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Een indicator voor visserij-inspanning uitgewerkt voor de Nederlandse boomkorvloot

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Inhoudsopgave

Samenvatting

In het kader van het visserijbeheer heeft het beleid behoefte aan een indicator voor visserij-inspanning die een bruikbare maat is voor het vangstvermogen van de vloot. In dit rapport wordt een indicator ontwikkeld die een directe relatie legt tussen de inzet (zeedag) en de gedurende deze zeedag geïnduceerde visserijsterfte (FPUE: partiele visserijsterfte per eenheid van visserij-inspanning). De FPUE geeft de bijdrage van ieder schip aan de visserijsterfte die gedurende een visreis op een doelsoort wordt veroorzaakt. De FPUE wordt berekend door de vangst van een visreis te delen door de totale internationale vangst en deze verhouding te vermenigvuldigen met de visserijsterfte uit de jaarlijkse toestandsbeoordeling. De indicator is getalsmatig uitgewerkt voor de boomkorvisserij. De wetenschappelijke onderbouwing van de ontwikkelde indicator (appendix 1) zal aan een wetenschappelijk tijdschrift worden aangeboden voor publicatie.

Voor de Nederlandse boomkorvloot (>300 pk) neemt de FPUE toe met het motorvermogen. De helling van de log-log relatie tussen FPUE en motorvermogen was ~0.8 voor tong en ~0.5 voor schol (Tabel 3). Bij een helling van 1.0 is er sprake van een rechtevenredige toename zoals impliciet wordt verondersteld bij het gebruik van de pk-dag als effort maat. De lagere hellingscoëfficiënt betekent dat de vangstefficiëntie minder sterk toeneemt dan het motorvermogen. Met de gevonden relaties van de FPUE en het motorvermogen kan de FPUE worden gestandaardiseerd naar een kotter van 2000 pk.

De gestandaardiseerde FPUE blijkt volgens een voorspelbaar patroon in ruimte en tijd te variëren (Figuur 5). Voor tong varieert deze tussen de 4.10^{-6} en 16.10^{-6}. De hoogste waardes worden in de vroege herfst bereikt. Zowel het niveau als het seizoenspatroon verschilt per visgrond (Figuur 6). Voor schol varieert de gestandaardiseerde FPUE tussen de 3.10^{-6} en 10.10^{-6} met een piek in januari in alle visgebieden en een dal in de periode van week 12 tot 36. Alleen op de visgronden in de centrale Noordzee ligt de FPUE gedurende het gehele jaar op een hoog niveau van 6.10^{-6} - 10.10^{-6}. De seizoensverschillen kunnen worden verklaard uit 1) de veranderingen in de ruimtelijke verspreiding ten gevolge van de seizoensmigraties tussen paai- en voedselgebieden en 2) de rekrutering van een nieuwe jaarklas uit de ondiepe kustgebieden in de herfst. Er blijkt geen duidelijk verband te bestaan tussen de FPUE van tong en schol (Figuur 7). In de winter is er in alle gebieden sprake van een hoge FPUE voor schol terwijl de FPUE voor tong hoog is in de zuidelijk visgronden en laag is in de centrale en zuidoostelijke visgronden. In de zomer is er zelfs sprake van een negatief verband tussen de FPUE voor tong en schol. Het ontbreken van een positieve relatie heeft belangrijke implicaties voor het visserijbeheer omdat het de mogelijkheid biedt voor het ontwerpen van beheersmaatregelen die de visserijsterfte voor tong en schol kunnen ontkoppelen.

In de tijdsperiode van 1990-2003 blijkt er een significante toename te zijn van de vangstefficiëntie van een gestandaardiseerde kotter (Tabel 3). De toename in de efficiëntie bedraagt 3% per jaar voor tong en 1.5% per jaar voor schol. De toename blijkt voor een deel toe te schrijven aan 1) het in de vaart komen van nieuwe schepen; 2) het upgraden van de motor; 3) de ervaring van de schipper[1] (Tabel 5). De bijdrage van de verschillende factoren verschilt voor tong en schol. Voor beide soorten is de ervaring van de schipper de belangrijkste factor (tong: 42%; schol: 48%). Vervanging van een schip geeft een bijdrage van 30% voor tong en 42% voor schol. Vervanging van de motor, tenslotte, geeft een bijdrage van 28% in tong en 10% in schol. De bijdrage aan de efficiëntie toename van een schip is geringer dan de gemiddelde toename in de efficiëntie van de vloot. Dit betekent dat de positie van een schip ten opzichte van haar nieuwere collega's afneemt. Door te investeren in een nieuwe motor of in een nieuw schip (casco en motor) neemt de efficiëntie sprongsgewijs toe. Vervanging van een schip na gemiddeld 21 jaar geeft een efficiëntie verhoging van 25% voor tong en 19% voor schol. Het vervangen van alleen de motor na gemiddeld 16 jaar levert een efficiëntieverhoging op van 15% voor tong en 3% voor schol. Bij deze schattingen is ervan uitgegaan dat de relatie tussen het vangstvermogen van een kotter en haar motorvermogen constant is.

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[1] Deze factor omvat ook aanpassingen aan vistuigen en investeringen in apparatuur aan dek en op de brug

De voorspelbaarheid van de partiele visserijsterfte die tijdens een zeedag wordt geïnduceerd heeft belangrijke consequenties voor het visserijbeheer. Het effect van een beperking van het aantal zeedagen is afhankelijk van de specificaties van de beheersmaatregel en de reactie van de vloot hierop. Een visser kan zijn beperkte zeedagen inzetten om een zo groot mogelijke FPUE[1] te bereiken op één van de doelsoorten, of een combinatie van de twee. Zo zou een beperking van het aantal zeedagen met 20% tot een afname in de cumulatieve FPUE voor tong hebben geleid van minder dan 10% indien de vloot de minste efficiënte tong reizen zou hebben geschrapt (Figuur 8a). Een dergelijke reactie zou tot een meer dan 20% reductie in de cumulatieve FPUE voor schol hebben geleid (Figuur 8b). Als de vloot de visreizen beperkt met de laagste gerealiseerde besomming, dan blijkt de reductie in zeedagen tot een bijna evenredige reductie in de cumulatieve FPUE voor tong te leiden (Figuur 8e) en tot een minder dan evenredige reductie in de cumulatieve FPUE voor schol (Figuur 8f).

Het biologisch advies is uitgedrukt in een visserijsterfte (F), waaruit een daarbij behorende vangst (TAC) wordt afgeleid. Met de in deze studie ontwikkelde indicator voor visserij-inspanning, die een directe relatie legt tussen de nominale inspanningsmaat (zeedag in combinatie met motorvermogen) en de veroorzaakte visserijsterfte, kan het biologisch advies direct worden doorvertaald naar de nominale inspanning. De voorspelbaarheid van het patroon in ruimte en tijd van de FPUE maakt het verder mogelijk om management scenario's te ontwikkelen voor de gemengde visserij waarbij rekening gehouden wordt met de toestand van de zwakkere soorten, b.v in de vorm van gebied- en tijdspecifieke inspanningsbeperkingen. De voorgestelde methode is algemeen toepasbaar omdat ze gebruik maakt van algemeen beschikbare gegevens over de vangst en inspanning (EU-logboek data bases) en schattingen van de visserijsterfte van de ICES werkgroepen. De beschikbaarheid van aanvullende informatie over individuele schepen (bouwjaar casco, bouwjaar motor, eigenaar) maakt het mogelijk de te verwachte veranderingen in de vangstefficiëntie ten gevolge van veranderingen in de vloot (sanering en nieuwbouw) in te schatten. Een zwak punt in de ontwikkelde methode is dat ze gebaseerd is op aanlandingsgegevens die mogelijk vertekend kunnen zijn door onvolledige vangstrapportages (high-grading, illegale aanvoer). Dit bezwaar geldt echter ook voor de huidige biologische modellen. Binnen het huidige systeem is de voorgestelde methode een bruikbaar instrument voor het oplossen van de beheersproblemen rond de gemengde visserijen.

