Wageningen IMARES
Institute for Marine Resources & Ecosystem Studies

Location IJmuiden
P.O. Box 68
1970 AB IJmuiden
The Netherlands
Tel.: +31 255 564646
Fax: +31 255 564644

Location Yerseke
P.O. Box 77
4400 AB Yerseke
The Netherlands
Tel.: +31 113 672300
Fax: +31 113 573477

Location Den Helder
P.O. Box 57
1780 AB Den Helder
The Netherlands
Tel.: +31 22 363 88 00
Fax: +31 22 363 06 87

Location Texel
P.O. Box 167
1790 AD Den Burg Texel
The Netherlands
Tel.: +31 222 369700
Fax: +31 222 319235

Internet: www.wageningenimares.wur.nl
E-mail: imares@wur.nl

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Stock assessment of North Sea plaice using surplus production models

Marcel Machiels, Sarah Kraak, Lisa Borges and Hans Bogaards

Commissioned by: Ministerie van Landbouw, Natuur en Voedselkwaliteit
Postbus 20401
2500 EK Den Haag

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Uitgebreide Nederlandse samenvatting

Plaats binnen het F-project

In het F1-werkpakket van het F-project houden we ons bezig met verbetering van de toestandsbeoordeling van schol en tong. Problemen rond de onzekerheid en bias in de toestandsbeoordeling en de gegevens die daarvoor worden gebruikt, worden onderzocht in een serie van kleinere deelstudies, die elk een probleem bestuderen. In vier deelstudies, producten A10, A11, A12 en A14, benaderen we het probleem van de onzekerheid in de toestandsbeoordeling. Dit rapport betreft product A10, onzekerheid in de toestandsbeoordeling van Noordzee schol aan de hand van "surplus productie modellen".

Onzekerheid

In bestandsschattingen zijn twee bronnen van onzekerheid te onderscheiden: onzekerheid ten gevolge van de gebruikte gegevens en onzekerheid ten gevolge van de aannames die gemaakt worden om het model te gebruiken. In een serie van vier deelstudies proberen we inzicht te krijgen in het aandeel van beide onzekerheidsbronnen in de totale onzekerheid van de bestandsschatting. In de eerste drie deelstudies onderzoeken we drie structureel zeer verschillende modellen voor de bestandsschatting. Deze modellen doen elk verschillende aannames over de populatiedynamica en de manier waarop je deze kunt reconstrueren vanuit de gegevens. Vergelijking van de modeluitkomsten (vierde deelstudie) geeft ons een beeld van de onzekerheid die veroorzaakt wordt door de modelkeuze. Binnen elk van de eerste drie deelstudies variëren we modelaannames, waardoor we inzicht krijgen in de onzekerheid veroorzaakt door deze aannames. Door het toepassen van de Bayesiaanse methode krijgen we informatie over de onzekerheid die door de gegevens veroorzaakt wordt. In deze deelstudie is het model dat we onderzoeken een zogenaamd "surplus productie model".

De Bayesiaanse benadering

Bayesiaanse statistiek wordt de laatste jaren meer en meer gebruikt voor bestandschattingen binnen en buiten ICES. Twee redenen om Baysesiaanse statistiek te gebruiken zijn:

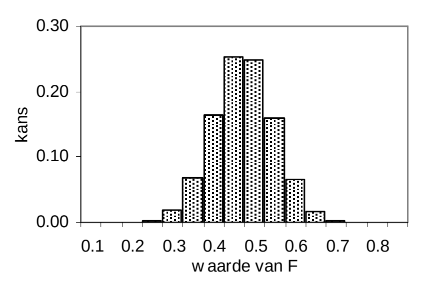
(1) dat onzekerheden in de schattingen expliciet gemaakt worden

(2) dat informatie uit andere bronnen meegenomen kan worden in een analyse.

Het feit dat de parameters met onzekerheid geschat worden maakt het mogelijk om deze onzekerheid ook door te vertalen naar de prognoses en te presenteren in de vorm van risicotabellen. Met zulke tabellen, waarin bijvoorbeeld de kans dat het bestand onder de limietwaarde (Blim) komt wordt aangegeven voor verschillende vangstopties, hebben de beheerders een instrument om beter de risico's in te schatten van de verschillende opties. In de traditionele optietabellen wordt de onzekerheid niet getoond, en wordt ten onrechte de indruk gewekt dat als de beheerder een bepaalde TAC kiest we zeker weten welke SSB er in het jaar daarna zal zijn.

1. Onderzekerheden expliciet gemaakt

In de Bayesiaanse statistiek wordt voor elke te schatten parameter (bijvoorbeeld visserijsterfte F) de waarschijnlijkheid berekend dat deze een bepaalde waarde heeft, gegeven de gebruikte gegevens. Er wordt dus niet een puntschatting van de parameter gegeven, maar een kansverdeling, zoals in de fictieve figuur hieronder te zien is.



Volgens deze fictieve figuur is kans dat F = 0.45 of F = 0.5 erg groot, maar er bestaat ook een kleine kans dat F = 0.3 of F = 0.65. Deze verdeling kan smal of breed zijn, wat overeenkomt met respectievelijk grote zekerheid of grote onzekerheid over de parameter. In de traditionele benadering maken we de mate van onzekerheid niet zichtbaar.

2. Kennis of informatie uit andere bronnen meenemen

Als men vooraf al een idee heeft rond welke waarde een bepaalde parameter zal zitten, bijvoorbeeld gebaseerd op andere studies, dan kan deze kennis meegenomen worden.

Het is bijvoorbeeld mogelijk dat een analyse van een eisurvey aangeeft dat de paaibiomassa (SSB) in een bepaald jaar tussen de 280.000 en de 300.000 ton ligt. Het is essentieel dat die andere analyse op andere gegevens gebaseerd is, zoals aantallen eieren uit een ei-survey. Dezelfde gegevens, zoals vangstgegevens, mogen niet twee keer worden gebruikt. Met deze extra informatie wordt voor elke te schatten parameter de waarschijnlijkheid berekend dat deze een bepaalde waarde heeft, gegeven de gebruikte data èn gegeven deze extra informatie. Zo kunnen resultaten van verschillende studies aan het model toegevoegd worden.

Surplus productie modellen

Surplus productie modellen (of dynamische biomassamodellen) zijn eenvoudige methoden om visbestandschattingen te doen en een visserijexploitatieniveau vast te stellen. Elke verandering van de toestand van het visbestand wordt uitgedrukt in visbiomassa. De modellen negeren de leeftijdstructuur en houden niet apart rekening met de groei, rekrutering of natuurlijke sterfte. Hiermee onderscheiden ze zich van de VPA (zoals XSA) en catch-at-age modellen (zie ook product A12) waar aantallen per leeftijdsgroep worden gebruikt.

Het doel van deze studie is om via verschillende benaderingen surplus productie modellen te gebruiken om de bestandgrootte en het exploitatieniveau van Noordzee schol vast te stellen en die te vergelijken met de referentiepunten voor dit bestand.

De toegepaste benaderingen om de waarden van de modelparameters te bepalen zijn:

- aanname van evenwichtsituatie;
- tijd variante regressie;
- tijdreeksanalyse met waarnemingsfouten;en
- Bayesiaans ruimte-tijd model.

De benaderingen worden methodologisch met elkaar vergeleken. Zo wordt inzicht verkregen in de mogelijkheden en beperkingen van de methode wat betreft beschikbaarheid van gegevens; lengte van de tijdreeks; en de exploitatiegeschiedenis van dit bestand. Het voordeel van een Bayesiaanse benadering is dat deze waarnemingsfouten of onzekerheden combineert met toestandonzekerheden of systeemfouten.

De gebruikte waarnemingset bestond uit een tijdreeks van aanlandingen van Noordzee schol en als index de aanlandingen per eenheid van visserij inspanning van de Nederlandse vloot (ICES-WGNSSK, 2005).

Uitleg Surplus productiemodellen

Uitgangspunt is een logistisch model dat veel in de ecologie gebruikt wordt:

$$P = r \cdot B\left(1 - B/K\right)$$

Waarbij de (surplus) productie *P* (hoeveelheid per tijdseenheid) een functie is van de intrinsieke groei *r* (per tijdseenheid), de biomassa van het visbestand *B* en de biomassa die het bestand uiteindelijk zal bereiken als er niet gevist wordt *K*, wat een maat is voor draagkracht van het systeem.

De productie is een parabolische (tweedegraads) functie van de biomassa. De productiviteit (P/B) is dan een lineaire functie van de biomassa (B).

$$P/B = r - \frac{r}{K} \cdot B$$

Bij een geëxploiteerd bestand wordt aangenomen dat de oogst (Y) evenredig is met de visserijinspanning en de omvang van de biomassa (B):

$$Y = q \cdot f \cdot B$$

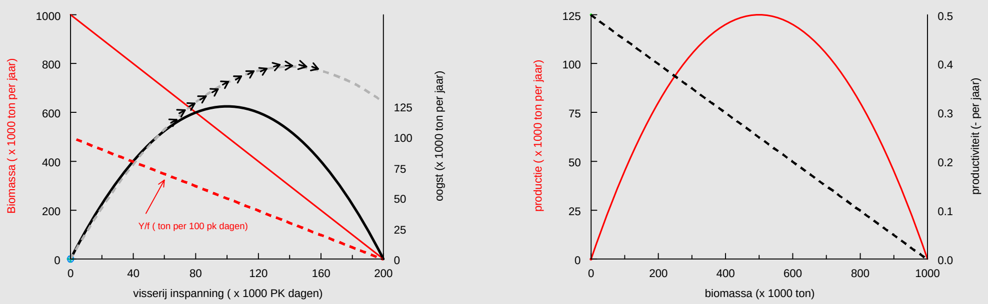
Waarbij *f* de visserijinspanning is en de vangbaarheid *q* een parameter voor de efficiëntie van het gebruikte vistuig. De variabele q is dimensieloos en geeft de fractie van de totale biomassa weer die gevangen wordt met één eenheid van visserijinspanning.

