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Modifications to the Design of the Trawl Survey for *Pandalus borealis* in West Greenland Waters: Effects on Bias and Precision

by

M.C.S. Kingsley[1], P. Kanneworff[2] and D.M. Carlsson[2]

Greenland Institute of Natural Resources
[1]P.O. Box 570, DK–3900 Nuuk, Greenland
[2]Pilestraede 52, P.O. Box 2151, DK–1016 Copenhagen K

Abstract

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A stratified random sample survey based on one-hour trawl stations has been carried out since 1988 as a component of the assessment of the stock of northern shrimp *Pandalus borealis* in offshore West Greenland waters. Survey procedures were reviewed in early 1998 and again in 1999, and the 1998 and 1999 survey practices were consequently modified as follows: in 1998 and 1999, 25% of the offshore stations, were shortened to 30 minutes, and in 1999 the tows at a further 30% of stations were shortened to 15 minutes; in 1999, the placing of stations independently and randomly was replaced by buffered random sampling, in which stations were randomly placed but prohibited from being closer together than a prescribed limit; also in 1999, 40% of station positions were fixed from the previous year.

Shortening the tows appeared to have no effect on the precision of the estimate of total biomass from the survey: 15-minute and 30-minute tows made catches that in a given stratum were no more variable than the 60-minute. Mixing of tow durations in a single survey allowed us to estimate the end error at +15% of the swept area of a 15-minute tow, and to predict that surveys based on short tows would be biased upwards relative to long-tow surveys.

Buffered random sampling gave an even distribution of stations within strata, and nearest-neighbour distances were on average increased by 50%. However, the statistical effects were small, and the estimated standard errors did not change much from previous years in which sampling was random and independent.

It appeared that fixing stations from year to year could double the precision of estimating change in total biomass.

Precision may be improved by using information on stratum variances from past surveys to predict future variation and re-allocate stations to increase sampling effort in strata with high variances in past years.

Introduction

The northern shrimp (*Pandalus borealis*) stock off West Greenland occurs in NAFO Divisions 0A and 1A–1F**,** mostly in water between 150 and 600 m deep. The offshore fishery for shrimp in Davis Strait (SubArea 1 and Division 0A) began as a multinational fishery around 1970. Landings have steadily increased since the beginning of the fishery to a level of around 70000 tons in the 1990s. Catch restrictions were enforced in 1977 and since then the stock has been managed by total allowable catch (Hvingel and Folmer 1998).

A trawl survey is a component of the assessment process for this stock, and has been carried out annually since 1988 (Carlsson and Kanneworff 1998a; b). The survey is based on a stratified random design. The survey area—waters from 150 to 600 m deep between the southern tip of Greenland and 72° 30’ N on the west coast—is divided into geographical sub-areas. For convenience in discussing the distribution of the stock, the areas are aggregated into regions: N(orth) comprising 9 areas lies between 69° 30’ N and 72° 30’ N; region D(isko) also of 9 areas comprises the inshore waters of Disko Bay and the Vaigat; W(est) (7 area) is the offshore Greenlandic waters from 69° 30’ N south and east to 48°20’ W about 60°10’ N; and the 2 small areas making up region S(outh) extend south to about 59°10’ N. C(anadian) waters on the Greenlandic shelf lie between about 67°25’ N and 68°40’ N and are divided into 2 areas (Table 1). Areas for which good bathymetry is available are further divided into depth strata: 150–200 m, 200–300, 300–400 and 400–600; those for which this information does not exist are also strata. The survey was initially designed on standard principles: trawl stations were allocated proportionally to stratum area; stations were reselected for every survey; stations were randomly and independently placed; tows lasted one hour offshore, although half-hour tows were always used in Disko Bay and Vaigat. The allocation of stations proportionally to stratum area has since been modified. Few stations are now allocated to the shallowest and deepest strata where commercially valuable large shrimp are relatively scarce and region N, largely abandoned by the fishery, is very sparsely sampled. The way in which stations were placed was modified *ad hoc* so that the worst features of independent random sampling were mitigated.

The design of the survey and the analysis of the resulting data were reviewed in 1998 and 1999 (Carlsson et al. 1998) and some changes were suggested. Among those that could modify the design and execution of the survey were: a) shorten the tows; b) abandon independent random placing of trawl stations; c) fix stations from year to year; d) review the allocation of stations. Most of these suggestions were simultaneously implemented in the 1999 survey. This document reviews the reasons for making such changes, their expected effects on the estimation of total stock biomass, and the results obtained.

