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Quota regulation and efficiency in the Dutch beam trawl fleet

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Abstract

One of the key assumptions in fishery assessment models is that Catch Per Unit of Effort (CPUE) may be used as an index of stock density. However, catchability may vary over time due to technological developments, changes in fishermen behaviour, or changes in the distribution of fish stocks

This paper studies the effect of management measures, in particular the system of Individual transferable quotas (ITQs), on variation in the catchability of target species of the Dutch beam trawl fleet, a mixed species fishery.

The underlying hypothesis is that in a situation of high ITQs relative to the stock size for target species, the catchability would be determined by technical efficiency only (i.e. vessel characteristics) but that the overall efficiency for target species would decrease when ITQ become more constraining. Non-linear regression models were used to link ITQ and catchability. Results of the analysis indicate quota management has affected efficiency for both target species sole and plaice, the results being more conclusive for the former than the latter. Differences in the relation between catchability and ITQ were found among vessels. No effect of ITQ constraint of target species on catchability of the non-target species dab was found. This result does not support the behavioural mechanism of decreasing catch efficiency for target species by redirecting effort to non-target species. To conclude, the results show that quota management put constraints on catch efficiency of Dutch beam trawl vessels for at least part of the fleet, but the underlying behavioural mechanism of reducing efficiency remains unclear.

Introduction

A common assumption underlying fish stock assessment is that Catch Per Unit of Effort (CPUE) may be used as an index of stock density (Mendelssohn and Cury 1989). The parameter linking CPUE and stock abundance (B) is defined as the catchability (q) (Gulland 1983):

$$CPUE = q \cdot B \qquad [1]$$

Catchability may vary in time owing to technological development (Robins, Wang and Die 1998),

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changes in the behaviour of fishermen (Gillis and Peterman 1998), or changes in the distribution of fish stocks (Mackinson et al. 1997; Mendelssohn and Cury 1989). Changes in q over time can be estimated by several methods (Millischer et al. 1999; Marchal et al. 1999), but most methods give no insight in the processes involved.

The Dutch beam trawl fishery is a mixed-species fishery. Landings in 1998 and 1999 mainly comprised of the two target flatfish species sole *Solea solea* (20%) and Plaice *Pleuronectes platessa* (48%). The Dutch landings of sole contribute up to 73% of the total for the North Sea, whereas Dutch plaice landings account for approximately 47% of the total (ICES 2000). Other marketable flatfish species (dab *Limanda Limanda*, turbot *Psetta maxima* and brill *Scopthalmus rombus*) account for 13% and roundfish species (cod *Gadus morhua* and whiting *Merlangus merlangius*) account for 10% of the total landings.

Fishing in European waters is managed by means of Total Allowable Catches (TACs), that are set annually for individual target species (Holden 1994; Daan 1997). The TACs determine the national quota for each country by a fixed share. The system of allocating the national quotas among vessels differs between nations. In the Netherlands, the national quotas for sole and plaice are split into Individual Transferable Quotas (ITQs) that are freely tradable and fully divisible (Salz 1996). Because fishermen differ with respect to the net return per unit of fish, a market for individual quota has developed (Grafton 1996; Salz 1996). Owing to the trade in quotas over time, ITQs vary among vessels, both in size and composition. For the non-target species (dab, turbot and brill) pooled quotas exist and individual vessels may try to increase their efficiency for these species by redirecting their fishing effort.

It has been hypothesised that the management regime is one of the possible causes for variations in efficiency. Quota management puts a constraint on catches, forcing fishermen to alter fishing behaviour (Pascoe et al. 2001). TACs are based on biological stock prognoses, but the proposals are subject to political negotiations before the final decisions are taken (Daan 1997). The uncertainty contained in the stock prognoses (Gascuel et al. 1998; Hilborn and Walters 1992) results in fluctuations between fishing rights and stock abundance. For instance, if the size of a stock is overestimated, fishing will not be constrained by quotas, and efficiency for target species will be maximised. This will result in maximum catchability, that is only limited by the "technical efficiency" of the vessel and accessibility of the stock (Millischer et al. 1999). On the other hand, if a stock is underestimated and TACs are set low, a severe constraint is put on the fishery and catchability for the species under consideration may decrease. Political negotiations may enlarge the effects of assessment uncertainty, because they do not address the possible imbalance between fishing rights and fish availability. These differences in catchability may be caused by changes in fishing behaviour, for instance by redirection of effort to non-quota species or high-grading.

We analyse the catch statistics of the Dutch beam trawl fleet to quantify the effect of the ITQ constraints on the efficiency for both target and non-target species. We do not have *a priori* knowledge about the level at which the ITQs put a constraint on the catchability. We hypothesise that in a situation of high ITQs relative to the stock size for target species, the catchability will be set by technical efficiency only. To analyse this non-linear relation we use non-linear regression models to link ITQ and catchability.

We hypothesise that the efficiency of Dutch beam trawl vessels for target species will decrease under increasing ITQ constraint, and that fishermen will try to make up for reduced catch efficiency on target species (sole and plaice) by redirecting fishing effort to non-target species (e.g. dab, turbot and brill).

Material and Methods

Datasets

Commercial landings are recorded in the Dutch Fishery Registration and Information System (VIRIS) database, which contains the logbook data of the Dutch fleet and of foreign boats landing in Dutch ports. The database is maintained by the General Inspection Service for monitoring and control. A first version was implemented in 1990, but a more versatile and complete version was introduced in 1995, when also the non-target species turbot and brill were included. The last modification stems from 1998, when also dab was included. Besides landings by different species, the VIRIS database contains data on nominal effort, vessel code, engine power and ICES rectangle of catch. We extracted data for the period 1994-2000 from VIRIS. No information is available on discards in VIRIS. To exclude the effects of differences in fishing power between vessels due to engine power (Gulland 1983; Rijnsdorp et al 2000), only observations from vessels of 1990-2000 hp that had been present during the entire period were selected. The selection resulted in a total of 13202 trips made by 43 beam trawlers. Zero catches, which accounted for less than 1.67 % of the observations, were excluded from the analysis.

