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Review

Standardizing commercial CPUE data in monitoring stock dynamics: Accounting for targeting behaviour in mixed fisheries

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Abstract

Catch per unit effort (CPUE) is commonly used as an indicator for monitoring developments in stock size. To ensure proportionality between average CPUE and total stock size, two processes that should be accounted for are the degree of targeting behaviour of the fleet and the management-induced responses in fishing behaviour. We studied the effect of restrictive individual quotas and targeting behaviour on average CPUE in the Dutch beam trawl fleet. Fishing opportunities varied in time and across species due to changes in quotas. Using catch and effort data by fishing trip of the total fleet and haul-by-haul data from a reference fleet, targeting behaviour of the beam trawl fleet was quantified for sole and plaice, at various space and time scales. Sole was targeted on all scales examined, whereas plaice was only targeted on a micro-scale of 10 × 10 nautical miles. When sole quota restrictions were relaxed, the fleet increasingly targeted sole instead of plaice. Targeting indices for sole and plaice were negatively correlated. Our findings indicate that catch and effort data by fishing trip are sufficient to characterise targeting behaviour on a macro-scale, whereas haul-by-haul data are needed to quantify the targeting on a micro-scale (30 × 30 nautical miles). The micro-scale targeting index can be used to standardize macro-scale CPUE data for bias due to variations in directed fishing among local fishing grounds.

Keywords: Catch; Effort; Plaice; Sole; Beam trawl; North Sea; Fisheries management

Contents

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1. Introduction

Catch and effort data of commercial fisheries can be an important source of information on trends in stock biomass. Time series of catch-rate (CPUE, catch per unit of fishing effort) are used to calibrate stock assessments which support the science-based management (Biseau, 1998; Laurec and Shepherd, 1983; Maunder and Punt, 2004; Pope and Shepherd, 1985). Moreover, they contribute to a common ground in discussions between fishers, fisheries managers and fisheries scientists on the state of the stock.

Changes in commercial catch-rates may not always reflect true changes in the fisheries resource (Walters, 2003). A bias in the CPUE time series as a biomass indicator may result in mismanagement of the fishery and in miscommunication between stakeholders. Bias in time series of commercial CPUE of marketable fish may be caused by several factors. Firstly, gear efficiency may increase due to technological innovations and improved skills of the crew (Marchal et al., 2002; Rijnsdorp et al., 2006; Salthaug, 2001). Because of increasing efficiency, a measure of effort presently used as a standard may not easily be compared with the same measure of effort 10 years ago. Secondly, there can be changes in the spatial distribution of target species. Spatial distribution may contract with declining population biomass, without affecting the fish densities in the core habitat of the species (Rose and Kulka, 1999). When fishers are mainly fishing these core habitats, contraction of the spatial distribution will result in a 'hyper stability' of the catch-rate (Harley et al., 2001; Hilborn and Walters, 1992; Paloheimo and Dickie, 1964). The opposite, 'hyper depletion', may also occur when CPUE decreases at a faster rate than abundance (Hilborn and Walters, 1992). An example of hyper depletion is when interference competition among fishing vessels results in decreasing catch-rates (Gillis and Peterman, 1998). Thirdly, environmental conditions can influence the catchability of target species, either through a change in the degree of concentration of a species; or through a change in the escape probability; or both (Horwood and Millner, 1998). Fourthly, discarding of marketable fish may bias CPUE, for instance if quotas are not sufficient to land all the fish caught (Anderson, 1994; Daan, 1997). Finally, a fleet may change its targeting behaviour, i.e. the extent to which a certain species is targeted or avoided. Targeting behaviour is reflected in the spatial distribution of the fleet relative to that of the fish stock. As fishing fleets tend to concentrate their effort in areas of high density of a target species, changes in spatial distribution of the fleet relative to that of a fish stock will result in changes in catchability, which lead to a biased perception of changes in stock size. This may be particularly relevant in the case of mixed fisheries where changes in market conditions, costs of fishing, or management measures (Dinmore et al., 2003; Poos et al., 2001) may result in changes in targeting behaviour of fishers.

