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**EMPIRICAL RESULTS ON PRECISION - EFFORT RELATIONSHIPS
FOR ACOUSTIC SURVEYS**

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ABSTRACT

Repeated echo integrator surveys using a rather dense survey grid were performed in areas where the effect of fish migration was assumed to be insignificant. Relative estimates of fish abundance representing different survey grid densities were calculated by using observations along all transects, each second transect, each third transect and so on. The "degree of coverage" of an area was defined as the ratio between "sailed" distance and the square root of the total area covered. Coefficients of variation of the relative estimates were calculated for each degree of coverage. Observations and results for different areas are compared and discussed, and curve fit between the coefficient of variation and the degree of coverage for the observations are presented. Coefficients of variation estimated from the inter-transect variation are compared with the observed ones.

1. INTRODUCTION

During acoustic surveys sampling is performed continuously along more or less equally spaced transects. In such cases there are no straightforward variance estimators for the total survey result. Some

authors have analysed various sources of random errors associated with the method (Moose and Ehrenberg 1971, Aksland 1976, Bodholt 1977, Ehrenberg and Lytle 1977, Lozow 1977). Several estimators of variance have been suggested by different authors (Shotton and Bazigos 1984). They are all based on various assumptions which tend to be difficult to evaluate. Therefore the users may have doubts whether the resulting confidence limits are realistic. In fact those variance estimators are used rather seldom, and most acoustic biomass estimates are reported as point estimates without any confidence limits.

The empirical variance of acoustic biomass estimates can be obtained from repeated surveys on a presumably constant fish biomass. Examples of such studies are Blindheim and Nakken (1971), Johannesson and Losse (1977), and Gerlotto and Stêquet (1983).

This work presents an empirical coefficient of variation for a number of repeated surveys and relates the observations to the applied levels of survey effort. Different measures of effort are applied by different authors, and there are different opinions on what is a convenient measure of effort. A justification for my definition of effort is given in the first part of the paper. This reasoning also leads to a simple estimator of the coefficient of variation for acoustic abundance estimates.

2. DEFINITION OF EFFORT

The total sailed distance or the total ship time would be direct measures of the effort. They are closely related to the cost of a survey, because running the vessel represents the main expense of acoustic estimation. These measures are not, however, globally related to the precision of the estimates. When studying precision - effort relationships, it is useful to have a measure of effort which makes this relationship as scale invariant as possible. The following reasoning leads to a useful definition.

The sampling along transects is far more intense than the sampling

perpendicular to the transect direction. An almost continuous band is sampled along the transects, while the distance between transects may vary from several hundred meters up to more than 30 nautical miles, depending on the size of the area to be surveyed. Thus for a given area the precision of a survey estimate mainly depends on the distance between transects, or more generally, the number of transects.

When the likely distribution area of a fish stock is known, the precision of the stock estimate should be related to the effort spent within that area only. Consider an echo integrator survey limited to a defined fish distribution area. Take the average integrator value (M_A) of each transect through the area to be independent, identically distributed stochastic variables. This means that each transect average is a relative estimate of average fish density for the whole area. The variance for the total average (\bar{M}_A) of n transects is then

(1) $\text{Var}(\bar{M}_A) = \frac{1}{n} \cdot \text{Var}(M_A)$, where $\text{Var}(M_A)$ is the inter-transect variance. If the relative fish abundance (t) is defined as a constant (K) times \bar{M}_A we have that $\text{Var}(t) = (K^2/n) \cdot \text{Var}(M_A)$.

The coefficient of variation, $\text{SD}(t) / \bar{t}$, is

$$(2) \quad \text{CV}(t) = \text{CV}(M_A) \cdot n^{-1/2}$$

In this equation the number of transects is a measure of the effort. The number of transects worked parallel to one side of a square can be expressed as N/\sqrt{A} , where N is the added length of all transects through the square and A is the area of the square. Then

$$(3) \quad \text{CV}(t) = \text{CV}(M_A) \cdot (N/\sqrt{A})^{-1/2}$$

I have used N/\sqrt{A} as a general definition of the "degree of coverage" (Aglen 1982). This definition appears to be convenient for comparison of the precision of different surveys where the shape of the survey area or the directions of the transects are different. It is evident

that in a long and narrow fjord with an unknown fish distribution pattern, a better coverage, requiring a higher survey effort, is obtained by working a certain number of transects along the fjord compared to working the same number of transects across the fjord. In this case N/\sqrt{A} gives a better description of the degree of coverage than the number of transects itself.

The number of transects can also be expressed by the total degree of coverage relative to the degree of coverage represented by one transect. When the average transect length is N_A equation (2) becomes

$$(4) \quad CV(t) = CV(M_A) \cdot [(N/\sqrt{A}) / (N_A/\sqrt{A})]^{-1/2} = a \cdot (N/\sqrt{A})^{-1/2}$$

Then a is the theoretical $CV(M_A)$ at a degree of coverage equal to 1.

This degree of coverage might be said to take into account both the size and shape of the area. It is scale invariant but this does not necessarily mean that it bears a "scale invariant" relationship to the precision. There are possibilities that the other factor of the expression [$CV(M_A)$ or a] depends on the size of the area. The results presented later in the paper are used to compare estimates of a in small and large areas.

If there is a dependence between transect estimates, the covariance between transects will introduce an additional term in equation (1), but $(1/n) \cdot \text{Var}(M_A)$ will remain an important part. This means that the number of transects or the defined degree of coverage is a useful measure of effort in any case. It is likely that the covariance term will be most important when the distance between transects is small, which means at high degree of coverage. Thus if empirical data for simplicity are fitted to the function

$$(5) \quad CV(t) = a \cdot (N/\sqrt{A})^b,$$

a significant contribution from the covariance term should result in an estimate of b different from the value based on independence $(-1/2)$.

Several authors have related the precision to the distance between transects (Blindheim and Nakken 1971, Cram and Hampton 1976 and Fiedler 1978). This is useful for studies within a given area, but it might be confusing when comparing different areas. Gerlotto and

Stequert (1983) have applied this measure of effort while comparing results from two areas. They conclude that the difference between the areas are caused by differences in the homogeneity of the fish distribution. However, much of the difference can be explained by a difference in degree of coverage.

A simulation study of the variance of hydroacoustic biomass estimates is presented by Kimura and Lemberg (1981). They have defined a "sampling index" which can be expressed as $0.5 \cdot (N/\sqrt{A})$. The reason for their definition is to have a scale invariant measure. The factor of 0.5 arises just because they started with a rectangle of shape 1×4 and referred results for other areas to this.

However, when presenting the results of the simulations, they present coefficient of variation versus number of transects. The differences shown between the simulation results for an area of shape 1×4 and an area of shape 2×2 then just reflects the differences in degree of coverage (or sampling index).

Francis (1984) considers this sampling index, and consequently my degree of coverage, as inadequate for two reasons;

"First, if two surveys with the same A and N are joined, then the sampling intensity of the resulting survey should be the same as that of the original surveys. With N/\sqrt{A} it is greater. Second, since sampling intensity is, roughly speaking, a measure of the proportion of fish schools that is likely to be encountered by a transect, it is a property not only of N and A but also of the size distribution of schools. A scale invariant measure such as N/\sqrt{A} would be appropriate only if, when the dimensions of the survey areas were doubled, so were those of the fish schools. The measure N/A is more suitable when comparing surveys where the size distributions of the fish schools are approximately the same in all surveys."

The purpose of my degree of coverage is to have a measure which bears approximately the same relationship to precision in small and large areas. It is not meant to be "a measure of the proportion of fish schools that is likely to be encountered by a transect". Such a measure would be inadequate for precision - effort comparisons because the sampled proportion required for a given precision will decrease as the area increases. It is well known that for a given precision a large population (or large area) requires a smaller proportion sampled compared to a small population (or small area).

