Investigations of a stock assessment in brown shrimp (*Crangon crangon*)
Part 2: Biomass model

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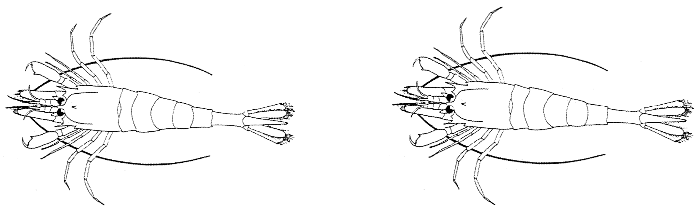

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Samenvatting

Het Ministerie van LNV, de gezamenlijke Producentenorganisaties voor de garnalenvisserij in Nederland, en de natuurorganisaties Stichting de Noordzee en de Waddenvereniging hebben het belang onderschreven van een gezamenlijk traject naar een verduurzaming van de garnalenvisserij en het verkrijgen van een MSC (Marine Stewardship Councel) certificering voor de garnalenvisserij. Om voor een MSC label in aanmerking te komen moet er aangetoond worden dat de gewone garnaal, *Crangon crangon,* niet overbevist wordt. Momenteel wordt de garnalenvisserij niet beheerd en is er geen officiële bestandschatting. Wel worden er door de ICES crangon werkgroep (WGCRAN, ICES working Group on crangon fisheries and life history) op een beschrijvende manier de fluctuaties in dichtheden van de gewone garnaal bijgehouden. Het is echter wenselijk om tot een meer kwantitatieve bestandschatting te komen, waardoor referentiepunten berekend kunnen worden die het beheer kunnen aansturen. In een vorig rapport ("Stock assessment in brown shrimp (*Crangon crangon*) part 1: investigation of possible methods"), hebben we onderzocht welke methodes gebruikt zouden kunnen worden voor een bestandschatting van garnalen. Aan de hand van deze inventarisatie leek een biomassa model (ook wel productiemodel genoemd) toepasbaar. Dit model berekent de dynamiek van het bestand in termen van verandering in totale biomassa in plaats van de meer gangbare berekening van aantallen per leeftijdsgroep en is al succesvol toegepast bij een andere kreeftachtige (*Pandalus borealis*). Het model heeft als voordeel dat de leeftijdsstructuur van de populatie niet meegenomen wordt en als data input alleen de visserijsterfte (totale garnalensterfte door de visserij) en een index voor vangst per eenheid van inspanning (CPUE, Catch per unit of effort) nodig is. Een belangrijke aanname van het model is dat het om één populatie gaat, met overal dezelfde dynamiek. Een tweede aanname is dat de beschikbare gegevens de ontwikkelingen van het bestand goed beschrijven.

Dit rapport beschrijft de uitwerking van het model voor garnalen, geeft een evaluatie van de resultaten en de inschatting van de ICES garnalen werkgroep (WGCRAN) over de toepasbaarheid ervan.

De belangrijkste conclusies van de analyse van het biomassamodel zijn dat de beschikbare data eigenlijk niet voldoende zijn voor een bestandschattingsmodel. Om echt harde conclusies te trekken of het wel of niet mogelijk is om dit model te gebruiken zou er een betere survey moeten plaatsvinden die het hele bestandsgebied van de garnalen bemonstert. Een jaarlijkse survey in het voorjaar en in het najaar zou de trends gedurende het jaar kunnen volgen. Gezien de complexiteit van de data en van de biologie van de garnalen is het wenselijk om tot een internationaal in ICES verband gedragen (en door de adviescommissie ACOM goedgekeurde) bestandsschatting te komen. Er zou dan een traject ingezet moeten worden waarbij het gebruikte model en mogelijke alternatieve modellen verder geanalyseerd worden. Dit zou in samenwerking met (internationale) experts op het gebied van bestandschattingen en op het gebied van garnalenbiologie uitgevoerd moeten worden.

Als input voor het biomassa model zijn de visserijsterfte en een maat voor de Catch per Unit of Effort (CPUE) gebruikt. De visserijsterfte is berekend door de aanlandingen van alle landen die in de Noordzee op garnalen vissen bij elkaar op te tellen. Door de WGCRAN worden de CPUE series die door de meeste landen verzameld worden als niet bruikbaar geacht voor een bestandsschatting om verschillende redenen. De enige naar het oordeel van de groep bruikbare CPUE serie is die afkomstig van de Demersal Fish Survey (DFS). Aan de DFS serie zitten echter ook een aantal nadelen omdat ten eerste niet het hele gebied waar de garnalenvisserij actief is door de survey wordt bemonsterd; er zijn aanwijzingen dat garnalen in de winter naar dieper water trekken (in de buurt van het Duitse eiland Sylt), waar de DFS niet komt, maar de garnalenvissers wel. Ten tweede suggereert de analyse van DFS data dat de trends wel eens gedreven zouden kunnen worden door lokale dynamiek: in de Ooster- en Westerschelde laten de dichtheden een neerwaartse trend zien, terwijl in andere gebieden de trend positief of neutraal is. Ten derde is er geen autocorrelatie tussen twee opeenvolgende jaren gevonden (op een enkel deelgebied na). Dit houdt in dat de hoeveelheid garnaal die er in het ene jaar is, niet veel informatie geeft over de hoeveelheid in het jaar daarop. Voor een betrouwbare bestandschatting is dit wel nodig. De reden dat de autocorrelatie niet is gevonden komt waarschijnlijk doordat er meerdere generaties per jaar voorkomen. Hierdoor zou er eigenlijk ook meerdere keren per jaar een survey uitgevoerd moeten worden.

Voor de modelanalyse van het biomassa model is besloten om de analyse in de eerste plaats met de CPUE index van de DFS survey uit te voeren. Dit omdat deze data door de WGCRAN werkgroep als best bruikbare werd gewaardeerd en ook omdat de andere series veelal geen realistische parameterwaarden gaven of helemaal geen uitkomsten. Een analyse met meerde indexen tegelijk resulteerde ook niet in realistische parameterwaarden.

De analyse van het biomassamodel met DFS data resulteert wel in een modeluitkomst met realistische parameterwaarden. De mediane waarde van de MSY (maximum sustainable yield) schatting ligt rond de 31500t) garnalen (95% betrouwbaarheidsinterval: 27000t-39 000t). Dit getal ligt in de buurt van de vangst van de laatste jaren. De schatting van de biomassa laat zien dat het totale bestand in het gebied dat door de DFS bemonsterd wordt tussen 1975 en 1995 toegenomen is, maar daarna weer afgenomen is.

Omdat de natuurlijke mortaliteit van garnalen erg hoog is, hebben we predatie door kabeljauw of wijting toegevoegd aan het model (uit ICES bestandsschattingen). Dit resulteert in modelparameters die dicht in de buurt liggen van de parameterwaarden zonder predatie. Dit komt doordat de predatie erg laag werd geschat door het model.

Tijdens de WGCRAN bijeenkomst in mei 2010 is commentaar geleverd op bovenstaande aanpak. In het algemeen vond men het een goed idee om een biomassa model analyse voorlopig op de agenda te houden. Echter, door de gecompliceerde ruimtelijke verdeling, de korte levenscyclus en vooral het gebrek aan een goede survey index werd ook sterk getwijfeld of betrouwbare referentiepunten met dit model berekend zouden kunnen worden.

Daarnaast zijn op verzoek van de Duitse overheid alternatieven voor een beheer van de garnalenstand aangedragen. Samengevat kwam dat neer op een 1. bedrijfssurvey waarbij bemonsterd wordt in de periode voordat de jonge garnalen de marktwaardige lengte bereikt hebben (in juli), 2. bijhouden van LPUE (Landings per unit of effort) op basis van de logboekgegevens gedurende het seizoen 3. een aanpak waarbij meerdere indicatoren voor het bestand geëvalueerd worden.

Summary

The Ministry of Agriculture, Conservation and Food quality, Producer organisations of the Dutch shrimp fisheries and NGO's (Stichting de Noordzee and Waddenvereniging) have underlined the importance of sustainable harvesting of brown shrimp in the North Sea and Wadden Sea. Also they would like the brown shrimp fishery to meet the conditions of an MSC (Marine Stewardship Council) certificate. The first principle that the shrimp fishery needs to fulfil in order to acquire an MSC-label states that the stock should not be overfished. A previous report ("Stock assessment in brown shrimp (*Crangon crangon*) part 1: investigation of possible methods") investigated the possibilities to assess the stock of the brown shrimp (*Crangon crangon*) and it was concluded that a stock assessment with a biomass dynamic model should be investigated. This model does not need demographic data and was used successfully in Northern shrimp (*Pandalus borealis*). The model only needs the total amount of shrimp landings and an index of catches per unit of effort (CPUE) to assess the stock. The main assumptions of the model are (1) the stock under study is a single stock and (2) the available index (CPUE, catch per unit of effort series) describes the trends in the population well.

