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An Experimental Investigation on Spatial and Depth Variation in Catch of Shrimp, Greenland Halibut and Redfish

by

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Abstract

An experimental bottom-trawl survey for shrimp was carried out in early August 1997 to examine small-scale spatial structure of shrimp population densities. The survey fished at 6 or 7 stations closely spaced along each of a series of transects. 4 transects were isobathic at depths between 250 and 500 m, and 2 more both covered a range of depths from 220 to 550 m. Catches of Northern shrimp (*Pandalus borealis*), Greenland halibut (*Reinhardtius hippoglossoides*) and redfish (*Sebastes* spp.) were weighed and sampled for investigation of size compositions. Seven (7) stations on each of 2 isobathic and one variable-depth transect were repeated on the following day. The catch data was deskewed with an nth-root transform. Between-days variation was measured with correlation coefficients, and the spatial structure of the resource with serial correlation coefficients along transects.

Day-to-day variation was small, and there was good correlation between days for all species, both overall and within transects. I.e. the catch on one day appeared to be a good predictor of the catch on the next day. There was an unexpected, and quite striking *lack* of serial correlation in catches along isobathic transects for all species, as though the resource was distributed by a random process. Along the variable-depth transects, there were higher serial correlations, and overall statistical significance, as though there was a depth response. But most of this was due to a clear depth response in the catches of Greenland halibut, which increased steadily with increasing depth. In the shrimp catches alone, there was little evidence of serial correlation or spatial structure.

Introduction

The spatial distribution of shrimp at and over the bottom is an important key-factor for the design of trawl surveys to estimate the total abundance of shrimp. In 1997 a special experimental trawl survey for Northern shrimp (*Pandalus borealis*) was conducted off West Greenland, designed to examine variation in the catch of shrimp within depth, between depths, and at a given station from day to day. This was done by trawling at stations systematically spaced along 4 transects that followed isobaths ranging from 250 to 550 m on the slopes of the Store Hellefiske Banke, and two transects that ranged in depth from 220 to 550 m. Three transects were repeated once on the next day, which also allowed the variation in catches over (short) time to be examined. The catch per haul of shrimp - and also of Greenland halibut (*Reinhardtius hippoglossoides*) and of redfish (*Sebastes* spp.) was weighed and sampled for investigation of size compositions. The fishing lasted from 31 July to 10 August 1997.

Details on vessel, trawling gear and trawl operations are given in Carlsson et al. (1997).

A preliminary report on this study was submitted at the November Scientific Council Meeting of the Northwest Atlantic Fisheries Organisation (Carlsson, 1997). The present report describes further analysis of data and conclusions arising from the analysis.

Materials and Methods

Variation Over Time

Seven (7) stations on each of 3 transects were repeated on the day after they were first trawled, to estimate the repeatability of trawl estimates of biomass density at a given site. Two of these transects were isobathic - one in 250-m-deep water on the south west slope of the bank, fished on 31 July and on 1 August, and one at 350 m on the north side fished on 8 and 9 August. The third repeated transect was fished - on 4 and 5 August - in depths ranging from 200 to 550 m on the south-west slope.

We calculated the simple product moment correlation coefficient of the catch on the first day with that for the second day for each species. However, for all three species, the data was dominated by two to four sets much larger than the others, which made a large contribution to the correlation calculations. For shrimp and halibut, these large-set stations lay close to the unit line, and apparently drove the correlation upwards, but for redfish they were off the unit line and probably lowered the correlation. To reduce the effect of these large sets, the data was transformed in two ways: an n^{th} root transform was used, n being chosen (separately for each species) to give zero skewness; and the data were transformed to ranks, i.e. the product-moment correlation was replaced by a rank correlation. As high correlations might be produced by having transects that differed greatly in average catch, we also calculated correlations within transects.

To check whether the catch at a station was lower on the second day, we regressed the second day's catch at each station on the first day's, using both weighted regressions of the untransformed data with no intercept and unweighted regression of the n^{th}-root transformed data. We also ranked all the sets for both days together for each species, and calculated the mean rank.

Spatial Structure

Isobathic transects were sampled at 250, 375 and 500m. on the southwest slope, and at 350 m on the northern slope, of the Store Hellefiske Banke off West Greenland. Each pass along a transect took one day, hauls being made only between 0900 and 1900 UTC. Two non-isobathic transects were also sampled, one on the northern slope, which went from 211 to 450 m deep, and one on the south-western slope which went from 210 to 510 m. There were 6 or 7 stations sampled on each transect. Each pass along a transect took one day, hauls being made only between 0900 and 1900 UTC (about 0520 to 1520 local sun time). Catches of shrimp, Greenland halibut and redfish were recorded.

