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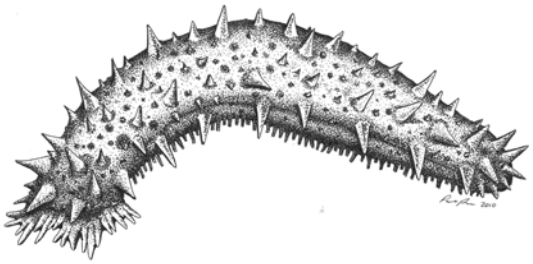
Pacific Region
Canadian Science Advisory Secretariat
Science Advisory Report 2010/080

ASSESSMENT FRAMEWORK AND MANAGEMENT ADVICE FOR THE BRITISH COLUMBIA GIANT RED SEA CUCUMBER (*PARASTICHOPUS CALIFORNICUS*) FISHERY



Drawing of Parastichopus californicus by Pauline Ridings

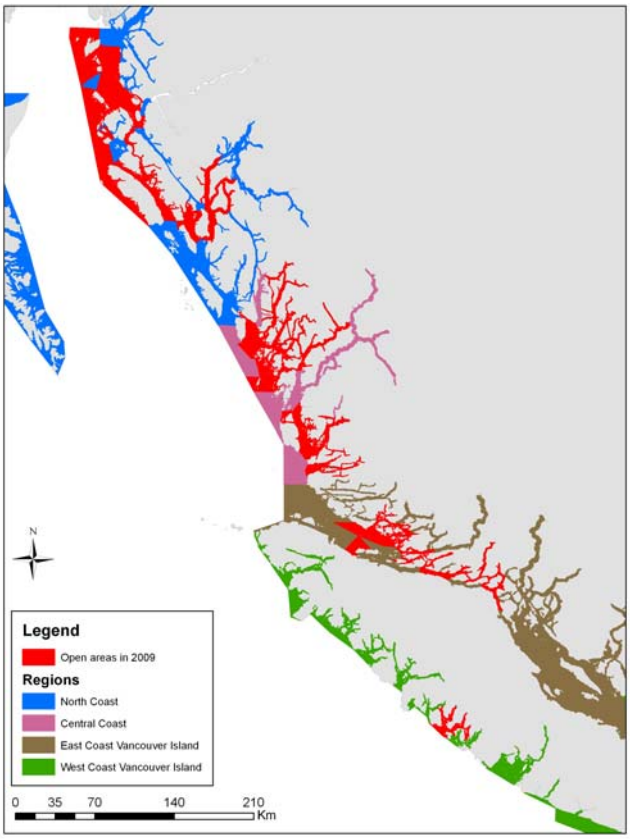


Figure 1: Areas of coastal British Columbia open for sea cucumber harvesting in 2009. The four main regions (North coast, Central Coast, West Coast Vancouver Island and East Coast Vancouver Island) are indicated.

Context

In 2008, the fishery for giant red sea cucumber (Parastichopus californicus) in British Columbia progressed into Phase 2 of the framework for the provision of scientific advice in support of the management of developing invertebrate fisheries (Perry et al. 1999, DFO 2008). Research methodology and biomass calculation protocols were developed during the Adaptive Management, or the Phase 1 fishery. Areas of coastline that had been closed during the Phase 1 fishery are considered for re-opening to commercial harvest. A description of the assessment framework and a review of the advice on harvest management, compliant with the DFO Sustainable Fisheries Framework, was requested by Resource Managers.

This Science Advisory Report has resulted from a Fisheries and Oceans Canada, Canadian Science Advisory Secretariat Pacific Regional Advisory Meeting. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