The main conclusion from the study is that the applicability of the biomass model for a reliable stock assessment of brown shrimp needs considerably more study and data collection. In addition, because of the complexity of the data and the biology of shrimp, cooperation and approval by (international) stock assessment and shrimp ecology experts as well as approval from the ICES advisory committee (ACOM) would be desirable. In addition, a better survey with more frequent sampling would increase the reliability of the model substantially.

As input for the model we used fishing mortality and a measure for CPUE. The total amount of shrimp landings were calculated as the sum of the landings from The Netherlands, Germany, Denmark and the UK. The CPUE series that are being collected by most countries are not thought suitable as input for an assessment because of different reasons. The only CPUE series that is judged as being reliable by the WGCRAN is the one derived from the Demersal Fish Survey (DFS). A disadvantage of the DFS data is that the DFS does not sample the whole fisheries area. In addition analysis of the DFS data suggests that the stock may be driven by local population dynamics and there is no positive autocorrelation between two successive years. This means that the shrimp abundance in one year does not give us any information of the stock size in the next year, which is necessary for a reliable stock assessment. The lack of autocorrelation is most likely caused by the occurrence of more than one generation per year. To overcome this, sampling should happen more frequently, at least twice a year.

We used the DFS data to explore the model. This index was valued as the best CPUE series by the ICES Crangon working group (WGCRAN). In addition, it was the only index that resulted in realistic parameter values. The median MSY value (maximum sustainable yield) was estimated at 31500t shrimp (95% confidence interval: 27000t-39 000t). These values are close to the weight landed annually for the last 10 years. However, because of the lack of a good index, these data have to be interpreted carefully.

During the WGCRAN meeting in May 2010 the work on the biomass model was discussed by international colleagues. In general, it was viewed as a good initiative and should remain on the agenda. However, because of the complicated life history, spatial distribution and the lack of a good CPUE index, there was also much doubt about whether reliable reference points could be estimated in future.
There were a couple of alternatives mentioned by the group members. In short these are (1) survey by the shrimp fleet early in the season to sample the pre-recruits (July), (2) keep track of LPUE (landings per unit of effort) during the season and (3) combine several stock size indicators.

1 Introduction

The Ministry of Agriculture, Conservation and Food quality, Producer organisations of the Dutch shrimp fisheries and NGO's (Stichting de Noordzee and Waddenvereniging) have underlined the importance of sustainable harvesting of brown shrimp in the North Sea and Wadden Sea. Also the Dutch shrimp fisheries are in an evaluation process of Marine Stewardship Council (MSC) to see if the brown shrimp fisheries meet the conditions of an MSC certificate. The first principle that the shrimp fishery needs to fulfil in order to acquire an MSC-label states that the stock should not be overfished. In a previous report (CO24/10) we investigated the possibilities to assess the stock of the brown shrimp (*Crangon crangon*) and concluded that a formal stock assessment for brown shrimp including an estimate of the effect of the fisheries on the population dynamics will be hampered because (1) demographic data on shrimp are lacking and there is more than one generation per year, (2) natural mortality is high due to predation by other species, (3) environmental conditions may play an important role in the population dynamics of shrimp and (4) the available data may not describe the trends in the stock accurately. We suggested that a stock assessment with a biomass dynamical model (also known as surplus production model) should be investigated because this model does not need demographic data and has been used successfully in crustaceans before (for example, Northern shrimp *Pandalus borealis*). The simplest type of this model only needs the total amount of shrimp landings and an index of catches per unit of effort (CPUE) to assess the stock in terms of biomass. The most important countries in the North Sea shrimp fishery, The Netherlands, Germany, Denmark and the UK, have registered landings for some decades. CPUE indices are available from logbook data and from Dutch and German survey data (DFS and DYFS). This report sets out to explore whether the biomass model can be used as a tool to assess the stock of the North Sea brown shrimp.

2 Summary Biomass model

The basic function used to model biomass dynamics is the logistic growth model (Verhulst 1838). In this model the total biomass of a population increases exponentially when the population is small, but its growth speed is reduced due to competing for some resource, such as food, when the population increases in size. Finally it will reach an equilibrium when the population has reached its maximum biomass level. The logistic growth model is formulated as

$$\frac{dB}{dt} = r \cdot B \cdot \left(1 - \frac{B}{K}\right) \tag{1}$$

in which B is the total stock biomass, dB/dt is the change of B in time t, K is the carrying capacity, and r is the growth rate. The carrying capacity is the maximum weight of shrimp possible in the system. In absence of mortality due to fishing or predation, this model is expected to reach an equilibrium when biomass equals the carrying capacity ($B = K$).

To include effects of fisheries, the logistic model was extended by Schaefer (1954) who added a term to model a fished stock, so that the rate of change is reduced by the yield (Y).

$$\frac{dB}{dt} = r \cdot B \cdot \left(1 - \frac{B}{K}\right) - Y \tag{2}$$

where Y is yield at time t. It is assumed that $Y = q \cdot f \cdot B$. With q being the catchability coefficient and f_t representing the fishing effort during period t. The equilibrium biomass of this model occurs when the yield (Y) equals the natural growth for each time step:

$$Y = r \cdot B \cdot \left(1 - \frac{B}{K}\right) \tag{3}$$

The Schaefer model can be used to estimate the parameters values of *r*, *K* and *q*. The basic approach to determine which parameter values fit the data best is to minimize the deviation between predicted and observed values by maximum likelihood. The first step is to estimate the stock size at the beginning of the available time series (*B0*) and then use the model to predict the stock biomass during the rest of the time-series. The parameter values for *K*, *r* and *q* and the predicted biomass at the beginning of the time series are then adjusted to provide the fit of the predicted model values that is closest to observed values. If these parameters are estimated, it is possible to assess a time series of the total biomass of the stock (*B*) and to estimate reference points (Hilborn & Walters 1992, table1).

If the parameters *K*, *r* and *q* are estimated, the Schaefer model provides estimates of a number of reference points which could be used for management (table 1). The maximum sustainable yield (MSY) is the equilibrium state of the stock (equation 3) for which the highest amount of shrimp biomass can be removed from the stock in each time step.

Table 1: reference points for the Schaefer model

Reference point	Estimate (Schaefer)
Maximum sustainable yield (MSY)	rK/4
Biomass at maximum sustainable yield (B_{MSY})	K/2

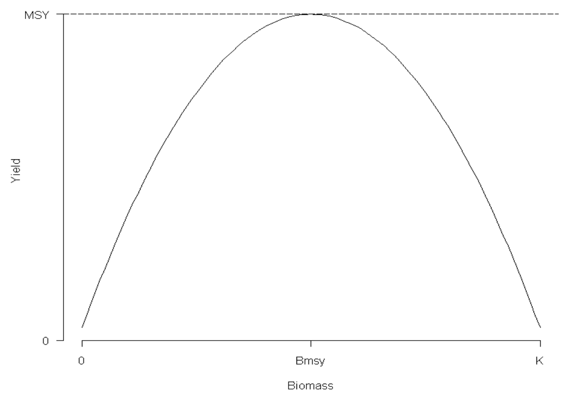


Figure 1 *Equilibrium state of biomass with harvest. The equilibrium that gives the highest possible sustainable yield is at MSY (maximum sustainable yield). In extensions of the Schaeffer model, the equilibrium state may also be skewed to the left or to the right (Pella and Tomlinson 1969).*

2.1 Predators

Many predator species feed on brown shrimp. Historically, cod and whiting were assumed to be the most important shrimp predators, but many other species are known to also feed on shrimp. Moreover, their importance in predation on shrimp has probably increased nowadays, because of the decline of the cod and whiting stocks. For cod and whiting official stock assessments are available and may be included in the model:

$$\frac{dB}{dt} = r \cdot B \cdot \left(1 - \frac{B}{K}\right) - Y - a \cdot P \qquad (5)$$

Where *P* is the biomass of the predator species and *a* is the predation rate.

3 Data

3.1 Landings

Commercial landings from The Netherlands, Germany, UK, France and Denmark are registered since 1973. The sum of these can be used as proxy for the total amount of shrimp landed from the North Sea area (figure 2), if they represent the total amount of catches well. For brown shrimp, however, cooked undersized shrimp are not recorded in the landed weight. Because the sieving process differs per country and as well as over the years, the error in this data is unknown but may be considerable (WGCRAN 2010, discussion). However, in the absence of a better estimate, the sum of these was used as the total weight of shrimp caught in the North Sea area (figure 2).

