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Assessing the Effect of Intra-Haul Correlation and Variable Density on Estimates of Population Characteristics from Marine Surveys

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SUMMARY

In a previous paper (Pennington and Vølstad, 1991, *Biometrics* **47,** 717–723), it was suggested that reducing the size of the sampling unit currently used in marine surveys could increase the precision of the resulting density estimates. But if unit size is reduced, fewer animals will be caught during a survey. Concern has been expressed that this reduction in total catch would lower the precision of estimates of population characteristics, such as age and length frequency distributions, of importance for stock management. In this paper we examine the effect of sampling unit size, intra-cluster correlation, and variable density on the precision of estimates of population characteristics. An examination of some survey data indicates that reducing the size of the sampling unit employed and using the time saved to take samples at more locations could also yield more precise estimates of population parameters.

1. Introduction

Marine trawl surveys are routinely used to measure the abundance or relative abundance of many fish stocks and for estimating population characteristics such as length and age frequency distributions. This information forms the basis for managing many fisheries throughout the world. For most surveys, a standard trawl is towed for usually a half hour or longer at each selected station (see, e.g., Sparre, Ursin, and Venema, 1989). Previous results (Pennington and Vølstad, 1991) indicate that reducing tow duration, i.e., the size of the sampling unit commonly used, and appropriately increasing the number of locations sampled could result in more precise abundance estimates. But this also reduces a survey's total towing time and hence the number of fish caught. For example, 100 ten-minute tows or 77 thirty-minute tows can be made during a routine survey on Georges Bank. The former strategy will produce more precise abundance estimates, but on average more than twice as many fish will be caught with the latter.

Concern has been expressed that if the size of the sampling unit is reduced, too few fish will be caught, especially when abundance is low, to provide adequate estimates of population characteristics. The perception of what is a sufficient sample size is usually based on the number of fish caught, which are often assumed to be a random sample from the population. But fish caught together are often more similar than those in the general population. It is well known that even low levels of intra-cluster correlation can greatly increase the variance of an estimate as compared with that from simple random sampling (see, e.g., Hansen, Hurwitz, and Madow, 1953). An additional factor of importance for marine surveys is that the density of marine animals is usually highly variable over a region, which in the presence of intra-cluster correlation contributes significantly to the variance of population parameter estimates.

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In this paper the effect of reducing the size of a survey's sampling unit on the precision of an estimate of the mean value of some quantity, such as length, age, or weight of stomach contents per individual is examined. Estimates of the mean are considered so that the effective sample size can be assessed. That is, we calculate the precision of estimates of the mean obtained by the actual number of fish sampled so that it can be compared to estimates of the number of fish from a random sample that would be sufficient to obtain the same precision. This latter number is taken to be the effective sample size. Motivated by experimental results, the variance of an estimate is related to unit size in Section 2 and then the effect of reducing tow duration to that appropriate for density estimates is assessed.

As an example, the precision of survey estimates of the mean length of Georges Bank haddock is examined in Section 3. Length is usually highly correlated with other measurements of interest, such as age or weight. The most striking feature of these data is that even though a total of several thousand fish from 60 or more locations were often measured, the same precision could have been obtained if it were possible to randomly sample as few as 30 fish from the population.

The analysis also provides further confirmation that the usual approximate formula for the standard error of the ratio estimator can appreciably underestimate the true value (Rao, 1968; Wu and Deng, 1983). In contrast, the jackknife estimate of the standard error, as suggested by Wu and Deng (1983), appears to produce more dependable estimates.

It is concluded in Section 4 that even if tow duration for these surveys is reduced, the resulting estimates will not be particularly precise because the sampling trawl used in standard surveys is basically the one used by fishermen. Commercial equipment is designed to catch as many fish as possible at one spot. But for assessment purposes, due to the nature of fish distributions, it appears that the best strategy is to sample a few fish from as many locations as feasible.

2. The Effect of Unit Size on Precision

Suppose n stations are chosen randomly in an area and at each station a trawl is towed for a fixed amount of time. Let m_i denote the number of fish caught at the ith station (m_i can equal 0). Then if x_{ij} is some measurement on each individual, the mean of x may be estimated using the ratio estimator,

$$\bar{x}_r = \Sigma\Sigma x_{ij}/\Sigma m_i.$$

The variance of $\bar{x}_r$ can be estimated using the usual approximation or the jackknife estimator (see, e.g., Cochran, 1977, pp. 155, 179).