The commercial CPUE in VIRIS was calculated by summarising the total catch (kg) in all rectangles during a trip, divided by the trip duration estimated in number of days at sea.

Data on ITQs were obtained from the Directorate of Fisheries of the Ministry of Agriculture, Nature Management and Fisheries for 1994-2000. These data are recorded on a year to year basis and represent the situation at the start of each year. No information is available on the fishing rights transferred during a year due to selling or hiring. The amount of ITQ in possession varies substantially among vessels. The ITQs for sole and plaice show a significant positive relationship (Pearson, r=0.72, df= 299, p<0.0001) (Fig. 1). Nevertheless, the spread around the regression line indicates differences among vessels in individual fishing rights with regard to the two main target species

Data on the stock abundance were available from two sources

- Estimates for sole, plaice and dab may be obtained from the BTS survey (Rogers et al 1997). Catches per haul in numbers per hour by length class were transformed to weights per hour by excluding undersized individuals and applying a standard length-weight relationship (table 1). A total stock index is given by the arithmetic average of the log-transformed CPUE (weight/hr) by ICES rectangle. Because the survey is performed during August and September the abundance index is calculated as a two-year running average (Fig. 2a). This BTS stock index is calculated from 1994 to 2000.
- Stock estimates for both sole and plaice may also be derived from fish stock assessments (ICES 2001). These stock indices are calculated using cohort analysis with the XSA tuning method (Darby and Flatman 1993; Shepherd 1999). The estimates of the biomass by age group refer to January 1st. To obtain a biomass available to the fishery in a given year, the biomass of two-year and older fish on July 1st was calculated as a two-year running average. These values were log-transformed (Fig. 2b). This XSA stock index is calculated from 1994 to 1999.

Comparison of the BTS survey and XSA stock estimates from 1985 onwards shows a correlation for both plaice (Pearson, r=0.92, df=12, p<0.0001) and sole (Pearson, r=0.95, df=12, p<0.0001).

The Relative Fishing Opportunity (RFO) was defined as the ITQ of a vessel j by the stock estimate (B) in a given year i:

$$RFO_{ij} = \frac{ITQ_{ij}}{B_i} \qquad [2]$$

With lower RFO values, the fishery is increasingly constrained by the quota management.

Statistical analyses

Non-linear regression model target species

We expect the effect of RFO on catchability to be non-linear over the entire parameter space, because the efficiency of a vessel for target species should decrease only below a particular threshold value. This threshold value (RFO_0) represents the point in relative fishing opportunity above which the catchability is independent of ITQ. Below this point, the vessels are assumed to be constrained by the ITQ and change their efficiency through changes in fishing behaviour. This is also referred to as the "strategic efficiency". A non-linear model would thus explain the effect of RFO on catchability better than a linear regression model. The non-linear regression model is built in two steps: the first step represents a linear regression model on log-transformed non-zero CPUE values. The estimate of stock biomass (survey or XSA data) is used as offset and the month as explanatory class variable:

$$^{10}\log(CPUE) = \mu + month_i + 1 \cdot {}^{10}\log(B) + \varepsilon_i \qquad [3]$$

Differences in catchability as a result of differences in RFO are thus part of the residuals of [3]. Subsequently, the effect of the RFO on the residuals is tested using non-linear regression. This was done using PROC NLIN in SAS (SAS Institute Inc. 1996). The non-linear model is segmented: i.e. for $RFO < RFO_0$, the equation relating y and RFO is quadratic (a parabola), while for $RFO \geq RFO_0$, the equation is constant (a horizontal line). The model thus has the form of:

$$Y = \begin{cases} \mu + \alpha \cdot RFO + \beta \cdot RFO^2 & \text{for RFO} < \text{RFO}_0 \\ p & \text{for RFO} \geq \text{RFO}_0 \end{cases} \qquad [4]$$

PROC NLIN is able to fit such a segmented model even when the joint point, RFO_0, is unknown. This is done by assuming that the curves are continuous (the two segments must meet at RFO_0), and smooth (the first derivatives are the same at RFO_0). These conditions imply that:

$$RFO_0 = \alpha / 2\beta \qquad [5]$$

and

$$p = \mu - \alpha^2 / 4\beta \qquad [6]$$

The segmented equation is thus defined by only three parameters. The Gauss-Newton iteration method was used for estimating the least squares approximation. Convergence was declared when the relative offset measure of Bates and Watts was smaller than 10^{-5} (Bates and Watts 1988). The significance level α was set to 0.05. The assumption of a normally distributed error term was tested by visual inspection of a probability plot of the residuals.

The analysis was applied to vessels combined. However, to distinguish between the catchability resulting from vessel characteristics (e.g. hull vintage, crew) and the catchability resulting from different ITQ constraints caused by year to year changes in the TAC, the non-linear model was also run for each ship separately.

Non-linear regression model non-target species

For non-target species a similar reasoning applied, because the effect of the RFO of target species is expected to have a non-linear effect on the efficiency for the non-target species dab, because the latter will level off above a particular threshold value. Thus the same model could be applied, but in this case the RFO applies to the target species, while Y applies to the non-target species.

Results

RFO

The calculated RFO for the Dutch beam trawl fleet based on BTS survey stock indices shows that the median RFO for plaice in the fleet segment fluctuated between years without a clear trend. The lowest median was observed in 1996, and the highest median in 1998. However, the fluctuation over the years was lower than the variation among individual vessels within a single year (Fig. 3a). The RFOs for sole increased from 1994 to 1995, and then slowly decreased until 2000. Also in this case, the variation among individual vessels was higher than fluctuations among years (Fig. 3b).

