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ABSTRACT: We analyzed catch per unit effort data collected near Kodiak Island during a side-by-side trawl comparison experiment between the National Marine Fisheries Service (NMFS) and the Alaska Department of Fish and Game (ADF&G) conducted in 1997. Using Kappenman's estimator, fishing power correction factors (FPCs) were estimated for 4 common species, and a mean squared error-based decision rule to determine whether the use of fishing power correction factors is warranted was applied in each case. The NMFS vessel–gear unit was considerably more efficient at catching walleye pollock *Theragra chalcogramma* (FPC = 3.84) and Pacific cod *Gadus macrocephalus* (FPC = 1.72) than its ADF&G counterpart, but the ADF&G vessel–gear unit was somewhat more efficient at catching arrowtooth flounders *Atheresthes stomias* (FPC = 0.73) and flathead sole *Hippoglossoides elassodon* (FPC = 0.75). The outcome of the decision rule suggests that fishing power correction factors should be applied for all 4 species when integrating the 2 agencies' survey data. Length-based FPCs, designed to fine-tune fishing power corrections to individual size categories, were not significantly different for Pacific cod (P = 0.91), arrowtooth flounder (P = 0.096), or flathead sole (P = 0.15). However, 3 significantly different length-based FPCs were obtained for walleye pollock (0–14 cm, 15–62 cm, and > 62 cm).

INTRODUCTION

The Alaska Fisheries Science Center (AFSC) of the National Marine Fisheries Service (NMFS) conducts biennial (triennial prior to 1999) groundfish trawl surveys in the Gulf of Alaska using a stratified random sampling design. The primary survey objectives are to provide abundance estimates of major commercial species and to monitor changes in abundance over time (Wilderbuer et al. 1998). Stock assessment models used by the AFSC's Resource Ecology and Fisheries Management division suggest that the biomass estimates of walleye pollock *Theragra chalcogramma* are too low, especially for the large size classes. Large walleye pollock may inhabit areas missed by the survey, which tends to sample at depths greater than the preferred depth of these fish. It is therefore possible that the "missing" fish are located in bays not extensively sampled by the survey.

Data collected by the Alaska Department of Fish and Game (ADF&G) during annual crab and groundfish trawl surveys at fixed stations around Kodiak Island, Shelikof Strait, and in several bays along, and islands off, the Alaska Peninsula, suggest a high abundance of walleye pollock (Urban 1997), especially in bays where ADF&G's sampling density is particularly high compared to that of NMFS surveys. Because the ADF&G survey area represents a subset of the NMFS Gulf of Alaska survey, integrating the 2 data sets would provide biomass estimates based on larger sample sizes, and with higher sampling densities in areas where some species, such as walleye pollock, may be especially abundant.

However, before combining these catch-per-unit-effort (CPUE) data sets, it may be necessary to correct for potential differences in fishing power between the 2 vessel–gear combinations because the 2 agencies employ substantially different trawl gear and methodologies. A difference in fishing power between 2 vessel–gear units exists when their CPUEs differ under equal conditions for the same density of organism (Beverton and Holt 1957). To determine whether a correction factor is warranted, one must first quantitatively compare the vessel–gear efficiencies and then

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refer to an objective decision rule specifying the minimum fishing power difference that justifies the adjustment of one of the data sets. Combining the data sets without considering such an adjustment may result in a biased mean CPUE estimate. In addition, because factors such as reactions to a trawl, bottom tending habits, and other ecological characteristics of fish are likely to be species-specific (Wakabayshi and Bakkala 1985), each species must be considered separately when generating fishing power correction factors (FPCs).

Several estimators of fishing power correction are currently in use including variations of the log-transformed multiplicative model (e.g., Sissenwine and Bowman 1978; Byrne and Forrester 1987) first proposed by Robson (1966), and the ratio of mean CPUEs (e.g., Koeller and Smith 1983; Wilderbuer et al. 1998) introduced by Beverton and Holt (1957). In addition, Kappenman (1992) proposed an estimator whose only assumption is that the 2 CPUE random variables of 2 vessel–gear units have distributions with the same shape but different scales. The latter estimator is not as heavily influenced by rare, inordinately large observations as the other 2, which suffer because their assumptions of comparable fish density in front of each net can easily be violated as a result of physical factors (Wakabayshi and Bakkala 1985) and because of patchiness in the fish distribution.

Many researchers have used these and other correction factors, but few have explicitly stated decision rules for when they should be applied. Munro (1998) pointed out that correcting fishing power differences is worthwhile only if it reduces the error in the estimate of mean CPUE. Using an estimate of the mean square error (MSE) as a measure of error between the estimator of mean CPUE and the true CPUE, he developed an objective decision rule which accounts for the cost of correcting as well as the benefit. The estimated MSE is a good measure of error for this application because the MSE explicitly accounts for the variance as well as the bias of the mean CPUE (Mood et al. 1974). A trade-off exists between these 2 components of the MSE because the variance of the FPC increases the total error of the mean CPUE while it simultaneously reduces the bias. An FPC is useful only when the bias reduction is sufficiently large to off-set the increase in variance.