The objectives of this paper are to (i) investigate targeting behaviour of the Dutch beam trawl fleet engaged in a mixed fishery, targeting flatfishes sole (*Solea solea* L.) and plaice (*Pleuronectes platessa* L.) and (ii) improve commercial CPUE as an estimate of the population biomass. Changes in targeting behaviour were analysed in relation to changes in the management regime, in particular the changes in annual quotas. Targeting behaviour was investigated on different temporal scales (week and month) and spatial scales: ca. 100 × 100; ca. 30 × 30 and ca. 10 × 10 nautical miles.

Table 1
Average annual catch per species (tonnes) per area (Fig. 1) and average prices per species (based on the period 2000–2004)

	North	Mid-east	Mid-west	South	Total	Average price
Sole	8	236	63	325	632	8.99
Plaice	95	565	246	531	1437	1.87
Other	4	32	11	52	99	4.25

2. Material

2.1. Beam trawl fleet

The Dutch beam trawl fleet consists of ca. 250 vessels and can be divided in two components: euro cutters with engine powers less than 221 kW, and large cutters, with engine powers of around 1471 kW. These large cutters are the subject of the analyses in this paper.

Target species of the beam trawl fleet are sole and plaice; by-catch species are turbot, brill, dab, cod and whiting (Daan, 1997). The importance of sole, plaice and by-catch species for large cutters is presented in Table 1. The two target species differ in their spatial distribution: sole is restricted to the south-eastern North Sea, plaice is distributed throughout the southern and central North Sea (Rijnsdorp and Van Beek, 1991; Rijnsdorp et al., 2006).

Most of the year-round fishing activity takes place south of 55°N latitude, the main distribution area of sole, where a minimum mesh size of 80 mm is allowed. In the area north of 55°N latitude the fishery uses a minimum mesh size of 100 mm and mainly catches plaice. In 2000 the border of the 100 mm area east of 5°E longitude was shifted to 56°N latitude. Large cutters are not allowed to fish within 12 nautical miles off the coast or in the main nursery ground of 0-group plaice: the Plaice box (Pastoors et al., 2000) (Fig. 1).

Landings of the beam trawl fleet are regulated by individual transferable quotas (ITQs) for sole and plaice, and national quotas for by-catch species (Daan, 1997). Since 2002 the EU has imposed an effort regulation restricting the number of days at sea (Anon., 2002).

2.2. Data availability

Fishing trip data from EU logbooks, comprising landed weight per species; fishing gear; fishing effort in days at sea by ICES rectangle (ca. 30 × 30 nautical miles); and ship identity code, are used from the period 1990–2004. Data from individual hauls are available from a sample of the fleet since 1993 (Rijnsdorp et al., 1998), comprising time and position of shooting and hauling the gear and catch weights of marketable plaice and sole. Table 2 gives an overview of the data used.

