Correcting bias in commercial CPUE time series due to the response of mixed fisheries to management

F.J. Quirijns and A.D. Rijnsdorp.
Netherlands Institute of Fisheries Research, P.O. Box 69, 1970 AB IJmuiden, The Netherlands
Phone: +31 255 564 769
Fax: + 31 255 564 644
Email: Floor.Quirijns@WUR.NL

Abstract

Catch per Unit Effort (CPUE) is an important source of information on the development of fish stocks. To get an unbiased estimate of CPUE one of the issues that need to be investigated is the effect of the response of a fleet to management measures. This paper deals with the effect of the response of the Dutch beam trawl fleet to catch restrictions on CPUE of sole and plaice. Using haul-by-haul data from a reference fleet, the directiveness of fishing effort was quantified for both species. The ratio of average CPUE in rectangles 30x30 Nautical miles and average CPUE from sub-squares in the larger rectangles of 10x10 Nautical miles was calculated for each week. The obtained value indicates to what extent fishermen direct fishing effort to the resource. Combination of the index for directiveness with a TAC (Total Allowable Catch) restriction index leads to a statistically significant relationship for plaice. For sole no such relationship was found, which may be due to the fact that sole TACs have not been as restrictive as plaice TACs. Our findings suggest that haul-by-haul data can be applied to quantify the effects of catch restrictions on a fleet's response. The index obtained through the method described may be used to correct CPUE time series for bias caused by directed fishing.

Keywords: catch, effort, North Sea, plaice, sole, beam trawl, CPUE

Introduction

Data on the catch and effort of commercial fisheries are an important source of information on the trend in the biomass of the fisheries resource. Commercial catch rates (CPUE, catch per unit of fishing effort) are used to calibrate stock assessments which form the basis for fisheries management (Laurec and Shepherd 1983, Pope and Shepherd 1985, Biseau 1998, Maunder and Punt 2004), and are important in the communication between fishermen, fisheries managers and fisheries scientists. However, trends in the commercial catch rate may not reflect the true trend in the fisheries resource (Walters 2003), which may result in a mismanagement of the fisheries resource and conflicts between stakeholders.

An unbiased estimate of the trend in the fisheries resource can be derived from data covering the total distribution area of the stock and obtained by a standardized fishing gear throughout the time period. In practice these conditions for an unbiased estimate will not be met in commercial fisheries. Fleets are unlikely to fish the entire distribution area of a stock as they will concentrate their activities on the fishing grounds yielding the highest catch rates. If a fish species tend to concentrate in certain areas, the catch rate may remain high even though the total biomass declines ('hyperstability' Hilborn and Walters 1992). Catch rates may further be reduced in relation to the density of fishing vessels on a local fishing ground due to interference (Gillis and Peterman 1998, Rijnsdorp et al. 2000a, 2000b, Gillis 2003). Furthermore, the efficiency of a fishing fleet will continuously improve by technical innovations and increased skills of the crew (Salthaug 2001, Marchal et al. 2002, Rijnsdorp et al. 2006). Increasing efficiency leads to

underestimation of CPUE. Finally, not all fish may be landed and registered due to the discarding of marketable fish due to catch restrictions (Anderson 1994, Daan 1997) or the maximization of the economic return (Gillis et al. 1995).
The effect of the response of a fishing fleet to management measures on resource estimates, in particular the level of catch restrictions for different target species, is another issue that needs to be investigated. Inter-annual differences in catch restrictions will likely generate a dynamic response of the fleet by redirecting fishing effort to the species with the least restrictive quantum. In the case of the Dutch beam trawl fleet targeting sole and plaice, we expect to find an effect of catch restrictions on the response of the fleet. A fleet can only respond to catch restrictions if the distribution of species differs, which enables the fleet to target a certain species composition. Sole and plaice differ in their large scale distribution due to differences in spawning and feeding areas as well as in their seasonal cycle in spawning and feeding (Rijnsdorp and Van Beek 1991). On top of these large scale differences, small scale differences may occur as both species show temporary concentrations (<2 weeks) at a spatial scale of less than 20-40 nm (Poos and Rijnsdorp in prep). Up to now no research has been reported in literature on the effects of the response of a fleet to catch restrictions on resource estimates.
In this paper we investigate the effects of the response of the Dutch beam trawl fleet to catch restrictions on CPUE. A method is developed to quantify the directiveness, i.e. a measure for the extent to which fishermen concentrate their effort in sub-squares where average CPUE is high, for sole and plaice.

