Living Resources Committee ICES CM 2003/G:01

Report of the

Working Group on *Crangon* Fisheries And Life History

Ostende, Belgium
15–19 October 2002

International Council for the Exploration of the Sea

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Contents

1 Introduction

1.1 Meeting place and date

The Working Group on *Crangon* Fisheries and Life History (WGCRAN), met in Ostende, Belgium from 15–19 October 2002.

1.2 Participants

Julian Addison	England
Ulrich Damm	Germany
Andy Lawler	England
Niels Lüthje	Germany
Thomas Neudecker	Germany
Hans Polet	Belgium
Frank Redant	Belgium
Andy Revill	England
Volker Siegel	Germany
Michael Smith	England
Per Sand Kristensen	Denmark
Axel Temming (Chair)	Germany

1.3 Terms of Reference

a) Collect and investigate available catch and landings data by vessel to refine fishery dependent indices of abundance (Section 2).

b) Apply the *Crangon* Y/R model with different effort scenarios (Section 3).

c) Investigate further the geographical and interannual differences in *Crangon* yields and their possible causes (Sections 2 and 4).

d) Discuss sampling strategies for future collections of biological data (Section 6).

e) Set up an inventory of existing data or data sets on *Crangon* densities, size composition and predator densities (Section 5).

1.4 Preparatory meeting on model development and application in Hamburg

A two day meeting from 18– 19 September was held in Hamburg with participants from UK and Germany to discuss the status of the Y/R model and to decide on final modifications prior to the meeting. It was decided that unpublished data on sex ratio and ovigerous females should be brought to the WG meeting for a comparative analysis. The results should form the basis for an improved parameterisation of the maturation process in the model. It was also suggested that size specific mortalities should be changed from step functions into a continuous functions prior to the meeting. Further the relevant scenarios for a model application were identified during this meeting.

1.5 Major achievements of the WG meeting

- Landings and effort statistics were compiled for 2001 and indicate a very high level of total landings (28674 t) as in previous years. If roughly converted with German mean prices these landings represent a total value of 108 Million €.
- For the first time log book data were available although not for all countries. A preliminary plot of the total landings by ICES rectangle reveals that the majority of the landings originates from a limited number of coastal rectangles in the southern North Sea.
- A first version of a *crangon* specific Y/R-model was presented at the meeting. The model represents a complex individual based forward simulation which mimics the seasonal development of the population and the fishery. A preliminary parameterisation of the model was presented that could reproduce the main observed seasonal patterns of population parameters, namely: the recruitment at 15 mm length, the commercial catches, the seasonal egg production and the mean annual size composition. When the model was used to predict the effects of different sea-

sonal effort patters it produced consistent results and demonstrated the potential of such a tool for a quantitative understanding of the *crangon* life cycle and the reactions of the population and the yields to such effort scenarios. The actual numbers, however, must be regarded as tentative given the remaining uncertainties in the present parameterisation.

- A comprehensive data set on the sex ratio and the fraction of ovigerous females by size and season was compiled and analysed at the meeting as a basis for an improved parameterisation of the maturation process in the Y/R-model.

2 Catch and effort statistics 2001

Landing statistics have been supplied for 2001 by all countries on a monthly basis. Effort data were supplied only by DK, D, B and UK as in previous years in different units.

2.1 Landings and effort data

2.1.1 Landings in 2001 and long term trends

Major trends by country are given in the following overview (see Figures 2.1.1.1 and 2.1.1.2, Table 2.1.1.1):

DK: 2001 landings were below the 2000 level by 498 tonnes (-21%) and 333 tonnes (-15%) below the 10 year mean (1992 to 2001).

D: 2001 landings were below the 2000 level by 3676 tonnes (-28%) and 1591 tonnes (-15%) of the 10 year mean (1992 to 2001).

NL: 2001 landings were above the 2000 level by 5531 tonnes (62%) and 4789 tonnes (50%) of the 10 year mean (1992 to 2001).

B: 2001 landings were above the 2000 level by 68 tonnes (21%) and 60 tonnes (-13%) below of the 10 year mean (1992 to 2001).

F 5a: 2001 landings were below the 2000 level by 81 tonnes (-17%) and 13 tonnes (3%) above of the 10 year mean (1992 to 2001).

F 5b: 2001 landings were below the 2000 level by 67 tonnes (-23%) and 45 tonnes (26%) above of the 10 year mean (1992 to 2001).

UK: 2001 landings were above the 2000 level by 969 tonnes (91%) and 958 tonnes (90%) of the 10 year mean (1992 to 2001).

EU: 2001 landings were above the 2000 level by 2326 tonnes (9%) and 3809 tonnes (16%) of the 10 year mean (1992 to 2001).

Major changes are visible for NL (+), UK (+), D (-) and DK (-). The increases most likely reflect corresponding increases in fishing effort, while a lower LPUE was calculated for countries with decreasing landings.

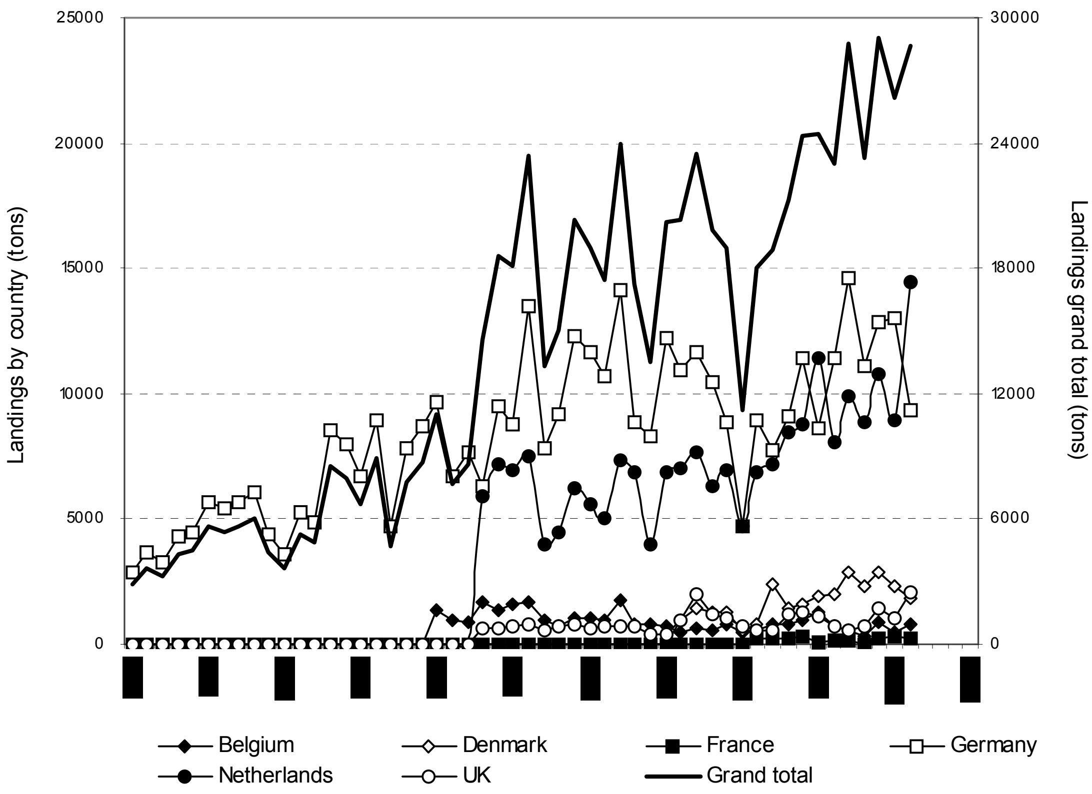


Figure 2.1.1.1 Landings by country and total EU landings.

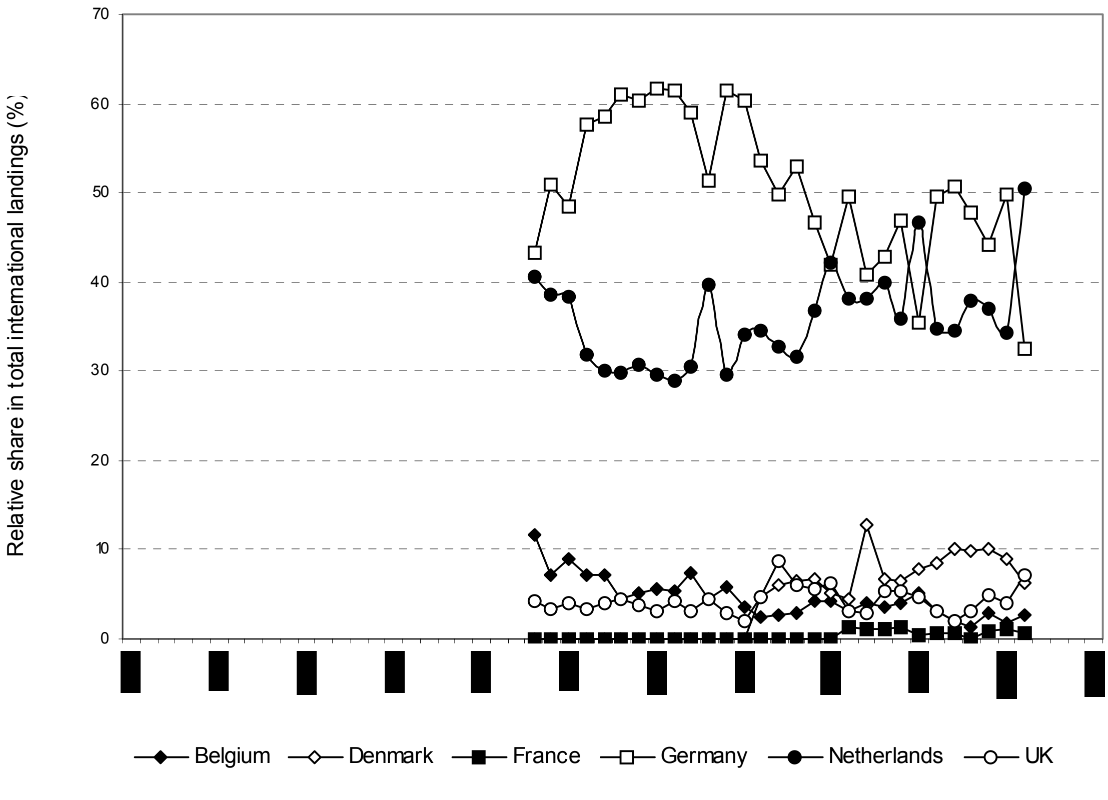


Figure 2.1.1.2 Relative share of countries in total EU landings.

Table 2.1.1.1 - Shrimp landings (in tons) by country, 1980-present.							
Year	Belgium*	Denmark	France	Germany	Netherlands	UK	Total
1981	958			10714	5036	727	17435
1982	1776			14152	7312	738	23978
1983	774			8829	6854	758	17215
1984	787			8283	3999	406	13475
1985	706			12247	6886	418	20257
1986	498	957		10909	7005	971	20340
1987	627	1440		11699	7706	2032	23504
1988	578	1293		10502	6271	1192	19836
1989	811	1286		8896	6983	1048	19024
1990	488	582		4694	4737	712	11213
1991	560	805	244	8950	6894	574	18027
1992	764	2392	232	7708	7193	559	18848
1993	785	1453	255	9090	8501	1163	21247
1994	979	1574	304	11445	8765	1302	24369
1995	1254	1905	113	8649	11384	1142	24447
1996	722	1984	135	11427	8036	741	23045
1997	594	2900	162	14619	9927	597	28799
1998	303	2307	0	11121	8849	736	23316
1999	842	2908	236	12838	10754	1450	29028
2000	492	2323	288	13009	8940	1069	26121
2001	788	1824	221	9333	14470	2038	28674

* Belgian figures deviate from previous reports because of inclusion of foreign landings.

2.1.2 Seasonality of landings

The landings pattern in DK exhibits two peaks, a dominant one in spring and a lower one in autumn. This is different to the situation in the other countries, where autumn is the main season. The German landings pattern is intermediate between the Dutch and the Danish pattern with elevated landings in spring and a pronounced autumn peak (Figure 2.1.1.3).

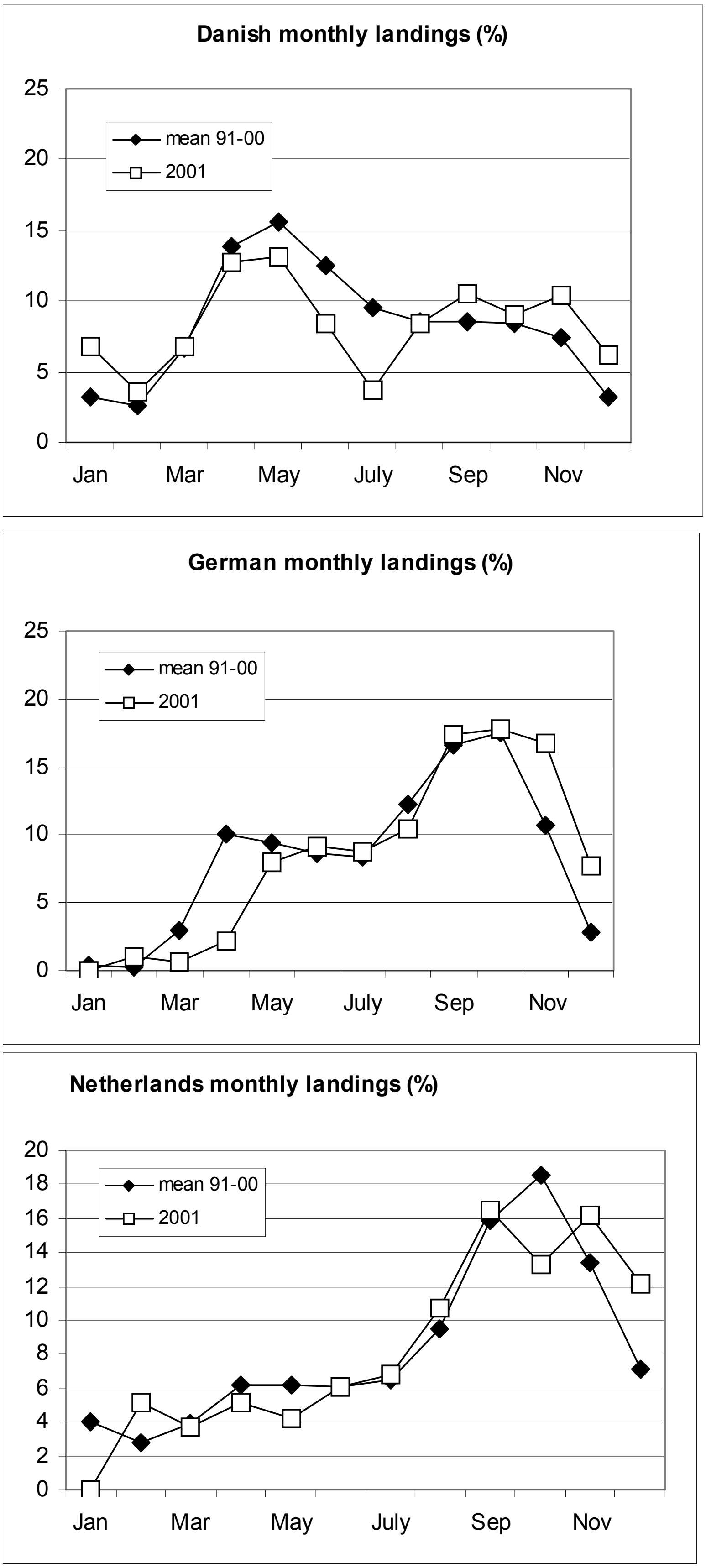
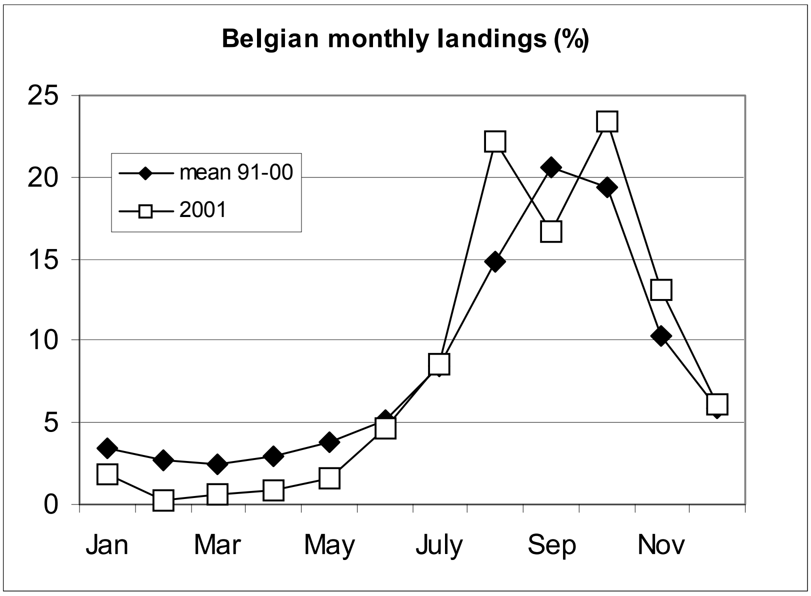


Figure 2.1.1.3 Relative monthly landings by country.



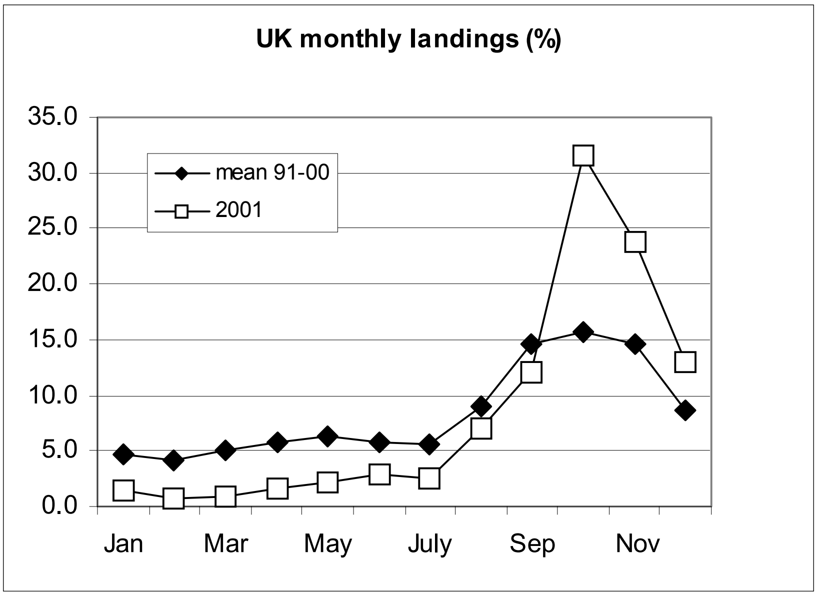


Figure 2.1.1.3 Continued. Relative monthly landings by country.

2.1.3 Effort and LPUE data

Effort

Effort data were presented by DK, D, B, and UK (Figures 2.2.1.1.–2.2.1.7). The analysis showed for:

DK: a decrease of effort by 12 % in fishing days compared to the previous year.
D: a decrease of effort by 4807 trips (17 %) compared to the previous year. It is stressed, that fishing trips are not a very good effort measure, this can be seen in the Belgian figure on the increase of fishing hours per trip over the last decade.
NL: no data
B: an increase of 27% in hp-fishing-hours compared to the previous year.
F: no data
UK: an increase of 11% in fishing days compared to the previous year.

Total EU effort is not presentable because of not comparable units and missing data.

2.1.4 Recent developments

There has been a trilateral market agreement in force between producer organisations in DK, D and NL since 1998 leading to a reduction in landings in some months of the year when total landings exceeded the market demands. It was especially effective in 1998, when high LPUE´s were observed e.g. in DK and D. This agreement was considered to distort the competition in the EU market to the disadvantage of the consumers and therefore declared illegal. The stop of organised reductions of supply have lead to a sharp decrease of producer prices in 2003. Subsequently a highly undesirable increase of fishing effort can be expected to compensate low prices with high quantities.

2.1.5 LPUE data

For countries with effort measured more accurately than trips, the development of the LPUE was calculated, to give an indication of the development of the stock situation:

DK: a decrease of LPUE at the beginning of the fishery followed by a general upward trend with strong oscillations (Figure 2.2.1.8).

B: a continuous decrease in the time series for LPUE in Belgian waters (trips with landings in foreign ports excluded, Figure 2.2.1.9).

UK: generally strong fluctuations superimposed on a decrease until the mid 90s followed by an increasing trend (Figure 2.2.1.10).

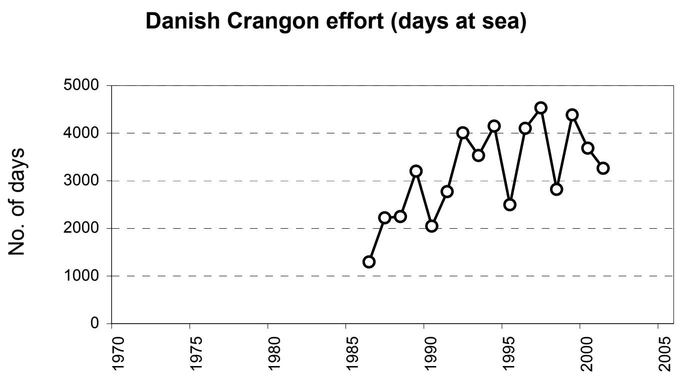


Figure 2.2.1.1 Danish fishing effort in the *crangon* fishery.

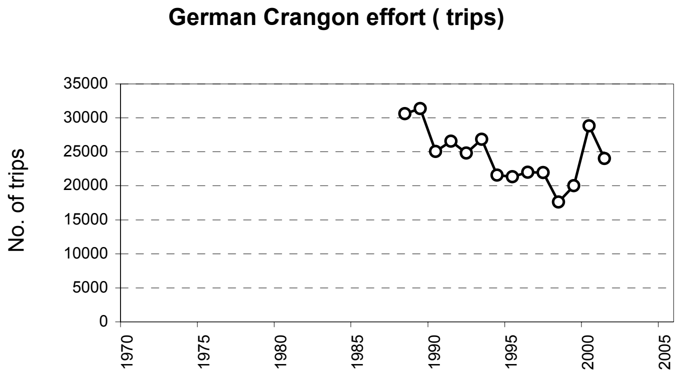


Figure 2.2.1.2 German fishing effort in the *crangon* fishery.

