The Feasibility of Reducing the Variance of Fish Relative Abundance Estimates by Integrating CPUE Data from Two Demersal Trawl Surveys in the Gulf of Alaska

Paul G. von Szalay

Reprinted from the Alaska Fishery Research Bulletin
Vol. 10 No. 1, Summer 2003

The Alaska Fishery Research Bulletin can be found on the World Wide Web at URL:
http://www.state.ak.us/adfg/geninfo/pubs/afrb/afrbhome.htm

Alaska Fishery Research Bulletin 10(1)1–13. 2003.

The Feasibility of Reducing the Variance of Fish Relative Abundance Estimates by Integrating CPUE Data from Two Demersal Trawl Surveys in the Gulf of Alaska

Paul G. von Szalay

ABSTRACT: Catch per unit effort data of walleye pollock *Theragra chalcogramma*, Pacific cod *Gadus macrocephalus*, arrowtooth flounder *Atheresthes stomias*, and flathead sole *Hippoglossoides elassodon* from the National Marine Fisheries Service and Alaska Department of Fish and Game 1999 and 2001 Gulf of Alaska bottom trawl surveys were integrated to evaluate the feasibility of reducing the variance of the National Marine Fisheries Service biomass estimates for these species. Because of differences in the spatial design and areas covered by the 2 surveys, 2 new strata, recognizing bays as a separate stratification element and made up of portions of some of the original National Marine Fisheries Service strata, were introduced. Variance estimates based on the combined surveys were similar (<10% difference) to those based exclusively on the National Marine Fisheries Service survey data for all species and both years except for walleye pollock in 2001 (84% higher for the integrated surveys). Biomass estimates were also similar (<10% difference) between the integrated and nonintegrated data for all species and both years except for walleye pollock in both 1999 and 2001 (22% and 82% higher estimates for the integrated surveys in 1999 and 2001, respectively). A potential reason for the unexpected increase in the biomass and variance estimates for walleye pollock is a significant time-dependence of the fishing power correction factor due to vertical migration of these fish. The appropriateness of integrating the data from these surveys is discussed.

INTRODUCTION

The Alaska Fisheries Science Center (AFSC) of the National Marine Fisheries Service (NMFS) conducts biennial (triennial prior to 1999) multi-species bottom trawl surveys of the entire continental shelf and upper slope of the Gulf of Alaska using a stratified random sampling design. The primary objective of this survey is to provide estimates of relative abundance for the major fish species that are used in stock assessment models for managing the commercial catch (Wilderbuer et al. 1998). Because the quality of these estimates is primarily measured by their variance, it is important to use a sampling strategy that minimizes the variability in the estimates of relative abundance that can be obtained with the available resources. Such a strategy involves both maximizing the number of stations sampled and the optimal allocation of sampling stations among strata. In this paper, I examine one approach to help achieve both objectives, that is, by incorporating stations sampled by another trawl survey using a different fishing gear than the NMFS survey. Relatively little has been reported on the direct data integration of separate trawl surveys. Calibration studies of different trawl gear have been carried out in the Baltic Sea in an attempt to combine data from surveys conducted by 2 different nations (Schultz and Grygiel 1984). Abundance data of Northeast Arctic cod *Gadus morhua L.* and haddock *Melanogrammus aeglefinus L.* from acoustic and trawl surveys are routinely combined in Norway (Engås and Godø 1989; Godø 1998), and NMFS formerly integrated Eastern Bering Sea trawl and acoustic abundance estimates for walleye pollock (Wespestad et al. 1996).

The other trawl survey I consider is the Alaska Department of Fish and Game (ADF&G) annual bottom trawl survey conducted in nearshore waters around Kodiak Island and the Alaska Peninsula. The primary objective of the ADF&G survey is to assess the relative abundance of Tanner crab *Chionoecetes bairdi*

Author: PAUL G. VON SZALAY is a Research Fishery Biologist at the Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE, Seattle, Washington 98115 USA. E-mail address: paul.von.szalay@noaa.gov
Acknowledgments: I thank David Somerton, Peter Munro, Libby Logerwell, Craig Rose, and Martin Dorn for their invaluable contributions to this paper. I would also like to express gratitude to all the scientists who participated in the 1999 and 2001 NMFS and ADF&G Gulf of Alaska trawl surveys, and to the crews of the R/V *Resolution*, F/V *Vesteraalen*, F/V *Morning Star*, and F/V *Dominator*.

and red king crab *Paralithodes camtschaticus*, but the incidental groundfish catch is also processed and analyzed for species composition and length-frequency distributions for commercially important species (Worton 2001).

Current stock assessment protocol of walleye pollock does not call for the direct integration of the estimates of relative abundance from these two surveys. Instead they are fit separately into an age-structured model using AD Model Builder (Fournier 2001). An alternative to this approach is to treat the 2 survey data sets as coming from a single source by tuning the data of one survey to that of the other and fitting the integrated estimate of relative abundance to the model. Integration of the 2 surveys can be accomplished if the relative fishing power of the 2 vessel-gear units is known. To provide this, a side-by-side trawl comparison experiment designed to calibrate the ADF&G and NMFS vessel-gear units was performed in October 1997 and fishing power correction factors (FPC) for 4 species were determined (von Szalay and Brown 2001). The F/V *Peggy Jo* and the R/V *Resolution* were the vessels used by NMFS and ADF&G, respectively, for this study. When combining the 2 surveys, it is important to realize that the variability associated with the FPC represents a new source of error in the estimate of relative abundance. This variability, in part, offsets the variance reduction achieved from the increased sampling density. The objective of this study was to determine whether the variance of the estimates of relative abundance for walleye pollock *Theragra chalcogramma*, Pacific cod *Gadus macrocephalus*, arrowtooth flounder *Atheresthes stomias*, and flathead sole *Hippoglossoides elassodon* could be substantially reduced by incorporating the ADF&G survey data into the NMFS sampling design using a restratified survey area that recognizes bays as a separate stratification element.

METHODS

Survey Designs

The process of generating an integrated estimate of relative abundance from the ADF&G and NMFS catch per unit effort (CPUE) data is complicated by the substantial differences in gear types and survey objectives between the 2 agencies. The ADF&G research vessel, R/V *Resolution*, is a 27.4-m stern trawler with an 800-hp engine using a 400-mesh Eastern otter trawl with a 21-m headrope and a 29-m footrope without roller gear (Worton 2001). The Eastern trawl is well-suited for sampling relatively smooth and soft bottom types (D. King, Alaska Fisheries Science Center, National Marine Fisheries Service, Seattle, personal communication). In fishing configuration the net averages approximately 15 m in width and 2 m in height for the depth range of the survey area. Because no net mensuration equipment was used, the average net spread (S in meters) for a tow was estimated using a regression formula, $S = 12.556 + 0.0169 \times$ (mean tow depth), established during a previous experiment with net mensuration.

