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4–9 October 2004

Copenhagen, Denmark

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Conseil International pour l'Exploration de la Mer

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1 Introduction

1.1 General business

The Working Group on *Crangon* Fisheries and Life History (WGCRAN) met in Copenhagen at the Danish Institute for Fisheries Research, Charlottenlund, from 4–9 October 2004 with the following Terms of Reference:

a) update statistics for landings and effort data for national fleets;

b) perform consistency checks, quality controls, and preliminary analysis of landings and effort data for *Crangon* fisheries from available EU logbooks from national fleets;

c) complete meta-database on sources of data for *Crangon* distribution and abundance (no further progress to be reported);

d) improve parameterisation and design of the Y/R model with regard to maturation and spawning cycle of females, treatment of two sexes and size selectivity of fishing, test the sensitivity of the model to variations in the mortality matrix and F/M ratio, and apply the model to an independent data set (UK Wash fishery);

e) evaluate studies on predation on *Crangon* in relation to estimates of mortality (no further progress to be reported);

f) consider environmental and other influences on recruitment success and productivity in *Crangon* fisheries;

g) review data on discarding of juvenile fish in *Crangon* fisheries following the introduction of new EU technical measures (no further progress to be reported).

A new Chair was elected on this meeting: Andrew Revill from CEFAS, UK. The WG suggested having the next meeting in May 2006, in IJmuiden, Netherlands with the following Terms of Reference:

a) update statistics landings effort national data;

b) consistency checks, quality controls and further analysis of log book data;

c) analyse trends in densities of shrimp and predators from DFS including (Belgian);

d) complete Meta data base on data sources;

e) improve parameterisation of the Y/R model;

f) evaluate studies on predation ;

g) review discard data.

1.2 Summary of major results and achievements of the WG meeting

- Total landings of 32 082 t in 2003 were highest on record. Total landings have stabilized over the last 8 years at around 30.000 t, which is 50% above the average landings of the period 1975–1995. Compared to the mean landings of the previous 10 years Danish and Dutch landings in 2003 have been considerably higher (65% and 27%), Belgian and German landings are close to average (9% and 5% higher) while French and UK landings are considerably below average (49% and 40% lower).
- The total value of the 2003 landings can be estimated as approx. 80 million €. The total value has dropped by 17% compared to the total landings value in 2002 (96 million €), reflecting a decrease in prices by 27% (based on German average prices). This price reduction is the consequence of a legal ban on variable weekly boat quotas that have previously been negotiated among fishermen from Denmark, Germany and the Netherlands to avoid price reductions due to over supply of the processing industry. Very recently an international producer organisation

has been established, which allows again coordinated quantity regulations for all members.

- The analysis of disaggregated German log-book data revealed a strong dependency of the estimated number of fishing days on the method of calculation. If the number of fishing hours is divided by 24, the mean annual effort of the German fleet amounts to 22,153 days compared to a mean number of fishing days of 39,335 which results from summation of all days with sea going activity as full (integer) days. This comparison reveals the potential for effort increase, once the current number of fishing days would be used, to define an upper effort limit.
- Log book data from the Netherlands lack square information. This lack of information prevents the compilation of any meaningful spatially disaggregated data set on catch, effort or LPUE. In addition the calculation method for the days at sea deviates from previous approaches and all other national data sets. This method biases the estimates of total effort downwards.
- The total effort as calculated with the available data sets suggests an overall increase in particular for the Danish and German fleets.
- The seasonally disaggregated mean hp-data of the Dutch fleet show a maximum mean value of more than 300 hp in winter months. This figure confirms previous unofficial reports of a participation of ever larger vessels in the shrimp fishery, now including vessels beyond the 300-hp Euro-cutter class. These vessels are partly operated with double crews to allow round the clock fishing.
- According to the information of the log books *Crangon* appears to be more widely distributed than previously documented with regard to a) water depth and b) Northern areas. In combination with the information on decreasing landings in French waters and decreasing densities in Western Belgian waters these findings can be interpreted as a South-North shift in *Crangon* densities.
- Analysis of time series of shrimp densities from DYFS surveys in Dutch and German waters revealed decreasing trends in inshore waters (North Frisia, Eastern Dutch Wadden Sea and Sheld estuary) and increasing trends in deeper off shore waters (Denmark, North Frisia, Dutch coast). These patterns suggest that shrimp might have shifted into deeper waters, presumably avoiding increasing maximum summer and autumn temperatures.
- Good and bad year classes differ between regions, e.g., 2001 was a year with low catches in Germany, but with good catches in the UK
- Shrimp densities obtained from the German Young fish Survey showed that shrimp abundance over the Wadden Sea was negatively related to winter NAO and water temperature in February but positively related to river run off in December. Shrimp densities for the North Frisian area were also positively related to river run off in December and negatively influenced by water temperature in March and gadoid abundance.
- Analysis of landings from the German fleet for the period July to December of each year showed these were negatively related to a winter NAO index and winter water temperature provided data before 1980 and after 1997 were excluded. The time series for this study was truncated to avoid bias due to changes in gear technology and technical measures. A corresponding analysis of Dutch landings data showed no relationships.
- Initial studies using LPUE data for The Wash fishery showed that shrimp abundance in each fishing season (1987 to 2000) could be linked to oxidised nitrogen levels and annual water temperatures and negatively influenced by the amount of fishing effort in an earlier period. Interaction between the two environmental variables suggests that at warmer water temperature shrimp abundance is enhanced with increasing oxidised nitrogen levels. Conversely at cooler water temperatures shrimp abundance is reduced as oxidised nitrogen levels increase. Recent inclusion of two extra data points (1987 to 2002) saw the environmental variables in the first model being substituted by an index of whiting abundance.
- Environmental variables were incorporated into linear and population dynamics models using LPUE data for The Wash (UK). Oxidised nitrogen levels exerted a

positive influence while temperature and predator abundance had a negative effect on LPUE. Oxidised nitrogen was the most significant effect followed by predator abundance with temperature rarely significant as a single effect. The density dependence introduced by the dynamics model was also significant.

- Only with very distinct peaks in deterministic data, of a quality not expected from sampling, were underlying growth parameters accurately recaptured from simulated data with known growth characteristics. Analyses performed using stochastic data with a modest CV (0.1) were much less successful with frequent parameter confounding and erroneous estimates of $\boldsymbol{L_\infty}$ and particularly $\boldsymbol{K}$, but reasonable performance in estimation of the timing and magnitude of seasonal oscillations. Estimation of mean/modal size was poorest around the size of selection and at larger sizes. Systematic bias in parameter estimates was not apparent with the exception of the Wetherall method using stochastic data.
- The Y/R simulation model was modified to allow a decoupling of growth and maturation by means of a predetermined minimum age at first maturity. With a minimum age of five months (after metamorphosis to the juvenile stage) the simulations values of relative seasonal egg production are in accordance with observations. Without this decoupling of growth and maturation it was not possible to mimic the September October minimum in relative seasonal egg production.
- Changes to the seasonal pattern of fishing mortality in simulations using the Y/R model parameterised for UK waters with reductions of F in summer and early autumn and increasing F in autumn, mid and late winter resulted in little or no gains and sometimes significant losses in yield. Displacing F to later in winter generally resulted in greatest losses. Spawning potential was generally impaired and again greatest losses corresponded to displacement of F to late winter.
- Simulated growth curves based on a temperature dependent growth model formulation revealed complex relationships between simple von Bertanlanffy growth parameters and simulated growth trajectories. Algebraic conversion to von Bertalanffy growth parameter equivalents based on the mean temperature in the field are biased.
- The method of generating stochastic deviates from mean daily growth rates produces an asymmetric distribution of growth curves, biased towards higher growth. If ‘fast growers’ are crucially important in the dynamics of the shrimp fishery then shape of the distribution and the magnitude of the CV may be influential and may require further investigation.

2 Catch and effort statistics from log books

2.1 Description of the national data sets

2.1.1 Denmark

The data on landings of *C. crangon* from Danish waters are given for the years 2000–2003. Based on logbook reports, the landing per unit and effort (LPUE) is estimated for 2002 and 2003 and compared to the long time trend between 1997 and 2003. The effort and landing per unit effort for the years 2000–2003 have been recalculated by applying an average figure on the horse power (hp) per vessel. The annual and monthly landings are based on reports from the industry. Reports on landings from other EU-countries (Dutch and German vessels in both 2002 and 2003) in Danish harbours are based on data delivered by the industry. Minor landings have taken place by British and Belgian vessels in 2002 and 2003. The effort and LPUE data for the vessels from the other EU-countries are based on the logbook data presented by the respective EU-countries.

2.1.2 Germany

Since 2000, the EU log sheet system is mandatory for the shrimp fishing fleet. The data are collected and stored by the BLE ("Bundesanstalt für Ernährung"). Data are available on the trip, the effort and the catch per species.

Data on the trip include the registration sign of the vessel and time and place of departure and arrival, respectively.

Recordings of fishing activities can appear several times per calendar day, once per day or once per two days, in the case of an overnight trip. Available data include the catch by species and product category, the fishing date and time (begin, end, duration), the number of hauls, the hours fishing the gear and mesh size, the statistical rectangle and relevant vessel characteristics. The catch weight estimated at sea is corrected at landing by means of the quantity registered in the sale. As for other species, a conversion factor is applied to convert from landing weight to fresh weight (=1.19), in this case to compensate for weight loss due to cooking at sea. The figures given in this report, however, are in terms of landing weight. According to the relational character of the data base, the whole set of information is repeated when a boat changes the rectangle, which adds complication to the analysis.

Only the weight of shrimps sold for human consumption is considered, disregarding the shrimps sieved out and degenerated after landing ("Siebkrabben", "Quetschkrabben"), and those landed for industrial processing to pet food ("Futterkrabben"). Also, the landings and effort of part-time fishermen are not included in the German data as used here.

2.1.3 Netherlands

The Dutch data from landings and effort are derived from the VIRIS (Visserij Registratie en Informatie Systeem) database which contains logbook data from all Dutch vessels landing both in Dutch and foreign harbours. Catches are registered by the fisherman in logbooks. These data are send to the national inspection service (AID) and stored into the VIRIS database

Because the registration of ICES rectangles is not mandatory for *crangon* fisheries, no trip specific information on rectangle is available. Only 18% of the total landing and 16% of the total effort (in the period 2000–2003) could be allocated to a certain rectangle, because these originated from trips during which other (quota regulated) species were caught as well (for which rectangle information is mandatory).

2.1.4 UK

Fisheries data for the brown shrimp fisheries in the UK are collected by fisheries officers and input into a central database. Fishery activity by the fleet is comprehensively reported for the main fishery in The Wash operating primarily from the ports of King's Lynn and Grimsby. Landings from the fisheries on the West coast (Irish Sea) have been less extensively reported in recent times.

Vessels over 10 metres make statutory landing declarations but this is not a legal requirement for vessels under 10 metres. Although some of the fleet in The Wash fishery are vessels below 10 metres the fleet land through only a few main merchants where landings information is often available. Fishing activity is reported from landings declarations from the over 10 metre vessels, and typically as summary records for the below 10 metre LOA boats. Summary records will generally have accurate information on landed weights but the fisheries officers will estimate effort information and fishing area. In most cases these estimates should be reasonable given the small size of these vessels often limiting the operational range of these boats to day trips in local ICES rectangles.

In the past working groups have used, UK fishing effort data and subsequently LPUE hours fished as a measurement of effort. To aid comparison with international statistics effort in terms of HP days has been computed. HP data is available for nearly all registered fishing vessels from 1988 but a meaningful index of effort in terms of HP days is not available for summary records. In 1988 only 75% of recorded landed weight had associated effort information in HP days, but from 1989 this proportion varied between 80% and 99%. Records with no effort information were excluded for the purpose of LPUE estimation and total effort has been estimated from the ratio of total landings to observed LPUE. Days fished is a relatively course measure of fishing time as it is recorded as whole days. This effort measure takes no account of time steaming between grounds but should be accurately recorded.

2.2 Landings

2.2.1 Time trends

The total landings of 32 082 t in 2003 were the highest on record, followed by 1997 (31 919 t) and 1999 (31 854 t). Total landings have stabilized over the last 8 years around 30 000 t, which is 50% above the average landings of the period 1975–1995. Compared to 2002, mainly Dutch and Danish and Belgian landings have increased, whereas UK landings have been more than halved. French landings were the lowest on record in 2003. Compared to the mean landings of the previous 10 years Danish and Dutch landings in 2003 have been considerably higher (65% and 27%), Belgian and German landings are close to average (9% and 5% higher) while French and UK landings are considerably below average (49% and 40% lower).

The total value of the 2003 landings can be estimated as approx. 80 million € if the German average price of 2.49 €/kg landed weight (cooked shrimp) is applied to all landings. The total value has dropped by 17% compared to the total landings value in 2002 (96 million €), reflecting a decrease in prices by 27% (based on German average prices). This price reduction is the consequence of a legal ban on variable weekly boat quotas that have previously been negotiated among fishermen from Denmark, Germany and the Netherlands to avoid price reductions due to over supply of the processing industry.

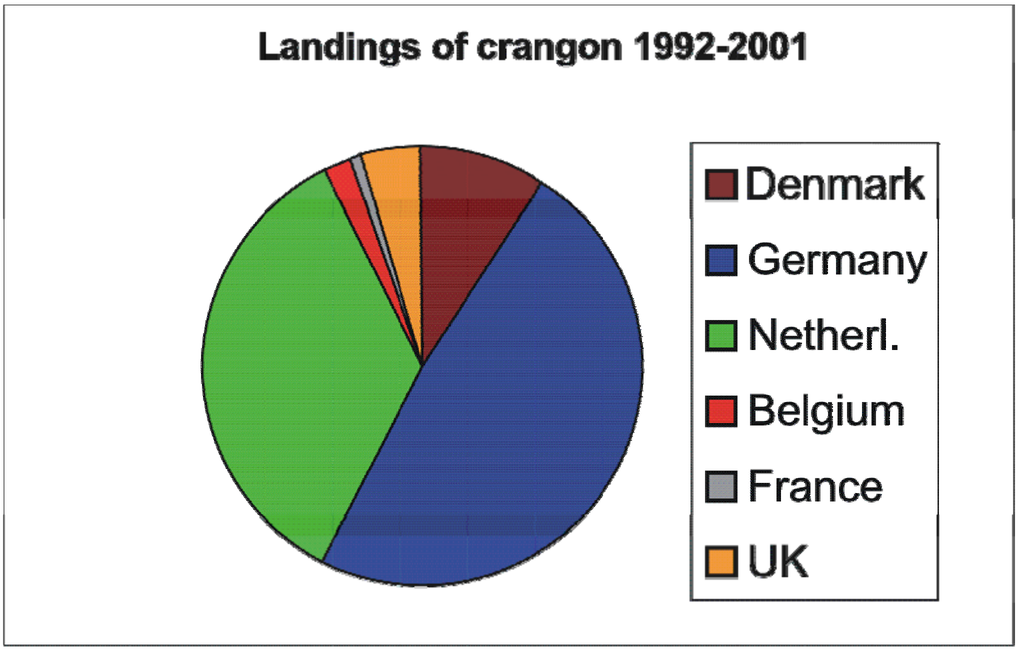

Figure 1: *Crangon* landings from 1992 to 2001 per Country.

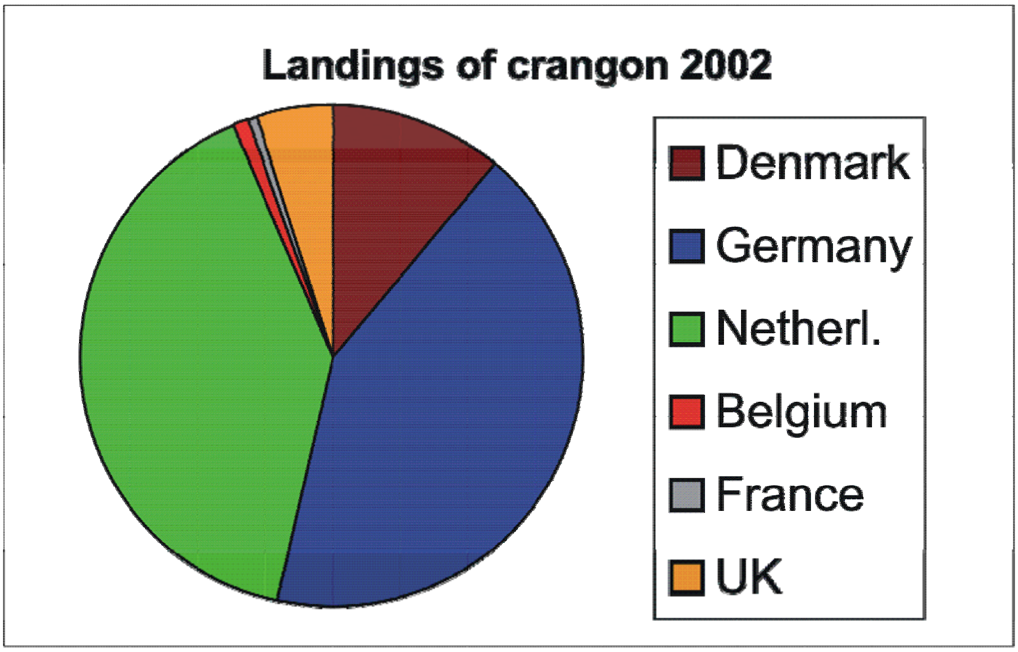

Figure 2: *Crangon* landings 2002 per Country.

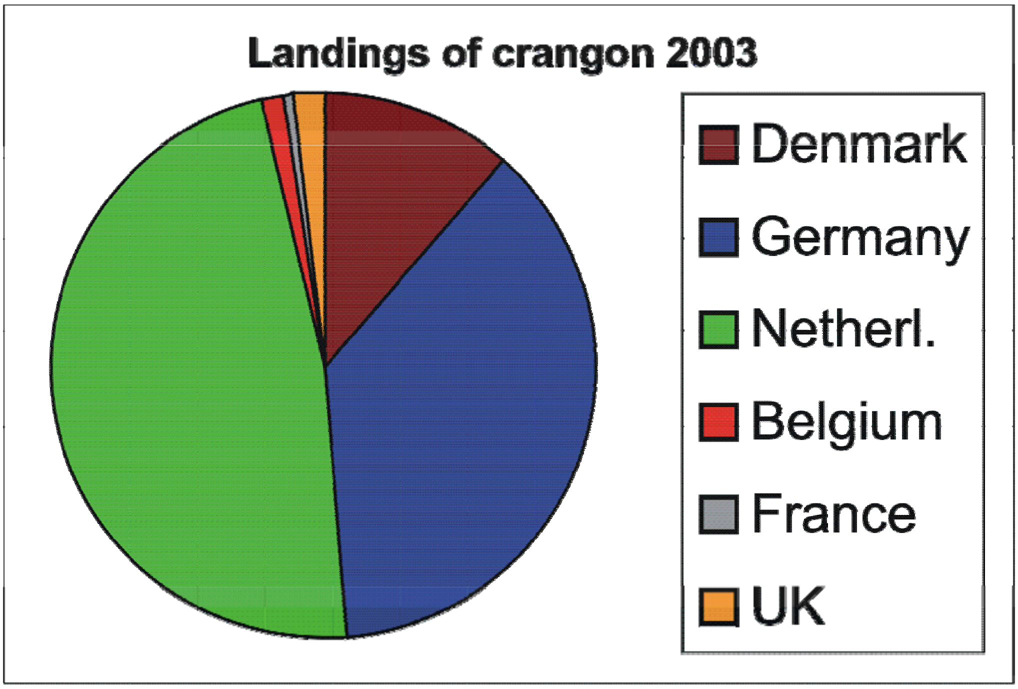

Figure 3: *Crangon* landings from 2003 per Country.

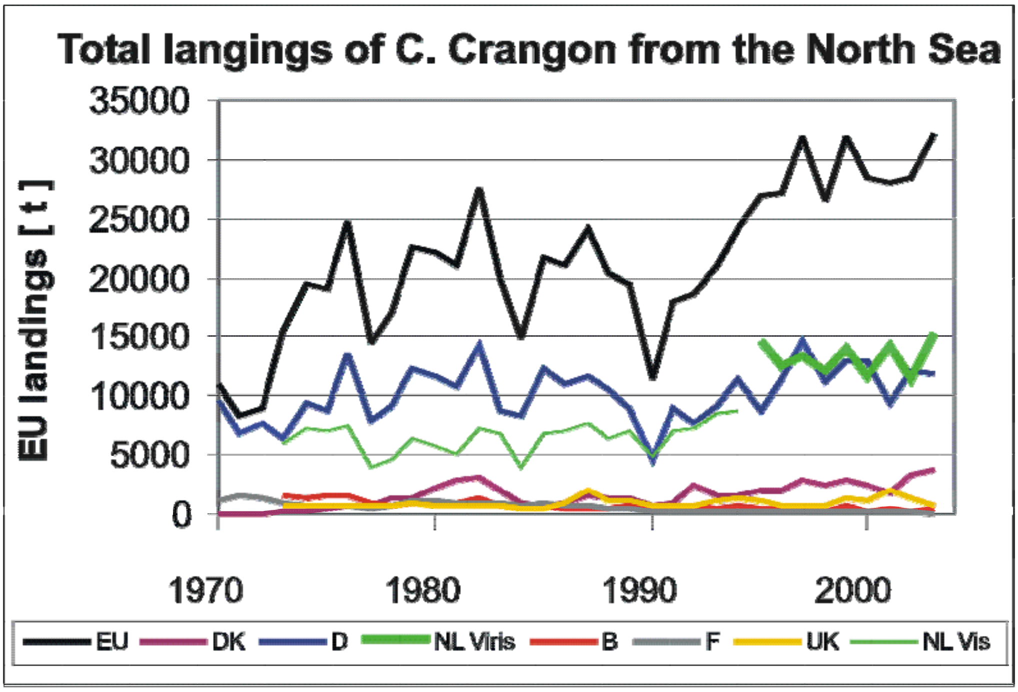

Figure 4: ***Crangon*** **landings per Country.**

Denmark

Between 2001 and 2002, the Danish landings of *C. crangon* have increased by 75% from ca. 1825 tonnes in 2001 to nearly 3,200 in 2002. Between 2002 and 2003 the landing increased only by 15% from ca 3200 tonnes to nearly 3700 tonnes (Figure 5).

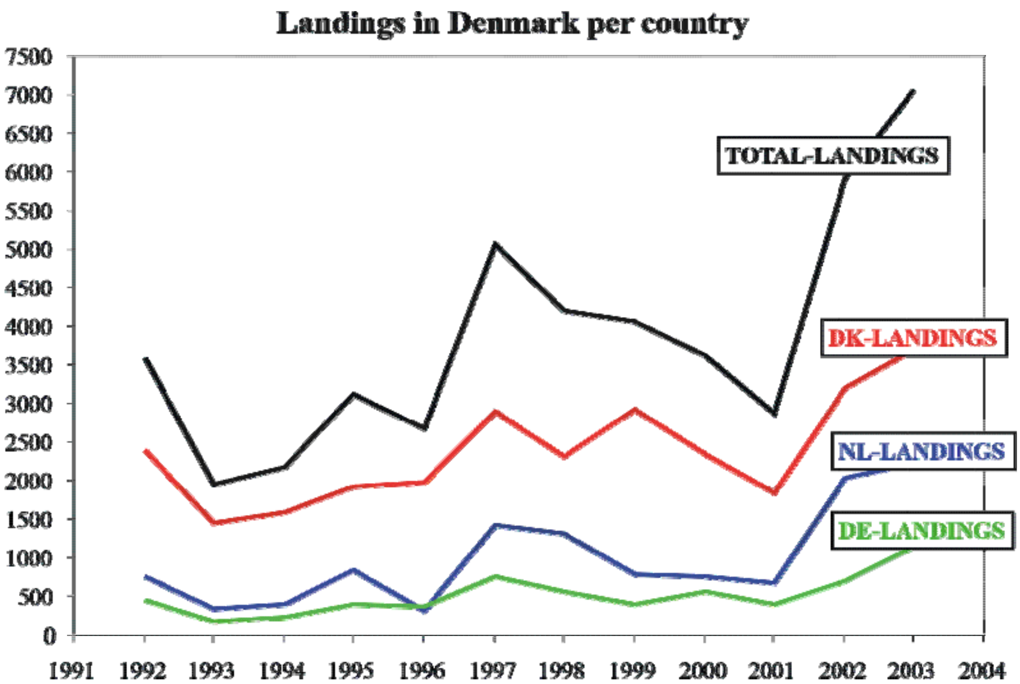

Figure 5: The Danish landings, and landings by other EU-countries of brown shrimps in Danish harbours.

Landings by German vessels, primarily in Havneby, increased from 375 tonnes in 2001 to 689 tonnes in 2002 and to 1146 tonnes in 2003, which is an annual increase of 84% and 66% respectively.

Landings by Dutch vessels, also primarily in Havneby, increased from 665 tonnes in 2001 to ca 2040 tonnes in 2002 and to 2223 tonnes in 2003, which is an annual increased of 207% and 9% respectively.

Belgium

Crangon landings by the Belgian fleet declined over the last thirty years. They have been below 1000 tonnes since the mid eighties. Prior to this period landings ranged between approx. 1000 and 1800 tonnes. An increasing share of the landings was brought to foreign harbours. While in the period 1970 to 1990 less than 20% of the catches were landed in foreign harbours, this value has reached around 50% in the last decade. These figures were not included in previous landing statistics of the Working Group.

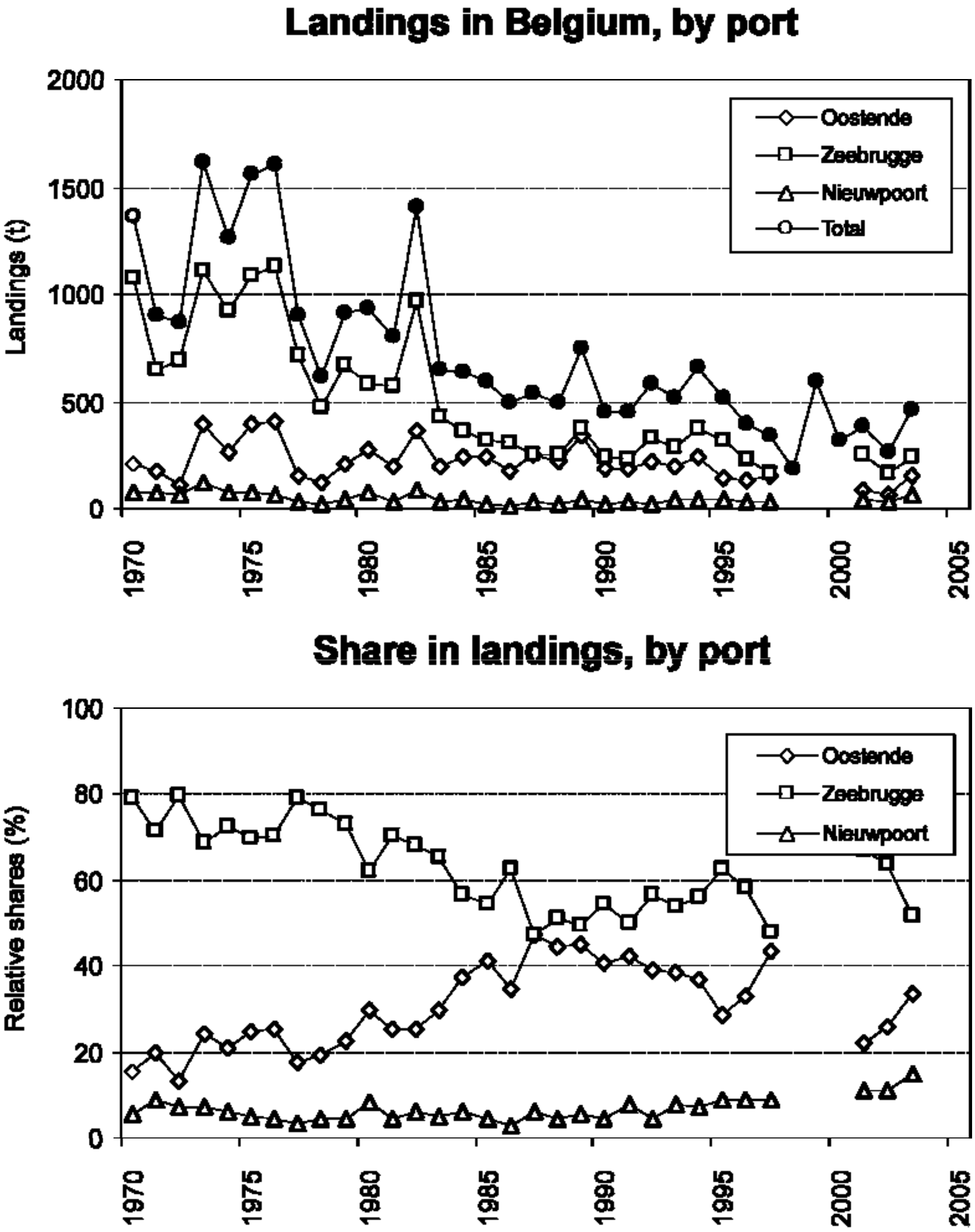

Figure 6: Belgian *Crangon*-landings in Belgium.

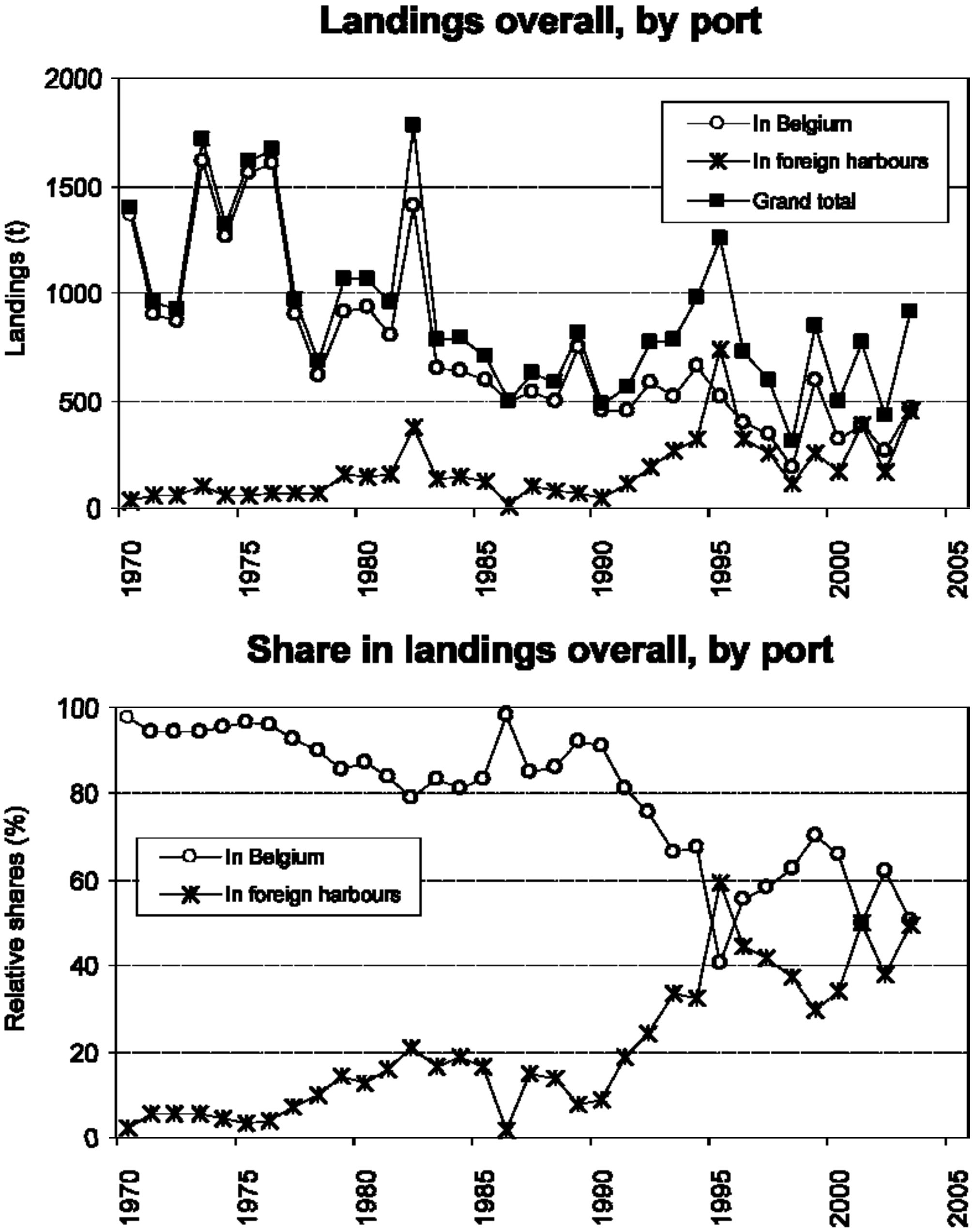

Figure 7: Belgian *Crangon*-landings in Belgium and foreign harbours.

United Kingdom

Annual landings of *Crangon* have continued to be highly variable over the past few years. The highest recorded landing of 1888 tonnes for 2001 was 85% higher than the average of the most recent 10 years (1018 tonnes). The 574 tonnes recorded for 2003 was 44% lower than this average.

2.2.2 Seasonal patterns

Landings in the Northern countries Denmark and Germany were considerably higher than average in the spring season 2003 but only slightly above average in the Netherlands and below average in Belgium. In 2002 the late summer landings were pronounced in Denmark and Germany (Figure 12 and Figure 13)

Denmark

The total landings in 2000 to 2003 were very variable during seasons especially the last couple of years (Figure 8). The average landings the last 4 years have also been higher during the second quarter. Especially in 2003 and in 2004 the landings in both the second and third quarters have been exceptional high compared to previous years (Figure 8 to Figure 11).