The RFO values for plaice calculated based on the XSA stock indices show a high in 1994 decreasing to 1999 with a local high during 1997 (Fig. 3c). The results for sole in indicate an increase during the first 4 years of the analysis, followed by a decrease from 1997 to 1999 (Fig. 3d).

Catchability target species

Plaice

The non-linear model indicates that RFO has a significant effect on the catchability for plaice based on the survey index (ANOVA, F=19.04, df=3,13198, $p<0.0001$) and the XSA index (ANOVA, F=123.18, df=3,11263, $p<0.0001$) (Table 2). The regression model explains 0.43% of the variance in the residuals from the initial linear model in case of the survey index and 3.18% in case of the XSA index. However, the form of the relationship between RFO and catchability is different for the two indices (Fig. 4). In the case of the BTS index the plateau value is reached at relatively low RFO values, suggesting that only 10.6% of all observations were affected by ITQ constraints. The difference in plaice catchability between the lowest RFO ($5.21 \cdot 10^{3}$) and RFO_0 ($1.28 \cdot 10^{4}$) (table 3) predicted by the model based on the BTS index is 44.17%.

In the case of the XSA index, the relationship between catchability and RFO does not reach a plateau, suggesting all catchability estimates are affected by constraining ITQs. The difference in plaice catchability between the lowest RFO ($3.30 \cdot 10^{-4}$) and the highest RFO ($2.70 \cdot 10^{-3}$) is as large as 77.9%. The distribution of the residuals was not different from normal.

Application of the non-linear model on individual vessels showed that the model did not have a significant effect for all vessels. 13 vessels showed convergence and had a significant effect in case of the BTS index, versus 29 in case of the XSA index out of the total of 43 vessels (Fig. 5). This way of incorporating vessels increases the explained variance to 10.2% (BTS) respectively 16.1% (XSA). Not all significant models predict an increasing efficiency at increasing RFO before reaching the plateau at RFO_0. The value for RFO_0 differs among the vessels, ranging from 13224 to 28425, in case of applying the BTS index. Thus, the estimates of the RFO_0 of individual vessels is higher than the RFO_0 value for the fleet as a whole. In contrast, the values of RFO_0 for individual vessels estimated using the XSA index, range from $4.29 \cdot 10^{-4}$ to $2.24 \cdot 10^{-3}$, which is lower than the RFO_0 for the fleet as a whole. For the BTS index, the values of RFO_0 and the plateau value of the significant models show no significant correlation (Pearson, r=0.206, df=11, p=0.499). In contrast, using the XSA index, these values do show a significant correlation (Pearson, r=0.391, df=27, p=0.036).

Sole

The non-linear effect of RFO for sole on sole catchability was significant either with the BTS index (ANOVA, F=321.78, df=3,13053, p<0.0001) or the XSA index (ANOVA, F=289.95, df=3,11130, p<0.0001) applied (table 2). The non-linear regression model explains 4.70 respectively 4.95 % of the variance in the residuals from the initial linear model. Trajectories of the relationship between RFO and catchability appear very similar for both indices and show a plateau (Fig 4). The plateau includes 3.7% of the observations in case of the BTS index and 6.4% in case of the XSA index. The difference in catchability between the vessels with lowest RFO and RFO_0 based on the model is calculated to be 82.7% in case of applying the BTS index and 85.4% in case of the XSA index. The distribution of the residuals appeared skewed to the left, as can also be seen in fig. 4 but were not considered to be non-normal.

Application of the non-linear model on individual vessels again showed that the RFO values did not have a significant effect for all vessels. Application of the BTS index resulted in 14 out 43 significant and converging models, while analyses using the XSA index resulted in 24 significant models. Again, the addition of vessels increases the explained variance, resulting in 12.7% explanation in case in the BTS index and 14.7% in case of the XSA index. The estimates of RFO_0 for each individual vessel lie within the same order of magnitude as the estimate for the fleet as a whole, ranging from $2.91 \cdot 10^4$ to $1.06 \cdot 10^5$ for the BTS index and $1.49 \cdot 10^{-3}$ to $6.74 \cdot 10^{-3}$ for the XSA index (Fig. 5) . Thus there is a difference in the amount of ITQ needed for unconstrained fishing among the individual vessels. The vessels also differ in the height of the plateau, indicating differences in maximum catchability and accessibility. The values for RFO_0 and the height of the plateau are correlated both in the case of applying the BTS index (Pearson, r=0.567, df=12, p=0.035) and the XSA index (Pearson, r=0.664, df=22, p<0.001).

Catchability non-target species

Because the analysis of sole gave a much more consistent answer to the effect of RFO on efficiency than the analysis of plaice, and the fact that sole is a much higher valued species than plaice, only sole RFO data were used to analyse the catchability for dab.

The non-linear model with the RFO for sole from the BTS index did not have a significant effect in predicting the catchability for Dab (ANOVA, F=1.97, df=3,5660, p=0.140) (Fig. 6a). If the analysis is applied to the individual vessels in the fleet, only 4 models have a significant effect, two of which showed a positive relation (Fig. 6b).

Discussion

The results indicate that the ITQ system adopted in the Netherlands has consequences for the efficiency of large beam trawl vessels. At the level of the fleet, a positive relation exists between the relative fishing opportunities and the efficiency for target species. The differences observed in plaice are much smaller than in sole, and the estimates of RFO_0 for plaice depend on the stock index applied. The non-linear model for plaice using the XSA stock index indicates that the positive relation between the size of the ITQ and the efficiency for plaice never reached a plateau. In contrast, the analysis using the survey stock index indicates that this plateau is reached at relatively low values of RFO.

The non-linear model used for sole suggests that the plateau for both stock indices is reached within the existing range of ITQ sizes. This suggests that not all vessels are restrained in all years, but are able to fully employ their efficiency at least in some years.

