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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 (1976-1995)

by

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Abstract

Five biomass indices for the northern shrimp stock in Davis Strait, derived from commercial catch per unit effort (CPUE) data, were analyzed by multiple regression to test their inherent biological and statistical assumptions and to construct a single time series to track the development of the stock during the period 1976 to 1995. Four of the indices were from offshore fisheries and have been used previously in stock assessments while the fifth was a new index derived from logbook data of the small vessel fleet in the inshore area around Disko Island.

The basic model for all indices linked catch rate to vessel fishing power, temporal and spatial availability of shrimp and overall annual abundance. In four of the indices, the temporal (month) and spatial (area) effects were modelled either as an interaction term or as an interaction in addition to the main effects. Other second order effects were treated as random error terms. Analyses showed that, for all indices, the model and error structures were correct.

A single index was produced by combining the five separate indices, weighted by the proportion of the total fishing grounds each represented. The series showed that, during the 1976 - 1988 period, stock biomass fluctuated dramatically at a level substantially higher than that observed from 1989 to 1995. Further, a declining trend was evident within the latter period. No adjustment for increases in technological efficiency over the 20 year period was possible. The integrated index showed some agreement with research survey biomass estimates but the contrast in the data was relatively low during the period of comparison (1988 - 1995).

Introduction

Catch and effort data from commercial fishing vessels provide a simple but important statistic in fisheries management. They are frequently used directly as an index of stock biomass and in VPA-tuning.

Catch per unit effort (CPUE) data are influenced by several factors. Such factors include seasonal variation in availability, difference between vessel fishing power, annual and areal variation in abundance. Therefore, methods for correcting CPUE data for effects other than abundance must be applied before using them in a biomass index.

The need to standardize CPUE to make it proportional to stock biomass has been approached in different ways (Gulland, 1956; Beverton & Holt, 1957). Gavaris (1980) and Kimura (1981) described an alternative and now widely used method based on the work of Gulland (1956) and Robson (1966) using a multiplicative model.

The use of a multiplicative model for CPUE standardization has recently been presented by Perodou & Prevost (1989) and Perodou (1994), southern red snapper, *Lutjanus purpureus*; Gasiukov (1991), *Chamsochephalus gunnari;* Large (1992), sole, *Solea solea;* Miyaki (1989) and Hoey *et al.* (1995), Atlantic swordfish, *Xiphias gladius*. Within NAFO, multiplicative models are frequently used to calculate commercial, CPUE-based biomass indices to trace annual fluctuations in the stock e.g. in the assessment of redfish (*Sebastes sp.*), silverhake (*Merluccius bilinearis*), Greenland halibut (*Reinhardtius hippoglossoides*) and northern shrimp (*Pandalus borealis*) (Anon., 1996).

The offshore fishery for shrimp in Davis Strait (SA 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 in SA 1 based upon seven trawlers was used (e.g Carlsson, 1985). This index was a simple average of the July-September period in Div. 1B. A multiplicative model comprising a Vessel, Area, Month and Year effect was introduced in 1990 based upon the same vessels as those included in the simple index (Lassen & Carlsson, 1990).

In 1985, a new logbook system was introduced for the Greenland offshore shrimp trawlers (>50 GRT) with haul to haul information on the size categories of shrimp in the catch. A new index for Div. 1B was calculated using the same model as previous (Carlsson and Lassen, 1991) but revised to include 22 vessels covering about 90% of the offshore catches by larger vessels in 1987, when the time series began. Furthermore, it avoided the influence of variable unreported discard by including only the large shrimp catch component for which discard is normally negligible (Lehmann & Degel, 1991).

Traditionally, the fishing grounds in Div. 1B and the Div. 1A area around Disko Island have been the most important but, since 1987, catches have increased in Div. 1C and 1D, and from 1990 these catches exceeded those from 1B (Carlsson *et al.*, 1993a). In recognition of this development in fishing pattern, a parallel "Large Shrimp" index for Div. 1CD was introduced in 1993 (Carlsson *et al.*, 1993b).

The Canadian fleet joined the fishery in 1979 and, for the first two years, fished in both Div. 0A and SA 1. From 1981, onward, fishing was restricted to Div. 0A within Canadian waters. The CPUE data from these vessels for the latter period qualified to enter the Canadian index for Div. 0A based on a multiplicative model which included Month, Vessel and Year effects (Parsons & Veitch, 1991). No area effect was necessary because of the limited fishing grounds available within the Canadian zone.

The Greenlandic small vessel fleet component (<80GRT) accounts for about 25-35% of the total nomimal catches in SA 0+1. Their fishing grounds are generally restricted to areas around Disko Island. No standardized index has earlier been made for this part of the fishery, but will be constructed in this paper.

The purpose of this paper is to combine the five temporally and geographically fragmented biomass indices to establish a single time series of commercial CPUE data for northern shrimp (*Pandalus borealis*) in Davis Strait from 1976 to 1995. This series should reflect the development of the stock over the same period for use in assessment of the stock status. Besides constructing a new index for the small vessel fleet component, the paper also reviews the biological and statistical assumptions behind four standardized biomass indices used in the assessment so far and examines whether these assumptions are fullfiled.

Theory, assumptions and problems of design

The indices were derived using a multiplicative model including the following variables: a. Individual vessel fishing power, b. Temporal availability of shrimp, c. Spatial availability, d. Annual biomass of shrimp.

The analysis is based on an approach similar to Large (1992) and the theory is described in Richards and Schnute (1992). The actual calculations were performed using the SAS computer system (Anon., 1988).

The model takes the form:

$$\text{CPUE} = \text{Vessel fishing power} * \text{Temporal availability} * \text{Area availability} * \text{Overall annual abundance}$$

This model was represented in logaritmic form:

$$\text{Log(CPUE)} = \text{Vessel fishing power} + \text{Temporal availability} + \text{Area availability} + \text{Overall annual abundance} + \varepsilon$$

ε is the error term assumed to be $N(0,\sigma^2)$.

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 relative distribution of the stock is constant over seasons and years (i.e. if the stock is twice the normal level, then the biomass in all areas is twice the normal level)
- The seasonal availability varies in a constant pattern between years

The validity of these assumptions is investigated by studying models which include the following interaction terms:

Vessel	*Area	(Vessel fishing power varies between areas).
	*Month	(Vessel fishing power varies between month).
	*Year	(Vessel efficiency depends on year ie. vessels change their efficiency out of phase).
Area	*Month	(Seasonal migrations).
	*Year	(Biomass distributions change between years).
Month	*Year	(The seasonal distributional pattern varies between years).