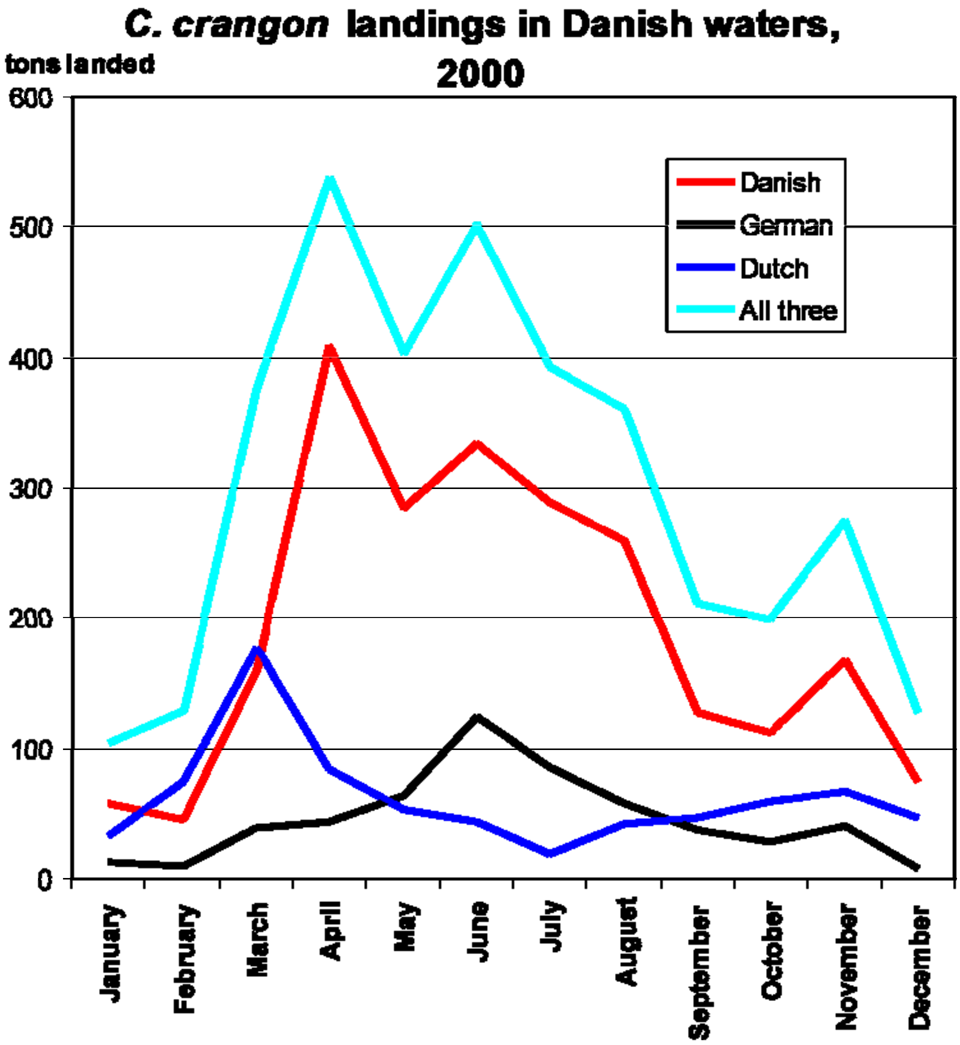

Figure 8: The Danish, Dutch and German landings of *C. crangon* caught in Danish waters and landed in Danish harbours in 2000.

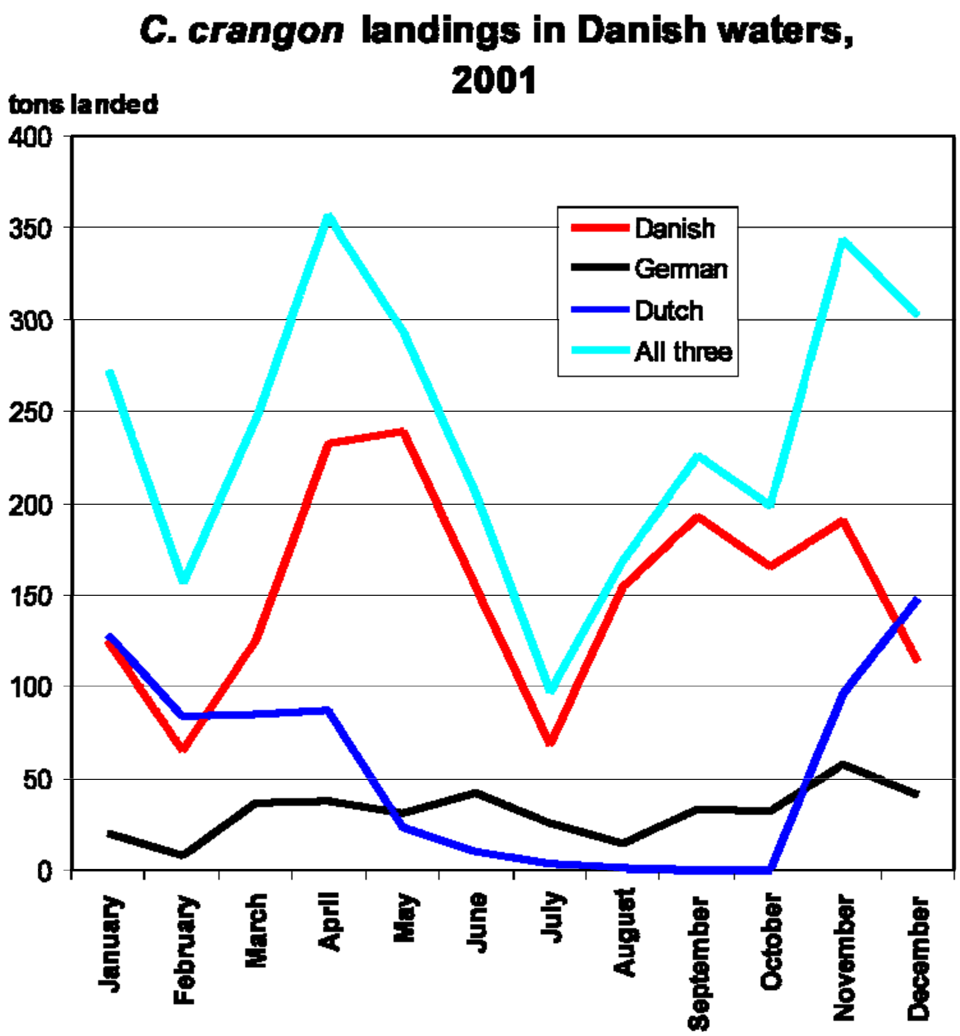

Figure 9: The Danish, Dutch and German landings of *C. crangon* caught in Danish waters and landed in Danish harbours in 2001.

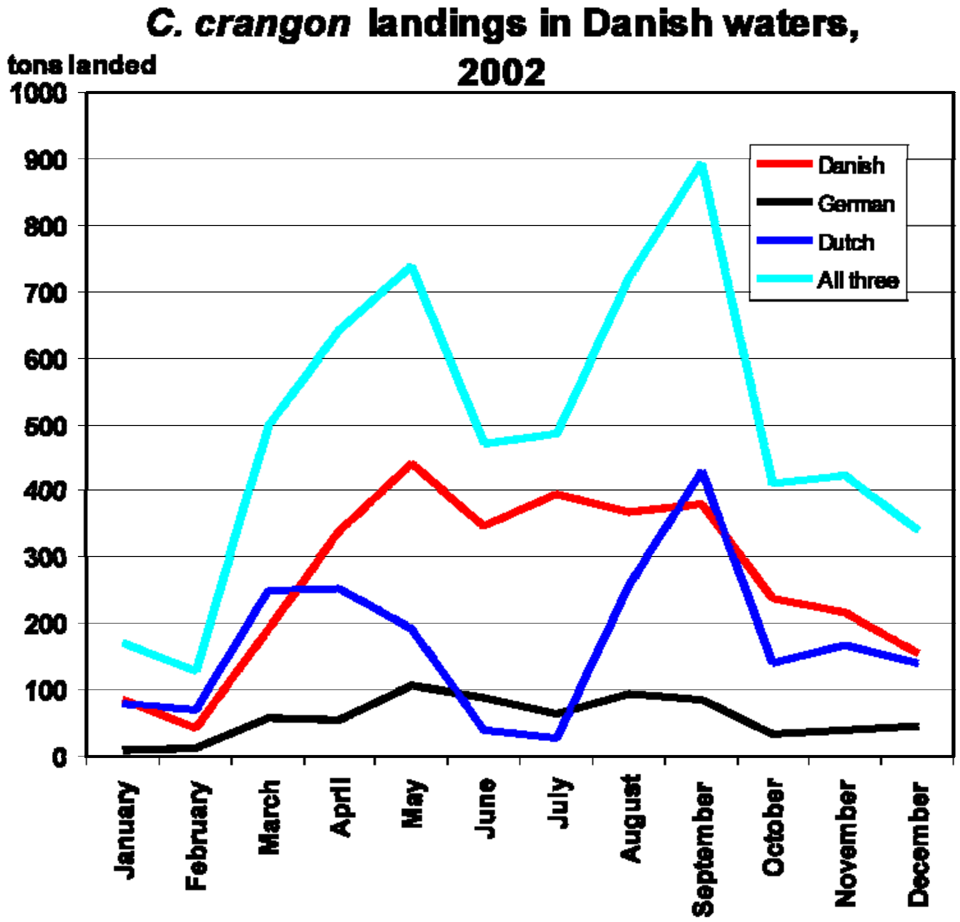

Figure 10: The Danish, Dutch and German landings of *C. crangon* caught in Danish waters and landed in Danish harbours in 2002.

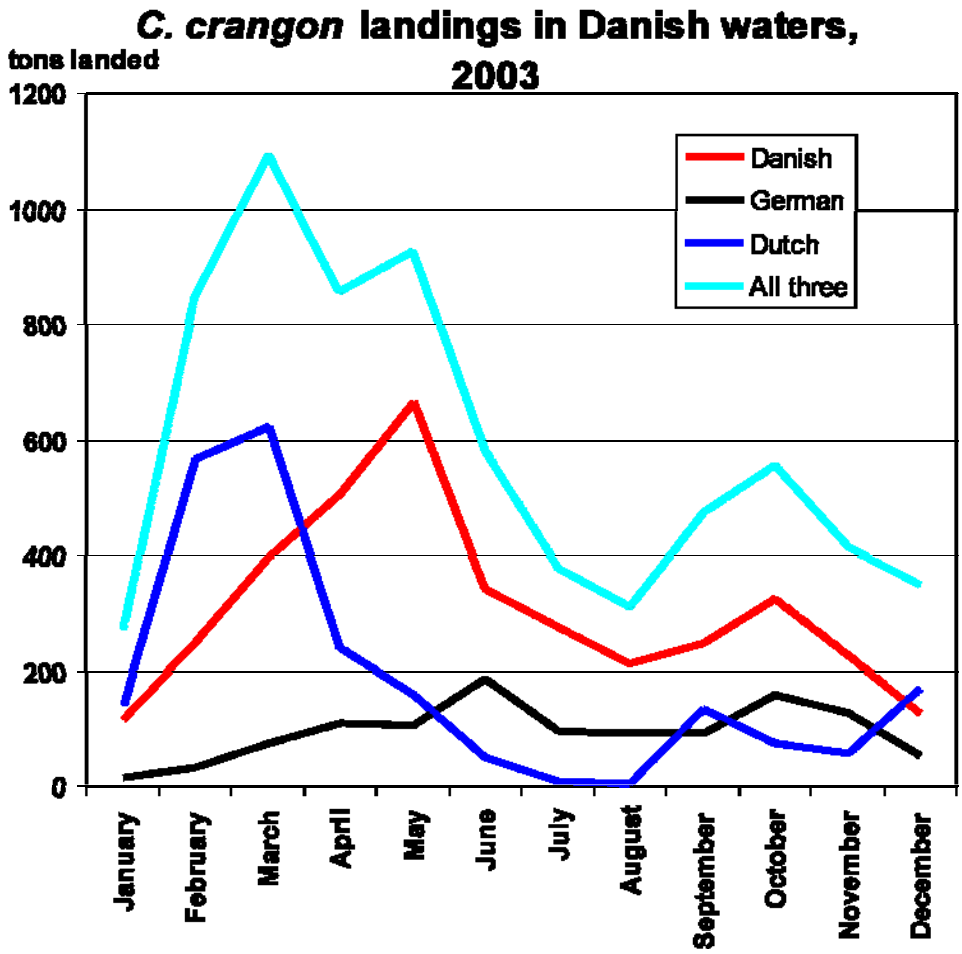

Figure 11: The Danish, Dutch and German landings of *C. crangon* caught in Danish waters and landed in Danish harbours in 2003.

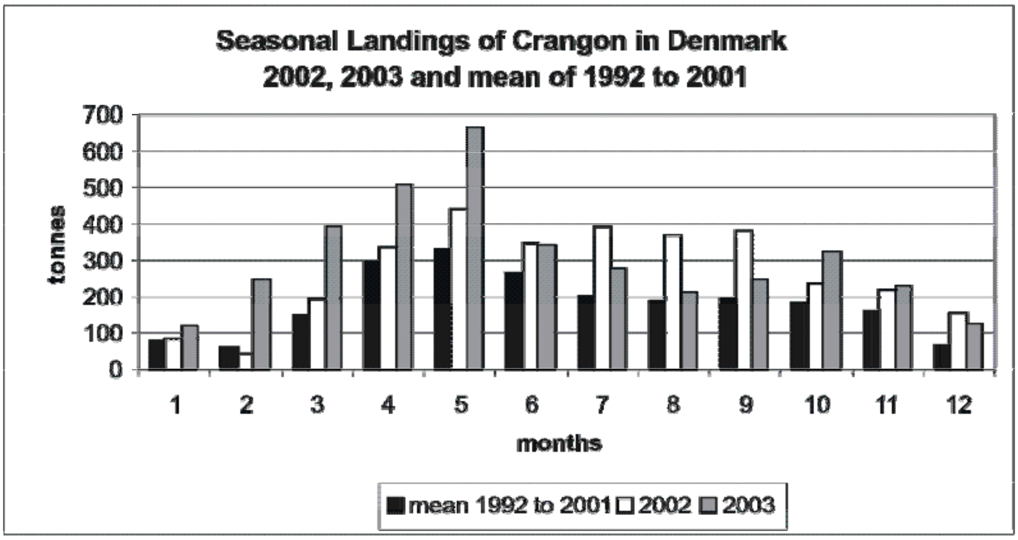

Figure 12: Danish seasonal landings of *Crangon.*

Germany

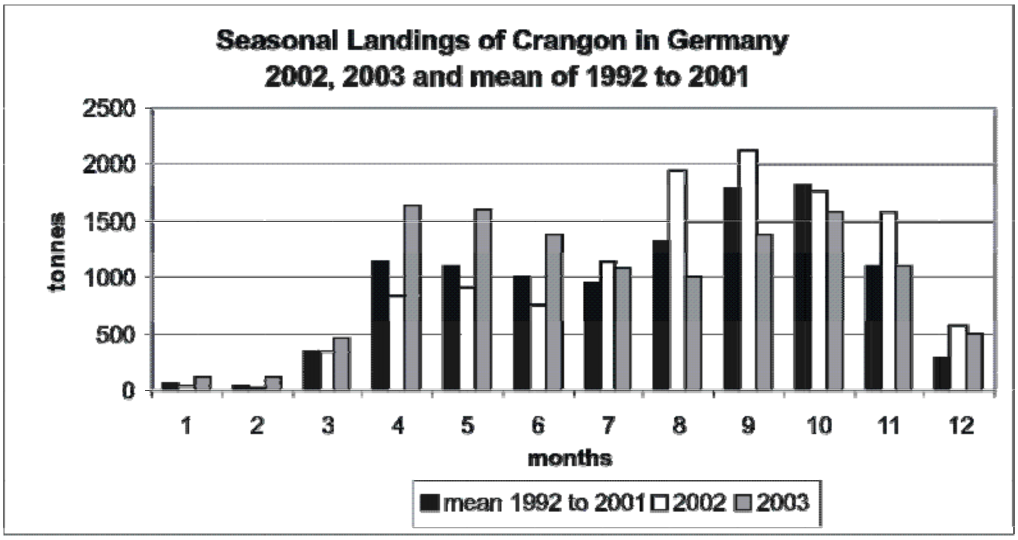

Figure 13: German seasonal landings of *Crangon.*

Netherlands

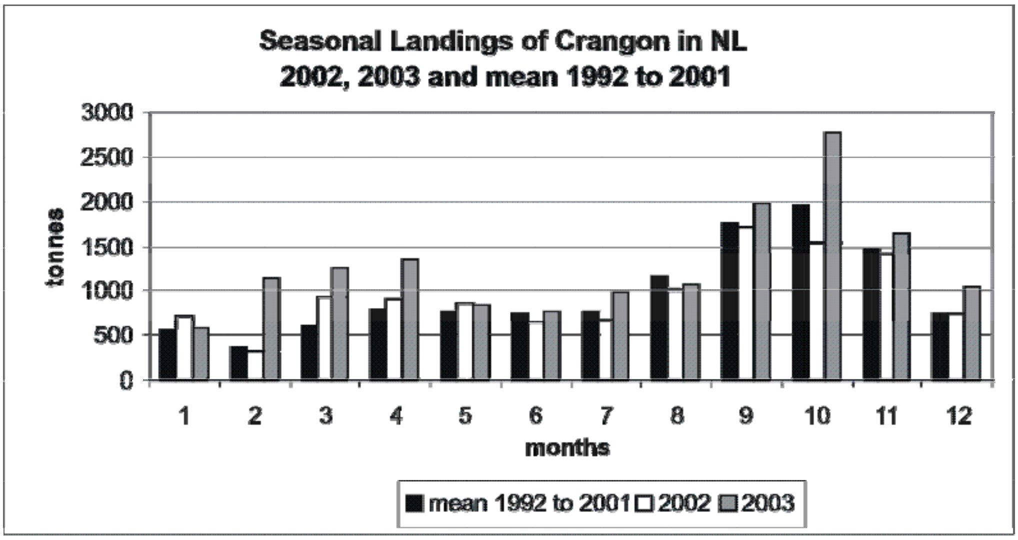

Figure 14: Dutch seasonal landings of *Crangon.*

Belgium

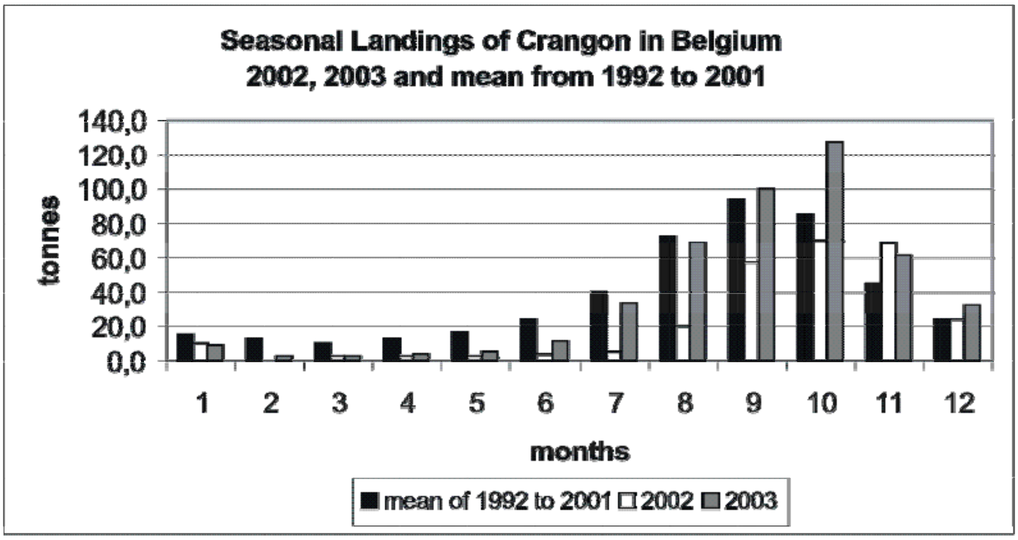

Figure 15: Belgian seasonal landings of *Crangon.*

France

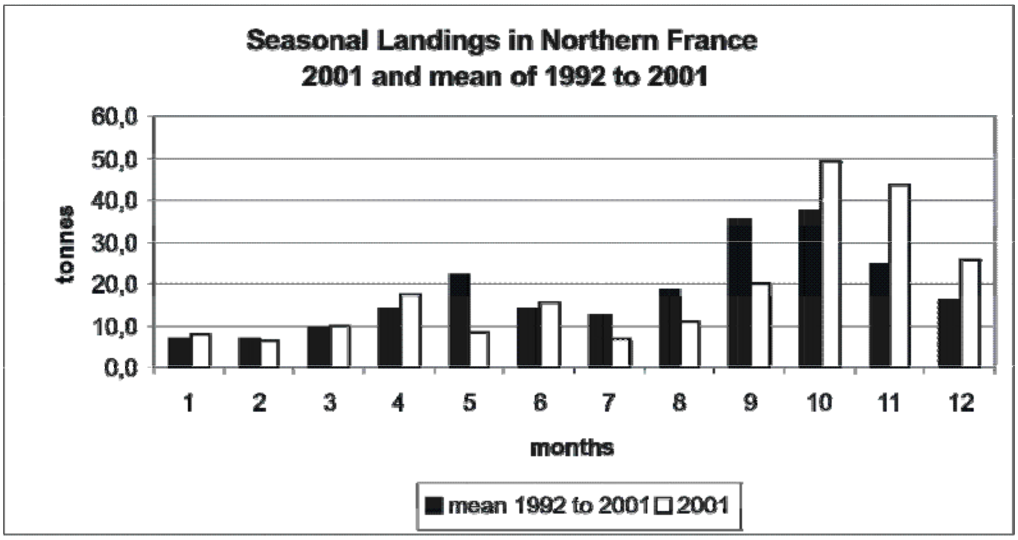

Figure 16: French seasonal landings of *Crangon.*

United Kingdom

Monthly landings in the early months of 2002 were higher than the average monthly landings (1992 to 2001) due to good recruitment in the latter half of 2001. Landings in the last half of 2003 were poor in comparison to the average monthly values.

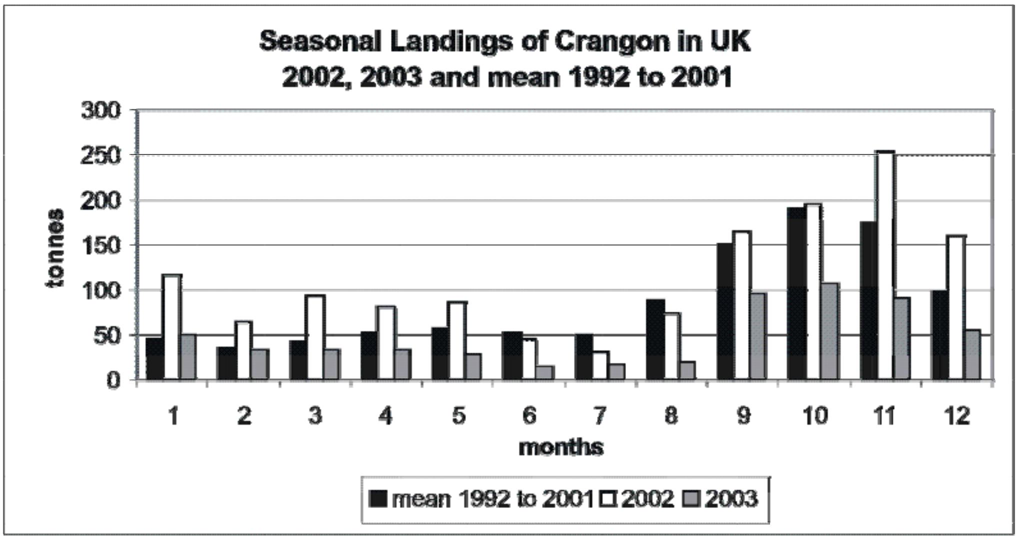

Figure 17: UK seasonal landings of *Crangon.*

2.2.3 Spatial patterns

All spatial patterns presented suffer from the lack of Dutch and Belgian contributions. Therefore only the Danish and German data can be interpreted for the northern region and the UK data for The Wash fishery. The UK catches are restricted to just three ICES squares 34F0 – 36F0 with almost no spatial variation on this scale. The German and Danish landings mainly originate from the squares closest to the coast (36F8 – 41F8 and 36F6 – 36F7). However in 2002 and 2003 the contributions from the neighbouring column of squares (37F7 – 41F7) is increasing in all quarters. This indicates that a higher share of the total catch was taken in deeper waters. Also remarkable is the extension towards fishing areas in Northern direction (40F7 and 40F8).

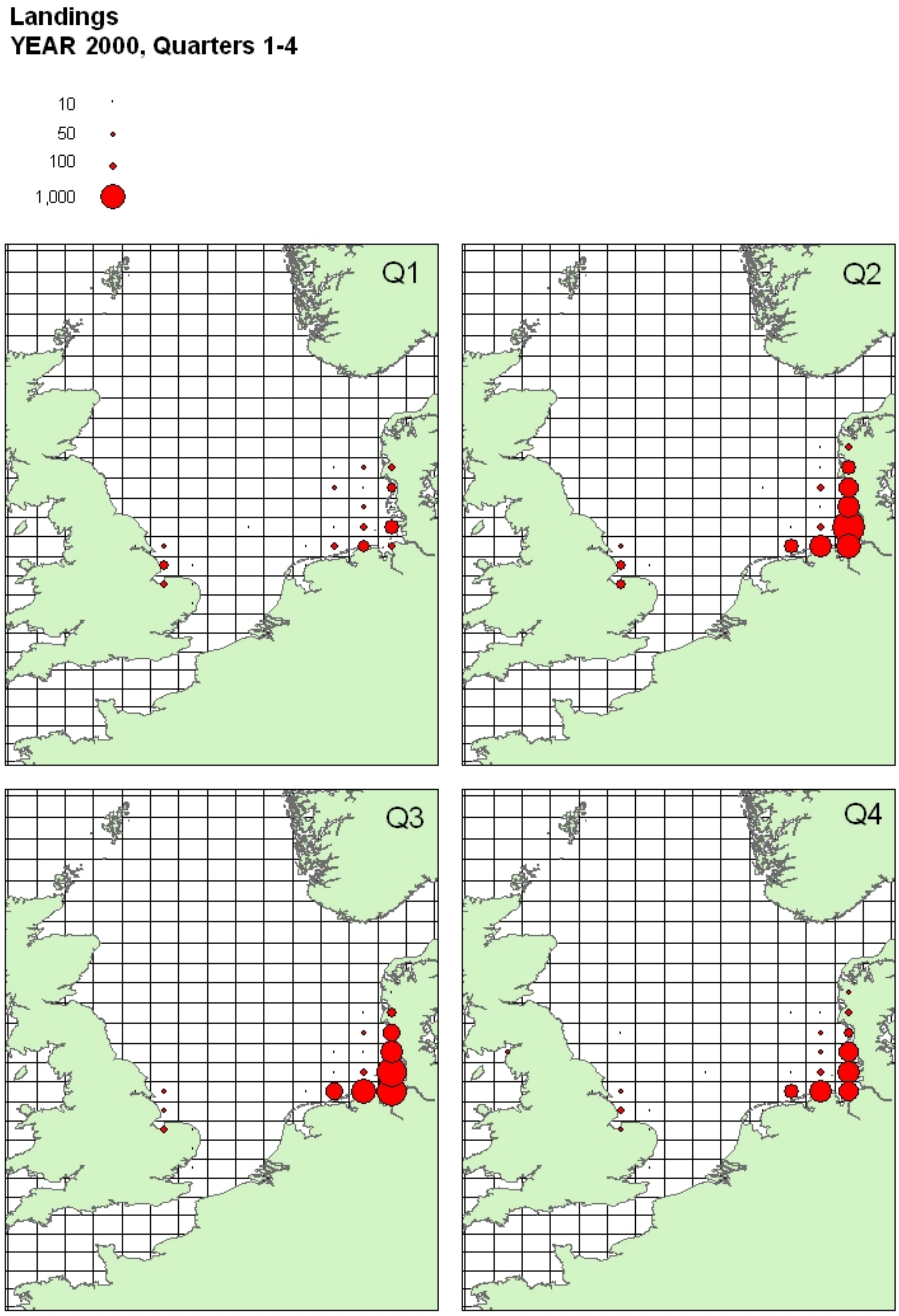

Figure 18: ***C. crangon*** **landings (tonnes) in quarter 1 to 4 in the year 2000.**

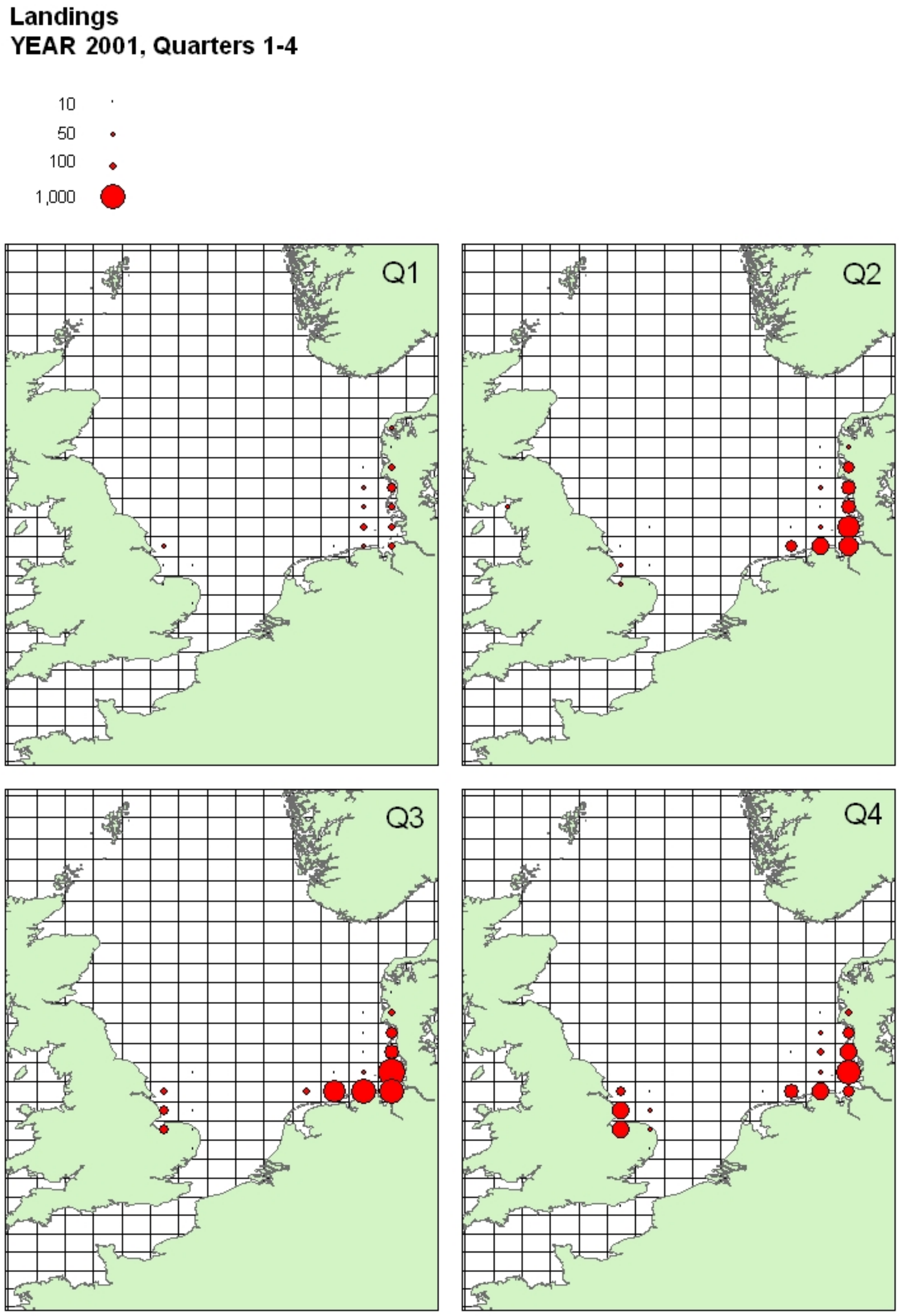

Figure 19: ***C. crangon*** **landings (tonnes) in quarter 1 to 4 in the year 2001.**

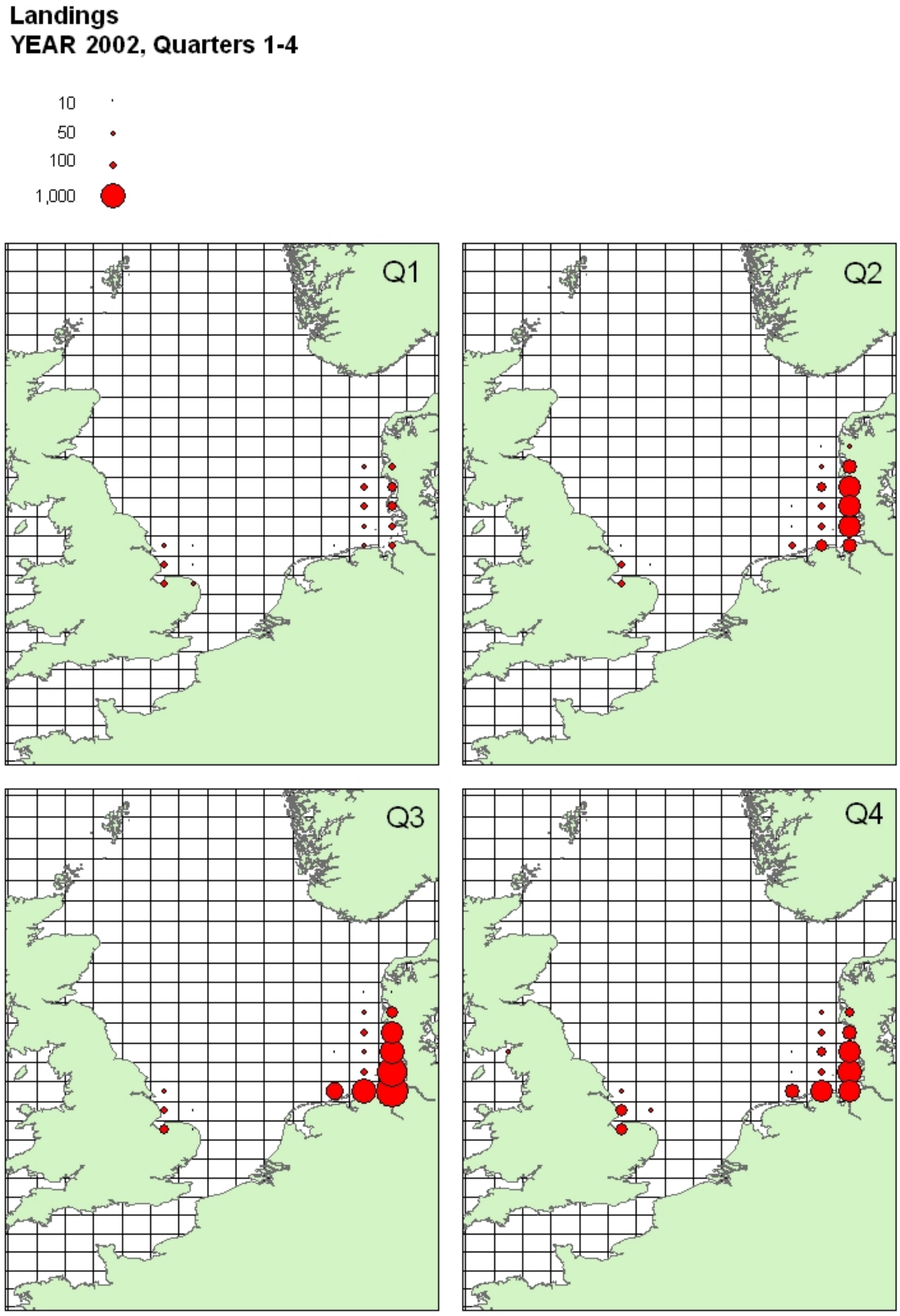

Figure 20: ***C. crangon*** **landings (tonnes) in quarter 1 to 4 in the year 2002.**

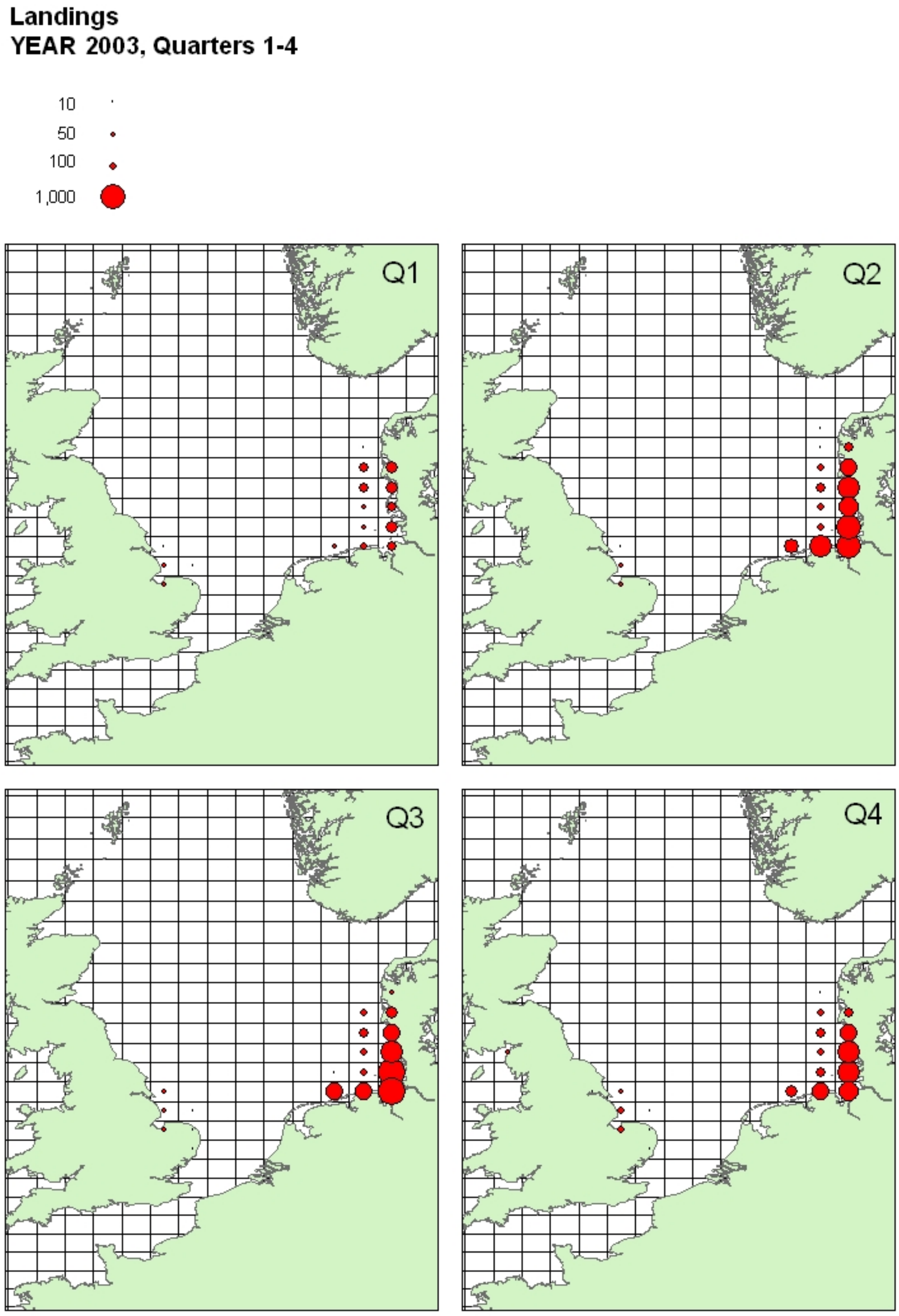

Figure 21: *C. crangon* landings (tonnes) in quarter 1 to 4 in the year 2003.