The NMFS chartered 3 stern trawlers in 1999: F/V *Vesteraalen*, F/V *Dominator*, and F/V *Morning Star* (Table 1). The power of the engines ranged between 1,725 hp and 2,000 hp. Two of these vessels, F/V *Vesteraalen* and F/V *Dominator*, were also used in 2001. All vessels in both survey years sampled with a standardized NMFS 4-seam, high opening polyethylene Nor'eastern (poly Nor'eastern) trawl with a 27-m headrope, a 37-m footrope, and 35.6-cm (14 in) bobbin roller gear (Martin 1997). On each NMFS vessel the net width and height was continuously measured using acoustic headrope and wing sensors. The net averaged 15–17 m in width and 6–8 m in height in fishing configuration. The poly Nor'eastern trawl is designed to

Table 1. Comparison of NMFS and ADF&G surveys, including vessels and gear types. The number of hauls in the second row refers to "good performance" tows, while those in parentheses in the third row include *all* hauls performed by each vessel.

	NMFS		ADF&G	
	1999	2001	1999	2001
Dates	May 10–July 23	May 17–July 25	June 16–Sep 23	June 18–Sep 4
Number of hauls	795	489	401	352
Vessels (hauls in parentheses)	F/V *Vesteraalen* (312) F/V *Morning Star* (248) F/V *Dominator* (310)	F/V *Vesteraalen* (260) F/V *Morning Star* (268)	R/V *Resolution*	R/V *Resolution*
Trawl gear	poly Nor'eastern	poly Nor'eastern	400-mesh Eastern	400-mesh Eastern
Depth range (m)	16–1,000	20–448	15–286	9–129

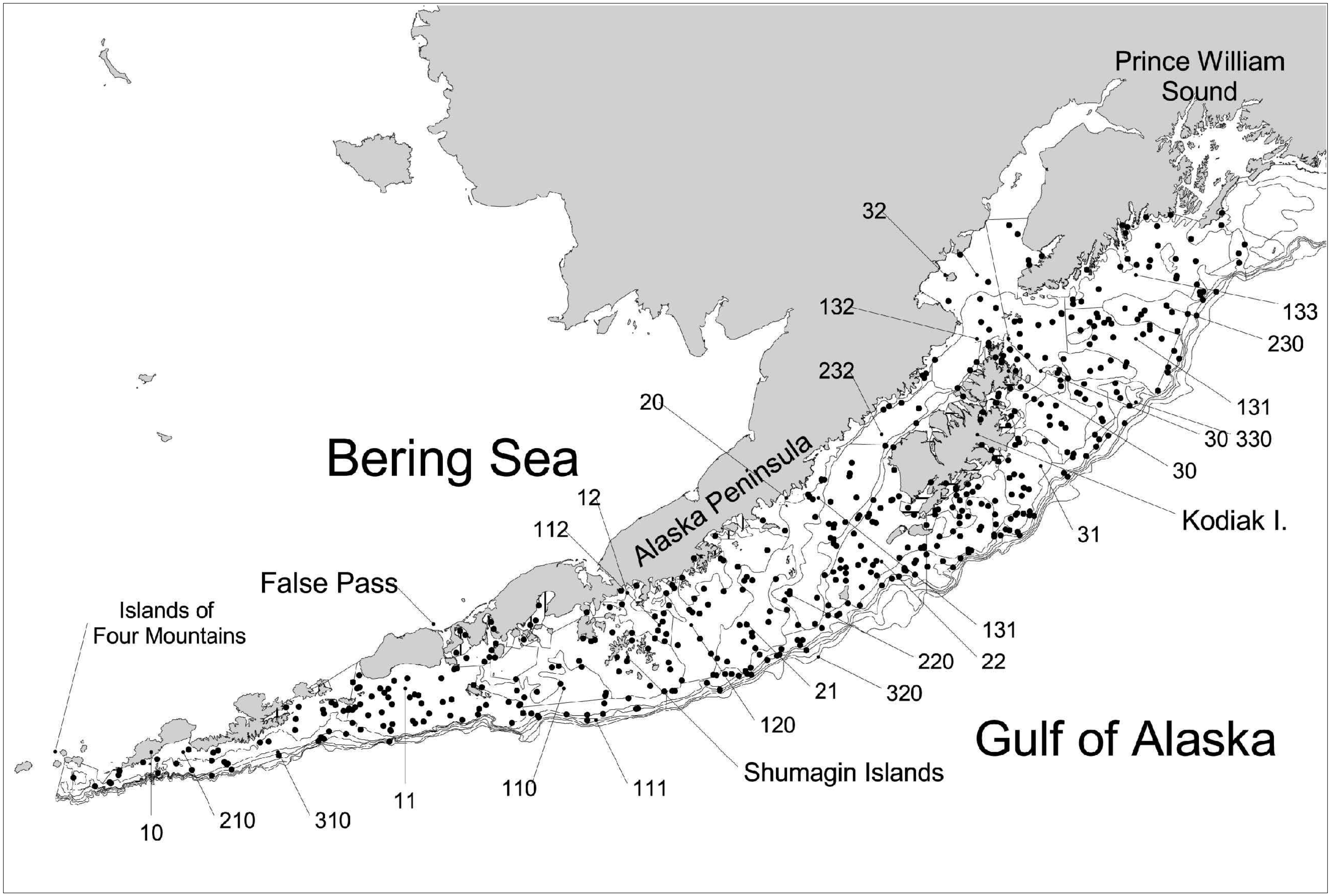

Figure 1. The NMFS Gulf of Alaska bottom trawl survey area in 2001. The NMFS trawl stations are indicated by dots (•). Numbers identify the NMFS strata.

sample moderately rough and irregular bottom types typically encountered throughout the Gulf of Alaska.

The NMFS employs a stratified random survey design over the entire shelf and upper continental slope of the Gulf of Alaska (to a maximum depth of 1,000 m). The survey area was reduced in size for the 2001 survey, spanning the area between the Islands of Four Mountains in the eastern Aleutian Islands and Prince William Sound, with depths greater than 500 m excluded from the survey (Figure 1). Hauls are allocated among the various strata according to a modified Neyman optimal allocation strategy (Cochran 1965) where the weighting factors are proportional to the mean commercial value of the principal groundfish species (Table 2). The duration of a standard NMFS haul during the 1999 and 2001 surveys was 15 minutes, measured from the time when the net first achieved standard fishing configuration at a speed of 5.6 km/hr (3 knots). The average towed distance was approximately 1.5 km.

The ADF&G survey differs in several respects from the NMFS survey. It samples a number of fixed and relatively uniformly distributed stations which are primarily confined to nearshore areas between Kodiak Island and False Pass (Figure 1). The bay areas are divided into subareas of approximately 4.6 km^2 each. Because of land boundaries, there is considerable variation in both size and shape of individual subareas. One haul is conducted in each subarea, and the trawl placement within a subarea was randomly chosen when the time series was initiated, subject to the constraint of the bottom being trawlable. The start locations of the stations have subsequently remained relatively fixed. The number of stations sampled varies between years; for example, 401 hauls were completed in 1999 and 352 hauls were completed in 2001. Much of the ADF&G survey area is in bays and other preferred crab habitat which, when combined, constitute a relatively small subset of the NMFS survey area. The standard ADF&G tow length during the 1999 and 2001 surveys was 1.85 km (1 nm) and was conducted at a constant speed of 3.70 km/hr (2 knots). While this survey is not a stratified random design like the NMFS survey, it is equivalent to one for species such as walleye pollock that are mobile on a scale at least as big as the survey strata (Pola 1985; Radchenko and Sobolevskiy 1993). This is because the fish randomize themselves from year to year within the strata in lieu of randomizing the station locations (Nicholson et al. 1991).