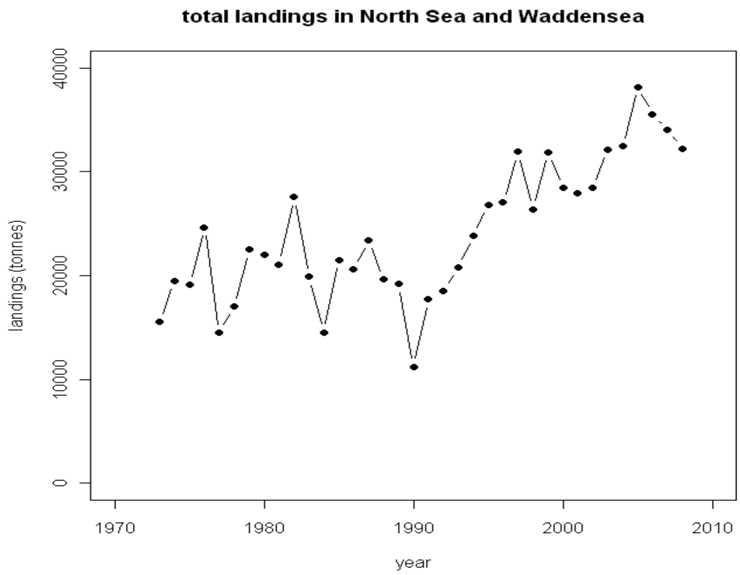


Figure 2 *Sum of the commercial landings from The Netherlands, Germany, UK, France and Denmark.*

3.2 Catch per unit of effort (CPUE) and Landings per unit of effort (LPUE) indices

<u>Commercial LPUE</u>
Time series of LPUE's of brown shrimp in the North Sea provided from logbook data from the commercial fleets and CPUE series from the Dutch DFS survey were used in the model (figure 3). Ideally, these indices should provide more or less similar results. However, correlations between the different series are often weak (figure 4).

The significance of the different CPUE series was often discussed at previous ICES WGCRAN meetings. The indices based on the commercial landings are not considered good descriptors of the stock because the fleets of the countries involved fish in different areas (figure 5). In addition, the calculation methods of the national CPUE's differs per country. German and Danish effort, for example, are calculated as the number of days at sea, whereas Dutch effort are calculated as the number of days at sea, minus one day (because this day is assumed to be used for transport to and from the fishing grounds). One day trips were included as one day. The Belgium effort is based on a reporting system that records the actual hours spent fishing (ICES 2005).

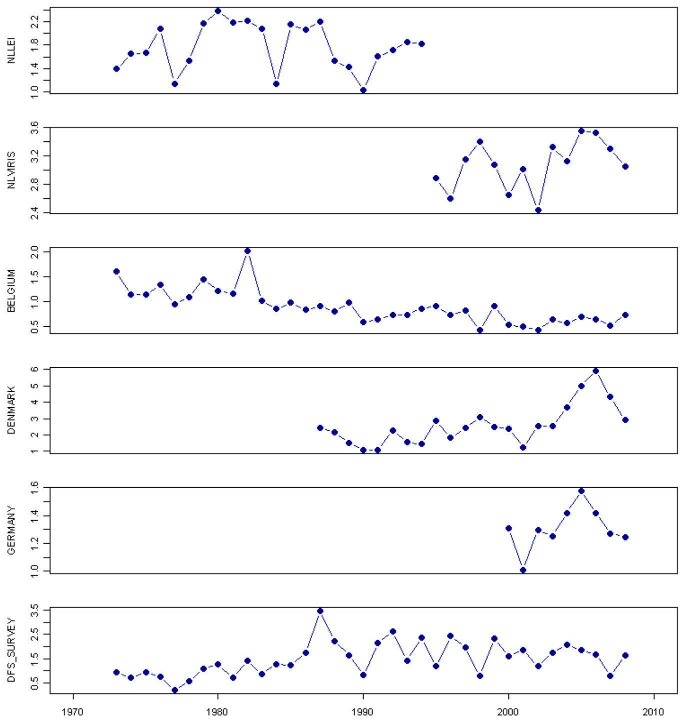


Figure 3 *CPUE indices (from top to bottom: Netherlands, series from LEI database, Netherlands, series from the Viris database, Belgium, Denmark, Germany, DSF Survey).*

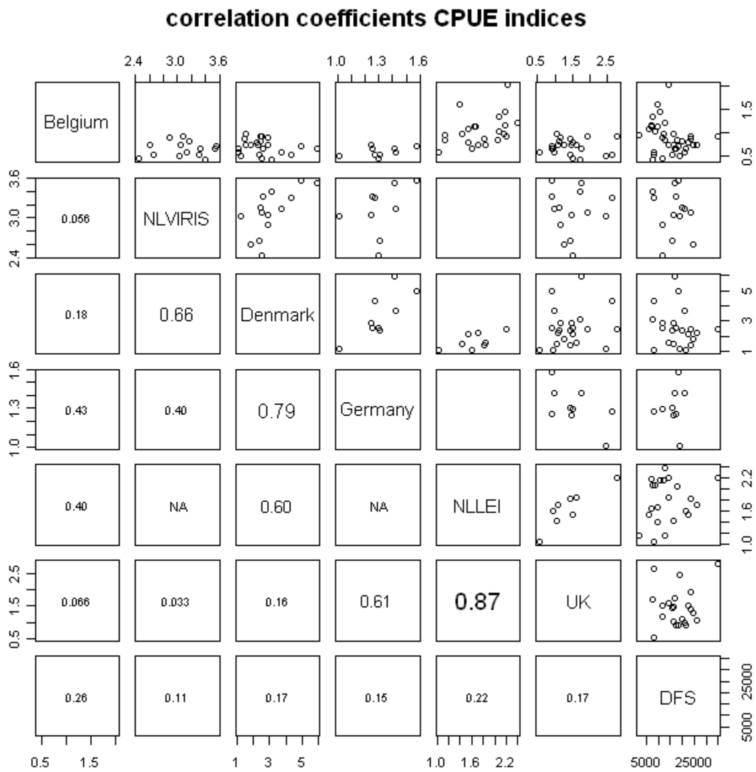


Figure 4 *Correlations between CPUE series. Data (top right panels) and correlation coefficients (lower left panels).*

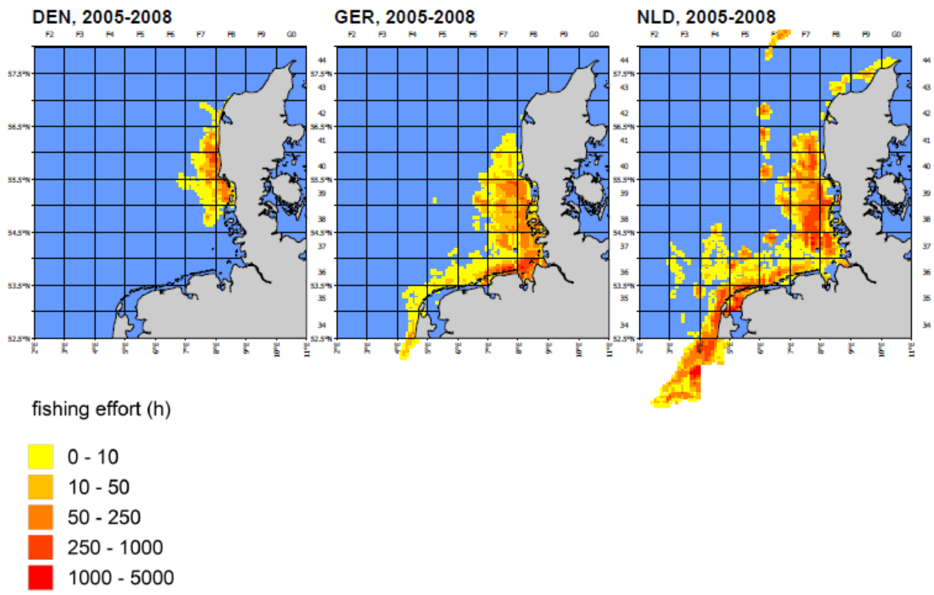


Figure 5 *Distribution of Shrimp Fisheries in the North Sea. Effort distribution of beamtrawls -31 mm mesh size <= 221kW. Based on VMS data, resolution: 3 x 3 nm squares. (Torsten Schulze, Heino Fock, vTI – Institute of Sea Fisheries, ICES 2010).*

<u>DFS data</u>

The Dutch Demersal Fish Survey (DFS) takes place annually in September-October since 1970. Every year 200–300 hauls of 15 min are made along the Dutch, German and Danish coast, as well as the Westerschelde, Oosterschelde, Wadden Sea and in the Eems-Dollard (figure 6). The length of the shrimp is measured from subsamples from the hauls and subsequently the weight is calculated from a length-weight relationship.

We first raised these data to obtain an estimate of the total weight per ha per subarea (ICES report 2010) and subsequently we averaged these weights over all subareas. The reason for this method is to ensure that all areas are represented equally. The subareas were chosen by the Crangon working group.