Denmark

Over the last two years there has been a trend towards more landings from ICES areas further offshore in the North Sea along the Jutland west coast. In the second and third quarters of 2002 and 2003 higher landings came from ICES squares north of the Horns Reef, which also is a change compared to previous years.

United Kingdom

The Wash fishery in the North Sea is the source of typically over 90% of the recorded landings for the United Kingdom. ICES squares F034 and F035 continue to be the most important.

2.3 Effort

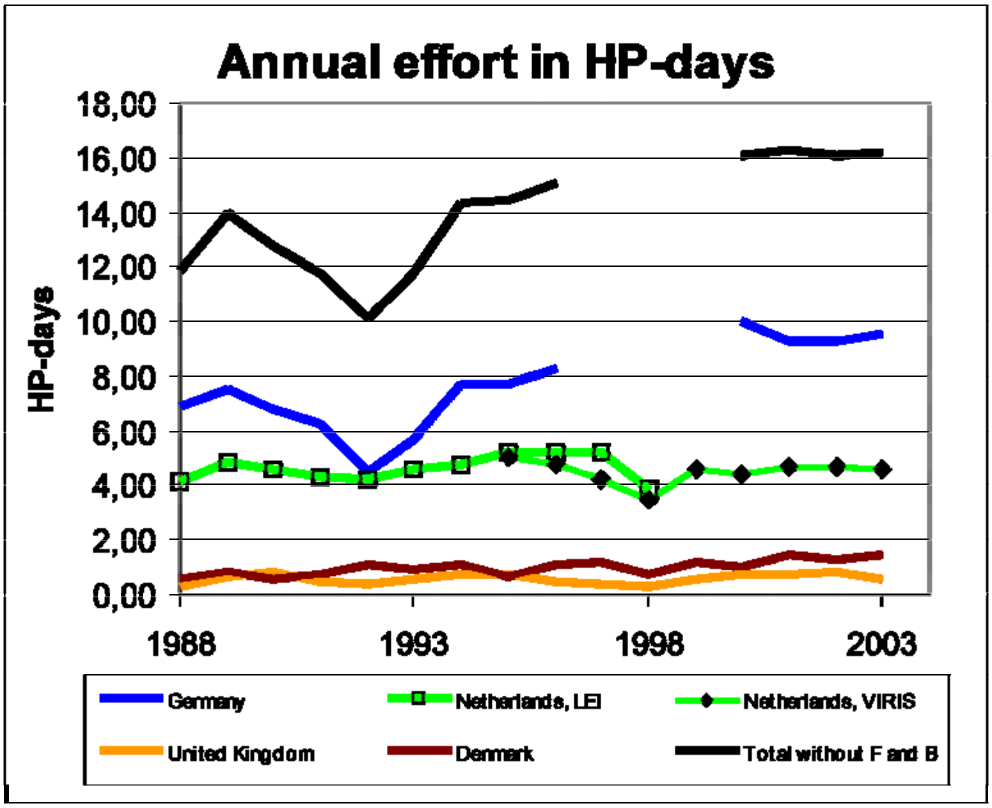

Figure 22: Effort of the individual countries between 1988 and 2003.

2.3.1 Problems in the definition of days at sea

Calculation of days at sea with different approaches.

During the compilation of national data sets it became obvious, that no standard definition for the calculation of days at sea exists.

Germany

Since the German data set was the only one available in a disaggregated format, it was used to calculate days at sea according to different definitions:

1) "decimal days", calculated as the number of hours out of port divided by 24;
2) "total days", total number of days with at least part of the day spent out of port as integer number rounded up to full days;
3) "NL-days", calculated for the Dutch statistics as (2) but one day subtracted for any trip longer than one day.

The application of these different measures revealed pronounced differences: The average numbers of decimal days at sea for the period 2000–2003 amounted to 22152, whereas the total days were 78% higher (39335 days). This definition of the total number of days at sea has been used previously, e.g., for the calculation of specific compensations in Germany and is also used in Danish official statistics. The total numbers of days at sea recorded for the compensation payments have been used to calculate the total effort in hp-days for the period 1986 – 1996. These data are included in the German effort graph (Figure 22). As was to be expected from the calculation method the NL-days calculated for the German fishery are substantially lower than the total days at sea: mean number 26718, corresponding to 121% of the decimal days or to only 68% of the total days.

Denmark

Fishing days were calculated as “total days” (see Germany, definition 2).

Netherlands

Days at sea for the Dutch data were calculated as the number of days at sea, minus one day (because this day is assumed to be used for sailing home). One day trips were included as one day. In the earlier series produced by LEI, the last day was counted, which explains the difference between the two series. For the LEI one day at sea can be a single tidal trip of approximately 4 to 6 hours or a full day at open sea of 24 hours. Therefore the apparent stagnation of Dutch effort data is most likely misleading and the increasing LPUE figures in recent years are likewise biased.

Belgium

The Belgian reporting system records the actual hours spent fishing and these can not be directly compared any of these measures.

France

No data were available for this fishery.

United Kingdom

Fishing days were calculated as “total days” (see Germany, definition 2).

2.3.2 Time trends

Denmark

The Danish effort data has been recalculated and expressed as hp-days using an average horsepower value of 265 hp for each vessel in the Danish brown shrimp fleet (Figure 23).

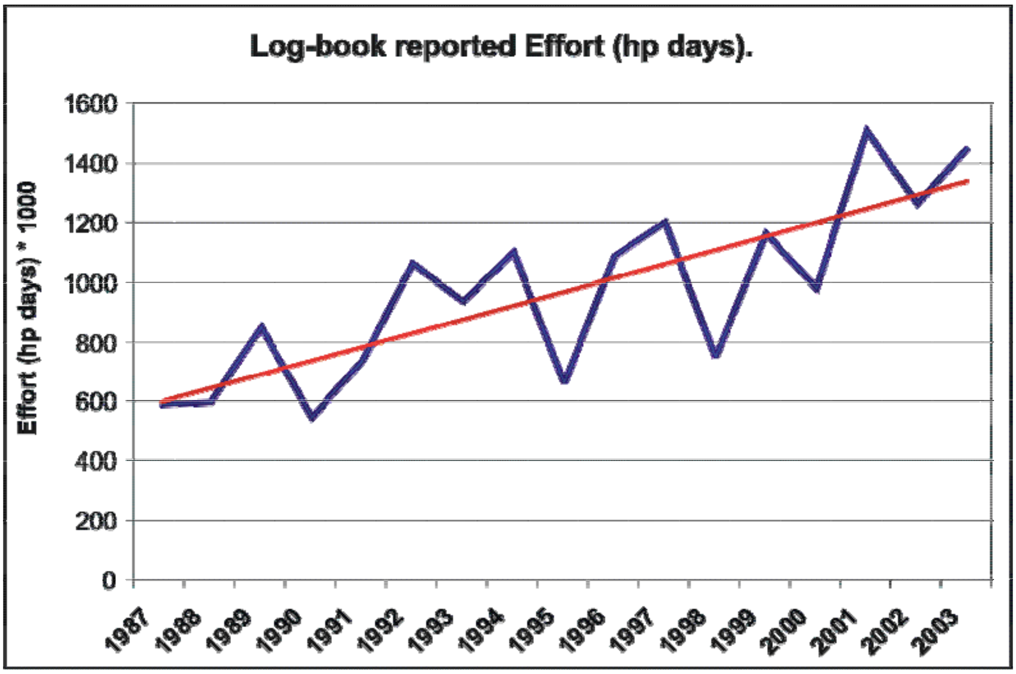

Figure 23: The Danish effort data converted to hp-days at sea in the brown shrimp fishery in the North Sea 1997–2003.

Since 1987 the annual effort has more than doubled from around 600,000 hp days to nearly 1,500,000 in 2003 (Figure 23).

Germany

The total numbers of days at sea recorded for the compensation payments for the period 1986 – 1996 have been combined with the recent data on hp-days at sea from log books. Taken together these suggest an increase in effort by 60% since 1986 (linear trend from 5.9 million hp-days in 1986 to 9.4 million hp-days in 2003, $r^2 = 0.57$,

Figure 22).

Netherlands

The mean number of hp days divided by the mean number of days at sea results in the mean hp value per vessel. In the period since 1995 mean hp has steadily increased from 260 to 280 hp (Figure 24). This is most likely caused by a larger share of larger vessels. The number of vessels landing brown shrimps has shown a reduction in 1998 but has increased since and reached the mid ninety level again. (Figure 25).

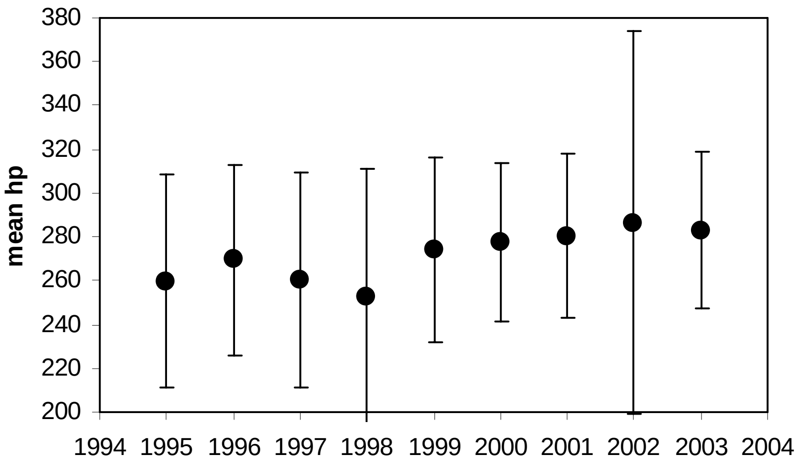

Figure 24: Mean (±SD) hp value for Dutch vessels in the period 1995–2003.

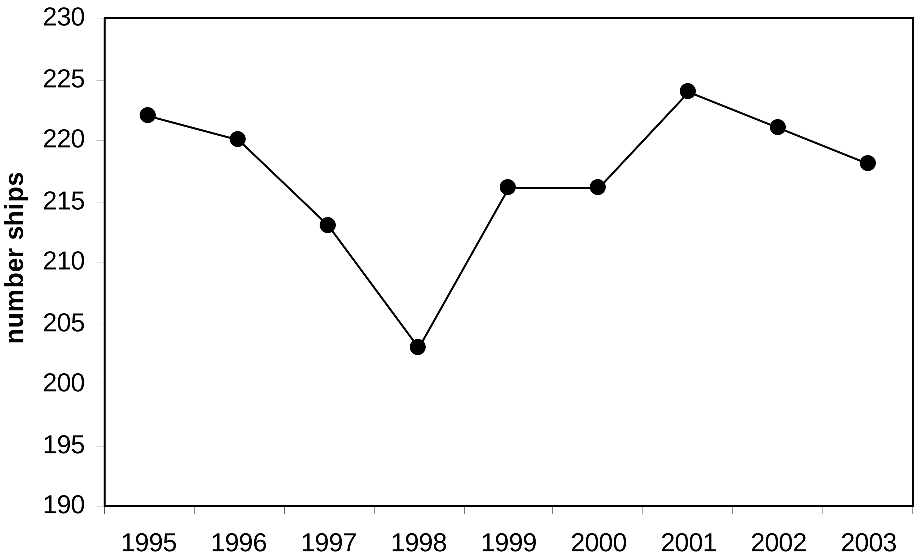

Figure 25: Number of Dutch vessels in the period 1995–2003.

United Kingdom

Since 1989 effort information in terms of hp-days is available for over 80% of the recorded landings. Total effort was estimated from the ratio of total landings to observed LPUE. This total effort has ranged from high values of around 800 thousand hp-days per annum in 1990, 1995, and 2002 to low values around 400 thousand hp-days in 1988, 1992, and 1998. The estimated effort for 2003 was 8% lower than the recent 10-year average of 683 thousand hp-hours. In 2001, the year of maximum landings, estimated fishing effort was, 801 thousand hp-hours, 17% above the 10 year average.

2.3.3 Seasonal patterns

Denmark

The effort in the Danish fishery is higher in spring than in autumn. This pattern was even more pronounced in 2002 while in 2003 effort was generally higher but also the relative share of the autumn season was considerably above the average. The share of the winter effort in 2003 amounted to 25%, which is higher than the mean share (19%) of the years 1992–2001.

The largest effort by the Danish fleet is seen in the second and third quarters. In 2003 high efforts were found in quarter 4 (Figure 26).

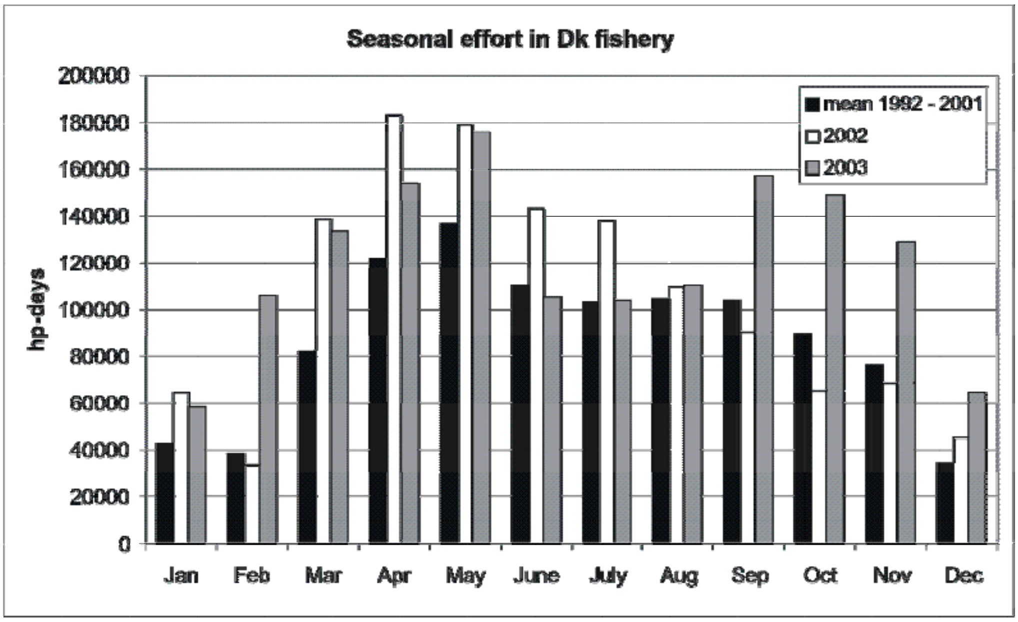

Figure 26: Seasonal effort in DK fleet.

Germany

The typical effort distribution is also found in 2002 and 2003 with high values between April and November. The effort in the winter fishery amounts to 10% of the total German effort in 2003.

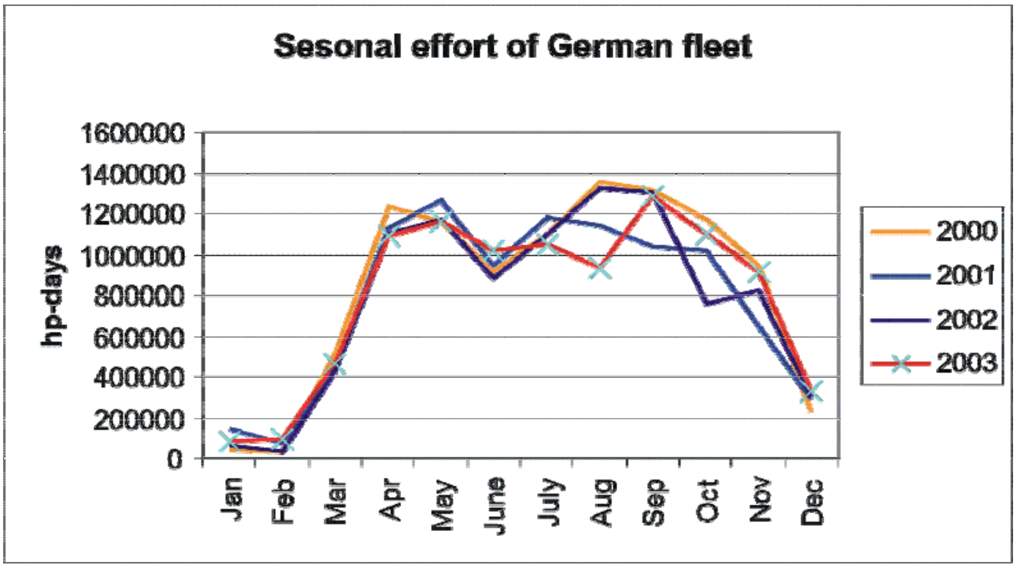

Figure 27: Seasonal effort of the German fleet in the period 2000 to 2003.

Netherlands

The seasonal effort patterns in 2002 and 2003 were close to the average pattern with a substantial effort contribution of the winter fishery (December–March). The effort in the winter fishery amounts to 29% of the total Dutch effort in 2003.

Mean hp value per vessel tends to vary over the season, with the lowest values recorded in the summer months and higher values in winter. This pattern is consistent over years (Figure 28). The reason for this might be that during the summer month's trawlers with mixed fisheries (flatfish and brown shrimp) target flatfish mainly and fish for brown shrimp when their quotas are full. This might also explain the slow increase in mean hp per vessel in recent years. Because of the low flatfish quota, the number of bottom trawlers, that used to primarily target flatfish, may have shifted to brown shrimp fisheries more. For the first time there is a proof for the participation of cutters beyond the "Euro-cutter class" in the winter shrimp fishery (Figure 28).

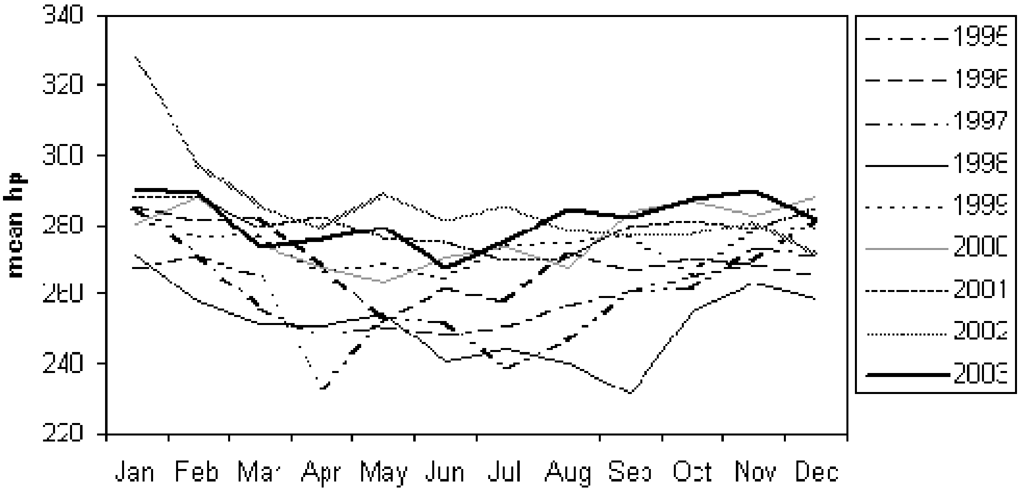

Figure 28: Seasonal patterns in mean hp value for Dutch vessels in the period 1995–2003.

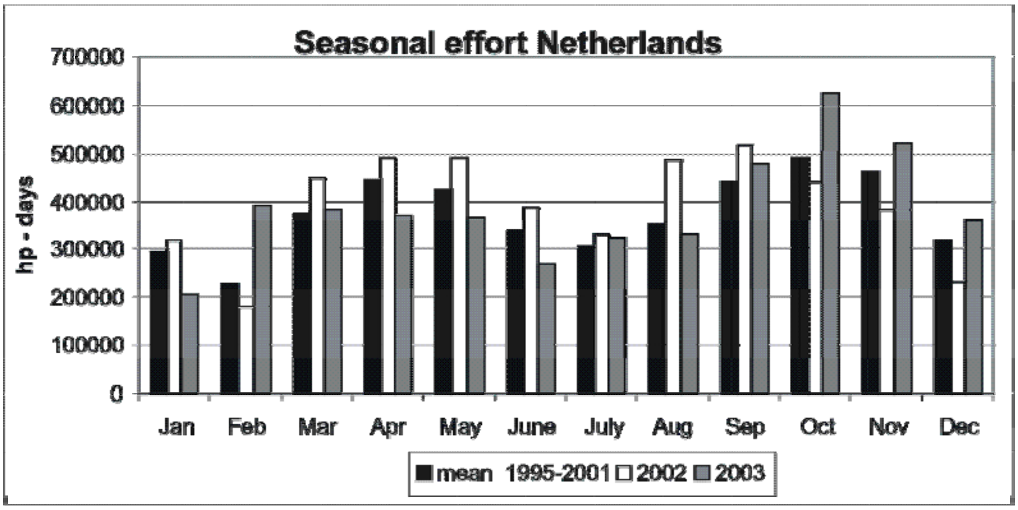

Figure 29: Seasonal effort in Netherlands fleet.

Belgium

The Belgian effort distribution is mainly shifted into the autumn fishery; especially in 2002 and 2003 the spring fishery was negligible.

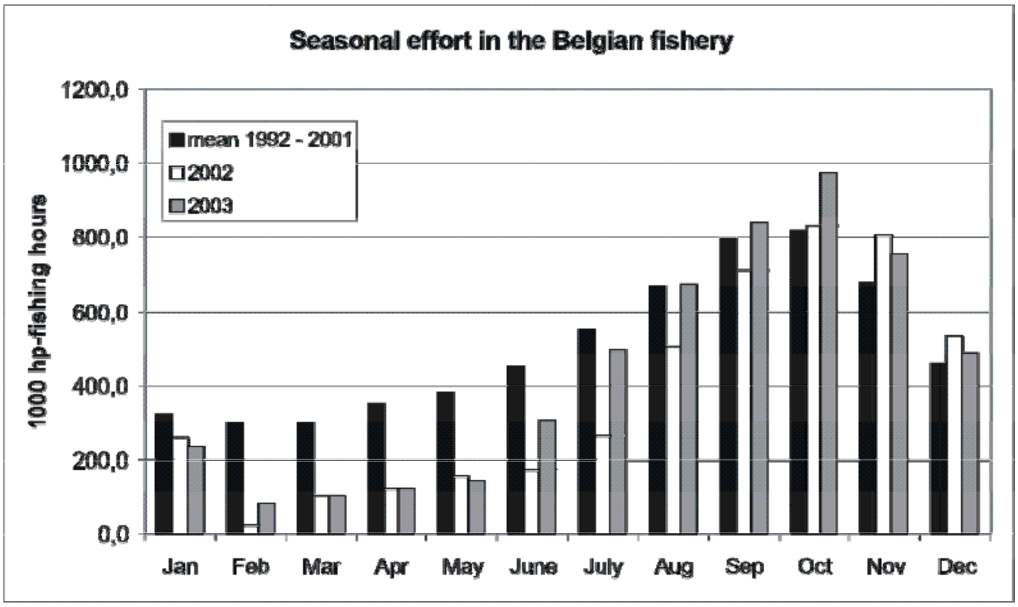

Figure 30: Seasonal effort in Belgium fleet.

United Kingdom

The effort is more evenly distributed over the season with on average 28% of the effort directed to the winter fishery. In 2003 this share increased to 36%.

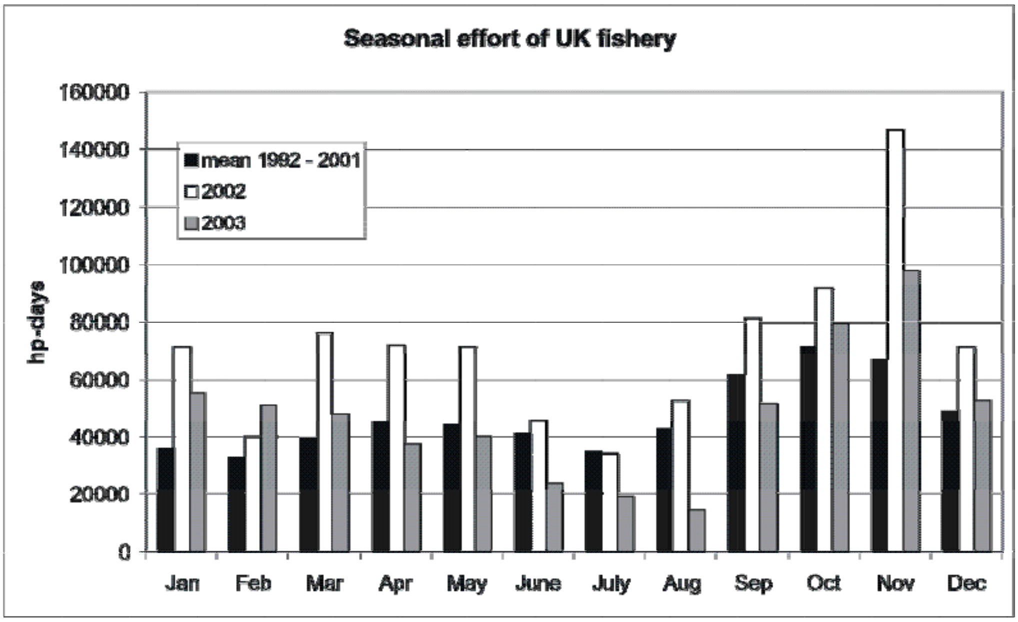

Figure 31: Seasonal effort in UK fleet.

2.3.4 Spatial patterns

The spatial effort distributions of the Danish, German and English fleets mimic largely the spatial patterns of the landings. Again, data from the Dutch fleet are missing.

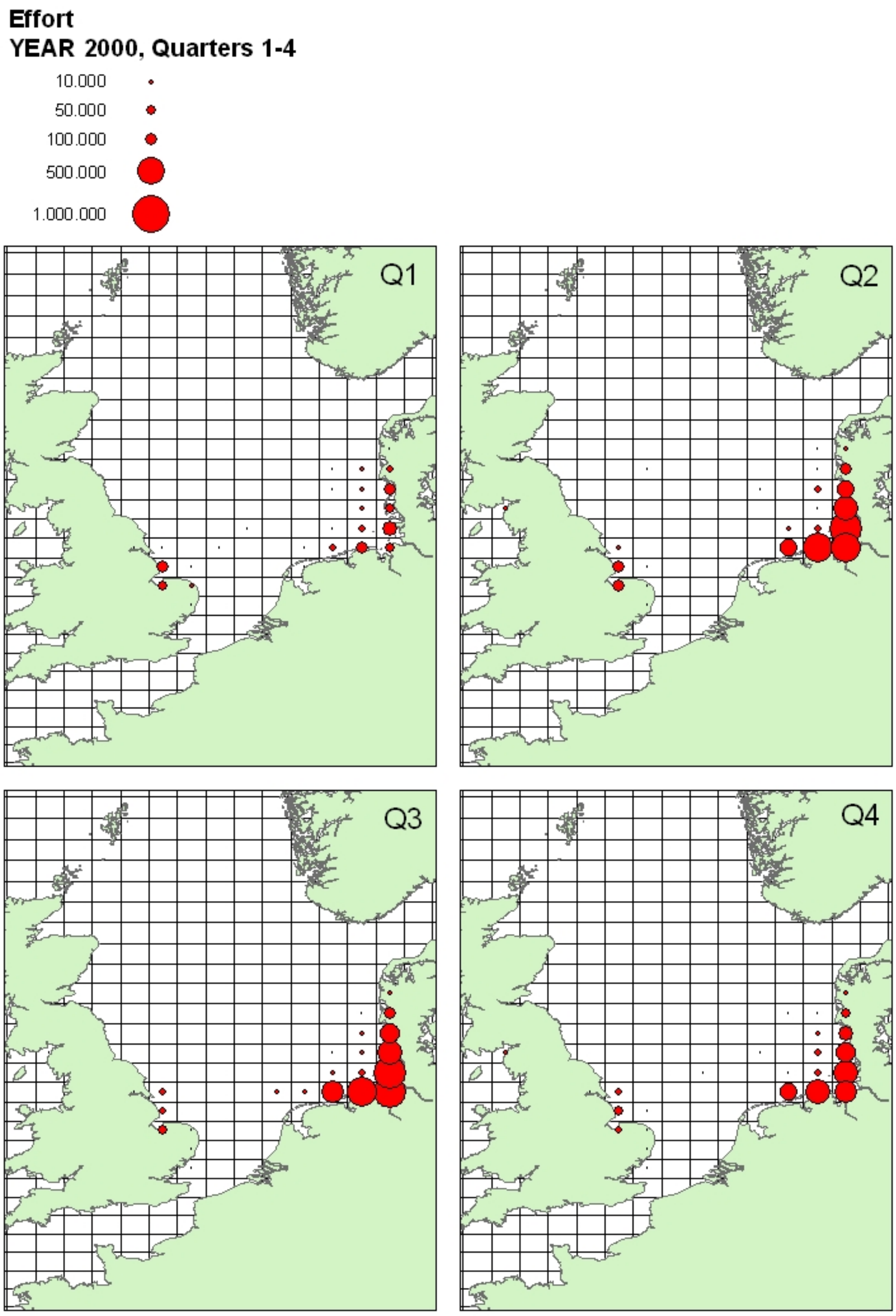

Figure 32: Spatial distribution of shrimping effort (hp-days) in the quarters 1 to 4 in 2000.

