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Contents

Executive summary

The ICES Working Group on Methods of Fish Stock Assessment (WGMG) met in Lisbon, Portugal from 8–12 October 2012. The focus of this year's meeting was to provide support to the ICES Strategic Initiative for Stock Assessment Methods (SISAM) by proposing both a selection of real datasets (both from within ICES and from other areas of the world) and the details of a stock assessment methods evaluation scheme that will make use of these selected datasets. A total of 14 datasets are put forward, reflecting a wide range of biological characteristics, data quality and availability issues, and assessment model types and problems. The evaluation scheme recommended is an amalgamation of three proposals submitted to the meeting, which approach the evaluation of assessment methods from different perspectives, ranging from robustness testing and investigating "grand questions" through simulations conditioned on real datasets, to a greater focus on model selection criteria (such as investigating the predictive ability of models). Aspects of the recommended evaluation scheme were trialled and have already yielded some informative results. A couple of novel model developments within the ICES community (a state-of-the-art web interface for facilitating all aspects of performing a stock assessment, and a framework for wide application of a flexible stock assessment model on data moderate stocks for which no assessments currently exists) are also presented.

1 Introduction

1.1 Terms of Reference (ToRs)

The Working Group on Methods in Fish Stock Assessment (WGMG) chaired by José A. A. De Oliveira, UK, met in Lisbon, Portugal 8–12 October 2012 to:

a) Assemble 10–12 datasets from ICES that characterize the breadth of life-history strategy, data quality, population dynamics, and assessment problems.

b) Prepare a publication (to be presented to the SISAM symposium), using these datasets, that explores providing guidelines on simulation testing of assessment models.

c) In preparation for the SISAM symposium and building on WKADSAM, pre-test/challenge a selection of stock assessment models on the assembled datasets.

d) Using these tests, and the newly developed model categorization scheme, highlight the strengths and weaknesses of the ICES approach and the current portfolio of stock assessment models used by ICES.

1.2 Background

Since 2010, the ICES Methods Working Group (WGMG) has been closely involved in the ICES Strategic Initiative for Stock Assessment Methods (SISAM; ICES, 2012a). This initiative was launched with a specially convened meeting tilted 'Workshop on Reviews of Recent Advances in Stock Assessment Models World-wide: "Around the World in AD Models"' (WKADSAM), held in Nantes 2010 immediately after the ICES Annual Science conference (ICES, 2010a). The heavy involvement of WGMG members during this workshop meant there was no WGMG meeting held that year.

The ICES SISAM initiative and associated symposium planned for Boston, July 2013 (http://ices.dk/iceswork/symposia/wcsam.asp) are important drivers for advancing the incorporation of relevant developments in stock assessment methods into the ICES advisory system so as to ensure ICES scientists can apply the best methods when developing management advice, and can make better use of available resources. It was decided during the 2011 meeting that WGMG would align its ToR for 2012 closely with SISAM, and act as a focal point for a strong ICES contribution to the 2013 symposium.

1.3 Report Structure

The report is structured around the above ToR. Section 2 (ToR a) provides a brief description of the datasets, which were selected to reflect a wide range of biological characteristics, data quality and availability issues, and assessment model types and problems. Section 3 (ToR b) first provides a summary of past simulation approaches, and then presents three proposals submitted to the meeting for setting up a simulation testing framework, and combines these three proposals into a single unified proposal, which is labelled the "SISAM assessment methods evaluation scheme". Section 4 (ToR c) provides example applications of aspects of this evaluation scheme. A couple of presentations on novel model developments are presented in Section 5, one related to a state-of-the-art web interface for facilitating all aspects of performing a stock assessment, and the other related to building a framework for wide application of a flexible stock assessment model on data moderate stocks for which no assessments currently exists, but yet data are currently being collected under the EU's Data Collection Framework. Conclusions and recommendations, and proposed ToRs for the next meeting of WGMG are provided in Section 6 (but also given in Annexes 3 and 4 respectively). The Annexes include further details on the review of past simulation approaches (Annex 5), further technical details of aspects of the proposed evaluation scheme (Annex 6), a more detailed description of the selected datasets (Annex 7), and a description of the baseline models used for the selected stocks (Annex 8).

2 Datasets

A set of 14 real datasets, capturing a range of assessment situations, has been put forward as a starting point for SISAM work. The following table (1 row per dataset) gives a brief summary with: stock leader, stock assessment method currently applied for that dataset, the SISAM model category (in square parentheses), possible alternative models that could be applied for the dataset (with model leaders given in round parentheses, but noting that applying other models would also be possible), some of the issues with the assessment, and some of the grand questions that the dataset may help tackle. The table is followed by a brief description of each dataset, with further details recorded in Annex 7, and found by going to the "Further info" links below.

Stock	Stock leader	Current assessment	Alternative models	Issues in assessment	Grand Questions
North Sea cod	José De Oliveira	SAM [7]	B-Adapt (Earl/Darby) [6]	Unallocated removals, varying M	
North Sea plaice (recon. discards)	David Miller	XSA [6]	NOAA Fisheries toolbox (?) [range]	Discard estimation	is VPA as good as SCAA
North Sea plaice	David Miller / Jan Jaap Poos	Aarts & Poos [7/8B]	Stock Synthesis (Methot) [8B]	Unlike haddock, no recruitment pulses	Discard Estimation
North Sea herring	Niels Hintzen	SAM [7]	NOAA Fisheries Toolbox (?) [range]	Internal vs. External est of S/R, stock sub-structure, varying M	Utility of age data
North Sea haddock	Coby Needle	XSA [6]	SAM (Nielsen) [7] SURBAR (Needle) [?]	Changes in selectivity, recruitment pulses, stock definition	Utility of age data, Is there a NS haddock stock?
Northern hake	Michel Bertignac	Stock Synthesis [8A]	Biomass Dynamic (Brodziak) [3]	Dome selectivity, lack of info on older individuals	
Spurdog	José De Oliveira / Tim Earl	Modified Punt-Walker [8B]	Stock Synthesis (?) [8B]	Sexual dimorphism	
Biscay anchovy	Leire Ibaibarriaga	BBM [4]	Age-structured production model (de Moor) [5] BREM (Trenkel) [4] BBM ext (Ibaibarriaga) [4]	Complexity, utility of age data	
Iberian sardine	Xana Silva	Stock Synthesis [8B]	SAM (Nielsen) [7]	Dome selectivity	Dome selectivity
Southern horse mackerel	Alberto Murta	AMISH [7]	SAM (Nielsen) [7] SCAA (Rademeyer) [7]	Year effects in survey, selectivity changes	
North Atlantic albacore tuna	Laurie Kell	Multifan-CL [8B]	Stock Synthesis (?) [8B] Adapt-VPA (?) [6]	Insufficient info to estimate selectivity and catchability for all fleets; uncertainty about growth curve and M	
US west coast canary rockfish	Rick Methot / Owen Hamel	Stock Synthesis [8B]		Dome selectivity, degree of contrast in time-series, impact of ageing error, steepness and some mortality fixed	Dome selectivity
Georges Bank yellowtail flounder	Chris Legault	Adapt-VPA [6]	ASAP (Legault) [7] SAM (?) [7] Stock Synthesis (?) [8B]	Retrospective patterns	Retrospective patterns
South African anchovy	Carryn de Moor	Bayesian age-structured [7]	BBM (Ibaibarriaga) [4]	Utility of age data, estimation of M	

SISAM Categories: 1-Catch only, 2-Time-series, 3-Biomass dynamic models, 4-Delay difference models, 5-Age-structured production models, 6-VPA-based approaches, 7-Statistical catch-at-age models, 8-Integrated Analysis (IA) models split into two sub-categories: 8A-IA models with length-based population dynamics, 8B-IA models with age-based population dynamics models. [See ICES 2012a for more details.]

North Sea cod:

- **Assessment models:** SAM (current); B-Adapt (used previously)
- **Data inputs:** Catch-at-age numbers and mean weights (1963-present); IBTS Q1 survey (1983-present); constant maturity ogive; multispecies variable M
- **Special features:** Iconic ICES stock; unallocated mortality (1993-present); multispecies M
- **Stock leaders:** José De Oliveira
- **Further info:**
  WG report, stock annex: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=31
  Benchmark: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=537

North Sea plaice:

- **Assessment models:** XSA (current); Aarts and Poos (2009) statistical catch-at-age model which estimates discards
- **Data inputs:** Catch-at-age numbers and mean weights (landings + reconstructed discards, 1957-present); Surveys: Isis Beam Trawl Survey (1985-present, ages 1-8), Tridens Beam Trawl Survey (1996-present, ages 1-9), Sole Net Survey (1982-present, ages 1-3); constant maturity ogive, constant M
- **Special features:** high proportion of discarding, trends in survey catchability due to shifts in population distribution
- **Note:** There are two datasets associated with this stock, one with reconstructed discards as an input, the other with only observed discards.
- **Stock Leader:** David Miller
- **Further info:**
  WG report, stock annex: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=31
  Benchmark: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=344

North Sea herring:

- **Assessment models:** SAM (current); ICA (used prior to 2012, but encountered technical difficulties in software implantation used)
- **Data inputs:** Catch-at-age numbers and mean weights (1947-present, excluding 1978-9 because catches during closure not assumed to be accurate; discards included when reported, but thought to be low); Surveys: Herring Acoustic Survey (1989-assessment year for 2-8+ winter ringers, 1997-assessment year for 1 wr), IBTS Q1 survey (1984-present for 1 wr), Spawning Component Abundance Index (SSB, 1972-assessment year), IBTS0 index of 0-ringer recruitment (1992-present); mean stock weights (1947-present), variable maturity ogive, multispecies variable M
- **Special features:** subpopulation structuring (but treated as single stock); underwent collapse
- **Stock leader:** Niels Hintzen
- **Further info:**
  WG report, stock annex: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=25
  Benchmark: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=557

North Sea haddock:

- **Assessment models:** XSA (current)
- **Data inputs:** Catch-at-age numbers and mean weights (1963-present); Surveys: IBTS Q1 survey (1982-present, back-shifted), English Q3 GF survey (1977-present, catchability change in 91/2), Scottish Q3 GF survey (1982-present, catchability change in 97/8); constant maturity ogive, constant M
- **Special features:** recruitment spikes; density-dependent growth by cohort; strong hypothesized links with neighbouring stock
- **Stock Leader:** Coby Needle
- **Further info:**
  WG report, stock annex: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=31
  Benchmark: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=529

Northern hake:

- **Assessment models:** SS3 length-based model (current)
- **Data inputs:** Seven commercial fleets: annual length–frequency distributions (1978-1989), quarterly length–frequency distributions (1990-present); Discard length frequency distributions by quarter for three fleets for some years; Survey relative indices of abundance and length–frequency distributions: French Evhoe groundfish survey (1997-present; Q4), French Ressgasc groundfish survey (1985-1997, Q1-4; 1998-2001, Q2 and 4), Spanish Porcupine groundfish survey (2001-present; Q3), Irish groundfish survey (2003-present; Q4); constant logistic maturity ogive, constant M (same for all ages)
- **Special features:** age data unreliable, therefore not used; quarterly data used
- **Stock leader:** Michel Bertignac (assisted by Carmen Fernández)
- **Further info:**
  WG report, stock annex: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=126
  Benchmark: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=441

Spurdog:

- **Assessment models:** based on Punt and Walker model for Australian school shark (current)
- **Brief description of model:** Age- and sex-structured model, but fits to length-based data (proportions in length categories for surveys and commercial fleets); extent of density-dependence in pup production estimated by fitting to two periods of fecundity data; growth parameters estimated internally
- **Special features:** long-lived, low-fecundity stock; age-length model
- **Data/parameter inputs:** Total landings by fleet (treated as catch, two fleets: 1905-2010, with assumptions about fleet split prior to 1980); GLM-standardized survey data (combining four Scottish surveys, 1990-2010); length-weight parameters (by sex); maturity parameters; natural mortality parameters; Scottish commercial proportions by length-category (1991-2004); England and Wales proportions by length category (1983-2001); Scottish survey proportions by length-category (1990-2010); fecundity data for two periods (1960 and 2005)
- **Stock leader:** José De Oliveira (assisted by Timothy Earl)

- **Further info:**
  WG report, stock annex: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=123
  Benchmark: Included in Section 2 (Appendix 2) of 2011 WG report

Biscay anchovy:

- **Assessment models:** Bayesian two-stage Biomass-based Model (current)
- **Brief description of model:** Bayesian two-stage biomass-based model (BBM), implemented in BUGS and run from R using the R2WinBUGS package, where the population dynamics are described in terms of biomass with two distinct age groups, recruits or fish aged 1 year, and fish that are 2 or more years old. The biomass decreases exponentially in time by a factor g accounting for intrinsic rates of growth (G) and natural mortality (M) which are assumed year- and age-invariant.
- **Data inputs:** Total catch for two periods during the year, with accompanying catch-at-age 1 for the first period; total biomass from DEPM and Acoustic surveys, with accompanying proportion of biomass at age 1 for each survey; all fish assumed mature at age 1, constant M (but recent closure has allowed evaluation), constant intrinsic growth rate
- **Special features:** short-lived
- **Stock leader:** Leire Ibaibarriaga
- **Further info:**
  WG report, stock annex: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=272
  Benchmark: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=345

Iberian sardine:

- **Assessment models:** SS3 (current), AMCI (previous model from Dankert Skagen)
- **Data inputs:** Catch biomass and proportions at age (1978-present, discards ignored, but thought to be low), mean catch weights at age (constant 1978-1989, annually varying thereafter), mean stock weights at age (from acoustic surveys); Surveys: joint Spanish and Portuguese acoustic survey (total numbers and proportions at age, 1996-present), joint Spanish and Portuguese DEPM survey (SSB indices, 1997, 1999, every three years after 1999); maturity-at-age from DEPM surveys, M decline with age
- **Special features:** short to intermediate lifespan; small pelagic; recruitment pulses with some regularity, downward trend in time; apparent change in fishery selectivity over time
- **Stock leader:** Alexandra Silva
- **Further info:**
  WG report, stock annex: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=272
  Benchmark: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=557

Southern horse mackerel:

- **Assessment models:** Assessment Method for the Ibero-Atlantic Stock of Horse-Mackerel (AMISH; current)
- **Brief description of model:** This method models the population numbers-at-age as projections forward based on recruitment estimates starting from the initial

population numbers-at-age (1992) and subsequent annual recruitment and fishing mortalities parameters. These underlying population numbers-at-age are fit through an observation model for parameter estimation via a penalized likelihood.

- **Data inputs:** Catch and mean weight-at-age (1992-present, discards ignored, but believed to be low); combined Spanish-Portuguese bottom-trawl survey (1992-present); constant maturity ogive, constant M
- **Special features:** year effects in combined survey index
- **Stock leader:** Alberto Murta
- **Further info:**
  WG report, stock annex: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=272
  Benchmark: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=529

North Atlantic Albacore:

- **Assessment models:** Multifan-CL (model used for management); alternative assessments also conducted with ASPIC, Adapt-VPA and SS3; ICCAT can also supply data in ASPIC, VPA-Suite and SS3 formats. It is intended to also evaluate the State-Space model (SAM) and Bayesian biomass dynamic models.
- **Data inputs:** Inputs for Multifan-CL are catch, catch-at-size (CAS) and effort by fishery, where effort is derived from standardized cpue by fishery (i.e. effort = catch/cpue). Data are by fishery, year and quarter, and go back to 1932. There are 10 fisheries/fleets: baitboat, longline, troll and midwater trawl. For the Adapt-VPA assessment, catch-at-age data are derived from length slicing, although it may also be possible to use some ALKs (some age reading data available) to derive CAA. Some tagging data also available.
- **Special features:** Insufficient information in the data to estimate selectivity and catchability for all fleets; uncertainty about the growth curve and M (therefore, 14 runs with Multifan-CL were conducted during the ICCAT assessment + several runs with Adapt-VPA and SS3). Growth, fecundity and M are assumed to be stationary. Suitable for tackling “grand questions”, since data go back to 1932 and there are important questions about the relative impact of assumptions about the biology and fisheries.
- **Stock leaders:** Laurie Kell
- **Further info:** http://www.iccat.int/Documents/Meetings/Docs/2009_ALB_ASSESS_ENG.pdf

US West Coast Canary Rockfish:

- **Assessment models:** Stock Synthesis (integrated length-age structured model). The disaggregated fleets and the heterogeneous data quality across fleets will require some extra work to get some other methods working for this stock. Pseudo-data can be readily generated by SS or by POPSIM.
- **Data inputs:** Catch, length- and age-frequency data from 11 fishing fleets, including trawl, non-trawl and recreational sectors. Two trawl surveys and a per-recruit survey provide relative biomass indices and fishery-independent biological information for information on the relative trend and demographics of the canary stock.

- **Special features:** The model includes age-varying natural mortality for females, time varying fishery selectivities with dome-shaped selectivities for most fleets and time-periods. One of the most uncertain parameters is the value of (Beverton–Holt) stock–recruitment steepness. This value has been estimated outside the model using a west coast rockfish-specific meta-analysis. There is also uncertainty in historical and recent discard rates. Ageing error is accounted for in the assessment, but nonetheless is another source of uncertainty. Based upon recent assessments, canary rockfish are considered overfished and are managed under a rebuilding plan. Suitable for tackling "grand questions", because questions include dome-selectivity, catch uncertainty, sensitivity to steepness assumption, degree of contrast in time-series, impact of ageing error.
- **Stock leaders:** Rick Methot and Owen Hamel
- **Further info:** http://www.pcouncil.org/groundfish/stock-assessments/by-species/canary-rockfish/

Georges bank yellowtail flounder:

- **Assessment models:** Adapt (NOAA Fisheries Toolbox VPA v3.1.1)
- **Data inputs:** Total catch-at-age numbers (including discards) and mean weights (1973-present); begin-year mean weights at age (1973-present); DFO spring survey with associated CV (1987-1994, 1995-present); NEFSC spring survey with associated CV (1973-1981, 1982-1994, 1995-present); NEFSC fall survey with associated CV (1973-1994, 1995-present); NEFSC scallop survey (age 1 only, 1982-1994, 1995-present); constant maturity-at-age; M=0.2 for all ages and years.
- **Special features:** There is an inconsistency in the basic data for this assessment: recent catches are low and survey indices have increased, yet there is no indication of expanding age structure. This is seen by comparing the simple metrics of relative F (catch/survey biomass) and survey Z (survival of age classes in the survey). The relative F shows a large dramatic decrease since 1995, while survey Z show no change over the entire time period. This inconsistency in the data leads to a strong retrospective pattern which has been observed in the "vanilla" VPA since 2005. Splitting the survey time-series was sufficient to reduce the retrospective pattern until recently. The 2012 assessment examined splitting the survey time-series, increasing recent catch, increasing recent M, increasing both recent catch and M, and making retrospective adjustments to the estimated population as means of addressing the retrospective pattern.
- **Stock leaders:** Chris Legault
- **Further info:** http://www2.mar.dfo-mpo.gc.ca/science/TRAC/rd.html

South African anchovy:

- **Assessment models:** Age-structured production model model (Bayesian).
- **Data inputs:** Annual juvenile (0 year old) and adult (1 year old) anchovy catch and mean catch weight; anchovy 1+ biomass and associated CV from the November acoustic survey; anchovy spawner (1+) biomass and associated CV determined by the DEPM; Proportion-at-age 1 (by number), with SE and weights-at-age in the November survey; anchovy recruitment and associated CV from the May recruitment acoustic survey; the date of the commencement of the annual recruit survey; juvenile anchovy catch and mean catch weight of individual

juvenile fish from 1 November in year y-1 to the day before the annual recruit survey in year y.

- **Special features:** short-lived
- **Stock leader:** Carryn de Moor
- **Further info:** http://www.mth.uct.ac.za/maram/pub/sisam/Background_on_SA_anchovy_assessment.docx

3 Simulation Approaches

3.1 Review

Available reports of the Methods WG (ICES 1983, 1984, 1985, 1987, 1988, 1989, 1991, 1993, 2001, 2003, 2004) were reviewed. Simulations work was identified in the reports for 1987, 1988, 1989, 2001, 2003 and 2004. A report from the National Research Council (NRC) of the United States of America (USA) on Improving stock assessments (NRC 1998), the final report of the EU Concerted Action FAIR PL98-4231 meeting held in 2000 (Patterson *et al*., 2000a), and a report of a study by the North East Fisheries Science (NEFSC) of the National Marine Fisheries conducted in 2008 (Brooks *et al*., 2008) were also reviewed. A brief review and summary of the approach to the simulations and of the results are presented below. Details of what was found in each report is provided in Annex 5.

While simulation studies to investigate the performance of stock assessment models have been done at other meetings of the Methods WG than whose reports were available, most of that work is believed to have involved observation error (adding random noise to the catch-at-age and stock size indices data) but also some process error (changes in catchability over time). Several different ways of "tuning" Virtual Population Analyses (VPA) were developed in ICES in the late 1970s - early 1980s (gamma method, Laurec-Shepherd, etc.) and the Methods WG was in fact set up to identify which ones performed acceptably. Extended Survivor Analysis (XSA) with shrinkage was found in 1991 to perform reasonably well under a wide range of circumstances.

The 1988 Methods WG in Reykjavik undertook a systematic evaluation of the performance of several methods under both observation and process error (changes in catchability as in previous studies).

Following a few high profile contentious stock assessments (e.g. bluefin tuna, cod, haddock and yellowtail on Georges Bank) the National Research Council of the United States of America was tasked with undertaking a review of stock assessment methods (NRC 1998). They generated a comprehensive set of simulated data with various observation and process errors. These datasets were submitted to analysts to apply different assessment methods. None of the methods performed well when applied blindly, as was probably expected, and performance improved with the intervention of the analysts. The EU Concerted Action (FAIR PL98-4231) meeting, held in Reykjavik in 2000, applied three series of tests designed to evaluate the performance of methods then in use to estimate uncertainty in stock assessment and management advice. The 2004 Methods WG used the same datasets, with some modification, to extend the analyses done during the NRC review. Details of the data, methods, and some results are in Annex 5.

The WG is not aware of previous studies that generated simulated data from one specific assessment model to be fitted by a different stock assessment model. This approach could be useful to identify how different settings of otherwise similar approaches may influence the results of the assessment, but it is unlikely to provide a fair comparison for models that are radically different.

3.2 Proposals

3.2.1 Proposal 1

Suggested sequential structure for simulation testing of assessment methods (Doug Butterworth)

Many past exercises involving simulation testing of assessment methods have, in my view, proved less useful than one might have hoped for the reason (again in my view) that they have been based on a range of idealised scenarios. Unsurprisingly there are seldom generic results which are valid across a wide range of circumstances, so that it can become difficult to use such results to specify the circumstances under which some result/advice applies, and hence to know whether it is pertinent to the assessment situation with which one might be faced with a particular stock.

The first and broad principle underlying the structure suggested below is that simulation testing should rather be based on actual situations, i.e. real resources and their associated data. Certainly then, at the end of a simulation testing exercise based upon a particular stock, one has results valid for that stock at least. But the further hope is that as examples of such testing exercises grow, a pattern of results will develop that will allow generic conclusions to be drawn, and hence then inferences made concerning (say) the best assessment approach to apply for yet another stock without again having to take that stock through this same simulation exercise.

Arising out of this principle there follows the concept that simulations should be "conditioned" on the situation believed to apply in respect of the stock concerned. This concept arises out of what has become standard practice in the simulation testing of Management Procedures (MPs) for setting catch limits for whale stocks as conducted in the IWC's Scientific Committee. MPs are intended to be robust against uncertainty, but there is no point in requiring robustness against uncertainties known not to apply for a particular stock. It is from this that the concept of "conditioning" of simulation tests arose: that the different population dynamics models used in testing MPs for a particular stock for robustness against uncertainty should all be required to be consistent with known information for that stock, e.g. a time-series of past catches (assuming that to be well determined).

For MP testing, the IWC approach (for any particular model structure assumed for a stock, e.g. a specific value for natural mortality) is to fit a population model based on that structure to yield one specific plausible reflection of the true underlying dynamics for that stock. Given those fixed underlying dynamics, a series of pseudo datasets is then created by generating observations (abundance indices, catch-at-age values, etc.) of the same form and number as the real data, which could have arisen given those dynamics, with the distribution functions used to generate the errors/residuals for those pseudo datasets being as estimated in the original fit of the population model to the actual data.

For the IWC SC in an MP context, it is those pseudo datasets that are used as the basis to develop the simulation tests: for each trial the MP is tested against a range of alternative scenarios for the dynamics which have been obtained by fitting the population model for the model structure concerned (under the same time-series of known historical catches) to each pseudo dataset in turn. Here it is suggested that **pseudo datasets generated in this same way** (conditioned on an estimate of the underlying situation of the stock concerned that is provided by the fit of the original assessment model) **could provide a basis for simulation testing of assessment methods**.

One would not work with only one model structure and assessment procedure to generate such pseudo datasets. Clearly alternative structure/assessment method combinations can be used to estimate alternative underlying dynamics that would also constitute alternative plausible descriptions of the resource's situation. These too can be used to generate further sets of pseudo datasets in the same way. An investigation of assessment method performance should involve not only tests against pseudo datasets generated from the same structure and model, but also from defensible alternatives similarly consistent with the available information, as each could represent the actual underlying situation.

Observation error

In the context considered here, observation error refers to mechanisms that do not change the underlying stock trajectory. Thus, for example, a residual generated from a survey sampling error distribution about the value expected given the underlying true abundance reflects an observation error. In contrast, a mechanism that leads to a change in the population trajectory (or its age structure), such as an alternative deviation about the stock recruitment function, or a variation in the selectivity at age for the fishery which would modify the splits of historic catches into ages, is considered process error.

As a first step in this process of simulation testing of assessment models, it is suggested that pseudo datasets involve the addition of observation errors only when generating pseudo data. There are two reasons for this:

simplicity at the initial stage of a complex exercise; and

ease of the comparison exercise for estimates obtained when applying assessment methods to simulated pseudo datasets (developed from a particular structure/model combination); if these datasets include only observation error, there remains only one underlying true value for any quantity of interest (e.g. current resource biomass, or an Fmsy TAC) against which to compare results from the different assessment methods.

Process error

In the IWC situation, where whale populations are generally assumed to have fairly slow and steady dynamics so that observation error dominates process error, process error has seldom been considered when generating MP trials because there has seemed to be no great need to include this. It is in any case problematic to do so, because if the underlying resource abundance differs from one pseudo dataset generation process to the next (e.g. through differing fluctuations in recruitment) upon what does one condition? For example, does one still condition on the historic catch series? However, if earlier recruitment in a particular year was lower than estimated under the original assessment based on the actual data, it may perhaps not even be possible to have taken that historic catch made that year without causing the extinction of the stock for the simulation in question. One could perhaps condition on the historic fishing mortality F rather than the historic catch each year, but then one is testing against scenarios that didn't actually happen and so can't actually reflect a possible reality, contrary to the conditioning concept.

The IWC SC has extended its MP testing process to include process error (essentially recruitment or natural mortality fluctuations) on two occasions, but for the whale population concerned their size was sufficiently small that the problem of extinction either did not arise, or arose so infrequently that the odd simulation where it did could simply be omitted without introducing more than negligible bias into the data generation process.

That, however, does not necessarily apply to typical fish stocks (except perhaps to long-lived ones, but there too recruitment may be highly sporadic), so a different approach is required if process error is to be introduced. The one suggested here could be applied whether the model includes random effects or is fully Bayesian. It requires effecting the integration concerned through an MCMC process, which creates equally likely scenarios (trajectories etc.), all of which are fully consistent with aspects of the real situation (such as historical catch series – though even for those one might wish to introduce the possibility of uncertainty which can be handled under this same approach), so that it respects the conditioning principle. The resultant pseudo dataset would then consist of n such MCMC realizations of the underlying dynamics, for each of which m realizations of observation error would be generated, giving nm pseudo datasets.

The difficulty that then arises is that the true value of certain quantities of interest (e.g. current abundance) will not be invariant across all such datasets, so that statistics measuring estimation performance will need to be based upon the differences between estimated and true values in circumstances where both vary from pseudo dataset to pseudo dataset. If these true values do not vary too much (say ~ 10%), that might not prove too problematic when it comes to interpreting results, but care may need to be taken in more extreme situations where that level of true variability is perhaps an order of magnitude greater.

3.2.2 Proposal 2

Plan for simulation studies (Richard Methot)

Given a time-series of catches, the ability of assessment models to infer the impact of those catches on a fish stock depends upon the type and precision of other available data, ability to deal with confounding factors that influence those data, and the degree of contrast in the time-series of data. Application of assessment models to simulated datasets allow for investigation of the robustness of model performance to each of these factors.

Two fundamental categories of data are (1) a measure of fish stock abundance; and (2) a measure of the proportions at age in the population. Each provides fundamentally different information about the effect of fishing on the fish stock.

> Abundance information provides inference about the effect of fishing in two possible ways. One is the rare case where the abundance information is a direct measure of fish abundance. In this case, the ratio of catch to survey abundance is directly informative. Much more commonly, the abundance information is a time-series index of stock abundance. In this case, contrast in the time-series is needed in order for the assessment model to infer stock abundance and fishing mortality rates from the available data. In this context, high contrast would mean that the time-series has periods with low catch from low abundance index allowing for an increasing index, and conversely high catch from high stock index causing a decreasing index. If the contrast is weak, these models cannot perform well at estimating absolute levels. If the data are biased, such as a drift over time in the calibration of the index to stock abundance, then this incomplete calibration will cause a bias in the assessment result.

Age composition provides inference about the effect of fishing by providing a measure of the total mortality rate experienced by adult fish. If the natural mortality rate is accurately estimated and the sample of age composition is an unbiased estimate of the population age composition, then the proportion of mortality caused by fishing is estimable. Then population abundance can be estimated by combining this estimate of fishing mortality with the absolute amount of catch that is causing this mortality. These estimates will be biased if the natural mortality value used is inaccurate, or if the age composition sample is biased by some differential sampling of old vs. younger fish (selectivity). If there is selectivity and it has a constant pattern over time, then analysis of the age composition data can estimate both the pattern of selectivity and the fishing mortality rates if there is contrast in a time-series of age composition data (high catch periods lead to fewer fish surviving to older age groups, and vice versa). However, if the degree of selectivity changes over time, then these changes are highly confounded with other factors (mean level of fishing mortality and time-trend in recruitment) and robust estimation of the model is doubtful.

The goal is to investigate model performance given a range of situations regarding data availability, precision, contamination, and contrast as described above. A structured way to approach this is to use a parametric bootstrap approach for each of several stocks. This approach has been used to investigate the performance of assessment models used in the US Northeast (Brooks *et al*., 2008), and incorporated within the Stock Synthesis assessment framework (Methot and Wetzel, in press). Piner *et al*. (2011) used the SS procedure to investigate model misspecification. Lee *et al*. (2011) applied it to investigate robustness with which the data available in actual assessment situations is sufficient to allow for internal estimation of natural mortality. Taylor and Methot (in press) used the procedure to investigate the performance of the assessment model in distinguishing dome-shaped selectivity from another phenomenon that can cause similar patterns in composition data.

In brief, the procedure involves:

1) Select a set of models, or structural configurations within a model

2) For each such model or model configuration: fit the model to available data

3) Generate expected values for each datum and the expected observation error for that datum given that fitted model

a) Use the estimation model as the data-generator also

b) Transfer estimated parameters to a separate data-generation model

4) [optional] re-generate the time-series of expected values incorporating random draw of population process errors

5) Generate numerous simulated datasets by randomly drawing from the parametric observation error around each estimated datum

6) Fit a range of assessment models (or model configurations) to each simulated dataset

7) Accumulate results of relevant quantities (degree of stock depletion, estimate of MSY, forecast of next year’s catch given estimate of Fmsy, etc.) for each model.

Data Generation: Two options exist for generation of the simulated datasets. One is to use the original estimation model as the data generation model (as is done in SS). The other is to take the estimated parameters from the estimation model and use these parameters in an independent model to do the data generation (as would be done where POPSIM is used to generate the simulated data). Inclusion of both of these data generation methods is advised because it provides for some evaluation of the degree of importance of structural differences among the data generation models.

Observation and Process Error: The above procedure deals with observation error only in generating the simulated datasets. In reality, the assessments may also contain various time-varying processes (annual recruitment deviations, temporal changes in selectivity, temporal changes in fishery cpue calibration, etc.). Some of these process errors affect only the observation process (e.g. temporal changes in cpue calibration or ageing error or survey selectivity), and others may affect the processes that affect the population (e.g. recruitment and fishery selectivity). The quality of the assessment model's estimates of the time sequence of these processes depends on the quality of the actual data. Without the optional step (4), all simulated data from a particular selected model will come from the same estimated sequence of these processes. In this case, it is reasonable to investigate the fidelity with which the estimation models (step 6) can recreate this sequence of estimated process deviations. It is possible to account for randomness in these processes by inserting an additional step (4) above. If this additional randomness is only in terms of observation processes, then step (7) is unaffected. However, if randomness is introduced in factors that affect abundance and mortality, then the basis for step (7) is more complex. For the purposes of the proposed study, it is recommended that the simulations be restricted to observation error only. Neither randomness in observation processes or in population processes will be included in the baseline study of the test stocks.

Model complexity: The testing procedure described here is designed to investigate model robustness within a restricted range of model complexity. Models with greatly varying degrees of complexity (e.g. a biomass dynamics model vs. a multiple fleet age-structured model with varying degrees of selectivity) differ principally in the degree to which they account for time-varying processes. Investigation of the relative performance of models that are that different in configuration must incorporate randomness in these processes.

Knowledge provided to the test teams: Assessment models are never applied blindly to datasets. The benchmark process provides a forum in which the characteristics of the situation and the data are openly investigated before model configurations are selected. Because the simulated datasets are based upon real assessments, the assessment documents will provide information on important configuration factors (M, degree of domed-selectivity, etc.). Because all this information is discoverable, it seems best to openly provide it to all teams that seek to apply an assessment model to the test datasets. The goal is to investigate model performance given random observation error, not to investigate the model's ability to independent estimate important structural factors.

What will we learn?: The various stocks that will be used as the basis for the tests will encompass a collection of differences in data types, time-series contrast, life history, and other factors. They have not been selected to represent a particular range of conditions. This means that the results of the simulation exercise will be an evaluation of the robustness of those assessments as conditioned on their current configuration and according to a collection of assessment approaches. This is the approach as used in Piner *et al*. (2011).

What will we not learn?: The observation error only approach does not lead to full investigation of model structural issues because all assessment models will attempt to use the best structure as represented by the current assessment. There will be different software and statistical implementations of that structure, but there is no reason to expect that the structure itself will be greatly different. One cannot learn about model structure without considering a range of alternative structures. For this, a more focused investigation of particular model features is needed. For example, as Lee *et al*. (2011) investigated robustness of M estimates, and as Taylor and Methot (in press) investigated dome-shaped selectivity.

Simulation Using POPSIM:

For stocks that will have data simulated using POPSIM, the following procedure is proposed:

a) The Steering Committee defines the "truth" for each scenario and fully parameterizes the operating model as noted above.

b) POPSIM is used to create n datasets for examination.

  i) For some models POPSIM will be able to create the complete set of appropriately formatted data for input to a NFT model

  ii) For other models, POPSIM will create a standardized set of output, most likely in an R list.

    1) The use of a standardized output file will ensure that scenarios can be created efficiently, but it will also require a standardized nomenclature for list elements. Eg $CAA for the catch-at-age matrix.

    2) Users will be required to post-process these input files into a standardized set of input files for their models. NEFSC can provide some assistance in this task but it not be possible to create standardized input sets for every model unless the model input structures are stable.

  iii) The details of what will be distributed to each modeller will need to be specified. POPSIM creates data rich modelling output. Will each modeller receive all the data or will the resolution of the data be adjusted for each modeller according to the data requirements. Examples: age only; age and length; age, length and lumped biomass; biological parameters, etc.

c) Configuration of the estimation model for parameters not included in the generating model is the responsibility of the end-user. For example, the definition of a plus group is a key decision, usually made after investigation of the data. Such tweaking of model parameterization is not part of the data simulation task. To make this process as fair as possible, we recommend that the individual modeller base the configuration of their models by examining a single realization of the simulated data. Each user would be provided with n+1 realizations. The first dataset would be used to parameterize the model. The remaining n datasets would be used to evaluate model performance.

d) While model specific input formats would be difficult to standardize, the success of this project relies on rigid specification of model outputs. We envision that the standardized output data will be assembled and compared by the NEFSC contract programmer. Results will then be made available to all participants in this exercise.

i) Standardized model outputs would likely be in the form of R lists.

ii) Basic Metrics for comparison are likely to include comparison of SSB, R, and F (or harvest rate).

iii) Useful but more difficult measures would be quantification of retro bias.

iv) Each comparison will be characterized by standard descriptive statistics: mean, variance, bias from true value, confidence interval etc.

3.2.3 Proposal 3

Comment about model selection and proposal (Anders Nielsen)

Introduction

Simulation studies are extremely useful for a large number of tasks related to modelling of almost any kind, especially for evaluating the more technical and frequentist aspects of model performance. It is, however, important to remember that the simulated cases are conditioned on a specific set of model assumptions, and so will all conclusions based on these simulations be. So, all conclusions that relate to real data, which are based on simulations, should be sceptically evaluated.

Standard simulation study

A standard simulation study, which will here be referred to as a 'within-model' simulation study, is simply the procedure of:

0. Estimate parameters from the real dataset
1. Simulate a dataset from the model using the estimated parameters
2. Estimate the parameters from the simulated dataset
3. Repeat from 1: until a predefined number of simulations are obtained

For the simulation study to be most relevant, it is important to make it as realistic as possible, for example with respect to the amount of data given, the number of missing observations, etc. The important aspect here is that the simulations are drawn from the same model as is used to estimate, so this setup should be ideal conditions for the model. No model assumptions are violated.

Such within-model simulations studies are valuable, and should routinely be conducted, for answering questions like:

- Are parameters identifiable with the typical amount of data available?
- Are there serious biases, which should possibly lead to a reformulation of the model?
- Is the model implementation correct?

Robustness checking via simulation

A different valuable use for simulation is robustness checking. Here, datasets are simulated from the model, except for specifically introduced violations of the models assumptions. For instance, in a fisheries context, the effect of introducing noise in natural mortality for a model assuming no noise could be investigated.

For robustness checking to be easily interpreted, it is important to know exactly how (and to what extent) the model assumptions are violated.

Comparing models for a given dataset

Turning now to the case of comparing several different models, a suggestion was made to use simulations to evaluate the performance of these models. The procedure for a set of different models M_1, M_2,..., M_n was:

0. Fit each model to the one true dataset X
1. Simulate a dataset from each model, based on the fit obtained in 0:
2. Fit each model to each simulated dataset
3. Repeat from 1: until a predefined number of simulations (N) are obtained

Completing this will result in $N \times n \times n$ simulated and fitted cases. From each of these cases, a measure of lack of fit compared to the fit from which the simulated case was generated, can be derived. These $N \times n \times n$ lack of fit measures, could then be summarized (summed or averaged) for each combination of simulation model and estimation model.

Lack of fit measure	Est. M_1	Est. M_2	Est. M_3
Sim. M_1	0.10	0.40	0.90
Sim. M_2	0.35	0.20	0.85
Sim. M_3	0.80	0.79	0.15
Total?:	1.25	1.39	1.90

A simulation approach like this needs to be carefully vetted before modellers will commit to the process, offer their time, and bring their models to the table. It is not obvious that the specific task of model selection for a given dataset is aided by simulation from a set of (more or less) wrong models. A number of obvious questions spring to mind:

1. How does this procedure compare models working on different data types, for example, an assessment model working on age data and one working on length data? Within the age-based model, there is no way of simulating the data needed for the length-based model?
2. Does the procedure favour similar models? If a pool of models are considered, where some of the models are similar in terms of the underlying model assumptions, then the lack of fit measures for those combinations will be small, but big compared to a single model with different assumptions. Computing the summary (like the total in the table above) would then tend to favour the similar models. In an assessment, this is a realistic scenario.
3. Is the procedure able to justly compare models, when some models assume large parts of data known, while others consider it subject to observation noise?
4. Finally, it would be good to develop a clear understanding of how the simulation procedure handles a typical problematic case, like when a model is over-fitting the data.

PROPOSAL: Prediction based model comparison

Prediction based model selection is used in many fields of science, and for assessment models it seems especially relevant, since short-term predictions are one of the main uses of this model class. In its simplest form, a part of the real data are used to estimate the model, and then the remaining data are predicted via the model and lack of fit measured.

The benefit of using a prediction-based approach is that it works on the actual true data.

It is, however, not straight-forward to use this approach in an assessment context. Many of the models cannot predict by themselves, as they are descriptive procedures, or contain independent year-specific parameters (e.g. $F_{a,y} = F_a F_y$), so additional assumptions are needed for prediction. Furthermore, certain dataseries may be considered too short to split.

So, if a prediction approach is desired, some addition is needed. For instance, an extended model view can be adopted, where the estimation model is coupled with a prediction rule, and this combination constitutes a model. It could also be considered to supply, for example, the average fishing mortalities for the years to be predicted, or simply the known total catch. Having specified these boundary conditions, the prediction approach is simply:

- Cut off 12 years, estimate, and predict data two years ahead
- Cut off 11 years, estimate, and predict data two years ahead
- ...

Notice that these steps are similar to what is routinely done when these models are used to provide short-term predictions.

Finally, consideration should be given to down-weighting (or ignoring) the prediction error for the recruitment, since those errors are expected to be much larger than the errors on other predictions.

Remember the basics

Comparing models for a given dataset should first and foremost focus on the actual observed data, so the basic model diagnostics (for example, residuals and retrospective analysis) should not be ignored.

3.3 Recommended Approach

THE SISAM ASSESSMENT METHODS EVALUATION SCHEME

Introduction

One of the key objectives of the SISAM World Conference on Stock Assessment Methods for Sustainable Fisheries (WCSAM, Boston, July 2013) is to provide advice on the relative strengths and shortcomings of various assessment methods when applied to a diverse set of real and simulated data. The selected stocks cover a range of assessment data availability and current modelling approaches as described in the SISAM Assessment Categorization (ICES 2012a). The results will be informative to assessment leads seeking advice on which current method to apply to their assessment situation, and will provide guidance to model developers who are working on next generation assessment methods. To this end, a scheme is set out below which intends to be inclusive, covering both more classical model selection techniques and also simulation approaches to test the performance of different methods in circumstances where data are generated from known underlying dynamics so that model-estimates can be compared with the underlying "truth".

Note that in the following paragraphs there are references to simulations including observation error and process error. In this context what is meant is:

<u>Observation error</u>: Randomness is incorporated in the generation of the data observed from a given population, but not in any process that would actually change the population trajectory; hence, the data generated could incorporate randomness in the abundance indices or catch observed from the given population (where simulations assume a single underlying actual, i.e. "true", catch trajectory), but not in recruitment or survival. This includes not only direct observation uncertainty that arises from, for example, the fact that surveys involve sampling error, but also other factors that lead to differences between observations and the underlying model such as variability from year-to-year in the catchability associated with an abundance index. Note potential ambiguity here with usage elsewhere, where for example the variable proportion of a population that has moved into an area at the time that area is surveyed each year, leading to additional variance in the index from the survey, is sometimes termed "process error", but in the context used here would be seen as a contributor to observation error.

<u>Process error</u>: This involves incorporating random error in processes that will change the population trajectory from simulation to simulation. Thus if recruitment each year is generated from a distribution about a stock–recruitment curve, the population trajectory for each simulation will depend on the time-series of residuals generated from that distribution. Similarly if variation in survival rates (natural mortality) is admitted, this will create inter-simulation trajectory variation. If selectivity-at-age has a variable component, this will impact the age-composition of the catch and hence in turn the population dynamics. Uncertainty in catch can also be treated as including process error (in addition to possible associated observation error) if the simulations for a particular stock take account of lack of certainty about the catches which were actually taken from the stock, thus impacting the different simulations differently.

The scheme

The scheme is divided into several steps (Figure 3.1). These rely primarily on first a selection of real datasets for actual stocks, and then using these datasets as a basis to condition pseudo datasets at a later stage. This is achieved by generating these pseudo datasets either directly from models fitted to the original data, or by using a population simulator broadly consistent with these datasets. Because of the increase in operational complexity of the scheme (and the associated increase in work effort), it is envisaged that progressively fewer stocks will be considered as one progresses through the various steps.

The scheme was developed from the three proposals given in Section 3.2, and as such encompasses tasks with a number of aims. Steps 1 and 2, and to some extent 3(a) and 4(a), aim to evaluate to what extent methods are suitable for a given real dataset. [Note that although Steps 1 and 2 have been distinguished, they actually characterize the extremes of a continuum related to the amount of time an analyst can afford to devote to the model fitting exercise in question.] Steps 3(b) and 4(b) aim to evaluate the robustness of models given a variety of plausible realities consistent with real datasets. Step 5 aims to investigate "grand questions" that may arise in the selection of assessment approaches (and associated data selection schemes).

STEP 1 deals with simply fitting a variety of models to a selection of real datasets. This is the least complex stage, and some models may not even be optimized (i.e. applied with standard settings only for features such as shrinkage, rather than fine-tuned in the spirit of a real stock assessment). It will be important that any analyst who takes part in this step makes clear to what extent, if any, such fine tuning has been carried out.

STEP 2 demands more rigour in demonstrating that the model provides a reasonable fit to the data, and will require that this be demonstrated through standard statistical diagnostic tests, e.g. consideration of time-series of residuals for evidence of model mis-specification, and for likelihood-based methods, criteria such as AIC might be used to select amongst alternative model variants. For selection amongst alternative models, prediction based (cross validation) methods can be used; here, the model's ability to predict actual data points, which are omitted when tuning the model, is measured (for details see Section 3.2.3).

STEP 3 introduces simulation approaches for the first time. These simulation approaches initially consider only observation error. These approaches can be applied at two levels: within models and across models

(a) Within-model simulation testing explores the estimation properties of the model and provides a minimum check as to whether the model is "self-consistent", i.e. provides estimates which are not substantially biased.
(b) The particular aim of cross-model simulation is to investigate model robustness. Using the example of a data-based simulation, where there are two candidate models, say M_1 and M_2, that incorporate only observation error (e.g. Adapt and XSA, both VPA-based methods) applied to a single real dataset, the approach fits each model to the real data to provide two plausible model realities (i.e. one reality per model) consistent with the real data, ensuring that the rigorous criteria of Step 2 are met in each case. The second stage is to generate pseudo data (using observation error only) from each of these model realities (100 pseudo datasets per model reality, resulting in 200 pseudo datasets in total). The final stage is to refit each of the two models to each of the pseudo datasets. This provides a 2×2

comparison of models fitted to pseudo data generated from model realities, where each cell reflects combination of statistics (as a minimum, the population abundance, fishing mortality and related statistics and plots in Section 4.1), as follows:

Model Realities	MODELS FITTED M_1	M_2
M_1	cell 1	cell 2
M_2	cell 3	cell 4

Step 3(a) would thus use cells 1 and 4, while Step 3(b) will use cells 2 and 3.

STEP 4 repeats Step 3, but this time incorporating both observation and process error in the simulation of pseudo datasets. From the description above of process error, this means that each pseudo dataset will also correspond to a different population trajectory.

Taking the example of Step 3 further to illustrate Step 4, consider a further assessment model, say M_3, that incorporates both observation and process error (e.g. SAM, essentially a time-series catch-at-age model). Because M_1 and M_2 allow only for observation error, the pseudo datasets generated from them would also incorporate only observation error (hence simulating according to Step 3). Because M_3 incorporates both process and observation error, the pseudo datasets generated from it could incorporate only observation error (hence simulating according to Step 3; this is the example that is provided in Section 4.1) or incorporate both observation and process error (hence simulating according to Step 4). In either case, the comparison between the 3 models would yield the following 3x3 matrix (extending the 2x2 example above):

Model Realities	M_1	MODELS FITTED M_2	M_3
M_1	cell 1	cell 2	cell 7
M_2	cell 3	cell 4	cell 8
M_3	cell 5	cell 6	cell 9

If the pseudo datasets from M_3 incorporate only observation error, then Step 3(a) would use cells 1, 4 and 9, and Step 3(b) would use the remaining cells (2, 3, 5, 6, 7 and 8).

If the pseudo datasets from M_3 incorporate both observation and process error, then Step 3(a) would use cells 1 and 4, Step 3(b) cells 2 and 3, Step 4(a) cell 9, and Step 4(b) cells 5, 6, 7 and 8.

The procedure for generating pseudo data that also include process error is more complex (see Annex 6).

STEP 5 aims, aided by real datasets, to investigate "grand questions" that may arise in the selection of assessment approaches (and associated data selection schemes), e.g. utility of ageing data, dome selectivity, changes in selectivity over time, importance of contrast in index time-series, retrospective patterns, etc. One of the requirements for the effective exploration of "grand questions" is that datasets should contain a sufficient range of contrasts to achieve this effectiveness, and it may often be the case that the real datasets selected do not meet this requirement. This step may therefore need to impose such a range of contrasts, either by tweaking the original data (changing them enough to exhibit the varying degrees of contrast needed for the exploration), or by using a population simulator, such as PopSim in the NOAA Fisheries Toolbox, to generate pseudo data with the required level of contrast. PopSim could be used in two different ways for this step: either to generate data broadly consistent with those for one of the datasets/stocks selected, or directly to create data for a more generic (e.g. "cod-like") stock.

Other issues

1. Top–down vs. bottom–up approach to generalization (for drawing conclusions applicable to a wide range of situations). Applying Steps 1-4 approaches generalization by starting off with specific cases (real datasets), and relying on repeated applications in a wide range of cases to start drawing general conclusions. In contrast, past simulation approaches have usually tackled this problem by starting generically through extensive use of population simulators to construct an underlying situation including certain characteristics of interest, in order to draw conclusions that could be applicable in such situations. There are merits to both approaches, but since the latter has been extensively applied in the past (some would argue with limited success in providing guidance in subsequent applications to specific situations), it is felt that the present scheme should put some more focus on the former. Nevertheless, Step 5 is more closely aligned with simulation approaches considered in the past, and it is also part of the present scheme. Note that applications of Step 5 do not necessarily require prior completion of Steps 1 to 4.
2. It should be clear exactly what constitutes any assessment model put forward (e.g. which specifications are tune-able and which are fixed). Tuning selections for the models put forward for Steps 3 and 4 should be made only on the basis of the original data. The analyst must make clear, when entering the simulation testing phase, whether such tuning is fixed or data-dependent; if the latter, the specification of the method must include a defined algorithm (that can be automated) which specifies how the tuning value can be selected/estimated given the pseudo datasets provided.
3. The generation of pseudo datasets needs to be very clearly specified and carefully carried out. For example, appropriate conditioning on real data may require the incorporation of autocorrelation in residuals so that the pseudo data have as closely as possible the same statistical properties as the real data appear to have under the particular model to which they are being fit (i.e. they are generated in a manner that is consistent with residual patterns). Further discussion may be necessary regarding how best to proceed in situations where the assessment method proposed takes no account of autocorrelation effects, but these are clearly evident from associated residual plots
4. Care must be taken in comparison processes to guard against focus on oversimplified statistics which might tend to favour assessment methods which are similar to each other.
5. This scheme is meant to be a first phase, during which, it is hoped, much will be learned which would then also aid in planning a possible continuation of this exercise.

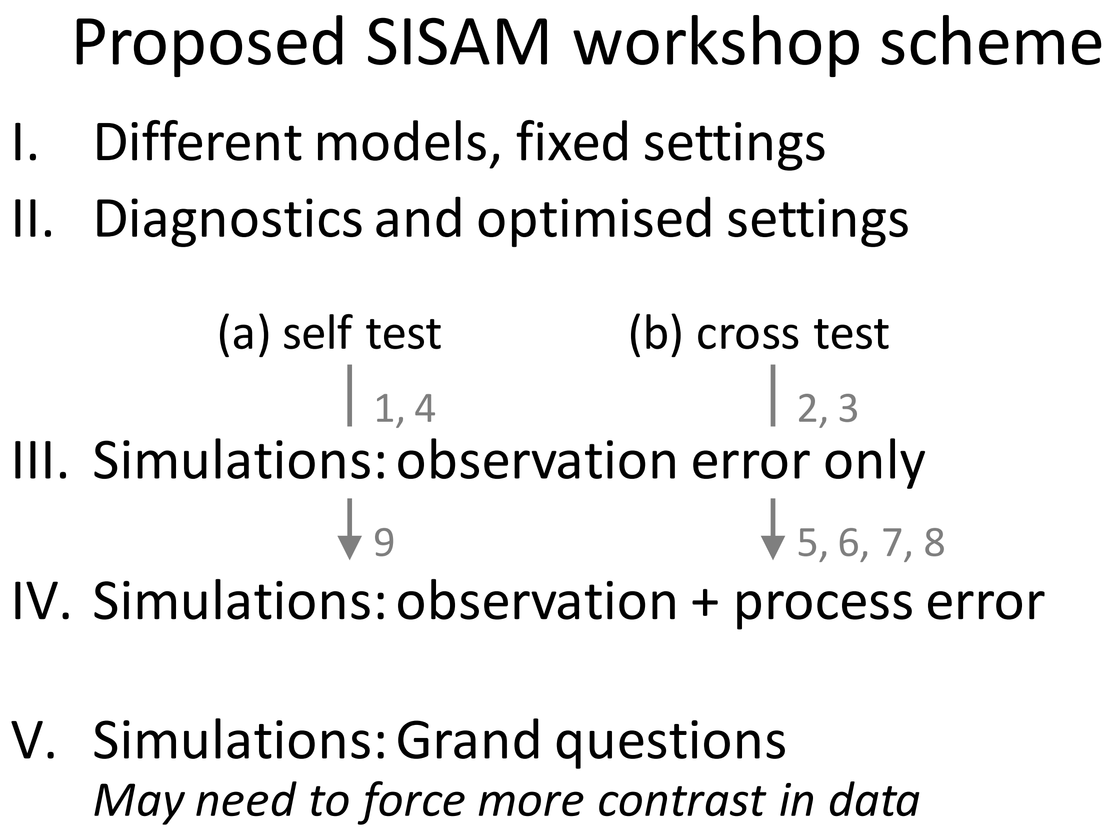


Figure 3.3.1. Flow diagram of proposed SISAM workshop scheme. The numbers 1-9 refer to the cells in the 2×2 and 3×3 matrices given in Section 3.3.

4 Example Applications

4.1 Simulation Testing of Adapt, XSA and SAM Using North Sea Haddock

Data

Simulations were based on the North Sea haddock dataset as assessed by ICES (2012b [WGNSSK]). The data contain catch-at-age from 1963-2011 at ages 0-8+. Three surveys cover this period, with two of these split due to gear change, making effectively five indices.

Approach

Three assessment methods were used, both as operating models (to simulate data), and assessment models. As operating models, these were fitted to the haddock data, resulting in best estimates of the underlying catch and survey indices, and of the observation error on them. The XSA and SAM fits were optimized to the data, corresponding to Steps 1 and 2 of the evaluation scheme in Section 3.3, whereas Adapt was only taken through Step 1, i.e. the model was not thoroughly optimized.

For Adapt and XSA, catch is assumed to be known exactly, and so the estimated observation error on these is zero. Estimated survey values are calculated by multiplying catchabilities at age by estimated numbers-at-age, and the log-catchability residuals give the observation errors on the log scale.

For SAM, catch can be calculated from the estimated numbers and F values using the Baranov catch equation, and log catch residuals can then be calculated. Estimated survey values are calculated from estimated numbers and catchabilities, along with their residuals on a log scale.

For all assessment methods, data are then simulated from each operating model by adding random uncorrelated noise sampled from a normal distribution (with standard deviation estimated from the log residuals) to the estimated log catch and estimated log surveys, to give sets of simulated data that can be assessed by each of the methods.

Mathematical details

Initial data:

$Catch(y, a)$ – catch numbers in year y at age a

$Index(f, y, a)$ – index for fleet f, in year y at age a

$Bio(y, a)$ – Biological parameters and data in year y at age a (M, mat, waa…)

For each stock assessment method (m) the following were found:

$N(y, a, m)$ – Numbers-at-age estimated by method m.

$F(y, a, m)$ – Fishing mortality-at-age estimated by method m.

$\overline{Catch}(y, a, m)$ – estimated catch for method m (=exact catch for XSA/Adapt).

$\overline{Index}(f, y, a, m)$ – estimated index from method m.

$Res_C(y,a,m)$ – log catch residuals from method m (=0 for XSA/Adapt).

$Res_I(f,y,a,m)$ – log survey residuals from method m.

$\sigma_C(a,m)$ – standard deviation of log catch residuals from method m.

$\sigma_I(f,a,m)$ – standard deviation of log survey residuals from method m.

Simulated catch and indices were created for each method using:[1]

$$Catch_{sim}(i,y,a,m) = \overline{Catch}(y,a,m) \times \exp(Norm(0,\sigma_C(a,m)))$$

$$Index_{sim}(i,f,y,a,m) = \overline{Index}(f,y,a,m) \times \exp(Norm(0,\sigma_I(f,a,m)))$$

Diagnostics

Following the initial assessments of the stock with Adapt, XSA and SAM, diagnostics were plotted (Figures 4.1.1-3) to show whether the model fit gave cause for concern. In each case, the standardized residuals contained patterns, suggesting that there are trends in the data that are not adequately explained by the models. These patterns were particularly apparent in the diagnostics from Adapt, a feature of only having taken the method to Step 1 in the evaluation scheme (Section 3.3). Another perspective on these residuals is shown in Figure 4.1.4, which plots the non-standardized residuals for each age and survey for all three methods. Patterns in residuals are a common feature of assessments, and without an objective indication of when to reject an assessment based on the diagnostics, these assessments were considered sufficiently good to test the simulation approach.

Other fitting issues

The assessment methods used on the simulated datasets were applied using exactly the same settings as when they were applied to the actual haddock data. Within a simulation framework it is important to have a model that can be applied repeatedly to data without the need for manual intervention, and will reliably converge to a solution.

Results

Plots for SSB, Fbar and Recruitment-at-age 0 are shown in Figures 4.1.5-7. In each set of nine plots, a row corresponds to an operating model. The black line indicates the 'truth' assumed by the operating model, and the red lines indicate the results of assessments performed on the simulated data. The columns correspond to the different models used to assess the simulated stocks. Plots on the diagonal indicate the self-consistency of each of the models, which is Step 3a in the evaluation scheme, Section 3.3.

Points raised by the exercise

A number of points were raised by this exercise that need to be considered when developing this method of cross-validation between models:

[1] It has been pointed out that the mean observation error may not be zero for all indices, but testing showed that correcting for this made little difference to the simulation outcomes.

- Plots on the diagonal of the results matrix indicate whether a model is self-consistent, and should be a part of the model testing for any new stock assessment method. In contrast, plots off the diagonal are harder to interpret, but may provide an insight into the relative structure of the methods being compared.
- Configuring the models based on the actual data may not result in the best performance of the models on simulated data. One possibility may be to configure the model based on one of the simulated datasets before running on all the other simulated datasets, but a consensus was reached that models should be configured based only on the data.
- No testing of metrics for comparing simulations to the 'truth' was investigated. It may be hard to get a metric that indicates how well the model represents the 'truth' reliably.
- For SAM, it is clear from the plot of self-consistency of Fbar that the model estimates are smoother than the underlying 'truth'. This is to be expected from a simulation approach that only considers observation error, so that N and F are taken as point estimates rather than recognizing the uncertainty that exists around these quantities.

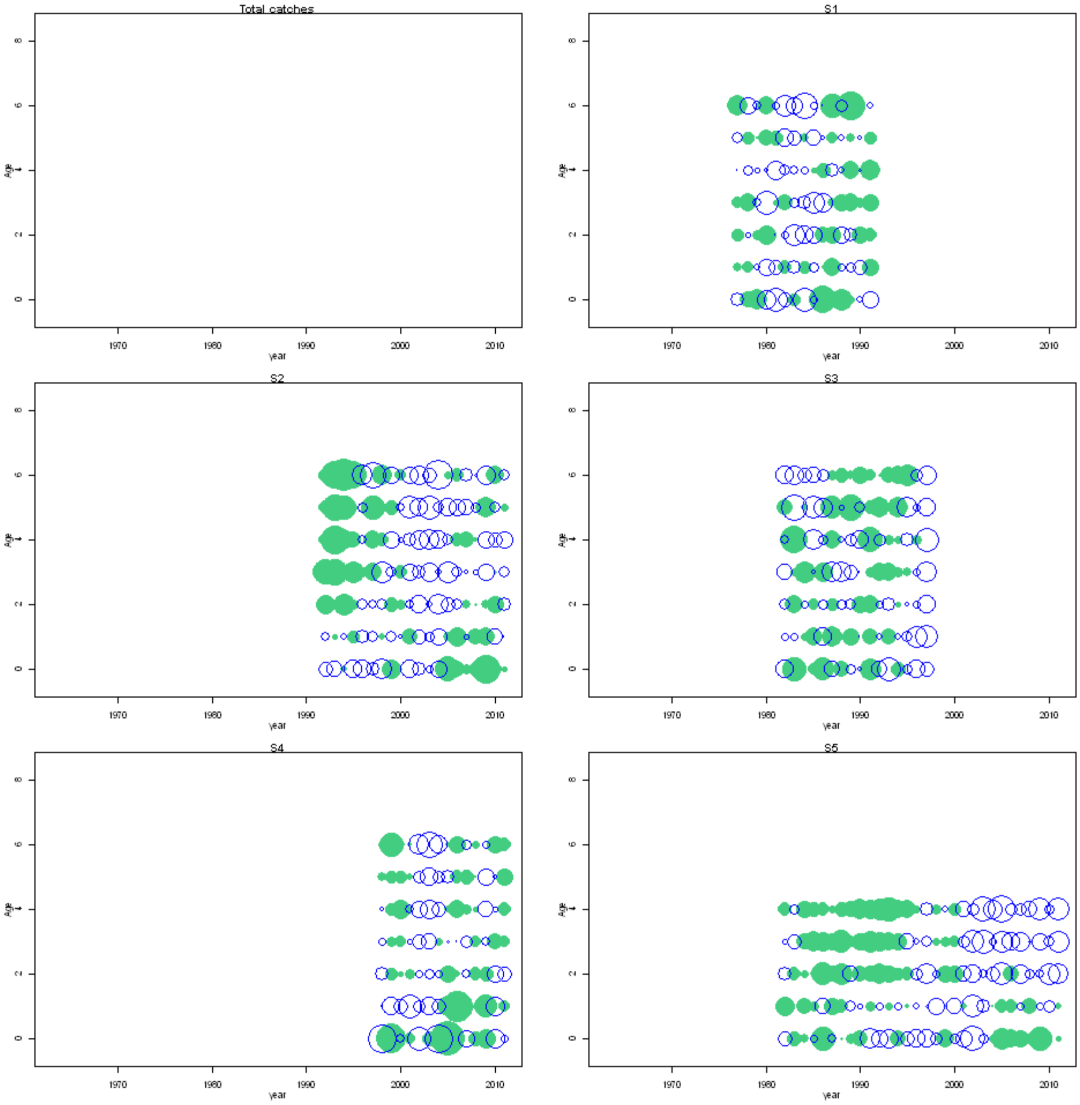


Figure 4.1.1. Standardized residuals for Adapt showing patterns in the residuals, particularly for survey S5.

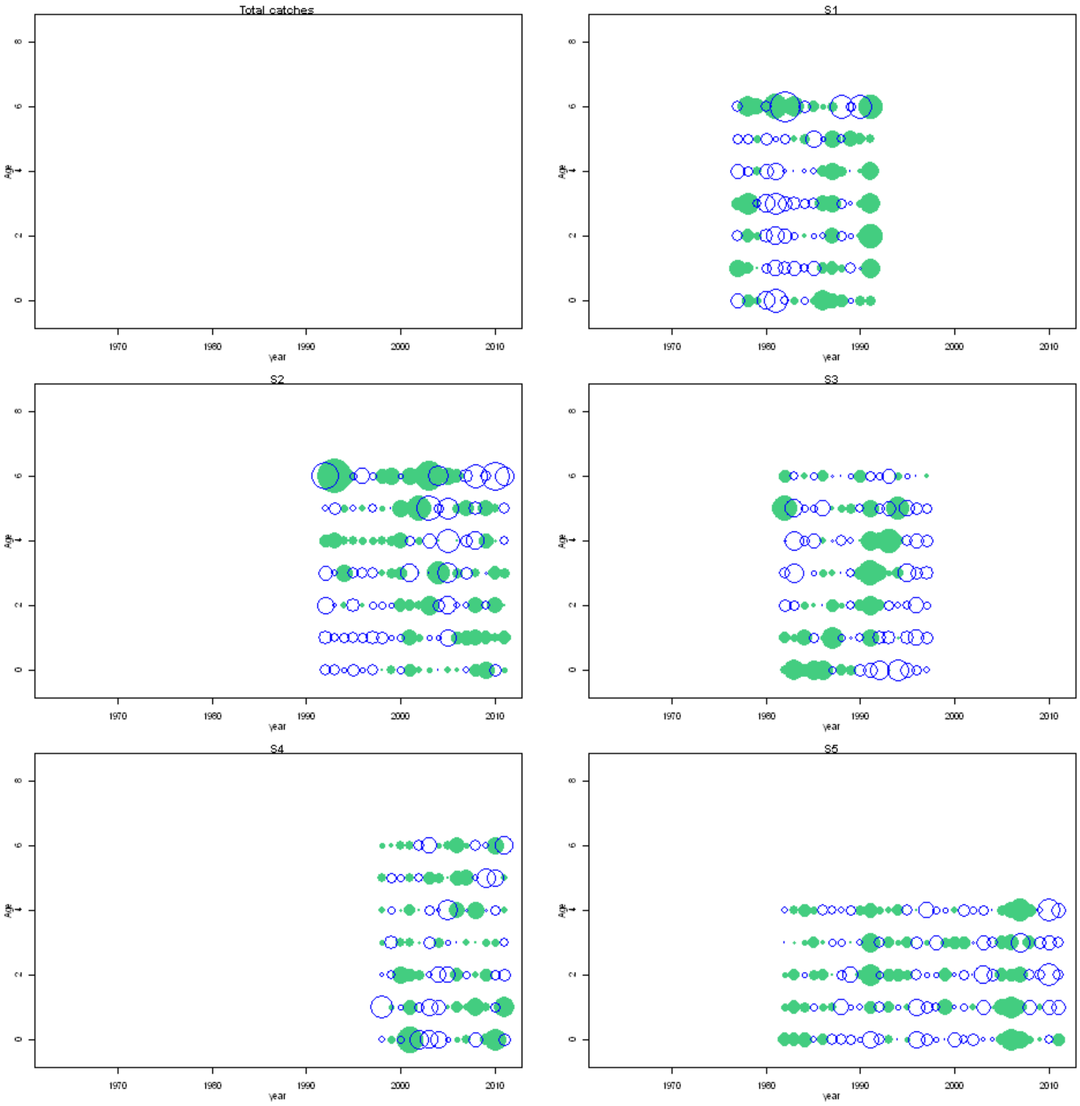


Figure 4.1.2. Standardized residuals for XSA.

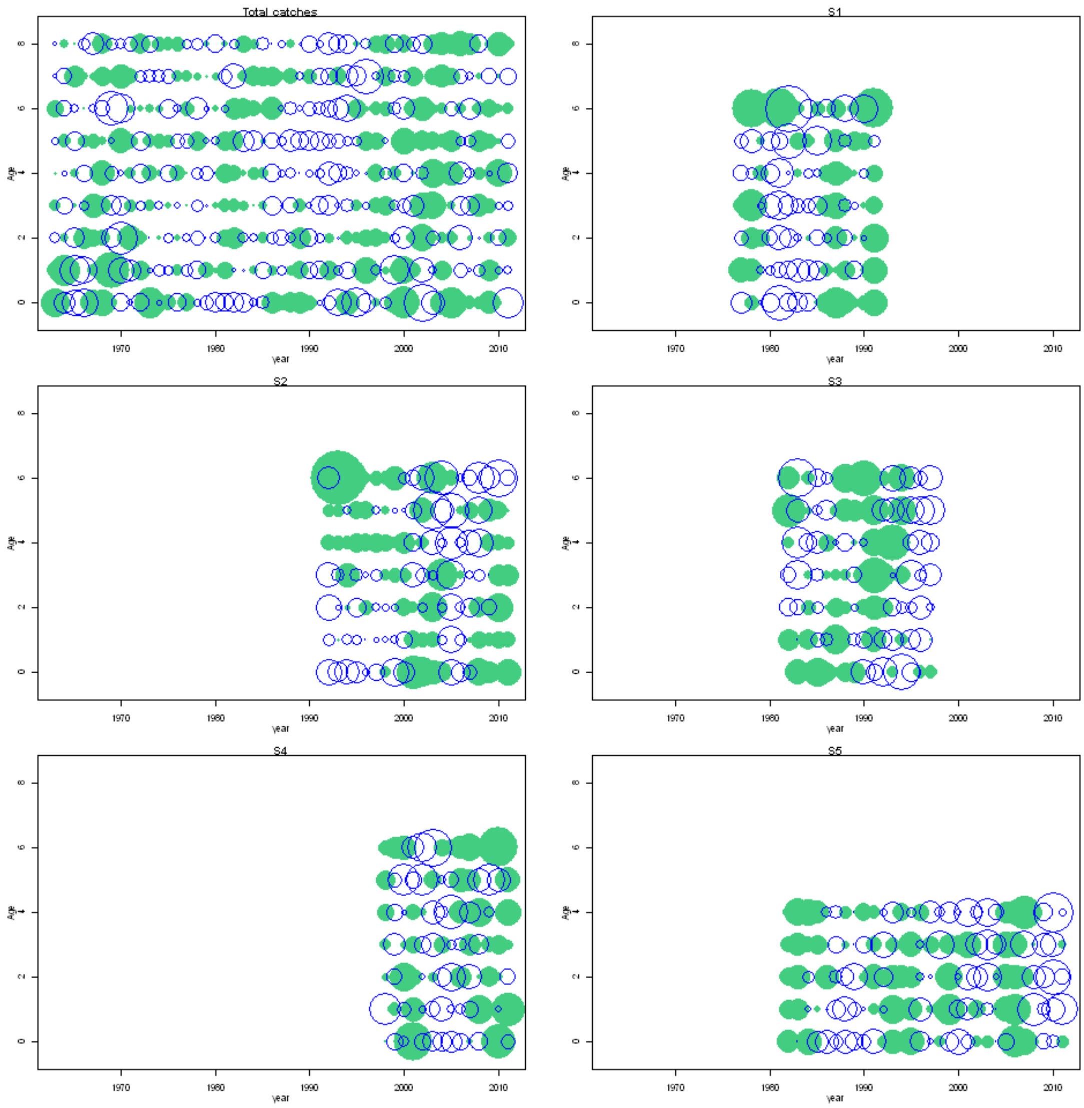


Figure 4.1.3. Standardized residuals for SAM.

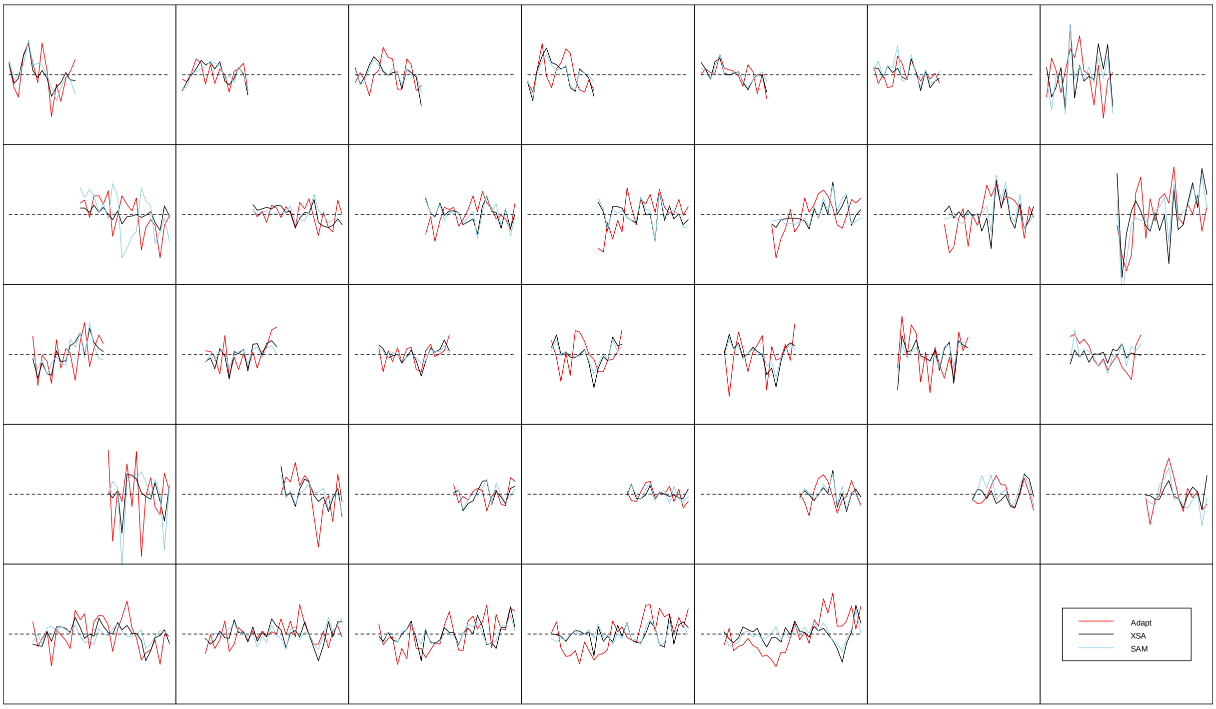


Figure 4.1.4. Non-standardized residuals for each survey (row) and age (column) from Adapt (red), XSA (black) and SAM (blue). Scales are consistent across plots.

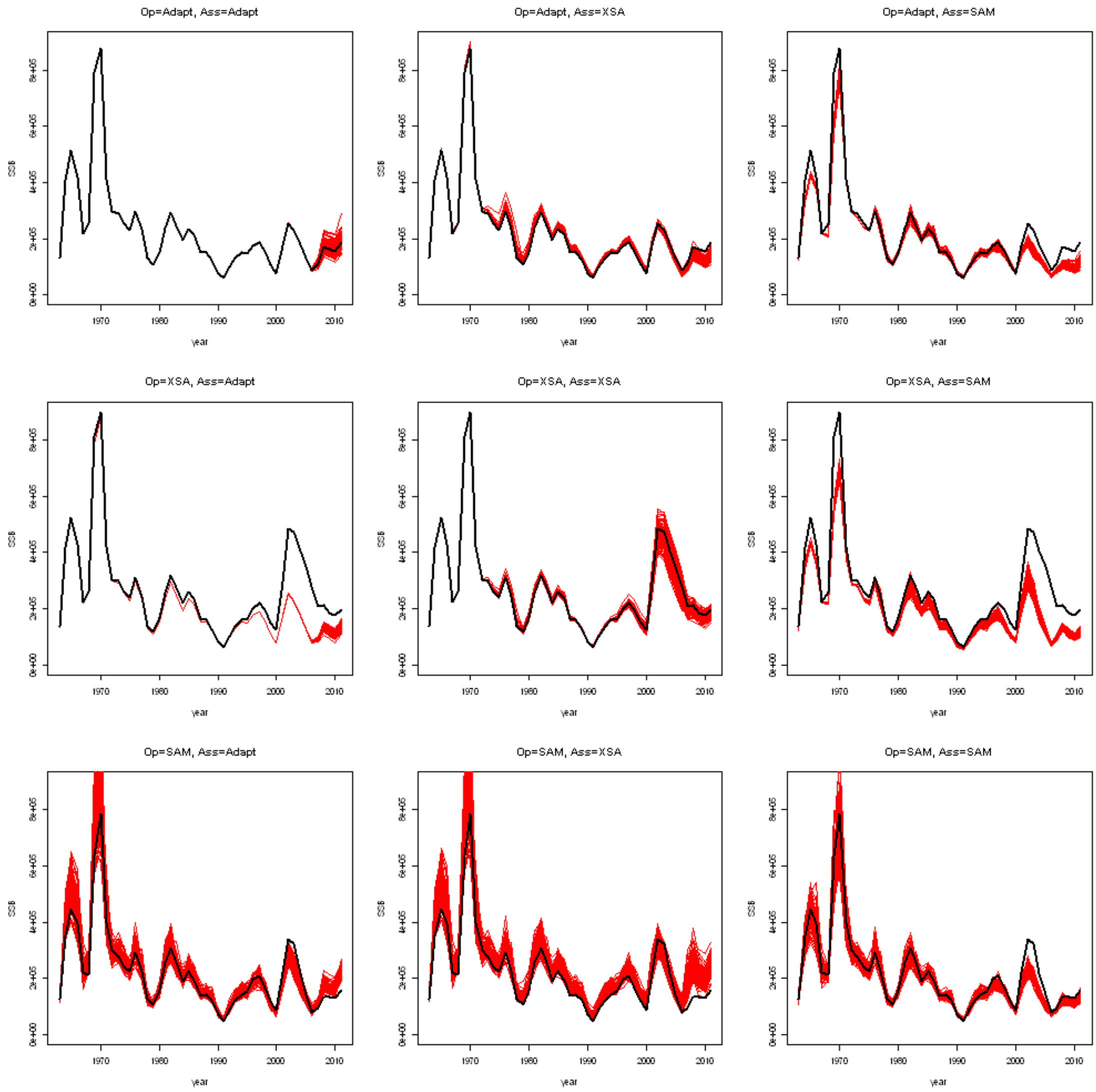


Figure 4.1.5. Simulation results for SSB.

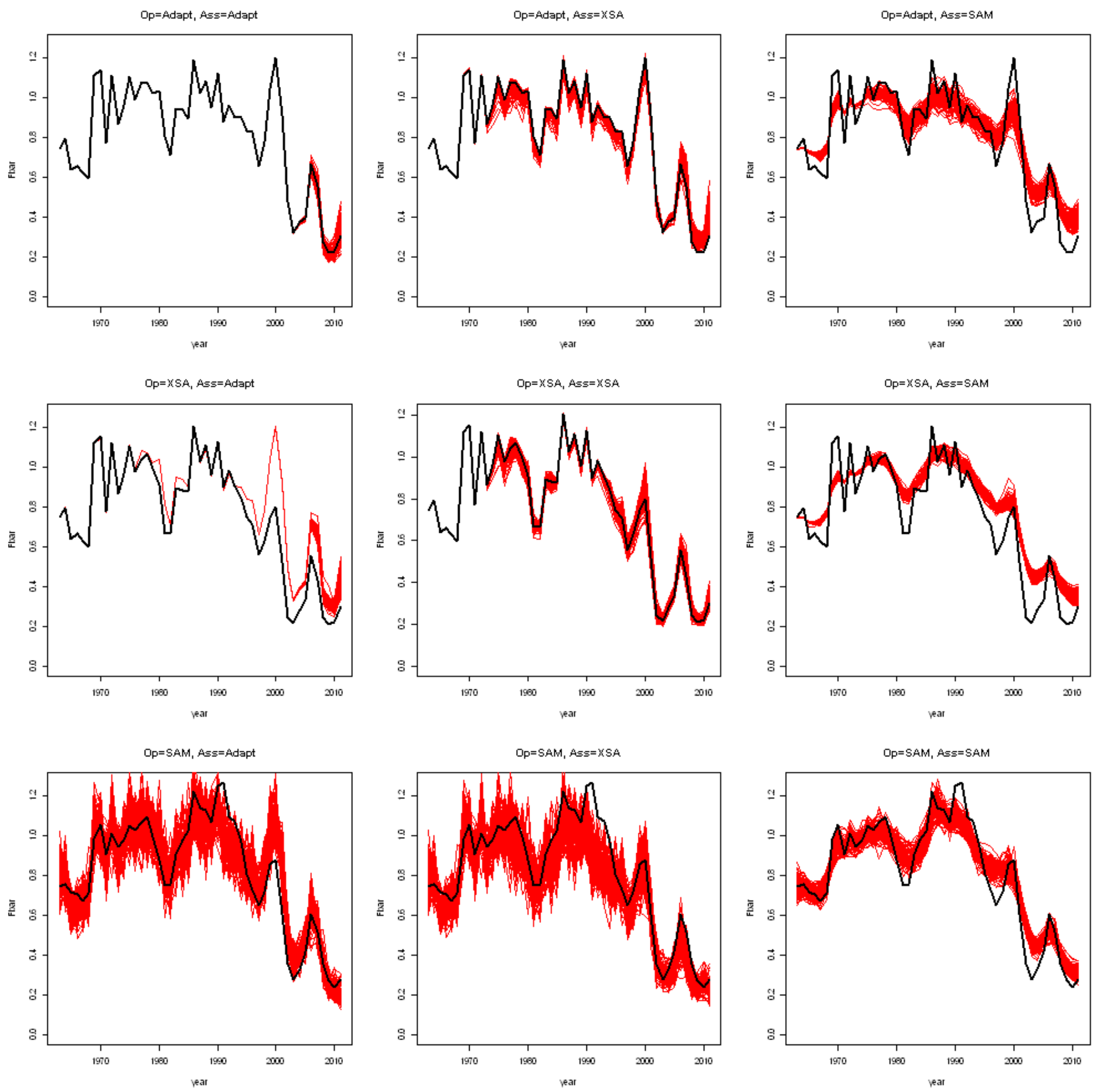


Figure 4.1.6. Simulation results for Fbar.

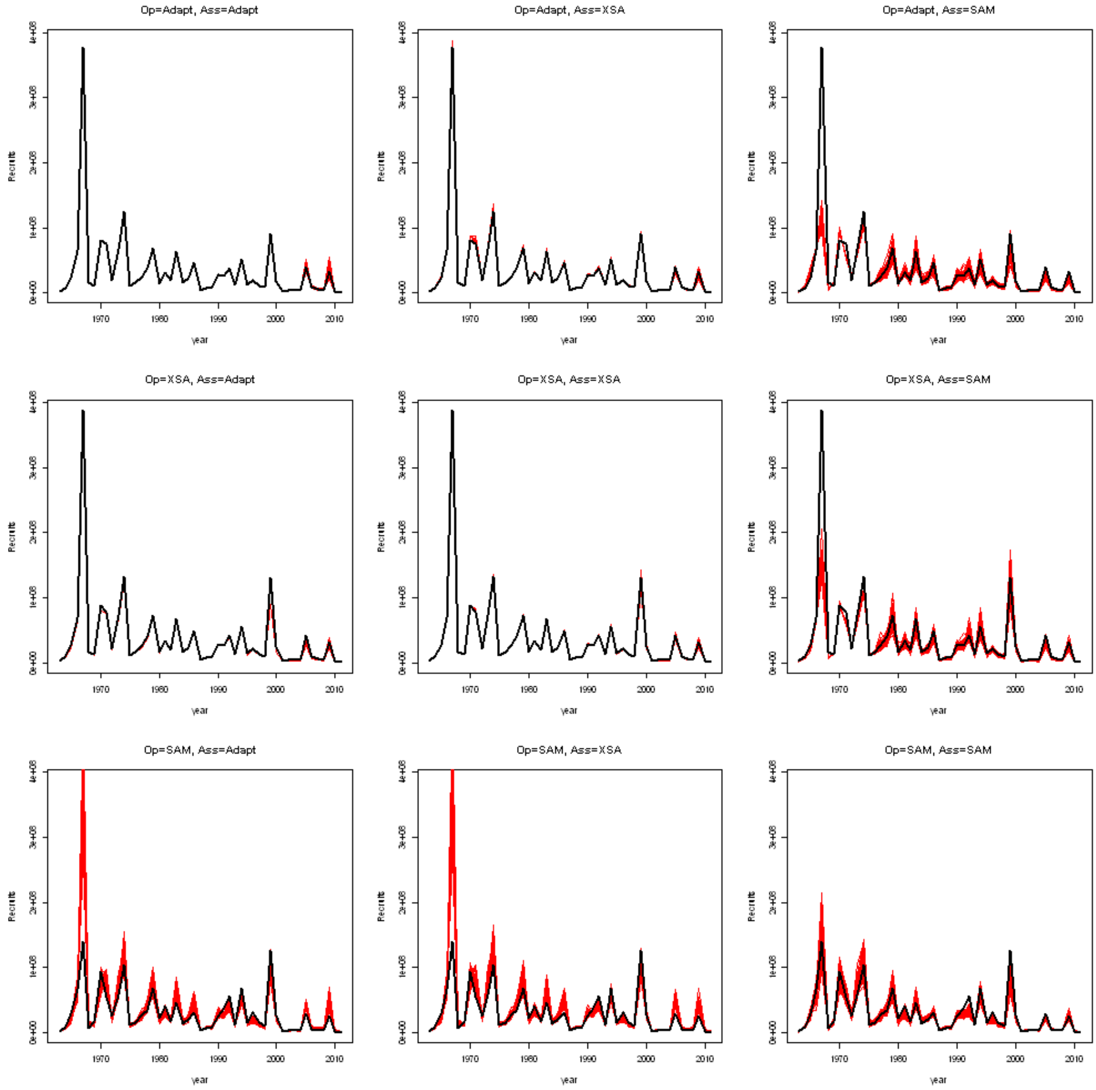


Figure 4.1.7. Simulation results for Recruitment-at-age 0.

4.2 Comparing the Predictive Power of Models

Fisheries stock assessment has the unenviable quality that the true dynamics of the stocks being assessed will never be known. This makes validation of assessment models challenging. One way around this is to create simulated versions of what reality could be and to test the assessment model's ability to reproduce this 'reality' given certain observations generated from that true population. This includes two important sets of assumptions: (1) assumptions on the dynamics and state of reality, and (2) assumptions on how we observe that reality. There is a fundamental problem with this approach: both the simulated reality and our observations from it are model results. So while we could produce the conclusion that our assessment model is capable of recreating our simulated reality given the assumed observation error, the question of how accurately and precisely the assessment model reflects the true population remains unanswered (though the simulation approach addresses it by considering a wide range of plausible models consistent with the data in the hope that these do encompass the true population, and seeking robust performance).