<u>Shorter tows.</u> Marine resources are often distributed with strong short-range spatial autocorrelation. Such a distribution implies that a small sample at a station provides almost as much information on the local density as a large one, at lower cost (Gunderson 1993). Existing information (which, however, related mostly to other marine species) appeared to show that a trawl tow lasting one hour and extending over 2½–3 miles was well into the area of decreasing returns of information. In 1998, about 25% of the offshore stations were sampled with half-hour tows. In 1999, it was planned that 25% would be sampled with half-hour tows and 25% with quarter-hour tows.

The expected benefit—being able to fish at more stations within the survey period—was realised. 230 stations were fished at in 1999, an increase of 36 stations (15.6%) over 1997 when all tows in the offshore survey lasted for one hour.

This document presents analyses of the effect of shorter tows on the accuracy of the survey.

<u>Non-independent sampling.</u> Medium-range spatial autocorrelation of resource density, which is also common, implies that information is inefficiently gathered if sampling stations are close together. Independent random sampling distributes sampling stations in such a way that nearest neighbours are often close together, while large spaces may be left blank. This is statistically inefficient, and also reduces the confidence of user groups (fishermen) in the survey results. Systematic sampling is more efficient for autocorrelated populations (Cochran 1977), but is inconvenient in stratified designs where the strata are of odd shapes and the sampling density varies from stratum to stratum.

For the 1999 survey buffered random sampling was used. I.e. stations were randomly placed subject only to a restriction that no two stations could be closer together than a certain limiting distance (the ‘buffer’). The limiting distance depended on the target stratum sampling density and was chosen by trial and error to be such that the required number of stations could be fitted into all the strata in about a one-hour computer run. To avoid a bias toward placing stations near the edge of the stratum, where there were fewer competing stations, a margin was placed round the stratum; dummy stations could be placed in the margin. The boundary was thus invisible to the sampling process, which was stopped when the required number of stations had been placed within the stratum.

Buffered sampling is expected to share the statistical properties of systematic sampling:

- the true standard error is less than that obtained by independent sampling;
- no unbiased estimate of true standard error is available;
- the expected value of the conventionally estimated standard error is increased, and *a fortiori* overestimates the true standard error;
- nearest-neighbour distances are uniform in systematic sampling and relatively uniform in buffered sampling, and differences between catches at neighbouring stations can provide a usable estimate of standard error that may be less biased than the conventional estimate.

These effects are correlated. If buffered sampling significantly reduces the true standard error, then *ipso facto* the conventional estimate may be expected to overestimate it. This document presents analyses of the effect of buffered sampling on the precision of the survey, and alternative estimates of standard error for selected strata.

<u>Fixed stations.</u> When surveys are designed using independent random sampling, stations are usually re-placed for each survey. The between-survey variation in the distribution of stations is thus maximised, and consecutive survey results are made statistically independent. The behaviour of the survey series is thus made independent of changes in the spatial distribution of the stock. However, sampling designs based on systematic or buffered sampling, with a more even distribution of stations, are less sensitive to changes in stock distribution. Therefore, there is less reason to select stations anew for each survey.

Fixing stations from survey to survey may permit more sensitive tracking of changes in stock size provided that the distribution of the stock changes little between surveys. In 1999, the positions of 40% of the stations were retained from those used in 1998. This document presents analyses of the between-year correlations in catches within strata, and assesses the usefulness of fixed stations in detecting changes in stock size.

<u>Station allocation to strata.</u> A major determinant of survey precision is the way in which stations are allocated to strata. It can be critically important to ensure that effort is allocated where variation is large. If there is a single stratum with high catches, high catch variation, and few stations, the precision of the entire survey may be irretrievably compromised. The effect of such a situation on the standard error of the estimate is aggravated by the associated reduction in the degrees of freedom, which further inflates any calculated confidence intervals. This document reviews the allocation of stations in the light of existing data on the distribution of biomass and the historical contributions that different strata have made to the uncertainty of the total estimate.

Methods

<u>Shorter tows.</u> We carried out a simple analysis and a complicated analysis. For the simple analysis, we classified tows by actual towing time to the nearest multiple of 15 minutes. For every combination of towing time class and stratum for which it was possible (i.e. at least 2 tows in the class and stratum) we calculated the mean and variance of nominal density (i.e. catch divided by nominal swept area). We then calculated the relationship between stratum mean density and the within-stratum density variance for each class of duration. We expected that for a given stratum mean density, shorter tows would be more variable.