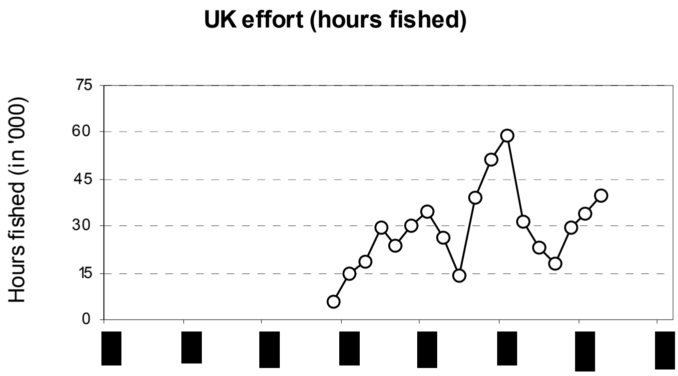


Figure 2.2.1.3 UK fishing effort in the *crangon* fishery.

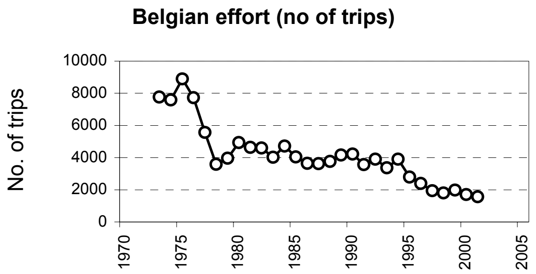


Figure 2.2.1.4 Belgian fishing effort (trips).

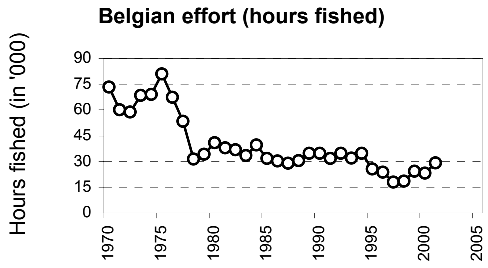


Figure 2.2.1.5 Belgian fishing effort (hours).

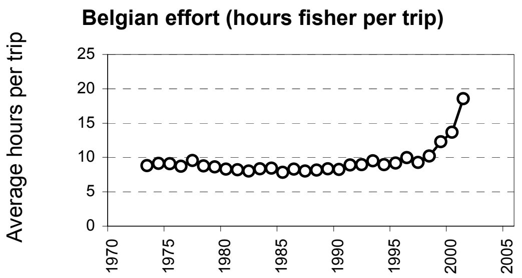


Figure 2.2.1.6 Belgian fishing effort, Trip duration.

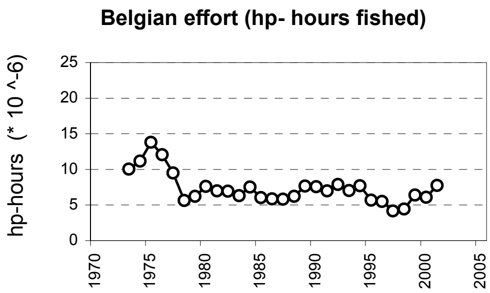


Figure 2.2.1.7 Belgian effort, hp-hours.

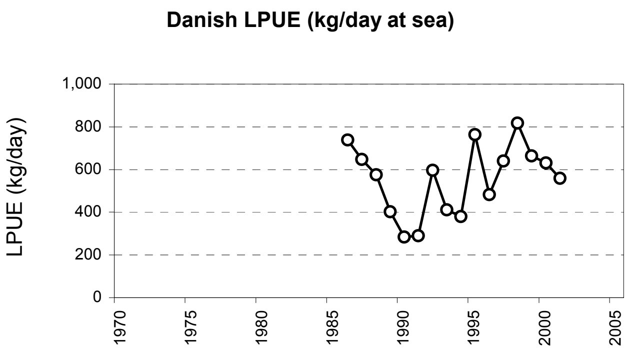


Figure 2.2.1.8 Danish landings per effort.

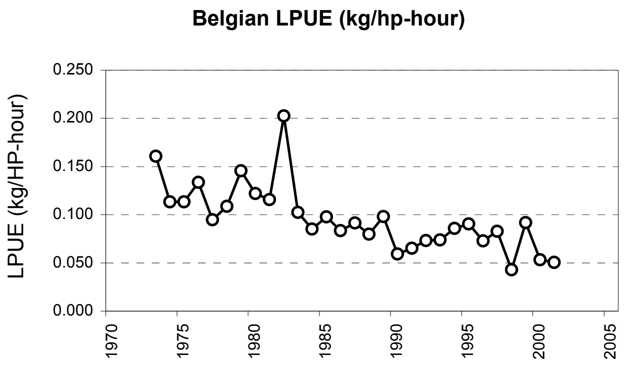


Figure 2.2.1.9 Belgian landings per effort.

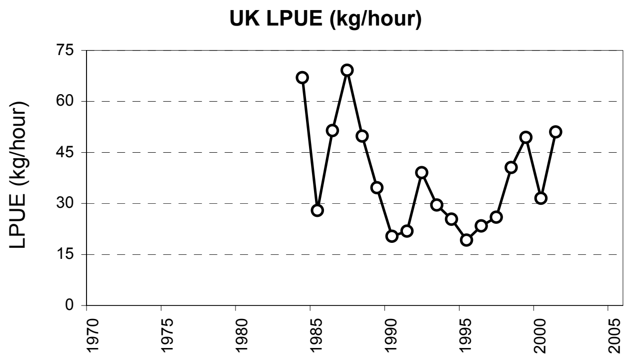


Figure 2.2.1.10 UK landings per effort.

2.2 Log-book data from 2001

The broad distribution of brown shrimp catches has long been established. However, data on fine-scale distribution of catches have never been available on a Europe-wide basis, and an attempt by the ICES WGCRAN to regionalize catches on the basis of Functional Units was not successful. Ports of landings and catch areas do not necessarily match because of the "long distance" fishing patterns of parts of the fleets. Since 1 January 2000 when it became compulsory for brown shrimp fishing boats to record catch and effort information on an ICES statistical rectangle basis, it is finally become possible to attribute brown shrimp catches to regions. In this paper the first data on catches per ICES rectangle are presented and evaluated.

Landings data by country and by ICES rectangle were supplied by members of the ICES WGCRAN for the year 2001. They contain landed weights of cooked brown shrimp, which were not raised to live weight as done for some fishery statistics. Most countries along the North Sea contributed (DK, D, NL, F, UK). Further information available on fishing effort and LPUE were not used, because yet no standardised units of effort are available. Landings data per rectangle were compiled in tables by month and aggregated for the year as given by the representatives for each country. They were also aggregated for Europe giving information on the reported total catch of shrimp per rectangle (Figure 2.2.1). The Netherlands, however, were able to supply only a small fraction of catches per ICES rectangle, but gave total catches for the country. It was not possible to raise them to the total landings of NL because of uneven distribution. Belgian data do exist, but were not available at the meeting.

Most countries for the first time presented catch data of brown shrimp based on logbook recordings to the WGCRAN. The known regional distribution of catches was confirmed, but for the first time proven by figures. Peak landings originate from a few rectangles of the coastal zones of the inner German Bight, but relatively high landings were reported from two rectangles in UK waters. As noted above, data for areas off the Netherlands and Belgium are missing. It is essential therefore that data for these two national fleets are made available so that an accurate regional distribution pattern of catches of brown shrimp becomes possible. For Germany it became obvious that there was a difference of 1553 tonnes between EU log book data and PO data, which could be explained only partly by landings in foreign countries.

ICES	E6	E7	E8	E9	F0	F1	F2	F3	F4	F5	F6	F7	F8	F9
42													21	
41												1	48	
40												29	477	DK
39	62				0						1	127	1018	
38											2	138	1266	
37	2	2			0	3				0	4	177	3038	
36	0			1	280	28				58	2043	2078	1897	
35					700	55				2				D
34					833	38								
33			UK			16								
32					0	14				NL				
31					1.4	1	6		B					
30					2	3								
29					0	134								
28					3									
27				4	53									
26							Landings [t] of Crangon per ICES-square 2001							
25							Total: 29149 tonnes							
24	4													
23		60			F		without		14442 tonnes from NL !!					
22		1					without		392 tonnes from B					
21			3				100 - 499 t							
20			3				500 – 999 t							
19							> 1000 t							
18			0											

Figure 2.2.1 Allocation of Crangon landings to ICES squares as reported by countries.

2.3 Catch composition

2.3.1 Analysis of Danish catch samples in 2000 and 2001

In the Danish *C. crangon* fishery along the west coast of Jutland between Thyborøn and the DK/DE-boarder monthly catch samples were taken on board three selected fishing vessels trawling in the most used area by the vessel in that particular month in 2000 (10 month (March-December)) and 2001 (12 month (January-December)) respectively. Samples of ~1 kg of shrimps ware random taken from the hopper just after the catch and before sorting. The samples were frozen for later analyses in the laboratory.The samples were sorted in three categories – males -, - ovigerous females - and - non-ovigerous females -. Each shrimp was measured (carapax length) in mm (below) and divided into mm-length groups in each of the three categories. A total of 18.866 shrimps was measured in 22 samples. Each mm-length group within each category was weighted in grams. Shrimps with carapax length >10 mm (>46 mm total length) were assumed to be consumption shrimps. The results are shown in Table 2.3.1.1.

The proportion of males varied in 2000 between 15.0% and 31.4% in the Danish brown shrimp catches and between 22.6% and 38.4% in the catches in 2001. On average the proportion of males in the catches in the 2001 were 50% higher than in the catches in 2000. The proportion of non-ovigerous females were of the same magnitude in both 2000 and 2001 and around 39%. The proportion of ovigerous females was much higher in 2000 compared to 2001 (Table2.3.1.1).

The Danish catch composition of brown shrimps by size and sex in 2000 and 2001 is shown in Figures 2.3.1.1–3. The proportion of males in the catches was high in the lover length classes between 18 and 46 mm, and very few males were larger than 50 mm (5.549 measured). In the catches the non-ovigerous females covered the whole length range observed between 18 mm and 70 mm (7.256 measured). In the catches the ovigerous females were larger and ranged between 34 mm and 70 mm (6.061 measured). The smallest shrimps were observed in the catches in the Southern most regions of the Danish fishing grounds and most conspicuous in 2001 (Figure 1, below). In both 2000 and 2001 the largest shrimps were caught around Horns Reef (Figure 2.3.1.2).

On all Danish fishing grounds the relative proportion of ovigerous females was larger in 2000 compared to 2001. On the other hand, the relative proportion of males was larger in 2001 compared to 2000 especially in the Southern and in the Northern regions. In 2000 the proportion of ovigerous females was relatively low compared to 2001 (Figures 2.3.1.1–3).

Table 2.3.1.1 Proportion (%) of males, non-ovigerous females and ovigerous females in the Danish *C. crangon* fishery in 2000 and 2001. Mean values January – December.

2000	South	Central	North	Mean	2*SD
Males	20.3	15.0	31.4	22.2	11.8
Ovi. females	40.9	42.8	39.8	41.2	2.1
Non-ovi. females	38.7	42.3	28.7	36.6	10.0
2001	South	Central	North	Mean	2*SD
Males	37.8	22.6	38.4	32.9	12.7
Ovi. females	22.4	31.6	24.9	26.3	6.7
Non-ovi. females	39.8	45.8	36.7	40.8	6.5

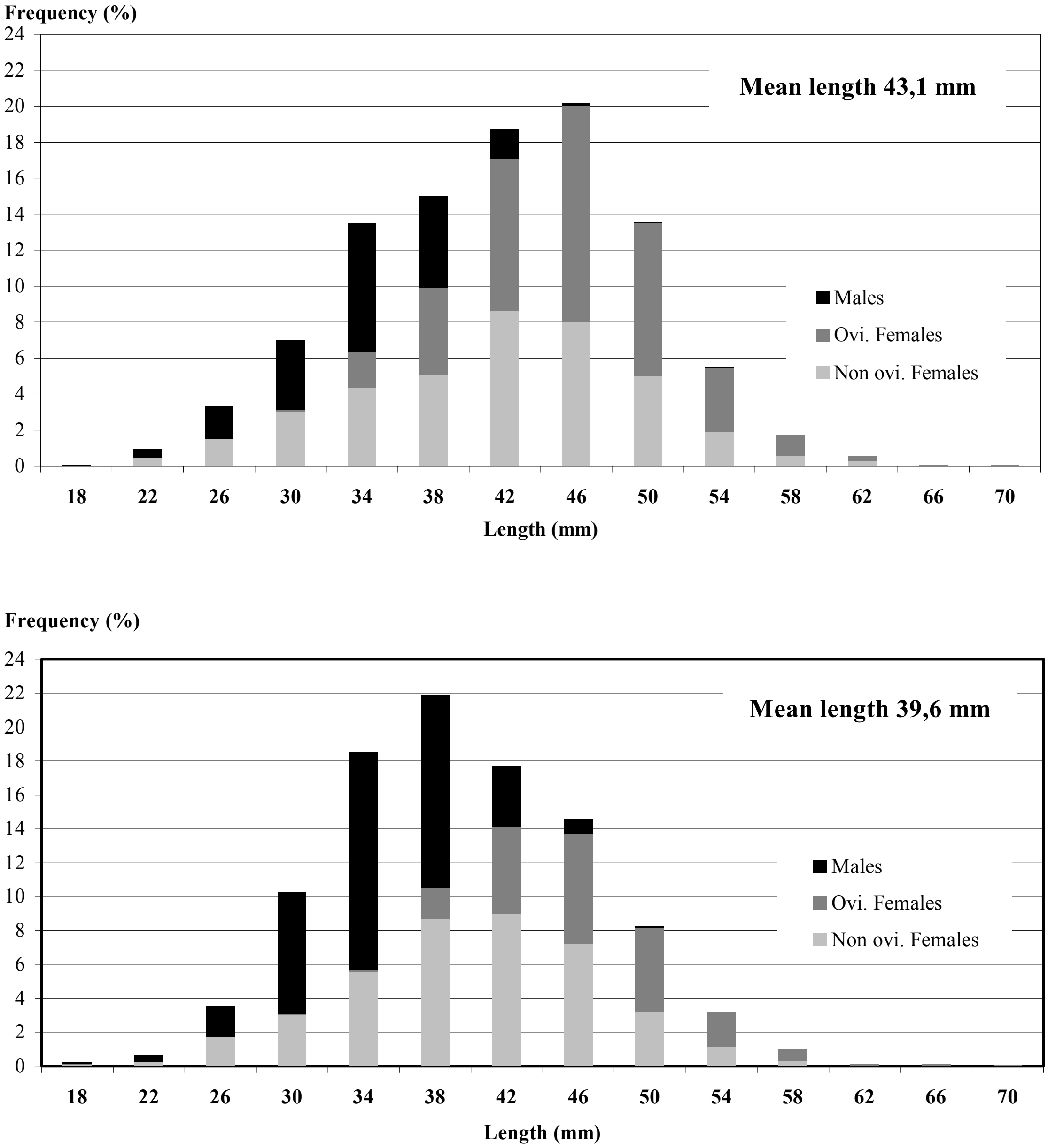
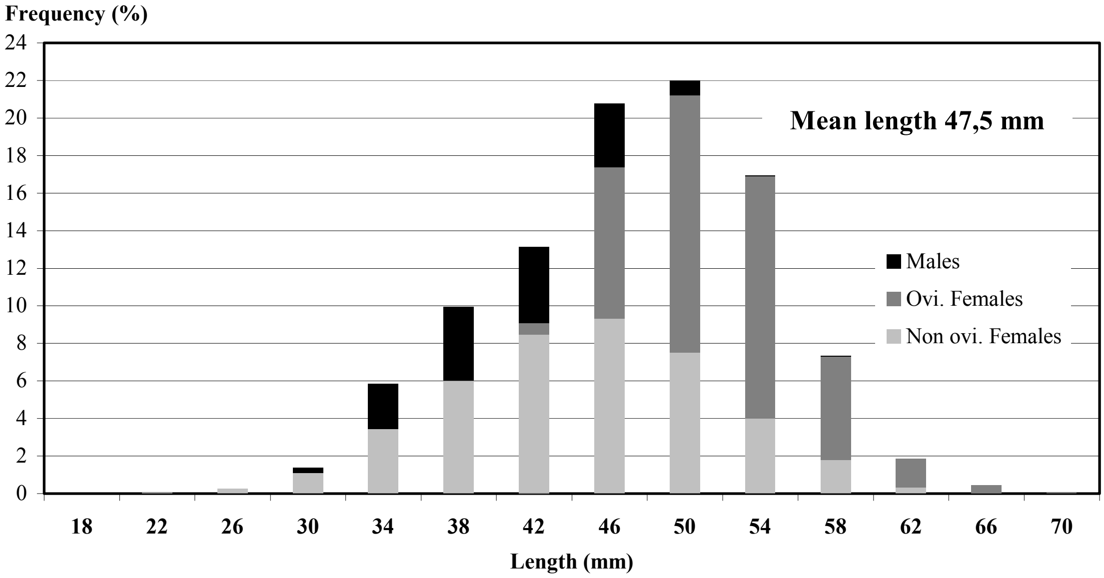


Figure 2.3.1.1. The relative proportion of males, non-ovigerous and ovigerous females in the Danish *C. crangon* fishery in the North Sea (*Southern part of the Danish fishing area*) in 2000 and in 2001.



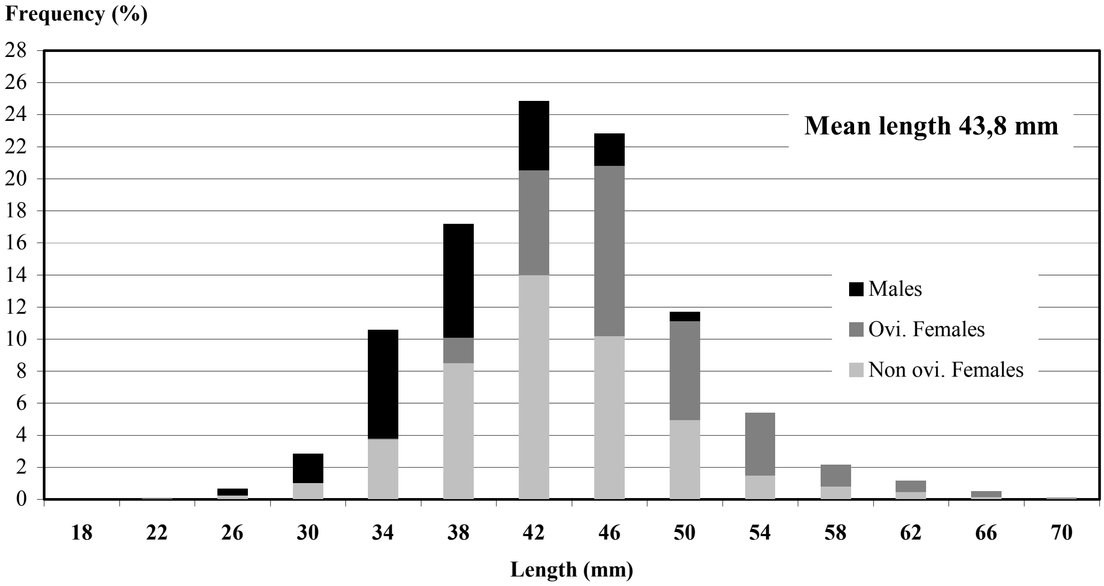
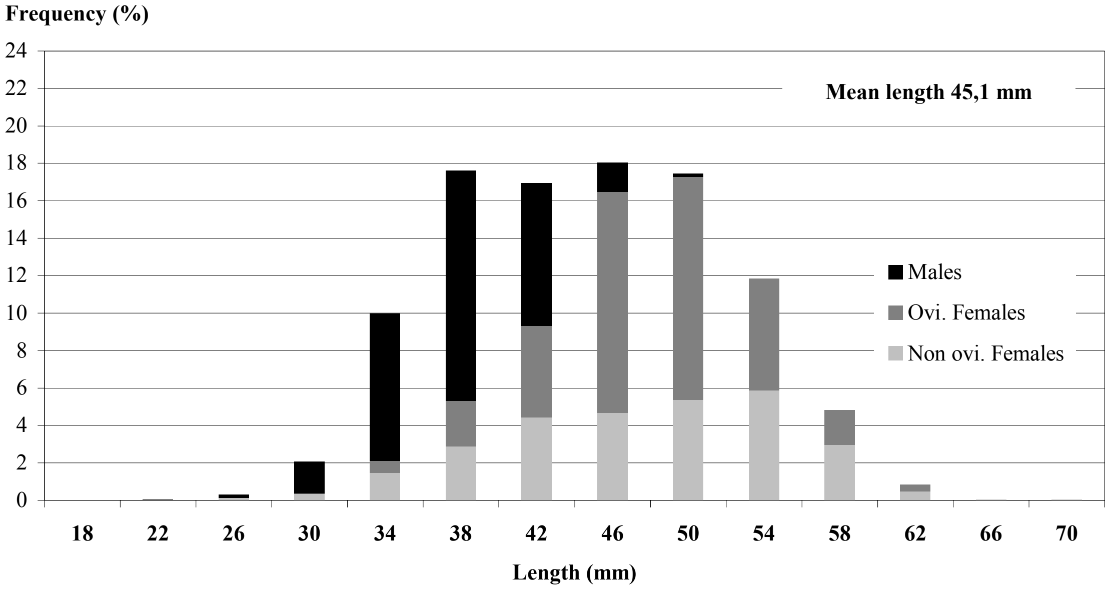


Figure 2.3.1.2. The relative proportion of males, non-ovigerous and ovigerous females in the Danish *C. crangon* fishery in the North Sea (*Central part of the Danish fishing area*) in 2000 and in 2001.



