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ALTERNATIVE SAMPLING AND ESTIMATION METHODS FOR MULTISPECIES TRAWL SURVEYS

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ALTERNATIVE SAMPLING AND ESTIMATION METHODS FOR MULTISPECIES TRAWL SURVEYS

A

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ABSTRACT

Multispecies demersal trawl surveys are used in the United States and internationally to estimate the relative abundance of commercial and non-commercial fish species. Their usefulness for estimating species' abundance is often limited by the variance associated with estimates. This study implemented and evaluated alternative sampling and estimation methods, with the goal to incorporate additional sources of information for increased precision of individual species' estimates from multispecies trawl surveys. First, habitat characteristics and past spatial distributions of four flatfish species' density were incorporated into a multispecies trawl survey design conducted in Kalsin and Middle Bays, Kodiak Island, Alaska. Stratification by depth and percent sand produced estimates of relative abundance with lower CVs than those from unstratified sampling. Additional decreases in relative precision were generally not achieved by estimating the relative abundance of multiple species from regions of species-specific suboptimal habitat. Second, a poststratification technique was used to incorporate species-specific habitat characteristics and previous distributions of species' density into the estimation of species' abundance from the Kalsin and Middle Bays' trawl survey. Poststratification by habitat gave estimates with lower variance and/or less design-bias than an unstratified estimator for all species in all years. Poststratification by habitat and fish density produced estimates with the least design-bias for all species in all years and the lowest variance when stratum sample sizes were sufficient. Third, mixed model linear regression (MMLR), empirical Bayes (EB) and hierarchical Bayes (HB) estimation methods were used to incorporate historical trends of yellowfin sole, *Limanda aspera*, biomass from the eastern Bering Sea trawl survey into annual biomass estimates. Using MMLR, EB, and HB methods resulted in biomass estimates that were less anomalous than survey estimates with respect to a linear regression trend. Estimates for all three methods had lower CVs than surveys in most years. The results of this thesis suggest that incorporating additional information into survey design and estimation can decrease the variability of survey estimates and/or correct for possible bias. Methods that can incorporate additional information, therefore, have the potential to improve survey assessments for management use.

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CHAPTER 1

Introduction

Multispecies demersal trawl surveys are used in the United States and internationally to estimate the relative abundance of commercial and non-commercial fish species. Large-scale trawl surveys are used in many regions across the United States including the Bering Sea (Armistead and Nichol 1993), Gulf of Alaska (Martin 1997), Pacific coast (Weinberg et al. 1994), Gulf of Mexico, southeast Atlantic, and northeast Atlantic (Azarovitz 1981; Clark 1998). Development of extensive time series of trawl survey data in the United States began in 1963 with surveys in the northeast Atlantic (Azarovitz 1981). The results of the surveys are used primarily for managing commercial fisheries (Azarovitz 1981; Lauth 1999).

Surveys often provide the only source of information about the status of fish stocks that is independent from commercial catch data. They are used along with commercial catch data for stock assessment and for setting harvest limits. Commercial fisheries data provide large sample sizes and broad geographic and temporal coverage. However, fishery-dependent data present a biased perspective of the population that may change over time and may not correlate well with true fish abundance (National Research Council 2000). On the contrary, survey information is often unbiased, but the number of samples is limited by cost. Even though survey-based population size estimates typically have high variability, they often track abundance trends more accurately than estimates based on catch data (Pennington and Stromme 1998). Surveys are of increasing importance for management due to the decreasing size of many fish populations and the quickly developing technology of the fisheries.

Surveys are used extensively for the management of fish stocks, but problems still remain in their design and analysis. Multispecies surveys sample numerous species, in part, because they coexist in the same habitat and, in part, because it is too expensive to survey each managed species separately (National Research Council 2000). While multispecies surveys are necessary, their designs are often sub-optimal for estimating the abundance of individual species. As a result, researchers need to explore alternative designs for data collection and analysis to increase the precision of individual species abundance estimates (National Research Council 2000). Chapters 2, 3 and 4 of this dissertation investigate alternative methods for survey design and analysis for multispecies survey data. The goal of each chapter is to evaluate the usefulness of a particular method or methods for multispecies surveys. Comparisons of methods are based primarily on the variance and coefficient of variation of the resultant estimates.

