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Ulrich, Clara; Boje, Jesper; Cardinale, Massimiliano; Gatti, Paul; le Bras, Quentin; Andersen, Michael; Hansen, Jakob Hemmer; Hintzen, Niels T.; Jacobsen, Jonathan B.; Jonsson, Patrik; Miller, David C.M.; Eg Nielsen, Einar; Rijnsdorp, Adriaan; Svedäng, Henrik; Wennhage, Håkan

Publication date:
2012

Document Version
Publisher's PDF, also known as Version of record

ICES CM 2012/N:02

EXTENDED ABSTRACT (article in progress) – NOT TO BE CITED WITHOUT PRIOR REFERENCE TO THE AUTHOR

Improving the assessment and management of the plaice stock complex between the North Sea and the Baltic Sea.

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1 Abstract

Plaice in Kattegat and Skagerrak have traditionally been considered as one stock unit. However the collected information on biology and fishery in areas between the North and the Baltic Seas suggest for changes in assessment units as well as in management areas. Plaice in Skagerrak (Division 20) is now considered to be closely associated with plaice in the North Sea and is proposed to be included in the North Sea plaice stock assessment, although it is recognized that local populations are present in the area. Therefore, specific management of the Skagerrak plaice is suggested. Plaice in Kattegat (Division 21), the Belts (Div. 22) and the Sound (Div 23) is considered a stock unit and is proposed to be assessed as such. However, separate management by area is also suggested to assure the preservation of the

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local populations. Plaice in the Baltic (Div. 24-32) is considered a stock unit and is proposed to be assessed and managed as such.

Pragmatic options are suggested for empirical harvest control rules accounting for the dynamic of local abundance, using a survey-based biomass indicator. For the future, new scientific analyses should be developed to better inform the origin of the catches, provided that additional resources are allocated to the annual monitoring of different stocks and components. Such information would provide on-going quantitative information on the degree of mixing of the various components, potentially allowing a more accurate assessment, management and conservation of the status of these.

2 Introduction

An essential prerequisite of sustainable fisheries is the match between biologically relevant processes and management action (Reiss et al. 2009). Management however, is often undertaken at the scale of large hydrographical basins with fixed administrative boundaries, which can often mismatch the ecological and/or genetic reality of the marine populations. Even when known and acknowledged (see e.g. review by Reiss et al., 2009), such a mismatch can often not be easily solved. This is partly because fisheries management has its own inertia and set of conflicting objectives, but partly also because the exact characterization and quantification of the mismatch, that could trigger improved action, is a difficult task (ICES 2011b). First the concept of a population must be defined. Two main points of view can be distinguished (Waples and Gaggiotti, 2006). The ecological one defines a population as a group of individuals of the same species that co-occur in space and time and have an opportunity to interact with each other. The second one is the evolutionary one, which defines a population as a group of individuals of the same species being genetically close enough that any member of the group can potentially mate with any other. Fisheries management is largely based on the first paradigm (and refer to the concept of stock as the discrete spatial unit of co-occuring populations), whereas stock sustainability is predominantly linked to the second (Reiss et al., 2009).

Fish are distributed in the sea depending on different biotic and abiotic factors. Fish species show complex life cycles that comprises of different life history stages (eggs, larvae, juveniles, adults) that differ in their habitat requirements and inhabit spatially segregated habitats and a population can only sustain itself when the habitats are connected and the fish can close the life cycle (Sinclair, 1988; Rijnsdorp et al., 2009). In a specific area, fish of different populations may mix during feeding while they segregate during the spawning period. Hence, it is important to know if the fish in a certain area belong to a single panmictic population, or belong to different populations (Metcalfe, 2006), that may co-occur during feeding for example. In this case the stock would be considered as the catch area although different genetic populations might be affected (Kell et al, 2009). All individual components would however need to be maintained and their dynamics monitored to ensure the overall sustainability of the stock. For some species, and herring in particular, it has been possible to monitor the relative proportion of each population in an area (e.g. Clausen et al., 2007, Kell et al., 2009, Bierman et al., 2010, Payne, 2010, ICES, 2011). But in most cases it is not possible, and fish stocks are usually assessed ignoring the underlying structure of population structure. This may lead to underestimated risks of stock collapse and local depletion, especially in a context of reduced abundance (Hilborn, 2003, Kell et al, 2009, Link et al., 2011, Ying et al., 2011).

The European plaice (Pleuronectes platessa, Pleuronectidae) is predominantly distributed within the North Sea but extends to adjacent waters. Plaice stock structure is made of different spawning components, which separate during spawning and mix during feeding. Juveniles of different spawning components mix also partly on nursery grounds (Hunter et al., 2004, Kell et al., 2004, Hufnagl et al., in review). Although there are several different spawning components, Hoarau et al. (2002, 2004) found weak genetic differentiation between the North Sea-Irish Sea, Norway, the Baltic and the Bay of Biscay using mt-DNA markers. In spite of the assumed connectivity between components, plaice abundance is assessed and managed as a suite of ten discrete stock units from the West of Ireland to the Eastern Baltic Sea. Only for the eastern English Channel is the connectivity with both the Western English Channel and the North Sea coarsely accounted for in stock assessment and advice (ICES, 2012).

On the other side of the North Sea, a single plaice stock has historically been defined in the transition area to the Baltic Sea, in ICES Division IIIa (covering two sub-divisions, Skagerrak (IIIa North) and Kattegat (IIIa South)). This area is characterised by a very steep salinity gradient and important mainstream currents (Danielssen et al,1997, Figure 1). Though, the assessment of this stock by the International Council for the Exploration of the Sea (ICES) has increasingly been deemed as unreliable due to high uncertainty and large retrospective patterns in the estimates of both fishing mortality and spawning stock biomass and has consequently been rejected as a basis for advice since 2005 (ICES, 2011a[2]). The annual advice for future catch opportunities has thus long been given without sound scientific basis (ICES, 2010a[3]). This has important political and socio-economic consequences, as this advice would then not follow the perceived fluctuations of abundance. In comparison, the neighbouring North Sea plaice stock has increased considerably in recent years, with subsequent TAC increases (ICES, 2011a). Although plaice is not among the highest valued species in the area, it is nevertheless targeted by a coastal fishery along the Danish Northwestern Jutland coast. It enters also a mixed trawl fishery together with cod and Nephrops. Thus, the scientific inability to deliver a robust stock assessment in area IIIa is a concern for the sustainability of the stock itself but also for the local fishery that exploits it. Incidentally, the lack of agreed assessment represents also an institutional barrier against fisheries ecolabelling, and this has contributed to creating mistrust and frustration among stakeholders. Overall, there has thus been increasing scope for improving the whole governance scheme around that stock.