Material

Beam trawl fleet

The Dutch beam trawl fleet consists of about 250 vessels, which can be divided in two components: euro cutters, with an engine power lower then 221 kW, and large cutters, with an engine power around 1471 kW. The analyses in this paper focus on the group of large cutters.
The fleet activity is distributed over the southern North Sea, from 51˚ up to 58˚ latitude. Most of the fishing activity takes place south from 55˚ latitude. The fleet of large cutters is not allowed to fish in the Plaice Box or the Dutch 12-miles zone (Figure 1). The fleet uses 80 mm mesh size south from the 100 mm minimum mesh size border and 100-120 mm mesh sizes north from this border.
Target species of the beam trawl fleet are plaice and sole. Sole and plaice differ in their large scale distribution, but due to partly overlap the beam trawl fishery is a mixed fishery. Turbot, brill, dab, cod and whiting are important by-catch species. The importance of each of these species is presented in Table 1, expressed in tonnes per year.
Regulation of the beam trawl fleet takes place by means of Individual Transferable Quotas (ITQs) for plaice and sole, and national quotas for by-catch species. Since 2002 also effort regulation has an increasing influence on fleet behaviour.

Data availability

Macro-scale data by ship are available since 1990. Catch per species and effort in days fished is registered by trip and ICES rectangle (30x30 Nautical miles). Micro-scale data are recorded by a reference fleet since 1993 (Rijnsdorp et al. 1998). The data contain catch of plaice and sole in individual hauls, hours fished and the location of the hauls. These haul-by-haul data are used for the analysis of differences in the micro-scale patterns in the CPUE of sole and plaice within ICES rectangles. The availability of data is summarized in Table 2.

Methods

CPUE - Micro scale resolution

Average CPUE was calculated by haul from the micro-scale data. Because the CPUE of beam trawlers is strongly affected by the engine power of the vessel (Rijnsdorp et al. 2000a), we first standardised the data to a vessel of 1471 kW (2000 hp) by fitting following regression:

$$CPUE = \frac{Catch}{\left(Effort * kW^{\beta} / 1471^{\beta}\right)}$$

Where β is 0.5162 for plaice and 0.8089 for sole (Rijnsdorp et al. 2006).
Each haul was assigned to a ~10x10 Nautical miles sub-square. These sub-squares were obtained by dividing ICES rectangles in 3x3 squares. The choice of the distance of 10 Nautical miles for the sub-squares is supported by the length of an average haul by a beam trawler, which is about 12 Nautical miles long (Rijnsdorp et al. 2000b). For each sub-square the weekly average CPUE was calculated for plaice and sole. Variation in CPUE patterns were investigated between weeks.
A selection of data was made before the analyses were carried out. Only data from the area where 80 mm mesh sizes are used were included, i.e. south from the 100 mm mesh size border. A second selection criterion was that only rectangles in which least 5 of the sub-squares contain information from 2 or more hauls per week were included. Finally, data had to be available in at least 7 years in each rectangle for the period 1993-2004.

Measure for directiveness

The directiveness of fishing effort of the fleet was quantified on the spatial scale of an ICES rectangle and a time step of a single week corresponding to a single fishing trip. The ratio of average CPUE by ICES rectangle and sub-square was taken, as derived from the Gulland index (Gulland 1955).

$$I = \frac{CPUE_{ij}}{\sum\left(CPUE_{ijk}\right) / N_{ij}}$$

CPUEij is the average CPUE in ICES rectangle i and week j; CPUEijk is the average CPUE in sub-square k in ICES rectangle i and week j; and Nij is the number of sub-squares. The more the fleet is targeting a species, the higher I. If a fleet is avoiding a species, I decreases.

In order to estimate the range of spatial differences in catch rates within an ICES rectangle and week, maximum and minimum values of the ratio between the highest and lowest CPUE in a sub-square and the average CPUE in a rectangle were quantified for each year. The weekly averages of these maximum and minimum values were calculated and averaged over all weeks within a year.

