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A Biomass Index for Northern Shrimp (*Pandalus borealis*) in Davis Strait Based on Multiplicative Modelling of Commercial Catch-per-unit-effort Data (1976-1997)

by

C. Hvingel[1], H. Lassen[2] and D.G. Parsons[3]

[1]Greenland Institute of Natural Resources, P.O. Box 570, DK-3900 Nuuk, Greenland
[2]Danish Institute for Fisheries Research, Charlottenlund Slot, DK-2920 Charlottenlund, Denmark
[3]Science Branch, Department of Fisheries and Oceans P.O. Box 5667, St. John's, Newfoundland, Canada A1C 5X1.

Abstract

Four biomass indices for the northern shrimp stock in Davis Strait, derived from commercial catch per unit effort (CPUE) data, were analysed by multiple regression to construct a single time series with the ultimate goal of tracking trends in stock biomass during the period 1976 to 1997. Indices from the offshore fisheries have been used previously in stock assessments while an index derived from logbook data for small inshore vessels operating around Disko Island has not been presented previously.

The analysis used multiplicative models and linked catch rate to vessel fishing power, temporal and spatial availability and overall annual biomass density. In three of the indices, the temporal (MONTH) and spatial (AREA) effects were modelled either solely as an interaction term or as an interaction in addition to main effects. Other second order effects were treated as random error terms. The final models contain an AREA*MONTH interaction term which corresponds to an annual migration or behavioural pattern. The procedure corrects for increases in technological efficiency over the 20-year period due to renewal of the fleets but changes in the efficiency of individual were not accounted for. . The analysis indicated that this latter effect is of less importance

The four indices were combined, weighted by the area of the total fishing grounds each index represented. The index is indicative of the biomass density for shrimps greater than about 17 mm CL. During the 1976-1988 period, the index was higher than from 1989 onwards. The combined index showed agreement with research survey biomass estimates but the contrast in the data was low during the period of comparison (1988-1997). The combined CPUE index was applied to the total catches to derive estimates of total standardised effort. This effort index increased substantially in the late 1980s.

Introduction

Catch and effort data from commercial fishing vessels provide simple but important statistics in fisheries management. They are frequently used directly to provide annual indices of stock biomass and in tuning of Virtual Population Analyses (Anon., 1996). Catch per unit effort (CPUE) data are influenced by several factors, including availability of target species, vessel fishing power and annual, seasonal and areal variation in biomass. Therefore, methods for correcting CPUE data for effects other than annual biomass changes must be applied before using them as biomass indices.

Standardising CPUE data to improve their relation to stock biomass density has been approached in different ways (Gulland, 1956; Beverton and Holt, 1957). Gavaris (1980) and Kimura (1981) described a now widely used method based on the work of Gulland (1956) and Robson (1966) using multiplicative models. The use of CPUE indices as biomass indicators depends critically on standardisation, especially of fleet efficiency. Pascoe and Robinson (1996) reviewed implications of efficiency increase and methods of quantification.

CPUE standardisation by multiplicative modelling has recently been used for southern red snapper, *Lutjanus purpureus* (Perodou and Prevost, 1989; Perodou, 1994); ice-fish, *Champsochephalus gunnari* (Gasiukov, 1991); sole, *Solea solea* (Large, 1992); Atlantic swordfish, *Xiphias gladius* (Miyaki, 1989; Hoey *et al.* 1995). Within the Northwest Atlantic Fisheries Organisation (NAFO), multiplicative models are frequently used to calculate commercial CPUE-based biomass indices to trace annual fluctuations in stocks, e.g. in the assessment of redfish (*Sebastes sp.*), silver hake (*Merluccius bilinearis*), Greenland halibut (*Reinhardtius hippoglossoides*) and northern shrimp (*Pandalus borealis*) (Anon., 1997).

The northern shrimp stock off West Greenland occurs in NAFO Divisions (Div.) 0A and 1A-1F, primarily in depths between 150 and 600 m (Fig. 1). The offshore fishery for shrimp in Davis Strait (Subarea 1 + Div. 0A) began as a multinational fishery around 1970. Since the first assessment of the stock in 1976, catch rate indices have been used as indicators of the status of the stock. Until 1989, an index from the Greenland fishery based upon seven trawlers was used (Carlsson, MS 1985). This index was a simple average of CPUE data by haul covering Div. 1B in which most of the fishery took place at the time. A revised version of this index based on a multiplicative model was introduced in 1990 (Lassen and Carlsson, MS 1990).

Based on a new logbook system introduced in 1985 a new standardised index for Div. 1B was calculated (Carlsson and Lassen MS 1991). This index included only shrimp larger than approximately 8g for which discard is normally negligible (Lehmann and Degel, MS 1991) and thus avoided the influence of variations in unreported discard. A parallel "Large Shrimp" index for Div. 1CD has been calculated since 1993 as the fishery had expanded to these areas during the late 1980s (Carlsson *et al.*, MS 1993; Siegstad *et al.*, MS 1995). CPUE data from logbooks from Canadian vessels fishing in Div. 0A were also used to construct a standardised index (Parsons and Veitch, MS 1991 and MS 1995).

In this paper the standardised CPUE indices for Div. 1B, 1CD and 0A are re-analysed and an additional new "inshore" index constructed. The purpose of our analyses was to combine these temporally and geographically fragmented indices into a single time series of standardised commercial CPUE data for northern shrimp in Davis Strait from 1976 to 1997. This series is discussed as a possible indicator of changes in stock biomass over the same period. The commercial fishery mainly exploits shrimp greater than 17 mm CL. The CPUE index is therefore indicative of the older male and the female stock combined. Discards of shrimp between 19 and 24 mm CL occur in varying amounts and this adds to the variability of the index.

