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# A Trawl Survey for *Pandalus borealis* in West Greenland.

by

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## Abstract

Stocks of northern pink shrimp Pandalus borealis have been assessed using CPUE data. Since 1988, a stratified random research trawl survey has also provided estimates of stock abundance, and on biological parameters of the resource. The survey covers the West Greenland fishing grounds between 150 m and 600 m deep, and occupies a research trawler for about 60 days. Stratification is based on depth, but strata are fairly small. Stations are allocated proportional to stratum area. Over time, the survey has changed. It has been extended into southern fishing grounds as the fishery developed there. Two-stage sampling was introduced to reduce the largest stratum standard errors, and a spline method was investigated for interpolation of additional stations. Gear changes have included replacing a 44-mm stretch mesh liner with 20-mm since 1993, and using a trawleye to time the tow start since 1997.

Biomass estimates have had error CVs of the order of 15–30%, and have not been correlated with CPUE. In 1997 a group comprising science management, biologists, fishery advisers, and external survey expertise reviewed the survey design. As a result of the review, changes to survey design were suggested: to abandon 2-stage sampling; to shorten the tows and increase their number, and to allocate more stations to the highest-yield group of strata. Making more tows would improve information about biological parameters, and even if tows were shorter might improve biomass estimation. Catches in a small sample of ½-hour tows in 1998 were no more variable than 1-hour tows in the same strata, although an experimental survey in that year showed no correlation between contiguous 1-hour tows and could not predict the effect of shorter tows.

Some changes to the analysis were also suggested. They included pooling the small design strata into 4 large groups based on depth, log transforming the data to reduce its skewness, and smoothing the survey results. Analysis of the series suggested that the stock biomass has not varied much over the period covered by the survey.

To implement some of these suggestions, a progressive shift toward ½-hour tows has been begun, and it is envisaged that some ½-hour tows will be experimentally carried out as pairs of 15-minute tows. The proportion of stations allocated to high-density strata has been increased. Buffered sampling has been used to control station placement, and to prevent stations from clustering within strata. A proportion of stations, randomly selected, has been fixed from year to year.

## Introduction

Catch and effort data from commercial fisheries is a major source of information in assessing stocks of all kinds of fish. However, this data source is concentrated on the part of the biological stock that is commercially fishable, and also on the most remunerative fishing grounds. To provide a wider coverage of the state of the biological stock, dedicated stock-assessment survey fishing is an indispensable adjunct to the collection of commercial fleet data.

*Pandalus borealis*, the northern shrimp, is fished in Greenland waters. With annual catches of—in recent years—around 60 000 tons, the fishery is both one of the leading fisheries for northern shrimp, and a major source of revenue for the Greenland fishing industry. Off the West Greenland coast, the stock is fished commercially in waters of intermediate depth. Such grounds are found in gullies that cross the continental shelf and lead toward the entrances of major coastal fjord systems, and also as a narrow band along the outer edge of the shelf. The fishery is therefore localised and patchy (Fig. 1).

Catch and effort data from the fishery, or at least from some component fleets, are available since 1976. Two periods can apparently be distinguished in the catch:effort series. From 1976 through 1988 catch:effort ratios were relatively high—mean 83% of the 1976 value; variable—CV 15½%; and erratic—first-order serial correlation 24¼%. Since 1989, the average CPUE has been lower at 67½% of the 1976 value (81½% of the 1976–88 mean), but also less variable with a CV of 8½%, and less erratic with an increasing trend and serial correlation 68½%.

Since 1988, the resource has also been monitored with a dedicated trawl survey, designed to produce both a quantitative estimate of its biomass and also estimates of the size composition of the biological stock. The series of survey results (1988–1998) has been variable (CV 23¼%), and randomly erratic (serial correlation 7¾%), and not correlated with the catch:effort series. In 1997, a group comprising science management, biologists, fishery advisors, and external expertise in fishery resource survey design and analysis was convened to review the design and performance of the survey and to recommend changes that might improve its performance.

