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AN EVALUATION OF SURVEY DESIGN FOR ESTIMATING THE FOOD CONSUMPTION BY FISH

by

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ABSTRACT

The effect of survey design on the precision of estimates of average fish stomach contents is examined. The contribution to the total variance from within and between tow variability in stomach contents is evaluated, and the implications for stomach sampling programs are discussed. As an example we have estimated the average amount of capelin in Barents Sea cod stomachs for years of very low, low and medium capelin abundance. The results indicate that to maximize precision for a given cost it is generally best to sample stomachs at as many locations as possible. A simulation study based on resampling from these data suggests that little is gained in precision by collecting 5 instead of 2 stomachs from each 5 cm length group of fish.

1. Introduction

Commercial fisheries often exhibit the effect of competition and predator-prey interactions among species. Multispecies models for assessment which take such factors into account have received much attention over the past decade. However, for such models to describe realistically the dynamics of fish stocks and their interaction, it is important that the input data for the models are representative and precise. Development of multi-species models and their effective application for management requires reliable information on the annual food consumption for the various predators by age group. Consumption is usually assumed to be directly related to average stomach contents and the precision of the estimates depend on the survey design for collecting stomachs (Pennington, 1985).

Predation contributes significantly to the natural mortality of many exploited fish stocks and may be the dominant factor affecting recruitment levels for many species (Sissenwine, 1984). Multispecies virtual population Analysis (MSVPA), which is presently used for management of many commercially important fish stocks in the North Sea, assesses predation through analysis of stomach contents data (see, e.g., Daan, 1987; Sparre, 1991). For Barents Sea capelin, estimates of predation mortalities are obtained from an area-divided multispecies model (MULTSPEC) (Bogstad and Tjelmeland, MS 1991). Input parameters for cod-capelin interaction and migration are estimated from stomach contents data obtained from trawl surveys.

Stomachs have been routinely collected from bottom trawl surveys on Georges Bank, in the Barents Sea and off Iceland and Newfoundland for a number of years. In the North Sea, a large international stomach sampling project was set up in 1981 to provide input data for the development of MSVPA (see Anon., 1982; Daan, 1987); a similar program is planned for 1991. The sample size which is adequate for estimating food consumption by fish is typically based on the total number of stomachs collected. For example, for the North Sea sampling program in 1981, the target sample size by species was 1500 stomachs per quarter. Bulked samples were obtained in 1981; i.e. stomachs from predators in the same length group were pooled. In general, the same strategy will be followed in 1991, but if time allows it is recommended that individual stomachs be collected (Anon., 1991).

Intuitively one would expect that if a large number of stomachs are collected, the resulting estimates of consumption or average stomach contents should be precise. However, it is well known that marine organisms; e.g., fish, euphasids, mysids and copepods and other taxa, often form schools, clusters or swarms. These patches often relate to social behavior and environmental factors which vary over time and space. Nutrient uptake, grazing and predation are likely to be involved in determining spacial distributions (Valiela, 1984). Considerable differences in abundance and stomach contents for various predators can thus be expected between locations, and through time. For such reasons, since fish are caught in clusters, the precision of population estimates depend not only on number of fish collected, but also on number of locations sampled and time periods (Pennington, 1985). In fact, the effective sample size could well be smaller than number of sample stations, due to intra-haul correlation and spacial-temporal differences in fish density (see Pennington and Vølstad, 1991b).

In this paper the effect of survey design on the variance of estimates of average stomach contents is evaluated. As an example we have estimated the average amount of capelin in Barents Sea cod stomachs for years of very low, low and medium capelin abundance. Results suggest that for the same number of fish sampled, the precision could be considerably increased by collecting fewer stomachs at each station and increasing the number of locations sampled.

2. Estimating average stomach contents

2.1. Estimation procedure

Suppose that individual stomach contents data are collected from bottom trawl hauls taken at *n* randomly selected locations and times in the area of interest. Since collection and processing of stomach contents data are expensive and time consuming, sample sizes are often limited by time constraints and available personnel. Therefore, stomachs are usually collected from a portion of fish from each haul. In practice it is not feasible to obtain true random samples of fish from the entire catch at a station. Hence, the catches of a species are often divided into length groups, and stomachs are collected from subsamples of fish which are approximately randomly selected within each group. This sampling procedure is essentially a two-stage sampling scheme, where the trawl stations are primary units and the stomachs collected are secondary units. Since primary units vary in size, i.e. catches vary from location to location, the population estimator for average stomach contents for a particular length group of fish is

$$\bar{x}_j = \Sigma M_{ij}\bar{x}_{ij}/\Sigma M_{ij} \quad (1)$$

where M_{ij} is the number of fish caught at station i within the length group j, and $\bar{x}_{ij}$ is the average weight of the stomach contents of the m_{ij} fish in the subsample from M_{ij} (see, e.g., Jessen, 1978; Cochran, 1977).

