Stock assessment in brown shrimp (*Crangon crangon*) part 1: Investigation of possible methods

Tessa van der Hammen & Jan-Jaap Poos

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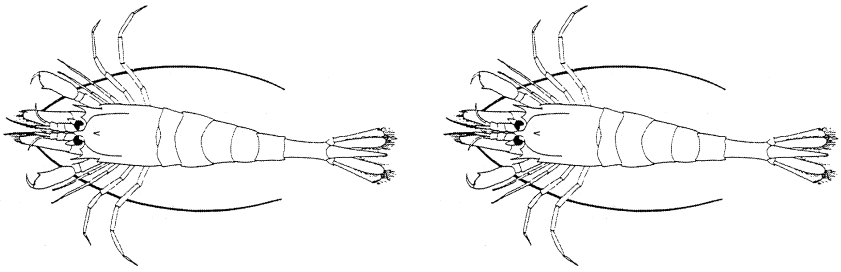

IMARES Wageningen UR

Institute for Marine Resources & Ecosystem Studies

Client: Directie AKV Ministerie LNV
t.a.v. Adriaan van der Schans
Postbus 20401
2500 EK Den Haag

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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. This report investigates the possibilities to assess the stock of the brown shrimp (*Crangon crangon*). For brown shrimp it will be difficult to assess the stock and to estimate the effect of the fisheries on the population dynamics 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 and (3) environmental conditions may play an important role in the population dynamics of shrimp. Therefore regular VPA analyses cannot be carried out. A stock assessment with a biomass dynamical model (or surplus production model) does not need demographic data. 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). Parameter values and probability of these parameters may be estimated with maximum likelihood methods or with Bayesian methods. The model can be extended by including effects of natural mortality and environmental conditions. However, whether it will be possible to find reliable parameter estimates depends strongly on the data. If there is poor contrast between the fishing effort and the stock abundance, it will be hard to accurately estimate these parameters. Alternatively, another method that may be worth investigating is the Catch – Survey (or Collie - Sissenwine) analysis. This method only needs two stages and has successfully been applied to northern shrimp (*Pandalus borealis*). Length frequency data from Dutch market samples or from Dutch or German surveys may be used to derive these two stages. However, even though both methods have been successfully applied for Northern shrimp (*Pandalus borealis*), it may be difficult to find accurate parameter estimates for brown shrimp. In a follow up report we will explore the different methods.

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 garnalen visserij 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. Het is echter bekend dat dit lastiger is voor garnalen dan voor veel vissoorten omdat (1) er geen demografische data beschikbaar zijn en er meerdere generaties per jaar voorkomen, (2) de natuurlijke sterfte door predatoren zoals vissen hoog is en (3) omgevingsfactoren zoals (water) temperatuur waarschijnlijk een grote rol spelen in de populatiedynamica. Bij een andere crustacea (*Pandalus borealis*) met een zelfde soort problematiek zijn twee methodes succesvol toegepast om tot een kwantitatieve bestandschatting te komen. In de eerste methode wordt een biomassa model (ook wel productie model genoemd) gebruikt. 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. Het model heeft als groot voordeel dat de leeftijdsstructuur van de populatie niet meegenomen wordt en de enige data die nodig zijn voor dit model is de totale garnalen sterfte (door de visserij) en een vangst per eenheid van inspanning index (CPUE, Catch per unit of effort). Visserijsterfte kan berekend worden door de aanlandingen van alle landen die in de Noordzee op garnalen vissen bij elkaar op te tellen. Deze data zijn beschikbaar sinds halverwege de jaren zeventig. CPUE indexen zijn ook beschikbaar via de logboek gegevens van de vissers, waarin de inspanning wordt bijgehouden, waarmee in combinatie met de vangst een CPUE index berekend kan worden. Deze gegevens kunnen echter een vertekend beeld geven omdat vissers actief op zoek gaan naar de plekken waar garnalen zitten. Een andere CPUE index kan verkregen worden door de gegevens van de Nederlandse en/of Duitse surveys. In Nederland wordt de DFS (Dutch Demersal Fish Survey) jaarlijks uitgevoerd. Elk jaar worden 200-300 trekken van 15 minuten langs de Nederlandse, Duitse en Deense kust gemaakt. Hieruit kan ook een CPUE index worden berekend. Een nadeel van deze serie is dat niet het hele gebied van de garnalen visserij door de survey wordt bemonsterd. Er zijn bijvoorbeeld aanwijzingen dat garnalen in de winter naar dieper water trekken (in de buurt van het Duitse eiland Sylt), waar de DFS niet komt. Duitsland verzamelt gegevens in een zelfde soort bemonsteringsprogramma (DYFS), met name in de Duitse Bocht en buiten de Duitse eilanden. De gegevens voor het biomassa model zijn dus in principe voorhanden. Dit betekent echter nog niet dat het eenvoudig is om tot goede parameterschattingen van het biomassa model te komen. Hiervoor moeten de data nog aan andere voorwaarden voldoen. Zo moet er een duidelijk verband zijn tussen de visserij inspanning en de bestandsgrootte; als er meer op garnalen gevist worden, is de verwachting dat de bestandsgrootte afneemt. Het is niet onwaarschijnlijk dat zo'n verband ontbreekt doordat de garnalensterfte ook afhangt van natuurlijke sterfte door predatie en dat de groei sterk afhangt van omgevingsfactoren zoals (water) temperatuur. Het is mogelijk om deze factoren mee te modelleren in het biomassa model. Echter, dan moet de kennis wel voorhanden zijn. Temperatuur is niet te voorspellen en hoewel het bekend is welke predatoren mogelijk een rol spelen in de predatie van garnalen, vaak zijn van deze soorten geen schattingen van hun dichtheden bekend (alleen van de commerciële soorten). Van enkele soorten, zoals kabeljauw en wijting, worden officiële bestandschattingen gemaakt die gebruikt kunnen worden. Het is echter maar de vraag of deze soorten momenteel nog voor de grootste predatiedruk zorgen bij garnaal. Van andere soorten kunnen eventueel nog schattingen gemaakt worden van hun aantallen door survey analyses. Een tweede methode om tot een bestandschatting te komen is door middel van een Collie Sissenwine model (ook wel catch survey model genoemd). Dit model is ook voor een andere crustacea (*Pandalus borealis*) succesvol gebruikt. Deze methode neemt wel demografische structuur mee, namelijk twee stadia (wel of niet volwassen). Deze stadia kunnen afgeleid worden uit lengte frequentie verdelingen, die beschikbaar zijn uit de Nederlandse en Duitse surveys en in Nederland ook uit een bemonsteringsprogramma van de aanlandingen. Voor deze methode gelden echter ook dezelfde voorwaarden voor de data als voor het biomassa model.

