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Trends in biomass and changes in spatial distribution of demersal fish species in Kattegatt and Skagerrak between 1981-2003

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Abstract

Overfishing and slow recovery of depleted fish stocks are currently a major global concern as they jeopardize the biological diversity of many marine ecosystems in major fishing areas. Accordingly, we analysed trends in biomass and changes in spatial distribution of 33 demersal fish species in a heavily exploited area, the Kattegatt and Skagerrak, between 1981 and 2003 using IBTS (International Bottom Trawl Survey) data. As in other exploited areas of the North Atlantic, the biomass, calculated as Catch Per Unit of Effort (CPUE), of round fishes (cod, pollack, hake and common ling) decreased drastically during this period possibly due to fishing pressure. However, other commercially important fish species (e.g. flat fishes) showed in this area a constant or increasing trend during the same period. Non-commercial species showed no or an increased trend in biomass (as much as 40 times in hagfish). Furthermore, a preliminary analysis of the spatial distribution of 12 selected fish species, explored by means of geostatistical methods and CV% (Coefficient of Variation), suggested a change in the degree of spatial aggregation as a function of the biomass.

Introduction

The status of commercially important fish populations has lately received much attention and has become an increasing concern. During the last few decades overexploitation has led to a worldwide decrease, and even collapse, in several fish stocks (e. g. see Myers and Worm, 2003). Fishing activities, with removal of target fish species and habitat perturbation, may also lead to changes in whole fish communities and of higher and lower trophic level (Jennings and Kaiser, 1998). As a matter of fact, the global collapse of predatory fish in the northern hemisphere has produced a change in the entire ecosystem and the species at lower trophic levels (zooplanktivorous pelagic fish and invertebrates) have steadily increased due to release from predation (Pauly et al., 1998; Myers and Worm, 2003).

The effects of changes in target fish abundance on their spatial distribution have been discussed to a great extent (e.g. Winters and Wheeler, 1985; Crecco and Overholtz, 1990; Gordoa and Hightower, 1991; Rose and Kulka, 1999 and references therein). This phenomenon, when not enough investigated, can in extreme cases lead to the collapse of commercial stocks (Rose and Kulka, 1999). Although the causes of the spatial redistribution of fish population in response to biomass variation are still poorly understood, density-dependent processes are often suggested as a possible explanation (Myers and Stokes, 1989; MacCall, 1990). Alternately, fish spatial distribution may also be affected by the degree of stock exploitation (Winters and Wheeler, 1985) and environmental factors (Corten and van de Kamp, 1996; Heessen, 1996; Rose and Kulka, 1999). Information about changes in spatial distribution of non-commercial species is scarce in literature (but see Heessen and Daan, 1996).

The eastern North Sea including Kattegatt and Skagerrak (ICES division IIIa) is a transitory area between the central North Sea and the Baltic Sea that has not received as much attention as other regions of the North Sea (see Daan et al., 1996). However, both the inshore and offshore eastern Skagerrak has undergone a high level of exploitation that has caused an abrupt reduction of several commercially important demersal species (Svedäng, 2002). Nevertheless, only cod has been to date extensively investigated in this area (Svedäng, 2002; Svedäng and Bardon, 2002). Furthermore, the spatial distribution of fish populations in response to either fishing pressure or environmental factors has not been explored in Kattegatt-Skagerrak and there are only few studies in literature for the North Sea (Heessen and Daan, 1996).

Factors affecting fish abundance and distribution often operate at regional scales (Heessen and Daan, 1996; Rose and Kulka, 1999). Accordingly, in this paper we investigated the changes in biomass and spatial distribution occurred to both commercial and non-commercial demersal fish species in the open areas of Kattegatt and Skagerrak during the last 23 years.

Materials and methods

Trends in biomass

In this study we analysed the trends in biomass of demersal fish species collected during the winter International Bottom Trawl Survey (IBTS) between 1981-2003 (Table I). The IBTS has been carried out in the Kattegatt and Skaggerak (ICES subdivisions 21 and 20, respectively) since 1979 in winter (January/February), and beginning from 1991 also in September, each year by the Swedish National Board of Fisheries on board the R/V "Argos". The main aim of the survey is to provide annual forecasts of recruitment in several commercial species but it has revealed to be also a reliable source of stock abundance data well in agreement with stock assessment estimations (Heessen, 1996). We used winter data because of a longer time series. Moreover, in winter most of the individuals recruited the last spawning season have already reached a size recruited by the gear (Heessen and Daan, 1996). The biomass was calculated as Catch Per Unit of Effort (CPUE) in weight (kg) per hour of trawling. Since CPUE data are usually approximately log normally distributed (Maunder and Starr, 2003), they were previously transformed to conform the assumption of normality and homogenous variance. According to the IBTS protocol (see for details ICES, 1992), the sampling area was stratified by ICES rectangles of 0.5º latitude and 1º longitude and each haul was swept, unless adverse environmental conditions, for 30 minutes at a speed of 4 knots over ground. Between 23 and 49 trawl hauls were performed each year, with a general increment in the last decade (Table I). The trawl employed was a standard GOV (Grand Ouverture Verticale) with a 16 mm mesh size.

Spatial distribution

We additionally analysed the change in spatial distribution of 12 selected fish species. They were chosen so as to represent three different fish groups. Accordingly, we analysed 5 commercial round fish (cod, pollack, saithe, haddock and whiting), 4 flat fish (plaice, flounder, long rough dab and lemon sole) and 3 not target fish species (Norway pout, poor cod and four-bearded rockling). The spatial distribution of the species was examined by means of kriging and using biomass values calculated as Ln CPUE. Two distribution maps were created for each species, in correspondence to the highest and lowest level of biomass observed in the time-series. The years 1981, 1982 and 1985 were avoided because of the low number of hauls in those years (Table I). For the sake of consistency, a linear variogram was always employed with slopes and nuggets effect values automatically (by the computer software) estimated. In order to confirm the visual interpretation of the distribution maps we used the coefficient of variation (CV%) between point estimates (hauls) as an index of the degree of fish aggregation/dispersion.

The CV% was calculated as:

$$CV\% = (SD / M) * 100$$

where SD and M are the standard deviation and the average among the hauls, respectively. It was supposed that high and low values of CV% would correspond to high and low degree of spatial aggregation, respectively (Hilborn and Mangel, 1997).

Kriging and statistical analysis were performed by using Surfer 8 (2002) and SPSS (1999) computer software, respectively.

