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Feasibility of multispecies groundfish bottom trawl surveys on the BC coast

Faisabilité d'un relevé au chalut de plusieurs espèces de poisson de fond le long de la côte de la Colombie-Britannique

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ABSTRACT

This paper explores the feasibility of a multispecies groundfish trawl survey along the British Columbia coast for stock assessment work. We investigate commercial trawl catches of species selected for (i) commercial value, (ii) bio-diversity concerns, (iii) spatial distributions, and (iv) suitability to trawl surveys. We identify stocks that meet precision criteria (CV ≤ 20%) for the indexing of relative abundance. We include recommendations for a Groundfish Synoptic Survey (GFSS) to start in 2003. Strata will be defined by Pacific Marine Fisheries Commission (PMFC) major areas and four depth intervals between 50 and 500 m. The initial year of the GFSS will focus on PMFC area 5AB to formalise design and verify precision levels determined herein. This paper is a planning document only and is not meant to provide advice to fisheries managers.

RÉSUMÉ

Dans ce document, nous étudions la faisabilité d’un relevé au chalut de plusieurs espèces de poisson de fond le long de la côte de la Colombie-Britannique pour les travaux en évaluation de stocks. Nous examinons les données de captures commerciales au chalut d’espèces choisies selon (i) leur valeur commerciale, (ii) les préoccupations liées à la biodiversité, (iii) leur répartition spatiale et (iv) leur pertinence pour les relevés au chalut. Nous identifions les stocks qui satisfont les critères de précision (coefficient de variation ≤ 20 %) pour le calcul de l’indice d’abondance relative. Nous présentons des recommandations pour le relevé synoptique du poisson de fond qui devrait débuter en 2003. L’échantillonnage sera stratifié selon les principales zones établies par la Commission des pêches maritimes du Pacifique (CPMP) et selon quatre intervalles de profondeur entre 50 et 500 m. Pour la première année du relevé, l’accent sera mis sur la zone 5AB de la CPMP afin d’établir formellement un plan d’échantillonnage et vérifier les niveaux de précision obtenus. Le présent rapport est un document de planification et ne vise pas à fournir des conseils aux gestionnaires.

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Introduction

Fishing surveys are one of the most powerful tools in fisheries stock assessment work (Gulland 1988). The most common use of survey time series data is for the estimation of relative abundance, usually mean CPUE, for a single species or for groups of species. Survey indices have also been used to scale biomass and recruitment estimates for catch-age analysis. Catch rate data collected on surveys must be of adequate statistical quality to provide an abundance index of required precision. There has been much debate about whether surveys should have a random or systematic design. Random allocation of survey stations within strata meets the requirement for most statistical analyses. However, it is generally acknowledged that a systematic design removes a strong source of variation in the CPUE index, namely zero catches, and provides better spatial coverage. In addition, multispecies surveys provide less precise estimates for individual species because it is not possible to optimize the survey design for every species.

The Department of Fisheries and Oceans (DFO) has conducted a large number of groundfish surveys over the last 60 years (Appendix 1). However, the only long time series of groundfish survey data is that from the Hecate Strait Assemblage Survey (Fargo et al. 1990), which has been conducted since 1984. Recently, groundfish abundance indices have also been calculated from a trawl survey designed for shrimp populations off the west coast of Vancouver Island (WCVI) (Sinclair 2001). Early surveys were largely exploratory. Survey work in the1940s and 1950s focused on the discovery of new fishing grounds. In the late 1960s and early 1970s surveys were initiated to facilitate the assessment of stock status. During the 1980s and 1990s surveys focused exclusively on abundance indexing.

In recent years, scientists have turned to multispecies surveys to reflect the concerns of an IVQ fishery. The groundfish trawl fishery on the Pacific coast catches approximately 250 fish species. To date, only 20 species stocks have been regularly assessed. The recent National Stock Assessment Review recommended developing a fishery-independent relative abundance index for each species exposed to fishing. Furthermore, recent legislation contained in the Species At Risk Act (SARA) requires the protection of rare and endangered species. Given finite resources, such concerns can best be addressed through multispecies surveys. This paper summarizes the results of a feasibility study for multispecies trawl surveys for stock assessment work. We investigate commercial trawl catches of species selected for (i) commercial value, (ii) bio-diversity concerns, (iii) spatial distributions, and (iv) suitability for trawl surveys. We identify stocks that meet precision criteria (CV ≤ 20%) for the indexing of relative abundance. We include recommendations for a Groundfish Synoptic Survey (GFSS) starting in 2003 to determine the actual precision of relative biomass estimates.

The choice of target CV for a stratified random survey is a compromise between cost and desired precision when assessing a stock. Starr and Schwarz (2000) describe a calculation of the biomass change that would be detectable from a given CV. For example, a 20% CV gives the ability to detect a relative biomass change of 50% between two observations with 95% confidence (assuming an underlying log-normal distribution; Figure 1). Similarly, a 30% CV can detect a 70% relative change. This calculation is approximate, and the actual level of detection depends on the number of available data points and the true underlying distribution. Nevertheless, we adopt a target sampling CV of 20% as an initial goal for species to be monitored by a trawl survey.

The calculation so far assumes that the survey CV is a reasonable estimate of the total error in the mean biomass index. Because the CV for any one survey is only an estimate of the sampling error, the estimate of a detectable decline is probably a minimum. A recent meta-analysis of 17 New Zealand trawl surveys operating over a period from the late 1970s to the late 1990s (Francis et al. 2001) showed that the level of variability assigned to survey population indices was probably being underestimated in stock assessment models. Francis et al. (2001) proposed that, on average, a process error of 20% should be included with the sampling error in an assessment model, where

$$CV_{TOTAL} = \sqrt{\left(CV_{SAMPLING}\right)^2 + \left(CV_{PROCESS}\right)^2}\ ).$$

The GFSS Working Group selected a stratified random design because it allows the greatest flexibility in the analysis and interpretation of the survey observations. It also makes fewer assumptions about the underlying distribution of the monitored fish populations. For instance, a fixed station design assumes that the distribution of the underlying fish population is static with respect to the station allocation scheme A failure of this assumption will lead to non-comparability between surveys. On the other hand, a stratified random design assumes that an unbiased estimate of the mean density within a stratum can be obtained in each year regardless of changes in the underlying distribution of the fish population. Although this is also a strong assumption, it is probably more likely than observing a static population distribution. Because of the computational advantages, stratified random designs for fishery independent surveys have been widely adopted by a number of world-wide fisheries agencies. Some examples include the New Zealand Ministry of Fisheries, the Australian Federal Fisheries Agency (CSIRO, Commonwealth Scientific and Industrial Research Organisation), the U.S. National Marine Fisheries Service (NMFS, Northeast Fisheries Science Center), and all east coast DFO Regions (Doubleday and Rivard 1980).

A stratified random design allows for the direct calculation of the observation error associated with each survey based on simple random sampling theory. Other survey designs, including fixed stations designs, cannot estimate this quantity without assuming that the stations were allocated randomly. Although observation error is not the only source of error associated with fishery independent trawl surveys, it is essential that the error associated with each species survey index be calculated. Otherwise, comparisons between years are meaningless.

The main disadvantage of a stratified random design lies in its implementation. Stations need to be randomly pre-selected, and the vessel master is required to occupy these stations in the selected sequence without concern for the trawlability of the station or the expected catch. In practise, these instructions are often difficult to implement, and randomly selected stations are discarded if there is danger of damaging or losing the fishing gear. This design also elicits complaints from the fishing industry that the survey is operating in areas that are not representative of the fishery or the target species, and therefore cannot be monitoring the population. These criticisms can be overcome either by educating the target client group or by restricting the selection of random stations to locations that have been towed successfully in the past. This latter approach was adopted in the design of a monitoring programme for Pacific cod in Hecate Strait (Sinclair and Workman 2002). In contrast, the WCVI longspine thornyhead survey selects random stations from a 500 m grid of possible locations within each stratum (Starr et al. 2002).

Methods

Species selection

The primary purpose of the proposed survey is to provide an abundance index for as many fish species/stocks as possible. In this review, we only consider a set of indicator species that might be representative of a wider array of population units (Table 1). We delimit stocks by allocating indicator species to combinations of Pacific Marine Fisheries Commission (PMFC) major areas based roughly on areas identified in current management plans and stock assessments. Considered individually, these stocks show the range of precision we can expect for both targeted and non-targeted populations. Indicator species are chosen to reflect the following characteristics or issues:

- total retained catch (10 dominant species);
- special interest to the trawl fishery, but currently low volume (e.g., petrale sole *Eopsetti jordani*);
- special interest to the hook and line fishery (e.g., yelloweye rockfish *Sebastes ruberrimus*)
- potential juvenile index (sablefish *Anoplopoma fimbria*)
- bio-diversity concerns (bocaccio *Sebastes paucispinus*, wolf eel *Anarrhichthys ocellatus*, sandpaper skate *Bathyraja interrupta*, big skate *Raja binoculata*, dogfish *Squalus acanthias*)

We exclude those benthic species which almost exclusively inhabit untrawlable bottom (e.g., prowfish *Zaprora silenus*) as well as species that are indexed by other surveys (e.g., Pacific hake *Merluccius productus*, longspine thornyhead *Sebastolobus altivelis*, Pacific halibut *Hippoglossus stenolepis*). We deliberately include some species that we assume are marginal candidates for effective indexing by bottom trawling. These include yellowmouth rockfish *Sebastes reedi* (semi-pelagic, aggregating) as well as sand sole *Psettichthys melanostictus* and shortraker rockfish *Sebastes borealis*, whose characteristic depth ranges are at the shallow and deep borders, respectively, of the proposed depth range for the survey.

Survey simulation model

As a planning tool for this study, we use the simulation model proposed by Schnute and Haigh (2003) for a survey with m strata and n_h tows in each stratum. Each tow i in stratum h produces a density measurement z_{his} of biomass per unit area for species s. In practice, z_{his} depends on several measurements from the tow: catch biomass C_{his}, effort (i.e., tow duration) E_{hi}, vessel speed u_{hi}, and net width w_{hi}. The ratio of biomass captured to area swept by the net gives the density measurement

$$(1) \qquad z_{his} = \frac{C_{his}}{u_{hi} w_{hi} E_{hi}} .$$

A typical tow captures several species s within the swept area, calculated in the denominator of (1) as the net width times the vessel speed times the set duration. The n_h tows in stratum h give the mean density estimate

$$(2) \qquad \bar{z}_{hs} = \frac{\sum_{i=1}^{n_h} z_{his}}{n_h}$$

for each species s. If stratum h has area A_h, then the survey gives the biomass estimate

$$(3) \qquad \hat{B}_s = \sum_{h=1}^{m} A_h \bar{z}_{hs} .$$

We explicitly assume that the density observed in commercially towed areas is the same as that in non-towed areas. Schnute et al. (1999, Figs. 6.1.1, 6.1.2) compared both swept area and impacted area to total stratum area. The impacted area at depths 400-1,000 m was about 25% of the stratum area. We acknowledge the probable bias that this assumption introduces to the biomass estimate (3). Additional data, such as bottom type classifications, might be used to estimate A_h more realistically.