Each agency conducted its survey at approximately the same time of the year in 1999 and 2001 (Table 1). The ADF&G survey started approximately 1 month after the NMFS survey, but because the 2 surveys generally did not coincide temporally or spatially with each other, there were substantial variations in the time difference between the two surveys at specific locations (Figures 2 and 3). For example, both ADF&G and NMFS sampled a large portion of the east side of Kodiak Island in early July, whereas ADF&G surveyed the bays around the Alaska Peninsula approximately 2 months later than NMFS.

Table 2. Area and sampling effort by stratum for NMFS and ADF&G, Gulf of Alaska surveys, 1999 and 2001. The numbers in columns 3–6 in a) and 3–4 in b) refer to the number of trawl hauls conducted in the respective strata.

a) Bay strata

		1999		2001	
Stratum	Area (km^2)	NMFS	ADF&G	NMFS	ADF&G
Kodiak Island	3,213	13	122	14	117
AK Peninsula	2,987	10	100	11	89
Total	6,200	23	222	25	206

b) All other strata[a]

		1999	2001
Stratum	Area (km^2)	NMFS	NMFS
10	7,939	19	1
11	13,683	29	36
12	5,003	9	12
13	12,399	26	20
20	7,443	15	10
21	7,302	17	13
22	10,116	19	29
30	4,204	7	23
31	15,296	34	36
32	9,887	22	7
33	5,260	12	10
35	1,348	4	5
110	4,245	9	6
111	8,152	17	16
112	2,224	5	6
120	10,934	24	16
121	7,735	17	19
122	5,011	11	22
130	7,897	18	24
131	7,337	16	16
132	10,981	24	14
133	12,078	26	14
134	5,026	11	21
210	2,788	8	9
220	10,018	30	14
221	1,528	5	8
230	6,660	21	14
231	1,623	5	5
232	3,208	10	2
310	2,531	12	6
320	1,604	8	5
330	2,912	14	7
Total	214,372	504	464

[a] These strata surveyed by NMFS only.

Description of the new strata

For the integration of the 2 surveys to be valid, the sampling scheme must be random or evenly dispersed within each stratum. Because of a difference in the spatial design of the ADF&G and NMFS strata, this requirement would not be satisfied if the ADF&G hauls were simply assigned to the original NMFS strata. Specifically, the NMFS strata containing ADF&G hauls would have a much higher sampling density in the bays, where the ADF&G sampling density is high, than outside the bays. To overcome this problem, 2 new strata made up of portions of some of the original NMFS strata were introduced. The new strata were designed so that both the ADF&G and NMFS sampling stations were relatively uniformly distributed within them, thereby producing a representative sampling pattern.

Whereas the original strata are categorized strictly by water depth, type of geographical area (e.g., banks, gullies, and slopes), and management area boundaries (Martin 1997), the 2 new strata also recognize bays as a potentially important stratification element. Both of the new strata are noncontiguous and are made up of several bays, or parts of bays around Kodiak Island (Figure 2) and the western part of the Alaska Peninsula near the Shumagin Islands (Figure 3). Combined, these 2 strata accounted for 222 of the 401 stations sampled in 1999 and 206 of the 352 ADF&G stations sampled in 2001 (Table 2). The ADF&G hauls conducted outside these 2 strata were not used in the integrated estimate of relative abundance calculations because they were neither randomly nor uniformly distributed within the NMFS survey strata. Furthermore, the estimates of relative abundance shown in this pa-

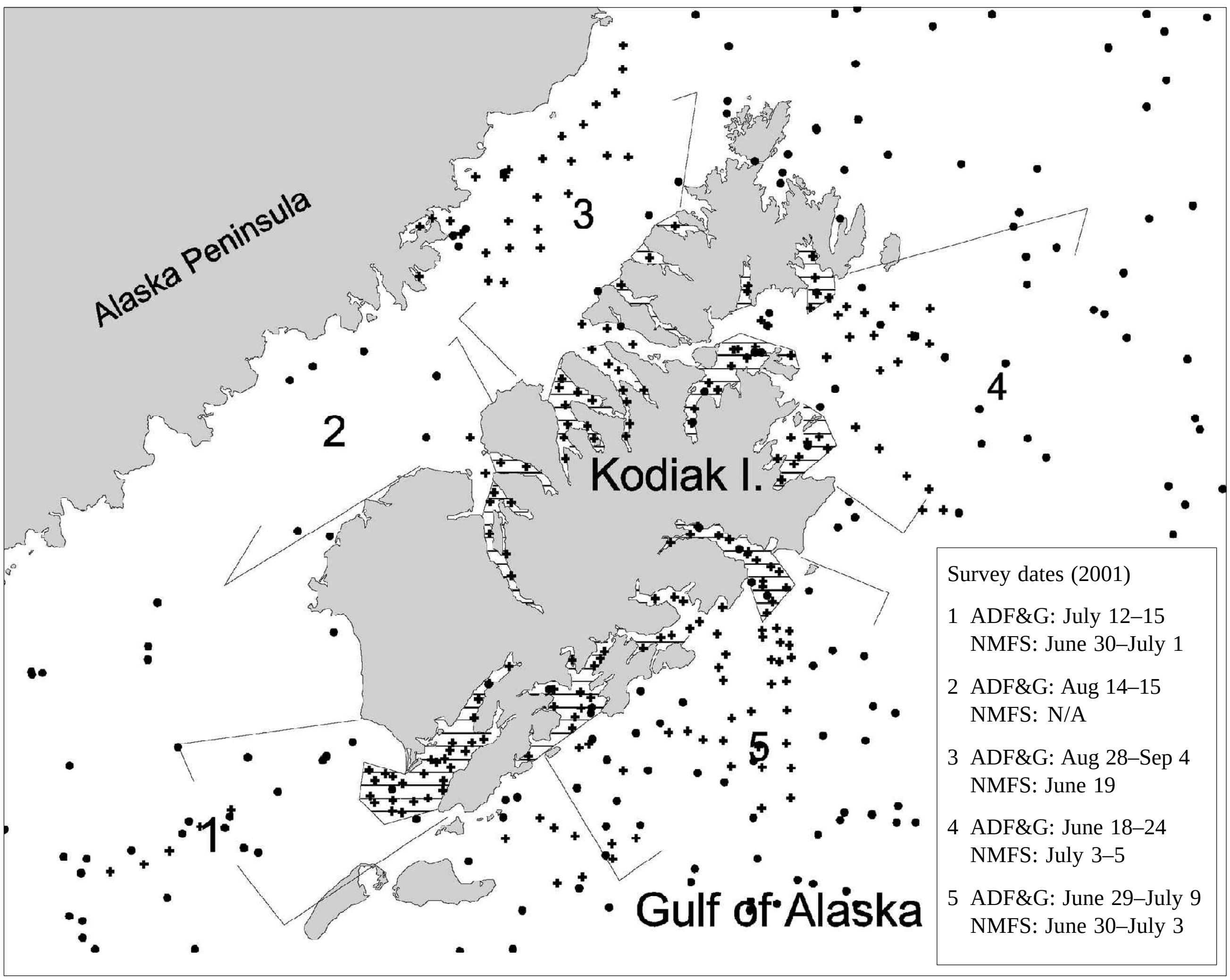

Figure 2. The Kodiak Island bay stratum. The shaded areas define this noncontiguous stratum. The dates indicate when the two surveys sampled different parts of the stratum. The plus signs (+) and dots (•) show the locations of the ADF&G and NMFS trawl stations, respectively.

per for 1999 only include data from strata within the reduced 2001 NMFS survey area so that interannual comparisons with 2001 could be made.