Als P en Y gelijk zijn, is het bestand in evenwicht en de grootte verandert niet. In dat geval zijn zowel B_e, de evenwichtsbiomassa als Y/f, de oogst per eenheid van visserijinspanning evenredig met de visserijinspanning en is de oogst een parabolische functie van de visserijinspanning.

$$B_e = K\left(1-\frac{q}{r}f\right) \quad ; \quad \left(Y/f\right)_e = K\cdot q\left(1-\frac{q}{r}f\right) \quad ; \quad Y_e = K\cdot q\cdot f\left(1-\frac{q}{r}f\right) \quad ;$$

Als het lukt om de model parameters K, r en q te schatten kan voor het visbestand een MSY (=r·K/4) en Fmsy (=r/2) geschat worden. Bovendien kan via een verschilvergelijking de toestand van het bestand en het exploitatieniveau worden bepaald en een tijdreeks van bestand biomassa en oogst gereconstrueerd worden:.

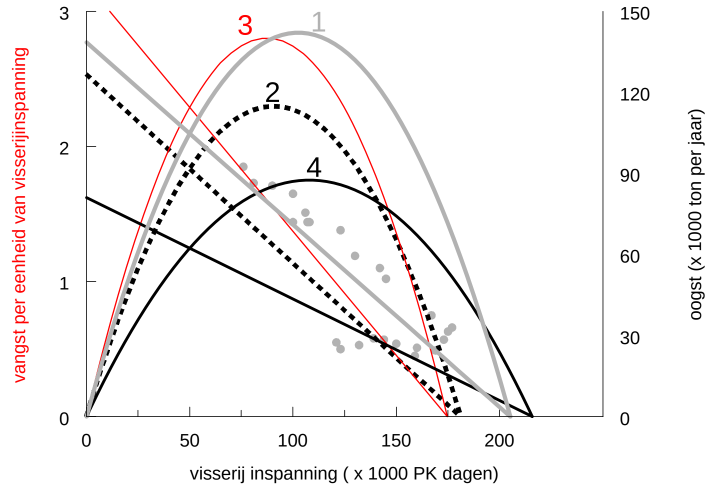
$$B_{t+1} = B_t + r\cdot B_t\cdot\left(1-B_t/K\right) - q\cdot f\cdot B_t \,.$$



Bovenstaande figuur laat de evenwicht en dynamische relaties van een surplus productie model met K=1 miljoen ton r=0.5 per jaar en q=0.0025 (-). De rechter figuur toont de productie en productiviteit van een bestand als functie van de biomassa. Deze productie functie is symmetrisch: het bestand neemt weinig toe bij lage en hoge biomassa's. De productiviteit is het hoogst (~r) bij een lage biomassa en neemt vervolgens lineair af tot nul als de draagkracht van het systeem bereikt wordt (B=K). De linker figuur toont de (evenwicht) oogst-visserijinspanning relatie of oogstcurve. De oogst stijgt als visserijinspanning toeneemt tot een maximale oogst (MSY) bereikt is. Bij nog hogere visserijinspanningen daalt de oogst weer tot het punt waar de visserijsterfte gelijk is aan de intrinsieke groeisnelheid r en de productie van het bestand nul is. De parabool met pijlen toont een dynamisch traject van een oogst-visserijinspanning relatie waarbij de visserijinspanning stijgt met ongeveer 10% per jaar vanaf een uitgangsituatie met een lage visserijinspanning. Het patroon is hetzelfde als de evenwichtcurve behalve dat de maximale oogst hoger is en gevonden wordt bij een hogere visserijinspanning. Deze oogsten zijn niet duurzaam omdat er ieder jaar meer van het bestand geoogst wordt dan dat er bijkomt: het bestand komt niet in evenwicht. Dit kan ertoe leiden dat de schattingen van de maximale oogst en de daarbij behorende visserijinspanning vaak te hoog zijn.

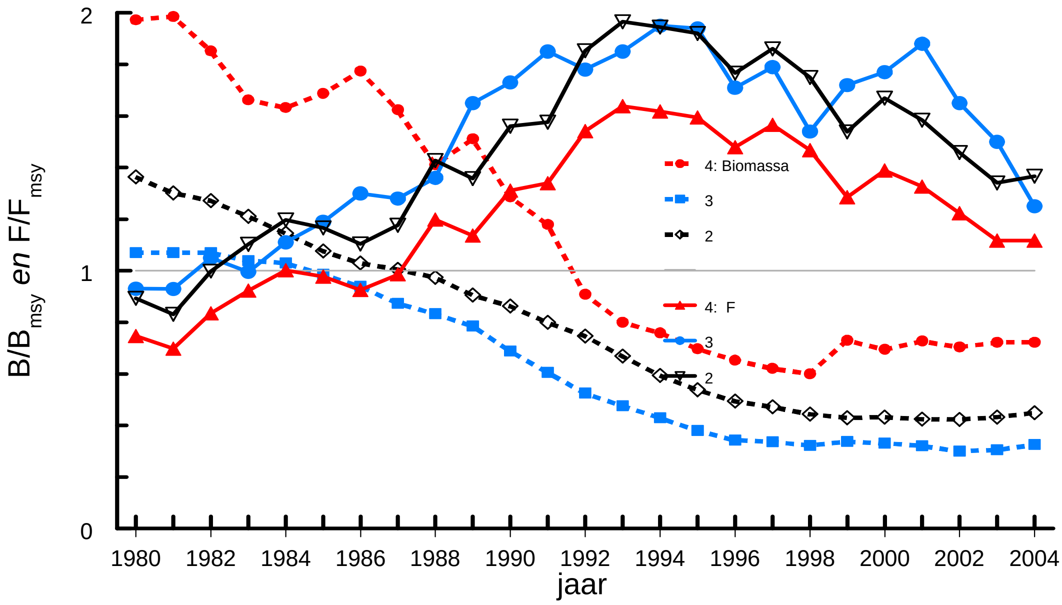
Resultaten

De geschatte waarden voor de parameters K, r en q verschilden afhankelijk van de gebruikte methode en daarmee liepen ook de schattingen voor de maximale oogst en de daarmee samenhangende visserijinspanning uiteen. Omdat K, r en q onderling verstrengeld zijn (een hoge waarde voor de ene parameter en lage waarde voor een andere geeft een zelfde resultaat als een lage waarde voor dezelfde parameter gecombineerd met een hoge waarde) is het resultaat samengevat in de volgende figuur met oogstcurven.



Figuur met statische oogst-curven 1: evenwicht; 2: tijd variante regressie; 3 tijdreeks analyse; 4: Bayesiaans. De rechte lijnen geven de geschatte relaties tussen oogst per eenheid van visserijinspanning en visserijinspanning weer (grijze punten zijn waarnemingen).

De maximale oogst varieert van 86 (Bayesiaans) tot 142 duizend ton (bij evenwicht aanname) per jaar. De schatting van de inspanning die daarvoor nodig is varieert van 90 tot 100 duizend PK dagen. De resultaten maken duidelijk dat de evenwicht aanname zeer onwaarschijnlijk is. De visserijinspanning neemt de eerste periode van de tijdreeks geleidelijk toe. Dit is een typisch voorbeeld van een “one way trip”: Aan het begin van de tijdreeks is de scholbiomassa hoog. Deze biomassa daalt door de visserij en door de toenemende inspanning blijft de aanwas van het bestand achter bij de oogst, waardoor de biomassa blijft dalen en de oogst steeds kleiner wordt. Dat het scholbestand overbevist is blijkt ook uit de volgende figuur.



Figuur met tijdreeksen van de verhouding tussen de geschatte biomassa’s (B) en visserij sterfte (F) en de biomassa en visserijsterfte die een maximale oogst opleveren. Gestippelde lijnen laten B/B_{msy} zien en doorgetrokken lijnen F/F_{msy}. Nummering is overeenkomstig die bij de oogstcurven gebruikt is.

Alle schattingen voor de biomassa in de laatste jaren zijn lager dan B_{msy} (ongeveer 50%) en de visserij sterfte is hoger dan de optimale F_{msy}. De visserijinspanning en daarmee de F is de laatste jaren wel gedaald, maar dat heeft niet geleidt tot een herstel van het scholbestand. Uit de ondermeer de Bayesiaanse analyse blijkt dat de foutenmarge van de hier gepresenteerde schattingen aanzienlijk zijn.

Discussie

Het blijkt mogelijk om op basis van alleen een tijdreeks van aanlandingen en visserijefficiëntie de bestandgrootte van Noordzee schol en het exploitatieniveau vast te stellen. Voor deze schattingen werd gebruik gemaakt van een simpel model waarmee ook mogelijke streefwaarden zoals maximale oogst en optimale visserijinspanning vastgesteld kunnen worden. De onbetrouwbaarheid van deze schattingen wordt vergroot door het feit dat de modelparameters verstrengeld zijn. Een Bayesiaanse benadering biedt hier misschien uitkomst door te zoeken naar informatieve voorafgaande (prior) verdelingen van die parameterwaarden om de betrouwbaarheid en nauwkeurigheid van de schattingen te verbeteren. In deze studie is gebruik gemaakt van niet-informatieve priors en de resultaten laten brede betrouwbaarheidsmarges zien. Hoewel de stelling “een vage uitspraak is eerder waar” statistisch klopt is het voor visstandbeheer nodig dat onzekerheden in bestandschattingen en voorspellingen zo goed mogelijk gekwantificeerd worden en dat de verschillende bronnen van onzekerheid of fouten onderscheiden kunnen worden. Deze kunnen dan weer dienen als basis voor het bepalen van de risico’s bij vooruitzichten van bepaalde beheersopties en daarmee samenhangende gevolgen voor het visbestand.

Bij de analyse is geen rekening gehouden met discards van ondermaatse schol, maar wordt enkel gebruik gemaakt van aanlandingen. Dat maakt de resultaten niet direct vergelijkbaar met de ICES schattingen. De schattingen voor biomassa en visserijsterfte correleren echter significant met de uitkomsten van de ICES werkgroep bestandschattingen voor Noordzee schol.