SUMMARY

- The fishery for the giant red sea cucumber in BC began in 1980, fueled by a market demand from Asia. By 1987, landings had increased dramatically and a series of management actions were implemented to control effort.
- In 1997, the fishery underwent an extensive review and was streamed into the Phased Approach for developing or data-limited fisheries. A ten-year adaptive management plan was implemented wherein commercial harvest was limited to 25% of the BC coast, and surveys and experimental fisheries were conducted to fill information gaps on biomass and productivity of the stocks.
- At the end of the period of research, the fishery progressed to Phase 2, 'fishing for commerce', in 2008.
- The stock assessment framework and decision rules for calculating sea cucumber biomass are described.
- Advice to fishery managers for precautionary development of the sea cucumber fishery is provided, including:
  - Use the lower 90% confidence bound on biomass estimates for quota-setting;
  - Survey Pacific Fishery Management Area Subareas prior to re-opening;
  - Use conservative baseline density estimates to set quotas in unsurveyed Subareas that remain open from the adaptive management regime;
  - A precautionary harvest rate of 6.7% of the estimated biomass is recommended, except in Subareas of low productivity or carrying-capacity; for which the original conservative harvest rate of 4.2 % is considered conservative and sustainable;
  - A limit reference point of 50% of the biomass in the unharvested state is recommended;
  - As new locations are re-opened to commercial harvest, set aside a network of no-take reserves to: protect a proportion of the stock from exploitation, provide a buffer against data uncertainties, and provide a control population in which environmental effects can be monitored independently of fishing activities.

BACKGROUND

Exploratory sea cucumber (*Parastichopus californicus*) harvesting began in British Columbia (BC) in the early 1970's, however landings were not recorded until the early 1980's. The fishery rapidly expanded during the mid-1980's, when landings nearly tripled (Figure 2). Initial management actions included area-closures and arbitrary regional total allowable catches (TAC), first implemented in 1986. This did little to limit the fishery, because as more licenses were issued, landings continued to increase and quota over-runs were common. There were concerns that some areas were experiencing a decline in catch per unit effort, which led to arbitrary TAC reductions in 1989. License limitations were implemented in 1991, and further TAC reductions occurred in 1993. In 1997, an extensive review of existing biological and fishery information for *P. californicus*, in BC and elsewhere, was conducted (Phillips and Boutillier 1998) and an overhaul of the fishery began. It was designated as a developing, or data-limited, fishery (Perry et al. 1999), followed by the implementation of an adaptive management framework, designed to allow for the precautionary management and sustainable development of the fishery. The sea cucumber fishery progressed from Phase 0 (Phillips and Boutillier 1998) to Phase 1 (Boutillier et al. 1998), during which time limited fishing was permitted and conducted in a manner that would allow assessment and evaluation of the impacts of the commercial fishery on sea cucumber stocks. At the end of a ten-year period of research and precautionary management, the fishery progressed to Phase 2, 'fishing for commerce' (Hand et al. 2008).