Estimator of integrated estimate of relative abundance and its variance

The estimator of the integrated mean CPUE, Z_{avg}, consists of 2 terms: one for strata with both ADF&G and NMFS hauls and another for strata sampled with NMFS hauls only. The term for strata with mixed NMFS and ADF&G hauls can be expressed as:

$$Z_{avg,h} = \frac{1}{n_h + m_h}\left[\sum_{i=1}^{n_h} x_{ih} + FPC\sum_{j=1}^{m_h} y_{jh}\right],$$

where $Z_{avg,h}$ is the mean integrated CPUE of stratum h; n_h and m_h are the number of hauls conducted by NMFS and ADF&G, respectively, in stratum h; x_{ih} and y_{jh} are the CPUE of the i^{th} and j^{th} hauls conducted by NMFS and ADF&G in stratum h; and the *FPC* is a species-specific fishing power correction factor that accounts for differences in catchability between the different gear types used by the 2 agencies (Table 3; von Szalay and Brown 2001).

Table 3. Fishing power correction factors (FPC) based on a side-by-side trawl comparison experiment conducted in October 1997. The FPC values indicate the fishing power of the NMFS vessel-gear unit relative to that of the ADF&G vessel-gear unit (von Szalay and Brown 2001).

Species	FPC	SD
Walleye pollock	3.84	1.26
Pacific cod	1.72	0.45
Arrowtooth flounder	0.73	0.10
Flathead sole	0.75	0.20

The average CPUE for strata containing only NMFS hauls is expressed as:

$$Z_{avg,h} = \frac{1}{n_h}\sum_{i=1}^{n_h} x_{ih},$$

and the overall average CPUE (Z_{avg}) was estimated by

$$Z_{avg} = \sum_{h=1}^{H} \frac{a_h}{A} z_{avg,h},$$

where A is the total survey area and a_h is the area of stratum h. Combining the 2 mean CPUE terms for

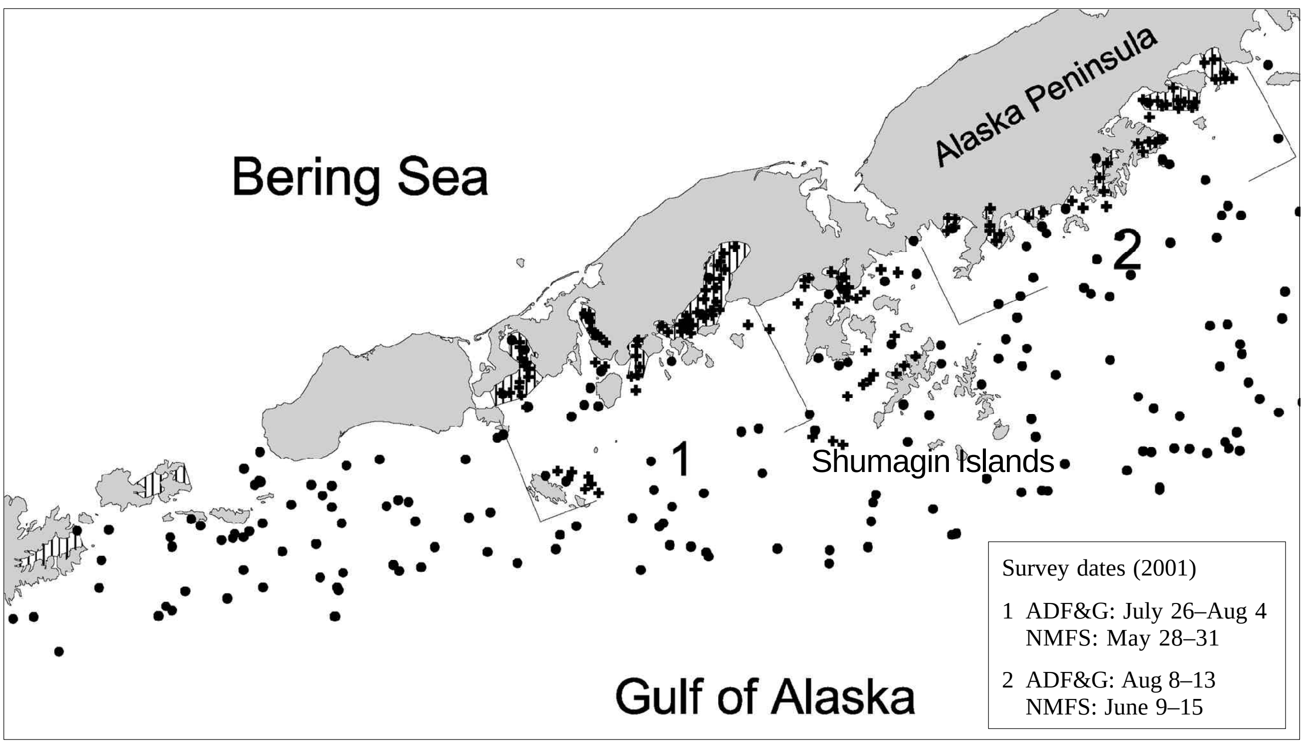

Figure 3. The Alaska Peninsula bay stratum. The shaded areas define this noncontiguous stratum. The dates indicate when the two surveys sampled different parts of the stratum. The plus signs (+) and dots (•) show the locations of the ADF&G and NMFS trawl stations, respectively.

strata with and without ADF&G hauls, and multiplying Z_{avg} by the total survey area, *A*, yields the following expression for the integrated estimate of relative abundance (*B*):

$$B = \sum_{h=1}^{H'} \frac{a_h}{n_h + m_h} \left[\sum_{i=1}^{n_h} x_{ih} + FPC \sum_{j=1}^{m_h} y_{jh} \right] + \sum_{h=H'+1}^{H} \frac{a_h}{n_h} \sum_{i=1}^{n_h} x_{ih}$$

where *H′* is the number of strata with mixed ADF&G and NMFS hauls, and *H* is the total number of strata.

The variance of *B*, obtained by applying the delta method (Seber 1982) to the

$$FPC \sum_{j=1}^{m_h} y_{jh}$$

term of the above equation, can be expressed as:

$$\operatorname{var} B = \sum_{h=1}^{H'} \frac{a_h^2}{(n_h + m_h)^2} [n_h^2 \operatorname{var} \bar{x}_h + m_h^2 \bar{y}_h^2 \operatorname{var} FPC + FPC^2 m_h^2 \operatorname{var} \bar{y}_h] + \sum_{h=H'+1}^{H} a_h^2 \operatorname{var} \bar{x}_h,$$

where $\bar{x}_h$ and $\bar{y}_h$ are the mean values of CPUE obtained by NMFS and ADF&G in stratum *h*. The covariance term of the delta method was excluded because there was no significant correlation between the *FPC* and the sum of the ADF&G CPUEs. Furthermore, there was very little correlation between the *FPC* and the size of the catch ($R^2 = 0.0225$; von Szalay and Brown 2001). The first sum in the variance expression represents the contribution to the total variance from strata with both NMFS and ADF&G hauls; the second sum is the contribution from strata with NMFS hauls only.

