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Report of the Benchmark Workshop on Pelagic Stocks (WKPELA)

17–21 February 2014

Copenhagen, Denmark

ICES
International Council for the Exploration of the Sea
CIEM
Conseil International pour l'Exploration de la Mer

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H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

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Executive Summary

WKPELA meeting was held in ICES HQ in Copenhagen from the 21–27 February 2014, to benchmark the assessments of herring in the Celtic Sea and mackerel in the Northeast Atlantic. The data compilation process and intercessional work began in October 2013. The assessment of both of these stocks was previously done using a statistical catch-at-age model ICA, which imposed structural assumptions on the data; the validity of some of these assumptions had been questioned in recent years.

In the case of NEA mackerel the previous assessment was not considered to give a reliable estimate of the development of the stock, and this assessment was limited by the lack of independent age-structured indices. New data which was examined for mackerel included fishery-independent data (acoustic surveys, bottom-trawl surveys, and a swept-area trawl survey), as well as a re-examination of the tagging data, landings and discard and biological data.

For NEA mackerel the benchmark workshop agreed updates to the input data on catch, weight-at-age, maturity ogive, and changes to the estimation methods for other assessment parameters such as proportion of F and M before spawning. There was also an agreement to include age-structured indices on adults (from the IESSNS swept-area trawl survey) and recruits (IBTS Q4 trawl survey), and to use the tagging data as an index of population abundance-at-age using a Petersen estimator. The IESSNS survey was proposed to be included in the assessment as an abundance index at age, although it was also suggested as a research need, to investigate its use as an index of relative proportions at age only (i.e. without the trend in abundance). The tagging index was considered to give useful information on population abundance at up to 2007, around which time the methodologies changed and the recapture rates dropped inexplicably. There is a research recommendation to investigate the changes in the tagging methodologies (both release and recapture), with a view to updating the tagging dataseries when the changes in observed recaptures has been resolved.

Two assessment models were explored, and one (SAM) was put forward as the method to be applied in the stock annex. The SAM model differs from the previous NEA mackerel assessment model in that it is a random effects model. This means that parameters such as for e.g. fishing mortality and initial population numbers are assumed to be correlated over time and are estimated using a random walk function, rather than by fitting to a fixed effect. The model is flexible and can cope with high levels of variance in the observation data, giving it an appropriate application in fisheries stock assessment.

The benchmarked assessment for NEA mackerel changes the perception of the development of the stock over time, whereby the biomass both in the early period (1980s) and more recently is higher than previously estimated, and F lower. Reference points were re-examined and the new perception of the stock resulted in a slight revision of these to a slightly higher B_{lim} (and thus B_{PA}), and commensurately F_{lim} and F_{PA}. F_{MSY} is now estimated to be slightly higher also and this is expected to lead to a revision of the management plan, notwithstanding the fact that the existing exploitation range in the management plan could be considered consistent with the PA.

In the case of Herring in the Celtic Sea, the input data remains the catch and biological data and the HERAS survey. There was a change to the natural mortality rate assumed, which brings this stock more in line with others in the European shelf area. The age range used from the survey and in the assessment was also revised as an

examination of the interpretation of the data by the assessment model showed that there was valuable signal in the youngest ages on the survey (1 ringer) and in the older ages in the catch (extension of the plus group from 6+ to 9+). Large changes in mean weights were observed for this stock and are expected to have an effect on reference points, however due to time constraints reference points for herring were not proposed by WKPELA, and it this work was to be undertaken in March 2014 by the HAWG (herring assessment working group).

Stock annexes for mackerel in the NEA Atlantic and herring in the Celtic sea were completed according to the work done.

1 Introduction

ACOM, under the advice of the assessment expert groups recommended that two pelagic stocks undergo a benchmark assessment in 2014. Each expert group compiled a provisional "issue list" of current assessment/data problems for each stock which was proposed to be benchmarked. These issue lists formed the basis of the benchmark process.

An individual scientist was asked to lead for each stock. These stock leaders were responsible for their team, the investigations and were asked to lead discussions during the plenaries. They were also responsible for the completion of the report sections and the stock annex.

The stock leaders were:

Herring in Division VIIaS VIIg VIIj (Celtic Sea)	Afra Egan, Ireland;
Mackerel in the Northeast Atlantic	Emma Hatfield, UK (Scot land)

The initial meeting in October 2013 used the issue list as a basis to open discussion about the approach and to encourage sharing of ideas across the stock teams. The product of the pre-meeting was a workplan and a prioritization of the issue list. The group emphasized that the data availability, quality and properties would play a dominant role in determining the appropriate assessment models. The operational practicalities of the assessment models would also be taken into account.

The stock teams worked by correspondence between the two meetings (via e-mail, and WebEx). Two plenary WebEx were held to identify progress and address problems. The stock teams were encouraged to submit their work in working documents at least a week prior to the final workshop in February 2014. The external experts then reviewed the submitted documents. The teams were encouraged to define criteria based on model diagnostics, rather than the final population dynamics, as the most appropriate way to judge the assessments.

The final meeting used the priorities issue list, the working documents and input from the reviewers to justify the approach for each stock. The first few days of the meeting were used agree the input dataseries in plenary. Then the stock teams examined and tested the appropriate stock assessments. The workshop also looked at reference points, especially when the perceived dynamics of a stock had changed as a result adjustments to the methodology. This was done for mackerel but not in detail for Celtic sea herring. In this case the reference points were looked at again by the HAWG which began before this report was completed.

2 Methods and overview

2.1 The SAM framework

The state–space model (SAM) was predominantly used by WKPELA. SAM is based on the TSA approach and is a random effects model. Experience with herring stocks from the WKPELA 2012 showed that a close analysis and strong understanding of the behaviour of the SAM models is required before it can be used for an assessment.

Although widely used during WKPELA, the SAM framework is still under development as a generic toolbox assessment approach. Its utility at the workshop thus still required the presence of the developer and some modifications to code had to be made during the meeting in order to facilitate the full analyses. Members of the workshop encountered minor differences in outputs between the R and linux (stockassessment.org) implementations. Despite the highlighting of several of these aspects back in 2012, WKPELA noted the following challenges are still outstanding: Although the model has just been published in a peer reviewed paper, and a course on its use has been given in ICES, there is no manual, where you would expect to find reference documentation on the meaning (labelling) of parameters and their recommended usage. Although further developed since 2012 the source code is not completely commented. Thus there is a high degree of knowledge required of both statistics and programming to run the model in an explorative way. All these issues make SAM difficult to implement appropriately for non-experts, and there is still a limited pool of SAM experts that can be used as a knowledge resource.

2.2 Issues to be considered for future benchmarking

There was a large disparity in both the scale of the issues and the scale of the scientific resources applied to the two benchmarked stocks. This difference led to the benchmarking of Celtic Sea herring being overshadowed by the volume of inputs and issues being dealt with for NEA mackerel. In hindsight these stocks were not well matched to be benchmarked together. Future benchmarks should be cognisant of the effects of such a mismatch when organising stocks to be dealt with at the same workshop.

The unique circumstances of the background to the previous attempted assessment on NEA mackerel in August 2013, created a very large workload on preparing new dataseries for the benchmark. The effect of this was to escalate the priority of resolving input data issues, at the cost of other issues. In hindsight, in addition to the data compilation workshop, the benchmarking process would have benefited from an assessment model workshop. At such a meeting there should have been several model interpretations of the data put forward, such that the final assessment would represent the most appropriate interpretation of the data given the assumptions, rather than what has been put forward by WKPELA 2014, which is an alternative assessment which does not have the specific problems highlighted for the previous approach.

2.3 External reviewers' comments

2.3.1 General observations of the benchmark process

The dedication and hard work of all participants was impressive. Everyone deserves commendation. The dedication to the work also led to a fair, iterative process that ultimately improved the stock assessment.

The reviewers all felt that they were allowed ample opportunity and were encouraged to give their own points of view. Thank you for the opportunity.

We recommend developing analyses to better understand the potential for bias in cpue estimates resulting from differences in day–night catch rates, spatial variation in survey coverage, and/or species distribution. This work should include development of predictive models (i.e. gams or similar) to understand variations in stock movement patterns and temporal and spatial migrations and resulting impacts on cpue estimates. This comment is relevant to nearly all survey data and indices of abundance for both herring and mackerel.

Presentations at future meetings would benefit from a clear proposal from the presenter on how to move forward. For example, "we propose to use these data in this way". Often, it was not clear whether certain data streams were being proposed for use in assessment or just being considered as auxiliary. Without a clear proposal, the reviewers (and likely participants) were often confused and this left Benchmark Chairs in the awkward position of often inferring a proposal without the same level of knowledge as the experts deriving the data streams. One way of achieving this would be to clearly identify the mandates for each stock and a group of people that prepare decisions for general approval. Otherwise there is nothing for reviewers to comment on and they find themselves making suggestions, which is inappropriate.

Details of input data were inconsistently presented between the stocks. In herring, the details of HERAS were an afterthought and we were largely presented with assessment modelling decisions and results. For mackerel, however, we painstakingly reviewed details of every possible input data stream. This was likely driven by the relative importance of herring to mackerel in the region and the relatively "good" behaviour of the herring assessment. We suggest greater standardization of how data are presented or an explicit acknowledgement that one assessment has generally well established inputs that may not need such extensive review. Perhaps ICES could develop best practice guidelines for how to present survey design and survey index calculations, i.e. what to present and how.

Reference points were often estimated using stock–recruit models fit external to the assessment model, which treats model output as data and the uncertainty related to using model output as data were often ignored. Furthermore, the stock–recruit models often made assumptions that were inconsistent with assumptions related to recruitment estimates in the assessment model. For example, SAM may assume a random walk in recruitment, but this temporal correlation was later ignored in fitting stock–recruit curves. The consequence is likely biased parameter estimates and biased reference points. Attempts should be made in future to estimate stock–recruit parameters internal to the assessment model or properly account for the uncertainty and autocorrelated nature of stock and recruitment estimates.

2.3.2 Specific observations on the assessments

SAM is being increasingly used as the preferred assessment modelling framework, and was ultimately the preferred model for herring and mackerel during this benchmark. Therefore, ICES should convene a group that prepares guidelines for the use of SAM: default options for species of different biology (short-lived, long-lived, widespread, etc.), guidelines for making various model choices (e.g. parameter coupling, variance parameter estimation or options for fixing such parameters, correlations among random walks, considering pros and cons of recruitment options, etc.), and model diagnostics and validation. Similarly, the choice of assessment model and settings should focus not only on model fit, but should also consider the consistency of model assumptions with regard to a stock's biology and data quality. For example, Dickey-Collas *et al*. (in press ICES JofMS) reviewed three different recruitment parameterizations (BH, random-walk, no recruitment model or "free estimation model") using the SAM assessment model fitted to three stocks of European herring. The case studies indicated that estimated time-series of recruitment were smoother when parameterized with the random walk, followed by the BH and free estimation models. Similarly, autocorrelation was highest for the random walk recruitment estimation. Dickey-Collas *et al*. point out that the impact of model choice used for recruitment parameterization will be greatest for data-limited stocks and will impact estimated management reference points. In the case of the mackerel and herring benchmarks, a random walk was used in the estimation of fishing mortality and recruitment, but it was not evaluated or made clear that a random walk is the best representation of pelagic life history. Future benchmarks should consider whether the assumptions of competing assessment models are appropriate matches for a stock's biology and quality of input data.

The expertise and education on the use of SAM should be expanded. Progress on assessments was far too reliant on individuals.

With respect to the SAM program itself, more work needs to be done to make diagnostics and model comparison statistics easily available. For example, likelihood profiles, residuals plotted against observations and evaluations of the validity of distributional assumptions for the random effect predictions. A likelihood function able to handle proportions-at-age data might also be added (i.e. multinomial with effective sample size being fixed or estimated).

3 NEA mackerel

3.1 Stock ID and substock structure

Atlantic mackerel (*Scomber scombrus*) occurs on both sides of the North Atlantic and has traditionally been grouped into five spawning components, some of which have been thought to be isolated natal homing stocks. Previous studies have provided no evidence of cross Atlantic migration and no, or weak, support for isolated spawning components within either side of the North Atlantic (Jansen and Gislason, 2013).

ICES currently uses the term "Northeast Atlantic (NEA) mackerel" to define the mackerel present in the area extending from the Iberian peninsula in the south to the northern Norwegian Sea in the north, and Iceland in the west to the western Baltic Sea in east.

In the Northeast Atlantic, mackerel spawn from the Mediterranean Sea in the south to Iceland in the north and from Hatton Bank in the west to Kattegat in the east. Spawning starts in January/February in the Mediterranean Sea and southern Spain and ends in July to the northwest of Scotland and in the North Sea (ICES, 2013). While spawning varies locally from day to day (Bakken, 1977; Iversen, 1981), it seems to form one large spatio-temporal continuum on the larger scale. However, relatively low levels of spawning in the English and Fair Isle channels separate the main spawning areas in the North Sea from the western areas along the continental shelf edge (Johnston 1977). Despite the lack of complete spatial or temporal separation, NEA mackerel have traditionally been divided into three distinct entities, namely the Southern, Western and North Sea spawning components (ICES, 1977; 2013). This excludes the less well known Mediterranean spawners.

Mackerel in the Northeast Atlantic			
Mainly distributed and fished in ICES Subareas and Divisions IIa, IIIa, IV, V, VI, VII, VIII, and IXa			
Spawning component	Western	Southern	North Sea
Main spawning areas	VI, VII, VIIIa,b,d,e	VIIIc, IXa	IV, IIIa

The Western component is defined as mackerel spawning in the western area (ICES Divisions and Subareas VI, VII, and VIII a,b,d,e). This component currently accounts for ~75% of the entire Northeast Atlantic stock. Similarly, the Southern component (~22%) is defined as mackerel spawning in the southern area (ICES Divisions VIIIc and IXa). Although the North Sea component has been at an extremely low level since the early 1970s, ICES considers that the North Sea component still exists as a discrete unit (~3%). This component spawns in the North Sea and Skagerrak (ICES Subarea IV and Division IIIaN).

Catches cannot be allocated specifically to spawning area components on biological grounds, but by convention; catches from the southern and western components are separated according to the areas in which these are taken.

Jansen and Gislason (2013) have recently proposed a new model where the population structure of mackerel is described as a dynamic cline, rather than as connected contingents. Temporal changes in hydrography and mackerel behaviour may affect the steepness of the cline at various locations (Jansen and Gislason, 2013; Jansen *et al.*, 2013).

3.2 Issue list

An issue list defining the issues the group felt should be taken up by WKPELA 2014was discussed during WGWIDE 2013 and further refined during the data collection workshop in October 2013. The finalized issue list is below.

Stock	**NEA mackerel**	
Stock coordinator	Name: Emma Hatfield	E-mail: e.hatfield@marlab.ac.uk
Stock assessor	Name: T. Brunel / T. Jansen / M. Payne / E. Hatfield	E-mail: thomas.brunel@wur.nl / tej@aqua.dtu.dk / mpa@aqua.dtu.dk / e.hatfield@marlab.ac.uk
Data contact	Name: Andy Campbell	E-mail: andrew.campbell@marine.ie

Issue	Problem/Aim	Work needed/ possible direction of solution	Data needed to be able to do this: are these available / where should these come from?
Tuning series	1. Egg survey 1.a. full time-series not used 1.b. use total combined NEA estimate? 1.c. Stage 1 egg mortality 1.d. issues with increase in interpolation and increasingly widespread low numbers 1.e. spatial coverage	1. Egg survey 1.a. extend time-series in history? 1.b. produce total NEA estimate? NS+W+S (see recent Jansen papers on NS mackerel component) 1.c. include egg mortality in the egg production estimate 1.d. alternative modelling approaches for SSB estimates (incorporating robust statistical treatment of estimates (e.g. replace nterpolation) and account for wide spread of very low values) - to be solved as part of statistical modelling 1.e. spatial coverage – spp distribution modelling & line up with survey coverage	1. Egg survey M. Payne 1.a. WGMEGS advise *F. Burns / C. van Damme / J. Ulleweit / A. Thorsen* 1.b. WGMEGS advise *F. Burns / C. van Damme / J. Ulleweit / A. Thorsen* 1.c. *C. van Damme / M. Payne* 1.d. *T. Brunel / C. van Damme / M. Payne* 1.e. *T. Brunel / M. Payne*
	2. No recruitment indices	2. Derive recruitment index – 2.a. IBTS Qs1 + 4? 2.b. IESSNS? 2.c. mackerel box / nursery areas.	2. Derive recruitment index – 2.a. data available *T. Jansen / T. Brunel / B. Roel / D. Reid* 2.b. data available *L. Nottestad / J-A. Jacobsen / G. Oskarsson / S. Jónsson / K. Utne* 2.c data available (short time-series) *B. Roel / J. van der Kooij / D. Reid*
Tuning series continued	3. Complete lack of age structured adult indices	3. Derive age structured indices 3.a. . Age structured adult index IBTS Q1? – not well supported 3.b. Age structured adult index IESSNS?	3. Derive age structured indices 3.a. data available? *T. Jansen/ T. Brunel* 3.b. data available? *L. Nottestad / J-A. Jacobsen / G. Oskarsson / S. Jónsson / K. Utne*
	4. Use of IESSNS	4. IESSNS issues: how to account for: 4.a. Finalize development of the "R" script for rectangles size, extend 2011 area and do re-estimates 4.b Decide on framework for uncertainty	4. IESSNS issues: - what is “standardized”? – needs group agreement *4.a L. Nottestad / J-A. Jacobsen / G. Oskarsson / S. Jónsson / K. Utne*

Issue	Problem/Aim	Work needed/ possible direction of solution	Data needed to be able to do this: are these available / where should these come from?
		estimates for the biomass estimates and do the estimates 4.c Address: issues regarding IESSNS made at WGISDAA 2013; different area surveyed each year; different gears used 4.d Documentation of the work, incorporate relevant information from other working documents, etc.	*4.b L. Nottestad / J-A. Jacobsen / G. Oskarsson / S. Jónsson / K. Utne* *4.c L. Nottestad / J-A. Jacobsen / G. Oskarsson / S. Jónsson / K. Utne* *4.d L. Nottestad / J-A. Jacobsen / G. Oskarsson / S. Jónsson / K. Utne*
Tuning series continued	5. Other surveys possibilities? (see below) 9.3.3.5 Special request, Advice October 2013 ICES advises that there is a need for a reliable age-structured fisheries-independent index for NEA mackerel stock assessment. Such an index should facilitate tracking of the relative abundance of year classes over time with acceptable accuracy and precision. ICES notes that a time-series of at least five years would be required for this index to contribute meaningfully to an age-based assessment 5.a. CPR data for mackerel larvae? 5.b. acoustic surveys	5.a. explore derivation of larvae index 5.b.1. IBTS Q3 / IESSNS overlap 2013 5.b.2. HERAS (NO) / IESSNS overlap 2013 5.b.3. HERAS (UKS / IRE) / IESSNS overlap 2013 5.b.4. IRE boarfish survey 2013	5. Are data easily available? Are either of these options feasible? 5.a. S. Pitois/ M. Payne / / J. van der Kooij 5.b. S. Fassler 5.b.1 J. van der Kooij / K. Utne 5.b.2 K. Utne / A. Slotte / L. Nottestad 5.b.3. S. Fassler / K. Utne / J. van der Kooij / C. O'Donnell 5.b.4. C. O'Donnell / K. Utne
Input Data (not including catch data)	1. Weight-at-age in the stock – modellingvs.lack of data for calculation. Only use survey data? Combine survey and fishery data 2. Maturity ogive 3. Variation due to errors in age determination 4. Fprop constant. Still appropriate given changes in spawning time? 5. Inclusion of tagging data 6. Natural mortality	1.a. Investigate for the core spawning area and period if there are catch data available. 1.b. Use data from Norwegian tagging program? Appropriate time of year but jigging so fish feeding and not spawning? 1.c. Computing new stock weights and comparing with previous time-series based on all available data 1.d. Investigate growth variability of the three spawning components (look for density-dependence effects, cohort effects, environmental effects 2. Revisit maturity ogive per spawning component 3. Model and incorporate errors in age determination – T. Brunel to make WKARMAC	1. *T. Brunel* 1.a. *T. Brunel / IMR / IEO* 1.b. *T. Brunel / IMR / IEO* 1.c. *T. Brunel / IMR / IEO* 1.d. A. Slotte / A. Olafsdottir 2. *T. Brunel + A. Slotte* Is current ogive still appropriate? Which appropriate surveys would collect these data – for discussion 3. *T. Brunel* For model developers Sensitivity analysis? 4. Need time disaggregated data to examine changes in mackerel fished prior to spawning.

Issue	Problem/Aim	Work needed/ possible direction of solution	Data needed to be able to do this: are these available / where should these come from?
		2010 data available to model developers 4. Replace / remove Fprop 5. Update time-series – to incorporate into new assessment 6. Investigate tagging data – to produce estimates of M	*A. Campbell / T. Brunel to do analysis* 5. *A. Slotte / IMR* and model developers 6. *A. Slotte / IMR* and model developers
Catch data	1. Unaccounted mortality 2. Discard / slippage estimation 3. Derive more "certain" time-series 4. Produce "gold standard" catch data THE ASSESSMENT MODELS USED HAVE TO BE ROBUST TO UNACCOUNTED MORTALITY IF BETTER CATCH DATA ARE NOT MADE AVAILABLE *SAM* WILL STILL BE BIASED TOWARDS THE CATCH DATA IF CATCH DATA ISSUES ARE NOT TAKEN INTO CONSIDERATION REALLY STRONG COLLABORATION BETWEEN MODEL DEVELOPERS WILL BE REQUIRED	1.a. Derive estimates – "quality flags" 1.b. Perform sensitivity analyses 2. Explore each institute's historical data to add more data from more fleets – to derive better discard estimates – or produce "quality flags" 3. Drop less "certain" years of catch data – get quality stamp 4. Industry need to provide more than quality indicators to produce an accurate reflection of catch removals over time.	D. Miller 1.a. *C. Sparrevohn* conversations with industry 1.b. WGWIDE 2013 & WKPELA –. for model developers New model needs development in close collaboration. Test highgrading etc assumptions. Do 1a (quality flags). Then 1b test model against those assumptions - for model developers 2. A. Campbell to contact relevant people - for model developers Test in conjunction with 1b. sensitivity analysis of catch data with simulated underreporting for a variety of reasons - for model developers 3. exploratory / sensitivity analysis work with new model – *C. Sparrevohn* and for model developers 4. *C. Sparrevohn* conversations with industry
Assessment method	1. Current assessment model is not and cannot be maintained 2. Evaluate other models 3. Incorporate tagging data 4. Investigate / explore more than one model 5. Include uncertainty on all inputs	1. RIP ICA. Evaluate other models 2. Evaluate other models 3. Adapt SAM – industry/science workshop autumn 2013 – including M N.B. all models tested need to incorporate other updated inputs too in a coherent and coordinated	Emma Hatfield Data from several sources. Models from DTU-AQUA, IMR. Others? IMARES,Cefas, MRI, MSS, MI, FAMRI, TI 1. *A. Nielsen et al. / T. Brunel / D. Miller /*

ISSUE	PROBLEM/AIM	WORK NEEDED/ POSSIBLE DIRECTION OF SOLUTION	DATA NEEDED TO BE ABLE TO DO THIS: ARE THESE AVAILABLE / WHERE SHOULD THESE COME FROM?
	Wish List *Incorporating the ecosystem*?	fashion. i.e. whoever is involved in this process has to participate in the benchmark process 4. Which models? If only FL SAM need to have justification for single approach. Reduce complexity given uncertainties? isVPA? D. Vasilyev A4A – JRC - C.Millar? Delayed difference models - Cefas? Other possibilities – simple and easy to implement – e.g. that used for boarfish – A. Campbell to develop 5. Use appropriate model	*A. Campbell* / *B. Roel* 2. *A. Nielsen et al.* / *T. Brunel* / *D. Miller* / *A. Campbell* / *B. Roel* 3. See "Input data" *A. Slotte* to lead Bergen workshop November 2013 to start process. 4. SAM – *A. Nielsen* et al a4a – *D. Miller* / *B. Roel* surplus production Bayesian – *A. Campbell* / *C. Minto* *DLS approach – J. Simmonds / Cefas / ALL at WKPELA* 5. *ALL*
Biological Reference Points	1. Investigate reference points under benchmarked assessment outcomes and in relation to the management plan	1. Calculate new reference points based on assessment results. Need clear guidance from ICES on how to provide advice to ACOM if reference points are deemed inappropriate given the new assessment results.	K. Enberg.

3.3 Scorecard on data quality

The accuracy (potential bias) of input data for the assessment is evaluated according to the scorecard developed by the Workshop on Methods to Evaluate and Estimate the Accuracy of Fisheries Data used for Assessment (WKACCU, ICES, 2008). The workshop developed a practical framework for detecting potential sources of bias in fisheries data collection programs. A scorecard was applied to indicators of bias for a suite of parameters that are important for stock assessments. The scorecard can be used to evaluate the quality of data sources used for stock assessments, and to reduce bias in future data collections by identifying steps in the data collection process that must be improved.

Mackerel	No bias	Potential bias	Confirmed bias	Comment
A. SPECIES IDENTIFICATION				
1. Species subject to confusion and trained staff				Egg identification, possible misidentification depending on area sampled, workshop reports WKFATHOM & WKMHMES
2. Species misreporting				
3. Taxonomic change				
4. Grouping statistics				
5. Identification Key				Workshops WKFATHOM & WKMHMES before each survey, produce an updated identification key in the reports
Final indicator				
B. LANDINGS WEIGHT				
Recall of bias indicator on species identification				
1. Missing part				
2. Area misreporting				Area misreporting is known to have taken place. The WG often corrected the catch data to account for this when information was available but is unlikely to have accounted for all misreporting by area.

Mackerel	No bias	Potential bias	Confirmed bias	Comment
3. Quantity misreporting				Underreporting of catch is known to have taken place to varying degrees since the start of the available catch time-series
4. Population of vessels				
5. Source of information				
6. Conversion factor				
7. Percentage of mixed in the landings				
8. Damaged fish landed				
Final indicator				
C. DISCARDS WEIGHT				
Recall of bias indicator on species identification				
1. Sampling allocation scheme				not all fleets are sampled for discards. Very poor sampling prior to 2002
2. Raising variable				a variety of raising procedures are used by the individual national sampling programmes. Information sparse prior to 2002 due to confidentiality issues
3. Size of the catch effect				
4. Damaged fish discarded				
5. Non response rate				
6. Temporal coverage				not all fleets are sampled
7. Spatial coverage				not all fleets are sampled

Mackerel	No bias	Potential bias	Confirmed bias	Comment
8. Highgrading				suspected to occur
9. Slipping behaviour				suspected to occur
10. Management measures leading to discarding behaviour				
11. Working conditions				
12. Species replacement				
Final indicator				
D. EFFORT				
Recall of bias indicator on species identification				
1. Unit definition				
2. Area misreporting				
3. Effort misreporting				
4. Source of information				
Final indicator				
E. LENGTH STRUCTURE				filled in by Secretariat
Recall of bias indicator on discards/landing weight				
1. Sampling protocol				
2. Temporal coverage				stock distribution timing changes
3. Spatial coverage				changing stock distribution

Mackerel	No bias	Potential bias	Confirmed bias	Comment
4. Random sampling of boxes/trips				
5. Availability of all the landings/discards				uncertainty in landing data
6. Non sampled strata				
7. Raising to the trip				
8. Change in selectivity				
9. Sampled weight				
Final indicator				
F. AGE STRUCTURE				filled in by Secretariat
Recall of bias indicator on length structure				
1. Quality insurance protocol				
2. Conventional/actual age validity				
3. Calibration workshop				2010 - wkarmac
4. International exchange				
5. International reference set				
6. Species/stock reading easiness and trained staff				see wkarmac
7. Age reading method				
8. Statistical processing				

Mackerel	No bias	Potential bias	Confirmed bias	Comment
9. Temporal coverage		X		stock distribution timing changes
10. Spatial coverage		X		changing stock distribution
11. Plus group	X			
12. Incomplete ALK	X			
Final indicator				
G. MEAN WEIGHT				filled in by Secretariat
Recall of bias indicator on length/age structure				
1. Sampling protocol	X			
2. Temporal coverage	X			
3. Spatial coverage	X			
4. Statistical processing	X			
5. Calibration equipment	X			
6. Working conditions	X			
7. Conversion factor		X		historic water content adjustments varied
8. Final indicator				
H. SEX RATIO				filled in by Secretariat
Recall of bias indicator on length/age structure				
1. Sampling protocol	X			2007 - wkmsmac

Mackerel	No bias	Potential bias	Confirmed bias	Comment
2. Temporal coverage		X		Survey is directed at covering whole spawning period, but recent survey in 2013 indicates that the beginning of the spawning may have been missed (WGWIDE and WGMEGS reports)
3. Spatial coverage		X		Survey is directed at covering whole spawning area, but recent survey in 2013 indicates that the edges of spawning may have been missed (WGWIDE and WGMEGS reports)
4. Staff trained	X			Planning meetings and workshops in the year before the survey (WGMEGS, WKMHMES & WKFATHOM reports)
5.Size/maturity effect	X			
6. Catchability effect	X			
Final indicator				
I. MATURITY STAGE				as egg development stage for the egg surveys
Recall of bias indicator on length/age structure				
1. Sampling protocol	X			Manuals produced in each planning group report (WGMEGS reports)
2. Appropriate time period		X		Survey is directed at covering whole spawning period, but recent survey in 2013 indicates that the beginning of the spawning may have been missed (WGWIDE and WGMEGS reports)
3. Spatial coverage		X		Survey is directed at covering whole spawning area, but recent survey in 2013 indicates that the edges of spawning may have been missed (WGWIDE and WGMEGS reports)

Mackerel	No bias	Potential bias	Confirmed bias	Comment
4. Staff trained				Planning meetings and workshops in the year before the survey (WGMEGS, WKMHMES & WKFATHOM reports)
5. International reference set				Workshops before the survey which produce an updated key (WKMHMES, WKFATHOM)
6. Size/maturity effect				
7. Histological reference				
8. Skipped spawning				
Final indicator				
Final indicator				

3.4 Multispecies and mixed fisheries issues

In the northern European waters, Northeast Atlantic mackerel is mainly targeted by RSW pelagic vessels using either trawls or purse-seine or freezer-trawlers. This pelagic fishery has only a minor mixture of other species. However, in especially Spain, France and Portugal there are large artisanal fleets where there might be some mixed fishery issues.

3.5 Ecosystem drivers

No additional considerations to the Stock Annex.

3.6 Stock assessment

3.6.1 Catch-quality, misreporting, discards

In preparation for WKPELA14, the available information on discarding and slipping of mackerel was reviewed (Campbell, 2014).

Although the discarding of fish in pelagic fisheries is generally considered to be lower than for demersal fisheries (due to the schooling nature and distribution of pelagic species which permits fishers to more accurately target the desired species), discarding of mackerel has been a consistent but variable feature of the fishery since it was first considered by the working group. A wide range of drivers that lead to discarding have been identified including vessel type and gear (e.g. freezer vessels which sort and process catch at sea tend to discard more than RSWs), regulatory structures (TAC limitation, MLS constraints), season (which affects the distribution and behaviour of the mackerel), target species and the level of technology available to the fishers.

A review of the previous mackerel working group reports (1980–2013), peer-reviewed and grey literature indicates that discarding of mackerel takes place for a number of reasons but principally for the purpose of the disposal of undersize fish. This discarding of small mackerel can result from the disposal of the entire catch prior to bringing it on board (slipping) or the disposal of only a portion of the catch (highgrading). Discarding of all size classes can occur in the event of gear failure or the deliberate discarding of the complete catch due to lack of quota, vessel storage or mixing with other species (most commonly herring or horse mackerel).

In some jurisdictions (where particularly large catches have been taken in recent years) discarding is illegal. Norwegian, Icelandic and Faroese vessels are not permitted to discard fish at sea, although slipping may be permitted under certain circumstances. One such circumstance is the case where the catch exceeds the storage capacity of the ship. Another example is in the Norwegian 7/8 rule where purse-seiners are allowed to release fish surrounded by the purse up to when 7/8 of the purse-seine total length has been retrieved.

Between 1978 and 2002, the only discard estimates provided to the working group were from the Netherlands. These estimates were based on confidential logbook information and, in order to maintain this confidentiality, no information on the source or raising procedures used for this dataset were detailed in the working group reports. These estimates applied only to the Dutch freezer trawler fleet which has traditionally accounted for 5–10% of the overall catch. No updates to these estimates are available such that the dataset remains unchanged prior to 2002.

Since 2002, a number of observer programmes, established under the Data Collection Regulation have provided information to the working group on the discarding practices of some EU fleets. In preparation for WKPELA 2014, updated discard estimates were provided from the Netherland, Spain and Portugal. These were used to update the time-series from 2002 onwards. Scottish, German, Danish and Irish observer programmes also contributed to the overall estimate of discards since 2002. The revisions to the dataset consist of annual increases of approximately 5–10 kt (overall working group catch during the period in question is of the order of 500–900 kt).

Only broad conclusions regarding discarding can be drawn. It is clear that the level of discarding has been underestimated throughout the entire time-series of catch data and that the level of underestimation is variable. In the most recent years, observer programmes have increased the available information although there remain significant knowledge gaps. It appears that discard rates have reduced in recent years. This may be as a result of improved technology which permits larger, more efficient vessels to more accurately target and monitor the catch process. Additionally, a larger proportion of the overall fishery now takes place in northern waters where discarding is illegal and the presence of juveniles and unwanted species is less likely.

The full time-series of discard estimates available is given in the text table below. Figures in parentheses represent estimates prior to the review undertaken for WKPELA 2014.

Year	Discards (t)	Year	Discards (t)	Year	Discards (t)
1978	50,600 (-)	1990	15,600 (-)	2002	23,774 (-)
1979	60,600 (-)	1991	30,700 (-)	2003	19,427 (9,481)
1980	21,600 (-)	1992	25,000 (-)	2004	19,962 (10,972)
1981	45,516 (-)	1993	18,180 (-)	2005	25,383 (19,760)
1982	25,350 (-)	1994	5,370 (-)	2006	26,593 (17,970)
1983	11,396 (-)	1995	7,721 (-)	2007	15,444 (8,616)
1984	12,302 (-)	1996	11,415 (-)	2008	36,398 (26,766)
1985	8,191 (-)	1997	18,864 (-)	2009	15,693 (12,854)
1986	7,431 (-)	1998	8,012 (-)	2010	12,814 (6,981)
1987	10,789 (-)	1999		2011	10,894 (9,012)
1988	35,566 (-)	2000	2,084 (-)	2012	15,380 (-)
1989	7,090 (-)	2001	1,188 (-)		

3.6.2 Surveys

The following surveys provide data for the NEA mackerel assessment:

Survey name	Survey Acronym	Type	Abundance data	Area and Month	Period
Internation Ecosystem Summer Survey in the Nordic Seas	IESSNS	Pelagic trawl Swept-area	Abundance at age	July–August Norwegian Sea, Iceland, West of Greenland	2007,2010–2013
Norwegian tagging program	-	Tagging-Recpature	Numbers released and numbers recaptures per year per year class	May Northwest Irland to North Scottland	1968–2012
Mackerel Egg Survey	MEGS	Egg survey	SSB index (Western and Southern spawning components)	March to July West Portugal to Feroes Islands	Every third year since 1992
Internation Bottom-trawl Survey	IBTS	Bottom trawl	Recruitment index	Quarter 4 Continental shelf from Northern Spain to North of Scottland	1998–2012

3.6.2.1 IESSNS survey

The main objective of the IESSNS survey in relation to quantitative assessment purposes is to provide reliable and consistent age-disaggregated abundance indices of NEA mackerel. Research vessels and chartered commercial fishing vessels from Norway (two vessels), Faroe Islands and Iceland (one from each country) were used in the Norwegian Sea and adjacent waters in July–August 2007–2013 (Nøttestad *et al.*, 2014). In 2007, the surveys were conducted by two Norwegian vessels only. The survey aimed at covering the outer borders (zero lines) of the mackerel distribution each year from 2007 in all directions except for in the southern region (south of 62°N in the North Sea). Due to the spatial expansion and increased geographical distribution of mackerel in the Nordic Seas from 2007 to 2013, the survey coverage differed somewhat from year to year in an effort to cover an expanding stock and at the same time a dynamically moving border (Figure 3.6.2.1.1). In 2011 available ship time limited the coverage in the northern areas therefore the coverage of the northernmost part of the stock was not complete in 2011. The temporal coverage was limited to 5–6 weeks period, in order to avoid any double or zero counting during the survey. The swept-area survey was designed with predominantly parallel east-west survey lines, and fixed sampling stations approximately 60 nautical miles apart at predetermined geographical positions (ICES 2013a, b; Nøttestad *et al*., 2014).

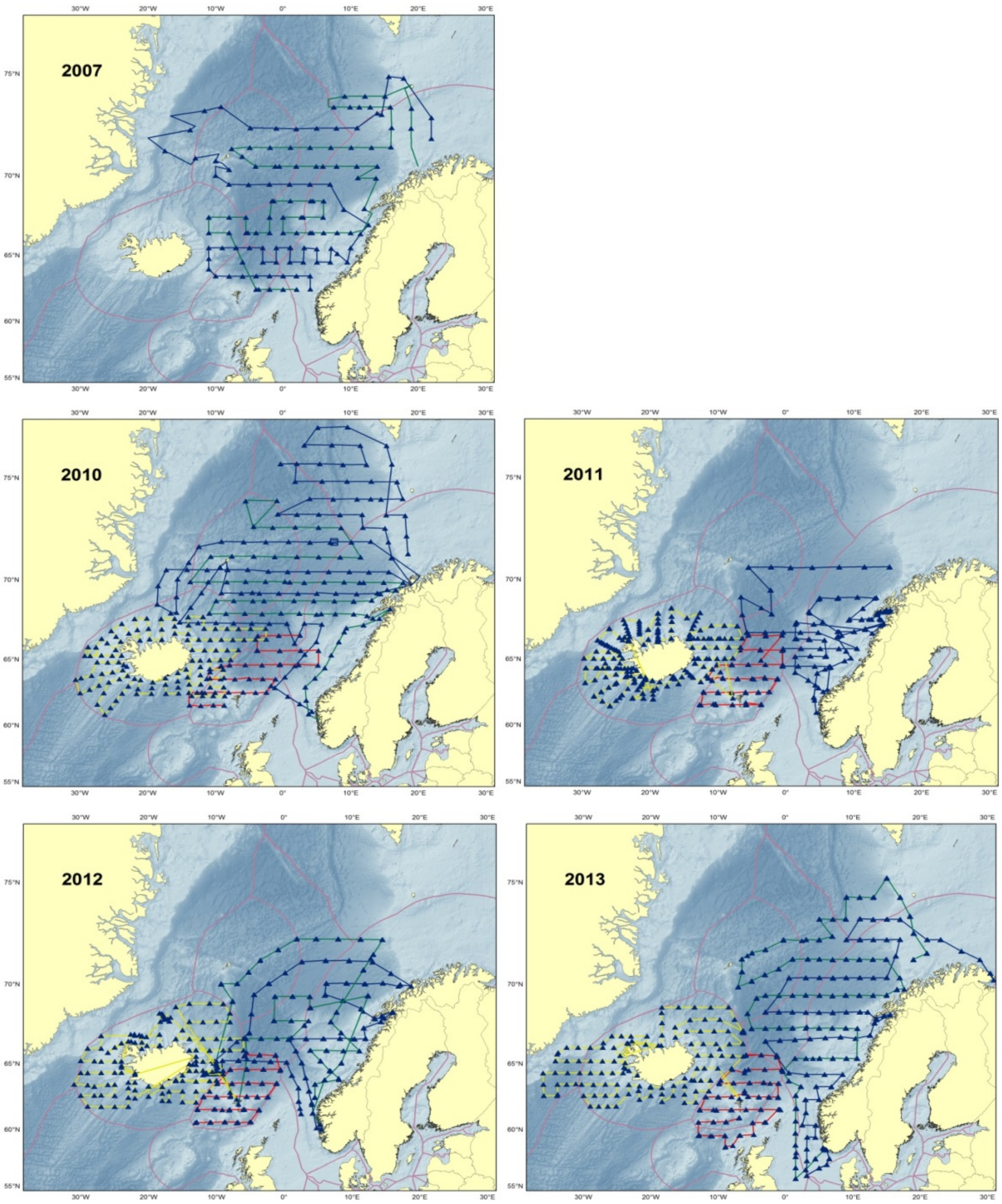


Figure 3.6.2.1.1a–e. Systematic predefined survey stations including pelagic trawl stations conducted on board two (2007), three (2011) and four (2010, 2012, 2013) highly equipped vessels from Norway (blue lines), Faroe Islands (red lines) and Iceland (yellow lines).