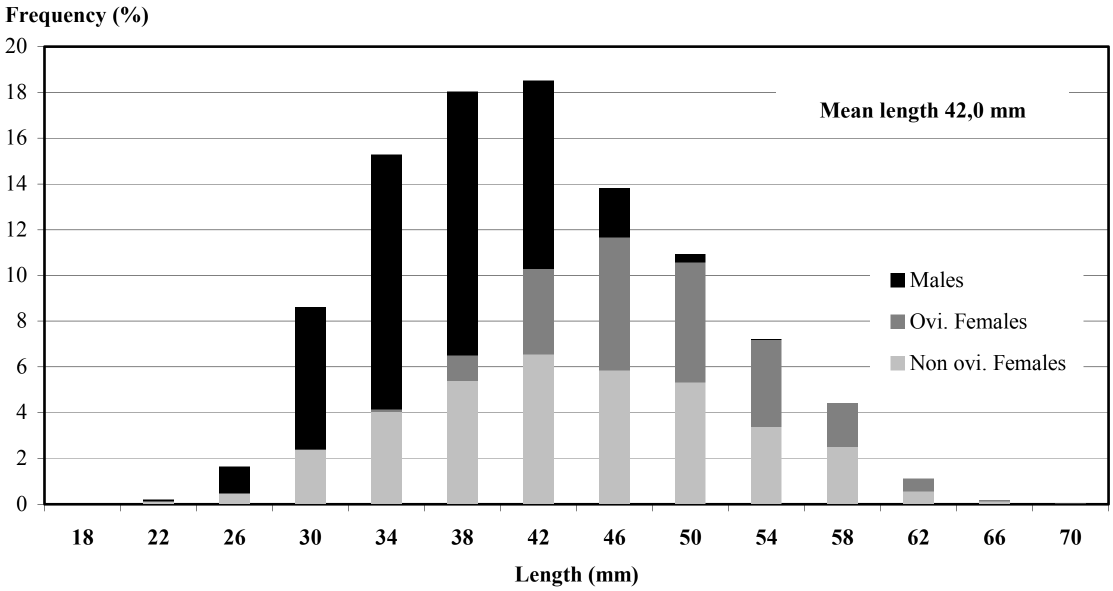


Figure 2.3.1.3. The relative proportion of males, non-ovigerous and ovigerous females in the Danish *C. crangon* fishery in the North Sea (*Northern part of the Danish fishing area*) in 2000 and in 2001.

2.4 Future use of EU log book data

Since 1 January 2000 it has become obligatory for fishing vessels greater than 10 m in length to record landings and associated effort for all species in EU log books. This means that data on *crangon* catch and effort should now be recorded by ICES statistical rectangle for all >10m vessels.

The accuracy and value of these data was discussed. Although EU log books are obligatory for the > 10m sector only, in many fisheries this sector may represent 80–90% of the total fishing effort, and thus landings per unit effort (LPUE) for this sector are likely to be an accurate index of LPUE for the whole fleet. Landings and effort data from EU log books were presented from UK *crangon* vessels in The Wash fishery for 1999, when some fishermen were voluntarily completing log books, and recording fine-scale geographical position of fishing areas. The Wash fishery has about 20 full time vessels over 10m fishing for *crangon* and these vessels contribute approximately 90% of the total fishing effort in this fishery. Only 7 of these 20 vessels participated in the voluntary scheme in 1999, but EU log book data for these 7 vessels provided very similar levels and trends in LPUE as the official landings and effort statistics for the whole fleet (Figure 2.4.1), suggesting that the EU log book data were sufficiently accurate to be used as an index of abundance for this fishery. It was stressed that it is particularly useful to have information on the spatial distribution of landings and effort data at a geographical scale of less than ICES statistical rectangle.

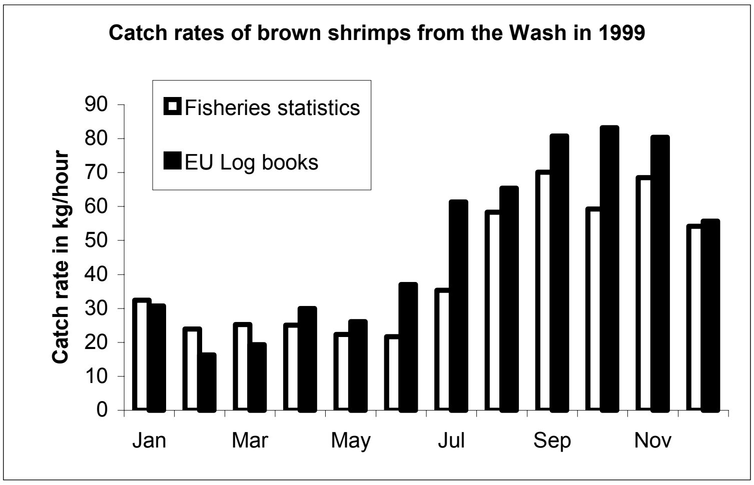


Figure 2.4.1 Comparison of Log book derived effort with official effort statistics.

In contrast, it was considered that the EU log book data for the *crangon* fisheries of Denmark, Germany and Belgium may have serious deficiencies. The contrast in the data sets from the various countries is probably due to differences in the scale of the fisheries and knowledge of the fishery practices of the individuals responsible for input of catch and effort data into databases. In all fisheries, errors may occur either in the recording of data by fishermen, or in transcription of this data to databases. In the UK *crangon* fishery, the local Fishery Officer is familiar with all the vessels and their skippers, and can therefore use that knowledge in identifying and correcting potential errors in the log book data before entering the data into a database. This is not necessarily the case for larger fisheries, like e.g. the UK fishery on *Cancer pagurus* where there are large numbers of vessels fishing many ICES rectangles). In such large fisheries data may be unreliable because individuals who are not familiar with the fishery and its practices will not necessarily identify obvious errors before inputting the data.

It was discussed therefore whether the errors in the log book data were beyond correction or whether it was possible to 'filter' the data to provide reliable indices for analysis of the state of the fisheries and stocks. The benefit of obtaining log book data for all >10m vessels is that reliable data on spatial distribution of landings and effort can be collated, although fine scale distribution cannot be revealed because the data is recorded at the scale of ICES statistical rectangle. However the data should provide LPUE data for all the fleet and by statistical rectangle and vessel category, e.g. by horsepower. In theory an estimate of total effort in the fishery can also be calculated. In practice, however, there may be many errors occurring in the input of such data. It was agreed however that the capability of such a system was too good to ignore and that filtering of the data could be performed to omit all uncertain data inputs and still provide an accurate estimate of LPUE for all components of the fleet and all geographical areas. It was also agreed that using the data for the portion of the fleet for which reliable data was available and raising up that data to gain an estimate of total effort for the whole fleet was preferable to calculating total effort from unreliable/uncertain data for a section of the fleet.

Some guiding principles were identified for filtering the data for each national database. Firstly, the data should be screened for landings from outlying ICES statistical rectangles for which landings of *crangon* are unknown by the national fleet. Secondly, the results should be screened for implausible figures, such as setting minimum and maximum values for landings and effort indices appropriate for each national fleet. Other filtering may apply to individual national fleets. The WG agreed that it should not be concerned that any filtering process may occasionally introduce additional errors by incorrectly modifying true data entries providing that these additional errors are rare in comparison with the frequency of correcting erroneous data entries.

It is requested that member countries bring their log book data to the next WG meeting in their national format, and that discussion would then ensure that similar protocols for filtering the data have been used.

The variety of electronic log book data schemes that are in use were discussed. These included systems which work on small vessels without computers from which data are downloaded by telephone link, to systems currently in operation for large vessels for which satellite data on vessel position is available. It was agreed that participants should retrieve appropriate information from various GPS/satellite systems for the next meeting.

3 The Yield per Recruit model

3.1 General model structure

The life cycle model simulates daily cohorts of fertilised eggs through the egg, larval, juvenile and adult stage. The relative number of cohorts starting on each calendar day is determined by a relative index of monthly egg production, which is derived from field data on the number of egg bearing females and a temperature dependent moulting rate term. The development times and growth rates are modelled as functions of environmental temperature. A first version of this model was used to predict the seasonal timing of the mass occurrence of early juvenile shrimp observed in the Wadden Sea areas and to reveal the relative contributions of summer and winter egg productions to this juvenile peak (Temming and Damm 2002).

A new extended model version is presented here, which includes also the mortality and spawning processes. The purpose of the extended model is twofold: 1) the simulated seasonal patterns of egg production and yield can be compared with two additional sets of independent field data to verify the model assumptions and the quantitative understanding of the life cycle and 2) once a consistent parameterisation is found, the model can be used to simulate the effects of changes in the fishing mortality patterns with regard to the size selectivity and seasonal distribution of fishing effort. The simulated seasonal egg production of the extended model can be compared with the relative index of seasonal egg production that is used to determine the number of daily egg cohorts. The model should be capable to reproduce the characteristic bimodal pattern with a distinct summer- and a winter egg production peak. Furthermore the model should produce a pronounced peak of the catches is autumn, which is regularly observed in the catch statistics. This peak is most likely originating from the peak of juveniles observed in May/June on the tidal flats which have grown to commercial size during summer. Therefore the seasonal pattern of shrimps attaining the 50mm length (as a proxy for the commercial size) can also be used as a simpler proxy for the increase of commercial catches in autumn. This output is more robust, since it is independent from biased parameters of the fishing mortality pattern.

The present extended model version simulates only the female part of the population. The currently available data do not allow an accurate parameterisation of *crangon* growth as a function of temperature, size and sex. Instead of using guessed values for both sexes we have decided to keep the number of uncertain parameters as low as possible and model females only. The rational for this decision is that the females entirely dominate the larger size classes and therefore also the commercial catches. The two sources of field data that are available for comparisons with model results, number of egg bearing females and commercial catches, can therefore be explained with the results from a model of the female subpopulation.

Cohorts are initiated daily over a four year period. The simulation results are presented only for the last year, when equilibrium conditions are approached and all size and age classes are present. All daily cohorts are computed sequentially and the results are aggregated during the total simulation time into the different result categories by calendar day and size class.

3.2 Material and Methods

Growth of juvenile and adult shrimp

Growth was modelled basically in the same way as described in Temming and Damm (2002) for the juvenile shrimp. The daily length increment was calculated from the first derivative of the Bertalanffy growth equation:

$$dl/dt = E - K * l$$

where the constant E is defined as $E = a + b * T$ with T= temperature following Kuipers and Dapper (1984) who have parameterised this equation with data from unpublished growth experiments of M. Fonds (NIOZ). This model version is termed type I in the following.

The model was extended to give a physiologically more realistic representation of the catabolic term K, which is typically exponentially temperature dependent:

$$K = c * e^{d * T}$$

The complete growth equation then reads:

$$dl/dt = a + b * T - c * e^{d * T} * l$$

This model version with the exponential temperature term is referred to as type II in the following.

Variability in growth

Variability in growth was introduced using a normally distributed random multiplier for the parameter c of the growth equation. The complete growth equation then reads:

$$dl/dt = a + b * T - c * (1 + s * r) * e^{d * T} * l \qquad \text{with}$$

r = random number, normally distributed with mean zero and standard deviation equal to one
s = standard deviation in percent of the mean, s was set to 0.3 in all model runs.

The variability is introduced in the model such that several daily cohorts, typically 50, are started at the same day. All individuals of a specific daily cohort have the same randomly allocated growth parameter throughout the entire simulation, but they differ from all other cohorts of the same starting day and all other cohorts from other starting days.

Parameterisation of the growth model

Three different sets of parameters were used in simulation runs, two of these refer to the simple model type I, the third to the extended model type II:

parameter	type I (slow)	type I (fast)	type II (fast)	dimension
a	0.1625	0.25	0	mm/day
b	0.01025	0.014	0.038	mm/day/°C
c	0.00403	0.0042	0.0017	1/day
d	0	0	0.087	1/°C

The parameter set for ‘type I slow’ are those estimated by Kuipers and Dapper (1984) from unpublished data of M. Fonds (NIOZ). These growth data, however, refer to a mixture of both sexes. Earlier studies by Meixner (1969) and Tiews (1954) have revealed pronounced growth differences between the sexes, with females growing faster than the males. From the female shrimp perspective these parameters do not describe maximum growth. Female shrimp, however, are responsible for most of the commercial catch. We have therefore modified the growth parameters such, that the majority of the juveniles observed at a length of about 15 mm in May/June grows to commercial size until September. This was done with both model types, I and II. The resulting growth curves are displayed in Figure 3.1.

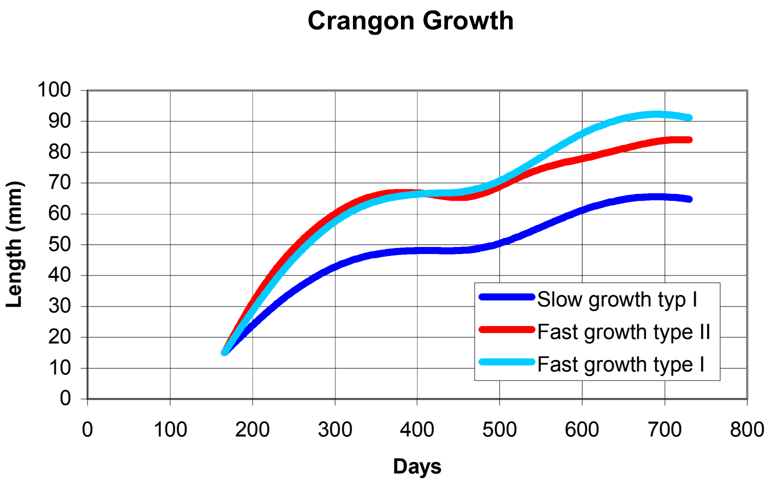


Figure 3.1 Crangon growth curves as used in the simulation model starting at 15 mm length in mid June.

Moulting

The moulting process was also modelled to trigger fertilisation and egg release. Although in reality growth in length and moulting are coupled processes, moulting intervals are calculated in the simulation independently. In Temming and Damm (2002) an equation is presented, which expresses the time between two moults as a function of the temperature and the age of the shrimp, expressed in total number of moults. The calculations follow the same scheme that was applied to control the egg development time with varying temperatures. Each day the fractional contribution of the moulting period is calculated using the daily temperature. If the sum of the fractions exceeds 1 the next moult is performed and if the cohort is mature, new eggs are fertilised and start their development.

Maturity

The size at first maturity is determined as a constant for each cohort at the start of the cohort in the egg stage. The sizes at first maturity vary randomly between cohorts in such a way, that the average pattern of the population matches corresponding field observations.

Mathematically the proportion of mature females (x) in is described as a function of length using the logistical equation:

$$x(l) = \frac{f * g * e^{h*(l-l_0)}}{1 + g * e^{h*(l-l_0)}}$$

with f, g, h and l_0 as constants, l = length in mm, x(l) = proportion of the mature females. The allocation of a random length at first maturity for a cohort starts with a random number equally distributed between 0 and 1. Then the inverse logistical equation is used to determine the length (l) for which the proportion x(l) equals the selected random number. This length is than allocated as length at first maturity for the respective cohort. Once the cohort has exceeded the allocated length at first maturity new fertilised eggs are introduced in the simulation for each remaining female at each moult. Presently the numbers are simply registered per length class and calendar day for the presentation as model output.

The parameters for the above equation are estimated from field data on the proportion of egg bearing females relative to all shrimp in a given length class. Such data were available from commercial catch samples of the German shrimp fleet covering all months and several decades. From a sub set of these data (years 1958– 962) one overall mean pattern was calculated. From these data the numbers of males per length class (Table 1) were subtracted to express the egg-bearing females relative to all females. The share of males shrimp per length class was extracted from Martens and Redant (1986). A logistical function was fitted to the female data by means of the solver function in Excel. The parameters were estimated as: f=59.086, g=0.054, h=0.272 and l_0=47.5 (Figure 3.2)

Table 3.1 Fraction of males in Belgian summer and winter samples (Martens and Redant, 1986).

length class	30–35	35–40	40–45	45–50	50–55	55–60	60–65
fraction males summer	52	46	35	30	9	2	0
fraction males winter	57	62	63	56	45	15	2

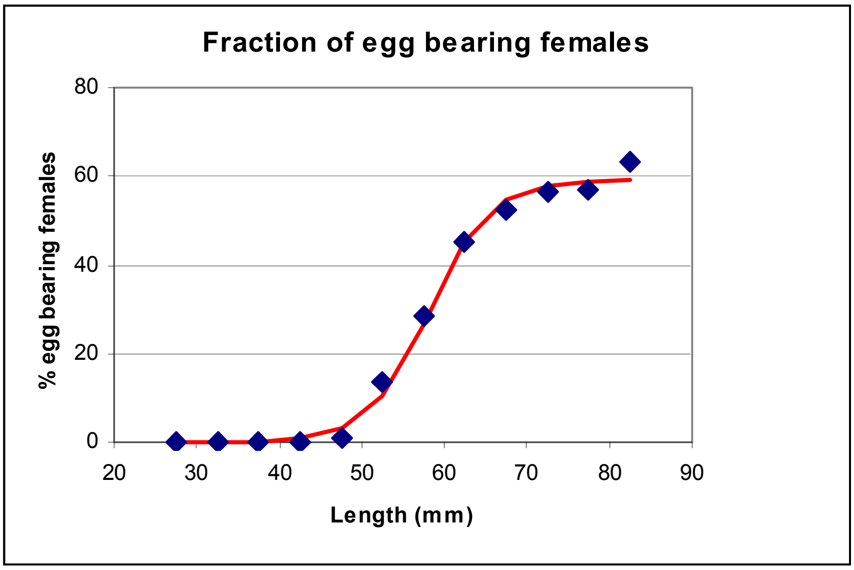


Figure 3.2 Fraction of egg bearing shrimp in relation to all shrimp per size class. Diamonds are mean observed values over all months from German catch samples (port Büsum) of the years 1958–62, line: fitted model.

Number of eggs per female

The total number of eggs that is allocated to each mature female after a moult in the simulation is estimated from data by Havinga (1930). A cube function was fitted to his data giving:

$N_{egg} = 0.01878 * l^3$

Mortality

Mortality was introduced initially, to investigate the role of the interaction of growth variability and size specific mortality. Evidence stems from work on fish larval survival, that only the fastest growing individuals will contribute to the surviving population if mortality is high and decreasing with size. The size dependency of mortality was parameterised using published allometric relations. Additional information on the level of total mortality in adult shrimp stems from length converted catch curve analysis applied to catch composition data of the German fleet (Temming *et al.* 1993). Initial simulations revealed however, that strong seasonal differences in mortality levels are required, to match the simulation results with any of the seasonal patterns from the field data.

Banse and Mosher (1980) have plotted production/biomass ratios of various invertebrate species on the mean weight of the organism at maturity and fitted an allometric function to these data. Production/biomass (P/B) ratios have been shown to be mathematically equivalent to the exponential coefficient of total mortality (Z). Their final model for invertebrate mortality reads:

$P/B = Z = 0.65 * W^{-0.37}$

With W = mean dry weight (g) of the species at maturity. This relationship was applied to the weights of different sizes of larvae, juveniles and adults. The dry weights of larvae stages calculated from an equation provided by Criales (1985):

$W_{larvae\_dry} = e^{2.7+0.222*stage}$ for zoea stages 1 to 6.

This leads to estimates of the dry weight in the range of 19 to 56µg and corresponding exponential mortality coefficients ranging from 21.9 to 14.5 y^{-1}, depending on the larval stage.

The weight of the juvenile and adult *crangon* was calculated from the length weight relationship provided by van Lissa (1977):

$W = 3.75 * 10^{-6} * l^{3.186}$

If dry weight is assumed to be 25% of the wet weight, this relationship predicts dry weights of shrimp between 158µg (5 mm) and 0.7 g (70mm) and the corresponding mortality estimates from Banse and Mosher's equation are 9.9 and 0.4 y^{-1}, respectively. Redant (1989) has compiled P/B values for various epibenthic species including C. *crangon*. The values for C. *crangon* range from 2.0 y^{-1} to 8.4 y^{-1}, however, most of the investigations were restricted to small shrimp only, e.g. the sub-population on the tidal flats. For shrimp larger than 45 mm total mortalities have also been estimated from length composition data and growth parameters (Temming *et al.* 1993). The estimates range from 2.9 to 7.7 y^{-1}, with lower values referring to the data of the years before 1970 and higher values thereafter. Results differ also between regions and methods (length converted catch curve vs. Wetherall *et al.*). Oh *et al.* (1999) derived an estimate of natural mortality for *crangon* in the Irish sea from length converted catch curves of M = 3.6 y^{-1}. These estimates are, however highly sensitive to the growth parameters used in the calculations, and these growth parameters are in both studies highly uncertain. Furthermore sexes were not explicitly separated in these calculations. When compared to the estimates of Banse and Mosher's allometric equation these values indicate a higher mortality for large shrimp, than predicted by the general model. This deviation can be expected, however, since the dominant predators of larger shrimp are juveniles of larger fish, like cod and whiting, which have no obvious restriction with regard to the size of shrimp consumed. In addition, the estimates from the length compositions include fishing mortality as well, which is also not size selective above the selection range.

Initial model runs were made with the following natural mortality levels: larvae: 17.7 y^{-1}, juveniles 5–20 mm: 10.2 y^{-1}, juveniles 20 – 50 mm: 4.5 y^{-1} and adults > 50 mm: 3.2 y^{-1}. Fishing mortality was assumed to be half the natural mortality of the adults: F = 1.6 y^{-1} so that the total mortality for the adult shrimps sums up to 4.8 y^{-1}. The values were chosen to reflect the orders of magnitude for the different life stages, taking into account the different sources of information. With these mortalities being constant for all seasons it was impossible to reproduce any of the seasonal population patterns derived from field data. The main reason was that the same mortality levels induced a much higher cumulative mortality for the winter egg production when compared to the summer egg production due to the long egg and larval development times. It was therefore essential to construct a mortality matrix with seasonally varying mortality levels. Some rough guidelines were developed for the distribution of mortality levels across the seasons: 1). The mean values should match the yearly values used before to ensure that natural mortality decreases continuously with size. 2) The seasonal changes follow an approximately continuous and unimodal pattern. 3) The natural mortality of adult shrimp should reflect approximately information on seasonal predation by the two most important predators, whiting and cod and 4) the fishing mortality should approximately follow the trend in nominal fishing effort. For the different size groups the following settings were made:

Larvae: The mortalities were approximately scaled in proportion to temperature based on general assumption that the turn-over in the pelagic system is correlated with temperature and the observation that numbers of potential predators are highest in summer time.