To relate $V(\bar{x}_r)$, the variance of $\bar{x}_r$, to tow duration, $V(\bar{x}_r)$ needs to be expressed in a form in which the sources of its variability can be assessed. We first consider the case when tow duration is fixed and then analyze the effect on $V(\bar{x}_r)$ of changing a standard survey's unit size to one that is efficient for estimating density.

The variance of $\bar{x}_r$ may be written as the sum of two components or

$$V(\bar{x}_r) = E_{\mathbf{m}}\{V(\bar{x}_r|\mathbf{m})\} + V_{\mathbf{m}}\{E(\bar{x}_r|\mathbf{m})\}, \tag{2.1}$$

where $\mathbf{m}$ denotes the vector of numbers caught.

To evaluate (2.1), it is assumed the fish are distributed so that the variability of x given m fish are caught is independent of m and equal to the population variance of x, i.e., $V(x|m) = \sigma_x^2$ for all $m > 0$. This implies that $E(x|m)$ is equal to the population mean for all $m > 0$. It is also assumed that the level of intra-haul correlation does not depend on m. Then it follows that the expected variance of the sum of the x's in a cluster of size m is given by

$$V(x_1 + \cdots + x_m|m) = m\sigma_x^2\{1 + (m-1)\rho\}$$

for all m, where ρ is the intra-haul correlation coefficient.

These assumptions, which were motivated by the characteristics of various survey data sets that we have examined, may not be valid, even approximately, if components of the stock are spatially segregated. For example, if x is fish length and the survey covers both nursery grounds where there are high densities of small fish and areas of adult fish with low densities, then $E(x|m)$ would not be independent of m. If this is the case, subareas for which the assumptions are approximately valid could, perhaps, be considered separately.

Since $E(x|m)$ does not depend on m, the second component in (2.1) is equal to zero. For the first component, it can be shown that

$$V(\bar{x}_r|\mathbf{m}) = \sigma_x^2\{1 + (\bar{m} - 1 + s_m^2/\bar{m})\rho\}/(\bar{m}n),$$

where $\bar{m}$ and s_m^2 are the sample average and variance of the m_i's, respectively. Therefore for large n, $V(\bar{x}_r)$ is approximately equal to

$$\sigma_x^2\{1 + (\bar{M} - 1 + \sigma_m^2/\bar{M})\rho\}/(\bar{M}n), \tag{2.2}$$

where $\bar{M} = E(\bar{m})$ and $\sigma_m^2 = E(s_m^2)$. Hence $V(\bar{x}_r)$ is a function of n, $\bar{M}$, σ_m^2, σ_x^2, and ρ. If the m_i's are equal, $\sigma_m^2 = 0$ and (2.2) reduces to the formula for the variance for equal cluster sizes (Cochran, 1977, p. 241). The term $\sigma_m^2/\bar{M}$ can be quite large for marine surveys, which greatly increases the variance as compared with the case of equal cluster sizes if $\rho > 0$.

Based on several trawling experiments, it was found that to an adequate approximation [see Pennington and Vølstad (1991) for details]

$$\bar{M}_t = m_0 t \quad \text{and} \quad \sigma_{m_t}^2 = m_0 t + b(m_0 t)^2,$$

where $\bar{M}_t$ and $\sigma_{m_t}^2$ are the mean and variance, respectively, of catch, m_t, for tow duration t, and b is a constant greater than zero. It was also shown that for a survey of fixed duration, C, the number of stations, n_t, that can be sampled with tow duration t is approximately defined by

$$C = (c_1 + t)n_t + c_2\sqrt{n_t}, \tag{2.3}$$

or

$$n_t = [\{(c_2^2 + 4(c_1 + t)C)^{1/2} - c_2\}/(2(c_1 + t))]^2, \tag{2.4}$$

where c_1 is time needed to set and retrieve the trawl at each station, and c_2 is a constant that depends on the area of the survey region. Finally, the optimum length of tow, t_0, for density estimation [i.e., the one that minimizes $\sigma_{m_t}/(\bar{M}_t\sqrt{n_t})$] is the iterative solution of (2.4) and