The available data set presents a problem of imbalance (i.e. there are empty cells). There are missing data for all combinations of vessel*month*area*year and there are different numbers of observations in each cell. The implications of such an unbalanced design is that some parameters may be 1. correlated, 2. estimated with high variance and 3. driven by few high leverage observations.

The latter problem was countered by weighting the observations in a cell by the number of observations.

Higher order interactions cannot be investigated on the available data sets because of the occurrence of many empty cells

Material and Methods

The northern shrimp stock off West Greenland covers the NAFO divisions 0A and 1A-1F in depths less than about 600 m, see fig. 1

There are two sources of data supplying the commercial CPUE data used in the assessment of the shrimp stock: a logbook database for the Greenlandic shrimp trawlers (>50GRT) fishing in SA 1 and a similar logbook data base documenting the Canadian shrimp fishery in Division 0A. The fishing areas are shown on fig. 1.

Based upon these logbooks four standardized CPUE-indices have been presented. The Greenlandic KGH-trawler index covering Div. 1B in the period 1976-1989 (Lassen and Carlsson, 1990), the Greenlandic 1B trawler index also covering Div. 1B but for the period 1987-1995 (Carlsson and Lassen, 1991; Siegstad et al., 1995), the Greenlandic 1CD trawler index covering Div. 1CD in the period 1987-1995 (Carlsson et al., 1993b; Siegstad et al., 1995) and the Canadian 0A trawler index covering Div 0A from 1981 to 1995 (Parsons and Veitch, 1995).

These four standardised CPUE indices were reconstructed using corrected data up to and including 1995. Furthermore a new index for the Greenlandic small vessel fleet component (<80GRT) fishing in the Disko Island area was constructed. The four revised indices and the new small vessel fleet index were then combined forming one 1976 to 1995 index of shrimp biomass.

1. Greenland commercial CPUE data

Catch and effort statistics of the shrimp fishery at West Greenland are collected through logbooks on a haul-to-haul basis. In NAFO SA 1 Greenlandic logbooks are available since 1976. These data include shrimp catch but only for a smaller part of the fishery and not from all seasons. With the introduction of a new Greenlandic logbook in 1985 covering the total offshore fishery by vessels larger than 50GRT, data now include catches seggregated in size groups and account for about 99% of the catches by the large fleet component (>80GRT) and 50% of the catches taken by the small vessel fleet (<80GRT).

Until the mid 1980's the fishery was mainly restricted to NAFO Div. 1B and the data series from that period consquently only present information of the population in that area. Thereafter, the fishery gradually expanded southwards to Div. 1C and 1D. From 1987 the analysis of the Greenlandic CPUE data is separated into Div. 1B and Div 1CD indices.

There are some limited data reported from Div. 1A other than the "Disko area" (=East of 56° W). 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. Very little effort is expended in Div 1E and 1F and thus these areas were excluded from the analysis as well.

Recording of catches by size groups in the new Greenlandic logbook made it possible to calculate catches of shrimp larger than a certain size. To avoid the unaccounted discard influencing the catch rates, only catches of shrimp larger than approximately 8.5g (count<120/kg) were included in the 1B and 1CD catch rate indices. Discard is for these size groups normally negligible (Lehmann & Degel, 1991). For the KGH index and the new small vessel index total catch, being the only observation available, was used.

The offshore shrimp fleet has varied over time. Between 1976 to early 1980s the KGH trawlers dominated but the fleet expanded drastically thereafter reaching a peak of about 50 vessels around 1990. The 1B and 1CD indices are calculated based on a subset of these vessels.

The main criteria for including an individual vessel in the 1B and 1CD indices was that it should belong to the offshore fleet component (>80GRT) and at least have operated for three years of fishing in the areas covered by the indices. Onboard sorting of the catch into size groups was also required. Thus 31 vessels were included in these calculations.

For the period covered by the small vessel index (1988-1995) logbooks are available from around 25 vessels. Only vessels below 80GRT were allowed and three years of sustained participation in the fishery were also required. This resulted in a subset of 18 vessels qualifying for this index.

The area structure in the models is based on the distribution of geographical well-defined fishing grounds (fig. 1). These areas are assumed to have a well-defined structure in distribution of shrimp abundance.

1.1. The Greenlandic NAFO Div. 1B trawler index, 1987-1995

The CPUE data for the 1B index was broken down into four areas largely constituting Div. 1B. Thus only data refering to the stratification 3, 4, 5 and 6 as shown in fig.1 were included in this index.

The data were grouped by Year (9), Month(12), Area(4) and Vessels(31) in total 13392 cells.

Due to ice, access to all or some of the fishing grounds in Div. 1B may be hampered in the first three months of the year and practically no effort is spent in areas 3, 4 and 5 in the first quarter by the vessels included in the 1B index. These months were therefore excluded from the model. Furthermore, access to area 3 for vessels above 80GRT has since 1990 been more or less restricted by legislation and therefore area 3 was omitted from the calculations. This brought the number of cells down from 13392 to 7533. However, only 2148 cells were represented in the data set, i.e. not all vessels had in all months and years fished all areas.

1.2. The Greenlandic small vessel index, 1988-1995.

Most of the fishery in Greenlandic waters conducted by vessels below 80 GRT is confined to areas around Disko Island i.e areas 1, 2 and 3 in figure 1. These three areas constitute the areal seggregation for this index.

Data are available since 1987 and 28 vessels are represented fishing from March-December. This amounts to a possible number of 7560 cells of which 1630 were covered by the data. On account of too few observations the year 1987, the month March and 10 vessels were excluded from the construction of the index. Consequently this model included 8 years, 18 vessels variable, 9 months and 3 areas. The number of possible cells were almost halved to 3888 of which 1430 were covered by the data.

.3. The Greenlandic 1CD trawler index, 1988-1995

The CPUE data for the 1CD index was broken down into three areas largely constituting Div. 1C and 1D. Thus only data refering to the stratification 7, 8 and 9 as shown in fig.1 were included in this index.

All 12 months were used since the ice problem is less marked here than in Div. 1B. The 1CD time series starts in 1987. However, the fishery was still in its infancy and only 36 observations (cells) were represented in the 1987 data. As most of these observations included very few hauls the 1987 data were not included in this index.

Consequently this model has 4 class variables: year, vessel, area and month with 8, 31, 3 and 12 levels respectively or 8928 cells of which 2812 were represented in the data.

1.4. The KGH index, 1976-1990

This data series covers the period 1976 to 1991. For the period 1987-1990 the data are also included in the 1B index presented above. Before 1987 only data on total shrimp catch and effort are available and therefore this index as opposed to the 1B and 1CD index will be affected by discards.