Om in te kunnen schatten of een betrouwbare bestandsschatting mogelijk is, moet de model analyse eerst worden uitgevoerd. Dit zal in een vervolgrapport gedaan worden. Als blijkt dat door de complicaties van of wel de ecologie van garnalen ofwel door de kwaliteit van de data het niet mogelijk is om tot een bestandschatting te komen, dan kan er nog naar andere opties gekeken worden om tot een zogenaamde *harvest control rule* te komen, zoals voor bestanden van enkele andere soorten is gedaan.

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 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 fishery must be conducted in a manner that does not lead to over-fishing or depletion of the exploited populations'. However, there is no control on the total quantity of brown shrimp landings in the North Sea and an official assessment of the stock size is lacking. To evaluate whether the brown shrimp stock is harvested sustainably, it is desirable to assess the stock size in a quantitative approach. This would allow the estimation of biological reference points, which can be used to define safe levels of harvesting (also called *harvest control rule*). This report was set out to investigate the possibilities to assess the stock of the North Sea brown shrimp.

2 Problem description

A stock assessment utilizes mathematical models to describe the past and current status of a fish stock. In addition, a stock assessment also attempts to make predictions about the future status of the stock and how the stock will respond to current and future fishing effort. There are several methods to assess the stock, each method with a set of data requirements and assumptions. For example, many stock assessment models are based on age- or stage structure of a population and therefore require data on age or stage of the fish.

How well a stock assessment describes the status of a fish stock depends on whether the assumptions of the methods are met. Firstly, most stock assessments assume that the stock under study should be a single population. If a stock consists of a number of (sub) populations, or if the population is in reality much larger than the stock included in the analysis, model estimates will probably not describe the population dynamics well. Secondly, an prerequisite for a stock assessment is the availability of data that represent the trends of abundances of the stock. Preferably such data should be the result of a well-designed fishery independent survey analysis that covers the total area of occurrence of a population. Thirdly, the stock assessment model should include the aspects that are the most important for the population dynamics of the species of interest. Often it is assumed that mortality caused by the fishery is important for the population dynamics. If so, the data requires contrasts between the fishing mortality and the stock size, i.e. high fishing mortality resulting in a reduction in stock size, or the opposite. If this contrast is absent, fishing mortality may not be the main factor that drives the stock size.

If the assumptions are not met, a stock assessment may be complicated because it will not be representative for what is really causing the trends in the stock abundance.

For brown shrimp, the main factors that complicate a stock assessment are:

(1) demographic data on shrimp is lacking, there is more than one generation per year and brown shrimp have a short life span (2 years).
(2) natural mortality is high, depends on the abundance of other predators and varies in time
(3) abiotic factors may play an important role in the reproduction and growth of shrimp population

1) Demographic data

Many fish stock assessments are based on age- or stage-structured models that use tools such as VPA (virtual population analysis) or SCAA (statistical catch at age). These models have the advantage that they can follow a cohort (age group) through time and implement age specific aspects such as fecundity and mortality. For brown shrimp these methods are not available because (1) they have a short life span (2 years), (2) there is more than one generation per year, (3) aging of shrimp is difficult and (4) historical data on shrimp age is lacking. It may be possible to estimate the age of shrimp by measuring their length and use a length age relationship to derive the age. However, this may not be very accurate and in addition, the length of the shrimp may depend on abiotic factors such as water temperature.