$$t = \{[c_1 + c_2/(2\sqrt{n_t})]/(m_0 b)\}^{1/2}. \tag{2.5}$$

We here assume that at each station fish are fairly well mixed so that $V(x|m_t)$ and ρ are independent of t. This is supported by some experimental results. For example, estimates of intra-haul correlation for some length measurements from several trawl experiments do not appear to vary significantly with tow duration (Godø, Pennington, and Vølstad, 1990). It then follows that the tow duration, t_0', that minimizes (2.2) subject to the constraint (2.3) is given iteratively by (2.4) and

$$t = \{[c_1 + c_2/(2\sqrt{n_t})]/(m_0(b + 1)\rho)\}^{1/2}. \tag{2.6}$$

From equations (2.5) and (2.6) it can be seen that $t_0' = \{b/[(1 + b)\rho]\}^{1/2}t_0$.

It may be noted that if $V(x|m)$ does not depend on m and is less than σ_x^2, then $E(x|m)$ will be a function of m and the second component in (2.1), $V_{\mathbf{m}}\{E(\bar{x}_r|\mathbf{m})\}$, will be nonzero. Given the assumption that fish are mixed at each station, it follows that for n fixed, $V_m\{E(\bar{x}_r|\mathbf{m})\}$ will be independent of tow duration and thus will decrease as the number of tows, n_t, increases. Therefore if ρ also does not depend on m, then t_0' will not necessarily minimize the variance of $\bar{x}_r$, but it would produce a smaller value of $V(\bar{x}_r)$ than that for any $t > t_0'$.

More generally, if the assumptions fail because components of the stock are highly segregated with respect to x, then smaller sampling units would usually be more efficient. But if ρ increases as tow duration decreases, then this would favor larger units and should be taken into account when determining an efficient tow duration for a survey.

The real problem in practice is not to find the exact tow duration that minimizes a particular quantity, but to decide whether, for example, a 10-minute tow will generally be more efficient than a 30-minute tow. This is not only because a marine survey has many objectives, but also because the optimum tow duration is a function of population parameters and available resources which change over time. Fortunately the values of t_0 and t_0' vary as the square root of the above parameters and the resulting variance curve is fairly flat around its minimum.

3. An Example: Determining Tow Duration for a Survey on Georges Bank

We show in this section how historical survey data can be used to assess the appropriate unit size for future surveys. Estimates of the mean length of Georges Bank haddock are considered here, but in practice all variables and species of interest can be treated in a similar fashion and a compromise unit size selected.

Fall trawl surveys have been conducted on Georges Bank, a region off the northeast coast of the

United States, by the National Marine Fisheries Service, Woods Hole, since 1963. The bank is divided into areal strata; within each a number of stations, approximately proportional to stratum area, are randomly selected. A cruise track is then determined that minimizes the total travel time between stations on the entire bank and at each station a trawl is towed for 30 minutes. The surveys usually take 6–7 days to complete.

In Section 3.1 the precision of estimates of the mean length of haddock obtained by the current survey design is examined. We assume that the sample of stations is approximately a random one from the entire area. Sampling is done proportional to stratum area because the spatial distribution of fish changes dramatically from year to year. Therefore in practice it is necessary to choose a unit size that will be adequate for the entire bank rather than for particular subareas.

We discuss in Section 3.2 the effects of areal stratification on these estimates of mean length. In Section 3.3 we determine a tow duration that appears to be more suitable for estimating population characteristics and density than the present standard of 30 minutes.

3.1 *Precision Obtained with the Current Tow Duration*

In Table 1 are ratio estimates of the mean length of haddock on Georges Bank for 1963–1988. Estimates of their standard errors were made using the usual approximation and the jackknife estimator (Cochran, 1977, pp. 153, 179). The approximation was on average 18% smaller than the jackknife values (Table 1).

It has been suggested that the usual approximation can seriously underestimate the true standard error (see, e.g., Rao, 1968; Cochran, 1977; Efron, 1982) and that the jackknife estimator is generally preferable (Wu and Deng, 1983).