The intial fishery was executed by 7 sister trawlers all operated by the "Kongelige Grønlandskė Handel" (KGH). Even though additional effort was added to the fishery the logbook information only cover the KGH trawlers until 1987 (Lassen et al., 1990). Therefore this time series is treated separately and only the 7 vessels were included in the analysis. The early fishery only covered NAFO Div. 1B and the index is restricted to this area.

The area stratification for the KGH index is the same as for the Greenlandic 1B trawler index, i.e. areas 3, 4, 5 and 6 as shown in fig. 1.

In the period 1976-1990 during which Div. 1B was covered by the KGH-trawler index more than 12.5% of the fishery took place in the first quarter. Therefore in contrast to the Greenlandic 1B trawler index 1987-1995 Jan-Mar was included in the analysis of the KGH index. Also, as free access to area 3 prevailed in those years this area was included.

Consequently this model has 4 class variables year, vessel, area and month with 16, 7, 4 and 12 levels respectively or 5040 cells of which 1389 were represented in the data.

2. Canadian Commercial CPUE Data

The Canadian logbook system has covered the Canadian shrimp fishery in the Davis Strait from the beginning of the fishery in 1979. There have been no major changes in this logbook system since the start.

Since 1981 Canadian 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 data items available are on a haul-by-haul basis: date, time, geographical position, depth, duration and total catch of shrimp in kg.

2.1. The Canadian 0A trawler index

The fishery in Div. 0A usually takes place from June-December and is restricted to a very limited area (fig. 1). Thus, no areal seggregation 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.

The data were grouped by Year (15), Vessel (29) and Month (7), in total 3045 cells.

Although the fishery takes place in June-December, the analysis was confined for the months July-November as the June and December effort was rather spotty, especially in recent years. This reduced the number of cells to 2175 of which only 478 are represented in the data.

3. Construction of the 1976-1995 time series

The model applied in these analysis, i.e.

Log(CPUE) = VESSEL+YEAR+MONTH+AREA

assumes that the geographical distribution of the shrimp is constant over time, hence an index from a subarea of the total area of occurrence would 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 five available indices.

This was done by calculating the average ratio between the indices using the KGH index as unit. The KGH index was chosen as unit because it is the longest time series. This calculation was done for the overlapping years ie. the years where the index and the KGH index both were available. The yearly abundance estimate of the 1B, 1CD, Small vessel and the 0A indices was then standardized by multipying this calculated mean ratio. Finally the indices were combined into a single abundance index by weighting each index with the area of the fishing grounds it represents. This was taken to be the area of sea bottom between 150-600m.

Results

The data show major haul-to-haul variation. The data applied in the analyses were the ratios between the catch and the corresponding effort for all cells (vessel, area, month and year).

To avoid cells with very few hours of effort having too much impact on the models in the estimation, the data were weighted by number of hauls.

1. The Greenlandic NAFO Div.1B Trawler index of large shrimps (count 120 or less)

The simplest model does not include any 2nd order effects:

log(CPUE) = VESSEL + AREA + MONTH + YEAR   Model 1

The ANOVA scheme of this model applied to the Greenland 1987-1995 1B data, weighted by the number of observations in each cell, showed that the R-square is only about 45 % and that even after the haul-to-haul variation has been removed by taking means within each cell, the Mean square error term is appreaciable as shown by the CV of 41 %. In this model all effects (Vessel, area, month and year) are significant at a 5 % level.

The assumptions of constant distributional and seasonal pattern were then investigated in a model where all second order effects were included (there are empty cells in the data set and therefore a full model including all possible interactions can not be applied):

log(CPUE) = Model 1 + Vessel*Area + Vessel*Month +....... + Month*Year   Model 2

This model including 622 parameters increased the R-squared to 76 %, but only reduced the CV to 33 %. The only two effects found to be non-significant were the AREA and the VESSEL*AREA effect (P>0.05). This suggests that vessels do not show any marked increased efficiency in particular areas as could be expected, but also that there is no time-independent well defined geographical distribution in the population. There are in a particular year diffferences in catch rates between areas. However, these areas with good and bad fishing vary between years. The analysis suggests that there are a marked seasonal pattern in the geographical distribution of the shrimp, i.e. the 2nd order effect MONTH*AREA is highly significant.

Examination of Cook's D influence statistic assured that the model was not driven by a few highly influencial points.

Inspection of a plot of the studentized residuals (Fig. 3) did not reveal any trend suggesting constant variance and independence of the errors. A normal probability plot indicated that errors were normally distributed. Plots of the residuals against the main effects of the model confirmed that the errors were independent of the main effects. However, these analyses suggested some outliers. Based on inspection of the raw data, 22 observations were defined as marked outliers and therefore excluded from the subsequent analyses.

It may be commented that the effects in the data set are partly confounded. This is best illustrated by the significance of the AREA effect in model 1 while this effect was not found to be significant in model 2, but is explained by the some of the 2nd order terms

Removing the non-significant area and vessel*area interaction from model 2 did not change the results appreciably and the R-square only decreased by 1%.

Recalculation of model 2 with the two non-significant terms removed and the remaining effects entered in order of decreasing model explanatory importance gave the following ANOVA table.

Effect	DF	Type I SS	Mean Square	Pr > F
YEAR	8	2478	309.7	<0.0001
VESSEL	30	4477	149.2	<0.0001
MONTH	8	734	91.8	<0.0001
MONTH*AREA	18	1005	55.9	<0.0001
YEAR*MONTH	64	1373	21.4	<0.0001
YEAR*VESSEL	181	2017	11.1	<0.0001
YEAR*AREA	16	139	8.7	<0.0001
VESSEL*MONTH	236	1040	4.4	<0.0001

The parameter estimates do not show a systematic effect of YEAR on CPUE between the various vessels for given areas and months. It was therefore considered that these variations were not part of the general structure of the system but rather noise and the effects were not included in the final analysis.

The vessel*month interaction was relatively inconsequential to the interpretation of the analysis and there was no explanation of why vessels should show different efficiency in different months. It would have been expected that vessels, e.g. due to skipper experiences, would have shown efficiency differences between areas rather than months. This Vessel*month effect was therefore also ignored.

In an assessment context interactions including YEAR cannot be included in the analysis but must be treated as random error terms. *This is because there is no possibility for predicting these effects.*

The Year*month effect represents changes in availabilty of shrimp to the trawl between years. and the Year*area effect geographical differences between years. The Year*vessel term represents efficiency increases of single vessels compared to the total fleet. Such increases, to be further discussed later, however are usually levelled out by the rest of the fleet being upgraded subsequently. Furthermore there is confounding where these three terms are included.

