Data evaluation of data limited stocks: Horse mackerel, Seabass, Greater Silver Smelt, Turbot and Brill

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Report number C166/13

IMARES Wageningen UR

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	BAS code: BO-20-010-004
Publication date:	25th of February, 2014

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record nr. 09098104,
BTW nr. NL 806511618

A_4_3_2-V12.3

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Summary

Several commercially important fish stocks are classified by ICES (International Council for the Exploration of the Sea) as “data limited” stocks, which are stocks for which the data are insufficient to perform a full analytical assessment and forecast. In this report available data and literature on North Sea horse mackerel, greater silver smelt, seabass, turbot and brill are analysed. The data in this report may be used in future for catch advice by ICES.

For seabass landings per unit of effort (LPUE) abundance indices from the main fleets that land seabass were made. 1) lines fishery: effort has increased substantially from 2005 to 2012; LPUE fluctuates without clear trend with somewhat higher LPUE in the last 3 years; 2) gillnet-seines fisheries: effort has increased substantially from 2000-2012; LPUE also increased substantially during the time series. This increase is not consistent in all ICES rectangles; 3) beamtrawl fishery: effort decreased substantially; LPUE increased between 2001 and 2007 and decreased in 2011 and 2012; 4) flyshoot fishery: effort increased substantially between 2000 and 2012; LPUE also increased. Data from the demersal fish survey was also analysed; in the Westerschelde juvenile seabass is caught in substantial amounts in recent years. If this trend continues, this series is useful as a fisheries independent abundance index. The Netherlands has recently started to estimate the recreational catches of seabass by means of a survey. This biennial survey should continue in order to get a reliable estimate of the yearly variation and to get a longer time series that can be included in the assessment.

For Greater silversmelt the Dutch commercial data show that the mean age and especially the maximum age in the catches decreased since the beginning of the time series. There are also indications that the weight at age is increasing since the middle of the 2000’s, possibly indicating increased growth rates. There are identification problems between lesser and greater silversmelt, which should first be solved, before the IBTS data can be used as an abundance index. In addition, the stock structure is not well defined and should be researched according to the ICES recommendations from WKDEEP (ICES 2010).

For horse mackerel an otholith shape analysis has already been done within the EU-project ‘Homsir’. They did not find differences in shape structure between the North Sea and the Western stock. A pilot of an alternative method using GCxGC-MS methods to distinguish between the two stocks has started in collaboration with another project financed by the Dutch Ministry of Economic Affairs. Also, a multi-annual management plan is currently been drafted to provide a rational for (trends based) TAC setting in the short term, and simultaneously prepare a roadmap for the development of an analytical assessment in the medium or long term.

Turbot and Brill are commercially important bycatch species. In the scientific paper presented in this report, the available data has been gathered and analysed in order to understand the biology and the population dynamics of these species, which will be helpful in future management. An analytic assessment for turbot is now available and was treated as indicative of trends in fishing mortality, recruitment, biomass, and future catches for the 2013 ICES advice.

1 Introduction

Several commercially important fish stocks are classified as “data limited” stocks in the light of the EU policy paper on fisheries management (17 May 2010, COM (2010) 241). For many of the stocks in this category, there is no management advice, due to the unknown status of the stocks. The reason for this is that the data and information available to perform analytical stock assessments are highly uncertain or lacking. Recently, most stocks are categorised according to the ICES approach of “data limited” stocks. According to the data and analyses that are available, each stock is assigned a category. The categories reflect the decreasing availability of data; the conclusions on the fishing pressure and state of the stock are likely to be less certain as one goes down the categories. Based on this categorization, a methodology may be applied that provides quantitative advice for the stocks given the information available. For some of these stocks, the goal is to improve the data availability for these stocks such that they will enter a higher category. In this report we have gathered and analysed available data on five of such data limited stocks: horse mackerel, turbot, brill, greater silversmelt and seabass (Table 1-1).

Table 1-1 Data limited stocks of economic importance for the Netherlands that are discussed in this report.

Species	*Area*
Turbot (*Scophthalmus maximus*)	North Sea
Brill (*Scophthalmus rhombus*)	North Sea
Greater Silversmelt (*Argentina silus*)	ICES Subareas I, II, IV, VI, VII, VIII, IX, X, XII and XIV and Divisions IIIa and Vb
Seabass (*Dicentrarchus labrax*)	Irish Sea, Celtic Sea, English Channel and southern North Sea
Horse mackerel (*Trachurus trachurus*)	North Sea

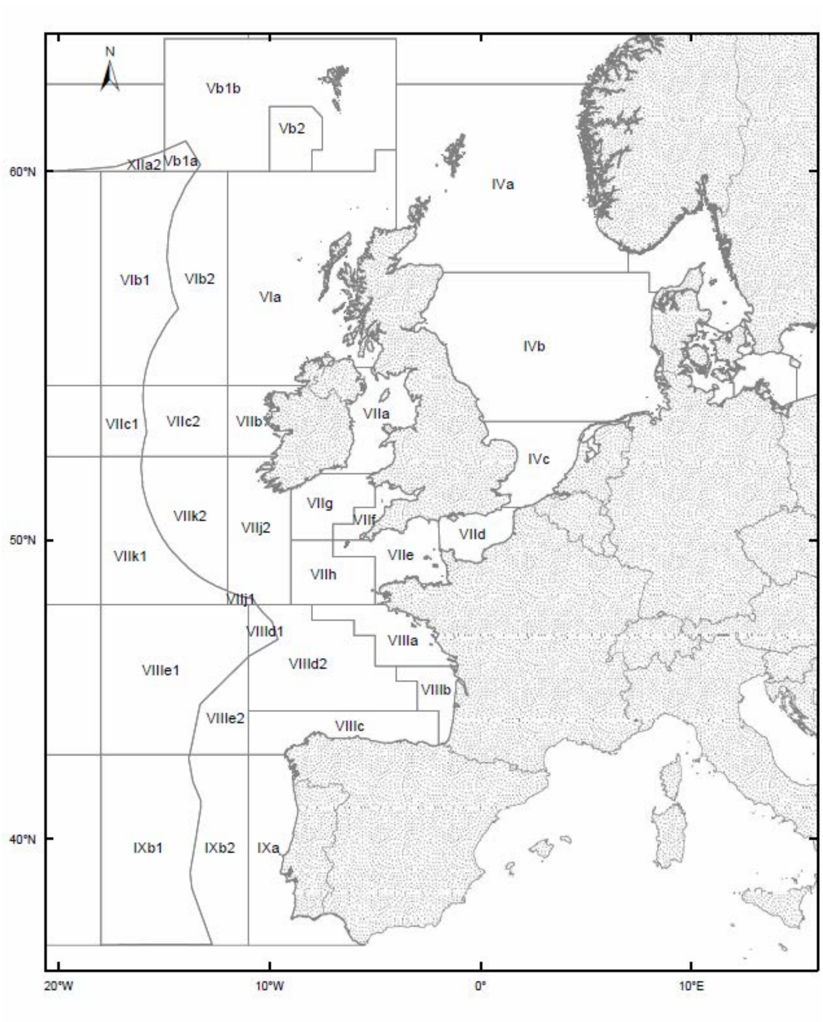


Figure 1-1 ICES areas. Source: www.ices.dk

2 Assignment

The Ministry of EZ asked to collate and analyse available data or literature on turbot, brill, greater silver smelt, seabass and horse mackerel (Table 1-1) in order to discuss the specific assignments below. The analyses can be used in evaluating the status of the stocks and can be used by ICES for its advice on these data limited stocks.

<u>Horse Mackerel</u>

The assignment was to explore possibilities to find out if horse mackerel landed as belonging to the North sea stock indeed belongs to the North Sea stock, or instead partly to the western stock. Specifically, a literature research was done into the use of otoliths to determine the stock boundaries. The result is used in the horse mackerel management plan.

<u>Seabass</u>

In this report, possibilities for monitoring were explored, taking the recommendations from the benchmark assessment of seabass in October 2012 into account. The European Commission proposed in 2012 to set a TAC for the (to date unregulated) seabass. There are indications that the stock shows signs of overfishing, such as the declining lengths in the landings. For that reason, more insight in the state of the stock is needed.

Greater silver smelt

The assignment was to explore opportunities to gain better insight in population structure, size and trends of the greater silver smelt stock. Availability of data was researched. The data was evaluated and possibilities to analyze the data were described.

The Netherlands has a significant share of the TAC of greater silver smelt in ICES areas V, VI, and VII (http://ec.europa.eu/fisheries/cfp/fishing_rules/tacs/info/com_2012_608_nl.pdf). The greater silver smelt is a "deep-sea species", and because of the lack of knowledge of the status of the stock, the ICES methods for data poor stocks are followed. Therefore, the advice is based on a comparison of the two most recent values of an abundance index with the three preceding values. However ICES also advises a precautionary buffer of 20% reduction of the landings, resulting in a final advice of 10% reduction in the landings.

Turbot and brill

Existing data were gathered to come to better understanding of the population dynamics. The results are described in a draft manuscript which was accepted for publication in The Journal of Sea Research (http://www.sciencedirect.com/science/article/pii/S138511011300124X).

3 Seabass (*Dicentrarchus labrax*)

3.1 Assignment

In this report, possibilities for monitoring were explored, taking the recommendations from the benchmark assessment of seabass in October 2012 into account. The European Commission proposed in 2012 to set a TAC for the (to date unregulated) seabass. There are indications that the stock shows signs of overfishing, such as the declining lengths in the landings. For that reason, more insight in the state of the stock is needed.

3.2 Biology

Seabass aggregate offshore to spawn; from February to May they spawn in the English Channel and eastern Celtic Sea. The larvae drift inshore to nursery areas in estuaries and shallow bays where they remain for around two years. Three-year-old fish migrate to over-wintering areas in deeper water, returning to large estuaries in summer. Older, mature individuals undertake annual migrations between inshore feeding areas and offshore spawning sites. There are indications that sea bass have strong site fidelity and return to the same spawning and feedings sites each year (ICES advice 2013).

3.3 Stock definition and ICES advice

The stock structure of seabass is currently uncertain. At present the populations around southern Ireland and in the Bay of Biscay are treated as separate from sea bass populations in Divisions IVbc, VIIa and VIId-h (Irish Sea, Celtic Sea, English Channel and southern North Sea, ICES advice 2013). The latest ICES advice (2013) is based on an analytical assessment (trends-based age and length analytical assessment, Stock Synthesis 3; NOAA Toolbox). The ICES advice is a 36% reduction of the commercial catches for 2014.

3.4 ICES Recommendations

3.4.1 Benchmark assessment 2012 (IBPNew 2012)/ ICES Celtic group 2013 (WGCSE)

In 2012 there was an ICES benchmark for seabass (ICES 2012d) and in 2013 the seabass catch advice was drafted by the ICES Celtic group (WGCSE 2013, ICES 2013b). The two ICES groups made the following recommendations:

1) *Relative abundance indices are needed for adult sea bass, or development of fishing effort series that are strongly correlated with fishing mortality*
2) *Recruitment indices are needed covering the main nursery areas over the full geographic range of the stock, including in France. The termination of the UK sea bass surveys in 2011, particularly the autumn Solent survey, will seriously impact the ability to continue an analytical assessment of this stock unless other time-series become available. WGCSE strongly advises the re-instatement of this survey, and the development of similar inshore surveys of young bass in France.*
3) *Further research is needed to better understand the spatial dynamics of seabass (mixing between ICES areas; effects of site fidelity on fishery impacts; spawning site–recruitment ground linkages; environmental influences).*
4) *Studies are needed to investigate the accuracy/bias in ageing, and errors due to age sampling schemes historically.*

5) *Continued estimation of recreational catches is needed across the stock range, and information to evaluate historical trends in recreational effort and catches would be beneficial for interpreting changes in age–length compositions over time.'*

<u>Conclusion recommendations</u>

With regard to the ICES recommendations, with the available Dutch data, the Netherlands can contribute to the following recommendations:

1) - Data from the Demersal Fish Survey (DFS) and the International Bottom Trawl Survey (IBTS) should be analysed to find out if the surveys catch sufficient seabass to calculate a reliable abundance index.
   - LPUE abundance indices can be developed using Dutch logbook data
2) - Data from the Demersal Fish Survey (DFS) catches only young seabass.
3) - With the available Dutch data, this question cannot be addressed. However additional research could be done to answer these questions.
4) - With the available Dutch data, this question cannot be addressed.
5) - In the Netherlands the estimation of recreational catches started in 2010 and is estimated biennially. The survey is repeated in 2012-2013 and will be repeated again in 2014-2015 (van der Hammen & de Graaf 2013).

3.4.2 Inter-benchmark

During the ICES Celtic working group (WGCSE 2013) an inter-benchmark was suggested which would include the following tasks:

'The intercessional work plan for the inter-benchmark is likely to include the following tasks:

- *Source and review information on historical catches and develop plausible scenarios including over the 20+ year burn-in period for the assessment*
- *Review the derivation and quality of historical fishery length/age composition data*
- *Expand UK fishery age compositions to all true ages*
- *Rationalise the fleet definitions, and reduce to the minimum sufficient to provide robust SS3 stock trends.*
- *Source and evaluate candidate LPUE or effort series for tuning abundance or fishing mortality on older ages.*
- *Collate and evaluate other survey data on seabass abundance that could be incorporated in the model.*
- *Determine the most robust approach to incorporating mean length at age and length at age distributions in SS3.*
- *Investigate potential biases in using combined-sex growth parameters.*
- *Further explore the sensitivity of the assessment to decisions on model structure and inputs.*
- *Consider if simpler assessment approaches area warranted.'*

3.5 Dutch Data

Dutch data that may give important information about the Dutch seabass catches and the trends in the stock:

- Commercial data, landings and effort data
- DFS (‘Demersal Fish Survey’)
- IBTS (‘International Bottom Trawl Survey’)
- Recreational fisheries survey (‘RecVis Survey’)

In addition, a year-round egg survey was carried out once in 2010 and may give information about the location and time of occurrence of seabass eggs.

3.5.1 Commercial data

Landings and effort data from the commercial fleet are available from the EU logbooks; market category composition of landings is available from the auction data (sales slips); and size and age data are available through market sampling.

EU logbook data

Official EU logbook data of the entire Dutch fleet are maintained by the NVWA (formerly known as the General Inspection Service, AID). IMARES has access to these logbooks and stores the data in a database (VISSTAT). EU logbook data contain information on:

- landings (kg): by vessel, trip, ICES statistical rectangle and species;
- effort (days absent from port): by vessel, trip and ICES statistical rectangle;
- vessel information: length, engine power and gear used.

Logbook data are available of the entire Dutch fishing fleet and of foreign vessels landing their catches in the Netherlands.

Auction data: landings by market category

Auction data cover both the total Dutch fishing fleet and foreign vessels landing their catches on Dutch auctions. These data are also stored in VISSTAT and contain information on:

- landings by market category (kg): by vessel, trip (landing date) and species

Market sampling data

In the IMARES market sampling data on length, age, sex and weight are collected for several commercially important species. For seabass this is done on an irregular basis and data is only available for some years (2005-2012, Table 3-1).

3.5.2 Results

Landings

Dutch Seabass landings have increased substantially from ~50 tonnes a year, to 300-400 tonnes a year since 2005 (Figure 3-1). Most catches are from ICES areas IVc and VIId (Figure 3-1). Seabass is landed in all quarters, but mostly in quarters 1 and 2 (Figure 3-2).

Most seabass is caught by beamtrawl, flyshoot, lines, seines and gillnets (Figure 3-3). The total landings by the beamtrawl fleet have decreased, whereas landings by lines and flyshoot have increased during the timespan of the series (Figure 3-3). The main reason for this is that the total effort of the beamtrawl has decreased, while the effort of the other fleets have increased (see section 3.5.3).

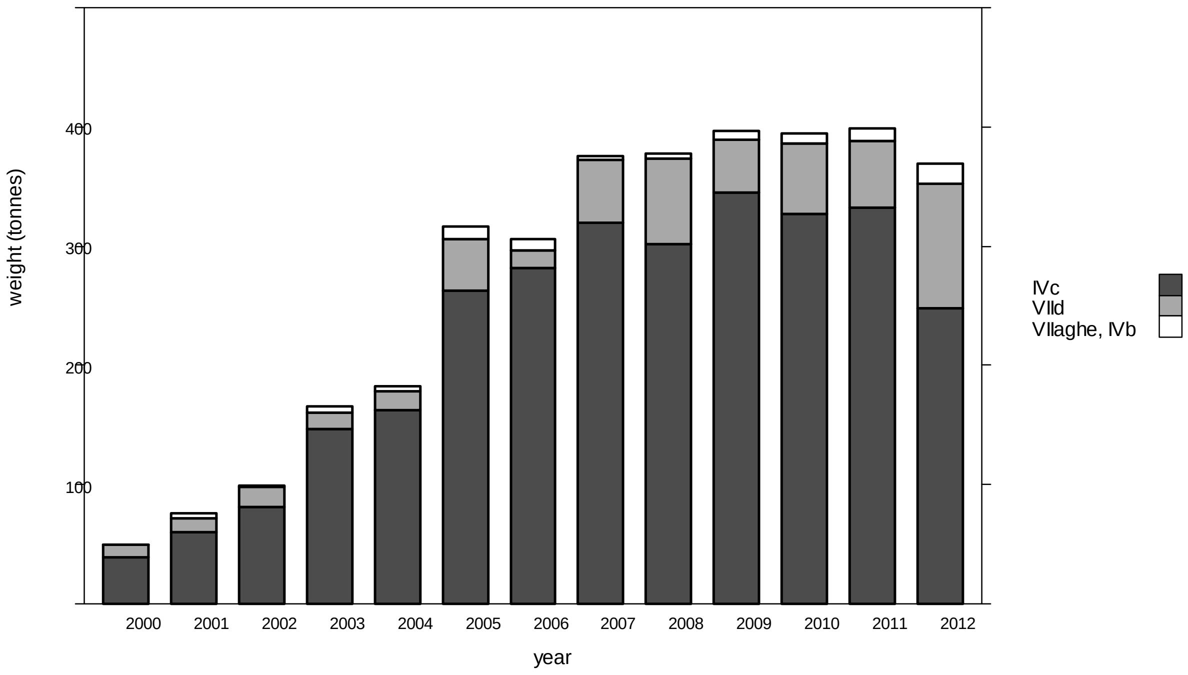


Figure 3-1 Dutch seabass landings by ICES area and year in the Celtic stock (IVbc, VIId, VIIa-h).

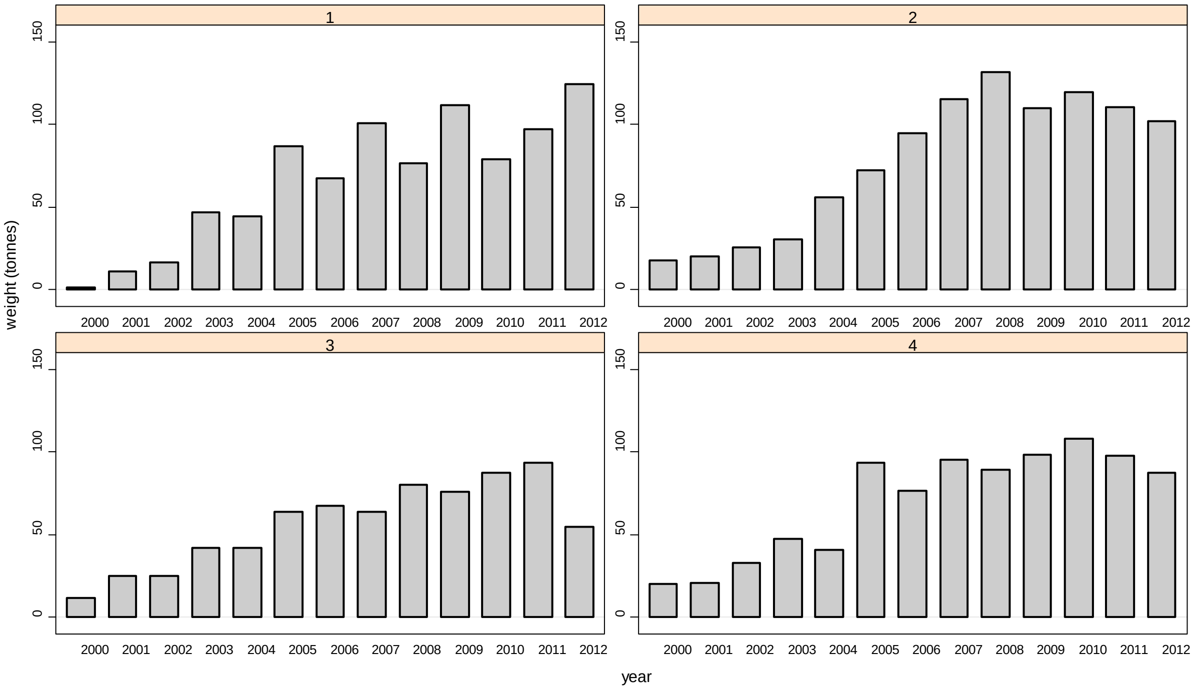


Figure 3-2 Dutch seabass landings by quarter

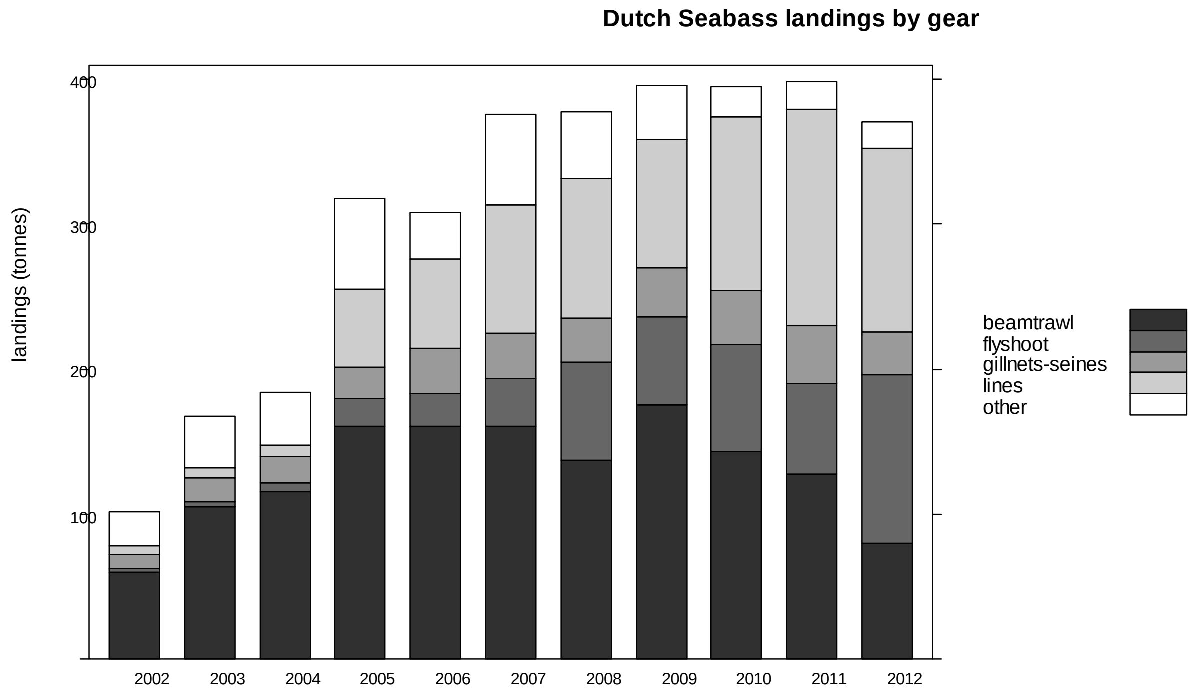


Figure 3-3 Yearly Dutch catches (tonnes) per gear and year.

<u>Spatial distribution landings</u>

Almost all seabass landed in Dutch harbours is caught in the southern north sea and in the English Channel (Figure 3-4). At the end of the winter, seabass migrates to the north and in the autumn seabass migrates back to the south. This is reflected in the quarterly landings, when relatively less seabass is caught in the south in quarter 3 (**Figure 3-5**).

Almost all landings in quarter 1 are from beamtrawlers and flyshoots, whereas catches by lines are mainly landed in quarters 2, 3 and 4. Most of the catches from gillnets and seines come from the Dutch coastal area in Q3 (Figure 3-6).

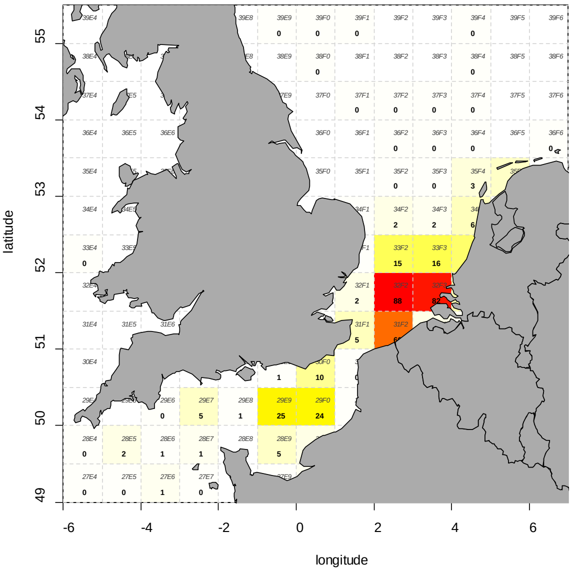


Figure 3-4 Yearly Dutch landings (tonnes) per ICES rectangle (average 2008-2012).

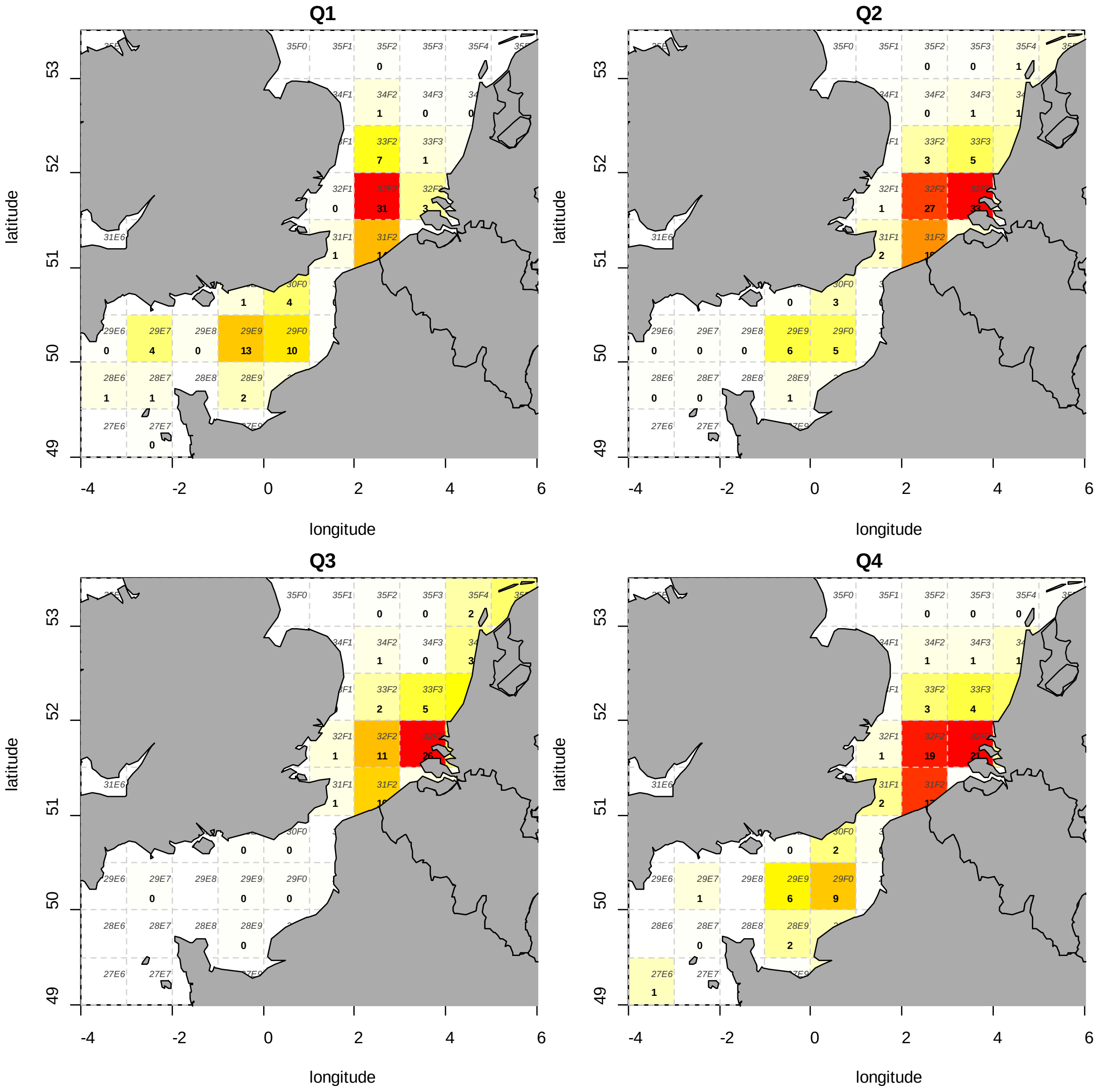
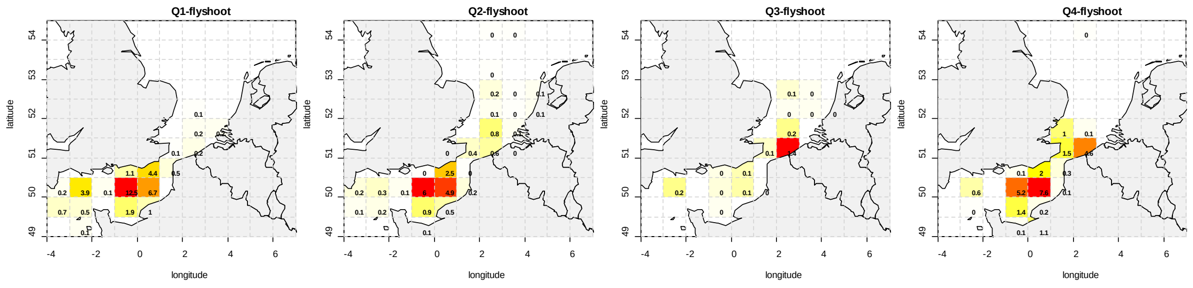


Figure 3-5 Quarterly Dutch catches (tonnes) per ICES rectangle (average 2008-2012).



