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Feasibility of a bottom trawl survey for three slope groundfish species in Canadian waters

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1. ABSTRACT

The feasibility for conducting research surveys using commercial bottom trawl gear targeted at three slope groundfish species located in the Pacific coast of Canada is presented. The objectives of such a survey are to generate comparable indices of population size over time which can be used as inputs into population assessment models for each of the three species. This feasibility analysis is based on the calculation of the variability in catch per hour for each species from commercial catch and effort data to determine the amount of stratification by depth and the number of tows required in each stratum to achieve a target level of precision. Of the three target species, longspine thornyheads appeared to be the least variable in commercial CPUEs and hence required the fewest tows to monitor the population. Shortspine thornyheads were of intermediate variability and Pacific ocean perch were highly variable. Pacific ocean perch have a completely separate spatial distribution from the two thornyhead species and can be monitored independently of the other two species. The two thornyhead species are spatially commingled, with shortspines having a more shallow distribution compared to the longspines. The final size and aerial extent of the survey will be dependent on the target precision level at which each species is required to be monitored. These decisions are largely management based or require additional stock boundary research. Several alternative options for number of strata and suggested levels of precision are presented, ranging from under 150 tows to nearly 400 tows for the entire survey, with estimated relative costs varying from ~$275,000 to nearly $800,000. An additional issue is that the performance of the nets while towing must be monitored electronically to ensure comparability both within and between surveys as it is likely that net efficiency will improve over time.

1.1 RÉSUMÉ

La présente étude vise à établir la faisabilité d'effectuer des relevés de recherche au chalut de fond commercial ciblant trois espèces de poisson de fond fréquentant le talus de la côte canadienne du Pacifique. De tels relevés visent à obtenir des indices comparables de la taille des populations au fil du temps qui peuvent être utilisés comme intrants dans des modèles d'évaluation des populations de chacune des trois espèces. Cette analyse de faisabilité repose sur le calcul de la variabilité des prises de chaque espèce par heure, issues des données commerciales sur les prises et l'effort, afin de déterminer le niveau de stratification selon la profondeur et le nombre de traits requis dans chaque strate pour obtenir un niveau cible de précision. Des trois espèces ciblées, c'est le sébastolobe à longues épines qui semble nécessiter le moins de traits pour contrôler la dynamique de ses populations étant donné la très faible variabilité de la CPUE commerciale qu'affiche l'espèce. Le sébastolobe à courtes épines montre une variabilité intermédiaire et le sébaste à longue mâchoire, une forte variabilité. Comme la distribution spatiale de ce dernier est complètement différente des deux espèces de sébastolobes, on peut contrôler la dynamique de ses populations indépendamment de ces deux dernières. La distribution saptiale de celles-ci se chevauche, le sébastolobe à courtes épines fréquentant des eaux moins profondes que le sébastolobe à longues épines. L'ampleur définitive et l'étendue aérienne du relevé dépendront du niveau cible de précision à lequel il faut contrôler la dynamique des populations de chaque espèce. Ces décisions relèvent en grande partie des gestionnaires ou requièrent d'autres recherches sur les limites des stocks. Plusieurs autres options quant au nombre de strates et aux niveaux suggérés de précision sont présentées, allant de moins de 150 traits à presque 400 traits pour l'ensemble d'un relevé, dont les coûts estimatifs relatifs varient d'environ 275 000 $ à presque 800 000 $. On doit aussi voir à surveiller la performance des chaluts par voie électronique lors du chalutage afin que les résultats puissent être comparés dans les limites d'un relevé et entre les relevés, car il est probable que l'efficacité des engins augmentera au fil du temps.

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2. Objectives of this paper

1. Investigate, using the Department of Fisheries and Oceans (DFO) PacHarvest catch and effort database (Appendix 1, page 35) , the feasibility of mounting a trawl biomass survey for slope groundfish species in Canadian west coast waters.

2. "Feasibility" in this context is defined as a) whether sufficiently precise estimates can obtained to detect reasonable levels of difference between successive biomass estimates; b) can this precision be obtained at a reasonable cost; and c) given that a) & b) are answered in the affirmative, where and when should such a survey take place?

3. Underlying assumptions made in this paper

1. The choice of three slope groundfish species to be included in this survey (longspine and shortspine thornyheads and Pacific ocean perch) was based on the conclusions of a meeting reported in Schnute et al. (1999). This meeting concluded that both longspine and shortspine thornyheads were "*excellent*" candidates for such a survey as these species were "*…always on the bottom, not aggregated*". The meeting also concluded that Pacific ocean perch were "*good*" candidates for a survey as this species was on the "*..bottom or dive to bottom*". All the other species considered were rated as "*good/minus*" to "*poor*" as the species "*…aggregation levels were very high*".

2. The choice of the geographical stratification used in any survey is, to a large extent, dependent on the question being posed, particularly with regard to the management of the stocks being surveyed. Unfortunately, no specific guidelines on this issue have been received. Therefore we have defaulted to the DFO "slope rockfish management areas" (SRF_Areas: Figure 1 and Table 1) which are currently used by DFO fishery managers to set quota limits for these species . The choice of finer geographical strata often have substantial cost implications and we have been reluctant to propose this without policy guidance. We also felt that the presentation of the results at this level of stratification would be indicative of the requirements of a survey and could be easily expanded into a more detailed design.

3. Two key assumptions have been made in this paper about the information contained in the DFO PacHarvest database:

   a. that the observed variances between tows are an estimate of the underlying population variance for the species being considered; and,

   b. that the observed spatial and depth distribution in the database are an accurate reflection of the species population distribution in those depths and areas.

   The survey design considerations presented in this paper will only be accurate if these assumptions are correct.

4. Introduction and background

The use of commercial fishing gear to estimate fish abundance is a well-established practise used on a world-wide basis to monitor demersal fish populations (Doubleday & Rivard 1981). The use of bottom trawl fishing gear is particularly powerful in the context of a fishery-independent trawl survey as the survey design can specify the locations and timing of tows, the type of gear used and otherwise standardise a generally diverse fishing operation. The objective of this type of survey is to generate an index of population abundance for the fish species of importance so that population changes over time will be tracked as the species is being fished.

Fishery-independent surveys can be typically used to generate two types of abundance indices:

1. An "absolute" biomass index which attempts to enumerate the actual size of the biomass vulnerable to the fishing gear.
2. A "relative" biomass index which estimates a biomass index which can be compared to successive indices which are comparably collected.

An absolute biomass index is a much more powerful piece of information as it scales the entire fish population independently of the catch. A relative biomass index relies on the removal of catch to scale the population size. This latter process can often be ambiguous, especially if the level of removals is not large relative to the population size.

An alternative procedure for creating an index of fish population abundance is to directly use the information generated from the activity of commercial fishing. This approach has several advantages, including low cost (as the data are collected routinely for other purposes), a large number of observations, and excellent coverage over the entire fishing season (although only where there is commercial fishing). Two approaches have been generally used to generate fish population abundance indices from such data:

1. One approach estimates the mean catch rate in the area swept by the commercial fishery and expands that estimate to the total area over which the fish population exists. This method is usually termed the "area swept" method and is identical to the procedure used by a fishery-independent trawl survey to estimate a population index. This method can be used to generate either an absolute or a relative population index. Schnute et al. (1999), Schnute & Haigh (2000) and Walters & Bonfil (1999) all use this procedure to generate absolute biomass indices.
2. The other approach uses a statistical method (usually a general linear model [GLM]) to explicitly model the effect of various indicators which can affect catch rates in commercial catch and effort data. This method employs explanatory variables associated with the catch to explain the variation of the dependent statistic (usually catch per unit effort). These models usually incorporate a categorical variable for time (usually by year) which is interpreted as the abundance index. This approach is commonly used in the analysis of fisheries data to generate relative abundance estimates (Quinn & Deriso 1999).

However, the use of commercial fishery data to estimate fish population abundance indices is highly problematic as there are many sources of potential bias which result from the way these data are collected. The most important bias comes from the fact that commercial fishing effort is not distributed randomly with respect to the area over which the fish are distributed. Fishermen typically will go to places where they expect to catch fish because they are creating income rather than measuring a fish population. Because of this inherent bias, it is unlikely that commercial fishing data can produce a reliable index of absolute population size. The generation of relative population abundance indices using general linear methods may have more potential, but these indices will also be affected by the non-random selection of fishing locations which is typical of commercial fisheries data. Given the methods which are currently available to analyse commercial catch and effort data, a fisheries-independent research survey is much more likely to provide a series of comparable population indices.

It is useful to examine the analytic methods used by two recent assessments of British Columbia slope groundfish to generate population biomass indices from commercial catch and effort data (Schnute et al. 1999; Walters and Bonfil 1999). Both papers followed similar strategies. They:

1. used the commercial trawl information to estimate the mean catch rate within small geographical areas (1 nm^2 blocks [Walters & Bonfil 1999] or 4 km^2 blocks [Schnute et al. 1999])
2. extrapolated from the fished blocks to the unfished blocks to estimate a total absolute biomass
3. used this biomass estimate within a fishery dynamics model to estimate the sustainable yield (Walters and Bonfil 1999 only).

Both Walters and Bonfil (1999, p.603) and Schnute et al (1999) identify three key issues that a swept area trawl survey needs to consider to generate a biomass estimate that can be used within a stock assessment. These issues apply to the design and analysis of a fishery-independent survey as well as to indices generated from the analysis of fisheries catch and effort data:

1. How should mean catch rate be converted to an area swept biomass estimate?
2. How should mean catch rates from fished areas be used to estimate the catch rates in unfished areas?
3. How can an annual estimate of abundance be generated from data which vary greatly within any one year?

The first issue is addressed within a fishery independent survey by standardising the gear and other variables associated with fishing (such as length of time fishing and vessel speed) to minimise the variability between tows. As each individual fisherman chooses whatever gear combination suits his fishing style and ability, this increases the level of variability in what is already a highly uncertain estimate. The slope groundfish catch and effort data used by Schnute et al. (1999) and Walters & Bonfil (1999) has an unquantifiable amount of additional variability as this database does not record important vessel and net characteristics with each tow (e.g. mean vessel towing speed and net dimensions).

The second issue is a major difficulty if the survey wishes to estimate an index of absolute abundance. This is one of the primary reasons that the bottom trawl survey method is not likely to provide a reliable estimate of absolute abundance. If the survey is only required to estimate an index of relative abundance, then the issue of untrawlable areas is less important. A survey will be representative of the trawlable areas and, to the extent that there is exchange between the trawlable and untrawlable areas, it may also be representative of the untrawlable areas.

The last issue is highly problematic for any research trawl survey as year-to-year variability may obscure population trends. Sampling precision for the survey is primarily a measure of within-year variability, but year-to-year variability may either flatten population trends or create spurious trends. A possible solution is to extend the survey over a wide enough time period so as to be confident that year-to-year variation (usually in terms of the timing of the peak fish abundance) is minimised but this solution will usually add greatly to the cost of the survey and may introduce problems of comparability within the time strata.

Schnute et al (1999, Section 8) identified several concerns voiced by the groundfish commercial fishing industry about estimating population abundance indices for slope groundfish for research purposes. They consequently listed a number of issues that needed to be addressed when designing such a survey. These issues include (a) the identification of trawlable areas, (b) the collection of information on how species density varies by time and depth, and (c) the development and evaluation of a depth-stratified survey. They also identified (Table 8.1 – Schnute et al. 1999) three of the slope groundfish species (Pacific ocean perch [POP], shortspine thornyheads [SST], and longspine thornyheads [LST]) which appeared to be the most likely (from a biological and behavioural perspective) candidate species for monitoring using commercial bottom trawl gear.