In this study we analyze the catch and effort data from a 1997 trawl comparison experiment between NMFS and ADF&G, which was designed to provide the necessary information for integrating the 2 agencies' survey data sets. The objectives were to estimate the difference in fishing power between the NMFS and ADF&G vessel–gear units, to determine the suitability of applying correction factors to the CPUE data, and to determine whether length-based FPCs are warranted for 4 species commonly encountered by both surveys: walleye pollock *Theragra chalcogramma*, Pacific cod *Gadus macrocephalus*, arrowtooth flounder *Atheresthes stomias*, and flathead sole *Hippoglossoides elassodon*.

METHODS

Experimental Design

A total of 33 hauls were conducted during a side-by-side trawl calibration study in October 1997 in waters off the east side of Kodiak Island, Alaska (Figure 1). Depths ranged between 93 m and 156 m, and the bottom was relatively smooth and soft throughout the study area. The chartered (NMFS) vessel F/V *Peggy Jo*, a 30.5-m stern trawler with an 875-hp engine, conducted 15-min tows at 5.56 km/hr (3 knots); the ADF&G vessel R/V *Resolution*, a 27.4-m stern trawler with an 800-hp engine, conducted 1.85-km (1 nmi) tows at 3.70 km/hr (2 knots). Each vessel employed the trawling methods standard to their respective surveys. Bottom trawling was conducted from the *Peggy Jo* with a NMFS 4-seam, high-opening polyethylene Nor'eastern trawl with a 27-m headrope, a 37-m footrope, and 35.6-cm (14-in) bobbin roller gear (Martin 1997). This trawl is capable of sampling moderately rough and irregular bottom types typically encountered throughout much of the Gulf of Alaska. Trawling was conducted from the *Resolution* with a 400-mesh Eastern otter trawl with a 21-m headrope and 29-m footrope without roller gear, which makes it well-suited for sampling relatively smooth and soft bottom types (D. King, AFSC, National Marine Fisheries Service, Seattle, personal communication). On each vessel the net width and height was continuously monitored using a system of headrope and wing sensors (SCANMAR). Actual distance fished was determined using a combination of global positioning system (GPS), footrope-mounted bottom-contact sensors, and headrope-mounted micro-bathythermograph units, which recorded depth and temperature. The 2 vessels maintained a minimum distance of separation (approximately 0.25 miles) to increase the probability that both sampled the same fish populations during each tow. Catches on each vessel were sorted, weighed, and enumerated by species using methods common to the respective surveys. Length-frequency measurements were collected for the 4 species mentioned in the introduction.