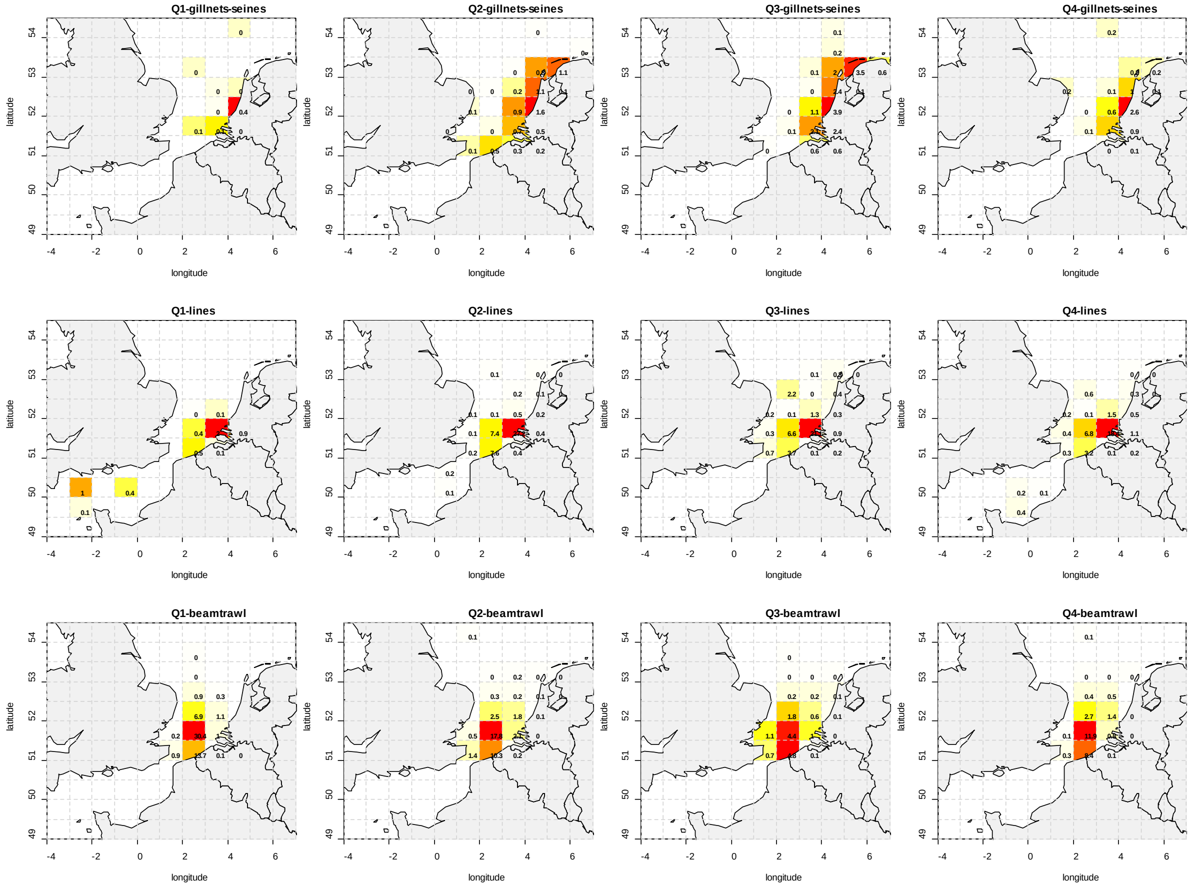


Figure 3-6 Quarterly Dutch catches (tonnes) per ICES rectangle and gear (average 2008-2012). 1st row: flyshoot, 2nd row: gill nets and seines. 3rd row: lines and 4th row: beamtrawl.

Available lengths/ages from market sampling

Market sampling is done since 2005 (Table 3-1). The age sampling frequency is now set triennially (2010, 2013 etc.). Every three years 4 samples of 15 fish (60 fish) are aged and every year the lengths of 24 samples of 15 fish (360 fish) are taken. Between 2005 and 2008 additional market sampling was done on an irregular basis.

Table 3-1 Nr seabass age and length samples from market sampling

Year	*Nr age samples*	*Nr length samples*
2005	44	46
2006	55	57
2007	110	125
2008	202	202
2009	0	609
2010	340	838
2011	0	704
2012	0	421

3.5.3 LPUE

A problem with commercial LPUE's (landings per unit of effort) for seabass is that the fishing effort is distributed across many areas where seabass have low probability of capture. British researchers created LPUE series by selecting gears with the highest seabass landings and by selecting the rectangles where seabass was caught in substantial amounts (Armstrong and Maxwell, WGNEW2012). We did similar analyses with Dutch data. LPUE's were calculated for five gear groups (gillnets & seines, lines, flyshoot and beamtrawl (Table 3-2) from 2000 to 2013. In addition, the following selection was made:

- Only those rectangles were selected which were visited in at least 11 out of 13 years (85%)
- Only those rectangles were selected were seabass was registered at least once
- For lines, the time series was limited to 2005-2012, because permits were obligated since 2005 for commercial line fishing
- Specific selections per gear are listed in (Table 3-2).

Table 3-2 LPUE series (gears and ICES rectangles selection). ICES area IVc is the southern North Sea, IVb is the central North Sea and VIId is the English Channel.

Gears	*Gear codes visstat database*	*ICES area*	*ICES rectangles*	*Other selections*
lines	"LH","LHM","LHP", "LL" and "LLS"	IVc	34F4, 35F4, 33F3, 33F4, 32F4, 33F2, 32F2, 32F3, 31F2, 31F3	The timeseries was restricted to years after 2005, due to obligation of permits for commercial line fishing since 2005.
Gillnets/seines	"GN", "GND", "GNS", "GTR" and "PS"	IVb,c	35F6, 36F6, 35F4, 35F5, 34F4, 34F5, 33F4, 34F3, 32F4,33F3, 32F2,32F3,31F3,31F4	Years > 2000 (catches registered since 2000).
beamtrawl	"TBB"	IVb,c	31F1, 31F2, 31F3, 32F1, 32F2, 32F3, 33F2, 33F3, 33F4, 34F2, 34F3, 34F4, 35F2, 35F3, 35F4, 36F2, 36F3, 37F1, 37F2, 37F3, 38F2, 39F6	Only vessels with kW > 221 were included in the analysis. Years > 2000 (catches registered since 2000).
flyshoot	"SDN" and "SSC"	VIId	29E7, 29E9, 29F0	Only ICES rectangles in area VII were included. In area IV 3 rectangles had enough sampled years, but only very little catches per rectangle.
twinrig	"OTT"	-	-	Not enough landings for a time series

3.5.3.1 LPUE methods

Landings Per Unit of Effort (LPUE) data were corrected for targeting behaviour as described below. The methods are similar to those used to analyse commercial LPUE data for North Sea plaice, described in van der Hammen et al. (2011). Landing rates (LPUE) were calculated for the period 2002-2012. Tables with landings, effort and LPUE are listed in Appendix B.

3.5.3.2 Correction for targeting behaviour

Fishers target fishing areas with high concentrations of fish. Dividing total landings by total effort without taking in account targeting behaviour may result in bias of commercial LPUE, because of possible changes in the spatial distribution of fishing effort. Therefore, a correction was carried out using EU logbook data. LPUE was first calculated per ICES rectangle, per year. Next, a selection was made in which only those rectangles visited by at least 11 out of 13 years (85% of the years) were included. This ensures that the LPUEs are valid for the core area of the fleet, and are not influenced much by many missing values. Subsequently, the LPUE's by ICES rectangles were averaged to calculate the LPUE by year for the core fishing area of the Dutch vessels by gear group in the North Sea and/or the English Channel. This removes the major effects of changes in spatial effort allocation due to – for instance – changing targeting behaviour (Figure 3-7).

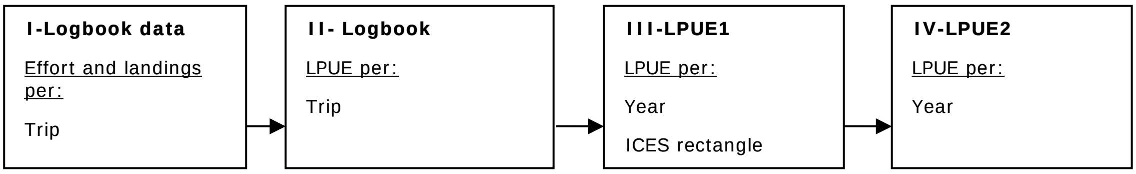


Figure 3-7 Flow diagram of LPUE correction based on landings and effort registered in logbooks.

3.5.3.3 Lines

For the lines fishery, the selection of ICES rectangles resulted in 10 rectangles, which all lay in ICES area IVc (Figure 3-11). The effort in days at sea for the commercial fisheries with lines has increased from less than 500 days at sea in 2005 to almost 1000 days at sea in 2011 (Figure 3-9). The landings also increased, from 52 tonnes to 147 tonnes in 2011 (Figure 3-10). The LPUE fluctuates without a clear trend from 2005- 2009, and had somewhat higher LPUE's in 2010-2012, the last 3 years of the time series (Figure 3-8). The highest LPUE is in ICES rectangle 32F2-F4, 31F2 and 34F4 (Figure 3-11). The trend also fluctuates between ICES rectangles (Figure 3-12).

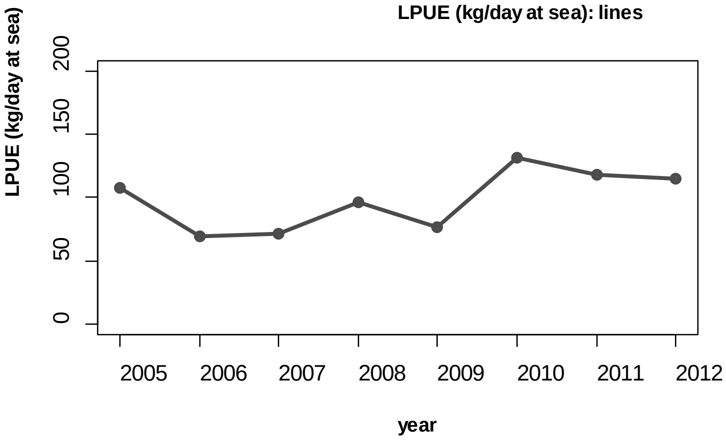


Figure 3-8 LPUE in kg per day at sea for the selected rectangles

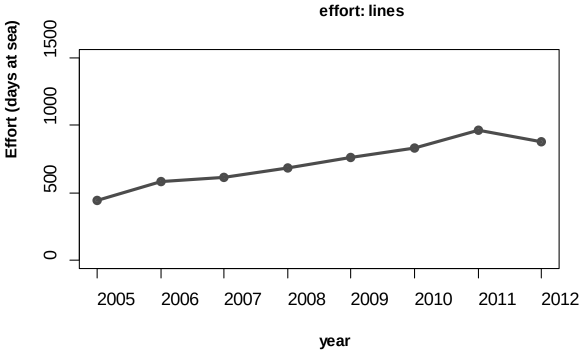


Figure 3-9 Effort in days at sea for the selected rectangles.

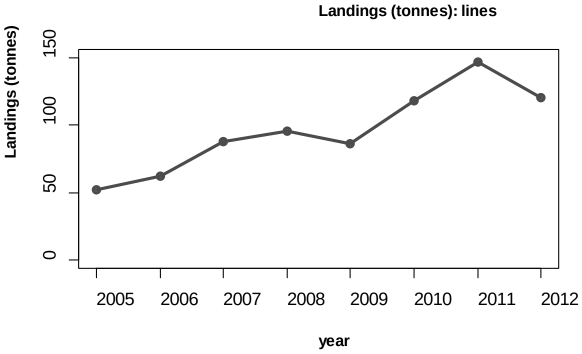


Figure 3-10 Landings in tonnes for the selected rectangles.

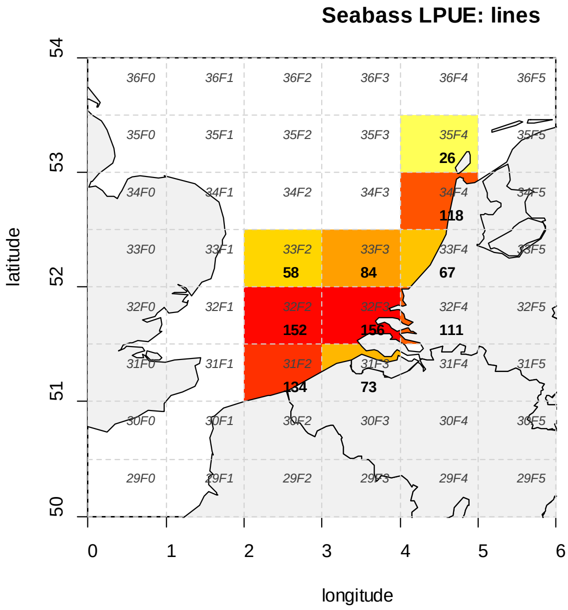


Figure 3-11 LPUE in kg per day at sea in the selected rectangles (2005-2012 average).

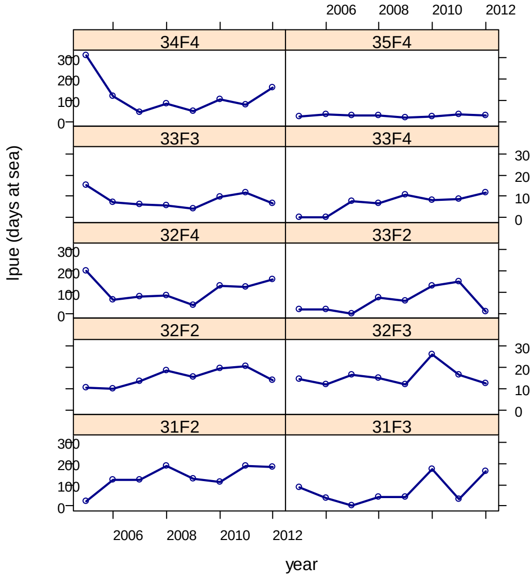


Figure 3-12 LPUE in kg per day at sea per year per selected rectangle.

3.5.3.4 Gillnets- Seines

For the gillnet and seine fisheries, the selection of ICES rectangles resulted in 14 rectangles in ICES area IVc and b (Figure 3-16). The effort in days at sea for these fisheries increased from less than 500 days at sea in 2000 to over 2200 days at sea in 2012 (Figure 3-14). The landings also increased, from 2.6 tonnes in 2000 to 28 tonnes in 2012 (Figure 3-15). The LPUE increased from 3kg per day in 2000 to 29kg per day at sea in 2012 (Figure 3-13). The highest LPUE is in 2011. The trend also fluctuates between ICES rectangles, with contrasting trends in some rectangles (Figure 3-17).

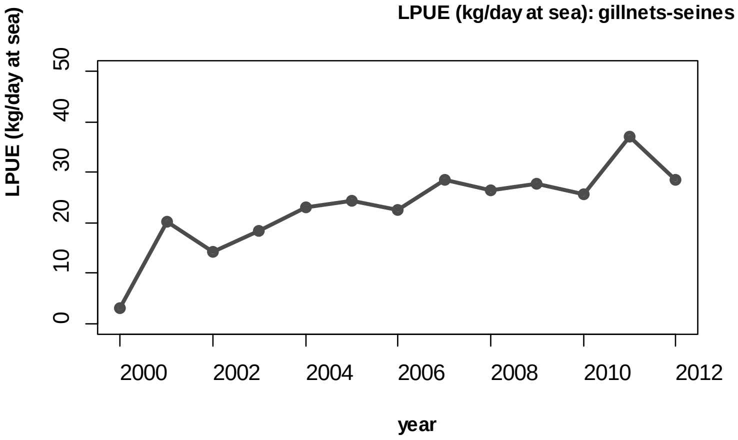


Figure 3-13 LPUE in kg per day at sea for the selected rectangles

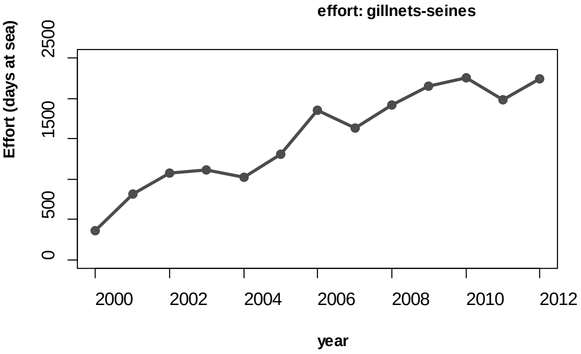


Figure 3-14 Effort in days at sea for the selected rectangles.

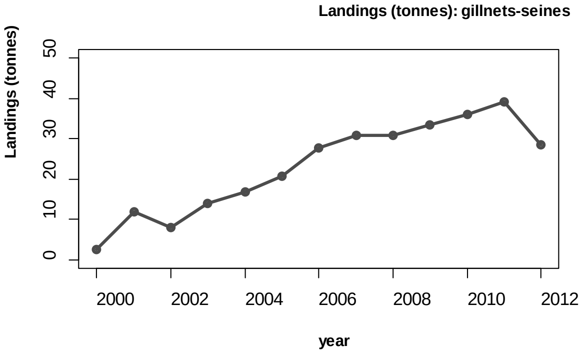
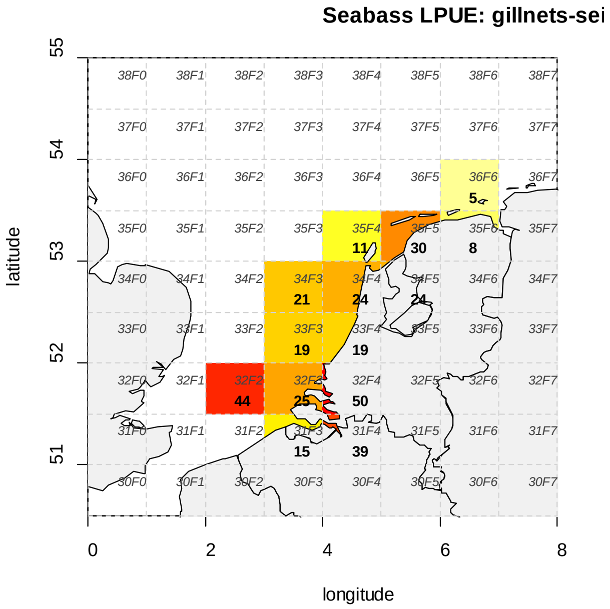


Figure 3-15 Landings in tonnes for the selected rectangles.



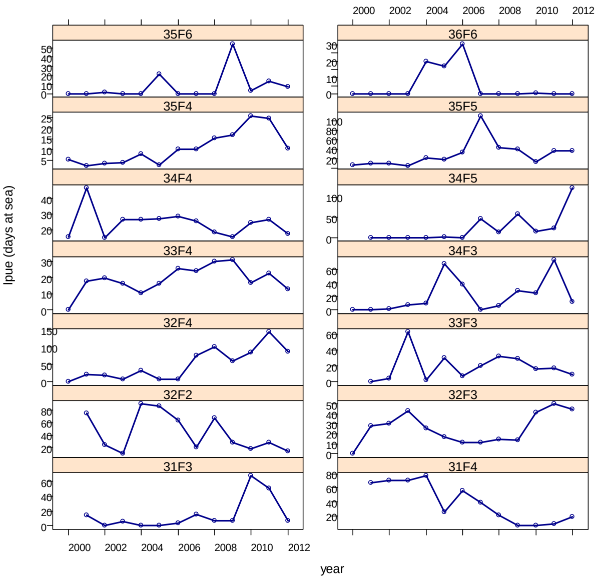


Figure 3-16 LPUE in kg per day at sea in the selected rectangles (2000-2012 average).

Figure 3-17 LPUE in kg per day at sea per year per selected rectangle. Note that the y-axis scales differ for each panel.

3.5.3.5 Beamtrawl

For the beamtrawl fishery, the selection of ICES rectangles resulted in 22 rectangles in ICES area IVb and c (Figure 3-21). The effort in days at sea for the large beamtrawlers in these rectangles has nearly halved from almost 30,000 days at sea in 2000 to less than 15,000 days at sea in 2012 (Figure 3-19). The landings increased from 31 tonnes at the beginning of the time series to around 150 tonnes between 2005 and 2009, but in recent years the landings decreased again (Figure 3-20). The LPUE has increased between 2001 and 2010 and decreased in 2011 and 2012 (Figure 3-18). On average, the highest LPUE's are found in the most southern part of the North sea (Figure 3-21). The trend fluctuates between ICES rectangles, although most rectangles in the southern north sea follow the trend of higher LPUE in the middle of the time series and lower at the end of the time series (Figure 3-22).

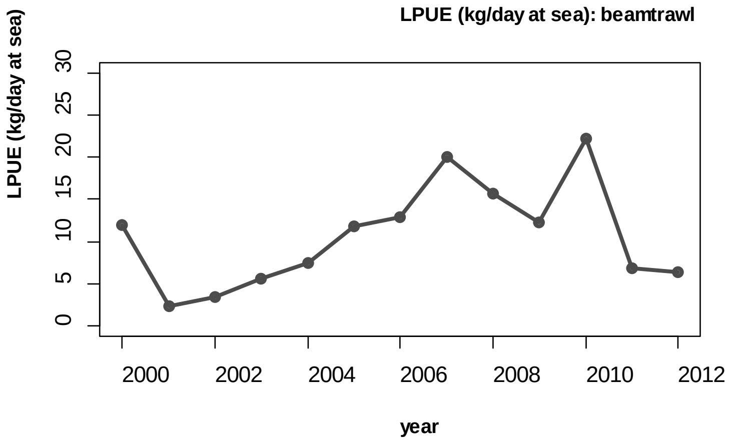


Figure 3-18 LPUE in kg per day at sea for the selected rectangles

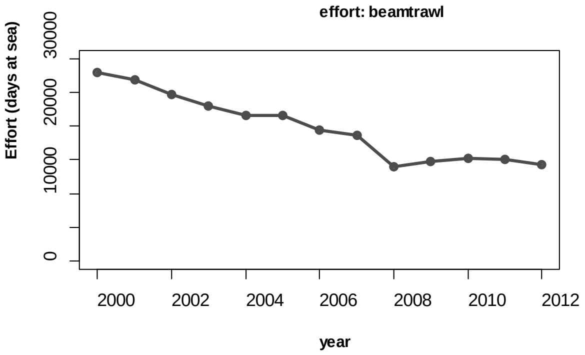


Figure 3-19 Effort in days at sea for the selected rectangles.

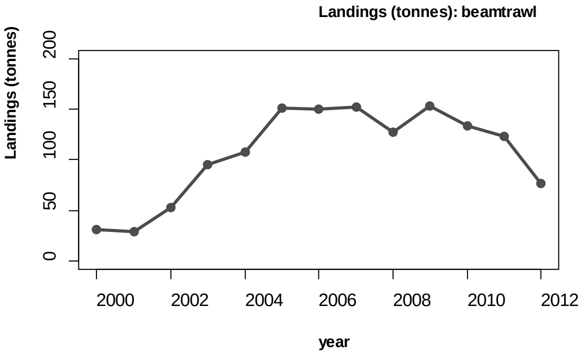


Figure 3-20 Landings in tonnes for the selected rectangles.

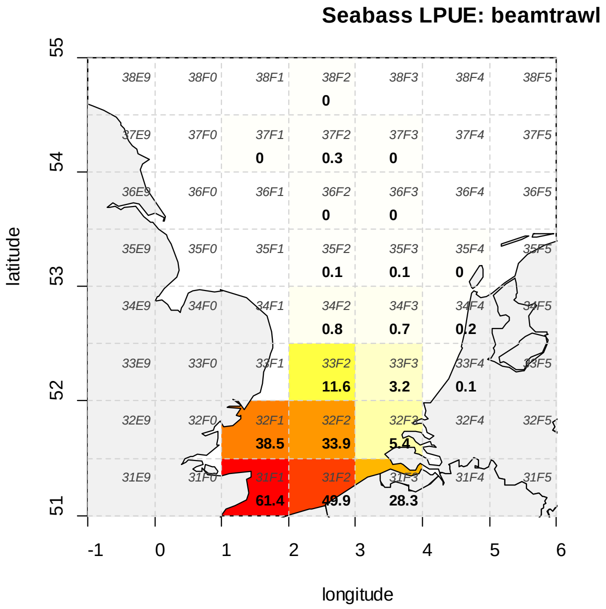


Figure 3-21 LPUE in kg per day at sea in the selected rectangles (2000-2012 average).

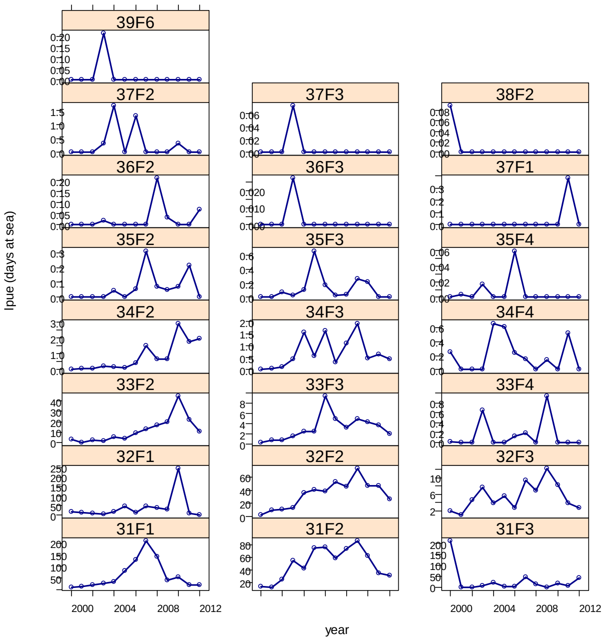


Figure 3-22 LPUE in kg per day at sea per year per selected rectangle. Note that the y-axis scales differ for each panel.

3.5.3.6 Flyshoot

For the flyshoot fishery, the selection of ICES rectangles resulted in 6 rectangles, 3 in ICES area IV and 3 in area VIId. The amount of catches in area IV and VII differed about a factor 30-50, with high catches in area VII and very low catches in area IV (close to 0). We therefore decided that the analysis was done for the 3 ICES rectangles in area VII only (Figure 3-23). The effort in days at sea for the flyshoot in these rectangles has increased from less than 100 days at sea in 2000 to almost 1000 days at sea in 2011 (Figure 3-24). The landings also increased, from 930 tonnes to 86484 tonnes in 2012 (Figure 3-25). The LPUE increases during the time series from less than 10 tonnes per day at sea in 2000 to almost 1000 tonnes per day at sea in 2012, with a small dip between 2009 and 2011 (Figure 3-23). On average, the highest LPUE is in ICES rectangle 29E9 (Figure 3-26). The trend also fluctuates between ICES rectangles (Figure 3-27).

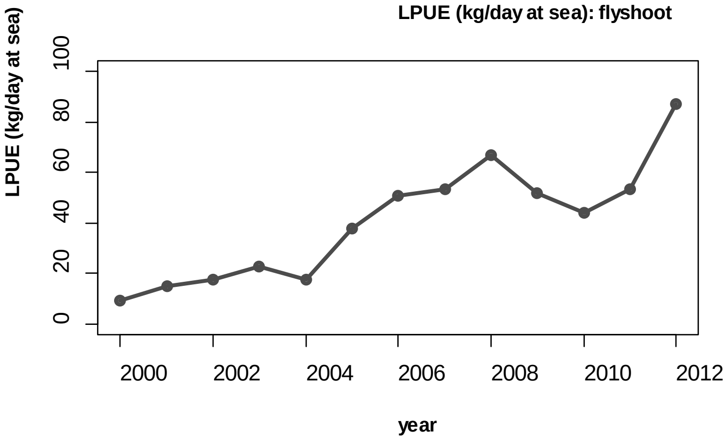


Figure 3-23 LPUE in kg per day at sea for the selected rectangles

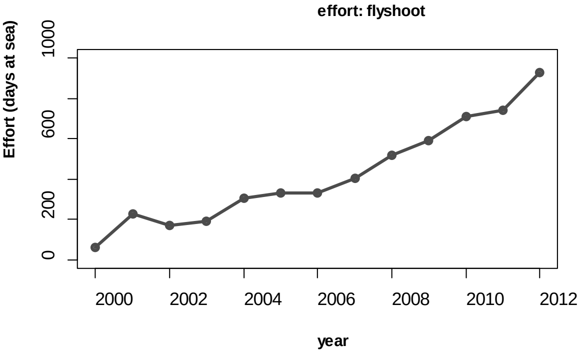


Figure 3-24 Effort in days at sea for the selected rectangles.

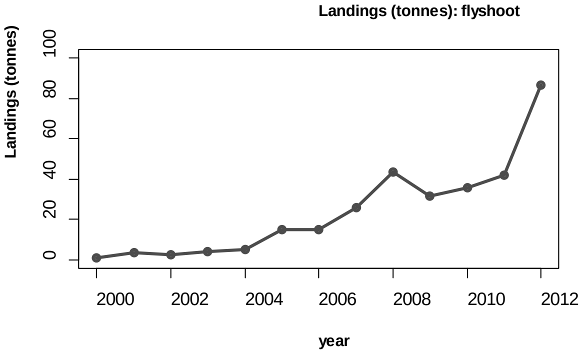


Figure 3-25 Landings in tonnes for the selected rectangles.