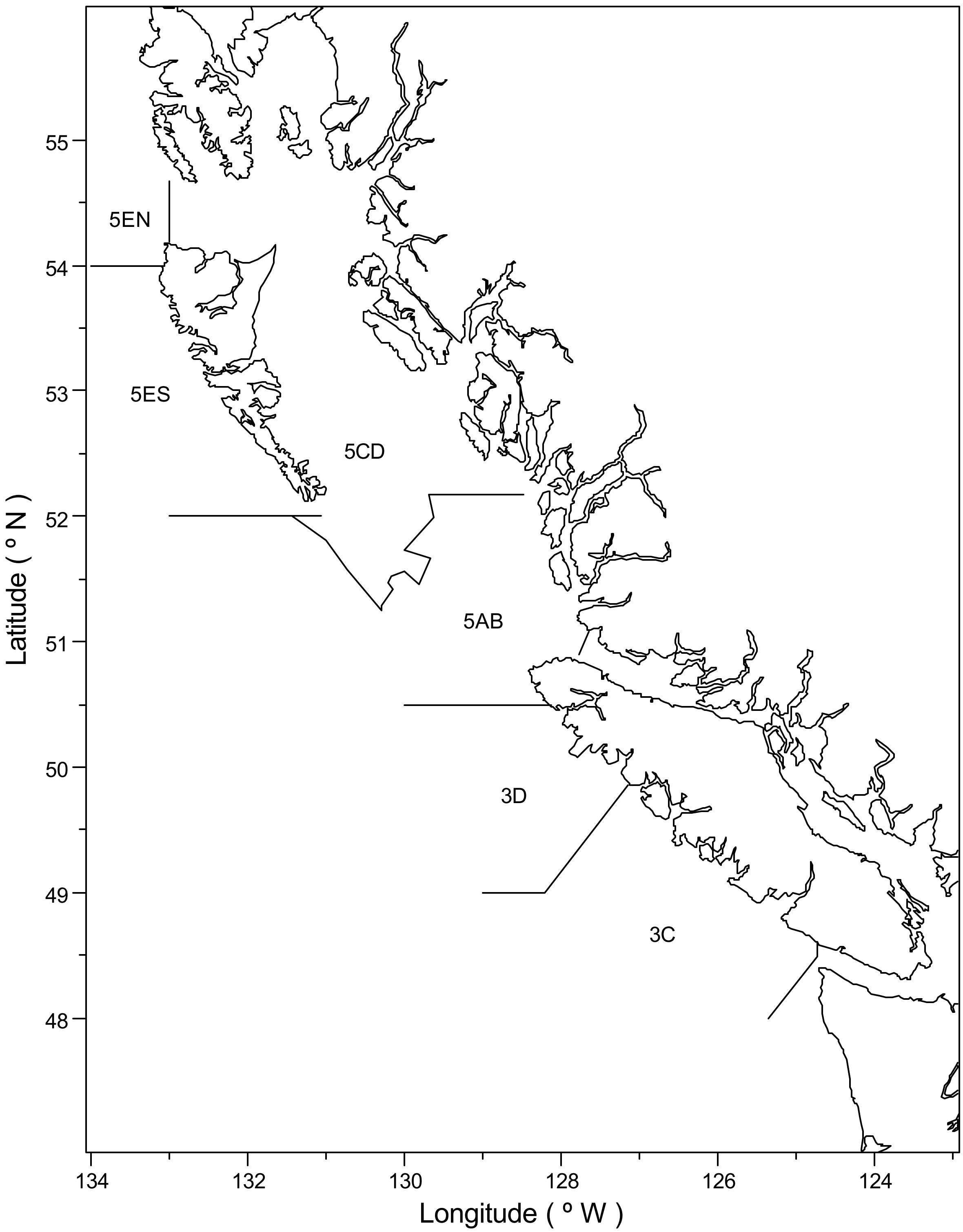

Figure 1. Map of the Pacific west coast of Canada showing the locations of the SRF_Areas (=slope rockfish management areas) referred to in the text (Table 1).

5. OBJECTIVES OF THE SURVEY

This document proposes a fishing industry-sponsored bottom trawl research survey with the following objectives:

1. Determine the relative abundance of the three target species (longspine thornyheads, shortspine thornyheads, and Pacific ocean perch) in all specified strata at the specified target coefficients of variation (CV).
2. Collect appropriate length and age information such that the length and age frequencies for the three target species can be determined in each target stratum.
3. Collect data associated with the performance of the net to measure comparability of effort within and between surveys.
4. Collect information on the variability of mean catch rates over time and area through direct experimentation to obtain a better understanding of how catch rates vary than is possible from the trawl data.

6. DATA SOURCES AND PREPARATION

The data used in this analysis were prepared as described in Appendix 1 (page 35). Note that CPUE in this paper always refers to the statistic of catch of a target species (in kilograms) per hour towed by bottom trawl gear (Section 13.1.5). There are six DFO management areas on the Canadian west coast which pertain to slope rockfish (abbreviated as "SRF_Area" – Figure 1 and Table 1)

Table 1. Codes and descriptors for the slope rockfish management areas (SRF_Area) used in this document (Figure 1)

Code	Description
3C	Southern Vancouver Island
3D	Northern Vancouver Island
5AB-GI	Queen Charlotte Strait: Goose Island Gully
5AB-MI	Queen Charlotte Strait: Mitchell Gully
5ES	West Coast Queen Charlotte Islands-South
5EN	West Coast Queen Charlotte Islands-North

7. METHODS

7.1 THEORY

As outlined by Schnute & Haigh (2000), Schnute et al (1999) and Walters and Bonfil (1999), obtaining estimates of the biomass begins with a random sample of tows. The catch is expressed as biomass per standard tow (using average speed of the tow multiplied by the time towed or, better still, the actual measured distance towed). The standardised tows are averaged and then multiplied by a factor that relates the area towed in a standard tow to the total area. The resulting estimates of biomass (relative or absolute) are summed across strata to give the estimate of overall biomass. Consequently the overall precision (expressed as standard error (*SE)* or as relative error (*RE;* i.e. % of the estimate) of the biomass estimate will depend upon the precision in each individual stratum. Generally, as strata are aggregated, the relative error of the aggregated estimates will improve, i.e. if each stratum has a S*E* that was 10% of the estimate, the overall estimate, over all strata, will generally have a relative error less than 10% of the overall estimate. Intuitively, errors in estimation for the individual strata tend to cancel each other out as strata estimates are aggregated. It should be noted that only sampling uncertainty can be controlled by sample sizes. Non-sampling errors which be may as large or larger than sampling errors cannot be easily quantified.

An important aspect of survey design is deciding upon an appropriate level of sampling effort which will depend upon the level of precision required for management of the fishery and assessment of the stock. For example, if the fishery is to be managed on an SRF_Area (Table 1) basis, then the estimate of abundance for each SRF_Area must have adequate precision. However, if the management level is directed at even larger units (e.g. the whole west coast of Vancouver Island), then estimates for strata that form the larger management area can be less precise; that is, higher levels of relative error can be accepted in each SRF_Area as long as the overall precision for the complete management unit is adequate.

For a single stratum, the precision of the mean catch rate from a series of tows can be estimated by:

$$SE_s = \sqrt{VAR_s / n_s} \qquad \text{Eq 1}$$

where

SE_s is the standard error of the mean CPUE for the survey in the stratum
VAR_s is the variability among individual CPUEs for tows (note that VAR_s applies to the underlying population being surveyed but is estimated from the commercial tows as a first approximation of the variance of the population), and
n_s is the number of tows randomly assigned to areas within the stratum

Some sampling textbooks adjust this with a finite population correction factor, but for planning purposes, Eq. 1 is a reasonable approximation. Note that the key assumption is that tows will be randomly assigned (in both time and space) to sweep areas within a stratum.

The precision of an estimate is often expressed by its relative error (*RE*), defined as

$$RE_s = \frac{SE_s}{m_s} \qquad \text{Eq 2}$$

where

m_s is the true mean density.

The *RE* is often used to set targets for precision, e.g. the *RE* of the estimate could be (quite arbitrarily) set to a 20% target. This would indicate that the sampling uncertainty is about 20% of the mean. Then the intervals:

$estimate \pm se$ or $estimate \pm 2se$

would correspond to approximate 68% and 95% confidence intervals for the true population value, and, after dividing all terms by the estimate, that there is about a 70% chance that the estimate obtained from a survey will be within 20% of the true value and about a 95% that the estimate obtained from a survey will be within 2 * 20% = 40% of the true value.

From knowledge of the $CV_S = \sqrt{Var_S} / m_S$ of the individual CPUE measurements, the necessary sample size to obtain an estimate with the specified precision can be estimated by solving the equation

$$n_s = CV_s^2 \Big/ RE_s^2 \qquad \text{Eq 3}$$

where

RE_s is set to the target level (e.g. 20%) and CV_p is estimated from the commercial trawl data.

The precision when strata are aggregated over several strata is determined from:

$$SE_{COMBINED} = \sqrt{\sum_{S=1}^{H} A_S^2 \, SE_S^2} \qquad \text{Eq 4}$$

where

A_S is the relative weighting factor for each stratum used to expand the individual mean CPUE to biomass estimates (in most instances, A_s will be the area of the stratum);
SE_S is the precision of the individual estimates of mean CPUE as determined by Eq. 1 above;
H is the number of strata being aggregated.

The *RE* of the combined estimate is determined as:

$$RE_{COMBINED} = \frac{SE_{COMBINED}}{\sum_{S=1}^{H} A_S m_S} \qquad \text{Eq 5}$$

There are many ways to allocate sample sizes within several strata to obtain the same overall aggregate precision. Cochran (1977) develops the theory of optimal allocation to get the best precision for a fixed number of tows and shows that the best precision is obtained if the number of tows allocated to a stratum is proportional to the product of the weighting factor and the standard deviation within the stratum, i.e. strata that are larger or more variable should receive more tows:

$$n_S = \frac{n A_S \sqrt{VAR_S}}{\prod_{S=1}^{H} A_S \sqrt{VAR_S}} \qquad \text{Eq 6}$$

where

n_s = the number of tows allocated a stratum

In the special case of roughly equal mean CPUE and equal CV of individual measurements in all strata, then the stratum standard deviations are approximately equal, and the above formula reduces in form to exactly the same as for a single stratum, i.e. 100 tows in a single stratum will give the same *RE* as 100 tows allocated to a larger area. This is the case when stratification is not beneficial. This counter-intuitive result is well known in survey methodology – i.e. it is the absolute number of samples that drives precision and not the relative size of the sample to the population size. For example, a political poll of 1000 people from British Columbia, or 1000 people from Canada, or 1000 people from the US properly chosen in a random fashion all have essentially the same sampling error.

7.2 General linear model

An approach using stepwise multiple linear regression where data are assumed to be derived from a lognormal distribution was used to estimate factors which affect the mean CPUE, the standard deviation of CPUE and the CV of CPUE based on the data from the commercial catch and effort database (see Appendix 1, Section 13.1.4 for how these data were generated). This approach is commonly used to analyse fisheries catch and effort data (Quinn & Deriso 1999).

Five factors (fishing year, month, 100 m depth band, SRF_Area and vessel) were modelled as categorical variables against the natural log of mean CPUE, the natural log of the standard deviation of CPUE and the natural log of the CV of CPUE. An additional analysis using the same three dependent variables was done only for the west coast of Vancouver Island by substituting 0.1° bands of latitude for the SRF_ Area categorical variable. The coefficients of the explanatory variables from these regressions were investigated qualitatively for trends in the three CPUE statistics that could be attributed to each factor analysed.

Note that a lognormal distribution was assumed for the distribution of the standard deviation and CV of CPUE. It is possible that a $\div^2$ distribution would be more appropriate. However, the lognormal distribution is a close approximation of the $\div^2$ and serves the purpose of this analysis which is to explore broad trends and relationships, rather than to make definitive hypothesis tests.

7.3 Proposed survey analysis

Papers that present methods to analyse data generated by a research random trawl survey are widely available in the literature (e.g., Doubleday & Rivard 1981; Francis 1984; Gunderson & Sample 1980, Gunderson 1993) and consequently will not be reproduced here. Schnute & Haigh (2000) present a clear and precise presentation of the “area-swept” method of estimating an abundance index from survey data which can serve as an example of the analytic method which will be followed.

8. Results

8.1 GLM analysis

The results of the GLM analysis described in Section 7.2 are presented in Figure 2 to Figure 5 and, in the case of longspine thornyheads, are compared to a similar analysis in Starr & Haigh (2000). Note that interaction terms between main factors have been ignored in this analysis as the intent was to look for broad associations and trends in the data. All of the plots show the "effects" of levels of the factors relative to the first effect.

