) of Subareas surveyed between 1998 and 2007. Precision is ((mean density – 90% LCB)/mean density)x 100.

Survey	Region	Year	PFMA	No. of transects	Precision	Mean density (c/m-sh)	90% LCB (c/m-sh)
Area 7	CC	1998	7-15	67	19	8.4	6.8
Area 7	CC	2002	7-15	67	16	10.8	9.1
Area 7	CC	2006	7-15	66	20	7.9	6.4
Area 7	CC	1998	7-17	112	15	16.1	13.7
Area 7	CC	2002	7-17	105	13	13.6	11.8
Area 7	CC	2006	7-17	105	12	14.4	12.6
Area 7	CC	1998	7-30	18	30	18.0	12.7
Area 7	CC	2002	7-30	18	28	16.0	11.5
Area 7	CC	2006	7-30	18	29	13.5	9.6
FitzHugh	CC	2002	8-3,4	122	26	12.1	9.0
FitzHugh	CC	2006	8-3,4	122	14	11.1	9.6
FitzHugh	CC	2002	8-5	23	19	15.3	12.4
FitzHugh	CC	2006	8-5	23	23	11.7	9.0
FitzHugh	CC	2002	8-6	12	35	38.2	24.9
FitzHugh	CC	2006	8-6	12	22	35.1	27.4
FitzHugh	CC	2002	8-16	37	20	13.6	10.9
FitzHugh	CC	2006	8-16	37	22	9.9	7.7
GilGribbell	NC	1999	6-3	75	14	11.9	10.2
GilGribbell	NC	2003	6-3	75	16	14.3	12.1
GilGribbell	NC	2007	6-3	73	17	14.2	11.9
GilGribbell	NC	1999	6-5	94	12	18.6	16.3
GilGribbell	NC	2003	6-5	110	10	17.7	15.9
GilGribbell	NC	2007	6-5	111	10	15.4	13.8
GilGribbell	NC	1999	6-6	39	15	32.3	27.5
GilGribbell	NC	2003	6-6	39	17	20.3	16.9
GilGribbell	NC	2007	6-6	40	17	19.9	16.4
GilGribbell	NC	1999	6-7	16	23	28.9	22.4
GilGribbell	NC	2003	6-7	16	25	18.8	14.1
GilGribbell	NC	2007	6-7	15	24	20.0	15.2
GilGribbell	NC	1999	6-27,28	12	47	26.5	14.1
GilGribbell	NC	2003	6-27,28	12	24	16.1	12.2
GilGribbell	NC	2007	6-27,28	12	23	15.1	11.7
Trutch	NC	2001	6-9	137	17	7.2	6.0
Trutch	NC	2005	6-9	137	16	7.2	6.0
A12	ECVI	2000	12-40	63	19	8.0	6.5
A12	ECVI	2004	12-40	63	21	5.2	4.1
A12	ECVI	2000	12-41	109	18	6.8	5.6
A12	ECVI	2004	12-41	66	19	9.6	7.8
Tofino	WCVI	2001	24-4	16	28	8.5	6.1
Tofino	WCVI	2005	24-4	14	20	10.6	8.5
Tofino	WCVI	2001	24-5	26	23	5.8	4.5
Tofino	WCVI	2005	24-5	26	22	6.5	5.1
Tofino	WCVI	2001	24-6	12	55	7.0	3.1
Tofino	WCVI	2005	24-6	13	47	4.3	2.3
Tofino	WCVI	2001	24-7	27	43	11.8	6.8
Tofino	WCVI	2005	24-7	27	29	5.0	3.6
Tofino	WCVI	2001	24-10	32	37	3.4	2.1
Tofino	WCVI	2005	24-10	32	39	3.1	1.9
Tofino	WCVI	2001	24-14	13	29	6.7	4.8
Tofino	WCVI	2005	24-14	12	35	4.5	2.9

Table 2. Mean annual landings (kg round weight) of Parastichopus californicus *for years targeted during 1997-2007 and 2004-2007, with shoreline length (km), survey status and harvest intensity (mean harvest per metre of shoreline, kg/km) by PFMA Subarea. Subarea Rank = [(Rank 97-07)/(# Yrs Harvested 97-07) + (Rank 04-07)*2/(# Yrs Harvested 04-07)]/3. Subareas are listed in order of decreasing priority to survey. Shaded rows are Subareas not yet surveyed.*