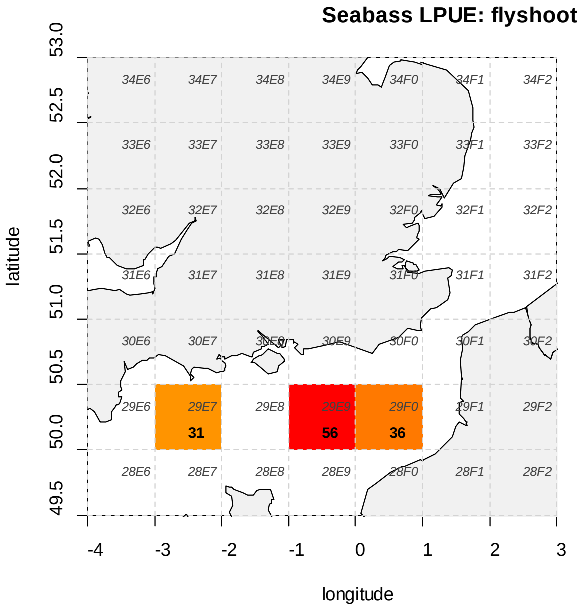


Figure 3-26 LPUE in kg per day at sea in the selected rectangles (2005-2012 average).

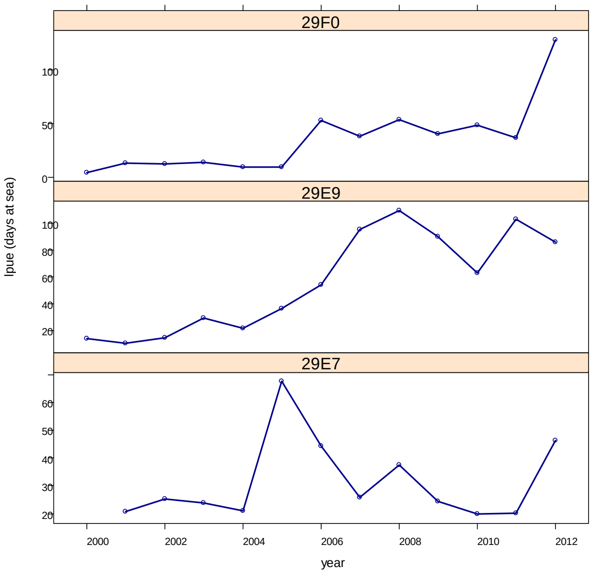


Figure 3-27 LPUE in kg per day at sea per year per selected rectangle. Note that the y-axis scales differ for each panel.

3.5.4 *Dutch Demersal Fish Survey (DFS)*

The Dutch Demersal Fish Survey (DFS) is part of an international inshore survey carried out by the Netherlands, The UK, Belgium and Germany (van Beek et al., 1989). The Dutch survey covers the coastal waters from the southern border of the Netherlands to Esbjerg, including the Wadden Sea, the outer part of the Eems-Dollard estuary, the Western Scheldt and the Eastern Scheldt. This survey has been carried out since 1970 in September–October.

Survey set-up

For each haul, the position, date, time of day, depth and surface water temperature were recorded. The Westerschelde and Wadden Sea are sampled with a 3m beam trawl, while along the Dutch coast a 6m beam is used. The beam trawls were rigged with one tickler chain, a bobbin rope, and a fine-meshed cod-end (20 mm). Fishing is restricted to the tidal channels and gullies deeper than 2 m because of the draught of the research vessel. The combination of low fishing speed (2–3 knots) and fine mesh size results in selection of mainly the smaller species and younger year classes. Sample locations are stratified by depth.

Analysis

Data from six distinct areas were analysed: the Dutch Western and Eastern Wadden Sea, the Dutch Wadden Sea coastal zone, the Southern coastal zone, the Western Scheldt and the Eastern Scheldt. Sampling effort has been relatively constant over the years. The mean abundance per area was calculated in the period 1970–2006 weighed by surface area for each depth stratum. Lengths of seabass are also measured in the DFS. For the Western Scheldt area, the analysis is also done by length class.

Results

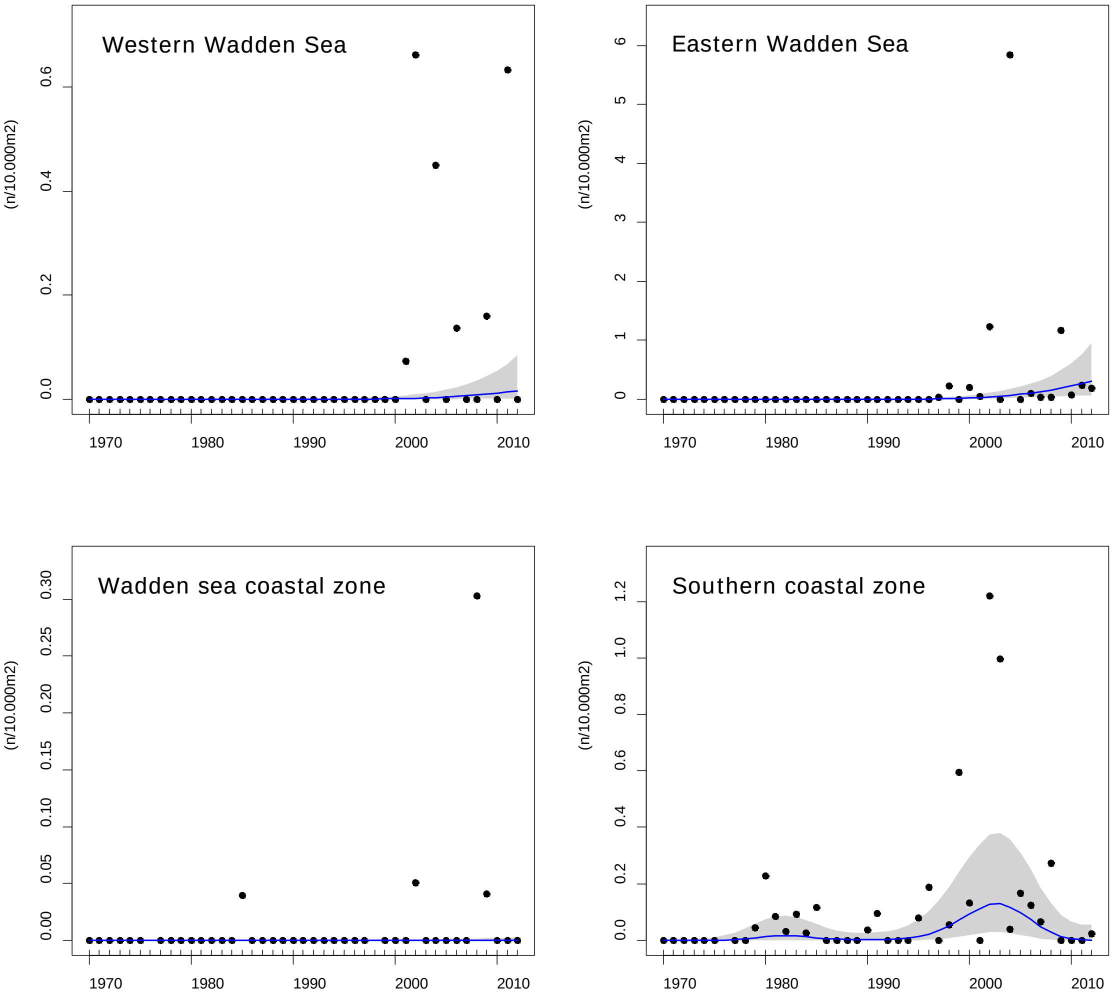
The analysis resulted in six time series (Figure 3-28), showing that seabass abundance increased in the last 10-15 years in all areas (Tulp 2008). However, in most areas, seabass is not caught frequently

(~1/10.000m2), only in the Western Scheldt the DFS catches seabass more frequently. The DFS abundance index is listed in Appendix A and available for the ICES Celtic Seas working group (WGCSE).

The analysis by length class shows high variation in the length distribution per year (Figure 3-29), but does not show a clear trend over the years. Seabass matures at around 41cm (females) or 34cm (males) (Table 3-3); the survey catches only juveniles (Figure 3-29).

Table 3-3 Length at maturity. Data source: IMARES market sampling

	L50% females	*L50% males*
NL (marketsampling 2005-2010)	41.4 cm	33.8 cm



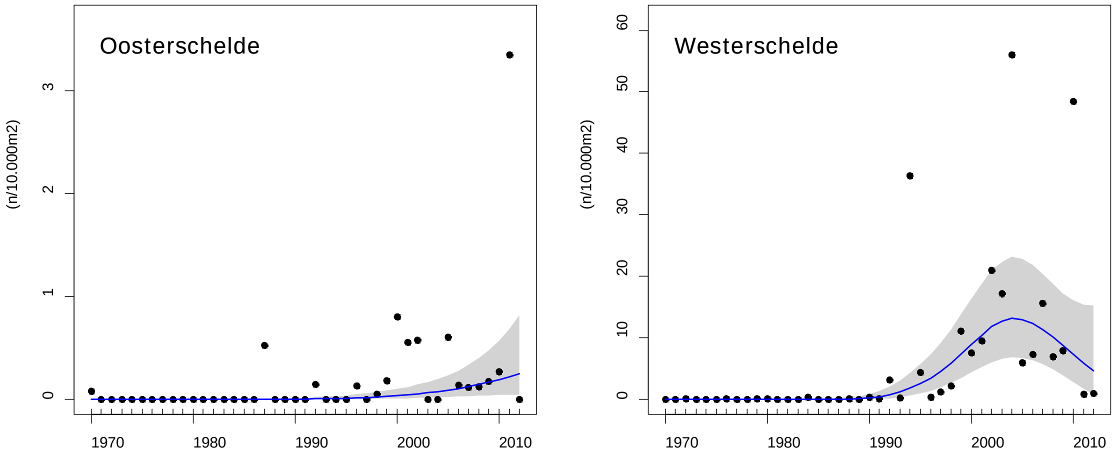


Figure 3-28 Time Series for the density of seabass from 1970 to 2012. Above: Wadden Sea, middle: coastal zone and below: Oosterschelde and Westerschelde. The black dots are the average densities in numbers per hectare. The blue line shows the trend. The gray areas indicate the upper and lower limit of the 95% confidence intervals (Tulp et al, 2008 and Tulp: personal communication).

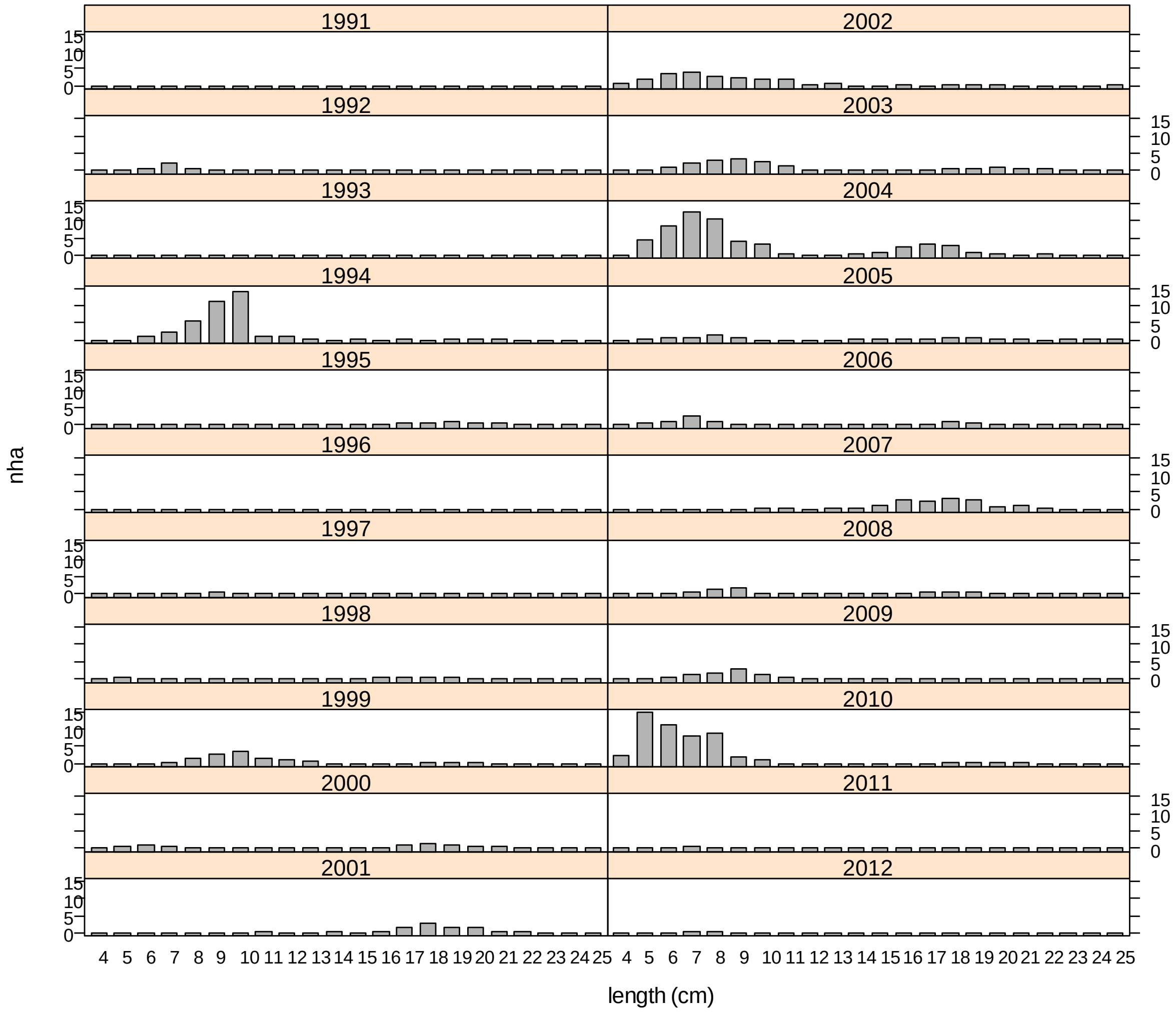


Figure 3-29 Number per 10.000 m^2 (nha) per length class and year in the Westerschelde.

3.5.5 Conclusions DFS

In the past, seabass was caught only occasionally by the DFS. Since the beginning of the 2000's seabass is caught more frequently, especially in the Westerschelde (Figure 3-28).

3.5.6 IBTS

Seabass is caught only sporadically in the IBTS. the majority of IBTS seabass catches are in the most southern North Sea and in the Channel. However, even there, the catches do not exceed approximately 2 fish per hour, which makes the IBTS not very suitable for an abundance index (Figure 3-30).

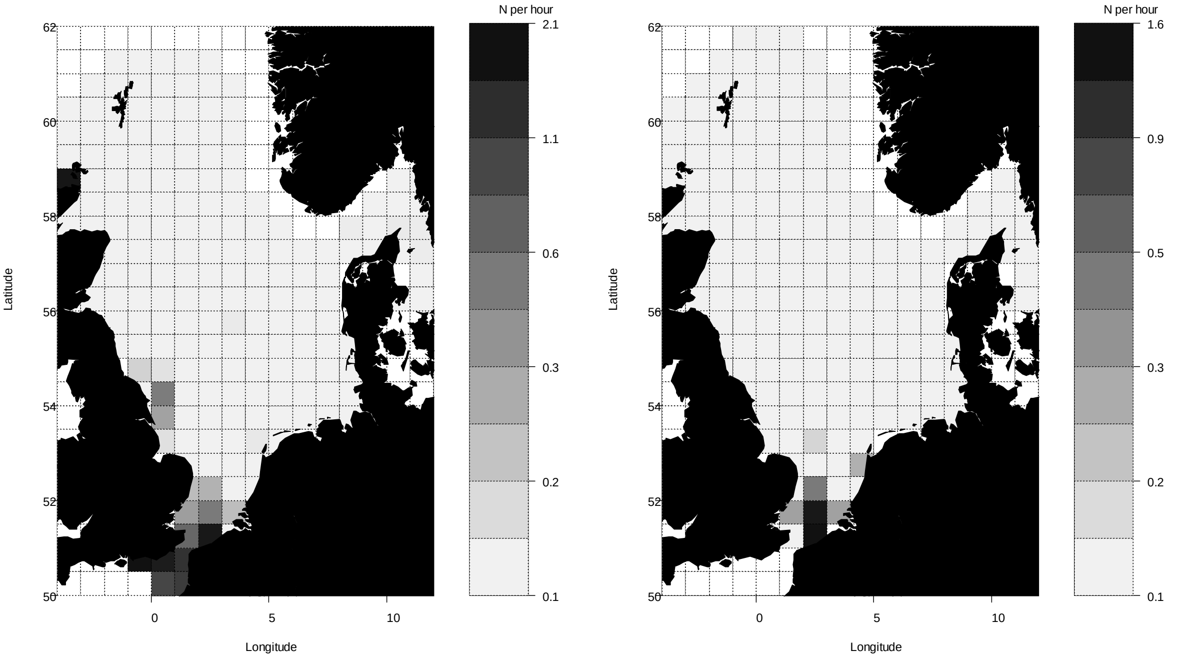


Figure 3-30 Number of Seabass per hour per ICES rectangle. IBTS survey Q1 (left, 1976-2012) and Q3 (right, average 1996-2012). There is no IBTS in the 2nd and 4th quarter. Data source: ICES database DATRAS

3.5.7 Year-round Egg Survey

In 2010 a year-round egg survey was carried out in the North Sea (personal communication Van Damme - IMARES). The purpose was to monitor the spatial distribution and seasonal patterns in the appearance of fish eggs and larvae on the Dutch continental shelf. The survey covered the southern North Sea and eastern English Channel. In each ICES rectangle 2-3 hauls were made with the Gulf VII plankton torpedo with a 20 cm diameter conical nose and a standard net of 280 µm or 500 µm mesh size. All egg and larvae data are stored in a central database at IMARES (FRISBE).

In the year-round egg survey, only few seabass eggs were found. All eggs were observed in April (very few) and May (almost all, Figure 3-31). Seabass eggs were found on several locations in the Southern north sea (Figure 3-32).

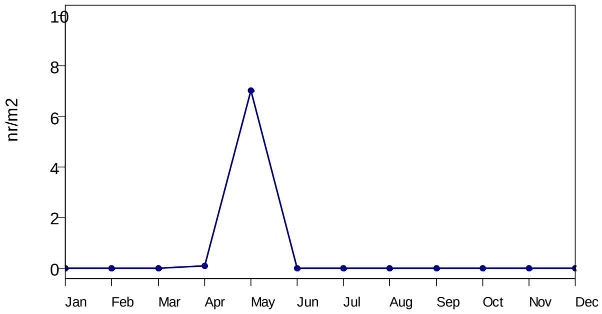


Figure 3-31 nr seabass eggs per meter per month

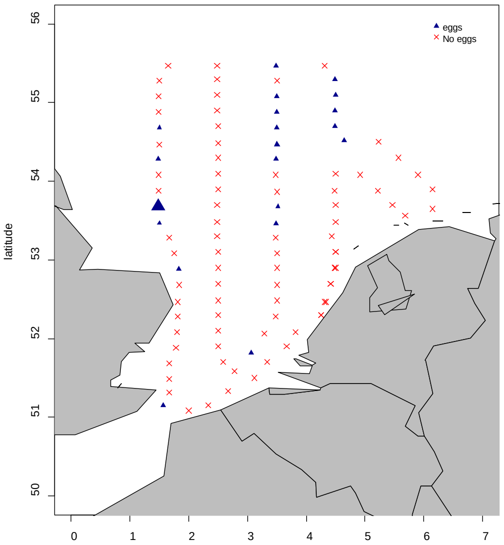


Figure 3-32 Locations where seabass eggs were found in May 2010. Blue triangles mark the locations where seabass eggs were caught. The size of the triangle shows the relative amount of eggs.

3.5.8 Recreational Fisheries

Seabass is an important species for recreational fishers in the UK, Ireland, France and the Netherlands. Recreational seabass catches are very difficult to assess, because recreational fishers are not registered, their total numbers are high and they often have low avidity. The catches are now estimated by many countries, but long-term trends are lacking and there is no procedure to include the recent data in the assessment. In the Netherlands the recreational catches are estimated biennially. The latest estimate is from 2010, resulting in estimates of approximately 234 000 seabasses being retained and 131 000 being discarded: a return rate of 36%. The impact of discarding on the survival and fitness of seabass is unknown. The estimated amount in weight is 138 tonnes, which is approximately 26% of the total landings (recreational and commercial, Table 3-4, van der Hammen & de Graaf 2013). This survey is repeated in 2012-2013 and will be repeated again in 2014-2015.

Table 3-4 Estimates of Dutch recreational catches (±standard error).

Recreational landings	***retained (thousands)***	***discarded (thousands)***	***retained (tonnes)***	***Dutch landings in area IVbc and VIId in 2010 (ICES 2012).***	**% recreational landings**
March 2010- February 2011	234 (±88)	131 (±35)	138 (±51)	391	26.1%

3.6 Conclusions Seabass

Abundance indices:

- LPUE indices from the main fleets that land seabass give insight in the effort and abundance trends

    - Lines: effort has increased substantially from 2005 to 2012; LPUE fluctuates without clear trend with somewhat higher LPUE in the last 3 years
    - Gillnet-seines: effort has increased substantially from 2000-2012; LPUE also increased substantially during the time series. This increase is not consistent in all ICES rectangles.
    - Beamtrawl: effort decreased substantially; LPUE increased between 2001 and 2007 and decreased in 2011 and 2012.
    - Flyshoot: effort increased substantially between 2000 and 2012; LPUE also increased.
- DFS: In the Westerschelde juvenile seabass is caught in substantial amounts in recent years. If this trend continues, this series is useful as a fisheries independent abundance index.

Recreational catches:

- The Netherlands has recently started to estimate the recreational catches of all species. This biennial survey should continue in order to get a reliable estimate of the yearly variation and to get a longer time series that can be included in the assessment.

4 Greater silver smelt (*Argentina silus*)

4.1 Assignment

The assignment was to explore opportunities to gain better insight in population structure, size and trends of the greater silver smelt stock. Availability of data was researched. The data was evaluated and possibilities to analyze the data were described.

The Netherlands has a significant share of the TAC of greater silver smelt in ICES areas V, VI, and VII (http://ec.europa.eu/fisheries/cfp/fishing_rules/tacs/info/com_2012_608_nl.pdf). The greater silver smelt is a "deep-sea species", and because of the lack of knowledge, the precautionary principle is followed, which means that catches are reduced as a safety measure.

4.1.1 Biology

‘Greater silver smelt is a benthopelagic deep-water species and lives in schools close to the bottom. Due to its low productivity, greater silver smelt can only sustain low rates of exploitation. Greater silver smelt is particularly susceptible to rapid local depletion due to its aggregating behaviour’ (from: ICES 2012e). Greater silver smelt mainly feeds on planktonic invertebrates and on small fishes. Spawning is from April to July. The eggs and juveniles are pelagic at depths of 400-500m (fishbase). Greater silver smelt is primarily fished in the depth range 100–700 m.

4.1.2 Stock identity and migration issues (from: ICES 2010, WKDEEP)

For greater silver smelt, ICES treats Subareas I, II, IV, VI, VII, VIII, IX, X, XII and XIV and Divisions IIIa and Vb as a single assessment unit. Only Division Va (around Iceland) is treated as a separate assessment unit.

During the ICES benchmark group on deep-water species (WKDEEP) 2010 meeting, data analyses generally grouped data into the three main fisheries areas: Iceland, Faroe Islands, and Norway.

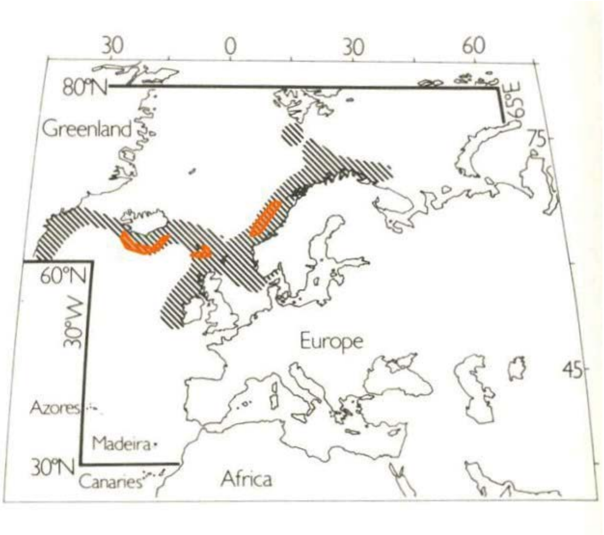


Figure 4-1 Distribution of greater silver smelt in the ICES area (Cohen, 1984). The locations of current direct fisheries are indicated in orange, from left to right: Iceland, Faroe Islands and Norway fisheries areas.

4.1.3 Advice 2013/2014

The biennial advice for 2013/2014 was a survey trends-based assessment. It was based on a combined abundance index, from the Faroese groundfish survey in Division Vb and from the Spanish Porcupine groundfish survey (VIIb-k). The combined survey index was used as an indicator of stock size (ICES 2012e).

The advice is based on a comparison of the two most recent index values with the three preceding values combined with recent landings data. This implies an increase in catches of at most 10%. However ICES also advises a precautionary buffer of 20% reduction of the catches. The final advice is therefore a 10% reduction in the catches.

4.1.4 Dutch commercial fisheries data

Landings data are available from the official EU logbooks of the entire Dutch fleet, which are maintained by the NVWA (formerly known as the General Inspection Service, AID). IMARES has access to these logbooks and stores the data in a database called VISSTAT. Logbook data are available of the entire Dutch fishing fleet and of foreign vessels landing their catches in the Netherlands. For greater silver smelt the logbook registration is not always accurate. Lesser silversmelt (*Argentina sphyraena,* ICES code ARY) and greater silversmelt (*Argentina silus,* ICES code ARU) are difficult to distinguish and are both used in the logbooks. However, lesser silversmelt is not expected to be caught and landed in substantial amounts (personal communication, S. Verver - IMARES). Therefore, the ICES codes ARG (all silver smelts), ARU (*Argentina silus*) and ARY (*Argentina sphyraena*) are all expected to all be greater silver smelt (*Argentina silus*). Almost all Dutch landings are from ICES area VI, west of Scotland and Ireland (Figure 4-3, Figure 4-2) and all are caught with pelagic otter trawls (gear code 'OTM'). The location of the Dutch catches is south from the direct fisheries area close to the Faroes Islands (Figure 4-1, Cohen 1984). Biological sampling is only done in the first two quarters and particularly in the second quarter (Q2) because most of the landings are from this quarter (Figure 4-4). Age readings from market samples of greater silver smelt are available from 1990 onwards (Table 4-1); 12 samples are planned per year in Q1 and Q2 each sample will consisting of 25 age readings. In order to correct for sample sizes per trip, the raising to the level of the fleet is first done per trip and consequently averaged over the trips. Analyses are done for Q2 only.

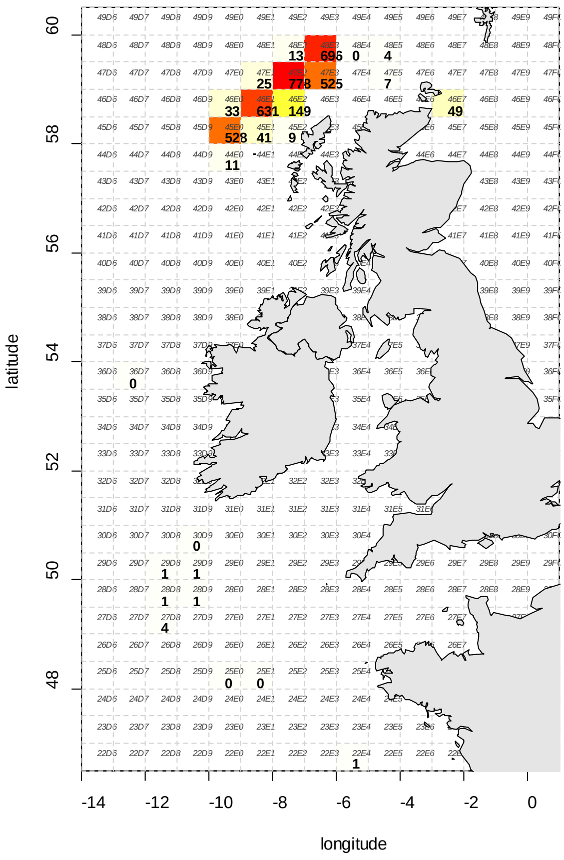


Figure 4-2 Yearly Dutch catches (tonnes) per ICES rectangle (average 2008-2012).

