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Long-term impact of different fishing methods on the ecosystem in the Kattegat and Öresund

NOTE

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NOTE

This document was requested by the European Parliament's Committee on Fisheries.

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Long-term impact of different fishing methods on the ecosystem in the Kattegat and Öresund

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Abstract

The differences in technical regulations between the Öresund and Kattegat were evaluated, as there is ban on towed fishing gears in the Öresund but no such limitations in the adjacent Kattegat. Former important fish species have either disappeared or are reduced to remnant populations in the Kattegat while the fish community in the Öresund is less affected. It is reasonable to believe that the higher fish productivity in the Öresund is linked to the absence of trawling within the Öresund.

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CONTENTS

LIST OF ABBREVIATIONS

Bpa	Precautionary biomass level
CPUE	Catch Per Unit Effort
FKA	Fartygs Kvot Andel (Vessel Quota Share)
IBTS	International Bottom Trawl Survey
ITQ	Individual Transferable Quota
ICES	International Council for the Exploration of the Sea
MPA	Marine Protected Area
PSU	Practical Salinity Unit
SD	Subdivision
SSB	Spawning Stock Biomass
STECF	Scientific, Technical and Economic Committee for Fisheries
TAC	Total Allowable Catches

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EXECUTIVE SUMMARY

Fishing is one of the most important factors currently affecting marine ecosystems. This activity affects marine life both directly and indirectly. The direct effects include increased mortality of both young and old animals of various kinds, and the physical disturbance caused by towed fishing gear in particular on seabeds and the organisms that are connected to those habitats. Indeed, the size structure of targeted fish stocks is profoundly altered, as fishing leads to a decline in the abundance of older and thereby bigger individual fish. The indirect effects include anticipated changes to competition and survivorship within and between species.

The marine ecosystem in the Kattegat has been considered to be rather productive, and the extremely low abundance of fish in sizes of commercial interest should be regarded as the final phase of an erosion process. This process started 150 years ago, when longline fishing began to take place on an industrial scale and resources like halibut and ling were exhausted. The degradation of the ecosystem, however, became much more severe when motor trawling was introduced at the beginning of the twentieth century. Species like haddock, pollack, whiting and turbot are no longer of commercial interest as they have successively become depleted. The cod stock in the Kattegat has shrunk to a remnant population over the last two to three decades. The decline of the cod stock in the Kattegat is linked to the disappearance of separate spawning aggregations/sub-populations in the Kattegat area. Such structural changes within the stocks are very alarming, as the disappearance of stock units could effectively hinder a recovery of depleted areas even after substantial reductions in fishing activity.

A near-total ban on towed fishing gear (i.e., otter and midwater trawls, Danish seine and purse seine) has been in place in the Öresund sea area between Denmark and Sweden since 1932, due to its status as a heavily trafficked sea area. In contrast, no such gear limitations have ever been enforced in the adjacent Kattegat sea area. This difference in technical regulations in similar ecosystems provides us with an opportunity to evaluate the efficiency of these different management schemes.

Consequently, our briefing paper

- analyses and compares two adjacent areas with different fishing regulations and observed fish abundance (i.e., the Kattegat and the Öresund) and, based on this analysis,
- provides evidence of the effects of different technical regulations (i.e., towed fishing gear is banned in the Öresund but not in the Kattegat) on similar ecosystems.

Different studies and available data from the area were explored in this briefing paper, which clearly shows that Atlantic cod in particular was much more abundant and had higher age diversity in the Öresund than in the Kattegat. On the whole, a great many of formerly important fish species have either disappeared or have been reduced to remnant populations in the Kattegat, while the fish community in the Öresund has been less affected. It is reasonable to believe that the much higher levels of productivity of cod and other demersal species in the Öresund is linked to the absence of trawling within the area.

It should also be observed that a prerequisite for such effects is the existence of rather stationary cod population units in the Öresund and the Kattegat. Due to the likelihood of natal migratory behaviour (i.e., that cod, in a manner similar to eels and salmon, return to their natal spawning areas) abandoned spawning sites in the Kattegat will only be slowly replenished by fish arriving from the Öresund or the North Sea.

1. BACKGROUND

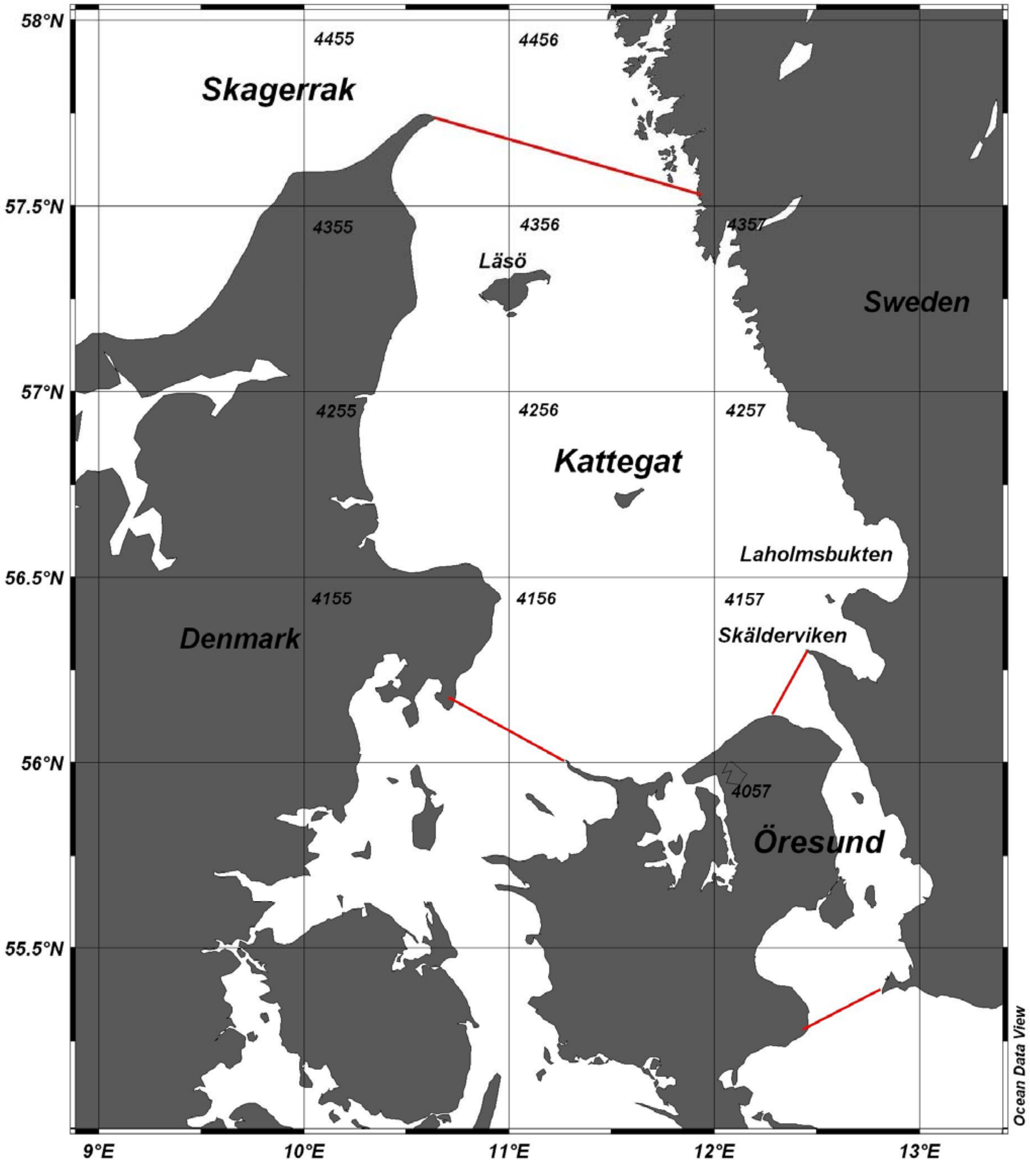
The depletion of marine fish stocks is a worldwide dilemma that threatens global food security (Botsford et al., 1997; Pauly et al., 1998; 2002; Hutchings and Reynolds, 2004; Mullon et al., 2005). Although there are encouraging signs of decreasing fishing mortality in some of the world's important fishing areas, new effective fishing regulation tools and management schemes are still needed (Worm et al., 2009). The need to evaluate and develop of the fisheries management is also repeatedly called for in the scientific literature and debate (e.g. Corkett, 1997; Castilla, 2000, Sissenwine and Symes, 2007; Costello et al., 2008; Froese et al., 2008, Cardinale and Svedäng 2009; Froese and Proelß, 2010, Svedäng et al., 2010a).

The collapse of the cod (*Gadus morhua*) stocks off the eastern coast of North America, which supported one of the world's most important fisheries for almost 500 years until the end of the twentieth century, is a striking example of mismanagement. Today most cod stocks in the northwest Atlantic have collapsed (Hutchings and Reynolds, 2004), and no recovery has been seen despite a fishing moratorium being in place since 1992 (Lilly et al., 2008). In the northeast Atlantic, stock declines are just as common, although stock productivity has hitherto remained, in general, at higher levels (Lilly et al., 2008), particularly in the Barents Sea. In the North Sea region, the erosion of the entire fish community has been taking place for more than a century (Mackinson, 2002), and in large parts of the North Sea cod is presently considered to be commercially extinct (Holmes et al., 2008). An even more profound reduction in demersal fish abundance has taken place in the eastern inshore of the Skagerrak and in the Kattegat (Svedäng, 2003; Svedäng and Bardon, 2003; Cardinale et al., 2009a,b). However, contrary to the Kattegat cod stock, which has been subject to a prolonged depletion since the 1980s (Svedäng and Bardon, 2003; Cardinale and Svedäng, 2004; Anon., 2009a), the stock in the Öresund is apparently still flourishing (Anon., 2009b; Svedäng et al., 2010a).

The aim of this study was to evaluate whether differences in stock productivity can be related to different technical fishing regulations. Since 1932, there has been a near-total ban in place on towed fishing gear in the Öresund between Denmark and Sweden (Anon., 1932), due to its status as a heavily trafficked sea area (Fig. 1). In contrast, no such gear limitations have ever been implemented in the adjacent Kattegat. The present and historical development of the fish stocks in the Kattegat and adjacent Öresund is elucidated in the briefing paper by comparing estimates of the abundance of various commercial demersal fish species such as cod, haddock (*Melanogrammus aeglefinus*) and plaice (*Pleuronectes platessa*).

These differences in abundance and size structure carry over to questions on stock separation (integrity) and migration patterns between the Kattegat and the Öresund. How the stocks intermingle and separate is, of course, essential for the understanding and interpretation of the evolution of the stock status in the two sea areas, and is discussed to some extent in a separate section of the briefing paper.

Map 1: The study area: The limits of the Öresund (SD 23) and the Kattegat (SD 21). The ICES statistical rectangles within the study area are shown.