Juveniles 5–20 mm: Basically the same pattern was applied as for larvae, but highest values were shifted into late summer and autumn, based on observations of seasonal predator densities in the Belgian (bib and whiting, Hamerlynck and Hostens 1993) and German Wadden Sea (whiting and cod, Jansen 2002).

Juveniles 20–50 mm: Again maximum mortalities were shifted into late summer and autumn. The maximum consumption of *crangon* (with length from 15 to 50mm) by whiting and cod in the northern German Wadden Sea was found between August and October (Jansen 2002). From stomachs sampled in coastal areas outside of the Wadden Sea in combination with consumption estimates using the multi-species virtual population dynamics model for the North Sea the maximum *crangon* consumption was estimated for the fourth quarter for cod and whiting (Table 2, Temming *et al.* 2000).

Table 3.2 Total consumption of shrimp by cod and whiting in t (Temming *et al.,* 2000).

Predator	Cod		Whiting	
Quarter	shrimp=<50mm	shrimp>50mm	shrimp=<50mm	shrimp>50mm
1	3079	1280	4591	915
2	2059	494	990	111
3	1110	1463	3222	537
4	11893	7697	34790	8549

Adults > 50 mm: Maximum mortalities were assumed for October, since predation by cod and whiting was highest in the 4th quarter (see above). Shifting the maximum further to the mid point of the quarter (November) lead to an extreme reduction of the winter egg cohorts, since eggs are carried by the females and die together with them.

Fishing mortality: Fishing mortality was assumed at full level for shrimp >=50 mm and zero for shrimp below 50 mm. This simplification is justified by experimental results demonstrating very high survival rates for discarded undersized shrimp (Lancaster and Frid 2002). The monthly pattern was adjusted to the mean effort pattern of the German fleet in kw-days at sea for the period 1986 – 1996 (Table 3, ICES 2001 and Temming *et al.* 2000). The full matrix of mortalities by size and month is given in Table 3.4.

Table 3.3 Fishing effort in kw-days, German fleet, mean figures 1986–1996.

Months	effort kw-days	F (per year)
Jan – Feb	18000	0.08
March, Dec.	133000	0.6
April - Nov.	595000	2.7

Table 3.4 Mortality coefficients by month and size class.

	M	M	M	M	F
Month/size	Larvae	5–20mm	20–50mm	>50mm	>50mm
1	4.0	3.0	2.5	1.1	0.1
2	4.0	3.0	2.8	1.1	0.1
3	4.8	3.5	3.0	1.1	0.5
4	5.0	4.0	3.0	1.1	2.2
5	10.0	4.5	4.0	4.5	2.2
6	20.0	5.5	4.0	4.5	2.2
7	30.0	7.0	5.0	4.5	2.2
8	40.0	20.0	5.0	4.5	2.2
9	40.0	25.0	6.0	4.5	2.2
10	30.0	25.0	8.0	6.7	2.2
11	20.0	17.0	7.0	3.4	2.2
12	5.0	4.5	3.5	1.1	0.5
Mean	17.7	10.2	4.5	3.2	1.6

Model outputs for comparisons with field data:

1) Relative index of seasonal egg production

The derivation of this index was presented in detail in Temming and Damm 2002, the index is shown in Figure 3.11 together with model predictions. In the model simulations all eggs of all cohorts are simply summed per calendar day, at the day of their fertilisation.

2) Relative number of shrimps attaining 15 mm (length of recruits on tidal flats)

This index was derived by Temming and Damm (2002) from monthly field data on the densities of juvenile recruits with mean sizes of approximately 15 mm on the tidal flats of the German Wadden Sea. These data were slightly modified into a format, that is more directly comparable to the model outputs. For each member of each simulated cohort the calendar day is registered when the length of 15mm was attained. These figures are summed per calendar day.

3) Relative length of shrimp attaining 50 mm (commercial length)

This index is identical to that for 15 mm shrimp in the way it is calculated. It can be compared with the seasonal pattern of commercial landings but no direct match should be expected. The comparison should reveal a pronounced increase of numbers of shrimp attaining 50mm before the peak of the commercial landings in September / October. Given the high mortalities and the information about maximum growth rates of *C. crangon*, the autumn increase in landings can only be caused by the recruits of the same season, that were observed in May June on the tidal flats at about 15 mm length and have grown to commercial size (about 50mm) during the summer.

4) Catch rates

Applying the fishing mortality rates in each daily time steps leads to the accumulation of monthly catches of shrimp > 50 mm in each cohort. These are finally added by month to be comparable with the monthly pattern of commercial catches. Contributions of males are not included in these simulated catches.

5) Length composition of the female sub-population

Since the model represents only the female sub-population, a direct comparison with length compositions from field data was not possible. Monthly length composition data for both sexes combined were available from the German by-catch sampling program Tiews (1990) for three different regions and more than three decades. Data on relative shares of males per length class for two seasons (summer, winter) were extracted from Martens and Redant (1986). The German length composition data were aggregated likewise to match the seasonal aggregation of Martens and Redant's data. Then the numbers of males were subtracted from the German data set to reveal an approximate size composition of the female sub-population. Finally the data sets of the two seasons were added to one mean yearly average pattern. This aggregated pattern is displayed in Figure 3.13 together with the simulated size compositions.

a) Scenario runs for which detailed outputs are presented

1) Standard run

The standard run is characterised by the following conditions:
Temperatures: German waters, two water bodies: inner coastal waters and off shore (see Temming and Damm 2002)
Location of larvae: always in off shore waters
Location of adults, eggs and juveniles: always in the warmer of the two water bodies
Relative egg production: bi-modal pattern (index of relative seasonal egg production)
Growth parameters: Fast growth, model type I
Longevity: 3 years
Natural mortality: seasonal patterns with summer/autumn peaks as in Table 3.4
Fishing mortality: 50% of adult mortality, seasonal pattern following nominal effort. Fishing mortality only effects shrimp of 50mm length and above. Catches likewise refer to shrimp of 50 mm and above.

2) Slow growth type I

All settings as in run 1 but parameters for slow growth of model type I used.

3) Fast growth type II

All settings as in run 1 but parameters for fast growth with model type II

4) No seasonal variation in natural mortality rates

All settings as in run 1 but no seasonal variability in natural mortality. In all months the yearly mean values of a size class are applied.

5) Larvae in warm water

All settings as in run 1 but the larvae are allocated to the warmer of the two water bodies at any time.

6) Dutch water temperatures

All settings as in run 1 but the two temperature data sets were taken from Dutch waters (see Temming and Damm, 2002)

7) Constant egg production

All settings as in run 1 but instead of the relative index of seasonal egg production a constant seasonal egg production was applied.

8) Constant fishing mortality

All settings as in run 1 but fishing mortality was set constant in all months.

9) standard run II

All settings were as in run 1 with the following exceptions: the initial number of eggs was fixed to generate a total catch with the standard pattern of monthly fishing mortalities of about 15000 t (the actual catch is 15474 t). Since in previous runs the fast growth with model type II gave the best agreement with observed data, growth parameters for fast growth type II were used. Furthermore two temperature data sets were included: one representing Dutch waters (as in run 6) and the German data set from the standard run (1). Larvae were allocated always to the warmer of the two water bodies representing off shore while all other stages could choose between the warmest of all four data sets at any time. The rational for this scenario is that with this setting the seasonal patterns of recruitment and commercial catches match sufficiently close with the observed patterns to allow the investigation of changes in the effort patterns. A biological justification for this scenario was given in Temming and Damm (2002): In order to explain the deviation between simulations and observations especially in the very cold year 1986 it was hypothesised that the early immigration wave of new recruits in the German waters originates from Dutch waters and that these larvae are transported with the residual currents to the German coast.

b) Scenario runs were only the total catch in tonnes is presented.

10) Temperature increase +1°C

All settings as in run 9 but all temperatures (German waters) were raised by +1°C.

11) and 12) Winter fishery

All settings as in run 9 but fishing mortality rate in January to March set to maximum value F=2.33 (run 11) or to half this value F=1.17 (run 12)

13) and 14) summer fishing stop

All settings as in run 9 but fishing mortality rate set zero in July and August. In run 13) no compensatory increase of F in other months was allowed, while in run 14) the remaining fishing mortalities were increase to yield the same yearly mean F as in run 9)

15) and 16) Fishing effort changes

In these two runs the monthly fishing mortality values were varied from half the standard value to three times the standard value (run 15) and in run 16) the same was done, but with a different initial F/M ration of 1 instead of ½ in the standard run, while the total mortality of the adult shrimp was kept at 4.74 as in run 1). The mean annual F was 2.37 y^{-1}

instead of 1.58 y^{-1}. Since the initial numbers of eggs were not readjusted, the total catches for the 100% fishing mortality run (reference) were higher than in the previous runs. The focus of the analysis was on the relative changes of catch levels.

<u>17 and 18) Changes of the minimum commercial size of the catches</u>

In these runs the minimum size of the commercial caches was set either as 45 mm (run 17) or 55 mm (run 18). The rationale for these scenarios is the observation of decreasing minimum sizes in the commercial shrimps that are used for human consumption over the last decades. These changes are related with the shift from home peeling in the fishing countries to peeling factories in foreign countries, today mainly Morocco. The simulations will indicate the potential of such changes to increase the total landings without effort changes.

3.3 Results

The seasonal pattern of juvenile shrimp attaining 15 mm length

The monthly pattern from the standard run (run 1) is plotted together with the mean pattern from field data. It is obvious, that predicted pattern is shifted into summer by approximately one month. The colours in the bars code the calendar months, in which these recruits started their simulated life as fertilized eggs. The first main peak of juveniles originates mostly from the winter egg production of the preceding winter (Figure 3.3). Summer spawned recruits occur between July (eggs fertilised in April) and October (eggs fertilised in August). Two of the alternative scenario runs (runs 5 and 6) reduce the deviation between observations and predictions. In run 5 the larvae are exposed to warmer water early in the season and this accelerates their development. In run 6 eggs and larvae are exposed to Dutch water temperatures, which increase earlier in the season compared to German temperature data set (Figure 3.4).

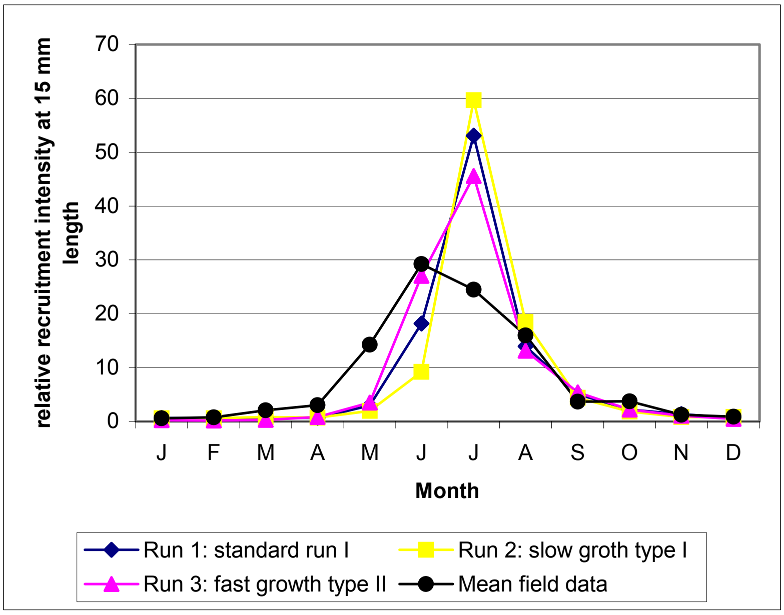


Figure 3.4.a Relative recruitment intensity at 15 mm length from runs 1–3.

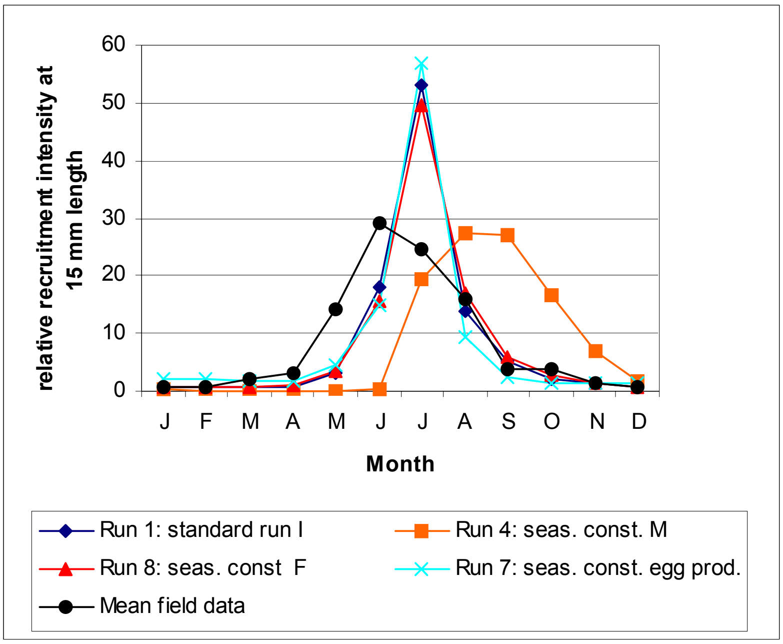


Figure 3.4.b Relative recruitment intensity at 15 mm length from runs 1, 4, 7, 8.

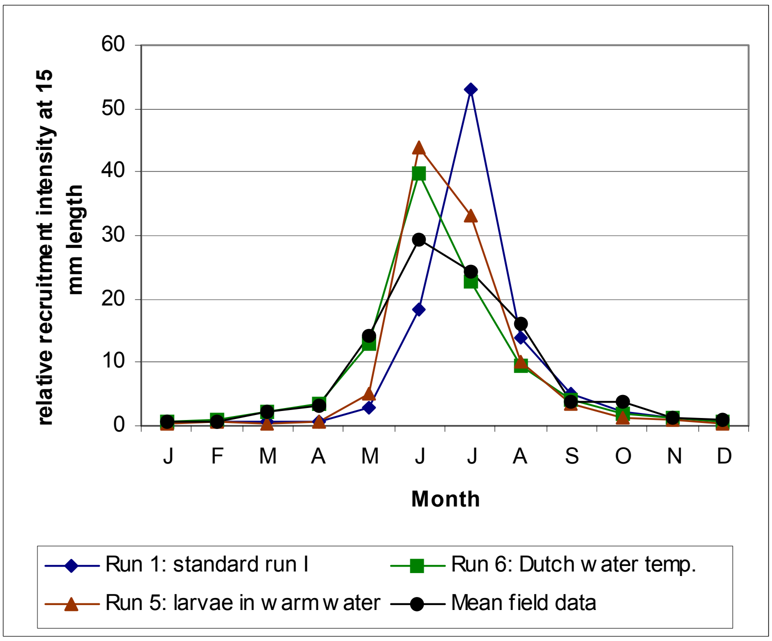


Figure 3.4.c Relative recruitment intensity at 15 mm length from runs 1, 5, 6.

The seasonal pattern of shrimp attaining commercial size (50 mm)

When the results from the standard run are compared to the monthly landings pattern, it is obvious, that the increase in 50 mm shrimp occurs to late in the season to explain the increase in landings during August and September (Figure 3.6). The cohorts that contribute most were started between November and March. (Figure 3.5). The deviation is reduced, if either Dutch water temperatures are used (run 6) or if the larvae are exposed to the warmer of the two water bodies at any time (run 5). Also the application of the fast growth model type II (run 3) generates a shift of the peak by approximately one month (Figure 3.6). The application of constant mortality values for all months (run 4) generates a peak that is shifted even further into the late autumn/winter when compared to the standard run. The application of the slow growth parameters (run 2) generates likewise a peak in late autumn/winter and generally a very flat seasonal pattern.

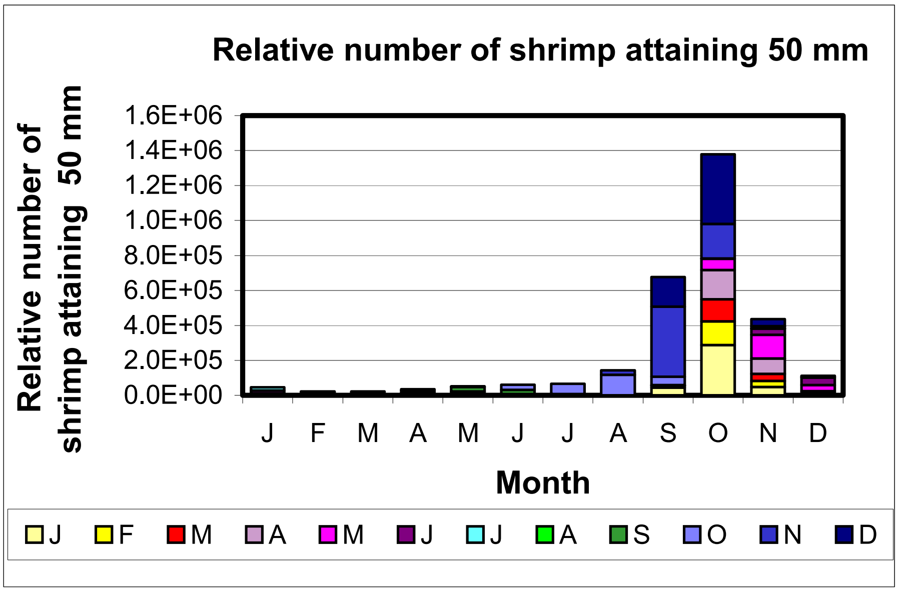


Figure 3.5 Relative numbers of shrimp attaining 50 mm from run1 (standard run I). Colours code the months when the respective cohorts started as fertilised egg.

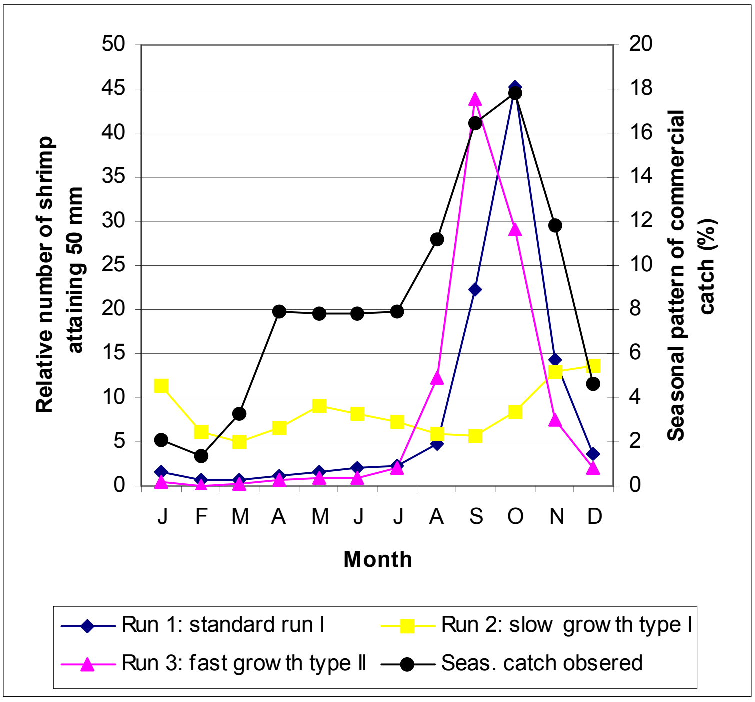


Figure 3.6.a Relative numbers of shrimp attaining 50 mm from run 1, 2, 3.

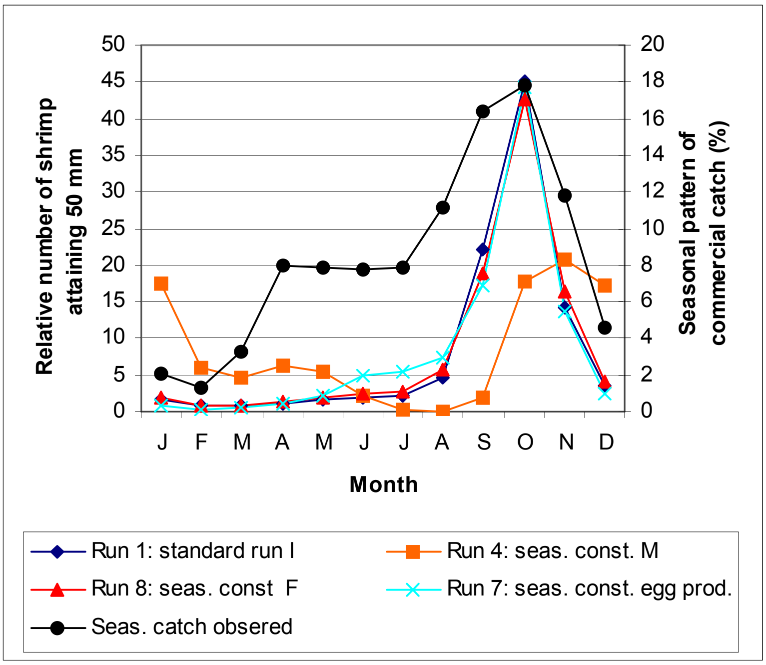


Figure 3.6.b Relative numbers of shrimp attaining 50 mm from run 1, 4, 7, 8.