The isobathic transects S-250 and N-350 and the variable-depth transect STR were repeated on the following day. The catches at each station were highly correlated between days, even within transects, so the two runs over each transect could not be considered independent tests for the existence of spatial structure. Therefore, the station means for the twice-sampled stations were used in the present analysis of spatial structure.

A species, or a population, is usually spatially structured simultaneously at several scales; typically there will be an area of distribution, within which there are smaller areas (often defined by habitat type, sometimes by a specie's gregarious behaviour) of (much) higher density. Maximum densities for gregarious marine animals are commonly orders of magnitude larger than the mean, although resident or territorial species may show approximately uniform distribution within areas of suitable habitat. Spatial structure dominates the design and interpretation of resource surveys, in that the survey must cover the area where the resource is distributed, and must sample that area well enough to estimate the number and the size of concentration areas, as well as the density within them. Large variations in density within the resource area inevitably increase the cost of surveys as well as the uncertainty of the results obtained.

Spatial structure was examined with serial correlation coefficients along transects. Data was transformed by taking the 4.95^{th} root, to reduce skewness. (This was an average exponent for the three species.) We also calculated the between- and within-transect variance; within-transect variance was calculated both conventionally and using serial differences. The joint significance of the serial correlation coefficients on the different transects was estimated by the 'sum of chi-squared' technique.

A simple model of survey results suggests that the estimate of the resource is given by the product of the estimated total area of concentrations and the estimated mean density within them. If stations are placed randomly and independently within a study area, and concentration areas are a small proportion of the total, the error coefficient of variation (ECV) of the estimate of the total area of the concentrations is roughly equal to the reciprocal of the square root of the number of sampling stations that encounter concentrations. (However, this estimate of uncertainty may sometimes be improved (i.e. reduced) with the use of additional knowledge of the frequency function of the size of concentration areas, or by using non-equi-probable sampling. If concentration areas are not a small fraction of the study area, the ECV can become much smaller.)

The error variance of the estimate of mean density within concentration areas is given by the between-station variance divided by the number of stations in concentration areas. This leads to a simple approximation for the expected total error coefficient of variation:

$$ECV \approx \sqrt{\frac{1}{n}\left(1+cv^2\right)} = \sqrt{\frac{\sum x^2}{\left(\sum x\right)^2}}$$

where ECV is the error coefficient of variation of the resulting estimate, n is the number of stations falling within concentration areas, and cv is the coefficient of variation of catches between stations within concentration areas. The x are the catches per station in concentration areas. Stations outside concentration areas do not affect this expression; and this corresponds to the obvious advantage of not wasting time by setting sampling stations outside the distribution area of the resource. Shorter sets at each station allow the total number of stations to be increased. Whether this reduces the ECV will depend on the effect of reducing set duration on cv. The trade-off is between the proportional increase in n and the proportional increase in $(1+cv^2)$. However, the effect of the 1 in $(1+cv^2)$ is to emphasise the importance of number of stations.

It is usually not too difficult to estimate how many more stations can be sampled if hauls are shortened, but a lot harder to predict how much the between-station variability will increase. This study was an initial attempt to estimate whether hauls could be shortened without a large effect on cv. The experiment consisted of sampling long hauls back-to-back along isobathic transects situated on the south-western and the northern slopes of the Store Hellefiske Banke off West Greenland.

Results and Discussion

Variation Over Time

The simple correlation coefficients for shrimp and halibut were very high, for redfish somewhat smaller but still significant (Table 1). For shrimp and halibut, the transformed correlations were lower, as the effect of the large sets in raising the correlation was reduced. For redfish, the effect was reversed, as the large sets for redfish had highly correlated ranks, but not very highly correlated values. However, overall, there was high correlation between catches on the two days for all species.

What was true overall was also true within transects (Table 2). On transect STR, which covered a range of depths, and had a high CV of catches, correlation coefficients tended to be as high as or higher than their overall values. On the constant-depth transects S-250 and N-350 they were lower—although generally still positive. Exceptions were shrimp on transect S-250, where the range of catches was large and the within-transect between-days correlation was extremely high (0.993 raw, 0.982 transformed); and halibut on transect S-250, where catches were very small and random at all stations on both days and the correlation was basically zero.

Regressions to compare the catches at a station on the two consecutive days did not show significant reductions in catch on the second day. Redfish catches appeared from most analyses to be higher on the second day, halibut catches lower, neither near significance. Shrimp catches appeared to be lower on the second day, but again this was due to change in catch at a small number of stations with large catches.

