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Assessing the Efficiency of the Groundfish Survey Design for the Scotian Shelf Summer Trawl Surveys -- 1980-1990

by

Stephen J. Smith
Marine Fish Division
Bedford Institute of Oceanography
Dartmouth, Nova Scotia
B2Y 4A2

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Abstract

Abundance estimates from groundfish trawl surveys are an important element in the evaluation of stock status. The precision of these estimates are a function of how well the stratified random design matches the distribution of the fish. In this study the current stratification scheme is evaluated for the major groundfish stocks monitored on the Scotia shelf in the July survey. The greatest gains in precision from the design were observed for the two haddock stocks, while gain in precision were less so for the cod stocks and the pollock stock. Overall the results appeared to reflect differences in the distributional behaviour of the species studied. That is, haddock appear to be more constant in the area that they are found in than either cod and pollock.

Résumé

Les estimations d'abondance provenant des campagnes d'évaluation du poisson de fond au chalut sont un élément important de l'évaluation des stocks. La précision de ces estimations détermine dans quelle mesure la formule d'échantillonnage aléatoire stratifiée correspond à la distribution du poisson. Dans la présente étude, on évalue la stratification des principaux stocks de poisson de fond observés sur la plate-forme néo-écossaise lors de la campagne d'évaluation de juillet. C'est à l'égard des stocks d'aiglefin que l'on a constaté les plus gros gains en matière de précision. Ces gains étaient moindres pour les stocks de morue et de goberge. Dans l'ensemble, les résultats obtenus semblent refléter les différences existant dans les habitudes de distribution des espèces étudiées. Ainsi, l'aiglefin semble être présent de façon plus constante que soit la morue ou la goberge dans la zone où il a été observé.

Introduction

One of the main benefits of using stratified random designs for trawl surveys is the potential to increase the precision of the abundance estimates over what would have been obtained had only simple random sampling been used. This gain in precision is a function of how well the strata boundaries match the distribution of the fish being surveyed and if the sets have been allocated in proportion to the variability of the strata. Gavaris and Smith (1987) evaluated the summer surveys for 4VsW cod (ages 5–12) for 1970 to 1984 and showed that the gain due to the strata boundaries was minimal while the allocation of sets to strata could result in estimate of abundance from the stratified random design being much less precise than if simple random sampling had been used. Smith and Gavaris (unpublished) redesigned the March survey for 4VsW cod by using fewer, larger strata based on historical distribution patterns. Results of this study showed that the main advantage of the larger strata was the increased flexibility for set to strata allocation strategies. There appeared to be very little gain from the strata boundaries themselves.

In this paper I extend the evaluation of the current stratification scheme for the summer survey to the major groundfish stocks on the Scotian Shelf (i.e. Haddock stocks: 4TVW and 4X; Cod stocks: 4Vn, 4VsW and 4X; and 4VWX+5 Pollock) for the period 1980–1990. As in Gavaris and Smith (1987), the precision of the stratified random mean abundance estimate is evaluated with respect to that which would have been obtained had a simple random sample design been used. The gain or loss in precision is categorized into its component parts: allocation and stratification.

Methods

Within the context of design-based theory, methods of increasing the precision of an estimate always involve the sampling plan. One sampling plan is said to give a more efficient estimate than another if the associated variance is smaller for the same total sample size. Gavaris and Smith (1987) evaluated the efficiency of the stratified random design for groundfish surveys by comparing the resultant variance to that which would have been obtained if a simple random sample design had been used. For our purposes this is the difference between $\mathrm{V}(\bar{y}_R)$, the variance of the sample mean from simple random sampling and the variance of the sample mean from stratified random sampling $\mathrm{V}(\bar{y}_{st})$. This difference can be estimated by (Sukhatme and Sukhatme 1970)

$$\widehat{\mathrm{V}}(\bar{y}_R) - \widehat{\mathrm{V}}(\bar{y}_{st}) = \sum_{h=1}^{L} \left(\frac{1}{n} - \frac{W_h}{n_h}\right) W_h\, s_h^2 + \left(\frac{N-n}{n(N-1)}\right) \left(\sum_{h=1}^{L} W_h\, (\bar{y}_h - \bar{y}_{st})^2 - \sum_{h=1}^{L} W_h\, (1 - W_h)\, \frac{s_h^2}{n_h}\right), \quad (1)$$

where,

$$
\begin{aligned}
n_h &= \text{the number of hauls or sets in stratum } h \ (h = 1, \ldots, L), \\
n &= \textstyle\sum_{h=1}^{L} n_h, \\
N_h &= \text{the total number of possible sets in stratum } h, \\
N &= \textstyle\sum_{h=1}^{L} N_h, \\
W_h &= N_h/N, \\
\bar{y}_h &= \text{the estimated mean abundance in stratum } h, \\
\bar{y}_{st} &= \textstyle\sum_{h=1}^{L} W_h \, \bar{y}_h, \text{ the estimated stratified mean,} \\
\text{and} \quad s_h^2 &= \text{the estimated variance in stratum } h
\end{aligned}
$$