Due to the two-stage sampling scheme, the variance of the estimated average stomach contents is affected by variability from two sources: (i) the variation in stomach contents between hauls and (ii) the variation within hauls. Omitting for convenience the finite population correction factors which are generally small for the first term, and small for large catches in the second term, the variance for a length group j is approximately

$$\sigma_b^2/n + \sigma_w^2/n\bar{m}. \qquad (2)$$

In (2), σ_b^2 and σ_w^2 are the (weighted) between and within tow variance in stomach contents, and $\bar{m}$ is average number of stomachs collected at each station (see Jessen, 1978, p. 292; the number of stomachs sampled from each tow is assumed to be fairly constant). Equation (2) is used to assess changes in sampling strategy, and the jackknife estimator is used to estimate the variance of (1) (see Efron, 1982).

2.2. Selecting an appropriate survey design

It can be seen from equation (2) that increasing the average number of stomachs, $\bar{m}$, subsampled from a length group at each station reduces only the contribution from the within tow variability. To reduce the first component in (2), the number of stations needs to be increased. Due to the patchy distribution of prey species, intra-haul correlation likely exists. In such cases it is generally best to sample at as many locations as possible.

The efficiency of a sampling scheme can be assessed using equation (2) and previous survey data. Simulations, based on resampling from actual data, also provides useful information for evaluating the efficiency of various survey designs.

3. Example: estimating average amount of capelin in Barents Sea cod stomachs

In this section we use previous survey data to assess the efficiency of different stomach sampling schemes. Estimates of the average weight of capelin in cod stomachs are examined. In practice other predator and prey species can be treated in a similar fashion.

Yearly combined bottom trawl and acoustic winter surveys have been carried out in the Barents Sea by the Institute of Marine Research, Bergen, Norway since 1981. The survey area is divided into strata and within each stratum a number of trawl stations, approximately proportional to stratum area, are allocated at random. Figure 1 is a map of the survey area. Individual stomachs for cod are routinely collected from these surveys; 5 stomachs per 5 cm length group are usually collected at a station. Capelin is generally the most important food item for North-East Arctic cod (see Mehl, 1989). At the time when the winter survey is conducted, cod prey on mainly mature capelin (> 14 cm).

In section 3.1 the precision of estimates of average weight of capelin in cod stomachs obtained by the current stomach sampling scheme is examined. We assume that the sample of trawl stations is approximately a random one from the entire area. Further, we assume that at each station the stomachs collected from a length group form a random sample from all the fish in that group.

We suggest in section 3.2 that for the number of stomachs collected fixed, it is more efficient to sample fewer stomachs at each station and increase the number of locations sampled.

3.1. Precision obtained with current design

In Table 1 are ratio estimates of the average weight of capelin in Barents Sea cod stomachs for length groups from 40 cm to 69 cm for 1985, 1987 and 1989. These years had medium, very low and low abundance of capelin, respectively. The length groups were chosen because capelin generally is not suitable as prey for small cod, and sample sizes for large cod are small. Estimates of the standard errors in Table 1 were made by jackknifing (see, e.g, Efron, 1982; or Cochran, 1977, p. 179). The low precision is due to large intra-haul correlation for stomach contents (see Table 1). This suggests that little is gained in precision by collecting many stomachs from each trawl haul.

3.2. A simulation study: resampling from survey data

To check the level of precision obtained by collecting 2 stomachs in each length group, as compared to the current scheme of collecting 5 stomachs, we ran simulations based on resampling from the survey data.

From each station, 2 stomachs were sampled at random with replacement from the total number of stomachs collected in that length group. Jackknife estimates of average stomach contents and their standard errors, based on equation (1), are in Table 1. As would be expected, due to large intra-haul correlation for stomach contents, the precision of these estimates is only slightly lower than for those based on all stomachs collected (Table 1).