To obtain information about quantity and composition of NEA mackerel in the survey area, pelagic trawls hauls were undertaken close to the surface at predefined geographical positions for all vessels and years from 2007 to 2013 (Figure 3.6.2.1.1a–e). Different pelagic trawls were applied prior to 2012 (Nøttestad *et al*., 2014). Nevertheless, towing speed and trawl duration were directly comparable and standardized between vessels and nations for all years, and the swept-area estimates were adjusted to compensate for changes in area swept by the different trawls used. Since 2012 all vessels applied a standardized Multpelt 832 pelagic trawl. The methodology of the survey is detailed in ICES (2013b) and Valdemarsen *et al*. (2014), and only the main features are addressed here. The trawls were towed at the surface with help of floats attached to the wings and the headline. Tow duration was 30 minutes and towing speed varied between 3.5–5.2 knots depending of vessel performance, current, wind and wave conditions. The towing distance was recorded for each haul, whereas the effective fishing period compared to the standardized towing period was explored by underwater cameras inside the trawl for selected stations (Rosen and Valdemarsen, 2014). The catch of the different species was weighed on board and a total of 100 mackerel individuals were sampled from the catch randomly and total length (±1 cm) and whole body weight (±0.1 g) recorded from each trawl haul. The otoliths from the first 25 individuals were retrieved for age reading. On basis of the catch data and operation of the trawling hauls, swept-area estimates of age-disaggregated indices and biomass are calculated for rectangles of 2° longitude and 1° latitude across the survey area (Figures 3.6.2.1.2 and 3.6.2.1.3).

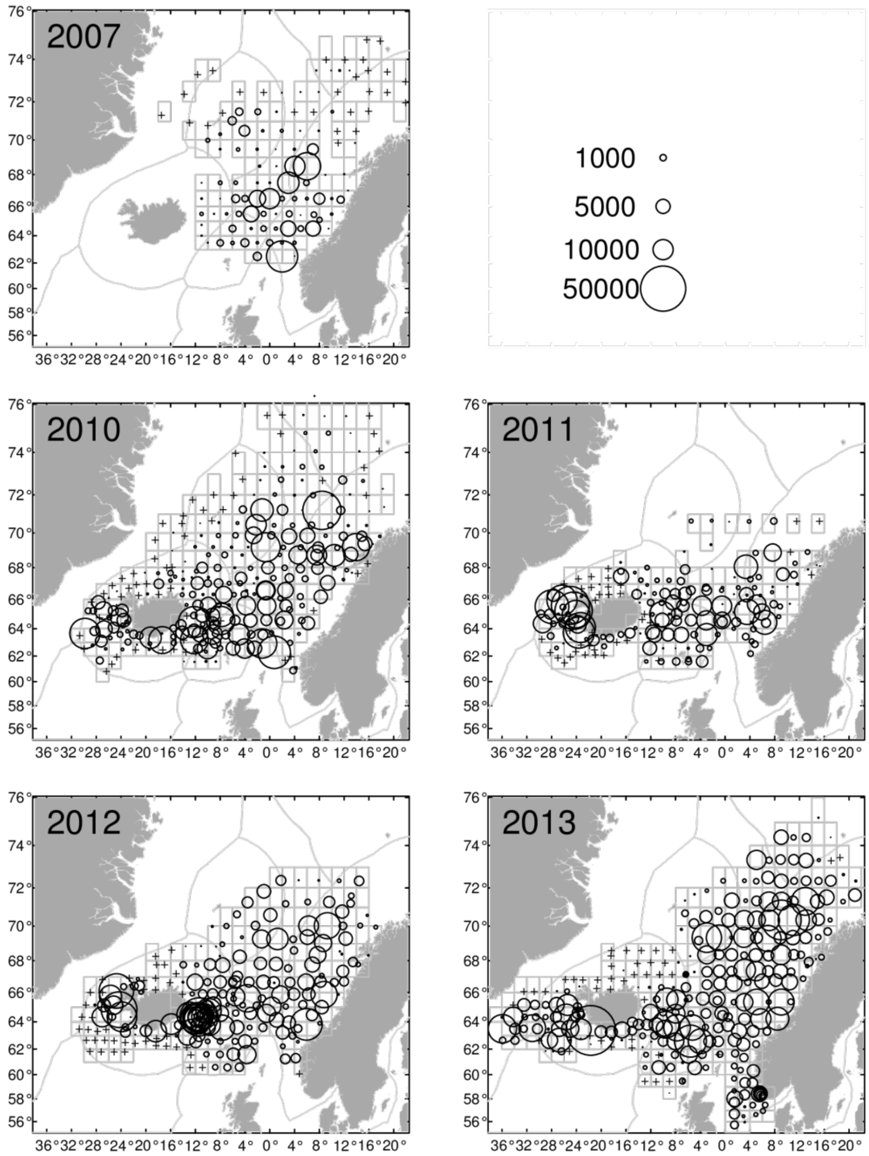


Figure 3.6.2.1.2.a–e. Average catch index (kg/km^2) presented as circles ranging from no catch (a +), >1000 kg/km^2 to >50 000 kg/km^2 for NEA mackerel in July–August 2007, 2010–2013. The spatial coverage varied from 0.926 million km^2 in 2007 to 2.410 million km^2 in 2013.

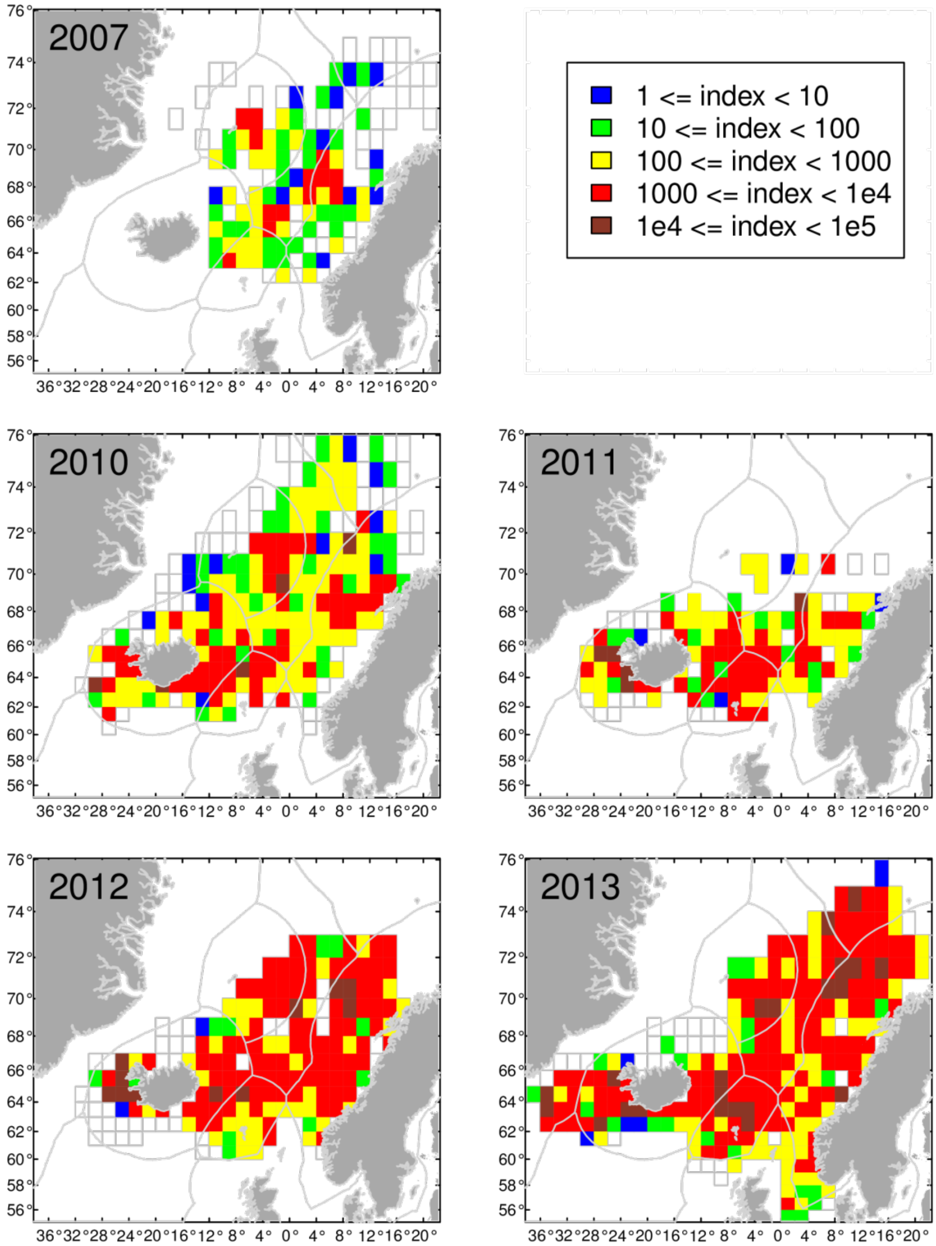


Figure 3.6.2.1.3a–e. Graphical representation of average catch index (numbers/km²) for NEA mackerel in July–August in 2007 and 2010–2013. The spatial coverage varied from 0.926 million km² in 2007 to 2.410 million km² in 2013. No catch is represented as open squares.

The internal consistency plot for the swept-area age-disaggregated indices using a CLR model is shown in Figure 3.6.2.1.4 (Nøttestad *et al.*, 2014). Based on these results (including the observation that the 2011 survey coverage was not sufficient) and the indication that age groups below age 6 were not fully recruited to the survey, it was decided that an age-disaggregated time-series for analytical assessment should be restricted to adult mackerel at age 6 years and older for the years 2007, 2010–2013.

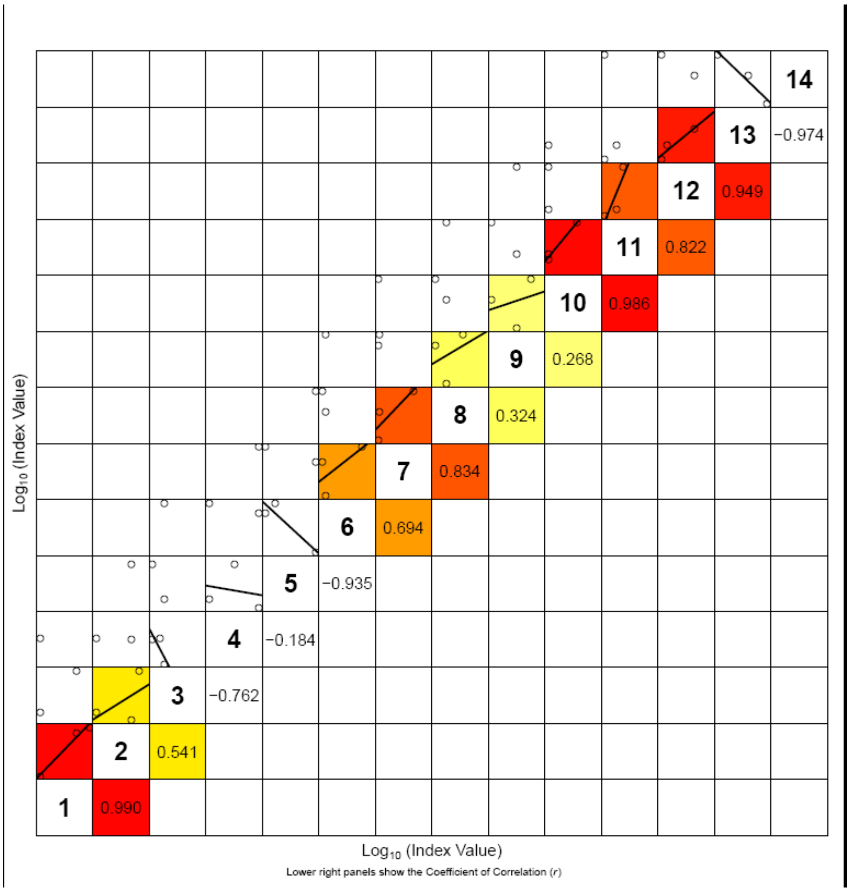


Figure 3.6.2.1.4. The internal consistency in the age-disaggregated data from the swept-area indices using a CLR model. Lower right panels show the coefficient of correlation (r).

Comparison of abundance estimates from swept-area and echosounder data sampled by HERAS survey in the North Sea area during the same period are discussed below on page 21.

As the area coverage by IESSNS has varied, it was suggested that some year classes could be insufficiently covered in some years if the spatial distribution was age dependent. Analyses of horizontal distribution of six year old mackerel show that they are found throughout the survey area in 2013 (Figure 3.6.2.1.5); which was the year with largest area coverage. Other age groups showed the same random pattern. Therefore there were no age-dependent spatial patterns in the survey indices.

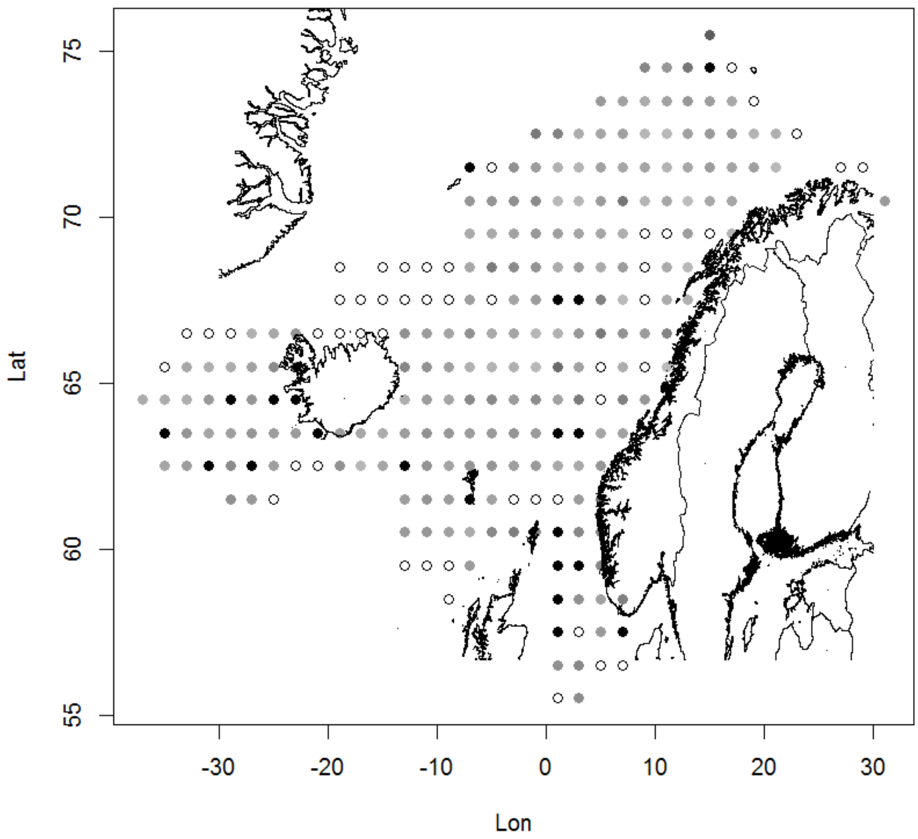


Figure 3.6.2.1.5. The horizontal distribution of 6 year old mackerel during summer 2013. Shading of the circles represents abundance, with darker shades for higher abundance. Open circles represent trawl hauls without six year old mackerel.

On the basis of issues addressed above regarding apparent lower catchability of fish at age <6, variable and expanding coverage of the annual surveys, uncertainty in catch efficiency with respect to vertical distribution of the stock in the North Sea, and the fact that the survey is only covering the migratory part of the stock leaving out mackerel further south, the WKPELA suggested not to use the standard age-disaggregated swept-area indices from the survey at present. Instead the group decided to scale the swept-area indices by the total area covered each year to produce density (cpue) estimates to be used as input for the analytical assessment. Because the relationship between the total stock abundance and that portion covered by the survey is unknown, it was suggested that a more appropriate use of the survey could be as an index of proportions of age where each year is scaled to 1.

Thus, two age-disaggregated indices were constructed for analytical assessment purposes. They were spatially restricted to Nordic Seas, leaving out North Sea south of 62°N, and delimited to age 6+. The former one took into account the apparent unstructured spatial distribution of the age groups (Figure 3.6.2.1.5) and consisted therefore of number-at-age 6–14 divided by total area covered and including mackerel each year (number per square km; Figure 3.6.2.1.7). Considering the unstructured spatial distribution within the survey area this index can be considered to be equivalent to cpue. The second one included number-at-age 6–14 across the whole area on a relative scale (adds up to 1 within a year; Figure 3.6.2.1.6).

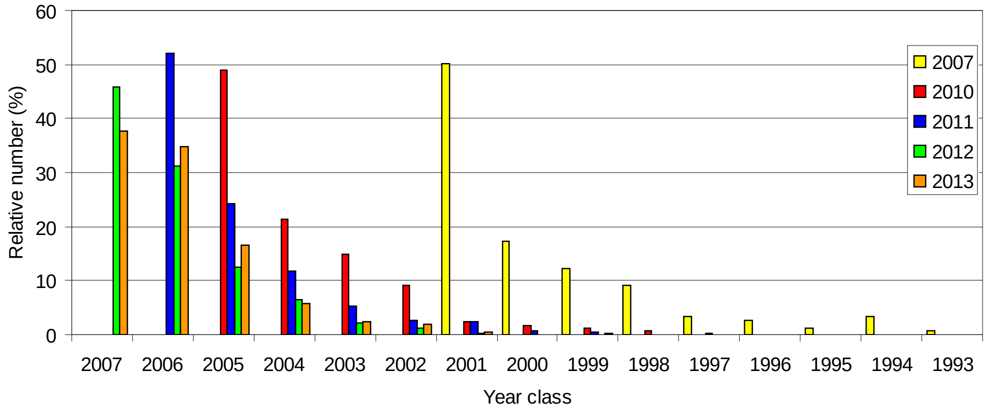


Figure 3.6.2.1.6. NEA mackerel. IESSNS relative number (%) within a year (different bars) for the different year classes at ages 6+ in Nordic Seas excluding North Sea south of 62°N (no data in 2008 and 2009).

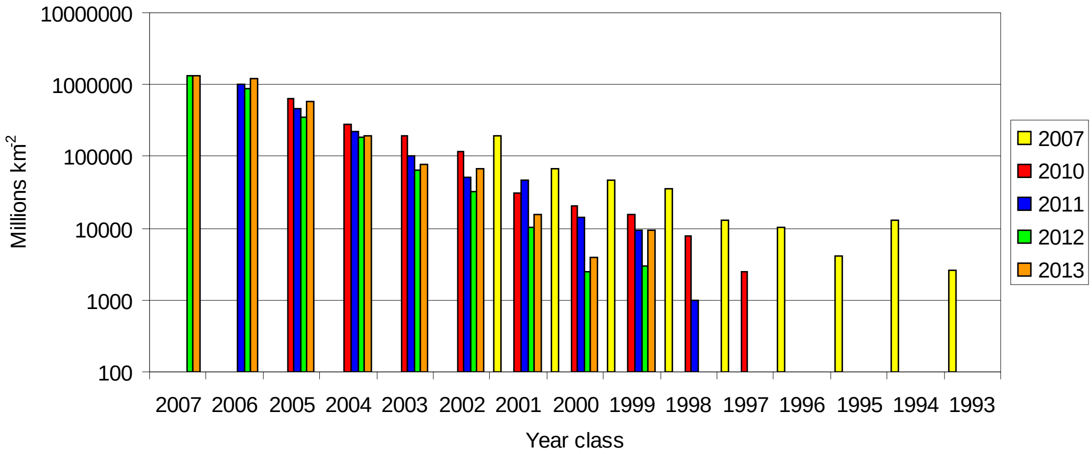


Figure 3.6.2.1.7. NEA mackerel. IESSNS swept-area abundance estimates ages 6+ scaled to covered area including mackerel within the Nordic Seas (excluding North Sea south of 62°N) for different year classes within each year (bars; log-scale millions km^{-2}). No data available from 2008 and 2009.

Conclusions

The IESSNS survey, which covers the summer (July–August) feeding grounds of NEA mackerel in Nordic Seas, has expanded in coverage since first taking place in 2007 and thereby followed the extension of the mackerel stock in recent years. WKPELA 2014 concluded that data from the IESSNS survey could be used to provide an age-structured index. Two types of age-disaggregated indices were proposed:

- age 6–14 swept-area abundance indices scaled by the total area covered each year (number per square km; equivalent to cpue),
- age 6–14 swept-area abundance indices scaled to unity each year.

Mackerel in the North Sea currently not covered by the IESSNS

Up until recently, the IESSNS has surveyed mackerel during the summer feeding season focusing on areas north of 62°N only, without covering the southern areas in the North Sea and west of Scotland. Yet particularly the northern North Sea has traditionally been an important area for mackerel during the feeding season and a recent study using opportunistically recorded acoustic data during the IBTS Q3 (van der Kooij *et al*., 2014) confirmed that mackerel biomass in the North Sea has increased between 2007 and 2012. In 2013, the IESSNS extended further south than in previous years. Consequently, some areas south of 62°N were covered concurrently by three different surveys (IESSNS, HERAS, and IBTS Q3) at about the same time. Each of these surveys was identified as being able to provide an index of mackerel abundance. The overlap in 2013 presented an opportunity to compare these different indices and get an idea about potential mackerel quantities south of 62°N (Fässler *et al*., 2014). From both the 2013 IBTS and HERAS surveys, mackerel schools were extracted from acoustic data using a multifrequency identification algorithm (Korneliussen. 2010). The resulting acoustic density was used to derive mackerel abundances for both the HERAS and IBTS Q3 surveys and was compared with swept-area derived abundance for the overlapping areas with the IESSNS. Results are presented in the associated Working Document by Fässler *et al*., 2014.

Mackerel biomass calculated using data from the three different surveys showed different values (Fässler *et al*., 2014). Acoustically derived biomass for the area covering the northern North Sea and west of Scotland, by HERAS was approximately three times lower than that obtained using the swept-area method from the IESSNS (78.5 kT and 247.2 kT respectively). For a (slightly different) area in the northern North Sea, the acoustically derived mackerel biomass from the IBTS data was three times higher than the swept-are estimate from the IESSNS. However when the acoustic densities were limited to the surface 30 m, a much lower acoustic biomass was obtained. When dividing acoustic densities of mackerel from the HERAS into 5 m depth bins, the majority of registrations were recorded between depths of 80 and 100 m, with additional peaks also at 10–35 m, 120–150 m and 170–180 m. Most of the acoustically derived mackerel biomass from the IBTS was found below the 40 m depth strata with particular peaks around 85–105 m and 155–165 m depth. No correlation could be found for the mackerel abundances by statistical rectangle in the overlapping area between both the IBTS and IESSNS, and the HERAS and IESSNS surveys.

It is worth emphasizing that the acoustic methods sample a different part of the water column compared to the swept-area method and none of the abundance estimates derived from the respective methods should be considered absolute. While the trawl sampling applied during the IESSNS exclusively sampled the top ~30 metres of the water column, acoustic methods used during the HERAS and IBTS are limited at shallow depths but provide information down to ~200 m. When considering the three surveys combined, results suggest on the one hand that the surface ~13 m, unsampled by acoustic methods, is important for mackerel, also in the northern North Sea. On the other hand, they indicate that in the northern North Sea, a significant proportion (if not the majority) of mackerel is located below the area sampled by the trawl. A study on the 2013 IESSNS acoustic data showed also that in the northern North Sea a larger component of the acoustically detected mackerel were found below the surface waters covered with the trawl, compared to the waters further north (Pena *et al*., 2014). This apparent behavioural difference in vertical distribution suggests firstly that, at least in isolation, the swept-area method as applied in the Nordic waters is not likely to be a suitable tool for sampling mackerel in the northern North Sea. Given the important contribution of this area to the mackerel population, surveys like the IBTS and HERAS could provide important supplementary information. It is strongly recommended to validate some of the schools in the acoustic data, assumed to be mackerel, using directed pelagic tows. Particularly the HERAS survey is suited to do this as it is already equipped with suitable pelagic gear. Further exploratory surface trawls should also be conducted in the northern North Sea to help further understand the importance of the subsurface areas and the qualitative extent of the mackerel distribution within the survey.

3.6.2.2 Tagging survey

Tag data description

Institute of Marine Research in Bergen has conducted tagging experiments on mackerel since 1969, both in the North Sea and West of Ireland during the spawning season May–June. However, only the information form mackerel tagged west of Ireland is used in the mackerel assessment. For the WKPELA benchmark on mackerel in 2014 we have developed a full time-series that can be used in assessment models. This is available as a flat file at the format showed in Figure 3.6.2.2.1 (See working document by Arni Magnusson on how to transfer tag–recapture information form an excel file format to a flat file). Below follows a full description of the content of this file, the different variables and how they have been estimated/measured, and how this has changed over time along with changes in methodology. Abundance estimation with use of these data and also a description of data has been published (Tenningen *et al.*, 2011).

ReleaseY	RecaptureY	Yearclass	Nscan	R	r	Type
2009	2010	2000	1209000	327	0	1
2009	2010	2001	2016000	808	0	1
2009	2010	2002	5661000	1261	0	1
2009	2010	2003	7326000	1029	0	1
2009	2010	2004	15180000	1775	1	1
2009	2010	2005	20948000	2257	1	1
2009	2010	2006	12486000	3194	0	1
2009	2010	2007	4429000	3061	0	1
2011	2012	1998	626000	85	0.151	2
2011	2012	1999	831000	53	0.071	2
2011	2012	2000	1037000	202	0.374	2
2011	2012	2001	1010000	326	0.788	2
2011	2012	2002	5379000	768	2.481	2
2011	2012	2003	10335000	825	2.053	2
2011	2012	2004	17393000	1297	2.725	2
2011	2012	2005	38212000	1702	3.097	2
2011	2012	2006	60751000	3170	5.706	2
2011	2012	2007	47101000	1986	2.965	2
2011	2012	2008	35550000	5408	4.802	2
2011	2012	2009	13615000	2589	3.182	2
2011	2013	2000	227000	202	0.262	2
2011	2013	2001	944000	326	0.596	2
2011	2013	2002	1310000	768	0.944	2
2011	2013	2003	4703000	825	1.372	2

Figure 3.6.2.2.1. Format of tag–recapture data to be used in the assessment of mackerel.

1) **ReleaseY**: This variable show the year of release. In the tag data delivered, we have only included tagging data on the western component, i.e. data from tagging west of Ireland and the British Isles during the spawning season. Note that each release year is based on many different releases at different positions over this area (Figure 3.6.2.2.2).

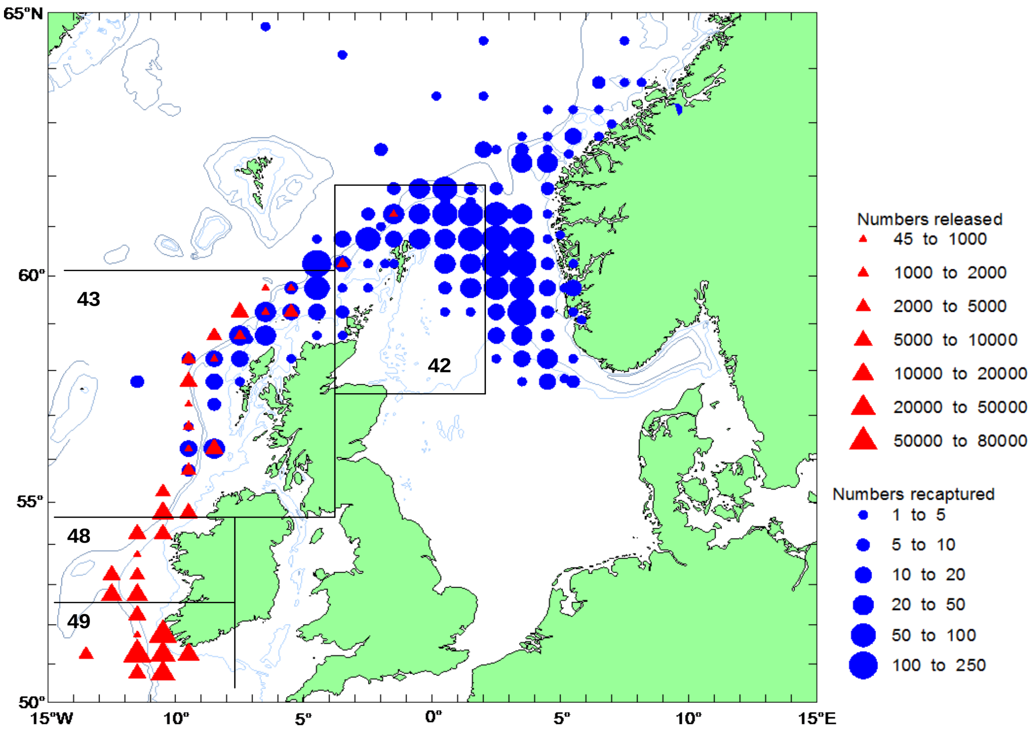


Figure 3.6.2.2.2. Positions (mean position in statistical rectangles) of released (red triangles) and recaptured (blue dots) in the Norwegian tagging programme of mackerel. Size of triangles and dots show numbers released and recaptured per position.

2) **RecaptureY**: recapture year is the year where we screened commercial catches for tags. There has been **two main seasons of commercial catches screened**. Firstly, January–February from the EU trawl fishery along the British Isles down to Ireland (Figure 3.6.2.2.2), where catches is delivered at Norwegian Factories. Secondly, the Norwegian purse-seine fishery during autumn September–November mainly in the northern North Sea (Figure 3.6.2.2.2). In the data of recaptures seasons are merged.

3) **Yearclass**: all data are year-class based, and the process of estimating numbers scanned (Nscan) and numbers released (r) by year class is described below.

4) **Nscan**: Number scanned by year class is estimated in similar manner as normally carried out in estimation of catch-at-age by the different countries, perhaps with a little more intensive sampling. **The way this has been done can be split into two periods, 1986–2010 and 2011–2013).** Until 2010, where we scanned internal steel tags (from releases 1977–2009), IMR paid externals to follow the screening process of commercial catches for human consumption at factories with conveyor belt systems. For each catch scanned for tags they length measured 100–200 fish and estimated mean weight. Mean weight was used to estimate numbers fish screened, and the

length measures was combined with an age–length key developed from full biological samples with aging from all catches in the same period and area as the catch screened for tags. Then in 2011 we started with RFID tagging with automated system for tag returns (see description below). From this year on we simply rely on the mean weight estimated by the factory itself (reported to the Sales organization for Pelagic Fish, data available to IMR) to estimate numbers scanned, and we use the estimated age distribution from all catches in the same period and area directly in to split the numbers into year classes. The first method with actual length measurements of each catch would of course reduce the uncertainty in age distribution per catch scanned. However, the method simply using the age distribution from the same period and areas as the catches screened is the same as used by all countries for estimation of catch by age, and uncertainty herein is comparable. On the other hand, the project gains a whole lot in the numbers of automatic RFID systems that can be placed out to increase the numbers scanned per year class per year, which should decrease uncertainty in the data. In the end number scanned by year class is summed over all factories, all catches, over the whole year. For both metal tagging detection and RFID scanning the efficiency is assumed to be 100%.

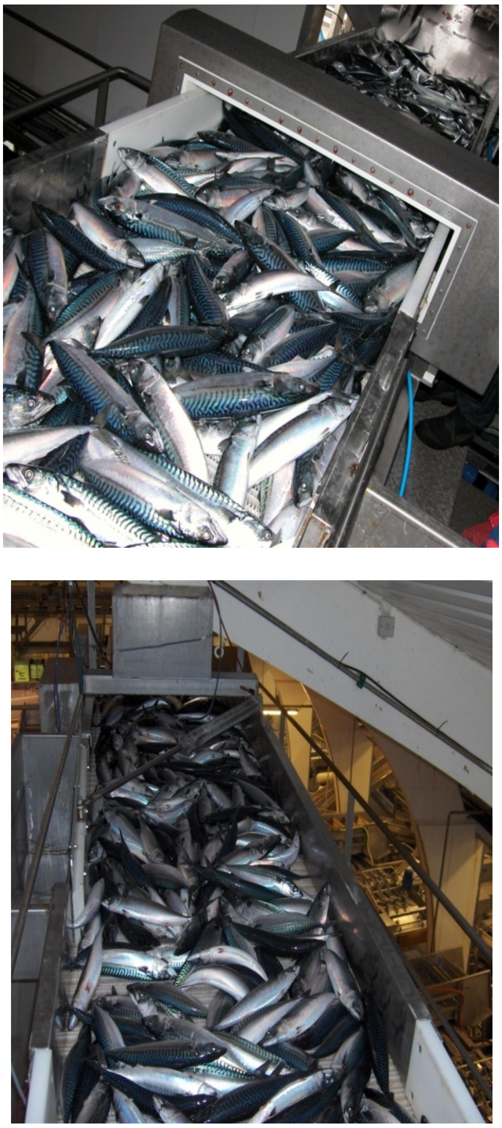


Figure 3.6.2.2.3. Metal detectors with deflector gates used 1986–2010 to recapture mackerel tagged 1977–2009 with internal steel tags.

Figure 3.6.2.2.4. RFID antenna (left) and reader system with GPRS in a waterproof locker on the wall (right) that automatically detects RFID tagged fish and updates IMR database over GPRS with necessary data.

5) **R**: Numbers released by year class is estimated by a combination of length measurements of each fish released, and length–age keys from the area period of tagging**. All fish released is length measured, both with the old method with steel tags and the new method with RFID**. With the old method up to 2009 we used a "writer" and had to register data on computer later on (Figure 3.6.2.2.5), whereas with the new RFID method starting in 2011 a hand-held computer stored tag code and length when tagging (Figure 3.6.2.2.6).

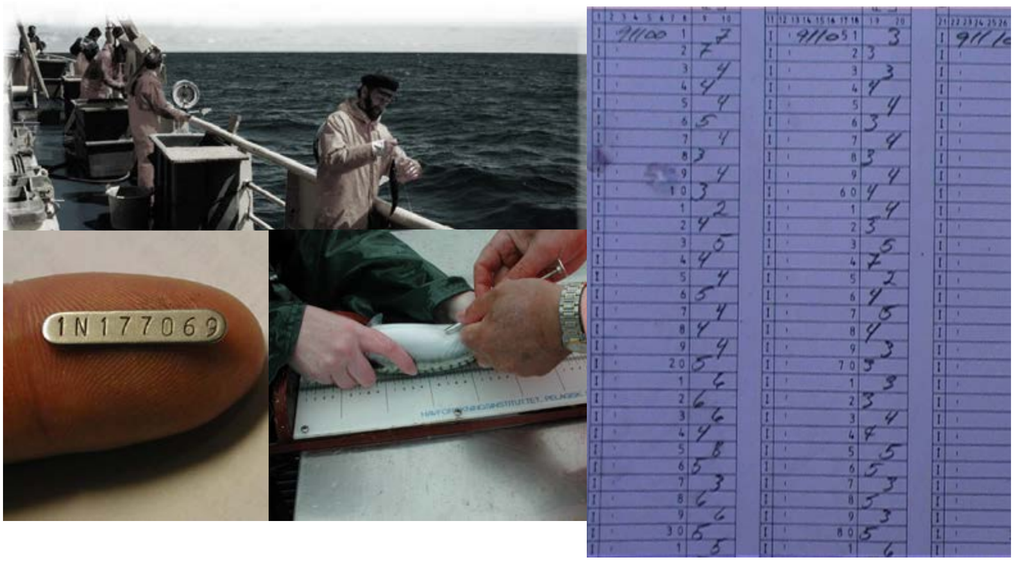


Figure 3.6.2.2.5. Tagging process with steel tags for the data included in tag file from releases 1977–2009.

Figure 3.6.2.2.6. Tagging process with RFID tags for the data included in tag file from releases 2011–2013.

During a day of tagging about 15–20% of the fish is discarded, not acceptable for tagging, and these ones are used in biological sampling for age–length keys**. Up to 2012 aging of these fish were done at random, whereas from 2012–2013 and onwards we stratify up to 20 fish per 1 cm group**, which was done to overcome problems with few fish or lacking fish in the smallest and largest fish tagged. We tag 20 000–40 000 fish per year, and get a wide length distribution. Note that there is an uncertainty in the actual length measurement of tagged mackerel. When measuring total length of mackerel we pinch the tail, this cannot be done when tagging, so the tagger "add" a little to normal total length to overcome this, and here there is an uncertainty involved.

6) **r**: Numbers recovered by year class per year is found with two different methods related to tagging technology, 1986–2010 for steel tags and 2011–2013 for RFID tags. For the old method, when a steel tag was recognized by the metal detector, about 50 fish were removed from the belt via a deflector gate system, and the external IMR responsible used a hand detector to find the tagged fish. The individual tagged fish were packed in plastic bags, frozen and shipped to IMR at the end of catch season. Here technicians did a full sample of the fish, found the tag (sometimes mistaken due to other metal objects in mackerel body), registered the tag code together with info from the individual fish, catch, position etc., and linked this to the release data in flat files. **Note that steel tagged fish was age read and the one tag was linked to one specific year class.** No need to explain that all this manual work cost a lot, and took a lot of time. After the introduction of RFID all this has changed. Now the RFID-antenna reader systems reports data on tag code, date, time, factory to IMR database automatically over GPRS net at the same time as it passes the antenna placed above the conveyor belt (Figure 3.6.2.2.7). Note that the RFID tagged fish recaptured and automatically stored in IMR database is directly linked to the age–length keys at the time and area of release. **Hence, note one RFID tag return is spread out on several different year classes with a number between 0.001 and 1 (we use three decimals) based on the length at release and age–**

length key of that release. So this is why from 2012 onwards (we only include in table returns the year after release) the numbers recaptured by year class is with three decimals. Note that all data analyses, handling of data in database (biological data, catch data, tag data), surveillance of RFID systems is handled by a web-based software (Fishweb) with different modules.

item	ReleaseArea	ReleaseDate	Recapture Plant	Recapture Area	Recapture Time
Mackerel	48F5	29.09.2011	Skude Fryseri	49E7	19.10.2013 14:53
Mackerel	32D8	14.05.2013	Egersund Seafood	50E8	19.10.2013 14:43
Mackerel	32D9	21.05.2013	Egersund Seafood	50E8	19.10.2013 09:58
Mackerel	33D7	01.06.2012	Norway Pelagic Selje	50E9	18.10.2013 17:37
Mackerel	32D8	23.05.2013	Norway Pelagic Selje	50E9	18.10.2013 17:02
Mackerel	48F5	30.09.2011	Norway Pelagic Selje	50E9	18.10.2013 11:34
Mackerel	32D7	16.05.2011	Egersund Seafood	49E9	17.10.2013 19:58
Mackerel	34D8	12.05.2012	Egersund Seafood	49E9	17.10.2013 16:17
Mackerel	32D7	29.05.2011	Egersund Seafood	49E9	17.10.2013 15:29

Figure 3.6.2.2.7. Picture of "Recapture module" of the RFID software solution continuously recording RFID tagged mackerel as they are recaptured in commercial catches at factories with RFID-antenna reader systems reporting to IMR database over GPRS. Note that recapture area is added manually based on information of catch.

7) **Type**: We have noted in the table the change from steel tags (Type 1) to RFID (Type 2), so that this may be taken into account in assessment, if one believes method influences the data. However, note that we do not believe the shift from steel to RFID have had an effect on tagging mortality, it is the process the tag is inserted that influences mortality not the tagging itself, see text below.

Tagging mortality: this is an important and uncertain component of the tagging data. Therefore it is also important to note that in 2006 we did a change in fishing method from manual jigging, with jigging wheels towards automatic jigging with jigging machines. During manual jigging we expected variation between fishermen, between years, in tagging mortality. This variation was expected to decrease when automatic jigging was introduced, i.e. same fishing and handling at every fishing station on the vessel (we have up to four stations along vessel), also same every year. Another thing we changed in 2006, linked to automatic jigging, was shift from throwing tagged fish directly to sea towards on starboard side, to a system with running waters in tubes and pipes across vessel releasing the fish on port side. Again, here the idea was that a normal problem with gannets picking up tagged fish easily seen thrown out on starboard windy side (when fishing we drift with wind), would be reduced if the fish were released through pipes with running water ending below waterline on the port side. Still, even though the variation in tagging mortality between, fishing stations and years may have been reduced, one cannot exclude that the change in 2006 actually may have increased tagging mortality, but it does not seem very likely to have happened.

For more information about the steel tag series, work and results see (uploaded to WKPELA SharePoint under WG documents):

- Tenningen, M., **Slotte, A** and Dankert Skagen. 2011.

For more information about the new RFID methodology see (uploaded to WKPELA SharePoint under WG documents):

- RFID software manual - MAN10032-4.pdf
- RFID hardware manual - MAN100151.pdf
- Protocol for testing RFID antenna-reader system at factories-ITP1012-1B.pdf
- Report of the tests of RFID systems - RFIDRPT10067-1.pdf

Tag data utilization in SAM assessment

The tag data time-series and how it has been developed is carefully described above under **Tag data description**. Based on changes in methodology described and potential problems with part of the time-series discovered in sensitivity runs of SAM, it was decided not to include this time-series fully in the final assessment. Below is a description of data included and excluded, and explanations behind decisions.

1) **Data included**: The data included releases with internal steel tags from 1977–2009 and screening of commercial catches at factories with metal detectors from 1986–2006. Reasons for this were threefold: Firstly, the methodology was the same both for release experiments and screening for all years, and all data handling related to it. Secondly, there were no reasons not to trust the screening process, meaning that externals running the metal detectors were trustworthy and run tests of efficiency according to plans. Thirdly, the data for this period was also very valuable as it overlapped with the period of the unreliable catch data, and it was decided to trust the tag data for this period to describe changes in the stock by having the catch data down weighted.