Results

CPUE - Micro scale resolution

There is weekly variation of CPUE patterns within ICES rectangles for both plaice and sole. The average CPUE of plaice and sole in each sub-square was quantified for all weeks and weekly patterns were compared. An example of the patterns found is presented in Figure 2 (plaice) and 3 (sole). In these figures the colored grid cells are the 10x10 Nautical mile sub-squares that contain data for the weeks presented. Changes in average CPUE within 10x10 nm sub-squares do not necessarily coincide for plaice and sole.

Measure for directiveness

The index for directiveness of effort to plaice shows a decrease from 1993 to 1994, from then onwards it is relatively stable, although another decrease is observed from 2000 to 2001 (Figure 4, left panel). The average index for plaice ranges from 1.01-1.13. If there would be no bias in CPUE caused by directed fishing, the average index would be 1, so directed fishing results in a bias in CPUE for plaice of up to 13%. In Figure 5 (left panel) it is shown that the average annual minimum and maximum range between approximately 0.4 and 2.1.

The index for directiveness of effort to sole varies from 1.03-1.08 (Figure 4, right panel). This means that directed fishing results in a bias in CPUE for sole of up to 8%. In some years an increase (1997, 2003) or a decrease (1996) is observed, these are relatively small changes. In Figure 5 (right panel) it is shown that the average annual minimum and maximum range between approximately 0.6 and 1.5.

When the index for directiveness is plotted against the TAC restriction index, i.e. the ratio between available quota and spawning stock biomass, we find a negative relationship for plaice and no relationship for sole (Figure 6). If the TAC restriction increases, directiveness for plaice decreases. Apparently the TAC restriction for sole has not influenced the directiveness of effort to the species.

Discussion

The method developed for quantifying the directiveness of fishing effort for plaice leads to promising result of a statistically significant relationship between the directiveness measure and the TAC restriction index for plaice. For sole, however, no such relationship was apparent, which may be due to the fact that sole TACs have not been as restrictive as plaice TACs.

The quantification of variations in the directiveness of the fishery for a particular fish species will depend on both the spatial and temporal scale used. The appropriate spatial scale will be primarily dependent on the scale at which the individual fishing vessel can detect the local concentrations of the target fish species. It has been shown previously that beam trawl vessels perform hauls of approximately 2 hours at a speed of 5-7 nm.h-1, covering a distance of 10-12nm per haul and tend to stay put on a local fishing ground by changing the course after each tow (Rijnsdorp et al. 2000a, Rijnsdorp et al. 2000b). Using geostatistic techniques, it was shown that the dimension of these local concentrations was generally smaller than 20-40nm and that they persisted for up to 2 weeks (Poos and Rijnsdorp in prep). Hence, a spatial scale of 10x10 nm and a temporal scale of 1 week is consistent with the scale of operation of the fleet. At this scale it is unlikely that the CPUE will not reflect the true density due to changes in the underlying fish distribution as in the case of hyperstability or hyperdepletion (Hilborn and Walters 1992).

A factor that may bias our estimate of the directiveness of the fishery is interference competition (Gillis and Peterman 1998, Gillis 2003). Interference competition among fishing vessels exploiting a local fish concentration will reduce the catch rate in proportion to the local density of fishing vessels. Hence, if interference competition occurs, our measure of directed fishing will be underestimating the true directiveness.

Another factor that may bias our estimate of the directiveness of fishing is the discarding of over-quota (high-grading), or the under- or misreporting of catches of marketable fish. In this case, the catch and effort statistics used will be flawed because unknown parts of the catch are actually not recorded. High-grading and under- or misreporting has a similar effect on the recorded catch rate as the re-directing of fishing effort to a fishing ground with a lower catch rate. Hence, the index of directed fishing developed may partly reflect variations in high-grading, under- or misreporting of catches. In the Dutch beam trawl fleet under- or misreporting are considered to be no problem.

Although high-grading may occur under certain circumstances, we believe that it will have not affected the annual variations in the index of directed fishing estimated in this study.

In order to derive a time series of catch rates that gives an unbiased estimate of the variations in biomass, we have to take account of the 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 or a quarter, will largely take account of the changes in spatial patterns and allow the estimation of a time series that is not affected by changes in the relative distribution of the fishing fleet relative to that of the fisheries resource. However, on the spatial scale of the ICES rectangle and within the temporal scale (month, quarter), the fish resource may locally form temporary concentrations that can be detected by the fishery. Our study showed that these concentrations indeed occurred within ICES rectangles. To obtain a series of the measure for directiveness of the fishing per year, haul-by-haul data are required that cover the entire fished area. At the moment, the available data collected by the Dutch reference fleet is not sufficient yet.