Material and Methods

1. Theory, assumptions and problems of design

We derived standardised indices separately for each area using multiplicative models, which included the following variables: (1) individual vessel fishing power, (2) seasonal availability, (3) spatial availability and (4) annual mean CPUE. The analysis is based on an approach similar to that presented by Large (1992) and based on the theory described in Richards and Schnute (1992). The input data were catch and effort of individual hauls grouped by vessel, area, month and year. These data were averaged by cell before used in the multiplicative analysis. The calculations were done using the SAS statistical software (Anon., 1988). The multiplicative model was represented in logarithmic form:

$$\ln Cpue_{ijkl} = \ln(u) + \ln(A_i) + \ln(S_j) + \ln(V_k) + \ln(Y_l) + \varepsilon_{ijkl} \qquad \text{Model 1}$$

Where $CPUE_{ilklm}$ is the mean CPUE for vessel k, fishing in the jth month in the ith area during the lth year (k = 1,..,n; j = 1,…,s; i = 1,…,a; l = 1,…,y); ln(u) is overall mean *ln*(CPUE); A_i is effect of the ith area; S_j is the effect of the jth month; V_k is the effect of the kth vessel; Y_l is the effect of the lth year; $\bullet_{ilkl}$ is the error term assumed to be normally distributed N(0, $\bullet^2/n$) where n is the number of observations in the cell. The standardised CPUE indices are the antilog of the year coefficient

This model is based on the following assumptions:

- The fishing power of each vessel is constant over time and space (i.e. does not vary by season, year or area)
- The geographical distribution of the stock is constant over seasons and years
- Seasonal availability varies in a constant pattern among years (i.e. periods of high and low availability occur at approximately the same time each year)

The validity of these assumptions was investigated by studying 2-way interactions among vessel, area, month and year. Higher order interactions were not investigated because of the occurrence of many empty cells.

The data sets are unbalanced, with a range of 0 to 784 hours of effort per cell. Up to ??% of the cells are empty. Parameter estimates of the vessel, month and area variable from a first run of model 1 were compared and cells were collapsed if the parameter estimates were within the distance of one mean standard error.

Variation in CPUE data is typically high and for that reason the analysis was done on cell averages. This approach was chosen to improve the signal-to-noise ratio. The calculations were repeated based on individual haul information and this did not change the annual abundance indices appreciably but the R^2 was only about 10 % making it difficult to investigate the model structure. We weighted the data to prevent inordinate influence of a few hauls on the model. Number of hauls was used as weighting factor as it is proportional to the variance of the mean Ln(CPUE) in a cell. In previous analyses weighting was done by omitting cells with zero catch (NAFO Div. 0A) or excluding cells with less than 10 hr effort (Div. 1B and 1CD).)

The criteria used for ignoring interactions was to investigate if these showed a systematic pattern between years, months and areas the relative importance measured on the F value and the amount that these interaction contributed to the overall explanation of the total variation in the data.

The analyses suggested a few outliers. These were investigated and only data points, which could be identified as erroneous, were excluded from the subsequent analyses.

2. Construction of the four individual CPUE indices.

Catch and effort statistics for the shrimp fishery at West Greenland are collected on a haul-by-haul basis through logbooks. Data items available are: date, time, geographical position, depth, tow duration and catch (kg) either by size group or total catch. The CPUE data are catch (kg) per hour trawling. For NAFO Subarea 1 Greenlandic logbooks are available since 1976 but only for a smaller part of the fishery. With the introduction of a new Greenlandic logbook in 1985, data now account for about 99% of the catches by the offshore fleet component (>80GRT) and about 50% of the catches taken by the inshore fleet (<80GRT). The Canadian logbook system has covered the Canadian shrimp fishery in the Davis Strait from the beginning of the fishery in 1979. Since 1981 Canadian shrimp fishing activity has been restricted to Div. 0A in an area extending from about 67° to 69° N and 58° to 60° W. This fishery thus covers the part of the stock area in the Canadian zone only (Fig. 1).

The fishery was mainly restricted to the shrimp grounds in NAFO Div. 0A and 1B up to the mid 1980's. Thereafter, the fishery gradually expanded southwards to Div. 1C and 1D. There are limited data reported from Div. 1A west of 56° W and some of these are actually misreported catches from Div. 1B and possibly even further south. Therefore, data referring to Div. 1A west of 56° have been discarded from the analysis. Little effort is spent in Div. 1E and 1F, as the fishery is relatively new so data from these areas were excluded from the analysis as well. The area definition is based on distinct fishing grounds.

The main criteria for including an individual vessel in either of the multiplicative models was three years of sustained participation in the fishery covered by the index. The recent introduction of twin-trawls in the fishery is not covered in the analysis; data on the few hauls done by these highly effective trawls were excluded from the analysis.

Thus, data are supplied by four different fleets largely fishing in separate areas and covering different time periods, Table 1. Therefore analyzing all data in a single model was not suitable, as such a model would have a preponderance of empty cells. It was decided to do separate indices by fleet which meant keeping the former 0A index as a unit, calculating a new inshore index and, in contrast to earlier practice, combining the data for Div. 1B and 1CD into a 1BCD index.

2.1. The Div. 1BCD index, 1987-1997

The CPUE data for the 1BCD index were grouped into seven areas largely constituting Div. 1B, 1C and 1D. Thus only data referring to Area 3-9 as shown in Fig.1 were considered for this index. Since 1990 access to Area 3 for vessels above 80GRT has been restricted by legislation and therefore data for Area 3 was omitted from the calculations. In 1987-88 the fishery in Div. 1C and 1D was still in its infancy and the few exploratory hauls from area 7-9 in 1987 and area 8-9 in 1988 were therefore also excluded.

32 vessel out of 64 vessels larger than 80GRT met the criteria for inclusion in the analysis. Based on a run of the main effects model (model 1) these 32 vessels were collapsed into 16 groups due to similarity of fishing power. A group included 1-5 vessels. By the same initial analyses the month variable were reduced from 12 to 7 levels. Areas 4, 6, 7, 8 and 9 were combined as they showed similar indices of relative shrimp availability. This left only two areas in the final analysis as area 3 was delete as explained above. Table 1 shows the time periods and the number of effect levels.

2.2. The KGH Div. 1B index, 1976-1990

This data series covers the period 1976 to 1990. For the period 1987-1990 the data are also included in the 1BCD index presented above. The initial off-shore fishery was executed by 7 sister trawlers (app. 750 GRT) all operated by the Kongelige Grønlandske Handel (KGH). Even though other vessels joined the fishery between 1976 and 1987, the logbook information is only reliable for the KGH trawlers before 1987 (Lassen *et al.*, 1990). Therefore this time series is treated separately and only data for these 7 vessels were included in the analysis. The early fishery only covered Div. 1B and the index is restricted to this area. Thus data from Area 3, 4, 5 and 6 (Fig. 1.) were considered for this index. In the period 1976-1990 there was free access to Area 3. Therefore in contrast to the 1BCD index 1987-1997 this area was included in this analysis.