While the goal of surveys generally is to get the most information for a given amount of effort, the focus of individual surveys may vary. Many multispecies trawl surveys do not focus on a particular species, but use a stratified random sampling design with strata boundaries set by depth and major geographic boundaries to estimate the abundance of all species. If the emphasis of a multispecies survey is to estimate most precisely the abundance of some limited group of species (e.g., the most commercially important, the most abundant), alternate survey designs might provide more efficient estimates of abundance (population estimates with reduced variance for the same overall sample size). In Chapter 2, I incorporate habitat characteristics and prior estimated density of four flatfish species into a sampling design for a multispecies trawl survey for juvenile fishes in Kalsin and Middle Bays, Kodiak Island, Alaska.

Poststratification is a method not often used for estimating the abundance of individual species from multispecies surveys. As most large-scale demersal trawl surveys are conducted with a stratified random survey design, there are two main ways in which poststratification can be applied. If a multispecies survey is stratified with large strata, unbiased estimates can be made by poststratifying each stratum by species-specific ranges of habitat characteristics that have a known relationship to species density. For individual species sampled with a multispecies survey for which stratified sampling was not effective in increasing the precision of abundance estimates, ignoring the sample stratification and poststratifying by species-specific habitat characteristics can be done, but will provide a biased estimate of abundance. In Chapter 3, I evaluate whether using poststratification by depth and percent sand and distributions of juvenile flatfish density from previous surveys can provide more precise and less design-biased estimates of individual species abundance from multispecies surveys when samples are not randomly selected.

Incorporating uncertainty (Hilborn and Walters 1992; Adkison and Peterman 1996) and information from multiple sources (Adkison and Peterman 1996) into survey estimation and stock assessment is currently recommended for the management of fisheries. Survey estimates are determined from one year's data and are frequently quite variable. Incorporating information from previous years into annual survey estimates may increase the precision of those estimates. In Chapter 4, I examine three methods to adjust annual estimates of abundance with information from trends over multiple years. These methods effectively incorporate both the variability in annual survey estimates and the variability associated with the trend. The three models examined are: mixed linear, empirical Bayes, and hierarchical Bayes.

Chapter 5 concludes the dissertation with a brief summary of the major findings and a discussion of the implications for management.

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CHAPTER 2

Multispecies survey designs with habitat and fish density information[1]

ABSTRACT

When developing a survey design to estimate fish abundance, it is important to learn as much as possible about the distribution of the target species. Habitat type and habitat quality are primary determinants for the distribution and survival of marine fishes, but rarely are habitat characteristics other than depth or broad geographic features used in trawl survey designs. If habitat associations can be determined and habitat types quantified, stratified sampling should be more efficient, that is, reducing the variance in population estimates for the same overall sample size. In addition, if the geographic distribution of species expand and contract in response to annual abundance changes, as described in MacCall's "basin model", relationships between fish density, fish distribution, and habitat characteristics may be used to construct more efficient sampling designs for monitoring population abundance.

Using concepts from the "basin model", a sampling design was developed for monitoring annual relative abundance (mean catch-per-unit-effort (CPUE)) of four of the most abundant species of flatfishes in Kalsin and Middle Bays, Kodiak Island, Alaska: age-0 rock sole (*Lepidopsetta* spp.), age-1 yellowfin sole (*Limanda aspera*), age-0 flathead sole (*Hippoglossoides elassodon*) and age-0 Pacific halibut (*Hippoglossus stenolepis*). This study

[1] Dressel, S.C. and B.L. Norcross. Multi-species survey designs with habitat and fish density information. Prepared for submission to North American Journal of Fisheries Management.