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[1] Omdat de FPUE de fractie van de biomassa aangeeft die per zeedag gevangen wordt kan ze ook als relatieve maat voor de vangst worden gezien. Omdat de beschikbare biomassa van jaar op jaar verandert zal een bepaalde constante FPUE tot verschillende vangsthoeveelheden leiden.

Appendix 1

Partial fishing mortality per fishing trip: a useful indicator for fishing effort in management of mixed demersal fisheries

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Effort management has been proposed as an alternative for quota management in mixed demersal fisheries. It requires a metric to estimate the fishing mortality imposed by a given quantity of nominal fishing effort. We estimate the partial fishing mortality rate imposed by one unit of fishing effort (FPUE) during individual fishing trips and explore the usefulness of this indicator for the management of North Sea beam trawl fishery of vessels (>225 kW) for sole *Solea vulgaris* and plaice *Pleuronectes platessa*. FPUE was positively related to engine power of the vessels, and showed an annual increase of 2.8% (sole) and 1.7% (plaice). The positive trend was due to an increase in skipper skills and investment in auxiliary equipment, the replacement of old vessels by new vessels and to a lesser extend an upgrade of engines. The FPUE imposed per day at sea by a 2000hp beam trawler was estimated at 1.0 x 10^{-6} (sole) and 0.6 x 10^{-6} (plaice) and showed substantial seasonal and spatial variations. FPUE of sole and plaice were negatively related in summer and showed no relationship in winter. Management implications of the predictive seasonal and spatial patterns in FPUE and the uncoupling of FPUE of plaice and sole are discussed.

Key words: fishing effort, fishing mortality, effort management, catchability, technological efficiency, beam trawl, sole, plaice

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Introduction

In European Union waters, fish stocks are managed by setting annual catch limits (total allowable catch, TAC), accompanied by technical measures such as gear restrictions, mesh size regulations and closed areas and seasons (Holden, 1994). Management has been unsuccessful for mixed fisheries (Holden, 1994; Commission, 2001) and several demersal stocks have declined to historic low levels while exploitation levels remain too high (ICES, 2004).

The main problem in managing mixed fisheries by single species TAC's is that these do not restrict the catch but only the (official) landings as the over-quota catch of a species may be discarded or landed illegally (Holden, 1994; Daan, 1997). This has two main effects: (1) fishing mortality is not constrained by the TAC, and (2) deteriorating catch statistics lead to inaccurate assessments and uncertainty in the advice. Effort management has been proposed as a possibility to resolve these problems and to improve the effectiveness of the management (Daan, 1997; Ulrich *et al.*, 2002; Shepherd, 2003).

A prerequisite for effort management is that the contribution of a unit of fishing effort to the fishing mortality of a species is known. Assessing this relationship is not without problems (Martell and Walters, 2002). Efficiency varies among individual vessels owing to differences in the skill of the fishers and vessel characteristics (Hilborn, 1985; Squires and Kirkley, 1999), and may increase over time owing to continuous developments in the fishing industry (Marchal *et al.*, 2001; Pascoe *et al.*, 2001; Marchal *et al.*, 2002; Ulrich *et al.*, 2002; O'Neill *et al.*, 2003). However, the efficiency may be affected also negatively or positively by management regulations, for instance by the introduction of a closed area (Marchal *et al.*, 2002; Marchal *et al.*, 2002 et al., 2002b), closed seasons, changes in mesh size, or cuts in quota (Poos *et al.*, 2001; Pascoe *et al.*, 2001; Rijnsdorp et al., 2001). Efficiency of vessels incorporates three interrelated aspects: a technical one, a biological one and an economic one. Gear efficiency may be defined as the fraction of the fish present in the path of a trawl that is retained by the gear. It may vary with physical conditions, the skill of the skipper and fish behaviour but is largely independent of the amount of fish present (although it may be influenced by catch rates). Catchability of a species refers to the chance that an individual in the population is caught by a gear, and thus depends on gear efficiency but also on the distribution of the fish in relation to the distribution of the fleet. Therefore, catchability is affected by the skills of skippers to locate the highest densities. Finally, the economic efficiency combines gear efficiency and catchability, but constrains individual vessels to fish only under profitable conditions by taking into account costs and returns.

Traditional stock assessment provides estimates of the catchability (q) by age group in tuning series, based on the linear relationship between fishing mortality (F) and effort (E):

$$F=q*E$$

Using the ratio of the catch of fleets or individual vessels relative to the international catch, the annual fishing mortality may be decomposed into the partial F imposed by these fleets or vessels (Beverton and Holt, 1957) during a specific period and expressed as the fishing mortality induced per unit of effort. This partial F can be interpreted directly as catchability (E=1) and integrates all aspects of gear efficiency, crew skills and the proportion of a species that is available at the fishing ground. Thus, the partial F approach should allow an evaluation of the sources of variability in the fishing mortality – effort relationship. We explore the various components of the process that leads from the operation of a single vessel on a fishing ground to the annual total fishing mortality imposed on a species by a mixed fishery, based on available data for the Dutch bottom trawl fleets targeting North Sea sole (*Solea solea*) and plaice (*Pleuronectes platessa*). Having quantified these components, we then comment on the usefulness of the partial F as an indicator of fishing effort in an effort management context.

Material and methods

Dutch bottom trawl fleet

Data on landings and hours fishing by trip are available for the Dutch bottom trawl fisheries since 1990. This data base (VIRIS) is held by the national fisheries inspection and comprises daily records of a.o. ship identity code, landings by species, area fished (ICES rectangle), gear. As the daily records are not always reliable, catches were summed by trip and assigned to the rectangle with the largest share of the trip catch. Technical characteristics of the vessels are registered in the vessel data base (NRVI) comprising a.o. identity code, engine power, vintage of hull, vintage of the engine, and ownership. For the analysis, individual vessels were uniquely coded when no change occurred in the hull, engine or ownership. The time that such a unit has been in operation (age) was calculated relative to the date of entry of the unit and expressed in decimal year. For vessels that entered the fleet before the study period, 1 January 1990 was taken as date of entry.

Rectangles were grouped into fishing areas that reflect the spatial distribution of the two flatfish species (Figure 1). Hence, coastal rectangles were distinguished that comprised the borders of the 12 nm zone (1, 2) and the plaice box (6,7,8), the offshore fishing grounds in the southern (3,4) and southeastern North Sea (5,10), the Dogger Bank (13,14) and the remaining central North Sea (15). In this classification, we took account of management regulations regarding mesh size (80mm south of the 55°N; 100mm north of the 55°N until 2000 when the line was shifted to the 56°N for the waters east of 5°E).

The fleet is dominated by beam trawlers, which contribute 57% of the total number of fishing days. In terms of landings, the beam trawl fleet dominates even more taking 99.5% and 98% of the landings of sole and plaice, respectively (Table 1). Landings taken with other gears are well below 1% of the total, except plaice landings taken with otter trawl (1.7%).

We focus on the fleet of large beamer trawlers (>300 hp) that operate in the offshore waters of the North Sea beyond the 12 nm coastal zone and outside the plaice box (Pastoors *et al.*, 2000). For this fleet, engine power has a large influence on the catch rate of a vessel (Zijlstra and De Veen, 1963; Rijnsdorp et al., 2000a), mainly through the effect of towing speed and number of tickler chains that can be deployed. The width of the beam trawl of the large trawlers is restricted to 12m.