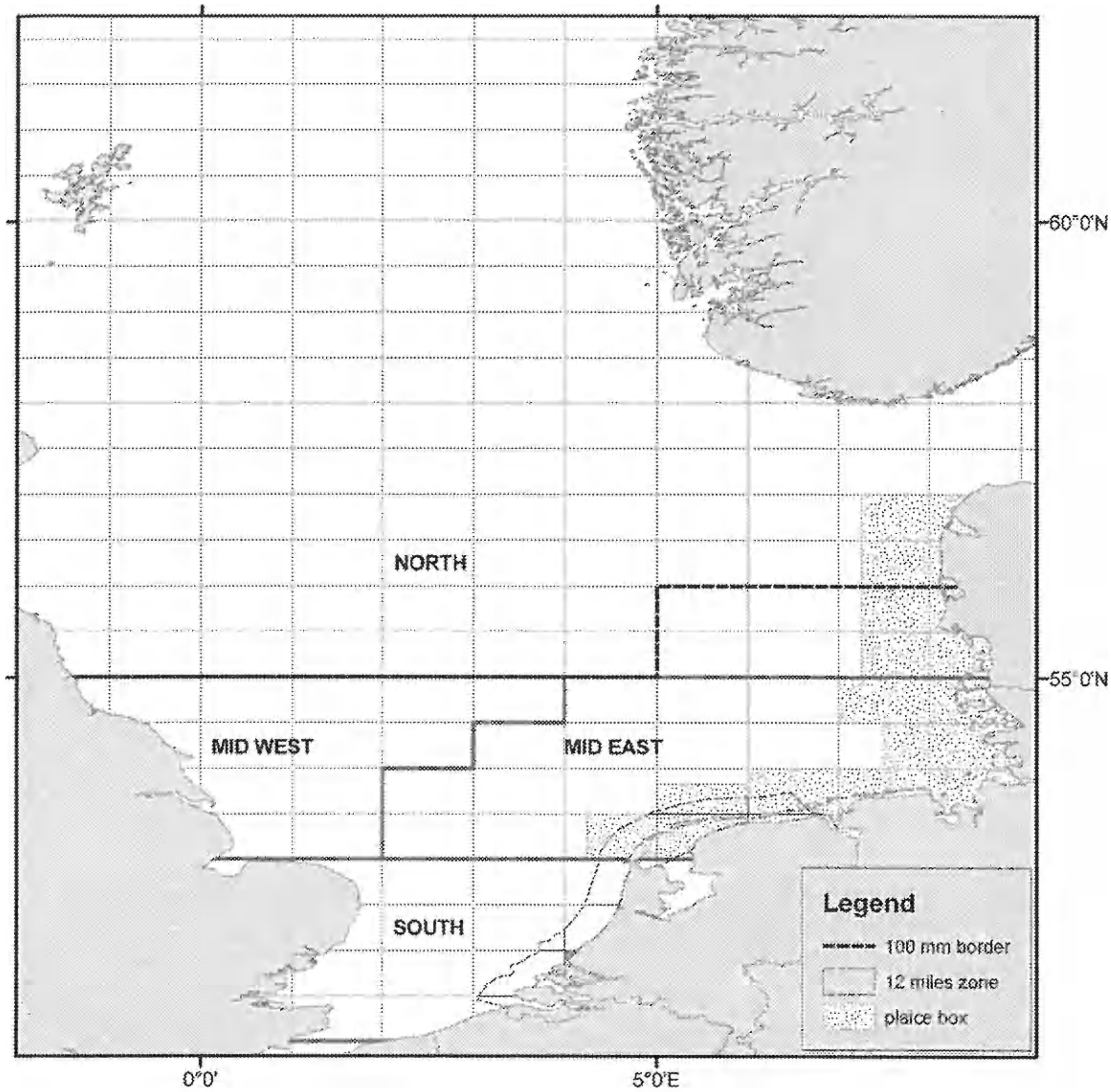

Fig. 1. North Sea map. The dotted area is the plaice box; the thick black dashed line is the border between the 80 mm mesh size area (south) and 100 mm mesh size area (north); the thin dashed line is the border of the 12-miles zone. The grid shows ICES rectangles and the thick grey lines show the borders between areas north, south, mid-east and mid-west.

3. Methods

3.1. CPUE

CPUE of beam trawlers is strongly affected by the engine power of the vessel (Rijnsdorp et al., 2000a). Data were standardized to a vessel of 1471 kW by applying the estimated relationship for this fleet from Rijnsdorp et al. (2006):

$$\mathrm{CPUE} = \frac{C}{E \times \mathrm{kW}^{\beta}/1471^{\beta}} \quad (1)$$

where C is the catch in kg; E the effort in days at sea; kW the engine power in kW; and β is a constant with value 0.8089 for sole and 0.5162 for plaice.

3.2. Micro-scale distribution of sole and plaice

The existence of variation in catch composition of sole and plaice within ICES rectangles is a pre-requisite for targeting behaviour on a micro-scale. Information on the relative micro-scale distribution of sole and plaice within a week can be obtained from comparison of catch composition in relation to distance between hauls. Catch composition was expressed as the proportion of sole in the catch (P_S), which was calculated through:

$$P_S = \frac{C_S}{C_S + C_P} \quad (2)$$

where C_S is the sole catch and C_P is the plaice catch.