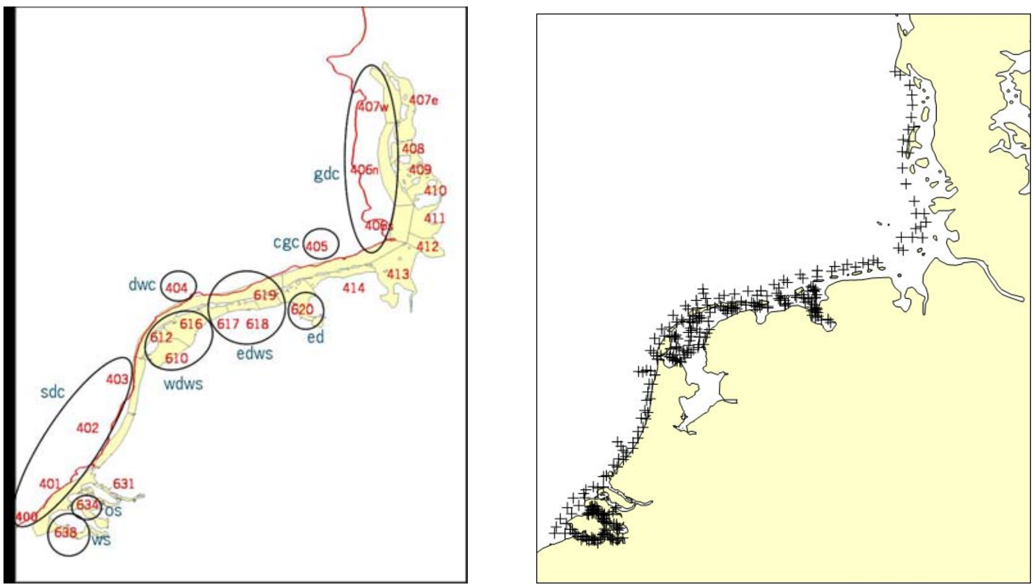


Figure 6 *DFS subareas (left) and DFS sample locations (right).*

3.3 Methods

Goodness of fit – maximum likelihood
The data are assumed to be log-normally distributed, with means and standard deviations predicted by the model. The total log-likelihood is the normal probability density of the log of the observed values with the estimated mean and standard error. To determine which parameter values fit the data best we minimized the deviation between predicted and observed values (maximum log-likelihood). We used an optimiser in R (the “optim” function, R2.10.1), which estimates the parameter values for K, r and q and the predicted biomass at the beginning of the time series to provide the fit of the predicted model values that is closest to observed values. Starting values were selected by hand.

Estimating uncertainty
Variability of estimates was assessed using bootstrap analysis. Bootstrapped estimates of the model parameters were derived by randomly resampling log errors. Confidence limits were approximated using percentiles of bootstrap estimates.

3.3.1 Discards

The total mortality caused by the fisheries is a sum of the mortality caused by the landings and by the discards. Therefore, discards should be added to the landings and could improve the model results. The discarding of non-marketable *C. crangon* in the North Sea is substantial in magnitude representing around 50% (Lancaster & Frid 2002) to over two-thirds of the shrimp catch by number (Van Marlen *et al.* 1998). However, most undersized shrimps are separated from the catches and returned to the sea alive (Lancaster & Frid 2002). Their survival rate seems to be high in the entire capture, hauling, riddling, discarding and bird predation processes: 75–80% survival is estimated for the Solway Firth (Ireland, Lancaster & Frid 2002) and for the Belgian fishery (Mistakidis 1958). We included an analysis of the biomass model for which we assumed that 50% of the total catch consists of undersized shrimp. We assumed that 75 % of these undersized shrimps, which are thrown overboard, survives. Thus, the total shrimp mortality caused by the fisheries was estimated to be 25 % higher than the actual landings. This is a rough and hypothetical estimate and does not take the additional sieving in the harbours into account. However, because the amount of undersized shrimp removed in the harbours is unknown and differs per harbour and in time, we did not make an assumption of these weights.

4 Results

Fitting the model with the DFS-index resulted in an optimum with parameter values and reference points listed in table 2. The results show that the estimated biomass increased since 1973 until the early 1990’s and decreased afterwards (figure 7c). The MSY is estimated at 30.6 (kt), a value that falls within in the order of magnitude of the current landings (figure 7a). The median values of the bootstrapping results are listed in the appendix. Including a discard percentage (+25 %, see above) resulted in only small differences in the estimated parameter values (appendix).

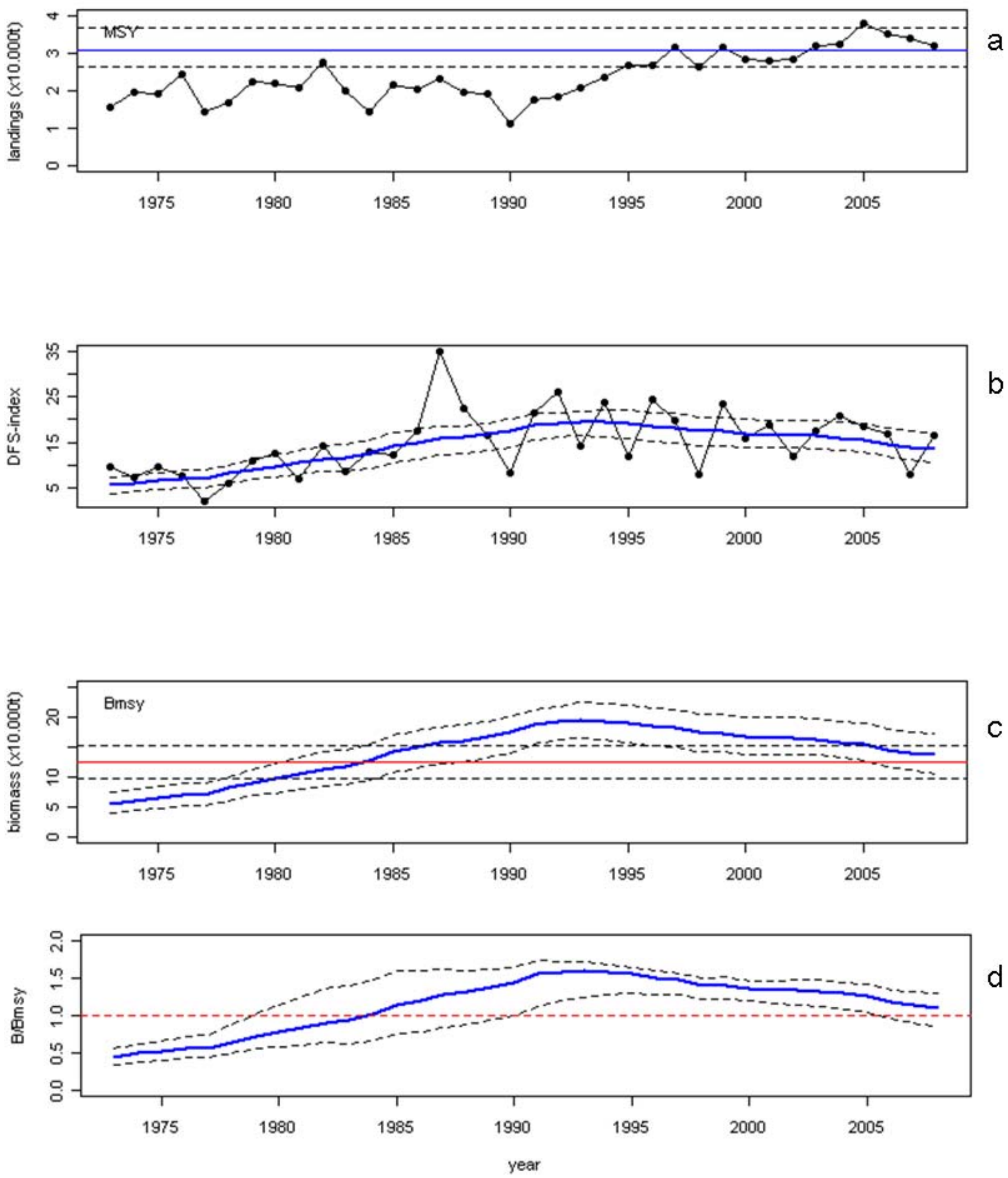


Figure 7 *a: catch data (summed over all countries) and the estimated MSY (blue line, median + 95% confidence limits) based on the DFS series. b: CPUE-series of the Dutch DFS data with the estimated model fit (blue line, median + 95% confidence limits). c: estimated biomass (blue line, median+ 95% confidence limits) and estimated Bmsy (red line, median + 95% confidence limits. d: Estimated stock biomass (B) relative to Bmsy (blue line, median + 95% confidence limits), the red broken line indicates the biomass at Bmsy.*

Table 2 DFS data: reference points and parameter values

parameter/reference point	DFS estimate
r	0.50
B0	5.4 (x 10.000 tonnes)
K	24.4 (x 10.000 tonnes)
MSY	3.06 (x 10.000 tonnes)
Bmsy	12.20 (x 10.000 tonnes)

4.1 Predators

For cod and whiting official stock assessments are available and may be included in the model. As a start we included the total biomass of cod in the North Sea and Skagerrak. This method assumes that the cod biomass in the shrimp fisheries areas is positively correlated with the total cod biomass in the North Sea, which may not be a realistic assumption. Model results show that the estimate of MSY (appendix) was only slightly higher than the estimate without predation by cod included in the model. Shrimp predation needs to be withdrawn from this value to get to a maximum yield per year, which depends on the amount of predators present per year. However, if it is as low as estimated for the recent years, the predation is negligible. The lack of a large difference was caused by a low estimated value of the predation rate (a = 0.008, eq 4), resulting in low predation estimates (figure 8). Inclusion of whiting resulted in even lower predation (results not shown). Whether these results are in reality caused by low predation is questionable, they are also likely to be caused by a lack of spatial and temporal resolution of the ICES stock assessment necessary to produce a suitable index of predation.