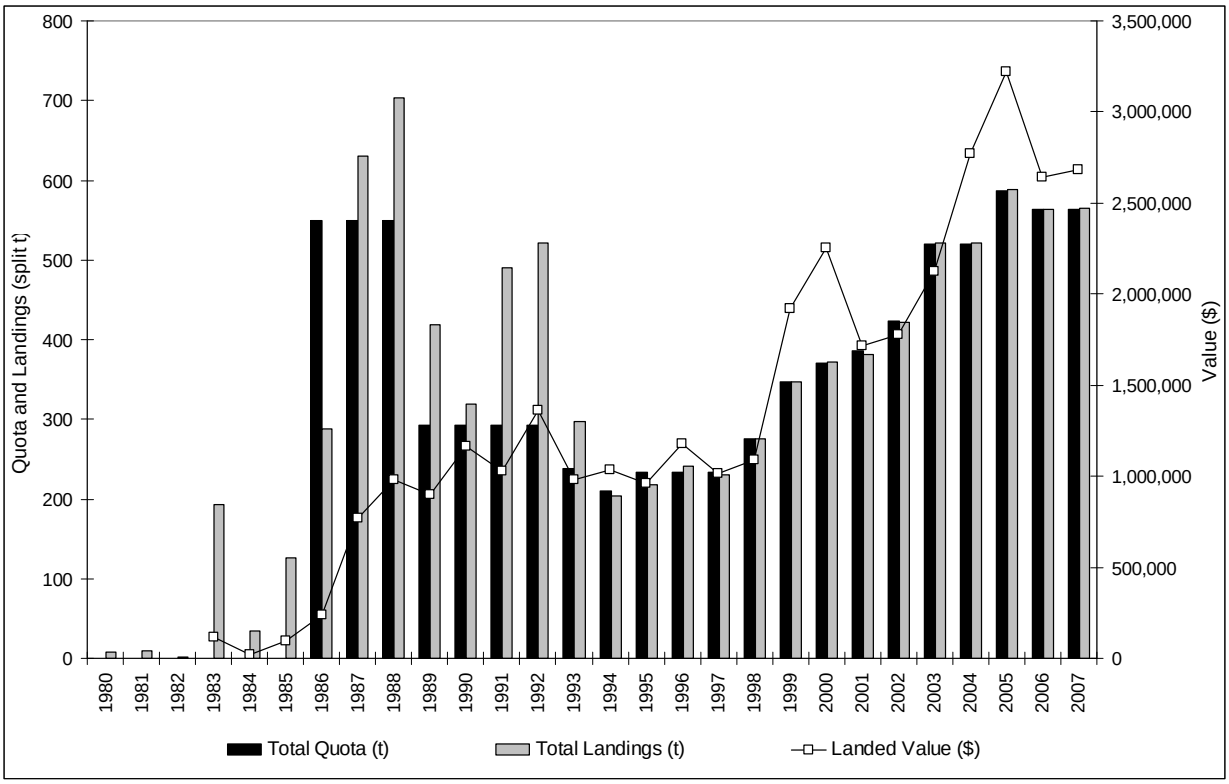


Figure 2. Annual quota, landings and value of the British Columbia sea cucumber (Parastichopus californicus) fishery from 1980 to 2007. Quota and landings are expressed in tonnes of split sea cucumber and landed value in Canadian dollars.

Detailed descriptions of the species' biology, methods of assessment techniques and results of the adaptive management can be found in previous publications (Boutillier et al. 1998, Hand and Rogers 1999, Campagna and Hand 2004, Humble et al. 2008, Hand et al. 2008) and a detailed description of the assessment framework is presented in Duprey et al. (2010).

The assessment and management approaches for the sea cucumber fishery in BC were developed in accordance with the framework that was developed in the Pacific Region in 1996 for new and developing (data-limited) invertebrate fisheries (Perry et al. 1999). A parallel National Policy was developed at the same time, termed the New Emerging Fisheries Policy (DFO 2008). Both initiatives defined a structured approach for the development of new or data-limited fisheries that consists of three phases (or stages): Phase 0 – assemble existing information and identify information gaps (Boutillier et al. 1998); Phase 1 – collect new information and evaluate alternative management strategies (Hand and Rogers 1999, Hand et al. 2008; and Phase 2 – implement precautionary and biologically-based management strategies, monitor on-going fishing activities and evaluate the impacts of fishing. The adaptive management strategy implemented for sea cucumber fishery during Phase 1 included restricting the existing fishery to 25% of the BC coastline and establishing no-fishing reserve areas in the remaining 75% of the coast, with some areas being used for experimental fishing.

When this strategy was initiated in 1997, the existing arbitrary TAC of 238 tonnes (split weight) was retained over static, non-contiguous areas, using the most conservative estimates of density and exploitation rate available. A conservative baseline density estimate for BC waters was established at 2.5 sea cucumbers per meter of shoreline (c/m-sh); this was the minimum value of all 90% lower confidence bound (LCB) calculated for *P. californicus* populations in Alaska (Larson et al. 1995). The exploitation rate was set at 4.2% of the estimated biomass for

the harvested area, which was the most conservative estimate used in adjacent Washington and Alaska *P. californicus* fisheries (Boutillier et al. 1998).

The Management Plan allowed TACs to be updated as surveys of BC populations were conducted and local densities were estimated. During Phase 1, several coastal areas open to sea cucumber harvesting were surveyed. These surveys provided area-specific density data for those surveyed areas and also resulted in a new baseline density estimate for un-surveyed open areas of 5.08 c/m-sh (Campagna and Hand 2004). Some area densities remained at 2.5 c/m-sh, due either to concerns about over-harvesting or to the possibility of overestimating biomass along highly exposed shoreline. Since 1997, the coast-wide TAC has increased 141%, from 238 tonnes to 575 tonnes (2009), as the knowledge of sea cucumber population biomass in BC waters has increased.

ASSESSMENT FRAMEWORK

The following summarizes each component of the Assessment Framework that is described in detail in the Assessment framework for sea cucumber (*Parastichopus californicus*) in British Columbia (Duprey et al. 2010).