The final model therefore only included the Month*Area interaction along with the main effects.

$$\text{Log(CPUE)}=\text{VESSEL}+\text{YEAR}+\text{MONTH}+\text{AREA}+\text{MONTH}*\text{AREA} \qquad \text{Model 3}$$

This interaction which reflects seasonal changes in shrimp availability between areas, increased the R-square to 50% compared to model 1 without the 2nd order term of MONTH*AREA which gave an R-square of 45 %.

This model also showed that for the 1B index the main AREA effect was not significant (i.e. that there is an area structure which, however, varies with season, possibly resulting from a repeated annual migrational pattern).

The remaining consideration focused on a version of Model 3 where the area and month main effects are included in the 2nd order interaction effect. The YEAR effect is the desired abundance index in logaritmic terms. This result is shown on

Fig. 2 after taking the antilog. The error bounds exp(standard deviations in log terms) are shown as bars.The results of the revised model only meant minor changes compared to the one used previously (Fig. 2).

2. The Greenlandic NAFO Div.1CD Trawler index of large shrimps (count 120 or less)

The analysis of this index followed a similar route as that taken for the analysis of the Div. 1B index.

Analysis of the residuals (as described above) from the first run including the four main effects and six first order interactions suggests that the model and error structure are correct. Thirteen outliers were detected and deleted before further analysis.The findings were also very similar to those for the Div. 1B index.

In the first run of model 2 (all 2nd order effects included) only the vessel*area interaction came out not significant (P>0.19). The R-square was 72%. Although highly significant the interactions between vessel*year and vessel*month are relatively unimportant whereas the month*year, month*area and year*area are of some importance.

Removing the non-significant vessel*area interaction did not change the results appreciably and the R-square only decreased to 71%.

Again for similar reasons as for the Div. 1B index 2nd order effects except for the MONTH*AREA interaction were included in the random noise as model 3 was used to construct the final abundance index.

The most conspicuous change in the time series of the revised 1CD model compared to earlier version is a steeper downward trend in 1988-1991. Otherwise differences are marginal (fig.2).

3. KGH-trawler index of total shrimp catches

The analysis followed similar routes as with the two previous indices presented. Initial runs detected one outlier which was deleted from the subsequent analysis.

The simple non-interaction model gave a R-square of 52 % while a run with all second order terms produced an R-square of 81%. The Area main effect and the Vessel*Area and Vessel*month interaction came out not significant. The remaining interactions do have some minor explanatory value of the data.

Removing the two not significant interactions from the analysis reduced the R-square to 79%.

Based on the same arguments as used above the model was reduced to a version of Model 3 where the month and area main effects are included in the MONTH*AREA effect. The most obvious change caused by the revision of this index is that the first point (1976) is moved from one of the lowest to one of the highest of the series (fig.2). In other respects changes are cosmetic.

4. The Greenlandic Small Vessel index, 1988-1995

The first run of the full model for this new index resulted in an R-square of 70% i.e. about the same level as for the other indices. Also only the vessel*area effect was not significant.

Analysis of the residuals suggests that the model and error structure are correct. However, 5 outliers were detected and excluded from further analysis which brought the R-square up to 75%. A run without the Vessel*area interaction did not change the result appreciablely. The remaining interactions including vessel had very low mean squares i.e a very small impact on the model. The remaining 2nd. order effects including year,month and area had some more, but still minor explanatory value of the data.

Including the significant interaction terms as part of the random noise in using model 3 as the final model reduced R-square to 46%. Year effects are shown in fig. 2.

5. The Canadian NAFO Div. 0A trawler index of total shrimp catches

The analysis of this index followed a similar route as that taken for the analyses above, except there was no need to include and area effect. Analysis of the residuals from the first run including the three main effects and three first order interactions suggests that the model and error structure are correct. Three outliers were detected and deleted before further analysis.

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 94%.

Removing the non-significant vessel*month interaction did not change the results appreciably and the R-square only decreased to 91%.

Again for similar reasons as for the above analyses model 1 without an area effect was used to construct the final abundance index, fig. 2. The revision of the model did not change the results appreciably.

6. An aggregated abundance index 1976-1995 for NAFO Div. 1B

The five fragmented abundance indices together with the final 1976-1995 abundance index are shown in table 2.

The last graph of figure 2 shows the five indices standardized to the KGH index by the mean ratio of the overlapping years. The indices show a reasonable agreement in development supporting the assumption that they are measuring the same thing.

In combining the five indices each index was weighted by the proportion of the total fishing ground they represent. The weighting factors are given in table 3 and the final index is shown in table 2 and figure 4.

The stock seems to have fluctuated by a factor of 2 within the last 20 years. Biomass declined from 1976 to 1979, increased to the highest value observed in 1987 but declined again to 1991, remaining low, thereafter. At lower stock size since 1989, a downward trend is still evident.

Discussion

Carlsson and Lassen (1990) presented the initial indices for the KGH and the 1B and 1CD logbook database. Parsons and Veitch (1995) have presented the SA 0A series. This re-analysis has not changed those index values appreciably. However the combination of the indices to construct a longer time series has not previously been attempted. The analysis presented here was also made in more details than those previously published.

Categorization of data. .

In the five models comprising the combined index, individual vessels were chosen as the unit of fishing efficiency. This variable alone does not account for improvement of vessel fishing power and it is therefore in the above analysis assumed that none is taking place. The vessel component will, however, over time include some element of technological improvements which in this study therefore was incorporated in the random noise. The magnitude of increase in efficiency can be substantial. For the US Pacific coast groundfish trawl fishery (1982-1989) the increase in fishing power has been estimated to 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.

Apart from an assumed slowly continuing improvement of vessel fishing power two distinctive points of increase in efficiency by the Greenlandic offshore fleet is recognised. Around 1980 more efficient gears were introduced and again in 1985-1986 where high opening trawls with KEVLAR netting and trawl positioning systems were taken into use (Carlsson, 1987).

The high 1987 value of the combined index (fig. 5) and also the spike in 1982 may thus be influenced by the above mentioned improvement of trawling gear. However, the Canadian 0A index shows the same "spikes" without the same events regarding distinctive increases in efficiency. This may indicate that the "spikes" primarily is due to the recruitment of strong year classes produced in the late 1970's and early 1980's.

Quantification of increase in efficiency of the fleets fishing in the Davis Strait has not yet been attempted and is beyond this study. Implementation of this effect in the biomass models is therefore not possible at the moment. However, the general trend in the biomass index series can be assumed to be biased upwards, especially in the later year of the time series, since the points of individual vessel increase in fishing power tend to be averaged out in the models as the pass down the time series.

The implications and methods of quantification of efficiency increase has recently been reviewed by Pascoe and Robinson (1996).