2) Data excluded:

- Steel tag screening data 2007–2010 were excluded from the time-series used in the assessment, this means that in reality releases from 2006–2009 were also excluded. The reasons for this were threefold: Firstly, the methods used to catch and handle mackerel changed in 2006, from manual jigging and tagged mackerel released at starboard side directly to sea, to automatic jigging machines and releasing tagger mackerel through pipe systems with running waters ending below surface at the port side. This change was done to reduce potential tagging mortality variation between manually operated tagging stations, and protect tags from gannets, i.e. potentially reducing tagging mortality. Still, one cannot exclude that this actually has increased the tagging mortality. Secondly, there were reasons to believe that problems in the screening process may have occurred after 2006. Problems occurred with externals doing the work with metal detectors, not testing the screening efficiency properly. It was also suspected that they reported a catch biomass that had been screen with metal detectors working fully, that was not true. Thirdly, the sensitivity runs with SAM suggested an increase in stock based on the screening years 2007–2010 that were far above signals from the other sources, which could be explained by both change in mortality from tagging and problems with screening.
- RFID time-series was not included. The reasons for this were threefold: Firstly, this time-series was also based on the same change in methodology

with automatic jigging system as in the 2006–2009 steel tag experiments, suggesting that it is not directly comparable with years prior to 2006 releases. We did not expect a change due to the actual a change in tag type, as tagging mortality will not change due to tag type, only change in handling. Secondly, there was a similar abrupt change in scale caused by RFID tagging data as the latest years of steel tags in SAM sensitivity runs that could support a change in tagging mortality with the automatic jigging. The actual screening efficiency of RFID has been properly tested prior to the benchmark as estimated between 99–100%, so the problem is not here. It was argued that the up scaling of mackerel biomass resulting from RFID data could not be properly explained. It was argued that the RFID time-series could not be connected with the steel tag series and must be treated as a separate series. Right now this time-series is only based on two tagging years, 2011–2012. Hence, it was decided that this time-series was for the future and that one after 2–3 more years could evaluate again the inclusion of this time-series in the assessment. It was strongly recommended to continue the time-series, especially given that the old time-series up to 2006 has turned out to be very valuable for the assessment.

3.6.2.3 Mackerel Egg Surveys

The NEA mackerel egg survey has been running triennially since 1977 and since 1992 has attempted to comprehensively survey both the southern and western components of the NEA mackerel stock. The North Sea survey has been running since 1968 and is currently completed in the year after the NEA mackerel egg survey (MEGS). The MEGS survey utilizes an adaptive survey methodology in the Northeast Atlantic that currently ranges from the Faroe Islands down as far south as Cadiz and provides a total annual egg production estimate (TAEP) for both components using the most recently spawned stage 1 mackerel eggs. The TAEP is then translated - after incorporating the relative realized fecundity estimate (RRF)- into a spawning-stock biomass estimate (SSB). (A comprehensive description of the methodologies utilized during the collection and subsequent analyses of the MEGS data can be found in the MEGS Survey and Fecundity manuals which are located as annexes in the 2103 WGMEGS report (ICES, 2013)). The SSB estimate provided by the triennial MEGS survey is the only source of fishery-independent data currently incorporated into the mackerel assessment and is a truly international survey with an indices of TAEP for the full time-series

Challenges Facing Current and Future MEGS Surveys

There are several significant challenges facing the MEGS survey, the most concerning of which is the temporal shift in the spawning pattern of the western mackerel to an ever earlier period within the calendar year. Evidence of this was first observed in 2010 when peak spawning was observed at unprecedented levels within the first survey period, midpoint at calendar day 84. With the nominal calendar day for the start of spawning in the western area set at day 41, this was already very close to that and despite commencing sampling in the western area two weeks earlier than 2010, the 2013 results yielded a spawning event in the western area that was both significantly larger but also much earlier with a calendar midpoint of day 68. This provides MEGS with a rather disturbing trend and also the very real possibility that spawning activity at the start of the season is being missed and therefore the submitted TAEP and SSB estimates are indeed underestimates. The survey has always been regarded and treated as an underestimate of total SSB; however the evidence indicates that for the 2013 survey estimate this may be higher compared to previous surveys. Is the survey failing to adequately survey a protracting spawning season that is commencing prior to the nominal start date?

Since 2007 the MEGS survey has also had to contend with a significant expansion of the spawning area. During the early years of the western MEGS survey sampling effort was prioritized within the peak spawning areas, notably the Porcupine Bank, Celtic Sea and Biscay regions. From 1986 and with increased survey effort, survey coverage was expanded northwards up to 59°30N. It was not however until 1995 that the adaptive survey methodology was fully implemented in an attempt to delineate fully the western boundaries of spawning. The main driver for adopting the adaptive approach over any 'standard area' was an acceptance that spawning activity was pushing through the boundaries of the 'standard area' and that significant spawning was taking place westwards and away from the 200m isobath where the main spawning aggregations are. From 1995 to 2004 this was achieved very effectively using the resources available to MEGS. In 2007 and to even greater degrees in 2010 and 2013, continuous spawning – albeit at relatively low levels – was recorded off the continental shelf west of Scotland as far as Hatton Bank at 20°W and this trend continued north into the new survey area north of 63°N around the Faroe Islands and south and east of Iceland. Other significant issues that occurred around this time included the withdrawal of Cefas from the MEGS survey although the impact of this was offset by the inclusion of Scotland funding a third survey. Despite the inclusion of the Faroe Islands and Iceland in 2010 the MEGS survey now finds itself fully stretched and in the position whereby in 2007, 2010 and 2013 not all boundaries in the north and west were fully delineated during all periods. The increase in overall survey area also means that an alternate transect design is now utilized routinely thereby increasing the number of interpolations used which correspondingly increases the overall CV of the survey. WGMEGS is well aware of all of the issues reported here and at its next meeting in Reykjavik in April 2014 it intends to tackle these issues whilst recognizing that any effective measures formulated will require additional survey resources and the call will go out to other nations with significant mackerel quota to offer survey time.

State of Historical MEGS dataset and current / future work

WKPELA was viewed as an ideal opportunity to explore and devise a new and more statistically robust method for estimating TAEP. In order to complete this task there was also a consequent necessity to recalculate the TAEP using the existing integration method for the entire survey series. This was especially relevant since WGMEGS had recently adopted the *Mendiola* mackerel development equation in 2011 (Mendiola *et al.*, 2006) and which was used in the 2013 TAEP estimation. This replaced the *Lockwood* equation (Lockwood *et al.*, 1981) and so therefore it is desirable to have complete TAEP/SSB indices for both with corresponding CV's. These multiple recalculations are however fully dependent on the historic dataset being collated and the data reformatted into a single coherent database. This forensic examination of the dataset (the first time it has been attempted) has proved to be a stiff challenge and has exposed numerous quality issues with the data from several of the earlier survey years. These issues are slowly being addressed and it is the intention of WGMEGS to incorporate all data from 1992 to 2013 in a standardized and coherent format such that full recalculations can be performed for both southern and western areas similar to that completed in the associated working document (Costas *et al.*, WD for

WKPELA 2014.) To estimate SSB from egg surveys it is equally important to have a good estimate of realized fecundity to convert the total egg production to spawning-stock biomass. Mackerel has always been considered a determinate spawner and in the past different methods have been used to estimate total realized fecundity (Damme and Thorsen, WD for WKPELA 2014). Currently the gravimetric method to estimate potential fecundity and the stereometric method to estimate atresia has been standardized and adopted by all participating institutes (Damme and Thorsen, WD for WKPELA 2014). An overview of realized fecundity and SSB for the MEGS time-series is given in the working document Damme and Thorsen (WD for WKPELA 2014).

In the absence of a fully standardized and quality checked database of egg observations, it was not possible to perform a full recalculation of the egg abundance indices, or to proceed further with applying modern statistical tools to the data. It was therefore the view of the benchmark working group that the "as-published" estimates contained in the various survey reports represent the state-of-the-art. These estimates have been collated and are included here as a working document. Work to produce a standardized approach is ongoing and it is the intention of the group that this will be available in time for the WGWIDE meeting in august 2014.

3.6.2.4 IBTS survey

A recruitment index was derived from catch data from the International Bottom Trawl Surveys (IBTS). Full documentation can be found in Jansen *et al*. (2014, WKPELA WD).

Trawling was done by research vessels from Scotland, Ireland, England and France collectively known as the international bottom-trawl surveys in October–December (IBTS Q4). The surveys sample the fish community on the continental shelf and upper shelf slope. IBTS Q4 covers the shelf from Spain to Scotland, excluding the North Sea. Trawling was done at 3.5–4.0 knots. Two trawls deviated substantially from the GOV-type, namely the Spanish BAKA trawl and the Irish trawl that was used from 1998 to 2002. The BAKA trawl had a vertical opening of only 2.1–2.2 m and was fished at only 3 knots. This was substantially less suitable for catching juvenile mackerel and therefore excluded from the analysis. The Irish trawl used in 1998 to 2002 was a GOV trawl in reduced dimensions. The reduced wingspread and trawl speed was accounted for in the model.

A geostatistical log-Gaussian Cox process mode model (LGC) with spatio-temporal correlations was used to describe the catch rates of mackerel recruits through space and time.

These catch rates were then averaged by year and expressed in relation to the mean of the time-series as a relative catch rate index.

The signal-to-noise ratio was examined by fitting similar models to the mackerel catch data in Q4 and Q1 (January–March), in the area where the two surveys overlapped (55–60°N, 4–10°W). The time-series from Q4 and Q1 were compared and found to be strongly positively correlated ($p<0.001$, $R^2=0.66$). The simplest explanation for this correlation is that catch rates in both surveys reflect the same recruitment signal from the mackerel population. It furthermore suggests that the applied method was appropriate to modelling the catch rates and the associated sampling noise. Finally, it indicates that the recruits are either relatively stationary from Q4 to Q1 or the time-series of the immigrants resembles the time-series of the emigrants. If there is any movement from Q4 to Q1, then we assume that the direction of the movement generally follow the environmentally driven southwestwards migration of the adults, away from the cooling waters in the downstream cold northwestern end of the shelf and shelf edge current (Jansen *et al.*, 2012b). In conclusion, model outputs from Q4 and Q1 can be combined to a model with a vast spatial coverage, where the recruits haven't been double counted due to temporal differences between surveys. The spatial catch rate surfaces could therefore be combined.

Field observations during acoustic and trawl surveys in October in the mackerel box (Celtic Sea, Peltic survey) suggested that mackerel catchability may increase exponentially with school size. Although the underlying mechanisms are likely to be complex there are several factors that appear likely. Fish in schools may not be able to successfully avoid an approaching trawl due to high fish densities limited movement; another possibility is that vessel avoidance may propagate through the school from fish in top of the school to those nearer the seabed. Visual exploration of echograms showed that an important contributing factor was density-dependent depth behaviour: small mackerel schools were generally observed in midwater whereas large and high density mackerel schools were consistently associated with the seabed. Schooling mackerel could therefore more easily out-manoeuvre the trawl, given the fact that they can escape in multiple directions. The proximity of larger schools to the seabed would make them more accessible to the bottom-trawl gear. This effect may be further amplified by the reported diving behaviour of the mackerel at the top of the school, in response to an approaching vessel (Slotte *et al.*, 2007). Although catchability is a complex process affected by many factors, the above observations suggest therefore that density-dependent transformations of the catch rates are required.

Conclusion

- The strong correlation between the independent sampled and modelled catch rate in Q1 and Q4 suggests that catch rates in both surveys reflect the same recruitment signal from the mackerel population. It furthermore suggests that the applied method was appropriate to modelling the catch rates and the associated sampling noise.
- A hypothesis of positive density dependant catchability was suggested and acoustic observations supporting the hypothesis were presented. Log transformation of the cpue index as well as modification of the index calculation was done to reduce the density effect. Correlations with the assessment recruitment time-series improved substantially in both cases, further supporting the hypothesis.
- Further work on extending the Q4-model with data from IBTS Q1 in the North Sea and other northern areas is recommended.
- The 4th quarter IBTS survey data is to be included in the assessment as an age structured index of 0 group mackerel.

3.6.2.5 Continuous Plankton Recorder (CPR) derived larval index to supplement the mackerel egg data from the triennial egg survey

Due to its wide distribution and highly migratory behaviour, dedicated surveys covering the entire NEA mackerel stock are expensive and logistically complex. The triennial egg survey (MEGS) has been the single most important fisheries-independent survey used for the stock assessment of NEA mackerel over the last decades. However, it takes place every third year and any additional data that could supplement this survey would be very helpful to underpin the management.

The Continuous Plankton Recorder (CPR) dataset covers large areas over prolonged periods of time at high spatial and temporal resolution. Although designed and traditionally used to sample and explore the zooplankton community, recently the value of the CPR dataset as a tool to provide novel information on fish larvae in support of assessment and ecological understanding of selected fish stocks (Pitois *et al.*, 2012; Lynam *et al.*, 2013). Positive results were also obtained for North Sea mackerel, where the larval index from the CPR was found to be a usable proxy for eggs hatched in the North Sea (Jansen *et al.*, 2012a).

The aim of this scoping study is to explore relationships between CPR derived larvae indices and the western MEGS derived mackerel eggs for the ten years that data were collected concurrently (triennially between 1977–2004). A positive relationship between the two would indicate that the CPR larval index could be used to predict the NEA mackerel spawning-stock biomass on an annual basis (including the years that no survey data exist). Apart from fine-tuning historic time-series, updating the larval time-series beyond 2005 would provide an opportunity to provide a priori information to support assessment.

Due to variable coverage between the CPR and MEGS data, a Log Gaussian Cox model was used to interpolate the MEGS data to match the spatial coverage with the larvae data from CPR. Preliminary results suggest reasonable agreement between the two time-series but irregularities in the egg database for some older surveys need to be thoroughly checked out before work can proceed. Although this study is too early to be considered for this (2014) benchmark, it is recommended that this work continues, and that the CPR samples are routinely processed to extract larval densities, should a reliable relationship been found between the MEGS and CPR data.

3.6.3 Weights, maturities, growth

- Proportion of natural and fishing mortality before spawning (M_{prop} and F_{prop})

Timing of spawning has changed over the period covered by the egg survey, which called for a revision of the M_{prop} and F_{prop} value. Assuming the natural mortality applies constantly over the years, M_{prop} is equivalent to the proportion of the year at which spawning occurs. Given that spawning usually occurs from February to July, spawning time was defined, as in the previous assessment, by the day of the year at which 50% of the annual egg production was reached. Using this definition, spawning time was calculated both for the southern and western spawning components by linearly interpolating between the points of the annual egg production curves, and determining the day at which half of the production is reached. The annual M_{prop} values for each component where then averaged, using the proportion of eggs produced by each component as a weighting factor. The resulting M_{prop} time-series shows a decline from 1992 until 2007, followed by a massive drop in 2010 (Figure 3.6.3.1).

Calculation of F_{prop} at age is explained in detail in a working document (Brunel, 2014a WD to WKPELA) and takes into account the M_{prop} values for each survey years and the proportion of catches taken before spawning time. Hierarchical clustering was applied to investigate the similarities in both the level of F_{prop} at age and the variations among age groups. It was concluded that F_{prop} could be averaged over ages 1–2, ages 3–4 and ages 5 and older. The final time-series of F_{prop} for all survey years are shown on Figure 3.6.3.2.

The matrices of M_{prop} and F_{prop} at age for all years were obtained by linearly interpolating between egg survey years. For the years after the most recent survey, the values for the year of the most recent survey should be used until a new survey is available, at which point they should be replaced by a linear interpolation.

- Mean weights-at-age in the stock

For NEA mackerel, mean weights-at-age in the stock are calculated as the mean of weight-at-age in the three spawning components, weighted by the size of each component as estimated by the egg surveys. Weights-at-age in the stock are used for the computation of SSB in the model and are hence calculated based on data corresponding to spawning time and coming from spawning grounds. For the western spawning component, the number of samples available from the commercial catches has dramatically declined in the recent years, resulting, in years when no samples for the egg survey are available, in very imprecise mean weights for this component.

In order to increase the number of samples available from the fishery for the western spawning component, new, less restrictive selection criteria were defined (Table 3.6.3.1). This was achieved by studying which areas were found to recurrently be part of the core spawning distribution, as reflected by the egg surveys from 1992 to 2013. More details about the method used can be found in a working document (Brunel, 2014b working document to WKPELA). Unfortunately, increasing the area over which catch samples could be used did not result in an increase in the number of samples available.

The possibility of using the catch samples over the first quarter instead of at spawning time for computing mean weights-at-age for the western spawning component was also explored, since much more samples are available from the January and February fisheries. A systematic difference was found in the mean weights, indicating a loss of weight between quarter 1 and spawning time, possibly due to the fact that the fish is migrating and not actively feeding.

The difference in mean weights according to the maturity stage of the fish was explored. Immature fish was significantly lighter than the mature fish of a same age, and it was decided to exclude the immature fish from the mean weight-at-age in the stock calculation. Stock weights being primarily used to compute the SSB, it should reflect the weight of fish contributing to the reproductive output. No systematic difference was found between the weight of prespawning, spawning and post-spawning fish (see working document), and all mature stages should then be used to compute the means.

The inclusion of the weights samples taken during the Norwegian tagging programme was investigated. For the time period where enough samples were available from both the catches and the tagging data to make a meaningful comparison, mean weights calculated from the tagging samples were in reasonable agreement with the other sources of data see working document). It was therefore concluded that this source of data was a useful complement to the catches and egg survey samples for computing the mean weights-at-age in the western spawning component.

The mean weights-at-age in the stock for the western spawning component was then calculated based on all catches, egg survey and tagging samples, corresponding to the spawning criteria in Table 3.6.3.1. Since no growth seems to take place between the month covering spawning, no monthly stratification was used when computing the mean weights at age. F_{prop} values show.

The time-series of the updated weights-at-age for the western component, the existing time-series for the North Sea and Southern component and the average over the three components are given on Table 3.6.3.2. The new NEA mackerel stock weights are in good agreement with the previous time-series, except for ages 1 and 2 which are now based on mature fish only. The new time-series incorporates more data than the previous one.

- Proportion of mature fish at age

The proportions of individuals mature at age used in the NEA mackerel assessment are calculated as the mean of the proportions of fish mature in each spawning component, weighted by the size of each component, as estimated by the egg surveys. The maturity ogives of the three spawning components are constant in time, and periodically revised (for the maturity ogives of each component, see the last available WGWIDE report). For the Western spawning component, the present ogive was estimated in 1985 from Dutch commercial and research vessel samples taken from April to August in ICES Subdivision VIa south, VIIb,e,f,g,h,j. (ICES 1997). New maturity data were analysed in 1996, but there was no major deviation from the 1985 values and the ogive was not changed.

Using the dataset collated to investigate mean weights in the stock in the western component, the proportion of fish mature at age was investigated. First, the mean proportions of individual mature were calculated separately for the three data sources, and compared with the maturity ogive previously used (Figure 3.6.3.3). The proportions calculated from the catch samples were very similar to the previous ogive (derived from similar type of data but for a much shorter time-series). The proportion mature calculated from the egg survey and tagging samples were much higher than the previous ogive for young ages. This corroborate the findings from the ICES (1997), which concluded that the egg survey and the tagging data were not appropriate to estimating a maturity ogive, because the fish was mainly sampled on the spawning grounds, and hence was representative mostly of the mature fraction of the young age classes.

The assumption of a time invariant maturity ogive is frequently made in assessments. However, this is ignoring the dynamic nature of fish biology. Since the growth and maturation are interrelated, and given the changes in growth which have happened in the recent history for NEA mackerel, temporal changes in maturation were investigated. Fitting a logistic regression to the maturity data from the commercial catch samples (February to July) indicated that age, but also length, significantly influenced the proportion of fish mature at age (see Brunel, 2014c working document to WKPELA). Fitting a similar model using groups of years as factor indicated that the age at 50% mature decreased from 2.7 years in the early 1980s to 1.9 years in the early 2000s and subsequently increased to around 2.3 in the most recent years. This overall trend is coherent with the changes in growth, especially the recent slowing of growth which is synchronous with a slowing maturation.

Proportions of mature fish at age were calculated grouping the data in blocks of five years, and moving this five year window from 1980 to 2012. The uncertainty associated to the time varying proportions of mature individuals is small, except for the age 1 fish. Proportions mature for age 1 also display very abrupt variations which are not reflected in the proportion mature at age 2 in subsequent years. The number of age 1 fish in the samples available from the catches is very low, especially for the year before 1995. It was hence judged more appropriate to replace the time varying proportions of mature fish at age 1 by the mean of the time-series. The resulting time-series for the western component is shown on Figure 3.6.3.4 and Table 3.6.3.3, together with the values used for the North Sea and Southern component and the weighted mean of the three components which was used as an input data in the assessment.

Table 3.6.3.1. New proposed data selection criterions for the computation of the mean weights-at-age in the western spawning component. The core of the spawning distribution was defined from the analysis of the annual egg production maps. The June data were arbitrarily not included since they are not representative of spawning time as define for the computation of M and F_{prop}.

Egg survey period	months	ICES subdivision
3	March	VIIb,j,h,VIIIa,b
4	April	VIa,VIIb,c,j,h VIIIa
5	May	VIa,VIIb,c,j,k,VIIIa,d
6	June	VIa,VIIb,j,h
7	July	NA

Table 3.6.3.2. Historic mean weight-at-age in the stock for each spawning component and for the whole stock (with relative proportions of each spawning component). Calculation of the mean weights-at-age in the stock of the NEA mackerel based on weighting by SSB's from egg surveys (1984–recent).

PROPORTION OF EACH SPAWNING COMPONENT BASED ON EGG SURVEYS																
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
North Sea	0.116	0.086	0.080	0.074	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037
Western	0.756	0.786	0.792	0.798	0.835	0.835	0.835	0.835	0.835	0.835	0.835	0.835	0.835	0.835	0.835	0.835
Southern	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128
Stock weights NORTH SEA MACKEREL																
Age	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.180	0.180	0.180	0.180	0.138	0.138	0.138	0.138	0.138	0.138	0.138	0.138	0.138	0.138	0.138	0.138
2	0.275	0.275	0.275	0.275	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230
3	0.330	0.330	0.330	0.330	0.314	0.314	0.314	0.314	0.314	0.314	0.314	0.314	0.314	0.314	0.314	0.314
4	0.415	0.415	0.415	0.415	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357
5	0.460	0.460	0.460	0.460	0.438	0.438	0.438	0.438	0.438	0.438	0.438	0.438	0.438	0.438	0.438	0.438
6	0.495	0.495	0.495	0.495	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464
7	0.525	0.525	0.525	0.525	0.418	0.418	0.418	0.418	0.418	0.418	0.418	0.418	0.418	0.418	0.418	0.418
8	0.550	0.550	0.550	0.550	0.471	0.471	0.471	0.471	0.471	0.471	0.471	0.471	0.471	0.471	0.471	0.471
9	0.565	0.565	0.565	0.565	0.529	0.529	0.529	0.529	0.529	0.529	0.529	0.529	0.529	0.529	0.529	0.529
10	0.590	0.590	0.590	0.590	0.545	0.545	0.545	0.545	0.545	0.545	0.545	0.545	0.545	0.545	0.545	0.545
12+	0.647	0.636	0.646	0.648	0.665	0.665	0.665	0.665	0.665	0.665	0.665	0.665	0.665	0.665	0.665	0.665
Stock weights WESTERN MACKEREL																
Age	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995

PROPORTION OF EACH SPAWNING COMPONENT BASED ON EGG SURVEYS																
0																
1								0.067			0.096	0.188			0.112	
2	0.193	0.163	0.138	0.165	0.199	0.246	0.171	0.150	0.175	0.158	0.161	0.183	0.202	0.185	0.157	0.195
3	0.283	0.248	0.197	0.217	0.244	0.278	0.264	0.225	0.235	0.221	0.244	0.242	0.259	0.262	0.234	0.271
4	0.307	0.299	0.285	0.263	0.280	0.302	0.287	0.305	0.298	0.258	0.284	0.302	0.307	0.321	0.295	0.318
5	0.337	0.315	0.358	0.325	0.308	0.322	0.338	0.356	0.349	0.325	0.322	0.344	0.357	0.355	0.362	0.377
6	0.352	0.356	0.340	0.409	0.381	0.333	0.336	0.404	0.397	0.377	0.377	0.387	0.395	0.408	0.413	0.427
7	0.373	0.396	0.391	0.384	0.421	0.394	0.344	0.396	0.455	0.370	0.430	0.421	0.419	0.431	0.459	0.454
8	0.406	0.409	0.442	0.419	0.437	0.436	0.421	0.405	0.449	0.438	0.439	0.494	0.459	0.457	0.476	0.487
9	0.407	0.434	0.436	0.462	0.476	0.423	0.424	0.459	0.473	0.411	0.488	0.497	0.488	0.475	0.488	0.503
10	0.459	0.422	0.453	0.446	0.499	0.507	0.451		0.509	0.406	0.464	0.550	0.513	0.517	0.550	0.506
11	0.500	0.510	0.525	0.536	0.501	0.529	0.482	0.468	0.580	0.463	0.480	0.526	0.545	0.552	0.592	0.556
12+	0.487	0.502	0.511	0.506	0.568	0.574	0.524	0.583	0.598	0.534	0.517	0.594	0.562	0.560	0.591	0.586
Stock weights SOUTHERN MACKEREL																
Age	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
0	0.063	0.063	0.063	0.063												
1	0.128	0.128	0.128	0.128	0.137	0.164	0.107	0.116	0.069	0.098	0.081	0.093	0.116	0.111	0.122	0.134
2	0.213	0.213	0.213	0.213	0.230	0.241	0.260	0.183	0.204	0.168	0.178	0.174	0.183	0.211	0.179	0.229
3	0.271	0.271	0.271	0.271	0.281	0.296	0.294	0.268	0.237	0.264	0.253	0.226	0.253	0.277	0.257	0.309
4	0.322	0.322	0.322	0.322	0.356	0.332	0.378	0.386	0.277	0.340	0.310	0.295	0.303	0.326	0.360	0.381
5	0.376	0.376	0.376	0.376	0.415	0.401	0.404	0.425	0.314	0.390	0.365	0.340	0.360	0.361	0.388	0.422
6	0.416	0.416	0.416	0.416	0.465	0.476	0.410	0.459	0.337	0.468	0.401	0.403	0.395	0.403	0.433	0.460
7	0.460	0.460	0.460	0.460	0.491	0.492	0.554	0.534	0.387	0.497	0.475	0.439	0.424	0.441	0.468	0.496
8	0.490	0.490	0.490	0.490	0.567	0.578	0.510	0.594	0.392	0.510	0.494	0.484	0.448	0.466	0.511	0.529

PROPORTION OF EACH SPAWNING COMPONENT BASED ON EGG SURVEYS															
9	0.505	0.505	0.505	0.505	0.559	0.581	0.429	0.621	0.403	0.542	0.525	0.505	0.465	0.495	0.541	0.554
10	0.530	0.530	0.530	0.530	0.546	0.595	0.554	0.592	0.476	0.542	0.507	0.521	0.508	0.492	0.551	0.582
11	0.553	0.553	0.553	0.553	0.582	0.590	0.649	0.629	0.490	0.591	0.574	0.517	0.524	0.514	0.600	0.588
12+	0.594	0.594	0.594	0.594	0.520	0.643	0.591	0.529	0.536	0.643	0.584	0.700	0.562	0.656	0.664	0.674
Stock weights NEA MACKEREL																
Age	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
0	0.063	0.063	0.063	0.063	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.120	0.118	0.118	0.117	0.114	0.118	0.111	0.076	0.106	0.109	0.096	0.174	0.112	0.111	0.114	0.114
2	0.205	0.179	0.159	0.179	0.204	0.244	0.184	0.157	0.181	0.162	0.166	0.184	0.201	0.190	0.163	0.201
3	0.287	0.258	0.217	0.233	0.251	0.281	0.269	0.234	0.238	0.230	0.247	0.243	0.260	0.266	0.240	0.278
4	0.322	0.312	0.300	0.282	0.293	0.308	0.301	0.318	0.298	0.272	0.290	0.303	0.308	0.323	0.306	0.327
5	0.356	0.335	0.368	0.341	0.326	0.336	0.350	0.368	0.348	0.338	0.332	0.347	0.360	0.359	0.368	0.385
6	0.377	0.376	0.362	0.416	0.395	0.356	0.350	0.414	0.392	0.392	0.383	0.392	0.397	0.410	0.418	0.432
7	0.402	0.415	0.411	0.404	0.430	0.407	0.374	0.415	0.445	0.388	0.435	0.423	0.419	0.432	0.459	0.458
8	0.434	0.431	0.456	0.438	0.455	0.455	0.434	0.431	0.442	0.449	0.447	0.492	0.458	0.459	0.480	0.491
9	0.438	0.454	0.455	0.475	0.489	0.447	0.428	0.483	0.466	0.432	0.494	0.500	0.487	0.480	0.496	0.511
10	0.484	0.450	0.473	0.467	0.507	0.519	0.467	0.509	0.506	0.429	0.473	0.546	0.513	0.515	0.550	0.517
11	0.520	0.524	0.536	0.544	0.513	0.538	0.506	0.492	0.567	0.482	0.495	0.526	0.543	0.547	0.592	0.560
12+	0.519	0.525	0.533	0.528	0.565	0.586	0.538	0.579	0.593	0.553	0.531	0.611	0.566	0.576	0.603	0.600

Table 3.6.3.2. Continued.

PROPORTION OF EACH SPAWNING COMPONENT BASED ON EGG SURVEYS																
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
North Sea	0.018	0.018	0.018	0.028	0.028	0.028	0.028	0.028	0.028	0.040	0.040	0.040	0.037	0.037	0.037	0.030
Western	0.773	0.773	0.773	0.848	0.848	0.848	0.873	0.873	0.873	0.760	0.760	0.760	0.770	0.770	0.770	0.740
Southern	0.210	0.210	0.210	0.124	0.124	0.124	0.099	0.099	0.099	0.200	0.200	0.200	0.193	0.193	0.193	0.230
Stock weights NORTH SEA MACKEREL																
Age	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000
1	0.138	0.138	0.138	0.138	0.120	0.120	0.120	0.114	0.114		0.083		0.104		0.100	0.113
2	0.230	0.230	0.230	0.230	0.209	0.209	0.209	0.233	0.233		0.172	0.173	0.221	0.179	0.200	0.174
3	0.314	0.314	0.314	0.314	0.295	0.295	0.295	0.271	0.271		0.229	0.247	0.269	0.237	0.231	0.260
4	0.357	0.357	0.357	0.357	0.342	0.342	0.342	0.341	0.341		0.262	0.269	0.315	0.304	0.309	0.307
5	0.438	0.438	0.438	0.438	0.364	0.364	0.364	0.400	0.400		0.313		0.342	0.326	0.333	0.357
6	0.464	0.464	0.464	0.464	0.437	0.437	0.437	0.445	0.445		0.369	0.327		0.372	0.368	0.378
7	0.418	0.418	0.418	0.418	0.444	0.444	0.444	0.489	0.489					0.337	0.348	0.428
8	0.471	0.471	0.471	0.471	0.429	0.429	0.429	0.467	0.467		0.510		0.366	0.441	0.441	0.486
9	0.529	0.529	0.529	0.529	0.509	0.509	0.509									0.454
10	0.545	0.545	0.545	0.545	0.606	0.606	0.606									0.425
11	0.550	0.550	0.550	0.550	0.643	0.643	0.643									0.510
12+	0.665	0.665	0.665	0.665	0.550	0.550	0.550									0.532
Stock weights WESTERN MACKEREL																
Age	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
0																

PROPORTION OF EACH SPAWNING COMPONENT BASED ON EGG SURVEYS																
1		0.078				0.108	0.114				0.084	0.142				
2	0.204	0.168	0.216	0.196	0.188	0.206	0.180	0.154	0.134	0.158	0.153	0.167	0.158	0.159	0.172	0.156
3	0.249	0.251	0.261	0.255	0.243	0.245	0.250	0.258	0.221	0.237	0.204	0.211	0.211	0.201	0.212	0.209
4	0.306	0.295	0.322	0.298	0.300	0.285	0.274	0.314	0.330	0.289	0.284	0.269	0.270	0.249	0.268	0.246
5	0.353	0.347	0.354	0.356	0.336	0.332	0.339	0.352	0.378	0.327	0.329	0.357	0.293	0.298	0.336	0.279
6	0.396	0.386	0.397	0.391	0.396	0.353	0.402	0.403	0.403	0.402	0.354	0.360	0.346	0.340	0.375	0.300
7	0.464	0.411	0.433	0.416	0.412	0.416	0.404	0.448	0.465	0.403	0.451	0.383	0.394	0.386	0.385	0.351
8	0.475	0.459	0.467	0.437	0.449	0.424	0.496	0.482	0.481	0.429	0.452	0.462	0.448	0.410	0.423	0.370
9	0.505	0.480	0.496	0.465	0.482	0.451	0.491	0.507	0.554	0.463	0.513	0.453	0.475	0.437	0.450	0.447
10	0.507	0.542	0.516	0.486	0.521	0.509	0.484	0.514	0.535	0.448	0.534	0.478	0.526	0.489	0.486	0.503
11	0.547	0.504	0.556	0.514	0.530	0.521	0.520	0.579	0.500	0.513	0.529	0.475	0.548	0.545	0.524	0.505
12+	0.568	0.541	0.581	0.545	0.575	0.543	0.538	0.591	0.608	0.554	0.587	0.510	0.556	0.578	0.534	0.575
Stock weights SOUTHERN MACKEREL																
Age	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
0																
1	0.100	0.099	0.118	0.085	0.127	0.117	0.094	0.125	0.169	0.090	0.077	0.107	0.112	0.112	0.123	0.102
2	0.165	0.178	0.185	0.172	0.196	0.206	0.176	0.168	0.169	0.178	0.129	0.135	0.165	0.179	0.213	0.143
3	0.281	0.235	0.255	0.227	0.259	0.233	0.245	0.260	0.210	0.228	0.210	0.187	0.213	0.218	0.243	0.202
4	0.319	0.310	0.294	0.307	0.320	0.293	0.283	0.346	0.315	0.297	0.308	0.224	0.250	0.259	0.265	0.253
5	0.363	0.344	0.357	0.344	0.382	0.335	0.353	0.375	0.368	0.345	0.338	0.306	0.293	0.290	0.301	0.292
6	0.413	0.367	0.370	0.401	0.404	0.392	0.378	0.423	0.397	0.391	0.393	0.338	0.367	0.362	0.329	0.327
7	0.447	0.398	0.391	0.421	0.445	0.428	0.423	0.449	0.448	0.436	0.443	0.443	0.361	0.367	0.357	0.352
8	0.469	0.439	0.415	0.439	0.470	0.457	0.441	0.487	0.482	0.458	0.439	0.400	0.409	0.388	0.386	0.381
9	0.506	0.450	0.459	0.450	0.491	0.489	0.478	0.497	0.497	0.417	0.491	0.438	0.408	0.385	0.398	0.431
10	0.525	0.481	0.478	0.498	0.502	0.504	0.489	0.537	0.543	0.523	0.483	0.454	0.499	0.461	0.434	0.476

PROPORTION OF EACH SPAWNING COMPONENT BASED ON EGG SURVEYS																
11	0.541	0.480	0.504	0.505	0.545	0.514	0.492	0.558	0.555	0.578	0.528	0.501	0.555	0.487	0.486	0.493
12+	0.597	0.545	0.523	0.538	0.570	0.645	0.551	0.584	0.558	0.614	0.590	0.510	0.568	0.536	0.470	0.492
Stock weights NEA MACKEREL																
Age	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.108	0.083	0.112	0.108	0.112	0.109	0.112	0.111	0.116	0.107	0.083	0.135	0.110	0.111	0.112	0.108
2	0.196	0.172	0.210	0.194	0.190	0.206	0.181	0.158	0.140	0.165	0.149	0.160	0.162	0.163	0.181	0.153
3	0.257	0.248	0.260	0.253	0.246	0.245	0.251	0.258	0.221	0.238	0.206	0.207	0.214	0.206	0.219	0.209
4	0.310	0.299	0.317	0.301	0.303	0.288	0.277	0.318	0.328	0.293	0.288	0.260	0.268	0.253	0.269	0.250
5	0.356	0.348	0.356	0.357	0.342	0.333	0.341	0.355	0.378	0.334	0.330	0.349	0.295	0.297	0.329	0.284
6	0.401	0.383	0.392	0.394	0.398	0.360	0.401	0.406	0.403	0.402	0.362	0.354	0.354	0.346	0.366	0.309
7	0.460	0.409	0.424	0.416	0.417	0.418	0.407	0.449	0.464	0.411	0.448	0.397	0.389	0.380	0.378	0.353
8	0.473	0.455	0.456	0.438	0.451	0.429	0.489	0.482	0.481	0.436	0.452	0.450	0.437	0.407	0.417	0.376
9	0.505	0.475	0.489	0.464	0.484	0.458	0.490	0.507	0.548	0.456	0.509	0.453	0.464	0.431	0.443	0.443
10	0.511	0.530	0.508	0.489	0.521	0.511	0.488	0.517	0.536	0.467	0.525	0.476	0.522	0.486	0.479	0.494
11	0.546	0.500	0.545	0.514	0.535	0.523	0.521	0.577	0.507	0.528	0.530	0.484	0.550	0.535	0.518	0.502
12+	0.576	0.544	0.570	0.547	0.573	0.556	0.540	0.591	0.604	0.569	0.590	0.515	0.562	0.572	0.525	0.555

Table 3.6.3.3. Historic proportions of fish mature at age for each spawning component and for the whole stock (with relative proportions of each spawning component).

PROPORTION OF EACH STOCK COMPONENT																
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
North Sea	0.116	0.086	0.079	0.073	0.032	0.032	0.032	0.032	0.032	0.032	0.0372	0.0372	0.0372	0.0372	0.0372	0.0372
Western	0.755	0.786	0.793	0.799	0.85	0.85	0.85	0.85	0.835	0.835	0.835	0.835	0.835	0.835	0.835	0.835
Southern	0.128	0.127	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.1278	0.1278	0.1278	0.1278	0.1278	0.1278
North Sea spawning component																
Age	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
0	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	0
2	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
3	1	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	1
5	1	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	1
7	1	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	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Western spawning component																
Age	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995

PROPORTION OF EACH STOCK COMPONENT																
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135
2	0.496	0.511	0.520	0.545	0.482	0.484	0.495	0.394	0.384	0.402	0.387	0.458	0.527	0.569	0.627	0.586
3	0.839	0.815	0.892	0.898	0.891	0.912	0.954	0.954	0.946	0.945	0.941	0.95	0.962	0.966	0.975	0.952
4	0.910	0.897	0.916	0.962	0.961	0.960	0.986	0.988	0.987	0.991	0.993	0.991	0.994	0.994	0.996	0.998
5	0.951	0.962	0.961	0.988	0.986	0.985	0.987	0.994	0.993	0.998	0.998	0.997	0.998	0.998	0.998	0.998
6	0.973	0.971	0.974	0.993	0.994	0.993	0.995	0.997	0.996	0.997	1	0.997	0.995	0.995	0.995	0.995
7	0.977	0.974	0.973	0.992	0.993	0.995	1	1	1	1	1	1	0.998	0.998	0.998	0.998
8	1	0.998	0.998	0.998	0.997	0.996	0.996	0.996	0.996	0.996	0.997	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Southern spawning component																
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
2	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
3	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
4	1	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	1
6	1	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	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

PROPORTION OF EACH STOCK COMPONENT																
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
NEA mackerel																
Age	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0.105	0.109	0.110	0.110	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
2	0.487	0.503	0.511	0.531	0.485	0.487	0.496	0.412	0.403	0.418	0.406	0.465	0.523	0.558	0.606	0.572
3	0.840	0.816	0.876	0.880	0.871	0.888	0.923	0.923	0.916	0.916	0.912	0.919	0.930	0.936	0.940	0.922
4	0.932	0.919	0.933	0.970	0.968	0.966	0.988	0.990	0.989	0.993	0.994	0.992	0.995	0.995	0.997	0.995
5	0.963	0.970	0.969	0.990	0.988	0.988	0.989	0.995	0.994	0.998	0.999	0.997	0.998	0.998	0.998	0.998
6	0.980	0.977	0.980	0.994	0.995	0.994	0.996	0.997	0.997	0.998	1	0.997	0.996	0.996	0.996	0.996
7	0.982	0.979	0.979	0.994	0.994	0.996	1	1	1	1	1	1	0.998	0.998	0.998	0.998
8	1	0.998	0.998	0.998	0.997	0.997	0.997	0.996	0.997	0.997	0.997	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 3.6.3.3. Continued.