investigated whether, given the same number of samples for the multispecies survey, estimates of relative abundance from sampling exclusively in sub-optimal habitat could be made with lower variance and coefficient of variation (CV) than estimates from across the full geographic distribution of these species. Estimates of relative abundance for the four species were compared using data from three sampling designs that were implemented in three separate years. The three sampling designs were unstratified sampling, sampling stratified by depth and percent sand, and sampling stratified by depth and percent sand with samples allocated only to regions of sub-optimal habitat. The size of estimated variances generally followed the size of relative abundance estimates. In the case where relative abundance estimates were similar between sampling designs, the stratified estimate had a lower variance. For all species, both stratified designs produced lower CVs than unstratified sampling. Yellowfin sole was the only species for which stratified sampling in sub-optimal habitats produced the lowest CV. For rock sole and flathead sole, stratified sampling across the entire survey region gave the lowest CV. Pacific halibut abundance decreased from 1995 to 1996 and their spatial distribution contracted so no estimate of relative abundance could be made by sampling in regions of sub-optimal habitat. The results of this study emphasize important drawbacks to sampling only in regions of sub-optimal habitat. First, if the distributions of various species differ, efficiency may not greater when sampling in sub-optimal habitat. Second, sample sizes for individual species may be small even if the overall sample size for the multispecies survey is large. Third, sampling in only a portion of a species' geographic distribution risks missing capture of a species entirely, which is unacceptable for management purposes.

INTRODUCTION

Developing a sampling design to provide information on the status of exploited fish stocks for management purposes requires more attention than it is often given (Mundy *et al.* 1985). In general, the maximum precision attainable in a fish survey is determined by the spatial distribution of the target species (Gunderson 1993). Therefore, it is important to learn as much as possible about the distribution of the target species when developing a survey design to estimate fish abundance.

Habitat type and habitat quality are primary determinants for the distribution and survival of marine fishes (Tanda 1990; Gadomski and Caddell 1991; Gibson and Robb 1992; Sogard 1992; Moles and Norcross 1995). Although knowledge of habitat characteristics related to species' distributions and previous determinations of fish density could be used to design surveys of abundance and might result in abundance estimates with smaller variances, rarely are habitat characteristics other than depth or broad geographic features used in trawl survey designs (e.g. Gulf of Alaska (Martin 1997), United States Pacific coast (Weinberg et al. 1994), United States Atlantic coast (Azarovitz 1981), Scotian Shelf and Bay of Fundy (Halliday and Koeller 1981), Grand Bank, St. Pierre Bank, Flemish Cap, and Gulf of St. Lawrence (Pitt et al. 1981)).

Density-dependent habitat selection (DDHS), as discussed by Verner (1964), Orians (1969), Fretwell and Lucas (1970), Fretwell (1972), Rosenzweig (1981), and others in the ecological literature, provides a framework with which to view the dynamic geographical distribution of a species. Changes in population size will change the population's density (the number of organisms per unit area), its geographic range, or some combination of the two (Sampson 1995). The theory of DDHS explains how a population's utilization of habitat and geographical distribution can alter with changes in abundance. The Fretwell-Lucas theory of DDHS is based on multiple discrete habitats that possess different levels of suitability for a species. "Suitability" is equated with "goodness", where "the goodness of each occupied habitat is related to the average potential contribution from that habitat to the gene pool of succeeding generations of the species" (Fretwell and Lucas 1970).

In the "basin model", MacCall (1990) extends previous models of DDHS to include continuous habitat, providing a more complete model to describe the dynamics and spatial distribution of fish species. According to the basin model, as population abundance increases, the density of fish in the most suitable habitat will increase until its relative suitability decreases below that of surrounding less suitable (sub-optimal) habitat (MacCall 1990). At this point, further increases in abundance will result in range expansion around most suitable habitat. As population size decreases and the density of individuals in the most suitable habitat decreases, fish from surrounding less suitable habitat will move into the most suitable habitat region, resulting in a contraction of the overall spatial distribution of the population. Field studies have shown the amount of expansion and contraction of a species' geographic distribution can vary both by species

(McConnaughey 1995) and age (Swain and Wade 1993). Expansion and contraction of a species' spatial distribution with changes in population abundance has been described for fish, birds, insects, reptiles, and small and large mammals (MacCall 1990), adult flatfish (McConnaughey 1995), and other groundfish (Rose and Leggett 1991; Crecco and Overholtz 1993; Swain and Wade 1993).