This article presents some characteristics of the survey design and performance, and reviews the alterations suggested, and the progress toward implementing them. (In general, the effects of implementing these changes can not yet be measured, until more data has been analysed.)

**Survey design**

The survey was designed as a stratified random sample survey (Carlsson and Kanneworff 1998a). While a principal objective was to estimate the commercially fishable biomass of northern shrimp, an important secondary objective was to estimate numbers and biomass in age (size) classes not yet recruited to the fishery.

The population to be sampled was the offshore West Greenland waters between 150 and 600 m deep. (A similar inshore survey of the Disko Bay and associated waters has, in the past, usually been treated separately (Carlsson and Kanneworff 1998b).) Strata corresponded to major latitude divisions of the West Greenland fishing grounds (Fig. 2), and were subdivided by depth, a practice that is common in fishery survey design and further justified by the depth preference of the species and the fishery alike. Stations were allocated to sub-strata proportional to area, with a minimum of 2 stations per stratum to allow standard errors to be estimated for all strata. Stations were randomly placed within strata.

The standard tow in the offshore survey has lasted 1 hour. Tows are normally oriented along isobaths. The fishing gear has been little modified over the history of the survey. The main changes have been a reduction in the size of the cod-end liner mesh (from 44 mm to 20 mm; in 1993), and the adoption of a trawl-eye to determine the start of effective fishing (in 1997).

The size composition, and other parameters, of the biological stock have been estimated from measurements made on a biological sample of the catch taken from the cod-ends at each station.

**Characteristics of the survey**

The survey typically take just over 60–65 days to complete, including some 30 stations directed not toward northern shrimp but to groundfish in shallower water and oceanographic stations at which no fishing is carried out.

The estimated error coefficient of variation of the biomass estimate has varied from about 14% to 24%. The total coefficient of variation of the series of estimates is 19%. This implies that most of the variation in the series of biomass estimates has been due to sampling variation in the survey, and little of it due to real variation in stock biomass. The series of survey results has slight (-0.06) negative skewness; i.e. there is so far no evidence that positively skewed catch data is reflected in a positively skewed population of estimates.

## Modifications made in the history of the survey

Within the period covered by the survey series, the distribution of the fishery has changed. Fishing grounds off southern West Greenland have become increasingly exploited, while some northern areas appear to have been largely abandoned (Hvingel and Folmer 1998). The allocation of survey stations has evolved in the same way, with increasing effort allocated in the south (south of about 62 deg. N). It is thought that this evolution reflects a changing distribution of the shrimp stock itself; but if this assumption were incorrect, biomass estimates made in different periods might be incompatible.

In this survey, and in other fishery surveys, a 2-stage sampling procedure was for a period applied to reduce the standard error of estimation. Extra stations were allocated in strata that in preliminary data analysis at sea had high variance in catch between stations (Francis 1984). This procedure was used in this survey from 1994 through 1997.

An alternative procedure for dynamic allocation and placing of stations, investigated for this survey, was a spline method developed by Stolyarenko (1987). This procedure fits a response surface—essentially a 2-dimensional polynomial—to the geographical distribution of the biomass indicated by the trawl results accumulated so far, and then places additional stations where the uncertainty of the surface, and therefore the benefit of additional information, is greatest.

## Survey review and suggested modifications

In 1997, the Greenland Institute of Natural Resources undertook a review of the West Greenland shrimp survey (Carlsson et al. 1998). The review group included science management, biologists, fishery advisors, and expertise on surveys. All aspects of the survey were examined in detail, with a view to suggesting modifications that might produce a lower standard error and a less variable survey result. Among the modifications suggested at this review, and later, were the following:

*Abandon dynamic allocation of stations*

The statistical properties of 2-stage sampling appear to be undesirable. In resource surveys, sample variance and sample mean are positively correlated (Taylor 1961). Therefore, adding stations in strata with high variance tends to add stations in strata with high mean catches. If these high catches are the result of sampling variation, and some inevitably are, the added stations produce lower results and the existing unbiased result is replaced by a downward-biased result (Francis 1991; Jolly and Hampton 1991). Examination of the data showed that the prediction from theory was borne out in practice; i.e. second-stage stations had lower mean catches than first-stage stations in the same strata.