The simulation model treats each measurement z_{his} as a random variable drawn from a compound binomial-gamma distribution with the vector of three parameters

$$(4) \qquad q_{hs} = (p_{hs}, m_{hs}, n_{hs})$$

for each species s and stratum h. Explicitly, the model assumes that tow i in stratum h fails to capture species s ($z_{his} = 0$) with probability p_{hs}. Otherwise, tows that catch species s ($z_{his} > 0$) follow a gamma distribution with mean m_{hs} and coefficient of variation r_{hs} determined by the parameter n_{hs}:

(5) $$r_{hs} = \sqrt{\frac{1}{n_{hs}}}\ .$$

Schnute and Haigh (2003) adopt the parametric form of the gamma distribution presented by McCullagh and Nelder (1989), with parameters (m, n), but they suggest using the parameter r in (5) for an intuitive understanding of n .

An application of the simulation model requires compiling values of the following quantities:

(a) the number m of strata and a list of relevant species,

(b) the surface area A_h of each stratum h ,

(c) a parameter vector q_{hs} for each species s in each stratum h ,

(d) the desired number of tows n_h in each stratum h .

One simulation generates a data set $\{z_{his}\}$ of density measurements that give the biomass estimate $\hat{B}_s$. Many simulations give a distribution of biomass estimates that can be used to assess the potential variability of a survey, given the input data listed above. Schnute and Haigh (2003) use this technique to assess the validity of bootstrap confidence intervals for the biomass. They also derive simpler analytical measures of uncertainty, based on straightforward calculations from the input data (a)-(d). In this paper, we use only these simple results to assess potential surveys. Nevertheless, the data compiled here will enable more intensive bootstrap analyses in the future.

From properties of the binomial-gamma distribution (Schnute and Haigh 2003), it follows that stratum h has density

(6) $$d_{hs} = (1 - p_{hs}) m_{hs}$$

of species s , with the associated variance

(7) $$s_{hs}^{2} = (1 - p_{hs})(1 + n_{hs} p_{hs}) \frac{m_{hs}^{2}}{n_{hs}} = (1 - p_{hs})(r_{hs}^{2} + p_{hs}) m_{hs}^{2}$$

among tows. It follows from (6) that the true biomass, known internally to the simulation model, is given by

(8) $$B_s = \sum_{h=1}^{m} A_h d_{hs}\ ,$$

which can be compared with the estimate $\hat{B}_s$ in (3) from simulated data $\{z_{his}\}$.

Furthermore, the exact variance of $\hat{B}_s$ is

$$(9)\qquad V[\hat{B}_s] = \sum_{h=1}^{m} \frac{A_h^2 s_{hs}^2}{n_h} .$$

In the list of input data for the simulation, items (a)-(c) act like background information for the survey. As shown explicitly in (9), the precision of the biomass estimate $\hat{B}_s$ depends on the number of tows (d). Given a fixed budget

$$(10)\qquad K = \sum_{h=1}^{m} n_h k_h ,$$

where the cost of a tow in stratum h is k_h, we define an optimal survey design for species s as one that allocates tow numbers n_h among strata to minimize the variance in (9). Schnute and Haigh (2003) show that the optimal design can be expressed analytically as

$$(11)\qquad n_{ns}^{*} = \frac{K A_h s_{hs}}{X_s \sqrt{k_h}} ,$$

where

$$(12)\qquad X_s = \sum_{h=1}^{m} A_h s_{hs} \sqrt{k_h} .$$

The allocation (11) depends on the species s. It gives higher priority to strata with large area, high variability of biomass density, and low cost per tow. Note that when the cost per tow is equal among all tows, (11) reduces to Neyman allocation (Cochran 1977). The minimal achievable variance is

$$(13)\qquad V_s^{*} = \min_{n_h} V[\hat{B}_s] = \frac{X_s^2}{K} .$$

In the analyses here, we use an equal cost $k_h = 1$ for a tow in every stratum h. Effectively, we measure the cost K in (10) by the total number of tows.

Stratification and tow allocation

Our simulation model requires estimates of the parameters q_{hs} in equation (4) for each species s and stratum h. We obtain these from historical fishing and survey records discussed in the sections below. In each case, we estimate p_{hs} as the observed proportion of tows with no catch of species s. Similarly, our estimates of m_{hs} and n_{hs} reflect the observed mean and coefficient of variation within tows that capture species s.

Schnute and Haigh (2003) show that these simple estimates of p_{hs} and m_{hs} agree with maximum likelihood estimates from the binomial-gamma distribution; however, the estimate of n_{hs} does not. This paper doesn't investigate the use of maximum likelihood estimates $\hat{n}_{hs}$ from historical data, although that approach remains an interesting topic for future research.

Our stratification scheme includes PMFC major areas and fixed depth zones (Figure 3). Examination of species depth distributions indicate strong separation by depth among species. We choose depth (D) zone boundaries of $50 < D \leq 125$ m, $125 < D \leq 200$ m, $200 < D \leq 330$ m, and $330 < D \leq 500$ m to reflect these associations between species and depth (Figure 2). We do not include depths less than 50 m because of difficulties fishing these waters with trawl gear. Depths over 500 m are already included in a trawl survey for longspine thornyheads (Starr et al. 2002), and we elect not to repeat that survey here. The PMFC major area boundaries define fish stocks for management purposes, and our survey design is consistent with historical stock definitions. Of the 28 possible area-depth strata, we remove the shallowest depth zone in PMFC area 5E, which contains no fishing event information to derive q_s, given the tow qualifications listed in the section on data selection below. This leaves 27 strata in the survey area covered by our study.

We investigate several tow allocation schemes with the intent of choosing one that provides a reasonably low coefficient of variation in the biomass estimate for most indicator species. These include:

1. equal allocation of sets among all strata,
2. allocation in proportion to the surface area of the strata,
3. allocation proportional to total fish catch in the strata,
4. allocation proportional to the observed mean density of all fish,
5. allocation to optimize the coastwide estimate of total fish biomass, and
6. allocation to optimize the coastwide biomass estimate for each species s.

The fifth allocation scheme requires an additional analysis from historical data, in which all biomass is treated as if it were one species. This gives estimates of the parameters q_{hs} for a hypothetical species s composed of all fish biomass captured by the tows under consideration.

Data selection and analysis

Commercial fisheries data are used for planning the coastwide groundfish trawl survey because they are the only data which cover the entire coast. We assume that commercial fishery effort reasonably approximates a stratified random survey. To minimize inter-tow variability, we need to conduct the survey during a period when fish populations are not migrating and are broadly distributed. Preliminary analyses indicate that several species tend to be fished in shallow water in summer (June – September) and deep water in winter (December – March). Migrations between areas tend to occur during spring (April-May) and fall (October-November). Inter-tow variability of CPUE tends to be higher in winter than summer. It is likely that survey fishing operations will be restricted to daylight hours. There is considerably more daylight in summer than winter at these latitudes. Furthermore, weather conditions are much more severe in winter than summer. Consequently, the proposed trawl survey should be conducted during the months of July – September.

Before deriving the model parameters q_s for each stratum, we qualify the commercial data from the PacHarvTrawl database (Feb 16, 1996 – Nov 15, 2002) as follows:

- observer log records;
- PMFC major areas 3C/D, 5A/B/C/D/E (codes 3-9);
- months July-September;
- depths 50-500 m;
- bottom trawl gear;
- no water hauls (success code 0 and 1);
- recorded effort greater than 0.

This yields 27,839 tows coastwide. We then stratify the tows by seven PMFC major areas and 4 depth (D) intervals: $1 = 50 < D \leq 125$ m, $2 = 125 < D \leq 200$ m, $3 = 200 < D \leq 330$ m, and $4 = 330 < D \leq 500$ m (Table 2). The strata h are labelled "major area-depth interval" (e.g., "3-1"). For each of the representative species in each stratum we estimate the model parameters (p, m, r) and calculate optimal tow allocations using the binomial gamma model. The model also estimates biomass and its CV. Note that the stratum 9-1 (PMFC code 9, depth interval 1) contains no commercial tows and cannot be used in the analysis (Table 2).

We use two cases to verify our assumption that commercial fishing data offer a reasonable proxy for survey data: the Hecate Strait Assemblage Survey (Fargo et al. 1990) and the WCVI Longspine Thornyhead Survey (Starr et al. 2002).

The Hecate Strait assemblage surveys have been conducted in the May-June period since 1984. The years of overlap between the survey and the observer data used in this analysis are 1996, 1998, 2000, and 2002. Commercial fishing sets in May and June and from that part of Hecate Strait covered by the assemblage survey are identified. We select ten species based on catch from both data sets. There are 387 fishing sets in the survey data and 3,271 sets in the commercial data that span the four overlapping years (Table 4). The depth distributions of the survey and commercial fishing operations are similar (Figure 4). Annual CVs (i.e., s / d) for each species in both the survey and commercial data are calculated and compared.

For the longspine thornyhead survey, model parameters used to predict survey CVs are derived from the commercial fishing data in the PacHarvTrawl database (Feb 16, 1996 – Nov 15, 2002) as follows:

- observer log records;
- PMFC major areas 3C/D (codes 3-4);

- months May-October;
- depths 501-1,600 m;
- bottom trawl gear;
- no water hauls (success code 0 and 1);
- recorded effort greater than 0.

This yields 8,397 tows. We then stratify the tows into the three depth intervals used in the 2001 longspine survey: (1) 501–800 m, (2) 801-1200 m, and (3) 1201-1600 m. Data for six species (longspine thornyhead, shortspine thornyhead *Sebastolobus alascanus*, Dover sole *Microstomus pacificus*, sablefish, roughscale rattail *Coryphaenoides acrolepis,* and pectoral rattail *Albatrossia pectoralis*) representative of this depth range are used to derive the model parameters (p, m, r). These parameters are used to estimate survey biomass and CV based on the 2001 survey tow distribution (Starr et al. 2002). The model CVs are then compared to the observed CVs from the 2001 longspine survey, using the depth stratification only. This approach was taken due to the limited numbers of survey tows in each area-depth stratum.