Source: Ocean data view

2. DESCRIPTION OF THE FISHERIES AND THEIR REGULATIONS IN THE ÖRESUND AND THE KATTEGAT

KEY FINDINGS

- The fisheries in the Öresund and Kattegat have a long history with the degradation of the demersal fish stock having begun in the middle of the nineteenth century. Trawling was adopted at the start of the twentieth century.
- Since 1932, there has been an almost total ban on towed fishing gears in the Öresund but no such limitations have ever existed in the Kattegat.
- The fishery in the Kattegat and Öresund is managed both by TAC and effort regulation.

Exploitation of the fisheries in the Öresund and the Kattegat for export and trade began in the Middle Ages. Apart from the herring (*Clupea harengus*) fishery, which dominated these sea areas for centuries, a semi-industrialised longline fishery targeting halibut (*Hippoglossus hippoglossus*), ling (*Molva molva*), cod, haddock and skates developed in the 1800s in the Kattegat-Skagerrak (Hasslöf, 1949). The development of the longline fishery led to partial overfishing in the area, and the fishery started to exploit more distant fishing grounds such as those along the Norwegian trench and around the Shetlands Islands. During the nineteenth century, attempts were made to introduce sailing trawlers to the Kattegat, but without success. In contrast, trawling with motor-equipped fishing vessels was rapidly adopted by the fishing industry at the start of the twentieth century, and this sector of the fleet had already became more important than the longliners before the First World War (Andersson, 1954). This technological revolution led to a renewed focus on the Kattegat and the Skagerrak, and technological advancements have led to higher efficiency and lower costs.

The First and Second World Wars led to a reduction in fishing activity in the Kattegat, although to a lesser extent than in the North Sea, especially during the First World War. The two world wars are in fact the only events to have temporarily changed fishing patterns. There is no evidence of economic crises or regulations that have changed or diminished the fishing activity in a detectable way (Cardinale et al., 2009a).

2.1. Öresund

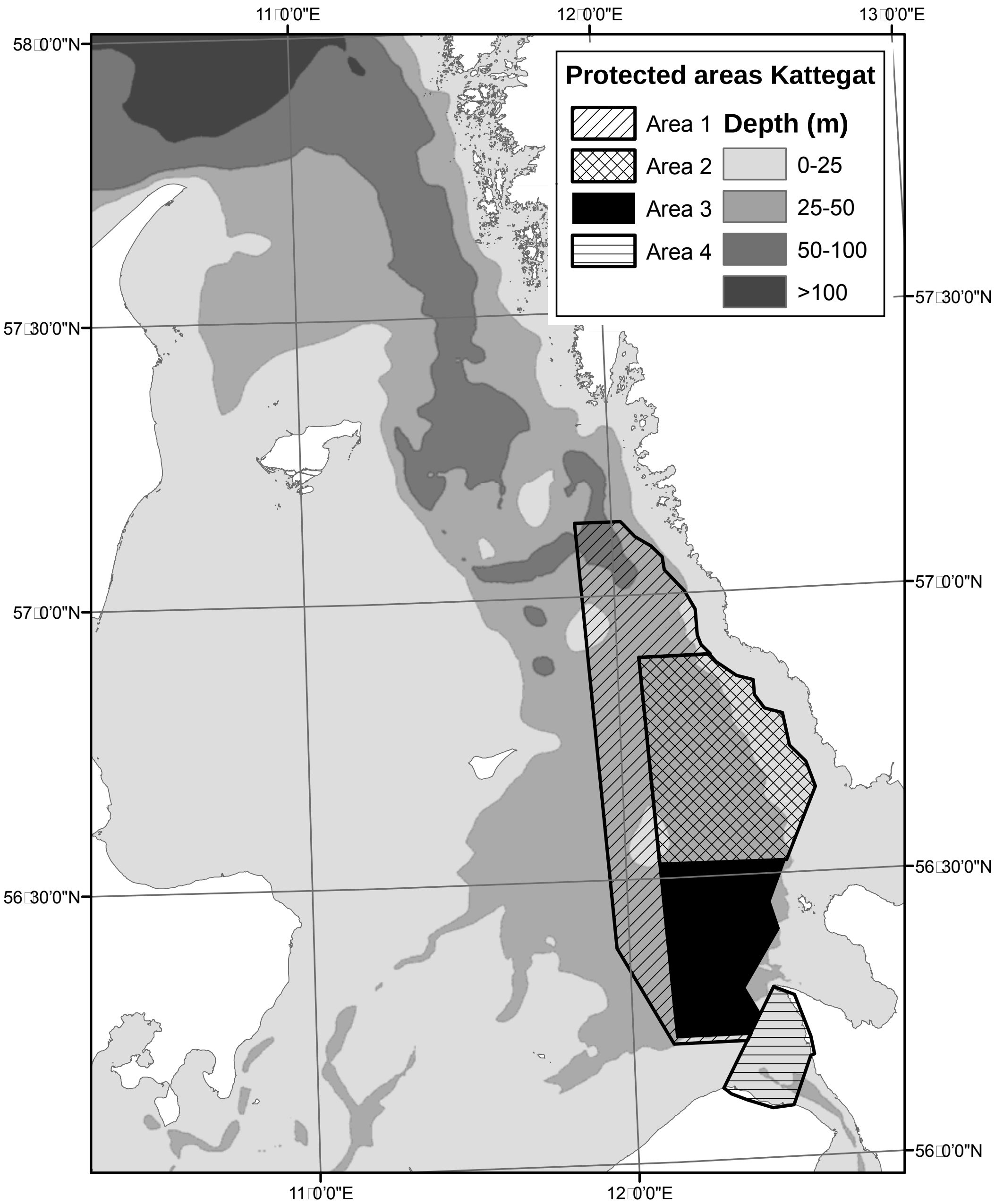
A near-total ban on towed fishing gear (i.e., otter and midwater trawls, Danish and purse seines) has been in place since 1932 in the Öresund sea area between Denmark and Sweden, due to its status as a heavily trafficked navigational area (Anon., 1932).

The trawling ban has not been implemented in a small part of the northern Öresund area adjacent to Kattegat (Map 2). In 2009, however, this trawl fishery became more restricted as trawling was banned from February to March (i.e., during the cod spawning period). This new regulation will be evaluated after three years.

The Danish and Swedish commercial fishery in the Öresund (ICES subdivision 23), which is assessed and regulated in connection with the western Baltic (e.g. Anon., 2009b), is essentially based on gill netting. The Öresund cod is managed as a part of the so-called western Baltic cod stock (which as a whole comprises the west Baltic Sea off Bornholm, the Öresund, and the Belt Sea). In the Öresund there is also a local fishery that harvests flatfish, herring (the migratory route of the eastern Baltic herring passes through the Öresund) and migratory stocks of garfish (*Belone belone*) and lumpsucker (*Cyclopterus lumpus*).

Aside from the professional fisheries, an extensive leisure fishery based on spinning gear is flourishing in the Öresund (e.g., Lagenfelt and Svedäng, 1999), as it is situated in the most densely human-populated part of Scandinavia.

Map 2: Definition of closed areas in the Kattegat, implemented from January 2009.



Area 1: Seasonally (1 January - 31 March) closed except for fishery equipped with selective gear with a very low catch of cod.
Area 2: Closed all year around except for fishery equipped with selective gear.
Area 3: Closed all year around for all fisheries including leisure fishery.
Area 4: Seasonally (February-March) closed except for fishery equipped with selective gear.

Source: Ocean data view

2.2. Kattegat

In the Kattegat, which is adjacent to the Öresund, no trawling ban on the fishery has ever been implemented. On the contrary, towed fishing gear is permitted close to the shoreline in most of the Kattegat.

The fisheries in the Kattegat and the Öresund are almost exclusively owned by the Danish and Swedish, who take about 70% and 30% of the catches, respectively. Cod is mainly taken by trawl, Danish seine and gill nets, with the former being the most important. Within the trawling group, three fleets have historically been significant: the *Nephrops norvegicus* (Norway lobster) fleet (mesh size 70-89 mm), the flatfish fleet (mesh size 90-104 mm) and the cod directed fleet (mesh size >105 mm). For decades, there has been a Swedish fishery targeting cod during the spawning season at the beginning of the year, and as by-catch in fisheries primarily targeting *Nephrops*. The status of the stock and the corresponding large cuts in quota has, however, reduced the targeted cod fisheries. Over the last few years, cod has mainly been caught as a by-catch species and landings are distributed throughout the year. It should be noted, however, that a considerable targeted cod fishery has historically been taking place in the border area between Kattegat and Öresund, where the trawl fishery has, since 2009, closed for two months out of the year.

Before 2007, quotas in Denmark were split into 14-days rations that were continuously adjusted, based on the amount of quota left. In 2007, this system was changed to a rights-based system (Vessel Quota Share, or FKA), which is best characterised as an Individual Transferable Quota (ITQ) system, since the fishermen can sell and buy fishing rights. In Sweden, the fisheries' landings are still regulated by weekly rations, which are administered by the Swedish fishermen's federation. The rations are continuously adjusted to the amount of quota remaining. Since 2003 the Swedish fisheries have also been characterised by long periods (usually in the second and third quarters of the year) during which the landing of cod is prohibited. These "cod stops" have an impact on discard rates and the size composition of the cod discards, but also on the behaviour of the fishing fleets.

In addition to Total Allowable Catches (TAC) regulations, fishing in the Kattegat is regulated by the number of fishing days. Analysis of the development of total fishing activity in the Kattegat by the Scientific, Technical and Economic Committee for Fisheries (STECF) through its Sub-group SG-MOS, showed that the total nominal effort (kWdays) of the Danish fleet in the Kattegat had been halved between 2000 and 2008. Fishing in the Kattegat is dominated by trawling, primarily with mesh sizes of 90-99 mm at present. A major shift in fishing gear occurred between 2003 and 2004, when the use of 70-89 mm trawls without sorting grids was banned. This caused an increase in the 90-99 mm trawl fishery in 2004. The activity of 90-99 mm trawls was stable between 2006 and 2008. Swedish nominal activity in the Kattegat was also stable during this period. In recent years, the use of trawls equipped with a species sorting grid in the *Nephrops* fishery, as well as trawls equipped with 120 mm escape windows, has increased.

Since nominal reductions in cod TAC had not resulted in a lowered fishing mortality, closed areas were implemented in the Kattegat in 2009 as a mean to achieve reductions in fishing activity in the spawning areas (Anon., 2009a, Map 2).

A stochastic state-space model (SAM) (Nielsen, 2008, 2009) is used for assessment of cod in the Kattegat (Anon., 2009a). Model configuration, including input data and results are available at www.kcod.stockassessment.org.

3. ECOSYSTEM DESCRIPTION: AN OVERVIEW OF THE CURRENT STATE OF THE ÖRESUND AND KATTEGAT ECOSYSTEMS

KEY FINDINGS

- Both the Öresund and the Kattegat show strong vertical stratification with a brackish upper water layer, and a heavy, oceanic water layer underneath.
- The areas show typical seasonality in terms of thermal regime.
- The productivity of the ecosystem is fairly high due to the inflow of nutrients and beneficial temperature conditions.
- The fish community is similar to those in the rest of the North Sea.
- Most commercial demersal fish stocks are recognised as commercially extinct except for sole and plaice.