References

Anderson, L. G. 1994. Highgrading in ITQ fisheries. Marine Resource Economics 9:209-226.

Biseau, A. 1998. Definition of a directed fishing effort in a mixed-species trawl fishery, and its impact on stock assessments. Aquatic Living Resources 11:119-136.

Daan, N. 1997. TAC management in North Sea flatfish fisheries. Netherlands Journal of Sea Research 37:321-341.

Gillis, D. M. 2003. Ideal free distributions in fleet dynamics: a behavioral perspective on vessel movement in fisheries analysis. Canadian Journal Of Zoology-Revue Canadienne De Zoologie 81:177-187.

Gillis, D. M., and R. M. Peterman. 1998. Implications of interference among fishing vessels and the ideal free distribution to the interpretation of CPUE. Canadian Journal Of Fisheries And Aquatic Sciences 55:37-46.

Gillis, D. M., E. K. Pikitch, and R. M. Peterman. 1995. Dynamic discarding decisions:foraging theory for high-grading in a trawl fishery. Behavioural Ecology 6:146-154.

Gulland, J. A. 1955. Estimation of growth and mortality in commercial fish populations. Her Majesty's Stationery Office, London (UK).

Hilborn, R., and C. J. Walters. 1992. Quantitative fisheries stock assessment: Choice, dynamics & uncertainty. Chapman & Hall.

Laurec, A., and J. G. Shepherd. 1983. On The Analysis Of Catch And Effort Data. Journal Du Conseil 41:81-84.

Marchal, P., C. Ulrich, K. Korsbrekke, M. A. Pastoors, and B. Rackham. 2002. A comparison of three indices of fishing power on some demersal fisheries of the North Sea. Ices Journal Of Marine Science 59:604-623.

Maunder, M. N., and A. E. Punt. 2004. Standardizing catch and effort data: a review of recent approaches. Fisheries Research 70:141-159.

Poos, J. J., and A. D. Rijnsdorp. in prep. The dynamics of small-scale patchiness of plaice and sole as reflected in the catch rates of the Dutch beam trawl fleet and its implications for the fleet dynamics.

Pope, J. G., and J. G. Shepherd. 1985. A comparison of the performance of various methods for tuning VPAs using effort data. Journal du Conseil Permanent International pour l'Exploration de la Mer 42:129-151.

Rijnsdorp, A. D., A. M. Buys, F. Storbeck, and E. G. Visser. 1998. Micro-scale distribution of beam trawl effort in the southern North Sea between 1993 and 1996 in relation to the trawling frequency of the sea bed and the impact on benthic organisms. Ices Journal Of Marine Science 55:403-419.

Rijnsdorp, A. D., W. Dekker, and N. Daan. 2006. Partial fishing mortality per fishing trip: a useful indicator for effective fishing effort in management of mixed demersal fisheries. Ices Journal Of Marine Science 63:000-000.

Rijnsdorp, A. D., W. Dol, M. Hooyer, and M. A. Pastoors. 2000a. Effects of fishing power and competitive interactions among vessels on the effort allocation on the trip level of the Dutch beam trawl fleet. Ices Journal Of Marine Science 57:927-937.

Rijnsdorp, A. D., and F. A. Van Beek. 1991. Changes in growth of plaice Pleuronectes platessa L. and sole Solea solea L. in the North Sea. Netherlands Journal of Sea Research 27:441-457.

Rijnsdorp, A. D., P. L. van Maurik Broekman, and E. G. Visser. 2000b. Competitive interactions among beam trawlers exploiting local patches of flatfish in the North Sea. Ices Journal Of Marine Science 57:894-902.

Salthaug, A. 2001. Adjustment of commercial trawling effort for Atlantic cod, Gadus morhua, due to increasing catching efficiency. Fishery Bulletin 99:338-342.

Walters, C. J. 2003. Folly and fantasy in the analysis of spatial catch rate data. Canadian Journal Of Fisheries And Aquatic Sciences 60:1433-1436.

Table 1. Catch per species (tonnes) per year.