Het surplus productie model wordt gekarakteriseerd als holistisch waarbij het visbestand en zijn omgeving wordt beschouwd als een georganiseerd geheel. Een ongeëxploiteerde bestand groeit naar een maximaal niveau en is vervolgens in evenwicht met zijn omgeving. Visserij wijzigt dit systeem en er zal zich na verloop van tijd een nieuw evenwicht instellen bij een bestandgrootte waar productie en oogst gelijk zijn. In tegenstelling tot de XSA bestandschattingen waar rekening gehouden wordt met jaarlijkse variatie in rekrutering en groei, houdt dit model alleen rekening met K als maat voor de maximale grootte van het bestand en r als maat voor de tijd dat het duurt om K te bereiken. Belangrijk uitgangspunt hierbij is dat het rekruteringniveau en groei van het Noordzee schol bestand geen trend vertonen. Uit eerdere studies blijkt dat de jaarlijkse rekrutering, geschat op basis van survey-indices (van Keeken, 2005) en de groei (van Keeken, 2004) een toename en afname in de tijd laat zien. Indien de rekrutering en/of groei de laatste jaren structureel veranderd zijn dient het surplus productiemodel opgesplitst te worden in tijdsperioden waar wel vaste parameter waarden gebruikt kunnen worden.

1. Introduction

Surplus production models are commonly used for fish stock assessments in situations when total landings and effort data are the only available sources of information. Surplus production models do not take the age structure of the population into account, and production (= growth + recruitment – natural mortality) is a function of population size in terms of stock biomass (B_t). The population size remains constant if the stock is harvested at the same rate as the production of the stock. This annual surplus production (P_t) is important to fisheries management because P_t, stock biomass (B_t) and yield (Y_t) are closely related. The resulting Maximum Sustainable Yield (MSY) reference points such as MSY, F_{msy} or f_{msy} (fishing mortality or effort required to yield MSY) and B_{msy} could be used as management benchmarks. Surplus production models use simple analytical and straight forwarded methods but the estimation of their parameters and reference points is sometimes problematical. Hilborn and Walters (1992) described various approaches that can be used to estimate the parameters namely equilibrium, time variant regression and time-series fitting with observation error.

Population dynamic models can be presented in a state-space form, starting with a first order auto-regression: $y_{t+1} = \Phi y_t + \varepsilon_{t+1}$ a future state of a process, y_{t+1} depend on its current state, y_t. Moreover, state-space models can include the randomness of population characteristics as well as the randomness in observations made on that population. A relevant state of a fish population is for instance the biomass of the exploited part of the whole population. In this case the state equation specifies the population biomass in the next year (B_{t+1}) as a function of the current population biomass (B_t), an increase due to net growth of the fish population (dB/dt), without explicit partitioning growth, recruitment and natural mortality, and a decrease due to removals from fishing (Y_t). The observations that are made are commercial yield (Y_t) and effort (f_t) time series data which quantify the removals and provide a relative measure or index of the population biomass ($I_t=Y_t/f_t$). A set of model parameters and an initial biomass as input can then produce a time-series of predicted stock biomasses for the duration of exploitation. Bayesian state-space models are used in stock assessments because of their clear and probabilistic portrayal of uncertainty on the population parameters and its natural extension to decision analysis (Punt and Hilborn, 1997; Hilborn and Mangel, 1997). Bayesian models are also used to incorporate existing prior knowledge and quantify uncertainty on the state of the stock in the analysis.

The North Sea plaice fishery is currently managed through output control in the form of TACs complemented by input regulations like days at sea restrictions and technical measures. The stock is exploited by several fisheries as target or by-catch but most of the catch is taken by a mixed beam trawl fishery. Fishery mortality (F, per year for landings excluding discards) for plaice increased, with considerable variation in the annual estimates, from circa 0.3-0.4 per year around 1970 to circa 0.5 to 0.6 per year around 1995, and a decrease since then (Figure 1). The spawning stock biomass (SSB) of plaice declined from 1970 onwards but showed a temporal increase in the 1980s when both recruitment and growth rate were higher (Figure 1). Recruitment estimates for plaice for recent year-classes are lower than average, which has a negative impact on the outlook of the North Sea plaice stock in the near future.

The aim of this study is to apply various approaches of surplus production models to assess the state of the North Sea plaice stock and estimate its target and limit reference points and thresholds by understanding the relative likelihood of possible states of the plaice stock and how the stock might respond to different management actions. Moreover, various estimation approaches are evaluated to gain knowledge of the use and limitations of these approaches in relation to data availability, exploitation history and length of the time series. The outcomes of the production model assessments is compared with those based on VPA and catch at age approaches in terms of uncertainty, biases, stability and precision of the parameters and reference points estimated.

2. Material and Methods

2.1 Equilibrium condition

Graham (1935) and Schaefer (1954; 1957) suggested a population biomass development following a sigmoid logistic curve.

$$\frac{dB}{dt} = r \cdot B_t - \frac{r \cdot B_t^2}{K}$$

dB/dt is logistic growth of the population biomass in the absence of exploitation. r (yr^{-1}) is the rate of increase in biomass for a sparse population and K or B_∞ is the environmental carrying capacity or the equilibrium size of the population in the absence of exploitation. The first term of this rate equation represents exponential increase which is limited by the second term. The state equation is:

$$B_t = \frac{K}{1 + c \cdot e^{-r \cdot t}}$$

Where B_t is the biomass of the fish stock that is vulnerable to fishing at the start of period t and c are constants.

For a harvested population the rate equation is as follows:

$$\frac{dB}{dt} = r \cdot B_t - \frac{r \cdot B_t^2}{K} - Y_t$$

Where, Y_t is harvest 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 catchability coefficient is assumed to be constant. According to this equation the yield is proportional to the population biomass. At equilibrium conditions (i.e. $B_{t+1}=B_t$), where dB/dt=0, the equilibrium yield (Y_e) equals

$$Y_e = r \cdot B_e - \frac{r \cdot B_e^2}{K}$$

Y_e is parabolic function of B_e, the population biomass at equilibrium ranging from 0 to K (or B_∞), showing that yield is maximum when biomass is reduced to half of the carrying capacity. Substituting Y_e with $F \cdot B_e$ ($= q \cdot f_t \cdot B_e$) gives

$$B_e = \frac{K \cdot (r - F)}{r}$$

F is the fishing mortality. F is the product of the catchability coefficient, q, and fishing effort , f, ($F=q \cdot f$). For values of F between 0 and r the population biomass at time asymptotically approaches equilibrium when F remains constant. The population biomass at which the maximum sustainable yield is harvested (B_{msy}) *equals* $K/2$ and the MSY itself, the maximum annual yield that the population can sustain, equals $r \cdot K/4$. Fishing mortality that results in harvesting MSY at equilibrium, $F_{msy}=MSY/B_{msy}=r/2$, equals half of the intrinsic growth rate of population biomass. At equilibrium condition the relationship between Y_e/f_e, yield per unit of effort, and f_e , effort, is linear under the assumption of the Schaefer model (Sparre and Venema, 1998). Fox (1970) developed a variation on the Schaefer surplus production model (Jensen, A.L., 2005) by using a log transformation on Y/f and relate this to effort via linear regression. Both models conform to the assumption that Y/f and B declines as fishing effort increases, but they differ in the sense that the Schaefer model implies one effort level for which Y/f equals zero, whereas in the Fox model, Y/f is greater than zero for all values of f. In this study linear regression analysis on observed LpUE data from Dutch beam trawlers and calculated effort, are used to assess the optimum effort, f_{msy} and MSY [Y/f = a - b□f → f_{msy} = a/2·b & MSY = $a^2/(4\cdot b)$]

The effect of the assumption of equilibrium is that when LpUE levels are declining the analysis results tend to be too optimistic, suggesting effort and yield levels can be maintained at higher levels then the true sustainable results. Alternative methods of producing non-equilibrium model fits have been developed for these and related circumstances (Schnute, 1977; Hilborn and Walters, 1992).

2.2 Time variant multiple regression

Schnute (1977) and Hilborn and Walters (1992) proposed transformation of the dynamic equations into a linear form followed by fitting the data via multiple linear regression to estimate r, q and K and use these to generate estimates and prediction of the exploitable plaice biomass and exploitation rate. These methods do not rely on the equilibrium assumption, but often rather odd assumption about the error structure are made. The standard surplus production model (dB/dt) is written as a difference equation:

$$B_{t+1} = B_t + r \cdot B_t - \frac{r}{K} \cdot B_t^{\,2} - Y_t \quad and \qquad I_t = \frac{Y_t}{f_t} = q \cdot B_t$$

where $LpUE_t$ is used as an index I_t, which is proportional to B_t These equations are rewritten and transformed into dynamic linear equations:

$$I_{t+1} = I_t + r \cdot I_t - \frac{r}{q \cdot K} \cdot I_t^{\,2} - q \cdot Y_t \quad or \quad \frac{I_{t+1} - I_t}{I_t} = r - \frac{r}{q \cdot K} \cdot I_t - q \cdot \frac{Y_t}{I_t}$$

For the multiple regression model the dependent variable is the ratio between (I_{t+1}-I_t) and I_t and as independent variables I_t and Y_t/I_t are used. So, if yield, and yield per unit of effort is known for a fish stock, q, r and K can be estimated. If density dependence is evident in the population, then the relative rate of increase in population size will decrease as population size increases. The relationship between surplus production and stock biomass through time is the basis for the relationship between fishing effort and potential yield for a fish stock. After estimating the parameter value of r, q and K the MSY and F_{msy} of the North Sea plaice population is estimated. The format for this approach is computationally easy, but it is not certain that the method provides reliable parameter estimates and may even estimate the MSY as negative (Walters and Hilborn, 1976).

2.3 Time-series fitting with observation error

The deterministic difference equation can be converted into a stochastic one by adding observation uncertainty or error. The start in this time-series fitting is to take an guestimate of 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 are then adjusted to provide the best fit of the predicted to observed time series of LpUE and yield data.

$$I_t = q \cdot B_t \cdot e^{\left(V_t \cdot \sigma_v - \frac{\sigma_v^{\,2}}{2}\right)} \qquad B_{t+1} = B_t + r \cdot B_t - \frac{r}{K} \cdot B_t^{\,2} - Y_t$$

Where, V_t represents the observation error, a normally distributed random variable with mean 0

and standard deviation σ_v. Because the random processes are usually multiplicative and to avoid negative values for the index of abundance log-normality is assumed. Predicted and observed values of the LpUE time series are compared. Because process uncertainty is not included, the state equation for stock dynamics is still deterministic. The negative log-likelihood of a single year is (Mangel and Hilborn, 1997):

$$L_t = \log(\sigma_v) + \frac{1}{2} \cdot \log(2\pi) + \frac{\left[\log(I_{est,t}) - \log(I_t)\right]^2}{2 \cdot \sigma_v^{\ 2}}$$

These individual negative log-likelihoods are summed over all years resulting in a total negative log-likelihood and this is minimized across the parameters r, K, q and σ_v.

