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Report of the Workshop on the Analysis of the Benchmark of Cod in Subarea IV (North Sea), Division VIId (Eastern Channel) and Division IIIa (Skagerrak) (WKCOD 2011)

7–9 February 2011

Copenhagen, Denmark

ICES
International Council for the Exploration of the Sea
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Executive summary

The ICES workshop on the analysis of the benchmark of cod in Subarea IV (North Sea), Division VIId (Eastern Channel) and Division IIIa (Skagerrak), WKCOD, met at the ICES headquarters (Copenhagen) during February 7–9, 2011. There were 19 participants from seven countries (Belgium, Denmark, Germany, Iceland, Norway, Spain, and UK), of which three participants were industry representatives and one was an external reviewer. The meeting was chaired by Einar Hjorleifsson (Iceland).

The meeting was designed to serve as an inter-benchmark protocol for the North Sea cod assessment and was tasked with reviewing the input data used and the assessment model and settings, proposing changes to them if deemed appropriate. Additional work, if required, was also to be identified.

A consensus of the data input, model assumptions and framework to be used in the 2011 cod assessment was reached at the WKCOD meeting. The conflict in the IBTS quarter 1 vs. quarter 3 surveys, an issue raised by the WGNSSK in 2010, was not fully resolved. The abundance indices in the quarter 1 survey were considered to more likely reflect stock trends in recent years, because of suspected changes in catchability in the quarter 3 survey in relation to recent changes in the spatial distribution of fish in the latter part of the year. It is recommended that further investigation be addressed within a working group on improving use of survey data for assessment and advice (suggested ToRs are in WKCOD report). Additionally, using both surveys in the assessment results in trends in unallocated removals that go against the prevailing hypothesis that the bias in landings in particular and potentially in discards estimates in recent years have declined compared with the earlier period. For these reasons it was agreed to use only the quarter 1 survey in the assessment for the time being.

The current assessment model (B-ADAPT) was considered to be too responsive to the noise levels in the surveys in recent years to form the basis for providing advice to a management regime which is based on the final year estimates of fishing mortality. An alternative model, SAM, which smoothes fishing mortality was adopted as the basis for an interim period (~two years) of assessments because of the more stable estimates of fishing mortality. The SAM model is considered an interim solution because it estimates bias in the total catch in the same way as the previous assessment model, whereas a model that estimates bias in landings and discards separately is considered a more suitable long-term solution.

Although the SAM model structure agreed at WKCOD is considered the most appropriate that could be fitted in the time available, a refined model structure will only be completed with further work. Consequently, WKCOD consider that if further refinements are found to be required before the WGNSSK 2011 meeting, these be presented to that meeting for adoption (WGNSSK comprises a large part of WKCOD participants). In the medium term WKCOD considered that the development of a model structure that models discard and landings separately is required due to the differing levels of noise associated with each data set. WKCOD recommended that the reference points are not revised in the short term until the assessment model has been finalised.

It was concluded that the factors for "unallocated mortality" estimated for North Sea cod were in agreement with the general perception of the extent of underreporting except for the most recent years. However, it was also recognized that "unallocated

mortality” in general is a result of discrepancies between model assumptions and observations. Alternative model assumptions, such as changes in natural mortality or survey catchability, might also explain the patterns observed.

1 Introduction

1.1 Terms or Reference (ToR)

2010/2/ACOM53 **Workshop on the analysis of the benchmark of cod in Subarea IV (North Sea), Division VIId (Eastern Channel) and Division IIIa (Skagerrak) (WKCOD)** that will serve as in Inter Benchmark Protocol, chaired by Einar Hjörleifsson (Iceland) will meet at ICES Headquarters 7–9 February 2011 to:

a) Review the input data within the current cod assessment methods, both data that are used in the current assessment and new datasets that could be developed and used.

b) Evaluate survey input data and their statistical power in describing changes in distribution of the cod stock.

c) Evaluate the time-trends in the stock distribution.

d) Describe the reasoning why data input should (not) be adapted.

e) Evaluate and define the assessment model and settings best suited to the available data.

WKCOD will inform ACOM if need be with draft recommendations on urgent further work by February 14 and will report in full by 1 March 2011 to ACOM.

2 Migrations and stock structure

A Working Document about North Sea cod movements and population structure was provided to the group by Wright, Neat and Righton (WD 7). The main findings are as follows:

1) The hypothesis that fish may be "lost" northwards out of the range of the survey appears inconsistent with recent and historical information on cod movements since age 2+ from the southern North Sea are only likely to migrate as far as the central North Sea.

2) Direct observations on cod in relation to sea temperature do not suggest they actively avoid the warm southern North Sea in summer.

3) As a proportion of cod from the eastern channel may migrate into the North Sea, abundance near the southern edge of the IBTSq3 survey may have been important to recent trends in IBTSq3.

4) Two subpopulations of cod have been indicated from genetic studies and there do appear to be long-term differences in recruitment trends. The presence of two subpopulations largely inhabiting different regions of the North Sea will mean that there is the potential for regional differences in mortality, because cod from the deep-water subpopulation would not be expected to re-colonize areas depleted in the southern North Sea.

With regards to point 1, The IBTSq1 survey takes place close to spawning time when cod aggregate around their spawning time (Wright *et al*., 2006; Fox *et al*., 2008). By the time the IBTSq3 survey takes place cod can have dispersed a substantial distance from their spawning grounds. Although there is insufficient tagging evidence to follow the seasonal movements of all recent cohorts, historical tag-recapture data together with geolocations from recent data storage tag experiments do provide a clear indication of the seasonal extent of movements. While a proportion of fish are resident throughout the year, those cod from IVb and c that do migrate generally do so in a northerly direction after the spawning season, i.e. after the Q1 survey (Righton *et al*., 2007, Figure 2.2). Consequently, a seasonal northward shift in density distribution between the Q1 and Q3 surveys may be expected. However, the extent of cod seasonal migrations throughout the North Sea is generally <200 kms (Neat and Righton, 2007; Righton *et al.*, 2007; Wright *et al*., 2006a,b). As such most cod from IVc and much of IVb would be expected to remain south of IVa (Figure 2.1) and hence should still be within the area of the Q3 survey. Cod in IVa do not typically exhibit a northward migration and those inhabiting depths >100m experience a much less pronounced seasonal increase in temperature (Wright *et al*., 2006; Neat and Righton, 2007; Righton *et al*., 2010, Figure 2.2). Consequently, although the northward and westward extent of the Q3 survey does not fully cover the range of North Sea cod, there is no reason to expect a mass displacement outside the region surveyed (see however Section 3.2.1 in this report).

With regards to point 2, there is little direct evidence on the suggestion that cod may be avoiding the warm summer temperatures in the southern North Sea. Neat and Righton (2007) compared the temperature experience of 129 DST tagged cod released in the northern and southern North Sea with independently measured contemporaneous seabed temperature data. The majority of cod experienced a warmer fraction of the sea than was potentially available to them (Figure 2.2). By summer, most of the individuals in the south experienced temperatures considered super-optimal for growth. Cooler waters were within the reach of the cod and a small number of individuals migrated to areas that allowed them to experience lower temperatures, indicating that the cod had the capacity to find cooler water. Most did not, however, suggesting that the changing thermal regime of the North Sea is not yet causing adult cod to move to cooler waters. It is nevertheless possible that temperature affects other aspects of cod behaviour that in turn affects their accessibility to the surveys. For example, data from DST tagged cod suggest that the fish are less vertically active in warm temperatures (Wright and Neat; unpublished analysis) and this may affect their susceptibility to capture by bottom trawl and also their likelihood of seeking hard ground for shelter which would again influence their susceptibility to bottom trawling.

With regards to point 3, the low density of cod from the southern North Sea may not only be linked to those that spawn in the North Sea that are surveyed in the IBTSq1 survey. A significant proportion of cod from spawning grounds in the eastern channel enter the North Sea during summer (Righton *et al*., 2007). Consequently, reductions in cod abundance or lower exchange rates from the eastern channel to IVc could influence cod abundance in the southern North Sea during the IBTSq3.

With regards to point 4, genetic evidence of structuring within the North Sea, based on microsatellite DNA (Nielsen *et al*., 2009) and more recently a suite of single nucleotide polymorphic DNA, indicates that there are at least two subpopulations within the North Sea, separated by a preference for the shallower (<100 m), warmer vs. deeper, cooler waters. Currently, the deeper-water subpopulation is the most commercially important. Analyses of survey data indicate that the spawning stock and recruitment trends of this subpopulation may differ from those in the southern North Sea, although further work is required (Holmes *et al*., 2008). Consequently, the suggestion of lower recruitment in the southern area does seem a reasonable explanation for the long-term trends, although clearly the seasonal re-appearance of age 2+ cod in IVc in the Q1 survey suggests that there are seasonal movements affecting distribution. The presence of subpopulations largely inhabiting different regions of the North Sea will also mean that there is the potential for regional differences in mortality, because cod from the deep-water subpopulation would not be expected to re-colonize areas depleted in the southern North Sea. However, lack of historical data at the required resolution will likely impede analytical assessments at the subpopulation level.

In addition to these points, an animation representing cod spatial and temporal distribution of cohorts of cod in the North Sea and IIIa, based on the work from Lewy and Kristensen (2008). Using IBTS data from 1991 to 2009, a Log Gaussian Cox model was fitted on IBTS data 1991–2009, in order to estimate spatial abundance surfaces (relative spatial distribution at each time-step) throughout the life of each cohort. Weekly surfaces are estimated on a grid surface (866 squares), and a movie animation using Adobe Flash allows lively visualization of cod distribution (see some examples Figure 2.3). It is difficult to summarize these animations into consistent and synthetic findings, and more work should be done to derive comparative metrics across cohorts.

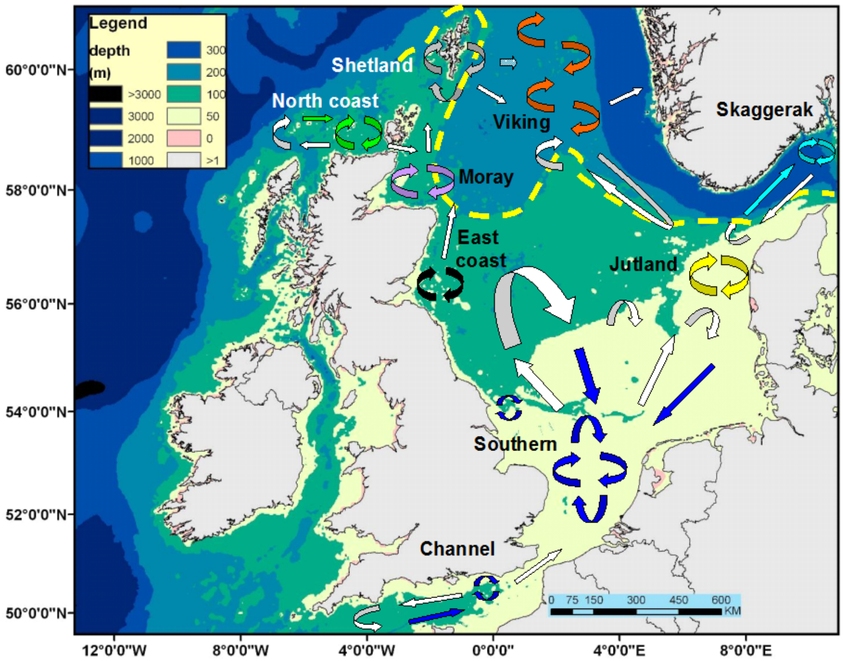


Figure 2.1. Schematic to illustrate proposed movements of cod that spawn in the North Sea. Resident groups and movements at spawning time (Q1–Q2) are represented by coloured arrows. Movements outside the spawning season are represented by white arrows. Data from: Shetland: Neat *et al.* (2006), Wright *et al.* (2006a); Viking: Neat *et al.* (unpublished), North Coast, Moray, East Coast; Wright *et al.* (2006b); Southern, Channel and Jutland; Righton *et al.* (2007), Skagerrak; Svedang *et al.* (2007). The dashed yellow line approximates the 100 m contour which can be used as a proxy to separate the northern deeper water subpopulation from the shallower water subpopulation mainly to the south.

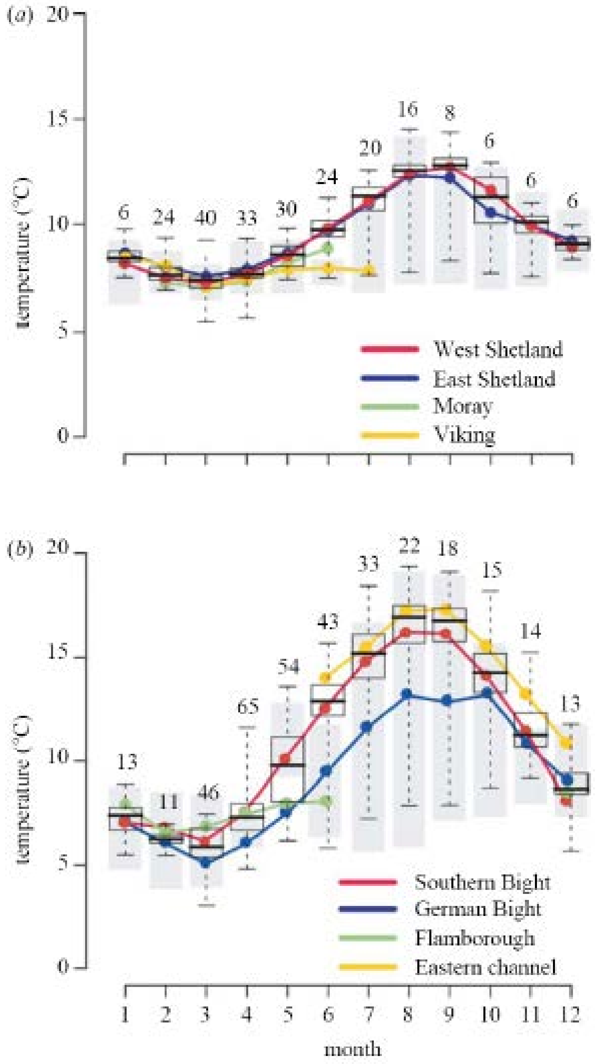


Figure 2.2. (a) Sea bottom temperatures and the monthly thermal experience of cod in the northern North Sea. The limits of the boxes show 25 (upper) and 75% (lower) quartile temperature ranges, while the black line shows the median temperature. Error bars/whiskers show the full range of the temperature experience. Numbers above the error bars indicate the number of cod at liberty during each month. Average monthly temperature experiences of cod from each release site are shown by colours. The range of CTD data in each month is represented by filled grey bars. (b) Same plot for the southern North Sea. From Neat and Righton, 2007.

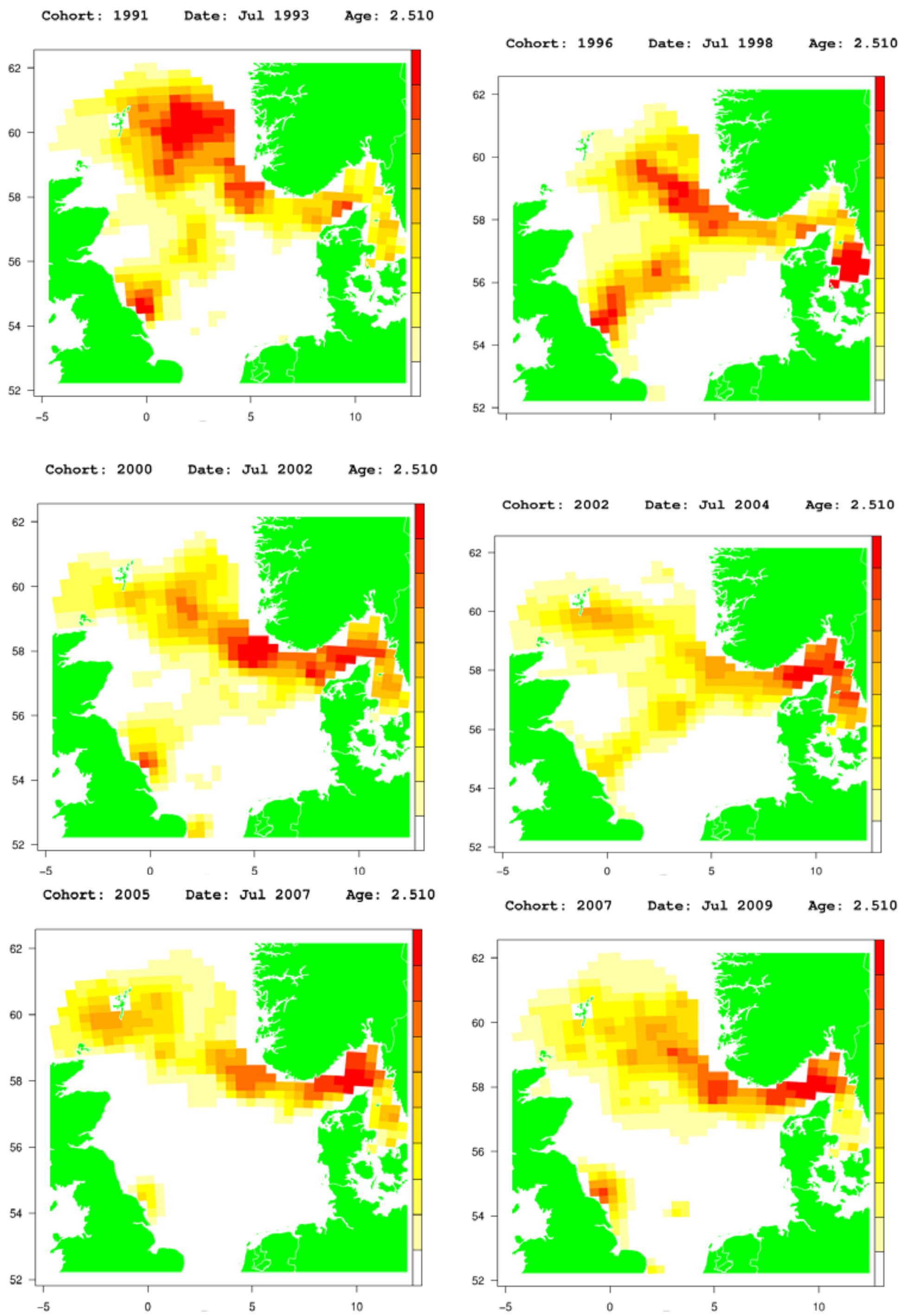


Figure 2.3. Relative distribution of 2-year old cod in July for some selected cohorts. Extracted from the animated display of weekly surfaces as estimated by Lewy and Kristensen (2008).

3 Compilation of available data

3.1 Potential bias in discard and landings data

This section summarizes material made available to WKCOD regarding availability of external quantitative and qualitative data related to the potential reduction in bias in the catch data in recent years.

3.1.1 Scottish discard estimates

A discard sampling scheme has been run in Scotland since 1978, covering (on average) 75 trips by Scottish vessels in the North Sea, West of Scotland and Rockall. The system used for raising sampled discard rates to fleet discard rates is currently under development at Marine Scotland-Science (MSS). In the new stratified system, the sample data are raised using the landed weight of demersal species (for sampled vessels in the strata) against fleet landings of demersal species (in the strata). Note that the use of this particular auxiliary variable (weight of demersal species landed) is not particularly satisfactory for estimating the discards of the *Nephrops* gears. This is because the incidence of 100% discarding of demersal fish are frequent and where landed, the weights of demersal fish landed are small compared with the weight of demersal fish landed by vessels using demersal gears. This issue is one of several being ad-dressed by new methodological developments.

An advantage of the new approach is that it permits the estimation of CVs and confidence intervals about the discard estimates. For cod in the North Sea in 2009, the estimates are as follows:

Fleet	Estimate	Lower bound	Upper bound	CV
Overall	6734 t	4400 t	9809 t	20.13%
Demersal gears	5776 t	3506 t	8616 t	
Nephrops gears	958 t	444 t	1713 t	

This gives an indication of the general level of uncertainty about Scottish discard estimates, although this will probably have changed through time. In addition, the table does not address the question of discard estimate bias, which has not yet been quantified.

3.1.2 Accuracy of Scottish landings data

Marine Scotland-Compliance (MSC: formerly Scottish Fisheries Protection Agency, SFPA) is the Scottish government department responsible for monitoring the Scottish fishing industry, and thereby attempting to ensure compliance with extant regulations. MSC operate a system intended to detect unreported or otherwise illegal fish landings (known as "blackfish"), in which there are two main categories:

1) **Suspected blackfish.** This is where MSC officers have reason to suspect that at least part of the catch has not been declared: that is, the logbook differs significantly from similar vessels in the same area, or there are re-ports from informants about a part of a landing being removed from the market, or officers suspected a landing took place when none was re-corded and they have enough information which would allow them to quantify that landing.

2) **Detected blackfish.** This is where a logbook was obviously amended immediately prior to the arrival of MSC officers, or where someone was prosecuted for under-declaration.

Time-series for these categories are shown in Figures 3.1.2.1 and 3.1.2.2. Actual tonnages cannot be given here, as that is confidential information, so both graphs are indexed so the amounts are a proportion of the maximum in the series, which in both cases occurred in 2003. Figures before 2001 were not collected in the same rigorous manner, so these cannot readily be compared with 2001 and beyond.

In the past few years the amount of blackfish has dropped so low as to be negligible (although the index time-series are not quite zero) and that trend has been consistent. While it has had an effect, it would be an oversimplification to suggest that the UK Registration of Buyers and Sellers (RBS) regulation was solely responsible for this behavioural change in the Scottish fleet. Other potential driving factors are:

1) Two large-scale decommissioning schemes targeted on whitefish vessels run by Scottish Government, which between them removed over half of the demersal fleet. This removed many vessels that were not viable within the quota available. It also freed up the trade in quota, meaning that those vessels which wished to operate legally at least had the option to buy quota and legitimise their operations. Prior to this there simply wasn't enough quota available for the size of the fleet.

2) The development of targeting and monitoring systems has significantly increased the pressure on the fleet. MSC are now able to know which vessels were landing most blackfish, where they normally landed it, what times of day they landed it, what days of the week, etc.. Those who were involved in the illicit trade were monitored all the time and many could not operate profitably, instead being driven to look for decommissioning. When RBS came along, MSC were also able to link buyers to miscreant vessels and target them directly, thus increasing the pressure further.

3) The RBS legislation for the first time made buyers culpable if they participated in blackfish. Many of them were unhappy with being liable to prosecution so they stopped buying illegal fish. This began to remove the demand side of the equation in the blackfish trade. Vessels operating legally found that they were making far better profits as they didn't have to sell fish cheaply on the black market and the prices of their catches were not undermined by a large-scale alternative black supply chain. That eventually led to skippers and vessel owners which were operating legally starting to work with MSC to target residual illegal activity among other vessels: they knew that other vessels operating illegally were undermining their businesses.

WKCOD concludes that the incidence of underreporting in the landings in the Scottish fleet fishing for cod has declined significantly since 2003 and is likely to be extremely low since 2006.

Misreporting (by area) in the Scottish fleet is detected by mainly manual means. Tamper-proof VMS has meant that vessels which are area misreporting have to physically make the voyage that they are claiming for: previously, they may have just entered fictitious voyages on their logsheets. Currently, all logsheets for vessels which have been in more than one ICES area during a voyage are inspected manually for suspicious or "miraculous" entries. This again allows compliance officers to know who is area misreporting and where they are doing it. Targeting for this aspect is fairly easy and those who persist have a very hard time avoiding detection. Most vessels have now bought or leased quota to align their entitlements with their fishing patterns. MSC also have automated routines which pick up suspicious catch rates (either high or low), and once highlighted, these are manually analysed to see what is happening. CCTV is also helping deter misreporting but that is still in its infancy.

One of the biggest issues with misreporting is the so-called French line where catch composition rules mean that some species are misreported on either side of the line. That does affect overall catch stats of course but does undermine other aspects of fisheries management. The problem of misreporting persists but it is small compared with what existed before. It does occur for particular reasons such as monk and hake in the North Sea and various species in the Faroese zone but is considered to be negligible for cod and haddock.