			1997-2007					2004-2007				
PFMAS	Shoreline (km)	Survey Status	mean landed weight (kg)	no. years harvested	rank of means	landings by shoreline (kg/km)	rank of landings by shoreline	mean landed weight (kg)	no. years harvested	landings by shoreline (kg/km)	rank of landings by shoreline	Survey Rank
7.22	12.8	Unsurveyed	12480	6	41	973.6	1	14522.0	3	1132.9	1	0.28
7.24	40.9	Unsurveyed	29301	10	15	717.1	6	45978.8	4	1125.3	2	0.53
5.05	13.3	Unsurveyed	10150	6	49	760.9	5	13456.3	4	1008.8	3	0.78
5.04	56.8	Unsurveyed	29641	10	14	522.3	9	42122.8	4	742.3	4	0.97
7.3	37.3	Surveyed	16113	9	32	431.6	15	22652.0	4	606.8	5	1.39
6.28	22.4	Surveyed	12314	9	42	549.5	8	12512.8	4	558.3	7	1.46
5.12	43.6	Unsurveyed	19237	9	29	441.4	14	25630.8	4	588.1	6	1.52
7.17	205.7	Surveyed	105730	10	1	514.0	10	114539.0	4	556.8	8	1.67
7.12	83.2	Unsurveyed	31393	11	13	377.4	18	46308.0	4	556.6	9	2.05
5.15	21.9	Unsurveyed	9916	8	50	452.6	13	11334.0	4	517.4	10	2.21
6.06	86.9	Surveyed	43601	10	7	501.7	11	36008.3	4	414.3	13	2.53
6.05	203.7	Surveyed	73954	11	2	363.1	19	82085.5	4	403.0	14	2.91
6.07	28.8	Surveyed	18871	10	30	654.6	7	10212.3	4	354.2	19	3.40
6.03	141.5	Surveyed	48087	10	5	339.7	21	52200.3	4	368.8	17	3.53
24.04	39.0	Surveyed	10906	11	44	279.6	28	13847.8	4	355.1	18	3.85
8.16	70.4	Surveyed	21438	10	24	304.3	22	22829.8	4	324.1	21	4.23
6.09	314.4	Surveyed	68382	10	3	217.5	36	103325.0	4	328.7	20	4.53
24.05	54.0	Surveyed	14385	9	37	266.4	29	16985.3	4	314.5	23	4.91
5.14	89.9	Unsurveyed	26668	6	17	296.7	25	28800.5	4	320.4	22	5.06
24.07	74.0	Surveyed	21954	11	23	296.7	26	20809.8	4	281.2	27	5.29
12.16	84.0	Unsurveyed	18815	11	31	223.9	34	24213.3	4	288.2	26	5.36
9.02	199.0	Unsurveyed	46421	8	6	233.3	33	58861.0	4	295.8	25	5.54
12.41	163.6	Surveyed	39800	11	8	243.3	32	44553.8	4	272.3	28	5.64
12.17	14.0	Unsurveyed	5859	8	64	419.7	16	5445.0	2	390.0	15	5.67
8.04	216.2	Surveyed	61151	11	4	282.8	27	56577.0	4	261.7	31	5.98
7.13	61.2	Unsurveyed	16039	9	33	261.9	30	16275.8	4	265.8	30	6.11
12.4	124.8	Surveyed	24704	9	21	197.9	40	33684.5	4	269.9	29	6.31
7.15	134.5	Surveyed	26238	11	19	195.0	41	32212.0	4	239.4	32	6.58
6.26	16.2	Unsurveyed	4915	11	73	303.2	24	3569.8	4	220.2	37	6.89
6.1	192.7	Unsurveyed	29182	11	16	151.5	53	43440.8	4	225.5	35	7.44

Table 2. Continued

PFMAS	Shoreline (km)	Survey Status	1997-2007 mean landed weight (kg)	no. years harvested	rank of means	landings by shoreline (kg/km)	rank of landings by shoreline	2004-2007 mean landed weight (kg)	no. years harvested	landings by shoreline (kg/km)	rank of landings by shoreline	Survey Rank
8.05	43.2	Surveyed	38483	3	9	891.3	3	21960.0	1	508.6	11	7.67
7.28	109.6	Unsurveyed	20154	6	25	183.9	44	25176.0	4	229.8	34	8.11
12.13	185.4	Unsurveyed	23976	11	22	129.3	60	39778.5	4	214.6	39	8.32
5.16	199.1	Unsurveyed	31451	10	12	158.0	49	42654.0	4	214.3	41	8.47
12.11	103.5	Unsurveyed	15866	10	35	153.4	50	19603.5	4	189.5	43	8.83
13.18	37.6	Unsurveyed	6523	11	60	173.3	46	6805.3	4	180.8	46	9.06
5.17	173.6	Unsurveyed	26291	10	18	151.4	54	31604.3	4	182.0	45	9.30
8.02	90.8	Unsurveyed	19938	8	27	219.5	35	20452.7	3	225.2	36	9.46
24.06	30.0	Surveyed	6456	10	61	215.2	37	6576.3	3	219.2	38	9.68
13.12	107.6	Unsurveyed	16036	10	34	149.0	55	16406.8	4	152.5	48	9.83
8.03	12.9	Surveyed	4408	3	75	342.7	20	3923.0	2	305.1	24	10.22
6.02	130.8	Unsurveyed	19971	9	26	152.7	51	18421.5	4	140.8	51	10.39
7.23	192.5	Unsurveyed	19394	10	28	100.8	67	26840.0	4	139.5	52	10.90
7.27	201.1	Unsurveyed	31818	5	11	158.2	48	35593.3	4	177.0	47	11.03
13.17	64.1	Unsurveyed	9752	10	51	152.1	52	7730.0	4	120.5	56	11.07
5.07	19.7	Unsurveyed	9222	1	53	468.4	12	9222.0	1	468.4	12	12.00
5.02	48.3	Unsurveyed	4973	8	72	102.9	66	5643.5	4	116.8	58	12.42
7.25	279.1	Unsurveyed	14748	10	36	52.8	82	27530.3	4	98.6	62	13.07
6.12	106.9	Unsurveyed	10572	10	47	98.9	68	8011.3	4	75.0	65	13.10
9.12	188.2	Unsurveyed	25498	5	20	135.5	58	35496.7	3	188.6	44	13.64
8.13	102.9	Unsurveyed	14144	10	38	137.4	57	13652.3	3	132.6	54	13.90
12.07	65.2	Unsurveyed	9312	10	52	142.8	56	8145.3	3	124.9	55	14.09
7.14	208.8	Unsurveyed	36033	5	10	172.6	47	48198.0	2	230.8	33	14.13
5.19	58.3	Unsurveyed	10726	6	45	184.0	43	7986.0	3	137.0	53	14.17
5.24	114.9	Unsurveyed	13145	9	40	114.4	63	13379.3	3	116.4	59	15.44
6.11	11.2	Unsurveyed	2841	2	82	253.5	31	4354.0	1	388.5	16	15.83
6.27	6.9	Surveyed	5526	7	66	804.2	4	1017.0	2	148.0	50	16.86
7.03	122.3	Unsurveyed	13741	9	39	112.4	65	6521.7	3	53.3	70	17.96
7.18	197.5	Unsurveyed	10962	7	43	55.5	81	13358.3	3	67.7	66	18.52
6.16	110.2	Unsurveyed	7591	7	59	68.9	77	6252.7	3	56.7	68	18.78
5.13	116.1	Unsurveyed	5397	9	68	46.5	83	2947.3	3	25.4	74	19.52
7.16	85.3	Unsurveyed	6354	4	62	74.5	73	4823.0	3	56.6	69	21.42
6.15	39.9	Unsurveyed	3814	6	77	95.7	69	3957.0	2	99.3	61	24.17