This model does not only produce parameter estimates, but also output, that is of value to the management and can be interpreted in terms of fishery performance, stock indicators and management targets. Standard output is the ratio between the current biomass and K or Bmsy, MSY, Fmsy, fmsy, F and the ratio between F and Fmsy (Prager, 1994). MSY may be interpreted as the potential long term average yield of the fishery system. Fmsy or fmsy are the mortality rate or fishing effort that results in yielding MSY if the stock biomass equals Bmsy, the biomass required to generate the maximum surplus production.

The plaice time-series data were used to fit the surplus production model using the software program ASPIC (Prager, 1994). This model assumes non-equilibrium conditions only observations error or uncertainty. Version 5.0 of this program is able to fit a model under the assumption that yield in each year is known more precisely than relative abundance, so the model can be conditioned on yield, rather then relative abundance or fishing effort. Moreover, bootstrapping can be used for bias correction and construction of approximate nonparametric confidence intervals of the estimated parameter values.

2.4 State space with observation and system errors

Several attempts were done to incorporate both observation errors and process errors in surplus production models (Millar and Meyer, 1999), but it is difficult to attain reliable maximum likelihood estimates at the same time of both process error and observation error variances. Here Bayes theorem provides a simple way to use all possible information. Prior knowledge is incorporated via the application of Bayes' rule:

$$\pi(\Theta|y) = \frac{\pi(\Theta) f(y|\Theta)}{f(y)}$$

Where *π(□ly)* is the posterior density of the parameter given the data *y*, *π(□)* the prior density, *f(yl□)* the likelihood, and *f(y)* the density of the data. So, information is taken from two sources, the data, via the likelihood, and the priors. It is generally recommended to use non-informative priors when specifying priors for Bayesian stock assessment, except when informative priors can be obtained by formal means, that is priors constructed by some predefined rules (Millar and Stewart, 2005).

Millar and Meyer (1999) and Meyer and Millar (1999) applied a Bayesian state-space approach of surplus production models for stock assessment purposes. They were able to combine error structures for the state and observation equations in one model. If multiplicative lognormal errors are assumed and the initial biomass is X% of the carrying capacity of the stock, K the stochastic form of the process equation becomes:

$$\log(B_{t+1}) = \log\left(B_t + r \cdot B_t \cdot \left(1 - B_t/K\right) - Y_t\right) + u_t \quad \underline{\&}$$

$$\log(B_1) = \log\left(X/100 \cdot K\right) + u_1$$

The actual biomass/time curve is characterize as unit less ($B'_t=B_t/K$) The stochastic form of the observation equation is:

$$\log(LpUE_t) = \log(q \cdot B_t) + v_t = \log(q) + \log(B_t) + v_t$$

The random variables v_t and u_t have mean 0 and variance τ^2 and σ^2 respectively. The unobservable variables in this model are K, r, q, σ^2, τ^2, $B_1 \cdots\cdots, B_t$, but it is enough to specify the priors on K, r, q, σ^2 and τ^2 (Millar and Meyer, 1999).

The Bayesian state space approach applied on North Sea plaice data was implemented using WinBUGS14 (Spiegelhalter et al., 2003). The model script used by Millar and Meyer (1999) was adapted for North Sea plaice. The joint posterior distribution of model parameters and augmented data was explored by Markov Chain Monte Carlo (MCMC) simulation. For each simulation two MCMC chains and one million iterations were used. Sampling took place every 50th iteration, after a burn-in of 500000 iterations. All results were based on the combined samples in both chains.

During the MCMC process two error messages frequently occur: (1) “cannot bracket slice for node xx” and (2) “undefined real results” In that case, at least one of the initial values and or at least one of the prior distribution was changed slightly and the case was rerun.

2.5 Data used

Table 1 includes the basic information used in all the analysis of this paper. The time-series of yield and LpUE of North Sea plaice from 1980 to 2004 (ICES-WGNSSK, 2005) are also presented in Figure 2. Technological advances and other improvements to fishing practices resulting in higher efficiencies of the fishing methods (Rijnsdorp et al 2006) have not been taken into account.

Table 1. Timeseries of yield and LpUE of Nord Sea plaice from 1980 until 2004. Yield is total landings for North Sea and LpUE is representative for the Dutch beam trawl fleet.

Year	landings (1000 tons)	LpUE (tons/ HP day)	Year	landings (1000 tons)	LpUE (tons/ HP day)
1980	140.0	1.73	**1992**	125.2	0.75
1981	139.7	1.85	**1993**	117.1	0.66
1982	154.6	1.71	**1994**	110.4	0.63
1983	144.0	1.44	**1995**	98.4	0.57
1984	156.2	1.44	**1996**	81.7	0.51
1985	159.8	1.51	**1997**	83.1	0.49
1986	165.4	1.65	**1998**	71.5	0.45
1987	153.7	1.44	**1999**	80.7	0.58
1988	154.5	1.19	**2000**	81.2	0.54
1989	169.8	1.38	**2001**	81.9	0.57
1990	156.2	1.10	**2002**	70.2	0.53
1991	148.0	1.02	**2003**	66.5	0.55
			2004	61.4	0.50

3. Results

3.1 Equilibrium condition

Figure 3 shows the scatter plot of $LpUE_t$ and Y_t against effort. Yield refers to the annual landings (1000 tons) and LpUE (Y/f) in tons per HP day. Effort (f) per year (1000 HP days) is estimated by taking the ratio of Y_t and $LpUE_t$.

The linear relationship between effort and LpUE found was LpUE = 2.77 – 0.0135·f, so Y = 2.77·f – 0.0135·f^2. r^2 was 0.84 and increased significantly to 0.99 in case LpUE observation after 1995 were omitted (Figure 3): *LpUE=2.77-0.0121·f.*

The predicted MSY equals then 0.25·$(2.77)^2$/0.0135 = 142 thousand tons per year and f_{msy}=0.5·2.77/0.0135 = 103 000 HP days. For 2004 the fishing effort was estimated to be 122 800 HP days, which should yield 136 thousand ton plaice under equilibrium condition. The observed landing for 2004 was 61.4 thousand tons or 43% of the predicted MSY. Here the basic problem of the equilibrium method becomes clear: an overestimation of the surplus production, specifically during a stock decline due to fisheries development because of violation of the basic assumption that the catches observed over the whole time series are sustainable.

3.2 Time variant regression

The following regression model was used in the analysis:

$$\frac{LpUE_{t+1} - LpUE_t}{LpUE_t} = r - \frac{r}{q \cdot K} \cdot LpUE_t - q \cdot \frac{Y_t}{LpUE_t}$$

The resulting parameter estimates and their confidence bounds (presented as SE) are presented in Table 2. The r^2 of the model was 0.08 (N.S.).

Table 2. Parameter estimates and standard deviation of the surplus production model using the regression method.

Parameter	***Mean estimate***	***Standard deviation***
r (yr^{-1})	0.35	0.32
K (thousand tons)	1314	1200
q (-)	0.00193	0.0016
MSY (thousand tons per year)	115	
Fmsy (yr^{-1})	0.175	

The estimated K, r and q were used to reconstruct the time-series of LpUE. Plaice biomass in the successive years from 1981 onwards was estimated as:

$$B_{t+1} = B_t + r \cdot B_t \cdot \left(1 - {B_t}/{K}\right) - Y_t$$

$$Y_t = B_t \cdot q \cdot f$$

$$I_t = B_t \cdot q$$

The plaice biomass for 1980 was estimated from LpUE/q = 896 thousand tons. Comparison of these estimates with the actual observations show a good fit (Figure 4). The r^2 of this fit was 0.93. A plot of the time series of the ratios F_t/Fmsy and B_t/Bmsy is shown in Figure 5. The exploitation rate is above Fmsy, except for the first two years of the time series. Estimated plaice biomass is below the estimated Bmsy. The current biomass is approximately half of the Bmsy. In Figure 6, a plot of LpUE and yield against effort is shown. Under equilibrium conditions the linear relation between Yield per unit of effort and effort is Y/f = 2.54 – 0.014·f, given the estimates for q, r and K. Giving and fmsy of 91 000 HP days and MSY of 115 000 tons plaice per year. Compared to the estimate under 1 this MSY estimate is 81 % lower.

Figure 6 shows the typical pattern of a one way trip (Hilborn and Walters, 1992; Cooper, 2006), when observing a fish stock while it was fished down from an initial situation of higher abundance that supported MSY. Giving the fishing effort applied in 2004, 122 800 HP days, the equilibrium biomass for sustainable yield of 100 tons equals 870 thousand tons. The estimated biomass in 2004 according to the simulation equals 295 thousand tons. Consequently the yield is lower then the estimated equilibrium yield.

3.3 Time-series fitting with observation error

In table 3 the results of the fit using the ASPIC program are presented. The estimated parameters values differed from those which were estimated with the former methods. K was estimated lower and r and q were higher.

Table 3. Parameter estimates and confidence of the surplus production model using time series analysis with bootstrapping (Prager, 1994).

Parameter	***Median estimate***	***approximate 80% confidence limits***
MSY (thousand tons per year)	140	130-146
Fmsy (yr^{-1})	0.35	0.25-0.42
r (yr^{-1})	0.69	0.5-0.84
K (thousand tons per year)	812	682-1041
q	0.00395	0.00292-0.00475

These parameter values were used to reconstruct the time series of LpUE. Comparison of these estimates with the observations show a good fit (Figure 7). The r^2 of this model fit to the observations was 0.96. A plot of the time series of the estimates of the ratios F_t/Fmsy and B_t/Bmsy is shown in Figure 8. The exploitation rate is above Fmsy, and the estimated plaice biomass is below the estimated Bmsy during the first 5 years of the time series. The estimate for current biomass is 30% of the Bmsy. σ_v of the all observation error was 0.093, corresponding to a CV of 10% around the observations.

3.4 State space with observation and system errors

An uninformative distribution was selected as prior for node K. A uniform distribution in the range from 10 to 4000 thousand tons was used initially. The use of a uniform distribution should be avoided in case it assigns zero probabilities to feasible values of the unknown (Punt and Hilborn, 1997; Walters and Ludwig, 1994). As an alternative the same range from 10 to 4000 thousand tons was taken as the interval of the 10^{th} and 90^{th} percentiles of a lognormal distribution with mean 7.7 (log thousand tons) and standard deviation of 0.5.