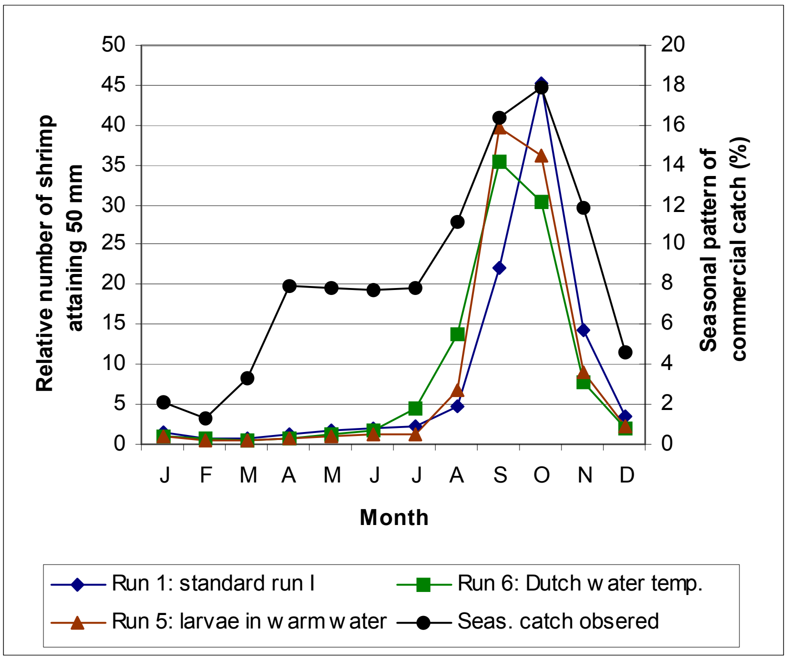


Figure 3.6.c Relative numbers of shrimp attaining 50 mm from run 1, 5, 6.

Commercial landings

The monthly pattern of simulated commercial landings from the standard run (1) does not match with the observed data (Figure 3.7). The main deviations are a delay of the increase in autumn by at least one month and an overestimation of the spring catches. A similar pattern results from run 7 with constant seasonal egg productions intensities (Figure 3.8). Assuming slow growth rates (run 2) leads to a disappearing of the autumn peak while constant mortality rates delay the autumn peak further into the early winter compared to the standard run (1). Allocating larvae to warm waters (run 5) or Dutch water temperatures (run 6) improve the location of the autumn peak but the closest match is achieved with the assumption of fast growth parameters and growth model type II (run 3). In run 9 the two effects of Dutch waters (run 5) and fast growth type II (run 3) were combined and this reveals a seasonal pattern of the simulated catches which is actually very close to the observed mean data (Figure 3.9). In the simulations the April values overshoot and the summer catches are somewhat underestimated. The commercial catches in the simulation originate mostly from winter eggs, with some contributions from the early summer production (April – June).

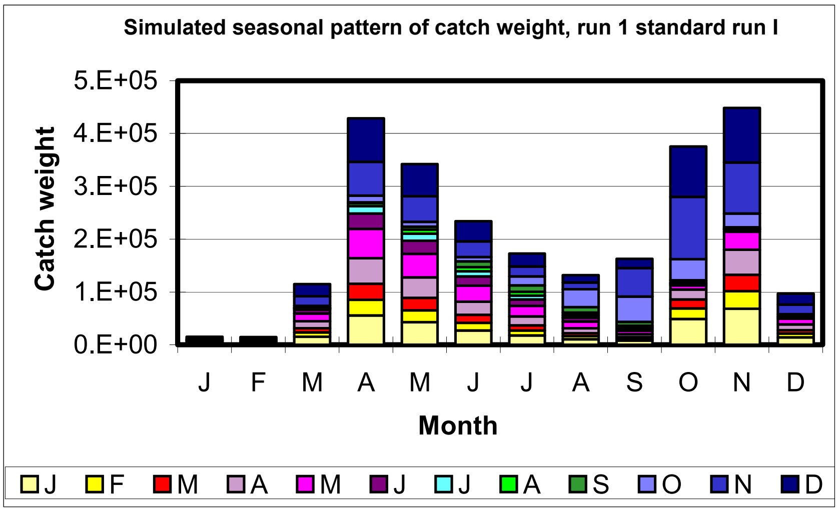


Figure 3.7 Simulated seasonal pattern of catch weight, run 1 standard run I. Colours code the month in which the cohort started as fertilised egg.

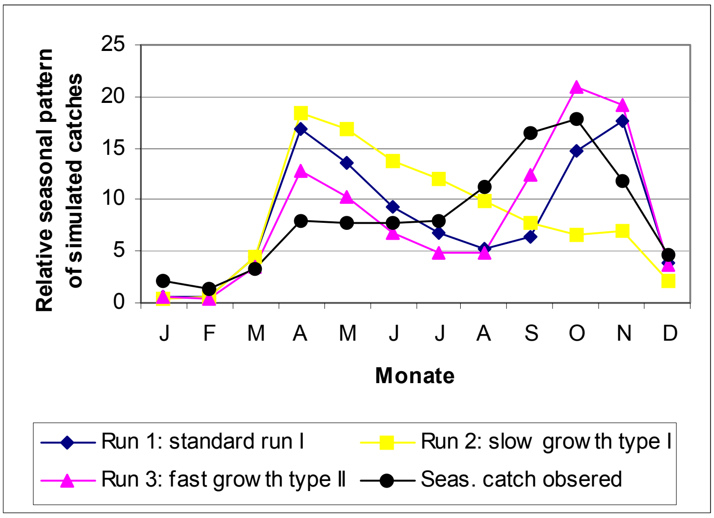


Figure 3.8a Simulated seasonal pattern of catch weight, run 1, 2, 3.

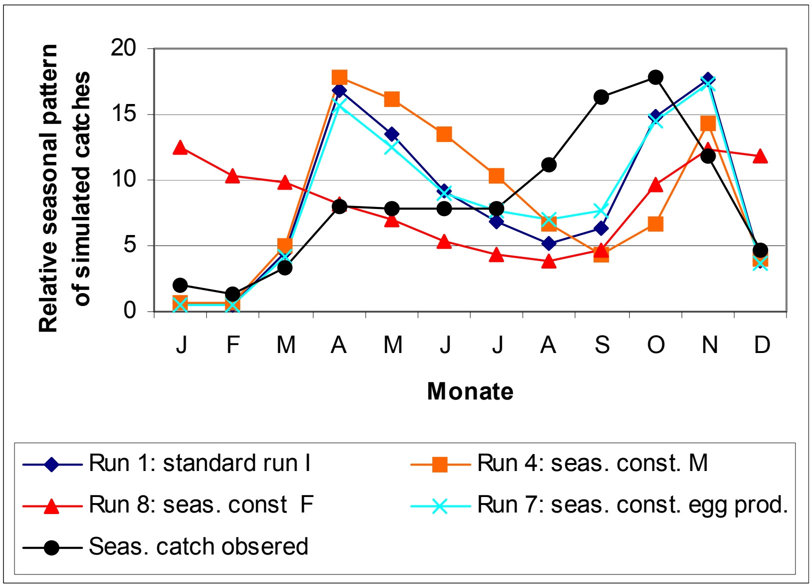


Figure 3.8b Simulated seasonal pattern of catch weight, run 1, 4, 7, 8.

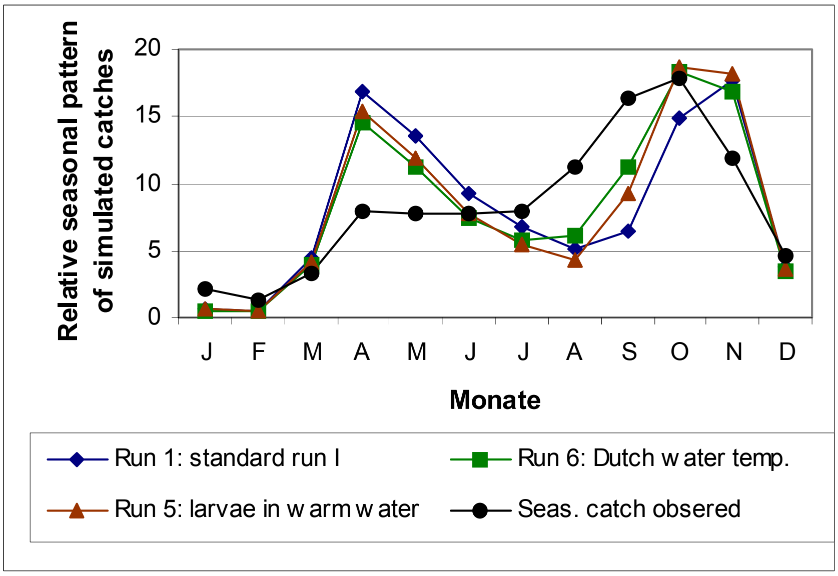


Figure 3.8c Simulated seasonal pattern of catch weight, run 1, 5, 6.

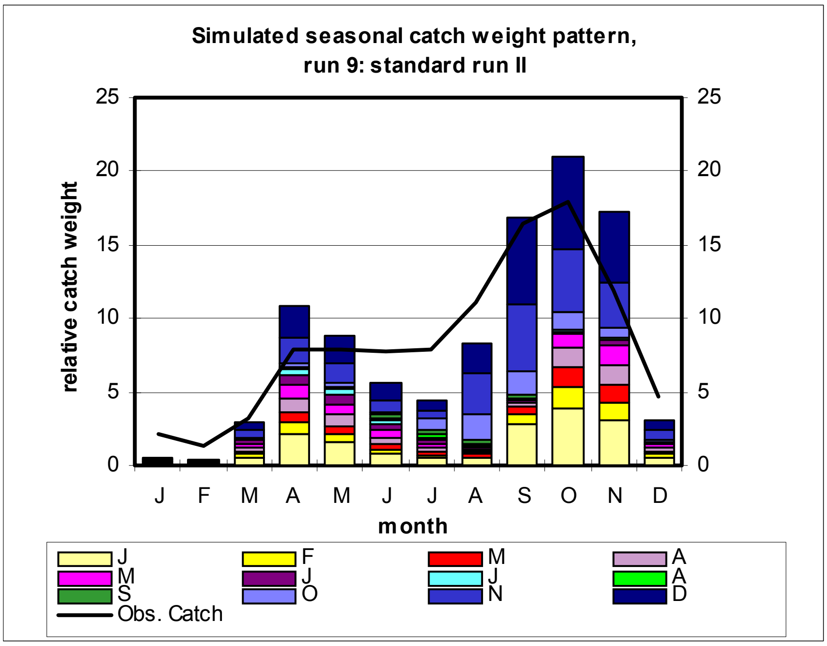


Figure 3.9 Simulated seasonal pattern of catch weight, standard run II (nr 9).

Seasonal egg production intensity

The standard run reproduces the summer peak in the field derived data, but underestimates the winter peak (Figure 3.10 and 3.11). The summer peak is mainly produced by cohorts originating from Summer eggs fertilised between May and September. Neither the use of constant mortalities (run 4), constant egg production intensity (run 7), larvae in warm waters (run 5) or Dutch water temperatures (run 6) leads to a pronounced winter peak in egg production (Figure 3.11). Only the introduction of fast growth with model type II (run 3) leads to a distinct winter peak, although shifted into the autumn by one month. The combination of Dutch temperatures and fast growth type II (run 9) yields a bimodal pattern with a pronounced winter peak, but as in run 3 the peak occurs about one month too early. The majority of the eggs is produced in the summer season with contributions from cohorts that were started between April and September. Cohorts that started (as fertilised eggs) in late summer (July – September) produce eggs mainly in the summer season, while cohorts from the winter and spring season produce eggs more evenly throughout the season (Figure 3.12).

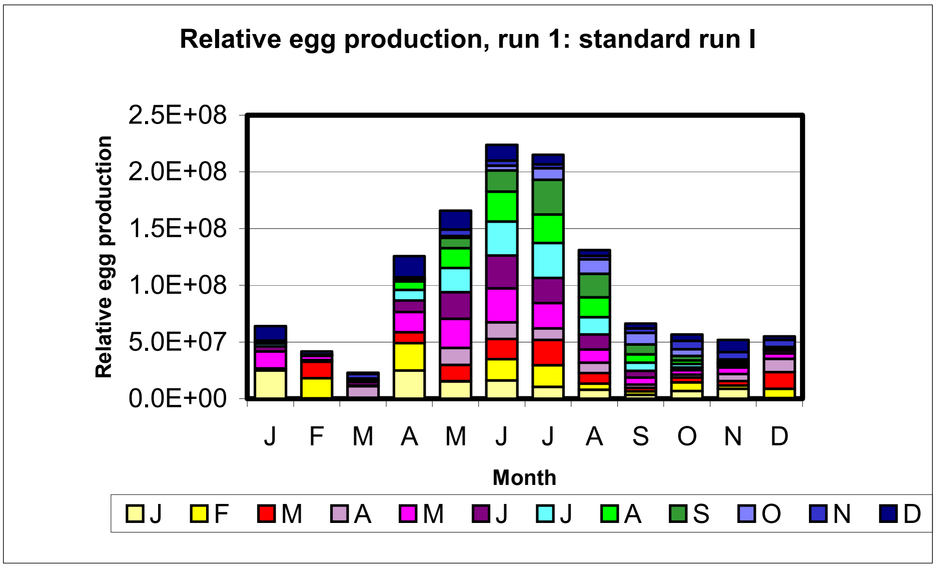


Figure 3.10 Relative egg production, run 1: standard run I. Colour codes the month in which the cohort has started as fertilised egg.

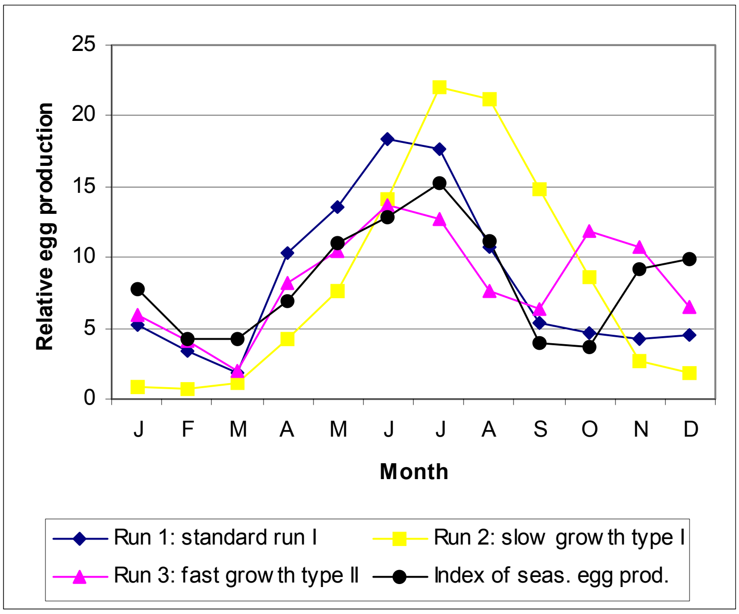


Figure 3.11a Relative egg production, run 1, 2, 3.

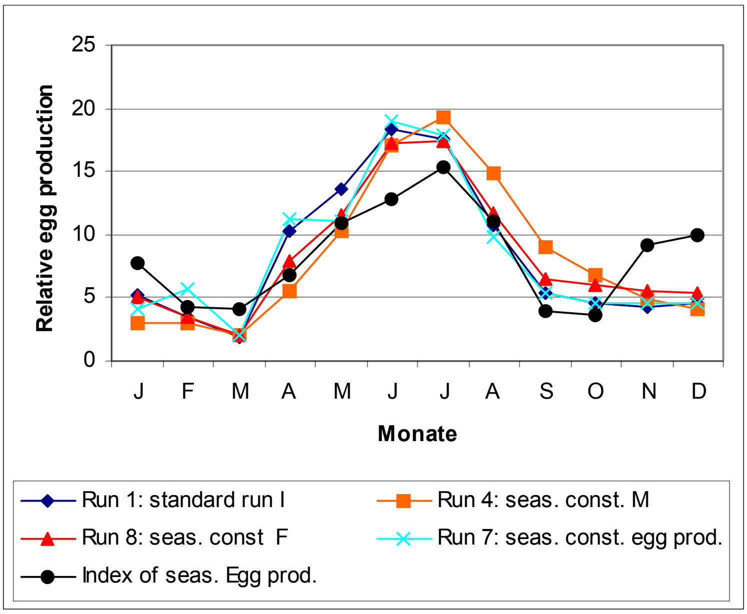


Figure 3.11b Relative egg production, run 1, 4, 7, 8.

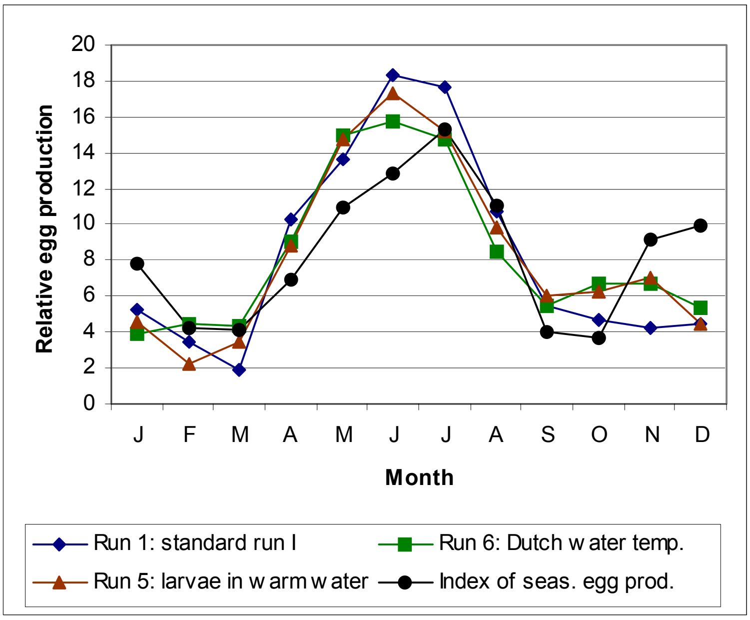


Figure 3.11c Relative egg production, run 1, 5, 6.

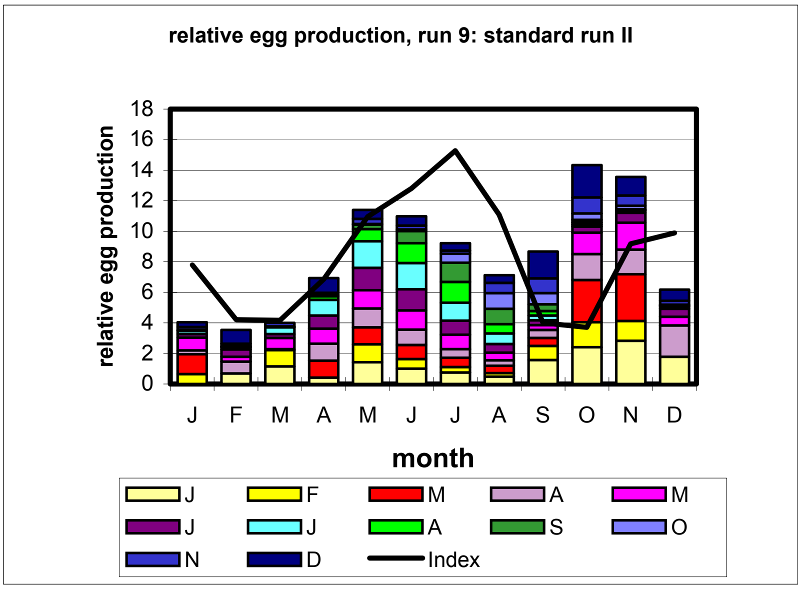


Figure 3.12 Relative egg production, run 9: standard run II.

Size composition of the shrimp population

The simulated average size composition of the female subpopulation with sizes >45 mm is displayed for the standard run together with the mean size composition derived from the German by catch samples. From the field data the estimated share of male shrimp was subtracted. The curve for the standard run (1) slightly underestimates the smaller sizes and likewise overestimates the abundance of larger shrimp (Figure 3.13). Neither constant egg production (run 7), fast growth typ II (run 3), larvae in warm water (run 5) nor Dutch water temperatures (run 6) change this pattern. The two options slow growth type I (run 2) and constant natural mortality (run 4) reverse the pattern with an overestimation of the abundance of small shrimp and underestimation of larger shrimp and give overall a worse fit to the field data. Applying a constant fishing mortality in all months (run 8) yields a size composition which is closest to the data, but still shows deviations as in run 1.

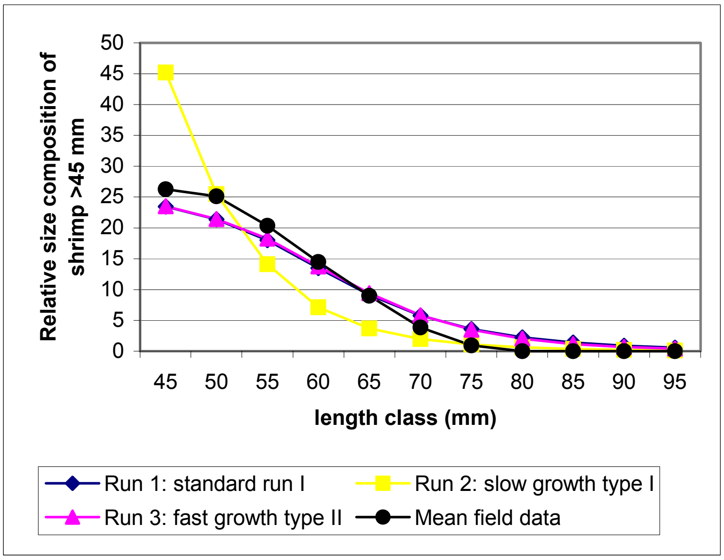


Figure 3.13a Relative size composition of shrimp >45 mm for run 1, 2, 3.

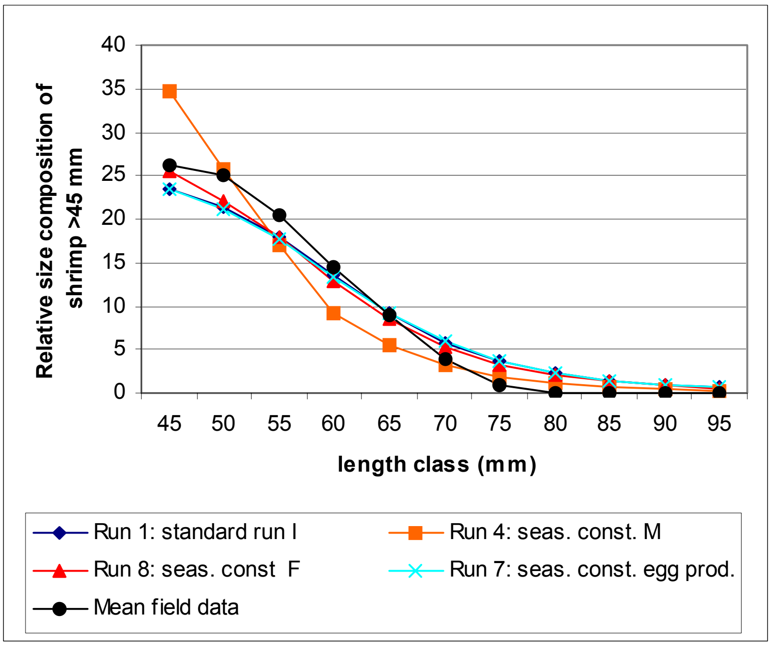


Figure 3.13b Relative size composition of shrimp >45 mm for run 1, 4, 7, 8.