The statistical properties of the spline method of dynamic station allocation are less evident, but may be similarly undesirable, with stations preferentially added in areas where catches, and therefore variability, are high.

Dynamic allocation of stations in ship-borne surveys also incurs logistic inefficiencies of extra steaming and back-tracking to add stations in areas already sampled. For these reasons, dynamic allocation of stations during the course of the survey was abandoned, in favour of a return to executing a fixed design.

*Use buffered sampling*

Placing survey stations by simple random sampling results in a survey with some desirable statistical properties, notably lack of bias and an unbiased estimate of error variance. It is also easy to do. However, it has some undesirable properties: it often produces a distribution of stations that looks uneven, with stations grouped in one part of a stratum while other areas are little covered. This does not help in securing acceptance of survey results among user communities. Associated with this is inefficient estimation when populations are spatially auto-correlated; information is inefficiently acquired by stations that are close together.

Systematic sampling is one alternative (Cochran 1977). It has some desirable statistical properties in sampling auto-correlated populations. Its drawbacks are its relative inflexibility—stations cannot easily be added or removed from the design–and that no unbiased estimate of the sampling error variance is available. It is frequently used—is in fact virtually standard—in designing transect surveys and is well suited to large areas with large, regular-shaped strata and uniform sampling densities. However, it is difficult to apply in stratified surveys where strata are irregular, where sampling density varies from stratum to stratum, and where a set number of stations are to be placed in each stratum. These are characteristics of the West Greenland shrimp survey, so systematic sampling did not appear appropriate.

Another possibility was buffered sampling, where stations are placed randomly, the only restriction being that no two stations can be closer together than a prescribed limiting distance. Depending on the limiting distance chosen, the result can be similar to random sampling (if stations are allowed to be close together) or an approximation to systematic sampling if the stations are forced to be far apart. This sampling method adapts well to stratified surveys with sampling densities that vary from stratum to stratum, and can be applied to irregularly shaped strata.

Like random and systematic sampling, this sampling procedure is unbiased. Its error properties should be between those of random and systematic sampling. I.e. in spatially autocorrelated populations it should be generally[1] more precise than simple random sampling—i.e. its true standard error should smaller—but like systematic sampling it has no unbiased estimate of error variance except in random populations.

Buffered sampling has been implemented for the 1999 survey, using a SAS program (written by DMC and PEK). The limiting distance was made as large as possible without imposing excessive difficulty in placing all the required stations (excessive difficulty being defined as more than an hour or two of running time on a fast PC). The result was an even distribution of stations within strata (Fig. 3). *Ad interim* the standard expression for calculating error variance will be used, accepting that it produces a slight overestimate, while alternatives such as nearest-neighbour differences will be investigated.

*Allocate more stations to high-catch strata*

The allocation of stations proportional to stratum area is not optimal in the sense of minimising the error variance of estimation of fishable biomass. Optimally, more stations would be allocated to strata most frequented by the large shrimp that are commercially most valuable. Allocation based on survey and fishery catches in the recent past might also improve survey efficiency (Smith and Gavaris 1993; Gavaris and Smith 1987), and would be allocated with respect to recent survey and fishery catch statistics. However, additional objectives such as estimation of size composition in the biological stock make it difficult to decide what is a truly optimal allocation of stations for this survey. (There is no formal weighting of different kinds of information in formulating management advice, so different objectives for the survey can not be weighted.) While other design options are being investigated, stations are still being allocated proportionally to stratum area.

