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Report of the Benchmark Workshop on North Sea Stocks (WKNSEA)

2–6 February 2015

Copenhagen, Denmark

ICES International Council for the Exploration of the Sea

CIEM Conseil International pour l'Exploration de la Mer

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Executive summary

The ICES Benchmark Workshop on North Sea Stocks (WKNSEA) convened at two meetings in Copenhagen, one data compilation workshop (10–13 November 2014) and the final benchmark meeting (2–6 February 2015).

In WKNSEA three stocks were benchmarked: Cod in IV, IIIaN and VIId, Sole in IV, and Red mullet in VIId, IV and IIIa. The most important conclusions for each stock were:

Cod in Area IV, IIIaN and VIId

WKNSEA examined information on whether cod in Subarea IV (North Sea), Subdivision IIIaN (Skagerrak) and Division VIId could be considered as a single functional unit for assessment purposes, or whether multiple assessments were needed in the future to address the dynamics of different stocks in the assessment area. The group concluded that strong evidence from several studies showed the North Sea cod population structure is complex, and at least two distinct stocks could confidently be assumed for the assessment area. Investigative assessment model runs supported the assumption of multiple stocks, but also showed that the aggregate stock dynamics are likely being adequately represented by the current stock assessment model. The working group was unable to compile model parameters and assign all required data to different stocks because of unknown mixing of stocks in different quarters and life stages. Further work will be needed to identify how to model multiple stocks in the most appropriate way. For the next benchmark, the aim should be to develop an assessment that adequately reflects the multiple stock structure. Data and input parameters will need to be compiled according to agreed boundaries. In the meantime, the survey biomass trends in subareas should be monitored.

As another important issue, WKCOD 2011 decided to exclude the IBTS Q3 survey from the assessment because of diverging signals between IBTS Q1 and IBTS Q3 survey indices in recent years, while the IBTS Q1 indices were considered more likely to reflect stock trends in recent years. WKNSEA analysed potential reasons for the conflicting signals, and evaluated whether the IBTS Q3 index could be included again in the assessment. A statistical approach (Delta-GAM) to derive the standardized survey indices provided an adequate solution. This change in estimation method for the Q1 and Q3 IBTS indices was significant, because it helped both indices to be incorporated into the stock assessment model, and made implicit allowance for the changes in survey vessels over space and time. The Skagerrak was identified as the region where most of the discrepancies between Q1 and Q3 occur. This region is surveyed by only one vessel and changes in sampling positions occurred in Q3 during the last years, leading to confounding issues. WKNSEA suggests a review of survey design.

Regarding input data, the incorporation of a trend in proportion mature at-age was the largest change, and was supported by empirical data. The change in proportion mature at-age made a substantial change to SSB and biomass reference points estimates, and recognized important biological changes occurring in the stock, but otherwise made no difference to assessment results (F and population numbers-at-age). Overall, the changes introduced in the benchmark resulted in hardly any changes to the terminal F estimate. Only SSB increased considerably, because of the assumption of a time varying maturity ogive. This led to a revision of biomass reference points. B_{lim} changed from 70 000 t to 103 000 t (SSB in 1996, when the last outstanding year

class was produced). B_{PA} and MSY $B_{trigger}$ changed from 150 000 t to 144 000 t by applying the default ICES rule (i.e. $B_{PA} = 1.4 * B_{lim}$).

Sole in IV

Historically the sole assessment was conducted without discards included, and a main aim of the benchmark was the incorporation of discards in the assessment. Because discard data were available for the period 2002–2013 only, selecting the right model to reconstruct the discard time-series was a principal issue for discussion. It was decided that discards could be incorporated in the stock assessment adequately by using the AAP model platform (Aarts and Poos, 2009), which used discard data for recent years to estimate a discarding ogive, which was then extrapolated into earlier years. This could not have been done using the previous stock assessment platform (XSA). AAP was chosen as the final assessment model. AAP and XSA model runs without discards produced very similar results.

Different options for inclusion and exclusion of time-series as tuning indices in the assessment were tested at the benchmark. A Dutch commercial lpue series had previously been used as a tuning index. However, the Dutch fleet changed considerably in the last years, shifting more and more fishing effort from traditional beam trawls to pulse trawls. In addition to the BTS-ISIS and SNS surveys, previously used in the sole assessment, new scientific survey indices from Belgium and Germany were made available to WKNSEA. Analyses showed that, in aggregate, the fishery-independent surveys were largely consistent with each other and their spatial coverage was considered sufficient for the purpose of stock assessment. The Belgian BTS survey would improve the coverage of the stock area as it was the only one to cover the southwestern part of the North Sea. However, model runs including it introduced relatively strong retrospective patterns. The German index only covers a small part of the stock area, and does not add new information to the assessment. The Dutch commercial tuning data were compromised by the recent change in fishing gear, with traditional gear declining and likely to shortly disappear, making it unavailable for future assessments, but the time-series of new gear (pulse trawl) still being short with unknown veracity as an abundance index. As a result of the above, the benchmark assessment eventually used the BTS-ISIS and SNS fishery-independent surveys only. Overall, the assessment results with and without commercial indices were very similar. The exclusion of the fishery-dependent data is expected to provide a potentially less precise, but likely unbiased, estimate of stock status. It is recommended that future assessments should attempt to incorporate the Belgian beam-trawl survey data once a longer time-series is available. Assessments should also investigate the addition of Dutch commercial pulse tuning data when a longer time-series becomes available.

Red mullet in IV, VIId and IIIa

Striped red mullet in VIId, IV and IIIa had been never benchmarked before. So far, red mullet was treated as a Category 3.2 data-limited stock, where the assessment was based on survey biomass trends only. The aim of this benchmark was to examine the available data and evaluate whether these were sufficient to inform an age-based assessment model (like XSA or a4a). This included considering whether information from the Channel Ground Fish Survey CGFS alone was enough to index the whole stock, because the IBTS surveys in the North Sea catch relatively few red mullet and age a very limited number of fish, leaving the Eastern Channel as the primary source of stock composition data for the entire stock region (which formally also includes the

North Sea, and the Skagerrak and Kattegat). Analyses suggested the extrapolation of the assessment results from the Eastern Channel to the southern North Sea had merit. It was less clear whether the assessment was valid for the other areas within the stock region, because the fishery catches were small and data were sparse. Most data had high variability (e.g. weights-at-age), presumably resulting from relatively small sample sizes.

The stock assessment with a4a agreed during the benchmark seemed reasonable given the available information, but the assessment needs to be further developed and reviewed once more information exists. A retrospective analysis indicated that recruitment estimates for the most recent years were very uncertain, and could be substantially revised when more years of data were added. On the other hand, the SSB trend estimated by the assessment was considered to be a more reliable indicator of stock status than direct use of the survey indices. Therefore, it was agreed that results generated by the benchmark assessment model could be used for providing fisheries advice under the ICES Stock Category 3 framework. To avoid tracking annual noise in this relatively uncertain assessment, it is suggested that the assessment is updated only every two or possibly three years. In addition, further sources of data should be investigated, including how to best incorporate these in stock assessment models (e.g. an integrated approach, combining the use of age and length data, would make it possible to use all available information.

1 Introduction

The following terms of reference were addressed during the WKNSEA meetings in 10–13 November 2014 (data compilation workshop) and 2–6 February 2015:

2014/2/ACOM32 A **Benchmark Workshop for North Sea Stocks** (WKNSEA), chaired by External Chair Matthew Dunn, New Zealand and ICES Chair Alexander Kempf, Germany, and attended by two invited external experts Carmen Fernandez, Spain and Kevin Piner, USA will be established and will meet at ICES HQ, Copenhagen, Denmark 10–13 November 2014 for a data compilation meeting and at ICES HQ, Copenhagen, Denmark for a five day Benchmark meeting 2–6 February 2015 to:

a) Evaluate the appropriateness of data and methods to determine stock status and investigate methods for short-term outlook taking agreed or proposed management plans into account for the stocks listed in the text table below. The evaluation shall include consideration of:

  i) Stock identity and migration issues;

  ii) Life-history data;

  iii) Fishery-dependent and fishery-independent data;

  iv) Further inclusion of environmental drivers, multi-species information, and ecosystem impacts for stock dynamics in the assessments and outlook.

b) Agree and document the preferred method for evaluating stock status and (where applicable) short-term forecast and update the stock annex as appropriate. Knowledge about environmental drivers, including multispecies interactions, and ecosystem impacts should be integrated in the methodology.

If no analytical assessment method can be agreed, then an alternative method (the former method, or following the ICES data-limited stock approach) should be put forward;

c) Evaluate the possible implications for biological reference points, when new standard analyses methods are proposed. Propose new MSY reference points taking into account the WKFRAME2, results and the introduction to the ICES advice (section 1.2), and WKMSYREF3.

d) Develop recommendations for future improving of the assessment methodology and data collection;

e) As part of the evaluation:

  i) Conduct a three day data compilation workshop (DCWK). Stakeholders are invited to contribute data (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality. As part of the data compilation workshop consider the quality of data including discard and estimates of misreporting of landings;

  ii) Following the DCWK, produce working documents to be reviewed during the Benchmark meeting at least seven days prior to the meeting.

The Benchmark Workshop will report by 1 April 2015 for the attention of ACOM.

STOCKS	STOCK LEADER
cod-347d	Jose De Oliveira
Mur-347d	Youen Vermard
Sol-nsea	David Miller

The assessment for North Sea cod was previously benchmarked in 2009 (ICES WKROUND 2009) and during an Inter-benchmark in 2011 (ICES-WKCOD 2011), and was thus due to be benchmarked under the standard three-year cycle. There were several principal issues under discussion. First, WKNSEA collected further information on whether cod in Subarea IV (North Sea), Subdivision IIIaN (Skagerrak) and Division VIId can be considered as a single functional unit for assessment purposes or whether multiple assessments are needed in the future to address the dynamics of different stocks in the assessment area. Secondly, WKCOD 2011 decided to exclude the IBTS Q3 survey from the assessment because of diverging signals between IBTS Q1 and IBTS Q3 survey indices in recent years. WKNSEA analysed again the reasons behind the observed conflicting signals and evaluated whether the IBTS Q3 index could be included again in the assessment with the help of newly developed statistical methods to standardize survey indices (delta-gam method). Next to this, WKNSEA determined the appropriate data configuration and input data (weight-at-age, maturity ogive, natural mortality) that should be used to conduct the annual cod assessments. For the first time InterCatch could be used to raise catch-at-age data in a consistent way back to 2002. Also for the first time a comparison between SAM and an A4A cod assessment was carried out. Finally, new reference points were determined based on the final benchmark assessment and WKMSYREF III guidelines.

The assessment for North Sea sole was previously benchmarked in 2010 (ICES WKFLAT 2010) and was thus due to be benchmarked again. In addition, so far the sole assessment has been conducted without discards included. This leads to problems under the landing obligation where advice based on catches is needed. The inclusion of discards into the assessment was one of the main priorities for this benchmark. The right model to reconstruct the discard time-series (data only available for 2002–2013) was a principal issue for discussion. Next to this, a Dutch commercial lpue series has been used so far as tuning index. However, the Dutch fleet changed considerably in the last years, shifting more and more fishing effort from traditional beam trawlers to vessels using pulse trawls. New scientific survey indices from Belgium and Germany were made available to WKNSEA as candidates to be included in the assessment. Therefore, different options for inclusion and exclusion of time-series as tuning indices had to be tested in addition to comparisons of results from different assessment models (XSA and AAP). WKNSEA determined the appropriate data configuration, input data and modelling approach that should be used to conduct the annual sole assessments and reference points were re-estimated based on the final benchmark assessment and WKMSYREF III guidelines.

Striped red mullet in VIID, IV and IIIa has been never benchmarked before. In WGNEW and last year in WGNSSK striped red mullet was treated as category 3.2 data-limited stock where the assessment is based on survey trends only. The aim of this benchmark was to screen the available data and evaluate whether the existing data are sufficient to inform an age-based assessment model like XSA or A4A. This included also the question whether information from the Channel Ground Fish Survey CGFS alone is enough to draw conclusions for the whole stock. WKNSEA determined the appropriate data configuration, input data and modelling approach that should be used to conduct the annual striped red mullet assessments. It was evaluated whether an age-based assessment would at least allow for a better category 3.2 assessment than direct use of survey indices, and whether additional useful information for the management of the stock can be drawn from the available data.

The report addresses the points mentioned for each stock through analyses of stock structure, input data and model settings to be used. It concludes with notes on future research needed to improve the assessments in the future and the comments of the external review panel. The updated Stock Annex which will form the basis of assessment updates for the next 3–5 years completes the report. This benchmark focused on single stocks. No new information (apart from new natural mortality estimates for cod) on multispecies and mixed fisheries issues were presented at this benchmark. Specific working groups (ICES WGSAM and ICES WGMIXFISH) deal with these issues in the North Sea ecoregion.

2 Description of the Benchmark Process

The ICES benchmark on North Sea stocks included the following steps:

1) A data call was issued 5 September 2014 for the North Sea stocks to be benchmarked in WKNSEA and WKPLE. The data call was based on the WGNSSK data call but asked for InterCatch data back to 2002 and additional data where needed (i.e. tagging data, maturity-at-length/age data). The deadline of the data call was 6 October 2014.

2) A data compilation workshop was held in Copenhagen, 10–13 November 2014. The main focus of this meeting was to review relevant datasets and consider information and issues for each stock, as well as prioritizing work in the run up to the actual benchmark. A summary was prepared on issues, data available, data gaps and planned working papers. The summary was sent to the external experts to facilitate the contact between the externals and stock coordinators.

3) On December 2, 2014, a WebEx was held with the external experts to discuss the main outcome of the Data Compilation Workshop, present conclusions and the work planned for the next two months to prepare for the benchmark workshop.

4) One week before the benchmark, the working documents to be discussed should have been provided to meeting participants. Deadline for documents was 26 January 2015 but most documents were ready a few days later. The following working documents were prepared before the meeting:

NS cod

WD1: Wright, P.J., Hemmer-Hansen, J., Hüssy, K. and Mariani. P. Population structuring of cod in the North Sea. 34pp.

WD2: Eero, M., Holmes, S.J., Jardim, E., De Oliveira, J.A.A., Ulrich, C., Berg, C. and Wright, P. Analyses of stock dynamics and fishing pressure of cod in the North Sea by sub-areas. 31pp.

WD3: Berg, C.W. Survey Index and Mean Weight-at-age Calculations for North Sea Cod from NS-IBTS data. 3pp.

WD4: Kempf, A. Background document on the new SMS key run 2014 – processes impacting the natural mortality estimates for cod. 20pp.

WD5: Wright, P.J. Changes in maturity and age related reproductive success of North Sea cod. 15pp.

WD6: De Oliveira, J.A.A. Preparation of catch data for North Sea cod. 69pp.

WD7: De Oliveira, J.A.A. and Nielsen, A. NS cod SAM assessment runs. 31pp.

WD8: De Oliveira, J.A.A. and Nielsen, A. Forecast methodology for October update: an illustration. 3pp.

WD9: Walker, N.D. Exploratory assessment of North Sea cod using a4a. 14pp.

NS sole

WD10: Haslob, H. Maturity-ogives of Sole (*Solea solea* L.) in the German Bight (2007, 2008, and 2010–2012). 7pp.

WD11: Haslob, H. The German Sole Survey Index – Update and revision of the time-series (1974–2012). 9pp.

WD12: Moreau, K. The Belgian Quarter 3 Beam Trawl Survey – sole index. 3pp.

Red mullet

WD13: Vermard, Y. Working document on raising procedures for Red Mullet. 11pp.

WD14: Vermard, Y. Working document on survey indices for Red Mullet. 9pp.

5) The benchmark meeting was held in Copenhagen, 02–06 February 2015.

The first two days of the benchmark meeting were devoted to presentations of working papers, presentation of input data and first results from assessment models. After each presentation, discussions were held and participants tried to reach conclusions. If conclusions were not reached the additional work needed was agreed between the external reviewers and the respective scientists.

In the following days the work conducted during the benchmark was reviewed until final conclusions could be reached. The last 1–2 days were used to derive new reference points based on the agreed assessments and externals were able to draft their conclusions and recommendations.

Notes on the benchmark process

The preparation of the benchmarks was not optimal. This was caused at first instance by several cases of late arrival of important input data. Despite an official data call and a data compilation workshop two months before the final benchmark meeting, important data were available only after Christmas or were not available before the benchmark meeting at all. The benchmark for witch had to be postponed to 2016 because data were not available in time.

In general, most of the preparation was finalised during the last week before the benchmark or even during the benchmark meeting. For future benchmarks it may be beneficial to have a formalised process when intermediate steps of the preparation have to be presented to the external reviewers to be able to discuss issues encountered well in advance of the benchmark meeting. For this, however, the availability of input data early in the process is an absolute prerequisite as well as the ability of involved scientists to do intersessional work. Often scientists simply don’t have the time for this because they are engaged in many other projects.

3 Cod

This section relates to the cod stock in the North Sea (Subarea IV), the Skagerrak (the northern section of Division IIIa) and the eastern Channel (Division VIId).

3.1 Stock ID and substock structure

A working document was presented to the workshop that summarised studies examining genetic differentiation and life stage connectivity in North Sea cod (Wright *et al.*, WD1). These studies provide strong evidence that the North Sea assessment region is comprised of more than a single population. The clearest evidence is for two populations; one inhabiting the northeast North Sea (termed 'Viking') and the other in shallower waters. This is supported by studies using both microsatellite DNA and single nucleotide polymorphisms (SNP) (Nielsen *et al.*, 2009; Poulsen *et al.*, 2011; Heath *et al.*, 2014; Wright *et al.*, WD1) that indicates that the Viking group is reproductively isolated from other cod spawning aggregations. Investigations of life-stage connectivity suggest that this isolation may have partly arisen through oceanographic barriers to early life-stage transport (Heath *et al.*, 2008; Munk *et al.*, 2009) as well as limited mixing of adults as they appear to remain within waters >100 m (Wright *et al.*, 2006a; Neat *et al.*, 2014). However, in addition, unpublished genetic and otolith microchemistry studies indicate that many Viking juveniles settle in the Skagerrak and subsequently make a return migration prior to spawning. This evidence is consistent with the observation that age 2+ abundance of a year class in the region does not reflect the relatively high abundance of 0- and 1-group cod (Svedäng and Svenson, 2006) and that a relatively strong year class of cod in 2001 in the Skagerrak was genetically assigned to originate from the North Sea (Knutsen *et al.*, 2004). Consequently, the reproductive isolation of Viking fish appears to be supported by both limited mixing with neighbouring groups and natal homing.

New SNP evidence presented in Wright *et al.* (WD1) also supports a separation of the North Sea and Norwegian coastal groups. This is consistent with extensive tag–recapture studies that have found these cod to show high site fidelity (Nedreaas *et al.*, 2008). Trends in juvenile abundance also vary at the scale of fjords (Rogers *et al.*, 2014) supporting the separation of Norwegian coastal cod from other regions of the assessment region.

Scales of larval transport (Heath *et al.*, 2008; Wright *et al.*, WD1), juvenile dispersal (Wright *et al.*, 2006a) and adult movements (Wright *et al.*, 2006b; Righton *et al.*, 2007; Svedäng *et al.*, 2007; Neat *et al.*, 2014) indicated from non-genetic methods suggest even finer scales of population structuring within the North Sea than that indicated by genetic evidence. From the eastern channel to Shetland the seasonal scales of adult movements are generally <200 km and the estimated levels of mixing of eggs and larvae based on larval transport models and otolith microchemistry does not indicate there is exchange across this range.

Whilst the population structuring evident in North Sea cod can be used to suggest alternative 'stocks', i.e. discrete groups of fish linked to a particular geographical area, it is important to note that the home ranges of different aggregations do overlap, particularly for certain life stages and outside the spawning period. In the Skagerrak, there appears to be extensive inter-mixing of pre-adult stages between local, Viking and possibly also shallow North Sea cod. Further whilst adult Viking cod appear to remain in depths >100 m, cod from the shallow water population may overlap with the western distribution of Viking cod outside the spawning period. Consequently, although an approximate home range can be defined for Viking cod, a separate stock assessment for this population would need to consider the level of mixing to estimate the proportion of catches composed of Viking cod, particularly in the Skagerrak. There are well developed ways to estimate mixing levels, including molecular and otolith based methods, although this would require a new level of information for the assessment.

In order to allow a comparison of putative population trends boundaries were proposed by Wright *et al*. (WD1) to explore whether there were subarea (substock) differences. It is important to note that these subarea boundaries do not represent a clear division in population range but rather reflect areas of low mixing. Based on the population evidence two subareas were first proposed, namely Viking (Figure 3.1.1, red area) and the rest of the assessment area (Figure 3.1.1, blue and green areas) with Skagerrak as a nursery area for Viking. A further division of the remaining North Sea was proposed between the northwest (NW, blue area) and south (S, green area) that corresponded to areas with limited exchange between southern and northern spawning aggregations (Figure 3.1.1).

Eero *et al*. (WD2) analysed potential differences in cod dynamics among the putative subareas of low exchange. It is important to emphasize that in addition to uncertainties related to the subarea definitions there were limitations on the area-disaggregated datasets (see Eero *et al*., WD2 for details), so the analyses should be considered as exploratory. The analyses included simple abundance and biomass trends from IBTS surveys, survey-based assessment analyses (SURBA), spatial trends in commercial landings and fishing effort and analytical assessment analyses by the subareas using the a4a stock assessment framework.

The analytical assessment results indicate that the largest biomass of adult cod in the North Sea is currently found in the Viking and Skagerrak area whilst the lowest is found in the Southern (S) North Sea. Cod densities, in terms of catch per unit of effort from research surveys are relatively similar in the Northwest (NW), Viking (V) and Skagerrak (Sk) areas in recent years, but notably lower in the South.

In terms of recent trends, both the survey data alone and analytical assessment analyses indicate more than doubling of the biomass of adult cod in the NW area since 2007. In the Viking and Skagerrak area, the analytical assessment also estimated an increase in biomass over time, which is supported by survey data. However, the increase in the V and Sk area is less compared to the NW. In the South, all analyses indicate a stable biomass in recent years, which is lower than other areas.

Given the lack of any genetic evidence for different populations, a combined NW (blue) and S (green) area was also considered ignoring the large differences both in trends and biomass between the two areas. Analyses based on the combined NW and S suggested the dynamics of that region was not substantially different from that in V and Sk. Available survey information also did not indicate major differences in recruitment production per unit of SSB between any of the sub-areas investigated (Figure 3.1.1), and no significant changes in R/SSB in 2003–2013 were detected.

The distribution of European cod landings between 2003 and 2013 show differences by subareas that generally follow the changes in stock distribution, with the highest landings in the Viking area in recent years where the cod biomass is estimated to be highest, and the landings show a declining trend in the South where the stock size is lowest, although no Norwegian landings data were included in these analyses. In the period from 2003–2013, fishing mortality on cod is indicated to have declined in all areas in the North Sea. However, survey data suggests that among the areas analysed, the total mortality is presently highest in the South, lowest in the Northwest, with intermediate level in the Viking and Skagerrak area. These differences were confirmed by the analytical assessment analyses. The assessment analyses merging NW and S indicated that the combined estimate of fishing mortality for these areas is somewhat lower than estimated for Viking and Skagerrak. The effort (without Norwegian data) of TR1 (bottom trawls and seines with mesh ≥100 mm) + TR2 (bottom trawls and seines with 70 mm <mesh <100 mm) fleet segments is currently highest in the low cod abundance area in the South, which may indicate that our assumption of spatial distribution of cod discards being similar to that of landings to be incorrect. This would influence the estimates of fishing mortalities by area, e.g. if the proportion of discards in the South is higher than assumed in the analytical assessment analyses, the fishing mortality in the South may be higher than that estimated in the assessment runs presented.

The different trends among subareas are consistent with evidence on population structure, as regional variation in environmental conditions, predation and fishing mortality would be expected to lead to some differences in substock trends. Differences in life-history traits have been found among the subareas consistent with population differences (Harrald *et al*., 2010; Wright *et al*., 2011; Yoneda and Wright, 2004). However, there is a clear need for improved data on spatial distribution of cod catches-at-age before firm conclusions on current fishing pressure on subpopulations and related management considerations can be drawn. Given the local changes in the NW subarea we need to understand whether the contrasting dynamics in this area reflects a subpopulation response to locally favourable conditions. Indeed, it is very important to determine the spatial scale over which management measures are affecting the North Sea cod stock, especially in relation to closed areas that are currently just applied to part of the stock range. The methods employed to consider regional trends by Eero *et al*. (WD2) provide a means of continuing substock monitoring, but more flexible approaches that allow mixing scenarios to be modelled (e.g. using a modelling framework such as GADGET, or the approach of Cunningham *et al*., 2007) instead of being fixed through data (as in Eero *et al*., WD2) would allow a range of mixing scenarios to be better explored, with the potential for estimating mixing parameters if appropriate data are available. Any changes to the current assessment area to better reflect population differences would also need to consider population mixing, especially in the Skagerrak.

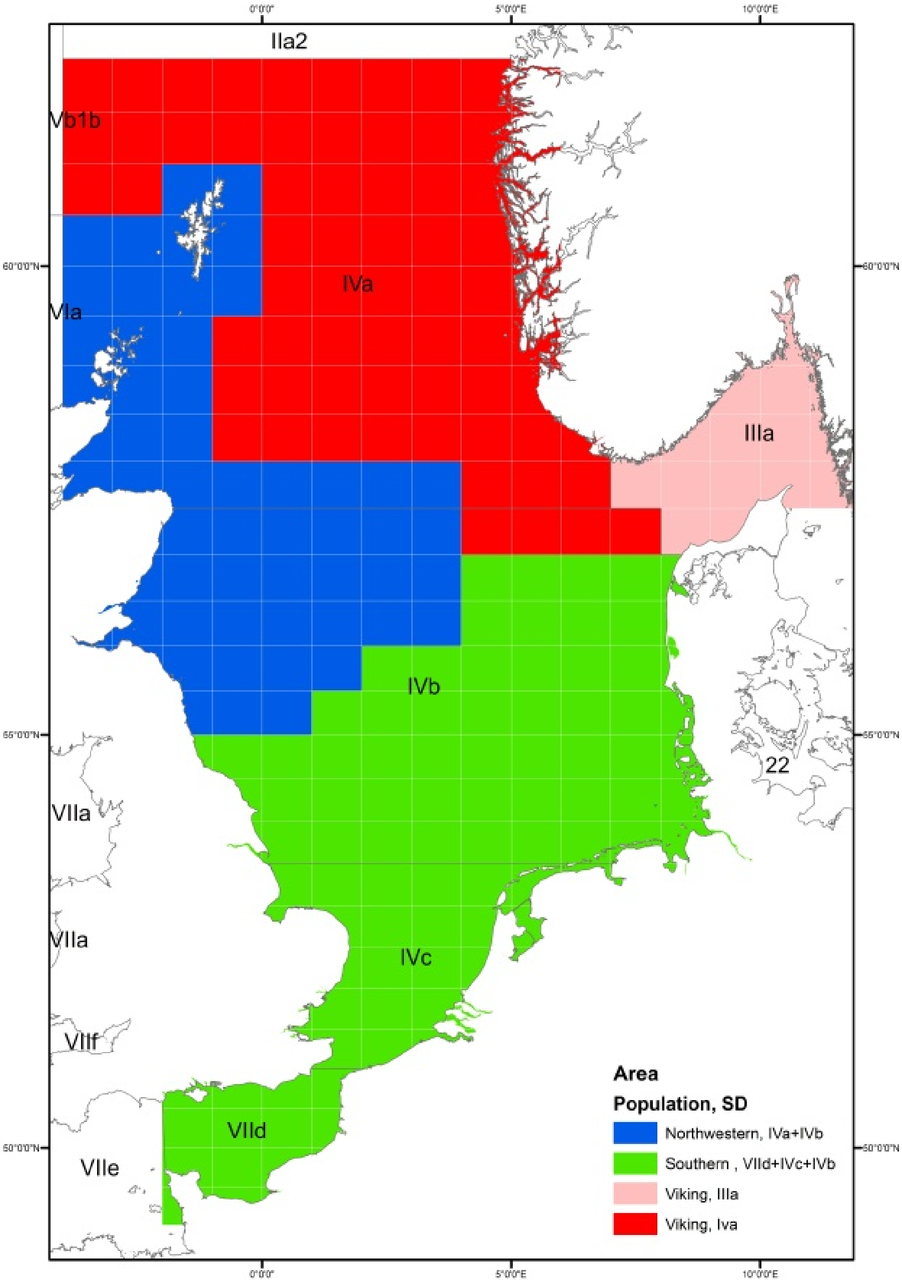


Figure 3.1.1. The subareas used in spatial analyses of North Sea cod based on the evidence presented in Wright *et al.* (WD1). The subareas are referred to: Sk (Skagerrak); V (Viking); NW (northwest) and S (south), corresponding to pink, red, blue and green colours on the map, respectively.

3.2 Issue list

This issue list is taken from Annex V of ICES-WGNSSK (2014). The "Comments" column indicates whether the issue was handled during this benchmark, and if yes, where it can be found.

ISSUE	PROBLEM/AIM	WORK NEEDED / POSSIBLE DIRECTION OF SOLUTION	DATA NEEDED TO BE ABLE TO DO THIS: ARE THESE AVAILABLE / WHERE SHOULD THESE COME FROM?	COMMENTS
1. Data to be Considered and/or quantified	Alternative tuning indices	Development of alternative tuning indices from commercial fleets and/or fisheries-science partnerships	National data sources	Not presented (due to the termination of several fishery-science time-series, and focus instead on IBTS Q3)
2. Tuning series	Apparent changes in IBTS Q1 and Q3 catchability; discrepancies between stock trends implied by fishery dependent and independent sources, and by different surveys.	Appropriate standardisation of indices, using statistical methods	Datras database	Section 3.6.2
3. Discards	Improved discard estimation	Discard rates from Scottish CCTV vessels	Scottish CCTV observations	Not presented (analyses not yet ready for implementation)
4a. Biological Parameters: Maturity	Evaluation of maturity: in recent years; North Sea cod has shown changes in maturity with fish maturing at a younger age and smaller size.	Following WKROUND in 2009, further investigations needed on issues linked to earlier maturity, for example relating the quality of reproductive output of young first-time spawners to recruitment success.	Maturity data from surveys (IBTS Q1); information on survival rates of eggs and larvae from fish maturing at a younger age and smaller size.	Section 3.6.3.2

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	Comments
4b. Biological Parameters: Natural Mortality	Inclusion of sensitivity tests for different time-series of M based on different assumptions in the diet selection model of SMS.	SMS runs using different assumptions in the diet selection submodel.	SMS key run ready to test different assumptions.	Section 3.6.3.3
5. Assessment method	Open to a range of assessment methods that would be appropriate for this stock (SAM and others)	Development of alternative models, and model configurations; WCSAM in Boston (July 2013) may be informative because NS cod is one of the datasets being used to test assessment methods.	Data that could support different model structure, e.g. if discards/landings are modelled separately; already available	Section 3.6.4
6. Biological Reference Points	Reference points will need to be re-evaluated on the basis of new assessments	Definition of suitable reference points following the determination of the most appropriate stock assessment method.	Stock assessment outputs.	Section 3.8
7. Other	Genetic work may indicate the need to reconsider stock identification and/or account for a spatial dimension in modelling	Further development of genetic studies	Samples collected and analysed as part of scientific research. Methods and data available to separate catches from different stock components.	Section 3.1

3.3 Scorecard on data quality

A scorecard was not used for this benchmark.

3.4 Multispecies and mixed fisheries issues

No new information was presented at the benchmark meeting apart from updated natural mortality estimates for cod (see Section 3.6.3).

Adult cod is a top predator in the North Sea ecosystem. Important commercial prey fish for cod are whiting, haddock, herring and cod itself. Cannibalism leads to relatively high F_{MSY} values when estimated in a multi-species context compared to single-species approaches (ICES-WGSAM 2012). Predictions also show that fishing cod at too low fishing mortalities may have negative consequences for the stock dynamics of whiting and haddock. Cod are predated upon by a variety of species through their life history. The Working Group on Multi-species Assessment Methods (ICES-WGSAM 2014) estimated predation mortalities using SMS (Stochastic Multi-Species Model) with diet information largely derived from the Years of the Stomach databases (stomachs sampled in the years 1981–1991). Long-term trends have been observed in several partial predation mortality model estimates with significant increases for grey gurnard preying on 0-group cod. In contrast, cannibalism on age 1 and age 2 cod decreased over the 1980s and 1990s in the model but increased again in recent years. The reason is that the lower fishing mortality rates increased the abundances of older cod compared to the still poor recruitment. Predation on older cod (age 3) increased due to increasing numbers of grey seals in the North Sea.

Cod are caught by virtually all the demersal gears in Subarea IV and Divisions IIIa (Skagerrak) and VIId, including beam trawls, otter trawls, seine nets, gillnets and lines. Most of these gears take a mixture of species, making the management of these mixed fisheries difficult, especially with regard to the upcoming landing obligation. In some of them, cod are considered to be a bycatch (for example in beam trawls targeting flatfish), and in others the fisheries are more directed towards cod (for example, some of the large meshed Otter Trawl fisheries and fixed gear fisheries). ICES WGMIXFISH-NS produces every year a mixed fisheries advice for the demersal stocks in the North Sea to inform managers about potential choke species and consequences of different management scenarios. Cod is currently the main choke species for the demersal fisheries in the North Sea and determines to which extent quotas of other species can be fished under a catch quota management (ICES-WGMIXFISH-NS 2014).

Further information can be found in the stock annex.

3.5 Ecosystem drivers

No new information has been presented at the benchmark.

Recruitment has been linked not only to SSB, but also to various environmental factors in the literature (e.g. temperature, plankton production timing and mean prey size, predator fields and the NAO). The assumption on whether SSB or other environmental factors mainly determine recruitment strength influences biomass reference points and the predicted recovery potential of North Sea cod considerable (see Section 3.8).

A meeting (2007) of the STECF reviewed the broad-scale environmental changes in the Northeastern Atlantic that has influenced all areas under the cod recovery plan (STECF-SGRST-07-01), and concluded that:

- Warming has occurred in all areas of the NW European shelf seas, and is predicted to continue.
- A regime shift in the North Sea ecosystem occurred in the mid-1980s.
- These ecological changes have, in addition to the decline in spawning stock size, negatively affected cod recruitment in all areas.
- Biological parameters and reference points are dependent on the time period over which they are estimated. For example, for North Sea cod F_{MSY}, MSY and B_{MSY} are lower when calculated for the recent warm period (after 1988) compared to values derived for the earlier cooler period.
- The decline in F_{MSY}, MSY and B_{MSY} can be expected to continue due to the predicted warming, and possible future change should be accounted for in stock assessment and management regimes.
- Modelling shows that under a changing climate, reference points based on fishing mortality are more robust to uncertainty than those based on biomass.
- Despite poor recruitment, modelling suggests that cod recovery is possible, but ecological change may affect the rate of recovery, and the magnitude of achievable stock sizes.
- Recovery of cod populations may have implications to their prey species, including *Nephrops*.

Further details can be found in the stock annex.

3.6 Stock assessment

3.6.1 Catch; quality, misreporting, discards

Norwegian coastal cod

Up until last year, Norwegian coastal cod was always included in Subarea IV North Sea cod catches, but not in Subarea IIIaN catches. Extensive tag–recapture studies (Nedreaas *et al*., 2007) have indicated Norwegian coastal cod to have high site fidelity, with very little movement into areas occupied by North Sea cod. Furthermore, new single nucleotide polymorphism analysis indicated that a sample from the Norwegian coastal cod population was different to North Sea cod samples, and therefore supported the separation of Norwegian coastal cod from North Sea cod (Wright *et al*., WD1). The decision was therefore taken to remove all Norwegian coastal cod data from North Sea cod catches (De Oliveira, WD6). This was done by using Norwegian coastal cod data that were available for the period 1977–2001 in order to calculate an adjustment factor to be applied to catch-at-age data (single multiplier applied to all ages in any given year, given that no age composition was available for the coastal cod data). This resulted in a very small downward adjustment to the total catch (mostly less than 1% but up to 2.5% in 2000 and 2001). The average adjustment for the period 1977–1981 (<1%) was used to adjust the catches prior to 1977.

InterCatch: 2002–2013

InterCatch was used for estimation of landings age composition, as well as the estimation of both discards numbers and age composition (De Oliveira, WD6). Data coordinators from each nation were tasked to input data for 2002–2013 into InterCatch, disaggregated by quarter and métier. The data from Norway excluded Norwegian coastal cod. Allocations of discard ratios and age compositions for unsampled strata were then performed in order to obtain the data required for the assessment. Although InterCatch was previously used to estimate 2011–2013 catch data, these years were re-calculated in InterCatch following the 2014 data call; catch data for the years 2002–2010 have now been processed through InterCatch for the first time.

The approach used for discard ratio allocations was to do it by area (IIIaN, IV and VIId) and treat FDF métiers separately (note, FDF métiers were not available prior to 2009), giving six broad categories (only three prior to 2009). Annual discards were first matched to quarterly landings. Then, within each of these six categories, ignoring country and season, where métiers had some samples these were pooled and allocated to unsampled records within that métier; this was done only for the most important métiers (those with greater than 1% of the landings in Area IV, 2.5% in Area IIIaN, and 2.5–5% in Area VIId). At the end of this process, any remaining métiers were allocated an all samples pooled discard ratio for the given category. Because no discard sampling was available for Area VIId in 2002–2003, and only minimal age-sampling, Areas IV and VIId were combined.

A similar approach was used for allocating age compositions, except that there were 12 broad categories because discards were treated separately to landings. Appendix 2 of De Oliveira (WD6) provides a detailed summary of the InterCatch input data, both in terms of the importance of métiers by landed weight and the proportional coverage for age data and discard ratios. This information was used to help guide the raising procedure.

Table 3.6.1.1 indicates the level of discard ratio coverage of the landings, together with the age coverage of both the landings and observed discards (InterCatch data: 2002–2013). Coverage for discard ratios and ages has been good (at least 50%) for Areas IV and IIIaN, but poor for Area VIId prior to 2009. Table 3.6.1.2 provides a comparison of the overall tonnage used in the 2014 assessment (“old”) and that being calculated through the InterCatch raising procedure of this document following the 2014 data call (“new”). There are some large discrepancies, particularly for discards prior to 2011; as noted above, these discards have been estimated for the first time in InterCatch, which has allowed a greater sharing of information by métier, which may underlie the discrepancies observed. Prior to the use of InterCatch, any raising for discard ratio and age composition estimation was conducted at the area level, and did not take métier information into account. Table 3.6.1.3 provides a similar comparison by age, and Table 3.6.1.4 weights-at-age.

The InterCatch raising procedure is a laborious one for NS cod, each year taking anything from 1.5 to 4 hours to complete (depending on number of strata and difficulties encountered). Furthermore, it is currently not possible to save the discard ratio allocations (although age allocations can be saved); this, combined with the length of time for raising, makes simple sensitivity testing difficult to achieve in InterCatch. For example, because of the low sample coverage for Area VIId compare to the other areas prior to 2009 (the year the DCF came into effect), an alternative (perhaps more defensible) procedure may have been to combine Areas IV and VIId for all the years

2002–2008 (instead of only for 2002–2003). It is recommended that this be done for the forthcoming WG.

Table 3.6.1.1. Proportion of landings (as a percentage) taken in each of three areas (first block), together with (by area) discard ratio coverage of the landings (second block), age coverage of the landings (third block) and age coverage of the observed discards (fourth block). Shaded cells indicate where there has been less than 50% coverage.

	Landings proportions (%)			Discard ratio coverage			Landings age coverage			Discards age coverage		
	IV	IIIaN	VIId	IV	IIIaN	VIId	IV	IIIaN	VIId	IV	IIIaN	VIId
2002	81	13	6	50%	73%	0%	64%	83%	0%	88%	69%	0%
2003	80	13	7	57%	67%	0%	59%	93%	3%	88%	42%	0%
2004	82	14	4	54%	67%	6%	68%	93%	7%	81%	94%	100%
2005	81	14	4	58%	55%	5%	75%	91%	4%	81%	82%	100%
2006	82	13	6	75%	66%	6%	77%	91%	14%	85%	96%	100%
2007	79	12	9	58%	60%	5%	71%	90%	11%	99%	92%	100%
2008	81	13	6	65%	59%	10%	73%	89%	16%	95%	100%	100%
2009	83	11	6	57%	85%	81%	72%	95%	80%	97%	93%	100%
2010	84	11	5	70%	77%	81%	80%	95%	84%	100%	90%	100%
2011	83	12	4	69%	83%	74%	72%	95%	74%	97%	90%	100%
2012	83	13	4	66%	79%	76%	82%	88%	81%	95%	89%	100%
2013	83	14	3	77%	72%	78%	82%	85%	81%	91%	96%	100%

Table 3.6.1.2. Comparison of overall tonnage for the "old" and "new" estimates of catch, landings and discards. Differences are shaded such that darker colours highlight greater differences.

	Catch (t)				Landings (t)		
	old	new	dif		old	new	dif
2002	60571	64098	6%	2002	54865	52187	-5%
2003	37244	34274	-8%	2003	30872	30194	-2%
2004	34037	36402	7%	2004	28188	27457	-3%
2005	34980	38647	10%	2005	28708	28113	-2%
2006	34640	37991	10%	2006	26590	25815	-3%
2007	48069	55942	16%	2007	24433	24223	-1%
2008	48661	52646	8%	2008	26847	26679	-1%
2009	44775	54280	21%	2009	30753	33315	8%
2010	47162	49234	4%	2010	37180	36746	-1%
2011	42356	40829	-4%	2011	32871	31950	-3%
2012	41591	40934	-2%	2012	32799	32166	-2%
2013	41632	41354	-1%	2013	31092	30586	-2%

	Discards (t)		
	old	new	dif
2002	5706	11911	109%
2003	6372	4081	-36%
2004	5849	8945	53%
2005	6272	10535	68%
2006	8050	12176	51%
2007	23636	31720	34%
2008	21814	25967	19%
2009	14022	20965	50%
2010	9982	12488	25%
2011	9485	8879	-6%
2012	8792	8768	0%
2013	10540	10768	2%

Table 3.6.1.3. As in Table 3.6.1.2, but showing difference by age for (a) catch, (b) landings and (c) discard numbers. Shaded #DIV/0! indicates that former data were zero, but the update is non-zero (unshaded means they are both zero).

(a)	Catch numbers						
	1	2	3	4	5	6	7+
2002	49%	103%	12%	11%	8%	10%	17%
2003	-31%	-24%	-7%	15%	-14%	-1%	14%
2004	66%	40%	21%	-19%	-8%	1%	-28%
2005	-6%	20%	60%	11%	10%	-15%	13%
2006	0%	264%	18%	-8%	4%	13%	-4%
2007	21%	10%	23%	1%	16%	7%	-5%
2008	48%	3%	-5%	9%	-3%	18%	-19%
2009	10%	22%	31%	8%	11%	-3%	-15%
2010	6%	18%	3%	2%	3%	-17%	-24%
2011	-10%	-18%	6%	-6%	1%	-22%	-23%
2012	38%	11%	-2%	-4%	-3%	-1%	-3%
2013	1%	-1%	0%	0%	-4%	-3%	-2%

(b)	Landings numbers						
	1	2	3	4	5	6	7+
2002	-38%	2%	4%	11%	8%	10%	17%
2003	10%	-8%	1%	16%	-11%	2%	15%
2004	3%	-16%	9%	-25%	-8%	1%	-28%
2005	-26%	1%	3%	3%	-3%	-17%	10%
2006	-23%	-7%	-4%	-9%	6%	14%	-4%
2007	7%	-4%	-12%	-6%	18%	9%	-4%
2008	-32%	0%	-7%	4%	-2%	20%	-17%
2009	-16%	10%	3%	7%	9%	-3%	-18%
2010	24%	-3%	3%	1%	3%	-17%	-24%
2011	10%	-13%	6%	-6%	1%	-22%	-23%
2012	6%	-2%	-1%	-2%	-3%	-1%	-3%
2013	-14%	-4%	0%	0%	-4%	-4%	-3%

(c)	Discards numbers						
	1	2	3	4	5	6	7+
2002	96%	405%	61%	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
2003	-33%	-39%	-31%	-20%	-100%	-100%	-100%
2004	74%	89%	70%	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
2005	-3%	48%	1550%	677%	1361%	308%	#DIV/0!
2006	2%	504%	139%	-5%	-68%	-76%	34%
2007	22%	15%	80%	30%	9%	-2%	-22%
2008	53%	4%	-4%	44%	-37%	-21%	-97%
2009	12%	29%	85%	11%	49%	5%	12%
2010	4%	34%	5%	25%	36%	-31%	-91%
2011	-14%	-21%	9%	-15%	-44%	-46%	-12%
2012	40%	18%	-6%	-22%	-6%	-20%	-3%
2013	4%	1%	1%	0%	2%	2%	2%

Table 3.6.1.4. As in Table 3.6.1.3, but showing weights-at-age differences for (a) catch, (b) landings and (c) discard.

(a)	Catch weights						
	1	2	3	4	5	6	7+
2002	-35%	-38%	-8%	-3%	3%	0%	-1%
2003	3%	4%	7%	3%	13%	-8%	-1%
2004	-17%	-26%	2%	0%	0%	1%	2%
2005	4%	-3%	-21%	-3%	2%	-4%	-2%
2006	21%	-66%	-8%	6%	1%	5%	3%
2007	25%	6%	-8%	-1%	9%	1%	4%
2008	42%	5%	0%	2%	9%	3%	3%
2009	4%	10%	1%	1%	2%	0%	12%
2010	14%	-6%	-1%	0%	0%	8%	6%
2011	19%	9%	0%	5%	4%	2%	-2%
2012	-14%	-11%	-1%	0%	1%	0%	0%
2013	0%	1%	-1%	-1%	0%	1%	1%

(b)	Landings weights						
	1	2	3	4	5	6	7+
2002	-17%	-8%	-4%	-3%	3%	0%	-1%
2003	-6%	-8%	2%	3%	11%	-9%	-1%
2004	10%	9%	6%	6%	0%	1%	2%
2005	-6%	-1%	-1%	0%	4%	-4%	-1%
2006	14%	10%	2%	4%	0%	5%	3%
2007	8%	6%	1%	0%	9%	1%	3%
2008	43%	-1%	-1%	1%	8%	3%	0%
2009	10%	6%	0%	1%	2%	0%	12%
2010	-11%	0%	-2%	0%	0%	8%	6%
2011	19%	2%	0%	5%	4%	2%	-2%
2012	3%	-1%	0%	0%	0%	0%	0%
2013	13%	2%	-1%	-1%	0%	1%	1%

(c)	Discard weights						
	1	2	3	4	5	6	7+
2002	-17%	-25%	21%	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
2003	1%	0%	-8%	-22%	-100%	-100%	-100%
2004	-17%	-30%	61%	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
2005	13%	21%	-25%	-45%	-5%	-21%	#DIV/0!
2006	29%	-72%	10%	96%	46%	17%	2%
2007	32%	8%	-10%	-5%	7%	5%	60%
2008	50%	10%	2%	23%	87%	16%	289%
2009	5%	17%	19%	4%	-3%	7%	0%
2010	20%	-6%	3%	-1%	-2%	58%	-6%
2011	7%	14%	3%	-1%	-2%	-10%	-15%
2012	-14%	-14%	-6%	-3%	6%	-2%	-1%
2013	0%	2%	1%	-1%	0%	0%	1%

3.6.2 Surveys

The last benchmark of North Sea Cod resulted in the exclusion of the IBTS quarter 3 survey index, because divergent trends in recent years were observed when the Q3 index was applied independently of the Q1 index (ICES-WKCOD 2011). At that time it was decided that until the reasons for the discrepancies were resolved, the Q1 was more likely to reflect the stock, and hence the Q3 index was dropped from the assessment. The indices were calculated using the standard stratified mean methodology (mean by rectangle within year, followed by mean over rectangles by year). This simple design based estimator is unable to account for systematic changes in experimental conditions (e.g. change of survey gear).

This section describes an alternative way of calculating standardized age-based survey indices based on GAMs and Delta distributions (see also Berg, WD3). The general methodology is described in Berg and Kristensen (2012) and Berg *et al.* (2014) and is implemented in R based on the DATRAS package (http://rforge.net/DATRAS/).

ALKs

Smooth spatially varying age–length keys are estimated using the methodology described in Berg and Kristensen (2012). Numbers-at-age are then calculated using the observed numbers-at-length and the estimated ALKs. This methodology was found to give higher internal consistencies in survey indices for haddock when compared to the current standard approach of estimating ALKs that are constant within ``Roundfish'' (RF) areas. It avoids *ad hoc* borrowing of samples from neighbour RF areas, when certain age groups are missing, and it provides an objective fill-in procedure for missing length groups also. This is possible because the probability of age given length is modelled using smooth functions of the length of a fish and the spatial coordinates where the haul was taken, rather than relying on some specific stratification of length and space. The methodology has been implemented in the DATRAS package with full source code available.

The differences between the standard ALKs and the ones used here were not investigated in detail by the WG, but comparisons of the survey indices calculated using the smooth ALKs and the stratified mean method with the standard DATRAS product survey indices displayed little differences, indicating that the choice of ALK method is not crucial for cod. Figure 3.2.1.1 provides a comparison of within-survey correlations for the previously-used ICES extended indices (ICES-WGNSSK 2014) and the GAM indices used in the final SAM model presented here (Section 3.6.4.3), and shows a higher internal consistency for the GAM indices apart from the oldest age for each survey. Figure 3.2.1.2 provides a comparison of between-survey correlations for each set of indices, and indicates a greater consistency between the GAM indices compared to the ICES indices.

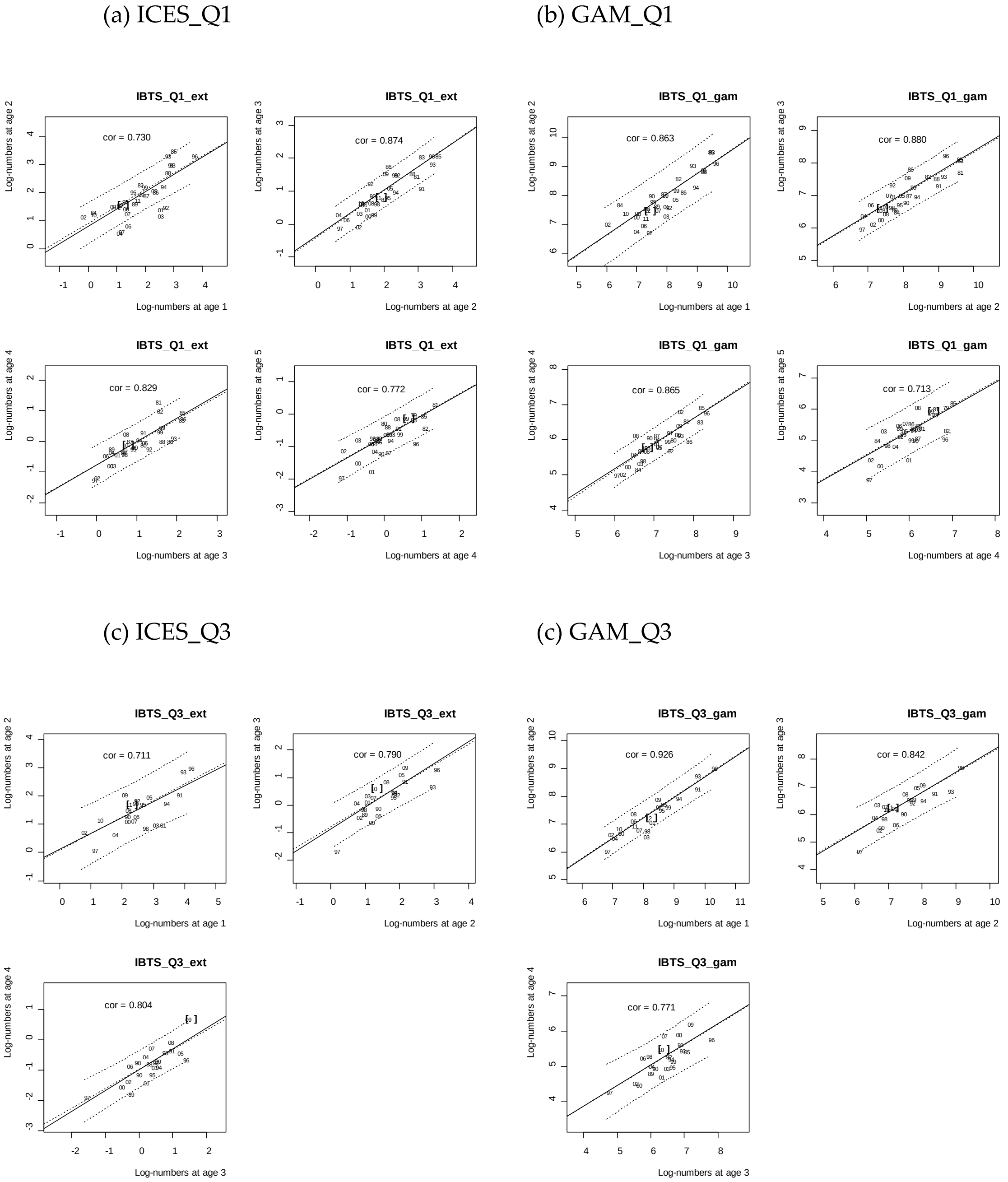


Figure 3.2.1.1. Within-survey correlations for: (a) ICES Q1, (b) GAM Q1, (c) ICES Q3 and (d) GAM Q3 survey indices (the ICES indices being the extended ones used in the 2014 assessment, and the GAM indices being the ones used in the final WKNSEA 2015 assessment model). Individual points are given by cohort (year class), the solid line is a standard linear regression line, the broken line nearest to it a robust linear regression line, and "cor" denotes the correlation coefficient. The pair of broken lines on either side of the solid line indicate prediction intervals. The most recent datapoint appears in square brackets.

(a) ICES Q1 and Q3 survey indices (b) Delta-GAM Q1 and Q3 survey indices

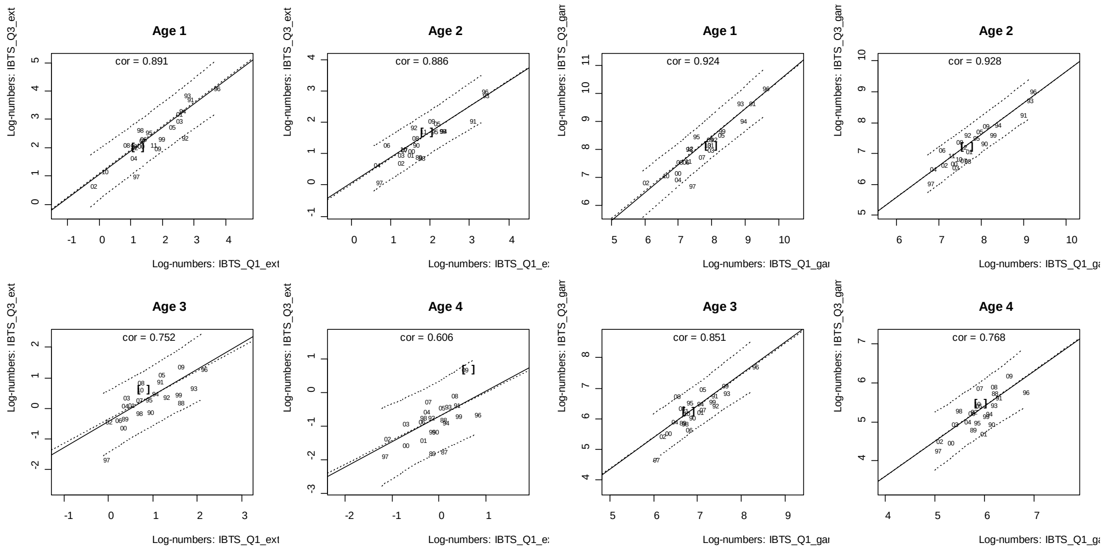


Figure 3.2.1.2. Between-survey correlations for (a) the ICES Q1 and Q3 and the (b) GAM Q1 and Q3 survey indices (the ICES indices being the extended ones used in the 2014 assessment, and the GAM indices being the ones used in the final WKNSEA 2015 assessment model). Individual points are given by cohort (year class), the solid line is a standard linear regression line, and the broken line nearest to it a robust linear regression line. The pair of broken lines on either side of the solid line indicate prediction intervals. The most recent data appear in square brackets.

Delta-GAM models

The primary purpose of the Delta-GAM model is to derive survey indices by age free of nuisance factors caused by changes in experimental conditions. The indices are obtained by summing filtered model predictions over a spatial grid. The model presented is able to account for changes in experimental conditions such as different gears, ship/country effects, day/night effects, and change in spatial coverage. Such effects may be balanced out by the relatively stable survey design in the later years; however, several changes in the gear used, proportion of night hauls, haul duration, etc. have occurred for most surveys during the entire time-series.

Each age group and quarter is modelled independently. The most complex equation considered for the expected numbers-at-age in the *i*th haul (or probability of non-zero catch for the presence-absence part), μ_i, is as follows:

$$g(\mu_i) = Year(i) + Gear(i) + U(i)_{ship} + f_1(Year_i, lon_i, lat_i) + f_2(depth_i) + f_3(time_i) + \log(HaulDur_i)$$

where the two first terms are categorical effects for year and gear type, *U* is a random vessel effect, f_1 is a three-dimensional tensor product spline (a 2D thin-plate spline basis for space and a 1D cubic spline for time), f_2 is a one-dimensional thin plate spline for the effect of bottom depth, and f_3 is a cyclic cubic regression spline on the time of day (i.e. with same start and end point).

The function *g* is the link function, which is taken to be the logit function for the binomial model. The strictly positive observations can be modelled using either a Gamma or a log-normal distribution, and a Gamma distribution was found to provide the best fit. The Gamma part of the delta-Gamma model is fitted with a log-link. The nuisance parts of the model (here gear, ship, time of day, and haul duration) are held constant when the filtered predictions on the grid are calculated so as to remove their effect on the index.

Model selection and Q1/Q3 discrepancies

Model selection can be based on likelihood ratio tests or information criteria such as AIC. This may not be the best way, however, because these are conditional on the model being correct, and the spatio-temporal smoother (which is not to be "standardized out") can be highly correlated with other variables that are clustered in space and/or time such as the vessel effects (which *are* to be "standardized out"). Overfitting may thus be an issue, and model selection should be based on additional criteria such as internal/external consistencies and/or based on diagnostics from the stock assessment model. Since criteria based on the stock assessment model are based on all surveys as well as commercial data and how well these fit together, whereas AIC applies to one survey only, the two may not point towards the same model, and overfitting could be an issue if AIC points towards a more complex model than the other criteria.

Another way to look at this problem is as a bias-variance trade-off: the simpler models will have less variance at the expense of some bias, i.e. assuming a stationary spatial effect will give a little bias since the spatial distribution at-age is probably not truly equal between years, but the estimates of the change in distribution over time may be so uncertain and confounded with changes in sampling positions and vessel effects that they are better left out of the model.

Ten possible models of varying complexity were considered (see Table 3.6.2.1). An important choice here is whether a 3D space-time smoother is necessary (lon, lat, time) as in models 7–10, or the spatial distribution can be considered stationary over the whole time-series (lon, lat) as in models 2–6.

The best model for the Q1 data included the space–time interaction (model 8), whereas in Q3 the stationary model seemed most appropriate (models 5 or 6) [note, the stationary model was second best for Q1 with only a slightly higher AIC]. All Delta-GAM models except the very simple year-effect only model (model 1) had better consistencies than the standard stratified mean approach, which is similar to the currently used index produced by DATRAS.

Table 3.6.2.1. Model selection criteria: Akaike's Information Criteria (AIC), average Internal Consistency over all ages (IC), average External Consistency (EC) between Q1 and Q3 (age a vs. a, EC1), EC for Q3 age a vs. Q1 age a+1 (EC2), and average over all consistencies (Avg C). Best values are in green. The asterisk indicates a model with a larger basis dimension for the space–time smoother (test for oversmoothing). All Q3 models contain a gear effect also, and all models include the haul duration offset.

Model	AIC Q1	AIC Q3	ICQ1	ICQ3	EC1	EC2	Avg C
Y	228989	118557	0.801	0.706	0.664	0.777	0.737
Y+s(lon,lat)	204315	96459	0.834	0.800	0.799	0.861	0.823
Y+(lon,lat)+Depth	202943	94357	0.835	0.801	0.790	0.857	0.821
Y+(lon,lat)+Ship	202600	96088	0.831	0.803	0.818	0.863	0.829
Y+(lon,lat)+Depth +Ship	201171	93964	0.832	0.804	0.811	0.856	0.826
Y+(lon,lat)+Depth +Ship+Time	200919	93868	0.837	0.804	0.809	0.857	0.827
Y+(lon,lat,t)	203992	98081	0.830	0.785	0.751	0.841	0.802
Y+(lon,lat,t)*	200752	95985	0.835	0.787	0.750	0.852	0.806
Y+(lon,lat,t) +Depth+Ship+Time	201346	95031	0.851	0.795	0.779	0.853	0.820
Y+(lon,lat,t) +Depth+Time	202946	95337	0.852	0.800	0.729	0.835	0.804
Strat.Mean	–	–	0.824	0.715	0.733	0.807	0.770

The model selection criteria are not pointing towards a single model as being the best for both quarters or all age groups, so the residuals and performance of the stock assessment model should be considered also. For simplicity the same model structure was used in both quarters and for all age groups, although the model is not limited to this.

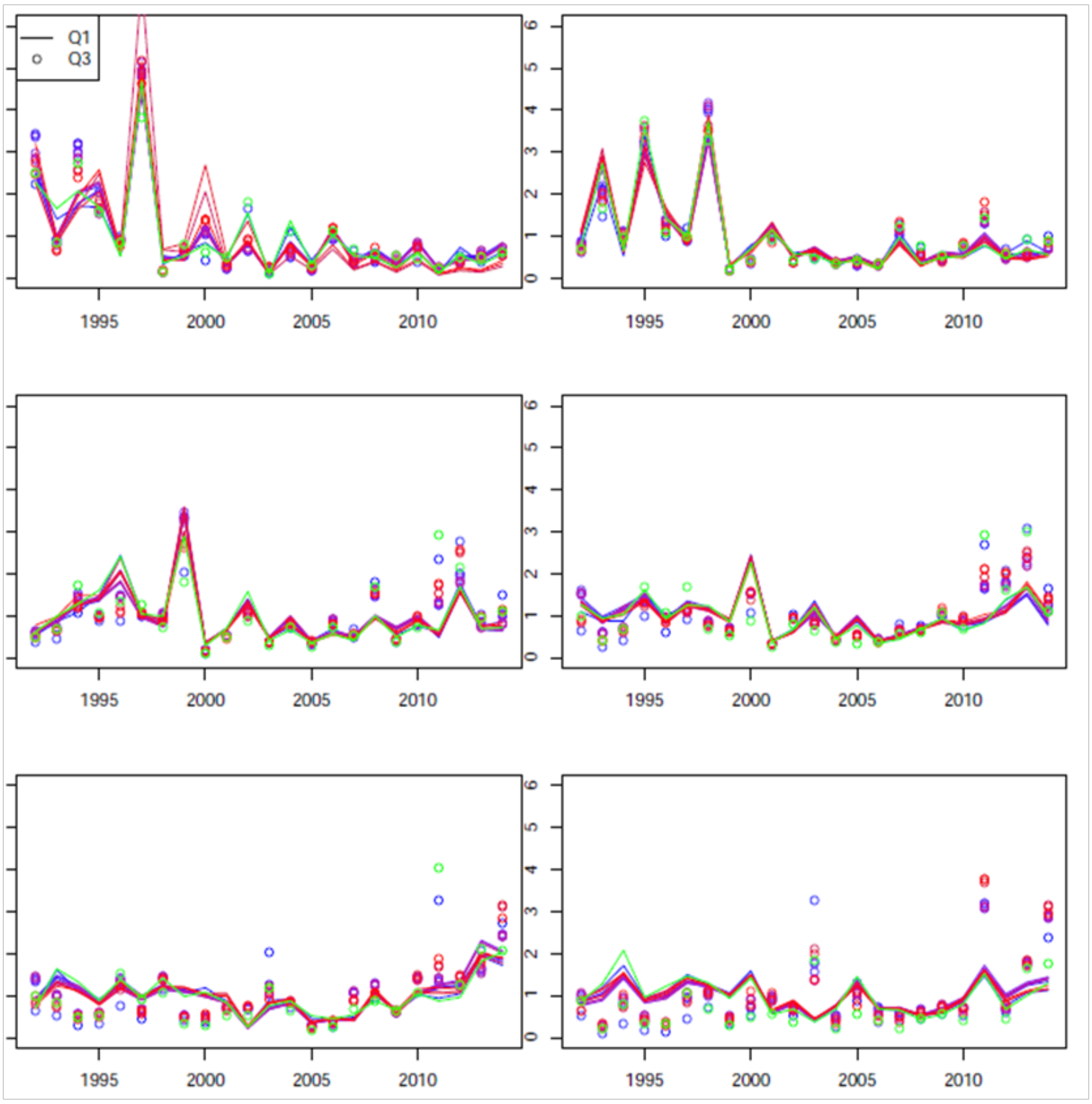


Figure 3.6.2.3. Scaled indices (divided by their mean) by age (row 1 contains ages 1 and 2, etc) in both quarters. Delta-GAM models are plotted using gradual (blue, purple, red) colours for increasing complexity (models 1—9), whereas green colours correspond to the stratified mean method. Note that except for the simplest model (blue), the effect of using different models is small for Q1 but for Q3 it is more pronounced. Note also the Q1/Q3 discrepancies in 2011–2014 and the spread of Q3 model estimated in these years.

Figure 3.6.2.3 indicates the effect of model choice on the resulting survey indices. The Q1 index appears quite robust to model choice, whereas the Q3 index is more sensitive, in particular the Q3 indices for the years 2011–2014 appear sensitive to model choice in addition to being larger relative to Q1. The 2011–2014 discrepancies coincide with the replacement of the "ARG" vessel with the "DANS" vessel in Skagerrak, as well as a change to a more randomized set of haul positions in Q3, but not in Q1 (see Figure 3.6.2.4).

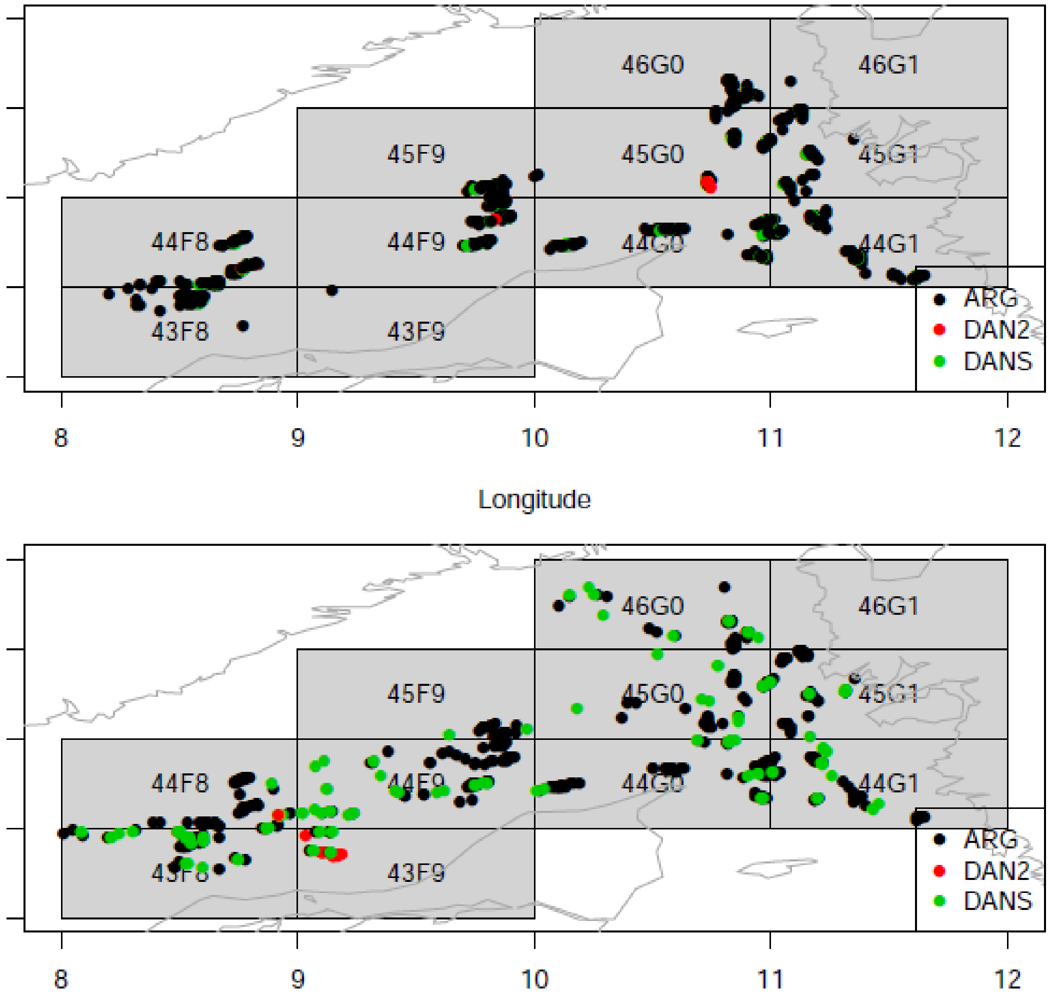


Figure 3.6.2.4. Haul positions in Skagerrak coloured by ship in Q1 (top) and Q3 (bottom).

Indeed, the Q1/Q3 discrepancies in that period disappear if Skagerrak is left out of the index area (Figure 3.6.2.5, but see also Figure 3.6.2.7). Another way to get rid of the residual patterns is to use the Delta-GAM model that includes a ship effect, but uses a stationary spatial effect rather than the time-varying one (best model in Q3 based on AIC anyhow). In the stationary model, the large catches observed by the "DANS" vessel in Skagerrak compared to the "ARG" vessel is explained by the ship effect, whereas they are attributed to space–time effect in the other model (see Figure 3.6.2.6). This confounding arises because only Sweden is covering the Skagerrak, so it is difficult to separate the effect of changing both the vessel and the sampling positions in Q3 from an increase in abundance. It must be recommended that other vessels in addition to "DANS" should sample in Skagerrak, and/or "DANS" should sample in the North Sea as well in order to ensure sufficient spatio-temporal overlap such that vessel effects may be estimated more reliably.

One other potential source of the Q1/Q3 discrepancies was investigated, namely migrations between the North Sea and Area VIa. This was investigated by combining the NS-IBTS survey with the SWC-IBTS survey to include a major part of VIa in an alternative index, and was motivated by the high abundances observed right at the border between IVa and VIa. The analysis showed that the VIa abundance has increased much more than the North Sea in the later years (possibly due to migrations) but that the differences between the alternative and the original index were relatively small, so this effect seems negligible.

The working group decided to recommend the Delta-GAM model with the stationary spatial effect and including the ship effect in both quarters. This decision was based on a combined assessment of the residuals (Figures 3.6.2.7) and variances from the SAM model as well as of the criteria presented in Table 3.6.2.1. The ability of the model-based approach to account for changes in survey design is also a major benefit compared to the current stratified mean approach. A good example of this is the expansion of the NS-IBTS survey to cover the channel (VIId) in the later years (missing squares in some years are not accounted for by the stratified mean method). Finally, the improved consistencies found both here and in Berg *et al.* (2014) for other species indicate that this methodology yields better indices.

However, the working group recommends that the model specification of the Delta-GAMs should be re-evaluated once more samples have been collected by the "DANS" vessel. Also, as recommended by IBTSWG and WGISDAA, swept area should be used to standardize instead of haul duration to remove possible bias from different riggings or gear specifications, but data on swept-area were not available at the time.

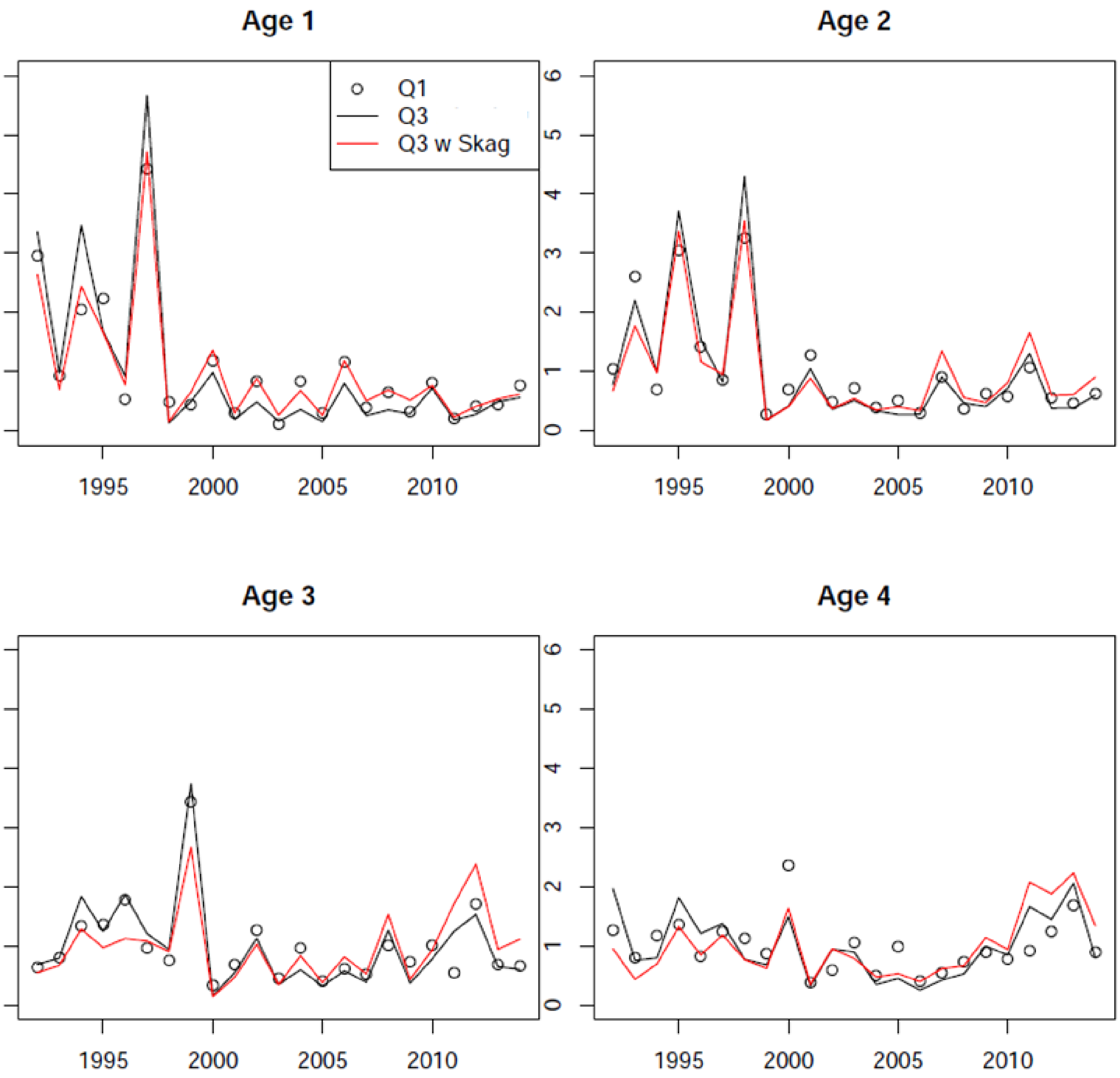


Figure 3.6.2.5. Effect of including/excluding Skagerrak in the index area. Black lines/dots are computed without Skagerrak.

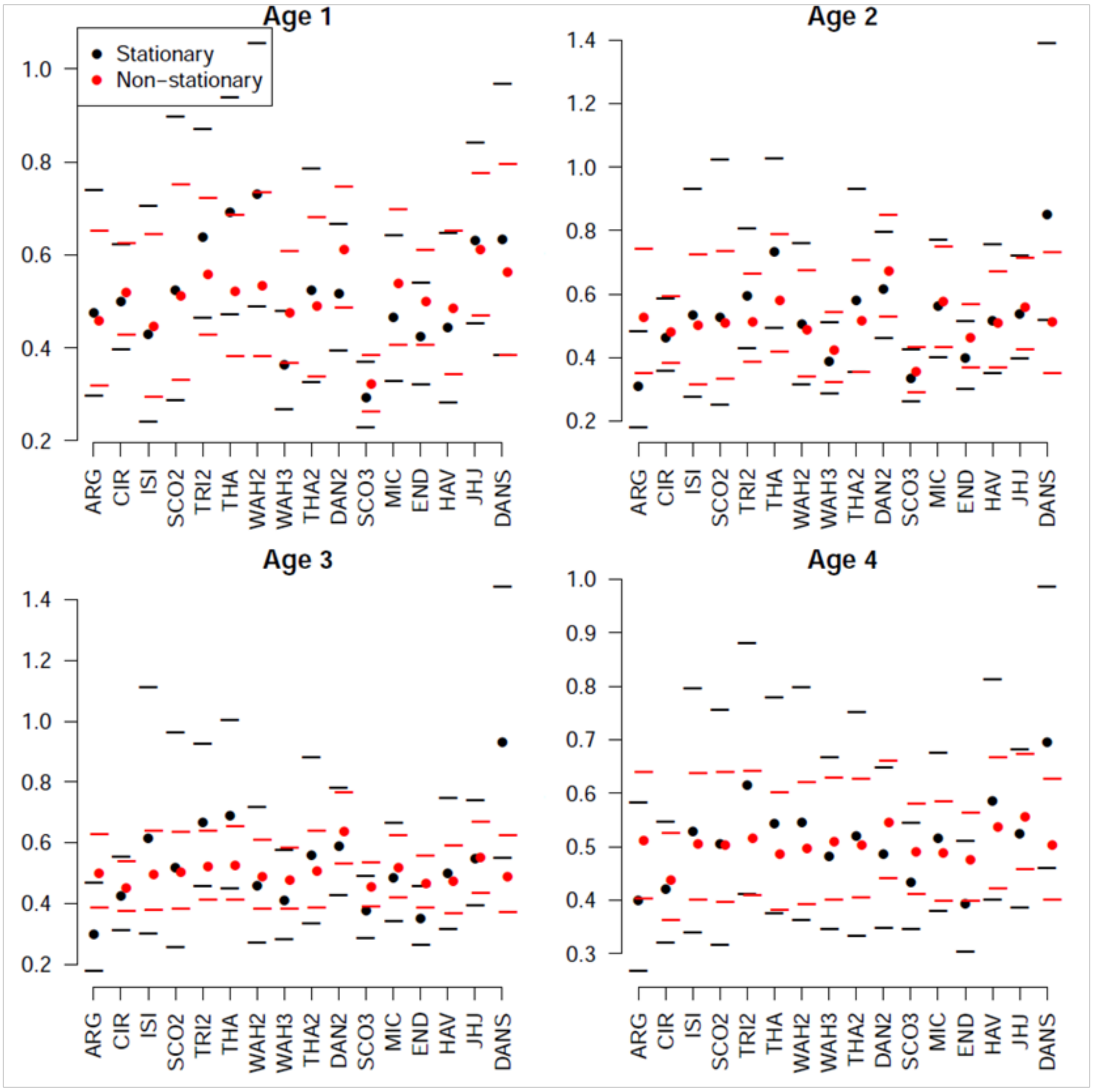
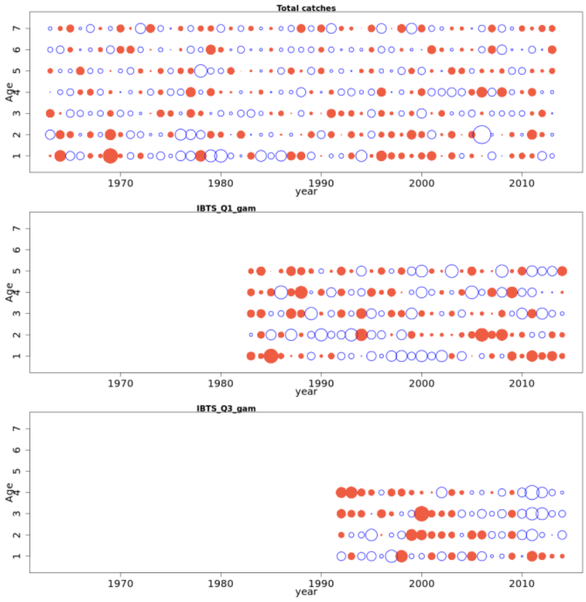


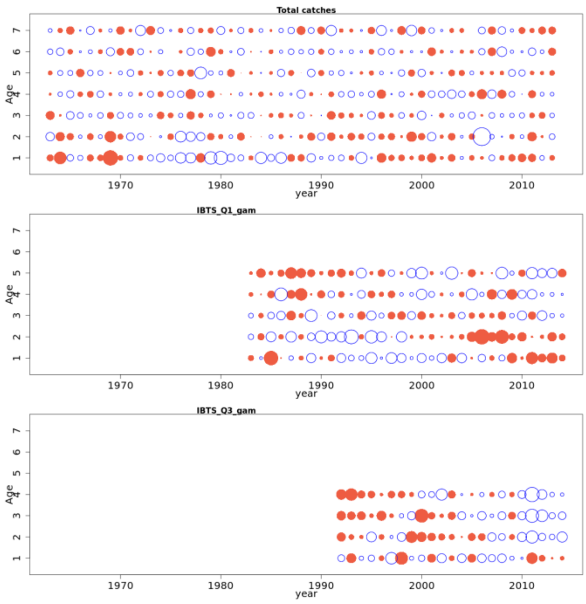
Figure 3.6.2.6. Estimated relative ship effects by age in Q3 by two different Delta-GAMs: one with a stationary spatial effect (black) and a time-varying spatial effect (red). Note the differences between the "ARG" and "DANS" vessels between models.

(a) stationary Delta GAM with ship effect

(b) non-stationary Delta-GAM with no ship effect



(c) non-stationary Delta-GAM with ship effect



(d) same as (c) but excluding the Skagerrak from Q3

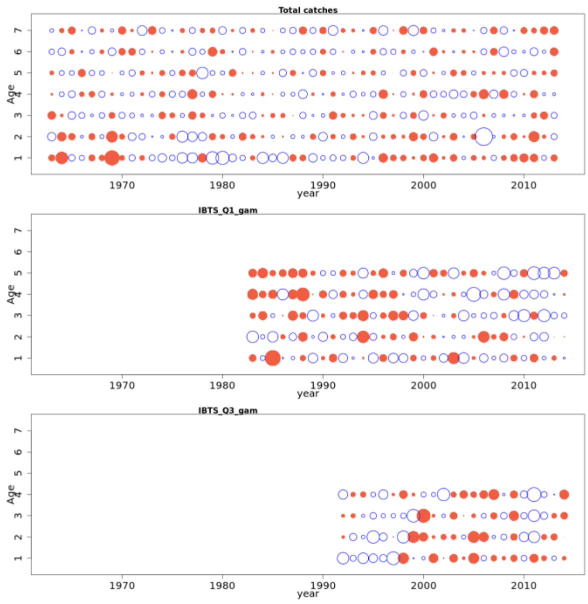


Figure 3.6.2.7. SAM residuals using: (a) stationary Delta-GAMs with ship effects (final model, filed as "nscod2015-base6" on stockassessment.org), (b) Delta-GAMs with space-time interaction but without ship effects ("nscod2015-base3-nonstat-noship"), (c) Delta-GAMs with both space–time interaction and ship effects ("nscod2015-base-Q1Q3gam"), and (d) same as (c) but excluding the Skagerrak from the Q3 survey ("nscod2015-base-Q1Q3gam-Q3noSkag").

3.6.3 Weights, maturity, growth, natural mortality

3.6.3.1 Weights and growth

Currently, weights-at-age in the stock are set equal to weights-at-age in the catch, and there was some discussion about whether weights-at-age in the stock should be derived from the NS-IBTS Q1 survey data (see Berg, WD3). Figure 3.6.3.1.1 compares the currently-used stock weights (same as catch weights derived from the whole year) with stock weights derived from the NS-IBTS Q1 survey using the Berg (WD3) methodology; this indicates that the survey weights are lower than the catch weights for ages 1–3, are similar for ages 4 and 5, but are larger for ages 6 and above. There are several issues with using the survey weights:

- the older ages are poorly sampled compared to the catch;
- no estimates are available prior to 1983, so an assumption of constant growth has to be made.

There was some discussion about whether to have a hybrid matrix with the Q1 survey providing weights for the younger ages (say 1–4) and the catch providing weights for the older ages (5+), but this would represent an inconstant time-series and it was decided to continue with the current catch weights as stock weights.

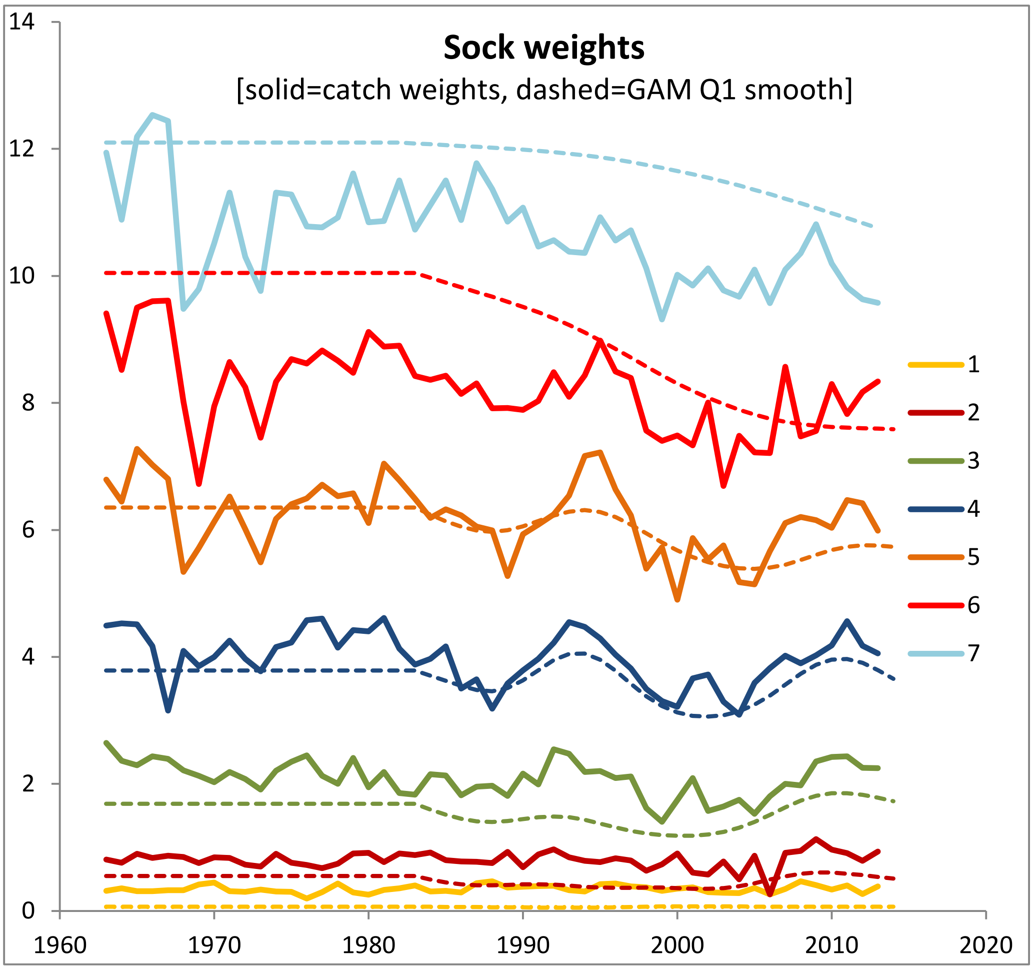


Figure 3.6.3.1.1. Currently-used stock weights (=catch weights) given as solid lines, compared to the stock weights derived from the NS-IBTS Q1 survey using the methodology of Berg (WD3), assuming that weights prior to 1983 are constant at the 1983 value.