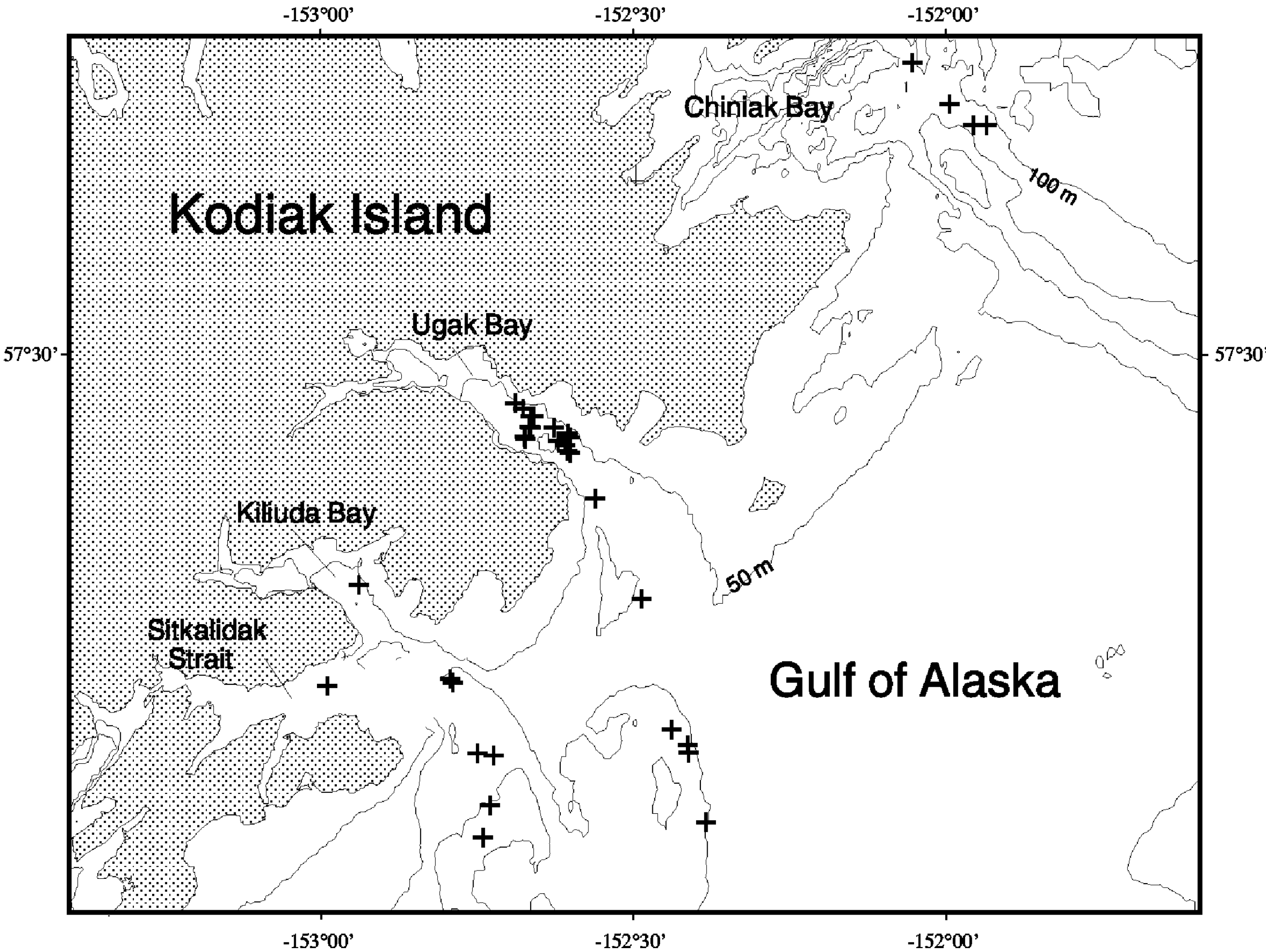

Figure 1. Study area in bays off of Kodiak Island. The "+" signs indicate stations where paired hauls were conducted.

Computing the Fishing Power Correction Factors

The estimator proposed by Kappenman (1992), currently used by the AFSC to calculate FPCs in multivessel trawl surveys in the Bering Sea (Goddard 2000), was used to estimate fishing power differences. Kappenman's estimator is based on the assumption that the unknown, but typically skewed, CPUE distributions for a given species are the same for both vessels, except possibly for the values of the scale parameters of the distributions. The FPC is defined as the ratio of these scale parameters. Thus, if X and Y are positive random variables representing the CPUEs obtained by the 2 vessels, and r is the ratio of the scale parameters, then X and rY have identical distributions. Because we wanted to recast the ADF&G data in terms of the broader NMFS survey, we selected the vessel using the NMFS methods and gear (*Peggy Jo*) as the standard vessel, X.

The first step in the Kappenman algorithm is to find an exponent d so that X^d and r^dY^d have approximately the same normal distribution. This is accomplished by solving an equation (Kappenman 1992, p. 2986, Equation 1) derived from a maximum likelihood estimation argument. Next, 2 conjectures are made; one states that the values of x_i^d and $r^dy_j^d$, where $i = 1,\ldots,n$ and $j = 1,\ldots, m$, are random samples of observations of X and Y, have the same distribution, and the other that they have different distributions. In the second step the predicted values of x_i^d and $r^dy_j^d$ are calculated from the observations in 2 ways. In one case the first conjecture is assumed to be correct, and in the second case the alternate conjecture is assumed to be correct. The sum of squares of the differences between the values of x_i^d and $r^dy_j^d$ and their predicted values are then calculated under the 2 assumptions. The difference between the 2 sums of squares is expressed in terms of a complex likelihood function. The

Table 1. Parameter values of the lognormal and gamma distributions for the simulation study to generate plots of MSE vs. FPD. The italicized values indicate the distribution used.

	Parameters of Simulated CPUE Distributions			
	lognormal		gamma	
Species	μ	σ	α	β
walleye pollock	*8.59*	*0.87*	0.725	8.74×10^{-5}
Pacific cod	*6.76*	0.48	*1.622*	1.47×10^{-3}
arrowtooth flounder	*9.04*	*0.66*	1.071	9.14×10^{-5}
flathead sole	9.75	0.67	*1.053*	4.39×10^{-5}

value of r that minimizes the sum of squares under the first conjecture relative to the second is chosen as the estimate of FPC (Kappenman 1992).

We used the bootstrapping method to estimate the variance of the Kappenman estimator because there is no analytical technique available to compute the variance of this estimator. The CPUE data from the 2 vessels were resampled 1,000 times, and an estimate of the FPC was calculated for each resample.

Decision Rule for Applying FPCs

Munro's (1998) decision rule for applying a fishing power correction to CPUEs is based on the mean squared error (MSE). The MSE is a measure of the error between an estimator and its parameter and can be written as the sum of the variance and the squared bias of the estimator

$$\mathrm{MSE}[\hat{C}] = \mathrm{Var}\ [\hat{C}] + b^2[\hat{C}],$$

where $\hat{C}$ is the estimator of the mean CPUE. The decision rule states that an FPC should only be applied if

$$\mathrm{MSE}\left[CPUE_{corrected}\right] < \mathrm{MSE}\left[CPUE_{uncorrected}\right],$$

where $CPUE_{corrected}$ and $CPUE_{uncorrected}$ are the mean CPUEs based on corrected and uncorrected CPUE data.