For node catchability, q , a non-informative prior was selected. To use a proper prior a gamma distribution for Q, the inverse of q, with a mean and variance of 200 was used in the range from 100 to 1000. The resulting prior distribution of q, ranged from 0.01 to 0.001. The diagnostics after using this prior showed that there was a serious autocorrelation of K, r and q. This is probably due to the fact that K is highly confounded with q. Therefore q was taken as the ratio of Q and K and the prior for Q was a lognormal distribution with mean of 0.5 and standard deviation 1.

The uninformative prior selected for r was uniform over the range 0.1 and 1.2, a range which covers all known r values for fish populations in temperate regions. Alternatively, a lognormal distribution was used with mean -1.2 and standard deviation of 0.7. These correspond with the 10th and 90th percentiles of 0.012 and 1.22 respectively.

An inverse gamma distribution was taken for the observation error variance, τ^2. A prior distribution for the LpUE index with an average of 0.1 was used such that the 10 and 90 percentiles on this prior were 0.05 and 0.15. The prior distribution for the coefficient of variation of the process variability σ^2 had an average 0.15 using an inverse gamma distribution. Values of 0.1 and 0.2 were taken as the interval between 10 and 90 percentiles.

Table 4. Parameter estimates and confidence of the surplus production model using Bayesian time series analysis (Millar and Meijer, 1994).

Parameter	***Median estimate***	***Approx. 95% confidence limits***
MSY (thousand tons per year)	86	43-137
Fmsy (F yr^{-1})	0.15	0.07-0.27
r (yr^{-1})	0.30	0.15-0.53
K (thousand tons per year)	1167	777-1645
q	0.00139	0.00102-0.0023
σ^2	0.043	0.031-0.060
τ^2	0.0046	0.0015-0.0039

Bayesian estimates of the time series of LpUE are shown in Figure 9. Comparison of these estimates with the observations show a very good fit and all observations are within the 95 confidence interval of the estimates. The r^2 of this model was 0.99. A plot of the time series of the estimates and confidence intervals of the ratios F_t/Fmsy and B_t/Bmsy is shown in Figure 10. The exploitation rate is above Fmsy, and the estimated plaice biomass is below the estimated Bmsy except during the first 10 years of the time series. The estimate for current biomass is 30% of the Bmsy. σ_v of the observation error was 0.21, corresponding to an CV of the error of 21% around the observations.

Current yields are lower then the long term potential maximum yield, so yield does not need to decrease. A comparison of the assessment result with the ICES working group estimates showed a high correlation. The correlation coefficient for the biomass estimates ranged from 0.94 for the Bayesian state space approach to 0.85 for the time variant method. The fishery mortality showed a correlation coefficient of 0.78 for the Bayesian state space approach with working group estimates to 0.53 for the stochastic time-series fitting with the ASPIC program.

4. Discussion

Dynamic surplus production assessment calculations can be carried out in any fisheries system that includes catch, effort and/or indices data. These simple models generate information needed to determine the status of the fish stock and the fisheries, like estimates of stock biomass and fishery mortality rate. Moreover, they provide also estimations of reference points like MSY, Bmsy and Fmsy and if necessary the associated uncertainties around these point estimates. The models focus on how fish stocks respond to variation in exploitation and quantify how fast a stock can be depleted when a fishery starts to develop and how quickly the fish stock can recover when fishing pressure is reduced. Preferably the time-series used should have wide dynamic range. The data should also show a considerable contrast. It is expected that using short data sets with less contrast show imprecise and/or inconsistent surplus production estimates. Starting with the initial state of the plaice stock at the start of the time-series (B_{1980}), the states of the successive years are determined by comparing the estimated surplus production, P_t, for all successive years with the estimated yield for the corresponding years, Y_t, which depends on the population biomass and the fishing effort. The biomass will increase during a year when yield is less then surplus production and vice versa.

The assumption of equilibrium permits an analytical solution but is at the same time highly unrealistic. In this study the results are only used for comparison and are not put forward as the result of a formal assessment. Equilibrium methods to estimate surplus production parameter values should be avoided (Hilborn and Walters, 1992), because the approach ignores the biological linkage between stock biomass in successive years. The logic behind equilibrium is that under those circumstances biomass and fishery mortality are related. In reality fish stocks never reach equilibrium because recruitment and fishery mortality vary from year to year.

In practice surplus production model parameters and MSY reference points are often difficult to estimate because the model is basically a simple non-linear function with parameters that are often confounded causing auto-correlated errors and are fitted to problematic fisheries data. Fmsy and Bmsy are often correlated. High correlations between parameter values will reduce the precision with which they can be determined. Van Keeken et al. (2004) concluded that plaice growth showed structural changes in time. This was also concluded for the recruitment pattern of plaice based on survey indices (van Keeken et al., 2005). When carrying capacity and recruitment levels of the plaice stock differ this means that the model parameters K and r should be estimated for periods were these parameters are assumed to remain constant.

The different approaches resulted in a range of MSY estimates from 86 to 140 thousand tons and Fmsy reference points between 0.15 and 0.35 per year. All the results consistently point at a situation of overexploitation, with Bmsy being higher then the current biomass and Fmsy lower then the current estimation range. In case the management target is set to yield MSY a further reduction in fishing effort is required because the stock is now at low production and cannot sustain high l effort and yield. The model analysis suggests, that despite having a number of years, when effort had supposedly declined the indicators show no signs of stock recovery yet. The plaice stock is most probably (consistent, but with large uncertainty) depleted down to 25% of the un-fished biomass.

Management actions can act in two different ways. Actions may be based on target references or limit reference points (Caddy and Mahon, 1995). A target reference point indicates to a state of a fish stock which is considered to be desirable and at which management action, either during fishery development or fish stock rebuilding, should aim. A limit reference point indicates a state of a fishery and/or a resource which is considered to be undesirable and which management action should avoid. Limit reference points are intended to provide guidance concerning management to protect the fish stock and fishery against long term damage. Danger zones are defined where the continuity of the resource becomes problematic and action is required (e.g. Bpa, Blim, Fpa and Flim) as currently used in ICES for plaice. The surplus production model estimates are suitable for generating target reference points.

Estimates of parameter values are only valuable if there is some idea of the uncertainty around their point estimates. Uncertainty in parameter estimates varied between the approaches. The multiple regression analysis resulted in standard deviations for each of the parameters, which were in the order of size of the values of the parameters as such and this is a signal not to take the values too seriously. The time series and Bayesian approach are useful for presenting uncertainties and making stochastic predictions. In the stock assessment accepted by ICES for management estimates of uncertainty with respect to model output and prediction are lacking. Inclusion of observation and system errors in the estimation procedure allows assessing the stock including the uncertainties that arise from the observations made and the system concerned. In this way predictions in the future can act as a basis for projections and risk assessment of available management options and constraints for the stock. Whether the model generates sufficient information on which management actions can be taken depends on the risk one is willing to accept. In case information from VPA models is used to make predictions, future recruitment are projected into the future in a stochastic way. The standard surplus production models include deterministic stock biomass projections without recruitment. In the deterministic equation catch is subtracted from the production function and projections only require predefined catches or efforts. Using a Bayesian approach it is relatively easy to make projected catches and efforts dictated by proposed management options (Caddy and Mahon, 1995). In the Bayesian framework many replicate projections are generated, and the proportion in which the stock biomass is greater than the reference can be represented. At this moment, using mostly non-informative priors for most nodes in the Bayesian model the advantage of the state-space approach over bootstrap methods is very limited, because of the wide confidence intervals of the estimates and the projections.

Plaice yield data only include the reported landings. The landing statistics are lower then true catches. Hammond and Trenkel (2005) proposed treating the actual catch as censored by bounding it at the lower end by the registered landings and at the upper end by c x landings, where $c>1$. Assessments increasingly rely on survey information because of problems with commercial fishery data, resulting in recommendation of leaving out landing data totally (Baare et al., 2005) and preference of (commercial) catch-free methods. Jacobson et. al. (2002) proposed a composite solution via an integration of assessment models and surplus production models, because of the benefits of summarizing assessment models in terms of surplus production, which is important for managers and the possibility of using all available information and data.

References

Baare, D.J., Needle, C.L., Burns, F. and Reid, D.G. 2005. Using survey data independently from commercial data in stock assessment. ICES Journal of Marine Science. 62(5) 996-1005.

Caddy, J.F., Mahon, R. 1995. Reference points for fisheries management. FAO Fisheries Technical Paper. No. 347. Rome, FAO. 1995. 83p.

Cooper, A.B., 2006. A guide to fish stock assessment. From data to recommendations. University of New Hampshire, Durham. 44 pp.

Fox, W.W. (1970) An exponential surplus-yield model for optimizing exploited fish populations. Transactions of the American Fish Society 99: 80-88.

Graham, M., (1935). Modern theory of exploiting a fishery and application to North Sea Trawling. J. Cons. CIEM, 10(3):264-74

Haddon, M., Hodgson, K. (2000) Spatial and Seasonal stock dynamics of Northern Tiger prawns using fine-scale commercial catch-effort data. FRDC Final Report, Fisheries Research Development Corporation [l1]

Hammond, T.R. and Trenkel, M., 2005. Censored catch data in fisheries stock assessment. ICES Journal of marine Science, 62: 1118-1130.

Hilborn, R. and Mangel, M., 1997. The ecological detective. Princeton University Press, NY. 330 pp.

Hilborn, R. & Walters, C.J., 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics & Uncertainty. Chapman and Hall, London. 570p.

ICES-WGNSSK (2005). Report of the Working Group on the Assessment of the Demersal Stocks in the North Sea and Skagerrak. ICES CM 2006/ACFM:09

Jacobson, L.D., Cadrin, S.X. and Weinber, J.R. 2002. tools for estimating surplus production and Fmsy in any stock assessment model. North American Journal of Fisheries Management, 22: 326-338.

Jensen, A.L. 2005. Harvest in a fluctuating environment and conservative harvest for a Fox surplus production model. Ecological Modelling, 182: 1-9.