PROPORTION OF EACH STOCK COMPONENT																	
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
North Sea	0.037	0.017	0.017	0.017	0.027	0.027	0.027	0.028	0.028	0.028	0.04	0.04	0.04	0.037	0.037	0.037	0.03
Western	0.835	0.772	0.772	0.772	0.848	0.848	0.848	0.873	0.873	0.873	0.76	0.76	0.76	0.77	0.77	0.77	0.74
Southern	0.127	0.209	0.209	0.209	0.124	0.124	0.124	0.099	0.099	0.099	0.2	0.2	0.2	0.193	0.193	0.193	0.23
North Sea spawning component																	
Age	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
0	0	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	0	0
2	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
3	1	1	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	1	1
5	1	1	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	1	1
7	1	1	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	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Western spawning component																	
Age	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012

PROPORTION OF EACH STOCK COMPONENT																	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135
2	0.604	0.631	0.654	0.629	0.659	0.654	0.729	0.734	0.75	0.733	0.732	0.640	0.611	0.606	0.557	0.568	0.546
3	0.945	0.898	0.917	0.917	0.932	0.936	0.977	0.964	0.965	0.966	0.964	0.953	0.960	0.960	0.956	0.960	0.972
4	0.996	0.982	0.984	0.984	0.984	0.981	0.993	0.988	0.988	0.989	0.992	0.991	0.994	0.99	0.996	0.995	0.995
5	1	0.996	0.996	0.996	0.996	0.995	0.999	0.999	0.997	0.998	0.998	0.998	0.997	0.999	0.999	0.999	0.998
6	0.997	0.997	0.99	0.998	0.998	0.997	0.999	0.999	0.998	0.998	1	1	1	1	0.999	0.999	0.998
7	0.998	1	1	1	1	0.998	0.998	0.998	0.998	0.998	1	1	1	1	1	1	1
8	1	0.997	0.997	0.998	0.998	0.998	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Southern spawning component																	
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
2	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
3	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
4	1	1	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	1	1
6	1	1	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	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

PROPORTION OF EACH STOCK COMPONENT																	
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
NEA mackerel																	
Age	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0.115	0.109	0.109	0.109	0.117	0.117	0.117	0.120	0.120	0.120	0.107	0.107	0.107	0.108	0.108	0.108	0.105
2	0.587	0.607	0.625	0.606	0.636	0.632	0.696	0.704	0.718	0.704	0.679	0.609	0.587	0.585	0.547	0.555	0.539
3	0.915	0.859	0.873	0.873	0.905	0.909	0.943	0.938	0.940	0.941	0.912	0.904	0.909	0.911	0.908	0.911	0.910
4	0.997	0.986	0.987	0.987	0.986	0.984	0.994	0.990	0.990	0.990	0.994	0.993	0.995	0.997	0.996	0.996	0.996
5	1	0.997	0.997	0.997	0.997	0.996	0.999	0.999	0.997	0.998	0.998	0.998	0.998	0.999	0.999	0.999	0.999
6	0.998	0.998	0.998	0.998	0.998	0.997	0.999	0.999	0.999	0.999	1	1	1	1	0.999	0.999	0.999
7	0.998	1	1	1	1	0.998	0.998	0.998	0.998	0.998	1	1	1	1	1	1	1
8	1	0.998	0.998	0.998	0.998	0.998	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

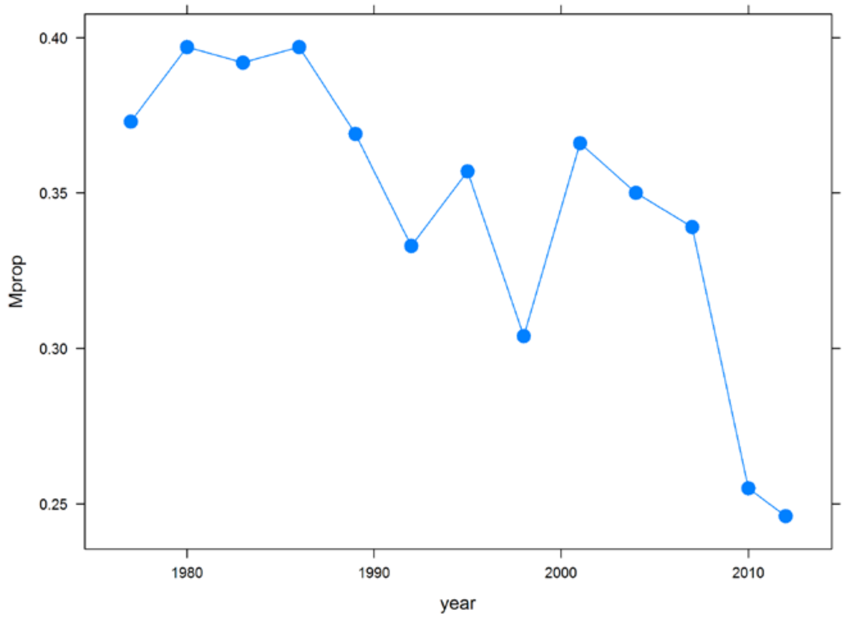


Figure 3.6.3.1. Time-series of the M_{prop} for each egg survey year.

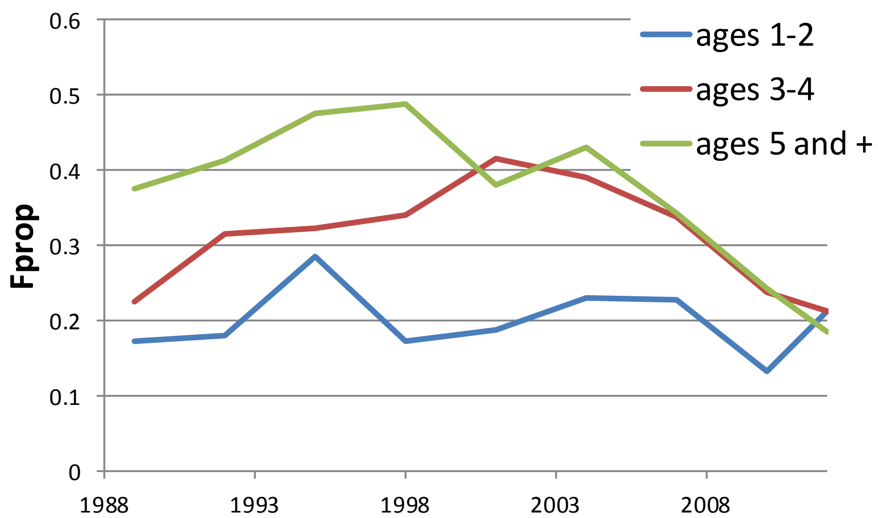


Figure 3.6.3.2. Time-series of F_{prop} averaged over age groups.

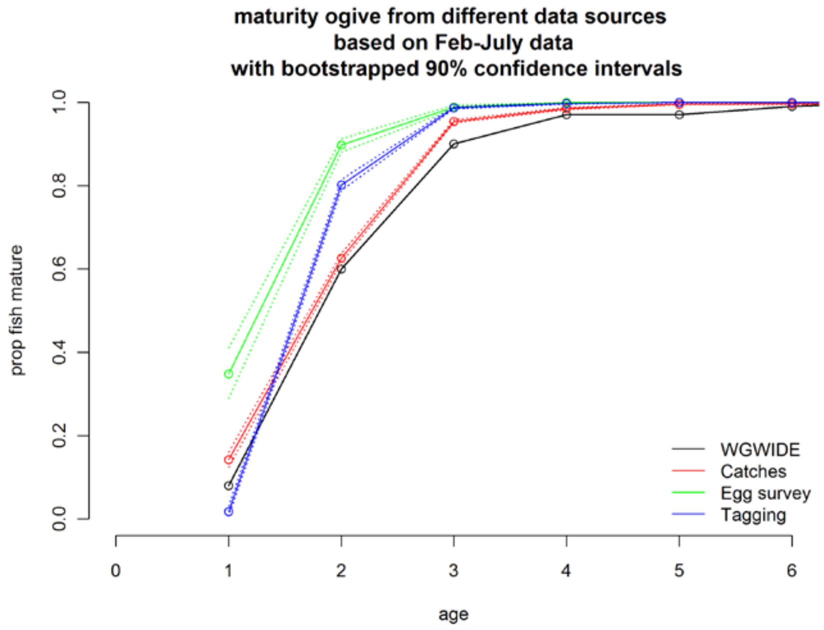


Figure 3.6.3.3. Average proportions of mature fish at age from the samples of the commercial catches, the egg survey and the Norwegian tagging programme compared with the maturity ogive used in the previous assessment for the Western spawning component.

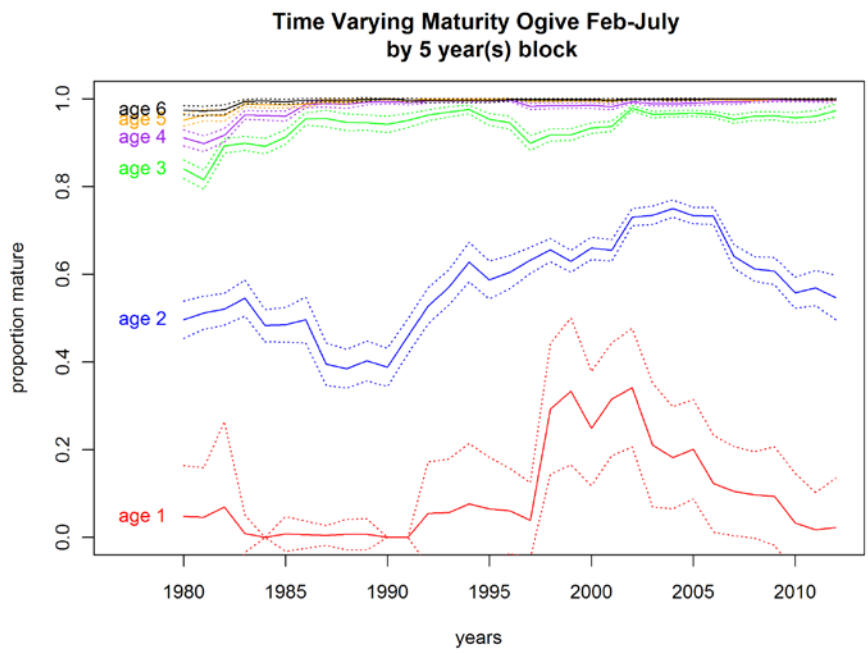


Figure 3.6.3.4. Proportion of individuals mature per age class and confidence intervals, calculated using a five year moving time windows.

3.6.3.1 Changes in mackerel growth from 1984 to 2013 (data not used for stock assessment)

Purse-seine samples were collected from the commercial Norwegian purse-seine fleet fishing in the northern North Sea (latitude 57°N to 65°N and longitude -6°W to 8°E) in September and October from 1984 to 2013. Mackerel samples were frozen at sea and sent to Institute of Marine Research, Bergen, Norway, for measuring and ageing of individuals (Mjanger *et al.*, 2012). Sample size was 100 randomly selected specimens. For each fish, total length (±1 cm), total weight (±1 g), age (years), sex, and maturity (8 stage-scale) were recorded. Age of caught mackerel ranged from 0 to 22 years old, but numbers were limited (n <10) for the youngest and oldest age class-year combinations, hence, analysis was limited to age classes 3 to 8 years. The age range 3 to 8 years represents >90% of the mature stock (Nøttestad *et al.*, 2010–2013). In total, 26 159 individuals, collected at 640 stations, were used for analysis. Altogether, 99.8% of all individuals were mature, including 98.3% of three year olds. Length of mackerel, aged 3 to 8 years old, ranged from 26 to 45 cm. To provide sufficient numbers (>10) of individuals per year; length combination, the length range was split into 2 cm length bins, and limited to lengths from 32 cm to 39 cm. A total of four length bins were produced, which included 89% of 3 to 8 year old mackerel. For more details see Olafsdottir *et al.* (2013).

Mackerel average annual weight-at-age ranged from 270 g to 720 g (Figure 3.6.3.1.1). Average weight was high early in the time-series, with some annual fluctuations from 1984 to 1995, after which weight declined until 1997, before increasing to a peak in 2002/2004. During the last decade, weight-at-age has declined continually, at record low values every year since 2010. Such is the rate of decline that in 2013 average weight-at-age was 33% to 40% lower than maximum annual value (Table 3.6.3.1.1). The annual trend in length-at-age was similar to the trend in weight-at-age, but the scale of change was smaller as average length-at-age, in 2013, was 9% to 14% lower than maximum annual value (Table 3.6.3.1.1). All age classes displayed similar annual trends in size-at-age.

Table 3.6.3.1.1. Proportional changes (%) in length-at-age, weight-at-age, and weight-at-length in 2013, September and October (in brackets), compared to overall mean (aver) for study period, from 1984 to 2013, and compared to maximum (max) annual average value recorded during study.

	Length-at-age			Weight-at-age		Weight-at-length	
Age (years)	Aver (%)	Max (%)	Aver (%)	Max (%)	Length interval (cm)	Aver (%)	Max (%)
3	-9 (-8)	-14 (-12)	-27 (-26)	-40 (-38)	32 – 33	-6 (-6)	-11 (-15)
4	-7 (-7)	-11 (-10)	-25 (-24)	-36 (-35)	34 – 35	-6 (-6)	-12 (-9)
5	-6 (-6)	-10 (-9)	-24 (-26)	-33 (-34)	36 – 37	-11 (-9)	-17 (-13)
6	-6 (-7)	-9 (-10)	-24 (-26)	-33 (-36)	38 – 39	-12 (-14)	-17 (-19)
7	-7 (-6)	-10 (-9)	-28 (-25)	-37 (-36)			
8	-7 (-7)	-10 (-10)	-27 (-27)	-37 (-36)			

The annual trend in mackerel weight-at-length varied between length classes with the general trend of declining weight in recent years (Figure 3.6.3.1.2). Annual average weight-at-length of the smallest mackerel (32–33 cm) ranged from 300 to 360 g with no distinct peak and slight decline in recent years. Weight-at-length of medium size fish (34–37 m) ranged from 370 to 520 g, it was highly variable from 1984 to 1995, then remained low until 2000, before increasing to a peak in 2005, it then declined continually to a record low value in 2013. Weight-at-length for the largest mackerel (38–39 cm) ranged from 480 g to 610 g. It was high from 1984 to 1994, declined suddenly in 1995 to 1997, then increased until 2003 before declining again and having record low values every year since 2011. In 2013, average weight-at-length, per length bin, was 11 % to 17 % lower than maximum annual value, and weight of larger individuals (>35 cm) declined more compared to smaller fish (<35 cm) (Table 3.6.3.1.1).

Mackerel weight-at-length declined significantly when mackerel spawning–stock biomass (SSB) increased (results from preliminary SAM run "no-split": weight-at-length = 45.8–9.3 * 10^{-6} * SSB; 95% CI: -1.2 * 10^{-5} to -4.5 * 10^{-6}; r^2 = 0.46, n=30) and when the Atlantic Multidecadal Oscillation (AMO) index was in a positive phase (weight-at-length = 9.4–1.7*10^{-2} * AMO; 95% CI: -1.2 * 10^{-2} to -58.7; r^2 = 0.24, n=30). These results suggest declining mackerel condition, observed in recent years, is likely a result of density-dependent effects, mediated via food availability, as temperatures were high. Weight-at-age and length-at-age is cumulative over time as mackerel size in specific age classes is constrained by growth in previous years; hence, direct influence of SSB and AMO were not tested. Analysis of SSB effects on mackerel growth needs to be redone once WKPELA releases a new officially accepted mackerel SSB estimate.

The WKPELA raised concerns that if mackerel growth was density-dependent there should be a cohort pattern in weight-at-age and condition, and asked for a figure displaying annual growth pattern for each age class. Analysis of annual growth anomalies, for age classes 3 to 8 years old, displayed strong annual signal in weight-at-age and weight-at-length but limited cohort signal (Figures 3.6.3.1.3 and 3.6.3.1.4). A strong annual growth signal is not surprising because all six cohorts present within each year utilize the same feeding grounds and, therefore, compete for the same feeding resources and experience the same temperature regime. In other words, we should expect annual growth of mature mackerel to be influenced by stock abundance not cohort abundance. Our results of a strong annual signal in mackerel growth are in agreement with results from research on growth of the Northwest Atlantic mackerel stock (Overholtz, 1989).

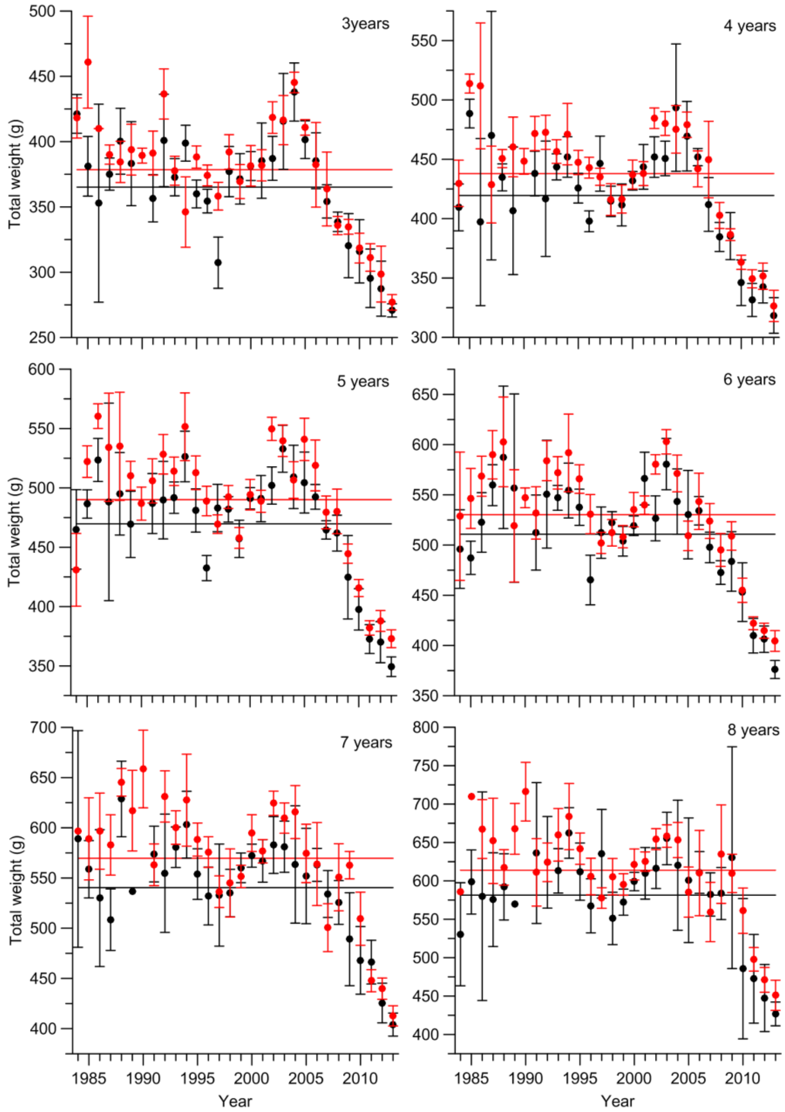


Figure 3.6.3.1.1. Annual average weight-at-age for 3 to 8 year old mackerel, in September (red filled circle) and October (black filled circle), from 1984 to 2013, and 95 % confidence intervals (CI, vertical bar). 95% CI not displayed due to large range for length age 7 in 1984, 1989 (September, 95% CI: 300–893 g; n = 3; October, 95% CI: 328–745 g, n = 3), and for age 8 in 1984, 1985, 1989 (September, 95% CI: 411–761 g, n = 5 ; September, 95% CI: 458–962 g, n = 4; October, 95% CI: 365–775 g, n = 4). Overall mean (horizontal line) was calculated as mean of annual averages from 1984 to 2013.

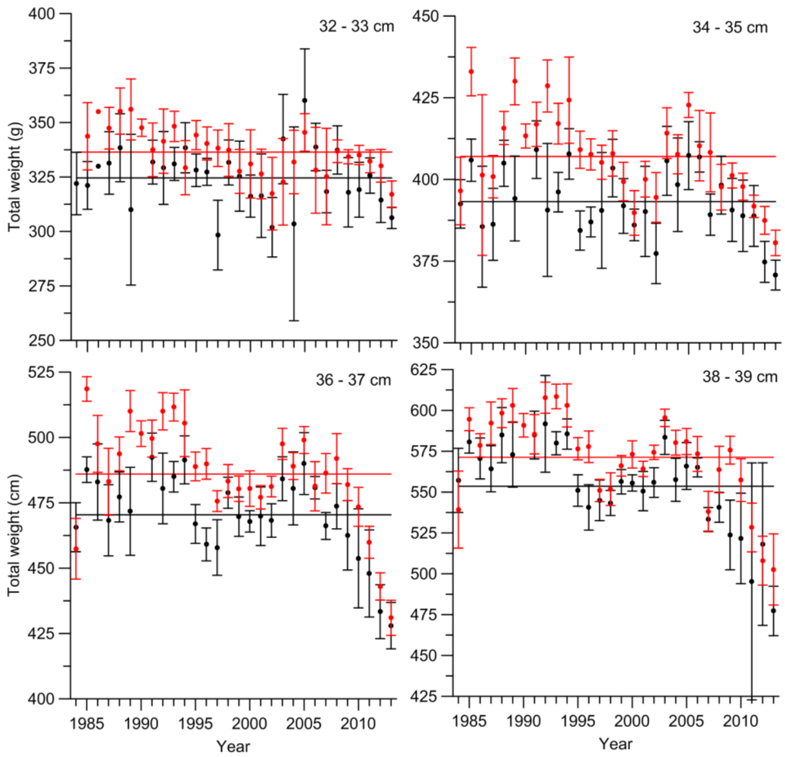


Figure 3.6.3.1.2. Annual average weight-at-length for 3 to 8 year old mackerel, in September (red filled circle) and October (black filled circle), from 1984 to 2013, and 95% confidence intervals (CI, vertical bar).Weight-at-length is calculated for four different 2 cm length bins for the length range from 32 cm to 39 cm, including 89% of 3 to 8 year old individuals. 95% CI not displayed for length bin 32–33 cm in 1986 due to large range (September, 95% CI: 164–546 g, n = 3; October, 95% CI: 203–457 g, n=3). Overall mean (horizontal line) was calculated as mean of annual averages from 1984 to 2013.

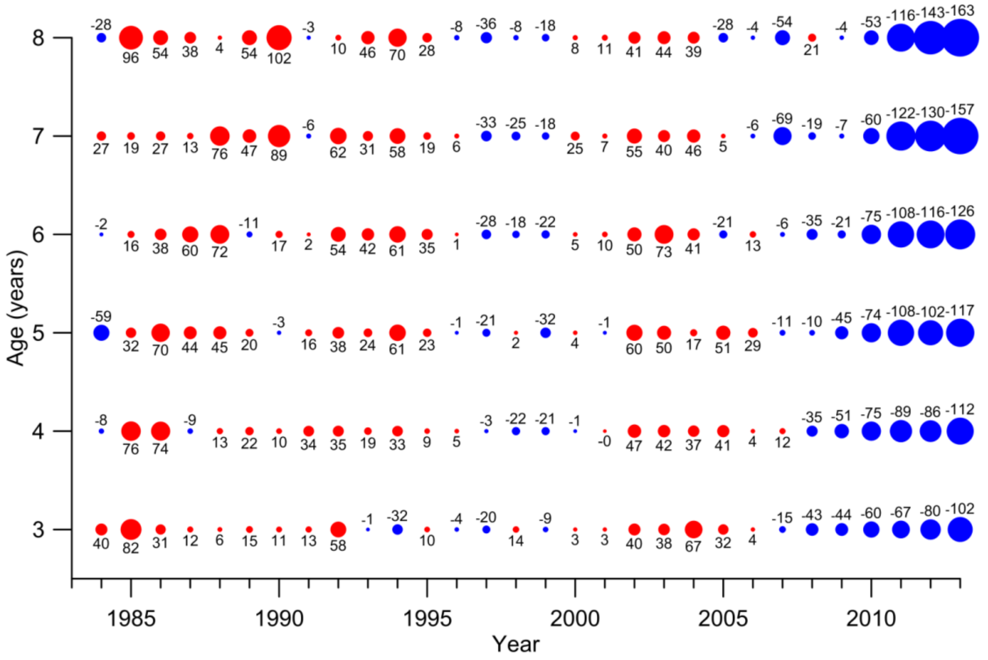


Figure 3.6.3.1.3. Weight-at-age anomalies for 3 to 8 year old mackerel in September from 1984 to 2013. Annual anomalies are calculated as the difference between annual mean and overall mean for each age class. Overall mean was calculated as mean of annual averages from 1984 to 2013. Red is positive anomaly and blue is negative anomaly. Values of anomalies (g) are displayed above or below symbol.

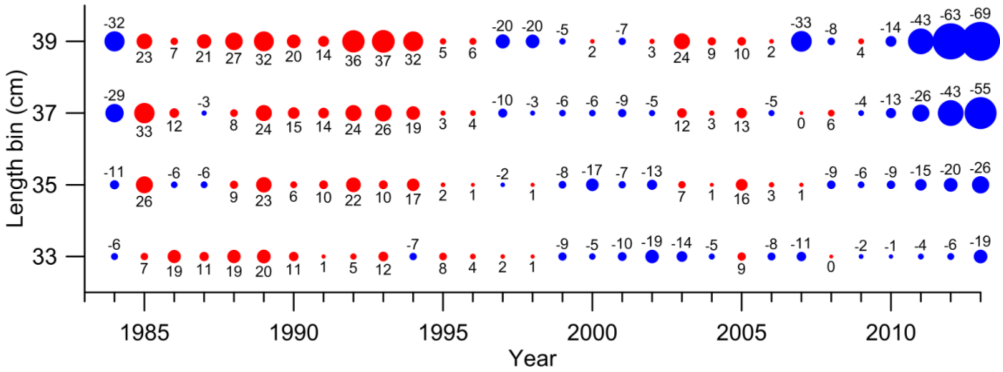


Figure 3.6.3.1.4. Weight-at-length anomalies for 32 cm to 39 cm, calculated for 2 cm length bins, mackerel in September from 1984 to 2013. Annual anomalies are calculated as the difference between annual mean and overall mean for each age class. Overall mean was calculated as mean of annual averages from 1984 to 2013. Red is positive anomaly and blue is negative anomaly. Values of anomalies (g) are displayed above or below symbol.

3.6.4 Stock assessment

Introduction

Previous NEA mackerel assessment

The previous assessment of NEA mackerel accepted after the 2007 benchmark used ICA-stock assessment model (Patterson and Melvin, 1996). The model was a combination of a statistical catch-at-age model using a separable assumption (12 year separable period) and a VPA for the earlier years. The model was tuned only by the triennial mackerel egg survey used as a relative SSB index. The catches-at-age and the egg survey had an equal weight in the statistical catch-at-age part of the model. In this configuration, ICA had always been quite stable, and no convergence problem had been observed.

The main issues with this assessment were related to the data. The most problematic data issue for NEA mackerel is the unknown amount of unreported catches in the past (see Section 3.6.1). At the time of the previous benchmark, it was assumed that the proportion of missing catches was constant over the years, and, under this assumption, it had been considered that the ICA assessment gave an accurate estimate of the fishing mortality, and that the estimated SSB could be used as an indication of the trend in the stock. Since 2007 it had become clearer that the accuracy of the reported catches had improved in recent years. A sensitivity analysis carried out during the 2013 WGWIDE (ICES 2013, D. Miller Working Document to WGWIDE), using an *ad hoc* correction of the historical catches based on information provided by the industry, demonstrated that a substantial time-varying bias in both SSB and F would result from the reduction of underreporting in the recent years.

The second problem with the previously benchmarked assessment was the lack of tuning data. The single index was available only every third year, which caused substantial revision of the perceived stock each time a new survey point was incorporated. Furthermore, the uncertainty in the stock estimate in the terminal assessment year increased as one moved away from the last available egg survey point. In the absence of other (especially recruit) indices, the recent estimates of stock size were reliant solely on catch information. This uncertainty in the recent years was a major source of concern for the accuracy of the short-term forecast, on the basis of which management advice is given.

Finally, the constant selection pattern assumption on which ICA is based has increasingly been challenged since the end of the 2000s when major changes in the fishery occurred.

In 2013, the ICA assessment was rejected. This decision was motivated by the accumulation of the problems listed above, which increased in magnitude in the recent years. The 2013 rejected assessment also showed the limit of the model due to the lack of data.

Assessment models tested during the benchmark

The principal problem with the previous assessment was the lack of data and the main goal of the 2014 benchmark was to investigate which additional sources of data could be used, and to choose existing models (or develop new ones) being able to incorporate these new data.

The longest available quantitative data source on mackerel is the tagging and recapture dataset from the Norwegian tagging programme. These data were used to determine the natural mortality of NEA mackerel (Hamre, 1978). It has also been incorporated in stock assessment models, such as AMCI to provide a basis for comparison with the accepted assessment in ICA (ICES, 2001).

Alternative to use tag-recapture information to generate an age-segregated fishery-independent index informing on numbers in a given cohort in a given year, efforts to incorporate tag-recapture information directly in SAM was undertaken. This was done in order to account for the large variations associated, a general feature of tag–recapture data. In preparation of the benchmark, two meetings with the objective to analyse the information given by the tagging data, and modify SAM (State–Space

Assessment Model, Nielsen and Berg, 2014) to allow for the incorporation of these data directly in the model by adding a likelihood component for the tag–recapture data, were held.

As an alternative to SAM, a mackerel assessment was also developed using CASAL (C++ algorithmic stock assessment library, Bull *et al*., 2012), which also offers the possibility to used tagging information.

A summary of the main features of these two models is given below.

- The SAM model modified to incorporate tagging data

The state–space assessment model (SAM) was identified early in the benchmark process as an ideal candidate to replace the ICA model.

In SAM, the "states" (fishing mortalities and abundances-at-age) are constrained by the survival equation and follow a random walk process.

SAM is a fully statistical model in which all data are treated as observations. The model estimates observation variances (lognormal error model) for each data source (catches and surveys), which can be used to describe how well each data source is fitted in the model (a low observation variance indicating a strong influence on the model fit). In order to incorporate the tagging information, tag recoveries for each year and each age class were modelled based on the number of fish screened in the processing factories, the amount of fish tagged in the previous years, and the corresponding abundances-at-age estimated by the model, conditional to a post-release survival rate (time invariant and for all ages) estimated by the model. Given the nature of these data (count data with overdispersion) a negative binomial error model was used.

Uncertainties (standard errors) are estimated for all parameters and for all states (F and Ns). This uncertainty is naturally incorporated in the short-term forecast.

SAM offers a fully statistical framework and model selection can be done based on model likelihood. This is particularly convenient in the context of a benchmark, where a range of different model configurations can be compared statistically. Uncertainties are generated for all estimated parameters.

SAM also offers the possibility to estimate catch multipliers. Catch multipliers are coded as an additive term in the lognormal observation model for the catches. This option is used for instance in the North Sea cod assessment.

The expectation from the SAM model modified to incorporate tagging data was that the information from the tags would be informative enough to enable the estimation of the catch multipliers to compensate for the historical underreporting.

During the mackerel benchmark, SAM was run online, using the stock assessment.org[1] webpage. Some of the diagnostics were produced by using the output of SAM in FLR.

For a more detailed description of the model, please refer to the Stock Annex and Nielsen and Berg, 2014.

- The CASAL model

[1] www.stockassessment.org

CASAL is a generalized age- or size-structured fish stock assessment model that allows for considerable flexibility in specifying the population dynamics, parameter estimation and model outputs. It can be used for a single stock for a single fishery or for multiple stocks, areas, and/or fishing methods. The data used can be from many different sources of information including commercial catch-at-age/size, survey and other biomass indices, survey catch-at-age/size and tag release and tag–recapture data. CASAL uses a quasi-Newton optimizer and scalar, vector and matrix types from the Betadiff automatic differentiation package. Estimation can be by maximum likelihood or Bayes. Full documentation of CASAL is provided in the CASAL User Manual which can be obtained, on request, from CASAL@niwa.co.nz. CASAL has been used to assess numerous stocks, particularly around New Zealand, and is routinely used to assess toothfish stocks within CCAMLR for which tagging data comprise an important source of information on stock abundance.

Strategy for model selection

During the course of the benchmark meeting, it appeared that SAM was more appropriate to carrying out exploratory runs, mainly because of the greater flexibility with which input data and model configuration can be modified. CASAL was, when possible, run in parallel with SAM to provide a basis for comparison. Most of the decisions were based on the exploratory runs from SAM, and the final assessment is using SAM. An equivalent final assessment using CASAL is presented in this report.

Most of the exploratory runs done were aiming to find an appropriate solution for dealing with the uncertainty in the past catches, and to incorporate new sources of data, since these were the two main challenges of the benchmark. Additional runs were also carried out to test the sensitivity of the assessment to the level of misreporting in the past, and to the inclusion of the different surveys. Optimization of the model configuration (binding or decoupling for parameters in SAM) was only briefly considered, mostly for lack of time. These model configurations might be revisited in the coming WGWIDE meetings.

Model effect

In order to assess the effect of the model chosen on the estimated stock, SAM was fitted to the same input data as the last accepted ICA assessment (WGWIDE, 2012). For lack of time, no CASAL assessment based on the 2012 data was available. The time-series of SSB, F and recruitment estimated by the SAM and ICA are shown in Figure 3.6.4.2.1.

The two models gave a quite similar description of the trends in the stock overall, but there were also some marked differences:

- For the historical period 1980–1990, the ICA estimates of SSB were substantially lower than the SAM estimates, while the opposite was observed for F estimates. For most of the time-series, the ICA estimates remained within the 95% confidence intervals of the SAM estimates (except for SSB between 1980 and 1985 where the ICA estimates were lower that the lower SAM confidence bound).
- The estimated F also diverged in the recent period (since 2005) with ICA estimating a substantially lower F than SAM.
- Recruitment was also comparable between the two models but the variations were not entirely synchronous (especially during the period of stable recruitment from 1985 to 2000). The magnitude of the strong year classes

(1984, 2002 and 2006) was larger in the SAM assessment. The 2005 year class, which was estimated to be as strong as the 2006 year class by ICA, was estimated to be low by SAM.

Although the general trends and the absolute levels were broadly in agreement between the two models, the choice of assessment model has nonetheless an influence on our perception of the dynamics of the stock.

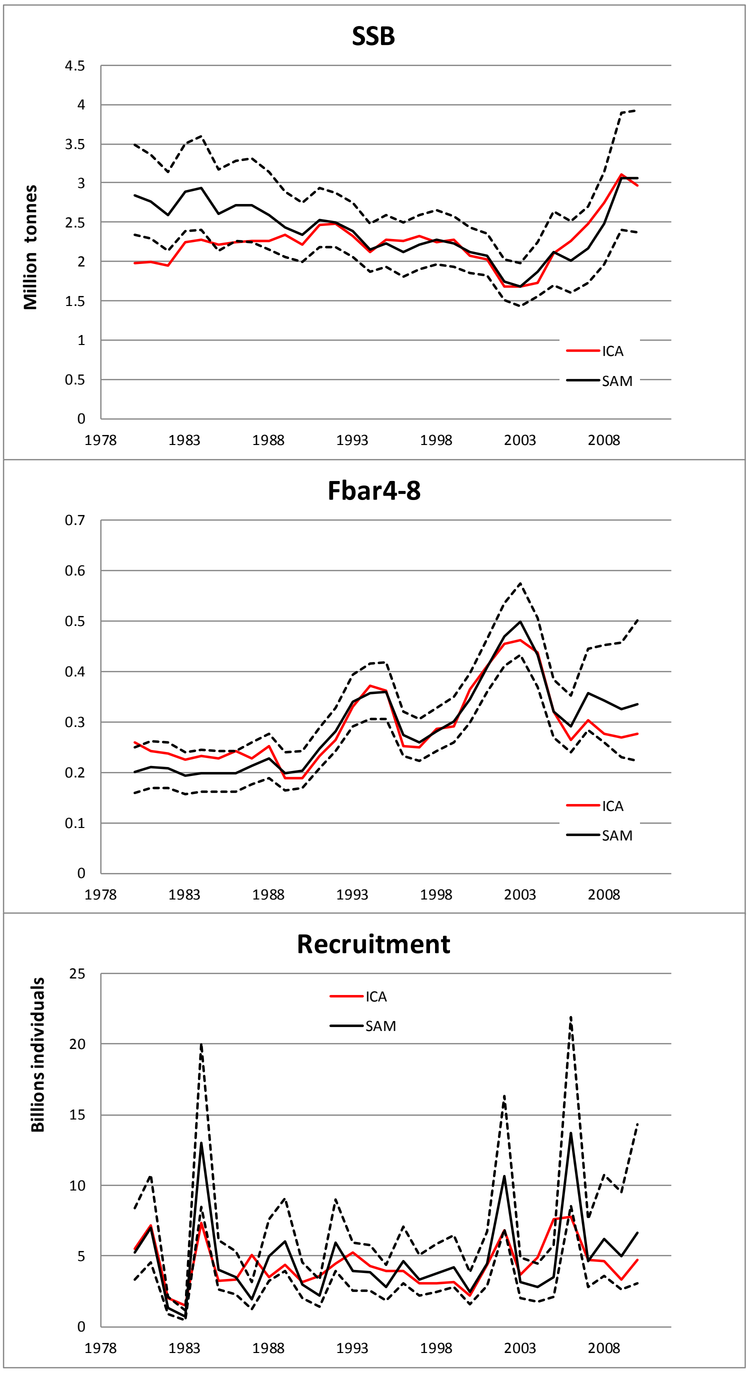


Figure 3.6.4.2.1. NEA mackerel summary plot from the ICA (red) and SAM (black with 95% confidence intervals in dashed line) assessment.

Options for the incorporation of tagging data

Introduction

Several important changes in the methods used in the Norwegian tagging programme took place during the period covered by the assessment (see Section 3.6.2.2 on the tagging data). These changes can be summarized as follows:

- Change from manual to automatic jigging and change in release procedure in 2006. Automatic jigging could potentially be more harmful for the fish and may have been one factor leading to increased post tagging mortality. On the other hand, the release procedure was improved to reduce the risk of predation by seabirds. Therefore the methodological changes occurring in 2006 are likely to have affected the post tagging survival rate, but the magnitude and direction of the change cannot be estimated externally to the model.
- Change from steel tags to RFID (Radio Frequency Identification) tags (starting in release year 2010). This change is expected to improve the cost-efficiency of the tag detection during the screening of catches. One downside of this change is that since the recaptured tagged fish are not physically recovered during screening with the new RFID tags, the age of the fish is not estimated through otolith reading, but inferred from an age–length key established during tagging operations. It is hence expected that the accuracy of the age estimation of the recaptured fish has decreased with the use of RFID tags compared to steel tags.
- Suspicions of problems with the estimation of the volume of catches effectively screened for the last years of the steel tag recaptures (recapture years 2007 to 2010). Indications of such problems was indicated looking at the raw tag–recapture data (Skagen, 2014, working document to WKPELA), however the exact year a change might have happened has not been fully investigated. If this is true, there would be a bias (underestimation) in concentration of tagged fish in the population, and hence the population will be perceived as larger than it actually is.

Such changes have consequences for the model and, if not dealt with appropriately, will result in inconsistencies in the model fit to the data, and subsequently in errors in the estimated stock abundances.

Different options to treat the tagging data in SAM were examined to investigate whether the tagging data could be used as a single homogenous time-series, or if the data from the different periods should be handled differently in the model. First, runs based on the entire tagging time-series were compared with runs for which either or both the last years of steel tag recovery (recapture years 2007–2010) and the recaptures of RFID tags (recapture years 2011–2012) were removed from the dataset. Alternatively, the model can treat the tagging data from different periods as different datasets, by estimating one survival parameter for each period. This option was also investigated by comparing runs treating the tagging data as a whole, and run splitting the tagging data in two series, pre and post 2006.

These options were compared based on diagnostics of the fit of the model to the data. Since not all runs are based on the same input data, the model fit are not strictly comparable using likelihood based criterions.

Results

For all the runs, observation variances for the catches were low (Table 3.6.4.3.1), slightly lower for run 1 (all data) and run 2 (removing RFDI tags), indicating that for all options, the model was closely following the information from the catch data from 2000 onwards. All runs also had a similar observation variance of the IESSNS survey, at values around 0.15, lower than for the other surveys. The estimates of over dispersion of the tag recaptures (same function but not directly comparable to survey observation variances) were also very similar between all runs.

The fit to the egg survey and, to a lesser extent, to the recruitment index were, however, substantially better (lower observation variance) when either all tags recaptured in 2007 and after were excluded or when the tagging data were split by introducing two tagging survivals, estimated prior and post 2006 (runs 4 to 6 respectively). In addition, the estimated catchability of the egg survey for runs 4 to 6 was higher (around 1.27) than in the runs 1 to 3 (less than 1). Run 3, in which the last years of steel tags recovery were excluded but not the RDFI tags recovery, had parameter values intermediate between runs 1 and 2 and runs 4 to 6.

The estimated post tagging survival rates for all years for runs 1 to 4 and for the first period for run 5 and 6 were all in range of values from 0.36 to 0.40. For runs 5 and 6, the survival rate for the recent period (after 2006) was estimated just above 0.10.

Residual plots are presented only for run 1 (Figure 3.6.4.3.1) and for run 5 (Figure 3.6.4.3.2). Residual plots for runs 2 and 3 were very similar to Figure 3.6.4.3.1 and residuals plot for runs 4 and 6 were comparable to Figure 3.6.4.3.2. Residuals for the fit to the catches did not show any age or temporal pattern and are not shown here. For the run using all tagging data as a single time-series (run 1), a strong temporal pattern is observed for the residuals to the egg survey, the model estimating a lower SSB than the egg survey index for the first half of the time-series, and a higher SSB in the second half. This problem was not observed when the tagging data are split (or when all data after 2007 are removed). Residuals to the recruitment index also showed a temporal trend which was comparable for run 1 and run 5 with mostly negative residuals from 1998 to 2005 (except 2002) and mostly positive residuals from 2006 to 2012 (except 2011). Residuals to the IESSNS were similar for run 1 and run 5, except for the year 2007 in run 5 where strong negative residuals were observed for most ages.

