ICES Journal of Marine Science, 60: 32–37. 2003
doi:10.1006/jmsc.2002.1330

Spatial and temporal aspects of the decline in cod (*Gadus morhua* L.) abundance in the Kattegat and eastern Skagerrak

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Svedäng, H., and Bardon, G. 2003. Spatial and temporal aspects of the decline in cod (*Gadus morhua* L.) abundance in the Kattegat and eastern Skagerrak. – ICES Journal of Marine Science, 60: 32–37.

We explored the temporal and spatial evolution of cod abundance along the Swedish west coast during the past 20–40 years. Analyses of cpue data from the Swedish Nephrops fishery revealed a persistent decline in offshore abundance since the beginning of the 1980s in both the Skagerrak and Kattegat, culminating in extremely low densities in the late 1990s. Owing to a lack of reliable logbook and survey data for the area inside the trawling limit, informal statistics such as records of sport fishing clubs and notes on catches made by a coastal fishermen were used to sketch the development of cod abundance in the coastal zone. These data indicate that the decline in catches of inshore cod preceded the one in offshore areas at the end of the 1970s. The information presented indicates that the depletion of the cod stock in these areas is much worse than suggested by routine annual assessments.

Keywords: abundance, cod, distribution, *Gadus morhua*, informal records, logbook data, temporal development.

Received 20 February 2002; accepted 25 October 2002.

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Introduction

The Skagerrak–Kattegat area is commonly described as a transition area between the North Sea and the Baltic regarding both hydrology (exchange of water) and demersal fish stock identity (ICES, 1998). Cod (*Gadus morhua* L.) spawning aggregations that may supply recruits to the area have been located in the adjacent eastern North Sea, based on evidence of a major transport of cod larvae in this direction (Munk *et al.*, 1995, 1999). However, information on the relative importance of different spawning stock components in the Skagerrak–Kattegat area is scarce, as well as on their dependence on stocks in adjacent North Sea and the Sound/Belt Sea. Prior to 1996, the stock in the Skagerrak was assessed separately from the North Sea stock, but in recent years Skagerrak, North Sea and Eastern Channel cod is considered a unit stock for management purposes (ICES, 2001a). In contrast to the offshore Skagerrak region, spawning aggregations are well known in the southern part of the Kattegat (Hagström *et al.*, 1990), and Kattegat cod is consequently assessed as a separate stock (ICES, 2001b). However, spawning aggregations have also been observed on the Norwegian and on Swedish Skagerrak coasts. The population structure and the affinity of coastal stock components to offshore components and components in adjacent areas still remain unanswered questions (Danielssen, 1969; Pihl and Ulmestrand, 1993; Danielssen and Gjøsæter, 1994; Godø, 1995). Also, recent as well as historic importance of local coastal stock components in terms of recruitment and biomass remains unknown (Svedäng, 2003).

Current assessments of the North Sea/Skagerrak stock and the Kattegat stock indicate large reductions in stock size over the last two or three decades (ICES, 2001a,b), while various time-series records have revealed even more persistent and severe declines in the abundance of large, adult cod since the beginning of the 1980s in the Kattegat (Hagström *et al.*, 1990) and Skagerrak (Fromentin *et al.*, 1998). More generally, abundance of demersal fish >30 cm, including cod, in the inshore fish

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community along the Swedish Skagerrak coast has been extremely low compared to historical records for the 1920s to 1970s (Svedäng, 2003).

Information on cod abundance used in current assessments of the Kattegat stock is available from both surveys and logbooks from specific fisheries (ICES, 2001b). However, these time-series are often excluded or at least down-weighted in the final assessment models (ICES 2001a,b), because they exhibit high temporal variability (Smith and Page, 1996). Consequently, assessments are highly dependent on the age distribution of declared total landings. In addition, spatial information on the evolution of adult cod abundance at well-known spawning sites (Hagström *et al.*, 1990) has never been evaluated in combination with routine assessments in these areas. Because many observational data are excluded and the underlying assumption of population structure may represent an over-simplification of the true situation, there is an apparent risk of misjudgements regarding stock status (Hutchings, 1996; Myers *et al.*, 1997).

We make a first attempt to explore the spatial and temporal evolution of the decline in cod abundance in both inshore and offshore areas of the Kattegat and eastern Skagerrak. For the offshore area, we test a null hypothesis of a simultaneous decline along the Swedish west coast from north to south. Because reliable logbook and survey data from inshore areas are lacking, we collected informal statistics such as private records from sport fishing clubs and coastal fishermen to sketch the evolution of cod abundance in the coastal zone. Neis *et al.* (1999) and Hutchings and Ferguson (2000) show that informal records may provide early signals of major changes in stock size.