2) Mortality

Another factor that complicates the assessment of shrimp stock is that natural (or background) mortality of the brown shrimp depends on the predation of shrimp by predators, such as fish, whereas for most commercial fish species, the catches by the fleet are the main source of mortality. If natural mortality is largely depending on abundances of predator species, it may be necessary to include these predators in the model as a function of predator density. In that case, the abundance of the predator species need to be estimated as well as their consumption rate of brown shrimp. The number of species that have been suggested to play an important role in the predation of shrimp is high; cod (*Gadus morhua*), whiting (*Merlangius merlangus*), dab (*Limanda limanda*), bib (*Trisopterus luscus*), bull rout (*Myoxocephalus scorpius*), hooknose (*Agonus cataphractus*), five-bearded rockling (*Ciliata mustela*), sea snail (*Liparis liparis*), dragonets, grey gurnard (*Eutrigla gurnardus*), crabs, solenette (*Buglossidium luteum*) and scaldfish (*Arnoglossus laterna*). For non-commercially exploited species little or no information about the size of these stocks and their predation rates of shrimp are known. However, it is likely that the abundances of these predators play an important role in the population dynamics of shrimp because of the predation pressure that they exert on the stock and therefore should be included in a stock size analysis.

3) Abiotic factors
Parameters that may be of importance for population dynamics of the shrimp stock, such as growth rate, fecundity and natural mortality may depend strongly on environmental conditions. Factors that have been suggested to influence these parameters include temperature, water temperature, salinity, dissolved oxygen winter temperature, North Atlantic Oscillation (NAO) and river run-off. Similar to predator induced mortality as described above, most of the effects of abiotic factors on the shrimp population dynamics are unknown and will therefore be difficult to implement in a model.

3 Assessment models

A simple model that is frequently used for stock assessments when demographic data is missing is the biomass dynamic model (Schaefer 1954, Pella and Tomlinson 1969, Hilborn and Walters 1992). This model ignores all the complexities of age structure, spatial structure and the population is described by a single number, population biomass. This model can be extended to include predation by other predators and abiotic factors. However, whether reliable parameter estimates can be found will largely depend on the data and the contrasts between catch, CPUE (catch per unit of effort), predator density and abiotic factors.

Another possibility for the assessment of shrimp is the Collie-Sissenwine, or catch-survey (C-S) model (Cadrin *et al* 1999). The Collie-Sissenwine model has only two stages rather than full age-structure, such as in SCAA or VPA. Instead of age, size based stages can be derived from length frequencies (Cadrin *et al* 1999). This model has the advantage that demographic information is included and may therefore include trends in the stage distribution of the stock. The Collie-Swissenwine model has been used for Northern shrimp (*Pandalus borealis,* Cadrin *et al* 1999), the Collie-Swissenwine model fit the data well (Cadrin *et al* 1999).

3.1 Biomass dynamic models

If data on the age structure of the population is lacking, models that use tools such as VPA (virtual population analysis) or SCAA (statistical catch at age) are not available to assess fish stocks. Biomass dynamic models only need total landings and effort data to assess stock size and estimate reference points to define safe levels of harvesting. Biomass dynamic models (also commonly called production or surplus production models) are therefore the major assessment tool for many fisheries that lack demographic data.
In contrast to age structured models, biomass models do not describe the stock in terms of numbers, but in terms of total biomass.

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

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

in which B is the total stock biomass and dB/dt is the change of B in time t, K is the carrying capacity, and r is the growth rate. 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).

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

where Y is yield at time t. It is assumed that $Y_t = q \cdot f_t \cdot B_t$. 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:

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

The Schaefer model can be used to estimate the parameters values of *r*, *K* and *q*, that give the best fit using either maximum likelihood (MLE) or Bayesian methods (see next chapter). If these parameters are estimated, it is possible to assess the size of the stock (B) and to estimate reference points (table1).

3.2 Reference points

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. Hence, from the viewpoint of the fishery, the biomass at the maximum sustainable yield (B_{MSY}) is usually most desirable stock and catch biomass, because it provides the highest amount of catch over a long time span (figure 1).

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
Fishing mortality for achieving MSY (F_{MSY})	r/2

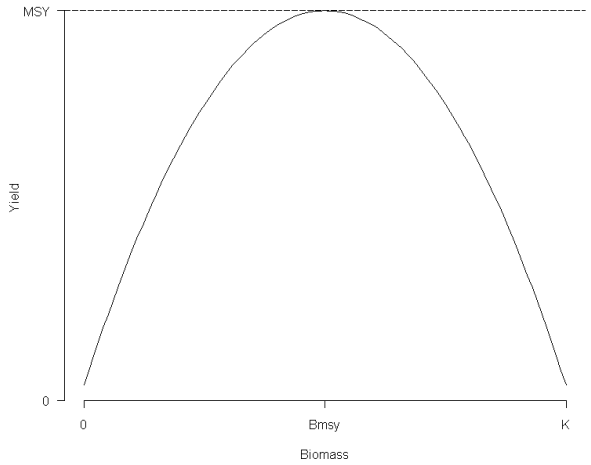

Figure 1: Equilibrium state of biomass with harvest. The equilibrium that gives the highest possible sustainable yield is at MSY (maximum sustainable yield).