An arcsin-transformation was used to normalise the proportion of sole in the catch between pairs of hauls. Differences in

Table 2
Overview of the data on large (ca. 1471 kW) beam trawl vessels analysed in this study

Year	Macro-/medium-scale		Micro-scale		
	Ships	Trips	Ships	Trips	Hauls
1990	238	8093	0	0	0
1991	222	7791	0	0	0
1992	206	7735	0	0	0
1993	202	7997	10	68	1559
1994	201	8376	6	71	1665
1995	208	8392	9	143	3511
1996	192	7176	11	245	5955
1997	213	8041	15	332	8274
1998	195	7902	8	124	2764
1999	164	6923	13	211	4869
2000	158	6793	10	186	4105
2001	156	6527	10	324	7457
2002	151	6123	15	109	2921
2003	140	5630	14	245	6341
2004	133	5478	14	247	5882

Macro- and medium-scale data are derived from EU logbooks containing catch and effort by vessel, trip and ICES rectangle. Micro-scale data are derived from private logbooks containing haul-by-haul data.

arcsin-transformed proportion of sole in the catch were related to distance between hauls using the variogram procedure in SAS (SAS Institute Inc., 2006).

3.3. *Relative fishing opportunity*

Quota restrictions for sole and plaice may vary from year to year due to variations in political choices and the level at which stock size is over- or under-estimated. A relative fishing opportunity (RFO) index was calculated as a measure for quota constraint of the fleet. It is defined as average quota per vessel (with Q as the Dutch quota and n as the number of Dutch vessels), divided by spawning stock biomass on 1 July (SSB):

$$\mathrm{RFO} = \frac{Q/n}{\mathrm{SSB}} \quad (3)$$

Hence, fishing opportunity will decrease if quotas are reduced at a given stock biomass, or if stock biomass is under-estimated.

3.4. *Targeting index*

The targeting index was calculated following Gulland (1955):

$$I = \frac{\overline{\mathrm{CPUE}}}{\sum(\mathrm{CPUE}_{ij})/N_{ij}} \quad (4)$$

where $\overline{\mathrm{CPUE}}$ is the average catch-rate over all observations; CPUE_{ij} the average catch-rate in spatial unit i and time step j; and N_{ij} is the number of spatial units. The nominator represents the average catch-rate of the fleet given its realised distribution. The denominator, $\sum(\mathrm{CPUE}_{ij})/N_{ij}$, represents the average catch-rate if the fleet would fish at random. A targeting index $I = 1$ thus reflects random fishing, while an index $I > 1$ reflects targeting, and an index $I < 1$ reflects avoidance of a species.

The scope for targeting, that depends on the heterogeneity in the distribution of the fisheries resource, was estimated from the observed maximum and minimum targeting index:

$$I_{\mathrm{M}} = \frac{\mathrm{CPUE_M}}{\sum(\mathrm{CPUE}_{ij})/N_{ij}} \quad (5)$$

where the $\mathrm{CPUE_M}$ is either the maximum or minimum CPUE_{ij} observed. Maximum and minimum values were averaged over the total time period. The range of potential values indicates the scope for targeting behaviour, by selecting fishing grounds with either a high or a low catch-rate.

After standardizing the targeting indices to the mean of the study period, the targeting index for each species I_i was related to the index for the other target species I_j and to the RFO for both target species, by means of a generalised linear model:

$$I_i = I_j + \mathrm{RFO}_i + \mathrm{RFO}_j + \mathrm{error} \quad (6)$$

3.5. *Spatial and temporal resolutions*

The targeting index was estimated on a macro-, medium- and micro-scale (Table 3). Both for the macro and medium scale, EU logbook data were used, whereas for the micro-scale, haul-by-haul data were used.

On the macro-scale, four fishing areas were distinguished (Fig. 1), that show differences in catches of sole and plaice (Table 1). The sizes of these areas are approximately 100 × 100 nautical miles (nmi). Targeting was determined by month. On the medium-scale, targeting was determined for ICES rectangles (0.5° latitude and 1° longitude: ca. 30 × 30 nmi) and by month. On the micro-scale targeting was estimated on a scale of ca. 10 × 10 nmi and with weekly time steps. Each haul was assigned to a 10 × 10 nmi sub-square. The choice of the distance of 10 nmi for the sub-squares is supported by the length of an average haul by a beam trawler (Rijnsdorp et al., 2000b). For each sub-square, the weekly average CPUE was calculated for sole and plaice.