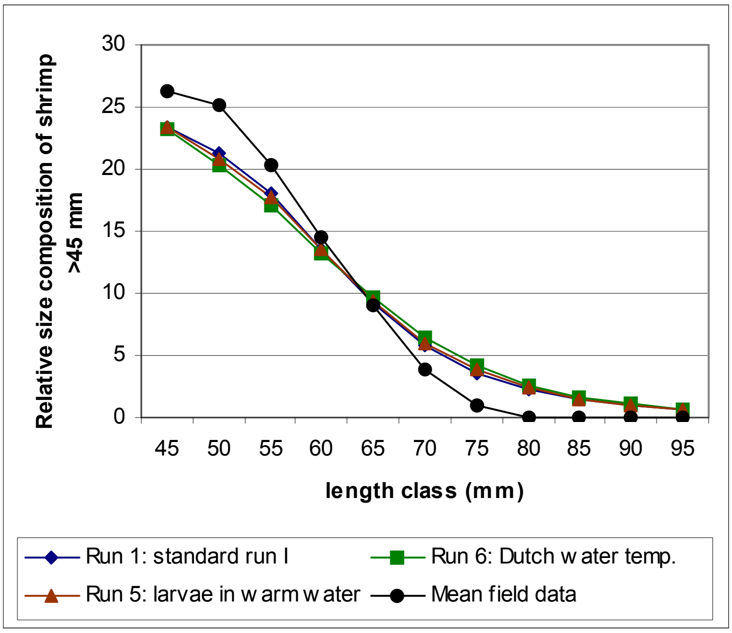


Figure 3.13c Relative size composition of shrimp >45 mm for run 1, 5, 6.

Age structure

The majority of shrimp larger than 40 mm between August and October is less than one year old, counted from the fertilisation day of the egg. Only in winter and spring significant numbers of shrimp older than 1 year can be found.

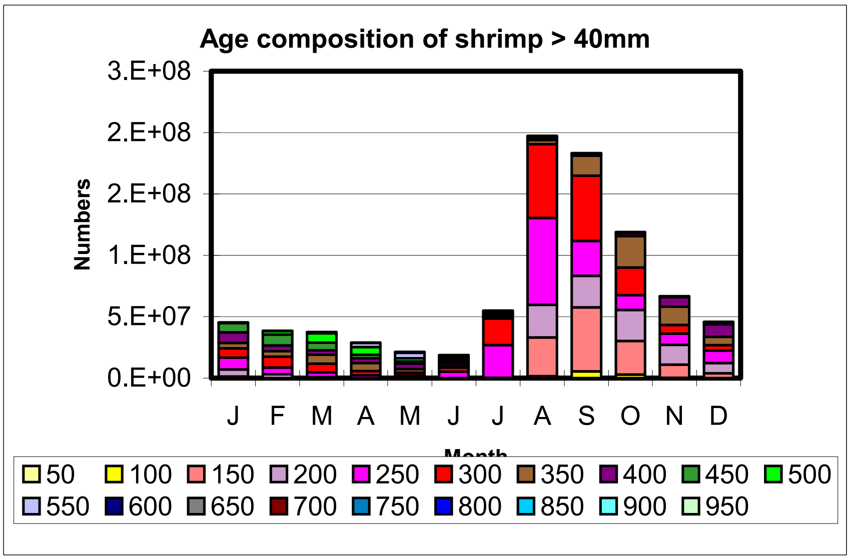


Figure 3.14 Age structure of the shrimp population >40 mm from run 3 with fast growth type II. Age is in days since fertilisation of the egg (50 day classes).

Temperature increase

The reference run for this scenario is run 9, which yields a total catch of 15474 t. The overall increase of temperature generates significantly higher catches of 24243 t (Table 5).

Table 3.5 Model catch in different scenarios.

Run	Model catch (t)	Scenario				
10	24243	Temp. + 1 °C				
11	17041	Winter fishery, January - March: F=0.5 x Fmax				
12	17675	Winter fishery, January - March: F= Fmax				
13	14009	Summer fishing stop, July+Aug.: F=zero, no comp.				
14	16189	Summer fishing stop, July+Aug.: F=zero, total F=const.				
15		F/M = 1/1 for F-factor = 1, variable F-factor				
		F-factor =	% change in catch	F	Z	F/M
15	20114	0.5	75	1.19	3.57	0.50
15	24145	0.8	90	1.90	4.28	0.80
15	26811	1	100	2.37	4.75	1.00
15	28425	1.5	106	3.56	5.94	1.49
15	30246	2	113	4.74	7.12	1.99
15	33116	3	124	7.11	9.49	2.99
16		F/M = 1/2 for F-factor = 1, variable F-factor				
		F-factor=	% change in catch	F	Z	F/M
16	10100	0.5	65	0.79	3.96	0.25
16	13000	0.8	84	1.26	4.43	0.40
16	15474	1	100	1.58	4.75	0.50
16	16541	1.2	107	1.90	5.07	0.60
16	18807	1.5	122	2.37	5.54	0.75
16	20504	2	133	3.16	6.33	1.00
16	23008	3	149	4.74	7.91	1.50

Summer fishing stop

The summer fishing stop in July and August leads to a loss in total landings of 1465 t, if the effort is not increased in the other months. If the total annual fishing mortality is kept as in the standard run by means of higher fishing mortalities in all other months the loss is turned into a slight gain of 715 t.

Winter fishery

Constant maximum fishing mortality in January to March generates an extra catch of 2201 t, while a winter fishery with three month with half the maximum fishing mortality yields 1567 t of extra catch. The winter fishery has also pronounced effects on the egg production in the subsequent season (Figure 3.15).

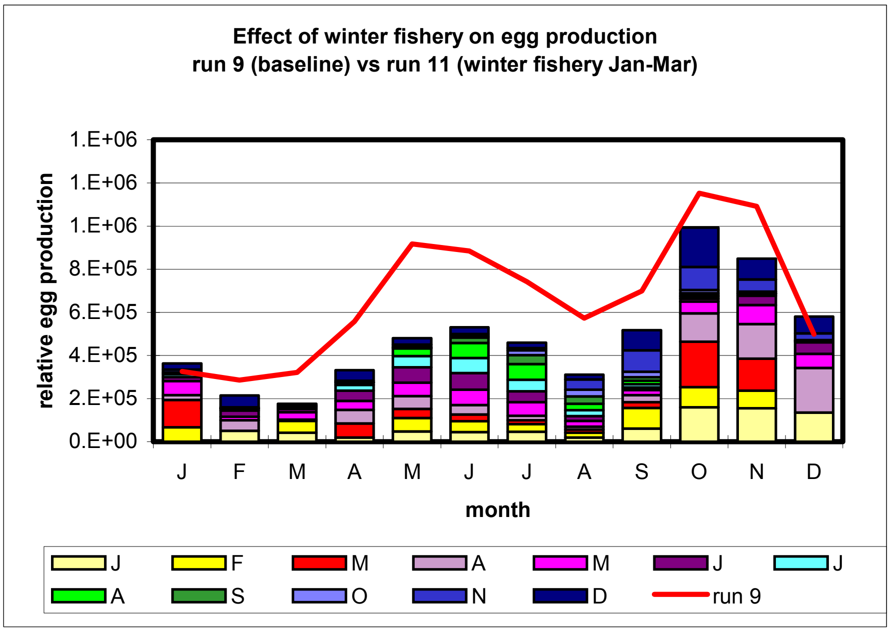


Figure 3.15 The effect of a winter fishery in January –March with full fishing mortality level on the egg production. Red line represents the baseline from run 9 (standard run II) compared to the results of run 11 (winter fishery).

Fishing effort changes

Changes in fishing mortality by a given factor generates less than proportional changes in the total catch. Halving F in the standard run (9) leads to a catch of 65% of the standard catch, while doubling the fishing mortality leads to only 133 % of the standard run catch. In these runs the ration of F to M was 0.5 as in the standard run and only the F values were changed without changing natural mortalities. The effects of F changes on the catch were even weaker, if an initial F to M ratio of one was assumed. Here a doubling of the F yielded only 13% more catch, while halving generated a loss of only 25%.

Changes in minimum commercial size

The total catches of the three scenarios with identical fishing mortalities are 15474 t (standard run 9 with 50 mm), 16324 t (run 17 with 45 mm) and 13900 t (run 18 with 55 mm). The gain in catches from a decrease of the minimum landing size of 55 mm down to 45 mm is 2424 t or 17.4% of the initial catch (with 45 mm).

3.4 Discussion

Parameter uncertainties

Growth

The currently used high growth rates for the females are supported by several published and unpublished experiments. Model growth rates of the fast growth option with growth model type II were 0.5 mm/day at a length 15mm and at 16°C. Larger shrimp of 45 mm length growth according to this model at 0.31 mm/day at 17.3°C. Similar growth rates for small shrimp were observed by M. Fonds (unpublished data), Meixner (1969) and Uhlig (2002). The growth rate of the larger shrimp (45 mm) is supported by data from Tetard (1985) who has followed the progression of modal length values in shrimp of the French coast. Under all circumstances can the growth rates predicted by the equation of Kuipers and Dapper (1984) be considered as unrealistically low, at least for the female part of the population. Neither the simulated catches, nor the seasonal pattern of egg production or the length composition can be correctly predicted if the slow growth type I is used in the simulations. This is partly because the equation is based on the unpublished data by M. Fonds, which refer to mixed sexes. However, the growth model type I also describes the data inadequately, since the decrease of growth rates with length is not independent of temperature as implied by the model structure. According to M. Fonds data growth rates of large shrimp do not increase to the same extent with high temperature as with small shrimp. This interaction between size and temperature is accounted for in the growth model type II (Temming *et al.* 2000). Fitting the growth model type II to the same data of M. Fonds already leads to higher predicted growth rates of shrimp below 50 mm in comparison to the prediction of the growth equation by Kuipers and Dapper (1984), even if the model is applied to identical temperatures. In our most realistic scenarios only this growth model is applied, however the parameters were not obtained from real data. The parameters from an initial fit to M. Fonds data were simply modified to reveal high growth rates for small shrimp at high temperatures but lower growth rates for large shrimp at high temperatures in comparison to the fast growth type I predictions.

Mortality

The mortality parameters can only be considered as rough guesses. The relations with size are based on a cross species analysis of P/B values, which may not be appropriate for the different life stages of a particular species. However, the simulation results not very sensitive to the actual mortality levels or to the slope of the mortality size relation. The critical part are the monthly differences. With size specific mortalities constant in all months it was impossible to reproduce any of the four field data sets. A central results from the model exercise is therefore that mortalities must differ dramatically between seasons. The allocation of monthly values was done in a rather heuristic way, highest mortalities were set in months with observed maximum densities of relevant predators. This approach can be refined with predator and area specific consumption rates, derived from available data. However the maximum consumption is not necessarily coincident with the maximum mortality, since mortality is determined by the consumption relative to the mean biomass in the interval considered. This aspect has not been investigated in detail, because only very limited data exist with regard to shrimp densities covering the entire depth range of their distribution area.

Maturation / Egg production

The current implementation of maturation and egg production needs refinement. Presently a mean yearly pattern of the share of egg bearing females per length class is used. Generally nothing is known directly about the maturation process. The data only record the share of berried females relative to total females and this is taken as a proxy for maturation. In these average data the maximum share of berried females does not exceed 60%, while this share can be as high as 80% for large shrimp in some months. However, the effects of a lower overall share of mature females on the results are limited, since this simply leads to a part of the model female population not participating in spawning at all. The percentage values of berried females from German samples are generally lower than those reported from other fisheries. A likely explanation for this discrepancy are differences in the sampling locations. German by-catch samples originate mostly from small vessels with a predominantly inshore fishing pattern. Samples from the Danish fishery, on contrast, stem only from waters outside of the Wadden Sea. Of more concern than the absolute levels are the deviations in the seasonal patterns. The most pronounced seasonal pattern in the share of egg bearing females is a general decrease to very low levels in September/October, which occurs with some deviations in samples from all regions investigated (see Section 3.6). This pattern is not fully reproduced in the simulated population. The model was set up with a yearly average maturity at size pattern to test, whether the autumn reduction in egg bearing females could be generated from the internal dynamics of the population. It would have been easy to reproduce the observed pattern with external forcing, e.g. by means of monthly data on the share of egg bearing.

Results of the best parameterisation

Recruitment

These results have extensively been discussed in Temming and Damm (2002). The main peak of juveniles observed in the Wadden Sea with lengths of 10 – 20 mm occurs in most simulations too late in the season. This can only be corrected with either Dutch water temperatures or with the exposition of larvae to the warmer of the water bodies at any time in German waters. We have applied the option with Dutch waters in our reference runs in order to generate a realistic seasonal catch pattern.

Catch rates

The monthly pattern of the catch rates is basically mimicked in the model runs, however the autumn peak occurs too late unless Dutch water temperatures are chosen as an option. Also the spring peak is too high in standard run I (run 1). The standard run II (run 9) in combining German and Dutch water temperatures with fast growth type II generates a monthly pattern that comes close to the observed one. Deviations occur in April where simulated catches are lower but still overestimated and in August, where simulated catches are too low. These deviations may originate from the use of the seasonal effort pattern as a template for the seasonal fishing mortality pattern. This implies that there are no seasonal differences in catchability. However, due to the seasonal migration patterns of the shrimp and due to the concentration of large parts of the fleet on shallow grounds in the Wadden Sea in late summer when the fishery concentrates on the new annual cohort, catchability will most likely vary during the season. Assuming a higher catchability in August due to the concentration of parts of the fishery in the Wadden Sea would translate into a higher fishing mortality in this month resulting in a higher catch. Likewise the catchability in April may be reduced due to the offshore migration of the adult shrimp population. Both effects would bring model results and observations in closer agreement. Nevertheless such adjustments were not made for the analysis presented here.

Egg production

The simulated patterns of the standard run (1) are entirely dominated by a very pronounced summer egg production followed by a very small winter peak. This large peak is due to large shrimp from the previous year, which according to growth model type I resume fast growth with the increasing spring temperatures. Since the number of eggs per female increases with a power of three to the body length, these large shrimp produce very high numbers of eggs per female. Due to the high temperatures also the moulting rates are fast, which leads to each female producing eggs batches at a higher frequency. These effects together generate the dominant summer peak. The application of fast growth type II restricts the temperature dependent growth of large shrimp and this reduces the summer peak considerably. Also the increased growth of the smaller shrimp leads to larger numbers of shrimp attaining size at first maturity in October and November and this contributes to a more pronounced winter peak. However, when compared to field data, this peak occurs by one months too early in the season. This bias is not easy to correct, since this larger shrimp are required in high numbers in September and October in order to simulate correctly the seasonal catch pattern of the commercial fleet. This implies that any modification in the growth or mortality patterns leading to the desired shift of the egg production peak later into the winter would also deteriorate the fit with the catch pattern.

The process that is not adequately represented is obviously the first maturation of the female shrimp. According to the data only very few female shrimp carry eggs in September and October. In case that the suppression of egg production in these months is the result of an internal regulation it can be incorporated easily into the model by reading in the observed values from each month. An alternative mechanism for the observed patterns would be a minimum age for maturity that prevents the new year cohort from becoming mature as early as September or October. This mechanism could explain the patterns on the assumption that most of the shrimp in all size classes in Autumn originate from the new cohort of the same year, because in the field data both small and large shrimp do nor carry eggs. Both options will be implemented in future versions of the program.

Size composition

The size compositions largely match the observed ones. However some degree of overestimation of larger sizes and underestimation of smaller sizes persists regardless of the options used in the runs. Part of the deviations results from a lack of winter samples from the commercial fishery, which results in these data being underrepresented in the field data set. The most likely explanation for the discrepancies is, however, the rough correction made for the male fraction of the. For this correction only limited data from a Belgian sampling program were available. Newly analysed data from Danish and German sampling programs will be used for an improved correction scheme.

General population dynamics

The structure of the shrimp population can be described as one major cohort wave that develops through the season. The recruitment peak from the winter egg production is rapidly followed by the fast developing cohorts from spring and early summer eggs. Together these form a major wave of adult shrimp from August to October. At this time of the year hardly any shrimp from the previous year are left, so that in essence the whole population is exchanged. This pattern emerges from a combination of the temperature synchronisation of the summer and winter cohorts and the high mortality levels. The shrimp from this combined winter/summer wave are the basis for the fishery in the autumn of the same year, as well as the following winter and spring. This explains why a complete failure of the fishery in autumn, as experienced in 1983 and 1990 is generally followed by a failure of the subsequent spring fishery.

The winter egg production is based o larger numbers of relatively smaller females, while the summer egg production is based on smaller numbers of larger females. These carry more eggs and moult at a higher frequency due to the high temperatures. The summer egg production is therefore more dependent on mortality and growth. This can be seen when the growth model is varied (run 1 versus run 3) or when a winter fishery is simulated (run 11). The summer egg production of a given year contributes mainly to summer spawning in the following year (especially from July and August), while the winter egg production leads to individuals spawning in all months of the year.

Results from the scenario runs 10–18

Temperature increase

The results from this overly simplistic test on the effect of changes in environmental conditions must be viewed rather as a system test than as an interpretable result. Due to the lack of realistic temperature patterns a constant delta-t was added in all months. The result is mainly an acceleration of development times during winter leading to earlier recruitment. These recruits have a longer growing season at higher temperatures leading to an earlier peak of catches in August and a total gain of catches of 6240 t from August to November. A more meaningful system test would be the investigation real temperature patterns in relation to the corresponding catch histories.

Summer fishing stop

The simulation of the summer fishing stop was mainly done to investigate the amount of compensatory increases in other months with either no effort increase or an increase to the same yearly fishing mortality level as before. If effort in the other month is not increased a net loss results. This net loss is however about 25% less than the sum of the losses in July and August in the standard run. The protection of shrimp in these months alone generated 500 t of additional catch in September. Increasing the effort in other months to reach the previous yearly F results in a net gain of 715 t. The losses in July in August are almost compensated for by the increased catches in September and October alone. This implies that an effort increase in the other months is not necessarily needed. However, the numbers from these scenarios are not applicable to the real fishery with the present model parameterisation, since the model catches in the Summer months are underestimated to some extent. Also in the real shrimp fishery the effects of prices should be considered in the determination of the optimal compensation strategy. Nevertheless these simulations have revealed strong evidence that such compensations will be possible without dramatic effort changes in other months.

Winter fishery

These runs were made to demonstrate the potential gains from a continuous fishery carried out through the winter months versus the effects on spring and summer catches as well as effects on the summer egg production. The net gain of three months of fishing with full fishing mortality amounts to about 2200 t. The actual catches in these three months are 4800 t, however catches in all following months decrease as a consequence of this fishery. The aggregated losses amount to 2600 t. The winter fishery essentially takes the same shrimp that could otherwise be caught in the following spring. The net gain results from the reduction in cumulative natural mortality if shrimp are caught at younger ages. The shift of fishing mortality into winter has also implications in the size of summer egg production peak, which is substantially decreased in this scenario. (Figure 3.14) This effect would have been even stronger, if fishing mortalities in November and December would have been raised to the same level.

Fishing effort changes

The results of the scenarios with variations in fishing effort illustrate that the predicted catch increases resulting from effort increases depended strongly on the assumed F/M ratio in the model. The smaller the current F component is in relation to M the larger future gains could be. This ratio is presently unknown but most likely it is smaller than 1. The scenario with F/M = 0.5 predicted a 22 % increases in yield as a reaction to increasing fishing mortality by 50%. Future efforts are needed to make use of available data on predator densities and stomach contents to better estimate the order of magnitude of the F/M ratio.

Changes in minimum commercial size

These runs were made to investigate the potential contribution in changes of the minimum landing size to the observed increases in total landings over the last decades. According to Tiews (19XX) this minimum size was 55 mm in the 1950s. The sieved catches in recent years contain larger shares of smaller shrimp with lengths down to 45 mm. The exact share of the different size classes is unknown, however. The results give some rough indication of the order of magnitude of this effect. A proper calculation, however requires a parallel simulation for male shrimps, since these are of particular importance in winter time. In recent years more data have become available which allow a better parameterisation of a model with both sexes.

3.5 Future work to improve the predation mortality patterns

In the current simulation model, the partitioning of total mortality (Z) over natural (M) and fishing mortality (F), and the seasonal distribution of M and F are based on the assumptions explained in Section 3. The partitioning of Z over M and F could be improved, if better estimates were available of the total removals by predation, to which the total removals by the fishery could then be compared. Estimates of the removals-at-length by the fishery can relatively easily be obtained from (a) sea or market samplings of the landed catches, and (b) estimates of the dead discards. The latter can be calculated from the numbers discarded by size class (obtained from sea sampling programs) and the corresponding discard mortality rates (obtained from the literature, e.g. Lancaster and Frid, 2002). Similarly, the seasonal distribution of M for the different size classes of shrimp could be refined, if better estimates of the monthly (or quarterly) removals by predation were available. Estimates of M which are solely based on estimates of the removals by predation, bear the risk of under-estimating overall natural mortality, since they do not account for other sources of natural mortality such as cannibalism, diseases, etc. It is, however, generally assumed however, that predation is the main source of natural mortality in *crangon*. In any case does the estimation of natural mortality coefficients from total predator consumption data require additional information on the biomass of shrimp per season and size class.