By the same argument it follows that when combining two equal areas with equal amount of sampling, the precision of the combined estimate will be better than the precision of each estimate. This is nicely reflected by a higher degree of coverage.

The "sampling intensity" (N/A) advocated by Francis is a measure of the proportion of the total area which is sampled. Generally a given sampling intensity will then give increased precision when the area is increased, even in the case of an unchanged size distribution of schools.

I realize that the size distribution of fish schools is of importance for the precision, but the defined degree of coverage is not based on the assumption that the size of the schools is scaled to the area. The degree of coverage will be a useful measure as long as an increased area gives improved statistics on each transect average due to longer transects. To maintain the precision on the total survey estimate, the distance between transects may be increased, thus producing approximately the same degree of coverage.

3. MATERIAL AND METHODS

Different series of repeated surveys are analysed. The series are worked in different areas of different size. The smallest is 0.17 square nautical miles and the largest about 50 000 square nautical miles. Figure 1 shows the location of survey areas. Table 1 summarizes important data about the surveys. References to more detailed descriptions of the surveys are listed in the table. Small (5-25 cm) pelagic fish which schooled by day and dispersed at night dominated during most surveys. The exceptions are the surveys in Lofoten and in the Gulf of Oman. Parallel transects were applied during most coverages. Some of the coverages in the fjords were made in a zig-zag pattern.

For each coverage, an average integrator value representing the target fish species is calculated. In the Barents Sea, only values obtained

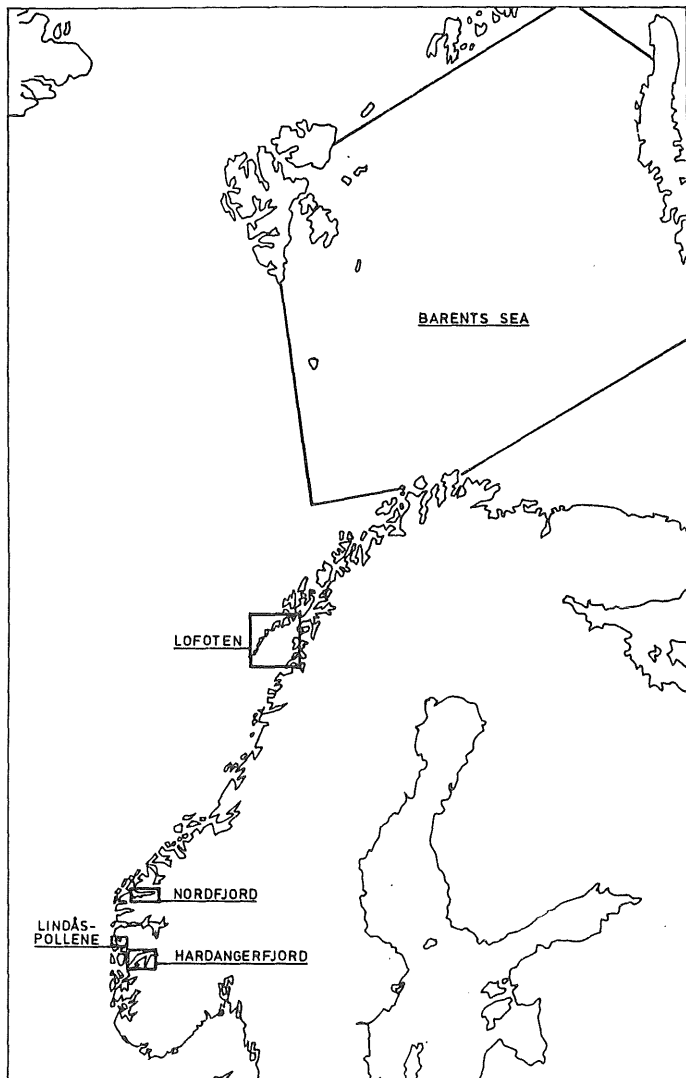


Figure 1.

Location of survey areas. Lindåspollene include Fjellangervågen, Straumsosen and Spjeldnesosen. Hardangerfjord includes Eidfjord and Samlafjord.

Table 1. Key data about the surveys. The footnotes give references to further descriptions of the surveys. Fjellangervågen, Straumsosen and Spjeldnesosen are parts of Lindåspollene, Eidfjord and Samlafjord are parts of Hardangerfjord (Figure 1).

Name of area	Dominating fish species	Vessel	Size of covered area (sq.n.mile)	Number of survey-series	Number of "dense" coverages each series	Time
1) Fjellangervågen	Sprat	M/B "H.Reush"	.17	1	4	Sep.77
1) Straumsosen + Spjeldnesosen	Herring	M/B "H.Reush"/ M/B "Daffy"	1.0	2	2-11	Sep.77,Mar.78
1) Outer Eidfjord	Sprat	R/V "P. Rønnestad"	13	2	5- 7	Feb.-Mar.78
1) Samlafjord	"	"	16	3	4- 8	Jan.-Mar.78
1) Nordfjord	"	"	22	1	9	Feb.78
1) Eidfjord	"	"	25	3	2- 6	Oct.77-Jan.78
2) Lofoten	Cod	R/V "G.O.Sars"	120	1	6	Mar.71
3) Gulf of Oman	Lanternfish	R/V "Dr.F.Nansen"	10 000	4	1- 3	Jan.-Mar.81, Feb.83,Sep.83, Nov.83
4) Barents Sea	Capelin	R/V "G.O.Sars"	50 000	5	1	Sep.-Oct.each year from -74 to 78

1) Aglen [1982b], 2) Blindheim and Nakken [1971]. 3) Aglen *et al.* [1982], Gjøsaeter and Tilseth [1983], Anon [1983], Strømme and Tilseth [1983], 4) Buzeta *et al.* [1975], Dommasnes *et al.* [1976], Dommasnes and Røttingen [1977], Monstad and Røttingen [1977], Dommasnes *et al.* [1979].

along 16 successive transects within the fish distribution area were applied. The other surveys did not extend outside the assumed fish distribution area. In Lindåspollene the coverages were rather uneven, and average values were calculated within subareas to give an area-weighted total average. In Lofoten isolines were drawn, and the results are given as the added product of average integrator value and area within isolines. The total result is in all cases considered a relative abundance estimate for which the symbol t is used throughout the rest of the paper.

From each original coverage estimates for more open survey grids were obtained by applying observations from each second transect, each third transect and so on.

In Aglen (1982a) and Aglen et al. (1982) I have evaluated the acoustic equipment of application. The equipment used in the fjords and fjord inlet had an unfavourable threshold setting that led to systematically higher integrator values during day compared to night. In these small areas it was possible to make separate coverages during day and night, and the results are treated separately. During some of the coverages in the Gulf of Oman there was also a tendency towards higher values during day compared to night. In this area day and night values are not treated separately.