Partial fishing mortality

Total F by quarter for both species was estimated by multispecies virtual population analysis (MSVPA) of quarterly catch at age data from the total international fleet (ICES, 2004b). However, in this model plaice and sole are not preyed upon and therefore the results reflect a quarterly single species VPA. Because of the higher temporal resolution, this model was preferable above the annual VPA routinely performed for management advice. The average F over age classes 2-8 was decomposed into partial F according to proportional catch, first by country, then by fleet, individual vessel, and finally by week (= trip). Thus, the partial F imposed by an individual vessel *i* per day in week *j* (FPUE or F_{ij}) was calculated as:

$$F_{ij}=(c_{ij}/C)*F/d_{ij}$$

where c_{ij} represents the vessel's catch, C = total quarterly landings, F = quarterly F of the total fleet and d is number of days fished. F_{ij} is determined by the gear efficiency of the individual vessel and the number of fish that is available in the area, and is a measure of the local catchability of a particular vessel.

This approach should be considered to be a rather crude approximation of the actual contribution of each trip to the total fishing mortality rate as we had to assume similarity in exploitation patterns among vessels and across weeks.

Statistics

Generalised linear models were used to analyse the contribution of temporal and spatial co-variables as well as ship characteristics to the variability in the FPUE (Proc genmod of SAS, 1999). As the F estimates from the VPA have not yet converged in the most recent years, they were down-weighted by applying a weight vector 1-exp(-0.68*(2004-year)) that increased the weight from 50% in the final year (2003) to >93% weight in years up-to 2000.

Seasonal patterns were modelled employing a periodic regression model:

$Y = \ln(P) + area*\Sigma^n(\sin^n t + \cos^n t)$

where P = engine power of the vessel; Area = code for the fishing area and $t=2\pi*weeknumber/52$ representing a periodic function with a period of 1 year. Higher order terms were included to fit seasonal peaks and lows of different levels at different time during the year.

In addition, seasonal patterns were modelled by estimating the partial F for each week*year combination separately:

$Y = \ln(P) + year*week + area*week$

Further the contribution of the hull vintage and engine vintage in combination with the time period that a fishing unit has been in operation to the variability in FPUE was estimated after taking account of the seasonal pattern by fishing area:

$Y = \log(P) + area*\Sigma^n(\sin^n t + \cos^n t) + vh + ve + tu$

where vh = hull vintage; ve = engine vintage and tu = time that a fishing unit has been in operation.

A survival analysis was conducted on the time period that a vessel (hull) or engine has been in operation using the “proc lifetest” of SAS (SAS, 1999), which computes nonparametric estimates of the survival distribution function.

Results

Fleet dynamics

The number of large demersal trawlers (>300hp) participating in the Dutch North Sea bottom trawl fisheries in the North Sea has declined progressively but stepwise since 1990 (Figure 2a), interspaced with periods of relative stability (1993-95, 1998-2000). The decline has been largely caused by the exit of older vessels with relatively small engine powers that has not been compensated for by replacements. New vessels mainly entered the fleet between 1990 and 1995. However, a much larger number has renewed the engine (Figure 2b). This resulted in a small but gradual increase in mean engine power from 1996 hp in 1990 to 2277 hp in 2003. The ageing of the beam trawl fleet is reflected in the increase in the proportion of vessels with a hull (or engine) of <=10year old from 62% (79%) in 1990 to 28% (53%) in 2000. The mean vintage increased between 1990 and 2003 at an annual rate of 0.64 (hull) and 0.76 (engine) (Table 5). Survival analysis revealed that the time interval when 25%, 50% and 75% of the vessels had left the fleet was 17, 21 and 26 years, respectively, whereas this was 10, 16 and 20 years for the engine.

The fleet generally operate throughout the year. Only short periods of reduced activity occur at the start and end of the year and during the spring, summer and autumn holidays (Figure 3). Among the international fleets, the Dutch fleet is responsible for more than 80% of the F of sole, while for plaice a peak of about 60% was reached in the 1980s, followed by a decline to about 50% in the 1990s (Figure 4). For both species, the beam trawl is the dominating fishing gear (Table 1).

Partial fishing mortality

Engine power, week and fishing area all explained a significant proportion of the variance in FPUE (Table 2). Engine power explained 20% and 6% of the variance in sole and plaice, respectively (model 1a). Adding the interaction of year*week (model 1b1) reduced the variance by 29% and 34%, respectively, and adding the interaction term area*week in stead (model 1b2) by 17% and 38%, respectively. If both interactions terms were included (model 1c), 57% and 56% of the variance was explained for sole and plaice, respectively. With this model, the FPUE can be estimated for a standard vessel in each week during 1990-2003, assuming an average seasonal pattern within each fishing area. For a 2000 hp vessel in the Southern Bight (area 3), FPUE showed a clear seasonal pattern during the entire period with high values in autumn and winter and low values in summer in both species (Figure 5). The results also showed a significant positive time trend in FPUE (model 1d; Table 2).

In a second analysis (model 2 and 3, Table 2), the seasonal pattern was modelled as a periodic function. The periodic terms were significant to the 3rd order. This model utilised a much smaller number of degrees of freedom as compared to model 1. The explained variance was smaller than when FPUE was estimated for each week separately. By including date *t*, the positive trend in FPUE (Figure 5) was shown to be significant (model 2b). Including the class variable area reduced the variance significantly by 8% in sole and 14% in plaice (model 3a vs model 2a). This model also showed a significant positive trend in FPUE, explaining 4.8% of the variance in sole and 0.2% in plaice (model 3b). The slopes of the time trends indicate that the FPUE increased by 2.7-3.2% per year in sole and 0.7-1.7% in plaice (Table 3).

Comparison of the seasonal pattern estimated by the periodic model with the FPUE estimates for individual weeks showed a rather close correspondence in plaice (Figure 5b). In sole, however, the periodic model showed consistent discrepancies with the weekly estimates during some periods. For instance, in 1996 and the autumn of 1998, the weekly estimates were consistently higher than the fitted values of the periodic model, whereas the weekly estimates in the winter of 1995 and 2001 were consistently lower. In some years, the autumn peak in sole also occurred earlier (1999) or later (1995, 2002) than predicted by the periodic model.

The average seasonal patterns as estimated by model 3b for the different fishing areas revealed a peak in autumn and a low in summer in most areas (Figure 6). Only in the eastern central North Sea, FPUE peaks in late autumn and reaches a low in early spring. A more than 100% difference among areas exists from November to April. In the remaining months, differences are less than 50%. FPUE for plaice shows a similar seasonal pattern in the southern and eastern areas with high values between November and January and low values between April and August, while the areas north of 55°N exhibit a different pattern with relatively high values throughout the year. Also, FPUE varies substantially among areas. In the southern North Sea, differences may be as high as 50%, whereas the values in the central North Sea may be up to 300% higher than in the southern areas. Hence, the contribution of a vessel to the total F depends to a large extent on fishing area and season. The maximum FPUE appears to be somewhat higher in sole than in plaice. This suggests that sole is the main target species in the beam trawl fishery.

A plot of weekly estimates of sole FPUE against plaice FPUE by area shows that the fisheries on the two species are to a large extent uncoupled (Figure 7). During summer, indicated by red, there is an overall negative relationship between the two FPUE, whereas during winter (blue) a high FPUE on plaice may coincide with both a high or low FPUE on sole.

Time trend in catchability

To explore the positive time trend observed in FPUE (as a measure of catchability), FPUE was analysed in relation to the vintage of the hull, the vintage of the engine and the time that a vessel has been in operation. ANOVA showed that FPUE showed a significant positive relationship with hull vintage, engine vintage and time in operation. These co variables together explained 3.9% and 1.2% of the variance in sole and plaice, respectively (Table 4). A substantial part of this variance, 1.8% in sole and 0.4% in plaice, could not be ascribed to a single co variable. The proportion of the explained variance that could be ascribed varied between 0.02% and 1.0%.