3.3 Predation

An advantage of biomass dynamics models is that predation terms can be added to the model:

$$\frac{dB}{dt} = r \cdot B \cdot \left(1 - \frac{B}{K}\right) - Y - a \cdot P \quad (4)$$

where a is the predation rates for the predator populations P. The predation rate can be modelled as single parameter, but can also be modelled as a functional response (Holling, 1959). For example Hvingel (2006) included a type III functional response to model predation rates of shrimp by cod. In a type III functional response saturation occurs at high levels of prey (shrimp) density, but at low prey density levels, the number of prey consumed and the density of the prey population is a more than linearly increasing function of prey consumed by predators. A type III functional response assumes learning time and/or prey switching. If desired, more than one predator can be added.

3.4 Abiotic factors

Similar to the addition of predator terms, abiotic factors such as temperature can be included in the model:

$$\frac{dB}{dt} = r \cdot B \cdot \left(1 - \frac{B}{K}\right) - Y + d \cdot T \quad (5)$$

Where T is temperature and d is the temperature effect on population growth.

3.5 Generalized biomass model

Pella and Tomlinson (1969) extended the Schaefer model to a more general model. This 'generalized' model is sometimes thought more realistic, or at least more adaptable to possible realities. The reason for adding this parameter is that the Schaefer model dictates that the yield curve (figure 1) is symmetric in relation to stock biomass, whereas in the Pella and Tomlinson model, an extra parameter, m, was added to modify the shape of the growth function:

$$\frac{dB}{dt} = r \cdot B - \frac{r}{K} \cdot B^m - Y \quad (6)$$

If m equals 2, it equals the Schaefer's model. If m differs from 2, the equilibrium state (figure 1) will be skewed to the left ($m < 2$) or to the right ($m > 2$). The shape parameter, m, also changes the equations of the reference points (Hilborn & Walters 1992).

3.6 CSA (Catch Survey Analysis or Collie Sissenwine Analysis)

Age structured models that use tools such as VPA (virtual population analysis) or SCAA (statistical catch at age) to assess fish stocks have the advantage that they include more biological realism and therefore may give more reliable parameter estimates. For example, a population consisting of many young individuals have less offspring than a population consisting of many adults. A model based only on biomass will not detect this difference, therefore age or stage models are preferred if possible. For brown shrimp age is difficult to estimate and there are no historical data of age structure of the stock. In addition, reproduction occurs all year round. Cadrin (1999) suggested a Catch Survey Analysis (or Collie Sissenwine Analysis) for northern shrimp (*Pandalus borealis*) stock assessment. Catch Survey Analysis only need two stages rather than full age-structure, for example recruitments (R) and fully recruited shrimp (N). For *Pandalus borealis*, these stages are derived from length frequency

distributions from survey data (Cadrin 1999). Growth was implemented by a 'von Bertalanffy' growth curve. To solve the year round reproduction period, all individuals that grow to recruited sizes in a given time step (year) are included as recruits, even if they grow to recruited size after the fishery occurs.

3.7 Alternative 'harvest control rules'

If a stock assessment via the traditional models does not result in reliable parameter values, it may be possible to find another solution to formulate a so called '*harvest control rule*'. Other species that have faced similar problems as for brown shrimp, but were able to define such a rule, are Norwegian lobster (*Nephrops norvegicus*) for which video surveys are used to assess the stock and horse mackerel (*Trachurus trachurus*) for which egg surveys are used to define a harvest control rule. Although the methods used for these species are not applicable for brown shrimp, they show that alternative methods to stock assessments based on traditional methods may be possible.

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. One draw back of survey data are they are vulnerable to changes in catchability which may need to be adjusted for.

Alternatively, having an absolute or consistent index of abundance for the stock is useful in itself as it can indicate that biomass is at levels 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. e.g. 0-33% = low, 34-66% =moderate, >67% = High.

4 Parameter estimation

Goodness of fit – maximum likelihood

The basic approach to determine which parameter values fit the data best is to minimizing the deviation between predicted and observed values (maximum likelihood). The first step is to guess the stock size at the beginning of the available time series 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.

Estimating uncertainty

To estimate uncertainty, two different methods can be used, bootstrapping or the Bayesian approach. In the bootstrapping method, the uncertainty in the parameter values will not be directly incorporated into the results, but the modeller will test how sensitive the model is to the use of that value. This would involve repeating the model calculations several times, using slightly different values for the parameter each time. This is called a bootstrap method. The degree to which those values has changed the outputs can then be examined.