Table 3
Spatial scales of CPUE used in the targeting index ($\sum(\mathrm{CPUE}_{ijk})/N_{ij}$)

Scale	Observation	Time step (j)	Small scale spatial unit (i)	Large scale spatial unit
Macro	CPUE by trip	Month	4 areas (Fig. 1)	North Sea
Medium	CPUE by trip	Month	ICES rectangles	North Sea
Micro	CPUE by haul	Week	10 × 10 nautical miles squares	ICES rectangle

3.6. Data selection

Trips longer than 1 week were excluded from the macro-scale analyses. Inclusion could bias the catch-rate estimate, because it is unknown whether vessels continue fishing on Sunday. In the macro- and medium-scale analyses all trips within ICES Area IV were included. In the micro-scale analyses all hauls in the 80 mm mesh-size area were included, i.e. south of 55°N latitude.

Thresholds for the minimum number of observations per spatial and temporal unit were set as follows. In the micro-scale analyses only rectangles with at least 5 out of 9 sub-squares containing information of 2 or more hauls per week were included. In the macro-scale analyses only rectangles that were fished during at least 2 trips in each month were included.

4. Results

4.1. Micro-scale distribution of sole and plaice

A pre-requisite for targeting behaviour on a micro-scale is variation in catch composition of sole and plaice within ICES rectangles. Differences in catch composition between hauls in relation to the inter-haul distance were used to study micro-scale differences in distribution of sole and plaice below 55°N latitude. A scatter plot of individual observations (Fig. 2) shows that catch composition is highly variable, even at small distances within an ICES rectangle (30 nmi). Catch composition data were arcsin transformed to normalise the distribution. To help interpreting differences in catch composition, the observations were expressed both as arcsin-transformed data and as a back-transformed percentage difference. This is acceptable since 90% of the observations fell within the range where the relationship of arcsin-transformed proportions is almost linear (20–70°). The median of the differences in the percentage of sole increases from 5% at zero distance to 14% at 30 nautical mile distance, whereas the 75 percentile increases from 10% to 24%

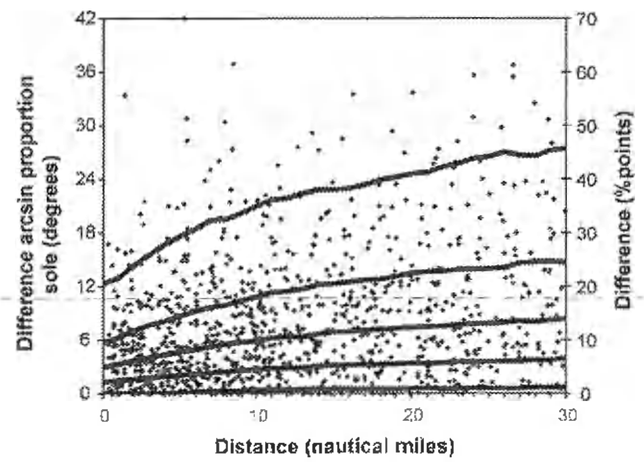

Fig. 2. Relation between difference in catch composition (proportion of sole in the catch) with distance between hauls. From top to bottom the heavy lines show the 95, 75, 50, 25 and 5 percentile of the distribution. The difference in catch composition was expressed as arcsin-transformed proportions (left hand Y axis) and percent-points (right-hand Y-axis).

Table 4
Spatial difference in the catch-rate at three levels of resolution reflecting the scope for targeting behaviour of the fleet when fishing for sole and plaice

Species	Resolution	N	Minimum, mean (standard deviation)	Maximum, mean (standard deviation)
Sole	Macro	179	0.31 (0.21)	1.28 (0.16)
	Medium	179	0.06 (0.12)	1.84 (0.59)
	Micro	472	0.60 (0.15)	1.40 (0.28)
Plaice	Macro	180	0.73 (0.13)	1.72 (0.42)
	Medium	180	0.36 (0.13)	2.53 (0.76)
	Micro	472	0.53 (0.20)	1.63 (0.59)

and the 95 percentile from 20% to 46% (Fig. 2). These results show that substantial differences in catch composition can be obtained within an ICES rectangle.

4.2. Relative fishing opportunity (RFO)

The RFO for sole increases from about 1 in 1990 to about 3 in 2002 and decreases to about 2.4 in 2004 (Fig. 3, left). The RFO for plaice varies around 1 with temporary peaks of 1.8 in 1994 and 1.4 in 1999 (Fig. 3, right).