Biomass Estimates

In the 2009 fishery, 117 Pacific Fishery Management Area Subareas (Subarea) were open to commercial fishing. Each Subarea is assessed separately and biomass is estimated annually. Three pieces of information are needed to calculate the biomass of sea cucumbers in a Subarea; shoreline length, density and average animal weight. The following equation is used to estimate the biomass:

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

The TAC is then calculated as:

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

Shoreline Length

Shoreline length was first measured in the mid-1990's and the original measurement is still in use, despite the fact that GIS software has evolved since that time and updated basemaps have become available. The higher estimate of shoreline length, and therefore biomass estimates, which resulted from these technological advances was considered unjustifiable: as a result original measurements have been retained. Lengths of shoreline segments are subtracted from the total Subarea length if an area is considered not suitable or is inaccessible for harvesting (for example un-navigable lagoons).

Density

The exposure of shoreline to ocean swell has been found to have a negative effect both on sea cucumber abundance and harvestability (Hand et al. 2008). As a result, very exposed shoreline is now attributed a density of 0 c/m-sh and exposed shoreline is attributed a density of 2.5 c/m-sh. The remaining shoreline in a Subarea is attributed either a surveyed density or, if no survey has occurred in the Subarea, a baseline density.

For surveyed Subareas, the density of sea cucumbers is calculated using an in-house program written in C++. This program calculates 75%, 90%, 95%, and 99% confidence bounds from the

survey transect data, via bootstrapping. Subareas containing fewer than ten transects are combined into Analysis Areas to meet requirements for data precision and statistical testing. Analysis Areas are created by merging data from Subareas that share similar habitat characteristics and oceanographic features.

A total of 61 (52%) of the 117 open Subareas in 2009 have been surveyed. Non-surveyed Subareas have historically been attributed conservative density estimates (Boutillier et al. 1998, Campagna and Hand 2004). In 2008, all survey data were re-analyzed to look for regional patterns in density. There were notable differences in linear density estimates across Regions. The minimum value of the 90% LCB of density estimates, by region, are now used as Regional baseline densities for unsurveyed areas as follows: North Coast = 6.0 c/m-sh, Central Coast = 6.0 c/m-sh, WCVI = 1.9 c/m-sh and ECVI = 4.1 c/m-sh.

Mean weight

Three sources of mean weight estimates exist: biosamples, permanent bio-transects and market samples. Selection criteria were developed to determine the appropriate weight estimate to use for each Subarea (Figures 3 and 4). Biosamples are collected during surveys, therefore most Subareas that have been surveyed also have a mean weight estimate based on biosample data. Permanent bio-transects were established to allow more data on sea cucumber weight to be collected without the high cost of conducting a full survey. For permanent bio-transects, sea cucumbers are collected from permanently placed transect lines immediately before the fishery opens; the data are used for determining quotas in the following year. Market samples were collected from the landed product between 1995 and 2003 for the estimation of mean weight. However, the program was stopped in 2003 as the data was considered to be biased and lacking in spatial resolution (Humble et al. 2008).