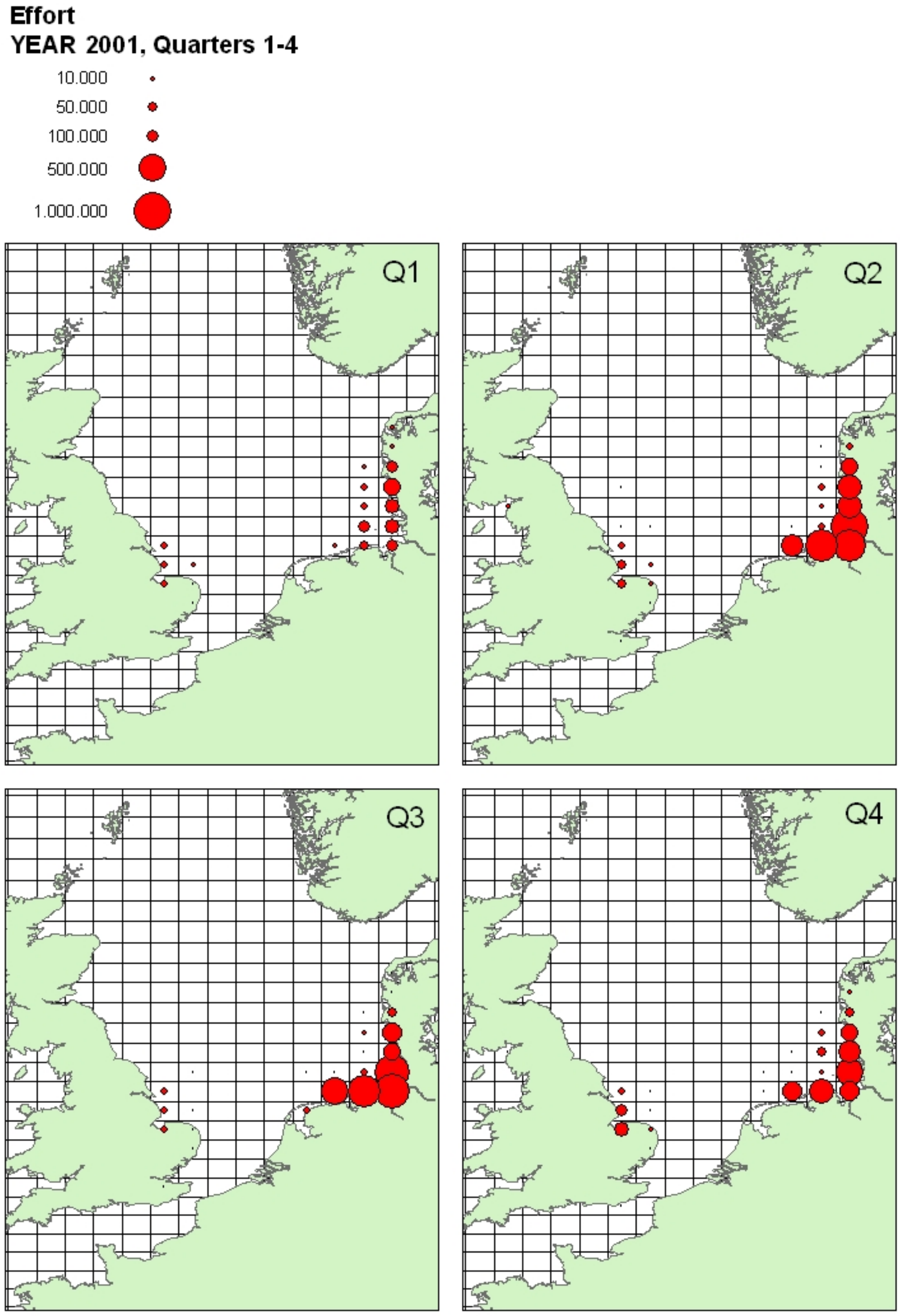

Figure 33: Spatial distribution of shrimping effort (hp-days) in the quarters 1 to 4 in 2001.

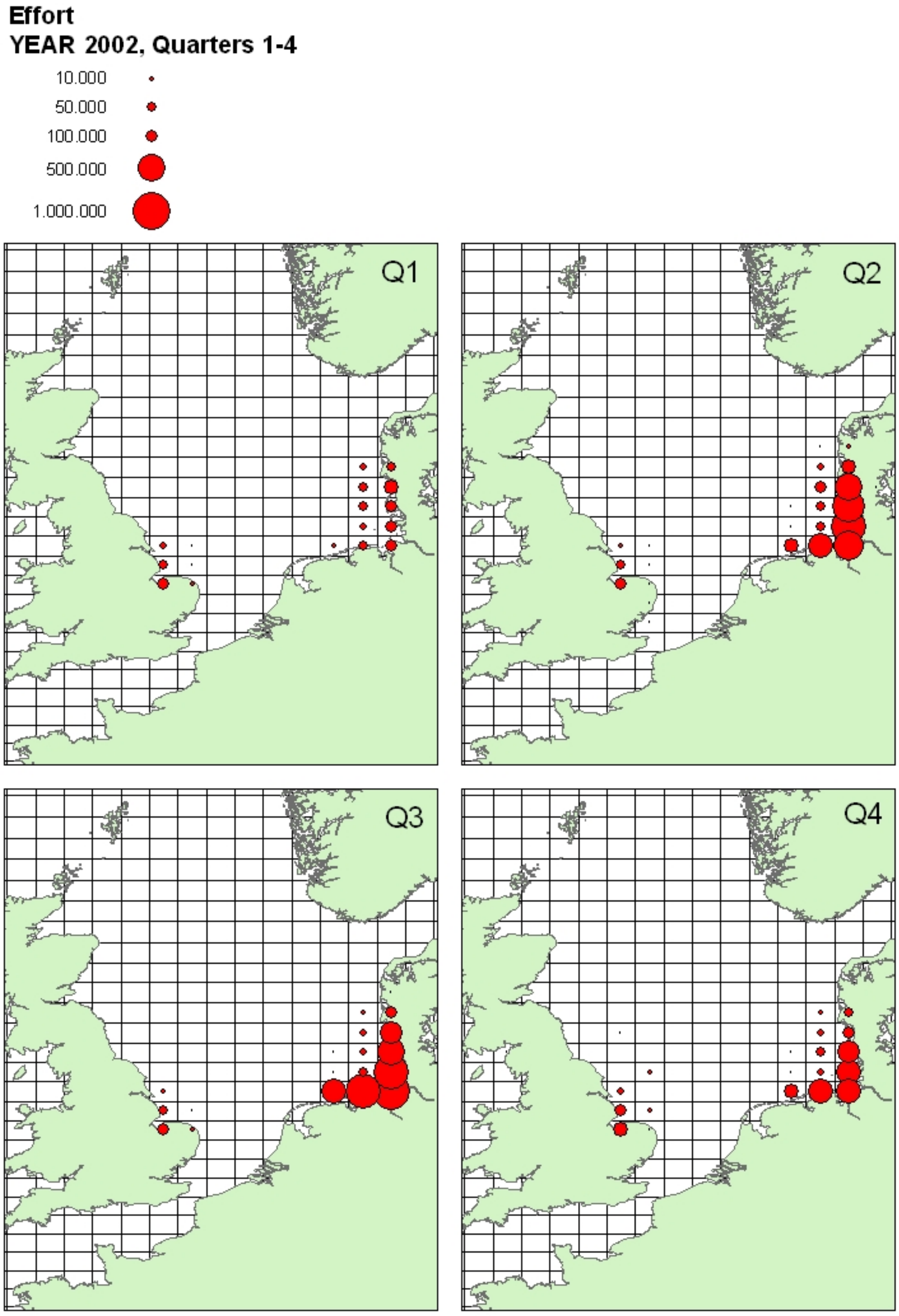

Figure 34: Spatial distribution of shrimping effort (hp-days) in the quarters 1 to 4 in 2002.

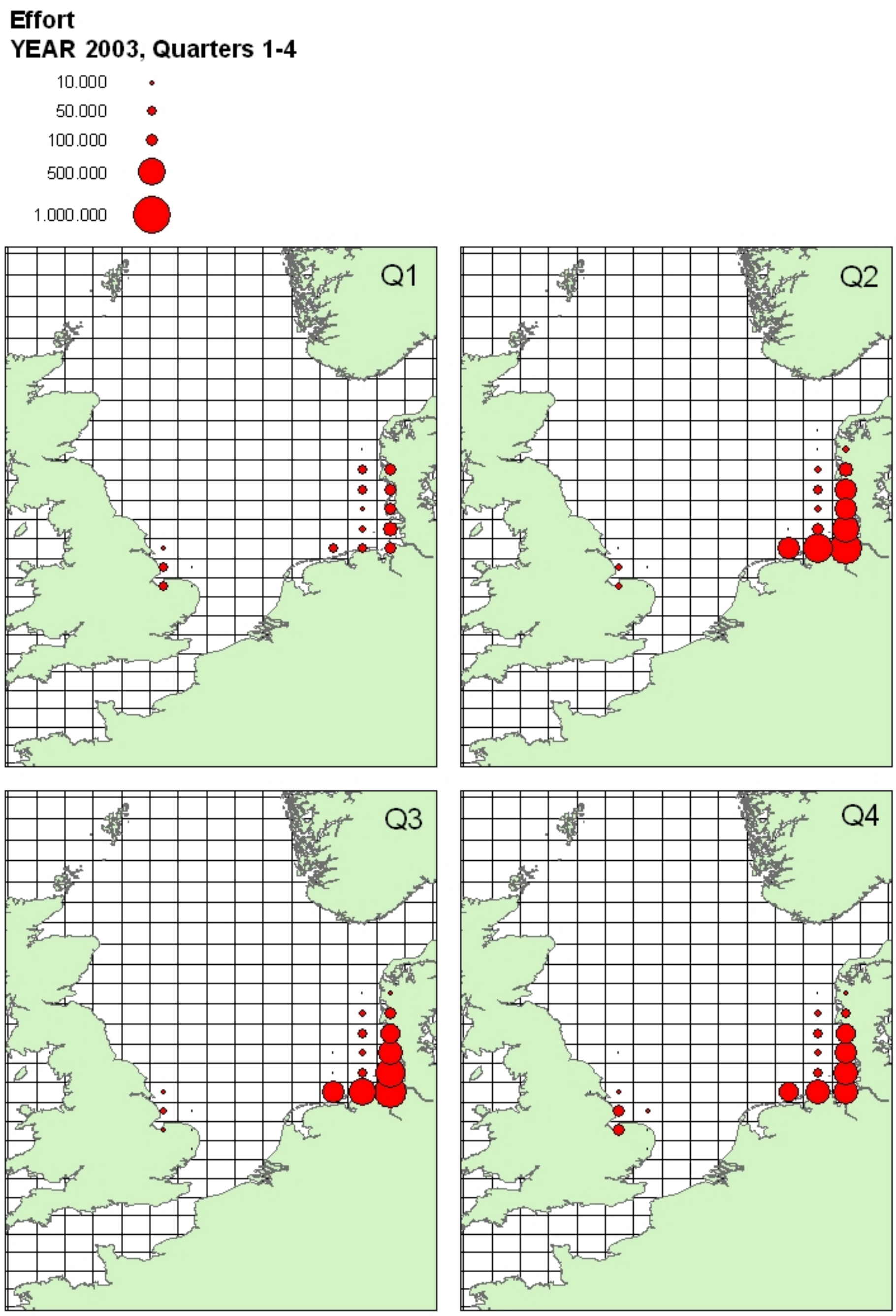

Figure 35: Spatial distribution of shrimping effort (hp-days) in the quarters 1 to 4 in 2003.

Denmark

During the last couple of years there has been a trend towards larger effort in the ICES squares north of the Horns Reef. The vessels have also been fishing for shrimps further away from the West coast of Jutland (Figure 35).

Belgium

A preliminary analysis of the spatial distribution of the shrimp landings (based on the annual landings by rectangle) shows a clear shift in shrimp directed fishing effort to the North. This is assumed to be the combined effect of two main driving forces: (a) the sharp decline in the abundance of shrimp, particularly in the western part of the Belgian coastal waters, which tends to force fishing effort towards the richer, more northerly shrimp grounds, and (b) the fact that a large number of Belgian shrimp trawlers is now owned by Dutch companies and therefore operates from more northerly Dutch ports.

United Kingdom

Spatial distributions of fishing effort by the UK fleet highlight the significance of the ICES squares F034 and F035 to The Wash fishery. Fishing effort in the Irish Sea on the West coast and some other minor fisheries goes largely unrecorded.

2.4 LPUE

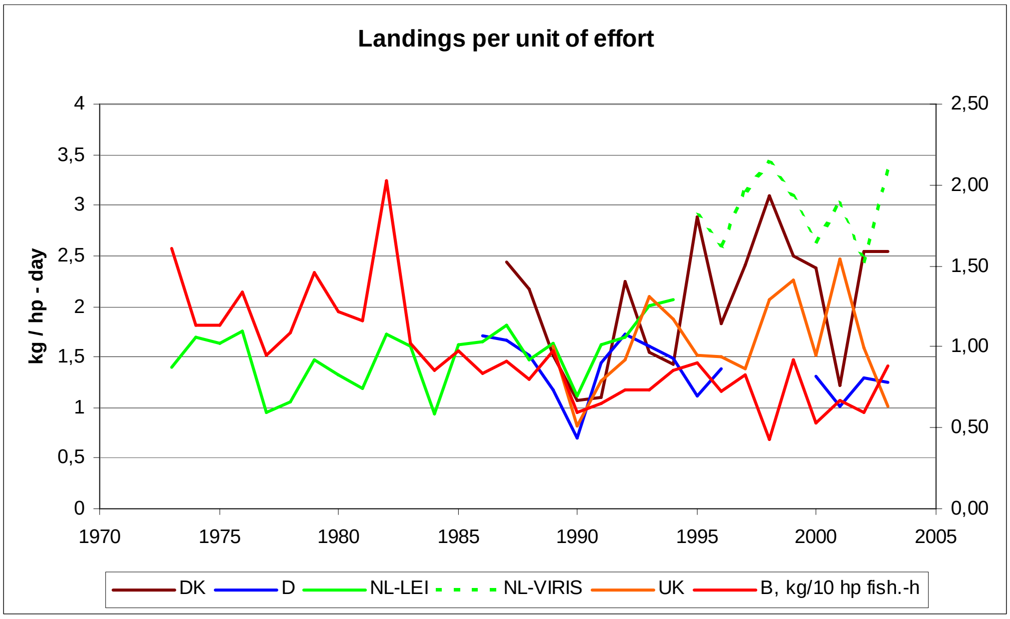

Figure 36: Landings per unit of effort per country.

2.4.1 Time trends

Denmark

Danish LPUE show an increasing trend over the time series, with a major interruption in 2001(Figure 37). The effort in total fishing days had also been converted into hp days using the mean horsepower of the vessels in the Danish fleet

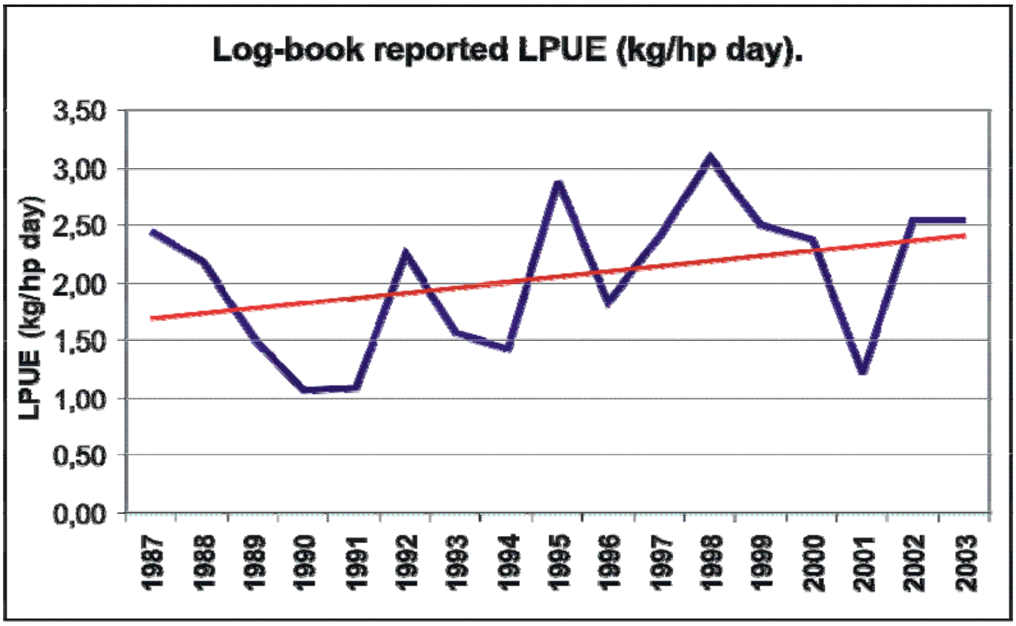

Figure 37: The annual corrected LPUE (kg/hp-day) for the Danish brown shrimp fishery in the North Sea between 1987 and 2003.

In 2000 the LPUE (kg/hp-day) were highest in the second quarters in most of the ICES squares the Danish brown shrimp fleet operates in. In the other years the LPUE are more or less evenly distributed from season to season. From 2000/2001 to 2002/2003 the LPUE increased from around 1.8 to 2.5 or around 40%. The overall trend between 1987 and 2003 is a clear increase of the LPUE with some variation between years around the trend line (

Figure 37).

Germany

LPUE values appear stable: recent values for the years 2001–2003, which were calculated from a different data source, are comparable to the latest figures of the earlier time series. While LPUE values of the Danish, German and Dutch fleets were close together, the deviations increase quite dramatically over the subsequent decade.

Netherlands

The plain data suggest higher LPUE in the recent decade compared to earlier data. However, the increase is mainly between the two different data sources and most likely due to the new way of effort (NL-days calculated as days at sea minus one day for any trip longer than one day) calculation.

Belgium

The extended downward trend in LPUE values has stabilised and changed into a considerable increase in 2003. The 2003 value matches the LPUE level of the late 1980s.

United Kingdom

The LPUE data reveal no pronounced trend, but 2003 was poor in relation to the recent 10-year average (down 39%). The first and second quarters of 2000 were especially high for ICES squares E936 and F036 and this result from the good recruitment in this area for the previous year. Less spatial variation and a more typical seasonal picture with peak LPUE in the third and fourth quarters is evident in 2001. These good catch rates carry over into the first quarter of 2002 especially in ICES square F134.

2.4.2 Seasonal patterns

The seasonal pattern of Denmark differs mostly from those of other regions with maximum densities in spring months. The other regions reveal highest densities in autumn between August and October. While the Dutch and German patterns are somewhat flat, the Belgium spring values are outstandingly low and generate a more pronounced peak in autumn. High shrimp densities in The Wash are more evenly distributed into late autumn and winter. In 2003 the spring values were especially high in the Dutch and Danish fishery.

Denmark

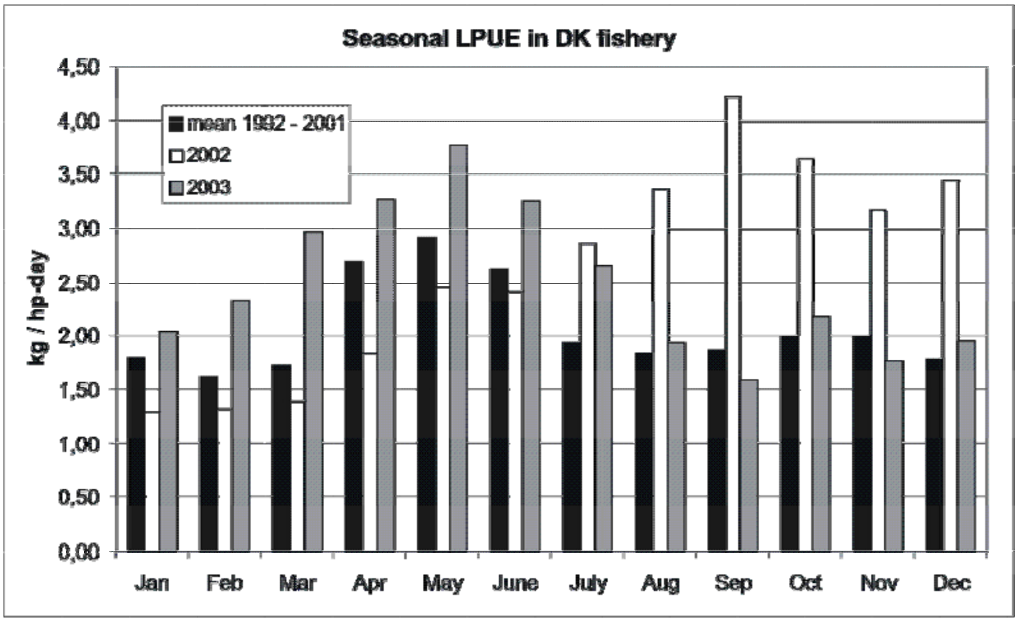

Figure 38: Danish seasonal LPUEs.

Germany

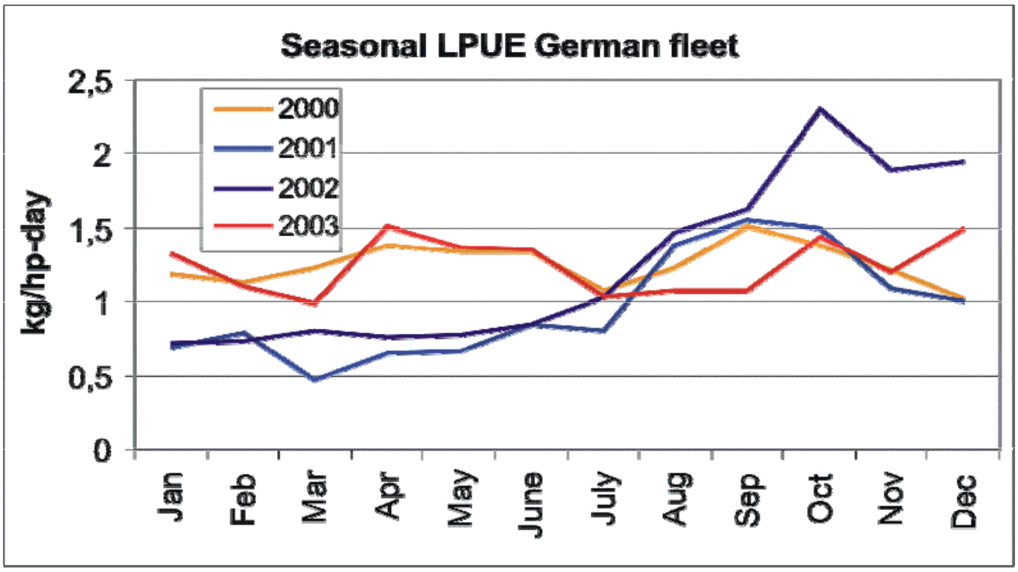

Figure 39: German seasonal LPUEs.

Netherlands

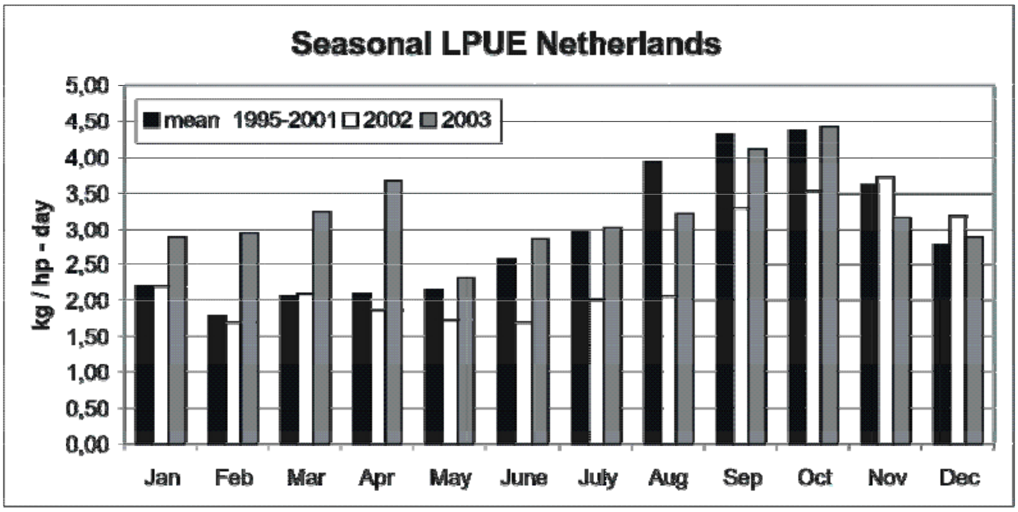

Figure 40: Dutch seasonal LPUEs.

Belgium

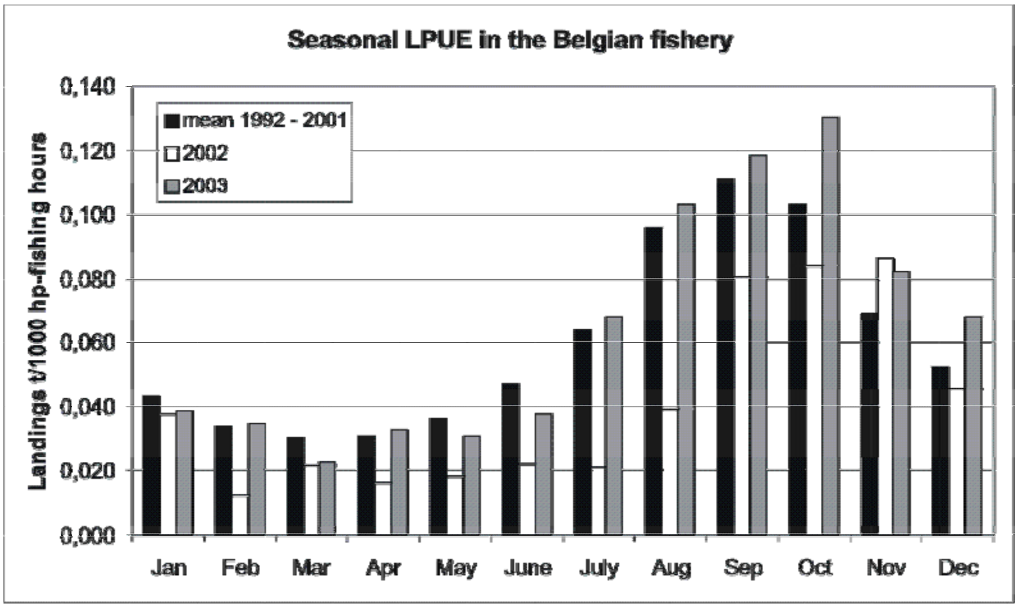

Figure 41: Belgian seasonal LPUEs.

United Kingdom

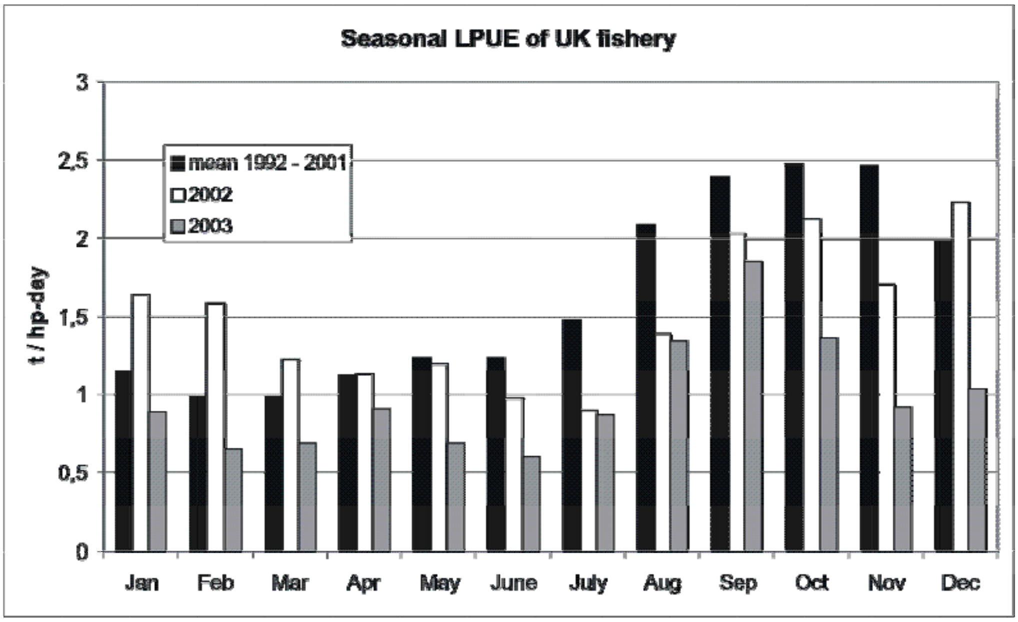

Figure 42: UK seasonal LPUEs.

2.4.3 Spatial patterns

These LPUE data include subset landings of the Dutch fleet, covering vessels that landed fish together with shrimp. To what extent these data are representative for the total fleet can not be judged.

2000: Densities as indicated by LPUE are high in the first Quarter in UK waters and off the Dutch coast. In the second quarter highest densities are recorded in Northern area and also in deeper waters (ICES squares 37F7 – 41F7). Third quarter values are highest in the South Western areas.

2001: The northern regions (Denmark and Schleswig Holstein coast of Germany) are characterised by low densities throughout the year. South Western areas show high values in quarters 1 and 3. Occasional catches are reported in deep waters in Northern areas (ICES squares 37F6 – 41F6).

2002: UK catch rates are low throughout the year. Quarter two values are low all over the area. Maximum values are recorded in the third quarter in Dutch and Belgian waters, but not in the UK

2003: UK catch rates are again low through out quarters one to three. Autumn catch rates are high in the South West and in the North but not in German central waters.

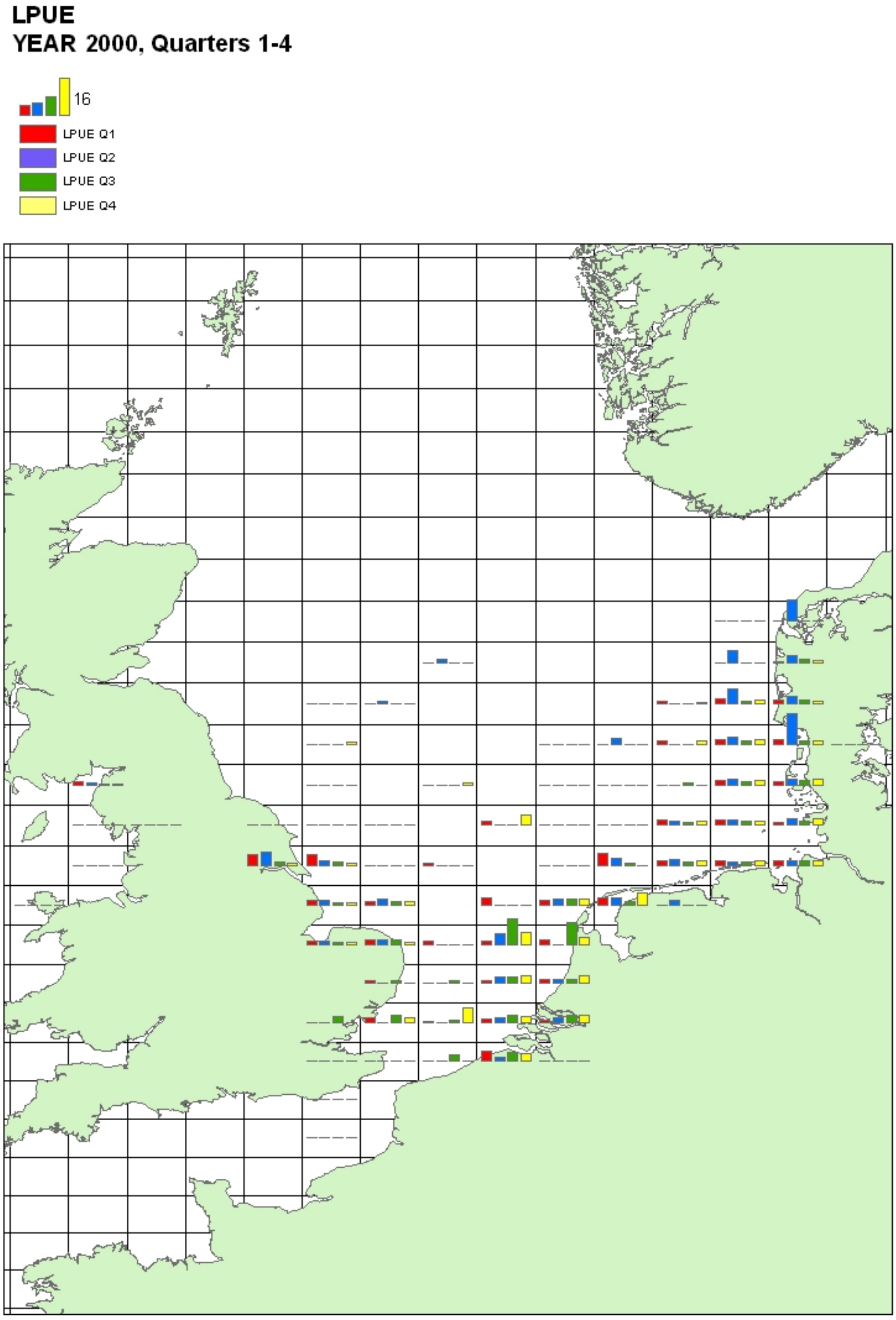

Figure 43: Landings Per Unit of Effort (tonnes/hp-day) per quarter in 2000.

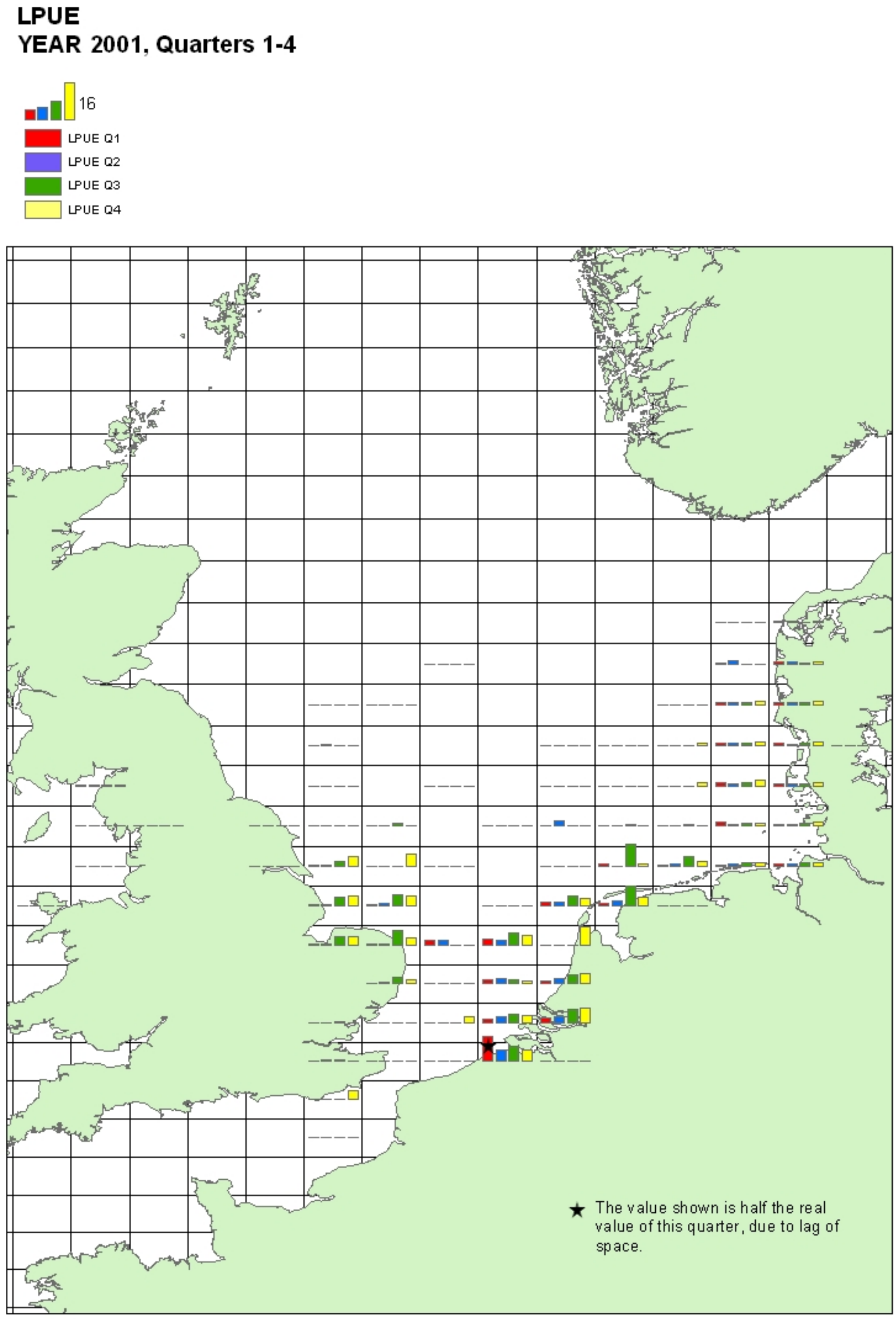

Figure 44: Landings Per Unit of Effort (tonnes/hp-day) per quarter in 2001.