Over the years, a number of initiatives have been taken within ICES to improve the assessment of this stock (e.g. ICES 2006), but with limited success. The current perception (ICES, 2011a) is that the assessment suffers from a number of issues beyond the scope of standard stock assessment assumptions, illustrated by the difficulty in tracking cohorts in the catch-at-age matrix. High individual variability in growth patterns (body size and otolith shape) has repeatedly been observed for this stock, which could arise from the heterogeneity of local hydrographical growth conditions and/or a mixing of different populations with own dynamics within the stock. This second hypothesis is sustained by the fact that plaice catches are predominantly taken in the south-western entrance of the Skagerrak where mixing may occur with North Sea plaice.

This study aims therefore at reconsidering the stock structure of plaice in this transition area at the local scale, and at revising the established assumptions about stock definition. Secondly, a new innovative and pragmatic approach is suggested for improving stock assessment and spatial management for the

[2] http://www.ices.dk/reports/ACOM/2011/WGNSSK/Sec 07 Plaice in IIIa.pdf
[3] http://www.ices.dk/committe/acom/comwork/report/2010/2010/ple-kask.pdf

fishery, which would ensure the monitoring and the preservation of the most depleted population components while allowing sustainable exploitation of the healthiest and most productive areas.

3 Material and Methods

A combination of extensive literature review and data analyses was used to produce the most complete picture of the plaice stock structure from the Eastern North Sea to the Baltic Sea. Noticeably, a significant part of the relevant information was found in the grey literature including ICES working group reports and unpublished master theses and laboratory studies.

Supplementary data analyses were performed using fisheries data including 1) Danish harbour sampling, 2) Danish and Swedish logbooks data and 3) survey data. In addition, some older tagging data were specifically gathered and analysed. The various data sources are briefly described.

3.1 Biological data

The Danish harbour sampling program samples plaice on a quarterly basis to construct Age-Length-Keys by commercial category and sub-area. On average, around 8300 fish are aged annually, of which 35-45% originate from the Skagerrak and 15-25% from the Kattegat, the rest being taken primarily in the North Sea and Belt Sea. Due to a number of external, practical and financial considerations the harbour sampling is however slightly skewed towards the Easterly side of the fishery in IIIa, although most landings originate from the more westerly areas.

3.2 Survey data

Plaice data from the NS IBTS (North Sea International Bottom Trawl Survey) were extracted from the ICES database DATRAS (http://datras.ices.dk/) for the period 2005 to 2010. These data include information on growth, sex and maturity for all individuals sampled. In addition, the IBTS data have been used do derive relative indices of spawning abundance in IIIa, derived from the work by Cardinale et al. (2011). In comparison to that study, the time series of spatial indices was restricted to the time frame of IBTS data only (since 1974), and not smoothed for year to year variation.

3.3 Fishery statistics

Commercial landings as reported through logbooks and sale slips are the primary source of information used in stock assessment, and their reliability is crucial. Tonnage information in logbooks is automatically crossed-checked with sale slips, therefore the reported quantities are considered reliable. Paper logbooks can however be subject to important area misreporting, driven for example by differences in available fishing opportunities and regulations across management areas. Misreporting in the Danish logbooks between the area IIIa and adjacent waters was suspected to have occurred in the past for a number of species (e.g. ICES, 2010b). Logbook data were therefore scrutinised for similar issues for plaice, considering that most landings in area IIIa are reported at the edge of the North Sea (Figure 2; See also ICES (2011a) for the landings distribution by area and country). Noticeably, ICES rectangle 43F8, where up to 40% of Skagerrak landings are reported, is administratively split between both management areas, and misreporting in this particular area could potentially have large consequences. The validity procedure included a cross-check of logbooks data since 2005 with Vessel Monitoring System (VMS) data, following the merging method developed by Bastardie et al. (2010) and Hintzen et al. (2011), allowing quantifying the amount of plaice misreporting (Gatti, unpublished[4]). For the vessels smaller than fifteen meters (more than 45% of the Danish plaice landings in area IIIa) for which no VMS are available, reported landing areas were checked against the departure harbour. Overall, no systematic area misreporting was observed for the period considered, and the mismatch between both data sources seemed to have declined over time (Gatti, unpublished). Although the possibility of area misreporting during the 1980 and 1990s cannot be ruled out, it is unlikely that this source of uncertainty is a significant factor of inconsistency in the data, and therefore the Danish logbooks can be considered to be sufficiently reliable to describe actual fishing patterns.

Swedish data were compiled from Swedish logbooks. Positions are based on gear set-positions for each effort as reported by fishers on a haul-by-haul basis, and the overall quality is judged reliable.

3.4 Tagging data

Nielsen et al. (unpublished[5]) compiled an extensive collection of historical (1903-1964) plaice tagging experiments in the fishing grounds around Denmark, where about 13000 fish were recaptured from an initial release of about 40000 individuals. The tagging started in 1903-4 in Kattegat, Skagerrak and the North Sea, while the Belt Sea taggings was initiated in 1922. Releases were performed in all seasons but mainly concentrated in March-May and Sepetember-November.

For the analyses of migrations between areas, recaptures are calibrated with nominal landings as a proxy for fishing effort, as measures of fishing effort was not available for the time series. The resolution of landing data is by year and ICES divisions for the years 1903 – 1971.

In the analyses a number of subareas were defined in order to reflect geographic groupings of the releases as well as fishing areas.

4 Results

4.1 Distribution

4.1.1 Spawning and egg/larvae drift

Spawning in the Kattegat usually occurs in late February and early March at depths between 30 and 40 meters (Nielsen *et al*., 2004a) and in temperatures at about 4 degrees Celsius (Simpson, 1959). The main plaice spawning grounds are located in the south-western part of the Kattegat (Johansen, 1912; Poulsen, 1939, Ulmestrand, 1992; Nielsen *et al*., 1998; 2004a). Spawning sites have also been indicated along the Swedish Kattegat coast (Trybom, 1909; Molander, 1923). Modelling has indicated that the Swedish coast was formerly occupied by extensive aggregations of adult fish during spawning time, and that the reduction of this component is mostly a recent feature (Cardinale *et al*., 2011).