3.6.3.2 Maturity

Maturity–age key

Maturity-at-age has changed in the North Sea stock with a positive trend over time (Cook *et al*., 1999; Yoneda and Wright, 2004). There are also substantial population level differences in maturation change, with no significant change in maturation probability in the northeast 'Viking' population since the 1970s but substantial increases in the northwest and southern North Sea (Wright *et al*., 2011; see Wright, WD5). Therefore, a maturity–age key was constructed for the assessment region that was weighted by population subarea. Records were extracted from the DATRAS Q1 exchange (CA) data that could be assigned to ICES rectangle. As subarea coverage was incomplete and sample size by age was often <10 individuals per area before 1978, only SMALK data from that year onwards were used to estimate year-specific maturity-at-age. Further, due to low sample sizes, only cod <6 years old were considered. Data for Skagerrak were only available after 1991 and so this region was not used in the construction of the maturity–age key. Proportion mature was derived from the numbers of individuals at each year (y), age (a) and population subarea (p) that were not immature. No account was made of any length stratified subsampling for maturity, although as mature cod are uncommon in catches most were sampled for maturity staging, and the length composition of SMALK samples tended to reflect the length–frequency composition of samples. In total 57 937 individual records were available, with 17 036 from Viking, 25 736 from the South and 15 165 from the Northwest.

Proportion mature at-age by year was estimated from:

$$M_{a,y} = \frac{\sum(N_{a,y,p} \,.\, M_{a,y,p})}{N_{a,y}}$$

Where *N* is the numbers of cod. Catch per hour for each subarea was calculated from numbers-at-age by haul from the Q1 survey, $n_{a,y}$, according to the procedure of Holmes *et al.* (2014; see also Eero *et al*., WD3), and was raised according to:

$$N_{a,y,p} = \frac{A_p}{A_s} \,.\, n_{a,y,p}$$

Where A_p is the area (km^2) of a population subarea (NW: 209 822 km^2; S: 732 104 km^2 and V: 233 372 km^2) and A_s is the swept area of the GOV, which is assumed constant and equal to the mid-range value estimated by Reid *et al*. (2000), which was 0.065 km^2. This gave an estimate of the number-at-age per year and population to weight maturity across the stock.

The new maturity–age key is shown in Figure 3.6.3.2.1. Whilst the maturity-at-age was similar to the fixed ogive currently used in assessments up until the mid-1980s the proportion mature at-age has since increased such that cod are generally maturing a year earlier than they used to. Although there are clear positive trends, there is also high inter-annual variability in maturity-at-age. Investigations of maturation reaction norms suggest that a temperature effect on gonad maturation is one source of this variability (Wright *et al*., 2011). Differences in size composition at-age will also influence this variation, since maturity is correlated with size. Finally, sampling intensity varied between years particularly when cod were scarce in the surveys and this will have added uncertainty to the estimates. The maturity ogives were smoothed because of the high inter-annual variability with the following code using the mgcv R package (degrees of freedom used for the spline smoother were selected automatically):

```
skipYears=1:10
columnsToSmooth=1:5
mo=prop.mature[-c(skipYears),]

for(cc in columnsToSmooth){
    ww = mo[,cc];
    tt = 1:length(ww)
    tmp = gam(ww ~ s(tt))
    mo[,cc] = predict(tmp);
}
prop.mature[-c(skipYears),]=mo
```

The workshop agreed that the estimation of maturity-at-age required further attention to consider the base approach for weighting subarea differences in maturity-at-age and the importance of sampling intensity to the inter-annual variation in maturity estimates.

Reproductive potential

The use of spawning–stock biomass as a measure of reproductive capacity has the implicit assumption that the eggs per adult biomass remain constant, i.e. there is no age or size related difference in relative fecundity (eggs.g^{-1}.body mass). However, the relative fecundity of cod does vary with age. For example in 2002–2003, five year old females from the northwest North Sea were found to have 1.36 and 1.14 times the relative fecundity of a three and four year old female, respectively (Yoneda and Wright, 2004). That study also found differences in the relative fecundity between the Viking and northwest subareas, with the latter having on average a 37% greater relative fecundity compared to the former. Fecundity–size relationships for the NW subarea were also found to have changed between the late 1960s and early 2000s. However, as such relationships are not routinely measured, there is no time-series available to provide robust estimates of annual total egg production.

When available, estimates of fecundity have been used to infer trends in stock egg production and survival between egg and age 1; there does appear to be a negative trend in North Sea cod survival since the mid-1980s (Wright, 2014). In addition there is a positive correlation between spawner mean age and survival (Wright, 2014; WD5), which might indicate that the offspring of younger individuals have a lower probability of survival. Possible reasons for an effect of spawner age on reproductive success include maternal effects on larval viability (Marteinsdóttir and Steinarsson, 1998) and/or the potential for a mismatch between spawning and optimal conditions for larval survival (Wright and Trippel, 2009), as there are age-related differences in the onset of North Sea cod spawning (Morgan *et al*., 2013). However, further work is needed to explore whether there is any causal significance of spawner age, accounting for the other factors influencing early survival rate such as predation pressure and the effects of warming before this metric can be considered as a measure of reproductive potential.

Concern was expressed at the workshop that accounting for the increase in maturity-at-age may give the impression that the spawning stock is in a better condition than it actually is. This is because there was age truncation in the spawning stock in the 1990s (Wright, 2014) and the stock is still recovering. The lower fecundity of younger age groups and the potential for a maternal age effect on survival, as found in North Sea haddock (Wright and Gibb, 2005), supports such concern and so it is important for managers to recognise that age structure of spawners may also be important to consider in the recovery of this stock and similar collapsed stocks.

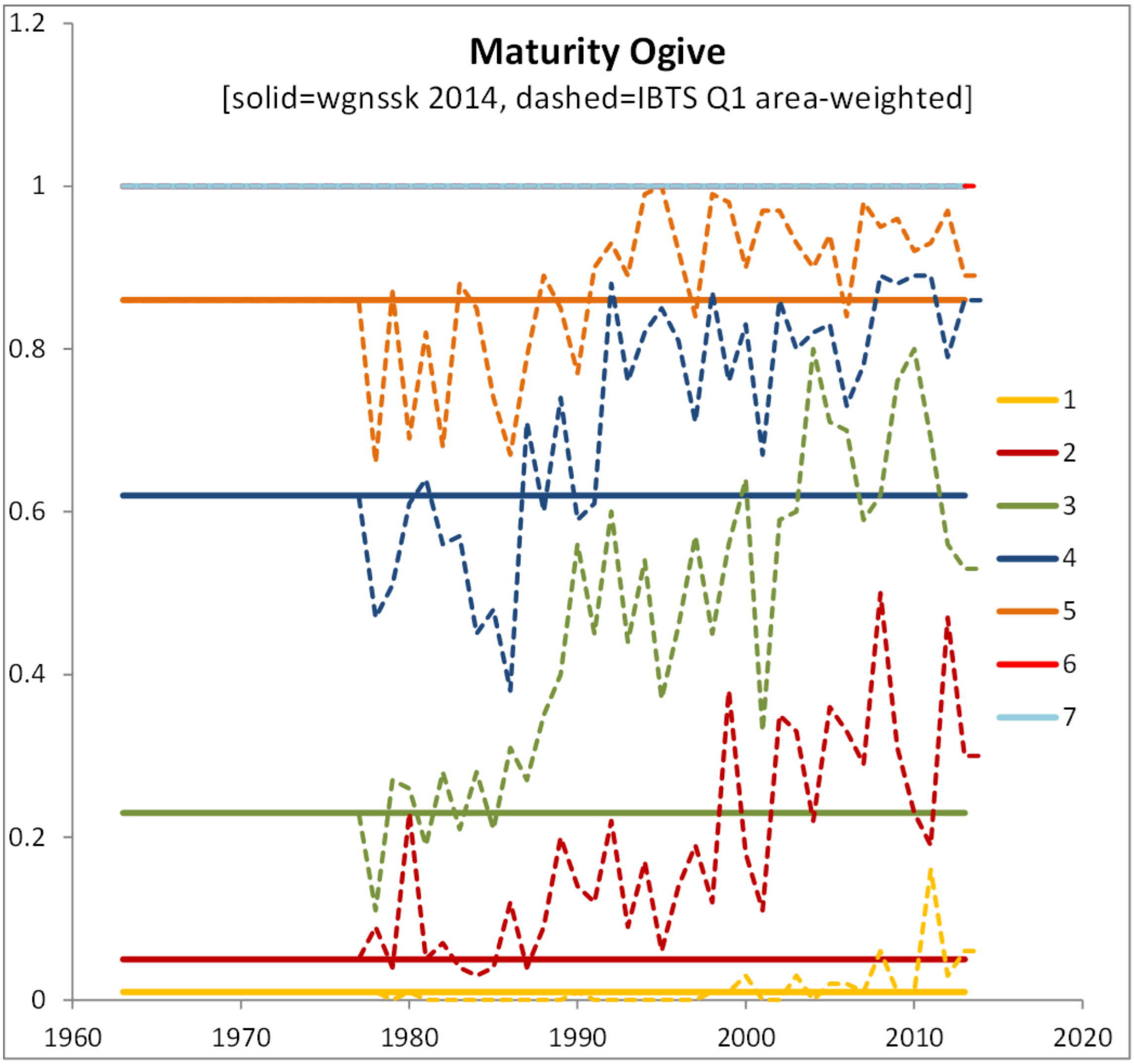


Figure 3.6.3.2.1. Annual variability in maturity-at-age in North Sea cod (dashed lines). Fixed maturity-at-age used in previous assessments (vertical solid lines) are given for comparison.

3.6.3.3 Natural mortality

Multi-species assessment Key run 2014

Since the benchmark in 2009 (ICES-WKROUND 2009) variable natural mortality estimates are used in the assessment for North Sea cod. An update of natural mortality estimates is produced by the Working Group on Multi-Species Stock Assessment Methods (WGSAM) every three years in so called key runs with the stochastic multi species model SMS. The model SMS (Lewy and Vinther, 2004) is a stock assessment model including biological interaction estimated from a parameterised size-dependent food selection function. The model is formulated and fitted to observations of total catches, survey cpue and stomach contents for the North Sea. Parameters are estimated by maximum likelihood and the variance/covariance matrix is obtained from the Hessian matrix.

In the present SMS analysis the following predator and prey stocks were available: predators and prey (cod, whiting, haddock), prey only (herring, sprat, northern and southern sandeel, Norway pout), predator only (saithe), no predator–prey interactions (sole and plaice) and 'external predators' (eight seabirds, starry ray, grey gurnard, western mackerel, North Sea mackerel, North Sea horse-mackerel, western horse-mackerel, grey seals, harbour porpoise and hake). The population dynamics of all species except 'external predators' were estimated within the model.

A working document (Kempf, WD4) was provided to WKNSEA describing the newest key run 2014 (ICES-WGSAM 2014) with focus on natural mortality estimates for cod. In general, the key run in 2014 is an update of the 2011 key run. But compared to the 2011 key run, the time-series of grey gurnard and raja abundances were revised, sandeel was split into a southern and northern component and hake was included as additional other predator in the model (but no cod was found in the available hake stomachs). In addition, the start year was changed from 1963 to 1974 because, for the early years, data on forage fish are highly uncertain.

Overall, the changes in estimated predation mortalities for cod were small between both key runs. However, a further change in the key run settings occurred after the WGSAM meeting. For age 3 cod a sudden jump in predation mortalities appeared in the original key run (Figure 3.6.3.3.1). This was caused by harbour porpoise which starts to prey on age 3 cod in the 1st quarter from 1998 onwards. The reason behind this is that the mean weight-at-age in the sea in the SMS input data are lower after 1998. Therefore, it just falls below the highest observed mean weight in harbour porpoise stomachs and harbour porpoise starts to prey on age 3 cod in the model. However, after 1999 no mean weight-at-age in the sea per quarter was available from WGNSSK and fixed values were used as input constant from 2000 onwards. In addition, the estimated mortality of cod eaten by harbour porpoise might be biased. A preliminary study of the effect of differences in digestion rate of different sizes of otoliths in harbour porpoise stomach content was presented to the group and demonstrated that the consumption of large fish may be overestimated, if diet is estimated directly from the presence of otholith in the stomach. ICES-WGSAM (2014) considered that this may potentially have a considerable impact on the estimated consumption of harbour porpoise and that the estimation of correction rates applicable to North Sea harbour porpoises should be a priority area of study before the next key run is conducted. However, as no quantitative correction factors were available to the group, no correction could be made during the WGSAM meeting. Therefore, it was suggested to take the alternative run as basis for the North Sea cod assessment because it is more consistent over time and more conservative by reducing the predation impact on large cod. The general trends stay the same as in the original key run (Figure 3.6.3.3.1 vs. Figure 3.6.3.3.2), only the absolute level of M2 values is different.

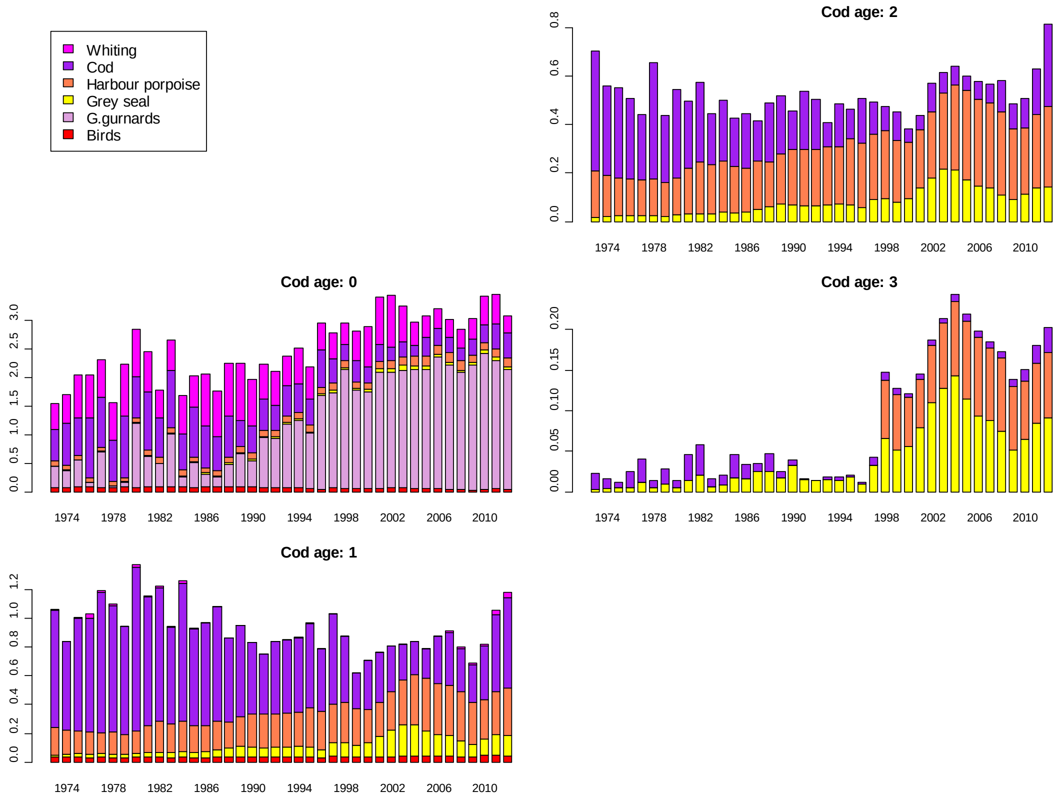


Figure 3.6.3.3.1. Partial predation mortalities over time estimated with the original 2014 key run.

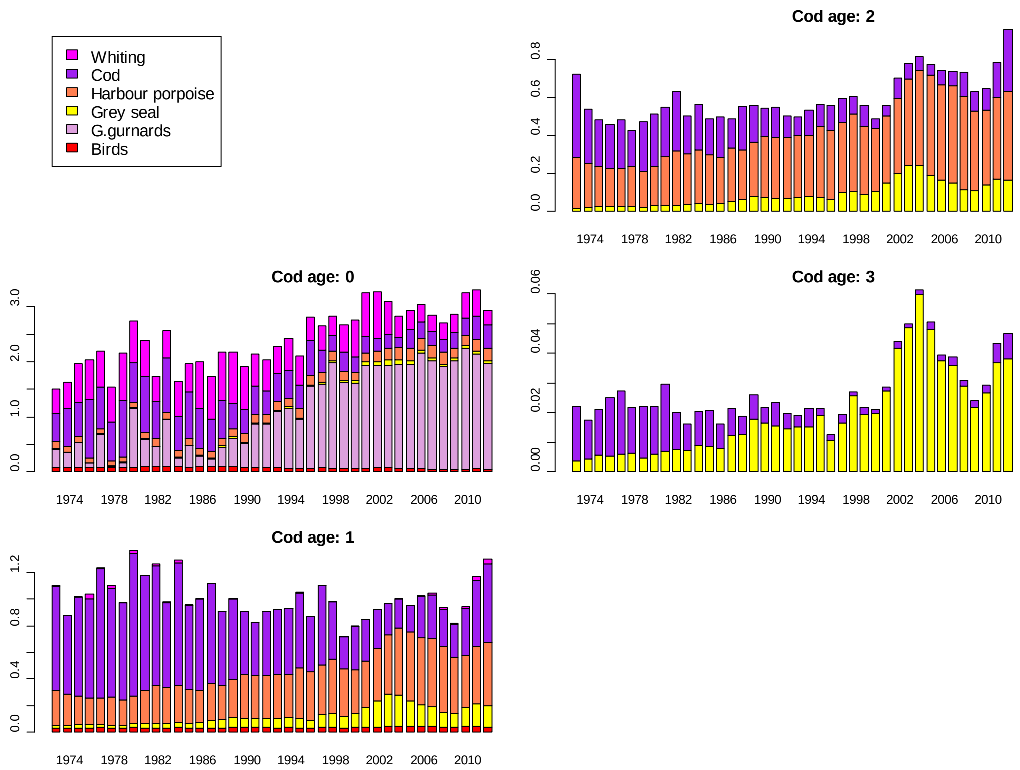


Figure 3.6.3.3.2.Partial predation mortalities over time estimated with the alternative key run 2014.

Sensitivity analyses

In the working document (Kempf, WD4) the driving factors behind the predicted changes in estimated predation mortalities over time were tried to be explained with a simple process understanding. Next to this, the assumptions behind the current relatively simple diet selection submodel were challenged. This was done by analyzing simple relationships between partial predation mortalities and the biomass of predators as well as trends in spatial predator-prey overlap between juvenile and adult cod of different age classes (diet selection submodel assumes a constant overlap in time). Also the observed and predicted predator–prey weight ratios were compared and the assumption of a uniform size selection inside an observed predator/prey weight ratio was questioned. Last but not least the sensitivity towards different stomach input data and associated changes in the importance of "Other Food" (1981 vs. 1991 stomach dataset) was already tested with the key run from 2011 but results are repeated here.

It could be concluded that the general trends over time in estimated predation mortalities are robust to the various assumptions made in the model and can be explained to a large extent by relatively simple mechanisms like changes in predator biomass, changes in total available food, or the ratio between predator biomass and prey biomass. The currently used diet selection submodel is adequate because no consistent changes in spatial predator–prey overlap over quarters and ages were found (Figure 3.6.3.3.3-4). The assumption of a uniform size selection did not give larger deviations from the observed distribution of predator/prey weight ratios in the stomachs (Figure 3.6.3.3.5–3.6.3.3.7). However, as demonstrated for the interaction between harbour porpoise and cod, the results are to some extent sensitive to the input values used for mean weight-at-age because predation only takes place in the model if the predator/prey weight ratio is inside observed boundaries. For future key runs more effort needs to be put into the control and update of mean weight-at-age values.

While the trends over time were robust, the absolute level of M2 was to a larger extent sensitive to the stomach data used (Figure 3.6.3.3.8). In former analyses carried out with the key run 2011 the predation mortalities were consistently lower in the run with the 1981 stomach data only compared to the key run and the run with 1991 stomach data only. The absolute level can also change whenever additional predators are taken into account. Therefore, reference points have to be estimated in line with the predation mortality estimates used in the assessment.

Conclusions

WKNSEA concluded that the usage of natural mortality estimates from SMS can be continued. As a basis the alternative key run without predation of harbour porpoise on age 3 cod should be used. In line with the recommendation from ICES-WGSAM (2014) and the procedure used so far, the M estimates need to be smoothed over time before they are used as input for the assessment (Figure 3.6.3.3.9). While the main trends over time are robust, estimated inter-annual changes in M are uncertain.

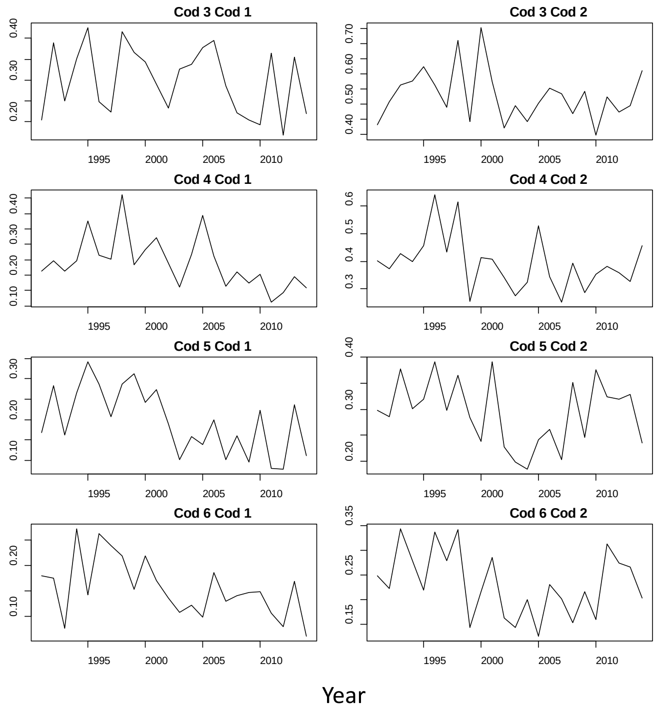


Figure 3.6.3.3.3. Spatial predator–prey overlap over time in the first quarter.

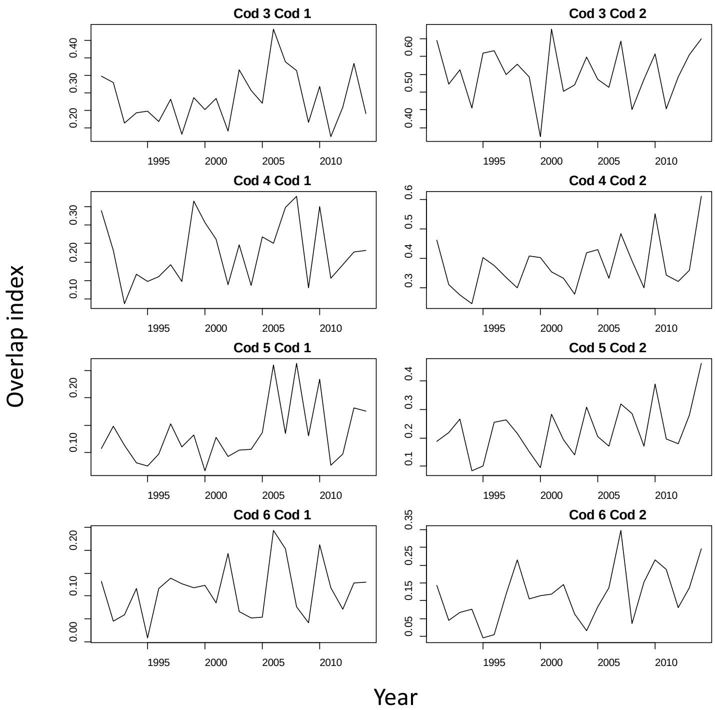


Figure 3.6.3.3.4. Spatial predator–prey overlap over time in the 3rd quarter.

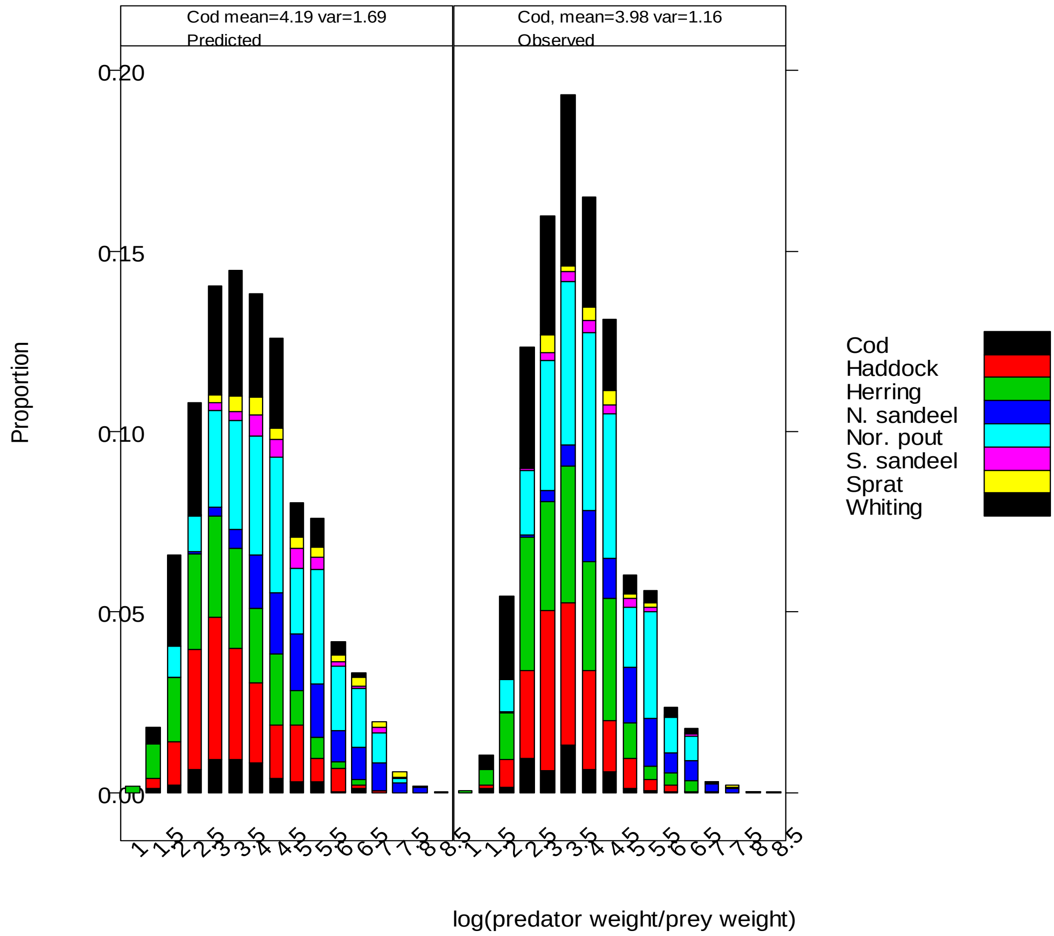


Figure 3.6.3.3.5. Observed and predicted distribution of log predator/prey weight ratios in the stomachs of cod >=30 cm. Similar results were obtained when selecting only cod >=50 cm or >=70 cm.

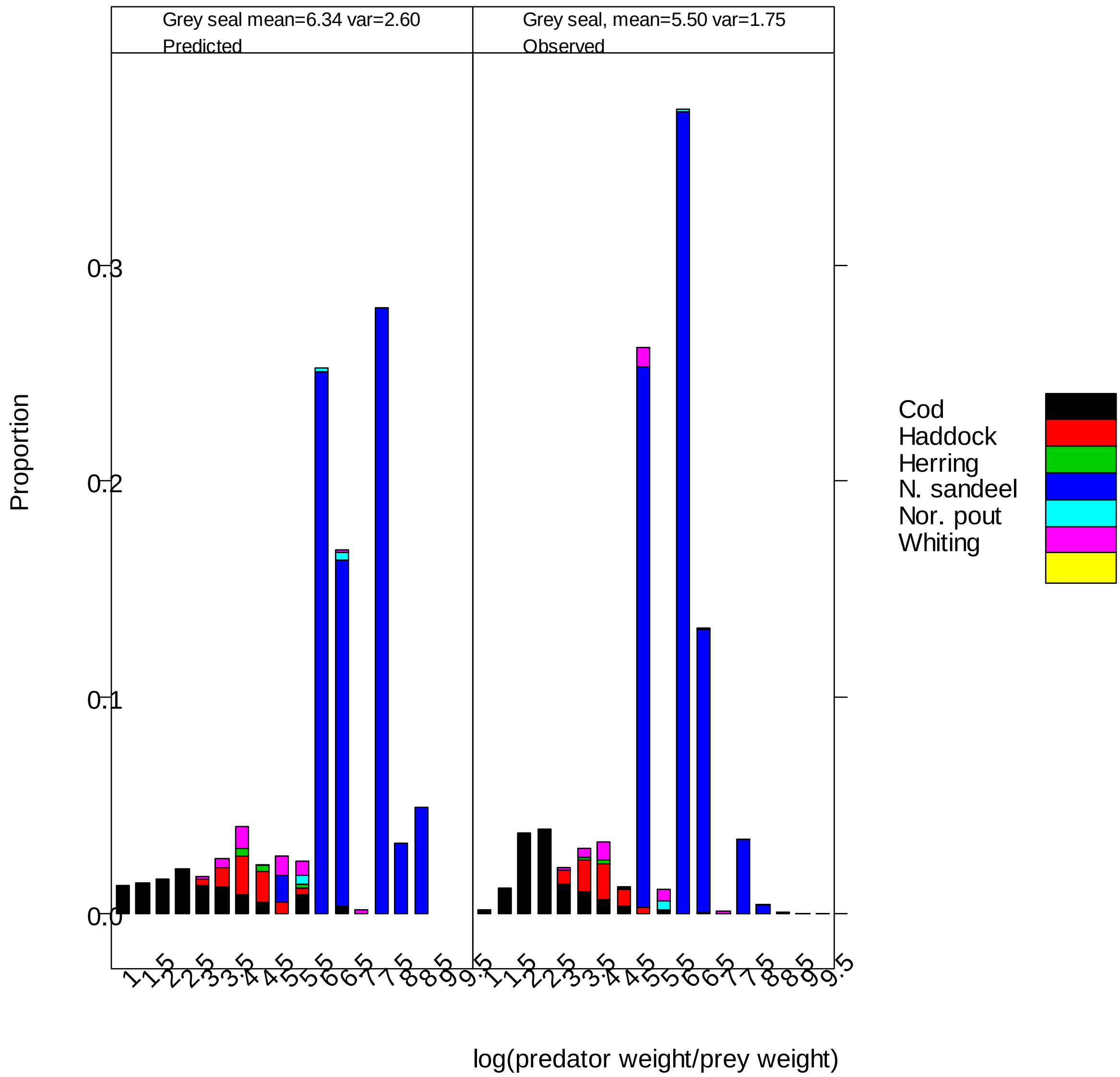


Figure 3.6.3.3.6. Observed and predicted distribution of log predator/prey weight ratios in the stomachs of grey seals.

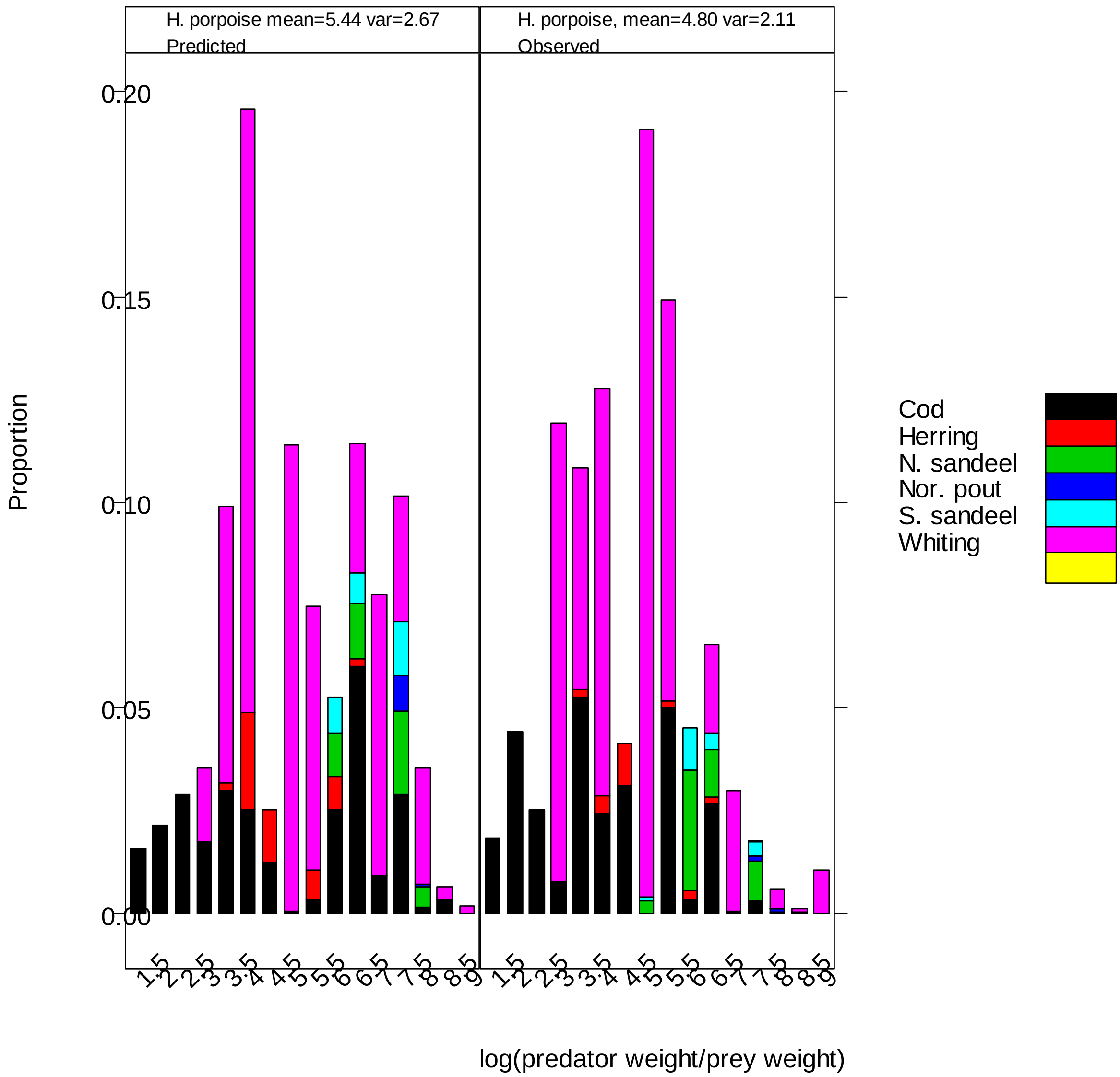


Figure 3.6.3.3.7. Observed and predicted distribution of log predator/prey weight ratios in the stomachs of harbour porpoise.

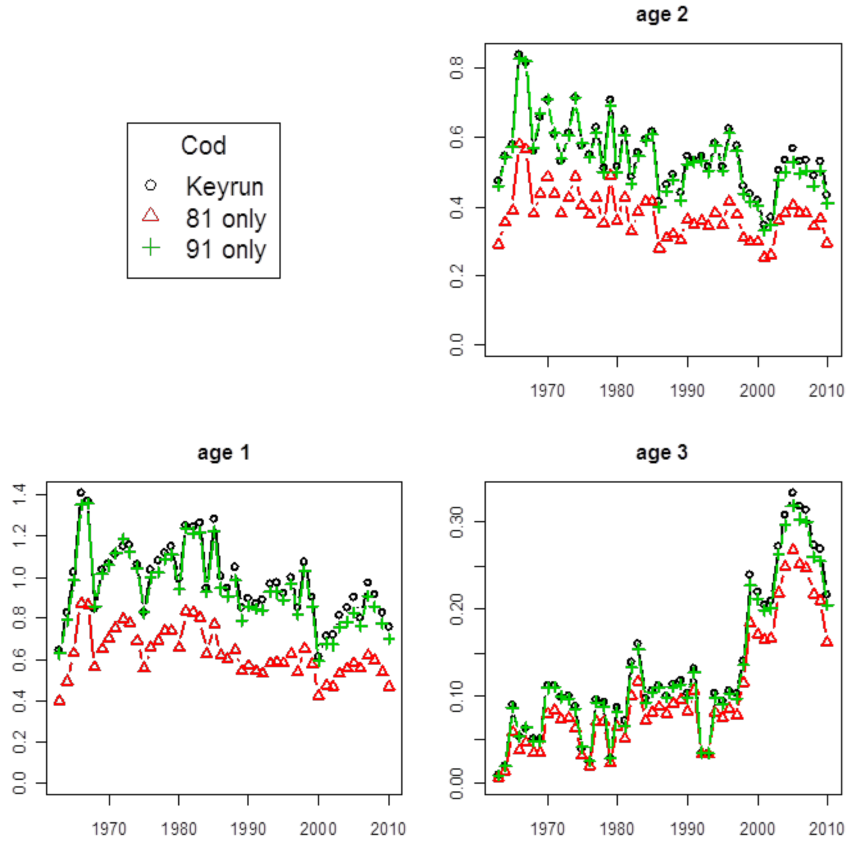


Figure 3.6.3.3.8. Comparison of predation mortalities estimated with the 2011 key run, a run with only 1981 stomach data included and a run with only 1991 stomach data included.

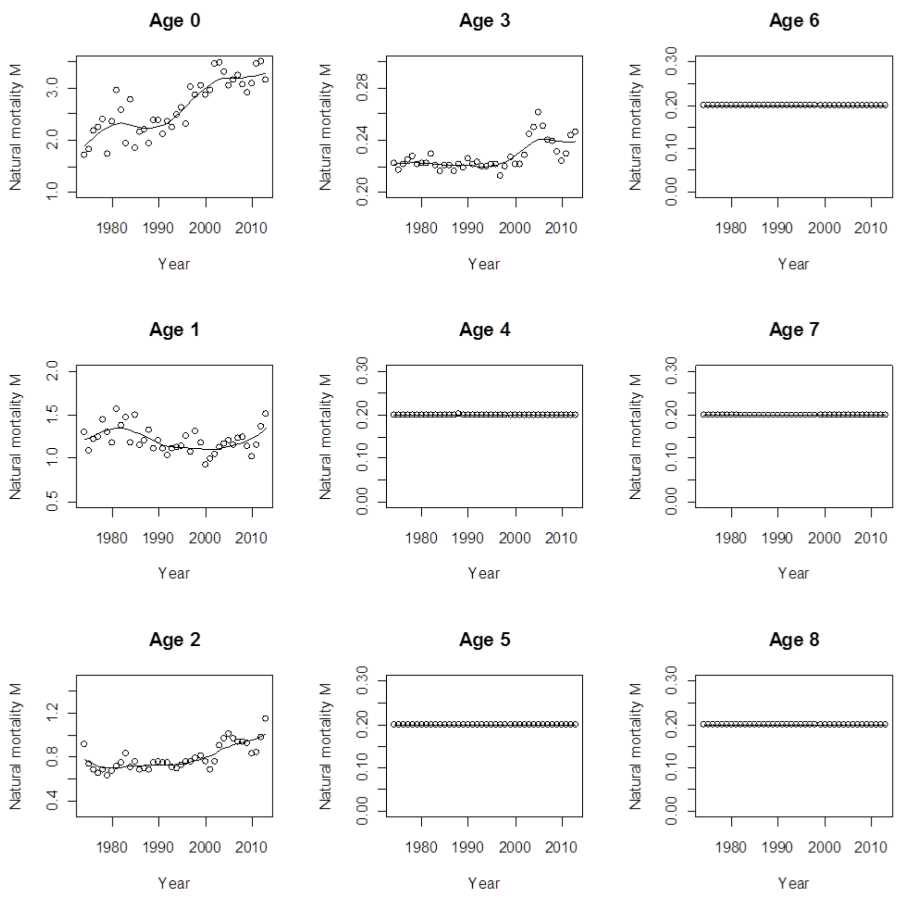


Figure 3.6.3.3.9. Smoothed (black line) and raw (black dots) natural mortality estimates by cod age class.

3.6.4 Assessment models

3.6.4.1 SAM

Introduction

SAM (State–space Assessment Model, Nielsen and Berg, 2014) has been used as the assessment model for North Sea cod since 2011, following acceptance at the last benchmark meeting held for the stock (ICES-WKCOD 2011; ICES-WGNSSK 2011). More details can be found in Nielsen and Berg (2014) and in the WKCOD-2011 report, but essentially SAM models recruitment from a stock–recruitment relationship, with random variability estimated around it, or as a random walk in log-space. Starting from recruitment, each cohort's abundance decreases over time following the usual exponential equation involving natural and fishing mortality. Instead of assuming catches to be known without error and simply subtracting those, SAM assumes that catches include observation noise, and that the survival process along cohorts is a random process. This has the consequence that estimated F-at-age paths display less interannual variability with SAM than with deterministic assessment models, because part of the observed fluctuations in catch-at-age are arising from observation noise instead of from changes in F.

SAM puts random distributions on the fishing mortalities F(y,a), where (y,a) denotes year and age. SAM considers a random walk over time for log [F(y,a)], for each age, allowing for correlation in the increments of the different ages. It has observation equations for both survey indices-at-age and observed catch-at-age, so catch-at-age data are never considered to be known without error. Additionally, in order to deal with the uncertain overall catch levels over the period 1993–2005, SAM estimates annual catch multipliers for this period.

An extension to allow for varying correlation between different ages is achieved by setting the correlation of the log F annual increments to be a simple function of the age difference (AR(1) process over the ages). By doing this, individual log F processes will develop correlated in time, but in such a way that neighbouring age classes have more similar fishing mortalities than more distant ones. This correlation structure does not introduce additional parameters to the model, and is referred to below as an AR correlation structure (see Nielsen and Berg, 2014 for more details).

Work using SAM prior to WKNSEA 2015

Several model runs were explored prior to the benchmark meeting, and these are described in De Oliveira and Nielsen (WD7). The approach taken for this work was to start with the final assessment used in 2014 (referred to as the 2014 baseline), explore the impact of data updates, one at a time, leading to a 2015 baseline assessment, then to perform sensitivity runs on the 2015 baseline related to the use of alternative data (e.g. survey indices) and alternative model settings.

Three data updates were considered, namely updates to the ICES extended NS-IBTS Q1 index (due to countries uploading revised data to DATRAS), an update of the natural mortality matrix (see Section 3.6.3.3), and updates to catch-at-age (related to processing data through InterCatch and removing Norwegian coastal cod; see Section 3.6.1). Figure 3.6.4.1.1 combines all the data changes. Although there are only relatively small changes to SSB and recruitment, F is estimated to be significantly higher in the 2000s compared to the 2014 baseline (median above the upper confidence bound of the 2014 baseline), which is largely due to the new InterCatch estimates; nevertheless, the most recent estimates of F are similar. Inclusion of these three data updates (ICES extended Q1 index, catch data and natural mortality) formed the new baseline (2015 baseline) for sensitivity testing.

The sensitivity analyses explored both alternative survey data inputs and model settings. The aim of exploring alternative survey data inputs was to re-introduce the NS-IBTS Q3 index, and to see whether the use of an alternative methodology to derive this index led to an improvement in the model fit to this time-series (see Section 3.6.2). Figure 3.6.4.1.2 compares original indices (ICES extended indices) with the corresponding Delta-GAM-based indices (assuming space–time interactions and a ship effect); although these indices appear to be quite similar, Figure 3.6.4.1.3 (a) and (b) indicates a marked deterioration in residual patters for the Q1 index when using the new methodology. Comparing Figure 3.6.4.1.3 (a) and (c), the introduction of the Q3 index (using the original ICES extended indices) continues to show residual patterns for the Q3 index, and this is not solved by moving to the new methodology: Figure 3.6.4.1.3 (d) continues to show poor fits to both the Q1 and Q3 indices. Excluding the Skagerrak from the new indices, however, did provide a clue to why this was occurring (see Section 3.6.2 and Figure 3.6.2.7 (d) therein).

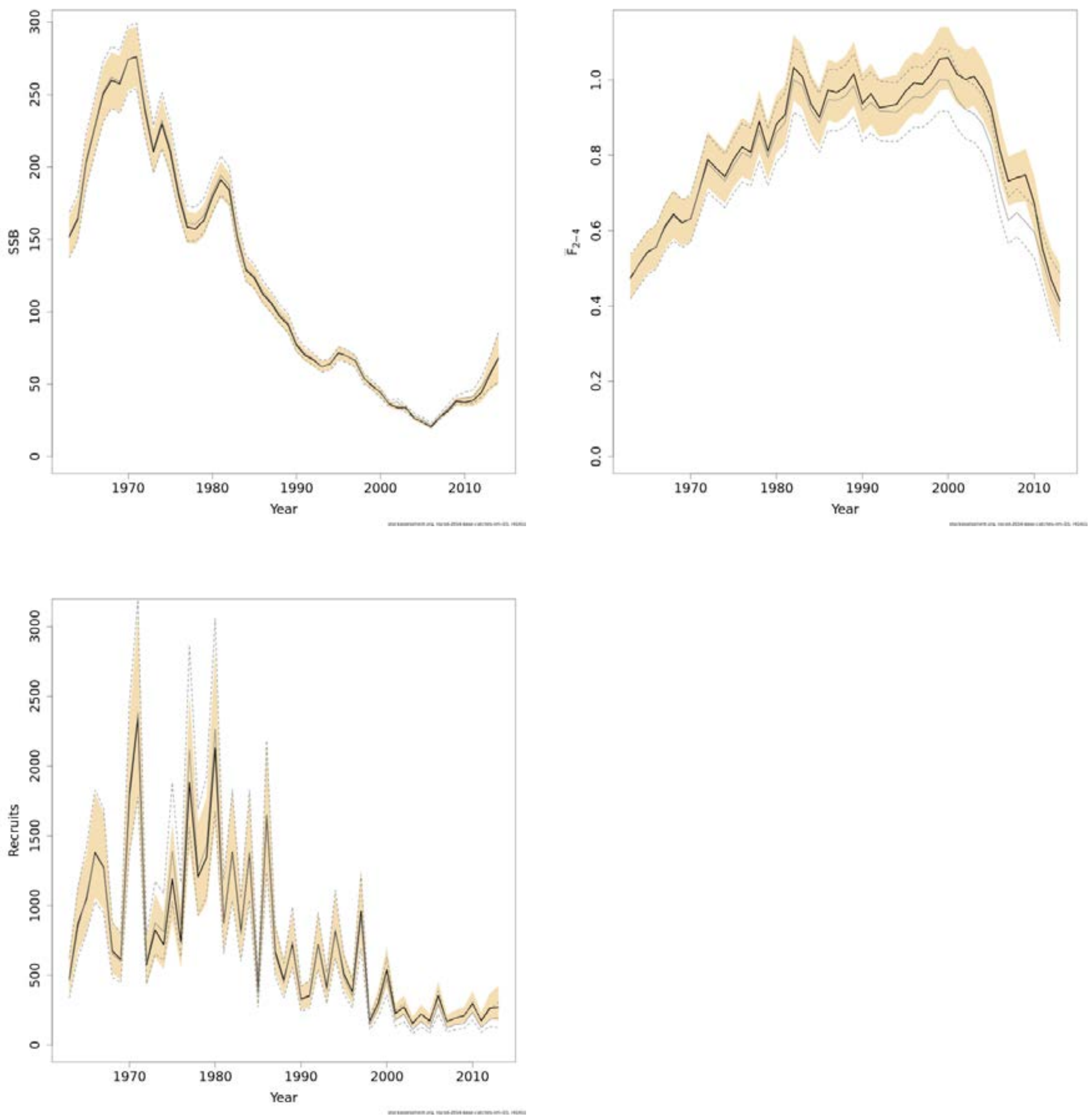


Figure 3.6.4.1.1. Impact of all data updates combined, resulting in 2015 baseline assessment (2014 assessment in grey).

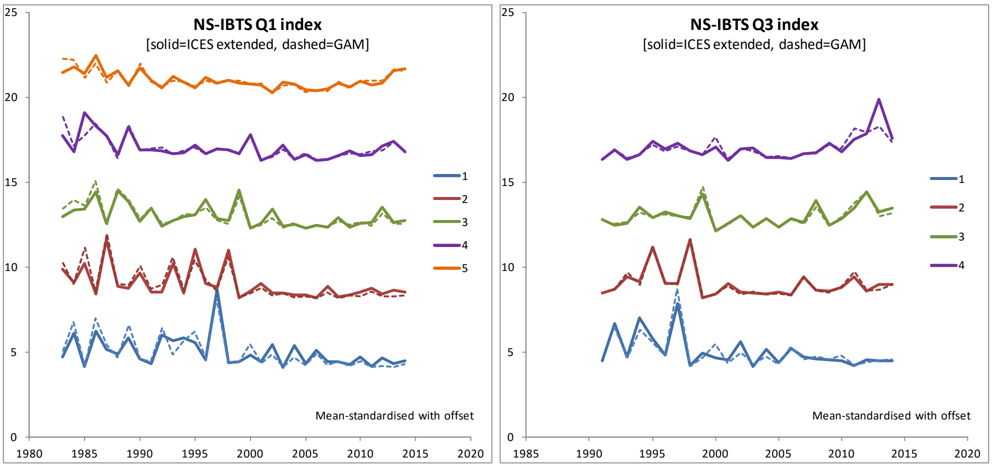
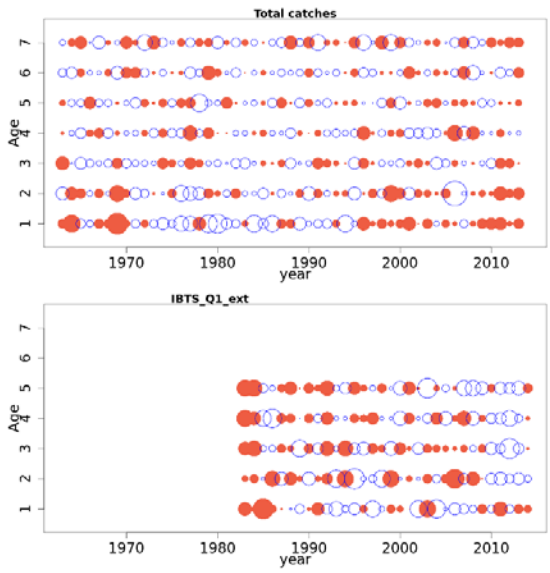
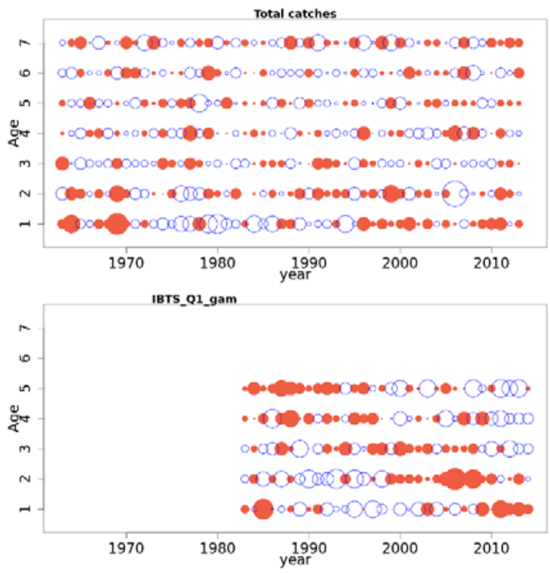


Figure 3.6.4.1.2. Comparison of the NS IBTS Q1 and Q3 indices when calculated by ICES (the extended index, solid lines), and by a Delta GAM (here simultaneously assuming space–time interactions and a ship effect, dashed lines). The indices are mean-standardised with an offset for ease of presentation.

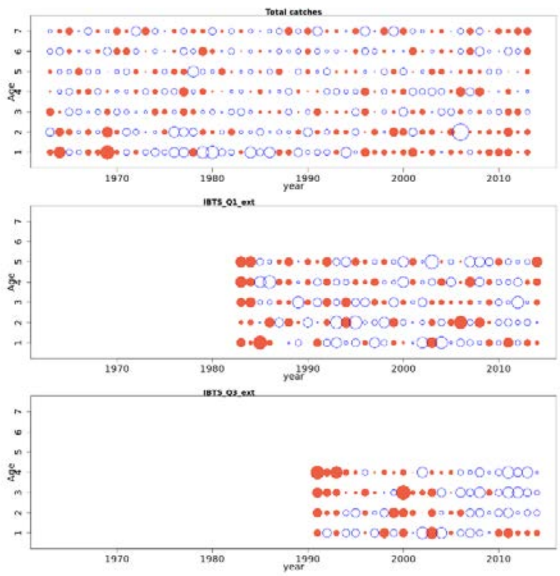
(a)



(b)



(c)



(d)

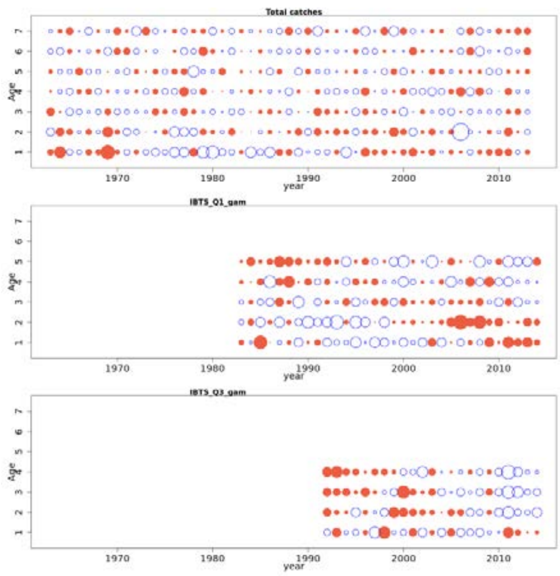


Figure 3.6.4.1.3. Comparing residual plots when using the ICES NS-IBTS extended indices (a and c), and when using the Delta-GAM NS-IBTS indices that include both space–time interactions and a ship effect (b and d). The top four set of plots (a and b) are for when only the Q1 index is used, and the bottom six (c and d) for when both the Q1 and Q3 indices are used. The 2015 base-line shown in Figure 3.6.4.1.1 corresponds to (a).

Extending the catch scaler until the final assessment year is not supported by WGNSSK for several reasons, but is nonetheless included as a sensitivity run. For example, catch multipliers after 2005 cannot be justified on the basis of any other information for this stock, particularly as catch information for this stock has vastly improved from 2006 onwards. A further concern is that as more years are added, the proportion of the time-series where catches are "trusted" (i.e. no catch multiplier is needed) becomes smaller and the overlap between the Q1 index and "trusted" catches become proportionately less, with the result that the estimation of the catch multiplier becomes less reliable and more unstable. Results are shown in Figure 3.6.4.1.4, indicating a catch multiplier that remains high in recent years, regardless of whether either the Q1 or the Q3 indices are used (see Figure 3.6.4.3.1 for comparison). This option is not included in any further work.

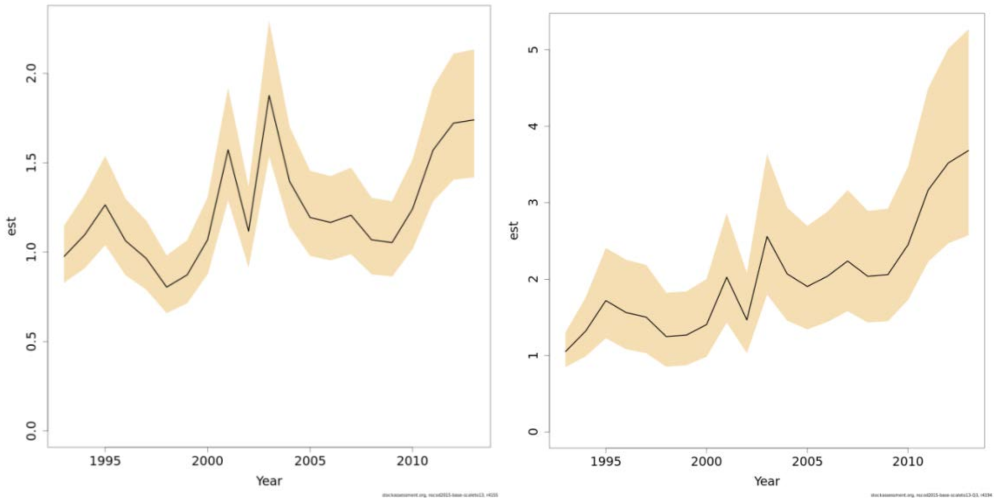


Figure 3.6.4.1.4. Extending the catch scaler to cover 1993-2013 for the ICES extended Q1 index only (left) or the ICES extended Q3 index only (right).

A sensitivity run also included an AR correlation structure over the ages of the log F annual increments: although there are only very minor changes to the population estimates (see De Oliveira and Nielsen, WD7), the improvement to the negative log-likelihood is substantial (from 120.65 for the 2015 baseline to 111.33).

Work using SAM during WKNSEA 2015

Following the presentation of De Oliveira and Nielsen (WD7), the workshop explored further runs in order to understand model behaviour and the impact of various changes. The process was interactive, each time working off a new baseline, exploring one change at a time. Table 3.6.4.1.1 describes the various baselines derived during the workshop.

Table 3.6.4.1.1. A description of the different assessment baselines derived at during the workshop. This is not a full description of the options explored, since several runs were based on each baseline, each time exploring a single change, and if accepted, this would be incorporated into the next baseline. Each empty cell takes on the settings of the first non-empty cell to the left of it in the same row. The sequence of baselines provides a timeline of how assessment runs were explored during the workshop.

	2014 BASELINE	2015 BASELINE	BASELINE 2	BASELINE 3	BASELINE 4	BASELINE 5	BASELINE 6 FINAL
Data							
Catch	Full catch-at-age, as at ICES-WGNSSK (2014)	InterCatch 2002–2013; exclude Norwegian coastal cod					
Natural mortality	2011 key run	2014 key run		2014 key run, pre-1974 equal to 1974			
Maturity	Constant			IBTS Q1-based, area-weighted, unsmoothed			IBTS Q1-based, area-weighted, smoothed
NS-IBTS Q1	ICES extended	Updated ICES extended		Delta-GAM, space–time interactions, ship effect	Delta-GAM, no space–time interactions, ship effect		
NS-IBTS Q3	Excluded			Delta-GAM, no space–time interactions, ship effect			
Model Settings							
AR correlation structure	No		Yes				
F variance structure	1+			1, 2+			
Stock–recruit model	Beverton–Holt					Random-walk	

Baseline 2 and associated runs

Baseline 2 incorporated the updates to the ICES extended NS-IBTS Q1 index, the catch-at-age data and the 2014 natural mortality key run, as well as an AR correlation structure for fishing mortality-at-age. The impact of several data changes was explored:

- the 2014 key run M values for 1963–1973 were set equal to 1974 instead of reverting to the 2011 key run values, thus avoiding a jump (Figure 3.6.4.1.5(a));

- alternative stock weights derived from the IBTS Q1 survey according to the methodology of Berg (WD3) were tried (smoothed values, and constant average) (Figure 3.6.4.1.5(b));
- the area-weighted variable maturity ogive as calculated in Section 3.6.3.2 (see also Figure 3.6.3.2.1) were used.

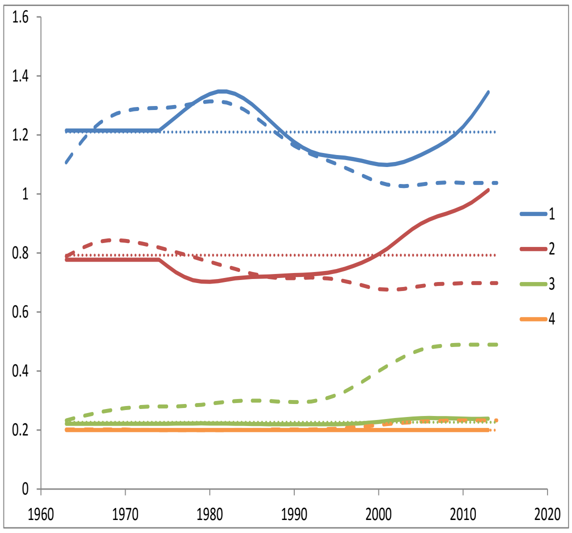
SSB estimates for each of these data changes are shown in Figure 3.6.4.1.6, with the variable maturity ogive showing the largest impact. Given the problems discussed in Section 3.6.3.1, the catch weights were continued to be used as stock weights, while both the 2014 key run Ms with constant prior to 1974 and the variable maturity ogive were taken forward into baseline 3.

A Delta-GAM for IBTS Q3 with no time-varying spatial effect, but including a ship effect, was found to resolve some (but not all) of the issues with the residual patterns for Q3 (Figure 3.6.4.1.7), so this index, together with a Delta-GAM for IBTS Q1 that included both a time-varying spatial effect and a ship effect, was incorporated into baseline 3.

Baseline 2 has a single variance parameter shared by all ages in the log F random walk process, and it was noted that this single parameter may be overly constraining the way the F at younger ages develops over time, given the changes in selectivity that have affected the smaller and bigger fish differently (e.g. avoidance of juveniles in recent years). Furthermore, it was also noticed that the observation variance parameters associated with age 1 in both the catches and surveys were large, and it was suggested that additional flexibility should be permitted to allow the model a better chance of fitting the data more closely. An additional run was therefore considered, separating out the log F random walk variances so that there was one for age 1 and another for ages 2+. Table 3.6.4.1.2 compares this run to baseline 2, and indicates that there was a significant improvement to the model (although only just), with age 1 and age 2+ standard deviations being 0.16 and 0.09 respectively for the split-variance run, compared to 0.09 for age 1+ in baseline 2. A further option was also tested (splitting into 1, 2 and 3+) but this did not yield a further significant improvement to the model fit compared to splitting into 1 and 2+. This separate variance option (1 and 2+) was subsequently incorporated into baseline 3.

Table 3.6.4.1.2 also shows another run that explored what happens to the model when the variance parameter associated with the Q1 index at age 1 was forced to a lower value. This run was requested due to concerns about the relatively poor fit to age 1 in the survey (standard deviation of 0.62 for baseline 2). Results indicate compensatory increases to recruitment variation (standard deviation increases from 0.46 to 0.59) and to the cohort process error (0.09 to 0.16) with a slight deterioration in the fits to the catch-at-age.

(a) (b)



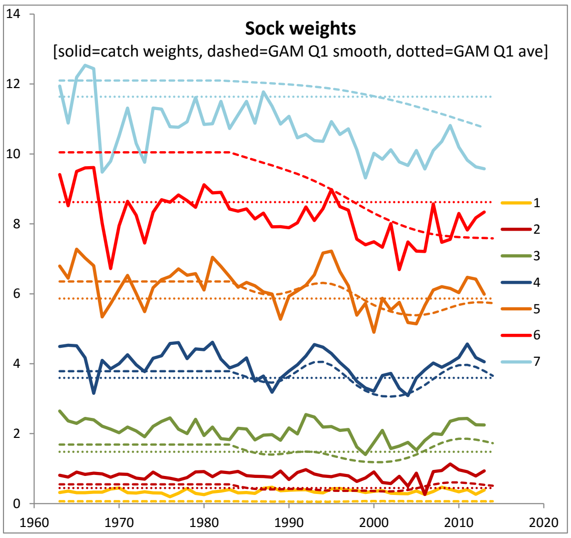


Figure 3.6.4.1.5. (a) natural mortality and (b) stock weights. For (a) the solid lines are the 2014 key run, with values from 1963–1973 assumed equal to 1974, the hashed lines are the 2011 key run estimates shown for comparison, and the dotted lines are the average of the 2014 key run estimates for the period 1974–2013. For (b) the solid lines are catch weights (used as stock weights in the 2014 and 2015 baseline), while the hashed lines are the smoothed values derived from NS-IBTS Q1 according to the method of Berg (WD3; note, values prior to 1983 are set equal to the 1983 value), and the dotted lines are the averages of the hashed lines for 1983–2013.

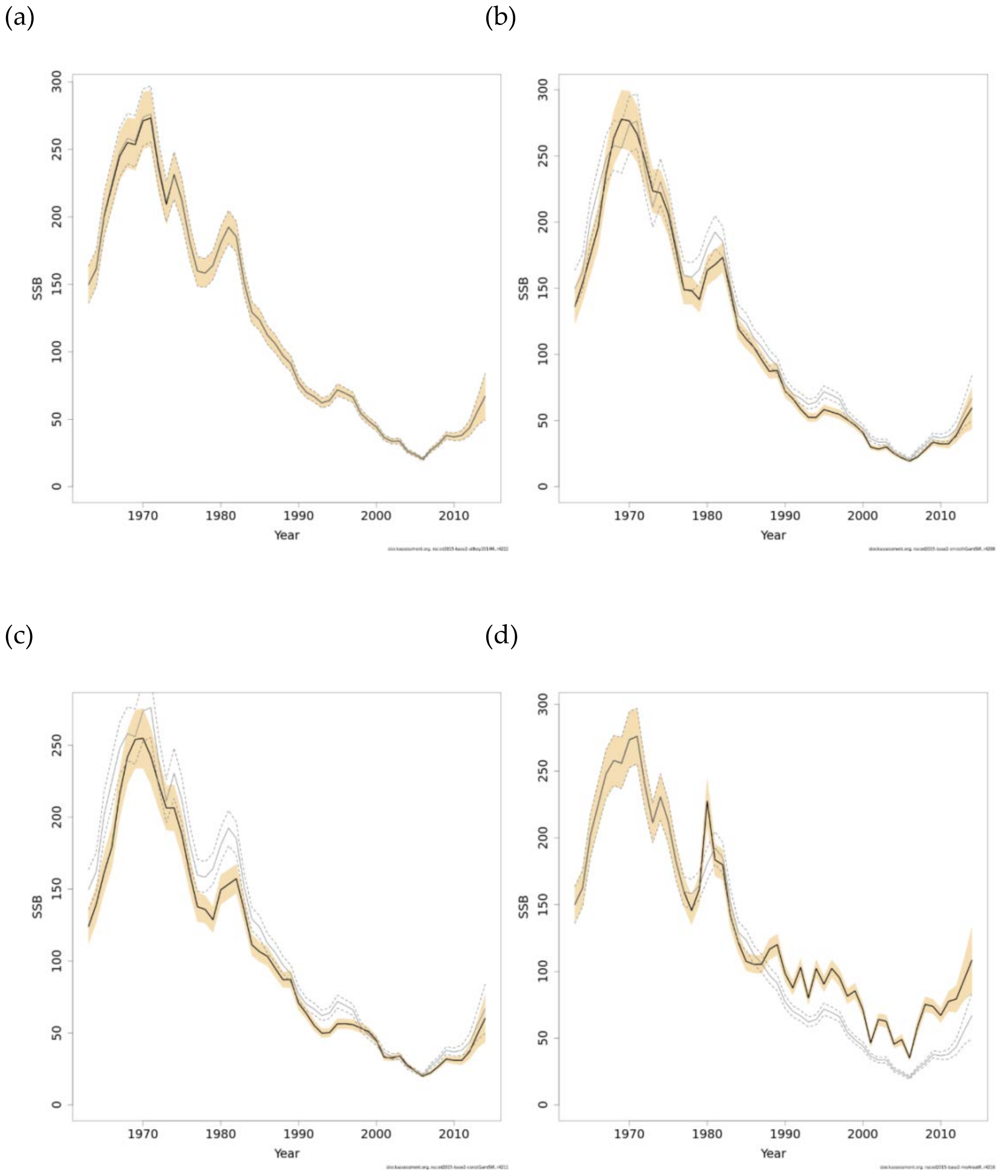


Figure 3.6.4.1.6. Impact of different data inputs: (a) the 2014 M key run with 1963 to 1973 held constant at the 1974 value (instead of reverting to the 2011 key run for those years), as shown in Figure 3.6.4.1.5(a), (b) smooth stock weights shown as hashed lines in Figure 3.6.4.1.5(b), (c) the average of the smooth stock weights for the period 1983–2013, shown as dotted lines in Figure 3.6.4.1.5(b), and (d) the variable maturity ogive, as shown in Figure 3.6.3.2.1. The grey curves (the same in all the plots) represent baseline 2.

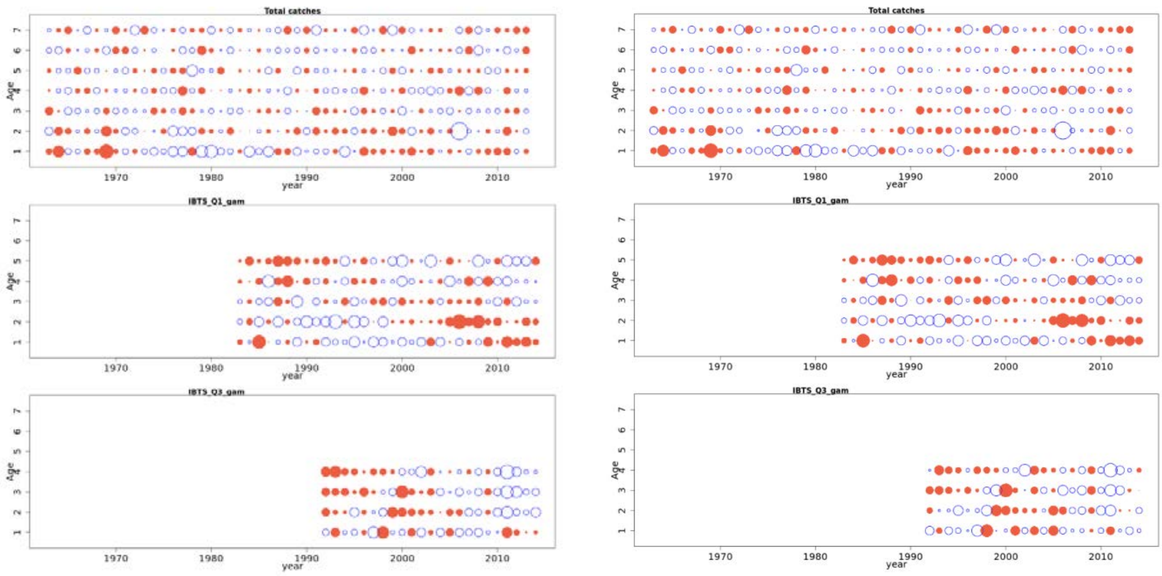


Figure 3.6.4.1.7. Residual plots for when Delta-GAM based indices are used: left when a time-varying spatial effect is included for both Q1 and Q3, and right when a time-varying spatial effect is included only for Q1 (i.e. spatial effects are time-invariant for Q3). In all cases, a ship effect is included.

Table 3.6.4.1.2. Comparison of the variance parameters associated with baseline 2 and some variants thereof. The first block refers to number of parameters (npar), negative log-likelihood (-lnL) and a p-value for testing significant improvements compared to the baseline. The second block refers to process error variation (first two to the F random walk process, and next two the recruitment variation and cohort process error respectively). The third block refers to observation error variation for catch-at-age (ages 1, 2 and 3+), and the fourth to observation error variation on the surveys (ages 1 and 2+). The final row is the correlation amongst ages in the F random walk process. The run "sep F var 1 vs. 2+" refers to having separate variances for the ages 1 and 2+ on the random walk F process, while run "Fix Q1 age 1" was an exploration of what happens when forcing the model (by introducing a penalty) to have a lower observation error variance on age 1 of the Q1 survey (shaded grey; note that the number in italics indicates that the model ran into a bound for that parameter).

	Baseline 2	sep F var 1 vs. 2+	Fix Q1 age 1
npar	29	30	29
-lnL	111.33	108.81	172.54
P value		0.025	
SdLogFsta_age1	0.09	0.16	0.09
SdLogFsta_age2+	0.09	0.09	0.09
SdLogN_age1	0.46	0.47	0.59
SdLogN_age2+	0.09	0.09	0.16
SdLogObs_C_age1	0.72	0.66	0.75
SdLogObs_C_age2	0.25	0.25	0.27
SdLogObs_C_age3+	0.08	0.08	*0.05*
SdLogObs_Q1_age1	0.62	0.63	0.19
SdLogObs_Q1_age2+	0.27	0.27	0.26
SdLogObs_Q3_age1	-	-	-
SdLogObs_Q3_age2+	-	-	-
rho	0.90	0.90	0.94

Baseline 3 and associated runs

Baseline 3 added the area-weighed variable maturity ogive, the 2014 M key run with values for 1963–1973 held constant at the 1974 values, the Q1 Delta-GAM with ship and time-varying spatial effects, and the Q3 Delta-GAM with ship and time invariant spatial effects to baseline 2, and also split the variance associated with the F random walk process into one for age 1 and another for age 2+. Investigations using this baseline included assuming a constant M-at-age at the average over the period 1974–2013 (dotted line in Figure 3.6.4.1.5(a)), which indicated that the model was insensitive to this (result not shown), and the impact of alternative model settings for the Delta-GAM survey indices on the SAM assessment. The focus of the latter was on the ship and spatial effects, and in particular having both surveys computed with either the combination of a ship effect but time-invariant spatial effect, or no ship effect but time-varying spatial effect, as discussed in Section 3.6.2 (see Figure 3.6.2.7).

Table 3.6.4.1.3 compares the various variance parameters, and indicates a better overall fit to the Delta-GAM with ship and time-invariant spatial effects for both surveys, but in particular, a substantial improvement of the fit to the age 1 Q1 survey (standard deviation improves from 0.58 in baseline 3 to 0.45). Given the preference (in AIC terms) for a Delta-GAM with ship and time-invariant spatial effects for Q3 (Section 3.6.2), and the desire to follow a consistent approach for both surveys, the Delta-GAM with ship and time-invariant spatial effects was selected for both surveys in further baselines considered.

Table 3.6.4.1.3. Comparison of the variance parameters associated with baseline 3 and some variants thereof. The run "Delta-GAM nonstat-noship" is where the Delta-GAM for both surveys has no ship effect and includes a time-varying spatial effect, while run "Delta-GAM stat-ship" is where the Delta-GAM for both surveys includes a ship effect but has a time-invariant spatial effect. See caption to Table 3.6.4.1.2 for further details.

	Baseline 3	Delta-GAM nonstat-noship	Delta-GAM stat-ship
npar	36	36	36
-lnL	138.15	141.06	128.54
SdLogFsta_age1	0.14	0.14	0.15
SdLogFsta_age2+	0.08	0.09	0.09
SdLogN_age1	0.59	0.58	0.59
SdLogN_age2+	0.11	0.11	0.12
SdLogObs_C_age1	0.65	0.66	0.65
SdLogObs_C_age2	0.25	0.24	0.24
SdLogObs_C_age3+	0.08	0.08	0.07
SdLogObs_Q1_age1	0.58	0.63	0.45
SdLogObs_Q1_age2+	0.26	0.22	0.24
SdLogObs_Q3_age1	0.31	0.34	0.35
SdLogObs_Q3_age2+	0.26	0.34	0.26
rho	0.90	0.92	0.92

Baseline 4 and associated runs

Baseline 4 added the Delta-GAM with ship and time-invariant spatial effects for Q1 (Q3 already having this configuration) to baseline 3. It was during the computation of six year retrospective plots for baseline 4 that it was discovered that the model did not produce a positive definite Hessian for some of the retrospective plots, and a further investigation showed that the model was not finding a solution for one of the Beverton–Holt parameters. The retrospective plots are derived in an automated fashion, and the problem could have been solved with a more careful selection of initial values, for example, but the problem is nevertheless indicative of a suboptimal parameterisation, so an alternative parameterisation of the stock–recruit function was sought. Although not influential in the model fit (indicated by the high standard deviation associated with the recruitment process of around 0.6; see Table 3.6.4.1.3), there was some unease expressed about the use of a Beverton–Holt formulation, given that this is subsequently ignored in any estimation of reference points. It was therefore decided to use a random-walk process instead, saving on two parameters in the model; this formulation too had minimal influence on model estimates.

Baseline 5 and associated runs

Baseline 5 replaced the Beverton–Holt stock–recruit model in baseline 4 with the recruitment random-walk process. Although some of the variation in the maturity ogive could be considered to be real, a large part would also be due to observation error (e.g. related to sampling), so it was felt that a more robust approach would be to use a smoothed version of the maturity ogive, as shown in Figure 3.6.4.1.8. Figure 3.6.4.1.9 compares SSB values for the smoothed and unsmoothed maturity ogive. The SSB based on the smoothed maturity ogive was considered to be more realistic, as SSB is not expected to have large interannual jumps, and this formed the basis of baseline 6, the final model put forward by the workshop (see Section 6.3.4.3).

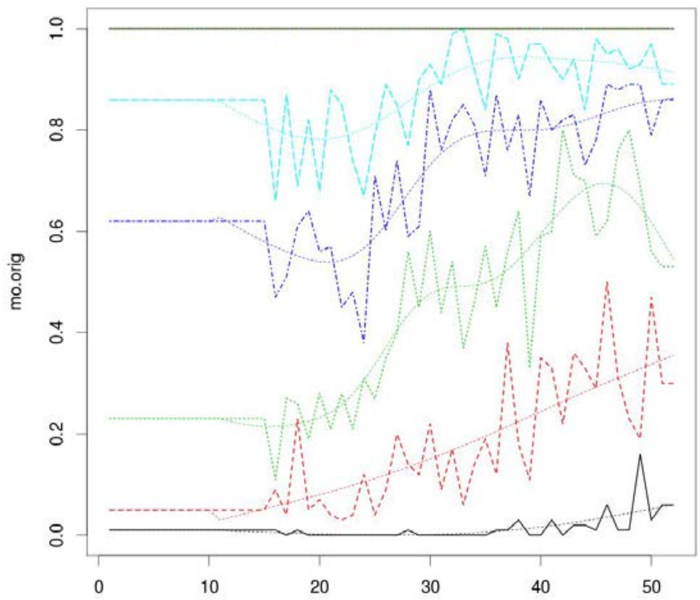


Figure 3.6.4.1.8. Comparison of the area-weighted variable maturity ogive shown in Figure 3.6.3.2.1 with a smoothed version (with the level of smoothing being optimised by generalised cross validation in the mgcv R-package.

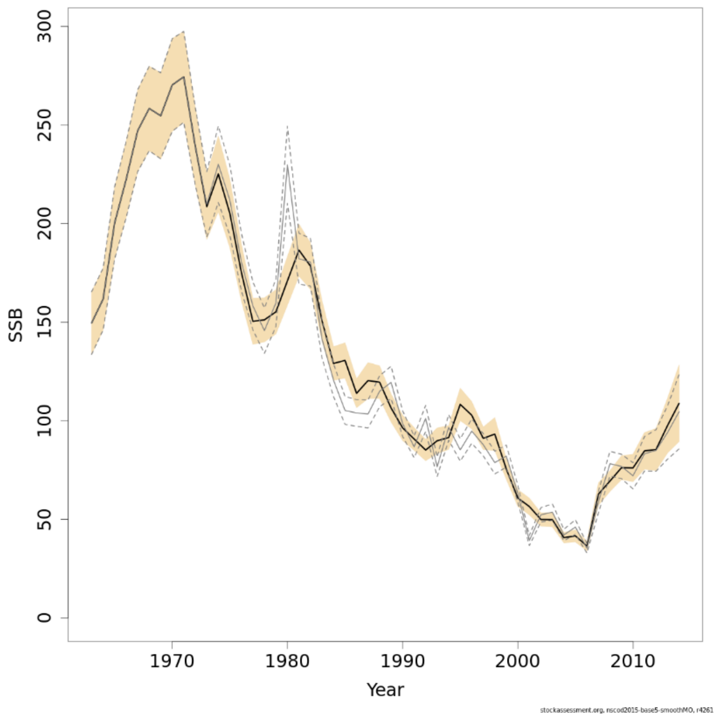


Figure 3.6.4.1.9. Plot showing the impact of smoothing of the maturity ogive (as shown in Figure 3.6.4.1.8) on estimates of SSB. The grey lines represent baseline 5 (unsmoothed maturity), while the black lines represent baseline 6 (smoothed maturity).

3.6.4.2 A4a exploratory runs

Alternative assessments of North Sea cod were carried out using the a4a modelling framework (Jardim *et al*., 2015). This framework relies on the specification of three log-linear submodels, one each for fishing mortality, survey catchability and recruitment. Exploratory assessments of North Sea cod using a range of submodels were presented in a working document (Walker, WD9). A focus of the benchmark was to use submodels similar in structure to what is used in SAM in order to better understand differences between the two models. Although initial modelling presented in Walker (WD9) used data corresponding to the 2014 baseline (Section 3.6.4.1), but also including the ICES Q3 extended index, the runs presented here use the data corresponding to the final assessment (presented in Section 3.6.4.3).

The fishing mortality submodel was set up as a tensor product of cubic splines with a component for the year effect on age one (Fishing mortality 1 in Table 3.6.4.2.1). This allowed age and year effects to interact but freed the first age class, which was to reduce patterns in the residuals. The survey catchability submodels were set up as smoothers over age with four degrees of freedom for the IBTS Q1 survey and three degrees of freedom for the IBTS Q3 survey. The stock–recruit submodel was a year-effect model with independently varying recruitment in each year. For consistency with SAM, observation variances were defined through the variance submodel. For the catch variance age classes 1 and 2 were split from older age classes and for the survey variances only age 1 was split from older age classes. The R syntax for the submodels is given in Table 3.6.4.2.1.

The number of degrees of freedom to use is estimated within SAM, but needs to be defined in a4a. This proved to be problematic as increasing the number of knots within the smoothers and tensor products of the fishing mortality submodel improved some diagnostics while deteriorating others. A potential solution to this is provided by Thorsen *et al*. (2015). Runs were performed using four knots for age and either six knots (best BIC) or 22 knots (best AIC) for years. The two runs provided similar estimates of catch, recruitment and SSB but showed differences in fishing mortality (Figure 3.6.4.2.1). The fishing mortality shape seems to depend heavily on the number and position of knots, which determine the position of peaks and troughs in the fishing mortality surface (Figure 3.6.4.2.1). Furthermore, it is not possible to use a varying number of knots for different age classes in a4a as is done in SAM.

Figure 3.6.4.2.2 shows the stock summary plots with a4a estimates of recruitment, harvest, catch and SSB when 22 knots are used to specify the level of smoothness for years in fishing mortality submodel 1. Figure 3.6.4.2.3 shows the associated residual plots and Figure 3.6.4.2.4 the fishing mortality surface and fishing mortality-at-age.

a4a produces similar estimates of catch, recruitment and fishing mortality to SAM (Figure 3.6.4.2.5). The estimates of SSB are also similar until the end of the time-series when a4a estimates a much higher SSB than SAM (49%). In particular, the two models lie outside of each other's confidence intervals in the last six years of the time-series. This was a cause of concern during the benchmark. One possible explanation was that age classes 6 and 7 are coupled within SAM but not for a4a. An alternative run of a4a was made where ages 6 and 7 were coupled in the fishing mortality submodel (Fishing mortality 2 in Table 3.6.4.2.1). However, making this adjustment meant that a4a would no longer run with the separate component for age 1s in the fishing mortality submodel. This change reduced the estimates of SSB within a4a (now 35% higher than SAM; Figure 3.6.4.2.6) but produced unsatisfactory residual plots with mostly negative catch residuals for age 1 and mostly positive residuals for age 2 (Figure 3.6.4.2.7).

Table 3.6.4.2.1. R syntax for the a4a submodels.

Submodel	Syntax
Fishing mortality 1	~ te(age, year, k=c(4, i)) + s(year, k=i, by=as.numeric(age==1)); i=6 or22
Fishing mortality 2	~ te(replace(age, age>6, 6), year, k=c(4, 22))
Survey catchability	~ s(age, k=4)
	~ s(age, k=3)
Recruitment	~ factor(year)
Variance	~ factor(replace(age, age>3, 3))
	~ factor(replace(age, age>2, 2))
	~ factor(replace(age, age>2, 2))

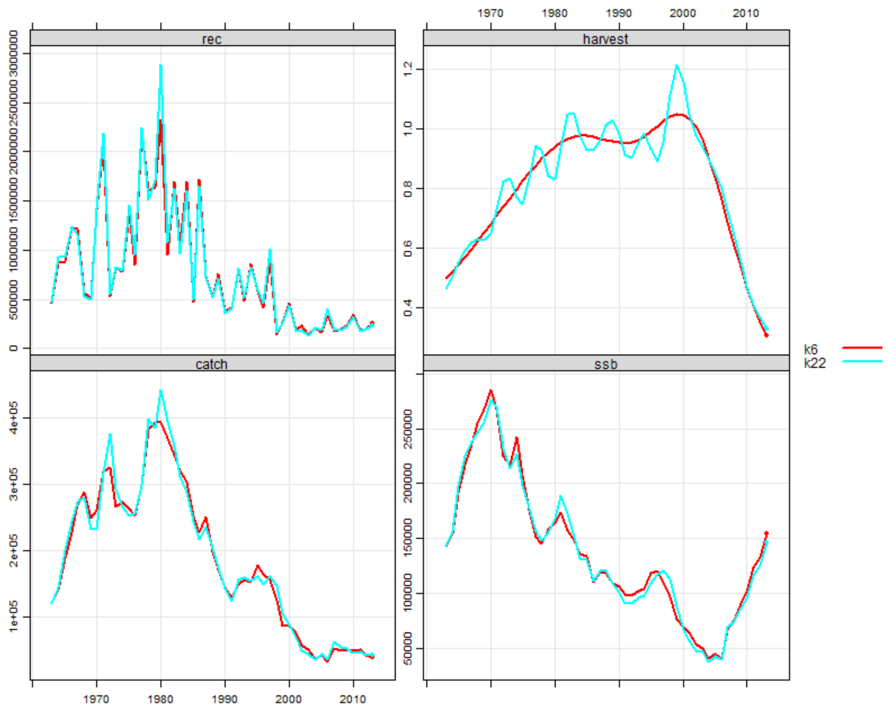


Figure 3.6.4.2.1. Stock summary plots for a4a using either 6 (red) or 22 (blue) knots in fishing mortality submodel 1.

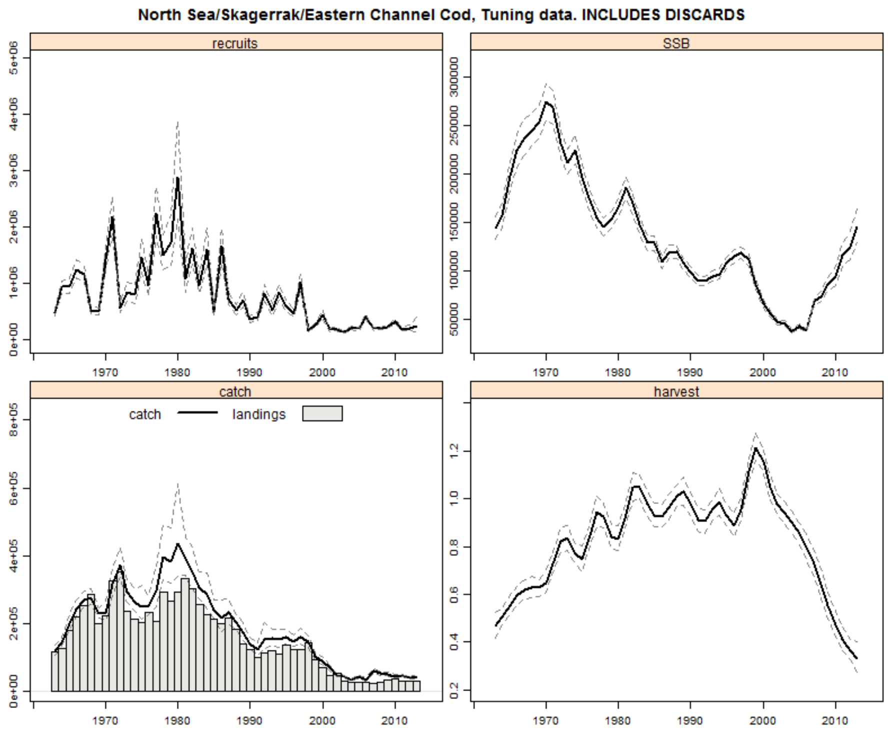


Figure 3.6.4.2.2. Stock summary plot for the a4a model with 22 knots in fishing mortality submodel 1.