Results

Comparison of commercial and survey data

Hecate Strait Assemblage Survey

The differences between CVs estimated with survey and commercial data are plotted in Figure 5. The CVs are similar for arrowtooth flounder *Atheresthes stomias*, big skate, Dover sole, English sole *Pleuronectes vetulus*, Pacific cod *Gadus macrocephalus*, Pacific halibut, and rock sole *Pleuronectes bilineatus*. The CVs are considerably higher in the commercial fishery for dogfish, Pacific sanddab *Citharichthys sordidus*, and rex sole *Errex zachirus*. In these cases, the commercial data would overestimate the number of tows required to achieve the target CV. Overall, there was good agreement between the survey and commercial data for species of commercial interest. However, the commercial data tend to produce higher CVs than the survey data for species of little commercial value.

WCVI Longspine Thornyhead Survey

Estimates of (p, m, r) from the commercial catch and effort data are provided in Table 5. There are sufficient data to estimate these parameters for the two shallower depth strata but the deepest stratum is poorly estimated because there are only four commercial tows in the database given the above qualifications (Table 5). The estimates of p generated from the commercial data are generally close to or higher than the survey-generated p (Figure 6) with a few exceptions (Dover sole in the middle depth stratum and sablefish in the shallowest stratum). The proportion zeros in the deepest stratum will not be reliably estimated. Mean densities for non-zero tows (μ) from the survey data are variable compared to the equivalent μ calculated from the commercial data (Figure 7), but show no consistent trend between the two sets of estimates (particularly when the rattail data are excluded). Any lack of correspondence in the mean density estimates should not affect the comparability of the variability estimates.

Model estimates of CV based on the commercial catch and effort data are comparable to but consistently higher than the sample-based CVs calculated from the 2001 longspine survey for three of the six species investigated (Table 6; Figure 8). Two of the six species (pectoral and roughscale rattail) are not commercial species and are badly estimated from the commercial data. The estimate of CV for the sixth species (Dover sole) is much higher when based on the commercial data than was observed in the 2001 longspine survey (33% vs. 14%; Table 6). It is not known why the CV for this species is so high when based on commercial data but it may be related to the fact that Dover sole is often an undesirable species when fished at these depths (because flesh quality is difficult to maintain on long trips) and is deliberately avoided, especially at the beginning of a trip. Therefore, the estimates of p and r generated from the commercial data are biased high.

The comparisons presented here indicate that a model based on a binomial-gamma distribution and using parameter values derived from commercial catch and effort data will generate reasonable predictions of survey CV for species taken in commercial quantities as long as the species is landed in proportion to its abundance. There is a suggestion that this procedure may tend to overestimate survey CVs, but this conclusion is only tentative, given the low number of available comparisons.

Survey design considerations

Table 7 shows the proportions of fishing tows allocated to each stratum under the five tow allocation schemes outlined above. The percentage allocations by major area are shown in Table 8. PMFC area 5C has the most bottom area in the depth range 50-500 m and is assigned 24% of available tows under allocation scheme 2. PMFC area 5B experienced the highest fish removal and gets 39% of tows under allocation scheme 3. Fish density appears to be fairly even coastwide with the exception of PMFC area 5C. Under allocation scheme 4, PMFC area 5D receives 20% of tows. And finally, the optimization equations based on total fish biomass using binomial gamma parameters assign PMFC area 5B 22% of available tows.

The optimization parameters and moment estimates for allocation scheme 5 (total fish biomass) are detailed in Table 9. The proportion of tows that caught no fish is generally low (p_h < 2% in most strata). The density m_h of fish in non-zero tows ranges from 912 kg·km^{-2} in stratum 7-4 to 14,512 kg·km^{-2} in stratum 8-3. Generally, m_h is greatest at depth intervals 2 and 3. The CV r_h of non-zero tows never falls below 0.6 and most often lies between 1 and 2. Some of the stratum parameters are probably not well estimated given the small number of tows N. Bottom areas are calculated from bathymetry data using a 1 km^2 grid along the BC coast (Schnute et al. 1999). Estimates of fish density d_h are calculated using a constant vessel speed of 5.37 km·h^{-1} (2.9 knots) and a net width of 43 m. The biomass estimates suggest a coastwide standing fish stock of 438,798 t, although we recognise the usual caveats when using commercial CPUE data.

We use the five allocation schemes to explore how variable biomass estimates are for each of the representative species (Table 10). The schemes certainly work better for some species than others. In particular, Dover sole, arrowtooth flounder, and Pacific ocean perch *Sebastes alutus* have the lowest CVs (~30%, *K*=100), while canary rockfish *Sebastes pinniger*, sandpaper skate, and sand sole have the highest CVs (>100%, *K*=100). For all species, allocation scheme 3 ($n \propto$ total fish catch) appears to be the least useful for survey purposes. Schemes 2 ($n \propto$ bottom area) and 5 ($n \propto$ optimal total biomass) yield very similar results. Perhaps given that fish densities are similar in most areas (Table 8, scheme 4), the binomial gamma optimization varies primarily with bottom area A.

In addition to the five allocation schemes above, we calculate CVs based on allocated tows optimized using the binomial gamma model for each species (Table 10, scheme 6). In effect, it shows the penalty we pay when implementing a multispecies survey. For instance, sand sole CV would decline from 200% to 90% (*K*=100) if the survey were optimized for this species alone.

Figure 9 illustrates how the CVs for the six schemes vary by species for all fish species combined and for the 24 representative species with $K = 1,000$. While the allocation scheme based on stratum area (scheme 2) appears to minimize the average estimated CVs for all species, a scheme that is optimized to estimate total fish biomass (scheme 5) does nearly as well, the only difference being that different species CVs are minimized in the two schemes. A tow allocation scheme based on total catch CPUE appears to be slightly more variable than either the optimal or the area-based schemes, although the differences are probably slight. Equal allocation of tows to all strata results in slightly higher CVs than for the three previous schemes, and allocating tows based on total catch clearly results in much higher CVs than for any of the other schemes. We choose to allocate tows based on stratum area as this yields the lowest average CV among species (22.6%) and is more straightforward to implement and explain.

As outlined above, we choose a set of species and area combinations to judge the potential of a coastwide survey to monitor fish stocks at levels that are realistic in terms of existing or future management requirements (Table 1). Sixty-five species-area combinations are obtained by adopting, for each species, the current DFO management targets based on standardized Canadian and U.S. groundfish catch reporting areas (Table 11). In some cases where there are no existing DFO management targets, we use targets based on closely allied species. We combine the two WCVI groundfish catch reporting areas into a single unit for all the slope rockfish species. Sablefish are separated arbitrarily into two stocks even though the current DFO management of this species treats it as a single coastwide unit.

Model predictions of CV based on an analysis of commercial catch and effort data are not optimistic for many of the 65 stocks (Table 11; Figs. 10-11). A coastwide survey of 1,000 tows results in a prediction of only 15 of the 65 stocks achieving a target CV of 20% or less (Table 12). Increasing the coastwide survey to 2,000 tows increases the number of stocks that achieve the 20% target to 29. Model predictions suggest that over 10,000 tows are required to achieve the 20% target for six of the 65 stocks (Table 11).

The model predictions of survey CV for a coastwide survey may be somewhat pessimistic, particularly for species which are not commercially important or taken as bycatch at relatively low levels. Reasons include:

- the proportion of zero-catch tows is probably overestimated for some of the stocks as these species are rare and not well enumerated in a commercial setting;
- comparison of model predicted CVs based on commercial data with survey CVs indicates that these surveys generally achieve lower CVs.

Even if the model predictions are accurate, a coastwide survey that enumerates approximately 15 stocks presently not being monitored (given a preliminary budget of 1,000 tows) would be an important addition to groundfish assessment on the west coast of Canada. Such a survey will also provide a considerable amount of information on species distribution and density that can be used to refine our survey methodology. Ultimately, we should be able to monitor many stocks (including those not covered in this paper) using this method.

An annual survey with about 1,000 tows would be logistically and economically difficult. At 8 tows per day, 1,000 tows would require 125 days (~18 weeks). Fortunately, the use of commercial data probably means that a 20% target CV can be achieved with fewer tows. As a first step, we suggest that the initial survey concentrate on a smaller piece of the BC coast. Based on predicted CVs (Table 11), PMFC area 5AB looks promising. Five important stocks in this region are predicted to reach the target CV based on a sampling intensity that assumes a coastwide budget of 1,000 tows: Pacific ocean perch (365 tows), silvergray rockfish *Sebastes brevispinis* (948 tows), Dover sole (500 tows), lingcod *Ophiodon elongatus* (593 tows), and rock sole (582 tows). The final budget and design of this initial survey would require further analysis.

Recommendations

The conclusions that stem from this paper rely on a simulation model with explicit assumptions. For instance, we use commercial trawl fishery data as a proxy for survey data. While we acknowledge that there are major differences between commercial and survey data, the trawl fishery database is the only source suitable for planning a coastwide groundfish trawl survey at present. Comparisons of survey and commercial data from Hecate Strait and for the WCVI longspine thornyhead survey indicate a general agreement in CV estimates for species of commercial interest. These comparisons also indicate that the commercial fishery data may overestimate the CVs for rare and bycatch species. In such cases, the predicted number of tows required to meet the target CV would be inflated. Despite the limitations, we **recommend** that the results based on the commercial data be used for planning purposes.

We also **recommend** that the coastwide trawl survey follow a stratified random design. Stratification should be based on the depth (D) ranges $50 < D \leq 125$ m, $125 < D \leq 200$ m, $200 < D \leq 330$ m, and $330 < D \leq 500$ m and adhere to the PMFC major area boundaries. Station allocation should be made in proportion to the surface areas of these strata.

Our analysis predicts that a survey of 1,000 tows on a coastwide basis would achieve a 20% target CV for only 15 stocks out of 65 tested. To verify this, we **recommend** that the Groundfish Synoptic Survey (GFSS), proposed herein, starts in PMFC major area 5AB in 2003 after suitable follow-up analyses are conducted to formalise the budget and design.

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Tables

Table 1. Indicator stocks used to examine index precision in the proposed survey.