The evidence of spawning in the Skagerrak is less clear and the various sources of information available are somewhat inconsistent or even contradictory. Johansen (1912) found few eggs and larvae in the

[4] Gatti, 2011. Source of uncertainties in the catch-at-age matrix of the IIIa plaice stock. Bachelor internship report, Agrocampus Ouest, Rennes, France. Unpublished.
[5] Nielsen, E., Boje, J., and Nicolaisen. H. Plaice tagging in Danish waters 1903-1964. Working Document to ICES (2006)

Skagerrak and therefore considered spawning in Skagerrak unimportant. The egg density in the North Sea off the north coast of Denmark was observed to be low by Taylor *et al*. (2007), but high by Munk *et al*. (2009). Potential inflow of North Sea eggs and larvae in Skagerrak is corroborated by particle drift modelling in the North Sea (Hufnagl *et al*., submitted), which predicts an inflow of North Sea water and thereby eggs and larvae into Skagerrak during spring. This pattern could be expected to be more pronounced nowadays, in the current period of record-high North Sea plaice abundance (ICES, 2012) and northerly shift in North Sea plaice distribution (Engelhard et al., 2011). However, low to moderate spawning activity was noticed in the south-western part of the Skagerrak by Molander (1923), Ulmestrand (1992) and Nielsen and Bagge (1985). The modelled results by Cardinale *et al*. (2011) also suggest that aggregations of adult fish during 1st quarter may occur along the Danish North coast. In addition, anecdotal information from the Danish fishing industry have reported large catches of spawning females along the Danish Skagerrak coast. However, there are very little records of spawning or spent females in Skagerrak in IBTS spring data (Gatti, unpublished).

These information indicate therefore that spawning in the Skagerrak is likely to occur, but a significant part of the eggs and larvae settling in shallow waters in the Skagerrak are considered to originate from the North Sea stock. This drift is reinforced during windy winters, where larvae may drift further into the Kattegat (Poulsen 1939, Nielsen *et al*., 1998).

Beyond the area IIIa, spawning is likely to take place in the Belt Sea and in the Sound (Svedäng *et al*. 2004). Free-floating eggs are found in the deeper basins in the southern Baltic Sea (Nissling *et al*. 2002). Both spermatozoa and eggs are adapted to the low salinity conditions that prevail in the southern Baltic Sea.

4.1.2 Nurseries

Plaice are dependent on shallow (0-3 m) sediment substratum as nursery grounds during their early juvenile stage (Gibson 1999). For plaice, variation in year-class strength is generated during the pelagic stages and subsequently dampened during the early juvenile stage indicating that density dependent processes are acting on the nursery grounds (van der Veer 1986, Beverton 1995). These nurseries are important for the population dynamic since a relationship between the nursery size and the population abundance has been hypothesized (Rijnsdorp *et al*., 1992; van der Veer, 2000).

In the Skagerrak-Kattegat area potential plaice nursery grounds are present along the Swedish west coast and along the Danish Kattegat coast (Wennhage *et al*., 2007). The lack of tides in the area makes the physical condition in the shallow nursery areas benign and stable (Gibson *et al*. 1998), but excludes the possibility for selective tidal transport as a mechanism for plaice larvae to reach nursery grounds. The Swedish Skagerrak coast is rocky, but contains many small nursery grounds within the complex archipelago. The inter-annual variation in supply of larvae to the Eastern Skagerrak nursery grounds is correlated to prevalence of onshore wind (Pihl 1990, Nielsen *et al*., 1998). Growth rate is negatively correlated and mortality positively correlated to settlement density in the area (Pihl *et al*. 2000). The Kattegat has more of an open coast with plaice nursery habitats fringing the coast. Juvenile recruitment in the nursery areas along the southern part of the Danish east coast drift mainly from the spawning areas in southern Kattegat (Nielsen *et al*. 1998).

4.1.3 Adults

The distribution of adults can be inferred from the commercial fishery data and the survey. The fishery operates year round in the area IIIa, without strong seasonal patterns. The most productive area is the

Danish North coast from the North Sea boundary to the most Northerly harbour of Skagen, and there is a continuum of catches from there to the North Sea (figure 2). There are less catches in the North of Kattegat and along the Swedish coast of Skagerrak. The fishery is also important in the Southwestern Kattegat and Belt Sea, and then in the Baltic Sea around the island of Bornholm. During spawning season, adults aggregations recorded by surveys reflect that general pattern (Cardinale et al., 2011).

Plaice is primarily caught by targeted Danish fisheries using selective gears such as gillnets and Danish seine, and also in demersal trawl mixed fisheries. Overall, trends in Danish landings in Skagerrak are largely comparable to those in the neighbouring North Sea subdivision IVb, whereas landings in Kattegat have continuously decreased (Figure 3). Beyond the effect of external factors linked to regulations and alternative fishing opportunities, such trends might also reveal a closer coupling in the dynamics of the plaice populations in Skagerrak and North Sea than with the Kattegat.

4.2 Migrations

The newly compiled Danish tagging data revealed stable migration pattern over the years. There was in general a high level of resident behaviour observed within the various sub-areas, and especially in the Belt and Western Baltic, in Kattegat and in the North Sea, where up to 90% of the fish were recaptured in the same area as they were released. However most of these were recaptured within the tagging year and future analyses of the data will exclude < 1yr in sea due to their non-informative status. In total, plaice migration into and out of the entire management area IIIa was in the range 5-10% of the tagged individuals (Table 1).

The recaptures from the Skagerrak releases exhibit the lowest rates of residency (52-57%) indicating that this area is a transitional area (Table 1). There is an easterly net flow towards the North of Kattegat which could reflect: (1) a spawning migration of a Skagerrak stock towards spawning around Skagen peninsula as suggested by Cardinale *et al*. (2011) or (2) a migration back from the spawning area to the feeding location. Relative little mix occurs between fish in the northern and southern Kattegat. However, southern Kattegat seems more connected to the Belts and the Baltic. Figure 4 summarizes the directions of the found migrations between the subareas. It appears that Skagerrak exhibit the most migratory fish, mainly towards northern Kattegat.

Swedish tagging experiments between 1903 and 1909 of plaice on the Swedish Kattegat coast indicated resident adult populations (Trybom, 1905; 1908; Molander, 1944). But juvenile fish tagged in the northern Kattegat migrated in a significant proportion towards western Skagerrak and the North Sea as they become older.

On the opposite, later tagging studies on the Swedish Skagerrak coast in the 1920s (Molander, 1923), and in the 1960s (Jacobsson, 1982), showed that the resident component was very small (estimated by maturity examinations), indicating that the coastal zone may function as a nursery area for offshore spawning stocks. At ages 2-4 years, maturing fish left the coast and swam towards the western Skagerrak and to various locations in the North Sea. It was noted that the size and age at which the plaice left their coastal nursery grounds varied systematically between fjords. It should also be observed that some tagged fish migrated for spawning to the northern part of the Swedish Kattegat coast (Molander, 1923).