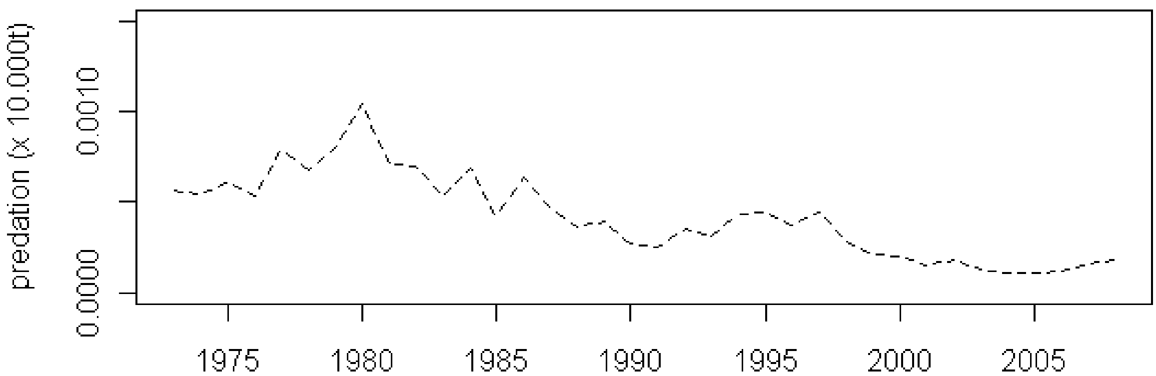


Figure 8 *Estimated total predation (shrimp biomass x10.000t) by Cod*

4.2 Other CPUE indices

Ideally, fitting the model to the other CPUE indices would result in similar parameter values and reference points. We fitted the model with each index separately. Fitting the German CPUE index series the model resulted in a higher MSY estimate than the estimate fitted DFS data. The Dutch Viris index series resulted in a very high value of MSY (figure 9, note the logarithmic y-axis). For Belgium and the Dutch LEI index series we found parameter values with higher estimates of the biomass at the beginning of the time series (in 1973, *B0*) than the estimated carrying capacity (*K*). Because this is highly unrealistic (*K* is the maximum weight of shrimp possible in the system) we have not shown these results. The Danish index did not result in convergence (no optimum found).

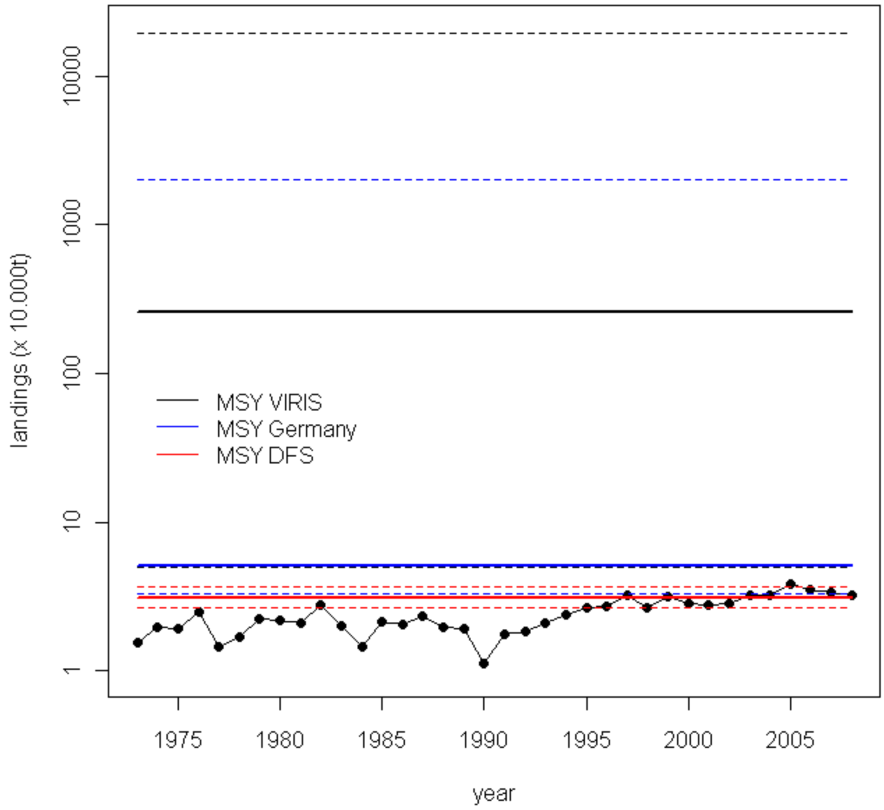


Figure 9 *MSY's per CPUE index. We could not find realistic parameter values for the indices of Belgium (B0>K), Lei (B0 > K) and Denmark (no optimum found).*

<u>Combining indices</u>

Indices can also be fitted simultaneously, which we did with the DFS, VIRIS and Danish data series. This resulted in even less contrast (figure 10) in the estimated fits because the indices indicate different stock trends. In addition, the biomass estimate and the reference points (figure 10) are highly uncertain and the estimated parameter values and reference points (appendix) may be unrealistic. For example, Tulp and Siegel (2010 WGCRAN report) estimated the total biomass (based on a swept area estimate) at around 20.000 to 30.000 tonnes, whereas the best estimate from this model varies between 490.000 tonnes and 1.499.000 tonnes. In addition, the variation is huge (figure 11, note the logarithmic scale). Combining other indices resulted in model fits with little contrast, with unrealistic parameter values or in some cases there was no model convergence (no optimum found, results not shown).

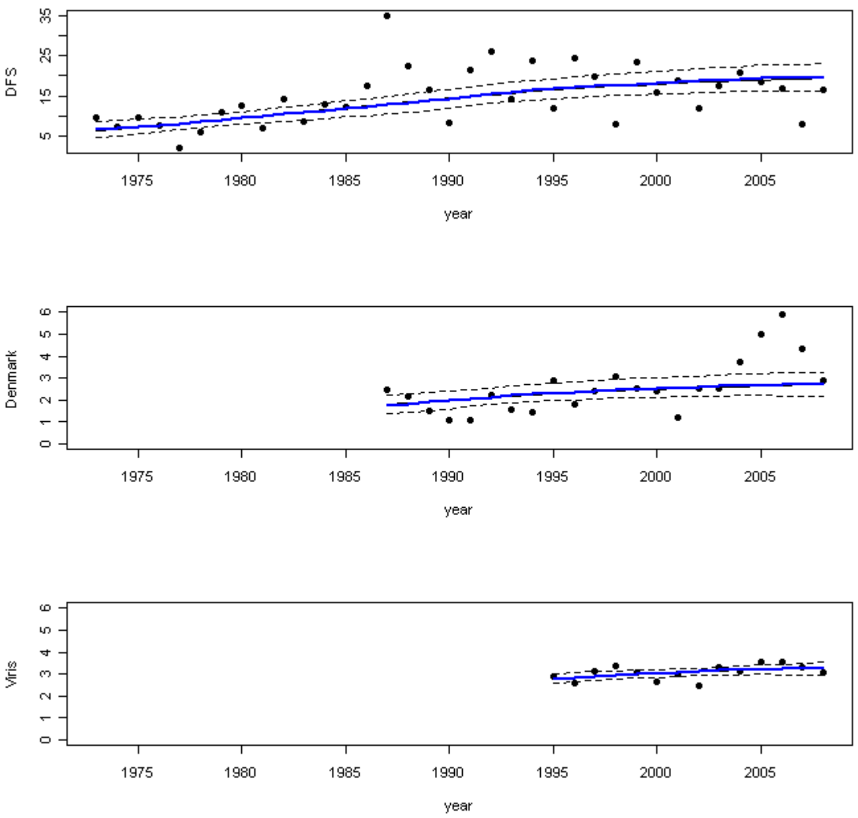
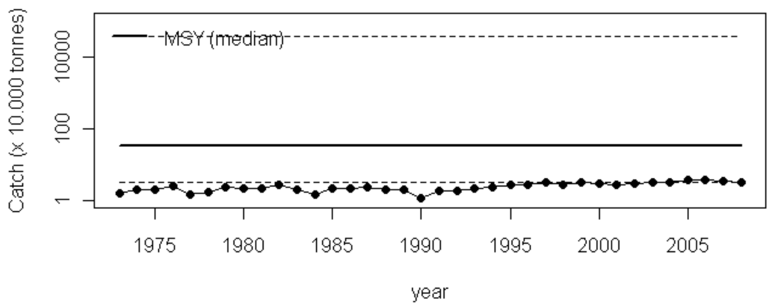


Figure 10 *Biomass model fitted with DFS/VIRIS/DK data. Upper graph: DFS index and the estimated fit (median+95% CI). Second graph: Danish CPUE-series with the estimated model fit (median +CI). Third graph: Viris CPUE series with the estimated fit. Lower graph estimated biomass and estimated Bmsy (medians +CI's).*