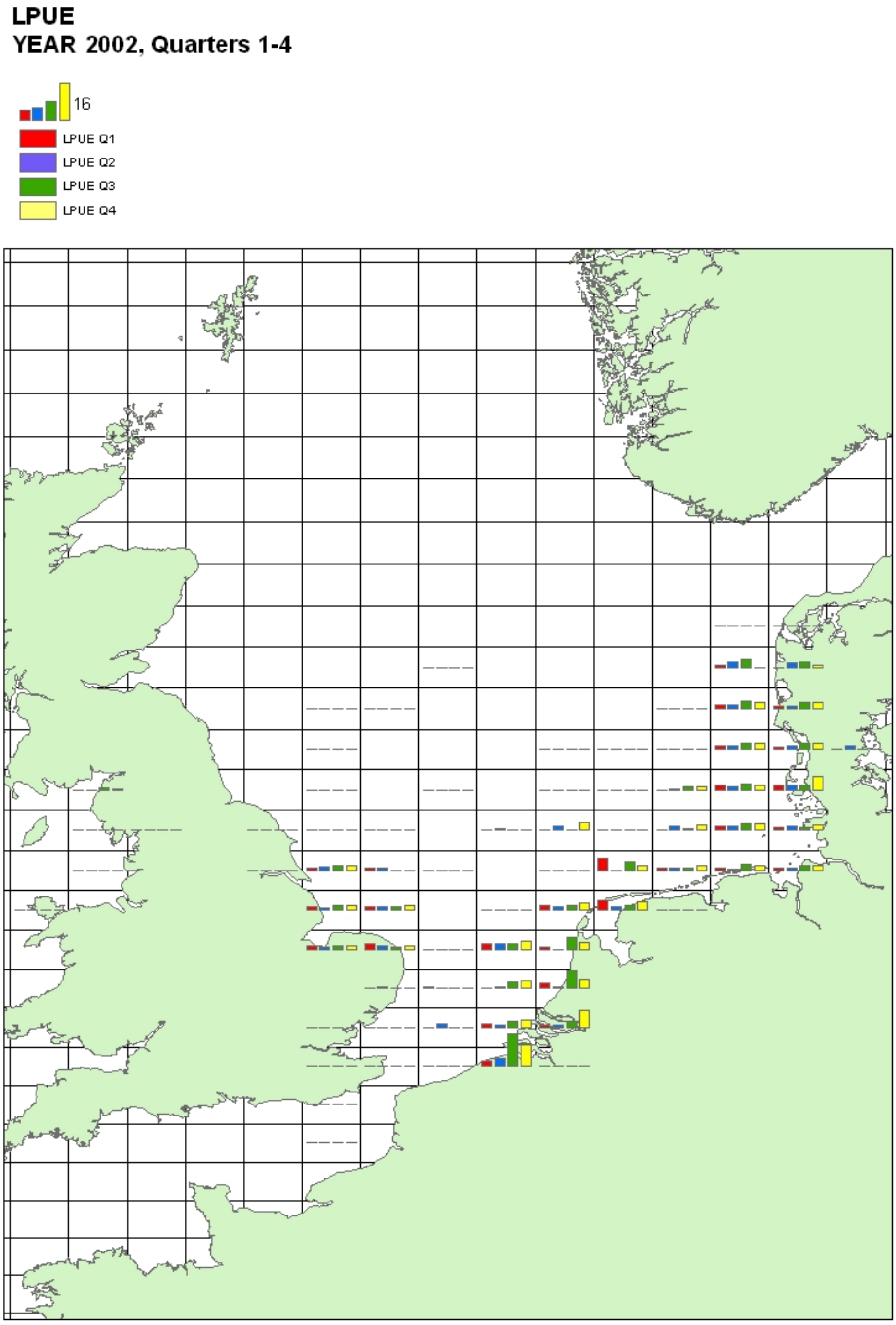

Figure 45: Landings Per Unit of Effort (tonnes/hp-day) per quarter in 2002.

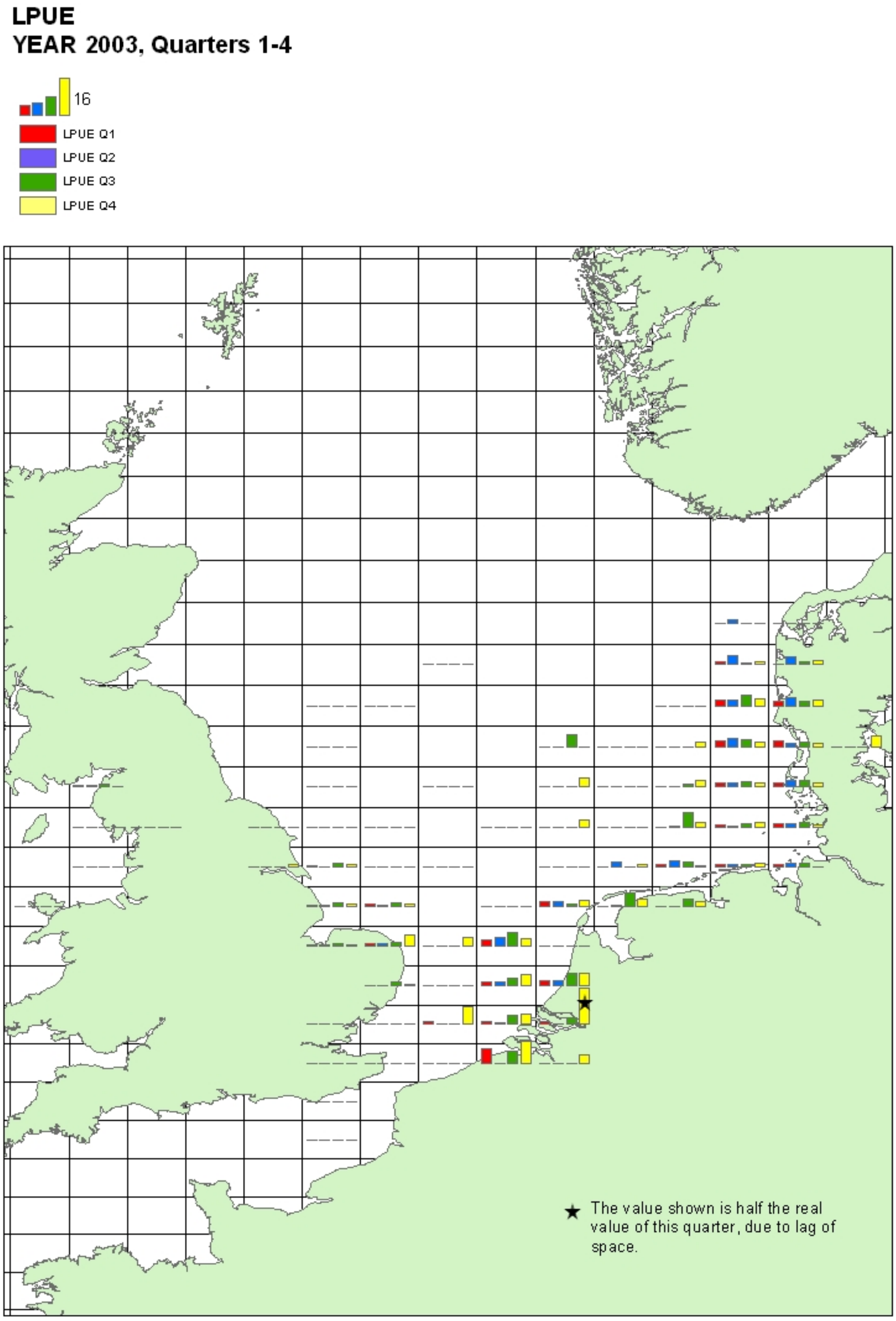

Figure 46: Landings Per Unit of Effort (tonnes/hp-day) per quarter in 2003.

Denmark

In the second quarter of 2000 the LPUE in the ICES square 42F8 was one of the highest observed the last 4 years along the Jutland west coast (Figure 43). The following years the LPUE has been lower. Generally the fishing activity for brown shrimps has increased in the ICES squares north of the Horns reef which are reflected in the increase in the LPUE's for the ICES squares north of the reef (Figure 46).

2.5 Investigation of the effect of vessel engine power on catch rates of German shrimp vessels

The disaggregated data set of German log book data from four years was analysed by means of a GAM model. The catch weight per fishing day, calculated as hours out of port divided by 24, was predicted applying a year and a month factor together with a smoothing term of the vessel engine power. Engine power turned out to have a highly significant effect on landings per day throughout the entire range of this variable. The typical seasonal pattern in CPUE emerges in the display of the month factors and the pattern of the year factors reveals low shrimp densities in 2001. The explained deviance of the model amounts to 14%, indicating a high variability in the data. This explains why earlier investigations with limited data sets failed to detect a significant influence of vessel engine power (Prawitt 1995).

Applied model:

```
CPUE.D ~ MONTH + YEAR + s(KW), family = poisson)
```

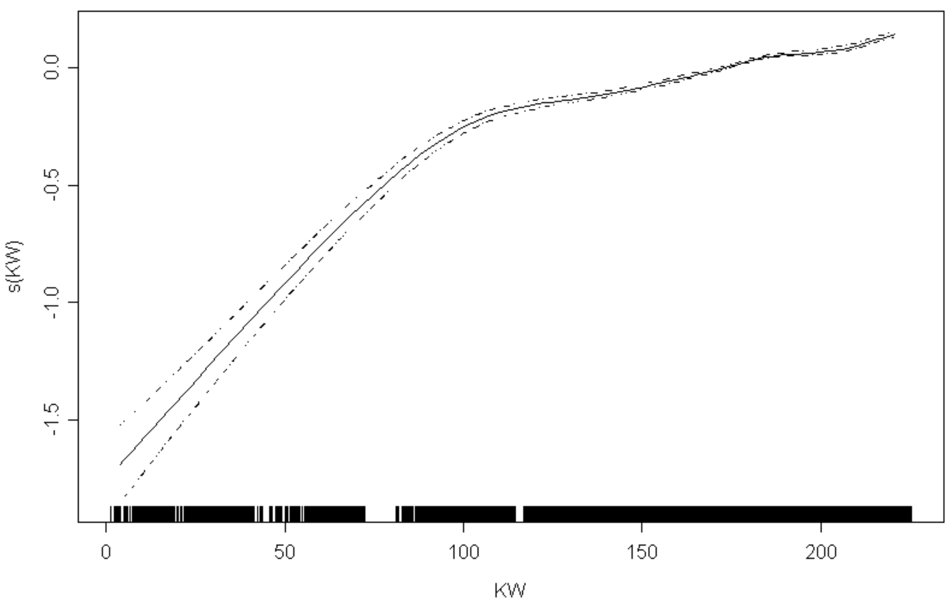

Figure 47: Effect of vessel engine power (kw) on catch per day. All log book data 2000–2003, Germany, GAM <- Catch/day~year+month+s(kw,3) poisson error.

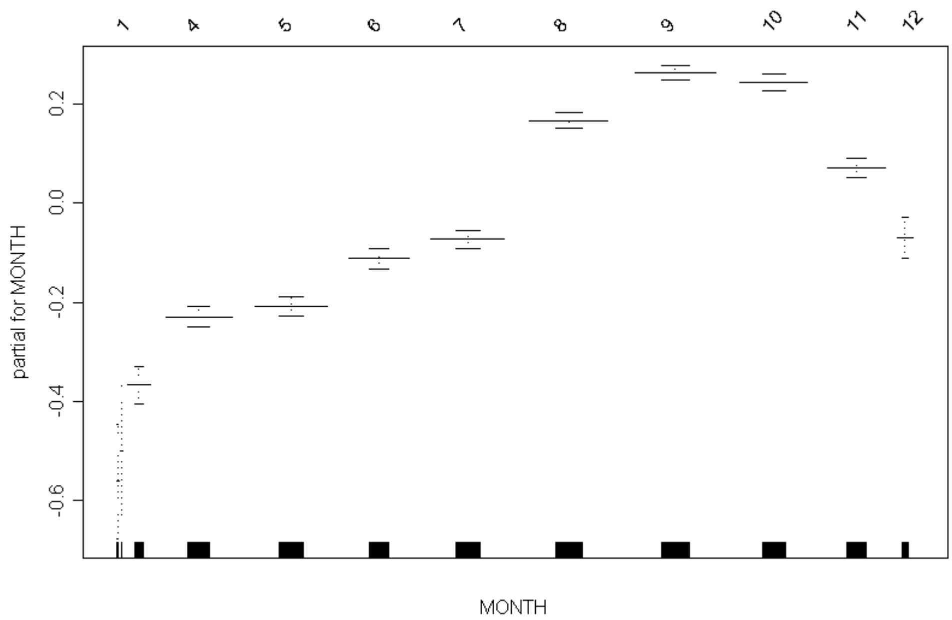

Figure 48: Effect of month on catch per day. All log book data 2000–2003, Germany, GAM<-Catch/day~year+month+s(kw,3) poisson error.

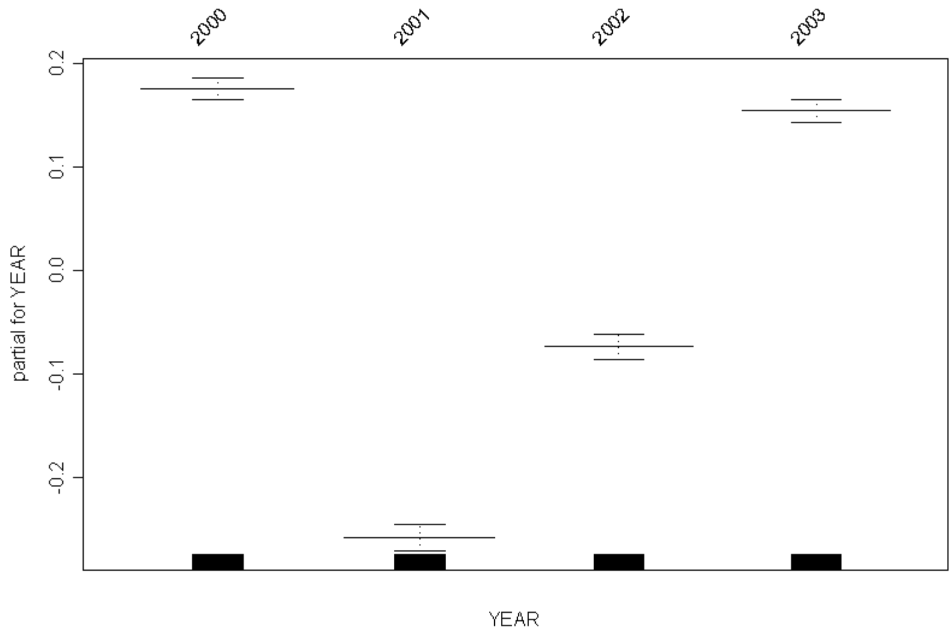

Figure 49: Effect of year on catch per day. All log book data 2000–2003, Germany, GAM<-Catch/day~year+month+s(kw,3) poisson error.

3 Stock trends from surveys

To describe trends in *Crangon* stocks two datasets were used. The Dutch Demersal Fish Survey is carried out by the Netherlands Institute for Fisheries Research and the German Demersal Young Fish Survey is carried out by the Bundesforschungsanstalt für Fischerei.

3.1 Dutch Demersal Fish Survey (DFS)

Data from the Dutch Demersal Fish Survey were used to describe distribution patterns in the period 1970–2003. This survey is carried out annually in September/October. The DFS was initiated in 1969 with the aim to develop abundance indices for 0 and 1 year group flatfish. The survey is conducted from September/October (estuaries) to October/November (coastal zone). In estuaries a 3 m shrimpnet is used, while in the coastal zone a 6 m beamtrawl is used, each with 20 mm stretched cod-ends. Every year 200–300 hauls of 15 min are made along the Dutch, German and Danish coast, as well as the Westerschelde, Oosterschelde, Wadden Sea and in the Eems-Dollard.

The survey is stratified to depth classes. Indices are calculated from the weighted mean according to the surface area of every depth class. As we were interested in trends in subareas, indices for the following areas were calculated separately: Danish coast, German Wadden coast (north of islands), German Bight, Eastern Wadden Sea, Western Wadden Sea, Dutch coast and the Scheldt estuary (only Westerschelde and Oosterschelde, Figure 56). Linear trends were fitted using loglinear regression models with water depth and year as explaining variables.

3.1.1 Distribution

Annual distribution maps for the total brown shrimp densities (n/ha) are presented in Figure 50 to Figure 55. These maps include all sizes. Year to year variations in densities are very large. Also the locations of concentrations are highly variable. In all years highest densities are found in the Dutch Wadden Sea. For some years (1997, 1998, 1999, 2002) data from the German and Danish coast are incomplete, due to bad weather.

3.1.2 Trends

The stock development is described by area-specific indices (Figure 57). All trends were tested using a log-linear model based on Poisson-distributed data, with depth and year as explaining variables. In all subareas the depth effect was significant ($P<0.05$). Mean total densities are declining significantly in the Scheldt estuary and in the Eastern Wadden Sea, are slightly but significantly decreasing in the German Bight and show a significant increase along the German Wadden coast, the Dutch Wadden coast and in the Western Wadden Sea. No significant change was found for the Dutch coast. In several areas year to year variations are increasing in recent years.

Trends for the largest size only (>54 mm) show similar patterns. The downward trend in the Eastern Wadden Sea is however less pronounced and the trends for the Danish coast and the Western Wadden Sea are no longer significant. Surprisingly the effect of water depth is not significant for the Western Wadden Sea (while it is significant for the other subareas).

3.1.3 Length frequency distribution

Dutch fishermen who go to the area around Sylt to fish for brown shrimp, have reported that one of the reasons is that shrimps are generally larger or in better condition there. We do not have data on condition, but length-frequency distributions indeed suggest that brown shrimp along the Danish and German Wadden coast are slightly larger than those in the Wadden Sea (Figure 58).

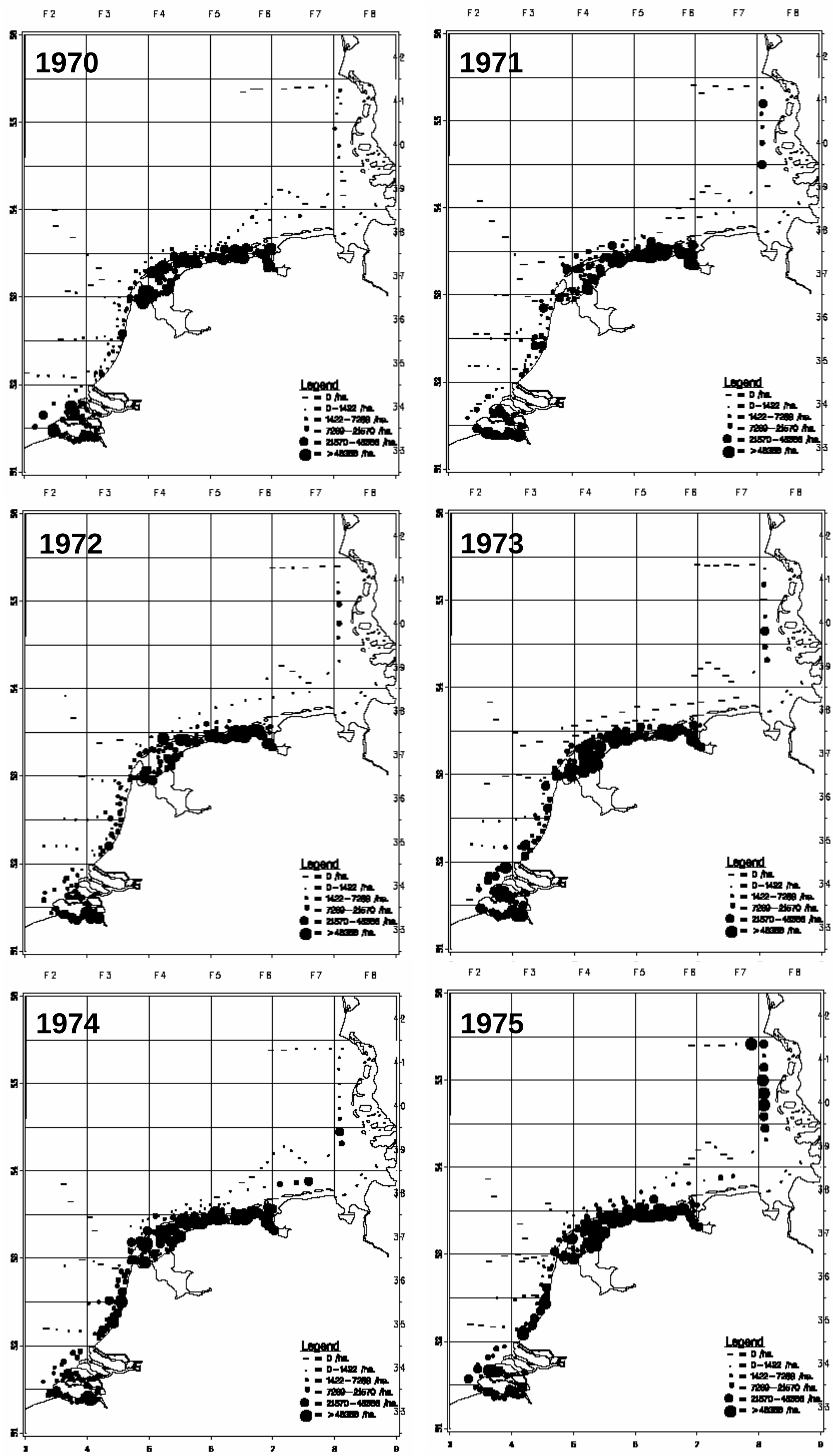

Figure 50: Distribution of brown shrimps (all sizes) in the years 1970–1975.

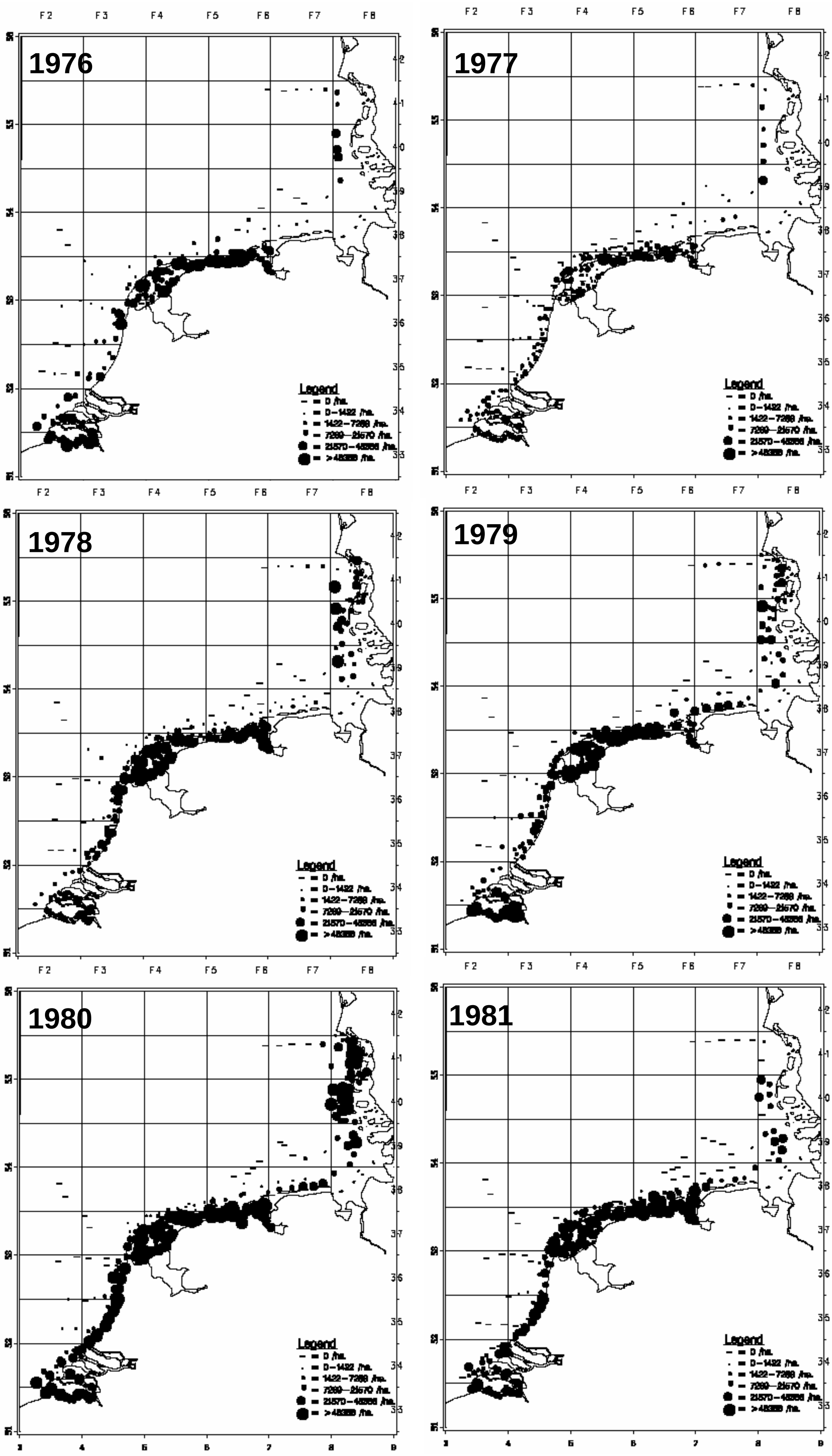

Figure 51: Distribution of brown shrimps (all sizes) in the years 1976–1981.

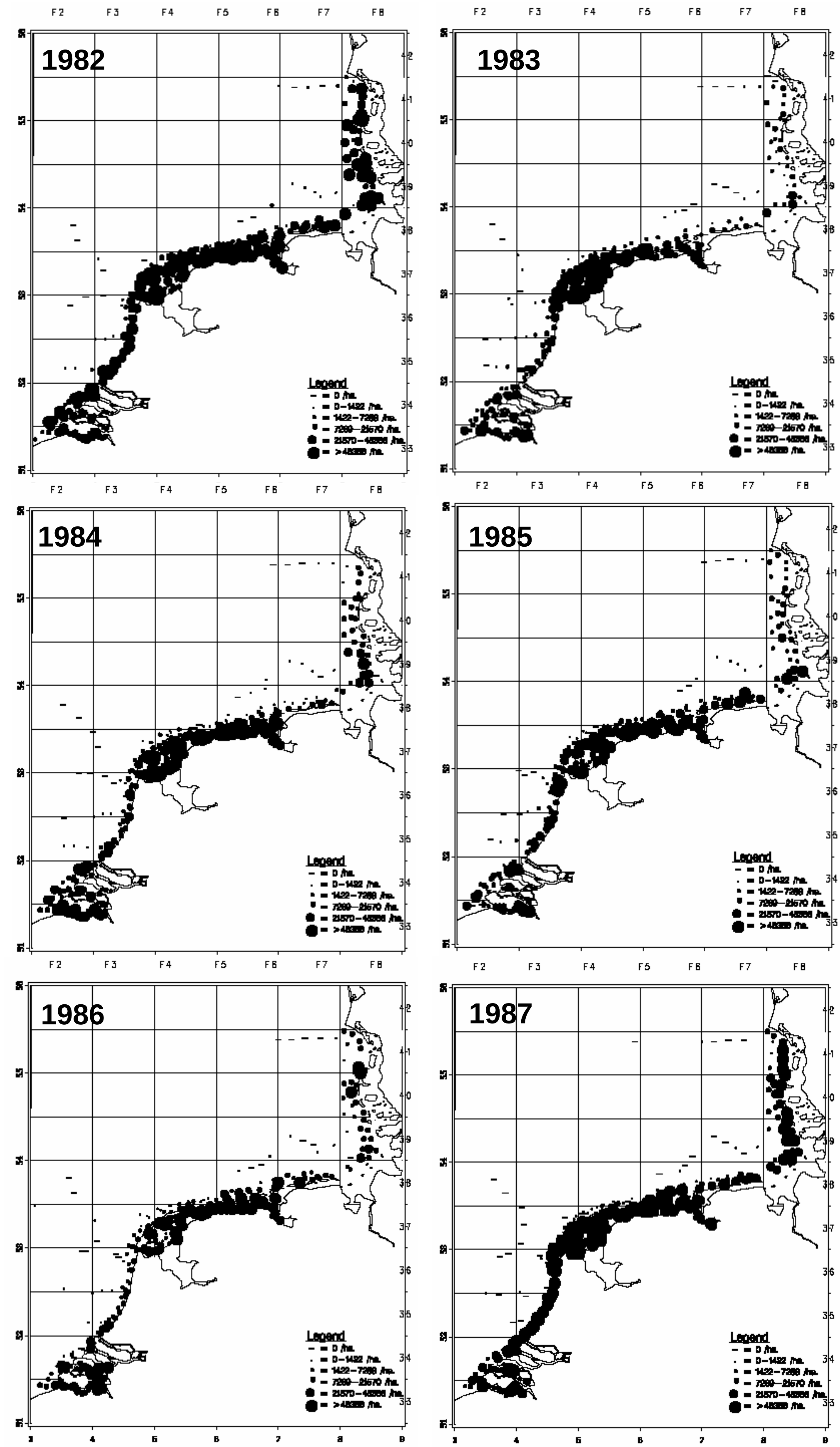

Figure 52: Distribution of brown shrimps (all sizes) in the years 1982–1987.

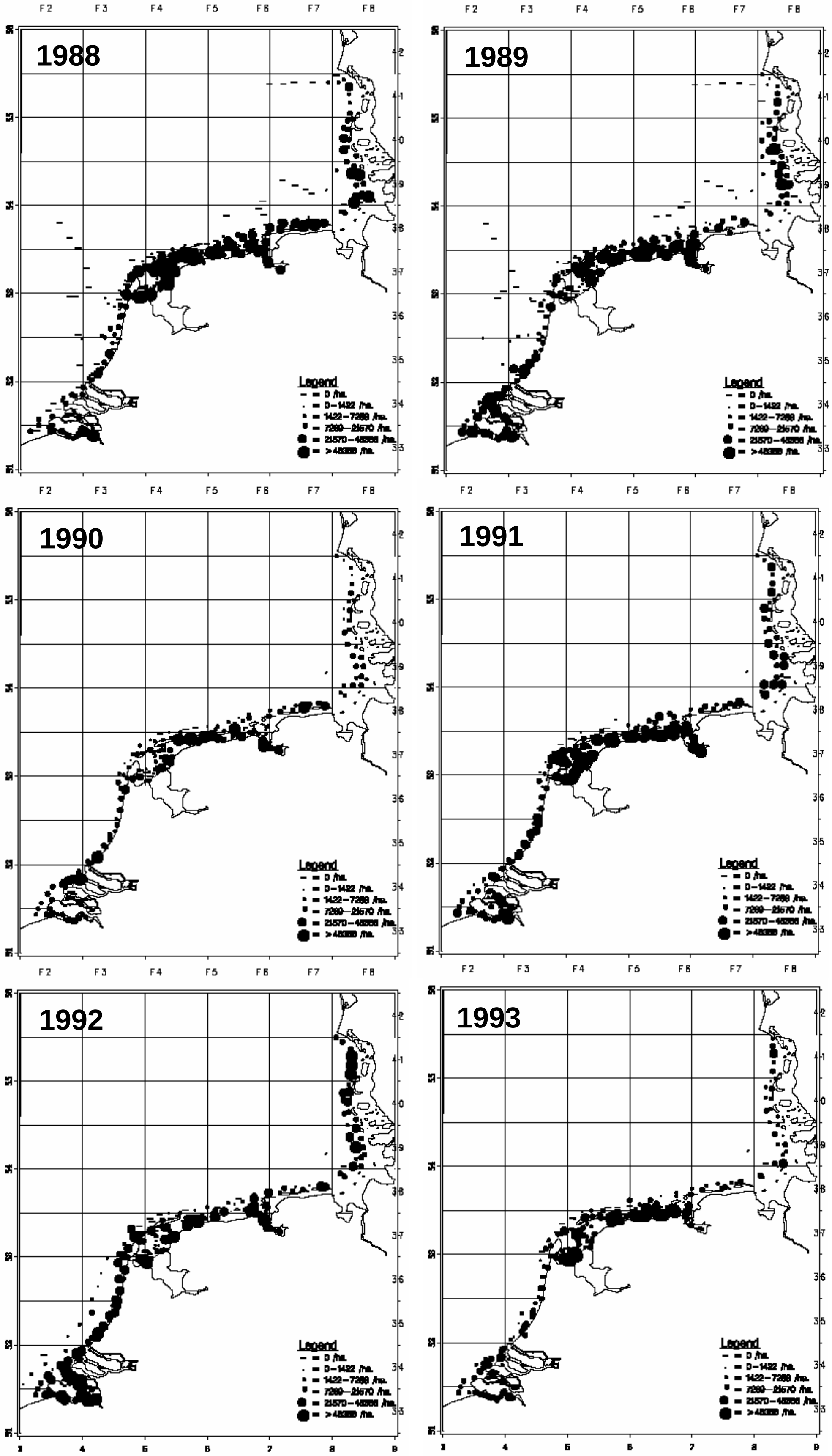

Figure 53: Distribution of brown shrimps (all sizes) in the years 1988–1993.