Following the strategy suggested by Munro (1998), the decision rule was implemented as follows. We simulated surveys by drawing 300 sets of 33 CPUEs for the standard NMFS vessel from either a gamma or a lognormal distribution, depending on which best fit the data from the trawl experiment. These distributions were chosen because of their right-skewed properties, their ability to assume a variety of distinctly different shapes, and their prior use by Kappenman (1992) and McConnaughey and Conquest (1993). The particular members of the lognormal and gamma families of distributions were derived from the mean λ and variance τ^2 of the NMFS CPUE data. The lognormal random number generator function in S-Plus (Becker et al. 1988) requires the parameters of the corresponding normal distribution as its arguments. We therefore back-transformed λ and τ^2 of the highly skewed CPUE data to the corresponding "normal parameters," μ and σ^2 using

$$\mu = 2\ln(\lambda) - \frac{1}{2}\ln\left(\lambda^2 + \tau^2\right)$$

and

$$\sigma^2 = \ln\left(\lambda^2 + \tau^2\right) - 2\ln(\lambda)$$

(Finney 1941). The shape α and rate β parameters of the gamma distribution are related to λ and τ^2 of the CPUE data according to

$$\alpha = \frac{\lambda^2}{\tau^2}$$

and

$$\beta = \frac{\lambda}{\tau^2}$$

(Rothschild and Logothetis 1986). Values obtained for μ, σ, α, and β are shown in Table 1.

A variable fishing power difference (FPD) with an assumed value was then imposed on a second set of CPUEs (ADF&G's) drawn from the same distribution (multiplying the simulated CPUEs by a constant) to simulate a potential catchability difference between the 2 vessels. The FPC was estimated for each simulated survey using the Kappenman estimator and was then multiplied by the CPUEs of the ADF&G vessel in order to correct for the differences in fishing power relative to the designated standard (NMFS) trawl.

The mean simulated CPUE of the combined data sets was estimated in 2 ways. In the first case the