Our most direct estimates of the stocks we are assessing are the observations we have taken (e.g. survey, catch sampling etc.). These data form the backbone of most assessment models. Given that we have no true reality with which to compare our assessment model results, these observed data are our best alternative. Additionally, no observation model is required when we compare our assessment model results with actual observations. However, while these data are the closest to unadulterated observations that we have, it must be noted that survey indices themselves are synthesized values coming out of a significant amount of number crunching and do not come without error.

Here we present a suggested approach for comparing alternative assessment models on the basis of how they are able to predict future observed index values. For stocks that have long enough time-series of data, models can be fit to a subset of the data (e.g. Y_1 *to* $Y_{f\text{-}x}$, where Y_f = the final year of data) and then we can compare how precisely and accurately they are able to predict the subsequent observed data not used in the fitting of the model. In other words, if we fit the model to the data, does that result in a coherent view of reality that can be predicted forward and used as a basis for management?

The Situation

In a general sense, in year *Y* we have available to us observed index and catch data up to year *Y-1* allowing us to estimate the stock at the start of year *Y*. We need to use this estimate to provide management advice for year *Y+1*. We do not yet have observations of catch in year *Y* itself, so an assumption needs to be made in order to project the stock to the start of year *Y+1*.

In this situation we can compare how our model estimated stock at the start of year *Y* and the projected stock at the start of year *Y+1* relates to the indices from those years (once they become available).

This general situation may differ between stocks; for example, indices may be available for the current year, sometimes all the catch will have been taken already, and sometimes we will be providing advice within the year or for multiple years, etc. So the temporal details of this generalized situation should not be interpreted too literally. A further assumption is that our model is estimating numbers at the start of the year, which may not be the case.

The Approach

There is no 'real' population. Below, the term 'model' refers to the assessment model fit to the subset of the data. This approach never deals with the model fit to the whole set of data and does not attempt to compare models in this way.

The approach is kept as simple as possible:

1. The model is fit to a subset of the data. These subsets are created by peeling away years from the end of the time-series as is done when creating retrospective model fits. The number of years you can go back depends on the length(s) of the available time-series.
2. The stock is projected through the intermediate year (i.e. the year in which the assessment is done) to the start of the following year (i.e. the year for which advice is needed).

   Some intermediate year options:

   - Use the observed total catch, *with or without uncertainty*.

- Use the observed landings (with or without uncertainty) only and make an assumption about, or allow the model to estimate, the discard proportion (if there is any).
- Use the observed catch (or landings) numbers-at-age, with or without uncertainty.
- Assume a level of *F* in the intermediate year (e.g. F_{sq}, three year average, etc.)
- For stocks that have them, assume the TAC is taken

If our data is any good, we should hope that there is a link between the observed index, the observed catch and the true population/fishery (e.g. if catch was large enough to impact on stock size, we would hope that this would be seen in the subsequent index of abundance). Hence this approach suggests the observed catch in some way, rather than making some assumption in the intermediate year, i.e. we are using a model to give us our estimate of the true population and we want to check if that estimate is OK. If it is, you should be able to feed in the observed catch and come out with something close to the observed index.

3. Check how well it has done. For each model fit to a subset of data, we can compare two years of model estimates and observed data:

   A. The model estimated index values in the intermediate year
   B. The model estimated index values for the year in which the advice is given

   Model estimated index values are calculated using the model estimated or projected numbers in these years and the model estimated *q* (mean and observed variance around this) and model estimated or projected numbers-at-age. Given that both a mean and variance can be estimated for *q*, this results in a distribution of expected index values.

   Each number-at-age estimate in each year can either be treated separately or estimates could be paired up by cohort. The proposed approach would exclude age 1 for (A) and ages 1 and 2 for (B) because most assessment models are not designed to predict future year-class strength. Similarly, the plusgroup could be left out and many indices do not include the plusgroup.

Evaluating performance

Problem: Blurs the line between model and observation uncertainty (the expected/observed index value contains observation error). RMSE may indicate one model did better, but that may be because the observed index value had significant observation error; i.e. is the model failing to predict the observations because of changes in how the observations correspond to reality or through model misspecification? Or alternatively, is it accurately predicting the observations even though there has been a change in how these relate to reality?

If appropriate (e.g. XSA), check what proportion fail to **converge**

Comparing model predictions with observations:

1. Calculate **(R)MSE** between the observed index values and the mean model expected values (*each year separately*)
2. **Statistical** comparison of expected and observed index at age values (e.g. paired t-test)

3. Compare the **distribution of predicted index values** from the model fits to the observed index values (which were not used in the fitting of the model; Figure 4.2.1)

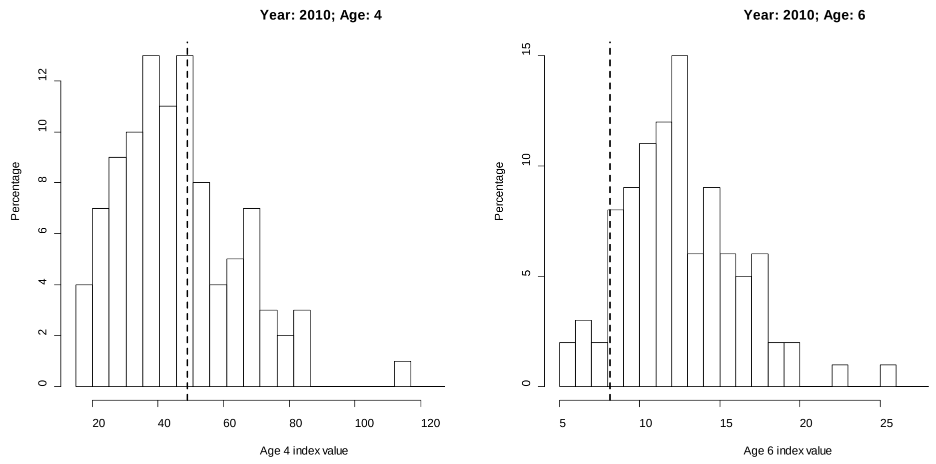


Figure 4.2.1. Example outputs comparing the distribution of model estimated/predicted index values and the observed index value (dashed line). Each plot shows the values for a given age in a given year.

Potential Complications

- There is a complication of when in the year the indices are observed. This can be circumvented by projecting the stock to the time of year when the indices are taken (may be different for each index) rather than projecting it for a full year, i.e. use a proportion of the catch and *M*. This gets around needing to know what *F* was in order to back calculate indices to the start of the year (when they would be comparable with the stock numbers in the index).
- This approach may be a glorified retrospective test. You would assume a model with large retrospective biases or variations would perform worse; i.e. would the size of retrospective simply be the over-riding factor determining how well models score in this?
- An alternative version could be done by removing data points at random and testing to see how the model fit to the remaining data predicts the missing data. However, certain models may not be able to fit to datasets with missing data points.
- It may be necessary to account for autocorrelation in model estimated *q* when determining the model estimated index values.

5 Modelling developments

5.1 Web based interface for collaborating on assessments (presented by Anders Nielsen)

Stockassessment.org is a user friendly interface to a state-space stock assessment model (SAM). It allows all who are interested to see all details of completed assessments. It allows users to submit data, configure and run assessments, and offer easy access to standard graphs and tables. Besides just being able to edit and upload data and change predefined settings, users can modify the actual source code for the assessment model (or submit new code), or to produce graphs and tables. The interface offers easy collaboration on setting up a stock assessment, and on working to refine it. The use of the interface was demonstrated to the working group.

Background

Collaboration at assessment working groups is often reduced to one or two members doing the actual assessment modelling, and the remaining working group members being left to review and comment on the results and diagnostics only. Part of the reason that most working group members don't reproduce the actual assessment, is that it takes a lot of work to get everything set up correctly. Typically, several programs (specific versions) need to interact and the data need to be in a specific format. The web interface completely removes this obstacle. Once the stock coordinator has set up an assessment, all members can reproduce the assessment and all the resulting graphs and tables simply by logging in and pressing `Go'. The members can also experiment with the model configuration and input data and easily compare the results. It is clearly beneficial to have more hands and eyes on the details of each assessment. It also takes some of the pressure away from the stock coordinator, as it allows more working group members to take part in the more technical configuration discussions. Finally, it improves the peer review process, which gives more correct assessments.

A pilot version of stockassessment.org was created in 2010, which did not allow users to submit their own data, and only had few options for configuring the assessments. Despite the fact that the pilot version could at best be described as a rough prototype, it became used for approximately 10 ICES stock, which indicated that there was a need for such a tool.

Building a secure interface

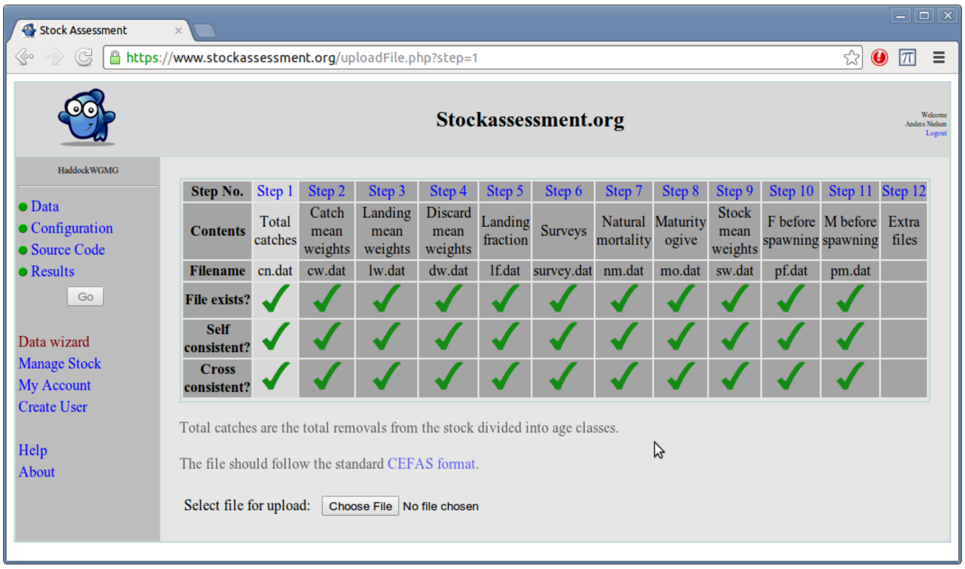
The main challenge in building the current version was security. When setting up a web page, which allows users to edit and run source code directly on the computer, it is crucial to ensure that it is not possible (on purpose, or by mistake) to misuse the computer, or to prevent or obstruct other users from legitimate use of the interface. To ensure this security, each user account is constructed such that it is possible, at the operating system level, to configure exactly where on the disk the user has access, and how many resources (CPU and memory) can be used.

Data wizard and error checking

The work flow for entering a new stock to the system has the following steps:

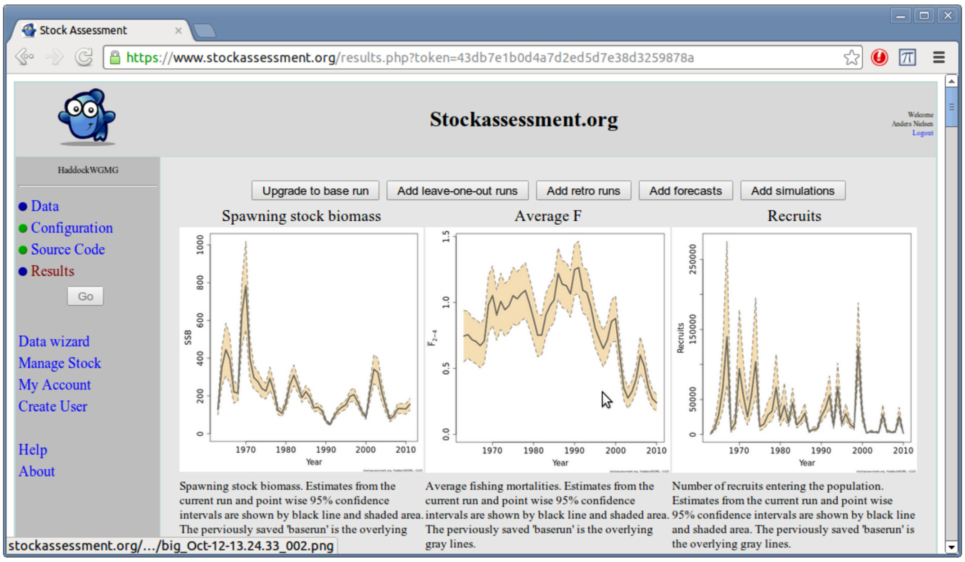
1. First the user is guided through a data wizard, where the needed files are uploaded one by one; at each step the data files are checked for errors and

consistency. When all files are uploaded, checks are conducted across files to ensure that they are cross-consistent.



2. When all data files are uploaded, a default configuration file is set up, and the model is - in principle - ready to run.
3. Instead of running the model right away, the user should first investigate the data, and ensure that all data is as expected. The system allows one-click graphical representation of all entered data, so it is easy to spot typos and strange data points.
4. Once the data has been carefully verified, the default configuration should also be examined.
5. When ready, the user can then press the `Go' button, and the model starts running. During the optimization of the likelihood (which should not take more than a minute), the system provides a dynamic graphical representation of the process. The negative log likelihood and the absolute maximum gradient component is plotted and updated during the process.

6. When the optimization is done all standard graphs and tables are produced, and the user has the choice of adding additional runs, forecasts, or model diagnostics such as retrospective plots.



7. When the user is satisfied with the assessment it can be made publicly visible, which means that all who enter the web page can see the setup and result.

Pulling together

The main motivation behind this interface is to enable fisheries scientists to work together on setting up the best possible assessments. Instead of having to go through the process of installing relevant programs and formatting datasets on each user's computer, this interface offers a platform that can be used by all on all platforms.

The interface works equally well for all types of users; some want to examine the results, some want to experiment with data and model assumptions, and some want to modify the source code for the assessment model itself.

Acknowledgements

Stockassessment.org is developed by Casper W. Berg and Anders Nielsen with support from DTU-Aqua and ICES.

5.2 Assessments for All: a4a (presented by Colin Millar)

Introduction

By the year 2020 there will be around 250 fish stocks in Europe for which there will be at least 10 years of data. This will be the result of the Data Collection Framework which has required since 2009 that the full catch be sampled, and some degree of biological sampling is also carried out. The information available on these stocks will vary from estimates of catch at length to estimates of total landings, most likely with auxiliary information in the form of survey indices and/or life-history parameters. Beddington *et.al* (2007) show that these intermediate data stocks that are not being scientifically assessed make up for 30% of stocks in the USA, 78% in New Zealand, 48% in Australia, 61% in the Northeast Atlantic, and 65% in Chile (Roa, pers. comm).

We will then have at our disposal a moderate amount of information for these stocks, and so they will not properly fit into the "data poor" stock definition. In addition, due to the large number of these stocks, it will not be logistically feasible to run on all of them any kind of complex and data-eager model that usually requires a high level of expertise.

We suggest here that to deal with these large number of stocks, the chosen assessment model should be flexible, but as automatic as possible, in the sense of being able to choose the right model structure and generate good starting values for parameter estimation. Such a model should require very little set up time, making it thus easier for less experienced users to run the model and still obtain sensible answers.

At the same time, stock assessment for management purposes requires good predictive power in a very complex management system. The approach taken here is to develop a Management Strategy Evaluation (MSE) framework, and make use of performance statistics to evaluate the predictive performance of the advice being given. Simultaneously, it will allow testing and design of Harvest Control Rules (HCRs) that are as robust as possible to uncertainties in scientific knowledge and make the best use of the information provided by this stock assessment method.

Having to apply stock assessment and advisory (i.e. projection) methods to a large number of stocks raises interesting challenges and creates opportunities worth exploring. For example, approaching stock assessment as a data generating engine, having a common stock assessment methodology or analysing massive stock assessment results, opens the possibility of issuing advice on a wider basis, such as in multistock frameworks, while promoting comparative analysis across stocks, taxa and regions.

Following its mission of anticipating policy implementation issues, JRC FishReg decided to move forward in tackling this issue with the "Assessment for All" (a4a) initiative, aiming to develop statistical methods to estimate the status of stocks with moderate dataseries (10-15 years), and to test the robustness of related management policies. In detail we aim to:

1. develop an assessment method targeting stocks that have a reduced biological knowledge base and moderate time-series of exploitation and relative abundance;
2. develop predictive methods for fish stocks with moderate dataseries, to test policy scenarios and their robustness to uncertainty in scientific knowledge, based on MSE algorithms;
3. trigger the discussion and explore tools for the problem of numerous stock assessments;
4. build capacity in stock assessment and fisheries management advice.

The initiative is coordinated by JRC FishReg (Ernesto Jardim). The initiative has assembled a network of scientists from the JRC, together with others from distinct regions: South Africa, USA, Canada, Australia, New Zealand and Europe.

The kick-off meeting took place in March 2012, during which a group of invited scientists were asked to collaborate on the definition and shaping of the initiative. One major conclusion was to base the a4a initiative on three major axis (i) methods development, (ii) simulation testing, and (iii) cooperation with scientists outside JRC through the promotion of a series of short visits of invited scientists.

The Assessment Model

The data we consider are catch-at-age a and year t, $C_{a,t}$, and abundance indices from several surveys for each age a and year t, $S_{a,t}$. The model is age structured where the number of fish in an age-class N at the start of the following year is the number of fish that survived the perils of the current year. We assume that fish die through the year at a constant rate e^{-Z} (Z is positive), and that this rate is due to natural causes (M)

and fishing (F) so that the total mortality rate is $Z = F + M$, giving the deterministic model:

$$N_{a+1,t+1} = \exp(-Z_{a,t})\ N_{a,t}$$

and if F and M are constant through the year, catches arise as a fraction of those fish that died, written here as the familiar Baranov catch equation

$$C_{a,t} = (F_{a,t}\ /\ Z_{a,t};\ 1 - \exp(-Z_{a,t}))\ N_{a,t}$$

Fishery-independent observations are provided by surveys. And since surveys observe a proportion Q_a of the population (that might vary by age) we model the survey index using

$$S_{a,t} = Q_a\ N_{a,t}$$

Finally, we assume that the logged data (catch and survey) are observations of the quantities $\ln C_{a,t}$ and $\ln S_{a,t}$ and that these are observed with Gaussian error with independent variances.

This model is completely determined given estimates of recruitment ($N_{1,t}$), catchability (Q_a) and fishing mortality ($F_{a,t}$), and each of these components are modelled using linear predictors in the same way as is done in linear or additive modelling. For example, a model with separable fishing mortality would be

$$\ln F \sim \text{age} + \text{year}$$

where age and year are treated as categorical variables. A model in which survey selectivity varies smoothly with age would be

$$\ln Q \sim s(\text{age})$$

where age is treated as continuous and $s()$ denotes a smoother such as a thin plate spline with fixed degrees of freedom.

The model interface is written in R with the minimization done using ADMB. The R code specifying the models in the above examples (assuming independent recruitments by year) would be:

```
Fmodel <- ~ factor(age) + factor(year)

Qmodel <- ~ s(age, k = 3)

Rmodel <- ~ factor(year)
```

These are then passed to the fitting function along with the catch, survey and other data (natural mortality, plus-group information, etc.)

Simulation Testing

Simulation testing is core to the success of the a4a initiative. To date two methods of conditioning the operating model that simulate the population have been developed and implemented.

1. Select a plausible set of life-history parameters to define the growth, productivity, natural mortality and reproduction in the stock. The next step is to define a history of exploitation. The current approach is to use a history of increasing exploitation followed by restricted fishing in an attempt to mirror exploitation patterns seen in practice. Adding variability in the exploitation or recruitment history provides a range of initial states for the operating model.
2. Use existing assessment of a stock and create noisy versions of the F and recruitment estimates. These can be made by adding correlated or uncorrelated

noise (the correlations can come from the estimates themselves or from the estimated variance-covariance matrix coming out of the stock assessment method). An alternative is fitting models (time-series or otherwise) to the data and simulating from these models; for example constant recruitment with AR1 noise. Each *F* and recruit results in a different population, i.e. different initial states for the operating model.

The above approaches have been used in three case studies so far. Testing robustness of harvest control rules for Baltic pelagic stocks, the robustness of MSY estimates in *Sardinella aurita* off the coast of Northwest Africa, and examining the costs of ignoring stock structure in a North Sea cod-like stock.

Visiting scientists

Visiting scientists are a major asset for the project. It allows JRC scientists to work with world class scientists in dedicated periods, promoting more in depth thinking and discussions about subjects related to scientific advice, fisheries management and stock assessment methods. Additionally, visiting scientists are invited to give a 1-2 hours seminar to JRC so that staff not involved in the project can take advantage of their presence.

Up to October 2012 there were four visits to JRC: Professor Henrik Gislason (DTU-AQUA), Dr Richard Hillary (CSIRO), Dr Raul Prellezo (AZTI) and Dr Sidney Holt (Independent consultant), to discuss progress on modelling and implementation issues as well as discuss the design of the generic framework being implemented. In November 2012, Professor Steve Cadrin (UMASS) will visit JRC with the same objective.

In 2013, 4 visits from within EU, 1 from USA and 1 from Australia are expected. A project meeting is being considered.

Achievements

- Definition of "moderate data stock" finalized.
- Simulation of 100+ stocks for model testing, using life-history parameters, trawl-like selection pattern and exploitation histories based on a development-high exploitation-recovery pattern.
- The first version of the assessment model is completed. Tests are in progress.
- The first version of the MSE algorithm is completed. Requires tying up and wrapping.
- The visiting scientists programme was successful with four visits during the first 6 month of the initiative.
- Two (grey) papers: Miller *et al*. (2012); Jardim *et al*. (2012).

6 Conclusions and Recommendations, and proposed ToRs

6.1 Conclusions and recommendations

Based on a wide range of biological characteristics, data quality and availability issues, and assessment model types and problems, WGMG have assembled 14 real datasets, both from within ICES and from other areas of the world, and make the following recommendation to SISAM:

> Use the proposed selection of datasets (Section 2) as a basis for running the SISAM assessment methods evaluation scheme.

The proposed SISAM assessment methods evaluation scheme (Section 3.3) is an amalgamation of three separate proposals submitted to WGMG, which approach the evaluation of assessment methods from different perspectives, ranging from robustness testing and investigating "grand questions" through simulations conditioned on real datasets, to a greater focus on model selection criteria (such as investigating the predictive ability of models). WGMG therefore makes the following recommendation to SISAM:

> Use the proposed assessment methods evaluation scheme (Section 3.3) for the SISAM Symposium workshop. It is not as yet clear what constitutes best practice in selecting amongst assessment approaches and appropriate simulating testing procedures to use to assist in this decision. It is hoped that further recommendations in this regard will eventuate from the SISAM workshop and Symposium.

An attempt was made to trial some aspects of the proposed evaluation scheme, which yielded informative results (Section 4). In particular, these trial runs have highlighted a further recommendation that WGMG targets at expert groups and benchmark meetings, namely:

> Don't use default settings on package assessment models to provide advice without first confirming that the results satisfy appropriate statistical diagnostics tests. In such circumstances, alternative settings need to be investigated.

Proposed ToRs for 2013

Background

As part of an effort to re-align the activities of WGMG with the needs of the ICES community with regard to support for longer-term methodoloigical issues (those not easily addressed within assessment expert groups and benchmark meetings themselves), the Chair of WGMG attended the WGCHAIRS meeting in January 2012 and asked for input for possible ToRs to be addressed during 2013, a request that was repeated by correspondence through the ICES secretariat later on during 2012. The result of these efforts, and from recommendations through expert groups, were the following requests from AFWG, WGNSSK, WKLIFE and NIPAG:

AFWG

The XSA model sensitivity to parameter "catchability dependent on stock size for ages" needs to be considered by the ICES methods study group (WGMG)

This is a topic that has been explored in depth in the past, and AFWG is encouraged to explore these studies (see e.g. Shepherd 1997 and references therein). Furthermore, if reference to these past studies is not sufficient, AFWG are encouraged to state the problem more specifically in order to allow WGMG to consider the problem in context and to better prepare a response that does not repeat past investigations.

It should be noted, however, that the "catchability dependent on stock size" option in XSA was designed for the treatment of ages considered to be recruits (Darby and Flatman, 1994), and there should be support (in terms of significant improvement in model fit to the data) for the additional model parameters this approach requires. Darby and Flatman (1994) provide guidelines for how to select the age at which catchability is independent of year-class strength, and it is not clear whether, when investigating this issue, AFWG has followed these guidelines.

WGNSSK

In 2010 the WG experienced significant discussions around differences in results from various statistical tools available to fit Stock Recruitment Relationships, and was concerned by the risk of poor fitting of this SRR, which can undermine the statistical estimation of Fmsy. The WG reiterates its recommendation that the WG on Methods for Fish Stock Assessments (WGMG) investigates this further and provides guidelines on optimal fitting

This topic may well be picked up by other ICES expert groups. WGMG are awaiting the outcomes from WKMSYREF, to be held in January 2013, to decide whether it is appropriate to take this request on as a ToR for 2013. A note to this effect is attached to the proposed ToR given in Annex 4.

WKLIFE

Further work can be conducted to develop understanding of systematic relationships between SPR reference points, life history and F_{MSY}, and to develop ICES guidelines for setting SPR reference points.

As before, this work may well be picked up by other ICES expert groups, and WGMG awaits the outcomes from WKMSYREF to see whether an appropriate ToR should be added for 2013.

NIPAG

1. *Advise on the applicability of length/age based models to Pandalus/fish stocks with only a few age classes.*
2. *Advise on the applicability of cohort based models for assumed lightly exploited stocks for which M is considered to be high, e.g. some Pandalus stocks.*
3. *Advise on the applicability of surplus production models for stocks where the effects of fishery removals may be small relative to the effects of predation and the environment, e.g. Bayesian state-space surplus production models applied to some Pandalus stocks.*
4. *Advise on methods for including numbers of small ('age-2') Pandalus shrimps in a surplus production model to modify future (net) recruitment.*

It would seem appropriate to address the topics raised by NIPAG within the context of a benchmark meeting first (with the appropriate research conducted and expertise applied), before specific methodological issues that would be appropriate to WGMG to address come to the fore. The above topics have been cast too generically and without alluding to any specific problems encountered. WGMG cannot be expected to perform benchmark assessments for particular stocks/species.

Proposals for 2013

In light of the limited response from other ICES expert groups, resulting in few workable potential ToRs, WGMG have proposed a set of ToRs that try to address some areas of concern currently within ICES, related to providing advice for the management of mixed fisheries and data-limited stocks in a way that is consistent with the precautionary and MSY approaches. It has also proposed a ToR that attempts to address the one ToR that this year's meeting was not able to address, namely the applicability of the SISAM evaluation scheme to ICES stock assessment approaches. These ToRs and corresponding scientific justification are given in Annex 4.

7 References

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Annex 2: Agenda

Day 1:

Intros and adoption of Agenda

Deals mainly with a discussion of the data sets (ToR a) forthcoming from ICES.

Day 2:

Deals mainly with simulation testing approaches (ToR b).

09h00: Simulations to find robust methods (Doug Butterworth via Skype)

10h00: Generating pseudo data and trying Doug's approach (Tim Earl)

11h00: Any other approaches?

Break into subgroups

[1. Review; 2. Simulation approaches; 3. Modelling (ToR c)]

16h00: Simulations to answer "grand questions" (Rick Methot via WebEx)

Day 3:

09h00: Developments in SAM (Anders Nielsen)

Continue subgroup work

16h00: Developments in a4a (Colin Miller)

Day 4:

09h00: Report back on Review and Modelling subgroup work

10h00: Pick up on data sets again (including ex-ICES stocks)

13h00: Simulation subgroup to meet (with Rick via Skype) and report-back afterwards

Continue subgroup work, finalize on data sets, start on Report

Can we say anything about ICES methods (ToR d)?

Day 5:

Report, Recommendations, ToR 2013, Venue

Annex 3: Recommendations

Recommendation	Addressed to
Use the proposed selection of data sets (Section 2) as a basis for running the SISAM assessment methods evaluation scheme.	SISAM
Use the proposed assessment methods evaluation scheme (Section 3.3) for the SISAM Symposium workshop. It is not as yet clear what constitutes best practice in selecting amongst assessment approaches and appropriate simulating testing procedures to use to assist in this decision. It is hoped that further recommendations in this regard will eventuate from the SISAM workshop and Symposium.	SISAM
Don't use default settings on package assessment models to provide advice without first confirming that the results satisfy appropriate statistical diagnostics tests. In such circumstances, alternative settings need to be investigated.	EGs (AFWG, HAWG, NWWG, NIPAG, WGWIDE, WGBAST, WGBFAS, WGNSSK, WGCSE, WGDEEP, WGHMM, WGEF and WGHANSA) and Bench mark workshops

Annex 4: WGMG terms of reference for the next meeting

The **Working Group on Methods of Fish Stock Assessments** (WGMG) chaired by José De Oliveira, UK, will meet in Reykjavik, Iceland, 30 September – 4 October 2013 to:

a) Develop and suggest ways to evaluate management approaches for all species in mixed fisheries, including data limited stocks, that have a high probability of being consistent with the precautionary and MSY approaches.

b) With regard to the ICES Data Limited Stock (DLS) approach:

   i) Investigate the robustness of the DLS approach as a framework for providing advice.

   ii) Consider ways of extending management approaches using only age-aggregated abundance indices, tested on data rich species with age data, to data-limited situations without age data.

c) Evaluate the outcomes from the Assessment Methods Evaluation Scheme, applied during the SISAM World Conference on Stock Assessment methods for Sustainable Fisheries (WCSAM, Boston, July 2013), and based on this, develop recommendations for stock assessment approaches within ICES.

Depending on the outcome of WKMSYREF (January 2013), a further ToR may be added regarding estimation of F_{MSY}.

WGMG will report by 1 November 2013 (via SSGSUE) for the attention of the SCICOM.

Supporting information

Priority	
Scientific justification	ToR 1: In 2012, ICES has provided information for the management of mixed fisheries (technical interactions) in the North Sea and for multispecies fisheries (biological interactions) in the Baltic Sea using approaches specific to the topic (e.g. MIXFISH and SMS). There is now a need to take into account technical interactions AND biological interactions simultaneously. ToR 2: The DLS approach developed and applied in 2012 provided a framework for giving advice for stocks, yet some of the methods within the approach remain untested, and it is not sure to what extent this approach is self-consistent (i.e. there is a negative correlation between the amount and quality of the information available, and the level of precaution adopted). This ToR aims to both evaluate the robustness of the approach as a framework for providing advice, and investigate further one of the methods most widely applied, using age-aggregated abundance indices. ToR 3: WGMG has provided strong support for the ICES SISAM intiative since its conception during WKADSAM in 2010 and leading up to WCSAM (the syumposium to be held in Boston during 2013), and this ToR aims to feed some of this work back to ICES by evaluating the outcomes of the workshop to be held as part of WCSAM and develop recommendations for ICES stock assessment approaches based on this evaluation.
Resource requirements	None.

Participants	Research scientists involved in stock assessment methods from the ICES area and elsewhere in the world.
Secretariat facilities	None, other than formatting and publishing of the final report.
Financial	None.
Linkages to advisory committees	ACOM has strongly supported the work of this group. WGMG will report to ACOM in 2013.
Linkages to other committees or groups	WGMG will report to SCICOM in 2013. WGMG involved with the ICES Strategic Initiative on Stock Assessment Methods (SISAM).
Linkages to other organizations	NAFO, ICCAT.

Annex 5: Review of past simulation approaches

WGMG 1987

An age-structured surplus production program was modified to produce data for the comparison of production models to incorporate a S-R relationship and the option to include measurement or process noise. A 20-year projection was run with increasing fishing effort for 10 years and then more slowly decreasing for the others 10 years. Two more projections were made: one with measurement noise and the other with process noise; in either case the noise was lognormal with a log s.d. of 0.2. Measurement noise was added to catch-at-age and effort, after the simulation; it was not added to weight-at-age. Process noise was added to fishing mortality, fecundity and the density-dependency parameters; it was not added to natural mortality and weight-at-age, but the report does not state what type of process noise was added. On the exact data, if given good starting points, the method easily found solutions close to the true ones. Where converged solutions were obtained, the estimates of MSY (and others) were generally reasonable, but the interpretation in terms of catchability and current biomass were not. On the noisy data sets similar results were obtained, except that failure was more common. The options for allowing the inclusion of measurement and process errors worked better on data sets where the errors were of the opposite type.

WGMG 1988

The 1988 report provides more information. Six datasets were generated with the following features:

	Catchability	F	Process and Measurement errors	Observation
Dataset 1	No trends in any fleet	0.4 for the whole 30 years	Log-Nnormal	Separable F at age for each fleet
Dataset 2	No trends in any fleet	0.1 for the whole 30 years	log-Normal	Separable F at age for each fleet
Dataset 3	Trends in the two commercial fleets for which effort data are available. No trends in other fleets	0.4 with steadily increasing trend	log-Normal	Separable F at age for each fleet
Dataset 4	Trends in all fleets for which effort data are available	0.8 in year 1 increasing to about 1.2 in year 30	log-Normal	Separable F at age for each fleet
Dataset 5	Trends in the two commercial fleets for which effort data are available. No trends in other fleets	0.4 with steadily increasing trend	Process noise is gamma-distributed on F-at-age and catch-at-age data; log-Normal noise retained on fish effort	Separable F at age for each fleet

	Catchability	F	Process and Measurement errors	Observation
Dataset 6	Trends in the two commercial fleets for which effort data are available. No trends in other fleets	0.4 with steadily increasing trend	Process noise is gamma-distributed on F-at-age and catch-at-age data; log-Normal noise retained on fish effort	F-at-age not separable for any fleet for the whole of the simulated time period

Noise was added to the output datasets in the form of process error and measurement error, but again it is not clear what was done exactly. Mean weight-at-age and proportion mature-at-age were assumed to be constant and known. Natural mortality rate was assumed to be constant (0.2) and known for all ages and years.

WGMG 1989 (general observations for the simulations of the WGMG 1988)

The 1988 WG meeting was held in Reykjavík and those who could not participate took advantage of the 1989 meeting to comment on what was done at the previous meeting. Participants commented that, on the basis of the limited simulations, certain methods do seem more promising for future applications and research and that it would be useful to include the prediction models in the calculations so as to evaluate the impact of uncertainties in short and long-term yield, population trends and catch trends under different management strategies.

VPA estimates (Pope 1972) generally converged to the same value when fishing mortality on a given cohort exceeded about 3. This meant that the lower the fishing mortality in recent years, the weaker this convergence. Weaker convergence of the VPA would, typically, translate into larger variances of stock size estimates for the last years. Very weak convergence of the VPA generally led to a situation where the catchability and fishing mortality cannot be estimated simultaneously. In some integrated methods, this translated into very high correlations between parameter estimates and the correlation matrix of parameters could be used to detect that such a problem existed. It should be stressed that all available methods required some restrictive assumption about either fishing mortality or catchability on, at least, one fleet/survey for the oldest age group(s). This usually took the form of assumed constancy of either the catchability or the local exploitation pattern on the oldest ages. Although this assumption could not usually be tested or verified, it was, however, essential. Furthermore, it was dangerous to assume low fishing mortality or reduced catchability on the oldest ages, since this may allow the method to converge to the ever-present trivial solution of the problem, with almost zero fishing mortalities everywhere.

From USA NRC Improving stock assessments (appendix E), 1998:

This is a summary of Appendix E: Five data sets were created. Each included reported catch, effort, and age composition, and a relative abundance index with survey age composition. Simulations were initiated from a pristine population condition, fished for 15 years before the data started to be collected for 30 years. The population contains ages 1 to 15, where age 15 represents fish of 15 years age and older. M was a random variable drawn as an annual value from a uniform distribution ranging from 0.18 to 0.27; recruitment was assumed to follow a Beverton–Holt model with autocorrelated errors. The error was set to be negative (–1) for declining data sets and to be positive for recovering stock. Population abundance and mortality equations follow the Baranov catch equation, with selectivity and catchability explicitly defined. Selectivity was assumed to have changed for some data sets and catchability was assumed to have an exponential time-trend and an allometric dependence on biomass. Effort was assumed to vary randomly and reported effort is the true effort for all data sets. Reported catch was estimated to be known relatively accurately (±3%) except in one case where 30% underreporting was assumed. Survey catchability was assumed to vary randomly, except in one case where survey catchability was assumed to change. Ageing error was generated with 0 bias at age 1, which increases linearly to –1 at age 15.

Implications of model results

The following are selected paragraphs from the NRC report:

The purpose of the simulation study was to probe the performance of commonly used stock assessment models under severe conditions where these models were suspected not to perform well. The data and models tested the effects of ageing error, variation in natural mortality, changes in fishery selectivity and catchability, a lack of proportionality in the relationship between fishery cpue and biomass, a change in survey selectivity, a dome-shaped selectivity curve for the survey, underreporting of catch, and random variability in the dynamics and sampling processes. These conditions are known to exist in actual stock assessments, and simulation results confirmed that these co-occurring complications can lead to substantial bias and variability in estimates of population and management parameters.

The committee's analysis indicates that high-quality data, fundamentally the availability of reliable indices to calibrate the models, are essential to produce reliable abundance estimates. In most cases, use of the fishery abundance index resulted in poor performance unless the model contained additional parameters to deal with the trend in the index.

Surplus production and delay-difference models did not perform as well overall as age-structured models; this is not surprising because the simulated data were designed for use with age-structured methods. Surplus production models require a straightforward and immediate response of the population to changes in harvesting levels. The simulated populations were more affected by recruitment fluctuations than by changes in harvest levels. The corruption of indices of abundance by catchability and selectivity changes and by underreporting of catch would make stock assessment with surplus production models nearly impossible. Better results were achieved for delay-difference models because analysts utilized an index of recruitment from the survey and/or fishery data, rather than relying on a stock–recruitment model. Using a knife-edge selectivity assumption in these models when there was an underlying selectivity pattern with age increased the uncertainty and potential bias in estimates of population parameters. Nevertheless, better results were obtained for these models when the survey index was used alone than when only the fishery index or both indices were used.

Among the age-structured models, simple models such as ASA, SS-P3, or NRC ADAPT performed reasonably well when only the survey index was used and when the dynamics of the population and harvest were not too complex. More complex models such as SS-P6, SS-P7, and ADMB4 were sometimes able to handle more complex dynamics and indices with trends. However, the success of these more complicated models depended on correct specification of the dynamic changes in selectivity, catchability, and natural mortality. Simulation results suggest that models with greater complexity offer promise for improving stock assessment. The Kalman filter (in DDKF) and generalized parametric approach (in AD Model Builder) allowed more realistic treatment of process and measurement errors. The Bayesian *treatment of parameters (also in AD Model Builder) provided a means for incorporating uncertainty directly into the analysis and yielded results in terms of posterior probability distributions, which explicitly presented uncertainty. The incorporation of functional dependence of catchability and flexibility in model specification (in SS-P6 and SS-P7) provided a more deterministic way of adding realism. Although no specific model outperformed others in the simulations, the committee was intrigued with how more complex models could reduce, at least partially, the biasing effects related to fishery catchability and selectivity changes.*

Simulation results showed that when there is substantial recruitment variability, production models do not perform well. Only with populations that exhibit a strong negative response to fishing should these models be used for routine assessment. Nevertheless, there will be situations in which data limitations preclude the use of other methods. Delay-difference models fared better than production models but worse than age-structured models. Although delay-difference models might be used in situations in which ageing is subject to great error or not possible, it would be more prudent to utilize the age or length information in stock assessments. One of the reasons delay-difference models performed as well as they did in the simulations was use of a recruitment index from the survey. Thus, the development of recruitment indices for use in stock assessments should be considered.

The major conclusion from the simulation study was that a good index of abundance is needed for useful stock assessment information, not that fishery indices should not be used. Much effort is required to validate any index as a measure of abundance."

EU Concerted Action FAIR PL98-4231, 2000:

The final report (Patterson *et al*., 2000a, 2001) summarized the results of the project, which focused on three specific questions (text take from Patterson *et al*., 2000a):

- Do different methods give similar perceptions of uncertainty in the short-term, with similar structural models?
- Do different methods provide accurate probability statements in the short-term, given that there is no violation of structural assumptions?
- Do eventual outcomes correspond to the predictions made in the medium-term using the methods considered?

An experimental protocol was set up to compare estimation methods (e.g. bootstrap vs. Bayesian) with classes of structural models (e.g. VPA vs. Separable) while constraining other features to be as close as possible in the context of each question. The first question was addressed by calculating short-term uncertainty estimates for three stocks – North Sea plaice, eastern Georges Bank haddock and sardine around the Iberian Peninsula – using a subset of real data (note, two of these stocks have been selected for the SISAM evaluation exercise proposed in Section 3). The extent to which the location and spread of the distributions, which determine the confidence statements, differ among models and approaches was examined (Gavaris *et al*., 2000). The second question was addressed by calculating short-term uncertainty estimates using simulated data of known characteristics. The methods were judged with respect to accuracy, i.e. whether they gave the right probability coverage (Restrepo *et al*., 2000). The third question was addressed through a probability approach applied to a selection of stocks from the ICES and NAFO areas. Forecasts from retrospective assessments were checked against the eventual outcome indicated by the latest assessment (Patterson *et al*., 2000b).

On the state of the practice of uncertainty estimation at the time, Patterson *et al*. (2000a) concluded that despite much progress in the development of methods, the extent to which probability distributions (calculated for management purposes) adequately represented the probabilities of eventual real outcomes was largely unknown. Despite its importance for fisheries management purposes, estimation of uncertainty was still regarded as an emerging science in which many assumptions remained untested. The project was thus seen as a first step in addressing the complex topic of evaluating uncertainty in the context of stock assessment and forecasting. On the basis of their tests, Patterson *et al*. (2000a) concluded that:

- *Choice of uncertainty estimation method does matter: making a choice from the palette of available methods can have large or significant implications for perceptions of the risks associated with forthcoming change in stock size.*
- *Challenged with testing using simulated data, it appears that methods that do not use bias-correction do tend to generate inaccurate inferences about stock size and future catches.*
- *When the forecasting capabilities of the models are tested with real data, it appears that the performance of some models for some parameters is adequate, but not for some models and other parameters. We conclude that the problem of appropriate uncertainty estimation in fisheries is a tractable one, but substantial additional work is required.*

From these conclusions, Patterson *et al*. (2000a) proposed the following strategy for addressing the problems raised:

1. *Methods routinely applied for stock assessment purposes and for uncertainty estimation should perform well when tested using simulated data. Present work suggests that bias-corrected variants of the traditional stock assessment tools should be developed.*
2. *Methods routinely applied for stock assessment purposes and for uncertainty estimation should provide diagnostics to evaluate the adequacy of the structural assumptions. Techniques for including model selection uncertainty, if one model is selected, or for admitting multiple models should be investigated.*
3. *The reasons for the systematically poor performance of ICES assessment procedures for many interest paremeters is currently unknown. Improved diagnostics should be devised to provide more detailed insights on the way in which the estimation of the uncertainty in various parameters differs from that desired. Application of the models to a library of real data has provided new insights into the ways in which assessment models fail in respect of providing appropriate confidence statements, and this work could be extended. Both the precision of the interest parameters and the accuracy of the uncertainty estimates can be investigated in this way.*
4. *Based on such new insights it should be possible to devise new methods, or propose modifications to existing methods, that would be robust to such failures. Any proposed new methods or modifications should be subjected to simulation tensting before re-exposing them to the library of real data. This approach should provide the assessment community with assessment procedures that have known characteristics of precision and bias when applied to real data, and the use of such procedures may be moderated accordingly.*
5. *In parallel with this approach, simulated data sets should be used to verify that implementations of models perform as intended, and to explore the response of assessment models to structural mis-specifications.*

WGMG 2001

The sensitivity of XSA results to survey uncertainty was investigated. A single fleet exploited the stock with a fixed selection pattern over time. Catchability was held constant and there were no stochastic components to the fleet dynamics. For all years and ages, survey cpues were generated for the start of the year. The indices had lognormal errors with a constant CV over all ages at 0.01, 0.1, 0.3, 0.5, 0.7 and 1.0. The simulated population model was used to generate 1000 replicate cpue data sets. One catch-at-age data set, without measurement error, was generated with ages 1-15 without plus group.

Three XSA assessment model structures were fitted to each of the replicated data sets. Each model formulation was based on the structure of the underlying simulated data. The first estimated all cohort terminal population numbers with the only model constraint being that catchability at age 15 was equal to age 14. The second and third models structures introduced two commonly used constraints that allow a reduction in the number of parameters estimated by the model, namely F shrinkage and a catchability plateau at a younger age. Within the F shrinkage model, the terminal population estimates at the oldest ages were derived from the average fishing mortality estimated for the five younger ages in the same year. This resulted in an XSA structure which is very similar to that of the most commonly used ADAPT formulation.

Results suggested that XSA estimation bias increases non-linearly with the CV of the cpue series. Without constraining assumptions, the bias is less than 10% for the majority of ages with CV values below 50%, and below 15% for CV values from 50-70%. This analysis was considered preliminary because only one level of fishing mortality and stock has been examined.

WGMG 2003

Two data sets were created: (1) without noise and (2) with noise.

(1) This data set has no measurement errors in catch or survey indices. It considers an age-structured population comprising 15 years, without a plus group. A constant natural mortality of 0.2 is assumed for all ages and years. The population structure in the first year is generated under equilibrium. The population is simulated forward over 41 years, with nominal fishing mortality maintained at $0.5*F_{MSY}$ during a burn-in period of 17 years, then increased gradually to $2*F_{MSY}$, maintained there during years 27-33, and subsequently reduced toward $0.5*F_{MSY}$. The fishery has a specific age-dependent exploitation pattern which is fixed over the period. Recruitment in each year is stochastic about a Beverton–Holt S-R relationship, with autocorrelation. The population is length-structured with a von Bertalanffy lengths-at-age growth model.

(2) The data produced at (1) was modified to produce random stochastic noise in the age disaggregated output. Fishery or survey data were modified using a random variable drawn from a specified lognormal distribution with a known CV.

WGMG 2004:

The Methods WG in 2004 examined the results of the NRC review and used the NRC data to do further analyses. The following are selected paragraphs from the WGMG 2004 report:

In general, the NRC data were generated to simulate violations of the typical assumptions of a number of assessment methods (e.g. changes in catchability through time, changes in fleet *selectivity) on top of process and observation error (e.g. variability in M, sampling variance in survey, ageing error in setting up catch-at-age, misreporting). 30-year time-series of data were provided to analysts, including: catches-at-age (15 ages), commercial effort data, and "survey" (in the sense of being less biased, albeit noisy) indices. Commercial cpue could be used for tuning in isolation or together with the survey indices.*

The first data set used by the group is identical to NRC set 3, which involves a change in survey catchability midway in the time-series, fleet catchability changing with stock abundance, and fleet selectivity shifting towards younger ages in the second half of the series. None of this information was known to the members of WGMG before the analyses were carried out, which were therefore blind tests. Since the focus here was on the capacity of diagnostics, the change in survey q was the main reason to choose this set, as this is a major violation of assumptions made in several of the methods considered and diagnostics should reflect it.

The second data set was an amendment of NRC set 4 (a relatively easy one, involving no change in survey q nor in fleet selectivity), with a general (albeit not simply linear) trend in misreporting in catches (not effort) simulated over the last 10 years, reaching 50% in the final year. This misreporting trend coincides with a strong decline in the simulated stock.

The third data set is identical with NRC set 5, where a stock recovery is simulated which means that fishing mortality is even lower than in other data sets. It conforms to the standard assumptions.

Conclusions

A total of ten assessment methods were applied to between one and three simulated datasets from the NRC collection. The purpose of the exercise was, primarily, to ascertain the ability of general data-screening and the diagnostics of each model to detect the model misspecifications in these datasets, and subsequently, to determine whether believing in and acting upon a particular diagnostic improves or worsens the fit of the assessment method to the truth.

The diagnostics currently available in these assessment methods are sometimes sufficient to indicate the presence of a problem and the general year or age range over which it applies (and therefore where we should be looking for further information), but they do not often indicate the cause of the problem and it is only very seldom that they can suggest courses of action to alleviate the problem. The exercise was carried out in ignorance of the features of the datasets being examined. Such blind testing is one good way to evaluate diagnostics, but in general, further information about the fishery, the survey, etc. would be required to make progress towards a better stock assessment. In no case did believing in and acting on a diagnostic appear to make the resulting assessment worse, but this may not hold in general.

The specific datasets used all involved much lower values of F than would be commonly encountered in current ICES stock assessments. With such values assessment methods can become unstable or unreliable. In addition, the more complex a model formulation, the more scope there would appear to be for the assessment method to bend to fit the characteristics of the data. For this reason, data evaluation should be done with simple models using limited assumptions.

Generalities are difficult to make on the basis of a limited number of datasets, and the continuation of this work would be beneficial.

Table 4.4.1.1 summarizes estimated interest parameters from the assessment methods used in these analyses. Before modifications were applied, there was a general tendency to overestimate both the depletion ratio (B30/B1) and the recruitment (GM-R 1–30). Estimates of mean F in the last year varied widely between methods. After modifications, all methods moved closer to the true values.

Table 4.4.1.1. Comparison of estimated parameters across methods for data set 1, before and after modifications suggested by diagnostics (* = modifications suggested by external information, specifically that the survey vessel changed in 2015).

Summary indicators before modification

Method	True	CSA	XSA	KSA	ICA	SURBA	CADAPT	CAMERA	Bayesian VPA
B30/B1	0.16	0.36	0.467	0.24–0.34	0.58	0.45	0.48	0.46	0.26
GM-R 1–30	412.2	422.2	848	506	882.2	702.8	720.0	444.1	320.4
F(5–10) in 30	n/a	n/a	0.125	0.38–0.48	0.09	0.386	0.14	0.23	0.02

Summary indicators after modification

Method	True	CSA*	XSA	SURBA*	CADAPT	CAMERA
B30/B1	0.16	0.194	0.182	0.369	0.20	0.18
GM-R 1–30	412.2	452.6	560	688.5	545.0	396.5
Fbar 5–10	0.402	n/a	0.578	0.350	0.43	0.50

General guidelines for stock assessment Working Groups related to ToR d)

The following are general guidelines that stock assessment Working Groups should follow for benchmark assessments:

- *A wide range of diagnostics, both data-screening and model-based (see, for example, Section 4.3.1), and assessment methods should be used to explore fully the data, starting with the simplest available methods. The requirement for a wide range is driven by the fact that there is no universally appropriate diagnostic or method.*
- *The lack of a retrospective pattern does not necessarily indicate a well-specified model.*

Evaluation of NMFS Toolbox Assessment Models on Simulated Groundfish Data Sets, 2008:

Executive summary

A simulation study was performed to evaluate the performance of five NOAA Fisheries Toolbox assessment models (AIM, ASPIC, SCALE, VPA, and ASAP). Data sets corresponding to three representative groundfish stocks (Georges Bank yellowtail flounder, Georges Bank cod, and white hake) were simulated with PopSim, a simulation program in the Toolbox. For each simulated stock, a base case data set was produced as well as three data sets with a known error. There were 12 data sets in total (three stocks with four data sets each) and for each data set, 100 random realizations were generated with PopSim. Each model performed an "assessment" on the simulated datasets, and the results were compared with the "true" value (i.e. the known parameter values used to generate the data sets). Results for each model in each of the 12 cases were summarized with respect to bias and precision (CV). The base case served as a benchmark to determine how well each model could replicate the truth and as a point of comparison for model performance on the data sets with known error. In general, no model was a clear winner in all cases. Data sets that reflected errors associated with sampling (aging error or number of length samples) were best handled by models that either did not use age (AIM) or models that incorporate error into catches (ASAP). The VPA, because it matches catch exactly, suffered the most bias and had the poorest precision in these cases. However, when the source of error introduced a "break" in the time-series (as in all of the yellowtail flounder *cases), none of the model configurations was robust to the effect. The "east coast" approach of tuning to age-specific survey indices appears to be robust to the shape of the selectivity function. In the case of misspecification of the fleet selectivity (assuming logistic when it is dome), both forward and backward projecting models were impacted, but the effect was only apparent at the oldest ages (as would be expected). ASPIC failed in all simulated data sets, but this was due to the nature of the simulated data (all of which were one-way trips), and not to deficiencies in the model.*

Each model was set to "typical" conditions, and the result from each data set were "final" in the sense that the analyst did not have the ability to examine diagnostics and reconfigure or re-run the model. This analysis was similar to what SISAM was planning on doing, i.e. generate simulated data from one model and see how different models perform on the simulated data. It should not be a surprise if some models do not perform well.

Annex 6: Further technical details of aspects of the evaluation scheme

Approaches to generate simulated data sets

Observation error only

1) Fit the model to the observed data, providing point estimates of the numbers-at-age by year and other similar quantities.

2) For each model fit to the observed dataseries, estimate the parameters of the assumed error distribution. For example, if a survey index at age $I_{y,a}$ is fitted to abundance assuming a lognormal error distribution:

$$\ln I_{y,a} = \ln q_a + \ln N_{y,a} + \varepsilon \qquad \text{where } \varepsilon \sim N(0;\sigma_a^2) \tag{1}$$

then the values of the σ_a's also need to be estimated, with care taken to allow for possible bias, for example through use of REML to adjusted for a reduced number of degrees of freedom. If there is evidence of autocorrelation in a particular set of residuals, the extent of this should also be estimated.

3) Equation (1) or its equivalent for the dataseries concerned (e.g. with catch-at-age proportions a multinomial distributional form might have been assumed) is then used to generate simulated or "pseudo" datasets. Thus for example for pseudo dataset *s*:

$$\ln I_{y,a}^s = \ln q_a + \ln N_{y,a} + \varepsilon^s \qquad \text{where } \varepsilon^s \text{ is generated from } N(0;\sigma_a^2) \tag{2}$$

4) In this way pseudo data are generated for each dataseries with which observation error might be associated to make up pseudo dataset *s*, with the whole process being repeated to generate as many pseudo datasets as required. A candidate assessment method would be fit to each of these pseudo datasets, with estimation performance relative to the "true" $N_{y,a}$ summarized by the values of an appropriately chosen set of statistics which characterize distributions of estimates across the simulated datasets.

Extension to include process error

For the purposes of initial explanation, consider a situation where past catches are known (effectively) exactly, and the only source of process error is variability in annual recruitment about the stock–recruitment relationship.

An example shows the problem of simply trying to duplicate the process above for generating pseudo datasets. Say that in the real data the catch in year 3 was very high, as a consequence of good recruitment in year 2, with the assessment model estimating a large positive residual about the stock–recruitment relationship in year 2. In a particular simulation run, the stock–recruitment residual generated for year 2 is negative, with the consequence that there are not enough fish present in the simulated numbers-at-age matrix at the start of year 3 to support the catch that was actually taken that year, and the population is consequently rendered extinct. Clearly that is not a scenario consistent with reality for the stock in question. One could simply eliminate simulations where extinction occurred, but that could lead to the set of accepted recruitment residuals exhibiting strong bias with respect to the distribution they are intended to reflect. A more careful approach is needed to ensure that the simulated datasets remain consistent with ones which could have arisen from the possible underlying realities as estimated by the assessment procedure under evaluation.

One way to do this, which is in any case that which might be used in the assessment process itself if random effects (mixed model) terms are present or the assessment method is Bayesian, is to use an MCMC algorithm to perform the integration required for the assessment, adding uninformative priors for certain parameters if needed (admitting that in non-linear models a prior that is uninformative for one parameter may nevertheless be somewhat informative for other model outputs of interest). Selections from the MCMC chain of parameter value vectors which is generated in this process each constitute equally likely realities consistent with the real data through the correlation structure which is automatically built into this estimation procedure. For each of n numbers-at-age matrices generated in this way, a number m of alternative sets of generated observation errors can be added to provide nm simulated datasets.

Another approach, although this does involve some approximation, involves generating alternative numbers-at-age matrices using the variance-covariance matrix estimated together with the assessment model parameters in the model fitting process. Thus, for example, if recruitment variability is the only source of process error involved, one starts by taking the point estimates of the starting numbers-at-age in the first year, recruitment residuals for each year, and the stock–recruitment relation parameters, and generates random realizations about these in line with the associated variance-covariance matrix. The catch equation is then used together with the total catch taken each year and realizations of the estimated age-specific selectivity vector (note that even if this is year-invariant, there will be estimation uncertainty associated with the values of its parameters) also generated in line with the variance-covariance matrix to construct the full numbers-at-age matrix for each of n simulations. These are then extended to nm simulated datasets when adding observation error as above. The process explained here is readily extended to include other sources of process error, such as annual variations in natural mortality or selectivity-at-age, again generating numbers-at-age matrices and associated parameter values in line with the overall variance-covariance matrix. Note that the problem illustrated by the original example is avoided because alternative recruitment residuals for each year are not generated from the stock–recruitment relationship itself, but rather from the error distribution associated with the residual as estimated in the original assessment process, with that residual generation also informed by taking account of covariances with other recruitment residuals and parameters estimated; it is this which maintains the consistency with the real data.

While these approaches might at first sight appear complex, note that they build on the structure of assessment models which take process error into consideration, and so constitute a logical way forward to generating pseudo data incorporating process error from the results of such models.

Note that in these generation processes, annual catch generation can involve only observation error, or both process and observation error. In the both cases, the past catch data are understood not to be exact, so that the assessment model fitting process includes a term that estimates the catch each year, but appropriately "near" to the inexact value provided from the data for that year. If only observation error is then to be generated, the catch series estimated in the model fitting process is assumed unchanged in projecting the resource dynamics forward in a way that is the same for every simulation, but error is added to those catches to provide different sets of simulated catches in each pseudo dataset. In contrast, if process error is included as well, either approach suggested above will treat the catch each year as an estimable parameter, and the actual underlying catches will change amongst the simulations in the datasets generated.

Annex 7: Detailed description of selected data sets

This Annex provides a more detailed description of the data sets and current assessment models applied to the stocks selected in Section 2. Note that material has been lifted from reports, and no attempt is made to change Table and Figure numbers.

1 North Sea cod

DATA:

Table 14.5a. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. Proportion mature by age-group.

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

Table 14.2c. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. Catch numbers-at-age (Thousands).

Catch numbers at age (thousands)

AGE/YEAR	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
1	19445	13118	114228	127146	61270	37101	5462	107718	305050	42274	112315
2	62594	28685	58520	84752	95756	106909	33005	42617	192757	247327	49230
3	7063	20220	17735	29916	32854	42784	31691	18640	17266	48304	55178
4	3536	4306	9182	6184	11261	12392	13710	13339	6754	5682	14072
5	2788	1917	2387	3379	3271	6076	4565	6297	7101	2726	2206
6	1213	1818	950	1278	1974	1414	2895	1763	2700	3201	1109
7	81	599	658	477	888	870	588	961	893	1680	1060
8	492	118	298	370	355	309	422	209	458	612	489
9	14	94	51	126	138	151	147	186	228	390	80
10	6	12	75	56	40	111	46	98	77	113	58
+gp	0	4	8	83	17	24	78	40	94	18	162
TOTALNUM	97232	70890	204093	253767	207823	208142	92610	191868	533377	352326	235958
TONSLAND	128704	130771	210287	259445	276416	305943	205576	244053	412490	387824	269241
SOPCOF %	100	100	100	100	100	100	100	100	100	100	100

AGE/YEAR	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
1	140339	170719	233649	549790	58774	619440	1252297	177157	250252	81211	605546
2	74878	63439	183912	99307	254204	96999	122460	223566	73747	140869	79022
3	11476	18944	18766	26087	17258	44653	35056	34901	60510	21687	31281
4	15824	4663	6741	4615	9440	4035	12316	9019	9567	11900	4264
5	4624	7563	1741	2294	3003	3395	1965	4118	3476	2830	3436
6	961	2067	3071	836	1108	712	1273	785	2065	1258	1019
7	438	449	924	1144	410	398	495	604	428	595	437
8	395	196	131	371	405	140	197	134	236	181	244
9	332	229	67	263	153	158	74	65	78	90	60
10	81	95	63	26	36	42	55	37	27	28	45
+gp	189	63	43	96	44	17	25	21	16	23	20
TOTALNUM	249535	268428	449108	684830	344834	769989	1426214	450405	400402	260672	725372
TONSLAND	254086	242304	307009	348974	329605	433252	589093	393394	357752	281388	380209
SOPCOF %	100	100	100	100	100	101	100	100	100	100	100

AGE/YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
1	72504	665992	49647	36942	200504	45932	61576	131989	38896	340260	61143
2	154827	38221	190476	72509	45109	102988	31950	42124	84390	42291	107670
3	19111	34413	9800	44172	18685	11985	17230	8684	11372	21306	12974
4	7823	5814	8723	3134	9866	4339	3310	5007	3190	3083	5301
5	1377	2993	1534	2557	1002	2468	1390	1060	1577	870	802
6	1265	604	1075	655	1036	310	1053	491	435	519	286
7	373	556	235	295	251	310	225	329	204	142	151
8	173	171	215	66	140	54	139	52	108	58	42
9	79	69	55	63	27	60	28	40	18	32	15
10	16	44	48	23	31	12	4	17	10	7	13
+gp	31	23	12	18	10	9	10	9	13	16	5
TOTALNUM	257577	748900	261822	160435	276661	168468	116916	189803	140212	408583	188400
TONSLAND	246131	343134	244052	194954	202055	152336	121030	150940	143609	210212	168283
SOPCOF %	100	101	100	100	100	100	100	99	100	100	99

AGE/YEAR	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1	19389	111077	16864	37491	46275	7820	20565	8911	13454	12792	28596
2	60181	43085	172877	15468	28683	54778	10492	19591	8744	13883	10495
3	24138	18687	18472	40662	6472	6972	15223	4629	6107	2973	5251
4	3169	6499	5967	4034	6697	1142	2519	2728	1965	1646	1068
5	1860	1238	2402	1446	1021	1080	366	460	988	478	483
6	399	700	509	626	385	144	349	68	150	394	153
7	162	153	236	223	139	84	51	50	43	44	117
8	88	47	41	91	40	27	31	13	23	11	22
9	43	14	16	14	18	14	13	7	8	8	4
10	4	15	4	10	5	6	5	3	3	2	2
+gp	8	10	12	2	1	1	0	1	0	0	0
TOTALNUM	109438	181526	217400	100066	89736	72069	49615	36462	31485	32232	46191
TONSLAND	140575	157774	186494	110405	85084	63565	60571	37244	34037	34980	34640
SOPCOF %	100	100	100	101	100	100	100	102	100	100	103

AGE/YEAR	2007	2008	2009	2010	2011
1	15862	8940	9220	10347	5385
2	27035	12565	11423	12004	15383
3	3949	11767	4198	5642	4713
4	1903	1212	3280	1618	1590
5	356	718	581	1303	613
6	139	183	261	238	586
7	39	71	60	87	69
8	38	33	29	19	26
9	6	21	20	9	5
10	1	4	9	5	10
+gp	0	3	2	3	2
TOTALNUM	49330	35517	29083	31275	28382
TONSLAND	48069	48661	44775	47163	42357
SOPCOF %	100	100	100	101	100

Table 14.3c. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. Catch weights at age (kg), also assumed to represent stock weights at age.

Catch weights at age (kg)

AGE/YEAI	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
1	0.314	0.357	0.313	0.314	0.326	0.328	0.416	0.449	0.313	0.300	0.335
2	0.808	0.762	0.900	0.836	0.868	0.847	0.755	0.845	0.834	0.729	0.700
3	2.647	2.367	2.295	2.437	2.395	2.215	2.127	2.028	2.188	2.080	1.912
4	4.491	4.528	4.512	4.169	3.153	4.094	3.852	4.001	4.258	3.968	3.776
5	6.794	6.447	7.274	7.027	6.803	5.341	5.715	6.131	6.528	6.011	5.488
6	9.409	8.520	9.498	9.599	9.610	8.020	6.722	7.945	8.646	8.246	7.453
7	11.562	10.606	11.898	11.766	12.033	8.581	9.262	9.953	10.356	9.766	9.019
8	11.942	10.758	12.041	11.968	12.481	10.162	9.749	10.131	11.219	10.228	9.810
9	13.383	12.340	13.053	14.060	13.589	10.720	10.384	11.919	12.881	11.875	11.077
10	13.756	12.540	14.441	14.746	14.271	12.497	12.743	12.554	13.147	12.530	12.359
+gp	0.000	18.000	15.667	15.672	19.016	11.595	11.175	14.367	15.544	14.350	12.886

AGE/YEAI	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
1	0.304	0.304	0.199	0.295	0.432	0.291	0.258	0.329	0.358	0.403	0.304
2	0.901	0.760	0.722	0.673	0.743	0.905	0.917	0.769	0.908	0.882	0.921
3	2.206	2.348	2.449	2.128	2.001	2.411	1.948	2.186	1.856	1.833	2.156
4	4.156	4.226	4.577	4.606	4.146	4.423	4.401	4.615	4.130	3.880	3.972
5	6.174	6.404	6.494	6.714	6.530	6.579	6.109	7.045	6.785	6.491	6.190
6	8.333	8.691	8.620	8.828	8.667	8.474	9.120	8.884	8.903	8.423	8.362
7	9.889	10.107	10.132	10.071	9.685	10.637	9.550	9.933	10.398	9.848	10.317
8	10.791	10.910	11.340	11.052	11.099	11.550	11.867	11.519	12.500	11.837	11.352
9	12.175	12.339	12.888	11.824	12.427	13.057	12.782	13.338	13.469	12.797	13.505
10	12.425	12.976	14.139	13.134	12.778	14.148	14.081	14.897	12.890	12.562	13.408
+gp	13.731	14.431	14.760	14.362	13.981	15.478	15.392	18.784	14.608	14.426	13.472

AGE/YEAI	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
1	0.314	0.293	0.437	0.466	0.364	0.382	0.392	0.395	0.327	0.305	0.420
2	0.800	0.782	0.773	0.753	0.931	0.690	0.889	0.970	0.845	0.788	0.768
3	2.132	1.822	1.955	1.974	1.810	2.165	1.994	2.545	2.478	2.188	2.207
4	4.164	3.504	3.650	3.187	3.585	3.791	3.971	4.223	4.551	4.471	4.293
5	6.324	6.230	6.052	5.992	5.273	5.931	6.082	6.247	6.540	7.167	7.220
6	8.430	8.140	8.307	7.914	7.921	7.890	8.033	8.483	8.094	8.436	8.980
7	10.362	9.896	10.243	9.764	9.724	10.235	9.545	10.101	9.641	9.537	10.282
8	12.074	11.940	11.461	12.127	11.212	10.923	10.948	10.482	10.734	10.323	11.743
9	13.072	12.951	12.447	14.242	12.586	12.803	13.481	11.849	12.329	12.223	13.107
10	14.443	13.859	18.691	17.787	15.557	15.525	13.171	13.904	13.443	14.247	12.052
+gp	16.588	14.707	16.604	16.477	14.695	23.234	14.989	15.794	13.961	12.523	13.954

AGE/YEAI	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1	0.433	0.386	0.372	0.317	0.354	0.372	0.456	0.275	0.341	0.348	0.217
2	0.831	0.797	0.633	0.732	0.903	0.605	0.916	0.752	0.671	0.895	0.771
3	2.095	2.117	1.622	1.405	1.747	2.093	1.712	1.533	1.713	1.945	1.972
4	4.034	3.821	3.495	3.305	3.216	3.663	3.857	3.191	3.096	3.695	3.610
5	6.637	6.228	5.387	5.726	4.903	5.871	5.372	5.113	5.172	5.055	5.590
6	8.494	8.394	7.563	7.403	7.488	7.333	7.991	7.270	7.426	7.555	6.848
7	9.729	9.979	9.628	8.582	9.636	9.264	9.627	8.630	8.675	9.607	8.911
8	11.080	11.424	10.643	10.365	10.671	10.081	10.403	12.056	9.797	11.229	10.639
9	12.264	12.300	11.499	11.600	10.894	12.062	10.963	12.846	11.684	11.501	12.216
10	12.756	12.761	13.085	12.330	11.414	12.009	12.816	10.771	13.058	13.333	9.212
+gp	11.304	13.416	14.921	11.926	15.078	10.196	11.842	17.351	14.140	15.340	10.773

AGE/YEAI	2007	2008	2009	2010	2011
1	0.276	0.330	0.390	0.293	0.335
2	0.863	0.904	1.029	1.028	0.835
3	2.187	1.971	2.335	2.453	2.424
4	4.064	3.834	3.972	4.199	4.349
5	5.607	5.692	6.041	6.049	6.245
6	8.467	7.228	7.538	7.692	7.710
7	8.917	9.321	8.795	9.234	9.216
8	9.902	9.879	10.212	10.311	9.495
9	12.358	11.596	9.999	10.801	11.499
10	13.725	15.278	11.915	11.462	15.754
+gp	8.154	13.295	13.597	10.522	12.421

Table 14.5b. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. Natural mortality by age-group.

	Age						
Year	1	2	3	4	5	6	7+
1963	1.107	0.789	0.233	0.202	0.2	0.2	0.2
1964	1.147	0.804	0.241	0.202	0.2	0.2	0.2
1965	1.184	0.819	0.248	0.202	0.2	0.2	0.2
1966	1.217	0.831	0.254	0.202	0.2	0.2	0.2
1967	1.242	0.839	0.261	0.202	0.2	0.2	0.2
1968	1.260	0.843	0.266	0.202	0.2	0.2	0.2
1969	1.273	0.844	0.271	0.202	0.2	0.2	0.2
1970	1.282	0.842	0.275	0.202	0.2	0.2	0.2
1971	1.287	0.838	0.277	0.201	0.2	0.2	0.2
1972	1.290	0.832	0.279	0.201	0.2	0.2	0.2
1973	1.291	0.826	0.280	0.201	0.2	0.2	0.2
1974	1.292	0.819	0.280	0.200	0.2	0.2	0.2
1975	1.293	0.811	0.280	0.200	0.2	0.2	0.2
1976	1.296	0.803	0.280	0.200	0.2	0.2	0.2
1977	1.301	0.795	0.282	0.200	0.2	0.2	0.2
1978	1.306	0.787	0.284	0.200	0.2	0.2	0.2
1979	1.311	0.779	0.286	0.200	0.2	0.2	0.2
1980	1.314	0.771	0.290	0.200	0.2	0.2	0.2
1981	1.314	0.762	0.293	0.200	0.2	0.2	0.2
1982	1.310	0.754	0.296	0.200	0.2	0.2	0.2
1983	1.301	0.746	0.298	0.201	0.2	0.2	0.2
1984	1.287	0.738	0.300	0.201	0.2	0.2	0.2
1985	1.269	0.730	0.300	0.201	0.2	0.2	0.2
1986	1.248	0.724	0.300	0.201	0.2	0.2	0.2
1987	1.226	0.719	0.299	0.202	0.2	0.2	0.2
1988	1.204	0.716	0.297	0.202	0.2	0.2	0.2
1989	1.183	0.715	0.296	0.202	0.2	0.2	0.2
1990	1.164	0.715	0.295	0.202	0.2	0.2	0.2
1991	1.149	0.716	0.295	0.202	0.2	0.2	0.2
1992	1.135	0.717	0.297	0.202	0.2	0.2	0.2
1993	1.124	0.716	0.302	0.203	0.2	0.2	0.2
1994	1.113	0.714	0.309	0.204	0.2	0.2	0.2
1995	1.102	0.711	0.319	0.205	0.2	0.2	0.2
1996	1.090	0.705	0.331	0.207	0.2	0.2	0.2
1997	1.077	0.698	0.346	0.209	0.2	0.2	0.2
1998	1.064	0.691	0.363	0.211	0.2	0.2	0.2
1999	1.051	0.683	0.381	0.214	0.2	0.2	0.2
2000	1.040	0.678	0.400	0.217	0.2	0.2	0.2
2001	1.032	0.676	0.417	0.220	0.2	0.2	0.2
2002	1.028	0.676	0.434	0.223	0.2	0.2	0.2
2003	1.027	0.679	0.449	0.225	0.2	0.2	0.2
2004	1.029	0.684	0.462	0.227	0.2	0.2	0.2
2005	1.032	0.688	0.472	0.229	0.2	0.2	0.2
2006	1.036	0.692	0.480	0.230	0.2	0.2	0.2
2007	1.038	0.695	0.484	0.231	0.2	0.2	0.2
2008	1.039	0.696	0.487	0.232	0.2	0.2	0.2
2009	1.039	0.697	0.489	0.232	0.2	0.2	0.2
2010	1.038	0.698	0.490	0.233	0.2	0.2	0.2
2011*	1.038	0.698	0.490	0.233	0.2	0.2	0.2

Table 14.6. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. Survey tuning cpue. Data used in the assessment are highlighted in bold text.

North Sea/Skagerrak/Eastern Channel Cod, Tuning data for standard survey. Updated 25 April 12
101
IBTS_Q1_ext, 6 is a plusgroup

1983	2011						
1	1	0	0.25				
1	5						year
1	**5.696**	**17.403**	**2.997**	**2.050**	**0.793**	1.275	1983
1	**17.107**	**9.913**	**4.375**	**0.930**	**0.995**	0.820	1984
1	**1.096**	**20.221**	**4.562**	**3.649**	**0.768**	1.103	1985
1	**18.112**	**3.793**	**7.787**	**2.756**	**1.368**	0.981	1986
1	**9.626**	**33.252**	**1.845**	**2.032**	**0.659**	0.792	1987
1	**6.990**	**7.737**	**7.960**	**0.702**	**0.865**	1.072	1988
1	**14.953**	**6.776**	**5.877**	**2.668**	**0.412**	0.944	1989
1	**4.606**	**15.376**	**2.141**	**1.046**	**0.965**	0.596	1990
1	**2.688**	**5.061**	**4.757**	**1.042**	**0.551**	0.773	1991
1	**16.439**	**4.821**	**1.364**	**1.023**	**0.312**	0.445	1992
1	**13.619**	**20.429**	**2.400**	**0.807**	**0.693**	0.356	1993
1	**14.856**	**4.510**	**3.015**	**0.860**	**0.486**	0.498	1994
1	**12.798**	**27.878**	**3.461**	**1.363**	**0.306**	0.348	1995
1	**4.384**	**9.512**	**6.368**	**0.796**	**0.663**	0.397	1996
1	**38.005**	**7.597**	**2.670**	**1.142**	**0.455**	0.392	1997
1	**2.951**	**27.555**	**2.309**	**1.087**	**0.552**	0.401	1998
1	**3.304**	**1.878**	**8.104**	**0.804**	**0.452**	0.509	1999
1	**6.639**	**5.537**	**0.889**	**2.152**	**0.436**	0.591	2000
1	**3.378**	**9.316**	**1.891**	**0.293**	**0.410**	0.251	2001
1	**11.491**	**4.240**	**4.540**	**0.671**	**0.143**	0.230	2002
1	**0.756**	**4.168**	**1.301**	**1.415**	**0.480**	0.205	2003
1	**8.370**	**2.114**	**1.525**	**0.435**	**0.556**	0.268	2004
1	**2.723**	**3.283**	**0.940**	**0.665**	**0.229**	0.435	2005
1	**8.131**	**1.644**	**1.316**	**0.261**	**0.156**	0.282	2006
1	**3.397**	**6.658**	**1.247**	**0.375**	**0.331**	0.352	2007
1	**3.620**	**2.279**	**3.090**	**0.721**	**0.464**	0.189	2008
1	**2.178**	**3.570**	**1.179**	**0.986**	**0.327**	0.272	2009
1	**5.814**	**4.635**	**1.862**	**0.648**	**0.533**	0.231	2010
1	**1.103**	**7.038**	**1.940**	**0.750**	**0.417**	0.408	2011
1	**5.144**	**3.529**	**4.942**	**1.214**	**0.326**	0.230	2012

MODEL:

SAM is a state-space model. 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. SAM 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, because part of the interannual changes estimated along cohorts are deemed to arise from "other sources of variability" instead of from changes in F.

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

SAM is considered more appropriate than VPA approaches such as B-Adapt, because the additional variability/uncertainty considered in various components of 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 previously mentioned, 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 the 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 biased. SAM is considered the most appropriate modelling approach for the North Sea cod stock assessment at this time.

Table 14.7a. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. SAM base run model specification (model.cfg file).

```
# Min Age (should not be modified unless data is modified accordingly)
1

# Max Age (should not be modified unless data is modified accordingly)
7

# Max Age considered a plus group (0=No, 1=Yes)
1

# The following matrix describes the coupling
# of fishing mortality STATES
# Rows represent fleets.
# Columns represent ages.
 1  2  3  4  5  6  6
 0  0  0  0  0  0  0

# The following matrix describes the coupling
# of fishing mortality PARAMETERS
# Rows represent fleets.
# Columns represent ages.
 0  0  0  0  0  0  0
 1  2  3  4  5  0  0

# 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
19
  # Then the actual years
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
2011
  # 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
 18   18   18   18   18   18   18
 19   19   19   19   19   19   19
# Define Fbar range
2 4
```

BASE FIT:

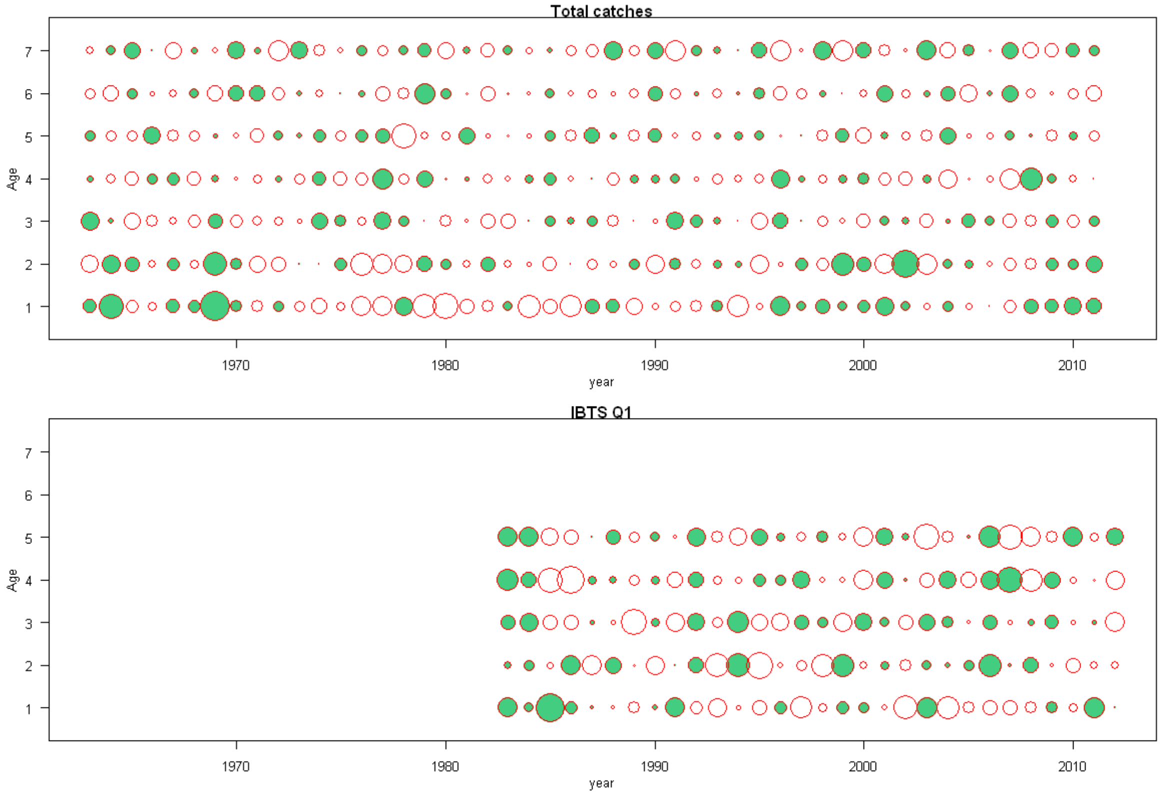


Figure 14.10. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. Normalized residuals for the SAM base run, for total catch and IBTSQ1. Empty circles indicate a positive residual and filled circles negative residual.

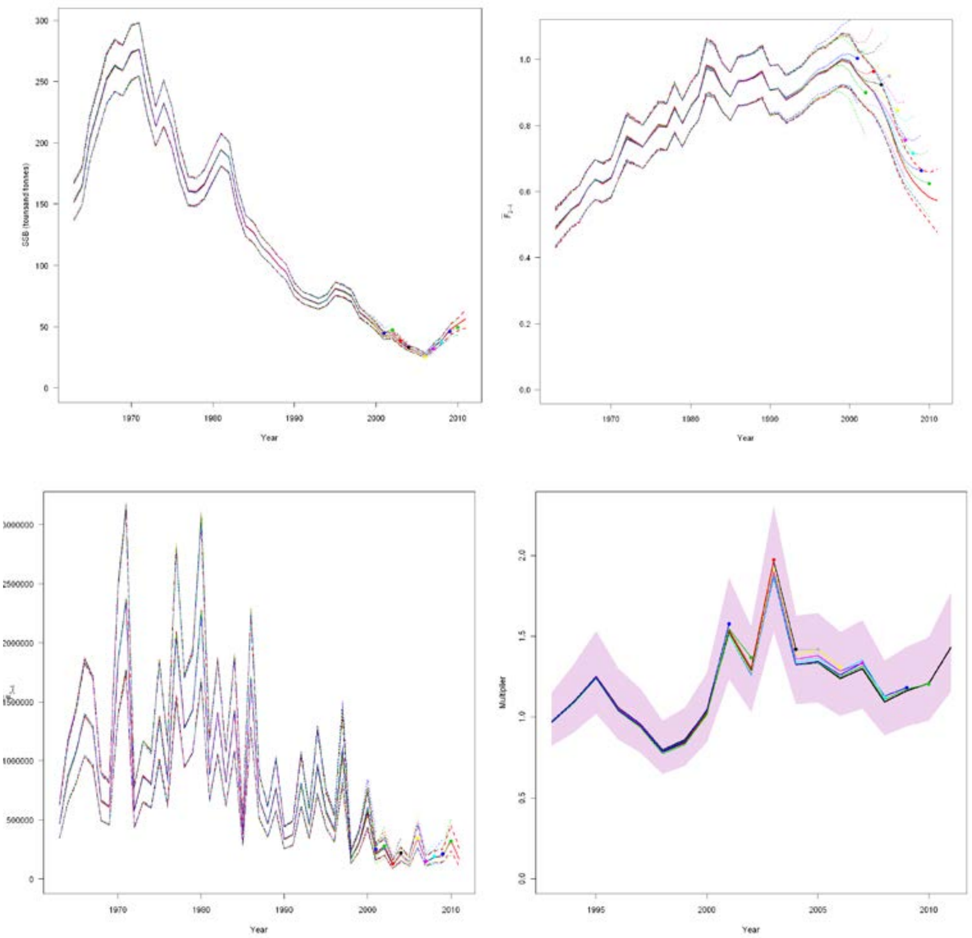


Figure 14.11. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. Retrospective estimates (10 years) from the SAM base run. Estimated yearly SSB (top-left), average fishing mortality (top-right), recruitment age 1 (bottom-left) and catch multiplier (bottom-right), together with corresponding point-wise 95% confidence intervals.