8.1.1 LONGSPINE THORNYHEADS

There is a slightly stronger decline in mean CPUE by fishing year for longspine thornyheads in this analysis (Figure 2) than when compared to the similar analysis for this species presented by Starr & Haigh (2000). This is likely due to the inclusion of more vessels over a greater depth range than were considered by Starr & Haigh, who confined their analysis to the top 12 ranked vessels within 701-1200 m only. The increasing trend in mean CPUE by depth band begins at a deeper depth than for shortspines and does not fall away as depths become greater. There is a declining trend in both the mean and standard deviation of CPUE into the winter months and consequently there is no change in the CV of CPUE over the year. There is no significant trend in any of the CPUE statistics over the SRF_Areas (Figure 2) which reflects the fact that there has been virtually no fishing for longspines other than in SRF_Areas 3C and 3D.

8.1.2 SHORTSPINE THORNYHEADS

There is no trend in the mean of CPUE for shortspine thornyheads by fishing year but there may be a decreasing trend in standard deviation and in the CV of CPUE over the four years of analysis (Figure 3). There is an increasing trend in mean CPUE up to the 701 –800 m depth bands, followed by a gradually decreasing trend. Standard deviation of CPUE follows a similar trend for this species, but it is not as pronounced. Consequently there is little change in the CV by depth. As for longspines, there is a declining trend in mean and standard deviation of CPUE into the winter months and an increasing trend in mean CPUE with the more northerly SRF_Areas (Figure 3).

8.1.3 PACIFIC OCEAN PERCH

Both the mean and standard deviation of CPUE by fishing year for Pacific ocean perch show a similar pattern (Figure 4), with no trend in the four years. However, there is a strong pattern by 100 m depth band for both mean and standard deviations of CPUE with both statistics being the largest in the 201 –300 m and 301– 400 m depth bands. There is a weak seasonal pattern with a decreasing trend in mean and standard deviation of CPUE into the winter months. There is an increasing trend in mean CPUE for the more northerly SRF_Areas (Figure 4).

8.1.4 ANALYSIS OF THE EFFECT OF LATITUDE ON THE WEST COAST VANCOUVER ISLAND

The GLM analysis was repeated by species for only the west coast of Vancouver Island in order to consider the effect of finer scale stratification in this area. The tows were analysed on the basis of 0.1° bands of latitude (Figure 5).

There is a pattern for the mean and standard deviation of CPUE for Pacific ocean perch, with peaks at 48.8°N and between 49.1-49.2°N. There are troughs between 48.8-49.1°N and following 49.3°N. As both the mean and standard deviations follow this pattern, there is little pattern in the CV of CPUE for this species (Figure 5). There is an increasing trend in the mean and standard deviation of CPUE for shortspine thornyhead with progressively more northerly latitudes but there is little change in the CV of CPUE for this species over the range of latitudes considered (Figure 5). There are low points in the mean and standard deviation of CPUE for longspine thornyheads at 48.4°N and 49.3°N (Figure 5). This pattern is consistent with that reported by Starr and Haigh (2000). However, it is not clear whether these troughs are sufficient to subdivide the west coast of

Vancouver Island beyond the present management divisions represented by the SRF_Areas defined in Table 1 and Figure 1.

8.1.5 PROPOSED STRATIFICATION

Based on the GLM analysis presented in this section, it appears that the main effect which requires stratification is for depth. None of the three species concerned are caught in significant numbers in the shallowest depth band (0-100m). Therefore, it is proposed that the survey does not consider depths less than 100 m. It is also proposed that the survey be limited to depths less than 1200 m, at least in the initial year. There are only a few tows at depths greater than this in the data set and there is a lower technical feasibility of towing reliably at these depths.

Pacific ocean perch are caught at reasonably high mean CPUEs at depths from 101 to 400 m (Figure 4) while shortspine thornyheads have a gradually increasing trend in mean CPUE, beginning with the lowest depth band (Figure 3). Longspine thornyheads are clearly not caught below the 601-700 m depth band and appear to plateau after the 801-900 m depth band (Figure 2) and shortspines are at their highest mean CPUE from 601 m to 800 m. While there is a clear rationale from this analysis to place a stratum boundary at the 400 m depth contour, there is no equivalent demarcation from this analysis for a deeper boundary and a boundary could be placed arbitrarily anywhere between 700 to 900 m. Alternatively, no boundary may be required in the deeper depths as the CVs for both species are uniform over the range of depths greater than 400 m. The proposed depth strata for this survey are summarised in Table 2.

The other level of stratification required would be geographical. A convenient aerial delineation would be to use the slope rockfish management areas (SRF_Areas) as these are the smallest units presently used to manage these three species (Figure 1 and Table 1).

Table 2. Proposed depth strata for the slope rockfish survey.

	Lower Bound of Depth	Upper Bound of Depth
Depth stratum 1	101 m	400 m
Depth stratum 2	401 m	800 m
Depth stratum 3	801 m	1200 m

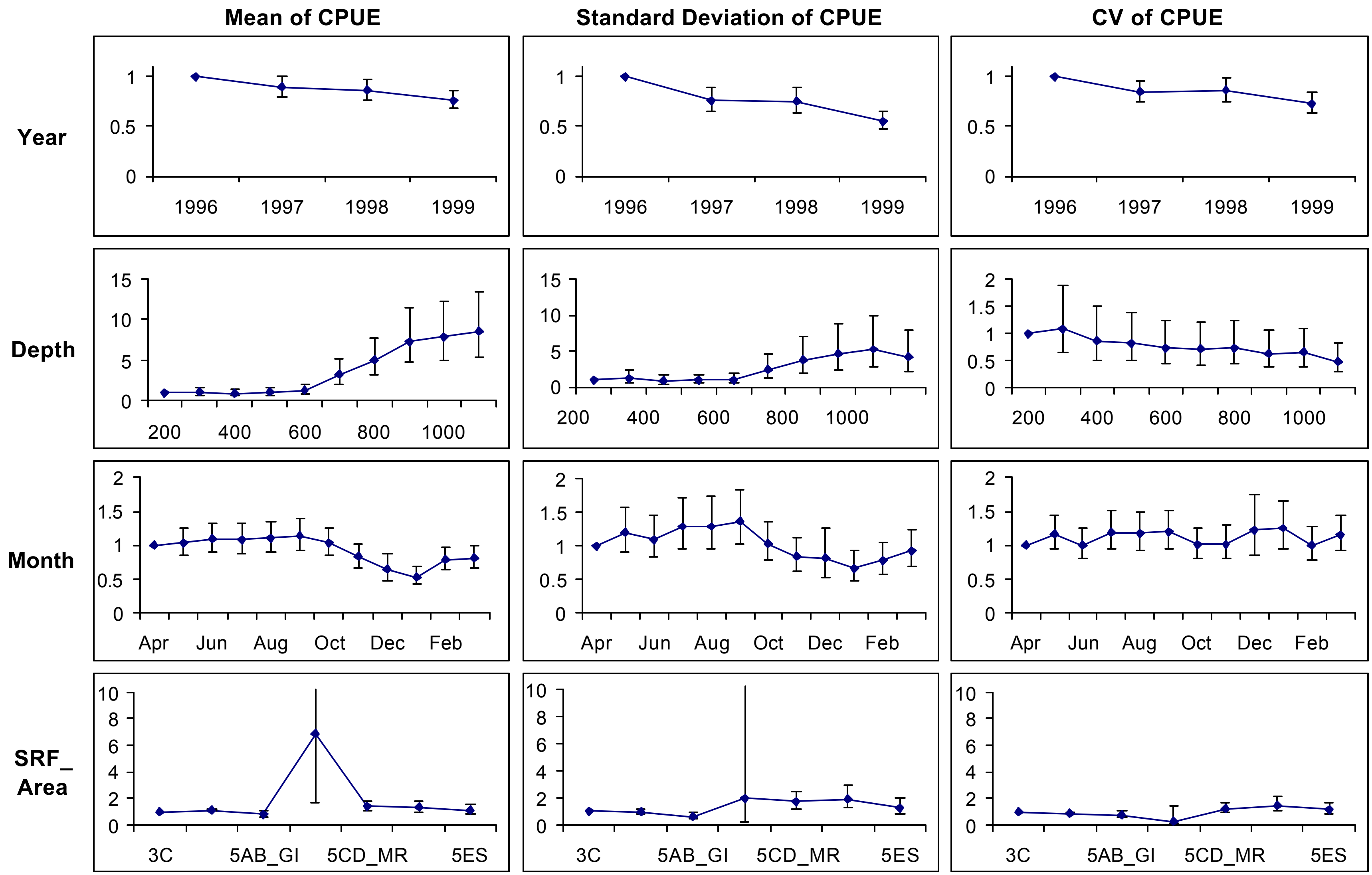

Figure 2. Plots of the exponentiated coefficients for the GLM analyses on three statistics for longspine thornyhead CPUE. Coefficients from each analysis for the 4 explanatory variables investigated are shown in each row. The plotted error bars represent 2 SE and all coefficients are relative to the first coefficient which is set equal to 1.0.

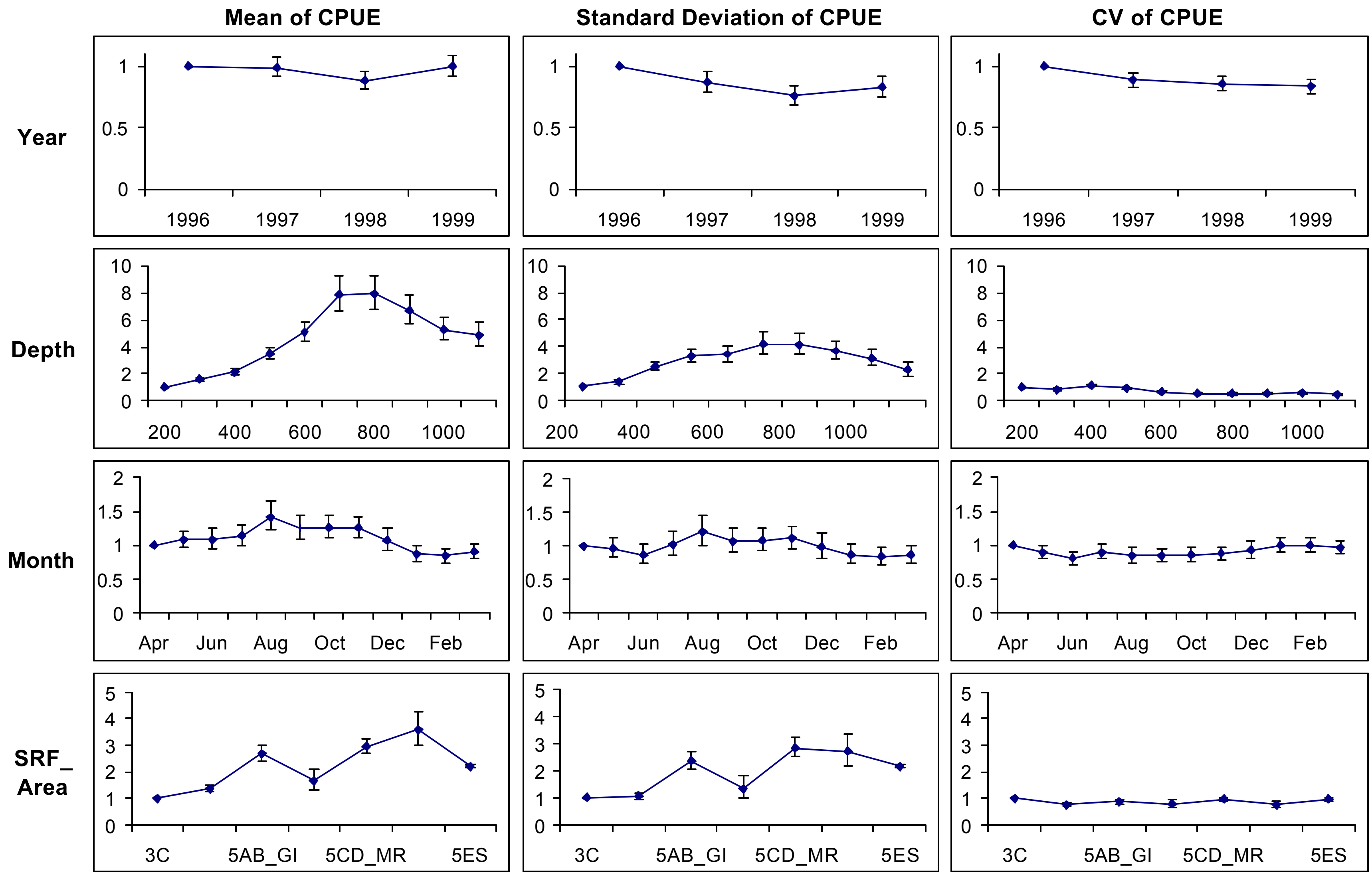

Figure 3. Plots of the exponentiated coefficients for the GLM analyses on three statistics for shortspine thornyhead CPUE. Coefficients from each analysis for the 4 explanatory variables investigated are shown in each row. The plotted error bars represent 2 SE and all coefficients are relative to the first coefficient which is set equal to 1.0.