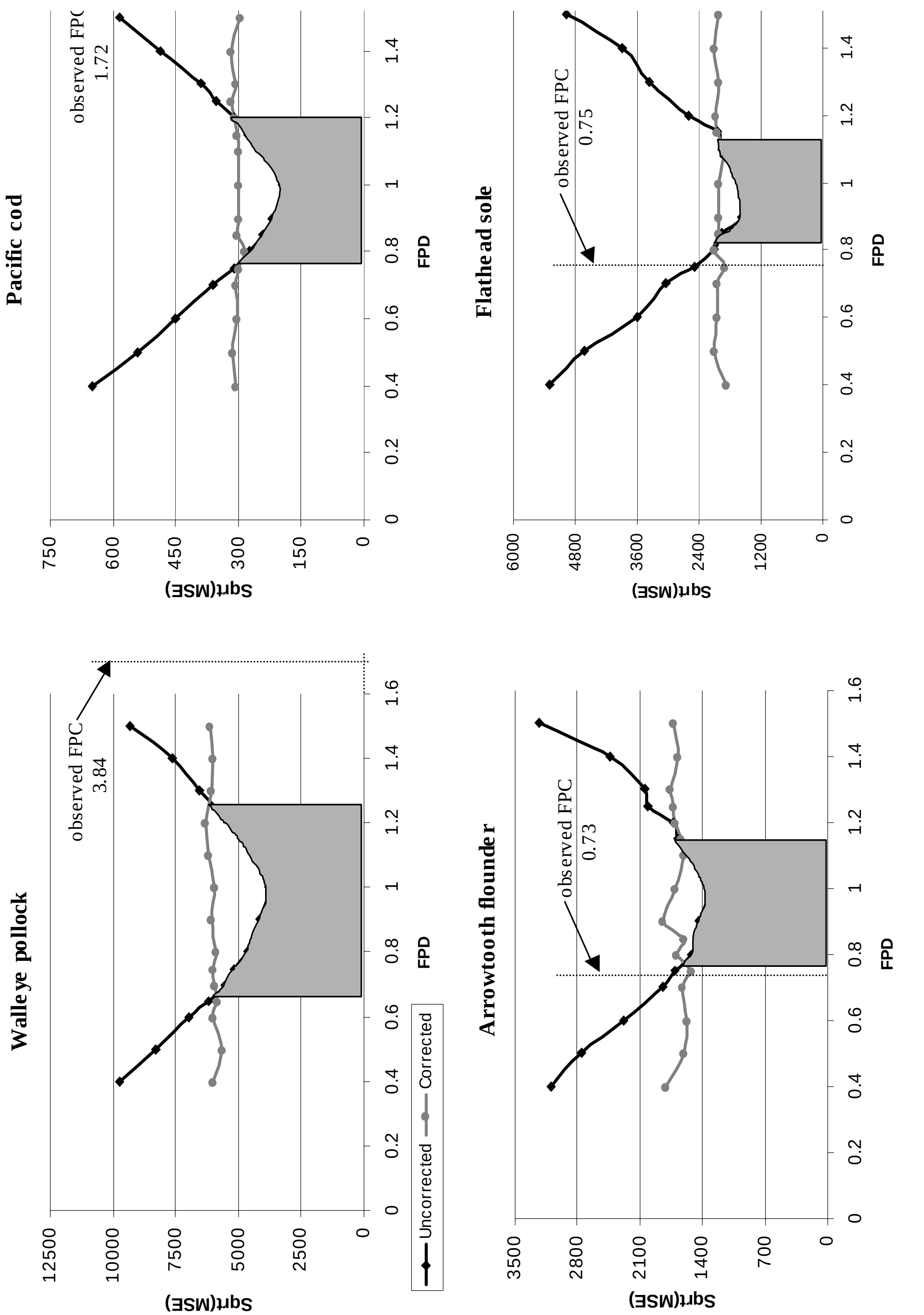

Figure 2. Mean square error (MSE) of the overall mean CPUE (combined data sets from the 2 vessels) for corrected and uncorrected ADF&G catches, as a function of assumed fishing power difference (FPD). The shaded areas indicate non-correction regions, or ranges of fishing power difference for which the MSE of the corrected catch data is greater than that of the corresponding uncorrected data. The U-shape of the uncorrected CPUE curves is due to the bias component of the MSE which increases as the imposed FPD differs from 1.0. The corrected CPUE curves are flat but have relatively high MSEs when the FPD is close to 1.0, reflecting the lack of a bias component and the additional variance associated with applying an FPC.

CPUEs of the NMFS vessel were combined with the uncorrected CPUEs of the ADF&G vessel, and in the second case they were combined with the corrected CPUEs. We estimated the MSE of the mean CPUE from its variance and estimate of bias for both the uncorrected and corrected cases. Bias was estimated as

$$b = \langle MSE_{sim} \rangle - \langle MSE_{obs} \rangle,$$

where b is the bias, $\langle MSE_{sim} \rangle$ is the mean of the simulated CPUEs, and $\langle MSE_{obs} \rangle$ is the observed mean CPUE from the side-by-side trawl experiment. This process was repeated for a range of different FPDs (Figure 2), and the resulting MSEs for both cases were plotted against the imposed FPD. Using our decision rule, the plots were used to establish the ranges of FPDs ("correction regions") for which an FPC was warranted.

Cut-off Points for Length-based FPCs

We examined the potential need for length-based FPCs for each species to see if we could obtain more accurate fishing power corrections for individual size categories. The fish length range was divided into 2 or more sub-intervals, each with a smaller difference in the length-frequency distribution between the 2 vessel–gear units than the full range. To identify suitable cut-off points in the length range, we used an algorithm that locates points where the rate of divergence between the cumulative length-frequency distributions (CFDs) is greatest. This intuitive approach was designed to maximize the difference in the length-based FPCs between the resulting length sub-intervals.

The divergence rate of the CFDs was computed by calculating the rate of change of the difference between the CFDs in 1-cm intervals. The resulting values were sorted, and the length associated with the highest rate of change was the first cut-off point. The percentage of overlap (Renkonen 1938; Schoener 1970; Hurlbert 1978; Krebs 1989) of the relative frequency distributions was then computed for each size interval to determine the degree of similarity between the distributions. This was done to verify the validity of assuming a constant FPC for a given size category. The percentage overlap, or overlap coefficient (OVC), is a number between zero and one (the closer to unity the greater the degree of similarity between the 2 distributions) and is defined as

$$\text{OVC} = \sum_{i=\min CPUE}^{\max CPUE} \left[\min\left(X_i, Y_i\right) \right],$$

where

$$X_i = \left(\frac{n_{i_x}}{\sum_{i=\min CPUE}^{\max CPUE} n_{i_x}} \right),$$

and

$$Y_i = \left(\frac{n_{i_y}}{\sum_{i=\min CPUE}^{\max CPUE} n_{i_y}} \right),$$

$n_{i(j)}$ (j=x or y) is the frequency of the i^{th} bin of a CPUE histogram, X_i and Y_i are the relative bin frequencies of the simulated and realized CPUE data of the i^{th} bin, and min*CPUE* and max*CPUE* correspond to the first and last bins of the CPUE histogram, respectively. The selectivities of the 2 vessels within a size interval were considered sufficiently similar for the purpose of using length-based FPCs if the OVC was greater than 0.7. We would calculate the FPC for both size intervals if the OVCs exceeded this threshold, otherwise we would not consider length-based FPCs for that species.

Next, we tested the hypothesis that the length-based FPCs were significantly different from each other, using the nonparametric Wilcoxon rank-sum test. The t test could not be used because the normality assumption of this test was not met even after applying various transformations to the data. Because the

Table 2. Mean CPUEs and fishing power correction factors. The corrections assume the NMFS vessel to be standard.

	Mean CPUE (kg/km²)		SD (kg/km²)				
Species	NMFS	ADF&G	NMFS	ADF&G	CPUE Ratio	FPC	SD
walleye pollock	31,042	8,298	37,898	9,744	3.74	3.84	1.26
Pacific cod	2,095	1,101	2,010	865	1.90	1.72	0.45
arrowtooth flounder	9,768	11,719	13,532	11,325	0.83	0.73	0.10
flathead sole	17,492	24,007	15,197	23,397	0.73	0.75	0.20

Kappenman estimator does not explicitly account for the pairing of the hauls in this experiment, an alternative estimator of FPC, the mean of the CPUE ratios, was used for the Wilcoxon test. We assumed that a length-based FPC was unwarranted if the null hypothesis (H_0: $\text{FPC}_{\textit{interval }1} - \text{FPC}_{\textit{interval }2} = 0$) was not rejected, and that it was potentially warranted if H_0 was rejected. In the latter case, a second cut-off point, identified as the length with the second highest rate of change between the CFDs by length, was considered provided it was different from the first one by at least 10 cm. Wilcoxon's rank-sum test was then applied to the CPUE ratios from the 2 new length sub-intervals resulting from the division of one of the original length intervals by the second cut-off point to test the hypothesis that the 2 new length-based FPCs were significantly different. This procedure was repeated until no further size classes with significantly different FPCs could be identified.