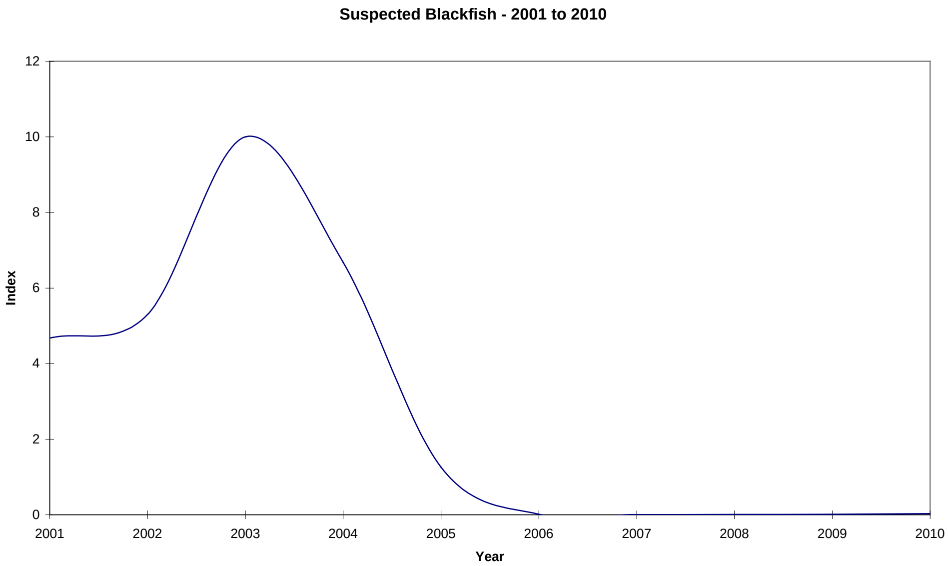


Figure 3.1.2.1. Index of suspected blackfish in Scottish landings 2001–2010, as compiled by Marine Scotland-Compliance. Data are scaled relative to the maximum in 2003.

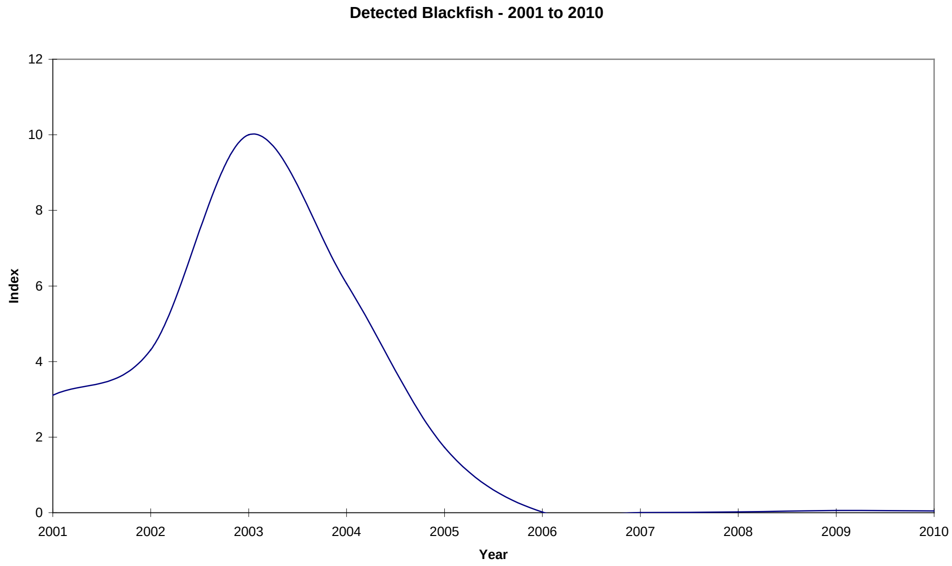


Figure 3.1.2.2. Index of detected blackfish in Scottish landings 2001–2010, as compiled by Marine Scotland-Compliance. Data are scaled relative to the maximum in 2003.

3.1.3 Danish Fisheries Control, - Control on cod landings

The text below is summary information from an internal report on the Danish Fishery Directorate's control of cod fisheries in the North Sea, the Skagerrak, and the Kattegat.

The new regulation system in Denmark: *"January 1st 2007 a new regulation for the demersal species (including cod) was carried through in Denmark. The new regulation implied a shift from a regime based on rations per period (individual non-transferable rations) to a regime based primarily on Fixed Quota Allocations (FQA). FQA-vessels were allocated a fixed share of that part of the Danish quota which is allocated directly to the fishermen. A small part (in quantity) of the demersal fishery is still regulated on the basis of rations, the Less Active Vessels. Another part is categorized as "Other vessels". They are in principle not allowed to catch those demersal species covered by the FQA-regime, e.g. cod. The new regulation regime caused a decrease in tonnage, engine power and number of commercial vessels".*

Analyse of the control of cod landings: *"The Directorate of Fisheries carries out a risk based cod control. It is carried out according to a control plan which classifies the fishery in different segments with related control marks… Approximately 5% of the total amount of landings which includes cod and approximately 10 % of the landed amounts of cod in the period from 2008 to June 30th 2010 has been controlled…(Infringements are observed on average at every tenth control. Infringements concern especially rules regarding how to keep the fishing logbook and rules regarding notification)".*

Analyse and estimates of whether there have been any indications of missing reports of landed cod: *"According to the Directorate of Fisheries the following indications would be a sign of missing reports of landed cod:*

- *Difference between submissions of logbook information and of sales notes.*
- *Difference in landing rates of cod for controlled and non-controlled fishing trips.*
- *Recorded infringements concerning missing registration of cod in logbook, missing prior notification and illegal placing on the market.*

- *Control results from accounts control at buyers, as well as the cooperation with the Danish Tax and Customs Administration (SKAT).*
- *The Inspectorates of Fisheries assessments of the extent of missing submis*sions of sales notes.

Based on the analysis in the report of these six indications the Directorate of Fisheries does not estimate that there is placing on market of illegal fish on a big scale".

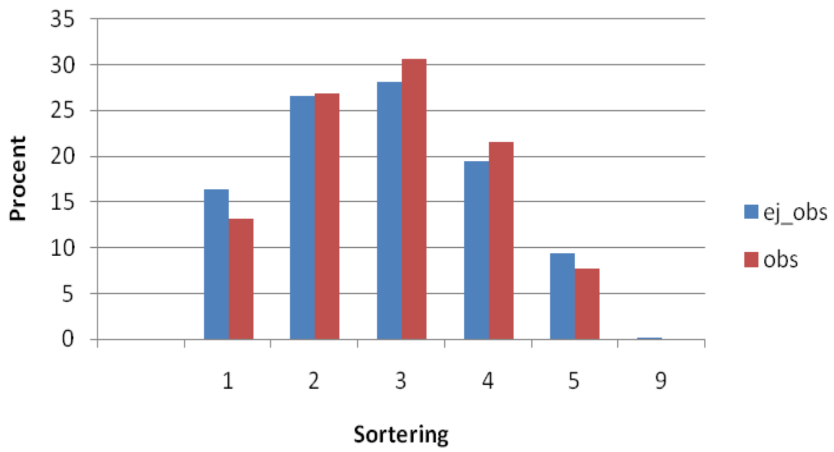
In addition to the internal report from Danish Fishery Directorate's, The Danish Fishermen's Association notes that they have been informed that the Danish Fisheries Directorate has calculated the difference between the total quantity of cod registered in the logbooks and the cod registered in sales receipts for Danish vessels over ten meters per quarter over the period 2008–2010 (for 2010 only the first half is included). It is demonstrated, that the difference (i.e. the misjudgement) varies between approx. 0.5% and 2.5%. The Danish Fisheries Directorate is therefore of the opinion, that there is no indication of lack of reporting of cod of any significance for vessels of ten meters and up.

3.1.4 Danish discard estimates

The size composition of landed cod from trips with and without an observer on board was compared to investigate potential observer effects on discard estimates (e.g. less discard with an observer on board). Danish fishing trips with an observer on board had a total cod landing in 2010 at around 50 t for the North Sea and 20 t for Skagerrak. Figure 3.1.4.1 shows the proportion of landed cod weight by commercial size classes for trips with and without an observer on board. For The North Sea the proportions of the smallest (size class 5) and the largest (size class 1) cod are actually lowest from trips with observers (Figure 3.1.4.1a). Such pattern is not expected if discard rates of mainly small cod is lower with an observer on board. For the Skagerrak (Figure 3.1.4.1b), the proportion of the smallest cod (size class 5) is however highest from observer trips.

As a consequence of conflicting signals from the two catch areas and the limited data sampling, it cannot be concluded that the present discard estimates are biased.

a) North Sea



b) Skagerrak

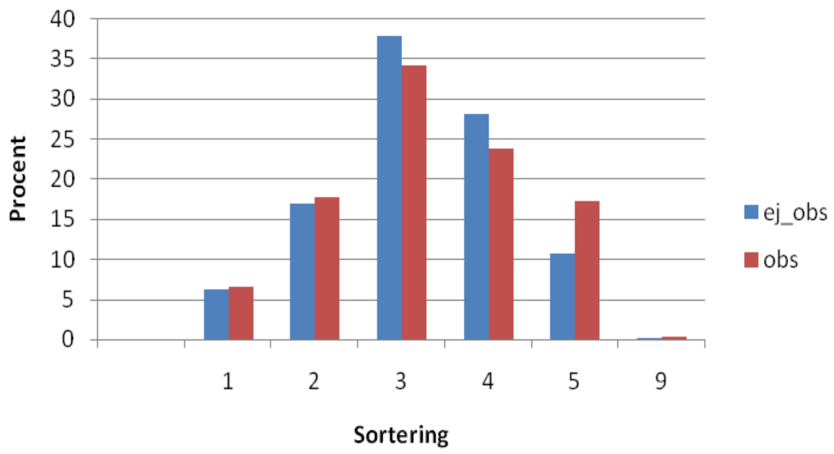


Figure 3.1.4.1. Landings distribution of cod by commercial size class (x-axis "Sortering") from trips with observer on board (label "obs") and without observer on board (label "ej obs") for the Danish fishery in a) North Sea and b) Skagerrak in 2010. Size class 5 includes the smallest cod, size class 1 the largest. Size class 9 is "mixed sizes".

3.2 Survey data

3.2.1 Area coverage

3.2.1.1 Autumn survey catch rates adjacent to the Shetland Isles

Fernandes and Coull (2011 WD 6) examined the catch rates of cod in additional survey stations sampled as part of the Scottish August groundfish survey to the north and west of the Shetland Isles (area A in Figure 3.2.1); stations outside the area usually sampled by the International Bottom Trawl Survey. Over the three years available for comparison catch rates in the additional areas were not significantly different from those around Shetland which were inside the area that is usually sampled by the IBTS survey (area B in Figure 3.2.1). The authors concluded that the density of cod in the region was adequately represented by the existing stations contained in the IBTS cod area and so the survey indices, expressed as average catch rates, should not have been biased by the presence of cod outside the survey area. (See also next section).

3.2.1.2 The Skagerrak and southern North Sea

An analysis of IBTSQ1 data by Rindorf and Vinther (WD 4 in ICES-WGNSSK, 2007) illustrated the increased importance of recruitment from the Skagerrak. The survey indices from IBTSQ1 and Q3 used in the stock assessment only included catch rates from the three most easterly rectangles of Skagerrak. WKROUND (2009) compared the standard and an extended area IBTS index which included extra rectangles for IBTS Q1 and Q3. The extended area indices demonstrated relatively minor changes in abundance for the ages used in the assessment. The largest changes occurred at the younger ages, particularly for age 0 in IBTSQ3, which is not used in the assessment. Based on improved fits to the extended indices and other benefits of using these indices (such as better coverage of the stock distribution area), WKROUND concluded that it would be beneficial for the North Sea cod assessment to use the extended indices in future analyses. Correspondence between WGNSSK and the IBTSWG during spring 2009 discussed the addition of the suggested areas to the calculation of the extended index. Some of the rectangles were not covered by surveys each year and a modified list was agreed (Figure 3.2.3).

After calculation of the extended area and standard indices using the IBTS Q1 2009 values, large differences between the indices were noted at the older ages that did not occur in previous years. There was insufficient time before the WGNSSK meeting to investigate the reason for the differences and therefore a decision was made to continue with the standard indices for a further year before the transition to the extended area surveys was undertaken. Subsequent work by the ICES secretariat identified that the difference between the 2009 indices may have resulted from the application of differing age–length keys for that year.

At WKCOD new values for the extended indices were provided for the IBTS quarter 1 and quarter 3 surveys; a comparison between the indices at age derived for each of the areas at age is shown in Figure 3.2.3 a and b. As was established by WKROUND the largest changes occur at the younger ages with minor differences at the oldest ages. WKCOD endorsed the previous work by WKROUND and agreed that the extended area should be deriving the IBTS indices used for the stock assessment. During the WKCOD meeting the survey indices that include station to west of Shetland were compiled. A comparison between the survey indices based on the extended area (Skagerrak and southern North Sea) and those including the survey stations west of Shetland demonstrate only minor differences (Figure 3.2.4a and b). WKCOD concluded that additions of the stations west of Shetland should be used in the age based survey indices used in the analytical assessments.

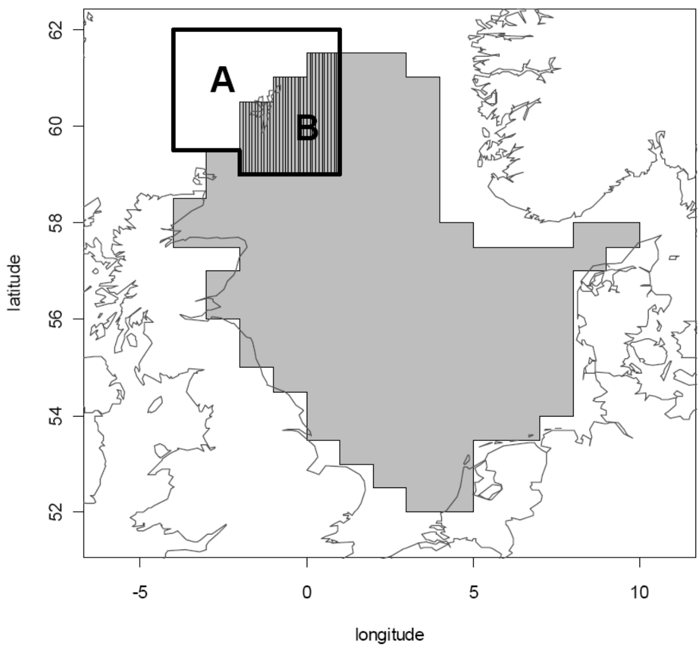


Figure 3.2.1. The IBTS cod area, shaded in grey; the Shetland demersal sampling area (thick black line) and two areas of interest to the northwest and southeast of Shetland Isles; lying outside and overlapping the IBTS cod area.

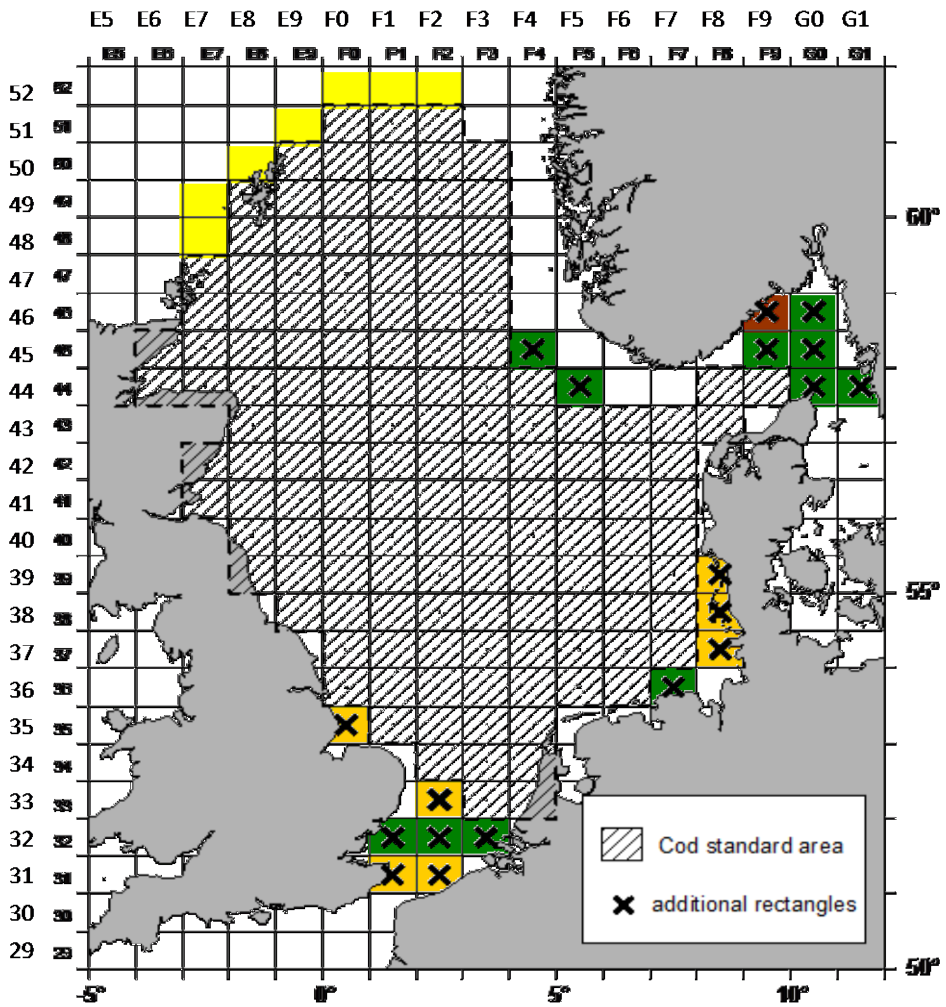


Figure 3.2.2. Extension of cod standard area used for the revision of IBTS indices. Crosses indicate suggested extensions to the survey; green squares indicate where the IBTS group indicate data are available; orange and brown squares indicate where intermittent coverage does not allow inclusion and the IBTS WG considered should be omitted; yellow squares indicate the exploratory extension around Shetland.

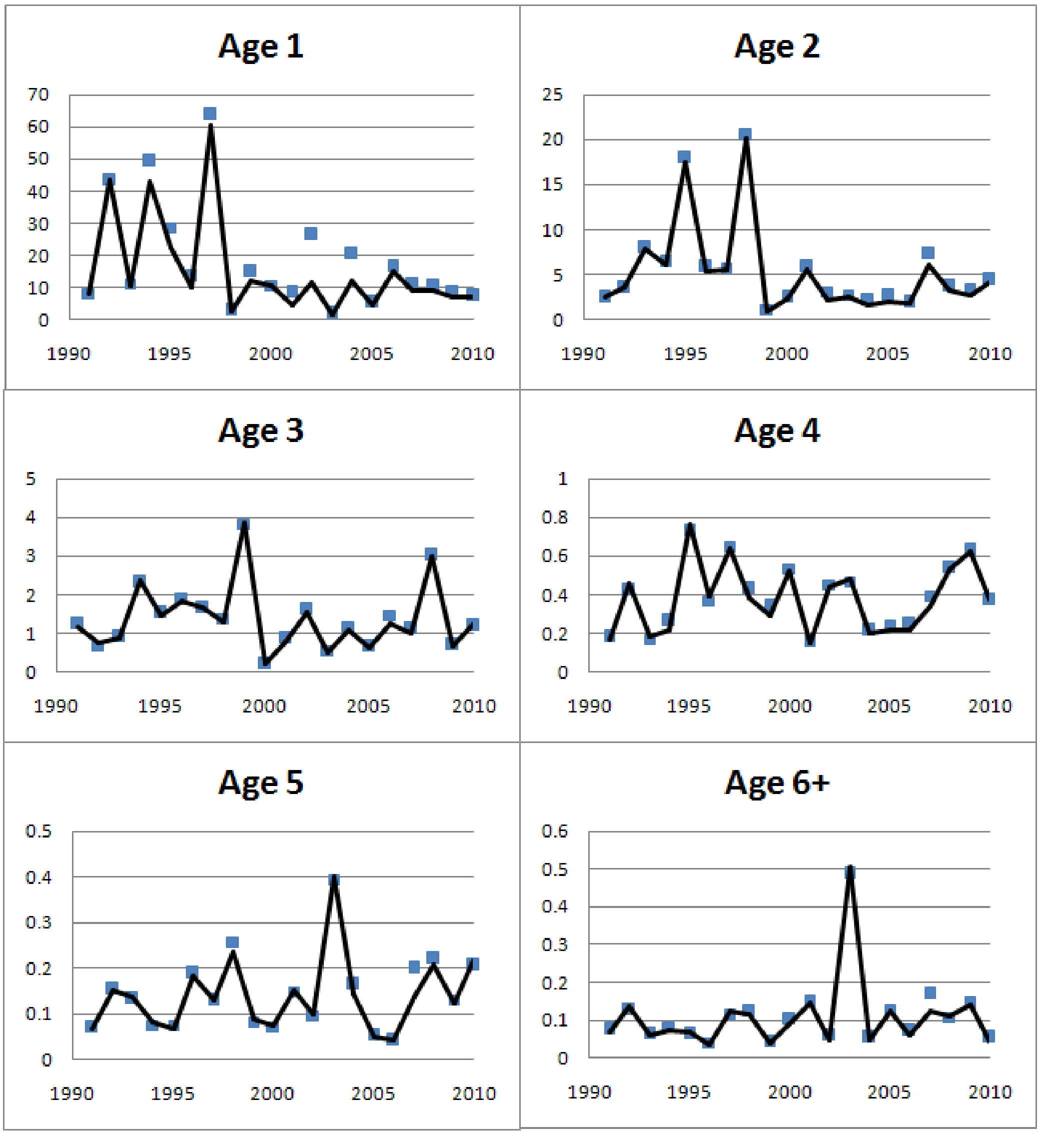


Figure 3.2.3a. IBTS Q3 indices at age calculated from the standard cod index area (line) and the extension of the index area to include the IBTSWG agreed squares in the Skagerrak and the southern North Sea (points).

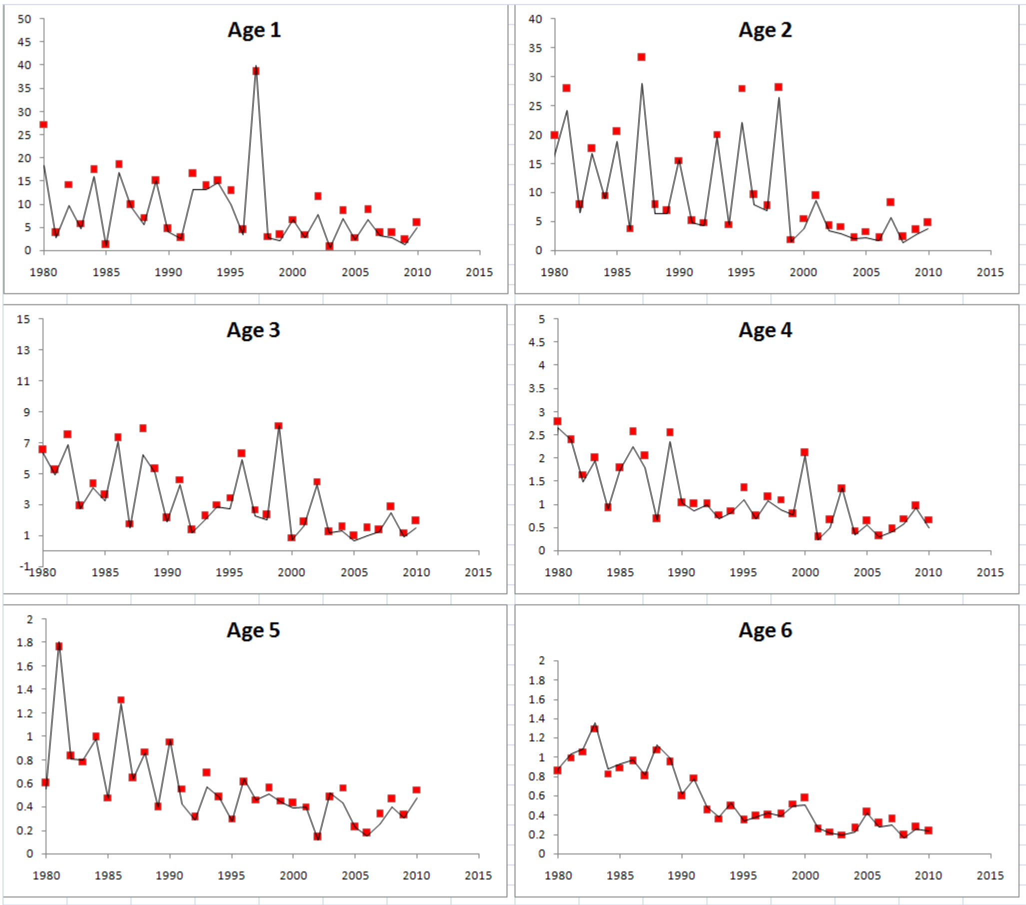


Figure 3.2.3b. IBTS Q1 indices at age calculated from the standard cod index area (line) and the extension of the index area to include the IBTSWG agreed squares in the Skagerrak and the southern North Sea (points).