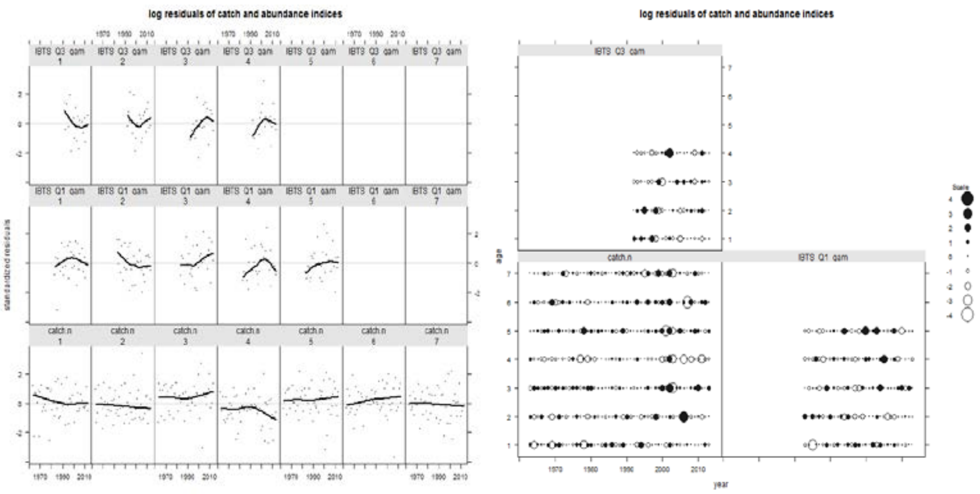


Figure 3.6.4.2.3. Residual plots for the a4a model using fishing mortality submodel 1 with 22 knots.

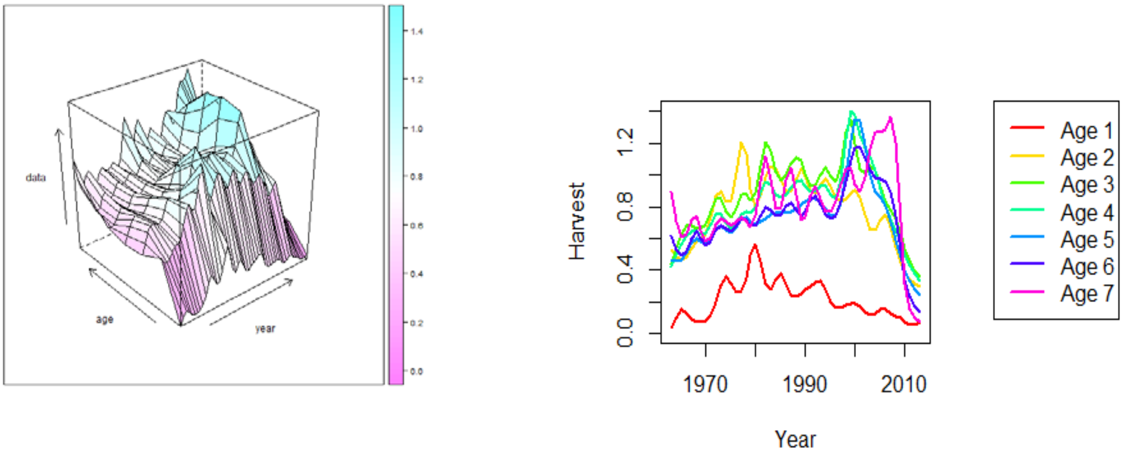


Figure 3.6.4.2.4. Fishing mortality surface plot (left) and fishing mortality-at-age (right) for the a4a model using fishing mortality submodel 1 with 22 knots.

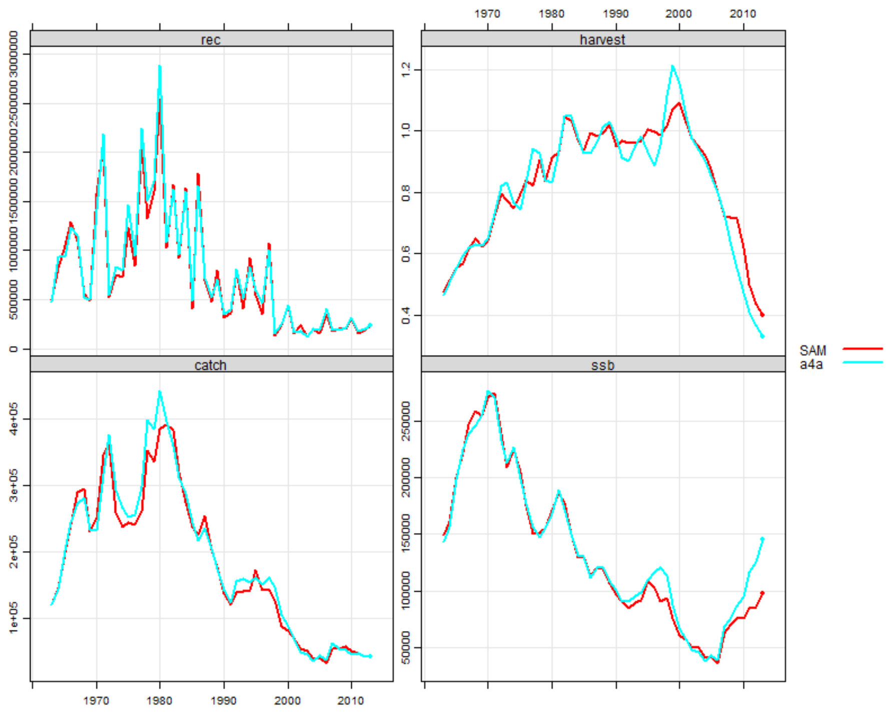


Figure 3.6.4.2.5. Stock summary plots for SAM (red) and a4a (blue) when using fishing mortality submodel 1 with 22 knots.

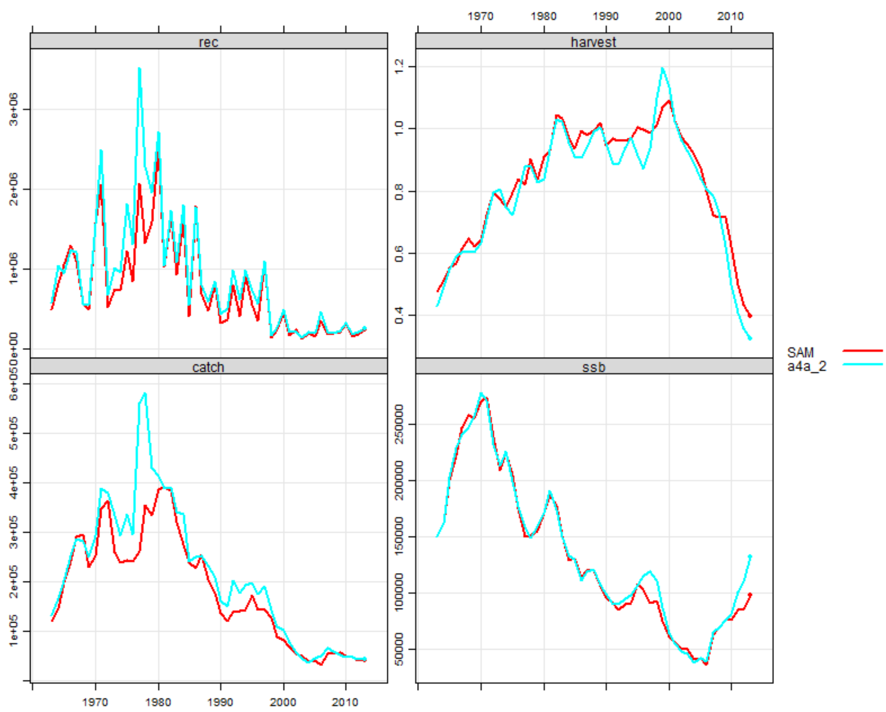


Figure 3.6.4.2.6. Stock summary plots for SAM (red) and a4a with age classes 6 and 7 coupled in fishing mortality submodel 2.

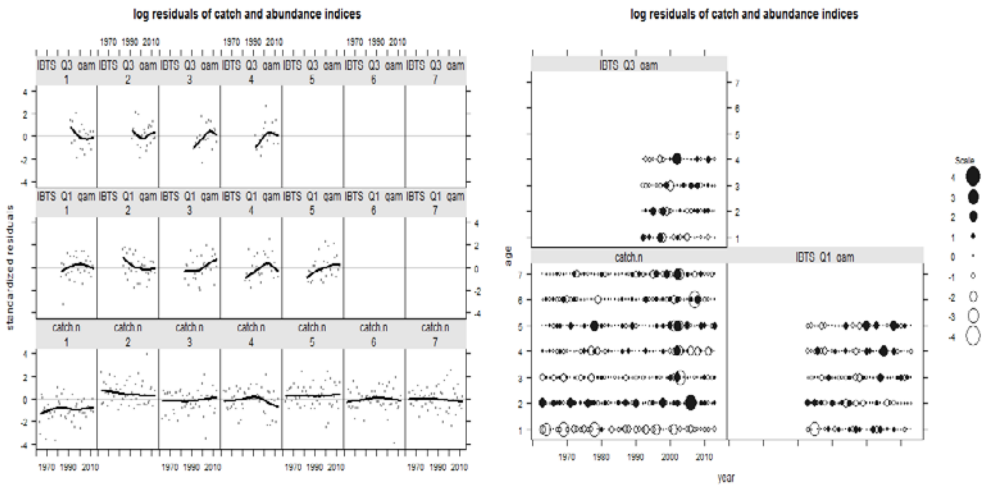


Figure 3.6.4.2.7. Residual plots for the a4a model with ages 6 and 7 coupled in fishing mortality submodel 2.

3.6.4.3 Final assessment model

The final assessment model for North Sea cod has the following features that differ from the assessment model used in 2014 (ICES-WGNSSK 2014):

Data

- Norwegian coastal cod removed from catch data;
- InterCatch estimates of landings and discards from 2002 onwards;
- M 2014 key run (smoothed values; set 1963–1973 equal to 1974);
- Area-weighted variable maturity derived from NS-IBTS Q1 (smoothed values; set 1963–1977 to previous constant key);
- GAM-based Q1 and Q3, both with ship effect and time-invariant spatial effect.

Model settings

- AR autocorrelation structure included;
- Separate out variance on F-at-age (1 vs. 2+);
- Random walk stock-recruit process.

Figure 3.6.4.3.1 compares the final assessment (WKNSEA 15) with the assessment of 2014 (WGNSSK 14), and includes the updated reference points (see Section 3.8). Figure 3.6.4.3.2 shows fishing mortality-at-age and by catch type (landings and discards), with the former indicating a shift in selection pattern over time. Figure 3.6.4.3.3 shows residual plots for the final assessment (right) and an assessment that was run last year based on both Q1 and Q3 surveys (left), indicating an improvement to the residuals for Q3, with similar residual patterns for Q1 and the catch-at-age. Figures 3.6.4.3.4–3.6.4.6 provide more details on the actual fits to data, while Figures 3.6.4.3.7–3.6.4.8 show other model diagnostics (leave-one-out runs and six year retrospectives), and Table 3.6.4.1.3 compares variance parameters from last year's model (2014 baseline) with the final assessment from this benchmark.

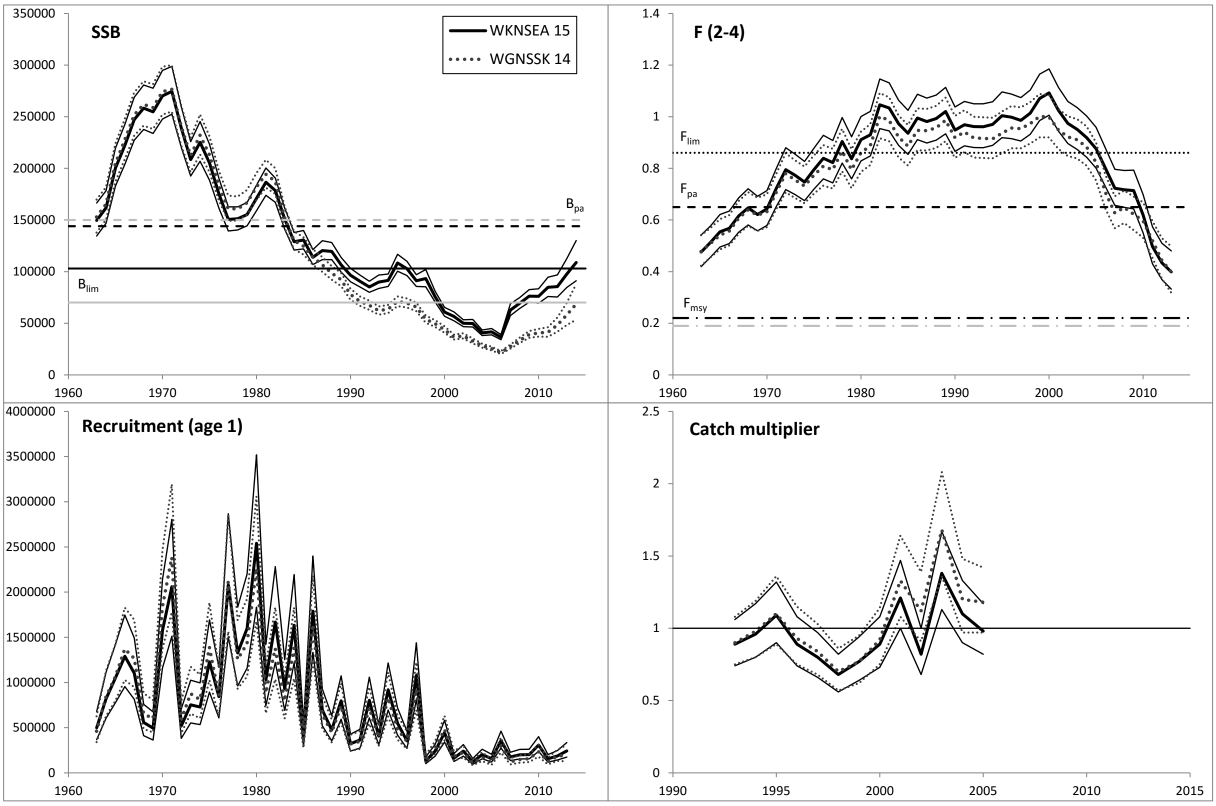


Figure 3.6.4.3.1. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. A comparison of the assessment in 2014 (WGNSSK 14) and the final assessment presented here (WKNSEA 15). Clockwise from top left, point-wise estimates and 95% confidence intervals of spawning–stock biomass (SSB), mean fishing mortality for ages 2–4 (F(2–4)), the catch multiplier, and recruitment (R age 1) for the two assessments. The heavy lines represent the point-wise estimate, and the light lines point-wise 95% confidence intervals. The horizontal solid lines in the SSB plot indicate B_{lim} (=70 000 t for WGNSSK 14 and 103 000 t for WKNSEA 15) and broken lines B_{PA} (=150 000 t for WGNSSK 14 and 144 000 t for WKNSEA 15), and those in the F(2–4) plot F_{PA}=0.65 and F_{lim}=0.86 (not re-estimated for WKNSEA 15), as well as F_{MSY} (=0.19 for WGNSSK 14 and 0.22 for WKNSEA 15). The horizontal broken line in the catch multiplier plot indicates a multiplier of 1. SSB is in tons, and R in thousands.

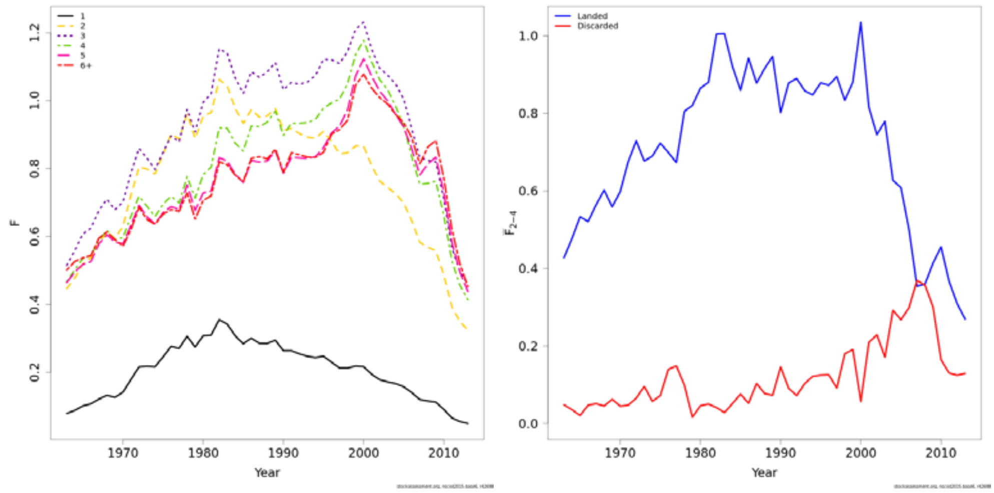


Figure 3.6.4.3.2. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. Final WKNSEA 15 SAM estimates of fishing mortality. The left panel shows fishing mortality for each age (indicating shifts in selection pattern over time), while the right panel shows mean fishing mortality for ages 2–4, but split into landings and discards components by using ratios calculated from the landings and discards numbers-at-age from the reported catch data.

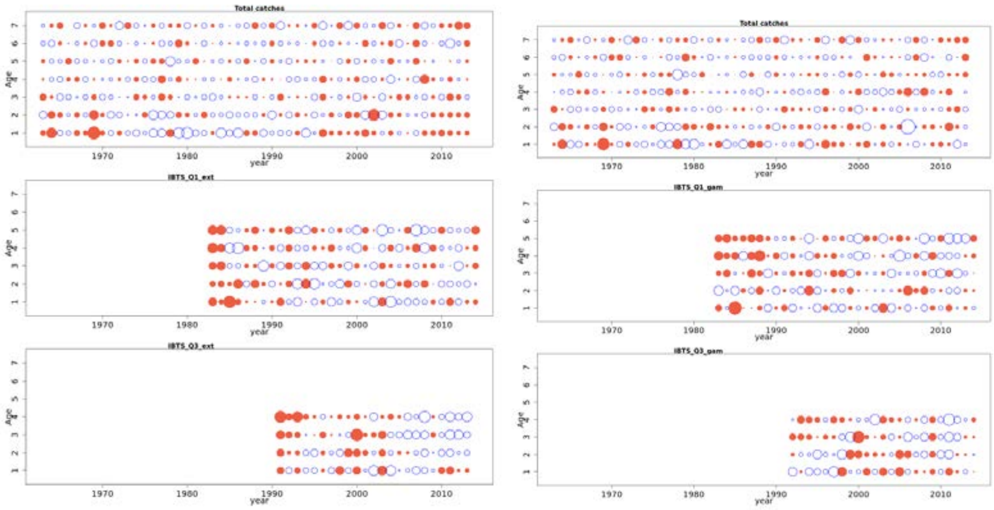


Figure 3.6.4.3.3. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. A comparison of residual plots for when both indices were included in last year's assessment (left; run last year, but not presented in the report) to the final WKNSEA 15 assessment (right). Note the indices used last year are the ICES extended indices (stratified mean approach), while the indices in the final WKNSEA assessment are the GAM-based ones (including ship effect and time-invariant spatial effect).

Table 3.6.4.3.1. Comparison of the variance parameters associated with the 2014 baseline (ICES-WGNSSK 2014) and the final assessment presented here (WKNSEA 2015). See caption to Table 3.6.4.1.2 for further details. Note that, because different data sets are used, -lnL values are not strictly comparable.

	2014 baseline WGNSSK 2014	baseline 6 WKNSEA 2015
npar	29	34
-lnL	122.76	141.6
SdLogFsta_age1	0.09	0.15
SdLogFsta_age2+	0.09	0.09
SdLogN_age1	0.50	0.75
SdLogN_age2+	0.10	0.11
SdLogObs_C_age1	0.74	0.64
SdLogObs_C_age2	0.22	0.24
SdLogObs_C_age3+	0.08	0.08
SdLogObs_Q1_age1	0.64	0.48
SdLogObs_Q1_age2+	0.25	0.24
SdLogObs_Q3_age1	-	0.37
SdLogObs_Q3_age2+	-	0.26
rho	0.81	0.92

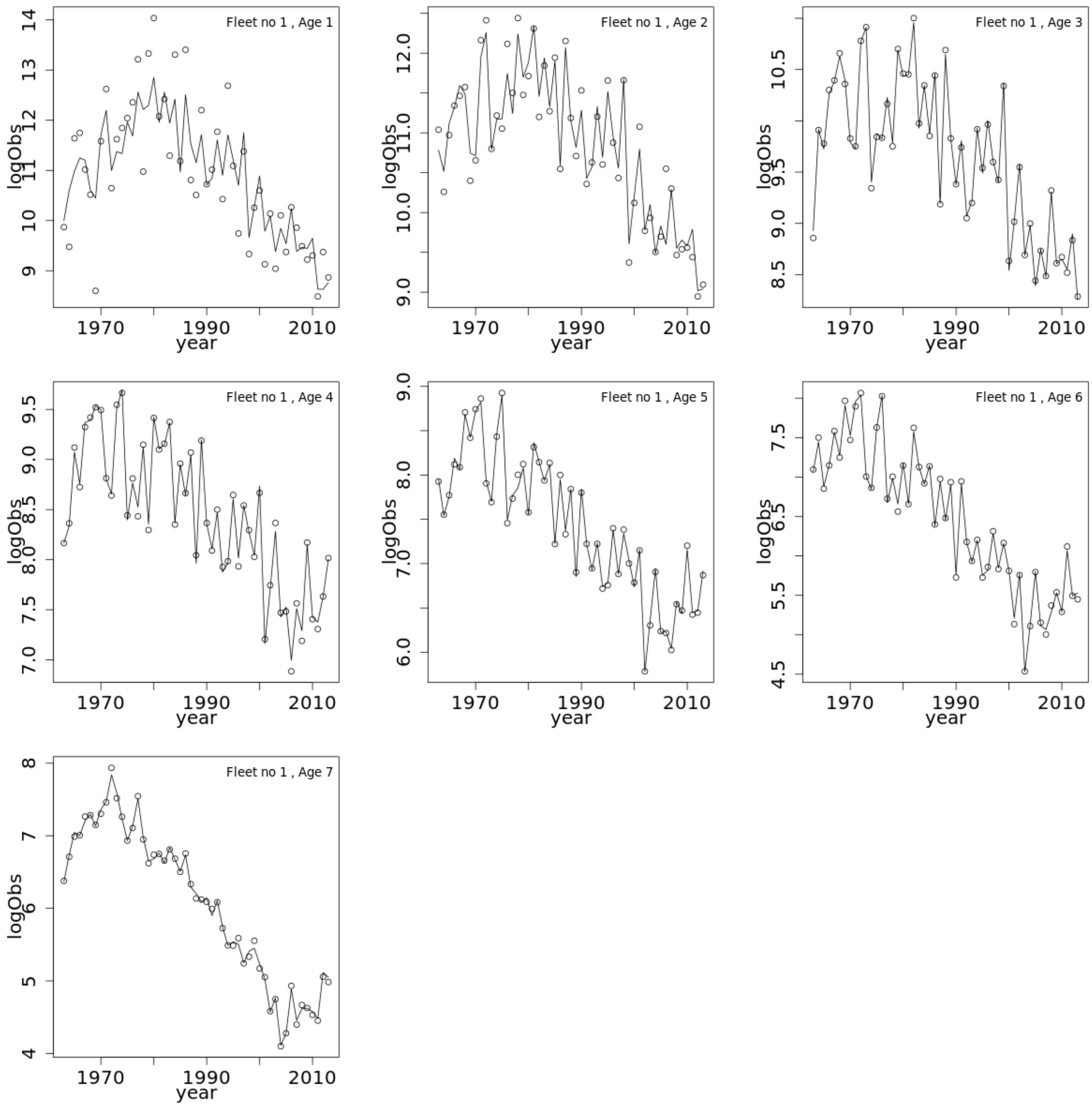


Figure 3.6.4.3.4. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. Fits to the catch-at-age data for the final WKNSEA 15 assessment.

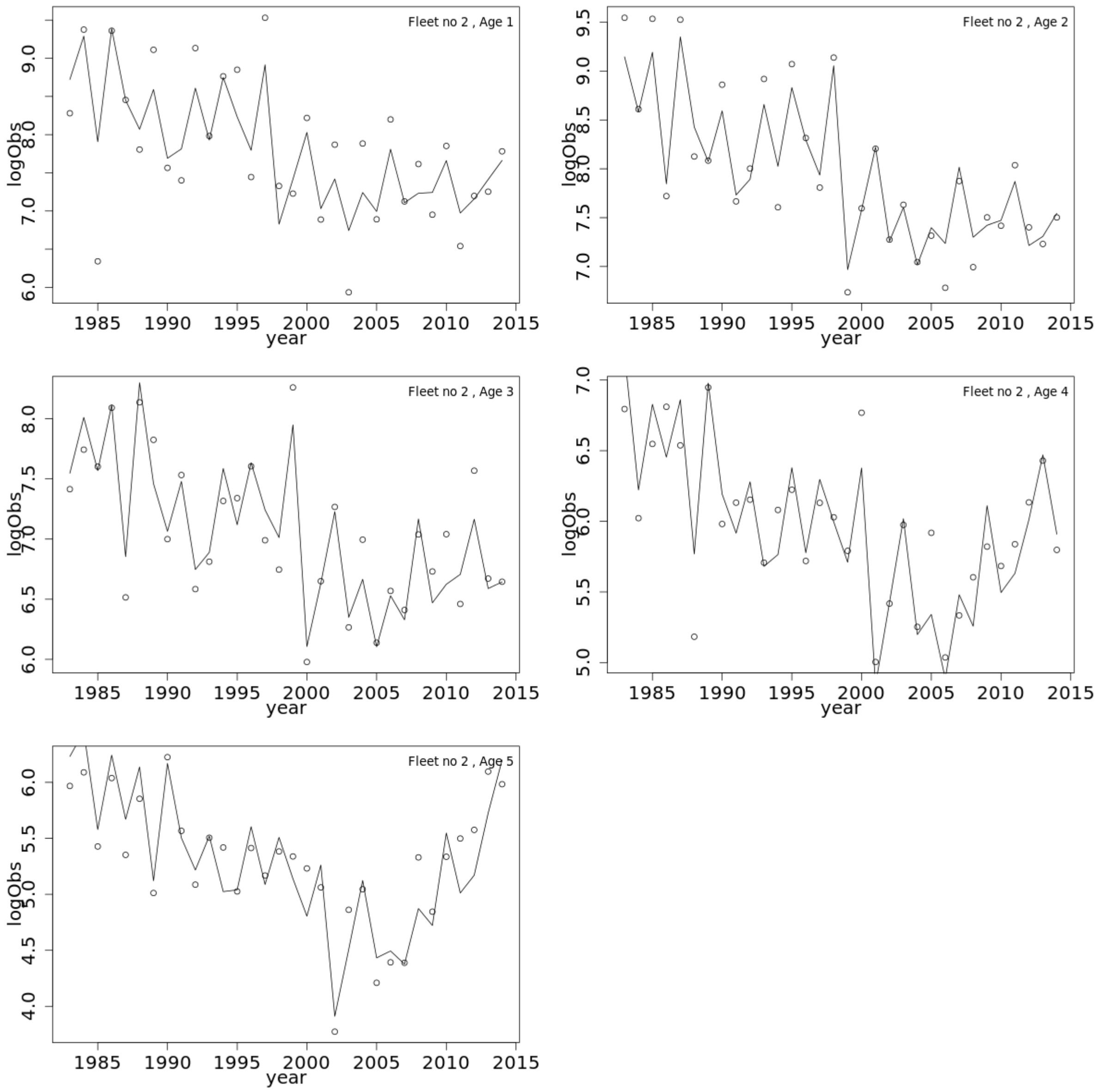


Figure 3.6.4.3.5. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. Fits to the GAM-based Q1survey index for the final WKNSEA 15 assessment.

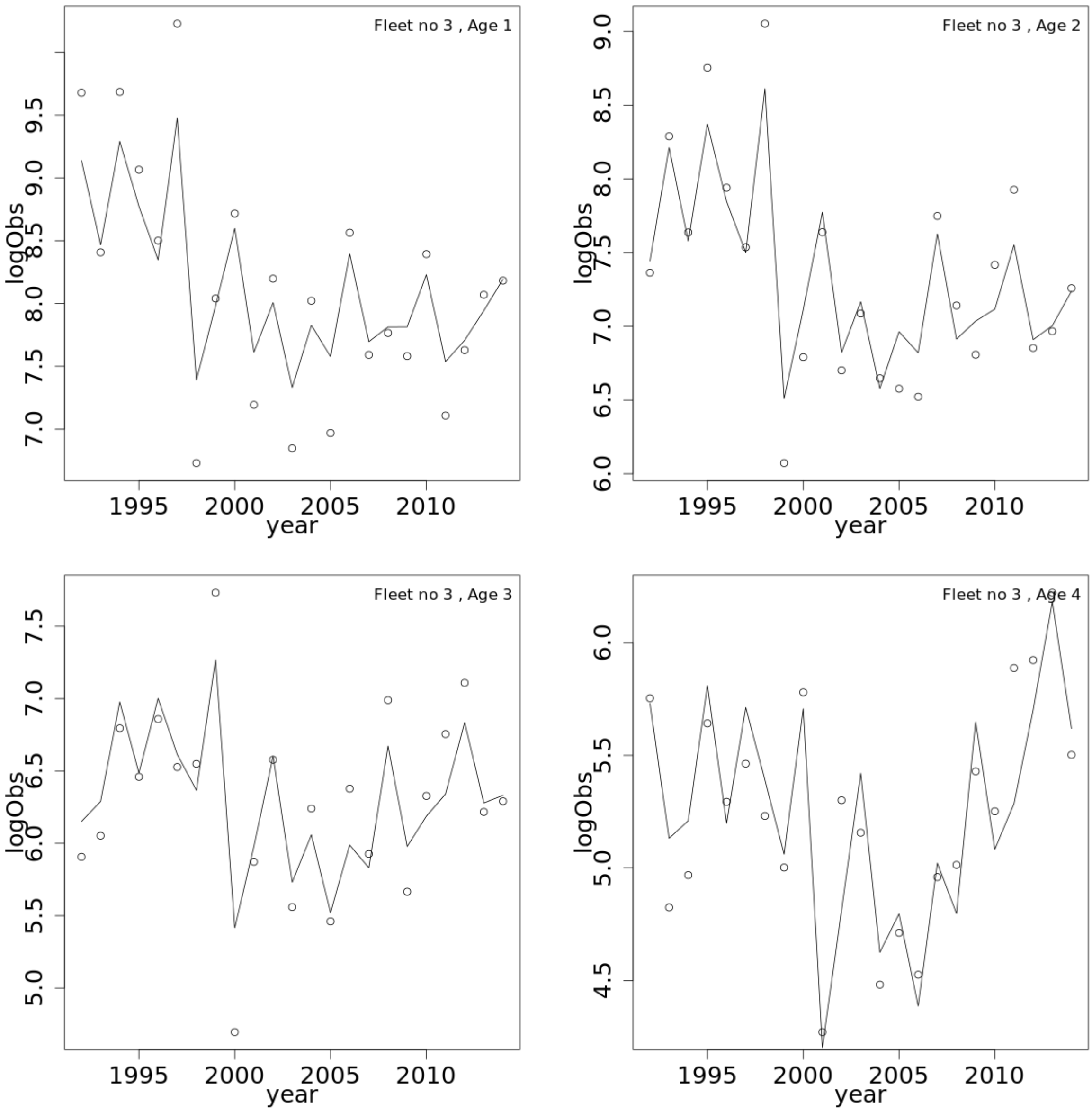


Figure 3.6.4.3.6. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. Fits to the GAM-based Q3survey index for the final WKNSEA 15 assessment.

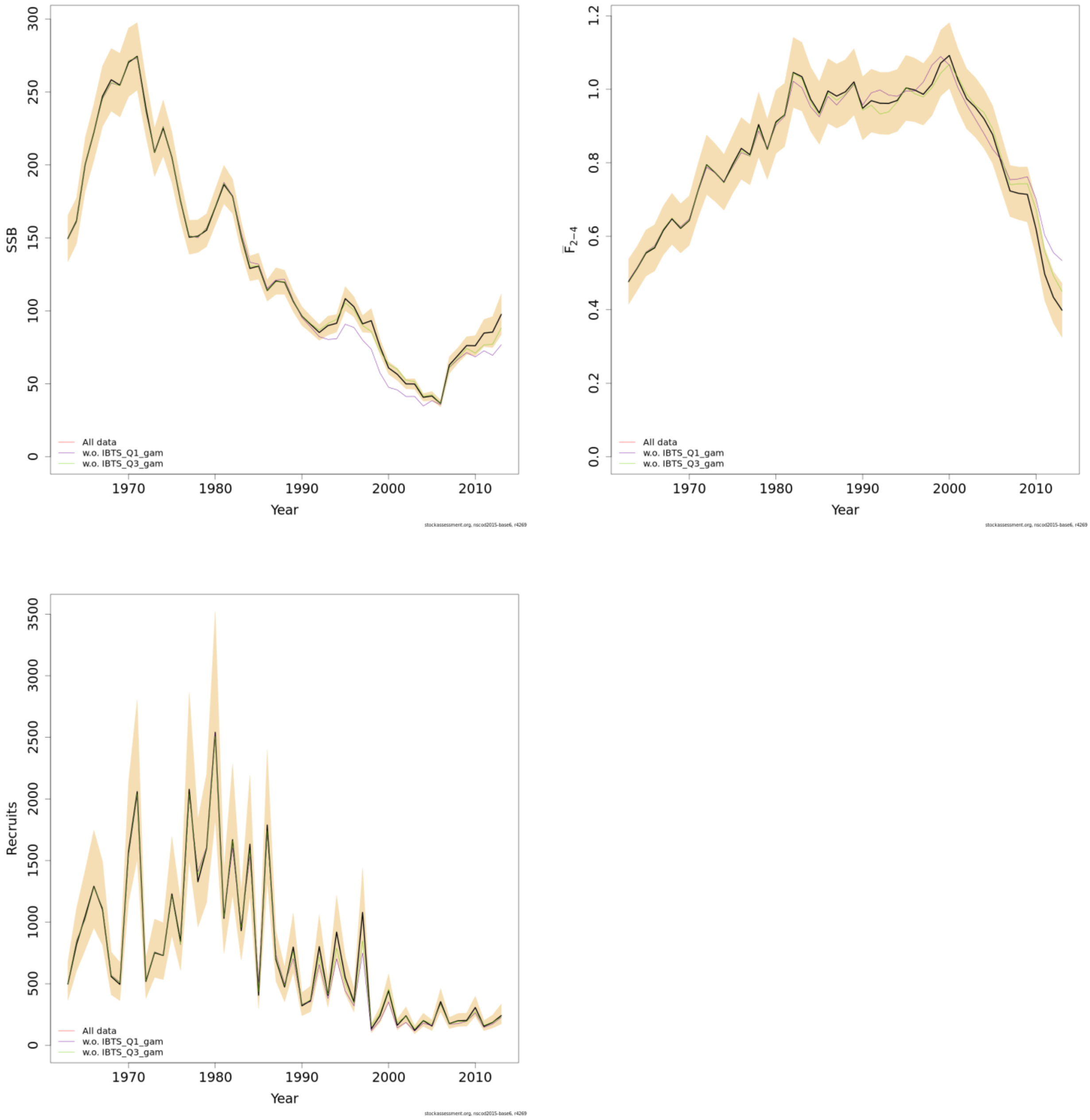


Figure 3.6.4.3.7. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. Leave-one-out runs, where each survey is left out of the model fit in turn (pink=without Q1 and green=without Q3; the black line with 95% confidence interval as a shaded region includes all data).

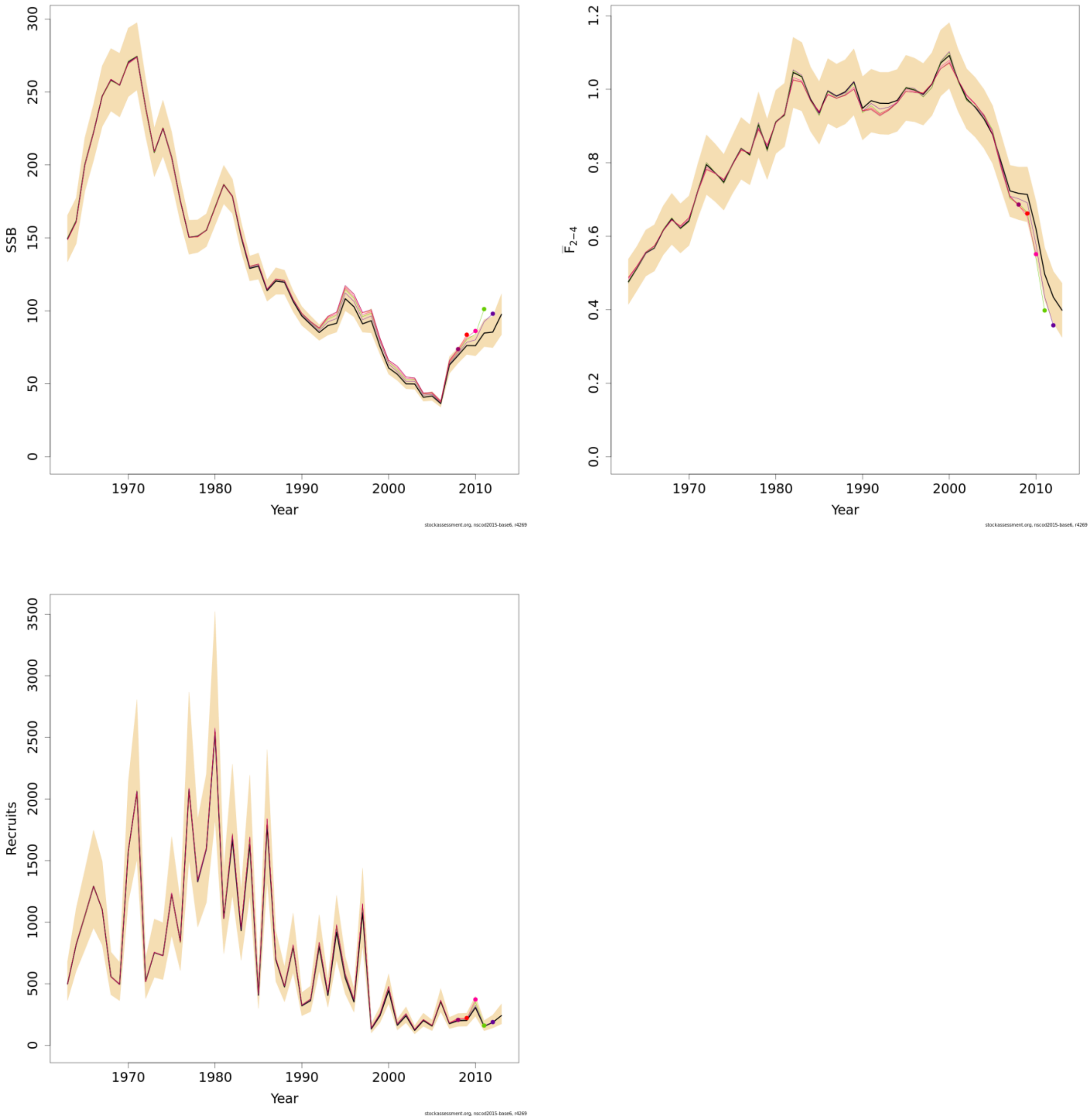


Figure 3.6.4.3.8. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. Retrospective estimates (6 years) for the final WKNSEA 15 assessment. Estimated yearly SSB (top-left), average fishing mortality (top-right) and recruitment age 1 (bottom), together with corresponding point-wise 95% confidence intervals shown for the full dataset run.

3.7 Short term projections

The May forecast

Forecasting takes the form of short-term stochastic projections (De Oliveira and Nielsen, WD7). These projections have in the past been carried out by starting at the final year's estimates, and the covariance matrix of those estimates. However, estimates of survivors are also available, and it is recommended that they form the starting point for the projections. A total of 1000 samples are generated from the estimated distribution of these estimates, with recruitment being sampled with replacement from the year 1998 to the final year of catch data (a period during which recruitment has been low). These replicates are then simulated forward according to model and forecast assumptions (Table 3.7.1), using the usual exponential decay equations, but also incorporating the stochastic survival process (using the estimated survival standard deviation) and subject to different catch-options scenarios.

Table 3.7.1. Forecast assumptions. [Note that the values that appear in the catch options table of the advice sheet are medians from the distributions that result from the stochastic forecast.]

Initial stock size	Starting populations are simulated from the estimated distribution at the start of the intermediate year (including co-variances).
Maturity	Average of final three years of assessment data
Natural mortality	Average of final three years of assessment data.
F and M before spawning	Both taken as zero.
Weight-at-age in the catch	Average of final three years of assessment data.
Weight-at-age in the stock	Assumed to be the same as weight-at-age in the catch.
Exploitation pattern	Fishing mortalities taken as a three year average scaled to the final year.
Intermediate year assumptions	Multiplier reflecting intended changes in effort (and therefore F) relative to the final year of the assessment
Stock–recruitment model used	Recruitment for the intermediate year onwards (the year the WG meets) is sampled, with replacement, from 1998 to the final year of catch data.
Procedures used for splitting projected catches	The final year landing fractions are used in the forecast period.

The October forecast

Since the Q3 index is now being re-introduced into the assessment, there is an opportunity to update the forecast in October following the NS-IBTS Q3 survey. It is recommended that the usual procedure be used to establish whether to re-open advice in the autumn (as described in ICES-AGCREFA 2008, and illustrated by De Oliveira and Nielsen, WD8 for North Sea cod). Once it has been established that advice should be re-opened for North Sea cod, the recommended procedure is to then re-run the assessment and forecast with the new Q3 data included, but to use the actual SAM estimate of recruitment for the intermediate year (the year following the final year of catch data), with recruitment for the years following the intermediate year being resampled, with replacement, from the period 1998 to the final year of catch data.

3.8 Appropriate reference points (MSY)

3.8.1 Reference points used so far

Table 3.8.1. Summary table of current stock reference points.

Reference point	Value	Technical basis
Current F_{MSY}	0.19	F_{MAX} 2010, within the range of fishing mortalities consistent with F_{MSY} (0.16–0.42).
Current B_{lim}	70 000 t	B_{loss} (~1995).
Current B_{PA}	150 000 t	B_{PA} = Previous MBAL and signs of impaired recruitment below 150 000 t.
Current $MSYB_{trigger}$	150 000 t	Default value B_{PA}

3.8.2 Source of data

Data used to derive stock–recruitment relationships and to conduct the MSY interval analysis were taken from the FLStock object created during ICES WKNSEA from the final SAM benchmark assessment.

3.8.3 Stock–recruitment relationship and new B_{lim} and B_{PA} reference points

The usage of a time varying maturity ogive increased the SSB values especially in the last two decades. This altered the SRR compared to the SRR from the latest accepted assessment carried out during WGNSSK 2014 (Figure 3.8.1). Therefore, it is necessary to re-estimate the reference points B_{lim} and B_{PA}. The so far used B_{lim} (70 000 tonnes) was estimated in 1999 and constitutes B_{loss} as observed in the assessments of that time.

For many stocks inside ICES the break point of the Hockey-Stick SRR is used as B_{lim}. However, it becomes obvious that there are periods of high and low recruits per SSB (Figure 3.8.2).These changes over time in R per SSB are discussed in literature to be caused by various environmental factors (e.g. O'Brien *et al.*, 2000; Beaugrand *et al.*, 2003; Kempf *et al.*, 2009) but also changes in the stock reproductive potential and stock structure are discussed (see Sections 3.1 and 3.6.3 for details). Therefore, to just use the breakpoint from a SRR which spans over different environmental and recruitment regimes was seen as not appropriate. Instead, it was suggested to use the biomass in 1996 as B_{lim}. The SSB in 1996 produced the last outstanding year class (1 079 490 thousands recruits) that was above the average observed between 1963 and 1996 (1 023 352 thousands) when the stock produced relatively high recruitment compared to recently observed values. Therefore, it can be argued that a SSB above the observed one in 1996 has the potential to produce high recruitment under sufficiently good environmental conditions and therefore impaired recruitment because of a too low SSB is avoided. The agreed benchmark assessment estimated the SSB in 1996 at103 000 tonnes. This leads to a B_{PA} = $B_{trigger}$ of 1.4 x 103 000 tonnes = 144 000 under the default rules.

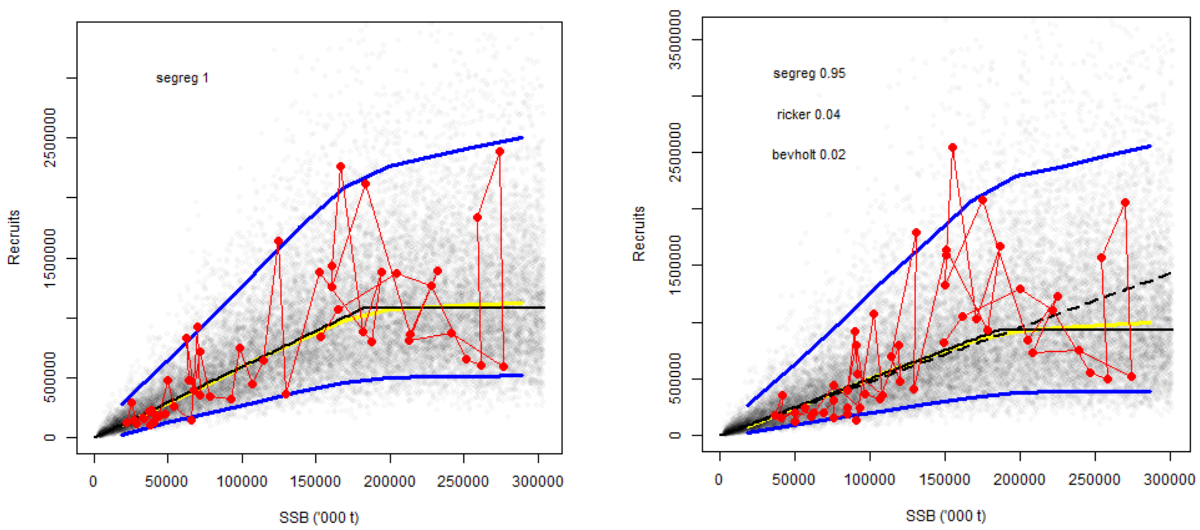


Figure 3.8.1. Stock–recruitment relationship for North Sea cod. Left: WGNSSK 2014 assessment. Right: WKNSEA 2015 assessment.

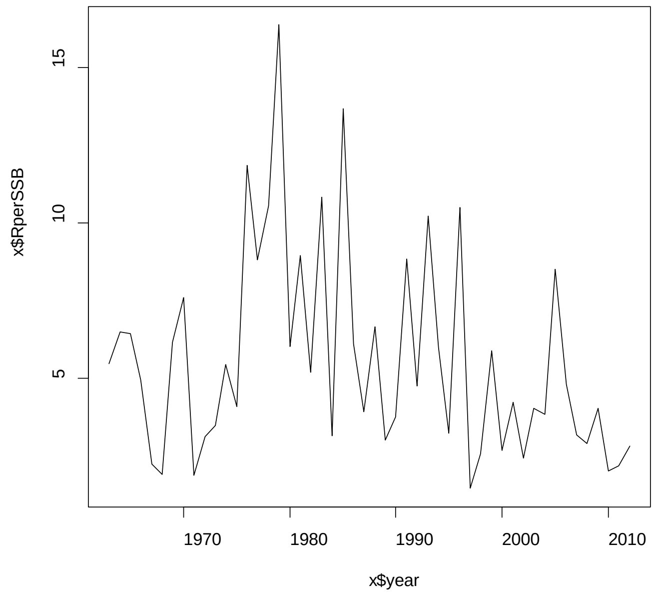


Figure 3.8.2. Recruitment per SSB over time.

3.8.4 Methods and settings used to determine ranges for F_{MSY}

All analyses were conducted with Eqsim in accordance with the guidelines from ICES WKMSYREF III (ICES-WKMSYREF3 2014). The assessment error in the advisory year and the autocorrelation was derived from the results of a recent evaluation of HCRs (De Oliveira, 2013), including the HCR used in the current plan. The approach was to compare the intended target F (the F from application of the current plan HCR) with the realised F:

$$F^{i}_{rat,y} = F^{i}_{realised,y} / F^{i}_{HCR,y}$$

This is derived for each projection year *y* (2014–2032) and simulation *i* (100 in total). Then for each simulation *i*, the error parameters are estimated by calculating the standard deviation and serial correlation of the vector $\ln(\underline{F}^{i}_{rat})$ (each element representing a year), and taking the mean across simulations. The associated R code is as follows:

```
frat<-window(fCbar,start=2014,end=2032)/window(ftgt,start=2014,end=2032)
cv<-apply(log(frat),6,function (x) sd(c(x)))
rho<-apply(log(frat),6,function (x) acf(c(x))$acf[2])
cv <- cv*sqrt(1-rho^2)
meancv<-mean(cv)
meanrho<-mean(rho)
```

This leads for North Sea cod to a cv of 0.24 and a phi of 0.27.

The new suggested values for B_{lim}, B_{PA} and $B_{trigger}$ were used in all Eqsim analyses (see above). Settings for the analysis are given in Table 3.8.2.

Table 3.8.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full dataseries (years classes 1963–2012)	R per SSB shows signs of reduced productivity especially after 1998. However SSB and recruitment went down in parallel together with an increase e.g. of temperature. Observations of recruitment at higher SSB (and better age structure) in the current climatic regime are needed to judge whether the currently observed low recruitment is caused by the low SSB (and unfavourable age structure) or unfavourable environmental conditions. According to WKMSYREF III rules only the segmented regression curve was used for the analysis. The Ricker has its peak well outside the observed range of S–R pairs, with the Beverton–Holt function almost identical to the Ricker within this observed range, both fitting almost a straight line through the origin.
Exclusion of extreme values (option extreme.trim)	No	
Mean weights and proportion mature; natural mortlaity	2009–2013	There is an increasing trend in mean weight-at-age over the last ten years. There is also an increasing trend in predation mortality in the latest years. Therefore a five year time period was chosen instead of a ten year period.

Data and parameters	Setting	Comments
Exploitation pattern	2009–2013	There is no change in exploitation pattern in the last ten years. However, substantial unallocated removals have been estimated for the years 2004 and 2005 in the assessment. Therefore, a five year time period was chosen instead of a ten year period.
Assessment error in the advisory year. CV of F	0.24	Estimated from recent MSE simulations
Autocorrelation in assessment error in the advisory year	0.27	Estimated from recent MSE simulations

3.8.5 Final Eqsim run

For the final Eqsim run, yield excludes discards, with F_{MSY} being taken as the peak of the median yield curve. However, the observed discards for age 3+ were added to the landings. Under the landing obligation, former discards above the minimum conservation reference size are landed and sold and therefore belong to the "wanted catch". Discarded fish at age 3+ can be assumed to be all above the minimum conservation reference size.

The F_{MSY} range is calculated as those F values associated with median yield that is 95% of the peak of the median yield curve. $F_{P.05}$, is the F value associated with risk 1=5% (where risk 1 is as defined in ICES-WKGMSE 2013).

The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was 0.22 (Figure 3.8.3). The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was estimated at 0.34 and the lower bound at 0.14. $F_{P.05}$ (based on the new B_{lim}=103 000) was estimated at 0.9 and therefore the upper bound does not need to be restricted because of precautionary limits. The median of the SSB estimates at F_{MSY} was 1 238 971 t and therefore well outside historically observed values (Figure 3.8.4).

When applying the ICES MSY harvest control rule with a $B_{trigger}$ at 144 000 t, median F_{MSY} was estimated at 0.22 with a lower bound of the range at 0.14 and an upper bound at 0.34 (Figure 3.8.5). The $F_{P.05}$ value increased to 1.07. The median of the SSB at F_{MSY} was also here well above observed historic values (Figure 3.8.6).

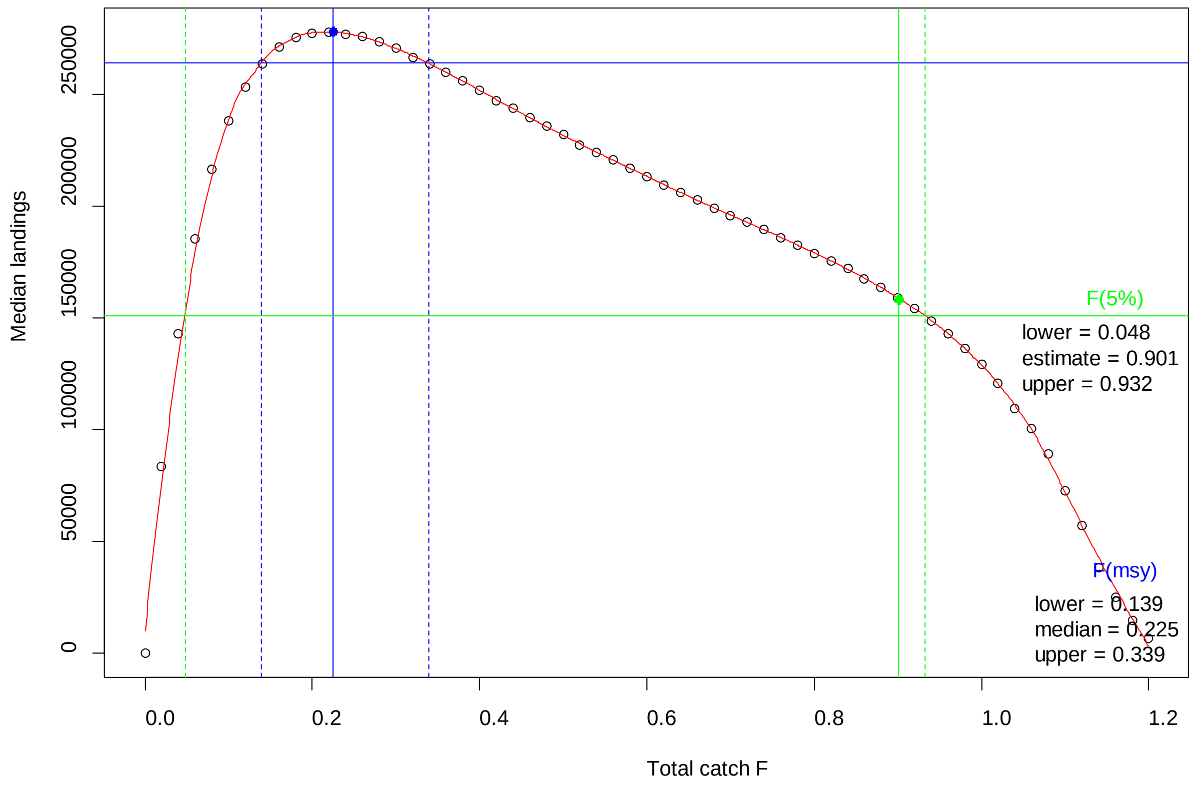


Figure 3.8.3. Cod, with fixed F exploitation. Left panel: Median landings yield curve with estimated reference points. Blue lines: FMSY estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{P.05}$=F(5%) estimate (solid) and range at 95% of yield implied by F(5%) (dotted).

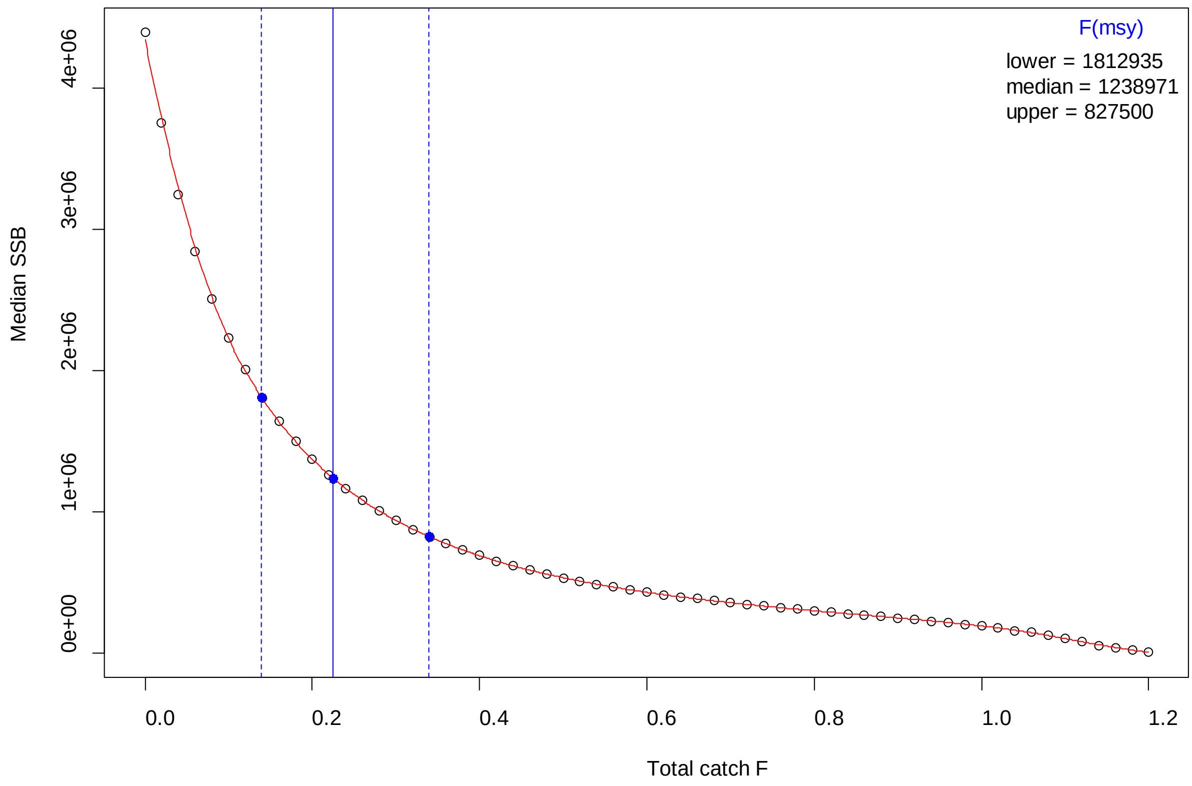


Figure 3.8.4. Cod (fixed F): median SSB blue lines show location of FMSY (solid) with 95% yield range (dotted).

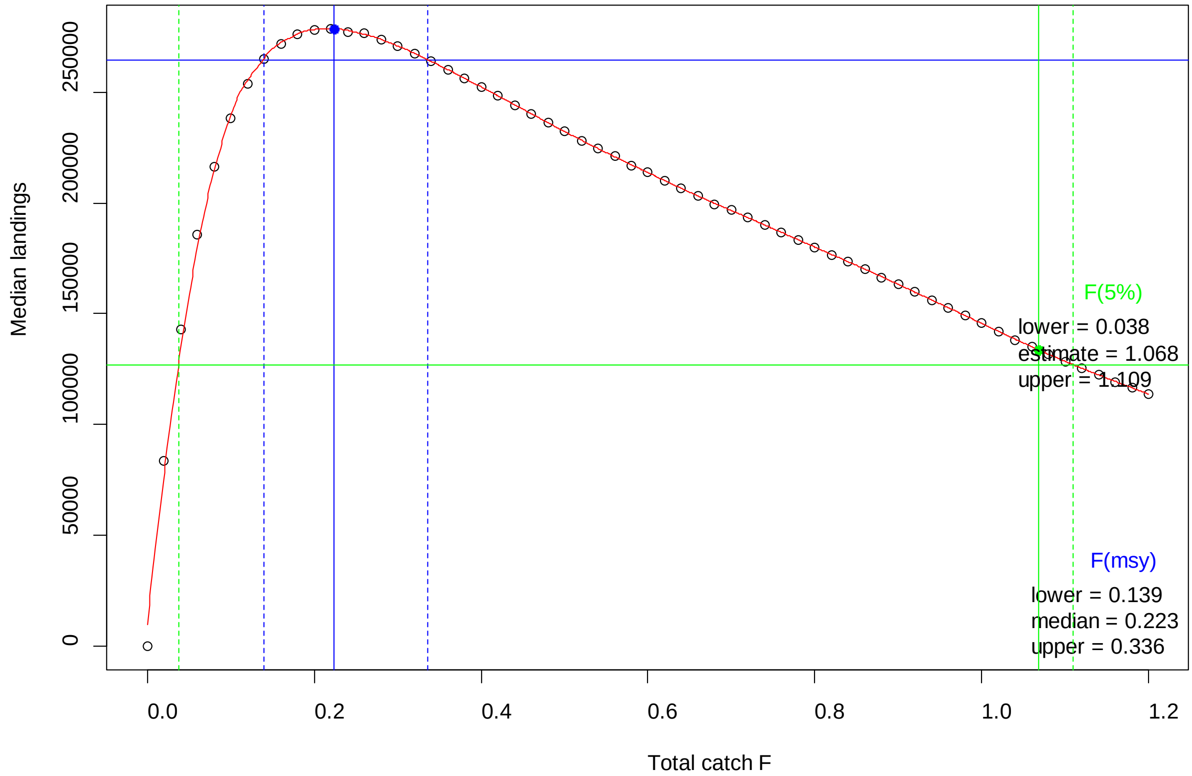


Figure 3.8.5. Cod when applying the ICES MSY harvest control rule with a $B_{trigger}$ at 144 000 tonnes. Median landings yield curve with estimated reference points. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: F(5%) estimate (solid) and range at 95% of yield implied by $F_{P.05}$=F(5%) (dotted).

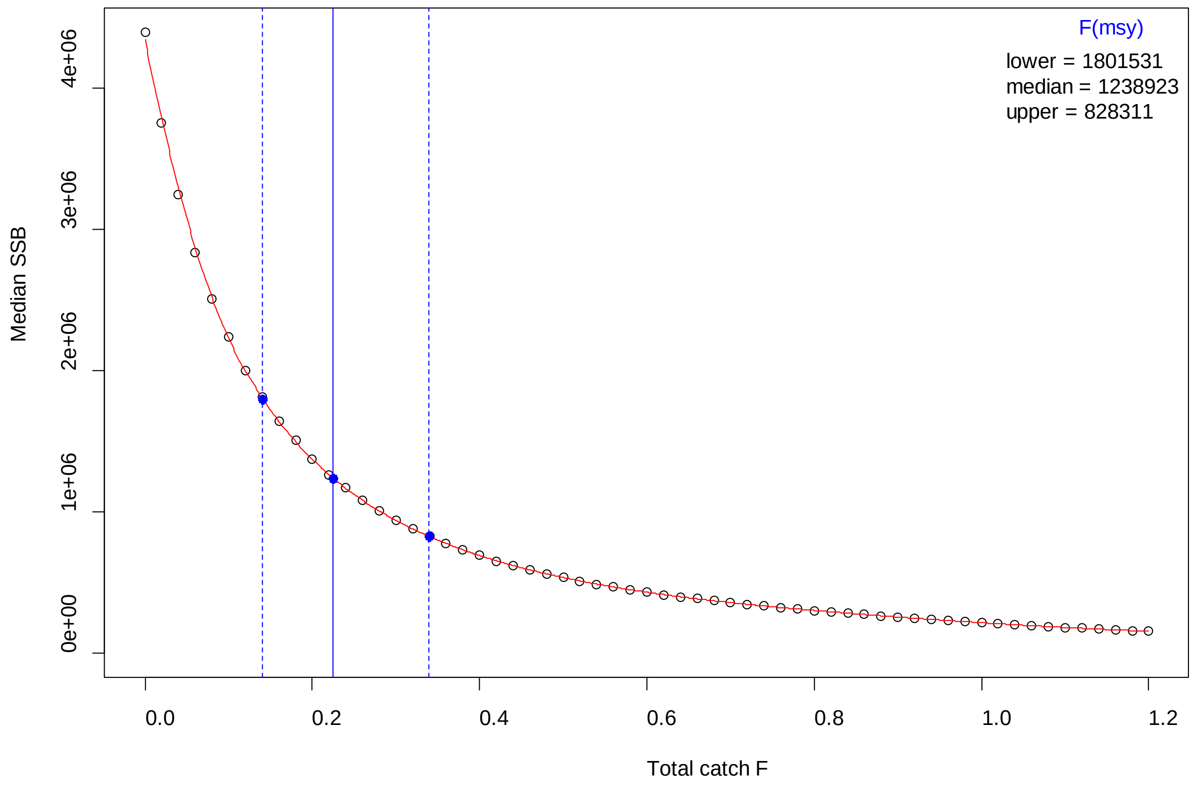


Figure 3.8.6. Cod when applying the ICES MSY harvest control rule with a $B_{trigger}$ at 144 000 t. Median SSB blue lines show location of FMSY (solid) with 95% yield range (dotted).

3.8.6 Sensitivity runs

Two sensitivity analyses were carried out, one considering a truncated pessimistic stock–recruit time-series (under the assumption that recruitment is environmentally driven and recruitment stays at currently (year classes 1997–2012) observed low levels despite an increase in SSB; Figure 3.8.7), and the other assuming that discards-at-age 3 onwards still continue. Only runs without HCR are described here.

For the first sensitivity test (pessimistic recruitment), the F_{MSY} value (0.23) and range (0.14–0.34) were insensitive to truncating the stock–recruit time-series to the currently observed low recruitment, and even though the $F_{P.05}$ value is reduced to 0.37, this would still not alter the upper bound of the F_{MSY} range (Figure 3.8.8). However, because of different S–R assumptions MSY yield and SSB values are affected (MSY reduced to 54 373 tonnes, and median SSB at F_{MSY} reduced to ~0.243 million tonnes).

For the second sensitivity test, the F_{MSY} value (0.20) and range (0.14–0.33) remained relatively insensitive to optimising yield when yield did not included fish discarded from ages 3 onwards (Figure 3.8.9). The MSY yield and SSB values only changed slightly (~257 thousand tonnes and ~1.348 million tonnes); the $F_{P.05}$ value effectively did not to change since $F_{P.05}$ depends on total F, and not on how F is split into landings and discards.

In conclusion the results on F_{MSY} ranges presented are robust to current recruitment assumptions and discarding practices. However, the results also show that the yield and SSB that can be expected is highly sensitive to the assumptions made for future recruitment. Therefore, to define $B_{trigger}$ via B_{MSY} is not possible for this stock until more observations are available about whether the current environmental conditions allow for higher recruitment with increasing SSB.

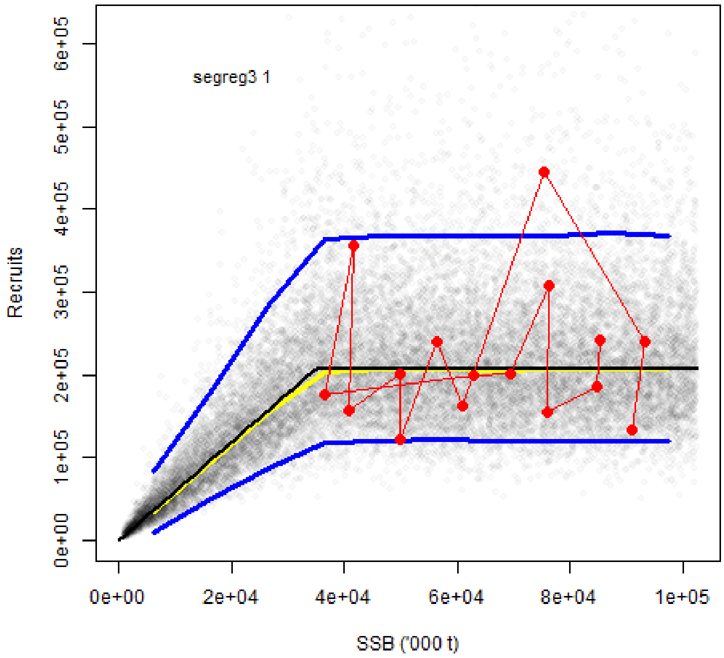


Figure 3.8.7. Truncated stock–recruitment relationship for year classes 1997 to 2012.

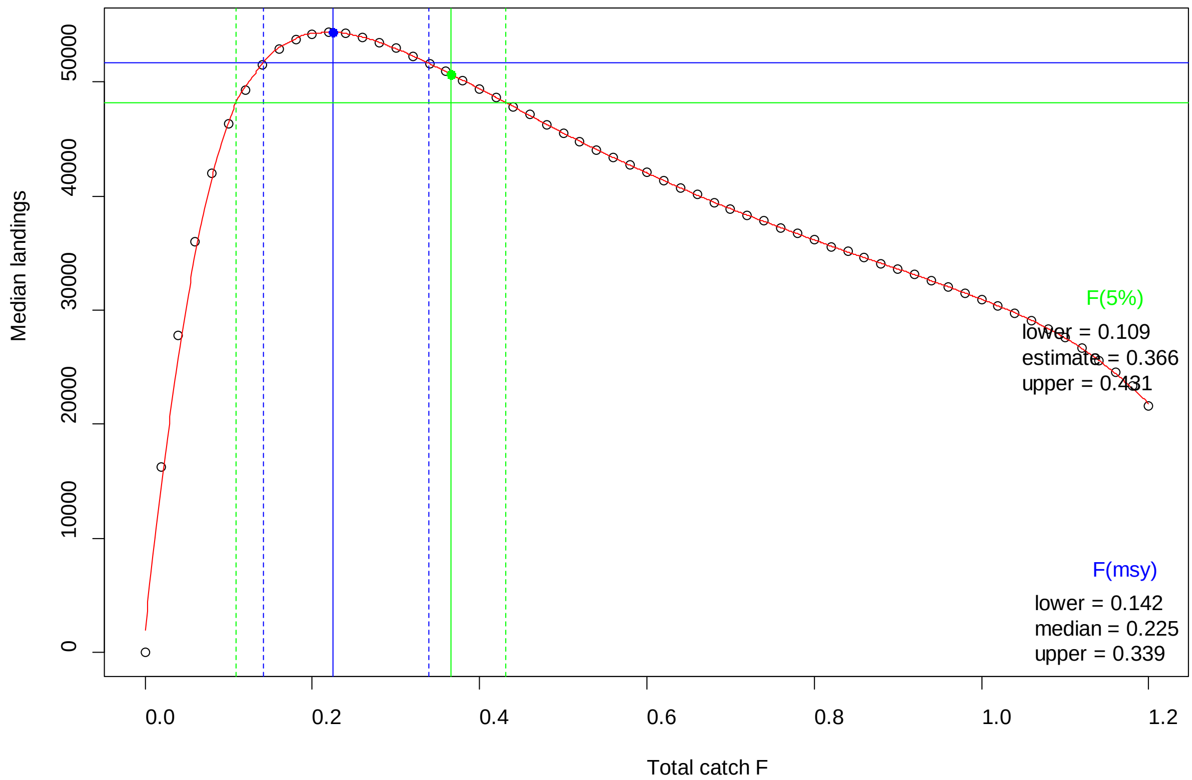


Figure 3.8.8. Cod without applying the ICES MSY harvest control rule and truncated stock–recruitment relationship. Median landings yield curve with estimated reference points. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{P.05}$=F(5%) estimate (solid) and range at 95% of yield implied by F(5%) (dotted).

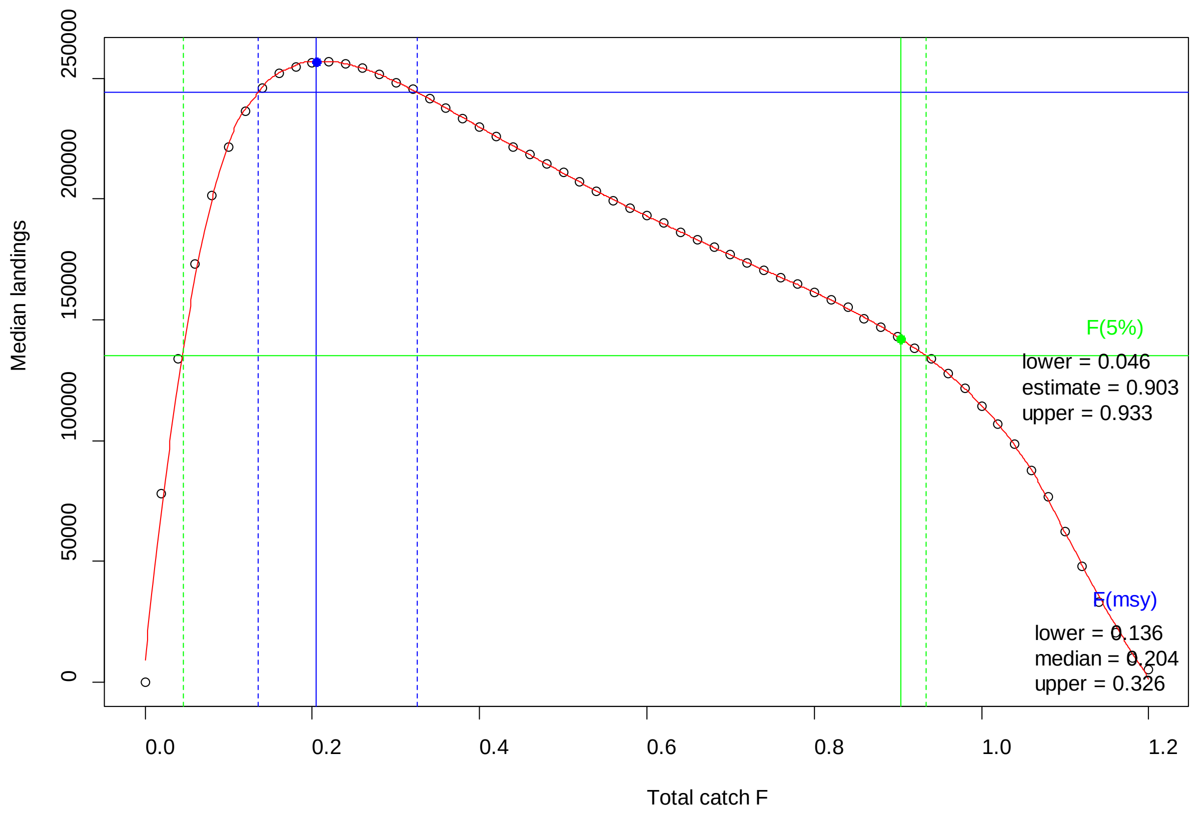


Figure 3.8.9. Cod without applying the ICES MSY harvest control rule and discarding of age 3+ cod. Median landings yield curve with estimated reference points. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{P.05}$=F(5%) estimate (solid) and range at 95% of yield implied by F(5%) (dotted).

3.8.7 Proposed MSY reference points

Table 3.8.3. Summary table of proposed stock reference points for method Eqsim (details in "Final Eqsim run" above).

STOCK	
Reference point	Value
F_{MSY} without $B_{trigger}$	0.22
F_{MSY} lower without $B_{trigger}$	0.14
F_{MSY} upper without $B_{trigger}$	0.34
New $F_{P.05}$ (5% risk to B_{lim} without $B_{trigger}$)	0.9
F_{MSY} upper precautionary without $B_{trigger}$	0.34
$F_{P.05}$ (5% risk to B_{lim} with $B_{trigger}$)	1.07
F_{MSY} with $B_{trigger}$	0.22
F_{MSY} lower with $B_{trigger}$	0.14
F_{MSY} upper with $B_{trigger}$	0.34
F_{MSY} upper precautionary with $B_{trigger}$	0.34
MSY (without HCR)	277 835 t
Median SSB at F_{MSY} (without HCR)	1 238 971 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary; without HCR)	827 500 t
Median SSB upper (median at F_{MSY} lower; without HCR)	1 812 935 t

3.9 Future Research and data requirements

3.9.1 Stock ID

Stock ID is clearly an issue for the North Sea cod stock as currently defined (Section 3.1), and future research should focus on the possibility of conducting assessments that allow for multiple stocks. The ability to allocate catch and survey data to stock, particularly where these data come from areas of overlap or substantial mixing, and to account for uncertainty about overlap/mixing rates, would need to be fully explored. In the meantime, the survey biomass trends in substock areas need to be monitored.

3.9.2 InterCatch

The recent data call (Autumn 2014) allowed catch estimates to be derived within InterCatch for the period 2002–2013, but the first attempt did not combine Areas IV and VIId for the period 2004–2008 (Section 3.6.1). Because the sampling in VIId was relatively poor for this period, it is recommended that VIId be combined with IV for both discard ratio and age allocation.

3.9.3 Survey

The current NS-IBTS survey design is such that only Sweden covers the Skagerrak. Furthermore, the replacement of the "ARG" vessel with the "DANS" vessel in the Skagerrak in 2011, together with a simultaneous change in the survey design by Sweden to a more randomised set of haul positions in Q3 (but not in Q1) coincides with an increase in abundance in that area. It is therefore difficult for any model to separate out the effects of changing both the survey vessel and sampling positions from a simultaneous increase in abundance (Section 3.6.2). It is therefore recommended that:

- the stated NS-IBTS design of vessel overlap (see NS-IBTS manual) be fully implemented in the Skagerrak (i.e. other vessels in addition to "DANS" sampling Skagerrak and, if possible, "DANS" sampling in the North Sea as well to ensure spatio-temporal overlap that will allow vessel effects to be estimated);
- the model specifications of the Delta-GAM be re-evaluated once more samples have been collected from "DANS;"
- swept-area be used for standardisation instead of haul duration to remove possible bias from different riggings or gear specifications.

3.9.4 Maturity

The estimation of maturity-at-age (Section 3.6.3.2) requires further attention to consider the base approach for weighting subarea differences in maturity-at-age and the importance of sampling intensity to the inter-annual variation in maturity estimates. Furthermore, concern was expressed that accounting for the increase in maturity-at-age may give the impression that the spawning stock is in a better condition than it actually is, given the possibility of lower fecundity of younger age groups and the potential for a maternal age effect on survival (as was found for North Sea haddock). However, further work is needed to explore whether there is any causal significance of spawner age, accounting for the other factors influencing early survival rate such as predation pressure and the effects of warming, before this metric can be considered as a measure of reproductive potential.

3.9.5 Forecast investigation

A comparison of forecast assumptions with subsequent realised values was presented during the benchmark (see De Oliveira and Nielsen, WD7) in order to explore potential biases in the North Sea cod short-term forecast methodology, but this comparison focussed on the 2013 forecast and subsequent 2014 assessment. Further such comparisons are needed, stretching further back in time, to get a better idea of these potential biases.

3.10 References

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4 Sole in Subarea IV

4.1 Stock ID and substock structure

Stock structure of North Sea sole was not discussed during the WKNSEA 2015. The North Sea sole is defined to be a single stock in ICES Area IV. The stock assessment is done accordingly, assuming sole in the North Sea is a closed stock. This approach was supported by a thorough population genetic analysis using neutral microsatellite markers and a miotochondrial marker by Cuveliers *et al*. (2012). This study showed genetic differences at a large scale, along a latitudinal gradient from the Skagerrak/Kattegat to the Bay of Biscay. At a smaller spatial scale within the North Sea however, the subpopulations seemed genetically homogeneous, probably due to a high level of gene flow and/or the high effective population size preventing strong effects of genetic drift. With respect to the temporal aspect, a remarkable high genetic stability was found from the 1950s up to present (Cuveliers *et al*., 2011).

4.2 Issue list

This section summarizes the perception of the issues brought forward when the benchmark was planned. The primary aim of this benchmark is to improve the data used in the assessment. There are no major issues related to the assessment model and with the data available there are no significant obstacles to producing an acceptable model fit. This may change however, with the inclusion of new indices. In recent WGNSSK meetings both XSA and SAM have been used, giving similar results despite fundamental differences in model structure.

4.2.1 Discards

Currently no discards are included in the assessment. With the pending landing obligation it is important to include discards into the catch estimates.

Discards will be used in the assessment for the first time, primarily based on Dutch and Belgian data. Full details of the raising process will be provided. Direct discard data estimates are available since 2002 (from observer and self-sampling programs). For discards prior to this two methods will be explored: reconstructions based on year-class strength, weights-at-age and fishing effort (Rijnsdorp and van Keeken, 2005) and using an assessment model that internally estimates discards (Aarts and Poos, 2009).

4.2.2 Index data

Currently, the XSA based stock assessment uses two research vessel survey indices (SNS and BTS-ISIS), and a commercial lpue from the Dutch beam trawl fleet >221 kW. A number of issues should be addressed with respect to these index series.

- Belgian BTS data from the southwestern part of the North Sea could be used to create an age-structured index of abundance.
- The German Solea survey could be used to create an age-structured index of abundance. Previously used in the assessment (up to 1995) but dropped after data were not available for a couple years.
- The Dutch beam-trawl fleet has seen substantial developments in gear use. The traditional beam trawl was gradually replaced by beam with wing profiles (“sumwings”) and puls trawls. These changes likely affect the

catchability of the beam-trawl gear, and alternative lpue indices from the Dutch beam trawl-fisheries in the North Sea will be examined.

Attempts to explore the potential to combine adjacent surveys into a single index of abundance from the whole distribution area were not undertaken during this benchmark. This will be looked into by WGBEAM in the near future.

4.2.3 Estimates of uncertainty in the assessment

The current assessment model (XSA) does not provide uncertainty estimates for estimated values. Other models can better handle incomplete discard estimates and provide estimates of uncertainty. So in addition to applying XSA, the AAP model (Aarts and Poos, 2009) and SAM (State–space assessment model) will also be fit. Model fits (maximum likelihood) will be compared and various diagnostics carried out.

4.2.4 Knife-edge maturity ogive

Natural mortality is assumed constant over ages and years (0.1, except for 1963 where a value of 0.9 was used to take into account the effect of the severe winter) and a knife-edge maturity ogive (assuming full maturation at age 3) is used in the current assessment.

Maturity data for recent years (2007–2008, 2010–2012, potentially longer) are available from the German Solea survey which is conducted during spawning season. Rijnsdorp *et al*. (2004) analysed changes in growth and maturity over time for sole and plaice in the North Sea and found indications of maturation at younger ages in the early 2000s compared to the past.

It is likely not possible to construct a time-varying ogive for the whole time-series, but a data-informed ogive that is constant over time would still represent an improvement over the knife-edge ogive currently used.

4.3 Scorecard on data quality

The scorecard on data quality was not used during the benchmark.

4.4 Multispecies and mixed fisheries issues

North Sea sole is taken mainly in a mixed flatfish fishery by beam trawlers in the southern and southeastern North Sea (see Figure 1 in Stock Annex). Directed fisheries are also carried out with seines, gillnets, and twin trawls, and by beam trawlers in the central North Sea. The minimum mesh sizes enforced in these fisheries (80 mm in the mixed beam-trawl fishery) are chosen such that they correspond to the Minimum Landing Size for sole (24 cm). Due to the minimum mesh size, large numbers of (undersized) plaice are discarded. Fleets exploiting North Sea sole have generally decreased in number of vessels in the last ten years. However, in some instances, reflagging vessels to other countries has partly compensated these reductions. Besides having reduced in number of vessels, the fleets have also shifted towards two categories of vessels: 2000HP (the maximum engine power allowed) and 300 HP (the maximum engine power for vessels that are allowed to fish within the 12 mile coastal zone and the plaice box).

In recent times the days at sea regulations, high oil prices, and different patterns in the history of changes in the TACs of plaice and sole have led to a transfer of effort from the northern to the southern North Sea. Here, sole and juvenile plaice tend to be more abundant leading to an increase in discarding of small plaice. A change in efficiency of the commercial Dutch beam trawl fleet has been described by Rijnsdorp *et al*. (2006). This change in efficiency is related to changes in targeting and the change in spatial distribution (Quirijns *et al*., 2008; Poos *et al*., 2010). An analysis of the changes in efficiency by the 2006 North Sea demersal assessment working group showed that the increase in efficiency was especially pronounced between 1990 (the beginning of the time-series for which data were available) to 1996–1998, after which the efficiency seemed to decrease slightly. The data for which this could be analyzed spanned 1990 to 2002, so the efficiency changes since 2002 could not be estimated.

More information on fishing effort restrictions and technical measures (mesh size regulations, minimum landing size, gear restrictions and closed areas) can be found in the stock annex.

4.5 Ecosystem drivers

Sole growth rates in relation to changes in environmental factors were analysed by Rijnsdorp *et al*. (2004). Based on market sampling data it was concluded that both length-at-age and condition factors of sole increased since the mid-1960s to a high point in the mid-1970s. Since the mid-1980s, length-at-age and conditions have been intermediate between the troughs (1960) and peaks (mid-1970s). Growth rates of the juvenile age groups were negatively affected by intra-specific competition. Length of 0-group fish in autumn showed a positive relationship with sea temperature in the 2nd and 3rd quarters, but for the older fish no temperature effect was detected. The overall pattern of the increase in growth and the later decline correlated with temporal patterns in eutrophication; in particular the discharge of dissolved phosphates from the Rhine.

Trends in the stock indicators e.g. SSB and recruitment, did not coincide, however, with observed patterns in eutrophication. In recent years no changes in the spatial distribution of juvenile and adult soles have been observed (Grift *et al*., 2004; Verver *et al*., 2001). The proportion of undersized sole (<24 cm) inside the Plaice Box did not change after its closure to large beamers and remained stable at a level of 60–70% (Grift *et al*., 2004). The different length groups showed different patterns in abundance. Sole of around 5 cm showed a decrease in abundance from 2000 onwards, while groups of 10 and 15 cm were stable. The largest groups showed a declining trend in abundance, which had already set in years before the closure.

Mollet *et al*. (2007) used the reaction norm approach to investigate the change in maturation in North Sea sole and showed that age and size at first maturity significantly shifted to younger ages and smaller sizes. These changes occurred from 1980 onwards. Size at 50% probability of maturation at-age 3 decreased from 29 to 25 cm.

4.6 Stock Assessment

4.6.1 Catch; quality, misreporting, discards

Landings data by country are available since 1957. These landings are age structured (Table 4.6.1.1). The Netherlands has the largest proportion of the landings, followed by Belgium. Discard data are available from the Netherlands, where a discard sampling programme has been carried out on board 80 mm beam-trawl vessels fishing for sole since 2000. At the start of the Dutch discards sampling programme only observer data were collected, from a relatively small fraction of the Dutch beam-trawl fleet. Since 2010, the observer programme is complimented by a self-sampling programme, with larger sample sizes, spread over several fisheries. Belgium documents discards through an observer programme since 2004 in the same fishing métier. The upcoming landing obligation makes it necessary to include discards into the catch estimates. Raising of the discards data for the Netherlands and Belgium was done by simply adding the data for the two sources. Germany, UK and Denmark also delivered discard data on North Sea sole to WKNSEA 2015, but these were not considered by this benchmark meeting, due to the relatively low contribution of the German exploitation to the total North Sea sole fisheries. For the next WGNSSK meeting, discards have to be raised via InterCatch for all fleets involved in the fishery.

The age-structured discards data indicate that most of the discarding takes place at ages 2–3 (Figure 4.6.1.1; Table 4.6.1.2). Comparing the landings-at-age to the total catch-at-age in the period for which discards samples are available confirms that the discards are a relatively small fraction of the catches, especially for the older ages.

Age and sex compositions and mean weight-at-age in the landings have been available for different countries for different years. Historic data are stored in a database at Imares, while in recent years data are available in InterCatch. In the more recent years, age compositions and mean weight-at-age in the landings have been available on a quarterly basis from Denmark, France, Germany (sexes combined) and the Netherlands (by sex). Age compositions on an annual basis were available from Belgium (by sex). Overall, the samples are representative of around 85% of the total landings. For the final assessment, the age compositions are combined separately by sex on a quarterly basis and then raised to the annual international total. Alternatively, sex separated landings-at-age and weights-at age can be calculated from the data. Since the mid-1990s, annual sole catches have been dominated by single strong year classes (e.g. the 2005 year class).

4.6.2 Surveys

4.6.2.1 Fishery-independent surveys

There are four trawl surveys that were considered for use as tuning indices in the assessment of North Sea sole.