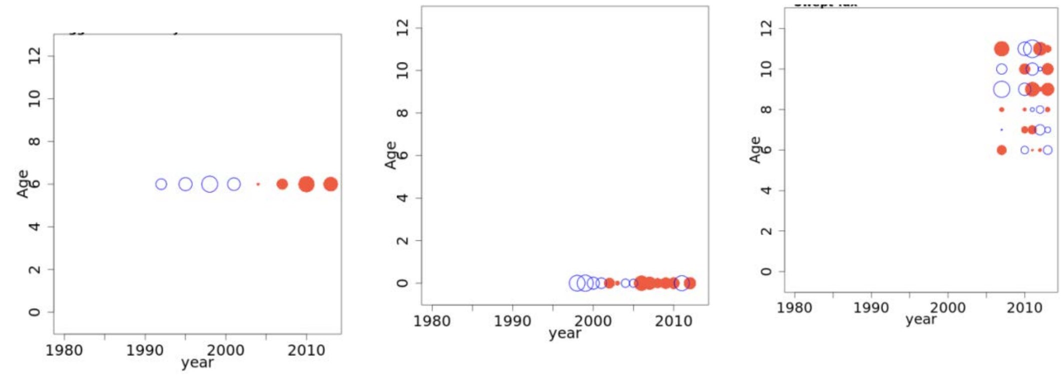
The runs 1 and 5 use the same input data and the model fit can hence be compared using likelihood based criterions such as AIC. The AIC for run 1 was 545, while for run 5 the AIC was 474. This indicates a substantial improvement in the model's likelihood for the price of one single extra parameter (a second tagging survival estimate).

While running SAM, it is possible to follow the objective function (negative log-likelihood) profile during optimization. The model used here first carries out parameter optimization on all input data excluding tagging data, and then incorporates the tagging data and carries out a second optimization. This results in a jump in the objective function profile when the tagging data are incorporated. For runs where the tagging data for recapture years between 2007 and 2010 were removed, only a minor jump was observed in the objective function, while when all years were used, the increase in objective function was large. This suggests that the information in the tagging recovered from 2007 to 2010 is very influential and, when incorporated in the model, generates a larger model readjustment (compared to the model without tagging data) than when those years were removed.

This perception that major changes have occurred in the tagging data at the end of steel tag recovery period is corroborated by results of runs from CASAL. Figure 3.6.4.3.3 shows a very low number of tags actually recovered in 2008, 2009 and 2010, compared to the prediction of the model. This may indicate an increased stock size that the model was not able to detect from the other sources of data. This may also be due to higher post-release mortality for those fish recapture in 2008, 2009 and 2010, an effective volume screened lower than reported or a problem with the assumption on the complete mixing within the cohort of the tagged fish in the recent year, in relation to the changes in fish distribution and migration. However, besides the work by Skagen (working document to WKPELA) it is at present not possible to conclude on the reason for these apparent changes in the tagging time-series.

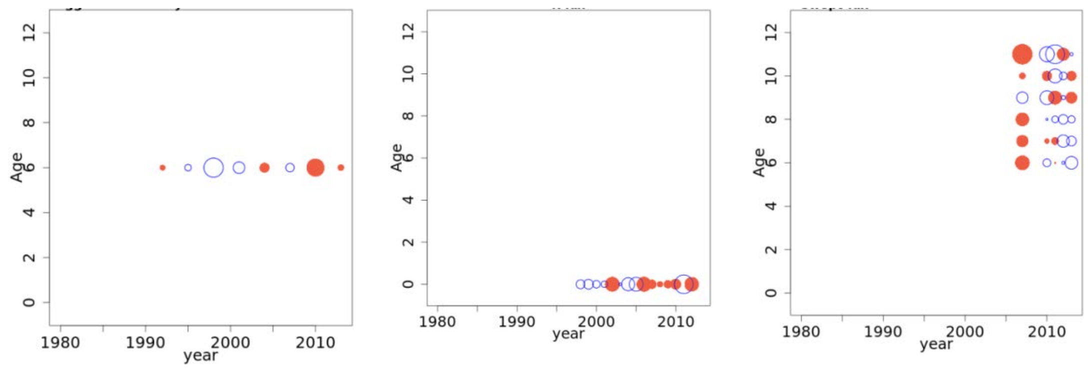
Table 3.6.4.3.1. Comparison of SAM parameter estimates from runs with different options for the inclusion of tagging data.

run number	1	2	3	4	5	6
Split in 2006	no	no	no	no	yes	yes
Tagging data	All	Excluding [2011:12]	Excluding [2007:2010]	Excluding [2007:12]	All	Excluding [2007:2010]
Observation variances						
Catches (ages 0 to 12+)	0.052	0.034	0.062	0.051	0.074	0.075
Egg survey (all ages)	0.633	0.672	0.474	0.185	0.198	0.212
R index (age 0)	0.570	0.580	0.550	0.470	0.420	0.434
IESSNS (ages 6 to 11)	0.146	0.156	0.144	0.179	0.153	0.146
Tags (over dispersion)	1.217	1.239	1.184	1.240	1.221	1.209
Catchabilities						
Egg survey	0.754	0.682	0.962	1.291	1.280	1.263
Tagging survival						
Period 1980–2012	0.380	0.406	0.359	0.372		
Period 1980–2005					0.359	0.360
Period 2006–2012					0.105	0.131



Egg survey Recruitment index IESSNS

Figure 3.6.4.3.1. Normalized residuals for the fit to the three surveys for run 1 (no split and including all tagging data). The three plots are on a different scale. Blue circles indicate positive residuals (observation larger than predicted) and filled red circles indicate negative residuals.



Egg survey Recruitment index IESSNS

Figure 3.6.4.3.2. Normalized residuals for the fit to the three surveys for run 5 (split in 2006 and including all tagging data). The three plots are on a different scale. Blue circles indicate positive residuals (observation larger than predicted) and filled red circles indicate negative residuals.

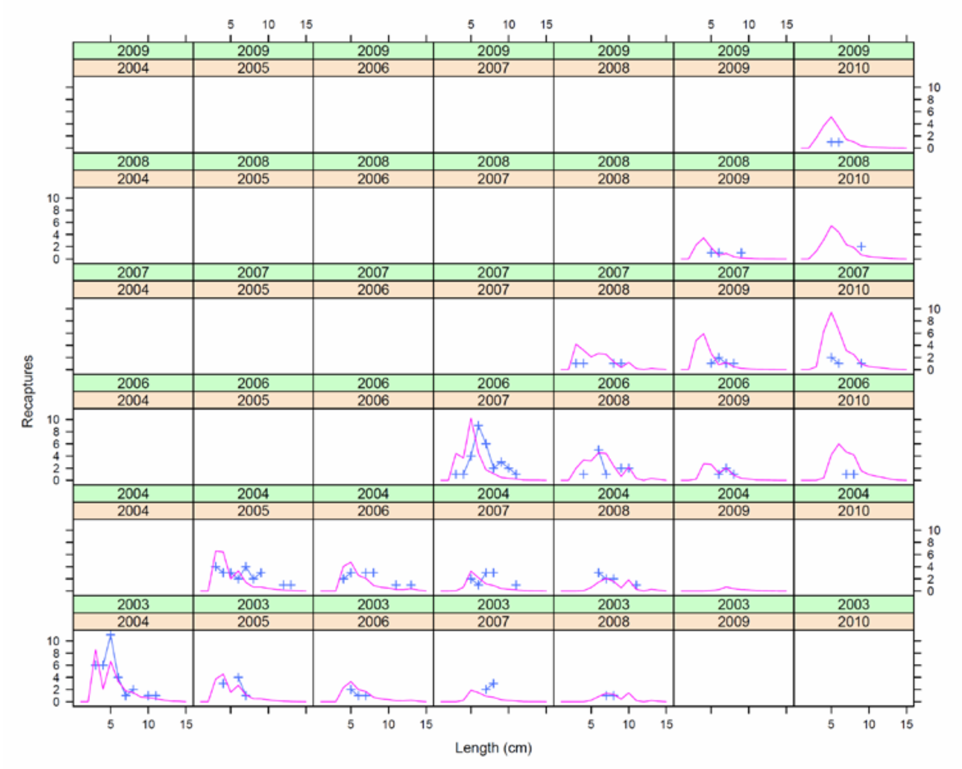


Figure 3.6.4.3.3. Observed (crosses) and expected (pink lines) tag recaptures-at-age for release years 2003 to 2009 from the CASAL assessment using one single post-tagging mortality (fixed at 60%). Tag release years along rows, tag–recapture years along columns.

Conclusion

Overall, runs excluding all the tagging data from 2007 onwards or estimating two survival parameters had a better fit to the data than runs using all the tagging data or excluding only the last years of steel tag recovery or the RFID tags.

On the basis of these exploratory runs, it was concluded that the tagging data should not be used as one single homogenous time-series in SAM.

Furthermore, the tagging data during the recent period (tags recovered since 2007) is also quite heterogeneous (suspicion of biased estimates of volume screened, and then change to a new detection method). Treating it as a consistent dataset, by estimating a separate survival parameter for this period is somewhat artificial and was hence considered to be inappropriate. Furthermore, it might also introduce unwanted instability in the assessment in the coming years given the survival parameter would be re-estimated annually. Therefore, the option consisting of removing all tagging data for recovery years since 2007 was preferred to the option of using a split in 2006, even though they give a very similar fit to the data.

It was also decided that the incorporation of the data corresponding to RFID tags should be re-evaluated in the near future, when more years of recovery are available to accurately estimate a separate survival parameter for these new data.

Solutions to the problem of underreporting in the historic catches

Introduction

Several options were considered to deal with the historic underreporting of the catches during the benchmark.

The first (and preferred) option consisted in estimating catch multipliers in SAM. The model was configured so that one catch multiplier for all ages was estimated for each of the historic underreporting periods (Klondiking: 1980–1989; highgrading: 1990–1999; lower misreporting: 2000–2005). In this configuration of the model, the only data that were considered to give absolute information were the catches-at-age from 2006 to 2012; the rest of the data only gave relative information, conditional to a scaling parameter estimated by the model (catchabilities of the surveys, survival for the tagging, catch multiplier for the catches). With this configuration, it was expected that the model would be able to use the information available for the misreporting period from the tuning series (egg survey and tags) to rescale the catches to a higher level.

The second option considered was to omit all sources of data for the period with suspicion of strong underreporting of the catches (1980 to 1999). The model was hence fitted on a dataseries starting in 2000.

In the second option, valuable information for the period pre-2000 was discarded (tagging data and egg survey). Therefore, a third option, consisting in removing only the catches prior to 2000 was considered. For practical reasons (limited time availability), it was chosen to implement the effect of the removal of the catch data by down-weighting the information from the catches prior to 2000. This was achieved by setting their variance to a high value (1 was chosen), while the variance for the catches from 2000 onwards was estimated normally. As a result, the influence of catches prior to 2000 for the assessment can be considered negligible.

Results

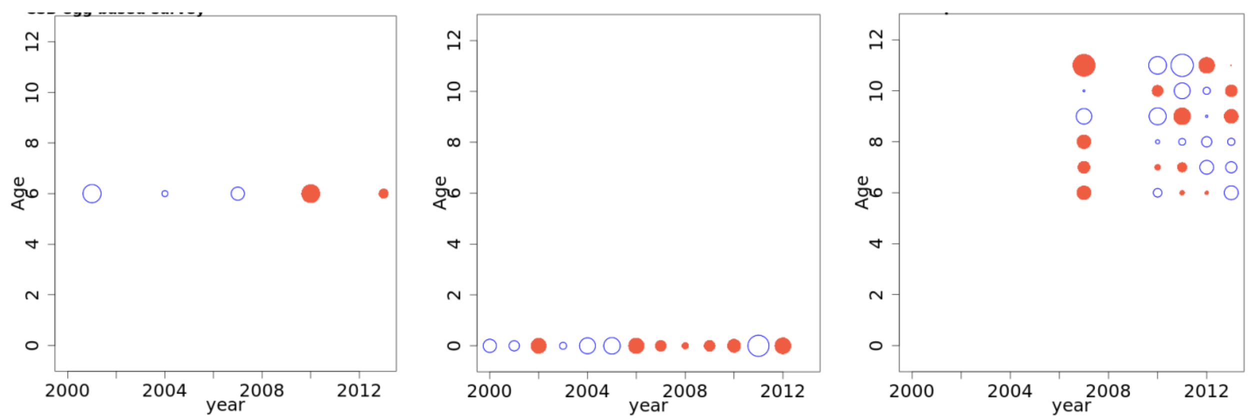
Letting the model estimate catch multipliers (option 1) did not seem to be an appropriate solution to correct for the historic catch misreporting. The catch multipliers were indeed estimated at 1.13, 0.93 and 1.11 for the three periods. Simmonds *et al*. (2010), using the same dataset in a Bayesian model (but assuming a catchability of 1 for the egg survey), estimated a catch multiplier value of 2.2 (between 1.7 and 3.6). The values obtained with SAM are not significantly different from 1, which means that, in practice, no real correction for underreporting is achieved using this model configuration.

Fitting the model excluding all data prior to 2000 (run 7) or down-weighting the catches for the year before 2000 (run 8) did not modify significantly the observation variances for the catches and of the surveys (Table 3.6.4.4.1). The catchability of the egg survey was similar in run 4 and 8, but lower for run 7, but the difference was not significant. The estimated post tagging survival rate was slightly lower for run 7. The only significant different was the higher overdispersion for the tag recoveries for run 7.

Residual plots for run 4 and run 8 were very similar, except for the period where the catches were down-weighted in run 8 where the residuals are irrelevant. Residuals for the recruitment index and the IESSNS in run 7 (Figure 3.6.4.4.1) were also very similar to the residuals from run 4 (comparable to Figure 3.6.4.3.2. A temporal pattern (negative and then positive residuals) was found in the residual pattern for the egg survey for run 7.

Table 3.6.4.4.1. Comparison of estimated parameters for different options for dealing with the historic catch data.

run number	4	7	8
catch data	All	Excluding [1980:1999]	Down-weighting [1980:1999]
Observation variances			
Catches (ages 0 to 12+)	0.051	0.053	0.073
Egg survey (all ages)	0.185	0.197	0.203
R index (age 0)	0.47	0.486	0.450
IESSNS (ages 6 to 11)	0.179	0.153	0.149
Tags (overdispersion)	1.240	1.526	1.204
Catchabilities			
Egg survey	1.291	1.168	1.258
Tagging survival			
Period 1980–2006	0.372		0.372
Period 2000–2006		0.341	



Egg survey Recruitment index IESSNS

Figure 3.6.4.4.1. Normalized residuals for the fit to the three surveys for run 7 (assessment starting in 2000). The three plots are on a different scale. Blue circles indicate positive residuals (observation larger than predicted) and filled red circles indicate negative residuals.

Conclusions

Down-weighting the catches prior to 2000 appeared to be an appropriate method to have a model independent from the unreliable catches in the underreporting period but still incorporating all other sources of data for this period. The overall fit to the data was quite similar to a model where past catches were not down-weighted. Down-weighting the catches prior to 2000 resulted in a substantial increase in the standard deviation of the abundances-at-age (results not shown here, but see the SSB time-series in the section on final assessment for illustration), which was considered to be a better representation of the actual uncertainty in the data than the somewhat narrower confidence intervals for the run 4.

Fitting the model on data starting in 2000 was judged less appropriate since it led to discarding valuable data and resulted in small changes in the model fit, with some (minor) indication of model misfit (residual pattern for the egg survey).

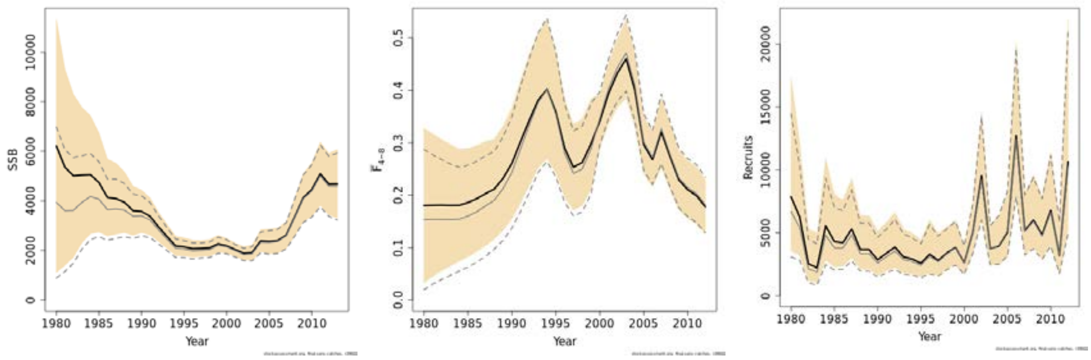
Sensitivity runs and parameters settings optimization

Sensitivity to the level of historic catches

In order to test if down-weighting the catches prior to 2000 effectively resulted in an assessment being independent of the level of catches for this period, a sensitivity run was carried out, doubling the catches (in the input catch data) for the years before 2000 while not changing the catches in the recent period (run 9).

Figure 3.6.4.5.1 shows a comparison of the stock trajectories from run 8 and from run 9. At the beginning of the time-series, SSB was estimated higher when the catches were doubled, but only until the early 1990s, which corresponds to the start of the egg survey. For the subsequent years, both runs estimated a very similar SSB. The SSB estimates from run 9 were always included within the confidence intervals of run 8. Similarly, a difference in FBAR estimated from run 8 and run 9 was observed for the 1980s and the early 1990s. The difference is, however, less marked than for SSB, and the confidence intervals for the two runs were fairly similar. Estimated recruitment time-series showed only some minor differences in the 1980s.

The model, therefore, is sensitive to the level of catch before 2000 and this mainly affects the SSB during the 1980s, but not in the recent times. The uncertainty on the SSB in these early years is, however, so high that SSB estimates before 1990 are practically of no use, and thus, the differences found in these sensitivity runs becomes irrelevant. After 1990 the model is insensitive to the catch levels prior year 2000.



SSB FBAR Recruitment

Figure 3.6.4.5.1. Sensitivity to the level of catches before 2000. Comparison of run 8 (actual catches, in grey with confidence interval in dashed grey lines) with run 9 (doubled catches before 2000, black lines and orange confidence intervals).

Sensitivity to the inclusion of each survey ("leave one out" runs)

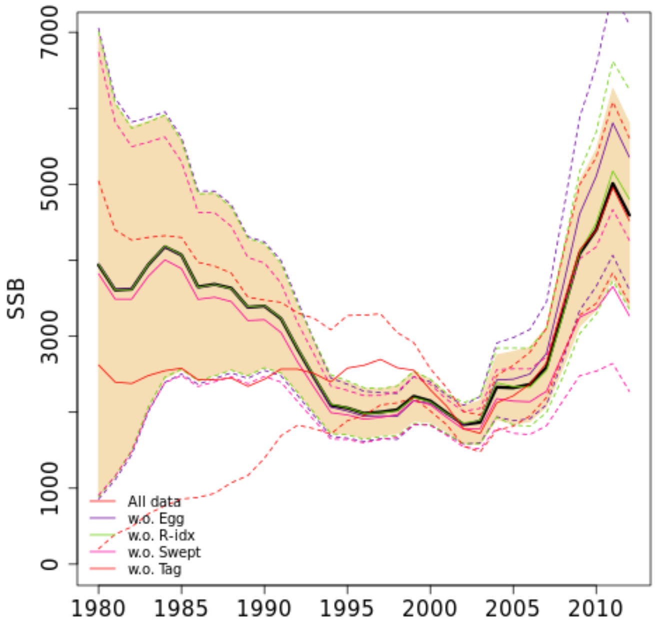
The influence of each individual survey and of the tagging data on the output of the assessment was investigated by running the model removing the surveys or tagging data successively and comparing the estimates of SSB and F_{BAR}.

The tagging data were found to be very influential. The model without tagging data estimated a completely flat SSB until the mid-2000s (end of the tagging data time-series), with estimates occasionally outside the confidence interval of the assessment including all sources of data (Figure 3.6.4.5.2). The trend in F_{BAR} was also affected for the same period as for SSB. There is no tagging data included after 2006 (since all tags recaptured in 2007 and after were removed), and the assessment from this year onwards was obviously thus not affected by the removal of the tagging data.

Among the survey indices, the recruitment index was the least influential, which was to be expected given the high observation variance for this index. Removing the recruitment index from the assessment (green lines on Figure 3.6.4.5.2) had almost no effect on the estimated SSB and F_{BAR} time-series (and confidence intervals). Removing the egg survey caused an upwards change in SSB (and the opposite for F_{BAR}) for the recent years, to values close to the upper confidence interval of the SSB of the model including all data. The earlier part of the SSB and F_{BAR} time-series were not affected. The exclusion of the IESSNS caused the opposite change in both SSB and F_{BAR}. It also resulted in a small revision of the SSB estimate in the 1980s and 1990s. Recent SSB and F_{BAR} estimates were outside the confidence interval of the assessment including all data sources.

The egg survey and the IESSNS both appear, therefore, to be quite influential in the assessment and to pull the estimated SSB and F_{BAR} in opposite directions. This can be explained by the fact that both surveys indicate an increasing stock since 2007, but the rate of increase in the IESSNS indices is much higher than in the egg survey. The overall assessment gives a similar weight to these two surveys and the rate of increase in the estimated SSB is intermediate between those excluding each survey.

SSB



FBAR

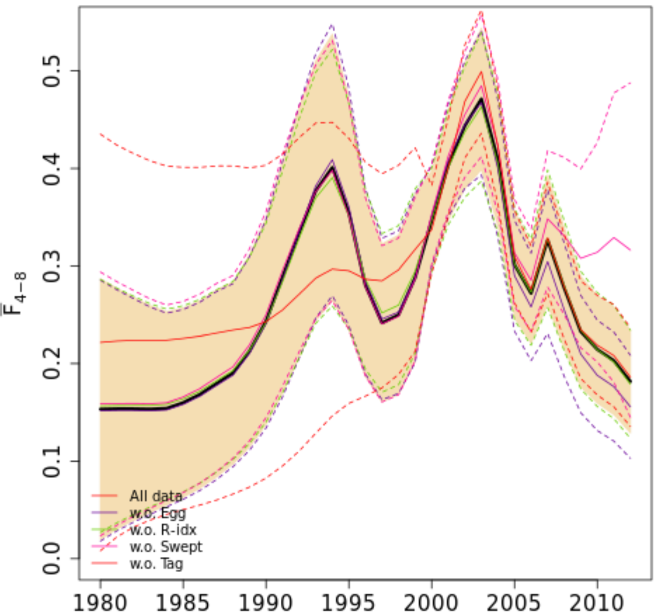


Figure 3.6.4.5.2. Assessment sensitivity to each tuning time-series. The run including all data (in black) is compared to runs excluding separately the egg survey (in purple), the recruitment index (in green), the swept-area survey (in pink) and the tagging data (in red).

Parameter configuration (catchabilities and observation variances)

Only two tests were carried out to compare different parameter configurations.

The first one consisted of estimating one single catchability for the swept-area survey; this compares to all the runs shown above, where one different catchability was estimated for each age in the index. This change in the model configuration led to significant model improvement (p<0.001), and it was adopted for the final model.

The second test was the decoupling of the observation variances for the catches. In the trial runs, one single observation variance was used for all ages. Different decoupling options were investigated. They resulted in an improvement which was significant. However, it created problems in terms of model convergence and stability (e.g. some of the observation variances for the catches were estimated on the lower bound of the interval in which the parameter could vary during optimization). Hence, it was judged that the improvement in the fit was not large enough to pay the price of an increased instability, and the initial setting -one single observation variance for all ages- was kept.

3.7 Final model

Final model configuration and input data

The final model configuration and input data are summarized in Table 3.7.1.1. The most crucial decisions made during the benchmark meeting can be summarized as follows:

- It was decided to incorporate the tagging data which proved to be very informative for the assessment.
- The inclusion of recent tagging data (recaptures after 2007) resulted in a deterioration of the model fit. Therefore the final model uses tags recaptured until 2006. The inclusion of the new RFID tags using a separate post release survival rate estimate should be re-evaluated in future when more data on RFID tagging becomes available with time.
- Down-weighting the catches for the years before 2000 was an effective way to reduce the influence of the unaccounted removals in the historic period. The resulting large confidence intervals on the abundance estimates for the early years in the assessment are considered to reflect well our current lack of knowledge of the size of the stock in the historic period.
- Despite the short length of the time-series and the persisting debate about the survey methodology, the IESSNS, as an age-structured, area-normalized index for age 6+ only, is used in the final assessment. It was argued that since the data seem to be adequately fitted in the model (low observation variance), and despite a strong year effect in 2007, this survey provided useful information for the assessment. Furthermore, given the concerns with the accuracy of the egg survey (early spawning not adequately covered in 2010 and 2013), it was decided not to give more credibility to either of these two surveys, even if their perception of the amplitude of the recent increase in the stock differed.

Table 3.7.1.1. Final assessment input data and parameter settings.

Input data types and characteristics:				
Name	Year range	Age range	Variable from year to year	Revised during WKPELA 2014
Catch in tonnes	1980–2012		Yes	Yes
Catch-at-age in numbers	1980–2012	0–12+	Yes	Yes
Weight-at-age in the commercial catch	1980–2012	0–12+	Yes	No
Weight-at-age of the spawning stock at spawning time.	1980–2012	0–12+	Yes	Yes
Proportion of natural mortality before spawning	1980–2012	0–12+	Yes	Yes
Proportion of fishing mortality before spawning	1980–2012	0–12+	Yes	Yes
Proportion mature-at-age	1980–2012	0–12+	Yes	Yes
Natural mortality	1980–2012	0–12+	No, fixed at 0.15	No

Tuning data:			
Type	Name	Year range	Age range
Survey (SSB)	ICES Triennial Mackerel and Horse Mackerel Egg Survey	1992, 1995, 1998, 2001, 2004, 2007, 2010, 2013.	Not applicable (gives SSB)
Survey (abundance index)	IBTS Recruitment index (log transformed)	1998–2012	Age 0
Survey (abundance index)	International Ecosystem Summer Survey in the Nordic Seas (IESSNS)	2007, 2010–2013	Ages 6–11
Tagging/recapture	Norwegian tagging program	1980–2006 (recapture years)	Ages 2 and older

SAM parameter configuration:		
Setting	Value	Description
Coupling of fishing mortality states	1/2/3/4/5/6/7/8/8/8/8/8/8	Different F states for ages 0 to 6, one same F state for ages 7 and older
Correlated random walks for the fishing mortalities	0	F random walk of different ages are independent
Coupling of catchability parameters	0/0/0/0/0/0/0/0/0/0/0/0/0 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 0/0/0/0/0/0/2/2/2/2/2/2/0	No catchability parameter for the catches One catchability parameter estimated for the egg One catchability parameter estimated for the recruitment index One catchability parameter estimated for the IESSNS (same for age 6 to11)
Power law model	0	No power law model used for any of the surveys

Coupling of fishing mortality random walk variances	1/1/1/1/1/1/1/1/1/1/1/1/1	Same variance used for the F random walk of all ages
Coupling of log abundance random walk variances	1/2/2/2/2/2/2/2/2/2/2/2/2	Same variance used for the log abundance random walk of all ages except for the recruits (age 0)
Coupling of the observation variances	1/1/1/1/1/1/1/1/1/1/1/1/1 0/0/0/0/0/0/0/0/0/0/0/0/0 2/0/0/0/0/0/0/0/0/0/0/0/0 0/0/0/0/0/0/3/3/3/3/3/3/0	Same observation variance for all ages in the catches One observation variance for the egg survey One observation variance for the recruitment index One observation variance for the IESSNS (all ages)
Stock recruitment model	0	No stock–recruiment model

Final model diagnostics

The estimated parameters for the final model and their uncertainty estimates are shown in Table 3.7.2.1.

The model still gives a very good fit to the catch data (lowest observation variance) and fits equally well to the egg survey and the IESSNS indices. The recruitment index has a substantially higher observation variance. CVs on the observation variances are usually large (from 19 to 49%). The catchability of the egg survey is of 1.281, significantly larger than 1, which implies that the final model still consider the egg survey index to be an overestimate. The uncertainty on the estimated catchabilities is higher for the recruitment index (due to lack of fit) and for the IESSNS indices (due to the small number of years available) and lower for the egg survey index. Post release survival for tagged fish is estimated at 37.2% with a low associated CV.

There are few strong correlations between the fitted parameters (Figure 3.7.2.1). There are, however, a number of exceptions with either positive or negative correlations. The random walk variance for the fishing mortalities appears to be negatively correlated to the observation variance of the catches (i.e. stable F with large residuals to the catches vs. variable F with good fit to the catches). The F random walk variance is also negatively correlated to the observation variance and the random walk variance for the recruits, which were both positively correlated. Importantly the scaling parameters for the model (catchabilities of the egg survey and the IESSNS indices and post-release survival rate) were all correlated. Otherwise, the majority of the other parameters appear independent of each other, which is an encouraging sign.

The residuals of the final model are very similar to those of the run 5 shown on Figure 3.6.4.3.2. Residuals for the catches do not show any temporal pattern. Residuals for ages 0 and 1 are larger than for subsequent ages 2 to 6. Residuals for ages 7 to 12 are also larger than for ages 2 to 6. This pattern could be corrected with a different configuration of the observation variance of the catches (for example by grouping age 0 and 1, ages 2 to 6 and ages 7 and older). This, however, resulted in a more unstable model, as mentioned earlier.

Residuals for the surveys are the same as for Figure 3.6.4.3.2, and detailed diagnostics are given on Figures 3.7.2.2 to 3.7.2.4. Residuals for the egg survey are generally low except for a large positive residual in 1998 and a large negative one in 2010. There is no indication of temporal autocorrelation in the residuals. Residuals to the recruitment index were on average larger, also without sign of temporal autocorrelation. Residuals for the IESSNS indices were in general small, except for the year 2007 where large negative residuals were observed for most ages; and in 2010 and 2011 for age 11.

Residuals for the tag recaptures do not show any temporal or age pattern (Figure 3.7.2.5).

Table 3.7.2.1. Final assessment estimated parameters.

Parameter	estimate	confidence interval	CV
F random walk variance	0.369	(0.287–0.473)	13%
log(N@age0) random walk variance	0.579	(0.383–0.875)	21%
log(N@age1 to 12+) random walk variance	0.181	(0.143–0.229)	12%
observation variance catches	0.090	(0.038–0.213)	49%
observation variance egg survey index	0.187	(0.101–0.347)	33%
observation variance recruit index	0.441	(0.265–0.735)	27%
observation variance IESSNS indices	0.220	(0.152–0.319)	19%
tag recaptures over dispersion	1.205	(1.120–1.352)	5%
catchability egg survey index	1.281	(1.064–1.541)	9%
catchability Recruitment index	$1.768*10^{-7}$	($1.261*10^{-7}$–$2.480*10^{-7}$)	17%
catchability IESSNS indices	$5.140*10^{-7}$	($3.843*10^{-7}$–$6.875*10^{-7}$)	15%
post tagging survival	0.372	(0.327–0.420)	6%

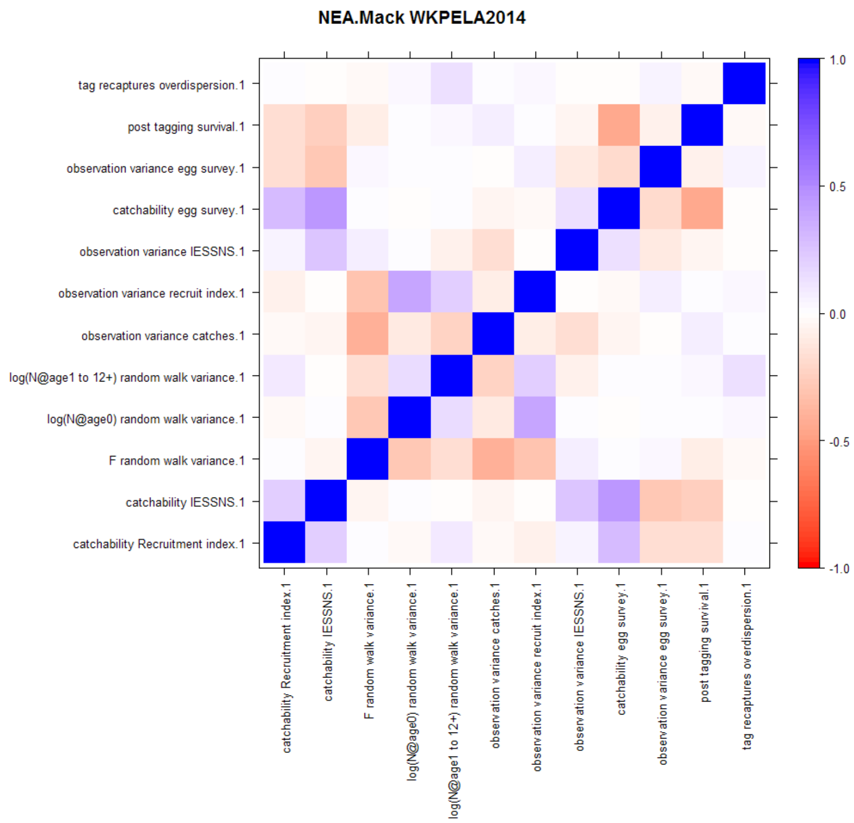


Figure 3.7.2.1. Parameter correlations for the final model. The horizontal and vertical axes show the parameters estimated by the model. The colouring indicates the (Pearson) correlation between the two parameters.

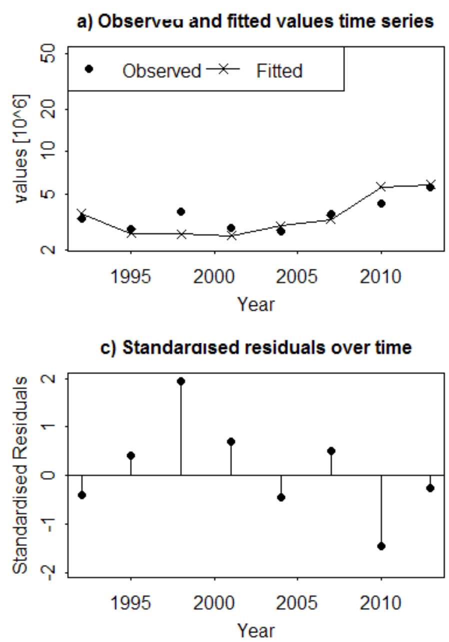


Figure 3.7.2.2. Model diagnostics for the fit to the egg survey index time-series.

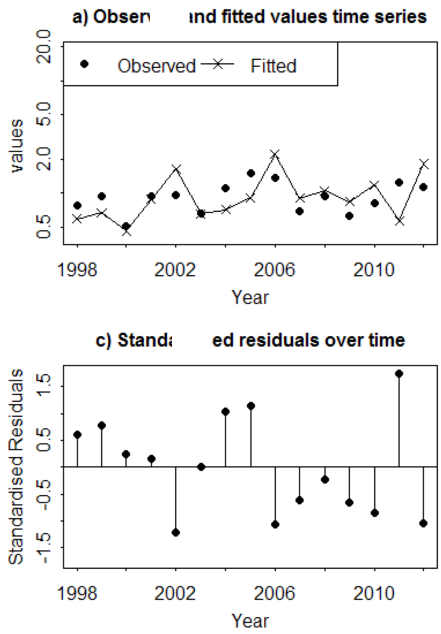


Figure 3.7.2.3. Model diagnostics for the fit to the recruitment index time-series.

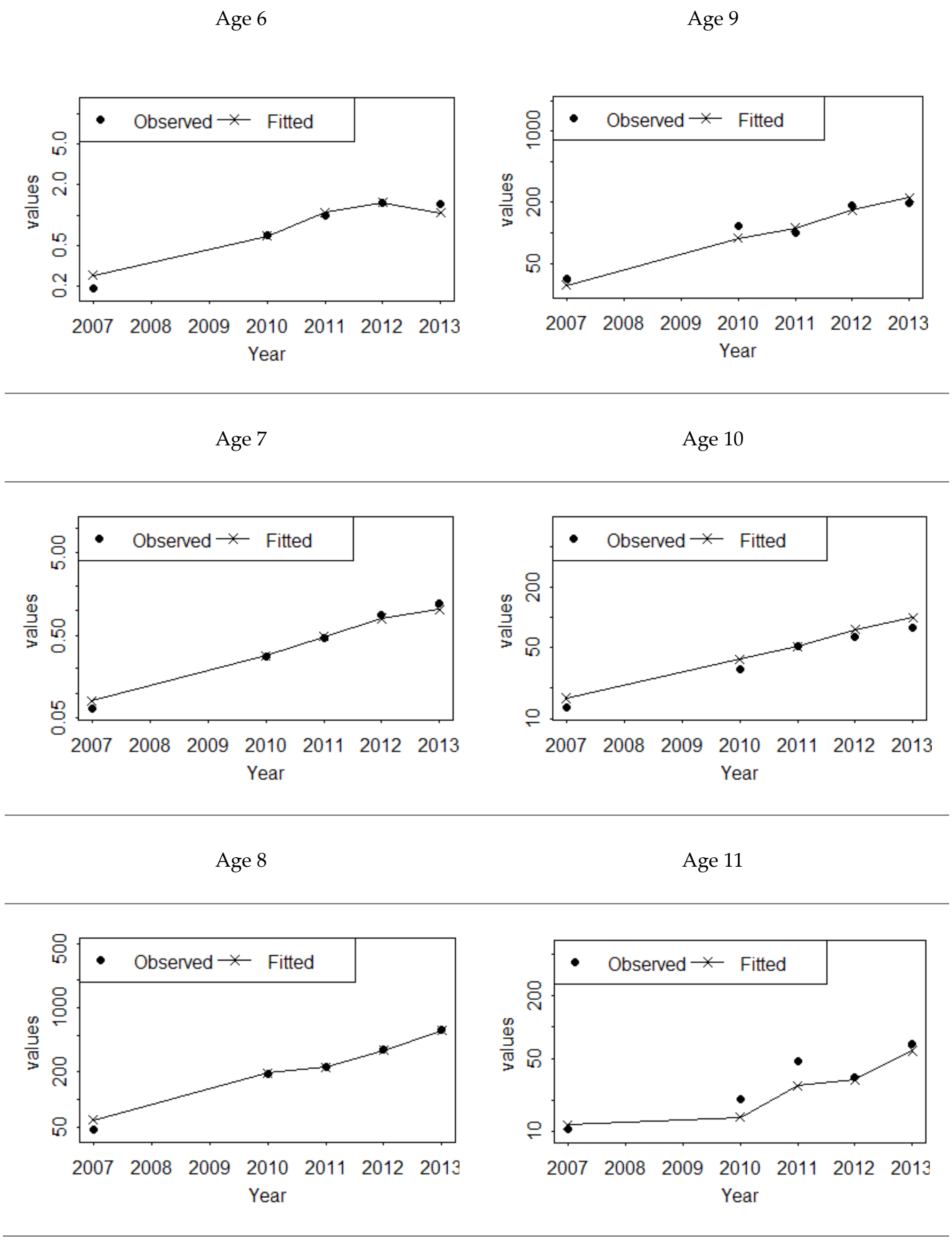


Figure 3.7.2.4. Fit of the final assessment to the IESSNS indices for ages 6 to 11 (observed vs. fitted).

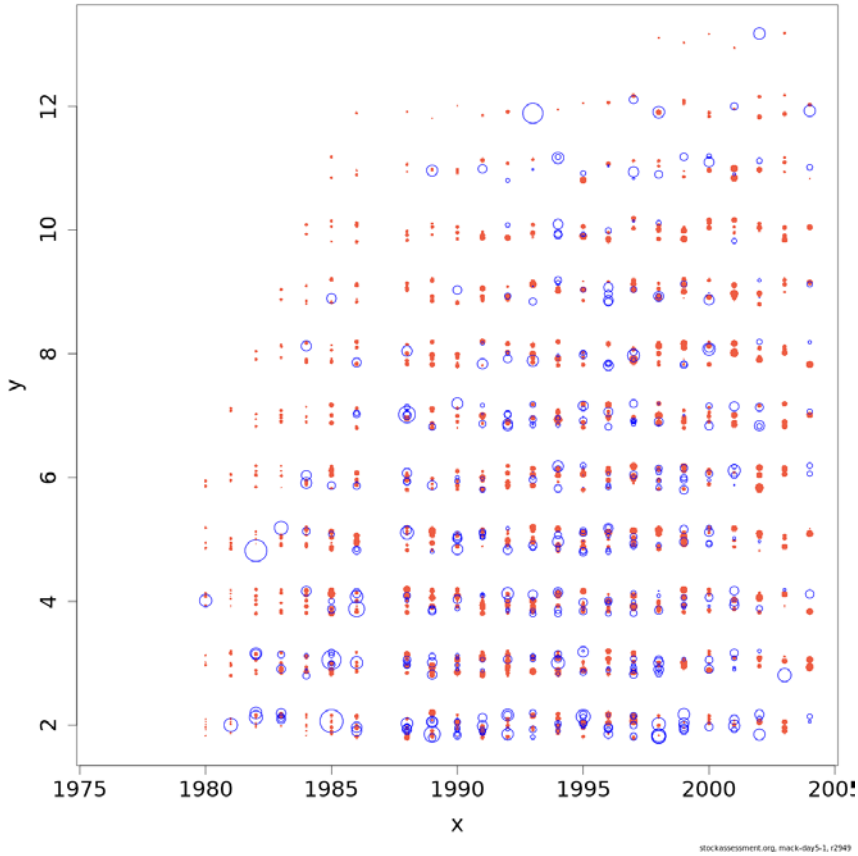


Figure 3.7.2.5. Normalized residuals for the fit to the recaptures of tags in the final assessment. The x-axis represents the release year, and the y-axis is the age of the fish at release. The different circles for a same x-y point represent the successive recaptures. Blue circles indicate positive residuals (observation larger than predicted) and filled red circles indicate negative residuals.