4. RESULTS AND DISCUSSION

4.1 The distribution of relative abundance estimates

The relative fish abundance estimates for all areas except the Gulf of Oman are reported in Aglen (1982). Due to the way the estimates are constructed, those representing a low degree of coverage are more numerous than those representing a high degree of coverage. In Figures 2-5 the single estimates from all series of surveys are shown as

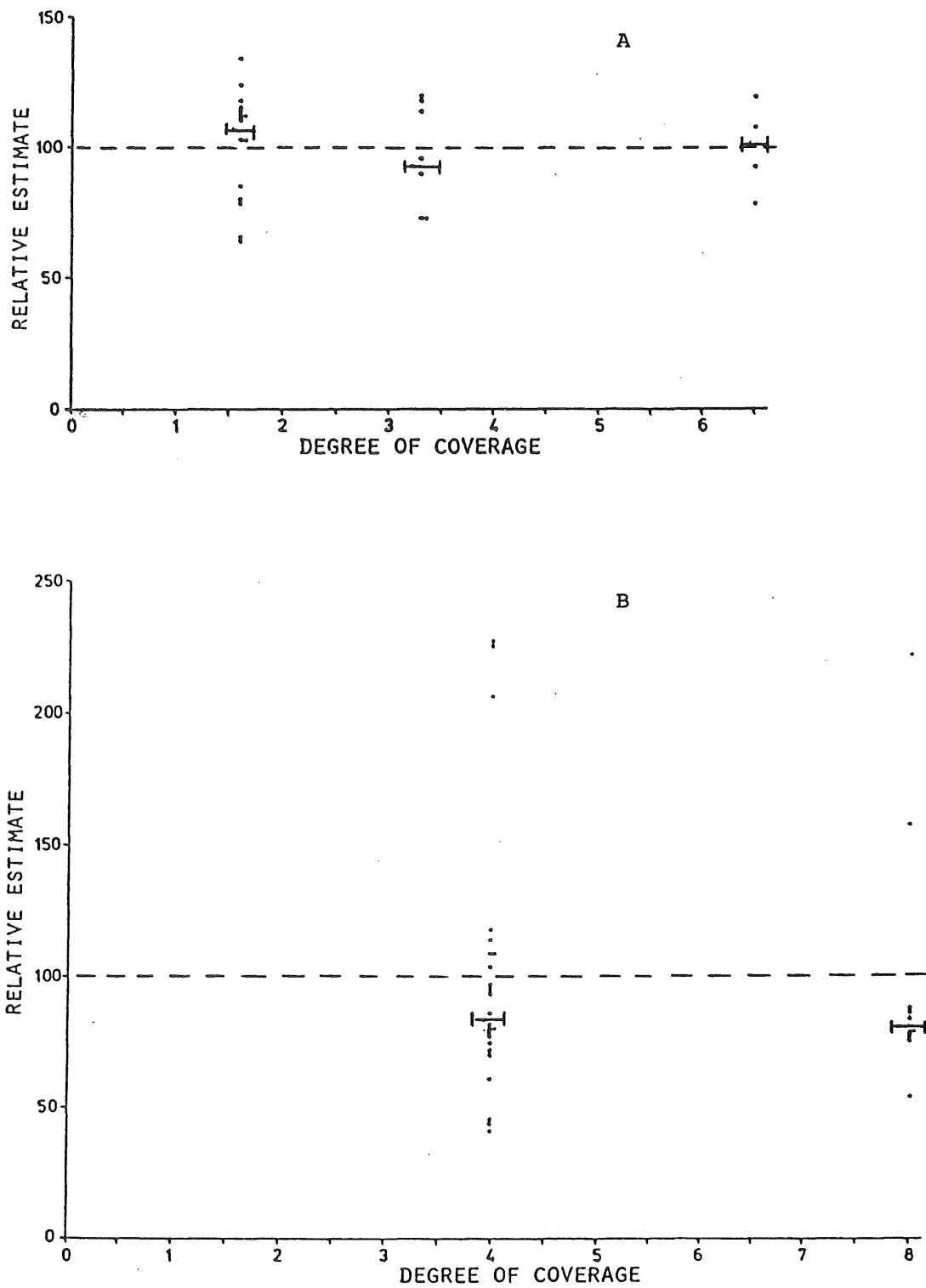


Figure 2. Scatter plots of relative fish abundance estimates. The median of the scatter is shown within intervals for the degree of coverage. A: Fjellangervåg, B: Straumsosen + Spjeldnesosen.

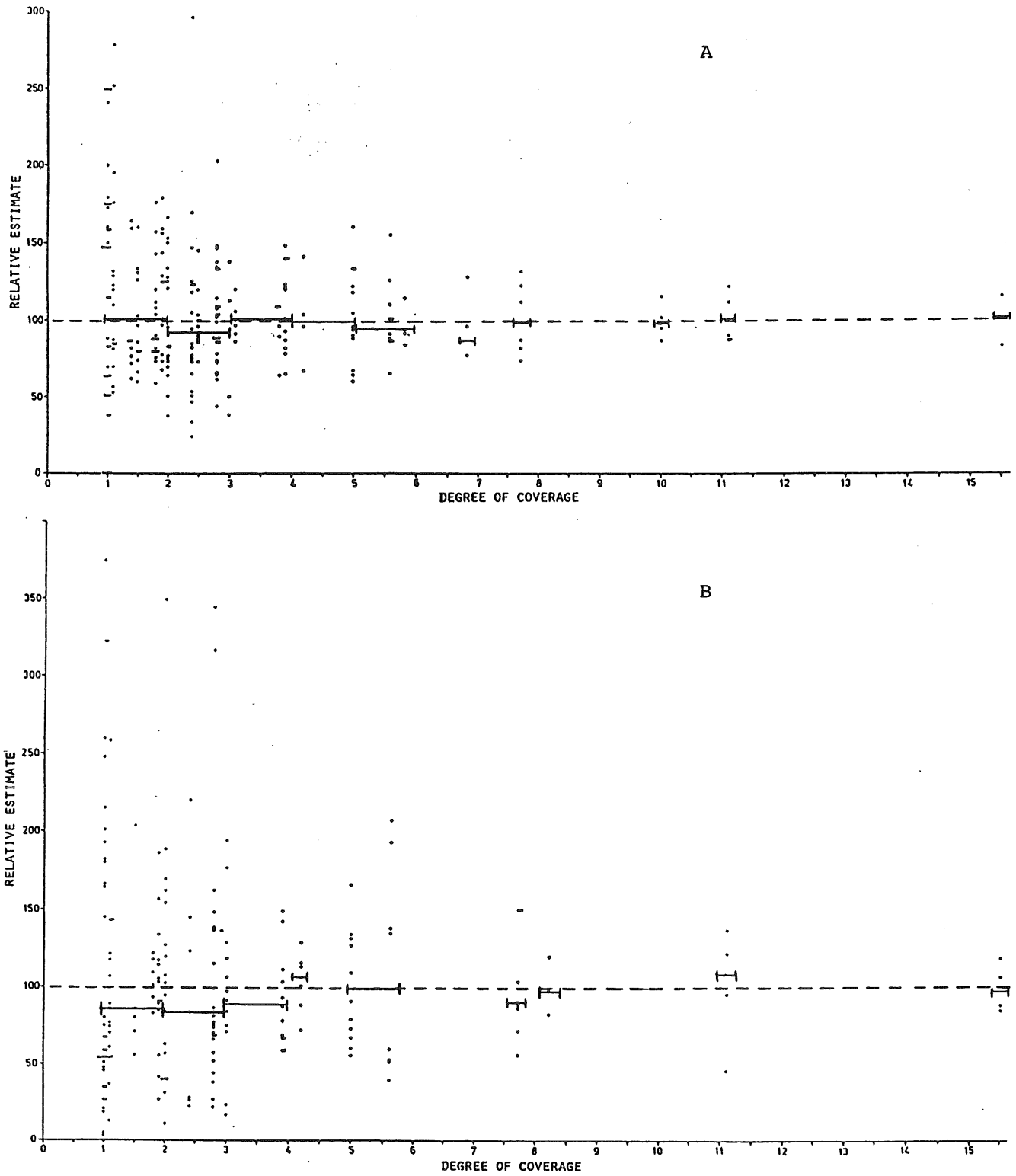


Figure 3. Scatter plots of relative fish abundance estimates. The median of the scatter is shown within intervals for the degree of coverage.
A: Fjords, night, B: Fjords, day.