Results

Trends in biomass

The 33 demersal fish species object of the present study (Table II) displayed large fluctuations in biomass in Kattegatt-Skagerrak during the period 1981-2003. Round fishes, which include the most important commercial species, such as cod saithe, hake and ling, showed a general decreasing trend in biomass, sometimes reaching drastic low values during the latest years as in the case of pollack (Fig. 1). On the other hand, whiting exhibited a remarkable stable biomass, whereas haddock and saithe showed large fluctuations without a clear-cut tendency (Fig. 1).

In contrast, the biomass values of flat fish species displayed a constant or slightly increasing general pattern (Fig. 1). A clear positive trend can be seen in plaice, dab, long rough dab, common sole and brill. Conversely, flounder and witch kept a fairly constant biomass. Turbot and lemon sole showed large fluctuations without a clear tendency.

Among the other fish species, the positive trend in biomass of hagfish, snake blenny, spotted dragonet and Norway pout is worthy of note. Poor cod and pearlsides were the only species that clearly decreased in biomass during the studied period. The other species either did not show any trend or a slightly increasing one (Fig. 1). For details about the biology/ecology and exploitation of the examined species see Knijn et al. (1993).

Spatial distribution

Although there were slight differences among years in the spatial location of the IBTS hauls, the Kattegatt area was evenly covered every year. The western region of the central Kattegatt is not part of the IBTS survey design. Moreover, the western and central regions of Skagerrak present a spatially irregular coverage in all the years (Fig. 2). These spatial unevenness need to be kept in mind when interpreting the distribution of the species as shown by the kriging. Therefore, in order to avoid misinterpretations of the maps, the locations of the hauls were also indicated (Fig. 2).

The analysis of the fish distribution showed that the 12 selected species tend to aggregate at low level of biomass and disperse over a wider geographic range at high abundances (Fig. 2). Concerning round fishes, this pattern is particularly evident for pollack and saithe that at very low levels of biomass aggregated in limited areas of the central Skagerrak and of the central Kattegatt Swedish coast, respectively. Both haddock and whiting distributed mostly in the Skagerrak and south Kattegatt at low abundance and over the whole studied area at high biomass, even though the change in whiting is not as obvious as for haddock. Cod seem to be spread over the whole Kattegatt at high biomass and to have a more patchy distribution at low levels of abundance (Fig. 2).

Flat fishes as well seem to some extent follow this pattern. Long rough dab and lemon sole aggregated in some areas of Kattegatt at low values of biomass and distributed along the whole Kattegatt and in Skagerrak at high abundance. Flounder seem to present a more patchy distribution at low value of biomass, even though the change is not striking. Plaice did not show any clear change.

Regarding the other fish species, poor cod and Norway pout populations were present in Skagerrak at low biomass and additionally in Kattegatt at high abundance (Fig. 2). Four-bearded rockling expanded over the whole studied area at high biomass.

The visual interpretations of the distribution maps are in good agreement with the degree of spatial aggregation among hauls calculated as CV%. The CV% value corresponding to the highest biomass was lower than the CV% value corresponding to the lowest biomass for all the species but plaice (Tab. III). Moreover, the relationships between biomass and CV% were all significant except for plaice (Fig. 3 and Table III).

Discussion

Trends in biomass

Overall, the results based on fish abundance data for Kattegatt and Skagerrak are similar to what has been found in other areas of the North Atlantic. That is, a steady decrease of several commercially important round fish (cod, pollack, hake, ling). Since all the non-commercial fish species did not show any decrease in biomass, the drop in round fish is probably due to fishing pressure. However, haddock and saithe seem to have undergone large fluctuation in biomass without any clear tendency. Whiting has maintained its biomass nearly constant during the period analysed. The results are in agreement with stock assessment values for cod, haddock saithe and hake evaluated for the whole North Sea, whereas concerning whiting are different compared to stock assessment values (ICES, 2003). However, it must be kept in mind that our analysis covered only a limited area of the North Sea and comparisons could be misleading. The discrepancy between stock assessment values and our biomass index suggest that in order to better understand the dynamics of fish stocks, the biomass estimation should be performed at regional and local scales and implemented by using as many data sets as possible.

Flat fish species did not decrease or, on the contrary, increased in biomass. This is in agreement with what found by Heessen and Daan (1996) in different areas of the North Sea and could be due to their different ecology and life history traits compared to round fishes. Flat fishes, having generally a more rapid growth and maturing relatively early are less vulnerable to intensive exploitation compared to round fishes, thus balancing the high mortality of the older and bigger individuals (Heessen and Daan, 1996; Jennings and Kaiser, 1998). On the other hand, there are indications of increased invertebrates productivity in coastal waters of the North Sea over the last two decades. This could have increased the food supply for juvenile flat fishes and, thus, positively affected the whole population (Rijnsdorp and van Leewen, 1996). However, IBTS is carried out in open waters where, even in a small system as the Kattegatt/Skagerrak, the increase in invertebrates as an effect of eutrophication could be supposed to be minor.

Species neither target nor common as by-catch in commercial fisheries (e. g. those with a vermiform body shape) showed a constant or increasing trend in biomass during the studied period. An extreme example is represented by the hagfish biomass that increased almost 40 times during the last decade. This species is a scavenger (Britton and Morton, 1994), feeding mostly on dead or dying carcasses of other organisms present on the sea bottom. Therefore, one possible explanation of its outburst could be the increased amount of discards from commercial vessels (Jennings and Kaiser, 1998). This mechanism could also in part explain the increased biomass of the flat fishes acknowledged to benefit from organisms damaged by the fishing activity (Millner and Whiting, 1996; Rijnsdorp and van Leewen, 1996; Jennings and Kaiser, 1998).

The drop in abundance of several top-predatory fish species (e. g. round fishes, see above) could represent an alternative explanation for the increase in abundance of several flat fishes and non-commercial species that could have been released from predation (Pauly et al., 1997; Myers and Worm, 2003). However, the predator-prey coupling is always difficult to demonstrate especially in high diversity systems as well as in exploited areas (Jennings and Kaiser, 1998) and the cascading impact on other parts of the ecosystem should be evaluated in order to provide evidence for this hypothesis.

The IBTS has been performed in Kattegatt and Skagerrak in a very highly standardised manner (unvaried sampling design, fishing procedure and gear used) since 1979. Therefore, in our study the factors affecting fish catchability and CPUE data in commercial fishery (as different fishing power, non-random trawling, diurnal and seasonal variation in fish distribution) (Garrod, 1964; Gulland, 1964) can be possibly ruled out. However, other possible sources of change in the availability of fish to the survey, as age-dependent behaviour (Swain et al., 1994), could not be excluded. Furthermore, the IBTS covers the open sea areas, thus missing the inshore part of the fish populations.