The first term on the right side of equation (1) above is referred to as the *allocation* component because it can be negative, zero or positive depending upon whether the allocation of sets to strata is arbitrary, proportional to strata sizes or proportional to strata variances. The second term on the right can be greater than or equal to zero according to whether the stratification was or was not successful in increasing the variance between strata over the variance within strata. This term is called the *strata* component. As in Gavaris and Smith (1987) the efficiency of the stratified random design is expressed as the relative efficiency,

$$
\mathrm{RE} = \frac{\left(\widehat{\mathrm{V}}\left(\bar{y}_R\right) - \widehat{\mathrm{V}}\left(\bar{y}_{st}\right)\right) \times 100}{\widehat{\mathrm{V}}\left(\bar{y}_R\right)}, \tag{2}
$$

where the variance of the mean of a simple random sampling design is estimated from the data collected from a stratified random design by

$$
\begin{aligned}
\widehat{\mathrm{V}}\left(\bar{y}_R\right) = &\left(\frac{N-n}{nN}\right) \sum_{h=1}^{L} W_h \, s_h^2 \\
&+ \left(\frac{N-n}{n(N-1)}\right) \left(\sum_{h=1}^{L} W_h \, \left(\bar{y}_h - \bar{y}_{st}\right)^2 - \sum_{h=1}^{L} W_h \, \left(1 - W_h\right) \frac{s_h^2}{n_h}\right)
\end{aligned} \tag{3}
$$

The percentage gain or loss in efficiency can be estimated individually for the allocation and strata components.

The age ranges chosen for each stock in the analyses are those suggested by the scientists responsible for their respective stocks as being important for the VPA/ADAPT analyses or for general trends in abundance.

Results

The strata map for the summer surveys on the Scotian Shelf is attached as Appendix I. The results for each of the stocks are presented in the tables and figures below. In each figure, the gain (or loss) in precision for each stock is presented relative to the variance from simple random sampling (SRS) as per equation 3. The allocation component and stratification components are plotted separately on the bar charts. The sum of these two components gives the total gain (sum>0) or loss (sum<0) in precision of the stratified random design. The vertical axis on the right side presents the scale for the coefficient of variation (CV) for the mean from SRS. This CV was calculated using the standard error instead of the standard deviation. As such this quantity represents the level of variation, given the same sample size, that the stratified design was supposed to improve upon.

The tables presented for each stock are used to characterize the temporal and spatial pattern of the within strata variation. Variation in this case is expressed as $W_h s_h / \sum W_h s_h$ and given as a percentage. In the population form (i.e. substituting S_h for s_h), this quantity is used to assign sets to strata to obtain that allocation which gives the maximum gain in precision. This estimate of percent variation was calculated for each stratum, each year and then ordered from largest to smallest within a year. The columns under **Percent of Variation** in the tables give the quartile bins for the percent variation. For example, in Table 1 and the row labelled 1981, strata 55 and 63 are in the bin labelled ≤ 50. This indicates that the largest percent variation occurred in stratum 55 and was > 25 but $< 50\%$ of the total variation over all strata. Stratum 63 had the next largest percent variation and the sum of strata 55 and 63 gave a cumulative percent variation which was also $\leq 50\%$. The addition of the third largest percent variation (stratum 65) gave a sum which was $> 50\%$ but $\leq 75\%$. The procedure was continued until the sum exceeded 75% and actual sum is given in the column labelled **Total Var. %**. The percent contribution of these strata to the stratified mean number is presented in the rightmost column. Finally, a number of strata in the tables have an asterisk assigned to them which indicate *stratum with negative gain*. These refer to the sign of the term $(1/n - W_h/n_h)\,W_h$ from the allocation term in equation 1. This term will be negative if the number of sets assigned to stratum h is less than expected for proportional allocation, i.e. $n_h < nN_h/N$. The asterisks flag strata which would contribute to a low or negative allocation component in that year.

Haddock

The survey estimates for the 4TVW haddock stock are calculated from catches in strata in the 4VW area only (strata 40–66; Appendix I) (K. Zwanenburg, pers. com.). The results in Figure 1 show that over the years used in this analysis the total relative efficiency of the stratified random design was always greater that zero. The relative efficiency ranged from a low in 1982 of 8.03% to 65.9% in 1989. With the exception of 1982 the relative efficiency for 4TVW haddock exceeded 23% in the remaining years.

The allocation component was less than zero for 1982 and 1985, and negligible in 1986. The stratification component dominated for most years with the exception of 1980 and 1988.

The CV for SRS ranged between 15 and 50% over the time period. The design resulted in a range of CVs for the stratified random mean of 15 to 39.5%. There doesn't appear to be any relationship between the gain in efficiency and the trend in SRS CV.