Material and methods

Offshore data

The offshore area is defined as the area outside the trawling limit (2 nm off the coastal base line, unless transferred closer to the coast). Abundance indices for cod above the minimum landing size (cpue: landings of cod >30 cm in kg h^{-1}) for 1978–1999 were based on logbook information derived from commercial fishing vessels equipped with single Nephrops trawls (70 mm cod end mesh size) fishing in the eastern Skagerrak–Kattegat area (56°30′–59°N 10°–13°E; Figure 1). This mixed fishery targets Norwegian lobster (*Nephrops norvegicus*), but takes a considerable bycatch of round- and flatfish. The locally based fishery is widely and fairly evenly distributed along the Swedish west coast all year round, deployed essentially the same gear over the last 20 years (for gear description see Ulmestrand and Larsson, 1991) and has provided an extensive data set covering about 1.6 million fishing hours over the period

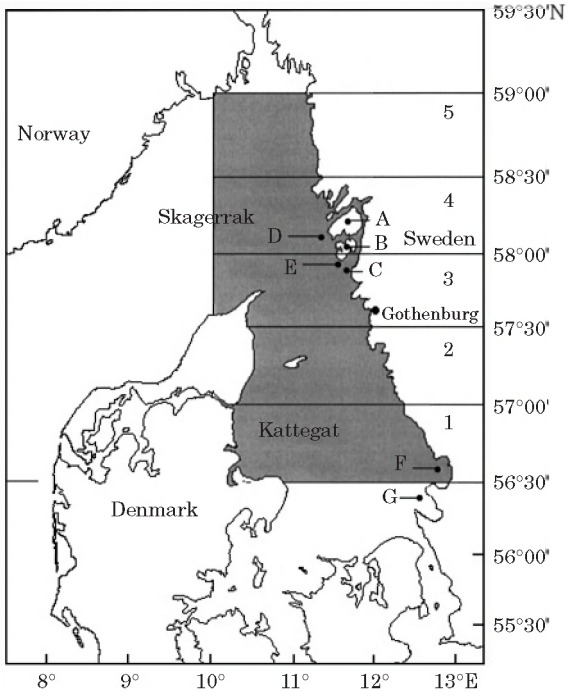

Figure 1. Study area in the Skagerrak and Katttegat (latitudinal intervals 1–5; A: island of Orust, B: island of Tjörn, C: island of Marstrand, D: outer skerry Måseskär, E: outer skerry Pater Noster skären, F: Laholmsbukten bay, G: Skälderviken bay.

1978–1999. Because Norwegian lobsters occupy specific habitat, the spatial distribution of fishing effort is assumed to be more or less constant from year to year. However, even if the fishery has been adjusted to some extent in recent years by deliberately targeting cod because of the increased market price, any estimate of a decline should be conservative (Harley *et al.*, 2001).

Because of missing data on a monthly basis by ICES statistical rectangle (0.5° latitude; 1° longitude), a comprehensive data set was produced by estimating quarterly mean cpue per 0.5° latitudinal interval (Figure 1). Mean cpue (ln transformed) was treated as dependent variable in a generalized linear model (GLM) with latitudinal interval and quarter as independent class variables and year as covariate or continuous variable (Model type III; SPSS® 10.0 for Windows). Each cell of the model (quarter within latitudinal interval) was tested for normality (Kolmogorov–Smirnov test with Lilliefors significance correction), showing that only 3 out of 20 cells slightly violated the assumption of normal distribution.

Inshore data

Informal statistics on cod abundance within the 2 nmi trawling limit were collected from professional coastal fishers and sport fishing clubs (sfc; for details see

Svedäng *et al.*, 2001), following a snowball sampling methodology (informants were asked to suggest names or societies for additional information; cf. Hutchings and Ferguson, 2000). Accepted material for analysis represented written daily notes on effort and catches, excluding retrospective compilations of historical catches. Trends in informal data sets were tested with Spearman's rank correlation coefficient ρ (Sokal and Rohlf, 1981).