Historical stock development

The perception of the stock has changed considerably compared to the previous ICA assessment. The stock is now estimated to have varied between 2 million tonnes in the late 1990s and early 2000s and 5 million tonnes in the recent years (Figure 3.7.3.1), while with the previous assessment, the minimum was at around 1.6 million tonnes and the maximum at 3 million tonnes. The general trend in fishing mortality is similar to the previous assessment, except for the recent period where the new assessment indicates a strong decline in FBAR, down to 0.18; the previous assessment estimated recent FBAR to be higher than 0.23. The recruitment time-series from the new assessment shows a clear increasing trend since the late 1990s in which two very large year classes (2 to 3 times the average) are superimposed (2002 and 2006). The amplitude for the large year classes in the previous assessment was not as large (1.5 to 2 times) and 2005 was also estimated to be a large year class.

Large confidence intervals are associated with the SSB in the years before 1992. This results from the absence of information from the egg survey index and the downgrading of the information from the catches and the assessment being only driven by the tagging data in the early period. The confidence intervals become narrower from the early 1990s to the mid-2000s, corresponding to the period where information is available from the egg survey index, the tagging data and (partially) catches. The uncertainty increases again in the recent years, for the period when the IESSNS indices are introduced, and where no tagging data are available. The SSB estimate for the final year is estimated with a precision of +/-30% (Figure 3.7.3.2). There is generally also a large uncertainty on the fishing mortality, especially before 1995. The estimate of F_{BAR} in the final year has a precision of +/-30%. The uncertainty on the recruitment is consistent throughout the whole time-series, except for the terminal year in the assessment, where the precision of the estimate is+/-80%.

There is some indication of changes in the selectivity of the fishery over the last 20 years (Figure 3.7.3.3). In the year 1990, the fishery seems to have exerted a high fishing mortality on the older fish (7 and older). This changed gradually until 2000, when the fishing mortality on younger ages (5 and 6 year olds) increased compared to the older fish. In the following years, the selectivity pattern changed again towards a lower fishing mortality on the age classes younger than seven years until 2008. Finally, in the recent years, the fishing mortality on younger ages (4 to 7) increased again compared to the older ages.

Given the short length of the IESSNS time-series, the retrospective analysis could not be carried out for more than three years (Figure 3.7.3.4). There was no systematic retrospective pattern. Removing one year (2012) of data (purple curve on Figure 3.7.3.4) had almost no effect on the assessment. Removing two and three years (2011 and 2010) affected the perception of SSB for the year 2009 and 2010 but did not affect the earlier years. This, however, changed the perception of F_{BAR} for the recent years, starting from 2005. Removing 2 or 3 years of data, leaves only 3 and 2 data points to estimate the catchability of the IESSNS, respectively, which is considerably increases the uncertainty on this parameter. In this situation, the IESSNS has a much lower influence on the assessment and the output is comparable to the run leave out the IESSNS (Figure 3.6.4.5.2). Hence the strong retrospective pattern is a consequence of the short length of the IESSNS time-series and does not necessarily indicate a systematic bias in the assessment. In both SSB and F_{BAR}, the revision when adding one additional year of data was an upwards change. For the recruits, the retrospective changes were similar to SSB. In all cases, the perceived stocks from the retrospective assessments were included within the confidence interval of the final assessment.

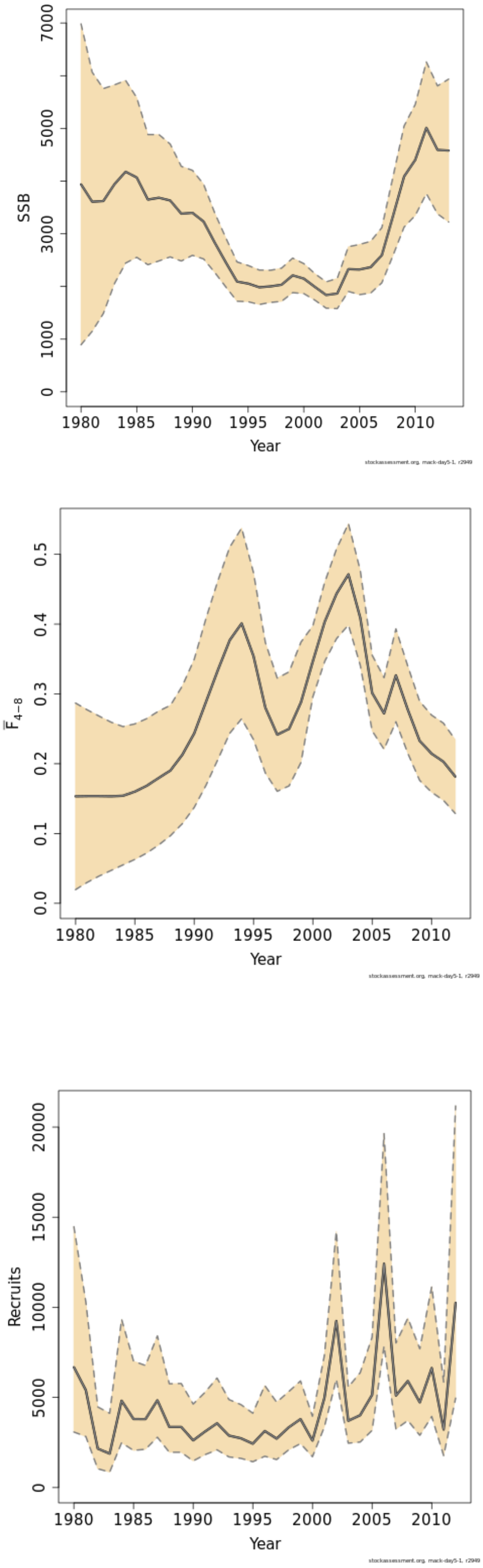


Figure 3.7.3.1. Perception of the mackerel stock, showing the SSB, FBAR 4–8 and recruitment (with 95% confidence intervals).

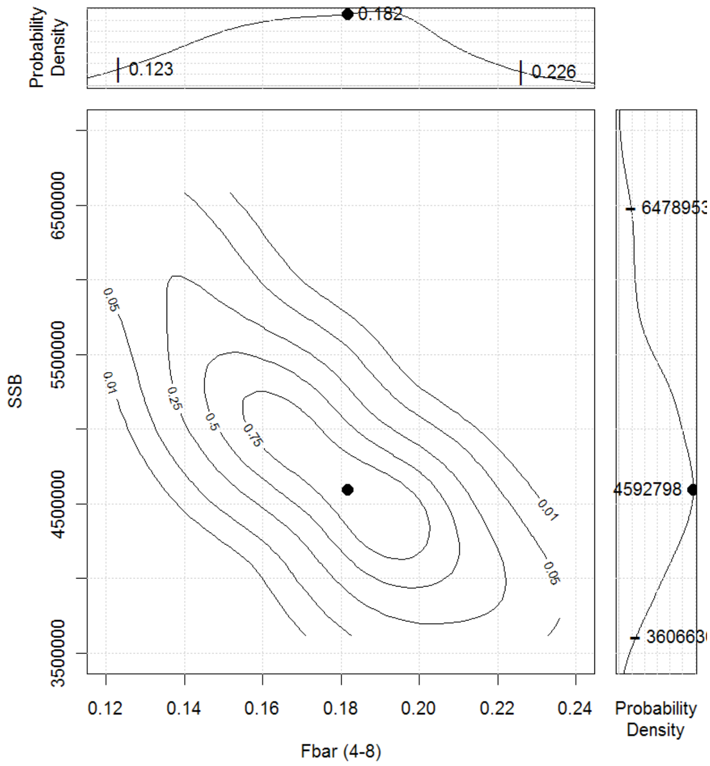


Figure 3.7.3.2. Joint distribution of the estimates of SSB and Fbar in 2012 resulting from the uncertainty in the parameters estimated by resampling parameters from the variance covariance matrix estimated by SAM.

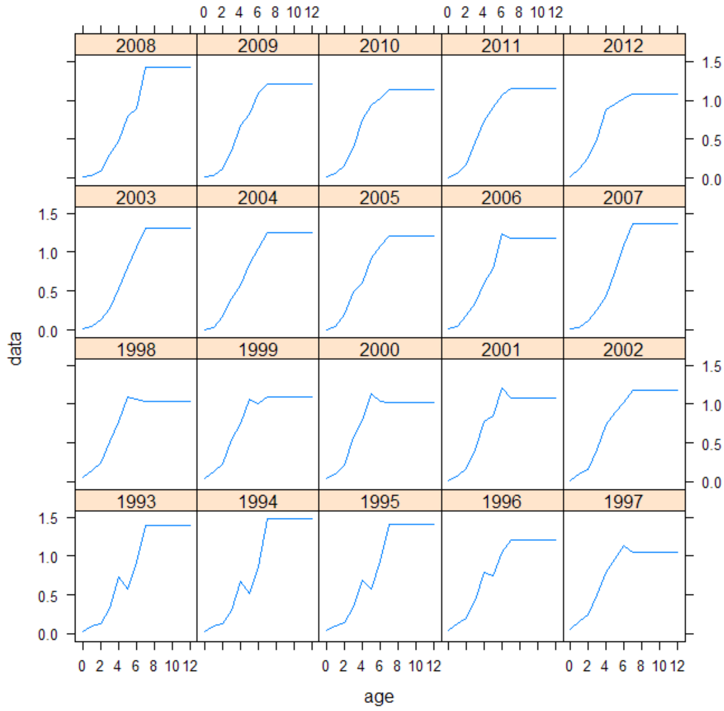


Figure 3.7.3.3. Estimated selectivity (fishing mortality divided by FBAR 4–8) for the period 1993 to 2012, calculated as the ratio of the estimated fishing mortality-at-age and the corresponding FBAR 4–8 values.

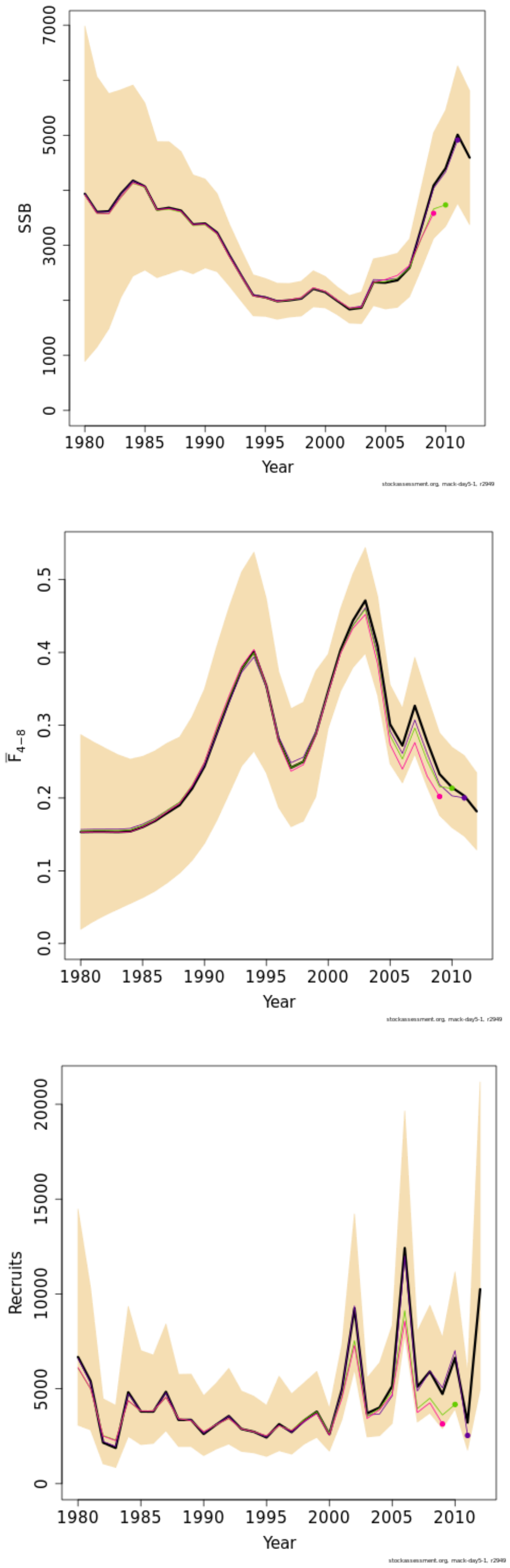


Figure 3.7.3.4. Retrospective plots for the final mackerel assessment for SSB, FBAR and Recruitment.

Comparative Final Assessment in CASAL

A comparative assessment was run in CASAL using the same data sources and model settings (to the extent possible) as those of the final SAM assessment. The results showed an improved fit to the data from those of the initial CASAL runs and generally corresponded well with the results of SAM. Consistent with the final SAM model, the assessment omitted tag data from 2005 onwards, included the swept-area survey for the years 2007 and 2010 to 2013 and the IBTSQ4 recruit index for age 0 as well as the triennial egg survey index. In addition all catch data were down-weighted prior to 2000. This was achieved in CASAL by reducing the effective sample size to an arbitrarily low value (2) for all years.

- CASAL model setup

The assessment model comprised a single area, age-structured and sex aggregated model with annual time-steps. A relatively simple annual cycle was assumed with each year divided into three periods. Periods 1 and 3 were effectively slots for the instantaneous events of recruitment and age incrementation. Spawning, fishing and tag release were all assumed to take place during the second period. Juveniles recruit to the fishery during the first period and age incrementation occurs during the last period. The duration of each period is less important than the sequence of events and the division of each process into these periods.

The model ran from age 1 to 15 with age 15 as a plus group. Natural mortality was fixed at 0.15 for all years and all ages. It was assumed that 25% of the mortality of period 2 occurs prior to spawning, which is consistent with a peak in spawning at around March/April and that the proportion of mature fish that spawn each year is equal to 1.0.

Tag releases were entered for length classes between 20 cm and 50 cm at 1 cm intervals. Since overall tag shedding is assumed to be zero the proportion of tag shedding in each period is also zero. A relatively high tag mortality of 0.4 has been assumed which occurs instantaneously at the same time as the tagging process. CASAL also has the ability to include a growth retardation in tagged individuals that may result from the stress of the tagging process. The so-called tag shock has been assumed to be zero in this instance such that growth is unaffected by tagging. Tag recaptures from fish that had been at liberty for up to five years were included in the model and all in-year recaptures have been excluded.

Parameters estimated by the model included virgin biomass and the parameters of the selection patterns. Year-class strength (YCS) multipliers were estimated for each year in the assessment time-series, however, YCS was fixed to 1 for the first 13 (1969–1980) and last two years (2011–2012) of the time-series since data were considered only sufficient to estimate YCS between 1981 and 2010. In addition, catchabilities were estimated for the survey abundance indices for comparison.

- Data weighting

Commercial catch-at-age and swept-area survey abundance data were modelled as proportions-at-age that summed to one in each year. These were assumed to be independently multinomially distributed and for this an effective sample size for each year must be specified. Since the actual sample size is unknown, the effective sample sizes for each year were estimated following a two-step procedure.

Initial estimates of the effective sample size were calculated by assuming a catch proportion-at-age CV of 0.3 for all years and ages, from which the effective sample size χ for each year was obtained by finding the value of χ that minimized η in the equation below (Hillary, personal comm.). cv_a is the coefficient of variation of the catch for each age group across all years. The second term of the equation is the cv of the proportion-at-age in the observed landings assuming a binomial distribution.

$$\eta_y = \sum_a \left[log(cv_a) - log\left(\frac{\sqrt{\chi \cdot o_{a,y} \cdot (1 - o_{a,y})}}{\chi \cdot o_{a,y}} \right) \right]^2$$

These initial effective sample sizes were subsequently revised through the iterative re-weighting procedure described in Francis (2011).

An initial observation error CV was estimated for the egg production abundance time-series from a loess smoother fitted to estimates for the period 1992 to 2013. The calculated CV related to the full time-series but was applied to observation of the series. The loess smoother provided a relatively good fit to the data and consequently the estimated CV was small (0.016). To prevent these data from being overly dominant in the model an additional process error CV of 0.30 was assumed. This process for determining the level of uncertainty about the egg abundance indices was a little *ad hoc*, but resulted in an overall level of uncertainty consistent with that estimated by the SAM model and suggested by Simmonds e*t al*. (2010).

Similarly, effective sample sizes and cvs were not available for the swept-area survey index or the recruit index and approximate values had to be assumed based on those estimated by the SAM assessment model. These approximations have been made since no alternative information could be provided.

- Assessment Results and Diagnostics

Fits to the egg abundance index (Figure 3.7.4.1) show general correspondence between the observed and fitted values throughout the time-series although the assessment estimates a slight reduction in SSB since 2010 whilst the survey indicates a continual increase in SSB from 2004 onwards.

Fits to catch proportion at age data for the IESSNS survey indices at ages 6 to 14 (Figure 3.7.4.2) show a general trend for positive residuals at the younger ages and negative residuals at older ages indicating that fewer fish are captured at older ages than predicted by the model. Constant selection across all ages has been assumed. Although no *a priori* reason for an alternative assumption on selection was considered, the results would suggest a higher selection at the younger ages (6 to 8) than fitted by the model.

The commercial catch proportions-at-age data were split into two periods (1988 to 1999; 2000 to 2012) and separate selection patterns fitted to each time period. The residuals (Figures 3.7.4.3 and 3.7.4.4) show a general trend for positive residuals at younger ages and negative residuals at older ages with the pattern becoming more pronounced for the period 2000 to 2012. The results indicate a persistent bias for negative residuals at the oldest ages which, again is most apparent in the recent time period indicating that fewer old fish were observed than expected by the model. Preliminary model runs investigated the option for dome shaped selection by allowing the model to fit selection at each age independently. The resulting selection patterns were clearly sigmoid and showed no indication of dome shaped selection. For the final comparative assessment the fitted selection patterns (Figure 3.7.4.8) were constrained to a sigmoid functional form.

The CASAL assessment ran from age 1 to 15+. Consequently the IBTSQ4 0-group recruitment index was shifted by one year and fitted at age 1. The results (Figure

3.7.4.5) show a good fit to the observations although the assessment provides underestimates for the 2005, 2006, 2011 and 2012 year classes which were all estimated to be large by the survey.

Tag recapture residuals by age class (Figure 3.7.4.6) show that, overall, tag–recapture residuals were centred around zero throughout the time-series with a slight tendency for persistent positive residuals at the older ages where data are scarce and the number of observations much smaller. Observed and predicted tag recaptures by age for each release and recapture year (Figure 3.7.4.7) show a relatively poor fit between observed and predicted recaptures in the early years (1984:1989) but a progressive improvement thereafter with particularly good fits during the period 1995 to 1999.

CASAL primarily uses tag data as an estimate of abundance to scale the assessment. Likelihood profiles of virgin biomass (B_0) (Figures 3.7.4.10 and 3.7.4.11) showed very divergent estimates of B_0 from the different data sources and particularly so for the tag data, which show considerable noise throughout the time-series but also some periods when consistently high or low values of B_0 are estimated. For example, tag data between 1993 and 1997 (which appear to fit particularly well from Figure 3.7.4.7) consistently estimate B_0 lower than other data sources. The overall estimate of B_0 (Figure 3.7.4.11, 14.4M tonnes) should therefore be interpreted with some caution.

The results of the comparative CASAL assessment (Figure 3.7.4.9) are broadly consistent with those of the final SAM assessment. SSB is estimated to have increased in recent years following a period of high recruitment. Recruitment in the most recent years is estimated to be closer to long-term mean values although the IBTSQ4 recruitment index (Figure 3.7.4.5) indicates potentially higher recruitment in these years. Fishing mortality increased to a peak during the early 2000s and has since declined.

There is a slight difference in the scaling of F and SSB between the SAM and CASAL assessments with CASAL estimating slightly higher SSBs and slightly lower fishing mortalities. However, the overall trends determined from the CASAL assessment are broadly consistent with those of the final SAM assessment and a number of similar and consistent findings were obtained from the two assessment approaches.

- Both assessment models struggled to fit the tag data in its entirety.
- The results of both SAM and CASAL are consistent with observations that the tag data are potentially informative but very noisy (Skagen. Note on tag estimates of stock abundance. Working Document to WKPELA, 2014)
- Both models provided improved fits when the early catch data were down-weighted.
- Catch proportion residuals from CASAL show strong temporal trends which supports the assumption of temporally varying selection as in SAM.
- Overall trends in spawning biomass, recruitment and fishing mortality are similar for both models.

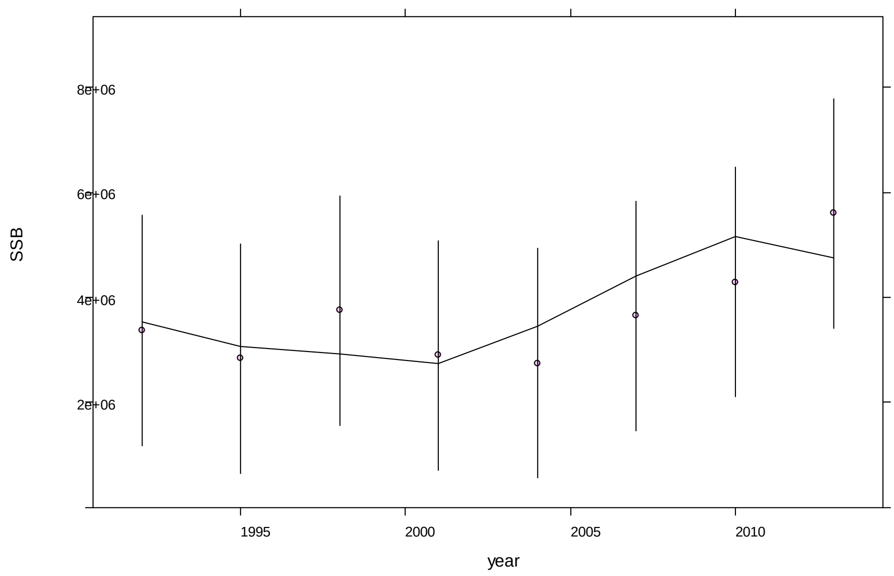


Figure 3.7.4.1. SSB estimates from the triennial egg survey. Observations with error bars showing ±2 standard deviations. Solid line shows model estimates.

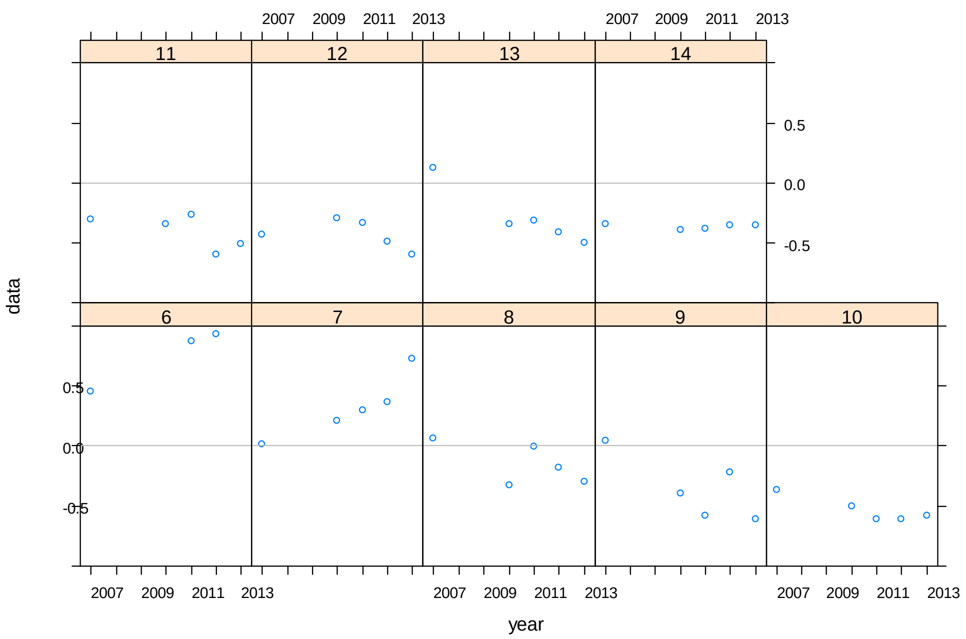


Figure 3.7.4.2. Catch proportion-at-age residuals for the IESSNS survey, ages 6 to 14 for the period 2007, 2010:2013.

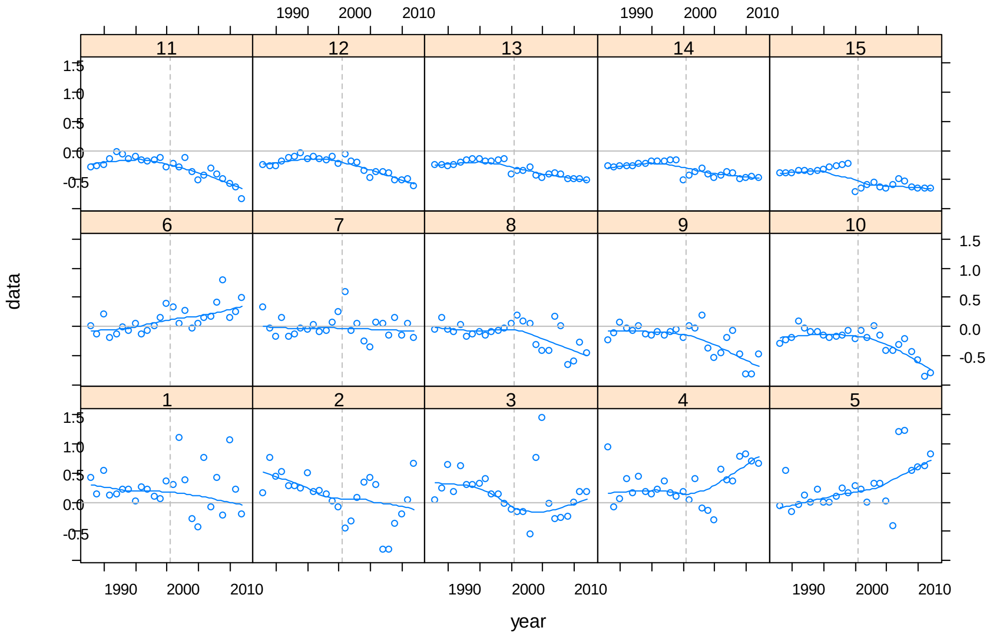


Figure 3.7.4.3. Catch proportion-at-age residuals by age for the commercial catch between 1988 and 2012. Separate selection patterns are fitted between 1988:1999 and 2000:2012.

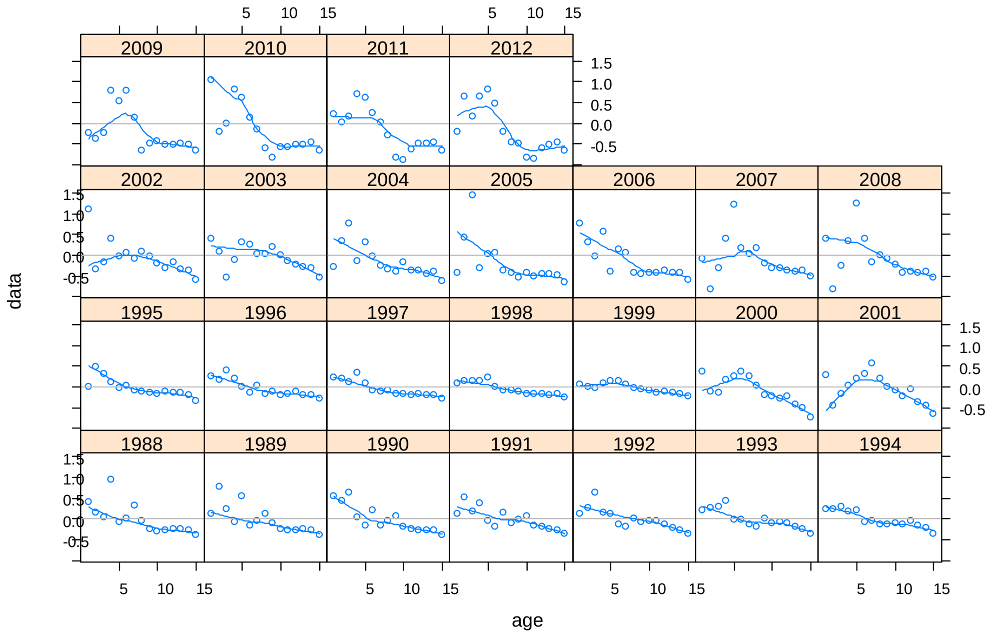


Figure 3.7.4.4. Catch proportion-at-age residuals by year for the commercial catch between 1988 and 2012. Separate selection patterns are fitted between 1988:1999 and 2000:2012.

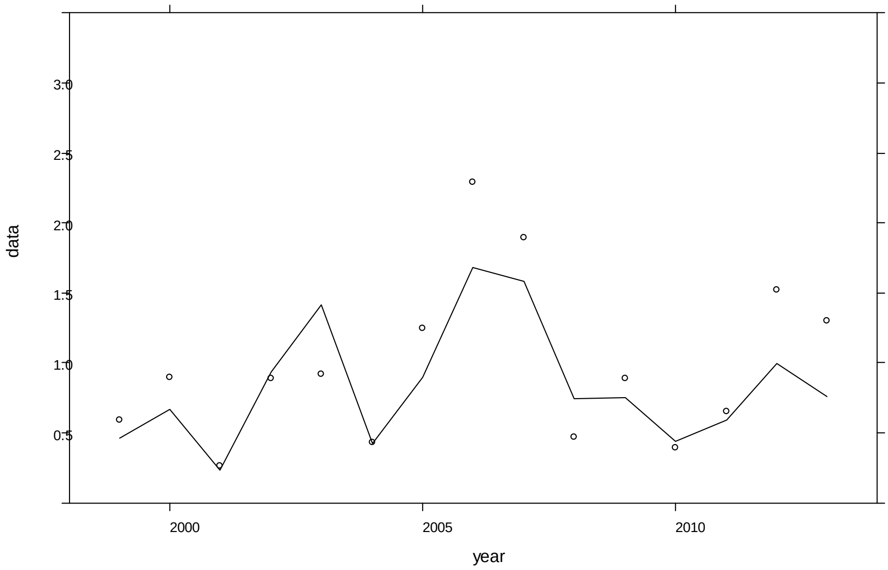


Figure 3.7.4.5. Predicted (solid line) and IBTSQ4 observed (points) recruitment-at-age 1. Note that the 0 group index has been shifted by one year to be included as a 1 group recruitment index.

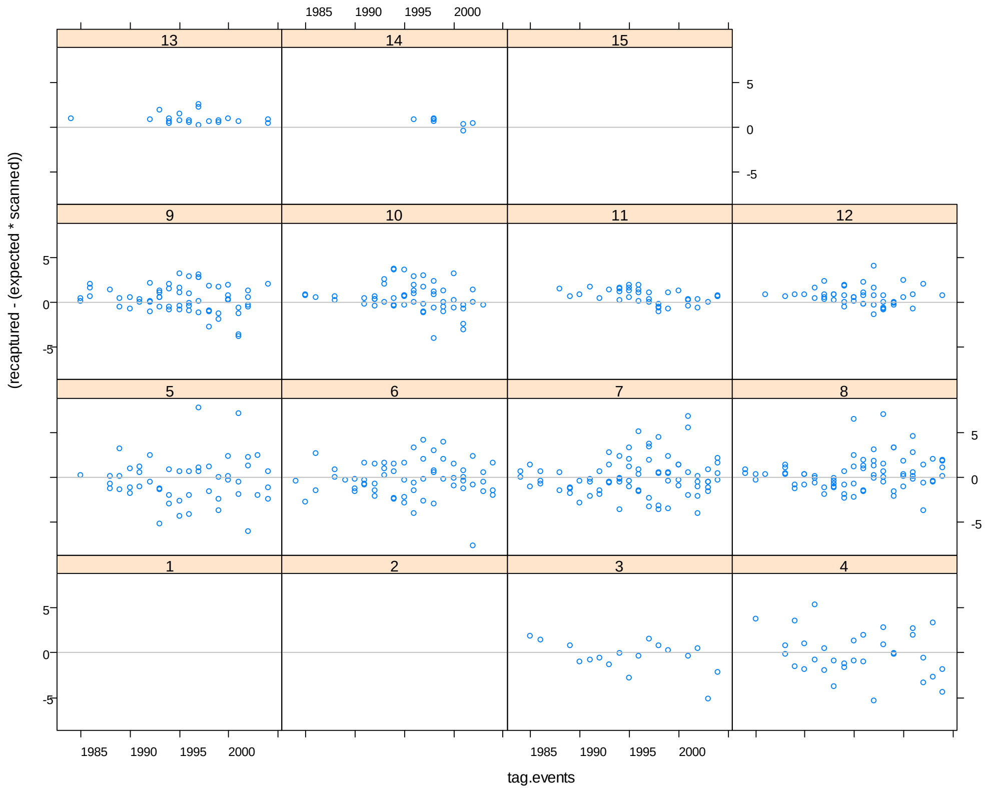


Figure 3.7.4.6. Tag–recapture residuals by age class for the period 1985 to 2013.

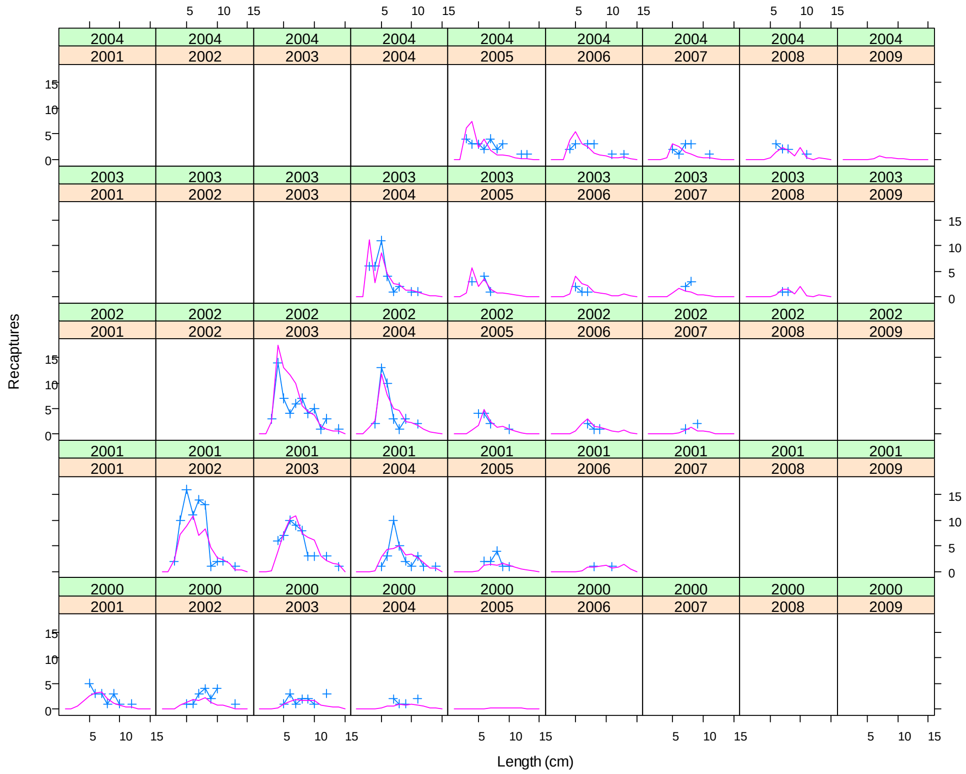


Figure 3.7.4.7. Observed and expected tag recaptures for releases between 2000 and 2004. Release years are shown along rows with recapture years down columns.

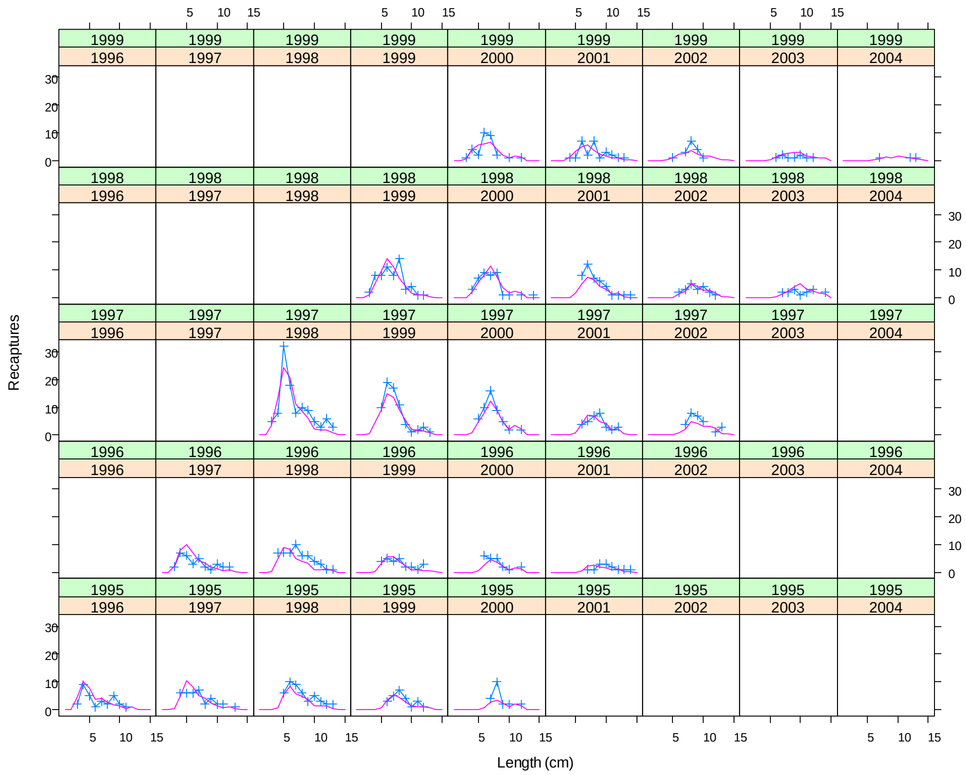


Figure 3.7.4.7. Cont. Release years 1995 to 1999.

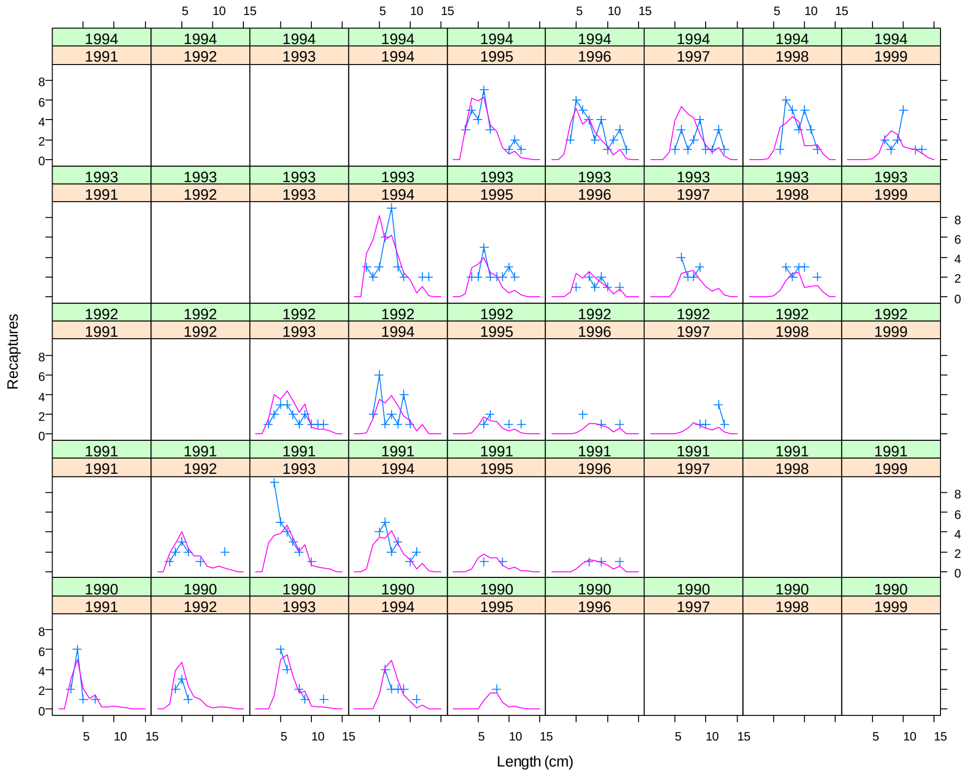


Figure 3.7.4.7. Cont. Release years 1990 to 1994.