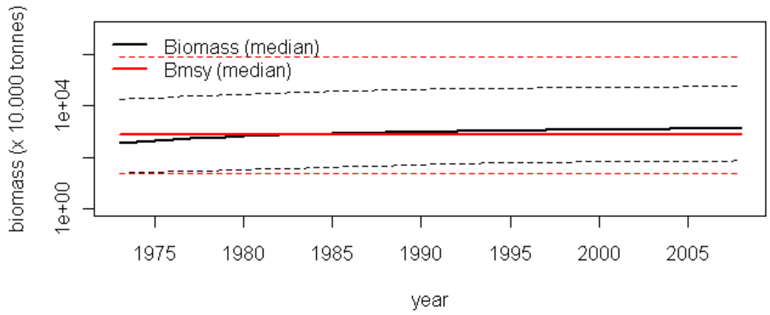


Figure 11 *Biomass model fitted with DFS/VIRIS/DK data on a log scale. Upper graph: catch data and estimated MSY (median+95% CI). Lower graph: estimated biomass and estimated Bmsy (medians +CI's).*

5 Discussion

Model

The study of the DFS data resulted in a shrimp biomass estimate that increased until the 1990 and slowly decreased since (figure 5). The MSY value had a median of 31500t. This value is more or less the weight landed annually for the last 10 years. In the last five years, the landings were slightly above the median MSY values. The biomass estimates from the survey indicate that the total stock in the area covered by the DFS survey increased in the period 1975-1995, but decreased since. The median stock biomass estimates are slightly above Bmsy, but the 95% confidence limits include this reference point.
However, these results have to be interpreted carefully. This is because two important assumptions of the model are not met. First, the value of the available data is questionable and second, trends in the population may be driven by local dynamics. Below we describe our main concerns.

Data

Landings: The catches are sieved twice. Once on board before cooking and once on land after cooking. Most of the shrimp on board are discarded and returned to the sea alive, whereas the cooked undersized shrimp are not recorded at all and thus not included in the total landings estimate. In addition, the commercial size of shrimp has decreased over the years, resulting in a change in the size of sieving grids on board and on land. However, none of this is recorded and also differs per country. Because large parts of the shrimp catches consists of undersized shrimp this may actually cause considerable changes in the total landings estimate.

CPUE series: The model requires one or preferably more than one time series of accurate catch and reliable survey data that represents a wide range of stock and harvest conditions. These should show more or less similar trends. However, the CPUE indices show rather different trends (figure 3). This issue has been discussed

for years at the ICES WGCRAN meetings (ICES 2005-2010), questioning the reliability of the different CPUE series. The indices based on the commercial landings are not considered a good descriptor of the stock because none of the fleets of the countries involved fish in the whole area. Also, the series are calculated in such a different manner that they can not be compared.
The sampling program by the DFS may not be extensive enough to describe the trends in the stock accurately, because of the large variability in time and space in shrimp abundance, which may not be observed with the current sampling program. Similar to the other series, the DFS does not cover the total fishing area. The main problem is that shrimp abundance as well as fishing intensity has increased substantially in the area west from the German island of Sylt, whereas the DFS does not sample this area. In addition, sampling is only in the middle of the catching season (September-October). Shrimp reproduces all year round with periods of high reproduction per year, but we sample only once a year. The frequent reproduction needs higher sampling frequency to track a positive stock recruitment relationship.

The variability of the indices results in very different parameter values and reference points depending on the index used (figure 7, appendix). Combining indices resulted in unrealistic values or model fits without much contrast (figures 10 & 11).

Subpopulations

One of the assumptions of the model is that the stock under study is a single stock. The parameters of the model, mainly r and K, are thus assumed to be equal for the total North Sea and Wadden Sea. In addition, the biomass of the stock in one year is assumed to be positively related to the biomass in the year before. An analysis of the DFS data per geographical subarea shows that the trends differ considerably per location (fig 12). Whereas for most areas the CPUE in the DFS has increased over the years, in other areas (Westerschelde, Oosterschelde), the trend decreased. In addition, significant positive autocorrelation was observed only in the Dutch Wadden coast, the Oosterschelde and the Western Dutch Wadden Sea (figure 12). A significant autocorrelation could be lacking because shrimp reproduces all year round, which needs a higher frequency of sampling to track a stock recruitment relationship.

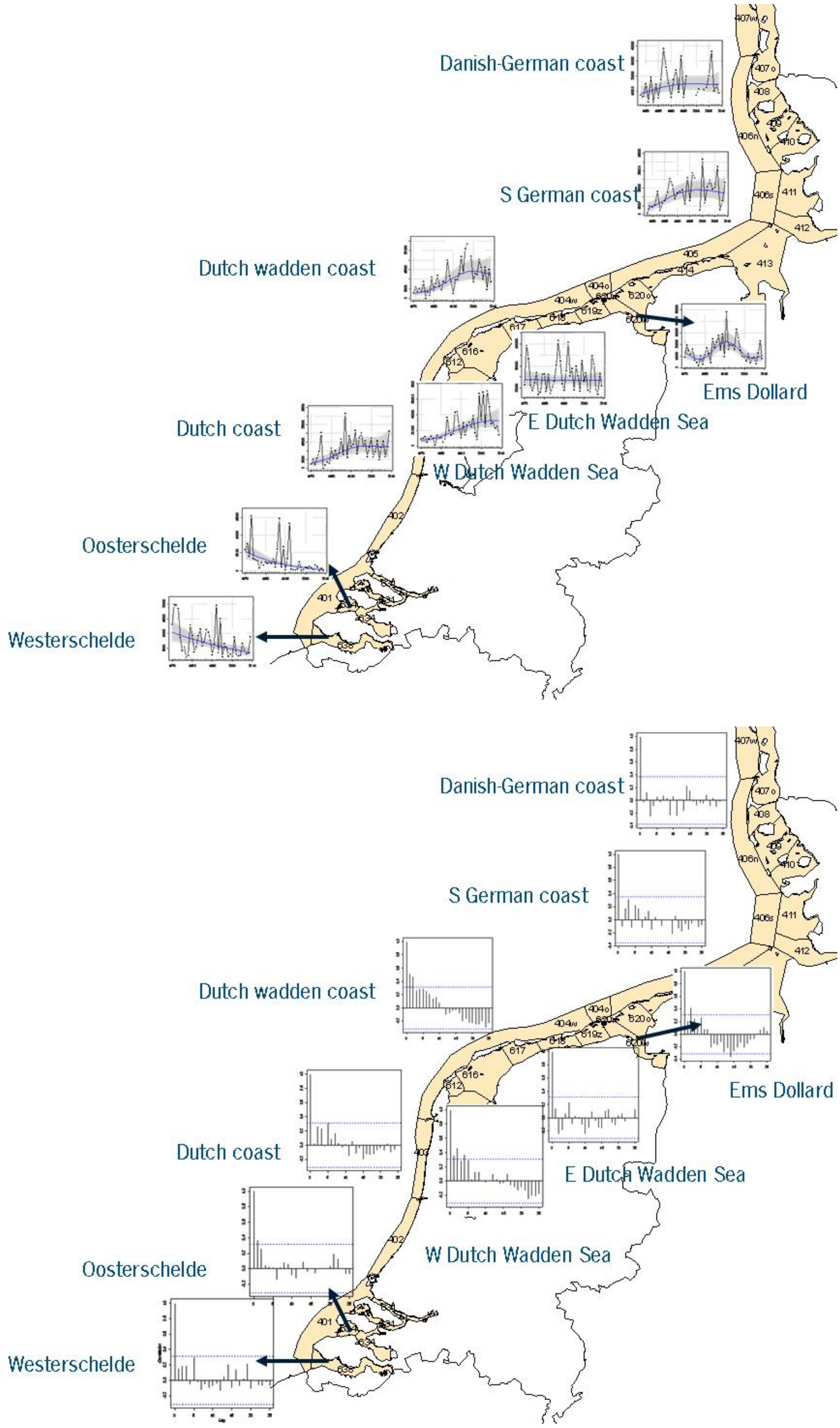


Figure 12 *Trends (CPUE, upper map) and autocorrelation (lower map) per area. If the second bar from the left in the autocorrelation graphs is higher than the blue dotted line, this means that there is a significant autocorrelation between one year and the next. This is only the case for the Oosterschelde, the Western Dutch Wadden Sea and the Dutch Wadden coast.*

Other short lived species
For another short lived species, *Pandalus borealis* (northern shrimp) biomass models have been applied for several stocks; off Iceland, in the Denmark Strait, in the Gulf of Maine and off West Greenland (Hvingel C & Kingsley 2006, Cadrin et al 2004) and often mimic the data well. Differences with the brown shrimp study are that a relationship between the fishing effort and the stock abundance was usually present for this species. This is likely caused by a good survey sampling and the longer lifespan of this species (2-4) year.

Krill (*Euphausia superba*) stock assessment faced similar problems as those encountered in this study in that the stock may consist of subpopulations that differ in their dynamics. This was solved by using a Generalized Yield Model (GYM) that allows the population dynamics to represent particular stocks by setting appropriate parameter values for growth, natural mortality and recruitment. At the moment, however, this method is not useful for brown shrimp, because it needs the input of a biomass estimate, growth rates per subpopulation, a mortality estimate and a recruitment estimate.