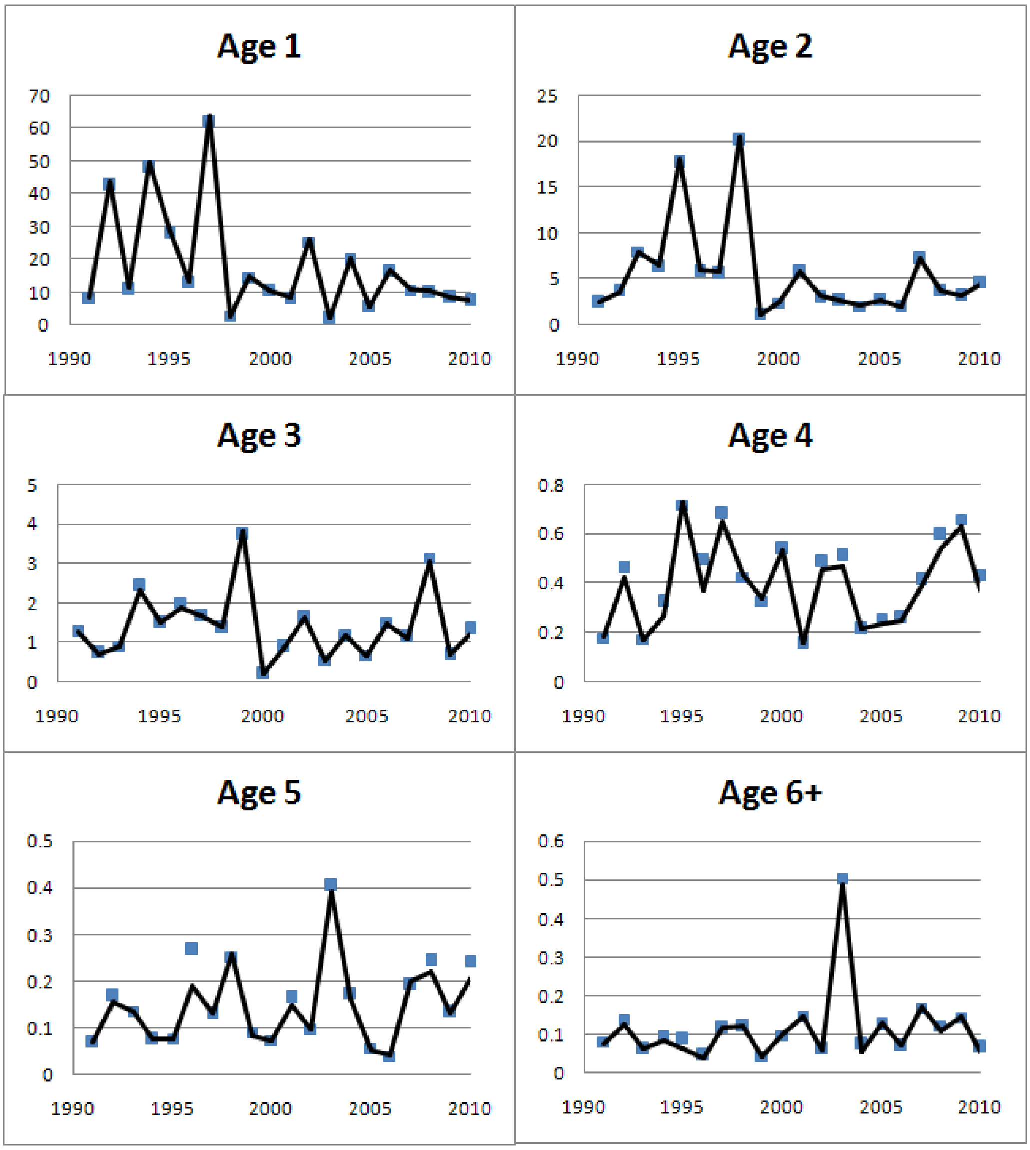


Figure 3.2.4a IBTS Q3 indices at age calculated from the extended index area which includes the IBTSWG agreed squares in the Skagerrak and the southern North Sea (Line) and the squares around Shetland (points).

Figure 3.2.4b. IBTS Q1 indices at age calculated from the extended index area which includes the IBTSWG agreed squares in the Skagerrak and the southern North Sea (Line) and the squares around Shetland (points).

3.2.2 Possible changes in catchability in IBTS quarter 1 and quarter 3

The 2010 assessment

Since 2004 the assessment of the North Sea cod has been conducted using the IBTSq1 and IBSTq3 surveys and models which estimate unallocated mortality from the stock (e.g. additional discarding, natural mortality and/or underreporting). In general, the assessment models provide similar estimates of the well-studied historical trends in the stock and fishery dynamics.

At the May 2010 meeting of the ICES North Sea stock assessment group (WGNSSK) it was noted that, when applied independently to the two survey-series (IBTSq1, IBTSq3) used for the assessment model calibration, diverging trends in recent fishing mortality estimates were observed. BADAPT assessments fitted to the first quarter survey-series indicated declining or stable mortality rates in recent years; when fitted to the third quarter survey, rapidly increasing mortality rates were estimated in recent years. The state space model SAM was less sensitive to the fitted data and indicated stable or declining rates. Independent of the model and dataset, SSB was estimated to be recovering but still well below safe level defined by precautionary reference level Bpa.

The WG could not identify the reasons for the differences between the survey information series concluding that there was insufficient time allowed to carry out a full analysis of the problem at the May meeting and recommended not using the assessment for advice until a full review and analysis could be conducted in time for the next release of ICES fisheries advice in October 2010.

Cod distribution in the surveys

Darby and Parker-Humphreys (2010) reviewed of maps of the spatial distribution of the IBTSq1 and IBTSq3 surveys in recent years to establish whether there have been any significant changes that could account for the differences in the mortality rate trends derived from the separate indices.

In spring the IBTSq1 survey has recorded cod as being distributed throughout the North Sea with a relatively stable spatial pattern of catches for all ages. Cod age 1 are generally distributed in the central North Sea in a band from the Skagerrak to the northeast coast of England. They spread northwest and southeast as the abundance increases. The contraction to the central belt is most noticeable in the distribution of the most recent weak year classes. Ages 2 and older are more wide spread, with concentrations on the northeast coast of England, between the Shetlands and Norway and between Norway and Denmark. The central tendencies of the spring concentrations have remained relatively stable through the time period, independent of the abundance.

The autumn distribution of cod in the IBTSq3 survey remained relatively unchanged until around 2003/2004, following which ages 2 and older have become increasingly concentrated in the northern region of the survey area. In recent years most of the positive catch rates of ages 3+ have been located in the most northerly areas of the survey against the northern boundary of the survey area. Catch rates in the southern region of the IBTSq3 survey area (the majority of rectangles) are very low or zero; this has been true of age 4 and 5 throughout the time-series but has been recorded in ages 2 and 3 since 2003/2004.

Darby and Parker-Humphreys (2011 WD 3) demonstrated that in recent years catch rates in the south are making less of a contribution to the survey index in quarter 3 than that for quarter 1 in which the relative contributions have been stable over the same period (Figures 3.2.5 and 3.2.6).

The reasons for the change in distribution of the quarter 3 survey are unknown. Either cod have changed their migration behaviour and are moving from the area in greater proportions or they have changed their local behaviour in the summer months and are becoming less catchable to the survey.

IBTS survey relative catchability changes

Rindorf and Vinther (2011 WD 1) and Darby and Parker-Humphreys (2011 WD 3) examined relative catchability changes in the catches of the IBTS quarter 1 and quarter 3 surveys. Both studies demonstrated that the catchability of the quarter 3 survey seems to have increased in recent years.

Figure 3.2.7 from Rindorf and Vinther (2011 WD1) shows the catch curves for the individual cohorts since 1990 using IBTSq1 (ages 1, 2, 3 ..) and IBTSq3 (ages 1.5, 2.5, 3.5..). Survey cpue decreased from age 1.5 to age 2 in all years and from age 2 to age 2.5 in all years but one in the cohorts from 1990 to 2001. However, the cohorts from 2002 and onwards has in the majority (four out of seven) of years exhibited increased catch rates from age 2 to 2.5. If it is assumed that the probability of obtaining this is equal to that seen in the early period (one in 12), the probability of obtaining this by chance in four years out of seven is <0.0001. Hence, there appears to have been a change in catchability or availability of age 2 or 2.5 cod over the period.

Figure 3.2.8 shows the consistency between catch rates with a time lack of a half-year. Given a linear relationship between cpue and stock size (cpue=N*q/effort) and a constant catchability and Z for the plot will demonstrate a straight line with intercept=ln(q1/q0)-Z and slope=1. Given a stock size dependent catchability (cpue=N^b*q/effort) the plot will demonstrate a straight line with intercept=-b1*Z+ln(q1)- b1/b0*ln(q0) and slope=b1/b0. The assumptions of constant catchability and Z for a longer period is unlikely, however given such assumptions for two periods (cohorts1982–2001 and 2002–2008) a consistent pattern appears for age 2 to 4. The intercepts have become larger for the first half-year (e.g. age 2 to age 2.5) and lower in the second half year. The change is consistent with an increase in catchability or availability of 2 and 3 year olds in the 3rd quarter. Hence, 1st quarter catches of age 2 are now followed by larger catches of age 2.5 than previously and this is again followed by lower catches in quarter 1 than would be expected from the higher quarter 3 catches. There was no evidence in a density-dependence in the change in catchability, as no slopes were significantly different between the two periods (P>0.2000 in all cases). However, there were significant changes in intercepts (equal to the effects of mortality and catchability). This can be caused by a change in the seasonal distribution of mortality (all mortality applied in the 2nd half of the year after 2002). However, this would not explain why there are now higher catches of 2-year olds in the 3rd quarter than in the 1st. In contrast to this, an increase in quarter 3 catchability should give identical numerical values which alternate between positive and negative values as is indeed seen in the data. The change in catch rate (equivalent to the change in catchability, if mortality and immigration remain constant) was close to 60% for ages 2 and 3, corresponding to catches in quarter 3 of these age groups being 60% higher than expected from the cohort size seen in quarter 1 surveys and the quarter 3 survey of the same cohort at age 1.5.

The conflict in the IBTS Q1vs.Q3 survey, an issue that had been raised by the WGNSSK in 2010 and subsequent working documents, was not fully resolved at the WKCOD meeting. It was concluded that until the reasons for the discrepancy have been resolved the quarter 1 survey is considered to more likely reflect actual stock trends in recent years, because of suspected changes in catchability/availability of cod in the quarter 3 survey in relation to recent changes in the fish distribution in latter part of the year. Additional considerations supporting this choice are given in Section 4.5.

It was recommended that further investigation would most appropriately be addressed within a working group on improving use of survey data for assessment and advice (suggested ToR will be part of the final WKCOD report).

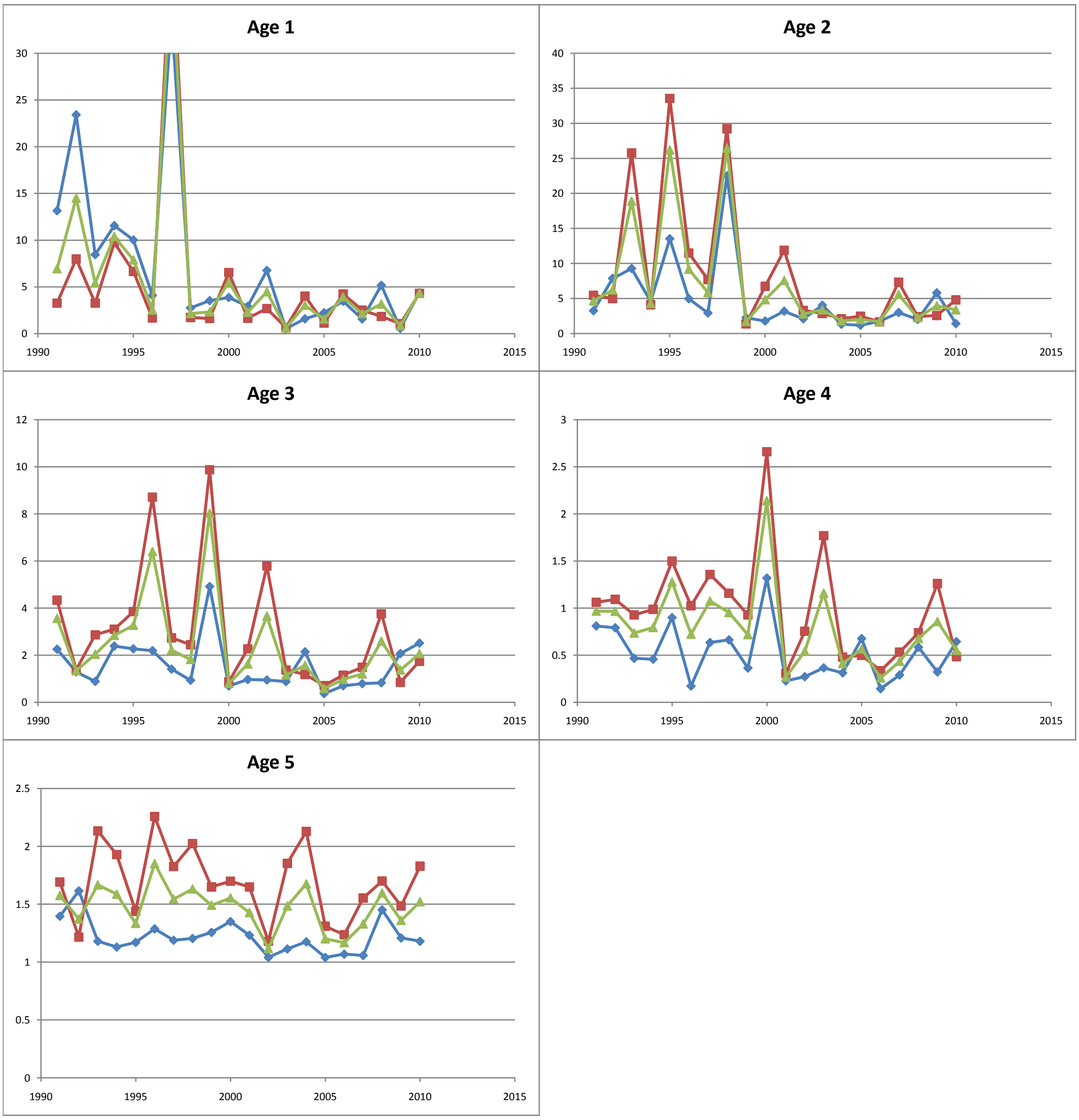


Figure 3.2.5. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. The time-series of IBTSq1 average survey catch rates at age for the northern (>= 56^0, red) and southern (blue) North Sea and the average index (green).

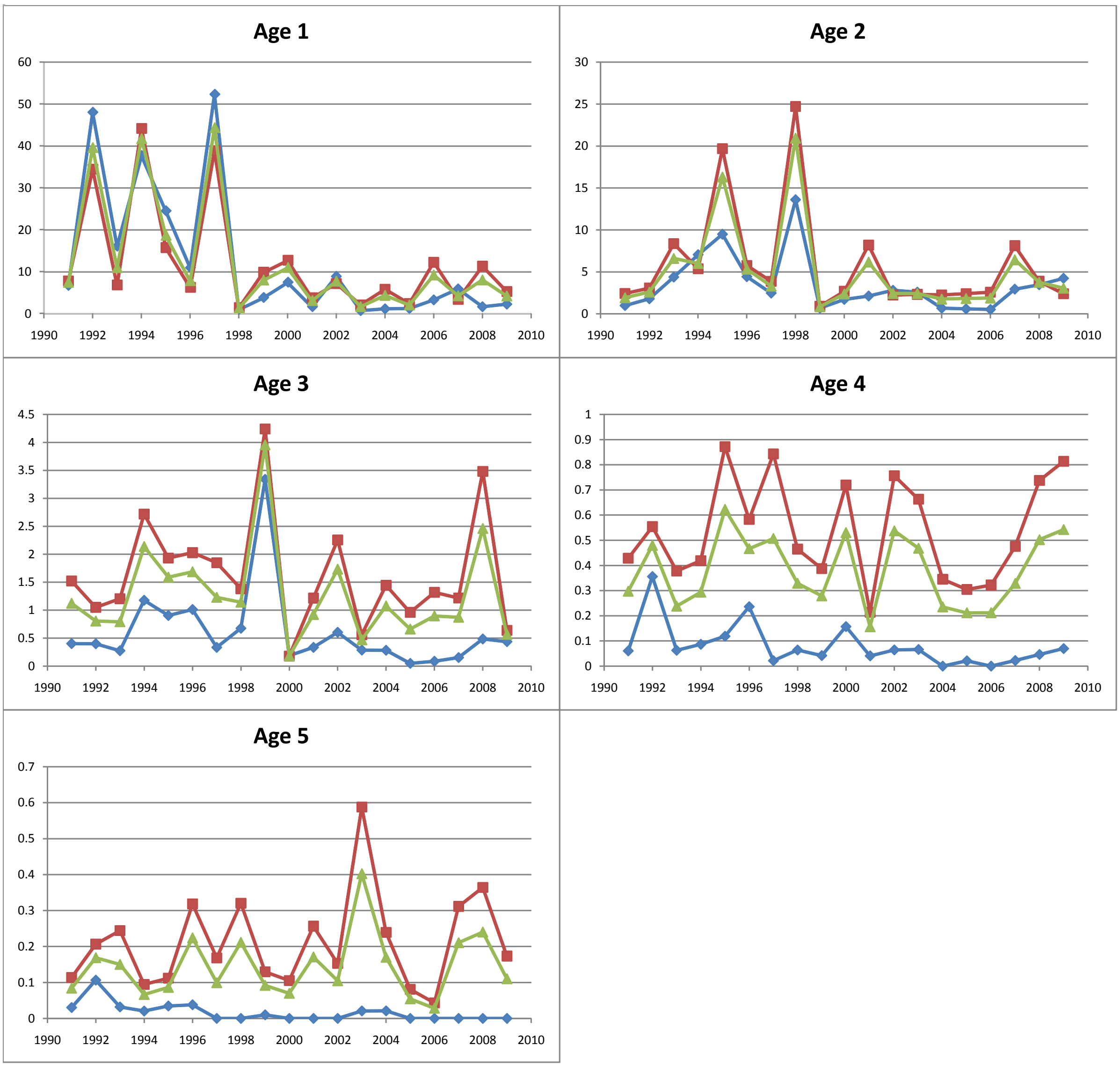


Figure 3.26. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. The time-series of IBTSq3 average survey catch rates at age for the northern (>= 56^0, red) and southern (blue) North Sea and the average index (green).

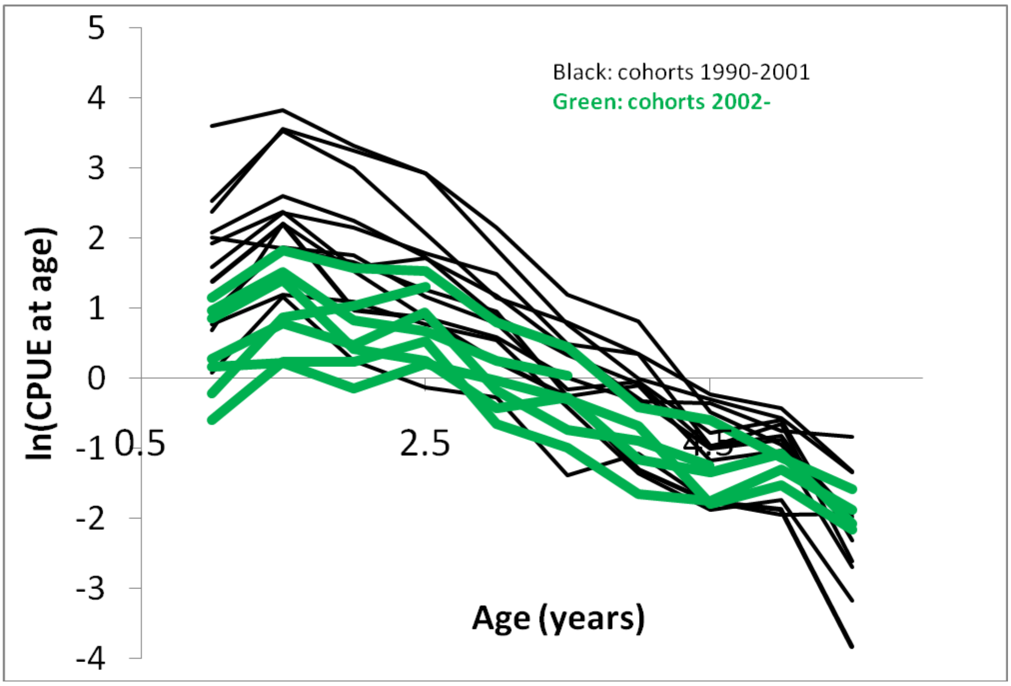


Figure 3.2.7. Catch curves for cohorts 1990–2008 based on IBTS Quarter 1 and 3.

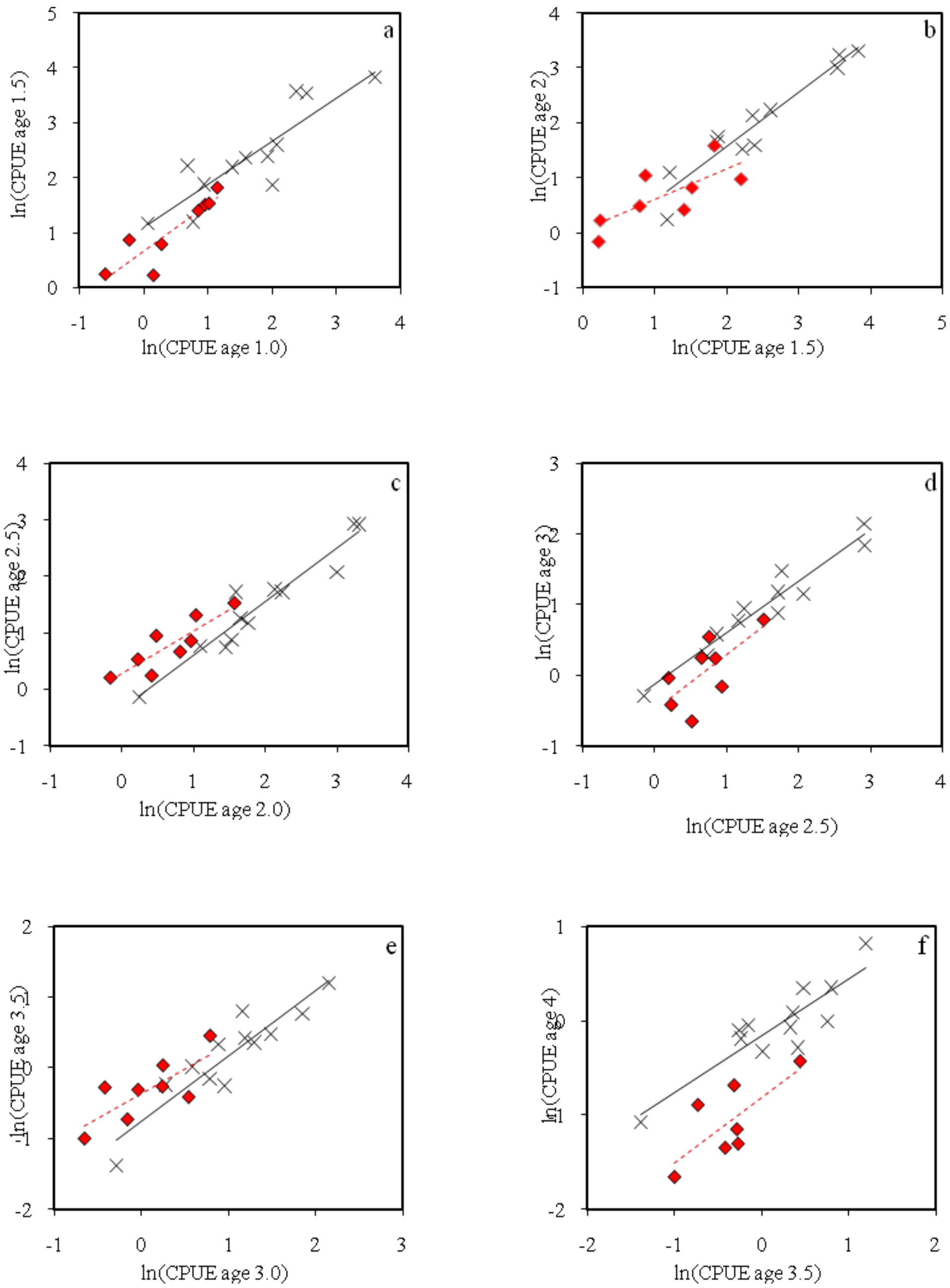


Figure 3.2.8. Consistency between quarter 1 and 3 catch rates of cohorts. Catch in quarter 3 of the cohort as a function of catch in quarter 1 of the same year (a, c and e) and catch in quarter 1 the subsequent year as a function of catch of the cohort in quarter 3 (b, d and f). Age 1 to 1.5 (a), age 1.5 to 2 (b), age 2 to 2.5 (c), age 2.5 to 3 (d), age 3 to 3.5 (e) and age 3.5 to 4 (f). Data points 1982 to 2001 are marked as crosses and 2002 to 2008 as diamonds.