All analyses indicated that the two measures on a station were highly correlated; i.e. the second day's set added little information on what was there. However, for practical purposes, the appropriate measure is the simple product-moment correlation coefficient, and this was imprecisely estimated with a small number of large sets dominating the statistical calculations.

Spatial Structure

The serial correlations along the isobathic transects were small. In fact, the largest two coefficients of serial correlation in absolute size were negative. There was no significant evidence of spatial structure (Table 3).

Variable-depth transects had positive serial correlations for all three species, and overall there was high statistical significance (Table 3). However, these correlations may have been due to apparent systematic change in density with depth. Catches of halibut increased almost linearly as the water got deeper. The overall high statistical significance of the serial correlation along the variable-depth transects was mostly due to catching more Greenland halibut in deeper water, which went for 58% of the total χ^2. If the results for shrimp and redfish were combined without the halibut data, the statistical significance level was only 5%.

Both shrimp and redfish showed peak catches when the water was about 400 m deep, and apparently became less abundant in deeper water (Figure 1). These patterns generally conformed to what was seen in the isobathic transects, except that while the 220-m stations on the variable-depth transects had low shrimp catches, the S-250 isobathic transect had large shrimp catches both on average and maximum, as well as high variation in catches. It was also the only isobathic transect that had anything like a positive serial correlation in shrimp catches between stations.

Of the three species, shrimp was the one with the lowest serial correlation on the variable-depth transects, and the only species for which the combined result for the two transects was not statistically significant.

Second-order serial correlations displayed no clear pattern, but appeared to be random. Some were high, but they were as likely to be high and negative as high and positive.

In order to study spatial structure by systematic sampling along a linear transect, the transect should be several times longer than the scale of the spatial structure being studied, while the station spacing should be several times smaller than the spatial structure. If 'several' meant, say, 4, a patch would be measured within about 25% of its size, the average of its density would be based on 4 stations, and the average patch size would be based on measures of four patches. However, this implies that there is some prior knowledge of the spatial structure being studied.

The lack of serial correlation along the constant-depth transects was unexpected. All considerations would lead one to expect some level of positive serial correlation between adjacent stations, but these correlations weren't just non-significant, they really were non-existent. For stations like these that were contiguous, this result was completely unlooked for. In fact it is unbelievable, and so unlikely that there is good justification for repeating the study. In doing so, it would appear to be appropriate to take longer transects and shorter hauls. It seems that it would not invalidate the study if the transects were so long that they took more than one day to run. Even if a transect were interrupted by bad weather it would still produce data at least equivalent to two shorter one-day transects.

The results from this initial study gave no indications that hauls could be shortened without losing information about density, or indeed much indication of what the effect would be of doing so. The model that arises is that shrimp, and other species, are in rather small extra-high-density clouds that occur randomly within areas of high average density.

References

Carlsson, D.M., 1997. A first report on a special study on variations in catch of shrimp (*Pandalus borealis*) by depth in West Greenland (NAFO Subarea 1) in 1997. NAFO SCR Doc. 97/108. Serial No. N2965.

Carlsson, D.M. and P. Kanneworff, 1997. Offshore stratified-random trawl survey for shrimp (*Pandalus borealis*) in NAFO Subarea 0+1, in 1997. NAFO SCR Doc. 97/101. Serial No. N2958.

Table 1: Overall correlations of catches of shrimp, Greenland halibut and redfish between days for 21 trawl survey stations on 3 transects repeated on the following day.

	Shrimp	Halibut	Redfish
Product-moment correlation coefficient (SE)	0.968	0.975	0.797
Skewness	2.82	2.99	2.79
N for n^{th}-root transform	3.61	5.00	21.28
P.-m. c.c. of transformed data (SE)	0.958	0.872	0.978
Rank correlation coefficient	0.951	0.908	0.948

Table 2: Within-transect between-days correlation coefficients of n^{th}-root transformed data for 21 trawl survey stations repeated on the following day, and within-transect c.v.s of untransformed data.

Transect	Species					
	Shrimp		G. halibut		Redfish	
	Corr.	C.V.	Corr.	C.V.	Corr.	C.V.
S-250	0.982	1.303	-0.200	0.737	0.942	0.741
N-350	0.670	0.249	0.560	0.598	0.671	0.660
STR	0.964	1.596	0.963	1.516	0.976	1.332

Table 3: Serial correlations of 4.95^{th}-root transformed data trawl survey transects off West Greenland.