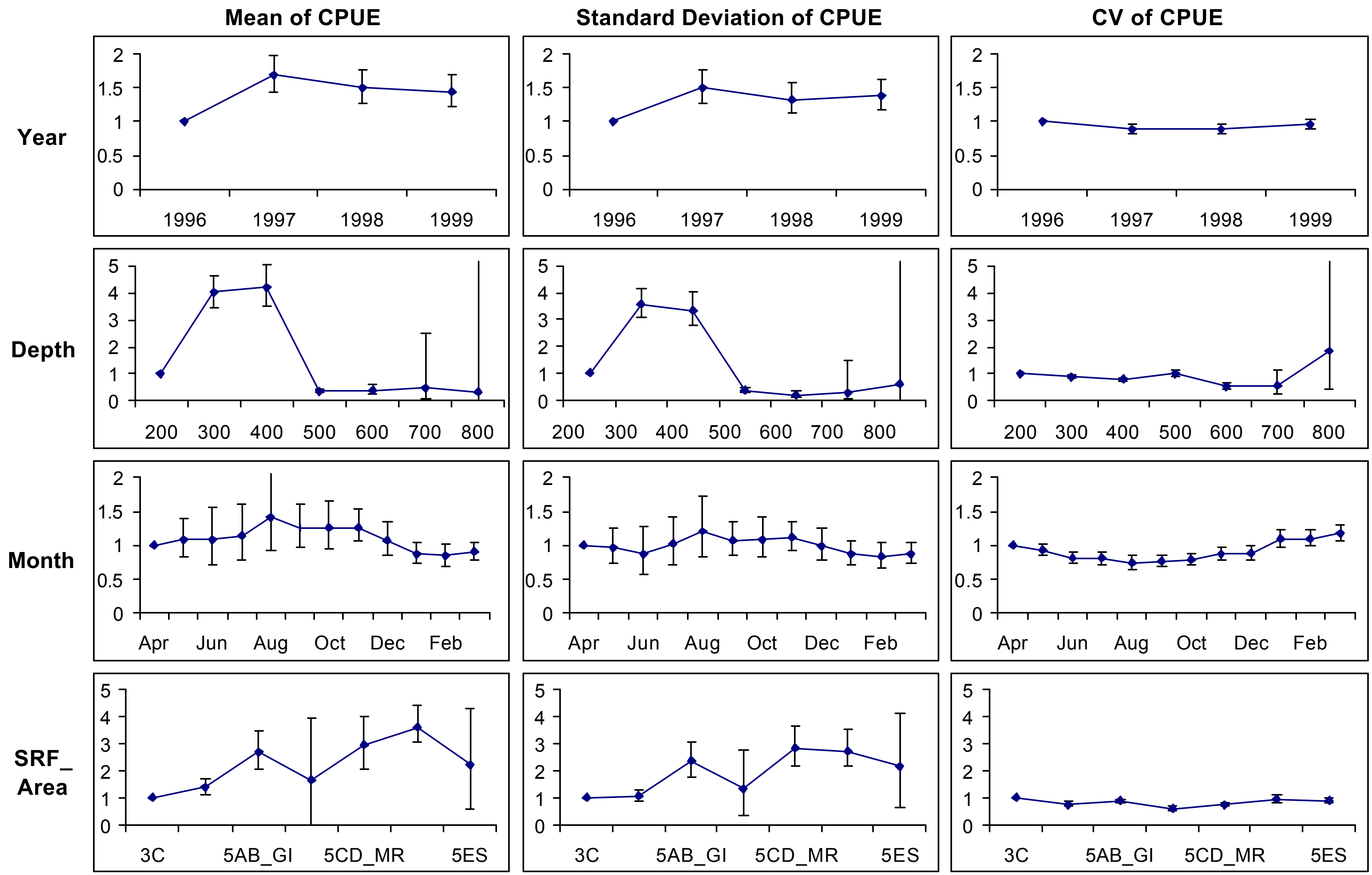

Figure 4. Plots of the exponentiated coefficients for the GLM analyses on three statistics for Pacific ocean perch CPUE. Coefficients from each analysis for the 4 explanatory variables investigated are shown in each row. The plotted error bars represent 2 SE and all coefficients are relative to the first coefficient which is set equal to 1.0.

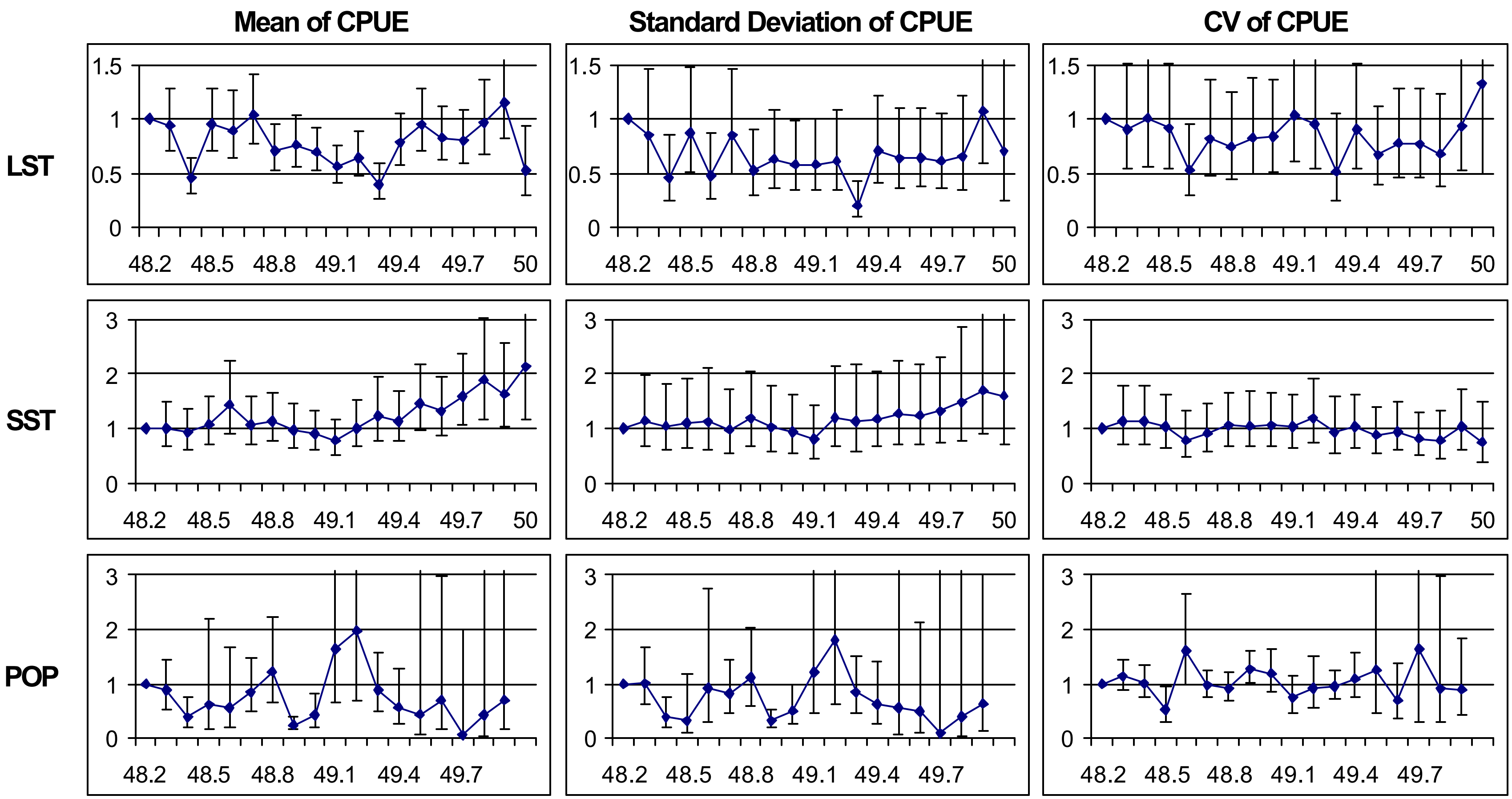

Figure 5. Plots of the exponentiated coefficients for west coast Vancouver Island latitude (0.1° bands) from the GLM analyses on three statistics for CPUE. Coefficients from each analysis by target species investigated are shown in each row. The plotted error bars represent 2 SE and all coefficients are relative to the first coefficient which is set equal to 1.0.

8.2 ANALYSIS OF CPUE STATISTICS

8.2.1 PROPOSED STRATIFICATION

Means, medians, standard deviations and CVs of CPUE (kg/h) for each of the three species using the proposed depth and area stratifications (Table 2) are presented in half-yearly blocks (Table 3, Table 4 and Table 5). Note that half-yearly blocks were added here to determine if there were major shifts in CV between the spring/summer and autumn/winter periods. This type of comparison is much less powerful than the GLM analysis presented in Section 8.1.

These statistics indicate several aspects of the proposed stratification beyond the initial GLM analysis presented in Section 8.1:

- The CVs for longspines are lowest in the deepest stratum (801-1200 m – Table 3), indicating that there is a requirement to stratify between the deepest and mid-range depths. It also appears that CVs for this species are slightly higher in the six winter months than in the summer months. This is reasonably consistent with the month effect presented in the GLM analysis (Table 3)
- The CVs for shortspine thornyheads are similar in the two deeper depth strata, indicating that there may be no need to stratify for this species in the deeper depths (Table 4). CVs for this species are nearly double in the shallow depth stratum
- The CVs for Pacific ocean perch range from 200 to 300% in the shallowest depth stratum (Table 5). This is a very high CV which will require a large number of tows to obtain estimates with an acceptable level of precision.

8.2.2 VARIABILITY OF CPUE BY VESSEL

An analysis of the CVs for CPUE at the level of individual vessels (Appendix 2; page 38) shows that some gain in precision will likely be made for the two thornyhead species if the survey is confined to the most experienced vessels. This is because the highest ranked vessels in terms of catch appear to have slightly lower (in the case of longspines) and much lower (in the case of shortspines) CVs than do the entire fleet. There appears to be no similar effect for Pacific ocean perch with the CVs being high even for the top-ranked fishermen.