Table 2. Continued

PFMAS	Shoreline (km)	Survey Status	1997-2007 mean landed weight (kg)	1997-2007 no. years harvested	1997-2007 rank of means	1997-2007 landings by shoreline (kg/km)	1997-2007 rank of landings by shoreline	2004-2007 mean landed weight (kg)	2004-2007 no. years harvested	2004-2007 landings by shoreline (kg/km)	2004-2007 rank of landings by shoreline	Survey Rank
6.14	60.4	Unsurveyed	3994	6	76	66.1	79	5798.5	2	96.0	63	25.39
24.1	53.0	Surveyed	3653	6	78	68.9	76	3024.0	2	57.1	67	26.56
8.06	22.0	Surveyed	8411	4	56	383.1	17	4706.0	1	214.3	40	28.08
13.23	70.9	Unsurveyed	5011	5	71	70.7	75	3117.5	2	44.0	72	29.00
13.13	31.4	Unsurveyed	6304	4	63	200.6	38	6073.0	1	193.2	42	31.17
7.21	67.7	Unsurveyed	5855	5	65	86.5	71	10134.0	1	149.6	49	37.40
5.18	25.8	Unsurveyed	4843	3	74	187.4	42	3106.0	1	120.2	57	42.67
5.2	129.8	Unsurveyed	10634	3	46	81.9	72	13448.0	1	103.6	60	48.00
13.16	60.8	Unsurveyed	7919	6	58	130.3	59	2536.0	1	41.7	73	51.94
5.21	72.9	Unsurveyed	8797	2	54	120.7	61	6260.0	1	85.9	64	52.83
12.09	1.9	Unsurveyed	1852	1	85	967.1	2	0.0	0	0.0	79	53.33
12.08	16.6	Unsurveyed	5058	4	70	303.8	23	0.0	0	0.0	79	54.58
7.32	76.3	Unsurveyed	5399	5	67	70.8	74	1822.0	1	23.9	75	54.93
24.14	29.0	Surveyed	5332	3	69	183.9	45	0.0	0	0.0	79	57.67
5.23	88.6	Unsurveyed	10329	4	48	116.6	62	0.0	0	0.0	79	57.83
6.08	43.2	Unsurveyed	8597	2	55	199.0	39	0.0	0	0.0	79	59.17
13.15	52.5	Unsurveyed	1874	2	84	35.7	84	1246.0	1	23.7	76	64.67
13.19	42.1	Unsurveyed	2900	2	81	68.9	78	541.0	1	12.8	78	65.00
7.2	29.0	Unsurveyed	3309	1	79	114.1	64	0.0	0	0.0	79	74.00
5.22	139.2	Unsurveyed	8106	1	57	58.2	80	6313.0	1	45.4	71	74.00
5.11	25.3	Unsurveyed	2192	1	83	86.5	70	0.0	0	0.0	79	76.00
8.07	194.0	Unsurveyed	3202	1	80	16.5	87	3202.0	1	16.5	77	80.33
13.14	16.7	Unsurveyed	352	1	87	21.1	85	0.0	0	0.0	79	81.00
5.01	38.3	Unsurveyed	747	1	86	19.5	86	0.0	0	0.0	79	81.33
12.01	0.9	Unsurveyed	0	0	88	0.0	88	0.0	0	0.0	79	82.00
7.02	6.5	Unsurveyed	0	0	88	0.0	88	0.0	0	0.0	79	82.00
7.26	17.8	Unsurveyed	0	0	88	0.0	88	0.0	0	0.0	79	82.00
13.2	26.4	Unsurveyed	0	0	88	0.0	88	0.0	0	0.0	79	82.00
4.03	30.8	Unsurveyed	0	0	88	0.0	88	0	0	0.0	79	82.00
7.19	33.0	Unsurveyed	0	0	88	0.0	88	0.0	0	0.0	79	82.00
9.01	59.6	Unsurveyed	0	0	88	0.0	88	0.0	0	0.0	79	82.00
8.14	70.1	Unsurveyed	0	0	88	0.0	88	0.0	0	0.0	79	82.00
7.31	75.2	Unsurveyed	0	0	88	0.0	88	0.0	0	0.0	79	82.00

Table 3. Mean and lower 90% confidence bound of density estimates from surveys in 2008 and 2009, with Subareas grouped into Analysis Areas. These Subareas were closed during the Phase 1 fishery

Survey	Region	PFMAS	Year	Transects	Precision	Mean density	90% LCB
Area 13	ECVI	13-7,8,9	2008	12	29.4	5.1	3.6
Area 13	ECVI	13-10	2008	11	28.1	8.9	6.4
Area 13	ECVI	13-11	2008	9	84.0	2.5	0.4
Area 13	ECVI	13-25	2008	12	48.6	7.2	3.7
Area 13	ECVI	13-24,26,27	2008	26	24.7	7.7	5.8
Area 13	ECVI	13-32,33,34	2008	11	55.0	2.0	0.9
Area 13	ECVI	13-35,36	2008	13	31.7	4.1	2.8
Area 13	ECVI	13-37,38,39	2008	14	45.0	4.0	2.2
Area 13	ECVI	13-40,41	2008	11	37.4	9.1	5.7
Area 13	ECVI	13-42	2008	11	30.6	7.2	5.0
Area 13	ECVI	13-43	2008	14	39.4	3.3	2.0
A910	CC	9-3,4,5,6	2008	17	30.8	3.9	2.7
A910	CC	9-7,8,9	2008	14	35.2	5.4	3.5
A910	CC	9-11	2008	14	36.5	15.9	10.1
A910	CC	10-3,4,5	2008	24	33.3	3.0	2.0
A910	CC	10-6	2008	11	29.0	3.1	2.2
A910	CC	10-7	2008	14	27.8	3.6	2.6
A910	CC	10-8,9,10	2008	10	37.1	3.5	2.2
A910	CC	10-12	2008	11	25.7	3.5	2.6
Area 13	ECVI	12-1,24	2009	11	43.4	5.3	3.0
Area 13	ECVI	12-2	2009	11	34.7	7.2	4.7
Area 13	ECVI	12-22	2009	11	41.5	9.8	5.7
Area 13	ECVI	12-23	2009	13	34.5	5.5	3.6
Area 12	ECVI	12-6,20	2009	43	20.3	7.9	6.3
Area 12	ECVI	12-26	2009	76	23.9	6.7	5.1
Area 12	ECVI	12-38,39	2009	94	22.8	5.7	4.4
Area 4	NC	4-1	2009	75	25.4	6.3	4.7
Area 4	NC	4-2*	2009	63	22.4	4.9	3.8
Area 4	NC	4-4,9*	2009	29	22.1	6.8	5.3
Area 4	NC	4-5	2009	39	22.2	14.4	11.2
Area 4	NC	4-12*	2009	37	33.3	2.7	1.8
Area 4	NC	4-13	2009	21	35.3	1.7	1.1
Area 3	NC	3-1	2009	37	30.5	5.9	4.1