RESULTS

The NMFS vessel–gear unit was more efficient at catching walleye pollock and Pacific cod than the ADF&G counterpart, but the ADF&G vessel–gear unit was more efficient at catching the 2 species of flatfish. The CPUE observations by the 2 vessels were well correlated as illustrated for walleye pollock and flathead sole in Figure 3. Mean CPUEs for the 2 vessel–gear units, the level of significance of the *t* test (H_0: $\text{CPUE}_{\text{NMFS}} - \text{CPUE}_{\text{ADF\&G}} = 0$), and the observed FPCs are listed in Table 2. The estimated FPCs for both walleye pollock and Pacific cod were far outside the non-correction region, and those for arrowtooth flounders and flathead sole were just outside the boundary of the non-correction region (Figure 2).

Except for walleye pollock, the relative size composition of all species was sufficiently similar between the 2 vessels (the OVC was at least 0.8 for all species and size categories) that no length-based FPCs were warranted ($P > 0.05$; Table 3) even when only 2 size classes were considered. However, the relative size composition for walleye pollock smaller than approximately 15 cm (Figure 4), the first cut-off point, was notably different. The length-based FPCs resulting from the first cut-off point were significantly different ($P = 0.0002$), but because it occurred at such a small size virtually all of the contribution to the total CPUE (i.e., all sizes combined) was from fish larger than the cut-off point (99.8% for NMFS and >99.9% for ADF&G). The second cut-off point for walleye pollock (62 cm), obtained by dividing one of the length intervals from the first cut-off (i.e., lengths >14 cm) into 2 sub-intervals (15–62 cm and >62 cm), resulted in 2 significantly different ($P = 0.030$) length-based FPCs (Table 4). The third cut-off point (44 cm) did not result in any additional significantly different length-based FPCs ($P = 0.71$).

DISCUSSION

The observed FPCs for walleye pollock and Pacific cod were so far outside the non-correction regions that the benefits of bias reduction clearly outweigh the cost of the added variance when an FPC is applied to the CPUE data. It is not as clear, however, whether correction factors should be used for arrowtooth flounders and flathead sole because the estimated FPCs for these species were barely outside the non-correction regions. Because these regions are only estimates, with errors around the upper and lower bounds, and because of the error associated with the FPC itself, Munro (1998) suggests that the conservative approach for these species would be to decide against using an FPC when it is only marginally outside.

The cost of following this advice is a mean CPUE for the pooled data that may be biased by as much as 25–27% (Table 2), and the resulting biomass estimate must therefore be treated with caution. Also, if an FPC is not applied when it is only marginally outside the

Table 3. Length-based FPCs for all species and one cut-off point. The *P* values indicate the level of significance of Wilcoxon's rank sum test statistic (H_0: $FPC_{\textit{interval }1} - FPC_{\textit{interval }2} = 0$).

		FPC		
Species	Cut-off Length (cm)	Length Interval 1	Length Interval 2	*P* value
walleye pollock	14	32.95	3.69	0.0002
Pacific cod	62	1.32	1.78	0.91
arrowtooth flounder	29	0.47	0.76	0.096
flathead sole	32	0.87	0.75	0.15

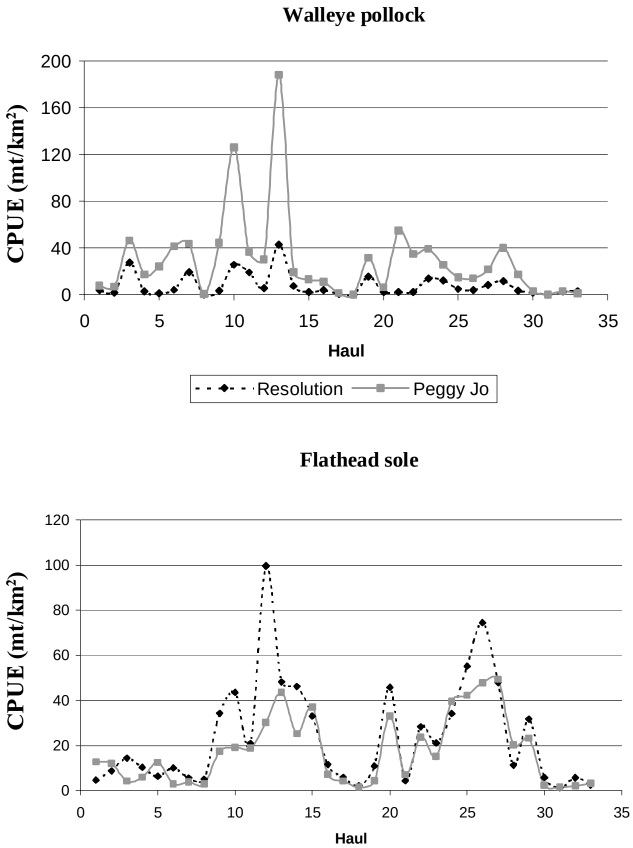

Figure 3. Raw CPUE data by haul number for walleye pollock and flathead sole. The R/V *Resolution* is the ADF&G vessel and the F/V *Peggy Jo* is the chartered NMFS vessel.