Species	Reason for inclusion	Stocks (Major Areas)	No. Stocks	3-letter code	Numeric Code
Pacific ocean perch	1	3+4, 5+6, 7, 9	4	POP	396
Yellowtail rockfish	1	3, 4+5+6+7+8+9	2	YTR	418
Yellowmouth rockfish	1	3, 4, 5+6, 7+8, 9	5	YMR	440
Arrowtooth flounder	1	3+4, 5+6+7+8+9	2	ARF	602
Silvergray rockfish	1	3+4, 5+6, 7+8, 9	4	SGR	405
Dover sole	1	3+4, 5+6, 7+8+9	3	DOL	626
Lingcod	1	3, 4, 5+6, 7+8, 9	5	LIN	467
Redstripe rockfish	1	3, 4, 5+6, 7+8, 9	5	RSR	439
Canary rockfish	1	3+4, 5+6, 7+8, 9	4	CAR	437
Rock sole	1	3+4, 5+6, 7+8	3	ROL	621
Pacific cod	2	3+4, 5+6, 7+8+9	3	PAC	222
Petrale sole	2	3+4+5+6+7+8+9	1	PEL	607
Redbanded rockfish	2	3+4, 5+6, 7+8, 9	4	RBR	401
Yelloweye rockfish	2	3+4, 5+6, 7+8, 9	4	YYR	442
Bocaccio	3	3+4+5+6+7+8+9	1	BOR	435
Sandpaper skate	3	3+4+5+6+7+8+9	1	SPS	058
Big Skate	3	3+4, 5+6, 7+8, 9	4	BIS	056
Wolf-eel	3	3+4+5+6+7+8+9	1	WOE	351
Spiny dogfish	4	3+4+5+6+7+8+9	1	DOG	044
Sablefish babies	5	3+4+5, 6+7+8+9	2	SBF	455
Greenstripe rockfish	6	3+4, 5+6, 7+8, 9	4	GSR	414
Rougheye rockfish	7	3, 4, 5+6, 7+8, 9	5	RER	394
Shortraker rockfish	7	3+4+5+6+7+8+9	1	SRR	403
Sand sole	8	3+4+5+6+7+8+9	1	SAL	636

Reasons for inclusion:

1. Top 10 species by retained volume
2. Special interest to trawl fleet (low volume)
3. Bio-diversity concern
4. Discard and bio-diversity concern
5. Possible juvenile index
6. Rockfish discard example
7. Rockfish possibly too deep for survey
8. Sole possibly too shallow for survey

Table 2. Number of qualified commercial tows in each stratum h. Depth intervals: 1 = 50-125 m, 2 = 125-200 m, 3 = 200-330 m, 4 = 330-500 m. These tows are used to calculate the input parameters for the binomial-gamma model.

PMFC	PMFC	Depth Interval			
Major Area	Code	1	2	3	4
3C	3	1,348	1,046	144	67
3D	4	183	842	242	112
5A	5	2,367	2,458	216	36
5B	6	5,339	2,340	2,796	136
5C	7	1,668	570	749	50
5D	8	3,042	1,386	49	66
5E	9		3	483	101

Table 3. Species used in the comparison of survey and commercial fisheries data in Hecate Strait.

Species
Arrowtooth flounder
Big skate
Spiny dogfish
Dover sole
English sole
Pacific cod
Pacific sanddab
Pacific halibut
Rock sole
Rex sole

Table 4. Number of tows selected from the survey and commercial fisheries data sets in Hecate Strait.

Year	Survey Sets	Commercial Sets
1996	101	1,079
1998	86	623
2000	106	881
2002	94	688
Total	387	3,271

Table 5. Parameter estimates by depth zone for six species of interest to the longspine thornyhead survey derived from commercial data from the west coast of Vancouver Island (PMFC area 3CD), assuming a constant speed of 3.9 km/h and a net width of 43 m. Estimated parameters are: p = proportion zero; m = mean density (kg/km^2) for non-zero tows; r = CV of m for non-zero tows; $n = 1/r^2$. NA: no data available to estimate the parameters.

Depth zone	p	m	r	n	**Number commercial tows**
Longspine thornyheads					
501-800	0.141	310	0.62	2.603	2,015
801-1200	0.016	438	0.661	2.288	6,378
1201-1600	0	411	0.8	1.562	4
Shortspine thornyheads					
501-800	0.018	239	0.688	2.113	2,015
801-1200	0.013	172	0.687	2.118	6,378
1201-1600	0	127	0.941	1.129	4
Dover sole					
501-800	0.102	286	2.27	0.194	2,015
801-1200	0.266	53	1.968	0.258	6,378
1201-1600	0	44	0.948	1.113	4
Sablefish					
501-800	0.025	190	1.419	0.496	2,015
801-1200	0.044	83	1.313	0.58	6,378
1201-1600	0	40	0.462	4.684	4
Roughscale rattail					
501-800	0.99	58	0.536	3.477	2,015
801-1200	0.986	62	0.619	2.606	6,378
1201-1600	NA	NA	NA	NA	4
Pectoral rattail					
501-800	0.989	33	0.695	2.07	2,015
801-1200	0.994	111	1.003	0.994	6,378
1201-1600	NA	NA	NA	NA	4

Table 6. Estimates of biomass (t), standard deviation (t), and CV (%) by depth zone and total survey for six species of interest to the longspine thornyhead survey using commercial data from the west coast of Vancouver Island (PMFC area 3CD). Assumptions: constant speed of 3.9 km/h, net width of 43 m, distribution of tows observed in the 2001 longspine survey. Survey CVs (%) are from Starr et al. (2002) based on the depth zone stratification only.

Depth zone	**Biomass (t)**	**Standard deviation (t)**	**CV (%)**	**Survey CV (%)**	**Number survey tows**
Longspine thornyheads					
501-800	376	60	16		24
801-1200	962	133	14		24
1201-1600	1,206	305	25		10
Total	2,544	338	13	10	58
Shortspine thornyheads					
501-800	332	48	14		24
801-1200	379	54	14		24
1201-1600	374	111	30		10
Total	1,085	133	12	8	58
Dover sole					
501-800	362	179	49		24
801-1200	86	42	48		24
1201-1600	129	39	30		10
Total	578	188	33	14	58
Sablefish					
501-800	262	77	30		24
801-1200	177	49	28		24
1201-1600	119	17	15		10
Total	558	93	17	12	58
Roughscale rattail					
501-800	1	2	232		24
801-1200	2	4	203		24
1201-1600		0			10
Total	3	4	159	10	58
Pectoral rattail					
501-800	1	1	237		24
801-1200	2	6	369		24
1201-1600		0			10
Total	2	6	284	16	58

Table 7. Allocation of tows as a proportion in each stratum *h* using the following schemes: 1 = equal; 2 = proportional to bottom area; 3 = proportional to total fish catch; 4 = proportional to mean fish density, 5 = optimal based on binomial-gamma density parameters for total fish.

h	1	2	3	4	5
3-1	0.0370	0.0681	0.0412	0.0283	0.0968
3-2	0.0370	0.0504	0.0386	0.0443	0.0630
3-3	0.0370	0.0117	0.0054	0.0576	0.0269
3-4	0.0370	0.0079	0.0013	0.0125	0.0015
4-1	0.0370	0.0324	0.0037	0.0253	0.0371
4-2	0.0370	0.0249	0.0474	0.0542	0.0341
4-3	0.0370	0.0061	0.0106	0.0402	0.0072
4-4	0.0370	0.0057	0.0032	0.0219	0.0027
5-1	0.0370	0.0471	0.0485	0.0163	0.0177
5-2	0.0370	0.0370	0.0999	0.0390	0.0322
5-3	0.0370	0.0169	0.0106	0.0566	0.0202
5-4	0.0370	0.0043	0.0008	0.0215	0.0016
6-1	0.0370	0.0573	0.1564	0.0224	0.0292
6-2	0.0370	0.0856	0.1096	0.0495	0.0998
6-3	0.0370	0.0708	0.1209	0.0469	0.0725
6-4	0.0370	0.0165	0.0041	0.0381	0.0182
7-1	0.0370	0.0780	0.0463	0.0244	0.0394
7-2	0.0370	0.0920	0.0173	0.0354	0.0836
7-3	0.0370	0.0601	0.0214	0.0244	0.0338
7-4	0.0370	0.0065	0.0004	0.0053	0.0005
8-1	0.0370	0.0523	0.1245	0.0487	0.0553
8-2	0.0370	0.0350	0.0601	0.0356	0.0185
8-3	0.0370	0.0355	0.0025	0.0862	0.0723
8-4	0.0370	0.0234	0.0014	0.0279	0.0294
9-1	0.0000	0.0000	0.0000	0.0000	0.0000
9-2	0.0370	0.0115	0.0001	0.0325	0.0050
9-3	0.0370	0.0392	0.0203	0.0668	0.0804
9-4	0.0370	0.0239	0.0035	0.0382	0.0214

Table 8. Percentage of tows allocated to each PMFC major area under the five allocation schemes detailed in Table 7.

PMFC	code	1	2	3	4	5
3C	3	15	14	9	14	19
3D	4	15	7	6	14	8
5A	5	15	11	16	13	7
5B	6	15	23	39	16	22
5C	7	15	24	9	9	16
5D	8	15	15	19	20	18
5E	9	11	7	2	14	11

Table 9. Binomial-gamma parameters and moment estimates for total fish by stratum h, with summaries by major area and total coast. Parameters: p = proportion of tows with no fish catch, m = mean density of fish (kg·km^{-2}) in non-zero tows, r = CV of m in non-zero tows. Constants: N = number of tows used to derive parameters; A = bottom area (km^2). Estimates: d = density of fish (kg·km^{-2}), B = biomass (t), n = tow allocation given K = 1000, CV = CV of B given n.

h	p	m	r	N	A	d	B	n	CV
3-1	0.0030	4,685	2.56	1,348	4,731	4,671	22,101	97	0.26
3-2	0.0086	7,370	1.43	1,046	3,500	7,307	25,573	63	0.18
3-3	0.0139	9,631	2.02	144	811	9,497	7,702	27	0.39
3-4	0.0000	2,055	0.76	67	552	2,055	1,135	1	0.76
4-1	0.0000	4,171	2.31	183	2,254	4,171	9,401	37	0.38
4-2	0.0059	8,999	1.28	842	1,728	8,946	15,458	34	0.22
4-3	0.0083	6,683	1.49	242	424	6,628	2,810	7	0.57
4-4	0.0179	3,680	1.08	112	394	3,614	1,424	3	0.63
5-1	0.0042	2,697	1.17	2,367	3,275	2,685	8,795	18	0.28
5-2	0.0024	6,441	1.14	2,458	2,569	6,425	16,506	32	0.20
5-3	0.0000	9,331	1.08	216	1,173	9,331	10,945	20	0.24
5-4	0.0000	3,554	0.86	36	300	3,554	1,066	2	0.61
6-1	0.0026	3,709	1.16	5,339	3,981	3,700	14,728	29	0.22
6-2	0.0026	8,191	1.20	2,340	5,949	8,170	48,602	100	0.12
6-3	0.0072	7,790	1.11	2,796	4,924	7,735	38,085	73	0.13
6-4	0.0441	6,572	1.43	136	1,145	6,282	7,193	18	0.35
7-1	0.0030	4,042	1.05	1,668	5,420	4,029	21,840	39	0.17
7-2	0.0088	5,891	1.30	570	6,393	5,839	37,332	84	0.14
7-3	0.0053	4,050	1.17	749	4,179	4,028	16,833	34	0.20
7-4	0.0400	912	0.63	50	453	875	397	1	0.67
8-1	0.0033	8,056	1.10	3,042	3,637	8,030	29,204	55	0.15
8-2	0.0043	5,902	0.75	1,386	2,436	5,877	14,316	18	0.18
8-3	0.0204	14,512	1.18	49	2,468	14,216	35,085	72	0.14
8-4	0.0000	4,610	2.30	66	1,625	4,610	7,491	29	0.43
9-2	0.0000	5,353	0.69	3	797	5,353	4,266	5	0.31
9-3	0.0269	11,325	1.54	483	2,725	11,021	30,031	80	0.18
9-4	0.0495	6,626	1.14	101	1,664	6,298	10,480	21	0.26
3				2,605	9,594		56,510	188	0.14
4				1,379	4,800		29,093	81	0.18
5				5,077	7,317		37,312	72	0.13
6				10,611	15,999		108,609	220	0.08
7				3,037	16,445		76,401	158	0.10
8				4,543	10,166		86,095	174	0.09
9				587	5,930		44,778	106	0.14
Total				27,839	70,251		438,798	999	0.04

Table 10. CV (%) for survey species under the five allocation schemes detailed in Table 7, given $K = 100$. Scheme 6 lists the CVs possible assuming that the survey is optimized for the binomial-gamma parameters of individual species. Note: to derive CVs for other budgets K, multiply the CV by the factor $\sqrt{100/K}$.