The parameter estimates for the effect of hull vintage and engine vintage can be related to the number of years after which 50% of the vessels or engines has been replaced. With the estimated survival time of 21 (hull) and 16 (engine) years, replacement of a vessel (hull) increases the efficiency by 25% (21*1.17) in sole and 19% (21*0.91) in plaice. Replacement of the engine increases the efficiency by 15% (16*0.91) in sole and 3% (16*0.19) in plaice. Combination of the average rate of increase of hull vintage, engine vintage and operation time, with the slopes of the catchability relationships (Table 4), the contribution of the three co variables to the overall increase in catchability can be estimated (Table 5). The overall trend in catchability is mainly due to the increase in efficiency during the time that a vessel unit is in operation (42% and 48% in sole and plaice, respectively). The replacement of vessels ranks second in importance, whereas the upgrading of the engine is of equal importance in sole but less important in plaice.

The parameter estimate for the effect of operation time on FPUE (model 4) is smaller than the overall increase as estimated by model 1-3 (Table 3). This implies that a vessel become less efficient relative to the fleet as new vessels enters the fleet.

Cumulative partial F by vessel

Because the partial F that a vessel imposes differs between areas and seasons, it is unlikely that the relationship between the partial F generated by a vessel during a year is proportional to the effort. The shape of this relationship was determined for each individual vessel by plotting the cumulative predicted values of FPUE against the cumulative effort after sorting the weeks in descending order of FPUE (Figure 8). The relationship was slightly convex for the (target) species for which the FPUE was sorted (Figure 8a1 and 8b1), whereas the relationship was slightly concave for the assumed bycatch species (Figure 8a2 and 8b2), but there was considerable variation among vessels. This means that for the target species, a small proportion of fishing trips contributed disproportionally to the annual partial F, while for the bycatch species the average cumulative F was slightly below the proportional relationship. The relationships only marginally differed between species, showing a slightly more convex shape if plaice was the target species. Because we sorted the predicted values after correcting for the variance explained by various factors and excluded random error, fishers should be able to select their best trips based on personal experience if faced with effort reductions. Thus, on average, a 40% reduction in fishing effort might lead to a reduction in F on the target species of

30% for sole and 20% for plaice, whereas the reduction in F on the bycatch species would be slightly larger than the effort reduction (45%and 50%, respectively). However, because fishers make individual choices, some targeting sole and others targeting plaice, the overall effect should be less than assuming that all target one species or the other. If the trips were sorted to the observed revenue per day at sea (Figure 8c and 8d), the cumulative relationships became more linear, especially in sole. The shapes of these relationships suggest that if the total allowable fishing effort is reduced and fishing vessels re-distribute their fishing effort so as to obtain the highest revenue, we may expect a slightly lower than proportional decrease in total F for sole, and a substantially less than proportional decrease in F for plaice.

Discussion

The seasonal patterns in FPUE and the differences between fishing areas (Figure 6) reflect changes in the availability of the two species owing to seasonal migrations of adult fish and to recruitment. Adult plaice migrate seasonally between the spawning grounds in the southeastern North Sea in winter and the feeding areas in the central North Sea in summer (De Veen, 1978; Rijnsdorp and Pastoors, 1995; Hunter *et al.*, 2003; Hunter *et al.*, 2004). Adult soles migrate in spring from offshore feeding areas to inshore spawning grounds along the continental and English coast (ICES, 1965, De Veen, 1996; Rijnsdorp *et al.*, 1992). Therefore, adult sole may become less vulnerable because the beam trawl fleet is not allowed to exploit the spawning grounds within the 12 nm zone or the Plaice Box. In autumn, a new year class leaves the cooling inshore waters and recruits to the offshore fishing grounds (Beverton and Holt, 1957; De Veen, 1978). Other factors affecting the observed patterns in FPUE relate to variations in the catch efficiency of the gear caused by changes in fish behaviour. During the spawning season, male plaice are easier to catch, because they appear to be more active (Rijnsdorp, 1993; Solmundsson *et al.*, 2003), while females may be less vulnerable because they spend a larger proportion of their time in midwater (Arnold and Metcalfe, 1996; Metcalfe and Arnold, 1997). Sole even can be observed near the surface during their spawning migrations (De Veen, 1967). Catchability may be affected also by water temperature (Woodhead, 1964; Winger *et al.*, 1999).

These factors may have contributed to the observed variation of the FPUE estimates around the fitted relationship (Figure 5). Seasonal changes in distribution may show variations between years owing to local variations in recruitment and/or spawning stock biomass. Inter-annual variations in distribution appear to be larger in sole than in plaice based on the proportion of the variance explained by the week*area interaction in model 1b2 (Table 2). Indeed, sole shows larger inter-annual variation in year-class strength as well as a lower spatial consistency across years as compared to plaice (Van Beek *et al.*, 1989; Rijnsdorp *et al.*, 1992; Fox *et al.*, 2000). Moreover, sole has been shown to exhibit a distinct evasive response to low water temperatures during cold winters (e.g. 1963 and 1996), when dense aggregations were formed in the relatively warm waters in the south-western North Sea (Woodhead, 1964; Horwood and Millner, 1998). Such aggregations should have positively affected the FPUE.

Trawling activities may also affect the catch efficiency. Disturbance on the fishing ground may make them less susceptible for being caught (Ona and Godo, 1990; Engas *et al.*, 1995; Albert *et al.*, 2004), negatively affecting the efficiency of trawlers working closely together in large numbers.. This process of interference competition or crowding effect is often assumed in fleet dynamic studies (Gillis and Peterman, 1998; Gillis and Frank, 2001; Gillis, 2003) and econometric studies (Pascoe *et al.*, 2001). So far, there is only indirect evidence for this effect (Gillis, 2003; Rijnsdorp *et al.*, 2000; Rijnsdorp *et al.*, 2000).

The observed increase in catch efficiency with engine power corroborates earlier studies (Zijlstra and de Veen, 1963; Rijnsdorp et al., 2000a; Pascoe et al., 2001). This increase is due to a combination of the increase in towing speed (Rijnsdorp et al., 2000a) and the larger number of tickler chains that can towed. Increasing the latter strongly enhances the catch efficiency for sole (Creutzberg *et al.*, 1987) because of their tendency to dig into the sediment in response to disturbance, whereas plaice will be more affected by towing speed because they attempt to swim away (Main and Sangster, 1981; Winger *et al.*, 1999).

In estimating FPUE we had to make a number of simplifications. The most important one is that we had to ignore the age composition of the individual landings, as these are not available.

Also, FPUE were estimated for individual weeks, whereas total F estimates were only available with a quarterly resolution. It is difficult to judge what kind of effects this may have had on the results in terms of bias, but they will undoubtedly contribute to the unexplained variance. However, we did not see consistent changes in the FPUE around the end of each quarter. We further assumed that logbook data accurately record the catch of individual vessels. This may not be true because the fishery is managed by individual transferable quota as shares in the Dutch part of the TAC. Such a management system may result in discarding of over-quota fish or the cheaper fraction of the catch to increase the overall value of the landings (Anderson, 1994; Gillis *et al.*, 1995; Gillis *et al.*, 1995). Although high grading is known to occur from time to time, no quantitative information is available.

Despite these uncertainties and weaknesses, our study seems capable of estimating the effect of engine power on the catch efficiency of the gear, as well as the effects of the spatial and temporal component on the fishing mortality induced during a fishing day. Also, it is clearly shown that the efficiency of the fleet has increased over time, irrespective of engine power.

The positive effect of operation time on the FPUE of a vessel implies that studying trends in fishing power using a subset of reference vessels and assuming that the efficiency of these does not change (Marchal *et al.*, 2001) may be inappropriate. The observed trend may reflect a gradual improvement of the skills of the crew as well as technological advances in auxiliary equipment (DGPS, echosounders, etc). Disentangling the contribution of technological improvements and fishing skill requires currently unavailable information on investments of individual vessels and acting crewmembers.