In the Bayesian approach pre-existing knowledge about the parameters can be assumed and relative levels of certainty for each of those values will be defined in so called priors. Uncertainty can be estimated with an "Markov Chain Monte Carlo" approach, which results in relative goodness-of-fit estimates for a range of values for all the parameters. An advantage of this approach is that it can pass the uncertainty through to the biological reference points. A disadvantage is that the results may be strongly influenced by the priors when the fisheries data lack signal.

5 Data

5.1 Landings

All EU vessels are required to report their landings, thus landing data are relatively complete. Commercial landings from The Netherlands, Germany, UK, France and Denmark are registered since 1973. The sum of these can be used as the total amount of shrimp landed from the North Sea area (figure 2, 3). However, this does not give insight into the extent of unreported landings or discards (see below).

5.2 Catch per unit of effort (CPUE) index

To fit predicted values by the model to data, a time series of a catch per unit of effort (CPUE) index is required. If information on the full catches is not available (e.g. because of discarding), landings per unit of effort (LPUE) may be used as a proxy for CPUE. The validity of using LPUE as a proxy for CPUE depends on (the variability of) the proportionality of discards and landings. Time series of LPUE's of brown shrimp in the North Sea are available from logbook data from the commercial fleets and CPUE series are available from the Dutch and German Surveys. Ideally, these indices should be comparable and provide more or less similar results. However, combining the available indices is complicated, because different units of effort were calculated for each country/time series (ICES 2005). Combing the indices is not necessary for a stock assessment, because predicted values are fitted to a single CPUE time series and assessments methods may also benefit from the use of multiple alternative CPUE indices. However, time series should give a representative estimation of the trends of abundance of shrimp in time. Fishery-dependent LPUE estimates may violate this assumption, because fishermen will actively fish in areas with high fish concentrations. Survey indices on the other hand often have the disadvantage that they do not cover the total area visited by the commercial fleet. Also, because sample size in such surveys is generally low, the uncertainty in the survey estimates is generally high.

Below, we describe the main LPUE and CPUE indices:

Netherlands, commercial fleet: Data of days at sea (das) and horse power days at sea (hpdas) from the commercial fisheries are available from the LEI and the Viris databases. In combination with the landings data, an effort index can be estimated (figure 4). This index is easily drawn from the database, but may be less accurate than survey data. In addition, fishermen will try to find areas with high densities of shrimp, their catches may therefore overestimate the real abundance.

Netherlands, DFS Survey: 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 5). The area and duration of every haul is registered. Therefore, an index of catch per unit of effort can be estimated from these data and used in the model. A disadvantage is that not the total area visited by the commercial fisheries is covered by the DFS. For example, brown shrimp probably occurs in high densities nearby the German island Sylt in winter, whereas the DFS does not cover this area (figure 5, 7). In addition, the survey takes place only in the autumn, whereas the shrimp abundance may show high fluctuation during the year.

Germany, DYFS Survey: From 1970 onwards Germany joined in with the Dutch initiative for an inshore beam trawl survey (figure 6). At first only aggregated data were collected, but from 1971 onwards data are available by haul. The survey area was extended in the following years and since 1974 the East Frisia, Elbe and Schleswig-Holstein regions are covered consistently. The Jade-Weser region has permanently been included in the monitoring programme since 2005, before it was only sampled occasionally. The DYFS survey gear is almost identical to the Dutch DFS gear (ICES, 2006). Mayor difference is the use of a tickler chain in the Dutch DFS, which was omitted in the German DYFS because of the excessive catch of dead shells on many of the German stations (pers com Rauck). Campaigns were carried out in both spring (April-May) and autumn (September-October) until 2005, only the autumn survey has been continued since 2005. It may be possible to estimate a CPUE index from this survey as well as length frequency distributions.

5.3 Discards

The total mortality caused by the fisheries is a sum of the mortality caused by the landings and by the discards. Therefore, an estimate of the discards of brown shrimp is also required. There is no legal minimum landing size for brown shrimps in the EU, but a minimum market size of 45 mm of total length, though shrimp as small as 20 mm are regularly caught in these fisheries (Van Marlen *et al.* 1998). 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).

Length frequency distribution
The Netherlands - market sampling: At Dutch harbours, random samples of shrimp were collected from the landings from 1973 to 1995 and from 2007 till now. From these samples data on size, weight and presence of summer or winter eggs were collected.

The Netherlands / Germany – DFS/DFYS Survey: Length-frequency distributions are available from the Dutch and German Demersal (Young) Fish Survey (DFS and DYFS), because subsamples from brown shrimp are measured (weight and length).