The basin model assumes that a fish species exists in an "ideal free distribution" (Fretwell and Lucas 1970); that the suitability of a habitat is linearly related to species density; and that a logistic growth model represents the changes in a species' geographic distribution with changes in abundance (MacCall 1990). The basin model was originally applied to a pelagic fish species, the California population of the northern anchovy, *Engraulis mordax* (MacCall 1990). However, the ideas of DDHS, changes in distribution with changes in population abundance, and the basin model have also been explored for multiple groundfish species and juvenile fishes (haddock, *Melanogrammus aeglefinus* – Crecco and Overholtz 1990; Atlantic cod, *Gadus morhua* – Rose and Leggett 1991; Swain and Wade 1993; juvenile fishes - Walters and Juanes 1993; English sole, *Parophrys vetulus* – Sampson 1995). In addition, the basin model can be extended to include multiple species (MacCall 1990).

Monitoring the annual abundance of juvenile flatfish is important as juveniles can serve as indicators of upcoming abundance trends of the adult population as well as indicators of climate change and pollution levels in coastal regions. Kalsin and Middle Bays, Kodiak Island, Alaska, serve as nursery areas to 11 juvenile flatfish species. Four of the most abundant are age-0 flathead sole (*Hippoglossoides elassodon*), age-0 rock sole (*Lepidopsetta* spp.), age-1 yellowfin sole (*Limanda aspera*) and age-0 Pacific halibut (*Hippoglossus stenolepis*) (Norcross et al., 1995). Sampling to monitor the abundance of fish species can be expensive, however. Obtaining data to construct estimates with high precision at low cost is desirable.

Based on the concepts of DDHS and the basin model, a survey design that will be referred to as the "monitoring strata method" was constructed for monitoring the annual relative abundance of juvenile flatfishes in Kalsin and Middle Bays. The monitoring strata method was based on the observation that juvenile flathead sole, rock sole, yellowfin sole, and Pacific halibut distribute relative to depth and sediment type (Norcross et al. 1995) and the assumption that their population dynamics and population geography follow the basin model. The goal of this study was to see whether the monitoring strata method could be used to estimate relative juvenile flatfish abundance with the same or greater precision, but fewer samples, than sampling across the entire survey region.

For the monitoring strata method, estimates of relative abundance were made from samples in regions of sub-optimal habitat for each species. The monitoring strata method involved estimating the mean catch-per-unit-effort (CPUE) of each species from samples in sub-optimal habitat for two reasons. First, estimates of mean CPUE were expected to have lower variance in regions of sub-optimal habitat. Trawl survey tows taken in regions of high species abundance have high associated variance (Taylor 1953; Forest and Minet 1981; Francis 1984). The variance of trawl samples may be reduced by decreasing the mean number of fish caught per tow (Taylor 1953). Therefore, given a gradient in the density of individuals across regions, the estimated variability may be lower in regions of low density. As the basin model assumes population density is directly proportional to habitat suitability (MacCall 1990), estimated variability may be lower in regions of sub-optimal habitat. The relative precision of estimates (coefficient of variation (CV)), that is the amount of precision independent of the mean, may not be less in regions of low density, however. So while sample allocation was based on the variance of species density, both the variance and the CV associated with estimates were calculated and compared after the surveys were complete.

The second reason the monitoring strata method estimated relative abundance from samples in sub-optimal habitat was that changes in annual density were predicted to be greater, hence more detectable for a given amount of effort, in those regions. The basin model suggests that the density of fish in optimal habitat may vary less than changes in overall abundance (MacCall 1990). Surveys of Atlantic cod (*Gadus morhua)* support this. When cod populations were at low abundance, densities increased slowly in regions where the cod concentrations were the highest and more rapidly in the surrounding regions (Swain and Wade 1993). Assuming the population dynamics and geography of juvenile flatfish behave similarly, regions of low density were expected to be regions with large changes in annual density.