A second contribution to the increase in catch efficiency is due to replacement of old vessels by new vessels. The rate of increase for sole appeared to be somewhat higher than for plaice. The difference may be related to the fact that sole is the main target of the fleet. The origin of this efficiency increase may be partly the same technological innovations as discussed above as well as improvements in propulsion. Using a stochastic frontier analysis of annual vessel records of the economic output no overall change in the efficiency was observed (Pascoe et al., 2001). This analysis investigated the contribution of several technical attributes of the vessel as well as changes in the management regime on the annual economic output of individual vessels, but did not consider changes in efficiency for individual fish species, nor did it take into account the important effect of the seasonal changes in availability of the species.

Our study showed that a standard 2000hp beam trawler would generate a fishing mortality rate of about 1.0×10^{-6} (sole) and 0.6×10^{-6} (plaice) per day at sea. This FPUE shows large seasonal variations and large differences between fishing grounds. The variations in FPUE induced on sole and plaice appear to be to a large degree uncoupled and fully dependent on the choice of fishing ground and fishing season. It is therefore surprising that the relationship between the cumulative F and the cumulative fishing effort found, after sorting the fishing trips of individual vessels in descending order of revenue, only weakly deviated from a linear proportional relation in sole. This suggests that for the target species of the beam trawl fishery, effort management would result in a close to proportional reduction in fishing mortality rate. However, the convex relationship observed for plaice indicates that a reduction in fishing effort is likely to result in a less than proportional decrease in F in bycatch species.

We conclude that the FPUE might be used as a tool in an effort management regime allowing a careful design that could take account of the predictable effects of seasonal changes in distribution on the catch efficiency of the gear, as well as of the gradual increase in the catch efficiency (technology creep). The approach seems particularly useful for mixed demersal fisheries and can easily be applied to other gear if data on the trip level are available to correct for seasonal changes in availability of the resource.

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Table 1. Overview of proportion of fishing effort and landings of sole and plaice by gear type in the Dutch bottom trawl fleets, 1995-2003.

Gear	Gearcode	Days at sea	Plaice	Sole
Gill net	GN/GNS	0.9%	0.0%	0.2%
Otter trawl	OTB	5.0%	1.7%	0.2%
Pair trawl	PTB	3.1%	0.1%	0.0%
Scottish seine	SSC	0.3%	0.1%	0.0%
Shrimp trawl	TBS	27.4%	0.0%	0.0%
Beam trawl (>300hp)	TBB_large	50.7%	92.1%	89.3%
Beam trawl (<=300 hp)	TBB_small	5.8%	5.9%	10.1%
Beam trawl total	TBB	56.5%	98.0%	99.5%
Rest		6.8%	0.1%	0.1%

Table 2. Percentage of the variance in ln-transformed partial fishing mortality per fishing trip (ln(F) per day at sea) by various analysis of covariance models with the explanatory variables: log-transformed engine power (ln(P), kW), time of the year (either with class variables week and year: model 1) or a periodic function (model 2 and 3) and fishing area. The model code (#) indicates the order in which the explanatory variables were included in the model: 1b1 and 1b2 are on the same level and follow 1a. All explanatory variables explained a significant part of the variance (P<0.001). Fishing areas are shown in Figure 1.

		Sole		Plaice	
	Number of observations	82195		89031	
#	Model	%explained	df	%explained	df
1a	ln(P)	20.4%	1	6.0%	1
1b1	ln(P) + year*week	49.5%	729	40.4%	729
1b2	ln(P) + area*week	37.6%	469	44.2%	671
1c	ln(P) + area*week + year*week	57.1%	1145	55.8%	1347
1d	ln(P) + area*week + t	41.2%	470	45.2%	672
2a	ln(P) + □□sin*t* + □□cos*t*	27.7%	6	28.0%	6
2b	ln(P) + □□sin*t* + □□cos*t* + t	32.5%	7	28.2%	7
3a	ln(P) + area* (□□sin*t* + □□cos*t*)	35.7%	54	41.8%	78
3b	ln(P) + area*(□□sin*t* + □□cos*t*) + t	39.5%	55	42.8%	79
4	ln(P) + area*(□□sin*t* + □□cos*t*) + vh + ve + t2	39.6%	57	43.0%	81

Table 3. Parameter estimates for the explanatory variables ln-transformed engine power (ln(P)) and time (t) in ln-transformed partial fishing mortality

		Sole		Plaice	
Model	Parameter	estimate	SE	estimate	SE
1e	ln(P)	0.8090	0.0058	0.5124	0.0058
	t	0.0278	0.0004	0.0174	0.0004
2b	ln(P)	0.8669	0.0059	0.4927	0.0062
	t	0.0317	0.0004	0.0074	0.0005
3b	ln(P)	0.8089	0.0058	0.5162	0.0059
	t	0.0280	0.0004	0.0165	0.0004
4	ln(P)	0.7211	0.0062	0.4447	0.0064
	vh	0.0117	0.0004	0.0091	0.0004
	ve	0.0091	0.0004	0.0019	0.0004
	t2	0.0181	0.0005	0.0115	0.0005

Table 4. Results of the analysis of variance of the ln-transformed partial fishing mortality in relation to the ln-transformed engine power (ln(P)), week, area, hull vintage (vh in year), engine vintage (ve in year) and time that the unit has been in operation (t2 in decimal year). The percentage explained variance of vh, ve and t2 was calculated against the full model (type3 analysis). The multicolinearity term indicates the proportion of the explained variance that could not be ascribed to a single co-variable.

	Sole			Plaice		
	%explained	df	P	%explained	df	P
ln(P) + area* ($\square^{\square}\sin t + \square^{\square}\cos t$)	35.7%	54	<0.001	41.8%	78	<0.001
Hull vintage (vh)	0.7%	1	<0.001	0.4%	1	<0.001
Engine vintage (ve)	0.5%	1	<0.001	0.02%	1	<0.001
Time in operation (t2)	1.0%	1	<0.001	0.3%	1	<0.001
multicolinearity	1.8%			0.4%		
Full model	39.6%	57		43.0%	81	

Table 5. Contribution of vintage of hull, vintage of engine and the time in operation to the positive trend in catchability.

		Sole			Plaice		
Covariable	Slope of time trend (A)	Slope from model 4 (B)	A*B		Slope from model 4 (B)	A*B	
Hull vintage (vh)	0.640	0.0117	0.0075	30%	0.0091	0.0059	42%
Engine vintage (ve)	0.764	0.0091	0.0070	28%	0.0019	0.0015	10%
Time in operation (t2)	0.584	0.0181	0.0105	42%	0.0115	0.0067	48%
Total trend in catchability			0.0251			0.0140	

Figure 1. Map of fishing areas distinguished.