Spatial distribution

Stock spatial distribution of fish is a task not extensively studied in fisheries science. Our analysis reveals a pattern common to all the selected fish species: a tendency to aggregate and disperse at low and high level of biomass, respectively. Even though we tried to be as consistent as possible in the analysis, the kriging method used is merely a qualitative and visual representation of the phenomenon that needed to be confirmed using quantitative statistical tools. We attempted to do so by means of the CV% between point estimates as index of the degree of spatial aggregation/dispersion. Although the CV% is widely used in ecological studies (Hilborn and Mangel, 1997), we are aware that its use as exploratory tool in a fishery context should be used cautiously. However, the trends in CV% values are in good agreement with the visual interpretation of the distribution maps. The fact that fish species seem to aggregate at low levels of biomass and disperse at high levels of abundances has previously been demonstrated for pelagic shoaling fish (reviewed by Winters and Wheeler, 1985) and for target demersal fish stocks as haddock and cod (see Crecco and Overholtz, 1990; Rose and Kulka, 1999, respectively). In our study we showed how the phenomenon of aggregation/dispersion might also occur to both flat fish and non-commercial fish species. As an exception, plaice do not seem to follow this pattern (both the visual interpretation and the CV% indicate a rather low correspondence between biomass and degree of aggregation). However, plaice biomass did not change in time as much as the other species selected, thus possibly not showing any evident change in distribution. Although the contraction and expansion behaviour of marine fish is considered to occur in response to density-dependent habitat selection mechanisms (MacCall, 1990), the factors originally triggering off these processes are still poorly understood. However, food requirement and predation avoidance possibly drive the observed pattern (MacCall, 1990). Another explanation could be the variation in fish spawning behaviour. In fact, since the data used were collected in February, i. e. at the beginning of the spawning season for several species, the observed changes in spatial distribution might be driven by density-dependent or habitat selection behaviour related to spawning. An additional reason for the changes in fish distribution could be associated to environmental shifts (Gordoa and Hightower, 1991; Rose and Kulka, 1999).

The results presented here suggest that the spatial pattern observed is related to intrinsic population factors (as density-dependent mechanisms and behaviour) because of the significant relationships between CV% and biomass levels common to all but one the analysed species compared to environmental changes. However, environmental forces can not be ruled out.

The implications of the spatial redistribution of fish stocks in response to either changes in their size or environmental factors are huge. Variations in fish spatial distribution can in some circumstances lead to overestimate the stock size and underestimate fishing mortality (Crecco and Overholtz, 1990; Rose and Kulka, 1999) with consequent risk for overexploitation and stock collapse. As a matter of fact, Rose and Kulka (1999) showed that the crash of northen cod stock off Newfoundland was a result of misinterpretation of commercial CPUE due to hyper-aggregation. Accordingly, they stressed how CPUE from the fishery should not be used as index of demersal fish abundances without a prior knowledge of the spatial characteristics of the population and of the fishing vessels (see also Harley et al., 2001; Salthaug and Aanes, 2003). Therefore, the change in spatial distribution of fish stocks in the Kattegatt-Skagerrak area presented in this paper is a phenomenon particularly important from an ecological as well as management perspective and needs to be carefully investigated in order to preserve endangered fish populations and their role in the ecosystem.

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Table I. Summary of the trawl hauls swept during the IBTS performed in Kattegatt and Skagerrak between 1981-2003.

Year	Period	No. hauls	Bottom depth (m)
1981	03-19 Feb	32	22-183
1982	09-18 Feb	23	30-232
1983	31 Jan-16 Feb	35	20-210
1984	06-21 Feb	35	21-135
1985	04-21 Feb	32	21-150
1986	03-19 Feb	42	21-248
1987	02-19 Feb	49	22-300
1988	01-18 Feb	39	22-265
1989	06-23 Feb	43	18-234
1990	05-21 Feb	45	18-235
1991	12-28 Feb	38	19-265
1992	03-20 Feb	43	18-258
1993	08-25 Feb	45	18-258
1994	31 Jan-17 Feb	48	18-259
1995	30 Jan- 16 Feb	48	19-228
1996	29 Jan-15 Feb	48	18-257
1997	27 Jan-13 Feb	46	19-250
1998	26 Jan-12 Feb	45	19-256
1999	25 Jan-11 Feb	46	18-256
2000	24 Jan-10 Feb	46	19-253
2001	22 Jan-08 Feb	45	18-233
2002	21 Jan-07 Feb	45	19-237
2003	27 Jan-12 Feb	46	19-257

Table II. List of the 33 fish species whose trends in biomass were analysed using IBTS data collected in Kattegatt and Skagerrak between 1981-2003.

	Latin name	English name
1	*Anarhichas lupus*	Wolffish
2	*Arnoglossus laterna*	Scaldfish
3	*Callionymus lyra*	Dragonet
4	*Callionymus maculatus*	Spotted dragonet
5	*Cyclopterus lumpus*	Lumpsucker
6	*Eutrigla gurnardus*	Grey gurnard
7	*Gadus morhua*	Cod
8	*Glyptocephalus cynoglossus*	Witch
9	*Hippoglossoides platessoides*	Long rough dab
10	*Limanda limanda*	Dab
11	*Lophius piscatorius*	Angler
12	*Lumpenus lampretaeformis*	Snake blenny
13	*Lycodes vahlii*	Vahl's eelpout
14	*Maurolicus muelleri*	Pearlsides
15	*Melanogrammus aeglefinus*	Haddock
16	*Merlangus merlangus*	Whiting
17	*Merluccius merluccius*	Hake
18	*Microstomus kitt*	Lemon sole
19	*Molva molva*	Ling
20	*Myoxocephalus scorpius*	Bullrout
21	*Myxine glutinosa*	Hagfish
22	*Platichthys flesus*	Flounder
23	*Pleuronectes platessa*	Plaice
24	*Pollachius pollachius*	Pollack
25	*Pollachius virens*	Saithe
26	*Raja radiata*	Starry ray
27	*Rhinonemus cimbrius*	Four-bearded rockling
28	*Scophthalmus maximus*	Turbot
29	*Scophthalmus rhombus*	Brill
30	*Solea solea*	Common sole
31	*Trachinus draco*	Greater weever
32	*Trisopterus esmarkii*	Norway pout
33	*Trisopterus minutus*	Poor cod

Table III. Coefficient of correlation (r^2) and significance level (p) of the relationships between biomass and CV% of the 12 selected species. For each species the observations were fitted by the curve with the highest r^2. The highest and lowest values of biomass observed during the studied period and the correspondent CV% are also shown (see text for details).
*: $p < 0.01$.