The Öresund together with the Belt Sea comprises the Danish straits, and constitutes the threshold for the Baltic Sea. The surface area is about 2,000 km^2. The Öresund is a relatively shallow area; the threshold between the Öresund and the Baltic Sea is located in the southern part of the Öresund and has two furrows at a depth of eight metres. The surface water usually flows northwards, and the salinity increases from about 8-9 PSU to about 15 PSU in the northern part of the Öresund. Circulation in the Kattegat/Öresund is influenced by exchanges with neighbouring seas (the Skagerrak, the Belt Sea, and the Baltic Sea) and depends on meteorological forcing; tides are much weaker here than in the southern North Sea. The horizontal exchanges can transport fish eggs and larvae among areas.

The Kattegat forms part of the transitional area between the North Sea and Baltic Sea. Its surface area is 22,000 km^2 and the mean depth is 23 metres (Anon., 2003). Hydrographical conditions are strongly influenced by the run-off of freshwater from the Baltic Sea and the input of Atlantic water from the west/northwest. As a result, the Kattegat has a strong latitudinal salinity gradient, from 15 to 25 PSU. The Kattegat is also stratified vertically due to the run-off of Baltic water and a sharp pycnocline (i.e., density gradient) separates surface water from inflowing high saline water from the Skagerrak and the North Sea.

Thermal conditions in the Kattegat and Öresund show strong seasonality. In some years, both areas are ice covered. Summer surface temperatures rise to 15-20 °C and a warm surface layer develops in spring. Thermal stratification dissolves in autumn and the surface, and less saline water layers become homogeneously mixed.

Oxygen deficiency may occur periodically in shallower areas after thermal stratification in late summer and in combination with long periods of calm weather. The problem is aggravated by large-scale eutrophication of the coastal waters. Demersal fish will swim out of low oxygen areas, and benthic organisms may experience mortality and reduced growth. Fish kills also, occasionally occur.

The fish community is similar to those in the rest of the North Sea and can be characterised as temperature-boreal (Muus and Nielsen, 1999). The community biomass is dominated by a relatively small number of species, which include flatfishes (primarily plaice, flounder (*Platichthys flesus*), dab (*Limanda limanda*), sole (*Solea solea*), turbot (*Psetta maxima*), but historically also halibut), gadoids (primarily cod, but historically also haddock, whiting (*Merlangius merlangus*) and pollack (*Pollachius pollachius*)), and pelagic fishes (e.g., herring, sprat (*Sprattus sprattus*)). The community is supplemented on a seasonal basis by migrant species, including mackerel (*Scomber scombrus*), garfish (*Belone belone*), and occasionally horse mackerel (*Trachurus trachurus*) (Muus and Nielsen, 1999).

Productivity is higher in the Öresund and the Kattegat than in the Baltic Sea, as is the diversity in terms of the number of fish species, the number of invertebrates, and the individual growth rates for most fishes. Where oceanic waters are encountered (i.e., mostly at greater depths), the production of commercially interesting shellfish such as blue mussels (*Mytilus edulis*), shrimp (*Pandalus borealis*), Norway lobster, crab (*Cancer pagurus*) and lobster (*Homarus gammarus*) is also high.

The higher salinity and greater inflow of nutrients are the main reasons why productivity and diversity are higher in the Öresund and the Kattegat than in the Baltic Sea. The strong currents in the area supply the Öresund and Kattegat with a continuous inflow of nutrients from the Atlantic Ocean, the Baltic Sea and southern North Sea, which supports plant plankton production. In addition, the temperature regime is more favourable in the Öresund and the Kattegat than in the Baltic Sea.

Apart from physical constraints, animals and plants interact and affect one another by predation and competition for space and food. Interactions between species and populations form the ecosystems and limit the number and growth of individuals. Man is presently one of the most important actors in marine ecosystems, and fisheries play a crucial role in the structuring of the marine environment. This influence occurs both directly and collaterally. Direct effects include increased mortality of both young and old animals of various kinds, and the physical disturbance of seabeds and organisms connected to those habitats. Due to the differences in fishing regulations, the impact on and disturbance of the ecosystem is also higher in the Kattegat than in the Öresund.

A significant number of formerly important fish species have either disappeared or have been reduced to remnant populations in the Kattegat (Anon., 2006). The size structure of these fish stocks has also been profoundly altered, as the abundance of older (and thus larger) individuals has diminished. The indirect effects, such as changes in competition and survivorship within and between species, are difficult to estimate.

The Kattegat cod biomass has fallen nearly continuously for the last three to four decades, and has been below safe biological limits since 2001 (Anon., 2009). Agreed TACs and reported landings have fallen continuously since 2000. The total reported landings of cod in the Kattegat in 2009 were 197 tonnes; during the 1970s reported annual landings fluctuated between 15,000 and 20,000 tonnes (Table 1). In 2002, ICES advised that a moratorium should be placed on the fishing of this stock, and that a rebuilding plan should be implemented in order to raise SSB above the agreed Bpa (10,500 tonnes). The decline of the cod stock in the Kattegat has been linked to the disappearance of separate spawning aggregations/sub-populations in the Kattegat area (Svedäng et al., 2010a, and the references therein). The biomass of plaice is uncertain but nevertheless continues to support important commercial fisheries. The sole biomass increased in the late 1990s and early 2000s, the herring biomass decreased in the 2000s, and nowadays Norway lobster has become the backbone of the demersal fishery.

In contrast, over the last decade the total reported landings of cod in the Öresund has hovered around 2,500 tonnes (Table 1).

Table 1: Official total landings of cod in the Öresund and the Kattegat (tonnes)

Year	Öresund	Kattegat		Year	Öresund	Kattegat
1971	-	15732		**1991**	1663	6834
1972	-	17442		**1992**	2739	6271
1973	-	18837		**1993**	1275	7170
1974	-	21880		**1994**	1628	7802
1975	-	15485		**1995**	3158	8164
1976	-	16275		**1996**	4031	6126
1977	1716	20119		**1997**	2663	9460
1978	1777	13390		**1998**	3074	6835
1979	2729	14830		**1999**	3521	6608
1980	3725	13509		**2000**	3149	4897
1981	2373	15337		**2001**	2817	3960
1982	1778	12465		**2002**	2409	2470
1983	1377	12828		**2003**	1924	2045
1984	1931	11886		**2004**	2320	1403
1985	1339	12706		**2005**	2621	1070
1986	975	9096		**2006**	1914	876
1987	1640	11491		**2007**	2713	645
1988	1276	5527		**2008**	2139	449
1989	828	8590		**2009**	-	197
1990	842	5936				

Source: www.ices.dk

4. STOCK SEPARATION ISSUES AND THE DISTRIBUTION OF STOCKS

KEY FINDINGS

- Identification of separate population units is important for sustainable fishery management.
- Cod spawn at several locations in the Kattegat and the Öresund.
- There are indications of significant transportation of cod larvae among other species from North Sea stocks into the Kattegat.
- Juvenile cod in the Kattegat are thus an assortment of North Sea and Kattegat stock components, and the proportion of the two stocks in the area varies between years.
- Return migration from the Kattegat towards the North Sea seems to take place between the ages of two and three.
- Kattegat and Öresund cod are well-separated from one another.

4.1. Stock separation

Fish encountered in the Öresund and the Kattegat may not belong to the same stock, due to the fact that the Öresund/Kattegat area is a nursery and feeding area for fish in the Skagerrak/North Sea and Baltic Sea, as well as an area that harbours local resident stocks. Knowledge about the number of stocks and how stationary or migrant they are, produces vital information to fisheries managers. Spatially separate stocks need individual, spatially sensitive management, or at least recognition, monitoring and a lowering of the general exploitation rate to levels where there the survival of the least productive stock elements is secured (Stephenson, 1999).

Cod and other commercially important marine species may occur across the North Atlantic in self-sustaining population units. Elaborated methodologies in genetics have indicated the existence of divergent cod sub-populations throughout the North Atlantic (Hutchinson et al., 2001; Ruzzante et al., 2001; Knutsen et al., 2003). It is worth noting the "iceberg" phenomenon concerning the identification of ecologically relevant population structures by using genetic markers (Hauser and Carvalho, 2008); many ecologically relevant and—for management—important population units will remain undetected, since a very low number of migrants between population units may prevent any differentiation. It is therefore pertinent to involve alternative methods for the identification of sub-population units, such as chemistry of earbones (i.e., otoliths (Gibb et al., 2007, Svedäng et al., 2010b), location of spawning grounds (Vitale et al., 2008), migratory studies (Pihl and Ulmestrand, 1993; Svedäng et al., 2007), and simple deduction from time series on the distribution of juveniles and adults (Stenseth et al., 2006; Svedäng and Svenson, 2006).

There are indications that cod larvae, originating from North Sea stocks, drift into the Kattegat and settle as juvenile fish (Munk et al., 1999; Cardinale and Svedäng, 2004). Tagging studies also suggest that the Kattegat may function as a nursery area for North Sea cod, and that return migration to the North Sea is common (Svedäng and Svenson, 2006; Svedäng et al., 2007). Most return migration from the Kattegat towards the North Sea seems to take place between the ages of two and three (Svedäng et al., 2007).

Furthermore, genetic surveys along the Skagerrak coast have shown that the composition of young-of-the-year cod changes consistently year-over-year, with variation in year class strength across the entire Skagerrak area (Knutsen et al., 2004). Thus, in years with a general low level of recruitment, juveniles were assigned to neighbouring coastal cod populations (i.e., reference material attained from adult, spawning fish), whereas in years with high levels of recruitment, the juveniles were assigned to reference populations sampled at spawning sites in the western part of the Skagerrak or in the eastern North Sea. This implies that immature cod that are also in the Kattegat are an assortment of North Sea and Kattegat cod stock components, where the proportion of the two stocks in the area varies between years.