Additionnally, three tagging experiments were conducted in the Baltic Sea (SD 25) on the Swedish east coast between 1908 and 1909. In spite of low recapture rates, the experiments indicated rather stationary behaviour with no reported recaptures outside the western Baltic, i.e. no reported recaptures from the Sound or the Belt Sea (Trybom 1911).

Finally, parasitism was used as a natural tag indicating that adult plaice residing in the Skagerrak between spring and autumn may migrate into the North Sea during the spawning period in winter. Skagerrak plaice is characterised by a high infestation rate with the parasite *Myxabolis aeglefinus*. Infestation rate was high throughout the year in Skagerrak plaice (>30%), but showed both a clear seasonal and latitudinal trend in North Sea areas (van Banning *et al*., 1978). Infestation rates were highest during the spawning period in the North Sea increasing from a maximum of about 1% in the Southern Bight and Flamborough spawning grounds, to 5-10% in the German Bight and 10% in the Fisherbank spawning ground.

Ultimately, it is important to notice that all the tagging data available were old (up to 100 years) and thus environmental conditions might likely have changed since then and consequently have changed population structure and dynamics. In addition, as shown in Cardinale *et al*. (2011) spawning stock contribution and location may now differ substantially.

4.3 Genetic structure

A number of studies have investigated the genetic population structure of plaice across its Northern European distribution (Hoarau *et al*. 2002, 2004; 2005; Watts *et al*. 2009: Was *et al*. 2010). In particular, transitions have been studied through samples from the North Sea, Western Baltic and Eastern Baltic. However, samples from IIIa have not been included in any of the studies. Generally, these studies have found very limited genetic structure using both nuclear microsatellites and mtDNA SSCP (Single Strand Conformation Polymorphism) analysis, the only exceptions being the very distinct off shelf populations from Iceland and Faeroe Islands (Hoarau *et al*. 2002; Was *et al*. 2010). Within the North Sea region, Hoarau *et al*. (2002; 2005) found no evidence of genetic structuring of populations, while they found that Western Baltic plaice were weakly distinguishable from North Sea/Irish Sea plaice using mtDNA analysis. This finding was, however, not corroborated by the microsatellite study by Was *et al*. (2010), who was not able to distinguish between Baltic and North Sea populations.

These results differ from recent genetic studies of other marine fish (including flatfish) in the transition area between the North Sea and the Baltic Sea, that revealed a relatively high degree of population structuring with a gradual genetic change correlating with the changes in environmental variables and salinity in particular (Limborg *et al*., 2009, Nielsen *et al*. 2004b, Hemmer-Hansen *et al*. 2007).

4.4 Growth and reproduction

Age-Length Keys (ALK) by sex and area during first quarter from 2005 to 2010 were combined from the Danish harbour samples and the IBTS data, and von Bertalanffy curves were fitted (figure 5). The ALKs are rather flat and spread, with overlapping distribution of ages across length. This variability is not *a priori* considered to reflect the actual uncertainty in the otolith aging itself, since there is a fair amount of consistency across the age interpretation of various experienced age readers (L. Worsøe Clausen, pers. Com.), especially for the younger ages. Rather, this reflects that the individual variability of growth for this stock is large and blurs the signal in data, contributing to the lack of cohort tracking in the catch-at-age matrix. This variability could be linked to either the heterogeneity of local hydrographical conditions impacting growth, and/or to catches originating from different populations.

First quarter IBTS data from 2005 to 2010 was used to draw maturity ogives in Kattegat and Skagerrak (figure 5). Every fish which had a maturity stage greater than or equal to 2 was considered to partake in reproduction and therefore counted in the mature population part. Maturity differences were found between Skagerrak and Kattegat. As Rijnsdorp (1989) shows in the North Sea, there is an increase of age at 50% maturity (A50) from South to North. On average, a Kattegat plaice matures earlier than Skagerrak one.

5 Discussion

5.1 Synthesis

This comprehensive work of both literature review of published and unpublished studies as well as compilation and analysis of various data suggest a complex picture of plaice stock structure between the North Sea and the Baltic Sea. The information available is often sporadic, fairly old, and sometimes inconsistent or even contradictory. Consequently, the linkages between units cannot be quantified nor precisely mapped.

However, some broad and qualitative patterns in plaice distribution and population dynamics have emerged. The area IIIa is highly heterogeneous in terms of hydrographical conditions, leading to potentially strong local forcing by salinity, stream and wind. There is evidence of spawning by local populations at both boundaries of the area (Western Skagerrak and SouthWestern Kattegat). But inflow of North Sea eggs and larvae is expected to be important. The importance of the Swedish coast as a spawning area has decreased to a very low level; however this area still acts as important nursery grounds connected to both the local and the North Sea spawning grounds. A westerly homing behaviour of the North Sea juveniles has been observed through the tagging studies, whereas some both-ways adult migration has been recorded at both boundaries and also within Skagerrak. The Northern Kattegat (around the Island of Læsø) seems to act as an internal border between Skagerrak and Kattegat, with lesser fish and fishing density and limited exchanges.

Although there is a continuum of plaice fishing from the North Sea to the Baltic Sea, the main fishery is primarily located towards the North Sea boundary (catches in the Western Skagerrak component normally constitute at least 90–95% of the total catches). Similar trends in catch rates and hydrographical features across this boundary suggest also that the increasing North Sea stock may extend beyond the administrative boundary. Therefore, catches in this area are expected to be a mix of i) adult North Sea plaice whose distribution extends beyond the North Sea boundary ii) juvenile North Sea plaice that hatched in area IIIa and return to the North Sea to spawn, and iii) local populations spawning along the Danish coast. In the area further East towards the Swedish coast and Northern Kattegat, fish densities have dropped to historically low levels (Cardinale et al., 2011) and catches are low; thus this area doesn't seem to beneficiate from North Sea adults. Therefore, catches in this area may be mostly constituted of categories ii) and iii) above. Finally, catches in the Kattegat (South from Læsø) and in the Belt Sea may mostly be constituted of local populations, although some North Sea juveniles (category ii) may still have settled in these more southerly areas.