Code	**Species**	**1**	**2**	**3**	**4**	**5**	**6**
ARF	Arrowtooth flounder	35	29	32	34	31	23
BIS	Big skate	65	50	44	75	64	30
BOR	Bocaccio	97	78	91	106	90	59
CAR	Canary rockfish	115	115	130	106	103	57
DOG	Spiny dogfish	119	89	115	135	85	51
DOL	Dover sole	33	28	36	32	31	19
GSR	Greenstriped rockfish	69	67	83	64	57	38
LIN	Lingcod	40	33	52	47	38	25
PAC	Pacific cod	67	52	55	71	59	31
PEL	Petrale sole	48	38	46	54	42	29
POP	Pacific ocean perch	32	30	85	26	25	18
RBR	Redbanded rockfish	85	58	86	82	60	36
RER	Rougheye rockfish	87	90	198	69	73	32
ROL	Rock sole	42	32	39	50	41	18
RSR	Redstripe rockfish	103	74	87	91	67	44
SAL	Sand sole	237	190	160	241	207	90
SBF	Sablefish	67	54	64	66	53	41
SGR	Silvergray rockfish	72	50	124	73	51	32
SKR	Shortraker rockfish	76	87	200	74	103	41
SPS	Sandpaper skate	123	108	100	118	127	70
WOE	Wolf eel	77	62	68	96	82	40
YMR	Yellowmouth rockfish	66	54	78	59	51	35
YTR	Yellowtail rockfish	90	81	173	93	77	49
YYR	Yelloweye rockfish	253	168	156	221	157	80
ZZZ	All fish species	17	15	30	16	13	13

Table 11. Model predicted CVs (%) for 65 stocks for coastwide surveys of 200, 500, 1,000 and 2,000 tows using allocation scheme 2 (Table 7). Also shown is the number of coastwide survey tows required to achieve an overall CV of 20% for each of the stocks. The CVs have been predicted based on an analysis of commercial catch and effort data. Species and area codes are provided in Tables 1 and 2, respectively. Shaded entries indicate CVs of 20% or less.

Species code	Major area stock combination	Number of coastwide tows				Number of coastwide tows to achieve 20%
		200	500	1,000	2,000	
POP	3+4	77	49	34	24	2,966
POP	5+6	27	**17**	**12**	**9**	365
POP	7	29	**18**	**13**	**9**	422
POP	9	57	36	25	**18**	1,622
YTR	3	103	65	46	33	5,283
YTR	4+5+6+7+8+9	69	44	31	22	2,394
YMR	3+4	149	94	66	47	11,052
YMR	5+6	55	35	24	**17**	1,498
YMR	7+8	101	64	45	32	5,124
YMR	9	56	35	25	**18**	1,554
ARF	3+4	37	23	**17**	**12**	683
ARF	5+6+7+8+9	25	**16**	**11**	**8**	306
SGR	3+4	96	61	43	30	4,606
SGR	5+6	44	28	**19**	**14**	948
SGR	7+8	50	31	22	**16**	1,230
SGR	9	101	64	45	32	5,148
DOL	3+4	33	21	**15**	**11**	560
DOL	5+6	32	**20**	**14**	**10**	500
DOL	7+8+9	27	**17**	**12**	**8**	358
LIN	3	49	31	22	**16**	1,216
LIN	4	69	44	31	22	2,394
LIN	5+6	34	22	**15**	**11**	593
LIN	7+8+9	47	30	21	**15**	1,105
RSR	3+4	126	80	57	40	7,989
RSR	5+6	96	61	43	30	4,594
RSR	7+8	66	42	30	21	2,187
RSR	9	102	65	46	32	5,241
CAR	3+4	158	100	71	50	12,477
CAR	5+6	83	53	37	26	3,463
CAR	7+8	84	53	37	26	3,502
CAR	9	422	267	189	133	89,040
ROL	3+4	68	43	30	21	2,301
ROL	5+6	34	22	**15**	**11**	582
ROL	7+8	30	**19**	**14**	**10**	457
PAC	3+4	57	36	25	**18**	1,605
PAC	5+6	56	35	25	**18**	1,562
PAC	7+8+9	50	31	22	**16**	1,232
PEL	3+4+5+6+7+8+9	27	**17**	**12**	**8**	362
RBR	3+4	71	45	32	22	2,500
RBR	5+6	63	40	28	**20**	1,981
RBR	7+8	59	37	27	**19**	1,756
RBR	9	115	73	52	36	6,659
YYR	3+4	107	68	48	34	5,712
YYR	5+6	167	106	75	53	14,017

Species code	Major area stock combination	Number of coastwide tows				Number of coastwide tows to achieve 20%
		200	500	1,000	2,000	
YYR	7+8	110	69	49	35	6,021
YYR	9	NA	NA	NA	NA	NA
BOR	3+4+5+6+7+8+9	55	35	25	**17**	1,517
SPS	3+4+5+6+7+8+9	76	48	34	24	2,901
BIS	3+4	81	51	36	26	3,267
BIS	5+6	65	41	29	21	2,129
BIS	7+8	43	27	**19**	**14**	931
BIS	9	212	134	95	67	22,401
WOE	3+4+5+6+7+8+9	44	28	**20**	**14**	972
SBF	3+4	64	41	29	20	2,058
SBF	5+6+7+8+9	44	28	**20**	**14**	980
GSR	3+4	63	40	28	20	2,003
GSR	5+6	69	44	31	22	2,412
GSR	7+8	111	70	50	35	6,159
GSR	9	166	105	74	52	13,723
SKR	3+4+5+6+7+8+9	62	39	28	**20**	1,914
SAL	3+4+5+6+7+8	135	85	60	43	9,047
DOG	3+4+5+6+7+8+9	63	40	28	**20**	1,999
RER	3+4	66	42	29	21	2,173
RER	5+6	96	61	43	30	4,650
RER	7+8	86	54	38	27	3,689
RER	9	100	64	45	32	5,044

Table 12. Number of stocks with CVs = 20% for four coastwide survey budgets based on commercial catch and effort data using allocation scheme 2 (Table 7). The total number of stocks is 65 (excluding YYR/9).

Number coastwide tows	Number stocks CV<=20%
200	0
500	7
1,000	15
2,000	29

Figures

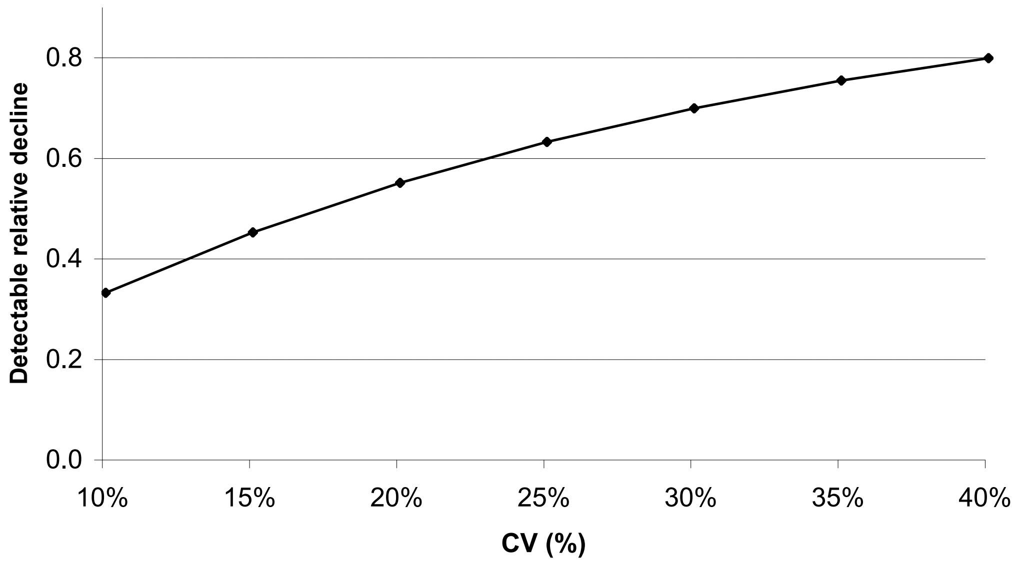


Figure 1. Approximate detectable decline in relative index for a range of hypothetical survey CVs (assuming an underlying log-normal distribution). The "detectable decline" is defined as non-overlapping 95% confidence bounds calculated by assuming that the first index is equal to 1.0.