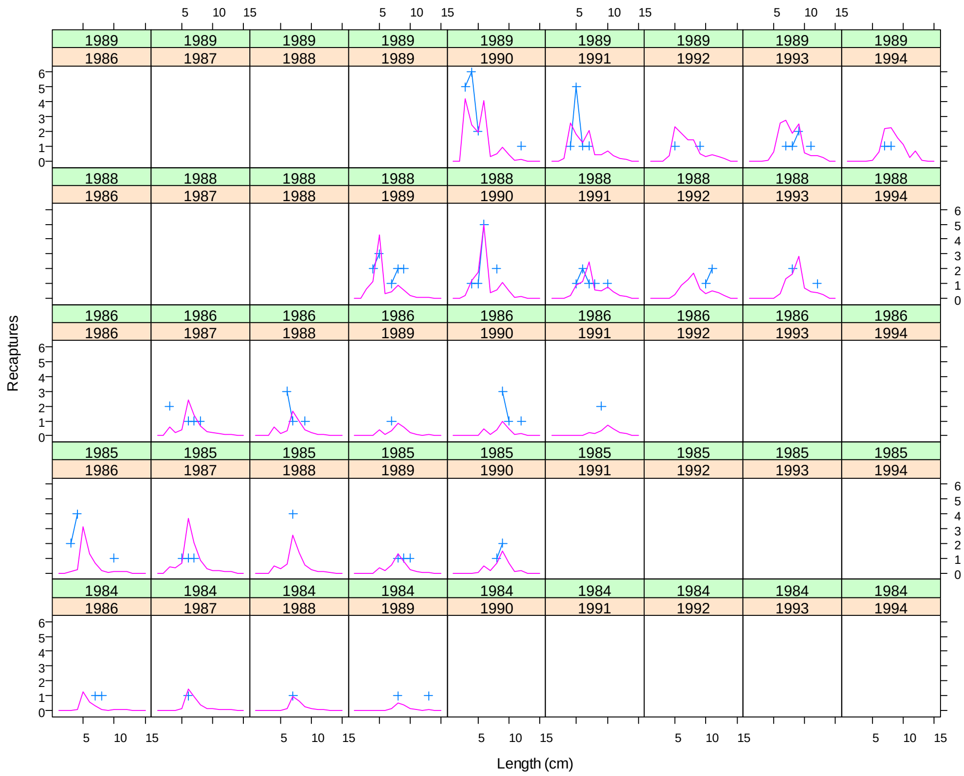


Figure 3.7.4.7. Cont. Release years 1984 to 1989.

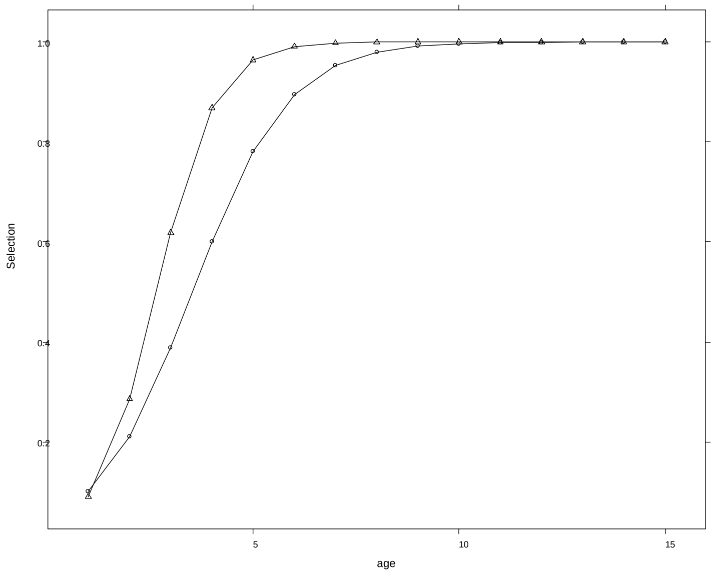


Figure 3.7.4.8. Fitted selection pattern 1988 to 1999 (triangles) 2000 to 2012 (circles).

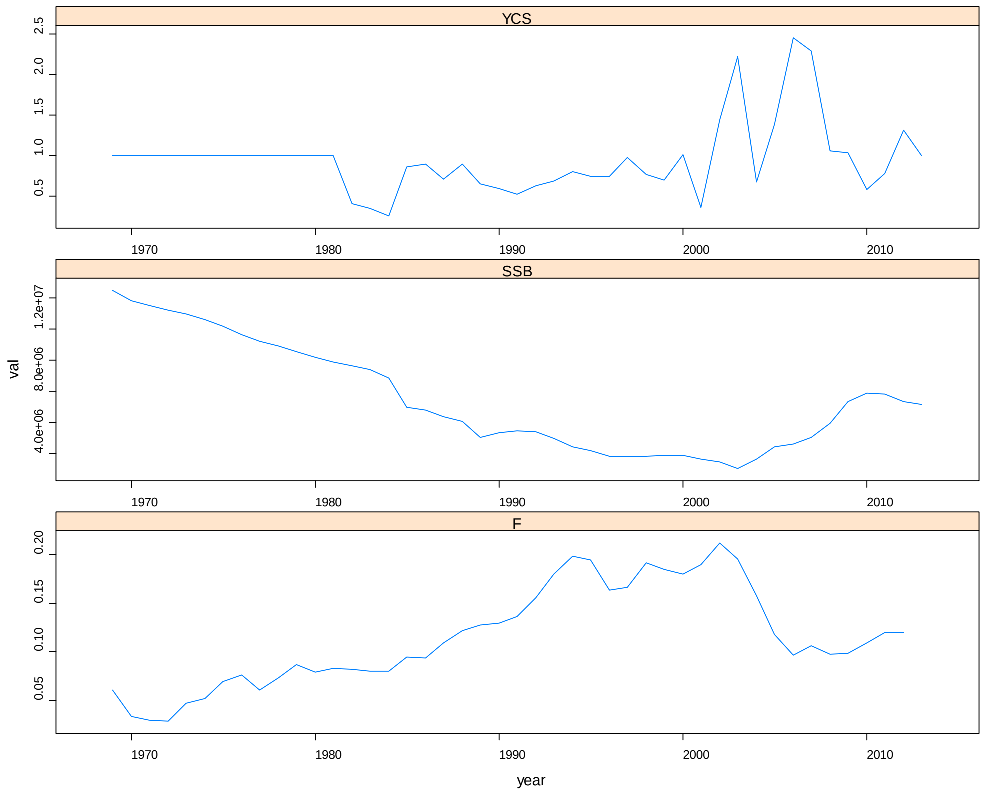


Figure 3.7.4.9. Estimated values of relative year-class strengths, SSB and fishing mortality.

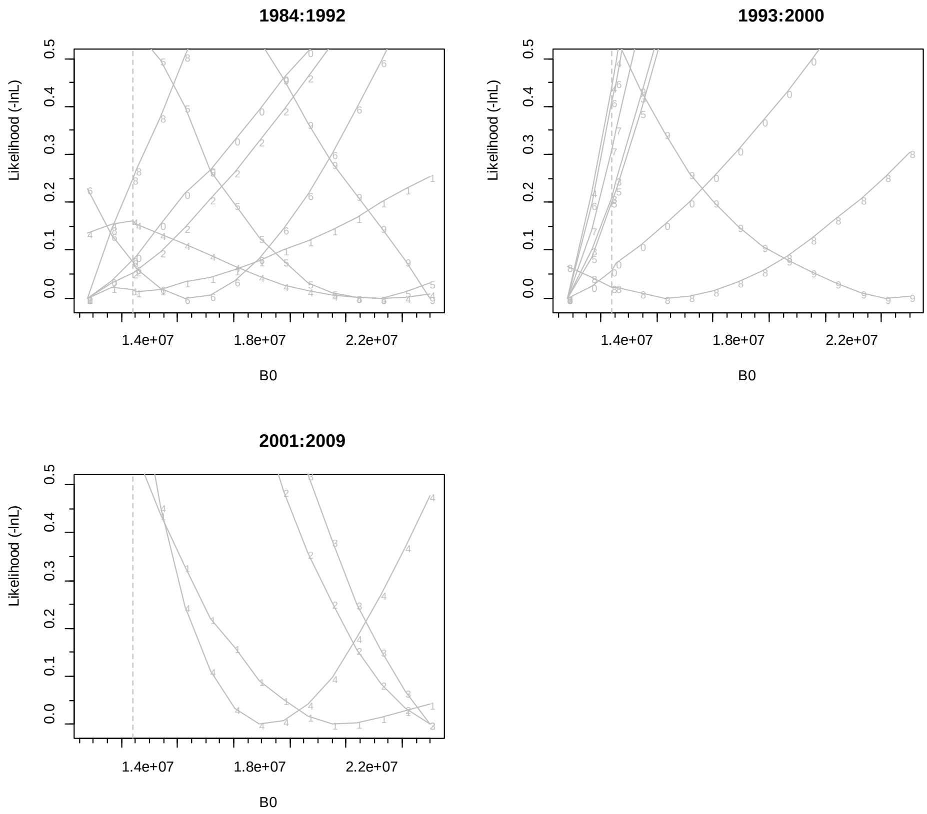


Figure 3.7.4.10. Likelihood profiles for virgin biomass (B_0) for tag data between 1984 and 2004. Vertical dotted line shows the overall model estimate of B_0.

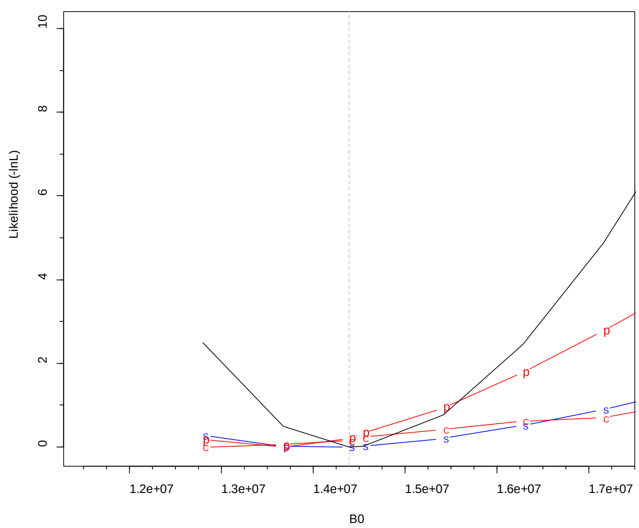


Figure 3.7.4.11. Likelihood profiles for B_0 for catch and survey data. Solid black line and vertical dotted line shows the overall model estimate of B_0 and likelihood profile.

3.8 Short-term projections

Calculation procedures for the short-term projections follow the methods from the benchmark in 2007, except for the inclusion of the new IBTS recruit index.

In a given assessment year Y, advice is given on catches for the following year Y+1 based on deterministic projections three years ahead (Y to Y+2). These projections are based on an assumption of the current year's (also called intermediate year) catch (see section below "Assumptions for the intermediate year catch") from which fishing mortality in the current year Y is inferred, and a range of management options for the advice year, Y+1, are provided.

Initial abundances at age

The survivors at the 1st of January of year Y estimated by SAM are used as starting abundances at age in the first year of the short-term forecast. The recruitment estimate at age 0 from the assessment in the terminal assessment year (Y-1) is considered too uncertain to be used, because this year class has not yet fully recruited into the fishery. The last (Y-1) SAM recruitment estimate is therefore replaced by predictions from the RCT3 software (Shepherd, 1997). The RCT3 software performs a linear regression between the IBTS recruitment index and the SAM estimates over the period 1998 to Y-2, and, based on this regression, predicts the Y-1 recruitment using the Y-1 IBTS index value. The final Y-1 recruitment is the average between the prediction from this regression and a time tapered geometric mean of the SAM recruitments up to Y-2, weighted by the inverse of their respective prediction standard errors. The historic performance of the IBTS index thus determines the influence of the Y-1 index value on the Y-1 recruitment produced by RCT3. A weak correlation of the survey index with the SAM estimates brings the RCT3 estimate close to the SAM geometric mean, while a strong correlation brings it close to recruitment predicted from the IBTS index for the year Y-1. The "time tapered geometric mean" is a weighted geometric mean, where the most recent years are given the highest weights. For 2011 and 2012, the IBTS index was high. However, because the historic performance was found to be relatively poor, RCT3 estimated the numbers of recruits to be 6 213 437 and 6 009 069 respectively. These values were closer to the geometric mean than to the IBTS index. The general process to be followed should be to fit the RCT3 model to the survey time-series, evaluate the diagnostics and see whether the survey information provides an improved estimate over just using the mean. Where the RCT3 estimates provide an improved estimate over just using the mean, they should be used, otherwise use a geomean. This would apply to Y-2 Y-1 and Y where there were R estimates from a survey available for year Y.

The abundance of the survivors-at-age 1 (in Y) used as starting values for the short-term forecast is then estimated by bringing forward recruitment-at-age 0 (in Y-1) applying the total mortality-at-age 0 in year Y-1 estimated by SAM.

Conditioning of the short-term forecast

Recruitment

The recruits at age 0 in year Y, Y+1 and Y+2 are set to the geometric mean. Possible to use RCT3 estimates for year Y when there is survey information available in year Y and there is information in the model above the geomean.

Exploitation pattern

The exploitation pattern (relative selection pattern) used in the predictions from Y to Y+2 is defined as the average of the exploitation pattern of the last three years in the assessment (Y-3 to Y-1), obtained by dividing the fishing mortalities-at-age of those three years by the value of Fbar4-8 in the corresponding years.

Maturity-at-age, weight-at-age in the catch and weight-at-age in the stock

The three year average of Y-3 to Y-1 is used for the proportion mature-at-age as well as stock and catch weights-at-age.

Proportion of natural and fishing mortality occurring before spawning

The three year average of Y-3 to Y-1 is used for the proportions F_{prop} and M_{prop}.

Assumptions for the intermediate year (Y):

The catch in the intermediate year (Y) is taken as a TAC constraint. The catch is estimated from declared quotas modified by e.g. paybacks (e.g. EU COMMISSION REGULATION (EC) No 147/2007), discards (assumed to be equal to the last reported discards in year Y-1), interannual transfers and expected overcatch. Scientists from the relevant countries present at the WGWIDE each year provide the information on interannual transfers and expected overcatch.

Management Option Tables for the TAC year

The different management options for the catch in Y+1 are tested, covering both the ICES approach to MSY and the management plan implemented for NEA Mackerel in 2009:

- CatchY+1 = zero

- CatchY+1 = TACY – 20%

- CatchY+1 = TACY

- CatchY+1 = TACY + 20%

- F_{BAR}Y+1 = management plan range in steps of 0.01

For e.g. -F_{BAR}Y+1 = 0.20

- F_{BAR}Y+1 = 0.21

- F_{BAR}Y+1 = 0.22

- F_{BAR}Y+1 = 0.25 (F_{MSY})

These options may be changed from year to year on the basis of client requests, and changes to:

Software implementation

The short-term forecast will be calculated in MFDP, FLR or StockAssessment.org. Testing will be done during the preparation of the advice in 2014.

3.9 Reference points

3.9.1 Introduction

The reference points previously evaluated for NEA mackerel are given in Table 3.8.1. These were reviewed or defined at the last benchmark in 2007. The values were temporarily suspended in 2013 as the assessment on which they were based was not used to give catch advice in that year.

3.9.2 Precautionary reference points

Blim **-** There is no evidence of significant reduction in recruitment at low SSB within the time-series (Figures 3.8.1 and 3.8.2) hence the previous basis for B_{lim} is retained. B_{lim} is taken as B_{loss}, the lowest estimate of spawning-stock biomass from the revised assessment. This was estimated to have occurred in 2002; B_{loss} =1 840 000 t.

Flim **-** F_{lim} is derived from B_{lim} and is determined as the F that on average would bring the stock to B_{lim}; F_{lim} = 0.39.

B_{pa} - The ICES basis for advice requires that a precautionary safety margin incorporating the uncertainty in actual stock estimates leads to a precautionary reference point B_{pa}, which is a biomass reference point designed to avoid reaching B_{lim}. Consequently, B_{pa} was calculated as B_{lim} * exp(1.645σ) where σ = 0.15 was taken as the assessment estimate of spawning biomass uncertainty in the most recent year; B_{pa} = 2 350 000 t.

Fpa **-** F_{pa} is derived from B_{pa} and is determined as the F that on average would bring the stock to B_{pa}; F_{pa} = 0.26.

3.9.3 MSY reference point estimation

The ICES MSY framework specifies a target fishing mortality, F_{MSY}, which, over the long term, maximizes yield, and also a spawning biomass, MSY $B_{trigger}$, below which fishing mortality is reduced proportionately relative to F_{MSY}. The ICES basis for advice notes that, in general, F_{MSY} should be lower than F_{pa}, and MSY $B_{trigger}$ should be equal to or higher than B_{pa}. ICES WKMSYREF2 (ICES 2014 WKMSYREF2) highlighted that the values of F_{MSY} should be checked using stochastic simulation to ensure that expected errors in the advice do not result in >5% probability of SSB< B_{lim}.

3.9.3.1 PlotMSY

The reference point estimation software plotMSY (ICES 2014 WKMSYREF2) was used to calculate yield and spawner biomass per recruit reference points (Table 3.8.3) and to evaluate the potential for determining parametric estimates of F_{MSY}.

The fit of Beverton–Holt, Ricker and hockey-stick models (Figure 3.8.1, Table 3.8.3) to the stock and recruit estimates indicated poorly determined parameter estimates for all models. The slope of the Beverton–Holt and Ricker models was ill determined and the hockey-stick breakpoint was estimated to be above the lowest spawning biomass in the time-series, which was considered an artefact of the distribution of the spawning stock and recruitment pairs at low spawning biomass.

3.9.3.2 Stochastic simulation

In the absence of well-defined parametric model fits a stochastic evaluation using equilibrium stochastic simulations (ICES 2014 WKMSYREF2) was carried out and tested for sensitivity to assumptions as listed in Table 3.8.4. Catch data up to 2000 were considered unreliable and down-weighted in the final assessment model. However, simulation runs which utilized only the stock and recruitment pairs after 2000 were regarded as unsatisfactory as they excluded a period of low recruitment during the 1990s potentially giving an over-optimistic perception for the future recruitment; the period 1990–2011 was taken as the best compromise available. Yield was considered as total catch, which is considered relevant to the situation from 2015 onwards when the fishery will be conducted under a discard ban for almost all participants.

F_{MSY} - Applying the WKMSYREF2 simulation approach the median value of F_{MSY} was F=0.31 was above F_{pa} and resulted in a greater than 5% probability of SSB<B_{lim} (Figure 3.8.3). Fulfilling the precautionary requirement of SSB having 5% or less probability of being reduced to below B_{lim} results in F_{MSY} = F <= 0.26 (Figure 3.8.4).

Maximum mean and median catches both occurred at a lower exploitation rate of F=0.25. Following the ICES guidelines (ICES 2013 WKMSYREF), F=0.25 would be an appropriate F_{MSY} target as on average it resulted in the highest mean yields with a low risk of reducing the spawning biomass below B_{lim}.

3.9.4 Advice under the current management plan

In comparison to the stock time-series used to evaluate the current management plan, in the new assessment recruitment is higher and fishing mortality estimates similar historically but lower in recent years, resulting in an increased spawning biomass. B_{lim} is slightly higher but occurred during the same years, which, given the increased recruitment, is likely to have a slightly lower probability of encounter at the same exploitation rates. The exploitation rate which maximizes yield, F_{MSY} =0.25, is considered precautionary as is the F target range in the current management plan (0.20 to 0.22) which is lower than F_{MSY}.

Given the combination of changes described above it is to be expected that the current management plan fishing mortality target range will still be precautionary, and ICES can continue to provide advice under this plan if requested to do so. However, the current management plan $B_{trigger}$ is below the revised B_{PA} and consequently the management plan should be re-evaluated prior to the release of advice for 2015 in order to determine the appropriate combination of $B_{trigger}$ and fishing mortality range that are consistent with the precautionary approach.

3.9.5 2014 Benchmark assessment revised reference points

The full list of revised reference points as revised and recommended by WKPELA (2014) are presented in Table 3.8.2. MSY $B_{trigger}$ and SSB trigger are not provided as an evaluation is required to update the values.

Table 3.9.1. ICES Reference points for NEA mackerel (ICES, 2012).

Type		Value	Technical basis
Management Plan	$SSB_{trigger}$	2.2 million t	Medium-term simulations conducted in 2008
	F target	0.2 to 0.22	Medium-term simulations conducted in 2008
MSY Approach	MSY $B_{trigger}$	2.2 million t	SSB associated with high long-term yield and low probability of stock depletion based on management strategy evaluation (ICES 2008)
	MSY target	0.22	F associated with above reference points
Precautionary Approach	Blim	1.67 million t	Bloss of the 2007 assessment of (Western, Southern components)
	B_{pa}	2.3 million t	Bloss of the 1998 assessment of the Western components inflated by 15% to account for the southern component
	F_{lim}	0.42	F_{loss}
	F_{pa}	0.23	F_{lim}*0.55 (CV=36%)

Table 3.9.2. Proposed revised ICES Reference points for NEA mackerel (ICES, 2014).

Type		Value	Technical basis
Management Plan	$SSB_{trigger}$	N/A	Revision required
	F target	N/A	Revision required
MSY Approach	MSY $B_{trigger}$	2.36 million t	Proxy based on Bpa
	MSY target	0.25	Stochastic simulation conducted at WKPELA 2014
Precautionary Approach	Blim	1.84 million t	Bloss in 2002 from WKPELA 2014 benchmark assessment
	B_{pa}	2.36 million t	exp(1.654*σ)*Bim, σ=0.15
	F_{lim}	0.39	F_{loss}, the F that on average leads to Blim
	F_{pa}	0.32	F that on average leads to B_{pa}

Table 3.9.3. Northeast Atlantic mackerel plotMSY stock and recruitment model parameter estimates.

Ricker

1000/1000 Iterations resulted in feasible parameter estimates

	Fcrash	Fmsy	Bmsy	MSY	ADMB Alpha	ADMB Beta	Unscaled Alpha	Unscaled Beta	AICc
Deterministic	0.769	0.249	2514880	589843	0.761	1.001	3.468	2.94E-07	31.30
Mean	0.843	0.265	3015688	660433	0.779	0.985	3.636	2.90E-07	33.50
5%ile	0.357	0.133	1795720	442386	0.629	0.364	2.108	1.07E-07	31.41
25%ile	0.540	0.189	2188585	547374	0.708	0.734	2.798	2.16E-07	31.95
50%ile	0.753	0.248	2577915	625765	0.771	0.987	3.439	2.90E-07	32.95
75%ile	1.014	0.310	3142378	719754	0.841	1.220	4.218	3.59E-07	34.37
95%ile	1.640	0.461	5493513	945741	0.957	1.642	5.837	4.83E-07	37.79
CV	0.520	0.413	0.655	0.332	0.131	0.383	0.325	0.383	0.062
N	1000	1000	1000	1000	1000	1000	1000	1000	1000

Beverton-Holt

1000/1000 Iterations resulted in feasible parameter estimates

	Fcrash	Fmsy	Bmsy	MSY	ADMB Alpha	ADMB Beta	Unscaled Alpha	Unscaled Beta	AICc
Deterministic	4.589	0.391	1754110	588950	1.256	1.368	4531190	3.04E+05	31.174
Mean	1.554	0.285	3276595	631697	0.999	1.329	7215745.36	2.05E+06	33.037
5%ile	0.343	0.106	1240062	415965	0.439	1.085	3866311	7.76E+04	31.234
25%ile	0.671	0.163	1806380	513659	0.767	1.220	4549545	3.99E+05	31.613
50%ile	1.191	0.234	2494105	582434	1.034	1.327	5504615	9.17E+05	32.475
75%ile	2.177	0.352	3595725	682629	1.251	1.425	7419820	2.15E+06	33.740
95%ile	3.872	0.632	7036237	898418	1.472	1.582	12976600	5806902.5	36.825
CV	0.728	0.649	1.263	0.542	0.328	0.115	1.240	2.682	0.058
N	815	1000	1000	1000	1000	1000	1000	1000	1000

Smooth hockeystick

1000/1000 Iterations resulted in feasible parameter estimates

	Fcrash	Fmsy	Bmsy	MSY	ADMB Alpha	ADMB Beta	Unscaled Alpha	Unscaled Beta	AICc
Deterministic	0.294	0.294	2366950	635656	0.548	0.889	0.917	2366030	31.368
Mean	0.311	0.310	2559015	697388	0.564	0.960	0.944	2557385.12	33.817
5%ile	0.198	0.198	1891589	497355	0.454	0.710	0.761	1890296	31.565
25%ile	0.253	0.252	2118403	588351	0.509	0.795	0.852	2116987.5	32.145
50%ile	0.302	0.302	2432160	668857	0.557	0.913	0.933	2430210	33.008
75%ile	0.355	0.355	2772343	771904	0.606	1.041	1.015	2771430	34.934
95%ile	0.473	0.472	3780635	997116	0.703	1.419	1.177	3779467	38.412
CV	0.264	0.263	0.235	0.227	0.134	0.235	0.134	0.235	0.069
N	1000	1000	1000	1000	1000	1000	1000	1000	1000

Per recruit

	F20	F25	F30	F35	F40	F01	Fmax	Bmsypr	MSYpr
Deterministic	0.575	0.411	0.310	0.241	0.192	0.188	0.868	0.545	0.146
Mean	0.558	0.399	0.301	0.234	0.187	0.185	0.947	0.540	0.147
5%ile	0.351	0.252	0.189	0.147	0.117	0.127	0.570	0.425	0.117
25%ile	0.484	0.351	0.265	0.206	0.163	0.164	0.727	0.494	0.135
50%ile	0.556	0.397	0.301	0.236	0.189	0.186	0.860	0.537	0.147
75%ile	0.634	0.455	0.343	0.267	0.213	0.209	1.066	0.587	0.159
95%ile	0.764	0.538	0.401	0.311	0.247	0.238	1.577	0.658	0.178
CV	0.222	0.215	0.212	0.210	0.211	0.188	0.368	0.132	0.125
N	1000	1000	1000	1000	1000	1000	993	993	993

Table 3.9.4. Basis and options tested for MSY values.

Parameter	Tested	Used	Comments
Mean weights-at-age in stock	2002 to 2011	2002 to 2011	Corresponding to recent growth
Mean weights-at-age in catch	2002 to 2011	2002 to 2011	
Maturity-at-age	2002 to 2011	2002 to 2011	Stable values
Natural Mortality	2002 to 2011	2002 to 2011	Fixed value of 0.15 at all ages
Fraction of M before spawning	2002 to 2011	2002 to 2011	Corresponding to recent variability of spawning time
Selection at age in the fishery	2002 to 2011 2007 to 2011	2007 to 2011	Reflecting recent changes in the fishery
Fraction of F before spawning	2002 to 2011 2007 to 2011	2007 to 2011	Corresponding to recent variability of fishery and spawning time
Stock–Recruit pairs	1980 to 2012 1990 to 2011 2000 to 2011	1990 to 2011	Short period implied higher recruitment that was considered potentially too optimistic. The longer period was considered too uncertain in recent years.
Stock models	Segmented regression, Combined Segmented regression Beverton–Holt Ricker	Combined models	For short period the segmented regression was preferred as the fit for other models was too uncertain. For the chosen period both model uncertainty and stochasticity were included. (Figure 3.8.1)

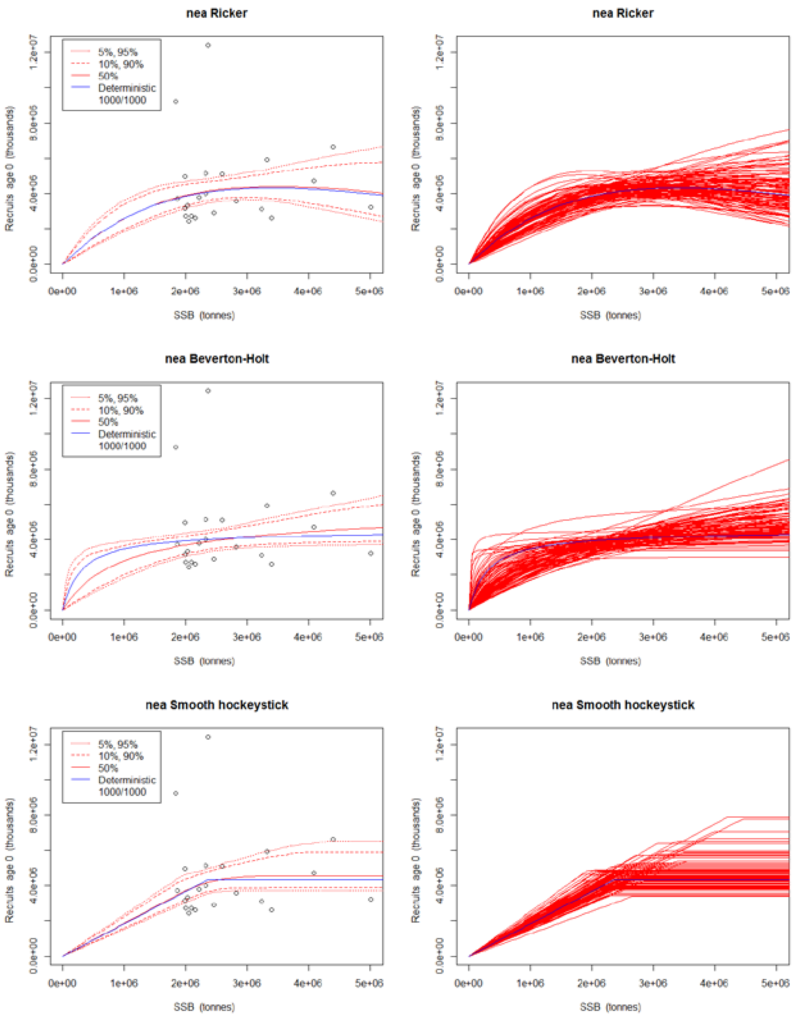


Figure 3.9.1. Northeast Atlantic mackerel plotMSY stock and recruitment model fits: Left - deterministic model fit (blue), median (solid red) and 5 and 95% (hashed red); right – 100 example fits.

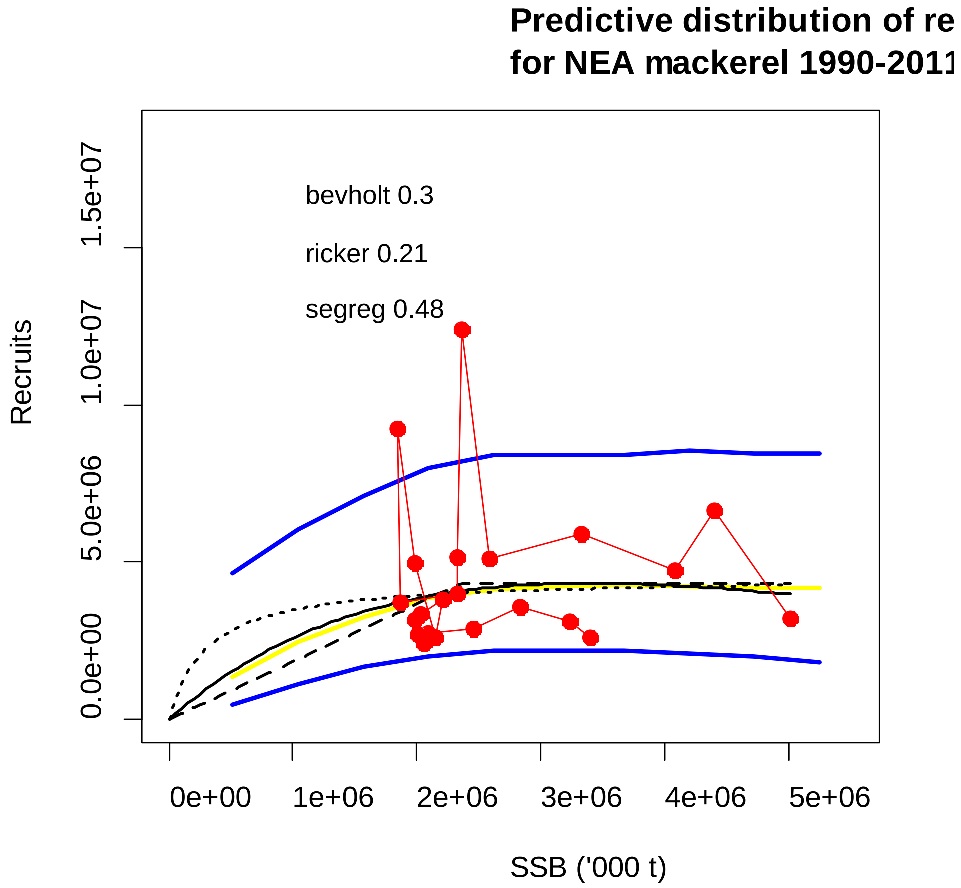


Figure 3.9.2. Stock and Recruitment data, models median and 5 and 95% on simulated recruitment.

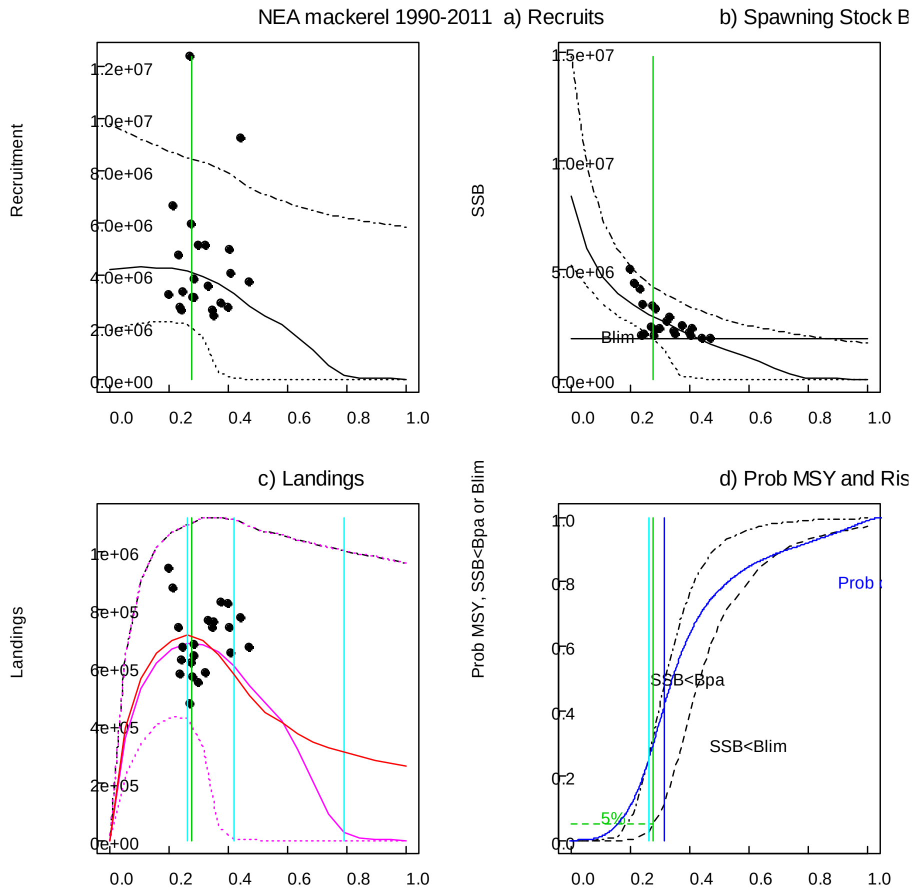


Figure 3.9.3. Stochastic equilibrium simulation under a fixed target F showing that Median FMSY = 0.31 is >ICES precautionary limit of 5% probability of SSB< Blim at F=0.26 and FMSY based on maximum mean catch =0.25.

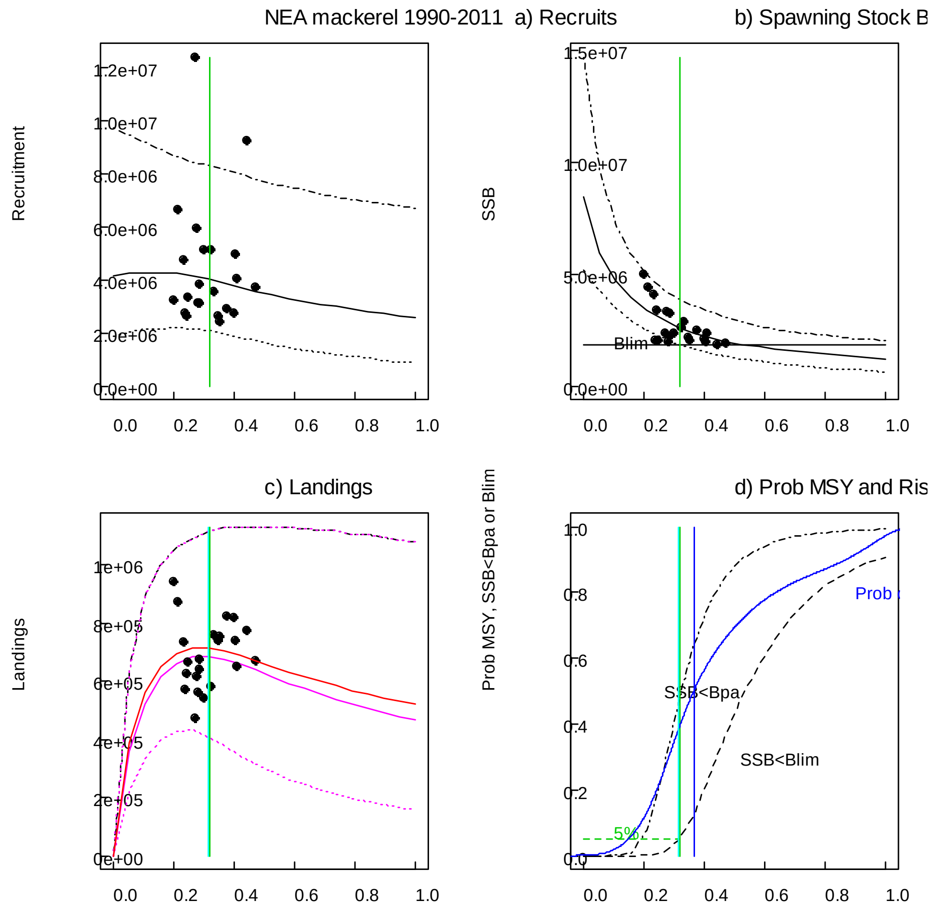


Figure 3.9.4. Stochastic equilibrium simulation under ICES HCR a target F and BTrigger =2 200 000 t Showing that exploitation up to F=0.31 is precautionary based on a limit of 5% probability of SSB<Blim this confirms that F based on maximum mean catch =0.25 would be an acceptable FMSY.

3.10 Data-limited approach

3.10.1 Introduction

WKLIFE (ICES, 2011) has limited simulation of Data Limited Stock (DLS) methods on specific generic fish populations with two different biological models of growth, maturation, fishery and recruitment variability, gadoid (cod) and 'herroid' (herring) models. These have been supplemented with some analyses on Icelandic saithe and haddock in WKLIFE3 (ICES, 2013).

WKLIFE tests were carried out based on exploitation at MSY and 2*F_{MSY}. For NEA mackerel this implies F~0.22 / F=~0.45 which would also be considered quite reasonable F starting points as they also correspond to the approximately the range of historic Fs that have been observed in the past either in the ICES assessments (ICES, 2011; 2012) or in models that assume catches (Simmonds, 2010).

In addition the specific simulation WKLIFE3 looked at DLS methods in general and concluded that in most cases the DLS methods when used correctly gave more conservative advice when information content was 'less'. WKLIFE3 also considered the use of the survey based catch related methods (e.g. Method 3.2) and concluded that catch scaled survey trend based DLS methods without targets generally need the precautionary buffer to be applied. This conclusion was based on a very limited number of simulations.

The DLS method most suited to the current information on SSB of NEA mackerel is DLS method 3.2 which can be summarized as follows:

C(y+1) = C(y) *Fac

Where Fac = 3(S(y)+S(y-1))/2(S(y-2)+S(y-3)+S(y-4) where S(y) is the survey index in year y

With an uncertainty cap if Fac>1.2 Fac=1.2, if Fac<0.8 Fac=0.8

With or without a PA buffer C(y) =C(y) or for the first occasion of the rule C(y)*0.8

In 2013, ICES gave advice on NEA mackerel based on recent catch, citing the preliminary nature of the survey, the lack of good uncertainty estimates, the lack of agreement on whether the precautionary buffer should be applied. WKLIFE3 examined the NEA mackerel advice in 2013 and made the following comment:

"Mackerel in the Northeast Atlantic: In the 2013 advice season, ACOM treated this stock in an *ad hoc* way rather than as a data-limited stock proposed by their own ADG. The rationale for this is neither adequately nor clearly explained in any ICES document. On balance, WKLIFE do not understand the rejection of the DLS guidance and support the ADG's recommendation to treat this stock with a Category 3 method incorporating the *precautionary buffer*."

At this benchmark it was decided to evaluate through simulation the use of the method 3.2 described above, resolve the issues of the consequences of the survey intermittent (triennial) survey and the inclusion or not of the uncertainty cap and PA buffer.