A run of the main effects model (model 1) showed that 6 of the seven vessels were very similar in fishing power and they were therefore treated as a group in the subsequent analysis. The month variable could be reduced from 12 to 10 levels and area 4, 5 and 6 combined as they had similar indices of relative shrimp availability, Table 1.

2.3. The Div. 0A index, 1981-1995

The fishery in Div. 0A usually takes place from June-December and is restricted to a very limited area (Fig. 1). Thus, no areal segregation was required for the 0A-index. A total of 48 vessels are represented in this data base but only a subset of 29 have operated in the area for at least three years and were therefore included in the analysis.

Although the fishery takes place in June-December, the analysis was confined for the months July-November as the June and December effort was sparse, especially in recent years.

2.4 The inshore index, 1988-1995.

The inshore shrimp fishery in Greenlandic waters is almost exclusively confined to areas around Disko Island in Div. 1A and 1B. This fishery is restricted to vessels below 80GRT and has in resent years accounted for about 25-35% of the total nominal catches in Subarea 0+1. No standardised index has earlier been presented for this fishery.

The areas included in the index were those shown as areas 1, 2 and 3 in Fig. 1. Comprehensive data are available since 1988 and 28 vessels are represented. The fishery occurs from March/April to December. Eight vessels were excluded as they fished irregularly in the area.

The vessel variable were reduced to 10 levels consisting of groupings of 1-3 vessels. The month variable from 9 to 5 levels.

3. Construction of the 1976-1995 time series

The model applied in this analysis assumes that the geographical distribution of the shrimp is constant between years and with a constant seasonal pattern. Hence an index from one Subarea of the total area of occurrence could serve as an index of the total population. Therefore, a combined total index of the development of the population biomass can be derived by aggregating the four available indices. This was done using a least squares method.

The combined series μ_{ij} was considered to reflect a series Y_j such that $\mu_{ij} = \alpha_i Y_j + \varepsilon_{ij}$. ε_{ij} were considered to be distributed with mean zero and variance σ_i^2. The variance was assumed to be inversely proportional to the area of fishing ground covered by the index, a_i. This was taken to be the area of sea bottom between 150-600m. Hence , the combined index could be constructed by minimising:

$$\sum_i a_i \sum_j (\mu_{ij} \div \alpha_i Y_j)^2$$

As discussed in the start of section 2 the use of a single multiplicative model was not found to be suitable because of the number of empty cells, the unbalanced data set and the differences between the inshore and the offshore fleets.

Results

1. The Div. 1BCD index

The assumptions of constant distributional and seasonal pattern were investigated in a model where all second order effects were included:

$$\text{Ln(CPUE)} = \text{Model 1} + \text{Ln}(A_i{*}S_j) + \ldots\ldots + \text{Ln}(V_k{*}Y_l) + \bullet_{ilkl} \qquad \text{Model 2}$$

The ANOVA scheme of this model applied to the 1987-1997 Div. 1BCD data. All effects were significant at a 5 % level and are in Table 2 listed in order of decreasing model explanatory importance (mean SS). Cook's D influence statistic (Anon., 1988) indicated that the model was not driven by a few highly influential points. Plotting the studentized residuals did not reveal any trend with neither the predicted CPUE nor with the main effects and the plot suggested constant variance of the errors. A normal probability plot indicated that errors were normally distributed.

The interactions including VESSEL were ignored. These were the interactions with the least influence and each of them explained less than 4 % of the total variation in model on the price of a large number of parameters (212) in the model. In total they explained a little more than 5 % of the total variation.

The major concern is the presence of interactions with YEAR. Such interactions may indicate violation of the basic assumptions mentioned under the Material and Methods section and the estimated YEAR effect may in this situation not be used as the biomass index sought (Anon 1995). The interactions found by the analysis may result from unsystematic changes in seasonality and area distribution between years and this would add to the variance of the CPUE indices but not introduce bias in the time trend.

The YEAR*MONTH effect represents seasonal changes in availability of shrimp to the trawl between years and was the most significant of the year interactions (Table 2). A plot of YEAR*MONTH effect against time suggests that the seasonality varied between years in the period 1985-1993 but this variability has been much less pronounced in recent years. A similar analysis for individual areas gave the same conclusion. Inspection of the overall time trend obtained by the two models did not indicate major differences but the variation between years in the YEAR effect from model 2 (with interactions) was higher. This however could indicate that the estimates from model 2 are not quite stable. It was concluded that the bias caused by ignoring the YEAR*MONTH interaction has little effect on the time series.

The YEAR*AREA effect represents differences in the geographical distribution between years. A plot of YEAR*AREA effect against time suggests that the significance of the interaction is driven by an abnormal year 1995 all other years do not seem to deviate from each another. It seems appropriate to include the effect in the random error.

The MONTH*AREA interaction suggests the existence of an areal difference in seasonality that was found to be consistent between years. This could reflect an annual migratory or behavioural pattern. This was the interaction with the highest mean square contribution. The final model therefore included the MONTH*AREA interaction along with the YEAR and VESSEL main effects.

$$\mathrm{Ln(CPUE)} = \mathrm{Ln}(u) + \mathrm{Ln}(V_k) + \mathrm{Ln}(Y_l) + \mathrm{Ln}(A_i{*}S_j) + \bullet_{ijkl} \qquad \text{Model 3}$$

Including this interaction increased the R-square slightly to 47.4% compared to 46.6% in the main effects model 1.The resulting index is shown on Figure 2A.

2. The KGH Div. 1B index

A run with all second order terms produced an R-square of 81%. The AREA main effect and the VESSEL*AREA and VESSEL*MONTH 2nd order effects were not significant. The remaining interactions do have some minor explanatory value of the data. Removing the two none significant interactions from the analysis reduced the R-square to 79%.

Based on similar arguments the model was reduced to a version of Model 3 where the MONTH and AREA main effects are included in the MONTH*AREA 2nd order effect, Table 2. The resulting index is shown in Figure 2B.

3. The Div. 0A index

The analysis of this index followed a similar route, as that taken for the analyses above, except there was no need to include an AREA effect. Inspection of the residuals from the first run did not identify deviations from the assumed model and error structure.

In the first run of model 2 (all three 2nd order effects included) only the MONTH*VESSEL interaction came out not significant. The R-square was 75%.

Again for similar reasons as for the above analyses model 1 without an AREA effect was used to construct the final biomass index. The resulting index is shown in Figure 2C and the ANOVA-scheme to match in Table 2.