The complex analysis fitted a comprehensive multivariate model to all the data. A mean density D_S was fitted for each stratum. Within-stratum density variance was modelled as a power function of the stratum mean density (Taylor 1961). Short-range (i.e. within-tow) density variation was modelled as an additional component of variance that was a multiple of the within-stratum variance. A fixed end error E was assumed for all tows. The input data for each station consisted of stratum S, nominal swept area N, and catch C. True swept area T_i for the i^{th} station was given by:

$$T_i = N_i + E$$

and predicted catch by:

$$P_i = D_S \cdot T_i$$

The total uncertainty variance of the predicted catch was estimated by

$$V_i = (D_S \wedge b) * (a \cdot T_i \wedge 2 + c \cdot \overline{T} \cdot T_i)$$

and the log. likelihood of the observation by:

$$2\ln(l) = -(C_i - P_i)^2 / (V_i) - \ln(V_i)$$

a, *b*, *c*, *E*, and the 52 stratum densities D_s were fitted simultaneously by a spreadsheet mathematical programming routine to maximise the sum of the log. likelihoods.

Non-independent sampling. The effect of non-independent sampling on survey precision was estimated by calculating how stratum mean density was related to estimated within-stratum density variance, and seeing whether that relationship was the same for buffered sampling as for the independent sampling of previous years. (If, for a given stratum mean density, estimated within-stratum variance increased, this would be *prima facie* evidence that the true standard error had been reduced, i.e. that the survey had been made more precise. See Cochran 1977)

The following analyses were performed:

- compare the distribution of nearest-neighbour distances under buffered sampling with that under independent sampling;
- compare the conventional estimate of within-stratum standard deviation with an estimate obtained from the sum of squares of near-neighbour differences;
- fitted an autocorrelation model to the relationship between the distance between two points and the difference between their densities;
- compare the variance-to-mean relationship under buffered sampling with that under independent sampling.

For all stations in region Disko we determined which were their nearest neighbours, regardless of stratum boundaries. We calculated the difference in density estimates between the neighbouring stations, and used the sum of squares of these differences as the basis for an estimate of the area standard error:

$$SE = \frac{\sqrt{\sum \Delta_i^2 / 2n_\Delta}}{\sqrt{n_S}}$$

Δ_i being the i^{th} nearest-neighbour difference in density, and n_Δ and n_S respectively the number of near-neighbour differences entering into the calculations and the number of stations in the area. We did the same for a composite area consisting of region Canada plus the five northern strata in region West, extending the measurements in this case to the three nearest neighbours, and compared the resulting estimates of standard error with conventional estimates.

A simple model of spatial autocorrelation was fitted to data from pairs of stations for regions W and C for 1998 and 1999:

$$\Delta \ln(Density) \cap \mathrm{N}(0, s^2 \cdot (1 - r^{Distance/k}))$$

where $\Delta \ln(Density)$ was the log. of the ratio of the nominal densities of two trawl stations that were in the same region, area, and depth stratum and were separated by ***Distance*** km; ***k*** (km) was an arbitrary scaling constant. The values of r and s^2 were fitted by maximum likelihood.

Fixed stations. There were in all 92 fixed stations. 21 strata each had only 1, 10 had 2, and 11 had 3 or more. We calculated the between-year correlation coefficients by stratum for the strata with 2 or more. We also calculated a stratified estimate of the biomass and its standard error for 1998 and 1999 separately, and the difference, as well as a stratified estimate of the change in biomass from the station-by-station differences. A similar, but separate, unstratified analysis was carried out for the 21 strata that had only one fixed station.

Allocation of stations. With the available information on the 1999 within-stratum variation, we designed an optimal allocation of stations as though we had had perfect knowledge in advance. We also estimated a predicted pattern of within-stratum variation from the exponentially smoothed survey results for 1994 through 1998, and used that to make an optimal allocation of stations. We calculated the resulting regional and overall standard errors of estimation for total biomass and their effective degrees of freedom (Satterthwaite 1946).

Results and Discussion

Shorter tows. The simple analysis showed no greater within-stratum variation in estimated density for short tows than for long ones (Fig. 1). The long tows were in fact slightly more variable in estimated density for a given stratum mean.

The complex analysis produced the same result, i.e. the only significant component of variance was that between stations (Table 2). We were unable to detect any increased variability in density estimates when tows were shorter: the maximum-likelihood estimate of the within-station component of variance was negative (Table 2). It was therefore constrained to be zero. These results justified using station density estimates unweighted by tow duration in calculating the stratum and overall biomass estimates.