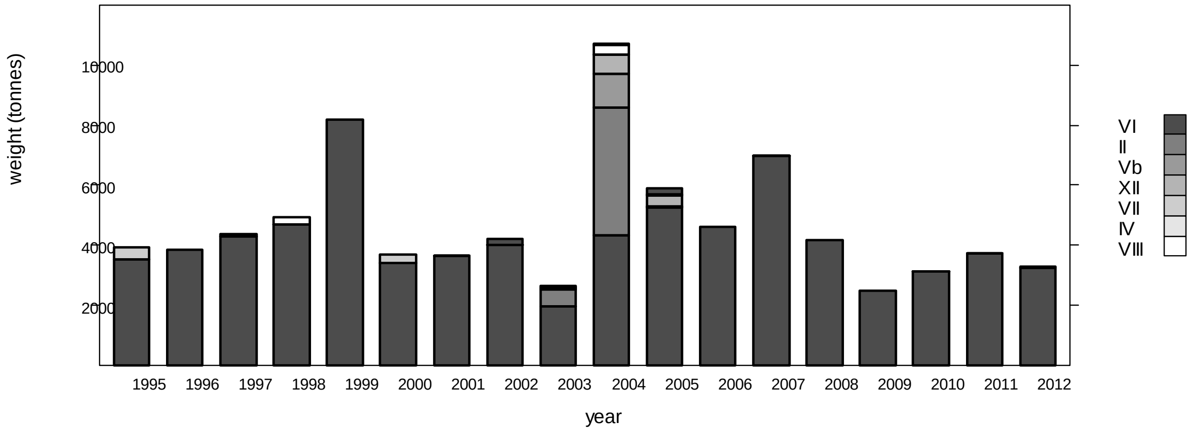


Figure 4-3 Dutch landings per ICES area

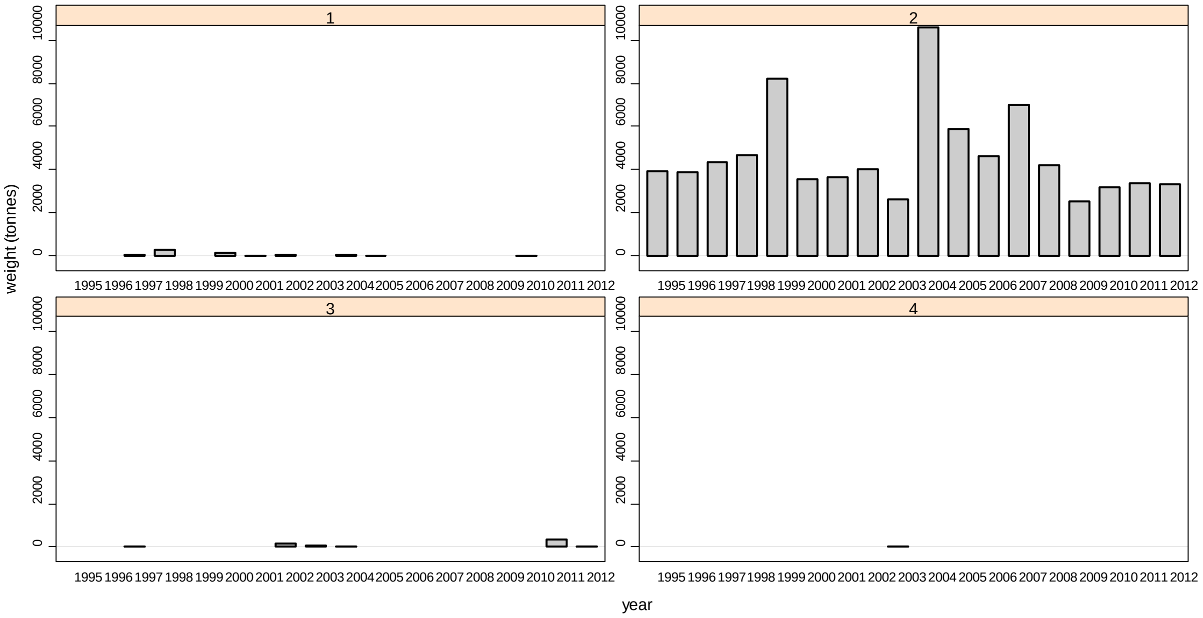


Figure 4-4 Dutch landings per quarter

Table 4-1 Nr stations (sampled hauls), age and length samples in Q2 (ICES area VI), source: IMARES' database FRISBE

year	*nr stations*	*nr age samples*	*nr length samples*
1990	25	633	633
1991	13	325	325
1992	12	300	300
1993	6	150	150
1994	11	275	275
1995	7	175	175
1996	9	225	225
1997	3	75	75
1998	5	125	125
1999	9	225	225
2000	5	125	125
2001	1	25	25
2002	12	300	1199
2003	8	195	611
2004	3	75	181
2005	15	375	1174
2006	24	600	2405
2007	30	750	2973
2008	23	554	2134
2009	12	295	954
2010	1	100	100
2012	6	143	494

4.1.5 Results

The average age of greater silver smelt in the Dutch catches is decreasing since the start of the biological sampling (Figure 4-7). Especially the first three years of the time series (1990-1992) older ages are caught than the other years (Figure 4-5). The maximum age observed in the catches has greatly decreased from 38 in 1990 to 14 years in 2012 (Figure 4-8).

The average length does not show a clear trend over the years in either the length distribution or the maximum length observed (Figure 4-6, Figure 4-9, Figure 4-10). However, in the years before 2003, larger amounts of smaller and of larger fish were caught than in later years, when the variation in the length distribution decreased (Figure 4-6).

The growth rate may have increased in the period 1990-2012: the weight at age and the length at age do not show a clear trend in the beginning of the time series, but seem to increase after the mid 2000's (Figure 4-11, Figure 4-12).

Females mature at a slightly earlier age and length than males (Figure 4-13, Figure 4-14). The age where 50% of the fish is mature (A50%) is 3.6 years and 4.6 years respectively for females and males (Table 4-3). This corresponds with lengths of 29 cm and 31 cm (L50%, Table 4-4). The length-weight relationship does not differ between males and females (Figure 4-15, Table 4-5). The Von Bertalanffy growth curve shows that females grow slightly faster and larger than males (Figure 4-16, Table 4-6). The ages where 50% is mature (A50%) estimated here, are lower than the A50%'s estimated at WKDEEP (Iceland: 6.54 (♀), 5.61 (♂), Faroe: 5.84 (♀), 7.60 (♂), Norway: 4.23 (♀), 5.12 (♂)) (ICES 2010). The differences are expected to be caused by location; Dutch catches are closest to the Faroe islands, but the A50% are closer to those estimated at the Iceland area.

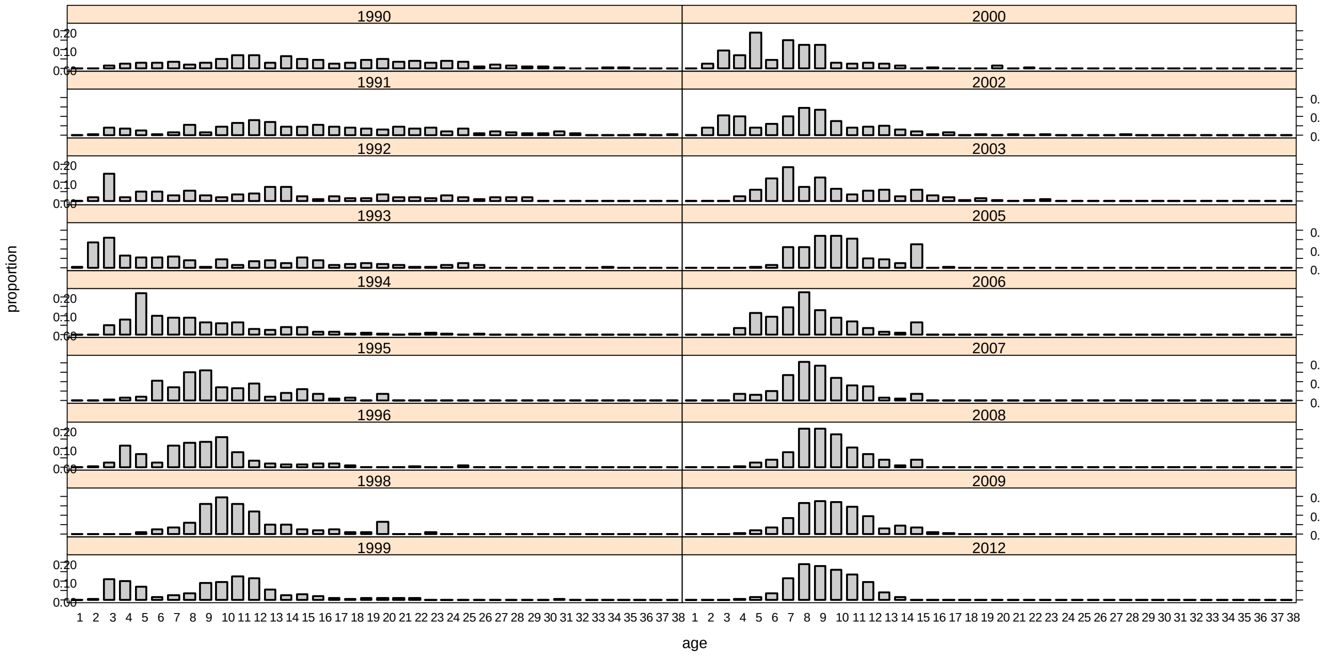


Figure 4-5 Age distribution in the Dutch catches in Q2, ICES area VI, per year.

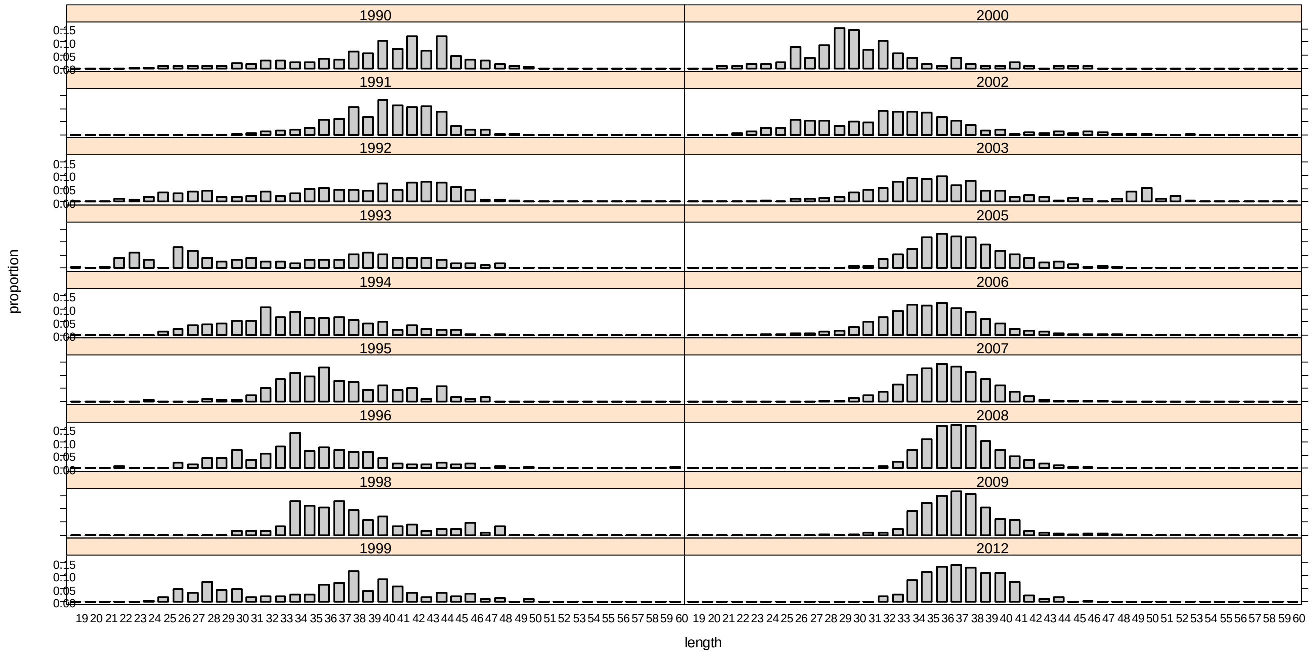


Figure 4-6 Length distribution in the Dutch catches in Q2, ICES area VI, per year.

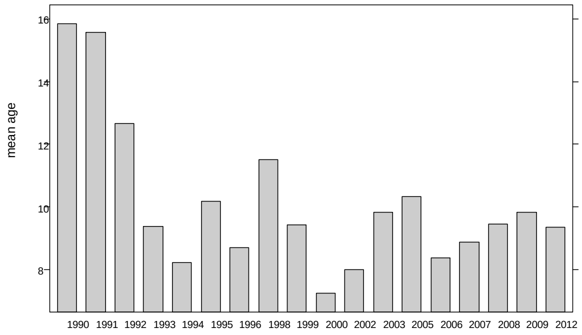


Figure 4-7 Mean age in the Dutch catches in Q2, ICES area VI, per year.

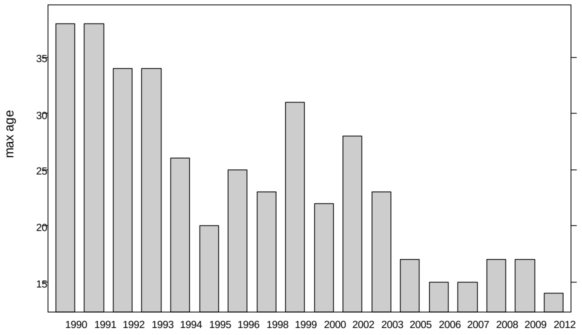


Figure 4-8 Maximum age in the Dutch catches in Q2, ICES area VI, per year.

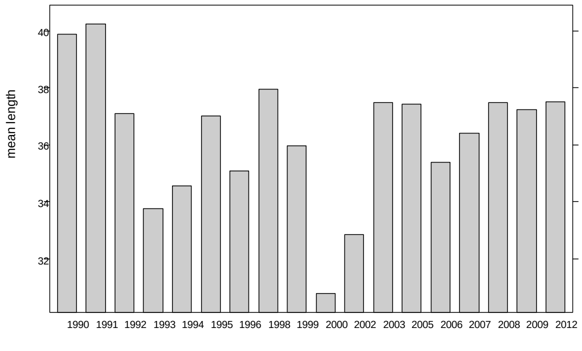


Figure 4-9 Mean length in the Dutch catches in Q2,

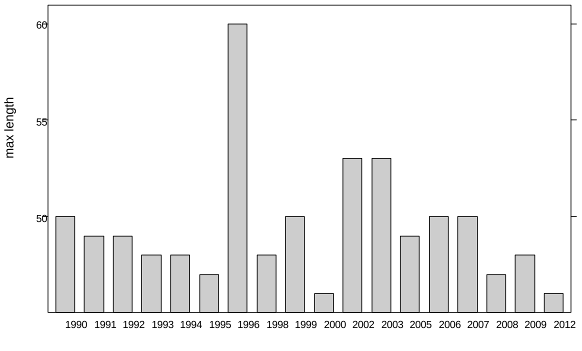


Figure 4-10 Maximum length in the Dutch catches in

ICES area VI, per year.

Q2, ICES area VI, per year.

Table 4-2 mean length and age in the catches in Q2 per year (ICES area VI)

year	*mean length*	*mean age*	*max age*	*max length*
1990	39.9	15.7	38	50.5
1991	40.2	15.6	38	49.0
1992	37.1	12.7	34	48.8
1993	33.8	9.4	34	48.2
1994	34.6	8.2	26	48.3
1995	37.0	10.2	20	46.9
1996	35.1	8.7	25	59.8
1998	37.9	11.5	23	48.5
1999	36.0	9.4	31	49.8
2000	30.8	7.2	22	46.1
2002	32.8	8.0	28	52.7
2003	37.5	9.7	23	53.2
2005	37.4	10.3	17	48.7
2006	35.4	8.4	15	50.2
2007	36.4	8.9	15	50.0
2008	37.5	9.4	17	47.0
2009	37.2	9.8	17	47.7
2012	37.5	9.3	14	46.0

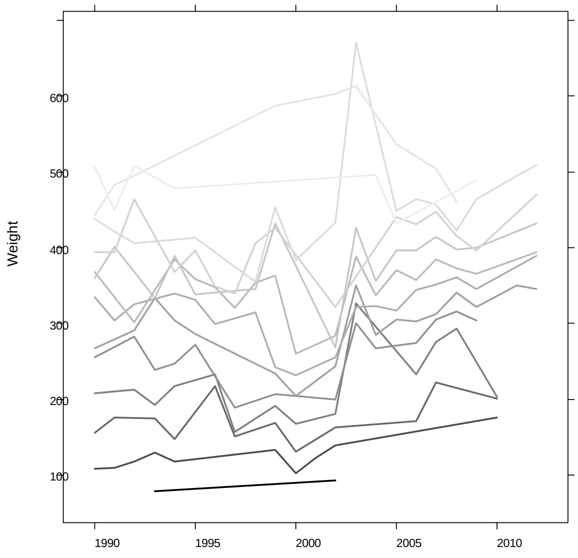


Figure 4-11 Weight at age per year. Ages 1-14, from dark grey to light grey.

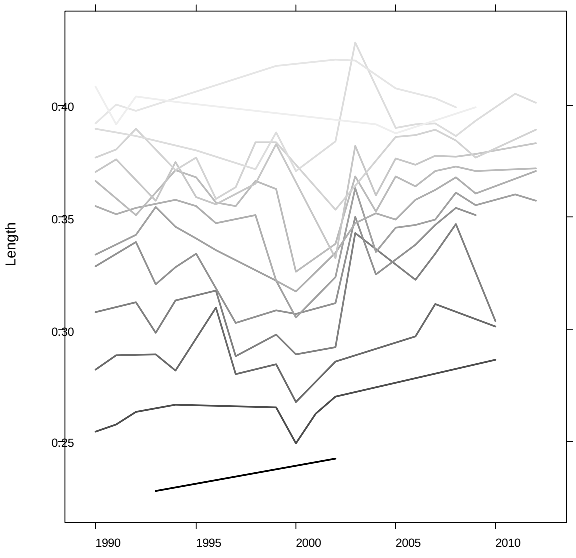


Figure 4-12 Length at age per year. Ages 1-14, from dark grey to light grey.

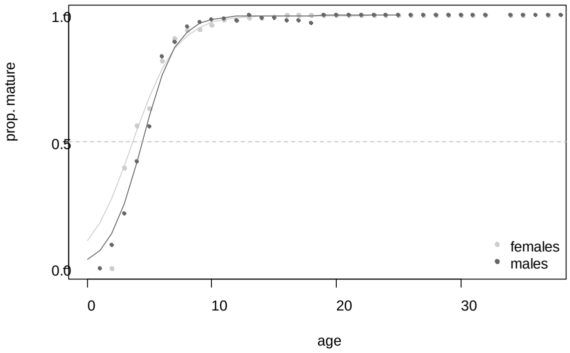


Figure 4-13 Age maturity ogive

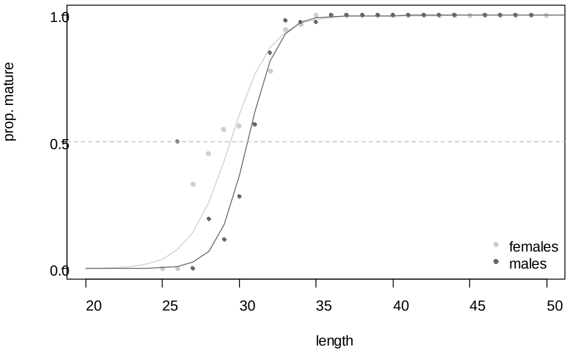


Figure 4-14 Length maturity ogive

Table 4-3 Age maturity ogive. Fitted probabilities.

Age (year)	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	***A50%***
prop. mature females	0.02	0.07	0.17	0.36	0.61	0.82	0.93	0.97	0.99	1.00	**3.55**
prop. mature males	0.00	0.01	0.04	0.12	0.32	0.64	0.86	0.96	0.99	1.00	**4.56**

Table 4-4 Length maturity ogive. Fitted probabilities.

Length (cm)	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*	*31*	*32*	*33*	*34*	*35*	*36*	*37*	***L50%***
prop. mature females	0.01	0.02	0.04	0.07	0.14	0.26	0.43	0.61	0.77	0.87	0.94	0.97	0.98	0.99	1.00	**29.40**
prop. mature males	0.00	0.00	0.00	0.01	0.03	0.07	0.17	0.37	0.62	0.82	0.93	0.97	0.99	1.00	1.00	**30.53**

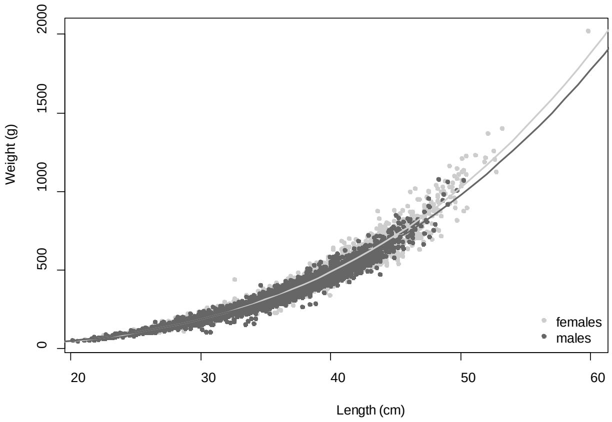


Figure 4-15 Length weight relationship

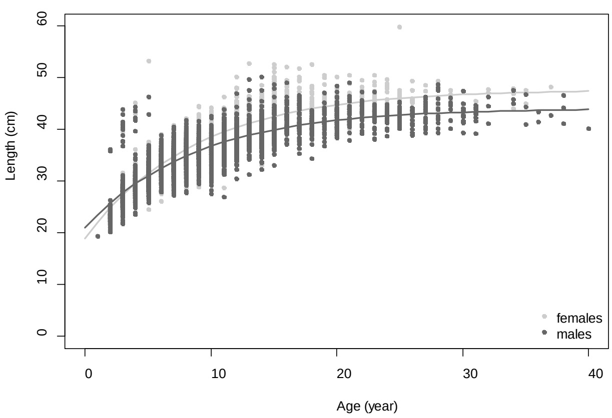


Figure 4-16 Von Bertalanffy growth

Table 4-5 *Length weight parameters*

Length weight parameters	a	b
females	0.00227	3.328944
males	0.00288	3.255385
combined	0.00222	3.331038

Table 4-6 *Von Bertalanffy growth parameters*

Von Bertalanffy parameters	t0	Linf	K
females	-4.40	47.61	0.114
males	-5.60	44.00	0.115
combined	-4.67	45.32	0.121

4.1.6 IBTS

Greater silversmelt is caught in the Northern North Sea and in the Skagerak/Kattegat in the IBTS Q3 (Figure 4-17). The number of smelt caught in the IBTS varies strongly between years without a clear trend (Figure 4-18). One problem is that proper identification from Lesser Silversmelt, which is also caught in the same time and area is difficult, which is a point of discussion if the data can be trusted to represent the abundance of Greater Silversmelt from the IBTS (personal communication H. Heessen - IMARES).

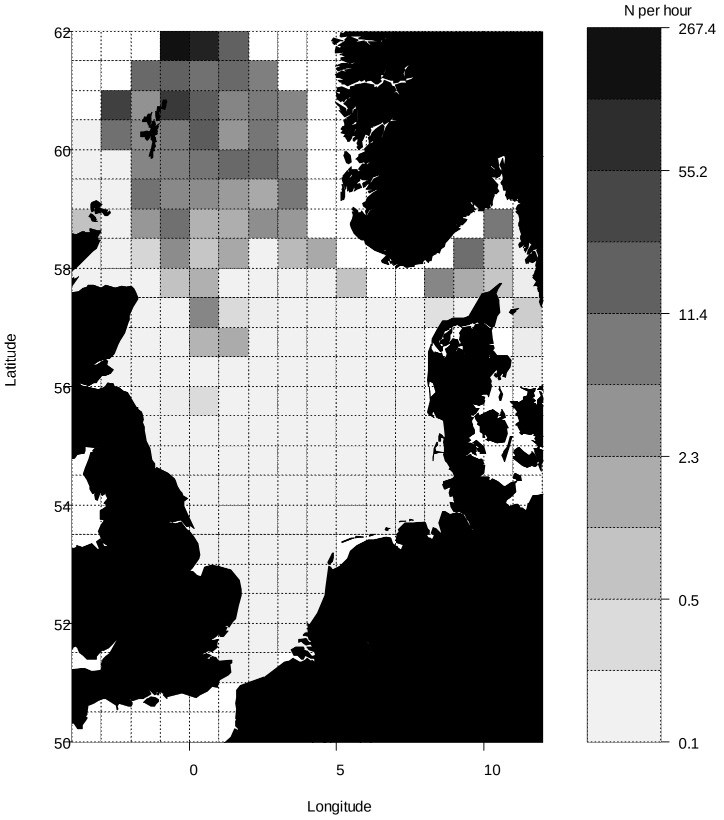


Figure 4-17 Number of Greater Silversmelt per hour per ICES rectangle. IBTS survey Q3 (1976-2012). Data source: Datras

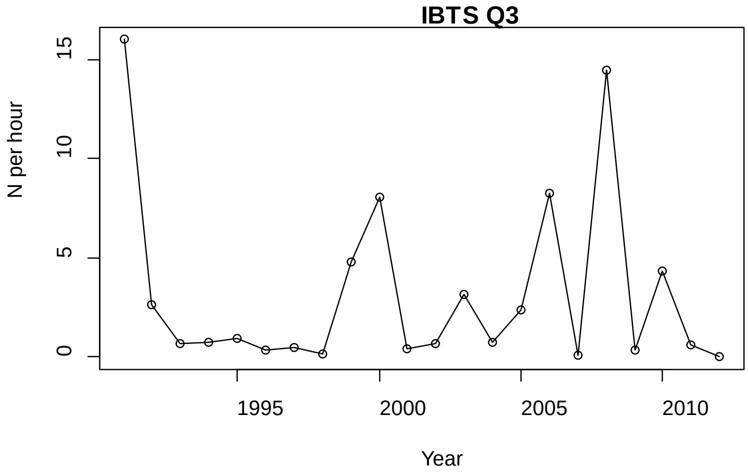


Figure 4-18 Abundance index Greater Silversmelt in area IV: data: IBTS Q3- Datras

4.1.7 Recommendations

4.1.7.1 ICES

Stock structure (ICES 2010, WKDEEP)

'*Stock identity is recognized as a key issue for this species. Although the Norwegian fishing grounds are somewhat distant from the other two, the fisheries off Iceland and the Faroe Islands are close, and linked bathymetrically by the Faroe Iceland Ridge. Given that the fisheries are large by volume, and research surveys demonstrate similar patterns in biomass indices and length, it is very important for future stock assessment that resources are put into attempting to resolve stock structure in the general region, including VI and VII and IIa and IVa. There are a large number of methods that can be applied to identify stock structure. No single technique has proven suitable across a wide range of fisheries, and the general intention in most stock structure studies now is to apply a holistic approach, and use several approaches. These include aspects of oceanography, morphometrics and meristics (including biological information of aspects such as age, growth, and reproduction), distributional information, tagging, and genetics. For greater silver smelt several aspects were recommended for further appraisal:*

- *Oceanographic conditions (e.g. current flows, both surface and seabed) between Iceland, Faroes, Norway, west of Scotland and Ireland, Skagerrak and northern North Sea.*
- *Genetic characteristics. These methods would focus on nuclear and mitochondrial DNA, but sampling considerations were important. Samples need to be taken in the different regions over several time periods. They should also span a wide size range of the fish.*
- *Morphometric and meristic characters. Studies on shape, size, and numerical characteristics of body parts etc. Can be done reasonably quickly and cheaply. This could also include exploratory analysis of otolith shape.*'

Data sampling (ICES advice 2012)

'*Improvements in data sampling that would be beneficial for the current assessment include:*

- *biological sampling from the EU fisheries*
- *improved biological sampling from the Norwegian fisheries*
- *establishing an acoustical survey time-series in Norwegian waters, and deeper stations in the Faroese surveys.*'

4.1.7.2 Dutch Data

- The Netherlands has sampled biological data since 1990 in quarter 1 and quarter 2 (see 4.1.4). This data should be made available to the ICES working group (WGDEEP).
- Acoustical survey methods could be explored in order to make new abundance indices. Recently, a pilot has been done in cooperation with Dutch trawlers. It should be explored if this is a possible cost efficient method to start a commercial LPUE series.
- Identification issues with lesser Silversmelt should be resolved.

4.2 Conclusions

Dutch commercial data:

- The mean age and especially the maximum age in the catches decreased since the beginning of the time series
- There are indications that the weight at age is increasing since the middle of the 2000's, possibly indication increased growth rates.

IBTS

- The identification problems between Lesser and greater silversmelt should first be solved, before the IBTS data can be used as an abundance index.

Currently, the advice is based on the ICES methods for data-limited stocks. The main issue with Greater silver smelt is that the stock structure is unknown. Therefore it is unclear how the state of the stock should be analysed.

- The stock structure should be researched according to the ICES recommendations from WKDEEP (ICES 2010).
- The Netherlands should provide ICES with the available Dutch biological data derived from market sampling.
- Effort should be done to distinguish greater from lesser silversmelt in the surveys as well as in the landings. This could also make the IBTS data suitable for an abundance index.

5 Horse mackerel (*Trachurus trachurus*)

Horse mackerel is a widely distributed pelagic species, occurring in the Eastern Atlantic from Norway to South Africa, as well as in the Mediterranean Sea (ICES 2012b). ICES distinguishes 3 stocks: the Southern, the Western and the North Sea stock, the last two being of importance for the Netherlands (Figure 5-1).

In recent years there has been no accepted ICES assessment to form the basis of advice for the North Sea horse mackerel stock. One reason for this is the lack of a scientific survey which is designed for assessing the state of this stock specifically (i.e. similar to the egg survey in the Western area, which is designed to assess the state of the Western horse mackerel stock. Another factor hampering the development of an analytical assessment is uncertainty in catch-at-age data. A lack of agreement between catch–at-age estimates from Dutch and German data makes it difficult to find clear cohort signals in the data. This discrepancy could be due to various reasons, including differences in fishing or sampling locations, misreporting of catch areas or catches comprising fish from more than one stock. The latter may specifically be the case for catches in division VIId, where the stock potentially mixes with Western horse mackerel at the time that the fishery takes place. As a consequence of having no accepted assessment, the ICES advice for the North Sea mackerel stock for in the period 2002 – 2010 was to not increase the catches above the long term average; for 2011 there was no ICES advice; for 2012 the advice was to reduce catches and for 2013 the advice was to reduce catches by 20% (ICES 2012c). The most recent advice was based on a newly developed approach by ICES for Data Limited Stocks (ICES 2012f).