To check whether the jackknife estimates for these data fairly reflect the true level of precision, we ran several simulations based on the observed data as in Wu and Deng (1983). Years with the

Table 1

Summary statistics for estimating the mean length of haddock on Georges Bank. The last two columns contain the number of fish actually measured and the estimated number needed to obtain the same precision if fish were randomly sampled. The standard errors of $\bar{x}_r$ were calculated using the usual approximation, jackknifing, and by substituting parameter estimates into equation (2.2).

Year	n	Number of nonzero tows	$\bar{x}_r$	Estimated S.E. Approx.	Jack.	Eq. (2.2)	Total number of fish	Random sample
1963	73	62	25.3	2.4	2.6	3.2	7,083	38
1964	73	60	33.7	1.1	1.1	1.4	8,411	83
1965	76	67	38.9	.6	.6	1.0	4,725	152
1966	74	53	40.0	2.8	3.1	2.4	1,505	20
1967	78	59	49.2	2.8	3.4	2.4	893	10
1968	80	36	57.0	1.0	1.0	1.9	414	97
1969	84	36	52.8	3.2	3.4	3.9	157	29
1970	81	40	50.7	3.1	4.8	4.7	450	9
1971	84	40	34.8	6.4	7.3	6.1	279	13
1972	85	49	28.6	3.5	4.0	4.5	639	24
1973	84	31	34.8	2.5	2.7	4.0	796	33
1974	85	32	38.8	3.2	3.6	4.0	247	21
1975	84	58	24.6	4.7	5.3	4.6	1,955	12
1976	78	36	34.6	.8	1.0	2.8	3,727	56
1977	112	56	45.2	.7	1.2	2.1	4,688	28
1978	175	124	33.1	4.2	4.7	4.3	4,353	16
1979	171	100	35.4	.5	1.3	3.8	12,208	28
1980	102	62	29.3	5.0	6.5	5.1	3,927	7
1981	82	43	43.9	1.9	2.1	2.2	930	33
1982	79	40	45.8	4.3	4.8	4.7	381	16
1983	81	52	32.5	3.4	3.7	4.2	772	25
1984	80	30	37.0	2.0	2.9	3.7	576	12
1985	77	41	25.6	2.3	2.9	3.9	1,136	21
1986	79	22	39.9	2.8	3.6	3.8	679	9
1987	77	25	31.2	7.1	10.7	7.3	419	3
1988	77	25	43.1	3.3	3.8	3.5	592	12
			Avg.	2.92	3.54	3.62		

largest numbers of positive tows were used in the simulations. For each year selected, 2,000 samples of size 30 were randomly chosen from the positive values. The results are in Table 2.

As Wu and Deng (1983) observed, the jackknife estimator appears to provide consistently more accurate estimates of standard errors and nominal 95% confidence intervals. But for samples of size 30, which is near the number of nonzero tows for many of the years (Table 1, col. 3), the jackknife estimate may also overstate the precision obtained (see Table 2).

Table 2

Simulation results for assessing the performance of the usual approximation and the jackknife estimator of the standard error of the ratio estimator. For each year selected, 2,000 *samples of size* 30 *were generated from the positive catches. The true* $\sqrt{\text{MSE}}$ *is based on the* 2,000 *simulations, and* $\text{CV}_{m\neq 0}$ *is the coefficient of variation for the nonzero catches.*

Year	$\text{CV}_{m\neq 0}$	True $\sqrt{\text{MSE}}$	Avg. S.E. Approx.	Avg. S.E. Jack.	Percent deviation from true $\sqrt{\text{MSE}}$ Approx.	Percent deviation from true $\sqrt{\text{MSE}}$ Jack.	Nominal coverage 95% confidence interval Approx.	Nominal coverage 95% confidence interval Jack.
1963	1.61	3.63	3.15	3.66	−13	1	89.2	91.8
1964	1.41	1.47	1.32	1.44	−10	−2	89.1	90.5
1965	1.42	.83	.78	.84	−6	1	90.7	91.8
1975	1.88	6.11	4.56	5.52	−25	−10	70.8	73.9
1978	2.52	6.92	5.26	7.04	−24	2	78.1	87.4
1979	6.81	2.84	1.64	2.53	−42	−11	81.8	89.7
1980	2.48	7.14	4.59	6.52	−36	−9	70.5	75.2

In the last two columns of Table 1 we compare the actual number of fish measured with the number that would have been needed to obtain the same precision if fish could be randomly sampled, i.e., the effective sample size. This was done using the jackknife estimate of the standard error and the usual estimate of the population standard deviation for length (Table 3, col. 2). Though these are rough estimates, they indicate that if fish could be sampled randomly, many fewer would be needed. In fact, the number appears often to be less than the number of tows that caught haddock (Table 1, col. 3).