Table 3. Summary statistics for longspine thornyhead CPUE (kg/h) by SRF_Area, half year and three proposed depth strata. CVs are given as a percentage. Stdev: standard deviation; N: Number of CPUE observations

Depth stratum	**SRF_Area**	**Half-year**	**N**	**Mean**	**Median**	**Stdev**	**CV**
101-400	3C	apr-sep	160	10	1	26	274
		oct-mar	321	6	2	13	217
	3D	apr-sep	38	3	0	7	209
		oct-mar	56	2	0	4	170
	5AB_GI	apr-sep	108	5	0	12	222
		oct-mar	204	5	0	13	275
	5AB_MI	apr-sep	7	0	0	0	
		oct-mar	21	6	0	11	193
	5CD_MR	apr-sep	232	7	0	17	232
		oct-mar	183	7	0	15	210
	5EN	apr-sep	6	4	2	5	119
		oct-mar	8	21	2	52	250
	5ES	apr-sep	31	5	0	16	319
		oct-mar	59	11	3	19	177
401-800	3C	apr-sep	783	47	43	37	79
		oct-mar	935	24	10	34	142
	3D	apr-sep	421	59	54	40	69
		oct-mar	171	32	22	29	92
	5AB_GI	apr-sep	194	37	29	30	79
		oct-mar	25	6	5	6	99
	5CD_MR	apr-sep	51	30	17	39	131
		oct-mar	57	17	6	32	194
	5EN	apr-sep	35	27	11	31	118
		oct-mar	141	20	9	28	144
	5ES	apr-sep	127	53	46	36	69
		oct-mar	97	21	15	18	86
801-1200	3C	apr-sep	3065	76	70	43	57
		oct-mar	1752	87	79	53	61
	3D	apr-sep	1134	78	69	49	63
		oct-mar	449	91	81	51	56
	5AB_GI	apr-sep	50	67	67	32	48
		oct-mar	1	0	0		
	5CD_MR	apr-sep	1	23	23		
		oct-mar	2	0	0	0	
	5EN	apr-sep	6	92	90	41	45
		oct-mar	45	61	65	36	59
	5ES	apr-sep	5	50	45	25	51
		oct-mar	6	46	42	24	52

Table 4. Summary statistics for shortspine thornyhead CPUE (kg/h) by SRF_Area, half year and three proposed depth strata. CVs are given as a percentage. Stdev: standard deviation; N: Number of CPUE observations

Depth stratum	SRF_Area	Half-year	N	Mean	Median	Stdev	CV
101-400	3C	apr-sep	1289	12	5	22	181
		oct-mar	2157	9	3	16	188
	3D	apr-sep	311	13	6	27	203
		oct-mar	593	10	5	15	142
	5AB_GI	apr-sep	1793	21	11	26	128
		oct-mar	1276	24	12	31	130
	5AB_MI	apr-sep	134	10	5	13	134
		oct-mar	208	15	10	18	114
	5CD_MR	apr-sep	4593	26	10	49	192
		oct-mar	2417	30	13	54	182
	5EN	apr-sep	85	41	16	55	133
		oct-mar	178	24	10	37	155
	5ES	apr-sep	436	18	7	29	161
		oct-mar	826	26	7	103	397
401-800	3C	apr-sep	1617	31	24	29	94
		oct-mar	2899	24	16	26	110
	3D	apr-sep	517	52	45	39	76
		oct-mar	226	53	44	41	77
	5AB_GI	apr-sep	253	54	51	37	68
		oct-mar	94	38	29	39	102
	5CD_MR	apr-sep	1	0	0		
		oct-mar	254	90	77	90	100
	5EN	apr-sep	297	101	74	102	101
		oct-mar	264	46	26	57	123
	5ES	apr-sep	436	71	52	70	99
		oct-mar	298	39	31	35	89
801-1200	3C	apr-sep	300	47	40	41	88
		oct-mar	3065	29	23	23	79
	3D	apr-sep	1752	29	23	26	88
		oct-mar	1134	41	37	29	70
	5AB_GI	apr-sep	449	34	29	28	82
		oct-mar	50	43	42	21	48
	5CD_MR	apr-sep	1	0	0		
		oct-mar	1	23	23		
	5EN	apr-sep	2	3	3	4	141
		oct-mar	6	50	48	23	46
	5ES	apr-sep	45	36	30	20	57
		oct-mar	5	45	37	25	56

Table 5. Summary statistics for Pacific ocean perch CPUE (kg/h) by SRF_Area, half year and three proposed depth strata. CVs are given as a percentage. Stdev: standard deviation; N: Number of CPUE observations

Depth stratum	SRF_Area	Half-year	N	Mean	Median	Stdev	CV
101-400	3C	apr-sep	2230	226	24	532	235
		oct-mar	3169	175	3	580	332
	3D	apr-sep	526	180	13	379	211
		oct-mar	937	153	0	444	290
	5AB_GI	apr-sep	5056	530	170	862	163
		oct-mar	2108	274	17	728	266
	5AB_MI	apr-sep	515	808	490	1042	129
		oct-mar	423	659	222	1061	161
	5CD_MR	apr-sep	5989	1024	435	2314	226
		oct-mar	2954	976	343	1997	205
	5EN	apr-sep	128	1206	21	3742	310
		oct-mar	274	557	28	1208	217
	5ES	apr-sep	698	932	269	1662	178
		oct-mar	1308	1442	408	2649	184
401-800	3C	apr-sep	638	19	0	81	425
		oct-mar	1354	19	0	125	656
	3D	apr-sep	54	64	0	272	421
		oct-mar	41	77	6	171	223
	5AB_GI	apr-sep	60	92	3	323	352
		oct-mar	75	76	21	248	328
	5CD_MR	apr-sep	1	0	0		
		oct-mar	234	162	0	816	504
	5EN	apr-sep	286	134	1	701	522
		oct-mar	245	5	0	20	360
	5ES	apr-sep	322	12	0	45	372
		oct-mar	155	138	0	541	392
801-1200	3C	apr-sep	146	147	10	353	239
		oct-mar	30	6	0	18	313
	3D	apr-sep	25	1	0	3	270
		oct-mar	3	0	0	0	90
	5AB_GI	apr-sep	5	0	0	0	
		oct-mar	2	948	948	1225	129
	5CD_MR	apr-sep	1	0	0		
		oct-mar	1	23	23		
	5EN	apr-sep	3	21	5	31	151
		oct-mar	7	45	43	24	53
	5ES	apr-sep	45	36	30	20	57
		oct-mar	6	37	33	29	77

8.3 REQUIRED SURVEY EFFORT

8.3.1 AERIAL EXTENT OF SRF MANAGEMENT AREAS BY PROPOSED DEPTH STRATA

Table 6 presents the approximate distribution of bottom area for the depth strata proposed in Section 8.1.5. This table is presented as these are the weights which will be used for allocating tow effort between strata when combining across strata (see Eq. 4, 5 & 6). Note that the majority of the area in these depth strata lies in the shallowest of the three defined depth strata.

Table 6. Area (km^2) by depth stratum and SRF_Area (Figure 1) for the proposed stratification of the slope rockfish survey. Data from Schnute et al. (1999)

	Depth Stratum (m)			
SRF_Area	**101-400**	**401-800**	**801-1200**	**Total**
3C	6,452	1,524	1,272	9,248
3D	948	920	752	2,620
5AB	13,480	956	520	14,956
5CD	24,808	984	472	26,264
5EN	1,680	544	228	2,452
5ES	1,452	1,408	1,228	4,088
Total	48,820	6,336	4,472	59,628

8.3.2 WITHIN A STRATUM

The analysis of the catch and effort database shows that POP is almost completely segregated by depth stratum (Table 5), while SST (Table 4) and LST (Table 3) are partially segregated by depth stratum. Consequently, the precision of the overall biomass estimate for POP will be determined by the precision of the biomass estimate in the first depth stratum while that for LST and SST will depend upon the precision of the combined estimate over the two strata.

The analysis of the mean CPUE for POP shows substantial variation in both the mean and standard deviation of CPUE by time of year and by major SRF_Area but the CV of the individual tows is roughly constant at 250% of the mean level. If CPUE is proportional to abundance, the fact that abundance seems to vary over time indicates that aggregations may be occurring, and so it may not be possible to survey this species with sufficiently precise estimates. Presumably, the maximum biomass observable is of interest. The GLM analyses showed that the mean CPUE and CV were roughly equal in all sub-areas. Under these conditions, the RE of the overall estimate is the same function of the total number of tows as for a single stratum, e.g.. 100 tows allocated to the 3C stratum will give a RE of the estimate of about 25%, while 100 tows allocated to the combined 3C and 3D areas in the proportion to the area (about 80 in area 3C and 20 in area 3D) will give an estimate for the combined areas also with a RE of about 25% (while the individual SRF_Areas will have poorer precision). Note also that the RE for this species may be overestimated if, as is suggested by experienced slope rockfish skippers, there is considerable avoidance behaviour exercised when fishing for this species.

Table 5 shows that the mean CPUE for POP differs between SRF_Areas 5AB and 5CD, but the CV is still relatively constant at 250%. Optimal allocation in this case does not give very different results than a simple area proportional allocation, given the same precision constraints. Tows were allocated for SST and LST respectively assuming a roughly constant CPUE and using CVs of 100% and 60% for the respective species in each of the two deepest depth strata (Table 7). A summary of the estimated required number of tows summed over all the depth strata to obtain a specified precision for the mean CPUE is shown in Table 7.

Table 7. Number tows required for each SRF_Area surveyed as a function of the target RE. This table is based on the assumption that each surveyed SRF_Area will have 3 depth strata and that the average CV for POP=250% (assigned to 101-400 m stratum); SST=100% (assigned to 401-800 m stratum); and LST=60% (assigned to 801-1200 m stratum – Table 3 to Table 5)

Target RE	Total number tows required	Number tows in 101-400 m stratum	Number tows in combined 401-1200 m strata
15.0%	338	278	60
17.5%	249	204	45
20.0%	190	156	34
22.5%	150	123	27
25.0%	122	100	22
27.5%	101	83	18
30.0%	84	69	15

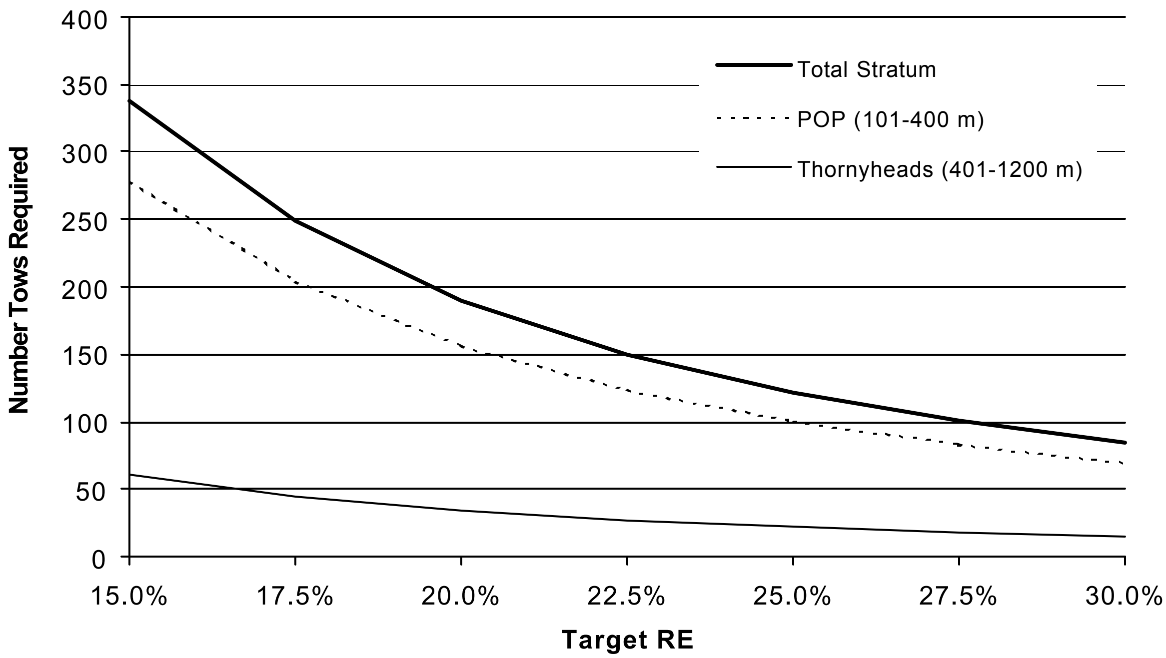

Figure 6. Relationship of the number tows required for each SRF_Area surveyed as a function of the target RE. This figure makes the same assumptions as described for Table 7.