6 Summary discussion at WG CRAN

6.1 Biomass model

In general the model study was viewed as interesting and the group suggested keeping the subject on the agenda for next year. However, it was also recognized that it will be difficult to apply any stock assessment model for brown shrimp because of its complicated life history, different trends per subpopulation and especially the lack of an extensive survey index.

Trends per subpopulation
There is evidence that parameters of the biomass model, such as the intrinsic growth rate (r) and the carrying capacity (K), are not constant in time and space. For example, the shrimp stock is moving north because the conditions in the south have deteriorated in time, whereas conditions in the north (west from Sylt) may have improved. This may be a problem, because the model assumes that the parameters do not change in time and space.
The Biomass model itself was also criticized. The model may be too simple. It assumes, for example the yield curve is a symmetric parabola in relation to stock biomass (Schaefer model), whereas the real shape is unknown. Even though other shapes of this relationship can be modelled if desired (i.e. Pella and Tomlinson model), it would be better if the shape chosen would be based on shrimp knowledge.

Data
Another important point that was raised is that the model requires a long time series of accurate catch and reliable survey data that represents a wide range of stock and harvest conditions. The sampling program by the DFS is not extensive enough to describe the trends in the stock accurately. There is a lot of variability in time and space in shrimp abundance, which may not be observed with the current sampling program. In addition, sampling is only once a year and in the middle of the catching season (September-October). The commercial CPUE series have the disadvantage that the way they are calculated may differ such that even the trends may not be comparable. In addition, none of the fleets of the countries involved (maybe apart from the Dutch fleet) fish in the whole area. The commercial CPUE indices and the survey data do not correlate very well. It was suggested to compare subareas of the DFS data and compare these with the different commercial indices to check for possible spatial effects in the commercial indices.

The landings data may not be totally reliable either. The catch is sieved two or three times, once on board before the cooking (most discarded shrimp survives), once on board after cooking and one more time on land. The catches are weighted only after all sieving processes. In addition, the sieving conditions may also have changed in time. It is a problem that we do not know what exactly is represented in the data.

Last, it was suggested that the model should be fitted with only the commercial size classes from the DFS included in the model (above 45mm). The reason for that is that most of the catch data consists of this size class.

6.2 Alternatives

6.2.1 Swept area approach

An alternative method of assessing the biomass from survey data for the brown shrimp is a swept area method of population estimation, where the catch rates are expressed as densities. They can be raised from current surveys to suitable spatial strata and combine them to estimate total biomass.
An absolute or consistent index of abundance for the stock is useful as it can indicate that the shrimp biomass is at a level from which high recruitments have been produced (i.e. the stock level is sufficient to produce sufficient recruitment under favourable conditions to replace the stock). The stock or index could be assessed relative to historic levels. In 1990, CPUE values were at low levels relative to other years, and the stock was able to recover in the years after 1990. However, using the CPUE level of 1990 as reference point was rejected by the ICES WGCRAN working group. The group reasoned that too much variation in the CPUE index remains unexplained. Therefore, it is uncertain that the stock would be able to recover from the 1990 level under all conditions (ICES 2009).

6.2.2 Co-management approach

Suggested at WGCRAN (ICES 2010, in prep)

An alternative strategy for stock monitoring and management could be based on large number of simultaneous standardised catches taken from commercial vessels. This survey should be carried out during early summer to sample the pre-recruits to the main autumn fishery as undersized shrimp. In the initial years the monitoring would lead to a reference data set of pre-recruit estimates and subsequent autumn catches and in time the data will allow the detection of unusual situations.

6.2.3 Keeping track on LPUE during the season

Suggested at WGCRAN (ICES 2010, in prep)

To maintain a certain level of the shrimp stocks, fisheries could keep track of their LPUE (landings per unit of effort) to track changes in shrimp stock developments during the season. Basis for the LPUE values would be the already established EU reporting system by log-books and landing protocols. Consequently, minimum levels of LPUE can be set by experts based on historical values.

6.2.4 A combination of indicators of stock status

Other suggestions by WGCRAN

Moving away from a more formal assessment a combination of (perhaps softer) stock parameters could be used to assess the stock status:

- Number of egg-bearing females as an indication of the reproductive potential
- Size composition
- Maximum length
- Size of distribution area
- Predator biomass

6.3 ICES guidelines

For many commercially exploited fish species, the International Council for exploration of the Sea (ICES), is requested to provide advice on the status of individual fish stocks and to give catch advice for these stocks. A document with a guideline to produce this advice on the status of these stocks is publicly available on the ICES website http://www.ices.dk/committe/acom/comwork/report/2010/2010/Introduction%20for%20Advice.pdf (see relevant text below). In this document ICES suggests a framework how to assess the fishing intensity relative to a desired level for stocks where estimates on the population size are absent and for short lived stocks for which population size estimates are carried out. The former approach only calls for a determination of the status of exploitation relative to FMSY (overfishing or no overfishing) and consideration of the stock trend (i.e. CPUE index), the latter needs a preliminary TAC, sampling just before the fishing season and an adjustment of the TAC based on this information . In detail this is formulated in the paragraphs below (6.3.1 and 6.3.2).

In the ICES view clearly management is possible independent of stock assessments, which is less strict than the MSC view (Food Certification International full assessment report, 2009). The interpretation of which rules to use depends on whether there is an accepted stock assessment or an indicator of the stock size. Whether the alternative provided in 6.3.1 is applicable to brown shrimp largely depends on the availability of a time series that describes the trend in the stock well. The alternative provided in 6.3.2 partly resembles the suggestion made by WGCRAN (paragraph 6.2.2), although the reference point is still a population size estimate, rather than some other proxy for stock size.

6.3.1 Stocks without population size estimates

"For many fish stocks, the data available are inadequate to estimate the current population size and the catch resulting from fishing at a desired F. However, other data may be available to allow ICES to assess the intensity of fishing relative to a desired level. For stocks without population estimates, ICES practice has been to base advice on recent average catches when there is no quantitative or qualitative evidence of declining abundance. The ICES MSY approach calls for a determination of the status of exploitation relative to FMSY (overfishing or no overfishing) and consideration of the stock trend. The following table is the framework for advice for stocks without population size estimates.

	No overfishing	*Overfishing or unknown exploitation status*
Decreasing stock trend	*Reduce catch from recent level at rate of stock decrease*	*Reduce catch from recent level at rate greater than the rate of stock decrease*
Stable stock trend	*Maintain catch at recent level*	*Reduce catch from recent level*
Increasing stock trend	*Increase catch from recent level at rate of stock increase*	*Maintain catch at recent level*

Fishery catch per unit effort data or resource survey abundance information may be used to assess population trends, taking into account uncertainty. Age or size composition data are often useful for assessing the status of the fishery relative to FMSY. However, there are situations where even this type of information is not available. In such cases, it might still be possible to give advice but the basis for this advice cannot be prescribed in advance. This approach is intended to move in the direction of MSY, but this is unlikely to be achieved without additional or more complete information."

6.3.2 Short lived stocks with population size estimates

"The future size of a short-lived fish stock is sensitive to recruitment because there are only a few age groups in the natural population. Incoming recruitment is often therefore the main component of the fishable stock. In addition, care must be given to ensure a sufficient spawning stock size as the future of the stock is highly dependent on annual recruitment. For short-lived species, estimates or predictions of incoming recruitment are typically very imprecise, as are any catch forecasts. For short-lived stocks, the ICES MSY approach is aimed at achieving a target escapement (BMSY-escapement, the amount of biomass left to spawn), which is more robust against low SSB and recruitment failure than a fishing mortality approach. The catch corresponds to the stock biomass in excess of the target escapement. No catch should be allowed unless this escapement can be achieved. For some short-lived species, assessments are so sensitive to incoming recruitment that the amount of biomass in excess of the target escapement cannot be reliably estimated until data available just prior to the fishery or during the fishing year have been analyzed. Therefore, an adaptive framework may be applied as follows:

1. Set a preliminary TAC such that there is high likelihood that the target escapement will be achieved or

exceeded. This preliminary TAC is likely to be considerably below the final TAC (step 3).
2. Assess the stock just before or during the fishing year, typically based on a survey or an experimental fishery.
3. Adjust the TAC based on the assessment in step 2 assuring that escapement is at or above the target.

The escapement level should be set so there is a low risk of future recruitment being impaired, similar to the basis for estimating Bpa in the precautionary approach. In short-lived stocks, where most of the annual surplus production is from recruitment (not growth), BMSY and Bpa might be expected to be similar. Therefore Bpa is a reasonable initial estimate of BMSY-escapement."

7 Conclusions

We encountered several difficulties when studying the biomass model for brown shrimp. The main problems are (1) the short life span of shrimp, (2) (sub)populations have their own dynamics at different locations causing high variability, (3) the landings data are inaccurate due to different sieving methods over the years, (4) background mortality (predation by natural predators) is not constant in time, (5) the survey data does not cover the whole geographical distribution of the shrimp stock. Apart from natural mortality and the occurrence of subpopulations, the reasons for these problems are mainly caused by the available data not meeting the demands for a stock assessment model. A more extensive survey covering the whole shrimp stock area and including a survey at the start of the growing season would exclude most of the above points; biannual data collection could track the trends during the year; the sieving methods and estimates of discards could be documented, such that a better estimate of total removal of shrimp is possible and the survey could be extended to cover the geographical distribution of the shrimp stock.