It may seem surprising that the effective sample size could be so much smaller than the number of fish measured. The reason that this could happen can be seen by considering the following simple example. Suppose fish occur only in clusters of size 1 or 1,000, the numbers of clusters of each size are equal, fish in clusters of size 1 are 10 cm and all the fish in the other cluster size are 50 cm. If two clusters are sampled randomly, then 1,001 fish would be measured on average and there is a 25% chance of getting a poor estimate (i.e., 10 cm) of mean length. But if a single fish could be randomly sampled from the population, then the probability of a poor estimate is only 1/1,001.

It is not only the mean that is imprecisely estimated, but the entire length distribution of the population. A typical example of this imprecision is shown in Figure 1. The stations from 1967 were randomly split into two groups and the resulting length frequencies plotted. As can be seen, the distributions appear to be markedly different.

3.2 *Effects of Stratification*

To take into account the areal stratification of trawl stations, a combined ratio estimator (Cochran, 1977, p. 165) would be appropriate, or

$$\bar{x}_{\text{st}} = \Sigma w_k \bar{x}_k / \Sigma\, w_k \bar{m}_k,$$

where for the kth stratum w_k is the proportion of survey area in the stratum, $\bar{x}_k$ is the average total fish length per tow, and $\bar{m}_k$ is the average catch per tow. Though seemingly awkward, this type of estimator is necessary because the proportion of fish in each stratum is unknown.

The average value of the jackknife estimates of the standard error of $\bar{x}_{\text{st}}$ for the haddock data was 3.52 as compared with 3.54 obtained assuming a simple random sample of stations. The average value of ρ within a stratum was smaller (.33) than the estimates for the entire area (.68).

The reason that this decrease in ρ did not result in more precise estimates can be seen from equation (2.1). Suppose the strata could be chosen small enough so that in each stratum $\rho = 0$. Then $E_m\{V(\bar{x}_{\text{st}}|\mathbf{m})\}$ could be relatively small, but $V_m\{E(\bar{x}_{\text{st}}|\mathbf{m})\}$ would increase since differences in abundance among the strata now become a factor.