4. The Inshore index

The first run of the full model for this new index, which included all main and 2nd order effects, resulted in an R-square of 70% about the same level as for the other indices. Also, only the VESSEL*AREA effect was not significant at the 5 % level.

Inspection of the residuals from the first run did not identify deviations from the assumed model and error structure.

The interactions including VESSEL had low mean squares, i.e. very small impact on the model and were ignored in the subsequent analysis. The remaining 2nd order effects including YEAR, MONTH and AREA had minor explanatory value of the data. The analysis conducted for the Div. 1BCD index was repeated for this index. Again the significance was driven by the 1995 abnormal year and the changes in the seasonal pattern in parallel to the behaviour of the index in the off-shore areas Div. 1 BCD.

In conformity with the model formulation for the Div. 1BCD index all 2nd order effects except for the MONTH*AREA interaction were excluded from the model and included as part of the random noise. The final model. Was therefore similar to model 3 presented for the Div. 1BCD index. Compared to the full 2nd order model, the R-square decreased to 48%. The resulting index is shown in Fig. 2D and the ANOVA-scheme to match in Table 2.

6. Combined index 1976-1995 for shrimp in Davis Strait

The four indices are shown in Table 2 and on Fig. 2E standardised to 1990. The indices are in reasonable agreement but show some divergence in most recent years. However, the 1997 index for Subarea 0A is based on few observations. The combined 1976-1997 index is given in Table 3 and Fig. 3.

The combined index may be interpreted as fluctuations by a factor of 2 around a constant level between 1976 and 1987 followed by a drop to a lower level in the late 1980's.

There are research survey data available from July-August for the period 1988-1997 (Carlsson and Kanneworff, MS 1997). The CPUE index and its relation to stock biomass can be examined by comparing survey results with the index. Figure 5 shows both indices. Except for the 1988 observation the CPUE series are within ±1.2 standard deviation of the mean. The survey series shows a similar pattern except for the 1993 observation. However, the contrast both in the CPUE data and in the survey results is low rendering this test weak. The survey series cannot help in revealing stock trends for the period with large changes in the CPUE values (1987-1989).

The combined index is expressed in relative CPUE units. Therefore, the total catch divided by the combined index provides an index of total effort in standardised units and this is shown in Figure 4 that also shows the catches. The standardised effort increased drastically after 1988 and the CPUE index responded with a decline as would be expected from single species fish stock assessment models, e.g. Beverton and Holt (1957)

Discussion

Introduction

The re-analysis of the logbook data for the KGH trawlers, The NAFO Div. 0A, 1B and 1CD indices did not appreciably change the data series previously published. The new inshore index follows the trend of the other indices (Fig. 2E).

CPUE as biomass indicator

CPUE indices reflect stock biomass but there is not necessarily proportionality. The relation also depends on the responds in fishing strategy to abundance changes (Hilborn and Walters 1992). The use of CPUE indices as biomass indicators should therefore be evaluated, e.g. using survey results. This was only possible for the period 1988-1997 and while this period showed good agreement there was little contrast in both the survey and in the CPUE series.

The use of a CPUE index as biomass indicator requires that the efficiency of the fleet does not change over time. Efficiency increases in a fishing fleet can result from introduction of new and more efficient fishing vessels in the fleet and withdrawal of older vessels and increased efficiency of existing vessels. increases in fleet efficiency can be substantial. For the US Pacific coast groundfish trawl fishery (1982-1989) the increase in fishing power has been estimated as almost 3% per year (Squires, 1994). Daan *et al.* (1994) estimated an increase of 4% per year in the efficiency of the North Sea cod fishery, 1963-1973.

Trawls in the Greenland shrimp fishery during 1976-1995 became much larger. While a standard shrimp trawl in the mid 1970s had an opening of approximately 1600 meshes, trawls of today are often more than 4000 meshes. In addition introduction of new technology, has caused two jumps in efficiency, around 1980 and again in 1985-1986 (Carlsson and Kanneworff, MS 1987). Although there is no information on whether a similar changes took place at the same time in the Canadian shrimp fishery in Div. 0A, it is likely given the adjacency and similarity in fishing practices. The introduction of better navigation equipment in the beginning of the 1990's have probably also increased the efficiency of the vessels.

Both the Greenlandic and the Canadian shrimp fishery is regulated and particularly the introduction of an ITQ system in the Greenlandic offshore shrimp fishery in 1991 has brought about a significant restructuring of the catching sector. This may well have increased the efficiency of the remaining fleet.

Figure 3 shows spikes for the Greenlandic KGH and the Canadian 0A indices in 1982 and 1987. Reading values from Table 2 for the KGH index, the increase for 1981/82 is 23 % while that for 1986/87 is 30 %. The Canadian data suggest increases of 18 % and 57 % respectively. These increases are possibly the combined effects of stock changes and increased efficiency. Although the available assessments were not able to decompose the changes into its components, there were some indications of recruitment to the fisheries of strong year classes produced in the early 1980's (Anon., 1991). For the 1981/82 increase seen in the Canadian fishery, likely there is an element of learning as the fishery then was quite new.

Our analysis assumes constant efficiency over time of individual vessels. However, the average CPUE achieved by new vessels in the model are compared with those of the older vessels already in the fishery. Therefore the analysis accounts for the increase in efficiency from renewal of the fleet but does not account for the technological improvements, which results from the upgrading of older vessels. The lack of importance of the YEAR*VESSEL term that includes efficiency increases of single vessels compared to the total fleet suggests that this has minor influence on the use of the CPUE index as a biomass indicator.
Figure 3 interpreted as a biomass index is expected to give a slightly optimistic view of the stock development.

Changes in stock and fishery that will affect the analysis

The effects in the data set are partly confounded due to empty cells, unbalance in the data and it is therefore difficult precisely to account for the cause of the interactions.
The implications of an unbalanced design in multiplicative analysis are that some of the parameters may be correlated, estimated with high variance and/or driven by a few high leverage observations, McCullagh and Nedler (1989).

The YEAR*AREA interaction was found to be random changes in good and bad areas between years. The interaction estimate may also be influenced by changes in the shrimp fishery in the period 1987-1995 from being mainly conducted in NAFO Div. 1A-1C to also include more southerly grounds. In 1995 there was shrimp fishery in all subdivisions in Subarea 1. (Hvingel, MS 1996). Results from the Greenlandic surveys (Carlsson and Kanneworff 1997), however, do not suggest that these changes in effort distribution resulted from changes in shrimp distribution. Hence the displacement of the fishery is probably determined by technological improvements allowing access to new grounds.