Keeken, O.A. van, Kraak, S.M.B. and Rijnsdorp, A.D. 2004. Growth and Maturity of North Sea plaice and sole. RIVO report C088/04. 44p.

Keeken, O.A. van, Grift, R.E. and Rijnsdorp, A.D. 2005. Surveys used in the stock assessment of North Sea plaice and sole. RIVO report C047/05. 55p

Meyer, M. and Millar, R.B. 1999. Bugs in Bayesian stock assessments. Canadian Journal of Fisheries and Aquatic Sciences, 56: 1078-1086.

Millar, R.B. and Meyer, R. 1999. Non linear state-space modeling of fisheries biomass dynamics using Metropolis-Hastings within Gibbs sampling. Tech. Rep. Stat9901. Department of Statistics. University of Auckland, Auckland, N-Z.

Millar, R.B., & Stewart, W.S. 2005. Automatic calculation of the sensitivity of Bayesian fisheries models to informative priors. Canadian Journal of Fisheries and Aquatic Sciences, 62(5): 1028-1036.

Punt, A. E. and Hilborn, R. 1997. Fisheries stock assessment and decision analysis: the Bayesian approach. Review in Fish Biology and Fisheries, 7: 35-63.

Prager, M.H. (1994) A suite of extensions to a nonequilibrium surplus-production model. Fishery Bulletin 92: 374-389.

Rijnsdorp, A. D., Daan, N., and Dekker, W. 2006. Partial fishing mortality per fishing trip: a useful indicator of effective fishing effort in mixed demersal fisheries. ICES Journal of Marine Science, 63: 556-566.

Schaefer, M.B. (1954) Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Bulletin, Inter-American Tropical Tuna Commission 1: 25-56.

Schaefer, M.B. (1957) A study of the dynamics of the fishery for yellowfin tuna in the Eastern Tropical Pacific Ocean. Bulletin Inter-American Tropical Tuna Commission, 2: 247-285

Schnute, J. (1977) Improved estimates from the Schaefer production model: Theoretical considerations. Journal of the Fisheries Research Board of Canada, 34: 583-603.

Sparre, S and Venema, S.C. 1998. Introduction to Tropical Fish Stock Assessment - Part 1: Manual. FAO Fisheries Technical Papers - T306/1Rev.2 407 pp ISBN: 9251039968.

Spiegelhalter, D.J., Thomas, A., Best, N.G. and Lunn, D. 2003. Winbugs user manual (Version 1.4). Cambridge: Mrc Biostatistics Unit, www.mrc-bsu.cam.ac.uk/bugs/

Walters, C.J. and Hilborn. R. 1976. Adaptive control of fishing systems. J. Fish. Res. Board Can. 33, 145-159.

Figures

Figure 1: Fishery mortality rate for landed fish (left axis, Fbar 2-6 human consumption) and SSB (right axis) for North Sea plaice. Estimations for F are represented by black dots and for SSB open red. Source: ICES-WGNSSK (2006).

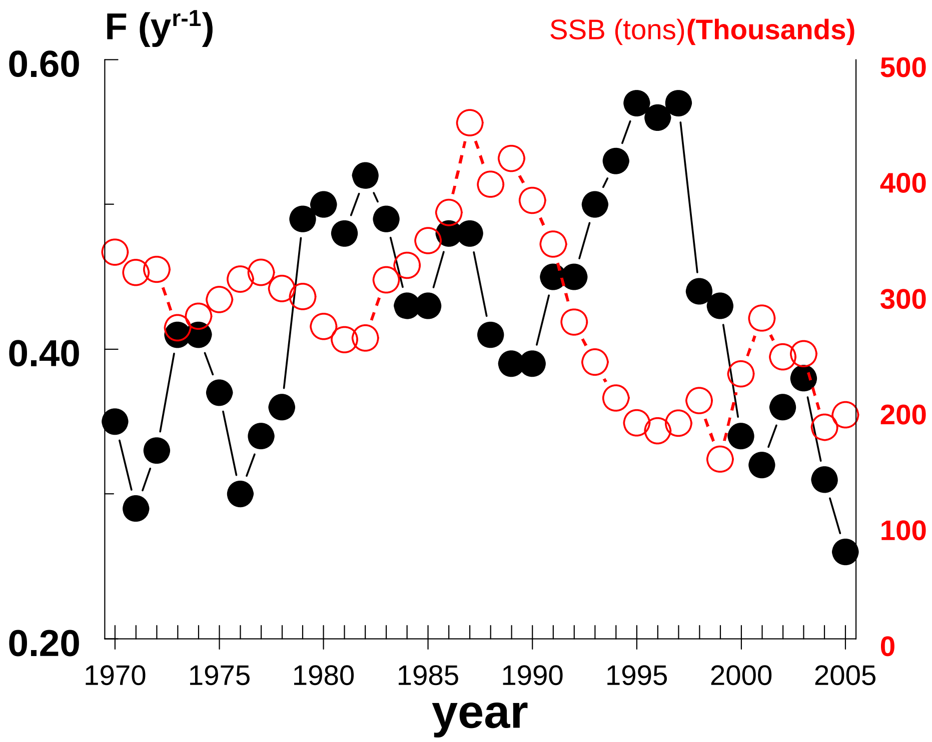


Figure 2: landings per unit of effort (left axis) and yield (right axis) for North Sea plaice. Open circles represent LpUE and closed black represent yields. Source: ICES-WGNSSK (2005).

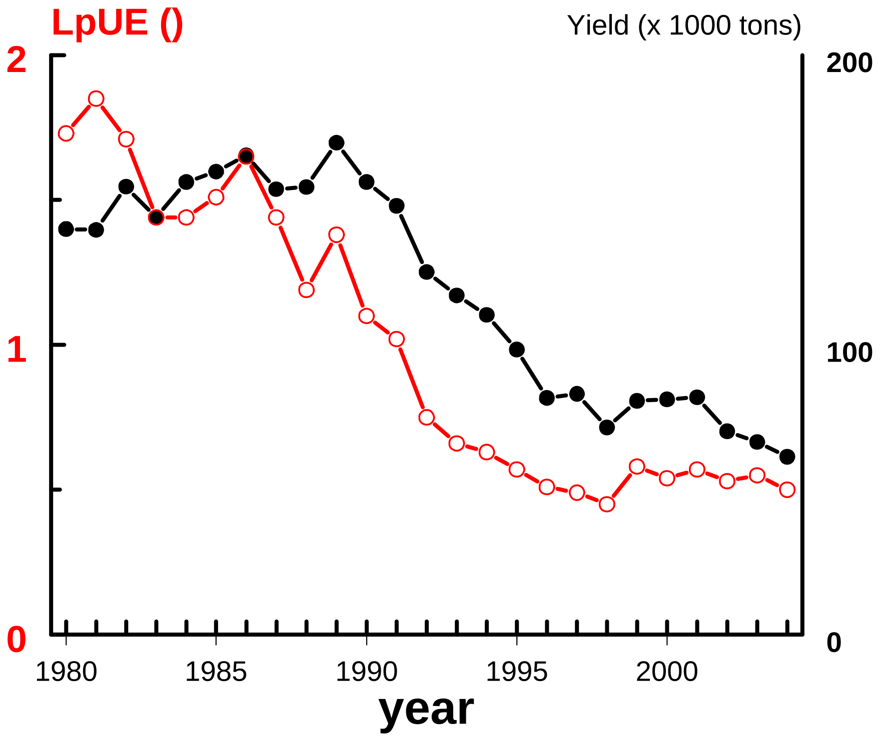


Figure 3. Yield (red squares) as landings (1000 tons) and landing per unit of effort (black and blue rounds) in tons per HP day, in relation to effort (1000 HP days) for North Sea plaice for the period 1980-2004. Black dots are the observations for the period 1980 to 1995. Estimates results from the linear regression are presented as blue lines for LpUE on effort and (red) parabola for yield. Broken lines represents estimates based on the regression for data from 1980 to 1996.

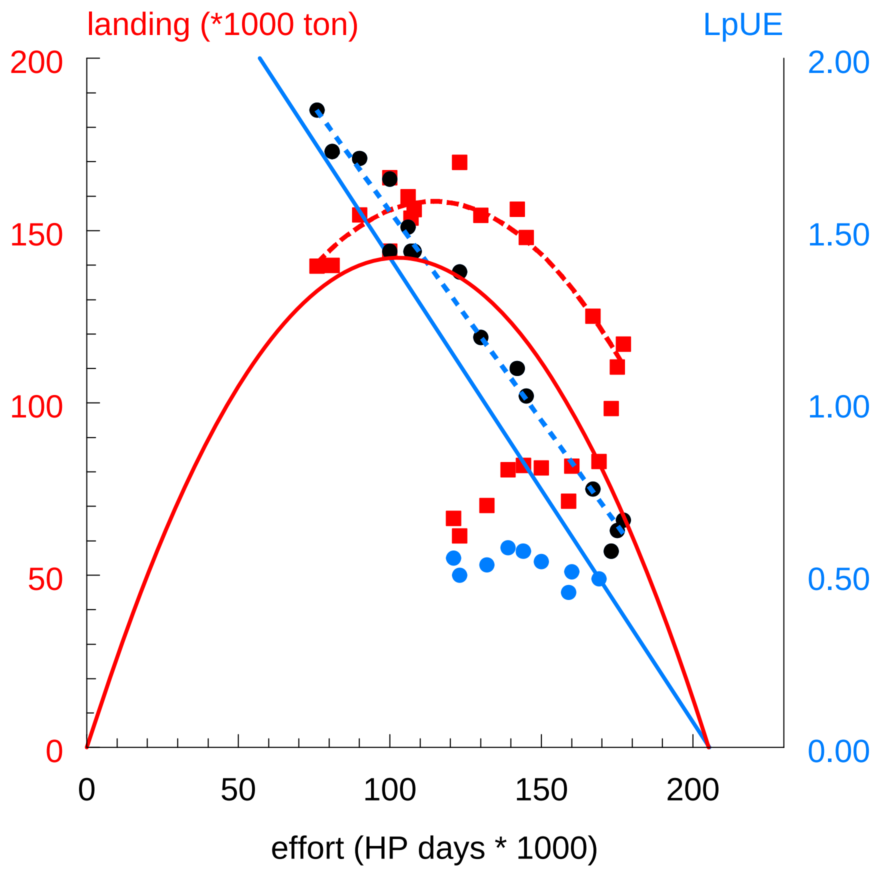


Figure 4: landings per unit of effort as observed for North Sea plaice (blue line) in comparison with fitted values, based on the estimated parameters K=1314 thousand tons, q=0.00193 (-) and r=0.35 (yr^{-1}) (red dotted line and open circles) from the time variant regression method.