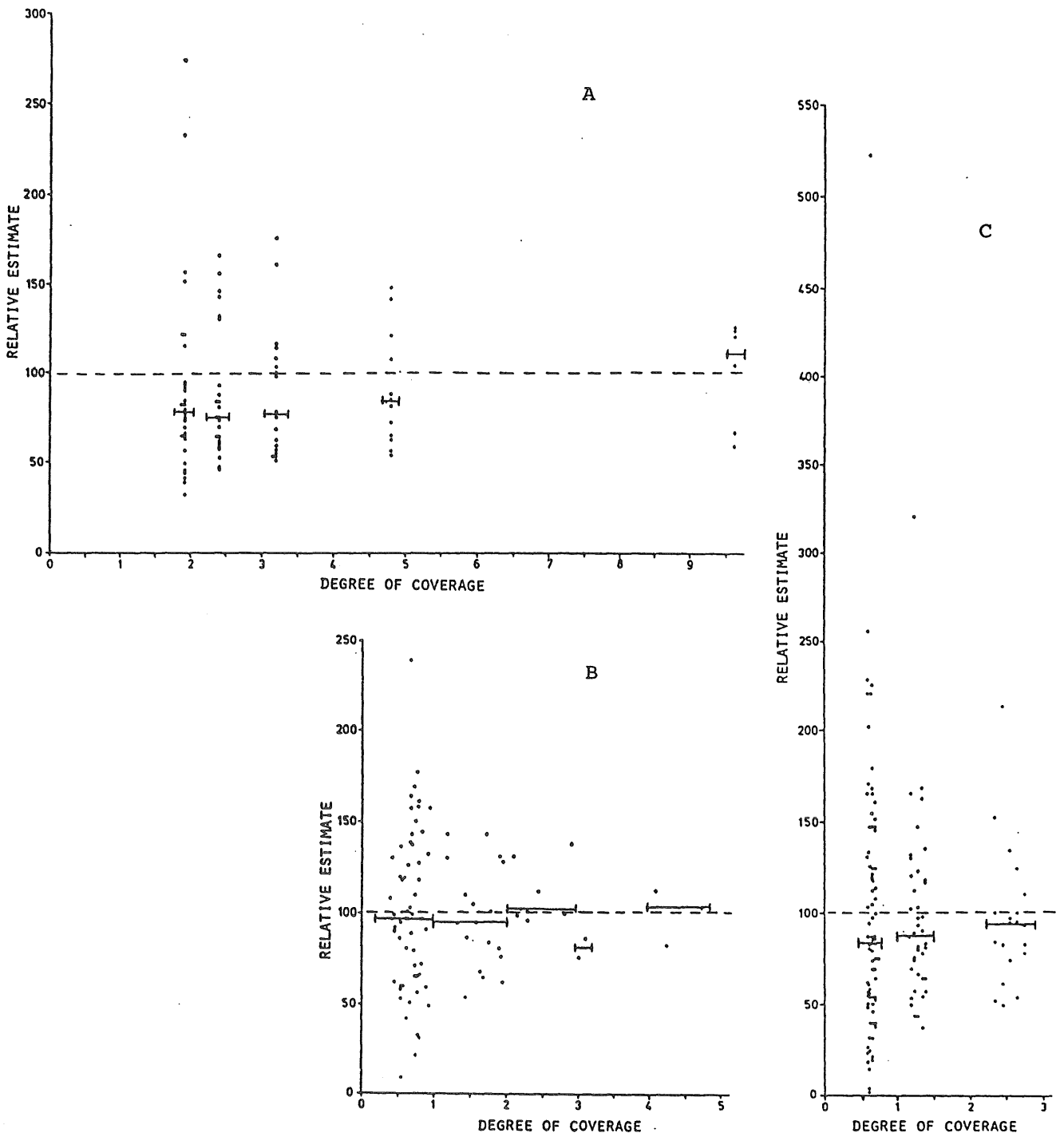


Figure 4. Scatter plots of relative fish abundance estimates. The median of the scatter is shown within intervals for the degree of coverage. A: Lofoten, B: Gulf of Oman, C: Barents Sea.

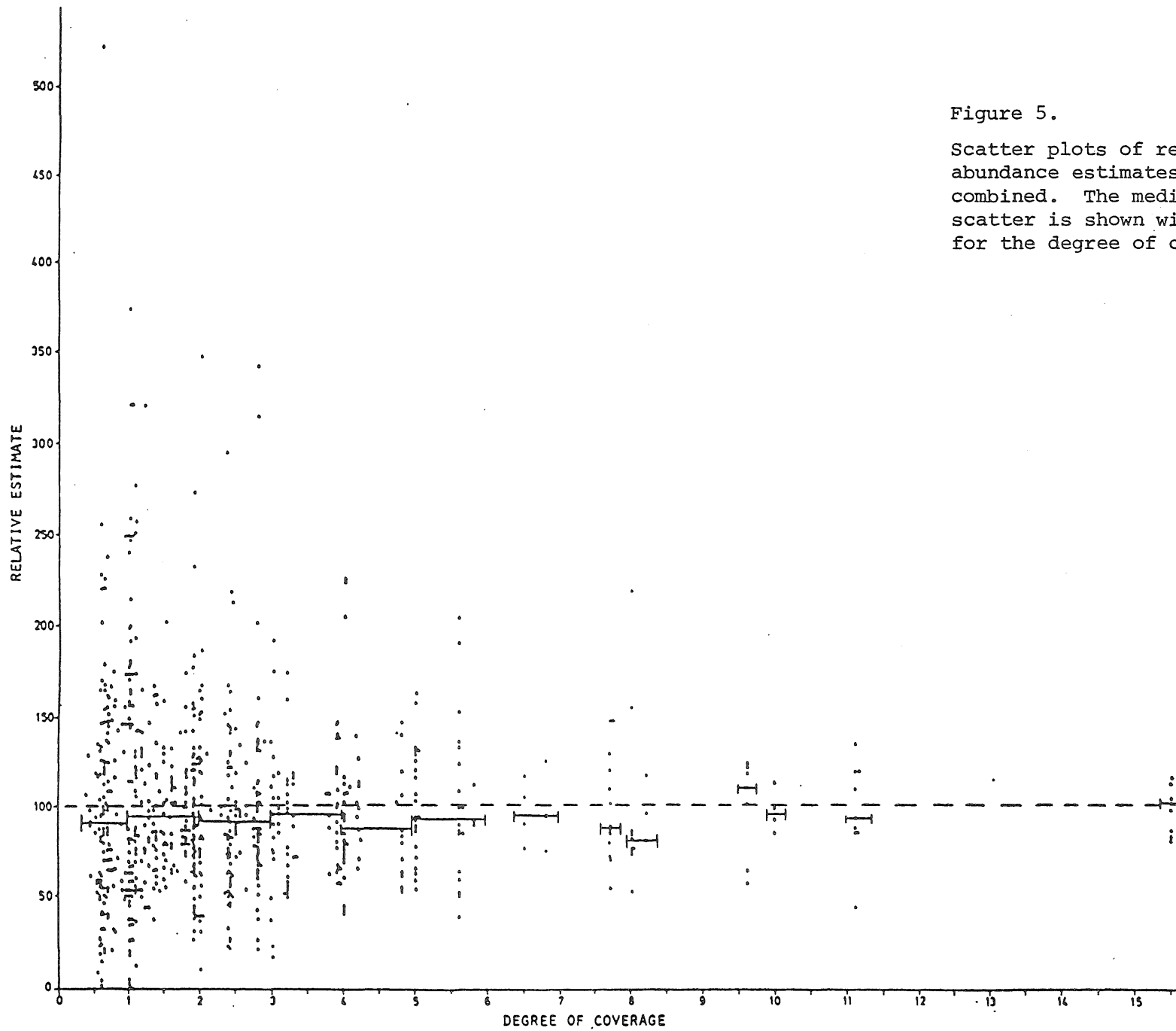


Figure 5.