RESULTS

The proportional changes in the estimates of relative abundance resulting from integrating the 2 surveys, compared to using only the NMFS data, were generally small (< 2.9%) for all species in both years except for walleye pollock (21.6% increase in 1999 and 81.6% increase in 2001), and flathead sole (10.3% increase in 2001; Table 4). The impacts on the variance estimates from survey integration were also generally modest (< 10%) for all species except walleye pollock in 2001 (84.0% increase) and flathead sole in 1999 (39.6% increase). Because the variance of the estimates of relative abundance increased at a rate less than the square of the mean, the coefficient of variation was lower for the integrated estimate in 1999 and 2001 for walleye pollock but was similar for the other species.

The large increase in the walleye pollock estimate of relative abundance resulting from survey integration reflects the high proportion of the population located in the 2 bay strata and is due to the great discrepancy in the catch rates between the 2 agencies in these strata (Tables 5 and 6). In 1999, the mean walleye pollock CPUE registered by both agencies was considerably greater for the 2 bay strata than in almost all of the other

Table 4. Relative abundance (B) estimates in metric tons (mt) based on the 1999 and 2001 NMFS Gulf of Alaska trawl survey and the integrated ADF&G and NMFS Gulf of Alaska trawl surveys. The integrated relative abundance estimates were generated using the new stratification scheme, which includes the 2 new bay strata mentioned in the text.

	1999							
	B			var B (*mt*²)			CV	
Species	NMFS only	Integrated	% Difference	NMFS only	Integrated	% Difference	NMFS only	Integrated
Walleye pollock	592,046	719,726	22.00	5.4E+10	5.6E+10	3.70	0.39	0.33
Pacific cod	284,706	292,921	2.90	1.8E+09	1.7E+09	-5.60	0.15	0.14
Arrowtooth flounder	971,062	970,962	-0.01	6.2E+09	6.1E+09	-1.60	0.08	0.08
Flathead sole	189,004	187,046	-1.00	5.3E+08	7.4E+08	40.00	0.12	0.15

	2001							
	B			var B (*mt*²)			CV	
Species	NMFS only	Integrated	% Difference	NMFS only	Integrated	% Difference	NMFS only	Integrated
Walleye pollock	208,545	379,077	82.00	3.8E+09	7.0E+09	84.00	0.30	0.22
Pacific cod	256,025	257,188	0.45	2.7E+09	2.7E+09	< 0.10	0.20	0.20
Arrowtooth flounder	1,369,977	1,372,185	0.16	2.3E+10	2.3E+10	< 0.10	0.11	0.11
Flathead sole	153,751	169,643	10.00	3.3E+08	3.0E+08	-9.10	0.12	0.10

strata. The only exception was Stratum 11 which was disproportionately influenced by one extremely large and rare walleye pollock catch, and which, if excluded, would have resulted in a mean CPUE of 5,598 kg/km^2 instead of 22,139 kg/km^2 for that stratum. In 2001 the mean walleye pollock CPUE was negligible in Stratum 11, whereas the means for the two bay strata again dominated most of the other strata. There was a great disparity in the walleye pollock catch rates in the Alaska Peninsula bay stratum between the 2 agencies in 2001. The mean CPUE of ADF&G was approximately 4 times greater than that for NMFS before applying the FPC,

Table 5. Mean CPUE values (kg/km^2) by stratum in 1999. The numbers in parentheses are the corresponding median CPUE values. The ADF&G numbers have not been corrected for fishing power differences.

Bay strata								
	Walleye pollock		Pacific cod		Arrowtooth flounder		Flathead sole	
Stratum	NMFS	ADF&G	NMFS	ADF&G	NMFS	ADF&G	NMFS	ADF&G
Kodiak bay								
Mean CPUE values	7,349	8,028	1,403	1,063	6,397	9,950	6,629	13,305
Median CPUE values	(6,034)	(2,920)	(604)	(607)	(3,554)	(5,700)	(3,765)	(10,300)
AK Peninsula bay								
Mean CPUE values	10,749	10,313	2,192	770	3,039	6,880	7,947	11,652
Median CPUE values	(8,975)	(2,165)	(2,194)	(417)	(2,090)	(4,821)	(6,097)	(9,249)

All other strata[a]				
	Walleye pollock	Pacific cod	Arrowtooth flounder	Flathead sole
Stratum	NMFS	NMFS	NMFS	NMFS
10	2,185 (182)	2,044 (0)	988 (236)	29 (0)
11	22,139 (537)	3,338 (324)	1,582 (470)	822 (56)
12	3,457 (800)	2,904 (2,544)	1,869 (293)	205 (13)
13	3,929 (7)	1,226 (26)	1,626 (249)	800 (150)
20	527 (0)	198 (194)	2,978 (343)	530 (3)
21	75 (57)	1,990 (36)	2,605 (466)	51 (0)
22	1,336 (0)	5,899 (213)	3,516 (140)	319 (0)
30	5,785 (100)	1,437 (608)	5,515 (1,437)	10,224 (107)
31	708 (21)	1,523 (276)	4,985 (520)	28 (0)
32	276 (2)	1,661 (0)	1,745 (18)	421 (0)
33	1,228 (336)	273 (0)	2,820 (1,343)	543 (241)
35	43 (0)	301 (253)	3,858 (2,551)	869 (479)
110	292 (14)	1,049 (817)	5,051 (5,620)	656 (328)
111	977 (209)	1,248 (662)	2,038 (1,134)	30 (0)
112	467 (339)	619 (83)	3,361 (3,250)	874 (667)
120	358 (10)	1,088 (0)	7,434 (4,742)	709 (612)
121	625 (10)	594 (49)	5,189 (1,690)	652 (136)
122	270 (11)	910 (481)	3,338 (2,108)	69 (0)
130	1,495 (7)	614 (371)	15,423 (11,386)	1,439 (977)
131	261 (11)	644 (66)	8,231 (1,754)	458 (0)
132	379 (235)	442 (401)	7,742 (5,787)	548 (101)
133	395 (110)	86 (0)	3,238 (2,594)	462 (41)
134	2,963 (0)	2,260 (0)	6,082 (1,974)	150 (0)
210	1,128 (827)	565 (0)	3,871 (2,595)	12 (7)
220	252 (191)	122 (54)	6,101 (3,923)	204 (145)
221	252 (128)	48 (24)	2,820 (1,604)	[b]
230	342 (290)	76 (15)	1,740 (1,233)	58 (5)
231	346 (16)	124 (0)	7,882 (9,069)	162 (151)
232	667 (667)	185 (185)	7,402 (7,402)	210 (210)
310	202 (84)	[b]	2,875 (1,052)	[b]
320	51 (5)	[b]	2,825 (2,361)	[b]
330	66 (0)	[b]	1,512 (1,353)	5 (0)

[a] These strata surveyed by NMFS only.
[b] No fish of this species were caught in this stratum.

and almost 16 times greater after correcting for fishing power differences (Table 7). The nominal catch rates were similar for the 2 agencies in 1999, but after correcting for fishing power differences the mean ADF&G CPUE was almost 4 times greater than that for NMFS. The results of Wilcoxon's rank-sum tests (Zar 1984) (this nonparametric test was used because of the skewed nature of the CPUE data) indicate that the differences in the mean CPUE values for walleye pollock were statistically significant in both bay strata in 2001 but not significant (α=0.05) in 1999 (Table 7).