Species	**Ln CPUE max (Kg)**	**CV%**	**Ln CPUE min (Kg)**	**CV%**	**Curve**	r^2	**p**
Cod	4.1	23.7	2.7	42.0	linear	0.60	*
Pollack	0.8	151.8	0.0	678.2	power	0.98	*
Saithe	0.8	153.6	0.1	441.6	power	0.75	*
Haddock	3.1	66.3	1.0	125.9	power	0.50	*
Whiting	4.8	23.9	2.9	47.2	linear	0.30	*
Plaice	2.2	51.5	1.3	50.4	linear	0.15	0.06
Flounder	2.4	77.7	1.4	99.0	power	0.73	*
Long rough dab	3.0	33.9	1.3	52.3	linear	0.76	*
Lemon sole	0.7	89.7	0.3	138.9	power	0.55	*
Norway pout	2.9	75.6	0.3	185.3	power	0.94	*
Poor cod	0.6	120.3	0.0	454.9	power	0.78	*
Four-bearded rockling	0.7	90.5	0.2	148.4	linear	0.70	*

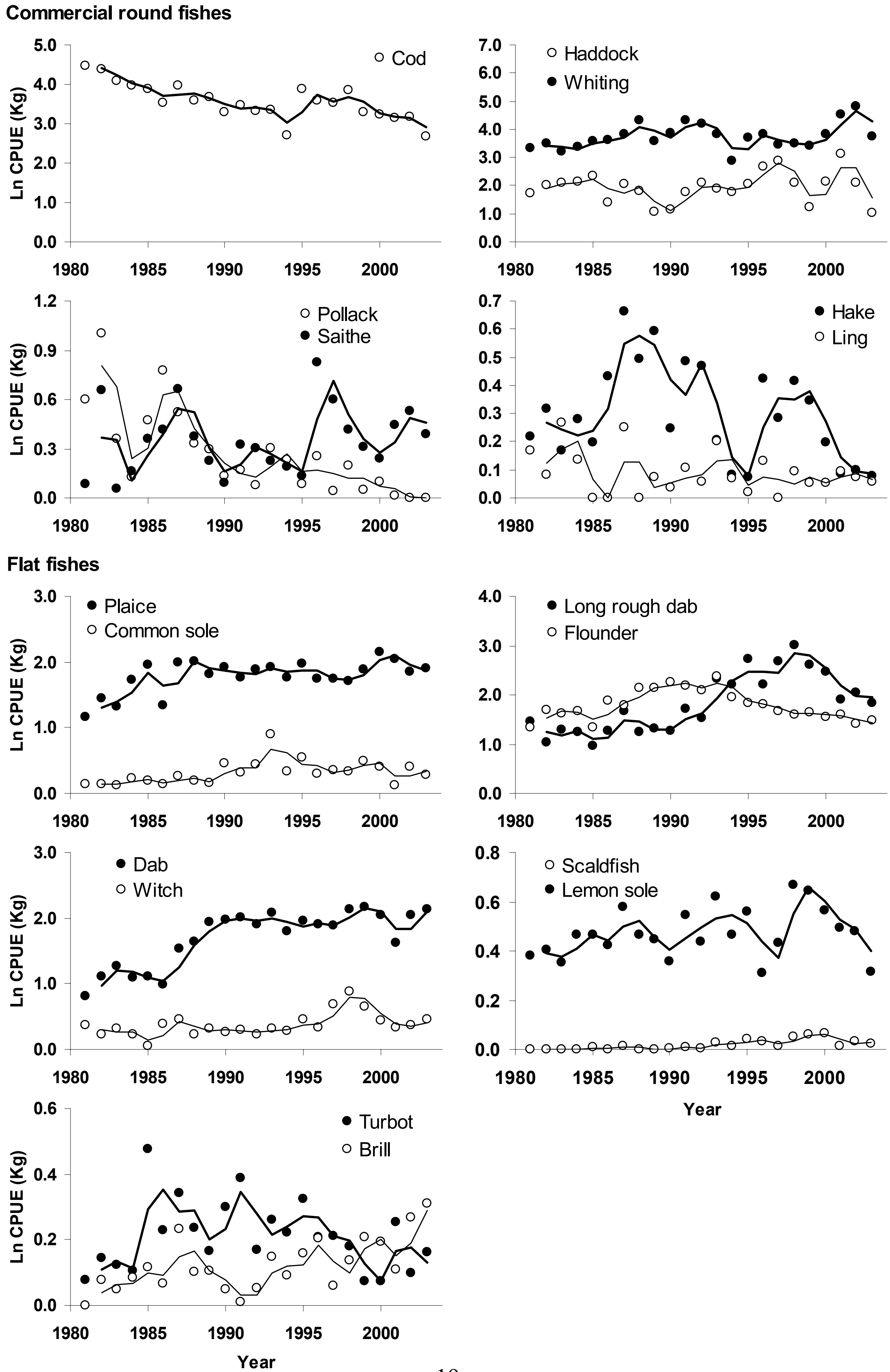
FIGURES LEGEND

Figure 1. Trends in biomass (calculated as Ln CPUE) of the 33 fish species collected during the IBTS performed in Kattegatt and Skagerrak between 1981-2003. The lines represent 2-years moving averages.

Figure 2. Spatial distribution of 12 selected fish species at the highest (left map) and lowest (right map) values of biomass observed during the IBTS performed in Kattegatt and Skagerrak between 1981-2003. The circles represent the hauls positions. The scale bars represent the biomass calculated as Ln CPUE (kg). Kriging interpolation method was employed to create the distribution maps (see text for details).

Figure 3. Relationships between biomass (calculated as Ln CPUE) and CV% of the 12 selected species. See Table III for details on the statistics.

Figure 1



Commercial round fishes
Cod
Haddock
Whiting
Pollack
Saithe
Hake
Ling
Flat fishes
Plaice
Common sole
Long rough dab
Flounder
Dab
Witch
Scaldfish
Lemon sole
Turbot
Brill
Ln CPUE (Kg)
Year

Figure 1, cont.