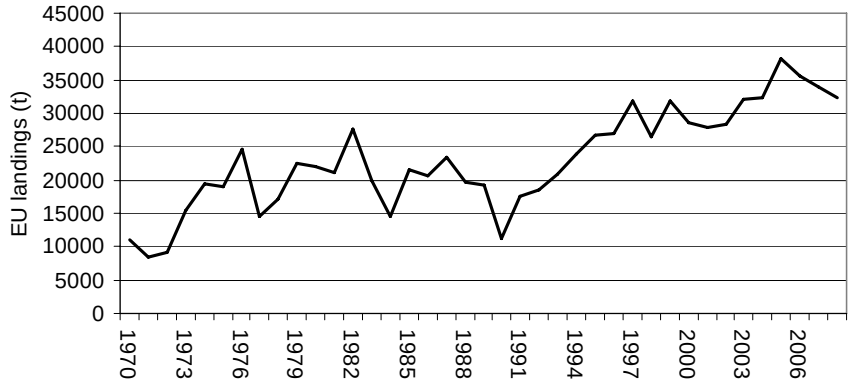

Figure 2: Total landings (tonnes) of Crangon crangon from the North Sea by all countries. From: ICES 2009

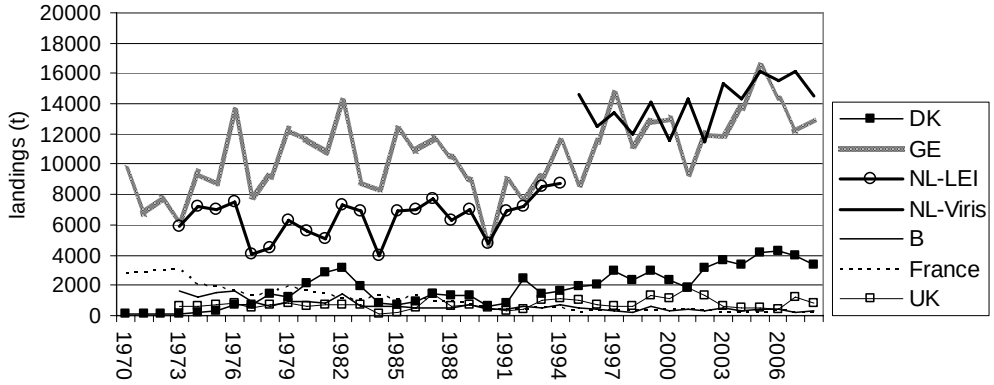

Figure 3: Total landings (tonnes) of Crangon crangon from the North Sea by country. From: ICES 2009

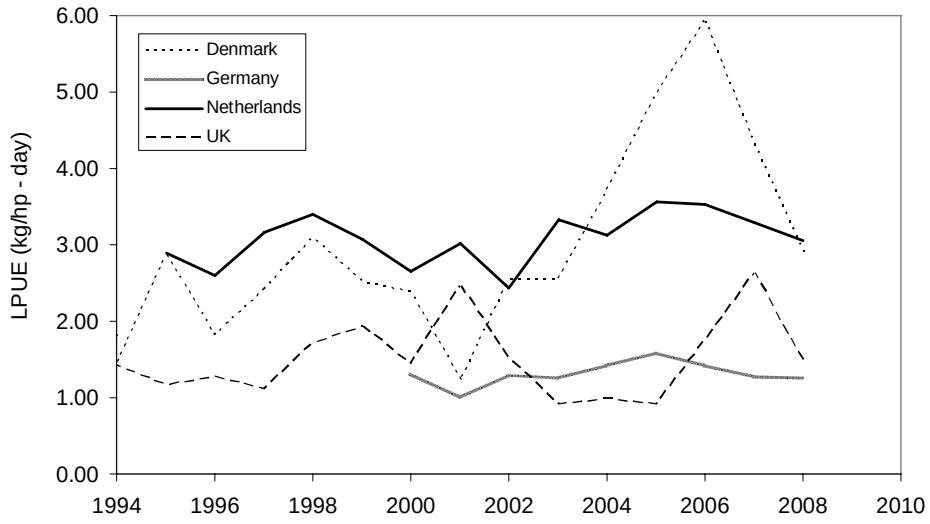

Figure 4: Landings per unit of effort. Units are different for the different countries: (DK) kg/hp-day; (NL) kg/hp-day ;(DE) 1973 - 1994 effort LEI, catch PO, 1995 -2003 catch + effort VIRIS; (BE) kg/10 hp-fishing hours.

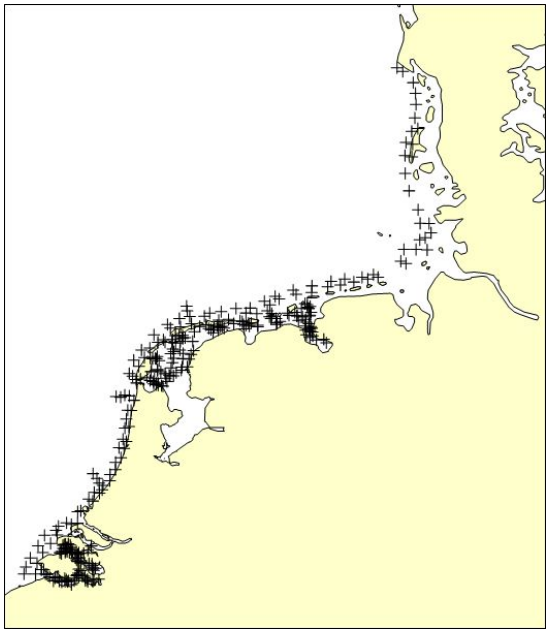

Figure 5: Area covered by the Dutch survey (DFS)