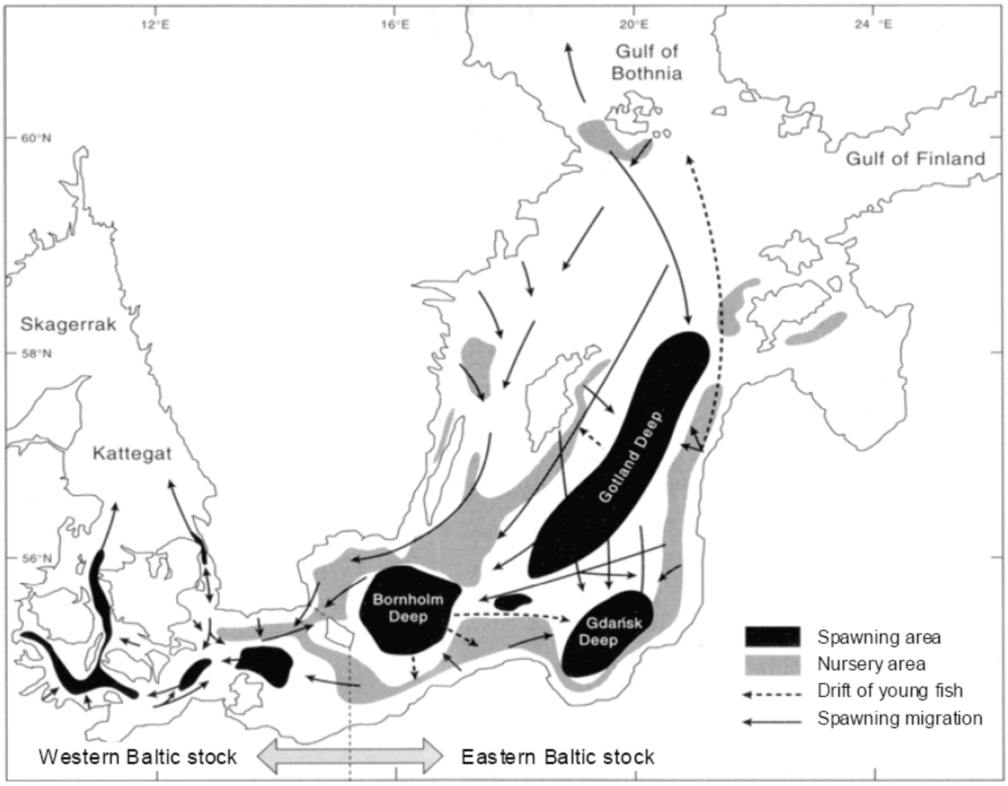
Similar to cod, the waters of the Skagerrak and the Kattegat seem to function as nursery areas for of variety of herring stocks originating from the adjacent North Sea or the Baltic Sea (Ruzzante et al., 2006). Thus, herring of local origin co-exist with juvenile and adult herring from both the western Baltic Sea and the North Sea (Ruzzante et al., 2006). After hatching in spring in the North Sea, some of the resulting larvae drift into the Skagerrak/Kattegat, where they stay for between one and two years before swimming back for spawning in the North Sea. Similarly, larvae also drift to the Skagerrak from spring spawning areas in the Kattegat and, in particular, in the western Baltic. In addition to the larval drift into the Skagerrak, adult herring of the western Baltic population also undergo annual feeding migrations towards the Skagerrak during summer. In other words, during the summer adult herring in the Skagerrak could be of local origin or could come from the Kattegat/the Western Baltic, whereas juvenile herring are mostly from the North Sea. During the winter, adult herring in the Kattegat are largely local in origin, whereas among juvenile herring, the North Sea origin dominates. In spite of extensive physical mixing that could significantly affect larval dispersal, the population structure is stable, showing significant genetic separation between all of the above mentioned stock components.

4.2. Spawning areas

The spawning areas for cod in the Öresund were described by Bagge et al. (1994, Map 3). The spawning of cod in the Kattegat was investigated by combining fishery data and survey information (Vitale et al., 2008) during the first quarter of the year that corresponds to the main spawning period of cod in the Kattegat (Vitale et al., 2005). Data from 1996 to 2004 indicate that cod catches in the Swedish bottom-trawl fishery were, to a large extent, made in spatially-restricted areas in the southeastern part of the Kattegat, either close to the entrance to the Öresund, or off the Swedish coast (Map 4).

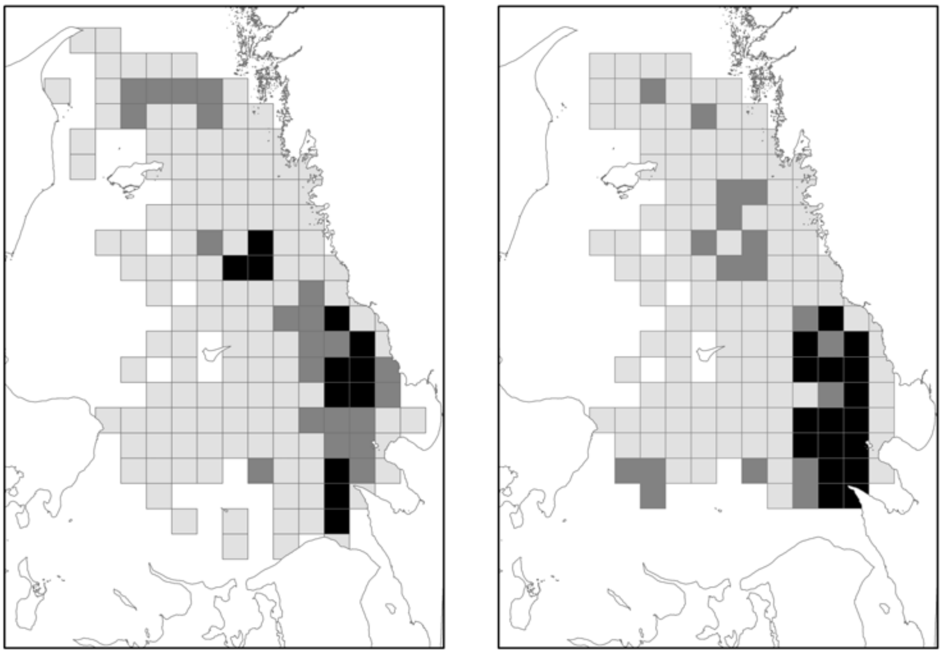
Before the stock decline in the 1990s, spawning cod could be found throughout the Kattegat, although the southern part was generally recognised as the main spawning area, particularly the bays of Skälderviken and Laholmsbukten (Hagström et al., 1990; Pihl and Ulmestrand, 1993; Svedäng and Bardon, 2003). Historically, large spawning aggregations were also observed in the Kungsbackafjorden Bay and north of Läsö (Hagberg, 2005). The stock decline coincided with the disappearance of large spawning aggregations and the abundance of adult fish in the area has dropped to very low levels (Cardinale and Svedäng, 2004).

Map 3: Spawning areas in the Baltic Sea including the Öresund



Source: Bagge et al. (1994).

Map 4: Commercial landings of cod in the first quarter of the year (left panel) and putative spawning grounds in the Kattegat 1996 – 2004 (right panel). Light grey: < 0.5 standard deviations above the mean; dark grey = 0.5 – 1.5 standard deviations above the mean; black > 1.5 standard deviations above the mean. Grid size approximately 10 x 10 km (i.e., 5 x 5 nautical miles).



Source: Vitale et al. (2008).

The issue of whether cod found in the Kattegat and the Öresund constitute separate populations was addressed in a study by deploying three independent methods: genetic surveys, tagging experiments and otolith chemistry analysis (Svedäng et al., 2010b). Although the genetic surveys showed no stock differentiation, the migratory patterns revealed in the tagging study suggested three putative spawning groups. This added evidence to previous studies that indicated spawning activity in the middle of the Öresund and in the southeastern part of the Kattegat, as well as at the border between the Öresund and the Kattegat (Bagge et al., 1994; Vitale et al., 2008). A subset of the tagged individuals was selected for analysis of otolith trace elements, thereby providing clear signal of separation between the three putative spawning populations. The identification of the spawning population unit at the border between the Öresund and the Kattegat is illustrative: no fish were tagged in this particular area; rather, they were identified by their recapture positions during the spawning period as coming from central Öresund, the Kattegat as well as the Skagerrak. The phenomenon where cod temporarily aggregate in this area during the spawning season but then abandon it for the rest of the year is also reflected in the fishing pattern shown by Danish fishers (Anon., 2009b). Nearly all cod fishing activity in this area is concentrated in the first quarter of the year (i.e., during the cod-spawning season). Furthermore, the tagging results from this study are concordant with previous tagging studies (summarised by Otterlind, 1984), which showed that some fish from the Öresund move northwards, whereas movements between the Öresund and the Baltic Sea to the south were seldom detected.

5. EVOLUTION OF THE COMMERCIAL FISH STOCKS, WITH A SPECIAL EMPHASIS ON COD

KEY FINDINGS

- The number of species and fish stocks of commercial interest has declined profoundly in the Kattegat.
- The size distribution of those stocks that remain in the Kattegat has been truncated.
- Cod and other demersal species are more abundant in the Öresund.
- Size and age distribution is also less truncated in the Öresund than in the Kattegat.
- Official landing statistics show us that the productivity in the Öresund is about 100 times higher than in the Kattegat.

The fish community in the Kattegat has changed profoundly over time. Some species such as common skate (*Dipturus batis*), sharks and halibut have more or less disappeared. For other species such as haddock, cod, pollack, plaice and turbot, an erosion of the population structure has occurred as the number of local populations has declined (Cardinale et al., 2009a,b; Svedäng et al., 2010a).

Along with the depletion of the population structure there has been a continuous truncation of the size composition over the twentieth century (Cardinale et al., 2009a, b). Swedish trawl surveys, which began at the start of the twentieth century, can be used to illustrate how this erosion of the size distribution has unfolded. The cumulative length distributions for haddock and plaice clearly show how the size distribution has changed in the Kattegat (Fig. 1). A comparison between the Öresund and the Kattegat for cod size distribution is also descriptive in this sense (Fig. 2).