Previous studies have usually shown that small samples can be more efficient than large ones for estimating density of many marine resources (Gunderson 1993; Pennington and Vølstad 1991; 1994). The inshore shrimp survey in Disko Bay and Vaigat, West Greenland, has always used 30 minutes as a standard tow duration, and results have never been noted as less precise than those of the one-hour-tow offshore survey. In 1998, about 25% of the tows in the offshore West Greenland shrimp survey were made to last 30 minutes, and a simple analysis did not show that they were on average any more variable than one-hour tows (Carlsson and Kanneworff, unpublished). In a 1997 experimental study of shrimp distribution, 7 one-hour tows were made contiguously along each of 3 constant-depth transects (Carlsson 1997; Kingsley and Carlsson 1998). That study showed no short-range correlation, but instead an apparent pattern of random variation between adjacent tows. This therefore would have predicted that longer tows would have gleaned some more precise information about local density than short ones; however, the coefficients of variation along the length of those transects were only 30–40%, compared with within-stratum coefficients averaging 100% that usually occur in the survey. The design and analysis of the 1999 survey did not provide information that would allow us to calculate an optimum tow duration.

The complex analysis also furnished an estimate of the end error of towing. This was about 3400 sq. m. (SE 1540 sq. m) or about 3¾% of the average area of a 60-minute tow (Table 2). From the small catches made in 5 experimental tows of zero duration the end error was estimated at about 3000 sq. m., but they were all made in the same place and may have cumulatively thinned the local density. Based on this estimate, a survey based on one-hour tows would produce a biomass estimate that is biased upwards by about 3¾%, one based on 30-minute tows would be biased by 7½%, and one based on 15-minute tows would be biased by 15%. The 1999 survey with roughly 29% one-hour tows, 44% half-hour, 3% ¾-hour and 23% 15-minute tows would be biased upward by nearly 8%; relative to the traditional survey with 76% offshore one-hour tows and 24% half-hour tows in Disko Bay, it would be biased upwards by about 3¼%, but it is roughly unbiased relative to a half-hour-tow survey. Designing surveys to use only 15-minute tows would result in estimates of biomass nearly 11% greater than those obtained from the traditional design.

We recommend that 60-minute tows should be discontinued. For 2000, we recommend a mixture (to be determined) of 15-minute, 30-minute, and 45-minute tows. We also recommend repeating this year's analyses to re-estimate the end error and the effect of shorter tows on the bias and precision of the survey result.

Non-independent sampling. Buffered sampling gave a more even spacing of stations (Fig. 2), and increased the mean nearest-neighbour distance. The statistical effects on the precision of the survey were hard to detect (i.e. undetectable). The power relationship of conventionally calculated within-stratum density SD and stratum mean density was looked at for 1997-99 (Fig. 3). There was some variation, it was not statistically significant ($F_{4, 138} = 1.947$), and standard deviations for 1999 were not larger than for the other two years. Buffered sampling has not increased the estimated standard deviation.

For random samples from autocorrelated populations, standard errors calculated from nearest-neighbour distances are under-estimates of the true survey standard error, while the conventional estimate is unbiased. However, if sampling is systematic, the conventional estimate is an overestimate, and an estimate based on nearest-neighbour distances is less biased. We calculated estimates of standard error based on the mean squared nearest neighbour differences, and on the mean squared differences up to the third nearest neighbours, for a large region comprising strata W1 through W5 and region C. We also calculated an unstratified SE for the same region using the conventional expression. The SE based on nearest-neighbour differences was 11% less than the conventional estimate, and that based on differences up to 3rd nearest neighbours was 4% greater. A simple 2-variable autocorrelation model was fitted to independently sampled data from 1998 and to buffered-sample data from 1999 for regions W and C (Table 3). The two years had spatial autocorrelation coefficients that were statistically significant (i.e. non-zero), but not significantly different. In 1998 the density was significantly more variable. (Fig. 4). The spatial autocorrelation is however not high enough for buffered sampling to have marked statistical effects on the precision of survey results, given that even under 'random' sampling ad hoc methods were used to control nearest-neighbour distances.

A disadvantage of buffered sampling was that stations were evenly spaced—which was the intention. However, this meant that there were no clumps of closely spaced stations that suggested themselves as a day's work, separated by long steams that could be done overnight.

We recommend retaining buffered sampling, and perhaps examining more efficient algorithms for selecting stations with a view to being able to use a higher packing constant.

<u>Fixed stations.</u> Year-to-year correlations of catches within strata were based on a total of 51 stations in 11 strata each having 3 or more fixed stations. They ranged from -0.317 to 0.996 and were overall significantly positive ($\Pi^2_{11} = 33.5$***). Of the correlations within strata that had only 2 fixed stations, 8 of 10 were +1 and the other 2 were -1.