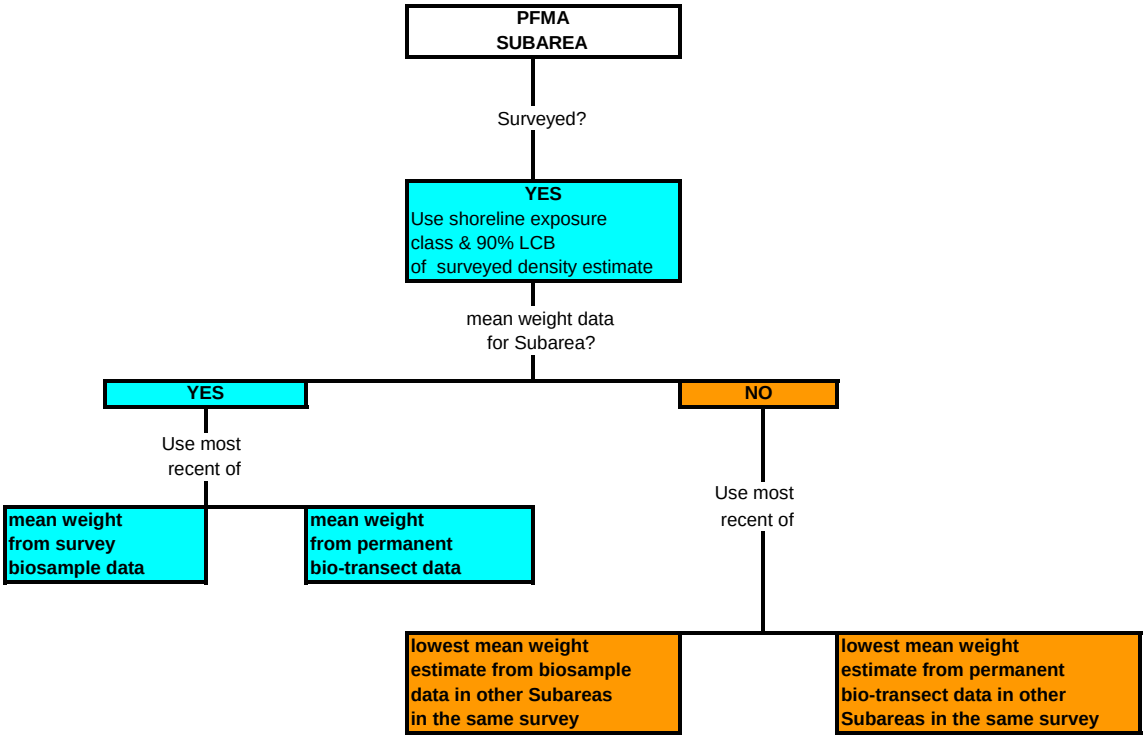


Figure 3. Decision tree on the data source to use to calculate PFMA Subarea biomass estimates when the Subarea has been surveyed (taken from Duprey et al. 2010).