Seven or fewer strata (out of 27) account for 77–81% of the total variation and 50–80% of the estimate of the mean number in the survey (Table 1). The spatial distribution of

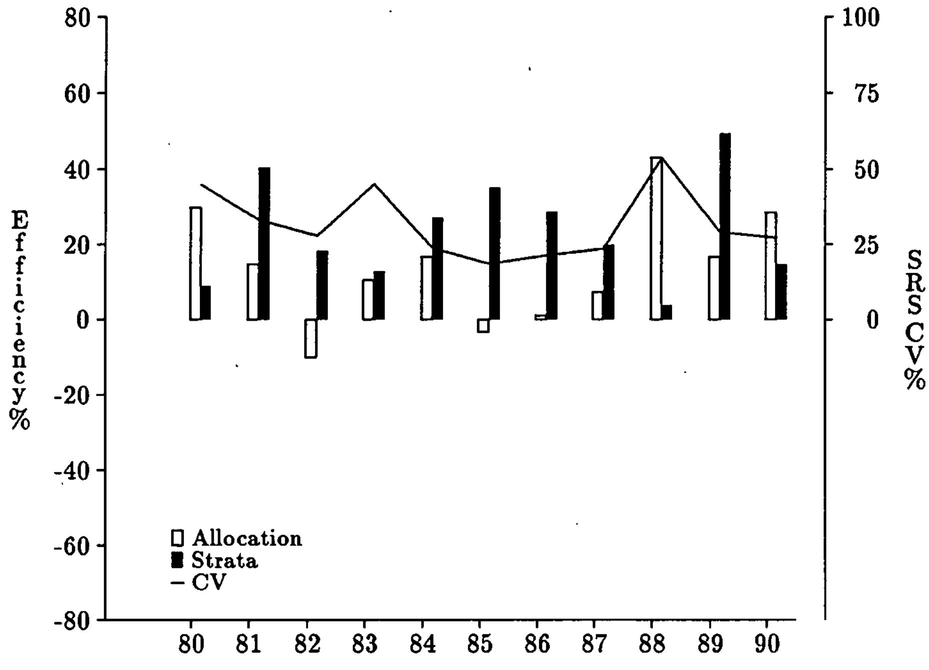

Fig. 1. Relative efficiency results for 4TVW haddock (ages 3–6)

this variation appears to be quite constant over time as there are only nine different strata involved over the 11 year period. Stratum 55 contains the largest proportion for eight years and is in the top three for the remaining years. Note that the two years with negative allocation components in Figure 1 are associated with years where negative gain strata are present and the proportions of variation associated with stratum 55 are small.

Table 1. Distribution of variation for 4TVW haddock

Year	Percent of Variation				Total Var. %	% Mean No.
	≤ 25	≤ 50	≤ 75	≤ 100		
80			55,63	56	81	71
81		55,63	65,60	64	77	78
82		47	64,55	62*	81	70
83			55	47	77	58
84		55,54	64,62*,47	58	77	66
85	55	62*,65*	56,59*,64	47	77	80
86		55	64,48,59*,56	65*	79	76
87		55,47	65	56	77	75
88			56,59*,65	55	79	72
89		56	65	55	77	50
90		56	59*,55	64	78	76

** stratum with negative gain*

The general indications are that the distribution of 4TVW haddock, as indicated by the number of strata associated with the major part of the total variation, has varied in extent over time but not in general location. Strata 55, 56, 62, 63 64 and 65 which cover the Sable Island, Middle and Western Bank areas appear to be the focus of the distribution. Strata 47 and 48, on top of Banquereau Bank were more prominent in the 1982–87 period when the estimated mean number overall strata was higher than it has been in the last three years.

The results for 4X haddock (Figure 2) are similar to those above with the stratified random design being more efficient than SRS for all years, except for 1985. Overall, the range of relative efficiencies for this survey is greater than for that for 4TVW with positive values of 12.8 (1986) to 72.2 % (1990). The result of −35.4% for 1985 is due to the large negative allocation component that year.