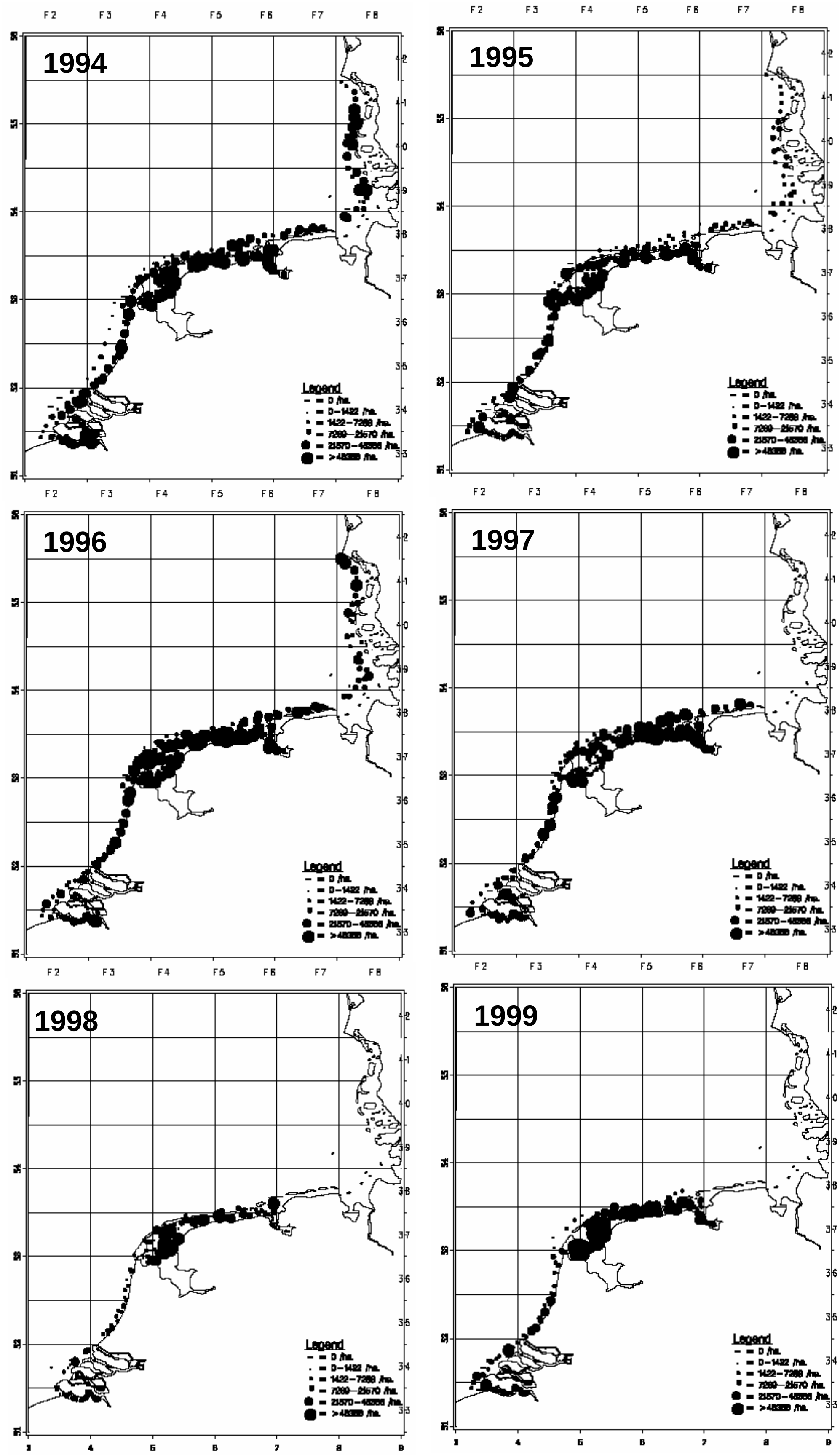

Figure 54: Distribution of brown shrimps (all sizes) in the years 1994–1999.

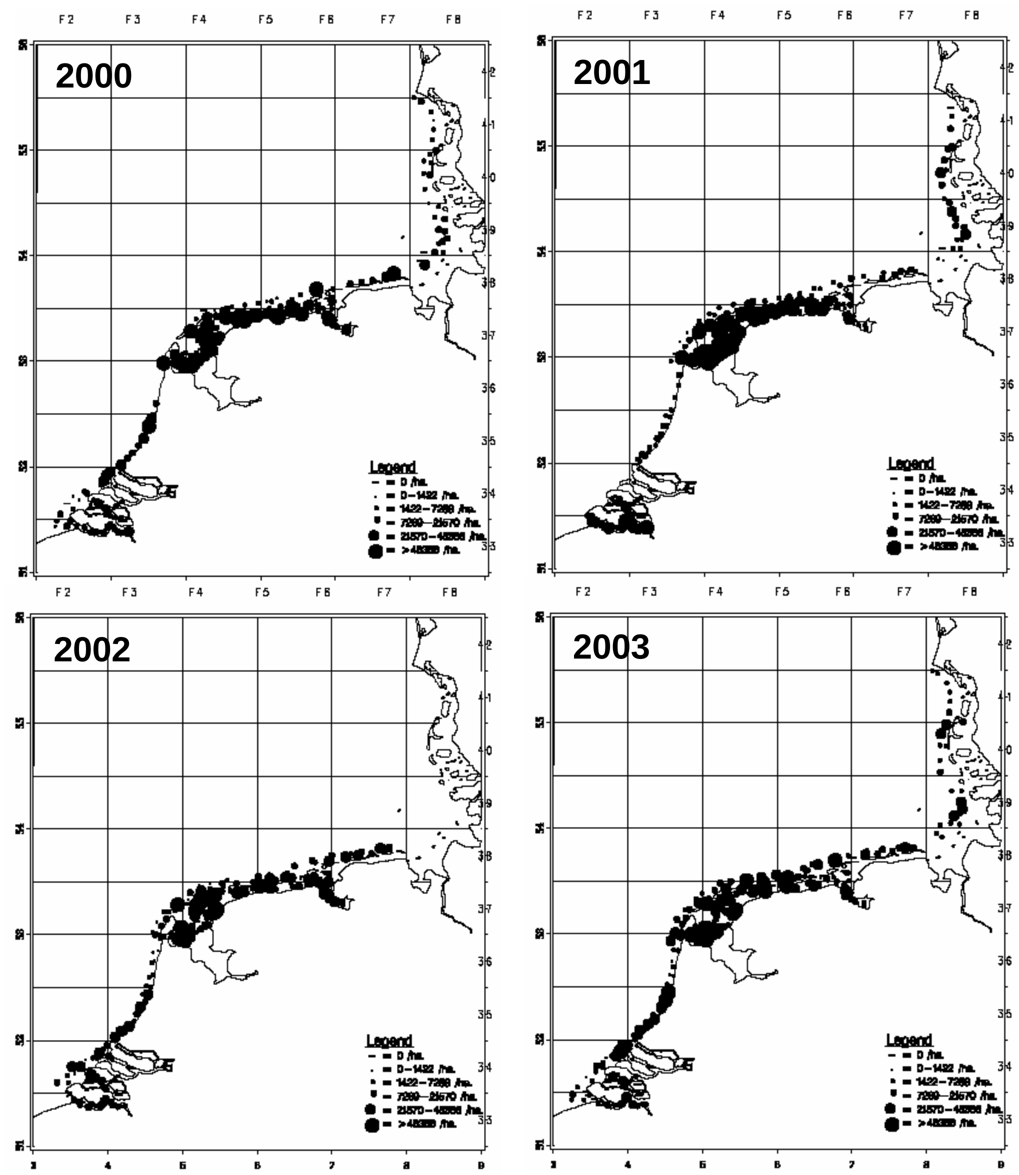

Figure 55: Distribution of brown shrimps (all sizes) in the years 2000–2003.

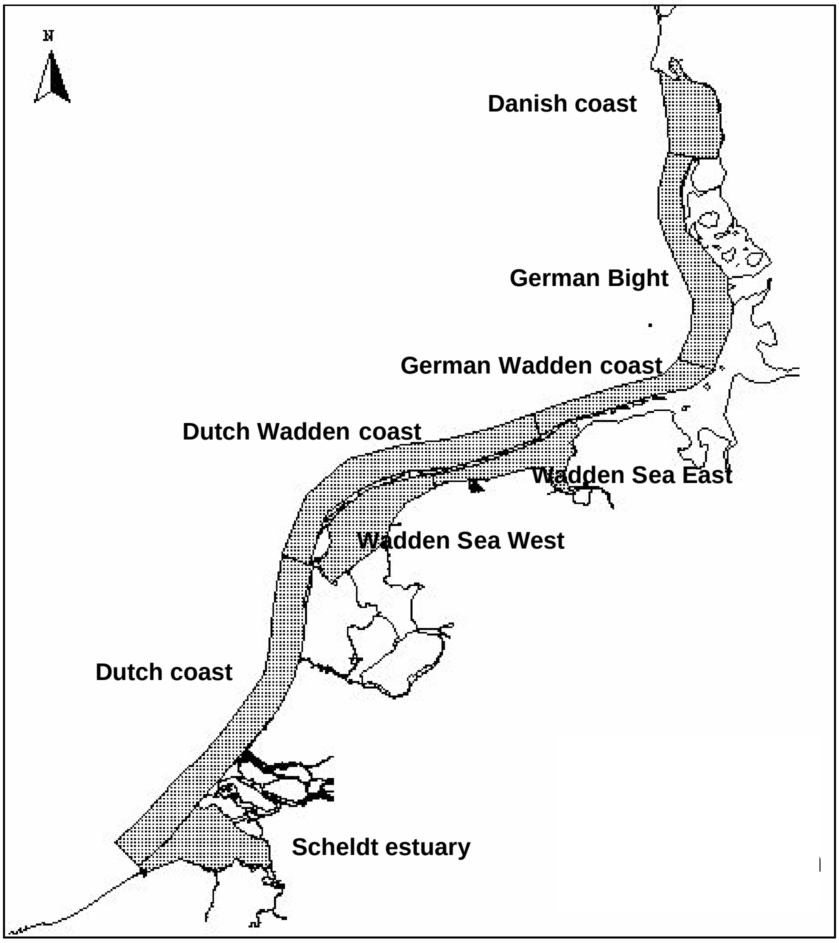

Figure 56: Map showing the eight different subareas.

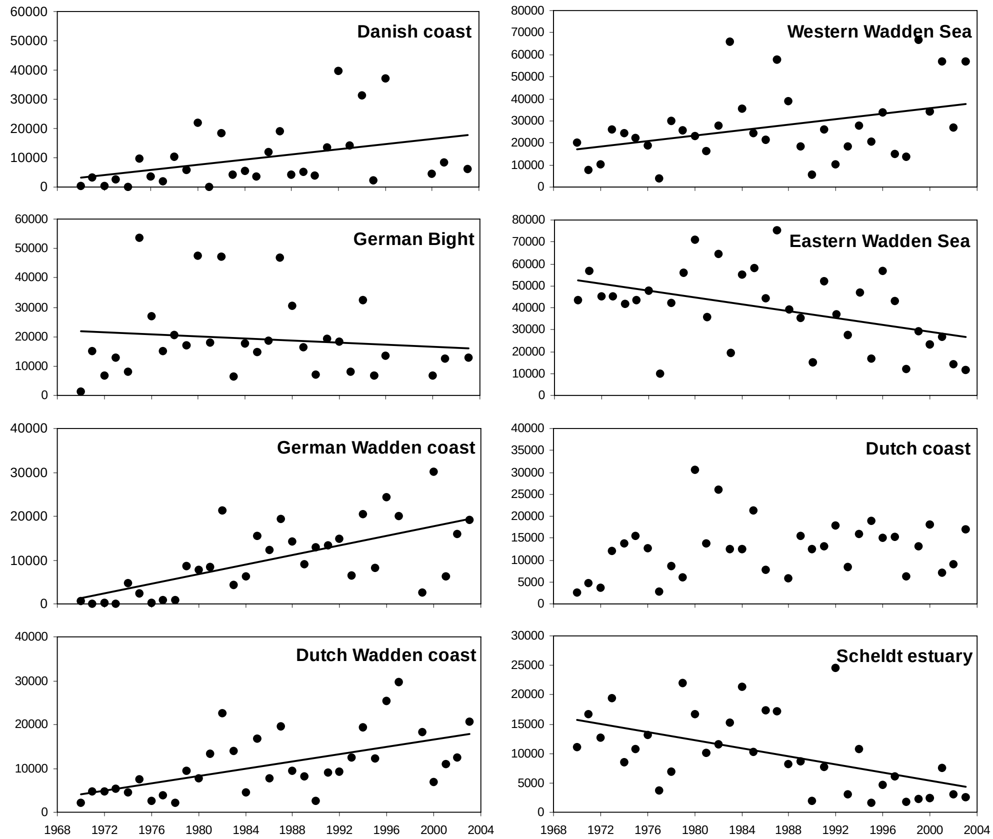

Figure 57: Indices (n/ha) in the eight different subareas for all sizes.

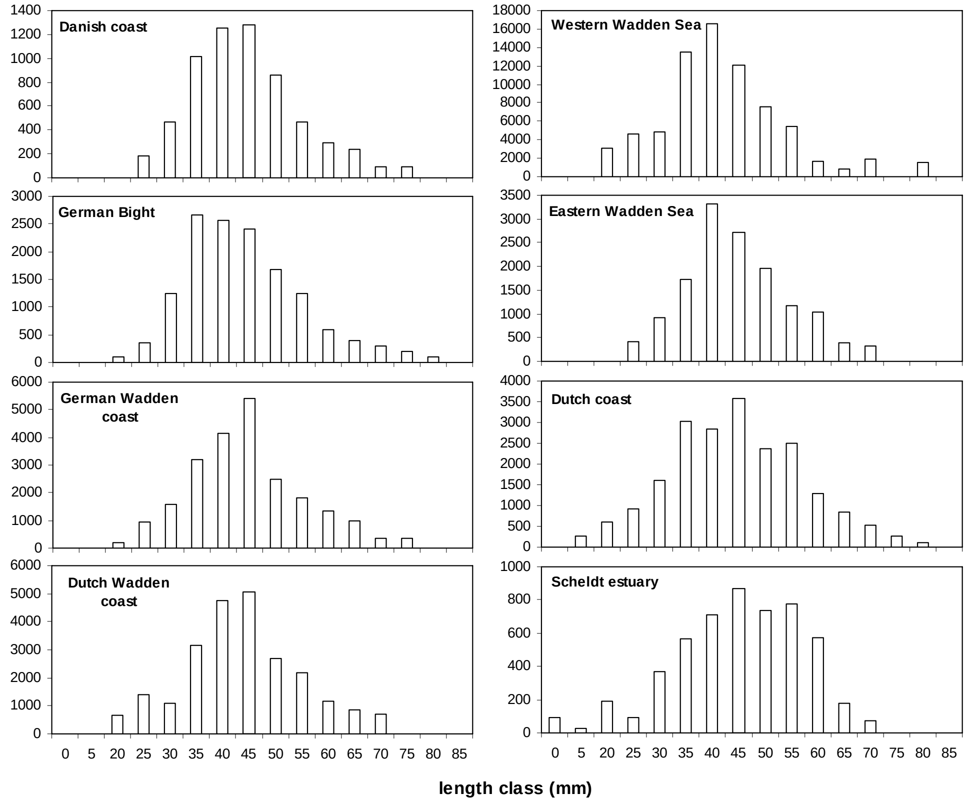

Figure 58: LF distributions of brown shrimp in the different subareas in 2003.

3.2 Seasonal and interannual variability in density from German DYFS

In the coastal zone of the German Bight the estimated median density of *C. crangon* is generally lower in spring than in autumn. The long-term mean density in autumn is approximately 1400 shrimp 1000 m^{-2} and thus four times greater than the spring mean which reaches no more than 350 shrimp 1000 m^{-2}. Over the years, densities of shrimp in spring varied by a factor 50. Although the actual density values in autumn are much higher than in spring, the relative amplitude of the variability is much lower in autumn with a maximum factor of 25 between the years with the lowest and highest densities.

For the overall study area the highest autumn densities of shrimp were observed during the early phase of the time series in 1975, 1980, and 1986. Exceptionally poor autumn seasons were identified in 1977, 1990, 1995, 1998, and 2001, with the majority of poor records in the more recent history of the time series. Seasonal shrimp densities were calculated separately for the subareas of East Frisia, the Elbe estuary, and North Frisia. Similar to the average density of the entire region, subarea densities being lowest in the Elbe estuary, followed by North Frisia and highest densities in East Frisia.

Interannual variability was rather high in all areas, but highest variability occurred in Eastern Frisia where density was also highest. There was no obvious trend in stock density in East Frisia, whereas the Elbe estuary showed a slight increase over the years since about 1987. On the contrary, North Frisia stock densities appear to decline constantly since 1987.

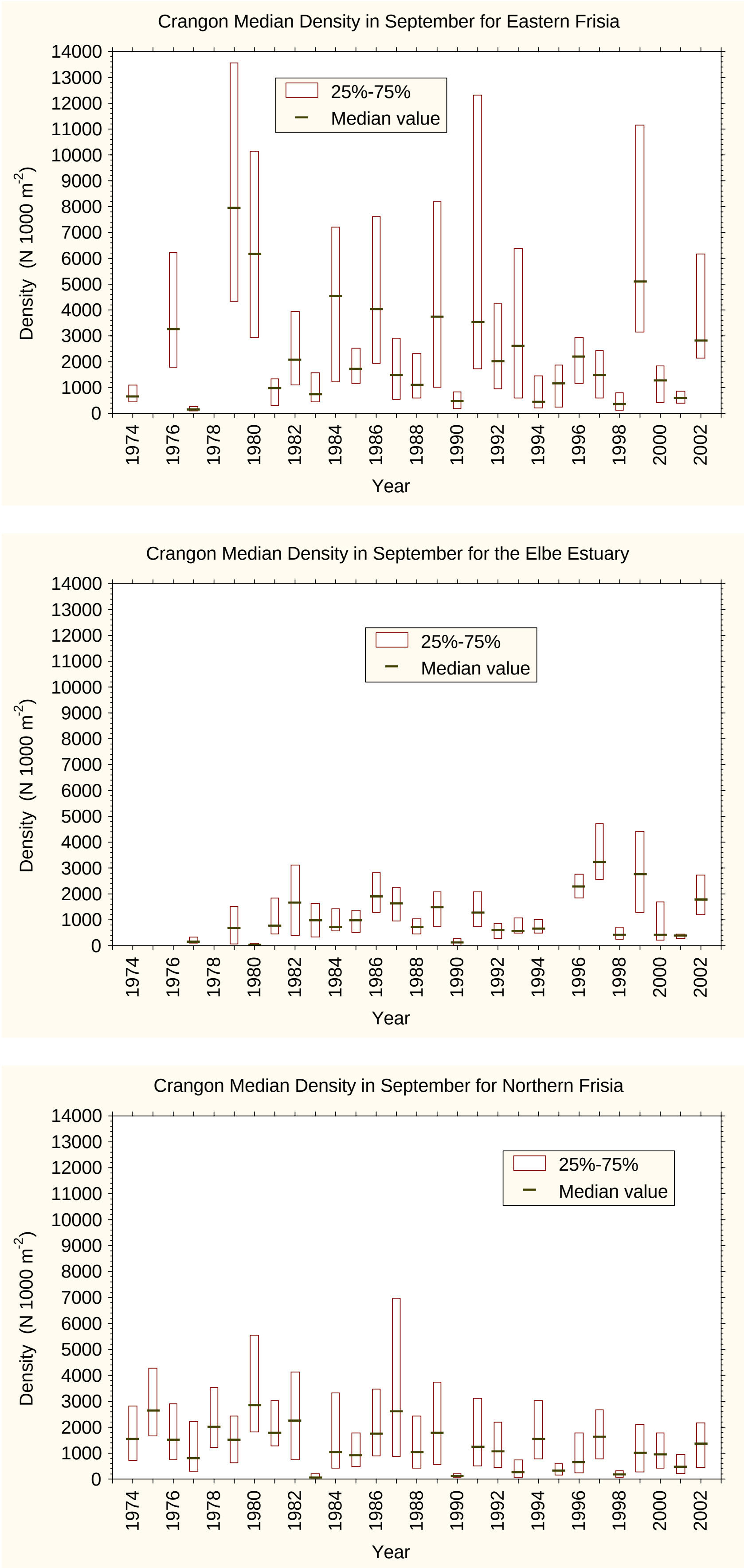

Figure 59: September *Crangon* median densities for Eastern Frisia, Elbe Estuary and Northern Frisia.

4 Factors influencing the annual variation of shrimp abundance

Fisheries and environmental data were investigated to determine the role of the climate, anthropogenic and biological factors on the success of a brown shrimp (*Crangon crangon)* fishery. Univariate and multiple regression techniques were used to determine which factors influence the productivity of The Wash shrimp fishery in the North Sea (East Coast of England). Two models were found that adequately describe the variance in two time series of catch rate (landings per unit effort or LPUE) data from 1987 to 2002.

The first model suggests that nutrient levels and water temperature are important factors in determining shrimp productivity for the fishing seasons 1987 to 2000. Because nutrient levels are correlated to fluvial flows from the main rivers and these flows are in turn related to rainfall this model was called the “climate model”. The second model infers that over the longer period from 1987 to 2002 whiting abundance regulates shrimp populations and was called the “mortality model”.

The amount of fishing effort in a previous time period is a factor common to both models and suggests that fishing mortality is also important.

It is likely that the success of the shrimp fishery in The Wash from 1987 has been dependent on a combination of nutrient input, prevailing water temperatures, fishing mortality and whiting abundance. To disentangle the exact contribution of each factor would be extremely difficult given the degree of correlation that exists between the index of whiting abundance and some of the other factors in the first model.

The fitted “climate model” for fishing seasons 1987 to 2000 was:

$$LogLPUE = -3.67\,(NO_x) - 2.61\,(T^0C) - 0.00007\,(EFFORT) + 0.34\,(NO_x * T^0C) + 32.45$$

Where NO_x is a mean concentration of oxidised nitrogen, T^0C is the mean annual water temperature and EFFORT is the hours fished by the fleet in the main season of the previous year.

The model explained 83% of the variance in logLPUE. The predicted LPUE based on this model is plotted against actual LPUE in.

The “Mortality Model” for data between the 1987 and 2002 fishing seasons (including 2001 and 2002):

$$LogLPUE = -0.00005\,(EFFORT) - 0.05\,(WHITING) + 4.43$$

Where *WHITING* is an annual index of whiting abundance in The Wash area. This model explains over 62% of the variance in shrimp catch rates. Predicted LPUE using this model are shown in Figure 65.

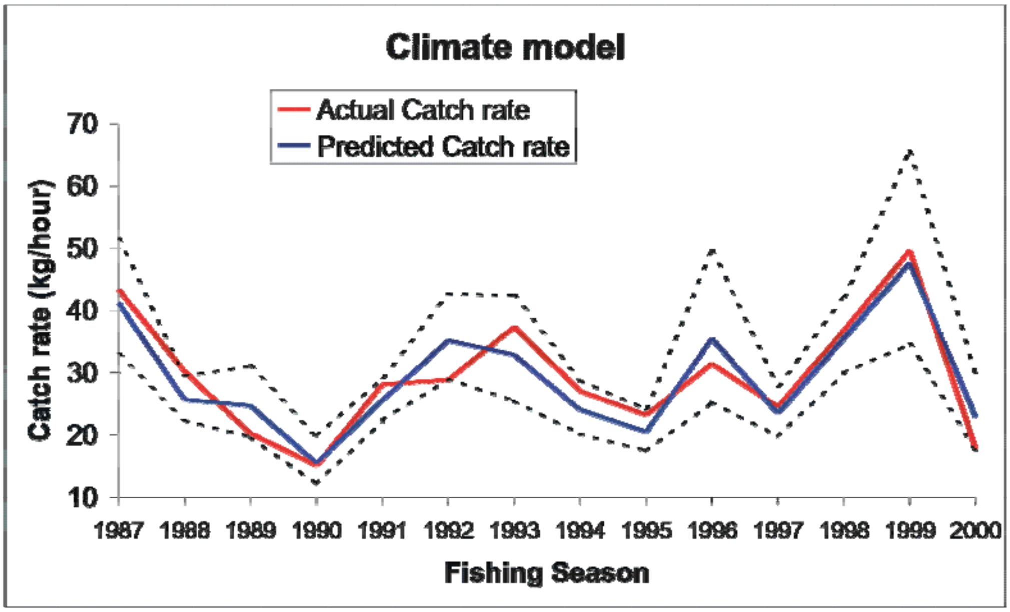

Figure 60: Predicted LPUE from climate model against observed LPUE for fishing seasons 1987 to 2000. 95% confidence limit of prediction is shown.

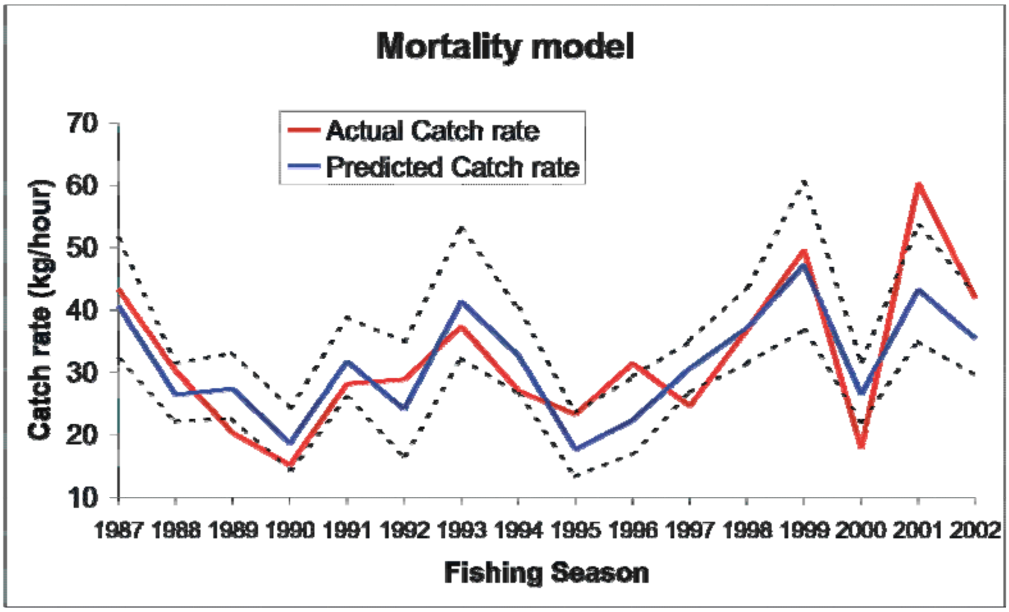

Figure 61: Predicted LPUE from mortality model against observed LPUE for fishing seasons 1987 to 2002. 95% confidence limit of prediction is shown.

The interaction term between oxidised nitrogen and water temperature in the climate model suggests alternative effects of NO_x on predicted LPUE at different water temperatures. The effect is positive at warmer water temperatures but negative at cooler water temperatures.

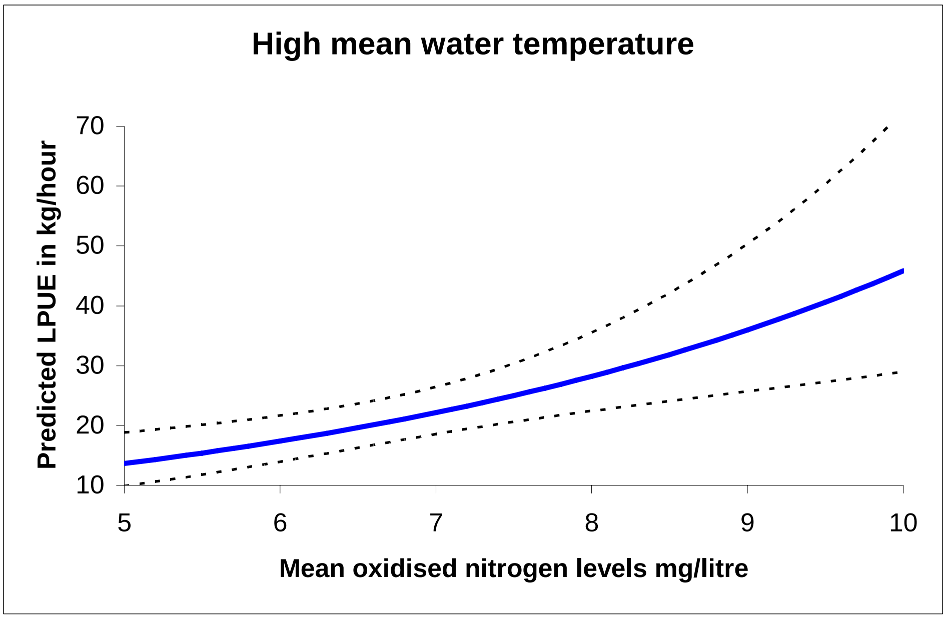

Figure 62: Relationship with predicted LPUE and oxidised nitrogen levels at a high mean water temperature of 11.50 C.

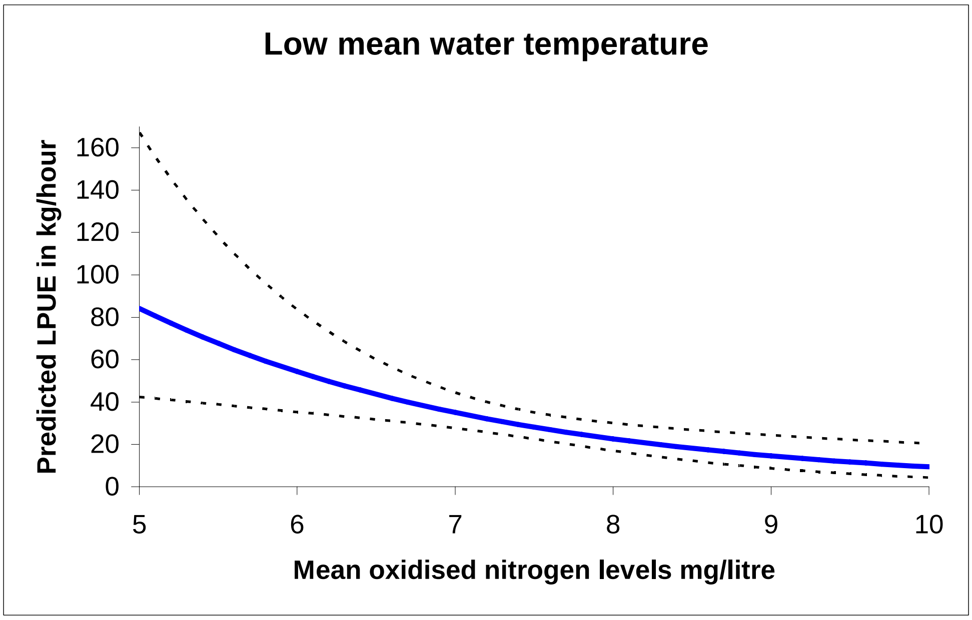

Figure 63: Relationship with predicted LPUE and oxidised nitrogen levels at a low mean water temperature of 9.50 C

The potential of both models for predicting LPUE for the last two fishing seasons based on models fitted to a truncated data series was tested.

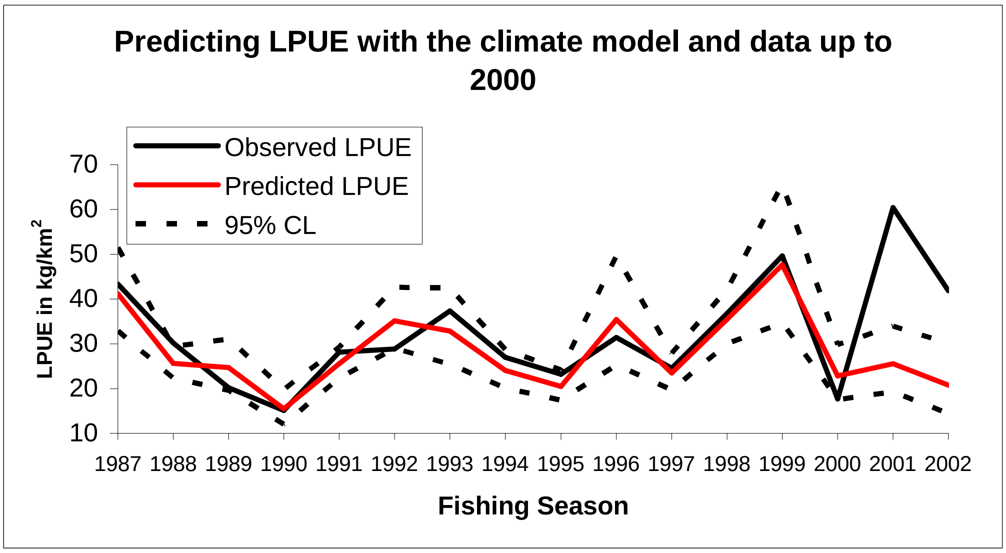

Figure 64: Predicting LPUE for last two fishing seasons using the climate model with data up to the 2000 fishing season.

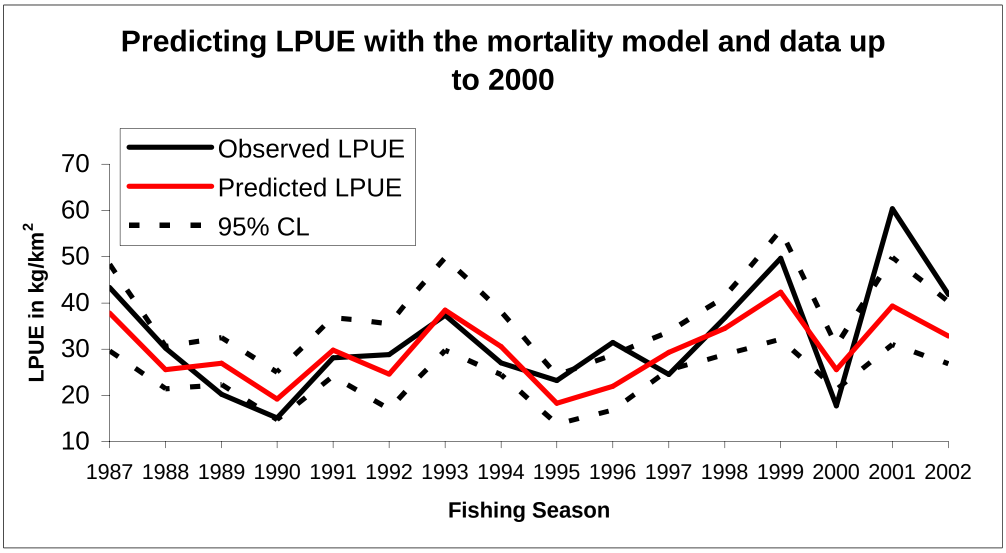

Figure 65: Predicting LPUE for last two fishing seasons using the mortality model with data up to the 2000 fishing season.