*Fix stations*

Stratified random fishery surveys are usually designed by re-placing sampling stations for each (annual) survey. This procedure yields estimation errors that are serially uncorrelated between years, and maximises random between-year variation, ensuring that changes in the biomass estimate due only to changes in stock distribution remain within the normal random variation and are not mistakenly ascribed to changes in stock size. However, if stock distribution is relatively stable, fixing stations from year to year may allow more sensitive between-year comparisons, as catches can be compared station by station. Fishery surveys that use systematic designs are less affected by changes in distribution, and often use fixed stations—to such an extent that 'fixed stations' and 'systematic sampling' are almost synonyms in fish stock survey parlance. Fixing stations from year to year has logistic advantages, as it may be possible to reduce the search time for good trawling bottom based on previous years' experience. However, fixing all stations fixes the entire survey design (for all time to come). Therefore, a compromise has been implemented of fixing a randomly chosen 50% of stations from year to year and re-placing the remainder. This will allow an assessment of the performance of a fixed-station design relative to that of resampling in estimating year-to-year changes in stock biomass, and retains flexibility in re-allocating stations between strata.

[1] i.e. provided the correlogram is everywhere concave upwards, which is commonly the case.

*Shorten tows*

Such information as exists appears to indicate that fishery resources have high short-range spatial correlation in biomass density (and other properties, such as mean size of organisms). A corollary is that small samples at a station may be as informative as large ones: high spatial correlation means that the second half of a large sample adds little information. Applied to the present case, this implies that tows shorter than the present standard of one hour might be more efficient (Pennington and Vølstad 1991; Gunderson 1993).

The optimum sample size depends on the fixed time per station and on the short-range spatial correlation: high fixed costs reduce the advantages to be gained from the shorter tows that are otherwise appropriate if spatial correlation is high. Steaming time per station is semi-fixed, becoming less if more stations are sampled and the stations therefore closer together. Data from the survey series shows an average steaming time per station of about 56 mins and a fixed time of about 45 minutes, of which about 20 minutes is search time and 25 minutes is gear handling. A simple analysis was carried out, which ignored complications such as steaming between stations at night and the different spacing of stations in different strata. Results showed that if tows lasted 30 minutes instead of 60, closer spacing could reduce average steaming time to about 50 minutes and about 30% more stations could be sampled. If tows were to be shortened to 20 mins, it appeared that 44% more stations could be sampled.

Sampling more stations would not have a proportional effect on the estimated error variance if shorter tows were inherently more variable. Spatial correlation of shrimp density was examined in the 1998 survey by experimentally carrying out 7 contiguous 60-minute tows along each of three isobathic transects. No spatial correlation could be detected; this result would not predict good results from short tows (Kingsley and Carlsson 1998). However, the within-transect CVs were about 30–40%, much less that the usual survey within-stratum CV which is of order 100%. I.e. the spatial correlation may have been low because the isobathic transects were too short to encounter great variations in density.

Also in the 1998 survey, about 50 of the standard 60-minute tows were experimentally replaced with 30-minute tows. They yielded catches that were no more variable than those obtained in 60-minute tows in the same strata, indicating that shorter tows would not incur large penalties of lower precision.

The effect of shorter tows continues to be studied in 1999, where 50% of the tows last 60 minutes, 25% last 30 minutes, and 25% last 15 minutes. As opportunity permits, some 60-minute tows will be carried out as pairs of contiguous 30-minute tows, and some 30-minute tows as pairs of 15-minute tows. It is expected that this will provide further information on the degree of spatial auto-correlation of the shrimp stock, and on the changes in survey precision resulting from shorter tows.

Increasing the number of stations would be expected to benefit the estimation of the biological parameters of the resource even more than the estimation of biomass. If size composition of fishery resources is spatially correlated more strongly than density—i.e. patches tend to consist of animals of similar size although the density within the patch may be variable—the gain in precision from more stations is only offset by a negligible penalty due to any increased variability associated with shorter tows and therefore smaller samples (Pennington and Vølstad 1994).

*Pool strata*

The major depth bands are divided into many small strata to control station placement, ensuring that stations are evenly distributed over the study area and that the survey is from that point of view acceptable. The statistical benefits of having very many strata are questionable: beyond 4–6 strata there tends to be little gain in precision.