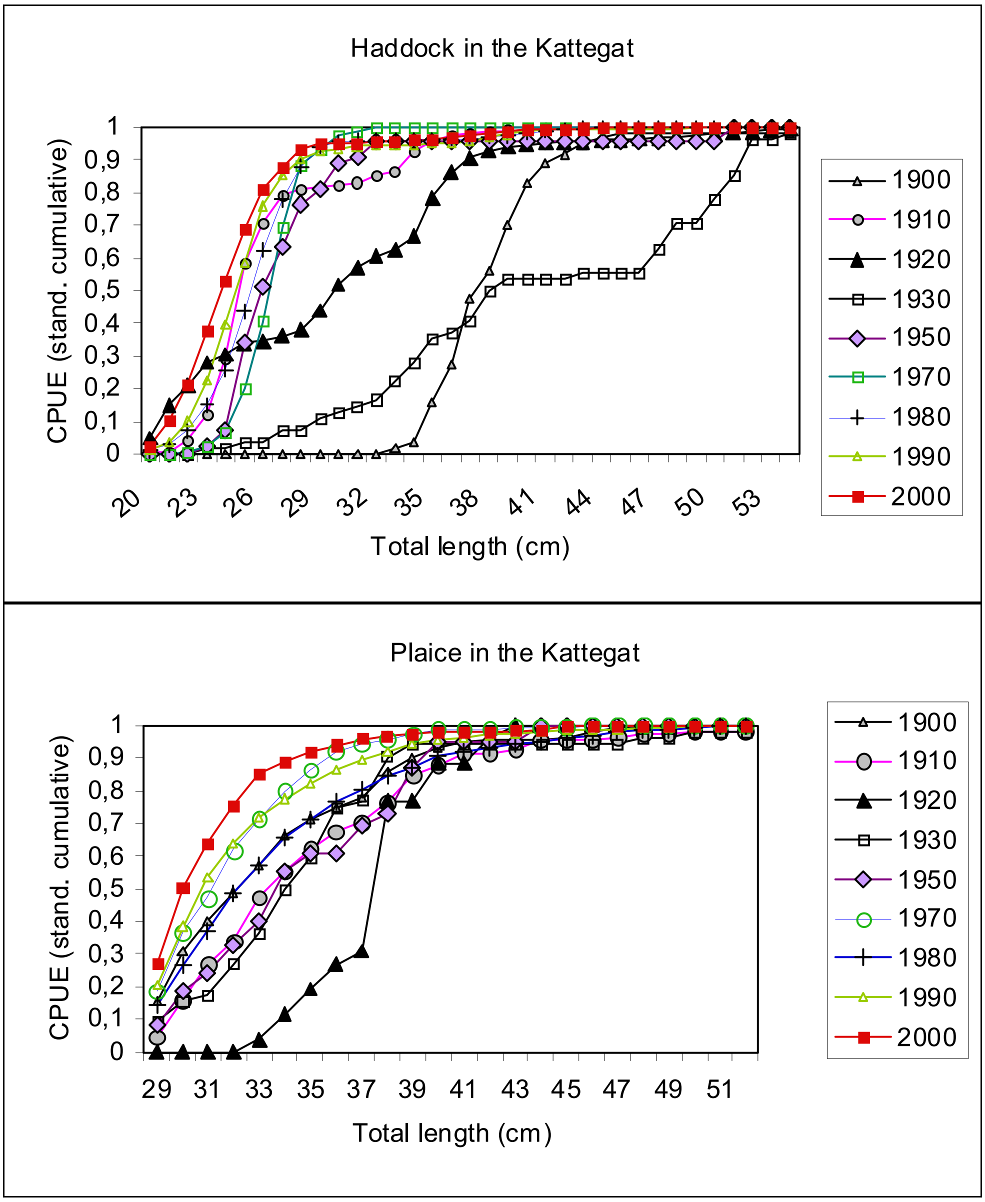
The history of haddock landings in the Swedish trawl fishery in the Kattegat and Skagerrak is illustrative for stock development during the twentieth century. Catches were initially high, especially during the 1920s (Fig. 3). They declined during the 1930s in the Kattegat in particular, but improved during and after the Second World War in the Skagerrak. Enhanced growth and recruitment in the 1960s in the Skagerrak resulted in a small recovery before the stock was virtually destroyed in the eastern North Sea thereafter.

Over the last three decades, the International Bottom Trawl Survey (IBTS) has systematically collected data on demersal fish stocks in the Kattegat and the Öresund for the last two decades. A 2003 analysis on the impact of the differential technical regulations in the Öresund and the Kattegat showed that spatial variation in the abundance of large-sized demersal fish corresponded to differences in technical fishing regulations (Svedäng et al., 2004). In no part of the Kattegat sea area could a similar abundance or size distribution of cod be found as in the Öresund. The pattern was similar for haddock, whiting, plaice and lemon sole (*Microstomus kitt*; Fig. 4).

The very different development of the cod stocks is even more pronounced when extending the time series on abundance (Fig. 5) and biomass to the present time (Fig. 6). The Kattegat cod stock has steadily declined over the last two decades, whereas the cod stock in the Öresund is stable and even shows signs of increase in recent years.

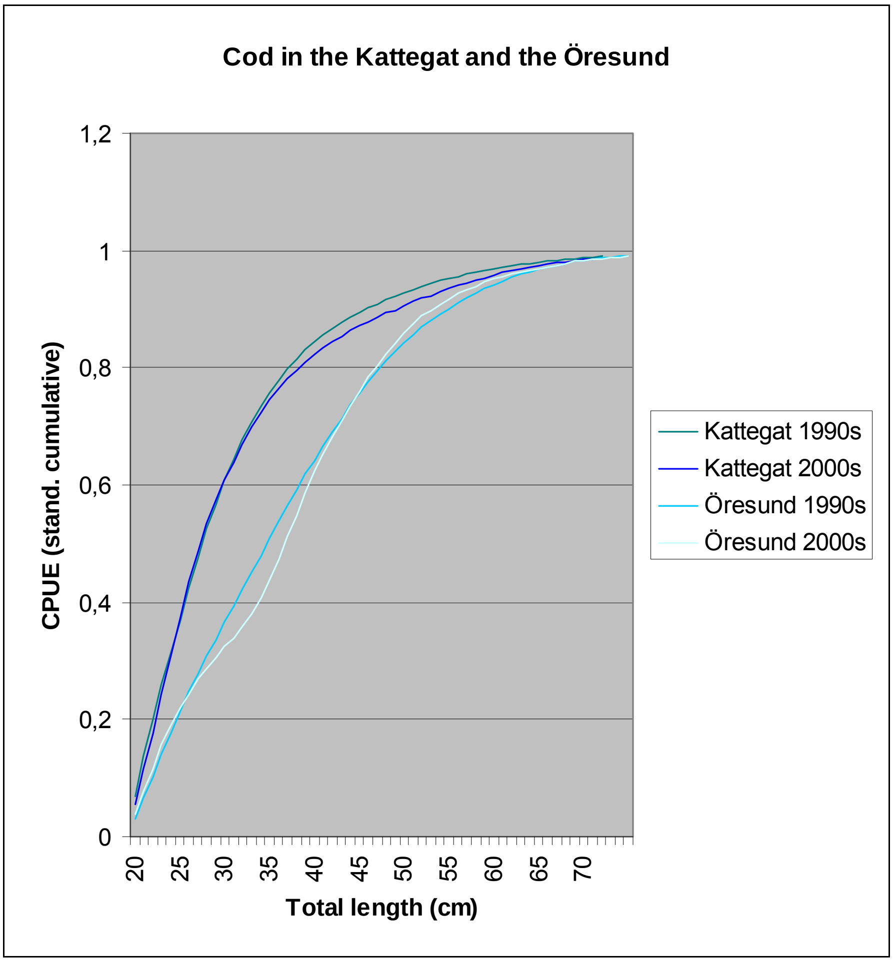
In addition, the total reported landings from the Öresund over the last decade have fluctuating around 2,500 tonnes. In other words, in an area only one tenth the size of the Kattegat, the production of prime predatory fish is ten times higher: the cod productivity per area unit is roughly 100 times higher in the Öresund than in the Kattegat (Table 1).

Figure 1: The cumulative length distribution for haddock and plaice in the Kattegat observed in Swedish trawl surveys, estimated per decade between 1901 and 2004. The catch per unit effort (CPUE) values have been standardised within decade.



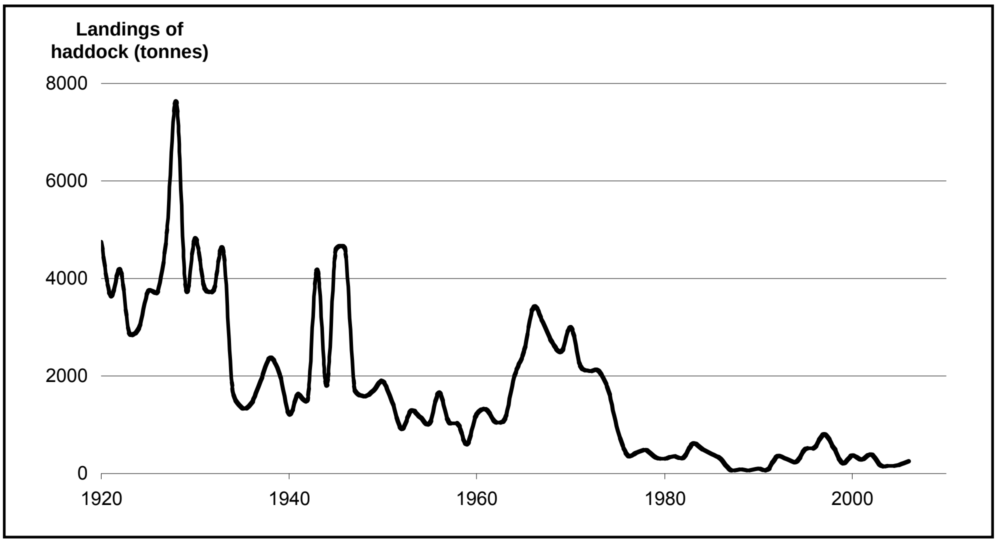
Source: Hagberg (2005)

Figure 2: The cumulative length distribution for cod in the Kattegat observed in Swedish trawl surveys, estimated per decade between 1990 and 2004. The catch per unit effort (CPUE) values have been standardised within decade (Modified from Hagberg, 2005).



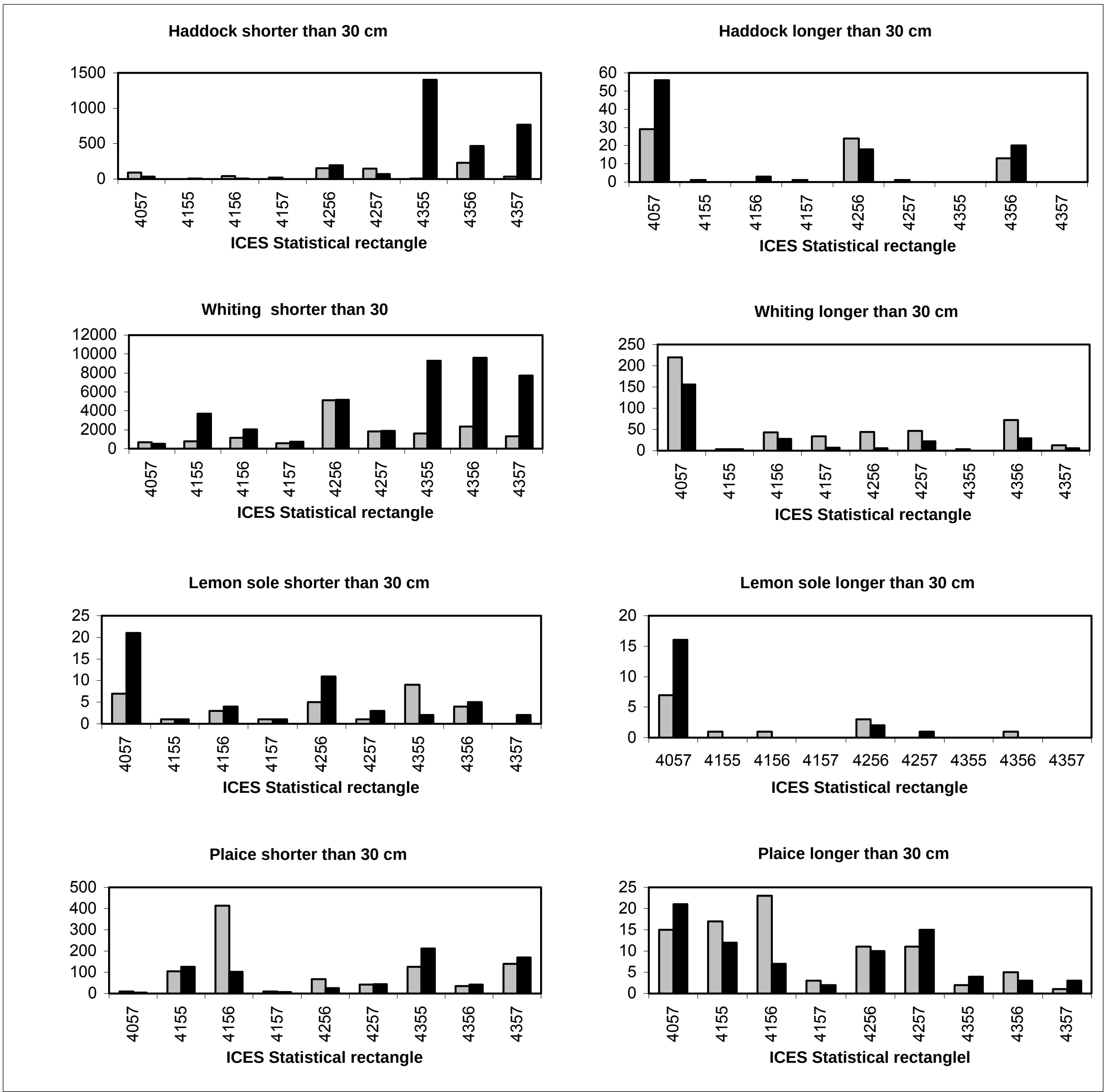
Source: Modified from Hagberg (2005)