Transect	Serial correlation of transformed data		
	Shrimp	Halibut	Redfish
Isobathic transects			
S-250	0.291		0.478
S-375	0.037	-0.653	0.302
S-500	0.056	0.344	-0.711
N-350	0.087	0.029	0.615
χ^2_4	2.78·	2.13·	5.69·
3 spp.: χ^2_{12} = 10.60·			
Variable-depth transects			
STR	0.507	0.982	0.667
NTR	0.735	0.683	0.770
χ^2_2	5.14·	16.24***	6.63*
3 spp.: χ^2_6= 28.02***			
Shrimp & redfish: χ^2_4=11.78*			

Note: for untransformed data, χ^2_{12} for the overall result for isobathic transects was 12.12·, and for TR transects χ^2_6 was 22.61

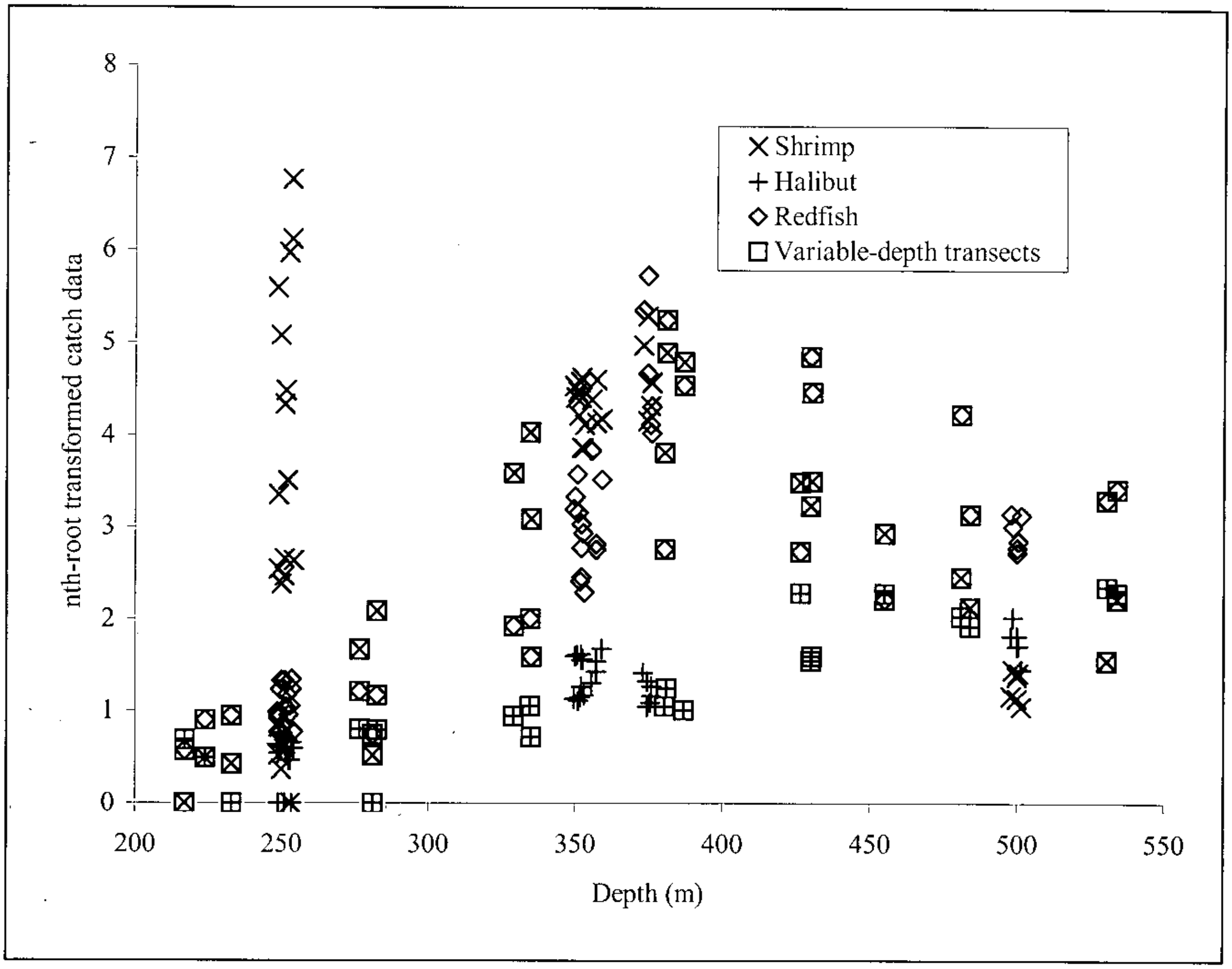

Figure 1: n[th]-root transformed catches of shrimp, Greenland halibut and redfish against depth for an experimental transect trawl survey off West Greenland, August 1997.