The stratified analysis of the data from 92 fixed stations in 21 strata each having 2 or more estimated a biomass of 188 550 mt (SE 41 174) in 1998 and 215 721 mt (SE 59 179) in 1999. The simple difference is 27 172 tons with SE 72 093. Using a stratified analysis of the station-by-station differences the estimated change in the total biomass is the same (of course) but its standard error is reduced by 52% to 34 875. I.e. from the results of this analysis, fixed stations would roughly double the precision of tracking changes from year to year in stock biomass. However, for the 22 strata which had only 1 fixed station each, an overall (unstratified) between-year comparison indicated low year-to-year correlation (0.226), and no great improvement from using a paired comparison: the standard error was reduced by 5%. This is probably because such strata are mostly poor and variable. (The combined standard error is 72 254 using an unpaired analysis and 35 177 using paired analysis.)

If independent random stations are re-placed every year, the between-year variation in estimating the biomass of an unevenly distributed stock is made large. Because the distribution of stations varies from year to year, the between-year variation in biomass estimate also becomes largely independent of whether the distribution of the stock remains the same, or varies from year to year. This avoids mistaking a change in stock *distribution* for a change in stock *biomass*. I.e. under independent random sampling, there is a reason for renewing the sample every year. However, using systematic sampling or a buffered-sampling approximation to it, the distribution of stations is more uniform and the estimate of stock biomass is less affected by changes in stock distribution. There is therefore less reason to continually re-place stations, and so in systematically sampled fishery surveys, stations are often fixed: this is so generally true, that in fishery survey parlance, 'fixed stations' is commonly used to mean 'systematic sampling'. I.e. while it appears that fixed stations are efficient at detecting changes in stock biomass, there are drawbacks to fixing stations unless sampling is buffered or systematic.

We recommend raising the proportion of fixed stations to between 60% and 70% in 2000. Consideration may also be given to incorporating paired analyses in the assessment procedure.

<u>Allocation of stations.</u> Previous studies have shown that survey stratification and good station allocation are effective in improving the performance of sample surveys (Gavaris and Smith 1987; Smith and Gavaris 1993). In particular, stratification on the basis of past fishery performance can be more effective than stratifying on the basis of known habitat characteristics. Therefore, it may be appropriate to use the data on stock distribution accumulated from past surveys or fishery monitoring to modify the allocation of stations to survey strata.

The survey biomass estimate for 1999 (287 402 mt) had a SE of 40550 (Table 4a), giving an error CV of about 14% on 8.8 effective degrees of freedom (Table 4a). If trawl stations had been optimally allocated to strata with foreknowledge of the variability that would be observed, and with a limit of 2 stations per stratum, the SE and ECV would both have been halved, and the effective degrees of freedom would have been increased to 149 (Table 4b). (This result would not have been much affected if the limit had been 3 stations per stratum instead of 2. It is however an unrealisable optimum, as the distribution could not be known in advance and will not be repeated.)

Stratum variances from 1994 through 1998 were exponentially smoothed ($pred._{t+1} = 0.2 \times actual_t + 0.8 \times pred._t$) and input to an optimal allocation algorithm. Such an allocation used in 1999 would have resulted in an ECV of 11.4% on 30.4 degrees of freedom (Table 4c, 4d). A limit of 3 stations per stratum would have given better results than 2 stations/stratum, because it would have protected better against high variability in strata that had never before, or not recently, had high catches or high variances.

The smoothing of past variances was extended to include the 1999 data and used to design an optimal allocation that may be considered for use in 2000 (Table 5). The most significant changes in station allocation consist of re-directing sampling effort between large or variable strata that already have more than the minimum number of stations. Most of the strata that have the minimum number of stations are small or poor, and do not change much.

Conclusion

The 1999 West Greenland trawl survey for northern shrimp mixed 15-minute, 30-minute and one-hour tows and also had 40% of stations fixed from the previous year. The station positions were chosen by buffered sampling, which was also an innovation. Analyses of this mixed design showed that there was high short-range spatial autocorrelation, so that short tows appeared to collect about as much information on local density as long ones. However, medium-range spatial autocorrelation appeared to be low, so that buffered random sampling offered little or no more precision than independent sampling. Within strata, catches at fixed stations appeared well correlated between years, and a stratified analysis of the year-to-year differences by station doubled the sensitivity of detecting changes in biomass.

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Tables

Table 1. Regions and stratification of the West Greenland shrimp survey.