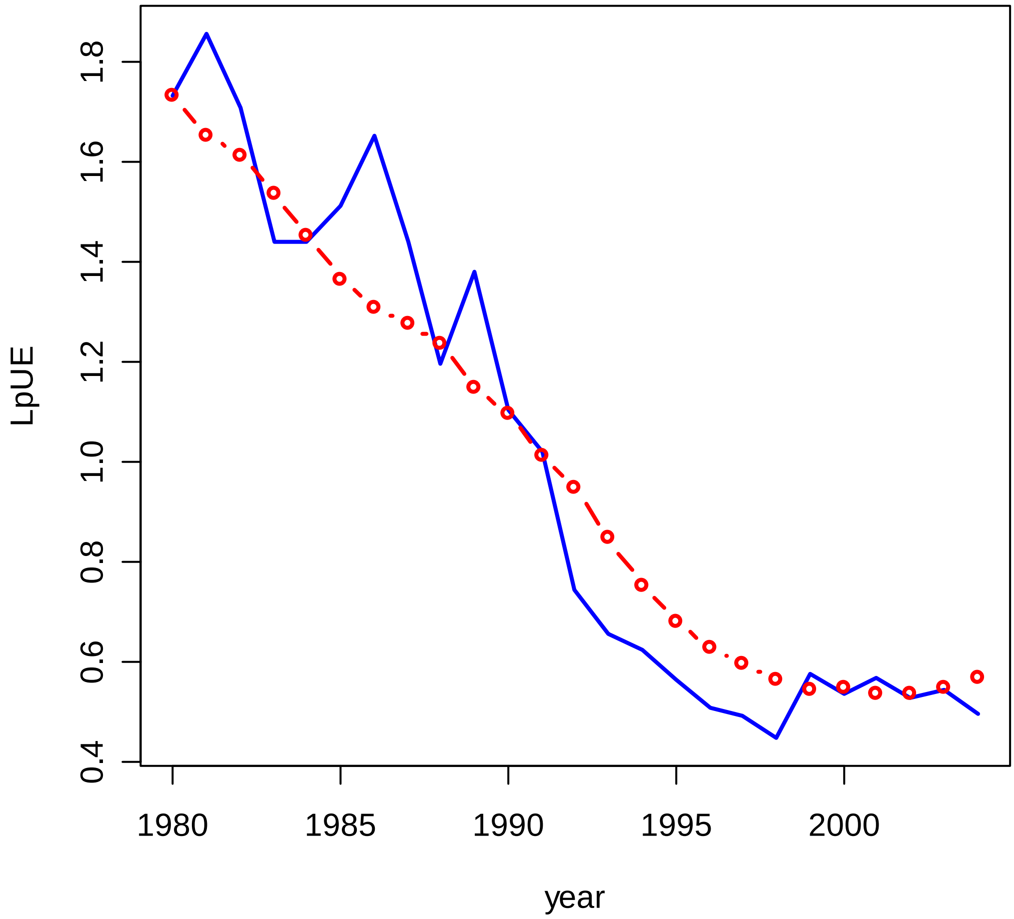


Figure 5. Time Plot of Estimated F/Fmsy and B/Bmsy ratios from the time variant regression method (F=red dotted line and open circles; Biomass is represented by the blue open circles).

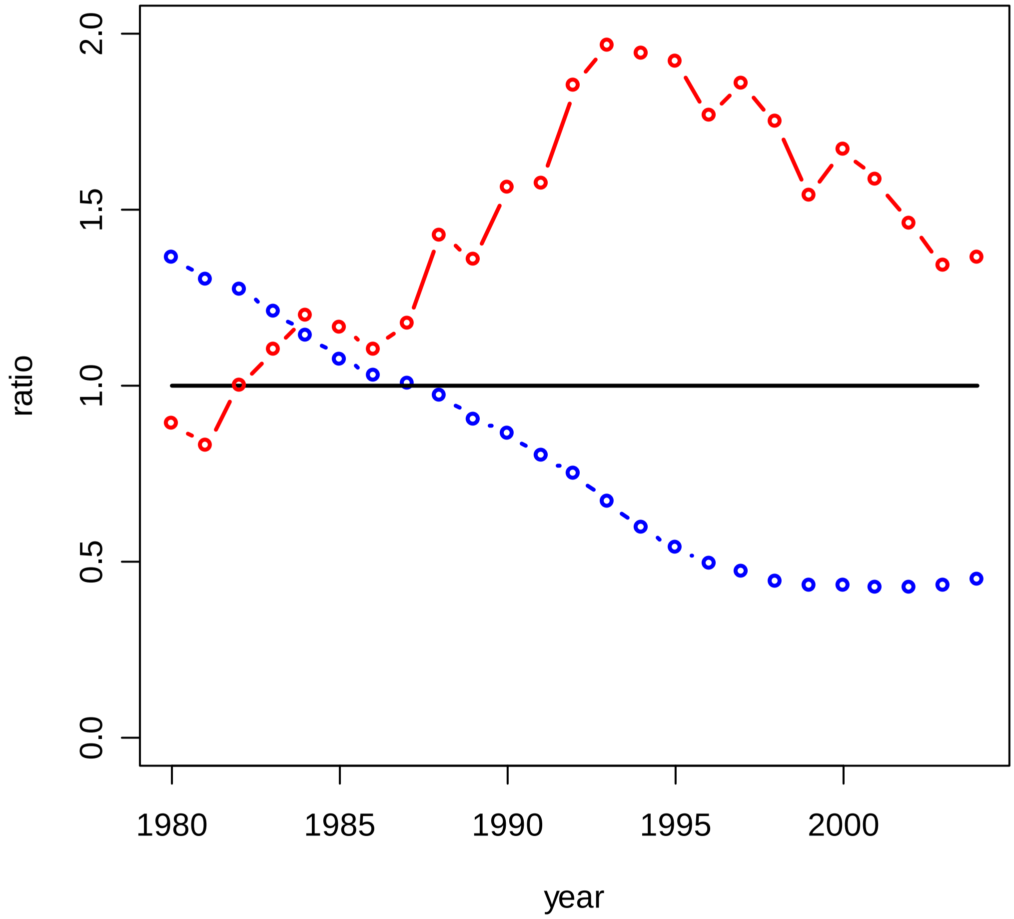


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Figure 6. Yield and landing per unit of effort in relation to effort for North Sea plaice at equilibrium using parameter estimates from the time variant regression method (K=1314 thousand tons, q=0.00193 (-) and r=0.35 per year), resulting in an illustration of a one way trip. Blue line is index (Y/f) and red parabola is yield curve (Y) as function of effort (f). Red squares represent observed landings and blue rounds represent LpUE.

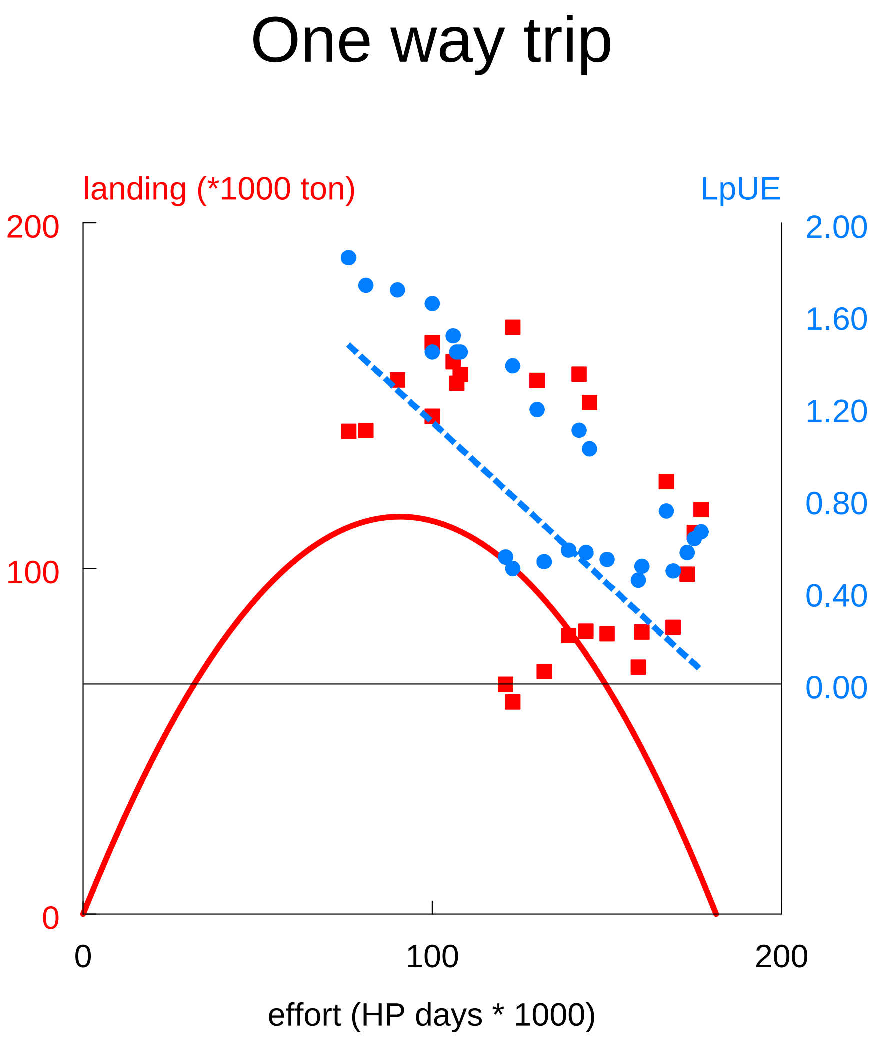

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Figure 7: landings per unit of effort as observed for North Sea plaice (observed LpUE red line and rounds) in comparison with fitted values (blue line) for the estimated parameters K=1314, q=0.00193 and r=0.35 from time-series analysis.