- the BTS-ISIS (Beam Trawl Survey, 1985-now, the Netherlands);
- the SNS (Sole Net Survey, 1970-now, the Netherlands);
- the BTS-Belgica (Beam Trawl Survey, 2006-now, Belgium);
- the BTS-Solea (Beam Trawl Survey, 1976-2012 Germany).

The BTS-ISIS (Beam Trawl Survey) is carried out in the southern and southeastern North Sea in August and September using an 8 m beam trawl (Figure 4.6.2.1). The SNS (Sole Net Survey) is a coastal survey with a 6 m beam trawl carried out in the 3rd quarter (Figure 4.6.2.2). SNS data for the years 2003 and 2012 were omitted from the time-series used in the assessment runs because of changes to the survey design or problems with obtaining sufficient samples. WKFLAT 2010 decided to use only the BTS-ISIS and the SNS surveys as tuning series. From then onwards, the BTS-ISIS and SNS indices, as calculated by WGBEAM, were used for tuning the stock assessment. Time-series for the BTS-ISIS and SNS surveys are given in Figure 4.6.2.3. Internal consistency plots for the BTS-ISIS and SNS surveys are given in Figure 4.6.2.4.

The Belgian BTS (RV Belgica) is carried out in the southern and southwestern North Sea in August and September using a 4 m beam trawl with 40 mm codend and tickler chains. It covers both in- and offshore areas including the Belgian waters, the French part of the North Sea, and UK waters west of 3°E and south of 54°N.

The Belgium age-structured BTS survey was available from 2006 onwards (Table 4.6.2.1). However, the 2006 data show a strong year effect with high estimates for a number of ages (most notably ages 1,4,5,7, and 9, Figure 4.6.2.3). Data available for this year were also recorded differently from the later years in the Belgium survey database. Hence, 2006 was omitted in stock assessment runs. The internal consistency of the survey is examined in Figure 4.6.2.5.

The German BTS (RV Solea I/ RV Solea II) covers coastal areas in the German Bight during April and May, and is thus the only presented survey carried out during the spawning season of sole. It uses a double 7 m beam trawl with tickler chains and a 75 mm mesh size in the codend. It was used in the assessment of North Sea sole prior to 1996 and then removed, probably due to a gap in the time-series in 1995. The index series is presented in Table 4.6.2.2. It should be noted that the last year that this survey was done was 2012, and no survey data are available since. Internal consistency plots for the German Solea survey are given in Figure 4.6.2.5. Although the survey appears fairly consistent, it appears to lack cohort signal since 2010, when it does not follow the same cohort pattern as the other research vessel surveys (Figure 4.6.2.3).

4.6.2.2 Commercial lpue

There is one commercial fleet available that can be used as a tuning series for the stock assessment, being the Dutch beam trawl fleet. This fleet takes more than 70% of the landings, and is relatively homogeneous in terms of size and engine power. The data from this commercial fleet can be estimated using two different methods. The first method uses the total landings, and creates the age distribution for these landings by segregating the total landings into market categories, with age distributions being known within market categories through market sampling. Effort for the Dutch commercial beam-trawl fleet is expressed as total HP effort days. Effort nearly doubled between 1978 and 1994 and has declined since 1996 (see Figure 4.6.2.6). Effort during 2008 was <40% of the maximum (1994) in the series. A decline of circa 25% was recorded in 2008 following the decommissioning that took place during 2008.

Alternatively, the data for the Dutch beam trawl fleet can be raised as described by (WGNSSK 2008, WD1). This "corrects" for the differences in targeting different species that may occur over time. This series is given in Figure 4.6.2.6.

However, substantial changes have occurred in recent years in the beam-trawl gear. The traditional beam-trawl gear has gradually been replaced by wing-shaped beams, and the puls gear was introduced. This may affect the gear efficiency: the puls gear is towed at a lower speed, and catches less sole per unit time when compared to the traditional beam-trawl gear (van Marlen *et al.*, 2012). However, the puls gear has been introduced recently and increases in catchability may occur as a result of changes on the gear. The "traditional" beam-trawl gear has almost completely disappeared (Figure 4.2.6.7), while the puls fishing has increased since 2010 (Figure 4.2.6.8).

The internal consistency of the traditional beam-trawl gear lpue series and the puls gear series is very high, especially for the older ages, for which the consistency of the research vessel survey indices is low (Figure 4.2.6.9). Comparing the time-series of the different age-structured lpue series reveals also a very high consistency, which is mainly caused by the fact that the series share their age–length-keys that are used to derive age structure (Figure 4.6.2.10).

4.6.3 Weights, maturities, growth

4.6.3.1 Weight-at-age

Weights-at-age in the landings are measured weights from the various national market sampling programmes. Weights-at-age in the stock are the 2nd quarter landings weights, as estimated by the FishBase database computer program used for raising North Sea sole data. Over the entire time-series, weights were higher during the 1980s compared to time periods before and after. Estimates of weights for older ages fluctuate more because of smaller samples sizes due to decreasing numbers of older fish in the stock and landings. The discards-at-age are estimated from the different sampling programmes since 2002. Discards weights-at-age for the period prior to 2002 are assumed to be equal to the average of the period 2002–2013.

Natural mortality

Natural mortality in the period 1957–2013 has been assumed constant over all ages at 0.1, except for 1963 where a value of 0.9 was used to take into account the effect of the severe winter (1962–1963; ICES-FWG 1979).

Maturity

The maturity-ogive is based on market samples of females from observations in the sixties and seventies. Mollet *et al*. (2007) described the shift of the age-at-maturity towards younger ages. A knife-edged maturity-ogive is used, assuming no maturation at-ages 1 and 2, and full maturation at-age 3. Recent estimates of maturity done in the German Solea survey suggests that the sole in that survey mature earlier than the knife-edged maturity-at-age 3 that is assumed now. However, because the German survey focuses on one of the spawning grounds of sole, the estimates derived from the survey could be positively biased.

4.6.4 Assessment model

The incorporation of discards in an assessment model where only part of the discards-at-age matrix is available can be done using a model like that in Aarts and Poos (2009), referred to as AAP model. There, spline smoothers are used to describe the F-at-age matrix, the catchabilities at age of the tuning indices, and the discards fraction at-age. Here, we propose to use a similar approach. There are three differences compared to the model by Aarts and Poos. 1) modelling of the F-at-age matrix by means of a tensor spline rather than using a full separability assumption. In the AAP model, the F-at-age matrix describing the F estimates for each year and age is built using a selectivity pattern over the ages (ranging between 0 and 1), an annually varying product of catchability and effort. Here, we describe the F-at-age matrix by using a design matrix for a tensor product smoother taken from the GAM function in R (Wood, 2006). The degree of smoothness depends on the dimensions of the bases for age and year. The design matrix is multiplied by the total number of parameters required to describe the tensor product smoother, being equal to the product of the bases for age and year. To ensure that the F-at-age matrix remains positive throughout the optimization, the tensor product smoother is exponentiated. 2) The proportion discarded at-age is described by a simple logistic function. 3) implementation of the maximum likelihood search in ADMB (Fournier *et al*., 2012) rather than in R.

In order to facilitate future use of the model, a generic assessment model is written that 1) is compatible with FLR, 2) allows adding any number of tuning indices, 3) deals with missing values in any of the data sources, and 4) takes a control object with the structural model assumptions. These include: 1) The number of parameters used for the tensor spline (for ages and years separately), the age at which the "q-plateau" starts for the tuning indices, and the number of parameters used for description of the selectivity at-age of the tuning indices.

As a first test of the correct implementation of the model, an assessment run was done with the tuning data that were used at WGNSSK 2014, omitting the discards data. The model results in terms of SSB and F are very similar to the XSA results obtained at WGNSSK (Figure 4.6.4.1). In addition, a retrospective analysis reveals that both models have approximately the same retrospective pattern (Figure 4.6.4.2). The estimated selectivities for the three tuning indices are similar to the existing XSA estimates, with the two research vessel surveys having high selectivities for the younger individuals, and the commercial LPUE catching mainly the older individuals (Figure 4.6.4.3).

Adding the discards time-series (which is available from 2002–2013) to the assessment changes the estimated SSB and Fbar (average F of ages 2–6). The SSB is estimated to be slightly higher (because the inclusion of the discards in the assessment implies more fish was available), and Fbar is also estimated to be higher, to accommodate the additional mortality caused by discarding (Figure 4.6.4.4). However, the largest difference between the model with and without discards is found in the recruitments (Figure 4.6.4.5). These are estimated to be higher when the discards are included, to account for the discarding, which occurs mainly at the younger ages (Figure 4.6.1.1).

The log-residuals of the landings-at-age and the discards-at-age matrix (Figure 4.6.4.6) indicate that for the landings-at-age, the largest residuals are found for the younger ages. This is caused by the low numbers of fish caught for these ages. For the discards-at-age, the log-residuals increase with age. This is caused by the zeros that are put into the assessment for these ages. The total estimated landings and discards appear to be well in line with the observations (Figure 4.6.4.7). The overall discards are low compared to the landings. The historic estimates of discards are in the same order of magnitude as the present discards, both in terms of the overall weight (Figure 4.6.4.7) as in terms of numbers-at-age (Figure 4.6.4.8). The estimated discards ratio is highest for age 1, and drops quickly, being approximatley 0.1 at age 4 (Figure 4.6.4.8).

The observation errors of the assessment model are estimated in the likelihood function. These sigmas are estimated as the exponent of a second order polynomial of age. The estimated sigma values are given in Figure 4.6.4.9. The lowest sigma values are estimated for the landings at-age matrix, and the lpue matrix. The reseach vessel survey indices have higher estimated sigma values, that increase with age. This is the result of the lower number of older ages caught by these surveys compared to the younger ages. The discards-at-age have the highest sigma values, probably caused by the low sample sizes, especially at the beginning of the time-series. Figure 4.6.4.10 shows the residuals from the different tuning indices.

The different options for including the lpue were studied. Finally it was decided to exclude any lpue series. The argument for excluding the lpue was that the lpue series has the potential to cause some bias in the assessment, because of the substantial changes in the Dutch beam trawl fleet from which the lpue series are derived. The lpue series get a lot of weight in the final estimates, mainly because of the large sample sizes available for estimating the age structure in the lpue series. However, the lpue also gets a lot of weight because there is by definition a large correspondence between the landings-at-age matrix and the lpue series, given that they come from the same age–length key. Overall results are similar between the assessments with and without the lpue time-series (Figure 4.6.4.11). The drawback of excluding the lpues is that the assessment will potentially become more uncertain towards its terminal year. This is readily visible from comparing the retrospective analyses from the assessment with and without the lpue series (Figure 4.6.4.11). The reason for this uncertainty is that the current tuning indices have low catchabilities for the older ages (see e.g. Figures 4.6.2.4 and 4.6.4.3). In addition, the western part of the distribution area is now not covered by the stock assessment. The "traditional" beam-trawl lpue series will likely end in the near future, given the current trend in fishing effort for that fleet component (Figure 4.6.2.7).The tuning index for the puls fishing is currently too short, but could be used when it is longer in the future. The lack of spatial coverage of the western part of the distribution area of the stock could potentially be solved by including the Belgium BTS survey. However, because of the short time-series that is currently available, the retrospective pattern that is observed in the assessment without the lpue is exacerbated (Figure 4.6.4.12).

To conclude, the benchmark group decided to use the AAP model, estimating historic discards while doing the stock assessment, with settings as detailed in the table below. The discards estimates from the different countries in the most recent years can then be used for the estimation. Because of the changes in the Dutch beam-trawl fleet over the last ten years, the benchmark group decided to exclude the lpue from the assessment. The BTS-ISIS and SNS surveys remain. Future benchmarks should study if the puls fishing lpue that is available since 2010 can be used in the future. Unfortunately, no other BTS (German, Belgium) could currently be included. However, the Belgium BTS survey has the potential to be included in the future, but is currently too short.

Setting/Data	Values/source
Catch-at-age	Landings (since 1957, ages 1–10) Discards (since 2002, ages 1–10)
Tuning indices	BTS-Isis 1985-assessment year, ages 1–9 SNS 1970-assessment year, ages 1–6
Plus group	10
First tuning year	1970
Time-series weights	No taper
Catchability catches independent of ages stock size for age >=	8
Catchability surveys independent of ages for ages >=	8
Tensor spline for catchability-at-age both indices k value ages	6
Tensor spline for F-at-age: k value ages	6
Tensor spline for F-at-age: k value years	22

4.7 Short-term projections

No work was done on the short term projections for this stock.

4.8 Appropriate reference points (MSY)

All data used came from the WKNSEA2015 final assessment.

Methods used

Current reference points are given in Table 4.8.1.1. The Eqsim software was applied to estimate new reference points. Runs with and without MSY $B_{trigger}$ were done for the Eqsim method. The total (catch) F was optimised for maximum landings.

Settings

Model and data selection settings are given in the table below and follow the settings chosen at the ICES workshop WKMSYREF3 (2014).

Data and parameters	Setting	Comments
Stock–recruit relationships	Ricker and Segmented regression	Beverton and Holt failed to provide a reasonable fit to the data (equated to geometric mean recruitment at all SSB).
SSB-recruitment data	Full data series excluding last 3 years (1957-2010)	Recent year-class strength is informed by less data than earlier year classes so these estimates are considered less reliable. This assumption is used in the short-term forecast for this stock (geometric mean recruitment excluding the last three years).
Exclusion of extreme values (option extreme.trim)	No exclusions	
Mean weights and proportion mature	2004-2013 (Eqsim)	No significant trends over the last ten years.
Exploitation pattern	2009–2013	Recent shift from traditional beam trawl to pulse trawl and sum wing gear with suspected different selectivity.
Assessment error in the advisory year. CV of F	0.23	Taken from WKMSYREF3
Autocorrelation in assessment error in the advisory year	0.24	Taken from WKMSYREF3

Results

Stock–recruitment relationship

The stock–recruit fits are shown in Figure 4.8.1.1. The SR scatter for North Sea sole is clustered mainly in the 30–50 000 t SSB range. There are no clear patterns, with both high (including a few spikes) and low recruitments found across the whole range of observed SSB. Above 80 000 t SSB, there are two of the lowest observed recruitments (the 1961 and 1962 year classes) and one of the highest observed recruitment (1958 year class). In general, the observed recruitment above the most commonly observed SSB range tends to be below average. The segmented regression shows a breakpoint at 26 300 tonnes (Figure 4.8.1.1, Table 4.8.1.1). The benchmark proposes this to be the new B_{lim} reference point. Using the current relationship between B_{lim} and B_{PA} (B_{PA}=1.4*B_{lim}), the B_{PA} reference point is then 37 000 tonnes.

In the Eqsim method, the segmented regression only has 15% of the weighting compared to 85% for Ricker (Table 4.8.1.2).

Proposed reference points

The Eqsim method resulted in a well-defined dome shaped landing yield curve (Figure 4.8.1.2, which corresponds to fixed F exploitation, i.e. without reducing F when SSB is <$B_{trigger}$). Median SSB estimates for the run without $B_{trigger}$ are given in Figure 4.8.1.3. Results for runs with $B_{trigger}$ (set to 37 000 t) are given in Figures 4.8.1.4 and 4.8.1.5. The upper limit of the F_{MSY} range is greater than the F that leads to a 5% probability of SSB<B_{lim}, but the estimated F_{MSY} is below this. The reference point values for the Eqsim method are shown in Tables 4.8.1.3 and 4.8.1.4. The summary of the runs with and without $B_{trigger}$ is also given in the table below.

Summary table of proposed stock reference points for method Eqsim. B_{lim} was set to 26 300 t. $B_{trigger}$ was set to 37 000 t.

STOCK	SOLE IN SUBAREA IV (NORTH SEA)
Reference point	Value
FMSY without Btrigger	0.39
FMSY lower without Btrigger	0.26
FMSY upper without Btrigger	0.55
New $F_{P.05}$ (5% risk to Blim without Btrigger)	0.39
FMSY upper precautionary without Btrigger	0.39
FMSY with Btrigger	0.45
FMSY lower with Btrigger	0.28
FMSY upper with Btrigger	0.67
$F_{P.05}$ (5% risk to Blim with Btrigger)	0.44
FMSY upper precautionary with Btrigger	0.44
MSY (maximum median landings for F without Btrigger)	18 800 t (landings)
Median SSB at FMSY (=0.39 year^{-1})	51 200 t
Median SSB lower precautionary (median at FMSY upper precautionary (=0.39 year^{-1}), without Btrigger)	50 700 t
Median SSB lower precautionary (median at FMSY upper precautionary (=0.44 year^{-1}), with Btrigger)	47 900 t
Median SSB upper (median at FMSY lower (=0.26 year^{-1}) without Btrigger)	67 800 t

Discussion/ sensitivity

A shorter time period (five years) was used for selectivity than for biological parameters (ten years). There are no clear trends in weight-at-age over the last ten years, but there has been some significant changes to the gears used in the Dutch beam-trawl fleet that takes >75% of the sole quota. These changes include a shift to pulse trawl gears and the increased use of sumwings. It is expected, though not fully quantified yet, that these gear changes will lead to changes in selectivity both through direct differences in the gear and changes in the speed and location of fishing with the new gears.

Sensitivity issues were discussed at the ICES workshop WKMSYREF3 (2014). The benchmark did not have time to conduct sensitivity runs. However, a sensitivity run based only on segmented regression stock–recruitment fits was requested by the external reviewers after the benchmark meeting, with the aim of trying to gain additional understanding of the results. This sensitivity run results in an F_{MSY} range (without $B_{trigger}$) that is 0.11–0.37 $year^{-1}$ (Figure 4.8.1.6).

The selection of stock–recruitment function has a big effect on the lower limit of the F_{MSY} range. Though there is limited empirical evidence for density-dependent reduction in recruitment at high SSB for flatfish species, the North Sea sole data do favour a Ricker fit over Beverton and Holt or segmented regression given the slightly lower recruitments at SSB >50 000 t and the two very low recruitments at rather large SSB values (above 80 000 t).

4.9 Future research and data requirements

Most of the future research and data requirements are given in the text of the chapter. All are listed below.

- The benchmark group suggests to re-evaluate the different tuning indices in a future benchmark, including the new lpue series and the Belgium BTS.
- The international discards should be raised to include all discards available in InterCatch before the next WGNSSK.
- Stations in the southwest of the BTS-Tridens survey area could be included in the BTS-ISIS index to increase the spatial coverage of the BTS index.

4.10 References

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Tables

Table 4.6.1.1. Landings-at-age.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1957	0	1472	10556	13150	3913	3041	6780	1803	529	5595	173	277	35	82	379
1958	0	1863	8482	14240	9547	3501	3023	4461	2264	731	5241	112	208	35	263
1959	0	3694	12139	10499	9060	5823	1217	2044	2598	1379	743	2902	102	129	413
1960	0	11965	14043	16691	9248	8313	4815	1583	1049	2782	986	512	3115	132	324
1961	0	972	50470	19403	12574	4760	3998	4338	847	1004	1735	1170	450	2574	422
1962	0	1584	6173	58836	15254	10478	4797	4087	2074	895	1530	971	1154	387	2513
1963	0	670	8271	8485	45823	8420	6603	2403	3365	1553	994	758	1763	410	2838
1964	53	150	2041	5518	3680	16749	3020	1749	790	842	478	210	458	325	600
1965	0	45180	1045	1534	4798	2381	11990	1494	1463	373	601	456	309	192	1146
1966	0	12145	132170	979	1168	3649	736	6255	694	759	284	468	119	86	708
1967	0	3769	26260	87039	1998	548	1962	777	5160	550	624	465	356	283	700
1968	1034	17093	13852	24894	48417	461	244	1639	323	4393	253	817	82	395	562
1969	404	24404	21884	5433	12638	25646	338	249	1214	295	3021	297	549	154	1063
1970	1299	6141	25996	8236	1784	3231	11961	246	140	686	169	2416	238	582	1143
1971	425	33765	14596	12909	4538	1459	2355	7300	194	235	836	294	1430	472	1382
1972	354	7511	36356	6997	4911	1548	517	1218	4654	119	99	487	118	912	1037
1973	716	12459	13025	16493	4101	2368	1013	779	1241	3400	225	303	508	112	1351
1974	100	15171	21248	5412	6965	1896	1563	649	396	601	2331	103	32	301	1382
1975	267	23193	28833	11839	2110	3870	798	916	513	236	255	1925	25	85	955
1976	1064	3619	28571	14316	4923	987	1950	562	434	208	199	135	1349	40	790
1977	1780	22747	12299	15593	7580	1812	325	1133	261	215	95	124	110	868	743
1978	27	24921	29163	6102	6610	4231	1730	608	643	190	234	122	106	68	875
1979	9	8280	41681	16259	3033	3262	1769	826	244	398	156	118	104	74	696
1980	650	1233	12762	18138	7444	1479	2241	1437	374	55	423	53	53	33	610
1981	434	29983	3344	7046	8439	3757	973	909	786	202	110	164	94	22	340
1982	2697	26799	46375	1868	3584	4855	1701	623	613	534	151	75	204	12	319
1983	391	34545	41551	21273	626	1383	1958	982	388	302	425	31	14	178	231
1984	192	30839	44081	22631	8821	744	857	1047	526	243	210	146	30	24	244
1985	163	16449	42773	20079	9307	3520	207	375	631	198	190	187	93	33	264
1986	372	9304	18381	17591	7698	5480	2256	109	281	616	353	171	125	104	302
1987	93	28896	21927	8851	6477	3102	1559	898	81	102	164	143	62	55	164
1988	10	13206	47135	15217	4377	3878	1549	890	523	38	34	85	42	10	108
1989	115	45652	17973	22295	4551	1627	1414	637	451	223	44	34	43	34	81
1990	854	11816	103380	9667	9099	3315	1032	1186	548	223	288	57	26	44	199
1991	118	12938	24985	76580	6609	3612	1706	707	718	299	276	334	14	15	134
1992	965	6730	43713	15961	37745	2440	2995	730	393	447	160	221	114	6	215
1993	53	49870	16575	31047	13709	23758	1472	1170	456	170	290	100	74	107	92
1994	709	7710	86349	13387	18513	5642	11174	458	905	262	72	208	75	41	239
1995	4766	12674	16700	68073	6262	7254	1981	5971	293	329	58	67	48	20	143
1996	170	18609	16005	16770	26946	3814	4725	932	3267	236	284	147	49	99	161
1997	1574	5987	23418	7253	5058	12667	1189	2303	330	1423	31	113	20	23	62
1998	242	56162	15011	14806	3466	1924	4727	787	1022	236	406	43	58	12	83
1999	284	15601	71730	8103	6049	1200	657	1964	328	487	43	173	8	35	58
2000	2329	14929	32425	42394	3257	2453	796	431	922	300	217	49	101	8	33
2001	857	25045	20925	19260	16211	1383	808	266	163	492	59	58	11	50	31

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2002	1046	10958	32570	12185	8145	6393	667	592	88	90	152	40	36	6	38
2003	1047	32295	17479	16072	5814	3902	2427	400	128	144	89	90	58	38	32
2004	516	14960	48003	9531	7462	2167	902	962	389	117	95	28	51	46	52
2005	1131	7254	22633	28875	4168	3861	1491	602	768	165	54	29	19	80	45
2006	7008	9966	10397	9606	10943	1617	1577	724	373	248	142	33	10	9	111
2007	315	39643	10820	6407	5706	5479	819	725	498	185	103	162	39	11	41
2008	1959	6325	37427	5996	2928	2393	2613	448	491	243	88	43	61	11	13
2009	1630	10417	10771	26548	3278	1652	1591	1532	312	489	120	84	51	31	89
2010	371	11659	13354	8530	13623	1817	907	809	1196	113	215	192	57	53	60
2011	44	11992	19788	8379	5070	6436	983	431	283	589	28	83	17	15	33
2012	0	5961	25290	10213	3878	1934	3506	562	232	246	274	37	97	39	51
2013	0	2532	26181	20218	5430	1930	1533	2158	238	96	155	116	25	33	67

Table 4.6.1.2. Discards-at-age used in the assessment.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2002	6461	12606	5212	1029	272	0	0	0	0	0	0	0	0	0	0
2003	1156	7152	5059	1212	381	0	0	0	0	0	0	0	0	0	0
2004	2936	12832	7449	1719	518	12	0	0	0	0	0	0	0	0	0
2005	2256	5622	4796	1258	375	63	22	0	0	0	0	0	0	0	0
2006	2390	5727	2705	654	197	28	18	7	0	0	0	0	0	0	0
2007	818	4923	3010	619	226	57	4	0	0	0	0	0	0	0	0
2008	1230	2704	1764	371	106	0	8	0	0	0	0	0	0	0	0
2009	2695	6480	3652	999	266	5	9	0	0	0	0	0	0	0	0
2010	5687	12164	6670	1544	493	31	10	2	2	0	0	0	0	0	0
2011	3457	10298	5482	1273	354	33	0	0	0	0	0	0	0	0	0
2012	4136	13974	6403	1392	438	7	0	0	7	0	0	0	0	0	0
2013	3936	9516	5790	1274	367	0	0	0	0	0	0	0	0	0	0

Table 4.6.2.1. Age-structured Belgium BTS data (available since 2006).

Age	1	2	3	4	5	6	7	8	9
Year									
2006	21.86	20.38	11.92	18.20	14.11	3.36	3.39	0.85	1.11
2007	16.46	20.48	9.17	3.02	6.42	6.42	1.57	1.28	0.80
2008	14.06	12.21	13.50	5.45	2.10	2.13	3.27	0.51	0.26
2009	11.13	12.14	13.91	8.88	3.40	1.04	2.29	1.83	0.55
2010	15.46	12.81	7.94	6.24	4.32	1.92	0.30	0.66	0.50
2011	13.99	27.96	9.27	4.74	5.09	5.35	1.54	0.46	0.88
2012	5.93	19.38	18.10	6.78	2.97	3.29	1.36	1.39	0.45
2013	7.41	10.34	24.35	11.08	3.66	1.03	1.94	1.87	0.40

Table 4.6.2.2. Age-structured German Solea data (available since 1996).

Age	2	3	4	5	6	7	8	9	10	11
Year										
1996	0.58	0.72	1.88	11.31	0.80	3.33	0.80	2.32	0.22	0.07
1997	0.51	8.54	3.12	2.94	9.74	0.41	1.33	0.60	0.60	0.14
1998	11.73	1.18	6.84	1.75	1.18	4.47	0.26	0.46	0.21	0.31
1999	14.78	62.94	6.25	9.75	3.05	2.13	10.67	0.46	1.07	1.07
2000	6.52	20.78	38.64	1.30	0.80	0.90	1.10	1.30	0.00	0.70
2001	9.94	7.44	15.83	16.28	0.59	0.52	0.22	0.37	0.59	0.22
2002	3.18	10.25	2.68	4.04	3.38	0.04	0.08	0.00	0.00	0.08
2003	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
2004	6.24	10.97	6.66	6.61	1.63	1.42	1.00	0.05	0.05	0.00
2005	0.96	8.36	4.90	2.06	1.93	0.83	0.57	0.26	0.00	0.00
2006	7.02	4.52	11.25	4.30	1.58	1.65	0.57	0.65	0.14	0.00
2007	16.58	4.38	3.32	2.37	1.07	0.59	0.12	0.24	0.00	0.00
2008	9.67	34.86	2.62	2.22	1.21	1.01	0.00	0.40	0.00	0.00
2009	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
2010	8.51	5.36	5.83	7.46	0.93	0.47	0.23	0.12	0.23	0.12
2011	3.87	5.77	1.39	1.14	0.95	0.13	0.00	0.06	0.00	0.00
2012	1.40	5.92	3.54	0.79	1.02	0.65	0.05	0.05	0.00	0.00

Table 4.8.1.1. Summary table of current stock reference points (before the WKNSEA 2015 benchmark).

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current F_{MSY}	0.22	Median of stochastic MSY analysis assuming a Ricker stock–recruit relationship (range of 0.2–0.25), WGNSSK 2010.
Current Blim	25 000 t	Bloss (WGNSSK 2011).
Current Bpa	35 000 t	Blim×e1.645σ, σ=0.20: approximately Blim*1.4.
Current MSYBtrigger	35 000 t	Default to value of B_{PA}.

Table 4.8.1.2. Summary table of the two stock–recruitment relationships used in EQSim.

Parameters

NUM	A	B	CV	MODEL	N	PROP
1	4.3109	26 305	0.796	segreg	146	0.146
2	8.9006	2.54E-05	0.773	ricker	854	0.854

Table 4.8.1.3. Summary table of the EqSim runs without Btrigger.

				MSY		LOWER		UPPER	
	F05	F10	F50	median	mean	Median	Mean	Median	Mean
catF	0.394	0.449	0.708	NA	0.46	NA	NA	NA	NA
lanF	NA	NA	NA	0.388	0.41	0.257	0.273	0.554	0.582
catch	20 565	20 622	17 922	NA	20 629	NA	NA	NA	NA
landings	NA	NA	NA	18845	18825	17956	19682	17945	19675
catB	50 745	45 339	26 495	NA	44 427	NA	NA	NA	NA
lanB	NA	NA	NA	51 247	49 104	67 779	NA	36 879	NA

Table 4.8.1.4. Summary table of the EqSim runs with Btrigger.

				MSY		LOWER		UPPER	
	F05	F10	F50	median	mean	Median	Mean	Median	Mean
catF	0.436	0.51	0.967	NA	0.55	NA	NA	NA	NA
lanF	NA	NA	NA	0.449	0.45	0.275	0.283	0.67	0.761
catch	21 054	21 171	17 754	NA	21 125	NA	NA	NA	NA
landings	NA	NA	NA	19 187	19 176	18 242	19 859	18 242	19 846
catB	47 857	42 616	26 500	NA	40 299	NA	NA	NA	NA
lanB	NA	NA	NA	46 816	46 854	65 216	NA	34 812	NA

Figures

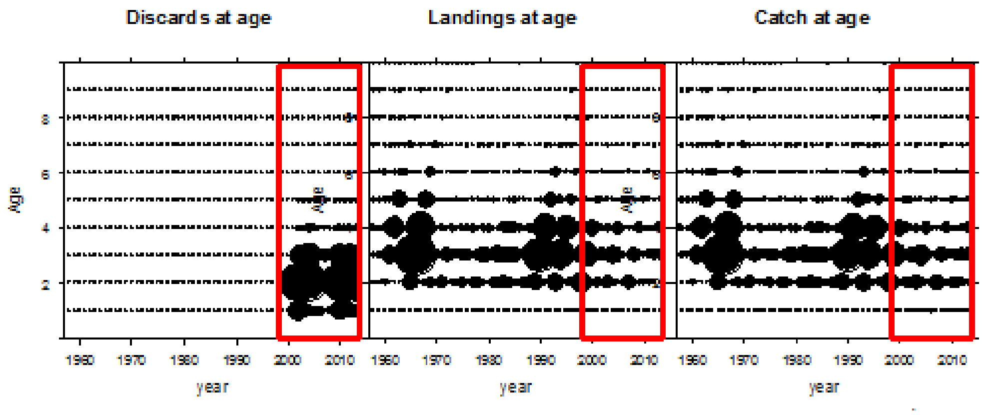

Figure 4.6.1.1. Discards-, landings-, and catch-at-age. The red box indicates the period for which discards estimates are available. Note that that the catch-at-age matrix is thus only complete for the area within the red box (2002–2013). Note that the bubbles are scaled differently for the different panels.

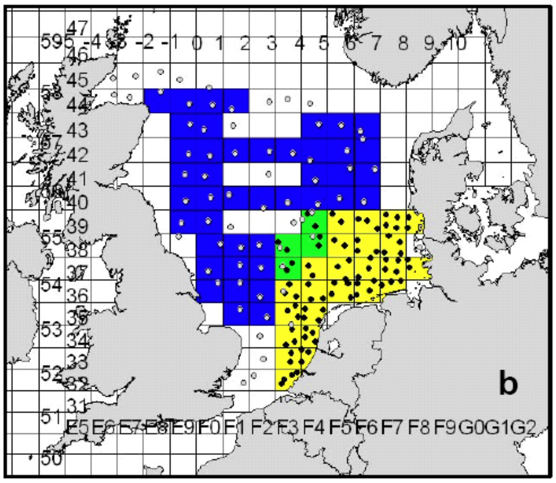

Figure 4.6.2.1. Spatial distribution of the two Dutch BTS surveys, the yellow area depicts the BTS-ISIS area (currently used in the assessment), and the blue area depicts the BTS-Tridens area (not used in the assessment).

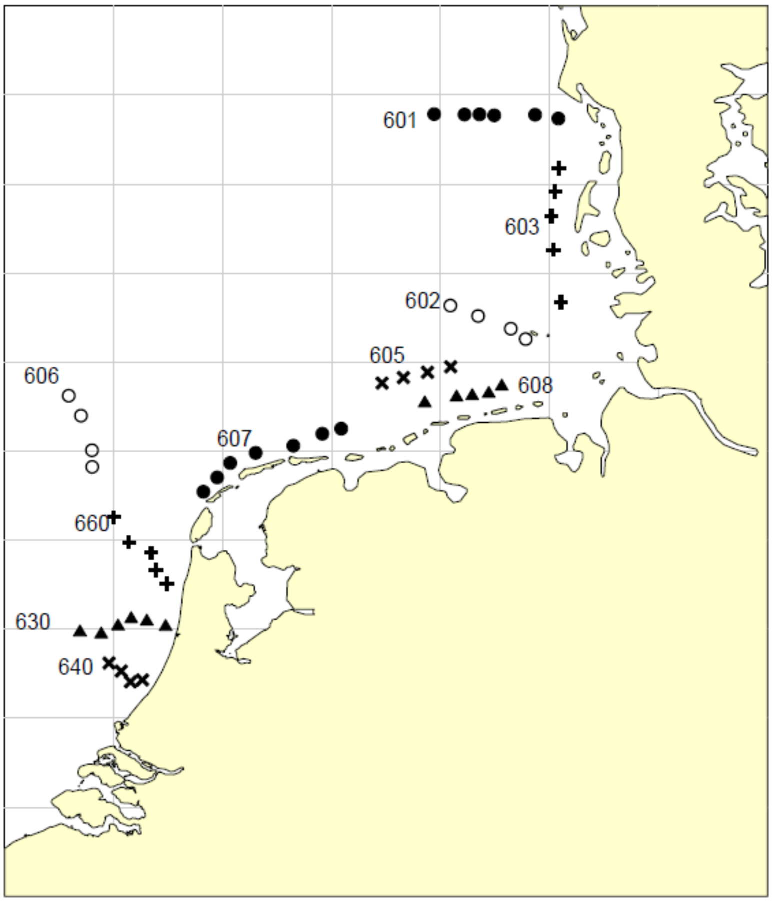

Figure 4.6.2.2. SNS survey stations (in 2010 as example), taken from IMARES report 11.006.

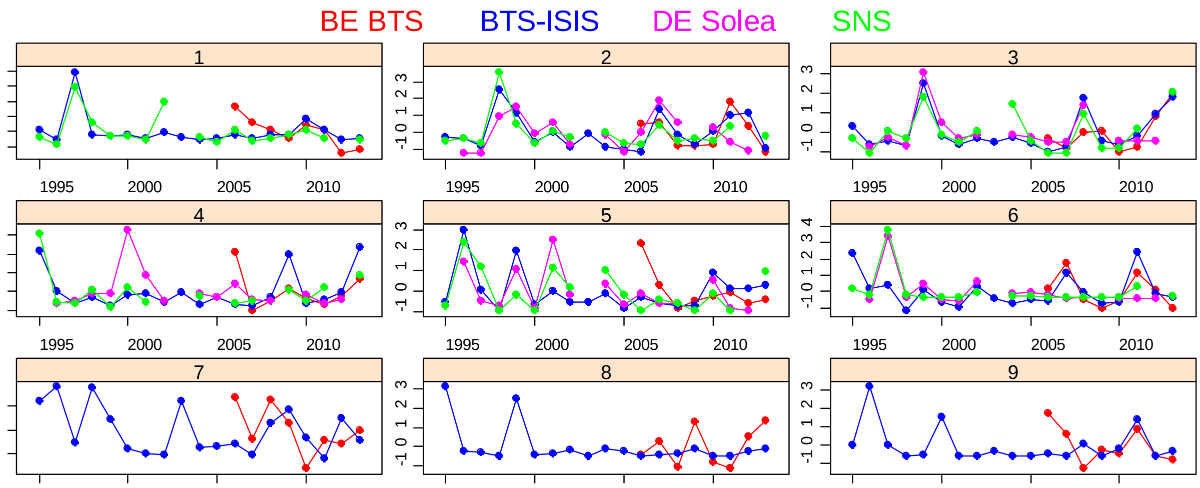

Figure 4.6.2.3. Time-series of the four age-structured research vessel survey indices.

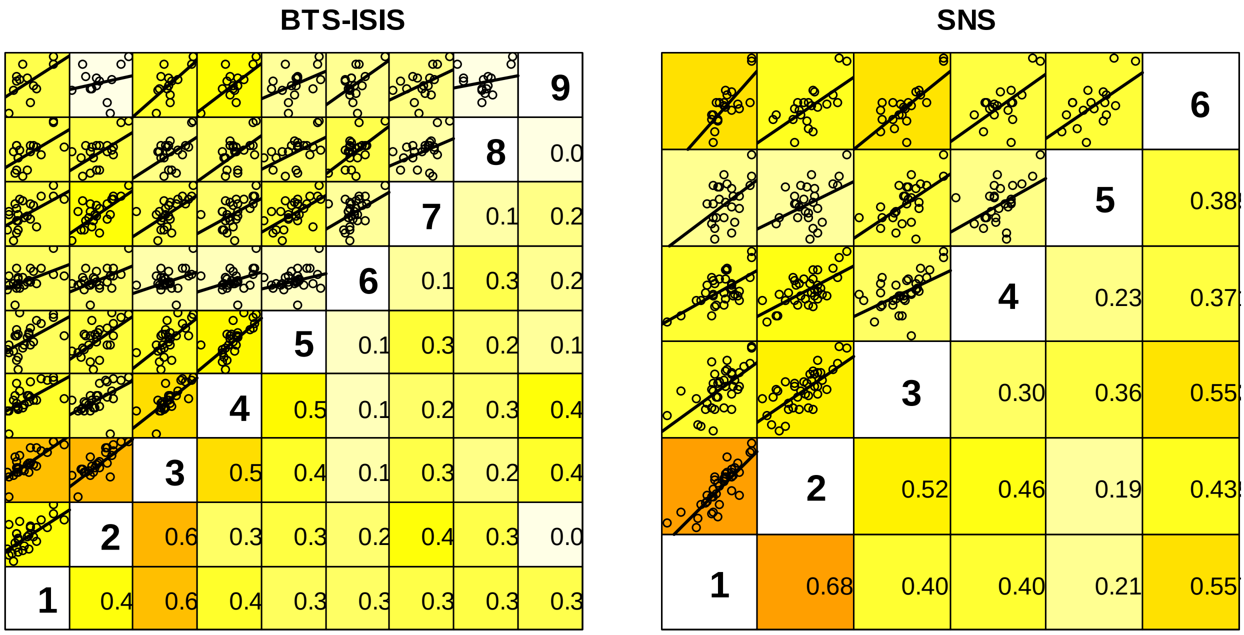

Figure 4.6.2.4. Internal consistencies of the BTS-ISIS and SNS surveys.

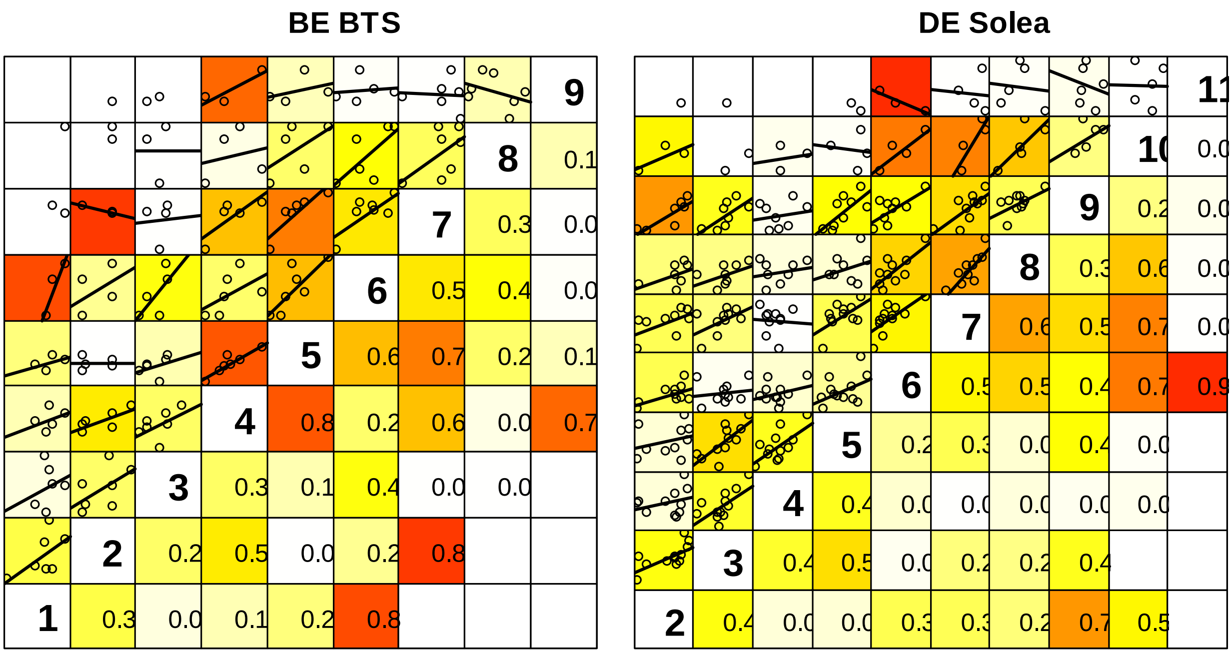

Figure 4.6.2.5. Internal consistencies of the Belgium BTS and the German Solea survey (since 1996).

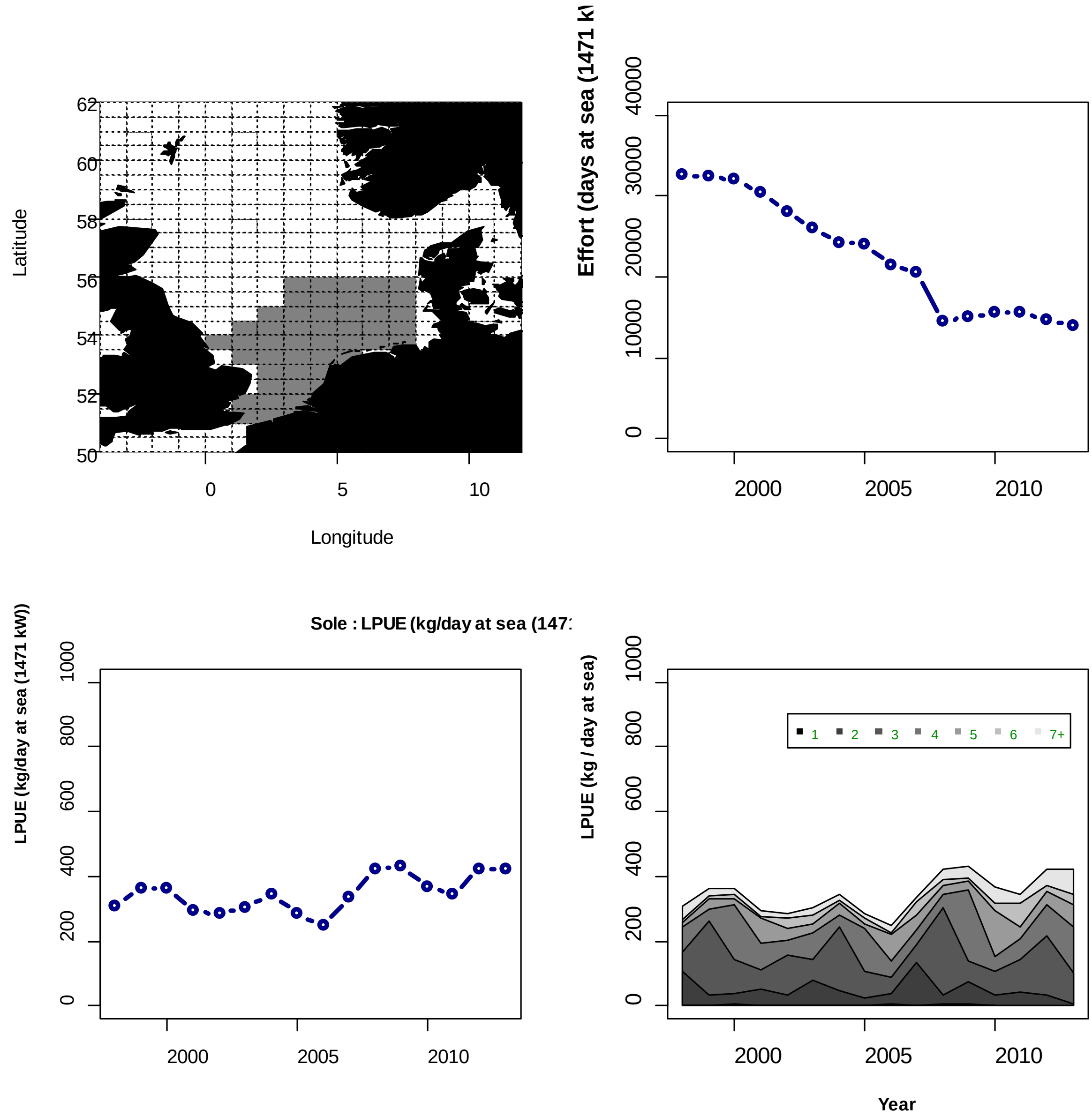

Figure 4.6.2.6. Basic information from the Dutch beam-trawl fleet information, including spatial distribution, total fishing effort, lpue, and age-structured lpue. Note that this lpue comes from the "corrected" lpue series, but includes all gears that are under the "TBB" fleet, including sumwings, and puls gears.

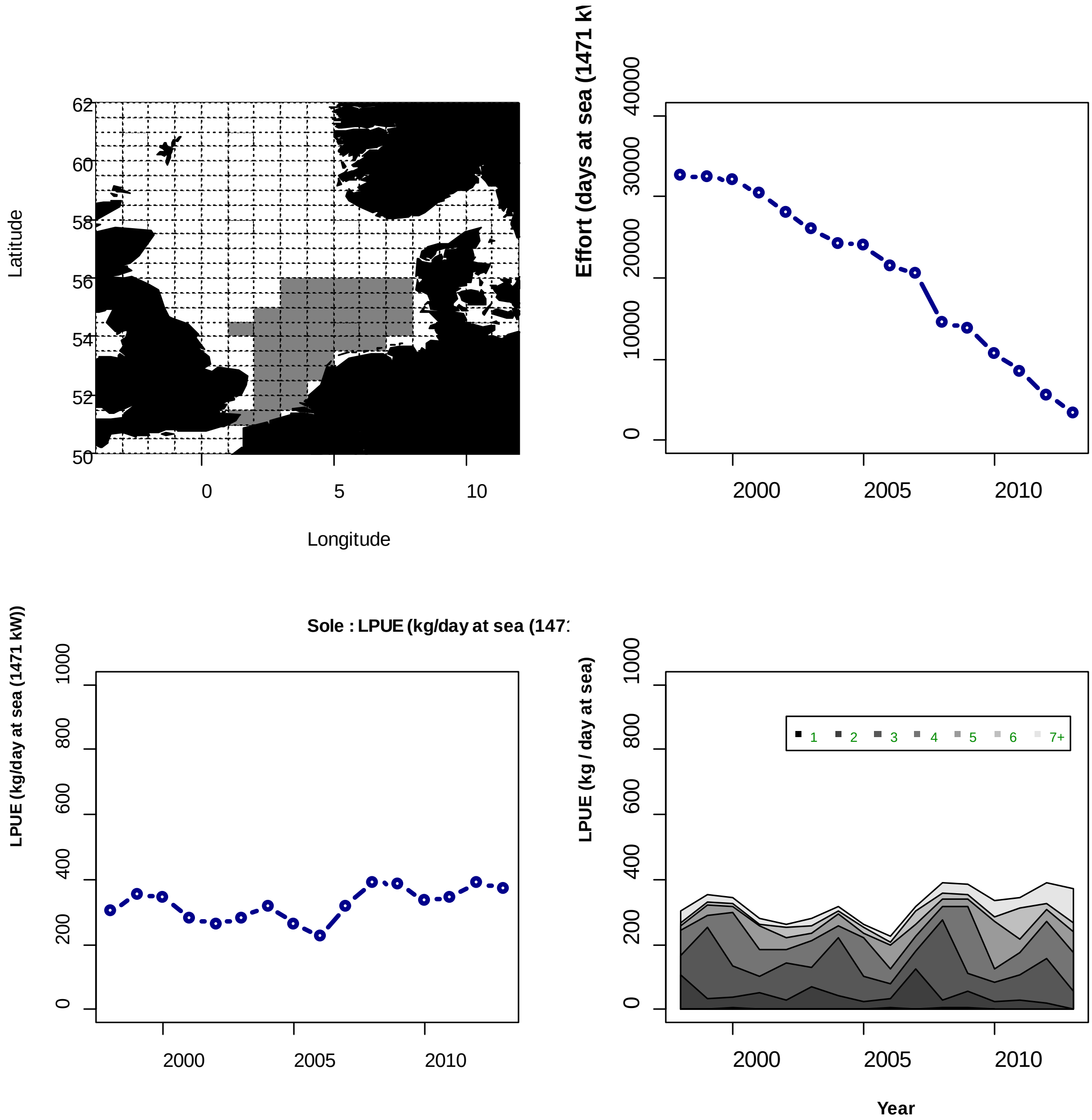

Figure 4.6.2.7. Basic information from the traditional Dutch beam-trawl fleet information, including spatial distribution, total fishing effort, lpue, and age-structured lpue. Note that this lpue comes from the "corrected" lpue series, and excludes sumwings and puls gears.

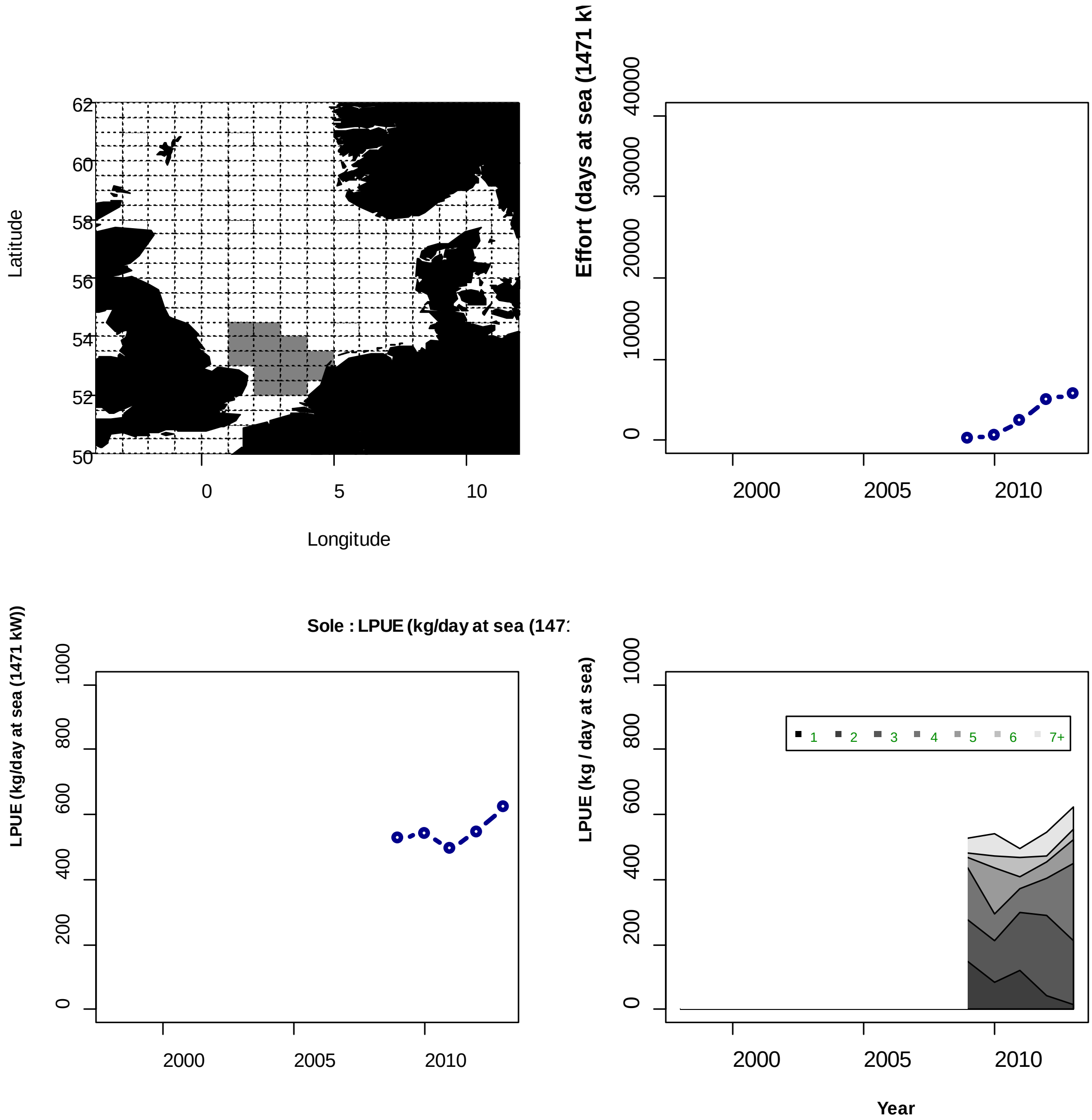

Figure 4.6.2.8. Basic information from the Dutch pulse-trawl fleet information, including spatial distribution, total fishing effort, lpue, and age-structured lpue.

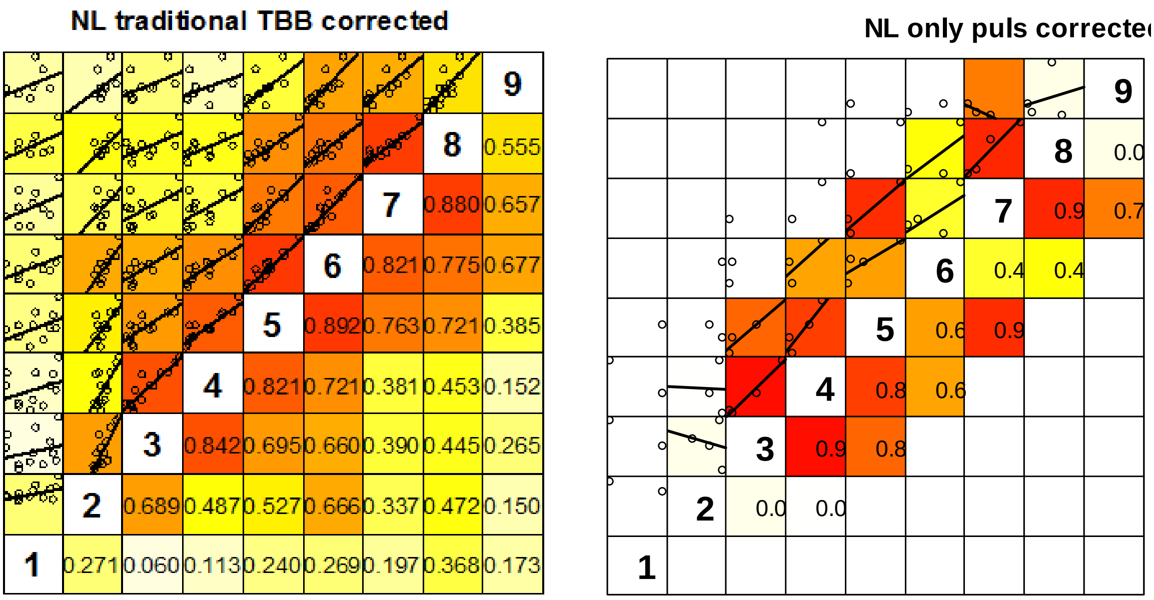

Figure 4.6.2.9. Internal consistency plots for corrected traditional beam-trawl and pulse-trawl lpue series.

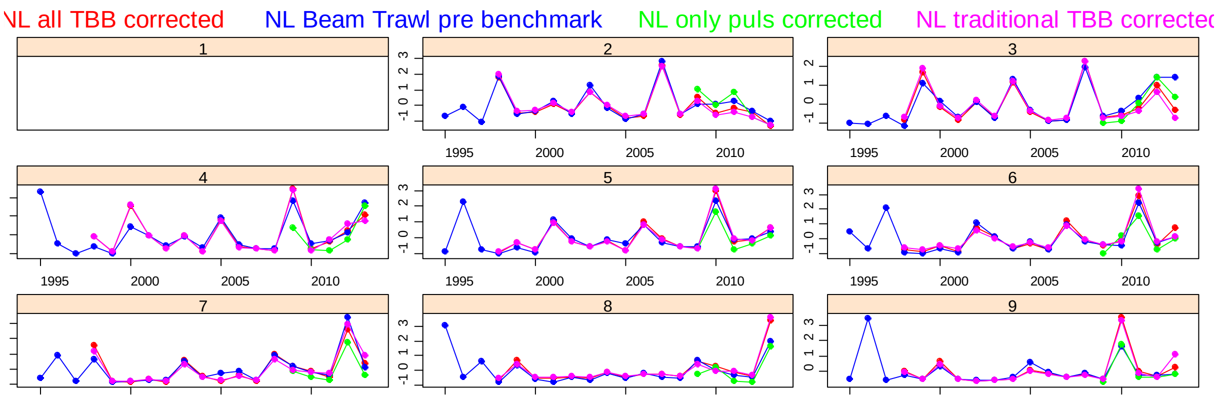

Figure 4.6.2.10. Time-series of the different Dutch lpue indices.

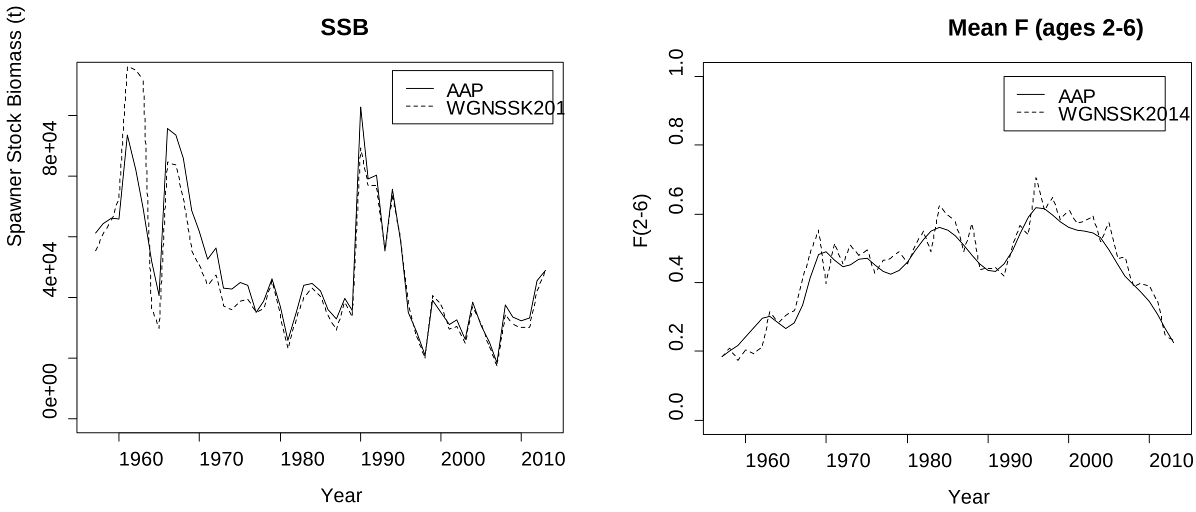

Figure 4.6.4.1. Comparison of SSB estimates and Fishing mortality estimates from the XSA as done at WGNSSK 2014, and the AAP model with the same data, but without inclusion of discards.

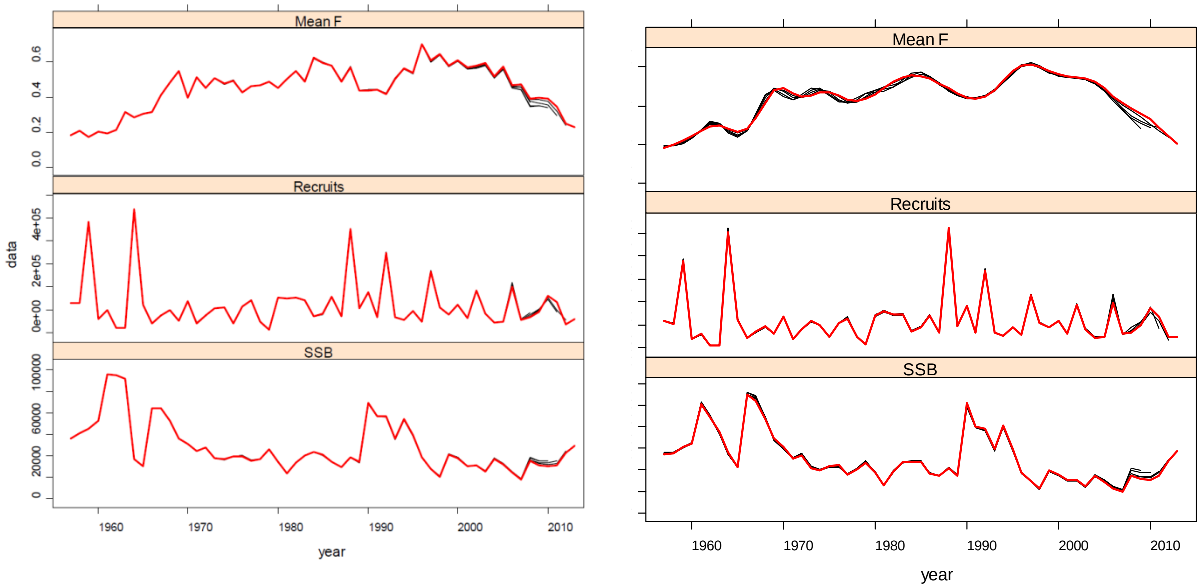

Figure 4.6.4.2. Comparison of retrospective analysis from the XSA as done at WGNSSK 2014, and the AAP model with the same data, but without inclusion of discards.

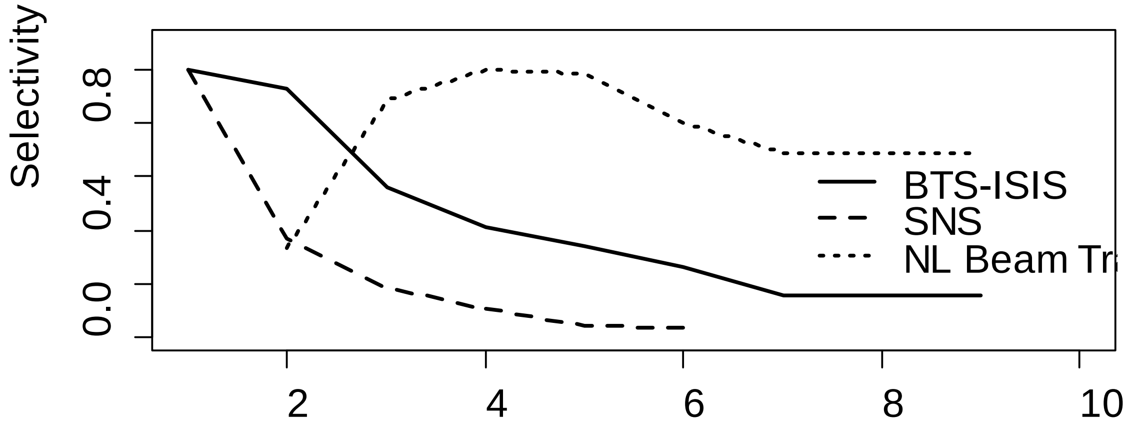

Figure 4.6.4.3. Selectivities of the three index series used in WGNSSK2014 when incorporated in the AAP model without discards.

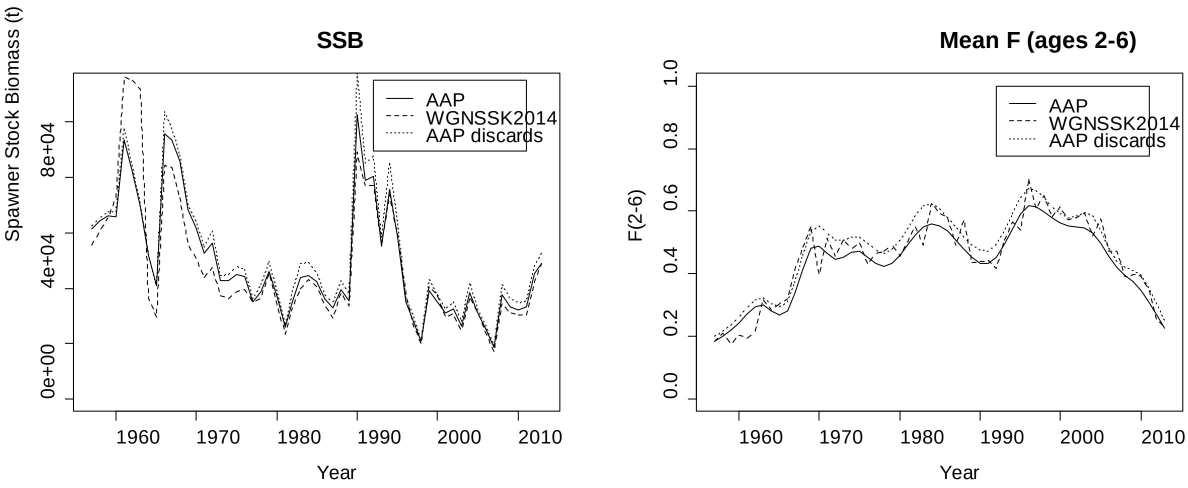

Figure 4.6.4.4. Comparison of SSB estimates and Fishing mortality estimates from the XSA as done at WGNSSK 2014, the AAP model with the same data, and the AAP model with inclusion of discards.

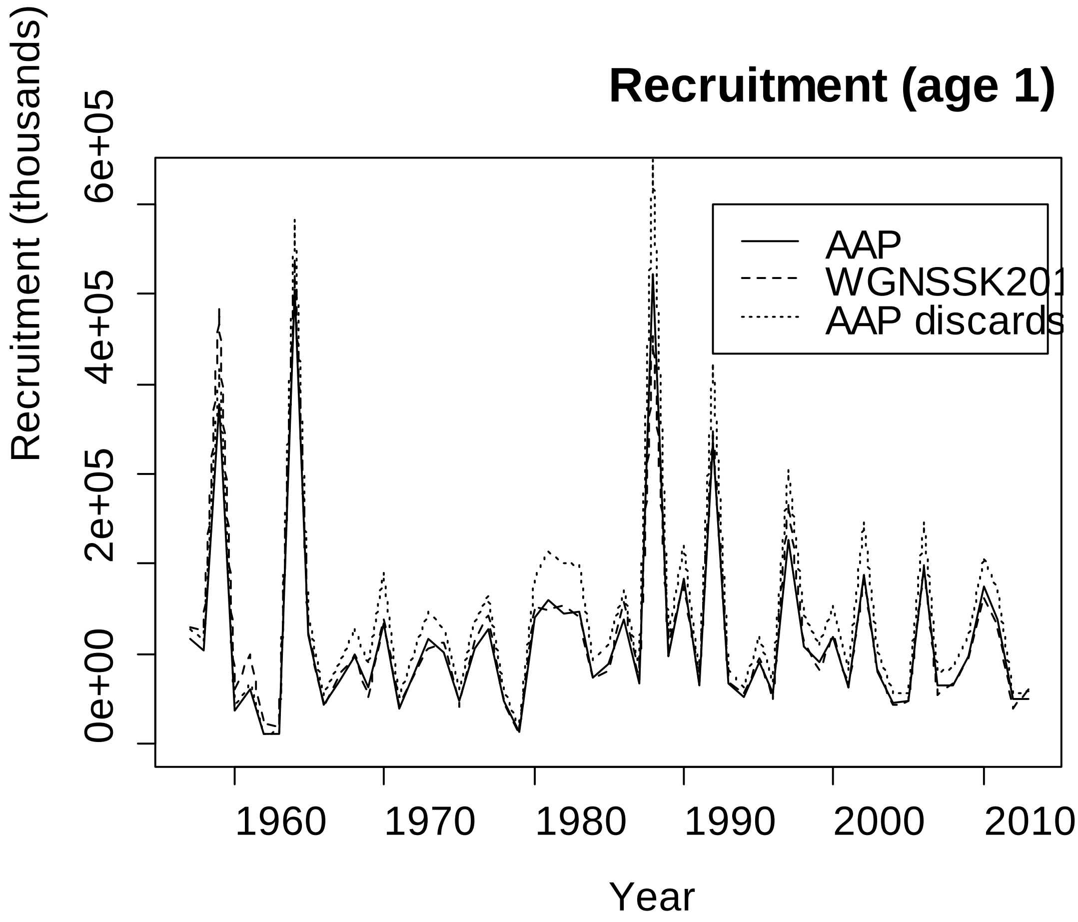

Figure 4.6.4.5. Comparison of SSB estimates and Fishing mortality estimates from the XSA as done at WGNSSK 2014, the AAP model with the same data, and the AAP model with inclusion of discards.

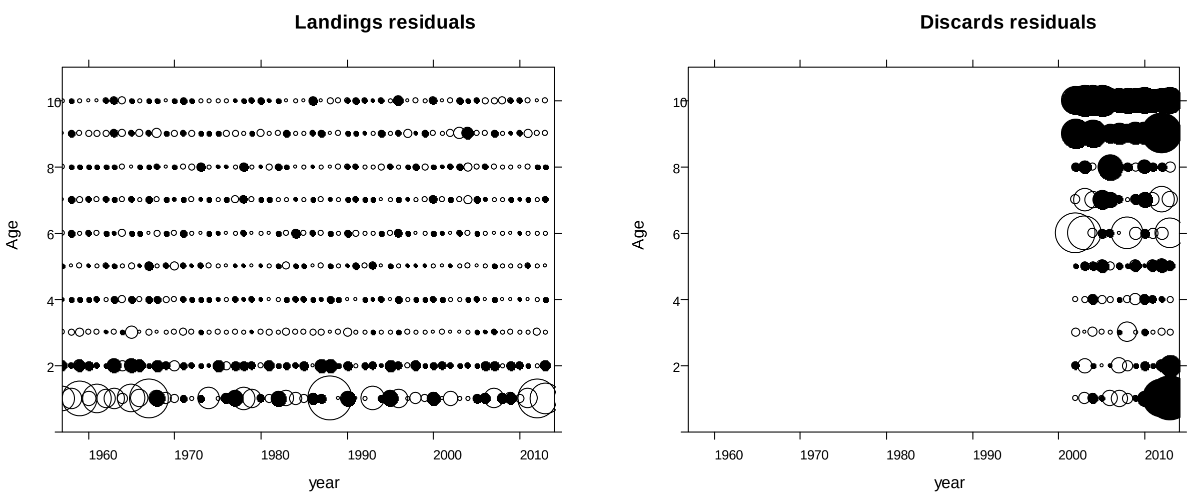

Figure 4.6.4.6. Landings and discards residuals-at-age from the AAP model with discards included.

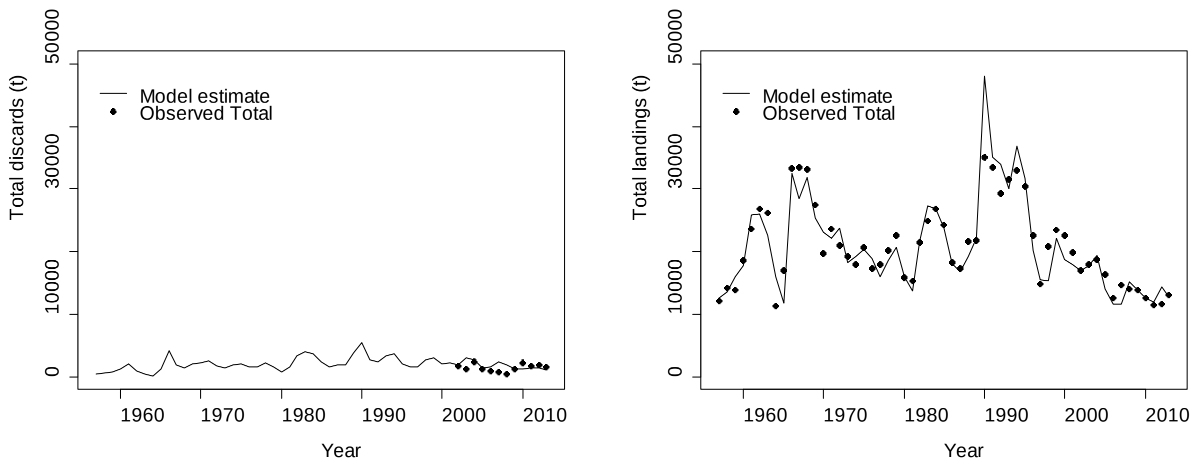

Figure 4.6.4.7. Model estimated discards and landings, and observations. Discards and landings are plotted at the same y-axis, for comparison.

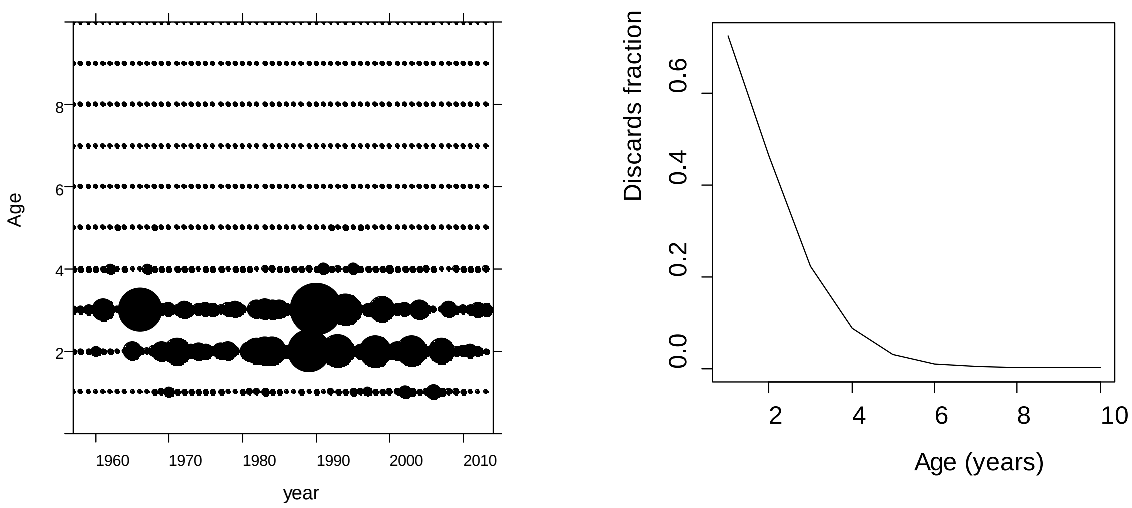

Figure 4.6.4.8. Model estimated discards-at-age (left panel), and discards ratio as a function of age.

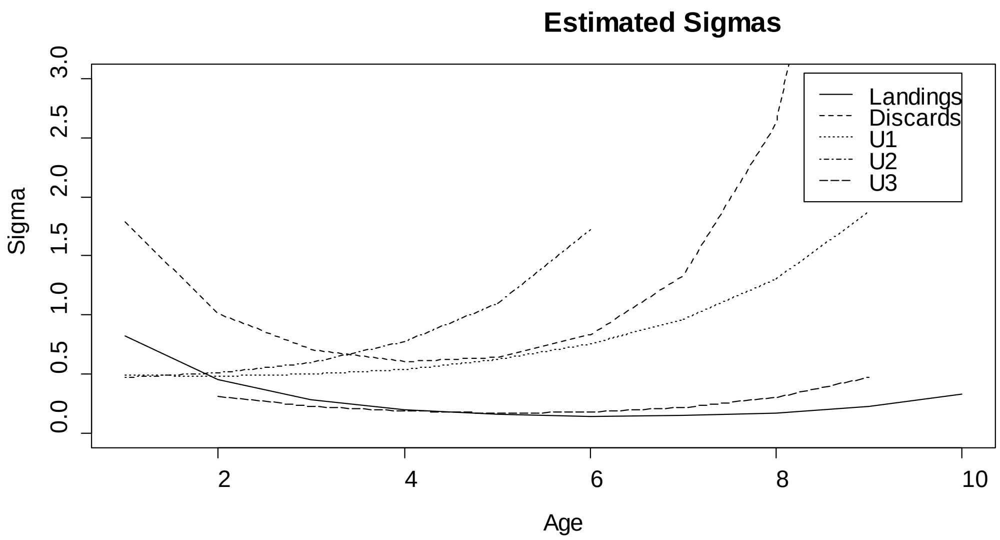

Figure 4.6.4.9. Model estimated sigmas of the different likelihood components.

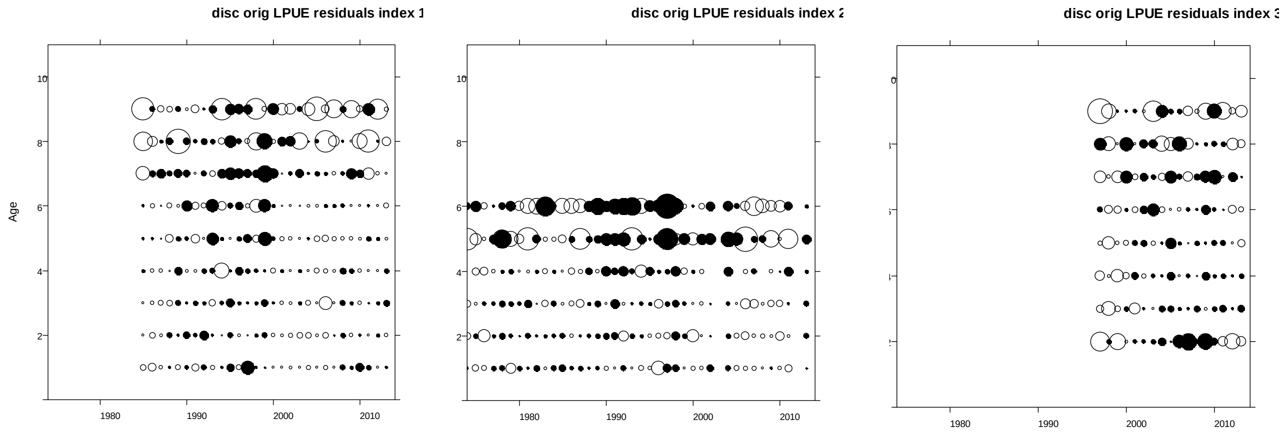

Figure 4.6.4.10. Residuals from the different tuning indices used in the model.

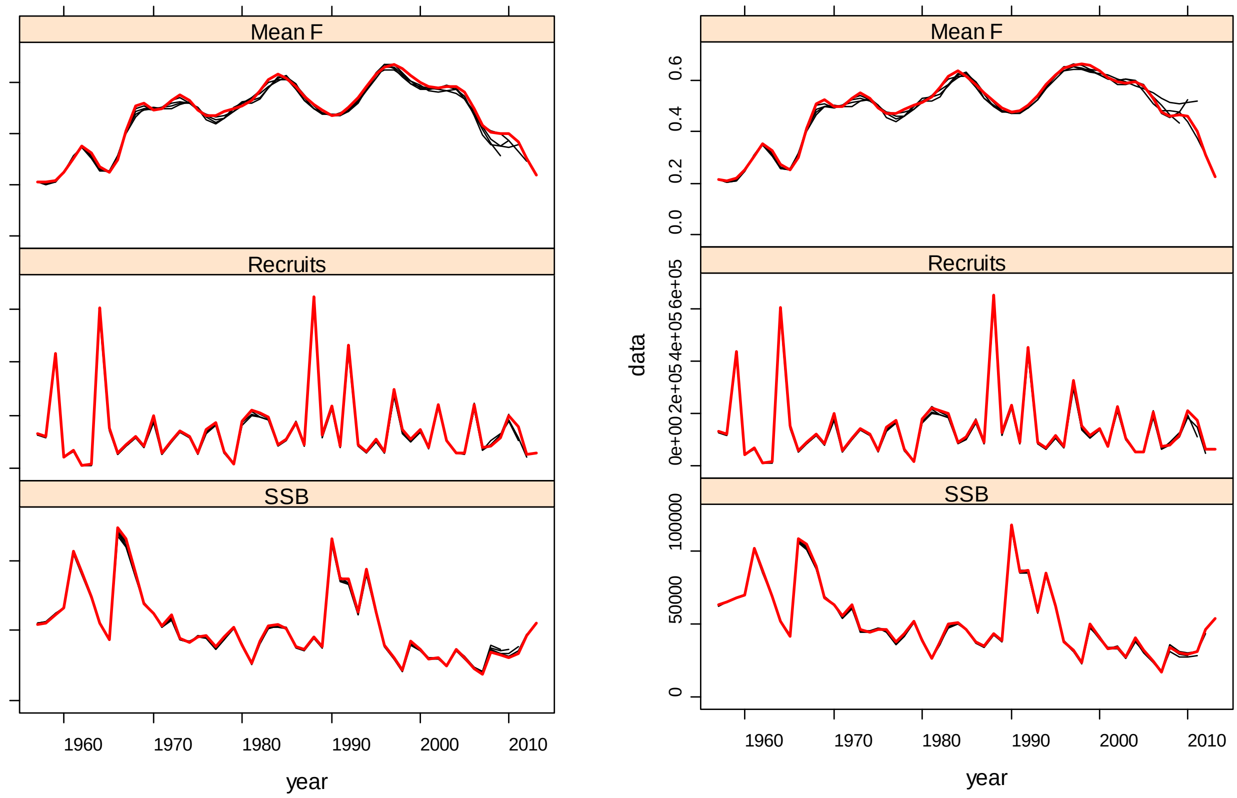

Figure 4.6.4.11. Retrospective analysis of the AAP model including discards with the original lpue series as used in WGNSSK 2014 (left panel) and the AAP model including discards, but without any commercial lpue tuning (Only BTS ISIS and SNS).

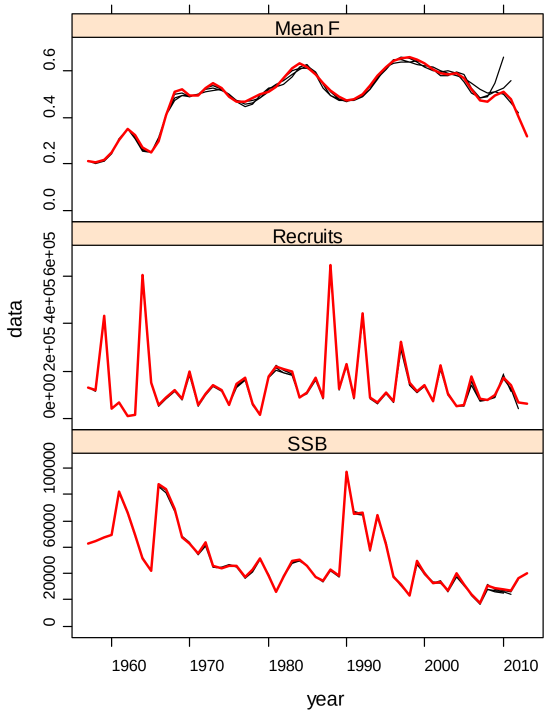

Figure 4.6.4.12. Retrospective analysis of the AAP model including discards, tuning with BTS ISIS, SNS, and the Belgium BTS survey.

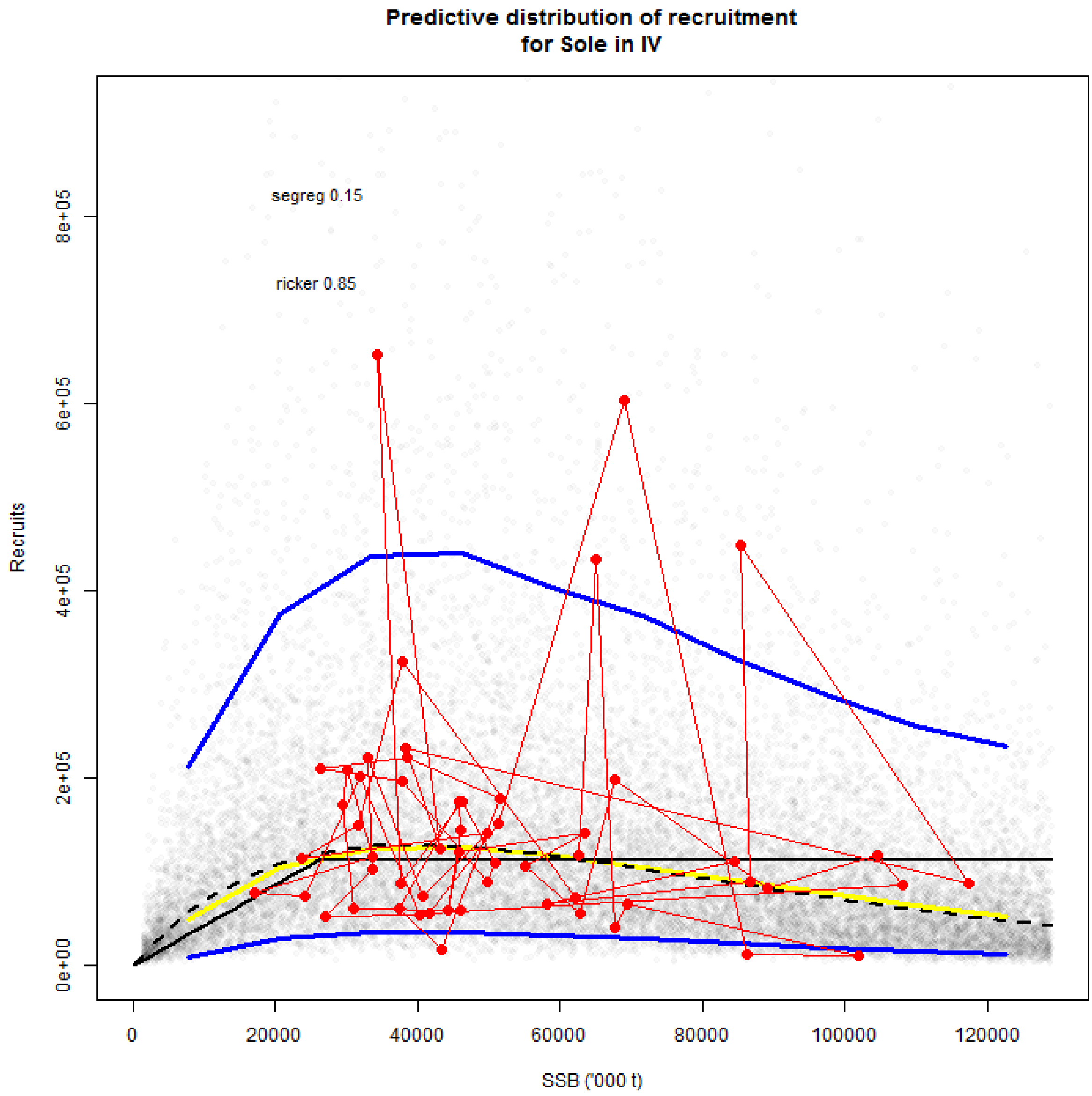

Figure 4.8.1.1. Stock–recruitment relationships as calculated by EqSim, following the settings of ICES WKMSYREF3.