Other fishes

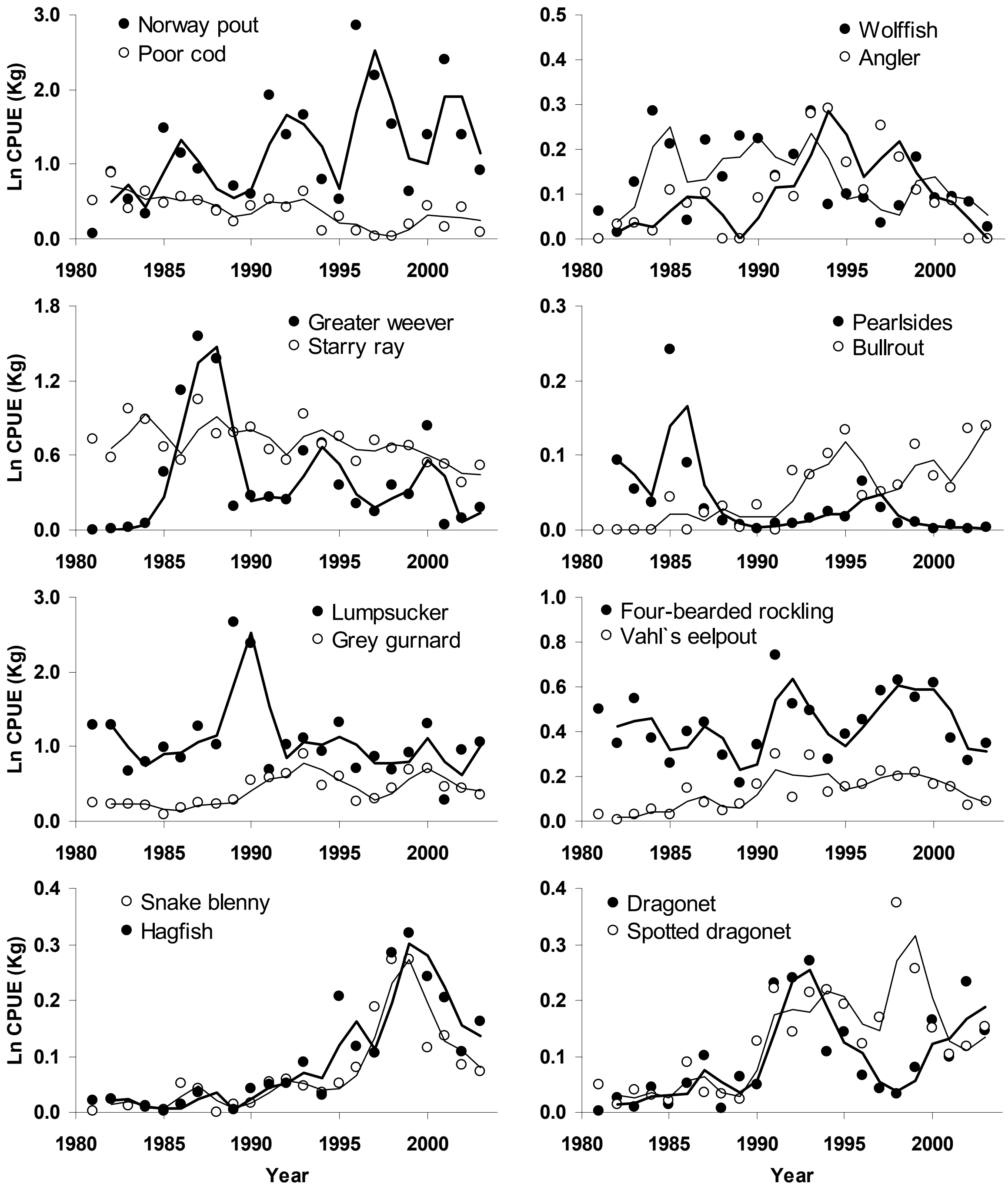


Figure 2

Commercial round fishes

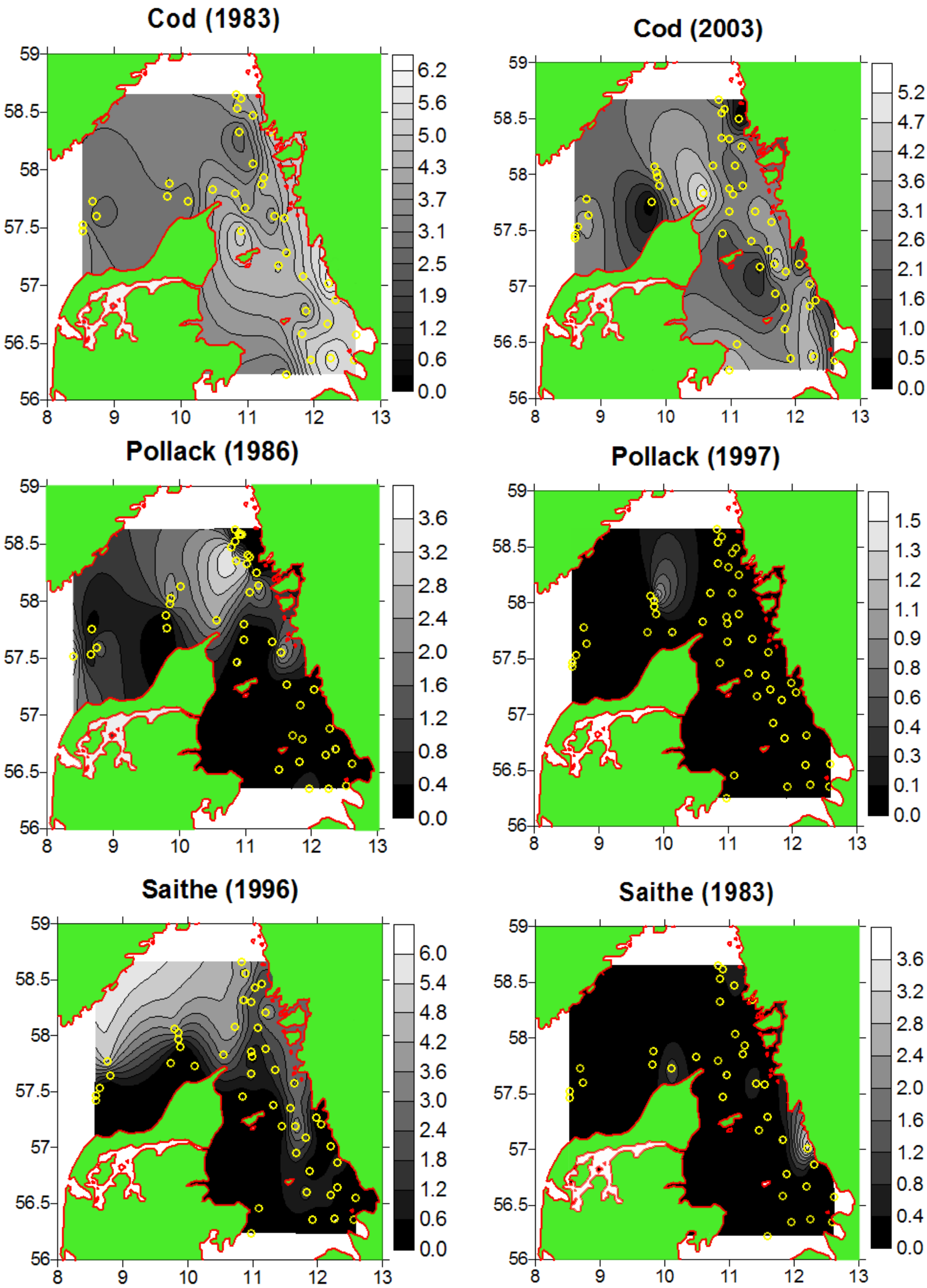
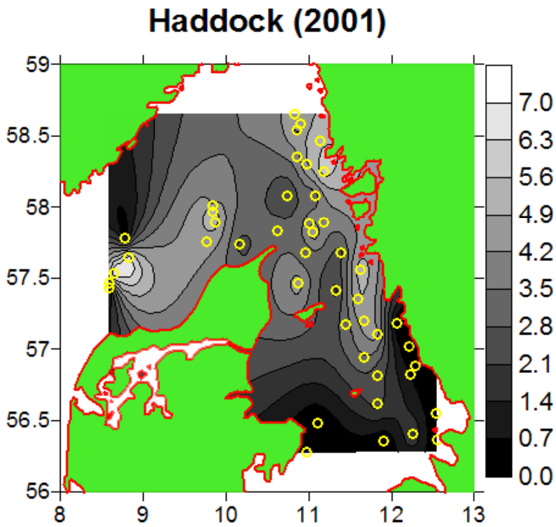
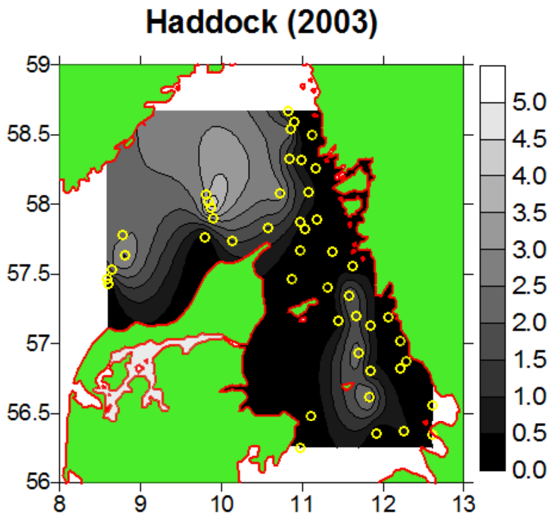