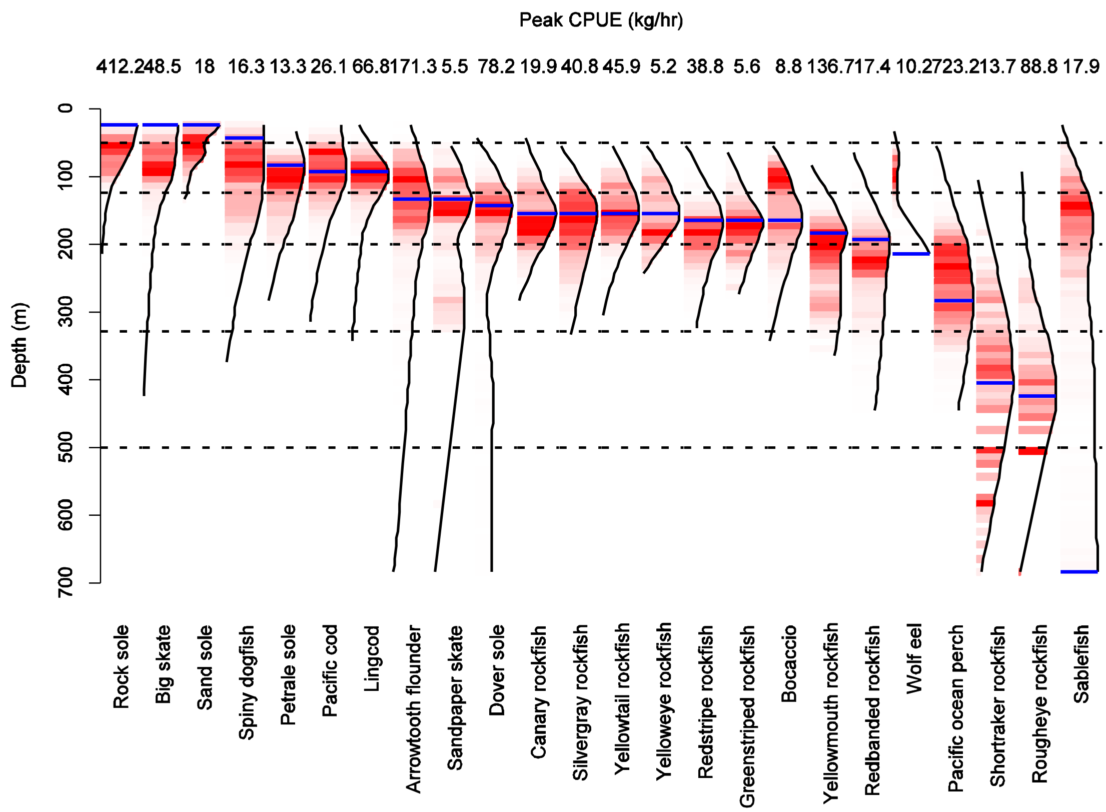


Figure 2. Coastwide CPUE distributions by depth for selected species used in this analysis. The distributions were derived from commercial fisheries data from February 1996 to September 2002. Data were selected for tows made with bottom trawl gear, at depths between 25 and 700 m, from July to September, in PMFC major areas 3CD and 5ABCD. Locally weighted (lowess) lines are fit to the data. Red shading indicates intensity of catch in 10 m depth intervals. The blue horizontal lines indicate depth of peak fitted CPUE. The dashed lines indicate proposed depth strata for the coastwide survey.

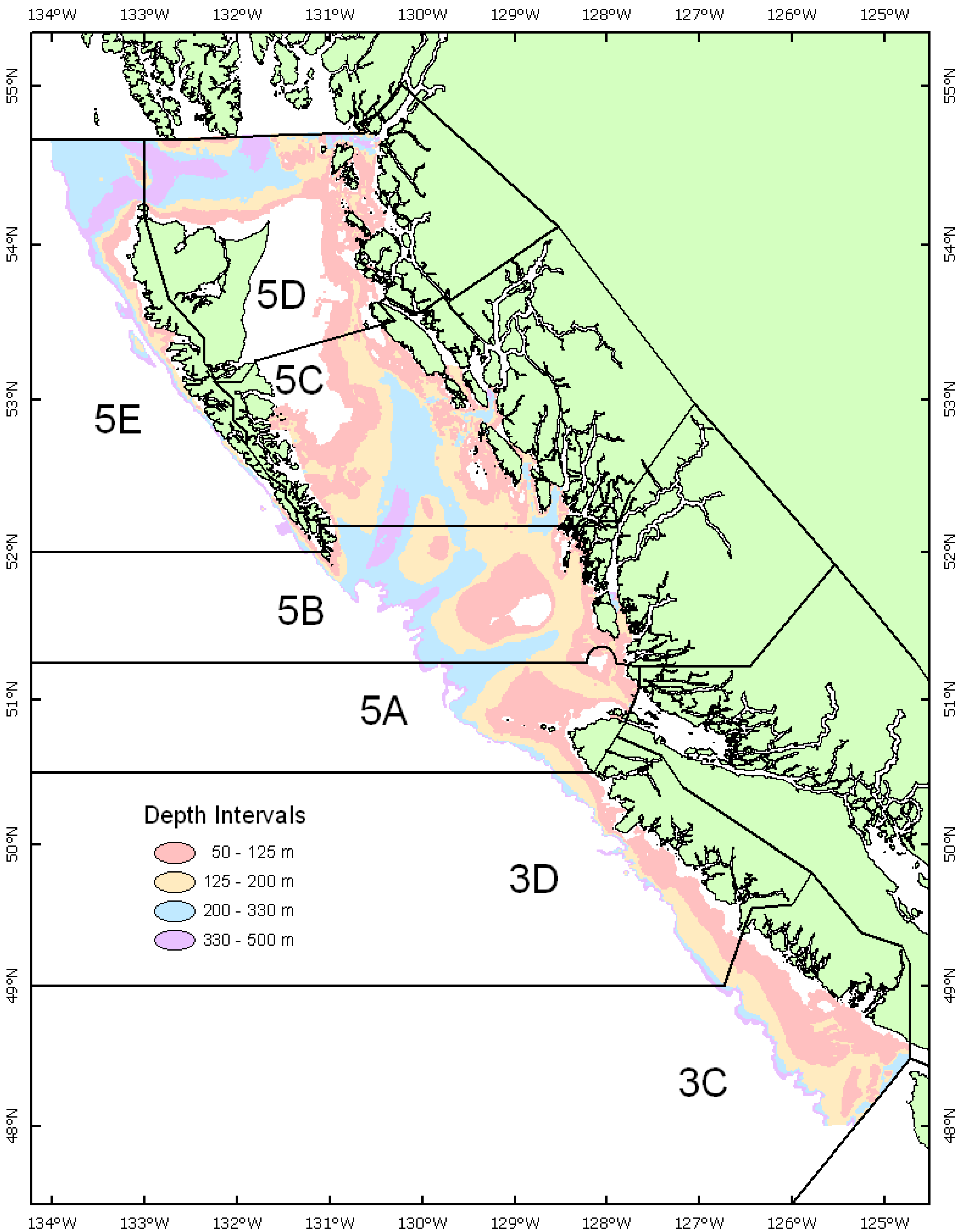
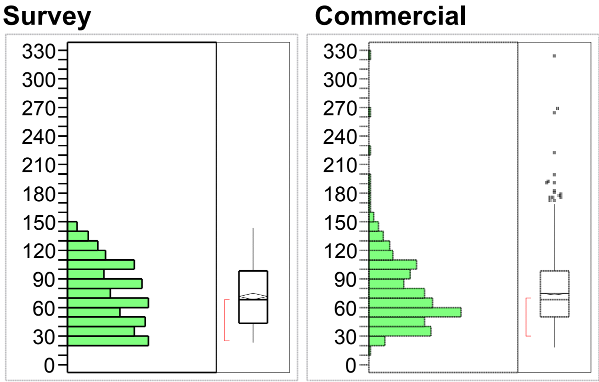


Figure 3. Map of the BC coast showing PMFC major areas and depth zone boundaries ($50 < D = 125$ m, $125 < D = 200$ m, $200 < D = 330$ m, and $330 < D = 500$ m).



		Survey	Commercial
75.0%	quartile	97.84	98.46
50.0%	median	67.67	68.00
25.0%	quartile	50.29	43.68
Mean		74.47	71.46
N		387	3271

Figure 4. Comparison of the depth (m) distributions of survey and commercial tows used in the Hecate Strait CV comparison.

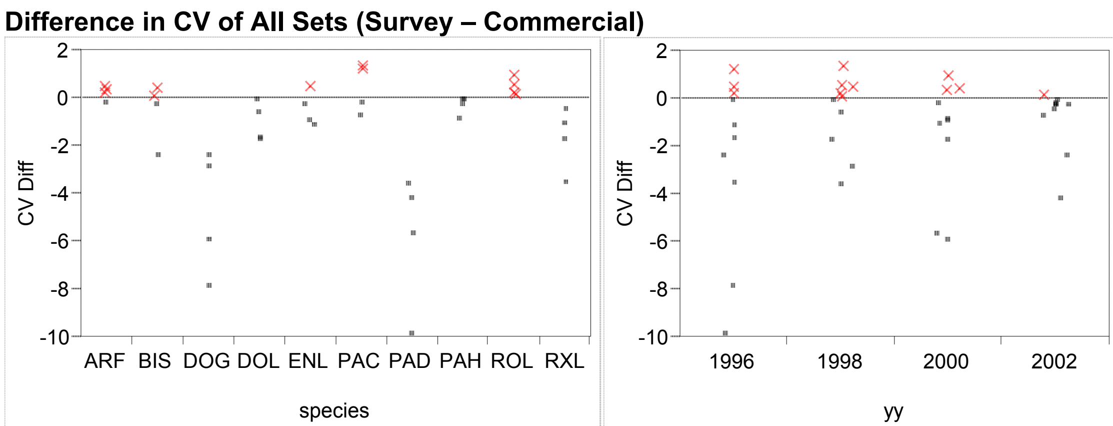


Figure 5. Differences between coefficients of variation (CV diff) calculated from survey and commercial data in Hecate Strait. Differences are shown for species in the left panel and by year in the right panel.

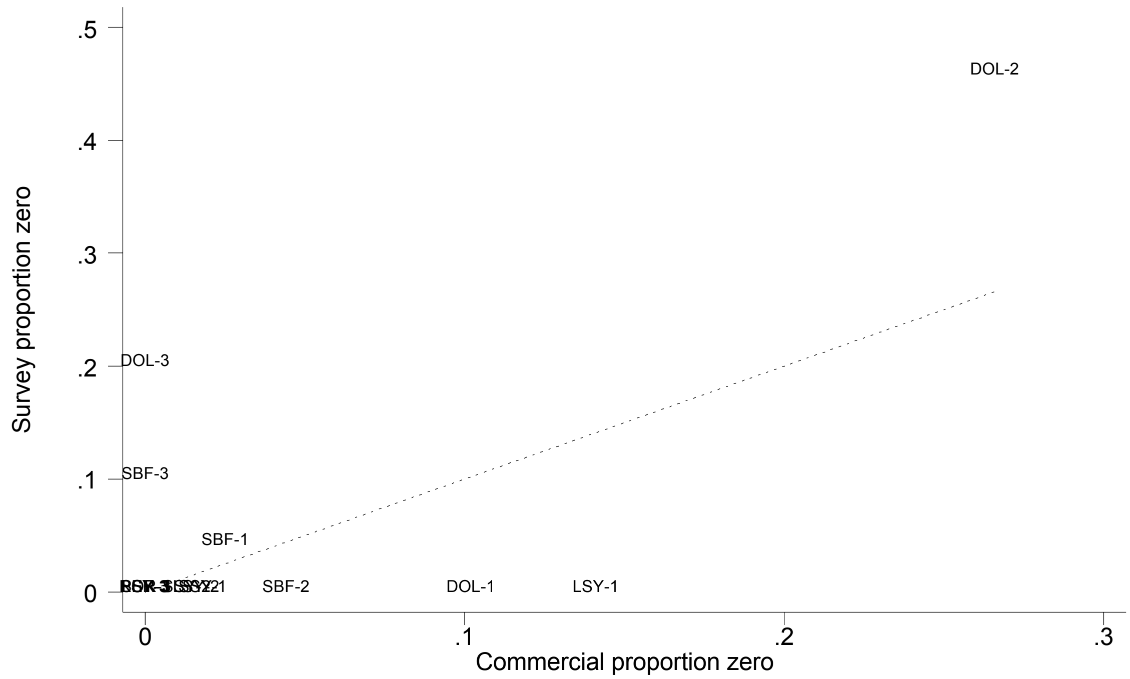


Figure 6. Comparison of *p* calculated from the commercial data with *p* from the 2001 longspine survey data for 14 species/depth zone combinations (the values for roughscale and pectoral rattail have not been plotted as these species are not commercially taken). Plotting symbols use the species codes provided in Table 7 and the following depth zone codes 1: 501-800 m; 2: 801-1200 m; 3: 1201-1600 m. Dashed line is 1:1.