Region	Description	No. of areas	Depth sub-stratification	Total area (sq. km)
C	Greenlandic continental shelf waters west of the dividing line, near 68° N; contiguous with region W	2	Yes	3442
D	Inshore waters of Disko Bay and Vaigat	9	No	9364
N	Offshore waters from 69° 30’ N to 72° 30’ N	9	No	38517
S	Southern offshore waters east of 48° 20’ W	2	No	6519
W	Offshore waters from 69° 30’ N south and east to 48° 20’ W at about 60° 25’ N	7	Yes	66853

Table 2. Maximum-likelihood estimates of the components of catch variability in a trawl survey for northern shrimp in West Greenland waters.

	Maximum likelihood estimate	Simple SE	Partial SE[2]
Exponent of stratum mean density (b)[1]	1.986	0.057	0.022
Coefficient of power function for between-station variance (a)[1]	0.972	0.284	0.165
Coefficient of power function for at-station variance (c)	-3.66E-2	6.40E-2	–
End error (E)[1] (sq. m.)	3393	1540	1538

[1] These estimates and their standard errors are made with the at-station variance constrained to be zero.
[2] i.e. with other variables constrained to remain at their maximum-likelihood values.

Table 3. Maximum-likelihood estimates of the parameters of spatial autocorrelation in the distribution of northern shrimp *Pandalus borealis* in West Greenland waters, survey regions ‘W’ and ‘C’.

	Maximum likelihood estimate	Simple SE
Within-stratum autocorrelation coefficient of log. density at 20 km distance	0.777***	0.038
Std deviation of log. density ratio for stations 20 km apart, 1998	2.92[1]	0.085
Std deviation of log. density ratio for stations 20 km apart, 1999	2.19[1]	0.062

***: statistically significant at 0.1%.
[1] exp(2.92) = 18.5; exp(2.19) = 8.94.

Table 4a. Results from the 1999 shrimp survey in West Greenland waters.

Region	Est. biomass	SE	d.f.	t_{95}	Confidence interval +/-	Confidence interval %
Canada	11901	9482	1.01	12.54	120483	1012.41
Disko	61183	8414	9.95	2.23	18759	30.66
North	14442	7803	1.89	4.79	37315	258.37
South	63684	32766	4	2.78	90974	142.85
West	136192	18684	15.36	2.13	39744	29.18
Overall	287402	40550	8.82	2.27	92022	32.02

Table 4b. Results of allocating stations to the 1999 survey strata based on foreknowledge of 1999 stratum variances, with a limit of 2 stations per stratum.

Region	Est. biomass	SE	d.f.	t_{95}	Confidence interval +/-	Confidence interval %
Canada	11901	4771	7.22	2.35	11219	94.3
Disko	61183	8357	17.04	2.11	17630	28.8
North	14442	5047	9.44	2.25	11343	78.5
South	63684	10922	44.00	2.02	22012	34.6
West	136192	15577	74.06	1.99	31037	22.8
Overall	287402	21909	149.11	1.98	43293	15.1

Table 4c. Hypothetical results of allocating stations to the 1999 survey strata based on 1994–1998 smoothed data, with a limit of 2 stations per stratum.

Region	Est. biomass	SE	d.f.	t_{95}	Confidence interval +/-	Confidence interval %
Canada	11901	9484	1.01	12.57	119199	1001.6
Disko	61183	10481	7.01	2.36	24777	40.5
North	14442	8355	1.94	4.58	38225	264.7
South	63684	20321	12.00	2.18	44275	69.5
West	136192	19514	13.45	2.15	42016	30.9
Overall	287402	32609	30.35	2.04	66564	23.2

Table 4d. Hypothetical results of allocating stations to the 1999 survey strata based on 1994–1998 smoothed data, with a limit of 3 stations per stratum.

Region	Est. biomass	SE	d.f.	t_{95}	Confidence interval +/-	Confidence interval %
Canada	11901	7743	2.02	4.28	33105	278.2
Disko	61183	10036	6.97	2.37	23751	38.8
North	14442	6822	3.87	2.82	19209	133.0
South	63684	22091	10.00	2.23	49222	77.3
West	136192	19097	21.97	2.07	39621	29.1
Overall	287402	32556	33.37	2.03	66214	23.0

Table 5. Optimal allocations of stations to strata based on exponential smoothing of stratum variances from 1994 through 1999, i.e. suggested for 2000.