Since 2010, management areas for horse mackerel in the northeast Atlantic have been realigned following the results of the HOMSIR project on horse mackerel stock identity (Homsir, 2003). The majority of North Sea horse mackerel landings are from the southern North Sea or the English Channel, very near to the border with the western horse mackerel stock. Despite the work done for the HOMSIR project, questions still remain about the distribution and movement of horse mackerel from the Western and North Sea stocks in the English Channel. If an analytical assessment model is to be used for the management of North Sea horse mackerel, the landings data need to be reliable i.e. it is necessary to be have information that it comes from the North Sea stock, or to have information on what proportion of the landings comes from this stock. Without reliable information on the origin of the catches, it will be difficult to establish an analytical assessment with which an absolute abundance estimate of the stock can be obtained. As an intermediate solution, information on relative developments of the stock can be used for trends-based informed TAC advice.

Such a trends-based approach as a base for management, are currently being considered. In 2013, in cooperation with CEFAS and industry stakeholders, IMARES attempts to develop a management plan for this stock, which includes a Harvest Control Rule (HCR) to provide a basis for TAC setting. Potential HCRs currently investigated use information on trends (e.g. in survey indices from the North Sea IBTS survey) in the North Sea stock. With the development of an assessment model, sensitivity of the assessment to uncertainty in catch composition (differing mixing ratios between the North Sea and Western stock) can also be addressed. This allows for investigation of the question of whether management action for the North Sea fisheries should be based on information on the North Sea stock alone (i.e. single stock approach) or whether management actions should also consider trends in the western stock (i.e. assuming some sort of linkages between these stocks). Knowing where the horse mackerel caught in the English Channel originate from will be important for deciding which approach to follow. Since North Sea horse mackerel is considered a data-limited stock, part of the management plan development focuses on recommending future research to strengthen the plan and confirm assumptions made. This will almost certainly require work on the distribution and migration of horse mackerel in this area in relation to fishing activity.

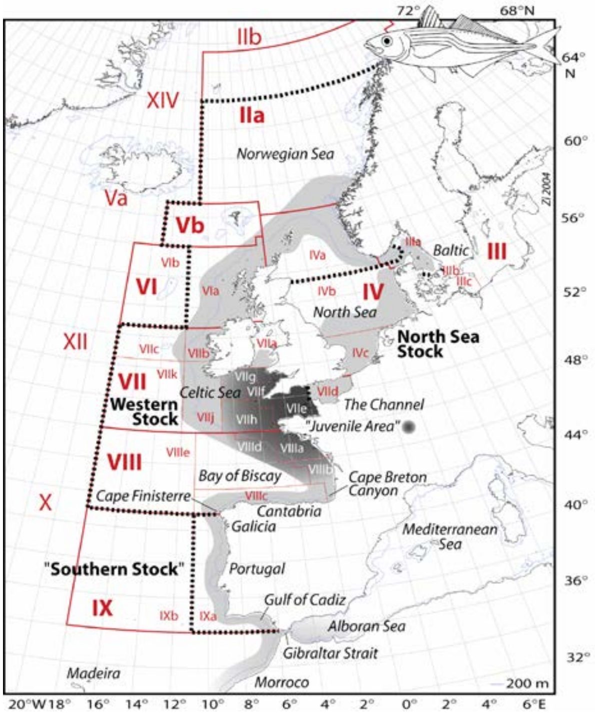


Figure 5-1 Distribution of Horse Mackerel in the Northeast-Atlantic and stock definitions. Map source: GEBCO, polar projection, 200 m depth contour drawn (ICES 2012b, WGWIDE).

5.1 Stock structure

The ICES Working Group WGWIDE has considered horse mackerel in the north east Atlantic as separated into three stocks: the North Sea, the Southern and the Western stocks (ICES 2012b). The catches are allocated to the three stocks as follows (Table 5-1):

- Western stock: 3-4 quarter: Divisions IIIa and IVa. 1-4 quarter: IIa, Vb, VIa, VIIa–c, e–k and VIIIa-e.
- North Sea stock: 1-2 quarter: Divisions IIIa and IVa. 1-4 quarter: IVb, c and VIId.
- Southern stock: Division IXa.

Table 5-1 Western and North Sea stock Horse Mackerel landings.

Quarterly landings (1000 t) by Division and Subdivision in 2011 (ICES 2012b).

Light grey: Western stock, dark grey: North Sea stock

Division	*1Q*	*2Q*	*3Q*	*4Q*	*TOTAL*
IIa+Vb	12	9	368	259	648
III	0.1	+	+	+	0.1
IVa	0		249	14474	14723
IVbc	1651	334	851	7622	10458
VIId	5801	90	6647	6349	18887

VIa,b	12525	6	585	26412	39528
VIIa–c,e–k	49937	24210	16814	18053	109014
VIIIa,b,d,e	523	1198	441	141	2303
VIIIc	3164	13278	10993	5938	33373
Sum	73613.1	39125	36948	79248	228934

+ less than 50 t

5.2 Assignment

The assignment was to explore possibilities to find out if horse mackerel landed as belonging to the North sea stock indeed belongs to the North Sea stock, or instead partly to the western stock. Literature research was done into the use of otoliths to determine the origin of the catches. The result is meant to be used in the horse mackerel management plan.

5.3 Otolith shape analysis

Otolith shape analysis can be used for fish species and stock identification. Otolith shapes are species-specific; often geographic variation in otolith shapes can be related to stock differences (Stransky et al. 2008). Otolith shape analysis has already been implemented for horse mackerel within the International HOMSIR project (Stransky et al. 2008). In 2000 and 2001, otoliths from 20 sampling areas were collected, covering the distributional range in the Northeast Atlantic and Mediterranean. This resulted in three distinct clusters of areas: a northern, an Ibero-Mauritanian and an eastern Mediterranean group (Figure 5-2). The authors did not find differences in otolith shape between the western stock and the North Sea stock, which is an indication that the Western and North sea stock can not be easily distinguished using otolith shape analysis. However, the North sea stock has only one sample location, which was sampled in two consecutive years (sample 05, Figure 5-2). Possibly, it would be worth sampling the North Sea more extensively, including some more southern parts. However, we propose to investigate the alternative method described in the next paragraph (5.4) first, because it may be a more sensitive and cost effective method.

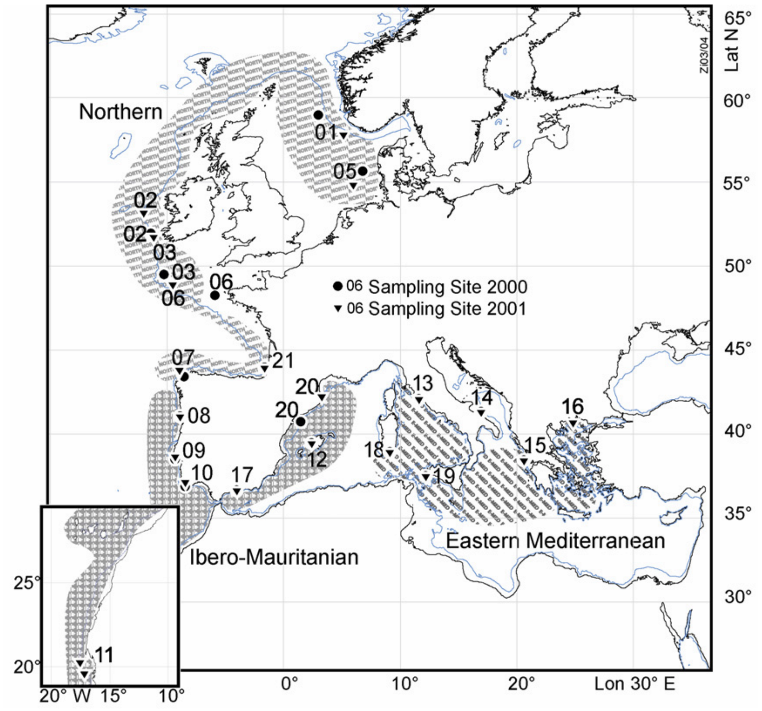


Figure 5-2 Proposed stock separation of horse mackerel by otolith shape analysis. From: Stransky et al. (2008)

5.4 Alternative method: Discriminating between landings from the North Sea Horse Mackerel and Western Horse-mackerel stocks using the GCxGC-MS fingerprint.

It may be possible to distinguish between individuals of the two stocks with Gas chromatography x Gas chromatography–mass spectrometry (GCxGC-MS). This is a technique which uses a 'fingerprint', showing the chemicals in the fish meat, which have been accumulated there through feeding and through respiration. Because individuals from different populations have different feeding and migratory routes history (Figure 5-3), they may have different chemicals stored, resulting in a different fingerprint. A pilot study has shown to be very effective in distinguishing between individual fish (sole, *Solea solea*) that forage in different locations (personal communication Van Damme - IMARES). IMARES has experience in the use of GCxGC-MS and the knowledge in the institute to perform this research. In addition, the method is relatively inexpensive.

Practically, the study would consist of taking samples from the fish auction from which it is sure that they belong to one of the two populations (e.g. west of Ireland and in the central North Sea during summer). The GCxGC-MS will first be used to detect differences between these two stocks. Consequently samples will be taken from the area in which the two stocks overlap (area VIId, Eastern English Channel) and the fingerprint will be used to determine to what stock these individuals belong. If successful, the result will be information on the degree that the North Sea and the western stock differ in their chemical composition and which fraction of the landings from area VIId belong to what stock. The results may benefit the development of an analytical assessment and future progress on a long-term management plan which can incorporate MSY reference points.

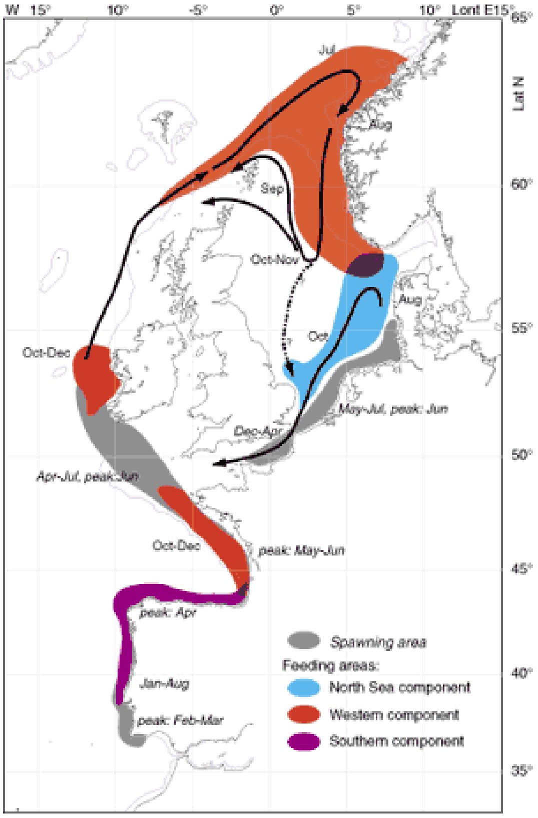


Figure 5-3 horse mackerel stocks and mirgration patterns. Source: Homsir.

5.4.1 Practical implementation

The method proposed above - to discriminate between landings from the North Sea stock and the Western stock using the GCxGC-MS fingerprint - will be a pilot, which aims at first to find out if the proposed method can be used. This method would consist of taking samples in ICES area VIIb,c,j,k or VIa,b and VIb,c from the Western en North Sea stock respectively (Table 5-2), which would take place in quarter 2 & 3, when the stocks are fully separated (Figure 5-3). In quarter 4, mixing of the two stocks will take place in area VIId (and possibly area VIIe) and samples from area VIId will be taken (Table 5-2). At present this pilot has started (samples are being taken) in collaboration with another BO project, on the horse mackerel management plan, where the preliminary results will also be presented.

Table 5-2 Sampling scheme

Stock	*Location (ICES area)*	*Period*	*Nr samples*
Western Stock	VIIb,c,j,k, VIa,b	Q3 (Jul-Sept)	5 locations (blocks), 5 fish/location
North Sea stock	VIb,c	Q3 (Jul-Sept)	5 locations (blocks), 5 fish/location
Mixed	VIId	Q4 (Jan-March)	5 locations (blocks), 5 fish/location

5.5 Management plan

In collaboration with industry stakeholders IMARES set out to develop a multi-annual plan for North Sea horse mackerel, which would take a step-wise approach, providing a rational for (trends based) TAC setting in the short term, and simultaneously prepare a roadmap for the development of an analytical assessment in the medium or long term. The process included evaluating the currently available data, conducting exploratory stock assessments, analysing the behaviour of a set of candidate harvest control rules (HCRs) (both in hind- and forecasts) and identifying knowledge gaps and plans for resolving these shortcomings in the future.

A draft multi-annual plan which could form the basis for TAC setting in the short term is currently being prepared for submission to ICES for external review. In addition, a roadmap for future improvement of the knowledgebase of the stock was prepared for inclusion in the multi-annual plan by seeking agreement on priorities in data gaps that – when resolved, if feasible with contribution by the industry - would benefit the further development of a fully analytical assessment in the medium to long term.

5.6 Conclusions horse mackerel

- Otholith shape analysis has already been done within the Homsir project. They did not find differences in shape structure between the North Sea and the Western stock. This is an indication that the two stocks can not be distinguished using otholith structure, but the sampling intensity in the North Sea is too low to conclude that it is not possible to distinguish the two stocks.
- A pilot of an alternative method to distinguish between the two stocks has started in collaboration with another BO project.
- A multi-annual management plan is currently been drafted to provide a rational for (trends based) TAC setting in the short term, and simultaneously prepare a roadmap for the development of an analytical assessment in the medium or long term.

6 Turbot (*Scophthalmus maximus*) and Brill (*Scophthalmus rhombus*)

6.1 Assignment

Existing data were gathered to come to better understanding of the population dynamics. The results are described in a draft manuscript which was accepted for publication in The Journal of Sea Research (Van der Hammen et al. in press, http://dx.doi.org/10.1016/j.seares.2013.07.001).

6.2 Results

A manuscript was written and accepted by the Journal of sea research (Van der Hammen et al., in press).

6.2.1 *Manuscript:*

Population ecology of turbot and brill: what can we learn from two rare flatfish species?

Tessa van der Hammen, Jan Jaap Poos, Harriët M.J. van Overzee, Henk J.L. Heessen, Arni Magnusson and Adriaan D. Rijnsdorp

Abstract

Turbot and brill are widely distributed in the Northeast Atlantic but occur at low abundance. They are ecologically very similar and closely related. The low abundance and the similarities make them particularly interesting to study the population dynamics because it raises the questions how the populations can sustain themselves at low abundances and how turbot and brill avoid strong interspecific competition. Knowledge of both species is hampered by lack of analysed data. The main objective of this study is therefore to increase the knowledge of turbot and brill and in particular to compare the two species in order to address the above questions. Based on biological samples collected in the North Sea, we calculated seasonal von Bertalanffy growth parameters, maturity ogives, monthly gonado-somatic indices (GSI) and condition factors (Fulton's K) and indices of inter- and intraspecific mean crowding and compared the results for turbot and brill. The main differences between the two species were found in their spawning period, with brill having a more protracted spawning period. Brill also showed an earlier peak in their GSI values, suggesting an earlier start of their spawning period. The mean crowding showed that interspecific competition was lower than intraspecific competition. The exploitation pattern was also studied. Turbot and brill are exploited as a bycatch species in the mixed demersal fishery. We found that productivity is highest in areas where the maximum temperature is close to the optimal temperature for growth (16 – 18ºC) and landings decrease where salinity falls below ~5 psu (turbot) and ~15 psu (brill). Recent fishing mortality rates of North Sea turbot are around 0.5–0.7, but there is no indication that recruitment is impaired at low levels of spawning stock biomass. We conclude that although both species have similar ecological characteristics, differences may reduce inter-specific competition.

Key words: population regulation, recruitment, distribution, growth, maturation, gonad weight, mortality, reproductive strategy, North Sea

Introduction

One of the fundamental questions in population biology is what determines the population size (Krebs, 1972). The processes that determine the population size may differ in relation to the position within the geographic distribution range. Miller et al. (1991) proposed a framework on the latitudinal patterns and the processes involved. Towards the polar side of the distribution, abiotic factors tend to dominate, whereas biological interactions dominate on the equatorial side. Another important factor is the availability of suitable habitat. In sole (*Solea solea*), a positive correlation was shown between population size and the surface area of nursery grounds across populations of common sole, suggesting that nursery habitat size might be a bottleneck determining the population abundance (Rijnsdorp et al., 1992). A similar relationship was found in Icelandic plaice (van der Veer et al., 2000) and may explain the differences in abundance across species living in the same geographical area (Gibson, 1994). The particular importance of the nursery grounds for flatfish may be related to the concentration phase in many flatfish species that occurs when the pelagic larvae settle in specific nursery habitats (Beverton, 1995).

Turbot (*Scophthalmus maximus*) and brill (*Scophthalmus rhombus*) are ecologically similar species that occur in relatively low abundance throughout their distributional range (Whitehead et al., 1986). Both species inhabit shallow soft bottom habitats where they feed on crustaceans and fish. Pelagic eggs are spawned offshore and larvae are transported by wind-driven currents to the surf zone of sandy beach nurseries (Riley et al., 1981; van der Land, 1991). Early demersal juveniles are restricted to the shallow sandy grounds on exposed shores (Besyst et al., 1999; Nissling et al., 2007; Riley et al., 1981). Variation in 0-group abundance across beaches and inter-annual variation in abundance may be related to variations in the transport of larvae towards the inshore nursery grounds (Haynes et al., 2011b; Nissling et al., 2006; Sparrevohn and Stottrup, 2008). Large specimens can be observed to a depth of about 100 m (Knijn et al., 1993; Kerby et al., this volume). The ecological similarity of turbot and brill raises the question whether the species differ in some characteristics to avoid competition.

The population dynamics of turbot and brill are particulary interesting to study because their low abundance may be informative about the minimum number of adult fish producing sufficient recruits to sustain the population. In fisheries management, the minimum spawning stock biomass is often pragmatically defined as the lowest level at which there is no sign of recruitment failure. In the period 1950-2000, demersal trawling in the North Sea has strongly increased, which may affect turbot and brill (Kerby et al., this volume). Because the low stock sizes, turbot and brill may be less resilient to potential Allee affects caused by decreases in the stock size, compared to stocks that occur in higher abundance. At low stock sizes, for example, the number of adults may be too low to find a mate, hampering successful reproduction (Stephens and Sutherland, 1999; Frank and Brickman, 2000).

Low abundance often results in lack of data, which makes it difficult to study the population dynamics. Turbot and brill are exceptions because their high market value makes them important bycatch species in mixed bottom trawl fishery. Usually, turbot and brill are not targeted but in the North Sea turbot may be targeted by gillnetters (Vinther, 1995) and sometimes by beam trawlers (Gillis et al., 2008). In the Baltic, turbot is targeted in a gillnet fishery (Draganik et al., 2005; Stankus, 2003). Since 2000, annual catch quotas are imposed by the European Commission. Although routine fisheries data are being collected on turbot and brill, neither species has attracted much research effort. A better understanding of the population ecology of these two rare flatfish species may indicate how many adults are required for sustainable production of recruits.

The main objective of this paper is to review and analyse the available data on turbot and brill to increase the general knowledge of these species. In addition, the paper attempts to answer two main research questions: (1) how can two closely related ecologically similar low-abundance flatfish species coexist together?; (2) is there reason to be concerned about the states of the turbot and brill stocks? We start with an analysis of the distribution, growth and reproductive biology of the North Sea turbot and brill populations and estimate the biomass, recruitment and exploitation rate of turbot. The analysis is based on data collected from landings statistics, market samples taken from the commercial landings and from several demersal fish surveys. These surveys cover most of the distribution of turbot and brill in the North Sea and include different size classes. Subsequently, the productivity of the North Sea stock is compared to the productivity of other stocks in the Northeast Atlantic. Results are discussed in light of latitudinal differences in population regulation, with particular focus on the hypothesis that the size of the nursery area determines population abundance.

Material and methods

Data sources

Data from beam trawl surveys

A number of beam trawl surveys were carried out to monitor flatfish and other demersal fish populations in the North Sea. All surveys took place in the period August to October, except for the beach survey which was carried out throughout the year. Each survey was designed for a specific depth zone and size range of demersal fish.

Beach surveys were conducted in the coastal waters of the Netherlands between 0.5 and 7 m depth using a 2-meter beam trawl from a rubber dingy (mesh size 5x5 mm; haul duration 5–15 min). The survey was conducted in different months between 1974 and 1985 and in 2011 (n=643 hauls; Bolle et al., 1994). In addition, 1-meter pushnet samples (n=75 hauls; 74.1 m^2 swept area) were obtained in the surf zone at ~50cm depth between 1979 and 1983.

The *Demersal Fish Survey* (DFS) is a yearly survey sampling in the 3 nautical mile coastal zone along the Dutch, German and Danish coast (from the southern Dutch border to Esbjerg: 6 m shrimp trawl) and the estuaries of the Schelde, Wadden Sea and Ems-Dollard (3 m shrimp trawl) since 1970 (n ≈ 250 hauls $year^{-1}$; mesh size 35x35 mm; towing speed 2.5 knots; haul duration 15 min; van Beek et al., 1989).

The *Sole Net Survey* (SNS) is a yearly survey, sampling the coastal zone along the Dutch, German and Danish coast from Hoek van Holland to Esbjerg, up to ~30 nm) offshore using a 6 m beam trawl since 1970 (n ≈ 70 hauls $year^{-1}$; mesh size 40x40 mm; towing speed 3.5 knots; haul duration 15 min; van Beek, 1997).

The *Beam Trawl Survey* (BTS) is a yearly survey, sampling the offshore waters of the North Sea (south eastern part since 1985; central part since 1996) with an 8 m beam trawl (n ≈ 150 hauls $year^{-1}$; mesh size 40x40 mm; towing speed 4 knots; haul duration 30 min; Bogaards et al., 2009; Rogers et al., 1998; http://datras.ices.dk/Documents/Manuals/Manuals.aspx).

Catch and effort statistics

International landings data for turbot and brill were available through the Eurostat database and were downloaded from http://www.ices.dk (Dec 2012). This database holds the officially recorded landings for all countries by ICES (International Council for the Exploration of the Sea) management area (Table 6-1). For the North Sea, landings data were available for each year since 1903. There were no records for the Dutch landings in the Eurostat database between 1984 and 1987. However, for the North Sea these missing landings were estimated based on confidential reports from fish auctions (Boon and Delbare, 2000; ICES, 2012).

Landings and effort data from the Dutch fleet were obtained from EU (European Union) logbooks and the market category composition of landings was obtained from auction sale slips. Official EU logbook data of the entire Dutch fleet were maintained by the NVWA (Netherlands Food and Consumer Product Safety Authority, formerly known as the General Inspection Service, AID) and contain information on (i) landings by vessel, trip, ICES statistical rectangle and species; (ii) effort (days absent from port) by vessel, trip and ICES statistical rectangle, calculated from trip departure and arrival time; and (iii) vessel information on engine power and gear used. Logbook data were available for the entire Dutch commercial fishing fleet and for foreign vessels landing their catches in the Netherlands.

Table 6-1 Mean annual landings of turbot and brill by ICES management area (2001–2010) and the surface area of the nursery and adult distribution area , the mean, minimum and maximum monthly temperature and the salinity in the waters between 5–50 m.

ICES	Area	Turbot landings	Brill landings	Habitat	Habitat	Latitude	T_{mean}	T_{min} (°C)	T_{max} (°C)	Salinity

code		(tonnes)	(tonnes)	2–50 m (10^6km^2)	<2m (10^3km^2)	(°N)	(°C)			(PSU)
I	Barents Sea	0.2	0.0	-	-	70	4.6	1.0	9.1	26.2
II	Norwegian Sea	6.5	0.1	2.7	46.9	65	6.8	3.7	10.5	33.3
IIIbcd	Baltic	320.2	63.0	9.5	17.1	57	9.7	3.8	16.4	26.5
IIIa	Skagerrak	154.5	135.4	2.8	61.0	56.0	8.3	2.3	15.3	10.5
IVa	North Sea north	100.6	7.0	1.1	9.0	60	9.1	5.7	13.1	34.1
IVb	North Sea central	2267.1	585.0	15.3	100.5	55	9.9	4.7	16.0	33.4
IVc	North Sea south	933.8	679.4	6.3	82.5	52	11.3	6.0	17.4	33.9
V	Iceland	2.3	0.2	0.9	11.4	63	6.2	3.2	9.8	34.3
VI	Northwest Scotland	27.4	14.3	1.7	4.8	57	9.8	6.6	13.3	33.9
VIIa	Irish Sea	97.2	91.5	2.9	21.3	53	11.2	6.9	16.6	34.0
VIIbc	West of Ireland	57.1	23.4	0.4	8.6	53	11.6	8.0	15.6	33.9
VIId	Eastern Channel	352.9	305.2	2.7	13.6	50	11.9	7.0	17.4	34.6
VIIe	Western Channel*	232.6	371.1	1.9	7.2	49	11.9	8.4	16.2	35.0
VIIfg	Bristol Channel	296.4	166.3	1.0	13.5	50	12.0	8.0	17.5	33.3
VIIhjk	Celtic Sea*	183.4	80.9	0.2	9.6	50	12.1	8.4	15.9	34.9
VIIIab	Bay of Biskay	165.7	132.1	2.0	45.5	46	13.9	10.9	17.9	35.0
VIIIcde	North Spain	24.8	5.4	0.3	4.9	44	15.0	12.2	18.6	35.2
IX	Portugal	80.5	56.0	0.8	5.2	40	15.6	13.7	17.6	34.6
Other areas		4.8	2.0							
Mean annual landings		5308.0	2718.3							

Market sampling data

Turbot and brill landings of commercial fisheries were sampled on a quarterly basis during the periods 1980-1990, 1998, and 2004-present, from randomly selected vessels at the major auctions in the Netherlands. For each vessel sampled, the landings were recorded and the length distribution was determined. Biological data was collected from a subset of the sampled vessels and processed in the laboratory to record gender, size (cm), age (years, birthdate 1 Jan), gutted weight, maturity stage (immature, ripening, spawning, spent) and gonad weight of females. The number of fish sampled was about 10 000 turbot and 5 000 brill.

Environmental data

Temperature and salinity data were obtained from the ICES Oceanographic database. Monthly mean bottom temperature and annual mean salinity (psu) were calculated for each ICES (sub)area from all stations between 10 and 50 m depth.

The surface areas of bathymetric zones by ICES (sub)area were obtained from http://topex.ucsd.edu/cgi-bin/get_data.cgi. The size of the nursery grounds was approximated as the surface area of the depth zone of 0–2 m. The size of the adult habitat was estimated as the surface area of the depth zone of 2–50 m.

Methods

Condition factors

In order to compare seasonal changes in the condition the total body and of the gonads of brill and turbot , we calculated Fulton's condition factor (K) and the gonado-somatic index (GSI), using market samples and survey data. The condition factor was calculated from the eviscerated body weight (W, in g) and the total length (L, in cm) of a fish: $K = 100 \times W/L^3$. For the reproductive organs the GSI was estimated based on gonad weight (G, in g); $GSI = 100 \times G/W$.

Maturity

In order to compare the reproductive biology between brill and turbot, we estimated maturity ogives, using binomial generalized linear models (GLMs) with a logit link fitted to data from market samples collected from March to July between 2004 and 2010. The proportion mature (p) at age (a) and length (l) were modelled as sex-specific (s) with a common slope but different intercepts: $logit(p) = \beta_{0,s} + \beta_1 \times l + \beta_2 \times a$. In addition, the ogives were fitted as a function of length only ($logit(p) = \beta_{0,s} + \beta_1 \times l$) and as a function of age ($logit(p) = \beta_{0,s} + \beta_1 \times a$).

Growth

In order to find out if there were differences in growth among seasons and to compare the growth between females and males, the model of Somers (1988) was fitted to age-length data from market and survey samples (BTS, DFS and SNS):

$$L_t = L_\infty \times (1 - \exp(-K(t-t_0) - S(t) + S(t_0))),$$
$$S(t) = CK/(2\pi) \times \sin(2\pi(t-t_s)),$$

where L_t is total length at age t, L_∞ is the asymptotic maximum length, K is the growth rate, t_0 is the theoretical age at which the average length would be zero, C modulates the amplitude of the growth oscillations, and t_s is the time between time age 0 and the start of the inflection point of the first sinusoidal growth oscillation. The C coefficient is restricted to values ≤ 1 to prevent unrealistic seasonal decreases in average length-at-age. The R source code for the Somers model was provided by García-Berthou et al. (2012).

Index of mean crowding

Two ecologically similar species feeding on the same resource are unlikely to coexist, unless there is at least some niche segregation (Tilman, 1994). Therefore, it is likely that turbot and brill are spatially segregated to some extent. Lloyd's index of mean crowding gives an estimate of the level that individuals (con- or heterospecifics) aggregate and can be used to estimate the potential intra- and inter-specific competition (Lloyd, 1967). This index (m) estimates the number of fish which an average fish shares its habitat with, including itself. As a proxy for intraspecific competition, index m_x was defined as

$$m_x = \frac{\sum_i x_i^2}{\sum_i x_i},$$

where m_x is the index of mean crowding, and x_i is the number of fish in spatial unit i.

The index was also used to estimate the competition among species or size- or age-classes x and y (Rijnsdorp and Van Beek, 1991), with m_{xy} being the competition experienced by x from y.

$$m_{xy} = \frac{\sum_i x_i y_i}{\sum_i x_i}.$$

The index was affected by the spatial scale that was chosen. Lloyd (1967) argued that the spatial scale should reflect the ambit of the individual, e.g. the distance that an individual can travel during the relevant time period. We used the area swept during a single haul as the relevant spatial scale. The area swept ranged from ~10 000 m^2 in the inshore waters to ~30 000 m^2 in the offshore waters. The spatial scale seems reasonable for the potential scale at which fish may compete. The difference in spatial scale between the inshore and offshore areas is consistent with the ontogenetic change in distribution and the increase in travel distance with body size. The index of mean crowding was estimated for different size classes of turbot and brill (< 10cm, 10–25cm, > 25cm), representing the 0-

group, 1-group and 2+ group. In addition, the mean crowding was analysed irrespective of fish size, and compared with the index of other flatfish species.