The different data sets considered were:

- Sfc A made notes of individual cod catches during organized fishing tours, 1955–1983. All material was based on coast-based rod fishing for cod with unbaited hooks (spinning). Cpue was estimated as mean catch in number per fisher per day trip (including zero catches). Because the activities took place from a large number of islets and skerries, the data set was grouped into two major geographical entities (Figure 1): (a) a southerly area between Gothenburg and Marstrand, and (b) a northerly area west of Tjörn and Orust including the outer skerries Pater Noster skären and Måseskär. Data sets (a) and (b) represented 1576 and 1210 fishing days of individual participants, respectively. The distribution of trip mean cpue was tested for normality within year and area (Shapiro–Wilk's test). For years represented by enough day trips, the assumption of normality was violated in 2 cells out of 15 for data set (a) and in none out of 10 cells for data set (b).
- Sfc B. In this case, no information was available on the individual catches per day trip, but only records of the total number of participants and the total number of cod caught were available for 1969–1997. Again, all material refers to spinning with unbaited hooks from the coast, targeting mainly cod. Fishing took place in the area from the island of Marstrand to the skerries west of Orust. The data set includes mean cpue for 87 day trips. For years represented by enough observations, the assumption of normality was violated in 2 cells out of 13 (Shapiro–Wilk's test).
- Professional inshore fisherman C recorded his monthly total catch of cod from the southern part of the Kattegat coast between 1975 and 1999, with the exception of 1991 and 1995–1996. He used a small trawl, Danish seine and pound nets, targeting cod in the bays of Laholmsbukten and Skälderviken (Figure 1), which represent a major spawning area (Hagström *et al.*, 1990).

Normalized indices of cod abundance were calculated for the three time series of sfc data and the offshore Nephrops fishery by expressing annually recorded values as percentages of the highest recorded value. To facilitate comparisons and assign trends, a three-year moving average was calculated for all series.

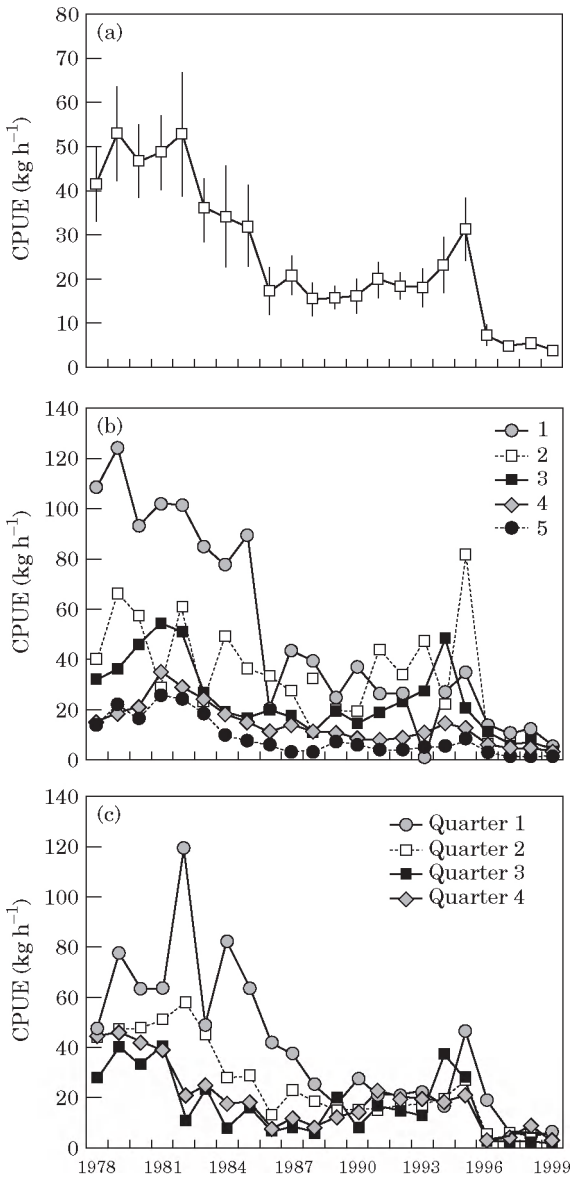

Figure 2. Mean annual cpue of cod (kg per trawling hour) in the Nephrops fishery, 1978–1999: (a) all latitudinal areas combined (error bars: ± s.e.); (b) by latitudinal area 1–5; (c) by quarter 1–4.

Results

Offshore abundance

According to the logbooks of the Nephrops fishery, the overall annual mean cpue of cod along the Swedish west coast has decreased by more than 90% between 1982 and 1999 (Figure 2a). However, the trends varied markedly at different latitudes (Figure 2b). Before 1986, cod abundance increased from north to south but in later years this pattern disappeared completely. Although

Table 1. Results for the final ANCOVA model of the effects of latitude, quarter, year and first-order interaction terms on ln transformed mean quarterly cpue (model type III; adjusted $r^2=0.62$).