This complex picture of stock structure, together with the diversity of local hydrographical conditions, leads to a difficult monitoring of the population dynamics in the area. Scientific data from surveys and harbour sampling show great individual variability of growth patterns, and the raising of these samples to the stock level produces a poor tracking of the cohorts. For the future, new scientific analyses should be developed to better inform the origin of catches, through e.g. crossing analyses of otoliths' shape and microstructure, with genetic or meristic analyses of harbor samples (Clausen et al., 2007). It is hypothesised that the apparent contradictions in the observed lack of genetic differentiation for plaice compared to other fish stocks may be due to the choice of genetic markers in the various studies. Traditional markers have evolved towards including new genes subject to environmental selection, which differentiates faster even under relatively high levels of migration (Nielsen *et al*. 2009). New findings of low but significant levels of population structuring or genetic isolation by distance (IBD) may have strong implications for interpretation of evolutionary separation, migration rates and associated population based management (see also Reiss *et al*. 2009). Therefore, updated analyses of plaice genetics in the transition area could potentially shed new light on the structuration of populations. Such information would allow disentangling the effect of genetic structuring from environment forcing in the growth patterns, and would provide quantitative information on the degree of mixing of the various components and more accurate assessment of the status of these.

5.2 Implications for stock assessment and management

5.2.1 New boundaries for ICES stock assessment

The collected information on biology and fishery of plaice in IIIa and adjacent waters suggest for changes in assessment units as well as in management areas. Plaice in Skagerrak is now considered to be closely associated with plaice in the North Sea and is proposed to be included in the North Sea plaice stock assessment, although it is recognised that local components (Figure 6, Eastern and Western) are present in the area. In the Western component, plaice would be constituted of a mixture of local components intermingling with the North Sea stock. In the Eastern component, adult plaice would only be constituted of local components although nursery grounds would also host North Sea juveniles. Therefore, separate management of the Skagerrak plaice would need to take place to assure the preservation of the local populations. Further south, plaice in Kattegat (SD 21), the Belts (SD 22) and the Sound (SD 23) is considered a stock unit and is proposed to be assessed as such. However, separate management for the Kattegat, the Belts and the Sound is suggested to take place to assure the preservation of the local populations. Plaice in the Baltic (SD 24-32) is considered a stock unit and is proposed to be assessed and managed as such.

ICES (2012a,b) produced exploratory assessments of these alternative stock definitions. A combined assessment of the Skagerrak with the North Sea stock shows an upward scaling of the total biomass by about 15% but does not affect the general trends. Meanwhile, the assessment of Kattegat plaice together with Belt and Sound is more internally consistent than what was previously observed when it was assessed together with Skagerrak.

5.2.2 An innovative approach for monitoring and managing local units

The revised stock structure suggests that plaice in Skagerrak has two components: Eastern and Western, the latter of which is closely related to the North Sea stock. According to the relative index of adult aggregation during spawning, suggested by Cardinale et al. (2011) and ICES (2012) as a proxy for a SSB index for local plaice units, the two local components in the Skagerrak show different trends in dynamics (Figure 6), with an increase in the West and a large decrease in the East.

ICES (2012a,b) considered a number of options for managing this complex situation. A pragmatic management approach would integrate an indexing of the Skagerrak TAC to the North Sea TAC, but with provisions explicitly linked to a monitoring of the dynamics in local components within Skagerrak. The preservation of the local components should be explicitly addressed in the management harvest control rules (HCR).

A proposal to achieve this was put forward by the North Sea RAC (ICES, 2012a), based on the status and trend of the North Sea plaice SSB in relation to the MSY biomass trigger, and on the trends in commercial landings per unit effort (lpue) of the Skagerrak stock. This overall approach seems relevant and globally sensible. However, ICES (2012 a,c) noted that the HCR as it was put forward was not considered precautionary in a few situations (for instance where the North Sea stock is rising and the Skagerrak stock is declining) because the local components would not be sufficiently protected. Additionally, there are concerns about the use of commercial lpue as abundance indices, and survey-based alternatives would not be biased by fishing opportunities and technical creep. ICES (2012a,c) suggested the use of survey-based indices of the different sub-components (Cardinale *et al*., 2011; Figure 6) as a suitable alternative to using commercial CPUE. These indices present the advantages of being based on standard survey data from the IBTS that is conducted every year, and can therefore be updated on a routine basis, and is able to distinguish between the various spatial aggregations at a fine scale.

A further lower abundance threshold was added to the rule to avoid a decline of the stock in case of low biomass situations (Table 2). Additionally, a method to define quantitative rules to identify increasing and declining trends needs to be developed.

6 Conclusion

Ultimately, this multi-disciplinary work represents a milestone in a long and comprehensive endeavour, whose starting point was poor fisheries management and unresolved stock assessment issues. This situation then required in-depth understanding and revision of basic biological hypotheses, which in turn led back to alternative approaches to fisheries management. An important step forward has been achieved in the understanding of the structure and connectivity of plaice populations in the transition area between the North Sea and the Baltic Sea. The complex picture of partly overlapping and interlinked populations with variable growth patterns supports the idea that the area IIIa cannot be considered and assessed as an isolated stock. There is a need to account for these linkages, while protecting the genetic diversity of the subpopulations from over- or skewed exploitation. Pragmatic approaches are now being implemented, that could form the basis of improving a sustainable management of the fishery of plaice in the Skagerrak-Kattegat area.

These outcomes could be achieved through a collaborative process of scientists improving biological knowledge through review and additional analyses, and stakeholders and advisory bodies leading the designing of innovative management approaches based on this new knowledge. Such a joint framework represents a positive and successful implementation of improved governance in European fisheries management. In addition, all investigations were performed using usual commercial and survey data, including the establishment of the spatial SSB relative index for the harvest control rule, and it is therefore considered that the whole approach could be applied to other areas and stocks.