Scatter plots of relative fish abundance estimates for all areas combined. The median of the scatter is shown within intervals for the degree of coverage.

percentages of the best estimate obtained during each series. The average of the coverages with highest degree of coverage is considered as the best estimate. In most cases the way the poorer coverages are constructed from the best coverages makes the average of the poorer coverages equal to the best estimate. This is not the case for the estimates from Lindåspollene and Lofoten, where integrator values are weighted by sub-areas. The reason for presenting the result in this way is to illustrate how the scatter of the estimates relates to the degree of coverage. Cases with only one or two estimates are not presented on Figures 2-5, because these should fall either on or to each side of the best estimate.

The median of the point scatter is drawn within intervals (Figures 2-5). Although there are some variation between areas, there seems to be a general tendency of the point scatter to be skewed towards low values, at least for low degrees of coverage. Regarding the medians, some of the differences between areas and differences between intervals of degree of coverage are incidental due to a low number of estimates. By considering all areas together, we get a larger material (Figure 5). Here all the medians with a degree of coverage less than 9 are below the mean.

Table 2 shows the observed frequency of underestimation and the probability of having a number of underestimates equal to or higher than the observed one in the case of a symmetrical distribution (a binomial case).

Table 2. Frequency of underestimation (f,%) and significance probability (p) within intervals of degree of coverage (N/vA). p is the probability of having a number of underestimates equal to or larger than the observed one in the case of a symmetrical distribution. n is the number of estimates.

N/vA	0.6-0.9	1.0-1.9	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-15.5
n	138	278	181	79	49	46	60
f	57.2	55.8	60.5	58.2	60.2	54.3	56.7
p	.053	.031	.003	.089	.099	.330	.174

The table presents the results within intervals for the degree of coverage. The significance probabilities are rather low for all intervals below 4.9. The material therefore gives strong reason to expect that at low degrees of coverage there is a larger probability of underestimation than of overestimation. At higher degrees of coverage the material does not show any clear tendency towards over- or under-estimation.

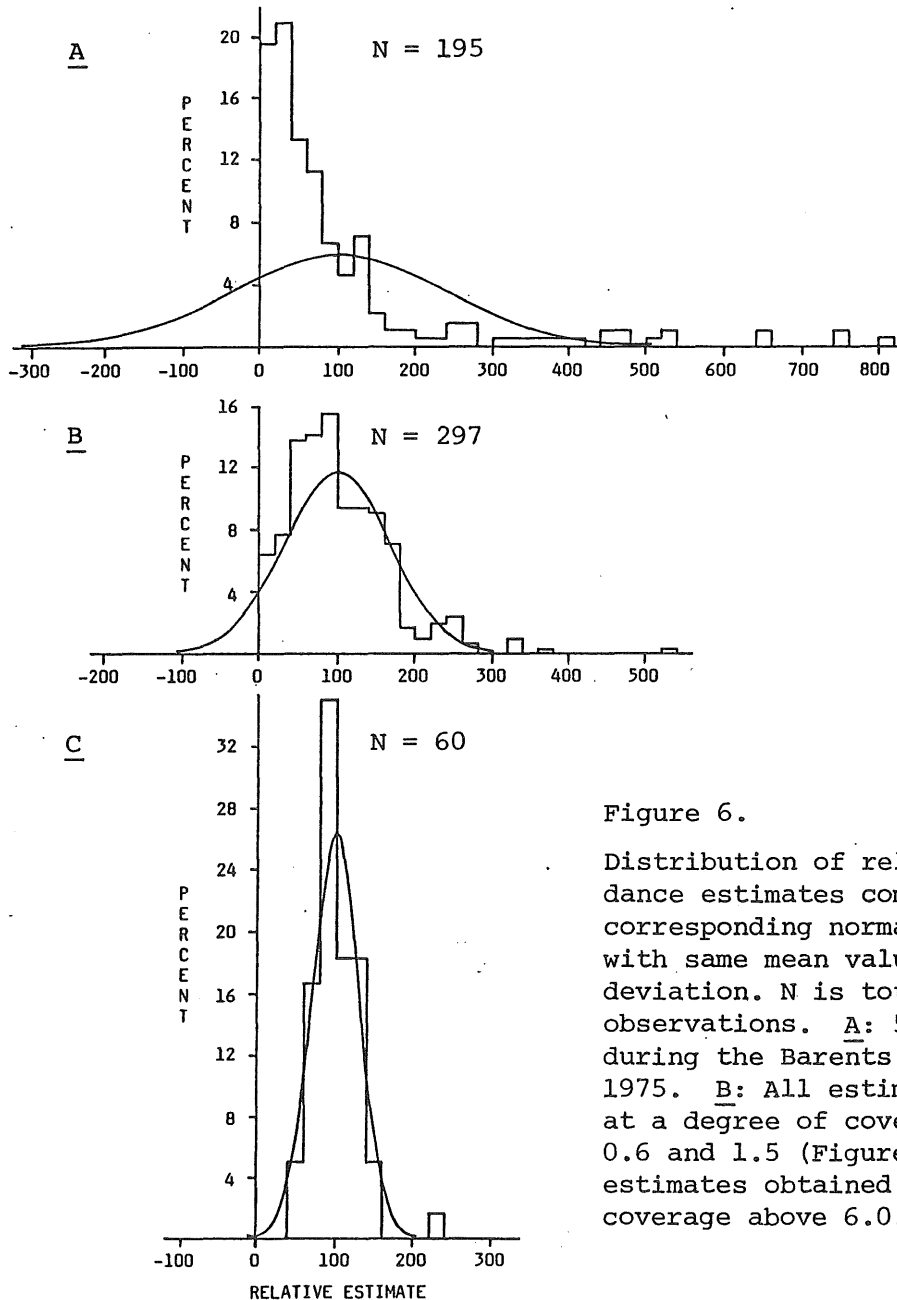


Figure 6.

Distribution of relative fish abundance estimates compared to the corresponding normal distribution with same mean value and standard deviation. N is total number of observations. A: 5-mile averages during the Barents Sea survey in 1975. B: All estimates obtained at a degree of coverage between 0.6 and 1.5 (Figure 5). C: All estimates obtained at a degree of coverage above 6.0.

There are no observations below a degree of coverage of 0.6, but it is easy to see that the scatter has to be more skewed as the degree of

coverage decreases. When the degree of coverage approaches zero, the scatter has to increase considerably and, as negative estimates are impossible, the distribution has to be more skewed. Figure 6A shows the distribution of 5-mile observations during one of the capelin surveys in the Barents Sea. If each 5-mile value is considered as an abundance estimate, Figure 6A is an example of a distribution of estimates obtained at extremely low degree of coverage (0.02).

It follows from the Central Limit Theorem that as the material increases (increasing number of single observations) the distribution of the total estimate will approach the normal distribution. This means that the distribution of survey estimates approaches the normal distribution as the degree of coverage increases. The three distributions shown in Figure 6 illustrate this trend. Figure 6B is the distribution of all estimates obtained at a degree of coverage between 0.6 and 1.5, which grossly corresponds to estimates based on one single transect. Figure 6C shows all observations obtained at a degree of coverage at or above 6.0 which represents a common coverage for a whole survey. The corresponding normal distribution with the same mean value and standard deviation as the observed ones are drawn on each figure.