Figure 3: Total landings of haddock in the Kattegat and the Skaggerak 1920-2006



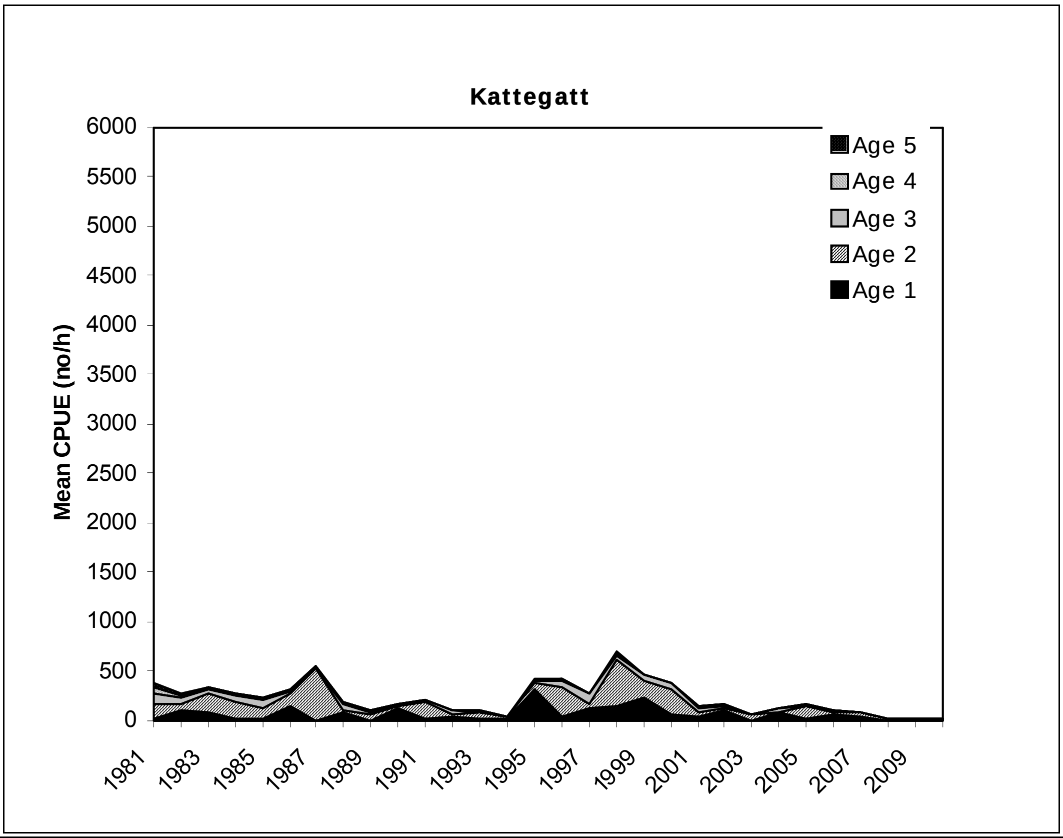
Source: The Swedish Statistical Central Bureau

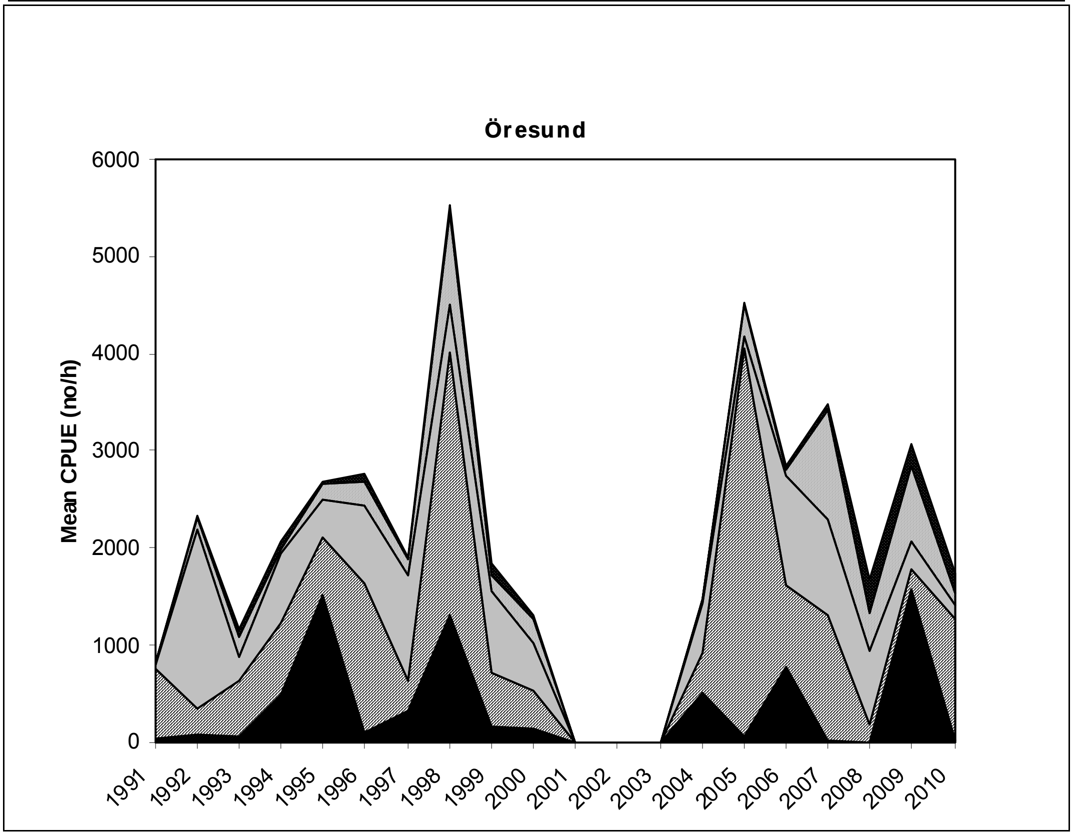
Figure 4: CPUE of haddock, whiting, plaice and lemon sole shorter (left panels) and longer than 30 cm in total length (right panels) in various ICES statistical rectangles of the Kattegat (c.f., Map 1) and the Öresund (i.e., ICES statistical rectangle 4057). Grey bars refer to first quarter of the year, black bars to third quarter.



Source: Svedäng et al., 2004

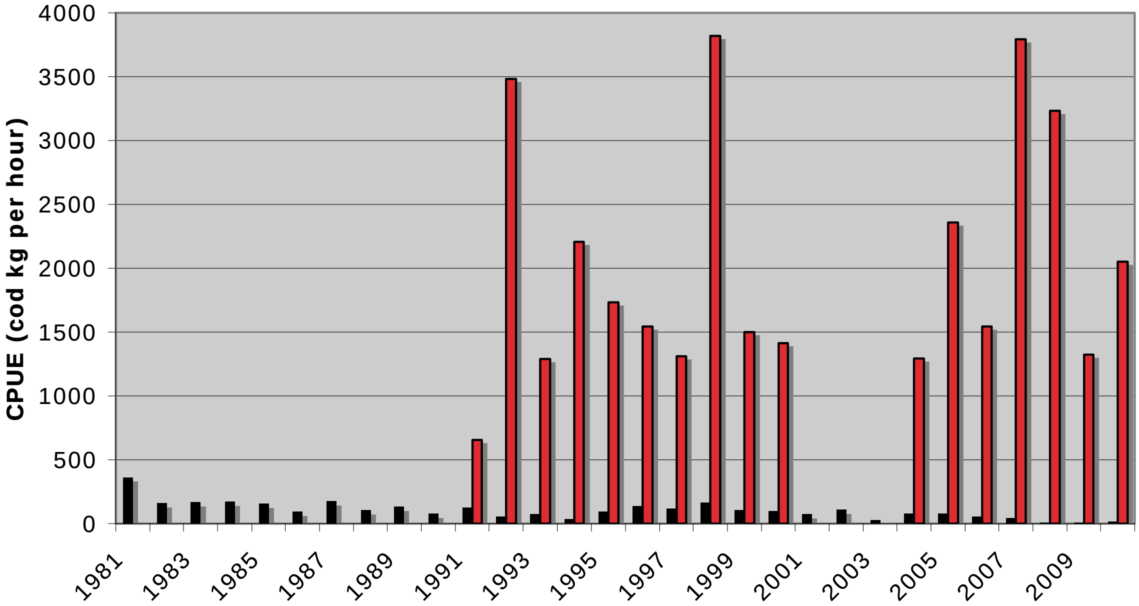
Figure 5: Age indices (1-5) for cod in the Kattegat (upper panel) between 1981 and 2010, and for cod in the Öresund (lower panel) between 1991 and 2000, and between 2004 and 2010.





Source: Swedish IBTS (ICES)

Figure 6: Biomass indices for cod in the Kattegat (black bars) between 1981 and 2010, and for cod in the Öresund (red bars) between 1991 and 2000, and between 2004 and 2010.



Source: Swedish IBTS (ICES)

6. ENVIRONMENTAL STATUS IN THE KATTEGAT AND ÖRESUND

KEY FINDINGS

- Temperatures are now as high or higher than at any time since ICES began measurements in 1921.
- Oxygen deficiencies may occur in both the Öresund and Kattegat in late summer at low wind stress. The problems are aggravated by eutrophication.
- The food web in the Kattegat in particular is believed to be profoundly altered due to the loss of the class of big predatory fish.

Summer sea surface temperatures in the Kattegat - Great Belt - Öresund region have increased by 2 °C between 1984 and 2001 (MacKenzie and Schiedek, 2006), and is likely contributing to some of the ecological changes seen in the Kattegat-Öresund. Temperatures are now as high or higher than at any time since ICES began measurements in 1921. The period of warm temperatures since the late 1980s to the early 1990s has caused the presence of some warm-adapted species (e.g., sole) to increase (Anon., 2006), as has also been observed in the North Sea and other areas of the northeast Atlantic (Brander et al., 2003; Perry et al., 2005).