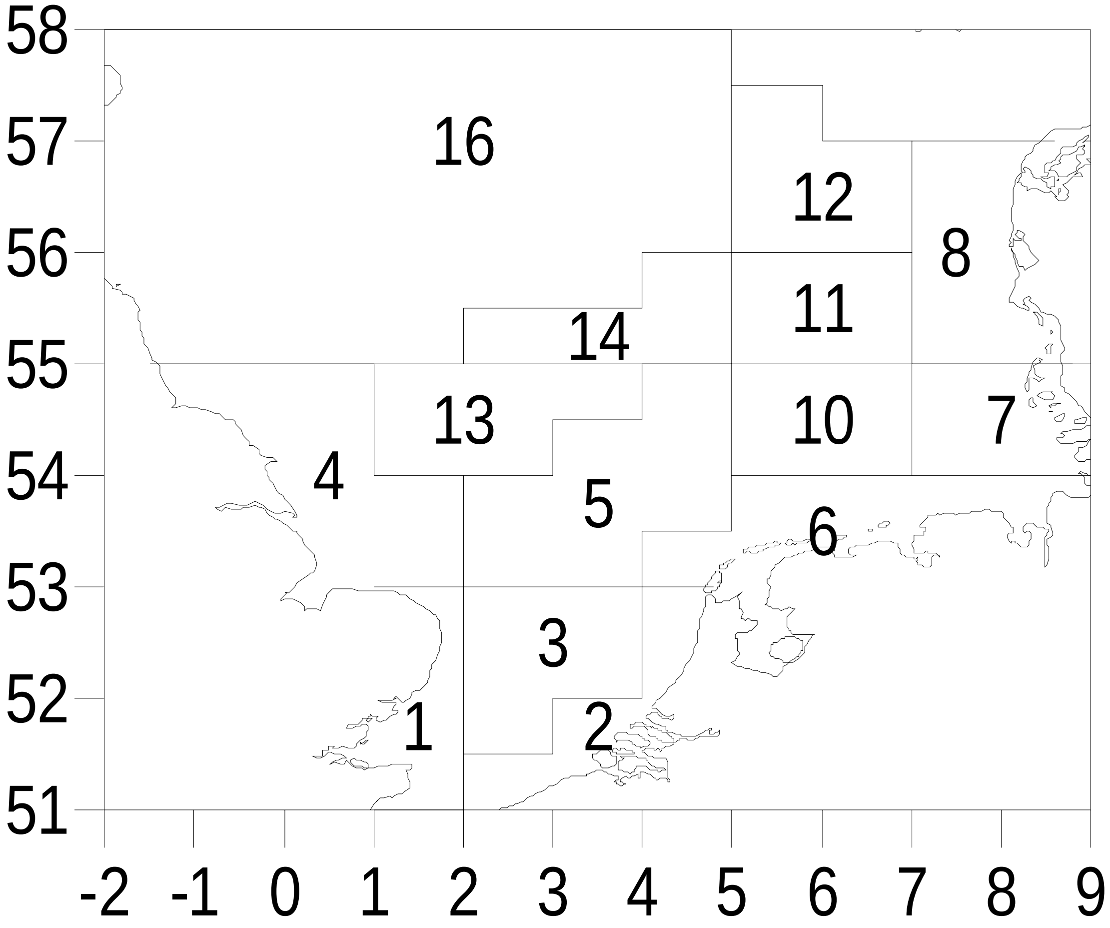
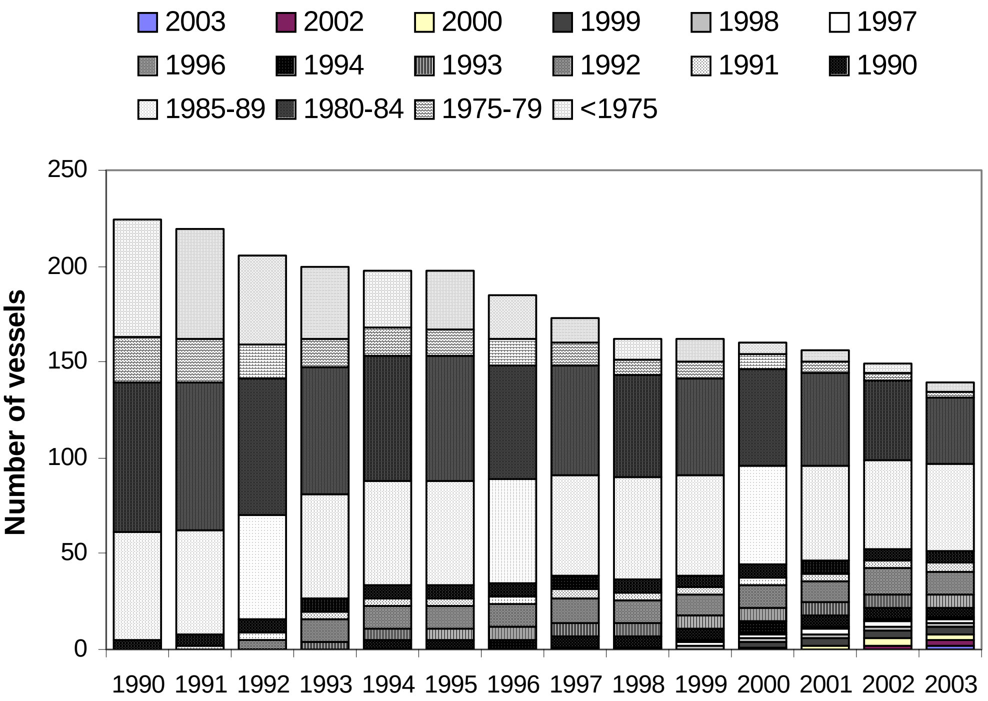


Figure 2a. Changes in the number and composition of the active beam trawl fleet by vintage (grouped in 5-yr periods before 1990) of the hull (a) and engine (b).

a) Vintage of hull



b) Vintage of engine

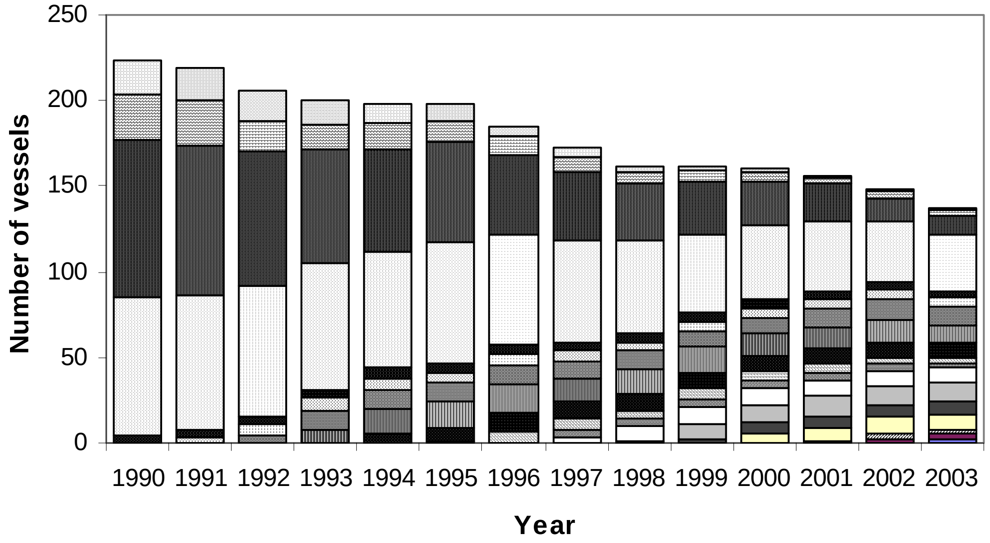


Figure 2b. Relationship between the mean and 95% confidence limits of the probability that a vessel or engine is in operation and the number of years elapsed since its introduction.

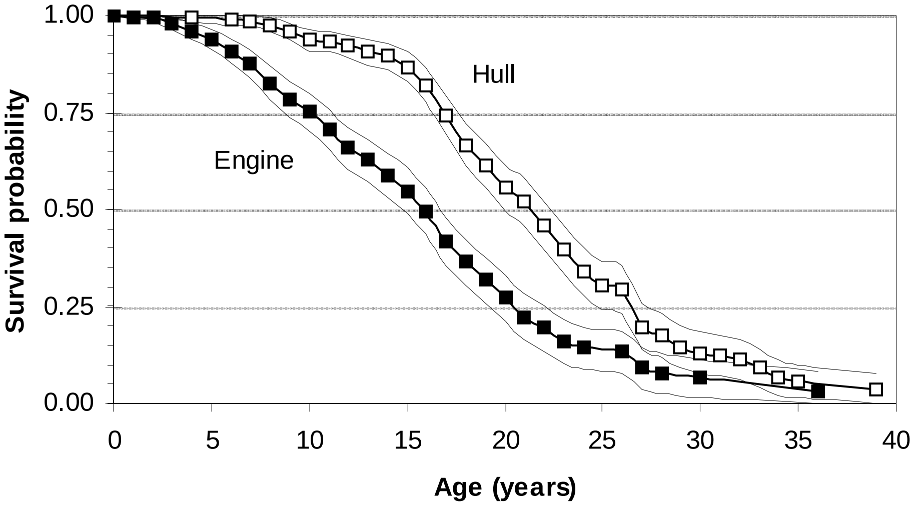


Figure 3. Seasonal pattern in total hours at sea (mean values for 1995-2003) for large and small beam (TBB) and otter trawlers (OTB).