correction region, the decision rule loses its objectivity. Rather than being a definitive rule, the decision of whether an FPC is sufficiently far outside the non-correction region is completely arbitrary. For these reasons, we suggest that Munro's decision rule be treated as an absolute and recommend that FPCs be applied to both the arrowtooth flounder and flathead sole data. Furthermore, we think it is important to consider ways of reducing the size of the non-correction region so that FPCs can be applied to more species.

By increasing the sample size (i.e., the number of paired hauls in the trawl-comparison experiment), it is possible to narrow the non-correction region as well as to more clearly define its boundaries. Wilderbuer et al. (1998) recommends a minimum of 50 hauls for a good estimate of the Kappenman estimator. Although the 33 hauls in this study fall short of this goal, we believe that our sample size was satisfactory because of the relatively narrow depth range and homogeneous substrate types of the experimental area. However, a larger sample size not only reduces the variance of the FPC realized in the trawl comparison experiment, and hence the uncertainty as to whether the FPC is inside or outside the non-correction region, it also improves the estimate of the underlying distribution of CPUEs. This can possibly result in more accurate FPCs from the algorithm that generates the simulated decision curves. More accurate FPCs coupled with more accurately simulated CPUE data, in turn, implies less bias, which reduces the MSE of corrected CPUE data and results in a narrower non-correction region.

A word of caution about the estimate of bias. The bias was estimated as the difference between the experimental data and the mean of the distributional fit to the data. Other distributions fit to the data (i.e., distributions other than the lognormal and gamma) possibly could provide other estimates of bias. Hence, the estimates used in this study are only as good as the distributional assumptions made, which, in turn, are based on a relatively small number of paired hauls.

The benefits of applying an FPC to the walleye pollock and Pacific cod CPUEs are clear according to the experimental data, but it is not as obvious whether the estimated FPCs are applicable when combining the NMFS and ADF&G surveys. For example, different survey areas might create differences in the relative catchability between the 2 gear types because different bottom types might affect the nets' bottom-tending abilities differently. We do not think this is a problem in the present context, however, because the ADF&G survey is confined to areas with a relatively smooth and soft bottom, much like the one where this study was conducted.

Depth may be a potential factor affecting the applicability of the estimated FPCs because it affects the vertical opening of the net, and hence the volume swept during a haul. Depth also affects the horizontal opening, but this is already accounted for in the calculation of effort, which is defined as the area swept between the net's on- and off-bottom positions. If the depth ef-

Table 4. Length-based FPCs for walleye pollock and multiple cut-off points. The *P* values indicate the level of significance of Wilcoxon's rank sum test statistic (H_0: $FPC_{interval\,1} - FPC_{interval\,2} = 0$).

Number of Cut-offs	Cut-off Length (cm)	Length Interval (cm)	FPC	*P* value
2	62	15–62	4.01	0.030
		>62	2.33	
3	44	15–44	4.76	0.71
		45–62	3.96	