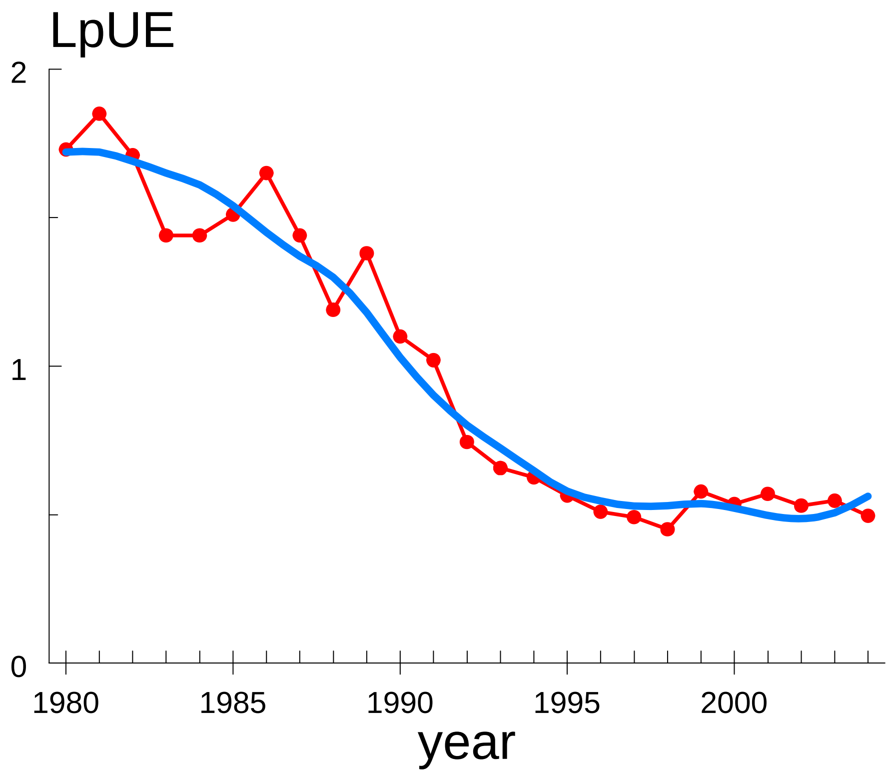

Figure 8. Time plot of Estimated F/Fmsy and B/Bmsy ratios from time-series analysis (F ratio=red dotted line and open circles; Biomass ratio is the blue scatter).

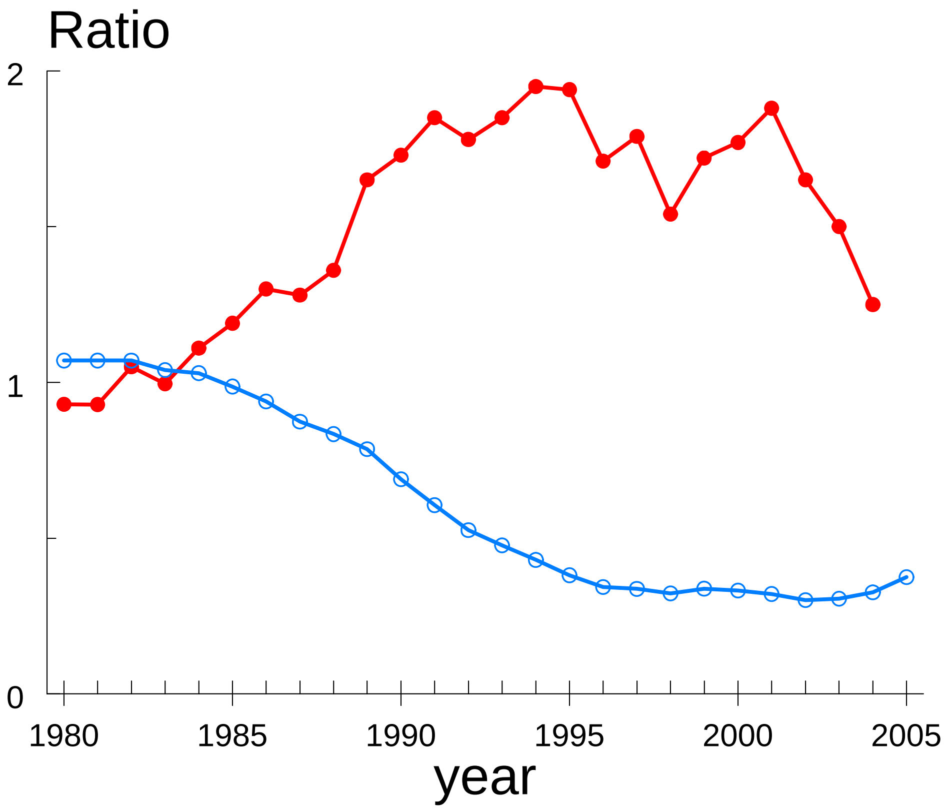

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Figure 9: landings per unit of effort (LpUE, tons/HP·days) as observed for North Sea plaice (blue line) in comparison with fitted values, based on the estimated parameters K=1314, q=0.00193 and r=0.35 (red dotted line and open circles) from Bayesian state space analysis

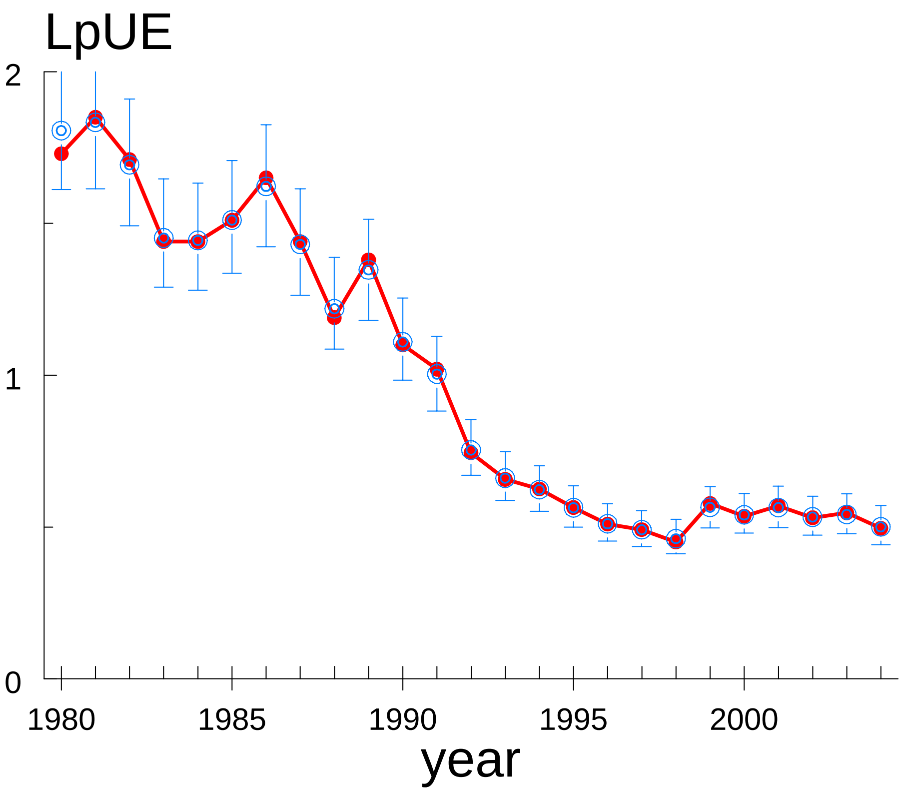
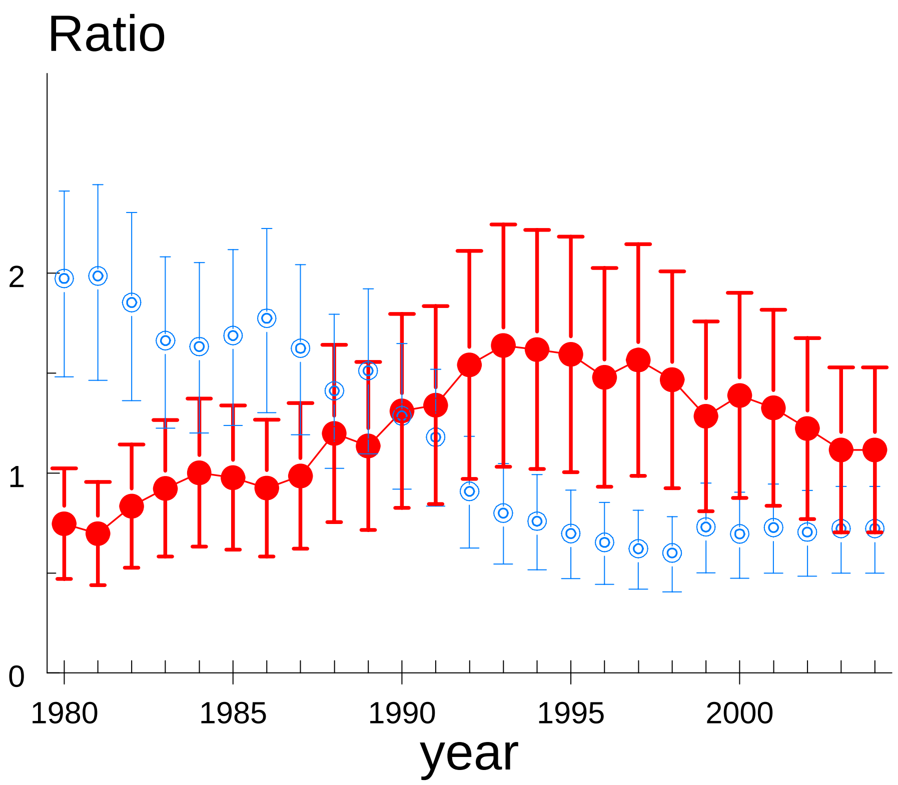


Figure 10. Time Plot of Estimated F/Fmsy and B/Bmsy ratios from Bayesian state space analysis (F ratio=red dotted line and open circles; Biomass ratio is the blue scatter)



Justification

This report

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has been produced with great care. The scientific quality has been peer-reviewed and assessed by or on behalf of the Scientific Board of Wageningen IMARES.

Drs. E. Jagtman
Head Fisheries Dept.

Signature: ___________________________

Date: 22 March 2007

Dr. A.D. Rijnsdorp
Scientific Board

Signature: ___________________________

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