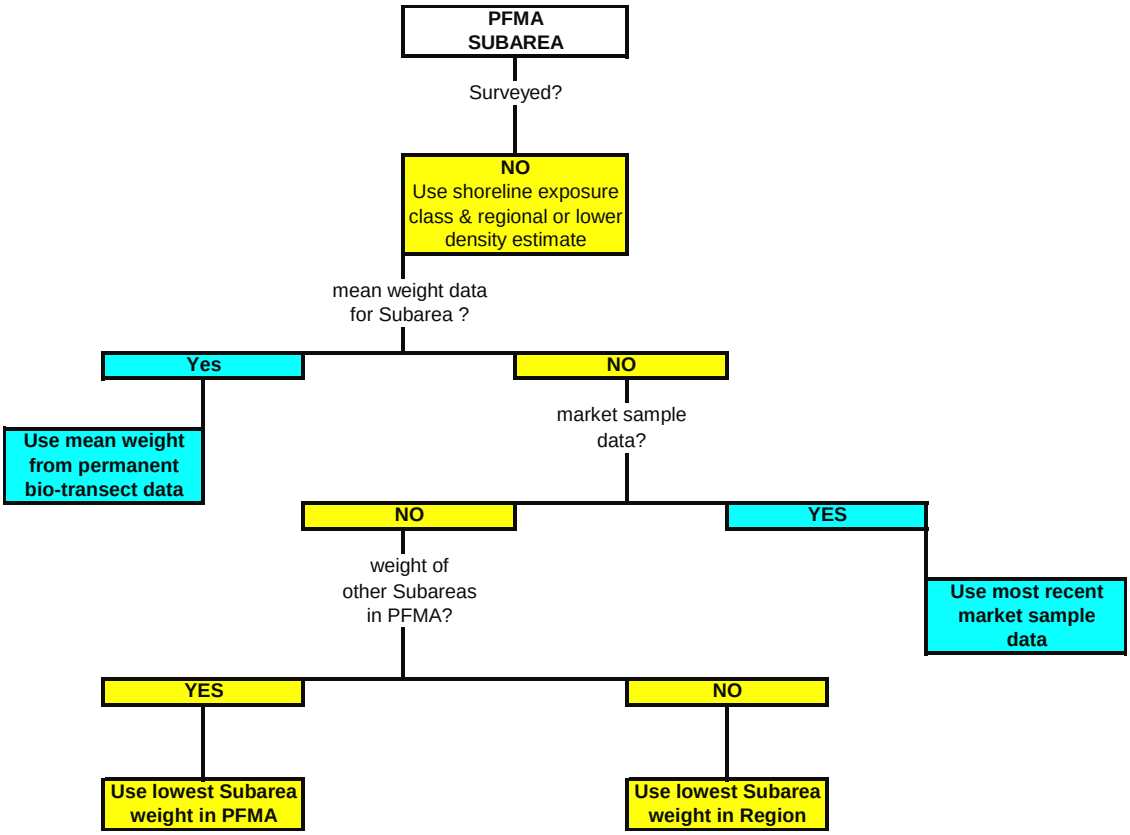


Figure 4. Decision tree on the data source to use to calculate PFMA Subarea biomass estimates when the Subarea has not been surveyed (taken from Duprey et al. 2010).

Harvest Rate

Experimental fisheries areas (EFAs) were established in 1997 to test the effects of varying exploitation rates, ranging from 0% control to 16%, on population dynamics (Hand et al. 2008). Data from ten years of monitored harvesting and surveying were used to construct a latent productivity model. The Maximum Sustainable Harvest Rate (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 was greater than those values, in each of the areas. The low value of 0.035 corresponded to a fjord-type habitat of low biomass density, identified as being unproductive for sea cucumbers and unlikely to be chosen as a harvest area by fishers (Hand et al. 2008). An annual harvest rate of 6.7 % was recommended for all Subareas except those where productivity or carrying capacity is considered to be low. In such cases, fishery managers can consider either a lower harvest rate or the Subarea should not be opened for commercial harvest. For unsurveyed Subareas open during Phase 1 of the fishery, model results indicate that the 4.2 % harvest rate has a high likelihood of being conservative and sustainable (Hand et al. 2008).

Recent examination of the location of harvest effort during the Phase 1 fishery revealed that nine Subareas open between 1997 and 2007 were not targeted for fishing. Since the quota allocated to these areas would have been taken from other Subareas in the same Quota Management Area, it is recognized that the effective harvest rate in the fished Subareas was higher than targeted.

Limit Reference Point

Results from the latent productivity model also included estimates of a limit reference point (LRP), which is the delineation between the Cautious and Critical stock status zones (DFO 2006). There were no data from the experimental fisheries to indicate how the sea cucumber population dynamics would behave when the hypothetical biomass became lower than the lowest end of the range of experimental data. In the model, if the biomass falls below the minimum value of the experimental data, the population is forced to crash. These lowest-biomass values were used as a basis to establish a limit reference point, since the modeled population did not show a decline in productivity at those levels. 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.

Establishing No-take Reserves

Upon commencement of Phase 2 of the fishery, Subareas have been reopened and a network of no-take reserves throughout the BC coast is being established (Hand et al. 2008). These reserves will serve as an additional control and buffer against uncertainty in stock assessment parameter estimates and provide valuable stock assessment information. By monitoring population trends in the absence of fishing and comparing to trends in harvested areas, the effects of natural phenomena such as climate change, El Niño/La Niña events and long-term recruitment trends can be examined and harvest effects can be better determined. Adult spillover, where animals inside the reserve migrate out into harvestable areas, and larval spillover, which would increase the productivity of local populations, are also considered to be of potential conservation benefit.

For *P. californicus*, determining the size, location and monitoring requirements of reserves is a challenge because information on adult movement patterns, ages at key life-cycle stages, and on recruitment and larval distribution patterns is limited. Reserve boundaries need to be easily defined in fishery management plans and easily recognized by fishers 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 one-two 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 ten transects to allow for confident use of bootstrapping techniques.

Ecosysystem Considerations

Sea cucumbers are harvested by divers who handpick individual animals from the sea floor. There is no bycatch mortality of other species or of undersize target species. There is no gear contact with the seabed and therefore there is little concern for physical disruption of the benthic habitat.

P. californicus feed on accumulated detritus on the seabed, mopping the organic deposits up with adhesive feeding tentacles that they draw into their mouths. Associated bacterial and fungal micro-organisms provide the main source of nutrients. The effect that a reduction in density of these animals has on ecosystem health is not known, and therefore the importance of maintaining a precautionary fishery is reinforced.