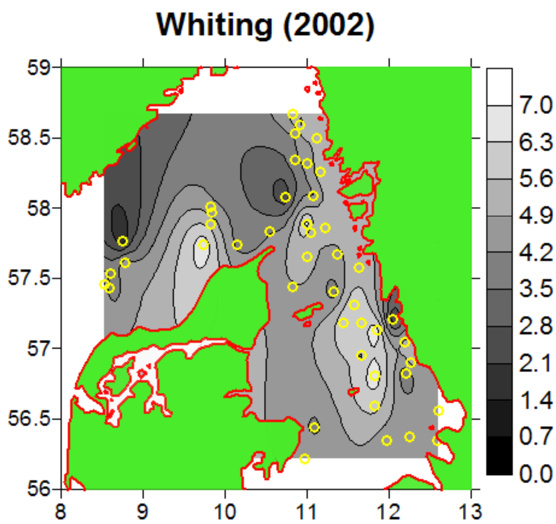


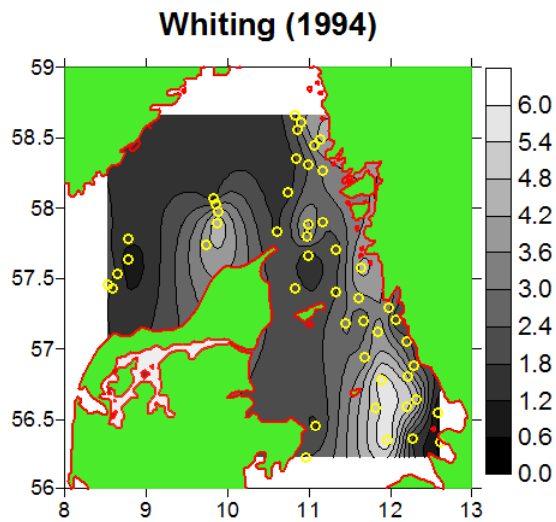
Figure 2, cont.

Commercial round fishes

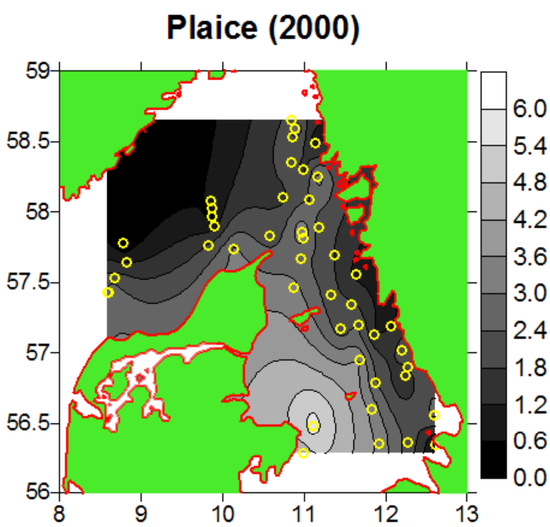








Flat fishes



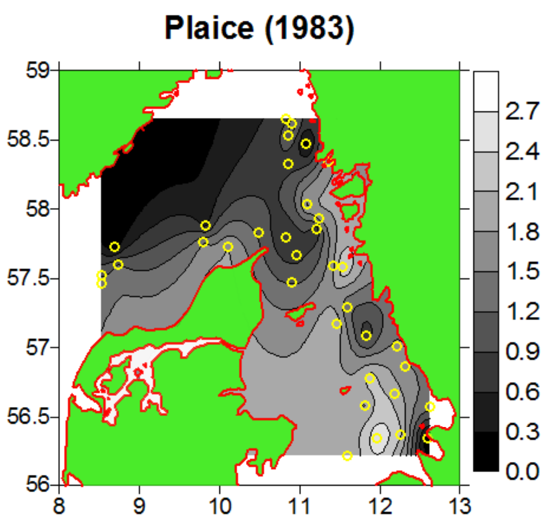


Figure 2, cont.