* all transects surveyed in these Subareas were used in this analysis, therefore results shown here may differ from those used by managers

Table 4. Results of population and biomass estimates derived from linear and spatial density calculations, compared to actual number and biomass harvested, for the Gulf Islands low, medium and high density sites.

Linear Method

Low Density Site: mean weight = 0.3790 kg, shoreline length=212m
10 Transects

	Density (sc/m-sh)	Number Harvested	Estimated Population	Kilograms Harvested	Estimated Biomass(kg)	Biomass estimate (% of harvest)	Population estimate (% under actual)
Mean	4.30	936	912	354.7	345.5	97.4	2.6
90% LCB	4.26	936	904	354.7	342.4	96.5	3.4
95% LCB	3.72	936	789	354.7	299.1	84.3	15.7
99% LCB	3.27	936	694	354.7	262.8	74.1	74.1

Medium Density Site: ean weight = 0.2990 kg, shoreline length=208m
10 Transects

	Density (sc/m-sh)	Number Harvested	Estimated Population	Kilograms Harvested	Estimated Biomass(kg)	Biomass estimate (% of harvest)	Population estimate (% under actual)
Mean	24.35	6,149	5,065	1,839.3	1,514.4	82.3	17.6
90% LCB	19.90	6,149	4,139	1,839.3	1,237.4	67.3	32.7
95% LCB	19.03	6,149	3,959	1,839.3	1,183.6	64.4	35.6
99% LCB	17.75	6,149	3,692	1,839.3	1,104.0	60.0	40.0

High Density Site: mean weight = 0.2400 kg, shoreline length=202m
9 Transects

	Density (sc/m-sh)	Number Harvested	Estimated Population	Kilograms Harvested	Estimated Biomass(kg)	Biomass estimate (% of harvest)	Population estimate (% under actual)
Mean	65.47	14,329	13,225	3,441.0	3,174.0	92.2	7.7
90% LCB	57.07	14,329	11,528	3,441.0	2,766.7	80.4	19.5
95% LCB	53.89	14,329	10,887	3,441.0	2,612.8	75.9	24.0
99% LCB	45.94	14,329	9,280	3,441.0	2,227.2	64.7	35.2

All Sites Combined: mean weight = 0.2630 kg, shoreline length=622m
29 Transects

	Density (sc/m-sh)	Number Harvested	Estimated Population	Kilograms Harvested	Estimated Biomass(kg)	Biomass estimate (% of harvest)	Population estimate (% under actual)
Mean	25.03	21,414	15,570	5,635.0	4,095.0	72.7	27.3
90% LCB	24.97	21,414	15,530	5,635.0	4,084.4	72.5	27.5
95% LCB	23.84	21,414	14,826	5,635.0	3,899.3	69.2	30.8
99% LCB	21.65	21,414	13,464	5,635.0	3,541.0	62.8	37.1

Table 4, cont'd.

Spatial Method

Low Density Site: mean weight = 0.3790 kg, habitat area=56,722 m^2
10 Transects

	Density (sc/m2)	Number Harvested	Estimated Population	Kilograms Harvested	Estimated Biomass(kg)	Biomass estimate (% of harvest)	Population estimate (% under actual)
Mean	0.02000	936	1,134	354.7	430.0	121.2	-21.2
90% LCB	0.01098	936	623	354.7	236.1	66.6	33.5
95% LCB	0.00958	936	544	354.7	206.0	58.1	41.9
99% LCB	0.00697	936	395	354.7	149.8	42.2	57.8

Medium Density Site: mean weight = 0.2990 kg, habitat area=26,368 m^2
10 Transects

	Density (sc/m2)	Number Harvested	Estimated Population	Kilograms Harvested	Estimated Biomass(kg)	Biomass estimate (% of harvest)	Population estimate (% under actual)
Mean	0.235266	6,149	6,203	1,839.3	1,854.8	100.8	-0.9
90% LCB	0.18345	6,149	4,837	1,839.3	1,446.3	78.6	21.3
95% LCB	0.175117	6,149	4,617	1,839.3	1,380.6	75.1	24.9
99% LCB	0.158325	6,149	4,175	1,839.3	1,248.2	67.9	32.1

High Density Site: mean weight = 0.2400 kg, habitat area=50,635 m^2
9 Transects

	Density (sc/m2)	Number Harvested	Estimated Population	Kilograms Harvested	Estimated Biomass(kg)	Biomass estimate (% of harvest)	Population estimate (% under actual)
Mean	0.299112	14,329	15,146	3,441.0	3,634.9	105.6	-5.7
90% LCB	0.207017	14,329	10,482	3,441.0	2,515.7	73.1	26.8
95% LCB	0.190308	14,329	9,636	3,441.0	2,312.7	67.2	32.8
99% LCB	0.164659	14,329	8,338	3,441.0	2,001.0	58.2	41.8

All Sites Combined: mean weight = 0.2630 kg, habitat area=133,725 m^2
29 Transects

	Density (sc/m2)	Number Harvested	Estimated Population	Kilograms Harvested	Estimated Biomass(kg)	Biomass estimate (% of harvest)	Population estimate (% under actual)
Mean	0.169884	21,414	22,718	5,635.0	5,974.8	106.0	-6.1
90% LCB	0.121032	21,414	16,185	5,635.0	4,256.6	75.5	24.4
95% LCB	0.112725	21,414	15,074	5,635.0	3,964.5	70.4	29.6
99% LCB	0.098719	21,414	13,201	5,635.0	3,471.9	61.6	38.4