	2000	2001	2002	2003	2004	Average Price (2000-2004)
Brill	1016	1122	952	965	804	7.14
Cod	3090	2087	2287	1407	1009	2.53
Dab	5664	4914	4080	3911	4044	1.23
Plaice	34230	32959	28081	25911	22574	1.87
Sole	15198	13461	12025	12427	12744	8.99
Turbot	2245	2248	1849	1813	1697	9.35
Whiting	876	1075	1217	536	498	0.98

Table 2. Number of large (>221 kW) beam trawl vessels, trips and hauls available in macro- and micro-data.

	Macro data		Micro data		
Year	Ships	Trips	Ships	Trips	Hauls
1990	401	13189	0	0	0
1991	383	13132	0	0	0
1992	350	12491	0	0	0
1993	355	13239	14	300	12578
1994	355	13815	7	251	10555
1995	352	13557	12	443	18515
1996	330	11641	15	531	20838
1997	311	10616	21	726	31406
1998	306	10900	11	495	20279
1999	295	10291	16	636	26400
2000	249	8909	13	478	18238
2001	251	8815	12	528	21444
2002	249	8396	24	236	9756
2003	259	8257	23	576	23953
2004	223	7751	17	265	10613

Figure 1. Map of the North Sea. The grey striped area is the Plaice box; the black thick line is the border between the 80 mm mesh size area (south) and 100 mm mesh size area (north); the dashed line is the border of the 12-miles zone. The grid shows ICES rectangles.

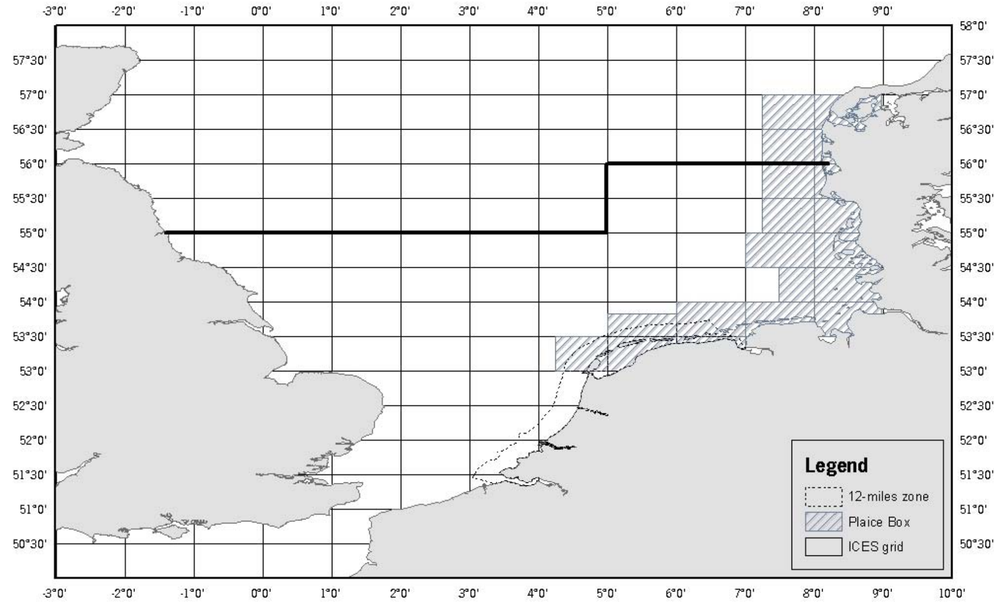

Figure 2. CPUE patterns on micro-scale resolution for Plaice. Week 10-12 in 2004.

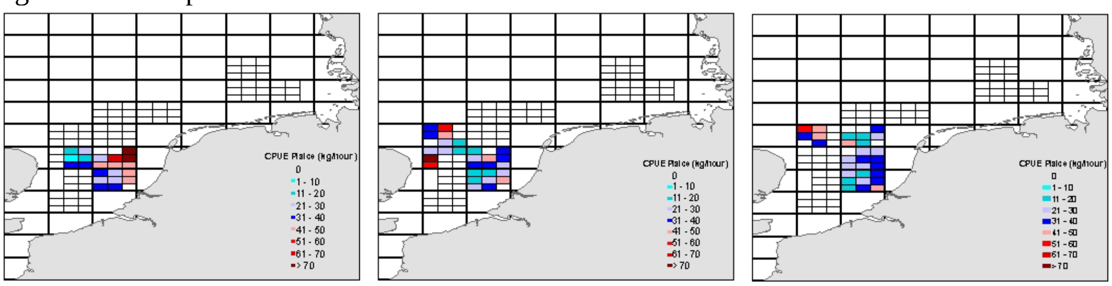

Figure 3. CPUE patterns on micro-scale resolution for Sole. Week 10-12 in 2004.