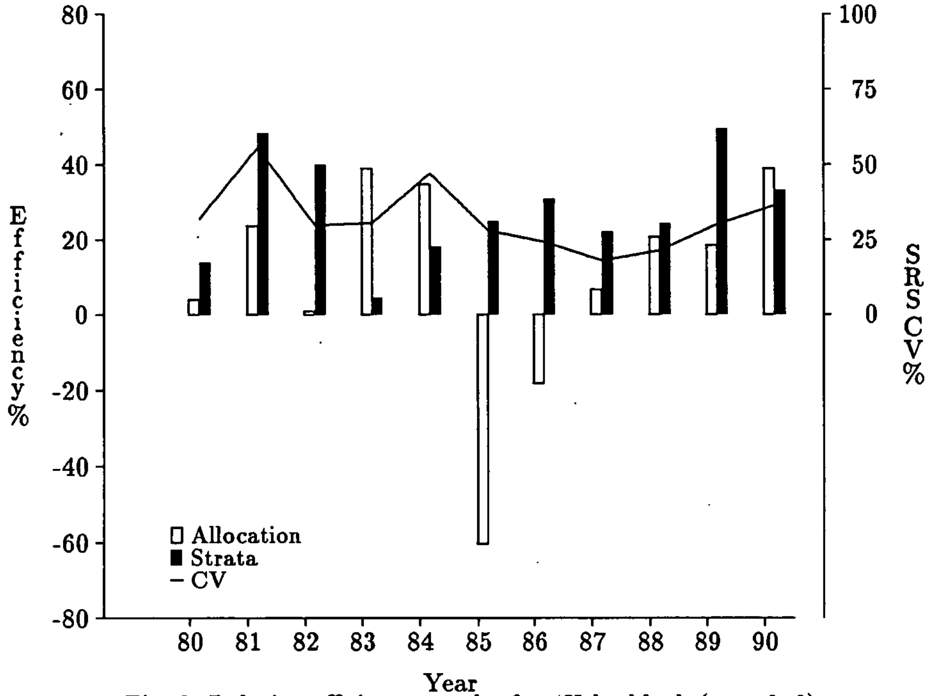

Fig. 2. Relative efficiency results for 4X haddock (ages 2–8)

The SRS CV ranges from 17 to 55.6% while the stratified design results in the CV for the stratified mean ranging from 15 to 32.6%. It should be noted here that although there are fewer strata (18) in this survey than in the 4TVW (27) the stratified design in 4X is more efficient with approximately one half the number of sets that are used in 4TVW.

The spatial distribution of the percent variation (Table 2) for this stock is also similar to 4TVW in that the major part of it is confined to just a few strata (2–6) and the number of distinct strata involved (9) changes little over time. The abundance estimates for the 4X stock are calculated using catches from strata 70–85 plus strata 90, 91 & 95 which are located on the Nova Scotia side of the Bay of Fundy (Frank et al. 1990). Catches from the strata on the New Brunswick side of the Bay of Fundy (92, 93 & 94) are assumed to consist of haddock from the Gulf of Maine stock. Stratum 90 which is a relatively small stratum on the Fundy side of Southwest Nova Scotia appears to be the dominant stratum with respect to variation and mean abundance (Frank et al., 1990; Table 10). This stratum is in the top three with respect to percent variation for all years with the exception of 1985 and 1986, when this stratum was not important at all. Note that these were the same two years that the allocation component was less than zero.

With respect the spatial distribution of percent variation, the haddock in 4X appear to concentrate in the nearshore area of Southwest Nova from Digby Neck (stratum 90) to Browns Bank (stratum 80) with secondary areas of concentration in the area surrounding

Table 2. Distribution of variation for 4X haddock

Year	Percent of Variation				Total	% Mean
	≤ 25	≤ 50	≤ 75	≤ 100	Var. %	No.
80		72*	90,81*	80	80	72
81			90	72*	79	75
82		81*	90	72*	77	68
83		90	76*,80,91		75	53
84			90,77*,81*		75	69
85			76*,85*,72*		76	65
86		81*	85*,70*	72*	76	60
87	76*	81,90	77,73	72	76	70
88	90	81	80,82,77	76*	79	70
89	80	90	72,81	77	81	80
90	80		90,81	77	76	71

** stratum with negative gain*

Roseway Bank (stratum 76) and the midwater depths (51–100 fathoms; stratum 72) east of LaHave Bank. The distribution of haddock from stratum 90 out to stratum 80 and east to 76 raises questions about the possible concentrations in the untrawlable and hence unsurveyed area between stratum 90 and stratum 81.

Cod

The survey abundance estimates for the 4Vn cod stock (May–December) are only based upon three strata (40–42) and between 9–17 sets each year (Smith and Lambert 1989). As a consequence, the results are expected to be more variable than those given above for haddock. Overall the stratified design does not seem to have provided any consistent advantage for 4Vn cod (Figure 3). The total relative efficiency ranges from −72.2 to 79.1% and the allocation and stratification components vary widely over years. In general the allocation of sets never appears to match the pattern of variation.

The three strata in this survey correspond to the three depth ranges used in the entire Scotian Shelf survey, i.e. stratum 40 $>$ 100 fms.; 50 fms. $<$ stratum 41 $\leq$ 100 fms.; and stratum 42 $\leq$ 50 fms.. The distribution of the fish, as inferred from the percent variation (Table 3), appears to either be in the shallow stratum (42) or the midwater stratum (41) with only occasional concentrations in the deeper water $>$ 100 fms.

The changing pattern of strata with negative gains in Table 3 reflects the change in numbers and locations of sets allocated to this portion of the Scotian Shelf survey over time. Obviously these changes did not result in optimal allocations of sets to strata.

The survey estimates for 4VsW cod are based upon catches from strata 43–66 (Fanning and MacEachern 1990). The efficiency results for this cod stock have already been presented for ages 5–12 for 1970–1984 in Gavaris and Smith (1987) and for 1979–1990 in Smith and Gavaris (unpublished). The disappointing results from this survey motivated the experiments to try alternate stratification and allocation patterns for the March survey for this stock.

The total efficiency for ages 4-9 (Figure 4) ranges from −67.7 to 47.7% with only four out of the 11 years being above zero. Sets are rarely allocated to the more variable strata and the stratification component is usually weak or nonexistent. Despite the poor performance, the range of CVs for the stratified mean is marginally less (22.5–59.2%) than it is for SRS CV (21–65.5%).