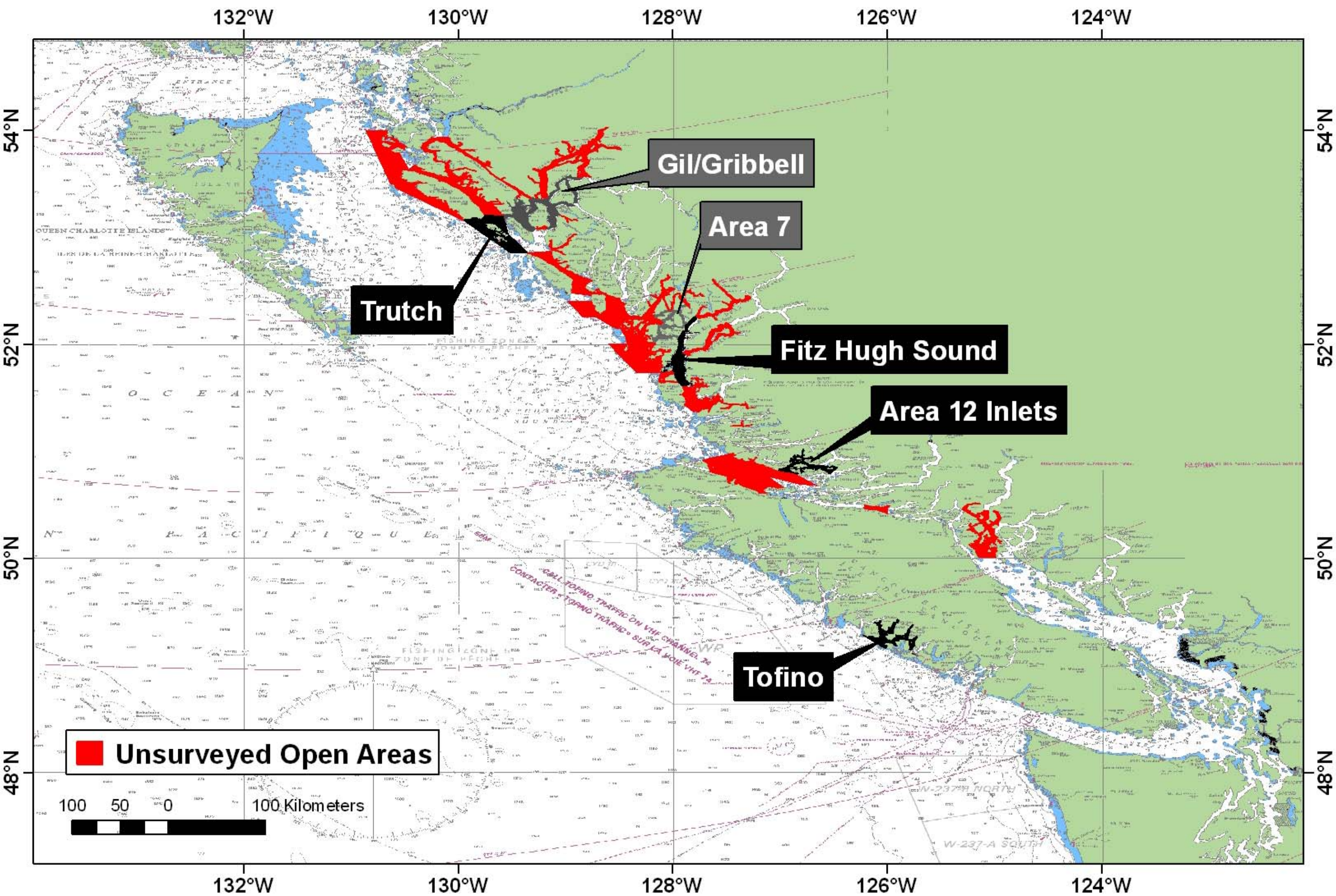

Figure 1. Surveyed areas (Trutch, Gil/Gribbell, Area 7, Fitz Hugh Sound, Area 12 Inlets and Tofino) and unsurveyed areas (unlabelled, in red) open to commercial harvest 1997-2007.