Flat fishes

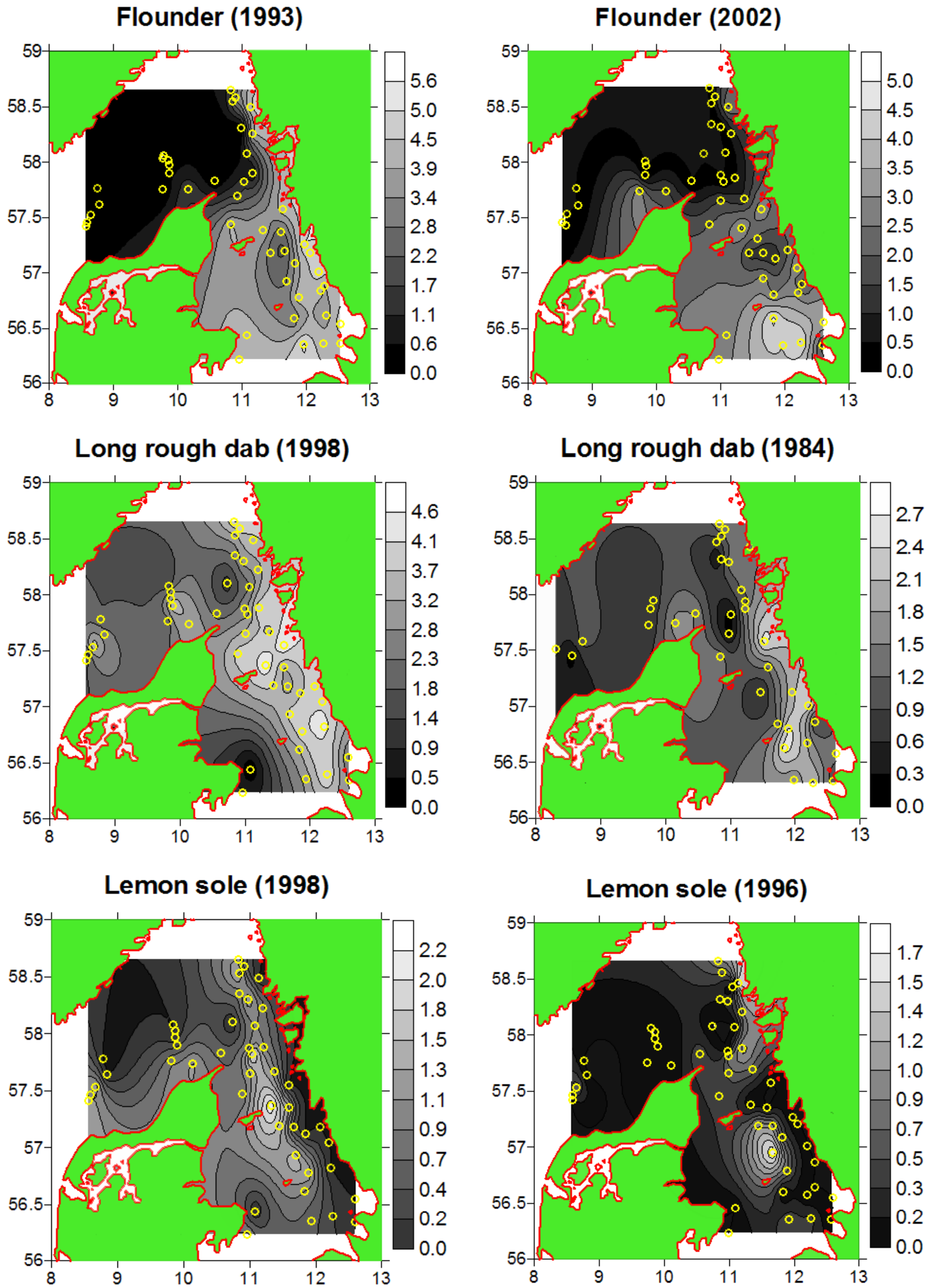


Figure 2, cont.