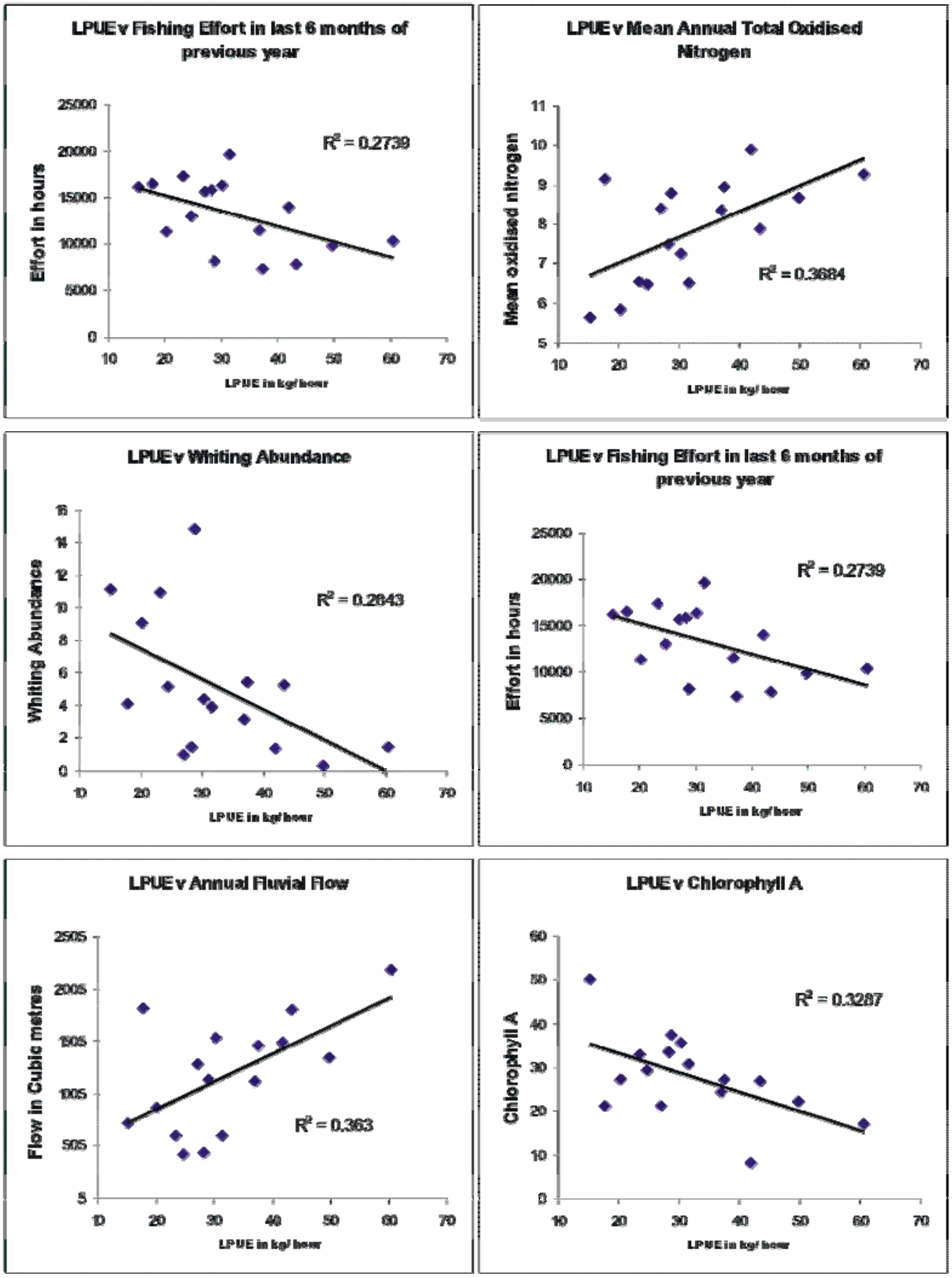

Figure 66: Relationship between Shrimp LPUE and mean annual water temperature, oxidised nitrogen, whiting abundance, fishing effort, fluvial flows and chlorophyll A. Oxidised nitrogen, chlorophyll and fluvial flow data copyright Environment Agency.

4.1 Preliminary modelling of trends in LPUE in The Wash *Crangon* fishery by incorporating environmental anomaly signals in linear and biomass dynamics models

Relationships between environmental factors and brown shrimp abundance indices have been indicated by a number of workers and abundance of key predator species has also been correlated with *Crangon* biomass, but there have been few studies suggesting relationships between successive generations of brown shrimps. An ad hoc modelling approach was used to carry out investigations into the effects of some environmental factors in linear models and simple models of the biomass dynamics. Fitting problems due to covariance between parameters were encountered with classical biomass dynamics models so a simpler Ricker stock recruitment relationship was used to model *Crangon* biomass dynamics as an alternative to a linear model. Justification for Ricker model was that the vast majority of the landings in a fishing season are the progeny of adult shrimps available to the fishery in the previous season; few adults survive into a second fishing season. The Ricker model is over compensatory which may be applicable if cannibalism occurs in *Crangon* as has sometimes been suggested. Environmental effects were included as anomalies from the mean. Initial experiments used an additive model and a Ricker model, both incorporating linear environmental effects that were exponential terms in the Ricker model. Significance of the fit was compared using and general form of an F test within model family, but the models could not be compared between families. A second set of experiments were carried out using a more structured approach that enable comparison of a Ricker model against the mean level. Akaike's information criterion corrected for small sample size (Burnham and Anderson, 2002) was used for comparison of models in addition to an F test.

Three models were used in total:

$$1) \qquad LPUE_t = \alpha + \gamma T_t + \delta ON_t + \varphi W_t + \varepsilon$$

$$2) \qquad LPUE_t = \alpha LPUE_{t-1} e^{-\beta LPUE_{t-1}} e^{\gamma T_t} e^{\delta ON_t} e^{\varphi W_t} + \varepsilon$$

$$3) \qquad LPUE_t = \alpha e^{-\beta LPUE_{t-1}} e^{\gamma T_t} e^{\delta ON_t} e^{\varphi W_t} + \varepsilon$$

where T was average near seabed temperature, ON was an index of oxidised nitrogen, W an index of whiting abundance, α, β, γ, δ, φ were coefficients and the errors (ε) were considered log normal. The Ricker model (2) was used with the observed LPUE series, offset by 1 year as both dependent and explanatory variables for the initial experiments, but subsequently an extra parameter LPUE at time t=1 was introduced and dynamics modelled forward as a single process through the whole time series and the fitted values were the explanatory variable. The former was considered statistically unsatisfactory as the variables were not independent and were considered as exact in one instance and with error in another. However, introducing an extra variable and fitting the model as a single process introduced problems in the minimisation of local solutions and parameter covariance were noted, but using multiple restarts appeared to result in unique global solutions.

Retrospective analyses were carried out for the initial experiments but not for the second set by successively removing the final year's data from the minimisation for the most recent six years. Such analyses can provide an indication of the stability of parameters as new data are included in the model and may indicate systematic bias, for example if the final point of the series is always revised in the same direction as each new data point is added.

Results (Table 1c to 1d) show that including oxidised nitrogen signals resulted in significant improvements to the fit when compared against the baseline model for all the models used. As single effects temperature was never significant and whiting was significant for 2 of the 4 models. When included with oxidised nitrogen both temperature and whiting were significant in all but the single process Ricker model. Using AIC the four 'best' models were the additive linear including oxidised nitrogen, the multiplicative exponential including oxidised nitrogen, the multiplicative exponential including oxidised nitrogen and whiting and the single process Ricker model without any environmental signals (Figure 67). However, the latter was largely driven by the most recent two LPUE values that were extreme low and high values. The first set Ricker models was not comparable with the other models, but produced a less extreme relationship (Figure 68). Using the observed LPUE series for both dependent and explanatory variables appeared to function quite well but was statistically unpalatable and results were not directly comparable with the more structured approach taken subsequently.

The signs of the coefficients were generally consistent throughout and in agreement with other workers, increasing temperature exerted a negative effect, increased oxidised nitrogen had positive influence and increased predator abundance, as expected, had a negative effect. Oxidised nitrogen reflected the overall level of LPUE fairly well, but did not capture recent fluctuations. Whiting abundance reflected the direction of year on year fluctuations well in recent time. The Ricker model captured the most recent wild fluctuations at the expense of fluctuations in the early part of the series. Other workers have used a negatively autocorrelated model to capture the same effect. Retrospective plots suggested that temperature fitted well with data until the mid 1990s, but its influence deceased with the addition of more recent data. The converse may apply for whiting abundance.

It may be possible to produce models based on simple dynamics and environmental effects that can explain much of the variation in shrimp annual LPUE. However relatively few data points were available and models incorporating several effects were heavily penalised in this respect. Model fits tended to be heavily influenced by extreme points in all the various explanatory data (including $LPUE_t$). It seems inevitable that extremes in the explanatory data will have high leverage in any correlation, particularly if they are distant from neighbouring points. This is slightly different to the problem warned against by Hilborn and Walters (1992), that outliers in the (S-R) relationship can be explained by one of a host of environmental factors.

Table 1a: Model parameters and goodness of fit statistics. Additive linear (F test compared against α).

MODEL PARAMETER	A	$A + \Gamma$T	$A + \Delta$ON	$A + \Phi$W	$A + \Gamma$T + ΔON	$A + \Gamma$T + EW	$A + \Delta$ON + ΦW	$A + \Gamma$T + ΔON + ΦW
A	29.56	29.83	30.31	29.95	44.39	24.61	28.56	62.51
Γ		-6.47			-3.51	-6.46		-3.18
Δ			5.45		4.75		4.07	3.39
Φ				-1.11		-1.10	-0.84	-0.78
SSQ	1.989	1.709	1.256	1.516	1.159	1.247	1.079	1.015
ResVar	0.142	0.131	0.097	0.117	0.097	1.104	0.09	0.092
R squared	0	0.14	0.37	0.24	0.42	0.37	0.43	0.49
F		2.129	7.599	4.064	4.299	3.575	4.535	3.521
Prob		0.168	0.016	0.065	0.039	0.061	0.034	0.052
AIC_c	-25.28	-24.40	-29.03	-26.20	-26.41	-25.31	-26.75	-23.73

Table 1b: Ricker model using observed LPUE for both x and y variables (F test compared against base Ricker).

MODEL PARAME-TER	AU EXP(-BU)	AU EXP(-BU) EXP(ΓT)	AU EXP(-BU) EXP(ΔON)	AU EXP(-BU) EXP(ΦW)	AU EXP(-BU) EXP(ΓT) EXP(ΔON)	AU EXP(-BU) EXP(ΓT) EXP(ΦW)	AU EXP(-BU) EXP(Δ ON) EXP(ΦW)	AU EXP(-BU) EXP(ΓT) EXP(ΔON) EXP(ΦW)
α	3.543	3.315	4.373	3.865	4.224	3.676	4.425	4.313
β	0.042	0.039	0.049	0.045	0.048	0.043	0.049	0.049
γ		-0.193			-0.069	-0.129		-0.050
δ			0.214		0.203		0.166	0.159
φ				-0.054		-0.051	-0.036	-0.036
SSQ	1.76	1.56	0.84	1.03	0.82	0.95	0.55	0.54
ResVar	0.147	0.142	0.076	0.094	0.082	0.09	0.055	0.06
R sq	0.04	0.15	0.54	0.44	0.55	0.48	0.70	0.71
F		1.408	12.125	7.76	5.80	4.31	10.94	6.78
Prob		0.260	0.005	0.021	0.021	0.045	0.003	0.011
AIC_c	-20.61	-18.25	-26.97	-24.04	-22.30	-20.21	-27.75	-21.56

Table 1c: Ricker single process (F test compared against base LPUE = αu).

MODEL PARAMETER	AU	AU EXP(-BU)	AU EXP(-BU) EXP(ΓT)	AU EXP(-BU) EXP(ΔON)	AU EXP(-BU) EXP(ΦW)	AU EXP(-BU) EXP(ΓT) EXP(ΔON)	AU EXP(-BU) EXP(ΓT) EXP(ΦW)	AU EXP(-BU) EXP(ΔON) EXP(ΦW)	AU EXP(-BU) EXP(ΓT) EXP(ΔON) EXP(ΦW)
LPUE1	24.58	28.75	28.67	29.38	28.75	29.31	28.72	29.38	28.86
α	1.023	26.552	25.235	18.558	26.539	18.068	25.835	18.558	13.738
β		0.114	0.112	0.101	0.114	0.100	0.113	0.101	0.090
γ			0.009			0.008	0.008		0.177
δ				0.202		0.189		0.202	0.265
φ					-0.00005		-0.00005	-0.000003	-0.004
SSQ	1.84	1.12	1.12	0.94	1.12	0.93	1.12	0.94	0.82
ResVar	0.142	0.093	0.101	0.085	0.102	0.093	0.112	0.094	0.091
R squared	0.07	0.44	0.44	0.53	0.44	0.53	0.44	0.53	0.59
F		7.76	7.14	5.27	3.56	3.24	2.17	3.20	2.78
Prob		0.016	0.064	0.025	0.064	0.07	0.16	0.07	0.09
AIC_c	-23.29	-26.95	-22.31	-24.89	-22.28	-19.16	-16.48	-19.06	-13.55

Table 1d: Multiplicative exponential (F test compared against α).

MODEL PARAMETER	A	A EXP(ΓT)	A EXP(ΔON)	A EXP(ΦW)	A EXP(ΓT) EXP(ΔON)	A EXP(ΓT) EXP(ΦW)	A EXP(ΔON) EXP(ΦW)	A EXP(ΓT) EXP(ΔON) EXP(ΦW)
α	29.559	29.559	29.559	29.559	29.559	29.559	29.559	29.559
γ		-0.217			-0.140	-0.175		-0.128
δ			0.178		0.159		0.138	0.122
φ				-0.046		-0.042	-0.030	-0.029
SSQ	1.99	1.71	1.31	1.46	1.20	1.28	1.11	1.02
ResVar	0.153	0.131	0.101	0.112	0.100	0.107	0.093	0.093
R squared	0.00	0.14	0.34	0.27	0.40	0.36	0.44	0.49
F		2.13	6.76	4.74	3.94	3.32	4.73	2.61
Prob		0.17	0.02	0.05	0.05	0.07	0.03	0.10
AIC_c	-25.30	-24.40	-28.40	-26.78	-25.88	-24.91	-27.03	-23.64

u: LPUE, T: temperature, On: oxidised nitrogen, W: whiting abundance

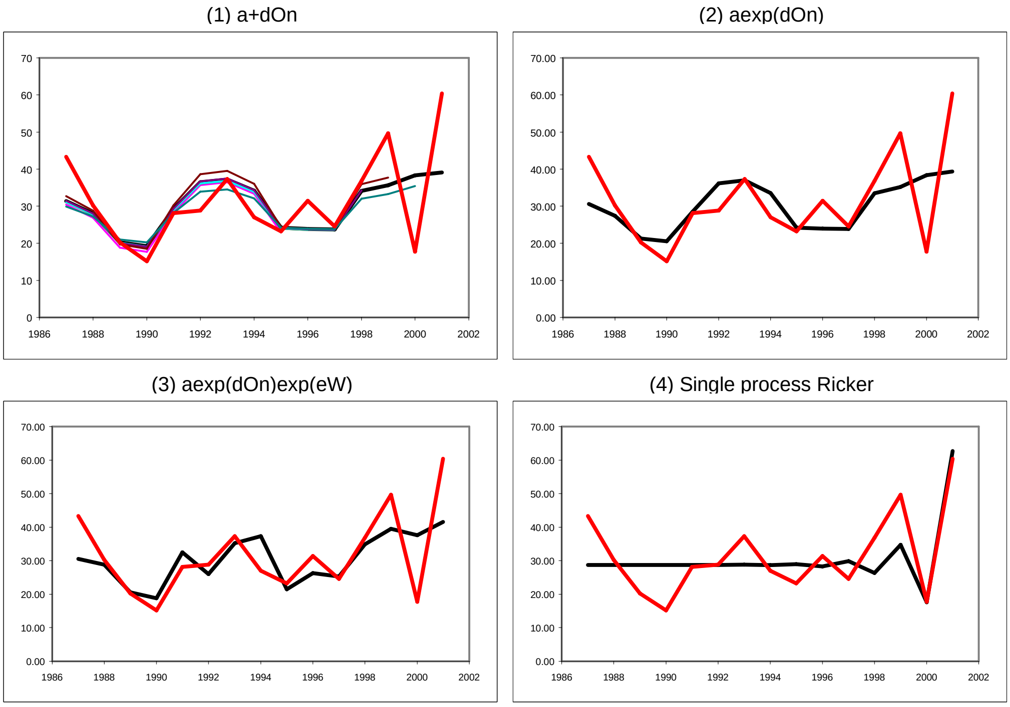

Figure 67: Time series for the four best fitting models.

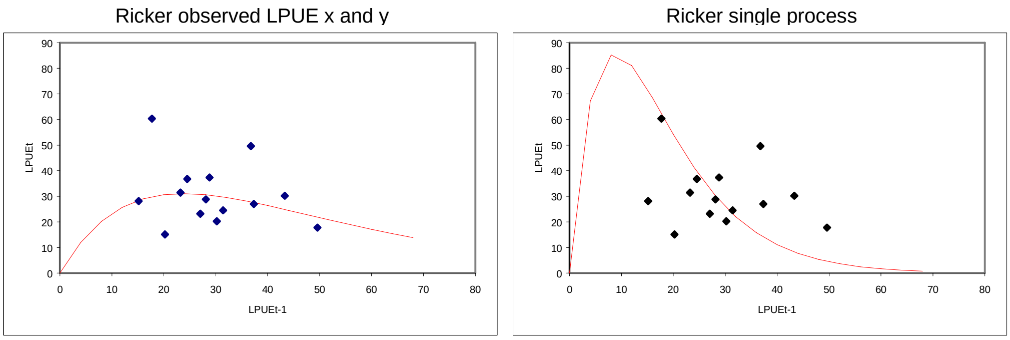

Figure 68: Ricker models, fitted to offset observed LPUE only and single process model.

References:

Burnham, K.P., and Anderson, D.R. 2002. Model selection and inference: a practical information theoretic approach. Springer-Verlag, New York. 488pp.

Hilborn, R., and Walters, C.J. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. (Chapman and Hall: New York.) 570pp.

4.2 Statistical analysis of factors influencing *Crangon* densities in the German Bight

Results of a time series analysis of 30 years of German data from the annual Demersal Young Fish Surveys in the German Bight were presented. *Crangon crangon* densities in the German Wadden Sea show a considerable degree of interannual variability, for the entire region in spring and in autumn as well as for three subareas, North Frisia, East Frisia and Elbe estuary.

Due to the variability in stock density, relationships were tested between shrimp density and environmental as well as biological variables which might explain most of the variance in the data set. Following the discussion in the published literature on potentially effective variables it was decided to include the following time series in the time series analysis:

a) monthly mean water temperature for September to April;
b) winter severity index;
c) mean monthly Elbe River runoff;
d) NAO winter index;
e) 0-group cod, whiting and the aggregated gadoid predator density index for autumn;
f) annual commercial landings for Germany, Germany plus Netherlands, and the landings of the second half-year.

On a large spatial scale, shrimp abundance in autumn was correlated with year-to-year changes in physical environmental and biological parameters, an inverse relationship with winter water temperature, a positive correlation with autumn river runoff, and an inverse relationship with the winter NAO index. Negative NAO values of the index indicate weaker-than-average transport rates and a cooling of Western Europe. This means that a strong negative NAO event of one winter is followed by strong *C. crangon* recruitment.

On a regional scale (North Frisia), density of Gadoid predators was an additional component affecting shrimp stock abundance. High numbers of gadoids in autumn reduce the shrimp stock significantly during the same time period.

No correlations to such parameters could be detected for the *C. crangon* stock in spring. Possible causes for the spring situation were discussed, such as the timing of spring immigration of *Crangon* into the Wadden Sea depending on the water temperature of the preceding months. This causes doubts on the representation of shrimp densities derived from spring surveys. Furthermore, the analysis showed, that the driving forces could be less clearly described for the East Frisia area, which after evaluating possible reasons was attributed to the localized distribution of sampling effort.

5 Life cycle

5.1 Growth

5.1.1 Application of standard methods to field data on length frequencies

A comprehensive dataset of monthly length distributions of female shrimps taken from monitoring surveys in The Wash fishery was analysed using standard techniques. The FiSAT stock assessment tools from FAO-ICLARM was used to carry out electronic length frequency analysis to determine von Bertalanffy growth parameters. The method of Battacharya was also used to separate cohorts from the length distributions. The seasonal von Bertalanffy model and daily increment models were fitted to a sequence of mean sizes of these cohorts using MS Excel solver.

Parameter estimates were variable between different time periods and the various methods of fitting suggesting problems with a lack of robustness in the techniques when applied to these data. Estimates of $\boldsymbol{L_\infty}$ were also lower than would be expected based on other work and predictions based on Wetherall plots using these data. Along with some evidence of negative growth over the spring and winter period this was taken as inferring downward bias in mean size of cohorts due to sequential recruitment or emigration of larger animals from the fishery. It may not be possible to accurately determine growth parameters from length distributions of shrimps. To aid comparative studies it is imperative that workers define explicitly what size parameter they are measuring.

5.1.2 Evaluation of the performance of simple graphical methods and modal progression techniques for estimating von Bertalanffy growth parameters using simulated shrimp length frequency data

Length frequency data were simulated using the UK implementation of the *Crangon* YPR model and incorporated daily spawning events, temperature dependent development and growth rates. Data were generated for three known sets of growth parameters and with three methods of uncertainty generation; deterministic, post hoc stochastic and model generated stochastic.

The simulated length frequency data were analysed using simple graphical methods (Ford, 1933; Walford, 1946; Gulland and Holt, 1959; Wetherall, *et al.*, 1987; Sparre, *et al.*, 1989) and modal progression techniques (Pauly and Gaschütz, 1979; Pauly and David, 1981; Pauly, 1986; Pauly and Morgan, 1987; Sparre, *et al.*, 1989; Gayanilo, *et al.*, 1996).

Deterministic simulations demonstrated that in spite of sequential spawning, temperature dependent development and growth tend to synchronise recruitment, resulting in one major recruitment pulse that can subsequently be followed through time. With deterministic data, graphical and modal progression techniques were sometimes able to track well the subsequent growth of this 'cohort' and provide good estimates of the 'true' growth rates.

However, in stochastic length distributions modes were less well discriminated, generally fewer data points (discernable modes) were available and growth parameters were often poorly estimated. Parameter confounding was common and parameter estimates were frequently erroneous, but it was difficult to identify any systematic patterns of mis-estimation. Performance was particularly poor for data at large sizes and around the size of selection.

Estimates of the seasonality effects, both amplitude and timing were reasonably well estimated by all methods, unless the overall model fit was very poor. ELEFAN produced relative errors in estimation of L_∞ of less than 10% with deterministic data, 10–20% underestimates with *post hoc* stochastic data and up to 15% with model generated stochastic data. Errors in K were considerably higher in most but not all cases. The automatic fitting function used in ELEFAN often produced higher convergence criterion (***Rn***) scores for fitted solutions than for the 'true' parameters and in general ***Rn*** values were low. Identifying modes using the Bhattacharya method was rather subjective and there was a tendency to introduce (too) many modes at larger sizes. Fitting growth curves to mean sizes estimated using the Bhattacharya method performed poorly, only achieving a relative error of less than 10% in L_∞ on one occasion with deterministic data. As with the other methods K was very poorly estimated. Removing peripheral data points from the minimisation generally resulted in improved estimates but introduced further subjectivity.

Graphical methods also suffered from subjectivity in deciding the number of points to be included in regressions and seasonal oscillations also caused problems for these methods. The modified Wetherall method produced biased (upwards) estimates of L_∞ with stochastic data. The stochastic data contained significant numbers of animals greater than L_∞.

The simulations demonstrated that in order to obtain reliable estimates of growth parameters very high quality length frequency data with distinct modes were required. In our simulations a relatively low CV (0.1) was used and the catch was sampled perfectly, whereas in reality additional uncertainty would be introduced by the sampling process.

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Wetherall, J. A., Polovina, J. J., and Ralston, S. 1987. Estimating growth and mortality in steady-state fish stocks from length frequency data. ICLARM Conf. Proc., 13:53–74.

5.2 Application of Y/R simulation model to the UK fishery

Evaluating potential management options for *Crangon* using a yield per recruit model: altering the seasonal pattern of fishing mortality

The *Crangon* fishery in The Wash (UK) provides an important source of income to the area as well as local employment. Some vessels operate year round, but the main fishery starts in late summer and peaks in the autumn. During the early part of this period much of the catch consists of small 'brood' shrimps that have a relatively low value. It has been suggested that reducing exploitation on these juveniles, which grow rapidly, might result in higher yields later in the season.

A deterministic version of the YPR model implemented at CEFAS with minor modifications reflecting the UK *Crangon* fishery was used to investigate the potential effects of a limited set of changes in fishing pattern.

The baseline model was run with the monthly pattern of fishing mortality proportional to the pattern of UK fishing effort. The monthly distribution of fishing mortality was then altered to evaluate the effects on yields and egg production of reducing fishing mortality on the "brood" shrimp just entering the fishery and increasing effort later in the year. Details of the alternative fishing mortality patterns are provided in Table 2, but in summary they were:

1) 'Baseline' - fishing mortality proportional to pattern of fishing effort in The Wash
2) 'OctNov' - fishing mortality reduced in August and September and increased in October and November
3) 'Winter' - fishing mortality reduced in August and September and increased in December and January

4) 'No Summ' - zero fishing mortality in June, July and August and increased fishing mortality in the period December to March inclusive.

Table 2: Seasonal patterns of fishing mortality applied (Ratio annual M:F = 2:1).

MONTH	'BASELINE'	'OCT NOV'	'WINTER'	'NO SUMM'
Jan	0.10	0.10	0.16	0.23
Feb	0.10	0.10	0.10	0.23
Mar	0.13	0.13	0.13	0.23
Apr	0.15	0.15	0.15	0.15
May	0.15	0.15	0.15	0.15
Jun	0.13	0.13	0.13	0.00
Jul	0.11	0.11	0.11	0.00
Aug	0.17	0.11	0.11	0.00
Sep	0.21	0.15	0.15	0.21
Oct	0.25	0.30	0.25	0.25
Nov	0.23	0.30	0.23	0.23
Dec	0.17	0.17	0.23	0.23
Total	1.91	1.91	1.91	1.91

The experiments were run over a range of four growth rates to assess the robustness of any conclusions to assumptions regarding growth. The "slow" growth rate (L_∞=91.2mm, K=0.91 @ 10.7^{o}C) did not produce the peak of recruitment at 45–50mm total length normally seen in the fishery around August to October, but recruitment at this size did not occur until December to March. Nevertheless it was retained for comparison with other results. The other growth rates used were "medium" (L_∞=96.8mm, K=1.24 @ 10.7^{o}C) and "fast" (L_∞=94.3mm, K=1.58 @ 10.7^{o}C) rates and one equating to a lower L_∞, but high K (L_∞=80mm, K=1.5 @ 10.7^{o}C), "80, 1.5".

In common with simulations carried out at the Working Group meeting in 2002 experiments were carried out under two assumptions regarding the ratio of annual natural mortality: fishing mortality; 2:1 and 1:1. Total mortality was fixed at 5.7, estimated from catch curves. In common with the working group model, selection was assumed to be knife edged and alternative options for the size of selection (45mm and 50mm total length) were included. The model is initiated by daily egg production which followed a double peaked input of eggs generated using a sine wave and similar to the German pattern as well as an alternative a uni-modal pattern estimated from UK data using the methodology of Temming and Damm (2002).

Summary metrics presented were the sum of daily yield and egg production over an annual period (averaged over the final 2 years of the simulations). Results (Figures 69 and 70) are presented relative to the baseline seasonal pattern of F for each scenario.

Changing the pattern of fishing mortality had little benefit in terms of yield (maximum gain 4%) and was generally detrimental if the F was displaced later than October and November, resulting in significant losses if F was displaced to the late winter. Spawning potential was generally impaired by the changes to fishing season and again the scenario with the displacement of F to late winter gave the greatest losses. There were occasional exceptions to this for the slow growth rate particularly at the higher size of selection. Relative results were generally robust to changing the ratio of annual M:F from 2 to 1, a reduction in the size of selection from 50mm to 45mm and changing the pattern of eggs input to the model form bimodal to unimodal.

Whilst we have explored the robustness of the model to some alternative growth rates, the ratio of annual M:F, we have not yet analysed effects due to seasonal patterns and levels of natural mortality at the life stages implemented. It is certain that the seasonal pattern of M will affect the outcome of alternative seasonal effort scenarios; further efforts to elaborate this will be needed. The present seasonal fishing regime follows a similar pattern to that assumed for natural mortality, peaking in the early autumn. It may be that the fishing fleet has evolved to take advantage of shrimp production in the same way as predators and that this is close to optimal for the fishery.

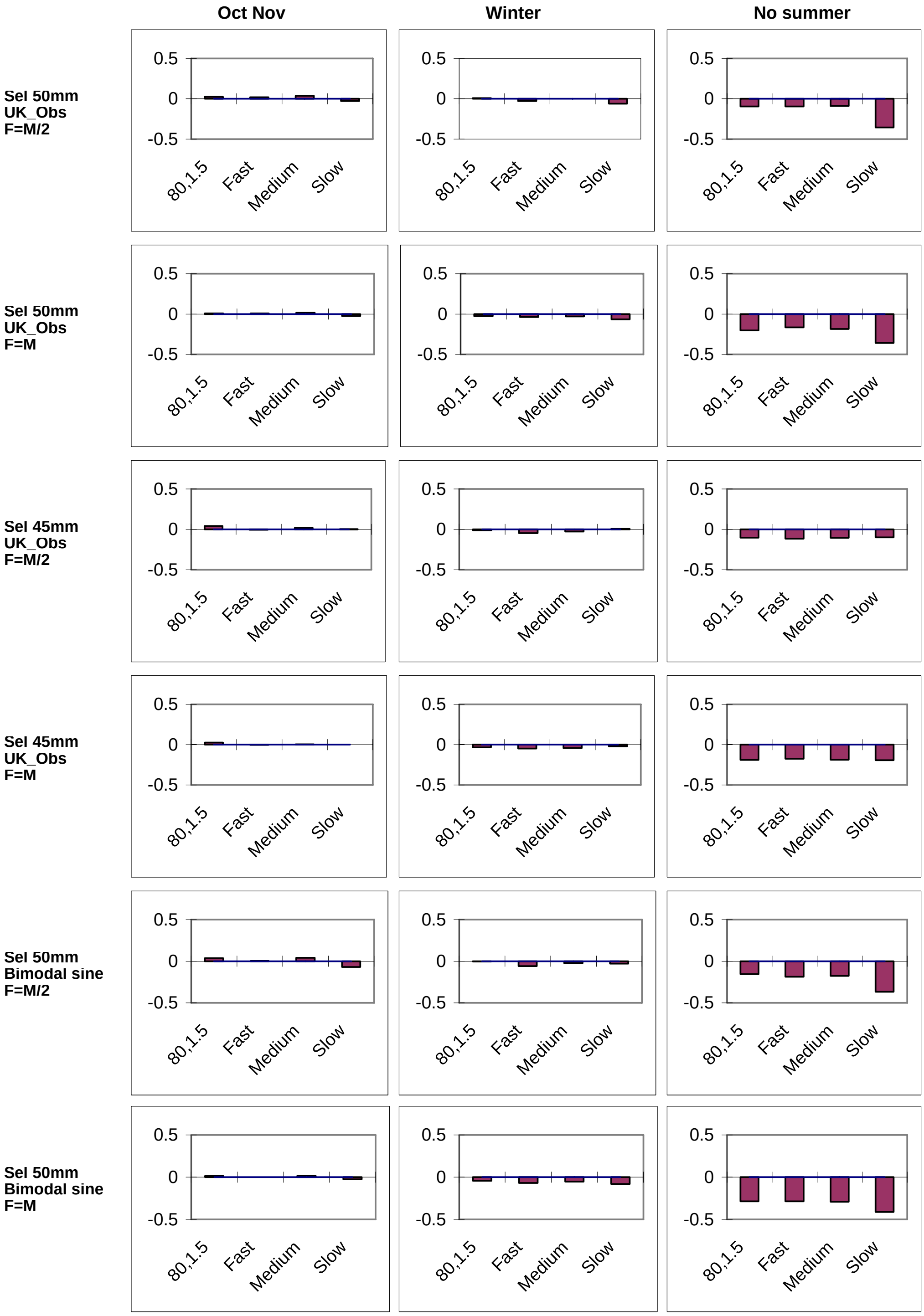

Figure 69: Effects of changing the seasonal pattern of fishing mortality. Change in yield relative to the base case for each growth rate, selection, annual M:F ratio and egg input scenario.