Instead of calculating a mean and error variance for each small stratum, it is possible to pool the data into depth-based ‘super-strata’ for analysis. The advantage is to produce four larger data sets, with, for example, more degrees of freedom for calculating confidence intervals and reducing the effect of rare large catches in strata containing few stations. The disadvantage is that the super-stratum data was analysed as though it was random when in fact it was more evenly distributed than a random sample, so the between-stratum variation is over-represented and slightly inflates the estimated error variance. Both the advantages and disadvantages are small.

A possible future development will be to apply buffered sampling to super-strata directly.

*Transform the data*

Highly skewed data may be analysed by treating it as a mixed distribution, and log-transforming the values that exceed a given limit (Pennington 1996). Provided the distribution of these values in the population approximates log-Normality, the use of this transform can give better estimates of population parameters. One of its effects is to reduce the effect of rare large catches on estimates of stock biomass. The performance of the transform depends on an appropriate choice of a limit between the values to be transformed and those to be used untransformed: applied to shrimp data, it appears to produce larger estimates if the limit value is small. In contrast, if the limit value is set higher, the skewness of the distribution above the limit—i.e. the values that are to be transformed—is thereby also increased and the use of the transform produces relatively smaller estimates of biomass.

*Smooth the results*

Under certain assumptions, a more precise estimate of the stock biomass in a given year may be generated by appealing to previous years' results than by relying on a single survey (Carlsson et al. 1998). The increase in precision depends on the relative magnitude of the random year-to-year variation in true stock size and the random error in estimation: if estimation error is high, the gain in precision may be considerable. Analyses indicate that the variance in stock biomass over the survey series to date has been of the order of 10% of the survey error variance.

**Implementation of modifications**

Modifications are of two kinds: changes to the survey design and execution, and changes to the analysis. Survey design and execution tends to be 'either-or'; a stratum is sampled in one way or another; a tow lasts one length of time or another length of time; a station is allocated in one stratum or another. In contrast, the same data can be analysed in more than one way and the results compared, so modifications to analysis methods are less irrevocable. However, there are obvious dangers in allowing different sets of results to be circulated without clear qualifications as to their validity.

The most significant change to the design of the survey is the start of what may become a progressive shift toward shorter tows. In future years the proportion of 60-minute tows may be further reduced and the proportion of 30-minute tows increased, with possibly a subsequent similar shift away from 30-minute tows toward 20- or 15-minute tows. The inclusion of tows of different durations in the same surveys will allow the results obtained from tows of different lengths to be compared before establishing any new standard. Under the most optimistic assumptions—i.e. that there were no increase in the variability of catches between stations—the standard error could be reduced by as much as 15–17% if 15-minute tows were exclusively used. This recommendation of the survey review is being progressively implemented. Other design changes that have been implemented—placing stations by buffered sampling, and fixing stations from year to year—are expected to improve the performance of the survey in detecting trends in biomass by amounts that are smaller and more difficult to detect.

The survey review has therefore resulted in the implementation of three changes in survey design. These are shortening tows, placing stations by buffered sampling, and fixing stations. Shorter tows were started in 1998, and the other two changes were first implemented together in 1999. It will be an interesting analytical problem to identify and estimate the effects of these changes in design; however, it is not expected to be an impossible one.

Classical analyses can be continued while revised methods are examined and validated. In this way, the results of log-transforming the larger catches have been evaluated and compared with the results obtained by standard analyses, and may therefore be regarded as partially implemented (Carlsson et al. 1998). Pooling stratified data into larger 'super-strata' also appears to have few drawbacks. It simplifies the analysis and presentation of results, and gives more tractable datasets.