However, for individual vessels the response to RFO differs. In the case of plaice, the model may even predict a negative relationship between the RFO and catchability and this applies for both stock indices. The vessels differ with respect to the height of the plateau indicating differences in technical efficiency and accessibility, and to the RFO_0 values indicating that the vessels differ with respect to the constraining effects of quota management. The positive relation between height of the plateau and RFO_0 observed for the XSA index suggests that vessels with a high technical efficiency need more quota for unconstrained fishing.

In the case of sole, all significant models of individual vessels show a positive relation between the catchability and RFO before reaching a plateau. Again, differences in RFO_0 and plateau values exist among individual vessels, indicating differences in technical efficiency and accessibility, but the positive relation between RFO_0 and the plateau value is even stronger than for plaice: more efficient vessels need more quota to reach maximum catchability. Thus, our results emphasise the need to look at the level of individual vessels when considering fleet behaviour, because individual differences in response may be averaged out in fleet-wide analyses.

Despite the uncertainty in stock estimates, the results indicate that quota management for sole is more restrictive than for plaice, which is supported by the comparison of the trajectories of annual international catches and TACs, for these two stocks: the trajectories for sole are very similar, while for plaice the TACs for are higher than the realised catches in earlier years (Fig. 7)(van Wijk et al 1999; ICES 2001).

The changes in efficiency of individual vessels as a result of ITQ size can only have resulted from changes in fishing behaviour. Possible mechanisms underlying such changes may be:

1. High-grading. When the ITQ constraint for either target species is high, an incentive is created for discarding part of the catch for that species (Anderson 1994). To the fishery, these fish represent a loss of potential income (Gillis et al. 1995). To scientists, these discards are an unaccounted and fluctuating component of the catch, that causes increased uncertainty in estimates of stock abundance and fishing mortality (Pikitch 1991). When high-grading increases, fishing mortality (F) will be underestimated and biomass overestimated in the non-converged part of cohort analysis.
2. Spatial redistribution of effort. Assuming knowledge on the distribution of target and non-target species, fishermen might go to other fishing grounds with lower catch rates of target species and higher catch rates of non-target species such as turbot, brill and dab. Such redirection of effort among species has been observed in industrial fleets in Brittany (Millischer et al. 1999). This mechanism would also have important consequences for stock assessment using commercial catch rates, because it implies that effort for the target species is overestimated in years when

ITQs restrain the fleet. The ability to switch among species in the beam trawl fishery strongly depends on the spatial segregation of these species. If this condition is met, the incentive for directing effort towards the non-target species depends on the relative economic net revenue per unit of effort.

No relationship has been found between the catchability of dab and the RFO for sole, the target species that appears to be most restrictive and is most valuable in the beam trawl fishery. Thus there is no indication of switching from target species to non-target species. However, there are several other, higher valued flatfish species with pooled quota, which could not be analysed because of a lack of reliable stock indices and/or catch and effort data. Even for dab, the catch and effort data only span 3 years, and therefor the results may not be very conclusive.

Our results confirm that CPUE is not always a good measure of stock abundance because it is subject to fishermen's behaviour. This point has been put forward before for other behavioural mechanisms such as effort allocation according to the Ideal Free Distribution (Gillis and Peterman 1998), differences in travel time because of changes in fuel costs (Sampson 1991).

Although the signals in stock estimate derived from XSA analysis and the BTS survey show a strong similarity, the estimated RFO calculated from these indices show a distinct dissimilarity, especially for plaice. Efficiency estimates depend strongly on the accuracy of the stock index, because any deviation from the actual stock abundance is interpreted as a change in catchability in the statistical model. Stock indices are seldom fully accurate. In the case of XSA, the results depend on cohort analysis outputs, which exhibit divergence problems for recent years (ICES 2000). The stock index calculated from BTS survey data may deviate from the actual stock size, owing to its restricted sample size. Therefor, the results are indistinguishable with regard to their accuracy of predicting the actual relation between RFO and catchability. Rerunning the analysis using future stock estimates or survey data might change the outcome of our study, especially during the most recent years, but could also, under status quo fisheries management, make the results from our study more solid.

Another drawback of the method used is that q is assumed constant over all stock sizes. This however, may not be true, especially if the spatial distribution changes with stock abundance (Swain and Sinclair 1994).

Because we use a spatially implicit model (i.e. does not incorporate fishing grounds), we are not able to distinguish between the effect of technical efficiency and of accessibility on catchability. Designing a spatially explicit model would allow comparison among vessels within a fishing ground and estimating the effect of ITQ under the same local conditions. This might also help to explain the differences found among the vessels.

To conclude, the results show that quota management put constraints on catch efficiency of Dutch beam trawl vessels for at least part of the fleet, but the underlying behavioural mechanism of reducing efficiency remains unclear.

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Table 1. Input parameters in stock index from BTS survey. Parameters a and b refer to standard length-weight relation $W=a*L^b$.

Parameter	MLS (cm)	a	b
sole	24	0.0036	3.313
plaice	27	0.0082	3.260
dab	15	0.0074	3.113

Table 2. Analysis of variance table non-linear model

	Plaice					Sole				
Source	SS	df	MS	F	p	SS	df	MS	F	p
BTS stock index										
Regression	3.41	3	1.13	19.0	<.0001	54.98	3	18.33	321.8	<.0001
Residual	788.0	13198	0.060			1115.1	13053	0.085		
Uncorrected total	791.4	13201				1170.1	13056			
Corrected total	791.4	13200				1170.1	13055			
XSA stock index										
Regression	23.40	3	7.801	123.18	<.0001	52.22	3	17.41	290.0	<.0001
Residual	713.2	11263	0.063			1002.3	11130	0.090		
Uncorrected total	736.6	11266				1054.6	11133			
Corrected total	736.6	11265				1054.6	11132			