4.3. Targeting index

Analysis of mean catch-rates in different areas showed a substantial heterogeneity in both species. Areas with best catches had catch-rates which were 2–30 times higher than in areas with lowest catch-rates (Table 4). The spatial heterogeneity in catch-rates occurred on all resolutions examined but was highest at the medium level of the ICES rectangle.

The targeting indices reveal that the fleet targets sole more strongly than plaice (Fig. 4). The targeting index for sole is above 1 at all resolutions, while that for plaice is below 1 on the macro- and medium-scale, but above 1 on a micro-scale. For sole, the targeting index is relatively close to the maximum index (Table 4). The results show that on the level of fishing area, reflected by the macro and medium scale, the fleet chooses to exploit areas with a high catch-rate of sole and a low catch-rate of plaice, whereas on the micro-scale of the ICES rectangle, the fleet selects fishing grounds with an above average catch-rate of both sole and plaice.

Most variation in the index between years is found on macro- and medium-scale, where the coefficient of variation for sole was 2.8% (macro) and 5.4% (medium) and for plaice 6.4% (macro) and 4.8% (medium). The variation between years in the index on micro-scale is less, with a coefficient of variation of 1.7% for sole and 2.3% for plaice.

The micro-scale targeting index for plaice is the only index showing a significant, positive correlation with RFO ($P < 0.05$). The other indices do not show any significant correlation with RFO. The indices for sole and plaice are negatively correlated (Table 5). Sole RFO shows a negative relation with the plaice-targeting index, which indicates that when fishing opportunities for sole improve, the fleet decreasingly targets plaice. RFO of sole and plaice do not show a significant effect on the sole index.