Grouping of data over time interval

Categorization of the data by some time period is often not appropriate as timing of environmental signals may vary from year to year and give rise to unnecessary time period * year interaction (Anon.,1992). But lacking a well-difined biophysical or oceanographic marker to categorize the data by, time period appeared the only option. No finer time scale than month seemed nessesary to capture seasonal variation, partly based on the advantage of averaging out the large haul to haul variations in CPUE.

The year element should be the factor tracing the annual biomass of the shrimp population in the models. In principle, no interactions between year and the other factors are allowed, as it is assumed that CPUE in any one year is a given proportion of CPUE in another year. However, inteactions with year did show up significant in all five analyses. We examined the parameter estimates and found no systematic effect of year on CPUE between the various vessels for given areas and months. These types of models should be closely scrutinized when interactions with year are present and the years which are affected most clearly identified.

Diel variation in catch rates were observed in the data throughout the whole area, but the pattern seemed a complicated one presumeably being dependent among other things on season, shrimp size and area (Parsons et al., 1991). Futher investigations specifically into diel shrimp migrations is needed before a proper variable to be used in the models can be generated. In these analyses diel migrations will add to the random noise.

Implications of design.

Besides empty cells, another imbalance in the CPUE data is the amount of information contained in each cell. In these models a non-empty cell may represent from 2 to 784 hr's of effort. To prevent relatively few hauls to have too much impact on the model some weighting of the data therefore seemed appropriate. In the Div. 0A model no weighting was previous used. In the Greenlandic models a sort of weighting was earlier done, rather arbitraily, by excluding cells with less than 10 hr's of effort. As the choice of which effort limit to use do have some effect on the results, weighting each cell by the number of hauls it represents seemed a more objective method.

A basic assumption for the use of these indices for assessment purposes and in general as stock indicators is that the index is proportional to stock biomass. There are survey data available from July-August for the period 1988-1995 (Folmer, Carlsson, Hvingel and Kanneworff. 1996). Figure 8 shows the combined index plotted against the survey biomass. Although the contrast in the CPUE data after 1988 is quite low for this period, there is some agreement between the indices if the 1988 values are omitted.

The commercial fishery exploits shrimp greater than 17 mm CL, corresponding to ages 4+. Northern shrimp change sex in West Greenland at about 24 mm CL and, therefore, the index is indicative of the older males and the female stock combined. The difference between an index based on the total catches and the indices from 1987 onwards based on larger shrimp is 1-2 yearclasses. As discussed previously discards of shrimp between 19 and 24 mm CL occur in varying amounts and this adds to the variability of the index. The combination procedure assumes that the recruitment does not vary strongly between neighboring year classes.

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Table 1. ANOVA schemes of the five final models used to calculate year effects.

Greenlandic 1B Trawler index 1987-1995

Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability of Ho	R-square
Total	2125	17530				
Error	2061	8835	4.3			
Model	64	8695	135.9	31.7	<0.0001	0.50
Year	8	2476	309.7	72.4	<0.0001	
Vessel	30	4477	149.2	34.8	<0.0001	
Area*Month	26	1740	66.9	15.6	<0.0001	

Greenlandic 1CD Trawler index 1988-1995

Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability of H0	R-square
Total	2801	20755				
Error	2729	10167	3.7			
Model	72	10588	147.1	39.5	<0.0001	0.51
Vessel	30	6220	207.3	55.6	<0.0001	
Month	11	2151	195.6	52.5	<0.0001	
Year	7	1254	179.1	48.1	<0.0001	
Area	2	335	167.4	44.9	<0.0001	
Area*Month	22	629	28.6	7.7	<0.0001	

Greenlandic KGH Trawler index 1976-1990

Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability of Ho	R-square
Total	1373	6025				
Error	1306	2604	2.0			
Model	67	3421	51.1	25.6	<0.0001	0.57
Year	14	1024	73.1	36.7	<0.0001	
Month*Area	47	2231	47.5	23.8	<0.0001	
Vessel	6	166	27.6	13.9	<0.0001	

Greenlandic Small Vessel index 1988-1995

Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability of H0	R-square
Total	1310	4244				
Error	1260	2194	1.7			
Model	50	2050	41.0	23.6	<0.0001	0.48
Area	2	429	214.4	123.1	<0.0001	
Year	7	209	29.8	17.1	<0.0001	
Vessel	17	818	48.1	27.6	<0.0001	
Month	8	462	57.8	33.2	<0.0001	
Area*Month	16	132	8.3	4.8	<0.0001	

Canadian 0A Trawler index 1981-1995

Source of variation	Degrees of freedom	Sum of squares	Mean square	F value	Probability of Ho	R-square
Total	474	4266				
Error	428	1477	60.6			
Model	46	2789	3.5	17.6	<0.0001	0.65
Month	4	367	91.8	26.6	<0.0001	
Vessel	28	1764	63.0	18.3	<0.0001	
Year	14	657	46.9	13.6	<0.0001	

Table 2. Year effects from the five indices 1B, KGH, 1CD, Small Vessel and 0A with the weighting factor used for integrating them in the combined index as also shown. (Note that the year effects of the five indices is not yet standardized to the KGH index).

	1B		KGH		1CD		Small Vessel		0A		Combined
Year	Index	Weight	Index	Weight	Index	Weight	Index	Weight	Index	Weight	index
1976	-	-	1.72	1.00	-	-	-	-	-	-	1.72
1977	-	-	1.60	1.00	-	-	-	-	-	-	1.60
1978	-	-	1.23	1.00	-	-	-	-	-	-	1.23
1979	-	-	1.06	1.00	-	-	-	-	-	-	1.06
1980	-	-	1.25	1.00	-	-	-	-	-	-	1.25
1981	-	-	1.24	0.87	-	-	-	-	1.48	0.13	1.27
1982	-	-	1.55	0.87	-	-	-	-	1.74	0.13	1.57
1983	-	-	1.35	0.87	-	-	-	-	1.36	0.13	1.34
1984	-	-	1.28	0.87	-	-	-	-	1.27	0.13	1.28
1985	-	-	1.38	0.87	-	-	-	-	1.09	0.13	1.34
1986	-	-	1.44	0.87	-	-	-	-	1.12	0.13	1.40
1987	2.25	0.37	1.85	0.49	-	-	-	-	1.71	0.13	1.91
1988	1.64	0.21	1.47	0.28	1.76	0.30	1.53	0.14	1.53	0.09	1.45
1989	1.07	0.21	1.09	0.28	1.36	0.30	1.22	0.14	1.12	0.09	1.07
1990	1.04	0.21	1.00	0.28	1.32	0.30	1.17	0.14	1.27	0.09	1.03
1991	0.94	0.41	-	-	1.07	0.30	1.03	0.21	1.10	0.09	0.89
1992	0.93	0.41	-	-	1.17	0.30	1.06	0.21	1.26	0.09	0.93
1993	1.07	0.41	-	-	1.14	0.30	1.22	0.21	1.19	0.09	1.00
1994	0.91	0.41	-	-	0.93	0.30	1.02	0.21	0.93	0.09	0.83
1995	1.00	0.41	-	-	1.00	0.30	1.00	0.21	1.00	0.09	0.88