Table 3. Parameter estimates for non-linear model

	Plaice				Sole			
Parameter	estimate	se	-95 cl	+95 cl	estimate	se	-95 cl	+95 cl
BTS stock index								
μ	-0.451	0.110	-0.667	-0.236	-0.449	0.038	-0.515	-0.383
α	$7.1 \cdot 10^{-5}$	$2.3 \cdot 10^{-5}$	$2.6 \cdot 10^{-5}$	$1.16 \cdot 10^{-4}$	$1.5 \cdot 10^{-5}$	$1.41 \cdot 10^{-6}$	$1.2 \cdot 10^{-5}$	$1.7 \cdot 10^{-5}$
β	$-2.76 \cdot 10^{-9}$	$1.14 \cdot 10^{-9}$	$-5 \cdot 10^{-9}$	$5.27 \cdot 10^{-10}$	$-9.62 \cdot 10^{-11}$	$1.4 \cdot 10^{-11}$	$^{-}1.24 \cdot 10^{-10}$	$-6.89 \cdot 10^{-11}$
RFO_0	12821				75493			
P	$2.87 \cdot 10^{-3}$				$9.93 \cdot 10^{-2}$			
XSA stock index								
μ	-0.1734	0.184	-0.210	-0.137	-0.472	0.037	-0.544	-0.400
α	170.1	27.80	115.4	224.8	325.3	32.55	261.5	389.1
β	$-2.13 \cdot 10^{4}$	$1.00 \cdot 10^{4}$	$-4.09 \cdot 10^{4}$	$-1.66 \cdot 10^{3}$	$-4.66 \cdot 10^{4}$	$6.85 \cdot 10^{3}$	$-6.01 \cdot 10^{4}$	$-3.32 \cdot 10^{4}$
RFO_0	$3.99 \cdot 10^{-3}$				$3.49 \cdot 10^{-3}$			
P	$1.66 \cdot 10^{-1}$				$9.55 \cdot 10^{-2}$			

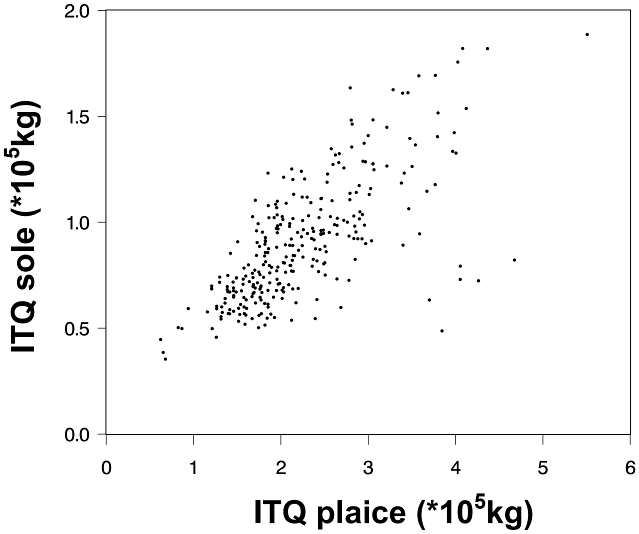

Fig. 1: ITQ for sole plotted versus the ITQ for plaice of beam trawl vessels with engine powers between 1990-2000 hp. Each diamond represents 1 vessel in 1 year.

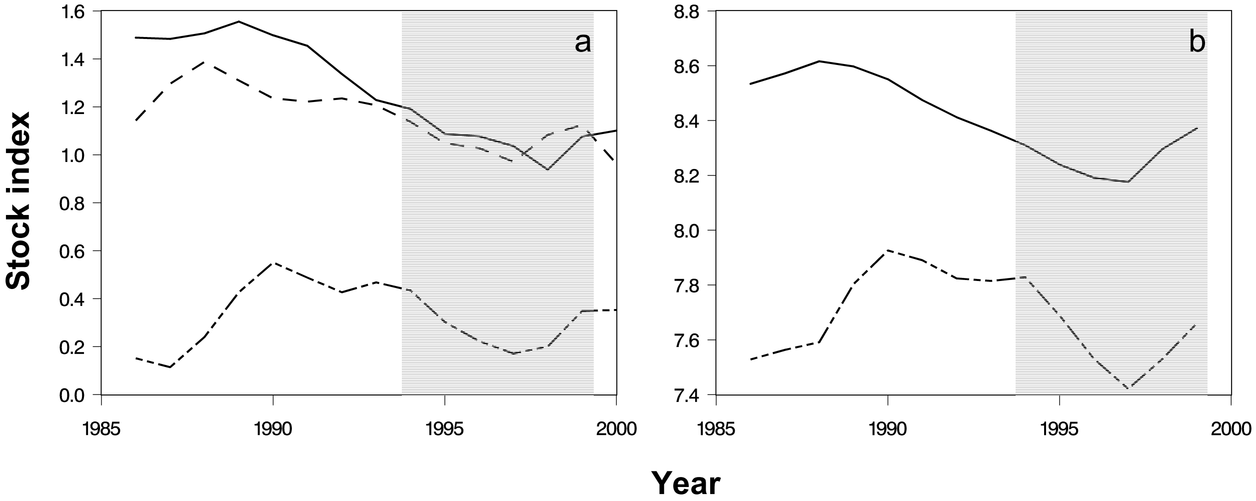

Fig.2: Stock index derived from BTS survey (a) and XSA analyses performed by the ICES working group on demersal stocks in the North Sea in 2001 (b).(——) Plaice, (— - - —) Sole and (— — — —) Dab. The shaded area represents the period during which analyses are applied.