Stock assessment

In order to model the stock status of turbot, the population dynamics were modelled using an age-structured population model using spline smoothers to describe annual changes in fishing mortality (Aarts and Poos, 2009; ICES, 2012). Age-structured data from different sources were used to fit the model parameters (ICES 2012; Weber, 1979; Boon and Delbare, 2000). The model was fitted using a likelihood function that is maximized using automatic differentiation in the AD Model Builder software (Fournier et al. 2012). Uncertainty of estimated model parameters was evaluated using MCMC (Markov Chain Monte Carlo; Gelman et al., 2004; Magnusson et al., in press). Detailed information about the methodology and the data are in the supplementary online material (SOM). The population model was developed in a sequence of ICES working groups. The main objective of this model was to evaluate the status of the stock to improve the management. Due to time limitations, the assessment was done for turbot only.

Results

Growth, condition and maturity

Turbot and brill from the North Sea showed sexually dimorphic growth with females reaching a larger maximum body size than males (Table 6-2, turbot ♂ L_∞ = 44.5 cm, K = 0.44, t_0 = –0.14 year, ♀ L_∞= 66.7 cm, K = 0.32, t_0 = 0.29 year; brill ♂ L_∞ = 43.3 cm, K = 0.48, t_0 = –0.27 year, ♀ L_∞ = 58.0 cm, K = 0.38, t_0 = –0.27 year). The highest somatic growth takes place in the 2nd half of the year (Figure 6-1).

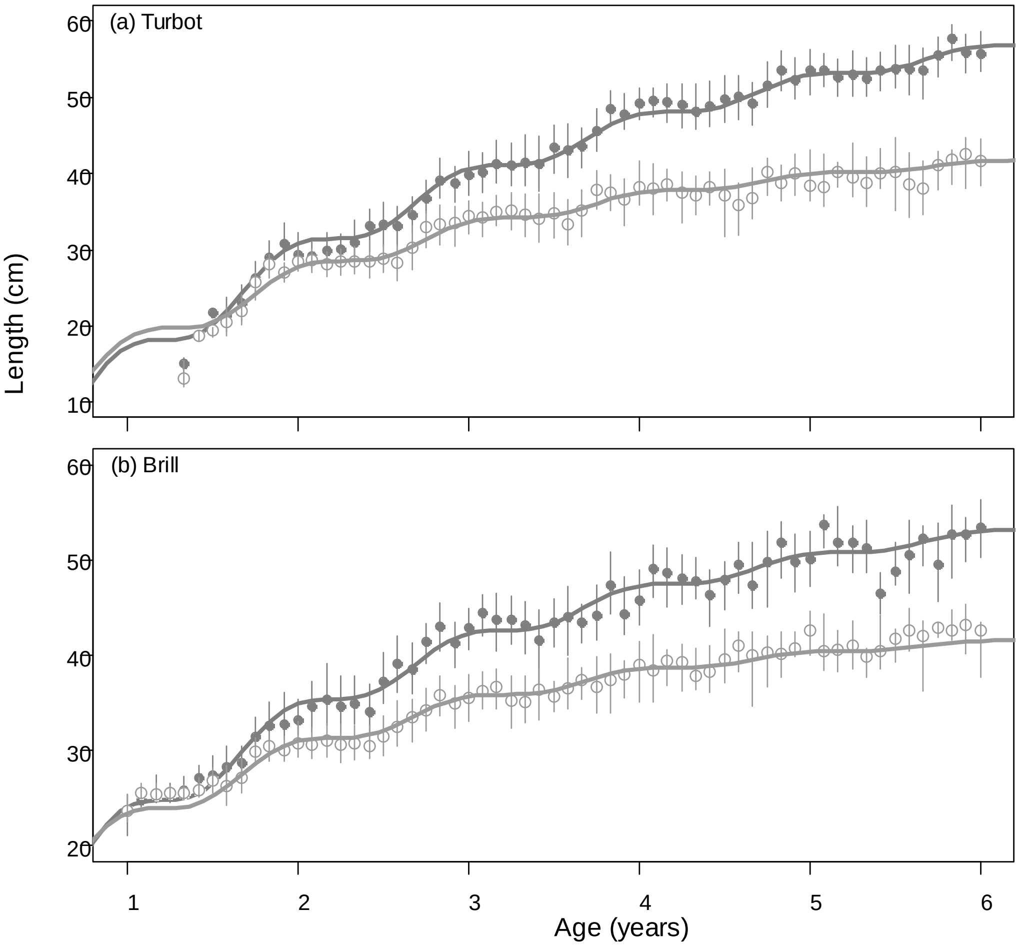


Figure 6-1. Changes in the mean length at age by month of (a) turbot and (b) brill males (○) and females (●). The vertical lines show the upper and lower quartiles and the thicker lines show the fitted seasonal von Bertalanffy growth curve.

Table 6-2. Von Bertalanffy growth parameters of turbot and brill reported from different stocks and time periods. The present study is a seasonal Von Bertalanffy (Somers model, see text). L_∞ is in total length (cm), t_0 and t_s are in years.

	Females					Males					Source
	L_∞	K	t_0	t_s	C	L_∞	K	t_0	t_s	C	
Turbot											
Baltic Sea	53.5	0.19	–0.28			44.2	0.45	–0.12			Stankus, 2003
North Sea	66.7	0.32	0.29	-1.29	1.00	44.5	0.44	–0.14	-1.22	1.00	present study
North Sea	64.8	0.26	–0.05			55.5	0.23	–0.2			Jones 1974
North Sea	64.1	0.23	–0.16			65.2	0.32	0.09			Mengi, 1963
Bay of Biscay	73.6	0.28	0.08			54.4	0.24	–0.22			Deniel, 1990
Adriatic Sea	81.5	0.21	–0.48			45.0	0.597	–0.01			Arneri et al., 2001
Black Sea (south)	103.9	0.12	–0.93			44.2	0.45	–0.12			Zengin et al., 2006
Brill											
North Sea	58.0	0.38	–0.27	–0.29	1.00	43.3	0.48	–0.27	-0.38	1.00	present study
Bay of Biscay	85.2	0.15				74.9	0.14				Deniel, 1981

Body condition (Fulton’s K) varied seasonally, with the condition index of adult turbot showing a peak in May–June and a low in August–September, while brill body condition peaked in February–April and reached a low in June–July (Figure 6-2a). Juvenile condition was highest in June–July in both species. The amplitude in body condition of adults ((max – min) / mean condition) was higher in turbot (0.15) than in brill (0.09). The body condition of turbot was about one third higher than brill reflecting the difference in body shape, as turbot has a more circular and thicker body. The seasonal cycle was also seen in gonad weights. The gonado-somatic index (GSI) of adult female turbot increased from a low of 2% of body weight in August–October to a peak in May–June (12%). The GSI peak in brill (10%) was lower than in turbot and observed in March–May (Figure 6-2b).

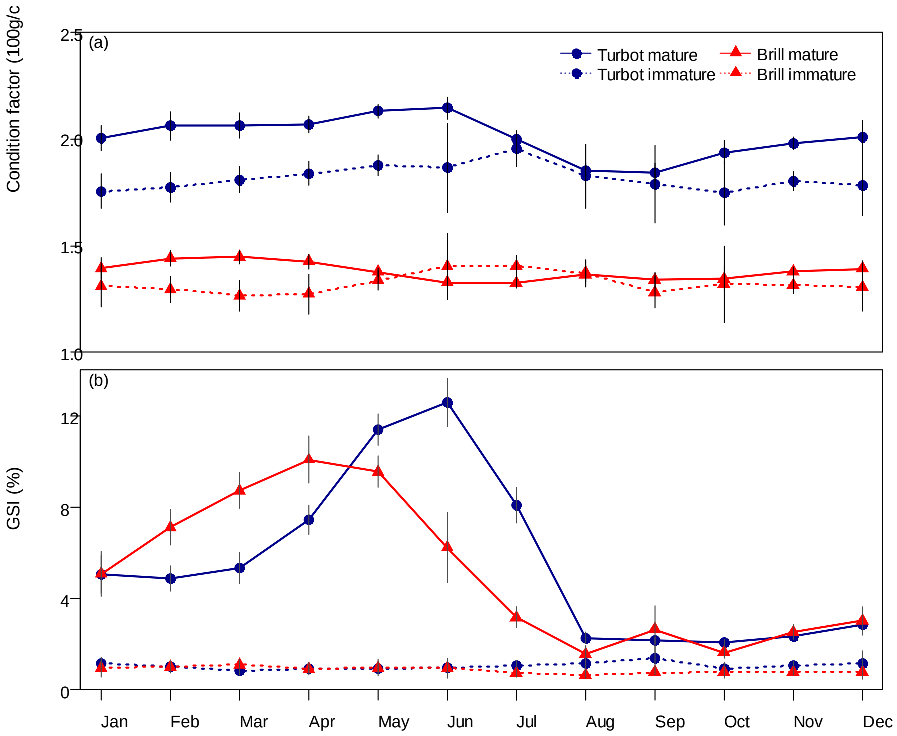


Figure 6-2 Seasonal changes in the mean and 95% confidence limits of (a) Fulton’s condition factor and (b) gonado-somatic index (GSI) of mature and immature turbot and brill.

Analysis of seasonal changes in maturity stages corroborated a more protracted spawning period in brill than turbot (Figure 6-3). Spawning brill were observed from February onwards, two months earlier than turbot, while the last spawning fish of both species were observed in August. From about May onwards, the proportion of spent adults increased and reached a maximum in July–August in brill and August–October in turbot. From the transition of the adults from the ripening to the spawning stage, and from the spawning to the spent stage, the start and end of the spawning period was estimated by logistic regression (Table 6-3), indicating a spawning duration of about 8 weeks, except for female turbot, for which it was 16 weeks.

Table 6-3 Date (in months) when 50% of the adult population has started spawning or reached the spent stage and spawning duration (weeks), estimated by logistic regression of maturity stages over time.

	Begin spawning (50% spawning + spent)	*End spawning (50% spent)*	*Spawning duration (weeks)*

Turbot female	5.7	7.4	7.6
Turbot male	5.5	7.3	7.9
Brill female	3.3	7.0	15.9
Brill male	4.3	6.2	8.0

Brill and turbot showed sex differences in age and size at 50% maturity. Female and male turbot matured at larger sizes than female and male brill (turbot ♂ $L_{50\%}$ = 17.9 cm, ♀ $L_{50\%}$ = 34.2 cm, brill ♂ = 18.4 cm, ♀ $L_{50\%}$ = 31.3 cm) and at older ages (turbot ♂, $A_{50\%}$=1.1 year, ♀, $A_{50\%}$=2.2 year; brill ♂, $A_{50\%}$=0.1 year, ♀, $A_{50\%}$=1.6 year). The low $A_{50\%}$ of brill males is due to the low number of immature individuals. Therefore, this estimate is probably underestimated.

Longevity was estimated from the market sampling data collected since 1980. The oldest age recorded in turbot was 35 years in both males (*n* = 2755) and females (*n* = 6965), as compared to 16 and 22 years in male (*n*=2951) and female (*n*=5039) brill, respectively.

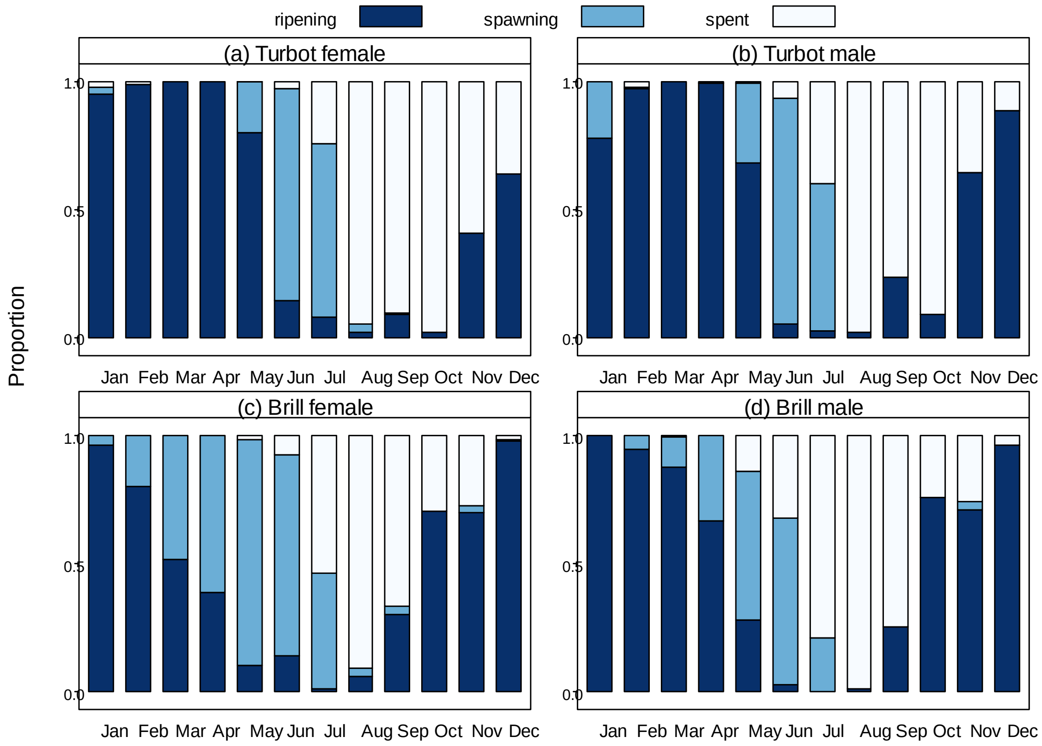


Figure 6-3. Seasonal changes in the proportion of adults that are in the ripening (dark blue), spawning (light blue) and spent stage (white).

Distribution and abundance

Survey data (DFS, SNS, BTS) collected since 1985 revealed that both species showed a clear ontogenetic change in distribution (Figure 6-5), with large fish occurring in deeper water than small fish. Fish ≤ 10 cm (0-group) are mostly confined to waters <10 m, although some were caught in waters down to 30 m. Fish of 10–25cm (1-group) mainly occurred in waters down to 30 m but their highest densities still occurred in waters <10 m. The larger fish were distributed down to 100 m depth. Brill appeared to occur slightly shallower than turbot. The smallest size class was underrepresented because the surveys did not include the surf zone (<1 m), where 0-group juveniles settle from June (brill) and July (turbot) onwards and remain there during their first months of their life (Figure 6-6).

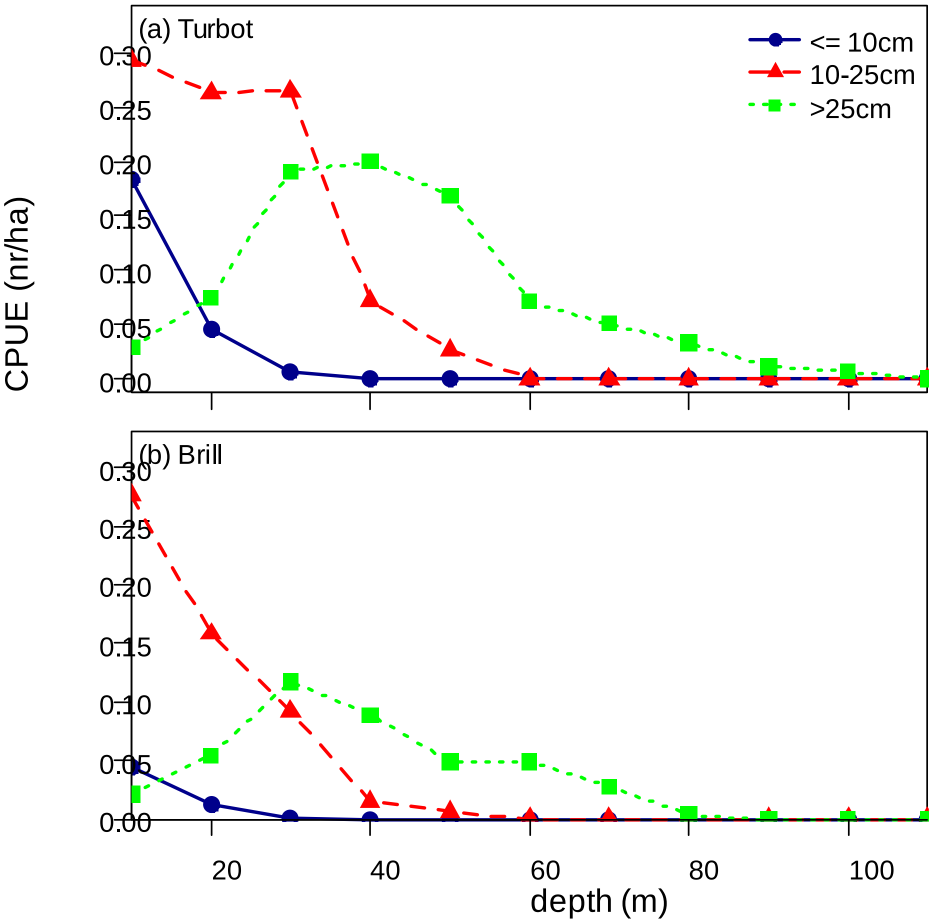


Figure 6-5 Bathymetric distribution of three different size classes of turbot and brill representing 0-group, 1-group and 2+ group.

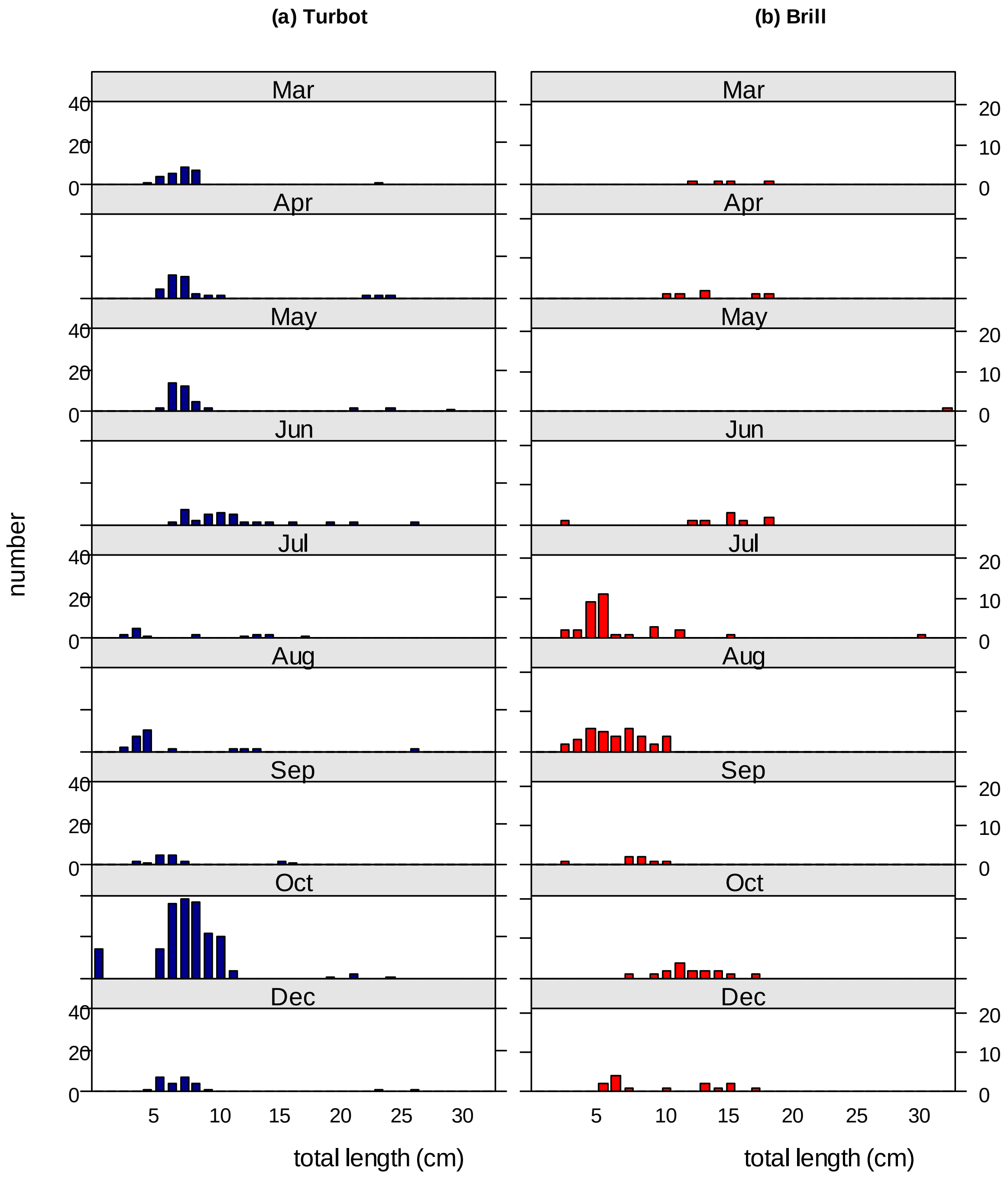


Figure 6-6. Monthly size distribution of turbot and brill sampled in the coastal zone of the Netherlands using pushnet (surf zone <0.5 m) and 2 m beam trawl (<5 m depth). In January, February and November no turbot or brill was caught.

In order to explore the potential spawning areas, the spatial pattern in commercial LPUE during the spawning period was compared to the pattern outside the spawning period for the largest size class comprising adult fish (Figure 6-7). During the spawning period, high catch rates of turbot were observed off the Danish coast, and in the inner German Bight and southern North Sea. Outside the spawning period, the highest catch rates were observed in rectangles located further offshore, except for rectangle 39F7 which shows high catch rates throughout the year. During the spawning period, local concentrations of brill were observed off the Danish coast and in the south-western North Sea.

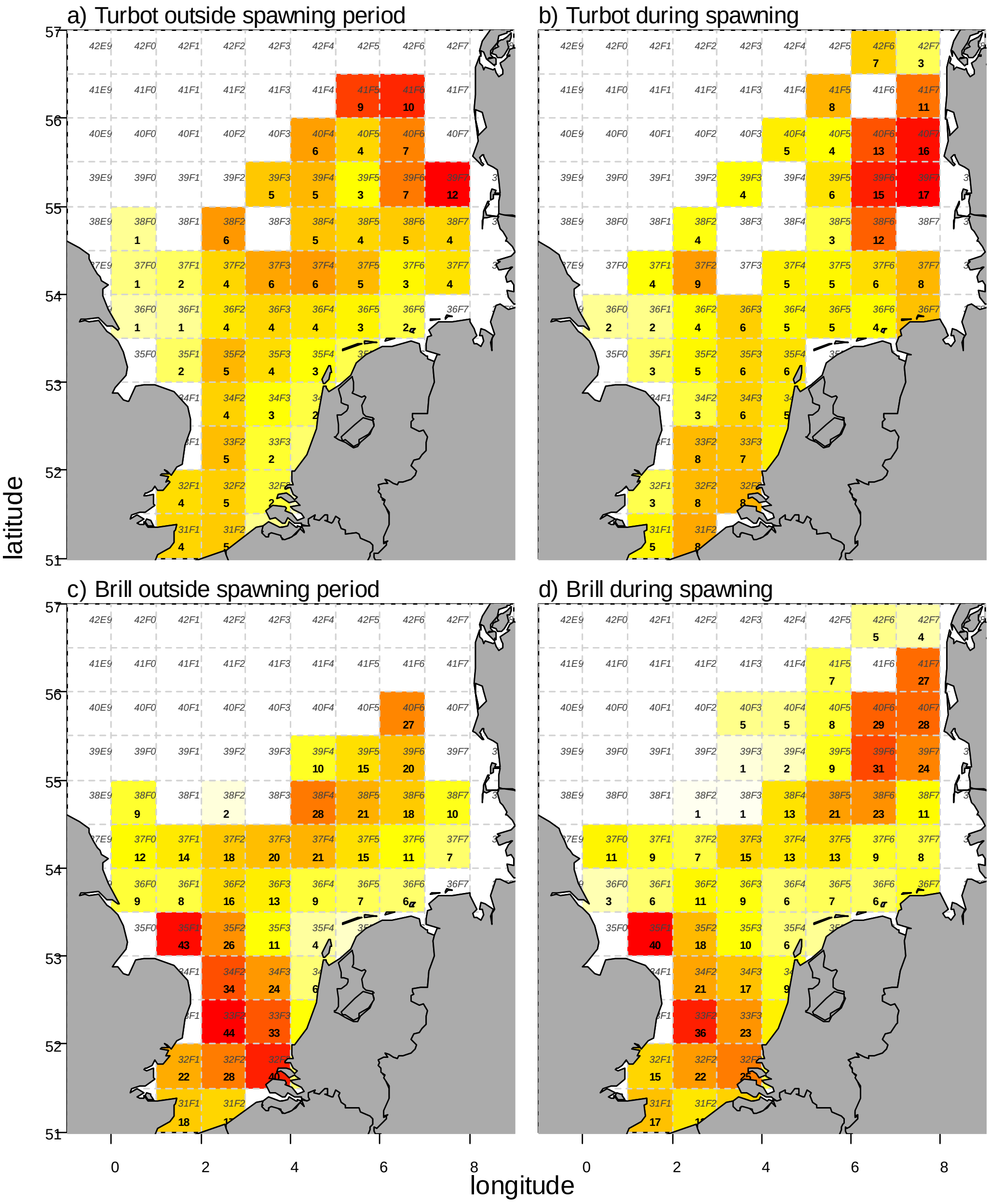


Figure 6-7 LPUE (kg/day at sea) per ICES rectangle for the Dutch beam trawl fleet > 221 kW, of the largest market category (1) consisting of > 4 kg turbot or > 1 kg brill, averaged over 2004–2010. a,c: outside spawning period (turbot: Jan–Apr and Aug-Dec, brill: Jan-Feb and Aug-Dec). b,d: during spawning period (turbot: May-Jul, brill: Mar-Jul). Only those rectangles are selected where turbot (a,b) or brill (c,d) was caught in all years 2004–2010. The colors indicate the levels of the LPUE.

To examine the potential number of competitors, we estimated an index of mean crowding, representing the number of conspecifics with which an average fish shares its habitat. The densities recorded were < 1 fish per hectare. These densities may not be representative for the potential number of competing conspecifics, since fish may have a heterogeneous distribution and may occur in dense patches. Because of the ontogenetic change in distribution, the index of mean crowding was estimated for separate size classes (Table 6-4), leading to estimates of intra-specific competition with the same size class: the smallest brill compete with 7.4 conspecifics per hectare, while the smallest turbot compete with 55.4 conspecifics per hectare. The index of mean crowding of the larger size classes was lower because the number of fish decreases with size. The competition with conspecifics of other size classes was lower due to the ontogenetic change in distribution. The competition among size classes was not symmetrical because of the differences in abundance among size classes. Hence, a larger fish shared its habitat with a larger number of conspecifics of a smaller size class, while a smaller fish shared its habitat with only a few larger sized conspecifics. Comparison of the index of mean crowding of turbot and brill with that of other flatfish species reflects the low overall abundance of the species. For example, the mean crowding of turbot or brill were 24 and 6 per hectare respectively, whereas for example dab (*Limanda limanda*), sole (*Solea solea*) or plaice (*Pleuronectes platessa*) have indexes of mean crowding of 15731, 5579 and 4727 per hectare, respectively.

To examine the potential number of inter-specific competitors, we estimated an index of mean crowding between turbot and brill (Table 6-4). The index of inter-specific competition was considerably lower than the index of intra-specific competition. For instance, the 10–25cm sized brill competed with 6.2 similar-sized conspecifics but only 0.87 similar sized turbot. Likewise, a 10–25cm sized turbot competed with 8.9 similar sized conspecifics and only 1.27 similar-sized brill. This indicates that both species, sharing the same distribution area, select different micro-habitats.

Table 6-4. Index of intra- and inter-specific mean crowding of species X on Y per size class. The index gives the number of turbot or brill with which an animal of Y is caught in the same tow as X. The index is a proxy of the number of animals per hectare of X with which Y may compete for resources. If species X and species Y are the same (both turbot or both brill) the values represent intra-specific indices of mean crowding. Otherwise, the values represent inter-specific indices of mean crowding

Species X		Species Y					
		Turbot			Brill		
		<10cm	10–25cm	>=25cm	<10cm	10–25cm	>=25cm
Turbot	<10cm	55.36	17.51	0.60	0.13	2.85	0.03
	10–25cm	5.91	8.93	0.80	0.04	0.87	0.08
	>=25cm	0.51	2.01	2.29	0.01	0.26	0.30
Brill	<10cm	0.53	0.45	0.04	7.41	1.36	0.00
	10–25cm	1.40	1.27	0.15	0.16	6.18	0.14
	>=25cm	0.05	0.34	0.50	0.00	0.42	2.29

Exploitation

In the Northeast Atlantic, turbot and brill are fished from Portugal in the south up to the coast of Norway and Iceland in the north. The annual landings of turbot (5 300 tonnes) are higher than those of brill (2 700 tonnes). The majority of the landings were reported from fishing areas between 49^o and 57^{o}N. Landings were positively correlated with available habitat of 2–50m (turbot r = 0.87, n = 16, P < 0.01; brill r = 0.59, n = 16, P < 0.05). The North Sea (IVabc) with the largest surface area contributed about 50% of the total international landings (Table 6-1).