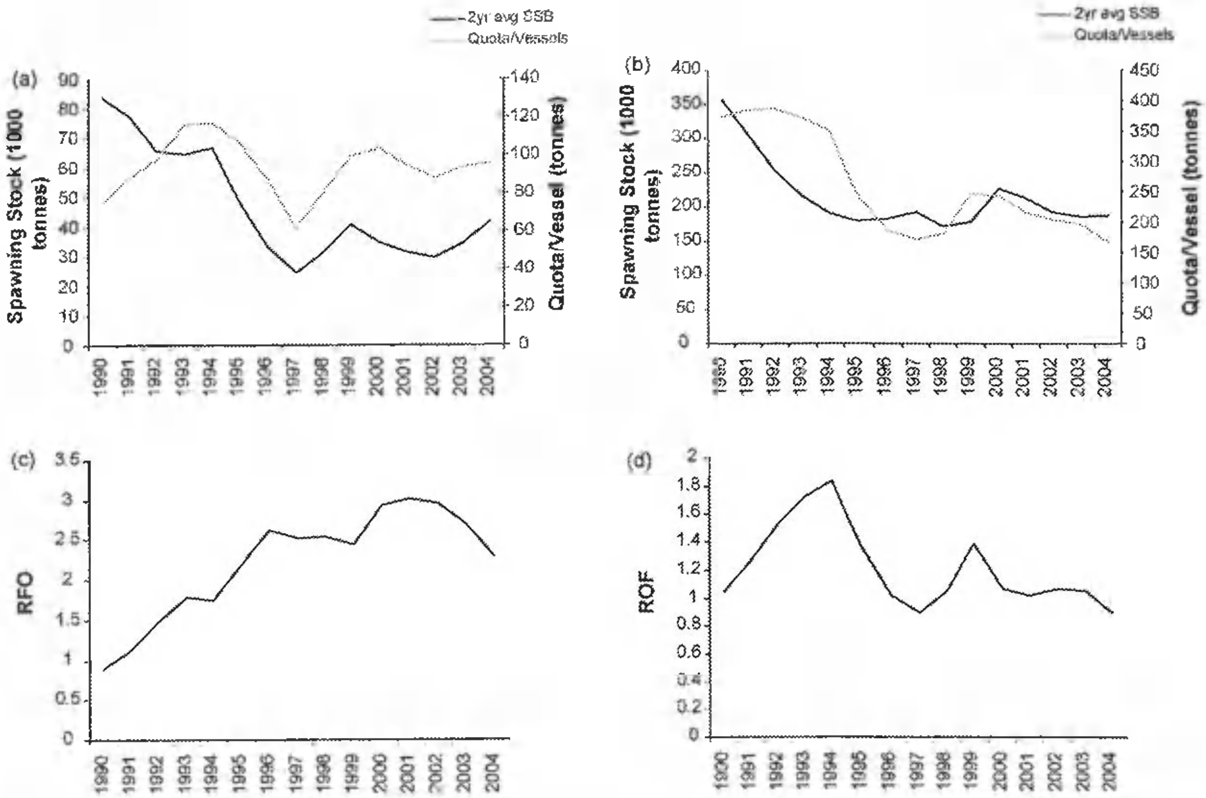

Fig. 3. Dutch quotas per vessel, 2-year running average of the spawning stock biomass (SSB) and relative fishing opportunity (RFO): (a) sole stock and SSB; (b) plaice stock and SSB; (c) sole RFO; and (d) plaice RFO.

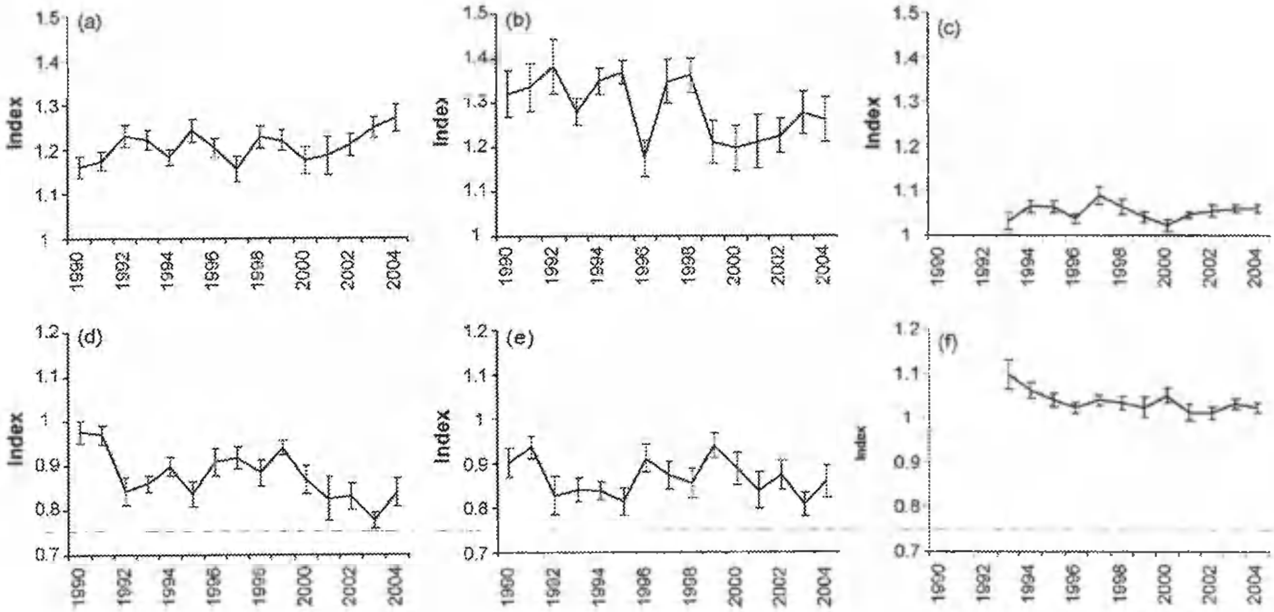

Fig. 4. Index for targeting behaviour on sole (a–c) and plaice (d–f) from 1993 to 2004. The error bars represent standard errors. Presented for different scales: macro (a, d), medium (b, e) and micro (c, f).