Source	SS	d.f.	MS	F-value	p
Corrected model	468	12	39	60	<0.001
Intercept	216	1	216	335	<0.001
Quarter	47	3	16	24	<0.001
Latitude	30	4	7	12	<0.001
Year	211	1	211	327	<0.001
Latitude*Year	30	4	8	12	<0.001
Error	274	426	1		
Total	3644	439			
Corrected total	742	438			

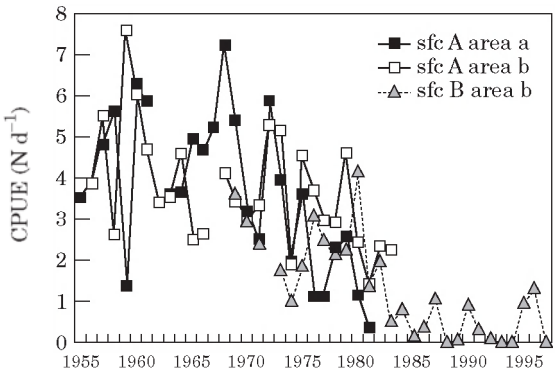

Figure 3. Mean cpue of cod in number per fishing participant and fishing trip for three sport fishing club data sets.

cpue progressed differentially over time, extremely low values were reached everywhere by 1996. In the southernmost region of the Kattegat (latitudinal interval 1), annual mean cpue decreased from >100 kg h^{-1} in 1978 to <5 kg h^{-1} in 1999, while in the northernmost region of the Skagerrak (interval 5), mean cpue decreased from about 15 kg h^{-1} to almost nil.

Seasonal patterns in cpue have also changed (Figure 2c). Before 1989, the spawning season (1st quarter) consistently yielded the highest cpue and the third quarter yielded the lowest values. However, from 1989 onwards this cyclic pattern disappeared completely.

An ANCOVA (Sokal and Rohlf, 1981) was performed on ln transformed cpue as a function of class variables latitude section (L) and quarter (Q), and of the continuous variable year (Y) treated as covariate, plus possible interaction terms according to the equation

$$\ln(\text{cpue})=a_0+a_1\ L+a_2\ Q+a_3\ Y+a_4\ LQ+a_5\ LY+a_6\ QY+a_7\ LQY.$$

The model was step-wise reduced by excluding the variable with the lowest F-value until all remaining variables contributed significantly to the variance explained. The final ANCOVA model

$$\ln(\text{cpue})=\ a_0+a_1\ L+a_2\ Q+a_3\ Y+a_4\ LY$$

showed that the effects of year, quarter, latitude, and the first-order interaction term between latitude and year were highly significant (Table 1). Most of the variation in cpue (52%) could be attributed to the effects of year and latitude. The significant interaction term between year and latitude was explained as an effect of an increase in cpue between 1993 and 1996 in the northern part of the Kattegat and the southern Skagerrak (latitudinal intervals 2, 3 and 4; Figure 2b and c).

Inshore cod abundance

The three time series obtained from sport fishing clubs (Figure 3; sfc A area a: archipelago between Gothenburg and Marstrand; sfc A area b: west of the islands of Tjörn and Orust (including the outer skerries Pater Noster skären and Måseskär; sfc B: same area b) varied regarding the period covered but all exhibit significant declines (Spearman's ρ: −0.57, $p<0.005$; −0.52; $p<0.005$; −0.78, $p<0.0001$; respectively). The declines do not completely coincide in time: in the more inshore area a, the decline occurred at an earlier stage than in the more offshore area b, at least for sfc A. The data from sfc B provide clear evidence that cod densities have remained extremely low throughout the 1980s.

A comparison between the (normalized and smoothed) cpue in the offshore Nephrops fishery in the Skagerrak (i.e. latitudinal interval 3–5) and in the three sfc data sets suggests that the decline in inshore areas preceded the decline offshore by about 5–10 yr (Figure 4).

The cpue data for fisherman C (Figure 5) clearly indicate a severe decline in cod abundance during the spawning season (1st quarter) in the 1980s. Catches during the other quarters remained fairly constant up to the early 1990s, but then dropped also. These data are largely in line with the observed decline in the offshore Nephrops fishery in this area (latitudinal section 1 in Figure 2b) and the observed changes in seasonal cpue (Figure 2c).