3.3 Additional information

3.3.1 Commercial cod catches rates around Shetland Isles

An analysis logbook information from Shetland whitefish trawler which has been fishing with similar gear in the waters around Shetland for more than 20 years was presented to the meeting in Napier (2011 WD 4) following a study conducted by the

North Atlantic Fisheries Centre, Shetland. The vessel's skipper made available his diaries and other records which provide a record of the location, duration and the quantities of marketable fish (by species and size grade) retained. The data were used to determine the vessel's average annual landings of selected whitefish species per unit of fishing effort for the years 2002, 2005, 2007 and 2009 in each ICES Statistical Rectangle. Average lpues were calculated separately for the areas inside and outside the area from which IBTS survey data are used in the ICES North Sea cod stock assessment; the boundary of which cuts through the area fished by the commercial vessel.

The vessel fished predominantly in the waters around the north of Shetland, especially in ICES statistical rectangles 50E8 and 50E9, which together accounted for about three quarters (74%) of its fishing time over the four years so far included in the analysis. Over the four years the vessel made a total of 3068 hauls, totalling 18 651 hours (average haul duration of 6.1 hours). About two thirds (69%) of the vessel's fishing time was spent inside the North Sea cod stock survey area, and one third (31%) outside. The proportions of her cod landings taken from the two areas were similar (70% inside, 30% outside). Between 2005 and 2009 the overall average cod lpue (all hauls) more than doubled, from 32 to 74 boxes per 100 hours fishing time (Figure 3.3.1). The increase was greater outside the North Sea survey area, where the lpue more than trebled, than it was inside.

WKCOD support the analysis of time-series from representative commercial vessels and consider that they provide a useful addition to the information used to support advice to managers; especially on the regional development of the cod substocks within the North Sea and the catch rates encountered by differing gear types.

After reviewing the commercial catch rates from the example vessel illustrated in Napier (2011 WD 4), WKCOD analysed UK commercial landings per unit of effort (days fishing) to the northeast and west of Shetland compared to the south and east (areas A and B in Figure 3.2.1). Analyses were conducted by gear type and vessel length. Landings per unit of effort (lpue) do not contain discard information or allow for reductions in catch/landings rates resulting from changes in fisher behaviour as part of the Scottish Conservation Credits programme; recent values are therefore likely to be underestimates of the catches and potential catch rates.

Vessels from 19–23 m had a slightly greater increase in their catch rates to the north and west of Shetland, as noted by Napier (2011 WD 4), by a factor of 4 compared to 3.5 in the east (Figure 3.3.2). When catch rates were averaged across other vessel lengths and across all vessels, the WKCOD analysis could not identify differing rates of increase to either side of the Shetlands but did demonstrate that all vessels have had strong increases in recent lpue around the Shetlands in recent years as reported by Napier (2011 WD 4). Rates in 2009 are similar to those observed 2000–2002 (Figure 3.3.2, top).

The cod catch rates in the NW compared with the SE demonstrate similar absolute values and similar trend over the time period 2000–2010. This is in line with the similarities observed in the densities in the Q3 survey observed in the last three years (Section 3.2.1) and supports the conclusion that exclusion of the survey area west of Shetland is unlikely to have caused significant bias in the survey indices given how they are currently compiled.

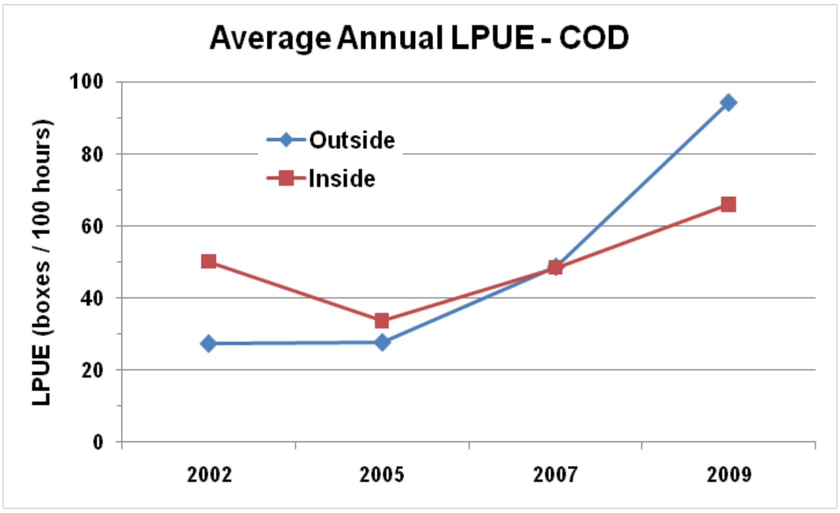


Figure 3.3.1. Changes in catch per unit of effort for a commercial vessel fishing to the north and west, compared to the same vessel fishing to the south and east of the Shetlands.

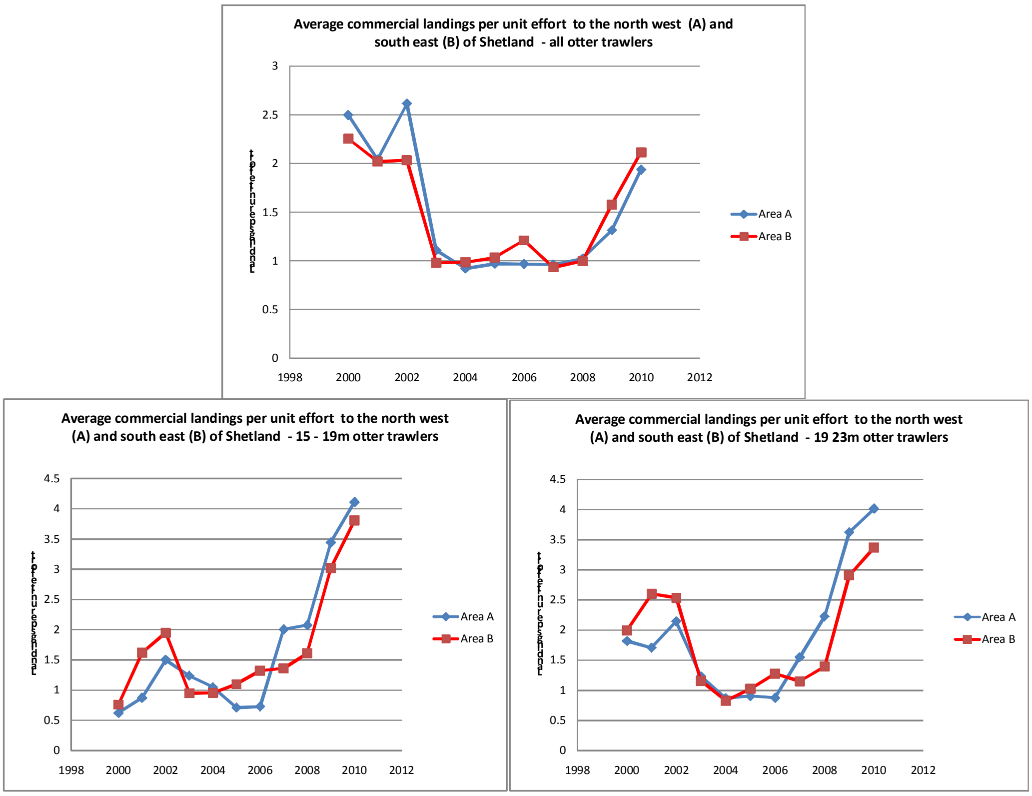


Figure 3.3.2. Changes in the time-series of officially reported landings per unit of effort for other trawlers fishing to the north and west (Area A), compared to the south and east (Area B) of the Shetlands.

3.3.2 Comparison between IBTS and commercial catch rates

Many fishermen do not consider the IBTS as representative for the stock status as the commercial fishery maintained viable catch rates also in areas where the IBTS reported no or low densities of cod above minimum landing size. In addition IBTS does not cover rough bottom where highest commercial cpue of cod is usually obtained and have thus a much less pessimistic perception of the status of the stock than the most recent assessments suggested. Against this background, a collaborative biologist-fishermen project on spatially explicit management methods for North Sea cod (REX) was established by DTU Aqua and the Danish Fishermen Association in summer 2006.

Based on the REX project, Wieland, Pedersen Beyer (WD 5) compare catch rates of cod by a commercial trawler with IBTS catches in small area of the North Sea in 2007 to 2010. Mean cpue at age for the surveys with the commercial trawler were significantly higher on rough bottom than on smooth bottom for all age groups in the years 2007 to 2009. However, the difference in cpue between the two bottom categories decreased for age 1 and age 2 in 2010 and for the older ages slightly higher catch rates on smooth than on rough bottom were observed in that year. More data and analysis on the distribution of cod on hard and soft bottom are needed to investigate the potential bias in the IBTS index which is mainly done on soft bottom.

Length distributions from the commercial trawler revealed peaks at about 30 cm (age 1) and 45 cm (age 2) but also a broad range of medium sizes (>55 cm, age 3 and 4) and even frequently larger (>85 cm, age 5 and 6+) cod. In contrast, the length distributions from the 3rd quarter IBTS were dominated by small (<45 cm) individuals and larger cod were generally rare. The small numbers of medium and large sizes of cod in the IBTS catches may, however, be as a result of the relative low sampling intensity in the study area and does not necessarily mean that the IBTS is not able catch representatively older ages (3+) of cod in general.

3.3.3 Some information about trends in fishing effort

The STECF SG-MOS 10-05 collected effort and catch information for EU member states to evaluate the implementation of fishing effort regimes in European waters. Summary figures are publicly available on STECF website, and can be used to inspect the main trends in effort and cpue reported, as supplementary information potentially indicative of trends in fishing mortality. Gear denominations are those used in the EU effort management plan, Appendix II to Annex IIa of Council Regulation 43/2009.

The main gear landing cod in EU is primarily TR1 (Bottom trawls, Danish seines and similar towed gear, excluding beam trawls, of mesh size equal to or larger than 100 mm), mainly operated by Scotland, Denmark and Germany (Figure 3.3.3), and then, to a smaller scale, GN1 (Gillnets and entangling nets, excluding trammelnets), mainly from Denmark, BT2 (Beam trawls of mesh size equal to or larger than 80 mm and less than 120 mm), mainly from the Netherlands, and TR2 (Bottom trawls, Danish seines and similar towed gear, excluding beam trawls, of mesh size equal to or larger than 70 mm and less than 100 mm), Figure 1. Trends in TR1 landings largely reflect the trends in TAC, which has increased in 2009.

Discards estimates have been provided for the main gears and member states. No estimates are available for GN1, but discards are assumed to be low in this fishery. Discards rates have been very high in the recent years, between 40 to 60% in TR1 and 50 to 70% in TR2 (Figure 3.3.4). However, discards rate have dropped in many of the main segments in 2009, likely owing to an increase in the TAC and the initiation of a number of cod avoidance schemes in Member States. Data for 2010 are not yet available.

In terms of fishing effort, there has been some decrease since the implementation of effort management plan in 2003, but this has levelled off in 2008 and 2009. The main cod fishing segment, Scottish TR1, has demonstrated decreasing effort until 2007, and then a slightly higher level in 2008 and 2009. In 2009, the effort reductions imposed by the Effort management plan were alleviated for this fleet owing to the implementation of conservation credit schemes, and therefore no further reductions were observed. Most drastic effort reductions in Denmark were observed in 2007, following the introduction of FKA (Vessel-based transferable quota).

In conclusion, and as noted by the STECF plenary (STECF PLEN 10-03), the effort and catch information reported by member States to the STECF-SGMOS 10-05 WG, indicates that fishing mortality is likely to have decreased somewhat from 2003 onward and to have remained stable over the period 2008–2009. Furthermore, STECF also noted that there is no evidence of a decline in fishing effort for the main fleets exploiting cod since 2008.

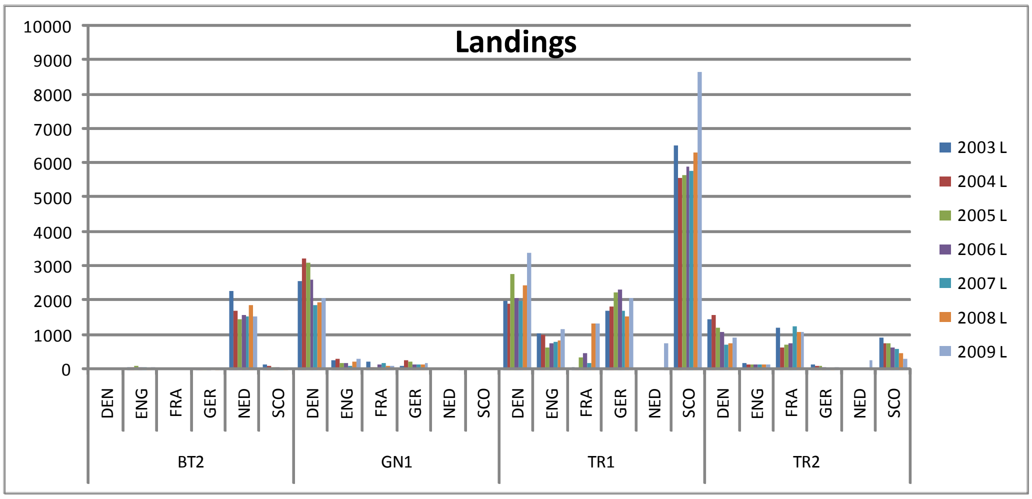


Figure 3.3.3. Cod landings in Area IV, IIIa and VIId broken down by main EU Member state and gear. Source STECF SG-MOS 10-05.

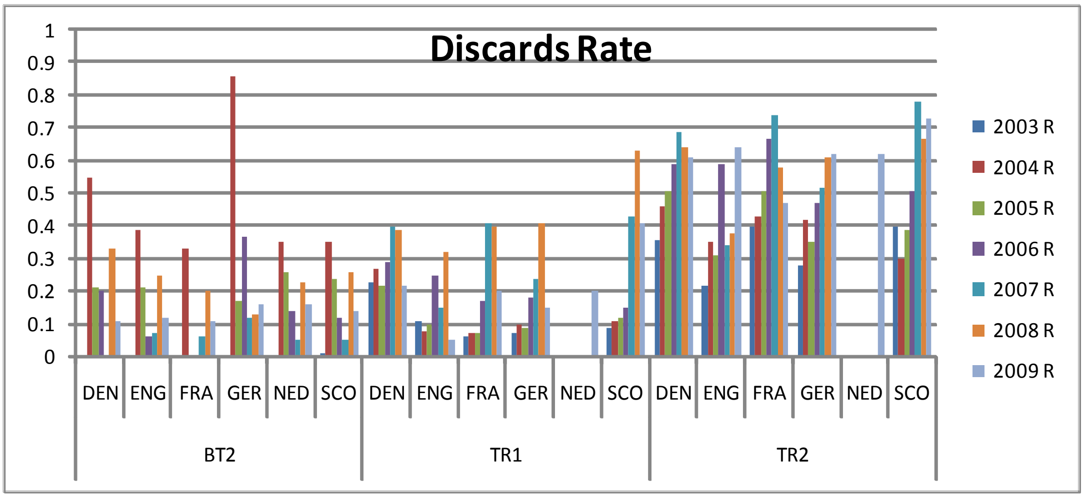


Figure 3.3.4. Cod discards rate in weight in area IV, IIIa and VIId broken down by main EU Member state and gear. Source STECF SG-MOS 10-05.

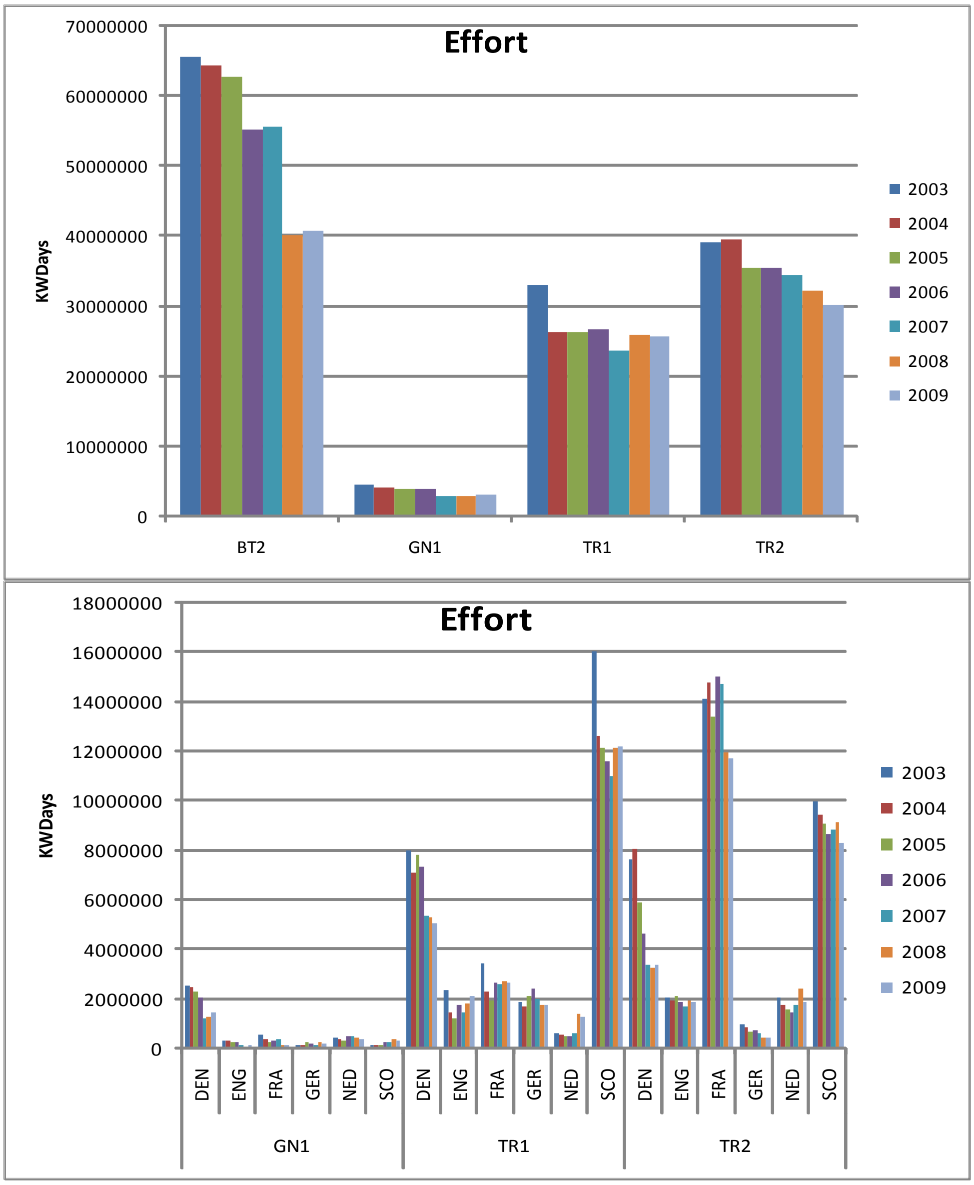


Figure 3.3.5. Fishing Effort in KWdays for the main gears in the Area 3b in Annex IIa of Council Reg (EC) 43/2009, including Skagerrak (IIIa), EU waters in the North Sea (IV) and Eastern English Channel (VIId), for all EU fleets (top) and broken down by main Member States (bottom).

3.3.4 Estimation of unallocated mortality in other stocks assessed by ICES

In cases where there is direct evidence of bias within Official landings (e.g. area-misreporting), working groups often directly estimate these “unallocated landings” and the estimates will appear on the input data tables within the reports. There are also a number of stocks where there is bias in the landings data which although widely acknowledged the magnitude of the bias is unknown. In addition there are stocks where there is significant divergence between survey data and landings data (see North Sea Whiting example below) which, under the assumption of constant survey catchability, implies that fish are being lost to the system (sometimes gained) without record. Assessment methods (SAM, TSA, B-Adapt) have been developed/adapted to try to estimate this “unallocated mortality”. Several reasons for the presence of unallocated mortality are cited: misreported landings, bias in discard estimation, changes in natural mortality or immigration/emigration from the assessment area. The following list of stocks gives an indication of the level of unallocated mortality coming from the assessments.

Cod in VIa

Cod in the west of Scotland (VIa) is assessed using TSA and includes an element of unaccounted mortality for the period 1995–2009 in order to account for unreported landings and natural mortality not covered by the assumption of M=0.2. During this period the removals to catch ratio is typically 3:1 or 4:1 (rising to 7:1 in one year).

Haddock in VIa

Haddock in the west of Scotland (VIa) is also assessed using TSA and estimates unallocated removals between 1995 and 2005. There is no supporting evidence of whether unallocated removals come from illegal landings or unaccounted natural mortality. During this period the removals to catch ratio reaches 3:1.

Cod in VIIa

Cod in the Irish Sea is assessed using B-ADAPT in order to estimate unallocated removals in response to suspected misreporting 2001–2009.

Cod in IIIa

Cod in the Kattegat is assessed using SAM with unallocated removals estimated between 2003–2009. The average of the removals to catch ratio is 5:1. Although some underreporting is suspected it is not possible to determine to what level the unallocated removals are a result of misreporting or changes to biology/ecology of the fish.

Inconsistency between survey data and catch data (Whiting example)

The status of the whiting stock in the North Sea and eastern Channel is uncertain. The present assessment is indicative of recent trends, but absolute levels of fishing mortality and biomass cannot be confidently estimated. The problem lies in a mismatch between the available catch and survey data during the period 1980 to 1995. The difference is that the surveys perceive an increasing SSB from 1985 to 1995 whereas the catch data demonstrate a stable or declining SSB.

To explain the mismatch between survey and catch data obvious possibilities are that the survey catchability was lower prior to 1990; the catch was over reported prior to 1990 or the catch is under reported since 1990; or natural mortality has increased since around 1990. As a consequence of the described problems with survey estimates, it was decided by ICES to shorten the time period of the assessment to the period after 1990 where catch data and survey data match better.