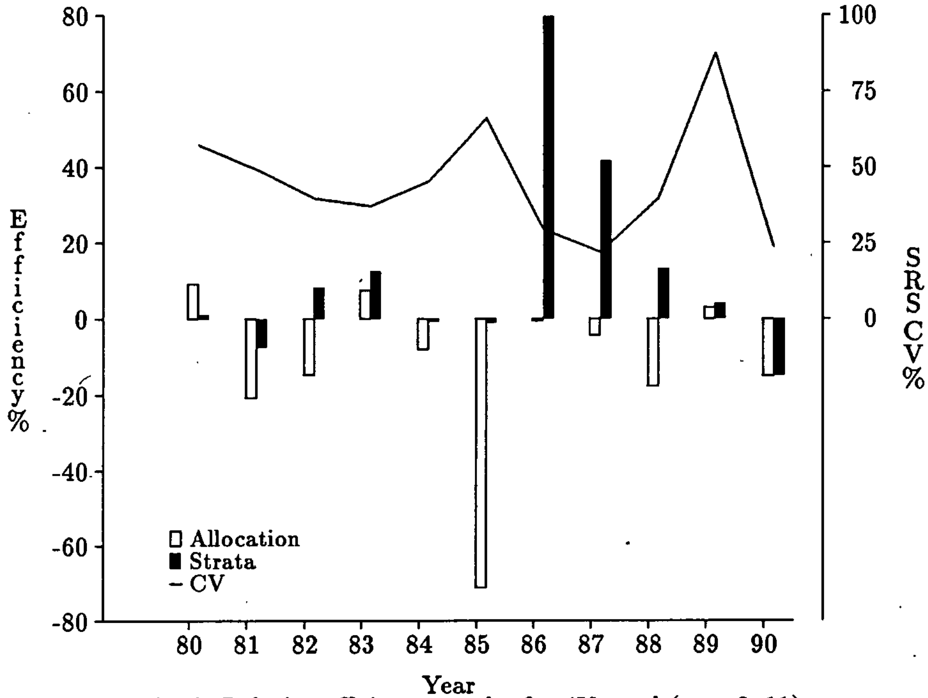

Fig. 3. Relative efficiency results for 4Vn cod (ages 3–11)

Table 3. Distribution of variation for 4Vn cod

Year	Percent of Variation				Total Var. %	% Mean No.
	≤ 25	≤ 50	≤ 75	≤ 100		
80				41	81	65
81			42*	40	96	90
82			42*	41	95	96
83				41	96	54
84			41	42*	99	98
85				42*	94	91
86			41	42*	96	99
87			42	41*	94	98
88			41*	42	100	90
89				41	98	96
90			42*	40	82	66

** stratum with negative gain*

The distribution of percent variation in Table 4 appears to be similar to that of 4TVW haddock with seven or less strata accounting for ≥ 75% of the variation in any one year and only nine different strata involved over the last 11 years. The distribution of the cod appears to have three foci — Misaine Bank area (strata 43, 44& 45); Banquereau Bank (strata 47& 48); and Sable and Middle Bank (strata 55, 56& 58). The design appears to result in a gain in precision when the distribution of cod resembles that of haddock, that is, the major part of the variation is concentrated in the Sable and Middle Bank areas (1982, 1989 & 1990). Sampling rates for stratum 44 in the Misaine Bank area appear to be the main culprit in those years for which efficiency is poor. Strata 43, 44 and 45 are in a mixed depth area where strata membership is defined by the depth of the sets made there. This makes it difficult to

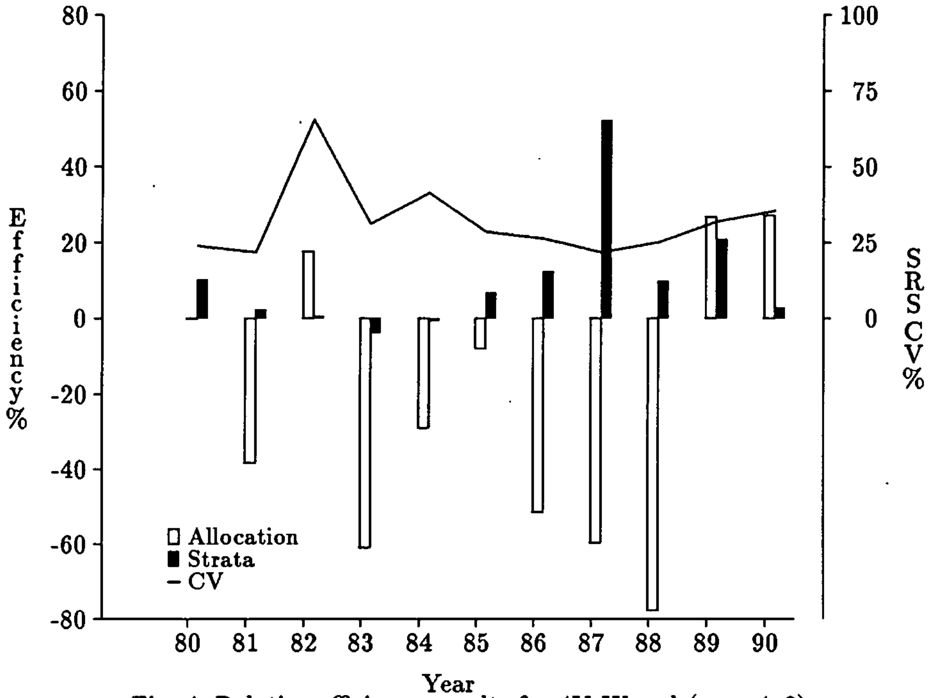

Fig. 4. Relative efficiency results for 4VsW cod (ages 4–9)