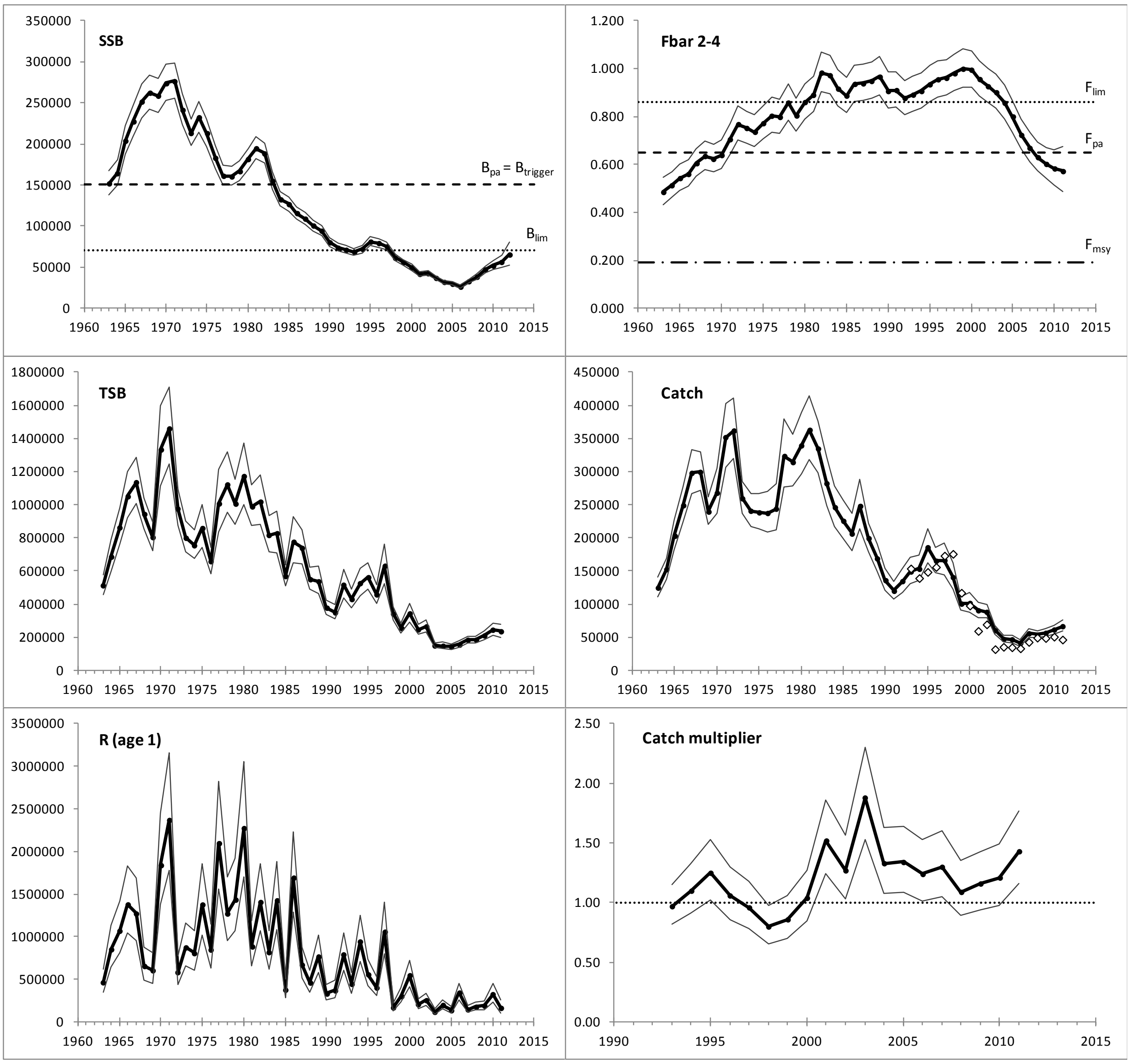
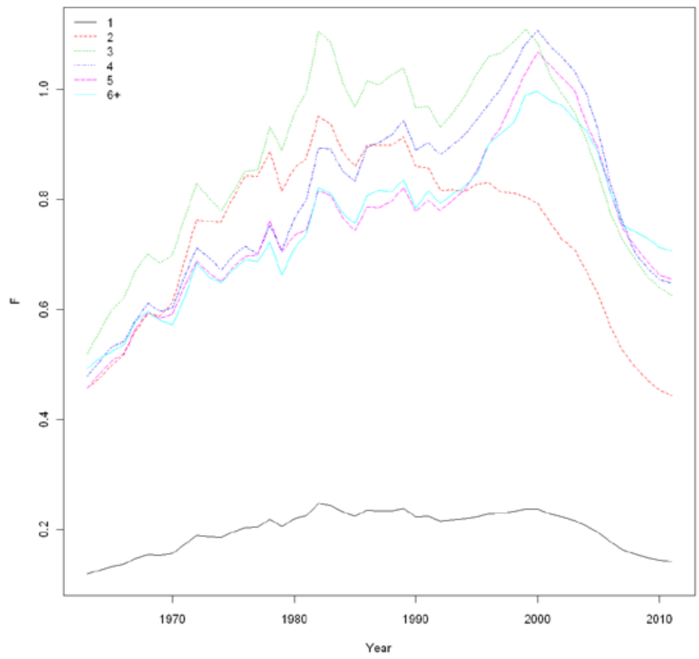


Figure 14.12. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. Clockwise from top left, point-wise estimates and 95% confidence intervals of spawning-stock biomass (SSB), total-stock biomass (TSB), recruitment (R(age 1)), the catch multiplier, catch and mean fishing mortality for ages 2-4 (F(2-4)), from the SAM base run. The heavy lines represent the point-wise estimate, and the light lines point-wise 95% confidence intervals. The open diamonds given in the catch plot represent model estimates of the total catch excluding unallocated mortality, while the solid lines represent the total catch including unallocated mortality from 1993 onwards. The horizontal broken lines in the SSB plot indicate Blim=70 000t and Bpa=150 000t, and those in the F(2-4) plot Fpa=0.65 and Flim=0.86. The horizontal broken line in the catch multiplier plot indicates a multiplier of 1. Catch, SSB and TSB are in tons, and R in thousands.



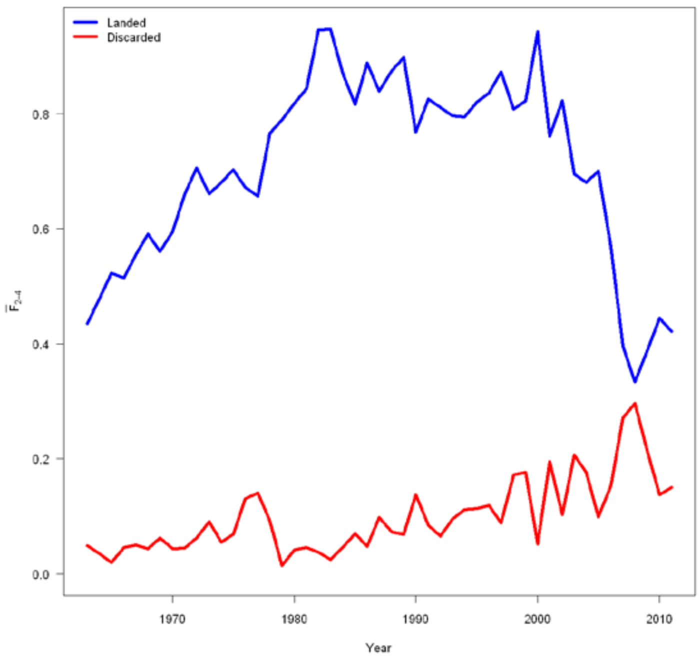


Figure 14.13. Cod in Subarea IV and Divisions IIIa (Skagerrak) and VIId. SAM model base run estimates of fishing mortality. The top panel shows mean fishing mortality for ages 2-4 (shown in Figure 14.12), but split into landings and discards components by using ratios calculated from the landings and discards numbers-at-age from the reported catch data, while the bottom panel shows fishing mortality for each age.

SOURCES: ICES 2012b (WGNSSK).

2 North Sea plaice

2.1 With reconstructed discards

DATA:

Natural mortality is assumed to be 0.1 for all age groups and constant over time. A fixed maturity ogive (Table 8.2.11) is used for the estimation of SSB in North Sea plaice.

Table 8.2.11. North Sea plaice. Natural mortality-at-age and maturity ate age vector used in assessments.

age	1	2	3	4	5	6	7	8	9	10
natural mortality	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
maturity	0	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0

To reconstruct the number of plaice discards at age before 2000, catch numbers-at-age are calculated from fishing mortality-at-age corrected for discard fractions, using a reconstructed population and selection and distribution ogives (ICES CM 2005/ACFM:07 Appendix 1). The discards time-series used in the assessment was derived from Dutch, Danish, German and UK discards observations for 2000–2009 (UK only to 2007), as is described in the stock annex. The Dutch discards data for 2010 were derived from a combination of the observer programme that has been running since 2000, and a new self-sampling programme. The estimates from both programmes were combined to come up with an overall estimate of discarding by the Dutch beam trawl fleet. For 2011, estimates were derived solely from the self-sampling data. There is an ongoing project within IMARES to validate these estimates by examining matched (same vessel and haul) trips where both observer estimates and self-sampling estimates are derived.

Landings at age are available for the North Sea (Table 8.2.2). The assessment of the stock also assumes that 50% of the quarter 1 (Q1) landings in the eastern channel (ICES area VIId) are actually migrants form the North Sea stock (Table 8.2.5). These two sources are summed to produce the total recorded landings of North Sea plaice. Discards numbers-at-age are available for the period prior to 2000 from reconstructions (Table 8.2.3a) and since then from estimates derived from observer or self-sampling programs (Table 8.2.3b). All these are summed together to produce the final catch-at-age matrix used in the current assessment (Table 8.2.6).

Table 8.2.2. North Sea Plaice. landed numbers-at-age.

Plaice in IV . landings.n
2012-04-29 12:42:33 units= thousands

year \ age	1	2	3	4	5	6	7	8	9	10
1957	0	4315	59818	44718	31771	8885	11029	9028	4973	10859
1958	0	7129	22205	62047	34112	19594	8178	8000	6110	13148
1959	0	16556	30427	25489	41099	22936	13873	6408	6596	16180
1960	0	5959	61876	51022	21321	27329	14186	9013	5087	15153
1961	0	2264	33392	67906	32699	12759	14680	9748	5996	14660
1962	0	2147	35876	66779	50060	20628	9060	9035	5257	12801
1963	0	4340	21471	76926	54364	31799	12848	6833	7047	16592
1964	0	14708	40486	64735	57408	37091	15819	6595	3980	16886
1965	0	9858	42202	53188	43674	30151	18361	8554	4213	17587
1966	0	4144	65009	51488	36667	27370	16500	10784	6467	14928
1967	0	5982	30304	112917	41383	22053	16175	8004	6728	11175
1968	0	9474	40698	38140	123619	17139	10341	10102	3925	13365
1969	3	15017	45187	36084	35585	102014	10410	6086	8192	16092
1970	76	17294	51174	56153	40686	35074	78886	6311	4185	14840
1971	19	29591	48282	33475	26059	22903	16913	29730	6414	16910
1972	2233	36528	62199	52906	23043	16998	14380	10903	18585	15651
1973	1268	31733	59099	73065	42255	13817	8885	9848	6084	23978
1974	2223	23120	55548	42125	41075	19666	8005	6321	5568	21980
1975	981	28124	61623	31262	25419	21188	11873	5923	4106	19695
1976	2820	33643	77649	96398	13779	9904	9120	6391	2947	12552
1977	3220	56969	43289	66013	83705	9142	5912	5022	4061	9191
1978	1143	60578	62343	54341	50102	35510	5940	3352	2419	7468
1979	1318	58031	118863	48962	47886	39932	24228	4161	2807	9288
1980	979	64904	133741	77523	24974	17982	13761	8458	1864	5377
1981	253	100927	122296	57604	35745	12414	9564	8092	4874	5903
1982	3334	47776	209007	69544	28655	16726	7589	5470	4482	8653
1983	1214	119695	115034	99076	29359	12906	8216	4193	3013	8287
1984	108	63252	274209	53549	37468	13661	6465	5544	2720	6565
1985	121	73552	144316	185203	32520	15544	6871	3650	2698	5798
1986	1674	67125	163717	93801	84479	24049	9299	4490	2733	6950
1987	0	85123	115951	111239	64758	34728	11452	4341	2154	5478
1988	0	15146	250675	74335	47380	25091	16774	5381	3162	6233
1989	1261	46757	105929	231414	52909	19247	10567	7561	2120	5580
1990	1550	32533	97766	110997	159814	26757	8129	4216	3451	3808
1991	1461	43266	83603	116155	72961	77557	14910	5233	3141	5591
1992	3410	43954	85120	72494	72703	33406	29547	6970	3200	6928
1993	3461	53949	98375	72286	51405	29001	13472	11272	3645	5883
1994	1394	45148	101617	80236	38542	20388	15323	6399	5368	5433
1995	7751	36575	81398	78370	36499	17953	9772	4366	2336	3753
1996	1104	42496	64382	46359	32130	14460	10605	4528	2624	4892
1997	892	42855	86948	43669	22541	13518	6362	3632	2179	4181
1998	196	30401	68920	56329	16713	6432	4986	2506	1761	3119
1999	549	8689	155971	39857	24112	6829	2783	2246	1521	3093
2000	2634	15819	39550	164330	14993	9343	2130	1030	940	2097
2001	4509	35886	52480	48238	89949	6836	4418	1127	637	2309
2002	1233	15596	58262	48361	36551	37877	4644	1788	742	1586
2003	694	42594	47802	48894	27126	15999	17069	1608	650	859
2004	543	10317	102332	35165	20527	11293	4787	4555	412	540
2005	2937	16685	26069	82278	17039	9533	5332	2614	2223	613
2006	355	18987	67465	25254	42525	6555	4967	2053	1235	1319
2007	1286	19205	37309	47053	14971	17142	2459	1856	543	1259
2008	380	10970	42865	37970	29476	5700	6752	912	673	896
2009	1492	10726	50436	33911	20969	16551	2987	3967	556	763
2010	2026	17947	39555	58341	21827	11739	9414	1763	2429	1243
2011	238	10354	42255	57233	48186	13549	6561	7055	1238	2816

Table 8.2.5. 50% of Q1 plaice landings in the eastern Channel (VIId). Assumed to be migrants from the North Sea stock (see text). Landing numbers-at-age.

Plaice in IV. 50% of Q1 VIId catches.

	age			units=	thousands					
year	1	2	3	4	5	6	7	8	9	10
1980	0	237	288	136	127.5	19	12	11.5	1	24
1981	0	219.5	1349	605	75.5	40.5	14	10.5	14.5	46.5
1982	0	124.5	1372	833	198	52.5	26	16.5	5	20.5
1983	0	272	635	1490.5	241.5	58	24.5	31.5	1	23.5
1984	0	167.5	1451.5	710	486.5	136	64	26.5	8.5	23
1985	0	513	1230.5	1231.5	107	156	44.5	25.5	35.5	11.5
1986	0	438	1396.5	924	379	143.5	68.5	18	5	8
1987	0	762.5	1490.5	875.5	326.5	110	119.5	39.5	27.5	18
1988	0	449.5	3735.5	1236	290	138	118.5	32.5	27.5	40
1989	0	326	1435	2384.5	694	150.5	78	46	21	45.5
1990	0	236	1736	1509.5	936	204.5	65.5	52.5	46	53.5
1991	0	525.5	1081.5	1141.5	633	429.5	77	31	29	28.5
1992	0	555.5	883.5	434.5	308.5	267	188.5	52	30	27.5
1993	0	682	758	317.5	141	119.5	90	74	26.5	35.5
1994	0	325.5	1383.5	785	220.5	107	84	69	71	72
1995	0	389	582.5	738.5	239.5	58.5	75	58	31	59.5
1996	0	434.5	716	390.5	373	125	48.5	45.5	42.5	80.5
1997	0	399.5	1458.5	843	274	189.5	124.5	49	28	76.5
1998	0	393.5	1687	868.5	136.5	37.5	43.5	22	15.5	48
1999	0	109	2338.5	1504	267	38.5	22.5	23	8	18
2000	0	191	1236	2603.5	692.5	121	30.5	9.5	14.5	28
2001	0	454.5	1147.5	606	563	82.5	18.5	5.5	3	15
2002	0	1680.5	926.5	414.5	323.5	219.5	55.5	17	5.5	18.5
2003	0	428	983.5	483	116	84	94.5	22.5	13.5	16.5
2004	0	473	1190.5	210.5	111.5	36	34.5	30.5	9	12
2005	0	132.5	702	655.5	122	51	28	24	14.5	12.5
2006	0	340.5	543.5	337.5	211.5	44.5	21	22.5	23	16
2007	0	131	522.5	475	243.5	186.5	51	14.5	5	22
2008	0	366	545.5	455	143.5	75.5	88.5	1.5	2	3
2009	0	373	690	163.5	116.5	53	32	9.5	3	11
2010	0	346.5	603	342	88.5	67.5	24	14	6	9.5
2011	5.5	472.5	699.5	262.5	199	30	6	11	2	8.5

Table 8.2.3a. North Sea Plaice. Discards numbers-at-age. Reconstructed data.

Plaice in IV . discards.n
2012-05-01 16:53:13 units= thousands

year	age 1	2	3	4	5	6	7	8	9	10
1957	32356	45596	9220	909	961	25	0	0	0	0
1958	66199	73552	23655	2572	2137	65	0	0	0	0
1959	116086	127771	46402	11407	4737	106	0	0	0	0
1960	73939	167893	44948	997	1067	519	0	0	0	0
1961	75578	144609	89014	538	1612	130	0	0	0	0
1962	51265	181321	87599	21716	799	186	0	0	0	0
1963	90913	136183	129778	9964	2112	188	0	0	0	0
1964	66035	153274	64156	33825	3011	323	0	0	0	0
1965	43708	426021	59262	3404	923	267	0	0	0	0
1966	38496	163125	349358	14399	1402	125	0	0	0	0
1967	20199	133545	87532	152496	623	260	0	0	0	0
1968	73971	72192	46339	26530	22436	58	0	0	0	0
1969	85192	67378	16747	19334	773	2024	0	0	0	0
1970	123569	152480	27747	1287	5061	161	0	0	0	0
1971	69337	96968	42354	2675	426	81	0	0	0	0
1972	70002	55470	33899	5714	567	73	0	0	0	0
1973	132352	49815	4008	673	1289	67	0	0	0	0
1974	211139	308411	3652	285	611	109	0	0	0	0
1975	244969	280130	190536	4807	253	123	0	0	0	0
1976	183879	140921	71054	18013	174	41	0	0	0	0
1977	256628	103696	79317	33552	9317	129	0	0	0	0
1978	226872	154113	27257	10775	1244	570	0	0	0	0
1979	293166	215084	57578	18382	589	310	0	0	0	0
1980	226371	122561	932	687	193	86	0	0	0	0
1981	134142	193241	1850	373	431	55	0	0	0	0
1982	411307	204572	4624	1109	216	98	0	0	0	0
1983	261400	436331	30716	2235	804	72	0	0	0	0
1984	310675	313490	52651	24529	1492	69	0	0	0	0
1985	405385	229208	35566	2221	200	78	0	0	0	0
1986	1117345	490965	48510	26470	1451	146	0	0	0	0
1987	361519	1374202	180969	1427	1348	248	0	0	0	0
1988	348597	608109	459385	61167	882	177	0	0	0	0
1989	213291	485845	193176	85758	7224	115	0	0	0	0
1990	145314	279298	168674	28102	5011	177	0	0	0	0
1991	183126	301575	141567	40739	5528	939	0	0	0	0
1992	138755	219619	94581	34348	4307	880	0	0	0	0
1993	96371	154083	48088	11966	1635	216	0	0	0	0
1994	62122	95703	35703	1038	822	144	0	0	0	0
1995	118863	82676	15753	860	663	120	0	0	0	0
1996	111250	331065	27606	3930	451	116	0	0	0	0
1997	128653	510918	193828	588	271	108	0	0	0	0
1998	104538	646250	191631	53354	297	33	0	0	0	0
1999	127321	208401	231769	54869	278	58	0	0	0	0

Table 8.2.3 b. North Sea Plaice. Discards numbers-at-age. Estimated from observer or self-sampling programs.

Plaice in IV . discards.n
2012-05-01 16:53:13 units= thousands

year	age 1	2	3	4	5	6	7	8	9	10
2000	103468	171213	51092	64971	1230	241	263	167	0	0
2001	30346	352452	186900	74744	54276	152	45	1	0	0
2002	309822	177574	76246	12113	1571	661	107	1	0	0
2003	67718	517641	52582	19130	3843	386	5751	1	0	0
2004	232936	179561	115746	6614	1047	232	37	1	0	0
2005	93585	324744	43297	19440	4098	5968	147	1	0	0
2006	220501	223814	107163	9129	2324	249	732	194	0	0
2007	77239	203775	66539	8999	736	6972	170	1644	0	0
2008	135339	251389	34997	4568	1644	328	8845	885	0	0
2009	148639	191957	66063	9165	1973	1106	136	3220	0	0
2010	165914	177912	58279	22582	2672	1726	2073	281	0	0
2011	117296	150354	60525	36447	12789	2920	143	2273	0	0

Table 8.2.6. North Sea plaice. Catch numbers-at-age including 50% of Q1 landings in the eastern channel (VIId). Final catch estimates used in the assessment of the stock.

Plaice in IV (+ 50% Q1 VIId) . catch.n
2012-05-01 16:53:27 units= thousands

year \ age	1	2	3	4	5	6	7	8	9	10
1957	32356	49911	69038	45627	32732	8910	11029	9028	4973	10859
1958	66199	80681	45860	64619	36249	19659	8178	8000	6110	13148
1959	116086	144327	76829	36896	45836	23042	13873	6408	6596	16180
1960	73939	173852	106824	52019	22388	27848	14186	9013	5087	15153
1961	75578	146873	122406	68444	34311	12889	14680	9748	5996	14660
1962	51265	183468	123475	88495	50859	20814	9060	9035	5257	12801
1963	90913	140523	151249	86890	56476	31987	12848	6833	7047	16592
1964	66035	167982	104642	98560	60419	37414	15819	6595	3980	16886
1965	43708	435879	101464	56592	44597	30418	18361	8554	4213	17587
1966	38496	167269	414367	65887	38069	27495	16500	10784	6467	14928
1967	20199	139527	117836	265413	42006	22313	16175	8004	6728	11175
1968	73971	81666	87037	64670	146055	17197	10341	10102	3925	13365
1969	85195	82395	61934	55418	36358	104038	10410	6086	8192	16092
1970	123645	169774	78921	57440	45747	35235	78886	6311	4185	14840
1971	69356	126559	90636	36150	26485	22984	16913	29730	6414	16910
1972	72235	91998	96098	58620	23610	17071	14380	10903	18585	15651
1973	133620	81548	63107	73738	43544	13884	8885	9848	6084	23978
1974	213362	331531	59200	42410	41686	19775	8005	6321	5568	21980
1975	245950	308254	252159	36069	25672	21311	11873	5923	4106	19695
1976	186699	174564	148703	114411	13953	9945	9120	6391	2947	12552
1977	259848	160665	122606	99565	93022	9271	5912	5022	4061	9191
1978	228015	214691	89600	65116	51346	36080	5940	3352	2419	7468
1979	294484	273115	176441	67344	48475	40242	24228	4161	2807	9288
1980	227350	187702	134961	78346	25295	18087	13773	8470	1865	5401
1981	134395	294388	125495	58582	36252	12510	9578	8103	4889	5950
1982	414641	252473	215003	71486	29069	16877	7615	5487	4487	8674
1983	262614	556298	146385	102802	30405	13036	8241	4225	3014	8311
1984	310783	376910	328312	78788	39447	13866	6529	5571	2729	6588
1985	405506	303273	181113	188656	32827	15778	6916	3676	2734	5810
1986	1119019	558528	213624	121195	86309	24339	9368	4508	2738	6958
1987	361519	1460088	298411	113542	66433	35086	11572	4381	2182	5496
1988	348597	623705	713796	136738	48552	25406	16893	5414	3190	6273
1989	214552	532928	300540	319557	60827	19513	10645	7607	2141	5626
1990	146864	312067	268176	140609	165761	27139	8195	4269	3497	3862
1991	184587	345367	226252	158036	79122	78926	14987	5264	3170	5620
1992	142165	264129	180585	107277	77319	34553	29736	7022	3230	6956
1993	99832	208714	147221	84570	53181	29337	13562	11346	3672	5919
1994	63516	141177	138704	82059	39585	20639	15407	6468	5439	5505
1995	126614	119640	97734	79969	37402	18132	9847	4424	2367	3813
1996	112354	373996	92704	50680	32954	14701	10654	4574	2667	4973
1997	129545	554173	282235	45100	23086	13816	6487	3681	2207	4258
1998	104734	677045	262238	110552	17147	6503	5030	2528	1777	3167
1999	127870	217199	390079	96230	24657	6926	2806	2269	1529	3111
2000	106102	187223	91878	231905	16916	9705	2424	1207	955	2125
2001	34855	388793	240528	123588	144788	7071	4482	1134	640	2324
2002	311055	194851	135435	60889	38446	38758	4807	1806	748	1605
2003	68412	560663	101368	68507	31085	16469	22915	1632	664	876
2004	233479	190351	219269	41990	21686	11561	4859	4587	421	552
2005	96522	341562	70068	102374	21259	15552	5507	2639	2238	626
2006	220856	243142	175172	34721	45061	6849	5720	2270	1258	1335
2007	78525	223111	104371	56527	15951	24301	2680	3515	548	1281
2008	135719	262725	78408	42993	31264	6104	15686	1799	675	899
2009	150131	203056	117189	43240	23059	17710	3155	7197	559	774
2010	167940	196206	98437	81265	24588	13533	11511	2058	2435	1253
2011	117540	161181	103480	93943	61174	16499	6710	9339	1240	2825

Table 8.2.7. North Sea plaice. Stock weight-at-age.

Plaice in IV . stock.wt
2012-05-01 16:53:41 units= kg

year \ age	1	2	3	4	5	6	7	8	9	10
1957	0.038	0.102	0.157	0.242	0.325	0.485	0.719	0.682	0.844	1.143
1958	0.041	0.093	0.180	0.272	0.303	0.442	0.577	0.778	0.793	1.112
1959	0.045	0.106	0.173	0.264	0.329	0.470	0.650	0.686	0.908	1.042
1960	0.038	0.111	0.181	0.272	0.364	0.469	0.633	0.726	0.845	1.090
1961	0.037	0.098	0.185	0.306	0.337	0.483	0.579	0.691	0.779	1.067
1962	0.036	0.096	0.173	0.301	0.424	0.573	0.684	0.806	0.873	1.303
1963	0.041	0.103	0.176	0.273	0.378	0.540	0.663	0.788	0.882	1.252
1964	0.024	0.113	0.184	0.296	0.373	0.477	0.645	0.673	0.845	1.232
1965	0.031	0.068	0.198	0.294	0.333	0.430	0.516	0.601	0.722	0.909
1966	0.031	0.099	0.127	0.305	0.403	0.455	0.503	0.565	0.581	0.984
1967	0.029	0.104	0.179	0.205	0.442	0.528	0.585	0.650	0.703	0.985
1968	0.055	0.094	0.175	0.287	0.344	0.532	0.592	0.362	0.667	0.887
1969	0.047	0.158	0.188	0.266	0.344	0.390	0.565	0.621	0.679	0.857
1970	0.043	0.113	0.236	0.274	0.369	0.410	0.468	0.636	0.732	0.896
1971	0.051	0.109	0.251	0.344	0.413	0.489	0.512	0.583	0.696	0.877
1972	0.056	0.158	0.218	0.407	0.473	0.534	0.579	0.606	0.655	0.929
1973	0.037	0.134	0.237	0.308	0.468	0.521	0.566	0.583	0.617	0.804
1974	0.049	0.105	0.217	0.416	0.437	0.524	0.570	0.629	0.652	0.852
1975	0.063	0.141	0.187	0.388	0.483	0.544	0.610	0.668	0.704	0.943
1976	0.082	0.169	0.226	0.308	0.484	0.550	0.593	0.658	0.694	0.931
1977	0.064	0.184	0.265	0.311	0.405	0.551	0.627	0.690	0.667	0.938
1978	0.064	0.151	0.319	0.373	0.411	0.467	0.547	0.630	0.704	0.943
1979	0.062	0.179	0.258	0.365	0.414	0.459	0.543	0.667	0.764	1.004
1980	0.049	0.163	0.289	0.428	0.444	0.524	0.582	0.651	0.778	1.058
1981	0.041	0.140	0.239	0.421	0.473	0.536	0.570	0.624	0.707	1.031
1982	0.048	0.128	0.250	0.351	0.490	0.589	0.631	0.679	0.726	0.981
1983	0.045	0.128	0.242	0.381	0.494	0.559	0.624	0.712	0.754	0.917
1984	0.048	0.129	0.216	0.413	0.464	0.571	0.649	0.692	0.787	1.028
1985	0.048	0.146	0.232	0.320	0.452	0.536	0.635	0.656	0.764	1.011
1986	0.043	0.126	0.245	0.311	0.440	0.533	0.692	0.779	0.888	1.092
1987	0.036	0.105	0.200	0.383	0.401	0.503	0.573	0.711	0.747	0.984
1988	0.036	0.097	0.172	0.264	0.426	0.467	0.547	0.644	0.706	0.973
1989	0.039	0.101	0.192	0.247	0.362	0.484	0.553	0.616	0.759	0.883
1990	0.043	0.108	0.176	0.261	0.343	0.422	0.555	0.647	0.701	0.969
1991	0.048	0.131	0.184	0.260	0.342	0.401	0.463	0.633	0.652	0.826
1992	0.043	0.121	0.199	0.270	0.318	0.403	0.500	0.573	0.683	0.833
1993	0.050	0.119	0.208	0.315	0.330	0.391	0.490	0.587	0.633	0.811
1994	0.053	0.141	0.214	0.290	0.360	0.404	0.462	0.533	0.653	0.797
1995	0.050	0.142	0.254	0.336	0.399	0.448	0.509	0.584	0.678	0.804
1996	0.044	0.117	0.229	0.368	0.390	0.462	0.488	0.554	0.660	0.815
1997	0.035	0.115	0.233	0.359	0.439	0.492	0.521	0.543	0.627	0.850
1998	0.038	0.081	0.207	0.333	0.474	0.577	0.581	0.648	0.656	0.809
1999	0.044	0.091	0.150	0.319	0.437	0.524	0.586	0.644	0.664	0.779
2000	0.051	0.106	0.165	0.219	0.408	0.467	0.649	0.695	0.656	0.786
2001	0.061	0.122	0.202	0.233	0.331	0.452	0.560	0.641	0.798	0.830
2002	0.048	0.118	0.213	0.301	0.319	0.403	0.446	0.612	0.685	0.872
2003	0.057	0.111	0.227	0.269	0.344	0.391	0.464	0.600	0.714	0.790
2004	0.047	0.116	0.201	0.306	0.384	0.430	0.489	0.495	0.780	0.876
2005	0.053	0.106	0.216	0.237	0.378	0.422	0.434	0.527	0.621	1.006
2006	0.052	0.130	0.190	0.316	0.354	0.424	0.439	0.506	0.583	0.730
2007	0.047	0.093	0.235	0.238	0.337	0.394	0.458	0.412	0.526	0.548
2008	0.048	0.114	0.196	0.274	0.355	0.429	0.484	0.627	0.598	0.730
2009	0.052	0.114	0.194	0.344	0.373	0.412	0.472	0.540	0.565	0.632
2010	0.053	0.116	0.179	0.340	0.361	0.401	0.448	0.572	0.568	0.644
2011	0.039	0.100	0.187	0.209	0.355	0.483	0.438	0.422	0.530	0.552

Table 8.2.10. North Sea plaice. Catch weight-at-age.

Plaice in IV . catch.wt
2012-05-01 16:54:23 units= kg

year \ age	1	2	3	4	5	6	7	8	9	10
1957	0.044	0.111	0.213	0.284	0.387	0.506	0.592	0.654	0.440	1.108
1958	0.047	0.106	0.195	0.272	0.349	0.481	0.546	0.654	0.707	1.055
1959	0.051	0.120	0.193	0.264	0.352	0.482	0.605	0.637	0.766	1.021
1960	0.045	0.115	0.205	0.289	0.380	0.483	0.605	0.688	0.729	1.101
1961	0.044	0.101	0.181	0.306	0.408	0.514	0.613	0.681	0.825	1.088
1962	0.042	0.099	0.180	0.266	0.384	0.520	0.551	0.669	0.751	1.090
1963	0.048	0.110	0.175	0.309	0.399	0.541	0.636	0.680	0.729	1.048
1964	0.032	0.126	0.205	0.272	0.382	0.488	0.633	0.705	0.743	1.012
1965	0.038	0.076	0.215	0.315	0.384	0.471	0.542	0.667	0.730	0.892
1966	0.038	0.104	0.149	0.319	0.435	0.492	0.569	0.635	0.703	0.950
1967	0.036	0.111	0.191	0.237	0.430	0.554	0.609	0.675	0.753	0.998
1968	0.060	0.117	0.226	0.279	0.348	0.531	0.607	0.613	0.706	0.937
1969	0.052	0.176	0.283	0.294	0.376	0.432	0.606	0.693	0.696	0.945
1970	0.049	0.131	0.264	0.343	0.385	0.430	0.486	0.655	0.725	0.869
1971	0.057	0.161	0.281	0.400	0.459	0.529	0.560	0.627	0.722	0.920
1972	0.067	0.209	0.295	0.418	0.500	0.555	0.625	0.664	0.693	0.965
1973	0.045	0.209	0.350	0.423	0.502	0.565	0.636	0.659	0.711	0.884
1974	0.057	0.121	0.355	0.419	0.490	0.573	0.631	0.719	0.733	0.960
1975	0.069	0.153	0.208	0.414	0.523	0.621	0.676	0.747	0.832	1.082
1976	0.088	0.182	0.265	0.355	0.522	0.607	0.657	0.723	0.760	1.005
1977	0.071	0.218	0.245	0.318	0.397	0.552	0.648	0.722	0.716	0.980
1978	0.070	0.188	0.307	0.353	0.417	0.469	0.587	0.662	0.748	0.916
1979	0.067	0.190	0.295	0.337	0.426	0.471	0.549	0.674	0.795	0.959
1980	0.056	0.198	0.348	0.405	0.478	0.550	0.596	0.672	0.783	1.027
1981	0.048	0.184	0.332	0.422	0.510	0.565	0.614	0.653	0.737	1.023
1982	0.056	0.152	0.310	0.423	0.515	0.609	0.667	0.716	0.742	0.988
1983	0.052	0.152	0.273	0.376	0.503	0.598	0.672	0.765	0.809	0.976
1984	0.053	0.149	0.261	0.320	0.472	0.600	0.672	0.713	0.823	1.017
1985	0.054	0.168	0.263	0.328	0.451	0.564	0.664	0.714	0.787	1.000
1986	0.049	0.141	0.273	0.311	0.416	0.481	0.667	0.742	0.843	1.001
1987	0.043	0.113	0.217	0.345	0.394	0.496	0.576	0.720	0.820	0.978
1988	0.043	0.102	0.196	0.274	0.442	0.502	0.598	0.688	0.800	0.998
1989	0.047	0.117	0.213	0.288	0.363	0.521	0.593	0.659	0.779	0.926
1990	0.053	0.129	0.208	0.287	0.356	0.439	0.588	0.681	0.749	0.986
1991	0.056	0.148	0.207	0.267	0.341	0.436	0.509	0.647	0.720	0.887
1992	0.055	0.145	0.223	0.273	0.328	0.413	0.522	0.595	0.703	0.875
1993	0.063	0.159	0.246	0.302	0.344	0.412	0.507	0.617	0.705	0.837
1994	0.064	0.177	0.252	0.328	0.383	0.436	0.489	0.595	0.713	0.881
1995	0.071	0.183	0.281	0.335	0.397	0.450	0.525	0.607	0.730	0.902
1996	0.054	0.140	0.266	0.339	0.411	0.477	0.492	0.581	0.710	0.845
1997	0.045	0.129	0.219	0.358	0.450	0.517	0.597	0.610	0.676	0.913
1998	0.047	0.094	0.206	0.296	0.484	0.593	0.622	0.683	0.688	0.896
1999	0.054	0.103	0.197	0.262	0.444	0.533	0.619	0.670	0.739	0.797
2000	0.063	0.123	0.206	0.268	0.405	0.472	0.612	0.592	0.727	0.858
2001	0.090	0.135	0.194	0.229	0.300	0.472	0.580	0.701	0.787	0.793
2002	0.057	0.131	0.221	0.287	0.335	0.433	0.490	0.678	0.746	0.882
2003	0.066	0.123	0.227	0.282	0.343	0.401	0.413	0.640	0.750	0.838
2004	0.054	0.124	0.220	0.304	0.385	0.429	0.503	0.551	0.789	0.861
2005	0.067	0.116	0.212	0.299	0.353	0.342	0.457	0.544	0.603	0.889
2006	0.060	0.139	0.212	0.301	0.388	0.401	0.441	0.466	0.533	0.754
2007	0.058	0.112	0.224	0.319	0.370	0.380	0.520	0.350	0.591	0.617
2008	0.057	0.122	0.243	0.326	0.392	0.441	0.359	0.463	0.640	0.637
2009	0.061	0.125	0.235	0.338	0.415	0.483	0.538	0.448	0.695	0.824
2010	0.062	0.131	0.219	0.308	0.393	0.435	0.455	0.566	0.679	0.640
2011	0.047	0.111	0.204	0.264	0.351	0.433	0.565	0.424	0.529	0.763

Table 8.2.12. North Sea plaice. Survey tuning indices.

North Sea plaice. Survey tuning indices
2012-05-01 16:46:56[1] units= NA

BTS-Isis (ages 1-8 used in assessment)

	Effort	1	2	3	4	5	6	7	8	9
1985	1	137	173.9	36.06	11.00	1.273	0.973	0.336	0.155	0.091
1986	1	667	131.7	50.17	9.21	3.780	0.400	0.418	0.147	0.070
1987	1	226	764.2	33.84	4.88	1.842	0.607	0.252	0.134	0.078
1988	1	680	147.0	182.31	9.99	2.810	0.814	0.458	0.036	0.112
1989	1	468	319.3	38.66	47.30	5.850	0.833	0.311	0.661	0.132
1990	1	185	146.1	79.34	26.35	5.469	0.758	0.189	0.383	0.239
1991	1	291	159.4	33.95	13.57	4.313	5.659	0.239	0.204	0.092
1992	1	361	174.5	29.25	5.96	3.748	2.871	1.186	0.346	0.050
1993	1	189	283.4	62.78	8.27	1.128	1.130	0.584	0.464	0.155
1994	1	193	77.1	34.46	10.59	2.667	0.600	0.800	0.895	0.373
1995	1	266	40.6	13.22	7.53	1.110	0.806	0.330	1.051	0.202
1996	1	310	206.9	21.47	4.47	3.134	0.838	0.044	0.161	0.122
1997	1	1047	59.2	17.18	2.67	0.257	0.358	0.157	0.111	0.000
1998	1	348	402.7	44.96	8.29	1.224	0.339	0.149	0.213	0.072
1999	1	293	121.6	171.25	3.39	1.956	0.127	0.130	0.027	0.030
2000	1	267	69.3	29.35	22.36	0.570	0.162	0.502	0.027	0.012
2001	1	207	72.2	17.84	9.17	8.716	0.270	0.131	0.038	0.040
2002	1	519	44.5	14.90	4.99	2.539	1.321	0.085	0.128	0.000
2003	1	133	159.1	10.06	5.55	1.426	1.133	0.638	0.111	0.096
2004	1	234	39.6	61.91	6.15	2.464	1.492	0.952	2.842	0.000
2005	1	163	66.2	6.76	12.79	1.084	1.164	0.290	0.152	0.492
2006	1	129	36.4	18.11	2.98	5.890	0.867	0.757	0.040	0.269
2007	1	312	67.2	19.71	14.42	2.942	6.085	0.684	0.831	0.156
2008	1	222	120.7	30.11	9.07	7.205	0.618	1.715	0.292	0.229
2009	1	409	105.2	45.98	13.01	4.029	3.474	0.574	2.128	0.278
2010	1	261	84.3	34.24	20.18	4.662	2.162	3.464	0.207	2.547
2011	1	486	148.2	55.30	20.07	12.904	3.945	2.243	2.263	0.232

BTS-Tridens (all ages used in assessment)

	Effort	1	2	3	4	5	6	7	8	9
1996	**1**	**1.643**	**6.02**	**4.45**	**2.90**	**2.04**	**1.57**	**0.721**	**0.415**	**0.190**
1997	**1**	**0.221**	**7.12**	**9.13**	**3.25**	**2.10**	**1.52**	**0.401**	**0.819**	**0.354**
1998	**1**	**0.228**	**32.25**	**9.57**	**4.87**	**2.20**	**1.27**	**0.929**	**0.762**	**0.304**
1999	**1**	**2.692**	**7.71**	**35.23**	**5.56**	**2.50**	**1.93**	**0.633**	**0.761**	**0.309**
2000	**1**	**4.795**	**13.45**	**12.91**	**16.96**	**2.88**	**1.72**	**0.933**	**0.805**	**0.218**
2001	**1**	**2.154**	**8.61**	**9.90**	**6.68**	**7.36**	**1.05**	**0.592**	**0.418**	**0.505**
2002	**1**	**18.553**	**12.91**	**9.54**	**6.41**	**4.18**	**4.42**	**0.743**	**0.741**	**0.394**
2003	**1**	**3.975**	**41.69**	**13.38**	**9.06**	**5.08**	**2.81**	**3.920**	**0.703**	**0.740**
2004	**1**	**5.985**	**15.78**	**31.49**	**9.43**	**4.32**	**2.44**	**1.242**	**2.500**	**0.409**
2005	**1**	**6.876**	**23.37**	**12.23**	**17.67**	**2.82**	**6.87**	**1.565**	**0.567**	**3.574**
2006	**1**	**6.725**	**32.19**	**25.73**	**11.37**	**10.92**	**1.99**	**3.897**	**0.864**	**0.723**
2007	**1**	**26.571**	**23.73**	**19.55**	**23.18**	**4.90**	**10.15**	**1.974**	**3.786**	**0.323**
2008	**1**	**17.467**	**50.46**	**25.59**	**18.39**	**18.97**	**6.24**	**12.747**	**2.657**	**6.749**
2009	**1**	**12.110**	**41.69**	**43.33**	**19.13**	**12.05**	**11.77**	**3.081**	**10.119**	**1.567**
2010	**1**	**26.180**	**35.72**	**34.56**	**30.09**	**13.41**	**5.70**	**12.234**	**2.744**	**6.362**
2011	**1**	**41.881**	**71.48**	**41.59**	**28.46**	**31.67**	**14.28**	**5.501**	**11.881**	**1.172**

Table 8.2.12. North Sea plaice. Survey tuning indices. (Cont'd).

SNS (ages 1-3 from 1982 onwards used in the assessment)

	Effort	1	2	3	4	5
1970	1	9311	9732	3273	770	170
1971	1	13538	28164	1415	101	50
1972	1	13207	10780	4478	89	84
1973	1	65643	5133	1578	461	15
1974	1	15366	16509	1129	160	82
1975	1	11628	8168	9556	65	15
1976	1	8537	2403	868	236	0
1977	1	18537	3424	1737	590	213
1978	1	14012	12678	345	135	45
1979	1	21495	9829	1575	161	17
1980	1	59174	12882	491	180	24
1981	1	24756	18785	834	38	32
1982	1	69993	8642	1261	88	8
1983	1	33974	13909	249	71	6
1984	1	44965	10413	2467	42	0
1985	1	28101	13848	1598	328	17
1986	1	93552	7580	1152	145	30
1987	1	33402	32991	1227	200	30
1988	1	36609	14421	13153	1350	88
1989	1	34276	17810	4373	7126	289
1990	1	25037	7496	3160	816	422
1991	1	57221	11247	1518	1077	128
1992	1	46798	13842	2268	613	176
1993	1	22098	9686	1006	98	60
1994	1	19188	4977	856	76	23
1995	1	24767	2796	381	97	38
1996	1	23015	10268	1185	45	47
1997	1	95901	4473	497	32	0
1998	1	33666	30242	5014	50	10
1999	1	32951	10272	13783	1058	17
2000	1	22855	2493	891	983	17
2001	1	11511	2898	370	176	691
2002	1	30809	1103	265	65	69
2003	1	NA	NA	NA	NA	NA
2004	1	18202	1350	1081	51	27
2005	1	10118	1819	142	366	8
2006	1	12164	1571	385	52	54
2007	1	14175	2134	140	52	0
2008	1	14706	2700	464	179	34
2009	1	14860	2019	492	38	20
2010	1	11947	1812	529	56	10
2011	1	18349	1143	308	75	60

MODEL:

The settings for the final assessment that is used as a basis for advice is given below:

Year	2011
Catch-at-age	Landings + (reconstructed) discards based on NL, DK + UK + GE fleets
Fleets (years; ages)	BTS-Isis 1985–2011; 1–8 BTS-Tridens 1996–2011; 1–9 SNS 1982–2011 (excl. 2003); 1–3
Plus group	10
First tuning year	1982
Last data year	2011
Time-series weights	No taper
Catchability dependent on stock size for age <	1
Catchability independent of ages for ages >=	6
Survivor estimates shrunk towards the mean F	5 years / 5 years
s.e. of the mean for shrinkage	2.0
Minimum standard error for population estimates	0.3
Prior weighting	Not applied

FLXSA.control(tol = 1e-09, maxit = 50, min.nse = 0.3, fse = 2.0, rage = -1, qage = 6, shk.n = TRUE, shk.f = TRUE, shk.yrs = 5, shk.ages= 5, window = 100, tsrange = 99, tspower = 0)

BASE FIT:

The XSA model converged after 41 iterations. The log-catchability residuals for the tuning fleets in the final run are dominated in the younger ages by negative values for the SNS tuning index in the most recent period, and positive values for the BTS-Tridens (Figure 8.3.4). This is potentially due to a shift in the location of juvenile plaice offshore, away from the SNS survey area towards the BTS-Tridens survey area. However, the importance of the SNS survey in estimating recruits in previous years results in this survey still carrying a much higher weighting for age 1 estimates than the BTS-Tridens. The high BTS-Tridens tuning index for 1 year old individuals leads to a large residual in the XSA assessment for this age in the survey in recent years.

Retrospective analyses of the XSA presented in Figure 8.3.5 indicate that historic estimates for SSB in 2006 and 2007 were much lower compared to the current estimate but since then the retrospective differences have been insignificant. This is reflected correspondingly in the estimates of fishing mortality. This is likely the result of the increase of younger individuals in the more northern region (surveyed by the Tridens but not by the higher weighted SNS), that have aged and therefore only recently have a high impact on the estimation of the stock size. The retrospective pattern of recruits shows a tendency to underestimate recruitment. This too can be explained by the change in distribution of juveniles and the relative weightings given to the different indices for the younger ages (SNS getting a higher weighting than is perhaps appropriate due to historically better representing the level of recruitment).

Figures 8.4.1 and 8.4.2 present the trends in landings, mean F(2–6), F(human consumption, 2–6), F(discards, 2–3), SSB, TSB and recruitment since 1957.

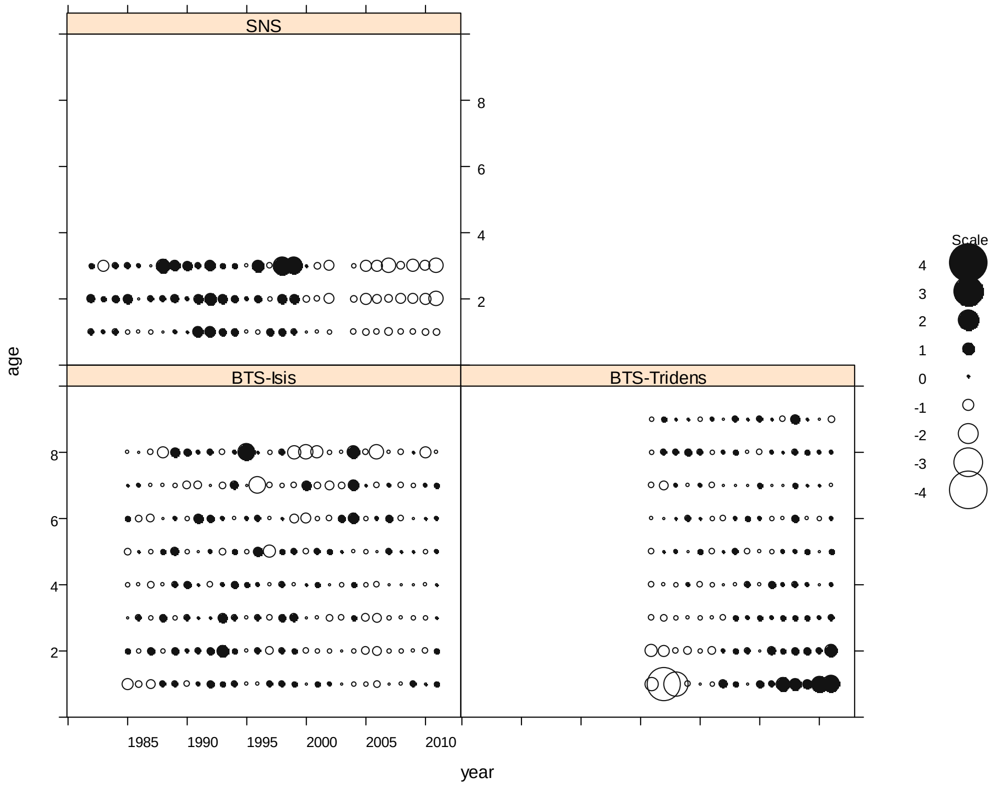


Figure 8.3.4. North Sea plaice. Log-catchability residuals for the final XSA run from the three tuning series.

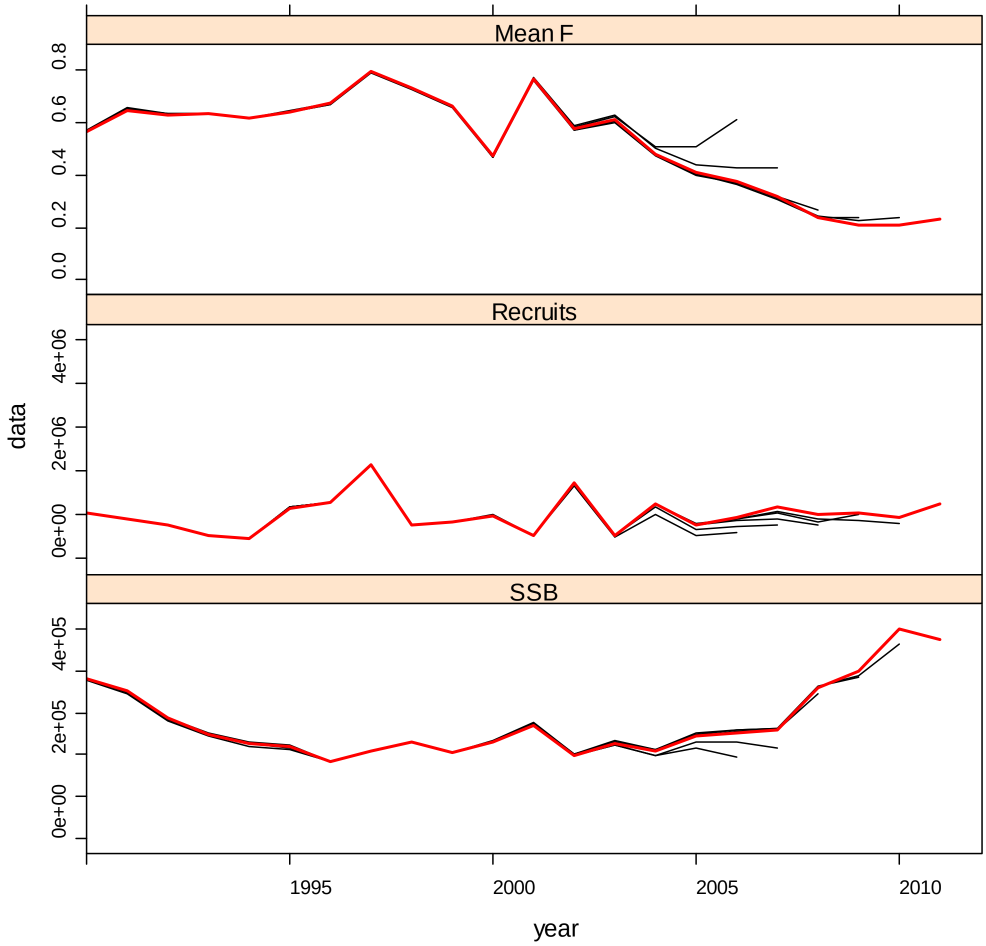


Figure 8.3.5. North Sea plaice. Retrospective pattern of the final XSA run with respect to SSB, recruitment and F.

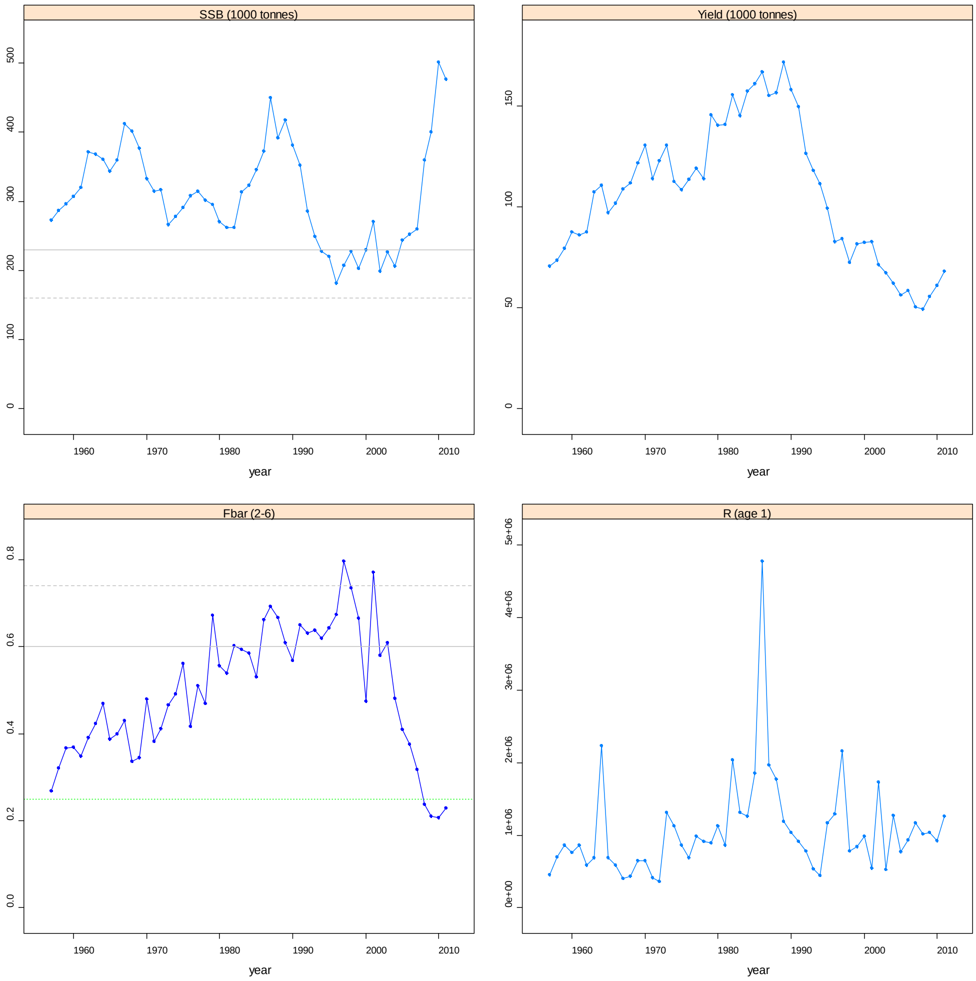


Figure 8.4.1. North Sea plaice. Stock summary figure, time-series on SSB (drawn line indicates B_{pa} , dashed line indicates B_{lim}), Yield, Fishing mortality (drawn grey line indicates F_{pa} , dashed grey line indicates F_{lim}, green dashed line indicates MP target F), and recruitment-at-age 1.

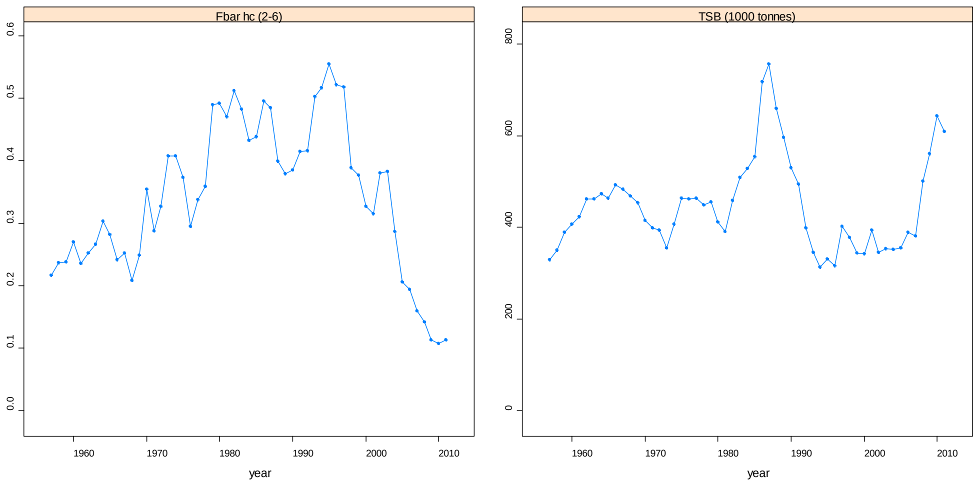


Figure 8.4.2. North Sea plaice. Stock summary figure. Time-series on human consumption (left) fishing mortality and total-stock biomass (right).

SOURCES: ICES 2012b (WGNSSK).

2.2 Without reconstructed discards

Candidate stock assessment models that are able to internally estimate historic discarding rates could be attempted on this stock. Essentially the current data on discards for the period prior to 2000 are model results rather than observations. The discard estimates since then have been raised from observations and samples taken for this purpose.

By omitting Table 8.2.3a, two removals tables can be made. In this case, for the period 2000-2011 total catch estimates are available, where the relationship between landings, discards and F can be seen. These can potentially be used to inform on expected discarding rates prior to this period, i.e. for the period 1957-1999 when only landings information is be available.

3 North Sea herring

DATA:

TABLE 2.6.3.1. North Sea Herring. CATCH IN NUMBER.

Units : thousands

year

age	1947	1948	1949	1950	1951	1952	1953	1954	1955
0	0	0	0	0	0	0	150000	219000	164000
1	0	3000	0	0	462000	722000	1023000	1451000	2072000
2	494000	247000	478000	535000	660000	1346000	1322000	1493000	1931000
3	415000	672000	644000	1039000	959000	576000	1003000	1111000	1032000
4	638000	328000	396000	617000	1255000	610000	474000	591000	479000
5	526000	601000	287000	290000	630000	652000	386000	361000	337000
6	756000	487000	652000	254000	262000	464000	473000	330000	232000
7	431000	400000	462000	331000	142000	236000	278000	379000	120000
8	1311000	917000	1037000	597000	445000	554000	392000	511000	215000

year

age	1956	1957	1958	1959	1960	1961	1962	1963	1964
0	96000	279000	97000	0	194600	1269200	141800	442800	496900
1	1697000	1483000	4279000	1609000	2392700	336000	2146900	1262200	2971700
2	1860000	1644000	1029000	4934000	1142300	1889400	269600	2961200	1547500
3	1221000	736000	999000	488000	1966700	479900	797400	177200	2243100
4	516000	644000	322000	497000	165900	1455900	335100	158300	148400
5	249000	344000	461000	233000	167700	124000	1081800	80600	149000
6	194000	207000	147000	249000	112900	157900	126900	229700	95000
7	104000	147000	73000	120000	125800	61400	145100	22400	256300
8	292000	253000	118000	301000	270600	143500	173100	93000	84000

year

age	1965	1966	1967	1968	1969	1970	1971	1972	1973
0	157100	374500	645400	839300	112000	898100	684000	750400	289400
1	3209300	1383100	1674300	2425000	2503300	1196200	4378500	3340600	2368000
2	2217600	2569700	1171500	1795200	1883000	2002800	1146800	1440500	1344200
3	1324600	741200	1364700	1494300	296300	883600	662500	343800	659200
4	2039400	450100	371500	621400	133100	125200	208300	130600	150200
5	145100	889800	297800	157100	190800	50300	26900	32900	59300
6	151900	45300	393100	145000	49900	61000	30500	5000	30600
7	117600	64800	67900	163400	42700	7900	26800	200	3700
8	491400	331800	254400	105500	52500	24200	12500	1500	2000

year

age	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
0	996100	263800	238200	256800	NA	NA	1262700	9519700	11956700	13296900
1	846100	2460500	126600	144300	NA	NA	245100	872000	1116400	2448600
2	772600	541700	901500	44700	NA	NA	134000	284300	299400	573800
3	362000	259600	117300	186400	NA	NA	91800	56900	230100	216400
4	126000	140500	52000	10800	NA	NA	32200	39500	33700	105100
5	56100	57200	34500	7000	NA	NA	21700	28500	14400	26200
6	22300	16100	6100	4100	NA	NA	2300	22700	6800	22800
7	5000	9100	4400	1500	NA	NA	1400	18700	7800	12800
8	3100	4800	1400	700	NA	NA	500	6600	4700	23100

year

age	1984	1985	1986	1987	1988	1989	1990	1991	1992
0	6973300	4211000	3724700	8229200	3164800	3057800	1302800	2386600	10331300
1	1818400	3253000	4801400	6836300	7867000	3145900	3020000	2138900	2303100
2	1146200	1326300	1266700	2137200	2232500	1593700	899300	1132800	1284900
3	441400	1182400	840800	667900	1090700	1363800	779100	556700	442700
4	201500	368500	465900	467100	383700	809300	861000	548900	361500
5	81100	124500	129800	245800	255800	211800	387500	501200	360500
6	22600	43600	62100	74700	128100	123700	80200	205300	375600
7	25200	20200	20500	23800	38000	61000	54400	39300	152400
8	29700	29200	28400	16200	23800	28200	40700	38600	62500

year

age	1993	1994	1995	1996	1997	1998	1999	2000	2001
0	10265400	4498900	7438469	2311226	431175	259526	1566349	1105085	1832691
1	3826800	1785200	1664874	1606393	479702	977680	303520	1171677	614469
2	1176300	1783200	1444061	642084	687920	1220105	616354	622853	842635
3	609000	489100	816703	525601	446909	537932	1058716	463170	485628
4	305500	347600	231794	172099	284920	276333	294066	646814	278884
5	215600	109000	118536	57586	109178	175817	135648	213466	321743
6	226000	91800	55128	22534	31389	88927	69299	82481	90918
7	188000	76400	41409	9264	11832	15232	27998	35706	38252
8	129000	116600	98200	21143	24467	20550	12228	17087	20602

TABLE 2.6.3.1 (cont) North Sea Herring. CATCH IN NUMBER.

age	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
0	730279	369074	715597	1015554	878637	621005	798284	650043	574895	778927
1	837557	617021	206648	715547	222111	235553	235022	175923	280728	159504
2	579592	1221992	447918	355453	401087	219115	331772	259434	293887	367820
3	970577	529386	1366155	485746	310602	417452	184771	106738	236804	275016
4	292205	835552	543376	1318647	464620	285746	199069	93321	126241	218711
5	140701	244780	753231	479961	997782	309454	137529	86137	83893	130127
6	174570	107751	169324	576154	252150	629187	118349	37951	61542	62938
7	48908	123291	104945	115212	247042	147830	215542	53130	33305	52081
8	43322	46715	97142	146808	106412	156750	117258	143131	113675	125734

TABLE 2.6.3.2 North Sea Herring. WEIGHTS AT AGE IN THE CATCH.

Units : kg

age	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957
0	0.015	0.015	0.0150	0.015	0.0150	0.015	0.015	0.0150	0.0150	0.015	0.0150
1	0.050	0.050	0.0500	0.050	0.0500	0.050	0.050	0.0500	0.0500	0.050	0.0500
2	0.122	0.122	0.1280	0.128	0.1340	0.137	0.137	0.1390	0.1400	0.140	0.1410
3	0.140	0.140	0.1450	0.151	0.1570	0.165	0.167	0.1690	0.1700	0.172	0.1730
4	0.156	0.156	0.1610	0.166	0.1760	0.183	0.190	0.1930	0.1950	0.197	0.1980
5	0.171	0.171	0.1760	0.180	0.1890	0.199	0.205	0.2110	0.2140	0.216	0.2180
6	0.185	0.185	0.1890	0.193	0.2010	0.210	0.218	0.2230	0.2280	0.231	0.2330
7	0.197	0.197	0.2010	0.204	0.2110	0.219	0.226	0.2330	0.2380	0.242	0.2440
8	0.242	0.242	0.2435	0.245	0.2475	0.251	0.254	0.2565	0.2595	0.261	0.2625

age	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
0	0.0150	0.0150	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
1	0.0500	0.0500	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
2	0.1410	0.1430	0.126	0.126	0.126	0.126	0.126	0.126	0.126	0.126	0.126	0.126
3	0.1740	0.1760	0.176	0.176	0.176	0.176	0.176	0.176	0.176	0.176	0.176	0.176
4	0.1990	0.2010	0.211	0.211	0.211	0.211	0.211	0.211	0.211	0.211	0.211	0.211
5	0.2190	0.2210	0.243	0.243	0.243	0.243	0.243	0.243	0.243	0.243	0.243	0.243
6	0.2340	0.2360	0.251	0.251	0.251	0.251	0.251	0.251	0.251	0.251	0.251	0.251
7	0.2450	0.2470	0.267	0.267	0.267	0.267	0.267	0.267	0.267	0.267	0.267	0.267
8	0.2635	0.2645	0.271	0.271	0.271	0.271	0.271	0.271	0.271	0.271	0.271	0.271

age	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
0	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.007
1	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.049
2	0.126	0.126	0.126	0.126	0.126	0.126	0.126	0.126	0.126	0.126	0.126	0.118
3	0.176	0.176	0.176	0.176	0.176	0.176	0.176	0.176	0.176	0.176	0.176	0.142
4	0.211	0.211	0.211	0.211	0.211	0.211	0.211	0.211	0.211	0.211	0.211	0.189
5	0.243	0.243	0.243	0.243	0.243	0.243	0.243	0.243	0.243	0.243	0.243	0.211
6	0.251	0.251	0.251	0.251	0.251	0.251	0.251	0.251	0.251	0.251	0.251	0.222
7	0.267	0.267	0.267	0.267	0.267	0.267	0.267	0.267	0.267	0.267	0.267	0.267
8	0.271	0.271	0.271	0.271	0.271	0.271	0.271	0.271	0.271	0.271	0.271	0.271

age	1982	1983	1984	1985	1986	1987	1988
0	0.010000	0.0100000	0.0100000	0.0090000	0.0060000	0.0110000	0.0110000
1	0.059000	0.0590000	0.0590000	0.0360000	0.0670000	0.0350000	0.0550000
2	0.118000	0.1180000	0.1180000	0.1280000	0.1210000	0.0990000	0.1110000
3	0.149000	0.1490000	0.1490000	0.1640000	0.1530000	0.1500000	0.1450000
4	0.179000	0.1790000	0.1790000	0.1940000	0.1820000	0.1800000	0.1740000
5	0.217000	0.2170000	0.2170000	0.2110000	0.2080000	0.2110000	0.1970000
6	0.238000	0.2380000	0.2380000	0.2200000	0.2210000	0.2340000	0.2160000
7	0.265000	0.2650000	0.2650000	0.2580000	0.2380000	0.2580000	0.2370000
8	0.274234	0.2745238	0.2746263	0.2821301	0.2572113	0.2881358	0.2565714

age	1989	1990	1991	1992	1993	1994	1995
0	0.0170000	0.0190000	0.0170000	0.0100000	0.0100000	0.0060000	0.0090000
1	0.0430000	0.0550000	0.0580000	0.0530000	0.0330000	0.0560000	0.0420000
2	0.1150000	0.1140000	0.1300000	0.1020000	0.1150000	0.1300000	0.1300000
3	0.1530000	0.1490000	0.1660000	0.1750000	0.1450000	0.1590000	0.1690000
4	0.1730000	0.1770000	0.1840000	0.1890000	0.1890000	0.1810000	0.1980000
5	0.2080000	0.1930000	0.2030000	0.2070000	0.2040000	0.2140000	0.2070000
6	0.2310000	0.2290000	0.2170000	0.2230000	0.2280000	0.2400000	0.2430000
7	0.2470000	0.2360000	0.2350000	0.2370000	0.2440000	0.2550000	0.2470000
8	0.2631489	0.2608182	0.2630415	0.2631664	0.2734558	0.2761973	0.2809153

TABLE 2.6.3.2 (cont). North Sea Herring. WEIGHTS AT AGE IN THE CATCH.

age	1996	1997	1998	1999	2000	2001	2002
0	0.0150000	0.0150000	0.0210000	0.009000	0.0150000	0.012000	0.0120000
1	0.0180000	0.0440000	0.0510000	0.045000	0.0330000	0.048000	0.0370000
2	0.1120000	0.1080000	0.1140000	0.115000	0.1130000	0.118000	0.1180000
3	0.1560000	0.1480000	0.1450000	0.151000	0.1570000	0.149000	0.1530000
4	0.1880000	0.1950000	0.1830000	0.171000	0.1790000	0.177000	0.1700000
5	0.2040000	0.2270000	0.2190000	0.207000	0.2010000	0.198000	0.1990000
6	0.2120000	0.2260000	0.2380000	0.233000	0.2160000	0.213000	0.2140000
7	0.2610000	0.2350000	0.2470000	0.245000	0.2460000	0.238000	0.2280000
8	0.2814938	0.2549437	0.2878952	0.267719	0.2731261	0.269744	0.2504017

age	2003	2004	2005	2006	2007	2008	2009
0	0.0140000	0.0140000	0.0110000	0.0100000	0.0124000	0.007900	0.0094000
1	0.0370000	0.0360000	0.0440000	0.0490000	0.0638000	0.053500	0.0514000
2	0.1040000	0.1000000	0.0990000	0.1170000	0.1214000	0.128800	0.1440000
3	0.1580000	0.1380000	0.1530000	0.1440000	0.1513000	0.179600	0.1811000
4	0.1740000	0.1830000	0.1660000	0.1720000	0.1634000	0.181200	0.2158000
5	0.1840000	0.2010000	0.2080000	0.1810000	0.1933000	0.183200	0.2162000
6	0.2050000	0.2160000	0.2230000	0.2200000	0.1900000	0.215700	0.2390000
7	0.2220000	0.2280000	0.2400000	0.2370000	0.2232000	0.216100	0.2428000
8	0.2366464	0.2545115	0.2653676	0.2460061	0.2374933	0.262076	0.2532723

age	2010	2011
0	0.0075000	0.008000
1	0.0571000	0.041300
2	0.1292000	0.131700
3	0.1669000	0.159300
4	0.1912000	0.183100
5	0.2203000	0.197000
6	0.2193000	0.216700
7	0.2160000	0.221100
8	0.2383892	0.231918

TABLE 2.6.3.3 North Sea Herring. WEIGHTS AT AGE IN THE STOCK.

Units : kg

age	1947	1948	1949	1950	1951	1952	1953	1954
0	0.0150	0.0150	0.0150000	0.0150000	0.0150000	0.0150000	0.0150000	0.0150000
1	0.0500	0.0500	0.0500000	0.0500000	0.0500000	0.0500000	0.0500000	0.0500000
2	0.1220	0.1220	0.1240000	0.1260000	0.1300000	0.1330000	0.1360000	0.1376667
3	0.1400	0.1400	0.1416667	0.1453333	0.1510000	0.1576667	0.1630000	0.1670000
4	0.1560	0.1560	0.1576667	0.1610000	0.1676667	0.1750000	0.1830000	0.1886667
5	0.1710	0.1710	0.1726667	0.1756667	0.1816667	0.1893333	0.1976667	0.2050000
6	0.1850	0.1850	0.1863333	0.1890000	0.1943333	0.2013333	0.2096667	0.2170000
7	0.1970	0.1970	0.1983333	0.2006667	0.2053333	0.2113333	0.2186667	0.2260000
8	0.2625	0.2625	0.2630000	0.2640000	0.2658333	0.2683333	0.2713333	0.2743333

age	1955	1956	1957	1958	1959	1960	1961
0	0.0150000	0.0150000	0.0150000	0.0150000	0.0150000	0.0150000	0.0150000
1	0.0500000	0.0500000	0.0500000	0.0500000	0.0500000	0.0500000	0.0500000
2	0.1386667	0.1396667	0.1403333	0.1406667	0.1416667	0.1463333	0.1510000
3	0.1686667	0.1703333	0.1716667	0.1730000	0.1743333	0.1790000	0.1833333
4	0.1926667	0.1950000	0.1966667	0.1980000	0.1993333	0.2076667	0.2156667
5	0.2100000	0.2136667	0.2160000	0.2176667	0.2193333	0.2263333	0.2330000
6	0.2230000	0.2273333	0.2306667	0.2326667	0.2343333	0.2486667	0.2626667
7	0.2323333	0.2376667	0.2413333	0.2436667	0.2453333	0.2636667	0.2816667
8	0.2771667	0.2795000	0.2815000	0.2828333	0.2840000	0.2936240	0.3034146

age	1962	1963	1964	1965	1966	1967	1968
0	0.0150000	0.0150000	0.0150000	0.0150000	0.0150000	0.0150000	0.0150000
1	0.0500000	0.0500000	0.0500000	0.0500000	0.0500000	0.0500000	0.0500000
2	0.1550000	0.1550000	0.1550000	0.1550000	0.1550000	0.1550000	0.1550000
3	0.1870000	0.1870000	0.1870000	0.1870000	0.1870000	0.1870000	0.1870000
4	0.2230000	0.2230000	0.2230000	0.2230000	0.2230000	0.2230000	0.2230000
5	0.2390000	0.2390000	0.2390000	0.2390000	0.2390000	0.2390000	0.2390000
6	0.2760000	0.2760000	0.2760000	0.2760000	0.2760000	0.2760000	0.2760000
7	0.2990000	0.2990000	0.2990000	0.2990000	0.2990000	0.2990000	0.2990000
8	0.3090087	0.3092903	0.3101214	0.3069573	0.3102731	0.3100755	0.3112209

TABLE 2.6.3.3 (cont). North Sea Herring. WEIGHTS AT AGE IN THE STOCK.

age \ year	1969	1970	1971	1972	1973	1974	1975	1976	1977
0	0.0150000	0.0150000	0.015000	0.0150	0.0150	0.015000	0.01500	0.0150000	0.015
1	0.0500000	0.0500000	0.050000	0.0500	0.0500	0.050000	0.05000	0.0500000	0.050
2	0.1550000	0.1550000	0.155000	0.1550	0.1550	0.155000	0.15500	0.1550000	0.155
3	0.1870000	0.1870000	0.187000	0.1870	0.1870	0.187000	0.18700	0.1870000	0.187
4	0.2230000	0.2230000	0.223000	0.2230	0.2230	0.223000	0.22300	0.2230000	0.223
5	0.2390000	0.2390000	0.239000	0.2390	0.2390	0.239000	0.23900	0.2390000	0.239
6	0.2760000	0.2760000	0.276000	0.2760	0.2760	0.276000	0.27600	0.2760000	0.276
7	0.2990000	0.2990000	0.299000	0.2990	0.2990	0.299000	0.29900	0.2990000	0.299
8	0.3088686	0.3090248	0.311952	0.3076	0.3078	0.308129	0.30775	0.3077143	0.306

age \ year	1978	1979	1980	1981	1982	1983	1984	1985
0	0.0150	0.0150000	0.0150	0.015	0.0150000	0.0150000	0.01733333	0.01566667
1	0.0500	0.0500000	0.0500	0.050	0.0500000	0.0500000	0.05666667	0.05633333
2	0.1550	0.1550000	0.1550	0.155	0.1550000	0.1550000	0.15033333	0.13800000
3	0.1870	0.1870000	0.1870	0.187	0.1870000	0.1870000	0.19033333	0.18700000
4	0.2230	0.2230000	0.2230	0.223	0.2230000	0.2230000	0.22966667	0.23233333
5	0.2390	0.2390000	0.2390	0.239	0.2390000	0.2390000	0.24333333	0.24666667
6	0.2760	0.2760000	0.2760	0.276	0.2760000	0.2760000	0.28200000	0.27466667
7	0.2990	0.2990000	0.2990	0.299	0.2990000	0.2990000	0.31066667	0.32100000
8	0.3096	0.3068571	0.3072	0.307	0.3074043	0.3091429	0.34351178	0.35438242

age \ year	1986	1987	1988	1989	1990	1991
0	0.0140000	0.00900000	0.00800000	0.008666667	0.01233333	0.01133333
1	0.0610000	0.05033333	0.04833333	0.043666667	0.05200000	0.05900000
2	0.1300000	0.12166667	0.12300000	0.122333333	0.12566667	0.13900000
3	0.1833333	0.17000000	0.16633333	0.165333333	0.17433333	0.18366667
4	0.2316667	0.21233333	0.20833333	0.204666667	0.21166667	0.21200000
5	0.2520000	0.23000000	0.22900000	0.228333333	0.24366667	0.23866667
6	0.2730000	0.24200000	0.24833333	0.252333333	0.27066667	0.26533333
7	0.3146667	0.27466667	0.25866667	0.261333333	0.28366667	0.27966667
8	0.3627746	0.30562963	0.28535714	0.288595745	0.30788452	0.30953886

age \ year	1992	1993	1994	1995	1996	1997
0	0.01033333	0.005666667	0.007333333	0.00600000	0.0060000	0.00500000
1	0.06366667	0.061000000	0.060000000	0.05733333	0.0540000	0.04866667
2	0.13666667	0.134000000	0.126333333	0.12933333	0.1296667	0.12333333
3	0.19400000	0.184333333	0.191666667	0.18566667	0.1993333	0.18333333
4	0.21400000	0.213000000	0.214333333	0.21066667	0.2273333	0.23033333
5	0.23433333	0.234333333	0.239666667	0.22433333	0.2343333	0.23733333
6	0.25300000	0.261666667	0.274666667	0.26800000	0.2736667	0.25666667
7	0.27166667	0.272666667	0.291333333	0.29333333	0.3006667	0.28033333
8	0.29870453	0.307936434	0.320523728	0.32614016	0.3270679	0.31004007

age \ year	1998	1999	2000	2001	2002	2003
0	0.005666667	0.00600000	0.005666667	0.00600000	0.006333333	0.006666667
1	0.047333333	0.05066667	0.051333333	0.05066667	0.047333333	0.047000000
2	0.116000000	0.11600000	0.115666667	0.12166667	0.128000000	0.123000000
3	0.187333333	0.17933333	0.183666667	0.17166667	0.171666667	0.173000000
4	0.241333333	0.22633333	0.221333333	0.21000000	0.205333333	0.202333333
5	0.264333333	0.25600000	0.248333333	0.23266667	0.228333333	0.222000000
6	0.283666667	0.27333333	0.278666667	0.25533333	0.248333333	0.242333333
7	0.286666667	0.27600000	0.286000000	0.27466667	0.270333333	0.265666667
8	0.308339011	0.27811880	0.284171183	0.27449422	0.286521182	0.284946134

year

TABLE 2.6.3.3 (cont) North Sea Herring. WEIGHTS AT AGE IN THE STOCK.

age	2004	2005	2006	2007	2008	2009
0	0.006666667	0.005733333	0.006766667	0.00610000	0.007933333	0.007233333
1	0.042000000	0.041433333	0.041000000	0.05133333	0.057700000	0.061433333
2	0.119333333	0.118100000	0.125666667	0.12800000	0.130366667	0.137366667
3	0.165333333	0.164433333	0.155400000	0.16073333	0.164200000	0.181000000
4	0.202666667	0.197900000	0.190900000	0.17956667	0.180766667	0.196866667
5	0.223000000	0.224500000	0.215800000	0.20680000	0.195433333	0.209966667
6	0.247666667	0.247833333	0.241900000	0.22356667	0.217700000	0.222500000
7	0.267666667	0.264866667	0.252133333	0.23780000	0.226066667	0.233633333
8	0.280490193	0.284945260	0.270223450	0.25648110	0.255556491	0.255759739

year

age	2010	2011
0	0.007133333	0.006666667
1	0.052233333	0.043166667
2	0.142266667	0.145300000
3	0.190366667	0.187433333
4	0.216266667	0.225066667
5	0.223600000	0.239366667
6	0.234200000	0.243500000
7	0.240100000	0.250766667
8	0.260682861	0.257247512

TABLE 2.6.3.4. North Sea Herring. NATURAL MORTALITY.

Units : NA

year

age	1947	1948	1949	1950	1951	1952	1953
0	1.3062962	1.3063903	1.3068821	1.3072083	1.3066220	1.3043784	1.3068605
1	0.8597480	0.8597415	0.8597118	0.8596935	0.8597301	0.8598630	0.8597093
2	0.3056970	0.3056669	0.3055191	0.3054245	0.3056036	0.3062708	0.3055162
3	0.2817484	0.2817165	0.2815592	0.2814580	0.2816484	0.2823597	0.2815574
4	0.2531908	0.2531580	0.2529935	0.2528867	0.2530850	0.2538308	0.2529940
5	0.2300403	0.2300068	0.2298389	0.2297298	0.2299323	0.2306936	0.2298396
6	0.2293962	0.2293629	0.2291975	0.2290907	0.2292906	0.2300393	0.2291965
7	0.2258074	0.2257749	0.2256149	0.2255120	0.2257058	0.2264292	0.2256128
8	0.2258074	0.2257749	0.2256149	0.2255120	0.2257058	0.2264292	0.2256128

year

age	1954	1955	1956	1957	1958	1959	1960
0	1.3093415	1.3088394	1.3036901	1.2931602	1.3192712	1.3217465	1.3063292
1	0.8595631	0.8596017	0.8599133	0.8605277	0.8589407	0.8588323	0.8597945
2	0.3047803	0.3049514	0.3064994	0.3096070	0.3017431	0.3011004	0.3058071
3	0.2807726	0.2809519	0.2826002	0.2859165	0.2775460	0.2768483	0.2818484
4	0.2521708	0.2523528	0.2540767	0.2575595	0.2488103	0.2480547	0.2532628
5	0.2289991	0.2291846	0.2309444	0.2345002	0.2255694	0.2247968	0.2301122
6	0.2283702	0.2285568	0.2302904	0.2337826	0.2249822	0.2242391	0.2294894
7	0.2248147	0.2249976	0.2266746	0.2300461	0.2215312	0.2208238	0.2259122
8	0.2248147	0.2249976	0.2266746	0.2300461	0.2215312	0.2208238	0.2259122

year

age	1961	1962	1963	1964	1965	1966	1967
0	1.2779437	1.2405107	1.4498257	1.3341230	1.2292427	1.1360167	1.0533453
1	0.8614710	0.8636000	0.8510058	0.8582902	0.8646056	0.8698533	0.8742452
2	0.3142394	0.3251448	0.2624238	0.2978870	0.3293404	0.3564009	0.3796720
3	0.2908419	0.3024979	0.2356937	0.2733594	0.3068488	0.3358097	0.3607781
4	0.2626962	0.2749736	0.2050645	0.2442764	0.2793030	0.3098633	0.3363605
5	0.2397436	0.2522790	0.1809156	0.2209336	0.2566889	0.2879006	0.3149562
6	0.2389587	0.2512436	0.1809803	0.2205236	0.2557409	0.2863048	0.3126683
7	0.2350598	0.2469035	0.1789569	0.2172865	0.2513544	0.2807976	0.3061220
8	0.2350598	0.2469035	0.1789569	0.2172865	0.2513544	0.2807976	0.3061220

year

age	1968	1969	1970	1971	1972	1973	1974
0	0.9805771	0.9186008	0.8673622	0.8247947	0.7939643	0.7755027	0.7636920
1	0.8778144	0.8804017	0.8820627	0.8831532	0.8837601	0.8837618	0.8832010
2	0.3993545	0.4145945	0.4255663	0.4340132	0.4379065	0.4368385	0.4349828
3	0.3819478	0.3985622	0.4107716	0.4201306	0.4248969	0.4246783	0.4230544
4	0.3589555	0.3770431	0.3907393	0.4012868	0.4073827	0.4086825	0.4078663
5	0.3380276	0.3565578	0.3706479	0.3814567	0.3878100	0.3893628	0.3885181
6	0.3350369	0.3527903	0.3660364	0.3760727	0.3815138	0.3819820	0.3802856
7	0.3275616	0.3444648	0.3569392	0.3663576	0.3711496	0.3709273	0.3688377
8	0.3275616	0.3444648	0.3569392	0.3663576	0.3711496	0.3709273	0.3688377

TABLE 2.6.3.4 (Cont) North Sea Herring. NATURAL MORTALITY.

age \ year	1975	1976	1977	1978	1979	1980	1981
0	0.7688703	0.7901108	0.8047986	0.8124459	0.8238513	0.8333298	0.8394171
1	0.8844545	0.8864425	0.8840221	0.8733575	0.8587716	0.8473594	0.8375958
2	0.4302030	0.4213890	0.4142544	0.4088044	0.4024214	0.3968846	0.3944146
3	0.4169843	0.4059054	0.3971144	0.3908862	0.3837073	0.3771918	0.3739079
4	0.4009955	0.3882011	0.3782681	0.3706733	0.3613179	0.3536230	0.3507997
5	0.3810519	0.3672796	0.3564138	0.3475373	0.3365057	0.3276900	0.3241351
6	0.3724155	0.3584487	0.3473240	0.3381604	0.3269489	0.3179354	0.3140861
7	0.3614341	0.3484669	0.3378787	0.3289188	0.3180598	0.3090793	0.3044325
8	0.3614341	0.3484669	0.3378787	0.3289188	0.3180598	0.3090793	0.3044325

age \ year	1982	1983	1984	1985	1986	1987	1988
0	0.8450021	0.8509293	0.8618818	0.8758657	0.8837108	0.8833518	0.8801386
1	0.8262204	0.8177263	0.8133933	0.8098846	0.8047687	0.8030194	0.8053149
2	0.3936631	0.3910560	0.3846764	0.3767758	0.3700325	0.3620220	0.3521287
3	0.3724725	0.3685723	0.3595125	0.3482600	0.3389950	0.3289309	0.3167563
4	0.3504278	0.3474814	0.3402310	0.3317459	0.3241989	0.3145318	0.3025221
5	0.3230039	0.3198456	0.3133267	0.3060806	0.2996061	0.2913129	0.2812120
6	0.3127191	0.3096080	0.3032829	0.2962165	0.2900961	0.2824154	0.2730801
7	0.3018394	0.2979753	0.2910907	0.2832448	0.2768250	0.2693836	0.2604610
8	0.3018394	0.2979753	0.2910907	0.2832448	0.2768250	0.2693836	0.2604610

age \ year	1989	1990	1991	1992	1993	1994	1995
0	0.8760232	0.8686097	0.8577137	0.8486048	0.8323958	0.8088519	0.7962212
1	0.8027804	0.7939753	0.7837381	0.7726129	0.7494854	0.7166964	0.6949720
2	0.3457447	0.3443718	0.3448689	0.3456637	0.3462418	0.3476941	0.3508561
3	0.3088644	0.3066102	0.3063299	0.3068890	0.3096982	0.3151729	0.3206849
4	0.2945958	0.2911509	0.2887064	0.2878693	0.2900670	0.2948533	0.3000248
5	0.2747040	0.2720989	0.2704650	0.2703406	0.2726507	0.2770603	0.2822178
6	0.2673958	0.2662294	0.2665871	0.2679837	0.2713861	0.2769124	0.2828047
7	0.2554274	0.2559625	0.2588839	0.2622695	0.2671514	0.2742681	0.2812562
8	0.2554274	0.2559625	0.2588839	0.2622695	0.2671514	0.2742681	0.2812562

age \ year	1996	1997	1998	1999	2000	2001	2002
0	0.7964933	0.8003559	0.8091044	0.8315196	0.8635228	0.8871207	0.9021687
1	0.6869137	0.6817761	0.6802653	0.6913413	0.7113333	0.7220006	0.7236466
2	0.3570840	0.3656584	0.3743015	0.3869205	0.4027811	0.4126429	0.4164810
3	0.3273645	0.3362859	0.3447364	0.3550340	0.3672442	0.3752758	0.3791293
4	0.3072634	0.3173345	0.3266605	0.3373851	0.3500588	0.3587136	0.3632873
5	0.2899977	0.3006973	0.3105983	0.3222252	0.3360710	0.3453713	0.3500951
6	0.2906329	0.3009355	0.3104069	0.3214765	0.3345297	0.3431944	0.3474571
7	0.2892593	0.2992269	0.3085044	0.3196391	0.3326829	0.3412380	0.3453142
8	0.2892593	0.2992269	0.3085044	0.3196391	0.3326829	0.3412380	0.3453142

age \ year	2003	2004	2005	2006	2007	2008	2009
0	0.9180715	0.9311605	0.9417495	0.9515479	0.9589797	0.9629198	0.9639524
1	0.7255318	0.7228521	0.7158512	0.7068146	0.6940013	0.6761454	0.6539054
2	0.4190357	0.4182149	0.4141342	0.4078147	0.3985226	0.3856549	0.3694447
3	0.3818664	0.3819880	0.3795281	0.3752508	0.3687520	0.3596482	0.3480426
4	0.3667856	0.3678416	0.3664798	0.3634001	0.3582492	0.3506907	0.3408148
5	0.3536407	0.3543872	0.3523644	0.3483950	0.3420464	0.3329287	0.3211651
6	0.3504963	0.3507288	0.3481721	0.3436320	0.3367076	0.3270346	0.3147281
7	0.3480817	0.3478837	0.3447272	0.3394611	0.3316919	0.3210542	0.3076583
8	0.3480817	0.3478837	0.3447272	0.3394611	0.3316919	0.3210542	0.3076583

age \ year	2010	2011
0	0.9630652	0.9600930
1	0.6284271	0.6718588
2	0.3504123	0.3823698
3	0.3342612	0.3571910
4	0.3289086	0.3484127
5	0.3070936	0.3303257
6	0.3001065	0.3244418
7	0.2918243	0.3183380
8	0.2918243	0.3183380

TABLE 2.6.3.5. North Sea Herring. PROPORTION MATURE.