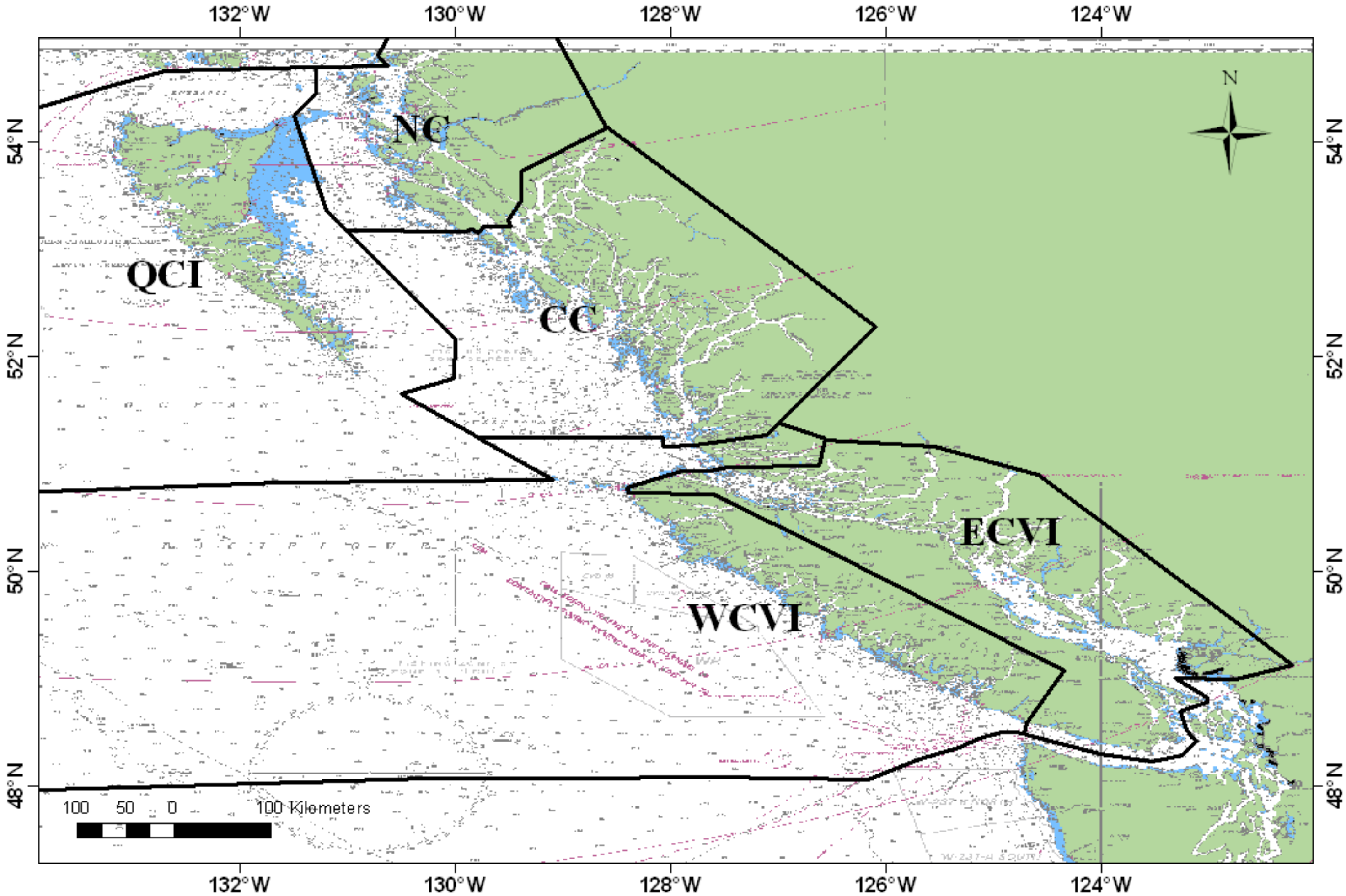

Figure 2. Fisheries and Oceans Canada Pacific Management Regions. QCI:Queen Charlotte Islands (Haida Gwaii), NC: North Coast, CC: Central Coast, ECVI: east coast Vancouver Island, WCVI: west coast Vancouver Island.

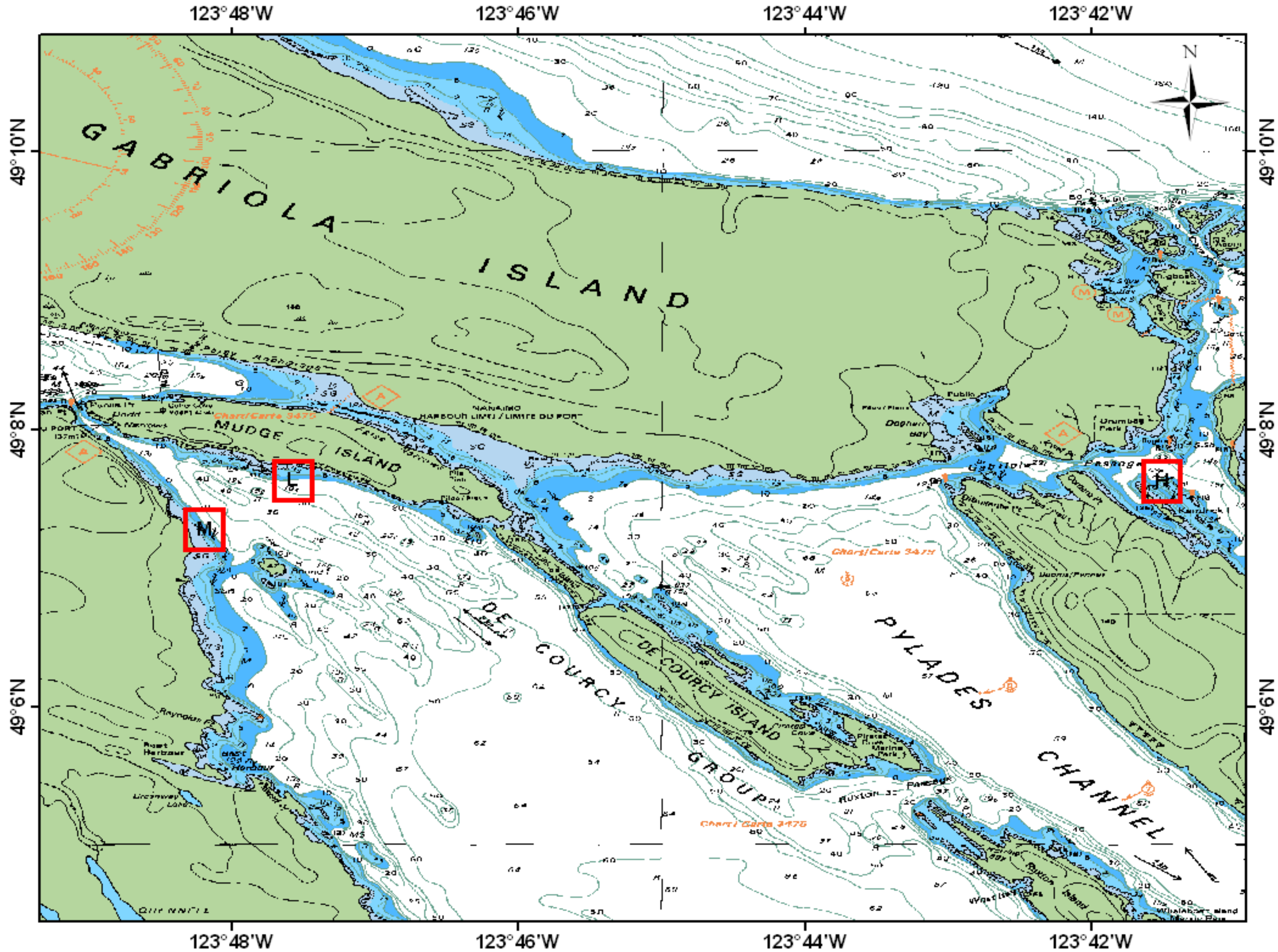

Figure 3. Overview of the 1997 Gulf Islands Intensive Sites. Red boxes illustrate the general location of the low (L), medium (M) and high (H) density sites.