CONCLUSIONS AND ADVICE

In support of Phase 2 management of this fishery, a review of the assessment framework and advice on harvest management, compliant with the DFO Sustainable Fisheries Framework (DFO 2009) was completed. The *Parastichopus californicus* fishery is managed in a precautionary manner: there are numerous protocols and decision rules in place that ensure the resource is not over-exploited. There is a growing system of no-take reserves being instituted throughout the BC coast; these reserves protect a portion of the adult population, providing a source of larvae to surrounding areas. Additionally, 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.

Using information collected during the Phase 1 period of this fishery, the updated assessment framework developed for sea cucumber (Duprey et al. 2010) provides the basis and protocols for calculating estimates of biomass, including data selection rules when multiple information sources are available. It is recommended that this assessment framework be re-evaluated in 1-2 years time, as statistical error in mean weight estimates will be available to assess and refine the framework. Advice, specific to the application of the assessment framework, includes:

- Shoreline length estimates continue to be based on the original measurement, even though more up-to-date measurements are available, because it is more precautionary;
- Closed, un-surveyed areas, under consideration for opening, should be surveyed to produce actual density estimates on which to base biomass estimates;
- The bootstrapped 90% lower confidence bound on linear density estimates, derived from dive surveys, are recommended as the density estimates to use for surveyed Subareas;
- Level of exposure to ocean swells is also taken into account when attributing density to shoreline in a Subarea: very exposed shoreline = 0.0 c/m-sh; exposed shoreline = 2.5 c/m-sh; remaining shoreline = Bootstrapped 90% lower confidence bound of density estimate;
- Hierarchical decision rules are described for determining the estimated mean weight at the Subarea level;
- Not all of the original 96 static Subareas, opened 1997–2007, have been surveyed. Unsurveyed Subareas are attributed a conservative Regional Baseline density estimate to derive biomass estimates. North Coast=6.0 sea cucumbers per metre of shoreline (c/m-sh), Central Coast=6.0 c/m-sh, East Coast Vancouver Island=4.1 c/m-sh, West Coast Vancouver Island=1.9 c/m-sh.

A review of specific guidance on harvest rates and limit reference points, compliant with the Sustainable Fisheries Framework (DFO 2009), along with specific management recommendations based on the availability of assessment data include:

- A precautionary harvest rate equal to 6.7% of the estimated biomass is recommended, except in areas of low productivity;
- Since many of the Subareas have not been surveyed, the productivity of a Subarea is often not known. The harvest rate of 4.2% used previously throughout the coast is conservative and sustainable (Hand et al. 2008) and is recommended for areas lacking information on productivity;
- Open areas with no historical fishing activity should not be allocated quota, as this would inflate the estimated biomass and increase the harvest rates in the fished Subareas in the same Quota Management Area;

- A limit reference point of 50% of the biomass in the un-harvested state is recommended, such that a Subarea will close if the biomass of the sea cucumber population falls below 50% of the un-harvested state (Hand et al. 2008);
- Subareas that have a Bootstrapped 90% Lower Confidence Bound less than 2.5 c/m-sh should not be considered for harvest. The population distribution in these areas is likely highly aggregated, and depletion of high-density patches could impair recovery;
- As the fishery expands and areas are re-opened, it is recommended that a network of long-term no-take reserves be implemented to protect a proportion of the stock from exploitation, provide a buffer against data and information uncertainties, and provide a control population in which environmental effects can be monitored independently of fishing.

Future work will focus on incorporating error in mean weight and shoreline length estimates into biomass calculations. Survey work continues in both new areas being considered for harvest and on currently-open areas that have not been surveyed. Research into the re-colonization of harvested areas is underway.

SOURCES OF INFORMATION

This Science Advisory Report has resulted from the Fisheries and Oceans Canada, Canadian Science Advisory Secretariat Pacific Regional Advisory Meeting of November 30 – December 2, 2010 on *Pacific Invertebrate SubCommittee Meeting: Pink and Spiny Scallop, Sea Cucumber, Central Coast Manila Clam, Geoduck Clam Aquaculture, and Shrimp Trawl*. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

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