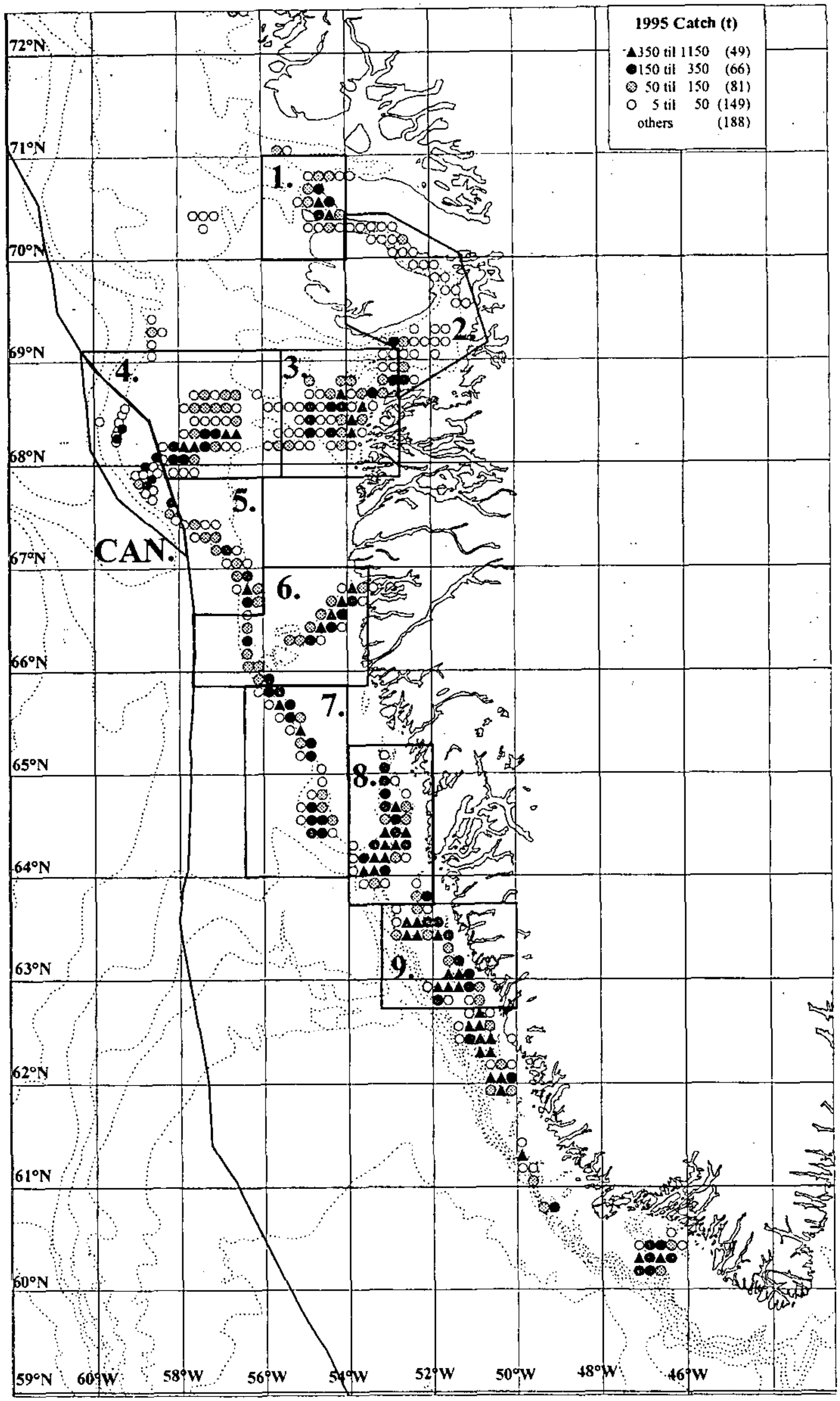

Figure 1. Distribution of shrimp catches in Davis Strait 1995. The areal segregation used in the multiplicative models are shown: area 1-3 is used in the Greenlandic small vessel index; area 3-6 In the Greenlandic KGH trawler index; area 4-6 in the Greenlandic NAFO Div. 1B trawler index; area 7-9 in the Greenlandic NAFO Div. 1CD trawler index; area CAN in the Canadian NAFO Div. 0A trawler index.