Area	Depth stratum			
	1	2	3	4
C1			2–2–3	1–2–3
C3		2–3–3	4–2–3	2–2–3
W1	2–2–3	14–3–3	24–10–8	2–2–3
W2	2–2–3	7–4–3	4–14–11	2–8–6
W3	2–2–3	14–9–8	7–4–3	8–3–3
W4	5–2–3	9–3–3	4–17–14	5–6–6
W5	3–3–3	9–17–14	4–7–5	7–4–3
W6	2–6–6	4–7–6	4–3–3	2–2–3
W7	2–2–3	3–6–6	2–2–3	

Area	Allocations	Area	Allocations	Area	Allocations
D1	3–6–5	N1	2–2–3	S1	5–21–17
D2	2–2–3	N2	4–3–3	S2	4–2–3
D3	4–4–4	N3	1–2–3		
D4	7–3–3	N4	2–3–3		
D5	3–2–3	N5	2–2–3		
D6	4–2–3	N6	3–2–3		
D7	6–2–3	N7	2–2–3		
D8	3–2–3	N8	2–2–3		
D9	5–3–3	N9	2–2–3		

Cell entries are the allocations of 230 stations to strata as follows: 1999 executed–2000 suggested with minimum 2 stations per stratum–2000 suggested with minimum 3 stations per stratum.

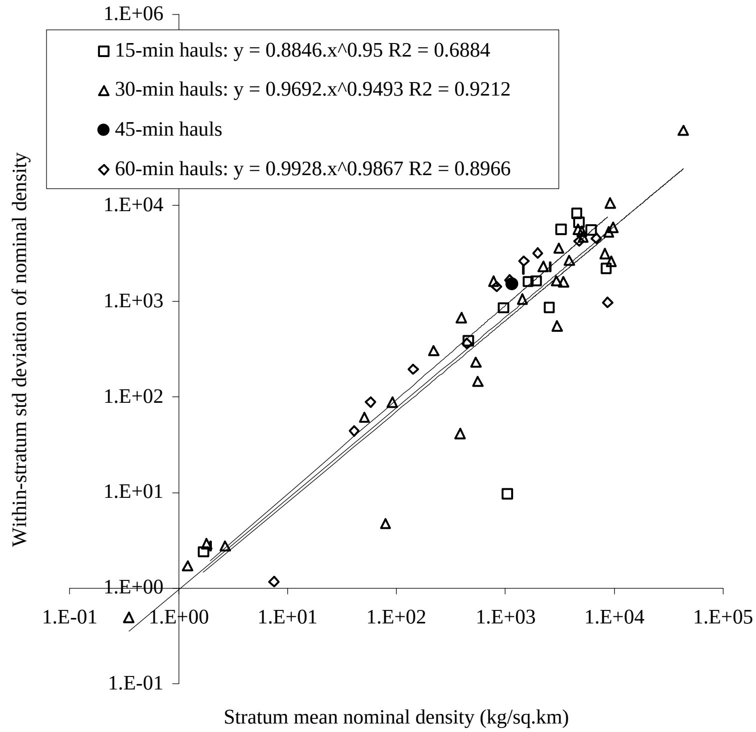

Figure 1. Within-stratum standard deviation of density (kg/sq. km) plotted against mean nominal density for trawls lasting approximately 15, 30 and 60 minutes in the West Greenland shrimp survey in 1999.

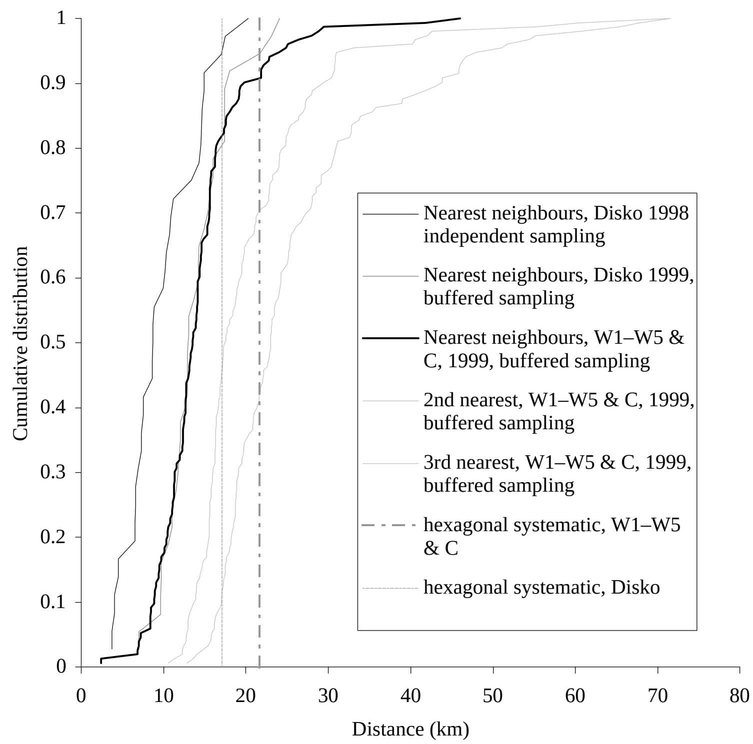

Figure 2. Near-neighbour distances in regions D, W, and C, with buffered sampling in 1999 and in region D under independent sampling in 1998.