Estimation of “unallocated mortality” is also done for other stocks for which ICES provide advice using a similar approach as applied for the North Sea cod. The factors for “unallocated mortality” is for some stocks estimated to be very high (around 5), for several years. Such high factors emphasize the uncertainty of the method and indicate that the estimated “unallocated mortality” includes other factors than unreported catches. Change in natural mortality, migration or in survey catchability will contribute the estimated factors. It is not possible to quantify the proportion coming from the unreported catches. For North Sea whiting, ICES could not solve the discrepancy between the signal from long-term survey information and reported catches, as observed for North Sea cod. Instead, ICES has chosen to skip older data in the assessment of whiting.

4 Analytical assessments

4.1 SURBA

SURBA is a separable survey-based model (Needle, 2003) which is used as an exploratory analysis for many ICES stocks, and as a full assessment model for a number of stocks in the Mediterranean and further afield. To date it has been available as a Windows executable written in Fortran-90, but a new implementation in R has recently been developed and it is this version (SURBAR) which is used here. Default settings have been used for the results presented in this Section.

Figures 4.1.1 to 4.1.3 summarize the SURBA model fits for North Sea cod, using both IBTS Q1 and Q3 survey indices. From Figure 4.1.1, mean Z has been fluctuating around or above 1.0 for most of the time-series, with some indication of a reduction in recent years. The relative SSB has increased recently from the minimum level in 2006. Recruitment has been low since the large 1996 year class.

Figure 4.1.2 shows log survey residuals, with smoothers to highlight any time-trends in residuals. The trends across most ages are opposing from around 1995 onwards, with residuals for IBTS Q1 decreasing and those from IBTS Q3 increasing. This supports the conclusion from elsewhere (see Section 3.2.3), that the stock signals from the two surveys are diverging (although we cannot conclude from this whether one survey or another is demonstrating a change in catchability; just that they are different). On the other hand, Figure 4.1.3 shows the results of retrospective runs. These are very consistent, which would suggest that the stock signals from the surveys are also very consistent.

For further discussion, see Section 4.5.

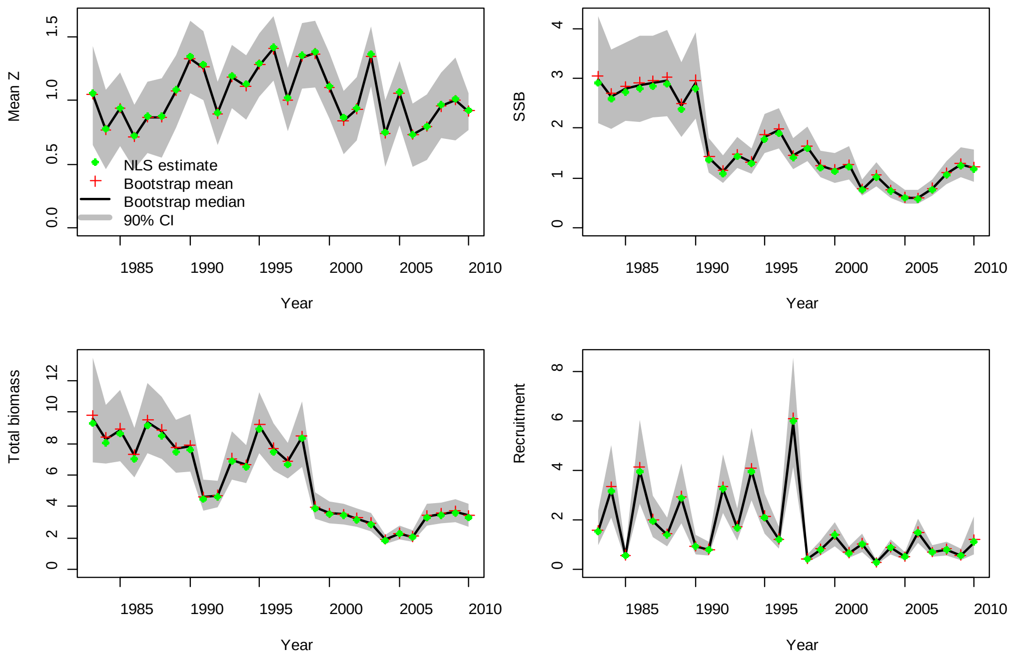


Figure 4.1.1. SURBA model fits for North Sea cod: stock summary. Plots give the point (NLS) estimate, along with the bootstrap estimates (mean, median and 90% confidence interval). SSB, TSB and recruitment are all presented on a relative scale.

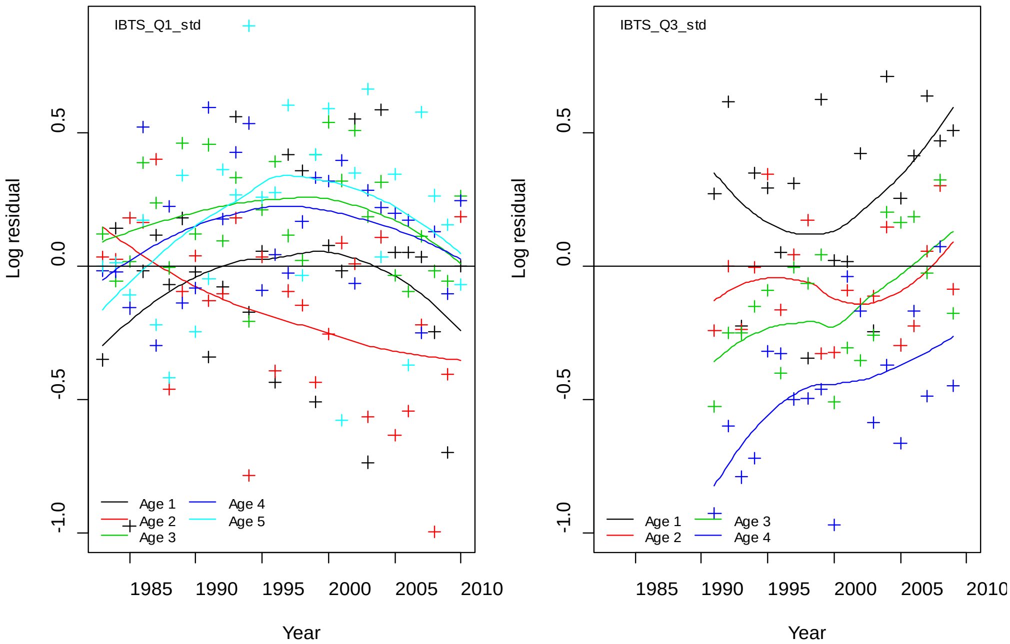


Figure 4.1.2. Log survey residuals for the North Sea cod SURBA analysis, for IBTS Q1 (left) and Q3 (right). The time-series trend for the residuals at each age have been summarized by a fitted loess curve (span = 1.0).

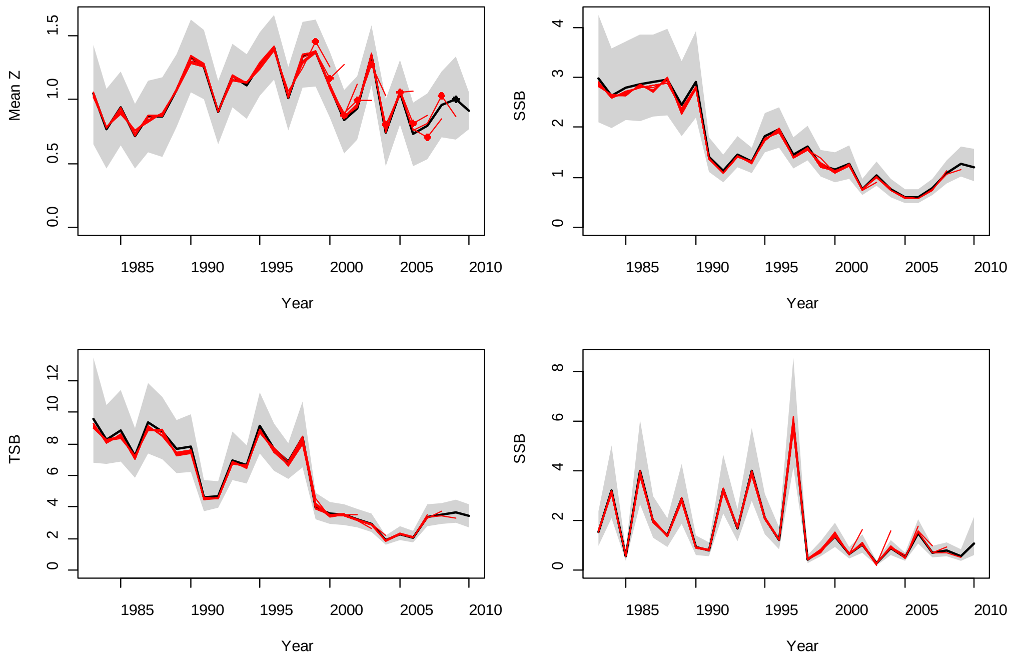


Figure 4.1.3. Retrospective SURBA model fits for North Sea cod: stock summary. In each plot, the black line gives the full time-series estimate (with 90% confidence interval as a grey band). Retrospective estimates are given as red lines. For mean Z (top left), the final-year estimate for each run is based on a three-year mean (rather than directly on data), so the penultimate-year estimates are highlighted with points as these represent the appropriate retrospective comparison. SSB, TSB and recruitment are all presented on a relative scale.

4.2 TSA

The TSA state-space modelling framework (Gudmundsson, 1994; Fryer, 2001) was used to assess stock trends in North Sea cod under various different model and data assumptions (Fryer, WD 8 and WD 9).

The results from four TSA models (Table 1) are presented below. The first three models (Catch, Catch+, Discards+) differ only in the years of commercial data that are included and whether the catch is modelled or whether discards and landings are modelled. All three models include both the IBTS Q1 and IBTS Q3 survey indices and allow the survey catchabilities to evolve over time (although assuming a common age selection pattern over time). The fourth model is identical with Catch+, but constrains the survey catchabilities to be constant. When included, the commercial data are assumed to be unbiased. When excluded, the commercial data are completely ignored in the model fitting process. However, catch multipliers for excluded years can be estimated as the ratio of the predicted catch to the reported catch.

Table 1. TSA models.

MODEL	RESPONSE	YEARS OF COMMERCIAL DATA	SURVEY CATCHABILITY
Catch	catch	1963–1992	varying
Catch+	catch	1963–1992, 2006–2009	varying
Discards+	discards and landings	1963–1992, 2006–2009	varying
Constant Q	catch	1963–1992, 2006–2009	constant

Stock summaries from the four assessments are shown in Figures 4.2.1–4.2.4. All demonstrate that in recent years mean F has been relatively stable and SSB has increased slightly. (The estimate of SSB sometimes decreases in 2010, but this should not be over-interpreted given the large confidence limits around the estimate).

Catch and survey standardized prediction errors from TSA Catch+ are shown in Figures 4.2.5–4.2.7. These are typical of the prediction errors from the various model fits. In general, the prediction errors are reasonable although there is a suggestion that the prediction errors for ages 3 and 4 for the IBTS Q1 survey tend to be positive (consistent with a change in survey catchability; see below). There are also some large positive prediction errors for ages 3 and 4 for the IBTS Q3 survey in recent years.

There is evidence of persistent changes in catchability of the IBTS Q1 survey from both TSA Catch+ and TSA Discards+ ($p < 0.0001$ in both cases). Figure 4.2.8 shows the estimated percentage change in catchability from TSA Catch+, suggesting that catchability increased between 1983 and the mid 1990s and has been relatively stable since. The estimated increase in catchability is somewhere between 50% and 100%. Such a large increase in catchability is unlikely, but coincides with a period of dramatic decline in stock size, possible changes in maturity, changes in vessels and tow duration, so some change in catchability is plausible. There is no evidence of persistent changes in catchability of the IBTS Q3 survey.

The estimated catch multipliers are shown in Figure 4.2.9. TSA Catch suggests high levels of unaccounted mortality in the mid 1990s and from 2001 onwards. TSA Constant Q gives a similar, but less extreme picture (and assumes no bias in the catch data from 2006 onwards). Neither TSA Catch+ nor Discards+ suggest any periods of large unaccounted mortalities.

Although all the models give a similar picture of stock trends, both in the long term and in recent years, none of the model fits is entirely satisfactory. If the catch data are assumed to be unbiased in recent years, then the best fits from a statistical perspective (based on likelihood ratio tests) are TSA Catch+ and TSA Discards+, but these suggest implausibly large increases in survey catchability and give no evidence of large unaccounted mortalities between 1993 and 2005. If survey catchability is held constant, then unaccounted mortalities between 1993 and 2005 are evident, but the model fit is markedly poorer.

For further discussion, see Section 4.5.

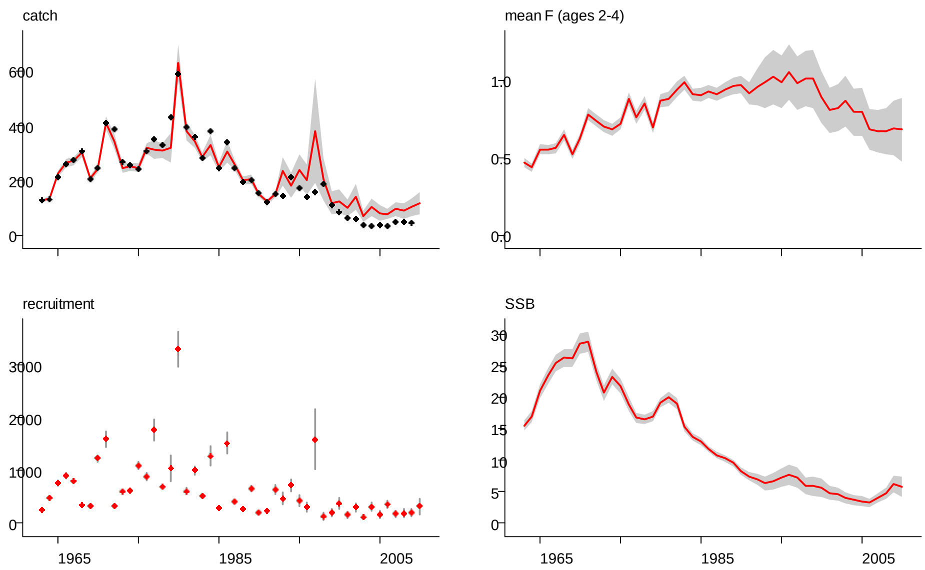


Figure 4.2.1. Stock summary from TSA Catch with fitted values (red lines or points), point wise 95% confidence bands (grey shading or error bars) and observed catch (black points).

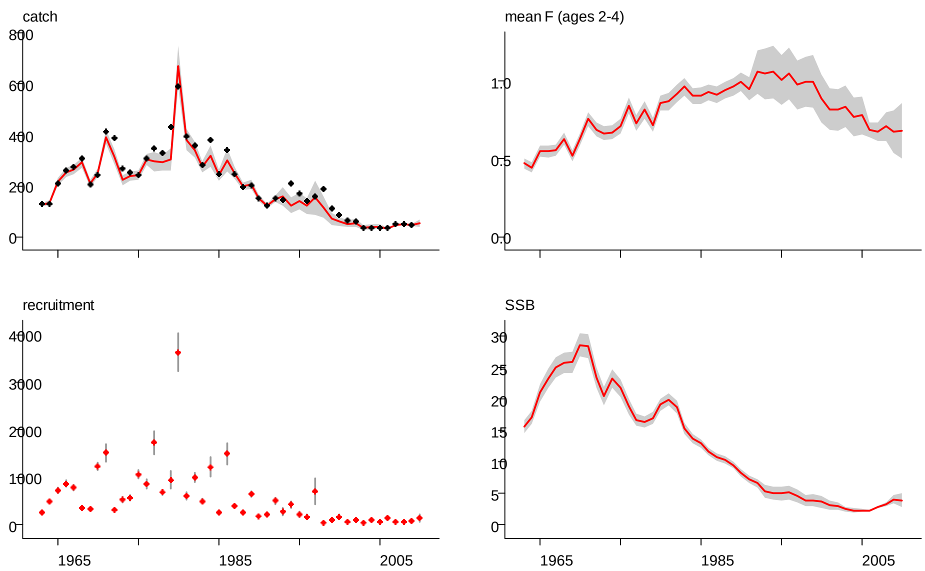


Figure 4.2.2. Stock summary from TSA Catch+ with fitted values (red lines or points), point wise 95% confidence bands (grey shading or error bars) and observed catch (black points).

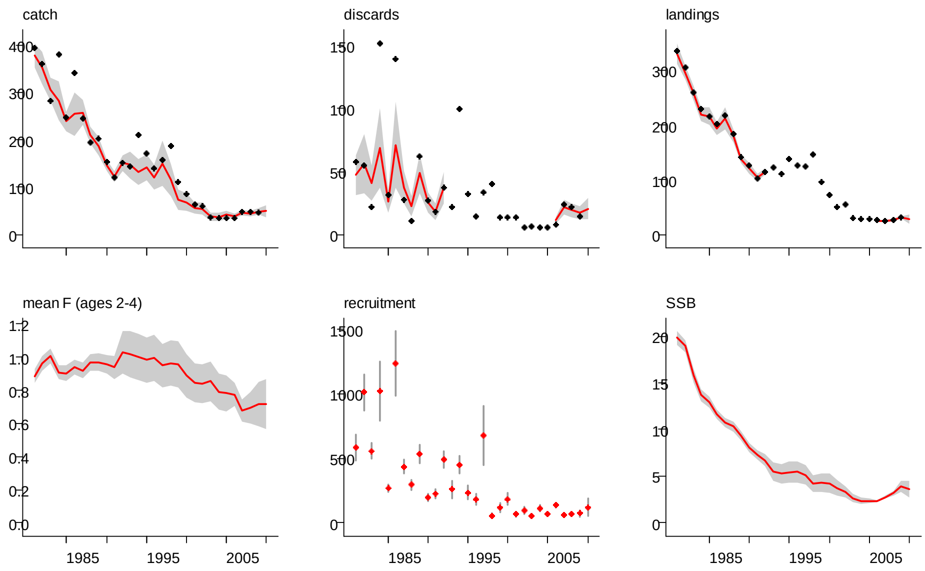


Figure 4.2.3. Stock summary from TSA Discards+ with fitted values (red lines or points), point wise 95% confidence bands (grey shading or error bars) and observed catch, discards and landings (black points).

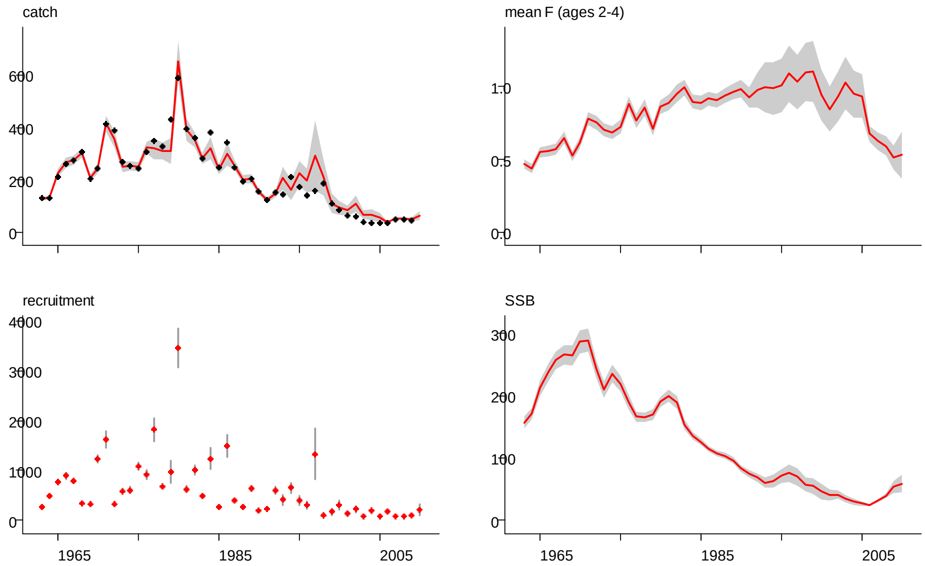


Figure 4.2.4. Stock summary from TSA Constant Q with fitted values (red lines or points), point wise 95% confidence bands (grey shading or error bars) and observed catch (black points).

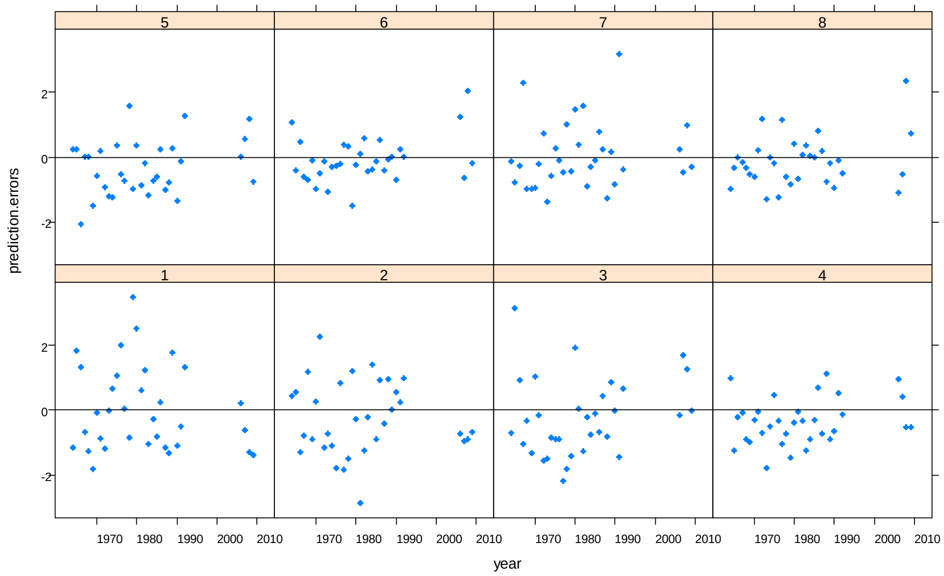


Figure 4.2.5. Catch standardized prediction errors from TSA Catch+.

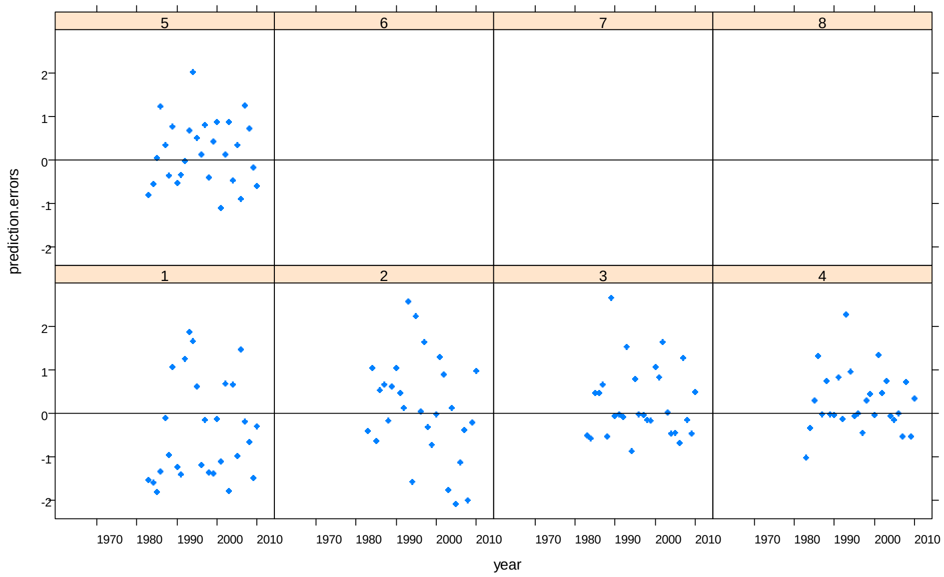


Figure 4.2.6. IBTS Q1 standardized prediction errors from TSA Catch+.