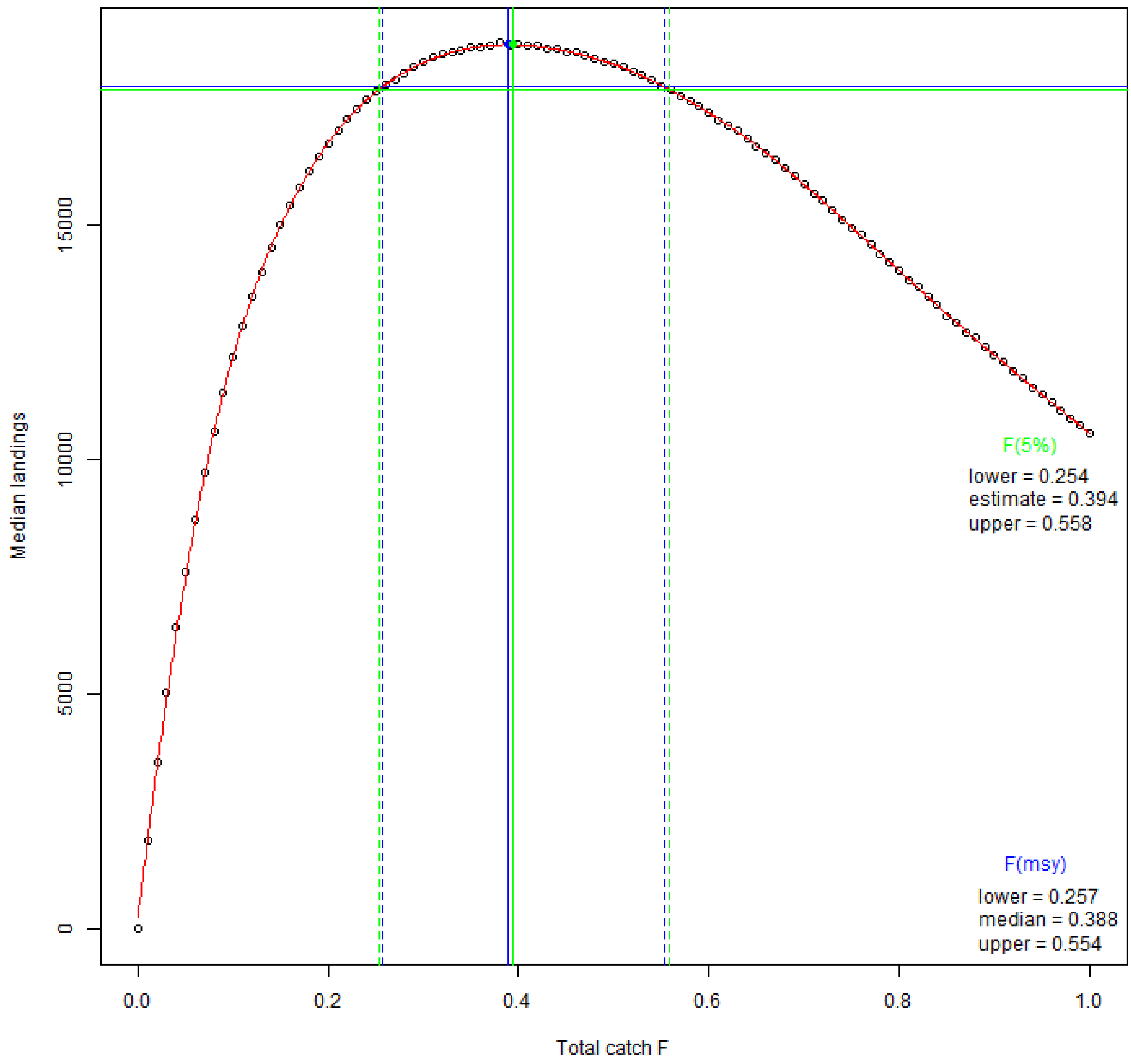

Figure 4.8.1.2. Estimated median long-term landings as a function of F_{BAR} (with fixed F exploitation, i.e. without $B_{trigger}$), following the settings of ICES WKMSYREF3.

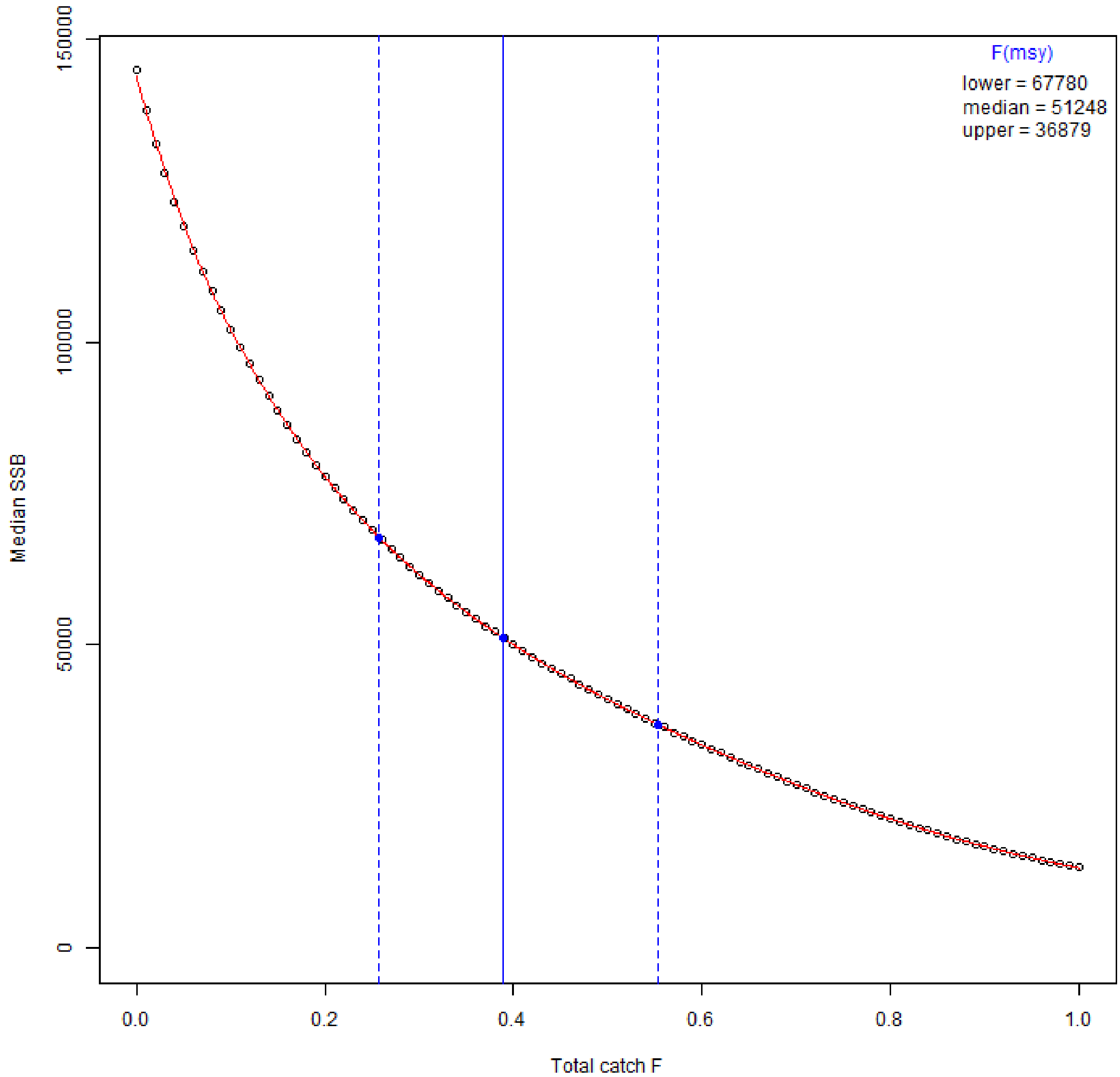

Figure 4.8.1.3. Estimated median long-term SSB as a function of F_{BAR} (with fixed F exploitation, i.e. without $B_{trigger}$), following the settings of ICES WKMSYREF3.

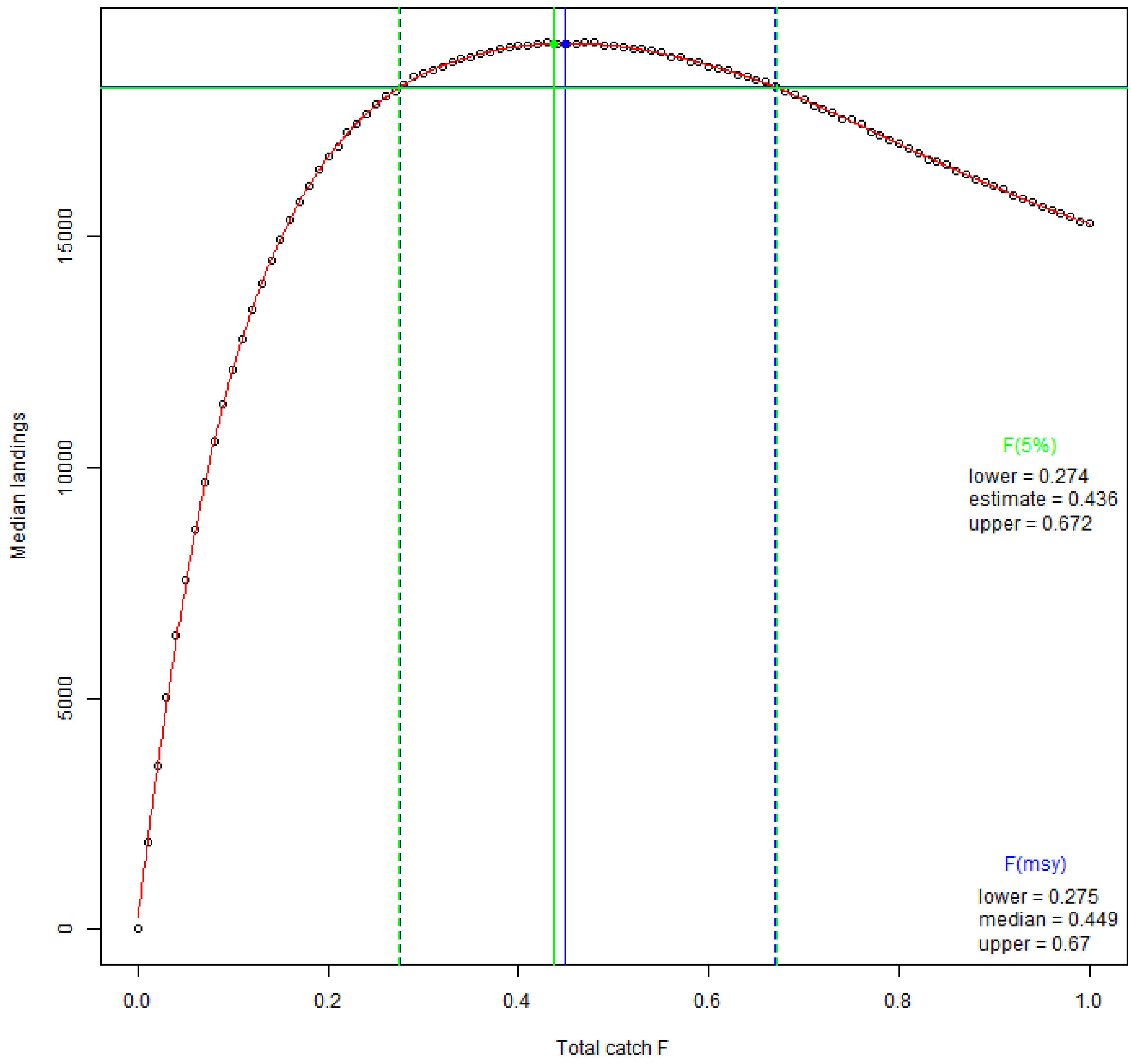

Figure 4.8.1.4. Estimated median long-term landings as a function of F_{BAR} (with $B_{trigger}$, being 37 000 t), following the settings of ICES WKMSYREF3.

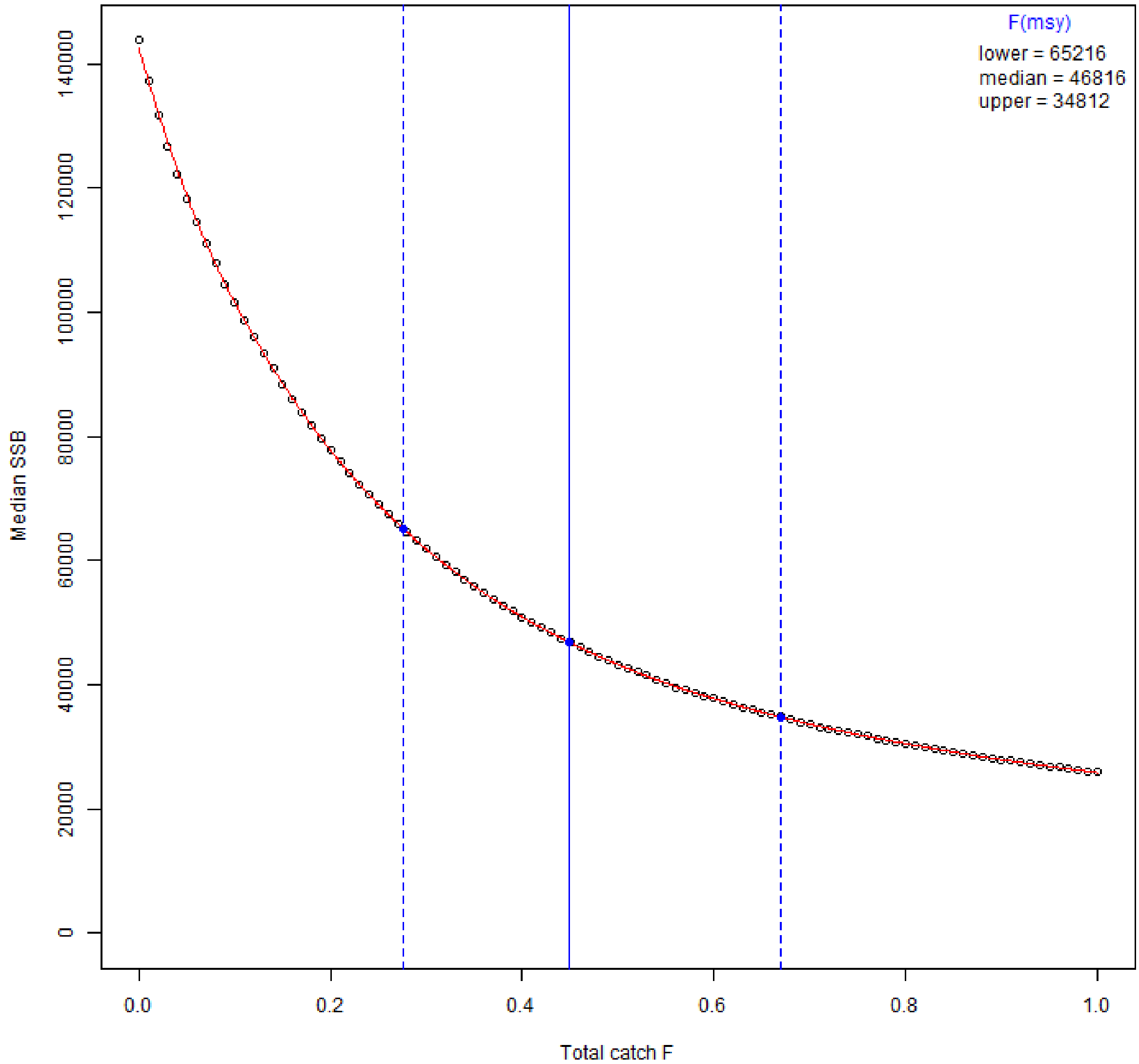

Figure 4.8.1.5. Estimated median long-term SSB as a function of F_{BAR} (with $B_{trigger}$, being 37 000 t), following the settings of ICES WKMSYREF3.

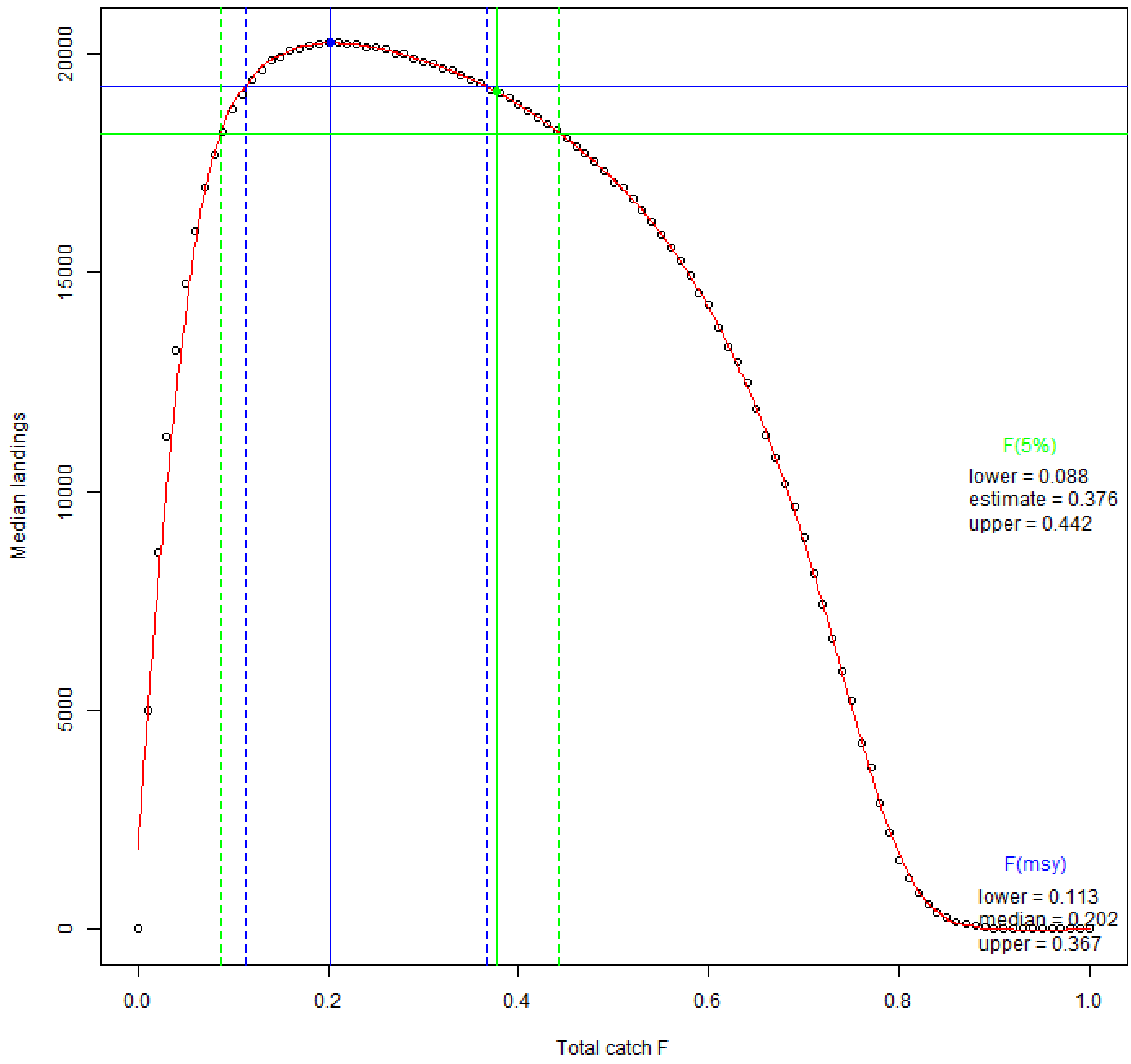

Figure 4.8.1.6. Estimated median long-term landings as a function of F_{BAR} (with fixed F exploitation, i.e. without $B_{trigger}$), for the sensitivity run with only segmented regression SR curve.

5 Stripped red mullet in IV, VIId and IIIa

5.1 Stock ID and substock structure

Due to the presence of striped red mullet in catches all year-round, Dunn (1999) suggested that a single stock should exist within the English Channel, although he could not determine whether this stock was distinct from other western stocks. He also suggested that striped red mullet might be a newly established stock in the North Sea.

In 2004 and 2005, a study using fish geometrical morphometry (Mahé *et al.*, 2005) was carried out in the Eastern English Channel and the Bay of Biscay. It pointed out a morphological difference on striped red mullets between those from the Eastern English Channel and those from the Bay of Biscay.

In 2010, in the Nespman project, a study based on the shape of the otoliths was conducted to differentiate stocks. The study area was divided into six geographic sectors: the NS (North Sea; ICES Division IVabc), the EEC (Eastern English Channel; ICES Division VIId), the WEC (Western English Channel ; ICES Division VIIe), the CS (Celtic Sea ; ICES Division VIIh), the NBB (North Bay of Biscay ; ICES Division VIIIa) and the SBB (South Bay of Biscay ; ICES Division VIIIb) (Figure 5.1.1).

In this work, three techniques were applied: a Fourier, a PCA and a Geodesic approach (In Benzinou *et al.*, 2013). Among these three techniques, the Geodesic approach reached the highest mean correct classification rate (30%). The confusion matrix of the Geodesic approach on the dataset with six geographic sectors, achieved by K-Nearest Neighbours classifier (Benzinou *et al.*, 2013), showed that populations of striped red mullet of Western English Channel and Eastern English Channel could be separated (Table 5.1.1).

In the north, it appears to be a continuum between the North Sea and the Eastern English Channel. In the same way, a continuum has been identified between the north and the south of the Bay of Biscay. Currently, we do not have enough data to separate the Bay of Biscay from the Celtic sea or the Western English Channel.

Therefore, for management purposes, two areas were considered for this species:

- the north area (III, IV & VIId)
- the south area (VI, VIIa,e,g,h,j, VIIIa,b & IXa)

These areas are the management areas currently used by ICES.

As stated by Mahé *et al.* (2005), there seem to be migration happening through the year from the eastern Channel to the North Sea. The average Catch per Unit of effort drawn from survey data (IBTS Quarter 1, IBTS Quarter 3 and CGFS quarter 4) (Figure 5.1.2) show a distribution pattern observed every year (figures for individual years not presented in this report), with a spatial distribution of this species in the western part of the North Sea during the first quarter and in the Southern part of the North Sea and the Eastern Channel during the third quarter and fourth quarter. These migrations were interpreted by Mahé *et al.* (2005) as spawning migration in the second quarter in the spawning areas located in the southern part of the North Sea and the Eastern Channel.

This spatial distribution of Red mullet in time and space seems coherent with spatial distribution of the landings as seen from InterCatch (Figure 5.1.3), where most of the landings in the North Sea are made in quarters 2 and 3 (mostly in the southern North

Sea but the spatial distribution at a finer scale than Subarea IV was not available) and the main fishing season in the Eastern Channel is during the third and fourth quarter with some years where the first quarter is also of importance (2005 and 2008 for example).

5.2 Issue list

- This stock has never been assessed. There is neither management plan nor minimum landing size for this stock. There are no catch projections and the advice is based on a biomass index used as indicator of (relative) stock size. The methods applied to derive quantitative advice were defined following rules for data-limited stocks.
- Some data were produced during former WGNEW based on official landings and survey indices. Striped red mullet has been sampled by France since 2004 but no age structure of the landing was produced from this sampling since.

Data available

Landings were submitted by métier to InterCatch by countries having fished Red Mullet in the Eastern Channel, North Sea or Skagerrak during the period 2003–2013.

Three surveys (CGFS: Channel Ground Fish Survey Q4 and IBTS Q1 and Q3 International Bottom Trawl Survey in the first and third quarters) provide cpues indices, relative abundance and biomass indices as well as cpues at-age from 2004 for CGFS. These surveys also provide some data on biology (maturity, sex ratio).

France has been sampling for red mullet since 2004, providing age structure of landing for the main fleet targeting red mullet (Otter Trawl). Sampling also provides some data on biology (maturity, sex ratio).

Data gaps / plans to solve the problems

- Age structure of the landings:

Only France provided age structure for Otter Trawlers. The other main fleet targeting Red Mullet (Dutch flyshooter) do not have age structure associated with its landings data. Even if both fleets target red mullet in the same area during the fishing season, there is no evidence that the selectivity patterns are identical.

Plan: landings by commercial categories are available for both fleets for the period 2004–2013. The landings proportion by commercial categories should be explored prior to raising procedures, to assess the potential impact of raising all landings using the French Otter Trawls age structure.

- Survey coverage

There is no evidence that the different surveys cover Red mullet life history in a sufficient way to be able to describe its dynamics. Furthermore, very limited age-structure data are available from both IBTS Q1 and Q3 making these indices hardly available for an age-based model.

Plan: Analyze additional size and age distribution of the different survey data time-series; as well of the landings data time-series. A comparative study of the size and age compositions in the different survey and commercial fishery data time-series in relation to their geographical coverage, and potential differences herein, will indicate how well the different time-series cover the different stock components and life stages. This should naturally be done under consideration of different gear selectivity and potential targeting in the different data time-series.

5.3 Scorecard on data quality

A scorecard has not been used during this benchmark.

5.4 Multispecies and mixed fisheries issues

Juvenile red mullet feed mainly on copepods and small benthic invertebrates. Adult red mullet feed on small crustaceans, annelid worms and mollusks, using their chin barbells to detect prey and search the mud. Red mullet juveniles, but also adults, can be prey of bigger demersal fish such as cod or whiting. However, no multispecies model is currently available to estimate multispecies interactions and derive predation estimates.

Landings of Red Mullet have been observed in the Eastern Channel since the beginning of ICES official statistics at the beginning of the 1970s. However, landings really became important and also recorded in the North Sea at the beginning of the 1990s (Figure 5.4.1). Historically, France has taken most of the landings (>90% of landings). This fishery is conducted by bottom trawlers using a mesh size of 70–99 mm in the eastern English Channel and in the southern North Sea. England also historically caught Red mullet in the same area using otter trawl.

From 2000 a Dutch fishery, using flyshooters has also developed. Flyshooters use the same mesh size of 70–99 mm in the Eastern Channel. Landings are now shared between French otters and Dutch flyshooters.

5.5 Ecosystem drivers

Striped red mullet (*Mullus surmuletus*) is a benthic species. Young fish are distributed in coastal areas, while adults have a more offshore distribution. Striped red mullet prefers sandy sediments.

From fishermen interviews, its spatial distribution seems highly correlated with temperature but it hasn't been studied in detail.

5.6 Stock assessment

5.6.1 Catch – quality, misreporting, discards

5.6.1.1 Catch data

Due to both the absence of minimum landing size and TAC, and its high commercial value, discard are assumed negligible and catches assumed equal to landings.

Landings have been provided to InterCatch by all countries catching Red mullet in this area (France, Netherlands, UK, Belgium, Denmark, Norway and Germany). InterCatch data and ICES official data are quite consistent (Figure 5.6.1.1.1). The main discrepancy is observed for France in 2008. This discrepancy was investigated with French administration and it appeared to be a problem in change in the landing database. The landings to be used in the assessment are the one uploaded in InterCatch as they were provided using the same database and procedures and are consistent with other data. Some inconsistencies in UK landings are also observed and should be further investigated. InterCatch landings were used in the input data for the assessment.

The main countries contributing to landings are France, Netherlands and UK.

More than 2/3 of French landings are coming from the Eastern Channel (Figure 5.6.1.1.2). Landings are nearly exclusively made by otter trawls using 70–99 mm mesh size.

This proportion of catches coming from the Eastern Channel is similar for the other main country catching Red mullet (Figure 5.6.1.1.3), The Netherlands. Most of the landings made in the Eastern Channel were made by boats using Scottish seine with 70–99 mm mesh size. In the North Sea, a higher diversity of gears and mesh size is observed.

The last country contributing to the landings (UK) also realizes most of its landings in the Eastern Channel. Most of them were realized using a Scottish seine with mesh size >120 mm (Figure 5.6.1.1.4).

5.6.1.2 Landings data

France provided age structure for the main fleet targeting Red Mullet. However the sampling only came from the Eastern Channel with very few samples from the North Sea. The Netherlands provided data by commercial catch categories and area. Landing data by country and year from Boulogne-Sur-Mer's auction market (main landing harbour for Red Mullet) were also available.

Figure 5.6.1.2.1 shows the comparison between ICES official landings, InterCatch landings and landings provided by the Boulogne-Sur-Mer auction market by commercial categories for French fleets. The main discrepancy observed has already been noted previously and is coming from the difference between official landings and data uploaded in InterCatch. Data from Boulogne sur Mer auction market follow the trends of the landings from Inter Catch. The difference between data from InterCatch and data from Boulogne auction market are landings made in another harbor.

Figure 5.6.1.2.2 shows the comparison between ICES official landings, InterCatch landings and landings provided by the Boulogne-Sur-Mer auction market by commercial categories for Dutch fleets. ICES official landings and landings uploaded in InterCatch are very consistent. Landings from InterCatch and landings coming from Boulogne sur Mer auction market are quite consistent in trends. Between 2010 and 2011, it appears that catches made in the Southern North Sea might have been sold in Boulogne sur Mer. However, landings figures from Dutch sale database, provided by commercial categories (red line) show completely different trends in both the Eastern Channel and the North Sea compared to the official landings and InterCatch values. These differences were interpreted as inconsistencies between databases and official and InterCatch values were used as considered accurate. It was then difficult to use the Dutch sale data by commercial categories to compare the catch distribution of the landings among commercial categories.

Figure 5.6.1.2.3 shows the comparison between ICES official landings, InterCatch landings and landings provided by the Boulogne-Sur-Mer auction market by commercial categories for English fleets. Some discrepancies are observed between the official landings and data uploaded in InterCatch. Landings made in Boulogne sur Mer auction market and data uploaded in InterCatch are consistent in the Eastern Channel except for 2007.

Based on exploration of the available data, landings data coming from Boulogne sur Mer auction data seem to be quite consistent with the official statistics and data uploaded in InterCatch. Dutch landings divided in Commercial Categories seem to

be very different from the official landings and won't be used to compare length structure of Dutch and French landings and assess the validity of raising all landings using French age structure.

5.6.1.3 Landings by commercial categories

Before sale, fish are sorted by weight; the European categories for Red Mullet are the following:

- Cat 10 corresponds to fishes of 500 grams or more;
- Cat 20 corresponds to fishes between 200 and 500 grams (Cat 21 = 300 to 500 grams and Cat 22 = 200 to 300 grams);
- Cat 30 corresponds to fishes less than 200 grams (Cat 31 = 150 to 200 grams and Cat 32 = 40 to 150 grams).

Based on these commercial categories it is then possible to compare a rough catch structure of the different countries (each country being characterized by a main métier as seen previously). Auction market landings data are available from 2000 to 2012.

Figures 5.6.1.3.1 and 5.6.1.3.2 show the proportion of landings by commercial categories from Boulogne-Sur-Mer's auction market. The main landed commercial category is the category 30 (fishes less than 200 grams). This category represents between 60 to 90% of the catches. The trends are quite similar between countries except for 2005 and 2012 where the Dutch fisheries landed mainly fishes of category 20 (between 200 and 500 grams).

Figure 5.6.1.3.3 show the observed weight-at-age and the different commercial categories for comparison. From 40 to 150 grams (commercial category 32), fishes are mainly age 1, from 150 to 200 grams (commercial category 31), they are mainly age 2, commercial category 22 is mainly composed of age 3 fish, the other categories are a mix of several ages.

Figure 5.6.1.3.4 compares French otter's lpues derived from the Eastern Channel and the North Sea. Lpue trends are the same in the North Sea and the Eastern Channel.

The landing data show that most of the catches are made in the Eastern Channel, where the French sampling is made for the otter trawl fleet (main French fleet). The available data show limited differences in the exploitation pattern of the different fleets in this area. The landing data by commercial categories do not show extreme differences in fleets' exploitation patterns.

The raising was then made using the French Otter Trawl sampling and raised to the other fleets.

5.6.2 Surveys

Three surveys might be used as indices for the assessment. CGFS (Channel Ground Fish Survey) occurs in the Eastern Channel in the last quarter, and the IBTS (International Bottom Trawl Survey) Q1 and Q3 occurring in the North Sea (and part of the Eastern Channel for the last years of the time-series of the first quarter survey).

These three survey catch red mullet even if the number of fishes caught during both IBTS are less important than during the Channel GroundFish Survey. Catch Per Unit of effort (Figures 5.6.2.1 to 5.6.2.4) and mean length of the population (Figure 5.6.2.5) can be derived from these surveys to check for consistency between areas. The limited number of fish caught during IBTS Q1 makes the comparison in term of trends difficult. However Figure 5.6.2.4 shows similar trends in both surveys occurring in two distinct areas (IBTS Q3 occurs in the North Sea and CGFS Q4 in the Eastern Channel) even if not all peaks are captured by both surveys.

Length measurements allowed for comparing length structure between IBTS Q1 and CGFS. Figure 5.6.2.5 compares the length structure of the catches during IBTS Q1 and the catches made during CGFS the previous year (previous quarter) and shows some consistencies in length structures. When high recruitment is caught by the CGFS (lengths between 10 and 18 cm) it is also seen by the IBTS Q1 three or four months later and the length structure is the shifted of several centimeters. Similarly, years without high recruitment the length structure composition is mainly flat in both surveys.

A very limited number of fish were aged during both IBTS surveys and sampling was not consistent across years (Tables 5.6.2.1 and 5.6.2.2). From 2004, Red mullet has been aged (Table 5.6.2.3) during CGFS and an index at-age could then de derived from this survey (Figure 5.6.2.6). Internal consistency of the age structures observed through CGFS is examined in Figure 5.6.2.7.

Conclusion on surveys

The three available surveys tend to show that migrations occur between the different areas. They all provide information on length structure but only CGFS has an age structure associated with the catches.

The observed length structure is in favour of a correct description of the length structure of the population by the CGFS. As the assessment models tried in this benchmark are aged-based models, only CGFS has been used as index making the hypothesis that it reflects the age structure of the whole population.

5.6.3 Weights, maturities, growth

5.6.3.1 Weights

Stock weights are coming from CGFS weights-at-age. Catch weights are direct outputs from InterCatch weight-at-age.

Figures 5.6.3.1.1 and 5.6.3.1.2 present the available weight-at-age time-series for ages 0 to 4. No trends are observed in stock weight but there might be some declining trends for the catch weight for the older ages. However, these weights are very sensitive to sampling and very variable from one year to another.

5.6.3.2 Maturities

In the Eastern Channel and North Sea, reproduction occurs between May and August with a reproduction peak in June. A second reproduction period might take place in December where mature females have been observed but these late reproduction period needs to be further documented.

Figure 5.6.3.2.1 presents the proportion of mature individuals per age class from sampling (commercial and survey) in the Eastern Channel. These observations are close to the values derived in Mahé *et al*., 2005. The maturity ogive used is then:

AGE	0	1	2	3	4	5	6
Maturity	0	0.54	0.65	1	1	1	1

5.6.3.3 Growth

Striped red mullet is a fast growing species. Figure 5.6.3.3.1 presents the mean length-at-age. Red mullet grow from 12 cm (observed during the fourth quarter) on average at age 0 to more than 20 cm at age 1. The distinction between age 0 and older individual is really clear at 16 cm.

5.6.3.4 Natural mortality

5.6.3.4.1 Jensen's second estimator (Jensen, 1996)

Jensen's second estimator is based on the estimation of K. Table 5.6.3.4.1.1 presents the estimated parameters of the von Bertalanffy growth curve based on sampling data. These estimations are a bit higher but in line with the estimations from Mahé *et al.*, 2013 who estimated K for females being at 0.196 and at 0.218 for males. Based on this estimation, Jensen's second estimator of M would be:

$$M = 1.5 \times K = 0.43$$

5.6.3.4.2 Gislason first estimator (Gislason *et al.*, 2010)

Gislason first estimator based on length are presented in Table 5.6.3.4.2.1 for the mean observed length-at-age.

$$M(l) = 1.73 l^{-1.61} \times L\infty^{1.44} \times K$$

5.6.3.4.3 Peterson and Wroblewski (Peterso and Wroblewski, 1984)

Peterson and Wroblewski estimator based on weight are presented in Table 5.6.3.4.3.1 for the mean observed weight-at-age.

$$M(w) = 1.28 w^{-0.25}$$

The evolution of the different M values at-age is presented in Figure 5.6.3.4.1.

Conclusion on natural mortality

In general, as expected, natural mortality rates are high for this species. These three mortalities will be tried in the assessment to see the impact of the natural mortality on the model fit.

5.6.4 Assessment model

5.6.4.1 Data exploration

Based on the raising procedures described previously a catch matrix was provided. Figure 5.6.4.1.1 presents the landings number-at-age. No fish of age 0 were landed prior to 2009. Very few fishes older than age 3 are observed in the landings.

Good recruitments are hard to track after age 2. The good cohort observed at age 1 in 2007 (2006 year class) can be tracked in 2008 but hardly later.

Log catch curves are presented in Figure 5.6.4.1.2. Due to the limited number of years, few cohorts are followed entirely.

Abundance index and internal consistency of CGFS are presented earlier in the report.

Two distinct aged-based models were tried during the benchmark. An XSA (using FLR and FLXSA) and a Statistical Catch-at-Age (using a4a).

5.6.4.2 XSA

Settings for the trial run of XSA were the following:

Assessment model:	XSA
Assessment software	FLR library
Fleets:	
FR Ground Fish Survey Age range Year range	1–4 2004 onwards
Catch/Landings	
Age range:	1–5+
Landings data:	2004 onwards
Discards data	None
Model settings	
Fbar:	1–3
Time-series weights:	None
Power model for ages:	No
Catchability plateau:	Age 3
Survivor est. shrunk towards the mean F:	3 years / 3 ages
S.e. of mean (F-shrinkage):	2.0
Min. s.e. of population estimates:	0.3
Prior weighting:	No

The M values applied for all ages and years were the constant value of 0.43 as estimated on Jensen's second estimator.

Proportion of M and F before spawning were assumed null for all ages.

The residuals presented in Figure 5.6.4.2.1 do not show any particular trends for age 3. For age 1 and 2 residuals are mostly positive at the beginning of the time-series and negative at the end. The retrospective analysis of this run presented in Figure 5.6.4.2.2 shows highly variables trends in F.

5.6.4.3 a4a

An assessment of Striped red mullet was carried out using the a4a modelling framework (Jardim *et al*., 2015). This framework relies on the specification of three log-linear submodels, one each for fishing mortality, survey catchability and recruitment.

The catchability and stock recruitment submodel were a year effect model for recruitment and an age factor (constant over years) for catchability. Two fishing mortality submodels were investigated: (1) a year and an age effect and (2) an age effect in combination with a smoother over the years with five knots (Table 5.6.4.3.1).

Sensitivity analysis on M values was run using the three M values at-age estimated previously, F_{BAR} was computed over age 1 and 2 and plus group was set to 4. Results of the different models and M values are presented in Table 5.6.4.3.2. AIC and BIC values were very similar for a given fishing mortality submodel. The fishing mortality submodel using a smoother over year returned a better AIC and BIC.

Results shown in Figures 5.6.4.3.1 to 5.6.4.3.5 are results using the natural mortalities estimates derived from Gislason first estimator and the fishing mortality submodel 2. This model configuration was chosen for the final benchmark assessment. High values of M for the first age as estimated by the Gislason first estimator allows for taking into account the biology of this species (fast growing species and high natural mortality on the young ages).

Residuals do not show any particular pattern or trends. The model has difficulties to reconstruct catch-at-age for some years (i.e. 2004). It reconstructs reasonably well the total landings (Figure 5.6.4.3.4) but has a high level of uncertainty for the first assessment year for SSB and a high level of uncertainty on recruitment for the last assessment year.

Figure 5.6.4.3.5 shows the retrospective analysis. Given the limited time-series, the retrospective analysis can either reflect issues of potential terminal bias but also, potentially, model variability due to limited data becoming even more limited as years are dropped.

SSB shows a retrospective pattern with a tendency to overestimate SSB values. The huge difference in SSB in 2004 could be interpreted by the uncertainty around this value observed in Figure 5.6.4.3.4.

Final model settings:

Setting/Data	Values/source
Catch-at-age	Landings (since 2004, ages 0–4+) InterCatch Discards are assumed negligible
Tuning indices	FR CGFS (since 2004 ages 0–4+)
Plus group	4
First tuning year	2004
Fishing mortality	~ s(year, k=5) + factor(age)
Survey catchability	~ factor(age)
Recruitment	~ factor(year)

5.7 Short-term projections

Not made for this stock due to the high level of uncertainty on recruitment the last year and the exploitation pattern of the fisheries at the moment that fish mostly on recruitment and age 1.

5.8 Appropriate reference points (MSY)

Not defined.

5.9 Future research and data requirements

Most of the uncertainty in the assessment carried out during the Benchmark might come from the absence of information from the North Sea (no age structure of the landings, no tuning fleet) and the lack of information on age structure of the landings of the Dutch fleet. However some length-based information is or might be made available for these areas and fleet. An integrated approach would then make it possible to use all the available information.

5.10 References

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Table 5.1.1. Striped red mullet. Confusion matrix (in %) for Geodesic approach on dataset (1) achieved by K-Nearest Neighbours classifier (Benzinou *et al.*, 2013). Mean correct classification rate was 30% (25% for PCA approach and 19% for Fourier approach).

Geodesic approach on Dataset (1)						
	Actual Class					
Estimated Class	NS	EEC08	WEC	CS	NBB	SBB
NS	**15**	20	11	8	5	11
EEC08	28	**44**	17	23	5	5
WEC	9	9	**22**	11	7	9
CS	24	15	24	**32**	15	13
NBB	10	5	16	13	**27**	22
SBB	14	7	10	13	41	**40**

Table 5.6.2.1. Number of fish aged during IBTS Q1.

	2007	2008	2009	2010	2011	2013	2014
0	0	0	0	0	0	0	0
1	0	5	1	32	0	0	26
2	1	7	2	6	20	2	2
3	0	13	1	1	1	0	0
4	0	4	0	1	1	0	0
6	0	1	0	0	0	0	0

Table 5.6.2.2. Number of fish aged during IBTS Q3.

	2007	2008	2009	2010	2011	2013	2014
0	2	0	0	0	0	0	0
1	60	0	12	0	0	0	0
2	12	0	3	0	0	0	0
3	3	0	0	0	0	0	0
4	2	0	0	0	0	0	0
6	0	0	0	0	0	0	0

Table 5.6.2.3. Number of fish aged during CGFS Q4.

	2006	2007	2008	2009	2010	2011	2012	2013	2014
0	40	8	3	80	35	1	48	20	34
1	49	91	26	92	45	63	12	14	30
2	22	1	44	14	13	5	9	4	11
3	21		3	7	1			1	
4	6		2	1	2		1		
5	1								

Table 5.6.3.4.1.1. Estimated von Bertalanffy growth curve parameters.

Linf	K	T0
34.5	0.2852	-2.572

Table 5.6.3.4.2.1. M values by age based on the mean length-at-age.

age	meanLength	M_Gislason
0	12.28	1.426
1	19.74	0.6641
2	23.88	0.4888
3	26.37	0.4164
4	28.79	0.3616
5	30.62	0.3275
6	29.8	0.3421

Table 5.6.3.4.3.1. M values by age based on the mean weight-at-age.

age	meanWt	M_Peterson
0	32.7	0.5353
1	103.6	0.4012
2	185.9	0.3467
3	253	0.3209
4	312.8	0.3044
5	485.8	0.2726
6	351.7	0.2956

Table 5.6.4.3.1. R syntax for the a4a submodels.

Submodel	Syntax
Fishing mortality 1	~ factor(year) + factor(age)
Fishing mortality 2	~ s(year, k=5) + factor(age)
Survey catchability	~ factor(age)
Recruitment	~ factor(year)

Table 5.6.4.3.2. AIC and BIC values for the different a4a models and M values.

	F ~ factor(year) + factor(age)	F~ s(year, k=5) + factor(age)
AIC_Constant	406.9	403.4
AIC_Gislason	407	403.2
AIC_Peterson	407.1	403.4
BIC_Constant	498.1	481.5
BIC_Gislason	498.2	481.4
BIC_Peterson	498.3	481.5

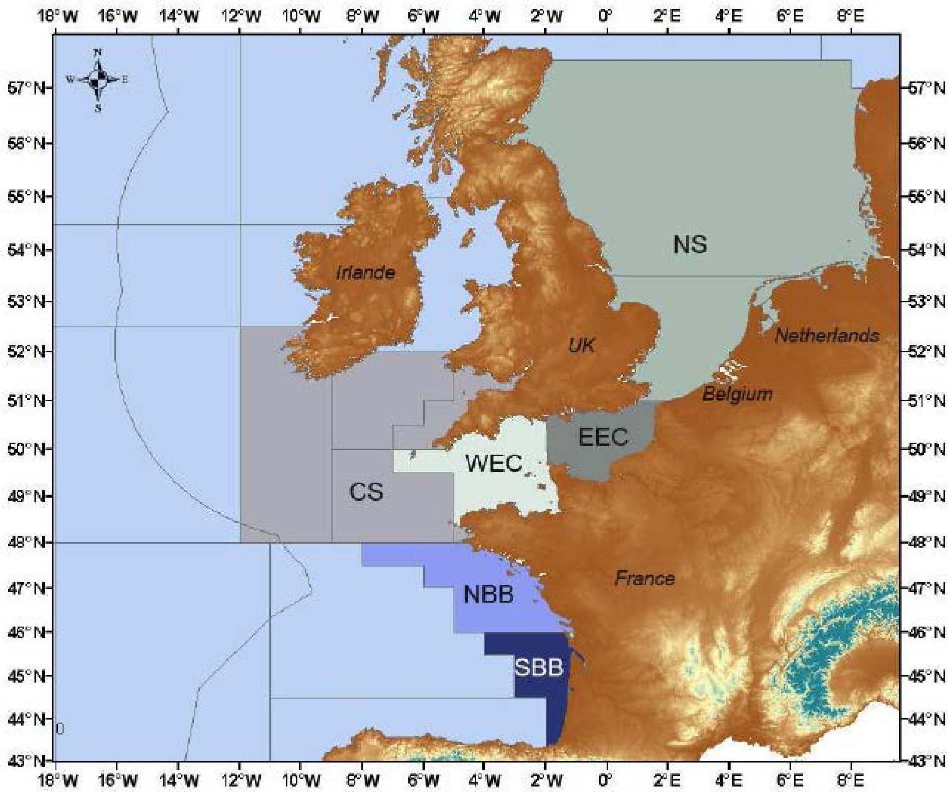

Figure 5.1.1. Striped red mullet. Map divided into six geographic sectors.

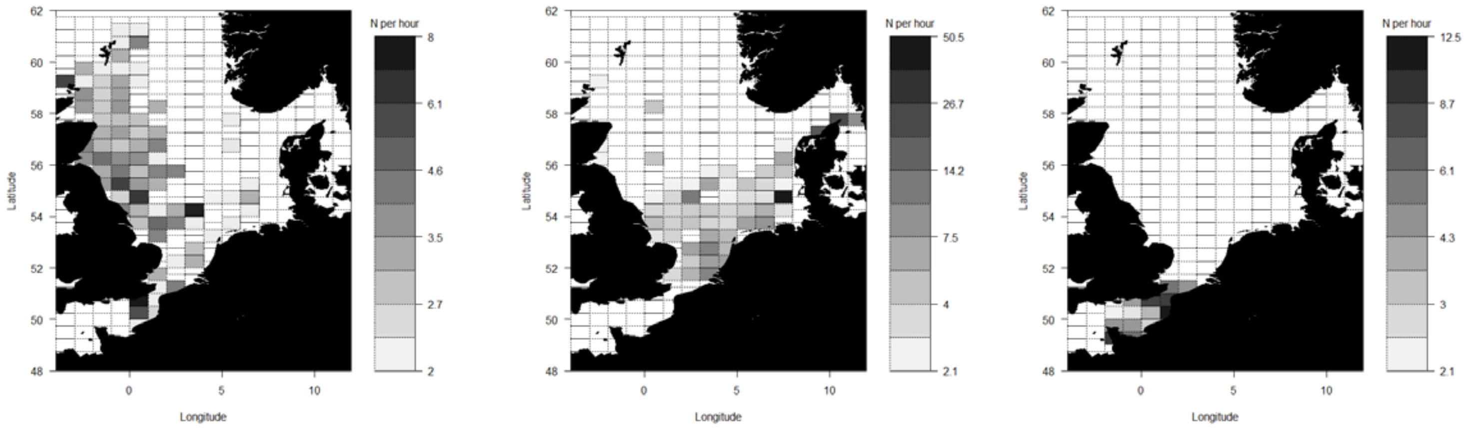

Figure 5.1.2. Striped red mullet. Average cpue (Number of fish per hour) over 2004–2013 for IBTS Q1 (left panel), IBTS Q3 (middle panel) and CGFS Q4 (right panel). The sampling area in IBTS Q1 encompasses the eastern part of the Eastern Channel and the North Sea, IBTS Q3 takes part in the North Sea only, and CGFS Q4 takes part only in the Eastern Channel.

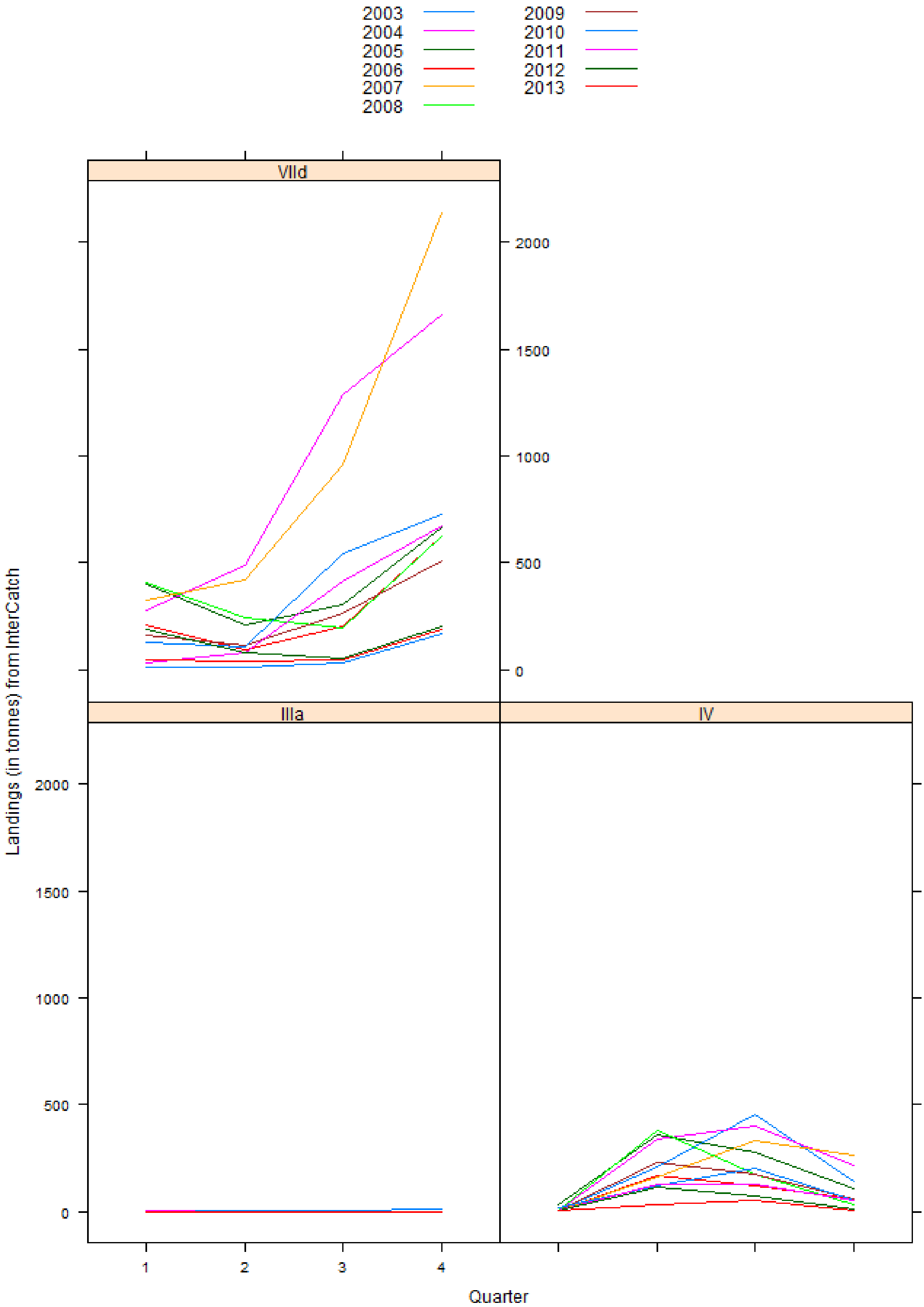

Figure 5.1.3. Striped red mullet, landings by quarter and areas.

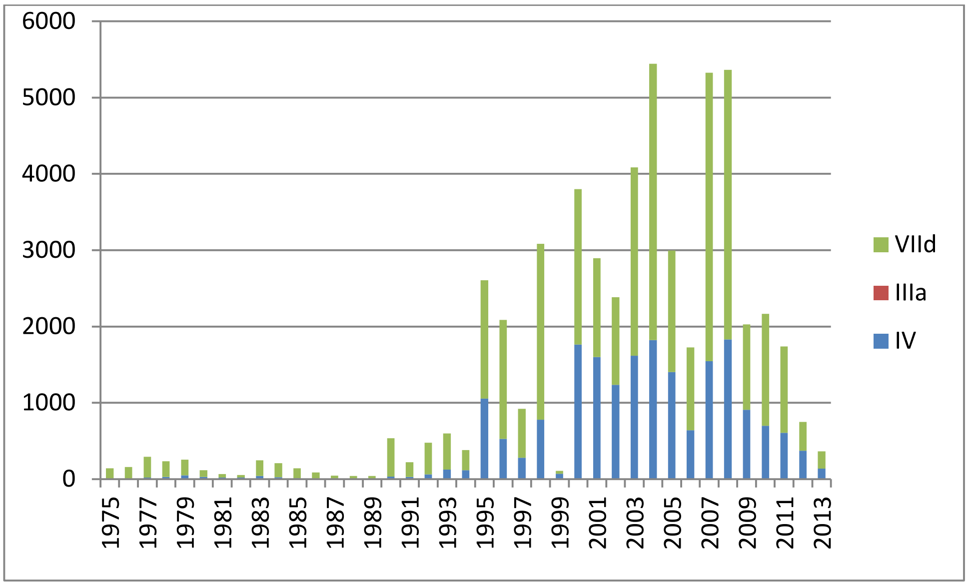

Figure 5.4.1. Striped red mullet landings in Subarea IV, and Divisions IIIa and VIId. Official and ICES landings (tonnes).

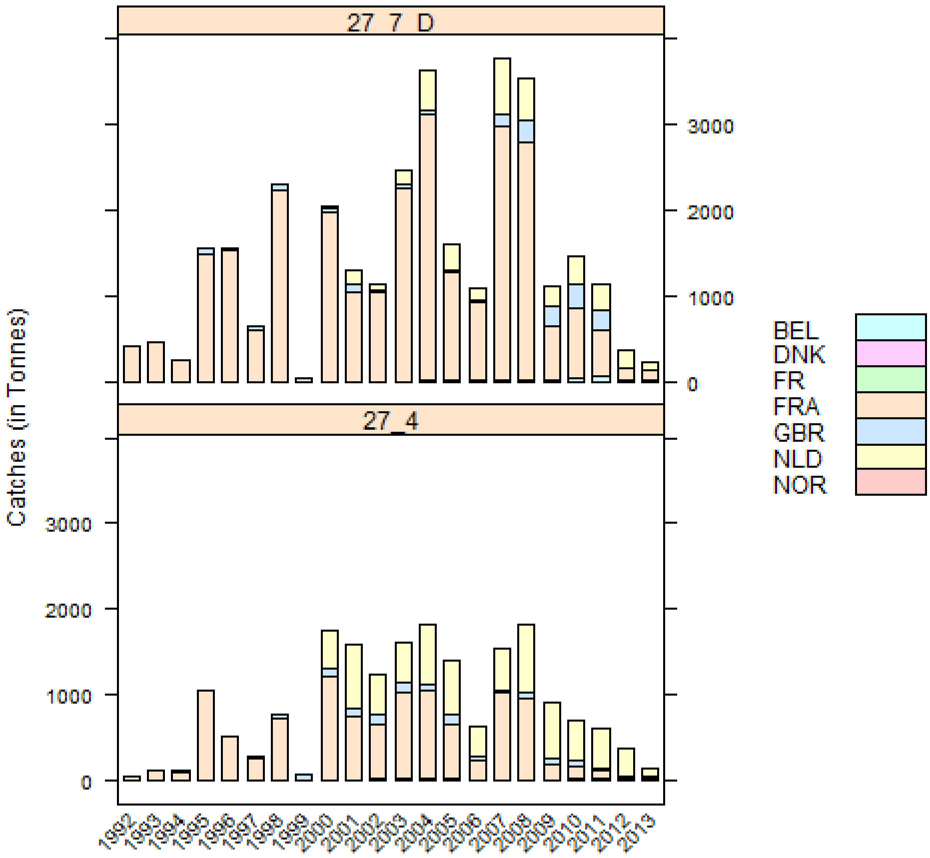

Figure 5.4.2. Striped red mullet landings in Division VIId (top panel) and Subarea IV (bottom panel). Official and ICES landings by country (tonnes).

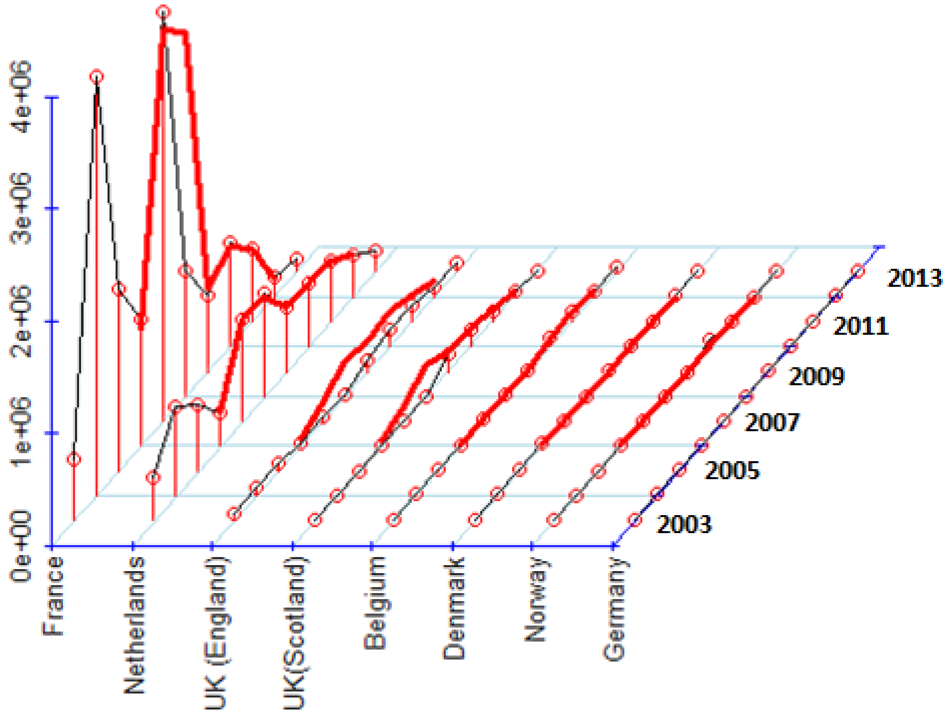

Figure 5.6.1.1.1. Comparison of ICES Official landings statistics (red line) and data uploaded in InterCatch (black line) (all areas, all gears and seasons).

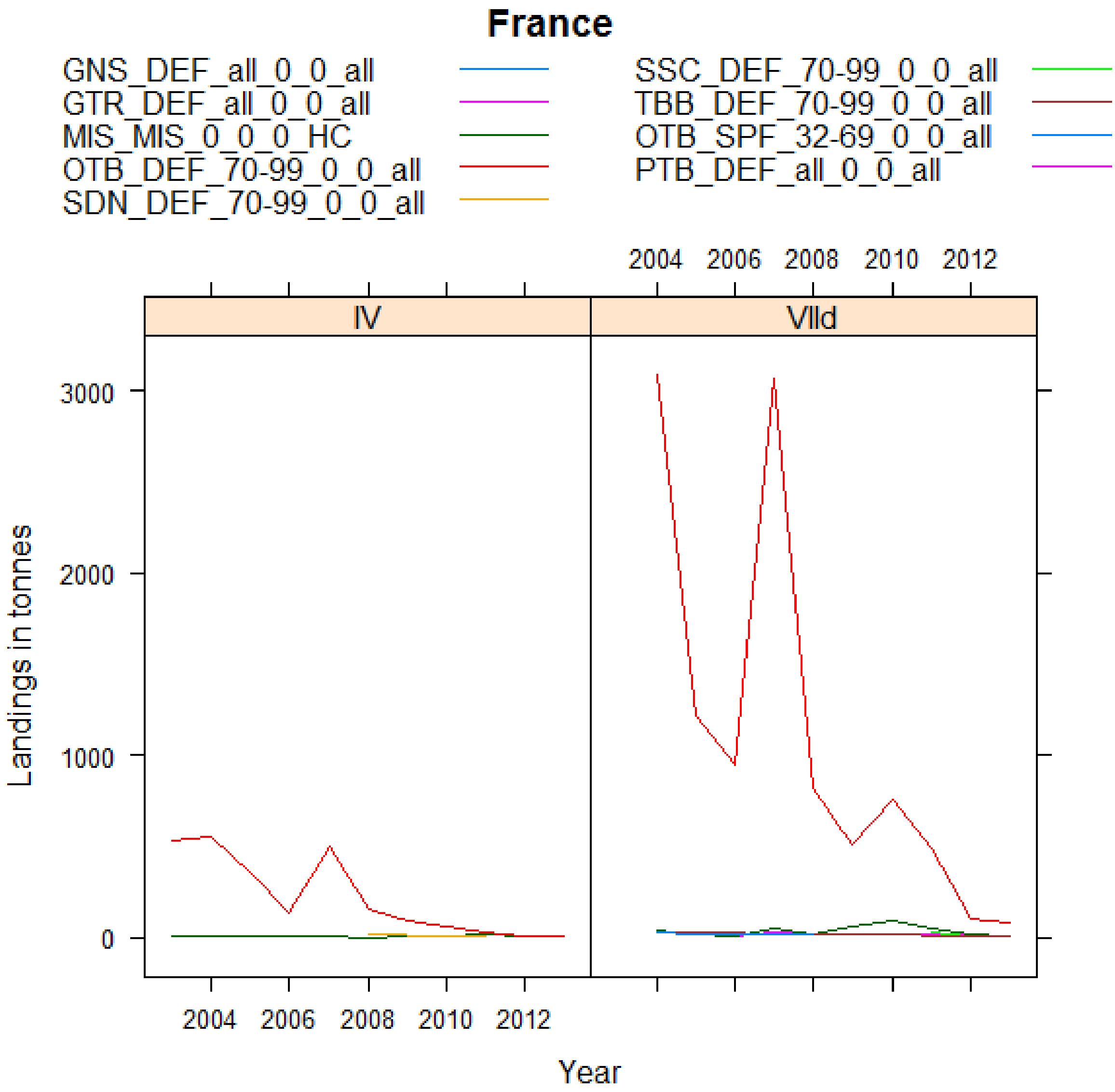

Figure 5.6.1.1.2. InterCatch landings by country (France) and gear.

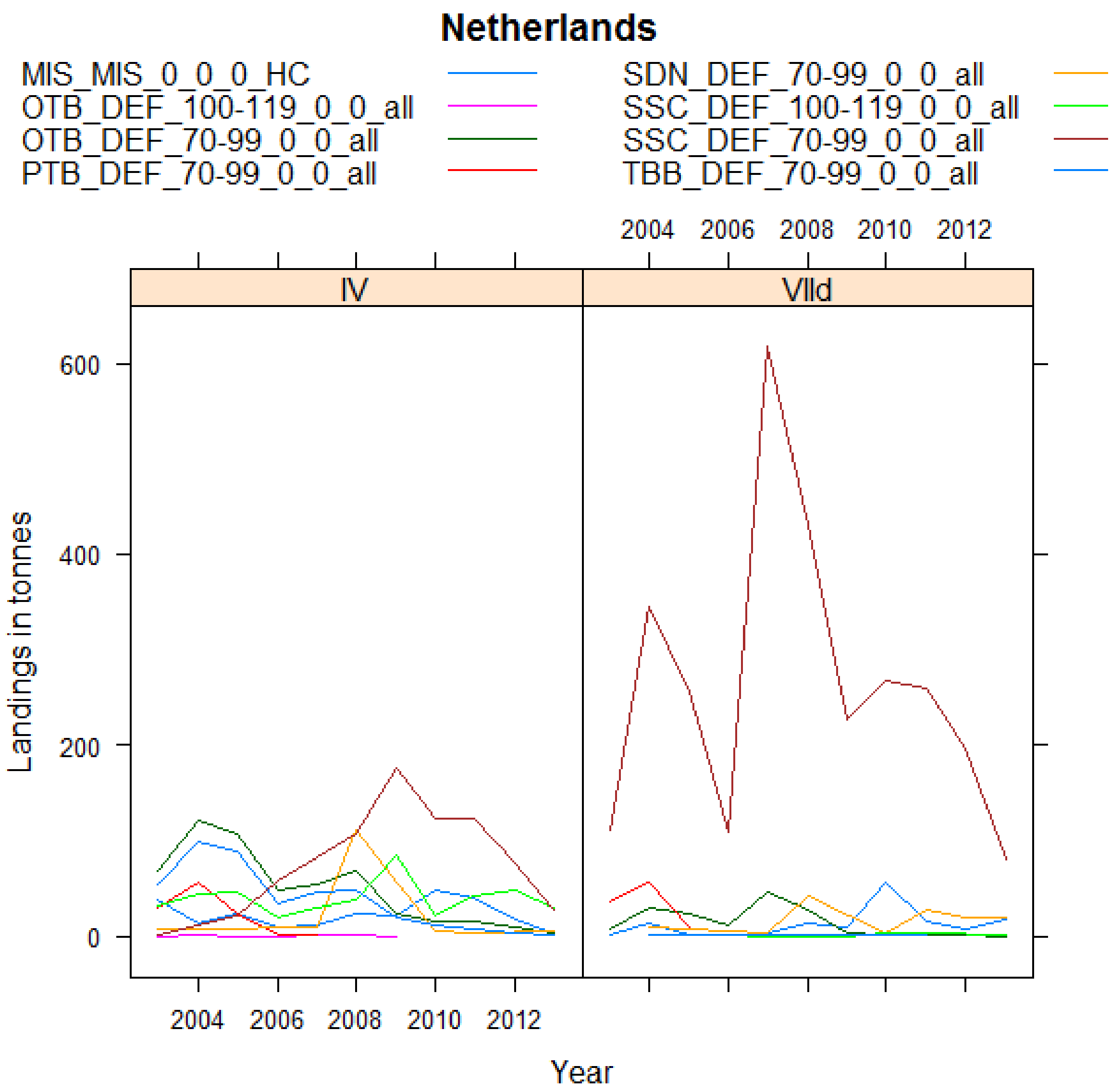

Figure 5.6.1.1.3. InterCatch landings by country (The Netherlands) and gear.

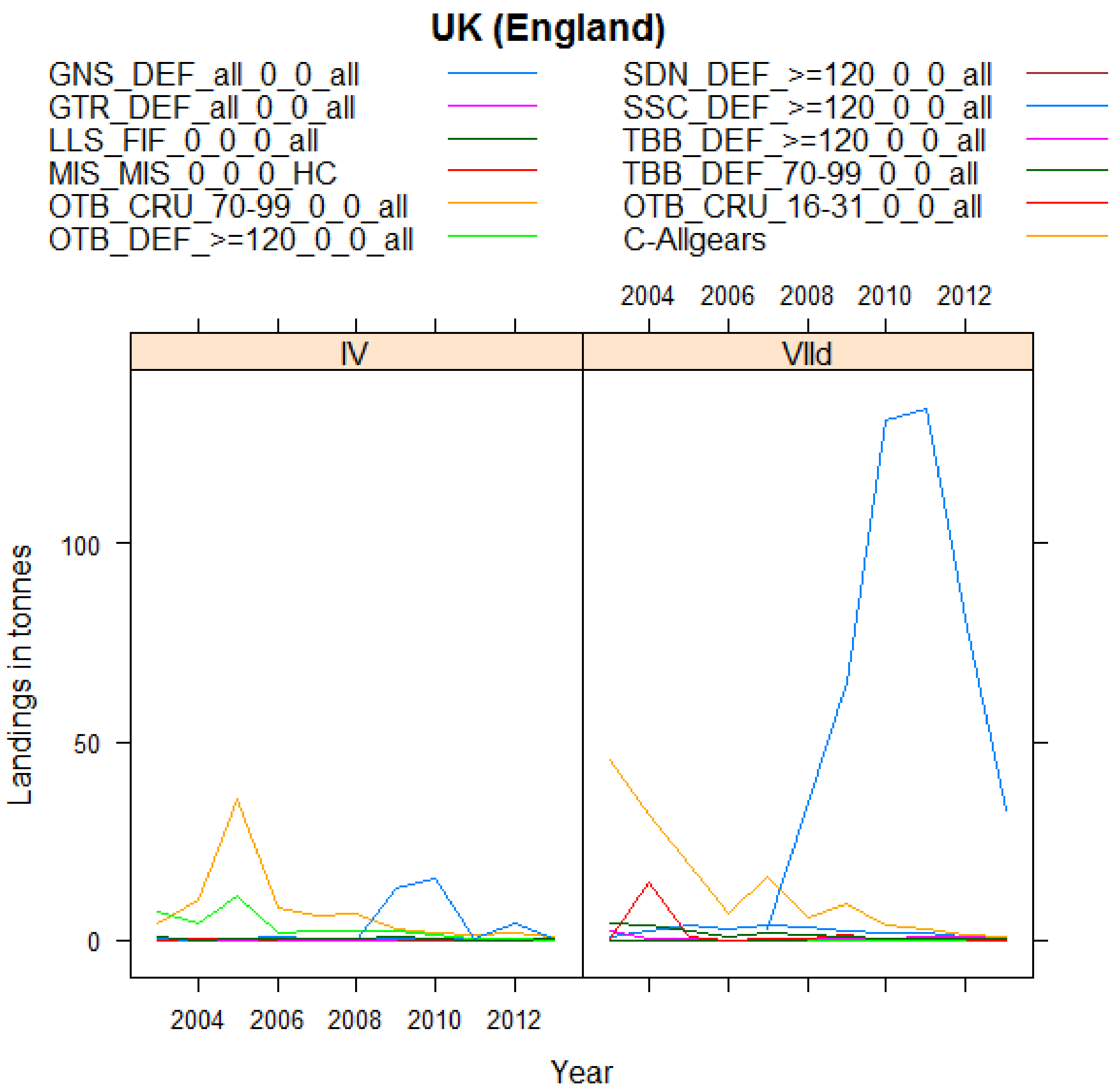

Figure 5.6.1.1.4. InterCatch landings by country (UK (England)) and gear.

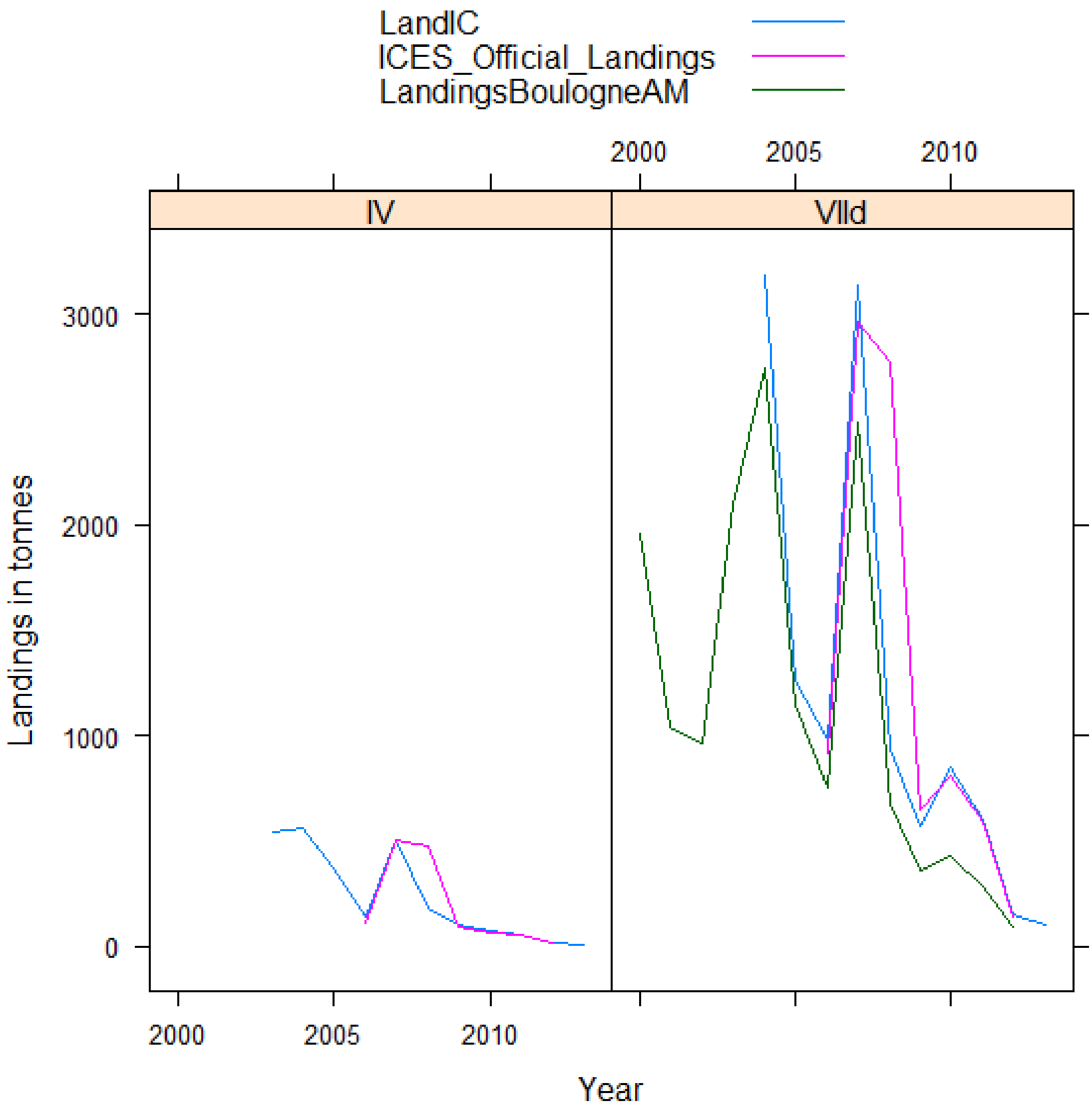

Figure 5.6.1.2.1. Comparison between official landings, InterCatch landings and data from Boulogne sur mer auction market data (France).

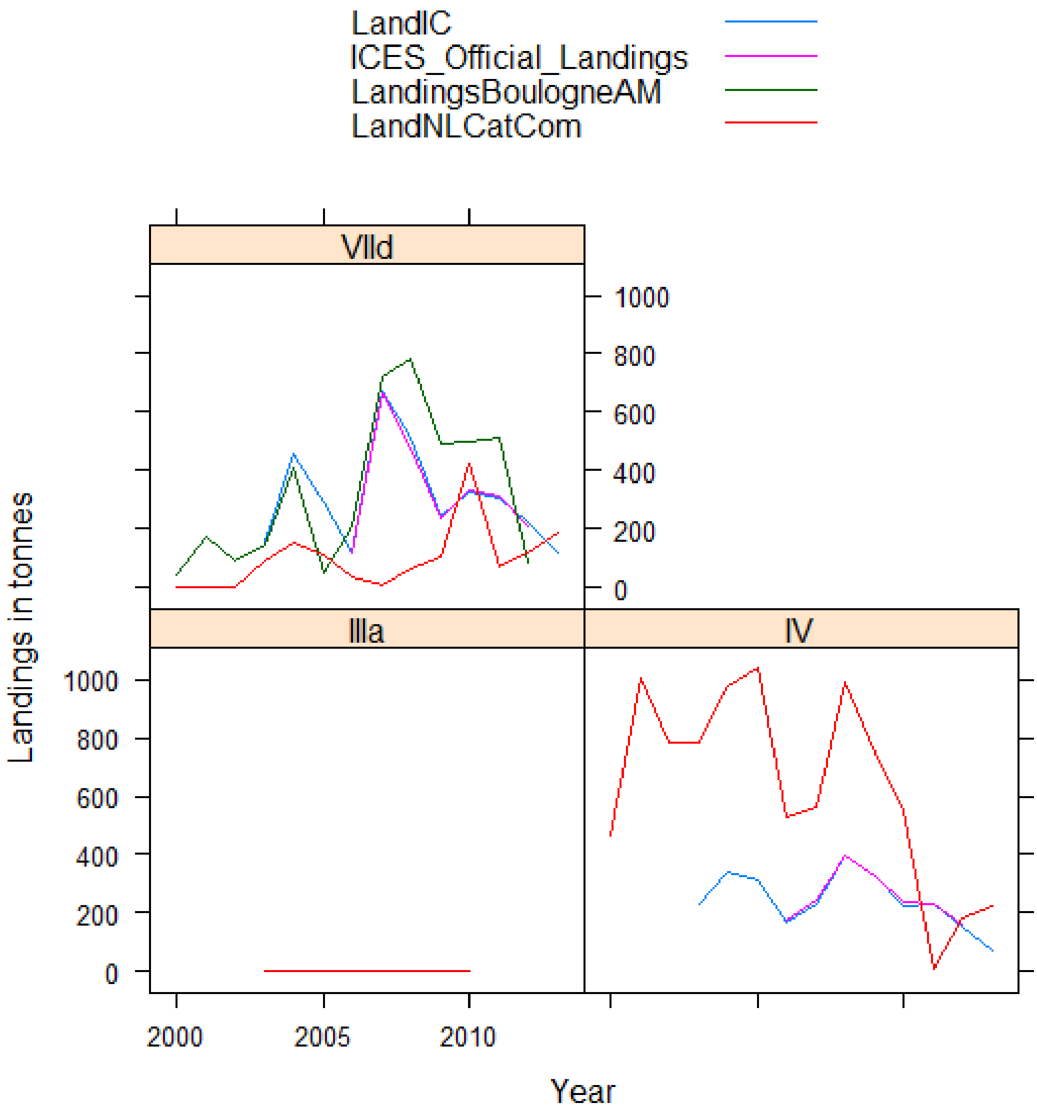

Figure 5.6.1.2.2. Comparison between official landings, InterCatch landings and data from Boulogne sur mer auction market data (The Netherlands).

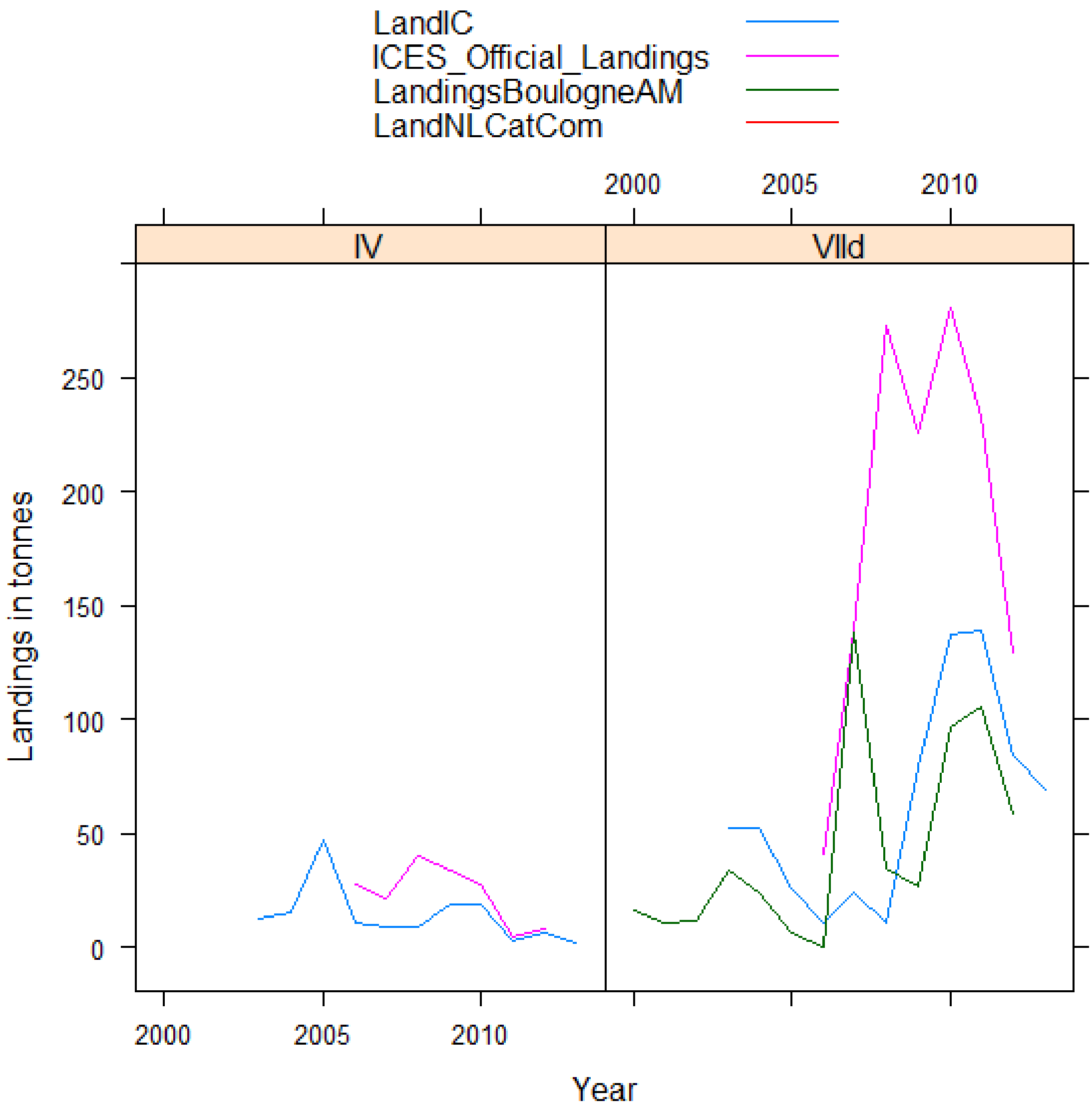

Figure 5.6.1.2.3. Comparison between official landings, InterCatch landings and data from Boulogne sur mer auction market data (UK England).

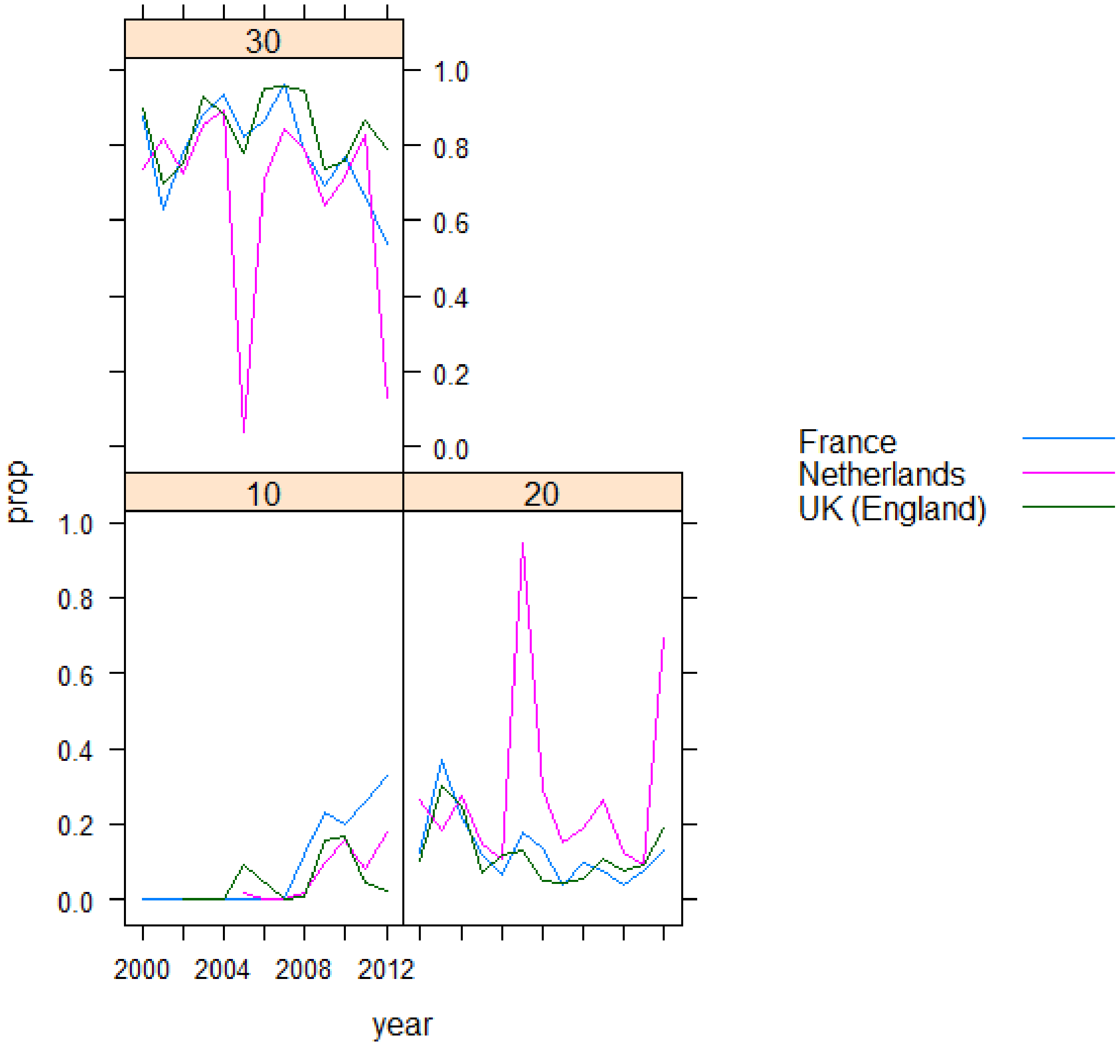

Figure 5.6.1.3.1. Proportion of Commercial categories in the landings by countries.