Estimates of the removals-at-length by predation are much more difficult to obtain than estimates of the removals by fishing, and require extensive data sets on, amongst others, the predator-prey-relationships between shrimp and its most important (demersal) predators, and the seasonal densities of the latter. Since these relationships are likely to differ between areas (in terms of both predator species involved and seasonal distribution of the prime predators) and between years, it is preferable that such calculations be made on an area-basis and over longer periods of time than just one year. Different possible approaches to resolve this problem were discussed, and a list of basic data that are required for such an exercise was drawn up. To calculate the removals-at-length by predation, three types of data are required, viz. (a) data on the share of *crangon* in the diet of its predators, (b) data on the daily ration of the predator by length and temperature and (c) data on the seasonal distribution and abundance (in absolute numbers) of the prime shrimp predators.

Potential prime shrimp predators

To start with, the WG has made a list of species that can be considered to be prime predators of *crangon* and that should be included in the exercise (see text table below). The list is based on the results of previous predation studies on *crangon* and needs to be complemented with bibliographic data on (a) the food composition of potential and/or alleged shrimp predators and (b) their relative abundance in different areas, viz. the English coastal waters, the Belgian coastal waters, the (Dutch and German) Waddensea and the Danish coastal waters.

Predator species		**Area**				
		English coast	**Belgian coast**	**Waddensea**	**Danish coast**	
Smelt	*Osmerus eperlanus*			X		
Cod	*Gadus morhua*		X	X		
Whiting	*Merlangius merlangus*		X	X		
Bib and poor cod	*Trisopterus spp.*		X			
Five-bearded rockling	*Ciliata mustela*		X			
Goby	*Pomatoschistus spp.*		X	X		
Gurnard	*Trigla spp.*		X			
Sea scorpion	*Myoxocephalus and Cottus*			X		
Armed bullhead	*Agonus cataphractus*		X	X		
Sea snail	*Liparis liparis*			X		

Daily intake of crangon by its predators

Estimates of the daily intakes of *crangon* by its prime predators are one of the key elements in the calculations. Since the simulation model uses separate estimates of **M** for different size classes of shrimp, the estimates of the daily intakes preferably should have the same resolution. Data on the food composition of the prime predators, and on the size classes of shrimp they feed on, can be extracted from the results of past and ongoing stomach sampling programs. Data of that type are available for some areas, viz. the Belgian coastal waters (past and ongoing stomach sampling program) and the German Wadden sea (available from unpublished reports and literature), but are mostly lacking for the other areas (English coast, Danish coast). One of the questions that therefore needs priority attention is to which extent the data for one area can be extrapolated to the others. Inter-annual and inter-area comparisons of the existing data sets might give an answer to this question. Data sets that are sufficiently large to allow such comparisons, however, are available for a limited number of species and areas.

Ideally, the stomach contents data should be made available to the WG in the format of predator-wise data matrices, giving (a) the weight-share of *crangon* in the stomach contents by predator size class (length of fish in 5 cm size classes), and (b) the average numbers of *crangon* (subdivided in 10 mm size classes) in the stomachs, equally by predator size class. An example of the latter is given in Figure 3.5.1

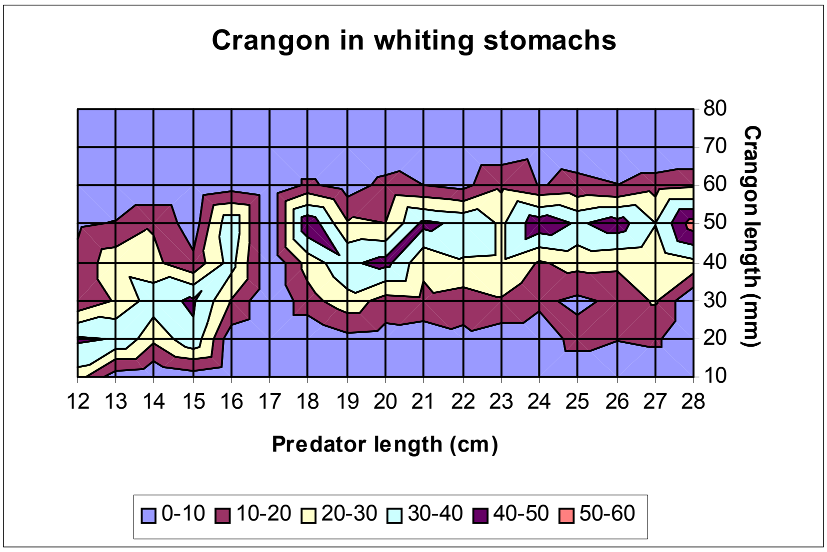


Figure 3.5.1 Example of predator size prey size specific stomach data. Whiting stomachs from Belgian coastal waters. Numbers refer to percent share per whiting length class.

Stomach contents data only give an instant picture of a predator's food composition (and of the relative share of *crangon* therein) and therefore need to be scaled over time to provide estimates of the daily intakes. Since food consumption rates (i.e. the quantities of food ingested relative to the predator's body weight) are linked to metabolic activity (which is both size and temperature dependent), these calculations should be done for each size class of predators and for each season separately. Such an approach however, requires extremely large sets of stomach contents data, and these are not available for all predator species. The consequence being, that for a number of species the calculations will most likely have to be made over a much larger spectrum of size classes (e.g. for all predator size classes combined) and over a larger time scale (e.g. on an annual instead of a seasonal basis) than would be desirable.

Daily intakes can be derived from the stomach contents data applying either the gastric evacuation rate approach or a energy budget approach. The energy budget approach can be expected to give the best estimates of the daily intake rates, but it is very unlikely that this approach can successfully be applied to all predator species. For some species, namely cod and whiting, the data available may be sufficient to allow both of the above mentioned approaches. This might be worth doing to find out whether the different approaches produce comparable outcomes in terms of quantities of *crangon* consumed annually. An analysis of the predator-shrimp interactions in the German Wadden Sea revealed that predator densities are far more variable than consumption rates per predator and deserve therefore most attention in the data compilation.

Predator densities

Data on predator densities (preferably by month or, if not available, by quarter) can be derived from the surveys that have been carried out in the different areas, although not necessarily over the same periods of time to which the stomach data refer. A prime limitation of the available survey data is the limited seasonal coverage, the most important survey, IYFS, is only conducted in autumn, except for Germany, where an additional spring survey is also performed. Extensive monthly data are only available from the German by-catch sampling program, but these data can not easily be converted into swept area estimates.

Survey data however, do not give absolute population densities. To calculate these, the survey data will have to be corrected for gear selectivity (which will definitely be the case for the smaller predator species, such as armed bullhead and gobies) and gear avoidance (which is most likely the case for the gadoid species). Information on these issues may be found in the literature, although it is unlikely that the necessary raising factors will be available for all *crangon* predators.

Eventually, the survey data will have to be raised across areas to estimates of overall population size by predator species and by size class. This procedure too will require careful examination of the basic data sets, in view of the heterogeneity in the spatial distribution of the different predator species.

3.6 The seasonal pattern of egg bearing females in different regions

During the preparatory meeting it was considered that the current implementation of the maturation process in the Y/R model needs to be refined. Members of the WG were therefore asked to bring recent unpublished data on the sex ratio and the fraction of ovigerous females females to the WG meeting, to allow a comparative analysis of these data. One of the guiding questions was whether the autumn low in ovigerous females occurs synchronised across all areas and sizes.

3.6.1 Danish commercial catches

Figures 3.6.1 and 3.6.2 show the length depended and monthly proportion of ovigerous females in relation to all shrimps (Figure 3.6.1) and in relation to only the female shrimps (Figure 3.6.2) in the Danish catches in 2000 and 2001 combined.

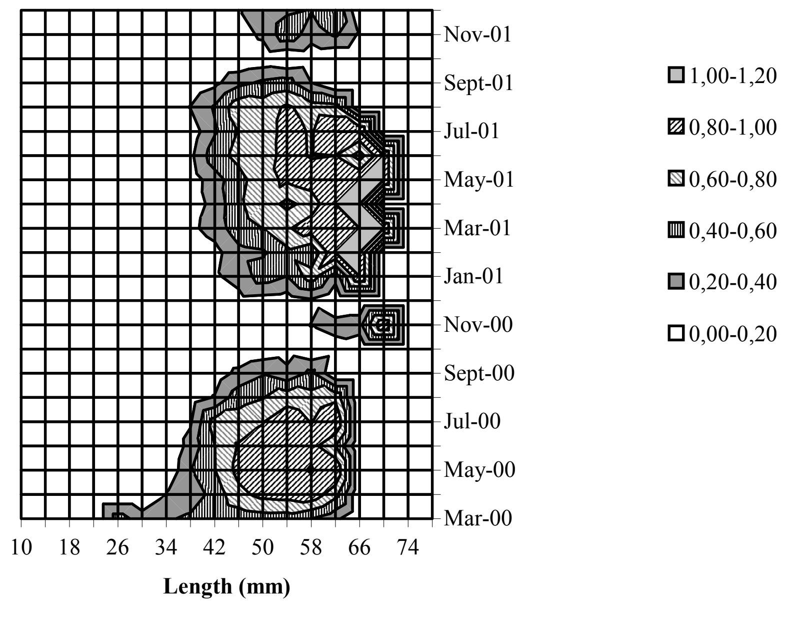


Figure 3.6.1. The proportion of ovigerous females of all shrimps in the Danish *C. crangon* fishery in 2000 and 2001.

In 2000 between March and September the proportion of ovigerous females of all shrimps measured was high (>60%) and in 2001 the proportion was likewise high between January and September (Figure 3.6.1). If one only looks at the proportion of females in the catches, the picture is almost the same (Figure 3.6.2). The average length of all shrimps was larger in 2000 than in 2001, which can be explained by the larger proportion of smaller males in the catches in 2001 compared to 2000. No ovigerous females were observed in the Danish catches between late September and October in both 2000 and 2001. The time gab between appearances of ovigerous females was larger in 2000 then in 2001 (Figure 3.6.1 and 3.6.2).

The Danish *C. crangon* catches in 2000 and 2001 consisted primarily of ovigerous and non-ovigerous females (>70%). The minor part of the males were assumed landed (<25%) as they mainly are below 10 mm in carapax length or 46 mm in total length. The length range for the males in this study is in agreement with the length range found in the work by Martens and Redant (1986).

The proportion of males was around 48% higher in 2001 compared to 2000. The proportion of the non-ovigerous females was only slightly lower 2000 (36.6%) compared to 2001 (40.8%).

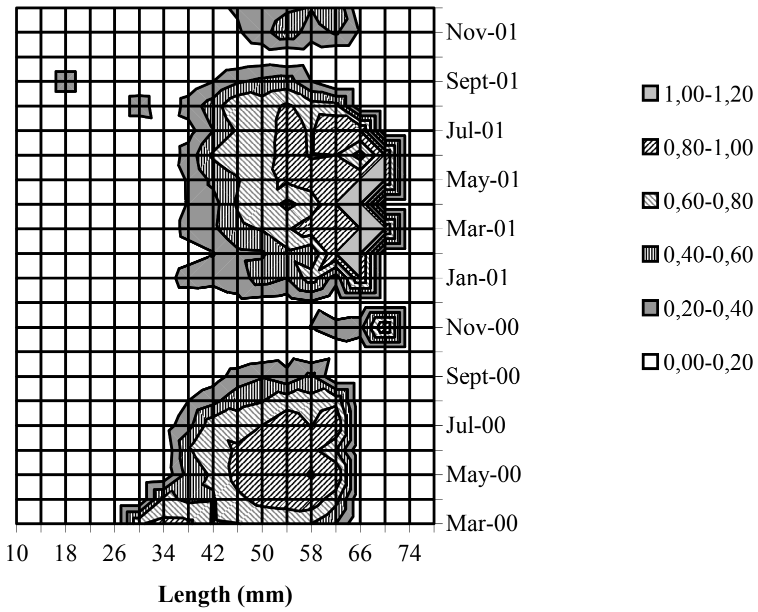


Figure 3.6.2. The proportion of ovigerous females of all females in the Danish *C. crangon* fishery in 2000 and 2001.

3.6.2 Germany

German commercial by-catch data

From 1955 to 1999 samples had been collected from the German *crangon* beam-trawl fishery. Size of beam trawls ranged from 6 to 11 m. Up to four ports at a maximum were sampled in parallel, however, length of time series for the various port varied. While the series of Northern Frisia (Büsum) ended in 1993, sampling continued until 1996 in Eastern Frisia, and finally ceased in 1999 for the Port of Cuxhaven at the River Elbe estuary. Sampling was undertaken routinely on at least a weekly basis from one to two vessel of each of the ports. Random samples of 10 litres were taken by the fishermen, deep frozen and passed to the institute in Hamburg. The entire samples were sorted to the species level and total numbers of specimens were counted. A sub-sample of at least 200 *Crangon* was measured using total length and an increment of 5 mm size classes. Sex was not identified, but ovigerous females were recorded.

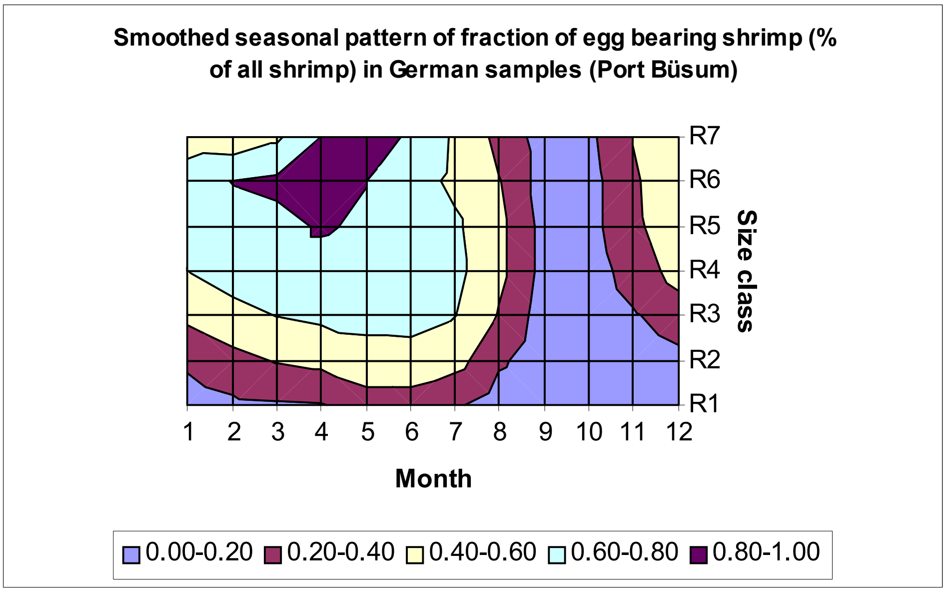


Figure 3.6.3.1 Smoothed seasonal pattern of fraction of egg bearing shrimp in the total by length class (R1=50–54.9mm, R2=55–59.9mm etc.) from North Frisian samples (Port Büsum).

German Demersal Young Fish Survey (DYFS)

Since 1974 the German DYFS has been routinely carried out twice a year in the Wadden Sea areas from Northern and Eastern Frisia and Elbe estuary. Commercial beam-trawl vessels have been chartered in April/May and September/October, but the standard fishing gear was a scientific 3m-beam-trawl with a mesh size of 20 mm (stretched mesh). number of stations increased over the years from about 100 stations at a minimum in early years to approximately 160 per season. 15-minute-tows with the prevailing tidal current are carried out at a towing speed of 3 to 4 knots. Fishing depth usually ranges between 2 to 15 m. Data on area swept are recorded for each station. The entire sample is sorted to the species level and total numbers of specimens are counted. A sub-sample of at least 200 *crangon* is measured. Between 1974 and 1996 only three size classes (<54, 55–67, > 67 mm) were recorded. From 1997 onwards total length measurements were carried out with an accuracy to 1 mm below. Ovigerous females are identified and measured separately. From these recent data examples are given for three years for the proportion of ovigerous females (Figure 3.6.3.2) and the share of males (Figure 3.6.3.3).

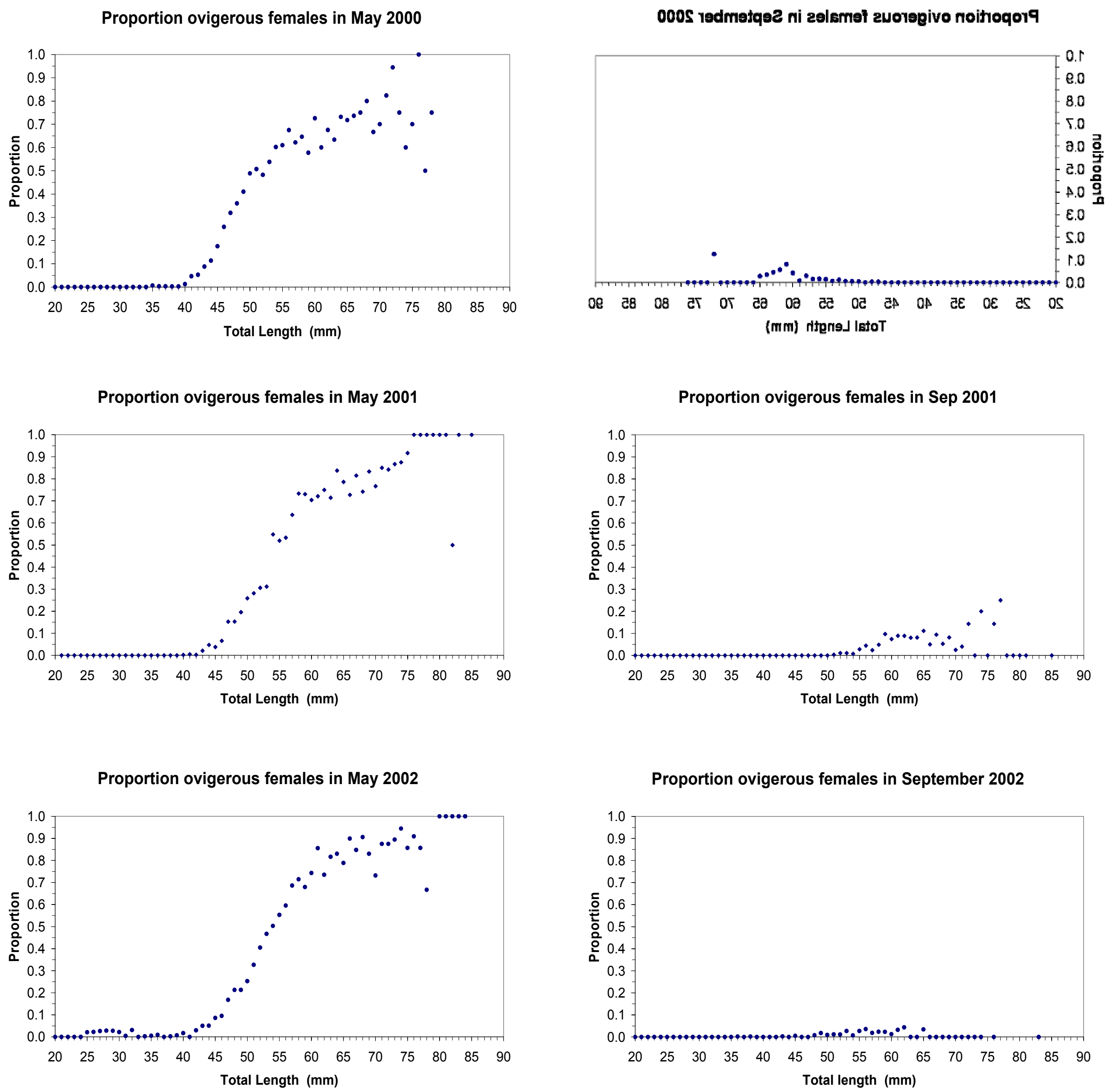


Figure 3.6.3.2 Percentage of egg bearing females relative to all shrimp for three years and two seasons based on data from the DYFS.

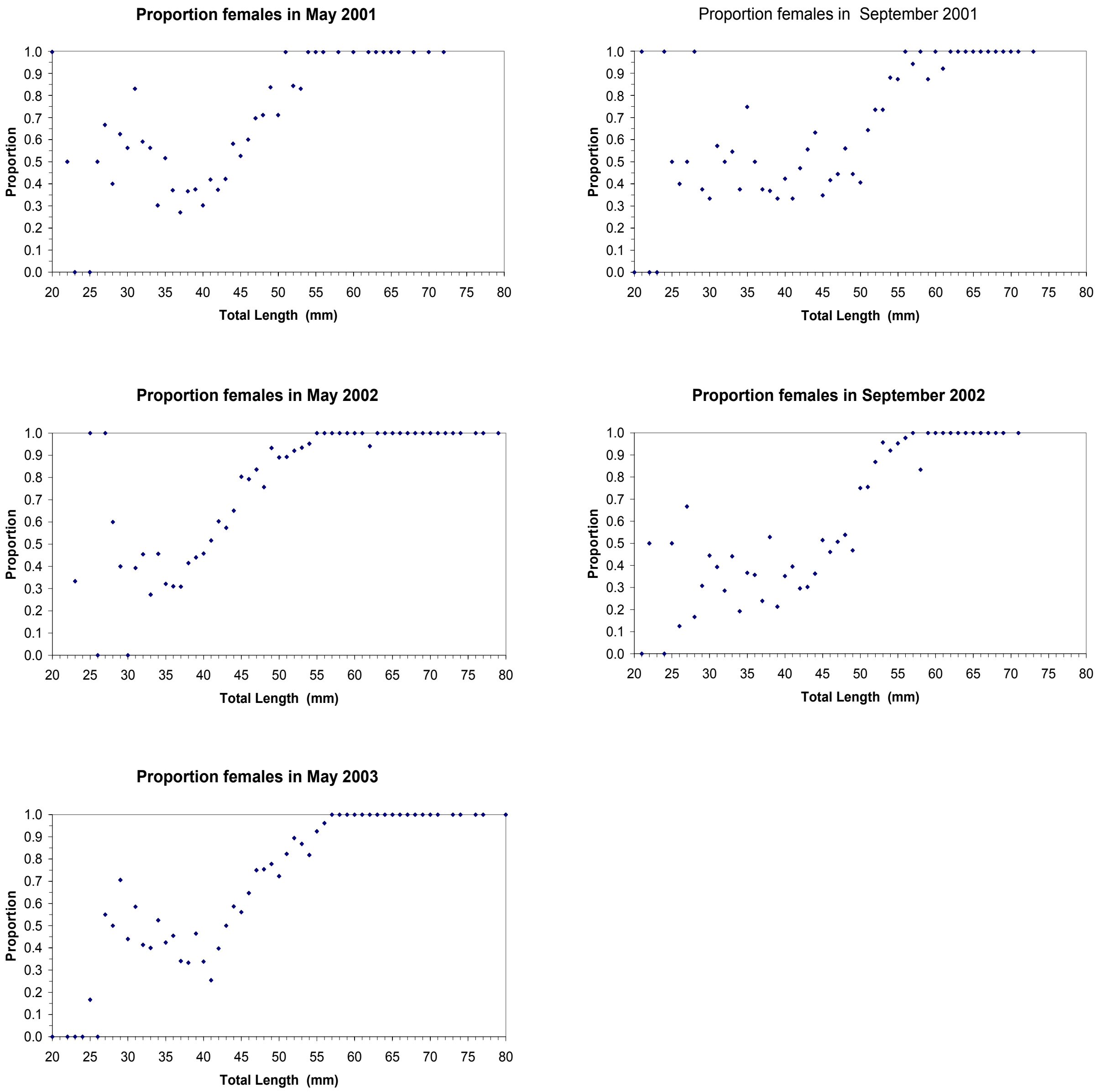


Figure 3.6.3.3 Percentage of females relative to all shrimp for three years and two seasons based on data from the DYFS.