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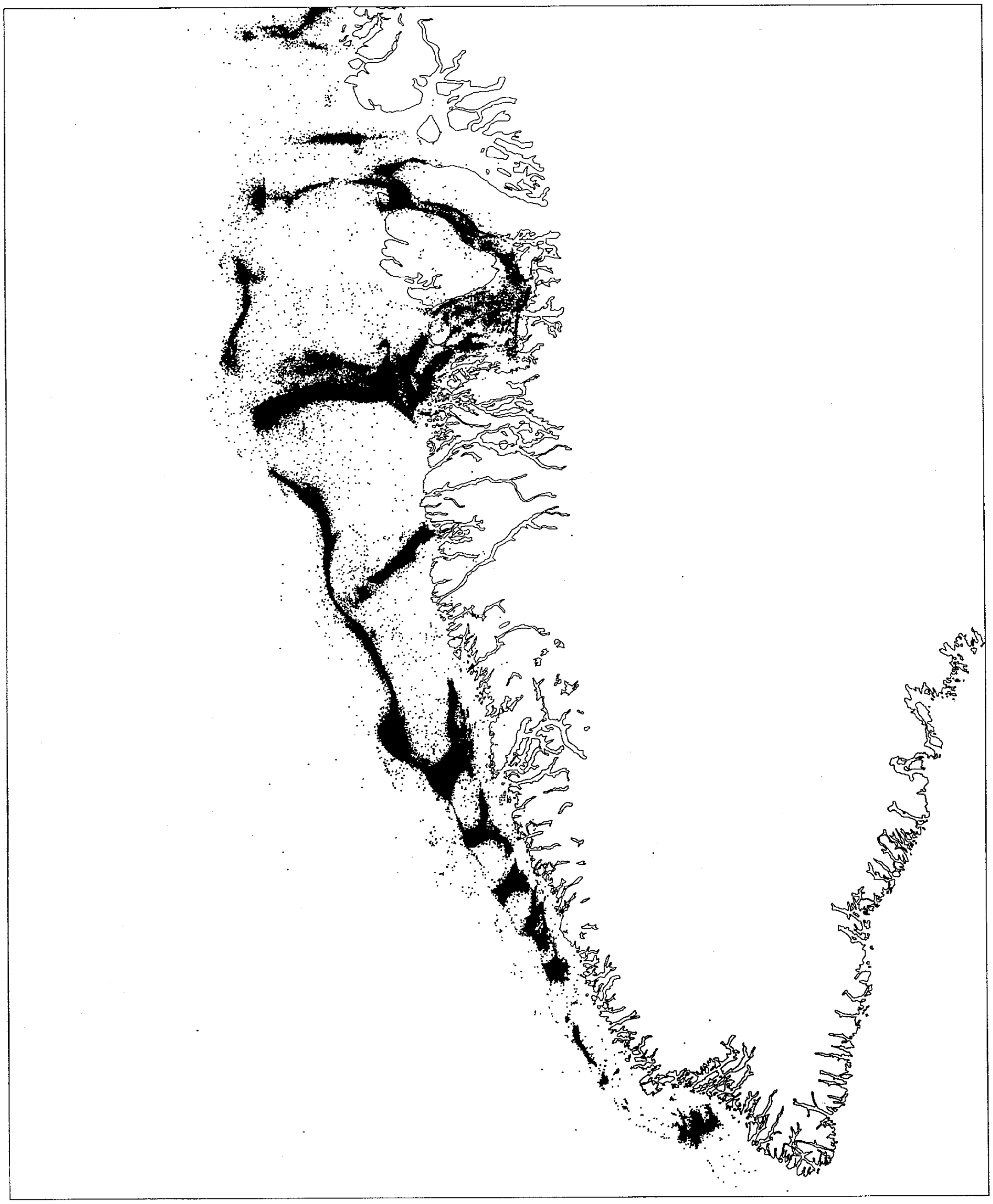

Fig. 1. Distribution of the shrimp fishery in West Greenland waters, from logbook positions 1991–1998.