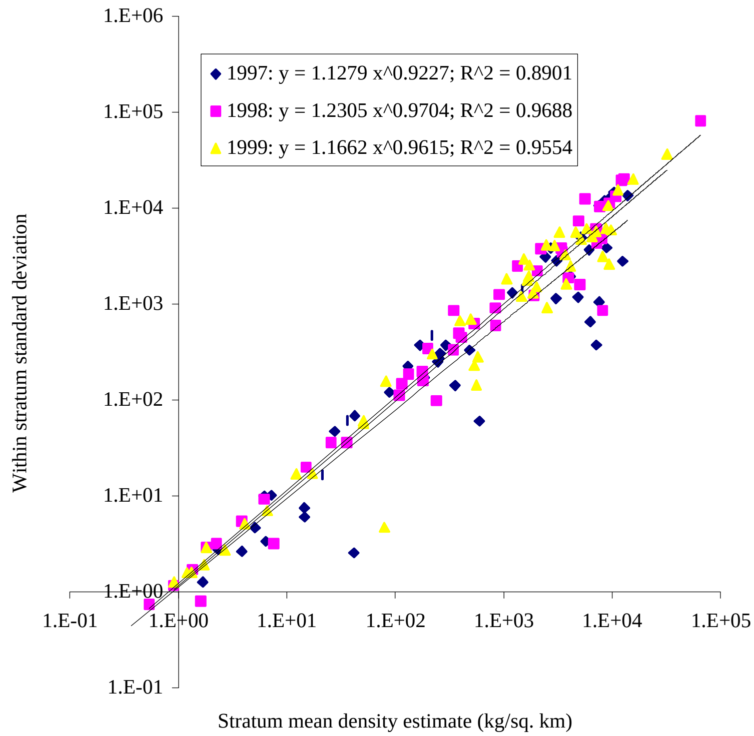

Figure 3. Stratum mean and conventionally estimated standard deviations of density estimates for independent random sampling (1997 and 1998) and for buffered random sampling (1999).

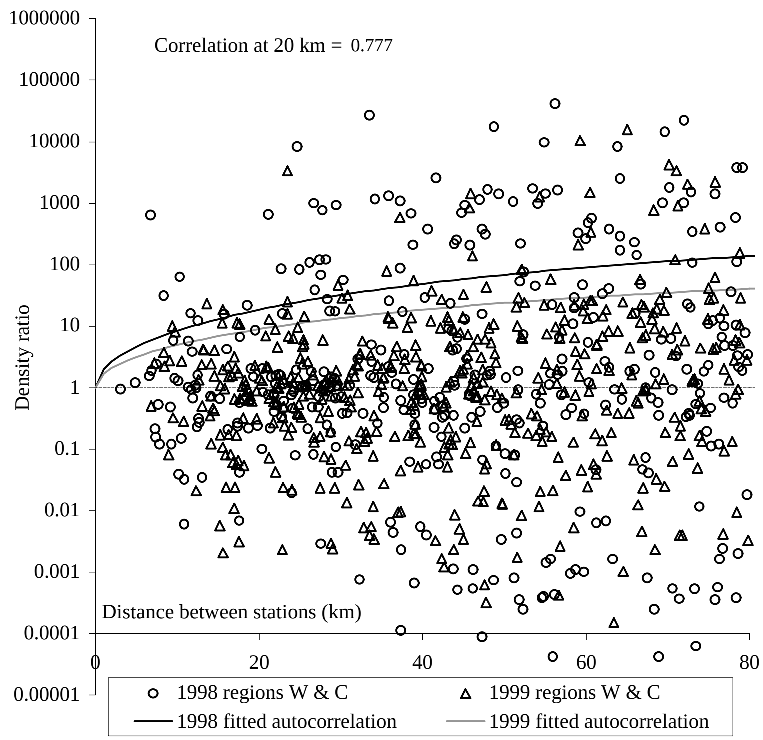

Figure 4. Within-stratum spatial autocorrelation functions for regions W and C of the West Greenland shrimp survey in 1998 and 1999.