5. Discussion

Our study showed that the large cutters of the Dutch beam trawl fleet targeted sole and plaice. Targeting behaviour of the fleet was measurable at different spatial scales. The fleet targets sole on all scales examined, whereas it only targets plaice on the micro-scale. The fleet can switch between target species, which can be concluded from the negative correlation between target-

Table 5
Results of the analysis of co-variance of (a) the targeting indices of sole (I_{sole}) and (b) the targeting index of plaice (I_{plaice}) in relation to the targeting index of the other species; the relative fishing opportunities for sole (RFO sole) and plaice (RFO plaice)

Parameter estimates	Explained (%)	d.f.	Estimate	S.E.	*P*
(a) Sole					
Intercept		1	0.0052	0.044	NS
I_{plaice}	42	1	−0.419	0.111	<0.0001
RFO sole	6	1	−0.0346	0.023	NS
RFO plaice	4	1	0.0300	0.025	NS
(b) Plaice					
Intercept		1	0.0908	0.053	NS
I_{sole}	25	1	−0.652	0.172	<0.001
RFO plaice	0	1	−0.0062	0.0311	NS
RFO sole	16	1	−0.0811	0.0268	<0.01

ing indices of sole and plaice. The fleet increasingly targeted sole instead of plaice when fishing opportunities for sole were relatively high.

The observed targeting on the different scales reflects different aspects of location choice of fishers. On the macro-scale (>100 nmi), fishers have to choose between fishing areas where the abundance of target species will differ in a predictable manner due to differences in habitat choice and seasonal dynamics of the species (Rijnsdorp and Van Beek, 1991). The choice of fishing areas may put particular constraints on the rigging of the gear (mesh size, number of tickler chains, type of ground rope). On the medium- and micro-scale, fishers have the problem of how to find local concentrations of the target fish species. It has been shown previously that beam trawlers perform hauls of approximately 2 h; covering a distance of 10–12 nmi per haul; and tend to stay put on a local fishing ground by changing the course after each haul if catch-rate is high (Rijnsdorp et al., 2000a,b). Using geostatistical techniques, it has been shown that the local concentrations were generally smaller than 20–40 nmi and persisted for up to 2 weeks (Poos and Rijnsdorp, 2007b).

This paper estimated variations in targeting behaviour of the fleet, seasonal and spatial dynamics of the species as well as of the fishing fleets. Aggregating commercial catch-rates at the level of ICES rectangles and in time periods of a month, means that changes in spatial patterns on the macro- and medium-scale are adequately accounted for and produce a time series that is not affected by changes in the distribution of the fishing fleet relative to that of the fisheries resource. However, the fact that beam trawl fishers exploit local fishing grounds on the micro-scale within an ICES rectangle implies that high-resolution data (10 × 10 nmi, 1 week) are needed to quantify the inter-annual variations in targeting and its effect on CPUE. In the time period studied, the micro-indices showed only modest inter-annual variations that were not significantly related to quota constraints. This suggests that the bias introduced by ignoring the micro-scale targeting, will not have a significant effect on the CPUE time series. However, the small sample size of the fleet for which micro-scale data were available (<20% of the Dutch fleet) may have reduced the power of the statistical test. The wide range of potential index values on the micro-scale, suggest that scope for targeting (or avoidance) behaviour may be large. This implies that under different constraints variations in micro-scale targeting may bias the CPUE index for stock biomass in the future. Collection of more comprehensive data on the catch-rate by individual tows in conjunction with the obligatory recording of fishing locations (Vessel Monitoring System), is important to assess the quality of the CPUE time series on stock biomass, and may provide data to correct CPUE time series for variations in micro-scale targeting.

Other factors that may cause bias in CPUE: increasing efficiency of the fleet, vessel interactions and high-grading need to be estimated separately. The increase in efficiency can be readily estimated from the time series of catch and effort data (Marchal et al., 2002) and was estimated to be 2.8% and 1.6% per year in the period 1990–2004 for sole and plaice, respectively (Rijnsdorp et al., 2006). Vessel interactions that reduce the catch-rate with increasing density of fishing vessels may be more difficult to analyse (Gillis, 2003), although Poos and Rijnsdorp (2007a) provided evidence for interference competition in the Dutch beam trawl fleet and estimated that a doubling of the vessel density within an ICES rectangle would reduce the catch-rate by approximately 10%. Discarding or non-reporting of a part of the catch of marketable fish will bias CPUE and may have a similar effect as the re-directing of fishing effort to a fishing ground with a lower catch-rate. Hence, the targeting index developed may partly reflect variations in high-grading, or misreporting of catches. In the Dutch beam trawl fleet misreporting is considered to be negligible, but high-grading may occur under certain circumstances (Quirijns, own observations). It is unlikely that these factors have influenced our conclusions.

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