Table 6. Mean CPUE values (kg/km^2) by stratum in 2001. The numbers in parentheses are the corresponding median CPUE values. The ADF&G numbers have not been corrected for fishing power differences.

Bay strata								
	Walleye pollock		Pacific cod		Arrowtooth flounder		Flathead sole	
Stratum	NMFS	ADF&G	NMFS	ADF&G	NMFS	ADF&G	NMFS	ADF&G
Kodiak bay								
Mean CPUE values	6,781	4,951	1,298	1,191	9,717	9,540	5,192	14,347
Median CPUE values	(5,039)	(2,656)	(551)	(464)	(924)	(6,534)	(4,249)	(9,798)
AK Peninsula bay								
Mean CPUE values	4,056	16,469	1,405	715	3,116	8,835	7,971	13,749
Median CPUE values	(3,352)	(5,331)	(1,306)	(388)	(1,290)	(5,948)	(7,590)	(11,670)

All other strata[a]								
	Walleye pollock		Pacific cod		Arrowtooth flounder		Flathead sole	
Stratum	NMFS		NMFS		NMFS		NMFS	
10	12	(1)	7,219	(0)	477	(114)	2	(0)
11	225	(0)	2,726	(265)	1,383	(411)	1,019	(69)
12	1,460	(338)	428	(375)	204	(32)	525	(34)
13	4,740	(8)	1,753	(37)	2,015	(308)	627	(21)
20	135	(0)	183	(179)	2,127	(245)	505	(3)
21	29	(22)	219	(4)	1,342	(240)	6	(0)
22	906	(0)	2,133	(77)	4,590	(183)	452	(0)
30	1,332	(23)	827	(350)	3,090	(805)	1,916	(20)31
13	(0)	762	(138)	1,804	(188)	15	(0)	
32	1,150	(8)	286	(0)	863	(9)	601	(0)
33	340	(93)	500	(0)	4,016	(1,912)	695	(309)
35	66	(0)	75	(63)	2,444	(1,616)	430	(237)
110	85	(4)	104	(81)	11,433	(12,720)	2,660	(1,330)
111	89	(19)	545	(289)	6,689	(3,723)	43	(0)
112	636	(461)	141	(19)	9,771	(9,448)	3,037	(2,319)
120	71	(2)	1,811	(0)	11,893	(7,587)	796	(687)
121	869	(14)	2,375	(197)	35,575	(11,583)	1,556	(325)
122	179	(7)	779	(412)	6,388	(4,035)	238	(0)
130	1,974	(9)	1,044	(631)	23,828	(17,591)	1,037	(704)
131	1,120	(48)	1,078	(110)	12,656	(2,697)	92	(0)
132	1,336	(830)	844	(765)	5,160	(3,857)	395	(73)
133	490	(136)	255	(0)	4,914	(3,937)	157	(14)
134	847	(0)	168	(0)	5,003	(1,624)	46	(0)
210	513	(376)	237	(0)	1,845	(1,237)	36	(20)
220	576	(437)	255	(112)	9,982	(6,419)	258	(184)
221	63	(32)	77	(38)	1,617	(920)	5	(0)
230	236	(200)		[b]	1,393	(987)	49	(4)
231	2,451	(116)		[b]	3,135	(3,607)	240	(224)
232	729	(729)	345	(345)	7,550	(7,550)	187	(187)
310	611	(253)		[b]	1,747	(639)	4	(0)
320	26	(0)		[b]	669	(559)		[b]
330	9	(0)		[b]	951	(851)	4	(0)

[a] These strata surveyed by NMFS only.
[b] No fish of this species were caught in this stratum.

Table 7. Mean CPUE values (kg/km^2) and the level of significance between ADF&G and NMFS in the bay strata. The ADF&G numbers have been corrected for fishing power differences.

	1999							
	Walleye pollock		Pacific cod		Arrowtooth flounder		Flathead sole	
Agency	AK Pen.	Kodiak	AK Pen.	Kodiak	AK Pen.	Kodiak	AK Pen.	Kodiak
NMFS	10,749	7,349	2,192	1,403	3,040	6,397	7,947	6,629
ADF&G	39,601	30,826	1,325	1,829	5,023	7,263	8,739	9,979
P	0.610	0.027	0.047	0.520	0.360	0.750	0.840	0.140
	2001							
	Walleye pollock		Pacific cod		Arrowtooth flounder		Flathead sole	
Agency	AK Pen.	Kodiak	AK Pen.	Kodiak	AK Pen.	Kodiak	AK Pen.	Kodiak
NMFS	4,056	6,781	1,405	1,298	3,116	9,717	7,971	5,192
ADF&G	63,241	19,014	1,230	2,049	6,449	6,964	10,312	10,760
P	0.009	< 0.010	0.067	0.920	0.074	0.110	0.310	0.020

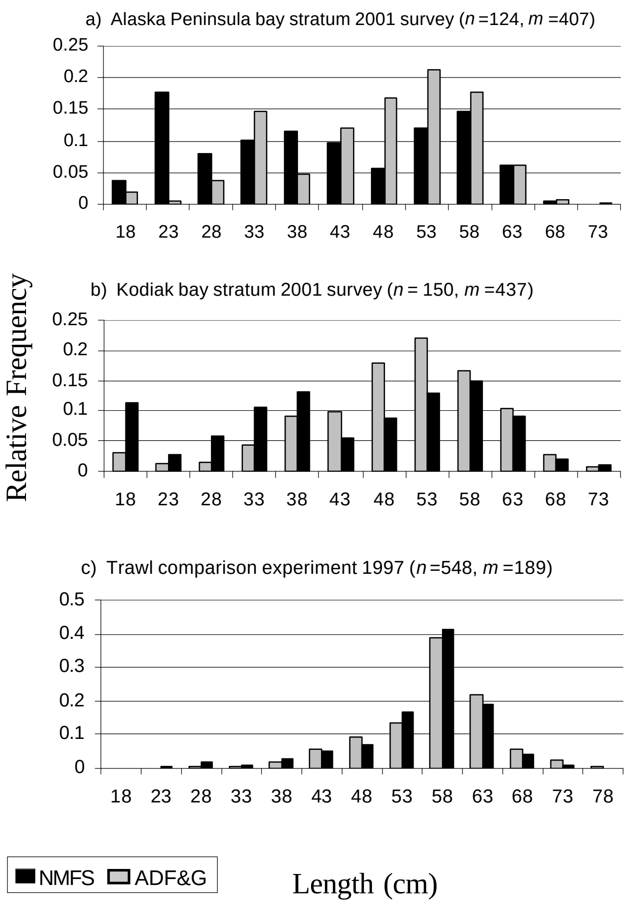

Figure 4. Relative length-frequency distributions of walleye pollock caught by NMFS and ADF&G. Sample sizes for NMFS (*n*) and ADF&G (*m*) are shown in each graph. a) Alaska Peninsula bay stratum, 2001 surveys b) Kodiak Island bay stratum, 2001 surveys c) Trawl comparison experiment, October 1997.