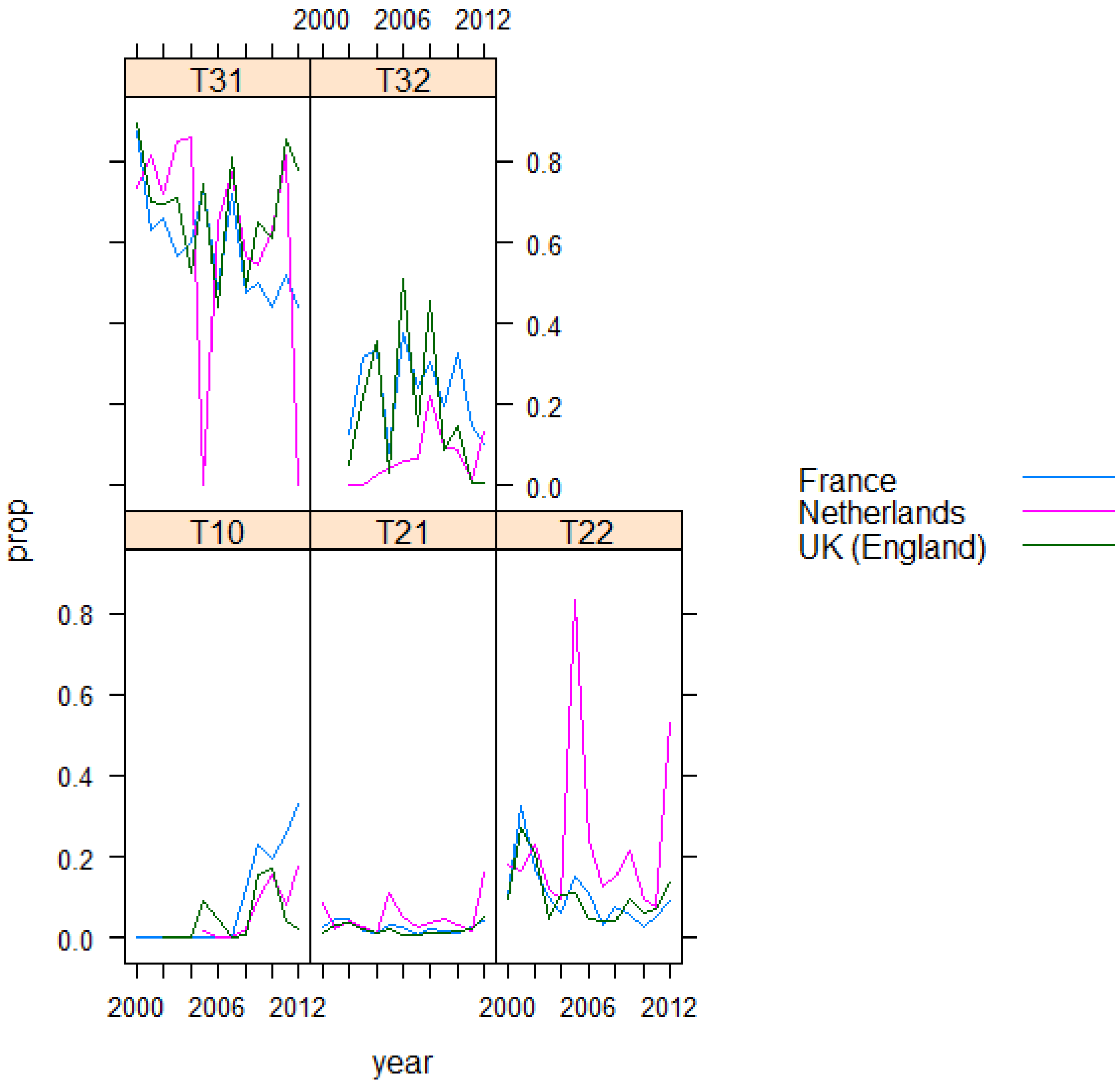

Figure 5.6.1.3.2. Proportion of commercial categories in the landings by countries (refined commercial categories).

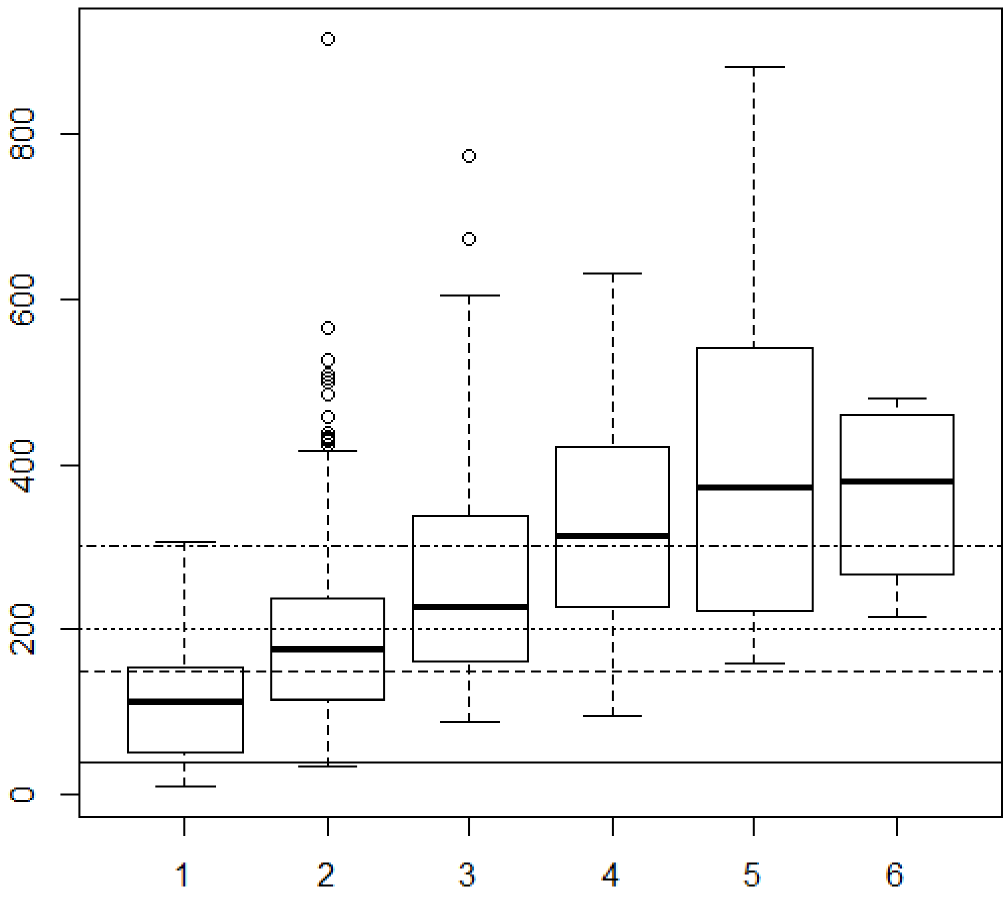

Figure 5.6.1.3.3. Weight-at-age from samplings (plain line 50 gr and then 150, 200 and 300 grams).

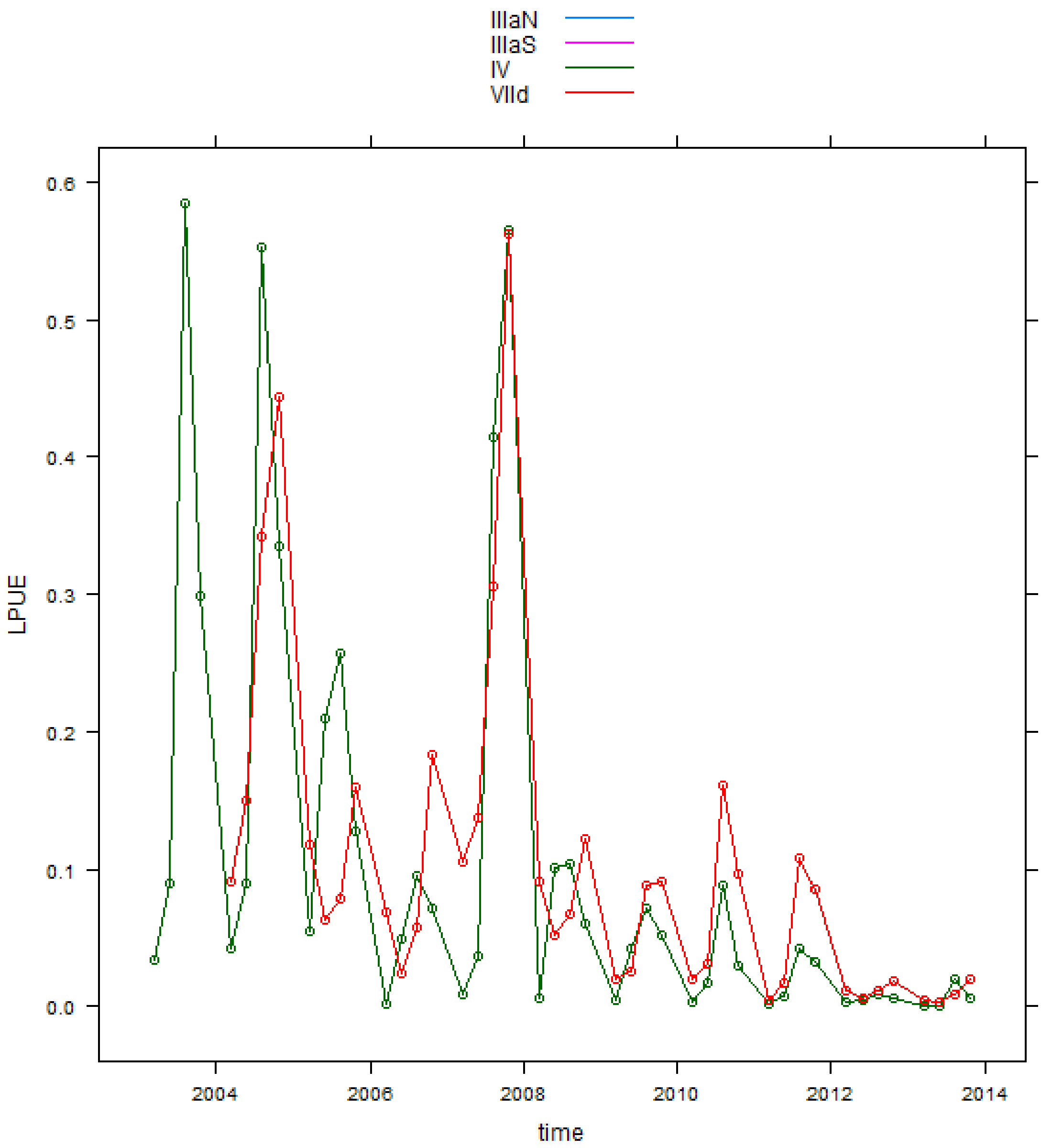

Figure 5.6.1.3.4. French Otters lpues derived by fishing areas.

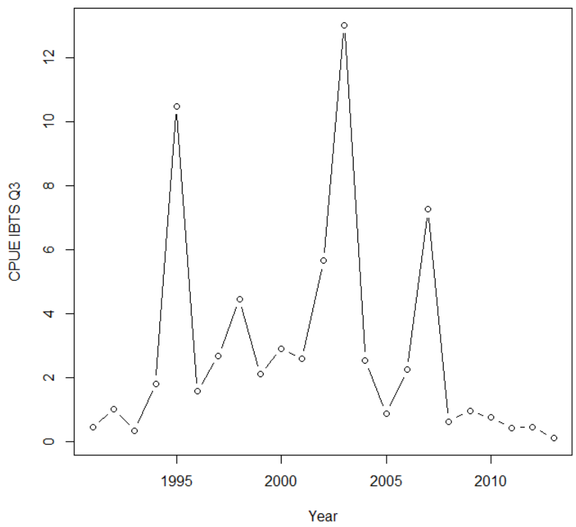

Figure 5.6.2.1. Cpue derived from IBTS Quarter 3 (number per hour).

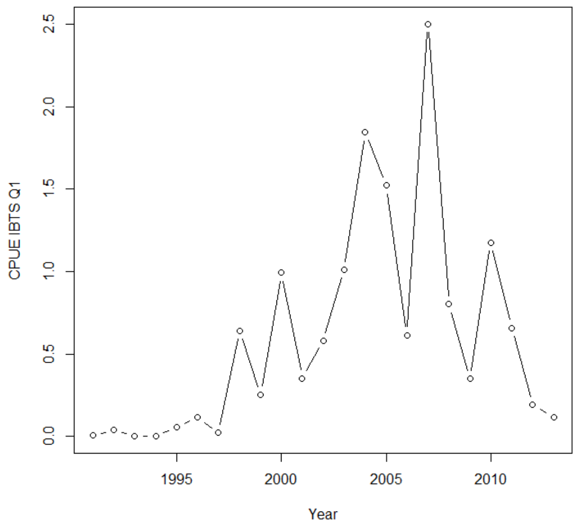

Figure 5.6.2.2. Cpue derived from IBTS Quarter 1(number per hour).

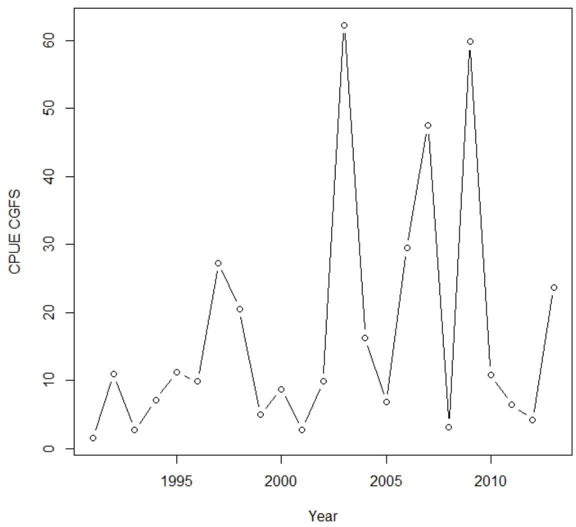

Figure 5.6.2.3. Cpue derived from CGFS Quarter 4 (number per hour).

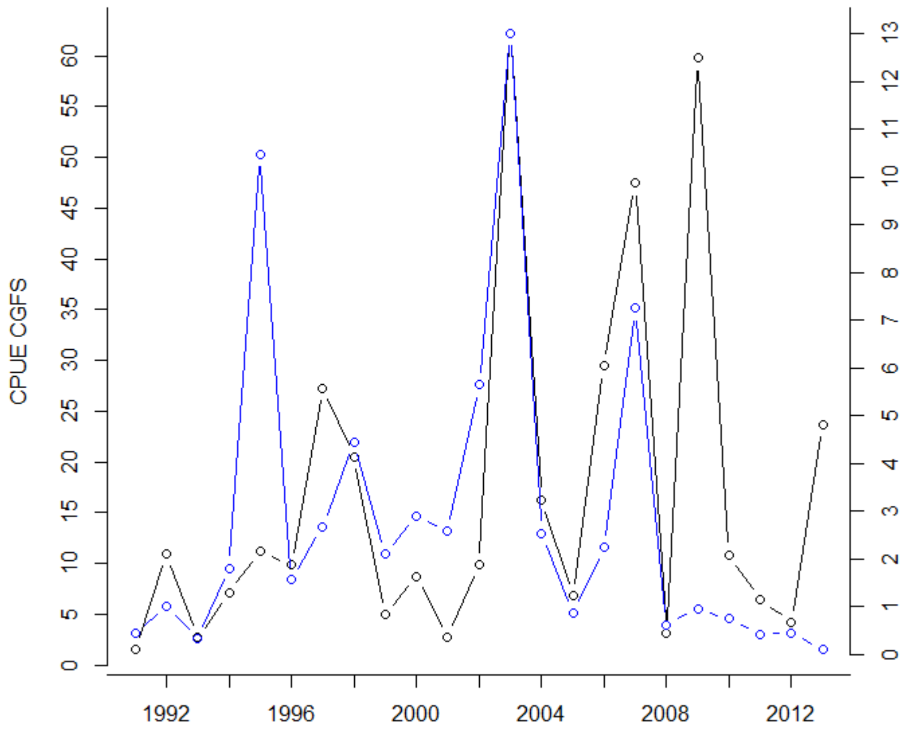

Figure 5.6.2.4. Comparison between cpue derived from CGFS Quarter 4 and IBTS Q3 (number per hour).

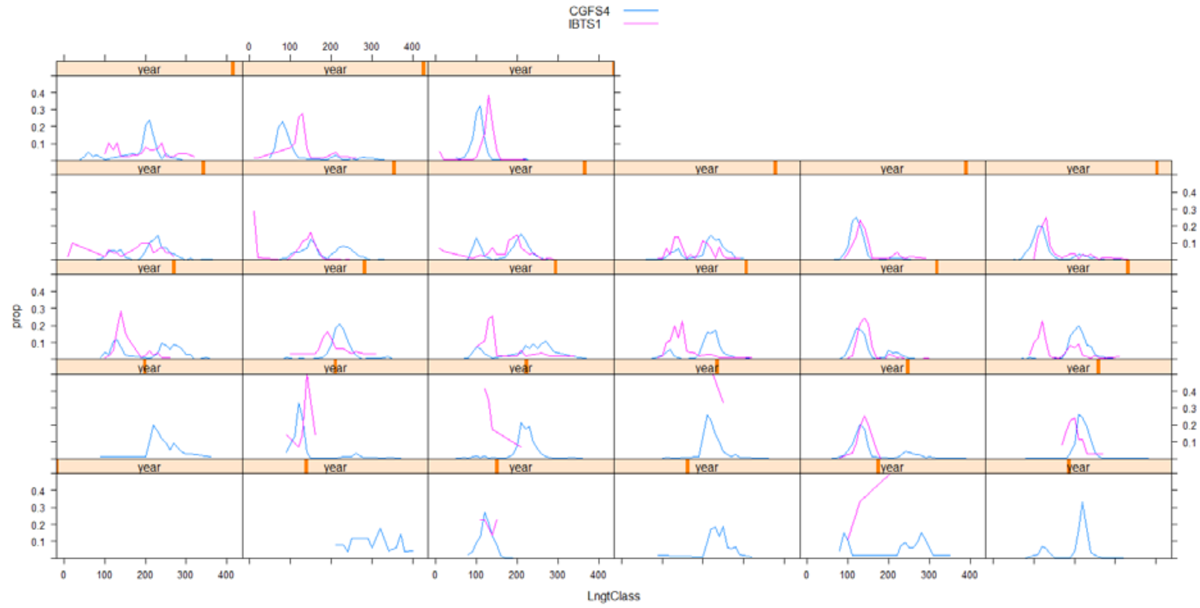

Figure 5.6.2.5. Comparison between length structures derived from CGFS Quarter 4 and IBTS Q1 the next year (next quarter).

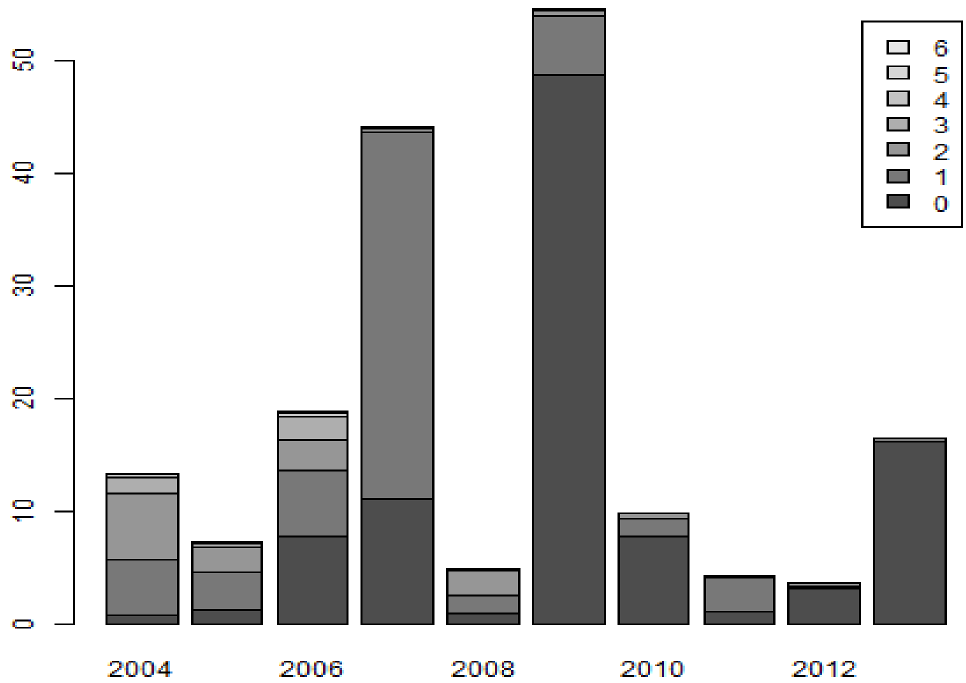

Figure 5.6.2.6. Standardized index-at-age of CGFS Quarter 4 survey.

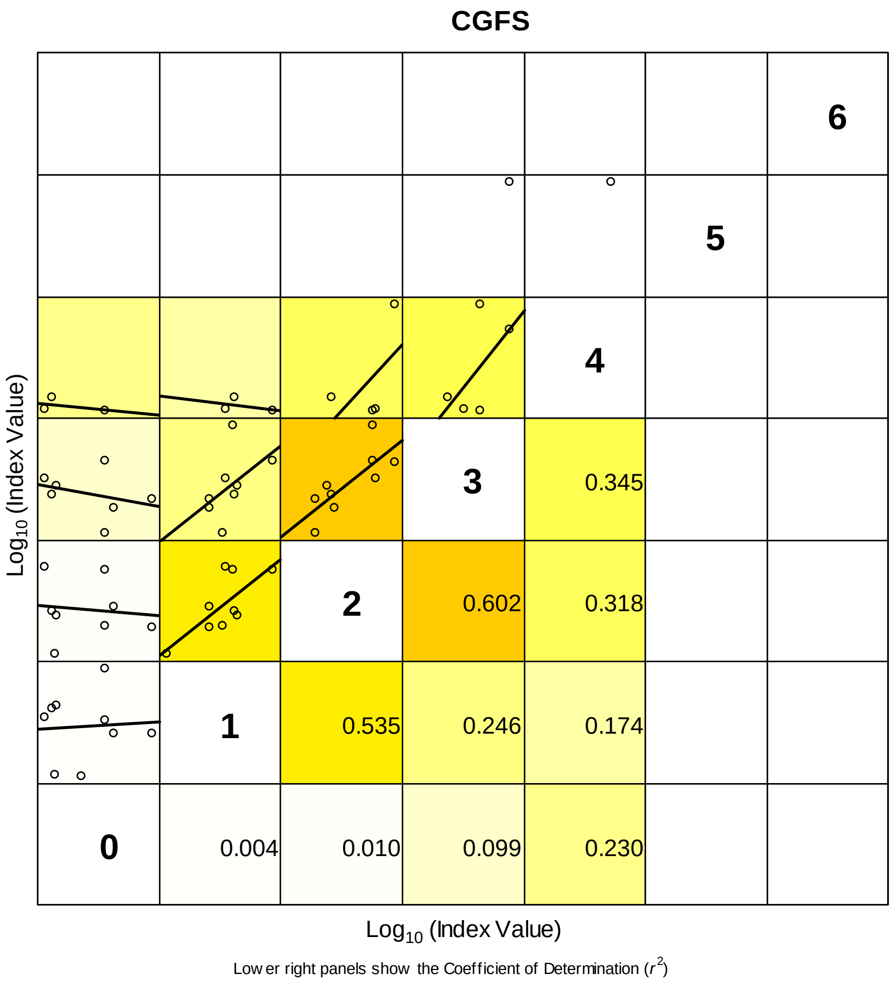

Figure 5.6.2.7. Internal consistency of CGFS Quarter 4 survey.

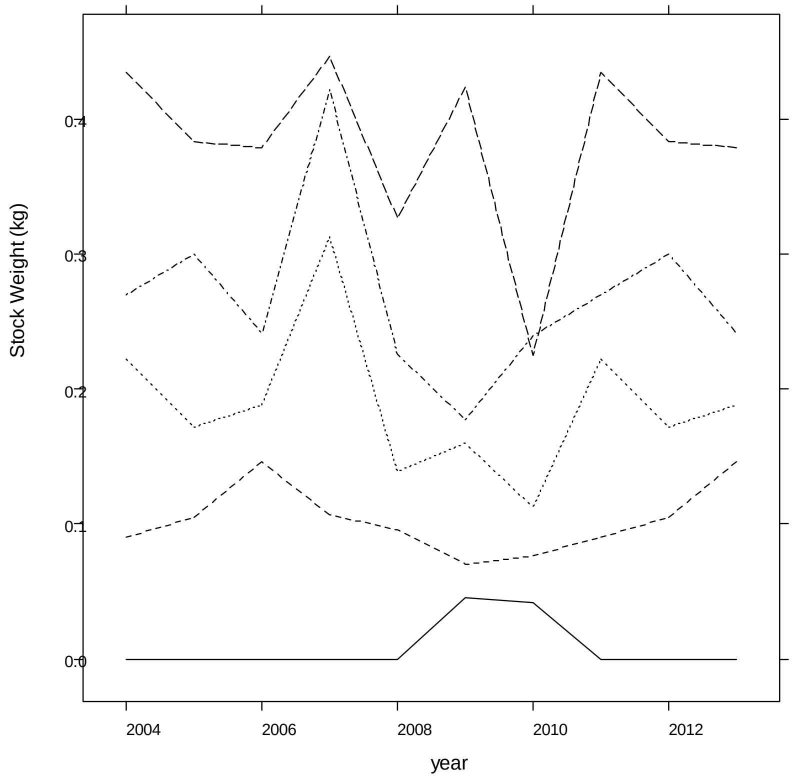

Figure 5.6.3.1.1. Stock weight.

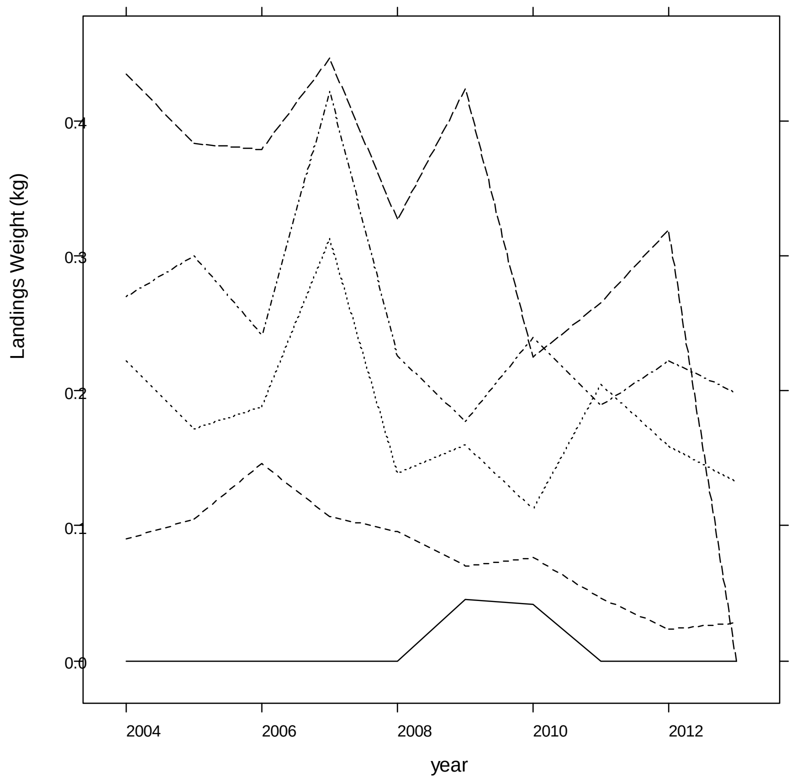

Figure 5.6.3.1.2. Catch weight.

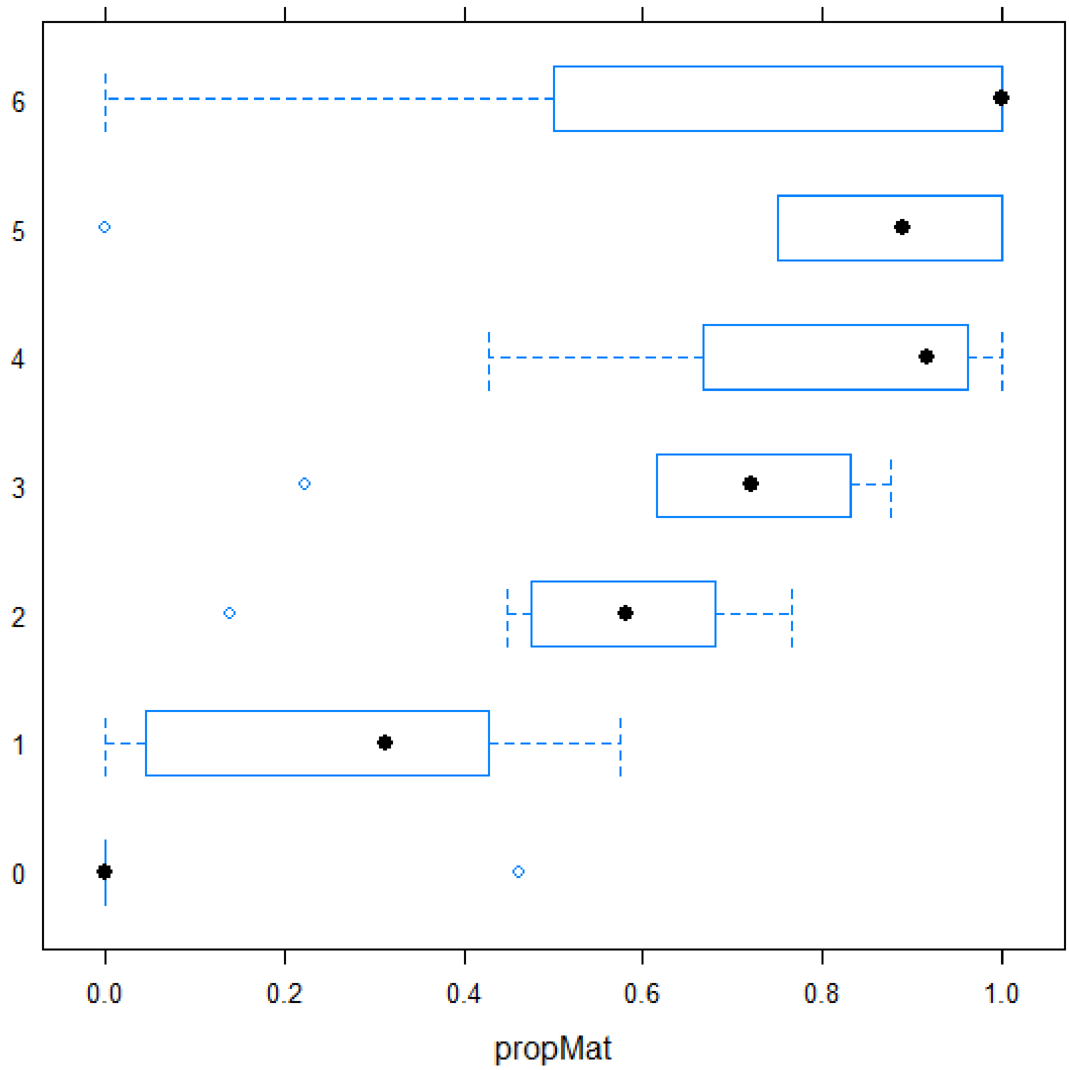

Figure 5.6.3.2.1. Proportion of mature individuals per age class.

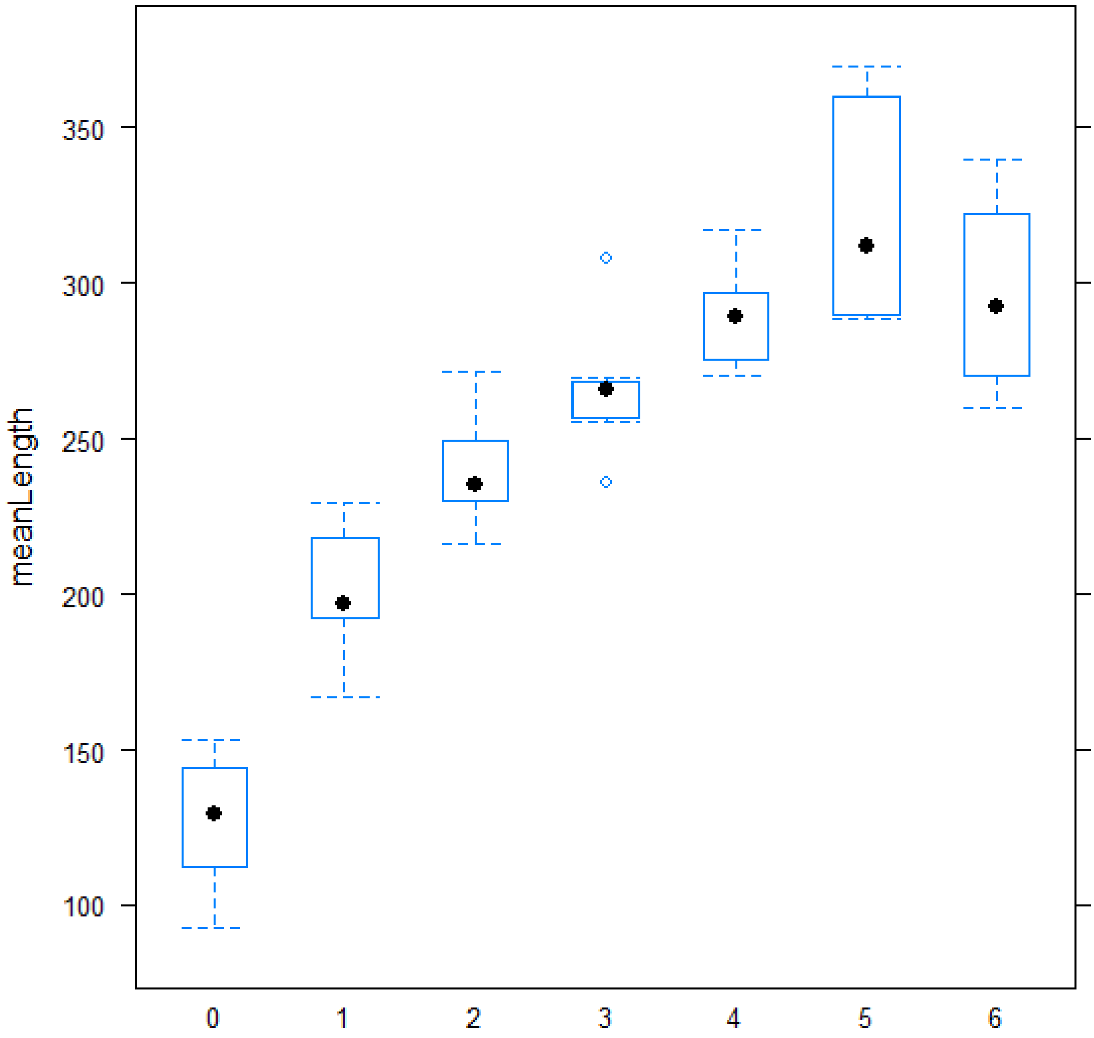

Figure 5.6.3.3.1. Mean length-at-age.

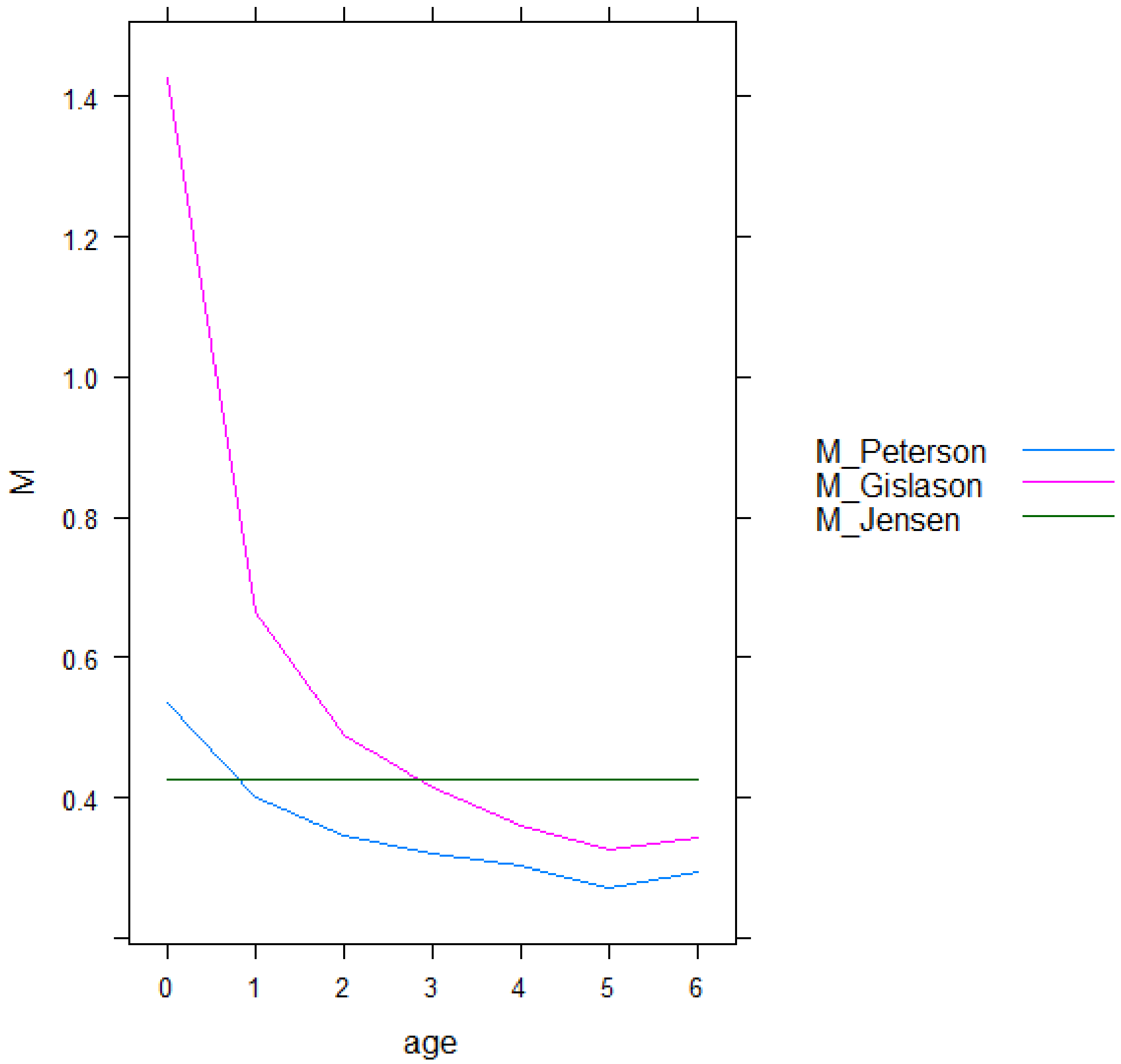

Figure 5.6.3.4.1. Comparison of M values.

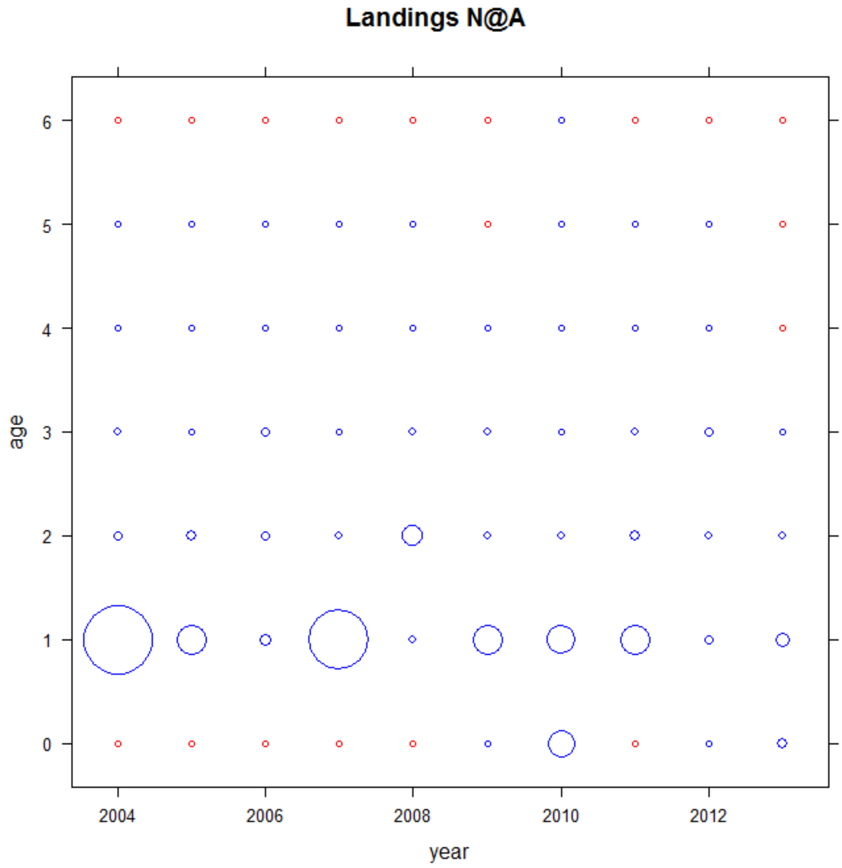

Figure 5.6.4.1.1. Age structure in the landings.

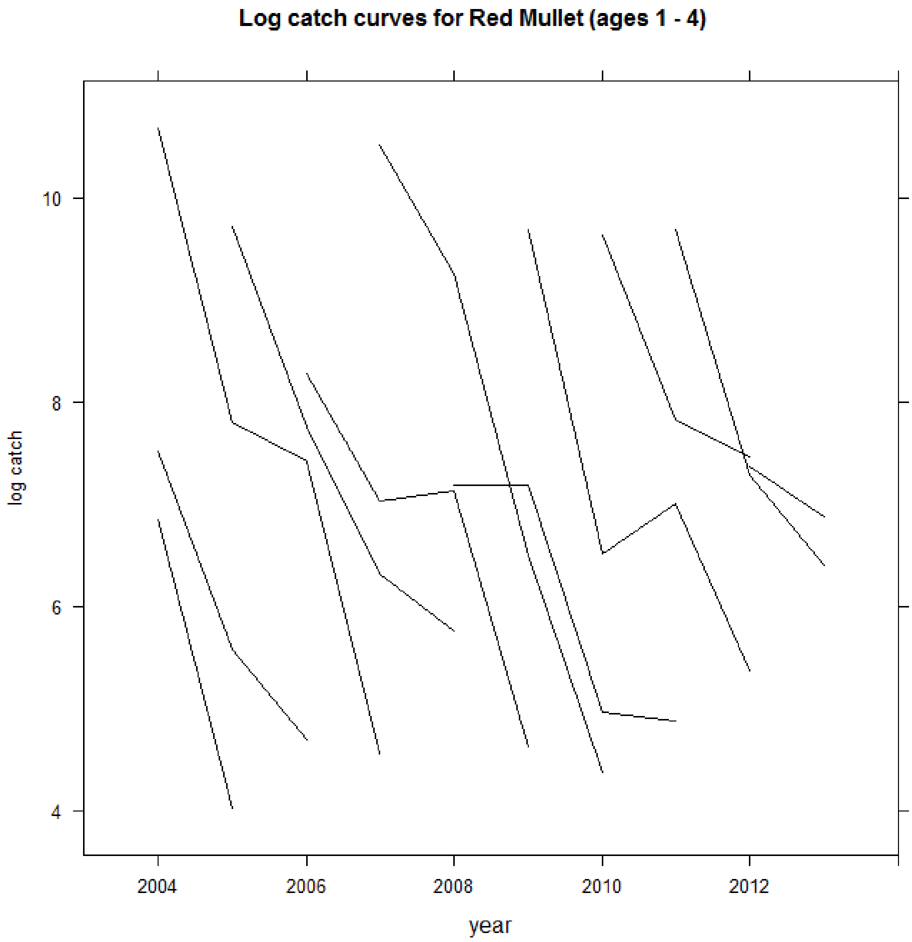

Figure 5.6.4.1.2. Log catch curves.

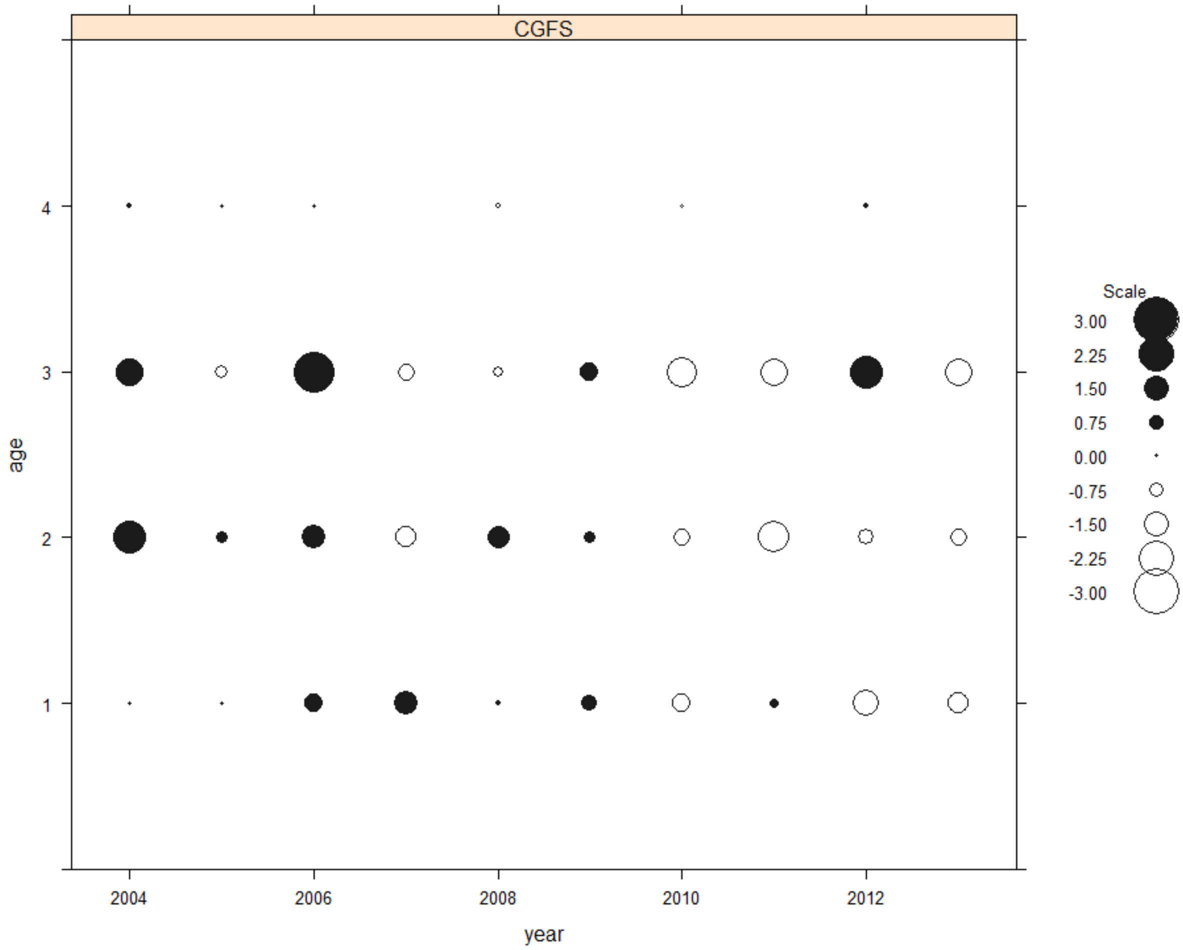

Figure 5.6.4.1.1. Residuals of the XSA run.

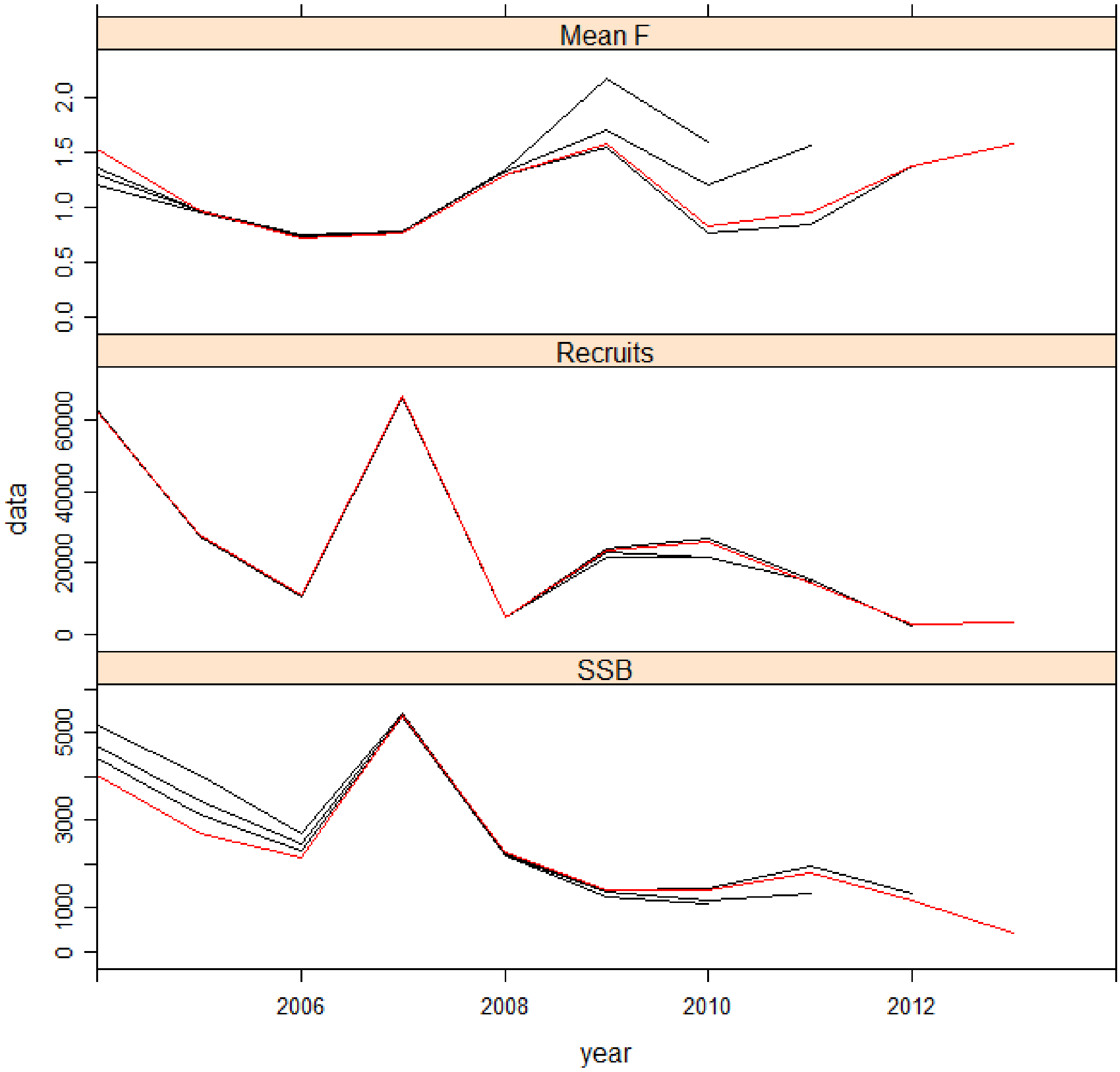

Figure 5.6.4.1.2. Retrospective analysis of the XSA run.

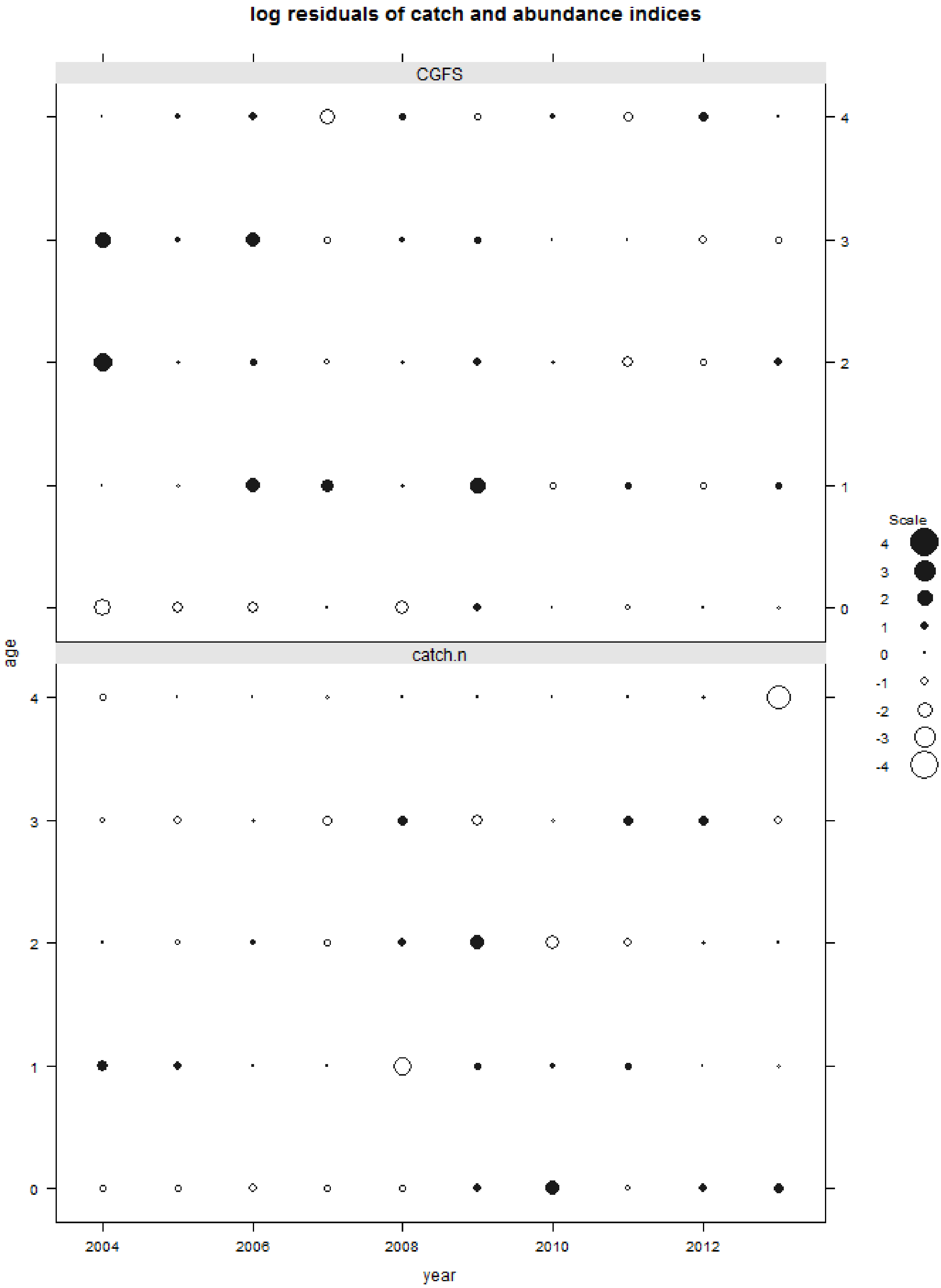

Figure 5.6.4.3.1. Residuals of the a4a run with M_Gislason and fishing mortality submodel 2.

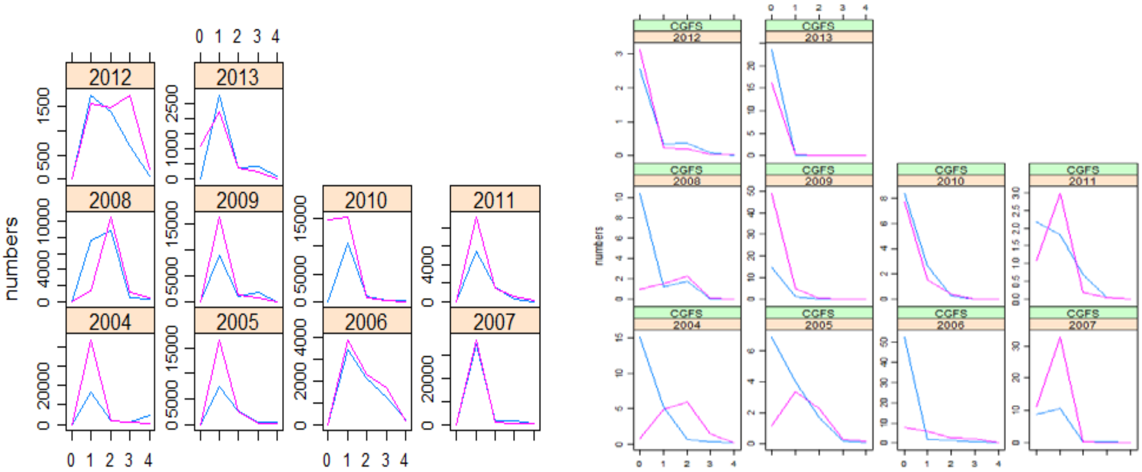

Figure 5.6.4.3.2. Observed (pink) and estimated (blue) catch numbers-at-age (left panel) and indices-at-age (right panel) with M_Gislason and fishing mortality submodel 2.

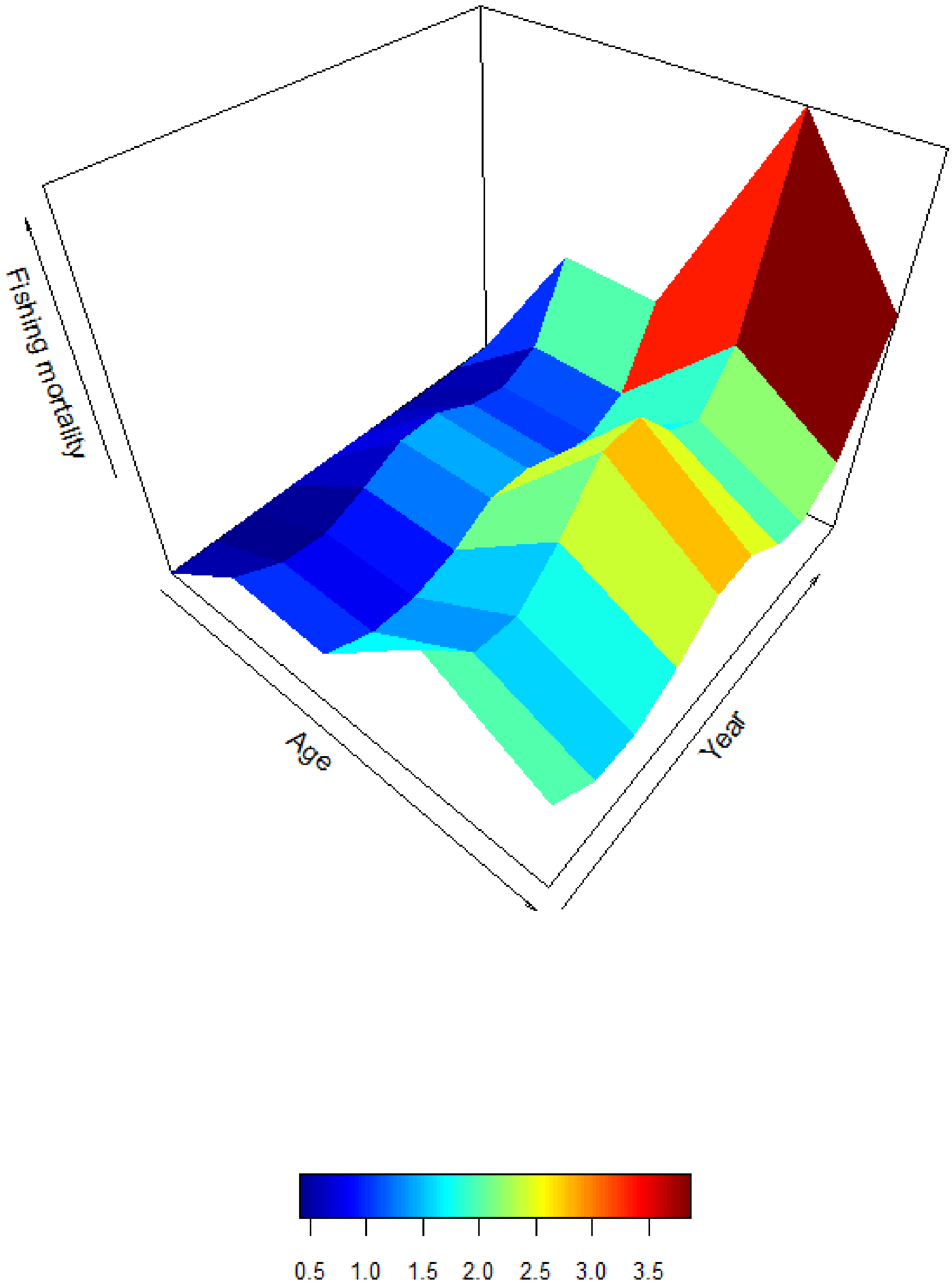

Figure 5.6.4.3.3. Fishing mortality surface plot with M_Gislason and fishing mortality submodel 2.

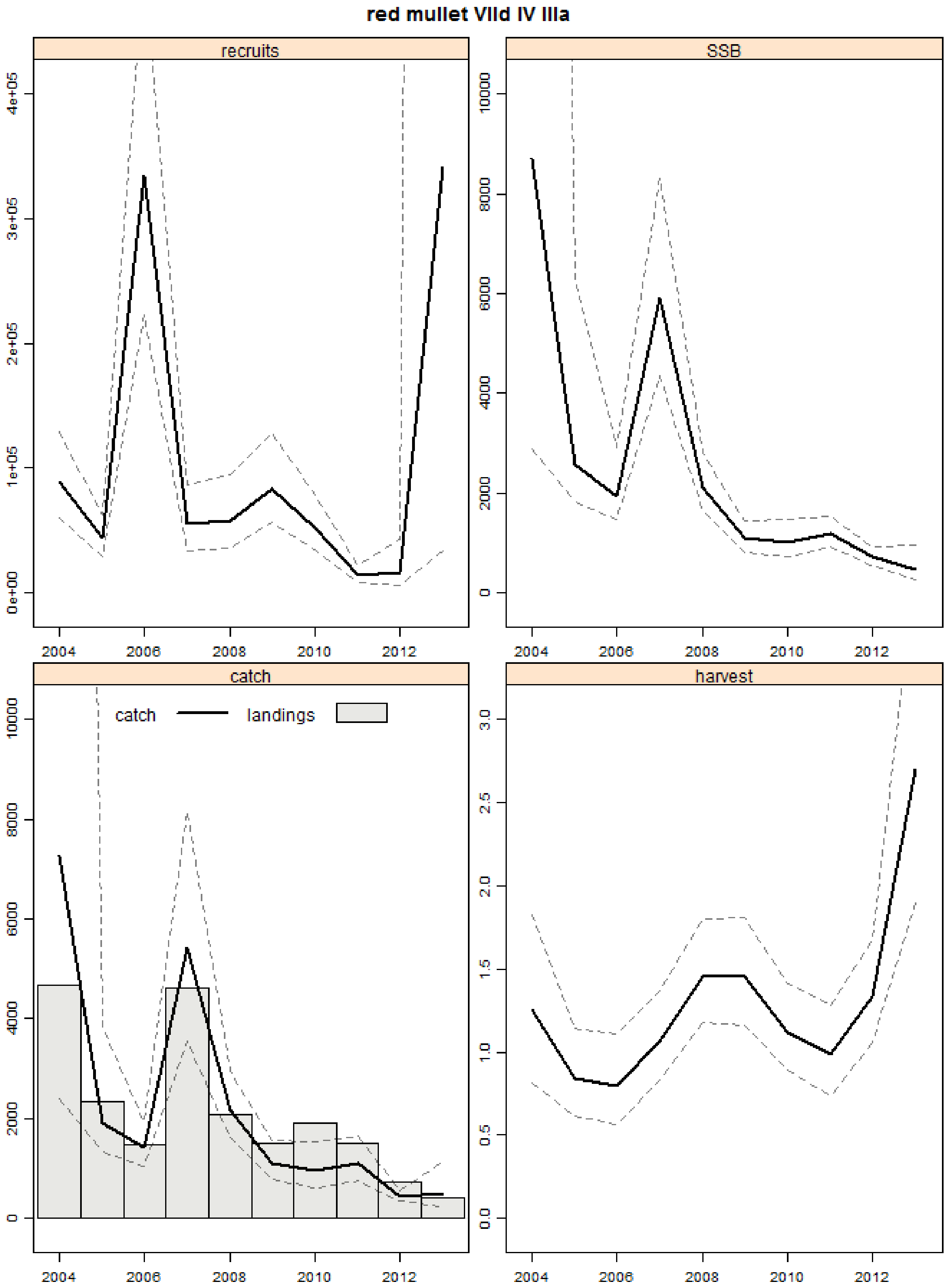

Figure 5.6.4.3.4. Stock summary plot for the a4a model with M_Gislason and fishing mortality submodel 2.

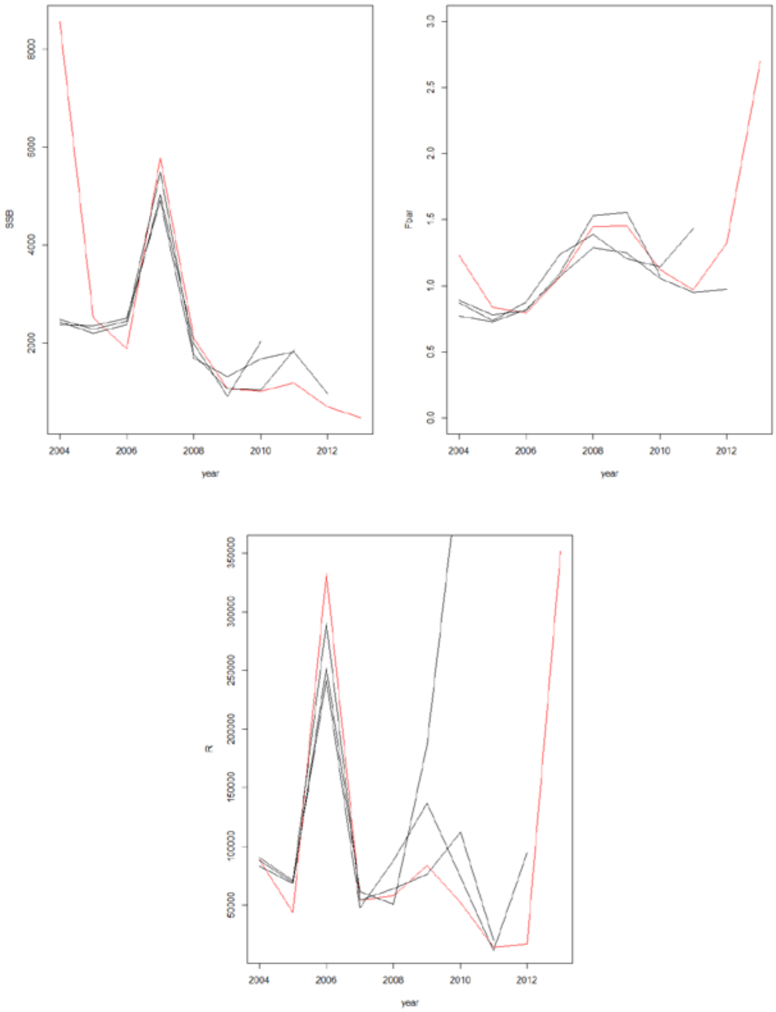

Figure 5.6.4.3.5. Retrospective analysis plot for the a4a model with M_Gislason and fishing mortality submodel 2 (from left to right panel: SSB, F_{BAR} and R).

6 External reviewer report

Matthew Dunn, Carmen Fernandez, and Kevin Piner acted as the external experts for the WKNSEA benchmark of North Sea Cod, Sole and Red Mullet. We reviewed data compilation and modelling methods from February 2–6th at a meeting attended by the assessment analysts.

The external reviewers would like to commend all of the participants for their effort during the benchmark process. All the assessment teams were asked to provide a large number of additional analyses during the meeting, and their responses to those requests were very helpful in furthering our understanding of each assessment. The work conducted by the analysts and other researchers was successful in bringing useful information forward to the management process.

On a less optimistic note, some working documents containing the main part of the methodological and assessment work were not available prior to the start of the benchmark meeting. We understand that scientists can be overloaded and this compromises their ability to deliver such work in advance of the benchmark. However, this reduces the quality of the review that can be provided, given the limited time available during the benchmark meeting itself. The reviewers recommend that ICES works to ensure sufficient preparatory work is conducted prior to the benchmark meeting, and that any relevant documents are available before the meeting. However, we do recognize that this may not be easy.

The following sections of this report cover what we believed to be the most crucial aspects of each stock assessment along with our recommendations. This report reflects solely the views of the external experts.

6.1 Cod

Major issues addressed at the benchmark

The main issues discussed with the cod assessment were focused on stock structure, trawl survey data, and maturity-at-age.

The primary issue in the North Sea cod assessment was stock structure. Strong evidence from several studies showed the North Sea cod stock structure is complex, and at least two stocks could confidently be assumed for the assessment area. However, a single North Sea stock was assumed for modelling purposes because the working group was unable to compile all model parameters and assign all required data to support assessments based on the presented stock structure. Further work was also needed to identify how to model multiple stocks in the most appropriate way (e.g. exploring relevant mixing scenarios, as the work presented at the benchmark also indicated some overlap between the different aggregations).

Research trawl survey catch-at-age was also considered in detail. Several alternative methods were used to estimate numbers-at-age. There was discussion about the analytical approach, in particular the use of vessel or time-varying area coefficients in the standardization because they were somewhat confounded (notably for the Skagerrak). The decision to use a vessel effect in the GAM was based primarily on the fit of the GAM (likelihood ratio criteria), and secondarily on an evaluation of the fit and residuals in the assessment model itself. The change in estimation method for the Q1 and Q3 IBTS indices was significant, because it helped both indices to be incorporated into the stock assessment model, and made implicit allowance for the changes in research vessels over space and time.

The incorporation of a trend in proportion mature at-age was supported by empirical data. The benchmark workshop group felt that it could not ignore the strong trends in proportion mature at-age. The change in proportion mature at-age made a substantial change to SSB and biomass reference points estimates, and recognized important biological changes occurring in the stock, but otherwise made no difference to assessment results (F and population numbers-at-age). It was also discussed during the benchmark workshop that the average age of the spawning cod population had decreased and this might result in lower reproductive potential, but the available information and knowledge was not sufficient to make a conclusion on this.

Modelling issues were less complex than data issues. Alternative modelling platforms, and alternative SAM model runs, produced largely similar results; however, this is not surprising given that all models made similar structural assumptions (e.g. modelling catch as catch-at-age). The primary issue in the base case was that survey number-at-age 1 and catch-at-age 1 were estimated with a large observation error in model runs, indicating a poor fit. The relatively poor fit to catch-at-age 1 was not thought to be problematic as the catch of this age was poorly known. The relatively poor fit to the survey estimate of number-at-age 1 was shown to result from a model conflict between numbers-at-age 1 and 2, and catches-at-age 1 and 2. However, with changes to the survey index estimation procedure (GAM), this issue was reduced. The Beverton–Holt stock–recruit relationship was abandoned because of poor fit to observations, and replaced with a random walk; this improved convergence in subsequent retrospective runs, but otherwise made no difference to results. Minor issues also discussed included the estimates of M, raising of catch data and catch scalars, estimation of stock weights for young fish, and correlation structure between estimates of F-at-age.

Use of final stock annex as basis for providing advice

A number of incremental changes were made to the stock assessment. Although there is evidence for multiple stocks, it is likely that the aggregate stock dynamics are being adequately represented by the current stock assessment model. We agree that results generated by the assessment model can be used for providing fisheries advice as an ICES Category 1 stock (stocks with quantitative assessments).

Recommendations for future work

Priorities are listed with the highest first:

1) The presentation of more relevant assessment details would have assisted the expert review of the assessments, and would help in future Benchmarks, for example (a) informative assessment model diagnostics, such as estimated observation error in Pearson residual plots; and (b) empirical estimates of observation error should also be provided, even if not used in the assessment model, to facilitate external evaluation of data.

2) Future assessments should allow for multiple stocks, and this work should be completed for the next Benchmark. The data and input parameters need to be compiled according to agreed boundaries, and analyses may include assessments under different stock structure assumptions, testing these assumptions through fits to the observed data. In the meantime, the survey biomass trends in substocks should be monitored.

3) A review of survey design should be completed, to enable better overlap of vessels and estimation of IBTS abundance indices (via GAM). This issue is most pronounced for the Skagerrak region, which is covered by only one vessel and where more uncertainties arose concerning the survey indices. It is also recommended that the specification of the GAM model used to standardize the indices be re-evaluated once more data become available.

6.2 Sole

Issues addressed at the benchmark

The main issues discussed at the benchmark were the use of fishery dependent lpue and independent survey data, and the inclusion of discards in the assessment.

The primary issue discussed was whether to use numbers-at-age data from research surveys, where catchability could be more confidently assumed to be temporally constant but spatially limited, versus commercial lpue, which were spatially extensive, highly sampled, but potentially biased. Analyses showed that, in aggregate, the fishery-independent surveys were largely consistent with each other and their spatial coverage was considered sufficient for the purpose of stock assessment. The Belgian BTS survey, not included in the assessment so far, would improve the coverage of the stock area as it was the only one to cover the southwestern part of the North Sea, but model runs including it introduced relatively strong retrospective patterns. The Dutch commercial lpue data were compromised by recent change in fishing gear, with traditional gear declining (and likely to shortly disappear, making it unavailable for future assessments), but the time-series of new gear (pulse trawl) still being short with unknown veracity as an abundance index. Model runs combining the two gear types were evaluated, but ultimately were not considered viable. After discussion of the pros and cons of the different options, the Benchmark assessment used fishery-independent surveys only, acknowledging that by excluding commercial lpue the terminal year estimates may become more uncertain.

Discards were incorporated in the stock assessment by using the AAP model platform, which used discard data for recent years to estimate a discarding ogive, which was then extrapolated into earlier years. This could not have been done using the previous stock assessment platform (XSA). AAP and XSA model runs without discards produced very similar results, showing the two platforms were otherwise comparable.

Use of final stock annex as basis for providing advice

Exclusion of the fishery-dependent data provided a potentially less precise, but likely unbiased, estimate of stock status. We agree that results generated by the assessment model can be used for providing fisheries advice as an ICES Category 1 stock (stocks with quantitative assessments).

Recommendations for future work

1) The presentation of more relevant assessment details would have assisted the expert review of the assessments, and would help in future Benchmarks, for example (a) informative assessment model diagnostics, such as estimated observation error in Pearson residual plots; and (b) empirical estimates of observation error should also be provided, even if not used in the assessment model, to facilitate external evaluation of data.

2) Future assessments should attempt to incorporate the Belgian beam-trawl survey data. Assessments should also investigate the addition of Dutch commercial pulse cpue data when a longer time-series becomes available.

6.3 Striped red mullet

Issues addressed at the benchmark

The primary topic discussed for striped red mullet was the quantity and representativeness of the observational data.

The IBTS surveys in the North Sea caught relatively few red mullet, leaving the Eastern Channel as the source of stock composition data for the entire stock region (which formally also includes the North Sea, and the Skagerrak and Kattegat). Discussions focused on the veracity of extrapolating results from the Eastern Channel region to the wider stock. Most data had high variability (e.g. weights-at-age), presumably resulting from relatively small sample sizes. Analyses suggested the extrapolation of the assessment results from the eastern English Channel to the southern North Sea had merit. It was less clear whether the assessment was valid for the other areas within the stock region, because the fishery catches were small and data were sparse.

Minor issues addressed included the selection of M, and the specification of smoothed parameters within the a4a assessment model.

Use of final stock annex as basis for providing advice

There is a relatively high uncertainty in this assessment, which comes from data limitation and uncertainty in spatial extrapolation of results. The stock assessment agreed during the benchmark seemed reasonable given the available information, but the assessment needs to be further developed and reviewed once more information exists. A retrospective analysis indicated that recruitment estimates for the most recent years are very uncertain, and can be substantially revised when more years of data are added. On the other hand, the SSB trend estimated by the assessment is considered to be a more reliable indicator of stock status than direct use of the survey indices. We agree that results generated by the benchmark assessment model can be used for providing fisheries advice under the ICES Stock Category 3 framework. To avoid tracking annual noise in this relatively uncertain assessment, we suggest that the assessment be updated only every two or possibly three years.

Recommendations for future work

1) The presentation of more relevant assessment details would have assisted the expert review of the assessments, and would help in future Benchmarks, for example (a) informative assessment model diagnostics, such as estimated observation error in Pearson residual plots; and (b) empirical estimates of observation error should also be provided, even if not used in the assessment model, to facilitate external evaluation of data.

2) Further sources of data should be investigated, including how to best incorporate these in stock assessment models.

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Annex 2: Stock Annexes

Stock Annex for North Sea cod

Stock	Cod in Subarea IV, Division VIId & Division IIIa West (Skagerrak)
Working Group	Working Group North Sea, Skagerrak and Kattegat
Date	February 2015
By	Several contributors, coordinated by José De Oliveira

A. General

A.1. Stock definition

Cod are widely distributed throughout the North Sea. Scientific survey data indicate that historically, young fish (ages 1 and 2) have been found in large numbers in the southern part of the North Sea, whilst in recent decades the Skagerrak has also become important. Adult fish have in the past been located in concentrations of distribution in the Southern Bight, the northeast coast of England, in the German Bight, the east coast of Scotland and in the northeastern North Sea. As stock abundance fluctuates, these groupings appear to be relatively discrete but the area occupied has contracted. During recent years, the highest densities of 3+ cod have been observed in the deeper waters of the central to northern North Sea.

Population genetic research has shown that Atlantic cod populations are structured over both large and smaller geographical scales, for instance between the North Sea and Baltic Sea (Nielsen *et al.*, 2003). Within the North Sea and neighbouring areas, several studies have indicated finer scale structuring on substock scales. Whilst differentiation was weak in past studies employing microsatellite DNA (typical of marine fishes with large population sizes and high dispersal potentials), the move to using suites of single nucleotide polymorphisms (SNP) has substantially increased the power and reliability of these estimates. Recent evidence points to two populations; one inhabiting the northeast North Sea (centred on the Viking Bank) and the other in shallower waters. This is supported by studies using both microsatellite DNA (Nielsen *et al.*, 2009) and SNPs (Poulsen *et al.*, 2011; Heath *et al.*, 2014; WD1 by Wright *et al.* in WKNSEA 2015). Investigations of life-stage connectivity suggest that this isolation may have partly arisen through oceanographic barriers to early life-stage dispersal (Heath *et al.*, 2008; Munk *et al.*, 2009) as well as limited mixing of adults as they appear to remain within waters >100 m (Wright *et al.*, 2006a,b; Neat *et al.*, 2014). However, the latest unpublished genetic and otolith microchemistry evidence also indicates that many Viking juveniles settle in the Skagerrak and subsequently make a return migration prior to spawning (WD1 by Wright *et al.* in WKNSEA 2015). This would explain the high abundance of 0- and 1-group cod in the Skagerrak, which is not reflected in age 2+ abundance (Svedäng and Svenson, 2006), and why a relatively strong year class of cod in the Skagerrak was genetically assigned to the North Sea rather than local adults (Knutsen *et al.*, 2004). Consequently, the reproductive isolation of Viking fish appears to be supported both by limited mixing with neighbouring groups and natal homing.

There may be further structuring within the North Sea than that indicated by the genetic evidence alone. There is extensive evidence for persistent resident behaviour in many groups of cod since the 1960s associated with spawning aggregations from the eastern channel north to Shetland (ICES-NSRWG 1971; Metcalfe, 2006; Neat *et al*., 2006; Wright *et al*., 2006b; Righton *et al*., 2007; Neat *et al*., 2014). Indeed, temporal changes in abundance and local genetic composition at one such spawning aggregation near Flamborough, off the northeast English coast, suggests that a complete collapse and re-colonisation of the area took place in the latter half of the twentieth century (Hutchinson *et al*., 2003). Potential larval transport (Heath *et al*., 2008; WD1 by Wright *et al*. in WKNSEA 2015) and juvenile dispersal derived from tag–recapture (Riley and Parnell, 1984) and otolith microchemistry studies (Wright *et al*., 2006a) indicate that early stages do not mix throughout the shallow North Sea region. Differences in life-history traits have been found among the shallow North Sea region consistent with some degree of segregation (Harrald *et al*., 2010; Wright *et al*., 2011), although the most pronounced differences are found in Viking, as these cod have retained a reproductive investment strategy similar to that reported decades ago (Yoneda and Wright, 2004; Wright *et al*., 2011).

In order to explore whether there are subarea differences in population synchrony, Holmes *et al*. (2014) divided the North Sea into three subareas, Viking, south and northwest. Using survey based indices of spawning–stock biomass they found significant differences among all three areas, although the most substantial difference was between Viking and the shallow areas.

Available information indicates that the majority of spawning takes place from the beginning of January through to April offshore in waters of salinity 34–35% (Brander, 1994; Riley and Parnell, 1984). Around the British Isles there is a tendency towards later timing with increasing latitude (ICES, 2005). Older females start to spawn earlier than young females, which may be important to age-related reproductive success (Morgan *et al*., 2013). Cod spawn throughout much of the North Sea but spawning adult and egg survey data and fishermen's observations indicate a number of spawning aggregations. Results from the first ichthyoplankton survey to cover the whole of the North Sea, conducted in 2004 to map spawning grounds of North Sea cod, are reported in Fox *et al*. (2008). This study compared the results from the plankton survey with estimates of egg production inferred from the distribution of mature cod in contemporaneous trawl surveys. The comparison found general agreement of hot spots of egg production around the southern and eastern edge of the Dogger Bank, in the German Bights, the Moray Firth and to the east of the Shetlands, which mapped broadly into known spawning areas from the period 1940–1970, but was unable to detect any significant spawning activity off Flamborough (a historic spawning ground off the northeast coast of England). The study showed that most of the major cod spawning grounds in the North Sea are still active, but that the depletion of some localised populations may have made the detection of spawning activity in the corresponding areas difficult (Fox *et al*., 2008).

At the North Sea scale, there has been a northerly shift in the mean latitudinal distribution of the stock (Hedger *et al*., 2004; Perry *et al*., 2005). However the evidence for this being a migratory response is slight or non-existent. More likely, cod in the North Sea are composed of a complex of more or less isolated substocks (as indicated above) and the southern units have been subjected to disproportionately high rates of fishing mortality (STECF-SGRST-07-01). Blanchard *et al*. (2005) demonstrated that the contraction in range of juvenile North Sea cod could be linked to reduced abundance as well as increased temperature, and further noted that the combined negative effects of increased temperature on recruitment rates and the reduced availability of optimal habitat may have increased the vulnerability of the cod stock to fishing mortality.

Rindorf and Lewy (2006) linked the northward shift in distribution to the effect of a series of warm, windy winters on larvae and the resultant distribution of recently settled cod, followed by a northwards shift in the distribution of older age groups (because of the tendency for northerly distributed juveniles to remain northerly throughout their life). They noted further that this effect is intensified by the low abundance of older age cod due to heavy fishing pressure. However, simulations of larval transport did not support the northward transport proposed (Heath *et al*. 2008). Northward adult movements are also unlikely as, based on 129 electronic tagging records, Neat and Righton (2007) found no evidence that adult cod in the southern North Sea moved away from the warm waters that were super-optimal for growth even though they had the capacity to find cooler water. This suggests that the thermal regime of the North Sea is not yet causing adult cod to move to cooler waters. Despite the drastic decline in stock abundance over the period 1983–2006, and the movement of the centre of gravity of the distribution towards the northeast; Lewy and Kristensen (2009) found that the spatial correlation and dispersion of IBTS Q1 survey catches remained unchanged throughout this 24-year period, with the concentration of the stock remaining constant or declining. They therefore concluded that cod does not follow the theory of density-dependent habitat selection, because stock concentration does not increase with decreasing stock abundance.

Several tagging studies have been conducted on cod in the North Sea since the mid-1950s in order to investigate the migratory movements and geographical range of cod populations (Bedford, 1966; ICES-NSRWG, 1971; Daan, 1978; Righton *et al*., 2007). These studies indicate that cod separate during the spawning season and, in some cases, intermix during the feeding season (Metcalfe, 2006; Neuenfeldt *et al*., 2013). Righton *et al*. (2007) re-analysed some of the historical datasets of conventional tags and used recent data from electronic tags to investigate movement and distribution of cod in the southern North Sea and English Channel. Their re-analysis of conventional tags showed that, although most cod remained within their release areas, a larger proportion of cod were recaptured outside their release area in the feeding season than the spawning season, and a larger proportion of adults were recaptured outside their release area than juveniles, with the displacement (release to recapture) occurring mostly to the southern North Sea for fish released in the English Channel, and to areas further north for fish released in the southern North Sea (see Table 5 in Righton *et al*., 2007). This suggests a limited net influx of cod from the English Channel to the southern North Sea, but no significant movement in the other direction (Metcalfe, 2006). Recent electronic tagging indicates that cod from the shallow water population inhabiting the east of Shetland may also overlap with the western range of Viking cod outside the spawning season (Neat *et al*., 2014).

The lack of obvious physical barriers to mixing in the North Sea suggests that behavioural and/or environmental factors are responsible for maintaining the relative discreteness of populations (Metcalfe, 2006). For example, Righton *et al*. (2007) conclude that behavioural differences between cod in the southern North Sea and English Channel (such as tidal stream transport being used by fish tagged and released in the southern North Sea to migrate, but rarely being used by those tagged and released in the English Channel) may limit mixing of adult cod from these two areas during feeding and spawning seasons. Robichaud and Rose (2004) describe four behavioural categories for cod populations: “sedentary residents” exhibiting year-round site fidelity, “accurate homers” that return to spawn in specific locations, “inaccurate homers” that return to spawn in a broader area around the original site, and “dispersers” that move and spawn in a haphazard fashion within a large geographical area. These categories are not necessarily mutually exclusive and behaviours in different regions may be best described by differing degrees of each category (Heath *et al.*, 2008).

Evidence from electronic tags suggest that cod populations have a strong tendency for site attachment (even in migratory individuals), rapid and long-distance migrations, the use of deeper channels as migratory "highways" and, in some cases, clearly defined feeding and spawning "hot spots" (Righton *et al.*, 2008; Neat *et al.*, 2014). Andrews *et al.* (2006) used a spatially and physiologically explicit model describing the demography and distribution of cod on the European shelf in order to explore a variety of hypotheses about the movements of settled cod. They fitted the model to spatial data derived from International Bottom Trawl Surveys, and found that structural variants of the model that did not recognise an active seasonal migration by adults to a set of spatially stable spawning sites, followed by a dispersal phase, could not explain both the abundance and distribution of the spawning stock. Heath *et al.* (2008) investigated different hypotheses about natal fidelity, and their consequence for regional dynamics and population structuring, by developing a model representing multiple demes, with the spawning locations of fish in each deme governed by a variety of rules concerning oceanographic dispersal, migration behaviour and straying. They used an age-based discrete time methodology, with a spatial representation of physical oceanographic patterns, fish behaviour patterns, recruitment, growth and mortality (both natural and fishing). They found that although active homing is not necessary to explain some of the subpopulation structures of cod (with separation possible through distance and oceanographic processes affecting the dispersal of eggs and larvae, such is in the Southern Bight), it may well be necessary to explain the structure of other sub-populations.

A.2. Fishery

Section A.2 was not updated during WKNSEA 2015. However, although outdated, some of the information is still relevant to the cod fishery at the present time. This section will be updated in due course.

Cod are caught by virtually all the demersal gears in Subarea IV and Divisions IIIa (Skagerrak) and VIId, including beam trawls, otter trawls, seine nets, gillnets and lines. Most of these gears take a mixture of species. In some of them cod are considered to be a bycatch (for example in beam trawls targeting flatfish), and in others the fisheries are directed mainly towards cod (for example, some of the fixed gear fisheries).

An analysis of landings and estimated discards of cod by gear category (excluding Norwegian data) highlighted the following fleets as the most important in terms of cod for 2003–2005 (accounting for close to 88% of the EU landings), listed with the main use of each gear (STECF SGRST-07-01):

- Otter trawl, ≥120 mm, a directed roundfish fishery by UK, Danish and German vessels.
- Otter trawl, 70–89 mm, comprising a 70–79 mm French whiting trawl fishery centered in the Eastern Channel, but extending into the North Sea, and an 80–89 mm UK *Nephrops* fishery (with smaller landings of roundfish and anglerfish) occurring entirely in the North Sea.
- Otter trawl, 90–99 mm, a Danish and Swedish mixed demersal fishery centered in the Skagerrak, but extending into the Eastern North Sea.
- Beam trawl, 80–89 mm, a directed Dutch and Belgian flatfish fishery.

- Gillnets, 110–219 mm, a targeted cod and plaice fishery.

For Norway in 2007, trawls (mainly bycatch in the saithe fishery) and gillnets account for around 60% (by weight) of cod catches, with the remainder taken by other gears mainly in the fjords and on the coast, whereas in the Skagerrak, trawls and gillnets account for up to 90% of cod catches.

With regard to trends in effort for these major cod fisheries since 2000, the largest changes to have happened in North Sea fisheries have involved an overall reduction in trawl effort and changes in the mesh sizes in use, due to a combination of decommissioning and days-at-sea regulations. In particular 100–119 mm meshes have now virtually disappeared, and instead vessels are using either 120 mm+ (in the directed whitefish fishery) or 80–99 mm (primarily in the *Nephrops* fisheries and in a variety of mixed fisheries). The use of other mesh sizes largely occurs in the adjacent areas, with the 70–79 mm gear being used in the Eastern Channel/Southern North Sea Whiting fishery, and the majority of the landings by 90–99 mm trawlers coming from the Skagerrak. Higher discards are associated with these smaller mesh trawl fisheries, but even when these are taken into account, the directed roundfish fishery (trawls with ≥120 mm mesh) still has the largest impact of any single fleet on the cod stock, followed by the mixed demersal fishery (90–99 mm trawls) in the Skagerrak.