Surveys in Kalsin and Middle Bays were conducted in 1993, 1995, and 1996. Based, in part, on species density, depth, and sediment grain-size data from 1993, flathead sole, rock sole, yellowfin sole, and Pacific halibut density are known to distribute relative to depth and percent sand in substrate (Norcross et al. 1995). As a result, 1995 sampling was stratified by depth and percent sand where ranges of habitat characteristics, rather than contiguous geographic areas, defined each stratum. In 1996, samples were allocated to species-specific monitoring strata based on species variance, cost (the hours taken to trawl and sort the tow) and stratum area from 1995. For each species, 1996 estimates of mean CPUE, variance, and CV were made only from their monitoring strata. The precision of species' estimates made in monitoring strata were then compared to those made across the whole survey region. Given nearly the same overall survey sample size, species variance and coefficient of variation (CV) were calculated in 1996 and compared to those calculated from unstratified sampling in 1993 and stratified sampling with equal allocation of samples to strata in 1995. In this study, estimates of mean CPUE (density) were not unbiased because samples were haphazardly selected across the survey region in 1993 and within each stratum in 1995 and 1996. No attempt was made to estimate the bias associated with density estimates. Instead this study focuses only on the precision (variance) and relative precision (CV) of density estimates.

Because the 1996 monitoring strata estimates were made from samples in a portion of the survey region and each species' distribution, a relationship between monitoring strata mean CPUE and overall mean CPUE was necessary for changes in annual monitoring stratum CPUE to reflect absolute changes in overall abundance. In fisheries management, fishing effort is often assumed to be proportional to fishing mortality, where the catchability coefficient (q), the fraction of the fish population removed per unit of fishing effort, is constant. Based on this assumption, population abundance (N) can be monitored by CPUE:

CPUE=qN

For most fish stocks however, q varies inversely with population abundance and geographical range inhabited by the population (Paloheimo and Dickie 1964). Therefore, if population abundance declines, the geographical range inhabited by a population gets smaller and q increases (Winters and Wheeler 1985). As a result, CPUE is curvilinearly related to population abundance (Paloheimo and Dickie 1964; Crecco and Overholtz 1990). If sampling in sub-optimal habitat is shown to be an efficient way of monitoring juvenile flatfish CPUE in Kalsin and Middle Bays, CPUE in sub-optimal habitat can be fitted to overall abundance using a nonlinear regression analysis, as done by Crecco and Overholtz (1990) for Georges Bank haddock. Then stratified estimates of CPUE in monitoring strata can be used to predict overall population abundance for flathead sole, rock sole, yellowfin sole, and Pacific halibut.

METHODS

Study area

The 1993, 1995 and 1996 surveys were conducted in Kalsin and Middle Bays, approximately 10 nmi southeast of the town of Kodiak, Alaska (Figure 2.1). Middle Bay is approximately 8 km long, with depths of 50 m at the mouth of the bay, and an area of approximately 21 km^2. Kalsin Bay is also approximately 8 km long, but reaches depths greater than 100 m at the mouth of the bay, and encompasses an area of approximately 34

km^2. The survey area included the combined area of the two bays and the area directly outside the mouths of the two bays, encompassing approximately 87 km^2.

Fish collections

Surveys were conducted jointly by the University of Alaska Fairbanks, Institute of Marine Science and the National Marine Fisheries Service, Alaska Fisheries Science Center, Kodiak Laboratory aboard an 8.2 m Boston Whaler. Samples were collected August 12 to 24, 1993; July 31 to August 11, 1995; and August 1 to 16, 1996, with a modified plumb-staff beam trawl designed to collect juvenile flatfish (Gunderson and Ellis 1986). In 1995, 1996 and for 28 quantitative tows in 1993, tows were made with a 3.05 m plumb-staff beam trawl. An additional 7 tows were made in 1993 with a 3.66 m plumb-staff beam trawl. Trawl nets were made of 7 mm square net mesh and a 4 mm codend liner, which retained flatfishes as small as 11 mm. Nets were equipped with a double tickler chain, two 18 kg weights on the lower wings, floats on the headrope and at each end of the beam, and 15 cm lengths of chain hung from the footrope at 15 cm intervals. The towline was deployed at a 5:1 line:depth ratio at stations less than 10 m deep and 3:1 ratio for depths greater than 10 m.