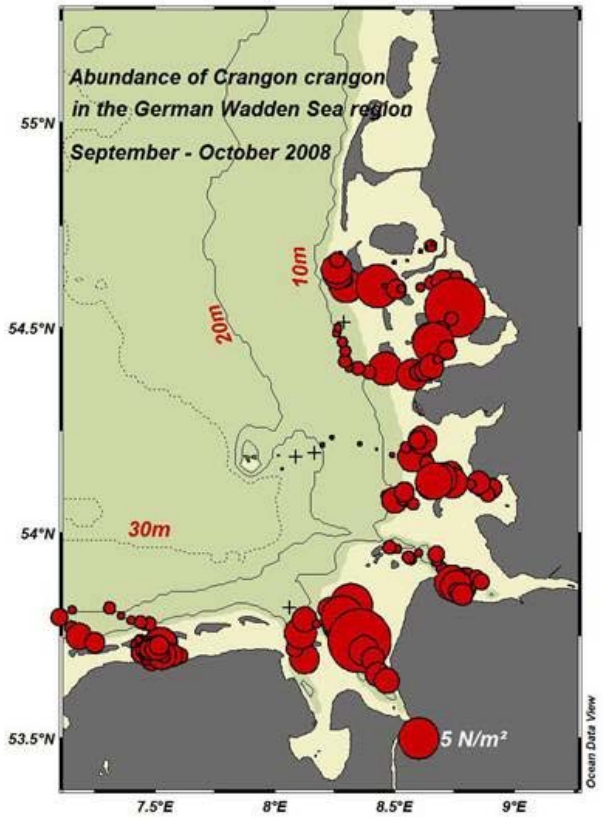

Figure 6: Area covered by the German survey (DYFS)

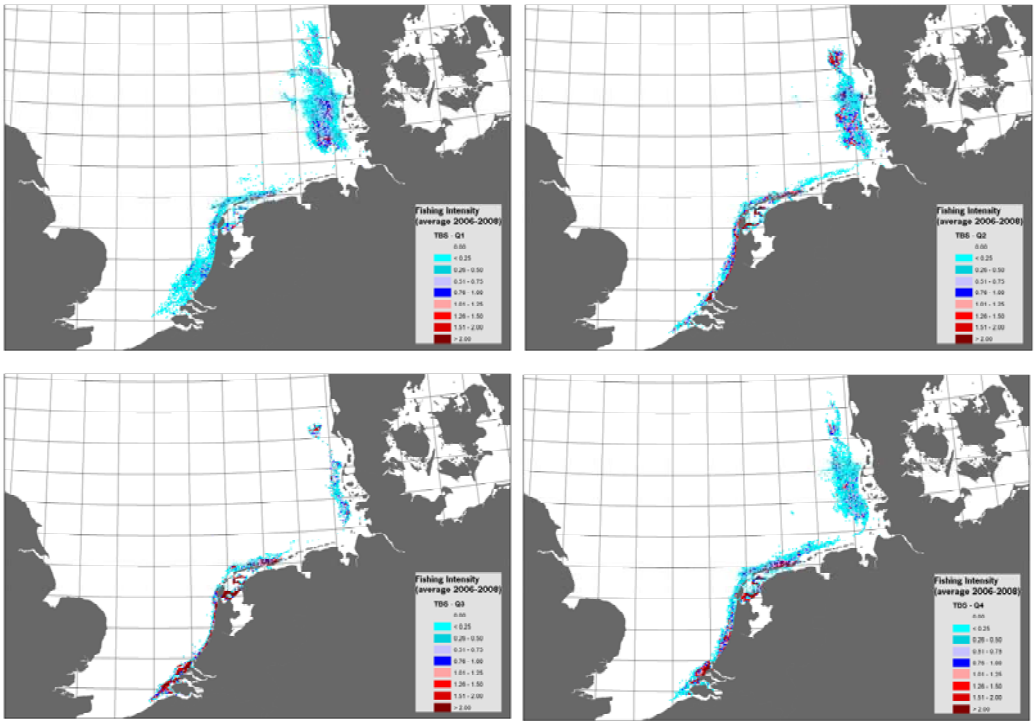

Figure 7: Fishing intensity per quarter between 2006 and 2008

6 Previous *Crangon crangon* evaluation of the stock

Welleman and Daan (2001) extrapolated the DFS catches to a larger area by multiplying the catches by the area in the North Sea covered by the DFS. In addition they estimated the consumption by cod and whiting and compared this consumption with the mortality caused by the fishery. They concluded that the brown shrimp stock remained stable from 1969 to 1999 and that predation by cod and whiting exceeds the landings by a factor two to twenty.