Technical conservation measures

The present technical regulations for EU waters came into force on 1 January 2000 (EC 850/98 and its amendments). The regulations prescribe the minimum target species' composition for different mesh size ranges. Additional measures were introduced in Community waters from 1 January 2002 (EC 2056/2001).

In 2001, the European Commission implemented an emergency closure of a large area of the North Sea from 14 February to 30 April (EC 259/2001). An EU-Norway expert group in 2003 concluded that the emergency closure had an insignificant effect upon the spawning potential for cod in 2001. There were several reasons for the lack of impact. The redistribution of the fishery, especially along the edges of the box, coupled to the increases in proportional landings from January and February appear to have been able to negate the potential benefits of the box. The conclusion from this study was that the box would have to be extended in both space and time to be more effective. This emergency measure has not been adopted after 2001. A cod protection area was implemented in 2004 (EC 2287/2003 and its amendments), which defined conditions under which certain stocks, including haddock, could be caught in Community waters, but this was only in force in 2004. A recent study on the use of MPAs to address regional-scale ecological objectives in the North Sea (Greenstreet *et al.*, 2009) concluded that MPAs on their own are unlikely to achieve significant regional-scale ecosystem benefits, because local gains are largely negated by fishing effort displacement into the remainder of the North Sea.

Apart from the technical measures set by the Commission, additional unilateral measures are in force in the UK, Denmark and Belgium. The EU minimum landing size (mls) is 35 cm, but Belgium operate a 40 cm mls, while Denmark operate a 35 cm mls in the North Sea and 30 cm in the Skagerrak. Additional measures in the UK relate to the use of square mesh panels and multiple rigs, restrictions on twine size in both whitefish and *Nephrops* gears, limits on extension length for whitefish gear, and a ban on lifting bags. In 2001, vessels fishing in the Norwegian sector of the North Sea had to comply with Norwegian regulations setting the minimum mesh size at

120 mm. Since 2003, the basic minimum mesh size for towed gears targeting cod is 120 mm.

Effort regulations in days at sea per vessel and gear category are summarised in the following table, which only shows changes in 2008 compared to 2007 (2006 is included for comparison). The changes (2007–2008) were intended to generate a cut in effort of 10% for the main gears catching cod.

Maximum number of days a vessel can be present in the North Sea, Skagerrak and Eastern Channel, by gear category and special condition (see EC 40/2008 for more details). The table only shows changes in 2008 compared to 2007, but 2006 is also included for comparison.

Description of gear and special condition (if applicable)	Area			Max days at sea		
	IV,II	Skag	VIId	2006	2007	2008**
Trawls or Danish seines with mesh size ≥ 120 mm	x	x	x	103	96	86
Trawls or Danish seines with mesh size ≥ 100 mm and < 120 mm	x	x	x	103	95	86
Trawls or Danish seines with mesh size ≥ 90 mm and < 100 mm	x		x	227	209	188
Trawls or Danish seines with mesh size ≥ 90 mm and < 100 mm		x		103	95	86
Trawls or Danish seines with mesh size ≥ 70 mm and < 90 mm	x			227	204	184
Trawls or Danish seines with mesh size ≥ 70 mm and < 90 mm			x	227	221	199
Beam trawls with mesh size ≥ 120 mm	x	x		143	143	129
Beam trawls with mesh size ≥ 100 mm and < 120 mm	x	x		143	143	129
Beam trawls with mesh size ≥ 80 mm and < 90 mm	x	x		143	132	119
Gillnets and entangling nets with mesh sizes ≥ 150 mm and < 220 mm	x	x	x	140	130	117
Gillnets and entangling nets with mesh sizes ≥ 110 mm and < 150 mm	x	x	x	140	140	126
Trammelnets with mesh size < 110 mm. The vessel shall be absent from port no more than 24 hours.	x		x	205	205	185*

*** For member states whose quotas less than 5% of the Community share of the TACs of both plaice and sole, the number of days at sea shall be 205.**

**** If member states opt for an overall kilowatt-days regime, then the maximum number of days at sea per vessel could be different to that set out for 2008 (see text below and EC 40/2008 for details).**

Additional provisions were introduced for 2008 (points 8.5–7, Annex IIa, EC 40/2008) to provide Member States greater flexibility in managing their fleets, in order to encourage a more efficient use of fishing opportunities and stimulate fishing practices that lead to reduced discards and lower fishing mortality of both juvenile and adult fish. This measure allowed a Member State that fulfilled the requirements laid out in EC 40/2008 to manage a fleet (i.e. group of vessels with a specific combination of geographical area, grouping of fishing gear and special condition) to an overall kilowatt-days limit for that fleet, instead of managing each individual vessel in the fleet to its own days-at-sea limit. The overall kilowatt-days limit for a fleet is initially calculated as the sum of all individual fishing efforts for vessels in that fleet, where an individual fishing effort is the product of the number of days-at-sea and engine power for the vessel concerned. This provision allowed Member States to draw up fishing plans in collaboration with the Fishing Industry, which could, for example, specify a target to reduce cod discards to below 10% of the cod catch, allow real-time closures for juveniles and spawners, implement cod avoidance measures, trial new selective devices, etc.

Incentives of up to 12 additional days at sea per vessel were in place for 2008 to encourage vessels to sign up to a Discard Reduction Plan (points 12.9–10, Annex IIa, EC 40/2008). The plan focused on discarding of cod or other species with discard problems for which a management/recovery plan is adopted, and was to include measures to avoid juvenile and spawning fish, to trial and implement technical measures for improving selectivity, to increase observer coverage, and to provide data for monitoring outcomes. For vessels participating in a Cod Avoidance Reference Fleet Programme in 2008 (points 12.11–14, Annex IIa, EC 40/2008), a further 10–12 additional days at sea was possible (over and above that for the Discard Reduction Plan). Vessels participating in this program were to meet a specific target to reduce cod discards to below 10% of cod catches, and be subject to observer coverage of at least 10%.

Under the provisions laid down in point 8.5 of Annex IIa (EC 40/2008), Scotland implemented a national kilowatt-days scheme known as the 'Conservation Credits Scheme'. The principle of this two-part scheme involved credits (in terms of additional time at sea) in return for the adoption of and adherence to measures that reduce mortality on cod and lead to a reduction in discard numbers. The initial, basic scheme was implemented from the beginning of February 2008 and essentially granted vessels their 2007 allocation of days (operated as hours at sea) in return for: observance of Real Time Closures (RTC), observance of a one net rule, adoption of more selective gears (110 mm square meshed panels in 80 mm gears or 90 mm square meshed panels in 95 mm gear), agreeing to participate in additional gear trials, and participation in an enhanced observer scheme.

For the first part of 2008, the RTC system was designed to protect aggregations of larger, spawning cod (>50 cm length). Commercial catch rates of cod observed on board vessels was used to inform trigger levels leading to closures. Ten closures occurred to the beginning of May and protection agency monitoring suggested good observance. The scheme was extended for the remainder of the year to protect aggregations of all sizes of cod. A joint industry/ science partnership (SISP) had a number of gear trials programmed for 2008 examining methods to improve selectivity and reduce discards, and an enhanced observer scheme was announced by the Scottish Government.

Observance of the above conditions also gave eligibility for vessels to participate in the second, enhanced, part of the Conservation Credits scheme.

Changes in fleet dynamics

The introduction of the one-net rule as part of the Scottish Conservation Credit Scheme and new Scottish legislation implemented in January 2008 were both likely to improve the accuracy of reporting of Scottish landings to the correct mesh size range, although some sectors of the Scottish industry have been granted derogations to continue carrying two nets (seiners until the end of January 2009, and others until the end of April 2008). The concerted effort to reduce cod mortality, through implementation of the Conservation Credit Scheme from February 2008, could have led to greater effort being exerted on haddock, whiting, monk, flatfish and *Nephrops*.

Shifts in the UK fleet in 2007/8 included: (a) a move of Scottish vessels using 100–110 mm for whitefish on west coast ground (Subarea VI) to the North Sea using 80 mm prawn codends (motivated by fuel costs, and could increase effort on North Sea stocks; the simultaneous requirement to use 110 square mesh panels may mitigate unwanted selectivity implications, see below); (b) a move away from the Farne Deeps *Nephrops* fishery into other fisheries for whitefish because of poor *Nephrops* catch rates (implying increased effort in whitefish fisheries); and (c) a move of Scottish vessels from twin trawls to single rig, and increased use of pair trawls, seines and double bag trawls (motivated by fuel costs). For 2008 in the Scottish fleet, all twin-rig gear in the 80–99 mm category have to use a 110 mm square mesh panel, but this also applied to single-rig gears from July 2008 onwards, which was likely to have improved whitefish selection. A large number of 110 mm square mesh panels have been bought by Scottish fishers at the beginning of 2008 in order to qualify for the Conservation Credit Scheme, which dramatically improved the uptake of selective gear. The ban on the use of multi-rigs in Scotland, implemented in January 2008, may have limited the potential for an uncontrolled increase in effective effort.

The Dutch fleet was reduced, through decommissioning, by 23 vessels from the beginning of 2008, while five Belgian beam trawlers (approximately 5% of the Belgian fleet) left the fishery in 2007, both changes implying reductions in effort in the beam trawl sector. The introduction of an ITQ regulation system in Denmark in 2007 might have influenced the effort distribution over the year, but this should not have affected the total Danish effort deployed or the size distribution of catches.

Dutch beam trawlers have gradually shifted to other techniques such as twin trawling, outrigging and fly-shooting, as well as opting for smaller, multi-purpose vessels, implying a shift in effort away from flatfish to other sectors. These changes were likely caused by TAC limitations on plaice and sole, and rising fuel costs. Belgian and UK vessels have also experimented with outrigger trawls as an alternative to beam trawling, motivated by more fuel efficient and environmentally friendly fishing methods.

The increased effort costs in the Kattegat (2.5 days at sea per effort day deployed) in 2008 has led to a shift in effort by Swedish vessels to the Skagerrak and Baltic Sea. There has also been an increase in the number of Swedish *Nephrops* vessels in recent years, attributed to the input of new capital transferred from pelagic fleets following the introduction of an ITQ-system for pelagic species, and leading to further increases in effort. The Swedish trawler fleet operating in IIIa has had a steady increase in the uptake of the *Nephrops* grid since the introduction of legislation in 2004 (use of the grid is mandatory in coastal waters), and given the strong incentives to use the grid (unlimited days at sea). Uptake of the *Nephrops* grid should have resulted in improved selection.

A squid fishery in the Moray Firth has continued to develop using very unselective 40 mm mesh when squid species are available on the grounds. Although the uptake was poor in 2007 due to the lack of squid, the potential for high bycatches of young gadoids in future, including those of cod and haddock, remains. This fishery may provide an alternative outlet for the Scottish *Nephrops* fleet seasonally, and hence reduce effort in the *Nephrops* sector.

A.3. Ecosystem aspects

Section A.3 was not updated during WKNSEA 2015. However, although outdated, some of the information is still relevant. This section will be updated in due course.

Cod are predated upon by a variety of species through their life history. The Working Group on Multi-species Assessment Methods (ICES-WGSAM 2008) estimated predation mortalities using SMS (Stochastic Multi Species Model) with diet information largely derived from the Years of the Stomach databases (stomachs sampled in the years 1981–1991). Long-term trends have been observed in several partial predation mortalities with significant increases for grey gurnard preying on 0-group cod. In contrast, predation mortalities on age 1 and age 2 cod decreased over the last 30 years due to lower cannibalism. Predation on older cod (age 3–6) increased due to increasing numbers of grey seals in the North Sea.

SMS identified grey gurnard as a significant predator of 0-group cod. The abundance of grey gurnard (as monitored by IBTS) is estimated to have increased in recent years resulting in a rise in estimated predation mortality from 1.08 to 1.76 between 1991 and 2003. A degree of caution is required with these estimates as they assume that the spatial overlap and stomach contents of the species has remained unchanged since 1991. Given the change in abundance of both species this assumption is unlikely to hold and new diet information is required before 0-group predation mortalities can be relied upon.

Several other predators contribute to predation mortality upon 0-group cod, whiting and seabirds being the next largest components. Speirs *et al*. (2010) developed a length-structured partial ecosystem model for cod and nine of its most important fish predators and prey in the North Sea, utilising time-series of stock biomass, recruitment and landings, as well as survey data on length distributions and diet data. Their results suggest that herring predation on early life-history stages of cod is dynamically important, and that high abundances of herring may lead to the decline of cod stocks, even during periods of declining fishing pressure. Furthermore, they show that the MSY of cod is strongly dependent on herring abundance, and that current levels of cod exploitation may become unsustainable if herring recruitment returns to historic high levels.

The consumption of cod in the North Sea in 2002 by grey seals (*Halichoerus grypus*) has recently been estimated (Hammond and Grellier, 2006). For the North Sea it was estimated that in 1985 grey seals consumed 4150 tonnes of cod (95% confidence intervals: 2484–5760 tonnes), and in 2002 the population tripled in size (21–68 000) and consumed 8344 tonnes (95% confidence intervals: 5028–14 941 tonnes). These consumption estimates were compared to the Total Stock Biomass (TSB) for cod of 475 000 tonnes and 225 000 tonnes for 1985 and 2002 respectively. The mean length of cod in the seal diet was estimated as 37.1 cm and 35.4 cm in 1985 and 2002 respectively. It should be noted, however, that seal diet analysis must be treated with a degree of caution because of the uncertainties related to modelling complex processes (e.g. using scat analysis to estimate diet composition involves complex parameters, and can overestimate species with more robust hard parts), and the uncertainties related to estimating seal population size from pup production estimates (involving assumptions about the form of density-dependent dynamics). The analysis may also be subject to bias because scat data from haul-out sites may reflect the composition of prey close to the sites rather than further offshore.

The effect of seal predation on cod mortality rates has been estimated for the North Sea within a multi-species assessment model (MSVPA), which was last run in 2007 during the EU project BECAUSE (contract number SSP8-CT-2003-502482) using revised estimates of seal consumption rates. The grey seal population size was obtained from WGMME (ICES-WGMME 2005) and was assumed to be 68 000 in 2002 and 2003 respectively. Estimates of cod consumption were 9657 tonnes in 2002 and 5124 tonnes in 2003, which is similar to the values estimated by Hammond and Grellier (2006). Sensitivity analysis of the North Sea cod stock assessment estimates to the inclusion of the revised multi-species mortality rates were carried out at the 2009 meeting of the WKROUND. Inclusion of the multi-species mortality rates for older ages of cod had a relatively minor effect on the high levels of estimated fishing mortality rates and low levels of spawning stock biomass abundance. This suggests that the estimates of seal predation will not alter the current perception of North Sea cod stock dynamics (also stated by STECF-SGRST-07-01).

The overlap between predator and prey is a key parameter in multispecies assessment models and is notoriously difficult to parameterise. Kempf *et al*. (2010) attempt this by using overlap indices derived from trawl surveys in a North Sea SMS model in order to investigate the recovery potential of North Sea cod. They found that the spatial–temporal overlap between cod and its predators increased with increasing temperature, indicating that foodweb processes might reduce the recovery potential of cod during warm periods. Furthermore, they found that multispecies scenarios predicted a considerably lower recovery potential than single-species ones.

A recent meeting (2007) of the STECF reviewed the broad scale environmental changes in the northeastern Atlantic that has influenced all areas under the cod recovery plan (STECF-SGRST-07-01), and concluded that:

- Warming has occurred in all areas of the NW European shelf seas, and is predicted to continue.
- A regime shift in the North Sea ecosystem occurred in the mid-1980s.
- These ecological changes have, in addition to the decline in spawning stock size, negatively affected cod recruitment in all areas.
- Biological parameters and reference points are dependent on the time-period over which they are estimated. For example, for North Sea cod F_{MSY}, MSY and B_{MSY} are lower when calculated for the recent warm period (after 1988) compared to values derived for the earlier cooler period.
- The decline in F_{MSY}, MSY and B_{MSY} can be expected to continue due to the predicted warming, and possible future change should be accounted for in stock assessment and management regimes.
- Modelling shows that under a changing climate, reference points based on fishing mortality are more robust to uncertainty than those based on biomass.
- Despite poor recruitment, modelling suggests that cod recovery is possible, but ecological change may affect the rate of recovery, and the magnitude of achievable stock sizes.
- Recovery of cod populations may have implications to their prey species, including *Nephrops*.

With the exception of the general effects noted above, the overall conclusion from the STECF meeting (STECF-SGRST-07-01) for the North Sea was that there is no specific significant environmental or ecosystem change in the Skagerrak, North Sea and eastern Channel (e.g. the effects of gravel extraction, etc.) affecting potential cod recovery.

The conclusions from the STECF meeting merit further discussion within ICES, which is ongoing (e.g. ICES-WKREF 2007).

A.4. Fisheries-science partnerships

Section A.4 was not updated during WKNSEA 2015. It has been left for information, but note that all three Fisheries-Science Partnerships have been discontinued.

UK – North East Coast Cod Survey

The NE Coast cod survey (De Oliveira *et al*., 2013) was a designated time-series survey conducted since 2003 as part of the UK Fisheries Science Partnership (FSP). The objective of the survey series was to provide year-on-year comparative information on distribution, relative abundance and size/age composition of cod and whiting off the NE coast of England. The surveys also provided data on catches of other species important to the NE coast fishery, including haddock. The population of cod in the survey area has primarily comprised 1- and 2-year-olds, with some 3- and 4-year-olds. Older fish have been scarce due to offshore migration of mature fish. The relative strength of recent year classes of cod, as indicated by the time-series of FSP catch rates of 1-year-olds, has been similar to the trends given by recent ICES assessments for North Sea cod, but did not pick out the 2009 year class as being any larger than the surrounding year classes, and estimated the 2011 year class to be very weak; in contrast, the assessment indicates relatively stronger 2009 and 2011 year classes (2009 being almost the same size as the 2005 year class). Furthermore, overall catch rates for cod in the 2012 FSP survey were below average for the time-series in terms of both total numbers (well below in this case) and total weight. However, it should be noted that this FSP survey only covers a small portion of the North Sea cod distribution area. A comparison of different seabed types indicates that for most years catches of cod are significantly greater on the hard ground, but that trends are similar between hard and soft ground. Unfortunately, due to FSP project priorities having changed slightly in 2013/2014, the North East cod FSP survey has been discontinued in lieu of other targets for the programme, so 2012 is the final year for this time-series.

UK – North Sea Whitefish Survey

The North Sea whitefish survey was designed to provide a time-series of information on commercial vessel catch per unit effort from representative fishing grounds within the North Sea, with the eventual aim of providing a long-enough time-series to be used to support the estimation of stock trends (Darby *et al*., 2013). The participating vessel used a combination of traditional English fishing gears appropriate to hard and soft ground in order to provide information on comparative catch rates. The tows were distributed over sub-areas defined to provide information on catch rate, size/age composition and species catch composition from as many different locations as feasible, given time and cost constraints, within the area where the fishery takes place, and not necessarily at constant locations each year. The size of the whole catch was recorded, but detailed measurements were made of the catches of cod, whiting and haddock, and of plaice if resources permitted. Surveys have been held in 2009–2012.

Cod catch rates have varied, with the hard ground catch rates being higher in 2009, soft ground catch rates in 2010 and similar rates on each ground type in 2011. The difference between ground types was constant across ages until 2012. In 2012, though, catches of cod at older ages were greater on soft ground, especially in the south, whereas in the north and at younger ages, catch rates were similar between ground types. Despite the substratum differences in catch rates, when averaged at an overall North Sea scale, the relative indices at age of cod, haddock and whiting abundance from the survey compare well with the ICES IBTSq3 survey data. However, the IBTS has greater selectivity at the youngest ages due to the smaller mesh size and therefore detected incoming year-class strength earlier than that of the North Sea Whitefish survey. Nevertheless, catches of older fish were more common and exhibited less noise in the North Sea Whitefish survey data than in the IBTSq3.

The results demonstrated the value in developing a time-series for gadoids based on commercial vessels. The North Sea Whitefish time-series showed consistent agreement with the IBTS survey, but with higher, less noisy catch rates at the oldest ages. As such a time-series continued to develop the results would allow differences in stock dynamics on hard and soft ground to be examined in detail and determination made of whether substratum type can affect survey estimates of stock abundance, especially as the stocks of cod and whiting rebuild under the current management regime, providing valuable input to the debate on the dynamics of the stocks and survey practices. Unfortunately, due to FSP project priorities having changed slightly in 2013/2014, the North Sea Whitefish survey has been discontinued in lieu of other targets for the programme, so 2012 is the final year for this time-series.

Denmark – RESOURCE Project

The Danish RESOURCE project represents the finalization of seven years of fishermen–scientists cooperation; a cooperation that was commenced on the initiative of the fishermen because they wanted to demonstrate that there are far more large Atlantic cod in the northeastern North Sea than indicated by the catch rates obtained from the International Bottom trawl Survey (IBTS). This earlier initiative developed into the REX project, a predecessor of RESOURCE (Wieland *et al.*, 2010). The RESOURCE project concentrated on the northeastern North Sea, focusing on the importance of the geographical distribution of Atlantic cod at different scales (Beyer *et al.*, 2012). The project collected data from fishermen and scientists and assimilated knowledge on fishery practice, the geographical distribution of cod in the North Sea, and the vital mechanisms or processes in the sea (larval drift, growth, recruitment) that are important to explain the distribution dynamics. It used the GeoPop statistical model to integrate data from trawl hauls (REX, RESOURCE, IBTS) in order to estimate the geographical distribution of cod by body size class, thus providing a possible way towards integrated stock assessments, combining space, time and fish size.

The project has demonstrated that, on a small geographical scale, it was difficult for the fisherman to obey the RTC (real-time closure) rules because the risk of catching small cod in a single haul was high, even if there were few small cod in the specific area. Furthermore, on a larger scale, data from REX/RESOURCE hauls gave a more nuanced picture of the geographical distribution of cod in the REX area as compared to the rough image produced by exclusive use of IBTS data. Future fishermen–scientists' projects should be result-based and focus on ecosystem research. Increased process knowledge and real time REX data will ensure the necessary understanding of the factors controlling the annual recruitment to the North Sea cod stocks.

B. Data

B.1. Commercial catch

Commercial catch-at-age from 2002 onwards have been estimated through InterCatch, following uploads by various nations of relevant landings data, and where available discards data, along with age compositions of both the landings and discards, by area (IV, IIIaN and VIId), quarter and métier. Prior to the reform of the EU's data collection framework in 2008 (see http://datacollection.jrc.ec.europa.eu/), sampling for discards and age compositions was poor in Area VIId, and this necessitated combining Areas IV and VIId for 2002–2008 in order to facilitate computations in InterCatch. Table B.1.1 indicates the level of discard ratio coverage of the landings, together with the age coverage of both the landings and observed discards (InterCatch data: 2002–2013). Coverage for discard ratios and ages has been good (at least 50%) for Areas IV an IIIaN, but poor for Area VIId prior to 2009.

Norwegian discarding is illegal, so although this nation has accounted for 7–14% of cod landings over the period 2002–2013 (InterCatch data), it does not provide discard estimates. Nevertheless, the agreed procedure applied in InterCatch is that discards raising should include Norway (i.e. Norway will be allocated discards associated with landings in reported métiers). Furthermore, tagging and genetic studies have indicated that Norwegian coastal cod are different to North Sea cod and do not generally move into areas occupied by North Sea cod. Therefore, Norwegian coastal cod data have been removed from North Sea cod data by uploading only North Sea cod data into InterCatch for 2002 onwards, and by adjusting catches prior to 2002 to reflect the removal of Norwegian coastal cod data (an annual multiplicative adjustment of no more than 2.5% was made using Norwegian coastal cod data; see ICES-WKNSEA 2015 for more details).

Table B.1.1. Proportion of landings (as a percentage) taken in each of three areas (first block), together with (by area) discard ratio coverage of the landings (second block), age coverage of the landings (third block) and age coverage of the observed discards (fourth block). Shaded cells indicate where there has been less than 50% coverage. Detailed results were reported in WD6 of ICES-WKNSEA (2015).

	Landings proportions (%)			Discard ratio coverage			Landings age coverage			Discards age coverage		
	IV	IIIaN	VIId	IV	IIIaN	VIId	IV	IIIaN	VIId	IV	IIIaN	VIId
2002	81	13	6	50%	73%	0%	64%	83%	0%	88%	69%	0%
2003	80	13	7	57%	67%	0%	59%	93%	3%	88%	42%	0%
2004	82	14	4	54%	67%	6%	68%	93%	7%	81%	94%	100%
2005	81	14	4	58%	55%	5%	75%	91%	4%	81%	82%	100%
2006	82	13	6	75%	66%	6%	77%	91%	14%	85%	96%	100%
2007	79	12	9	58%	60%	5%	71%	90%	11%	99%	92%	100%
2008	81	13	6	65%	59%	10%	73%	89%	16%	95%	100%	100%
2009	83	11	6	57%	85%	81%	72%	95%	80%	97%	93%	100%
2010	84	11	5	70%	77%	81%	80%	95%	84%	100%	90%	100%
2011	83	12	4	69%	83%	74%	72%	95%	74%	97%	90%	100%
2012	83	13	4	66%	79%	76%	82%	88%	81%	95%	89%	100%
2013	83	14	3	77%	72%	78%	82%	85%	81%	91%	96%	100%

Discard numbers-at-age were estimated for Areas IV and VIId by applying the Scottish discard ogives to the international landings-at-age for years prior to 2002, while those in IIIaN were based on observer sampling estimates. Table B.1.2 reports the discard ratio coverage of the most important métiers (those that comprised 1% or more of cod landings over all areas and quarters for 2011–2013.

Table B.1.2. Discard ratio coverage by métier and country for the years 2011–2013 for those métiers which comprised 1% or more of cod landings over all areas and quarters.

2011

	Belgium	Denmark	France	Germany	Netherlands	Norway	Sweden	UK (England)	UK(Scotland)
GNS_DEF_120-219_0_0_all	NA	1.0000000	NA	NA	NA	NA	NA	NA	NA
GNS_DEF_all_0_0_all	NA	NA	NA	NA	NA	0	NA	0.1071281	NA
GTR_DEF_all_0_0_all	NA	NA	0.3652579	NA	NA	NA	NA	NA	NA
LLS_FIF_0_0_0_all	NA	NA	NA	NA	NA	0	NA	NA	NA
MIS_MIS_0_0_0_HC	NA	0.1012391	NA	NA	NA	NA	NA	NA	NA
OTB_CRU_70-99_0_0_all	NA	NA	NA	NA	NA	NA	NA	0.8271698	NA
OTB_CRU_90-119_0_0_all	NA	1.0000000	NA	NA	NA	NA	NA	NA	NA
OTB_DEF_>=120_0_0_all	NA	1.0000000	NA	0.9938589	NA	0	NA	0.9973467	1
OTB_DEF_>=120_0_0_all_FDF	NA	1.0000000	NA	NA	NA	NA	NA	NA	1
OTB_DEF_70-99_0_0_all	NA	NA	0.6850180	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all	NA	1.0000000	NA	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all_FDF	NA	1.0000000	NA	NA	NA	NA	NA	NA	NA
SSC_DEF_100-119_0_0_all	NA	NA	NA	NA	0	NA	NA	NA	NA
TBB_DEF_>=120_0_0_all	3.581356e-05	NA	NA	NA	NA	NA	NA	NA	NA
TBB_DEF_70-99_0_0_all	NA	NA	NA	NA	0	NA	NA	NA	NA

2012

	Belgium	Denmark	France	Germany	Netherlands	Norway	Sweden	UK (England)	UK(Scotland)
GNS_DEF_120-219_0_0_all	NA	1.0000000	NA	NA	NA	NA	NA	NA	NA
GNS_DEF_all_0_0_all	NA	NA	NA	NA	NA	0	NA	NA	NA
GTR_DEF_all_0_0_all	NA	NA	0.6967654	NA	NA	NA	NA	NA	NA
LLS_FIF_0_0_0_all	NA	NA	NA	NA	NA	0	NA	NA	NA
MIS_MIS_0_0_0_HC	NA	0.0000000	NA	NA	NA	NA	NA	NA	NA
OTB_CRU_90-119_0_0_all	NA	1.0000000	NA	NA	NA	NA	NA	NA	NA
OTB_DEF_>=120_0_0_all	NA	1.0000000	NA	0.9834082	NA	0	NA	NA	1
OTB_DEF_>=120_0_0_all_FDF	NA	1.0000000	NA	0.9658608	NA	NA	NA	NA	1
OTB_DEF_70-99_0_0_all	NA	NA	0.7796973	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all	NA	0.7133178	NA	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all_FDF	NA	1.0000000	NA	NA	NA	NA	NA	NA	NA
SSC_DEF_>=120_0_0_all	NA	NA	NA	NA	0	NA	NA	NA	NA
TBB_DEF_>=120_0_0_all	0	NA	NA	NA	NA	NA	NA	NA	NA
TBB_DEF_all_0_0_all	NA	NA	NA	NA	0	NA	NA	NA	NA

2013

	Belgium	Denmark	France	Germany	Netherlands	Norway	Sweden	UK (England)	UK(Scotland)
GNS_DEF_120-219_0_0_all	NA	1.0000000	NA	NA	NA	NA	NA	NA	NA
GNS_DEF_all_0_0_all	NA	NA	NA	NA	NA	0	NA	NA	NA
LLS_FIF_0_0_0_all	NA	NA	NA	NA	NA	0	NA	NA	NA
MIS_MIS_0_0_0_HC	NA	0.0000000	NA	NA	NA	NA	NA	NA	NA
OTB_CRU_90-119_0_0_all	NA	1.0000000	NA	NA	NA	NA	1	NA	NA
OTB_DEF_>=120_0_0_all	NA	1.0000000	NA	0.8996081	NA	0	NA	NA	0.9999979
OTB_DEF_>=120_0_0_all_FDF	NA	1.0000000	NA	0.8963346	NA	NA	NA	NA	0.9973569
OTB_DEF_70-99_0_0_all	NA	NA	0.8093578	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all	NA	0.8255804	NA	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all_FDF	NA	1.0000000	NA	NA	NA	NA	NA	NA	NA
SSC_DEF_>=120_0_0_all	NA	0.9506375	NA	NA	NA	NA	NA	NA	NA
SSC_DEF_100-119_0_0_all	NA	NA	NA	NA	0.6776727	NA	NA	NA	NA
TBB_DEF_>=120_0_0_all	0.4450264	NA	NA	NA	NA	NA	NA	NA	NA
TBB_DEF_70-99_0_0_all	NA	NA	NA	NA	1.0000000	NA	NA	NA	NA

For cod in IV, IIIaN (Skagerrak) and VIId, ICES first raised concerns about the misreporting and non-reporting of landings in the early 1990s, particularly when TACs became intentionally restrictive for management purposes. Some WG members have since provided estimates of under-reporting of landings to the WG, but by their very nature these are difficult to quantify. In terms of events since the mid-1990s, the WG believes that under-reporting of landings may have been significant in 1998 because of the abundance in the population of the relatively strong 1996 year class as two year-olds. The landed weight and input numbers-at-age data for 1998 were adjusted to include an estimated 3000 t of under-reported catch. The 1998 catch estimates remain unchanged in the present assessment, apart from the small adjustment for the removal of Norwegian coastal cod data (see above).

For 1999 and 2000, the WG has no *a priori* reason to believe that there was significant under-reporting of landings. However, the substantial reduction in fishing effort implied by the 2001, 2002 and 2003 TACs is likely to have resulted in an increase in unreported catch in those years. Anecdotal information from the fisheries in some countries indicated that this may indeed have been the case, but the extent of the alleged under-reporting of catch varies considerably. Since the WG has no basis to judge the overall extent of under-reported catch, it has no alternative than to use its best estimates of landings, which in general are in line with the officially reported landings. An attempt is made to incorporate a statistical correction to the sum of reported landings and discards data in the assessment of this stock. Buyers and Sellers legislation introduced in the UK towards the end of 2005 is expected to have improved the accuracy of reported cod landings for the UK. This has brought the UK in line with existing EU legislation.

Age compositions

Age compositions are currently provided by Denmark, England, France, Germany, the Netherlands, Scotland and Sweden. However, not all of the most important métiers (those that comprised 1% or more of cod landings over all areas and quarters) are sampled (Table B.1.3), and the Netherlands does not routinely provide age compositions (except for one métier in 2012).

Table B.1.3. Age coverage by métier and country for the years 2011–2013 for those métiers which comprised 1% or more of cod landings over all areas and quarters.

2011

	Belgium	Denmark	France	Germany	Netherlands	Norway	Sweden	UK (England)	UK(Scotland)
GNS_DEF_120-219_0_0_all	NA	1	NA	NA	NA	NA	NA	NA	NA
GNS_DEF_all_0_0_all	NA	NA	NA	NA	NA	0	NA	0.6624181	NA
GTR_DEF_all_0_0_all	NA	NA	0.3652579	NA	NA	NA	NA	NA	NA
MIS_MIS_0_0_0_HC	NA	1	NA	NA	NA	NA	NA	NA	NA
OTB_CRU_70-99_0_0_all	NA	NA	NA	NA	NA	NA	NA	0.9937665	NA
OTB_CRU_90-119_0_0_all	NA	1	NA	NA	NA	NA	NA	NA	NA
OTB_DEF_>=120_0_0_all	NA	1	NA	0.9692616	NA	0	NA	0.9973467	1
OTB_DEF_>=120_0_0_all_FDF	NA	1	NA	NA	NA	NA	NA	NA	1
OTB_DEF_70-99_0_0_all	NA	NA	0.6850180	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all	NA	1	NA	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all_FDF	NA	1	NA	NA	NA	NA	NA	NA	NA
SSC_DEF_100-119_0_0_all	NA	NA	NA	NA	0	NA	NA	NA	NA
TBB_DEF_>=120_0_0_all	0	NA	NA	NA	NA	NA	NA	NA	NA
TBB_DEF_70-99_0_0_all	NA	NA	NA	NA	0	NA	NA	NA	NA

2012

	Belgium	Denmark	France	Germany	Netherlands	Norway	Sweden	UK (England)	UK(Scotland)
GNS_DEF_120-219_0_0_all	NA	1	NA	NA	NA	NA	NA	NA	NA
GNS_DEF_all_0_0_all	NA	NA	NA	NA	NA	0.9992355	NA	NA	NA
GTR_DEF_all_0_0_all	NA	NA	0.7192067	NA	NA	NA	NA	NA	NA
LLS_FIF_0_0_0_all	NA	NA	NA	NA	NA	0.0000000	NA	NA	NA
MIS_MIS_0_0_0_HC	NA	1	NA	NA	NA	NA	NA	NA	NA
OTB_CRU_90-119_0_0_all	NA	1	NA	NA	NA	NA	NA	NA	NA
OTB_DEF_>=120_0_0_all	NA	1	NA	0.9501721	NA	0.5850162	NA	NA	1
OTB_DEF_>=120_0_0_all_FDF	NA	1	NA	0.8544592	NA	NA	NA	NA	1
OTB_DEF_70-99_0_0_all	NA	NA	0.7796973	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all	NA	1	NA	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all_FDF	NA	1	NA	NA	NA	NA	NA	NA	NA
SSC_DEF_>=120_0_0_all	NA	NA	NA	NA	0	NA	NA	NA	NA
TBB_DEF_>=120_0_0_all	0	NA	NA	NA	NA	NA	NA	NA	NA
TBB_DEF_all_0_0_all	NA	NA	NA	NA	1	NA	NA	NA	NA

2013

	Belgium	Denmark	France	Germany	Netherlands	Norway	Sweden	UK (England)	UK(Scotland)
GNS_DEF_120-219_0_0_all	NA	1	NA	NA	NA	NA	NA	NA	NA
GNS_DEF_all_0_0_all	NA	NA	NA	NA	NA	0.9898023	NA	NA	NA
LLS_FIF_0_0_0_all	NA	NA	NA	NA	NA	0.0000000	NA	NA	NA
MIS_MIS_0_0_0_HC	NA	1	NA	NA	NA	NA	NA	NA	NA
OTB_CRU_90-119_0_0_all	NA	1	NA	NA	NA	NA	1	NA	NA
OTB_DEF_>=120_0_0_all	NA	1	NA	0.8996081	NA	0.6049244	NA	NA	0.9999979
OTB_DEF_>=120_0_0_all_FDF	NA	1	NA	0.8963346	NA	NA	NA	NA	0.9973569
OTB_DEF_70-99_0_0_all	NA	NA	0.8093578	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all	NA	1	NA	NA	NA	NA	NA	NA	NA
SDN_DEF_>=120_0_0_all_FDF	NA	1	NA	NA	NA	NA	NA	NA	NA
SSC_DEF_>=120_0_0_all	NA	1	NA	NA	NA	NA	NA	NA	NA
SSC_DEF_100-119_0_0_all	NA	NA	NA	NA	0	NA	NA	NA	NA
TBB_DEF_>=120_0_0_all	0	NA	NA	NA	NA	NA	NA	NA	NA
TBB_DEF_70-99_0_0_all	NA	NA	NA	NA	0	NA	NA	NA	NA

Landings in numbers-at-age for age groups 1–11+ and 1963–present form the basis for the catch-at-age analysis but do not include industrial fishery bycatches landed for reduction purposes. Bycatch estimates are available for the total Danish and Norwegian small-meshed fishery in Subarea IV and separately for the Skagerrak.

Data exploration

Data exploration for commercial catch data for North Sea cod currently involves:

a) expressing the total catch-at-age matrix as proportions-at-age, normalised over time, so that year classes making above-average contributions to the catches are shown as large positive residuals (and vice-versa for below-average contributions);

b) performing log-catch-curve analyses to examine data consistency, fishery selectivity and mortality trends over time; the negative slope of a regression fitted to ages down a cohort (e.g. ages 2–4) can be used as a proxy for total mortality.

B.2. Biological Information

Weight-at-age

Mean catch weight-at-age is a catch-number weighted average of individual catch weight-at-age, available by country, area and type (i.e. landings and discards). For ages 1–9 there have been short-term trends in mean weight-at-age throughout the time-series with a decline over the recent decade at ages 3–5 that recently seems to have been reversed. The data also indicate a slight downward trend in mean weight for ages 3–6 during the 1980s and 1990s. Ages 1 and 2 show little absolute variation over the long term.

Using weight-at-age from annual ICES assessments and International Bottom Trawl Surveys, Cook *et al*. (1999) developed a model that explained weight-at-age in terms of a von Bertalanffy growth curve and a year-class effect. They found that the year-class effect was correlated with total and spawning–stock biomass, indicating density-dependent growth, possibly through competition. Further evidence for density-dependent growth had previously been found by others (Houghton and Flatman, 1981; Macer, 1983; Alphen and Heessen, 1984), although they pointed to different mechanisms (Rijnsdorp *et al*., 1991; ICES, 2005). Results from Macer (1983) imply that juvenile cod compete strongly with adults, while the data from Alphen and Heessen (1984) suggest strong within-year-class competition during the first three years of life.

Growth rate can be linked to temperature and prey availability (Hughes and Grand, 2000; Blanchard *et al*., 2005). Growth parameters of North Sea cod given in ICES (1994) demonstrate that cod in the southern North Sea grow faster than those in the north, but reach a smaller maximum length (Oosthuizen and Daan, 1974; ICES, 2005). Furthermore, older and larger cod have lower optimal temperatures for growth (Björnsson and Steinarsson, 2002), and distributions of cod are known to depend on the local depth and temperature (Ottersen *et al*., 1998; Swain, 1999; Blanchard *et al*., 2005).

Differences in mean length by age and sex can also be found for mature vs. immature cod (ICES, 2005). For example, Hislop (1984) found that within an age group, mature cod of each sex are, on average, larger than immature cod.

Natural mortality

Since the benchmark in 2009 (ICES, WKROUND 2009) variable natural mortality estimates are used in the assessment for North Sea cod. An update of natural mortality estimates is produced by the Working Group on Multi-Species Stock Assessment Methods (WGSAM) every three years in so called key runs with the stochastic multi species model SMS. The model SMS (Lewy and Vinther, 2004) is a stock assessment model including biological interaction estimated from a parameterised size dependent food selection function. The model is formulated and fitted to observations of total catches, survey cpue and stomach contents for the North Sea. Parameters are estimated by maximum likelihood and the variance/covariance matrix is obtained from the Hessian matrix.

In the most recent SMS analysis (ICES, WGSAM 2014), the following predator and prey stocks were available: predators and prey (cod, whiting, haddock), prey only (herring, sprat, northern and southern sandeel, Norway pout), predator only (saithe), no predator prey interactions (sole and plaice) and 'external predators' (eight seabirds, starry ray, grey gurnard, western mackerel, North Sea mackerel, North Sea horse mackerel, western horse mackerel, grey seals, harbour porpoise and hake). The population dynamics of all species except 'external predators' were estimated within the model.

A working document (Kempf, WD4) was provided to ICES, WKNSEA (2015) describing the latest key run 2014 (ICES, WGSAM 2014) with focus on natural mortality estimates for cod. In general, the key run in 2014 is an update of the 2011 key run. But compared to the 2011 key run, the time-series of grey gurnard and raja abundances were revised, sandeel was split into a southern and northern component and hake was included as additional other predator in the model (but no cod was found in the available hake stomachs). In addition, the start year was changed from 1963 to 1974 because, for the early years, data on forage fish are highly uncertain.

Overall, the changes in estimated predation mortalities for cod were small between the 2011 and 2014 key runs. However, a further change in the 2014 key run settings occurred after the WGSAM meeting. For age 3 cod a sudden jump in predation mortalities appeared in the original key run. This was caused by harbour porpoise which starts to prey on age 3 cod in the 1st quarter from 1998 onwards. The reason behind this is that the cod mean weight-at-age in the sea in the SMS input data are lower after 1998. Therefore, it just falls below the highest observed mean weight in harbour porpoise stomachs and harbour porpoise starts to prey on age 3 cod in the model. However, after 1999 no mean weight-at-age in the sea per quarter was available from WGNSSK and fixed values were used as input constant from 2000 onwards. In addition, the estimated mortality of cod eaten by harbour porpoise might be biased. A preliminary study of the effect of differences in digestion rate of different sizes of otoliths in harbour porpoise stomach content was presented to the group and demonstrated that the consumption of large fish may be overestimated, if diet is estimated directly from the presence of otholiths in the stomach. ICES, WGSAM (2014) considered that this may potentially have a considerable impact on the estimated consumption by harbour porpoise and that the estimation of correction rates applicable to North Sea harbour porpoises should be a priority area of study before the next key run is conducted. However, as no quantitative correction factors were available to the group, no correction could be made during the WGSAM meeting. Therefore, it was suggested to take the alternative 2014 key run as basis for the North Sea cod assessment because it is more consistent over time and more conservative by reducing the predation impact on large cod. The general trends stay the same as in the original key run; only the absolute level of M2 values is different.

Table B.1.4 gives the values for natural mortality, as derived by ICES, WGSAM (2014). These values will continue to be used until the next key run is performed, scheduled for 2017. In the meantime, values from M-at-age from 2014 onwards will be kept constant and set equal to the 2013 values.

Table B.1.4. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. Natural mortality by age-group.

	Age						
	1	2	3	4	5	6	7+
1963	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1964	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1965	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1966	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1967	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1968	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1969	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1970	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1971	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1972	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1973	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1974	1.215	0.777	0.221	0.200	0.2	0.2	0.2
1975	1.238	0.755	0.222	0.200	0.2	0.2	0.2
1976	1.261	0.735	0.222	0.200	0.2	0.2	0.2
1977	1.285	0.719	0.223	0.200	0.2	0.2	0.2
1978	1.307	0.709	0.223	0.200	0.2	0.2	0.2
1979	1.325	0.703	0.223	0.200	0.2	0.2	0.2
1980	1.339	0.702	0.223	0.200	0.2	0.2	0.2
1981	1.347	0.705	0.222	0.200	0.2	0.2	0.2
1982	1.348	0.710	0.222	0.200	0.2	0.2	0.2
1983	1.340	0.714	0.222	0.200	0.2	0.2	0.2
1984	1.325	0.717	0.221	0.200	0.2	0.2	0.2
1985	1.304	0.719	0.221	0.200	0.2	0.2	0.2
1986	1.279	0.720	0.221	0.200	0.2	0.2	0.2
1987	1.252	0.721	0.220	0.200	0.2	0.2	0.2
1988	1.226	0.722	0.220	0.200	0.2	0.2	0.2
1989	1.200	0.724	0.220	0.200	0.2	0.2	0.2
1990	1.177	0.725	0.220	0.200	0.2	0.2	0.2
1991	1.158	0.726	0.220	0.200	0.2	0.2	0.2
1992	1.144	0.728	0.220	0.200	0.2	0.2	0.2
1993	1.134	0.730	0.220	0.200	0.2	0.2	0.2
1994	1.129	0.733	0.220	0.200	0.2	0.2	0.2
1995	1.126	0.739	0.220	0.200	0.2	0.2	0.2
1996	1.123	0.747	0.221	0.200	0.2	0.2	0.2
1997	1.119	0.756	0.222	0.200	0.2	0.2	0.2
1998	1.113	0.767	0.223	0.200	0.2	0.2	0.2
1999	1.106	0.781	0.226	0.200	0.2	0.2	0.2
2000	1.100	0.796	0.228	0.200	0.2	0.2	0.2
2001	1.098	0.815	0.231	0.200	0.2	0.2	0.2
2002	1.102	0.836	0.234	0.200	0.2	0.2	0.2
2003	1.109	0.859	0.237	0.200	0.2	0.2	0.2
2004	1.120	0.881	0.239	0.200	0.2	0.2	0.2
2005	1.133	0.900	0.241	0.200	0.2	0.2	0.2
2006	1.146	0.914	0.241	0.200	0.2	0.2	0.2
2007	1.162	0.925	0.241	0.200	0.2	0.2	0.2
2008	1.179	0.934	0.240	0.200	0.2	0.2	0.2
2009	1.201	0.943	0.239	0.200	0.2	0.2	0.2
2010	1.228	0.955	0.239	0.200	0.2	0.2	0.2
2011	1.262	0.971	0.238	0.200	0.2	0.2	0.2
2012	1.303	0.991	0.238	0.200	0.2	0.2	0.2
2013	1.345	1.014	0.239	0.200	0.2	0.2	0.2
2014*	1.345	1.014	0.239	0.200	0.2	0.2	0.2

***A new key run was performed in 2014 with data up to 2013 (ICES-WGSAM 2014), so 2014 M-values are assumed equal to 2013.**

Maturity

Until 2015 the maturity values applied to all years were left unchanged from year to year. They were estimated using the International Bottom-trawl Survey series for 1981–1985. These values were derived for the North Sea.

Age group	Proportion mature
1	0.01
2	0.05
3	0.23
4	0.62
5	0.86
6	1.0
7+	1.0

However, maturity-at-age has changed in this stock with a positive trend over time (Cook *et al.*, 1999; Yoneda and Wright, 2004). There are also substantial population level differences in the rate of maturation change, with no significant shift in maturation probability being detected in Viking but substantial declines in the northwest and southern North Sea (Wright *et al.*, 2011). In order to address these changes in the stock, a maturity–age key has been constructed for the assessment region that was weighted by population subarea. As variation in sampling intensity added to the interannual variation, a smoother was applied to the maturity–age key. This smoothed maturity–age key was then applied to the estimation of spawning–stock biomass, using the following R-code (based in the R mgcv package):

```
skipYears=1:10
columnsToSmooth=1:5
mo=prop.mature[-c(skipYears),]

for(cc in columnsToSmooth){
    ww = mo[,cc];
    tt = 1:length(ww)
    tmp = gam(ww ~ s(tt))
    mo[,cc] = predict(tmp);
}
prop.mature[-c(skipYears),]=mo
```

The time-varying maturity ogive now used in the assessment is given in Table B.1.5. These values are the result of the smoothing code given above, and will change as each new year of data is added, and annual updates will be given in the WG report.

Table B.1.5. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. Maturity by age group.

	Age						
	1	2	3	4	5	6	7+
1963	0.010	0.050	0.230	0.620	0.860	1	1
1964	0.010	0.050	0.230	0.620	0.860	1	1
1965	0.010	0.050	0.230	0.620	0.860	1	1
1966	0.010	0.050	0.230	0.620	0.860	1	1
1967	0.010	0.050	0.230	0.620	0.860	1	1
1968	0.010	0.050	0.230	0.620	0.860	1	1
1969	0.010	0.050	0.230	0.620	0.860	1	1
1970	0.010	0.050	0.230	0.620	0.860	1	1
1971	0.010	0.050	0.230	0.620	0.860	1	1
1972	0.010	0.050	0.230	0.620	0.860	1	1
1973	0.009	0.030	0.230	0.628	0.855	1	1
1974	0.008	0.036	0.225	0.615	0.843	1	1
1975	0.008	0.041	0.220	0.603	0.831	1	1
1976	0.007	0.047	0.216	0.591	0.820	1	1
1977	0.006	0.052	0.215	0.580	0.809	1	1
1978	0.005	0.057	0.215	0.569	0.800	1	1
1979	0.004	0.063	0.216	0.560	0.792	1	1
1980	0.004	0.069	0.220	0.551	0.787	1	1
1981	0.003	0.074	0.225	0.545	0.783	1	1
1982	0.002	0.080	0.232	0.540	0.782	1	1
1983	0.002	0.086	0.242	0.539	0.783	1	1
1984	0.001	0.092	0.258	0.543	0.787	1	1
1985	0.001	0.099	0.279	0.551	0.793	1	1
1986	0.000	0.105	0.306	0.567	0.802	1	1
1987	0.000	0.112	0.337	0.588	0.813	1	1
1988	0.000	0.119	0.372	0.614	0.826	1	1
1989	0.000	0.127	0.405	0.643	0.841	1	1
1990	0.000	0.135	0.436	0.674	0.856	1	1
1991	0.001	0.143	0.460	0.704	0.871	1	1
1992	0.001	0.151	0.477	0.731	0.886	1	1
1993	0.002	0.159	0.486	0.754	0.900	1	1
1994	0.003	0.168	0.490	0.772	0.912	1	1
1995	0.003	0.177	0.492	0.785	0.922	1	1
1996	0.005	0.186	0.493	0.793	0.930	1	1
1997	0.006	0.195	0.498	0.797	0.936	1	1
1998	0.008	0.205	0.508	0.799	0.940	1	1
1999	0.010	0.215	0.524	0.800	0.943	1	1
2000	0.012	0.225	0.544	0.800	0.944	1	1
2001	0.014	0.234	0.569	0.800	0.944	1	1
2002	0.016	0.244	0.595	0.801	0.943	1	1
2003	0.019	0.254	0.621	0.803	0.942	1	1
2004	0.022	0.264	0.645	0.807	0.940	1	1
2005	0.025	0.274	0.667	0.812	0.939	1	1
2006	0.029	0.283	0.683	0.819	0.937	1	1
2007	0.032	0.292	0.693	0.827	0.936	1	1
2008	0.036	0.302	0.695	0.835	0.934	1	1
2009	0.040	0.311	0.688	0.842	0.932	1	1
2010	0.044	0.320	0.673	0.848	0.929	1	1
2011	0.048	0.329	0.649	0.853	0.926	1	1
2012	0.052	0.337	0.618	0.857	0.922	1	1
2013	0.056	0.346	0.583	0.860	0.918	1	1
2014	0.060	0.355	0.545	0.862	0.914	1	1

In the analysis of International Bottom-Trawl Survey maturity data, Cook *et al*. (1999) found that although accounting for changes in growth and maturity for North Sea cod altered the scale of SSB values, it did not make substantial changes to trajectories over time, and did not substantially alter the estimates of sustainable exploitation rates for the stock. The WKNSEA 2015 benchmark found, similarly, that although the SSB values were changed, the variable maturity ogive had no other material effect on assessment results.

The use of spawning–stock biomass as a measure of reproductive potential has the implicit assumption that the eggs per adult biomass remain constant, i.e. there is no age or size related difference in relative fecundity (eggs per gram of body mass). However, the relative fecundity of cod does vary with age and has changed over time. Rijnsdorp *et al*. (1991) found that relative fecundity of cod from the southern and central North Sea in the late 1980s was approximately 20% higher than that in the early 1970s, an increase that coincided with a four-fold decline in spawning–stock biomass. Yoneda and Wright (2004) found that fecundity–size relationships for the northwest North Sea cod also changed between the late 1960s and early 2000s and this was not related to any increase in individual condition. In 2002–2003, five year old females from the northwest North Sea were found to have 1.36 and 1.14 times the relative fecundity of a three and four year old female, respectively. That study also found differences in the relative fecundity between the Viking and northwest sub-areas, with the latter having on average a 37% greater relative fecundity than the former.

Recruitment

Recruitment has been linked not only to SSB, but also to temperature (Dickson and Brander, 1993; Myers *et al*., 1995; Planque and Fredou, 1999; O'Brien *et al*., 2000), plankton production timing and mean prey size (Beaugrand *et al*., 2003), the NAO (Brander and Mohn, 2004; ICES, 2005) and the demographic composition of spawners (Wright, 2014).

B.3. Surveys

Four survey series are available for this assessment:

- English third-quarter groundfish survey (EngGFS), ages 0–7, which covers the whole of the North Sea in August–September each year to about 200 m depth using a fixed station design of 75 standard tows. The survey was conducted using the Granton trawl from 1977–1991 and with the GOV trawl from 1992–present. Only ages 1–6 should be used for calibration, as catch rates for older ages are very low.
- Scottish third-quarter groundfish survey (ScoGFS): ages 1–8. This survey covers the period 1982–present. This survey is undertaken during August each year using a fixed station design and the GOV trawl. Coverage was restricted to the northern part of the North Sea until 1998, corresponding to only the northernmost distribution of cod in the North Sea. Since 1999, it has been extended into the central North Sea and made use of a new vessel and gear. Only ages 1–6 should be used for calibration, as catch rates for older ages are very low.
- Quarter 1 international bottom-trawl survey (IBTSQ1): ages 1–6+, covering the period 1976–present (usually data are available up to the year of the assessment for this survey, whereas it is only available up to the year prior to

the assessment year for the other surveys). This multi-vessel survey covers the whole of the North Sea using fixed stations of at least two tows per rectangle with the GOV trawl.

- Quarter 3 international bottom-trawl survey (IBTSQ3): ages 0–6+, covering the period 1991–present. This multi-vessel survey covers the whole of the North Sea using fixed stations of at least two tows per rectangle with the GOV trawl. The Scottish and English third quarter surveys described above contribute to this index.

Since the EngGFS and ScoGFS already form part of the IBTSQ3 survey, the WG only considers the IBTSQ1 and IBTSQ3 surveys for assessments.

The last benchmark of North Sea cod resulted in the exclusion of the IBTS Q3 survey index, because divergent trends in recent years were observed when the Q3 index was applied independently of the Q1 index (ICES, WKCOD 2011). At that time it was decided that until the reasons for the discrepancies were resolved, the Q1 was more likely to reflect the stock, and hence the Q3 index was dropped from the assessment. The indices were calculated using the standard stratified mean methodology (mean by rectangle within year, followed by mean over rectangles by year). This simple design based estimator is unable to account for systematic changes in experimental conditions (e.g. change of survey gear). Given these issues, an alternative methodology that calculates standardized age-based survey indices based on GAMs and Delta-distributions (see also Berg WD3; ICES, WKNSEA 2015) has now been adopted. The general methodology is described in Berg and Kristensen (2012) and Berg *et al.* (2014) and is implemented in R based on the DATRAS package (http://rforge.net/DATRAS/).

Description of methodology

Smooth spatially varying age–length keys are estimated using the methodology described in Berg and Kristensen (2012). Numbers-at-age are then calculated using the observed numbers-at-length and the estimated ALKs. This methodology was found to give higher internal consistencies in survey indices for haddock when compared to the current standard approach of estimating ALKs that are constant within "Roundfish" (RF) areas. It avoids *ad hoc* borrowing of samples from neighbouring RF areas, when certain age groups are missing, and it provides an objective fill-in procedure for missing length groups also. This is possible because the probability of age given length is modelled using smooth functions of the length of a fish and the spatial coordinates where the haul was taken, rather than relying on some specific stratification of length and space. The methodology has been implemented in the DATRAS package with full source code available. The differences between the standard ALKs and the ones used here were not investigated in detail, but comparisons of the survey indices calculated using the smooth ALKs and the stratified mean method with the standard DATRAS-produced survey indices displayed little differences, indicating that the choice of ALK method is not crucial for cod.

The primary purpose of the Delta-GAM model is to derive survey indices by age free of nuisance factors caused by changes in experimental conditions. The indices are obtained by summing filtered model predictions over a spatial grid. The Delta-GAM model is able to account for changes in experimental conditions such as different gears, ship/country effects, day/night effects, and change in spatial coverage. Such effects may be balanced out by the relatively stable survey design in the later years;

however, several changes in the gear used, proportion of night hauls, haul duration, etc. have occurred for most surveys during the entire time-series.

Each age group and quarter is modelled independently. The most complex equation considered for the expected numbers-at-age in the *i*th haul (or probability of non-zero catch for the presence-absence part), μ_i , is as follows:

$$g(\mu_i) = Year(i) + Gear(i) + U(i)_{ship} + f_1(Year_i, lon_i, lat_i) + f_2(depth_i) + f_3(time_i) + \log(HaulDur_i)$$

where the two first terms are categorical effects for year and gear type, U is a random vessel effect, f_1 is a 3-dimensional tensor product spline (a 2D thin-plate spline basis for space and a 1D cubic spline for time), f_2 is a 1-dimensional thin plate spline for the effect of bottom depth, and f_3 is a cyclic cubic regression spline on the time of day (i.e. with same start and endpoint). The function g is the link function, which is taken to be the logit function for the binomial model. The strictly positive observations can be modelled using either a Gamma or a log-normal distribution, and a Gamma distribution was found to provide the best fit. The Gamma part of the delta-Gamma model is fitted with a log link. The nuisance parts of the model (here gear, ship, time of day, and haul-duration) are held constant when the filtered predictions on the grid are calculated so as to remove their effect on the index.

Ten possible models of varying complexity were considered during the 2015 WKNSEA benchmark (ICES, WKNSEA 2015). An important choice was whether a 3D space–time smoother f_1 (Year, lon, lat) was necessary, or whether the spatial distribution could be considered stationary over the whole time-series f_1(lon, lat). The best model (in AIC terms) for the Q1 data included the space–time interaction f_1(Year, lon, lat), whereas for Q3, the stationary model using f_1(lon, lat) (and including ship effects) seemed most appropriate.

A comparison of the effects of all ten models on the resultant indices indicated that the Q1 index was reasonably robust to model choice, but that the Q3 index showed greater sensitivity, particularly for the latest years (2011+) where the Q3 index showed bigger increases than Q1 for several ages, the timing of which coincided with the replacement of the Swedish "ARG" vessel with "DANS", and the simultaneous introduction of a more randomised set of haul positions for Q3 (but not Q1) for "DANS". These changes also coincided with an increase in the IBTS Q3 index in the Skagerrak over this period, and because the Swedish survey is the only one covering the Skagerrak, a confounding effect arises where it is difficult to separate out the effects of changing both the vessel and sampling positions in Q3 from a simultaneous potential increase in abundance. This confounding was noted, because when the stationary model was used for Q3, the large catches observed by "DANS" in the Skagerrak compared to "ARG" were explained by the ship effect, whereas they were attributed to space–time effect in the non-stationary model.

Given all these factors and the fact that the stationary model including ship effects was best for Q3, WKNSEA decided to adopt the stationary model using f_1(lon, lat) and including a ship effect for Q3, and since the stationary model was also second best for Q1 with only a slightly higher AIC compared to the non-stationary model, it was decided, for the sake of consistency, to adopt the same model for Q1. Consideration of the effect of model choice on assessment residuals also played a role in model choice (ICES, WKNSEA 2015), with the final choice exhibiting improved residual patterns for Q3 compared to those seen in the past (ICES, WKCOD 2011). All Delta-GAM models except the very simple year effect only model had better consistencies than the standard stratified mean approach, which is similar to the currently used index produced by DATRAS.

In summary the final Delta-GAM models selected for NS-IBTS Q1 and Q3 comprised a stationary model using f_1(lon, lat), and included ship, year, depth, time-of-day and haul-duration effects. In addition, the Q3 model also included a gear effect (Q1 only has a single gear, GOV, so this effect is not an issue).

Data exploration

Data exploration for survey data for North Sea cod currently involves:

a) expressing the survey abundance indices (IBTSQ1 and IBTSQ3) in log-mean standardised form, both by year and cohort, to investigate whether there are any year effects, and the extent to which the surveys are able to track cohort signals;

b) performing log-catch-curve analyses on the abundance indices to examine data consistency and mortality trends over time; the negative slope of a regression fitted to ages down a cohort (e.g. ages 2–4) can be used as a proxy for total mortality;

c) performing within-survey consistency plots (correlation plots of a cohort at a given age against the same cohort one or more years later) to investigate self-consistency of a survey;

d) performing between-survey consistency plots (correlation plots of a given age for IBTSQ1 against the same age for IBTSQ3) to investigate the consistency between surveys;

e) applying a SURBA analysis to the survey data for comparison with models that include fishery-dependent data.

B.4. Commercial cpue

Reliable, individual, disaggregated trip data were not available for the analysis of cpue. Since the mid-to-late 1990s, changes to the method of recording data means that individual trip data are now more accessible than before; however, the recording of fishing effort as hours fished has become less reliable because it is not a mandatory field in the logbook data. Consequently, the effort data, as hours fished, are not considered to be representative of the fishing effort actually deployed.

The WG has previously argued that, although they are in general agreement with the survey information, commercial cpue tuning series should not be used for the calibration of assessment models due to potential problems with effort recording and hyperstability (ICES, WGNSSK 2001), and also changes in gear design and usage, as discussed by ICES, WGFTFB (2006; 2007). Therefore, although the commercial fleet series are available, only survey and commercial landings and discard information are analysed within the assessment presented.

B.5. Other relevant data

The annual North Sea Fishers' Survey presents fishers' perceptions of the state of several species including cod; the survey has been carried out annual since 2003, following a pilot in 2002 (Napier, 2014). In addition, a number of collaborative research projects (Fisheries-Science partnerships) have in the past been reported to the WGNSSK. These studies have provided time-series of quantitative information have been relatively local, whereas those with wider coverage have been qualitative. The studies have therefore been used to corroborate assessment results and highlight differences in perception, and have proven useful in examining the dynamics of sub-stocks within the North Sea, for instance local recruitment, and thereby in the provision of advice to managers. However, there are no currently active Fisheries-Science partnerships for North Sea cod.

C. Historical stock development

Model used as a basis for advice

The state–space model SAM (Nielsen and Berg, 2014) offers a flexible way of describing the entire system, with relative few model parameters. It allows for objective estimation of important variance parameters, leaving out the need for subjective *ad hoc* adjustment numbers, which is desirable when managing natural resources.

For North Sea Cod two survey indices (IBTS Q1 and Q3) are used, along with the total catch-at-age data. No commercial fleets with effort information are used. A recruitment random walk process is used to model recruitment (in log scale), but there is no visual difference in the results if a Ricker or Beverton–Holt curve is used in its place. Fishing mortality random walks are allowed to be correlated among the ages.

For North Sea Cod the model is extended to allow estimation of possible bias (positive or negative) in the reported total catches from 1993 to 2005. The model assumes that reported catches should simply be scaled by a year and possibly age-specific factor $S_{a,y}$. This leads to the following updated catch equation for the total catches.

$$\log C_{a,y}^{(\circ)} = -\log S_{a,y} + \log\left(\frac{F_{a,y}}{Z_{a,y}} (1 - e^{-Z_{a,y}}) N_{a,y} \right) + \varepsilon_{a,y}^{(\circ)}$$

In the main scenario considered the multiplier $S_{a,y}$ is set according to:

$$S_{a,y} = \begin{cases} 1, & y < 1993 \text{ or } y > 2005 \\ \tau_y, & 1993 \le y \le 2005 \end{cases}$$

It is assumed that the fishing mortalities corresponding to total catches are identical for the two oldest age groups $F_{a=6,y} = F_{a=7+,y}$ in order to make the model identifiable.

The total vector of model parameters for this model is:

$$\vartheta = (Q_{s=1,a=1,2,3,4,5}, Q_{s=2,a=1,2,3,4}, \sigma_R^2, \sigma_S^2, \sigma_{F,a=1,2+}^2, \sigma_{0,a=1,2,3+}^2, \sigma_{s=1,a=1,2+}^2, \sigma_{s=2,a=1,2+}^2, \tau_{1993}, \tau_{1994}, \ldots, \tau_{2005}, \rho)$$

The Q parameters are catchabilities corresponding to the survey fleets (these parameters are survey- and age-specific, covering ages 1–5 for IBTS Q1 and ages 1–4 for IBTS Q3). The variance parameters σ_R^2, σ_S^2, and $\sigma_{F,a=1,2+}^2$ are process variances for recruitment, survival, and development in fishing mortality respectively (the latter separately for ages 1 and 2+). The remaining σ^2 parameters are describing the variance of different observations divided into fleet and age classes. Finally the τ parameters are the scaling factors for the total catches, and ρ is the correlation parameter (among the ages) for the random walks on the fishing mortalities.

The WKNSEA benchmark introduced an extension to allow for varying correlation between different ages by setting the correlation of the log F annual increments to be a simple function of the age difference (AR(1) process over the ages). By doing this, individual log F processes will develop correlated in time, but in such a way that neighbouring age classes have more similar fishing mortalities than more distant ones. This correlation structure does not introduce additional parameters to the model, and is referred to below as an AR correlation structure (see Nielsen and Berg, 2014 for more details).

Model used: SAM (with correlated fishing mortality-at-age based on an AR correlation structure)

Software used: Source code and all scripts are freely available at http://www.stockassessment.org [Username: guest; Password: guest]

Model Options chosen:

A configuration file is used to set up the model run once the data files, in the usual Lowestoft format, have been prepared. The file has the following form:

```
# Min Age (should not be modified unless data is modified accordingly)
 1
 # Max Age (should not be modified unless data is modified accordingly)
 7
 # Max Age considered a plus group (0=No, 1=Yes)
 1
 # The following matrix describes the coupling of fishing mortality
 # Rows represent fleets.
 # Columns represent ages.
 1      2       3       4       5       6       6
 0      0       0       0       0       0       0
 0      0       0       0       0       0       0
# Use correlated random walks for the fishing mortalities
# (0 = independent, 1 = compound symmetry correlation over ages for time incre-
ments,
#  2 = AR(1) correlation over ages for time increments)
2
 # Coupling of catchability PARAMETERS
 0      0       0       0       0       0       0
 1      2       3       4       5       0       0
 6      7       8       9       0       0       0
 # Coupling of power law model EXPONENTS (if used)
 0      0       0       0       0       0       0
 0      0       0       0       0       0       0
 0      0       0       0       0       0       0
 # Coupling of fishing mortality RW VARIANCES
 1      2       2       2       2       2       2
 0      0       0       0       0       0       0
 0      0       0       0       0       0       0
 # Coupling of log N RW VARIANCES
 1      2       2       2       2       2       2
```

```
# Coupling of OBSERVATION VARIANCES
1      2       3       3       3       3       3
4      5       5       5       5       0       0
6      7       7       7       0       0       0
# Stock-recruitment model code (0=RW, 1=Ricker, 2=BH, ... more in time)
0
# Years in which catch data are to be scaled by an estimated parameter
# first the number of years
13
# Then the actual years
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005
# Then the model config lines years cols ages
 1    1    1    1    1    1    1
 2    2    2    2    2    2    2
 3    3    3    3    3    3    3
 4    4    4    4    4    4    4
 5    5    5    5    5    5    5
 6    6    6    6    6    6    6
 7    7    7    7    7    7    7
 8    8    8    8    8    8    8
 9    9    9    9    9    9    9
10   10   10   10   10   10   10
11   11   11   11   11   11   11
12   12   12   12   12   12   12
13   13   13   13   13   13   13
# Define Fbar range
2      4
```

Input data types and characteristics:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1963–present	-	Y
Canum	Catch-at-age in numbers	1963–present	1–7+	Y
Weca	Weight-at-age in the commercial catch	1963–present	1–7+	Y
West	Weight-at-age of the spawning stock at spawning time.	Weca used for West	Weca used for West	Weca used for West
Mprop	Proportion of natural mortality before spawning	1963–present	1–7+	N
Fprop	Proportion of fishing mortality before spawning	1963–present	1–7+-	N
Matprop	Proportion mature at-age	1963–present	1–7+	Y
Natmor	Natural mortality	1963–present*	1–7+	Y

***Updated values for natural mortality will only be provided every three years.**

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1	IBTS-Q1, stationary delta-GAM with ship effect	1983–final year of catch data + 1	1–5
Tuning fleet 2	IBTS-Q3, stationary delta-GAM with ship effect	1992–final year of catch data*	1–4

***When performing autumn short-term forecast, this becomes 1992–final year of catch data + 1.**

Recruitment estimation

Estimation of recruitment is an integrated part of the model. Recruitment parameters are estimated within the assessment model. Currently the assumed parametric structure is a random walk model.

D. Short-term projection

Due to the uncertainty in the final year estimates of fishing mortality, the WG agrees that a standard (deterministic) short-term forecast is not appropriate for this stock. Therefore, stochastic projections are performed, from which short-term projections are extracted.

Forecasting takes the form of short-term stochastic projections. These projections have in the past been carried out by starting at the final year's estimates, and the covariance matrix of those estimates. However, estimates of survivors are also available, and now form the starting point for the projections. A total of 1000 samples are generated from the estimated distribution of these estimates, with recruitment being sampled with replacement from the year 1998 to the final year of catch data (a period during which recruitment has been low). These replicates are then simulated forward according to model and forecast assumptions (Table B.1.6), using the usual exponential decay equations, but also incorporating the stochastic survival process (using the estimated survival standard deviation) and subject to different catch options scenarios.

Table B.1.6. Forecast assumptions. [Note that the values that appear in the catch options table of the advice sheet are medians from the distributions that result from the stochastic forecast.]

Initial stock size	Starting populations are simulated from the estimated distribution at the start of the intermediate year (including co-variances).
Maturity	Average of final three years of assessment data.
Natural mortality	Average of final three years of assessment data.
F and M before spawning	Both taken as zero.
Weight-at-age in the catch	Average of final three years of assessment data.
Weight-at-age in the stock	Assumed to be the same as weight-at-age in the catch.
Exploitation pattern	Fishing mortalities taken as a three year average scaled to the final year.
Intermediate year assumptions	Multiplier reflecting intended changes in effort (and therefore F) relative to the final year of the assessment.
Stock–recruitment model used	Recruitment for the intermediate year onwards (the year the WG meets) is sampled, with replacement, from 1998 to the final year of catch data.
Procedures used for splitting projected catches	The final year landing fractions-at-age are used in the forecast period.

E. Medium-term projections

Medium-term projections are not carried out for this stock.

F. Long-term projections

Long-term projections are not carried out for this stock.

G. Biological reference points

The reference points for cod in IV, IIIaN (Skagerrak) and VIId were reviewed at WKNSEA 2015. B_{lim}, B_{PA}, F_{MSY} and MSY $B_{trigger}$ were revised as follows (note that F_{lim} and F_{PA} were not reviewed at WKNSEA 2015):

	Type	Value	Technical basis
Precautionary approach	B_{lim}	103 000 t	SSB in 1996 that led to the last substantial year class
	B_{PA}	144 000 t	B_{lim} *1.4
	F_{lim}	0.86	F_{lim} = F_{loss} (from the 1998 assessment)
	F_{PA}	0.65	F_{PA} = Approximately 5th percentile of F_{loss} (from the 1998 assessment)
Targets	F_y	0.4	EU/Norway agreement December 2009
MSY approach	F_{MSY}	0.22 with range 0.14–0.34	EQSIM estimates based on WKNSEA 2015 assessment using the full recruitment time-series and assuming the optimised yield comprises landings for ages 1 and 2, and catches for ages 3+.
	MSY $B_{trigger}$	144 000t	B_{PA}

F_{lim} and F_{PA} unchanged since 1998.

H. Other issues

No other issues.

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Stock Annex for North Sea sole

Stock	North Sea sole
Working Group	WGNSSK
Date	16 February 2015
By	Jan-Jaap Poos and Ruben Verkempynck

A General

A.1 Stock definition

The North Sea sole is defined to be a single stock in ICES Subarea IV. The stock assessment is done accordingly, assuming sole in the North Sea is a closed stock between regions of Subarea IV(a,b,c). This approach was supported by a thorough population genetic analysis using neutral microsatellite markers and a mitochondrial marker by Cuveliers *et al*. (2012). This study showed genetic differences at a large scale, along a latitudinal gradient from the Skagerrak/Kattegat to the Bay of Biscay. At a smaller spatial scale within the North Sea however, the subpopulations seemed genetically homogeneous, probably due to a high level of gene flow and/or the high effective population size preventing strong effects of genetic drift. With respect to the temporal aspect, a remarkable high genetic stability was found from the 1950s up to present (Cuveliers *et al*., 2011).

A.2 Fishery

North Sea sole is taken mainly in a mixed flatfish fishery by beam trawlers in the southern and southeastern North Sea (see Figure 1). Directed fisheries are also carried out with seines, gillnets, and twin trawls, and by beam trawlers in the central North Sea. The minimum mesh sizes enforced in these fisheries (80 mm in the mixed beam-trawl fishery) are chosen such that they correspond to the Minimum Landing Size for sole. Due to the minimum mesh size, large numbers of (undersized) plaice are discarded. Fleets exploiting North Sea sole have generally decreased in number of vessels in the last ten years. However, in some instances, reflagging vessels to other countries has partly compensated these reductions. Besides having reduced in number of vessels, the fleets have also shifted towards two categories of vessels: 2000 HP (the maximum engine power allowed) and 300 HP (the maximum engine power for vessels that are allowed to fish within the 12 mile coastal zone and the plaice box).

The first ten years of the millennium the days at sea regulations, high oil prices, and different patterns in the history of changes in the TACs of plaice and sole have led to a transfer of effort from the northern to the southern North Sea. Here, sole and juvenile plaice tend to be more abundant leading to an increase in discarding of small plaice. A change in efficiency of the commercial Dutch beam trawl fleet has been described by Rijnsdorp *et al.* (2006). This change in efficiency is related to changes in targeting and the change in spatial distribution (Quirijns *et al.*, 2008; Poos *et al.*, 2010).

In more recent years the Dutch beam-trawl fleet has changed considerably. New gears were adopted, such as the sumwing, and the pulse trawl. These new gears probably have different gear selectivity (van Marlen *et al.*, 2014) compared to the traditional beam-trawl gears.

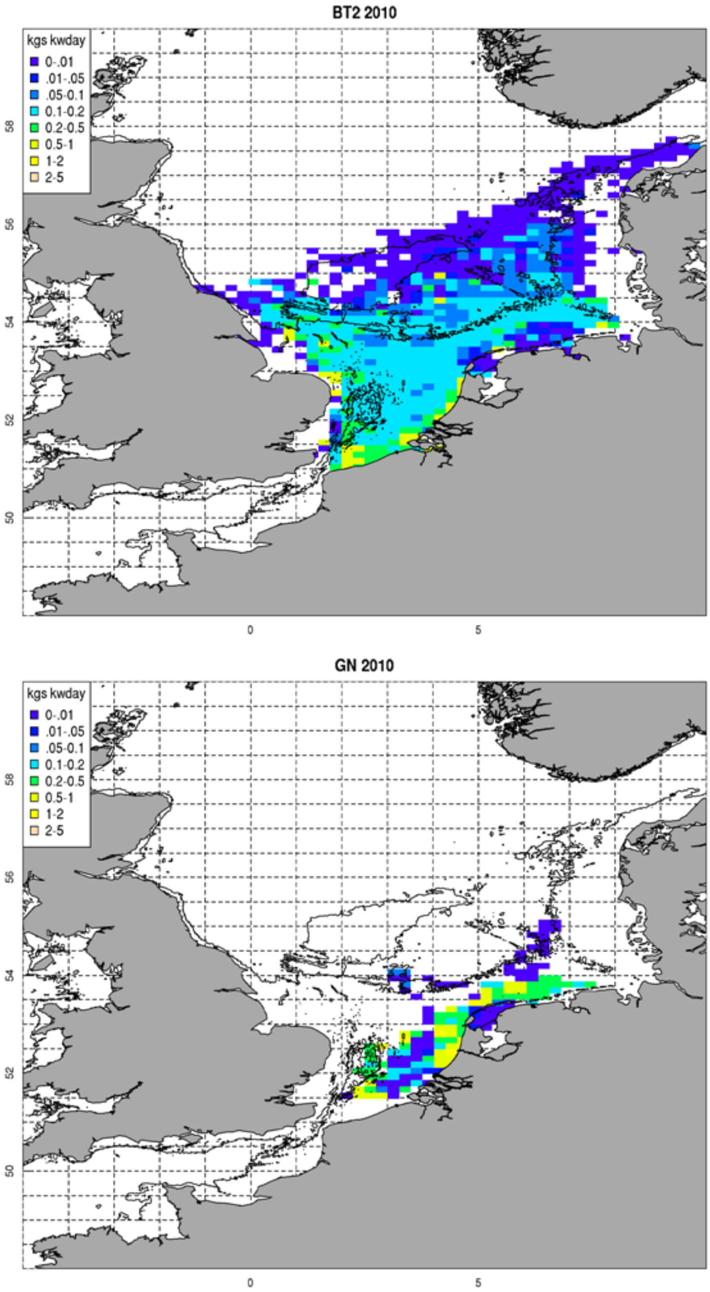

Figure 1. Landing rates (kgs kwday-1) in 2010 by Dutch flagged BT2 (beam trawlers working 80–89 mm mesh, top) and GN (gillnetters, bottom). Data are based on combining VMS and logbook data. 40 m depth contour also added.

Conservation schemes and technical conservation measures

Fishing effort has been restricted for demersal fleets in a number of EC regulations (EC Council Regulation No. 2056/2001, No. 51/2006, No. 41/2007 and No. 40/2008, annex IIa). For example, for 2007, Council Regulation (EC) No 41/2007 allocated different days at sea depending on gear, mesh size, and catch composition: Beam Trawls could fish between 123 and 143 days per year. Trawls or Danish seines could fish between 103 and 280 days per year. Gillnets could allowed to fish between 140 and 162 days per year. Trammel nets could fish between 140 and 205 days per year.

Several technical measures are applicable to the mixed fishery for flatfish species in the North Sea: mesh size regulations, minimum landing size, gear restrictions and a closed area (the plaice box).

Mesh size regulations for towed trawl gears require that vessels fishing North of 55°N (or 56°N east of 5°E, since January 2000) should have a minimum mesh size of 100 mm, while to the south of this limit, where the majority of the sole fishery takes place, an 80 mm mesh is allowed. In the fishery with fixed gears a minimum mesh size of 100 mm is required.

The minimum landing size of North Sea sole is 24 cm. The maximum aggregated beam length of beam trawlers is 24 m. In the 12 nautical mile zone and in the plaice box the maximum aggregated beam length is 9 m. A closed area has been in operation since 1989 (the plaice box). Since 1995 this area was closed in all quarters. The closed area applies to vessels using towed gears, but vessels smaller than 300 HP are exempted from the regulation.

A.3 Ecosystem aspects

Sole growth rates in relation to changes in environmental factors were analysed by Rijnsdorp *et al.* (2004). Based on market sampling data it was concluded that both length-at-age and condition factors of sole increased since the mid-1960s to a high point in the mid-1970s. Since the mid-1980s, length-at-age and conditions have been intermediate between the troughs (1960) and peaks (mid-1970s). Growth rates of the juvenile age groups were negatively affected by intra-specific competition. Length of 0-group fish in autumn showed a positive relationship with sea temperature in the 2nd and 3rd quarters, but for the older fish no temperature effect was detected. The overall pattern of the increase in growth and the later decline correlated with temporal patterns in eutrophication; in particular the discharge of dissolved phosphates from the Rhine. Trends in the stock indicators e.g. SSB and recruitment, did not coincide, however, with observed patterns in eutrophication.

In recent years no changes in the spatial distribution of juvenile and adult soles have been observed (Grift *et al.*, 2004). The proportion of undersized sole (<24 cm) inside the Plaice Box did not change after its closure to large beamers and remained stable at a level of 60–70% (Grift *et al.*, 2004). The different length groups of sole showed different patterns in abundance. Sole of around 5 cm showed a decrease in abundance from 2000 onwards, while groups of 10 and 15 cm were stable. The largest groups of sole showed a declining trend in abundance, which had already set in years before the closure.

Mollet *et al.* (2007) used the reaction norm approach to investigate the change in maturation in North Sea sole and showed that age and size at first maturity significantly shifted to younger ages and smaller sizes. These changes occurred from 1980 onwards. Size at 50% probability of maturation at-age 3 decreased from 29 to 25 cm.

B Data

B.1 Commercial catch

Landings data by country and TACs are available since 1957. The Netherlands has the largest proportion of the landings, followed by Belgium. Discards data are only available since 2002, with the Netherlands, Belgium, Germany, and Denmark each starting their observation programs in a different year. The discards percentages observed in the Dutch discard sampling programme were much lower for sole (for

2002–2008, between 10–17% by weight) than for plaice. No significant trends in discard percentages have been observed since the start of the programme.

Age and sex compositions and mean weight at age in the landings have been available for different countries for different years. In the more recent years, age compositions and mean weight-at-age in the landings have been available on a quarterly basis from Denmark, France, Germany (sexes combined) and The Netherlands (by sex). Age compositions on an annual basis were available from Belgium (by sex). Overall, the samples are representative of around 85% of the total landings. For the final assessment, the age compositions are combined separately by sex on a quarterly basis and then raised to the annual international total. Alternatively, sex separated landings-at-age and weights-at age can be calculated from the data. Since the mid-1990s, annual sole catches have been dominated by single strong year classes (e.g. the 2005 year class).

B.2 Biological

Weight-at-age

Weights-at-age in the landings are measured weights from the various national market sampling programs. Weights-at-age in the stock are the 2nd quarter landings weights, as estimated by the Fishbase database computer program used for raising North Sea sole data. Over the entire time-series, weights were higher during the 1970s and 1980s compared to time periods before and after. Estimates of weights for older ages fluctuate more because of smaller samples sizes due to decreasing numbers of older fish in the stock and landings.

Natural mortality

Natural mortality has been assumed constant over all ages at 0.1 since the start of the assessment period (1957), except for 1963 where a value of 0.9 was used to take into account the effect of the severe winter (1962–1963; ICES, FWG 1979).

Maturity

The maturity ogive is based on market samples of females from observations in the sixties and seventies. Mollet *et al*. (2007) described the shift of the age at maturity towards younger ages. A knife-edged maturity-ogive is used, assuming no maturation at ages 1 and 2, and full maturation at age 3.

Surveys

There are five trawl surveys that could potentially be used as tuning indices for the assessment of North Sea sole.

- The BTS-ISIS (Beam Trawl Survey)
- The SNS (Sole Net Survey)
- The UK Corystes survey
- Belgium BTS survey
- German BTS survey

The BTS-ISIS (Beam Trawl Survey) is carried out in the southern and southeastern North Sea in August and September using an 8 m beam trawl. The SNS (Sole Net Survey) is a coastal survey with a 6 m beam trawl carried out in the 3rd quarter. Data from 2003 and 2012 were omitted from the assessment because of changes in the survey in that year, or because not enough stations were sampled. 2003 the SNS survey was carried out during the 2nd quarter and data from this year were omitted from the assessment. The research vessel survey time-series have been revised by WGBEAM (ICES, WGBEAM, 2009). WKFLAT 2010 decided to not use the UK Corystes survey because of lack of information on the raising procedure and spatial coverage of the UK Corystes series. WKNSEA 2015 decided not to use the German and Belgium BTS surveys. The German BTS survey was not used because it failed to detect cohort signals since 2010 and because the index was unavailable since 2012. The Belgian BTS survey was not included because it was only available since 2007 and because including it was found to increase the retrospective pattern in the assessment; however, WKNSEA 2015 recommended attempting its incorporation again in the future. In the assessment, the BTS-ISIS and SNS indices, calculated by WGBEAM, are used for tuning the stock assessment.

B.3 Commercial lpue

There is one commercial fleet available that can be used as a tuning series for the stock assessment, being the Dutch beam-trawl fleet. This fleet takes more than 70% of the landings, and is relatively homogeneous in terms of size and engine power. The data from this commercial fleet can be estimated using two different methods. The first method uses the total landings, and creates the age distribution for these landings by segregating the total landings into market categories, with age distributions being known within market categories through market sampling. Effort for the Dutch commercial beam-trawl fleet is expressed as total HP effort days. Effort nearly doubled between 1978 and 1994 and has declined since 1996. Effort during 2008 was <40% of the maximum (1994) in the series. A decline of circa 25% was recorded in 2008 following the decommissioning that took place during 2008.

Alternatively, the data for the Dutch beam trawl fleet can be raised as described by (WGNSSK 2008, WD1). This allows reviewing the lpue trends in different areas of the North Sea. The data are based on various sources (WGNSSK 2008, WD1). There is a clear separation in lpue between areas, with the southern area producing a substantially higher lpue than the northern area. Average lpue of a standardized NL beam trawler (1471 kW) over the period 1999 to 2007 was 266 kg day-1, and the data have a significant (P<0.01) temporal trend of -6.1 kg day-1 year-1.

The beam-trawl fleet has changed gear use over the last ten years, switching from the traditional beam-trawl gear to wing-shaped gear and subsequently also to puls fishing. In 2014, there was only very limited effort left with the traditional gear. As a result of the changes in the gear, the catchability has likely changed. Hence, WKNSEA 2015 decided not to use the lpue series in the assessment. However, WKNSEA 2015 recommended investigating the possible incorporation of the Dutch commercial pulse cpue data when a longer time-series becomes available.

C Historical stock development

WKNSEA 2015 decided that an AAP (Aarts and Poos, 2009) model was appropriate for the assessment of this stock. The previously used XSA assumes the catch-at-age matrix is complete and without error. The AAP method is a variety of statistical catch-at-age model that uses splines to estimate the selectivity patterns in the surveys and for the catch-at-age matrix. Spline smoothers are used to describe the F-at-age matrix, the catchabilities at-age of the tuning indices, and the discards fraction-at-age. The main reason for changing from XSA to AAP was to be able to incorporate the incomplete time-series of discards consistently into the assessment.

There are three differences compared to the model by Aarts and Poos. 1) modelling of the F-at-age matrix by means of a tensor spline rather than using a full separability assumption. In the AAP model, the F-at-age matrix describing the F estimates for each year and age is built using a selectivity pattern over the ages (ranging between 0 and 1), an annually varying product of catchability and effort. Here, we describe the F-at-age matrix by using a design matrix for a tensor product smoother taken from the GAM function in R (Wood, 2006). The degree of smoothness depends on the dimensions of the bases for age and year. The design matrix is multiplied by the total number of parameters required to describe the tensor product smoother, being equal to the product of the bases for age and year. To ensure that the F-at-age matrix remains positive throughout the optimization, the tensor product smoother is exponentiated. 2) The proportion discarded at-age is described by a simple logistic function. 3) implementation of the maximum likelihood search in ADMB (Fournier *et al.*, 2012) rather than in R.

The AAP model 1) is compatible with FLR, 2) allows adding any number of tuning indices, 3) deals with missing values in any of the data sources, and 4) takes a control object with the structural model assumptions. These include: 1) The number of parameters used for the tensor spline (for ages and years separately), the age at which the “q-plateau”starts for the tuning indices, and the number of parameters used for description of the selectivity-at-age of the tuning indices.

The SAM model is a state–space assessment model. An advantage of using AAP and SAM over XSA would be that they take into account (and show) the uncertainty of the assessment inputs and outputs. The SAM model has been run in some years in parallel to the main assessment model for the sole stock, but it was not presented or discussed at WKNSEA 2015.