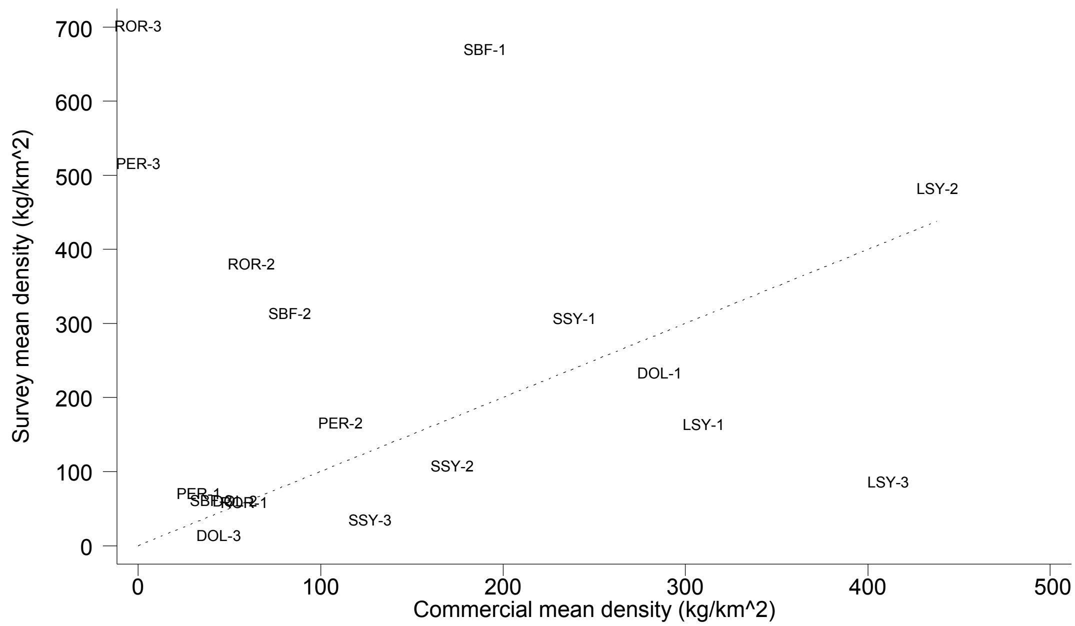


Figure 7. Comparison of μ (kg/km^2) calculated from the commercial data (assuming a constant speed of 3.9 km/h and a net width of 43 m) with μ (kg/km^2) from the 2001 longspine survey data for 18 species/depth zone combinations. Plotting symbols use the species codes provided in Table 7 and the following depth zone codes 1: 501-800 m; 2: 801-1200 m; 3: 1201-1600 m. Dashed line is 1:1.

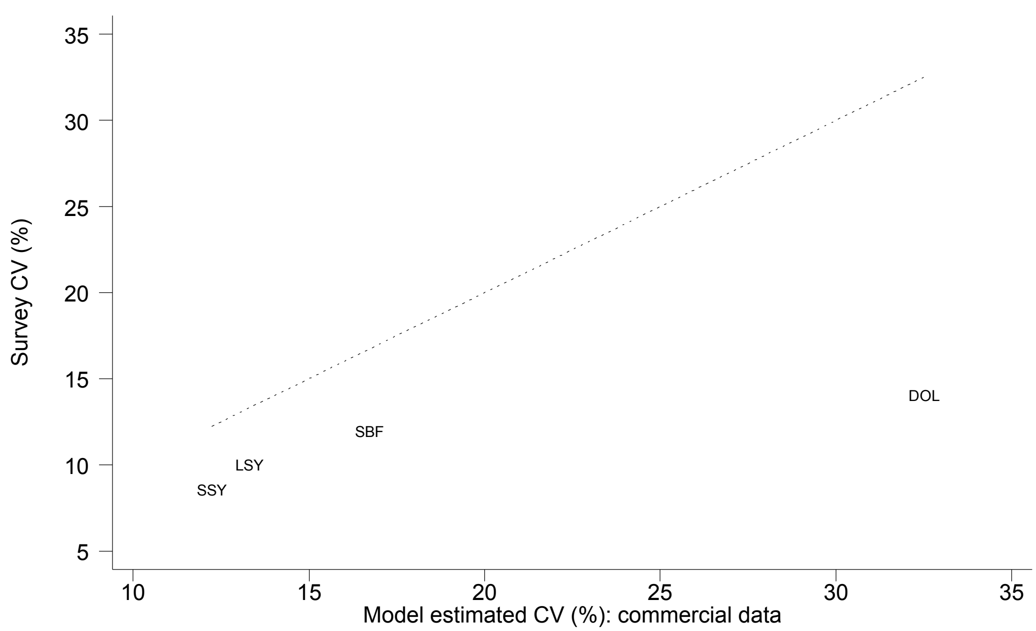


Figure 8. Comparison of model estimated CV calculated from the commercial data with the observed CV from the 2001 longspine survey data for 4 species where there are sufficient commercial data. Plotting symbols use the species codes provided in Table 7. Dashed line is 1:1.

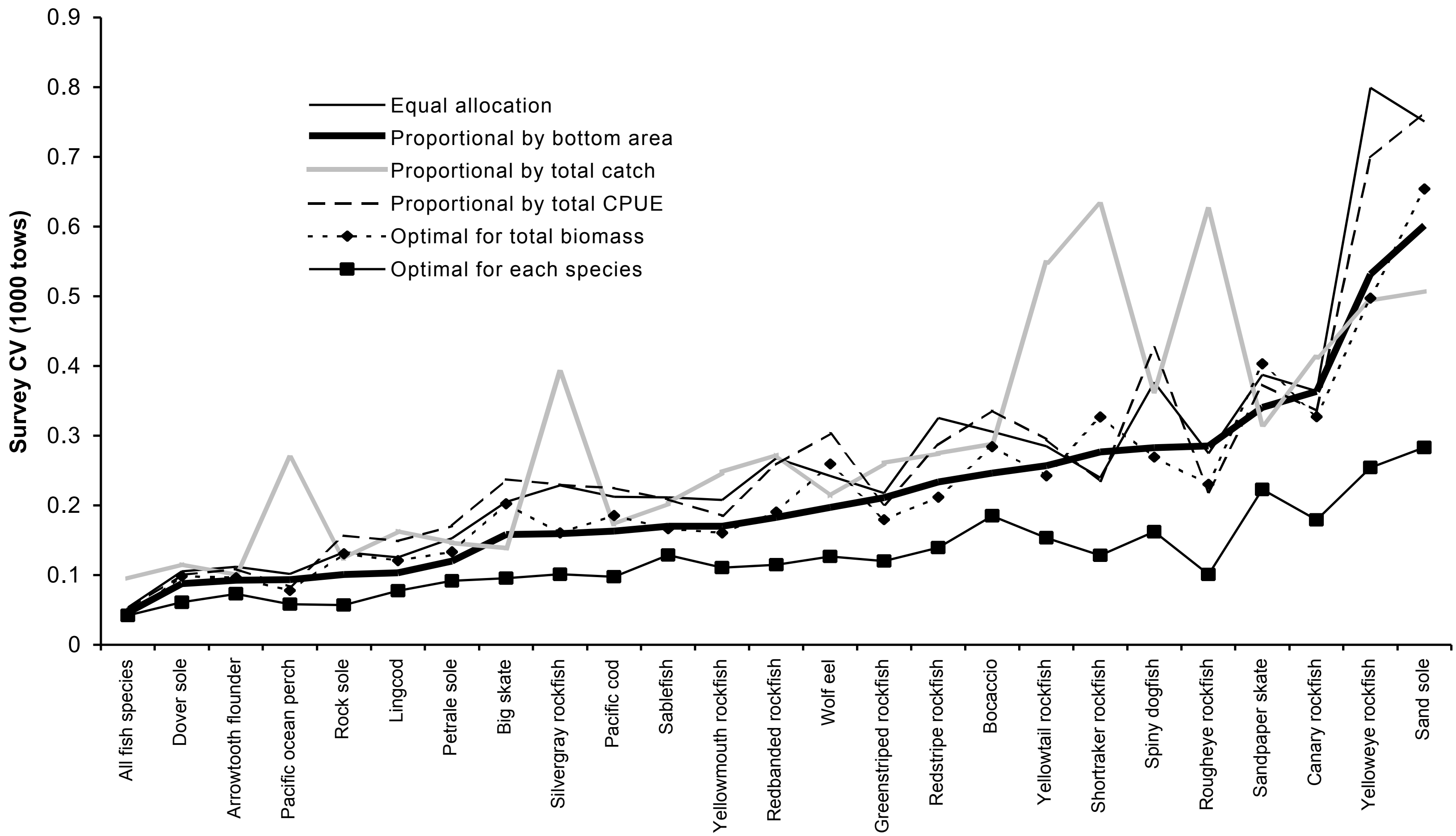


Figure 9. Comparison of estimated coastwide CVs for total fish catch and for the 24 representative species using the five allocation schemes outlined in Table 7 and a sixth scheme that optimizes for each species. The species have been sorted in ascending order of CV based on allocation scheme 2 (proportional to bottom area) using 1,000 tows in a coastwide survey of PMFC major areas 3C-5E (codes 3-9).