The productivity of the stocks (average annual landings per unit of adult habitat) showed a dome-shaped relationship with temperature. Peak productivity occurred at a mean monthly temperature around 12.9°C in both species as indicated by fitting a 2nd order polynomial through the log-transformed productivity against temperature (turbot r = 0.89, P < 0.01; brill r = 0.94, P < 0.01, Figure 6-8a and b). When productivity was fitted against the maximum or minimum seasonal temperature, the highest productivity levels were at 17.4°C (maximum seasonal growth) or 10.1°C (minimum seasonal growth) for turbot, and 17.7ºC (max) or 10.1ºC (min) for brill. In the Baltic Sea, a clear gradient in the landings occurred from relative high landings in the saline western part to low and eventually no landings from the inner Baltic (Figure 6-8c). Turbot landings drop to zero when salinities drop below 5 psu, whereas brill landings already drop to zero at salinities below 15 psu.

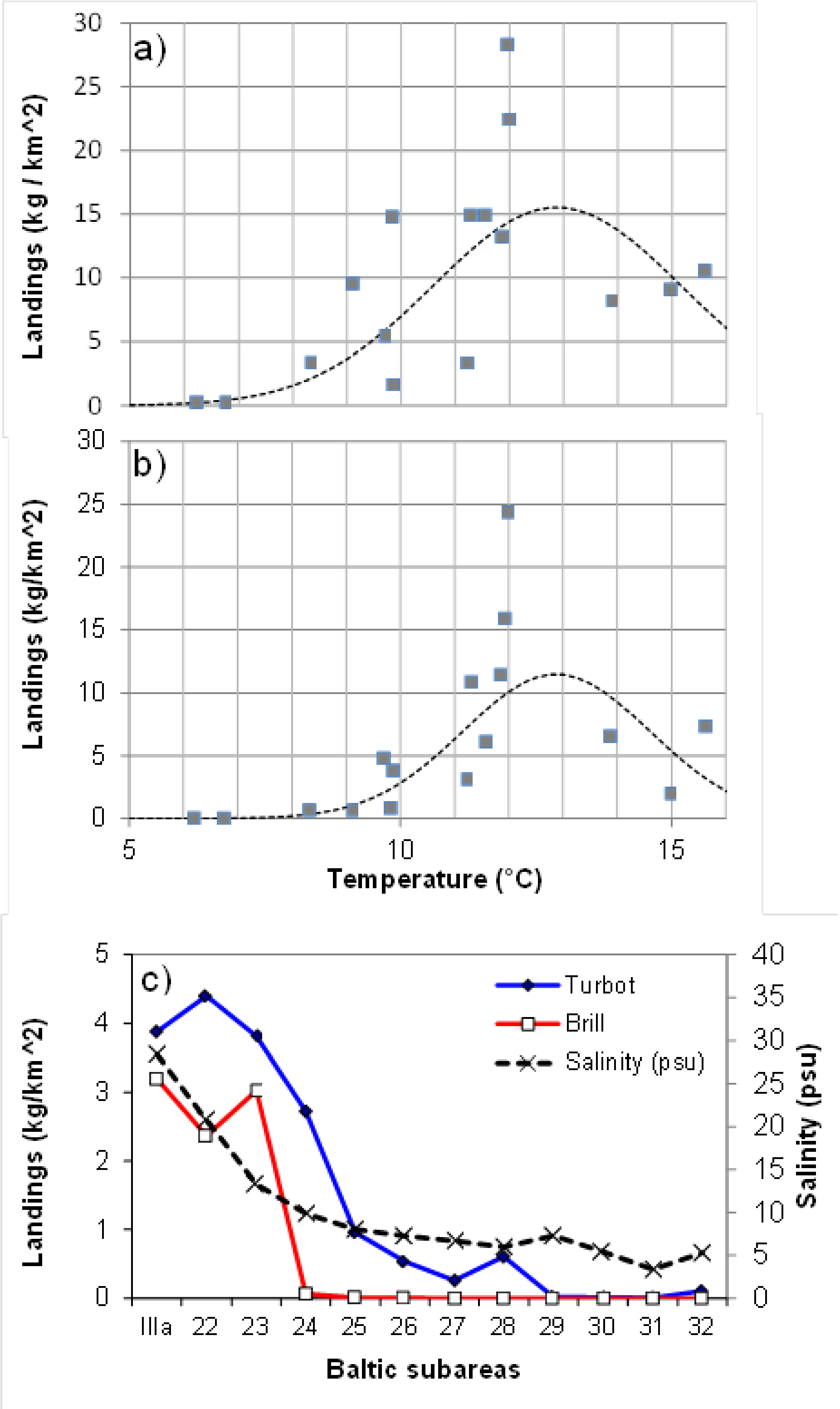


Figure 6-8. Landings per unit area (kg/km^2) by ICES (sub)area in relation to the mean monthly temperatures of (a) turbot and (b) brill. The dashed line shows the 2nd order polynomial of the log(landings) against temperature. Data for western Channel were combined with Celtic Sea. Panel (c) shows the landings per unit area and the mean salinity (psu) for the management subareas in the Baltic Sea. The management areas run from the Skagerrak (IIIa) and the outer Baltic (area 22) to the inner Baltic (area 31 and area 32).

Landings of North Sea turbot and brill have fluctuated around 4 500 tonnes in turbot and 1 000 tonnes in brill since 1903 (Figure 6-9). Landings of both species showed a decreasing trend and reached a low during World War I (1914-1918). After the war, landings increased and peaked around 1920 and declined to the long-term average thereafter. A similar pattern was observed after World War II, although the peak in brill was very modest and the landings well below the long-term average in the 1950s and 1960s. Current turbot landings (3 000 tonnes) are below the long-term average, while those of brill (1 275 tonnes) are above the long-term average. The temporal trends in landings of turbot and brill appear to be very similar, except in the 1950s and 1960s.

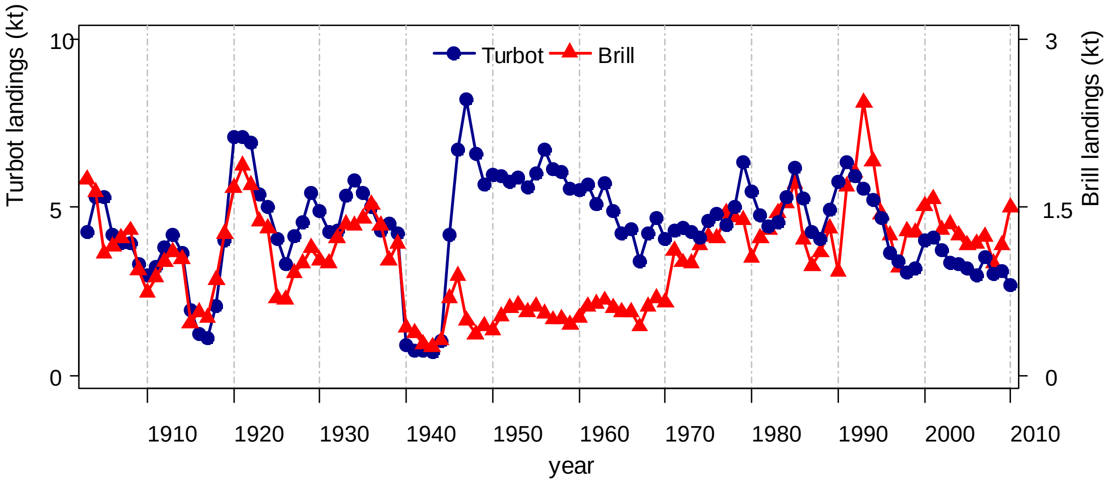


Figure 6-9 Annual international landings (1000 ton) of North Sea turbot and brill in ICES area IV.

For turbot, a stock assessment was carried out to assess the status of the stock. The assessment was based on age composition data of the landings that were available since 1977 (SOM). The estimated spawning stock biomass (SSB) decreased from about 10 000 tonnes in the late 1970s to a minimum of 4 000 t in 2004 (Figure 6-10a), followed by an increase to about 5 000 tonnes in 2010. The changes in SSB coincided with the initial increase and subsequent decrease in the fishing mortality rate. The current estimated F of 0.45 year^{-1} is substantially lower than the peak of F=0.67 year^{-1} in the beginning 2000s. The sudden increase in fishing mortality is the result of changes in the catch-at-age matrix following the decrease in minimum landing size. Recruitment has varied without a clear trend around a mean of 4.5 million 1-year olds. Historical recruitment estimates have relatively wide confidence limits due to limited sampling levels, but have improved in later years (Figure 6-10c). The stock-recruitment relationship does not indicate that recruitment is impaired at the lower range of observed SSB (Figure 10d). The fishing mortality rate at maximum yield per recruit is achieved was estimated around $F_{2\text{–}6}$ =0.32 year^{-1}, well below the exploitation level estimated for the recent decades (SOM).

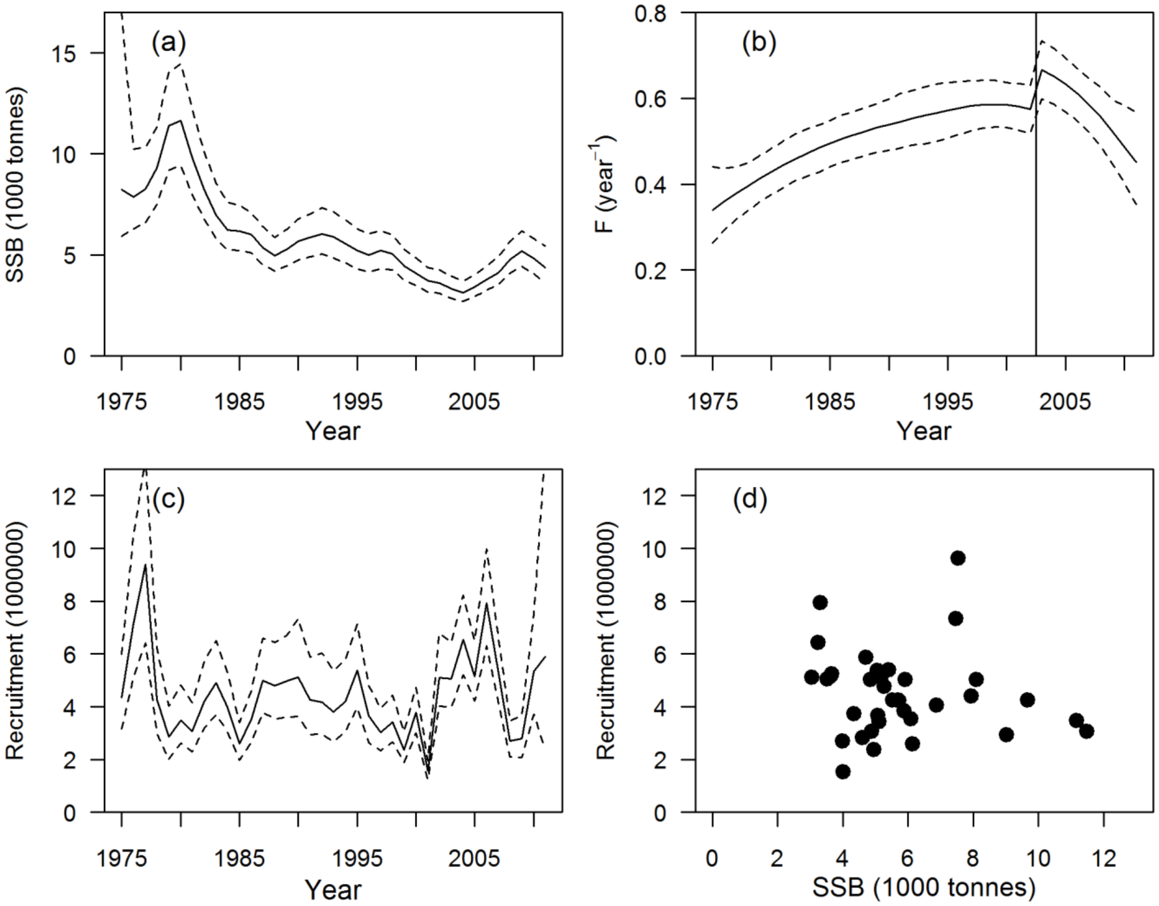


Figure 6-10 Results of the stock assessment of North Sea turbot: (a) spawning stock biomass ; (b) mean fishing mortality rate of age groups 2–6; (c) number of 1-year old recruits; (d) stock-recruitment relationship. The dashed lines show the 95% confidence intervals. The jump in fishing mortality in 2003 is due to the reduction in minimum landing size (indicated by the vertical line).

Discussion

This study highlighted that turbot and brill show temporal and spatial differences as well as similarities. Brill had an earlier timing of spawning and a longer spawning period than turbot. This could also be seen in the energy acquired during the spawning period: turbot has a larger amplitude in body condition and a higher maximum GSI. We showed that there is spatial overlap during the spawning period of adult stages of turbot and brill. However, the intra-specific competition of turbot and brill was found to be higher than the inter-specific competition, suggesting aggregation on a smaller scale. The maximum productivity was similar for both species and is expected in areas with a maximum temperature of 17.4°C. North Sea turbot was highly exploited. However, the stock-recruitment relationship does not indicate that recruitment is impaired at the lower range of observed SSB. Below we describe each finding in more detail.

Biology

Timing of spawning

This study indicated that brill had an earlier timing of spawning than turbot and a more protracted spawning period, based on monthly market samples (Figure 6-3). This was in agreement with results from plankton surveys (van der Land, 1991), where eggs and 0-group fish of brill were observed over a prolonged period. Van der Land (1991) recorded turbot eggs in the coastal waters of the south-eastern North Sea between the late March and July with peak densities in May-June, whereas brill eggs were occasionally encountered between April and July with a peak in May. A monthly ichthyoplankton survey of the Dutch continental shelf showed turbot eggs between May and July, with peak numbers in June (van Damme, pers. comm.). The succession of maturity stages in turbot was similar to those reported by Jones (1974). The earlier start of spawning in brill is reflected in the earlier arrival of 0-group in the nursery grounds. An earlier spawning in brill was also observed in the Bay of Biscay (Deniel, 1981). Nissling et al. (2006) suggested that the timing of spawning in turbot was adapted to the optimum temperatures for egg development.

Growth and reproduction

The growth rates of turbot observed in this study are close to growth rates reported in the North Sea in the past (Jones, 1974; Mengi, 1963). Only for male turbot, L_∞ appears lower (Table 6-2).

We found that the onset of sexual maturity of turbot and brill was quite similar. For both species, the smallest males sampled from commercial landings were almost all mature. Based on the growth rates, we can infer that most of the males became mature at the age of 1 at a size well below 30 cm (turbot ♂, $L_{50\%}$= 17.9, $A_{50\%}$=1.1; brill ♂, $L_{50\%}$= 18.4, $A_{50\%}$=0.1, Table 6-5). The low $A_{50\%}$ of brill males is due to the low number of immature individuals. Therefore, this estimate is probably underestimated. Females matured at ages 1-3 at a size of about 30 cm (turbot ♀, $L_{50\%}$= 34.2, $A_{50\%}$=2.2; brill ♀, $L_{50\%}$= 31.3, $A_{50\%}$=1.6, Table 6-5). The size and age at first maturity of turbot observed in this study was substantially lower than in 1967 (Jones, 1974), which has also been reported for other flatfish (plaice - van Walraven et al., 2010; sole - Mollet et al., 2007) and may be related to a fisheries-induced evolutionary response (Heino, 1998; Jørgensen et al., 2007).

Table 6-5 Parameter estimates (SE) of the logistic regression of the proportion of mature fish as a function of total length (cm) or age (years). The low $A_{50\%}$ of brill males is due to the low number of immature individuals. Therefore, this estimate is probably underestimated.

	species	sex	β_0	β_1	n	p	$L_{50\%}/A_{50\%}$
Length	Turbot	female	-19.8 (1.1)	0.6 (0.03)	2679	<0.001	34.2
		male	-5.2 (1.5)	0.3 (0.05)	1326	<0.001	17.9
	Brill	female	-18.2 (1.2)	0.6 (0.04)	1751	<0.001	31.3
		male	-4.5 (1.2)	0.2 (0.04)	1013	<0.001	18.4
Age	Turbot	female	-9.2 (0.5)	4.1 (0.21)	2652	<0.001	2.2
		male	-3.0 (1.5)	2.8 (0.71)	1291	<0.001	1.1
	Brill	female	-7.9 (0.7)	4.9 (0.36)	1727	<0.001	1.6

		male	-0.2 (0.4)	1.7 (0.25)	979	<0.001	0.1

This study showed that turbot and brill differ in their reproductive strategy with regard to the seasonal cycle in energy stores and reproductive investment: turbot has a larger amplitude in body condition, a higher maximum GSI and a shorter spawning period, which are characteristics of a capital spawning strategy (Rijnsdorp and Witthames, 2005; van Damme et al., in prep) and consistent with a determinate fecundity type (McEvoy and McEvoy, 1992; Jones, 1974; Nissling et al., in press). In contrast, the ovary of brill contains several batches of oocytes at different stages of maturity, indicating intermittent release of ripe eggs in the course of a long spawning season and an indeterminate fecundity (Caputo et al., 2001). The relatively low GSI, in combination with a low amplitude in the body condition and the protracted spawning period observed in brill suggests an income spawning strategy where reproductive investment is (partly) supported by the energy acquired during the spawning period (Rijnsdorp and Whitthames, 2005; van Damme et al., in prep). The above interpretation is consistent with the reproductive investment that was estimated from the fecundity and egg size: fecundity was higher in turbot (1 078 eggs/g body weight) than in brill (465 eggs/g body weight) (Jones, 1974). This difference was mainly due to the difference in egg size. Expressed as the volume of eggs per g body weight, the reproductive investment of brill (535 mm^3 / g) was only 10% lower than in turbot (593 mm^3 /g; Jones, 1974). However, fecundity of brill may be underestimated as they are indeterminate spawners (Caputo et al., 2001). Brill having a more protracted spawning period than turbot has also been observed in the Mediterranean (Caputo et al., 2001).

Niche segregation

Turbot and brill share several ecological characteristics. However, they also differ in a number of characteristics, which may reduce the inter-specific competition. This study showed a spatial overlap of adult stages of turbot and brill during the spawning period, indicating that the spawning areas overlap. However, the difference in timing of spawning will reduce the potential competition for food between planktonic larvae and early demersal stages, although the slightly larger eggs of brill need longer to hatch (Jones, 1972).

The temporal niche segregation will only apply to the larval cohorts of brill that were spawned in the beginning of the spawning period. The larvae from later spawning events will co-occur in the plankton and on the nursery grounds. The first feeding stages of turbot and brill feed on *copepod nauplii* (Lebour, 1919; cited in Jones, 1972). Gut contents of turbot larvae of 3.5–16.9 mm length off the northeast coast of England showed a wide variety of planktonic crustaceans, mainly cladocerans *Podon leuckarti* and *Evadne nordmanni* and copepodites of five species of calanoid copepods (Last, 1979). Young turbot larvae that were offered natural food preferred *copepod nauplii*, while older larvae preferred juvenile and adult stages of *Paracalanus sp*., *Centropages sp*. and harpacticoids (van der Meeren, 1991). Competition between co-occurring turbot and brill larvae, however, may further be reduced by size differences; turbot larvae being smaller than brill larvae (Table 6-6).

In the early demersal stage, turbot and brill may potentially compete for food as they have comparable prey spectrums, mainly feeding on large and mobile prey (e.g. fish, mysids, Besyst et al., 1999). However, differences in the timing of spawning time result in temporal partitioning of settlement, reducing inter-specific competition for food. Haynes et al. (2011a) observed that inter-specific competition for food did not occur on west of Ireland nursery grounds.

Table 6-6. Size (mm) of egg and larval stages of turbot and brill

	Turbot	Brill	Source
Eggs	0.9–1.2	1.2–1.5	1
Larvae at hatching	2.7–3.0	3.8	1, 2
First feeding	3.6–3.8		2
Metamorphosis	22–30	17	2, 3
Settlement	>=27		4

Sources: (1) Jones, 1972; (2) Al-Maghazachi and Gibson, 1984; (3) Jones, 1973; (4) Jones, 1974.

Population ecology

Turbot and brill have complex life cycles. Individuals of each life history stage have different habitat requirements and inhabit spatially distinct habitats. Populations can only survive in areas where these habitat requirements are fulfilled and where there is connectivity between the habitats of successive life history stages (Sinclair, 1988, Petitgas et al., 2013).

Connectivity between spawning and nursery grounds

Larvae of turbot and brill occur in the surface layer where they are transported by wind driven currents. Riley et al. (1981) showed that the abundance of 0-group turbot along the English coast was correlated with wind direction during the spawning period. The connectivity between spawning and nursery areas was affected by the duration of the pelagic phase and by the distance between the spawning and nursery grounds (Hufnagl et al., this volume). Turbot has a relatively long pelagic phase for which estimates vary between 45-72 days (age at metamorphosis: Al-Maghazachi and Gibson, 1984; Jones, 1973) and 29-39 days (based on daily growth patterns in otoliths: Haynes et al., 2011b). Several papers showed that turbot migrate towards coastal waters to spawn (Stankus, 2003; Vinther, 1995).The connectivity may still be critical since eggs were observed in waters at 10-50 miles from the coast (van der Land, 1991; van Damme et al., pers comm).

We expect the connectivity between the spawning and nursery area to be affected by the seascape. In areas where the adult habitat is (partly) enclosed by suitable nursery grounds, such as in the Baltic, the probability that pelagic larvae reach suitable nursery grounds will be more insensitive to variations in wind driven transport compared to seascapes with an open coast such as along the west coast of Ireland, France, Spain or Portugal. A study of the connectivity using realistically parameterised hydrodynamic models for different seascapes may test this hypothesis and explore the possible influence on the differences in the productivity levels across management areas. Such models have been employed successfully to study the connectivity issues in other flatfish species (Bolle et al., 2009; de Graaf et al., 2004; Fox et al., 2009; Lacroix et al., in press; van der Veer et al., 1998; Hufnagl et al., in press).

Ontogenetic changes in competition

We found that the number of co-occurring conspecifics decreased with increasing body size. For demersal stages, the index of mean crowding was highest for the smallest size class. The mean density of the 0-group at the nursery grounds in September is ~4 individuals per 1000 m^2, (range: 0.1 – 18.5, Haynes et al., 2010). A crude estimate of the density of pelagic turbot larvae at hatching was obtained from the observed densities of pelagic eggs (about 1 m^{-2}; van der Land, 1991) and the size (Ø = 1 mm) and temperature (T = 14°C) dependent mortality rate (Pepin, 1991). If we assume that larvae are aggregated at the surface (Russell, 1976), the density of hatching larvae in June will be about ~ 2 individuals per 1 000 m^2, which is lower than the estimated density on the nursery grounds. This simple calculation suggests that competition is most likely to occur in the time period following settlement, being consistent with the hypothesis that nursery habitat is a bottleneck in the population ecology of flatfish (Rijnsdorp et al., 1992; Beverton, 1995).

If the nursery grounds are indeed a bottleneck, one would expect that the relationship of productivity with temperature is better if productivity is expressed per unit nursery area instead of per unit adult habitat. However, expressing the productivity per unit adult habitat resulted in a higher r value for the relationship between productivity and temperature compared to expressing the productivity per unit nursery area (turbot: $r_{adult} = 0.89$, $r_{nursery} = 0.87$; brill: $r_{adult} = 0.94$, $r_{nursery} = 0.92$). The lack of agreement between the expectation and our results may be due to the rather crude estimate of the nursery habitat used. The size of the 0-2 m depth band is only a proxy of the surface area of the surf zone habitat, which is the key nursery habitat. It ignores the sediment characteristics as well as the availability of suitable food. Nissling et al. (2007) showed that feeding incidence of early demersal stages of turbot was related to the abundance of their main prey suggesting that mysid abundance determines the quality of the nursery grounds.

This study revealed that the intra-specific competition of turbot and brill was much higher than the inter-specific competition, suggesting that both species used specific micro-habitats within an overall similar distribution area (Knijn et al., 1993). Comparison of the index of mean crowding of turbot and brill with other flatfish species, corroborated the low number of conspecifics sharing the same habitat. The index of mean crowding in sole, plaice and dab was more than 10^3 times higher.

Minimum number of adult fish required for successful spawning

An important question in fisheries science is the number of adult fish required for successful reproduction, in particular at which level of spawning stock biomass (SSB) depensation occurs. One of the mechanisms that may lead to depensation is the reduced probability of adults finding a mate. The low abundance of turbot and brill may provide insight in the densities at which depensation may occur.

The stock-recruitment relationship of turbot did not indicate impaired recruitment at the minimum level of SSB, suggesting that adult biomass was sufficient for successful reproduction. The available data on the spawning of turbot and brill indicated that spawning occurred over a rather large area at low densities. Cameron et al. (1992) recorded turbot eggs in the German Bight at densities up to 0.4 eggs/m^2. Van der Land (1991) reported egg densities in the southeastern North Sea of 1.0 and 0.1 eggs/m^2 for turbot and brill, respectively. Combined with an estimate of the relative fecundity of turbot of 10^6 eggs kg^{-1} (Jones, 1974), the density of 1.0 eggs m^{-2} corresponds to an estimate of 1 spawning female of $W = 2$ kg body size per 2×10^6 m^2 (40 cm). A similar calculation for plaice (20 eggs m^{-2}; 265×10^3 eggs kg^{-1}; $W = 0.75$ kg) and sole (10 eggs m^{-2}; 800×10^3 eggs kg^{-1}; $W = 0.5$ kg) results in 25-100 times higher densities of spawning females: 1 spawning female per 10^4 m^2 and 4 per 10^4 m^2 for plaice and sole, respectively. This indicates that turbot and brill were able to reproduce successfully at very low adult densities. This raises the question if the precautionary level of SSB used in current fisheries management for plaice and sole are too precautious. Knowledge on differences in behavioural mating mechanisms among flatfish species is lacking and is difficult to research, so the question cannot be answered.

Stock productivity

The productivity of a stock is determined by the level of recruitment, the somatic growth rate and the mortality rate. Landings were positively related to the surface area of suitable habitat and therefore the landings per unit habitat were used as a proxy for the productivity of a population to study the latitudinal pattern in productivity. This proxy was crude since it assumes that the possible differences in fishing mortality across the management areas did not affect the recruitment and the yield. The stock assessment of North Sea turbot did not provide evidence that recruitment was impaired although the stock was exploited well above F_{MAX} and the yield per recruit was reduced between 25% - 45% of the potential maximum. There is a potential for bias in our estimates of productivity among areas caused by different fishing pressures in these areas. We hypothesize that the different fishing pressures for turbot can be inferred from the observed differences in fishing mortality of the commercially important flatfish species, sole (*Solea solea*). Peak fishing mortality on sole occurred in the North Sea and the fishing mortality of the other stocks ranged between 63% - 95% (Mollet et al., in press). Assuming similar relative fishing mortalities among turbot stocks, would suggest that the productivity may be biased by less than 37%.

The productivity showed a dome-shaped relationship with both latitude and temperature. Maximum productivity was observed in areas with a maximum summer temperature of 17.4°C, close to the optimal temperature for growth for 50 g turbot (16 - 19°C), but above the optimal temperature for larger sized turbot (13-16°C for 100 g turbot; Imsland et al., 1996). The higher optimal temperatures reported for smaller turbot (19.6 - 23.0 °C for 5 - 20 g turbot; Imsland et al., 2000) will match the higher seasonal maximum temperatures in the shallow nursery grounds. We conclude that temperature mediated growth rate of juveniles and adults is a factor involved in determining the latitudinal pattern in landings. This inference is in agreement with the difference in growth of turbot between the Baltic and the North Sea and Bay of Biscay (Table 6-2).

A second factor that may constrain the productivity is the temperature conditions required for survival and growth of eggs and larvae. High egg survival occurs between 12–18 °C, while survival was reduced at 9 and 21°C (Devauchelle et al., 1988; Nissling et al., 2006). Growth and development of turbot larvae requires a minimum temperature of 5.3 °C (Weltzien et al., 1999). At high latitude, productivity may also be reduced if 0-group fish are unable to reach the minimum body size required to survive the winter conditions. A minimum size requirement for winter survival of 0-group individuals is a common phenomenon in fish (Post and Evans, 1989).

Low salinity may explain the decrease in productivity toward the inner Baltic. At low salinities the hatching rate of turbot eggs is reduced and a higher rate of deformities is observed (Devauchelle et al., 1988). Although Baltic Sea turbot may be adapted to lower salinities (Karås and Klingsheim, 1997, but see Florin and Hoglund, 2007), the viable hatch was significantly lower at < 7 psu compared to 7–15 psu, implying lower egg survival in subdivision (SD) 29 and 30 compared to in SD 24–28. In SD 31, salinity conditions are insufficient for egg development (Nissling et al., 2006).

A comparison of the maximum body size across regions shows that the L_∞ of female turbot increases from the Baltic, southward along the Atlantic coast , to the Mediterranean and Black Sea (Table 6-2). The latitudinal pattern in males is less clear. In addition to the possible effect of temperature (Daufresne et al., 2009; Baudron et al., 2011), the lower L_∞ may be related to the higher reproductive investment in the Baltic (Nissling et al., 2013) leaving a smaller proportion of the surplus production available for somatic growth, similar to the pattern observed in sole (Mollet et al., in press).

Genetic studies revealed that Baltic turbot differed from turbot in the North Sea with the Kattegat being a transition zone (Nielsen et al., 2004). The difference in reproductive investment indicated by higher fecundity and lower maximum body size in the Baltic, and the difference in sensitivity for low salinities (Karås & Klingsheim, 1997) may reflect local genetic adaptation to low salinity conditions in the Baltic. Local adaptation is consistent with the counter-gradient growth patterns reported by Imsland et al. (2000). Growth rate of northern populations was higher at a given temperature than the growth rate of turbot of southern origin. Local genetic adaptation may act at relatively small spatial and ecologically relevant scale (Volckaert, 2013). The smallest spatial scale of adaptive divergence in flatfish was documented for turbot over a distance of just 60 km (Imsland and Jonassen, 2001). Inshore species tend to have more genetically fragmented populations than offshore species, while coastal species like turbot and brill exhibit intermediate genetic fragmentation (Volckaert, 2013).