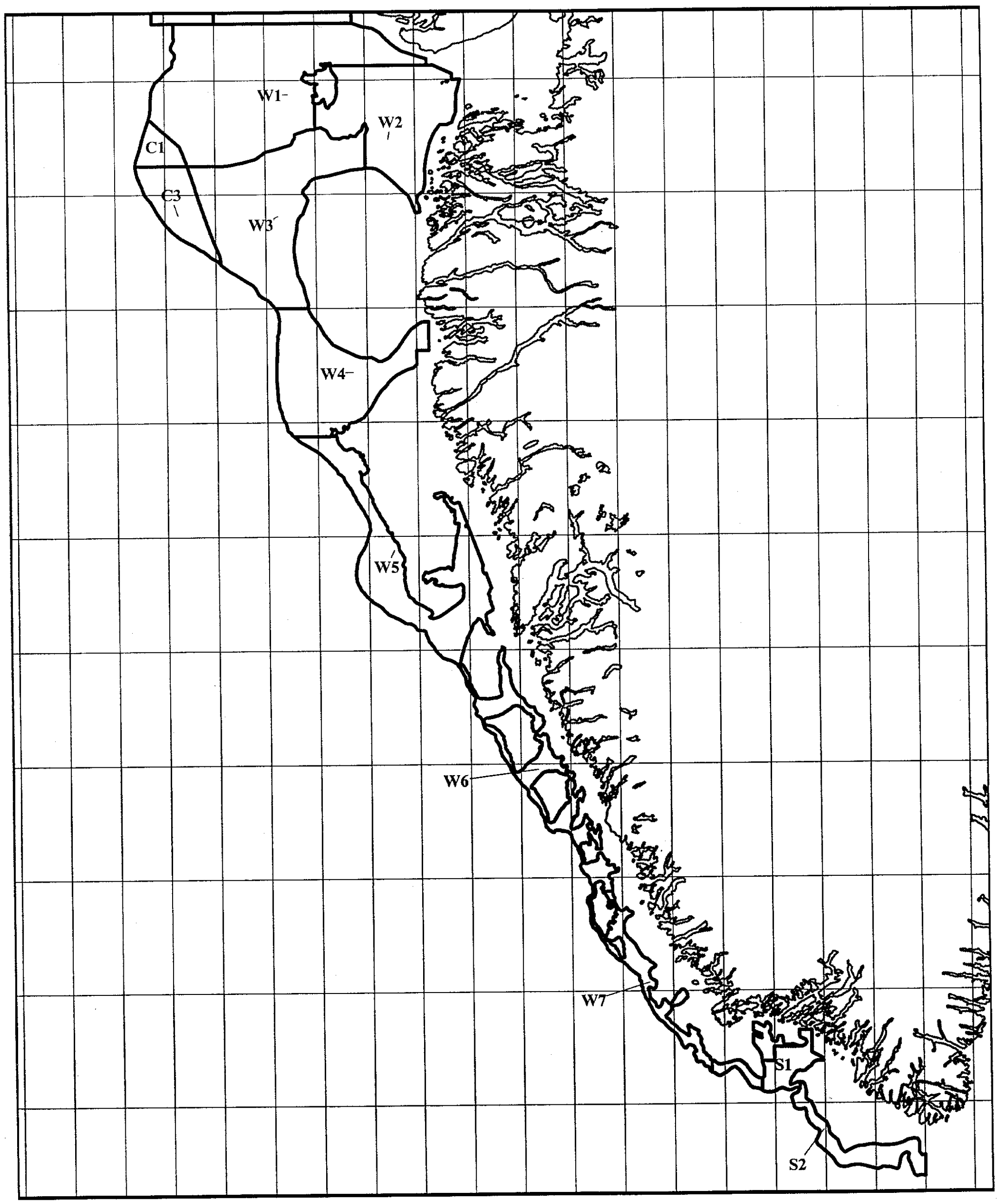


Fig. 2. Stratification scheme of the West Greenland trawl survey for northern shrimp, south of Disko Bay.