A Kolmogorov-Smirnov goodness-of-fit test (Zar 1984) indicated that the relative length-frequency distributions of walleye pollock greater than 17 cm were significantly different ($P < 0.001$) for the 2 agencies in both of the bay strata in 2001. The mean fork lengths of walleye pollock caught by NMFS in the Alaska Peninsula and Kodiak Island bay strata were 41.6 and 44.4 cm, respectively. The corresponding means for ADF&G were 47.4 and 50.1 cm. The discrepancy in the distributions was particularly noticeable in the Alaska Peninsula bay stratum, which ADF&G sampled approximately 2 months later than NMFS (Figures 3 and 4).

DISCUSSION

To achieve minimum variance (Cochran 1965), the optimal sampling strategy calls for the allocation of greater effort in strata that are larger, more variable or contain higher density. However, because the NMFS survey considers many species simultaneously, sampling for multiple species may yield estimates with considerably less precision than could be achieved in a single-species survey. Walleye pollock is an example of such a species. Data from the ADF&G demersal trawl survey indicate that a large proportion of the Gulf of Alaska walleye pollock biomass was concentrated in a relatively small area of bays around Kodiak Island and along the Alaska Peninsula (Urban 1997). According to data from the 2001 NMFS and ADF&G surveys, as much as 27%–52% of the Gulf of Alaska walleye pollock biomass may be concentrated in a number of bays around Kodiak Island and the Alaska Peninsula, which comprise only 2.6% of the NMFS Gulf of Alaska survey area. Because of this high concentration in a relatively small area there is a great potential for reducing the variance of the NMFS walleye pollock estimate of relative abundance by substantially increasing the sampling density in the bays. This can be accomplished by incorporating the AFD&G survey data, which is highly concentrated in the bays.

The large increase in the integrated walleye pollock estimate of relative abundance in 2001, compared to the estimate based exclusively on the NMFS survey data, was unexpected. Although not as dramatic as in 2001, incorporating the ADF&G data in 1999 also resulted in a substantial increase in the walleye pollock estimate of relative abundance. In stratified random sampling, the allocation of sampling effort among the strata should affect the variance of the estimate of relative abundance but not the abundance estimate itself if the populations sampled under the different allocation schemes are identical. To determine whether the observed increases were statistically significant, I tested the null hypothesis of equal mean CPUE for ADF&G and NMFS in the 2 bay strata after correcting for fishing power differences. The difference in mean CPUE was significant in both strata in 2001 (Wilcoxon rank-sum test; $P < 0.01$) and in the Kodiak Island bay stratum in 1999 ($P = 0.027$) but not in the Alaska Peninsula bay stratum ($P = 0.610$). The magnitude of the difference for the Alaska Peninsula bay stratum in 2001 was sufficiently great (Table 7) to account for approximately 80% of the discrepancy in the relative abundance estimate between the 2 sampling schemes. Because the differences in the walleye pollock estimates were both large and statistically significant in 2001 as well as in one of the strata in 1999, some process other than random sampling error must have occurred.

The experimentally determined FPC by von Szalay and Brown (2001) was assumed to be temporally and spatially invariable when the 2 survey data sets were combined. The FPC for walleye pollock may be a function of depth and bottom type because the vertical net opening and the bottom-tending abilities of the NMFS and ADF&G trawls may respond differently to changes in these parameters. Thus, the value of the FPC appropriate for each time and place may differ from the experimentally determined value due to differences in the survey and experimental conditions. This is not a satisfactory explanation for the observed discrepancy in mean CPUE here because the ranges of both depth and bottom type in the 2 bay strata were similar to those in the area in which the FPC trawl comparison experiment was conducted (von Szalay and Brown 2001).

Nevertheless, there is strong evidence in the survey data against a temporally or spatially constant FPC for walleye pollock. The mean CPUE of the ADF&G survey in the Alaska Peninsula bay stratum was approximately 4 times greater than the mean CPUE of the NMFS survey in 2001 before correcting for fishing power differences. This implies an FPC of 0.25, using the convention of stating the efficiency of the NMFS vessel-gear unit as a fraction of the ADF&G vessel-gear unit. In 1999, the mean walleye pollock CPUE for the 2 agencies were almost identical in the Alaska Peninsula bay stratum, implying an FPC of approximately 1. Both of these findings are in sharp contrast to the experimentally determined FPC of 3.84 for walleye pollock. Because the vertical opening of the NMFS net is approximately 3.5 times greater than the ADF&G net and the horizontal spreads are similar, the magnitude of the experimentally observed FPC for walleye pollock may be explained in terms of the difference in the volume swept between the 2 vessel-gear units. This argument can only be used for semi-demersal species such as walleye pollock if they are evenly distributed throughout the bottom 7 m (approximate average height of the NMFS net) of the water column. For a more strictly demersal species, such as arrowtooth flounder, the greater height of the NMFS net does not translate into higher efficiency (Table 3).

The inconsistency in the walleye pollock FPC between the trawl comparison experiment and the surveys may be due to the time lag between the 2 surveys rather than to physical differences such as depth and bottom type between the experimental and survey areas. This may be especially true in the Alaska Peninsula bay stratum which NMFS surveyed in late May and early June, approximately two months before ADF&G (Figure 3). For a semi-demersal and highly mobile species such as walleye pollock, it is possible that the fish underwent substantial vertical or horizontal migrations during this time interval. The walleye pollock length-frequency distributions, which indicate that NMFS and ADF&G sampled different populations (Figure 4), support this hypothesis ($P<0.001$, Kolmogorov-Smirnov goodness-of-fit test). Furthermore, because no such difference in length-frequency distributions was observed ($P = 0.700$) in the side-by-side trawl comparison experiment to estimate the FPC for the ADF&G vessel (von Szalay and Brown 2001), the available evidence indicates that the difference in length-frequency distributions observed for the surveys is not due to differences in gear-selectivity but is perhaps due to the difference in the population at the time of sampling.

A temporal change in the availability of walleye pollock to the 2 trawl surveys due to vertical movement could account for the apparent difference in CPUE. Although diurnal vertical movement of walleye pollock is well documented (e.g., Abe et al. 1999; Brodeur and Wilson 1996; Tang et al. 1995), seasonal patterns of vertical migratory behavior have not been examined. However, there is considerable anecdotal evidence indicating seasonal vertical movements of walleye pollock associated with spawning and feeding behavior. During NMFS acoustic stock assessment surveys of the spawning population in Shelikof Strait and the Shumagin Islands in late February 1994 and 1995, adult walleye pollock were densely congregated near the bottom prior to spawning. Shortly after spawning, however, the fish dispersed and migrated up in the water column (C. Wilson, Alaska Fisheries Science Center, Seattle, personal communication). Adult walleye pollock have in some years also been observed engaging in feeding frenzies near the surface in bays around Kodiak Island in late May, resulting in walleye pollock catches of up to a metric ton in salmon purse seines (J. Stintson, Alaska Dragger Coalition, Kodiak, personal communication). Moreover, while taking acoustic measurements of walleye pollock and macrozooplankton in Prince William Sound, G. Thomas (Prince William Sound Science Center, Cordova, personal communication) observed adult walleye pollock co-occurring with the macrozooplankton in the surface 50 m in the early spring when the macrozooplankton underwent a seasonal ontogenetic migration to the surface to feed and reproduce. In late spring the vertical distribution of the walleye pollock and macrozooplankton structures again mimicked each other as the macrozooplankton underwent their late spring reverse vertical migration.