Conclusions

The analyses suggest that the highest densities of turbot and brill in the North Sea occur during the early demersal phase after the fish have settled on the highly restricted nursery grounds. As such the species conform to the concentration and nursery size hypothesis (Beverton, 1995; Rijnsdorp et al., 1992; van der Veer et al., 2000). Although both species have similar ecological characteristics, differences were observed in the size at hatching and in the timing and duration of the spawning period which may reduce the interspecific competition. Landings per unit of habitat are highest in areas with a maximum temperature between 16-18ºC. Although North Sea turbot has been intensively exploited (F between 0.34 and 0.66 year^{-1}), the stock-recruitment relationship does not indicate that recruitment is impaired at the lower range of observed SSB. Given low egg densities, which indicate a very low density of adults, this raises the question at what level of SSB the density of adults may become too low and recruitment will be impaired.

6.2.1.1 Supplementary on-line material

Stock assessment of turbot

Data

Landings data for turbot in the North Sea is available from ICES, recorded in the Eurostat database (ICES 2012). In the 1950s the UK was the biggest contributor to the landing that fluctuated around 6000 tons per year (Fig. S1). Currently, the landings are around 2700 tons per year, with the Netherlands being the biggest contributor. The age structure of the landings is estimated using data from different sources in different time periods (ICES 2012) (Fig. S2). Starting in 1975, there is a 4 year time period for which the age structure is available in Weber (1979). The second dataset spans the period 1981-1990, is derived from landings in the Netherlands (Boon and Delbare 2000). The third dataset spans the period 2000 – 2002, supplied to ICES by CEFAS and based on the UK landings of turbot. The final dataset stems again from the Netherlands, covering 1998 and 2004-2011, supplied by IMARES to ICES and based on the Dutch landings of turbot from the North Sea.

One fisheries dependent catch-per-unit-effort time series from the Dutch 80 mm beam trawl fleet, and two fisheries independent catch-per-unit-of-effort time series from research vessel surveys are available for turbot in the North Sea. The fisheries dependent catch-per-unit-effort time series is collected throughout the year. Potential changes in catchability owing to changes in vessel targeting are corrected for using the method described in Quirijns et al (2008). The fisheries independent time series (BTS-ISIS and SNS) are collected over a short period (August–September) of each year.

Method

The population numbers-at-age and fishing mortality-at-age are estimated using a discrete-time age-structured population dynamics model, similar to that in Aarts and Poos (2009), and done by ICES (ICES 2012). In the model, all fish in the North Sea are considered to be a single closed population. The basis is that the numbers-at-age of a single cohort over time decrease as a result of mortality

$$N_{a+1,t+1} = N_{a,t} \mathrm{e}^{-Z_{a,t}},$$

where $N_{a,t}$ are the numbers at age a at time t, and $Z_{a,t}$ the total mortality. The vector $N_{1,t}$ is the “recruitment” of one-year-old fish into the population. The total mortality is composed of natural mortality rate M (year^{-1}) and the fishing mortality rate $F_{a,t}$ (year^{-1}) such that

$$Z_{a,t} = M + F_{a,t}$$

Natural mortality is assumed to be constant (0.2) in time and equal for all ages. Fishing mortality $F_{a,t}$ is modelled as the separable process of an inter-annually variable mean and an age-dependent selectivity pattern $f_{a,t}$. The interannually variable mean term in the estimate of $F_{a,t}$ is also described by a smooth function of time, constructed using five b-spline basis functions $h_k(t)$ (de Boor, 2001). The selectivity pattern $f_{a,t}$ defines the relative probability that an individual of age a in the population is caught and is constrained to have a maximum of 1. Similar to Aarts and Poos (2009), $f_{a,t}$ is a smooth function of age, constructed using four b-spline basis functions $h_k(a)$ (de Boor, 2001), using an inverse-logit function to constrain it between 0 and 1. Because there is a clear change in the available catch-at-age data used to estimate the model parameters, two different selectivity patterns are estimated for two time periods, where two additional parameter is estimated in the latter period, describing the difference in catchability for ages 1 and 2. Similar to many other assessment techniques, we assume that the fishing mortality for the older ages is equal, in this case ages 7 to 9.

The estimated landings $L_{a,t}$ for age a and year t is calculated using the Baranov catch equation

$$L_{a,t} = \frac{F_{a,t}}{Z_{a,t}} N_{a,t} \left(1 - \mathrm{e}^{-Z_{a,t}}\right)$$

Hence, the model assumes no fish is discarded, supported by the observations of negligible discarding in the Dutch discards sampling programme over the last 10 years.

CPUE data

One fisheries dependent catch-per-unit-effort time series from the Dutch beam trawl fleet ($U_{a,t}^1$), and two fisheries independent catch-per-unit-of-effort time series from research vessel surveys ($U_{a,t}^2$, $U_{a,t}^3$) are available for turbot in the North Sea. The fisheries dependent catch-per-unit-effort time series is collected throughout the year, while the fisheries independent time series are collected over a short period (August–September) of each year. The population numbers-at-age $N_{a,t}$ are estimated on 1 January of year t. The expected catch-per-unit-effort series are calculated from the age-dependent catchability and the numbers at age in the population, correct for the decline in numbers because of mortality

$$U_{a,t}^1 = q_a^1 N_{a,t} \mathrm{e}^{(-\delta^1 Z_{a,t})}$$

Where q_a^1 is the age dependent catchability for time series $U_{a,t}^1$, and $\delta^1$is the midpoint of the timing of the catch per unit effort, expressed as a fraction of a year. The same procedure is done to yield $U_{a,t}^2$ and $U_{a,t}^3$

Derived estimates

Two derived time series are important from the stock assessment of turbot, the spawning stock biomass (SSB) and the mean fishing mortality over ages 2-6 ($\bar{F}_{2-6}$). SSB is a vector calculated as the sum over ages of the product of numbers-at-age, weight-at-age $W_{a,t}$, and maturity-at-age $S_{a,t}$ such that

$$SSB = \sum_a N_{a,t}\, W_{a,t} S_{a,t}$$

The mean fishing mortality over ages 2-6 is calculated as the arithmetic mean of the estimated fishing mortalities over ages 2-6.

Yield per Recruit analysis

In order to explore the potential effect of fishing on annual landings, the 'Yield per Recruit' model (YpR) of Beverton & Holt (1957) was used. The YpR-model calculates the fate of a cohort in terms of its growth, maturation and mortality (natural and fishing), assuming constant recruitment (N1=1). The numbers at age in the cohort are assumed to decay according to the age-dependent total mortality. Natural mortality, fishing mortality, weight-at-age and maturity-at-age were taken from the stock assessment. YpR calculations were carried out for a range of fishing mortality rates varying between $\bar{\mathrm{F}}_{2-6}$ = 0 to 1.

Likelihood function

The available datasets for parameter estimation are (i) landings-at-age, and (ii) cpue series from the Dutch beam trawl fleet and two surveys. The data are assumed to be log normally distributed, with means and age-specific standard deviations predicted by the model. There were 12 zero values in a total of 772 observations in the datasets and to allow using a lognormal distribution in the likelihood function, a small constant equal to half of the lowest observed value within each dataset was added. The sum of the log-likelihood components for all data sources was calculated, as

$$\ell = \ell_L + \ell_{U^1} + \ell_{U^2} + \ell_{U^3},$$

$$\text{where } \ell_L = \sum_{a,t} \log\left(\mathrm{n}\left(\log(L_{a,t})\,; \log(\hat{L}_{a,t})\,, \sigma_a^L\right)\right)$$

$$\ell_{U^1} = \sum_{a,t} \log\left(\mathrm{n}\left(\log(U_{a,t}^1)\,; \log(\hat{U}_{a,t}^1)\,, \sigma_a^{U^1}\right)\right)$$

$$\ell_{U^2} = \sum_{a,t} \log\left(\mathrm{n}\left(\log(U_{a,t}^2)\,; \log(\hat{U}_{a,t}^2)\,, \sigma_a^{U^2}\right)\right)$$

$$\ell_{U^3} = \sum_{a,t} \log\left(\mathrm{n}\left(\log(U_{a,t}^3)\,; \log(\hat{U}_{a,t}^3)\,, \sigma_a^{U^3}\right)\right)$$

Here, $\mathrm{n}\left(\log(L_{a,t})\,; \log(\hat{L}_{a,t})\,, \sigma_a^L\right)$ is the normal probability density of the log of the observed values $L_{a,t}$, with mean $\log(\hat{L}_{a,t})$ and standard deviation σ_a^L. Because residual plots for initial model runs suggested that the residual variability differed with age σ_a^L, $\sigma_a^{U^1}$, $\sigma_a^{U^2}$, and $\sigma_a^{U^3}$ values are modelled as the exponent of a source dependent level, and an age dependent pattern, equal for all sources.

Parameter and uncertainty estimation

In total, the model consists of 80 estimable parameters, of which 45 parameters are used to estimate recruitment and the starting population, 12 parameters are used to estimate the age dependent standard deviations for the data sources, and 23 parameters are used to estimate the fishing mortality and CPUE series catchabilities. All model fitting was done in ADMB (Fournier et al., 2012).

The negative of the likelihood function is minimized using a quasi-Newton algorithm with derivatives obtained using automatic differentiation. Convergence is declared once the derivatives are smaller than 10^{-4}.

Markov chain Monte Carlo simulation is used to approximate the posterior distribution of estimated parameters (Gelman et al., 2004; Magnusson et al., in press), SSB, and $\bar{F}_{2-6}$. The algorithm used for MCMC in ADMB is a random walk Metropolis–Hastings algorithm. The initial point is the mode of the specified objective function, and the proposal covariance is the inverse Hessian, both calculated using automatic differentiation. The MCMC simulation is run for 1 million iteration and thinned to keep every 1000th iteration. The confidence interval is estimated from the thinned MCMC iterations using the quantile method.

Results

The selectivity of the catch-at-age matrix clearly shows an increase of selectivity at age at the younger ages, and a relatively flat selectivity at the older ages (Fig. S3). The selectivity of the ages 1 and 2 in the period starting in 2000 is clearly higher than in the earlier period, consistent with the observed increase in landings of ages 1 and 2 in the later period. The two survey CPUE series are estimated to have a selectivity that declines with age (Fig. S4). This can be explained by the fact that the surveys sample mainly in the coastal areas. Also, the fishing speed is around 4 knots, giving large turbot the opportunity to outswim the gear. The CPUE series derived from the Dutch 80 mm beam trawl fleet is similar to the selectivity estimated for the catch-at–age matrix, which can be explained by the large contribution of this fleet to the overall catches of turbot in the North Sea. Derived result in terms of trends of fishing mortality, recruitment, and SSB over time are in the main text.

The Yield per recruit analysis indicates a yield per recruit of approximately 0.82 kg at a fishing mortality $\bar{F}_{2-6}$of 0.32 (Fig. S5). The SSB per recruit at this fishing mortality is approximately 2.0 kg. At the most recent estimate of $\bar{F}_{2-6}$ (~0.45) the YpR is about 0.80 and the SSB per recruit is approximately 1.3 kg.

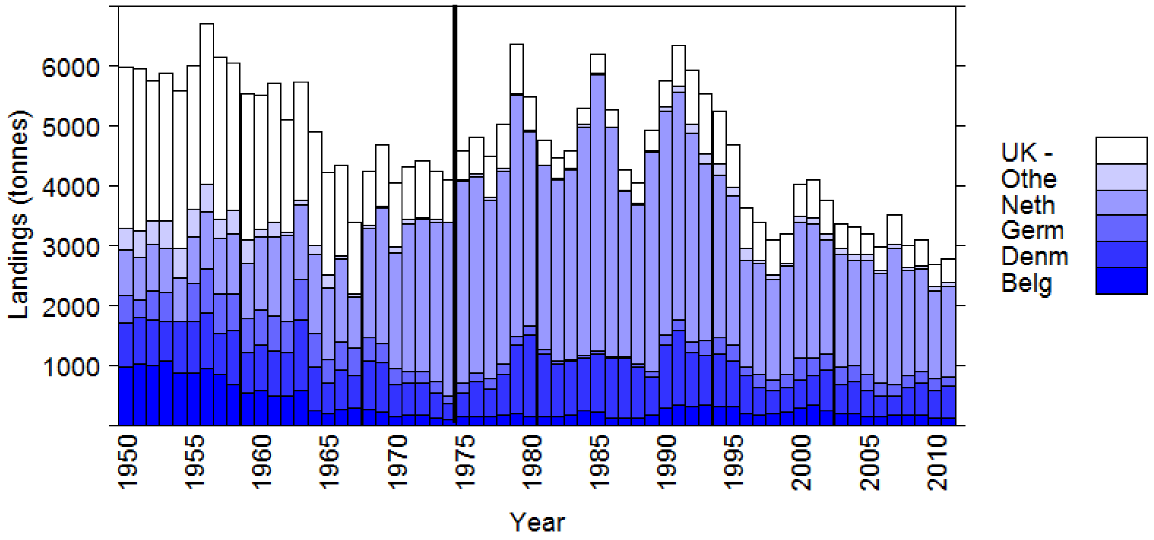


Fig. S1. Landings in IV by different countries from Eurostat (taken from ICES 2012). The vertical line indicates the year from which age-structured data is available.

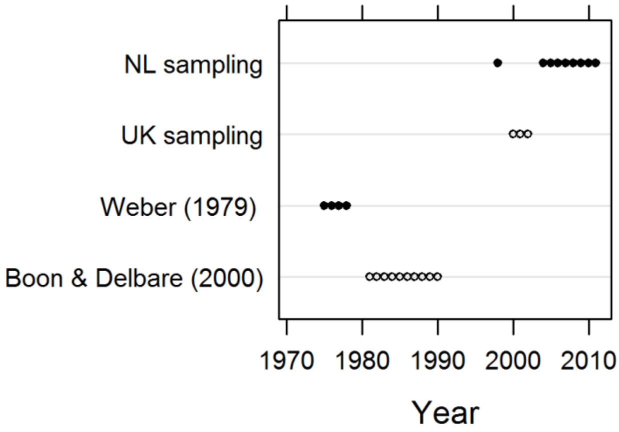


Fig. S2. Source of age data for creating catch at age data. The availability of sex separated information is indicated by a closed black dot and sex combined date is indicated by an open circle (adapted from ICES 2012).

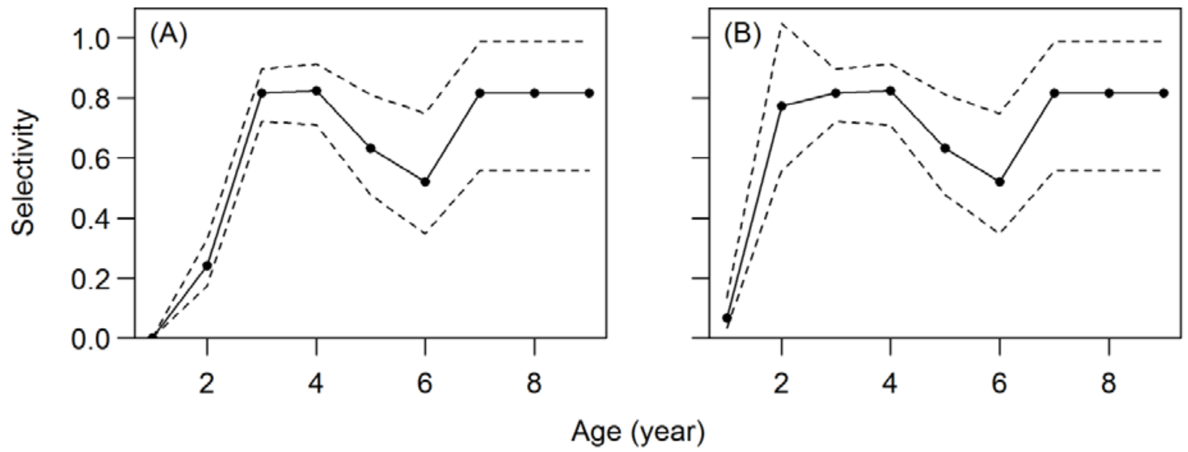


Fig. S3. Selectivities estimated for the catch-at-age data for the two periods 1975-2000 (A) and 2001-2011 (B). Drawn lines indicate MCMC medians and dashed lines indicate 95% confidence bounds as indicated by MCMC (adapted from ICES 2012).

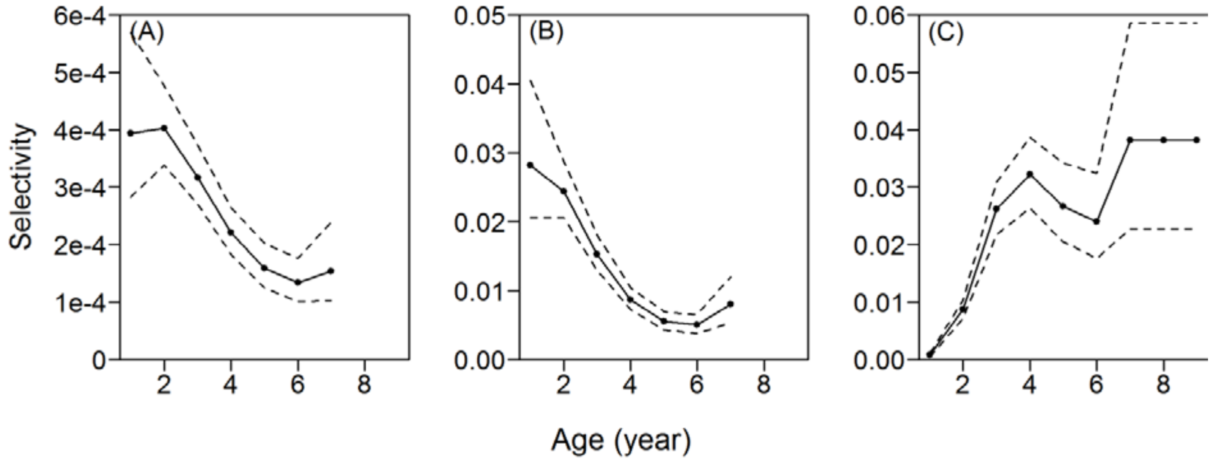


Fig. S4. Selectivities estimated for the three CPUE series: (A) BTS, (B) SNS, and (C) Dutch 80 mm beam trawl fleet. Drawn lines indicate MCMC medians and dashed lines indicate 95% confidence bounds as indicated by MCMC (adapted from ICES 2012).

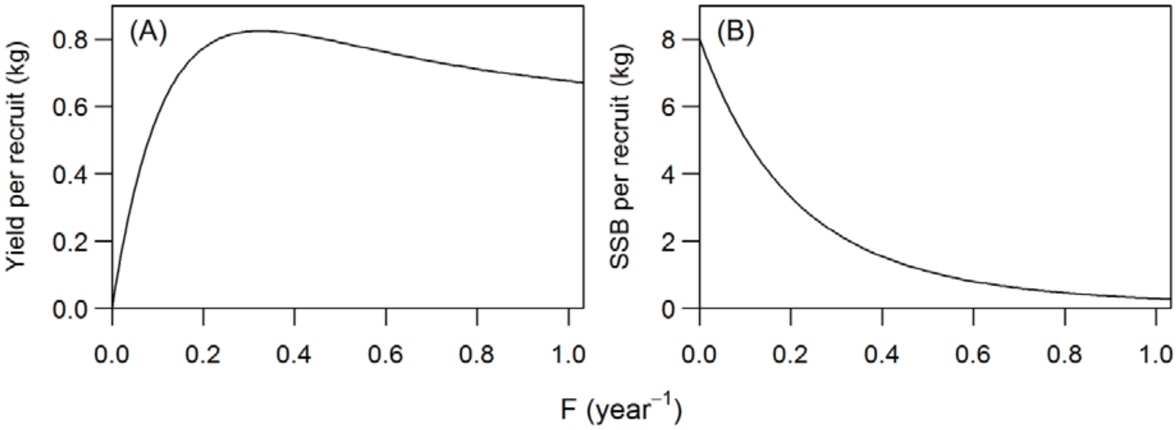


Fig. S5. (A) Yield per recruit and (B) Spawning Stock Biomass per recruit as a function of $\bar{F}_{2-6}$ for turbot, based on the stock assessment (adapted from ICES 2012).

Conclusions

Turbot and Brill are commercially important bycatch species. In this paper, the available data has been gathered and analysed in order to understand the biology and the population dynamics of these species, which will be helpful in future management. An analytic assessment for turbot is now available and was treated as indicative of trends in fishing mortality, recruitment, biomass, and future catches for the 2013 ICES advice (ICES 2013c).

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Justification

Report number: C166/13

Project Number: 430860104

The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: ir. F.J. Quirijns

Senior Fisheries Scientist

Signature:

Date: 25th of February, 2014

Approved: drs. J.H.M. Schobben

Head of Fish department

Signature:

Date: 25th of February, 2014

Appendix A. DFS timeseries Seabass

Table 0-1 DFS timeseries Seabass (n/10.000m2).

year	*Western Dutch Wadden Sea*	*Eastern Dutch Wadden Sea*	*Dutch Wadden coast*	*Southern Dutch coast*	*Oosterschelde*	*Westerschelde*
1970	0.000	0.000	0.000	0.000	0.077	0.000
1971	0.000	0.000	0.000	0.000	0.000	0.000
1972	0.000	0.000	0.000	0.000	0.000	0.092
1973	0.000	0.000	0.000	0.000	0.000	0.000
1974	0.000	0.000	0.000	0.000	0.000	0.000
1975	0.000	0.000	0.000	0.000	0.000	0.000
1976	0.000	0.000	NA	NA	0.000	0.066
1977	0.000	0.000	0.000	0.000	0.000	0.000
1978	0.000	0.000	0.000	0.000	0.000	0.000
1979	0.000	0.000	0.000	0.045	0.000	0.063
1980	0.000	0.000	0.000	0.228	0.000	0.064
1981	0.000	0.000	0.000	0.085	0.000	0.000
1982	0.000	0.000	0.000	0.031	0.000	0.000
1983	0.000	0.000	0.000	0.093	0.000	0.000
1984	0.000	0.000	0.000	0.027	0.000	0.386
1985	0.000	0.000	0.040	0.117	0.000	0.000
1986	0.000	0.000	0.000	0.000	0.000	0.000
1987	0.000	0.000	0.000	0.000	0.523	0.000
1988	0.000	0.000	0.000	0.000	0.000	0.075
1989	0.000	0.000	0.000	0.000	0.000	0.000
1990	0.000	0.000	0.000	0.038	0.000	0.323
1991	0.000	0.000	0.000	0.095	0.000	0.129
1992	0.000	0.000	0.000	0.000	0.143	3.205
1993	0.000	0.000	0.000	0.000	0.000	0.290
1994	0.000	0.000	0.000	0.000	0.000	36.397
1995	0.000	0.000	0.000	0.079	0.000	4.322
1996	0.000	0.000	0.000	0.188	0.129	0.330
1997	0.041	0.000	NA	NA	0.000	1.238
1998	0.230	0.000	0.000	0.000	0.048	2.197
1999	0.000	0.000	0.000	0.055	0.185	11.139
2000	0.199	0.000	0.000	0.595	0.805	7.503
2001	0.044	0.074	0.000	0.132	0.551	9.561
2002	1.233	0.661	0.050	0.000	0.572	20.933
2003	0.000	0.000	0.000	1.222	0.000	17.253
2004	5.842	0.449	0.000	0.996	0.000	56.001
2005	0.000	0.000	0.000	0.040	0.608	6.031
2006	0.107	0.137	0.000	0.167	0.135	7.313
2007	0.033	0.000	0.000	0.123	0.117	15.655
2008	0.041	0.000	0.303	0.065	0.122	6.980
2009	1.170	0.160	0.041	0.275	0.171	7.989
2010	0.075	0.000	0.000	0.000	0.267	48.489
2011	0.246	0.633	0.000	0.000	3.347	0.809
2012	0.189	0.000	0.000	0.000	NA	NA

Table 0-2 DFS nha per length class (m) and year for the Westerschelde.

	0.04	*0.05*	*0.06*	*0.07*	*0.08*	*0.09*	*0.10*	*0.11*	*0.12*	*0.13*	*0.14*	*0.15*	*0.16*	*0.17*	*0.18*	*0.19*	*0.20*	*0.21*	*0.22*
1970	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1971	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1972	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.08	0.08	0.08	0.08	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.13	0.13
1991	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.52	2.09	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.99	2.19	5.32	11.31	13.91	1.05	1.05	0.06	0.00	0.06	0.00	0.12	0.00	0.06	0.12	0.06	0.00
1995	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.17	0.39	0.54	1.05	0.56	0.66	0.18
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1997	0.00	0.06	0.00	0.25	0.31	0.37	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	0.00	0.21	0.11	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.26	0.42	0.47	0.31	0.15	0.10	0.05
1999	0.00	0.00	0.00	0.20	1.45	2.52	3.45	1.34	1.17	0.63	0.00	0.00	0.00	0.00	0.10	0.06	0.08	0.00	0.00
2000	0.17	0.55	1.10	0.50	0.22	0.23	0.07	0.00	0.00	0.04	0.09	0.14	0.27	1.07	1.17	0.76	0.58	0.44	0.08
2001	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.16	0.00	0.00	0.20	0.13	0.38	1.59	2.62	1.75	1.75	0.43	0.22
2002	0.69	1.91	3.53	3.76	2.57	2.47	1.81	1.95	0.33	0.76	0.00	0.00	0.09	0.00	0.39	0.16	0.12	0.00	0.00
2003	0.00	0.26	0.85	2.26	2.81	3.45	2.69	1.46	0.12	0.00	0.00	0.00	0.00	0.09	0.33	0.54	0.74	0.49	0.49
2004	0.00	4.63	8.46	12.52	10.54	4.04	3.38	0.56	0.07	0.14	0.19	0.83	2.45	3.10	2.67	0.80	0.53	0.16	0.26
2005	0.00	0.06	0.44	0.81	1.28	0.61	0.00	0.00	0.00	0.00	0.08	0.08	0.31	0.06	0.58	0.44	0.13	0.20	0.00
2006	0.00	0.30	0.77	2.49	0.83	0.22	0.00	0.00	0.00	0.00	0.07	0.07	0.14	0.21	0.78	0.51	0.14	0.21	0.00
2007	0.00	0.00	0.00	0.08	0.00	0.00	0.27	0.34	0.00	0.27	0.27	1.15	2.73	2.19	3.24	2.74	0.71	0.96	0.21
2008	0.07	0.29	0.00	0.39	1.21	1.60	0.20	0.00	0.00	0.00	0.00	0.00	0.07	0.40	0.39	0.47	0.20	0.21	0.13
2009	0.00	0.19	0.49	1.15	1.45	2.99	1.07	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.07	0.07	0.12	0.00
2010	2.12	14.79	11.42	7.85	8.69	2.06	1.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.06	0.06	0.20	0.00
2011	0.00	0.00	0.00	0.35	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.19	0.09	0.00	0.00
2012	0.00	0.00	0.00	0.17	0.39	0.06	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00

Table 0-2 DFS nha per length class (m) and year for the Westerschelde. *Continued*

	0.23	***0.24***	***0.25***	***0.26***	***0.27***	***0.28***	***0.29***	***0.3***	***0.31***	***0.32***	***0.33***	***0.34***	***0.35***	***0.36***	***0.37***	***0.38***	***0.39***	***0.40***
1970	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1971	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1972	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

1991	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.00	0.07	0.00	0.08	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
1995	0.17	0.06	0.11	0.05	0.12	0.00	0.00	0.00	0.00	0.05	0.00	0.05	0.00	0.00	0.05	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.05	0.11	0.11	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1997	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	0.00	0.00	0.04	0.04	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	0.00	0.04	0.00	0.09	0.09	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	0.00	0.00	0.11	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00
2003	0.14	0.21	0.11	0.00	0.00	0.10	0.00	0.00	0.00	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	0.00	0.00	0.00	0.07	0.13	0.15	0.06	0.06	0.06	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.08	0.07	0.33	0.30	0.12	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	0.00	0.00	0.00	0.07	0.07	0.07	0.07	0.07	0.08	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00
2007	0.00	0.07	0.07	0.00	0.06	0.07	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2008	0.20	0.34	0.14	0.29	0.30	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2009	0.00	0.00	0.00	0.00	0.06	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00
2011	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.00	0.00	0.00	0.00	0.13	0.06	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix B. LPUE tables

Table B-1 Catches, effort and LPUE values

	Gillnets-seines			*Beamtrawl*			*Flyshoot*			*Lines*		
year	Catches (kg)	Effort (days at sea)	LPUE (kg/day at sea)	Catches (kg)	Effort (days at sea)	LPUE (kg/day at sea)	Catches (kg)	Effort (days at sea)	LPUE (kg/day at sea)	Catches (kg)	Effort (days at sea)	LPUE (kg/day at sea)
2000	2609	359	3.1	30923	27987	12.0	930	63	9.5			
2001	11790	811	20.2	29215	26824	2.3	3335	226	15.0			
2002	8112	1073	14.3	52534	24756	3.4	2572	168	17.3			
2003	14083	1115	18.5	95697	22939	5.6	3857	1889	22.7			
2004	16750	1025	23.0	107912	21529	7.5	5299	306	17.6			
2005	20824	1304	24.2	151675	21595	11.7	14935	331	37.9	52005	440	107.2
2006	27720	1847	22.4	150303	19413	12.9	15207	333	50.6	62052	581	68.9
2007	30737	1625	28.4	152008	18709	20.1	25845	405	53.2	87448	611	71.3
2008	30850	1920	26.3	127571	14047	15.6	43505	516	67.0	95209	685	96.2
2009	33379	2144	27.6	152941	14701	12.2	31804	588	51.9	86182	760	76.4
2010	35910	2254	25.7	133075	15219	22.2	35739	711	44.0	118374	831	131.5
2011	39114	1982	37.0	123112	15137	6.8	41985	743	53.6	147069	961	118.0
2012	28470	2242	28.6	76115	14277	6.3	86484	928	86.9	120317	877	114.8