3.6.3 United Kingdom

Length frequency distributions were compiled from survey data undertaken on chartered vessels using commercial gear. Catches are sampled before any riddling. Up to 32 key stations were sampled on a monthly basis, with additional stations sampled in November. Sampling was undertaken over a number of days, sometimes discontinuous, and it was therefore not always possible to synchronise the sampling to mid-month.

Length frequency distributions, standardised to area swept, were derived by sex using carapace length and 0.5 mm size classes. At the working group these length classes were scaled to total length using the conversion.

Total length = 6 + 4 * Carapace length

Samples were available for all months in the years 1996–1999. In 1995 and the years 2000 and 2001 only partial temporal coverage was achieved. Proportions of females ovigerous (i.e. ovigerous females/all females) by length class and month for the years with complete coverage are shown in figures 3.6.4.2 and 3.6.4.3.

Several points emerge:

1) A strong peak occurs in February and March where >80% of females are ovigerous.
2) A second peak occurs during June, July and August. This peak is less striking, larger females have a high proportion (>80%) ovigerous, but a lower proportion (60%–80% or even 40% to 60%) of smaller females is ovigerous.

3) In October the proportion of ovigerous females of all lengths is less than 0.2 and this is also usually the case November (1996, 1998, 1999) and sometimes in September (1997). Even when a higher proportion of egg bearing females is observed in September and November, it is generally observed over only a few size classes.

The duration of the period of reduced proportions of egg carrying females extends over a period approaching 3 months, and when the annual distributions are combined (Figure 3.6.4.3) over the period September to November.

In order to enable comparison with proportions expressed in terms of total numbers (males and females) the monthly proportions of males in the length distributions are presented in Figure 3.6.4.1. Below around 45mm the proportion of males is high in all months except July and/or August.

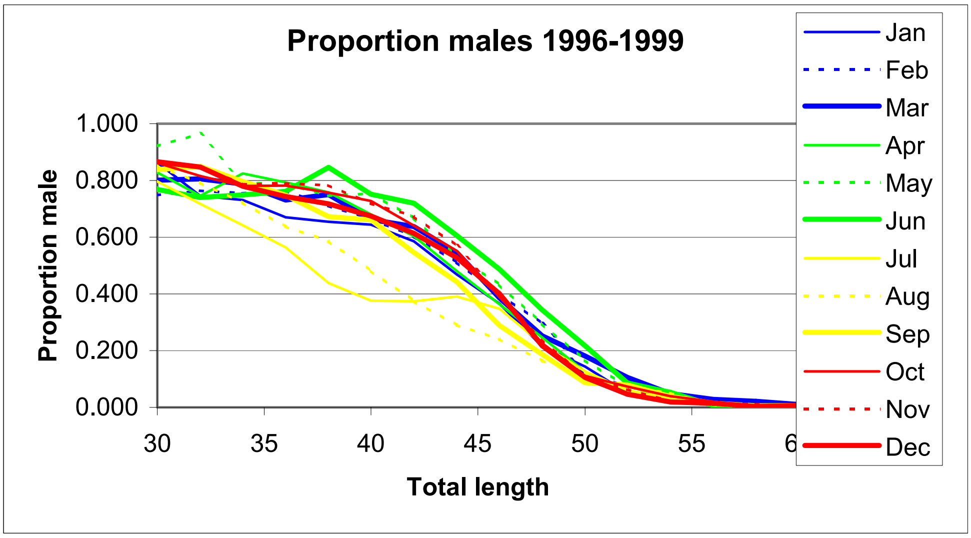


Figure 3.6.4.1 Proportion of males in UK samples.

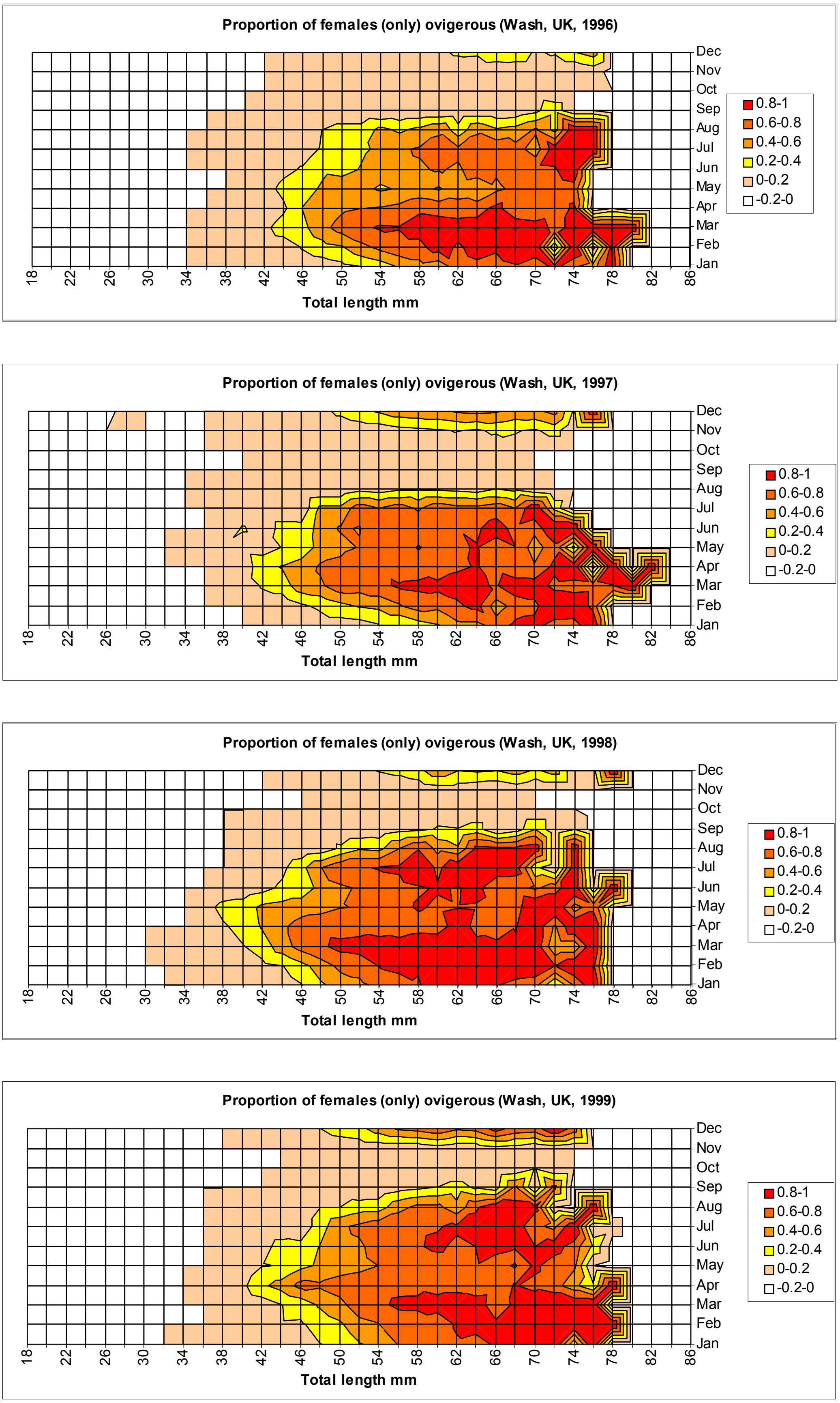


Figure 3.6.4.2. Seasonal patterns of egg bearing females by length (1996–1999).

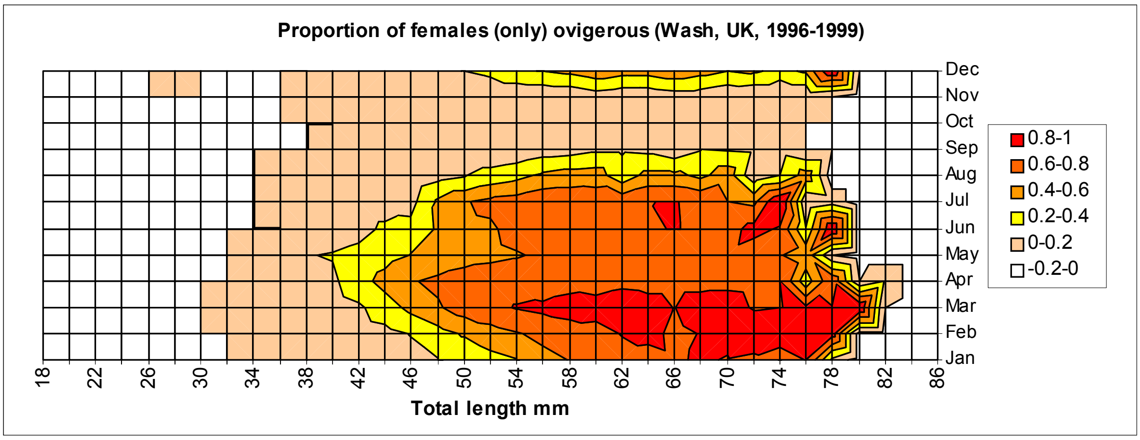


Figure 3.6.4.3. Combined years seasonal pattern of egg bearing females by length.

3.6.4 Conclusions

The comparison (see also Figure 3.6.5.1) of the different data set reveals several important aspects:

1) Overall the patterns are very similar across all areas with high values in spring and low values in autumn.
2) In most data sets the low values occur likewise in all size classes. This applies also to the increasing figures in November wit the exception of the smallest size classes.
3) In the UK pattern the period with low numbers of egg bearing shrimp is extended by one month into November. A similar observation can be made in the Danish data but only in one of the two years analysed (2000).
4) In the Danish data the summer decrease is delayed by approximately one month.
5) The maximum values in spring in the German data set are lower than in other areas, because in this data set males are not distinguished from non berried females. Recent German data from the IYFS reveal fractions up to 100% (berried females per all females).
6) In UK data and in part of the Danish data berried females occur with sizes as small as 34 mm. Such small sizes at maturity are not confirmed by the Germans IYFS data.

The newly available data sets will be used to improve the parameterisation of the Y/R model as described in Section 3. It is planned to investigate to which extent the observed shifts between regions can be related with differences in the local temperature regimes. Further investigations are needed to understand the observed differences in first maturity.

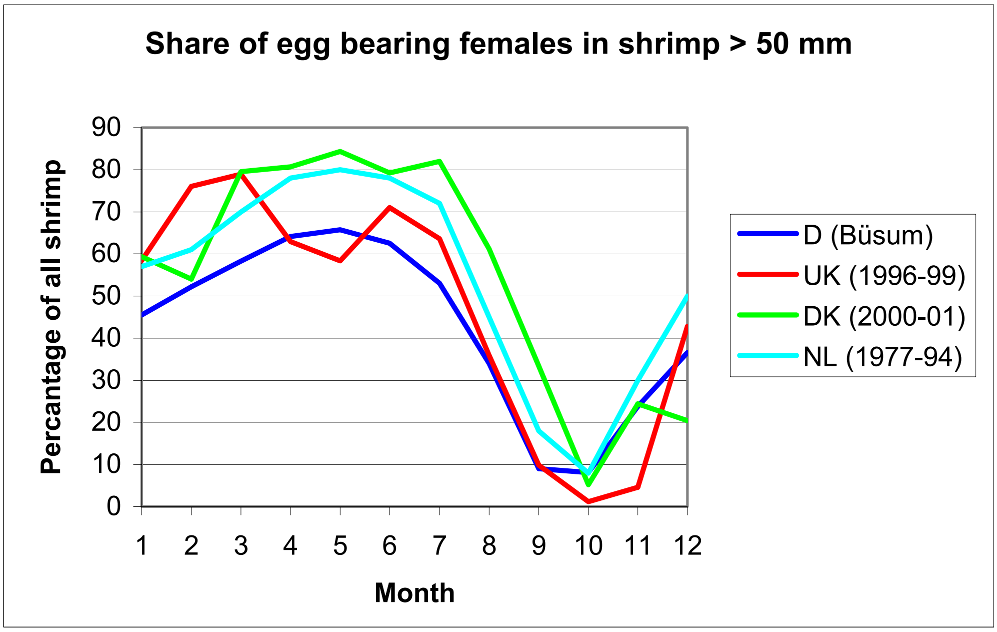


Figure 3.6.5.1 Comparison of fraction of egg bearing shrimp by months for shrimp > 50mm from different regions.

4 Factors influencing catch rates

Landings of brown shrimp were correlated with time series of annual sunspots, the North Atlantic Oscillation index (NAO-index), sea surface temperatures, predator abundance and regional brown shrimp abundance indices. Their preliminary results show an interesting, high correlation between German landings aggregated as “year class” (July to next year’s June) with winter (Dec to March) water temperatures. This may contribute to a prediction model for shrimp landings, though no explanations for causes and impacts during the life cycle of C. *crangon* can be given.

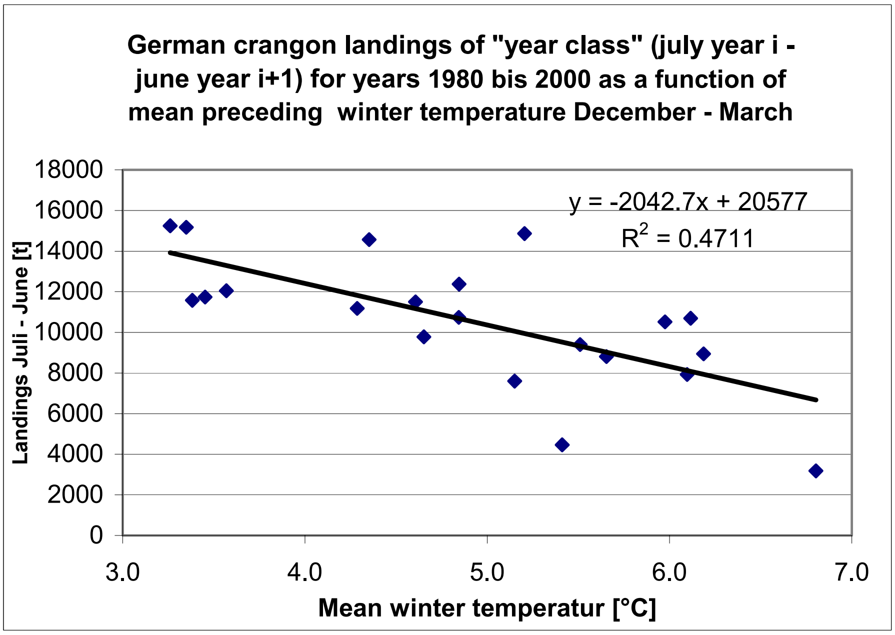


Figure 4.1.1. Correlation of German landings and winter temperature.

5 Data inventory

A table format for a common data inventory was outlined during the meeting. Preliminary versions were set up for UK, Belgian and German waters. In the present size these tables, however, can not be presented in this report and these will be made available on the web at a later stage.

6 Future sampling strategies and research planning

Sampling strategies

Discussions on this issue were initiated on this meeting and require continuation in the future. Some general aspects emerged during these discussions

- Measurements of shrimp should be made in mm whenever possible.
- sub samples should be sexed from all investigations, also the ovigerous females should be recorded separately.
- Sampling schemes on commercial vessels should record precise and comprehensive additional information on fishing location, fishing time, gear etc.
- Sampling schemes on commercial vessels suffer often from a representative coverage of the distribution area of the stock. If only few boats in a larger fishery are sampled and the fishing patterns are not coherent with regard to fishing grounds, fishing times or fished water depths, sampling of a limited number of boats may not represent the whole fleet. Nevertheless. In the absence of comprehensive scientific surveys covering the different seasons and extended areas such samples represent a very valuable source of information. Often the samples from the commercial fleets are the only source of information on the seasonal changes in fishery.
- In order to obtain a reliable picture of the seasonal and spatial distribution of both shrimp and by-catch species and extension of the present IYFS survey into at least four seasons for a limited number of years was considered as the best option. Such a project would allow also the investigation of by-catch avoiding strategies with regard to seasonal and spatial closures of the fishery.

Discard reduction strategies

Discarding of commercial and non-commercial flatfish and roundfish species is an omnipresent and a well-documented phenomenon in the *crangon* fisheries. A recently introduced EU fisheries technical conservation (850/98) requires member states to implement national legislation making the use of either sieve nets or sorting grids compulsory in their *crangon* fisheries by 2002. Such legislation is presently being drafted and implemented by member states. A recent analysis of discard data and the selectivity parameters of the new technical measures being introduced by member states indicates that they will have variable efficacy. The new technical measures will be most efficacious to protect larger by –catch fish and should do much to mitigate the detrimental impact upon stocks. These technical measures will however have only limited efficacy for small by-catch species such as 0-group plaice which are not effectively released from the trawls in sufficient quantity. The overall efficacy of this European technical measure will therefore be significantly diluted indicating the need for further research, with particular emphasis on the Wadden Sea fisheries and the mitigation of small 0-group fish discards in this region.

Technological developments

The BFAFi-IFF institute (Germany) has conducted initial experiments to develop an alternative technological device (plaice escape panel) that can be fitted to trawls to release juvenile flatfish whilst retaining the shrimp catch. Research will continue into this field.

Recent Belgian research (RvZ) has concentrated on an electrified beam trawl system, which reduces by-catch, discarding and potentially benthic impact and can potentially be developed for commercial use in the EU C.*crangon* fisheries.

Initial research looks very promising but has now ceased. Further research and development is required, preferentially on a multi-national European basis into this technology.

Alternative management strategies

The biological and economic consequences arising from spatial and temporal closures of zones within the Wadden Sea fisheries remain unknown and are in need of investigation.

Evaluation of the efficacy of the newly introduced technical measure

The mandatory introduction of sieve nets / sorting grids throughout the EU fisheries is predicted to give rise to variable efficacy between fisheries. An evaluation of the efficacy of this technical measure after its introduction is desirable to both validate the predictive techniques used and give an accurate account/assessment of performance within these fisheries for management.

Optimal parameterisation of the crangon yield per recruit life history model

Preliminary experiments using the model suggest this may be a valuable tool for investigating the effects of various management options for Crangon fisheries as well as giving insight in to the biology and population dynamics. However, at present, the model has been parameterised primarily using published data from various sources and there may be a need to improve the consistency of the model parameterisation.

i) Estimation of growth rates from field data and laboratory experiments.
ii) Revised mortality estimates using length composition data from different sources and revised growth rates.
iii) Estimation of the total mortality rates applying on a fine temporal scale and on different size components of the shrimp population.
iv) Clarification of the relationship between fishing effort and mortality and the proportions of mortality due to fishing and predation.
v) Analyses to clarify the understanding of maturity and the spawning process on a fine temporal scale and in particular to identify the mechanisms involved in reduced egg-bearing in September to November.
vi) Analyses to investigate the drivers for shrimp recruitment and production and the significance (or lack of it) of any relationship between stock and recruitment.

Long term trends in regional stock densities

The analysis of existing historical EU survey data to identify shifts in the abundance of *C. crangon* in a Northerly direction / to deeper waters as a consequence of climatic change is worthy of further investigation.

Fisheries derived indices of abundance (commercial LPUE)

A standardised pan-European technique for the determination of fishery derived LPUE of *C. crangon* abundance based on data obtained from the newly introduced logbooks is desirable.

Coastal zone management /ecological / environmental impacts of shrimp fishing

The environmental and ecological impacts of shrimp fisheries are unknown and speculative without much needed further research. These important coastal fisheries should feature in future coastal zone management strategies. Such a task will be problematic unless the current impact knowledge deficit is rectified.

Genetic ID of stocks

The stock /population identity of *C. crangon* is poorly understood at present and research to identify and isolate genetic markers specific to such stocks is currently underway in the UK (CEFAS). This remains a continuing research need, which may be successfully addressed through the existing UK research programme.

7 Recommendations

WGCRAN recommends to have a meeting from 4–9 October 2004 in Copenhagen, Denmark, to address the following terms of reference:

1) Update statistics for landings and effort data for national fleets (action 1.2.2).
2) 2. Perform consistency checks, quality controls and preliminary analysis of landings and effort data for *crangon* fisheries from available EU log books from national fleets (actions 1.2.1, 1.2.2).
3) Complete the meta-database on sources of data for *crangon* distribution and abundance (action 1.2.2).
4) Improve the 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) (actions 1.2.1, 1.5, 1.6, 3.16).
5) Evaluate studies of predation on *crangon* in relation to estimates of mortality (actions 1.2.1, 1.5, 1.6).
6) Consider environmental and other influences on recruitment success and productivity in *crangon* fisheries (action 1.3).
7) Review new data on discarding of juvenile fish in *crangon* fisheries following introduction of new EU technical measures (action 3.16).

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