Sampling strategy can also be assessed using equation (2) and estimates of the between and within sampling variability. For example, in 1985, 196 cod were sampled in the 45-49 cm length class from 23 stations, $\hat{\sigma}_b^2 = 1227$ and $\hat{\sigma}_w^2 = 768$ (Table 1). Then for the current sampling scheme the standard error (*se*) is approximately

$$\{(1227/23) + (768/196)\}^{1/2} = 7.6.$$

[Note: Again, the jackknife estimator is used to estimate the *se* in applications. Equation (2), though crude, is useful for assessing relative changes in the *se* for different sampling strategies]

For 2 stomachs sampled from each of the 23 stations,

$$se \doteq \{(1227/23) + (768/46)\}^{1/2} = 8.3.$$

For 2 stomachs sampled from 46 stations

$$se \doteq \{(1227/46) + (768/92)\}^{1/2} = 5.9.$$

That is though only 92 stomachs are processed from 46 stations, the *se* is much smaller then if 196 stomachs are taken from 23 stations. In fact if all the stomachs were sampled from the 23 stations, the second term in eq. (2) would be zero (finite population correction factors are zero in the second component) and the se would be approximately

$$(1227/23)^{1/2} = 7.3.$$

4. Conclusions

There is no reason to believe that the above examples are extreme for marine populations (see also Pennington et al., 1981). Due to the generally patchy distributions of predators and their prey, spacial and temporal differences in consumption is expected. Such intra-haul correlation, along with highly variable density of predators between locations, greatly inflates the variance of population estimates of consumption. To obtain reliable estimates of total annual consumption it is important that stomachs are collected from the entire distribution area of the species under consideration, and that samples are taken throughout the year and throughout the day. Since what is of interest is an estimate of the mean stomach contents of a population, it is important to use a weighted estimate (eq. (1)). It is not apparent what an unweighted estimate, i.e. the usual average, is estimating and the two values can be quite different.

When resources for collecting and processing stomachs are limited the best strategy would be to collect stomachs from as many locations as possible and, if necessary, reduce the number of stomachs collected from each haul. In the North Sea, stomach samples are typically bulked. The usual justification for pooling stomachs within a length group is that the collection and analysis of individual stomachs are vastly more time consuming. If a strategy of collecting and analyzing 2 stomachs per 5 cm length group is employed, little time is saved by pooling the stomachs. Likewise, as seen, bulking provides little additional precision. In addition, some multispecies models may require information on individual meal size.

Generally, the total number of trawl stations taken in an area is relatively small. Therefore the standard errors of population estimates of consumption would be relatively large even if stomachs were collected from all stations. One possible way of increasing the precision would be to decrease the tow duration presently used in many areas (see Pennington and Vølstad, 1991a,b). For no extra cost, the number of stations could be increased resulting in more precise estimates of population parameters and of abundance. An additional benefit would be that the need for subsampling would be reduced due to smaller catches on average.

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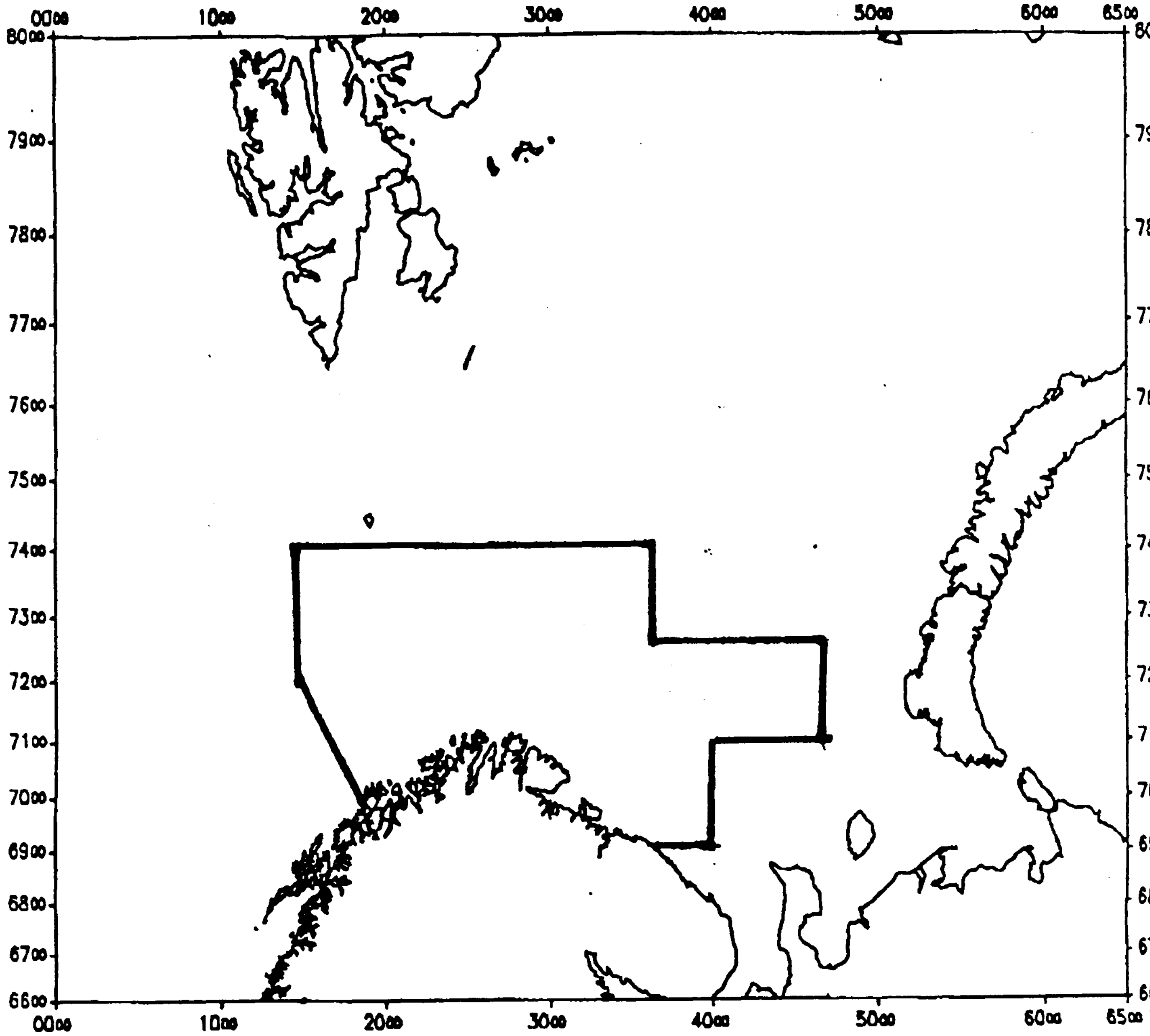