The YEAR*MONTH interaction reflect variation in the environment, e.g. ice coverage but also the fishing opportunities elsewhere (e.g. off East Greenland and on the Flemish Cap). However, the biological seasonality is caused by changes in the environment which timing varies between years. Therefore, the analysis could be refined if data on an environmental indicator of stock distribution were available (Anon., 1992). Such biophysical or oceanographic marker has yet not been identified.

The final model used in our analysis includes the second order effect AREA*MONTH. This means that the availability of shrimp do not show a geographical constant pattern throughout the year. This could be a result of changes in shrimp behaviour with size combined with an uneven geographical distribution of sizes or stems from a seasonal migration pattern. Seasonal migrations of shrimp in in-shore West Greenland waters have been proposed by Horsted and Smidt (1956). They found that changes in distribution in some fjords were correlated with bottom water temperature. Migration of berried females into shallower water was also observed. Seasonal migration in the offshore areas has not previously been proposed

Diurnal variation in catch rates were observed in the data throughout the whole area, but the pattern seemed complicated presumably being dependent among other things on season, shrimp size and area (Parsons *et al.*, MS 1991). In the analyses presented above diel migrations will add to the random noise.

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Table 1. Summary of number of cells and effect levels in the four indices used in this analysis.

	Class variable (no of levels)				No. of cells		
Index	Year	Season	Area	Vessel	Total	Available	Vessel size (GRT)
1BCD	11 (1987-97)	12 (Jan-Dec)	6	32	9207	2403	80-2500
0A	17 (1981-97)	5 (Jul-Nov)	1	29	2465	478	500-2000
Inshore	10 (1988-97)	9 (Apr-Dec)	3	18	4860	1855	50-80
KGH	15 (1976-90)	12 (Jan-Dec)	4	7	5040	1374	800

Table 2. ANOVA schemes of the five final models used to calculate YEAR effects.

	Full model						Final model				
	Source	df	ss	mss	F	r	df	ss	mss	F	r
Div. 1BCD index 1987-97	Total	6094	36320				6094	36320			
	Error	5774	15255	2.6			6056	19116	3.2		
	Model	320	21065	65.8	24.9	0.58	38	17204	452.7	143.4	0.47
	Vessel	15	13421	894.7	338.6		15	13420	894.7	283.5	
	Month	6	1206	201.1	76.1		6	1207	201.1	63.7	
	Area	1	144	143.8	54.4		1	144	143.8	45.6	
	Year	10	2156	215.6	81.6		10	2156	215.6	68.3	
	Month*Area	6	278	46.3	17.5		6	278	46.3	14.7	
	Year*Month	60	1857	30.9	11.7						
	Year*Area	10	112	11.2	4.2						
	Year*Vessel	108	1352	12.5	4.7						
	Vessel*Area	15	74	4.9	1.9						
	Vessel*Month	89	466	5.2	2.0						
KGH Div. 1B index 1976-90	Total	1370	5994				1370	5994			
	Error	1191	1761	1.5			1336	2806	2.1		
	Model	179	4233	23.7	16.0	0.71	34	3188	93.8	44.7	0.53
	Vessel	1	265	265.3	179.5		1	265	265.3	126.3	
	Month	9	2028	225.4	152.5						
	Year	14	666	47.6	32.2		14	952	68.0	32.4	
	Year*Vessel	12	133	11.1	7.5						
	Year*Area	14	317	22.6	15.3						
	Year*Month	110	765	7.0	4.7						
	Month*Area	9	46	5.1	3.5		19	1971	103.7	49.4	
	Vessel*Month	9	13	1.4	1.0						
	Vessel*Area	1	0	0.2	0.2						
	Area	1	0	0.1	0.1						
Div. 0A index 1981-97	Total	520	4875				520	4875			
	Error	415	1199	2.9			494	1745	3.5		
	Model	105	3677	35.0	12.1	0.75	26	3130	120.3	34.1	0.64
	Month	1	337	336.6	116.5		1	337	336.6	95.3	
	Vessel	9	1868	207.5	71.9		9	1868	207.5	58.7	
	Year	16	925	57.8	20.0		16	925	57.8	16.4	
	Year*Vessel	57	400	7.0	2.4						
	Year*Month	15	122	8.1	2.8						
	Vessel*Month	7	25	3.6	1.2						
Inshore index 1988-97	Total	1854	6487				1854	6487			
	Error	1645	2332	1.4			1822	3442	1.9		
	Model	209	4155	19.9	14.0	0.64	32	3045	95.2	50.4	0.47
	Area	2	650	325.0	229.3		2	650	325.0	172.1	
	Month	4	815	203.9	143.8		4	815	203.9	107.9	
	Vessel	9	1001	111.2	78.5		9	1001	111.2	58.9	
	Area*Month	8	117	14.6	10.3		8	117	14.6	7.7	
	Year	9	462	51.3	36.2		9	462	51.3	27.2	
	Year*Area	18	253	14.0	9.9						
	Year*Month	35	390	11.1	7.9						
	Year*Vessel	71	303	4.3	3.0						
	Vessel*Area	18	61	3.4	2.4						
	Vessel*Month	35	104	3.0	2.1						

Table 3. YEAR effects standardised to 1990 of the individual time series of the Div. 1BCD, KGH Div.1B, inshore and Div. 0A indices. The index resulting from combining these four indices are shown in the right collum.