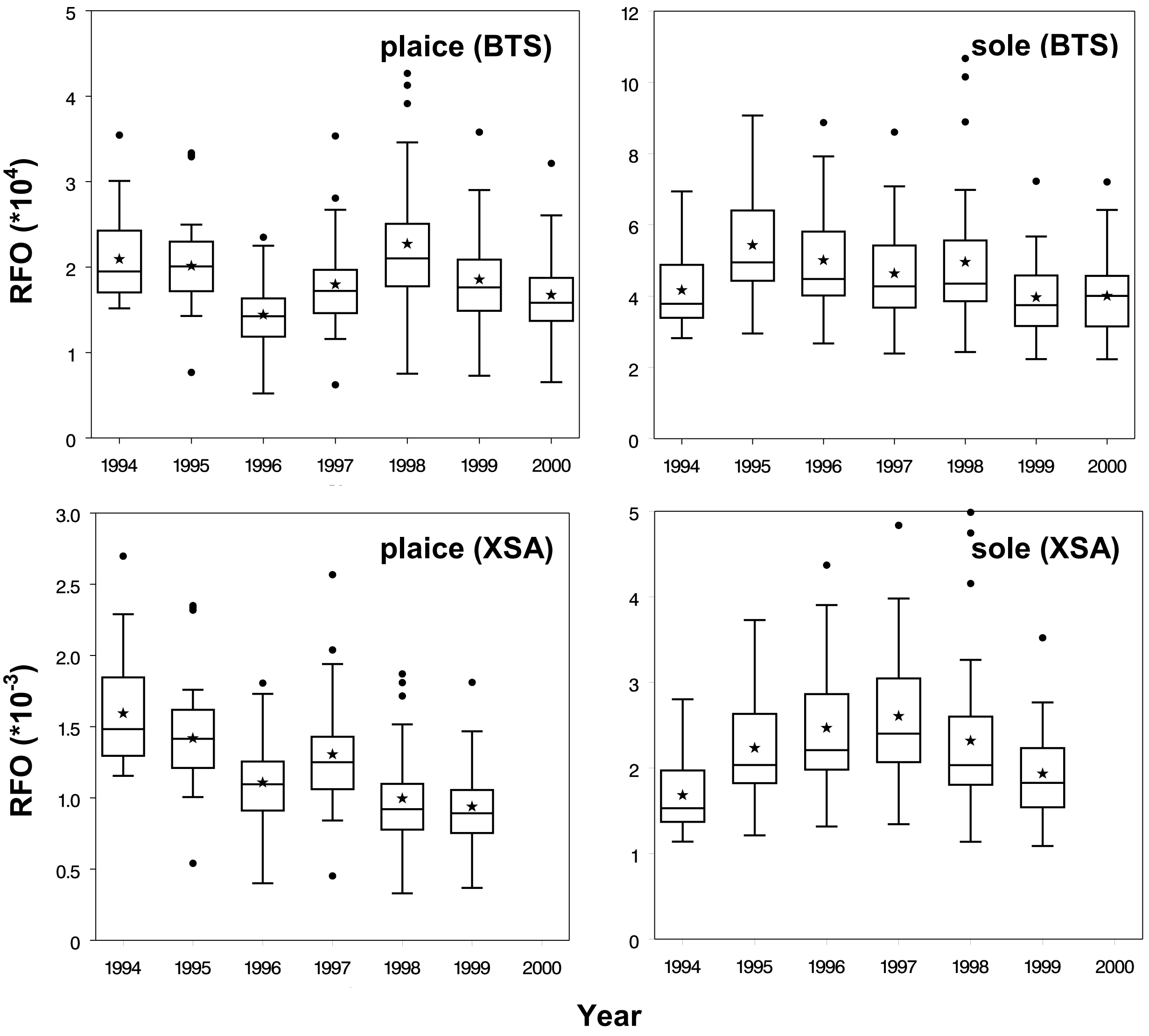

Fig. 3: Box and whiskers plot of Relative Fishing Opportunities over time for plaice and sole using BTS stock index and XSA stock index. Means (*),medians, quartiles and outliers (●) are given for the 1990-2000 hp engine class.