Oxygen depletion events in the Kattegat, the Öresund and neighbouring fjords and estuaries occur due to the interaction of eutrophication with specific hydrographic events (Anon., 2003; Ærtebjerg et al., 2003). Such oxygen-depleted bottom areas have increased steadily in Kattegat since the 1970s. These events have reduced the size of habitats for benthic fish species and kill benthic prey for fish species (Pihl, 1994).

Brown algae (*Fucus spp.*), red algae and eelgrass (*Zostera marina*) have diminished in the Kattegat due to eutrophication (Wallentinus, 1996), whereas opportunistic filamentous algae have increased. Thus, important spawning and feeding grounds for coastal spawning species such as herring, flatfish and many limnic species are decreasing. On the contrary, the eelgrass meadows are still thriving in the Öresund. The more viable plant communities in the Öresund are unexpected, as it is also an area enriched by nutrients. A tentative explanation may be the much higher abundance of large predatory fish in the Öresund (c.f. Moksness et al., 2008).

The non-native seaweed *Sargassum muticum* has expanded rapidly in the Kattegat since the late 1980s (Wallentinus, 1996), and *Graciliaria vermiculophylla*, first observed in eastern Skagerrak in 2003, was also found in the Kattegat in 2005. *G. vermiculophylla* can have negative effects on eelgrass (and hence important fish habitats) due to its competitive dominance for light.

The most important predator of cod in the Kattegat over the last few decades has presumably been adult cod foraging on juvenile cod. As other predator species such as whiting, pollack and haddock have declined, there are no other common predatory fish to take over its role. Due to the decline of the cod stock, natural mortality could have possibly decreased since the 1980s. Increasing harbour seal populations during the last few decades, partly coinciding in time with the decline of the cod stock, could to some extent have led to increased natural mortality of juvenile cod. Adult cod feed on herring, and tagging studies using data storage tags clearly indicate an active, almost semi-pelagic feeding behaviour, at least for cod bigger than 40 cm (Svedäng, unpubl. data). There are no indications that cod in the Kattegat is experiencing food limitation, since growth patterns in both the Kattegat and the Öresund are very similar, although cod density is much higher in the Öresund than in the Kattegat. There is some evidence that the productivity of the benthic fish community has increased since the late 1950s due to eutrophication (Nielsen and Richardson, 1996).

7. CONCLUSIONS AND RECOMMENDATIONS

KEY FINDINGS

- It is natural to believe that the much better performance of the cod stock in the Öresund in particular is related to the absence of trawling.
- It is unlikely that the difference is caused by more severe environmental problems in the Kattegat, as the Öresund is enclosed by the most densely human-populated and cultivated area in Scandinavia.
- A prerequisite for these effects of the differences in technical regulations is the existence of separate, rather stationary fish stocks in the two areas.
- It is suggested that fisheries management of the Kattegat has been a fiasco, and the better management of the Öresund is just incidental.
- The findings presented in this briefing paper call for much more restrictive management actions.

The strikingly different development of the demersal fish communities in the two adjacent sea areas is best illustrated by the remarkably good performance of the cod stock in the Öresund, and the fact that the Kattegat cod is on the verge of extinction. The Öresund is enclosed by the most densely populated and cultivated area in Scandinavia, and is therefore unlikely to be cleaner or less disturbed than the rest of the Kattegat (Anon., 2003). As the Öresund cod stock is so much denser and has much higher age diversity compared to the Kattegat cod, it is natural to believe that this is related to the absence of trawling in the Öresund. Similar differences in size distribution between the two watersheds for other demersal fishes such as lemon sole, plaice, haddock and whiting support this interpretation.

This finding suggests that fisheries management in the Kattegat has been unsuccessful since performance is much better by all measures in the Öresund, where there have been real and binding restrictions in place due to traffic regulations (the trawling ban). Amazingly, it could be claimed that the Öresund cod, as part of the so-called western Baltic cod stock is, in fact, not managed at all. The quotas set for the entire western Baltic cod stock never limit the fishing activity in the Öresund, and the cod stock in the Öresund only constitutes a minor part of the total stock. What really matters for the productivity of the Öresund cod stock is the traffic ban on towed fishing gear.

This means that a much less technologically advanced fishery, based primarily on gill net fishing, is much more rewarding: the total production of cod is higher in the much smaller Öresund area than in the entire Kattegat area, and the recreational in Öresund fishery is also thriving.

The reason for the higher abundance of cod and other species like haddock, whiting, plaice, and lemon sole in the Öresund can presumably be regarded as an effect of differences in size selectivity between gill net and trawl fisheries. Demersal trawling dominates the exploitation pattern in the Kattegat, whereas fish stocks in the Öresund are almost exclusively exploited by gill netting. Gill net size selectivity depends on mesh size (Holst et al., 2002), in other words the catchability of a certain mesh size is confined to a rather limited fish size interval, being almost nil for fish outside this interval. The “catchability window” of an otter trawl is different from that of gill nets, as there is hardly any upper fish size limit at which catchability is essentially reduced (Harley and Myers, 2001). The relatively high total mortality for fish between the ages of three and five in the Öresund is likely to be relaxed at higher ages and will, therefore, give rise to a bulk of big-sized fish. In addition, the fishing mortality rates between the ages of zero and one are certainly diminutive in the Öresund. In contrast, the discard rates of juveniles in the Kattegat are considered to be at relentlessly high levels (Anon., 2007).

Marine protected areas (MPAs) have been advocated as a mean for resolving the problem of over-exploitation of fishery resources (e.g. Roberts et al., 2001). The results of this study support this point of view. However, the situation in the Kattegat is only eased to a minor extent by the presence of an adjacent MPA of a considerable size (the surface of the Öresund is about one-tenth the size of the Kattegat). More importantly, this example of an existing MPA shows the weakness of the restricted spatial preservation concept. As the prohibited area in the Öresund was instituted in 1932, it has apparently not been successful in sustaining the population structure in the heavily exploited Kattegat. In other words, the demersal stock decline has not been effectively halted by the presence of an adjacent MPA, and spill over effects are not detectable.

The increasing knowledge of the complex population structure of many fish species in temperate regions (e.g., Smedbol and Wroblewski, 2002) points at the importance of preserving whole species complexes instead of a few selected sub-populations (Frank and Brickman, 2001; Smedbol and Stephenson, 2001). For instance, since a single cod population spawns and aggregates in a number of locations (thus showing important structure on a subpopulation) it is questionable as to whether preserving a fraction of a population distribution area will be effective in terms of overall productivity and diversity. The decline of the Kattegat demersal fish community is partly due to erroneous concepts concerning recruitment and fish stock separation, leading to spurious assumptions on the recovery potential of many fish stocks.

Achieving the goal of preservation and recovery of the ocean’s former productivity is relatively straightforward since reducing fish mortality is the only thing that really matters. This is a trivial problem, technically speaking, as fisheries could be downsized by abolishing subsidies and through taxation. Increasing the selectivity of the fisheries also means that juveniles and the bulk of big fish should be spared. With better selectivity, there is also an opportunity to increase yields from the stocks without jeopardising their existence (Froese and Proelß, 2010).

It should also be remembered that other ecosystem aspects are supportive of passive fishing techniques such as gill netting over more disruptive, active techniques such as bottom trawling. An ecosystem approach to fishery could materialise by shifting from the use of active fishing gear to the use of passive gear. Indeed, such a change will not necessarily reduce the fisheries’ benefits to human society.

REFERENCES

- Andersson KA (1954) Fiskar och Fiske i Norden. Bokförlaget Natur och Kultur, Stockholm.
- Anonymous, (1932), *Kommissionen med Danmark angående fiskeriförhållandena i det till Sverige och Danmark gränsande farvattnen. (The joint commission with Denmark concerning the fisheries in waters of Sweden and Denmark).* Stockholm, 31 december 1932. In Swedish.
- Anonymous, (2003), *Swedish national report on eutrophication status in the Kattegat and the Skagerrak*, *Ospar Assessment 2002*. SMHI Report Oceanography 31.
- Anonymous, (2006), *Introduction*, In: *Report of the Baltic Fisheries Assessment Working Group (WGBFAS)*, ICES CM 2006/ACFM:24.
- Anonymous, (2007), *Cod in the Kattegat*, In: *Report of the Baltic Fisheries Assessment Working Group (WGBFAS)*, Available at www.ices.dk
- Anonymous, (2009a), *Cod in the Kattegat*, In: *ICES WGBFAS Report*. Available via http://www.ices.dk
- Anonymous, (2009b), *Cod in subdivision 22-24*, In: *ICES WGBFAS Report*. Available via http://www.ices.dk
- Ærteberg G, Andersen JH, and Hansen OS, (2003), *Nutrients and eutrophication in Danish marine waters. A challenge for science and management,* Ministry of the Environment, National Environmental Research Institute, Copenhagen, pp. 126.
- Bagge O, Thurow F, Steffensen E, and Bay J, (1994), *The Baltic Cod,* Dana, 10:1-28.
- Botsford LW, Castilla JC, and Peterson CH, (1997), *The management of fisheries and marine ecosystems,* Science, 277: 509-515.
- Brander KM, (2003), *What kinds of fish stock predictions do we need and what kinds of information will help us to make better predictions,* Scientia Marina, 67: 21–33.
- Cardinale M, and Svedäng H, (2004), *Modelling recruitment and abundance of Atlantic cod,* Gadus morhua, *in the eastern Skagerrak-Kattegat (North Sea): evidence of severe depletion due to a prolonged period of high fishing pressure,* Fisheries Research, 69: 263-282.
- Cardinale M, and Svedäng H, (2008), *Mismanagement of fisheries: policy or science?*, Fisheries Research, 93: 244–247.
- Cardinale M, Hagberg J, Svedäng H, Bartolino V, Gedamke T, Hjelm J, Börjesson P, and Norén F, (2009a), *Fishing through time: population dynamics of plaice (*Pleuronectes plates*) in the Kattegat-Skagerrak over a century*, Population Ecology, 52: 251-262.
- Cardinale M, Linder M, Bartolino V, Maiorano L, and Casini M, (2009b), *Conservation value of historical data: reconstructing stock dynamics of turbot during the last century in the Kattegat-Skagerrak,* Marine Ecology-Progress Series, 386: 197-206.
- Castilla JC, (2000), *Roles of experimental marine ecology in coastal management and conservation,* Journal of Experimental Marine Biology and Ecology, 250: 3-21.
- Corkett CJ, (1997), *Managing the fisheries by social engineering: a re-evaluation of the methods of stock assessment*, Journal of Applied Ichthyology, 13: 159-170.
- Costello C, Gaines SD, and Lynham J, (2008), *Can catch shares prevent fisheries collapse?*, Science 19: 1678-1681.
- Frank KT, and Brickman D, (2001), *Contemporary management issues confronting fisheries science,* Journal of Sea Research, 45: 173-187.