Year	1BCD	KGH	Small Vessel	0A	Combined
1976	-	1.68	-	-	1.51
1977	-	1.57	-	-	1.41
1978	-	1.21	-	-	1.08
1979	-	1.07	-	-	0.96
1980	-	1.25	-	-	1.12
1981	-	1.22	-	1.15	1.12
1982	-	1.51	-	1.35	1.37
1983	-	1.32	-	1.07	1.19
1984	-	1.28	-	0.99	1.14
1985	-	1.38	-	0.86	1.21
1986	-	1.46	-	0.88	1.28
1987	1.86	1.81	-	1.38	1.66
1988	1.19	1.44	1.29	1.22	1.21
1989	1.04	1.09	1.02	0.90	0.98
1990	1.00	1.00	1.00	1.00	0.93
1991	0.98	-	0.87	0.88	0.91
1992	1.08	-	0.91	1.01	1.00
1993	1.05	-	1.02	0.96	1.00
1994	1.05	-	0.86	0.74	0.95
1995	1.16	-	0.85	0.82	1.04
1996	1.26	-	0.84	0.76	1.10
1997	1.21	-	0.84	0.60	1.05

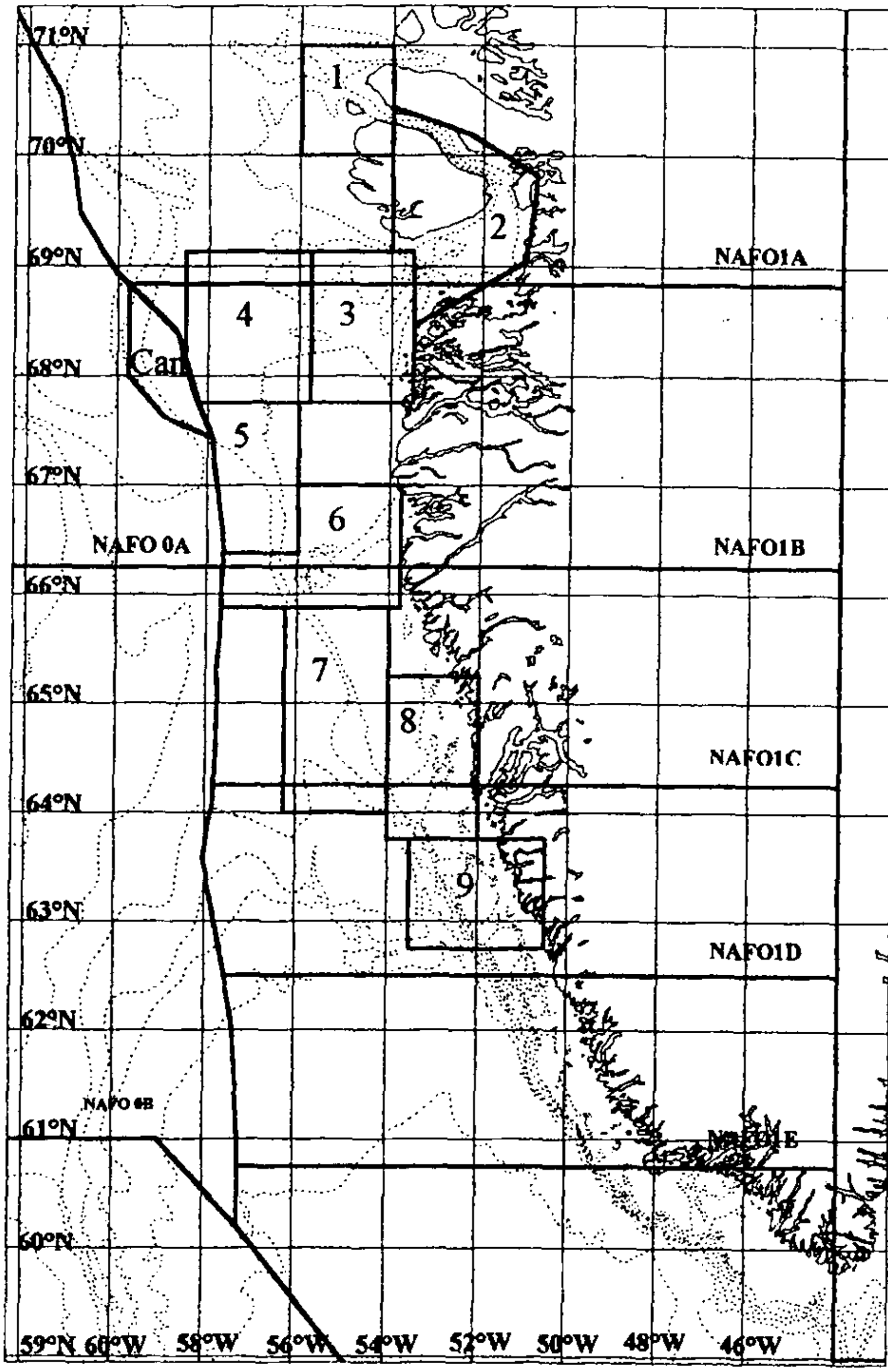


Figure 1. Area stratification used in the multiplicative models for standardising commercial catch-rates of shrimp at West Greenland: areas 1-3 are included in the inshore index; 3-6 in the KGH Div. 1B index; 4-9 in the Div. 1BCD index, area "Can" in the Div. 0A index.

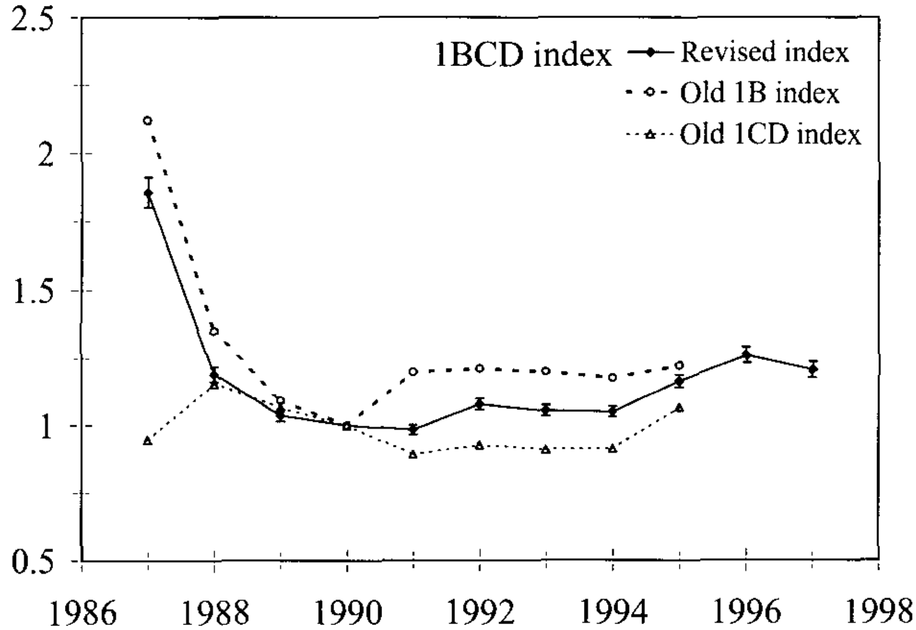


Figure 2 A.