Discussion

This sketch of the temporal and spatial development of cod abundance along the Swedish west coast during the past 20–40 years indicates a profound decline, culminating in extremely low densities in the late 1990s. The null hypothesis of a continuous decline along the entire coast between 1982 and 1999 is supported by all data sets,

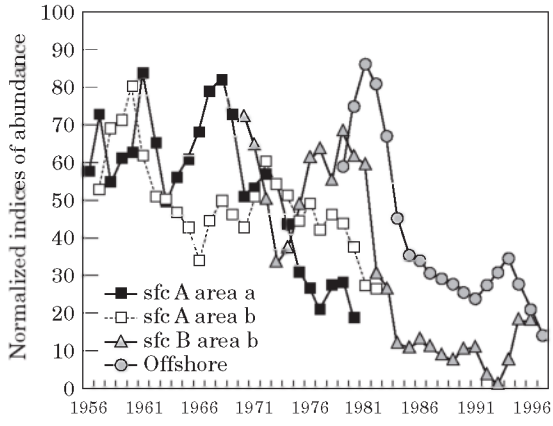

Figure 4. Moving averages (3 years) of normalized cpue indices of cod abundance for three sport fishing club data sets and the offshore Nephrops fleet in latitudinal intervals 3–5.

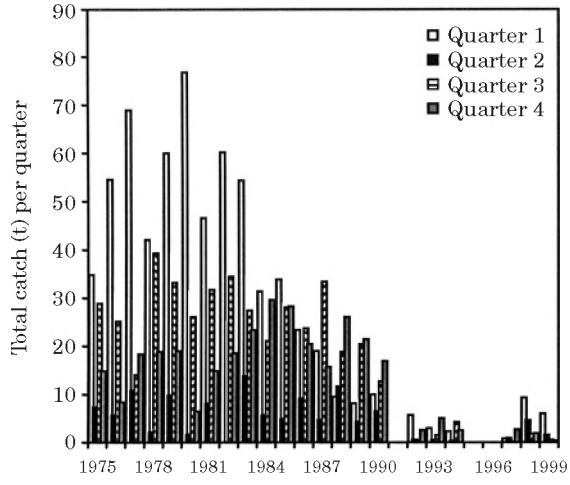

Figure 5. Total catch of cod by quarter made by a fisherman C in the bays of Laholmsbukten and Skälderviken, 1975–1999 (blanks: no data).

although there are differences in timing among the various latitudinal sections and between inshore and offshore regions. In particular, the severe drop in the offshore Kattegat region was not matched by similar declines in more northerly regions (Figure 2b). Also, there appears to have been a temporary increase in abundance in the northern Kattegat/southern Skagerrak during the mid-1990s.

The seasonal pattern in cpue in the offshore Nephrops fishery with highest densities during the spawning season might well be related to spawning migrations. Tagging experiments have shown a northward migration in January/February from the Sound to the southern Kattegat and to a lesser degree from the Belt Sea (Bagge and Steffensen, 1980). The pronounced decline observed in the first quarter and the absence of a seasonal signal during the last 10 years in both offshore waters (Nephrops fishery) and inshore Kattegat (fisherman C) would suggest an almost total disappearance of spawning aggregations.

Declines in cod abundance in the Kattegat and eastern Skagerrak have been reported previously (Hagström *et al.*, 1990; Pihl and Ulmestrand, 1993). Also, current cod stock assessments as well as International Bottom Trawl Surveys (ICES, 2001a,b) have indicated major reductions in stock size in these areas. However, according to the information presented here, which is supported by surveys in inshore areas in 2000 and 2001 (Svedäng, 2003), the depletion appears to be much more severe than concluded by the current stock assessments: according to the Nephrops fishery cod abundance was reduced by more than 90% between 1982 and 1999, whereas the routine assessment indicated a reduction of the Kattegat stock biomass by 50–55% during the same period (ICES, 2001b). This alarming status might be a signal that the original population structure has broken down by the loss of various spatial components. Following Hutchings (1996), we would argue that the present lack of information on spatial and temporal variation in abundance going into routine stock assessment may well lead to overly optimistic estimates of the present status.

The relationship between cpue and abundance is considered by Harley *et al.* (2001) as hyperstable, meaning that cpue remains relatively high even when absolute fish abundance is decreasing. Because both commercial and sport fishers tend to increase fishing efficiency thanks to technological improvements, recent cpue estimates may be expected to be biased upwards relative to estimates for the past. Therefore, observed declines in cpue might represent even steeper declines in absolute abundance, making our conclusions about the alarming status of the cod stock even more robust.

The sport fishing club data indicate that the inshore decline preceded the offshore reduction by about five to ten years. This temporal shift might be linked to a complex stock structure with a variety of local components that do not mix homogeneously with adjacent offshore components (Danielssen, 1969; Pihl and Ulmestrand, 1993; Danielssen and Gjøsæter, 1994; Godø, 1995). Although inshore demersal fish abundance in recent years seems to be regulated by recruitment from offshore spawners (Svedäng, 2003), the possibility that the situation in the past has been different cannot be excluded.

Acknowledgements

We thank fishers and sport fishing clubs for fruitful cooperation.

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