Model used as a basis for advice

The North Sea sole advice is based on the AAP stock assessment. Settings for the final assessment are given below:

Setting/Data	Values/source
Catch-at-age	Landings (since 1957, ages 1–10) Discards (since 2002, ages 1–10)
Tuning indices	BTS-Isis 1985-assessment year, ages 1–9 SNS 1970-assessment year, ages 1–6
Plus group	10
First tuning year	1970
Time-series weights	No taper
Catchability catches independent of ages stock size for age >=	8
Catchability surveys independent of ages for ages >=	8
Tensor spline for catchability-at-age both indices k value ages	6
Tensor spline for F-at-age: k value ages	6
Tensor spline for F-at-age: k value years	22

The SAM model

The SAM model (settings in this table are as used when running the SAM model in previous years; it was not presented or discussed at WKNSEA 2015).

Setting/Data	Values/source
Catch-at-age	Landings (since 1957, ages 1:10)
Tuning indices	BTS-Isis 1985–assessment year 1–9 SNS 1982–assessment year 1–4 NL-beam trawl index 1997–assessment year 2–9
Plus group	10
First tuning survey year	1982
Catchability independent of ages for ages >=	7
Prior weighting	Not applied

D Short-term projection

The short-term projection can be done in FLR using FLSTF. Weight-at-age in the stock and weight-at-age in the catch are taken to be the mean of the last three years. The exploitation pattern is taken to be the mean value of the last three years, scaled to the last years F. Population numbers-at-ages 2 and older are survivor estimates from the assessment model, unless there is consistent indication from the most recent recruitment surveys of a stronger or weaker year class. These indications should come from RCT3 analyses. Numbers at age 1 are either obtained from RCT3 (usually for age-1 abundance in the “intermediate” year) or are taken from the long-term geometric mean (usually for age-1 abundance in years after the “intermediate” year).

In the last few years, management options have been given for the assumption that F in the “intermediate” year is equal to the average estimate for F of the last three assessment years scaled to the last year’s F. While this is considered to be the default procedure for this stock, other options may also be considered if deemed more realistic by the assessment WG or ACOM.

E Medium-term projections

Generally, no medium-term projections are done for this stock.

F Long-term projections

Generally, no long-term projections are done for this stock.

G Biological reference points

Reference points were revised at WKNSEA 2015. B_{lim} was defined by the breakpoint in a segmented regression of the stock–recruitment relationship, resulting in 26 300 t, and B_{PA} was set at 37 000 t using the default multiplier of 1.4. F_{MSY} ranges can be determined with EqSim, where the upper boundary is never allowed to exceed the value of F that corresponds to 5% long-term probability of SSB<B_{lim}. Using a combination of Ricker and Segmented Regression stock–recruitment relationships, this results in the range 0.26–0.39 (if no $B_{trigger}$ is used in the calculation of the upper boundary) or 0.26–0.44 (if $B_{trigger}$ is used in the calculation of the upper boundary). A process to make final proposals for F_{MSY} ranges is ongoing in ICES.

	Type	Value	Technical basis
Precautionary approach	B_{lim}	26 300 t	Breakpoint in segmented regression stock–recruitment relationship
	B_{PA}	37 000 t	1.4 *B_{lim}
F_{MSY}	F_{MSY}	0.39	EQsim estimate without using $B_{trigger}$, using a combination of Ricker and Segmented Regression stock–recruitment relationships.
Targets	F_{mgt}	0.2	EU management plan

(unchanged since 2015).

H Other issues

None identified.

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Stock Annex for Striped Red Mullet in Divisions IIIa, VIId and Subarea IV

Stock	Red Mullet in Division IIIa, VIId and Subarea IV
Working Group	WGNSSK
Date	February 2015
By	Youen Vermard

A General biology

The striped red mullet (*Mullus surmuletus*) is a benthic fish, which is found along the European coasts from the South of Norway and North of Scotland including the Faroe Islands in the North, to the Strait of Gibraltar in the South. This species is also found in the northern part of western Africa and in the Mediterranean and Black Seas (Quéro and Vayne, 1997). Striped red mullet is considered occasional off Norway, around Ireland, at the north coasts of England and in the West of Scotland (Davis and Edward, 1988; Gibson and Robb, 1997).

Analysis of British commercial landings revealed a strong concentration of this species in the central pit of the western Channel during winter (Dunn, 1999). The scientific survey CGFS (Channel Ground Fish Survey), carried out every year by Ifremer in the eastern Channel since 1988, showed that young individuals are distributed in coastal areas, while adults exhibit preferentially an offshore distribution in the eastern part (Carpentier *et al*., 2009). Striped red mullet is accommodated to deep water and elevated temperatures (ICES, 2007b), and tolerates weak and high salinity (corresponding respectively to juvenile and adult habitats) and is rarely found in the transitions zones of intermediate salinity. This species is found mostly on sandy substratum (Carpentier *et al*., 2009). Food of striped red mullet is primarily composed of crustaceans and molluscs.

In the English Channel, the first sexual maturity was identified on fish of 16.2 cm for the male and 16.7 cm for the female (Mahé *et al*., 2005).

B Management regulations

Before 2002, a minimum landing size was set at 16 cm in France. This minimal size requirement has been afterwards removed and it resulted on catch of immature individuals (<14 cm), which have recently been targeted and landed.

C Stock ID and possible management areas

Due to the presence of the striped red mullet in catches all year round, Dunn (1999) suggested that a single stock should exist within the English Channel, although he could not determine whether this stock was distinct from other western stocks. He also suggested that it might be a newly established stock in the North Sea.

In 2004 and 2005, a study using fish geometrical morphometry was carried out in the Eastern English Channel and the Bay of Biscay. It pointed out a morphological difference on striped red mullets between those from the Eastern English Channel and those from the Bay of Biscay.

In 2010, within the Nespman project, a study based on the shape of the otoliths was conducted to differentiate stocks. The study area was divided into six geographic sectors: the NS (North Sea; ICES Division IVabc), the EEC (Eastern English Channel; ICES Division VIId), the WEC (Western English Channel; ICES Division VIIe), the CS (Celtic Sea; ICES Division VIIf,g,h,j), the NBB (North Bay of Biscay; ICES Division VIIIa) and the SBB (South Bay of Biscay; ICES Division VIIIb) (Figure 1).

In this work, three techniques have been applied: a Fourier, a PCA and a Geodesic approach (Benzinou *et al*., 2013). Among these three, Geodesic approach reached the highest mean correct classification rate (30%). The confusion matrix of Geodesic approach on the dataset with six geographic sectors, achieved by K-Nearest Neighbours classifier (Benzinou *et al*., 2013) showed that populations of striped red mullet of Western English Channel and Eastern English Channel could be separated (Table 2).

In the north, the striped red mullet population appears to be a continuum between the North Sea and the Eastern English Channel. In the same way, a continuum has been identified between the north and the south of the Bay of Biscay. Currently, we do not have enough data to separate the Bay of Biscay from the Celtic sea or the Western English Channel.

Therefore, for management purposes, two areas could be considered for this species:

- the north area (III, IV & VIId)
- the south area (VI, VIIa,e,g,h,j-VIIIa,b & IXa)

These areas are the management areas currently used by ICES.

As stated by Mahé *et al*. (2005), there seems to be migration happening through the year from the eastern Channel to the North Sea. The average Catch per Unit of effort drawn from survey data (IBTS Quarter 1, IBTS Quarter 3 and CGFS quarter 4) (Figure 2) show a distribution pattern observed every year (figures for individual years not presented in this report), with a spatial distribution of this species in the western part of the North Sea during the first quarter and in the southern part of the North Sea and the Eastern Channel during the third quarter and fourth quarter. These migrations were interpreted by Mahé *et al*. (2005) as spawning migration in the second quarter in the spawning areas located in the southern part of the North Sea and the Eastern Channel.

This spatial distribution of Red mullet in time and space seems coherent with spatial distribution of the landings as seen from InterCatch (Figure 3), where most of the landings in the North Sea are made in quarters 2 and 3 (mostly in the southern North Sea but the spatial distribution at a finer scale than Subarea IV was not available) and the main fishing season in the Eastern Channel is during the third and fourth quarter with some years where the first quarter is also of importance (2005 and 2008 for example).

D Fisheries data

According to ICES statistics, in the Atlantic Ocean, the fishery of this species was only conducted by Spain and Portugal from 1950 to 1975; then France also started to take part in the fisheries. From 1950 to 1975, fishing of striped red mullet was carried out nearby the Spanish coasts and in the Bay of Biscay. From 1990, catches strongly increased, essentially due to France, but also to England and Netherlands fisheries. It could be explained by the beginning of exploitation of the striped red mullet in the English Channel and in the North Sea (Figure 4 and 5).

In the Eastern Channel and Southern North Sea, the main country fishing on striped red mullet was historically France; from 2000, catches are shared by French, Dutch and English fisheries (Figure 6). French fisheries target striped red mullet in spring and autumn, depending on the abundance using bottom trawlers with a mesh size of 70–99 mm in the Eastern Channel and south of the North Sea (Figure 7).

Dutch fisheries are targeting striped red mullet using Scottish seines (Figure 8). This fishery consists of boats between 24–40 meters (most of them being old beam trawlers) fishing most of the time in the North Sea and in the Channel in the winter.

The last country contributing to the landings (UK) also realizes most of its landings in the Eastern Channel. Most of them were realized using a Scottish seine with mesh size >120 mm (Figure 9).

Due to both the absence of minimum landing size and TAC, and its high commercial value, discard are assumed negligible and catches assumed equal to landings.

France provides age structure for the main fleet targeting Red Mullet since 2004. However the sampling only came from the Eastern Channel with very few samples from the North Sea. Other countries catching red mullet in these areas do not provide age structure for the different fleets.

The landing data show that most of the catches are made in the Eastern Channel, where the French sampling is made for the otter trawl (main French fleet). The available data show limited differences in the exploitation pattern of the different fleets in this area. The landing data by commercial categories do not show extreme differences in fleets exploitation patterns.

The raising was then made using the French Otter Trawl sampling and raised to the other fleets.

E Survey data

Three surveys might be used as indices for the assessment. CGFS (Channel Ground Fish Survey) occurs in the Eastern Channel in the last quarter, and the IBTS (International Bottom Trawl Survey) Q1 and Q3 occurring in the North Sea (and part of the Eastern Channel for the last years of the time-series of the first quarter survey).

These three survey catch red mullet even if the number of fishes caught during both IBTS are less important than during the Channel GroundFish Survey. Catch per Unit of effort (Figure 10 to 12) and mean length of the population (Figure 13) can be derived from these surveys to check for consistency between areas. The limited number of fish caught during IBTS Q1 makes the comparison in terms of trends difficult. However Figure 14 shows similar trends in two surveys occurring in distinct areas (IBTS Q3 occurs in the North Sea and CGFS Q4 in the Eastern Channel) even if not all peaks are captured by both surveys.

Length measurements allowed for comparing length structure between IBTS Q1 and CGFS. Figure 13 compares the length structure of the catches during IBTS Q1 and the catches made during CGFS the previous year (previous quarter) and shows some consistencies in length structures. When high recruitment is caught by the CGFS (lengths between 10 and 18 cm) it is also seen by the IBTS Q1 three or four months later and the length structure is then shifted several centimetres. Similarly, in years without high recruitment the length structure composition is mainly flat in both surveys.

A very limited number of fish were aged during both IBTS surveys and sampling was not consistent across years (Tables 2 and 3). From 2004, Red mullet has been aged (Table 4) during CGFS and an index at-age could then de derived from this survey (Figure 15). Internal consistency of the age structures observed through CGFS is examined in Figure 16.

F Biological

Weight-at-age

Weights-at-age in the landings are measured weights from the French national market sampling program. Weights-at-age in the stock are the 4th quarter weights, as seen during the CGFS. Figures 17 and 18 present the available weight-at-age time-series for ages 0 to 4. No trends are observed in stock weight but there might be some declining trends for the catch weight for the older ages. However, these weights are very sensitive to sampling and very variable from one year to another.

Natural mortality

Gislason first estimator based on length is presented in Table 5 for the mean observed length-at-age.

$$M(l) = 1.73l^{-1.61} \times L\infty^{1.44} \times K$$

High values of M (Table 5) for the first age allows for taking into account the biology of this species (fast growing species and high natural mortality on the young ages).

Maturity

In the Eastern Channel and North Sea, reproduction occurs between May and August with a reproduction peak in June. A second reproduction period might take place in December where mature females have been observed but these late reproduction period needs to be further documented.

The maturity ogive used is derived from Mahé *et al.*, 2005:

AGE	0	1	2	3	4	5	6
Maturity	0	0.54	0.65	1	1	1	1

G Historical stock development

Advice was historically given based on ICES approach to data-limited stocks and based on trends in survey indices and landings.

WKNSEA 2015 decided that an a4a (Jardim *et al.*, 2015) stock assessment model, developed during the benchmark, should be used for providing advice. Because of the relatively high uncertainty in this assessment, it was agreed that the results generated by this assessment model should be used under the ICES Stock Category 3 framework.

The a4a stock assessment framework relies on the specification of three log-linear submodels, one each for fishing mortality, survey catchability and recruitment. For red mullet, the catchability and stock recruitment submodels are a year effect model for recruitment and an age factor (constant over years) for catchability. The fishing mortality submodel is an age effect in combination with a smoother over the years with five knots.

Model used as a basis for advice. Settings for the final assessment are given below:

Setting/Data	Values/source
Catch-at-age	Landings (since 2004, ages 0–4+) InterCatch Discards are assumed neglictible
Tuning indices	FR CGFS (since 2004 ages 0–4+)
Plus group	4
First tuning year	2004
Fishing mortality	~ s(year, k=5) + factor(age)
Survey catchability	~ factor(age)
Recruitment	~ factor(year)

H Data requirements

Regular sampling of striped red mullet catches must be continued under DCF. Sampling in the Eastern Channel and in south North Sea started in 2004.

The FR-CGFS should continue to provide an abundance index series-at-age. However, the FR-CGFS survey is not funded by DCF. In the same way, it does not exists any survey in the Western Channel (VIIe) which extended to French and English waters, whereas catches of the striped red mullet in this geographical area in particular, are as significant as catches in the Celtic sea.

Most of the uncertainty in the assessment carried out during the Benchmark might come from the absence of information from the North Sea (no age structure of the landings, no tuning fleet) and the lack of information on age structure of the landings of the Dutch fleet. However some length-based information is or might be made available for these areas and fleet. An integrated assessment approach would then make it possible to use all the available information.

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Table 1. Striped red mullet. Confusion matrix (in %) for Geodesic approach on dataset (1) achieved by K-Nearest Neighbours classifier (*In* Benzinou *et al.*, submitted). Mean correct classification rate was 30% (25% for PCA approach and 19% for Fourier approach).

Geodesic approach on Dataset (1)						
	Actual Class					
Estimated Class	NS	EEC08	WEC	CS	NBB	SBB
NS	**15**	20	11	8	5	11
EEC08	28	**44**	17	23	5	5
WEC	9	9	**22**	11	7	9
CS	24	15	24	**32**	15	13
NBB	10	5	16	13	**27**	22
SBB	14	7	10	13	41	**40**

Table 2. Number of fishes aged during IBTS Q1.

	2007	2008	2009	2010	2011	2013	2014
0	0	0	0	0	0	0	0
1	0	5	1	32	0	0	26
2	1	7	2	6	20	2	2
3	0	13	1	1	1	0	0
4	0	4	0	1	1	0	0
6	0	1	0	0	0	0	0

Table 3. Number of fishes aged during IBTS Q3.

	2007	2008	2009	2010	2011	2013	2014
0	2	0	0	0	0	0	0
1	60	0	12	0	0	0	0
2	12	0	3	0	0	0	0
3	3	0	0	0	0	0	0
4	2	0	0	0	0	0	0
6	0	0	0	0	0	0	0

Table 4. Number of fishes aged during CGFS Q4.

	2006	2007	2008	2009	2010	2011	2012	2013	2014
0	40	8	3	80	35	1	48	20	34
1	49	91	26	92	45	63	12	14	30
2	22	1	44	14	13	5	9	4	11
3	21		3	7	1			1	
4	6		2	1	2		1		
5	1								

Table 5. M values by age based on the mean length at age.

age	meanLength	M_Gislason
0	12.28	1.426
1	19.74	0.6641
2	23.88	0.4888
3	26.37	0.4164
4	28.79	0.3616
5	30.62	0.3275
6	29.8	0.3421

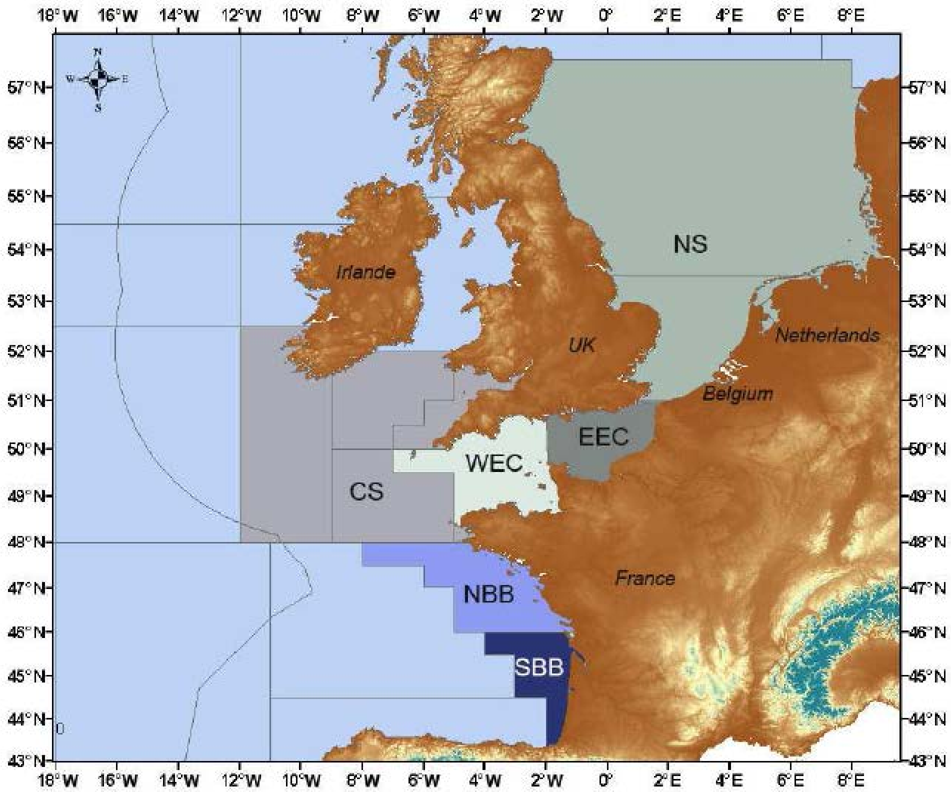


Figure 1. Striped red mullet. Map divided into six geographic sectors.

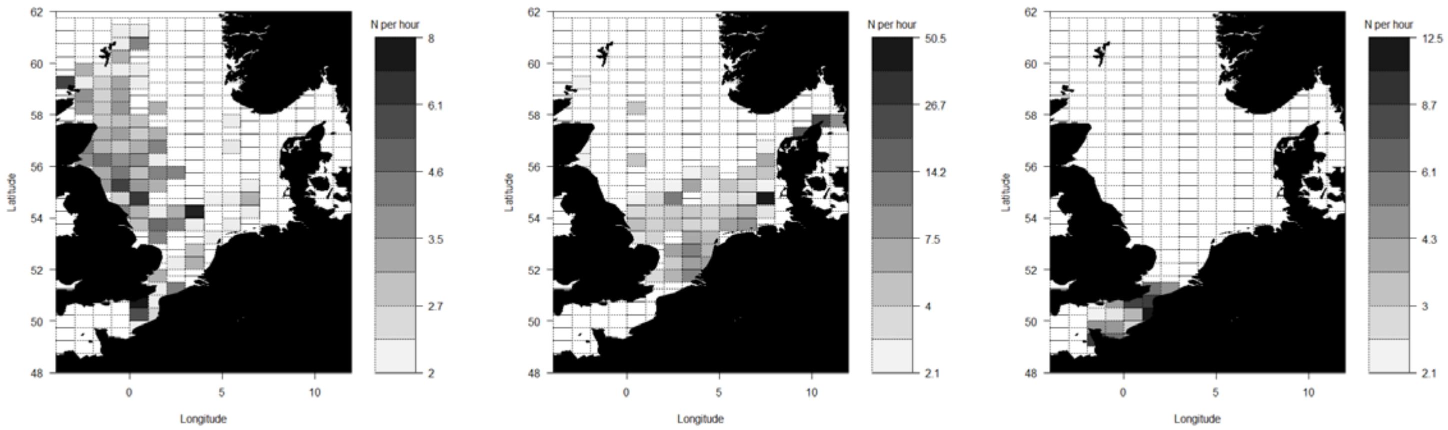


Figure 2. Striped red mullet. Average cpue (Number of fish per hour) over 2004–2013 for IBTS Q1 (left panel), IBTS Q3 (middle panel) and CGFS Q4 (right panel). The sampling area in IBTS Q1 encompasses the eastern part of the Eastern Channel and the North Sea, IBTS Q3 takes part in the North Sea only, and CGFS Q4 takes part only in the Eastern Channel.

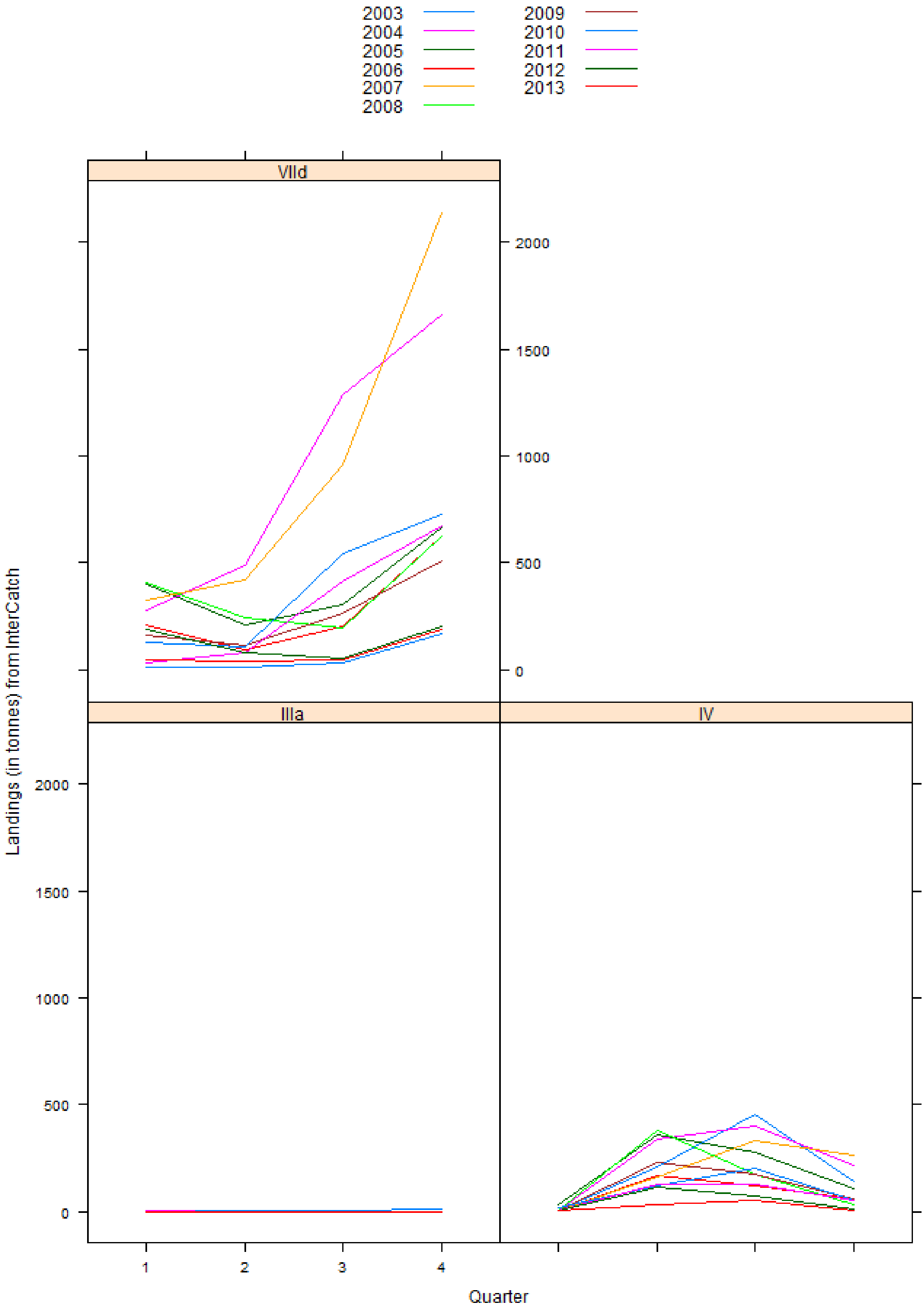


Figure 3. Striped red mullet, landings by quarter and areas.

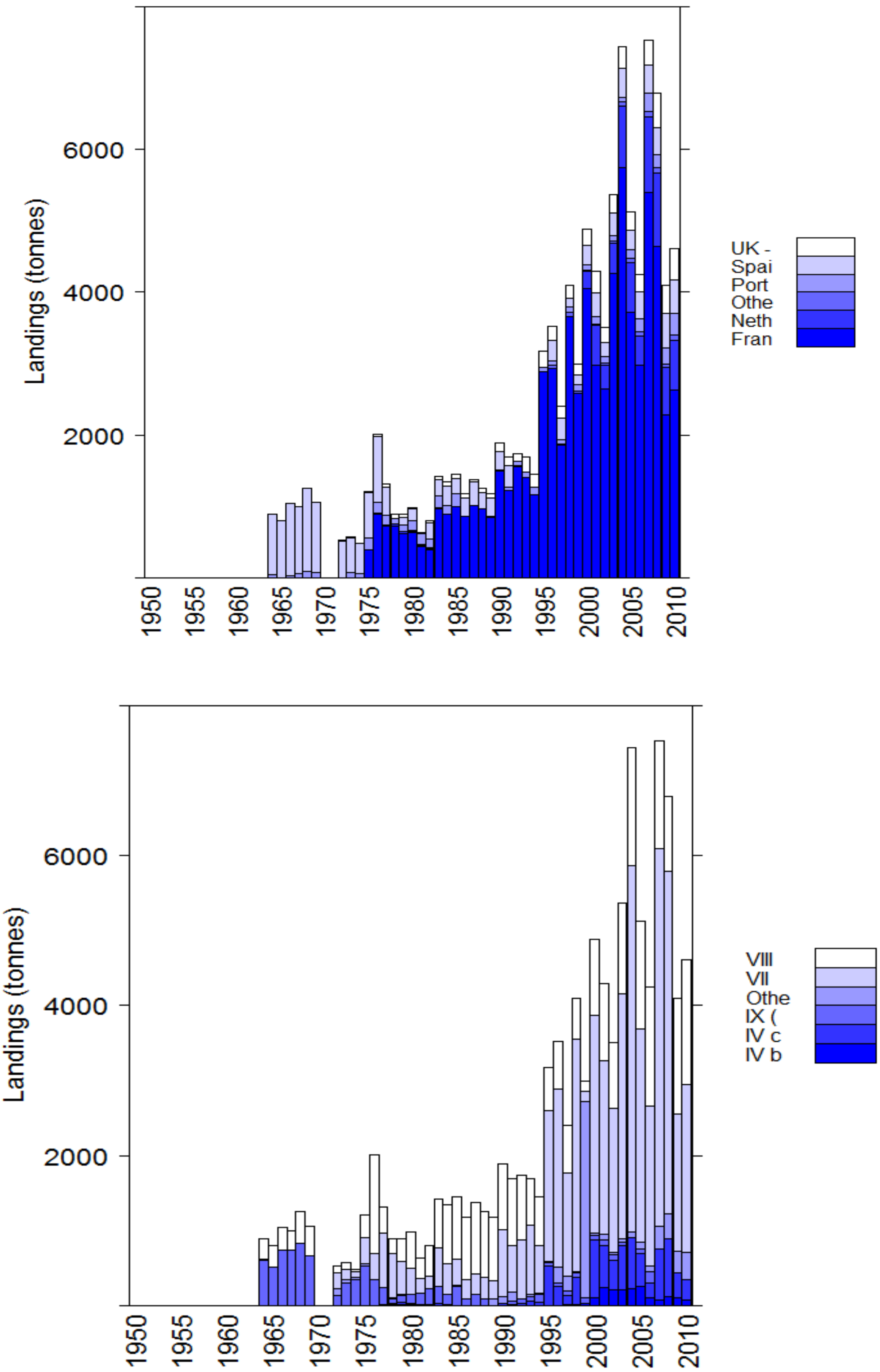


Figure 4. Striped red mullet. Landings per country (top panel) and per ICES area (bottom panel). As officially reported.

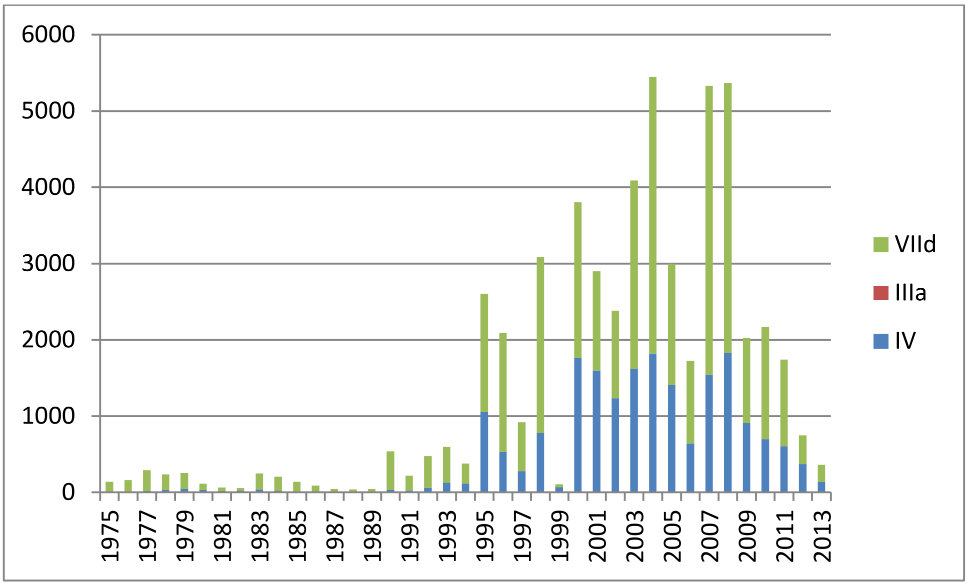


Figure 5. Striped red mullet landings in Subarea IV and Divisions IIIa and VIId. Official and ICES landings (tonnes).

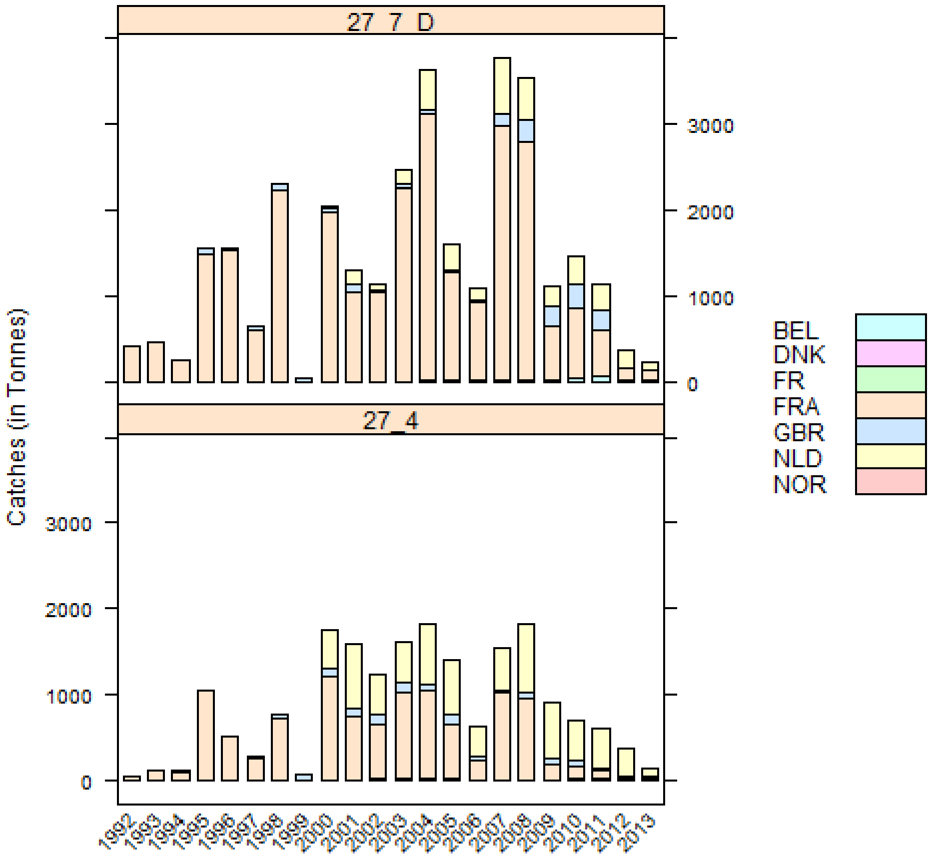


Figure 6. Striped red mullet landings in Division VIId (top panel) and Subarea IV (bottom panel). Official and ICES landings by country (tonnes).

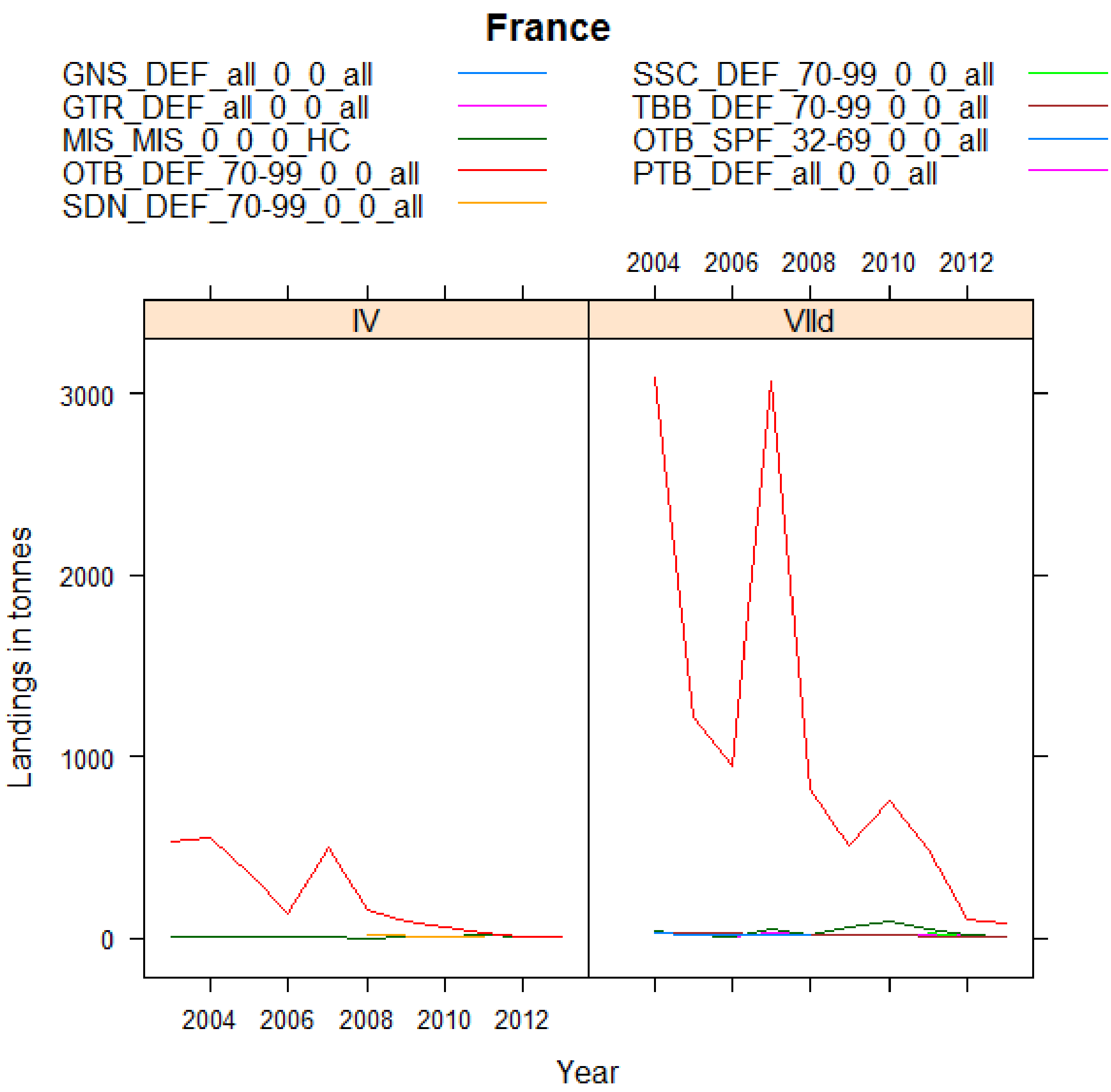


Figure 7. InterCatch landings by country (France) and gear.

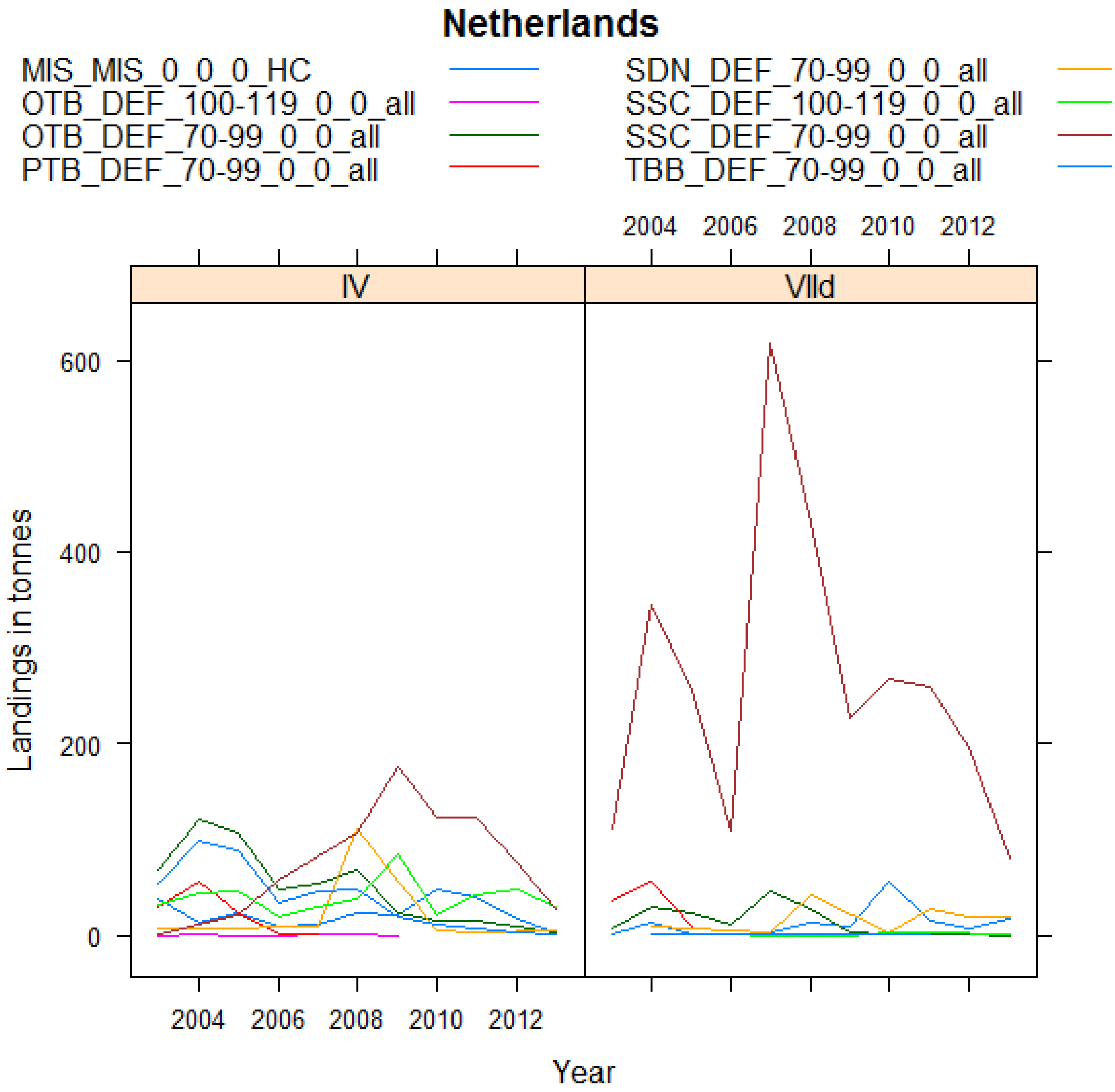


Figure 8. InterCatch landings by country (The Netherlands) and gear.

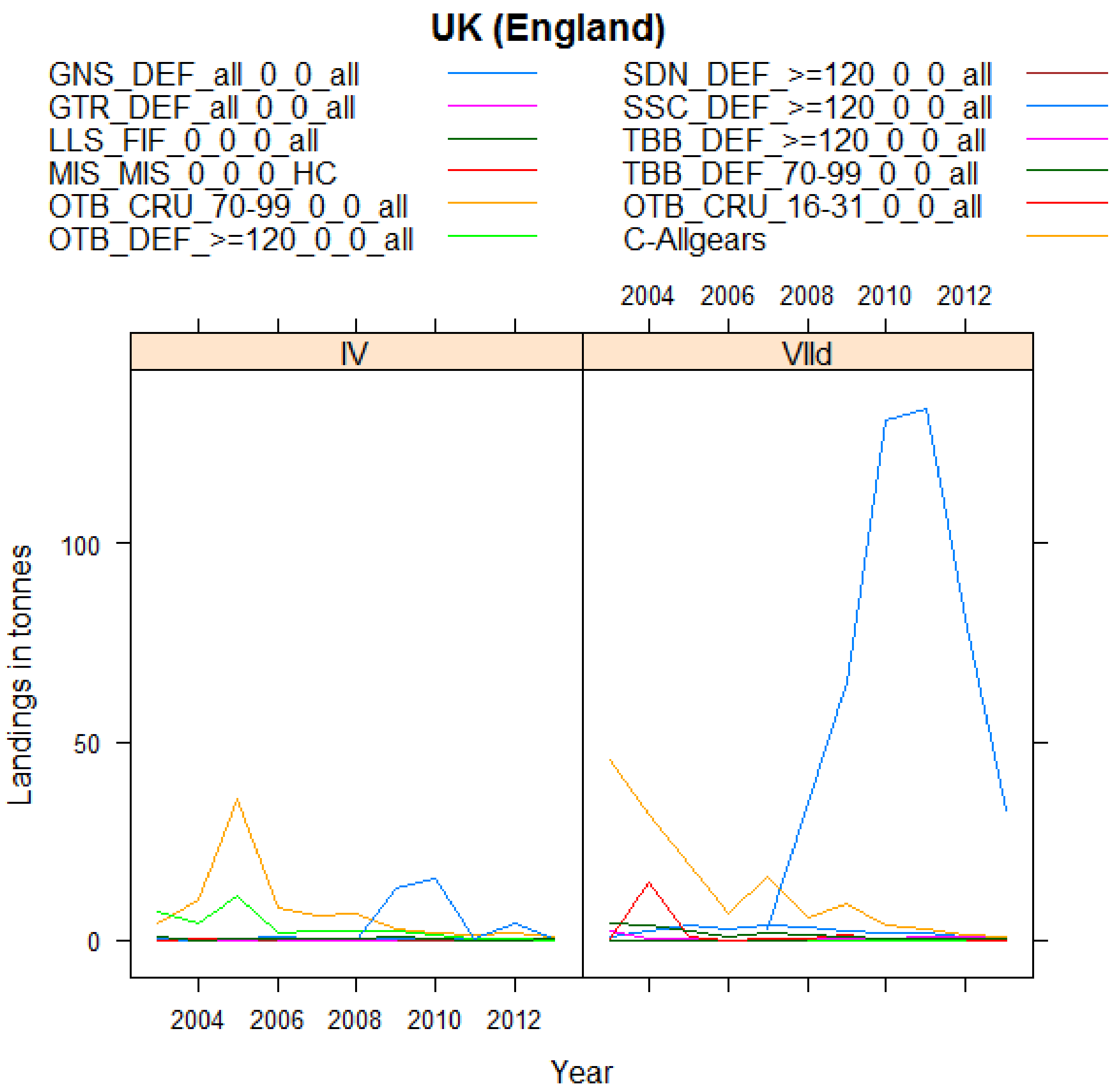


Figure 9. InterCatch landings by country (UK (England)) and gear.

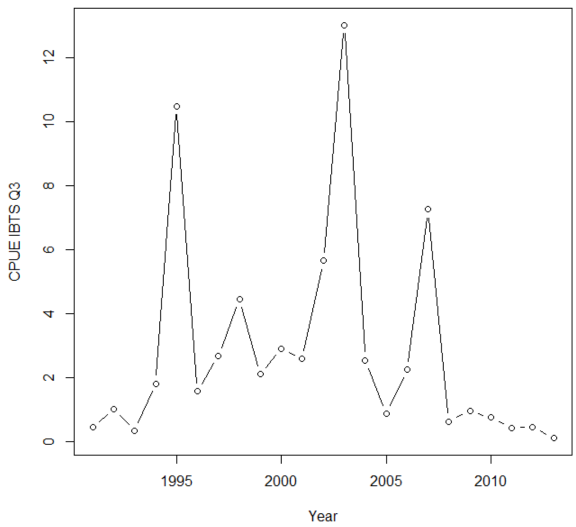


Figure 10. Cpue derived from IBTS Quarter 3 (number per hour).

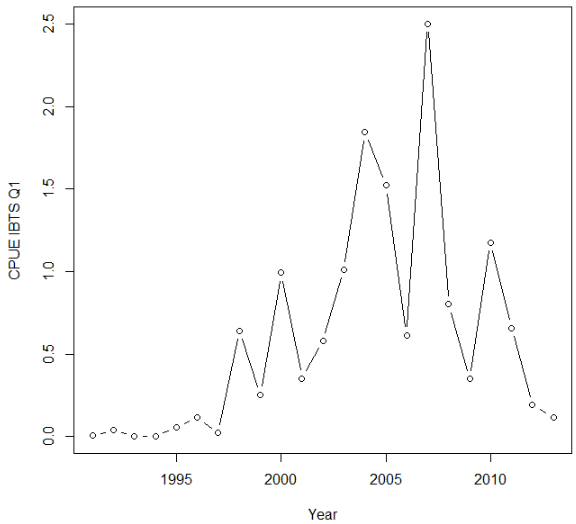


Figure 11. Cpue derived from IBTS Quarter 1(number per hour).

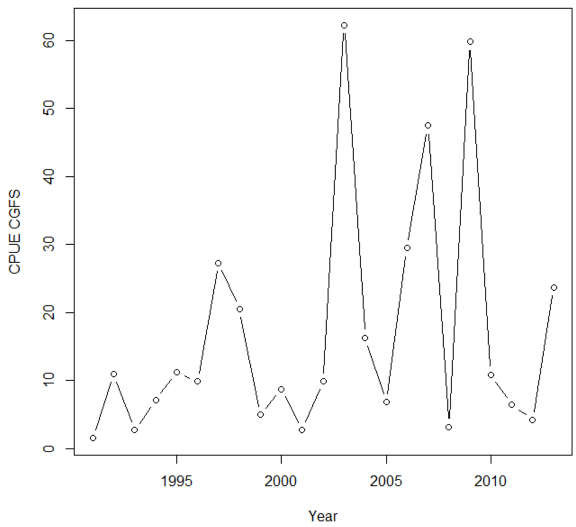


Figure 12. Cpue derived from CGFS Quarter 4 (number per hour).

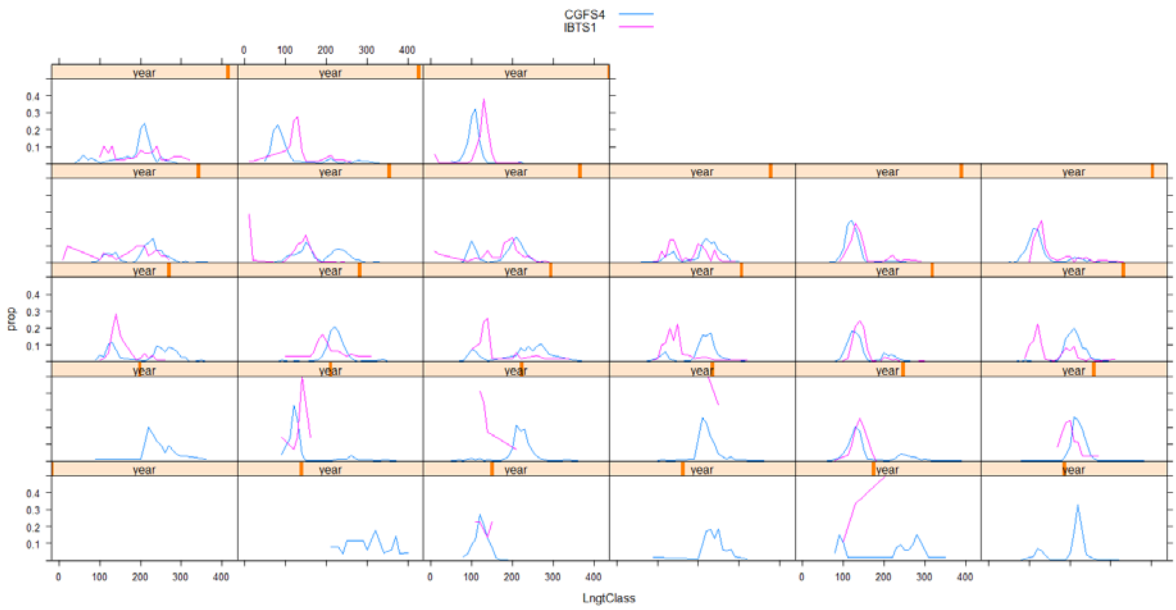


Figure 13. Comparison between length structures derived from CGFS Quarter 4 and IBTS Q1 the next year (next quarter).

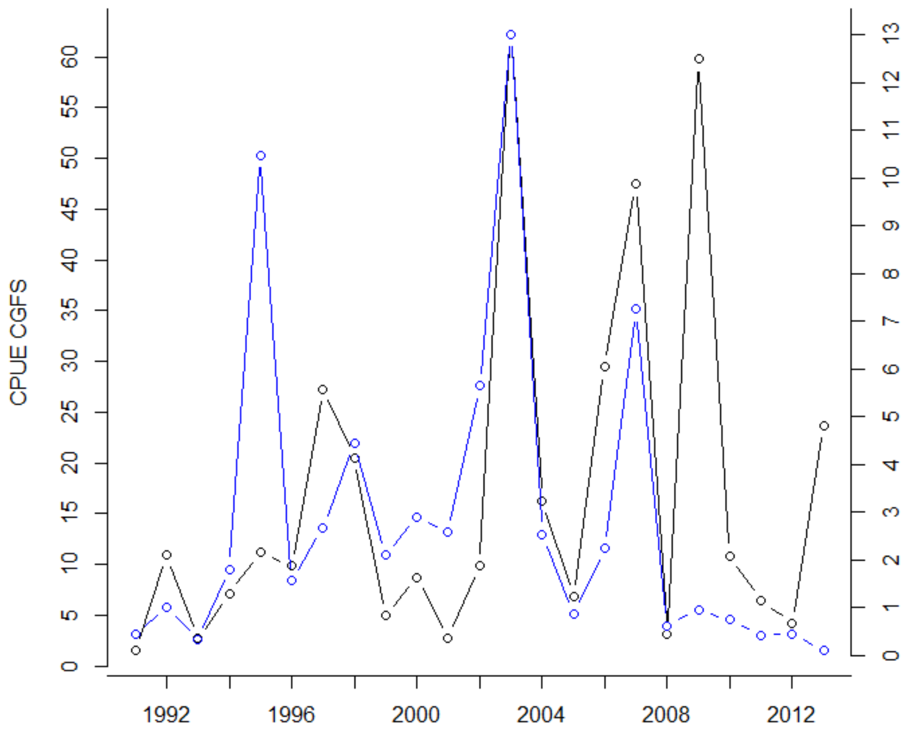


Figure 14. Comparison between cpue derived from CGFS Quarter 4 and IBTS Q3 (number per hour).

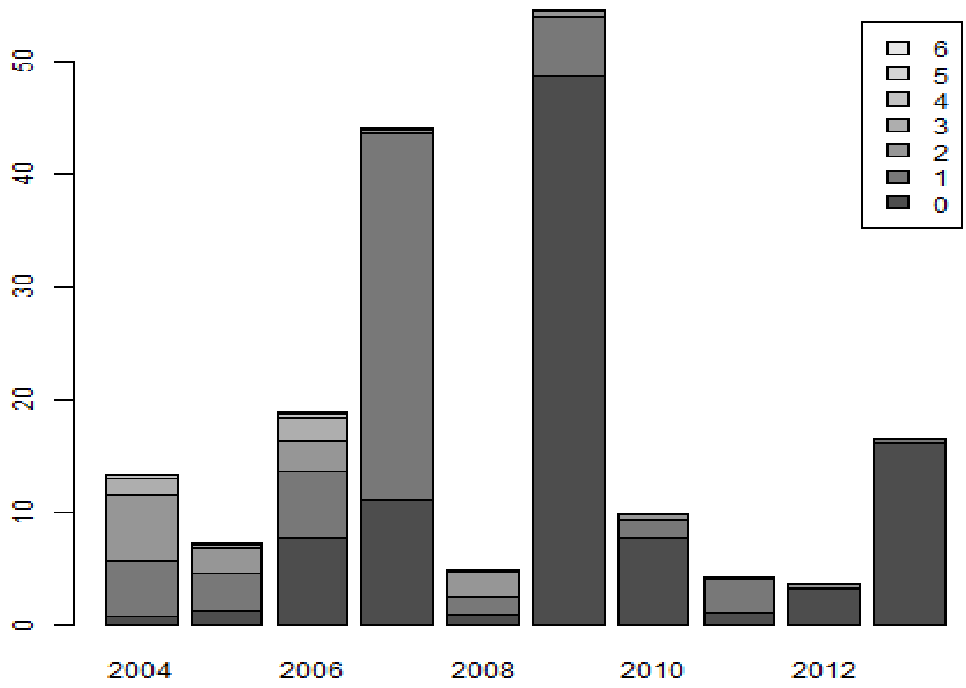


Figure 15. Standardized index at age of CGFS Quarter 4 survey.

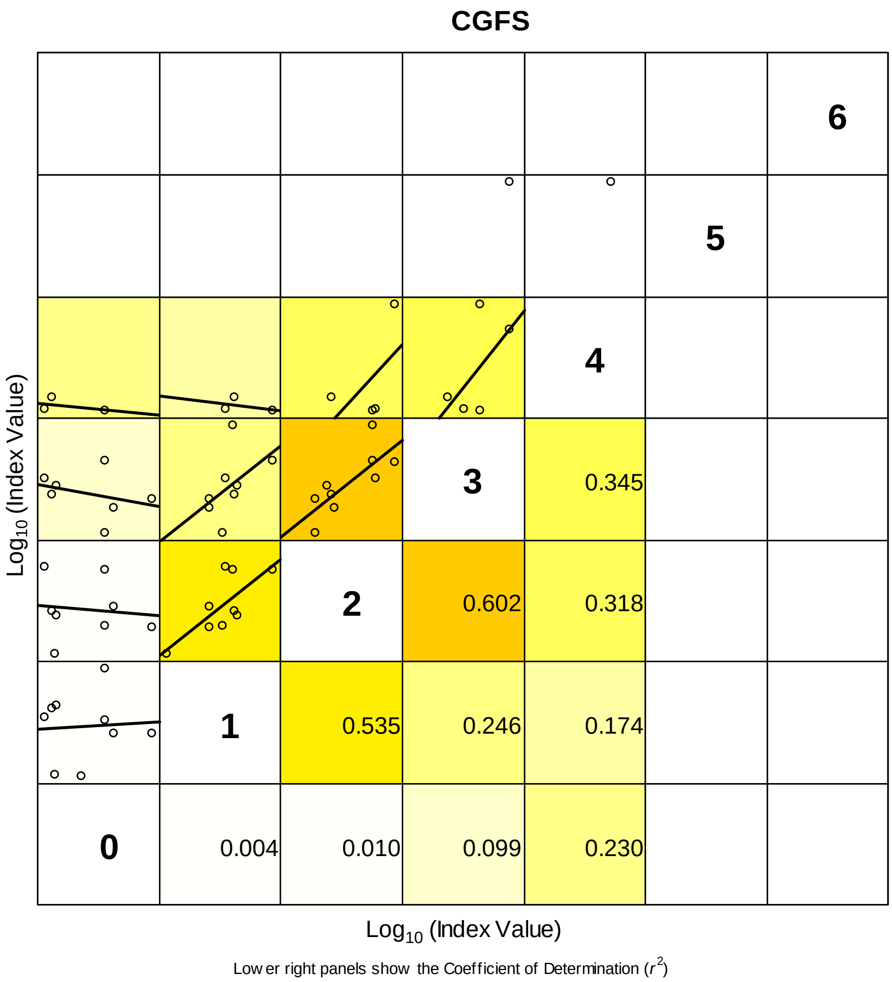


Figure 16. Internal consistency of CGFS Quarter 4 survey.

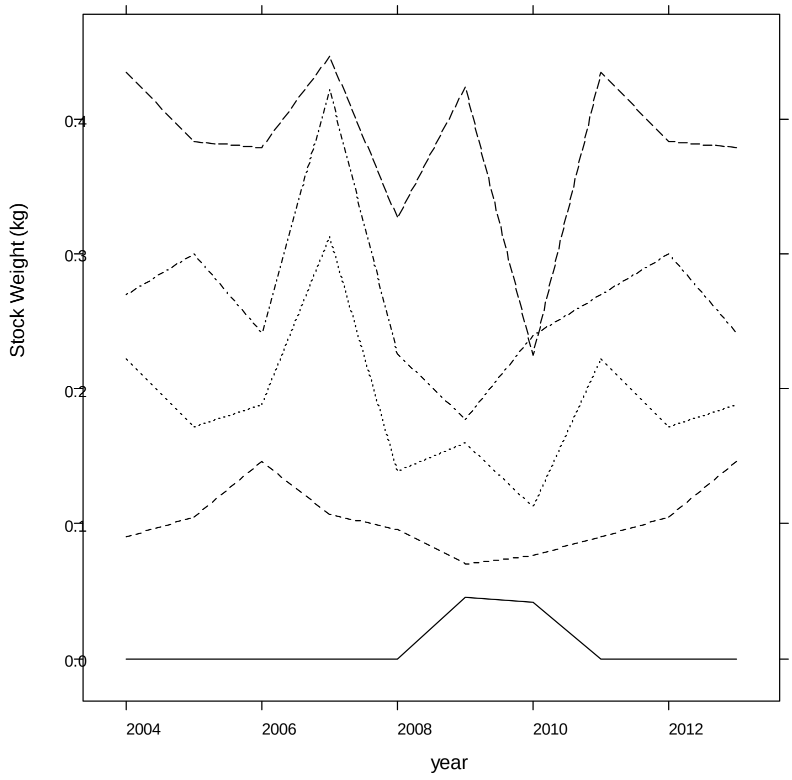


Figure 17. Stock weight.

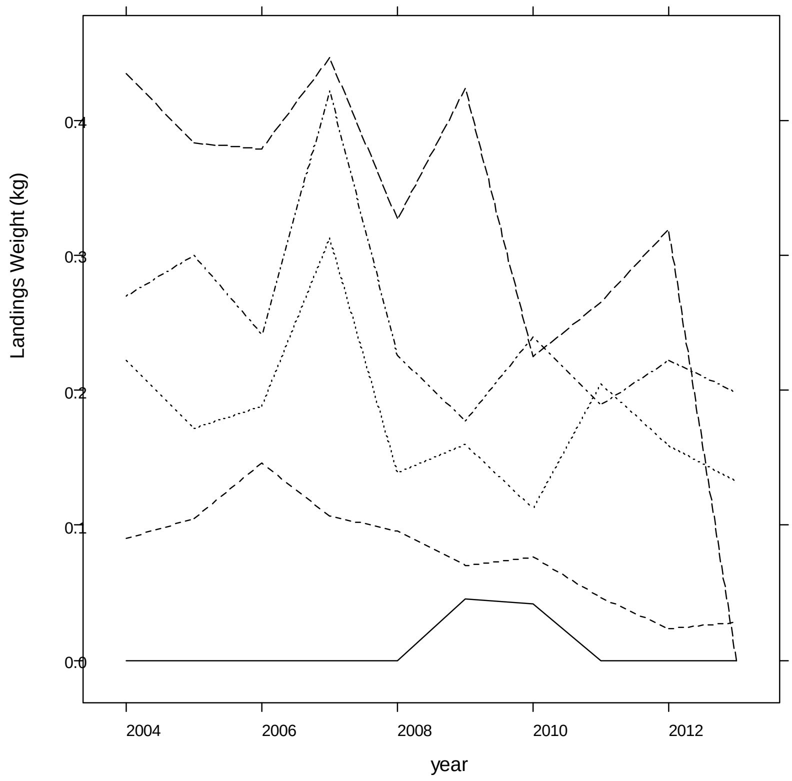


Figure 18. Catch weight.

Appendix 1: ELEMENTS OF BIOLOGY ON Red Mullet in the Eastern Channel

Excerpts from the project InterReg 3A CHARM Phase II.

Mullus surmuletus

Linnaeus,1758

Rouget barbet de roche
Red mullet

© IFREMER

Embranchement-Phylum : Chordata
Classe-Class : Actinopterygii
Ordre-Order : Perciformes
Famille-Family : Mullidae

Biologie - Le rouget barbet adulte se nourrit de petits crustacés, annélides et mollusques, utilisant ses barbillons mentonniers pour détecter les proies et fouir la vase. En Manche, la période de frai s'étale de mai à juillet. Les œufs pélagiques incubent en 3 à 8 jours selon la température. Après éclosion, les larves pélagiques résorbent leur vitellus en 4 jours et migrent vers la côte en automne. Les juvéniles de plus de 5 cm de long rejoignent les fonds sableux ou coquilliers de plus de 10 m de profondeur. La croissance la première année est particulièrement rapide.

Caractères démographiques - Taille maximale 42 cm ; taille commune 15-35 cm ; taille commerciale minimale 19 cm (UE) ; longévité maximale 11 ans ; âge et taille à maturité 1-2 ans et 16-19 cm ; paramètres de von Bertalanffy : taille asymptotique L_{inf} = 51.35 cm, taux de croissance k = 0.186 an^{-1}, âge théorique t_0 = -1.21 ; paramètres de fécondité *alpha = n/a* et *beta = n/a*.

Environnement - Poisson benthique vivant sur les fonds rocheux, à graviers ou sableux du plateau continental et du bord du talus, entre 10 et 300 m de profondeur. Espèce préférant les eaux marines ayant des températures comprises entre 8 et 24°C.

Répartition géographique - Atlantique est, de la Norvège et du nord des îles britanniques jusqu'au Sénégal et les îles Canaries ; mer Méditerranée et mer Noire.

Biology - Adult red mullet feed on small crustaceans, annelid worms and molluscs, using their chin barbels to detect prey and search the mud. In the English Channel, spawning occurs from May to July. The pelagic eggs incubate in 3 to 8 days, depending on temperature. After hatching, the pelagic larvae absorb their vitellus in 4 days, and they migrate to the coast in the autumn. Juveniles of length greater than 5 cm return to sandy and shelly substrates deeper than 10 m. Growth during the first year of life is particularly fast.

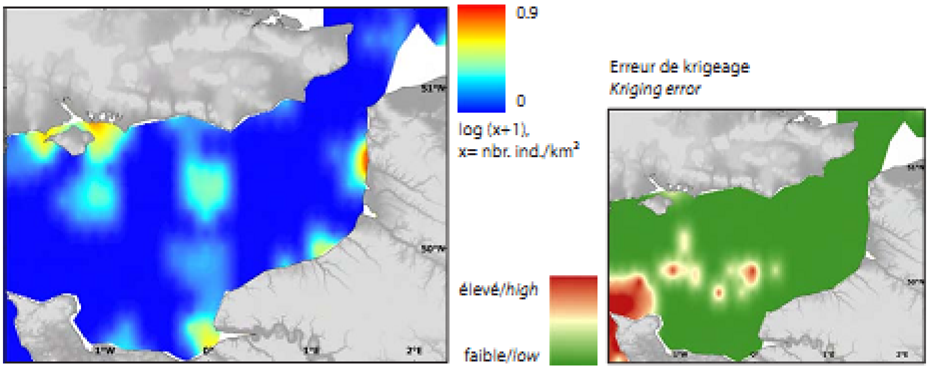
Life history parameters - Maximum length 42 cm; common length 15-35 cm; minimum landing size 19 cm (EU); maximum lifespan 11 years; age and length at maturity 1-2 years and 16-19 cm; von Bertalanffy parameters: asymptotic length L_{inf} = 51.35 cm, growth rate k = 0.186 year^{-1}, theoretical age t_0 = -1.21; fecundity parameters *alpha = n/a* and *beta = n/a*.

Environment - Red mullet is a benthic fish that lives on pebbly, gravelly and sandy substrates of the continental shelf and on the continental slope between 10 and 300 m depth. The species is mostly found in marine waters with temperatures between 8 and 24°C.

Geographical distribution- Eastern Atlantic, from Norway and the northern British Isles, down to Senegal and the Canary islands; also in the Mediterranean and Black Seas.

< 1 An / Year old - Mullus surmuletus

Abondance pluriannuelle
en juillet (BTS, 1989-2006)
Multi-annual abundance in July (BTS, 1989 -2006)



Les rougets barbets de taille inférieure à 17.3 cm ont été considérés comme ayant moins d'un an. Les aires de distribution et les modèles d'habitat (en octobre) ont été faits séparément pour les individus de moins de un an et ceux de plus d'un an. Les rougets barbets sont mal échantillonnés par le chalut à perche utilisé pendant les campagnes BTS et donc il n'est pas possible de montrer les distributions annuelles en cette saison. Les deux cartes de juillet présentent donc les abondances moyennées (ou pluriannuelles) sur les années 1989 à 2006 ; aucun modèle d'habitat n'a satisfait les critères de sélection pour présentation dans l'atlas.

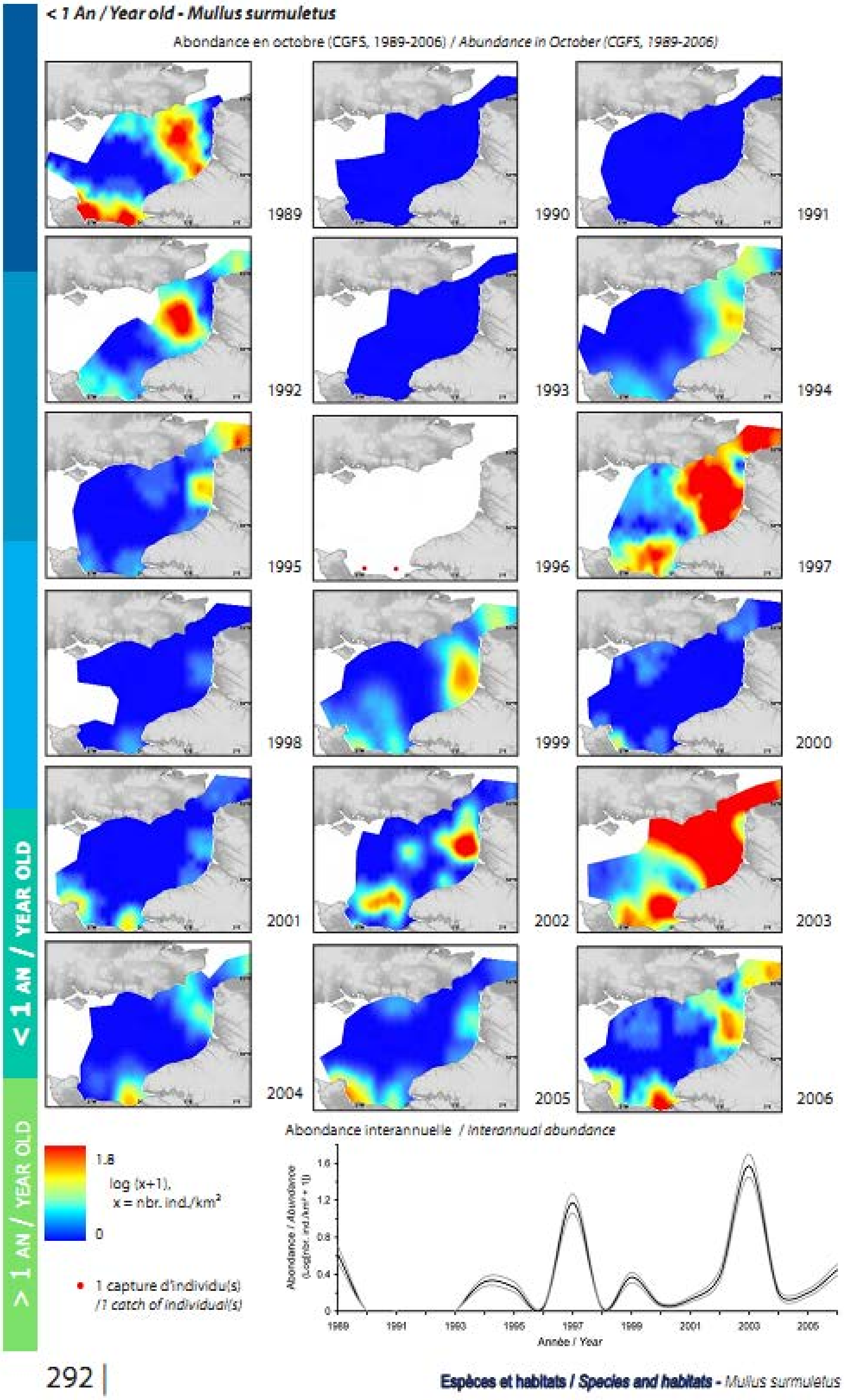
< 1 an

Durant la campagne BTS en juillet, les jeunes de moins d'un an sont présents dans les estuaires et autour de l'île de Wight. Certaines années, très peu de jeunes ont été échantillonnés pendant la campagne CGFS en octobre. Quand ils étaient présents, ils ont surtout été trouvés dans les zones à fonds sableux, au large de la côte d'Opale et de la baie de Seine et dans le sud de la mer du Nord. Le modèle d'habitat préférentiel montre toute la zone du détroit comme étant favorable pour la présence de ce jeune stade, ainsi que la baie de Seine, ce qui est en accord avec les observations de campagnes. Il faut cependant prendre en compte l'erreur du modèle qui est importante dans les zones de fortes abondances. Le modèle d'habitat potentiel est très semblable au modèle d'habitat préférentiel : il favorise les zones à faible influence des courants de marées mais où dominent les graviers et les cailloutis.

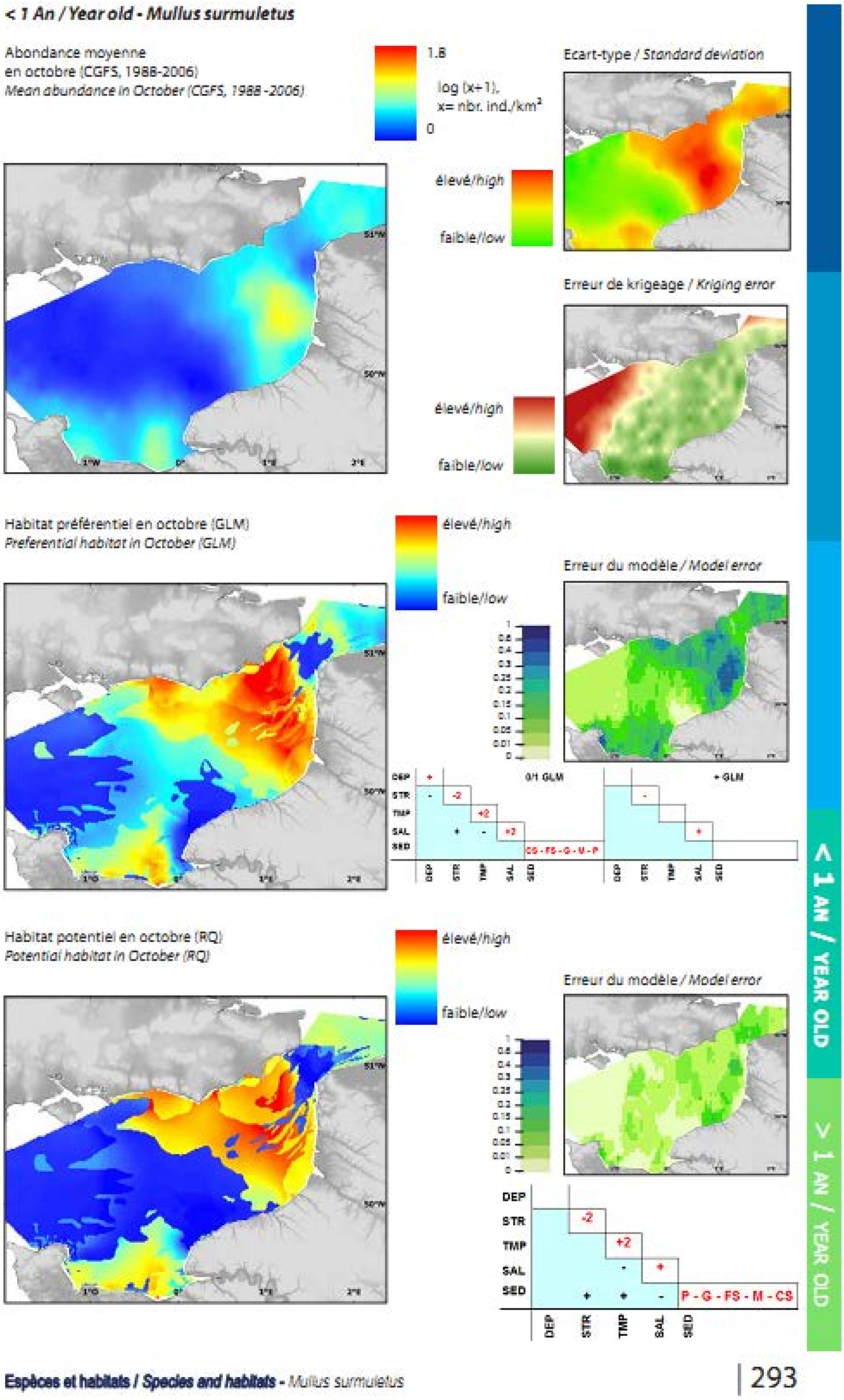
Red mullet less than 17.3 cm in length were considered as being less than one year old, and the distribution patterns and habitats (in October) were defined separately for young and older individuals. Red mullets are not representatively sampled by the beam trawl used during the July BTS survey; as a result, annual maps are not shown for this season. The two July maps hence show average (or multi-annual) distribution over 1989-2006; no habitat model passed the selection criteria for inclusion in the atlas.

< 1 year old

In July, young individuals (less than one year old) were present in estuaries and around the Isle of Wight. In some years, very few young individuals were found during the CGFS surveys (October). When they were present, they were mainly found in areas with sandy sediments, off the Opale coast and the Bay of Seine and in the southern North Sea. The preferential habitat model shows the Dover Strait and the Bay of Seine as favourable for this young stage, which agrees with the survey data. Nevertheless, the model error was great in high abundance areas. The potential habitat model was very similar to the preferential habitat model, favouring areas with weak bed shear stress and the presence of gravels and pebbles.

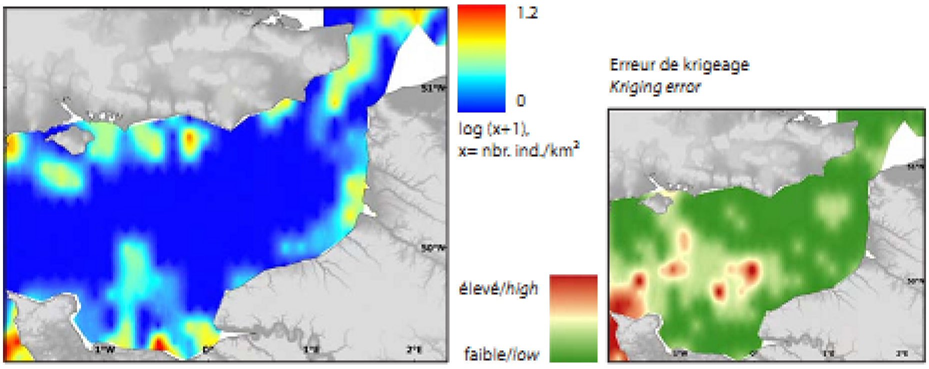


< 1 An / Year old - Mullus surmuletus
Abondance en octobre (CGFS, 1989-2006) / Abundance in October (CGFS, 1989-2006)
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Abondance interannuelle / Interannual abundance
1.8
log (x+1),
x = nbr. ind./km²
0
1 capture d'individu(s)
/1 catch of individual(s)
Année / Year
< 1 AN / YEAR OLD
> 1 AN / YEAR OLD
292 |
Espèces et habitats / Species and habitats - Mullus surmuletus


< 1 An / Year old - Mullus surmuletus
Abondance moyenne
en octobre (CGFS, 1988-2006)
Mean abundance in October (CGFS, 1988 -2006)
1.8
log (x+1),
x= nbr. ind./km²
0
Ecart-type / Standard deviation
élevé/high
faible/low
Erreur de krigeage / Kriging error
élevé/high
faible/low
Habitat préférentiel en octobre (GLM)
Preferential habitat in October (GLM)
élevé/high
faible/low
Erreur du modèle / Model error
0/1 GLM
+ GLM
DEP
STR
TMP
SAL
SED
CS - FS - G - M - P
Habitat potentiel en octobre (RQ)
Potential habitat in October (RQ)
élevé/high
faible/low
Erreur du modèle / Model error
DEP
STR
TMP
SAL
SED
P - G - FS - M - CS
< 1 AN / YEAR OLD
> 1 AN / YEAR OLD
Espèces et habitats / Species and habitats - Mullus surmuletus
293

> 1 An / Year old - Mullus surmuletus

Abondance pluriannuelle
en juillet (BTS, 1989-2006)
Multi-annual abundance in July (BTS, 1989-2006)



> 1 an

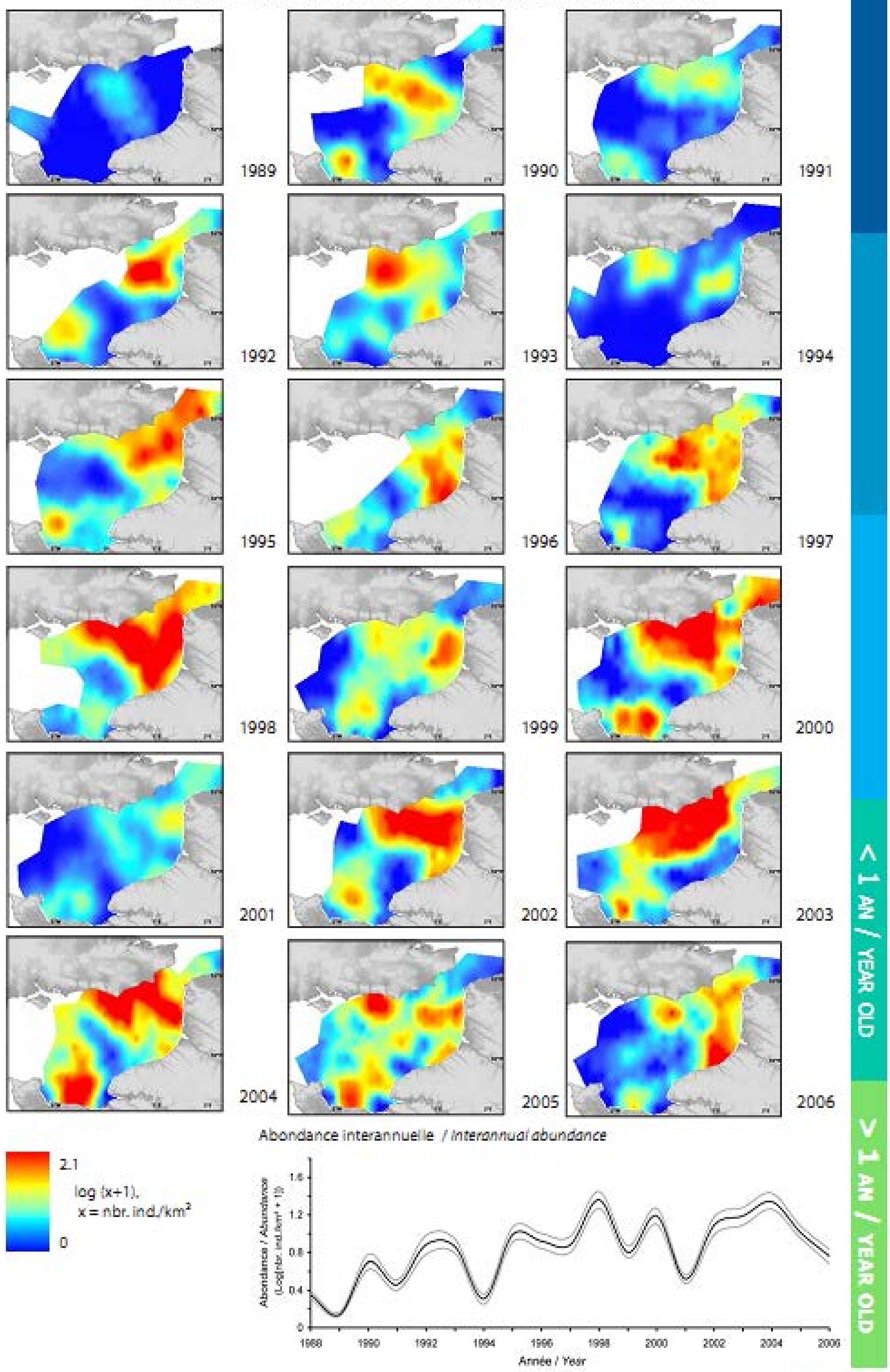
Les individus de plus d'un an se situent également le long des côtes mais avec une distribution plus étendue en juillet. En octobre, ils se répartissent dans les mêmes zones que les jeunes mais avec une distribution plus étendue vers le large, ce qui est conforme au modèle d'habitat préférentiel. L'habitat potentiel est très semblable à l'habitat préférentiel, favorisant des zones tempérées à forte influence océanique et avec des sédiments grossiers.

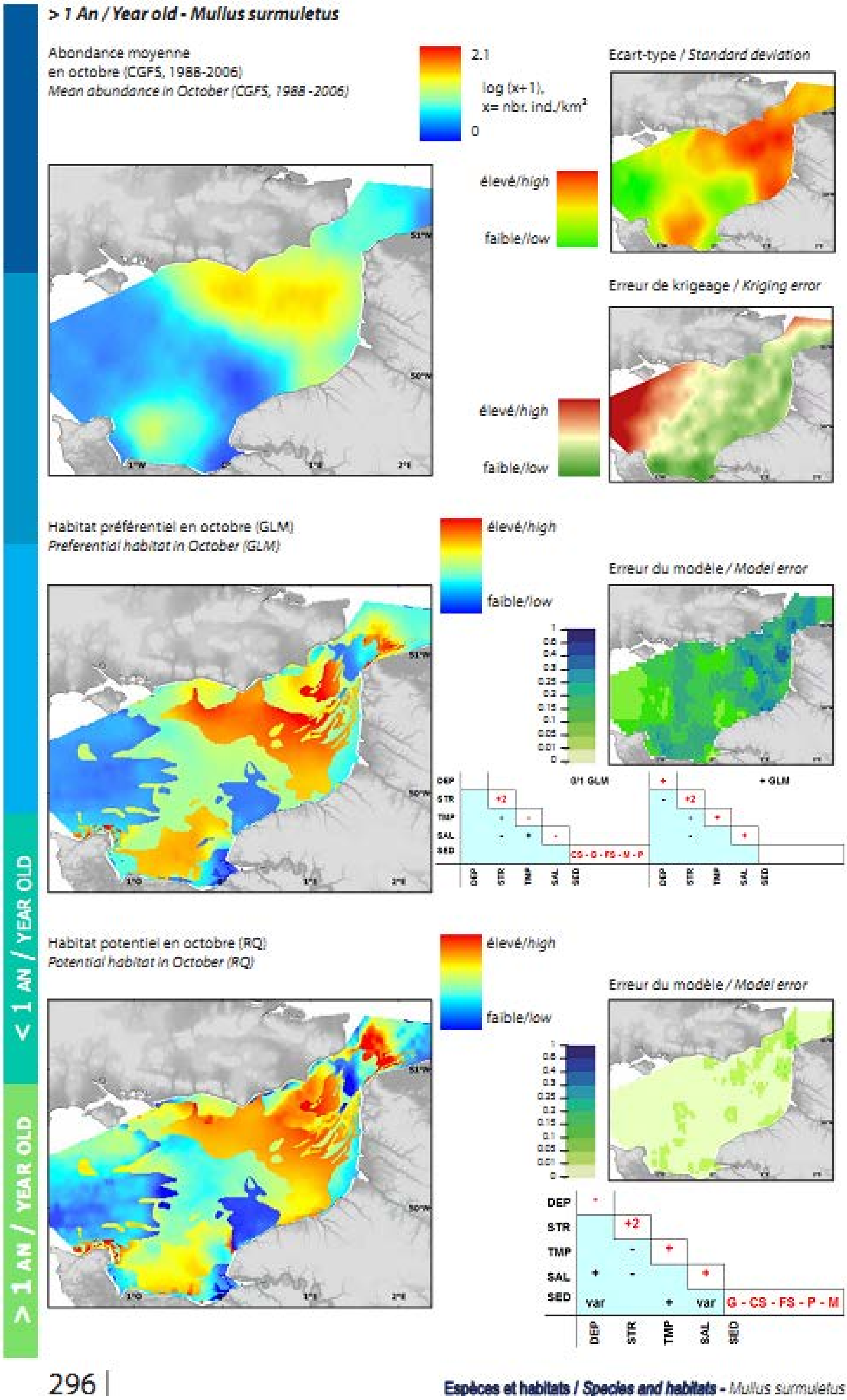
> 1 year old

In July, older fish were also found along the coasts but the distribution was more dispersed. In October, older individuals were found in the same areas as the younger ones, but their distribution spreading further offshore, which agrees with the preferential habitat model. The potential habitat was similar to the preferential habitat, favouring temperate areas with a strong oceanic influence and coarse sediment types.

> 1 An / Year old - Mullus surmuletus

Abondance en octobre (CGFS, 1989-2006) / *Abundance in October (CGFS, 1989-2006)*




> 1 An / Year old - Mullus surmuletus
Abondance moyenne
en octobre (CGFS, 1988-2006)
Mean abundance in October (CGFS, 1988-2006)
2.1
log (x+1),
x= nbr. ind./km²
0
Ecart-type / Standard deviation
élevé/high
faible/low
Erreur de krigeage / Kriging error
élevé/high
faible/low
Habitat préférentiel en octobre (GLM)
Preferential habitat in October (GLM)
élevé/high
faible/low
Erreur du modèle / Model error
0/1 GLM
+ GLM
DEP
STR
TMP
SAL
SED
CS - G - FS - M - P
Habitat potentiel en octobre (RQ)
Potential habitat in October (RQ)
élevé/high
faible/low
Erreur du modèle / Model error
G - CS - FS - P - M
< 1 AN / YEAR OLD
> 1 AN / YEAR OLD
296
Espèces et habitats / Species and habitats - Mullus surmuletus