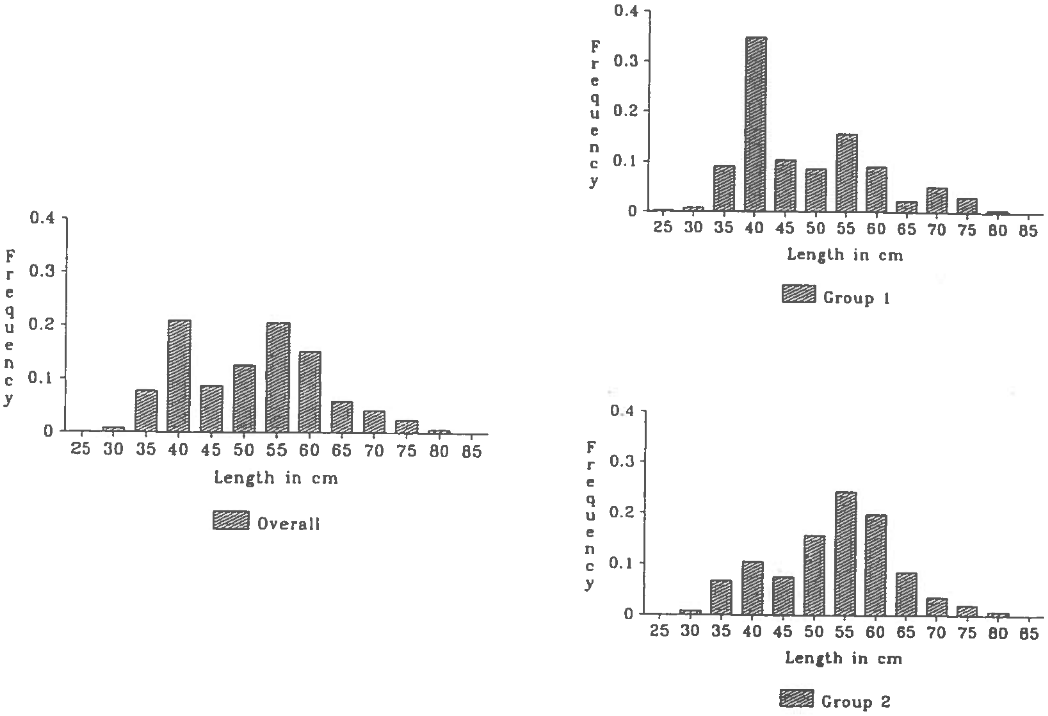

Figure 1. The overall length-frequency distribution of haddock for 1967 is based on 893 fish from 59 stations. The stations were randomly split into two groups. The distributions for groups 1 and 2 are based on 384 and 509 fish, respectively.

3.3 *Selecting an Appropriate Tow Duration*

The sampling trawl used for the Georges Bank surveys takes 30 minutes to set and retrieve, or $c_1 = 30$. The areal parameter, c_2, is 530 minutes. In Table 3, column 6 contains estimates of $m_0 b$ for each year. Estimates of the optimum tow duration for estimating density [from equations (2.3), (2.4), and (2.5)] are in column 7. The estimates were less than or nearly equal to 10 minutes for all years except for 1969 (16.8 minutes).

No significant relationship between $V(x|m)$ and m or between $E(x|m)$ and m was detected for any year, which together implies $V(x|m) \approx \sigma_x^2$ and $E(x|m)$ is approximately equal to the population mean, nor did ρ appear to depend on m. Furthermore, based on experimental data for haddock it appears that for the tow durations examined (5 min. to 2 hours), $V(x|m_t)$, $E(x|m_t)$, and ρ do not vary with tow duration. Therefore it is assumed that $V(\bar{x}_r)$ is minimized if t is $\{b/[(b+1)\rho]\}^{1/2}$ times the optimum tow duration for density. Estimates of this factor are in Table 3, column 8. To further check the suitability of equation (2.2), estimates of the population parameters for the 30-minute tows were substituted into equation (2.2) (Table 1, col. 7).

Based on the above, it appears that the current 30-minute tow duration could be safely reduced to 10 minutes. Tows less than 10 minutes for these routine surveys are not considered feasible (or acceptable) at this time because for very short tows the sampling properties of the standard trawl are not well known. To measure the possible gains to be had by using 10-minute tows, estimates from equation (2.2) of $V(\bar{x}_r)$ for 10-minute tows divided by that for 30 minutes are given in Table 3, column 11, as are ratios of $\sigma_m^2/(\bar{M}^2 n_t)$ for the density estimates, column 10. Column 9 gives estimates of the number of 10-minute tows, n_{10}, for each year.

4. Conclusions

Reducing tow duration for surveys on Georges Bank should result in more precise estimates. However, given the high cost of these surveys, the standard errors would still be relatively large. The problem is that apparently haddock should be sampled from as many locations as possible, but the sampling gear, which is essentially the one used by fishermen, is designed to maximize catch at one location. The gear is fairly large and is towed by fishermen for 2 hours or longer. Consequently, it is not primarily designed to be rapidly set and retrieved.

But this limits the number of stations that can be sampled during a survey. The variance of the estimates was approximately reduced by a factor of n_{30}/n_{10} if 10-minute rather than 30-minute tows

Table 3

Parameter estimates for determining the effect of reducing unit size for the Georges Bank surveys. In column 10 are estimates of the resulting reduction in $(\text{cv}_m)^2/n_t$ *for density,* R_1*, and in the last column that for* $\text{Var}(\bar{x}_r)$*,* R_2.