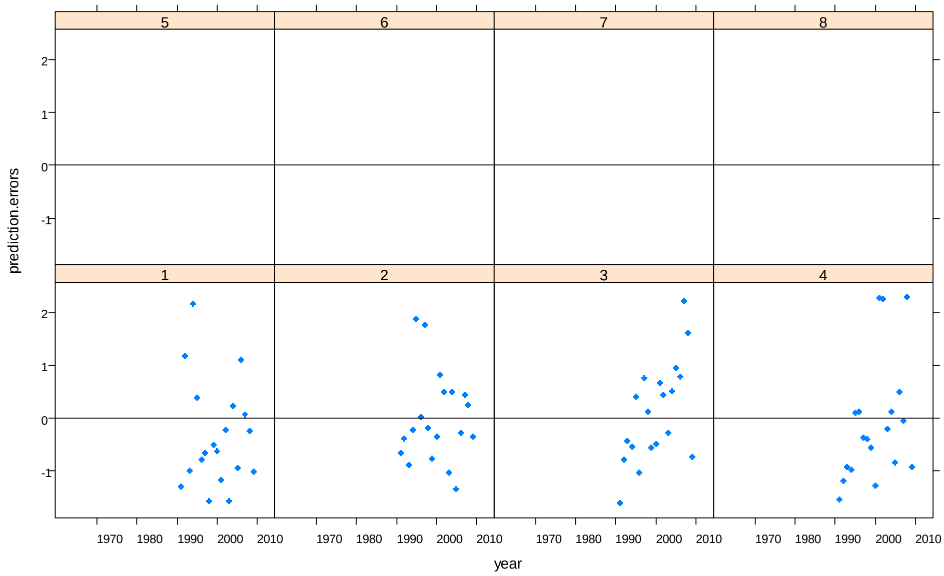


Figure 4.2.7. IBTS Q3 standardized prediction errors from TSA Catch+.

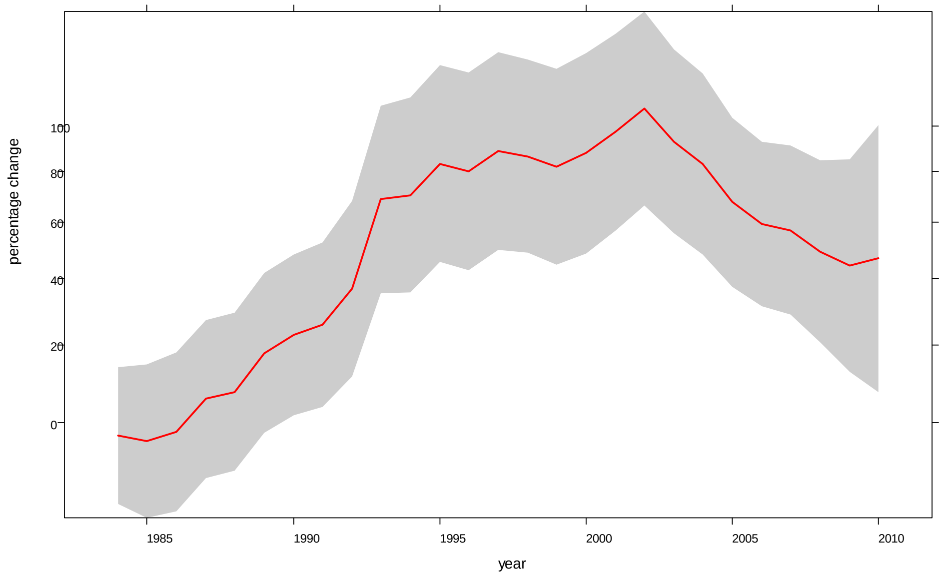


Figure 4.2.8. Estimated percentage increase in catchability of IBTS Q1 survey (red line) with point wise 95% confidence bands (grey shading) from TSA Catch+.

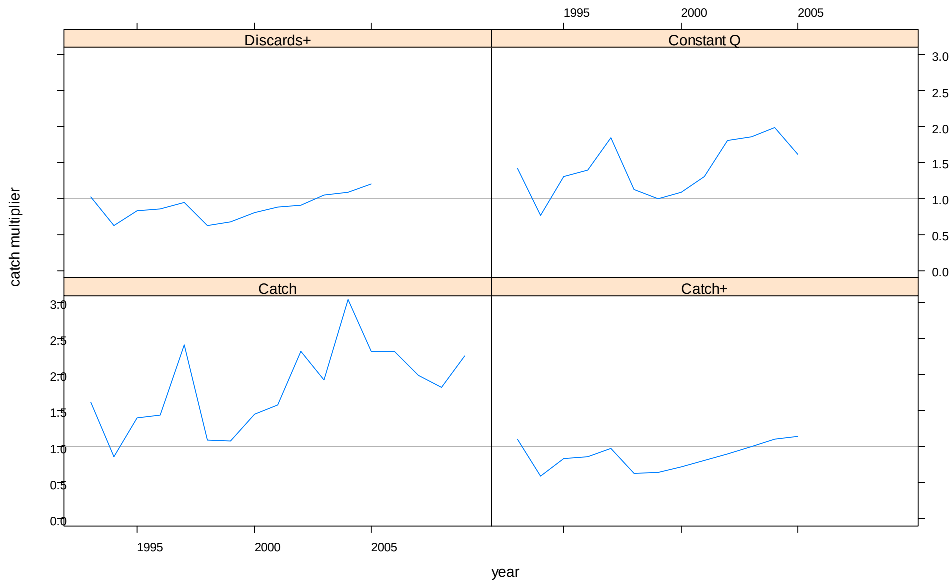


Figure 4.2.9. Catch multipliers from the four models.

4.3 B-Adapt

B-Adapt is a VPA based model which estimates bias in catch landings for a number of years when misreporting is thought to be possible. The version presented to this workshop is re-coded in AD Model Builder; it differs from the previous (Fortran) version by transforming the objective function from least-squares to a penalised likelihood formulation (Earl, Darby and Oliveira, WD10). The likelihood comprises three components, one dealing with survey data, and the remaining two placing a penalty on the amount of year-to-year variation allowed in either the total catch or the fishing mortality per age class. These penalties are needed in order to derive model estimates to a reasonable level of precision. A number of simulation tests were carried out using an operating model with known characteristics to generate data; these tests explored different weightings for the penalty components of the likelihood, the ability of the model to pick up periods of misreporting, and the effect of increased error in the catches on model performance. These tests are described in the WD2 submitted to WKCOD. Model fits to the NS cod dataset are also explored in the WD.

Figure 4.3.1 shows the catch, recruitment, catch multiplier, Fmean and SSB from the assessment using the re-written code and the same data as the 2010 assessment. Figure 4.3.2 shows the Fmean comparing the point estimates of the previous model (green) with the re-written model (black). These point estimates are very similar between models. The blue and red lines indicate 95% confidence intervals; in the Fortran version these were obtained by bootstrapping whereas the ADMB code uses the delta method provided in that framework.

Concerns were raised that the estimates of F vary considerably from year to year, which, when combined with a management system that relies on the final-year estimate of F for effort management, can lead to effort management that will also vary considerably from year to year.

For further discussion, see Section 4.5.

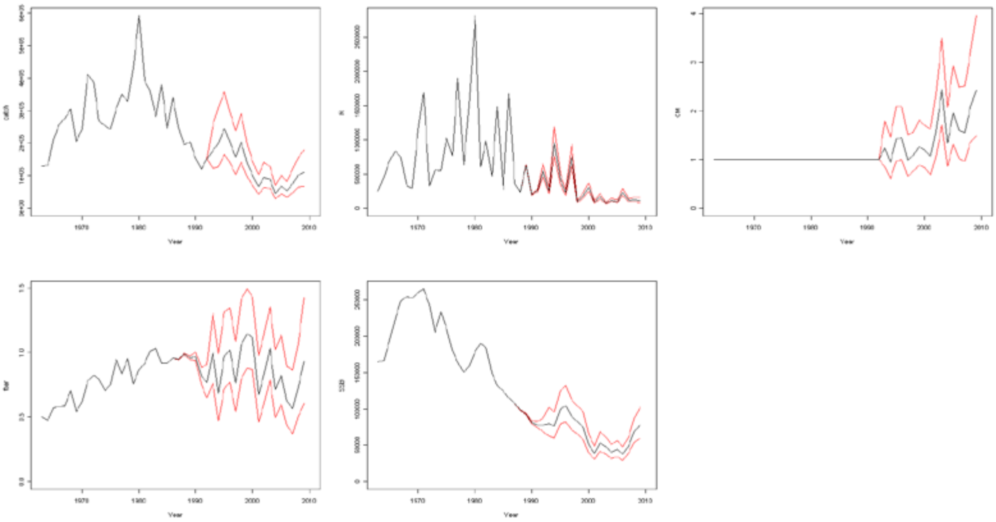


Figure 4.3.1. Existing 2010 assessment using the re-written B-ADAPT software.

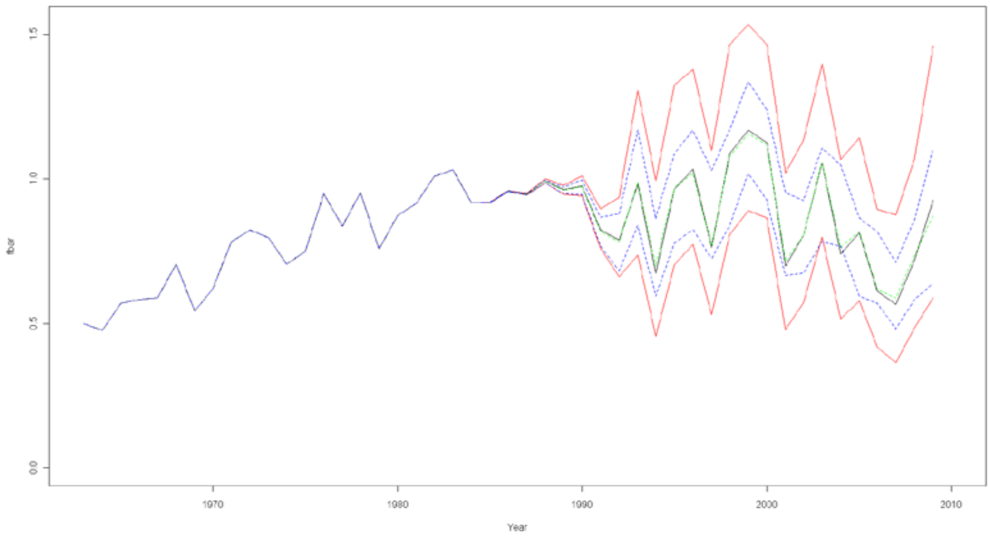


Figure 4.3.2. Comparison of the existing B-ADAPT model (blue and green) with the re-written model (red and black).

4.4 SAM

4.4.1 Introduction

State-space models were introduced in assessment by Gudmundsson (1987, 1994) and Fryer (2001). State-space models offer a flexible way of describing the entire system, with relative few model parameters. State-space models allow for objective estimation of important variance parameters, leaving out the need for subjective *ad hoc* adjustment numbers, which is desirable when managing natural resources. The state-space framework is unfortunately rather computational demanding, so previous approaches have either used linear approximations (the extended Kalman filter), or simulation bases approaches (MCMC). For these reasons state-space assessment models have not yet become widespread. Here a state-space assessment model is presented, which is based on the Laplace approximation (e.g. MacKay, 2003) and

Automatic Differentiation. It is implemented in AD Model Builder (http://www.admb-project.org), which makes these tools easily available. A description of the general modelling framework can be found in stock annex.

4.4.2 North Sea cod

For North Sea cod the model is extended to allow estimation of possible bias (positive or negative) in the reported total catches in the years 1993–2009. 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:

$$S_{a,y} = \begin{cases} 1, & y < 1993 \\ \tau_y, & y \geq 1993 \end{cases}$$

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 in this model is:

$$\vartheta = (Q_{a=1,2,3,4,5}^{(s=1)}, \sigma_R^2, \sigma_S^2, \sigma_F^2, \sigma_{\circ,a=1,2,3^+}^2, \sigma_{s=1,a=1,2^+}^2,$$
$$\tau_{1993}, \tau_{1994}, \ldots, \tau_{2009}, \alpha, \beta, \rho)$$

The Q parameters are catchabilities corresponding to the survey fleet. The three variance parameters σ_R^2, σ_S^2, and σ_R^2 are process variances for recruitment, survival, and development in fishing mortality respectively. 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, α and β are the parameters of the Beverton–Holt recruitment function, and ρ is the correlation parameter for the random walks on the fishing mortalities.

The Beverton–Holt recruitment function is used in the results demonstrated here, but there is no visual difference in the results if a Ricker curve or simply a random walk recruitment is used in its place. The fishing mortality random walks are allowed to be correlated.

Before, during, and after the working group a number of model runs were conducted, among them:

- Both Q1 and Q3 IBTS surveys and multipliers on years 1993–2009 (See further comments below).
- Both Q1 and Q3 IBTS surveys and multipliers on years 1993–2009 but separate in two age groupings (1–3 and 4+). This run demonstrated a borderline significance compared to the model above, with higher catch scaling needed for the younger age class. This development should be followed in the coming years.

- Both Q1 and Q3 IBTS surveys, but with no multiplier on catches 2007–2009, single multiplier for years with estimated catch multiplier (1993–2006). This run revealed that forcing the catch multiplier to one would affect the catch multiplier in previous years. Furthermore this was a significantly worse model fit.
- Both Q1 and Q3 IBTS surveys and without any catch multipliers, all catches assumed unbiased. Again a significantly worse model fit.
- Both Q1 and Q3 IBTS surveys and multipliers on years 1993–2009 but separate in two age groupings (1–3 and 4+), but multiplier fixed to 1 on 4+ in 2007–2009.
- Following the working document for this meeting Rindorf and Vinther (2011), which indicated that the IBTS Q3 survey had changed catchabilities from (and including) the year 2003, the IBTS Q3 survey was split into two surveys. This allows the model to fit separate model parameters for the two periods, so it is a model extension. The likelihood ratio test gave a p-value of 0.40, which indicates that this model extension was not significant.
- Only Q1 survey and multipliers on years 1993–2009. Similar to the chosen configuration but with the correlation coefficient fixed to $\rho = 0$. The model allowing correlation between the random walks on fishing mortalities was a significant model improvement.

All the runs with both Q1 and Q3 indicated a mismatch between Q1 and Q3, and between Q3 and the prevalent hypothesis about the trends in reported catches in recent years. A comparison of the results from the base model (using both Q1 and Q3 survey, first and last bullet point above) and the model using only Q1 survey is provided in Figures 4.4.1.

For further discussion, see Section 4.5.

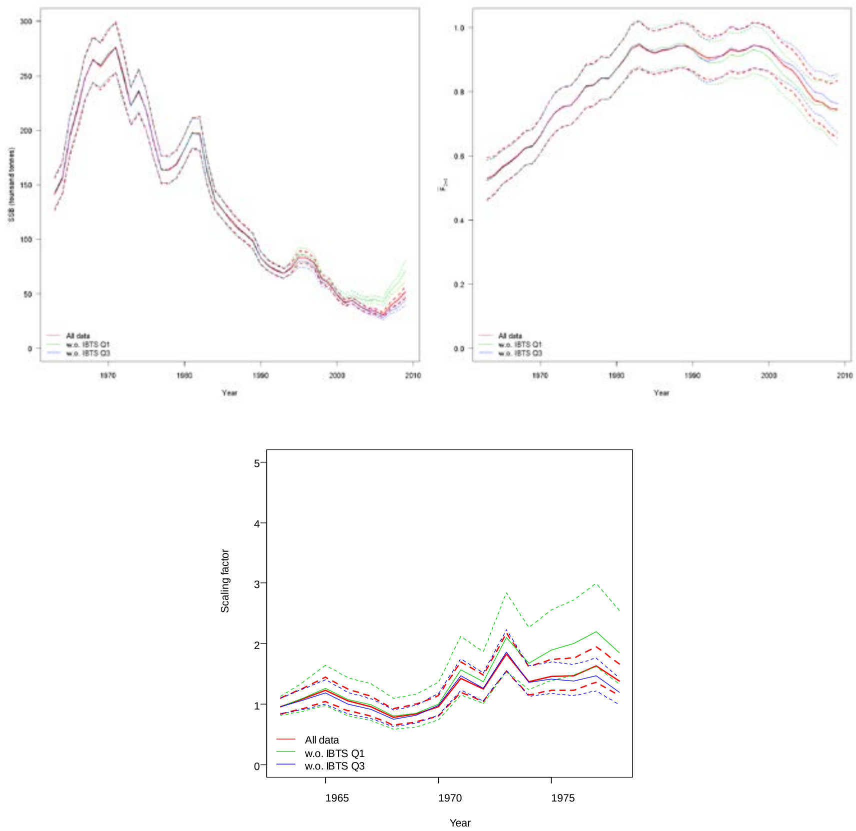


Figure 4.4.1. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. The May 2010 WGNSSK comparison between the spawning biomass, fishing mortality and catch multiplier trends from fits of the SAM model to the two survey series (note w.o. indicates without that series). Fits to the IBTSQq3 survey indicate higher SSB in recent years as a result of higher estimates of catch multipliers; fishing mortality rates exhibit little variation between fits.

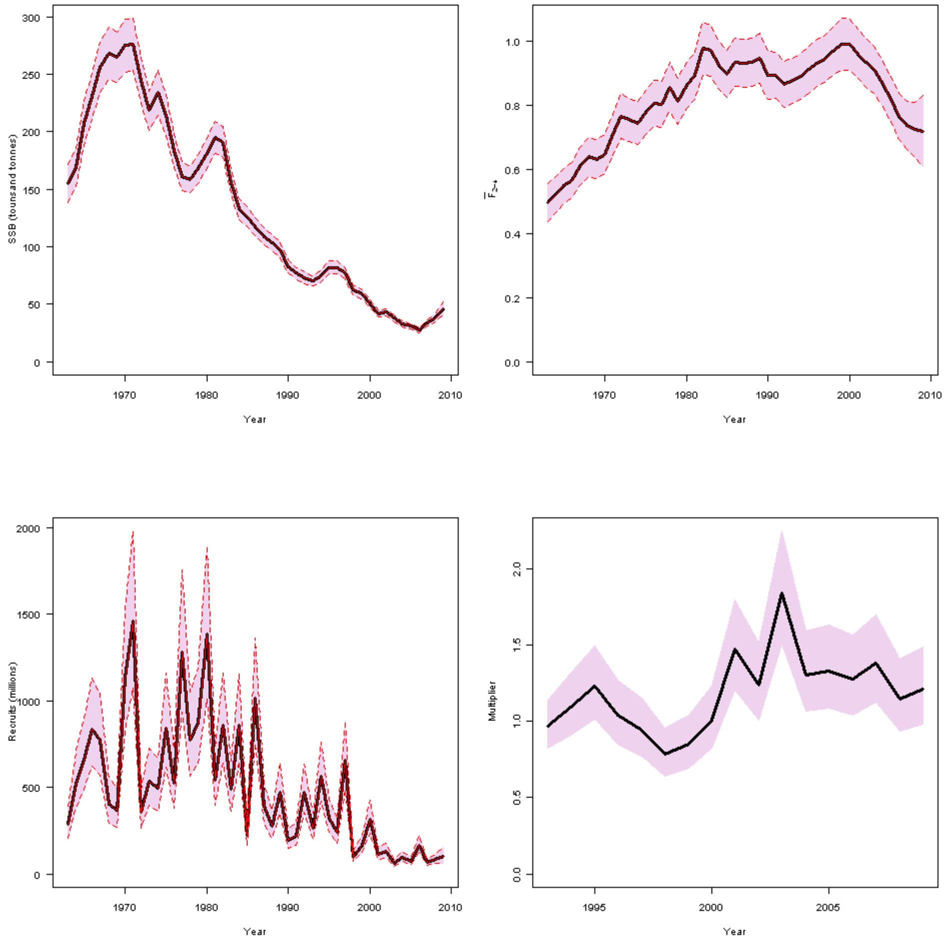


Figure 4.2.2. Spawning–stock biomass, fishing mortality, recruitment and catch multiplier estimated via the standard state-space model (first scenario) and corresponding 95% confidence interval (shaded areas).

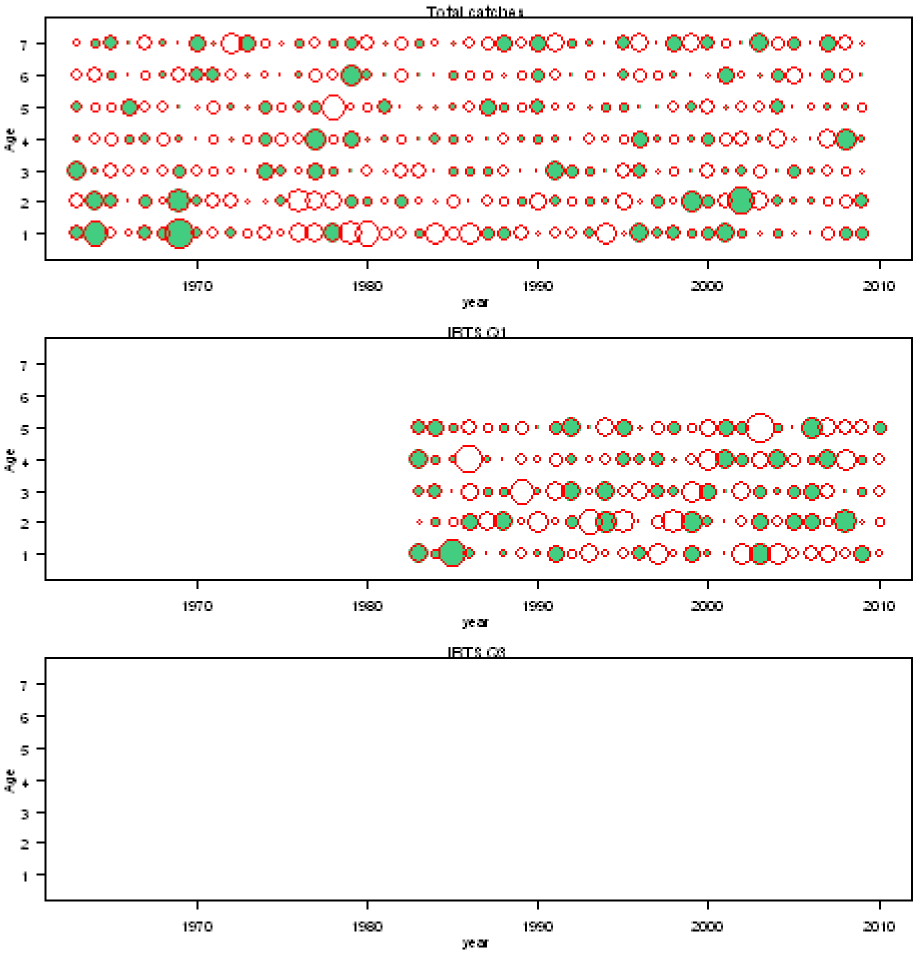


Figure 4.4.3. Residuals from the final model.

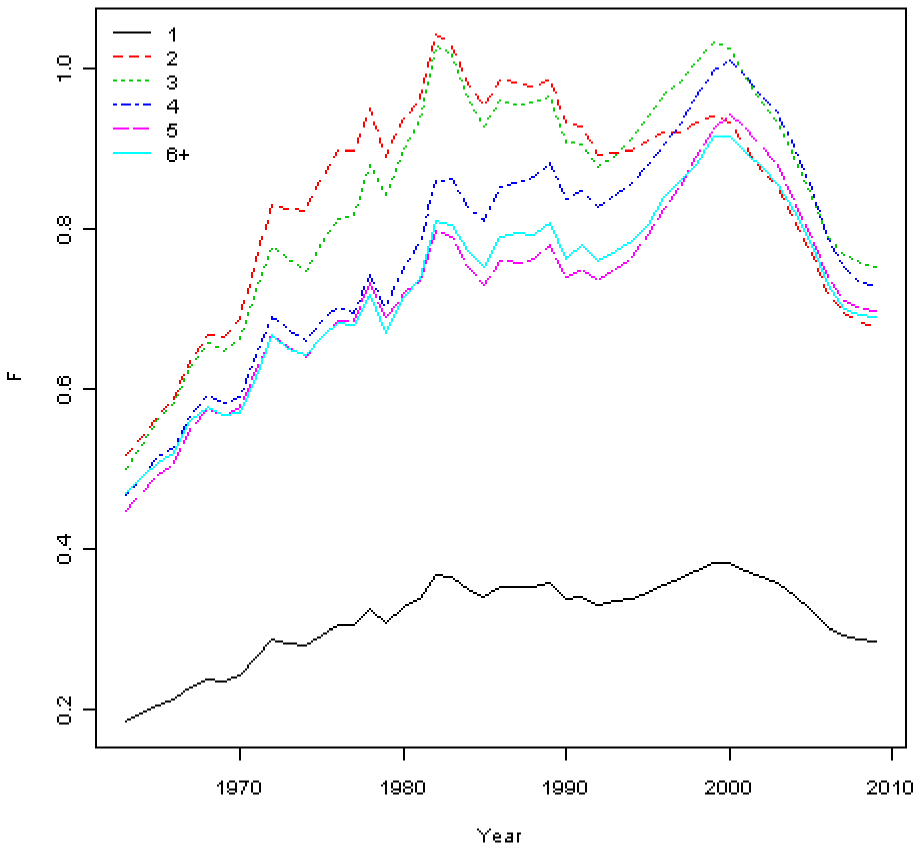


Figure 4.4.4. Fishing mortalities at different ages for the final model.