Figure 1. Map of the Barents Sea with boundaries of survey area.

Table 1. Jackknife estimates of average weight (in grams) of capelin in Barents Sea cod stomachs for years of medium, very low and low capelin abundance. Estimates of standard errors based on all stomachs collected (m_0) are in the second column, and in the third column are the simulation results (resampling of 2 stomachs in each length group, 500 simulations). The estimates of between tow and within tow variances, $\hat{\sigma}_b^2$ and $\hat{\sigma}_w^2$ respectively, and the intra-haul correlation $\hat{\rho}$ are from ANOVA of stomach contents for the $n_{mi\neq0}$ tows sampled for stomachs (* are missing values).

1985 Medium abundance								
Length	$\bar{x}$	$\hat{SE}_{All}$	SE_{Sim}	$n_{mi\neq0}$	m_0	$\hat{\sigma}_b^2$	$\hat{\sigma}_w^2$	$\hat{\rho}$
40-44	18.7	4.1	5.1	32	178	294	435	.40
45-49	26.8	8.3	9.2	23	196	1227	768	.62
50-54	25.2	8.3	9.6	22	158	1092	1111	.50
55-59	39.3	19.2	20.3	19	95	3388	2440	.58
60-64	40.4	21.7	22.7	19	99	5162	2180	.70
65-69	57.3	27.8	28.8	19	80	6964	2661	.72

1987 Very low abundance								
Length	$\bar{x}$	$\hat{SE}$	SE_{Sim}	$n_{mi\neq0}$	m_0	$\hat{\sigma}_b^2$	$\hat{\sigma}_w^2$	$\hat{\rho}$
40-44	1.1	.5	.7	36	161	3	19	.16
45-49	.5	.3	.4	34	128	1	7	.08
50-54	.0	.0	.0	24	96	*	*	*
55-59	.2	.2	.2	21	91	3	0	*
60-64	.0	.0	.0	19	88	*	*	*
65-69	.0	.0	.0	17	57	*	*	*

1989 Low abundance								
Length	$\bar{x}$	$\hat{SE}_{All}$	SE_{Sim}	$n_{mi\neq0}$	m_0	$\hat{\sigma}_b^2$	$\hat{\sigma}_w^2$	$\hat{\rho}$
40-44	6.5	1.8	2.5	61	266	97	275	.26
45-49	9.0	3.4	3.8	64	295	460	279	.62
50-54	9.9	4.2	4.7	69	305	722	499	.59
55-59	14.6	6.4	6.7	66	295	1830	609	.75
60-64	6.7	2.6	3.1	59	225	373	485	.43
65-69	5.4	3.7	4.0	43	119	900	508	.64