8.3.3 TEMPORAL ISSUES

8.3.3.1 Length of tow

There is evidence in the data that the CV is related to the length of time towed. Summarising the CV of CPUE by the length of time towed shows a decline the mean CV of CPUE for both longspine (Table 8) and shortspine (Table 9) thornyheads. This effect seems to disappear in both species after about 3 to 4 hours of towing, but this observation would suggest that survey tows should be in the order of at least 3 to 4 hours to minimise the CV. A similar summary for Pacific ocean perch does not show an equivalent trend, as CVs appear to be in the 200–300% range regardless of the length of the tow (Table 10).

Table 8. Estimated CV of CPUE (in %) for longspine thornyheads for depth stratum 3 (801-1200 m) in all SRF_Areas by half-yearly block ordered by the length of the tow (in hours).

Half year and hour	SRF_Area 3C	3D	5AB_GI	5CD_MR	5EN	5ES
apr-sep						
1	153	112				
2	92	49				
3	67	84	114		35	55
4	63	80	75			67
5	58	68			32	72
6	55	64				71
7	53	58	40			39
8	53	58	62			72
9	43	60	39			40
10	41	50	43			59
11	40	55	32			
12	38	51	19			
oct-mar						
1	146	58				
2	79	68				83
3	61	74				
4	61	45				
5	61	51				
6	57	55				
7	55	55				
8	58	58				
9	51	43				
10	72	55				
11	61					
12	46					

These results suggest that SST and LST are less aggregated than POP. As tow time increases for the first two species, areas of sparse and higher abundance are more likely to be averaged out with longer tows in the first two species, but the tow times are not long enough for this "averaging" to take place for POP.

8.3.3.2 Distribution of tows over the fishing season

Analysis results presented in Table 3 to Table 5 and in Figure 2 to Figure 4 suggest that there is a relatively strong seasonal effect on mean CPUE or its standard deviation for all three species, particularly for longspine thornyheads. Each species shows a drop in both mean CPUE and standard deviation of CPUE beginning in the late summer or early autumn and continuing to December or January. This is followed by a gradual increase into the spring. As both the mean and standard deviation show this trend, CPUE CVs for all three species are relatively constant through the year. It is possible that this observed drop in mean CPUE during the winter months is more related to weather effects than a true drop in abundance. Depending on how the survey is implemented, it may be possible to spread out the research tows over a relatively long period to smooth out any year to year variations caused by variability in seasonal behaviour.

Table 9. Estimated CV of CPUE (in %) for shortspine thornyheads for depth stratum 2 (401-800 m) in all SRF_Areas by half-yearly block ordered by the length of the tow (in hours).

Half year and hour	3C	3D	5AB_GI	5AB_MI	5CD_MR	5EN	5ES
apr-sep							
1	155	158	152		114	136	123
2	122	104	119		113	93	143
3	114	85	80		72	99	105
4	117	64	49		67	109	72
5	79	91	53		85	92	46
6	67	56	50		55	101	48
7	82	49	20			52	65
8	48	30	29			71	40
9	38	41	35				43
10	41	42	37				44
11	41	24	64				32
12	49	16	57				
oct-mar							
1	136	135	121		155	114	124
2	127	112	112		91	113	102
3	115	54	75		87	84	99
4	101	71	64		79	84	63
5	97	58			108	73	71
6	86	71			68	76	26
7	71	55				49	35
8	83	29					30
9	39	25					24
10	74	49					
11							
12							

Table 10. Estimated CV of CPUE (in %) for Pacific ocean perch for depth stratum 1 (101-400 m) in all SRF_Areas by half-yearly block ordered by the length of the tow (in hours).

Half year and hour	3C	3D	5AB_GI	5AB_MI	5CD_MR	5EN	5ES
apr-sep							
1	242	373	221	161	191	162	151
2	218	193	144	134	164	195	174
3	225	185	146	90	124	189	177
4	200	152	152	105	134	268	152
5	275	101	126	78	113	181	101
6	197	140	211	111	100		
7			107		113		
8	140		100		173		
oct-mar							
1	314	343	363	207	188	159	148
2	257	255	248	158	160	178	166
3	300	228	221	125	147	202	146
4	264	189	161	125	141	194	109
5	321	171	185	107	116	326	92
6	235	129	130	18	103	74	72
7	223		173		102		
8	142	28	151				

8.3.4 TARGET RE

The choice of target RE is a compromise between cost and desired precision when assessing a stock. If the main consideration is to detect a decline (or rise) in relative biomass, a 20% RE implies that it would take an ~50% relative change to be 95% confident that the survey will detect that decline between any two observations (Figure 7). The corresponding calculation for a change in relative biomass with a 30% RE is ~70% relative change. These calculations are meant to provide an approximation of the degree of change that would be detectable given a specific level of RE. The actual level of detection will depend on the number of available data points and the apparent effectiveness of the survey.

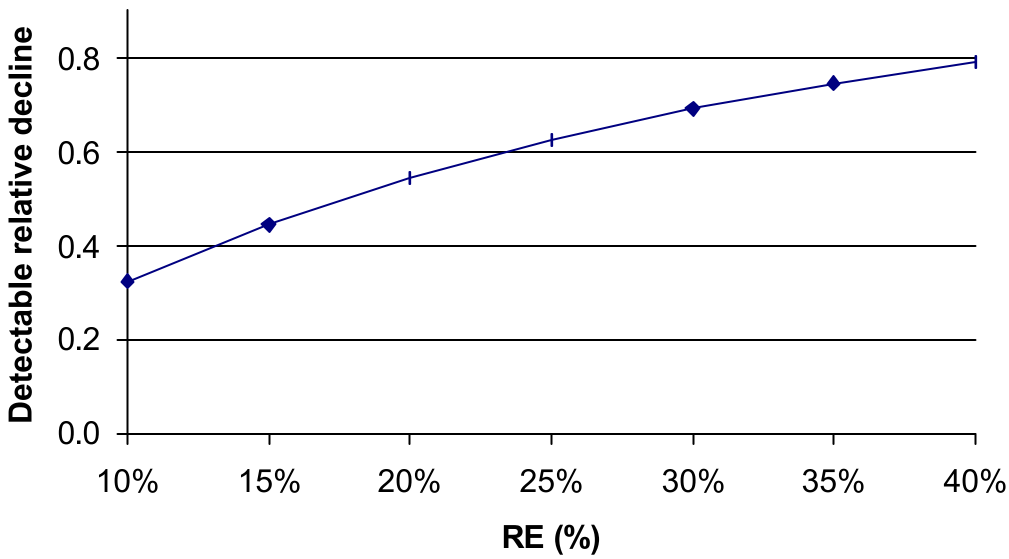

Figure 7. Approximate detectable decline in relative index for a range of hypothetical survey REs (assuming a log-normal distribution). The "detectable decline" is defined as non-overlapping 95% confidence bounds calculated by assuming that the first index is equal to 1.0.

Note that this calculation assumes that the RE is a reasonable estimate of the total error in the mean biomass index. Because the RE is only an estimate of the sampling error, then this estimate of a detectable decline is probably a minimum. Therefore, it is proposed that the initial target RE for any species to be monitored by this survey should be no greater than 20%.

9. DISCUSSION AND CONCLUSIONS

The analyses presented in this paper to estimate of the level survey effort required for a new slope rockfish survey were deliberately kept as simple as possible as a more complex analysis appeared to be unwarranted, given the potential for large non-sampling errors that may have biased the estimates of mean CPUE and the CV of CPUE in an unknown direction and by an unknown amount.

9.1 SURVEY COVERAGE

Expanding the results presented in Table 7 and Figure 6 to a total survey principally requires decisions on how many SRF_Areas constitute a "stock" for the purposes of a stock assessment or management. There is little purpose to achieving a high level of precision for an individual SRF_Area if it is deemed that the entire west coast of Vancouver Island constitutes a single stock unit for longspine thornyheads, given the dispersal capacity for this species (Starr & Haigh, 2000). The tow requirements specified in Table 7 will then apply to the entire west coast rather than to a single SRF_Area. Conversely, it may be decided that the west coast of the Queen Charlotte Islands constitutes a separate stock unit for longspines which requires independent monitoring, then each unit will need a full complement of tows as specified in Table 7.

Various options for a total survey are explored in Table 11, with varying components of aerial coverage and proposed target REs . Options 1 and 2 cover only the west coast of Vancouver Island with two different levels of proposed target REs. Options 3 to 7 add different levels of coverage to the base WCVI coverage proposed in Options 1 and 2. Option 3 covers the west coasts of Vancouver Island and the Queen Charlottes and can be considered a "thornyhead" option. Options 4 and 5 cover the west coast of Vancouver Island and add the Central Coast at different precision levels. Options 6 and 7 progressively add in the west coast of the Charlottes and Hecate Strait. Tow requirements for these options range from less than 150 tows to nearly 400 tows, depending on the number of areas to be covered and the desired precision, with an associated range of costs from ~$275,000 to $800,000 (Table 11).

Table 11. Options for surveys based on the same assumptions as detailed for Table 7 with the additional assumptions that a survey of the west coast of Vancouver Island would cover the two SRF_Areas (3C and 3D) and that a survey of the entire B.C. coast would combine the two outer west coast Queen Charlottes SRF_Areas (5ES and 5EN – Figure 1). Cost estimates are based on a value of $2,000 per tow, based on the assumption that a reasonable charter cost was $8,000 per day and that 4 tows per day could be achieved on average (including positioning and bad weather days)

		Target RE		Required Number Tows			Cost of
		POP	Thornyheads	POP	Thornyheads	Total	survey
Option 1	WCVI	20%	20%	156	34	190	$384,481
Option 2	WCVI	30%	15%	69	60	129	$261,042
Option 3	WCVI + WCQCI	30%	20%	69	68	137	$277,231
Option 4	WCVI + 5AB	20%	20%	312	34	346	$700,160
Option 5	WCVI + 5AB	30%	20%	138	34	172	$348,057
Option 6	WCVI + WCQCI +5AB	20%	20%	312	68	380	$768,962
Option 7	WCVI + WCQCI +5AB+5CD	30%	20%	207	68	275	$556,486

Once the decision has been made as to the number of areas to be surveyed and the precision which is required, then it is reasonably straightforward to allocate the specified number of tows to the appropriate areas and depth strata. Table 11 already specifies the number of tows required in the shallowest (101-400 m) depth stratum as this is the area being monitored for Pacific ocean perch. Allocating the required tows between the mid-level depth stratum (401-800 m) which is targeted at shortspine thornyheads and the deepest stratum (801-1200 m – targeted at longspines) requires the application of Eq. 6 (Section 7.1) with the appropriate target REs and aerial weighting factors.

9.2 SURVEY DELIVERY MODELS

Two models are proposed which can deliver this survey. The first is a more traditional model using chartered vessels which will fish at the direction of research scientist. As two of the proposed target species for this survey are the two thornyhead species, it is likely that the chartered vessel would have to be selected from one of the top-ranked vessels identified in Table 15 as this fishery is highly specialised and requires specialised knowledge and fishing gear.

The second model would make use of the fishing effort already in place for commercial fishing purposes. This model proposes to use the presence of dedicated observers who are required by regulation to be on board all vessels fishing slope rockfish (for management purposes) by asking each vessel to undertake one or two research tows on every trip throughout the season. This model would have the advantage that research tows would be spread out through the entire season and thus would reduce the seasonal timing problem associated with research trawl surveys identified in Section 2. However, this model would introduce an additional level of variability into the analysis which would be difficult to control or to factor out of the analysis (see Sections 4 and 8.2.2 for discussion on this topic). It is quite possible that the additional variability introduced by the use of multiple vessels may negate the advantages of wider temporal coverage and reduced costs.

Whichever model is chosen is partially dependent on the resolution of the requirement to monitor net performance during the research tows (see Section 9.3.1). It may be that a combination of the two models will be able to be followed, given the availability and likely transferability of the monitoring equipment.