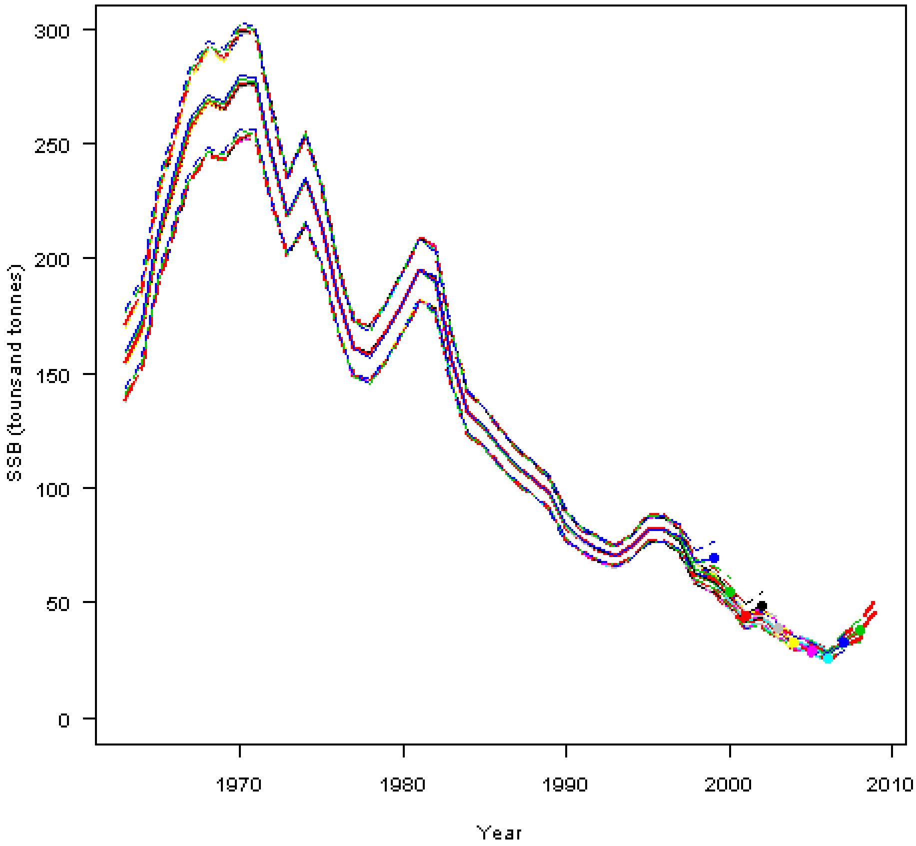


Figure 4.4.5. Retrospective for SSB for the final model.

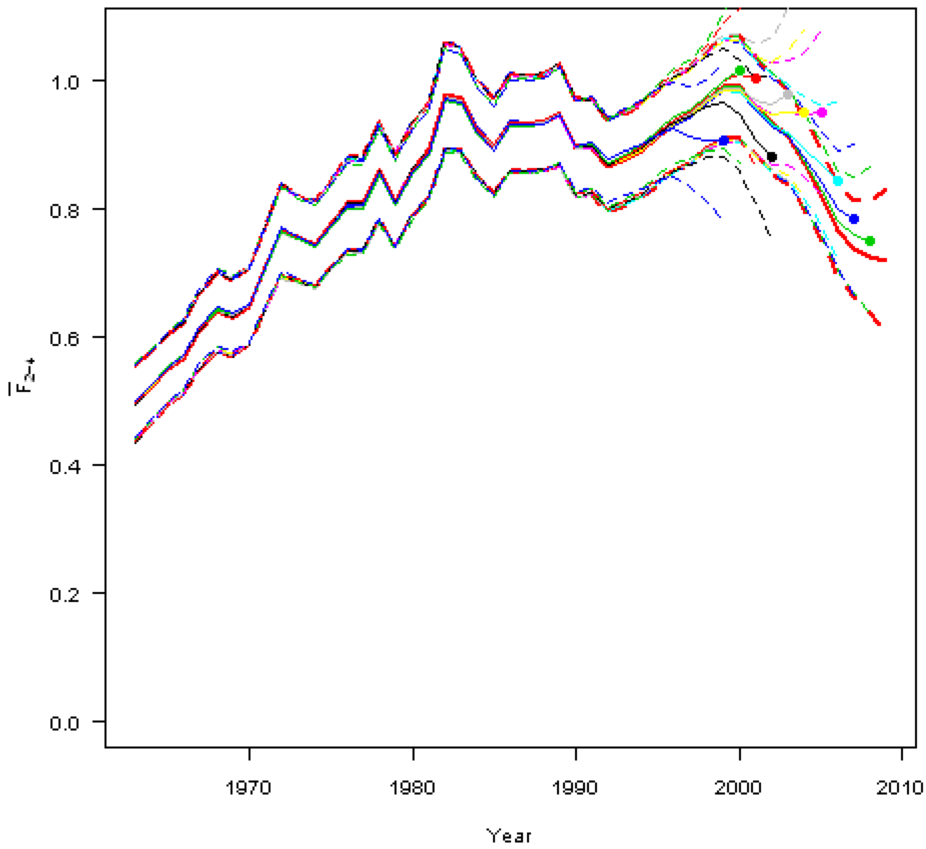


Figure 4.4.6. Retrospective for $\overline{F}_{2-4}$ of the final model.

4.5 Discussion and conclusions

Assessment models considered during the workshop were: SURBA, B-Adapt, TSA and SAM. A description of these models has been presented in previous sections, including relevant references to working documents.

SURBA does not use catch data at all, with results based on survey indices. As a consequence, it can only provide estimates of total mortality Z and cannot separate natural and fishing mortality. Estimates of population abundance are on a relative rather than on an absolute scale, given that the surveys' catchabilities are unknown.

The other three models use both catch and survey data. Several configurations were explored for all of them, but the main ones in all cases were based on the assumption that the catch data after 1992 are uncertain, particularly with regards to total amount caught (in weight). B-Adapt and SAM both estimate an annual multiplicative factor for the catch-at-age data after 1992, which is assumed to be the same for all ages but different between years, whereas TSA does not use catch data at all after 1992.

Methodologically, B-Adapt is an extension of Adapt, the main feature being the estimation of the abovementioned catch multiplicative factors. Therefore, B-Adapt is based on the VPA principle and treats the catch-at-age data as exact (except for the annual multiplicative factors after 1992, which are unknown parameters). Survey indices-at-age are treated as observations and linked to underlying model abundances via log-Normal distributions. Smoothing penalties on the interannual variability of either total annual catch in weight or on F-at-age are used to help stabilize results.

TSA and SAM can be both viewed as state-space models. Recruitment is modelled from a stock–recruitment relationship, with random variability estimated around it. Starting from recruitment, each cohort's abundance decreases over time following the usual exponential equation involving natural and fishing mortality. TSA applies this equation deterministically. SAM, on the other hand, assumes that there is random variability around the exponential equation, which would account for demographic variability and features such as migration or departures from the assumed natural mortality values. This has the consequence that estimated F-at-age paths display less interannual variability with SAM than with the other assessment models considered at the workshop, because part of the interannual changes estimated along cohorts are deemed to arise from "other sources of variability" instead of from changes in F.

Both TSA and SAM put 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. TSA models log [F(y,a)] using a similar, but more complex structure, incorporating persistent and transitory variability components and, like SAM, correlation between the ages.

Both TSA and SAM have 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, as already indicated, in order to deal with the uncertain overall catch levels after 1992, SAM estimates annual catch multipliers after 1992 (as B-Adapt does), whereas TSA completely ignores the catch data after 1992.

SURBA was considered as an exploratory rather than a full assessment tool. Of the other three models, the general approach followed by TSA or SAM was considered more appropriate than the VPA approach on which B-Adapt is based because the additional variability/uncertainty considered in various components of TSA or SAM seems realistic and gives rise to results that are less reactive to noise in the catch or survey data or to potential changes in survey catchability. As already explained, the fact that SAM considers random variability of the annual survival process along cohorts separately from fishing mortality produces smoother estimated F paths over time. Because the current management regime for North Sea cod stock is strongly focused on F estimates in the final assessment year, it is important that these estimates do not change too suddenly in response to some data values which may end up just representing noise. Additionally, SAM utilizes the age structure of the observed catch even in years when the overall catch value is considered highly uncertain, whereas TSA does not use any aspect of the catch data during those years, potentially missing a relevant source of information. Balancing all these considerations, the conclusion was reached that SAM was the most appropriate modelling approach for the North Sea cod stock assessment at this time.

B-Adapt, SAM and TSA estimated very similar overall trends in F over time (see Figure 4.5.1).

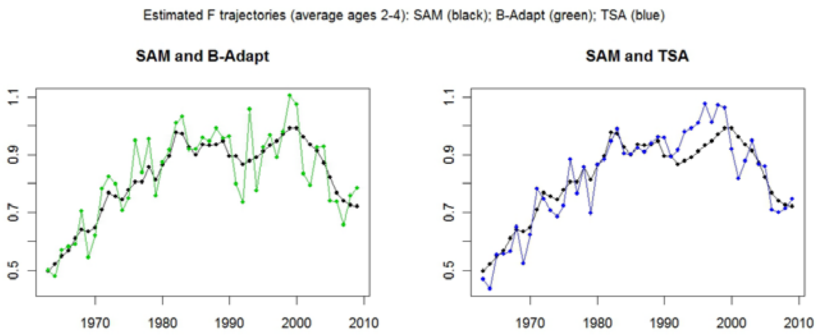


Figure 4.5.1.

Once the decision to use SAM was reached, several model configurations were considered and compared. Only the IBTS Q1 survey was finally used as a tuning index given:

- the conflicting signals between IBTS Q1 and Q3 in recent years;
- quarter 1 survey is considered to more likely reflect actual stock trends in recent years, because of suspected changes in catchability/availability of cod in the quarter 3 survey in relation to recent changes in the fish distribution in latter part of the year;
- external information suggesting that the bias in landings in particular and potentially in discards estimates in recent years have declined compared with earlier period were not supported by a declining trend in the catch multiplier when Q3 survey was included in the assessment.

The annual catch multiplicative factors were estimated for every year starting from 1993, as part of the assessment. Given that information from national authorities indicates that the level of catch misreporting has been decreasing and is likely to have become negligible since about 2006, the issue of whether the catch multiplicative factor should be set equal to 1, instead of estimated, as of 2006 was discussed. However, information from national authorities refers only to landings rather than to the whole catch. Because discarding is known to be very substantial and there are some question marks about the quality of the discards estimates (e.g. suggestions that crews may discard less when an observer is on board), the decision was taken not to fix the catch multiplicative factor to 1 in recent years until issues related to the quality of landings and discards estimates separately have been investigated.

Figure 4.5.2 presents the estimates from the SAM configuration approved at the workshop and compares them with the B-Adapt results from the WGNSSK 2010 report. Note that the B-Adapt assessment conducted by WGNSSK 2010 included both Q1 and Q3 IBTS surveys.

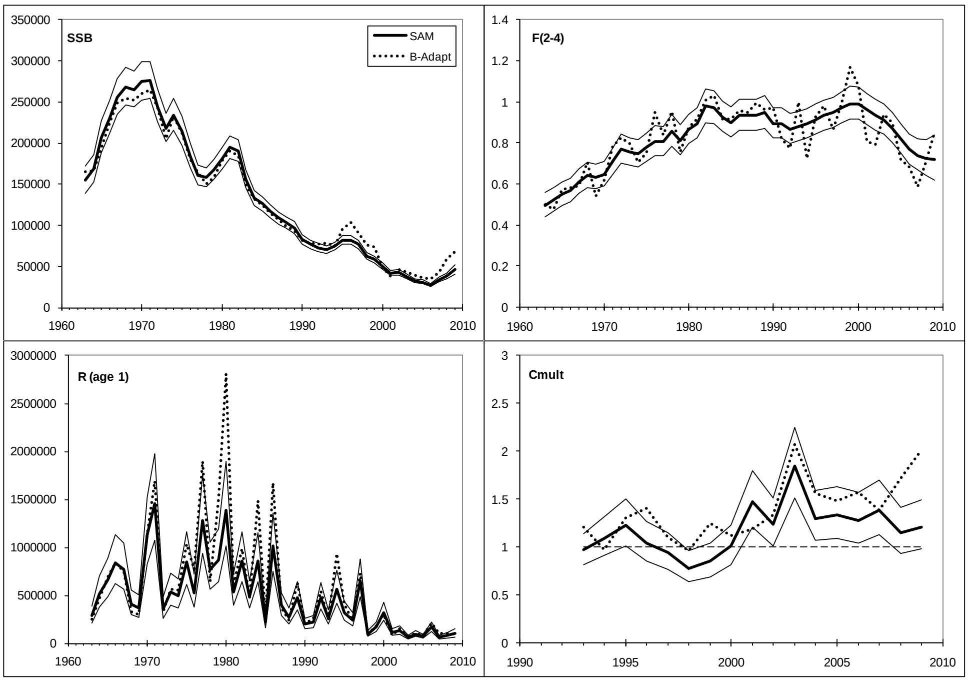


Figure 4.5.2. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. Estimated SSB, F (2–4), recruitment (age 1) and the catch multiplier from the SAM model. Solid black lines (heavy lines=estimate, light lines=point-wise 95% confidence intervals) are from the SAM model, and dotted lines from the final B-ADAPT run (median estimates).

Historical SSB trends are similar to those resulting from the previous assessment; recent increases are estimated to be less than before as a consequence of lower catch multipliers in recent years; the stock is still well below Bpa. Fishing mortality is declining rather than increasing sharply and is still well above the target.

Recruitment variability has been reduced historically as a result of catch and survey data being estimated to be less reliable at the youngest ages. The estimated CVs for observed catch-at-age 1, survey index-at-age 1 and the stock–recruitment relationship are all very large: 89%, 72% and 56%, respectively. Hence, unsurprisingly, the age 1 catch residuals are very large in some years and this could provide an explanation for the difference with B-Adapt recruitment estimates, given that B-Adapt follows exactly the catch data (except that there are annual catch multipliers estimated after 1992). The large age 1 catch residuals obtained with SAM are a further indication of the need to re-evaluate discards estimates or to examine the possibility of accounting for landings and discards separately in future developments of the assessment model.

Additionally, the fact that the CVs of the observed age 1 catch and survey index and the stock–recruitment relationship are all so large suggests that these three sources of information are to a large extent ignored in the SAM recruitment estimation, which might therefore be more influenced by age 2 abundance estimates and model assumptions about F-at-age 1. The CV of the survival process is assumed to be the same for all ages (estimated at 0.11) and this might have an impact on recruitment estimates (and, hence, age 1 catch and survey residuals) because it constraints the changes permitted between abundance at ages 1 and 2 of a cohort. These issues seem of interest in future model explorations.

Finally, the high correlation (0.84) estimated for the increments of log[F(y,a)] across ages suggests that the model might react a bit slowly if different changes in selectivity start to happen for different ages (for example, as a consequence of discard reduction policies). Annual assessment results should be monitored closely, via retrospective analyses and other model diagnostics.

SAM was adopted by the workshop as a basis for assessments for an interim period (~two years), while additional analyses are carried out with the aim of providing a more suitable long-term solution. Although the SAM model structure agreed at the workshop is considered the most appropriate that could be fitted in the time available, a refined model structure will only be completed with further work. Consequently, if further refinements are found to be required before the WGNSSK 2011 meeting, they should be presented to that meeting for adoption (WGNSSK comprises a large part of WKCOD participants). In the medium term WKCOD considered that the development of a model structure that models discard and landings separately is required due to the differing levels of noise associated with each data set. WKCOD recommended that the reference points are not revised in the short term until the assessment model has been finalised.

Settings of SAM model agreed at the Workshop

The final settings of the SAM model agreed at the workshop are as follows:

Data

- **Commercial catch: catch** numbers-at-age, ages 1–7+, years 1963–present
- **Tuning indices**: IBTS Q1 index-at-age, ages 1–5, years 1983–present

Catch multiplier: unknown parameters, set annually for years 1993–present, constant across ages

Population dynamics

- **Recruitment in year y**: Log-Normal, with median given by a Beverton–Holt relationship (with unknown "a" and "b" parameters) based on SSB in year y-1 and unknown coefficient of variation.
- **Abundance down cohorts**: Log-Normal with median given by the usual exponential equation (based on M and F) and unknown coefficient of variation (assumed to be the same for all ages).

Assumptions about F

- F of the plus group age assumed equal to F of the last true age.
- For each true age, log[F(y,a)] follows a random walk in time with the same standard deviation assumed for all ages. The random walk increments are correlated across ages, with the unknown correlation parameter assumed to be the same across all ages.

Observation equations

- **Observed catch numbers-at-age**: Log-Normal with median given by the model estimate (Baranov catch equation times the catch multiplier, for the relevant years) and unknown coefficient of variation. There are separate coefficients of variation for ages 1, 2 and 3+.
- **Observed survey indices-at-age:** Log-Normal with median given by abundance-at-age at survey time multiplied by the survey's catchability-at-age and unknown coefficient of variation. There are separate coefficients

coefficients of variation for ages 1 and 2+. There is a separate survey catchability parameter for each age, which is assumed to be constant over time.

All unknown model parameters are estimated jointly with population abundances and F-at-age.

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Annex 2: Stock Annex

Stock	Cod in Subarea IV, Division VIId and Division IIIa West (Skagerrak)
Working Group	Working Group North Sea, Skagerrak and Kattegat
Date	February 2011
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. 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.

North Sea cod is really a meta-population of subpopulations with differential rates of mixing among them (Horwood *et al*., 2006; Metcalfe, 2006; Heath *et al*., 2008). A genetic survey of cod in European continental shelf waters using micro-satellite DNA detected significant fine scale differentiation suggesting the existence of at least four genetically divergent cod populations, resident in the northern North Sea off Bergen Bank, within the Moray Firth, off Flamborough Head and within the Southern Bight (Hutchinson *et al*., 2001). The differentiation was weak (typical of marine fish with large population sizes and high dispersal potentials), but significant, with the degree of genetic isolation weakly correlated with geographical separation distance. This recent genetic evidence is largely consistent with the limited movements suggested by earlier tagging studies (ICES-NSRWG 1971, Metcalfe, 2006; Righton *et al*., 2007). Furthermore, Holmes *et al*. (2008) found significant differences in SSB trends between spawning areas in the North Sea, consistent with asynchronous population dynamics across spawning areas and providing support for the concept of meta-population structure.

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). 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 historical spawning ground off the northeast coast of England). The study indicated that most of the major cod spawning grounds in the North Sea are still active, but that the depletion of some localized 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 of 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 stock 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 population 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 as a consequence of heavy fishing pressure. In contrast, Neat and Righton (2007) analysed the temperature experienced by 129 individual adult cod throughout the North Sea, and found that the majority experienced a warmer fraction of the sea than was potentially available to them (although they had the capacity to find cooler water), with individuals in the south in summer experiencing temperatures considered super optimal for growth. This suggests that the thermal regime of the North Sea is not yet causing adult cod to move to cooler waters.

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 support the existence of regional populations of cod that separate during the spawning season and, in some cases, intermix during the feeding season (Metcalfe, 2006). 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 reanalysis of conventional tags revealed 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).

The lack of obvious physical barriers to mixing between different subpopulations in the North Sea suggests that behavioural and/or environmental factors are responsible for maintaining the relative discreteness of these populations (Metcalfe, 2006). For example, Righton *et al*. (2007) conclude that behavioural differences between cod in the southern North Sea and English Channels (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 cod from these two areas during feeding and spawning season. 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). 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 recognize 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 active homing is not necessary to explain some of the population structures of cod (with separation possible through distance and oceanographic processes affecting the dispersal of eggs and larvae, such is in the Southern Bight), but that homing behaviour may be necessary to explain the structure of other subpopulations.

A.2. Fishery

Cod are caught by virtually all the demersal gears in Subarea IV and Divisions IIIa (Skagerrak) and VIId, including beam trawls, otter trawls, seinenets, 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 centred 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 centred 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, because of 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.

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 summarized in the following table, which only demonstrates 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 demonstrates 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
Trammel nets with mesh size < 110 mm. The vessel shall be absent from port no more than 24h.	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 from that set out for 2008 (see text below and EC 40/2008 for details).**

Additional provisions were introduced for 2008 (points 8.5–8.7, 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 12.9–12.10, 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 12.11–12.14, 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 programme 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 lead to greater effort being exerted on haddock, whiting, monk, flatfish and *Nephrops*.

Shifts in the UK fleet in 2007/2008 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 as a result of 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

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 as a consequence of lower cannibalism. Predation on older cod (age 3–6) increased because of 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 have 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.

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 (21 000–68 000) and consumed 8344 tonnes (95% confidence intervals: 5028–14941 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 at 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 multispecies 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 multispecies mortality rates were carried out at the 2009 meeting of the WKROUND. Inclusion of the multispecies 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).

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 depend on the time period over which they are estimated. For example, for North Sea cod FMSY, MSY and BMSY are lower when calculated for the recent warm period (after 1988) compared to values derived for the earlier cooler period.
- The decline in FMSY, MSY and BMSY can be expected to continue as a consequence of the predicted warming, and possible future change should be accounted for in stock assessment and management regimes.
- Modelling reveals 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).

B. Data

B.1. Commercial catch

The WG estimate for landings from the three areas (IV, IIIa-Skagerrak and VIId) in 2006 and 2007 were based on annual data, as opposed to quarterly data prior to 2006, because of ongoing difficulties with international data aggregation procedures, particularly with regard to discard raising.

France, Belgium and Sweden, who respectively landed 9%, 5% and 2% of all cod for combined Area IV and VIId, do not provide discard estimates for this combined area. Similarly, Belgium and Germany, who each land 2% of all cod in Area IIIa, do not provide discard estimates for this area. Norwegian discarding is illegal, so although this nation landed 14% and 6% of all cod in combined Area IV and VIId, and Area IIIa respectively, it does not provide discard estimates. Although the Netherlands (7% of all cod landed in IV and VIId, 1% in IIIa) does provide discard data for Area IV, these are based on very low sample sizes for cod, and are therefore not reliable enough to be raised to fleet level. All percentages quoted in this paragraph refer to landings in 2007.

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 2006. For 2006, Denmark was excluded from this calculation as they provided their own discard estimates. For 2007, Scottish, Danish, German and England & Wales discard estimates were combined (sum of discards divided by sum of landings) and used to raise landings-at-age from the remaining nations in Subarea IV to account for missing discards. Discard numbers-at-age for IIIa-Skagerrak were based on observer sampling estimates. For 2006 and 2007, Danish and Swedish discard estimates were combined (sum of discards divided by sum of landings) and used to raise landings-at-age from the remaining nations in Division IIIa-Skagerrak to account for missing discards. Although in some cases other nations' discard proportions were available for a range of years, these have not been transmitted to the relevant WG data coordinator in an appropriate form for inclusion in the international dataset.

For cod in IV, IIIa-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 underreporting 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 underreporting of landings may have been significant in 1998 because of the abundance in the population of the relatively strong 1996 year class as 2-year-olds. The landed weight and input numbers-at-age data for 1998 were adjusted to include an estimated 3000 t of underreported catch. The 1998 catch estimates remain unchanged in the present assessment.

For 1999 and 2000, the WG has no *a priori* reason to believe that there was significant underreporting 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 underreporting of catch varies considerably. Because the WG has no basis to judge the overall extent of underreported 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, Germany, the Netherlands, Scotland and Sweden.