Table 4. Distribution of variation for 4VsW cod

Year	Percent of Variation				Total	% Mean
	≤ 25	≤ 50	≤ 75	≤ 100	Var. %	No.
80	47	44*	45,43,58	57,64	85	81
81		44*,47	43,59*	56	77	76
82				55	76	62
83		59*	55	47	77	68
84		43	44*		75	70
85		43	59*,44*	45	82	80
86		44*	47	43	87	81
87			44*,55	45	77	84
88		44*	58,59*	45	76	70
89		56	47	44*	79	77
90		55	56	44*	78	64

** stratum with negative gain*

designate allocation schemes for these strata because it depends heavily upon the accuracy of the charts and navigation equipment.

The 4X cod results (Figure 5) resemble the other cod stocks in that the allocation component is either weak or negative. However, the stratification component is much stronger here than for either 4Vn or 4VsW and appears to be as strong as that noted for 4X haddock. The positive total efficiency values ranges from 12.2 to 63.3% with one negative value of −45.9%. The range for the SRS CV is 16–45.7% and the resultant range for the stratified mean is 11.8 to 37.1%.

The distribution of the cod in 4X appears to more diffuse than it is for either the other cod or haddock stocks (Table 5) with between 2–8 strata accounting for ≥ 75% of the

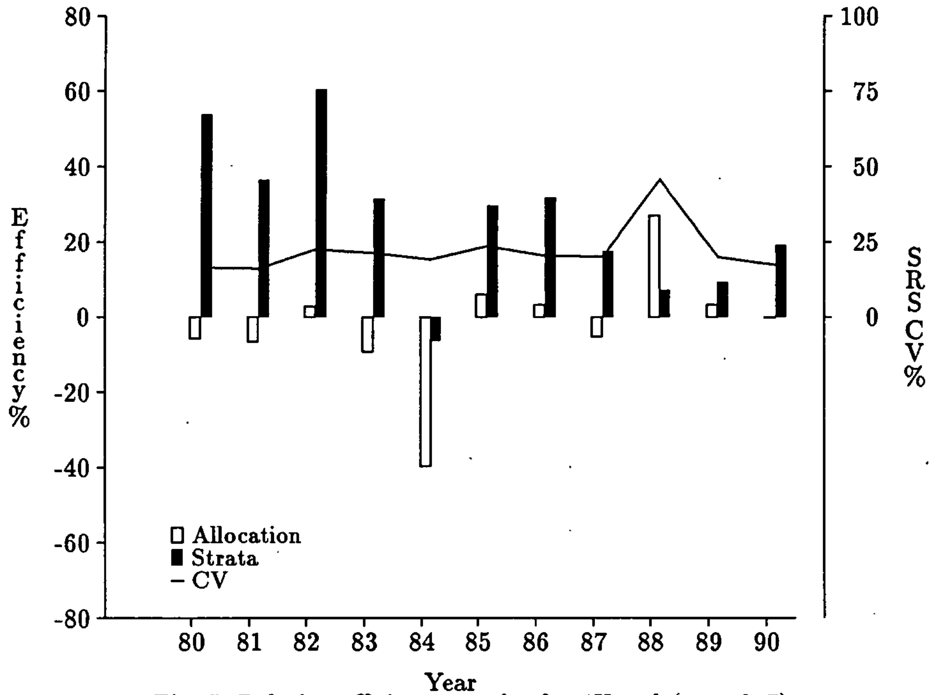

Fig. 5. Relative efficiency results for 4X cod (ages 2–7)

variation. The strata for this survey (70–95) include the three strata (92–94) on the New Brunswick side of the Bay of Fundy (Campana and Hamel 1990). There are 14 out of a total of 21 strata which have been categorized as high variability strata in Table 5. There do not appear to be easily identifiable foci of distribution; the cod are distributed from Fundy to LaHave most years. However, in 1988 which was the only year in which the allocation component was significant (Figure 5), the cod were mainly caught in the Brown's Bank area (strata 80 & 81) which is more frequently an area of concentration for haddock.