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8 Figures

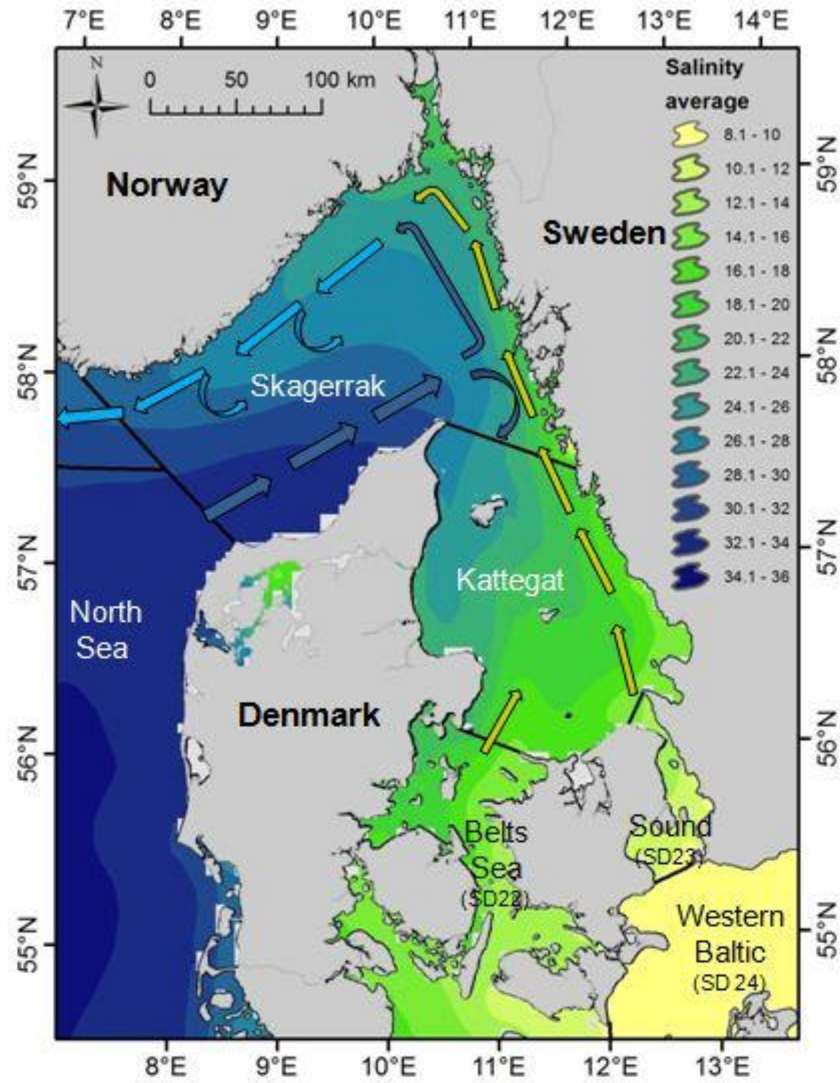

Figure 1. Hydrographical map of the area with average surface salinity and currents (Yellow: Baltic current , Dark blue: North jutland current , Azure: Skagerrak costal current). Salinity data from Danish Hydraulic Institute. Currents redrawn from Danielssen et al. (1997).

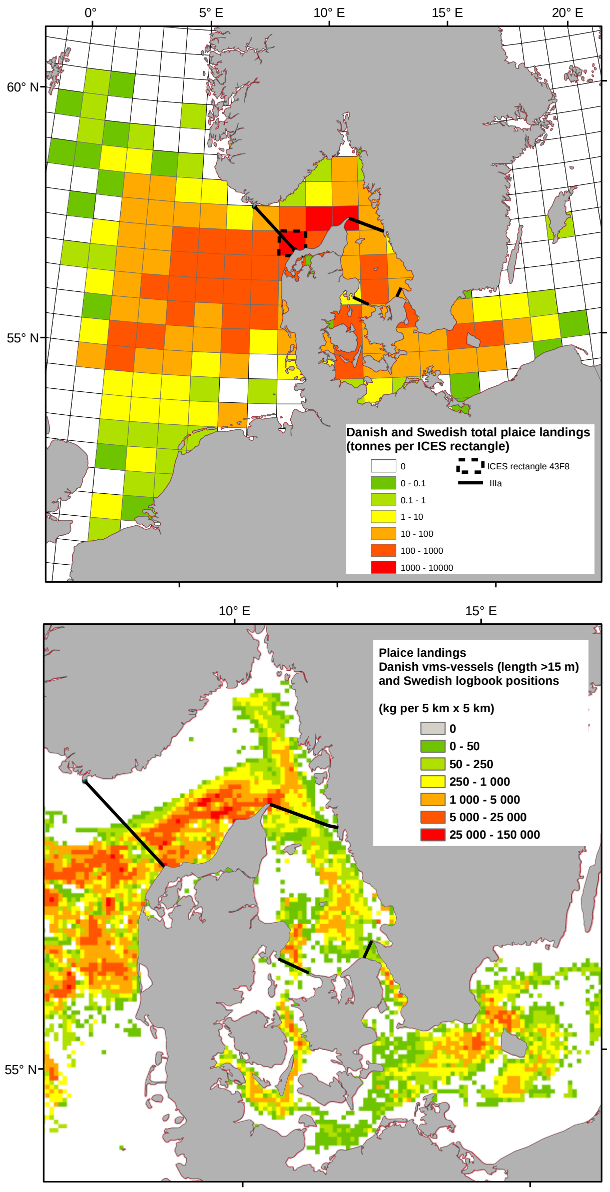

Figure 2. Danish and Swedish plaice landings in 2009. Top: By ICES rectangle, all vessels included. Bottom: by 5*5 km grid, including the most spatially detailed information available (Sweden: logbooks information by haul, all vessels. Denmark: logbooks crossed with VMS data, vessels above fifteen meters). Black lines show boundaries of IIIa sub-areas.