Units : NA

year

age	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

year

age	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
0	0	0	0	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
1	0	0	0	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00
2	1	1	1	1	1	1	1	1	1	1	0.82	0.82	0.82	0.82	0.82
3	1	1	1	1	1	1	1	1	1	1	1.00	1.00	1.00	1.00	1.00
4	1	1	1	1	1	1	1	1	1	1	1.00	1.00	1.00	1.00	1.00
5	1	1	1	1	1	1	1	1	1	1	1.00	1.00	1.00	1.00	1.00
6	1	1	1	1	1	1	1	1	1	1	1.00	1.00	1.00	1.00	1.00
7	1	1	1	1	1	1	1	1	1	1	1.00	1.00	1.00	1.00	1.00
8	1	1	1	1	1	1	1	1	1	1	1.00	1.00	1.00	1.00	1.00

year

age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.0	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.0	0.00	0.00	0.00	0.00
2	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.7	0.75	0.8	0.85	0.82	0.91	0.86
3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.0	1.00	1.0	0.93	0.94	0.97	0.99
4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.0	1.00	1.0	1.00	1.00	1.00	1.00
5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.0	1.00	1.0	1.00	1.00	1.00	1.00
6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.0	1.00	1.0	1.00	1.00	1.00	1.00
7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.0	1.00	1.0	1.00	1.00	1.00	1.00
8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.0	1.00	1.0	1.00	1.00	1.00	1.00

year

age	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.50	0.47	0.73	0.67	0.61	0.64	0.64	0.69	0.67	0.77	0.87	0.43	0.70	0.76	0.66
3	0.99	0.61	0.93	0.95	0.98	0.94	0.89	0.91	0.96	0.92	0.97	0.93	0.65	0.96	0.88
4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.98
5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

year

age	2007	2008	2009	2010	2011
0	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00
2	0.71	0.86	0.89	0.45	0.87
3	0.92	0.98	1.00	0.90	0.84
4	0.93	0.99	1.00	1.00	1.00
5	1.00	1.00	1.00	1.00	1.00
6	1.00	1.00	1.00	1.00	1.00
7	1.00	1.00	1.00	1.00	1.00
8	1.00	1.00	1.00	1.00	1.00

TABLE 2.6.3.6/7. North Sea Herring. FRACTION OF NATURAL MORTALITY AND HARVEST BEFORE SPAWNING.

Units : NA

year

age	1947-2011
0	0.67
1	0.67
2	0.67
3	0.67
4	0.67
5	0.67
6	0.67
7	0.67
8	0.67

TABLE 2.6.3.8. North Sea Herring. SURVEY INDICES.

SCAI - Configuration

Spawning component abundance index

min	max	plusgroup	minyear	maxyear	startf	endf
NA	NA	NA	1972	2011	NA	NA

Index type : biomass

SCAI - Index Values

Units : NA

age \ year	1972	1973	1974	1975	1976	1977	1978	1979
all	3384.85	3322.852	2215.229	1363.273	1206.67	1618.491	2129.141	3251.282

age \ year	1980	1981	1982	1983	1984	1985	1986	1987
all	3547.903	4053.179	5084.589	7785.163	12240.83	15294.27	14510.45	18484.93

age \ year	1988	1989	1990	1991	1992	1993	1994	1995
all	26409.63	22346.76	20980.77	14339.93	7395.23	5014.908	4299.909	5387.032

age \ year	1996	1997	1998	1999	2000	2001	2002	2003
all	7016.717	10176.78	13334.14	14337.54	16375.35	21908.42	26259.78	34623.69

age \ year	2004	2005	2006	2007	2008	2009	2010	2011
all	38037.62	32361.66	30073.28	30985.21	38571.01	49553.53	51363.65	53594.87

HERAS - Configuration

Herring in Sub-area IV, Divisions VIId & IIIa (autumn-spawners) . Imported from VPA file.

min	max	plusgroup	minyear	maxyear	startf	endf
1.00	8.00	8.00	1989.00	2011.00	0.54	0.56

Index type : number

HERAS - Index Values

Units : NA

age \ year	1989	1990	1991	1992	1993	1994	1995	1996	1997
1	-1	-1	-1	-1	-1	-1	-1	-1	9361000
2	4090000	3306000	2634000	3734000	2984000	3185000	3849000	4497000	5960000
3	3903000	3521000	1700000	1378000	1637000	839000	2041000	2824000	2935000
4	1633000	3414000	1959000	1147000	902000	399000	672000	1087000	1441000
5	492000	1366000	1849000	1134000	741000	381000	299000	311000	601000
6	283000	392000	644000	1246000	777000	321000	203000	99000	215000
7	120000	210000	228000	395000	551000	326000	138000	83000	46000
8	66000	176000	145000	218000	296000	350000	212000	339000	237000

age \ year	1998	1999	2000	2001	2002	2003	2004	2005	2006
1	4449000	5087000	24736000	6837000	23055000	9829400	5183700	3114100	6822800
2	5747000	3078000	2923000	12290000	4875000	18949400	3415900	2055100	3772300
3	2520000	4725000	2156000	3083000	8220000	3081000	9191800	3648500	1997200
4	1625000	1116000	3140000	1462000	1390000	4188900	2167300	5789600	2097500
5	982000	506000	1007000	1676000	794600	675100	2590700	1212900	4175100
6	445000	314000	483000	450000	1031000	494800	317100	1174900	618200
7	170000	139000	266000	170000	244400	568300	327600	139900	562100
8	166000	141000	217000	157000	270500	323200	527650	233200	154700

age \ year	2007	2008	2009	2010	2011
1	6261000	3714000	4655000	14577000	10119000
2	2750000	2853000	5632000	4237000	4166000
3	1848000	1709000	2553000	4216000	2534000
4	898000	1485000	1023000	2453000	2173000
5	806000	809000	1077000	1246000	1016000
6	1323000	712000	674000	1332000	651000
7	243000	1749000	638000	688000	688000
8	217000	455000	1720000	2729000	1737000

TABLE 2.6.3.8 (Cont.) North Sea Herring. SURVEY INDICES.

```
IBTS-Q1 - Configuration

Herring in Sub-area IV, Divisions VIId & IIIa (autumn-spawners) . Imported from
VPA file.
      min       max plusgroup   minyear   maxyear    startf      endf
     1.00      1.00        NA   1984.00   2012.00      0.08      0.17
Index type : number

IBTS-Q1 - Index Values

Units  :  NA
   year
age     1984    1985     1986     1987     1988     1989     1990     1991
  1 1515.627 2097.28 2662.812 3692.965 4394.168 2331.566 1061.572 1286.747
   year
age     1992     1993     1994     1995     1996     1997     1998    1999
  1 1268.145 2794.007 1752.053 1345.754 1890.872 4404.647 2275.845 752.862
   year
age     2000     2001     2002   2003    2004     2005    2006     2007    2008
  1 3725.131 2499.391 4064.829 2836.7 979.036 1010.443 892.843 1321.279 1791.55
   year
age     2009     2010     2011     2012
  1 2339.641 1323.363 2937.234 1352.965

IBTS0 - Configuration

Herring in Sub-area IV, Divisions VIId & IIIa (autumn-spawners) . Imported from
VPA file.
      min       max plusgroup   minyear   maxyear    startf      endf
     0.00      0.00        NA   1992.00   2012.00      0.08      0.17
Index type : number

IBTS0 - Index Values

Units  :  NA
   year
age  1992  1993  1994 1995  1996  1997 1998 1999  2000  2001  2002 2003 2004
  0 200.7 190.1 101.7  127 106.5 148.1 53.1  244 137.1 214.8 161.8 54.4 47.3
   year
age 2005 2006 2007 2008 2009 2010 2011 2012
  0 61.3 83.1 37.2 27.8 95.8 77.1   77   68
```

MODEL:

TABLE 2.6.3.9. North Sea Herring. STOCK OBJECT CONFIGURATION

```
      min       max plusgroup   minyear   maxyear   minfbar   maxfbar
        0         8         8      1947      2011         2         6
```

TABLE 2.6.3.10. North Sea Herring. FLSAM CONFIGURATION SETTINGS.

```
name           : Final Assessment
desc           :
range          :       min       max plusgroup   minyear   maxyear   minfbar
maxfbar
range          :         0         8         8      1947      2012         2
6
fleets         :   catch    SCAI   HERAS IBTS-Q1   IBTS0
fleets         :       0       3       2       2       2
plus.group     : TRUE
states         :          age
states         : fleet      0  1  2  3  4  5  6  7  8
states         :   catch    1  2  3  4  5  6  7  8  8
states         :   SCAI    NA NA NA NA NA NA NA NA NA
states         :   HERAS   NA NA NA NA NA NA NA NA NA
states         :   IBTS-Q1 NA NA NA NA NA NA NA NA NA
states         :   IBTS0   NA NA NA NA NA NA NA NA NA
logN.vars      : 1 2 2 2 2 2 2 2 2
catchabilities :          age
catchabilities : fleet      0  1  2  3  4  5  6  7  8
catchabilities :   catch   NA NA NA NA NA NA NA NA NA
catchabilities :   SCAI    NA NA NA NA NA NA NA NA NA
catchabilities :   HERAS   NA  3  3  4  4  5  5  5  5
catchabilities :   IBTS-Q1 NA  1 NA NA NA NA NA NA NA
catchabilities :   IBTS0    2 NA NA NA NA NA NA NA NA
power.law.exps :          age
power.law.exps : fleet      0  1  2  3  4  5  6  7  8
power.law.exps :   catch   NA NA NA NA NA NA NA NA NA
power.law.exps :   SCAI    NA NA NA NA NA NA NA NA NA
power.law.exps :   HERAS   NA NA NA NA NA NA NA NA NA
power.law.exps :   IBTS-Q1 NA NA NA NA NA NA NA NA NA
power.law.exps :   IBTS0   NA NA NA NA NA NA NA NA NA
f.vars         :          age
f.vars         : fleet      0  1  2  3  4  5  6  7  8
f.vars         :   catch    1  1  2  2  3  3  4  4  4
f.vars         :   SCAI    NA NA NA NA NA NA NA NA NA
f.vars         :   HERAS   NA NA NA NA NA NA NA NA NA
f.vars         :   IBTS-Q1 NA NA NA NA NA NA NA NA NA
f.vars         :   IBTS0   NA NA NA NA NA NA NA NA NA
obs.vars       :          age
obs.vars       : fleet      0  1  2  3  4  5  6  7  8
obs.vars       :   catch    3  4  4  4  4  4  5  5  5
obs.vars       :   SCAI    NA NA NA NA NA NA NA NA NA
obs.vars       :   HERAS   NA  6  7  7  7  7  8  8  8
obs.vars       :   IBTS-Q1 NA  1 NA NA NA NA NA NA NA
obs.vars       :   IBTS0    2 NA NA NA NA NA NA NA NA
srr            : 0
timeout        : 3600
```

TABLE 2.6.3.11. North Sea Herring. FLR, R SOFTWARE VERSIONS.

```
R version 2.13.2 (2011-09-30)

Package  : FLSAM
Version  : 0.43-2
Packaged :
Built    : R 2.13.2; ; 2012-02-29 10:51:36 UTC; windows

Package  : FLCore
Version  : 2.4
Packaged :
Built    : R 2.13.2; i386-pc-mingw32; 2011-10-05 12:21:01 UTC; windows
```

BASE FIT:

TABLE 2.6.3.25. North Sea Herring. FIT PARAMETERS.

	index	name	value	std.dev
1	1	logFpar	-8.867300	0.073463
2	2	logFpar	-12.747000	0.102680
3	3	logFpar	-0.088344	0.067555
4	4	logFpar	0.064684	0.064893
5	5	logFpar	0.166520	0.086515
6	6	logSdLogFsta	-0.531250	0.098520
7	7	logSdLogFsta	-1.128100	0.131600
8	8	logSdLogFsta	-1.191500	0.131040
9	9	logSdLogFsta	-0.675200	0.114870
10	10	logSdLogN	-0.585680	0.118510
11	11	logSdLogN	-1.886700	0.138690
12	12	logSdLogObs	-1.246000	0.167620
13	13	logSdLogObs	-1.028700	0.197670
14	14	logSdLogObs	-1.435600	0.516920
15	15	logSdLogObs	-1.825500	0.264500
16	16	logSdLogObs	-1.274400	0.176040
17	17	logSdLogObs	-0.949780	0.208450
18	18	logSdLogObs	-1.634000	0.111920
19	19	logSdLogObs	-1.421100	0.137030
20	20	logScaleSSB	-4.197400	0.080261
21	21	logSdSSB	-0.891740	0.117990

TABLE 2.6.3.26. North Sea Herring. NEGATIVE LOG-LIKELIHOOD.

604.594

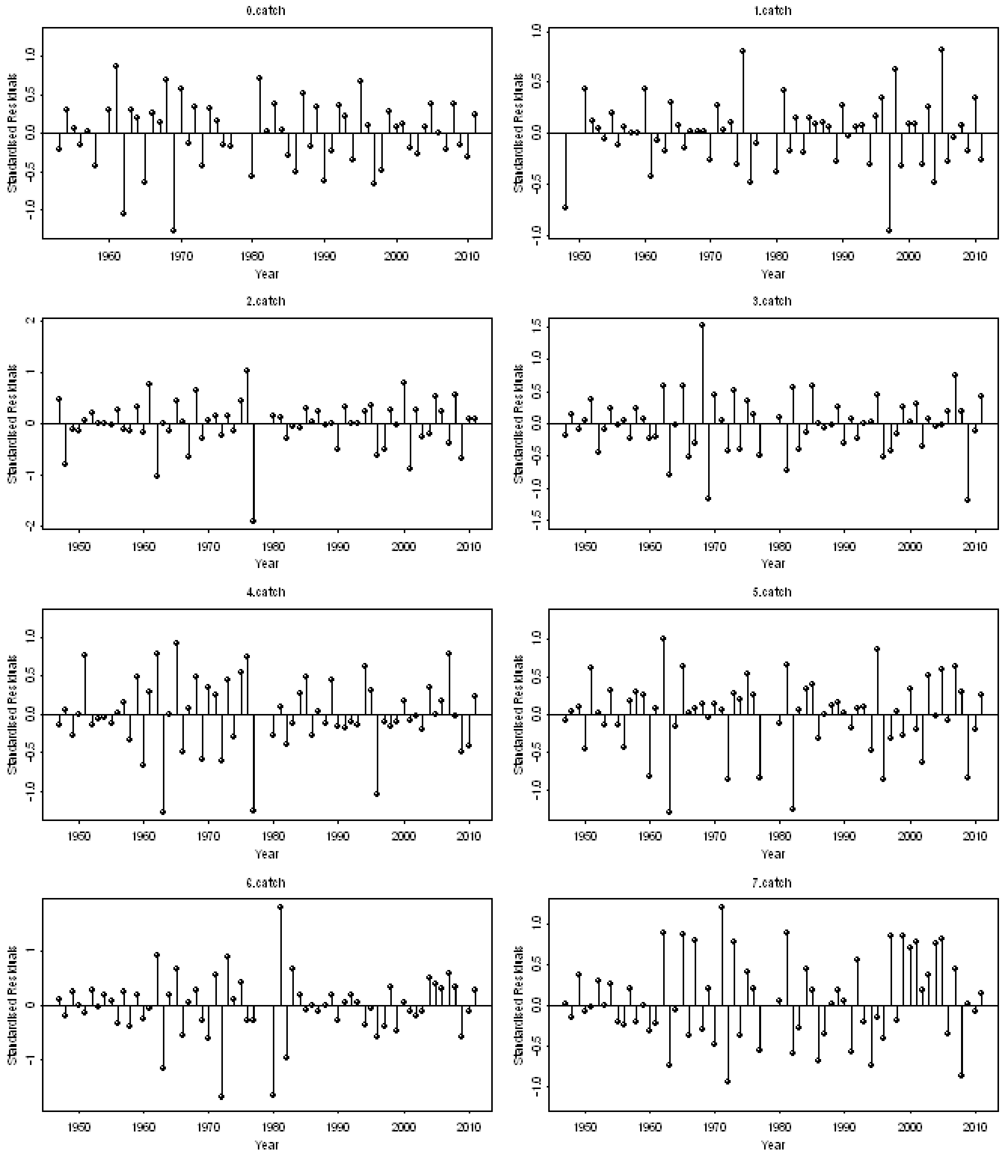


Figure 1. North Sea herring. Diagnostics of the assessment model fit to the catch-at-age time-series: observation vs. standardized residuals.

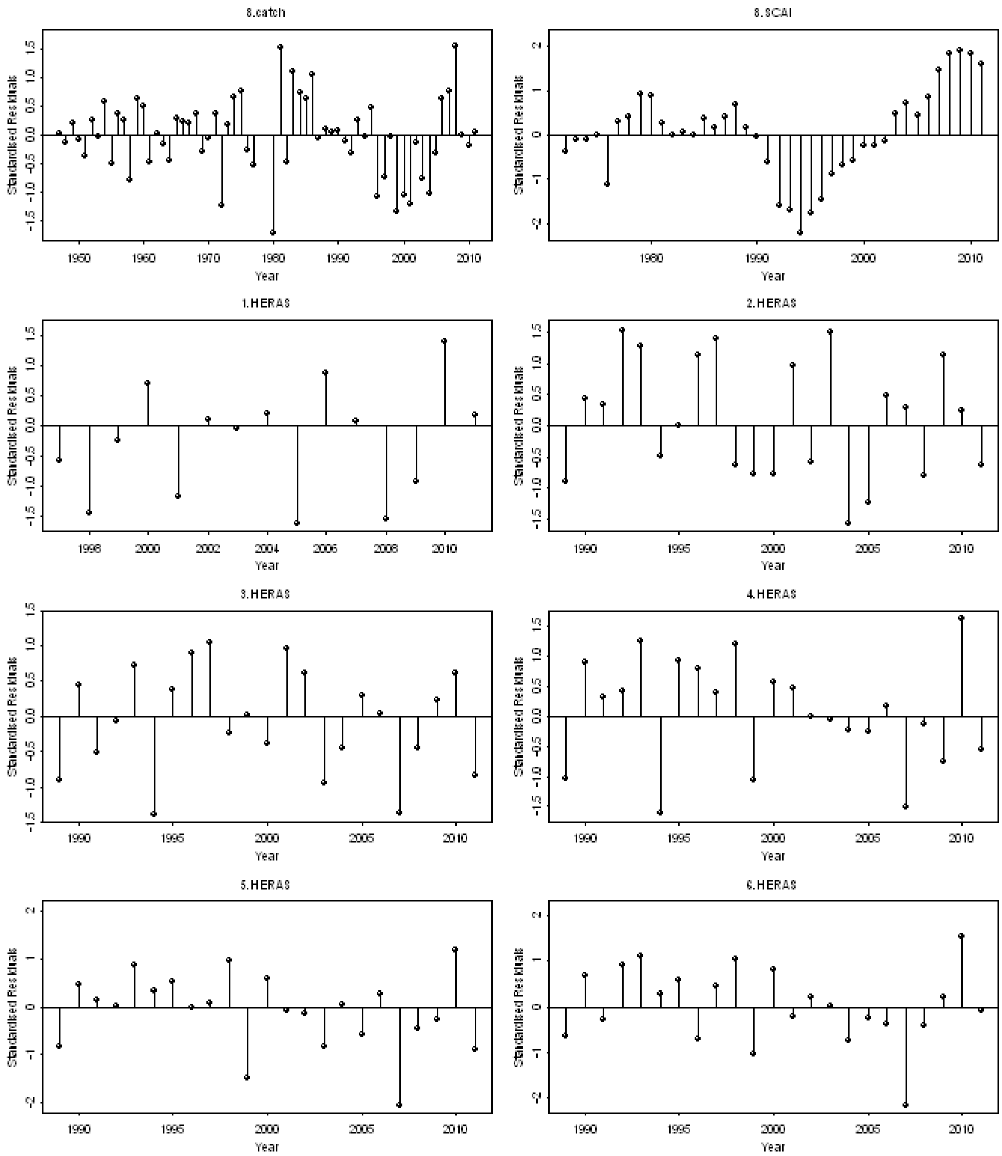


Figure 2. North Sea herring. Diagnostics of the assessment model fit to the catch-at-age, SCAI SSB index and HERAS index time-series: observation vs. standardized residuals.

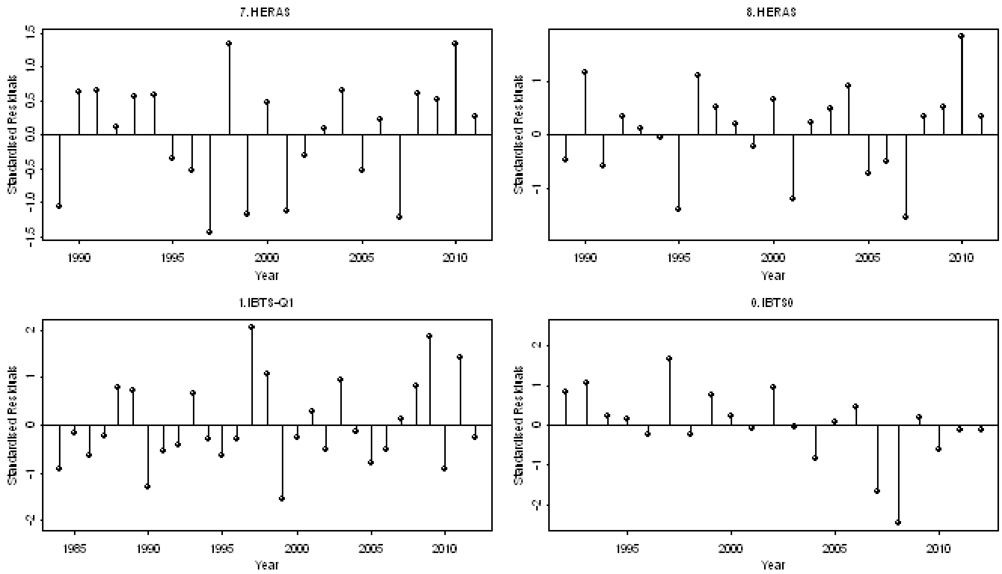


Figure 3. North Sea herring. Diagnostics of the assessment model fit to the HERAS index, IBTS-Q1 index at age 1 wr, and the IBTS0 index at age 0 wr time-series: observation vs. standardized residuals.

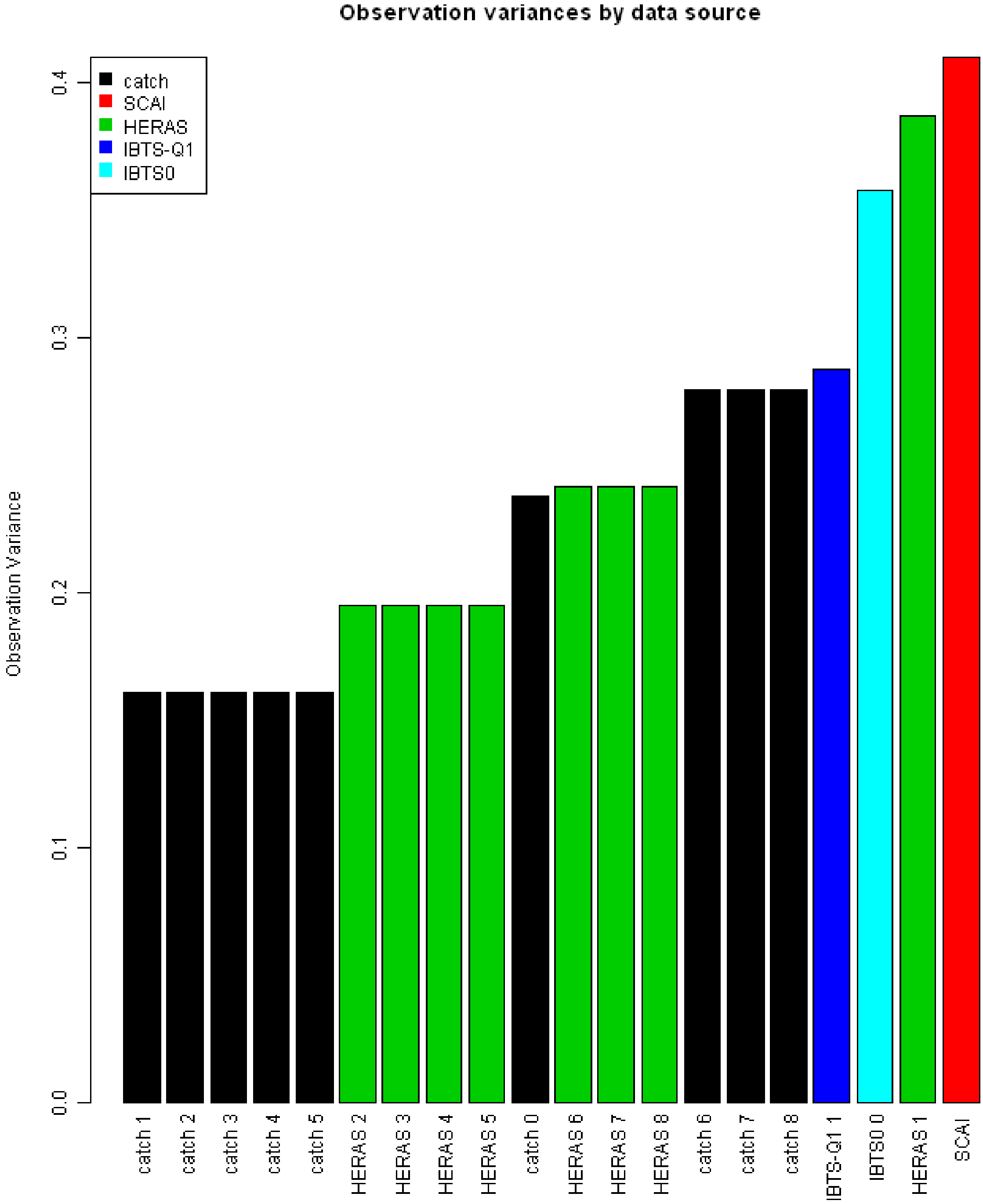


Figure 2.6.1.26. North Sea herring. Observation variance by data source as estimated by the assessment model. Observation variance is ordered from least (left) to most (right). Colours indicate the different data sources. Observation variance is not individually estimated for each data source individually thereby reducing the parameters needed to be estimated in the assessment model. In these cases of parameter bindings, observation variances have equal values.

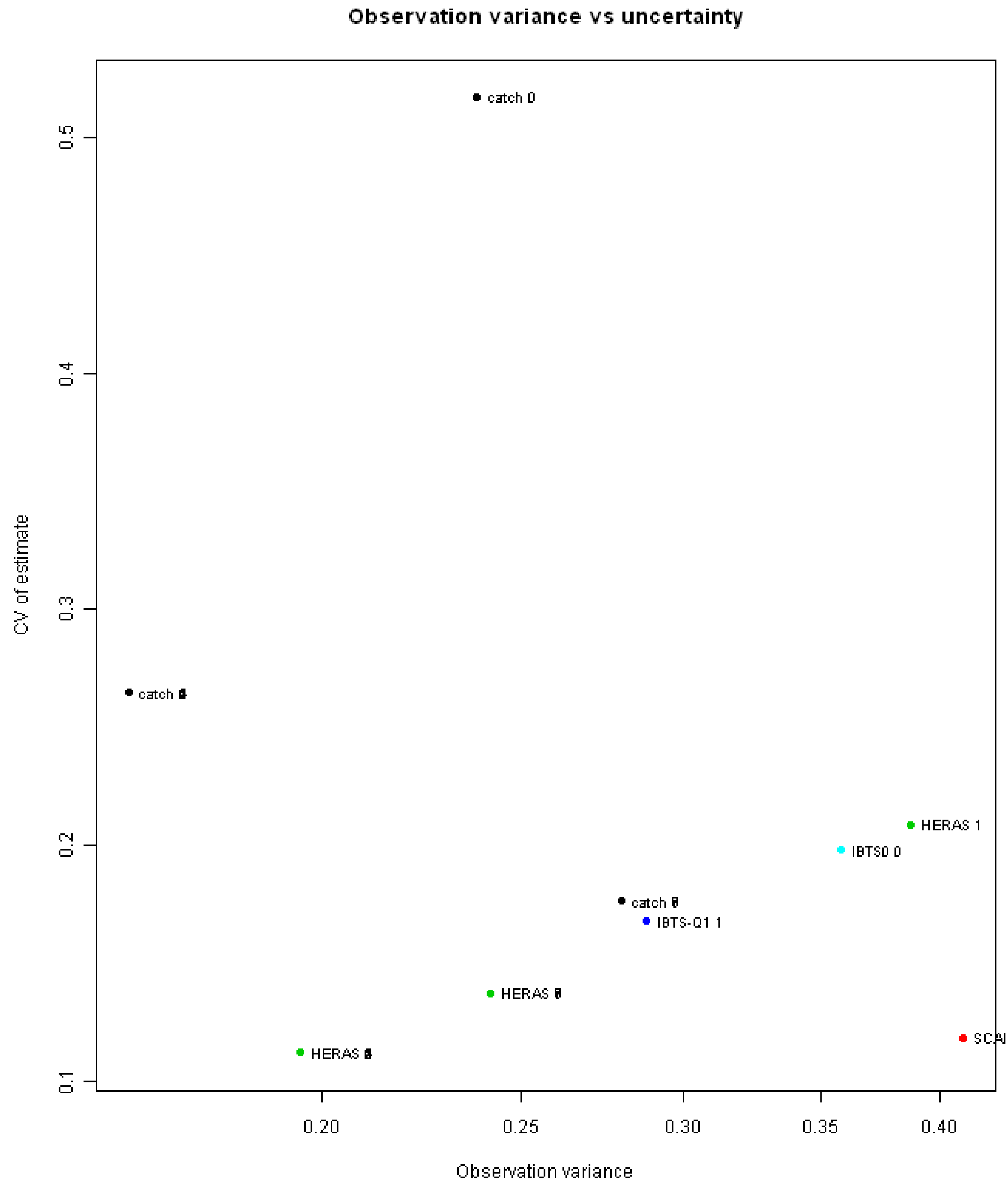


Figure 2.6.1.27. North Sea herring. Observation variance by data source as estimated by the assessment model plotted against the CV estimate of the observation variance parameter.

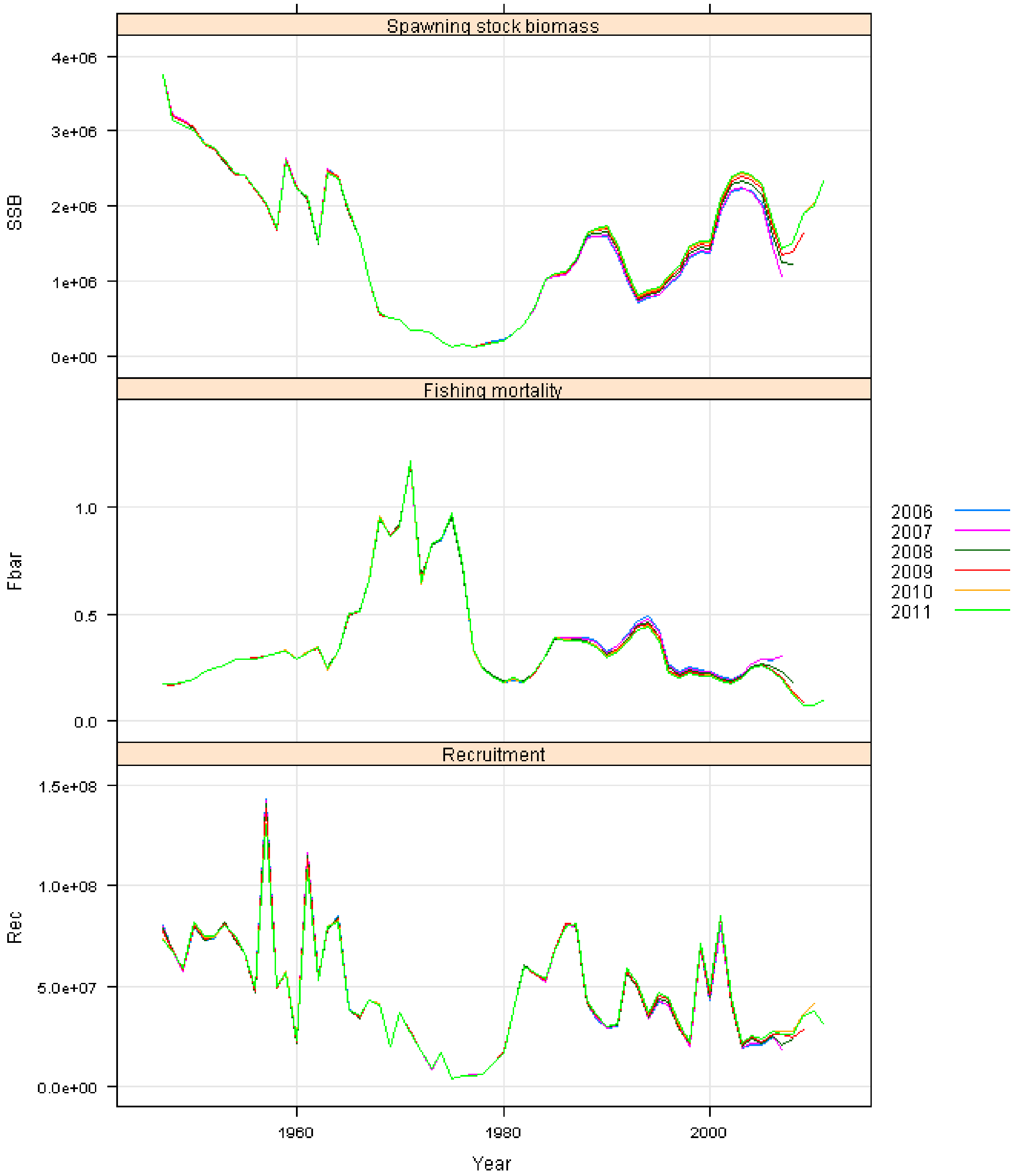


Figure 2.6.1.28. North Sea herring. Retrospective pattern of SSB (top panel) F (middle panel) and recruitment (bottom panel) for the assessments with respectively terminal years in 2011 to 2006.

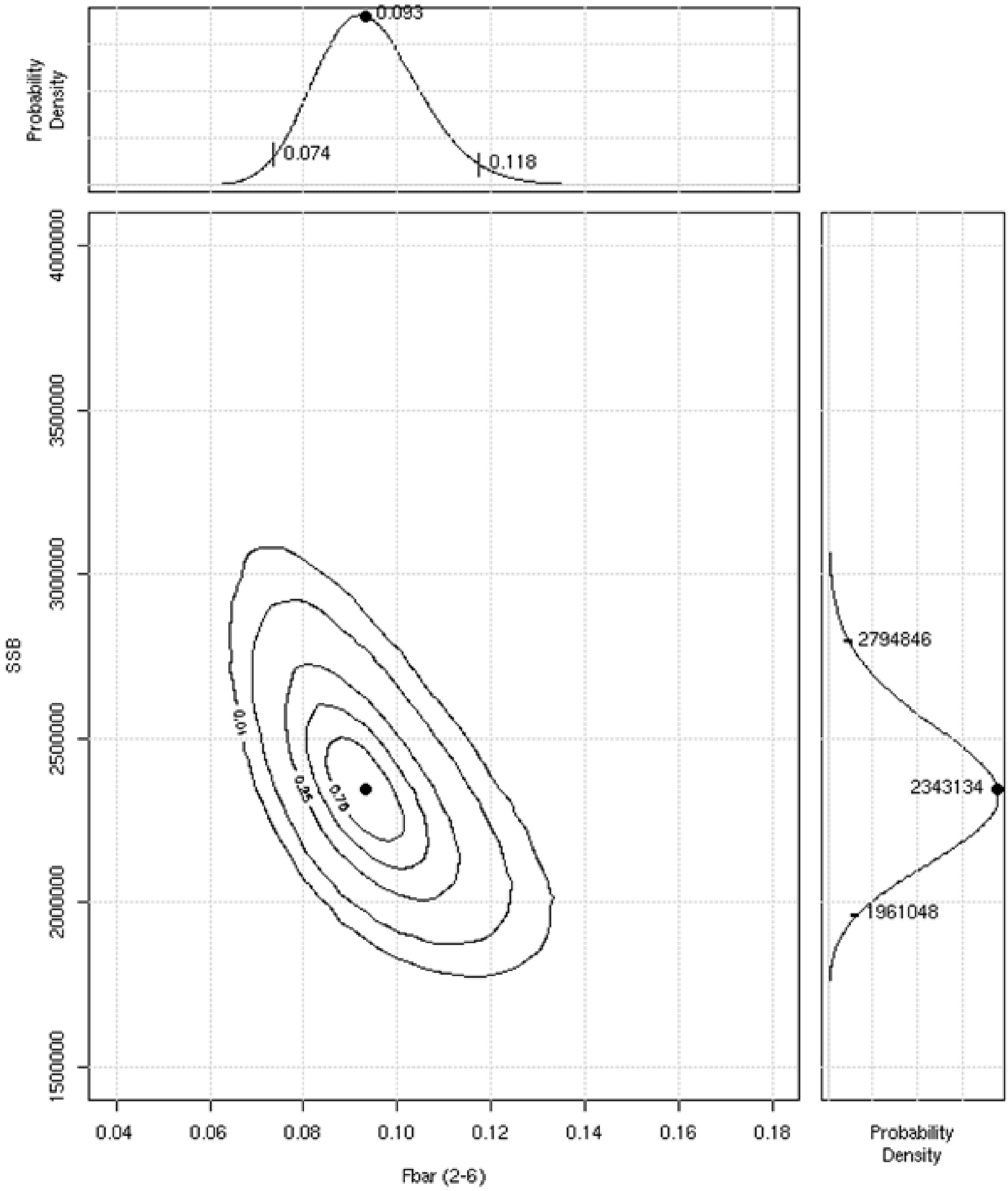


Figure 2.6.1.29. North Sea herring. Model uncertainty; distribution and quantiles of estimated SSB and F2-6 in the terminal year of the assessment. Estimates of precision are based on a parametric bootstrap from the FLSAM estimated variance / covariance estimates from the model.

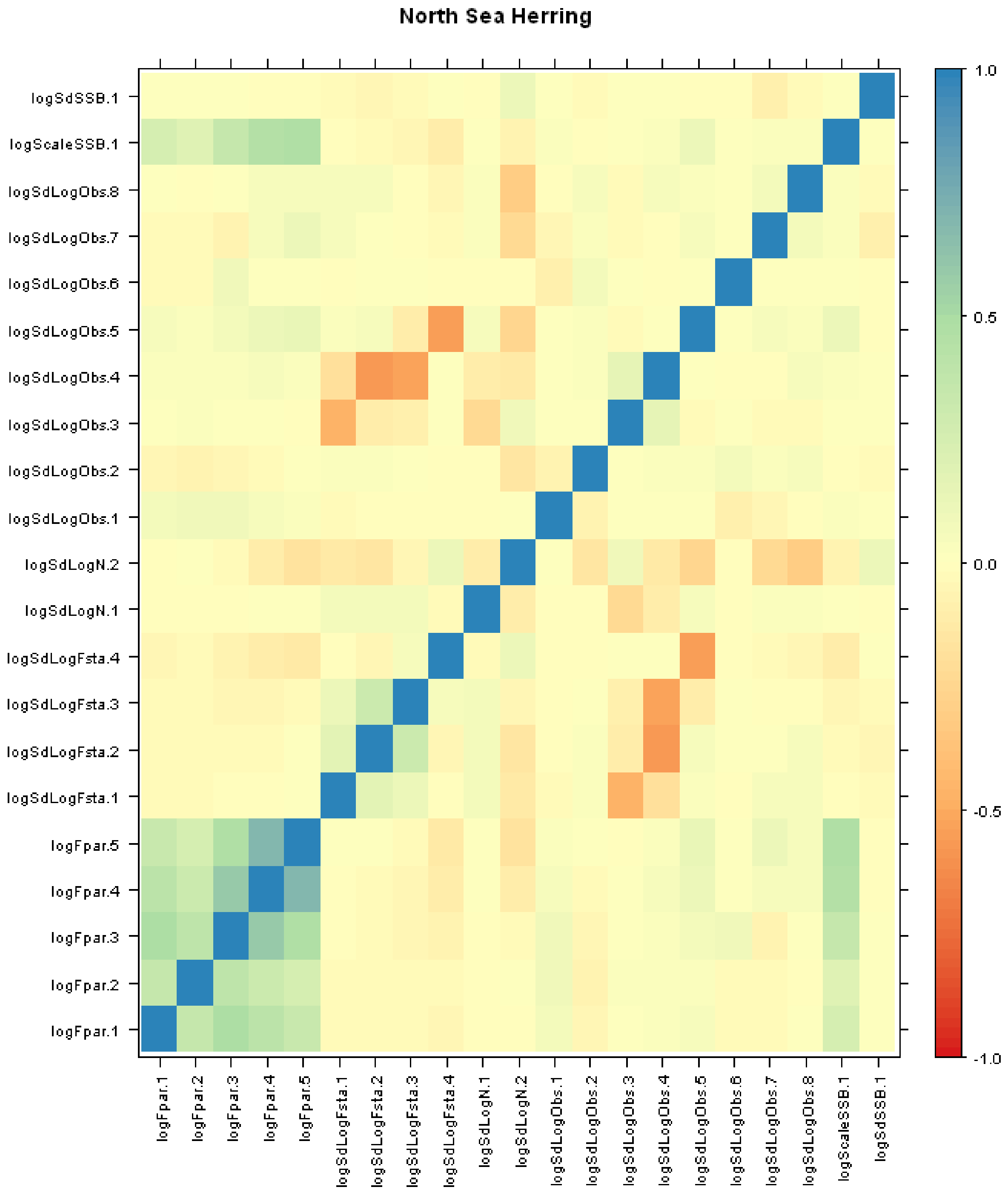


Figure 2.6.1.30. North Sea herring. Correlation plot of the FLSAM assessment model with the final set of parameters estimated in the model. The diagonal represents the correlation with the data source itself.

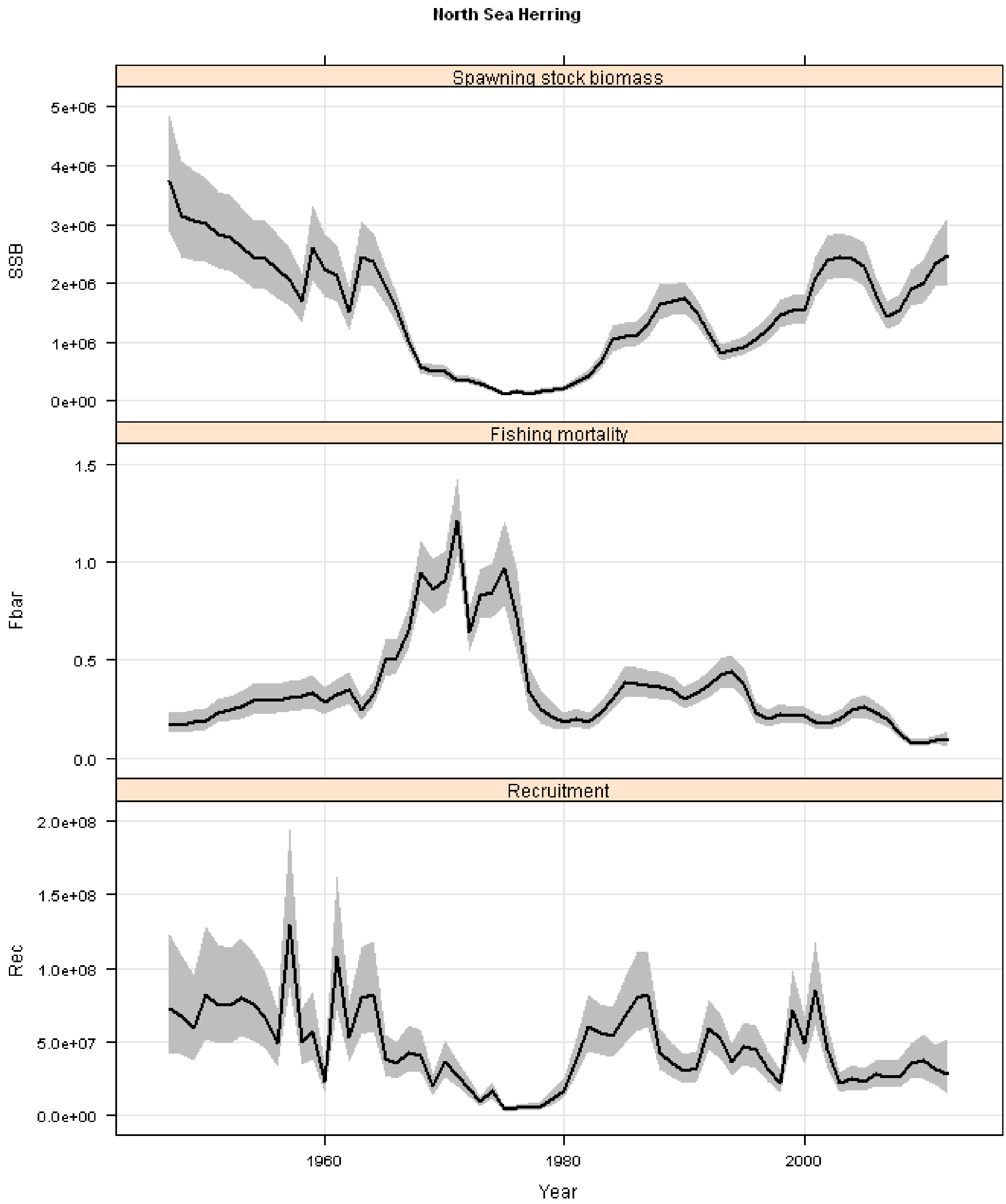


Figure 2.6.3.1 North Sea herring. Stock summary plot of North Sea herring with associated uncertainty for SSB (top panel), F ages 2-6 (middle panel) and recruitment (bottom panel).

SOURCES: ICES 2012c (HAWG).

4 North Sea haddock

DATA:

Age	0	1	2	3	4	5	6	7	8+
Natural mortality	2.05	1.65	0.40	0.25	0.25	0.20	0.20	0.20	0.20
Proportion mature	0.00	0.01	0.32	0.71	0.87	0.95	1.00	1.00	1.00

Table 13.2.2.1. Haddock in Subarea IV and Division IIIa. Numbers-at-age data (thousands) for total catch. Ages 0-7 and 8+ are used in the assessment.

	0	1	2	3	4	5	6	7	8+
1963	1359	1305779	334952	20959	13025	5780	502	653	642
1964	139777	7425	1295364	135110	9067	5348	2405	287	492
1965	649768	367501	15151	649053	29485	4659	1971	452	238
1966	1666973	1005922	25657	6423	412510	9978	1045	601	280
1967	305249	837154	89068	4863	3585	177851	2443	215	307
1968	11105	1097030	439210	19592	1947	2529	45971	325	59
1969	72559	20469	3575922	303333	7595	2410	2515	19128	231
1970	924601	266150	218362	1908087	57430	1177	1197	256	6051
1971	330673	1810248	70951	47518	400415	10372	462	195	1907
1972	240896	676000	586824	40591	21211	157994	3563	190	480
1973	59872	364918	570428	240603	6192	4467	39459	1257	299
1974	601412	1214415	175587	331871	54206	1873	1348	10917	306
1975	44946	2097588	639003	58836	108892	15809	982	620	3062
1976	167173	167693	1055190	210308	9950	31186	4996	206	899
1977	114954	250593	106012	390343	40051	4304	6262	1300	368
1978	285842	454920	146179	30321	113601	8703	1264	2075	613
1979	841439	345399	203196	41225	7402	28006	2236	262	714
1980	374959	660144	331838	72505	10392	1897	8061	598	403
1981	646419	134440	421347	142948	15204	2034	457	2498	251
1982	278705	275385	85474	299211	41383	3377	713	279	840
1983	639814	156256	251703	73666	127173	16480	1708	297	319
1984	95502	432178	167411	122783	22067	32649	3789	596	261
1985	139579	178878	533698	78633	37430	5303	7355	965	378
1986	56503	160359	178798	323638	27683	9690	1237	1810	489
1987	9419	277704	250003	47379	67864	4761	2877	545	1068
1988	10808	29420	484481	89071	13431	18579	1602	639	412
1989	10704	47271	35096	182331	18037	2631	4045	508	338
1990	55473	81335	101513	18673	56696	3732	877	1320	355
1991	123910	224136	78092	23167	3882	12524	976	401	830
1992	270758	194249	252884	32483	6550	1250	4861	454	749
1993	141209	345275	261834	108395	7105	1697	450	1138	457
1994	85966	96850	296528	100466	29609	1920	573	191	713
1995	201260	296237	85826	167801	25875	7645	511	127	142
1996	148437	46689	357942	56894	55147	7503	3052	756	125
1997	28855	132262	85854	213293	15272	15406	1892	679	103
1998	22115	82770	166732	49550	107995	5741	3562	472	171
1999	84408	80970	121249	87242	24739	39860	2338	1595	393
2000	6632	349062	88624	43351	26356	6026	8707	560	282
2001	2531	85435	632880	32343	8886	4122	1561	1305	280
2002	50754	18400	66343	242196	6547	2038	1066	549	752
2003	9072	19547	14261	44747	109063	1970	602	271	244
2004	1030	10538	18122	6574	34945	91121	723	147	137
2005	4814	10505	18394	11385	3329	25077	58753	314	145
2006	2412	106505	26164	16813	7482	2970	13685	30229	179
2007	1788	18788	155750	13899	6463	2353	1426	5973	6871
2008	1940	12595	29534	70920	4170	1441	648	311	3710
2009	8462	6044	14868	20335	71832	1348	510	313	941
2010	1557	70768	15442	17412	10721	33501	595	258	335
2011	2939	4361	60149	16676	13838	11169	21488	589	403

Table 13.2.3.1. Haddock in Subarea IV and Division IIIa. Mean weight at age data (kg) for total catch. Ages 0-7 and 8+ are used in the assessment. Mean stock weights at age are assumed to be equal to mean weight at age in the total catch

	0	1	2	3	4	5	6	7	8+
1963	0.012	0.123	0.253	0.473	0.695	0.807	1.004	1.131	1.228
1964	0.011	0.118	0.239	0.403	0.664	0.814	0.909	1.382	1.331
1965	0.010	0.069	0.226	0.366	0.648	0.845	1.193	1.173	1.696
1966	0.010	0.088	0.247	0.367	0.533	0.949	1.266	1.525	1.955
1967	0.011	0.115	0.281	0.461	0.594	0.639	1.057	1.501	1.996
1968	0.010	0.126	0.253	0.510	0.731	0.857	0.837	1.606	2.342
1969	0.011	0.063	0.216	0.406	0.799	0.891	1.031	1.094	2.178
1970	0.013	0.073	0.222	0.352	0.735	0.873	1.191	1.362	1.462
1971	0.011	0.107	0.247	0.362	0.506	0.887	1.267	1.534	1.349
1972	0.024	0.116	0.243	0.388	0.506	0.606	1.000	1.366	1.742
1973	0.044	0.112	0.241	0.373	0.586	0.649	0.725	1.044	1.731
1974	0.024	0.128	0.227	0.344	0.549	0.892	0.896	0.952	1.723
1975	0.020	0.101	0.242	0.357	0.450	0.680	1.245	1.124	1.183
1976	0.013	0.125	0.225	0.402	0.512	0.589	0.922	1.933	1.426
1977	0.019	0.109	0.243	0.347	0.602	0.614	0.803	1.181	1.900
1978	0.011	0.144	0.256	0.420	0.443	0.719	0.745	0.955	1.654
1979	0.009	0.096	0.292	0.444	0.637	0.664	0.934	1.187	1.377
1980	0.012	0.104	0.286	0.488	0.733	1.046	0.936	1.394	1.761
1981	0.009	0.074	0.265	0.477	0.745	1.148	1.480	1.180	1.688
1982	0.011	0.100	0.293	0.462	0.785	1.170	1.441	1.672	1.520
1983	0.022	0.136	0.298	0.449	0.651	0.916	1.215	1.162	1.555
1984	0.010	0.141	0.302	0.489	0.671	0.805	1.097	1.100	2.051
1985	0.013	0.149	0.280	0.481	0.668	0.858	1.049	1.459	1.937
1986	0.025	0.124	0.242	0.397	0.613	0.863	1.257	1.195	1.915
1987	0.008	0.126	0.267	0.406	0.615	1.029	1.276	1.433	1.673
1988	0.024	0.166	0.217	0.418	0.590	0.748	1.284	1.424	1.783
1989	0.027	0.198	0.304	0.372	0.606	0.811	0.982	1.364	1.756
1990	0.044	0.195	0.293	0.434	0.474	0.772	0.971	1.168	1.860
1991	0.029	0.179	0.322	0.473	0.640	0.651	1.042	1.232	1.583
1992	0.018	0.108	0.307	0.486	0.748	1.016	0.896	1.395	1.784
1993	0.010	0.116	0.282	0.447	0.680	0.894	1.173	1.102	1.753
1994	0.017	0.116	0.251	0.420	0.597	0.943	1.209	1.570	1.616
1995	0.013	0.102	0.301	0.366	0.597	0.768	1.118	1.444	1.866
1996	0.019	0.128	0.248	0.398	0.491	0.795	0.879	0.855	1.924
1997	0.021	0.134	0.286	0.362	0.591	0.621	0.921	0.974	1.893
1998	0.023	0.154	0.258	0.405	0.442	0.660	0.769	1.113	1.345
1999	0.023	0.168	0.244	0.365	0.480	0.500	0.691	0.785	0.838
2000	0.048	0.120	0.256	0.370	0.501	0.618	0.653	1.104	1.232
2001	0.021	0.110	0.217	0.315	0.472	0.706	0.762	0.975	1.769
2002	0.016	0.100	0.270	0.329	0.541	0.745	0.931	0.849	1.637
2003	0.030	0.097	0.214	0.329	0.406	0.682	0.791	1.158	1.635
2004	0.053	0.177	0.256	0.410	0.404	0.445	0.744	1.070	1.646
2005	0.055	0.200	0.295	0.387	0.522	0.484	0.521	0.882	1.345
2006	0.048	0.122	0.289	0.358	0.470	0.545	0.546	0.549	1.270
2007	0.039	0.163	0.227	0.423	0.498	0.624	0.718	0.716	0.753
2008	0.038	0.181	0.257	0.365	0.607	0.701	0.842	1.109	0.904
2009	0.048	0.208	0.306	0.323	0.386	0.718	0.908	1.008	1.186
2010	0.030	0.084	0.302	0.412	0.457	0.467	0.704	0.987	1.633
2011	0.017	0.174	0.260	0.400	0.433	0.466	0.527	0.637	0.906

Table 13.2.6.1. Haddock in Subarea IV and Division IIIa. Data available for calibration of the assessment. Only those data used in the final assessment are shown here.

EngGFS Q3 GRT						
Years 1977 – 1991	Ages 0 - 6	Period 0.5 – 0.75				
53.48	6.681	3.206	6.163	0.925	0.073	0.091
35.827	13.688	2.618	0.239	2.22	0.214	0.005
87.551	29.555	5.461	0.872	0.108	0.438	0.035
37.403	62.331	16.732	2.57	0.273	0.042	0.142
153.746	17.318	43.91	7.557	0.742	0.064	0.003
28.134	31.546	7.98	11.8	1.025	0.237	0.098
83.193	21.82	10.952	2.143	2.174	0.265	0.04
22.847	59.933	6.159	3.078	0.418	0.478	0.103
24.587	18.656	23.819	2.111	0.698	0.196	0.128
26.6	14.974	4.472	3.382	0.277	0.175	0.038
2.241	28.194	4.31	0.532	0.686	0.048	0.033
6.073	2.856	18.352	1.549	0.16	0.279	0.041
9.428	8.168	1.447	3.968	0.253	0.031	0.061
28.188	6.645	1.983	0.287	0.878	0.048	0.026
26.333	11.505	0.961	0.231	0.048	0.219	0.005

EngGFS Q3 GOV						
Years 1992 – 2011	Ages 0 – 6	Period 0.5 – 0.75				
246.059	58.746	29.133	1.742	0.146	0.037	0.251
40.336	73.145	17.435	4.951	0.176	0.048	0.000
279.344	23.990	26.992	2.511	0.894	0.058	0.003
53.435	113.775	13.223	11.032	0.827	0.275	0.021
61.301	26.747	43.044	3.603	2.052	0.207	0.088
40.653	45.346	12.608	19.968	0.719	0.718	0.067
15.747	26.497	16.778	4.079	4.141	0.226	0.141
626.610	16.551	8.404	3.663	1.258	1.201	0.040
92.139	249.813	4.528	1.634	0.740	0.336	0.350
1.097	28.622	96.498	3.039	0.828	0.350	0.135
2.721	3.954	22.559	60.583	0.542	0.097	0.153
3.199	6.015	1.247	13.967	45.079	0.719	0.026
3.398	6.599	3.864	0.448	6.836	17.406	0.217
122.383	9.740	5.992	2.584	1.249	6.617	3.654
12.838	54.403	3.226	1.137	0.426	0.148	0.861
8.463	10.628	43.401	1.402	0.624	0.092	0.078
2.613	6.494	5.801	18.534	0.727	0.266	0.137
28.978	5.532	6.781	4.636	7.147	0.108	0.099
3.065	46.229	2.959	2.103	2.175	3.716	0.284
0.549	2.792	35.592	1.785	1.396	1.168	3.147

Table 13.2.6.1. cont. Haddock in Subarea IV and Division IIIa. Data available for calibration of the assessment. Only those data used in the final assessment are shown here.

ScoGFS Aberdeen Q3						
Years 1982 - 1997	Ages 0 - 6	Period 0.5 – 0.75				
1235	2488	996	1336	115	7	2
2203	1813	1611	372	455	53	12
873	4367	788	336	55	65	9
818	1976	2981	232	103	14	22
1747	2329	574	598	36	27	4
277	2393	704	106	128	8	5
406	467	1982	170	27	23	2
432	886	214	574	31	4	7
3163	1002	240	32	103	7	1
3471	1705	178	21	5	16	2
8270	3832	963	48	8	3	8
859	5836	1380	269	6	4	1
13762	1265	2080	210	53	2	0.5
1566	8153	734	926	74	28	2
1980	2231	4705	231	206	22	6
972	2779	849	1397	66	56	6

ScoGFS Q3 GOV						
Years 1998 - 2011	Ages 0 - 6	Period 0.5 – 0.75				
3280	6349	1924	490	511	24	18
66067	1907	1141	688	197	164	6
11902	30611	460	221	130	73	27
79	3790	11352	179	65	40	18
2149	675	2632	6931	70	37	18
2159	1172	307	2092	4344	22	17
1729	1198	547	101	819	1420	9
19708	761	657	153	112	347	483
2280	7275	272	158	33	14	73
1119	1810	5527	117	57	11	5
1885	733	1002	2424	28	24	6
9015	877	547	469	1185	37	8
115	8328	680	297	303	811	4
317	252	5192	284	127	101	285

Table 13.2.6.1. cont. Haddock in Subarea IV and Division IIIa. Data available for calibration of the assessment. Only those data used in the final assessment are shown here.

IBTS Q1 (backshifted)				
Years 1982 - 2011	Ages 0 - 4	Period 0.99 – 1.0		
302.278	403.079	89.463	116.447	13.182
1072.285	221.275	127.77	20.41	20.9
230.968	833.257	107.598	32.317	3.575
573.023	266.912	303.546	17.888	6.49
912.559	328.062	45.201	58.262	4.345
101.691	677.641	97.149	12.684	13.965
219.705	98.091	274.788	16.653	2.113
217.448	139.114	32.997	50.367	3.163
680.231	134.076	25.032	4.26	8.476
1141.396	331.044	17.035	3.026	0.664
1242.121	519.521	152.384	8.848	1.076
227.919	491.051	97.656	23.308	1.566
1355.485	201.069	176.165	24.354	5.286
267.411	813.268	65.869	46.691	7.734
849.943	353.882	466.731	24.987	15.238
357.597	420.926	103.531	112.632	8.758
211.139	222.907	127.064	48.217	36.65
3471.461	99.409	44.915	23.230	14.879
890.441	1994.289	61.581	11.612	6.588
57.073	471.432	1302.933	8.732	6.714
89.991	39.267	241.529	532.024	5.354
71.877	79.617	35.471	173.617	329.991
69.976	60.993	32.625	10.997	61.287
1212.163	47.784	28.576	8.977	4.404
109.095	963.357	36.577	15.511	3.191
60.075	106.486	239.315	14.783	1.554
74.687	140.045	102.941	135.663	2.523
686.096	72.383	68.144	51.624	91.102
46.416	772.865	98.972	35.182	46.947
14.468	55.952	396.448	20.685	13.202

MODEL

The final FLXSA assessment uses the following settings. Note that the earlier XSA assessment did not use a power model on any ages. Due to a coding error, the FLXSA implementation used from 2008-2010 included a power model assumption for age-0. This was noted and corrected at the 2011 WG meeting. In all other respects, the FLXSA settings are the same as those used last year (except for the addition of another year of data). XSA and FLXSA settings from a number of recent years are compared in the Stock Annex.

Assessment year		2012
q plateau		6
Tuning fleet year ranges	EngGFS Q3	77-91; 92-11
	ScoGFS Q3	82-97; 98-11
	IBTS Q1*	82-11
Tuning fleet age ranges	EngGFS Q3	0-7
	ScoGFS Q3	0-7
	IBTS Q1*	0-4
*Backshifted		

FLXSA.control(tol = 1e-9, maxit = 200, min.nse = 0.3, fse = 2.0, rage = -1, qage = 6, shk.n = TRUE, shk.f = TRUE, shk.yrs = 5, shk.ages= 3, window = 100, tsrange = 99, tspower = 0)

Log-catchability residuals are given in Figure 13.3.5.1, and a comparison of fleet-based contributions to survivors in Figure 13.3.5.2. Summary plots for the final assessment are given in Figure 13.4.1. A retrospective analysis, shown in Figure 13.4.2., indicates very little retrospective bias in the assessment.

BASE FIT

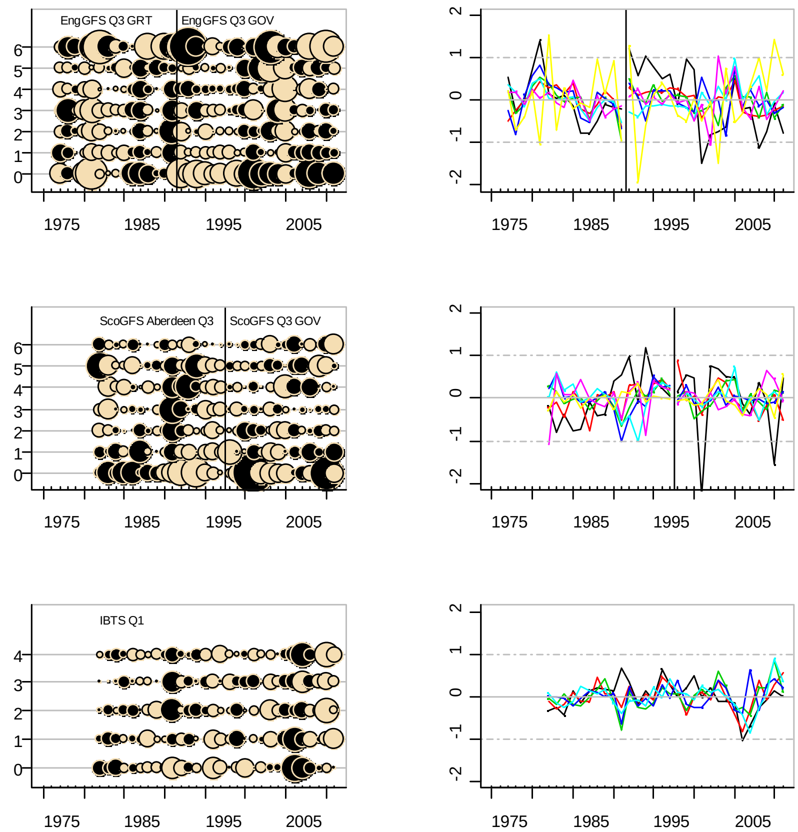


Figure 13.3.5.1. Haddock in Subarea IV and Division IIIa. Log-catchability residuals for final XSA assessment. Both EngGFS and ScoGFS are split when used as tuning indices, and this split is shown by vertical lines on the relevant plots.

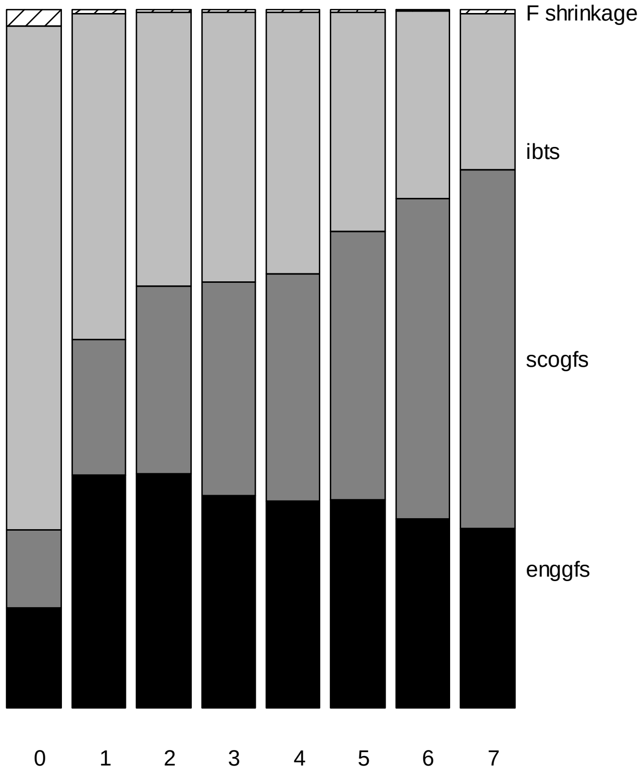


Figure 13.3.5.2. Haddock in Subarea IV and Division IIIa. Contribution to survivors' estimates in final XSA assessment.

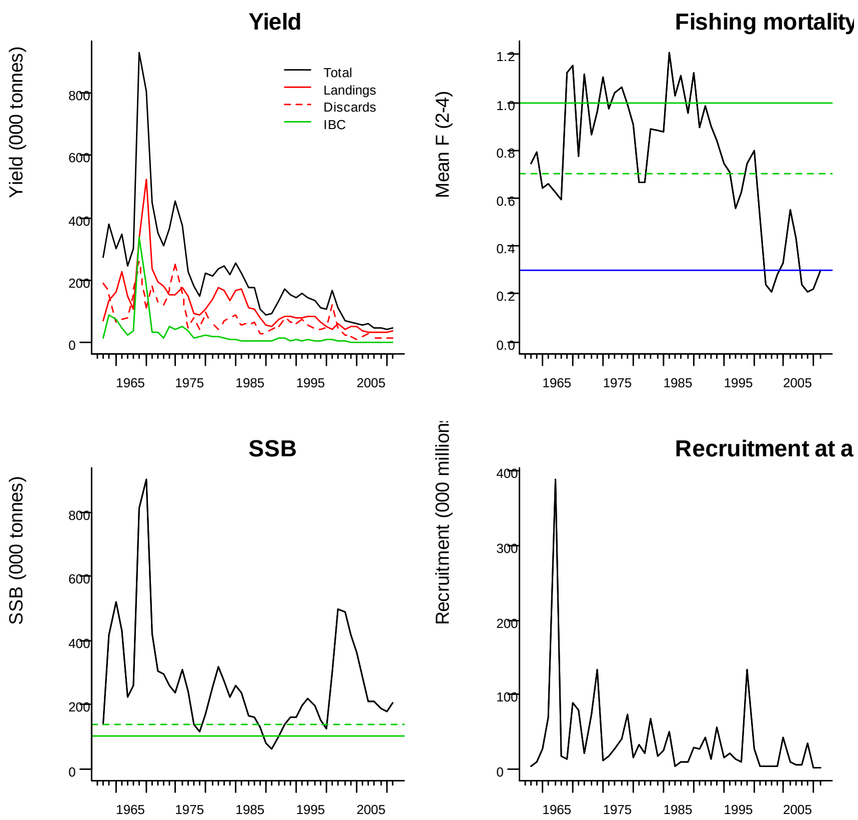


Figure 13.4.1. Haddock in Subarea IV and Division IIIa. Summary plots for final XSA assessment. Dotted horizontal green lines indicate F_{pa} (top right plot) and B_{pa} (bottom left plot), while solid horizontal green lines indicate F_{lim} and B_{lim} in the same plots. The solid blue line in the top right plot represents the target F (0.3) in the EU-Norway management plan, which is also considered to be a proxy for F_{msy}.

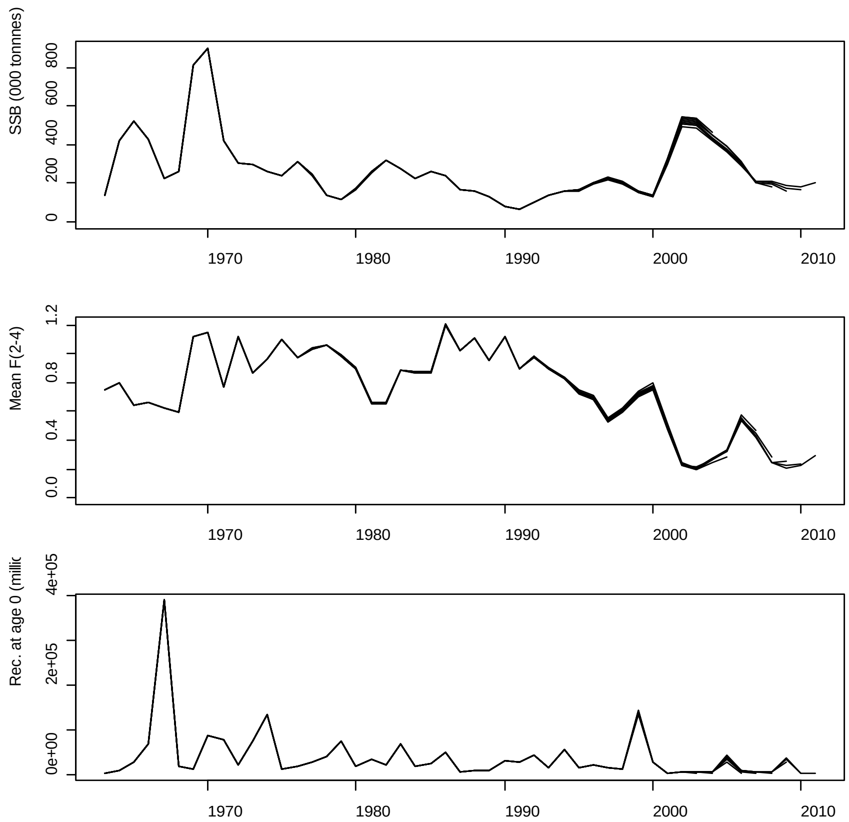


Figure 13.4.2. Haddock in Subarea IV and Division IIIa. Eight-year retrospective plots for final XSA assessment.

SOURCES: ICES 2012b (WGNSSK).

5 Northern hake

DATA:

Input data for SS3

The overall fishery prosecuting the northern stock of hake has been categorized into 7 "fleets", 4 of which use trawl gears, whereas the remaining three use gillnet, longline and a combination of several gears (Table 4). For each fleet, estimates of landings in weight and length–frequency distributions are available. For some fleet only, discards in weight and length–frequency distribution are used.

Table 4. Fleets characteristics and data available for SS3 (Length–Frequency distribution (LFD) and weight of landings and discards).

Fleets	Description	FU	Landings (quarterly)	Discards (quarterly)
SPTRAWL7*	Spanish trawl in VII	04	Yearly : 1978-1989 (LFD+tonnage) Quarterly: 1990-2010(LFD+tonnage)	1994, 1999, 2000, 2003–2008 (LFD + Weight)
FRNEP8	French trawl targeting *Nephrops* in VIII	09	Yearly : 1978-1989 (tonnage) Yearly : 1985-1989 (LFD) Quarterly : 1990-2010 (LFD+tonnage)	2003–2008 (LFD + Weight)
SPTRAWL8	Spanish trawl in VIII	14	Yearly : 1978-1989 (LFD+tonnage) Quarterly: 1990-2010(LFD+tonnage)	2005–2008 (LFD + Weight)
TRAWLOTH	All other trawl	05 + 06 + 08 + 10	Yearly : 1978-1989 (LFD+tonnage) Quarterly: 1990-2010 (LFD+tonnage)	
GILLNET	Gillnet all countries	03 + 13	Yearly : 1978-1989 (LFD+tonnage) Quarterly: 1990-2010 (LFD+tonnage)	
LONGLINE	Longline all countries	01 + 02 + 12	Yearly : 1978-1989 (LFD+tonnage) Quarterly: 1990-2010 (LFD+tonnage)	
OTHERS	Everything else all countries	15 + 16 + 00	Yearly : 1978-1989 (LFD+tonnage) Quarterly: 1990-2010 (LFD+tonnage)	

*** FU04 (and consequently SPTRAWL7) landings and discards contain small amount from area VI as, in some cases, the sampling programme does not allow to make the distinction between area VII and VI.**

For the two Spanish trawl fisheries, it is thought that discarding became much more substantial starting from 1998. For the French *Nephrops* fishery, discarding is thought to have occurred already from 1978. The remaining 4 fisheries (TRAWLOTH, GILL-NET, LONGLINE, OTHERS) are assumed not to discard any fish.

Several surveys provide relative abundance indices of abundance and length distributions (Table 5).

Table 5. List of surveys used in SS3.

Surveys	Area	Years	Quarter
EVHOE-WIBTS-Q4	Bay of Biscay and Celtic Sea	1997–(y*-1)	4
RESSGASC	Bay of Biscay	1985–1997 1998–2001	1, 2 ,3 and 4 2 and 4
SPPGFS-WIBTS-Q4	Porcupine Bank	2001–(y*-1)	3
IGFS-WIBTS-Q4	North, West and South of Ireland	2003–(y*-1)	4

* y = assessment year

No commercial fleet tuning data are used.

MODEL:

The assessment is a length-based approach using the Stock Synthesis assessment model. This approach allows direct use of the quarterly length composition data and explicit modelling of a retention process that partitions total catch into discarded and retained portions.

The underlying population can be partitioned in time to include as many seasons within a year as required. This is important where temporal aspects of biology (like growth in the case of hake), or fishing activity dictate finer than annual-level representation, however all the basic input data must then be partitioned to the level of the underlying dynamics.

Recruitment is based on a Beverton–Holt function parameterized to include the equilibrium level of unexploited recruitment (R0) and the steepness (h) parameter, describing the fraction of the unexploited recruits produced at 20% of the equilibrium spawning biomass level. Annual deviations can be estimated for any portion of the modelled time period (or the whole period), and the expected recruitments are bias-corrected to reflect the level of variability (sigmaR, an input quantity) allowed in these deviations.

Growth is described through a von Bertalanffy growth curve with the distribution of lengths for a given age assumed to be normally distributed. The CV of these distributions is structured to include two parameters which can be estimated or fixed, defining the spread of lengths at a young and old age with a linear interpolation between. In addition to growth, the relationships between weight and length, fecundity and length as well as maturity-at-length are all generalized to allow parameters to be estimated or fixed, temporally invariant or not. All model parameters can vary over time either as a function of annual deviations about a mean level, user defined ‘blocks’ of years in which the parameters differ or a combination of the two.

All model expectations for comparison with data are generated as observations from a ‘fleet’, either a fishery or a survey/index of abundance. Each fleet has unique characteristics defining relative selectivity across age or size, and can be structured to remove catch or collect observations at a particular time of the year or season. All fleets may be considered completely independent, or parameters may be shared among fleets where appropriate via ‘mirroring’.

A suite of selectivity curves including logistic-based shapes of up to eight parameters, power functions and nonparametric forms can be explored through relatively simple modification of the input files.

The kinds of data that model expectations can be fit to include: absolute or relative abundance, length–frequency distributions, age frequency distributions (either total or conditional by length), length-at-age, body weight, and proportion discard. Each of these can be from the retained, discarded or total removals by a specific fleet. Each source has an error distribution (either normal, lognormal or multinomial) associated with it, described by either an input sample size or standard deviation.

SS3 settings (input data and control files):

Years: 1978 to present, 1 area, 4 seasons, both sexes combined.

Length Frequency Distribution are available on a yearly basis from 1978 to 1989 and on a quarterly basis from 1990 to present. No age data are used.

Initial equilibrium catch: annual average of 5 years (1978–1982) for each fishery.

Variability for landings, discards and survey abundance indices are entered as standard deviation in log-scale, as follows:

Landings (tonnes): 10% variability

Discards (tonnes): 50% variability

Survey abundance indices: variability externally estimated. As the latter represents only the surveys internal variability, extra variability was added (increment to CV in SS3 control file) according to how representative each survey was felt to be of stock abundance (i.e. the area coverage of the survey as compared to the spatial distribution of the stock). Surveys' CV were increased by 0.1 (EVHOE-WIBTS-Q4), 0.2 (RESSGASC, IGFS-WIBTS-Q4), 0.3 (SPPGFS-WIBTS-Q4).

Length compositions were assigned the following sampling sizes in the SS3 input data file, on the basis of how representative they were felt to be :

Landings: 125 for all fleets, except SPTRAWL7 for which 50 was used for 1978-1997 and 200 was used from 1998 onwards

Discards: 50 for SPTRAWL7 and SPTRAWL8, 80 for FRNEP8

Surveys: 125

The following multipliers were subsequently applied to the latter sample sizes in the SS3 control file:

Landings and discards: 0.5 for all fleets, except LONGLINE to which a factor of 1 was applied

Surveys: 1 (EVHOE-WIBTS-Q4), 0.525 (RESSGASC, IGFS-WIBTS-Q4), 0.35 (SPPGFS-WIBTS-Q4)

M=0.4.

von Bertalanffy growth function: Linf=130 cm, K and mean length-at-age 0.75 estimated. Same growth parameters apply to all fish (across morphs, years, etc.)

Maturity ogive: length-based logistic, externally estimated and assumed constant over time

Recruitment allocation for Quarter 2 to 3 estimated with respect to Quarter 1. Quarter 2 allocation is time-varying, with annual deviates. Quarter 4 allocation set to 0.

Beverton–Holt stock–recruitment relationship: steepness h=0.999, sigma_R=0.4, R0 estimated.

Recruitment deviations starting in 1970.

F estimation method = 2 (F by fishery and quarter treated as unknown parameters)

Surveys catchabilities constant over time.

RESSGASC survey entered as 4 separate surveys (1 per quarter). Catchabilities are quarter-specific but all quarters use the same selectivity-at-length.

Selectivity only length-based (no age selectivity considered)

Selectivity-at-length uses Pattern 24 (double normal function, with 6 parameters) for fleets SPTRAWL7, FRNEP8, SPTRAWL8, GILLNET, LONGLINE and all surveys. TRAWLOTH and OTHERS use Pattern 1 (logistic function, with 2 parameters). When Pattern 24 is used, parameter P5 is not used except for SPTRAWL7 and SPTRAWL8.

Selectivity-at-length constant over all years.

Retention patterns for fisheries with discards: length-logistic with asymptotic retention = 1 in all cases, and unknown L50 and slope. For SPTRAWL7 and SPTRAWL8, two different patterns of retention over time are assumed, one for years 1978–1997 and the another one from 1998 onwards.

BASE FIT:

Residuals of the fits to the surveys log(abundance indices) are presented in Figure 3.4. The greater part of the upward trend in relative abundance observed in all three contemporary trawl surveys (EVHOE-WIBTS-Q4, SpPGFS-WIBTS-Q4 and IGFS-WIBTS-Q4) has been captured by the model but there is still some residual trend apparent in the graphs. Pearson residuals of their length frequency distributions show a "fairly random" behaviour with no particular trend or lack of fit (Figure 3.5, where blue and red circles denote positive and negative residuals, respectively). Residuals of the length frequency distributions of the commercial fleets landings and discards (not presented in this report but available on the Share-point) show some patterns, as mentioned in the benchmark report (ICES, 2010).

The assessment model includes estimation of size-based selectivity functions (selection pattern at length) for commercial fleets and for population abundance indices (surveys). For commercial fleets total catch is subsequently partitioned into discarded and retained portions. Figure 3.6 presents selectivity (for the total catch; black lines) and retention functions by fleet (red and green lines) estimated by the model. For the Spanish trawl fleets in VII and VIII, a retention function is estimated for years 1978-1997 and another one for 1998-present. This change in retention was clearly noticed when examining the length frequency distributions of the landings and might be due to a stricter enforcement of the minimum landing size. For the French trawlers targeting Nephrops in VIII, the same retention function is assumed throughout the entire assessment period (1978-present). The assessment currently assumes that the other commercial fleets do not discard fish, although this assumption should be revised as more information on discards becomes available.

The assessment model also estimates the growth rate K from a von Bertalanffy growth model (with L infinite fixed at 130 cm, in accordance with the Stock Annex). This year K is estimated at 0.177, close to last year's estimate.

The retrospective analysis (Figure 3.7) shows that for F and SSB the model results are not very sensitive to the exclusion of recent data. For 2006 and 2007, the patterns observed indicate a tendency to underestimate SSB and overestimate F over the last years, but for more recent years (2008 to 2010), the trends in F and SSB remain fairly stable over the whole series. Some retrospective pattern is observed for recruitment but here again, the decreasing trend after 2008 is relatively well defined.

F2010 (average of F-at-length over lengths 15-80 cm) was estimated at 0.39 and SSB at 131 075 t.

Summary results from SS3 are given in Figure 3.8.