- Froese R, Stern-Pirlot A, Winker H, and Gascuel D, (2008), *Size matters: How single-species management can contribute to ecosystem-based fisheries management,* Fisheries Research, 92: 231-241.
- Froese R, and Proelß A, (2010), *Rebuilding fish stocks no later than 2015: will Europe meet the deadline?*, Fish and Fisheries (in press).
- Gibb FM, Gibb IM, and Wright PJ, (2007), *Isolation of Atlantic cod (*Gadus morhua*) nursery areas,* Marine Biology, 151: 1185-1194.
- Hagberg J, (2005), *Utökad analys av historiska data för att säkerställa referensvärden för fisk (Improved analysis of historical data for ensuring fish reference points)*, Swedish Board of Fisheries (in Swedish), 22 p.
- Hagström O, Larsson P-O, and Ulmestrand M, (1990), *Swedish cod data from the international young fish surveys 1981-1990*, ICES CM 1990/G:65.
- Harley SJ, and Myers RA, (2001), *Hierarchial Bayesian models of length-specific catchability or research trawl surveys*, Canadian Journal of Fisheries and Aquatic Science, 58: 1569-1584.
- Hasslöf O, (1949), *Svenska västkustfiskarna: Studier i en yrkesgrupps näringsliv och sociala kultur (The Swedish west coast fishermen: Studies on the industrial life and social culture of an occupational class) ,* Skrifter utgivna av bohusläns museum och Bohusläns hembygdsförbund, Nr 18. Risbergs tryckeri AB, Uddevalla. In Swedish.
- Hauser L, and Carvalho GR, (2008), *Paradigm shifts in marine fisheries genetics: ugly hypotheses slain by beautiful facts,* Fish and Fisheries, 9: 333–362.
- Hakansson, 2002
- Holmes SJ, Wright PJ, and Fryer RJ, (2008), *Evidence from survey data for regional variability in cod dynamics in the North Sea and West of Scotland*, ICES Journal of Marine Science, 65: 206-215.
- Holst R, Wileman D, and Madsen N, (2002), *The effect of twine thickness on the size selectivity and fishing power of Baltic cod gill nets*, Fisheries Research, 56: 303-312.
- Hutchings JA, and Reynolds JD, (2004), *Marine Fish Population Collapses: Consequences for Recovery and Extinction Risk*, Bioscience, 54: 297-309.
- Hutchinson WF, Carvalho GR, and Rogers SI, (2001), *Marked genetic structuring in localised spawning populations of cod* Gadus morhua *in the North Sea and adjoining waters, as revealed by microsatellites,* Marine Ecology Progress Series, 223: 251-260.
- Knutsen H, Jorde PE, André C, and Stenseth N CHR, (2003), *Fine-scaled geographical population structuring in a highly marine species: the Atlantic cod,* Molecular Ecology, 12: 385-394.
- Knutsen H, André C, Jorde PE, Skogen MD, Thuróczy E, and Stenseth NC, (2004), *Transport of North Sea cod larvae into the Skagerrak coastal populations,* Proceedings of the Royal Society Series B, 271: 1337–1344.
- Lagenfelt I, and Svedäng H, (1999) *Fisk och fiske i Västerhavets och Öresunds kustområden. (Coastal fish and fisheries in Öresund, Kattegat and Skagerrak)*, With English Summary. Fiskeriverket rapport, 1999:7. 51 p.
- Lilly GR, Wieland K, Rothschild BJ, Sundby S, Drinkwater KF, Brander K, Ottersen G, Carscadden JE, Stenson, GB, Chouinard GA, Swain DP, Daan N, Enberg K, Hammil MO, Rosing-Asvid A, Svedäng H, and Vázquez A, (2008), *Decline and recovery of Atlantic cod (*Gadus morhua*) stocks throughout the North Atlantic, pp. 39–66*. In: *Resiliency of Gadid Stocks to Fishing and Climate Change* (Kruse, G., Drinkwater, H., Ianelli, K., Link, J. N., Stram, J.S., Wespestad, D. L., and Woodby, D., Eds.), Fairbanks, AK: Alaska Sea Grant College Program, AK-SG-08-01.

- Mackenzie B, and Schiedek D, (2007), *Long-term sea surface temperature baselines—time series, spatial covariation and implications for biological processes,* Journal of Marine Systems 68: 405–420.
- Mackinson S, (2002), *Representing trophic interaction in the North Sea in the 1880s using the Ecopath mass-balance approach*, In: *Fisheries impacts on North Atlantic ecosystems: models and analyses* (Gúenette S, Christensen V, and Pauly D, Eds.), Fisheries Centre Research, Reports 9: 35–98.
- Moksnes P-O, Gullström M, Tryman K, and Baden S, (2008), *Trophic cascades in a temperate seagrass community,* Oikos, 117: 763-777.
- Mullon C, Freon P, and Cury P, (2005), *The dynamics of collapse in world fisheries,* Fish and Fisheries, 6: 111-120.
- Munk P, Larsson PO, Danielsen D, and Moksness E, (1999), *Variability of frontal zone formation and distribution of gadoid fish larvae at the shelf break in the northeastern North Sea,* Marine Ecology Progress Series, 177: 221-233.
- Muus BJ, and Nielsen JG, (1999), *Sea fish,* Scandinavian Fishing Year Book, Hedehusene, Denmark.
- Nielsen A, (2008), *State-space assessment model for cod in the Kattegat*, Working Document 7, ICES WGBFAS 2008.
- Nielsen A, (2009), *State-space fish stock assessment model as alternative to (semi-) deterministic approaches and stochastic models with a high number of parameters*, Working Document 14, ICES WKROUND.
- Nielsen E, and Richardson K, (1996), *Can changes in the fisheries yield in the Kattegat (1950-1992) be linked to changes in primary production?*, ICES Journal of Marine Science, 53: 988-994.
- Otterlind G, (1984), *Cod migration and transplantation experiments*, ICES CM 1984/ J:13.
- Pauly D, Christensen V, Dalsgaard J, Froese R, and Torres FC, Jr. (1998), *Fishing down marine food webs,* Science, 279: 860-863.
- Pauly D, Christensen V, Guenette S, Pitcher TJ, Sumaila UR, Walters CJ, Watson R, and Zeller D, (2002), *Towards sustainability in world fisheries*, Nature, 418: 689-695.
- Perry AL, Low PJ, Ellis JR, Reynolds JD, (2005), *Climate change and distribution shifts in marine fishes,* Science, 308, 1912-1915.
- Pihl L, (1994), *Changes in the diet of demersal fish due to eutrophication - induced hypoxia in the Kattegat, Sweden*, Canadien Journal of Fisheries and Aquatic Science, 51: 321-336.
- Pihl L, and Ulmestrand M, (1993), *Migration pattern of juvenile cod (*Gadus morhua*) on the Swedish west coast,* ICES Journal of Marine Science, 50: 63-70.
- Roberts CM, Bohnsack, Gell F, Hawkins JP, and Goodridge R, (2001), *Effects of marine reserves on adjacent fisheries*, Science, 294: 1920-1923.
- Ruzzante DE, Taggart CT, Doyle RW, and Cook D, (2001), *Stability in the historical pattern of genetic structure of Newfoundland cod (*Gadus morhua*) despite the catastrophic decline in population size from 1964 to 1994*, Conservation Genetics, 2:257-269.
- Ruzzante DE, Mariani S, Bekkevold D, et al., (2006), *Biocomplexity in a highly migratory marine pelagic fish*, Proceedings of the Royal Society London, Series B, 273:1459–1464.
- Sissenwine M, and Symes D, (2007), Reflections on the common fishery policy. Report to the General Directorate for Fisheries and Maritime Affairs of the European Commission, July 2007. www.greenpeace.org/raw/content/sweden/rapporter.../fisheries-policy.pdf
- Smedbol RK, and Stephenson R, (2001), *The importance of managing within-species diversity in cod and herring fisheries of the north-western Atlantic,* Journal of Fish Biology, 59: 109-128.

- Smedbol RK, and Wroblewski JS, (2002), *Metapopulation theory and northern cod population structure: interdependency of subpopulations in recovery of a groundfish population*, Fisheries Research, 55: 161-174.
- Stenseth N-C, Jorde PE, Chan K-S, Hansen E, Knutsen H, André C, Skogen MD, and Lekve K, (2006), *Ecological and genetic impact of Atlantic cod larval drift in the Skagerrak*, Proceedings of the Royal Society of London Series B, 273: 1085-1092.
- Stephenson RL, (1999), *Stock complexity in fisheries management: a perspective of emerging issues related to population sub-units*, Fisheries Research, 43: 247–249.
- Svedäng H, (2003), *The inshore demersal fish community on the Swedish Skagerrak coast: regulation by recruitment from offshore sources*, ICES Journal of Marine Science, 60: 23-31.
- 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.
- Svedäng H, and Svenson A, (2006), *Cod* Gadus morhua *L. populations as behavioural units: inference from time series on juvenile abundance in the eastern Skagerrak*, Journal of Fish Biology, 69: 151-164.
- Svedäng H, Hagberg J, Börjesson P, Svensson A, and Vitale F, (2004), *Bottenfisk i västerhavet (Demersal fish in the Swedish west coast). Swedish Board of Fisheries*, Finfo 2004:6. (In Swedish).
- Svedäng H, Righton D, and Jonsson P, (2007), *Migratory behaviour of Atlantic cod Gadus morhua: natal homing is the prime stock-separating mechanism*, Marine Ecology-Progress Series, 345: 1-12.
- Svedäng H, Stål J, Sterner T, and Cardinale M, (2010a), *Subpopulation structure in cod (*Gadus morhua*) puts strain on the management toolbox*, Reviews in Fisheries Science, 18: 139–150.
- Svedäng H, André C, Jonsson P, Elfman M, and Limburg K, (2010b), *Homing behaviour and otolith chemistry suggest fine-scale sub-population structure within a genetically homogenous Atlantic cod population*, Environmental Biology of Fishes (accepted after minor revision).
- Vitale F, Cardinale M, and Svedäng H, (2005), *Evaluation of the temporal development of the ovaries in cod (*Gadus morhua*) from the Kattegat and Sound*, Journal of Fish Biology, 67: 669–683.
- Vitale, F., Börjesson, P., Svedäng, H., and Casini, M. (2008), *The spatial distribution of cod (*Gadus morhua *L.) spawning grounds in the Kattegat, eastern North Sea*, Fisheries Research, 90: 36-44.
- Wallentinus I, (1996), *Effects of eutrophication on macroalgal communities along the Atlantic shores (the Swedish west coast, Norway, and Iceland)*, In: *Schramm, W, R L Fletcher & P N Nienhuis (eds) Marine benthic vegetation in Europe. Recent changes and the effects of eutrophication*. COST 48, Springer Verlag, Berlin pp. 165-184.
- Worm B, Hilborn R, Baum JK, et al. (2009), *Rebuilding global fisheries,* Science, 325: 578-585.

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