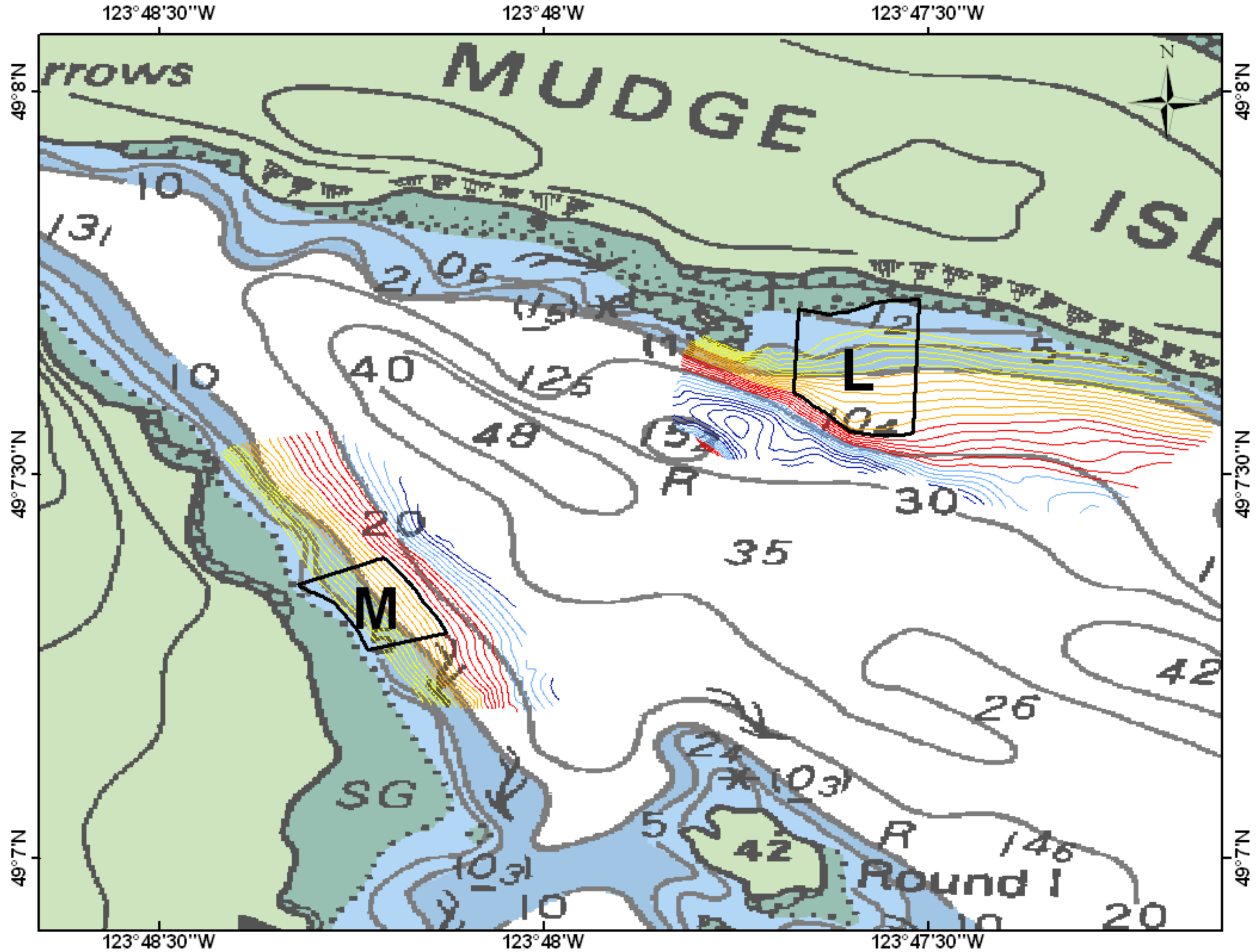

Figure 4. Gulf Islands low and medium density site boundaries with depth contours collected with Quester Tangent single-beam echo sounding.