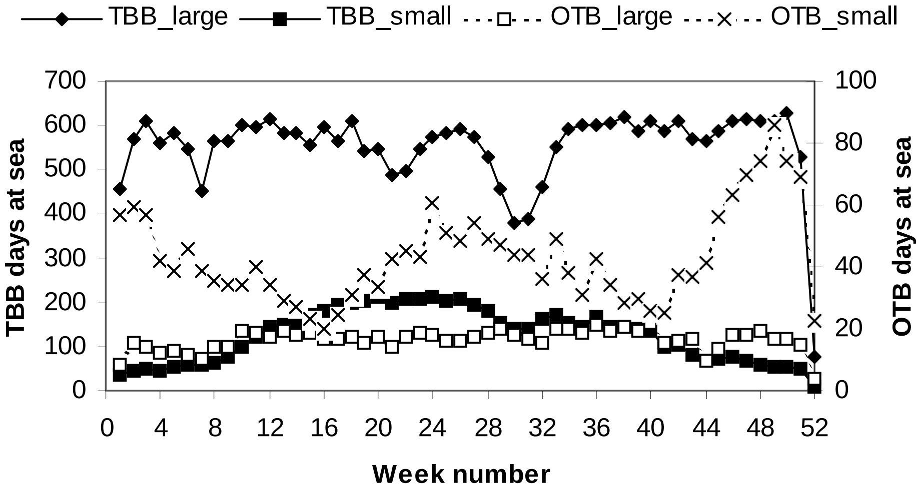


Figure 4. Contribution of the various countries to the fishing mortality rate of sole (a) and plaice (b). Country codes are: B – Belgium; DK – Denmark; UK – United Kingdom; NL – Netherlands.

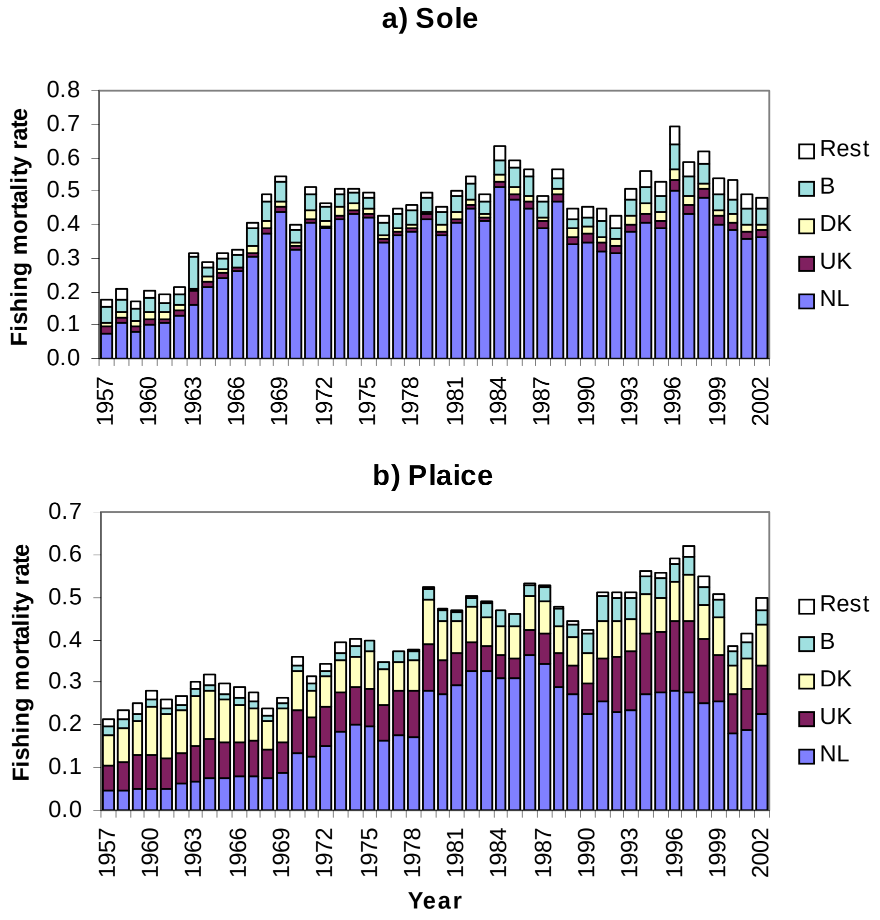
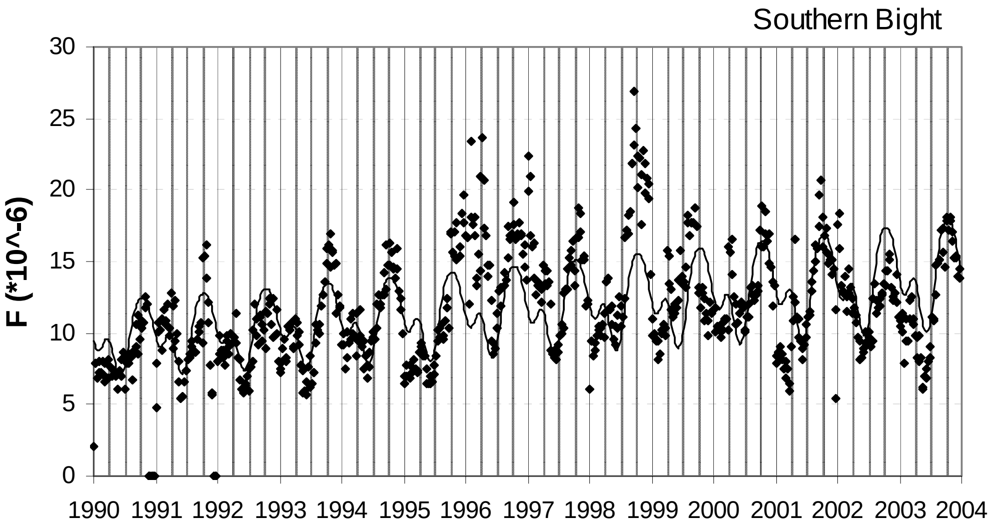


Figure 5. Seasonal pattern in partial fishing mortality estimated from the model: ln(F)= ln(hp) + year*week + area*week (diamonds) and ln(F) = ln(hp) + (sint + cost) + area*($\sin^2$t + $\cos^2$t) + area*($\sin^3$t + $\cos^3$t) + date (full lines) for a 2000 hp trawler in area 3 (Southern Bight).