9.3 SURVEY PROTOCOL

9.3.1 SAMPLING PROTOCOL

All research tows performed by this survey will require biological sampling to characterise the catch. The following sampling is required for every tow:

1. Determine the catch by weight and by number for every marine species of interest. The number of marine species of interest will be determined in advance based on consultation within the B.C. fisheries science community
2. Determine the length frequency by sex for the three target species. This requirement will likely require random sub-sampling of the catch
3. Determine the age frequency by sex for the three target species (random sub-sampling may be required)
4. Determine the sexual maturity by sex for each of the three target species (random sub-sampling may be required)
5. The biological sampling requirements specified in Requirements 2-4 may be repeated for other marine species of interest, depending on the consultation described in Requirement 1

9.3.2 RANDOMISATION PROTOCOL

The survey design based on the discussion presented in Section 7.1 presumes that all tows are randomly allocated within a depth-area stratum. This presents some practical difficulties in implementation as the research vessel will be sent to perform tows in locations which are not trawlable. At this point, it is proposed that each research vessel will be allocated a series of random tow locations from which to select the required research tows. If a location is unfishable because of factors that are unlikely to be associated with bottom abundance (e.g. weather at the surface), it will be skipped and another random location chosen. Locations that are deemed to be untrawlable because of bottom conditions which preclude the use of the fishing gear will also be re-randomised, but this choice is problematic because it brings us back to the central problem in determining absolute biomass estimates: how are the CPUE estimates extrapolated from fished to unfished areas? As noted previously, this cannot be resolved by using the bottom trawl method. It is probably preferable to concentrate only on fishable areas and assume that the abundance in these areas will provide a relative index of change in stock size for the target species.

Tows should be spread out as much as possible within a fishing season. The GLM analysis presented in Figure 2 to Figure 4 shows that mean CPUEs are reasonably consistent over the summer months for all three target species. Year-to-year seasonal variability can often affect the catchability of fish so it would be desirable to spread out the implementation of this survey over as broad a period as possible. Of the two delivery models proposed in Section 9.2, the second model which makes use of commercial vessels who undertake research tows while on a fishing trip would automatically spread out the research effort over a wide time period. The more traditional model of chartering a dedicated research vessel is much more susceptible to year-to-year seasonal variability. Therefore, if this delivery model is selected, then it may be desirable to undertake a number of charters which are spread out over a longer period of the year.

9.3.3 NET MONITORING PROTOCOL

One issue that has become clear during the preparation of this paper is that the performance of the net during each research tow requires some level of electronic monitoring. This requirement stems mainly from observation of the highly specialised thornyhead fishery which is presently utilising commercial trawl gear near to its limits of effective fishing. Fishing in this fishery is usually done with a very steep warp ratio (up to 1.4) over very long tows (the mean tow length is ~9 to 10 hours) at a very slow towing speed (~4 km/hr). This implies that the cable towing the net is approximately at a 45° angle with the bottom and that small amounts of swell or an uneven bottom will cause the net to bounce off the bottom, thus reducing its catching power. This effect is probably not particularly important during commercial fishing operations, but it may become crucial for the long-term comparability of this survey. This is because it is likely that fishing efficiency will improve over the years and, unless the amount of time the net is in contact with the bottom is measured, comparability with later (likely to be more efficient) surveys will be lost.

Other issues affect the catching power of the net at these depths. For instance, the net can become clogged with mud and other debris which can reduces its efficiency. Such tows need to be identified as they occur. The degree to which the net is fully deployed in terms of the width of the doors and the wings will also affect its catching power. If the wings of the net are not fully extended, then the catching power may be reduced compared to a larger vessel which may have the wings deployed.

These issues are already a problem. Starr & Haigh (2000) present a plot of the relative CPUE of the 12 top-ranked vessels fishing for longspine thornyheads (Starr & Haigh [2000]: Figure 22) which shows that there is a more than two-fold difference in the mean CPUE between the highest and lowest vessel. It is likely that this amount of difference will affect the comparability of the tows and the problem will become greater as the fishery matures and becomes more efficient.

It is known that very few vessels fishing for slope groundfish in B.C. waters currently use net monitors. Therefore, the cost of purchasing net monitors for all vessels participating in the survey may also be included in the initial start-up costs of the survey.

9.4 DIRECTED EXPERIMENTS TO BETTER UNDERSTAND VARIATION IN CPUE

It is suggested that additional funding be provided for direct experimentation and measurement using bottom trawl survey methods. Possible experiments include:

1. Repeated surveys of a restricted area over a short period of time to test the comparability of the method
2. Comparison of several areas, some intensively fished and with others unfished to see if the method can detect differences in abundance

These experiments need to be separately designed once agreement is reached that they are required. The implementation of this work can be phased over several years.

9.5 SAMPLING AND NON-SAMPLING ERRORS

It is important to remember that there are many sources of error that can enter into estimates of biomass. These can be broadly classified into sampling and non-sampling errors. Sampling errors are uncertainty in the final answer caused by the fact that only a sample was taken and not a census. For example, it is impossible to count every fish along the coast of B.C., so a sample is taken and the answer extrapolated. The science of statistics can quantify and control the sampling errors – generally the larger the sample taken (i.e. more tows), the smaller the sampling errors.

Non-sampling errors are uncertainty caused by all other factors. Often these can be as large or larger than sampling errors. For example, as noted by Schnute et al (1999), uncertainty in the average boat speed led to a factor of almost 3 difference in biomass estimates. The other major non-sampling error is the factor used to inflate the biomass density estimates. Schnute et al (1999) and Walters and Bonfil (1999) used quite different factors which led to a factor of 10 difference in the estimates of biomass. Unfortunately, no amount of statistical wizardry can compensate for non-sampling errors. Some of these can be controlled by careful study design (e.g. measuring boat speed and net performance) while others may be unknowable (e.g. do fish live in untrawlable areas?)

10. RECOMMENDATIONS

The following are the recommendations for a slope rockfish survey:

1. Convene a joint DFO/Industry working group to design a specific survey directed at longspine thornyheads (LST), shortspine thornyheads (SST) and Pacific ocean perch (POP) to be initially undertaken in the 1 April 2001–31 March 2002 fishing year. This survey should attempt to address current management goals for these three species.
2. Stratify the survey into three depth strata, each targeted at one of the survey target species: 101-400 m (POP); 401-800 m (SST); and 801-1200 m (LST).
3. Geographical stratification will depend on management requirements and biological stock definitions. It is recommended that the survey be confined to the west coast of Vancouver Island in the first year to test the feasibility of the survey design and to concentrate on implementation issues rather than on extending the coverage to a wide area.
4. Delivery of the survey can be accomplished by either of two models:
    a. Charter one or more commercial vessels to undertake the required number of tows. This model presumes the presence of one or more scientific technicians on board the vessel to collect the requisite scientific information associated with each tow; or,
    b. Allocate the required tows to actively fishing commercial vessels which will undertake one or more research tows during every fishing trip. This model presumes that the scientific observers currently required to be present on all slope rockfish trips will collect the requisite scientific information associated with these research tows.
5. Tows within each stratum will be allocated randomly according to the protocol specified in Section 9.3.1. Every research tow will be standardised as much as possible with respect to: a) tow speed; b) distance and direction towed; c) net characteristics including cod-end mesh size, door-spread and headline height.
6. Every research tow will require the monitoring of the amount of time the net is in contact with the bottom. Additional monitoring of the spread of the doors and the amount of material in the cod-end would also be desirable.
7. Direct experimentation to test some of the assumptions inherent in survey methodology would be desirable. Such experiments could include the reproducibility catch rates from successive tows and experimental depletion of populations in restricted fishing areas. Such experiments would require specialised design before being undertaken.

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13. APPENDIX 1: DATA PREPARATION NOTES

13.1 CATCH AND EFFORT DATA

13.1.1 DATA SOURCE

All catch and effort data were obtained from a summary table (B7_SRFTable) generated from the PacHarvest database held by the Department of Fisheries and Oceans at the Pacific Biological Station on 05 October 2000. See Schnute et al. (1999) for a description of this database, including the available data fields.

13.1.2 DATA PREPARATION AND GROOMING

Records satisfying the following conditions were kept for the analysis in this report:

- Tow start date after 28 February 1996
- Bottom trawl type
- Outside of the Strait of Georgia (i.e. <> SRF_Area=SG)
- Fishing success code <=1 (code 0= unknown; code 1= useable)
- Valid SRF_Area code
- Valid depth field

Codes and descriptors for the slope rockfish management areas (SRF_Areas) are described in Table 1 and mapped in Figure 1. Fields or derived fields that were kept in the data set are described in Table 12.

Table 12. Fields kept in the data set used to analyse longspine thornyhead catch and effort data. LST: longspine thornyheads; SST: shortspine thornyheads; POP: Pacific ocean perch

Field	Description
Vessel	Coded
Month	From March 1996 to July 2000
Standardised fishing year	01 April – 31 March
Latitude	In 0.1° bands
SRF_Area	Slope Rockfish Management Area (see Table 1 for code descriptors)
Depth	In 100m bands
Effort	Tow time in hours
Catch	kg for three species (LST, SST & POP)
CPUE	kg/hour

13.1.3 DEFINITION OF ZERO CATCHES

There were over 4000 tows in B7_SRFTable (out of ~ 100,000 over the 4+ year period) that recorded no catch of any species. When these tows were examined in detail, they often had fishing "success codes" in the database that indicated the tow had failed in some manner (mostly gear malfunction or "water haul"). Therefore, all tows with a "success" code > 1 were dropped (code 0 = "unknown"; code 1 = "successful"). This dropped ~ 5,000 tows, some of which reported catch and left ~ 1,300 tows that had no catch at all.

Many tows only record a catch for a few species. For the purposes of this analysis, it was decided that, in addition to the zero catches defined in the previous paragraph, tows within defined depth ranges which did not record one of the three target species (Pacific ocean perch, shortspine and longspine thornyheads) were designated as a zero tow, on the presumption that a tow on the bottom within each of these depth ranges would have caught the species (Table 13). The number of tows which were set to zero based on these criteria were relatively small in most of the depth bands (Table 14).

Table 13. Ranges of depth over which each species was considered to be fully vulnerable. Tows which were within the specified depth range for a species but which did not record the species were treated as a null catch for that species.

	Lower Bound of Depth	Upper Bound of Depth
Pacific ocean perch	300 m	500 m
Shortspine thornyheads	400 m	1500 m
Longspine thornyheads	800 m	1500 m

Table 14. Total number of tows and tows with zero catches for longspines used in this analysis. Zero tows for each species in the highlighted areas were defined as specified in Table 13 or because the "success code" was less than '2' and no catch of any species was recorded. Zero tows for a species outside of the highlighted areas were designated from the "success code" only. Shaded cells indicate the depth range by species where null catches were deemed to be zero

	Pacific Ocean Perch			Shortspine Thornyheads			Longspine Thornyheads		
	All tows	Zero tows	% Zero	All tows	Zero tows	% Zero	All tows	Zero tows	% Zero
100	355	105	30%	147	105	71%	107	105	98%
200	6112	365	6%	3088	365	12%	466	365	78%
300	14233	3701	26%	7238	279	4%	558	279	50%
400	5970	1098	18%	5970	1662	28%	410	110	27%
500	3281	1983	60%	3281	534	16%	472	66	14%
600	265	32	12%	1762	188	11%	455	32	7%
700	46	15	33%	952	52	5%	649	15	2%
800	19	8	42%	1461	32	2%	1461	115	8%
900	29	19	66%	2612	45	2%	2612	61	2%
1000	30	24	80%	2936	62	2%	2936	55	2%
1100	6	5	83%	962	18	2%	962	19	2%
1200				72	1	1%	72	1	1%
1300				6		0%	6		0%
1400				3		0%	3		0%
1500				4		0%	4	1	25%

13.1.4 ADDITIONAL GROOMING DONE FOR THE GLM ANALYSIS

Further grooming of the catch and effort data for the three species was done to perform GLM (general linear model) analyses. This additional grooming consisted of:

- Reducing the range of depths considered from 101 m to 1200 m
- Dropping all tows begun after 31 March 2000 or before 1 April 1996
- All data were collapsed to strata consisting of the summed catch and effort by vessel, fishing year, month, SRF_Area and 100 m depth band. This was done so that the GLM could be based on the variability of CPUE by this level of stratification

- Strata (i.e. vessel, year, month, SRF_Area and 100 m depth band) for which the CV statistic was undefined were dropped from the analysis.
- The data set was restricted to include only those vessels which had valid observations in at least 10 strata over the four year period

13.1.5 CPUE STATISTIC USED IN THE ANALYSIS

The CPUE statistic chosen for this analysis was catch for any of the target species per hour towed as there appeared to be a strong linear relationship between catch and time towed for the two thornyhead species and there was no suggestion in the data that net saturation was occurring (Figure 8). However, there appears to be a very weak relationship between catch and effort for POP.