In the case of normally distributed estimates, the confidence interval is estimated from the empirical standard deviation. Figure 7 compares the 90% confidence intervals based on the normal distribution with the intervals covering 90% of the observed values. The figure is based on the total material and illustrates one result of the trend discussed above: Confidence intervals assuming normally distributed estimates give a reasonable fit to the observations at a high degree of coverage, while they fit poorly at a low degree of coverage. Here asymmetric confidence intervals appear more realistic.

Shotton and Bazigos (1984) point out that the assumption of normality is often weakly supported by real data. They also raise the question: "How seriously does the failure of our assumptions affect the methods we use?" The data presented here show that the distribution of estimates obtained at a common (but moderate) degree of coverage are reasonably close to a normal distribution. The material leaves some doubt about whether the observations belong to an exact normal

distribution, but an assumption of normality will not in this case seriously affect the methods.

Jolly and Hampton (1987) claim that "if a survey has accumulated enough information for estimating biomass with reasonable precision, the departure from normality should be small". Figure 7 gives some support to this statement.

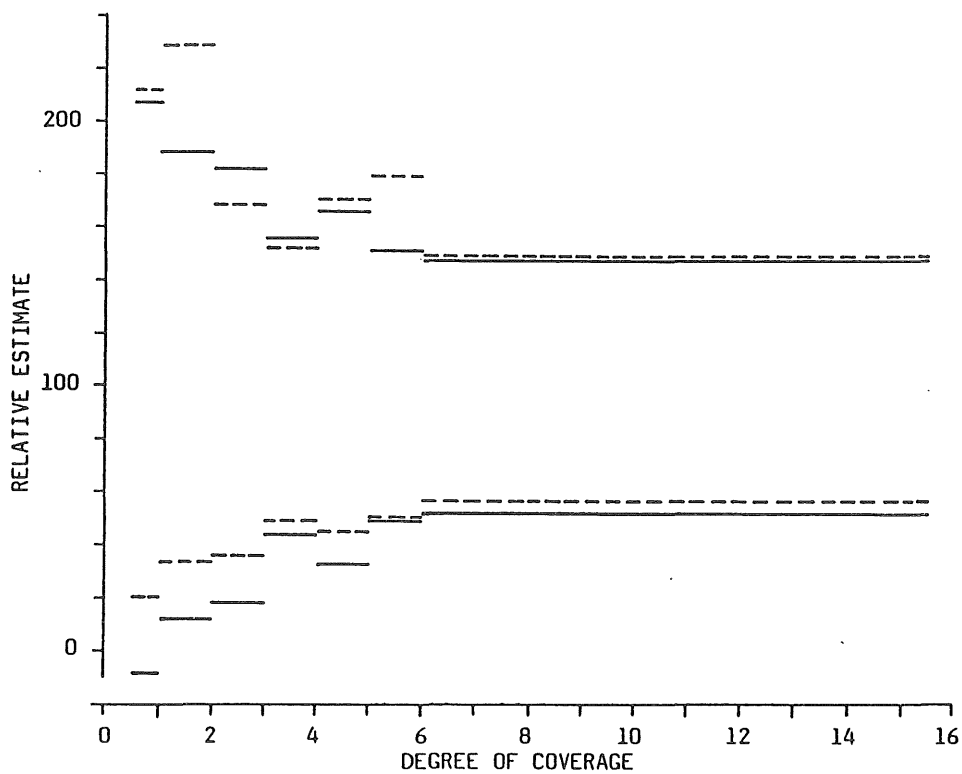


Figure 7. 90 % confidence limits based on the normal distribution (whole lines) compared to observed 90-percentiles (broken lines).

4.2 Observed coefficients of variation

To avoid the uncertainties connected with estimation of confidence intervals, I have chosen to express the precision in terms of the coefficient of variation. This is defined as the ratio between the empirical standard deviation and the mean value of the observations.

It does not require any assumptions about the sampled distribution.

Calculated coefficients of variation for each series of surveys are shown in Figure 8. The lines connecting the points belonging to the same series indicate considerable differences between series, even in the same area. The point at the right end of each curve is in many cases based on only two estimates, while the point on the left end is in most cases based on more than 10 estimates. Therefore the differences between the series are most evident at low degrees of coverage, which may be interpreted as differences of $CV(M_A)$ or a in equations (2)-(5).

The differences between series of surveys and between areas are to some extent caused by differences in fish distribution patterns. It is worthwhile to comment on each area. These comments also refer to the scatter plots shown in Figures 2-5.

In the smallest area, Fjellangervåg, (Fig. 2A and 8A) a rather homogeneous scattering layer gave a low coefficient of variation even at low degree of coverage. In Straumsosen + Spjeldnesosen (Fig. 2B and 8A) a couple of large schools dominated the total estimate in some of the coverages leading to a high coefficient of variation even at a reasonable degree of coverage. In these cases the coefficient was kept at the same level when the coverage was reduced, because then at most one of the large schools occurred in each coverage.

In the Fjords (Figures 3A,3B,8B and 8C) day-time observations and night-time observations are treated separately. Schooling during daytime made the fish distribution more patchy, on a small scale, compared to night. This seems to explain the tendency towards higher coefficients of variation during day. There are also large differences between series of coverages during day. The upper curve in Figure 8C represents a series of coverages when the total estimate was dominated by a few large schools, while the lowest curves represent cases when a number of small schools were distributed over the whole surveyed area.

In Aglen (1982a) I have shown that the night-time observations in the fjords and fjord inlets were influenced by the threshold effect: low volume densities of fish were more seriously underestimated than were

densities. During night, scattering layers of variable densities occurred. Therefore the coefficient of variation of the night-time observations might have been smaller if better equipment with negligible threshold problems had been used. Day-time schools were not significantly influenced by the threshold.