<u>Final conclusion biomass model</u>
Therefore, at this point we conclude that the applicability of the biomass model for a reliable stock assessment of brown shrimp needs considerable more study and data collection. Because of the complexity of the data and the biology of shrimp, cooperation and approval by (international) stock assessment and shrimp ecology experts as well as approval from the ICES advisory committee (ACOM) would be desirable.

<u>Potential use of the reference points derived from biomass models</u>
The use of reference points in the management of any resource is the responsibility of the management bodies involved. Given the uncertainty of the estimates derived from the biomass model, some caution should be used when using these in management. One could envisage a system where the lower confidence bounds of MSY are used as a landings target, while the biomass is monitored through the index, and the landings and/or fishing effort are adjusted downward if the index indicates that the stock falls below *Bmsy*. The inclusion of alternative survey series could function as a similar indicator for stock size that ensures that the stock does not decrease below undesired levels.
However, as described above, there are additional uncertainties in the model estimates, the most important being caused by the quality of the available data, unknown levels of natural mortality and a high variability caused by local dynamics. These uncertainties can not be quantified at the moment and therefore pose an unknown additional risk. Knowledge about this risk can be obtained by more frequent sampling and research on the natural mortality of shrimp. It is, however, up to the management bodies to decide which risk can be accepted and which costs could be involved in risk reduction.

8 Quality Assurance

IMARES utilises an ISO 9001:2000 certified quality management system (certificate number: 08602-2004-AQ-ROT-RvA). This certificate is valid until 15 March 2010. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Environmental Division has NEN-AND-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2013 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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Justification

Rapport C072/10
Project Number: 430.8601.003

The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: I. Tulp
Researcher

Signature:

Date: 1 September 2010

Approved: Drs. J. Asjes
Head of Department Fish

Signature:

Date: 1 September 2010

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Number of pages	27
Number of tables:	2
Number of graphs:	13
Number of appendix attachments:	1

Appendix A

Model results

DFS

```
       r                K               B0                q1               sd1
 Min.     :0.23   Min.    :17.70   Min.   : 2.49   Min.   :0.37   Min.   :0.20
 Median   :0.52   Median  :24.67   Median : 5.32   Median :0.99   Median :0.37
 Mean     :0.53   Mean    :24.95   Mean   : 5.44   Mean   :0.99   Mean   :0.37
 Max.     :1.00   Max.    :68.84   Max.   :16.34   Max.   :1.00   Max.   :0.56
7.5Conf   :0.75           :31.29           :7.69          :0.99          :0.48
2.5Conf   :0.36           :19.48          :3.56           :0.99           :0.26
```

```
msy             Bmsy             Fmsy
Min.     :2.65   Min.   : 8.85   Min.   :0.11
1st Qu.  :2.95   1st Qu.:11.50   1st Qu.:0.23
Mean     :3.23   Mean   :12.48   Mean   :0.26
Median   :3.15   Median :12.33   Median :0.26
3rd Qu.  :3.39   3rd Qu.:13.18   3rd Qu.:0.28
Max.     :8.94   Max.   :34.42   Max.   :0.50
7.5Conf  :3.91          :15.64          :0.37
2.5Conf  :2.72          :9.74           :0.18
```

VIRIS

```
      r                K                 B0                 q1
 Min.   :0.00026   Min.   :1.727e+01   Min.   :    5.68   Min.   :3.295e-05
 Median :0.25      Median :3.418e+03   Median :   12.60   Median :2.230e-01
 Mean   :0.21      Mean   :2.404e+05   Mean   : 3273.02   Mean   :1.673e-01
 Max.   :0.81      Max.   :9.290e+06   Max.   :90165.91   Max.   :4.093e-01
7.5Conf :0.75             :31.29           :7.69           :0.99          :0.48
2.5Conf :0.36             :19.48          :3.56           :0.99           :0.26
```

```
sd1               msy               Bmsy
Min.    :0.028   Min.   :    2.54   Min.   :8.64e+00
Median  :0.088   Median :  207.85   Median :1.71e+03
Mean    :0.086   Mean   :  907.13   Mean   :1.20e+05
Max.    :0.15    Max.   :39836.14   Max.   :4.65e+06
7.5Conf :3.91          :15.64             :0.37
2.5Conf :2.72          :9.74              :0.18
```

Germany

```
r                    K                  B0                  q1
 Min.   :0.0006815   Min.   :1.289e+01   Min.   :4.032e+00   Min.   :1.556e-07
 Median :0.8141309   Median :2.555e+01   Median :5.717e+00   Median :2.029e-02
 Mean   :0.7408664   Mean   :3.157e+04   Mean   :2.671e+03   Mean   :1.812e-02
 Max.   :0.9999976   Max.   :7.038e+06   Max.   :6.411e+05   Max.   :2.974e-02
```

```
         sd1              msy                Bmsy
Min.   :0.01597   Min.   :1.010e-01   Min.   :6.445e+00
Median :0.06403   Median :5.116e+00   Median :1.277e+01
Mean   :0.06382   Mean   :7.756e+02   Mean   :1.579e+04
Max.   :0.11658   Max.   :2.166e+05   Max.   :3.519e+06
```

DFS+ VIRIS + GERMANY

```
       r                 K                  B0                  q1                 sd1
 Min.   :  0.02206   Min.   :3.540e+01   Min.   :6.873e+00   Min.   :2.357e-07   Min.   :  0.2277
 Median :  0.12642   Median :1.444e+03   Median :3.600e+02   Median :1.468e-02   Median :  0.4140
 Mean   :  0.13773   Mean   :4.786e+05   Mean   :1.289e+05   Mean   :1.730e-01   Mean   :  0.4140
 Max.   :  0.38592   Max.   :1.023e+08   Max.   :2.707e+07   Max.   :9.910e-01   Max.   :  0.6558
 7.5Conf   : 0.29           :1671189             :411512             :0.83               :0.54
 2.5Conf   : 0.05           : 48.33              :8.91               :0.01               :0.29
```

```
q2                  sd2                 q3
Min.      :-17.183   Min.   :  0.1951   Min.   :-17.104
Mean      : -6.527   Mean   :  0.3767   Mean   : -6.338
Median    : -6.201   Median :  0.3787   Median : -5.987
Max.      : -1.723   Max.   :  0.5493   Max.   : -1.663
7.5Conf   : -2.04           :  0.47            :-1.88
2.5Conf   :-13.11           : 0.27             :-12.94
```

```
      sd3               msy                 Bmsy
Min.   :  0.03269   Min.   :3.029e+00   Min.   :1.770e+01
Median :  0.09405   Median :3.271e+01   Median :7.219e+02
Mean   :  0.09273   Mean   :1.222e+04   Mean   :2.393e+05
Max.   :  0.14915   Max.   :2.503e+06   Max.   :5.115e+07
7.5Conf   :0.13            :37430.47           :835594.73
2.5Conf   :0.06             :3.21              :24.17
```

DFS + discard

```
  r               K                  B0                 q1                sd1
 Min.   :0.16   Min.   :  18.91   Min.   :   2.85   Min.   :0.0031   Min.   :0.1932
 Median :0.59   Median :  25.50   Median :   5.49   Median :0.99     Median :0.3824
 Mean   :0.59   Mean   :  62.19   Mean   :  14.35   Mean   :0.98     Mean   :0.3759
 Max.   :0.99   Max.   :5725.57   Max.   :1622.39   Max.   :0.99     Max.   :0.5070
```

```
msy              Bmsy
Min.   :  3.32   Min.   :   9.46
Median :  3.76   Median :  12.75
Mean   :  5.38   Mean   :  31.10
Max.   :224.89   Max.   :2862.79
```

DFS+COD

```
      r                K               B0                q1               sd1
 Min.   :0.1718   Min.   :18.28   Min.   : 2.974   Min.   :0.3020   Min.   :0.1914
 Median :0.5779   Median :23.70   Median : 5.529   Median :0.9998   Median :0.3724
 Mean   :0.6514   Mean   :24.86   Mean   : 5.762   Mean   :0.9790   Mean   :0.3700
 Max.   :0.9998   Max.   :89.46   Max.   : 23.83   Max.   :1.0000   Max.   :0.5137
7.5Conf :0.9998         :40.88          : 9.96           :0.9999          :0.4739
2.5Conf :0.3461         :19.49          : 3.84           :0.9999          :0.4791
```

```
a              msy              Bmsy
Min.   :0.5428   Min.   : 2.503   Min.   : 9.139
Median :0.6406   Median : 3.393   Median :11.848
Mean   :0.6557   Mean   : 3.943   Mean   :12.431
Max.   :0.7311   Max.   : 14.73   Max.   :44.729
       :0.7310          : 6.15           :20.441
       :0.5857          : 2.702          : 9.746
```