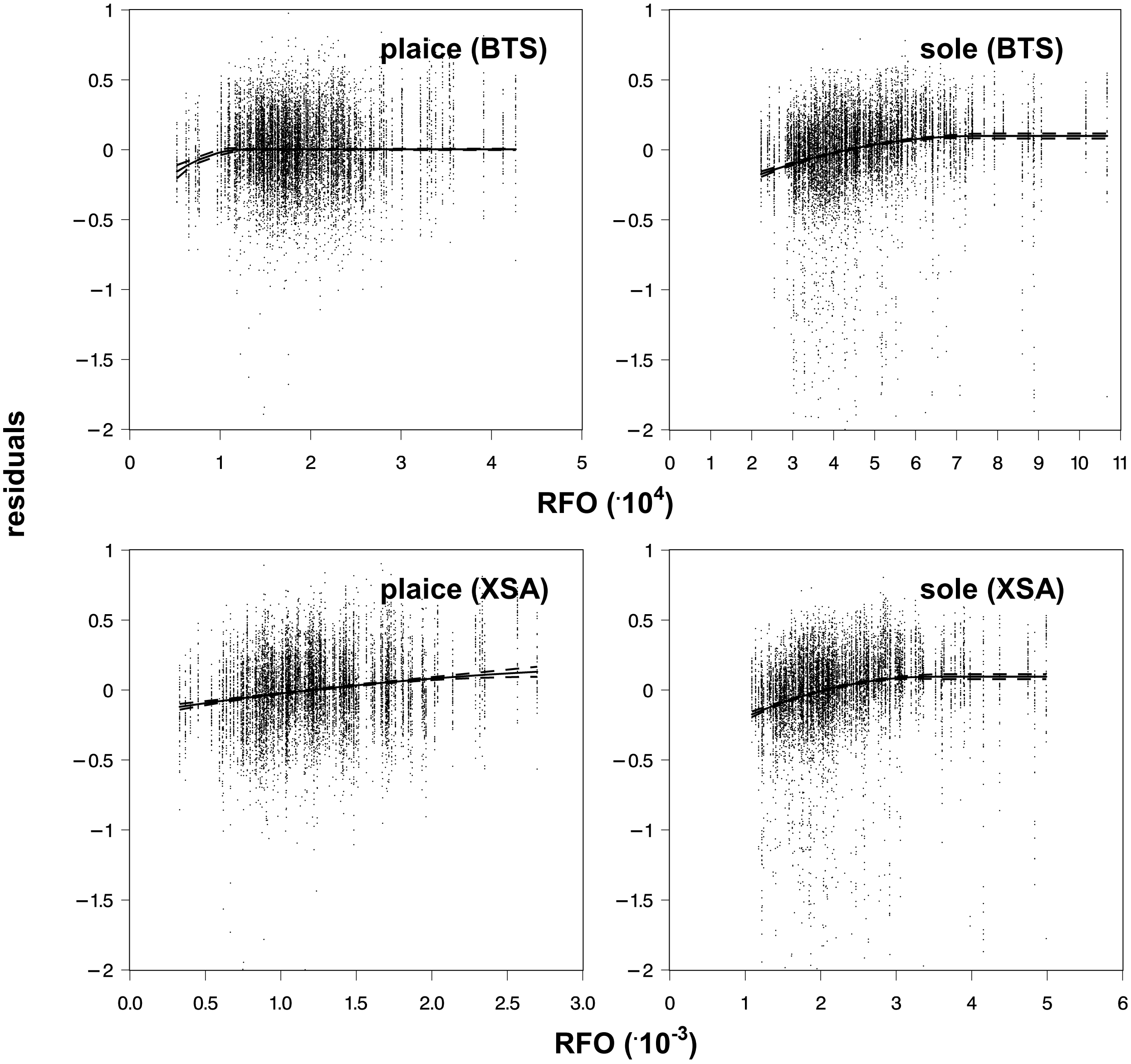

Fig. 4: Observed $^{10}Log(q)$ and the non-linear model prediction of the effect of relative fishing opportunities for plaice and sole using the BTS index and the XSA index. Each dot represents the standardised catchability per trip. Drawn lines represent model predictions and broken lines represent 95% confidence limits of the model.

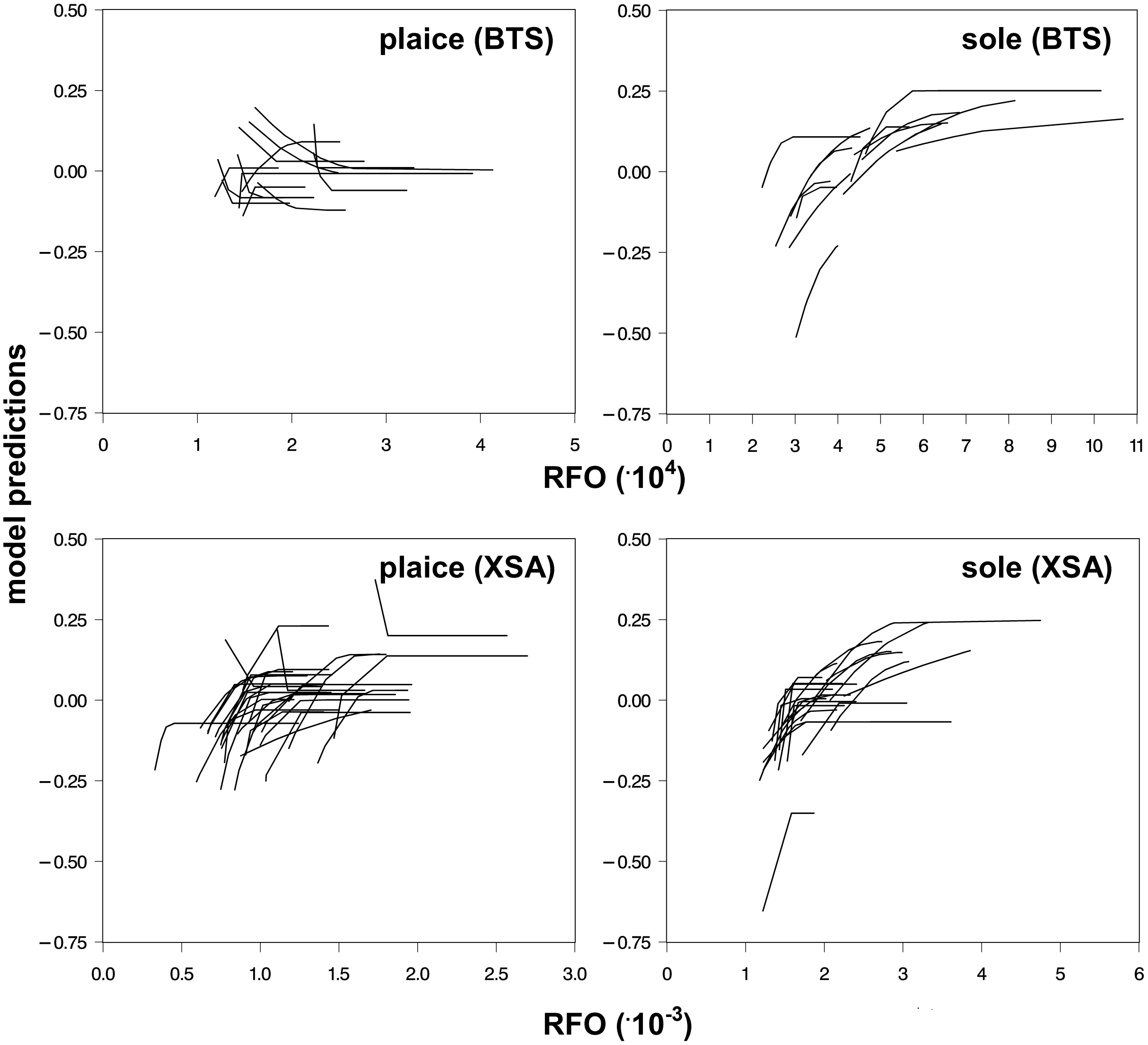

Fig. 5: Observed $^{10}Log(q)$ and the non-linear model prediction of the effect of relative fishing opportunities for plaice and sole tested for individual vessels. Each line represents the predicted values of a significant non-linear model on the residual of the General model.