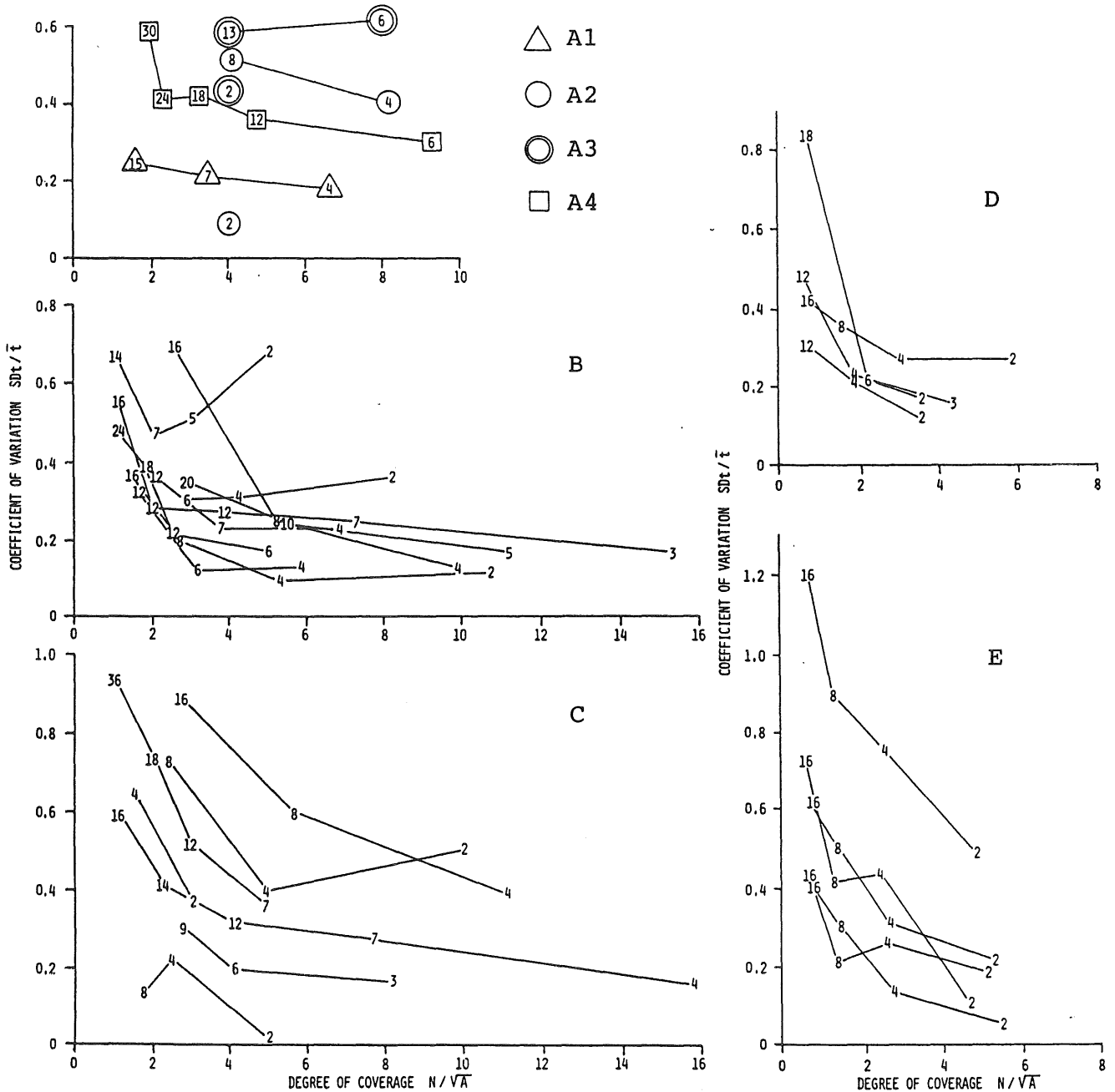


Figure 8. Coefficient of variation versus degree of coverage. The number of estimates is given at each point. Points belonging to the same series of surveys are connected with lines. A1: Fjellangervåg, A2: Straumsosen + Spjeldnesosen, night, A3: Straumsosen + Spjeldnesosen, day, A4: Lofoten, B: Fjords, night, C: Fjords, day, D: Gulf of Oman, E: Barents Sea.

Schooling by day was less pronounced in Lofoten, and much of the variability shown in Figures 4A and 8A may have been caused by larger-scale patches. In addition, significant amounts of fish may have migrated into or out of the area (Blindheim and Nakken 1971). In the Gulf of Oman (Figures 4B and 8D) most of the fish were found in nearly continuous scattering layers. Some high-density areas, typically extending 20-30 nautical miles may have caused much of the experienced variability. In addition, the mentioned tendency of differences between day and night may have caused some variability. In the Barents Sea (Fig. 4C and 8E) it was both a small scale patchiness due to schooling by day and a number of patches in a larger scale (10 to 50 nautical miles extension).

To examine differences between areas, a curve fit is made for each of the areas with more than 12 points. The points are fitted to equation (5) by an iteration program (Dixon *et al.* 1983), searching for the values of a and b giving the minimum sum of squares. The points are given weight equal to the square root of the number of observations (n). The parameters giving the best fit are shown in the following table, together with their asymptotic standard deviation.

	a	SD(a)	b	SD(b)	n
Fjords, night	.52	.05	-.47	.11	32
Fjords, day	.79	.10	-.46	.14	23
Gulf of Oman	.41	.05	-.53	.22	13
Barents Sea	.53	.06	-.56	.21	20

In equation (5) a describes the level of the curve and b the shape of the curve. The differences between the estimated values of b are all less than the calculated standard deviations. Even though it is not known what kind of distribution the estimates of the parameters belong to, it can be concluded that the differences are not significant as long as they are smaller than the standard deviations. By the same argument it can also be concluded that the estimated values of b are not significantly different from -0.50 which is the theoretical value assuming independent transect estimates.

Some of the differences between the estimated values of a are larger compared to the asymptotic standard deviations. The most outstanding value is the one representing daytime observations in the Fjords. This seems to be significantly larger than all the others. The differences between the other values does not appear to be significant.

Schooling by day in the Fjords is already mentioned as a reason for high variability. In Straumsosen + Spjeldnesosen day and night observations were also treated separately, but no curve fit is made due to few observations. In Figure 8A the same tendency of higher coefficients of variation during day is visible. Thus the general trend of the data from these small areas is that the coefficient of variation is higher for schooled fish (during day) compared to dispersed fish (during night). The two points of high coefficient of variation observed during night in Figure 8A represent a period just prior to spawning. Most of the herring were concentrated in a small part of the total area, and did not disperse much during night.

The observations in the Barents Sea were made on both schooled and scattered fish. The curve fit for this area gives values quite close to the values for scattered fish in other areas (fjords during night and Gulf of Oman).

It seems likely that the precision of the surveys in the Barents Sea was less sensitive to schooling than the surveys in the small areas discussed above. The reasons are given below.

In the Barents Sea the transects were long compared to the average distance between schools so that each transect hit a number of schools. In the small areas the transects were much shorter compared to the distance between schools so that many transects did not hit any school, while a few hit one or more, thereby giving a high inter-transect variation and a high coefficient of variation for a given degree of coverage. During night the schools usually dispersed in both areas, so that the average "school distance" was considerably reduced and many "schools" even overlapped. This situation clearly reduced the inter-transect variation in the small areas. In the Barents Sea the probability of hitting a reasonable number of schools by a transect

was already high during day, and the improvement due to reduced school distance has probably had less impact on the overall precision.

As mentioned, much of the variability observed in the large areas is caused by larger-scale patches. In the Barents Sea during day such patches were recorded as groups of schools. The distance between such patches did not significantly decrease when the schools dispersed. Thus the variability caused by large-scale patches is not likely to have changed much from day to night.

Standard echo integrator surveys do not give precise information on the size of or distance between groups of schools, but most surveys on schooled fish show that schools tend to occur in groups. Fiedler (1978) shows the distribution of size of school groups observed during sonar surveys on anchovies in the California current. The diameter of the groups ranged from 1 to 60 nautical miles. The mode of the distribution was at 9 nautical miles. Cram and Hampton (1976) show results from airplane mappings of pilchard schools off the southwest coast of Africa. They found elongated groups of schools with a typical width of 3 to 5 nautical miles and lengths ranging from 5 to 50 nautical miles. The distance between neighbouring groups was in the order of 10 to 100 nautical miles.

Based on the above discussion some generalisations might be made. If we assume that the distance between schools and the size of schools are approximately the same in small and large areas, the precision is most sensitive to schooling in small areas. This does not necessarily mean that the precision for a given degree of coverage is poorer in small areas, because in large areas larger-scale patches may have the same impact on precision as individual schools have in small areas.

4.3 Predicted coefficients of variation

The fitted equations represent averages of various fish distribution patterns and survey grids. These might be useful as a guide to the necessary effort during planning of a survey, but when calculating the

precision of the survey results, it is important to be able to utilize the variability of the data collected during that particular survey. Through the paper I have considered the transect-to-transect variation together with the degree of coverage as key parameters determining the precision. In the case of independence between transects, equation (2) gives an unbiased estimate of the coefficient of variation. To look for indications of inter-transect dependence, I have calculated the autocorrelation between neighbouring transects for some coverages. These are shown in Table 3.