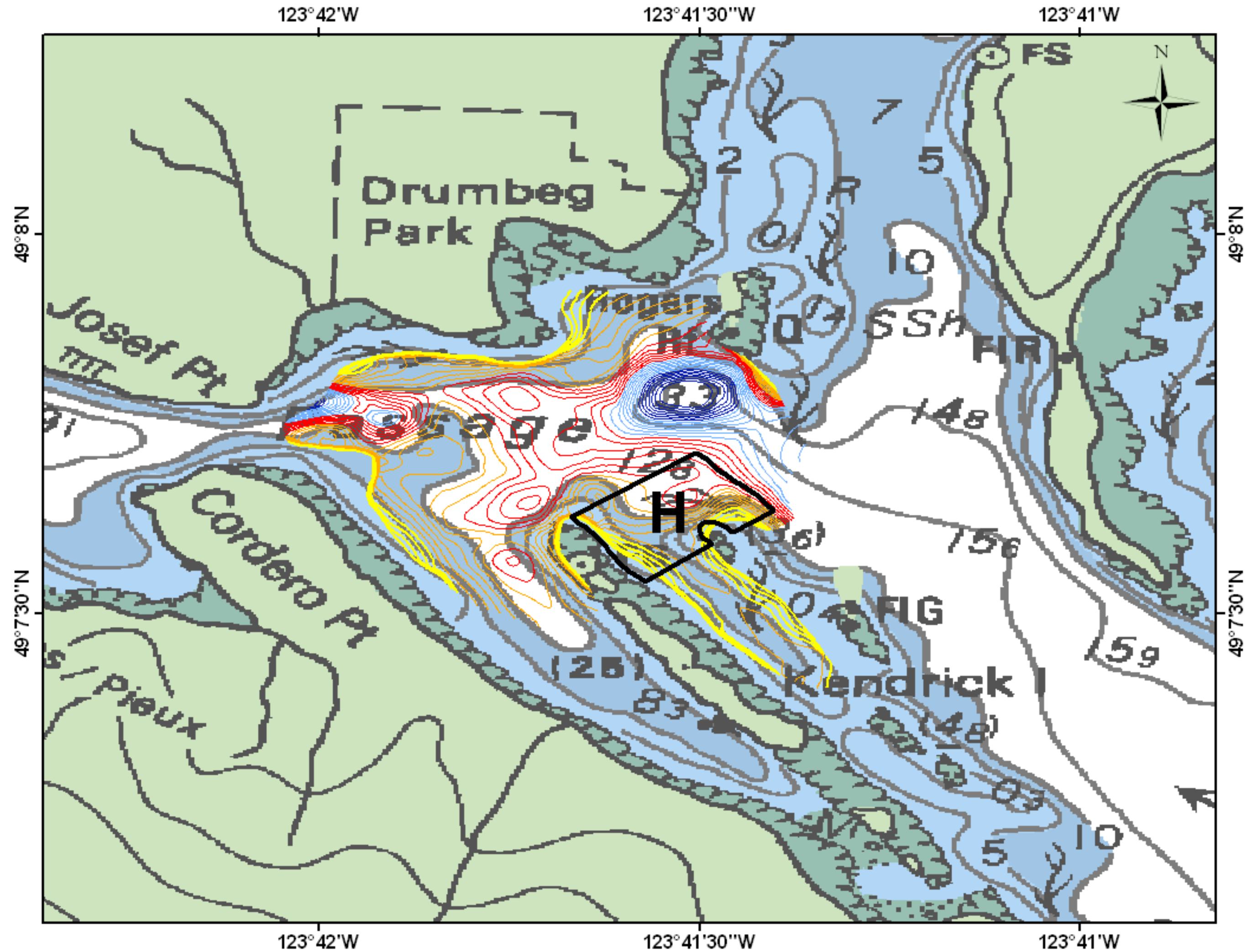

Figure 5. Gulf Islands high density site boundaries with depth contours collected with Quester Tangent single-beam echo sounding.

10 APPENDIX 1. PSARC INVERTEBRATE SUBCOMMITTEE – REQUEST FOR WORKING PAPER

PART 1: DESCRIPTION OF THE REQUEST – TO BE FILLED BY THE CLIENT REQUESTING THE INFORMATION/ADVICE

Date *(when initial client's submission is sent to Science) (15/09/2009)***:**

Directorate, Branch or group initiating the request and category of request	
Directorate/Branch/Group	Category of Request
☒ Fisheries and Aquaculture Management	☒ Stock Assessment
☐ Oceans & Habitat Management and SARA	☐ Species at Risk
☐ Policy	☐ Human impacts on Fish Habitat/ Ecosystem components
☒ Science	☐ Aquaculture
☐ Other (please specify):	☐ Ocean issues
	☐ Invasive Species
	☐ Other (please specify):

Initiating Branch Contact:	
Name: Erin Wylie/Rick Harbo	Telephone Number: (250) 756-7271
Email: erin.wylie@dfo-mpo.gc.ca	Fax Number: (250) 756-7162

Issue Requiring Science Advice (i.e., "the question"):
Issue posed as a question for Science response.

Preparation of a stock assessment framework is requested to provide a detailed description of assessment protocols in order to document and evaluate the current sea cucumber stock assessment program and identify and prioritize future research.

Rationale for Advice Request:
What is the issue, what will it address, importance, scope and breadth of interest, etc.?

In 1997, an adaptive management plan was developed for the sea cucumber fishery to focus the fishing effort, study the effects of annual harvest and determine the most appropriate harvest rate for the British Columbia fishery. Under this plan, the commercial fishery was limited to 25% of the coast in static areas, up to 25% was allowed for research and 50% remained closed. The adaptive management plan was expected to continue for 10 years.

In 2002 a paper was developed using all information to date to determine the most appropriate baseline density for unsurveyed areas. The baseline density for most unsurveyed areas doubled.

In 2005 a paper was written that reviewed the fishery to date and recommendations were provided on options for a rotational harvest strategy. No changes were implemented at that time, pending completion of the full 10-year data set, as originally planned under the adaptive management plan.

In 2007, after 10 years of survey and experimental fishery data collection, a Working Paper was presented on all information gathered to date, and recommendations were made on the re-opening of parts of the coast to commercial harvest.

Details of the process and decision rules of biomass calculation and stock assessment need to be documented, including density estimates, mean weights, exposure categories, shoreline lengths and harvest rates. Uncertainty and bias in parameter estimates for quota calculation need to be documented in order to support the development of conservation-based management strategies.

Questions/Issues to be Addressed:

- Document current protocols for the collection and analysis of data on sea cucumber density, average sea cucumber weight and shoreline length and describe decision rules for applying all sources of data to estimate cucumber population abundance.
- Describe and evaluate data precision, accuracy and sources of bias, and make recommendations, where necessary, for improved methods.
- Compare and analyse the difference in using shoreline length vs. estimated spatial area for quota calculation.
- Describe the decision rules for biomass estimation for unsurveyed areas.
- Currently quotas are calculated using the lower 90% CI of biomass estimates. Is this appropriate and are we confident enough in the density estimates to provide a range in biomass estimates, as is done in other fisheries?
- Is the current advice on harvest rates appropriate for all areas?
- What are recommendations for developing ‘no take’ zones, including size of area and density of resident populations.
- What is the recommended limit reference point and are there minimum density and/or minimum average animal size where areas should not be opened to fishing?
- What research activities are required to support assessment and monitoring of sea cucumber populations in BC.

Possibility of integrating this request with other requests in your sector or other sector’s needs?

N/A

Intended Uses of the Advice, Potential Impacts of Advice within DFO, and on the Public:
Who will be the end user of the advice (e.g. DFO, another government agency or Industry?). What impact could the advice have on other sectors? Who from the Public will be impacted by the advice and to what extent?

Resource Managers, Research Scientists, Commercial Industry Association

11 APPENDIX 2. FLOW CHART OF DENSITY AND WEIGHT DECISION CRITERIA