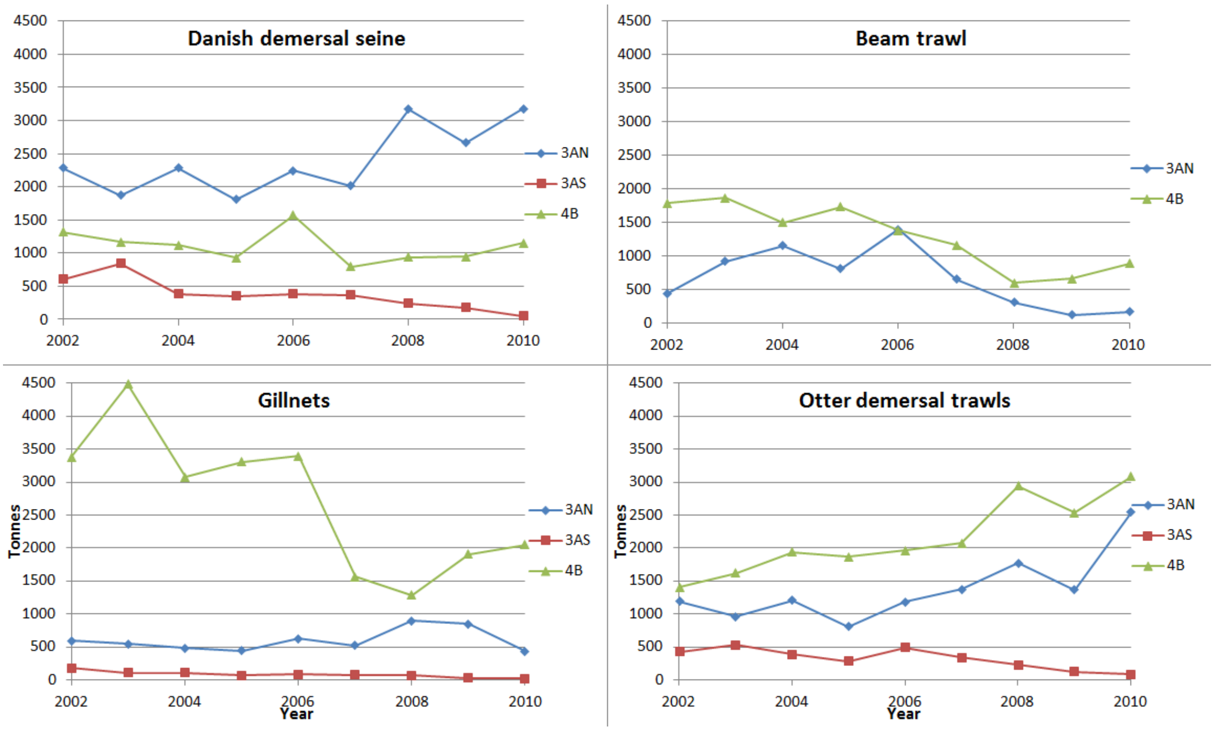

Figure 3. Danish plaice landings by gear in Kattegat (3AS), Skagerrak (3AN) and Central North Sea (4B).

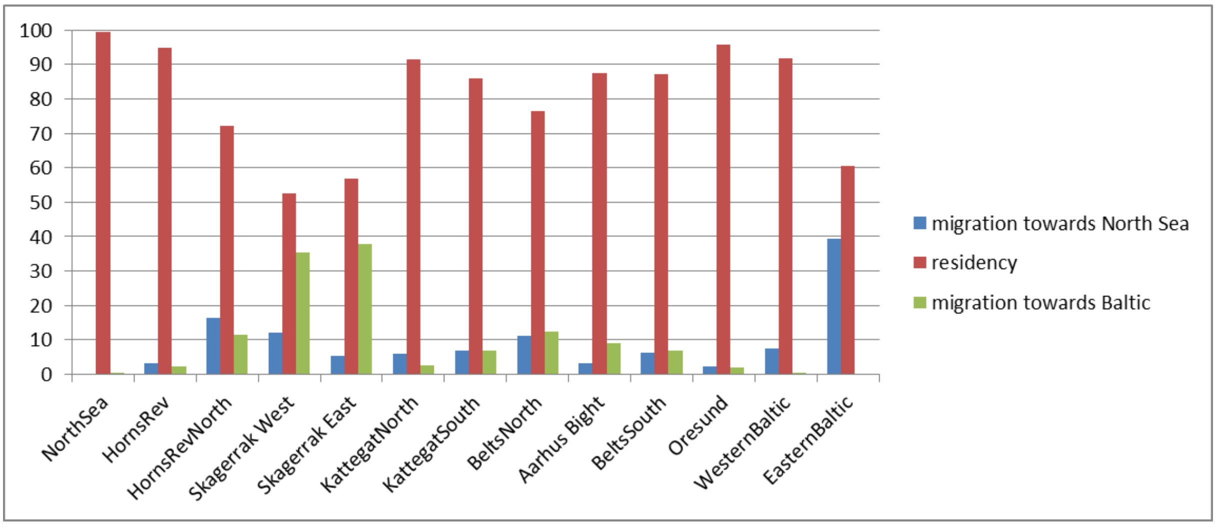

Figure 4 Proportion of recaptures corrected for the differences in recapture probability between areas.