In the UK shrimp fishery a biomass model was used which included factors for predation, nutrient levels (nitrates) and water temperature (ICES 2005). There was a negative relationship between an index of predator abundance (whiting) and an index of shrimp abundance (modified CPUE from survey data). It was concluded that the method was sensitive to outliers in the data but it did try to incorporate factors which were thought to be influential on shrimp productivity. It was also concluded that the ICES stock assessment lacked the spatial and temporal resolution necessary to produce a suitable index of whiting predation (thus, survey data should be used). The timing and local abundance of key sizes of whiting seemed critical.

Descriptive
Formal stock assessments have never been carried out, but trends in the stock have been evaluated in a descriptive manner by the WGCRAN (ICES working group on crangon fisheries and life history).

7 Conclusions and recommendations

7.1 Biomass dynamic models

To estimate reference points for brown shrimp using biomass dynamical models, the only data needed are landings (catch) and a landing (catch) per unit effort index. The available data as described in chapter 5 covers the necessary input needed for a biomass model and it may thus be a good starting point for the assessment of the brown shrimp stock. However, to estimate reliable parameter values, the data set should meet certain criteria. It is likely that some parameters (in particular r and K) can not be estimated separately. This can happen if shrimp predation by natural predators (such as fish species) is substantial, if environmental conditions such as temperature are relatively important for the growth of the shrimp stock or if the shrimp stock consists of several (sub) populations. If so, the relationship between trends in the CPUE index and the landings time series will be weak or absent, causing estimation of the parameters to be problematic. Unfortunately, for brown shrimp, the data do not suggest a good stock/recruitment relationship from one year to the next. Catch rates and landings often recover from low levels in a previous year or are poor following a good year but the relationship between spawning stock size and recruitment is not understood (ICES 2009). However, the assessment should be carried out before conclusions can be drawn.

Predation can be included in a biomass dynamical model, if information on the stock sizes of the predators is available. For cod and whiting official stock assessments are available and may be included in the model. However, the ICES stock assessment may lack the spatial and temporal resolution necessary to produce a suitable index of predation. Estimates of predator abundances may also be computed by the survey data. However, it is uncertain if the inclusions will improve the fit substantially. It also means that extra parameters have to be estimated, such as the predation rate (parameter a in equation 4). In addition, including predation may only increase the fit of the model if there is a clear connection between the predator stock size and the CPUE.

Abiotic factors, such as (water) temperature, may affect the growth of the brown shrimp population. These factors can be included in the model, but may increase the uncertainty of the parameter values in the same manner as the inclusion of predation. In addition, abiotic factors can not be predicted, which complicates the assessment of a future stock.

7.2 Generalized biomass model

The Pella and Tomlinson model provides more flexibility compared to the Schaefer's model. However, the model is also more often volatile and the estimates of the parameters may have higher variances and be less reliable. Ecological knowledge of the value of m is lacking for brown shrimp, therefore it seems more reasonable to start with the Schaefer's model, where the m parameter is assumed known.

7.3 CSA (Catch Survey Analysis or Collie Sissenwine Analysis)

For *Pandalus borealis*, the CSA model seems to give a good fit to the data (Cadrin 1999). For brown shrimp a time series of length frequency distributions are available from surveys as well as from market sampling. However, the available data need careful study before it is possible to evaluate this method for brown shrimp. Length data are available for brown shrimp, but because (1) brown shrimp are fast growing, (2) growth depends on temperature, (3) the recruitment period is prolonged and (4) there is more than one abundance peak per year, it may be too complicated to use this model.

7.4 Research recommendations

It is essential for a stock assessment that the ecology of the species is fully understood. Brown shrimp is well studied, but because it is a prey species and involved in many trophic interactions, it remains difficult to understand which are the main aspects that influence the population dynamics of brown shrimp.

Apart from understanding of the brown shrimp ecology, well-designed datasets are needed. Data collection on brown shrimp is required by the EU Data Collection Regulation, which covers landings and effort data. Estimates of the discards of shrimp are also necessary. A discard sampling program has started for the Wadden Sea area (Tulp *et al* 2009), but estimates of discards should be made elsewhere as well.

The Dutch and German survey data are originally set-up for estimation of the abundance of young flatfish rather than for shrimp. In addition, the distribution of the shrimp has changed in time (to the north and to deeper water in winter time). This means that not the entire brown shrimp fishing area is covered by the survey. An extension of the survey including the total fishing area may be worth exploring. Such extension of the survey may also give insight in the spatial variability of brown shrimp abundance. If the spatial variability of brown shrimp abundance is large, this may result from unknown stock structure. Future research could use genetic tools to estimate stock structure.

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

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

Approved: dr. I. Tulp
Researcher

Signature:

Date: March 23, 2010

Approved: Drs. J. Asjes
Head of Department

Signature:

Date: March 23, 2010

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