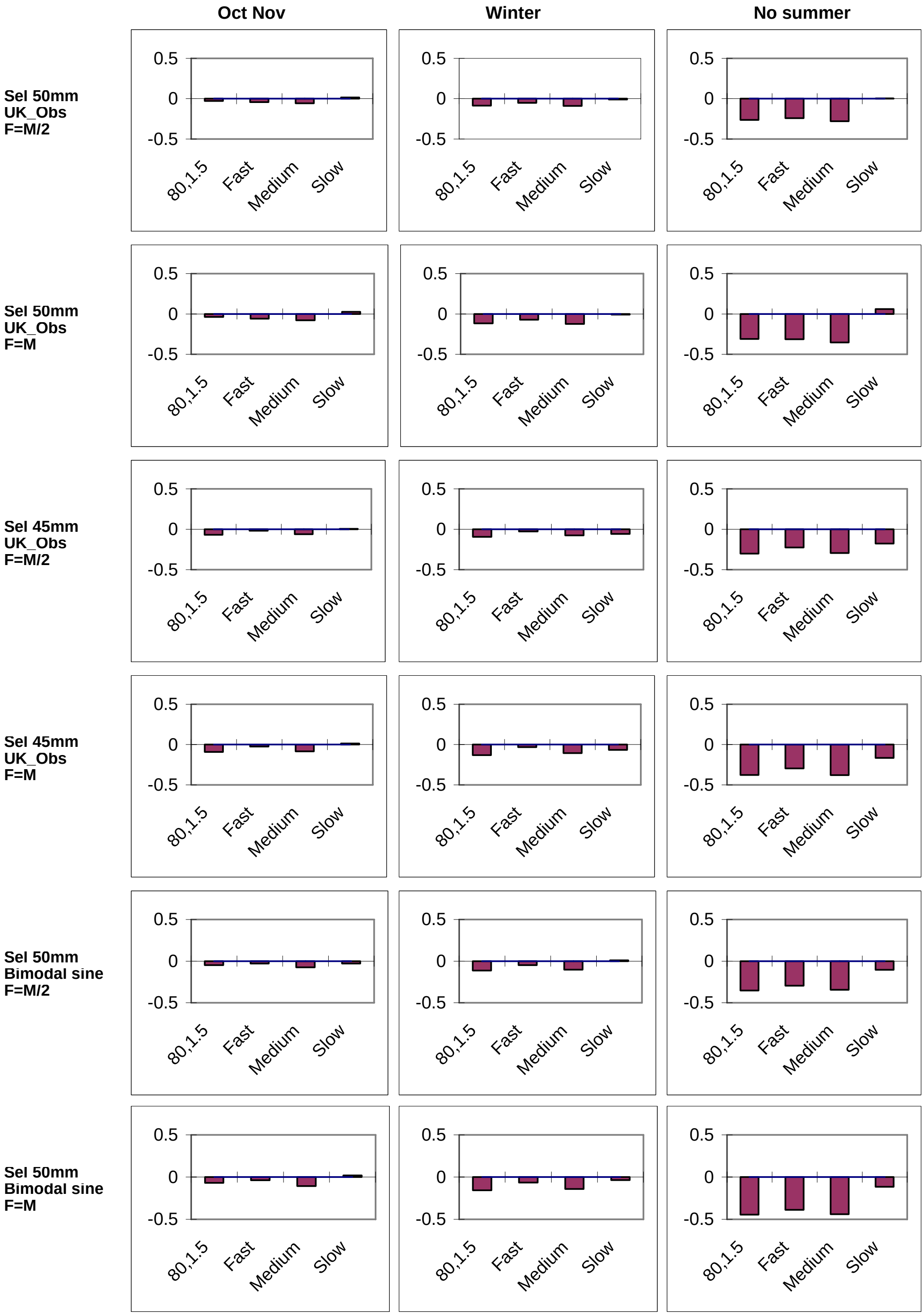

Figure 70: Effects of changing the seasonal pattern of fishing mortality. Change in egg production relative to the base case for each growth rate, selection, annual M:F ratio and egg input scenario.

This study provides a preliminary comparative investigation of the effects of potential changes in fishing activity on shrimp yields and spawning stock. Management performance was evaluated in terms of total yield in weight and egg production relative to a base case. It would be interesting to incorporate economic factors into the yield evaluations, particularly as the value of shrimps increases with their size. Carrying out similar analyses, but taking account of the size distribution of the landings to estimate their value might provide rather different results.

The requirements of the major shrimp processor also heavily influence the market demand and prices for shrimps and it would therefore also be pertinent to attempt to take account of regular seasonal fluctuations in shrimp value. The modelling exercise also highlighted the need to obtain better information regarding growth, size and seasonally dependent levels of natural mortality and the relative importance of fishing and natural mortality.

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5.3 Further development the Y/R simulation model

5.3.1 Growth submodel

Growth of the brown shrimp (*Crangon crangon*) in The Wash, North Sea

Distributions of female shrimps taken during monthly surveys were analysed to investigate the growth dynamics of brown shrimps in The Wash. Results using three alternative techniques were presented and comparisons made with other relevant studies. The seasonal von Bertalanffy growth model was fitted using both Electronic length frequency analysis and MS Excel Solver to fit to a sequence of cohort mean sizes. These cohorts were separated from the length distributions using the method of Battacharya. Daily increment models were also fitted to these size sequences. Results from the ELEFAN analysis showed that values for the von Bertalanffy parameter $\boldsymbol{L_\infty}$ varied from 62 to 69 mm TL whilst $\boldsymbol{K}$ ranged from 1.1 to 2.0 yr^{-1}, dependent on fishing season and the length of the time series. Models fitted by MS Excel Solver gave estimates of $\boldsymbol{L_\infty}$ ranging from 70 – 77 mm TL and estimates of $\boldsymbol{K}$ from 0.8 to 1.6yr^{-1}. Values of the amplitude of the seasonal effect $\boldsymbol{C}$ and the winter point $\boldsymbol{WP}$ were typically 1 and 0.1 suggesting no growth during the winter. Our estimates of $\boldsymbol{L_\infty}$ were typically much lower than those from previous authors working in the North Sea. Daily increment models fitted to these data predicted growth within the range of other authors. We conclude that although our data are spatially comprehensive and our models fitted our data well, sequential recruitment is likely to have biased downwards the mean sizes of the cohorts. As such the true growth parameters of *Crangon* in The Wash may not be accurately estimated from our length distributions.

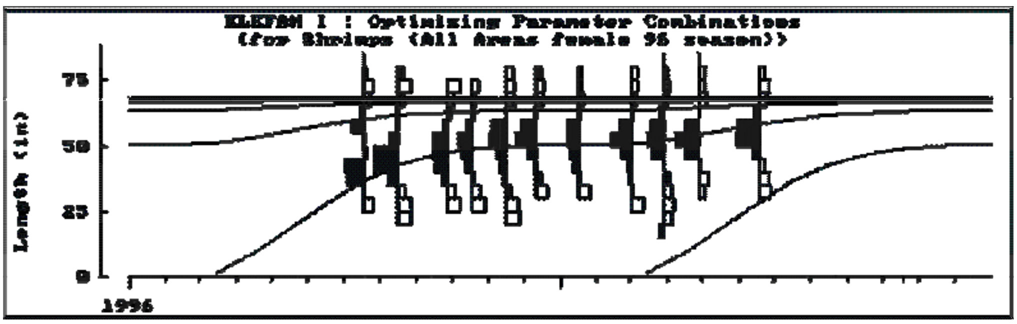

Figure 71: 1996/1997 fishing season (L_∞= 68mm, K= 1.4yr^{-1}, C=1.0 and WP= 0).

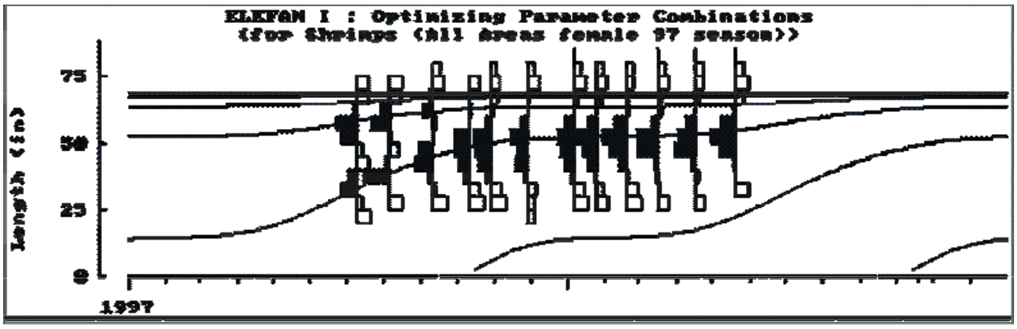

Figure 72: 1997/1998 fishing season (L_∞= 69mm, K= 1.2yr^{-1}, C=1.0 and WP= 0.1).

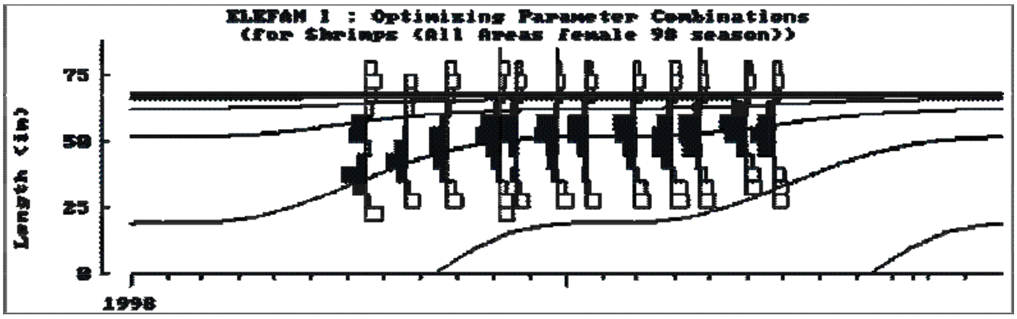

Figure 73: 1998/1999 fishing season (L_∞= 68mm, K= 1.1yr^{-1}, C=1.0 and WP= 0.1).

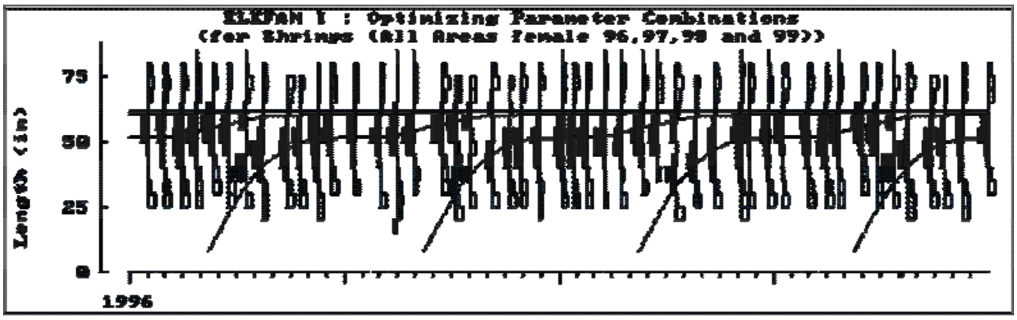

Figure 74: 1996 to 1999 inclusive (L_∞= 62mm, K= 2.0yr^{-1}, C=1.0 and WP= 0.05).

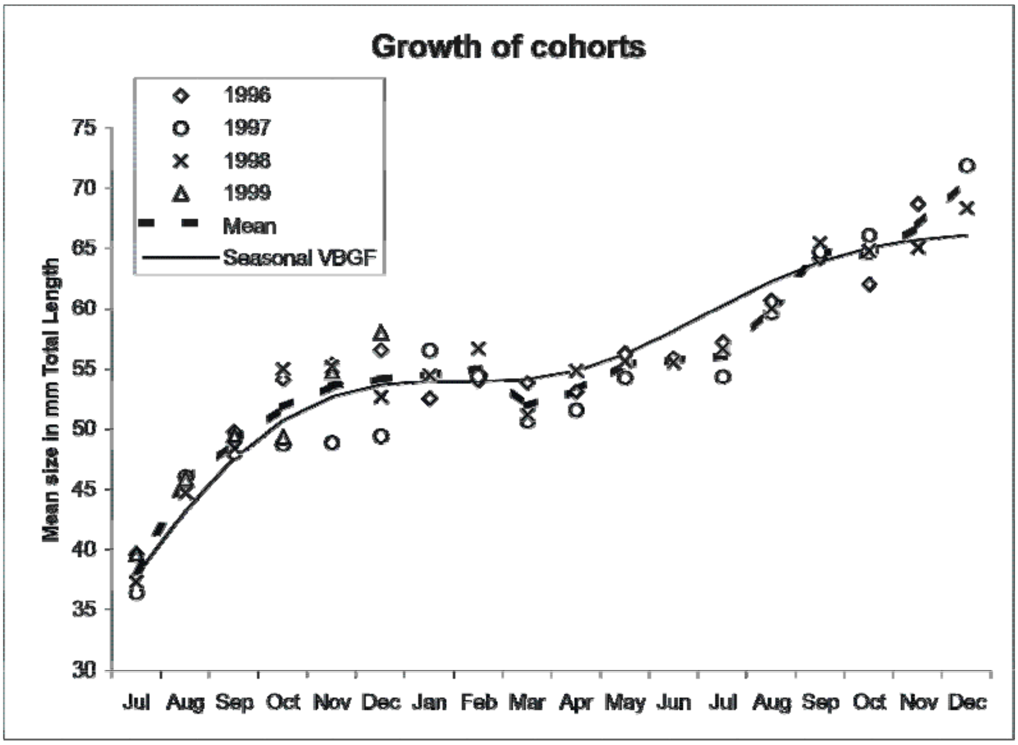

Figure 75: Growth of the recruiting cohorts over 18 months (1999 6 months only) with a fitted seasonal von Bertalanffy model (L_∞ = 73.44, k =0.99, t_0 = -0.2, C=1 and WP = 0.13).

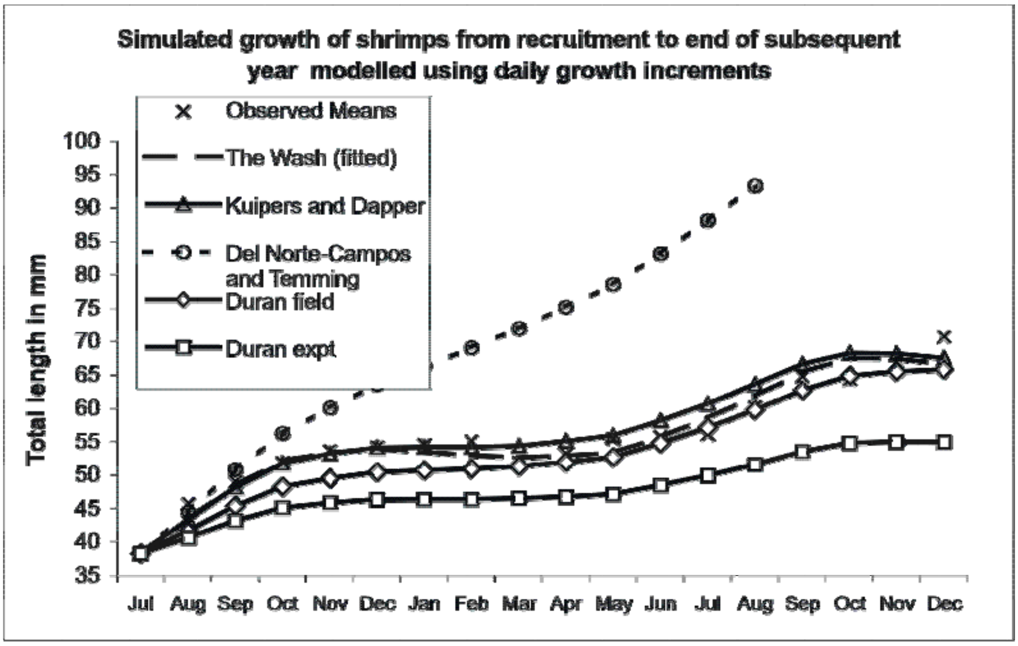

Figure 76: Growth of shrimps using daily growth increments based on Kuipers and Dapper (1984), Del Norte-Campos and Temming (1998), Duran (unpublished thesis, 1998) and data from the current study. All modelled using mean monthly water temperatures from The Wash.

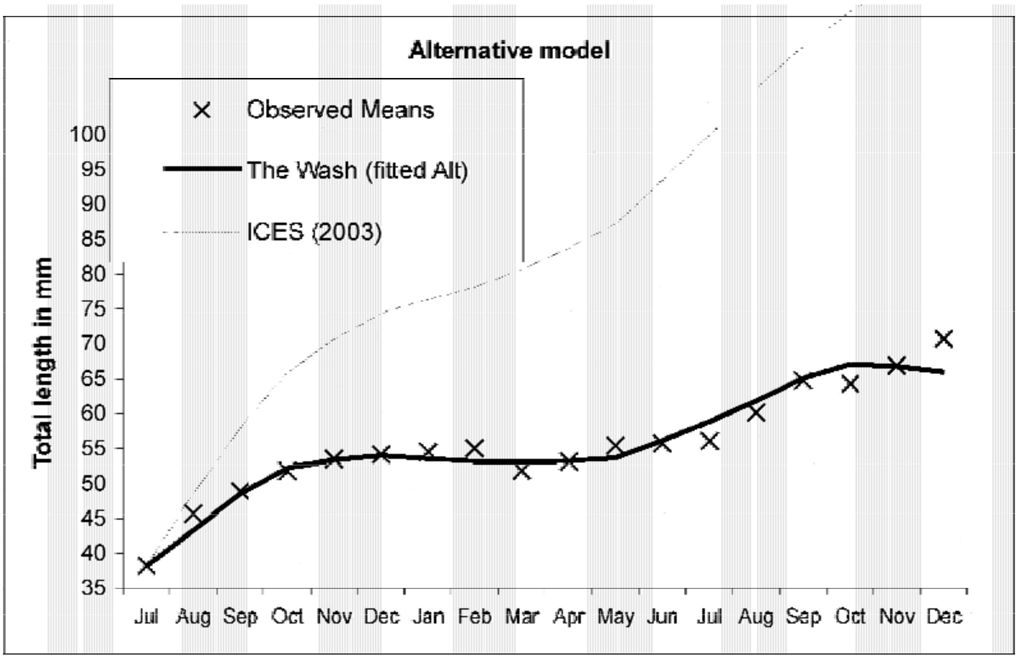

Figure 77: Growth of shrimps based on daily growth increments using the alternative ICES (2003) model and data from the current study. All modelled using mean monthly water temperatures from The Wash.

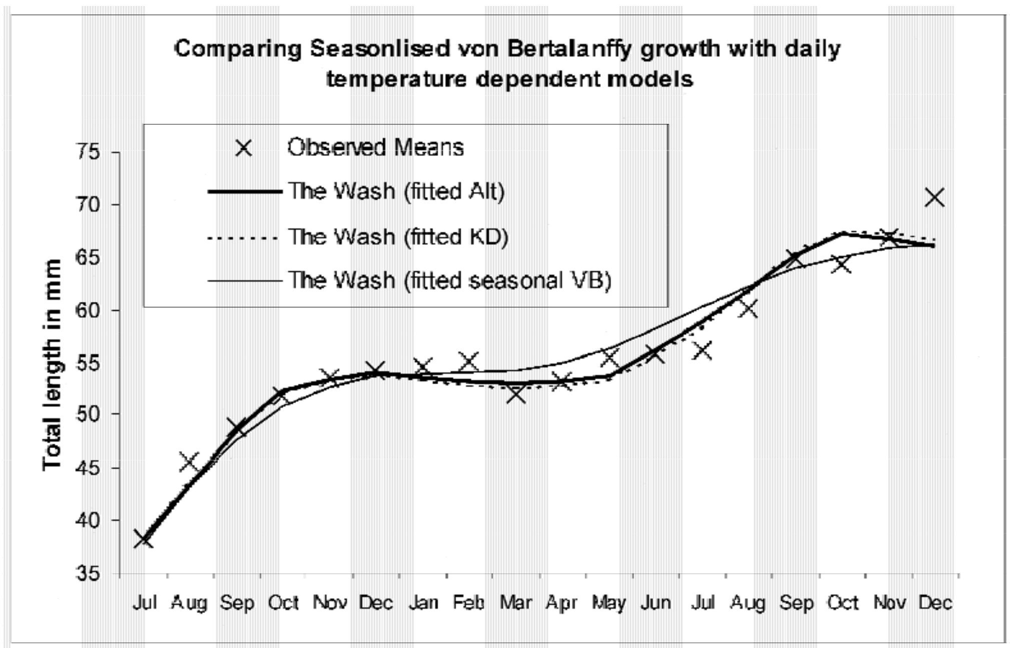

Figure 78: Comparison of model fits for seasonalized von Bertalanffy, the Kuipers and Dapper (1984) daily temperature dependent growth model and the ICES (2003) alternative model. All fitted to The Wash data using mean monthly water temperatures from The Wash.

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Del Norte-Campos, A.G.C., and Temming, A. 1998. Population dynamics of the brown shrimp *Crangon crangon* L., in shallow areas of the German Wadden Sea. Fish. Man, Ecol., 5: 303–322.

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5.3.2 Life cycle, maturation

In the last report of WGCRAN a number of model runs of the full version of the life cycle model were presented. Of these one considered to be most close to the different types of observed data (seasonality of recruitment and catches and relative egg production, size composition). This run was termed “standard run II”. The main unsatisfactory aspect of this simulation was a mismatch in the seasonal pattern of relative egg production. In order to match the seasonal pattern of catches with maximum values in late summer and autumn, which was considered to be the priority aspect for scenario tests with changed fishing patterns, high growth rates had to be assumed in the model (Figure 79). Since in the current model implementation maturity is coupled to growth, this fast growth leads inevitably also to maturation at young ages, and subsequent fertilisation and egg production. Therefore increasing egg production is predicted for September and maximum values for October and November. In field data, however, both September and October exhibit the lowest values (Figure 80).

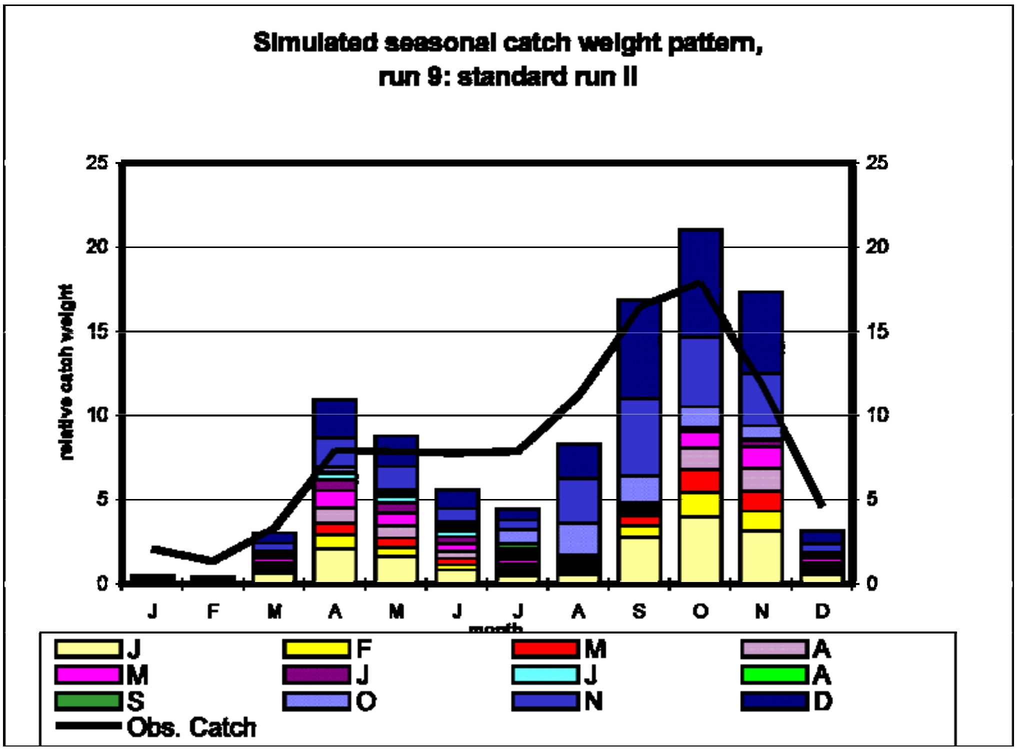

Figure 79: Best run from Ostende meeting (standard run II) Used for scenario analysis.

One potential mechanism that could achieve a decoupling of maturation and growth is a genetically determined minimum age at first maturity. This mechanism was implemented and tested in a series of simulations. The optimal fit to the observed data was achieved with a minimum age of 150 days calculated from the start of the juvenile stage with a length of 5 mm (Figure 81). An alternative mechanism could be a hormone controlled suppression of maturation at this time of the year, which may be triggered through day-length. This would be even easier to implement in the simulation model and the results would obviously match the observations.

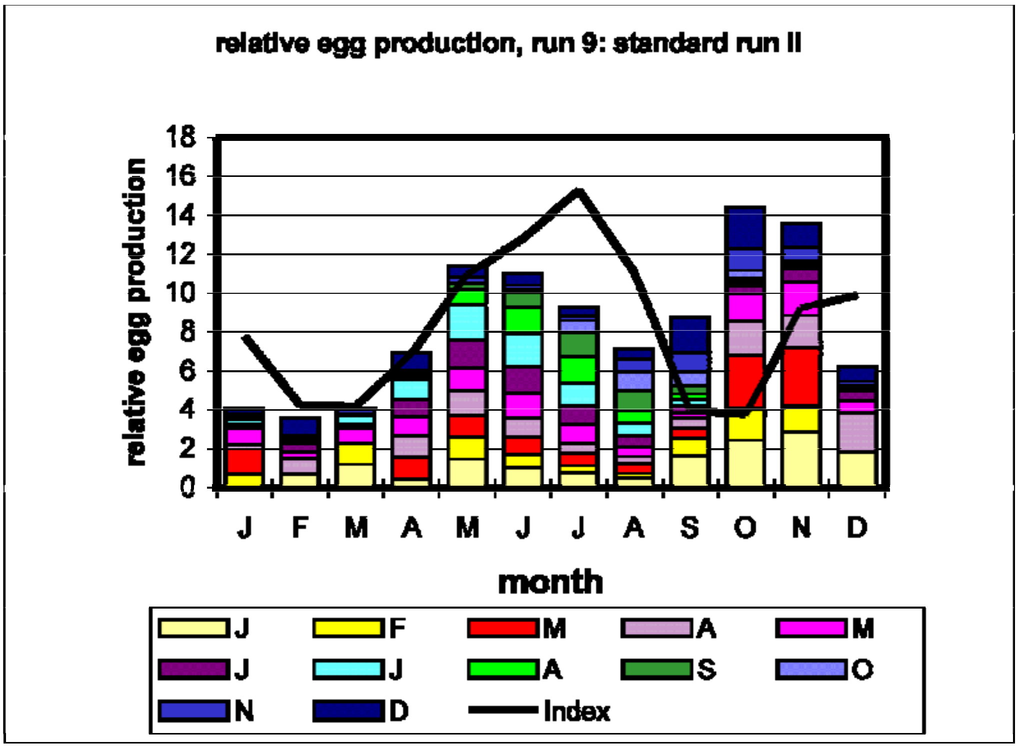

Figure 80: Best run from Ostende meeting. Note: spawning intensity pattern mismatch.

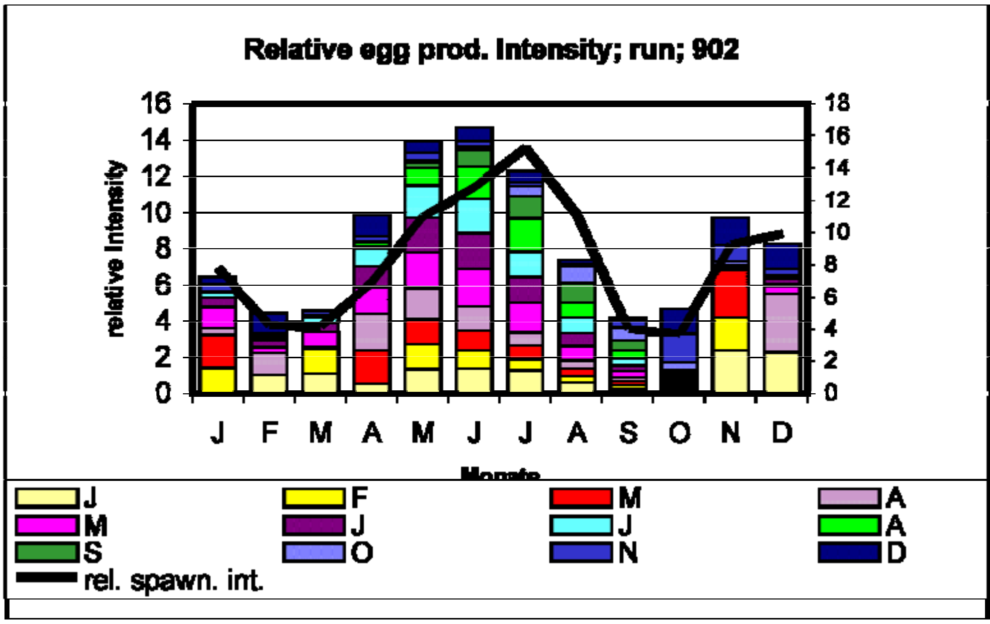

Figure 81: New version with min age for maturity of 150 days since juvenile stage of 5mm length.

5.3.3 Modelling issues — growth

Growth rates in the YPR model (ICES, 2003) are implemented using a temperature dependent daily increment model based on the von Bertalanffy first derivative.

$$\frac{\Delta l}{\Delta t} = a + bT - ce^{dT} l$$

where ***T*** is temperature and ***l*** is length and ***a***, ***b***, ***c*** and ***d*** are parameters.

Simulations showed that the algebraic conversion from the first derivative of the von Bertalanffy growth equation apply for a given constant temperature, but as temperature variation and the ***d*** parameter are increased from zero the resulting growth curves no longer correspond to the direct von Bertalanffy equivalents, but to curves with lower L_∞ and higher ***K*** (Figure 82).

Algebraic conversion to von Bertalanffy equivalents, of growth rates required by the YPR model to match observed recruitment patterns suggested the growth rates required were higher than those estimated from data. However, seasonal temperature fluctuations mean these direct algebraic equivalents are not appropriate. An implication is that the growth rates required by the YPR model may not actually imply unrealistically high values of L_∞ but do imply high values for ***K*** (Table 3).

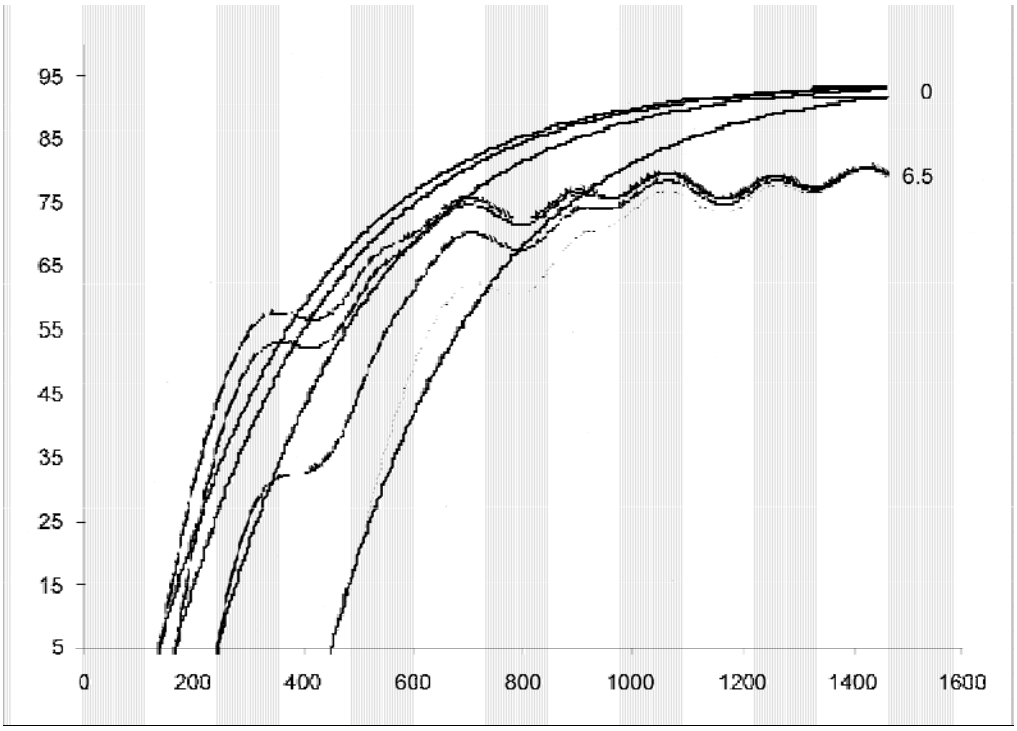

Figure 82: Growth curves for 4 cohorts spawned at quarterly intervals with constant temperature 10.7°C (amplitude = 0) and modelled as a sine wave (amplitude 6.5 = total variation 13°C) about this mean level.

Table 3: YPR model and (seasonalized) von Bertalanffy equivalent growth parameters used in UK simulation experiments evaluating methods growth rate estimation

	G1	G2	G3
a	-0.1214331	-0.10864765	0.0511322
b	0.04235	0.03073	0.02581
c	0.00086	0.00048	0.00129
d	0.13142	0.14533	0.08096
Approximate equivalent seasonalized von Bertalanffy growth parameters for the simulated seasonal temperature regime			
K	1.5	1.0	1.2
L_∞	80	80	100
C	1.0	1.0	0.5
t_s	0.55	0.55	0.55
φ'	9.17	8.76	9.39
Equivalent von Bertalanffy growth parameters at constant temperature of 10.71°C			
K	1.3	0.8	1.1
L_∞	94.2	97.5	106.6
φ'	9.34	8.97	9.45

Generation of stochastic deviates

The method of generating stochastic deviates produces a distribution of growth curves in which the median is higher than the mean (expected value) and upper quantiles are further from the mean than corresponding lower quantiles. It has been suggested that 'fast growers' are crucially important in the dynamics of the shrimp fishery and if this is the case then shape of the distribution and the magnitude of the CV may be influential.

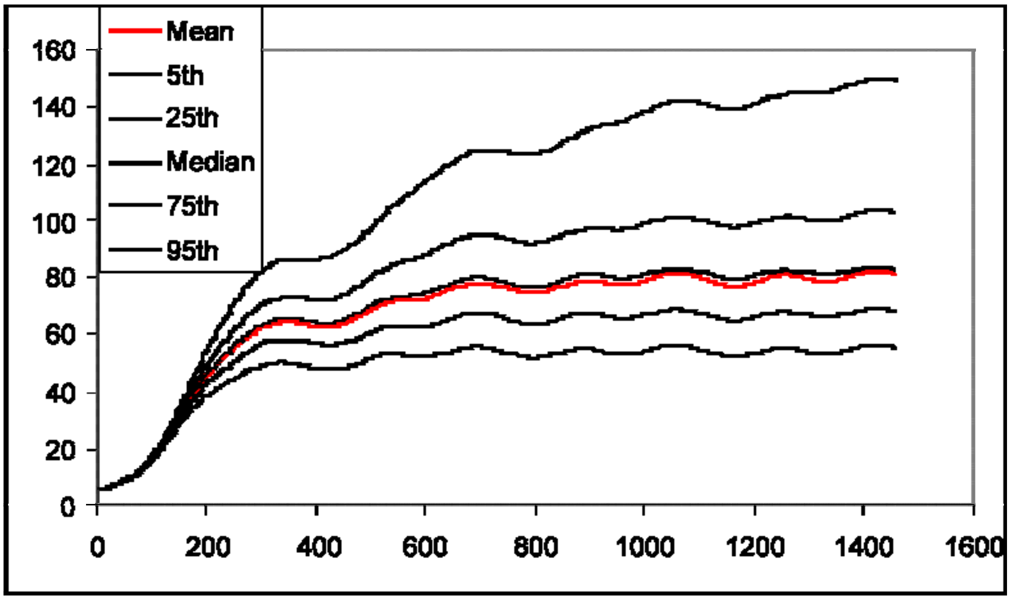

Figure 83: Deterministic (red) and stochastic growth curves (black) based on 5th, 25th, 50th, 75th, 95th percentiles of parameter c with a CV of 0.3.

References

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