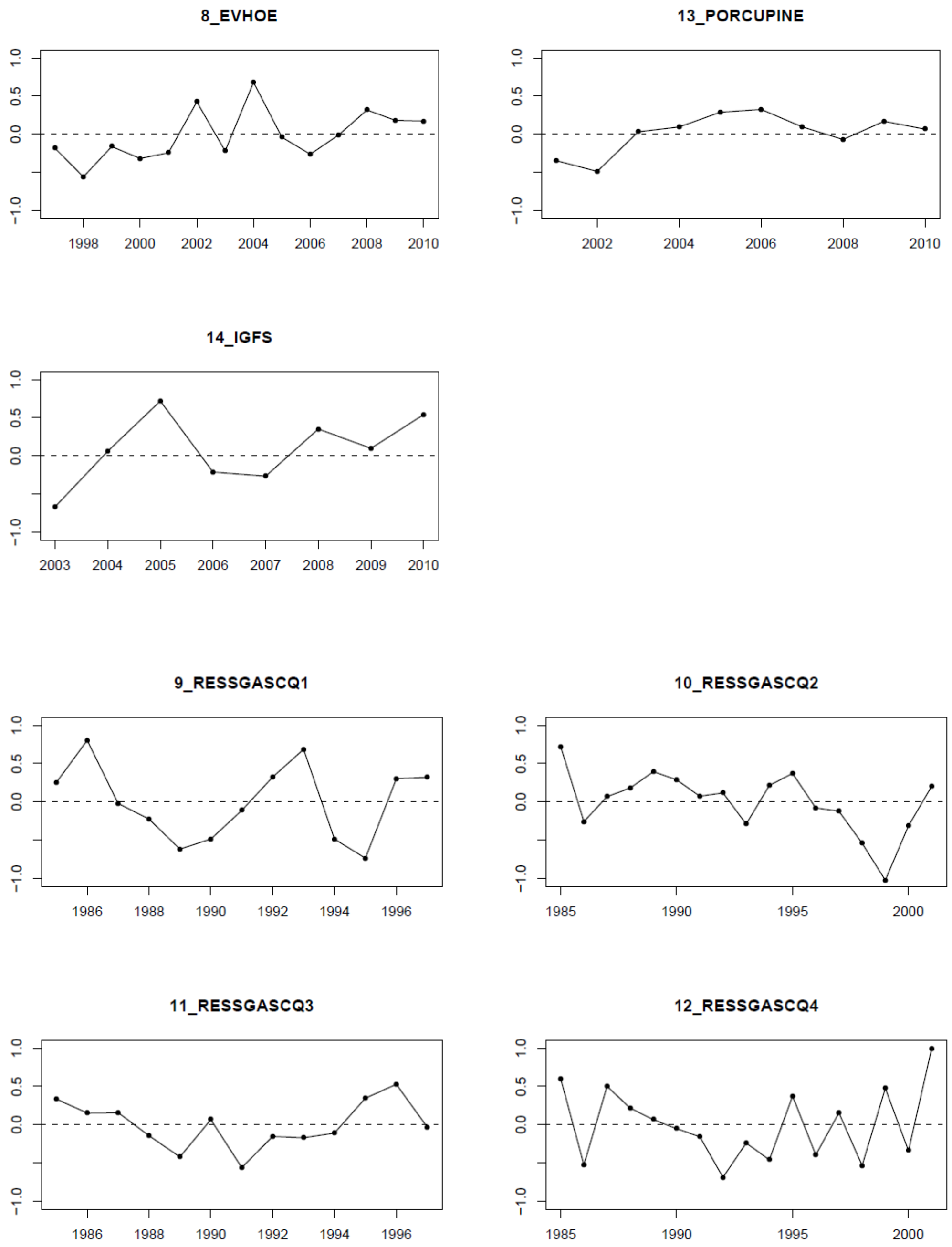


Figure 3.4. Hake in Division IIIa, Subareas IV, VI and VII and Divisions VIIIa,b,d (Northern stock). Residuals of the fits to the surveys log(abundance indices). For RESSGASC, fits are by quarter.

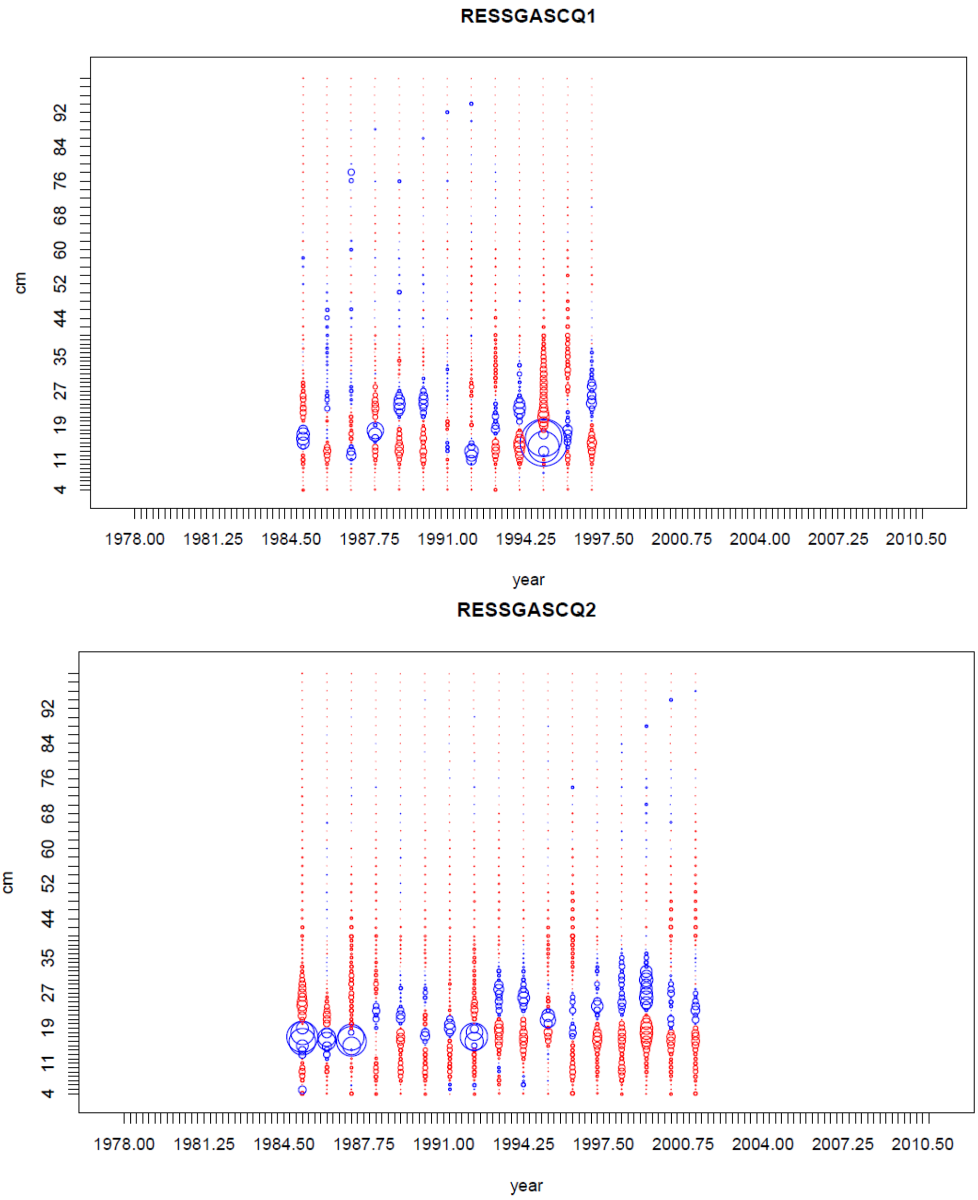
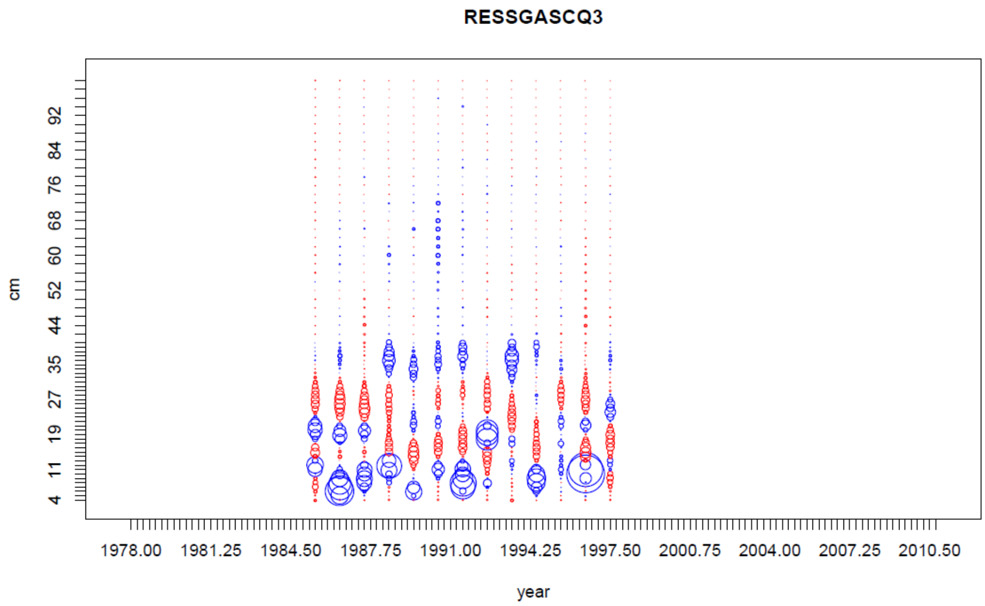


Figure 3.5. Hake in Division IIIa, Subareas IV, VI and VII and Divisions VIIIa,b,d (Northern stock). Pearson residuals of the fit to the length distributions of the surveys abundance indices. For RESSGASC, fits are by quarter. Blue and red denote positive and negative residuals, respectively.



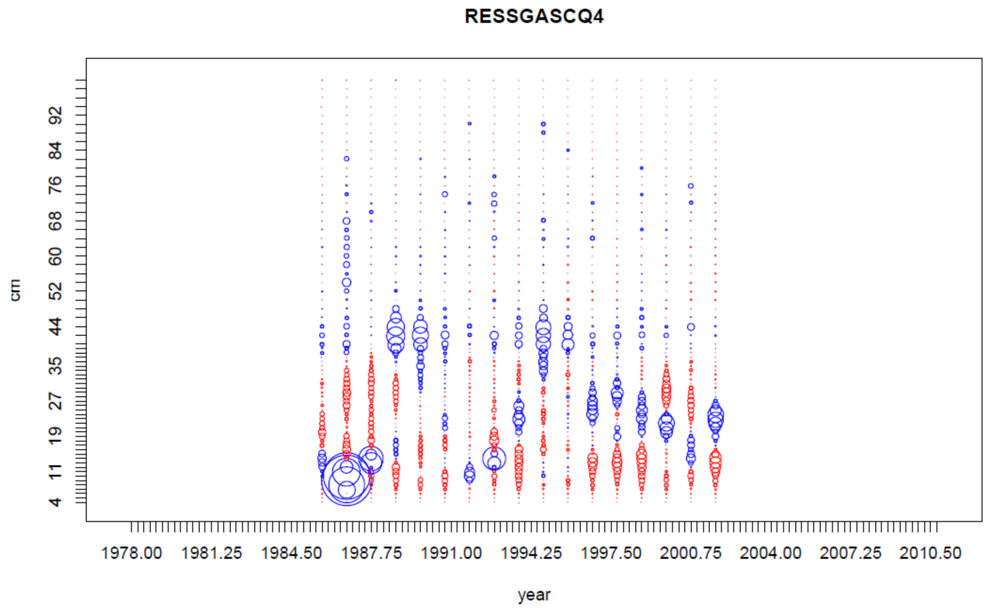


Figure 3.5 (continued). Hake in Division IIIa, Subareas IV, VI and VII and Divisions VIIIa,b,d (Northern stock). Pearson residuals of the fit to the length distributions of the surveys abundance indices. For RESSGASC, fits are by quarter. Blue and red denote positive and negative residuals, respectively.

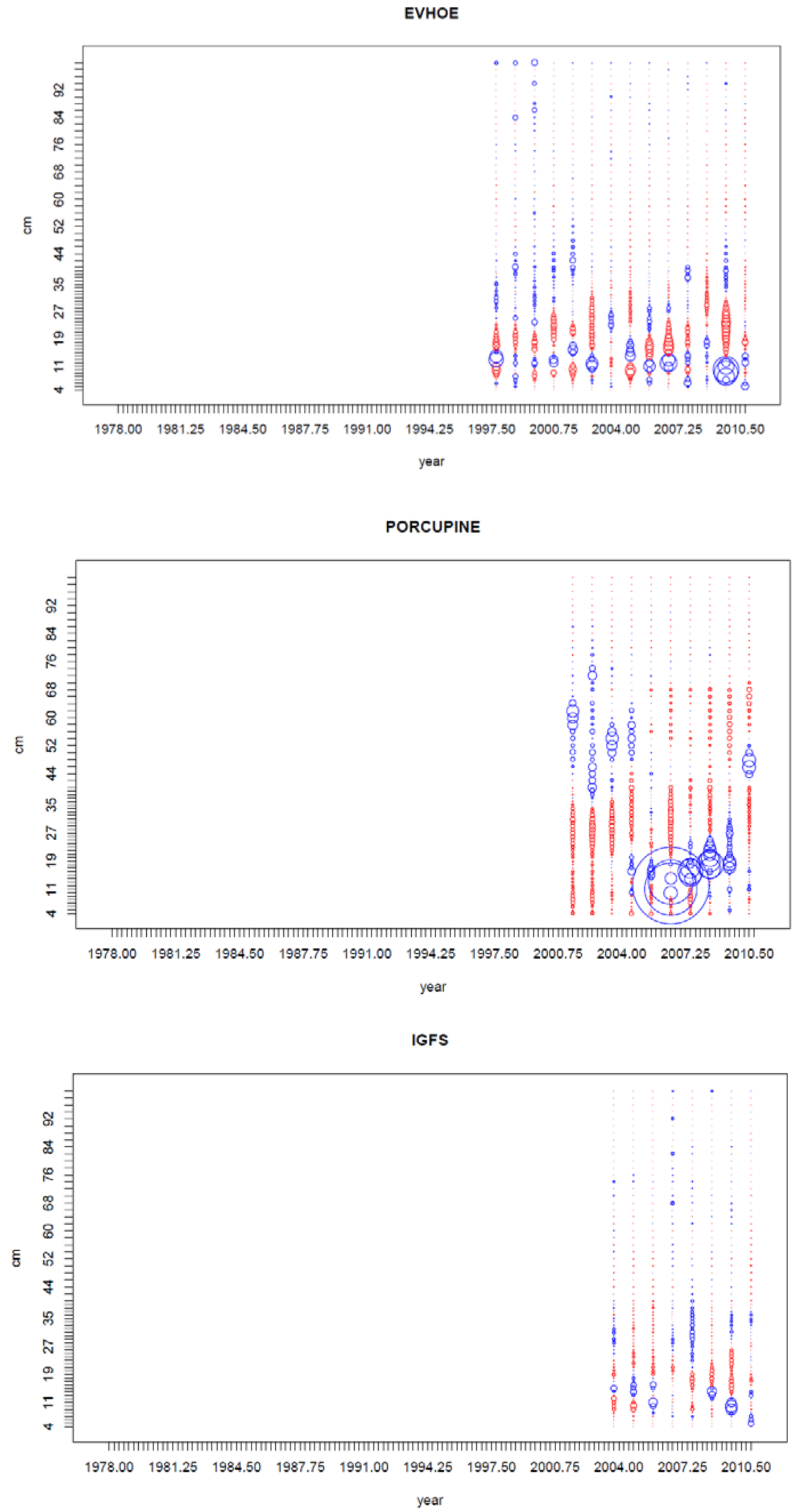


Figure 3.5. (continued) Hake in Division IIIa, Subareas IV, VI and VII and Divisions VIIIa,b,d (Northern stock). Pearson residuals of the fit to the length distributions of the surveys abundance indices. Blue and red denote positive and negative residuals, respectively.

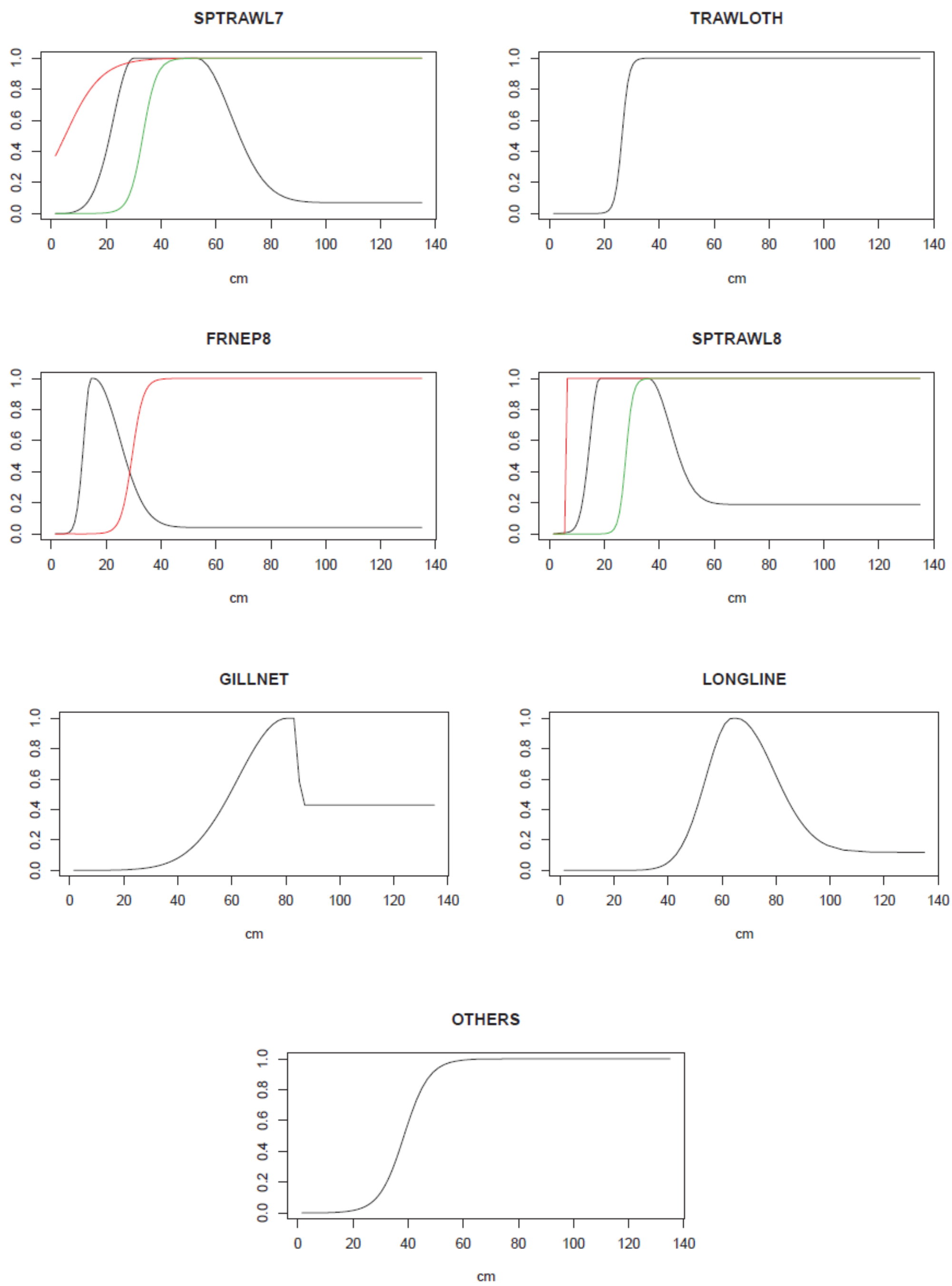


Figure 3.6. Hake in Division IIIa, Subareas IV, VI and VII and Divisions VIIIa,b,d (Northern stock). Selection patterns (black) and retention functions at length by commercial fleet estimated by SS3. For SPTRAWL7 and SPTRAWL8, retention functions from 1978 to 1997 are in red and retention functions after 1998 are in green. For FRNEP8, the retention function, valid for all the period (1978 to 2010), is in red.

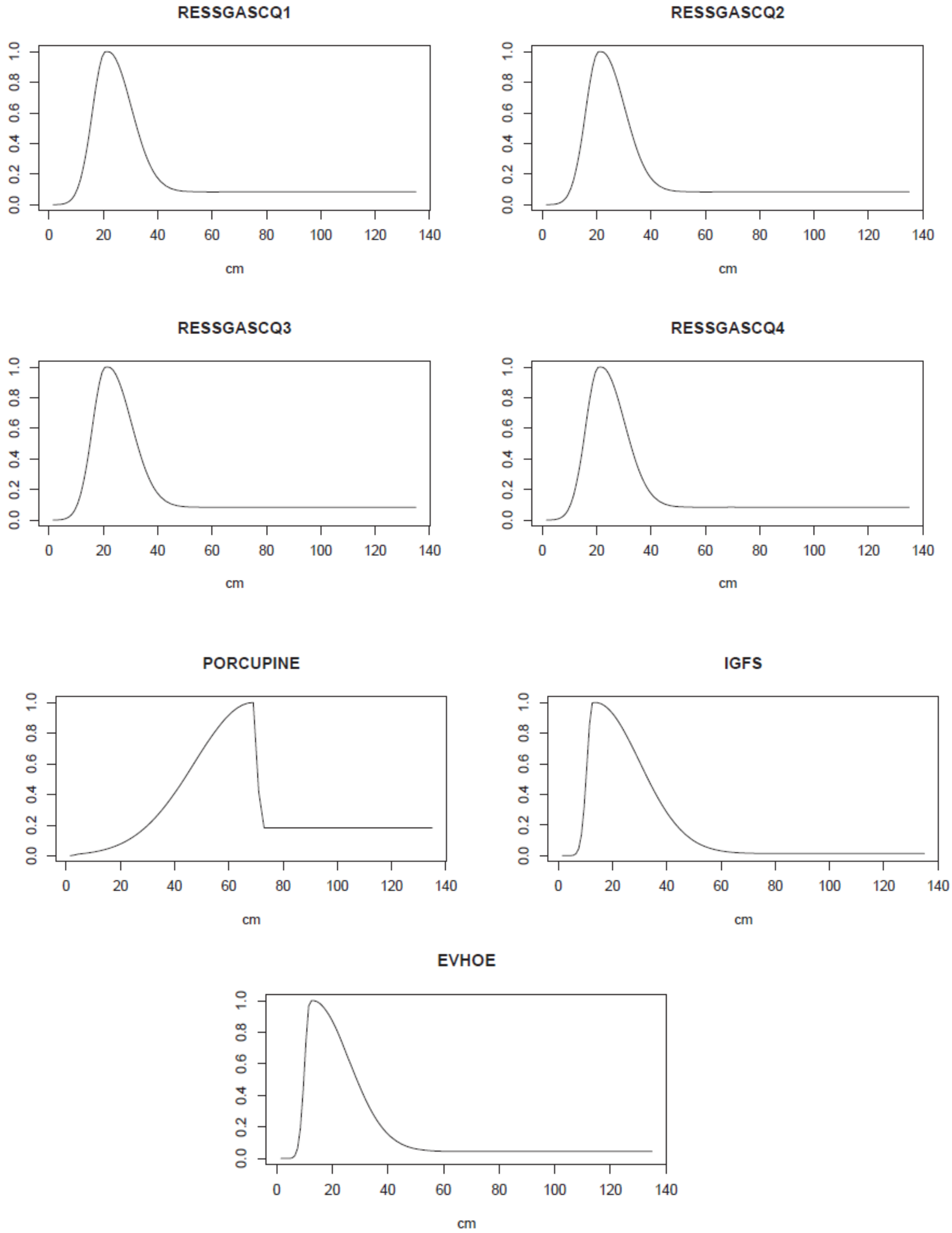


Figure 3.6 (continued). Hake in Division IIIa, Subareas IV, VI and VII and Divisions VIIIa,b,d (Northern stock). Selection patterns at length for surveys estimated by SS3.

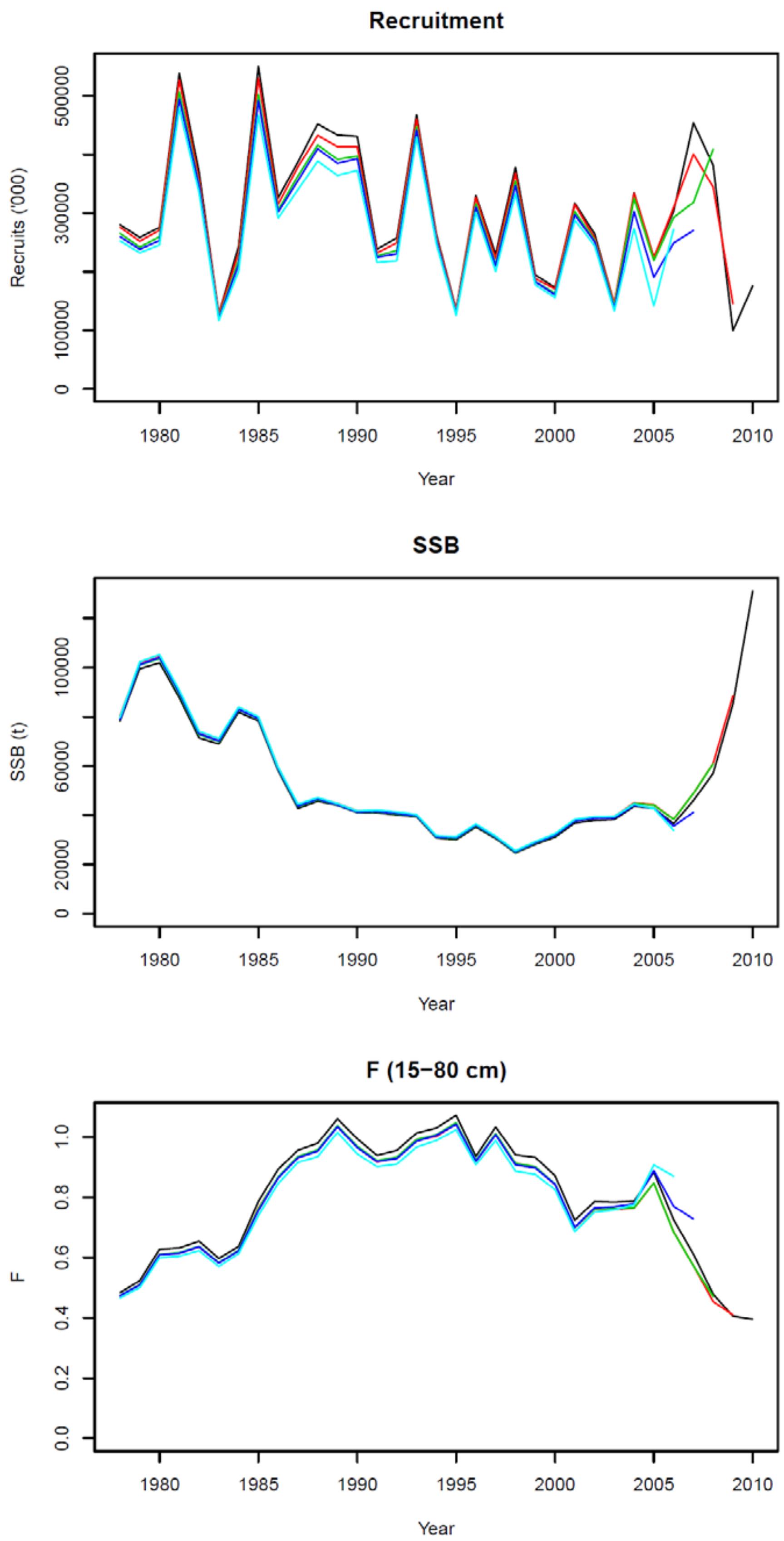


Figure 3.7. Hake in Division IIIa, Subareas IV, VI and VII and Divisions VIIIa,b,d (Northern stock). Retrospective plot from SS3.

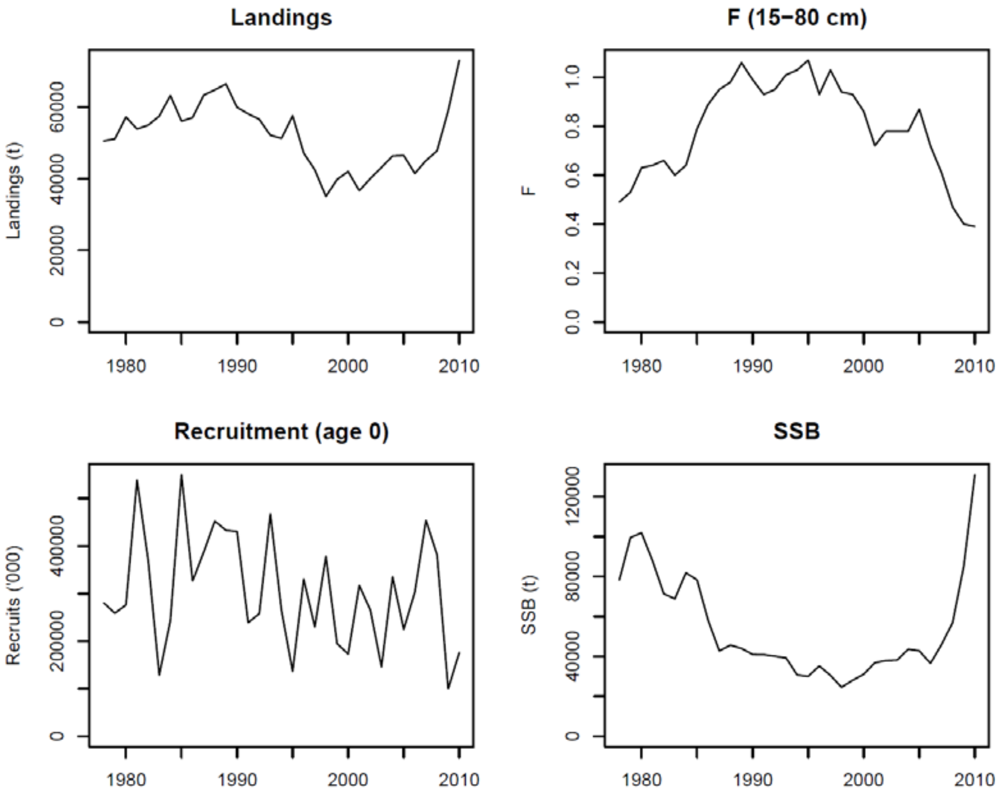


Figure 3.8. Hake in Division IIIa, Subareas IV, VI and VII and Divisions VIIIa,b,d (Northern stock). Summary plot of stock trends.

SOURCES: ICES 2010b (WKROUND); ICES 2012d (WGHMM).

6 Spurdog

DATA:

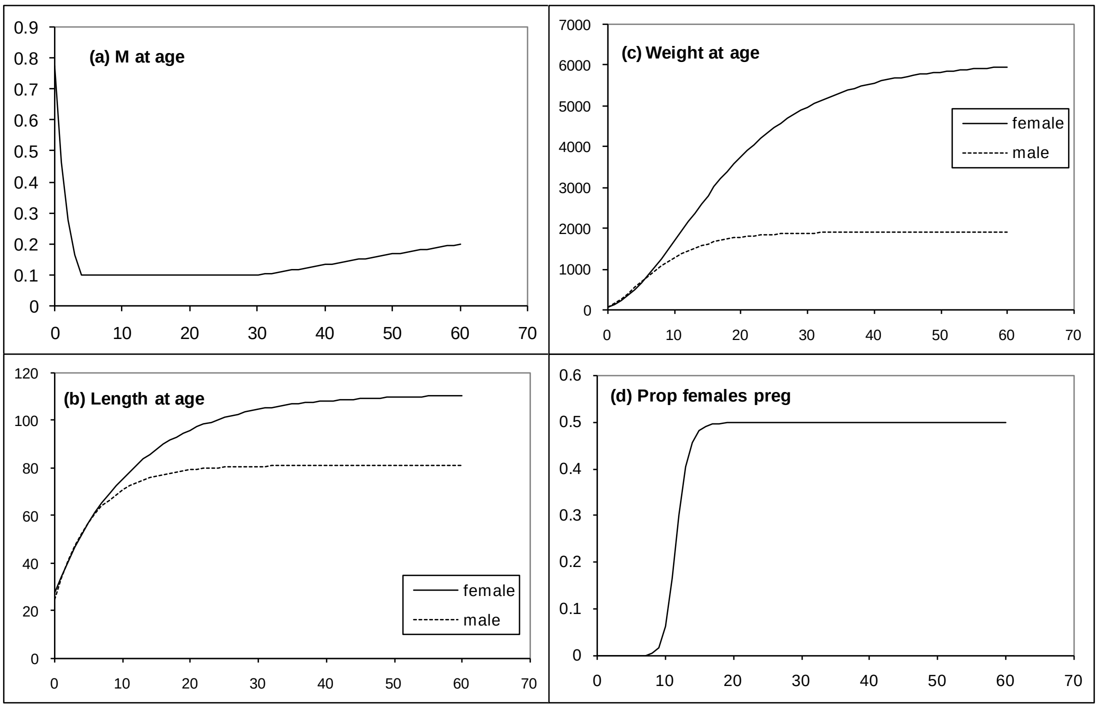


Figure 2.20. Northeast Atlantic spurdog. A visual representation of the life-history parameters.

Table 2.7. Northeast Atlantic spurdog. Landings used in the assessment, with the allocation to "Non-target" and "Target" as assumed for the base case run. Estimated Scottish selectivity (based on fits to proportions by length category data for the period 1991–2004) is assumed to represent "non-target" fisheries, and estimated England and Wales selectivity (based on fits to proportions by length category data for the period 1983–2001) "target" fisheries. The allocation to "Non-target" and "Target" shown below is based on categorizing each nation as having fisheries that are "non-target", "target" or a mixture of these from 1980 onwards. An average for the period 1980–1984 is assumed for the "non-target"/"target" split prior to 1980, while all landings from 2008 onwards are assumed to come from "non-target" fisheries.

	Non-target	Target	Total		Non-target	Target	Total		Non-target	Target	Total
1905	3503	3745	7248	1941	4224	4516	8740	1977	20420	21832	42252
1906	1063	1137	2200	1942	5135	5490	10625	1978	22828	24407	47235
1907	690	738	1428	1943	3954	4227	8181	1979	18462	19739	38201
1908	681	728	1409	1944	3939	4212	8151	1980	20770	20198	40968
1909	977	1045	2022	1945	3275	3501	6776	1981	20953	19009	39962
1910	755	808	1563	1946	5265	5630	10895	1982	16075	16327	32402
1911	946	1011	1957	1947	8164	8729	16893	1983	17095	19951	37046
1912	1546	1653	3199	1948	9420	10071	19491	1984	15047	20147	35194
1913	1957	2093	4050	1949	11120	11890	23010	1985	17048	21626	38674
1914	1276	1365	2641	1950	11961	12789	24750	1986	15138	15772	30910
1915	1258	1344	2602	1951	17060	18241	35301	1987	19557	22797	42354
1916	258	276	534	1952	19597	20953	40550	1988	17292	18277	35569
1917	164	175	339	1953	18464	19742	38206	1989	15354	14923	30277
1918	218	233	451	1954	19607	20963	40570	1990	14390	15516	29906
1919	1285	1374	2659	1955	20843	22284	43127	1991	14034	15529	29563
1920	2125	2271	4396	1956	22691	24260	46951	1992	15711	13335	29046
1921	2572	2749	5321	1957	22023	23547	45570	1993	12268	13369	25637
1922	2610	2791	5401	1958	24355	26039	50394	1994	9238	11613	20851
1923	2733	2922	5655	1959	22905	24489	47394	1995	12104	9214	21318
1924	3071	3284	6355	1960	26096	27901	53997	1996	10026	7269	17295
1925	3247	3472	6719	1961	27896	29825	57721	1997	9157	6190	15347
1926	3517	3760	7277	1962	27671	29585	57256	1998	8509	5410	13919
1927	4057	4338	8395	1963	30103	32185	62288	1999	7233	5152	12385
1928	4602	4920	9522	1964	29068	31078	60146	2000	9282	6607	15889
1929	4504	4816	9320	1965	23843	25493	49336	2001	9513	7180	16693
1930	5758	6156	11914	1966	20642	22071	42713	2002	6019	5001	11020
1931	5721	6117	11838	1967	21320	22796	44116	2003	7167	5080	12247
1932	8083	8643	16726	1968	27085	28958	56043	2004	5717	3647	9364
1933	9784	10460	20244	1969	25166	26908	52074	2005	4165	4192	8357
1934	9848	10530	20378	1970	22983	24574	47557	2006	2616	1439	4055
1935	10761	11505	22266	1971	22063	23590	45653	2007	1770	1083	2853
1936	10113	10812	20925	1972	24365	26051	50416	2008	1737	0	1737
1937	11565	12365	23930	1973	23880	25532	49412	2009	2561	0	2561
1938	8794	9402	18196	1974	22078	23606	45684	2010	2384	0	2384
1939	9723	10396	20119	1975	21322	22797	44119				
1940	4556	4872	9428	1976	21295	22769	44064				

Table 2.8. Northeast Atlantic spurdog. Delta-lognormal GLM-standardized index of abundance (with associated CVs), based on Scottish groundfish surveys.

Year	Index	CV
1990	161.2	0.33
1991	94.3	0.33
1992	79.9	0.32
1993	152.5	0.32
1994	136.8	0.36
1995	52.4	0.46
1996	86.0	0.36
1997	54.9	0.36
1998	81.6	0.35
1999	178.7	0.34
2000	73.1	0.37
2001	95.8	0.34
2002	94.6	0.34
2003	88.5	0.35
2004	63.4	0.37
2005	80.4	0.37
2006	65.2	0.36
2007	91.0	0.33
2008	77.3	0.36
2009	65.2	0.37
2010	95.5	0.56

Table 2.9. Northeast Atlantic spurdog. Scottish survey proportions-by-length category for females (top) and males (bottom), with the actual sample sizes given in the second column.

	$n_{psur,y}$	16-31	32-54	55-69	70+
Females					
1990	539	0.0112	0.2685	0.1265	0.1272
1991	962	0.0636	0.1218	0.1092	0.1123
1992	145	0.1430	0.1514	0.2055	0.0424
1993	398	0.1259	0.1635	0.0788	0.1296
1994	1656	0.0744	0.2426	0.0519	0.0352
1995	2278	0.0572	0.3087	0.0779	0.1520
1996	230	0.0722	0.2381	0.0831	0.0684
1997	167	0.0438	0.2011	0.0955	0.0815
1998	446	0.0361	0.2404	0.1201	0.1731
1999	186	0.0316	0.0787	0.0331	0.1079
2000	1994	0.0962	0.2136	0.0456	0.1149
2001	118	0.0132	0.2060	0.0735	0.1363
2002	148	0.0428	0.0789	0.1773	0.1879
2003	224	0.0123	0.1578	0.0788	0.1898
2004	63	0.0412	0.0834	0.1240	0.0597
2005	121	0.0243	0.1434	0.1568	0.0756
2006	92	0.0360	0.1130	0.1727	0.0413
2007	148	0.0314	0.1628	0.0866	0.1810
2008	232	0.0708	0.1590	0.0127	0.1047
2009	233	0.0427	0.1175	0.2547	0.1167
2010	3483	0.2101	0.2125	0.1145	0.0004
Males					
1990	1044	0.0204	0.1300	0.0575	0.2587
1991	1452	0.0711	0.1273	0.0824	0.3123
1992	154	0.2324	0.0534	0.0504	0.1215
1993	644	0.0503	0.1202	0.1555	0.1762
1994	2467	0.0832	0.1809	0.1472	0.1847
1995	1905	0.0566	0.1259	0.0478	0.1738
1996	453	0.0597	0.1480	0.1237	0.2068
1997	270	0.0228	0.1033	0.0803	0.3716
1998	436	0.0207	0.0974	0.0969	0.2155
1999	503	0.0269	0.2437	0.1136	0.3646
2000	2045	0.0100	0.1144	0.0799	0.3255
2001	221	0.0141	0.1045	0.0753	0.3771
2002	264	0.0252	0.0654	0.1209	0.3016
2003	392	0.0209	0.0818	0.1257	0.3328
2004	190	0.0045	0.1397	0.1250	0.4225
2005	225	0.0297	0.0572	0.1506	0.3622
2006	180	0.0846	0.0992	0.1027	0.3505
2007	262	0.0048	0.1643	0.1555	0.2135
2008	395	0.0699	0.1482	0.0669	0.3678
2009	417	0.0252	0.1247	0.0719	0.2466
2010	2465	0.0035	0.1699	0.0817	0.2074

Table 2.10. Northeast Atlantic spurdog. Commercial proportions-by-length category (males and females combined), for each of the two fleets (Scottish, England & Wales), with raised sample sizes given in the second column.

	$n_{pcom,j,y}$	16-54	55-69	70-84	85+
Scottish commercial proportions					
1991	6167824	0.0186	0.4014	0.5397	0.0404
1992	6104263	0.0172	0.1844	0.7713	0.0272
1993	4295057	0.0020	0.2637	0.7106	0.0236
1994	3257630	0.0301	0.3322	0.5857	0.0520
1995	5710863	0.0112	0.2700	0.6878	0.0309
1996	2372069	0.0069	0.4373	0.5416	0.0142
1997	3769327	0.0091	0.3297	0.5909	0.0702
1998	3021371	0.0330	0.4059	0.5286	0.0325
1999	1869109	0.0145	0.3508	0.5792	0.0556
2000	1856169	0.00001	0.1351	0.7683	0.0967
2001	1580296	0.0021	0.2426	0.7022	0.0531
2002	1264383	0.0529	0.3106	0.5180	0.1186
2003	1695860	0.0011	0.2673	0.5729	0.1587
2004	1688197	0.0106	0.2292	0.6893	0.0708
England & Wales commercial proportion					
1983	243794	0.0181	0.4010	0.4778	0.1030
1984	147964	0.0071	0.2940	0.4631	0.2359
1985	97418	0.0015	0.1679	0.6238	0.2068
1986	63890	0.0004	0.1110	0.6410	0.2476
1987	116136	0.0027	0.1729	0.5881	0.2362
1988	168995	0.0085	0.0973	0.5611	0.3332
1989	109139	0.0011	0.0817	0.5416	0.3757
1990	39426	0.0168	0.1349	0.5369	0.3115
1991	42902	0.0013	0.1039	0.5312	0.3637
1992	23024	0.0003	0.1136	0.4847	0.4013
1993	15855	0.0012	0.1741	0.4917	0.3331
1994	14279	0.0026	0.2547	0.3813	0.3614
1995	48515	0.0007	0.1939	0.4676	0.3378
1996	16254	0.0082	0.3258	0.4258	0.2402
1997	22149	0.0032	0.1323	0.4082	0.4563
1998	21026	0.0007	0.1075	0.4682	0.4236
1999	9596	0.0037	0.1521	0.5591	0.2851
2000	10185	0.0001	0.0729	0.4791	0.4480
2001	17404	0.0024	0.1112	0.4735	0.4128

Table 2.11a. Northeast Atlantic spurdog. Fecundity data for 1960, given as length of pregnant female (l^f) and number of pups (P'). Total number of samples is 783.

l^f	P'	l^f	P'	l^f	P'	l^f	P'	l^f	P'	l^f	P'	l^f	P'	l^f	P'	l^f	P'	l^f	P'	l^f	P'	l^f	P'
73	3	84	4	86	3	87	7	88	3	89	4	90	1	91	7	93	3	94	5	96	10	101	11
73	3	84	6	86	3	87	8	88	5	89	4	90	3	91	8	93	4	94	5	96	10	101	7
75	3	84	6	86	3	87	9	88	5	89	5	90	3	91	8	93	5	94	6	96	7	102	5
77	3	84	3	86	4	87	2	88	6	89	7	90	5	91	3	93	5	94	6	96	7	102	10
78	3	84	3	86	4	87	5	88	6	89	8	90	6	91	4	93	5	94	7	96	8	102	3
79	2	84	4	86	4	87	5	88	6	89	8	90	8	91	4	93	5	94	8	97	4	103	14
79	3	84	4	86	4	87	5	88	7	89	5	90	5	91	7	93	5	94	8	97	4	103	9
79	4	84	4	86	5	87	5	88	8	89	6	90	6	91	4	93	6	94	8	97	7	103	15
79	4	84	5	86	5	87	6	88	6	89	6	90	6	91	5	93	8	94	9	97	2	103	9
79	3	84	6	86	5	87	5	88	6	89	8	90	7	91	7	93	9	94	9	97	3	103	15
80	4	84	6	86	5	87	5	88	8	90	1	90	7	91	7	93	5	94	9	97	3	105	11
80	3	84	4	86	6	87	6	88	9	90	2	90	9	91	8	93	5	94	11	97	3	110	8
80	4	84	4	86	2	87	7	89	3	90	3	90	10	92	2	93	5	94	3	97	4	117	9
80	5	84	6	86	3	87	7	89	3	90	3	91	2	92	4	93	6	94	3	97	4		
80	2	84	6	86	4	87	7	89	4	90	3	91	3	92	5	93	6	94	8	97	4		
80	3	84	6	86	4	87	8	89	4	90	3	91	4	92	7	93	6	94	9	97	5		
80	3	84	6	86	5	87	9	89	4	90	5	91	5	92	2	93	8	94	9	97	6		
80	5	84	3	86	5	88	2	89	6	90	5	91	5	92	2	93	9	94	9	97	6		
81	1	84	4	86	5	88	2	89	2	90	5	91	6	92	2	93	9	94	11	97	7		
81	3	84	4	86	5	88	2	89	2	90	6	91	6	92	2	93	4	95	3	97	3		
81	3	84	4	86	6	88	4	89	3	90	7	91	7	92	2	93	6	95	6	97	5		
81	3	84	6	86	6	88	4	89	3	90	1	91	2	92	2	93	6	95	6	97	6		
81	6	84	6	86	7	88	5	89	3	90	2	91	2	92	3	93	6	95	8	97	7		
81	3	84	6	86	5	88	5	89	3	90	2	91	2	92	3	93	7	95	3	97	4		
81	3	84	6	86	6	88	5	89	3	90	3	91	2	92	3	93	9	95	4	97	6		
82	3	85	3	86	7	88	5	89	3	90	3	91	2	92	3	93	9	95	4	97	8		
82	4	85	3	86	7	88	6	89	4	90	3	91	3	92	3	93	9	95	4	97	9		
82	4	85	4	86	7	88	1	89	4	90	3	91	3	92	4	93	9	95	5	97	9		
82	4	85	5	86	8	88	2	89	4	90	4	91	4	92	4	93	9	95	7	97	4		
82	5	85	5	86	1	88	3	89	4	90	4	91	4	92	5	93	10	95	7	97	6		
82	6	85	5	86	2	88	3	89	4	90	4	91	4	92	5	93	11	95	7	97	7		
82	1	85	5	86	2	88	3	89	4	90	4	91	4	92	6	93	1	95	9	97	7		
82	4	85	5	86	3	88	3	89	4	90	4	91	4	92	6	93	4	95	6	97	9		
82	4	85	7	86	4	88	3	89	4	90	4	91	4	92	6	93	7	95	9	97	6		
82	6	85	1	86	5	88	3	89	4	90	5	91	4	92	6	93	4	95	7	97	8		
82	6	85	3	86	6	88	4	89	4	90	5	91	5	92	7	93	6	95	8	97	9		
82	5	85	3	86	7	88	4	89	5	90	5	91	5	92	7	93	6	95	10	98	1		
82	6	85	3	86	7	88	4	89	5	90	5	91	5	92	8	93	6	95	11	98	5		
82	5	85	4	86	7	88	4	89	5	90	5	91	5	92	9	93	7	95	11	98	6		
82	6	85	4	86	8	88	5	89	5	90	6	91	6	92	4	93	9	95	11	98	9		
82	5	85	4	87	2	88	5	89	5	90	6	91	6	92	5	93	9	95	4	98	9		
83	3	85	5	87	3	88	5	89	5	90	6	91	6	92	6	93	9	95	7	98	8		
83	2	85	5	87	4	88	5	89	6	90	8	91	6	92	6	93	9	95	8	98	8		
83	2	85	3	87	5	88	5	89	6	90	9	91	6	92	6	93	10	95	11	98	9		
83	3	85	4	87	6	88	5	89	6	90	4	91	7	92	7	93	11	95	11	98	12		
83	4	85	4	87	3	88	5	89	6	90	4	91	7	92	8	94	5	95	11	98	8		
83	5	85	5	87	4	88	5	89	6	90	4	91	7	92	6	94	6	96	4	98	8		
83	4	85	5	87	4	88	6	89	6	90	5	91	7	92	6	94	6	96	4	98	9		
83	4	85	5	87	4	88	6	89	7	90	5	91	4	92	7	94	6	96	9	99	6		
83	5	85	6	87	5	88	6	89	4	90	5	91	4	92	10	94	7	96	4	99	6		
83	5	85	6	87	5	88	6	89	4	90	6	91	4	92	3	94	9	96	5	99	8		
83	5	85	6	87	5	88	6	89	4	90	6	91	4	92	3	94	3	96	5	99	4		
83	6	85	7	87	7	88	6	89	4	90	6	91	4	92	4	94	3	96	5	99	8		
83	4	85	4	87	3	88	4	89	4	90	6	91	5	92	5	94	3	96	5	99	15		
83	4	85	5	87	4	88	5	89	4	90	7	91	6	92	6	94	4	96	6	99	8		
83	4	85	7	87	5	88	5	89	5	90	7	91	6	92	6	94	4	96	6	100	6		
83	6	85	8	87	5	88	5	89	5	90	7	91	6	92	7	94	4	96	6	100	9		
83	4	85	3	87	5	88	6	89	6	90	7	91	6	92	7	94	5	96	6	100	10		
83	4	85	4	87	6	88	6	89	6	90	9	91	6	92	7	94	5	96	8	100	14		
83	4	85	5	87	6	88	6	89	6	90	9	91	7	92	10	94	5	96	5	100	7		
83	6	85	6	87	7	88	5	89	6	90	5	91	7	92	6	94	6	96	5	100	10		
84	3	85	7	87	7	88	5	89	7	90	6	91	7	93	1	94	6	96	6	100	14		
84	3	85	4	87	7	88	6	89	3	90	6	91	8	93	4	94	6	96	6	101	4		
84	3	86	2	87	5	88	6	89	5	90	6	91	8	93	5	94	7	96	8	101	6		
84	4	86	3	87	5	88	6	89	6	90	7	91	8	93	6	94	7	96	8	101	6		
84	6	86	3	87	5	88	6	89	6	90	7	91	8	93	7	94	7	96	7	101	10		
84	3	86	4	87	6	88	7	89	8	90	8	91	4	93	8	94	7	96	7	101	7		
84	3	86	5	87	6	88	8	89	8	90	9	91	5	93	1	94	7	96	8	101	9		
84	3	86	2	87	7	88	8	89	3	90	10	91	7	93	2	94	8	96	10	101	11		
84	4	86	2	87	7	88	9	89	3	90	1	91	7	93	2	94	4	96	10	101	9		

Table 2.11b. Northeast Atlantic spurdog. Fecundity data for 2005, given as length of pregnant female (l^f) and number of pups (P'). Total number of samples is 179.

l^f	P'	l^f	P'	l^f	P'	l^f	P'	l^f	P'	l^f	P'	l^f	P'	l^f	P'	l^f	P'	l^f	P'	l^f	P'	l^f	P'
84	6	92	9	94	11	97	5	98	12	100	7	101	14	102	13	103	11	105	16	107	11	109	18
87	8	92	5	95	7	97	12	98	7	100	12	101	9	102	12	103	11	105	15	107	12	109	13
89	6	92	8	95	9	97	7	98	13	100	11	101	14	102	13	103	11	105	15	107	15	109	16
89	6	92	9	95	10	97	12	98	13	100	12	101	10	102	5	103	16	105	5	107	16	110	15
89	5	92	3	95	11	97	14	98	10	100	8	101	10	102	13	104	14	105	16	107	17	110	10
89	3	93	5	96	11	97	14	98	7	100	9	101	10	102	12	104	11	105	19	107	12	110	13
89	8	93	3	96	10	97	7	98	12	100	10	101	12	102	17	104	12	105	11	108	16	111	19
89	5	93	9	96	7	97	7	98	12	100	9	102	17	102	13	104	14	105	8	108	13	112	17
90	9	93	4	96	7	98	12	98	10	100	9	102	3	103	14	104	14	105	17	108	16	112	12
90	7	93	11	96	11	98	12	99	10	100	12	102	15	103	11	104	15	105	13	108	14	112	16
90	9	94	8	96	10	98	7	99	11	100	14	102	16	103	14	104	13	106	16	108	14	113	15
90	4	94	6	97	12	98	16	99	8	101	17	102	13	103	14	104	14	106	16	108	12	113	21
91	6	94	9	97	6	98	8	99	11	101	13	102	10	103	13	104	17	106	14	109	15	114	14
91	6	94	5	97	8	98	11	99	12	101	13	102	12	103	16	105	15	106	7	109	13	116	16
92	8	94	9	97	8	98	5	99	11	101	6	102	13	103	15	105	12	107	12	109	10		

MODEL:

The statistical analysis of survey data provides a delta-lognormal GLM-standardized index of abundance (with associated CVs), based on Scottish groundfish surveys. The assessment assumes two "fleets", with landings data split to reflect a fleet with Scottish selectivity ("non-target fleet"), and one with England and Wales selectivity ("target fleet"). The non-target and target selectivities were estimated by fitting to proportions-by-length-category data derived from Scottish and England and Wales commercial landings databases.

The assessment is based on an approach developed by Punt and Walker (1998) for school shark (*Galeorhinus galeus*) off southern Australia. The approach is essentially age- and sex-structured, but is based on processes that are length-based, such as maturity, pup-production, growth (in terms of weight) and gear selectivity, with a length–age relationship to define the conversion from length to age. Pup-production (recruitment) is closely linked to the numbers of mature females, but the model allows deviations from this relationship to be estimated (subject to a constraint on the amount of deviation).

The implementation for spurdog was coded in AD Model Builder (Otter Research). The approach is similar to Punt and Walker (1998), but uses fecundity data from two periods (1960 and 2005) in an attempt to estimate the extent of density-dependence in pup-production and fits to the Scottish groundfish surveys index of abundance, and proportion-by-length-category data from both the survey and commercial catches (aggregated across gears). Five categories were considered for the survey proportion-by-length-category data, namely length groups 16–31 cm (pups); 32–54 cm (juveniles); 55–69 cm (subadults); and 70–84 cm (maturing fish) and 85+ cm (mature fish). The first two categories were combined for the commercial catch data to avoid zero values.

A closer inspection of the survey proportions-by-length-category data showed a greater proportion of males than females in the largest two length categories. This could indicate a lower degree of overlap between the distribution of females and the survey area compared to males, and requires both a separate selectivity parameter to be fitted for the largest two length categories, and the survey proportion-by-length-category data to be fitted separately for females and males. However, the small numbers of animals in the largest length category (85+) resulted in the occurrence of zeros in this length category, so the approach this year has been to combine the two largest length categories (resulting in a total of four length categories: 16–31 cm, 32–54 cm, 55–69 cm, and ≥70 cm) when fitting to survey proportions-by-length-category data for females and males separately.

The only estimable parameters considered are the total number of pregnant females in the virgin population ($N_0^{f,preg}$), Scottish survey selectivity-by-length-category (4 parameters), commercial selectivity-by-length-category for the two fleets (6 parameters, three reflecting non-target selectivity, and three target selectivity), extent of density-dependence in pup production (Q_{fec}), and constrained recruitment deviations (1960–2010). Although two fecundity parameters could in principle be estimated from the fit to the fecundity data, these were found to be confounded with Q_{fec}, making estimation difficult, so instead of estimating them, values were selected on the basis of a scan over the likelihood surface. The model also assumes two commercial catch exploitation patterns that have remained constant since 1905, which is an oversimplification given the number of gears taking spurdog, and the change in the relative contribution of these gears in directed and mixed fisheries over time, but sensitivity tests are included to show the sensitivity to this assumption. Growth is considered invariant, as in the Punt and Walker (1998) approach, but growth variation could be included (Punt *et al*., 2001).

BASE FIT:

Model fits

Fecundity data available for two periods presents an opportunity to estimate the extent of density-dependence in pup-production (Q_{fec}). However, estimating this parameter along with the fecundity parameters a_{fec} and b_{fec} was not possible because these parameters are confounded. The approach therefore was to plot the likelihood surface for a range of fixed a_{fec} and b_{fec} input values, while estimating Q_{fec}, and the results are shown in Figure 2.21. The optimum in Figure 2.21c indicates that the data does contain information about Q_{fec}, but the lack of a clearly defined optimum (the curve is flat around the optimum) indicates that this information is limited. Therefore, although the two periods of fecundity data are essential for the estimation of Q_{fec}, further information that would help with the estimation of this parameter would be useful. Figure 2.21d indicates a near-linear relationship between Q_{fec} and MSYR (defined in terms of the biomass of all animals $\geq l_{mat00}^{f}$), so additional information about MSYR levels typical for this species could be used for this purpose (but was not attempted here).

The value of Q_{fec} chosen for the base case run (1.98) corresponded to the lower bound of the 95% probability interval shown in Figure 2.17c. Lower Q_{fec} values correspond to lower productivity, so this lower bound is more conservative than other values in the probability interval. Furthermore, sensitivity tests presented later show that higher Q_{fec} values are associated with a deterioration in the model fit to the Scottish survey abundance index.

Figure 2.22 shows the model fit to the Scottish surveys abundance index, Figure 2.23a to the Scottish and England and Wales commercial proportion-by-length-category data, and Figure 2.23b to the Scottish survey proportion-by-length-category data, the latter fitted separately for females and males. Model fits to the survey index and commercial proportion data appear to be reasonably good with no obvious residual patterns, and a close fit to the average proportion-by-length-category for the commercial fleets. Figure 2.23b indicates a poorer fit to the survey proportions compared to the commercial proportions.

Figure 2.24 compares the deterministic and stochastic versions of recruitment, and plots the estimated recruitment residuals normalized by σ_r. The fits to the two periods of fecundity data are shown separately in Figure 2.25a, but are combined in Figure 2.25b to demonstrate the difference in the fecundity relationship with female length for the two periods, this difference being due to Q_{fec}.

Estimated parameters

Model estimates of the total number of pregnant females in the virgin population $(N_0^{f,preg})$, the extent of density-dependence in pup production (Q_{fec}), survey catchability (q_{sur}), and current (2011) total biomass levels relative to 1905 and 1955 (B_{depl05} and B_{depl55}), are shown in Table 2.12a ("Base case") together with estimates of precision. Estimates of the natural mortality parameter M_{pup}, the fecundity parameters a_{fec} and b_{fec}, and MSY parameters ($F_{prop,MSY}$, MSY, B_{MSY} and MSYR) are given in Table 2.12b. Table 2.13 provides a correlation matrix for some of the key estimable parameters (only the last five years of recruitment deviations are shown). Correlations between estimable parameters are generally low, apart from the commercial selectivity parameters associated with length categories 55–69 cm and 70–84 cm, and Q_{fec} vs. q_{sur}.

Estimated commercial- and selectivity-at-age patterns are shown in Figure 2.26, and reflect the relatively smaller proportion of large animals in the survey data when compared to the commercial catch data, and the larger proportion of smaller animals in the Scottish commercial catch data compared to England and Wales (see also Figure 2.23). It should be noted that females grow to larger lengths than males, so that females are able to grow out of the second highest length category, whereas males, with an L_∞ of <85 cm (Table 1 in the stock annex) are not able to do so (hence the commercial selectivity remains unchanged for the two largest length categories for males). The divergence of survey selectivity for females compared to males is a reflection of the separate selectivity parameters for females/males in the largest length category (70+ for surveys).

A plot of recruitment vs. the number of pregnant females in the population, effectively a stock–recruit plot, is given in Figure 2.27a together with the replacement line (the number of recruiting pups needed to replace the pregnant female population under no harvesting). This plot illustrates the importance of the Q_{fec} parameter in the model: a Q_{fec} parameter equal to 1 would imply the expected value of the stock–recruit points lie on the replacement line, which implies that the population is incapable of replacing itself. A further exploration of the behaviour of Q_y and $N_{pup,y}$ (equations 2a and b in the stock annex) is shown in Figure 2.27b. A 6-year retrospective analysis (the base case model was re-run, each time omitting a further year in the data) was performed, and is shown in Figure 2.30 for the total biomass (B_y), mean fishing proportion ($F_{prop5\ 30,y}$) and recruitment (R_y). Landings and estimates of recruitment, mean fishing proportion (with $F_{prop,MSY}$=0.029) and total biomass, together with estimates of precision, is given in Figure 2.34.

Table 2.12a. Northeast Atlantic spurdog. Estimates of key model parameters, with associated Hessian-based estimates of precision (CV expressed as a percentage and given in square parentheses) for the base-case run, and two sensitivity tests for assuming alternative selectivity-at-age prior to 1980.

	Base case		Tar 4: historic non-target		Tar 5: historic target	
$N_0^{f,preg}$	96 851	[2.1%]	92421	[2.3%]	102 650	[2.2%]
Q_{fec}	1.985	[2.0%]	2.039	[2.7%]	1.949	[1.7%]
q_{sur}	0.000638	[23%]	0.000576	[28%]	0.000651	[22%]
B_{depl05}	0.147	[29%]	0.181	[36%]	0.131	[28%]
B_{depl55}	0.182	[29%]	0.225	[35%]	0.160	[27%]

Table 2.12b. Northeast Atlantic spurdog. Estimates of other estimates of interest for the base-case run, and two sensitivity tests for assuming alternative selectivity-at-age prior to 1980. [Note, estimates of M_{pup}, a_{fec} and b_{fec} are the same in all cases.]

	Base case	Tar 4: historic non-target	Tar 5: historic target
M_{pup}	0.757		
a_{fec}	-12.615		
b_{fec}	0.184		
$F_{prop,MSY}$	0.0291	0.0298	0.0276
MSY	20451	20461	20848
B_{MSY}	964562	928275	1018670
M_{SYR}	0.0294	0.0308	0.0285

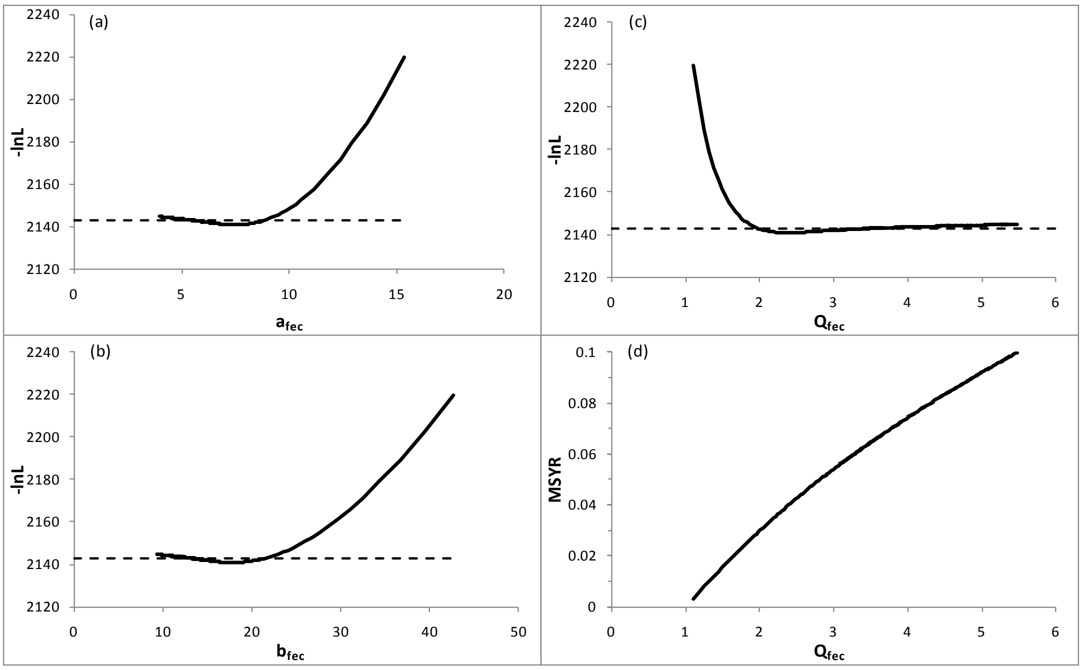


Figure 2.21. Northeast Atlantic spurdog. Negative log-likelihood (-ln*L*) for a range of (a) a_{fec} and (b) b_{fec} values, with (c) corresponding Q_{fec}. Plot (d) shows MSYR (MSY/B_{MSY}) vs. Q_{fec}. Using the likelihood ratio criterion, the hashed line in plots (a)-(c) indicate the minimum –ln*L* value + 1.92, corresponding to 95% probability intervals for the corresponding parameters for values below the line.

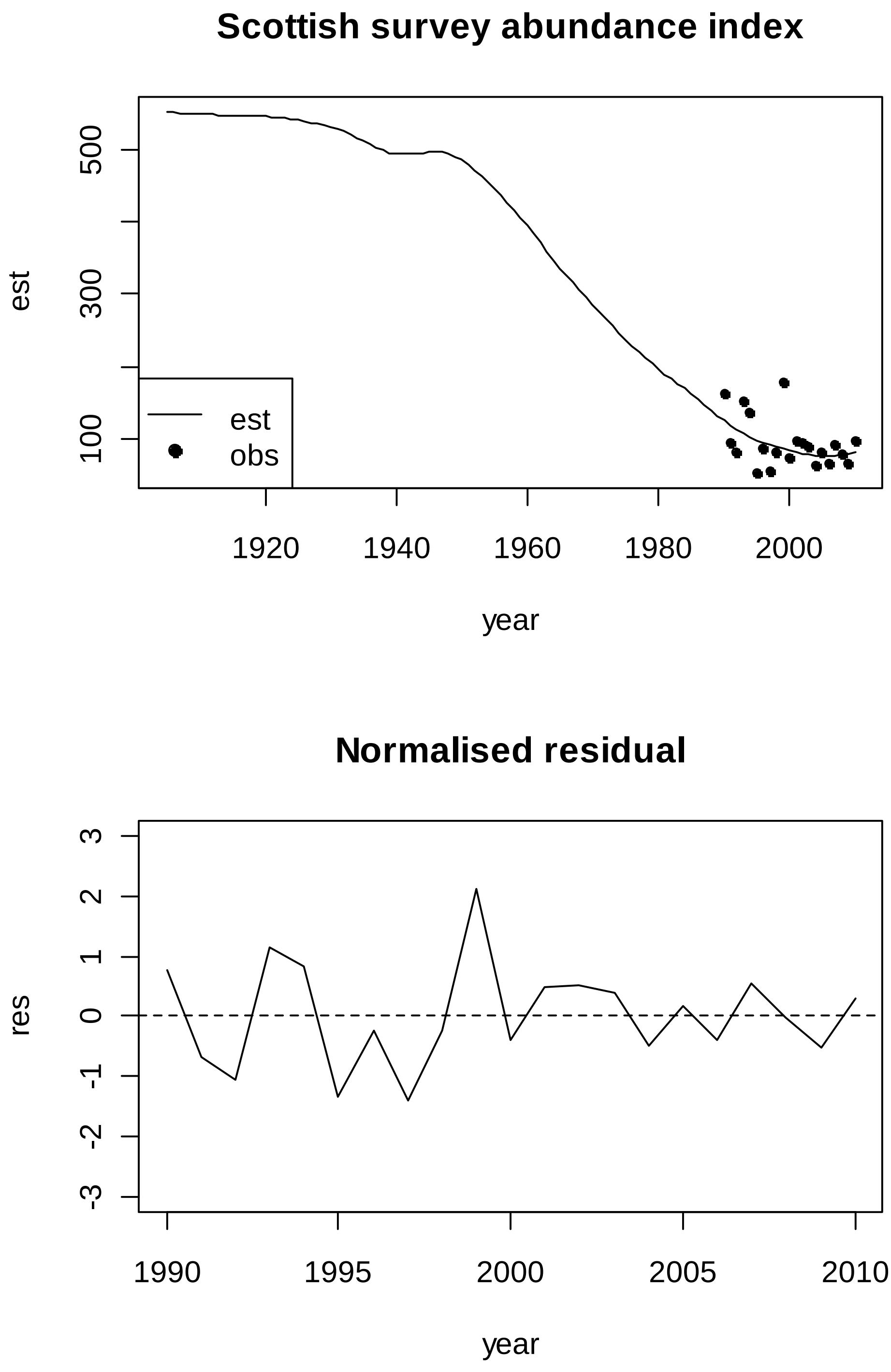


Figure 2.22. Northeast Atlantic spurdog. A Model fit to the Scottish surveys abundance index (top panel), with normalized residuals ($\varepsilon_{sur,y}$ in equation 2.9b; bottom).

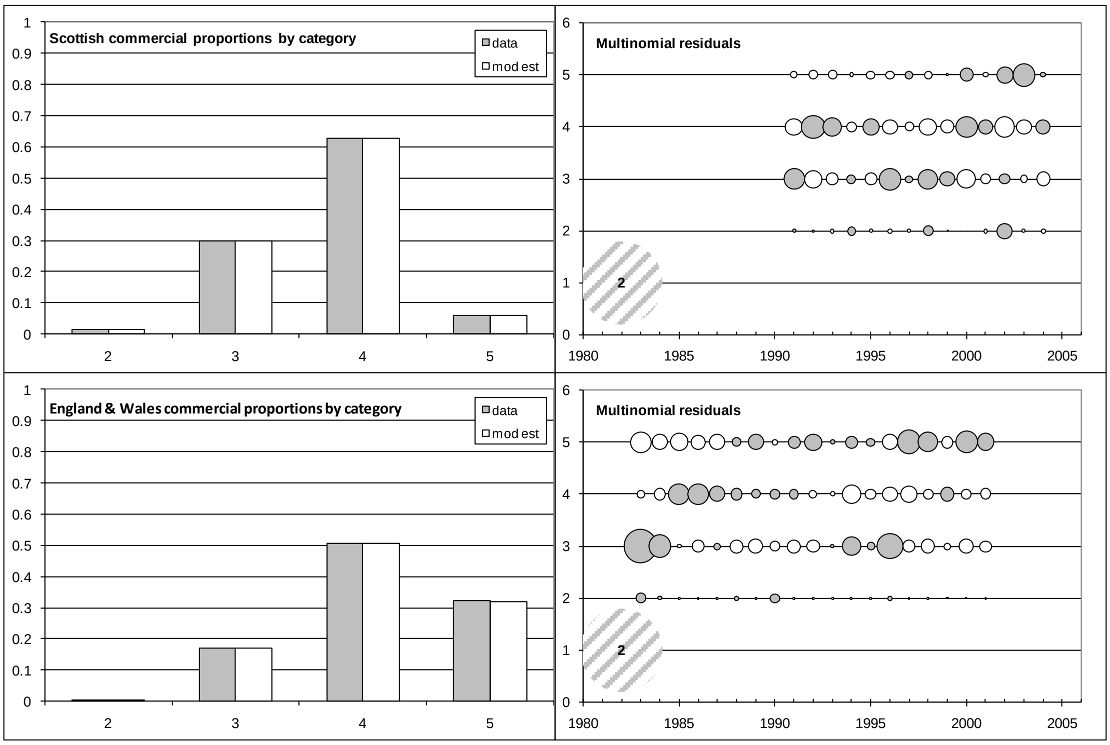


Figure 2.23a. Northeast Atlantic spurdog. Model fits to the Scottish (top row) and England and Wales (bottom row) commercial proportions-by-length category data for the base-case run. The left-hand side plots show proportions by length category averaged over the time period for which data are available, with the length category given along the horizontal axis. The right-hand side plots show multinomial residuals ($\varepsilon_{pcom,j,y,L}$ in equation 2.10b), with grey bubbles indicating positive residuals (not the same interpretation as residuals in Figure 2.18), bubble area being proportional to the size of the residual (the light-grey hashed bubble indicates a residual size of 2, and is shown for reference), and length category indicated on the vertical axis. The length categories considered are 2: 16–54 cm; 3: 55–69 cm; 4: 70–84 cm; 5: 85+ cm.

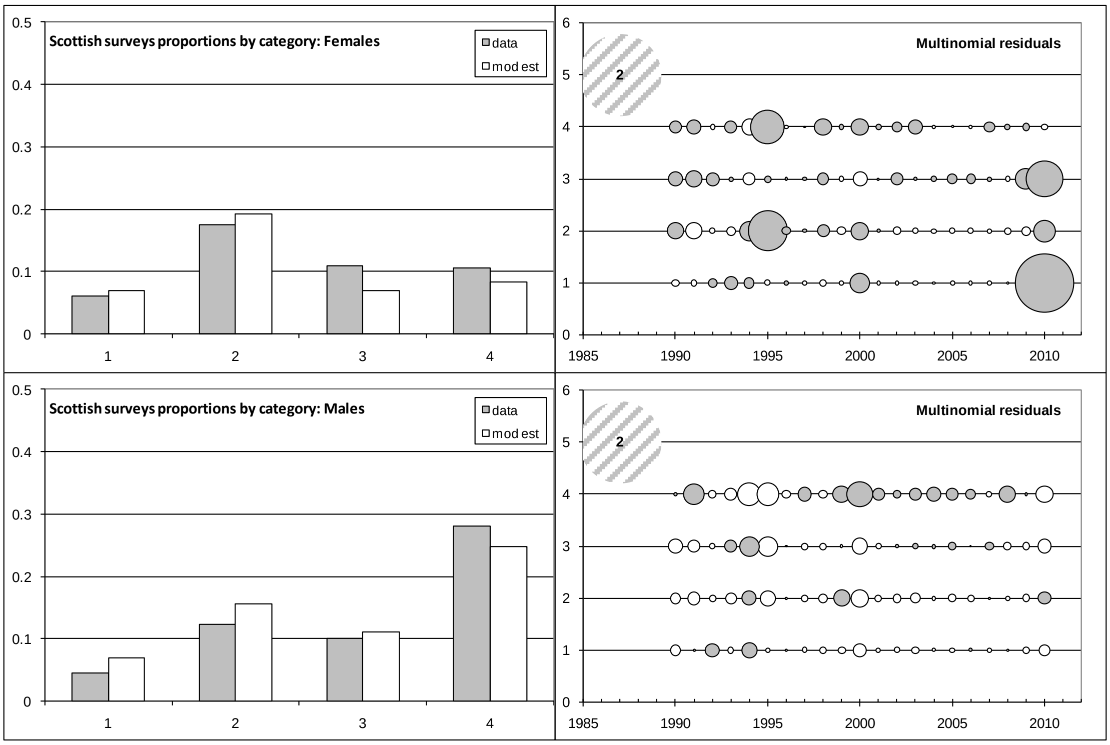


Figure 2.23b. Northeast Atlantic spurdog. Model fits to the Scottish survey proportions-by-length category data for the base-case run for females (top row) and males (bottom row). A further description of these plots can be found in the caption to Figure 2.19a. Length categories considered are 1: 16–31 cm; 2: 32–54 cm; 3: 55–69 cm; 4: 70+ cm.

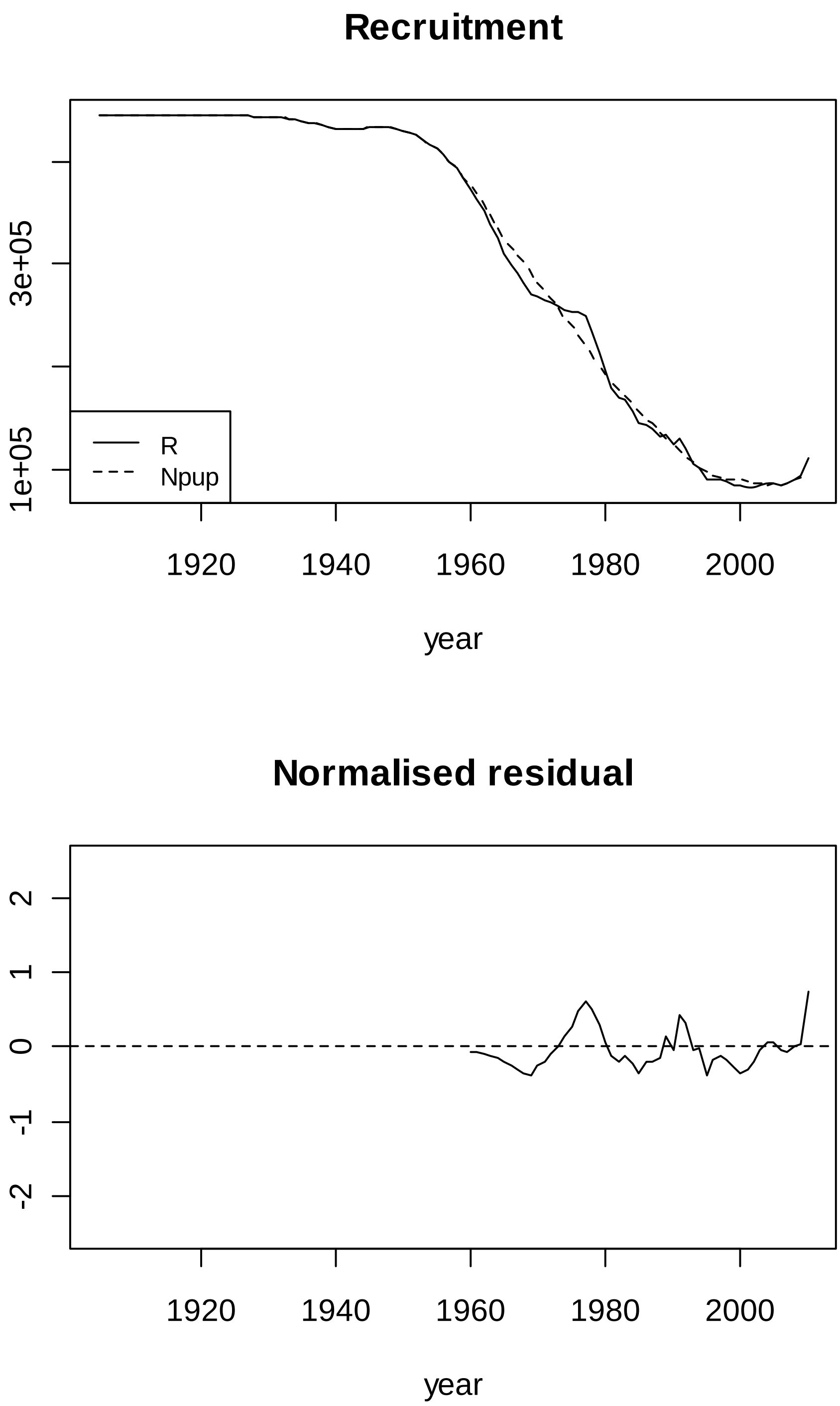


Figure 2.24. Northeast Atlantic spurdog. A comparison of the deterministic (N_{pup}) and stochastic (R) versions of recruitment (equations 2.2a–c; top panel) with normalized residuals ($\varepsilon_{r,y}/\sigma_r$, where $\varepsilon_{r,y}$ are estimable parameters of the model; bottom).

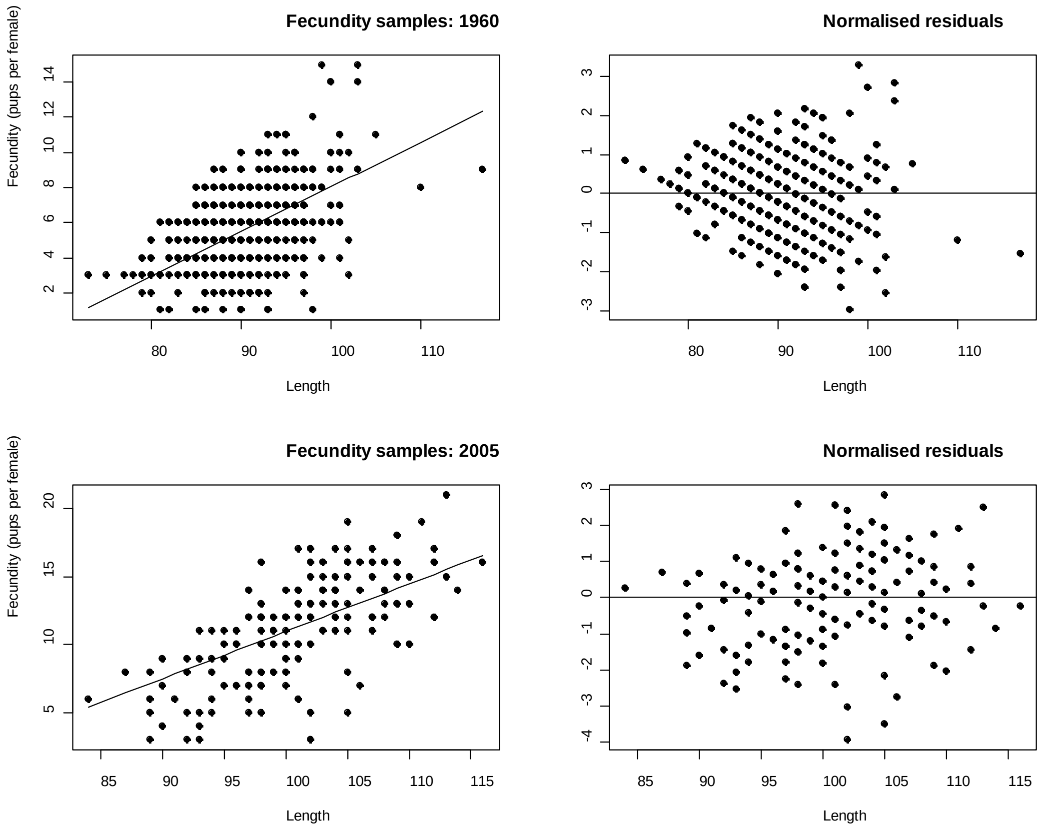


Figure 2.25a. Northeast Atlantic spurdog. Fecundity data from two periods: top–1960 and bottom–2005, with fits shown on the left, and normalized residuals ($\varepsilon_{fec,k,y}$ in equation 2.11b) on the right.

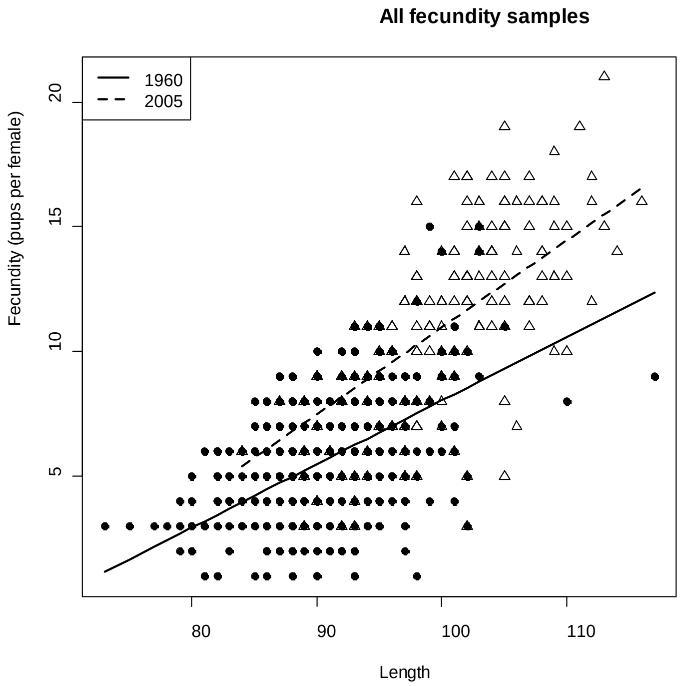


Figure 2.25b. Northeast Atlantic spurdog. Plotting all the fecundity data together, with the fitted curves (open triangles=1960, solid circles=2005; note overlap of triangles with circles).

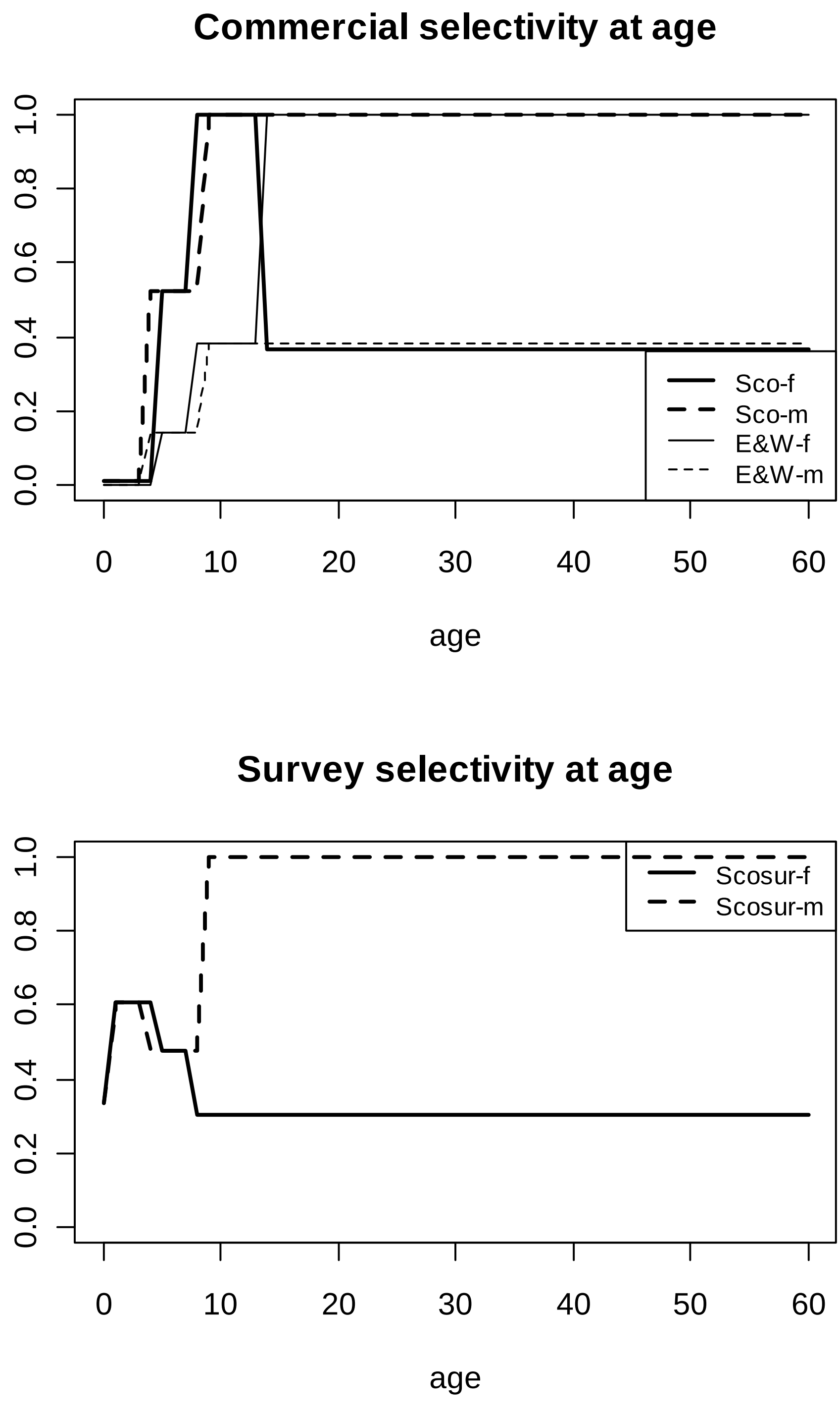


Figure 2.26. Northeast Atlantic spurdog. Estimated commercial (top panel) and survey (bottom) selectivity-at-age curves for the base-case run. The two commercial fleets considered have Scottish (Sco) and England and Wales (EandW) selectivity, which differ by sex because of the life-history parameters for males and females (Table 2.5). The survey selectivity relies on Scottish survey data.