Year	$\hat{\sigma}_x$	$\hat{\rho}$	$\hat{m}$	s_m	$\widehat{m_0 b}$	$\hat{t}_0$	$\sqrt{\{\hat{b}/[(\hat{b}+1)\hat{\rho}]\}}$	n_{10}	R_1	R_2
1963	16.1	.68	97.0	172.7	10.4	2.3	1.1	94	.78	.78
1964	9.7	.41	115.2	186.6	10.1	2.4	1.3	94	.78	.74
1965	7.4	.40	62.2	97.0	5.0	3.3	1.3	99	.78	.76
1966	13.6	.58	20.3	34.2	1.9	5.4	1.1	95	.80	.81
1967	10.6	.68	11.5	25.8	1.9	5.4	1.1	101	.80	.81
1968	10.1	.36	5.2	13.3	1.1	7.1	1.6	104	.82	.90
1969	17.9	.83	1.9	3.6	.2	16.8	1.0	109	1.0	.98
1970	14.1	.56	5.6	21.3	2.7	4.5	1.3	105	.79	.80
1971	25.5	.79	3.3	7.4	.5	10.5	1.0	109	.86	.86
1972	19.6	.77	7.5	4.1	1.2	6.7	1.0	110	.81	.82
1973	15.2	.55	9.5	28.7	2.9	4.3	1.3	109	.79	.79
1974	16.1	.76	2.9	6.9	.5	10.5	1.1	110	.86	.88
1975	17.5	.90	23.3	54.9	4.3	3.6	1.0	109	.75	.78
1976	7.3	.64	47.8	194.2	26.3	1.4	1.2	101	.77	.78
1977	6.3	.48	41.9	216.2	37.2	1.2	1.5	148	.76	.81
1978	18.5	.93	24.9	76.2	7.7	2.5	1.0	235	.75	.75
1979	7.0	.62	71.4	637.5	189.7	.5	1.3	229	.75	.75
1980	16.0	.89	38.5	126.0	13.7	1.9	1.0	134	.77	.77
1981	11.7	.54	11.3	23.0	1.5	6.1	1.2	106	.80	.83
1982	18.5	.71	4.8	11.9	.9	7.9	1.1	102	.83	.84
1983	18.6	.78	9.5	19.8	1.3	6.5	1.0	105	.81	.83
1984	9.9	.65	7.2	28.4	3.7	3.9	1.2	104	.79	.79
1985	13.4	.85	14.8	38.2	3.3	4.1	1.0	100	.78	.79
1986	10.2	.73	8.6	32.3	4.0	3.7	1.1	102	.79	.79
1987	18.1	.90	5.4	19.4	2.3	4.9	1.0	100	.80	.79
1988	12.5	.80	7.7	19.9	1.7	5.7	1.0	100	.80	.80

were used. Further gains could be had if the time to set and retrieve the net, or c_1, were decreased. For example if $c_1 = 5$, then 165 stations could be sampled on Georges Bank using 10-minute tows versus 77 for the present design. A smaller value of c_1 would also significantly reduce the optimum tow durations [eqs (2.5)–(2.6)].

Similar results seem to hold in other regions. For example, experiments in the Barents Sea indicate that for several demersal species, a reduction in tow duration down to 5 minutes should not result in any significant loss in precision of mean length estimates (Godø et al., 1990).

In some situations, such as when large areas are covered by relatively few stations, not much precision may be gained by reducing tow duration. But overall survey efficiency could be improved by such reductions. By reducing tow duration, if appropriate, fewer fish would be handled on average, the need to subsample, which is difficult to do at sea, is lessened, and the reduced number of measurements that are taken could be made more accurately.

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Résumé

Dans un précédent article (Pennington et Vølstad, 1991, *Biometrics* **47,** 717–723) nous suggérions que réduire la taille des unités d'échantillonnage en usage dans les enquêtes halieutiques pouvait augmenter la précision des estimations de densité. Mais si la taille de l'unité est diminuée, moins d'animaux seront capturés durant une campagne d'échantillonnage. Le risque que cette réduction diminue la précision des estimations de caractéristiques des populations importantes pour la gestion des stocks, comme les distributions de fréquence d'âge ou de longueur, a été un sujet de préoccupation. Dans cet article nous examinons l'effet de la taille de l'unité d'échantillonnage, de la corrélation intra-agrégat, et d'une densité variable sur la précision des estimations de caractéristiques des populations. L'examen de données d'enquête indique que réduire la taille des unités d'échantillonnage employée et utiliser le temps ainsi économisé pour obtenir des échantillons en un

plus grand nombre de sites pouvait aussi fournir des estimations plus précises des paramètres de population.

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