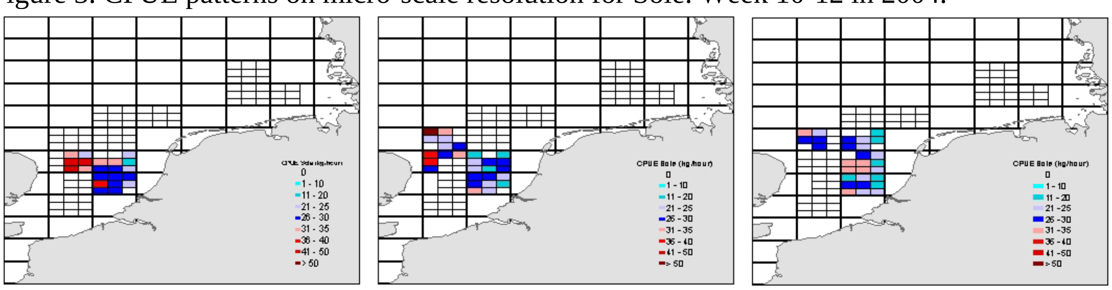

Figure 4. Index for directiveness of fishing on Plaice (left) and Sole (right) from 1993-2004. The error bars represent standard errors.

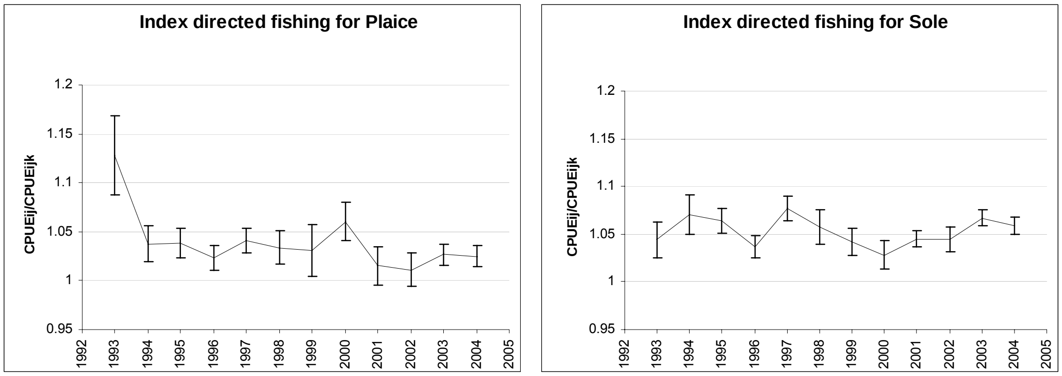

Figure 5. Average range of the index for directiveness of fishing on Plaice (left) and Sole (right) from 1993-2004. The dotted lines represent the average maximum and minimum values for index.

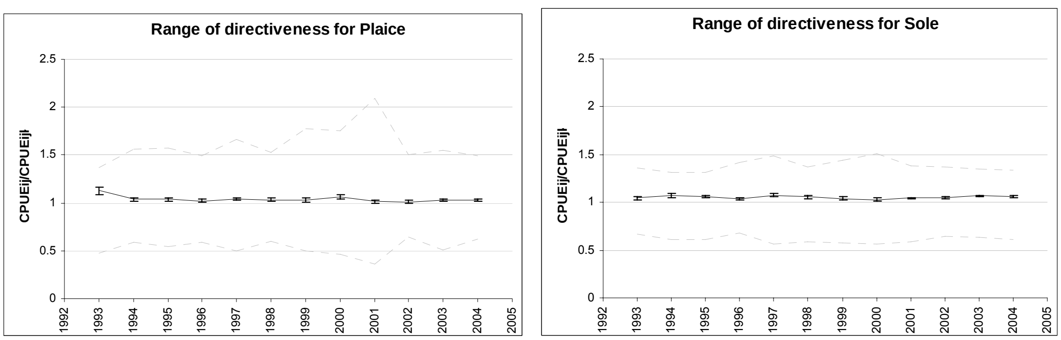

Figure 6. Relationship between the index for directiveness of fishing and the TAC restriction index, for Plaice (left) and Sole (right).