This anecdotal evidence indicates that adult walleye pollock spend a substantial amount of time off the bottom at least in some areas and during certain times of the year. A large portion of the Gulf of Alaska walleye pollock population, located in the bays around the Alaska Peninsula, may therefore have been unavailable to NMFS in late May and early June, but became available to ADF&G later in the season because of seasonal vertical migration. This behavior, which changes the availability of the fish to the trawl gear during the course of the survey, turns the FPC into an unpredictable function of the time lag between the two surveys and renders the integration of walleye pollock survey data invalid. Cotter (2001) recently identified this weakness of extrapolating the vessel-gear unit effect observed during a side-by-side trawl comparison experiment to a whole survey region and season. While it is not appropriate to do this extrapolation for highly mobile and semi-demersal species such as walleye pollock, it may be possible for other less mobile species. For example, there was no statistically significant difference in the FPC-adjusted mean CPUEs for arrowtooth flounder in either 1999 or 2001 (Table 7). However, because the variance was not reduced much or consistently for any of the species considered in this study, there is no obvious benefit in combining the 2 surveys.

While none of the 3 NMFS survey vessels used during the 1999 and 2001 surveys were the same as the one used for the 1997 calibration study (F/V *Peggy Jo*), they were all assumed to have the same fishing power as the F/V *Peggy Jo* because both gear and operational procedures were standardized in both studies. Because of the substantial difference in horsepower between these vessels and the F/V *Peggy Jo* (approximately 1,900 hp for the 1999/2001 survey vessels vs. approximately 900 hp for the F/V *Peggy Jo*), it is possible that the FPC values used in the integrated calculations of relative abundance (Table 3) understate the true fishing power differences between the NMFS and ADF&G vessels. This would result in an even greater discrepancy in the relative abundance estimates for walleye pollock between the NMFS-only and integrated surveys.

In conclusion, in order to make the integration of the CPUE data from the 2 surveys valid for a highly migratory species such as walleye pollock, it is imperative that the 2 surveys be coordinated temporally in the bay strata. This would eliminate the apparent time-dependence on the fishing power correction factor, but would not guarantee a significantly reduced variance of the estimate of relative abundance. Another study in which the 2 surveys are temporally coordinated would be necessary to determine this. Alternatively, the Alaska Fisheries Science Center may consider increasing its survey effort in the high-abundance bay strata, which has the advantage of not relying on a fishing power correction, thus reducing the variance even further than the combined survey approach. For less migratory species, such as the other 3 species considered in this study, it may not be as important that the 2 surveys be temporally synchronized in order to integrate them. However, this study provided no evidence that the variance of the integrated estimate of relative abundance would be significantly reduced, suggesting that the current NMFS sample sizes may be sufficient for these species.

LITERATURE CITED

Abe, K., K. Iida, and T. Mukai. 1999. Diurnal changes of area backscattering coefficient during the acoustic surveys of walleye pollock. Nippon Suisan Gakkaishi 65(2):252–259.

Brodeur, R. D., and M. T. Wilson. 1996. A review of the distribution, ecology, and population dynamics of age-0 walleye pollock in the Gulf of Alaska. Fisheries Oceanography 5(Supplement 1):148–166.

Cochran, W. G. 1965. Sampling Techniques, 2nd edition. Wiley, New York.

Cotter, A. J. R. 2001. Intercalibration of North Sea international bottom trawl surveys by fitting year-class curves. ICES Journal of Marine Science 58:622–632.

Engås, A., and O. R. Godø. 1989. The effect of different sweep lengths on the length distribution of bottom-sampling trawl catches. Journal du Conseil. Conseil International pour l'Exploration de la Mer 45(3):263–268.

Fournier, D. 2001. AD Model Builder. Otter Research, Naniamo, B.C.

Godø, O. R. 1998. What can technology offer the future fisheries scientist–possibilities for obtaining better estimates of stock assessment by direct observations. Journal of Northwest Atlantic fishery science 23:105–131.

Martin, M. H. 1997. Data report: 1996 Gulf of Alaska bottom trawl survey. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-82.

Nicholson, M. D., T. K. Stokes, and A. B. Thompson. 1991. The interaction between fish distribution, survey design, and analysis. International Council for the Exploration of the Sea Council Meeting 1991/D:11.

Pola, N. B. 1985. Numerical simulation of fish migrations in the Eastern Bering Sea. Ecological Modeling 29:327–351.

Radchenko, V. I., and Y. I. Sobolevskiy. 1993. Seasonal spatial distribution dynamics of walleye pollock, *Theragra chalcogramma*, in the Bering Sea. Journal of Ichthyology 33(2):63–76.

Schultz, N., and W. Grygiel. 1984. First results of intercalibration of young fish trawls used in the Baltic Sea by GDR and Poland. International Council for the Exploration of the Sea Council Meeting 1984/J:6.

Seber, G. A. F. 1982. The estimation of animal abundance, 2nd edition. The Blackburn Press, Griffin, London.

Tang, Q., W. Wang, Y. Chen, F. Li, X. Jin, X. Zhao, J. Chen, and F. Dai. 1995. Stock assessment of walleye pollock in the North Pacific Ocean by acoustic survey. Journal of Fisheries of China/Shuichan Xuebao 19(1):8–20.

Urban, D. 1997. Bottom trawl survey of crab and groundfish: Kodiak Island, Chignik, and South Peninsula Areas, 1996. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 4K97-58, Kodiak.

Wespestad, V., J. N. Ianelli, L. Fritz, T. Honkalehto, and G. Walters. 1996. Bering Sea-Aleutian Islands walleye pollock assessment for 1997. Section I, pages 51–73 *in* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pacific Fisheries Management Council, Anchorage, Alaska.

von Szalay, P. G., and E. Brown. 2001. Trawl comparisons of fishing power differences and their applicability to National Marine Fisheries Service and Alaska Department of Fish and Game trawl survey gear. Alaska Fishery Research Bulletin 8(2):85–95.

Wilderbuer, T. K., R. F. Kappenman, and D. R. Gunderson. 1998. Analysis of fishing power correction factor estimates from a trawl comparison experiment. North American Journal of Fisheries Management 18:11–18.

Worton, C. 2001. Bottom trawl survey of crab and groundfish: Kodiak Island, Chignik, South Alaska Peninsula, and Eastern Aleutian Island Areas, 2000. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K01-53, Kodiak.

Zar, J. H. 1984. Biostatistical Analysis, 2nd edition. Prentice-Hall, Englewoods Cliffs, New Jersey.