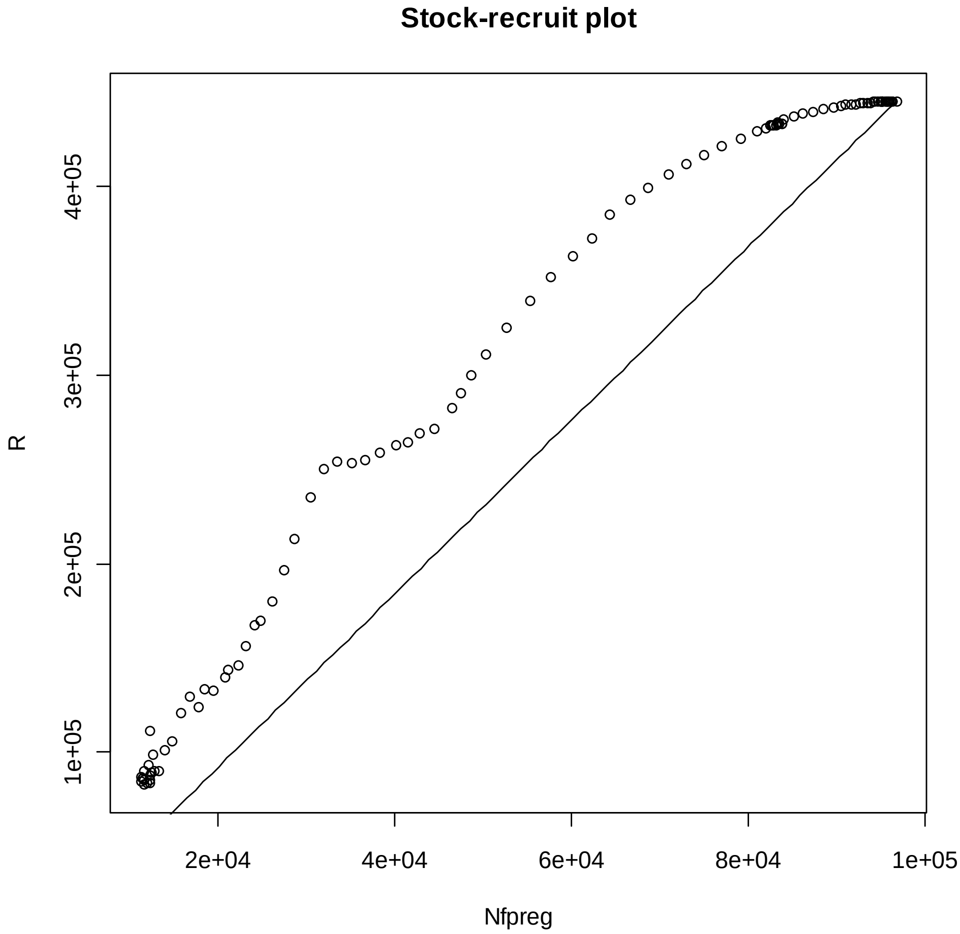


Figure 2.27a. Northeast Atlantic spurdog. A plot of recruitment (*R*) vs. number of pregnant females (open circles), together with the replacement line (number of recruiting pups needed to replace the pregnant female population under no harvesting).

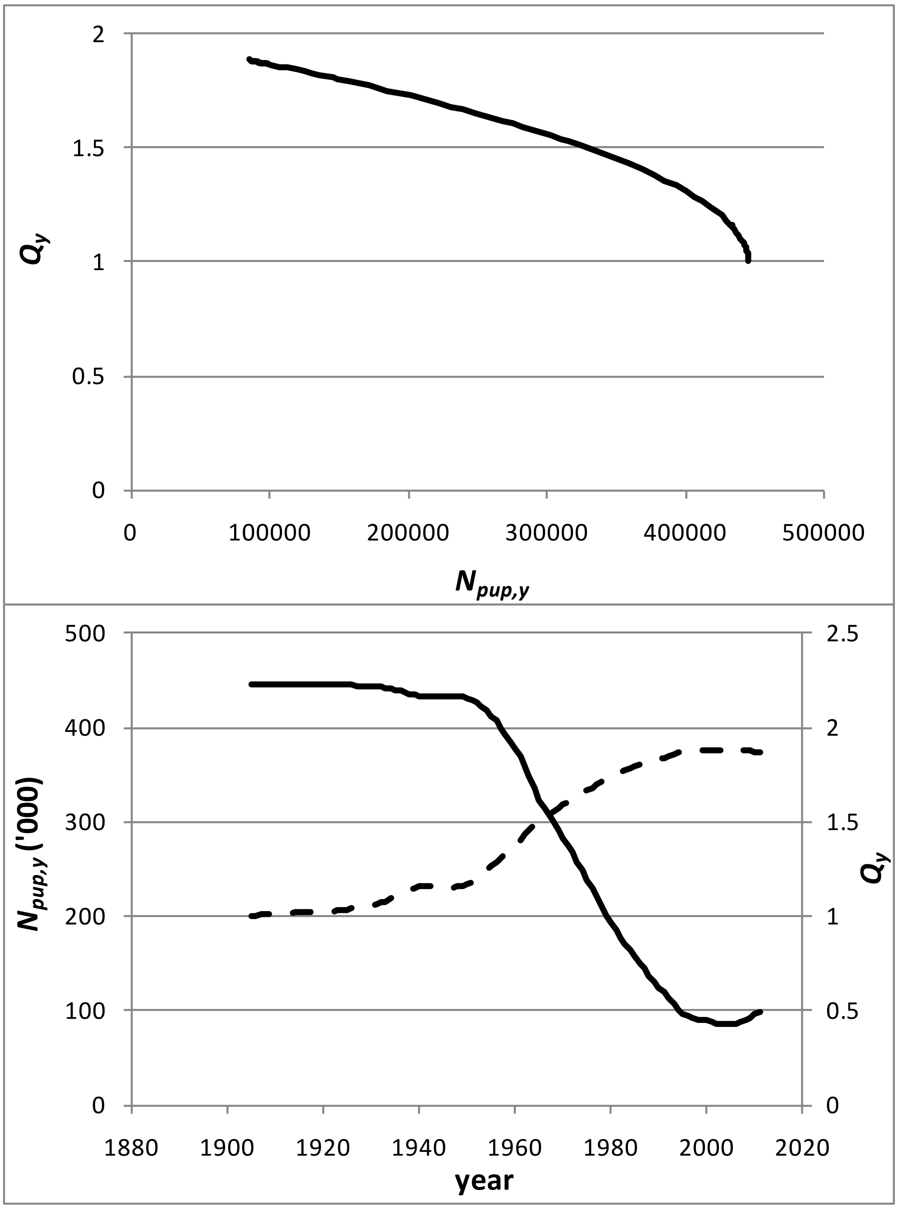


Figure 2.27b. Northeast Atlantic spurdog. A plot of the density-dependent factor Q_y (equation 2.2b) against the number of pups $N_{pup,y}$ (top), and both plotted against time (bottom; solid line for $N_{pup,y}$, and hashed line for Q_y).

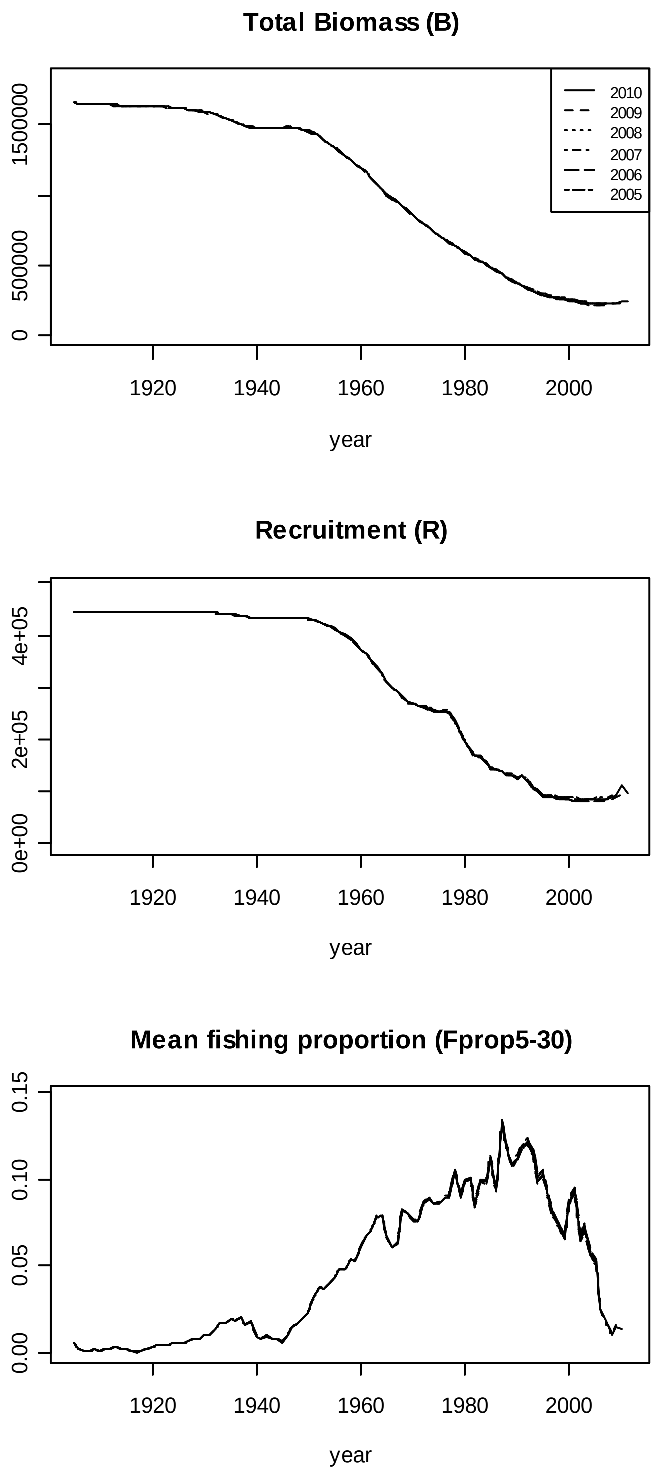


Figure 2.30. Northeast Atlantic spurdog. A repeat of Figure 2.25 (omitting probability intervals for clarity), giving a 6-year retrospective comparison (the model was re-run, each time omitting a further year in the data).

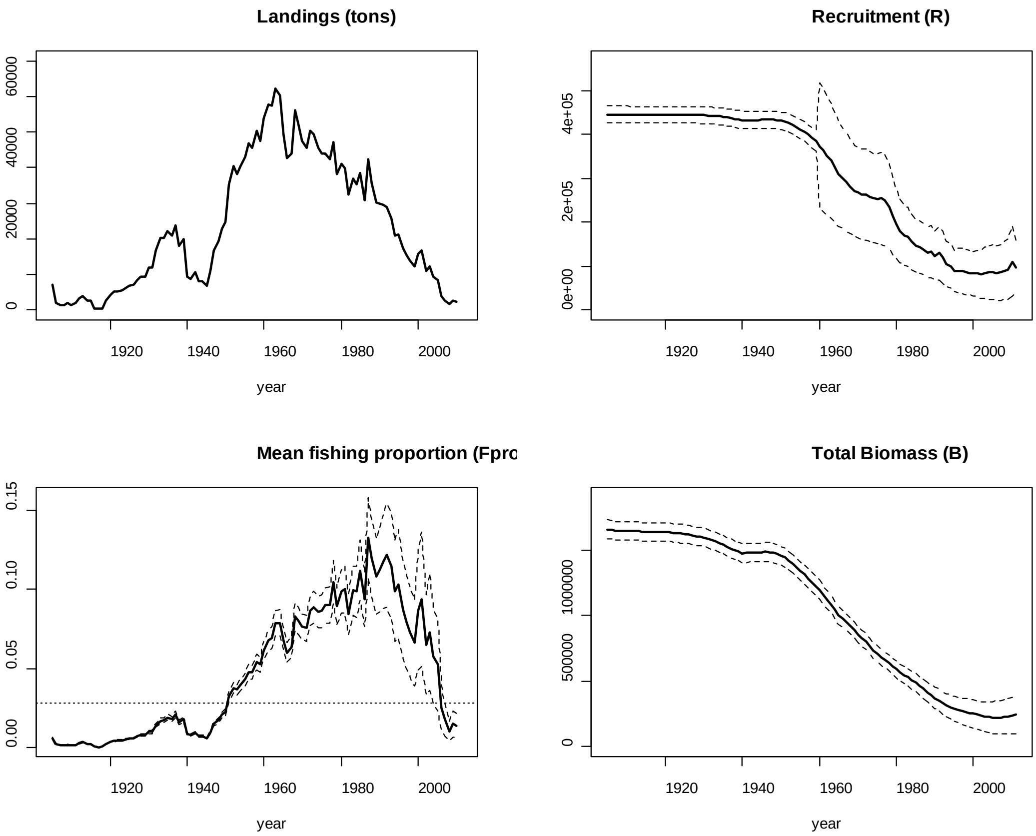


Figure 2.34. Northeast Atlantic spurdog. Summary four-plot for the base-case, showing long-term trends in landings (tons), recruitment (number of pups), mean fishing proportion (average ages 5–30, dotted horizontal line=F_{MSY}=0.028) and total biomass (tons). Hashed lines reflect estimates of precision (±2 standard deviations).

SOURCES: ICES 2012e (WGEF); Punt and Walker (1998); Punt *et al.* (2001).

7 Biscay anchovy

DATA:

Maturity-at-age

Anchovies are fully mature as soon as they reach their first year of life, in the spring the year after the hatch.

Natural mortality and weight at age in the stock

Natural mortality is fixed at 1.2.

In the Bayesian Biomass Model the parameter *g* describes the annual change in mass of the population by encapsulating the growth in weight (G) and the natural mortality (M) of the population as G-M (0.52-1.2=-0.68).

There is evidence that this parameter *g* is not constant across age groups. An extension of the current assessment method separating the growth in weight and the natural mortality parameters and splitting each of them by age class (Ibaibarriaga *et al.*, 2011) suggests larger growth and smaller natural mortality of the age 1 class than the 2+ age class. Previous works by Petitgas *et al.* and Uriarte *et al.* (WDs in ICES 2010c [WGANSA]) also indicated lower natural mortalities than the one currently assumed.

The data used for the assessment are given in Table 3.5.1.1. The input data entering into the assessment of the anchovy stock consist of:

- total biomass estimated by DEPM and acoustics surveys
- proportion of the biomass at age 1 estimated by the DEPM and acoustic surveys
- total catch during the first period (from 1st January to 15th May)
- total catch during the second period (from 15th May to 31st December)
- catch-at-age 1 (in mass) during the first period (from 1st January to 15th May)

Table 3.5.1.1: Bay of Biscay anchovy: Input data for BBM.

			CATCH DATA			DEPM		ACOUSTICS	
Year	h1	h2	C(y,1,1)	C(y,1,1+)	C(y,2,1+)	B(y,1)	B(y,1+)	B(y,1)	B(y,1+)
1987	0.3068	0.1940	2711	8318	6543	14235	29365	NA	NA
1988	0.3253	0.1774	2602	3864	10954	53087	63500	NA	NA
1989	0.2820	0.2328	1723	3876	4442	7282	16720	6476	15500
1990	0.3070	0.2057	9314	10573	23574	90650	97239	NA	NA
1991	0.2347	0.1984	3903	10191	8196	11271	19276	28322	64000
1992	0.2542	0.2184	11933	16366	21026	85571	90720	84439	89000
1993	0.2368	0.2378	6414	14177	25431	NA	NA	NA	NA
1994	0.2331	0.2050	3795	13602	20150	34674	60062	NA	35000
1995	0.2917	0.1751	5718	14550	14815	42906	54700	NA	NA
1996	0.2756	0.1978	4570	9246	23833	NA	39545	NA	NA
1997	0.2078	0.2624	4323	7235	13256	38536	51176	38498	63000
1998	0.1992	0.2567	5898	7988	23588	80357	101976	NA	57000
1999	0.2304	0.2626	2067	10895	15511	NA	69074	NA	NA
2000	0.2569	0.1999	6298	12010	24882	NA	44973	89363	113120
2001	0.2984	0.2195	5481	11468	28671	69110	120403	67110	105801
2002	0.1833	0.2389	1962	7738	9754	6352	30697	27642	110566
2003	0.2997	0.2795	625	2379	8101	16575	23962	18687	30632
2004	0.2989	0.2126	2754	4623	11657	14649	19498	33995	45965
2005	0.1138	0.0741	102	790	372	2063	8002	2467	14643
2006	0.3266	0.0741	484	815	947	15064	21436	18282	30877
2007	0.3181	0.0590	20	67	73	16030	25973	26230	40876
2008	0.2610	0.1991	0	0	0	7579	25377	10400	37574
2009	0.2610	0.1994	0	0	0	9295	24846	11429	34855
2010	0.3134	0.2221	1723	3447	6655	33725	42979	64564	86355
2011	0.2927	0.2575	2747	8307	6182	140555	172223	115379	142601
2012	0.3368	NA	557	3882	NA	11127	36200	73843	186865

h1 and h2 denote the fractions of year to the time point within each period when commercial catch is assumed to take place

MODEL:

Model used

The assessment for the Bay of Biscay anchovy population is a Bayesian two-stage biomass-based model (BBM; Ibaibarriaga *et al.*, 2008), where the population dynamics are described in terms of biomass with two distinct age groups, recruits or fish aged 1 year, and fish that are 2 or more years old. This method was approved in the Benchmark Workshop on Short-lived species (ICES 2009a [WKSHORT]) that took place in August 2009.

The biomass decreases exponentially on time by a factor g accounting for intrinsic rates of growth (G) and natural mortality (M) which are assumed year- and age-invariant. Two periods are distinguished within each year. The first begins on 1 January, when it is assumed that age incrementing occurs and age 1 recruit enter the exploitable population, and runs to the date when the monitoring research surveys (acoustics and DEPM) take place. The second period covers the rest of the year (from 15th May to 31st December). Catch is assumed to be taken instantaneously within each of these periods.

The observation equations consist on log-normally distributed spawning-stock biomass from the acoustics and DEPM surveys, where the biomass observed is proportional to the true population biomass by the catchability coefficient of each of the surveys, and the beta distributed age 1 biomass proportion from the acoustics and DEPM surveys, with mean given by the true age 1 biomass proportion in the population.

The model unknowns are the initial population biomass (in 1987), the recruitment (age 1 in mass on the 1st January) each year, the catchability of the surveys and the variance related parameters of the observation equations. The model can be cast into a Bayesian state-space model framework where inference on the unknowns is done using Markov Chain Monte Carlo (MCMC).

Software used

The model is implemented in BUGS (www.mrc-bsu.cam.ac.uk/bugs/) and it is run from R (www.r-project.org) using the package R2WinBUGS.

Model Options chosen

Catchability for the DEPM SSB is set to 1 because it is assumed to be an absolute indicator of biomass and for consistency with the past practice in the assessment of this stock. Catchability of the acoustic biomass is estimated. DEPM and acoustic surveys are assumed to provide unbiased proportion of age 1 biomass estimates in the stock. The first set of priors as defined in Ibaibarriaga *et al*. (2008) is used. The length of the MCMC run, the burn-in period (removal of the first draws to avoid dependency on the initial values) and the thinning to diminish autocorrelation should be enough to ensure convergence and obtain a representative joint posterior distribution of the parameters.

BASE FIT:

The historical series of spawning-stock biomass (SSB) from the DEPM and acoustic surveys are shown in Figure 3.5.1.1. The trends in biomass from both surveys are similar. In particular, from 2003 to 2010 a parallel trend but with larger biomass estimates from the acoustic surveys is apparent. This year both surveys give completely different estimates. The acoustic biomass estimate is the largest of their historical series, indicating an increase with respect to last year's biomass. In contrast, the DEPM biomass estimate decreases significantly with respect to last year. Similar discrepancies between DEPM and acoustic surveys (though of smaller magnitude) occurred in 1991, 2000 and 2002. The agreement between both surveys is higher when estimating the age structure of the population. Figure 3.5.1.2 compares the historical series of the proportion of age 1 biomass of DEPM and acoustic surveys. However, it should be noted that this year the age 1 proportion in numbers from the DEPM and acoustic survey are rather different.

Figure 3.5.1.3 shows the historical series of age 1 and total catches in the first period (1st January-15th May) and of the total catches in the second period (15th May-31st December), which are used in BBM. In the past catches in the second period were larger than in the first period and most of the catches in the first period corresponded to age 1. In the last two years (2010 and 2011) catches in the first period are larger than in the second period and the majority of the catches in the first period corresponded to age 2 and older individuals. After various fishery closures due to the low level of the population, in 2010 the fishery was reopened. In 2012 the total catch in the first period was approximately 3900t.

Figures 3.5.1.4 and 3.5.1.5 compare prior and posterior distribution of the parameters. Summary statistics (median and 95% probability intervals) of the posterior distributions of recruitment (age 1 in mass at the beginning of the year), SSB (at spawning time which is assumed to be 15th May) and harvest rates (catch/SSB) are shown in Figure 3.5.1.6. The largest probability intervals correspond to the period in which some data are missing. In general recruitment is highly variable from year-to-year. Recruitment in 2012 is at levels similar to 2006, though with larger uncertainty. The median SSB has decreased from last year to intermediate levels in the historical series. The harvest rates in 2010 and 2011 are smaller than the levels observed before the fishery closure in 2005.

Figure 3.5.1.7 shows the posterior distribution of current level of spawning-stock biomass in 2012.

The observation equations of the model refer just to the age 1 biomass proportion and total biomass indices from the research surveys (DEPM and acoustics). Figure 3.5.2.1 shows the posterior distribution of spawning-stock biomass from BBM in comparison to the estimates from the DEPM and acoustic surveys (corrected by their catchability, which is assumed to be 1 for the DEPM and estimated as 1.16 for the acoustic survey). In most of the years the SSB estimates of the surveys taking into account their standard errors fall within the 95% posterior probability intervals from the assessment. In this last year both estimates are outside this interval. Figure 3.5.2.2 shows the posterior distribution of age 1 proportion in mass from BBM in comparison to the estimates from the DEPM and acoustic surveys. In all the years the age 1 biomass proportion estimates of the surveys are within the 95% probability intervals from the assessment. Pearson residuals of the four indices do not reveal any clear pattern (Figure 3.5.2.3).

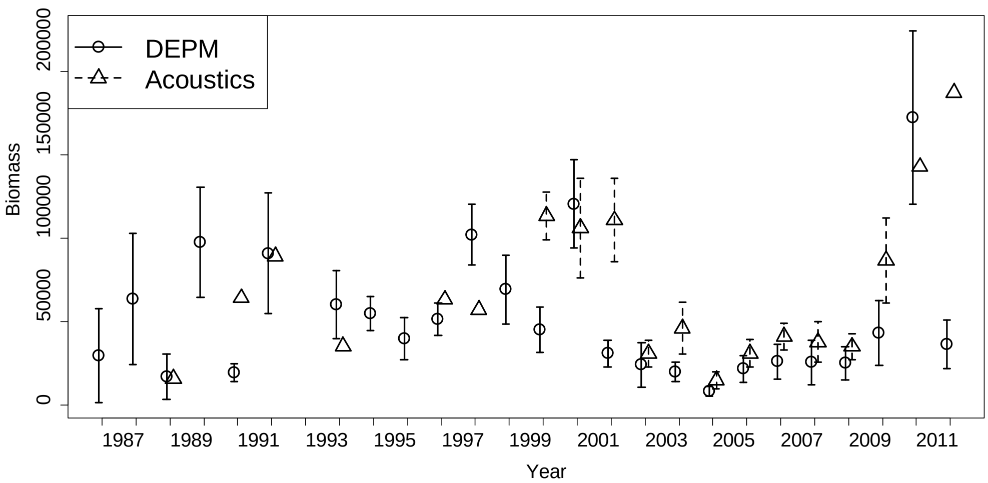


Figure 3.5.1.1. Bay of Biscay anchovy: Historical series of spawning-stock biomass estimates and the corresponding confidence intervals from DEPM (solid line and circles) and acoustics (dashed line and triangles).

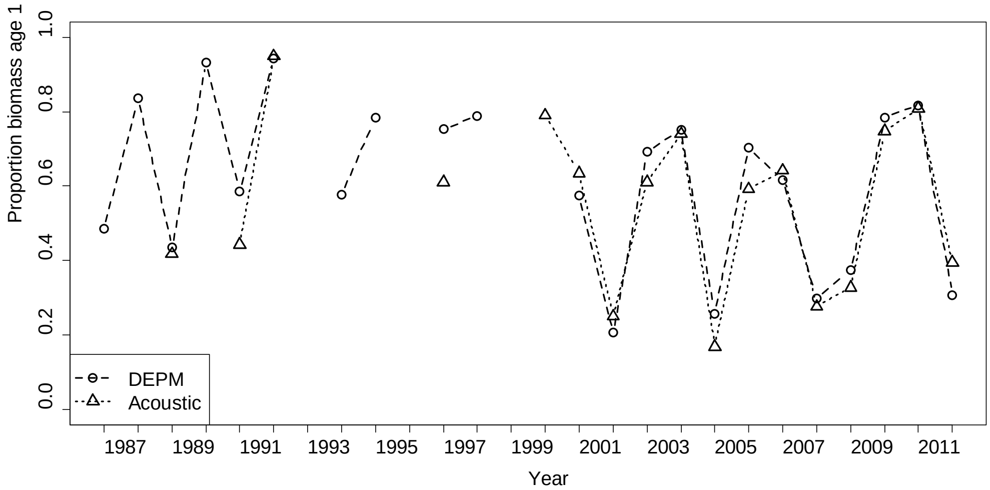


Figure 3.5.1.2. Bay of Biscay anchovy: Historical series of age 1 biomass proportion estimates from DEPM (dashed line and circles) and acoustics (dotted line and triangles).

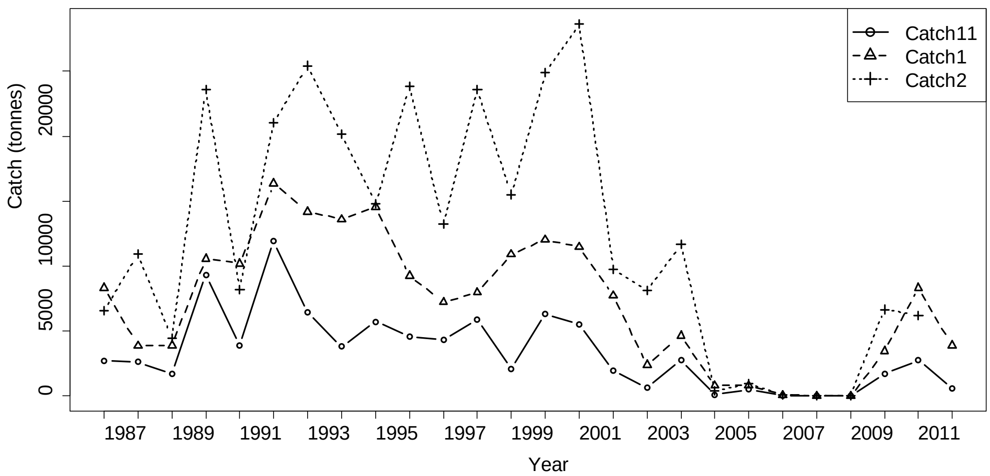


Figure 3.5.1.3. Bay of Biscay anchovy: Historical series of age 1 and total catch in the first period (1st January-15th May; solid line and open circle and dashed line and triangle respectively) and of total catch in the second period (15th May-31st December; dotted line and cross).

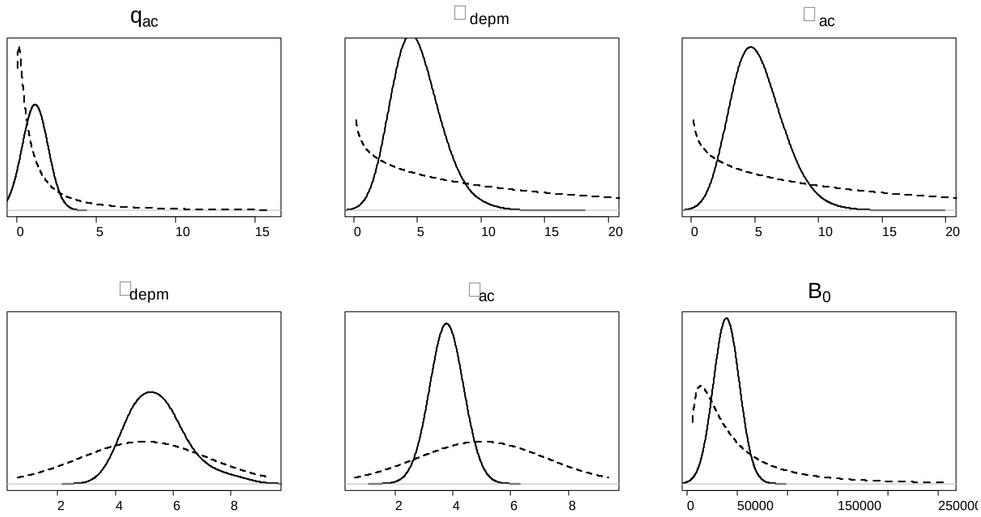


Figure 3.5.1.4. Bay of Biscay anchovy: Comparison between the prior (dotted line) and posterior distribution (solid line) for some of the parameters of BBM.

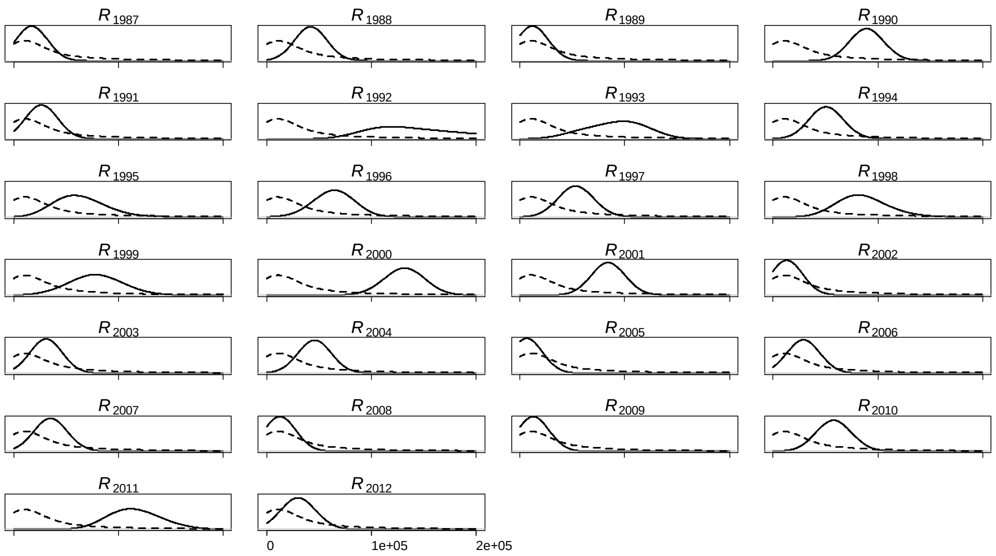


Figure 3.5.1.5. Bay of Biscay anchovy: Comparison between the prior (dotted line) and posterior distribution (solid line) for recruitment in BBM.

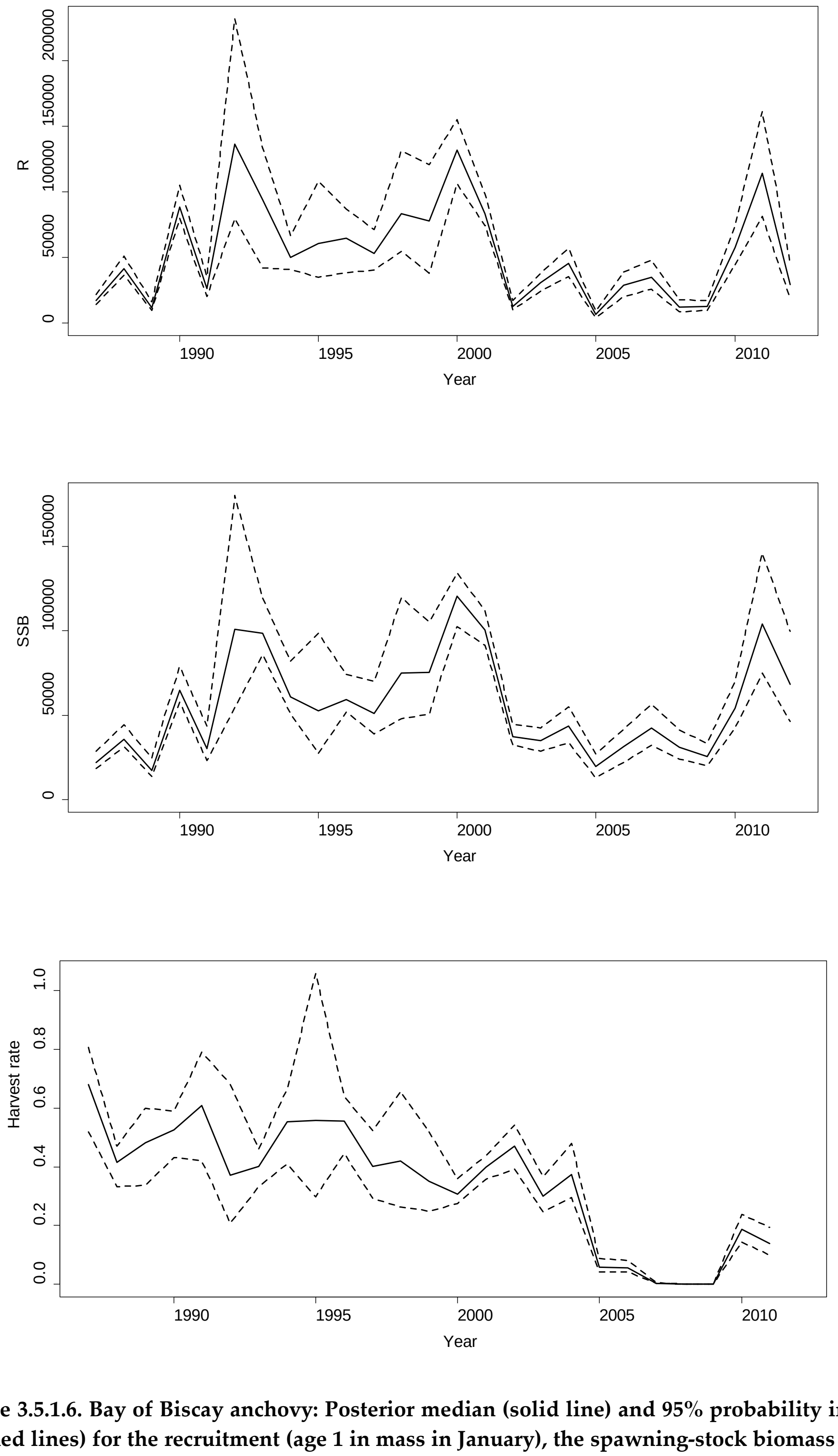


Figure 3.5.1.6. Bay of Biscay anchovy: Posterior median (solid line) and 95% probability intervals (dashed lines) for the recruitment (age 1 in mass in January), the spawning-stock biomass and the harvest rates (Catch/SSB) from the BBM.

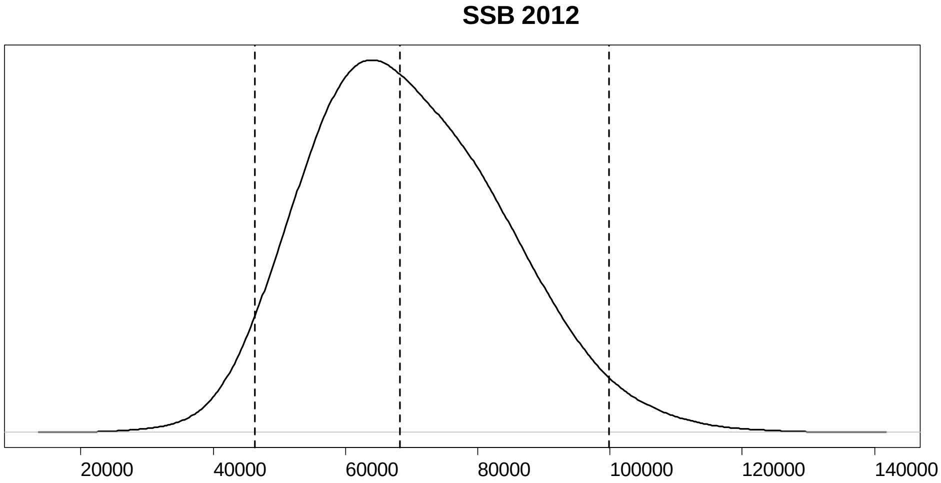


Figure 3.5.1.7. Bay of Biscay anchovy: Posterior distribution of spawning biomass in 2012 from BBM. Vertical dashed lines correspond to posterior median and 95% probability intervals.

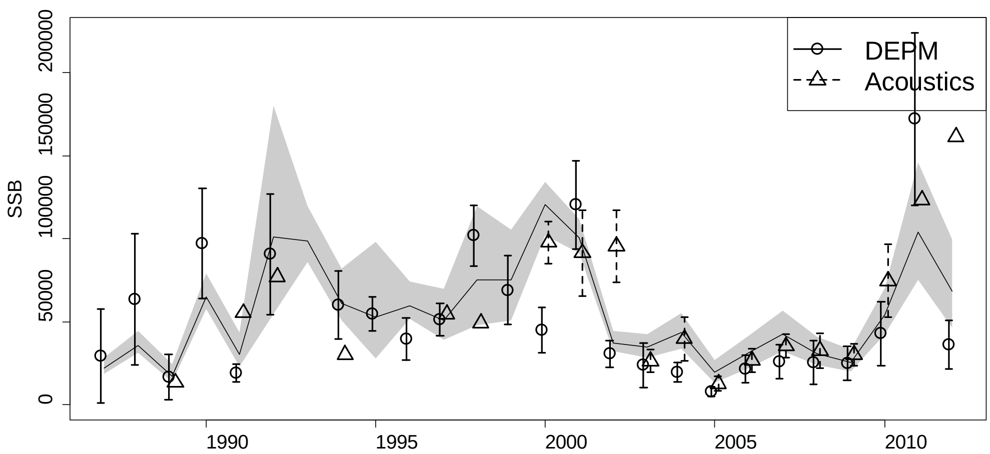


Figure 3.5.2.1. Bay of Biscay anchovy: Comparison of the SSB posterior 95% probability intervals from the BBM (grey area) and the SSB indices corrected by their catchability with the corresponding confidence intervals from DEPM (open circle and solid line) and Acoustics (triangle and dashed line).

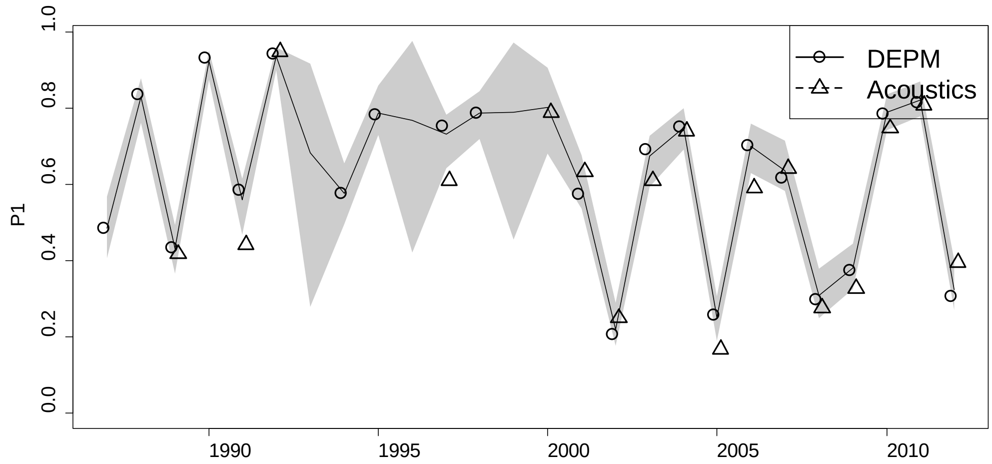


Figure 3.5.2.2. Bay of Biscay anchovy: Comparison of the age 1 biomass proportion posterior 95% probability intervals from the BBM (grey area) and the point estimates from DEPM (open circle) and Acoustics (triangle).

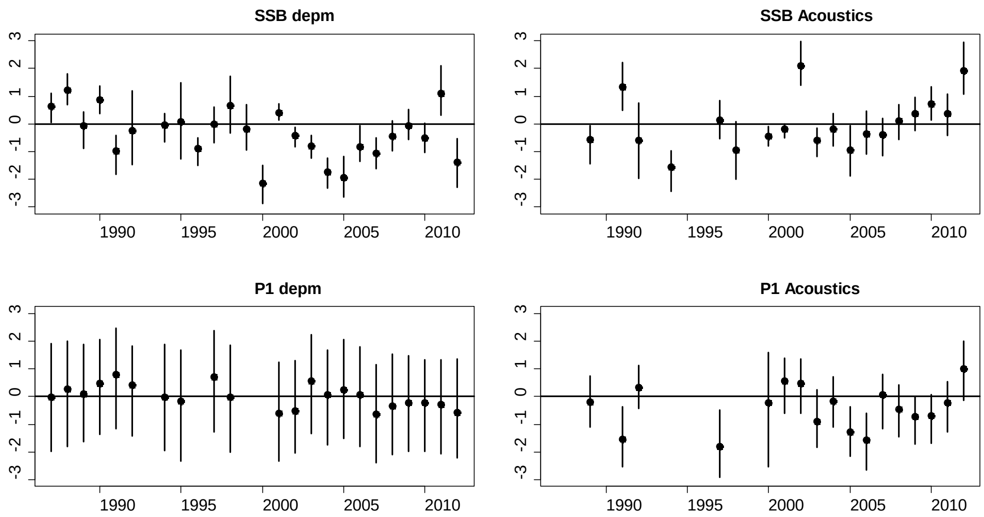


Figure 3.5.2.3. Bay of Biscay anchovy: Pearson residual medians and 95% probability intervals to the four indices used in the BBM.

SOURCES: Ibaibarriaga *et al.* (2008); Ibaibarriaga *et al.* (2011); ICES 2009a (WKSHORT); ICES 2010c (WGANSA); ICES 2012f (WGHANSA).

8 Iberian sardine

DATA:

Input data include catch (in biomass), age composition of the catch, total abundance (in numbers) and age composition from an annual acoustic survey and spawning–stock biomass (SSB) from a triennial DEPM survey. Considering the current assessment calendar (annual assessment WG in June in year y+1), the assessment includes fishery data up to year y and acoustic data up to year y+1.

Maturity-at-age

Following the Stock Annex (ICES 2012g [WKPELA]), in DEPM years maturity-at-age is obtained from the survey samples. For 2011, maturity-at-age is:

Age	0	1	2	3	4	5	6+
Proportion mature	0.00	0.99	1.00	1.00	1.00	1.00	1.00

Natural mortality

Following the Stock Annex (ICES, 2012g [WKPELA]), natural mortality is:

	M, year^{-1}
Age 0	0.8
Age 1	0.5
Age 2	0.4
Age 3	0.3
Age 4	0.3
Age 5	0.3
Age 6	0.3
Mean (2-5)	0.3

Sardine in VIIIc and IXa: Catch-at-age data.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6
1978	869	2297	947	295	137	42	16
1979	674	1536	956	431	189	93	36
1980	857	2037	1562	379	157	47	30
1981	1026	1935	1734	679	195	105	76
1982	62	795	1869	709	353	131	129
1983	1070	577	857	803	324	141	139
1984	118	3312	487	502	301	179	117
1985	268	564	2371	469	294	201	103
1986	304	755	1027	919	333	196	167
1987	1437	543	667	569	535	154	171
1988	521	990	535	439	304	292	189
1989	248	566	909	389	221	200	245
1990	258	602	517	707	295	151	248
1991	1581	477	436	407	266	75	105
1992	498	1002	451	340	186	111	81
1993	88	566	1082	521	257	114	120
1994	121	60	542	1094	272	113	72
1995	31	189	281	830	473	70	64
1996	277	101	348	515	653	197	47
1997	209	549	453	391	337	225	70
1998	449	366	502	352	234	179	106
1999	246	475	362	340	177	106	73
2000	490	355	314	256	194	98	64
2001	220	1172	256	196	126	75	50
2002	107	587	754	181	112	56	40
2003	198	319	446	518	114	61	51
2004	590	181	264	387	378	78	55
2005	169	1006	266	207	191	117	46
2006	18	250	777	129	108	121	81
2007	199	82	313	536	80	83	121
2008	298	219	183	370	412	65	109
2009	378	354	196	125	252	197	84
2010	278	517	263	136	83	129	183
2011	342	452	383	122	88	41	111

Table 7.4.1a. Sardine in VIIIc and IXa: Mean weights-at-age (kg) in the catch.

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6+
1978	0.017	0.034	0.052	0.060	0.068	0.072	0.100
1979	0.017	0.034	0.052	0.060	0.068	0.072	0.100
1980	0.017	0.034	0.052	0.060	0.068	0.072	0.100
1981	0.017	0.034	0.052	0.060	0.068	0.072	0.100
1982	0.017	0.034	0.052	0.060	0.068	0.072	0.100
1983	0.017	0.034	0.052	0.060	0.068	0.072	0.100
1984	0.017	0.034	0.052	0.060	0.068	0.072	0.100
1985	0.017	0.034	0.052	0.060	0.068	0.072	0.100
1986	0.017	0.034	0.052	0.060	0.068	0.072	0.100
1987	0.017	0.034	0.052	0.060	0.068	0.072	0.100
1988	0.017	0.034	0.052	0.060	0.068	0.072	0.100
1989	0.013	0.035	0.052	0.059	0.066	0.071	0.100
1990	0.024	0.032	0.047	0.057	0.061	0.067	0.100
1991	0.020	0.031	0.058	0.063	0.073	0.074	0.100
1992	0.018	0.045	0.055	0.066	0.070	0.079	0.100
1993	0.017	0.037	0.051	0.058	0.066	0.071	0.100
1994	0.020	0.036	0.058	0.062	0.070	0.076	0.100
1995	0.025	0.047	0.059	0.066	0.071	0.082	0.100
1996	0.019	0.038	0.051	0.058	0.061	0.071	0.100
1997	0.022	0.033	0.052	0.062	0.069	0.073	0.100
1998	0.024	0.040	0.055	0.061	0.064	0.067	0.100
1999	0.025	0.042	0.056	0.065	0.070	0.073	0.100
2000	0.025	0.037	0.056	0.066	0.071	0.074	0.100
2001	0.023	0.042	0.059	0.067	0.075	0.079	0.100
2002	0.028	0.045	0.057	0.069	0.075	0.079	0.100
2003	0.024	0.044	0.059	0.067	0.079	0.084	0.100
2004	0.020	0.040	0.056	0.066	0.072	0.082	0.100
2005	0.023	0.037	0.055	0.068	0.074	0.075	0.100
2006	0.031	0.042	0.056	0.068	0.073	0.078	0.100
2007	0.028	0.054	0.071	0.074	0.085	0.086	0.100
2008	0.025	0.043	0.066	0.074	0.075	0.083	0.100
2009	0.020	0.041	0.065	0.075	0.079	0.083	0.100
2010	0.026	0.046	0.061	0.075	0.082	0.084	0.100
2011	0.024	0.045	0.064	0.073	0.077	0.077	0.100

Table 7.4.1b. Sardine in VIIIc and IXa: Mean weights-at-age (kg) in the stock.

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6+
1978	0	0.015	0.038	0.050	0.064	0.067	0.100
1979	0	0.015	0.038	0.050	0.064	0.067	0.100
1980	0	0.015	0.038	0.050	0.064	0.067	0.100
1981	0	0.015	0.038	0.050	0.064	0.067	0.100
1982	0	0.015	0.038	0.050	0.064	0.067	0.100
1983	0	0.015	0.038	0.050	0.064	0.067	0.100
1984	0	0.015	0.038	0.050	0.064	0.067	0.100
1985	0	0.015	0.038	0.050	0.064	0.067	0.100
1986	0	0.015	0.038	0.050	0.064	0.067	0.100
1987	0	0.015	0.038	0.050	0.064	0.067	0.100
1988	0	0.015	0.038	0.050	0.064	0.067	0.100
1989	0	0.015	0.038	0.050	0.064	0.067	0.100
1990	0	0.015	0.038	0.050	0.064	0.067	0.100
1991	0	0.019	0.042	0.050	0.064	0.071	0.100
1992	0	0.027	0.036	0.050	0.062	0.069	0.100
1993	0	0.022	0.045	0.057	0.064	0.073	0.100
1994	0	0.031	0.040	0.049	0.060	0.067	0.100
1995	0	0.029	0.050	0.062	0.072	0.079	0.100
1996	0	0.021	0.042	0.050	0.057	0.065	0.077
1997	0	0.024	0.032	0.052	0.059	0.064	0.072
1998	0	0.029	0.037	0.048	0.054	0.059	0.066
1999	0	0.024	0.040	0.052	0.059	0.067	0.073
2000	0	0.017	0.043	0.056	0.061	0.067	0.067
2001	0	0.021	0.041	0.060	0.071	0.072	0.074
2002	0	0.024	0.040	0.055	0.068	0.074	0.074
2003	0	0.019	0.043	0.053	0.065	0.070	0.076
2004	0	0.020	0.045	0.061	0.069	0.076	0.100
2005	0	0.019	0.045	0.059	0.068	0.073	0.079
2006	0	0.030	0.042	0.060	0.068	0.068	0.075
2007	0	0.039	0.054	0.062	0.070	0.076	0.077
2008	0	0.017	0.052	0.065	0.070	0.080	0.087
2009	0	0.020	0.053	0.060	0.065	0.069	0.076
2010	0	0.018	0.042	0.058	0.064	0.064	0.071
2011	0	0.026	0.048	0.058	0.065	0.066	0.067

Sardine in VIIIc and IXa: Spring acoustic survey data, numbers-at-age (thousands).

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6
1996	1636	2136	2505	3257	600	37
1997	6401	3501	1677	1384	1426	264
1998	2146	4118	2271	1468	1206	1005
1999	5926	2713	1595	969	624	533
2000	6673	2456	1657	999	721	681
2001	19660	1037	702	480	374	250
2002	13041	6998	1164	1131	566	442
2003	5885	4584	3568	1009	570	338
2005	22922	1302	685	763	653	369
2006	7455	8309	577	443	578	607
2007	1645	3085	4001	637	283	704
2008	4020	1098	998	1972	211	494
2009	7096	667	419	691	773	497
2010	7340	702	537	188	269	366
2011	765	1033	337	209	115	388

Sardine in VIIIc and IXa: DEPM survey data, spawning-stock biomass (thousand tons).

Year	SSB
1997	308
1999	383
2002	195
2005	383
2008	652
2011	465

MODEL:

The sardine assessment is an age-based assessment using Stock Synthesis, and assuming a single area, a single fishery, a yearly season and genders combined. A table describing the main features of Stock Synthesis is presented in Annex 8.

Model structure and assumptions:	**WGHANSA 2012/SS3**
Recruitment	No SR model; annual recruitments are parameters, defined as lognormal deviations from a constant mean value penalized by a sigma of 0.55 (the standard deviation of log(recruits) estimated in WGANSA 2011)
Initial population	N-at-age in the first year are parameters, derived from an input initial equilibrium catch, the geometric mean recruitment and the selectivity in the first year.
Fishery selectivity-at-age	S-at-age 0 used as the reference; S flat from age 3 to age 5
Fishery selectivity over time	Time-varying (random walk) in 1978-1990; Fixed over time in 1991-2011
Survey selectivity-at-age	S-at-age 1 used as the reference; S flat from age 2 to age 5; fixed over time
Acoustic survey catchability	Acoustic and DEPM are relative indices of abundance

Objective function:	**WKPELA 2012/WGHANSA 2012**
Weights of components	All components have equal weight
Data weights	- Sample size of age compositions by year - Acoustic and DEPM abundance observations with equal weight = CV=25%

BASE FIT:

The model fit to the surveys is shown in Figures 7.5.1.1 and 7.5.1.2. Figure 7.5.1.3. shows catch-at-age residuals and acoustic survey residuals. The assessment summary plots are in Figure 7.5.2.1.

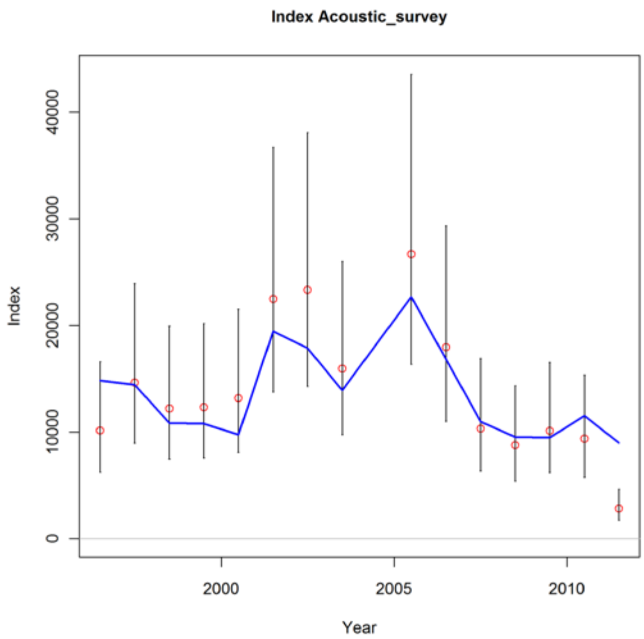


Figure 7.5.1.1. Sardine in VIIIc and IXa: Model fit to the acoustic survey series. The index is total abundance (in thousands of individuals). Bars are standard errors re-transformed from the log scale.

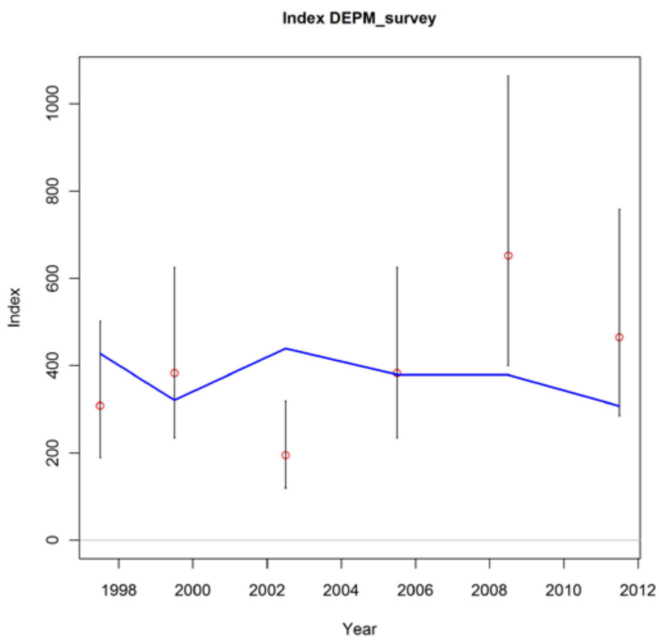
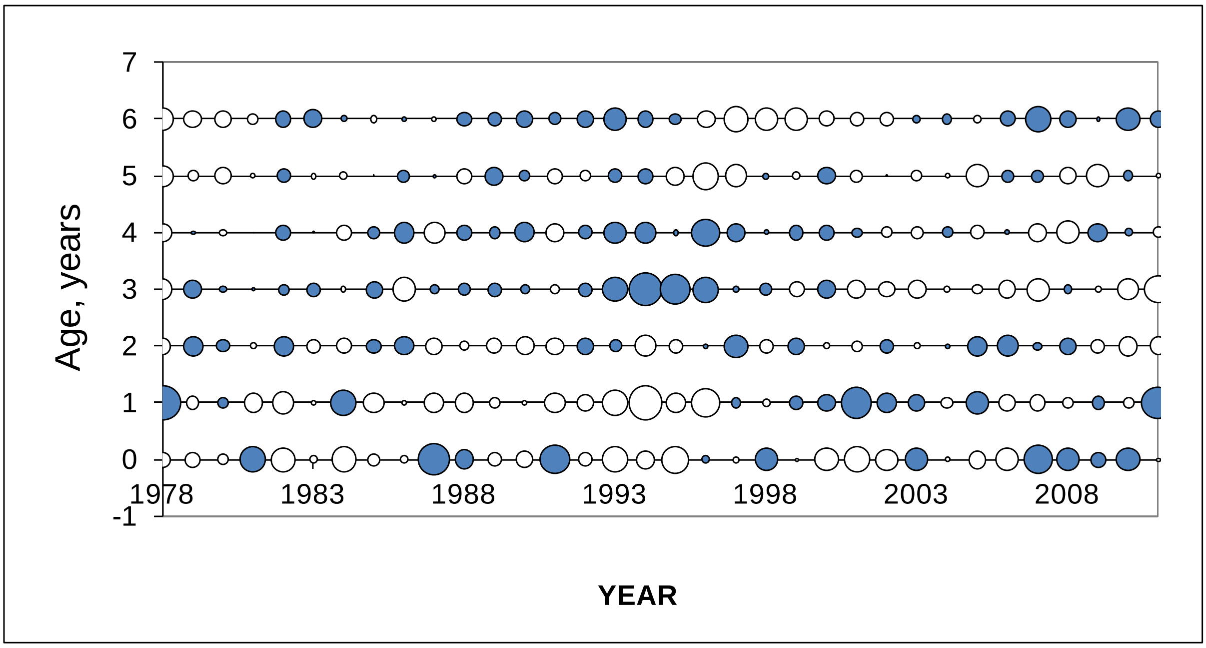


Figure 7.5.1.2. Sardine in VIIIc and IXa: Model fit to the DEPM survey series. The index is SSB (in thousand tons). Bars are standard errors re-transformed from the log scale.



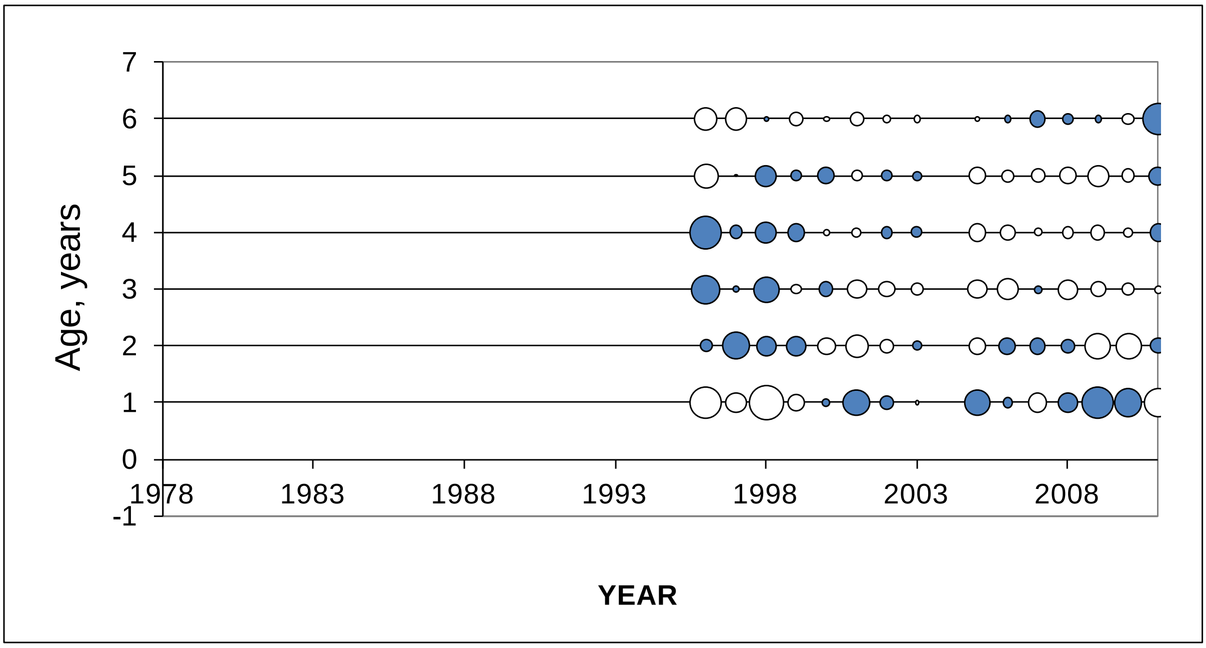


Figure 7.5.1.3. Sardine in VIIIc and IXa: Model residuals from the fit to the catch-at-age composition (a) and the acoustic survey age composition (b). Solid symbols correspond to positive residuals. Residuals are in the range [-2.9,3.1] for catch and in the range [-3.4, 2.9] for survey age compositions.

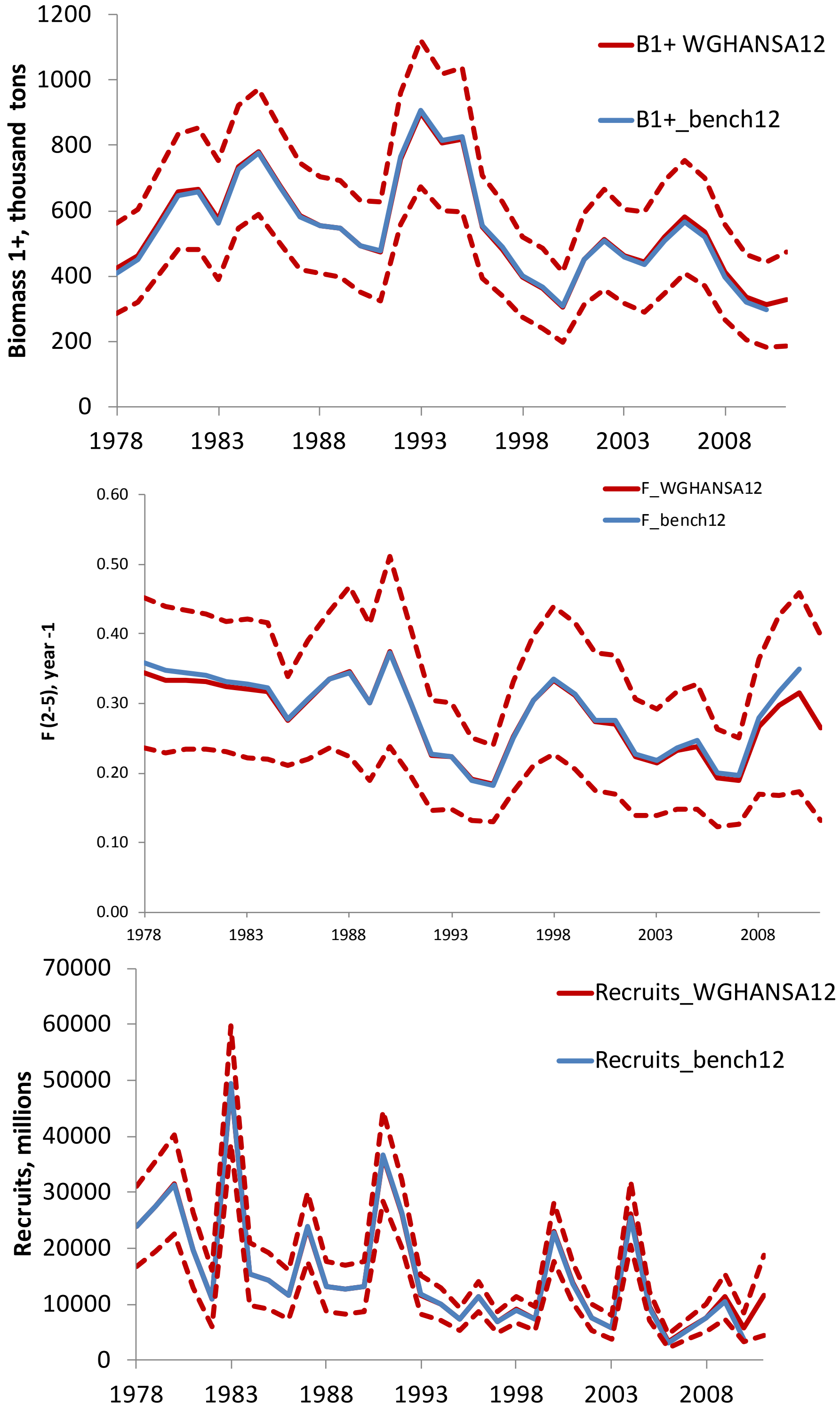


Figure 7.5.2.1. Sardine VIIIc and IXa: Historical B1+ (top), F (middle) and recruitment (bottom) trajectories in the period 1978 – 2011. The WKPELA 2012 assessment is shown for comparison.

SOURCES: ICES 2012f (WGHANSA); ICES 2012g (WKPELA 2012).

9 Southern horse mackerel

DATA:

Mean weight (kg) at age in the catch and stock

Taking in consideration that the spawning season is very long, spawning is almost from September to June, and that the whole length range of the species has commercial interest in the Iberian Peninsula, with scarce discards, there is no reason to consider that the mean-weight in the catch may be significantly different from the mean weight in the stock.

	AGES											
YEAR	0	1	2	3	4	5	6	7	8	9	10	11+
1992	0.03	0.03	0.04	0.07	0.1	0.13	0.15	0.17	0.19	0.2	0.23	0.3
1993	0.02	0.03	0.04	0.07	0.09	0.13	0.17	0.21	0.24	0.24	0.25	0.3
1994	0.04	0.04	0.06	0.07	0.09	0.13	0.16	0.19	0.23	0.25	0.27	0.34
1995	0.04	0.03	0.06	0.08	0.1	0.12	0.16	0.17	0.2	0.22	0.23	0.31
1996	0.02	0.05	0.07	0.09	0.11	0.14	0.17	0.19	0.22	0.24	0.26	0.31
1997	0.03	0.03	0.05	0.07	0.11	0.14	0.17	0.2	0.24	0.26	0.26	0.36
1998	0.03	0.03	0.04	0.07	0.1	0.13	0.17	0.21	0.17	0.24	0.25	0.35
1999	0.02	0.04	0.06	0.08	0.11	0.14	0.16	0.19	0.22	0.25	0.27	0.36
2000	0.02	0.03	0.05	0.09	0.11	0.13	0.16	0.19	0.22	0.24	0.25	0.31
2001	0.02	0.03	0.07	0.08	0.09	0.13	0.16	0.18	0.2	0.23	0.24	0.31
2002	0.03	0.03	0.04	0.07	0.1	0.12	0.15	0.17	0.2	0.23	0.25	0.31
2003	0.02	0.03	0.05	0.06	0.09	0.12	0.15	0.18	0.2	0.23	0.25	0.31
2004	0.04	0.03	0.05	0.08	0.12	0.16	0.18	0.21	0.23	0.25	0.27	0.33
2005	0.02	0.03	0.04	0.07	0.12	0.15	0.17	0.18	0.22	0.24	0.25	0.3
2006	0.03	0.03	0.05	0.06	0.09	0.13	0.14	0.17	0.19	0.23	0.25	0.33
2007	0.03	0.05	0.06	0.07	0.09	0.11	0.16	0.19	0.23	0.22	0.24	0.3
2008	0.02	0.05	0.06	0.08	0.1	0.13	0.15	0.17	0.2	0.21	0.23	0.32
2009	0.02	0.03	0.06	0.09	0.11	0.13	0.15	0.17	0.18	0.21	0.24	0.36
2010	0.02	0.04	0.06	0.08	0.11	0.14	0.16	0.18	0.19	0.2	0.24	0.38

Maturity-at-age

A single maturity ogive is used for the whole assessment period, which is an average of all maturity ogives estimated in the past, with the values for each age weighted by the corresponding number of samples that were used to estimate it.

Age	0	1	2	3	4	5	6	7	8	9	10	11+
Prop mature	0	0	0.36	0.82	0.95	0.97	0.99	1.0	1.0	1.0	1.0	1.0

Natural mortality

The natural mortality used in the assessment is:

Age	0	1	2	3	4	5	6	7	8	9	10	11+
M	0.9	0.6	0.4	0.3	0.2	0.15	0.15	0.15	0.15	0.15	0.15	0.15

Southern horse-mackerel catch (thousands) at age data

	AGES											
YEAR	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11+**
1992	11684	95186	145732	40736	12171	9102	5018	6864	5155	4761	13973	14354
1993	6480	66211	137089	100515	35418	13367	12938	10495	6597	5552	4497	14442
1994	12713	63230	86718	96253	28761	7628	4398	3433	5209	4834	6047	12264
1995	7230	55380	31265	52030	28199	11010	4003	3139	2720	3352	2530	31343
1996	69651	13798	14021	28125	33937	9861	6611	4501	4164	5504	3306	14243
1997	5056	295329	112210	26236	17168	12886	7780	7169	3938	3867	2425	8847
1998	22917	95950	320721	68438	18770	11317	9712	20627	12760	6686	6212	11323
1999	51659	29795	26231	66704	42960	15700	13840	7555	4175	4790	2475	7417
2000	12246	72936	23547	41618	35968	18643	17254	12118	7915	5227	3124	3557
2001	105759	77364	31261	24104	23721	16794	15391	14964	9795	3310	2023	3989
2002	18444	94402	84379	26482	13161	11396	10263	12501	10156	7525	3607	4433
2003	40033	6830	36754	28559	21931	12790	14751	13582	10631	6492	3531	2333
2004	7101	126797	58054	18243	8328	13586	11836	14878	10542	3876	5258	5318
2005	21015	108070	49197	24289	17877	11334	11179	7927	9124	7445	5502	11420
2006	3329	92563	92896	22665	6738	13176	11892	6029	7303	8070	8947	15322
2007	2885	16419	27667	44357	20534	8187	4459	3563	5975	4748	4943	30001
2008	48380	54167	31951	28058	16616	7194	4782	3660	4579	3975	4537	24990
2009	22618	85415	32416	8482	9774	7162	3289	2860	2791	3579	4236	39096
2010	81048	102016	33906	17496	11979	7569	3847	3942	2452	2671	2977	32284

Time-series of cpue at age from Portuguese and Spanish combined bottom-trawl surveys

	AGES											
YEAR	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11+**
1992	329.80	355.18	113.91	39.86	18.19	7.23	4.94	5.21	2.75	2.34	4.71	5.14
1993	1451.63	190.41	192.85	119.00	27.93	3.65	2.64	3.64	3.34	4.83	2.91	9.42
1994	2.92	7.19	49.85	45.43	18.91	4.67	2.11	1.51	0.90	0.90	1.20	13.08
1995	16.63	65.59	93.95	56.94	25.36	4.82	1.00	1.17	0.49	0.24	0.47	8.86
1996	1144.25	7.94	12.92	20.88	20.98	3.98	1.72	0.79	0.63	1.32	0.29	4.74
1997	844.41	59.49	98.25	29.31	47.69	27.66	5.71	4.97	2.42	2.95	1.18	3.49
1998	77.56	32.60	91.63	13.27	4.92	2.73	1.52	1.76	0.40	0.13	0.07	0.21
1999	104.54	22.23	41.79	49.25	4.13	1.42	0.83	0.31	0.34	0.99	1.16	3.65
2000	2.53	15.45	20.78	23.35	11.36	6.34	3.40	2.01	1.88	1.29	0.31	1.05
2001	545.08	1.88	3.50	2.75	3.80	5.48	6.72	11.52	7.62	3.66	2.43	2.64
2002	32.48	2.05	6.87	11.31	9.00	4.63	1.75	1.58	3.96	3.51	4.56	9.90
2003	63.14	7.62	7.64	14.79	13.16	3.77	2.06	1.33	0.84	0.75	0.52	0.67
2004	82.37	31.80	113.13	49.83	11.15	5.61	2.49	5.18	6.38	1.08	0.48	0.23
2005	1451.28	1188.35	191.08	65.29	32.23	14.03	16.40	16.68	12.89	6.78	4.08	11.82
2006	84.21	76.75	204.14	50.90	3.05	9.78	7.06	5.80	2.37	1.32	0.65	0.50
2007	34.22	0.72	23.34	37.79	28.39	7.16	2.68	1.80	0.65	0.71	1.54	3.25
2008	48.47	21.67	33.39	19.25	24.72	17.12	2.39	0.82	1.23	1.76	1.24	4.43
2009	1436.39	66.51	98.83	36.26	29.36	8.13	2.21	1.26	0.94	0.58	0.55	4.60
2010	62.23	24.76	44.67	36.77	41.74	16.23	7.47	5.28	4.33	3.29	3.17	9.48

MODEL:

The Assessment Model for the Ibero-Atlantic Stock of Horse Mackerel (AMISH) is adapted from AMAK (Assessment Model from Alaska, available from the NOAA fisheries toolbox) which is used in many stock assessments in North American waters (e.g. Atka mackerel, eastern Bering Sea pollock, Pacific Ocean perch). It is a well-tested and widely used methodology, which has also been adopted by the South Pacific Regional Fishery Management Organization (SPRFMO) for the assessment of Chilean jack mackerel (*Trachurus murphyi*). This method (Lowe *et al.*, 2009) employs an explicit age-structured model with the standard catch equation as the operational population dynamics model (e.g. Fournier and Archibald 1982; Hilborn and Walters 1992; Schnute and Richards, 1995). It models the population numbers-at-age as projections forward based on recruitment estimates leading up the initial population numbers-at-age (in 1992 for this case) and subsequent annual recruitment and fishing mortalities parameters. These underlying population numbers-at-age are fit through an observation model for parameter estimation via a penalized likelihood applied to a quasi-Newton minimization routine with partial derivatives calculated by automatic differentiation (Griewank and Corliss, 1991). The automatic differentiation and minimization routines are those from the package AD Model Builder (ADMB). A more detailed description of the method is given in Annex 8.

BASE FIT:

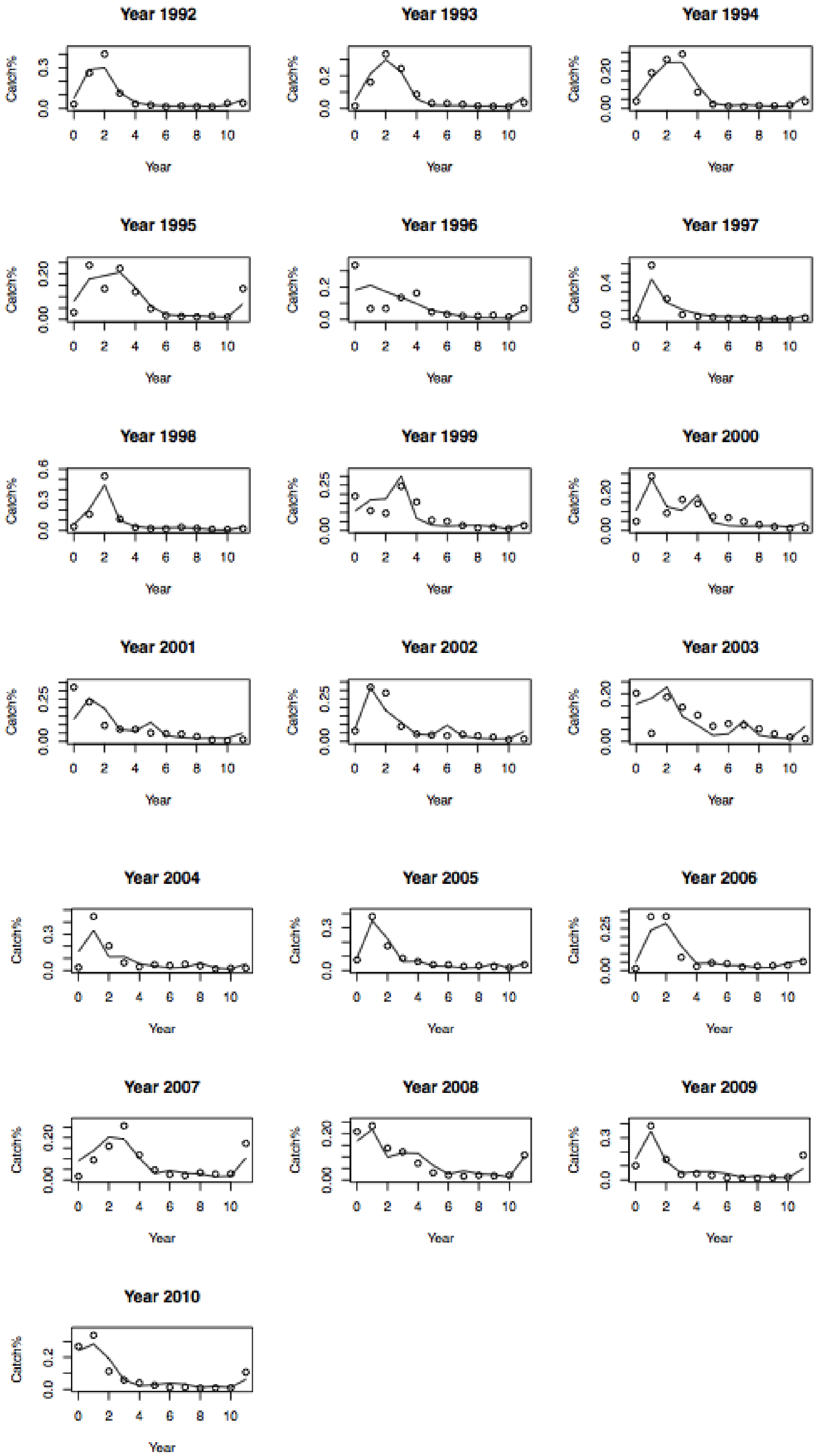


Figure 7.5.2.3. Southern horse mackerel. Comparison of proportions at age of the abundance indices observed in catch data and those fitted by the AMISH model. Observed values =dots; fitted values = solid lines.

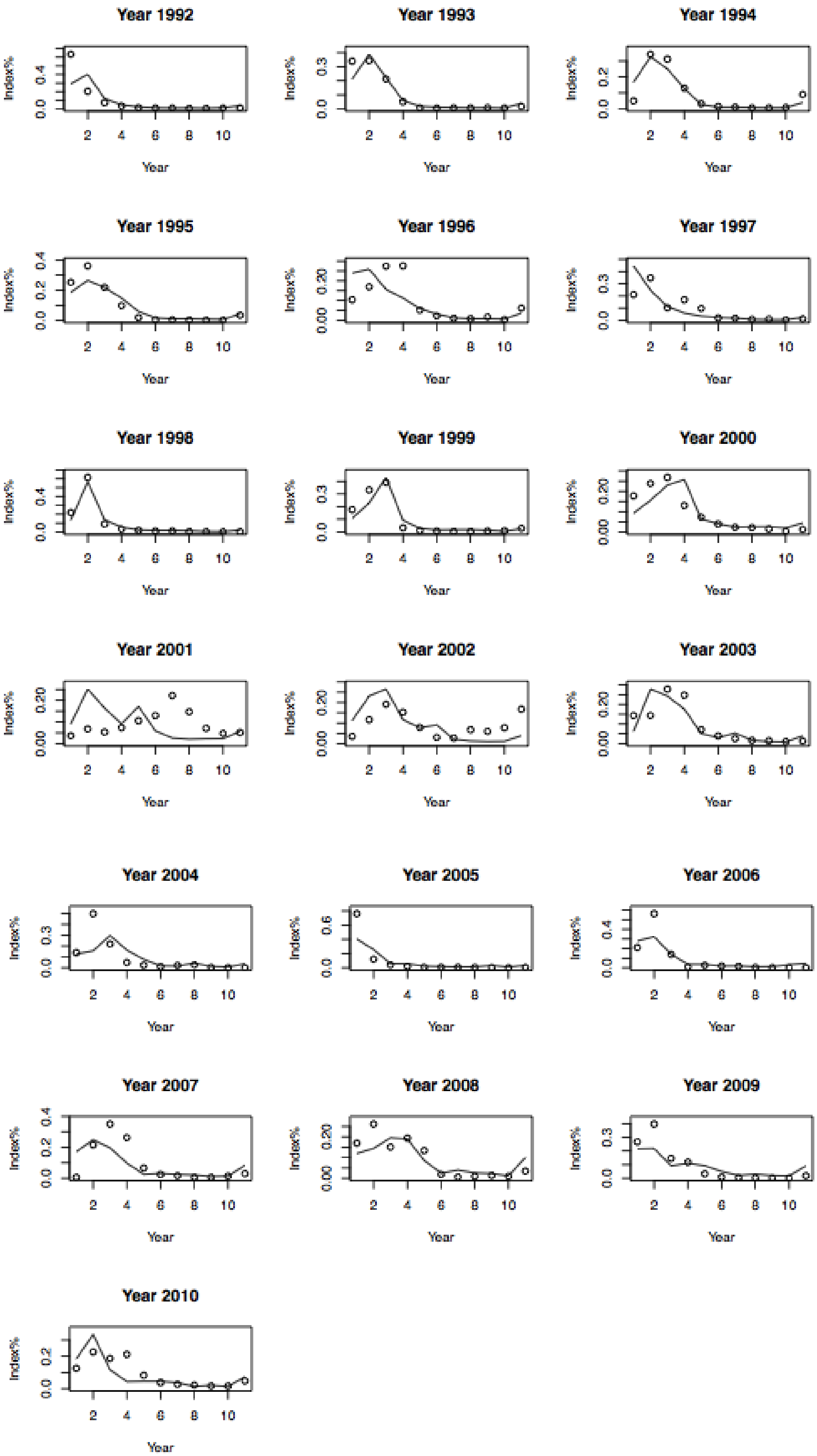


Figure 7.5.2.5. Southern horse mackerel. Comparison of proportions at age of the abundance indices observed in bottom-trawl survey and those fitted by the AMISH model. Observed values =dots; fitted values = solid lines.

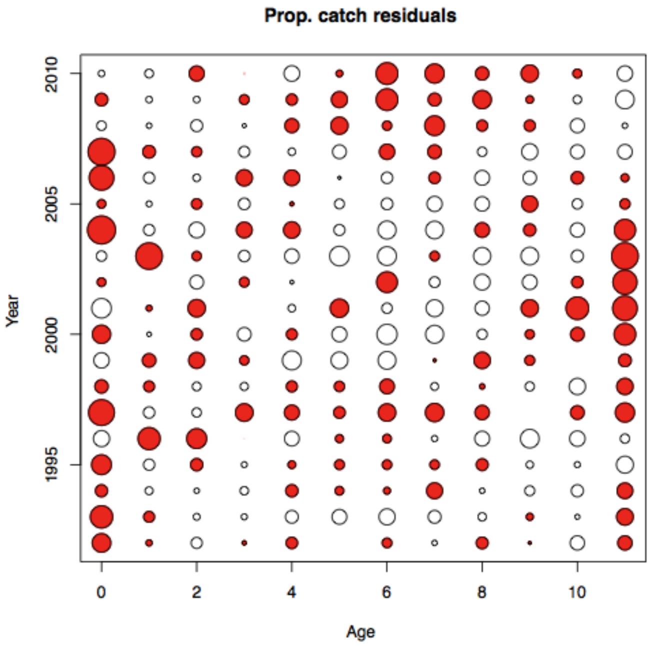


Figure 7.5.2.4. Southern horse mackerel. Bubble plot of catch data residuals from the AMISH.

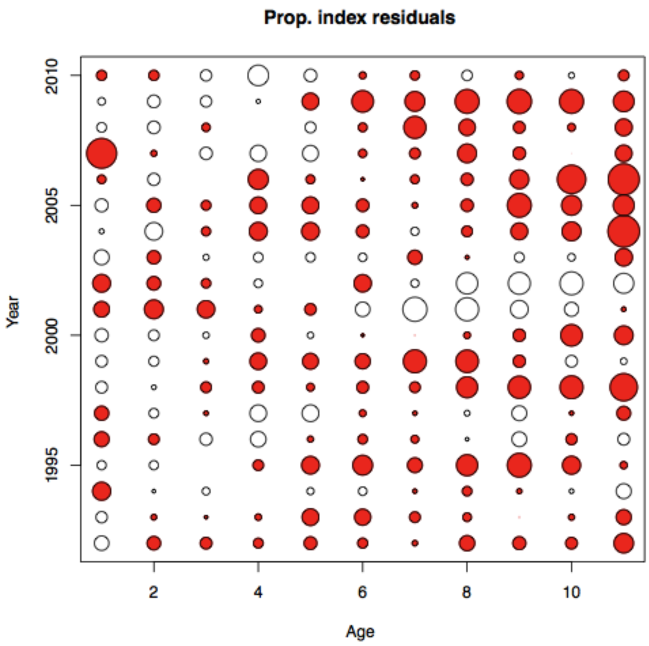


Figure 7.5.2.6. Southern horse mackerel. Bubble plot of bottom-trawl survey residuals from the AMISH.