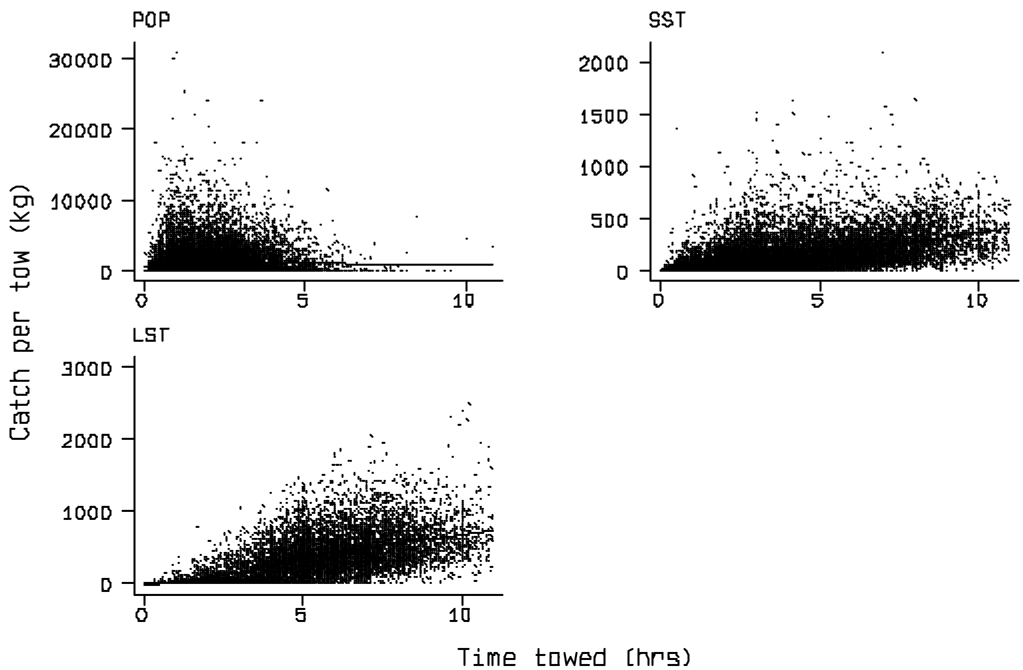

Figure 8. Plot of catch per tow vs. effort by tow for the data set used for the GLM analysis by species (truncated at effort=11 hr). Lowess smoothed lines (span=80%) also shown. LST: longspine thornyheads; SST: shortspine thornyheads; POP: Pacific ocean perch

14. APPENDIX 2. VARIABILITY OF CPUE BY INDIVIDUAL VESSELS

14.1 RANKING OF VESSELS BY CUMULATIVE TOTAL CATCH

The cumulative distributions of total catch by vessel is substantially different for the three target species, with a much larger number of vessels contributing to the overall POP catch compared to the number of vessels contributing to the LST or SST catch (Figure 9). Eighty percent of the total four year LST catch is taken by only 12 vessels while the comparable percentage for SST is 24 vessels (Table 15). The top thirty vessels only account for 67% of the total POP catch and it takes 43 vessels to get to the 80% level.

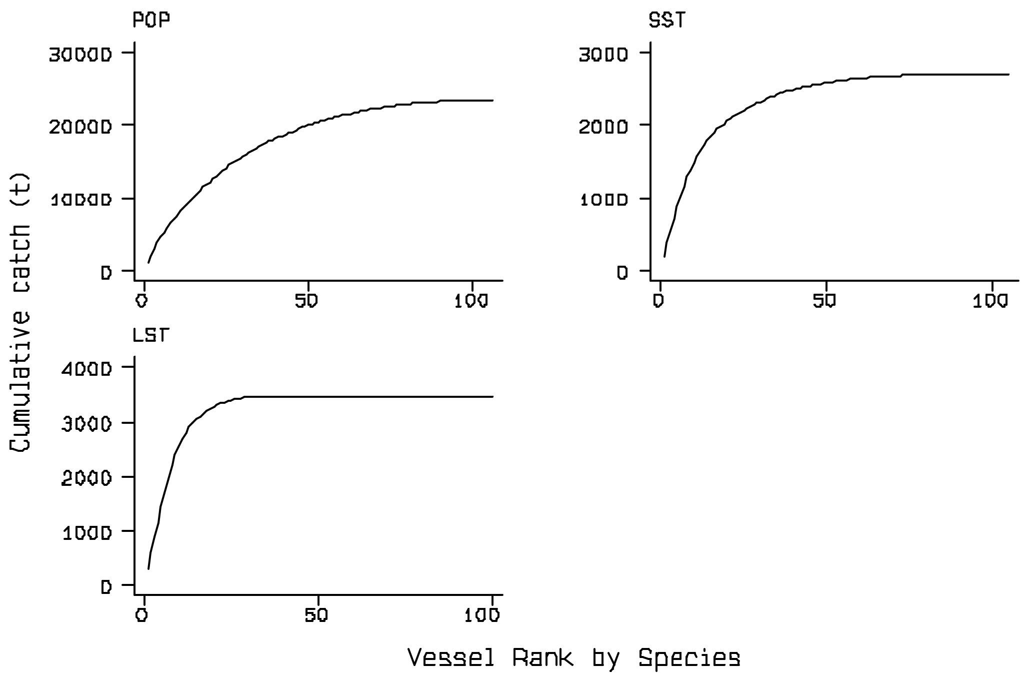

Figure 9. Cumulative catch (summed over 4 years from April 1996 to March 2000 for all SRF_Areas) by ranked vessel in terms of total catch for the three target species.

14.2 CVS OF CPUE BY TOP-RANKED VESSELS

The highest ranked vessels had slightly lower CVs for longspine thornyhead CPUE than the overall mean CPUE CV for that species (compare Table 16 with Table 3), with CVs in the high 40% range compared to nearly 60% for the entire fleet. Shortspine CPUE CVs were much lower for the top-ranked vessels compared to the overall average, with values in the 60-80% range compared to nearly 100% for the entire fleet (compare Table 17 with Table 4). With the possible exception of the one or two highest ranked vessels, the CV for CPUE for Pacific ocean perch was the same for the top-ranked vessels compared to the total fleet (compare Table 18 with Table 5).

Table 15. Cumulative percentage of catch (summed over 4 years from April 1996 to March 2000 for all SRF_Areas) by ranked vessel and species

	species		
rank	POP	SST	LST
1	4.3	7.5	9.3
2	8.6	14.0	17.5
3	12.5	20.5	25.5
4	16.1	26.7	33.3
5	19.5	32.4	41.0
6	22.7	37.8	48.6
7	25.2	42.7	56.2
8	27.6	47.4	63.6
9	30.0	51.6	69.4
10	32.3	54.9	73.3
11	34.6	58.1	77.0
12	36.8	61.3	80.5
13	39.0	64.1	84.0
14	41.2	66.4	86.0
15	43.1	68.3	87.7
16	45.0	70.3	89.2
17	46.9	72.1	90.6
18	48.7	73.5	91.9
19	50.4	74.8	93.2
20	52.1	76.1	94.2
21	53.8	77.2	95.0
22	55.4	78.3	95.9
23	57.0	79.4	96.6
24	58.6	80.4	97.4
25	60.2	81.5	98.1
26	61.8	82.5	98.5
27	63.1	83.5	98.8
28	64.5	84.4	98.9
29	65.8	85.3	99.1
30	67.0	86.2	99.2

Table 16. Summary statistics for longspine thornyhead CPUE by combined SRF_Area 3CD and the 801-1200 depth stratum and by half year for the top 12 ranked vessels in terms of total 4 year cumulative catch. CVs are given as a percentage

Vessel Rank	Depth stratum	Half-year	Number tows	CV of CPUE (%)
1	801-1200	apr-sep	289	44
		oct-mar	175	48
2		apr-sep	354	45
		oct-mar	223	53
3		apr-sep	231	53
		oct-mar	209	60
4		apr-sep	809	50
		oct-mar	53	44
5		apr-sep	356	53
		oct-mar	130	54
6		apr-sep	395	47
		oct-mar	99	63
7		apr-sep	377	47
		oct-mar	155	47
8		apr-sep	171	49
		oct-mar	151	46
9		apr-sep	185	56
		oct-mar	177	53
10		apr-sep	279	51
		oct-mar	109	34
11		apr-sep	153	57
		oct-mar	3	108
12		apr-sep	87	48
		oct-mar	107	66

Table 17. Summary statistics for shortspine thornyhead CPUE by combined SRF_Area 3CD and the 401-800 depth stratum and by half year for the top 20 ranked vessels in terms of total 4 year cumulative catch. CVs are given as a percentage

Vessel Rank	Depth stratum	Half-year	Number tows	CV of CPUE (%)
1	401-800	apr-sep	174	106
		oct-mar	201	88
2		apr-sep	291	66
		oct-mar	96	92
3		apr-sep	160	77
		oct-mar	205	94
4		apr-sep	129	63
		oct-mar	144	69
5		apr-sep	119	78
		oct-mar	106	69
6		apr-sep	80	113
		oct-mar	44	78
7		apr-sep	121	79
		oct-mar	226	101
8		apr-sep	61	93
		oct-mar	106	124
9		apr-sep	136	75
		oct-mar	30	120
10		apr-sep	35	94
		oct-mar	164	89
11		apr-sep	127	56
		oct-mar	65	72
12		apr-sep	126	56
		oct-mar	70	84
13		apr-sep	87	67
		oct-mar	103	80
14		apr-sep	78	86
		oct-mar	196	114
15		apr-sep	32	138
		oct-mar	144	116
16		apr-sep	85	79
		oct-mar	137	125
17		apr-sep	96	87
		oct-mar	266	89
18		apr-sep	83	97
		oct-mar	120	141
19		apr-sep	17	164
		oct-mar	84	91
20		apr-sep	66	115
		oct-mar	132	133

Table 18. Summary statistics for Pacific ocean perch CPUE for SRF_Area 5AB and the 101-400 depth stratum and by half year for the top 25 ranked vessels in terms of total 4 year cumulative catch. CVs are given as a percentage

Vessel Rank	Depth stratum	Half-year	Number tows	CV of CPUE (%)
1	101-400	apr-sep	391	142
		oct-mar	323	176
2		apr-sep	381	283
		oct-mar	389	203
3		apr-sep	310	243
		oct-mar	422	210
4		apr-sep	262	138
		oct-mar	261	257
5		apr-sep	361	281
		oct-mar	367	230
6		apr-sep	300	340
		oct-mar	451	291
7		apr-sep	117	159
		oct-mar	178	206
8		apr-sep	478	182
		oct-mar	359	229
9		apr-sep	437	150
		oct-mar	237	270
10		apr-sep	89	185
		oct-mar	281	212
11		apr-sep	251	188
		oct-mar	185	143
12		apr-sep	297	167
		oct-mar	191	181
13		apr-sep	264	220
		oct-mar	244	270
14		apr-sep	290	172
		oct-mar	233	219
15		apr-sep	346	135
		oct-mar	215	261
16		apr-sep	361	196
		oct-mar	192	322
17		apr-sep	470	219
		oct-mar	241	271
18		apr-sep	306	143
		oct-mar	230	287
19		apr-sep	328	172
		oct-mar	239	199
20		apr-sep	148	243
		oct-mar	154	285
21		apr-sep	284	235
		oct-mar	102	221
22		apr-sep	340	171
		oct-mar	193	261
23		apr-sep	230	173
		oct-mar	297	245
24		apr-sep	224	222
		oct-mar	209	188
25		apr-sep	119	231
		oct-mar	96	147