Table 5. Distribution of variation for 4X cod

Year	Percent of Variation				Total	% Mean
	≤ 25	≤ 50	≤ 75	≤ 100	Var. %	No.
80		91,72*	76*,81*,95	80,93	83	73
81	85*	90,80	76*,92,72*,77*	81*	76	66
82	81*	92	93,72*,90	84*	77	68
83	76*	92	80,81*,72*	77*	78	73
84		81*,85*	91,77*,95	93	79	71
85		90	92,90	72*	76	64
86		92,93	85*,81*,76*,80	77*	79	69
87	90	77,80,84*	85,81,92,94		75	76
88			80	81	83	69
89	76*	90	93,81,77		75	73
90	81	91,76*	92*,72*,73	80	77	58

** stratum with negative gain*

Pollock

The pollock results are given in Figure 6. The stratified design appears to be of little

Table 6. Distribution of variation for 4VWX pollock

Year	Percent of Variation				Total Var. %	% Mean No.
	≤ 25	≤ 50	≤ 75	≤ 100		
80		62		60*	83	78
81		84*	62,90,70		75	74
82			85	92	82	70
83		64	70	60*	78	74
84		59*	52,60*	76*	79	84
85		72*	90,70,45	62	78	76
86	85	59,62	52,81,60	91	79	66
87			60,71,40,41	77	79	78
88			85,76	59	82	63
89	60	82	85,64	72	76	71
90		76	70,81	60	88	88

* *stratum with negative gain*

use in increasing the precision of the pollock estimates of abundance over that obtained from simple random sampling. The total efficiency results range from −71.5 to 17.9% with only two years above zero. The allocation scheme did not match the variable strata for 10 out of 11 years and the stratification component was virtually nonexistent. The poor performance of the design resulted in the range for the stratified CV being greater (20.7–55%) than that estimated for the SRS CV (20.3–48%).

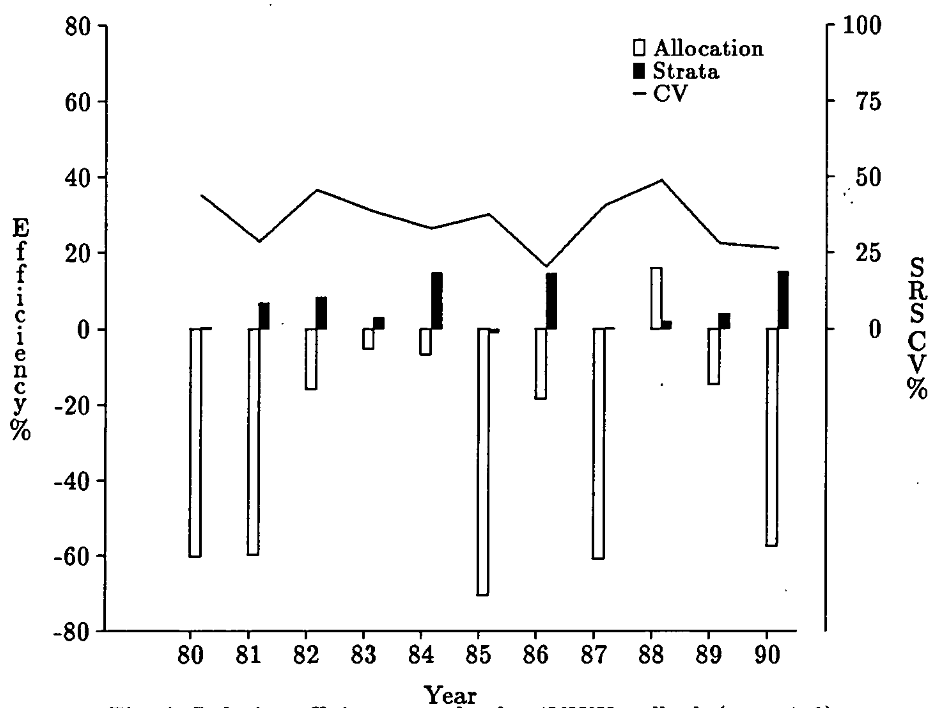

Fig. 6. Relative efficiency results for 4VWX pollock (ages 4–9)

The abundance estimate for the Scotian Shelf portion of the 4VWX+5 pollock stock is derived from catches in the 4VWX area only (strata 40–95) (Annand et al. 1990). The distribution of the percent variability (Table 6) appears to be confined to a few strata most years but 23 different strata out of a total of 48 appear in the table.

Discussion

The general set allocation pattern used for the Scotian Shelf survey was put into place in 1970 when the series was initiated. Changes to this pattern have come about more or less due to the caprice of mechanical breakdown, weather and decisions made by the respective chief scientists. In general, it can be said from the results given above that the both the strata boundaries and the set allocation scheme favour the distribution of haddock more than they do the other two species.

The proceeding analyses also confirm the results of Gavaris and Smith (1987) and Smith and Gavaris (unpublished), that the allocation component is the most important with respect to loss in precision. This component is the one which we have the most control over and therefore, it may be possible improve the situation somewhat for the cod stocks analysed here. The results of the cod and haddock surveys in the 4VW area indicate that there are 11 strata in common, which are important with respect to the amount of variation contained within them. It may be possible to reallocate sets to this portion of the survey in such a manner as to benefit the three stocks located there. Perhaps reallocating sets so that the term $((1/n) - (W_h/n_h))\, W_h$ is positive for these key strata could a useful approach.