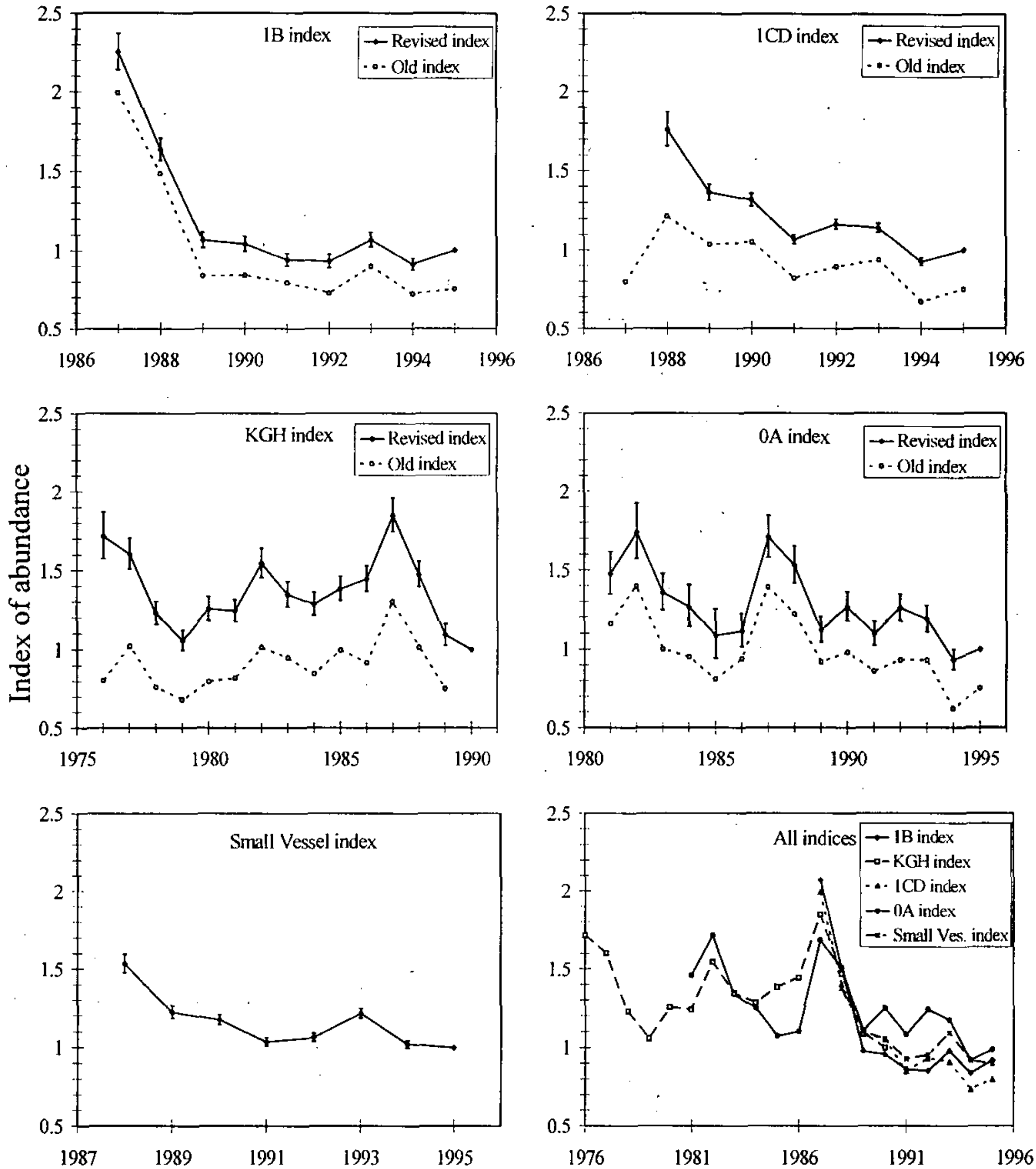

Figure 2. Year effects from the four revised 1B, 1CD, KGH and 0A indices together with their older versions as taken from Siegstad *et al.* (1995), Parsons *et al.* (1995) and Lassen *et al.* (1990). The old version of the indices was standardized to 0.75 for the latest year of the time series, while the revised was standardized to 1 for better graphic presentation.

Also the new Small Vessel index is depicted. The final graph shows all five indices standardized to the level of the KGH index. Standard error is shown as errorbars.

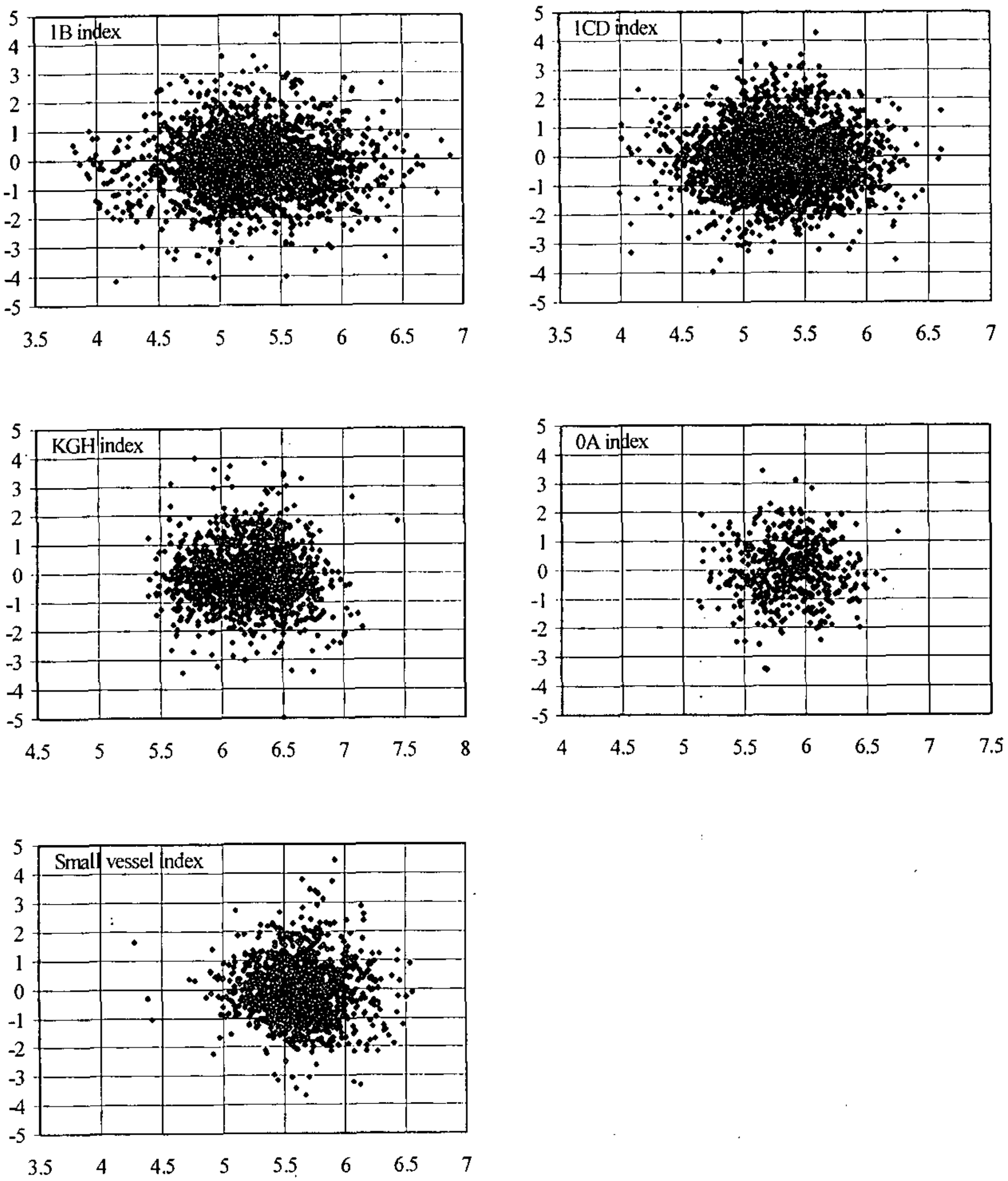

Figure 3. Scatterplot of studendized residuals against estimates of the final models used to calculate the annual abundance index.