Table 3. Autocorrelation (r) between neighbouring transects.
 n=number of transects, d=distance between transects (nautical miles).
 *: significantly different from zero at 10% level
 **: significantly different from zero at 5% level

	Survey		d	n	r	
S M A L L A R E A S	Fjellangervåg, sep-77 (night)	coverage 1	.06	11	.562*	
		coverage 2	.06	11	.199	
		coverage 3	.06	11	.807**	
		coverage 4	.08	7	.259	
	Samlafjord, mar-78 (night)	coverage 1	.5	8	.367	
		coverage 2	.5	8	-.477	
		coverage 3	.5	8	-.154	
	Eidfjord, mar-78 (day)	coverage 1	.5	32	.113	
		coverage 2	.5	32	.159	
		coverage 3	.5	32	.492*	
	L A R G E A R E A S	Gulf of Oman, jan-81	coverage 1	20	6	.837*
			coverage 2	20	6	.127
coverage 3			20	6	.117	
feb-83		coverage 1	20	8	-.185	
		coverage 2	20	8	.598	
sep-83			20	12	.081	
nov-83			20	12	.266	
Barents Sea		1974		25	16	.385
		1975		25	16	-.103
		1976		25	16	.178
	1977		25	16	.179	
	1978		25	16	-.063	

A few of the autocorrelations are significantly different from zero according to a t-test given by Zar (1974). All significant values are positive. With the number of applied transects, this test requires

rather high absolute values to give significance. If there is a general independence, negative autocorrelations should be as likely as positive ones (a binomial case). The table shows two negative values in the small areas and three in the large areas. In the case of independence, the probability of having the observed number or less of negative values is 0.06 for the small areas, 0.07 for the large areas and 0.009 for the total.

The conclusion has to be that some positive dependence between neighbouring transects exists, at least for some of the coverages. Such dependence seems to exist even in the large areas where the distance between transects is large.

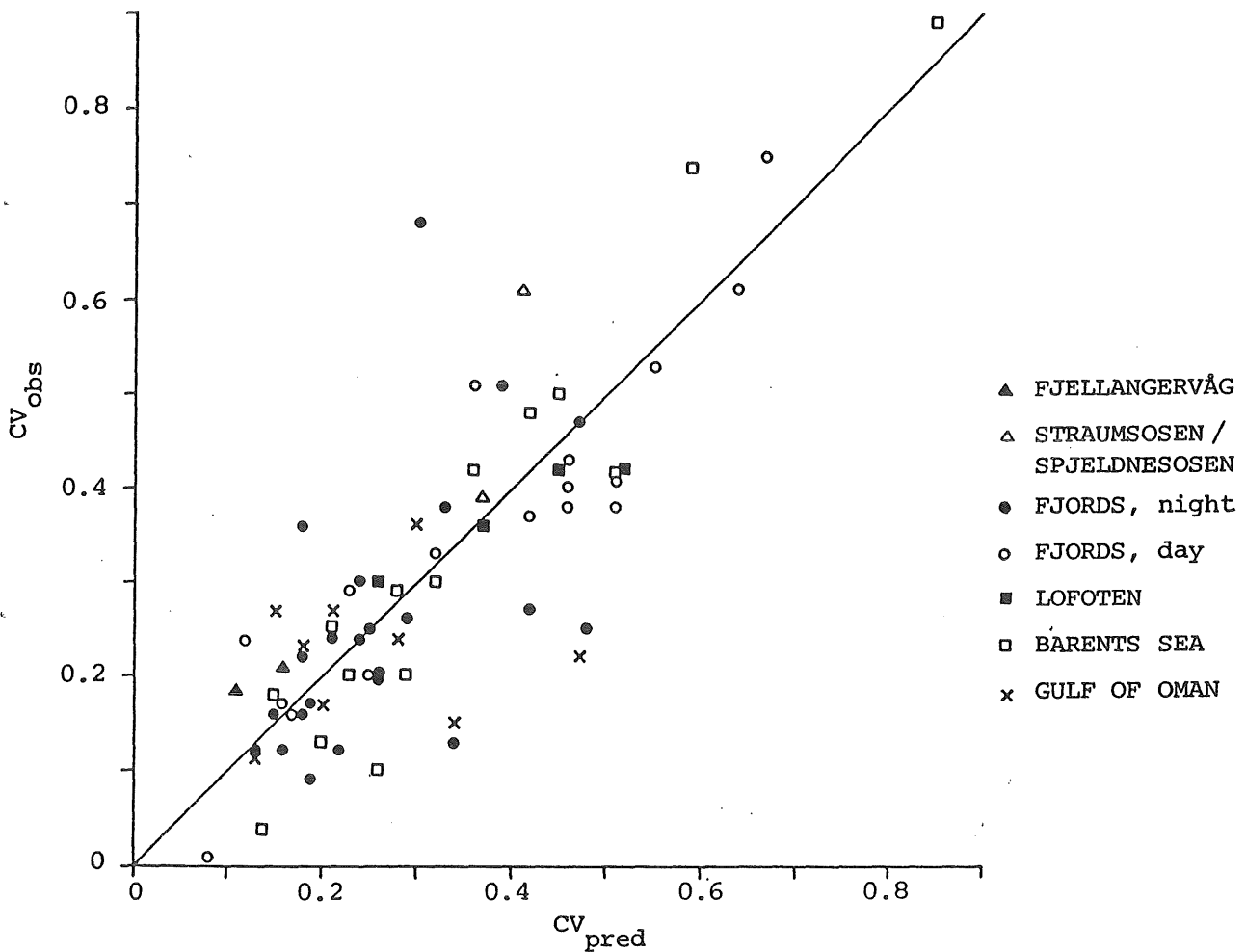


Figure 9. Observed values of coefficient of variation (CV_{obs}) plotted against predicted values (CV_{pred}). The 1:1 line is shown.

An important question is whether the dependence leads to serious

biases when using equation (2) to estimate the coefficient of variation for survey estimates. Figure 9 compares the observed coefficients of variation with those predicted from equation (2). The observations of $CV(t)$ for single transects are not presented because in those cases $CV(t) = CV(M_A)$ and the points have to fall on the 1:1 line in Figure 9.

A linear regression of the points give $CV(obs) = 0.94 \cdot CV(pred) + 0.02$, and the correlation coefficient is 0.819. Applying estimators given by Zar (1974), the 95% confidence limits for the slope is 0.67 and 1.21 and for the intercept -0.07 and 0.11. A regression through the origin gives 0.91 and 1.04 as confidence limits for the slope. These confidence limits are based on unverified assumptions about normality. It is, however, clear that the regression does not give evidence of bias when using equation (2) or (4) to estimate the coefficient of variation of survey estimates. The estimated confidence limits indicate that if a bias exists, it is of minor importance for this material.

5. CONCLUSIONS

The defined degree of coverage seems convenient for comparisons of precision - effort relationships from different areas. The scatter of relative abundance estimates shows the same tendency in small and large areas: for a common degree of coverage the distribution of estimates is not seriously different from a normal distribution, while it becomes increasingly skewed towards low values for decreasing degrees of coverage. The general relationship between the coefficient of variation and the degree of coverage appears similar in small and large areas. In small areas the coefficients of variation observed for schooled fish tended to be higher than those observed for dispersed fish.

The likely dependence of neighbouring observations may be the main reason why the precision of acoustic survey results is estimated so seldom. The examined material shows that such a dependence tends to

occur both in small and large areas. However, the dependence does not appear strong enough to cause any serious bias when estimating total variance from the inter-transect variance.

A common degree of coverage for stock assessment surveys is of the order of 10 which gives coefficients of variation ranging from 0.1 to 0.4. For this degree of coverage the precision gained by a moderate increase in effort is quite small. The largest gain in precision will in many cases be achieved by searching for periods when the fish distribution is most favourable, thus reducing the inter-transect variation.

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