Density of flatfish species was expressed as CPUE values standardized to 1000 m^2 tow area. The sampling area of each tow was calculated as 0.74 of the beam length, the effective width of the beam trawl (Gunderson and Ellis 1986), multiplied by the distance towed based on Global Positioning System (GPS) coordinates. In 1995 and 1996 tows were made for 10 minutes, or less when necessary to keep the net from overfilling, and distances were determined from GPS readings for each individual tow. Beginning and ending GPS coordinates were not recorded for tows in 1993. Instead station locations were estimated based on bathymetry and shoreline landmarks. Therefore, least trimmed squares robust regression (S-Plus 1994) was used to establish a relationship between tow time and GPS estimated tow distance based on samples made with the same vessel in 1994 (Norcross et al. 1995), 1995 and 1996. The regression relationship was then used to estimate the distance towed for 1993 samples based on their tow time.

Tows were made during daylight and primarily on a rising tide. Fish were identified to the lowest possible taxon and measured to the nearest millimeter total length. At the time of collections, all rock sole were identified as *Pleuronectes bilineatus.* Due to Orr and Matarese's (2000) revision of the genus, we refer to these fishes as *Lepidopsetta* spp. in this paper, as both *L. bilineata* and *L. polyxystra* were identified in the study area during 1996 sampling. Fish ages were determined by length-frequency analysis.

Depth and sediment collections

Two groups of habitat parameters, depth/temperature and sediment grain-size, explain most of the observed geographical distributions of all four species of juvenile flatfishes (Norcross et al. 1995). Therefore, depth and percent sand in sediment were used for survey stratification in 1995 and 1996. Sediment samples were collected from each 1993 sample site using a sediment grab (0.06 m^3 Ponar grab) for grain-size analysis.

Sediment samples were also collected in Kalsin and Middle Bays in 1991, 1992, and 1994 (Norcross et al. 1995). Sediment samples were analyzed for grain-size using a sieve/pipette procedure (Folk 1980) and the percentage of gravel, sand, and mud were estimated following the Wentworth scale (Sheppard 1973).

A map of the study region with depth contours was digitized and 1991-1994 measurements of percent sand at sampling sites were added by latitude and longitude coordinates and kriged (a geostatistical method of interpolating values for points that were not physically sampled) over the study region using a linear isotropic model (Surfer 1995) (Figure 2.2). Surfer was used to plot and calculate the area within each 1995 and 1996 sediment-depth combination strata and of the entire survey region. The total area in the sampling region, as determined in the Surfer program was 87.15 km^2 (Tables 2.1 and 2.2).

Unstratified sampling: 1993

Because no prior information existed on juvenile flatfish habitat in southcentral Alaskan waters, sampling in 1993 was conducted both to estimate abundance and to identify habitats that support juvenile flatfish (Norcross et al. 1995). Sampling was unstratified and the goal was to sample throughout the study region in as many habitats as possible within the constraints of bottom type suitable for trawling.

Stratified sampling with equal allocation: 1995

Sampling in 1995 was stratified by depth and percent sand in sediment. Depth stratification was in 5 or 10m increments. Sediment was stratified into three levels following Folk's sediment classification (1980): 0-50% sand, 51-90% sand, and 91-100% sand. Three tows were allocated to as many strata as possible within the given amount of effort available for the total survey. For three depth and sediment combinations that were present in both bays, three tows were allocated in each bay for a total of six tows per stratum (Table 2.1). Ten of the most prevalent combinations of depth and sediment classifications were represented in 1995 strata. At each sampling site, the cost of sampling was recorded.

Monitoring strata: 1996

The 1996 survey had approximately the same number of samples as 1995 and was stratified, but with fewer strata and more samples allocated to each stratum. Flathead sole, rock sole, yellowfin sole, and Pacific halibut CPUEs from 1993 and 1995 sampling were compared with depth and percent sand to select strata boundaries for the 1996 survey (Figures 2.3 and 2.4). Percent sand was divided into three categories and depth was divided into two categories (Table 2.2). Regions greater than 30 m depth with 81-100% sand in sediment were not found in 1993 and 1995 sampling. As a result, the remaining five strata were used to characterize the study area.