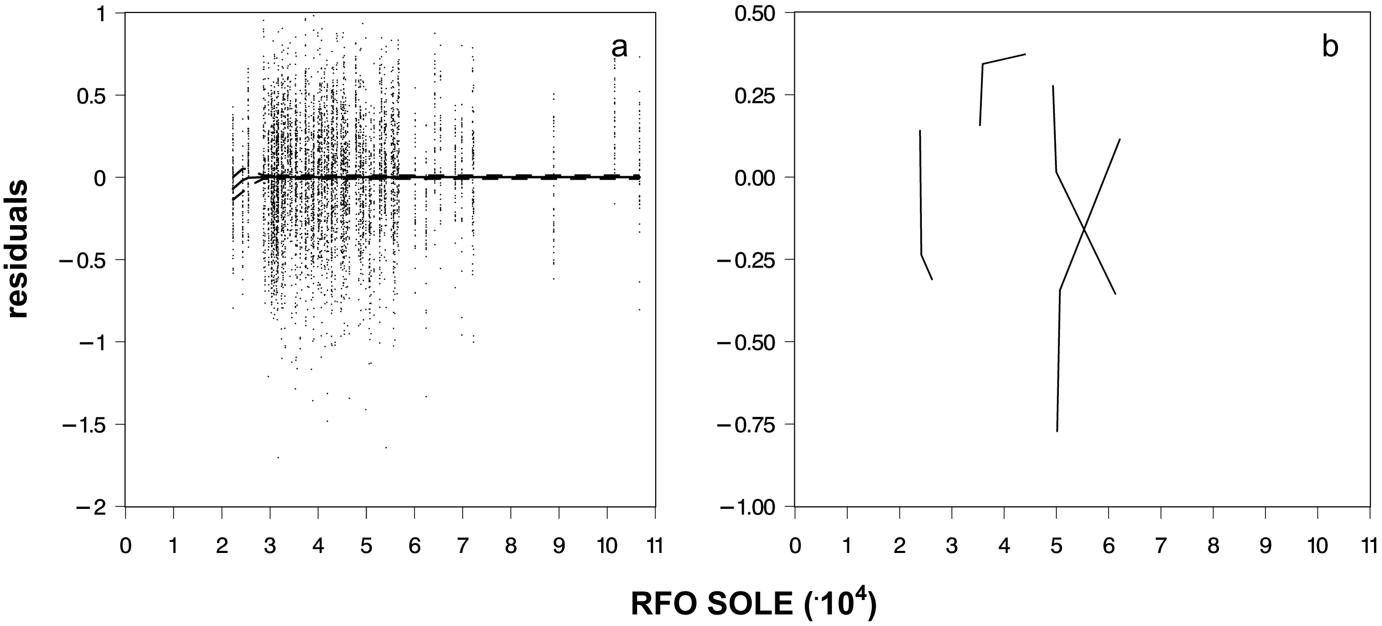

Fig. 6: a) Observed ^{10}Log(q) and the non-linear model prediction of the effect of the RFO for sole on the residuals from the General Model of dab CPUE. Each dot represents the standardised catchability per trip. Drawn line represent model predictions and broken lines represent 95% confidence limits of the model. b) Observed ^{10}Log(q) and the non-linear model prediction of the effect of the RFO for sole on the residuals from the General Model of dab CPUE tested per individual vessel. Drawn lines represent significant models.

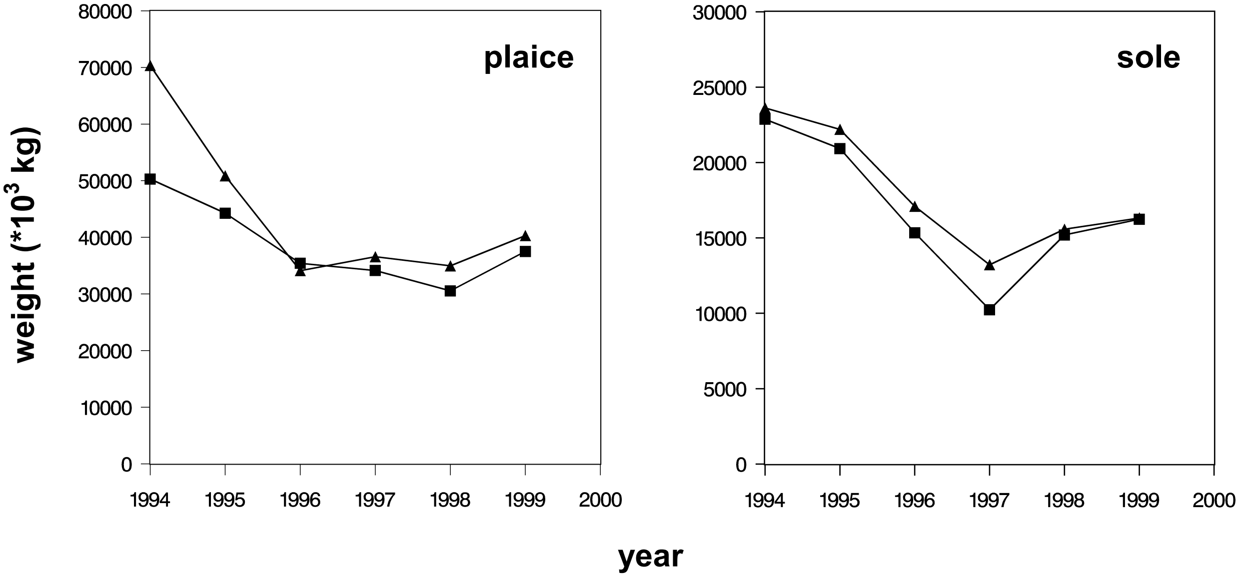

Fig. 7: Time series of Dutch landings (■) and fishing rights (▲) in ICES area IV for plaice and sole. Sources: (van Wijk et al. 1999; ICES 2001)