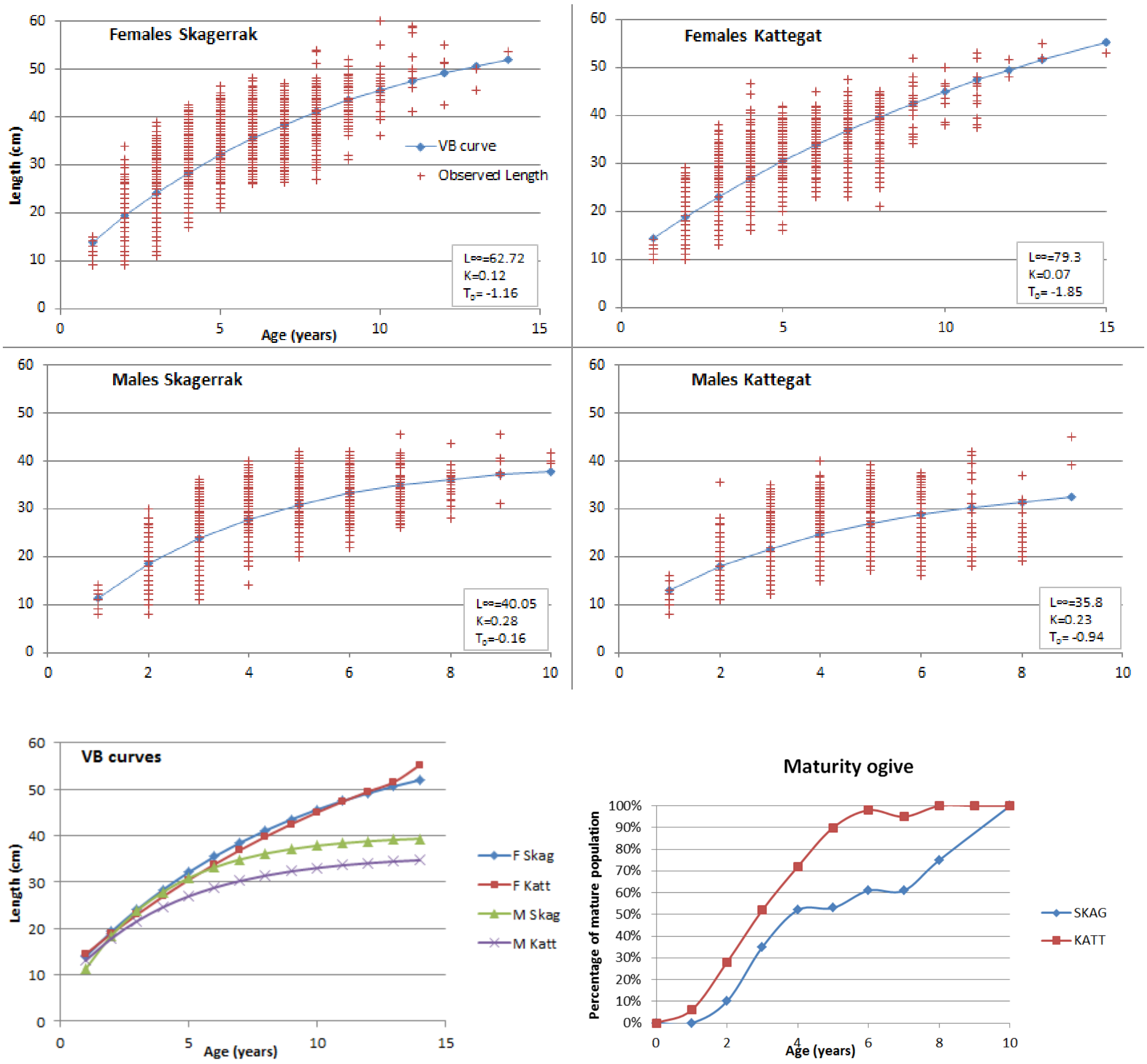

Figure 5: Age-Length Keys and Maturity ogive by area

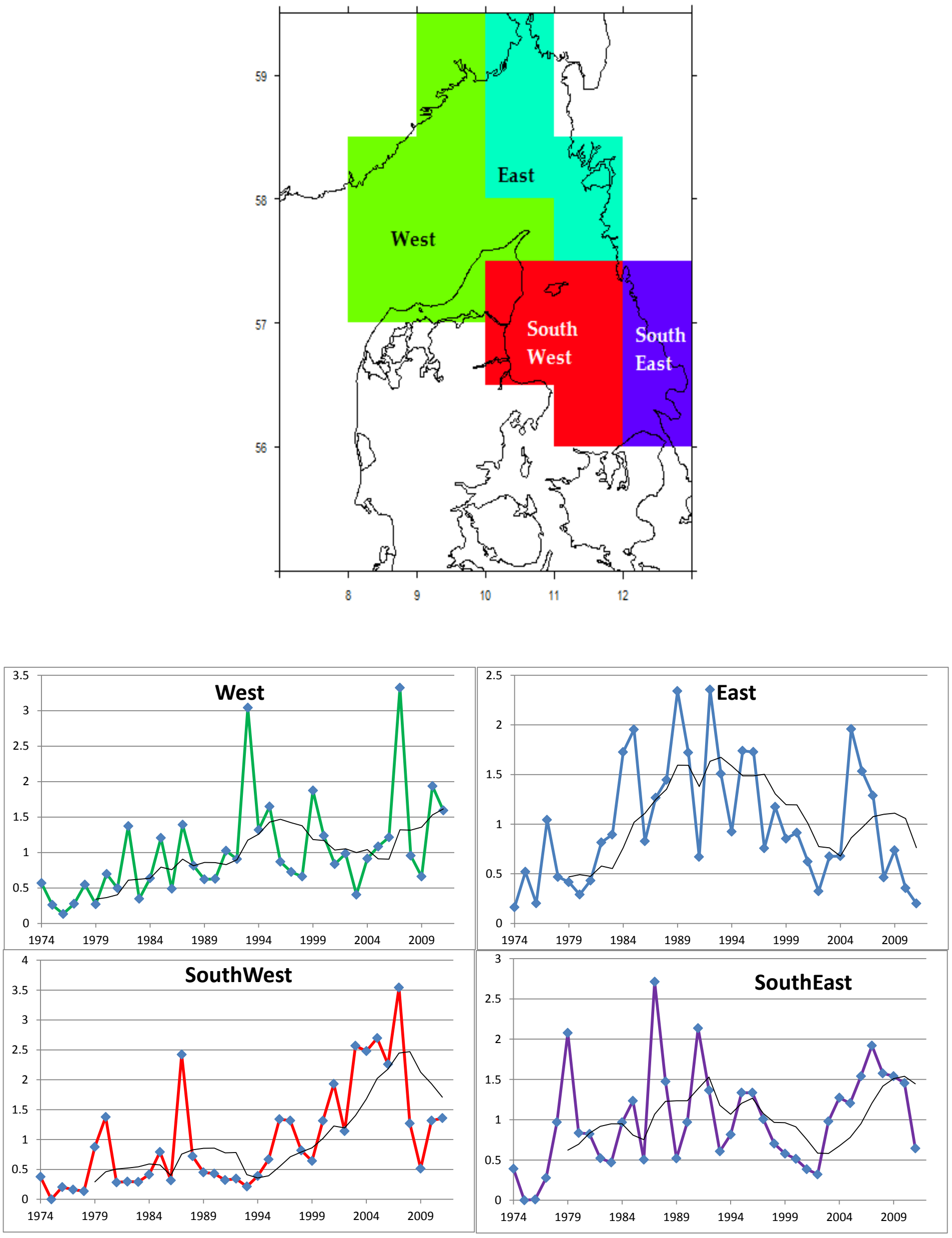

Figure 6. Plaice in the Skagerrak and Kattegat. Top : Local components in the area (based on putative spawning subareas) in ICES statistical rectangles. The light blue and green areas describe the Eastern and Western Skagerrak stock components; the dark blue and red areas describe the Eastern and Western Kattegat stock components. Bottom : Trends in the relative index of local components in the Skagerrak and Kattegat (adapted from Cardinale *et al.*, 2010). The thin black line is a 6-year moving average. From ICES, 2012.

9 Tables

Table 1.

Recaptures by management area (column percentages) Data adjusted for fishing effort.

	Release management area			
Recapture management area	22-24	25-32	IIIa	IVabc
22-24	**97**	39	2	0
25-32	0	**61**	0	0
IIIa	3	0	**95**	10
IVabc	0	0	3	**90**

Table 2 Interim HCR (From ICES, 2012)

North Sea SSB		**Skagerrak Survey abundance** RISING ↗	**Skagerrak Survey abundance** STABLE / FALLING → ↘
Above MSY $B_{trigger}$ ✓	RISING ↗	Skagerrak TAC increase with same rate as NS SSB** *(a)*	Skagerrak TAC remain at same level as previous year *(b)*
	STABLE / FALLING → ↘	Skagerrak TAC remain at same level as previous year *(c)*	Skagerrak TAC decrease with same rate as NS SSB ** *(d)*
Below MSY $B_{trigger}$ ✗	RISING ↗	Skagerrak TAC remain at same level as previous year *(e)*	Skagerrak TAC remain at same level as previous year *(f)*
	STABLE / FALLING → ↘	Skagerrak TAC decrease with same rate as NS SSB ** *(g)*	Skagerrak TAC decrease with the rate of the NS SSB ** *(h)*