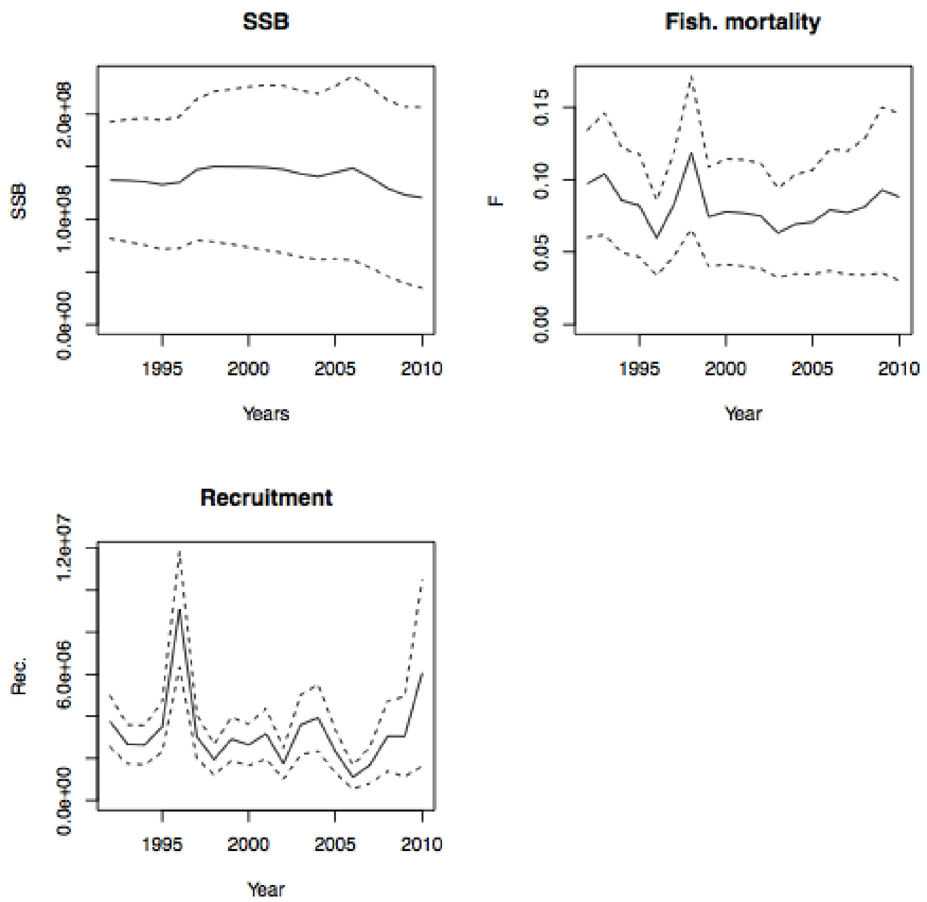


Figure 7.5.1.2. Southern horse mackerel. Final assessment. Stock summary. Plots of SSB (females), recruitment and fishing mortality. SSB and catch are in tons, and recruitment in thousands.

SOURCES: ICES 2011a (WGANSA 2011) and ICES 2011b (WKBENCH 2011)

10 North Atlantic albacore

DATA:

The full set of data are available from the ICCAT Secretariat. Historical data sets will be available for download from http://code.google.com/p/mse4mfcl/. Data summaries are provided in the ICCAT 2009 assessment report (see section “Sources” below). There is an R package R4MFCL that can be used to extract data and results for use in R (http://code.google.com/p/r4mfcl/).

MODEL:

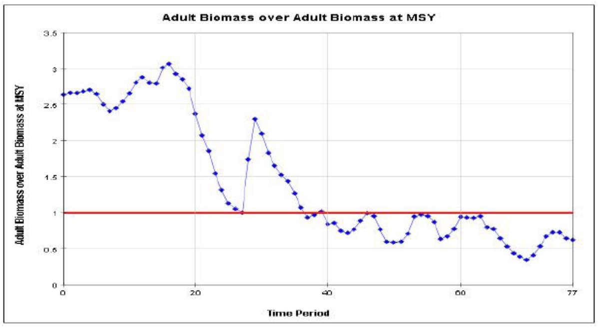
ICCAT tend to base advice on more than one model run e.g. in order to consider model uncertainy. Therefore there is not a single “best fit”. A table describing the main features of Multifan-CL is presented in Annex 8.

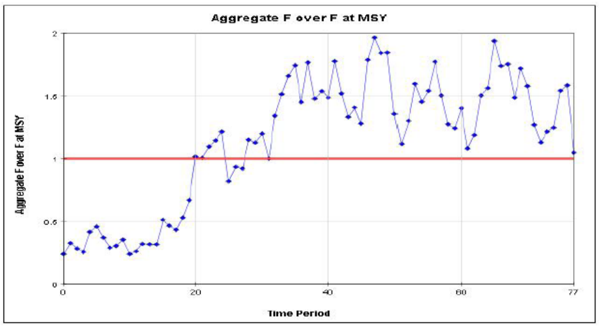
BASE FIT:

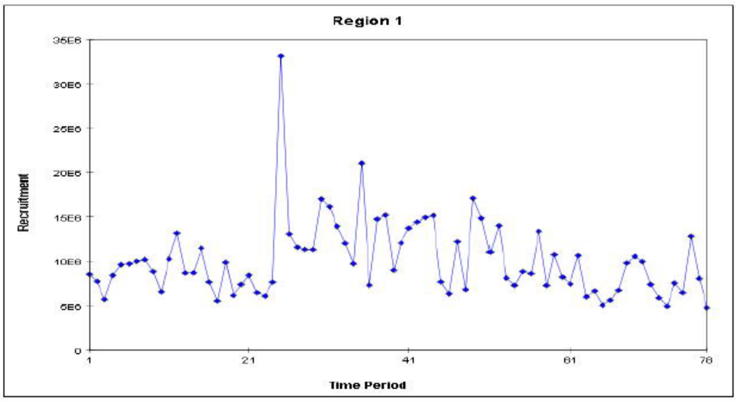
The ICCAT 2009 report presents many different assessments, of which 14 are conducted with Multifan-CL. The following table presents a brief description of the settings and results of these 14 assessments. The runs highlighted in yellow were not considered good fits and were, therefore, discarded. The remaining 4 runs were taken forward when providing advice. Of these, Run 4B was considered as the main one (details and discussion in the ICCAT 2009 report).

Run	*Definition*	*ObjFun*	*#Param*	*AIC*	*MeanF year*	*MSY*	*S15,1*	*S15,2*	*S15,3*	F_{MSY}	SSB_{MSY}	$SSB0/SSB_{MSY}$	SSB_{cur}/SSB_{MSY}	F_{cur}/F_{MSY}
4A	Continuity 1: new data, 2007 Executable	93933.7	1527	96988	0.245	28560	0.42	0.19	0.42	0.166	58170	2.57	0.66	1.06
4B	Continuity 2: new data, 2009 Executable	95632.8	1436	98505	0.274	29000	0.49	0.21	0.49	0.175	53660	2.64	0.62	1.04
4C	Run4B + Change input variances as suggested by SS3 runs	89031.1	1436	91903	0.284	29950	0.63	0.31	0.63	0.173	56050	2.96	0.60	1.11
4D	Run4B + Assume ages 5+ have same selectivity	94284.0	1406	97096	0.035	61490	0.21	0.07	0.21	0.192	96150	4.77	3.37	0.02
4E	Runs 4C and 4D together	87921.6	1406	90734	0.015	128800	0.23	0.11	0.23	0.019	202700	5.26	3.95	0.001
4F	Run4B + Estimate growth curve internally	96221.4	1437	99095	0.107	43920	0.86	0.36	0.86	0.15	77880	3.89	2.54	0.32
4G	Run4B+Constant q for all fisheries	95052.9	1324	97701	0.249	28630	0.41	0.20	0.41	0.18	52810	2.35	0.51	1.25
4H	Run 4B+ Include M at age vector	95595.5	1436	98468	0.252	30450	0.50	0.24	0.50	0.18	38640	3.44	0.94	0.81
4I	Run 4B + Include tagging data	95214.7	1438	98091	0.359	29520	0.45	0.28	0.45	0.17	55280	2.34	0.47	1.06
4K	Run 4I, estimating M	95238.1	1449	98136	0.381	30620	0.40	0.26	0.40	0.18	63720	2.17	0.38	1.21
4L	Run 4B, change initial condition for Z from 10 to 5 years	95488.3	1436	98360	0.566	30970	0.84	0.41	0.84	0.17	60240	1.71	0.21	1.85
4N	Run 4B, ungroup fisheries for selectivity estimation	95788.9	1476	98741	0.254	28090	0.45	0.19	0.53	0.18	53220	2.65	0.76	1.00
4O	Run using annual catch rather than quarterly catch. Same specifications as 4B	36931.9	637	38206	0.528	33580	0.79	0.22	0.79	0.17	53110	2.31	0.22	1.43
4P	Run 4B, enforcing dome shaped selectivity for surface fleets	94481.6	1425	97332	0.365	30490	0.00	0.00	1.00	0.17	49560	2.70	0.55	0.74

Some results for Run 4B:







SOURCES: ICCAT (2009); http://www.multifan-cl.org/

11 US West Coast canary rock fish

DATA:

More details of the data used for this assessment can be found in Wallace and Cope (2011). The following sources of data were used for the 2011 assessment:

1) Fishery-independent data: bottom trawl survey-based indices of abundance and biological data (age and length) from 2003-2010 (NWFSC survey) and 1980-2004 (Triennial survey).

2) Prerecruit survey index of recruitment strength from 2001-2010.

3) Estimates of fecundity, maturity, length-weight relationships and ageing error from various sources.

4) Commercial (targeted and bycatch) and recreational landings from 1916-2010. Eleven fleets are considered: 1) Southern California trawl, 2) Northern California trawl, 3) Oregon trawl, 4) Washington trawl, 5) Southern California non-trawl, 6) Northern California non-trawl, 7) Oregon and Washington non-trawl, 8) Southern California recreational, 9) Northern California recreational, 10) Oregon and Washington recreational and 11) the canary bycatch from the at-sea whiting fishery. Removals associated with research projects (the trawl surveys, and other much smaller sources of permitted mortality due to scientific research) are treated as a fishing fleet, only in that the removals are included in the total.

5) Estimates of discard rates, total mortality and discard mortality (recreational only) from various sources.

6) Research catches from 1977-2010.

7) Fishery biological data (age and length) from 1968-2010.

The following table gives an idea of the complexity of the data used in this assessment (ignore the X and N symbols in the table):

	1916-27	1928-31	1932-49	1950-65	1966-67	1968-72	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Catches																																												
S. CA trawl						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N	N	N	N	N	N	N	N
N. CA trawl	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N	N	N	N	N	N	N	N
OR trawl		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N	N	N	N	N	N	N	N
WA trawl			N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N	N	N	N	N	N	N	N
S. CA non-trawl						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N	N	N	N	N	N	N	N
N. CA non-	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N	N	N	N	N	N	N	N
OR/WA non-trl																				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N	N	N	N	N	N	N	N
S. CA Rec.														X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N
N. CA Rec.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N
OR/WA Rec.									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N
At-sea whiting																									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N	N
Foreign					X	X	X	X	X	X																																		
Research											X			X			X			X			X			X			X			X			X		X	X	X	X	X	X	N	N
WCGOP																																			X	X	X	X	X	X	X	X	N	N
Fishery Data																																												
Age																																												
S. CA trawl														X	X		X	X	X																	X	X							
N. CA trawl														X	X	X	X	X	X		X														X	X	X	X	X				N	
OR trawl														X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N
WA trawl														X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N
OR/WA non-trl																															X	X		X	X	X		X	X					
WCGOP																																						X	X	X	X		N	N
At-sea whiting																																					X	X	X	X	X		N	N
Length																																												
At-sea whiting																																					X	X	X	X	X	X	N	N
S. CA trawl												X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N
N. CA trawl												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
OR trawl							X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N
WA trawl						X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N
S. CA non-trawl												X	X	X					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X		N	
N. CA non-															X	X	X	X							X	X	X	X	X	X	X	X	X	X	X	X	X							
OR/WA non-trl														X								X		X						X	X	X	X	X	X	X		X		X	X			
S. CA Rec.														X	X	X	X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N

	1916-27	1928-31	1932-49	1950-65	1966-67	1968-72	1973-77	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Fishery Data																																								
Length																																								
N. CA Rec.										X	X	X	X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N
OR/WA Rec.										X	X	X	X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N	N
WCGOP discards																															X	X	X	X	X	X	X	X	N	N
Survey data																																								
Index																																								
Triennial survey										X			X			X			X			X			X			X			X			X						
NWFSC survey																																	X	X	X	X	X	X	N	N
Pre-recruit index																															X	X	X	X	X	X	X	X	N	N
Age																																								
Triennial survey													X						X			X			X						X			X						
NWFSC survey																																	X	X	X	X	X	X	N	N
Length																																								
Triennial survey													X			X			X			X			X			X			X			X						
NWFSC survey																																	X	X	X	X	X	X	N	N
For comparison																																								
PGCT hook-and-line																																			X	X				
YOY core area													X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
NWFSC Hook and Line																																		X	X	X				
N. CA trawl CPUE												X	X	X	X	X	X	X	X	X	X	X	X	X	X	X														
OR/WA Rec.																												X	X	X										
N. CA Rec. CPFV CPUE																	X	X	X	X	X	X	X	X	X	X	X	X												

MODEL:

A table describing the main features of Stock Synthesis is presented in Annex 8.

MODEL SETTINGS IN BASE FIT:

Particular details of the model settings used in this assessment can be found in Wallace and Cope (2011).

The assessment is sex-specific, including separate growth curves for males and females. Natural mortality is allowed to increase (linearly) for females starting at age 6 (assumed fixed at 0.06) and reaching an estimated asymptote at age 14, after which the estimated mortality is constant. Natural mortality of males at all ages are assumed equivalent to young females. The sex-ratio at birth is fixed at 1:1, although by allowing increased natural mortality on females, size-based selectivity, and dimorphic growth this can vary appreciably due to differential mortality by age and sex.

For the internal population dynamics, ages 0-39 are individually tracked, with the accumulator age of 40 determining when the 'plus-group' calculations are applied. Since the time-series is started in 1916, the stock is assumed to be in equilibrium at the beginning of the modelled period.

Time-invariant sex-specific growth is fully estimated in the assessment (with the length-at-age 1 assumed to be equal for males and females). The log of the unexploited recruitment level for the Beverton–Holt stock–recruit function is treated as an estimated parameter in the assessment. Steepness (0.511) and recruitment variability (0.5) are fixed parameters. Recruitment deviations are estimated for each year of the period informed by the data (1960+).

Double-normal selectivity was used for all fishing and survey fleets. For fleets that showed strongly dome-shaped selectivity, the descending width parameter was estimated to allow the ability to fit a greater range of domed shapes. Time-blocks of constant selectivity by fleet were considered. For survey fleets, catchability parameters were directly estimated.

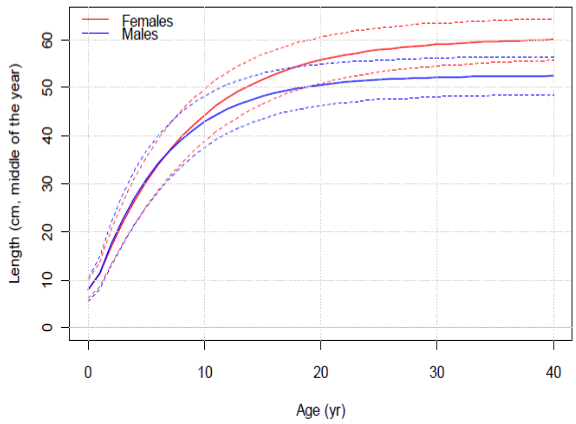
A full list of all estimated parameters and values of key parameters that are fixed is provided in the following table:

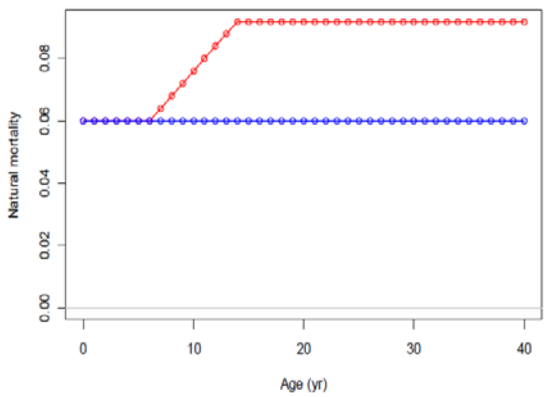
Parameter	Number estimated	Bounds (low, high)	Prior (Mean, SD)
Natural mortality (M, male and female to age 6)	-	NA	Fixed at 0.06
Natural mortality (M, female age 14+, as exp. offset)	1	(-3,3)	Uniform
Weight length coefficient (a)	1	(-3,3)	1.55E-05
Weight length exponenet (b)	1	(-3,3)	3.03
Length at 50% maturity	1	(-3,3)	40.5
Maturity logistic slope	1	(-3,3)	-0.25
Fecundity eggs/grams intercept	1	(-3,3)	1
Fecundity slope	1	(-3,3)	0
Stock and recruitment			
Ln(R_0)	1	(5,11)	Uniform
Steepness (h)	-	NA	Fixed at 0.511
σ_r	-	NA	Fixed at 0.50
Ln(Recruitment deviations): 1960-2009	50	(-10, 10)	Uniform
Catchability			
Ln(Q) – NWFSC survey	-	Analytic solution	
Ln(Q) – Triennial survey (1980-1992)	-	Analytic solution	
Ln(Q) – Triennial survey (1995-2004)	-	Analytic solution	
Ln(Q) – Pre-recruit survey	-	Analytic solution	
Selectivity (double normal)			
Fisheries:			
Length at peak selectivity	25	(20,60)	Uniform
Width of top (as logistic)	-	NA	Fixed at -4.0
Ascending width (as exp[width])	24	(-1,10)	Uniform
Descending width (as exp[width])	7	NA	Fixed at 1.0
Initial selectivity (as logistic)	-	NA	Fixed at -9.0
Final selectivity (as logistic)	23	(-5,5)	Uniform
Surveys:			
Length at peak selectivity	2	(15,66)	Uniform
Width of top (as logistic)	2	(-4,4)	Uniform
Ascending width (as exp[width])	2	(-1,10)	Uniform
Descending width (as exp[width])	-	NA	Fixed at 1.0
Initial selectivity (as logistic)	1	(-5,5)	Fixed at -9.0
Final selectivity (as logistic)	2	(-5,5)	Uniform
Individual growth			
Females:			
Length at age 1	1	(2,10)	Uniform
Length at age 20	1	(45,75)	Uniform
von Bertalanffy K	1	(0.01,0.25)	Uniform
CV of length at age 1	1	(0.01,0.25)	Uniform
CV of length at age 20 offset to age 1	1	(-3,3)	Uniform
Males:			
Length at age 1 offset to females	-	NA	Fixed at 0.0
Length at age 20 offset to females	1	(-3,3)	Uniform
von Bertalanffy K offset to females	1	(-3,3)	Uniform
CV of length at age 1 offset to females	1	(-3,3)	Uniform
CV of length at age 20 offset to females	1	(-3,3)	Uniform
Total: 99 + 50 recruitment deviations = 149 estimated parameters			

RESULTS OF BASE FIT:

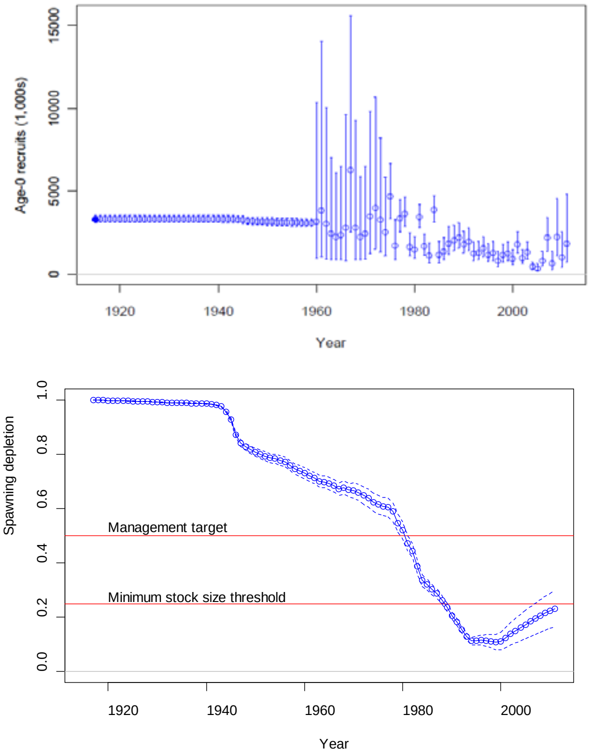
A full set of results and diagnostics (including fits to abundance indices, to length frequency distributions, to age-at-length data, and corresponding residuals) is presented in Wallace and Cope (2011). Here, only a brief summary is shown.

The next 2 graphs show the estimated growth curves (by sex) and the natural mortality values (by sex; only M for females at age 14 is estimated in the assessment).

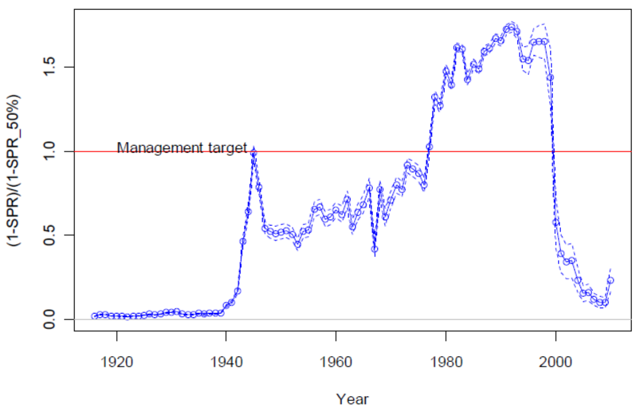




Estimated recruitment (top) and depletion (bottom), with 95% confidence intervals:



Spawning potential ratio relative to target (1-SPR)/(1-SPR50%):



SOURCES: **Wallace and Cope (2011).**

12 Georges Bank yellowtail flounder

DATA:

Table 19a. Recent three year averages of partial recruitment to the fishery, maturity, beginning of year weights at age and catch weights at age used in projections.

	Age Group					
	1	2	3	4	5	6+
Partial Recruitment to the Fishery						
	0.006	0.119	0.503	1	1	1
Maturity						
	0	0.462	0.967	1	1	1
Fraction of M before Spawning = 0.4167						
Fraction of F before Spawning = 0.4167						
Jan-1 Weight for Population (kg)						
	0.099	0.197	0.375	0.479	0.595	0.828
Average Weight for Catch (kg)						
	0.152	0.329	0.443	0.537	0.669	0.828

Table 17. Beginning of year weight (kg) at age for Georges Bank yellowtail. The 2012 values are set equal to the average of the 2009–2011 values.

	Age Group					
Year	1	2	3	4	5	6+
1973	0.055	0.292	0.403	0.465	0.564	0.778
1974	0.069	0.186	0.416	0.530	0.598	0.832
1975	0.068	0.191	0.410	0.524	0.613	0.695
1976	0.061	0.188	0.415	0.557	0.642	0.861
1977	0.071	0.192	0.404	0.587	0.704	0.931
1978	0.057	0.191	0.418	0.601	0.713	0.970
1979	0.068	0.183	0.381	0.578	0.713	0.950
1980	0.056	0.192	0.403	0.551	0.732	1.072
1981	0.078	0.184	0.397	0.546	0.681	0.840
1982	0.072	0.192	0.403	0.564	0.675	1.082
1983	0.107	0.185	0.364	0.543	0.694	1.010
1984	0.109	0.183	0.335	0.470	0.627	0.797
1985	0.132	0.242	0.347	0.493	0.604	0.800
1986	0.135	0.248	0.442	0.583	0.741	1.015
1987	0.074	0.242	0.423	0.606	0.727	0.875
1988	0.058	0.199	0.425	0.604	0.758	0.975
1989	0.059	0.184	0.413	0.633	0.776	1.053
1990	0.070	0.170	0.359	0.552	0.706	0.845
1991	0.078	0.158	0.327	0.438	0.650	0.877
1992	0.060	0.188	0.294	0.441	0.563	1.110
1993	0.062	0.170	0.333	0.428	0.545	0.863
1994	0.162	0.161	0.317	0.423	0.558	0.775
1995	0.138	0.230	0.300	0.405	0.535	0.768
1996	0.075	0.219	0.335	0.438	0.573	1.012
1997	0.179	0.190	0.336	0.468	0.630	0.947
1998	0.124	0.256	0.360	0.472	0.591	0.966
1999	0.147	0.256	0.389	0.523	0.642	0.901
2000	0.182	0.278	0.420	0.552	0.700	0.954
2001	0.204	0.288	0.420	0.542	0.707	1.027
2002	0.250	0.309	0.417	0.553	0.714	1.068
2003	0.202	0.318	0.425	0.560	0.740	1.048
2004	0.166	0.258	0.397	0.527	0.689	0.956
2005	0.074	0.268	0.361	0.511	0.668	0.991
2006	0.059	0.192	0.376	0.499	0.674	0.996
2007	0.110	0.170	0.356	0.474	0.661	1.023
2008	0.018	0.216	0.347	0.467	0.605	0.962
2009	0.107	0.124	0.362	0.473	0.610	0.929
2010	0.125	0.224	0.376	0.475	0.596	0.808
2011	0.066	0.242	0.386	0.489	0.579	0.747
2012	0.099	0.197	0.375	0.479	0.595	0.828

Table 6. Total catch-at-age including discards (number in 000s of fish) for Georges Bank yellowtail flounder.

	AGE												
Year	1	2	3	4	5	6	7	8	9	10	11	12	**Total**
1973	359	5175	13565	9473	3815	1285	283	55	23	4	0	0	34037
1974	2368	9500	8294	7658	3643	878	464	106	71	0	0	0	32982
1975	4636	26394	7375	3540	2175	708	327	132	26	14	0	0	45328
1976	635	31938	5502	1426	574	453	304	95	54	11	2	0	40993
1977	378	9094	10567	1846	419	231	134	82	37	10	0	0	22799
1978	9962	3542	4580	1914	540	120	45	16	17	7	6	0	20748
1979	321	10517	3789	1432	623	167	95	31	27	1	3	0	17006
1980	318	3994	9685	1538	352	96	5	11	1	0	0	0	16000
1981	107	1097	5963	4920	854	135	5	2	3	0	0	0	13088
1982	2164	18091	7480	3401	1095	68	20	7	0	0	0	0	32327
1983	703	7998	16661	2476	680	122	13	16	4	0	0	0	28672
1984	514	2018	4535	5043	1796	294	47	39	0	0	0	0	14285
1985	970	4374	1058	818	517	73	8	0	0	0	0	0	7817
1986	179	6402	1127	389	204	80	17	15	0	1	0	0	8414
1987	156	3284	3137	983	192	48	38	26	25	0	0	0	7890
1988	499	3003	1544	846	227	24	26	3	0	0	0	0	6172
1989	190	2175	1121	428	110	18	12	0	0	0	0	0	4054
1990	231	2114	6996	978	140	21	6	0	0	0	0	0	10485
1991	663	147	1491	3011	383	67	4	0	0	0	0	0	5767
1992	2414	9167	2971	1473	603	33	7	1	1	0	0	0	16671
1993	5233	1386	3327	2326	411	84	5	1	0	0	0	0	12773
1994	71	1336	6302	1819	477	120	20	3	0	0	0	0	10150
1995	47	313	1435	879	170	25	10	1	0	0	0	0	2880
1996	101	681	2064	885	201	13	10	5	0	0	0	0	3960
1997	82	1132	1832	1857	378	39	43	7	1	0	0	0	5371
1998	169	1991	3388	1885	1121	122	18	3	0	3	0	0	8700
1999	60	2753	4195	1548	794	264	32	4	1	0	0	0	9651
2000	132	3864	5714	3173	826	420	66	38	4	0	0	0	14237
2001	176	2884	6956	2893	1004	291	216	13	4	0	0	0	14438
2002	212	4169	3446	1916	683	269	144	57	10	6	0	0	10911
2003	160	3919	4710	2320	782	282	243	96	47	23	2	0	12585
2004	61	1152	3184	3824	1970	889	409	78	74	18	2	0	11661
2005	60	1579	4031	1707	392	132	37	16	0	0	0	0	7954
2006	152	1293	1626	947	364	124	66	14	7	3	0	0	4596
2007	51	1491	1705	662	136	44	9	2	0	0	0	0	4101
2008	29	493	1903	855	125	17	8	0	0	0	0	0	3430
2009	17	284	1266	1361	516	59	10	4	0	0	0	0	3517
2010	2	139	644	890	445	87	10	2	0	0	0	0	2219
2011	11	161	763	908	312	67	8	1	0	0	0	0	2231

Table 7. Mean weight at age (kg) for the total catch including US and Canadian discards, for Georges Bank yellowtail flounder.

	Age											
Year	1	2	3	4	5	6	7	8	9	10	11	12
1973	0.101	0.348	0.462	0.527	0.603	0.690	1.063	1.131	1.275	1.389	1.170	
1974	0.115	0.344	0.496	0.607	0.678	0.723	0.904	1.245	1.090	1.496	1.496	
1975	0.113	0.316	0.489	0.554	0.619	0.690	0.691	0.654	1.052	0.812		
1976	0.108	0.312	0.544	0.635	0.744	0.813	0.854	0.881	1.132	1.363	1.923	
1977	0.116	0.342	0.524	0.633	0.780	0.860	1.026	1.008	0.866	0.913		
1978	0.102	0.314	0.510	0.690	0.803	0.903	0.947	1.008	1.227	1.581	0.916	
1979	0.114	0.329	0.462	0.656	0.736	0.844	0.995	0.906	1.357	1.734	1.911	
1980	0.101	0.322	0.493	0.656	0.816	1.048	1.208	1.206	1.239			
1981	0.122	0.335	0.489	0.604	0.707	0.821	0.844	1.599	1.104			
1982	0.115	0.301	0.485	0.650	0.754	1.065	1.037	1.361				
1983	0.140	0.296	0.441	0.607	0.740	0.964	1.005	1.304	1.239			
1984	0.162	0.239	0.379	0.500	0.647	0.743	0.944	1.032				
1985	0.181	0.361	0.505	0.642	0.729	0.808	0.728					
1986	0.181	0.341	0.540	0.674	0.854	0.976	0.950	1.250	1.686			
1987	0.121	0.324	0.524	0.680	0.784	0.993	0.838	0.771	0.809			
1988	0.103	0.328	0.557	0.696	0.844	1.042	0.865	1.385				
1989	0.100	0.327	0.520	0.720	0.866	0.970	1.172	1.128				
1990	0.105	0.290	0.395	0.585	0.693	0.787	1.057					
1991	0.121	0.237	0.369	0.486	0.723	0.850	1.306					
1992	0.101	0.293	0.365	0.526	0.651	1.098	1.125	1.303	1.303			
1993	0.100	0.285	0.379	0.501	0.564	0.843	1.130	1.044				
1994	0.193	0.260	0.353	0.472	0.621	0.780	0.678	1.148				
1995	0.174	0.275	0.347	0.465	0.607	0.720	0.916	0.532				
1996	0.119	0.276	0.407	0.552	0.707	0.918	1.031	1.216				
1997	0.214	0.302	0.408	0.538	0.718	1.039	0.827	1.136	1.113			
1998	0.178	0.305	0.428	0.546	0.649	0.936	1.063	1.195	1.442			
1999	0.202	0.368	0.495	0.640	0.755	0.870	1.078	1.292	1.822			
2000	0.229	0.383	0.480	0.615	0.766	0.934	1.023	1.023	1.296			
2001	0.251	0.362	0.460	0.612	0.812	1.011	1.024	1.278	1.552			
2002	0.282	0.381	0.480	0.665	0.833	0.985	1.100	1.286	1.389	1.483		
2003	0.228	0.359	0.474	0.653	0.824	0.957	1.033	1.144	1.267	1.418	1.505	
2004	0.211	0.292	0.438	0.585	0.726	0.883	1.002	1.192	1.222	1.305	1.421	
2005	0.119	0.341	0.447	0.597	0.763	0.965	0.993	1.198	1.578	1.578		
2006	0.100	0.310	0.415	0.557	0.761	0.917	1.066	1.185	1.263	1.224	1.599	
2007	0.154	0.290	0.409	0.542	0.784	0.968	1.108	1.766				
2008	0.047	0.302	0.415	0.533	0.675	0.882	1.130					
2009	0.155	0.328	0.434	0.538	0.699	0.879	1.050	1.328				
2010	0.174	0.323	0.432	0.519	0.661	0.777	0.997	1.175				
2011	0.126	0.336	0.462	0.553	0.646	0.739	0.811	0.851				

Table 9. DFO spring survey indices of minimum swept-area abundance for Georges Bank yellowtail flounder in thousands of fish and thousands of metric tons, along with the coefficient of variation (CV) for the biomass estimates.

Year	Age1	Age2	Age3	Age4	Age5	Age6+	B(000mt)	CV(B)
1987	75.2	751.1	1238.5	309.7	54.9	30.9	1.250	27%
1988	0.0	1116.5	801.9	383.6	174.9	14.8	1.235	22%
1989	71.8	645.8	383.2	185.2	41.8	14.1	0.471	26%
1990	0.0	1500.9	2281.1	575.0	131.3	8.6	1.513	22%
1991	15.4	539.6	745.8	2364.1	330.3	9.1	1.758	33%
1992	34.8	6942.1	2312.0	622.4	219.8	18.8	2.475	16%
1993	49.4	1528.8	2568.8	2562.9	557.5	81.8	2.642	15%
1994	0.0	3808.4	2178.6	1890.1	491.4	130.0	2.753	23%
1995	132.0	786.5	2737.4	1600.8	406.6	63.6	2.027	20%
1996	280.5	4491.0	5769.2	3399.8	726.5	77.2	5.303	22%
1997	13.6	7849.2	8742.1	10293.6	2543.2	421.5	13.293	23%
1998	561.7	2094.3	3085.9	2725.6	1250.4	351.2	4.293	24%
1999	99.8	13118.5	13101.2	4822.9	3364.5	1383.5	17.666	32%
2000	6.8	8655.8	17256.5	12100.9	3187.6	2319.8	19.949	25%
2001	183.3	12511.6	26489.4	8368.0	2881.0	1507.2	22.158	42%
2002	55.5	7522.3	19503.3	7693.6	3491.7	1781.4	20.699	31%
2003	56.3	7476.4	15480.7	6971.1	2151.0	1249.9	16.249	32%
2004	20.6	2263.5	10225.3	5788.7	1429.2	890.5	9.054	31%
2005	377.3	1007.5	17581.9	12931.4	3581.9	983.8	13.357	53%
2006	391.5	3076.8	11696.4	4132.7	515.4	149.4	6.579	44%
2007	108.9	7646.4	17423.7	8048.5	1439.1	156.2	13.344	43%
2008	0.0	30382.5	107131.7	35919.3	5067.8	34.5	67.319	94%
2009	13.4	5370.4	86753.6	73553.8	12513.9	2996.1	72.044	79%
2010	0.0	307.6	5906.1	13170.2	2221.7	804.5	9.138	29%
2011	13.9	409.3	3831.5	5159.9	1069.5	205.8	3.830	29%
2012	27.9	405.2	5183.7	7183.4	1946.9	284.9	5.620	36%

Table 10. NEFSC spring survey indices of minimum swept-area abundance for Georges Bank yellowtail flounder in thousands of fish and thousands of metric tons, along with the coefficient of variation (CV) for the biomass estimates.

YEAR	AGE1	AGE2	AGE3	AGE4	AGE5	AGE6+	B(000MT)	CV(B)
1968	181.2	3227.3	3474.3	295.2	70.9	300.8	2.709	23%
1969	1046.8	9067.8	10793.9	3081.4	1305.2	678.2	10.842	29%
1970	78.4	4364.8	5853.3	2350.9	553.0	302.0	4.994	15%
1971	810.4	3412.9	4671.6	3202.9	757.1	310.6	4.483	19%
1972	137.0	6719.3	6843.1	3595.8	1093.7	232.0	6.266	21%
1973	1882.9	3184.3	2309.4	1036.7	399.4	210.2	2.852	17%
1974	308.2	2168.5	1795.5	1225.0	336.9	273.8	2.640	18%
1975	409.2	2918.0	809.1	262.6	201.5	86.3	1.626	22%
1976	1008.4	4259.0	1216.0	302.4	191.2	108.4	2.206	17%
1977	0.0	654.0	1097.7	363.7	81.9	12.8	0.970	31%
1978	912.2	778.4	494.4	213.9	25.7	7.7	0.720	19%
1979	394.0	1956.8	395.2	328.3	58.7	88.7	1.234	21%
1980	55.3	4528.6	5617.2	460.6	55.0	35.3	4.325	35%
1981	11.4	995.9	1724.2	698.9	206.9	56.9	1.903	33%
1982	44.1	3656.5	1096.5	992.5	444.5	88.3	2.426	20%
1983	0.0	1810.0	2647.8	514.4	119.6	237.3	2.564	30%
1984	0.0	90.3	806.0	837.9	810.4	236.5	1.598	43%
1985	106.4	2134.2	254.4	273.4	143.4	0.0	0.959	51%
1986	26.6	1753.0	282.6	54.6	132.9	53.2	0.823	31%
1987	26.6	73.3	133.0	129.3	51.0	53.2	0.319	37%
1988	75.5	266.9	355.2	234.7	193.2	26.6	0.549	26%
1989	45.2	391.3	737.7	281.0	59.3	43.5	0.708	26%
1990	0.0	63.7	1074.7	358.4	112.2	100.8	0.678	32%
1991	422.5	0.0	246.9	665.1	255.5	20.0	0.612	25%
1992	0.0	1987.7	1840.7	621.8	160.0	16.7	1.520	46%
1993	44.7	281.1	485.8	307.9	26.0	0.0	0.468	26%
1994	0.0	602.3	614.7	343.6	140.4	38.7	0.641	22%
1995	39.0	1144.6	4670.4	1441.7	621.5	9.5	2.504	60%
1996	24.4	958.1	2548.6	2621.8	591.6	56.2	2.769	31%
1997	18.2	1134.5	3623.1	3960.7	682.3	129.7	4.231	24%
1998	0.0	2020.1	1022.2	1123.4	737.1	339.6	2.256	22%
1999	48.7	4606.3	10501.7	2640.5	1575.2	756.3	9.033	42%
2000	177.3	4677.6	7440.5	2828.5	789.2	508.4	6.499	23%
2001	0.0	2246.7	6370.5	2340.0	469.2	439.7	4.859	33%
2002	182.4	2341.5	11971.1	3958.4	1690.3	845.4	9.282	26%
2003	196.1	4241.4	6564.9	2791.9	428.6	836.9	6.524	40%
2004	47.1	957.3	2114.4	659.9	247.7	263.8	1.835	27%
2005	0.0	1953.5	4931.0	2332.7	261.8	111.4	3.307	33%
2006	493.5	907.8	3419.2	2112.7	307.7	79.8	2.349	19%
2007	87.1	4899.7	6079.1	2762.3	540.0	125.2	4.563	22%
2008	0.0	2206.7	4921.5	1681.1	300.3	26.6	3.152	22%
2009	218.8	546.4	6978.7	4456.8	964.1	186.3	4.619	22%
2010	16.5	662.8	5181.0	8057.2	2584.0	613.9	5.662	27%
2011	26.9	236.6	3116.0	3512.9	914.1	100.6	2.419	23%
2012	92.7	530.1	3476.9	6141.4	1563.6	180.3	3.878	49%

Table 11. NEFSC fall survey indices of minimum swept-area abundance for Georges Bank yellowtail flounder in thousands of fish and thousands of metric tons, along with the coefficient of variation (CV) for the biomass estimates.

YEAR	AGE1	AGE2	AGE3	AGE4	AGE5	AGE6+	B(000MT)	CV(B)
1963.5	14289.1	7663.6	10897.1	1804.0	480.5	532.7	12.413	19%
1964.5	1671.3	9517.3	7097.2	5791.2	2634.2	473.3	13.168	40%
1965.5	1162.1	5537.0	5811.9	3427.8	1600.9	250.6	8.852	32%
1966.5	11320.3	2184.4	1635.3	871.9	98.3	0.0	3.813	32%
1967.5	8720.8	9131.0	2646.7	1006.7	299.3	132.3	7.445	26%
1968.5	11328.3	11702.5	5588.9	722.7	936.8	56.4	10.227	23%
1969.5	9656.7	10601.8	5064.1	1757.4	327.0	447.7	9.519	26%
1970.5	4474.9	4981.2	3051.2	1894.7	438.2	77.8	4.833	28%
1971.5	3520.0	6770.9	4769.9	2183.8	483.4	289.1	6.178	21%
1972.5	2416.9	6332.8	4682.3	2032.9	592.1	331.7	6.142	28%
1973.5	2420.4	5336.0	4954.5	2857.4	1181.2	599.9	6.299	30%
1974.5	4486.7	2779.5	1471.6	1029.1	444.3	368.1	3.561	19%
1975.5	4548.6	2437.3	851.7	555.2	324.4	61.1	2.257	16%
1976.5	333.5	1863.9	460.3	113.6	118.5	97.3	1.463	25%
1977.5	906.7	2147.1	1572.8	615.4	102.3	105.7	2.699	20%
1978.5	4620.6	1243.3	757.2	399.2	131.6	34.9	2.274	20%
1979.5	1282.0	2008.5	253.7	116.7	134.3	108.6	1.450	29%
1980.5	743.6	4970.0	5912.0	662.0	212.3	250.9	6.412	22%
1981.5	1548.2	2279.4	1592.8	570.5	76.4	52.8	2.500	32%
1982.5	2353.3	2120.3	1543.4	410.4	86.6	0.0	2.203	30%
1983.5	105.7	2216.4	1858.5	495.7	29.9	47.7	2.068	22%
1984.5	641.6	388.1	296.7	236.0	72.7	60.7	0.576	31%
1985.5	1310.2	527.5	165.9	49.1	78.3	0.0	0.688	26%
1986.5	273.4	1075.1	338.7	71.9	0.0	0.0	0.796	37%
1987.5	98.7	388.8	384.6	51.4	77.1	0.0	0.494	28%
1988.5	18.2	206.7	104.0	26.6	0.0	0.0	0.165	32%
1989.5	241.0	1934.1	750.4	76.6	54.0	0.0	0.948	58%
1990.5	0.0	359.2	1429.9	285.8	0.0	0.0	0.703	33%
1991.5	2038.8	267.0	426.2	347.2	0.0	0.0	0.708	29%
1992.5	146.8	383.9	691.0	157.1	139.4	26.6	0.559	30%
1993.5	814.6	135.2	568.8	520.4	0.0	21.4	0.529	42%
1994.5	1159.8	214.6	954.1	692.2	254.9	54.8	0.871	32%
1995.5	267.7	115.4	335.2	267.2	44.6	12.1	0.344	35%
1996.5	144.3	341.3	1813.8	433.5	72.7	0.0	1.265	58%
1997.5	1351.8	517.7	3341.0	2028.5	1039.8	79.8	3.670	35%
1998.5	1844.4	4675.3	4078.9	1154.6	289.5	71.7	4.220	34%
1999.5	2998.7	8175.9	5558.9	1390.3	1394.2	252.8	7.738	21%
2000.5	610.8	1647.5	4672.5	2350.3	919.7	802.6	5.666	49%
2001.5	3414.2	6083.6	7853.7	2524.8	1667.8	1988.2	11.213	40%
2002.5	2031.4	5581.8	2064.5	576.1	295.6	26.6	3.644	51%
2003.5	1045.3	4882.8	2725.9	548.0	97.0	185.7	3.919	33%
2004.5	850.3	5346.1	4862.4	2044.4	897.1	170.7	4.966	46%
2005.5	304.0	2033.6	3652.1	595.9	179.3	0.0	2.391	52%
2006.5	6012.1	6067.2	3556.7	1132.9	247.7	44.4	4.388	27%
2007.5	1026.5	11110.9	7634.7	1939.6	371.3	90.9	7.912	31%
2008.5	162.8	6963.2	9592.7	1002.8	0.0	0.0	6.900	28%
2009.5	445.8	4169.4	11531.5	2072.0	588.3	57.9	6.797	27%
2010.5	115.4	2661.6	4205.3	719.7	272.7	0.0	2.242	30%
2011.5	234.4	2795.0	3756.5	1079.7	141.8	9.6	2.380	26%

Table 12. NEFSC scallop survey index of abundance (stratified mean #/tow) for Georges Bank yellowtail flounder and index of total biomass (stratified mean kg/tow). Note the values for 1989 and 1999 are considered too uncertain for use as a tuning index and the 1986, 2000, 2008, and 2011 surveys did not fully cover the Canadian portion of Georges Bank (D. Hart, pers. comm.).

YEAR	AGE1	AGE2	AGE3	AGE4	AGE5	AGE6+	B(KG/TOW)
1982.5	0.3505	0.5851	0.2863	0.1768	0.0541	0.0000	0.527
1983.5	0.1389	0.5693	0.5811	0.0828	0.0176	0.0339	0.699
1984.5	0.2021	0.2606	0.0935	0.0813	0.0765	0.0089	0.244
1985.5	0.2717	0.4373	0.0131	0.0158	0.0295	0.0000	0.143
1986.5							
1987.5	0.1031	0.0776	0.1154	0.0541	0.0069	0.0029	0.187
1988.5	0.1175	0.0172	0.0324	0.0475	0.0401	0.0000	0.108
1989.5							
1990.5	0.1020	0.0257	0.3312	0.0861	0.0356	0.0126	0.245
1991.5	1.9094	0.0000	0.1248	0.1383	0.0296	0.0000	0.377
1992.5	0.3032	0.1281	0.3407	0.2285	0.0482	0.0030	0.409
1993.5	1.1636	0.1966	0.2860	0.1457	0.0081	0.0000	0.427
1994.5	1.4197	0.3308	0.4193	0.2807	0.0614	0.0246	0.603
1995.5	0.5183	0.4546	0.7705	0.5047	0.1627	0.0091	0.846
1996.5	0.3673	0.3037	0.8574	0.7357	0.3089	0.0188	1.271
1997.5	0.9682	0.3956	1.2006	0.9694	0.2008	0.0362	1.659
1998.5	1.7583	0.8858	0.7353	0.9479	0.5744	0.1074	2.041
1999.5							
2000.5							
2001.5	0.8943	0.4727	1.0595	0.5453	0.1249	0.1669	1.525
2002.5	0.9561	0.2885	0.8333	0.3803	0.2290	0.1358	1.336
2003.5	0.7469	0.6047	0.9887	0.6538	0.1330	0.1980	1.783
2004.5	0.3459	0.4124	0.7100	0.1994	0.0415	0.0175	0.777
2005.5	0.4657	0.3523	0.5743	0.2279	0.0842	0.0090	0.623
2006.5	1.9150	0.9652	0.6833	0.3202	0.0429	0.0247	0.880
2007.5	0.5074	1.6374	1.1764	0.3705	0.0592	0.0040	1.265
2008.5							
2009.5	0.2021	0.0775	0.7519	0.6516	0.1352	0.0162	0.719
2010.5	0.0862	0.2131	0.5783	0.9095	0.2878	0.0581	0.749
2011.5							

DATA CONFLICT:

The relative F (catch/survey biomass) decreased dramatically in 1995 while the survey Z (cohort specific estimates) do not show a decline. The data conflict can be seen as two questions: 1) is if F really did decrease dramatically in 1995, where are the old fish and 2) if F really is still high why are the strong management measures not working? There are no indications of problems with ageing this species that could explain the lack of old fish. Spatial distribution has changed, with an area previously known as the “yellowtail hole” in Canadian waters no longer supporting a directed fishery. There is a lack of old fish in the population and catch relative to a population in equilibrium fished at the target F.

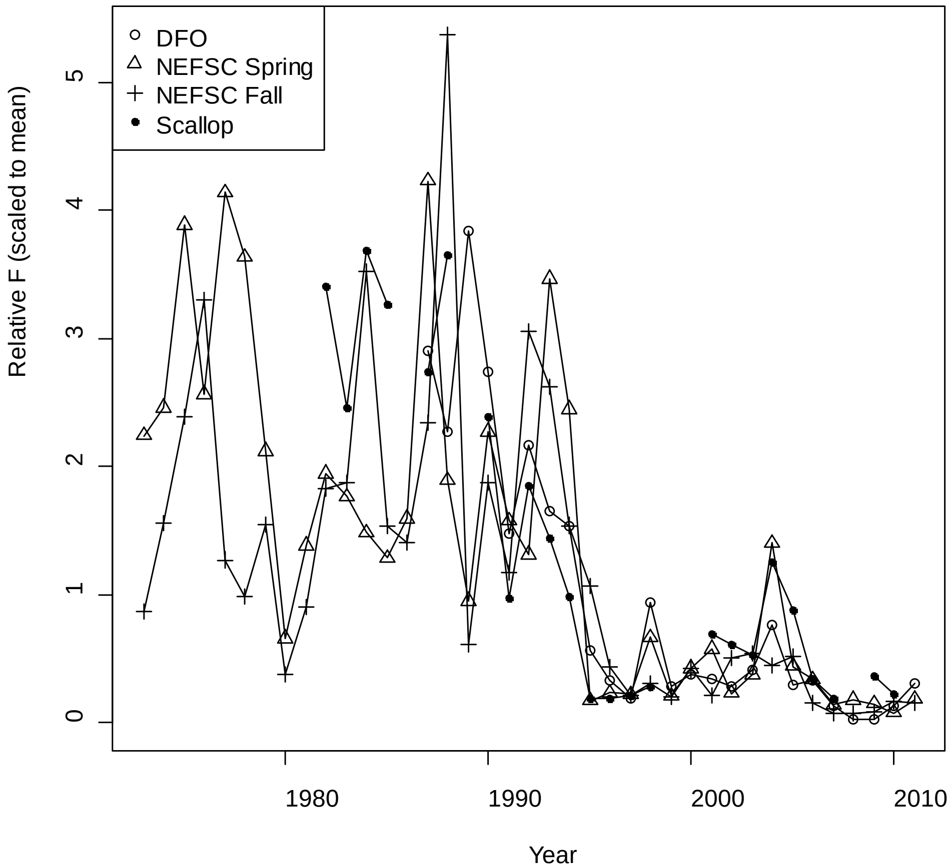


Figure 19. Trends in relative fishing mortality (catch biomass/survey biomass), standardized to the mean for 1987–2010.

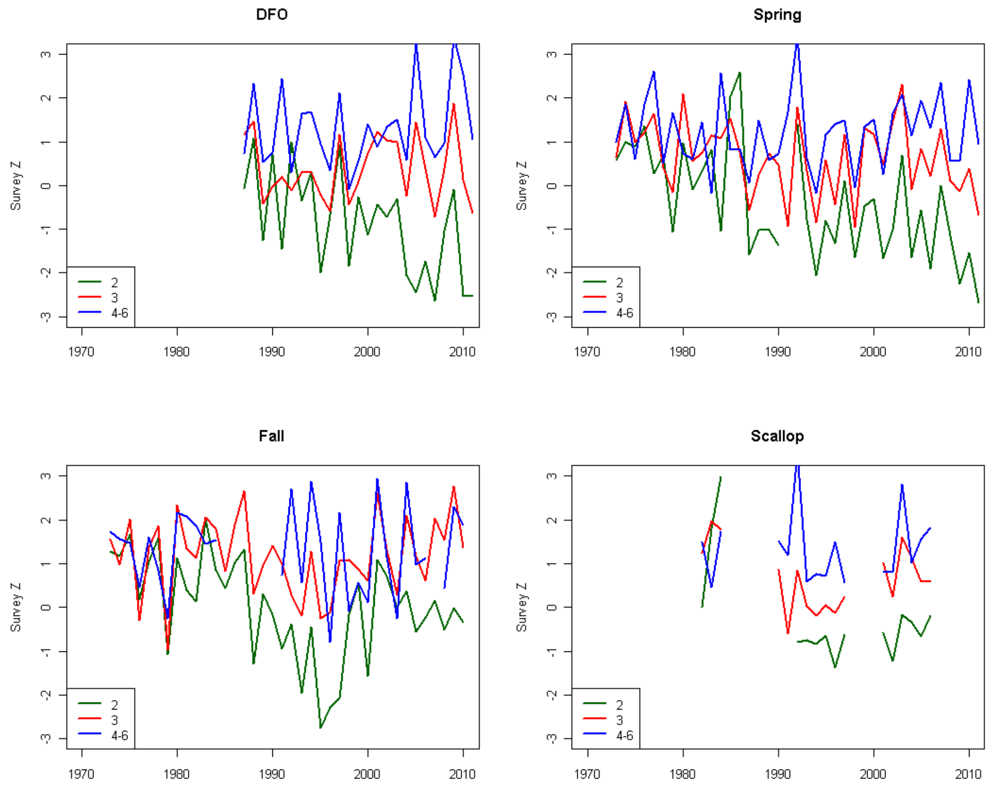


Figure 20. Trends in total mortality (Z) for ages 2, 3, and 4-6 from the four surveys.

MODEL:

The VPA is calibrated using the adaptive framework ADAPT (Conser and Powers, 1990; Gavaris, 1988; Parrack, 1986) to calibrate the sequential population analysis with the research survey abundance trend results, specifically the NOAA Fisheries Toolbox VPA v3.1.1. The model formulation employed assumed error in the catch-at-age was negligible. Errors in the abundance indices were assumed independent and identically distributed after taking natural logarithms of the values. The exception to this assumption is the DFO survey values for 2008 and 2009 were downweighted (residuals multiplied by 0.5) to reflect the higher uncertainty associated with these observations relative to all other survey observations. Zero observations for abundance indices were treated as missing data, because the logarithm of zero is undefined. The annual natural mortality rate, M, was assumed constant and equal to 0.2 for all ages and years. The fishing mortality rates for age groups 4, 5 and 6+ were assumed equal. Both point estimates and bootstrap statistics of the estimated parameters were derived using only the US software for this assessment.

BASE FIT:

Table 13. Statistical properties of estimates for population abundance and survey calibration constants (scallop x103) for Georges Bank yellowtail flounder for the Split Series VPA.

		BOOTSTRAP			
Age	Estimate	Standard Error	Relative Error	Bias	Relative Bias
Population Abundance					
2	2417	1313	54%	287	12%
3	1951	746	38%	119	6%
4	2990	961	32%	145	5%
5	2219	540	24%	86	4%
Survey Calibration Constants					
DFO Survey: 1987-1994					
2	0.145	0.049	34%	0.010	7%
3	0.232	0.032	14%	0.002	1%
4	0.389	0.072	18%	0.003	1%
5	0.436	0.094	22%	0.009	2%
6+	0.254	0.062	24%	0.005	2%
DFO Survey: 1995-2012					
2	0.375	0.093	25%	0.006	2%
3	1.898	0.385	20%	0.042	2%
4	2.549	0.519	20%	0.037	1%
5	1.969	0.428	22%	0.035	2%
6+	1.325	0.267	20%	0.018	1%
NMFS Spring Survey: Yankee 41, 1973-1981					
1	0.007	0.006	79%	0.002	25%
2	0.076	0.013	18%	0.001	1%
3	0.096	0.016	17%	0.002	2%
4	0.093	0.011	12%	0.001	1%
5	0.076	0.015	20%	0.001	2%
6+	0.072	0.023	32%	0.004	5%
NMFS Spring Survey: Yankee 36, 1982-1994					
1	0.004	0.001	24%	0.000	2%
2	0.046	0.014	31%	0.002	4%
3	0.095	0.015	15%	0.002	2%
4	0.152	0.020	13%	0.001	1%
5	0.229	0.046	20%	0.006	3%
6+	0.423	0.094	22%	0.016	4%
NMFS Spring Survey: Yankee 36, 1995-2012					
1	0.007	0.002	32%	0.000	4%
2	0.167	0.023	14%	0.002	1%
3	0.715	0.109	15%	0.009	1%
4	0.856	0.156	18%	0.011	1%
5	0.670	0.127	19%	0.017	3%
6+	0.525	0.093	18%	0.005	1%
NMFS Fall Survey: 1973-1994					
1	0.040	0.010	26%	0.002	4%
2	0.088	0.014	16%	0.000	1%
3	0.150	0.016	11%	0.001	1%
4	0.156	0.021	13%	0.001	1%
5	0.205	0.041	20%	0.003	2%
6+	0.306	0.064	21%	0.007	2%
NMFS Fall Survey: 1995-2011					
1	0.075	0.017	23%	0.002	2%
2	0.350	0.125	36%	0.022	6%
3	0.796	0.169	21%	0.019	2%
4	0.554	0.103	19%	0.012	2%
5	0.518	0.132	26%	0.015	3%
6+	0.364	0.136	37%	0.018	5%
NMFS Scallop Survey: 1982-1994					
1	0.026	0.008	32%	0.001	5%
NMFS Scallop Survey: 1995-2011					
1	0.058	0.008	15%	0.001	1%

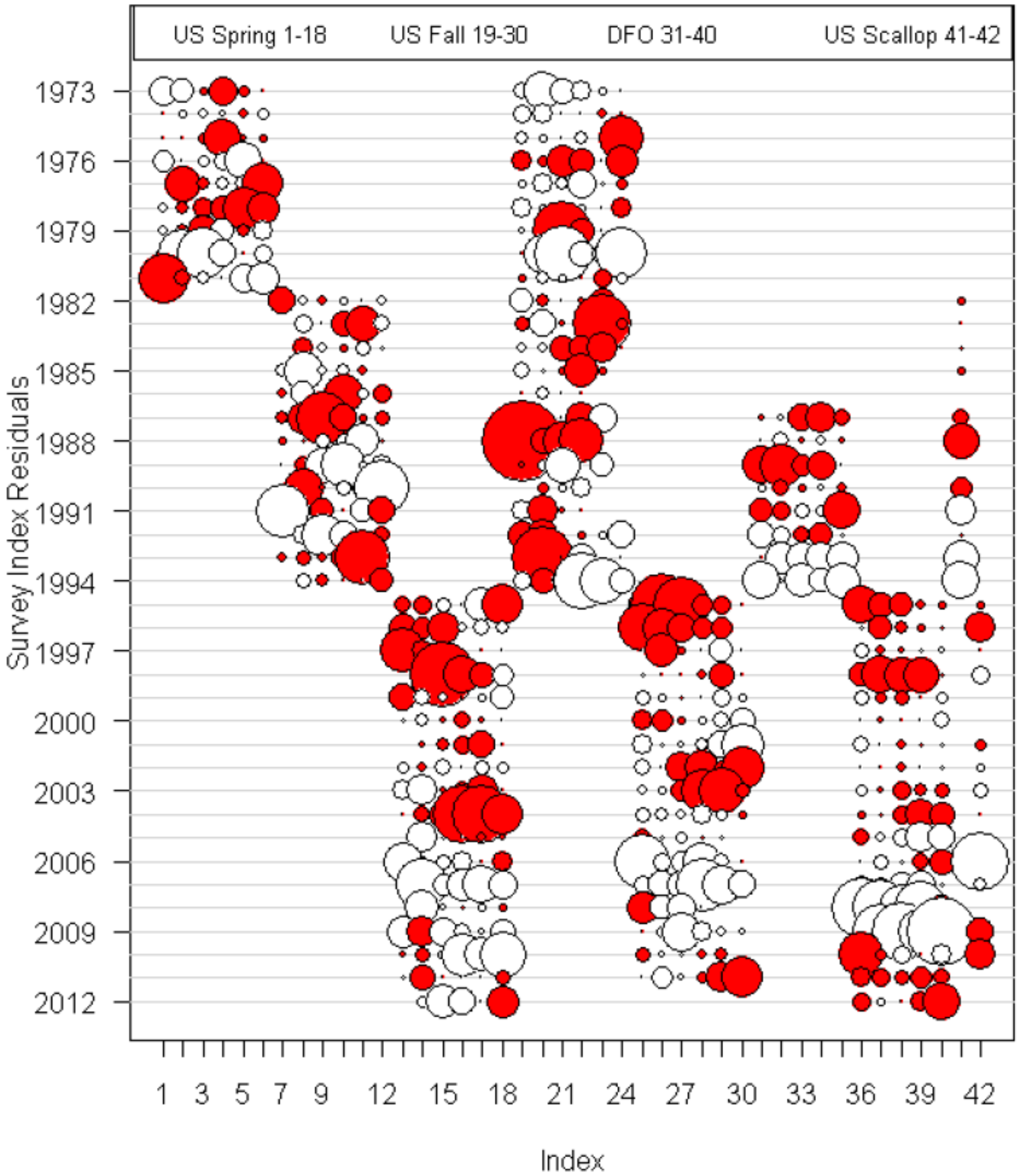


Figure 24. Age by age residuals from the Split Series VPA for log scale predicted minus observed population abundances, Georges Bank yellowtail flounder (bubble size is proportional to magnitude). The red symbols denote negative residuals, and white symbols denote positive residuals.

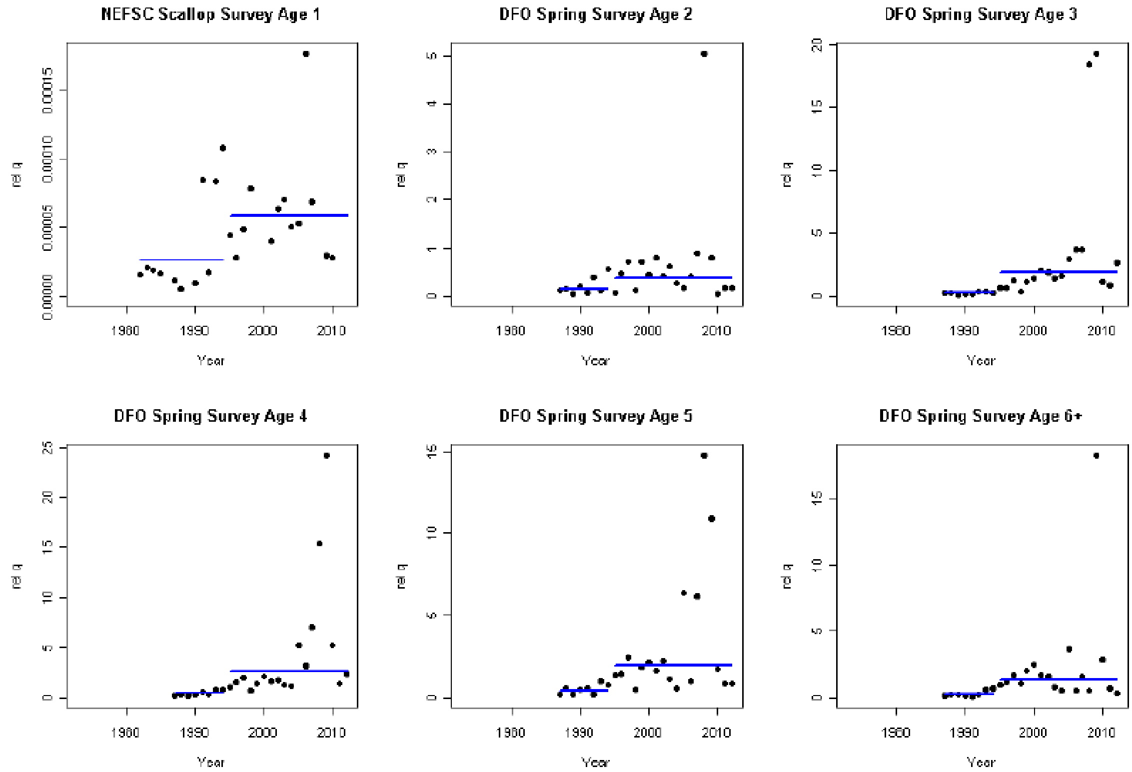


Figure 25a. Estimated catchability coefficients (q) from the split series VPA (lines) and relative q values for the NEFSC scallop survey at age 1 and the DFO survey at ages 2 through 6+. The relative q values are computed as the observed survey value (as a minimum swept-area estimate) divided by the population abundance at that age at the start of that year (no adjustment for timing of the survey).

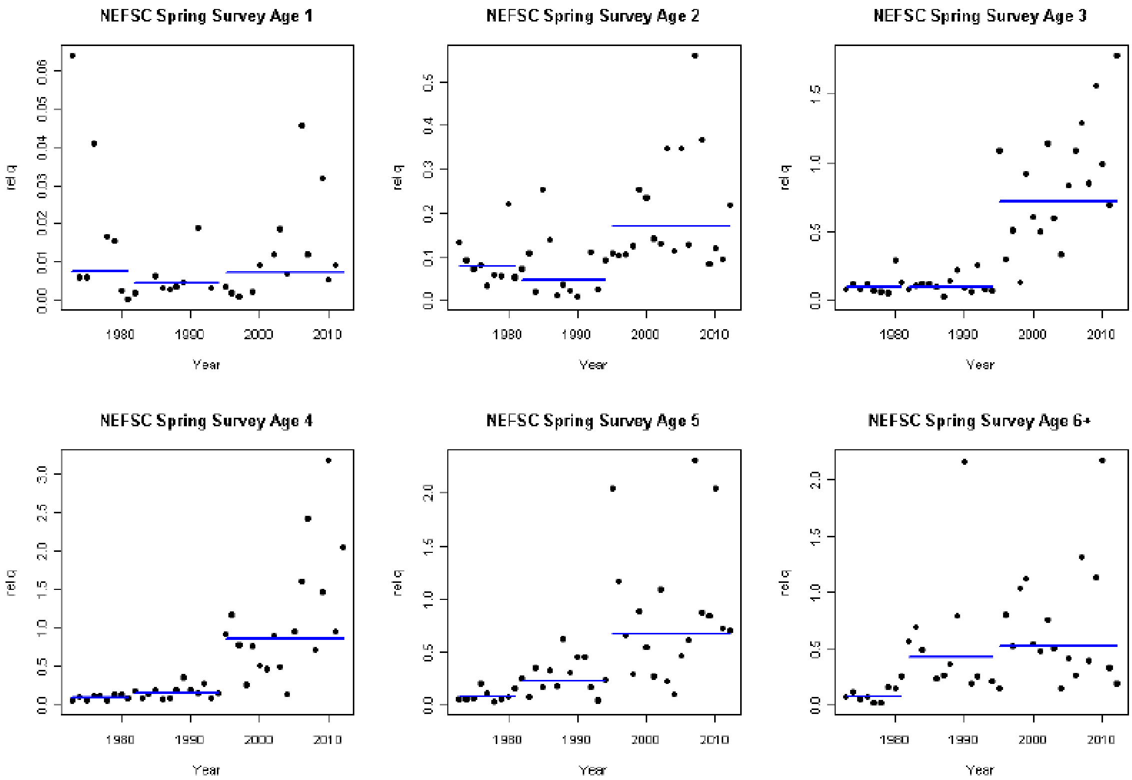


Figure 25b. Estimated catchability coefficients (q) from the split series VPA (lines) and relative q values for the NEFSC spring survey.

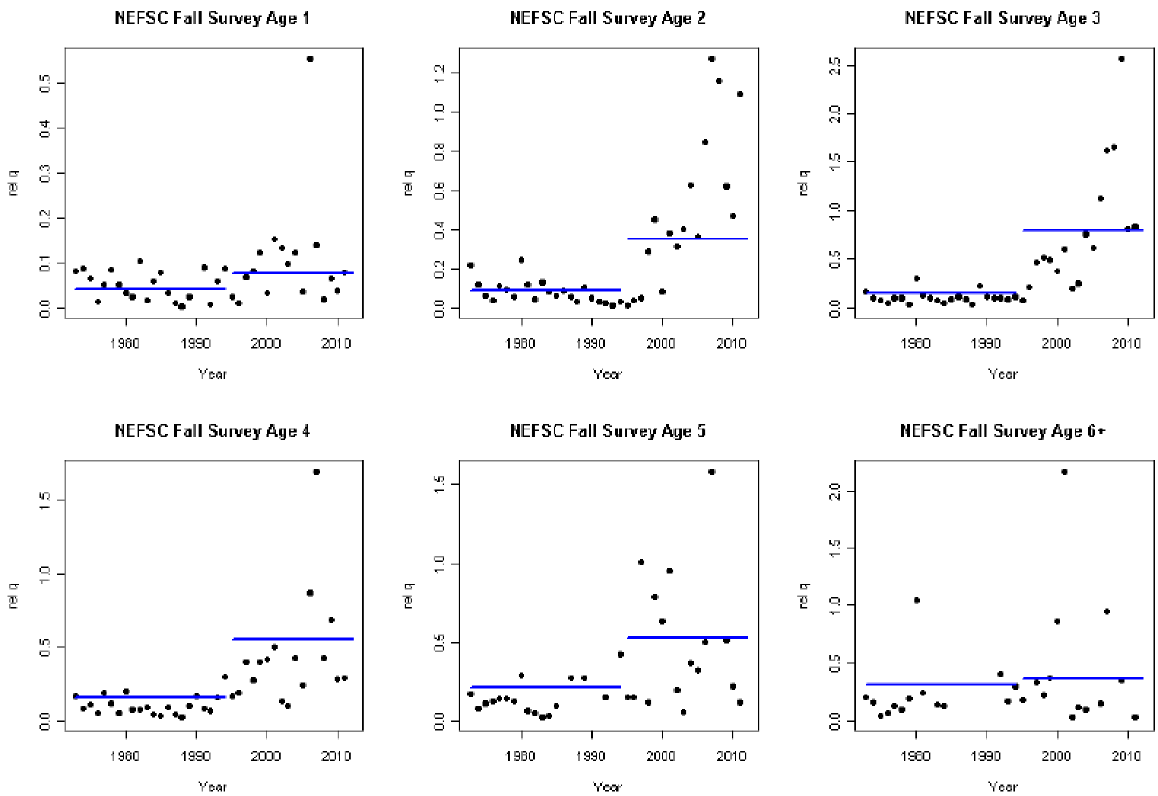


Figure 25c. Estimated catchability coefficients (q) from the split series VPA (lines) and relative q values for the NEFSC fall survey.

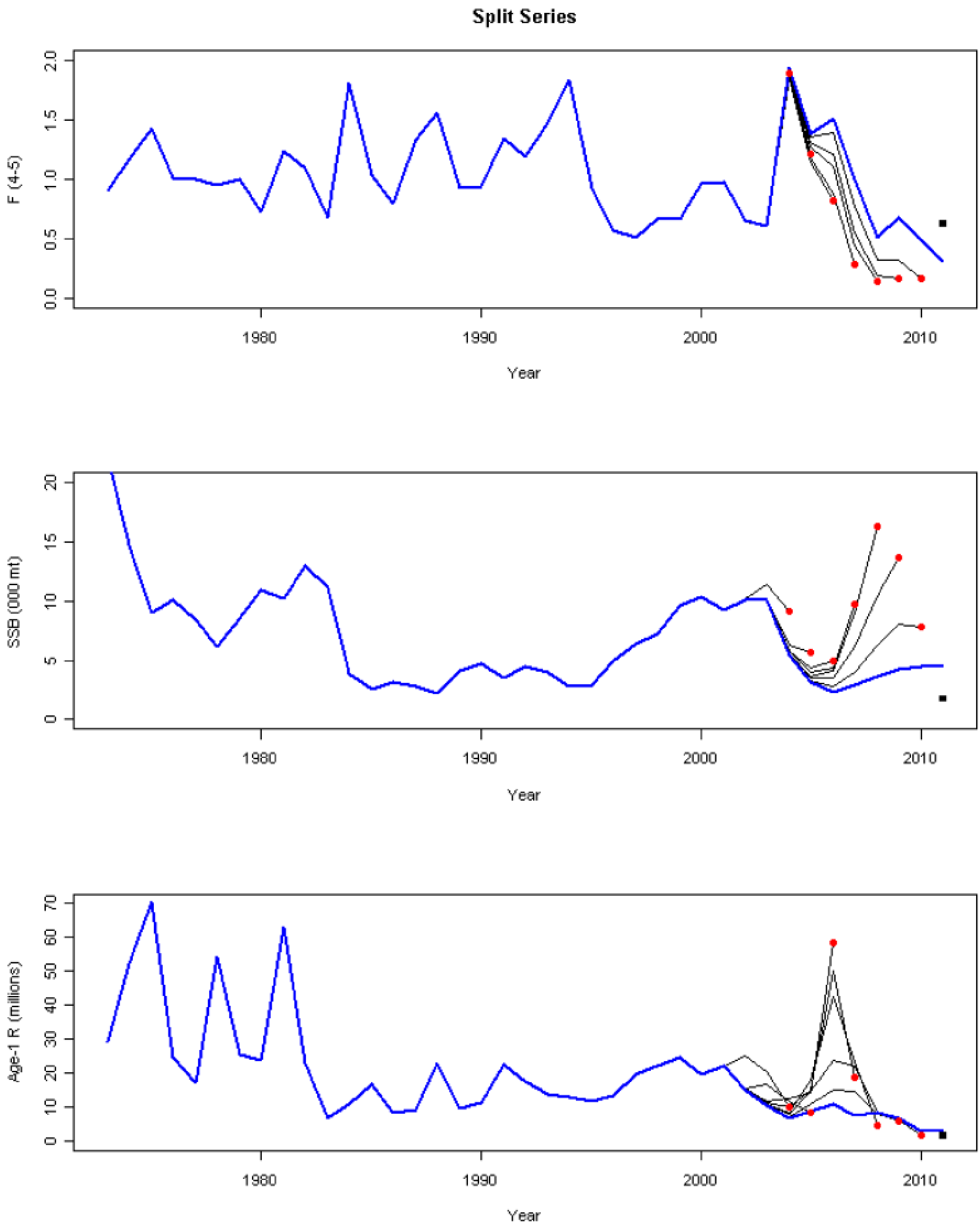


Figure 26a. Retrospective analysis of Georges Bank yellowtail flounder from the Split Series VPA for age 4+ fishing mortality (top panel), spawning-stock biomass (middle panel), and age 1 recruitment (lower panel). The black squares show the rho adjusted values for 2011.

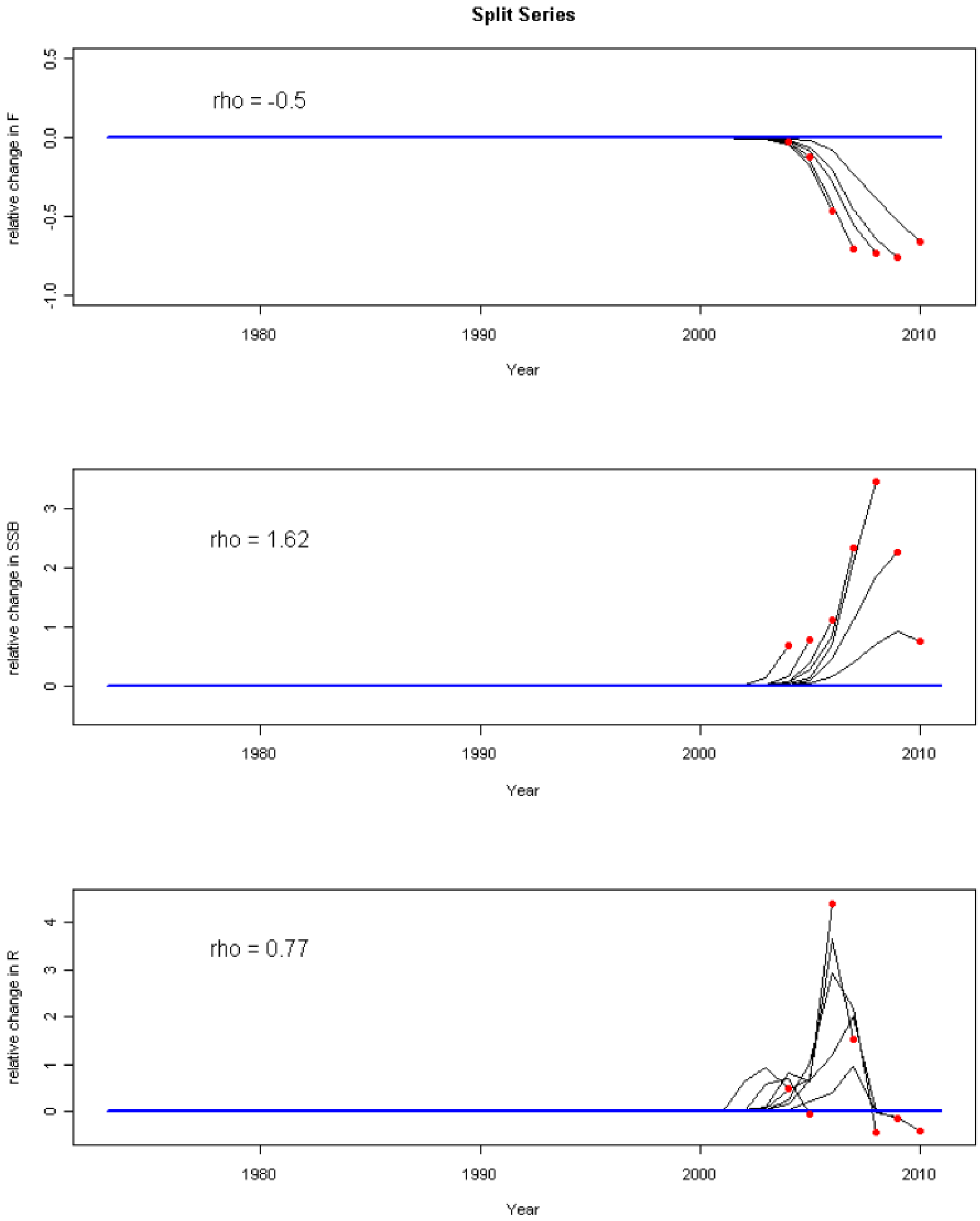


Figure 26b. Relative retrospective plots for Georges Bank yellowtail flounder from Split Series VPA with Mohn's rho calculated from seven year peel for age 4+ fishing mortality (top panel), spawning-stock biomass (middle panel), and age 1 recruitment (lower panel).

ALTERNATIVE MODEL FORMULATIONS

The fourth and final set of sensitivity analyses examined alternative “fixes” to the retrospective pattern. Specifically, the Single Series VPA was used as a base and then either the natural mortality or catch matrix was multiplied by a constant for a range of years and ages. This approach of increasing M or catch in recent years has been shown in the past to be an alternative way to fix the retrospective pattern (Legault 2009). Due to the inability of the Split Series approach to remove the retrospective pattern, the timing of when to apply the multiplier was not known, so a brute force approach was utilized. The year blocks were defined by starting at 1990 and progressing annually through to 2011. The M or catch within the given year block was multiplied by a value ranging from 1.5 to 5 in steps of 0.5. This resulted in a total of 176 combinations (22 years X 8 multipliers) for both M and catch. For each combination, the Mohn’s rho for spawning-stock biomass was computed based on the usual seven year peel. These rhos were plotted as a function of the start of the time block and the multiplier to determine which combination produced the least retrospective pattern. For natural mortality, there were a range of year block and multiplier combinations that resulted in essentially zero SSB retrospective pattern. The zero rho combinations all required M multipliers of more than four. For example, when the year break is 2005 and the M multiplier is 4.5, natural mortality would increase suddenly from 0.2 to 0.9 for all ages between 2004 and 2005 to reduce the SSB rho to 0.05. For catch, none of the combinations reduced the SSB rho to zero or below. The lowest SSB rho was 0.18, which was for the year break staring in 2005 and catch multiplier of 5. Recognizing that retrospective patterns do not have to be confined to a single source, a range of combinations of M and catch multipliers was considered for the year break starting in 2005. The SSB retrospective pattern could be reduced to zero for a number of combinations of M and catch multipliers, but all required at least one of the multipliers to be 2.5 or greater.

There are a number of alternative “fixes” to the retrospective patterns, but none of them can be explained by biology or fishery practices. Thus, each would have to be considered as aliasing unknown mechanisms in the same manner as the Split Series “fix.” Three alternative “fixes” were selected, all with break year 2005: M multiplier=4.5, catch multiplier=5, and M multiplier=2.5 combined with catch multiplier=3.5. The alternative fixes have different implications for the time-series and 2011 estimates of fishing mortality rate, spawning-stock biomass, and recruitment (Figure 39a-b). These three alternative retrospective “fixes” will also be considered in the projections described in the Outlook section below.

These sensitivity analyses demonstrate the 80% confidence intervals for the Split Series VPA do not fully capture the total uncertainty in the assessment.

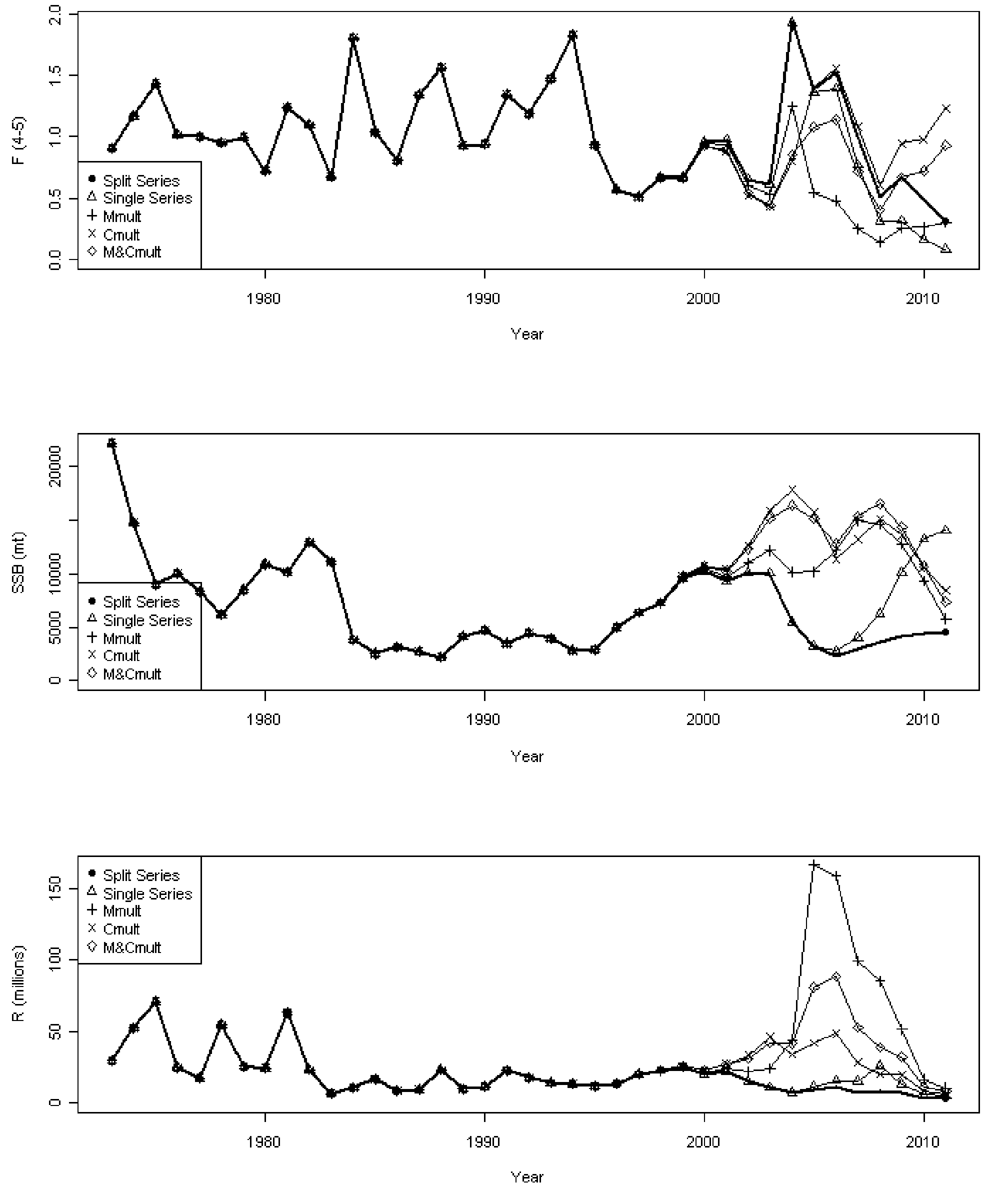


Figure 39a. Fishing mortality rate (ages 4-5; top panel), spawning-stock biomass (mt; middle panel), and age 1 recruitment (millions of fish; bottom panel) for the Split Series VPA, Single Series VPA, and three alternative fixes with the break year in 2005 (Mmult=4.5, Cmult=5, M&Cmult=2.5&3.5, respectively).