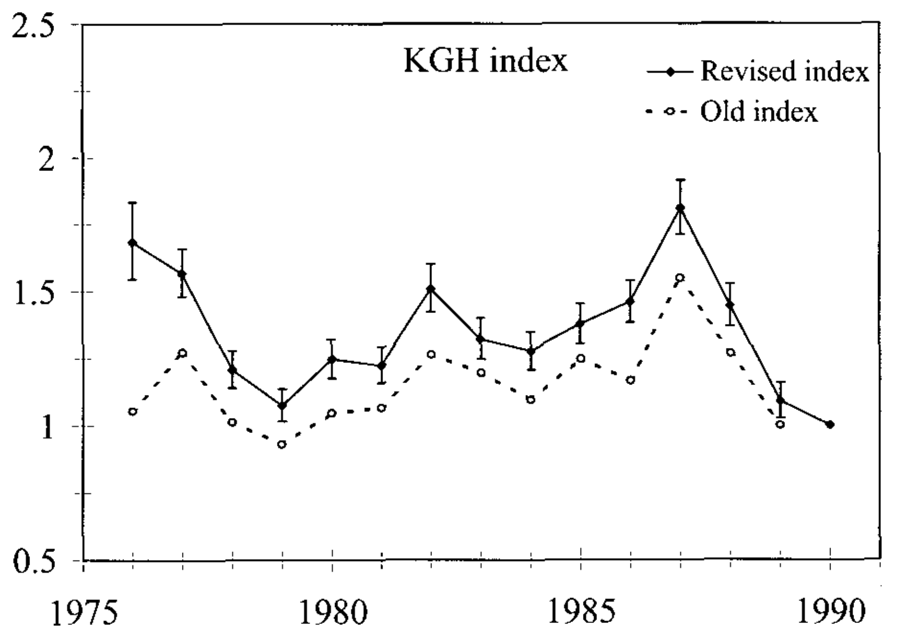


Figure 2 B

Figure 2. Index values of the new and three revised CPUE indices of northern shrimp at West Greenland. The revised indices (1BCD, KGH and 0A) are shown parallel with their older versions as presented in Siegstad *et al.* (MS 1995), Parsons and Veitch (MS 1995) and Lassen and Carlsson (MS 1990). Standard errors are shown as error bars.

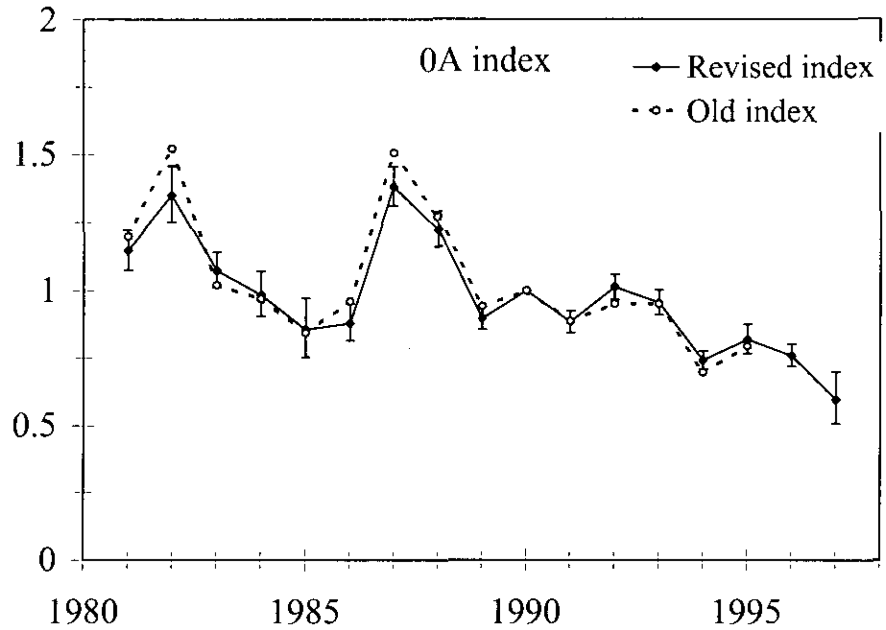


Figure 2 C

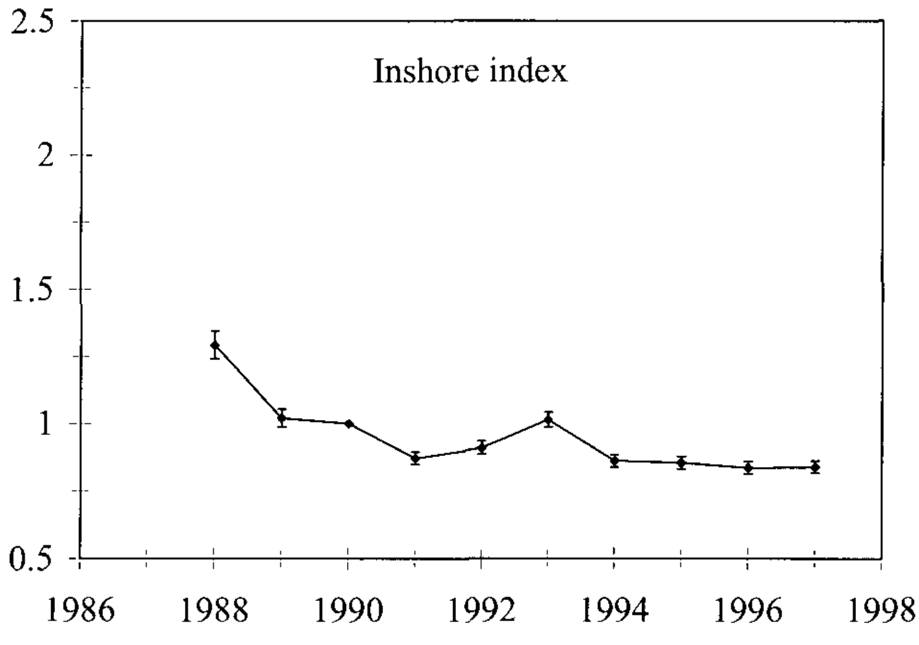
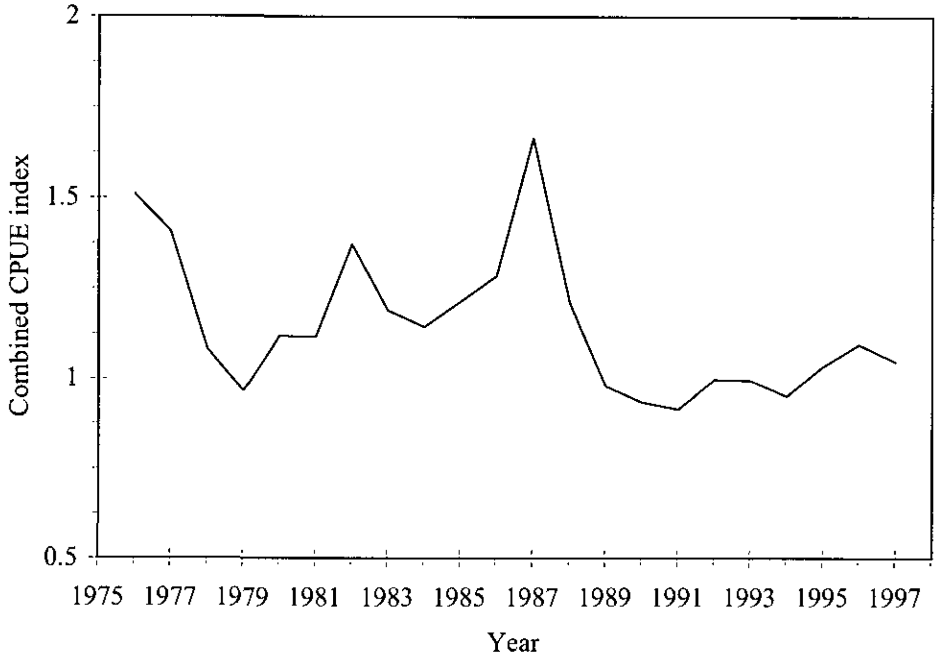