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.

During the five years 2003–2007, an average of 82% (84% in 2007) of the international landings in number were accounted for by juvenile cod aged 1–3. In 2007, age 1 cod comprised 32% of the total catch by number, and age 2 (the 2005 year class), 55%.

Estimated total numbers discarded have varied between 35 and 55% of the total catch numbers since 1995, but have demonstrated an increase to above 70% in 2006 and 2007, because of the stronger 2005 year class entering the fishery (estimated to be almost the size of the 1999 year class), and a mismatch between the TAC and effort. Historically, the proportion of numbers discarded at age 1 have fluctuated around 80% with no decline apparent after the introduction of the 120 mm mesh in 2002. For 2004–2007, it is estimated to be at around 90%. At ages 2 and 3 discard proportions have been increasing steadily and are currently estimated to be 75% and 38% respectively in 2007. Note that these observations refer to numbers discarded, not weight.

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, normalized over time, so that year classes making above-average contributions to the catches are demonstrated as large positive residuals (and vice-versa for below-average contributions);

b) applying a separable VPA model in order to examine the structure of the catch numbers-at-age before they are used in catch-at-age analyses, in particular whether there are large and irregular residuals patterns that would lead to concerns about the way the recorded catch has been processed;

c) 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 demonstrate 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 of density-dependent growth had previously been found by others (Houghton and Flatman, 1981; Macer, 1983 and 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.

Maturity and natural mortality

Values for natural mortality are assumed to be variable in time. The natural mortality values are model estimates from multispecies models (SMS and 4M) fitted by the Working Group on Multi Species Assessment Methods (ICES-WGSAM 2008, see Table 1.1).

The maturity values are applied to all years and are 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

Relative fecundity appears to have changed over time, with values in the late 1980s being approximately 20% higher than those in the early 1970s, an increase that coincided with a fourfold decline in spawning-stock biomass (Rijnsdorp *et al*., 1991; ICES, 2005).

In an analysis of International Bottom Trawl Survey maturity data, Cook *et al*. (1999) found that proportion of fish mature-at-age is a function of both weight and age. They used a descriptive model based on both age and weight to reconstruct the historical series of maturity ogives where no observations existed, and calculated new spawning–stock sizes that could be compared to those estimated by the conventional assessment. They 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.

Recruitment

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

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.

The recent dominant effect of the size and distribution of the 1996 and, to a lesser extent, the 1999 and 2005 year classes are clearly apparent from maps of the IBTS distribution of cod (ages 1–3+). However, fish of older ages have continued to decline as a result of the very weak 2000, 2002 and 2004 year classes. The abundance of 3+ fish is at a low level in recent years.

An analysis of the third quarter Scottish and English survey data by Parker-Humphries and Darby (WD 24 in ICES-WGNSSK 2006) demonstrated that the extremely high catch rates estimated for ages 2–4 in a single station in the third quarter Scottish survey in 2004 resulted in the estimation of a strong reduction in mortality in 2004 followed by high mortality in 2005. When the station with high catch rates was removed, total mortality was then consistent with values obtained in previous years. The WG agreed that it would be *ad hoc* and statistically inappropriate to remove the station from the calculation of the Scottish index. After reviewing the information available on survey catch rates and spatial distribution, the WG decided to discontinue the use of the English and Scottish surveys on their own in the cod assessment because of the current low catch rates recorded by these surveys and the potential for noise at the oldest ages because of low sampling levels. Instead, the WG decided to use the IBTSQ3 survey, which incorporates both the Scottish and English surveys, together with the IBTSQ1 survey.

An analysis of IBTSQ1 data by Rindorf and Vinther (WD 4 in ICES-WGNSSK 2007) illustrated the increased importance of recruitment from the Skagerrak. Up until 2008 (ICES-WGNSSK 2008) the survey indices from IBTSQ1 and Q3 used in the stock assessment only include catch rates from the three most easterly rectangles of Skagerrak. More of the Skagerrak area should be considered for inclusion in the IBTS standard areas for abundance indices, in order to produce an unbiased abundance index for the management unit (IV, IIIa-Skagerrak and VIId) of cod. Furthermore, the Skagerrak is almost entirely covered by a single vessel in both the IBTSQ1 and Q3 surveys. This is not advantageous as it does not allow for a comparison of cod catchability between vessels, which is essential to comparison of catch rates between roundfish areas. In the North Sea, each rectangle is covered by at least two nations to reduce bias in indices.

WKROUND (2009) compared the standard and extended IBTS index for ages 1–5 for IBTSQ1 and 1–4 for IBTSQ3 with an extended are index. The largest changes in abundance were observed at the younger ages, particularly for age 0 in IBTSQ3 (not used in the assessment). Residual plots indicated a slight improvement in fit for the extended indices run compared to the standard indices run. Given the improved fit for the extended indices and other benefits of using these indices (such as better coverage of the stock distribution area) the group recommended that it would be beneficial for North Sea cod to use the extended indices in future assessments.

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 standardized 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 because of potential problems with effort recording and hyper-stability (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 covers the years 2003–2008, (Laurenson, 2008). In addition, a number of collaborative research projects are reported to the WGNSSK each year. To date the studies providing 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. The studies have proven useful in examining the dynamics of substocks within the North Sea, for instance local recruitment, and thereby in the provision of advice to managers.

C. Historical stock development

Available stock assessment models

WKCOD (February 2011) considered two candidate assessment models for North Sea cod, B-Adapt and SAM, with a third model TSA used for exploratory analysis. B-Adapt is a VPA model used until 2010 as a basis for providing advice for North Sea cod, but was considered by WKCOD to be inappropriate to an effort management system that relies on the final year estimate of F, because it provides estimates of F that vary too widely from year to year. WKROUND (January 2009), recommended that SAM be run in parallel with B-Adapt, both models estimating catch multipliers from 1993 onwards to account for "unallocated mortality". WKCOD now recommends SAM, with correlated fishing mortality-at-age, and using the IBTS Q1 survey as the only tuning index (i.e. omitting the IBTS Q3 survey), as the most appropriate assessment model for North Sea cod for an interim period only. This is so that issues related to changes in survey catchability (the reason IBTS Q3 has been omitted) and discard modelling are further explored, and it is to be hoped in future a more suitable model-data configuration for North Sea cod can be found.

The state-space assessment model contains two parts. A process of underlying unobserved states α, here the log-transformed stock sizes $\log N_1,\ldots,\log N_A$ and fishing mortalities $\log F_{i_1},\ldots,\log F_{i_n}$. The second part of the state-space assessment model describe the distribution of the observations x given the underlying states α. Here x consist of the log-transformed catches and survey indices.

The transition equation describes the distribution of the next years state from a given state in the current year. The following is assumed:

$$\alpha_y = T(\alpha_{y-1}) + \eta_y$$

The transition function T is where the stock equation and assumptions about stock--recruitment enters the model. The equations are:

$$\log N_{1,y} = \log(R(w_{1,y-1}p_{1,y-1}N_{1,y-1} + \cdots + w_{A,y-1}p_{A,y-1}N_{A,y-1}))$$

$$\log N_{a,y} = \log N_{a-1,y-1} - F_{a-1,y-1} - M_{a-1}\,, \quad 2 \le a < A$$

$$\log N_{a,y} = \log(\exp(\log N_{a-1,y-1} - F_{a-1,y-1} - M_{a-1}) + \exp(\log N_{a,y-1} - F_{a,y-1} - M_a))\,, \quad a = A$$

$$\log F_{a,y} = \log F_{a,y-1}\,, \quad 1 \le a \le A$$

Here M_a is the age specific natural mortality parameter, which is most often assumed known from outside sources. $F_{a-1,y-1}$ is the fishing mortality. The function R describes the relationship between stock and recruitment. The parameters of the chosen stock--recruitment function are estimated within the model. Often it is assumed that certain F_a parameters are identical (e.g. $F_{A-1} = F_A$).

The prediction noise η can be assumed to be uncorrelated Gaussian with zero mean, and three separate variance parameters. One for recruitment σ_R^2, one for survival σ_S^2, and one for the yearly development in fishing mortality σ_F^2.

An additional option is to use correlated random walks to describe the fishing mortalities at the different ages. The the correlated random walks for the vector

$$\log F_{,y} \sim N(\log F_{,y-1}, \Sigma)$$

where $\Sigma_{i,j} = \rho_{i,j}\sqrt{\Sigma_{i,i}\Sigma_{j,j}}$ with $\rho_{i,j} = 1$ when $i = j$ and $\rho_{i,j} = \rho$ when $i \neq j$.

The combined observation equation is given by:

$$x_y = O(\alpha_y) + \varepsilon_y$$

The observation function O consists of the familiar catch equations for fleets and surveys, and ε_y of independent measurement noise with separate variance parameters for certain age groups, catches, and survey indices. An expanded view of the observation equation becomes:

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

$$\log I_{a,y}^{(s)} = \log\left(Q_a^{(s)} e^{-Z_{a,y}\frac{D^{(s)}}{365}} N_{a,y}\right) + \varepsilon_{a,y}^{(s)}$$

Here Z is the total mortality rate $Z_{a,y} = M_a + F_{a,y}$, $D^{(s)}$ is the number of days into the year where the survey s is conducted, and $Q_a^{(s)}$ are model parameters describing catchabilities. Finally $\varepsilon_{a,y}^{(\circ)} \sim N(0, \sigma_{\circ,a}^2)$ and $\varepsilon_{a,y}^{(s)} \sim N(0, \sigma_{s,a}^2)$ are all assumed independent and Gaussian.

The likelihood function for this is set up by first defining the joint likelihood of both random effects (here collected in the α_y states), and the observations (here collected in the x_y vectors). The joint likelihood is:

$$L(\theta,\alpha,x) = \prod_{y=2}^{Y}\{\phi(\alpha_y - T(\alpha_{y-1}),\Sigma_\eta)\}\prod_{y=1}^{Y}\{\phi(x_y - O(\alpha_y),\Sigma_\varepsilon)\}$$

Here θ is a vector of model parameters. Since the random effects α are not observed inference should be obtain from the marginal likelihood:

$$L_M(\theta,x) = \int L(\theta,\alpha,x)d\alpha$$

This integral is difficult to calculate directly, so the Laplace approximation is used. The Laplace approximation is derived by first approximating the joint log likelihood $\ell(\theta,\alpha,x)$ by a second order Taylor approximation around the optimum $\hat{\alpha}$ w.r.t. α. The resulting approximated joint log likelihood can then be integrated by recognizing it as a constant term and a term where the integral is know as the normalizing constant from a multivariate Gaussian. The approximation becomes:

$$\int L(\theta,\alpha,Y)d\alpha \approx \sqrt{\frac{(2\pi)^n}{\det(-\ell_{\alpha\alpha}''(\theta,\alpha,Y)|_{\alpha=\hat{\alpha}_\theta})}}\exp(\ell(\theta,\hat{\alpha}_\theta,Y))$$

Taking the logarithm gives the Laplace approximation of the marginal log likelihood

$$\ell_M(\theta,Y) = \ell(\theta,\hat{u}_\theta,Y) - \frac{1}{2}\log(\det(-\ell_{uu}''(\theta,u,Y)|_{u=\hat{u}_\theta})) + \frac{n}{2}\log(2\pi)$$

Model used as a basis for advice

The state-space models SAM 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 only one survey index (IBTS Q1) is used, for the time being, and the total catch-at-age data. No commercial fleets with effort information are used. The Beverton–Holt recruitment function is used, but there is no visual difference in the results if a Ricker curve, or simply a random walk recruitment is used in its place. Fishing mortality random walks are allowed to be correlated.

For North Sea Cod the model is extended to allow estimation of possible bias (positive or negative) in the reported total catches from 1993 onwards. 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:

$$S_{a,y} = \begin{cases} 1, & y < 1993 \\ \tau_y, & y \geq 1993 \end{cases}$$

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:

$$\vartheta = (Q_{a=1,2,3,4,5}^{(s=1)}, \sigma_R^2, \sigma_S^2, \sigma_F^2, \sigma_{\circ,a=1,2,3^+}^2, \sigma_{s=1,a=1,2^+}^2,$$
$$\tau_{1993}, \tau_{1994}, \ldots, \tau_{2009}, \alpha, \beta, \rho)$$

The Q parameters are catchabilities corresponding to the survey fleet. The three variance parameters σ_R^2, σ_S^2, and σ_F^2 are process variances for recruitment, survival, and development in fishing mortality respectively. 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, α and

β are the parameters of the Beverton–Holt recruitment function, and ρ is the correlation parameter for the random walks on the fishing mortalities.

Model used: SAM (with correlated fishing mortality-at-age)

Software used: Source code and all scripts are freely available at http://www.nscod.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 (* indicates where changes may need to be made to accommodate a further year of data):

```
# Survey q-scaling coefficient (better name wanted)
#
# Rows represent fleets.
# Columns represent ages.
 0  0  0  0  0  0  0
 0  0  0  0  0  0  0

# The following matrix describes the coupling
# of fishing mortality variance parameters
# Rows represent fleets.
# Columns represent ages.
 1  1  1  1  1  1  1
 0  0  0  0  0  0  0

# The following vector describes the coupling
# of the log N variance parameters at different
# ages
 1  2  2  2  2  2  2

# The following matrix describes the coupling
# of observation variance parameters
# Rows represent fleets.
# Columns represent ages.
 1  2  3  3  3  3  3
 4  5  5  5  5  0  0

# Stock recruitment model code (0=RW, 1=Ricker, 2=BH, ... more in time)
2

# Years in which catch data are to be scaled by an estimated parameter
  # first the number of years
17*
  # Then the actual years
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
2009*
  # Them 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
14   14   14   14   14   14   14
15   15   15   15   15   15   15
16   16   16   16   16   16   16
17*  17*  17*  17*  17*  17*  17*

# 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+	N
Natmor	Natural mortality	1963–present*	1–7+	Y

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

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1	IBTS-Q1	1983–final year of catch data + 1	1–5

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 Beverton–Holt model.

D. Short-term projection

As a consequence of the uncertainty in the final year estimates of fishing mortality, the WG agrees that a standard (deterministic) short-term forecast is not appropriate to this stock. Therefore, stochastic projections are performed, from which short-term projections are extracted. The stochastic projections are carried out by starting at the final year's estimates, and the covariance matrix of those estimates. 1000 samples are generated from the estimated distribution of the final year's estimates. Those 1000 replicates are then simulated forward according to the model and subject to different scenarios.

Model used: SAM (with correlated fishing mortality-at-age)

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

Initial stock size:

Starting populations are simulated from the estimated distribution of the final year's estimates (including covariances).

Maturity:

Average of final three years of assessment data (constant for North Sea cod).

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:

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 is resampled from the 1997–most recent year classes.

Procedures used for splitting projected catches:

Average over the last three years landing fractions are used in the prediction 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 Precautionary Approach reference points for cod in IV, IIIa (Skagerrak) and VIId have been unchanged since 1998. They are:

	Type	Value	Technical basis
Precautionary approach	B_{lim}	70 000 t	B_{loss} (~1995)
	B_{pa}	150 000 t	B_{pa} = Previous MBAL and signs of impaired recruitment below 150 000 t.
	F_{lim}	0.86	$F_{lim} = F_{loss}$ (~1995)
	F_{pa}	0.65	F_{pa} = Approx. 5th percentile of F_{loss}, implying an equilibrium biomass >B_{pa}.
Targets	F_y	0.4	EU/Norway agreement December 2009

Unchanged since 1998.

Yield and spawning biomass per Recruit F-reference points:

	Fish Mort	Yield/R	SSB/R
	Ages 2–4		
Average last 3 years	0.70	0.34	0.45
F_{max}	0.19	0.62	3.36
$F_{0.1}$	0.13	0.59	4.73
F_{med}	0.84	0.28	0.30

Estimated by ICES in 2010, based on the assessment performed in 2009 (ICES-WGNSSK 2009), and making the same assumptions about input values underlying the MSY analysis presented in Section 14.6 (ICES-WGNSSK 2010).

H. Other issues

No other issues.

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Table 1.1. Variable natural mortality (M) values for North Sea cod, based on multispecies considerations. The seal diet data were originally collated from information sampled over a period of years (ICES, 1997). Data were then transformed to diet by age using age–length keys. Finally this set of data was allocated to one year (1985). Because of the stock structure of cod in this particular year, with a relatively low abundance of age 6, the M2 for this age becomes higher than for both younger and older cod. It is considered that, for assessment purposes, the M2 values for age 6 should be replaced by the M2 values for age 5, as reflected here.

	1	2	3	4	5	6	7+
1963	0.78	0.42	0.33	0.22	0.21	0.21	0.20
1964	0.82	0.43	0.34	0.22	0.21	0.21	0.20
1965	0.85	0.44	0.35	0.22	0.21	0.21	0.20
1966	0.87	0.45	0.36	0.22	0.21	0.21	0.20
1967	0.89	0.46	0.37	0.22	0.21	0.21	0.20
1968	0.91	0.46	0.37	0.22	0.21	0.21	0.20
1969	0.92	0.47	0.38	0.22	0.21	0.21	0.20
1970	0.92	0.47	0.38	0.22	0.21	0.21	0.20
1971	0.92	0.47	0.38	0.22	0.21	0.21	0.20
1972	0.93	0.47	0.38	0.22	0.21	0.21	0.20
1973	0.92	0.46	0.38	0.22	0.21	0.21	0.20
1974	0.92	0.46	0.37	0.22	0.21	0.21	0.20
1975	0.92	0.45	0.37	0.22	0.21	0.21	0.20
1976	0.92	0.45	0.37	0.22	0.21	0.21	0.20
1977	0.92	0.44	0.36	0.22	0.22	0.22	0.20
1978	0.92	0.43	0.36	0.23	0.22	0.22	0.20
1979	0.92	0.43	0.36	0.23	0.22	0.22	0.20
1980	0.91	0.42	0.36	0.23	0.22	0.22	0.20
1981	0.90	0.41	0.36	0.23	0.22	0.22	0.20
1982	0.89	0.41	0.36	0.23	0.22	0.22	0.20
1983	0.87	0.40	0.36	0.23	0.22	0.22	0.20
1984	0.85	0.39	0.36	0.23	0.22	0.22	0.20
1985	0.83	0.38	0.36	0.23	0.23	0.23	0.20
1986	0.81	0.38	0.36	0.23	0.23	0.23	0.20
1987	0.79	0.37	0.36	0.24	0.23	0.23	0.20
1988	0.77	0.36	0.37	0.24	0.23	0.23	0.20
1989	0.75	0.35	0.37	0.24	0.24	0.24	0.20
1990	0.73	0.35	0.38	0.24	0.24	0.24	0.20
1991	0.72	0.34	0.39	0.25	0.24	0.24	0.20
1992	0.70	0.34	0.40	0.25	0.25	0.25	0.20
1993	0.70	0.34	0.41	0.26	0.25	0.25	0.20
1994	0.69	0.33	0.42	0.26	0.25	0.25	0.20
1995	0.68	0.33	0.43	0.26	0.26	0.26	0.20
1996	0.67	0.32	0.44	0.27	0.26	0.26	0.20
1997	0.65	0.31	0.44	0.27	0.26	0.26	0.20
1998	0.63	0.31	0.45	0.27	0.27	0.27	0.20
1999	0.61	0.30	0.45	0.27	0.27	0.27	0.20
2000	0.58	0.29	0.44	0.27	0.27	0.27	0.20

	1	2	3	4	5	6	7+
2001	0.56	0.29	0.44	0.27	0.27	0.27	0.20
2002	0.53	0.28	0.43	0.27	0.27	0.27	0.20
2003	0.51	0.28	0.42	0.27	0.27	0.27	0.20
2004	0.50	0.27	0.41	0.27	0.27	0.27	0.20
2005	0.49	0.27	0.40	0.26	0.26	0.26	0.20
2006	0.47	0.27	0.39	0.26	0.26	0.26	0.20
2007	0.46	0.26	0.38	0.26	0.26	0.26	0.20

Annex 3: Recommendations

Recommendation	Adressed to
1. Establish a working group on improving use of survey data for assessment and advice (see draft resolution below). It is proposed that the group could evaluate the IBTS Q1/Q3 surveys, accounting for distribution changes, north–south stock structure, and possible catchability differences for different survey components	IBTSWG, SCICOM/ACOM
2. Stock data problem relevant to data collection (see below)	PGCCDBS, Norway, delegates of member states
3. Generate new IBTS Q1 survey, including coastal squares in the south and squares to the west of Shetland.	WGIBTS
4. Evaluate potential changes in reference points in light of historical recruitment being different in the new modelling framework and potentially reevaluate the cod management plan. WKCOD recommends that these are not evaluated until the assessment has been finalised (model discards and catches separately)	WKROUNDMP/WGNSSK
5. 1) Investigate the potential for an observer effect in discards leading to bias in discard estimation: i) Compare landed length distributions (cod) for similar vessels fish-ing in similar areas at similar times, with and without observers. Hypothesis: observed vessels discard less (and hence land more) small fish. ii) Compare camera-based discard estimates from comparable trips, with and without observers. Won't work for cod, as these "cannot" be discarded, but observer effects might be detectable for haddock, whiting, etc.	WGNSSK 2011

Stock data problems relevant to data collection

Stock	Data Problem	How to be addressed in DCR	By who
Stock name	Data problem identification	Description of data problem and recommend solution	Who should take care of the recommended solution and who should be notified on this data issue.
Cod 347d	Uncertainty and bias in discard data	Most countries supply discard data for North Sea cod but sampling levels for discard are still quite low for the main fleets of most countries. Information on CVs (or similar measures) and bias (coverage in space and time, changes in fishermen behaviour) would help to judge on the reliability of submitted data.	Delegates of the member states and Norway; PGCCDBS
COD 347d	Bias in reported landings	Unallocated removals are a major issue in the assessment of North Sea cod. In recent years more and more doubt is expressed by the industry and scientists that the large numbers of unallocated removals estimated by the assessment models are valid. Any information available on detected or suggested misreportings would help to clarify whether misreporting is still going on or whether other explanations (underestimates of discard, highgrading, changes in the catchability of scientific surveys) are more likely explanations.	Delegates of the member states and Norway, PGCCDBS, Comission, North Sea RAC.

Draft Resolution: A **Working Group on Improving use of Survey Data for Assessment and Advice** [WGISDAA] will be established (Co-Chairs: C. Lordan, Ireland and S. Smith, Canada) and will meet at ICES Headquarters, date-month-year to:

a) Develop a framework and methodology for the analysis of fishery-independent survey information for stock assessment and advisory purposes.

b) Explore and suggest refinements to current survey designs that will improve the quality of data used to support assessment and advisory processes.

c) Investigate methods of combining and or improving indices across multiple surveys and other ways of consolidating survey-derived data.

d) Develop methods for use of survey derived indices and other survey data products as a basis for scientific advice (this should include evaluation and, if appropriate, development and implementation of the method proposed in the EC's TAC setting policy statement (COM(2010)241 Annex 4).

e) Request priority case studies from assessment working groups to support the initial activities of the WG.

WGISDAA will report by date-month-year for the attention of ACOM and the Science Committee Steering Group on Ecosystem Surveys Science and Technology.

Annex 4: List of working documents

WD1: Anna Rindorf and Morten Vinther. Survey catches of cod in the North Sea: changes in catchability or abundance?

WD2: Anders Nielsen. The State-space Assessment Model SAM for North Sea Cod.

WD3: Chris Darby and Matt Parker-Humphreys. A further investigation IBTS North Sea cod catch indices.

WD4: Ian R. Napier. Changes in the Catch Rate of Cod by a Shetland Whitefish Vessel. Preliminary Analysis.

WD5: Kai Wieland, Eva Maria Pedersen and Jan E. Beyer. Changes of cod abundance in the northeastern central North Sea based on surveys with a commercial trawler 2007 to 2010.

WD6: Paul G. Fernandes and Kenny Coull. The distribution of cod around the Shetland Isles in 2007, 2009 and 2010.

WD7: Peter Wright and Francis Neat. The IBTS surveys and North Sea cod movements and population structure.

WD8: Rob Fryer. TSA: current implementation.

WD9: Rob Fryer. TSA assessments of North Sea cod.

WD10: Timothy Earl, Chris Darby and José De Oliveira . Likelihood-based B-Adapt in ADMB.