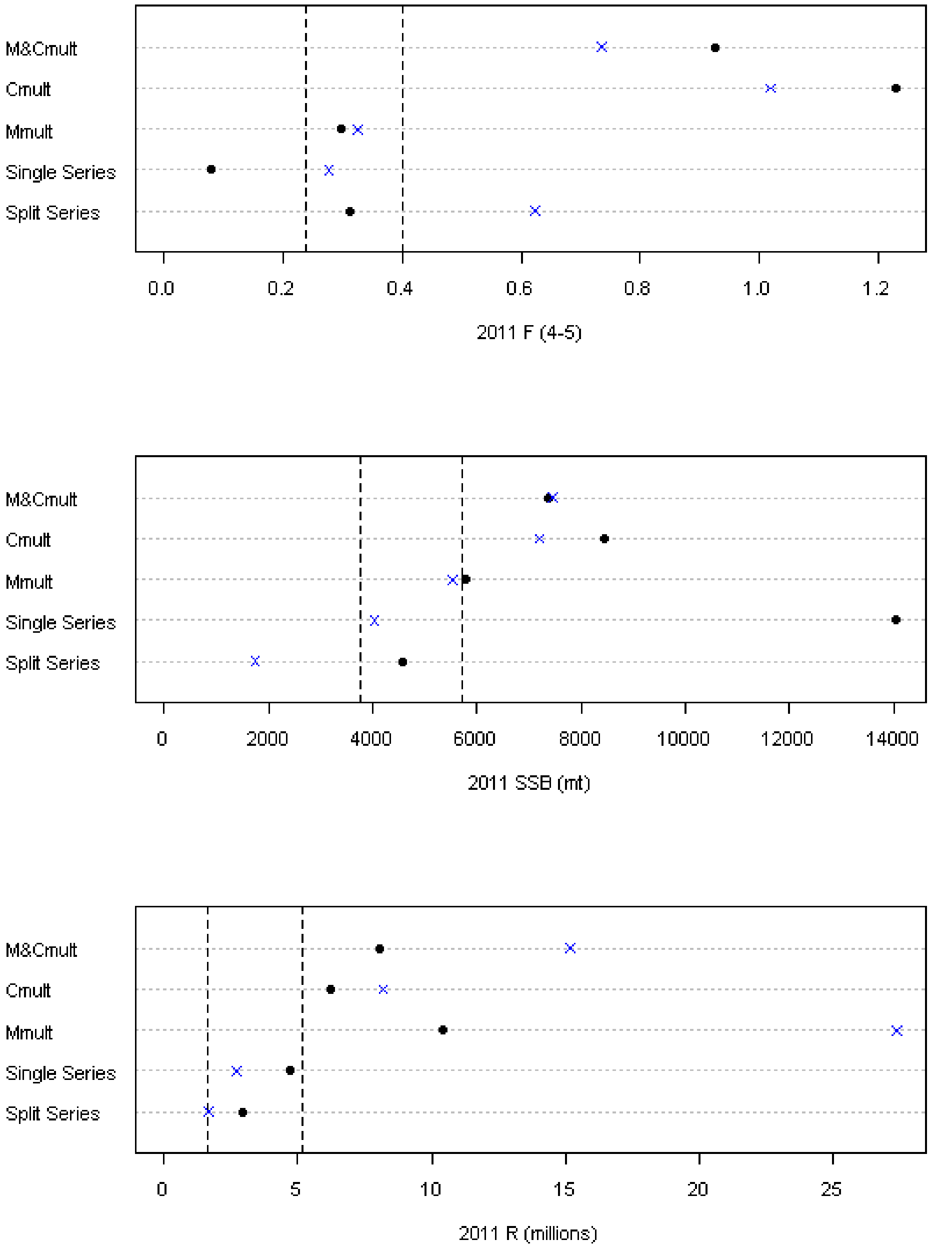


Figure 39b. Dotcharts of 2011 fishing mortality rate (ages 4-5; top panel), spawning-stock biomass (mt; middle panel), and age 1 recruitment (millions of fish; bottom panel) for the same five runs identified in Figure 39a. The filled circles denote the point estimates while the blue crosses denote the rho adjusted values for each run. The vertical lines denote the 80% confidence interval for the Split Series VPA.

SOURCES: Conser and Powers (1990); Gavaris (1988); Legault (2009); Legault *et al.* (2012); Parrack (1986)

13 South African anchovy

DATA:

The data used for this assessment, extracted from de Moor *et al*. (2012), is listed in the following tables. Ageing "data" – the proportion of the anchovy of age 1 in the annual anchovy survey, together with an SE – is not strictly data but from the posterior output from a Bayesian analysis of survey length distribution data; these values are treated as "data" in the assessment.

Annual juvenile (0 year old) and adult (1 year old) anchovy catch (in billions) and mean catch weight (in grams) [Note: annual data for year y consists of data from November y-1 to October y]:

Year	Catch		Catch weight	
	0 year olds	1 year olds	0 year olds	1 year olds
1984	29.987537	9.416485	5.654	10.210
1985	33.371373	7.860243	5.744	11.225
1986	50.114319	6.250229	4.535	11.569
1987	30.206807	31.995000	6.895	12.255
1988	52.937734	17.038205	6.225	14.099
1989	19.137241	14.209377	6.392	12.324
1990	32.073406	1.128842	4.304	11.971
1991	25.051411	1.226593	5.550	9.794
1992	59.888922	7.809713	4.235	12.220
1993	32.142345	9.063604	4.157	11.274
1994	20.916611	5.796501	4.349	11.221
1995	39.863617	1.677212	4.036	9.491
1996	6.245386	1.364796	4.738	9.445
1997	11.868556	0.072043	5.008	13.424
1998	21.938896	0.704636	4.553	11.324
1999	34.803815	0.454625	4.991	11.293
2000	44.709797	3.412580	5.120	11.304
2001	54.329708	4.228331	4.557	8.949
2002	44.238443	1.839153	4.427	10.839
2003	62.448521	1.144999	3.880	11.795
2004	39.672506	1.150048	4.618	7.945
2005	31.523186	10.084982	5.670	10.261
2006	29.611774	1.384965	4.070	10.863
2007	47.756279	1.765222	4.848	11.197
2008	49.966639	4.824806	4.087	11.439
2009	34.725644	4.592258	4.163	7.974
2010	39.494059	3.479163	4.680	10.031
2011	23.569693	1.666248	4.243	11.799

Anchovy 1+ biomass (in tons) and associated CV from the November acoustic survey; anchovy spawner (1+) biomass and associated CV determined by the DEPM; Proportion-at-age 1 (by number), with SE in brackets and weights-at-age (in grams) in the November survey :

Year	Hydroacoustic survey		DEPM		Proportion-at-age 1	SE	Weight-at-age 1	Weight-at-age 2+
	1+ Biomass	CV	1+ Biomass	CV				
1984	1553813	0.282	1100000	0.45	0.251	0.26	15.497	15.408
1985	1366294	0.211	616000	0.40	0.818	0.16	13.564	18.998
1986	2568625	0.172	2001000	0.35	0.616	0.14	10.118	16.168
1987	2108771	0.157	1606000	0.30	0.700	0.19	10.468	16.714
1988	1607060	0.222	1679000	0.35	0.525	0.23	11.985	12.675
1989	751529	0.167	421000	0.35	0.055	0.05	11.623	15.02
1990	651711	0.183	723000	0.58	0.898	0.14	10.27	16.928
1991	2327834	0.159	2913000	0.35	0.777	0.23	9.375	13.576
1992	2088025	0.161	3600000	0.31	0.474	0.18	9.909	12.412
1993	916359	0.209	770000	0.34	0.693	0.27	11.526	13.275
1994	617276	0.159			0.371	0.24	12.31	15.569
1995	601271	0.217			0.639	0.09	6.807	12.775
1996	162048	0.410			0.299	0.04	7.834	17.083
1997	1482633	0.267			0.791	0.15	13.998	16.743
1998	1229132	0.217			0.677	0.13	12.182	19.905
1999	2052156	0.156			0.884	0.12	12.029	19.728
2000	4653779	0.125			0.848	0.17	9.371	13.833
2001	6720287	0.107			0.793	0.11	7.016	13.034
2002	3867649	0.154			0.773	0.18	9.355	11.921
2003	3563232	0.236			0.927	0.11	9.987	15.483
2004	2044615	0.131			0.923	0.13	12.326	17.117
2005	3077001	0.144			0.368	0.20	9.923	17.42
2006	2106273	0.136			0.583	0.17	12.703	18.499
2007	2506984	0.157			0.705	0.10	8.67	18.462
2008	3598790	0.120			0.804	0.06	7.054	16.234
2009	3792547	0.136			0.823	0.14	10.053	16.566
2010	2077414	0.144			0.771	0.14	11.468	12.353
2011	754124	0.204			0.744	0.15	11.88	18.114

Anchovy recruitment (in billions) and associated CV from the May recruitment acoustic survey; the date of the commencement of the annual recruit survey; juvenile anchovy catch (in billions) and mean catch weight of individual juvenile fish (in grams) from 1 November y-1 to the day before the annual recruit survey in year y:

Year	Recruit numbers	CV	Start date of Recruit survey	Time of recruit survey after 1 May	Juv. catch before survey	Juv. catch weight before survey
1984						
1985	83.454	0.276	20-May	0.613	12.286	4.781
1986	139.311	0.184	10-Jun	1.300	21.078	4.623
1987	124.450	0.167	20-Jul	2.613	14.325	7.849
1988	129.023	0.164	27-Jun	1.867	13.416	4.447
1989	33.128	0.205	08-Jun	1.233	12.459	5.840
1990	51.140	0.225	22-Jun	1.700	31.038	4.329
1991	113.584	0.151	07-May	0.194	12.484	5.220
1992	93.681	0.161	13-May	0.387	12.200	3.947
1993	115.058	0.266	21-May	0.645	1.471	5.551
1994	30.554	0.184	05-May	0.129	4.316	4.700
1995	110.439	0.179	10-Jun	1.300	12.433	5.665
1996	25.771	0.220	05-Jun	1.133	4.080	4.528
1997	90.210	0.186	17-May	0.516	0.163	6.241
1998	136.518	0.150	20-May	0.613	5.995	6.264
1999	199.228	0.158	10-May	0.290	1.772	5.056
2000	624.675	0.168	15-May	0.452	7.990	5.990
2001	627.200	0.135	05-May	0.129	4.908	5.347
2002	520.413	0.115	05-May	0.129	2.581	7.000
2003	430.308	0.189	14-May	0.419	3.023	4.990
2004	238.569	0.219	08-May	0.226	3.923	5.762
2005	176.917	0.273	13-May	0.387	3.821	6.550
2006	117.465	0.174	19-May	0.581	0.883	5.220
2007	506.703	0.184	18 May	0.548	5.824	5.626
2008	563.156	0.202	21 May	0.645	3.698	6.664
2009	363.387	0.189	15 May	0.452	7.398	3.440
2010	383.328	0.267	27 May	0.839	6.921	5.057
2011	104.166	0.283	27 May	0.839	5.781	5.030

MODEL

The South African anchovy population was modelled using an age structured production model (de Moor and Butterworth, 2009, de Moor and Butterworth 2012). The model includes estimating the stock–recruitment curve parameters within the overall fit to the data, and uses Bayesian estimation, implemented numerically with the Markov Chain Monte Carlo method, and using the Bayesian Output Analysis package to check convergence to the posterior distribution.

BASE FIT

In the plots that follow, the base fit is labelled "ABH". It assumes that natural mortality is time-invariant, and uses the Beverton–Holt stock–recruit function.

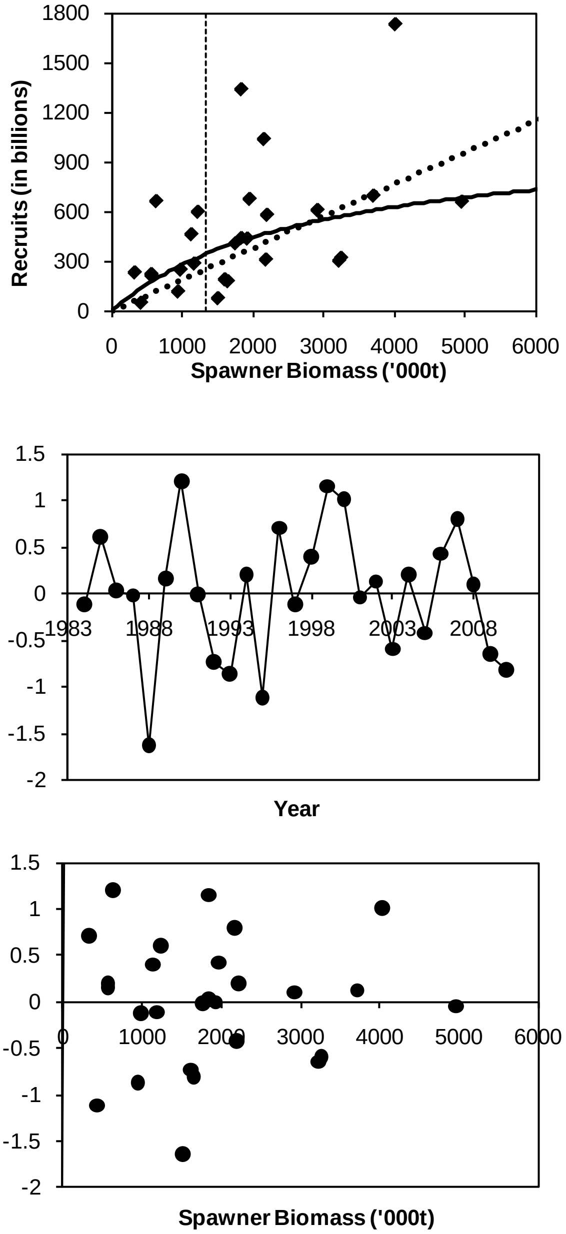


Figure 1. Model predicted anchovy recruitment (in November) plotted against spawner biomass from November 1984 to November 2010 for ABH with the Beverton–Holt stock recruitment relationship. The vertical thin dashed line indicates the average 1984 to 1999 spawner biomass (used in the definition of risk in OMP-04 and OMP-08). The dotted line indicates the replacement line. The standardized residuals from the fit are given in the lower plots, against year and against spawner biomass.

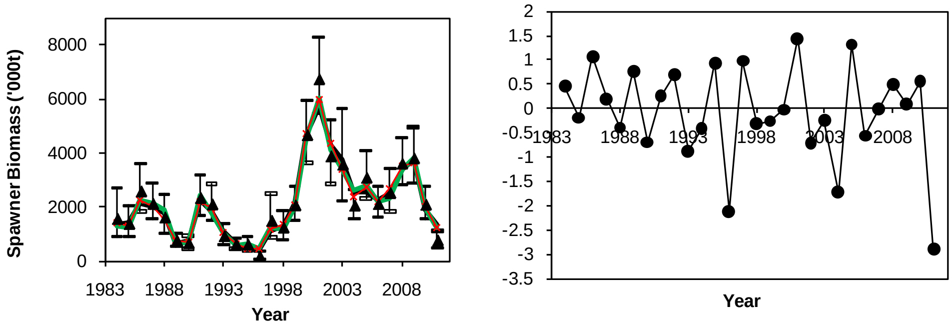


Figure 3. Acoustic survey results and model estimates for November anchovy spawner biomass from 1984 to 2011 for A_{BH} (black), A_{prop} (alternative time-series of proportion-at-age 1 data; green) and A_{noprop} (no proportion-at-age 1 data; thin red line with crosses). The survey indices are shown with 95% confidence intervals. The standardized residuals (i.e. the residual divided by the corresponding standard deviation, including additional variance where appropriate, given in equation (A.9)) from the A_{BH} fit are given in the right hand plot.

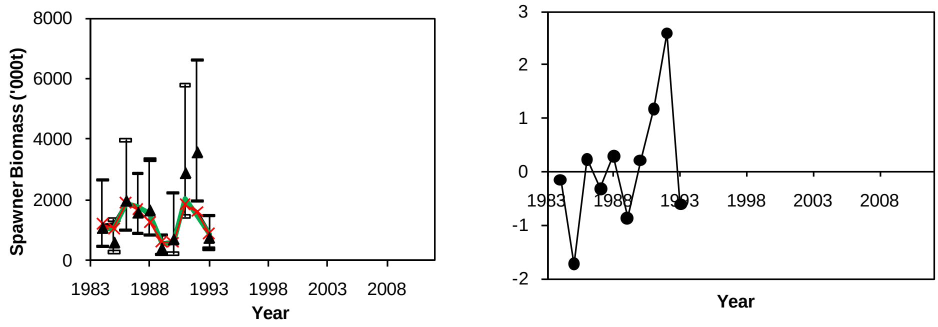


Figure 4. Egg survey results and model estimates for November anchovy spawner biomass from 1984 to 1993 for A_{BH} (black), A_{prop} (alternative time-series of proportion-at-age 1 data; green) and A_{noprop} (no proportion-at-age 1 data; thin red line with crosses). The survey indices are shown with 95% confidence intervals. The standardized residuals from the A_{BH} fit are given in the right hand plot.

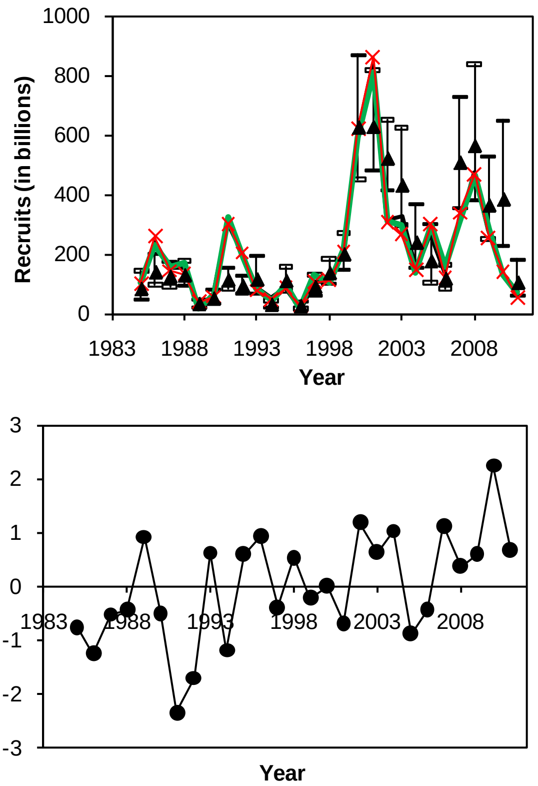


Figure 5. Acoustic survey results and model estimates for anchovy recruitment numbers from May 1985 to May 2011 for A_{BH} (black), A_{prop} (alternative time-series of proportion-at-age 1 data; green) and A_{noprop} (no proportion-at-age 1 data; thin red line with crosses). The survey indices are shown with 95% confidence intervals. The standardized residuals from the A_{BH} fit are given in the right hand plot.

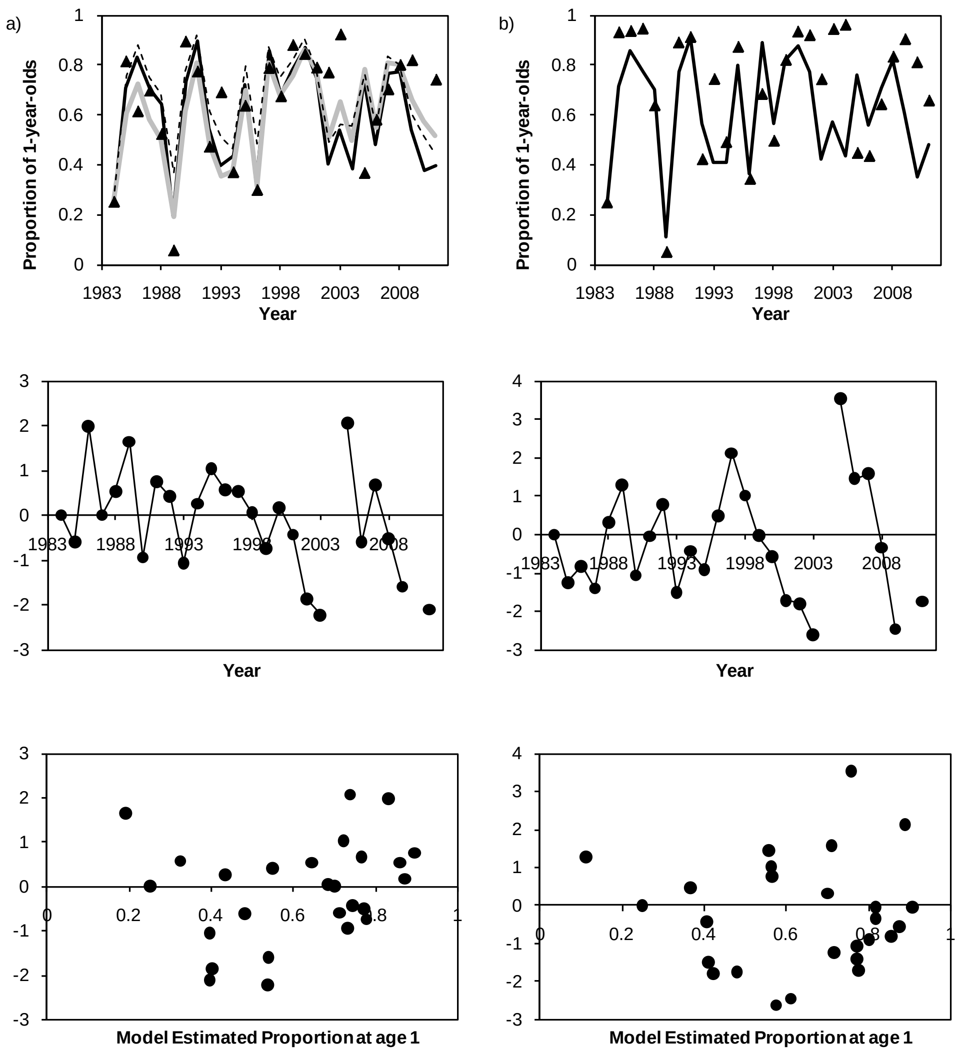


Figure 6. Acoustic survey results and model estimates for proportions of 1-year-olds in the November survey from 1984 to 2011 for a) A_{BH} (black), A_{Neff} (constant average rather than annually varying effective sample sizes for the proportion-at-age 1 inputs; dashed), and A_{Mad} (annually varying adult natural mortality; grey), and b) A_{prop} (alternative time-series of proportion-at-age 1 data). The standardized residuals from the A_{BH} and A_{prop} fits are given in the middle and right hand plots, against year and against model estimates of proportions at age 1.

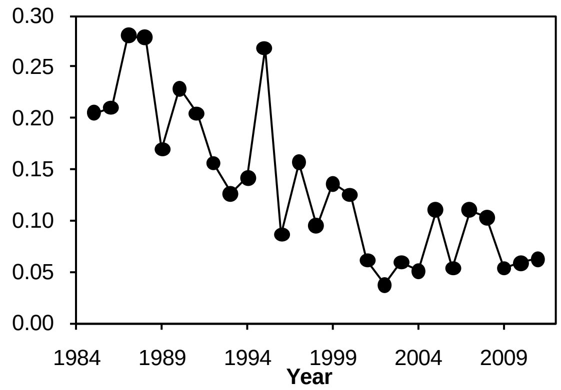


Figure 7. The historic harvest proportion (catch by mass as a proportion of 1+ biomass) for anchovy for ABH.

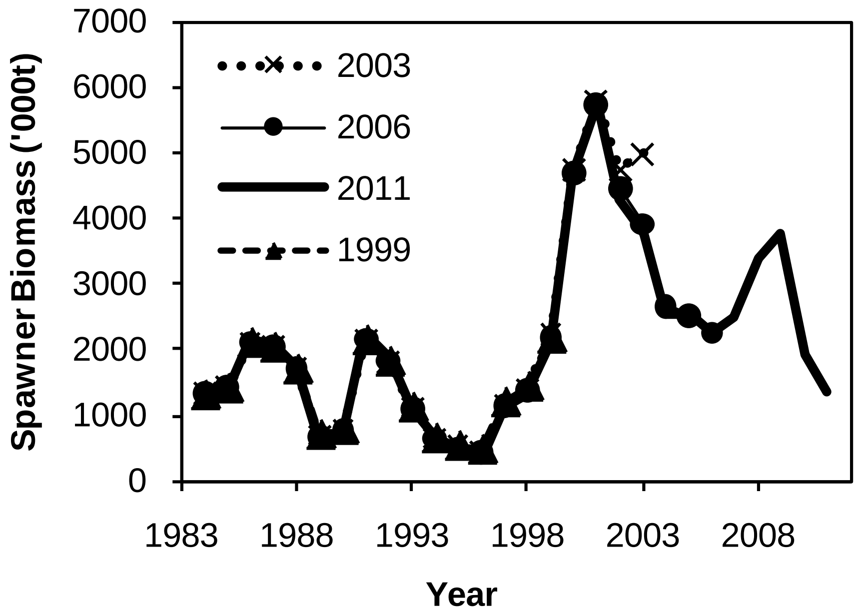


Figure 9. The model predicted November anchovy spawner biomass for ABH and the retrospective runs A2006 using data up to 2006, A2003 using data up to 2003 and A1999 using data up to 1999.

SOURCES: de Moor and Butterworth (2009); de Moor and Butterworth (2012); de Moor *et al.* (2012)

Annex 8: Description of baseline models for the selected stocks

1 SAM (North Sea Cod, North Sea Herring):

Model &Version	State-space Assessment Model (SAM). 0.2-r
Category	(1) Age based
Model Type	SAM is a time-series model designed to be an alternative to the (semi) deterministic procedures (VPA, Adapt, XSA, ...) and the fully parametric statistical catch-at-age models (SCAA, SMS, ...). Compared to the deterministic procedures it solves the problem of falsely assuming catches-at-age are known without errors, and in addition the problem of selecting appropriate so-called 'schrinkage', and in certain cases convergence problems in the final years. Compared to fully parametric statistical catch-at-age models SAM avoids the problem of fishing mortality being restricted to a parametric structure (e.g. multiplicative), and many problems related to having too many model parameters compared to the number of observations (e.g. borderline identification problems, convergence issues, asymptotic results, ...)
Data used	Total catch-at-age data and survey indices. Natural mortality M (possibly varying by year). Mean weights by age in stock and catch. Proportion mature.
Model assumptions	Log catches and log indices are assumed to follow normal distributions. Fishing mortalities are assumed to follow random walks (separate for age groups). Natural mortality, proportion mature and weights are assumed know. Further the model is build around the usual stock and catch equations. This simple model further has the advantage that it can easily be adapted to cases where assumptions need to be adjusted.
Estimated parameters	Observation errors, process errors, survey-catchabilities, and depending on configurations the stock–recruitment parameters are estimated. In addition the fishing mortalities and stock sizes are predicted (also for the historic period).
Objective function	The joint likelihood of observations, unobserved random variables (fishing mortalities and stock sizes), and model parameters is set up, then the marginal likelihood is computed by integrating* out the unobserved random variables. The marginal likelihood is optimized to give the maximum likelihood estimates of the model parameters. *) Note: The integration is carried out via the highly efficient Laplace approximation built into AD Model Builder, but has been validated via an unscented Kalman filter, and importance sampling.
Minimization	Quasi-Newton algorithm aided by automatic differentiation (as implemented in AD Model Builder)
Variance estimates and uncertainty	Based on Hessian and delta method. Profile likelihood and MCMC validation is available without additional coding.
Other issues	Many features are not covered above. The main advantage of having a very simple base model as described is that case specific issues can be dealt with easily. For instance for North Sea cod the model includes estimation of a catch multiplier which explains a mismatch between surveys and catches. For some stocks a technical creep has been tried, and for others climate variables has been included to improve the stock–recruitment relationship. Finally, the maximum likelihood framework of this model allows statistical significance tests to be performed.

Quality control	SAM has been tested via simulation studies, output diagnostics, and by comparing to results from other models.
Restrictions	At the time of writing SAM is only a single area and single species model. If the fishing mortality in the last year jumps by many times the levels seen in the past, then the time-series nature of the model will dampen the jump. This is equivalent to the effect of year-schrinkage, but in SAM it is objectively estimated.
Program language	AD Model Builder. To make it more accessible an online version is available for certain stocks, and that is based on a mix of php and R scripts calling the main program.
Availability	http://stockassessment.org
References	Origin of state-space models in Assessment: Gudmundsson (1987), Gudmundsson (1994), Fryer (2001). The Laplace approximation and its use in AD model Builder: Skaug and Fournier (2006). Detailed description of the model: Section 8 in ICES (2009b) [WGMG]
Applications	SAM is currently run for the following stocks in ICES: Kattegat Cod, Western Baltic Cod, Sole in 3A, Eastern Baltic Cod, North Sea Sole, Plaice in 3A, and North Sea Cod. Of these the state-space assessment model is primary for the first three stocks, and included as exploratory for the remaining. In addition to the stocks mentioned above it has been applied to applied to other stocks (Western Baltic spring-spawning herring, North Sea Haddock, 3PS Cod, and Georges Bank Yellowtail Flounder) for testing purposes, and has performed well.

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.

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 $i \ne j$.

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:

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

$$\log I^{(s)}_{a,y} = \log\left(Q^{(s)}_a e^{-Z_{a,y}\frac{D^{(s)}}{365}} N_{a,y}\right) + \varepsilon^{(s)}_{a,y}$$

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 $Q^{(s)}_a$ are model parameters describing catchabilities. Finally $\varepsilon^{(\circ)}_{a,y} \sim N(0,\sigma^2_{\circ,a})$ and $\varepsilon^{(s)}_{a,y} \sim N(0,\sigma^2_{s,a})$ 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

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

2 XSA (North Sea Plaice, North Sea Haddock):

Model & Version	XSA (forms part of the suite: Virtual Population Analysis, version 3.1)
Category	Age-based
Model Type	XSA (extended survivors analysis) is VPA-derived method that works in backwards mode and assumes catch-at-age data are exact. It is in extension of Survivors Analysis (Doubleday 1981) and was developed to overcome the deficiencies of ad hoc tuned VPA methods (which include sensitivity to observation errors in the final year, and the failure to utilize full information on year-class strength from the catch-at-age data). XSA focuses on the relationship between cpue and population abundance, allowing the use of a more complicated model for the relationship between cpue and year-class strength at the youngest ages than was the case for ad hoc tuned methods. It is best suited for situations where the catch-at-age data are considered reliable (e.g. observation error in the catch is small, and much lower than that in the fleet tuning indices used), and where fishing mortality has been relatively high (appreciably higher than natural mortality).
Data used	Requires catch-at-age data and associated mean weights-at-age for the full time period and all ages considered, and at least one time-series of fleet tuning indices-at-age (commercial or survey cpue; does not need to span either the full time period or all ages considered). Maturity-at-age and natural mortality-at-age can either be fixed inputs or estimates derived elsewhere, and mean stock weights-at-age data could be survey-derived or set equal to mean catch weights-at-age. The package does not allow for gaps in the catch-at-age data (i.e. they need to be contiguous).
Model assumptions	Fleet catchabilities-at-age are assumed to be constant with respect to time (for ages considered to be "recruited"), or dependent on year-class abundance (for ages to be treated as "recruits"), describing the relationship between catchability and abundance with a power law. XSA assumes that catchability is independent of age (constant) for all fleets above a specific, user-defined age. The procedure uses the catchability value derived for the selected age to calculate estimates of population abundance for all older ages. A default constraint is imposed to ensure that, at the very least, the catchability of the oldest true age is fixed to that of the preceding age. Shrinkage is used to incorporate the mean, with an appropriate weight, into the model in order to reduce prediction variance at the cost of a bias towards the mean. The strength of the bias towards the mean (strength of the shrinkage) should be dependent on the quality of the data to which the model is fitted. Estimates derived from poor quality data (low signal to noise ratio) should have a greater contribution from the mean (heavier shrinkage), while those derived from good quality data, where the variance of the prediction from the fitted model will be smaller, should be less influenced by the mean (lighter shrinkage). Two forms of shrinkage are employed, namely shrinkage to the population mean, first used in RCT3 (Shepherd 1997), and shrinkage to a mean of the most recent F values. The number of years and ages used for the shrinkage mean is user-customized to the dimensions of the data set. Plus-group assumptions: hanging plus-group, calculated on the basis of F assumptions (set equal to the F at the oldest true age), plus-group catch and Baranov catch equation.
Estimated parameters	Extimates catcability parameters

Objective function	There is no explicit objective function, but XSA uses an iterative algorithm until convergence is achieved (described under "minimization"). Various options are available for time-series weighting (e.g. to give more weight to recent data) and shrinkage of the weighted estimates. Where more than one tuning fleet is used, fleet weighting can be applied to allow down-weighting of all estimates from that fleet.
Minimization	The XSA algorithm performs: a cohort analysis of the total catch-at-age data to produce estimates of population abundance-at-age, and total fishing mortalities adjustment of the tuning index to the beginning of the year accounting for mortality calculation of fleet-based estimates of population abundance-at-age from the adjusted tuning index values and fleet catchabilities calculation of a least-squares estimate (weighted mean) of the terminal population (survivors at the end of the final year) for each cohort in the tuning range using the fleet-derived estimates of population abundance-at-age. These terminal populations are used to initiate the cohort analysis in the next iteration. The algorithm terminates when the following criterion is met: $\sum_a \left\lvert F_{a,Y,i} - F_{a,Y,i-1} \right\rvert < 0.0001$ for fishing mortalities at ages a, final year Y and iteration i.
Variance estimates and uncertainty	XSA produces internal and external standard errors of terminal population estimates. The internal standard errors are derived by combining the standard errors associated with each estimate in the weighted mean and corresponds to the within samples variance of the fleet-based terminal population estimate. The external standard errors are the standard errors of the terminal population estimates derived at each age and corresponds to the between samples variance. If the values of the internal and external standard errors differ significantly, this indicates a discrepancy between the individual estimates generated by the fleet catches. It is possible to obtain, for each fleet and each age in the cohort's history, the estimate of the terminal population at the end of the final assessment year and its raw weight. These are used with the individual estimates of survivors to calculate the fleet-based and overall weighted means. Scaled weights can be derived, and are a measure of the proportional contribution of the fleet's estimates (for all ages) to the overall survivors estimate for the cohort. This allows contributions from each fleet to be compared.
Restrictions	XSA only handles the data described under "data used" (catch-at-age data and tuning indices at age)
Program language	Fortran 77
Availability	The XSA package is available as part of a suite of VPA methods (Virtual Population Analysis, version 3.1), and can be downloaded from the ICES website (www.ices.dk)
References	Doubleday (1981), Darby and Flatmann (1994), Shepherd (1997), Shepherd (1999)
Applications	The mainstay of many ICES stock assessments for many years, and currently remains the most widely used method for ICES.

3 Stock Synthesis (Northern hake, Iberian sardine, US West Coast Canary Rockfish)

Model & Version	Stock Synthesis (SS) version 3.10b
Category	(1) Age-based; (truly both age- and length-based)
Model Type	SS is a generalized age- and length-based model that is very flexible with regard to the types of data that may be included, the functional forms that are used for various biological processes, the level of complexity and number of parameters that may be estimated. Numbers-at-age for each yearclass are tracked for each of several cohorts defined in terms of sex, mean growth pattern, and birth season. The recruitment of each cohort can be apportioned among areas and movement among areas can occur seasonally. The distribution of size-at-age for each cohort follows a normal distribution to allow for implementation of length-selectivity and to derive fishery specific body weight-at-age. Further, each cohort can be subdivided by size among several morphs (platoons) in order to allow for fishery size-selectivity to cause size survivorship within each cohort.
Data used	There is no minimum data requirement. Gaps can be included in all data sources, although catch is normally modelled as known for each time-step. Data types include: catch, discards (in biomass or as a fraction of landings), indices of abundance (surveys or fishery cpue), mean body weight (across sampled ages), length compositions, age compositions, weight compositions, conditional age-at-length compositions, mean length-at-age, mean weight-at-age, tag releases and recaptures, stock composition data (e.g. microchemistry or genetic data) among the model identities defined as growth patterns environmental data Bins structure for composition data are separate from bins for population dynamics calculations and includes aggregation in largest and smallest bins.

Model assumptions	Numerous selectivity options are available as a function of length or age and age- and length-based selectivity can be combined. Fishing mortality can be applied as a continuous rate or in the middle of the season using Pope's approximation. Fleets and surveys can mirror selectivity of each-other or use different forms. Population plus group is aggregated, but the maximum number of ages is unrestricted. Maturity is logistic, growth follows von-Bertalanffy or Richards growth-curve. Natural mortality may be a single value, a piecewise linear function of age, a Lorenzen function, or a vector of values at each age (with or without interpolation across seasons). Movement can be included between any pairs of areas in spatial models and movement rates is a 2-parameter dog-leg shaped function of age. Recruitment is a single value in each year based on various spawner-recruit options, which is then assigned to areas, genders, growth-patterns, growth-morphs, etc. according to a set of parameters that may be fixed or time-varying. Annual total recruitment is defined as a lognormal deviation from a spawner-recruitment function, or from a constant mean value. Substantial controls are provided to account for the consequences of estimating recruitment variability in data-poor eras of the modelled time-series.
Estimated parameters	Long list of possibilities is difficult to fully enumerate. Possible estimated parameters include those controlling growth, weight-at-length, maturity, selectivity at length and/or age, spawner-recruit relationship, annual recruitment, distribution of recruitment among various partitions of population structure, movement rates, tagging mortality and reporting rates, catchability (including possible non-linear relationship with abundance), parameters controlling offsets in the above relationships across genders or growth patterns, and parameters controlling temporal variation in any other parameters. In general, all parameters may be fixed across all years or time-varying according to a block structure, a set of random deviations, a random walk, or a smooth trend over time. Priors can be included on any parameter as normal, log-normal, beta.
Objective function	Objective function is a combination of components for cpue or abundance index (lognormal or normal) fishery Discard biomass (normal) fishery or survey Mean body weight (normal) fishery or survey Length composition (multinomial) fishery or survey age composition (multinomial) fishery or survey Mean size at age (normal) Initial equilibrium catch (normal) Recruitment deviations (lognormal) Random parameter time-series deviations (normal) Parameter priors Penalty on negative abundance
Minimization	Minimization is implemented using standard ADMB process. Minimization occurs in phases, and all parameters may be assigned to a phase in which estimation will begin.
Variance estimates and uncertainty	Variance estimates for all estimated parameters and numerous derived quantities are calculated either the Hessian matrix or from MCMC calculations, both implemented using standard ADMB algorithms. Parametric bootstrap data sets can be generated in order to evaluate the reproducibility of model results.
Other issues	Any other features or issues not covered above, e.g. the possibilities for model extensions.

Quality control	Numerous tests have been conducted using this model. Those published in peer reviewed literature include Yin and Sampson (2004), which reached the conclusion that "For all the output variables examined the estimates appeared to be median-unbiased", and Schirripa *et al.* (2009), which focused on incorporating climate data, but provided an additional check of the ability of the model to estimate parameters using simulated data. Various ongoing research projects have determined that SS is capable of estimating parameters used to simulate data. These include the work of Lee *et al.* (2011) and separate projects being conducted by Ian Taylor, Tommy Garrison, and Chantel Wetzel, all associated with the University of Washington. The simulations studies have included data simulated within stock synthesis as well as data generated from independent operating models written in R. SS has been used for dozens of stock assessments around the world. The area of highest used is on the US Pacific Coast. Numerous stock assessments conducted by NMFS scientists at the Northwest and Southwest Fisheries Science centers using SS have been reviewed by a stock assessment review (STAR) panel which includes independent CIE reviewers. These assessments are then reviewed by the Scientific and Statistical Committee of the Pacific Fishery Management Council.
Restrictions	Single species assessments only. Growth transition matrices (e.g. those used for invertebrates) are not possible. Recruitment is a function of global spawning output, so true metapopulation structures are not yet possible.
Program language	ADMB
Availability	The model and a graphical user interface are available from the NOAA Fisheries Stock Assessment Toolbox website: http://nft.nefsc.noaa.gov/. Only executable code is routinely distributed, along with a manual and sample files. However, under certain circumstances, source code may be obtained from the author upon request and with agreement to certain restrictions. An set of R routines to process and view model output is available from http://code.google.com/p/r4ss/. These routines were initially developed by Ian Stewart and Ian Taylor.
References	Lee *et al.* (2011), Methot (1990, 2000, 2009, 2010), Methot and Taylor (2011), Schirripa *et al.* (2009), Wang *et al.* (2009), Yin and Sampson (2004).
Applications	SS has been used for dozens of stock assessments around the world. The area of highest used is on the US Pacific Coast where it was first applied in the late 1980s. Application species for production assessments have included dozens of groundfish stocks, numerous tuna stocks, other large and small pelagics, sufclams, toothfish, sharks and various other fish. Exploratory analyses have been conducted for shrimps and various other species.

4 Modified Punt-Walker (Spurdog)

Population dynamics model

The model is largely based on Punt and Walker (1998) and Punt *et al*. (2001).

Basic Dynamics

The population dynamics for spurdog are assumed to be governed by:

$$N^s_{y+1,a} = \begin{cases} \Phi^s R_{y+1} & a = 0 \\ (N^s_{y,a-1} e^{-M_{a-1}/2} - \sum_j C^s_{j,y,a-1}) e^{-M_{a-1}/2} & 0 < a \le A-1 \\ (N^s_{y,A-1} e^{-M_{A-1}/2} - \sum_j C^s_{j,y,A-1}) e^{-M_{A-1}/2} + (N^s_{y,A} e^{-M_A/2} - \sum_j C^s_{j,y,A}) e^{-M_A/2} & a = A \end{cases} \quad \text{A4.1a}$$

where s=f or m, Φ^s is the sex ratio (assumed to be 0.5), R_y the recruitment of pups to the population, $N^s_{y,a}$ the number of animals of sex s and age a at the start of year y, M_a the instantaneous rate of natural mortality-at-age a, $C^s_{j,y,a}$ the number of animals caught of sex s and age a in year y by fleet j, and A the plus group (60). Total biomass is then calculated as:

$$B_y = \sum_s \sum_a w^s_a N^s_{y,a} \quad \text{A4.1b}$$

where w^s_a is the begin-year mean weight of animals of sex s and age a.

Recruitment

The number of pups born each year depends on the number of pregnant females in the population as follows:

$$N_{pup,y} = \sum_{a=1}^{A} P'_a P''_a N^f_{y,a} \quad \text{A4.2a}$$

where P'_a is the number of pups per pregnant female of age a, and P''_a the proportion females of age a that become pregnant each year. Q_y, the density-dependence factor that multiplies the number of births in year y, is calculated as follows:

$$Q_y = 1 + (Q_{fec} - 1)(1 - N_{pup,y} / R_0) \quad \text{A4.2b}$$

where Q_{fec} is the parameter that determines the extent of density-dependence, and R_0 the virgin recruitment level (see "Initial conditions" below). Recruitment in year y is the product of these two equations, and in order to allow for interannual variation in pup survival rate, "process error" is introduced to give the following:

$$R_y = Q_y N_{pup,y} \, e^{\varepsilon_{r,y}} \quad \text{A4.2c}$$

where the recruitment residuals $\varepsilon_{r,y}$ are estimated (see equation A4.9a below).

Fecundity

Fecundity, expressed as number of pups per pregnant female of age *a*, is modelled as follows:

$$P'_a = \begin{cases} 0 & l_a^f < l_{mat00}^f \\ b_{fec}\left(l_a^f + \sqrt{(l_a^f + a_{fec}/b_{fec})^2 + \gamma^2} - \sqrt{(a_{fec}/b_{fec})^2 + \gamma^2}\right)/2 & l_a^f \geq l_{mat00}^f \end{cases} \qquad \text{A4.3}$$

where l_{mat00}^f is the female length-at-first maturity (Table A4.1), and γ is set at 0.001. The bent hyperbola formulation (Mesnil and Rochet, 2010) given in the bottom line of equation A4.3, is to ensure that if parameters a_{fec} and b_{fec} are estimated, P'_a remains non-negative and the function is differentiable for $l_a^f \geq l_{mat00}^f$.

Estimated fishing proportion and catch-at-age

Catches are assumed to be taken in a pulse in the middle of the year, with the fully selected fishing proportion $F_{j,y}$ being estimated from the observed annual catch (in weight) by fleet $C_{j,y}$ as follows:

$$F_{j,y} = \frac{C_{j,y}}{\sum_a e^{-M_a/2} \sum_s w_{a+\frac{1}{2}}^s S_{com,j,a}^s N_{y,a}^s} \qquad \text{A4.4a}$$

where $w_{a+\frac{1}{2}}^s$ is the mid-year mean weight of animals of sex *s* and age *a*, and $S_{com,j,a}^s$ the selectivity-at-age of animals of sex *s* and age *a* caught by fleet *j*. For the purposes of estimating a mean fishing proportion trajectory, the mean effective fishing proportion over ages 5–30 is calculated as follows:

$$F_{prop5-30,y} = \sum_j \frac{1}{26} \sum_{a=5}^{30} \left[\frac{\sum_s S_{com,j,a}^s N_{y,a}^s (F_{j,y} S_{com,j,a}^s)}{\sum_s S_{com,j,a}^s N_{y,a}^s} \right] \qquad \text{A4.4b}$$

Catch-at-age (in numbers) is estimated as follows:

$$C_{j,y,a}^s = F_{j,y} S_{com,j,a}^s N_{y,a}^s e^{-M_a/2} \qquad \text{A4.4c}$$

Commercial selectivity

Commercial selectivity-at-age is calculated from commercial selectivity-by-length category parameters as follows:

$$S_{com,j,a}^{s*} = \begin{cases} S_{c2,j} & 16 \leq l_a^s < 55 \\ S_{c3,j} & 55 \leq l_a^s < 70 \\ S_{c4,j} & 70 \leq l_a^s < 85 \\ 1 & l_a^s \geq 85 \end{cases} \qquad \text{A4.5a}$$

so that:

$$S_{com,j,a}^s = S_{com,j,a}^{s*} / \max_j (S_{com,j,a}^{s*}) \qquad \text{A4.5b}$$

where l_a^s is the length-at-age for animals of sex s. Selectivity-by-length category parameters $S_{c2,j}$, $S_{c3,j}$ and $S_{c4,j}$ (j=*non-tgt* or *tgt*) are estimated in the model.

Survey selectivity

Survey selectivity-at-age $S_{sur,a}^{s}$ for animals of sex s is calculated in the same manner as commercial selectivity, except that there is only one survey abundance-series (the index j is dropped from the above equations) and different length categories (the 16–54 cm category is split into 16–31 and 32–54, and the 70-84 and 85+ categories are combined into a single 70+ category), leading to four selectivity parameters to be estimated (S_{s1}, S_{s2}, S_{s3} and S_{s4}), the first three applying to the smallest length categories (16-31, 32-54 and 55-69), regardless of sex, and the fourth (S_{s4}) to the 70+ category for females only (assuming 1 for males in this length category).

Initial conditions

The model assumes virgin conditions in 1905, the earliest year for which continuous landings data are available, with the total number of pregnant females in the virgin population, $N_0^{f,preg}$, treated as an estimable parameter in the model. Taking the model back to 1905 ensures that the assumption of virgin conditions is more appropriate, although it also implies that exploitation patterns estimated for the most recent period (1980+) are taken back to the early 1900s. Taking the model back also allows early fecundity data to be fitted. Virgin conditions are estimated by assuming constant recruitment and taking the basic dynamics equations forward under the assumption of no commercial exploitation. Virgin recruitment (R_0) is then calculated as follows [note: $\sum_{i=0}^{-1}()$ is defined as 0]:

$$R_0 = \frac{N_0^{f,preg}}{\Phi^f \left[\sum_{a=0}^{A-1} P_a'' e^{-\sum_{i=0}^{a-1} M_i} + P_A'' \frac{e^{-\sum_{i=0}^{A-1} M_i}}{1-e^{-M_A}} \right]} \qquad \text{A4.6}$$

Natural mortality for pups (M_{pup})

With the possibility of estimating the fecundity parameters a_{fec} and b_{fec} (equation A4.3), the natural mortality parameter M_{pup} (Table A4.1) needs to be calculated so that, in the absence of harvesting, the following balance equation is satisfied:

$$\frac{1}{\Phi^f} = \sum_{a=0}^{A-1} P_a' P_a'' e^{-\sum_{i=0}^{a-1} M_i} + P_A' P_A'' \frac{e^{-\sum_{i=0}^{A-1} M_i}}{1-e^{-M_A}} \qquad \text{A4.7}$$

Estimating MSY parameters

Two approaches were used to derive MSY parameters. In order to derive MSYR, the ratio of maximum sustainable yield, MSY, to the mature biomass (assumed to be the biomass of all animals $\geq l_{mat00}^f$) at which MSY is achieved (MSY/B_{MSY}) is calculated. This follows the same procedure for calculating MSYR as Punt and Walker (1998), and ensures that MSYR is comparable among different stocks/species, which would then allow MSYR estimates for other stocks/species to be used to inform on the likely range for spurdog. The selectivity for this first approach is therefore simply:

$$S_{MSY,a}^{s,mat} = \begin{cases} 0 & l_a^s < l_{mat00}^f \\ 1 & l_a^s \geq l_{mat00}^f \end{cases} \qquad \text{A4.8a}$$

However, an estimate of $F_{prop,\mathrm{MSY}}$ is needed from the assessment, which should correspond to the selection patterns of the fleets currently exploiting spurdog. The second approach was therefore to use selection patterns estimated for the non-target and target fleets (average over most recent five years; equations A4.4a-b) to estimate $F_{prop,\mathrm{MSY}}$. The selectivity for the second approach is therefore calculated as follows:

$$S_{MSY,j,a}^{s,cur} = \bar{f}_{rat,j}\, S_{com,j,a}^{s} \qquad \text{A4.8b}$$

where $S_{com,j,a}^{s}$ is from equation A4.5b, and $\bar{f}_{rat,j}$ is a five-year average as follows:

$$\bar{f}_{rat,j} = \frac{1}{5}\sum_{y=yend-4}^{yend} \frac{F_{j,y}}{\sum_j F_{j,y}} \qquad \text{A4.8c}$$

where $F_{j,y}$ is from equation A4.4a, and *yend* is the most recent year of data used in the assessment. In order to calculate MSY parameters, the first step is to express population dynamics on a per-recruit basis. Therefore, taking equations A4.1a and A4.4c, the equivalent per-recruit equations (dropping the y subscript) are given as:

$$N_{pr,a}^{s} = \begin{cases} \Phi^s & a = 0 \\ \Phi^s \prod_{i=0}^{a-1} \left(1 - \sum_j F_{mult} S_{MSY,j,i}^{s}\right) e^{-M_i} & 0 < a \leq A-1 \\ \Phi^s \dfrac{\prod_{i=0}^{A-1} \left(1 - \sum_j F_{mult} S_{MSY,j,i}^{s}\right) e^{-M_i}}{\left(1 - \sum_j F_{mult} S_{MSY,j,A}^{s}\right)(1 - e^{-M_A})} & a = A \end{cases} \qquad \text{A4.8d}$$

where s represents sex, F_{mult} replaces $F_{j,y}$ as the multiplier that is used to search for MSY, and the selection pattern $S_{MSY,j,a}^{s}$ reflects either the first approach (equation A4.8a, defined in terms of animals all animals $\geq l_{mat00}^f$ only, so subscript j and the summation over j is dropped) or the second approach (equation A4.8b, reflecting exploitation by current fleets, so subscript j and the summation over j is kept). Equation A4.2a therefore becomes:

$$N_{pup,pr} = \sum_{a=1}^{A} P_a' P_a'' N_{pr,a}^{f} \qquad \text{A4.8e}$$

Recruitment can be expressed in terms of $N_{pup,pr}$ by re-arranging equations A4.2b-c (omitting the process error term) as follows:

$$R = \frac{R_0}{N_{pup,pr}}\left[1 - \frac{(1/N_{pup,pr} - 1)}{Q_{fec} - 1}\right] \qquad \text{A4.8f}$$

Yield can then be calculated as follows for the first (Y^{mat}) and second (Y^{cur}) approaches:

$$Y^{mat} = R\sum_{s}\sum_{a=0}^{A}\left(F_{mult}S^{s,mat}_{MSY,a}w^{s}_{a}N^{s}_{pr,a}\right) \qquad \text{A4.8g}$$

and

$$Y^{cur} = R\sum_{s}\sum_{a=0}^{A}\sum_{j}\left(F_{mult}S^{s,cur}_{MSY,j,a}w^{s}_{a+\frac{1}{2}}N^{s}_{pr,a}e^{-M_a/2}\right) \qquad \text{A4.8h}$$

MSY is found by solving for the F_{mult} value that maximizes equation A4.8g or A4.8h, and the corresponding $F_{prop,\mathrm{MSY}}$ is calculated using equation A4.4b (replacing $F_{j,y}$ with F_{mult}, $S^{s}_{com,j,a}$ with $S^{s}_{MSY,j,a}$, and $N^{s}_{y,a}$ with $N^{s}_{pr,a}$). Here, equation A4.8g has been used for the purposes of calculating MSYR, and equation A4.8h for estimating $F_{prop,\mathrm{MSY}}$.

Likelihood function

Survey abundance index

The contribution of the Scottish survey abundance index to the negative log-likelihood function assumes that the index $I_{sur,y}$ is lognormally distributed about its expected value, and is calculated as follows:

$$-\ln L_{sur} = \tfrac{1}{2}\sum_{y}[\ln(2\pi\sigma^{2}_{sur,y}) + \varepsilon^{2}_{sur,y}] \qquad \text{A4.9a}$$

where $\sigma_{sur,y}$ is the CV of the untransformed data, q_{sur} the survey catchability (estimated by closed-form solution), and $\varepsilon_{sur,y}$ the normalized residual:

$$\varepsilon_{sur,y} = [\ln(I_{sur,y}) - \ln(q_{sur}N_{sur,y})]/\sigma_{sur,y} \qquad \text{A4.9b}$$

$N_{sur,y}$ is the "available" mid-year abundance corresponding to $I_{sur,y}$, and is calculated as follows:

$$N_{sur,y} = \sum_{s}\sum_{a}S^{s}_{sur,a}[N^{s}_{y,a}e^{-M_a/2} - \sum_{j}C^{s}_{j,y,a}/2] \qquad \text{A4.9c}$$

Commercial proportion-by-length-category

The contribution of the commercial proportion-by-length-category data to the negative log-likelihood function assumes that these proportions $p_{j,y,L}$ for fleet j and length category L (combined sex) are multinomially distributed about their expected value, and is calculated as follows (Punt *et al.*, 2001):

$$-\ln L_{pcom,j} = k_{pcom,j}\sum_{y}\sum_{L}\varepsilon_{pcom,j,y,L} \qquad \text{A4.10a}$$

where $k_{pcom,j}$ is the effective sample size, and the multinomial residual $\varepsilon_{pcom,j,y,L}$ is:

$$\varepsilon_{pcom,j,y,L} = -\frac{n_{pcom,j,y}}{\overline{n}_{pcom,j}} p_{j,y,L}[\ln(\hat{p}_{j,y,L}) - \ln(p_{j,y,L})] \qquad \text{A4.10b}$$

with $n_{pcom,j,y}$ representing the number of samples on which estimates of proportions by length category are based, and $\overline{n}_{pcom,j}$ the corresponding average (over y). Because actual sample sizes were not available for the commercial data (only raised sample sizes), all model runs assumed $n_{pcom,j,y} = \overline{n}_{pcom,j}$, ICES (2010d [WGEF]) concluded that model results were not sensitive to this assumption. Four length categories are considered for the commercial proportions-by-length (16–54 cm; 55–69 cm; 70–84 cm; and 70+ cm), and the model estimates $\hat{p}_{j,L,y}$ are obtained by summing the estimated numbers caught in the relevant length category L and dividing by the total across all the length categories. The effective sample size $k_{pcom,j}$ is assumed to be 20 for all j (but a sensitivity test explores alternative assumptions).

Survey proportion-by-length-category

The negative log-likelihood contributions (-lnL_{psur}) for the Scottish survey proportions-by-length category are as for the commercial proportions, except that there is only one survey abundance series (the j index is dropped in the above equations), and different length categories (the 16–54 cm category is split into 16–31 and 32–54, and the 70-84 and 85+ categories are combined into a single 70+ category). The effective sample size k_{psur} is assumed to be 10, and reflects the lower sample sizes for surveys relative to commercial catch data (Punt *et al.*, 2001).

Fecundity

The contribution of the fecundity data from two periods to the negative log-likelihood function assumes that the data are normally distributed about their expected value, and is calculated as follows:

$$-\ln L_{fec} = \tfrac{1}{2} \sum_{y=1960;2005} \sum_{k=1}^{K_y} [\ln(2\pi\sigma_{fec}^2) + \varepsilon_{fec,k,y}^2] \qquad \text{A4.11a}$$

where K_y represents the sample sizes for each of the periods (K_{1960}=783, K_{2005}=179), k the individual samples, and $\varepsilon_{fec,k,y}$ is:

$$\varepsilon_{fec,k,y} = [P'_{k,y} - \hat{P}'_{k,y}] / \sigma_{fec} \qquad \text{A4.11b}$$

where $P'_{k,y}$ represents the data and $\hat{P}'_{k,y}$ the corresponding model estimate calculated by multiplying equation A4.3 with Q_y in equation A4.2b and substituting the length of the sample in equation A4.3 (where the age subscript a is replaced by the sample subscript k). A closed-form solution for σ_{fec} exists as follows:

$$\sigma_{fec} = \sqrt{\frac{\sum_{y=1960;2005} \sum_{k=1}^{K_y} (P'_{k,y} - \hat{P}'_{k,y})^2}{(K_{1960} + K_{2005})}} \qquad \text{A4.11c}$$

Recruitment

Recruitment (pups) is assumed to be lognormally distributed about its expected value, with the following contribution to the negative log-likelihood function:

$$-\ln L_r = \tfrac{1}{2}\sum_y [\ln(2\pi\sigma_r^2) + (\varepsilon_{r,y}/\sigma_r)^2] \qquad \text{A4.12}$$

where $\varepsilon_{r,y}$ are estimable parameters in the model, and σ_r is a fixed input (0.2 for the base case).

Total likelihood

The total negative log-likelihood is the sum of the individual components:

$$-\ln L_{tot} = -\ln L_{sur} - \sum_j \ln L_{pcom,j} - \ln L_{psur} - \ln L_{fec} - \ln L_r \qquad \text{A4.13}$$

Life-history parameters and input data

Calculation of the life-history parameters M_a (instantaneous natural mortality rate), l_a^s (mean length-at-age for animals of sex s), w_a^s (mean weight-at-age for animals of sex s), and P_a'' (proportion females of age a that become pregnant each year) are summarized in Table A4.1.

Table A4.1. Northeast Atlantic spurdog. Description of life-history equations and parameters.

Parameters	Description/values	Sources
M_a	Instantaneous natural mortality-at-age a: $$M_a = \begin{cases} M_{pup} e^{-a \ln(M_{pup}/M_{adult})/a_{M1}} & a < a_{M1} \\ M_{adult} & a_{M1} \le a \le a_{M2} \\ M_{til} / [1 + e^{-M_{gam}(a-(A+a_{M2})/2)}] & a > a_{M2} \end{cases}$$	
a_{M1}, a_{M2}	4, 30	expert opinion
M_{adult}, M_{til}, M_{gam}	0.1, 0.3, 0.04621	expert opinion
M_{pup}	Calculated to satisfy balance equation A4.7	
l_a^s	Mean length-at-age a for animals of sex s $$l_a^s = L_\infty^s (1 - e^{-\kappa^s (a - t_0^s)})$$	
L_∞^f, L_∞^m	110.66, 81.36	average from literature
κ^f, κ^m	0.086, 0.17	average from literature
t_0^f, t_0^m	-3.306, -2.166	average from literature
w_a^s	Mean weight-at-age a for animals of sex s $$w_a^s = a^s (l_a^s)^{b^s}$$	
a^f, b^f	0.00108, 3.301	Coull *et al.*, 1989
a^m, b^m	0.00576, 2.89	
l_{mat00}^f	Female length-at-first maturity 70 cm	average from literature
P_a''	Proportion females of age a that become pregnant each year $$P_a'' = \frac{P_{\max}''}{1 + \exp\left[-\ln(19) \frac{l_a^f - l_{mat50}^f}{l_{mat95}^f - l_{mat50}^f}\right]}$$ where $P_{\max}''$ is the proportion very large females pregnant each year, and l_{matx}^f the length at which x% of the maximum proportion of females are pregnant each year	
$P_{\max}''$	0.5	average from literature
l_{mat50}^f, l_{mat95}^f	80 cm, 87 cm	average from literature

5 BBM (Biscay Anchovy)

Model & Version	BBM: Two-stage biomass-based model
Category	length/stage based
Model Type	Bayesian state-space model with stochastic recruitment process and deterministic population dynamics. Model dynamics described in terms of biomass and separated into two stages (recruits -age 1- and older individuals). Biomass decrease due to growth and natural mortality encapsulated into a unique parameter (g) age and time invariant. Catches are just considered instantaneous removals from the available population. Observation equations consist on total biomass and age 1 biomass proportion from the research surveys. The model was constructed for short-lived species with highly variable recruitment, as an alternative to fully age-structured models. The model is based on the work by Roel and Butterworth (2000). Similar models are those in Collie and Sissenwine (1983), Mesnil (2003) and Trenkel (2008).
Data used	Total biomass and age 1 biomass proportion from the research surveys are included in the observation equations. Total catch and age 1 catch (in mass) before and after the research surveys are accounted for as removals of the population. Intrinsic growth and natural mortality rates are assumed to be known and age and time invariant. Fractions of the years when the surveys and the catches occur are also needed.
Model assumptions	The biomass decrease parameter (intrinsic growth and natural mortality) is age and time invariant. The catchability of total biomass from the research surverys are assumed to be constant in the whole time-series. The age 1 proportion from the research surveys are assumed to be unbiased estimates of the age 1 proportion in the population. This implicitly means that the surveys's catchability is constant across ages. The prior distributions are centred at values that are considered realistic and chosen to have substantial but not unreasonably large dispersion. Sensitivity to the prior distributions of recruitment and initial biomass is tested in Ibaibarriaga *et al.* (2008).
Estimated parameters	Initial biomass, average and precision (inverse of variance) of the normal process error for log-recruitment, survey catchability for total biomass from the research surveys and precisions of the observation equations of total biomass and age 1 biomass proportion from the research surveys. In addition, the biomass decrease rate due to growth and natural mortality can also be estimated.
Objective function	The joint posterior probability density function (pdf) of the unknowns is the product of the pdf's of observations, states and priors. The total biomass from the research surveys is log-normally distributed. The age 1 proportion from the research surveys follows a beta distribution. The stochastic recruitment process is log-normal. The prior distributions for the survey catchabilities, the initial biomass, the mean of the recruitment process, the variance-related parameter of the age 1 proportion observation equations and the biomass decrease parameter are log-normal, whereas the prior distributions of the precisions of the total biomass observation equations and the precision of the recruitment process are gamma distributed. In addition, an indicator function (takes value 1 or 0) that indicates whether the restrictions imposed by the catches (biomass must be larger than the catches) are fulfilled or not is included.
Minimization	Bayesian inference conducted using Markov chain Monte Carlo (MCMC) techniques.
Variance estimates and uncertainty	The joint posterior distribution of the parameters is obtained from the MCMC runs.

Other issues	Currently the model is specifically designed for the Bay of Biscay anchovy, but it could be modified and adopted to different stocks and assumptions. The model is currently being extended. The new model allows separating the natural mortality and growth process and splitting them by age group (recruits and olders) and incorporates total catch and age 1 catch proportion into the observation equations.
Quality control	The model has been tested on simulated data sets that were generated conditioned on the model itself. No robustness test has been performed.
Restrictions	Due to the high correlations between the parameters when all the parameters are estimated the problem is undetermined and the solutions might be affected by the chosen prior distributions. The model does not provide fishing mortality estimates; instead harvest rates (catch/biomass) are used. Also, as the model is biomass-based, recruitment refers to age 1 biomass at the beginning of the year.
Program language	The model is written in WinBUGS and it is run from R using the R2WinBUGS library. Analysis of the results is conducted in R using the coda library.
Availability	The program is available from the authors on request.
References	Ibaibarriaga *et al.* (2008), Anchovy assessment working groups from 2005 onwards (WGMHSA 2005–2007, WGANC 2008, WGANSA 2009–2011, WGHANSA 2012) and benchmark workshop on short-lived species (ICES 2009a [WKSHORT])
Applications	From 2005 onwards it is used to assess the Bay of Biscay anchovy stock (Latest reference: ICES 2012f [WGHANSA]). Within the EU-project SARDONE it has also been applied to the Aegean Sea anchovy.

6 AMISH (Southern Horse Mackerel)

A model similar to the one adopted by the South Pacific Regional Fishery Management Organization (SPRFMO) for the assessment of Chilean jack mackerel (*Trachurus murphyi*) was modified for application to southern horse mackerel. This method (Lowe *et al.*, 2009) models the population numbers-at-age as projections forward based on recruitment estimates leading up to the initial population numbers-at-age (in 1992 for this case) and subsequent annual recruitment and fishing mortalities parameters. These underlying population numbers-at-age are fitted through an observation model for parameter estimation via a penalized likelihood applied to a quasi-Newton minimization routine with partial derivatives calculated by automatic differentiation (Griewank and Corliss, 1991). The automatic differentiation and minimization routines are those from the package AD Model Builder (ADMB). A similar model is currently used in many stock assessments in North American waters (e.g. Atka mackerel, eastern Bering Sea pollock, Pacific Ocean perch). It is a simple, well tested, and widely used methodology. The population equations, model fitting components, and model settings are listed in Tables A6.1–4.

The approach differs from the XSA methods in that:

- calculations proceed from the initial conditions to the present and into the future,
- the catch-at-age is not assumed to be known exactly,
- the inclusion of annual estimates of sampling variability (for both age composition and survey index precision) is allowed,
- fishing mortality is separable but selection-at-age is allowed to change gradually over time,
- separate components of the fishery are treated independently,
- some parameters, which are assumed constant in XSA, such as the catchability coefficients associated with tuning indices, may be allowed to change over time,
- statistical basis allows for careful consideration of data quality and the impact on the uncertainty of estimates.

The model begins in the first year of available data with an estimate of the population abundance-at-age. Recruitments are estimated for each year. In subsequent ages and years the abundance-at-age is reduced by the total mortality rate. This projection continues until the terminal year specified. If data are unavailable to estimate recruitment, the model will use the geometric mean value and hence can be projected to any arbitrary year (assuming specified catches).

The fishing mortality rates for each sector in the fishery are assumed to be separable into an age component (called selectivity) and a year component (called the F multiplier). The selectivity patterns are allowed to change over time. Expected catches are computed according to the usual catch equation using the determined fishing mortality rate, the assumed natural mortality rate, and the estimated population abundance described above. The statistical fitting procedure used with the model will try to match the indices and the catch-at-age. The emphasis of each of these sources of information depends on the values of the relative weights assigned to each component by the user.

The minimization processes proceeds in phases, in which groups of parameters are estimated simultaneously, while the remaining parameters are maintained at their initially assigned values. Once the objective function is minimized for a particular phase, more parameters are treated as unknown and added to those being estimated. This process of estimation in phases continues until all parameters to be estimated contribute to the objective function and the best set of all parameters that minimize the objective function value is determined.

Model Options chosen:

The objective function is the sum of a number of negative log-likelihoods generally following two types of error distributions: the lognormal and multinomial and details are listed in Table A6.3. The specifications of input sampling levels (in terms of sample size or variance term) are prespecified in Table A6.4.

The separability in the fishing mortality was allowed to vary according to a shift in fleet composition. An F multiplier was estimated for the first year, and was allowed to change in time by estimating deviations to this parameter for each year. The fishing mortality at each age, year and fleet resulted from the product of the F multipliers by the selectivity parameter at each age and fleet. Three selectivity vectors were estimated, corresponding to blocks of fleets sharing a similar selectivity-at-age. This is a useful feature of the model that helps to avoid overparameterisation. By looking at the plots of catch-at-age by fleet, it was decided to have a common selectivity for the purse-seine fleets, together with the Portuguese bottom-trawl fleet, another one for the artisanal fleets and a third one just for the Spanish bottom-trawl fleet. One catchability parameter for the abundance index was kept fixed over time.

The model fitting is affected by statistical weights (lambdas or inverse variance functions) as part of the objective function. Specified input variance assumptions can influence the fitting of the model, by attributing a lower or higher importance to different data sources that contribute to the objective function. The variance assumption assumed the highest precision for landings data by year and fleet. The fishery proportions-at-age for the moment were assumed to have an “effective sample size” of 100 compared to the value of 10 specified for the survey estimates of age composition. The survey index data were fitted assuming that the coefficient of variation was 30%. These values are typical for this type of information and diagnostic plots of model fits confirmed that they are reasonable. As more data become available, these assumptions can be modified to more appropriate and potentially time-varying values.

Table 1. Symbols definitions used for model equations.

General Definitions	Symbol/Value	Use in Catch-at-age Model
Year index	i	
Age index	j	
Mean weight in year i and age j	W_{ij}	
Maximum age beyond which selectivity is constant	*Maxage*	Selectivity parameterization
Instantaneous Natural Mortality-at-age	M_j	Fixed in time: M = 0.9, 0.6, 0.4, 0.3, 0.2, 0.15,…, 0.15
Proportion of females mature at age	p_j	Definition of spawning biomass
Sample size for proportion in year i	T_i	Scales multinomial assumption about estimates of proportion at age
Survey catchability coefficient	q^s	Prior distribution: $lognormal(\mu_{q^s},\sigma_{s}^{2})$
Stock–recruitment parameters	R_0,h,σ_R^2	Unfished equilibrium recruitment, steepness, variance
Virginal biomass	φ	Spawning biomass per recruit when there is no fishing

Note that the number of selectivity parameters estimated depends on the model configuration.

Table 2. Variables and equations describing implementation of the horse mackerel assessment model.

Eq. Description	Symbol/Constraints	Key Equation(s)
Survey abundance index by year (δ represents the fraction of the year when the survey occurs)	I_i	$I_i = q \sum_j N_{ij} W_{ij} S_j e^{-\delta Z_{ij}}$
Catch biomass by year	C_i	$\hat{C}_{ij} = \sum_j N_{ij} W_{ij} (1 - e^{-Z_{ij}}) F_{ij} / Z_{ij}$
Proportion at age j in year i	P_{ij}, $\sum_j P_{ij} = 1$	$P_{ij} = C_{ij} / \sum_j C_{ij}$
Numbers at age in first year and age	$j = 0$, i = first year (1992)	$N_{ij} = e^{\mu_R + \epsilon_i}$
Numbers at age in first year	$0 < j < 11$, i = first year (1992)	$N_{ij} = e^{\mu_R + \epsilon_{1993-j}} \prod_j e^{-M_j}$
Numbers at age in first year in age plus-group	$j = 11+$, i = first year (1992)	$N_{ij} = N_{i,j-1} / (1 - e^{-M_{j-1}})$
Numbers at age 0 in remaning years	$j = 0, \sum_i \epsilon_i = 0$	$N_{ij} = e^{\mu_R + \epsilon_i}$
Numbers at age in remaining years	$0 < j < 11$	$N_{ij} = N_{i-1,j-1} e^{-Z_{i-1,j-1}}$
Numbers at age group plus in remaining years	$j = 11+$	$N_{ij} = N_{i-1,j-1} e^{-Z_{i-1,j-1}} + N_{i-1,j} e^{-Z_{i-1,j}}$
Catchability of abundance index	μ^s	$q_i^s = e^{\mu s}$
Instantaneous fishing mortality		$F_{ij} = e^{\mu + \eta_j + \phi_i}$
Mean fishing effect	μ	
Annual effect of fishing mortality in year i	$\phi_i, \sum_i \phi_i = 0$	
Age effect of fishing (regularized) in years with time variation allowed	$\eta_{ij}, \sum_j \eta_{ij} = 0$	$s_{ij} = e^{\eta_j}$
Age effect of fishing (regularized) in years where selectivity is constant over time	$\eta_{ij} = \eta_{i-1,j}$	
Natural mortality vector	M_j	
Total mortality	Z_{ij}	$Z_{ij} = F_{ij} + M_j$
Spawning biomass (spawning takes place at mid January)	B_i	$B_i = \sum_j N_{ij} e^{-(0.5/12) Z_{ij}} W_{ij} p_j$
Recruitment at age 0 (Beverton-Holt function)	$\ddot{R}_i$	$\ddot{R}_i = \alpha B_i / (\beta + B_i)$, $\alpha = 4hR_0/(5h-1)$, $\beta = B_0(1-h)/(5h-1)$, B_0 is virgin biomass, R_0 is recruitment at virgin biomass, and $h = 0.8$

Table 3. Specification of objective function that is minimized (i.e. the penalized negative of the log-likelihood).

Likelihood/penalty component		**Description / notes**
Catch biomass likelihood	$L_1 = \lambda_1 \sum_i ln(C_i/\hat{C}_i)^2$	Fit to catch biomass in each year
Abundance indices	$L_2 = \sum_s \lambda_2^s \sum_i ln(I_i^s/\hat{I}_i^s)^2$	Survey abundances
Proportion at age	$L_k = \sum_{k,i,j} \tau_i^k P_{ij}^k ln(\hat{P}_{ij}^k)$	$k = 3$ for the fishery and $k = 4$ for the survey
Penalty on smoothness for selectivities	$L_k = \sum_k \lambda_k \sum_j (\eta_{j+2}^l + \eta_j^l - 2\eta_{j+1}^l)^2$	$k = 5$ for the fishery and $k = 6$ for the survey
Penalty on recruitment regularity	$L_7 = \lambda_7 \sum_i \epsilon_i^2$	Influences estimates where data are lacking (e.g., if no signal of recruitment strength is available, then the recruitment estimate will converge to median value).
Penalty on recruitment curve	$L_8 = \lambda_8 \sum_i ln(N_{i,0}/\hat{R}_i)^2$	Conditioning on stock-recruitment curve (but reduced to have negligible effect on estimation).
Overall objective function to be minimized	$\dot{L} = \sum_k L_k$	

Table 4. Input variance (σ2) or sample size (τ) assumptions and corresponding penalties (λ) used on log-likelihood functions in the base model.

Likelihood component	σ^2	τ	λ
Landings	0.05	-	200
Combined index	0.3	-	5.556
Fishery age composition	-	100	-
Survey age composition	-	10	-
Time-change in fishery selectivities	0.8	-	0.78
Fishery age-specific penalties	1.0	-	0.5
Fishery descending selectivity-with-age penalty	10	-	0.1
Time-change in survey selectivities	0.8	-	0.78
Survey age-specific penalties	1.0	-	0.5
Survey descending selectivity-with-age penalty	10	-	0.1
Recruitment regularity	10	-	0.1
S-Recruitment curve fit	1.9	-	0.14

7 MULTIFAN-CL (North Atlantic Albacore Tuna)

Model & Version	MULTIFAN-CL, version 1. (But we have not yet implemented a structured versioning system – this is currently being done)
Category	Age structured (i.e. population at age is modelled), but length-based (uses length and weight data to inform age and some processed (selectivity) have a length-based option.
Model Type	MULTIFAN-CL is a computer program that implements a statistical, length-based, age-structured model for use in fisheries stock assessment. The model is a convergence of two previous approaches. The original MULTIFAN model (Fournier *et al.*, 1990) provided a method of analysing time-series of length–frequency data using statistical theory to provide estimates of von Bertalanffy growth parameters and the proportions-at-age in the length–frequency data. The model and associated software were developed as an analytical tool for fisheries in which large-scale age sampling of catches was infeasible or not cost-effective, but where length–frequency sampling data were available. MULTIFAN provided a statistically based, robust method of length–frequency analysis that was an alternative to several ad hoc methods being promoted in the 1980s. However, MULTIFAN fell short of being a stock assessment method as the endpoint of the analysis was usually estimates of catch-at-age (although later versions included the estimation of total mortality and yield-per-recruit). The second model (actually the first, in terms of chronology) was that introduced by Fournier and Archibald (1982). The FA model was a statistical, age-structured model in which estimates of recruitment, population-at-age, fishing mortality, natural mortality and other estimates useful for stock assessment could be obtained from total catch and effort data and catch-at-age samples. In principle, the estimates of catch-at-age obtained from the MULTIFAN model could be used as input data to the FA model and a complete stock assessment analysis conducted. Such a sequential approach to length-based stock assessment modelling had several serious limitations. First, it was extremely unweildy. Second, it was difficult to represent and preserve the error structure of the actual observed data in such a sequential analysis. This made estimation of confidence intervals for the parameters of interest and choice of an appropriate model structure for the analysis problematic. It was clear that an integrated approach was required, one that modelled the age-structured dynamics of the stock, but which recognized explicitly that the information on catch-at-age originated with length–frequency samples. The early versions of MULTIFAN-CL, which were developed for an analysis of South Pacific albacore (Fournier *et al.*, 1998), provided the first attempt at developing a statistical, length-based, age-structured model for use in stock assessment. Subsequent versions of the software have added new features, the most important of which have been the inclusion of spatial structure, fish movement and tagging data in the model (Hampton and Fournier 2001). MULTIFAN-CL is now used routinely for tuna stock assessments by the Oceanic Fisheries Programme (OFP) of the Secretariat of the Pacific Community (SPC) in the western and central Pacific Ocean (WCPO). Beginning in 2001, the software gained additional users, with stock assessment applications to North Pacific blue shark, Pacific blue marlin, Pacific bluefin tuna, North Pacific swordfish and Northwest Hawaiian lobster underway or planned.

Data used	Catch in number or in weight (but must be consistent within fishery). Missing data allowed if effort is available. Effort in consistent units within fishery. Missing data allowed if catch is available. Length frequency. Missing data allowed. Weight frequency. Missing data allowed. Tagging data, for whatever period may be covered by the programme. Minimum data requirements would be catch, either length or weight frequency data for each defined fishery, maybe possible to configure the model without effort data but not ideal.
Model assumptions	Selectivity may be estimated as a length or age based process. A number of methods used to contrain parameterization, including functional forms and cubic splines. Catchability may be specified as constant over time, or varying via a random walk process. Deviations in the latter constrained by prior of mean zero and specified variance. Flexible time-stepping for random walk. If assumed constant over time, catchability by be linked across fisheries of the same gear in different model regions to allow cpue to indicate relative abundance spatially. Seasonality may be estimated as a separate process. A separate random effect called effort deviations is also modelled and constrained by priors of mean zero and specified variance. Fishing mortality is the product of selectivity, catchability and effort. Growth may be estimated in VB or Richards formulations. Also allow deviations from the growth curve for a specified number of age classes. Natural mortality may be estimated as an age invariant or age-specifc parameter set. Smoothing penalties used to constrain variability. Recruitment may be specified as occurring with monthly to annual periodicity. This specification defines an 'age class' and the time-stepping in the model. Estimate an overall recruitment scaling factor, with temporal and regional deviates, all of which may be constrained by priors. Movement among defined model regions occurs and parameters may be related to age in a simple functional form. Maturity-at-age is specified and used to define spawning biomass. There are currently no sex-specific aspects to the model.
Estimated parameters	The following parameters may be estimated: Growth Natural mortality Mean recruitment, spatial and temporal deviates. Mean recruitment may be integrated into a Beverton–Holt SRR and steepness may be estimated or specified. Selectivity Catchability mean, seasonality, temporal deviates, effort deviates. Movement Reporting rates if tagging data are used
Objective function	Components for catch (lognormal), length frequency (robust lognormal), weight frequency (robust lognormal), tagging (negative binomial with option for zero inflation). Priors for all estimated parameters, additional smoothing penalties to constrain variability and avoid overfitting. Option for exact catch, in which case there is no catch likelihood. Weighting for length and weight frequency specified as 'effective sample size' and may be fishery specific. Weighting for tag data controlled by specified or estimated over-dispersion parameters for the negative binomial.
Minimization	Minimization technique used to fit the model to data. Automatic differentiation – same source code as ADMB.

Variance estimates and uncertainty	Variance-covariance matrix for model parameters derived from Hessian. Variance and confidence intervals for dependent quantities may be derived using the Delta method. Probability distributions for certain management quantities, e.g. F/FMSY and B/BMSY are obtained by likelihood profiling. Structural and data uncertainty handled in grid-wise structural sensitivity analyses.
Other issues	Model is continually being extended. There is also a java based utility for examining results and an R library for generating various diagnostics and results summaries. A stock projection capability is incorporated, with option for stochastic projections incorporating variability in recruitment, estimated terminal population and projected effort deviations. Either catch or effort can be used to drive the projections. Software to facilitate set up of projections is currently under development.
Quality control	Ad hoc testing regime for checking new code. Several structured simulation testing studies, e.g. Labelle (2005).
Restrictions	Of course there are many! Cannot currently handle sex-specific data or model multiple stocks.
Program language	C++
Availability	Executables may be downloaded from www.multifan-cl.org. Source code may be provided under certain circumstances.
References	Fournier and Archibald (1982), Fournier *et al.* (1990), Fournier *et al.* (1998), Hampton and Fournier (2001). Published references, grey literature, manuals. See www.multifan-cl.org.
Applications	Too numerous to note here. Routinely used for annual assessments of skipjack, yellowfin and bigeye tuna in the western and central Pacific, and albacore in the South Pacific. Has also been used from time to time for North Pacific albacore, North Pacific bluefin, swordfish (North and Southwestern Pacific), blue marlin, striped marlin, blue shark (North Pacific), Hawaiian rock lobster, Indian Ocean yellowfin, Atlantic Ocean bigeye and Atlantic Ocean albacore.

8 ADAPT-VPA (Georges Bank yellowtail flounder)

[Note that this was taken from ICES (2010a) {WKADSAM}, and although the version number differs from that used as the baseline model for this stock, differences between the versions are minor]

Model & Version	Adapt VPA 3.0.3
Category	Age-based
Model Type	This version of virtual population analysis is part of the NOAA Fisheries Toolbox (NFT), but traces its lineage from Gavaris and Conser, and incorporates features introduced by Mohn, Powers, Restrepo, and Darby. As with all VPA models, it performs best in situations of high fishing mortality rates and strong production ageing programs that minimize uncertainty in the catch-at-age data. This model has been programmed to work with the NOAA Fisheries Toolbox (NFT) population simulator (PopSim) and has outputs that can be used in the NFT age structured projection program (AgePro).
Data used	Catch-at-age is required for all years and is entered as a single year by age matrix. Tuning indices (either from surveys or catch per unit of effort) are typically entered as age-specific time-series, but grouped ages can also be used. Weight at age is entered as three separate year by age matrices for catch, Jan-1 population biomass, and spawning-stock biomass. Biological parameters are entered as year by age matrices for natural mortality and maturity. Gaps are allowed in the tuning indices.
Model assumptions	Catch-at-age is assumed to have negligible error relative to the error in the tuning indices. Selectivity is derived from the fishing mortality values calculated back through each cohort. The model can be run with or without a plus group. The model assumes only a single area and one sex, so migration and sexual dimorphism are not explicitly modelled. There are no priors used in the model.
Estimated parameters	The parameters of the model are a set of population abundances at age in the year following the last year of catch data. The index catchability coefficients are nuisance parameters calculated internally from the observed and predicted values during each iteration. Optionally catch multipliers can be estimated, similar to North Sea cod.
Objective function	The objective function is simply the sum of squared residuals (optionally weighted) between the logarithms of the observed and predicted indices. Each index observation can be weighted independently. There are no priors.
Minimization	The IMSL implementation of the Levenburg-Marquardt algorithm is used for minimization.
Variance estimates and uncertainty	Variances are available directly as a result of the Levenburg-Marquardt minimization as well as through optional bootstrapping of index residuals.
Other issues	The model has a built in retrospective analysis which successively removes years of data from the most recent year backwards, re-runs the model, collects the results, and provides graphical displays. Each retrospective "peel" can be opened independently in the GUI for full analysis if desired.
Quality control	Quite a bit of testing has been conducted; however, results are not easily accessible. Through use as the main age-based stock assessment model in the Northeast Fisheries Science Center for many years, it has been compared to many other models and always produced similar results when formulated similarly.
Restrictions	Single area model. No length information can be included directly (must be converted to age first).

Program language	The executable is written in Fortran with a GUI available for Windows machines.
Availability	The program is available as an executable only. It is available with a GUI from the NOAA Fisheries Toolbox (NFT) website http://nft.nefsc.noaa.gov.
References	A reference manual is distributed with the GUI. Collie (1988), Conser and Powers (1990), Gavaris (1988, 1993), Gulland (1965), Mohn and Cook (1993), Patterson and Kirkwood (1995), Pope (1972).
Applications	This model was been the workhorse of the Northeast Fisheries Science Center in the US. It has been used for most of the groundfish species in the region for the past two decades.

9 Age-structured production model (South African anchovy)

Model & Version	Age-Structured Production Model
Model Type	ASPM is a generalized age-structured model that is very flexible with regard to the types of data that may be included, the functional forms that are used for various biological processes, the level of complexity and number of parameters that may be estimated. For South African anchovy the ASPM model uses annual time-steps for a single stock and is not sex-structured. Recruitment is governed by an estimated stock–recruitment relationship.
Data used	Annual catch-at-age (assumed known without error) Annual hydroacoustic survey estimates of May recruit numbers and November 1+ biomass, with CVs Annual (1984-1993 only) estimates of November spawning biomass, with CVs from DEPM (Daily Egg Production Method) surveys Annual proportion-at-age 1 in November, with SEs Annual catch and population weights-at-age Gaps can occur in all data time-series, although catch is normally modelled as known for each time-step.
Model assumptions	Log survey indices are assumed to follow normal distributions Proportions-at-age 1 are assumed to follow multinomial distributions (the SEs quoted correspond to an effective sample size) Hydroacoustic survey indices of abundance are assumed to provide a relative index of unknown (time-invariant) bias DEPM indices of abundance are assumed to provide measures of absolute biomass Time-invariant natural mortality and age at maturity, and annual weights-at-age are assumed known Maturity and recruitment are both assumed to occur in a single pulse at 1 November each year Catch is assumed to occur in a single pulse during the year (the date of which differs between ages and over time) Prior distributions were chosen to be relatively uninformative Assumptions can easily be modified for robustness testing
Estimated parameters	Initial numbers-at-age Residuals about the stock–recruitment curve and the standard deviation in these residuals Multiplicative bias on the hydroacoustic estimates of 1+ biomass and recruitment and on the proportions-at-age 1 Additional variance in the hydroacoustic estimates of recruitment
Objective function	Objective function is the negative log joint posterior distribution, with contributions consisting of Log hydroacoustic 1+ biomass (normal) Log hydroacoustic recruitment (normal) Log DEPM SSB (normal) Proportion-at-age 1 (multinomial) Parameter priors (mostly uniform on the parameter or on the log of the parameter; normal priors on residuals about the stock recruitment curve) Penalty on negative numbers-at-age (must be zero for acceptable result)
Minimization	Minimization is implemented using standard ADMB process.
Variance estimates and uncertainty	Variance estimates for all estimated parameters and some derived quantities are calculated from posterior distributions MCMC is run using ADMB.

Quality control	Robustness tests to key model assumptions have been performed
Restrictions	Currently set up for a single stock/species of anchovy. (Other ASPM models have been applied to multistocks/species.) The model does not provide fishing mortality estimates; instead harvest proportions (catch/biomass) are used.
Program language	ADMB
Availability	The executable program is available from the lead author on request
References	de Moor and Butterworth (2009, 2012), de Moor *et al.* (2012)
Applications	ASPMs have been applied to, among others, hake, rock lobster, abalone, toothfish, sardine, anchovy, round herring and horse mackerel resources in South Africa.