Other fishes

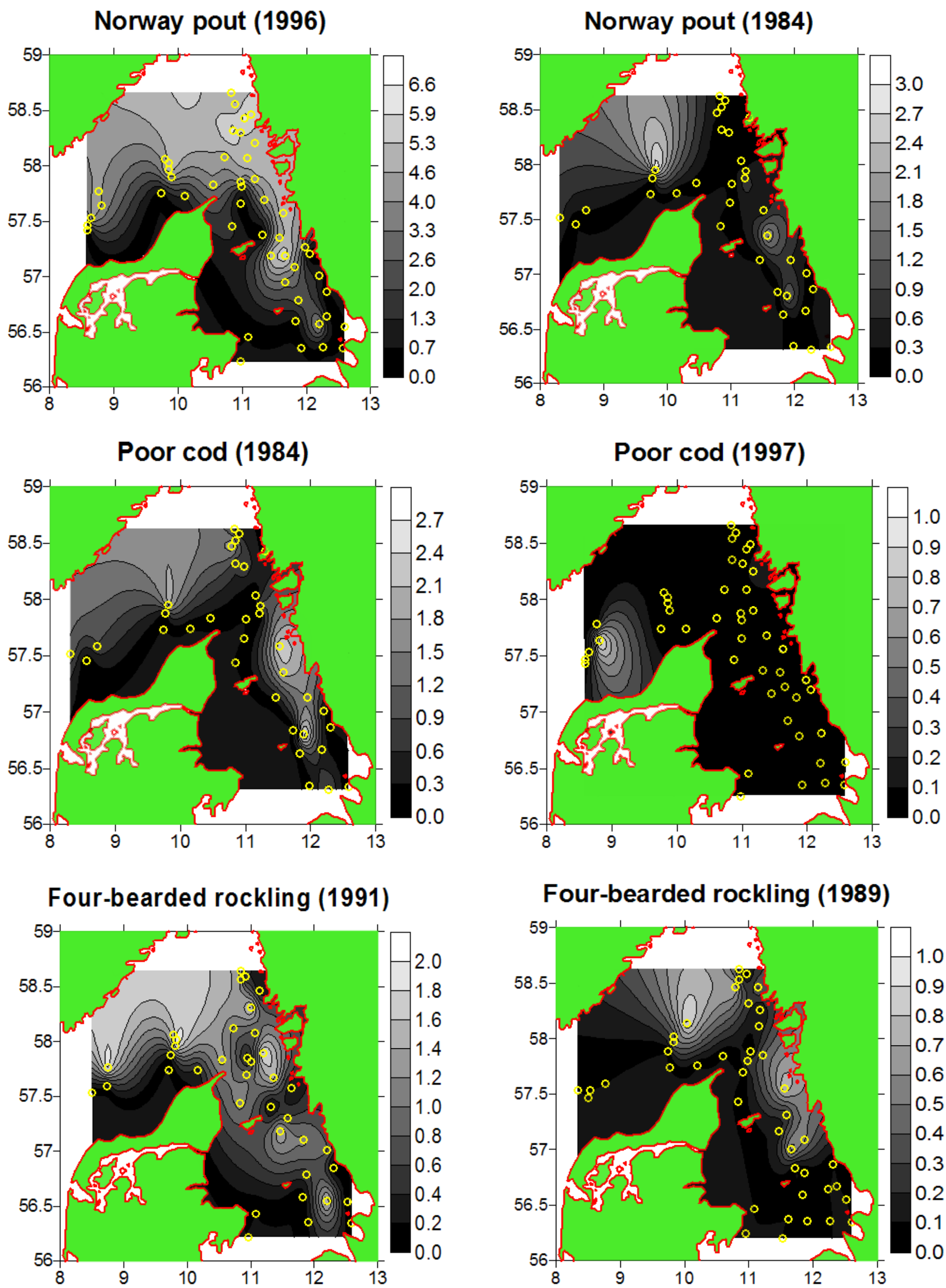
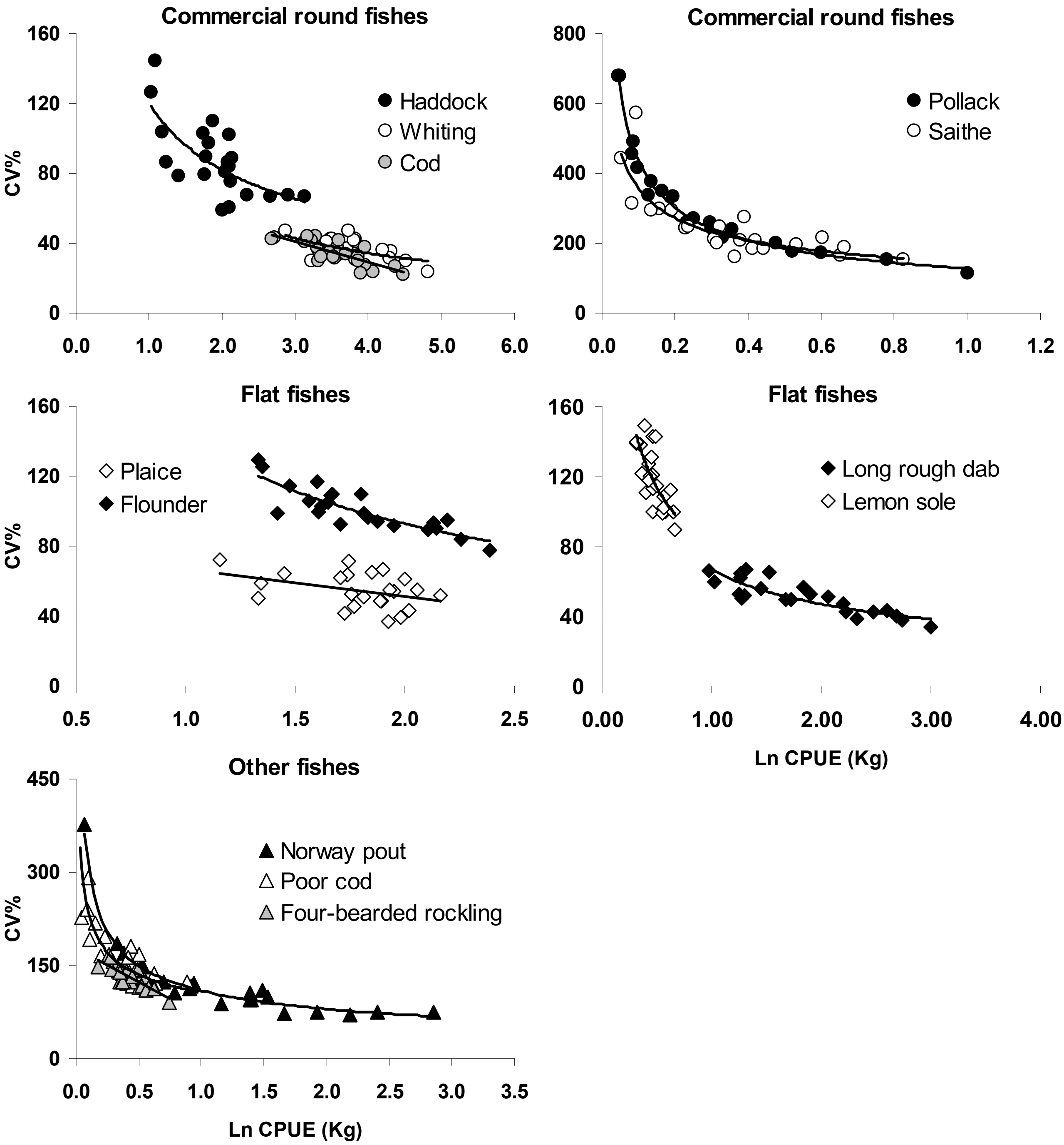


Figure 3


Commercial round fishes
CV%
Haddock
Whiting
Cod
Commercial round fishes
Pollack
Saithe
Flat fishes
CV%
Plaice
Flounder
Flat fishes
Long rough dab
Lemon sole
Ln CPUE (Kg)
Other fishes
CV%
Norway pout
Poor cod
Four-bearded rockling
Ln CPUE (Kg)