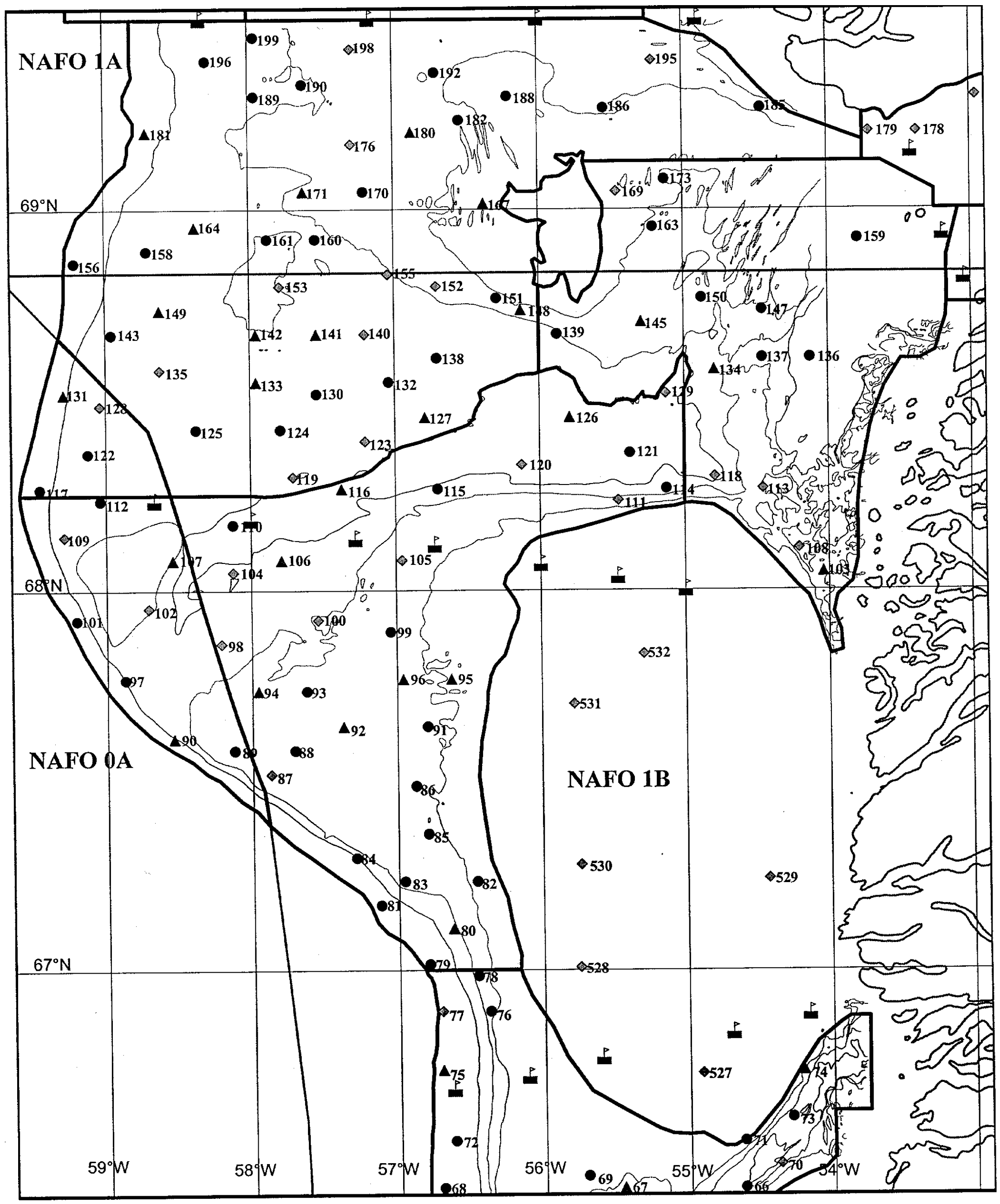


Fig. 3. Stations placed by buffered sampling in strata W1 through W4 of the West Greenland shrimp survey in 1999.