The 4X area appears to be less consistent with respect to the degree of coincidence in distribution of cod and haddock. The sampling rates for more of the strata need to be adjusted in this area and more sets may be required in total to apply the approach suggested above for 4VW. Note however, that the greater stratification effect in this area for both cod and haddock may indicate that one need only minimize the possibility of large negative values of the allocation component and not worry too much about increasing it far beyond zero.

Given that pollock are highly variable with respect to which strata are more variable from year to year and the stratification component was negligible, it appears that it may not be feasible to easily improve upon the current survey design. The best that could be done is to assign sets strictly proportional to the size of the strata and expect to do no worse than a simple random sample. It does not appear however, that solutions for pollock would be compatible with those for either cod or haddock.

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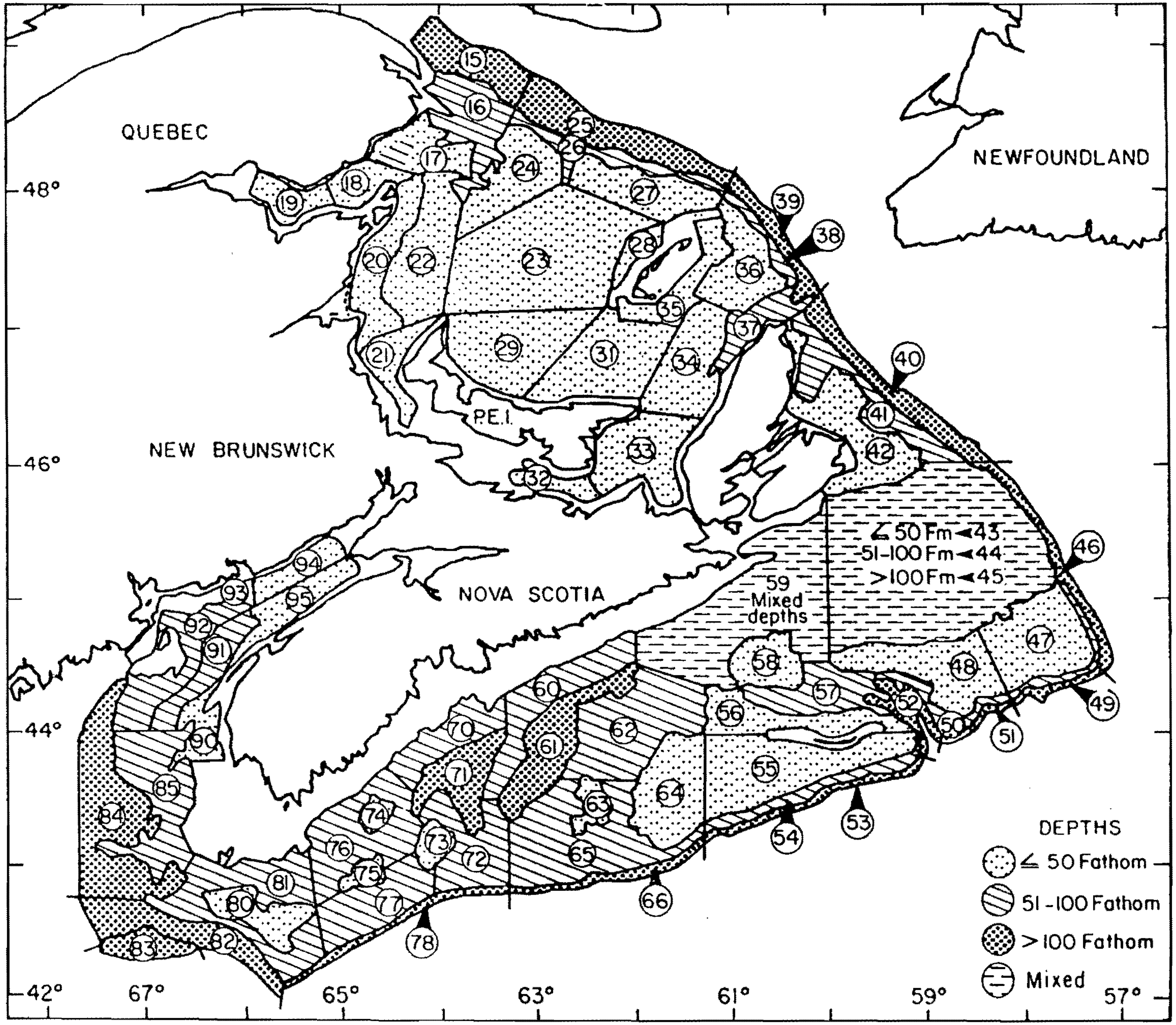
APPENDIX I:


QUEBEC
NEWFOUNDLAND
NEW BRUNSWICK
NOVA SCOTIA
P.E.I.
48°
46°
44°
42°
67°
65°
63°
61°
59°
57°
59
Mixed
depths
≦50 Fm◄43
51-100 Fm◄44
>100 Fm◄45
DEPTHS
≦ 50 Fathom
51 - 100 Fathom
>100 Fathom
Mixed