For each of the four species, the optimum allocation of samples (Thompson 1992) for 1996 strata was calculated based on the relative area in each stratum, the estimated cost of sampling in each stratum, and the estimated standard deviation of species' stratum abundance. Sample allocation was calculated for each species-stratum combination as,

$$n_{ih} = \frac{(c - c_0) N_h \sigma_{ih} / \sqrt{c_h}}{\sum_{k=1}^{L} N_k \sigma_{ik} \sqrt{c_k}}$$

where n_{ih} is the number of tows in the sample from stratum h for species i, c is the overall cost (hrs) of the survey, c_0 is the "overhead" cost (hrs) of the survey, which for this study was zero, N_h is the number of possible tows in stratum h, c_h is the cost (hrs) of sampling in stratum h, and σ_{ih} is the standard deviation of species i in stratum h. High sample sizes resulted for strata with high variances, large areas, and low costs, while low sample sizes resulted from the opposite (Table 2.2). Cost estimates from 1995 tows were used to estimate the average cost of sampling in each 1996 stratum. CPUEs from 1995 tows were used to estimate the standard deviation of abundance for each species in each 1996 stratum.

Because this was a multispecies survey with a limited number of total samples, it was not possible to sample the maximum number, or even the average number, of the optimally allocated tows specified for the four species in each stratum (Table 2.2). Instead, samples were allocated to strata so that the optimum allocation sample sizes were met or exceeded for as many species as possible. To do so, the first samples were collected in the stratum with the lowest optimum allocation sample size among all species-stratum combinations. Additional samples were collected in the stratum with the next lowest sample size. This process continued until the survey ended. A minimum of two samples per stratum was set to guarantee sampling in all five strata. A stratum was designated a "monitoring stratum" for a species if the number of samples made in that stratum during 1996 sampling was equal to or greater than the optimal number of samples specified for that species-stratum combination (Table 2.2).

When optimally allocating samples, strata that are allocated a low number of samples result, in part, from a low standard deviation of fish CPUE. When sampling fish populations, low standard deviation estimates are known to correspond to low abundance estimates (Taylor 1953; Francis 1984). Therefore, unless cost and stratum size were not overwhelmingly influential, it is likely that monitoring strata chosen for each species in 1996 sampling (Table 2.2) were those that comprised regions of low abundance for that species in 1995. To check this expectation, each species' 1995 CPUEs were kriged over the survey region and the locations of 1995 tows that had depth and percent sand characteristics within those of the monitoring strata chosen for 1996 sampling were plotted by latitude and longitude (Figures 2.5-2.8). As most monitoring strata sites fell in regions of low abundance for each species in Figures 2.5-2.8, it appeared that the monitoring strata allocation method was an effective way to sample in low abundance regions (sub-optimal habitat) while still incorporating cost and stratum size considerations.

To see whether estimating relative abundance with the monitoring strata method produced lower estimated variances and CVs than sampling across the entire survey region, the variance and CV of monitoring strata estimates were compared with stratified estimates of mean CPUE (1995) and unstratified estimates of mean CPUE (1993).

RESULTS

Flatfish CPUE values were calculated for a total of 112 tows in Kalsin and Middle Bays during 1993, 1995, and 1996 (Figure 2.9). Thirty-five tows were made in 1993, 38 in 1995, and 39 in 1996. An unstratified mean CPUE, variance, and CV were calculated for species in 1993 (Table 2.3).

In 1995 three tows, or six when stratum included regions in both bays, were completed in every stratum except stratum ten where only two were completed due to time limitations (Table 2.1). Mean CPUE, variance, and CV were calculated for each species in each 1995 stratum and stratified mean CPUEs, variances, and CVs were calculated across all strata for each species (Table 2.3). In 1996, flathead sole was monitored in strata one, two, three, and four with a total of 37 tows; rock sole was monitored only in stratum four with a total of 7 tows; yellowfin sole was monitored in strata one, three, four, and five with a total of 26 tows; and Pacific halibut was monitored in strata one and four with a total of 11 tows (Table 2.2). Mean CPUE, variance, and CV were calculated for each species in each 1996 monitoring stratum and stratified mean CPUEs, variances, and CVs were calculated for each species across their monitoring strata (Table 2.3). Samples taken outside a particular species' monitoring strata were not included in their 1996 mean CPUE estimate.

In general, the size of the overall variances across the three sampled years followed the size of the overall mean CPUEs, but the effects of sample size and stratification were also apparent (Table 2.3). For flathead sole, overall means and variances were greater in 1993 than