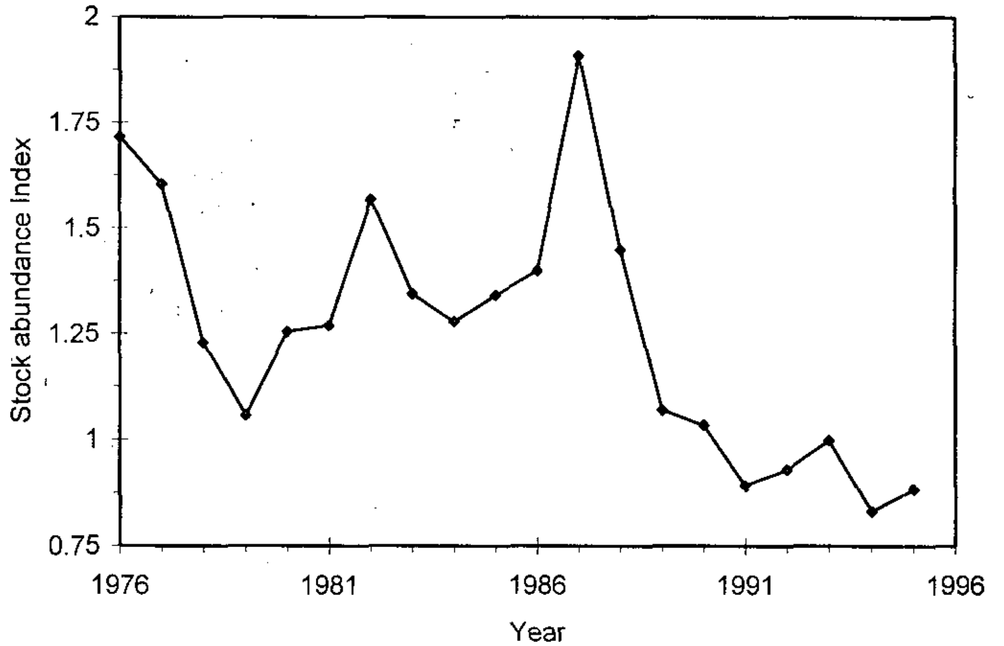

Figure 4. The combined index of the Davis Strait shrimp stock 1976-1995.

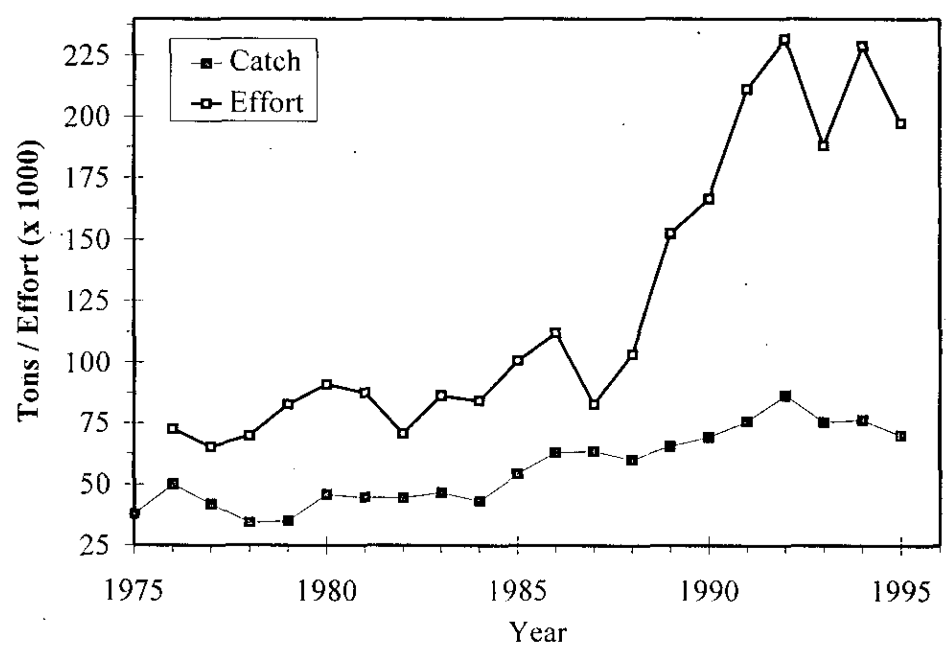

Figure 5. Total nominal catches in SA. 0+1 (tons * 1000) and standardized nominal effort (hr's * 1000) 1975-1995 (1994-1995 data are preliminary). The standardized effort is calculated by dividing total catch by the mean CPUE from the three fleets (Canadian, Greenlandic large and small vessel fleet), as back calculated from the new combined CPUE index using 1995 as a standard.

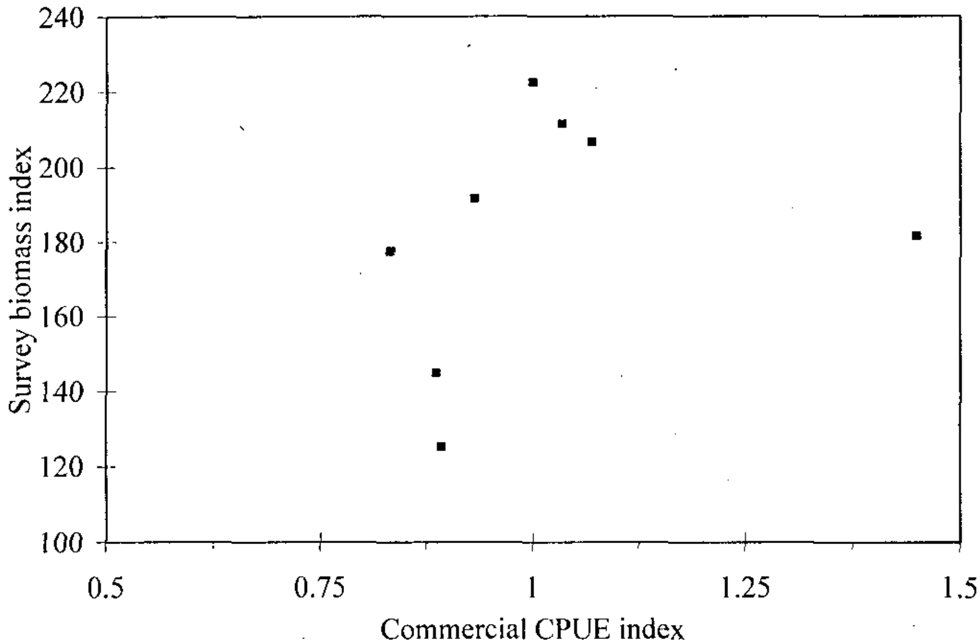

Figure 6. Annual shrimp biomass index from the Greenlandic Davis Strait survey against the combined commercial CPUE index as presented in table 2.