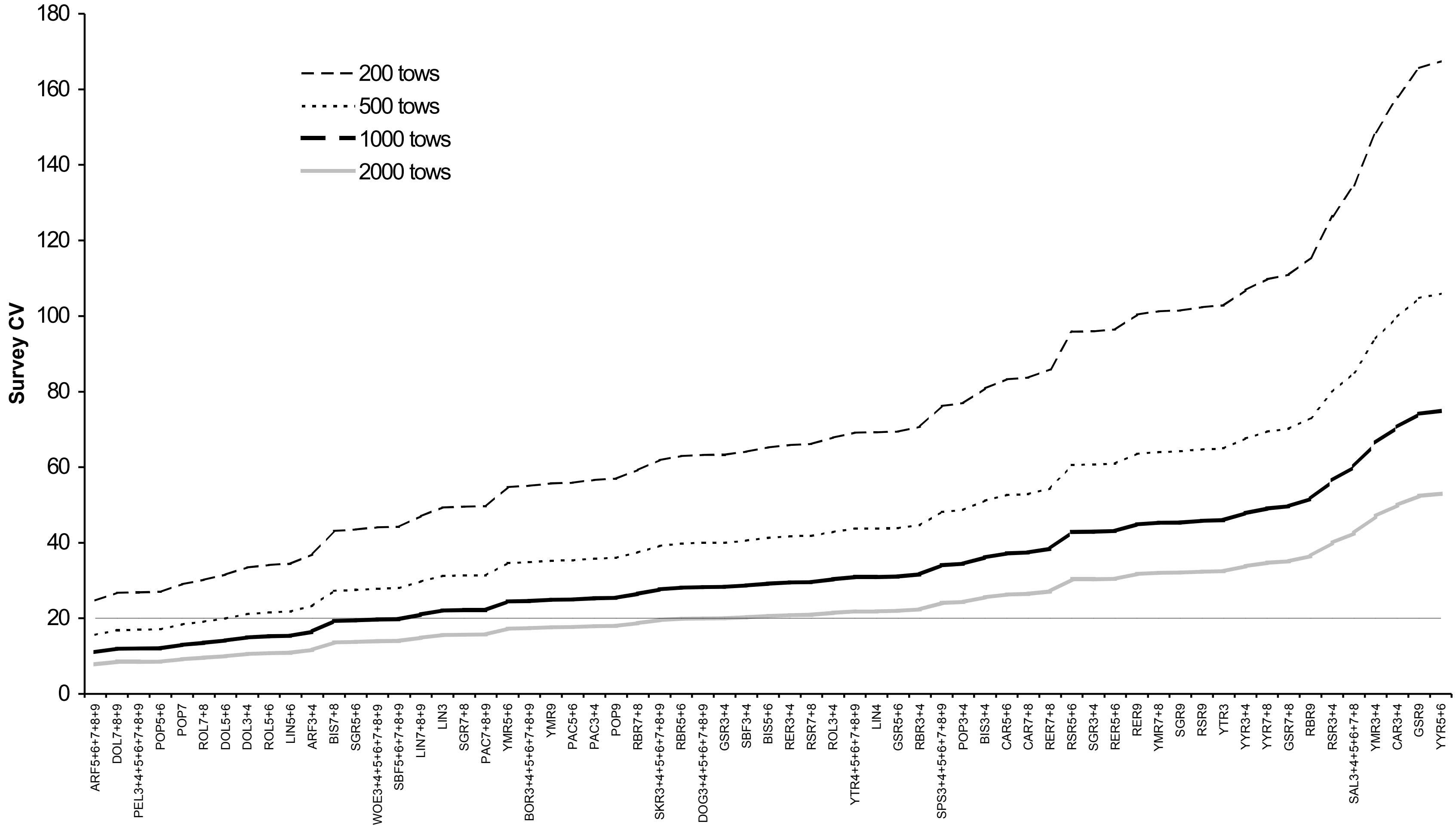


Figure 10. Plots of model predicted CVs (%) for 63 stocks relevant to existing and potential management requirements for coastwide surveys of 200, 500, 1,000 and 2,000 tows using allocation scheme 2 (Table 7). The CVs have been predicted based on an analysis of commercial catch and effort data. The stocks have been sorted in ascending order of CV. A horizontal line corresponding to a target CV=20% has been plotted for reference. Species and area codes are provided in Tables 1 and 2.

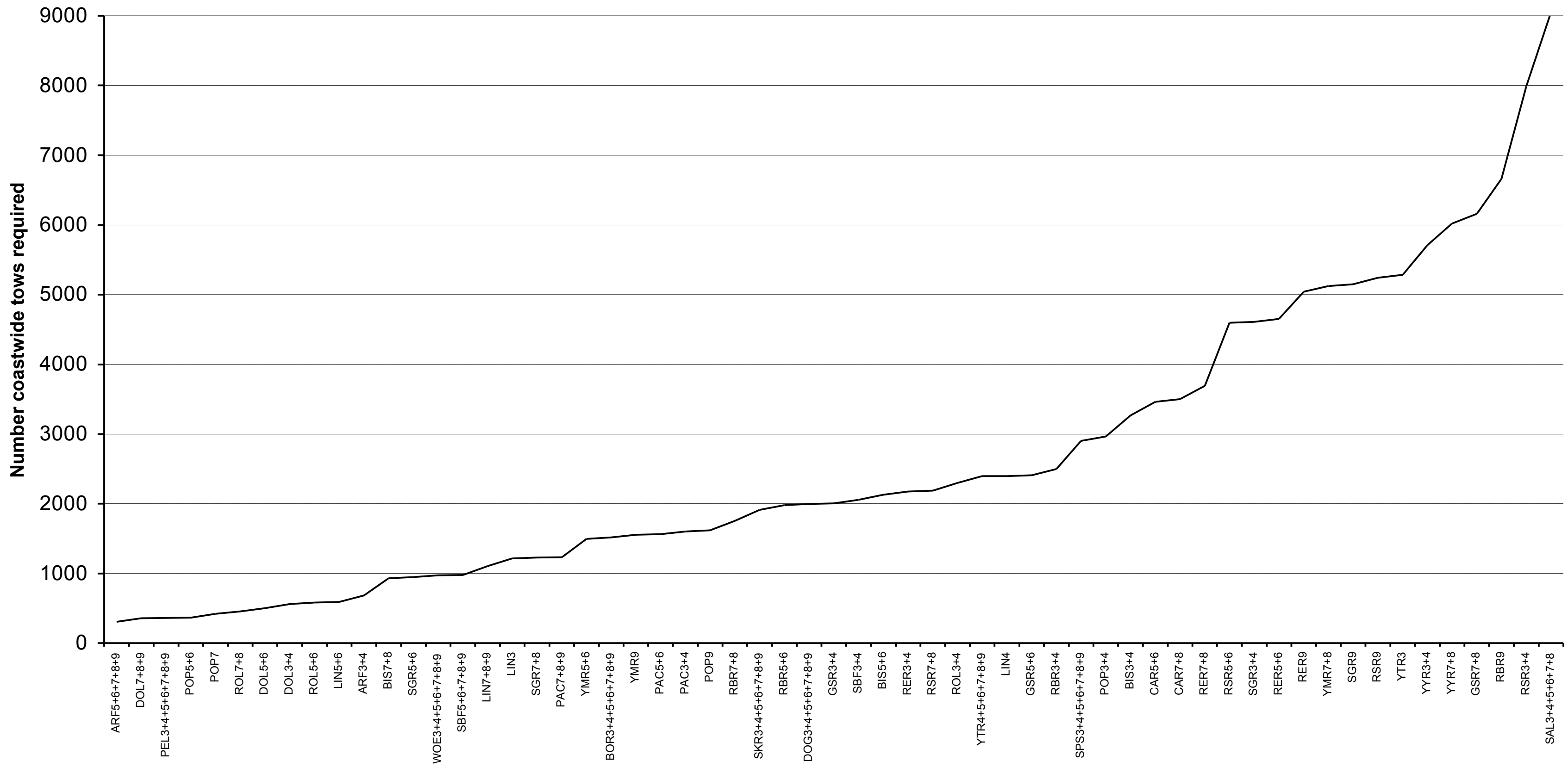


Figure 11. Number of tows in a coastwide survey required to achieve an overall CV of 20% for 59 stocks relevant to existing and potential management requirements using commercial catch and effort data based on allocation scheme 2 (Table 7). Stocks requiring more than 10,000 tows have not been plotted, and the stocks have been sorted by ascending CV. Species and area codes are provided in Tables 1 and 2.

Appendix 1. Summary of several existing groundfish surveys currently undertaken on both the east and west coast of North America. This list is not exhaustive but does cover existing surveys on Canada's Pacific Coast with examples of surveys in other jurisdictions. Number of sets, depth range, number of vessels and duration are approximate from the most recent surveys. Survey areas have been pulled from published cruise reports or estimated by the authors. The proportion of area covered is the sum of trawled area (mean net width × mean tow length) divided by the total survey area.

Survey name	Area	Survey design	Number of sets	Depth range	Vessels	Duration	Survey area (km^2)	Proportion of area covered
Pacific Region								
Hecate Strait survey	Hecate Strait	Systematic stratified	100 - 110	18 - 150	1	20	11,250	0.030%
Offshore Shrimp Survey	West Coast Vancouver Island	Systematic	70 - 130	60 - 200	1	28	4,500	0.054%
Slope rockfish assessment Surveys	Queen Charlotte Sound	Stratified random	110	140 - 300	2	11	4,200	0.109%
	West Coast Vancouver Island	Stratified random	100	150 - 450	1	21	2,300	0.181%
	West Coast Queen Charlotte Islands	Stratified random	110	180 - 625	1	18	3,200	0.143%
Sablefish Trap Survey	Entire Coast of BC	Index sites	40 - 70	275 - 1200	1	18 - 25	19,100	N/A
IPHC Long line Halibut Survey	Pacific Coast Oregon to Bering Sea	Systematic	1235	35 - 500	14	45	425,000	N/A
NMFS Triennial West Coast Bottom Trawl Survey of Groundfish Resources	West coast of North America From point Conception to Vancouver Island	Systematic random	600	55 - 500	2	60	59,365	0.039%
WDFG Groundfish assessment surveys	Puget sound and Southern Georgia Strait	Stratified systematic	110	10 - 220	1	24	2,840	0.034%

Survey name	Area	Survey design	Number of sets	Depth range	Vessels	Duration	Survey area (km^2)	Proportion of area covered
Gulf Region								
4T Demersal Multispecies	S. Gulf of St. Lawrence	Stratified random	175	-	1	21	73,000	0.010%
Maritimes Region								
4VWX Demersal Multispecies	Scotian Shelf	Stratified random	200	-	1	28	183,000	0.005%
5Ze Demersal Multispecies	Georges Bank	Stratified random	100	-	1	14	57,000	0.007%
4VsW Demersal Multispecies	Eastern Scotian Shelf	Stratified random	125	-	1	15	92,000	0.006%
Newfoundland Region								
2GHJ3KLNO Multispecies Trawl Survey	Grand Banks and the Coast of Labrador	Stratified random	600 - 750	45 - 1500	2	60 - 90	650,000	0.002%