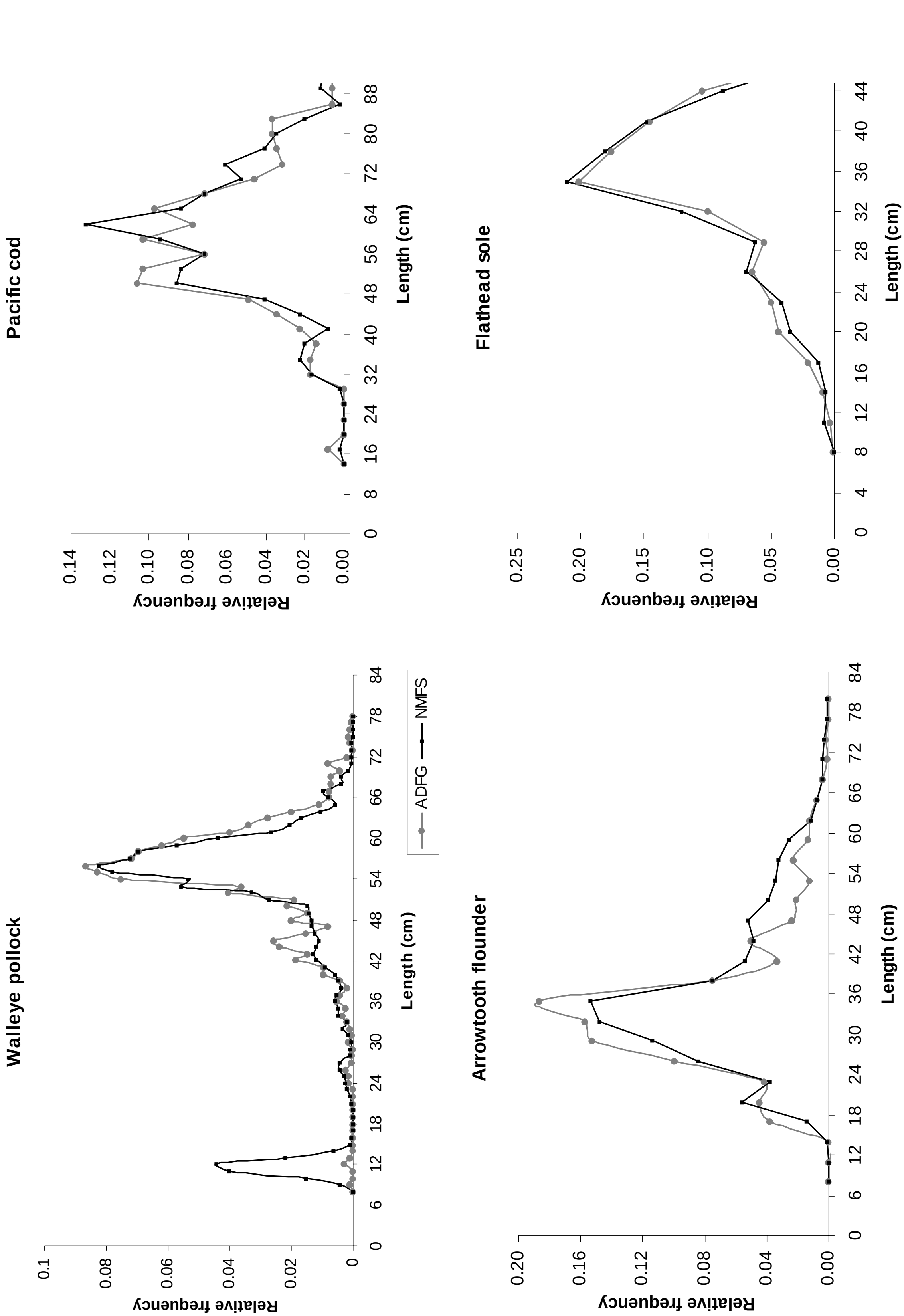

Figure 4. Relative length-frequency distributions of NMFS and ADF&G catches, combining data from all 33 hauls.

fect differs greatly between the 2 nets, the FPC for a semidemersal species such as walleye pollock becomes a function of depth, and the estimated FPC is no longer applicable to the survey data. Because of the narrow depth range of the study area, we did not observe any significant trends in the vertical opening with depth for either net and were not able to determine the relationships between FPC and depth. This potential problem for walleye pollock is not likely to be important for the 2 species of flatfish and Pacific cod, however, because they are more closely associated with the bottom.

A major reason for using Kappenman's estimator was its relative insensitivity to outliers in the form of vastly different catch rates between the 2 vessels in a comparative trawl experiment. Outliers for occasional haul pairs are more likely due to the 2 vessels sampling different populations than to differences in gear performance, and they should be expected in the Gulf of Alaska where the bottom type, and hence fish abundance (Love and Ebeling 1978; Larson 1980; Krieger 1993), has been shown to be patchy on scales of the order of 100 m or less (von Szalay 1998). The Kappenman estimator was also specifically designed to cope with unpaired data, such as that obtained from a multivessel trawl survey, and only assumes that the CPUE random variables have distributions with the same shape but different scales (Wilderbuer et al. 1998).

We do not recommend applying a separate FPC to walleye pollock smaller than 15 cm even though the first cut-off point resulted in 2 length-based FPCs that were significantly different. Because fish smaller than 15 cm account for much less than 1% of the catch by weight, the potential improvement in the biomass estimate would be insignificant. More important, because of their small size, it may not be possible to determine their selectivity to the trawl gear with satisfactory precision because the selectivity may be highly dependent on the amount of catch present in the codend. That is, small fish are much more likely to pass through the net if the net is empty than when there is a substantial catch in it. The uncertainty of the length-based FPC estimate is thus too high for very small fish. Furthermore, because abundance estimates are very sensitive to the FPC, and the FPC estimate for juvenile walleye pollock is very high (Table 3), it would be inappropriate to apply a separate FPC to juvenile walleye pollock unless its precision is significantly improved. Until then, we recommend that the same FPC value be applied to juveniles as to fish in the next larger length interval, 15–62 cm.

We do, however, recommend the use of length-based FPCs for walleye pollock in the length intervals resulting from the second cut-off point, 15–62 cm and >62 cm. Because the FPC for the largest fish (>62 cm) was considerably smaller than that of the intermediate-sized fish (15–62 cm), the combined mean CPUE could be substantially biased for strata with a high abundance of very large walleye pollock (e.g., bay areas) if separate FPCs are not applied. A possible reason for the decline in fishing power difference between the 2 vessel–gear units with increasing fish size is that larger walleye pollock may be more bottom-tending than the smaller fish. Given that the vertical opening of the NMFS net is more than 3 times higher than that of the ADF&G net, this would explain why the NMFS vessel–gear unit is more efficient at catching small walleye pollock than the ADF&G vessel–gear unit, whereas the fishing power differences between the 2 surveys are less pronounced for larger fish.

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