a) Sole



b) Plaice

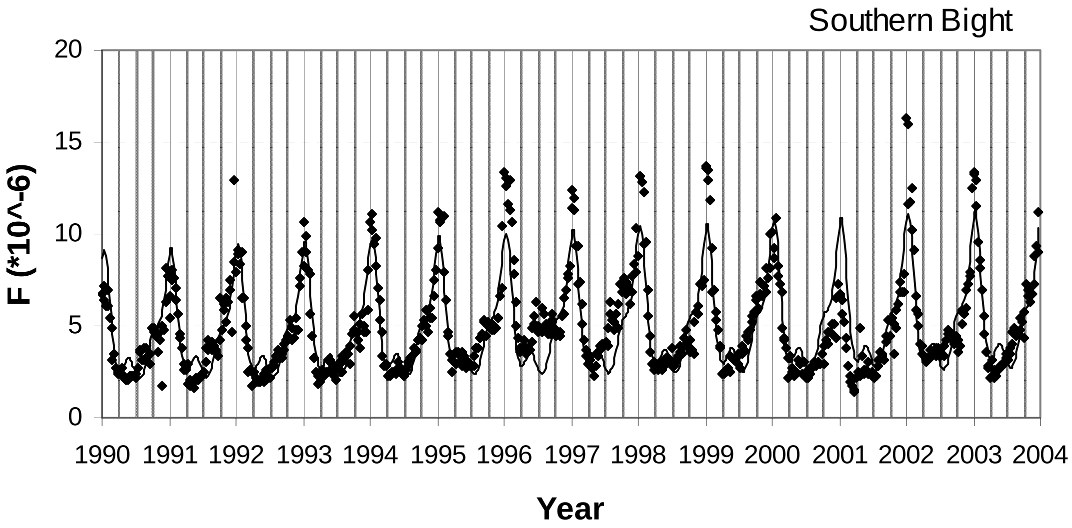
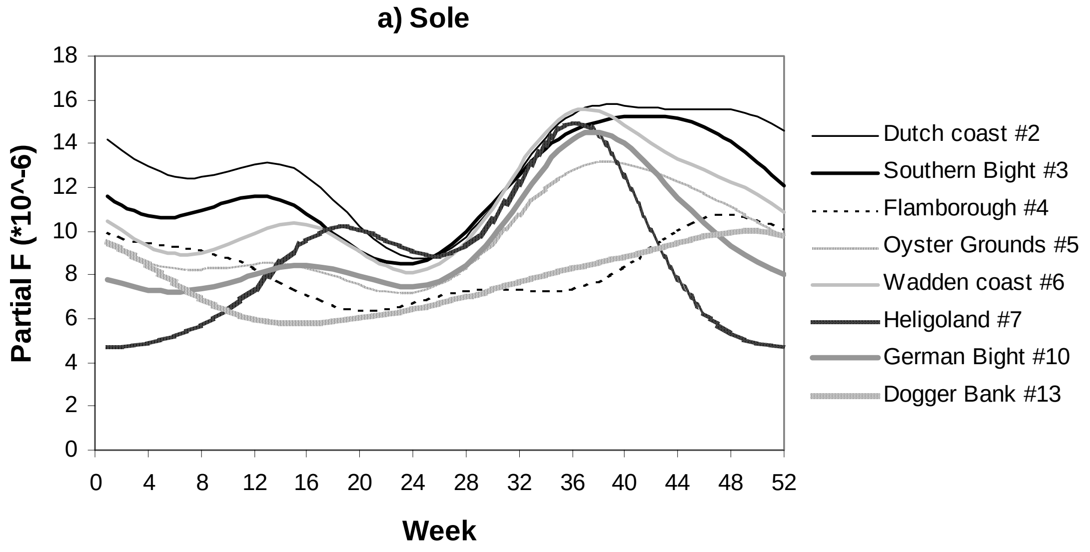


Figure 6. Seasonal patterns in partial F for sole (a) and plaice (b) estimated by model 3b for a vessel of 2000 hp. Fishing grounds are shown in Figure 1.



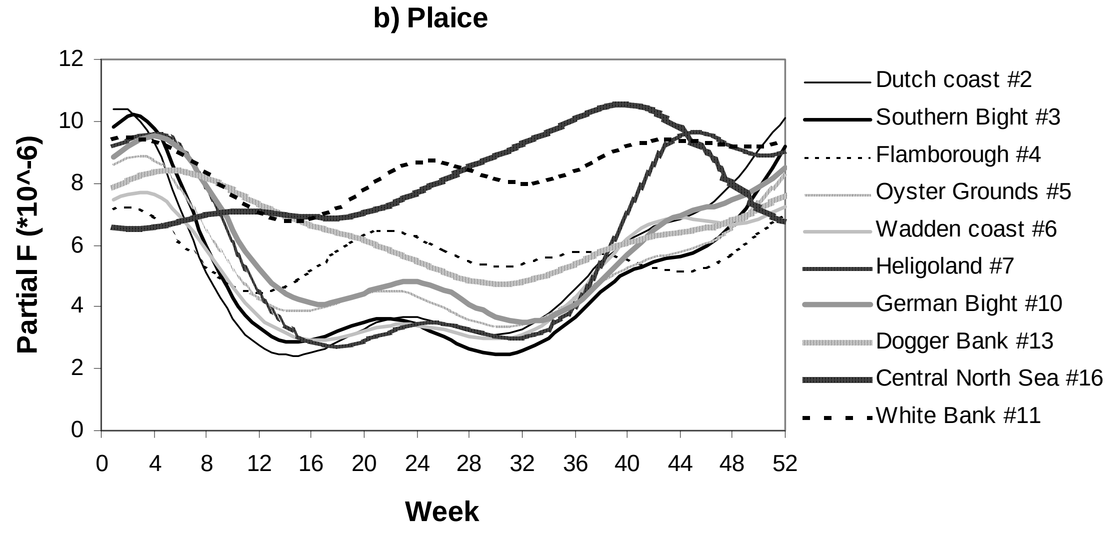


Figure 7. Seasonal patterns in the relationship between the partial fishing mortality for sole and plaice in different areas of the North Sea. The colours indicate the season (deep blue = December – January; deep red = June – July. The numbers indicate the area codes from Figure 1.

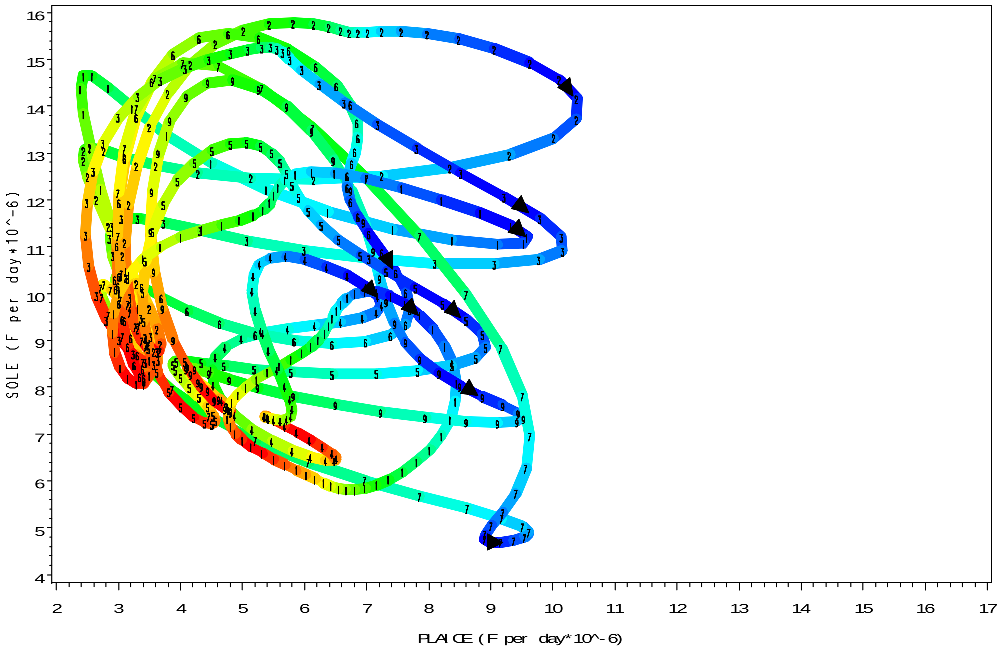


Figure 8. Relationship between the cumulative proportion of the predicted FPUE and the cumulative effort for individual vessels in 2000 when the trips were sorted in descending order of the FPUE of sole (a, b), plaice (c, d) and observed revenue (e, f). The heavy black line shows the average relationship over all ships.