Figure 2D

Figure 2. Continued.



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igure 3. The combined CPUE index of the Davis Strait shrimp stock 1976-1997.

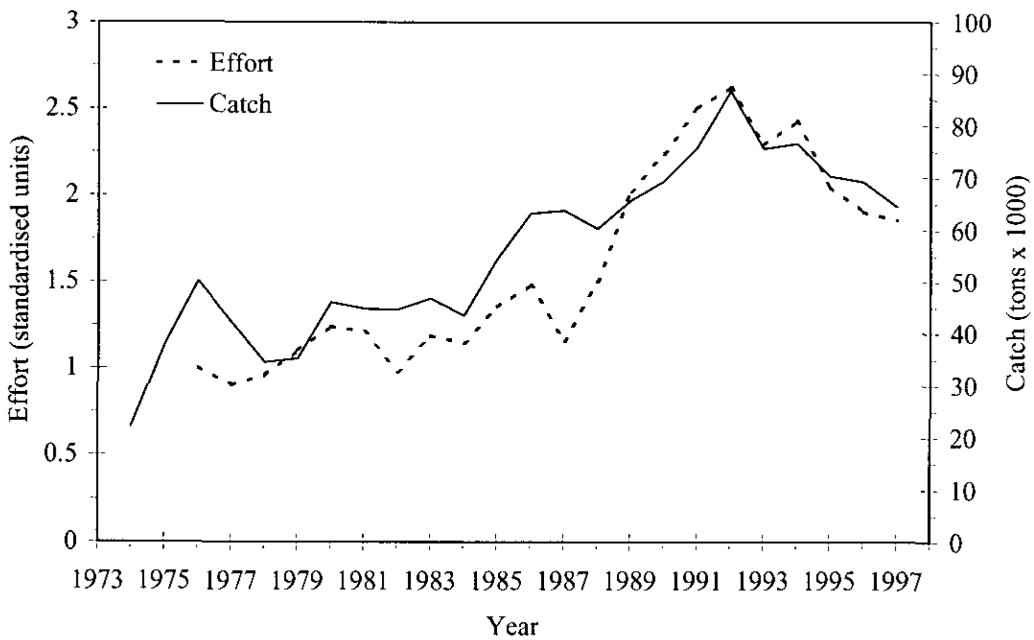

Figure 4. Total catches in SA. 0+1 (tons * 1000) and standardized effort 1975-1997. The standardized effort is calculated by dividing total catch by the combined CPUE index , Table 2 and Figure 3.

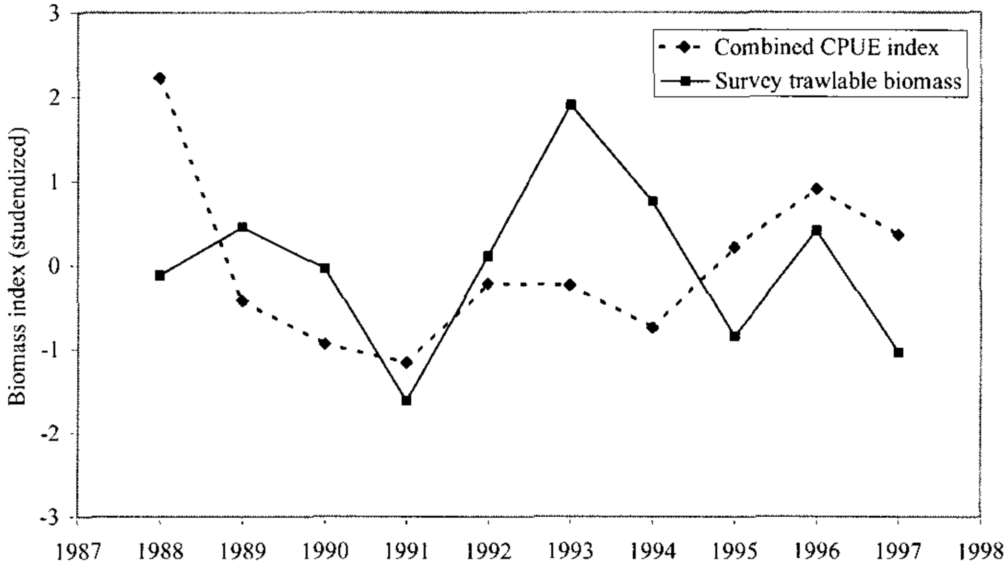

Figure 5. Annual shrimp biomass index from the Greenlandic Davis Strait survey (Carlsson and Kanneworff 1997) and the combined commercial CPUE index as presented in Table 2.Both indices were studendized, i.e the mean 1988-1997 was subtracted and the difference divided by their standard deviation.