3.10.2 Simulation methods

A MSE simulation framework in FLR was modified to implement tests of this approach. The version and method was chosen based on sufficient capability to do the work and code that was relatively easy to modify. Software used was R version 2.10.1 (2009-12-14), Core package of FLR, fisheries modelling in R. Version: 2.3-644. Flash Version: 0.7.0.

3.10.2.1 Implementation of the method 3.2 for NEA mackerel

This method would only be utilized in the absence of an agreed assessment. The WG has available potentially the sources of information that are currently considered for inclusion in an assessment.

The triennial egg survey index of SSB with a CV of the order of 24% (The egg survey does not include egg mortality so it is not an SSB estimate) three years of IESSNS survey which is considered as an estimate of age proportion at 6 and older but not as an index of stock abundance for these or younger mackerel.

Composite IBTS bottom-trawl index of recruitment with a CV of 100%.

While both the IESSNS and the IBTS are candidate values for an assessment model they need this type of approach to be used for catch options. It was considered that only the triennial egg survey gave a more or less complete index of SSB. Previous MSE evaluations had indicated that harvest rates based on a percentage of assessed

SSB were potentially more robust as catch setting information than the classical use of F based exploitation thus the use of a catch relative to the SSB index had already been implicitly considered for this stock. As the survey is carried out triennially setting the catch for three years (y+1 to y+3) is applicable and the method becomes.

C(y+1,y+2,y+3) = C(y) *Fac

Where Fac = 9(5S(y)+S(y-3))/6(S(y)+7S(y-3)+S(y-6))

where S(y) is the survey index in year y and Fac is unmodified if an uncertainty cap is not applied.

With an uncertainty cap	if Fac>1.2 Fac=1.2, if Fac<0.8 Fac=0.8
Without a PA buffer	C(y) = C(y)
With a PA buffer	C(y) = 0.8C(y) for the first occasion of the rule

This gives four possible DLS management options which are tested.

1) Without uncertainty cap and PA buffer
2) Without PA buffer with uncertainty cap
3) With PA buffer and without uncertainty cap
4) With PA buffer and uncertainty cap

3.10.2.2 Biological model

The overall parameterization of the biological model is a simple FLR population model with one fleet.

- Population and catch weights and maturities at age from 2014 files.
- Selection is taken from the 2009 assessment (Figure 3.9.1) as age proportions in the catch are thought to be (relatively) reliable fitted selection should be (relatively) realistic for simulations, even though catches may have been incorrectly reported.
- S–R function
  - Simple model; Hockey-stick, with breakpoint at B_{loss} (Figure 3.9.2).
  - If catches are linked to the assessment then relative performance should be OK.
  - Slope to origin from B_{loss} should be (largely) independent of catch error.

All precautionary considerations are related to B_{loss}/HS within the simulations to there is internal consistency between simulation and criteria. While parameterizing the model with an assessment that may be suspect might be questioned, the only alternative model currently available during this benchmark (Simmonds, 2010) is trivially different in the context of the stock dynamics to be tested; it gives very similar variability of recruitment and dependence of recruitment on SSB. So although the model might be scaled differently it would be substantively similar in its behaviour.

3.10.2.3 Egg survey

Egg survey triennial estimates simulated as observed SSB with lognormal error with sigma =0.24, treated as an index. Only values from 2009, 2006 and 2003 and subsequent 3 year values used with DLS method.

3.10.2.4 Population starting options tested

1) Historic: F and SSB from 2009 which gives rapidly rising SSB, and F~=F_{MSY} with approximately population estimation uncertainty (CV=24%) to give variable starting point.
2) F_{MSY}: F=0.22 1981 to 2009 approximately F=F_{MSY}. Variable populations resulting from recruitment variability.
3) 2F_{MSY}: F=0.45 1981 to 2009 approximately F=F_{MSY}. Variable populations resulting from recruitment variability.

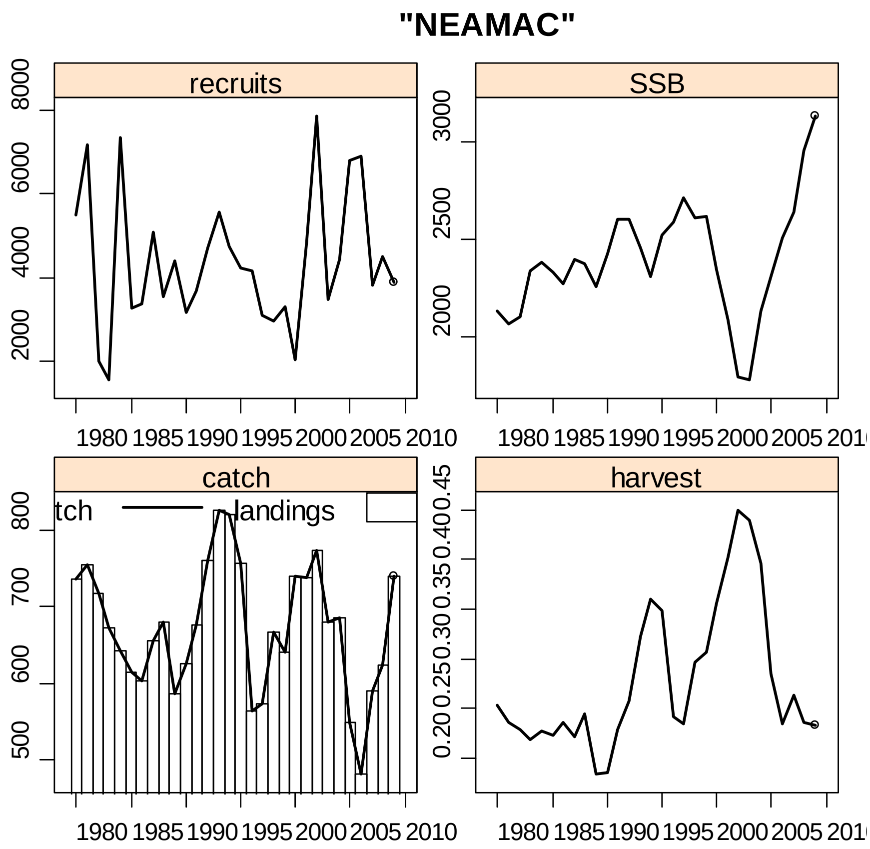


Figure 3.10.1. NEA mackerel assessment recruits, SSB, F, catch and landings used to parameterize the DLS simulations.

3.10.3 DLS Simulation Results

As noted above 12 runs were tested, four rule implementation options (with and without PA buffer and uncertainty cap) with three different stock starting conditions (Historic, F=0.22 and F=0.45). In all cases the stock develops from 1981 to 2009 and DLS management is simulated to start in 2009 with first year of catch under this regime in 2010. The model runs for 30 years to 2039.

Examples of stock dynamics are given in Figures 3.9.3 to 3.9.7.

The performance of the DLS method is considered in the context of ICES precautionary criteria. Figure 3.9.8 contains a summary of 5% of SSB. From these lines it is fairly clear that the inclusion of the precautionary buffer has a major influence on the likelihood that more SSB has a greater than 5% probability of SSB<the breakpoint in the S–R function. In all without cases a precautionary buffer a significant proportion of stocks collapse. In these simulations the inclusion of the PA buffer appears to protect the stocks, independent of the starting point. This suggests that this approach is safe, but better understanding of the mechanisms that stabilize the stock under this DLS rule would be helpful. The inclusion of the ±20% cap on TAC change appears to help.

3.10.4 DLS Method Conclusions

The relatively simple simulations carried out here which are provide very clear guidance that exploitation using the DLS approach and the triennial egg survey requires the inclusion of the PA buffer at 20% in the first year of implementation and benefits from the use of the uncertainty cap at 20% on each change of three year TAC. It seems unlikely that this conclusion would change if parameterization was changed, or for example greater variability was included in the assessment. The simulations also suggest that the inclusion of the uncertainty cap at 20% reduces the probability of SSB<B_{loss}. These simulations support the view that should the assessment be considered unreliable the DLS 3.2 rule applied using the egg survey, with PA buffer and uncertainty cap would be suitable for the short term.

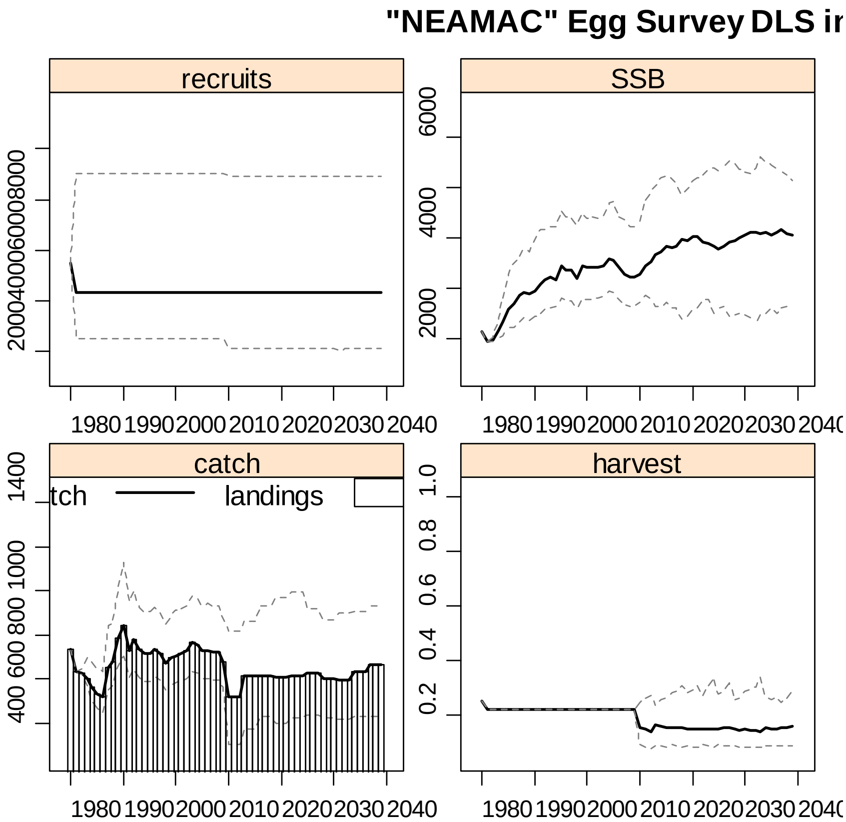


Figure 3.10.3. NEA mackerel simulated recruits, SSB, F, catch and landings from the DLS simulations. Stable F=0.22 PA Buffer included cap on TAC change not included.

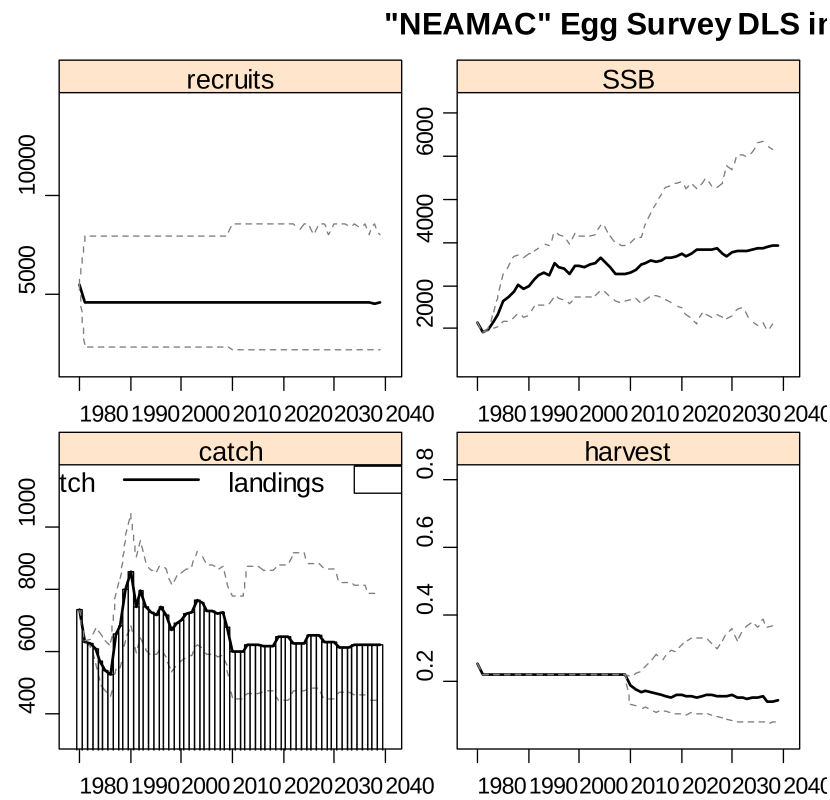


Figure 3.10.4. NEA mackerel simulated recruits, SSB, F, catch and landings from the DLS simulations. Stable F=0.22 PA Buffer and cap on TAC change included.

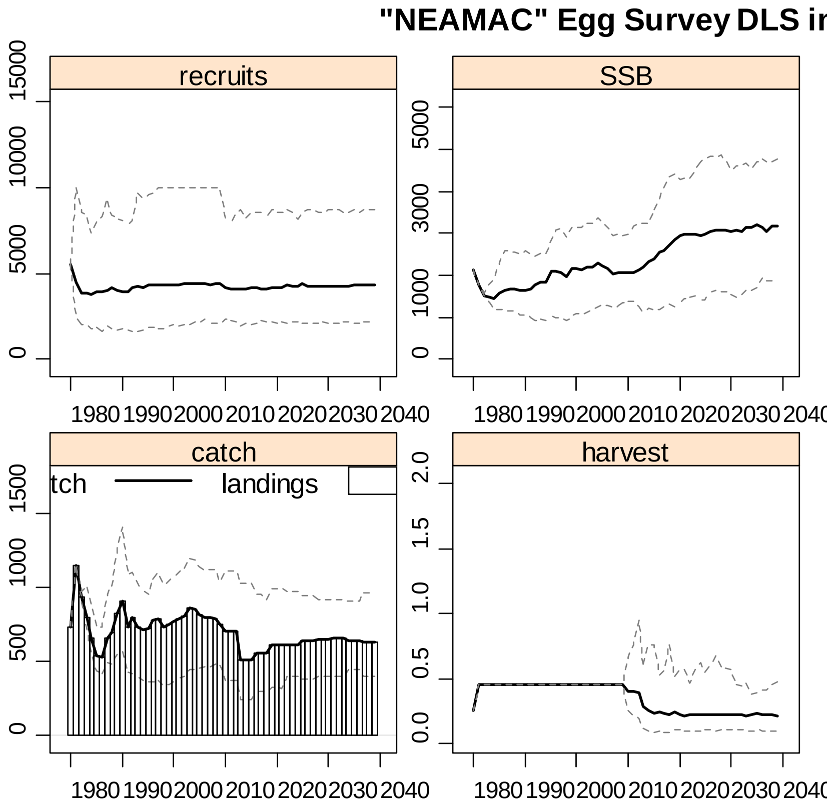


Figure 3.10.5. NEA mackerel simulated recruits, SSB, F, catch and landings from the DLS simulations. Stable F=0.45 PA Buffer included cap on TAC change not included.

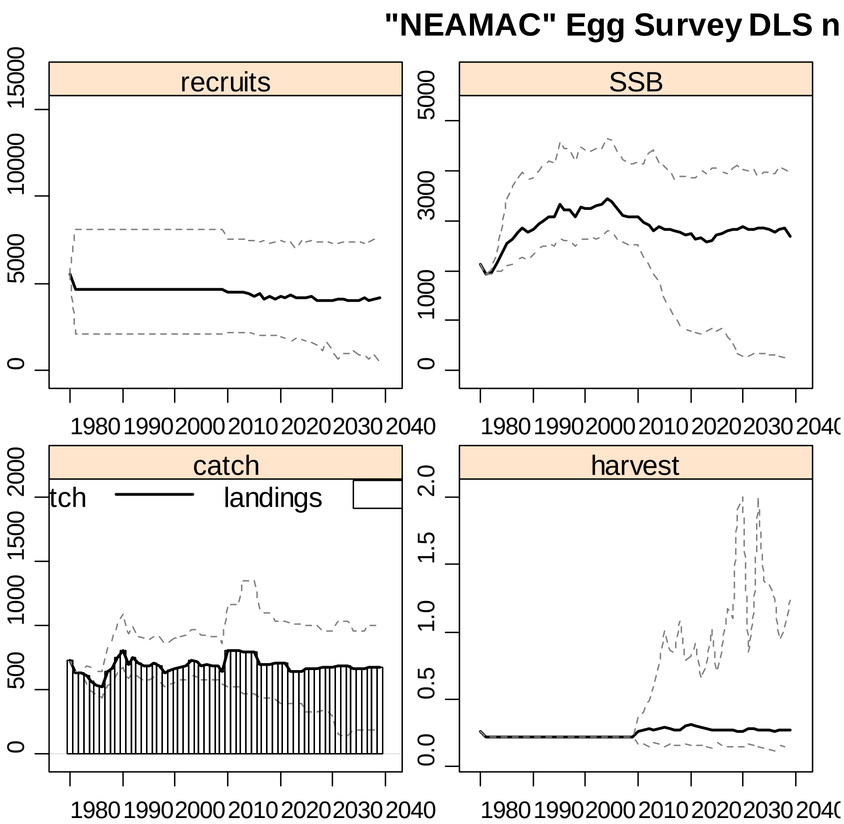


Figure 3.10.6. NEA mackerel simulated recruits, SSB, F, catch and landings from the DLS simulations. Stable F=0.22 No PA Buffer nor cap on TAC change included.

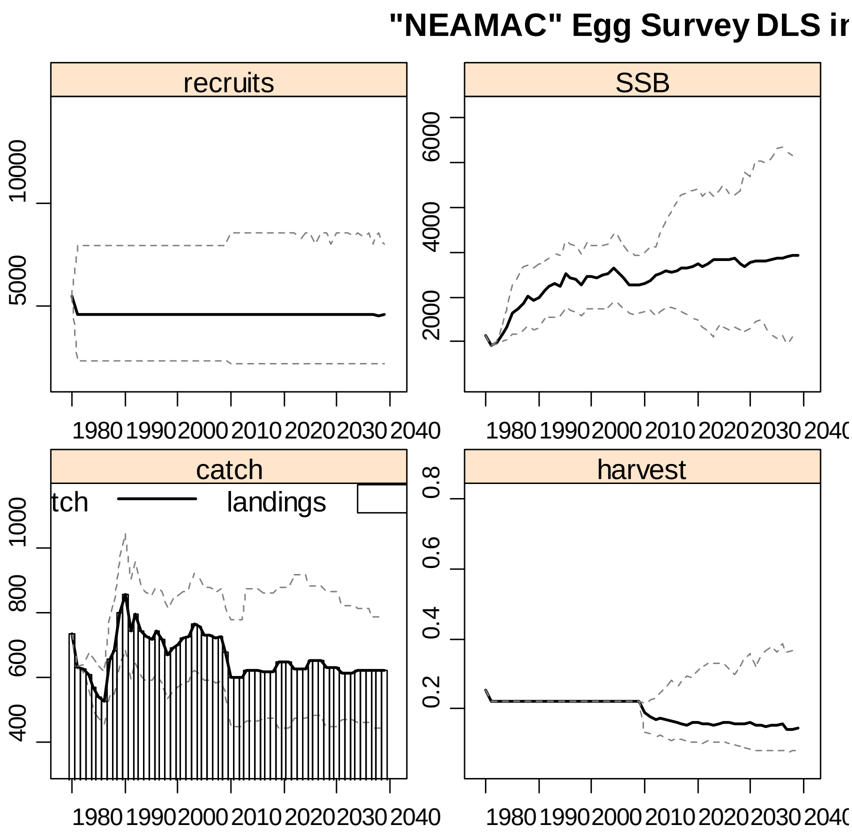


Figure 3.10.7. NEA mackerel simulated recruits, SSB, F, catch and landings from the DLS simulations. Stable F=historic PA Buffer and cap on TAC change included.

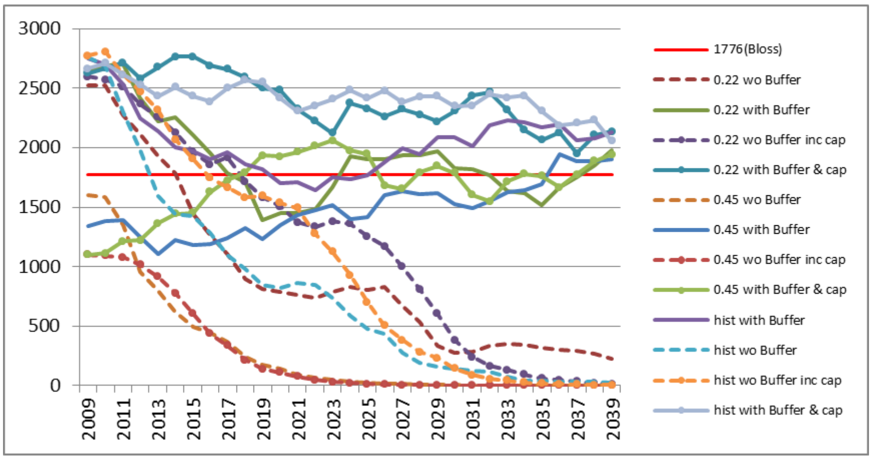


Figure 3.10.8. Summary of NEA mackerel DLS simulations in terms of ICES precautionary criteria. Three starting options 1) stable F=0.22, 2) stable F=0.45 and 3) historic state in 2009. Two options for calculating future catch are tested 1) PA Buffer included (solid lines) or not (dotted lines) 2) cap on TAC change included (symbol on the line) or not (no symbol). These results clearly demonstrate that it is essential to include the precautionary buffer if the lower 5% on SSB is to be kept above the breakpoint on the S–R relationship. The inference that the inclusion of the buffer provides safe exploitation is conditional on the assumptions which may not include sufficient variability.

3.11 Future research and data requirements

What	Section in wkpela report	Recommendation for:
Age reading issues mackerel Consider problems in Ageing for the stock at 6+ (difference between IESSNS cohort follow up and rest of age readers)		PGCCDBS, WGBIOP
The International Ecosystem Survey in the Nordic Seas (IESSNS). For next benchmark: Look at impact of solar elevation angle as measure of daytime and weather conditions etc. instead of a simple two state parameter. Look at the method for calculating CVs – There is doubt about the current estimates as these were all similar.		WGIPS & WGISSDA
The International Ecosystem Survey in the Nordic Seas (IESSNS): In order to quantify the abundance of 6+ fish in the North Sea (using IBTS and HERAS acoustic information as presented in the report) trawl samples are needed. Calculate true swept-area (Use average trawl width measures for every single haul) – Recalculate the index and compare with the current index. Pre- IBP (explore the effective tow time during fishing – fish may enter the net at hauling etc)		WGIPS & IBTSWG
The International Ecosystem Survey in the Nordic Seas (IESSNS). Before a possible Inter benchmark: Calculate true swept-area (Use average trawl width measures for every single haul) – Recalculate the index and compare with the current index. Pre- IBP (explore the effective tow time during fishing – fish may enter the net at hauling etc)		WGIPS & WGISSDA
Tagging program and data: Continue tagging program using RFIDs and standard estimation methodologies See reviewers comment on no-longer ageing When a sufficient time-series is available, explore incorporation in assessment.		Relevant countries, WGWIDE
Egg survey: WKPELA recommends to have the historic mackerel egg survey database and fecundity database quality checked and finalized for WGWIDE 2014. The time-series of TAEP and SSB calculations should be updated for the surveys using a consistent development equation from 1992-2013 for the WGWIDE 2014 meeting.		WGMEGS, WGWIDE

What	Section in wkpela report	Recommendation for:
Egg survey: WKPELA recommends to collect mackerel egg and adult samples in January/February 2015 to check for continued early spawning of mackerel. Planning of the 2016 mackerel egg survey should endeavour to capture the early spawning period.		WGMEGS
Recruitment index mackerel: Investigate density effects on catchability (In the benchmark, log transformation of the cpue index is used as an abundance index because a density-dependent catchability coefficient is likely.)		WGWIDE
Recruitment index mackerel (data): Investigate how to improve coverage of the important areas during surveys (specifically, extend the Scottish survey to Donegal bay).		Wgibts
Recruitment index mackerel (model): Include additional gear effects in the recruitment model. Make use of existing French-Irish intercalibration data, to account for the two gear types ´GOV´ and ´French trawl´. (Teunis - IBP) Consider inclusion of first quarter NS-IBTS data in the model (Teunis - IBP)		WGWIDE member from GNI.
Continuous Plankton Recorder (CPR) for the mackerel survey Examine whether the larvae data from the Continuous Plankton Recorder (CPR) from 1984-2004 can be used. [Cefas – Sophy Pittois]		WGWIDE – next benchmark
Alternative explanations for the drop in mean weight-at-age in recent years should be investigated, including the possibility of sampling bias due to shifting spawning timing, the effect of spatial expansion of the stock, and density-dependence.	recommendation from reviewers	WGWIDE – next benchmark
Weight- and length-at-age for mackerel: Further investigate the density-dependence work is needed		PGCCDBS, WGWIDE – next benchmark
Stock assessment model The RFID tagging data were not included in the final assessment because it was considered to be a too short time-series. The incorporation of the data corresponding to RFID tags should be re-evaluated in the near future, when more years of tag recoveries are available to accurately estimate a separate survival parameter for this new data.		WGWIDE – next benchmark
The IESSNS it still a short time-series (5 years) and the catchability estimated by the model is still very uncertain. The incorporation of this survey in the assessment should be re-evaluated in the near future when more survey years are available. Specifically WGWIDE should explore the use of the IESSNS index as multinomial in SAM (only use the age distributions, not the abundance)		WGWIDE –

What	Section in wkpela report	Recommendation for:
The triennial egg survey: WGWIDE should consider the influence of the lack of egg-survey data in inter-egg-survey year assessments, and propose settings to be added to the Stock Annex for future years		WGWIDE
SAM model should be adapted so that the post tagging survival is modelled as a random walk, to allow for temporal variability of this parameter.		WGWIDE – next benchmark
Current M value was estimated using both tagging-recapture information and catches from the 1970, which are now know to be severely underestimated. The estimation of M should be revisited using most recent and accurate data.		WGWIDE – next benchmark

3.12 External Reviewers comments

No documents thoroughly describing the technical aspects of the SAM and CASAL models was available, nor a narrative of prior investigations and decisions. Such descriptions and proposals for the use of survey indices and stock assessment model formulations prior to the meeting would give the reviewers and participants a better understanding of issues and ease time constraints. This comment is especially true of SAM, which formed the basis for the final model and is increasing in use in the broader ICES Community.

In the IESSNS survey, work using cameras and other studies to understand gear performance should continue and would be of broad international interest.

Continued collection and improvement of all the data sources considered during the benchmark would not only be useful but is considered imperative. Including but not limited to: tag program, IESSNS, egg survey, IBTS (recruit index), and larval survey.

We recommend that work continue to evaluate the egg survey database, standardize the time-series, and improve CV estimates.

Expanding some survey indices to areas south of the Norwegian Sea (west of Scotland, west of Ireland, Celtic Sea, Bay of Biscay) may inform stock structure, migration, and other aspects of biology. Such survey expansion may also increase information on mackerel age 2–5, which generally seemed to be lacking.

Methods to improve the calculation of landings and discards should continue.

Participants made several suggestions for alternative uses of the tagging data and this should be considered (e.g. Seber instead of Petersen estimator, different statistical distributions). As these alternatives are considered, best practices and preferred alternatives should be developed in advance of future benchmark meetings.

Several data sources seem to have age compositions that were generally agreed to be reliable while trend data were more open to scrutiny. Development of a modelling option that considers age composition without survey trend would be useful. Similarly, the consideration of assessment models that can incorporate *a priori* data weighting during model fit would be beneficial, alongside SAM that essentially self-weights.

The potential circularity of how natural mortality was determined using tag data and assuming that historic catch information was reliable, and how tag data were subsequently used in this benchmark assessment should be explored for consequences on the stock assessment. More broadly, analyses should likely be done to evaluate if the currently assumed value for natural mortality is appropriate to mackerel given what is known about species longevity, growth characteristics, and their role as forage.

We recommend considering an extension of the recruit index by integrating the quarter 1 data from the North of Scotland with the current data from quarter 4 to create a single recruit index. This new index should then be compared to the recruit index derived from quarter 4 data alone, and if reasonable, replace the current recruit index in the model.

A number of questions remain regarding the potential effects of the different changes that happened in the tagging programme. It would be useful to compile all available and new results in a single document which can be evaluated. The issues to investigate are (some have already been investigated):

- effect of change in tag type;
- effect of fish catching method (hand catching to machine method);
- assumption of random mixing of tagged fish with the broader population;
- switching from ageing individuals at recapture to applying an age–length key; this can be done by analysing the historic data where both types of information are available.

Following this investigation, using the most recent years (2007 onwards) of tag data in a stock assessment model should be reconsidered, including suggestions for how the data should be included in the assessment model (e.g. are separate survival parameters among time periods needed?)

Alternative explanations for the drop in mean weight-at-age in recent years should be investigated, including the possibility of sampling bias due to shifting spawning timing, the effect of spatial expansion of the stock, and density-dependence.

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4 Herring in the Celtic Sea (VIIaS VIIg VIIj)

4.1 Stock ID and substock structure

The herring (*Clupea harengus*) to the south of Ireland in the Celtic Sea and in Division VIIj comprise both autumn and winter spawning components. For the purpose of stock assessment and management, these areas have been combined since 1982. The inclusion of VIIj was to deal with misreporting of catches from VIIg. The same fleet exploited these stocks and it was considered more realistic to assess and manage the two areas together. This decision was backed up by the work of the ICES Herring Assessment Working Group (HAWG) in 1982 that showed similarities in age profiles between the two areas. In addition, larvae from the spawning grounds in the western part of the Celtic Sea were considered to be transported into VIIj (ICES, 1982). Also it was concluded that Bantry Bay which is in VIIj, was a nursery ground for fish of south coast (VIIg) origin (Molloy, 1968).

A study group examined stock boundaries in 1994 and recommended that the boundary line separating this stock from the herring stock of VIaS and VIIb,c be moved southwards from latitude 52°30'N to 52°00'N (ICES, 1994). However, a recent study (Hatfield *et al.*, 2007) examined the stock identity of this and other stocks around Ireland. It concluded that the Celtic Sea stock area should remain unchanged.

Some juveniles of this stock are present in the Irish Sea for the first year or two of their life. Juveniles, which are believed to have originated in the Celtic Sea move to nursery areas in the Irish Sea before returning to spawn in the Celtic Sea. This has been verified through herring tagging studies, conducted in the early 1990s, (Molloy *et al.*, 1993) and studies examining otolith microstructure (Brophy and Danilowicz, 2002). Recent work carried out also used microstructure techniques and found that mixing at 1 winter ring is extensive but also suggests mixing at older ages such as 2 and 3 ring fish. The majority of winter spawning fish found in adult aggregations in the Irish Sea are considered to be fish that were spawned in the Celtic Sea (Beggs *et al.*, 2008).

Age distribution of the stock suggests that recruitment in the Celtic Sea occurs first in the eastern area and follows a westward movement. After spawning herring move to the feeding grounds offshore (ICES, 1994). In VIIj herring congregate for spawning in autumn but little is known about where they reside in winter (ICES, 1994). A schematic representation of the movements and migrations is presented in Figure 1. Figure 2 shows the oceanographic conditions that will influence these migrations.

The management area for this stock comprises VIIaS, VIIg, VIIj, VIIk and VIIh. Catches in VIIk and VIIh have been negligible in recent years. The linkages between this stock and herring populations in VIIe and VIIf are unknown. The latter are managed by a separate precautionary TAC. A small herring spawning component exists in VIIIa, though its linkage with the Celtic Sea herring stock area is also unknown.

4.2 Issue list

The following issues were identified:

- Tuning series: Celtic Sea Herring Acoustic survey: are there issues with double counting? Need to look at survey design; the impact of transect spacing; possible revision of dataseries and reworking of the time-series;

- Data: Investigate non-Irish landings over time; Consider utility of IBTS data;
- Discard information currently not available for the assessment Need to quantify discards in recent years and provide estimates;
- Irish Sea Mixing: is any new information available that is relevant?
- Precision in ageing: evaluate if precision is acceptable;
- Maturity Ogive: survey and sampling data: are any alternative data available? Is the existing assumption of 50% mature at 1-ring valid?
- Natural mortality: In view of developments in NS and IS herring, is there a basis to change the time invariant M at age currently in use. Splitting work underway in Northern Ireland;
- Assessment:
    - Current assessment model is not and cannot be maintained. Large year classes now a significant component of the plus group.
    - Investigate cause of year effects in the survey data.
    - Analysis of any retrospective bias.
    - Ages in the tuning series.
    - Implement the assessment using the SAM model.
    - Comparison of available stock assessment models and assumptions.
    - Examine the impact of changing the plus group on the assessment diagnostics.
    - Model bias in the survey.
    - Perform sensitivity runs with different model input data configurations.
    - Analyse performance of different ages in the assessment model.

4.3 Multispecies and mixed fisheries issues

Mixed fisheries interactions are not considered to be of importance for this stock, though small quantities of fish are landed and discarded in mixed fisheries, their proportion of the total catches is very small.

4.4 Species interactions and ecosystem drivers

The ecosystem of the Celtic Sea is described in ICES WGRED (2007b). The main hydrographic features of this area as they pertain to herring are presented in Figure 1.4. Temperatures in this area have been increasing over the last number of decades. There are indications that salinity is also increasing (ICES, 2006a). Herring are found to be more abundant when the water is cooler while pilchards favour warmer water and tend to extend further east under these conditions (Pinnegar *et al*., 2002). However, studies <u>to date</u> have been unable to demonstrate that changes in the environmental regime in the Celtic Sea have had any effect on productivity of this stock. Further work is required, because there is now evidence of a change in productivity (Section 4.7).

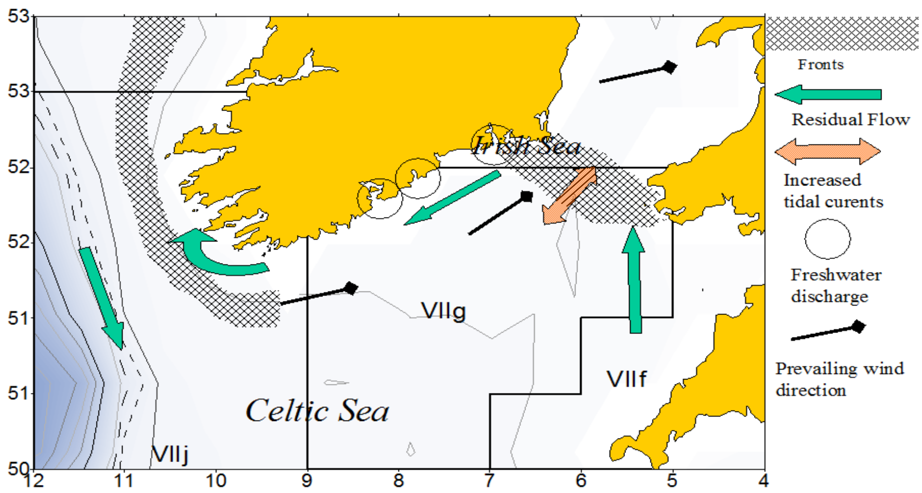


Figure 4.4.1. Herring in the Celtic Sea. Schematic presentation of prevailing oceanographic conditions in the Celtic Sea and VIIj (ICES, 2005c, SGRESP).

Herring larval drift occurs between the Celtic Sea and the Irish Sea. The larvae remain in the Irish Sea for a period as juveniles before returning to the Celtic Sea. Catches of herring in the Irish Sea may therefore impact on recruitment into the Celtic Sea stock (Molloy, 1989). Distinct patterns were evident in the microstructure and it is thought that this is caused by environmental variations. Variations in growth rates between the two areas were found with Celtic Sea fish displaying fastest growth in the first year of life. These variations in growth rates between nursery areas are likely to impact recruitment (Brophy and Danilowicz, 2002). Larval dispersal can further influence maturity-at-age. In the Celtic Sea faster growing individuals mature in their second year (1 winter ring) while slower growing individuals spawn for the first time in their third year (2 winter ring). The dispersal into the Irish Sea which occurs before recruitment and subsequent decrease in growth rates could thus determine whether juveniles are recruited to the adult population in the second or third year (Brophy and Danilowicz, 2003).

The spawning grounds for herring in the Celtic Sea are well known and are located inshore close to the coast. These spawning grounds may contain one or more spawning beds on which herring deposit their eggs. Individual spawning beds within the spawning grounds have been mapped and consist of either gravel or flat stone (Breslin, 1998). Spawning grounds tend to be vulnerable to anthropogenic influences such as dredging and sand and gravel extraction. The main spawning grounds are displayed in Figure 4, whilst the distributions of spawning and non-spawning fish are presented in Figure 5.

Herring are an important component of the Celtic Sea ecosystem. There is little information on the specific diet of this stock. Farran (1927) highlighted the importance of *Calanus* spp. copepods and noted that they peaked in abundance in April/May. Fat reserves peak in June to August (Molloy and Cullen, 1981). Herring form part of the food source for larger gadoids such as hake. A study was carried out which looked at the diet of hake in the Celtic Sea. This study found that the main species consumed by hake are blue whiting, poor cod and Norway Pout. Quantities of herring and sprat were also found in fish caught in the northern part of the Celtic Sea close to the Irish coast. Large hake, >50 cm tended to have more herring in their stomachs than smaller hake (Du Buit, 1996).

Recent work by Whooley *et al*. (2011) shows that fin whales *Balaenoptera physalus* are an important component of the Celtic Sea ecosystem, with a high re-sighting rate indicating fidelity to the area. There is a strong peak in sightings in November, and fin whales were observed actively feeding on many occasions, seeming to associate with sprat and herring shoals. These authors go on to suggest that the peak in fin whale sightings in November may coincide with the inshore spawning migration of herring. Fin whales tend to be distributed off the south coast in VIIg in November, but further east, in VIIaS by February (Berrow, personal communication). This suggests that their occurrence coincides with peak spawning time in these areas.

4.5 Stock assessment

The Celtic Sea Herring stock has been assessed using ICA (Integrated Catch-at-age Analysis) for a number of years. This was based on a benchmark conducted in 2007, and an inter-benchmark procedure in 2009 (ICES, 2007, 2009). The main disadvantages of ICA for the assessment of Celtic Sea Herring are as follows:

- Maximum length of a time-series is 59 years;
- The core minimization library is no longer maintained which leads to an inability to fix any technical issues that may arise;
- Reliance on the assumption of separability (eight years in this case) allowed model fitting at the expense of realism. Changes in selection during this period are not considered;
- Unexplained retrospective patterns appeared in the assessment since 2010, leading to difficulties in forecasting and framing management advice.

Due to the issues with the ICA model the exploration of an alternative assessment model is therefore an important component of the benchmark work for the Celtic Sea herring stock.

4.5.1 Catch quality, misreporting, discards

Table 4.5.1 shows the trends over time in catch data quality. Landings data are currently expected to be very well estimated, with the best quality landings data coming from the early years when commercial transactions were available, and there was no incentive to misreport (no quotas). Discarding was high during 1980s until late 1990s, though available estimates may be too low. Since then the main reason to discard has been unwanted catch. Like all pelagic fisheries, discarding is known to occur but estimates are unavailable at present. Measures taken in 2012 have reduced the risk of discarding through more flexible individual boat quota regulations.

Table 4.5.1. Catch data quality over time.

Time period	1958–1977	1977–1983	1983–1997	1998–2004	2004–present
Type of fishery	Cured fish	Closure	Herring roe	Fillet/whole fish	Fillet/whole fish
Quality of catch data	High	Medium	Low	High/medium	High/medium
Source of landings data	Auction data	Auction data	Skipper EC logbook estimate	Skipper logbook EC estimate	Weighbridge verifications
Discard Risk Levels	Low	Low	High	Medium	Medium*
Incentive to discard	None	None	Maturity stage		Size grade, market vs. quota, insufficient storage
Allowance for water (RSW tanks)	na	na	na	20%	2%

Some information on discards is available from independent work conducted by the Irish Whale and Dolphin Group, and from the Irish national pelagic observer programme. The latter programme did not record any instances of discarding though coverage is very low. The IWDG programme achieved 5% coverage of the Irish fishery in 2013 and recorded a rate of discarding of 0.8% of observed catch indicates that discarding was very small and was not a significant issue in this fishery (McKeogh and Berrow, 2014). The vast majority of herring discarding observed were due to faulty equipment or blue sharks blocking the pump causing overflow. A similar study in the previous year (Lyne and Berrow, 2012) also found that discarding was less than 1% of catch. Boyd *et al.* (2012) recorded some slippage been in the fishery where errors in targeting and fishing on inconclusive marks lead to discarding of mixed catches of mackerel, sprat and herring. A discard rate of <1% was also reported by Lyne and Berrow (2012) during ten trips surveyed in 2012/2013 season. It is not clear how representative these estimates are of total discarding, as they are taken from low observer coverage.

4.5.2 Surveys

Acoustic surveys have been carried out on this stock from 1990–1996, and again from 1998–2013. During the first period, two surveys were carried out each year designed to estimate the size of the autumn and winter spawning components. The series was interrupted in 1997 due to the non-availability of a survey vessel. Since 2005, a uniform design, randomized survey track, uniform timing and the same research vessel have been employed. The time-series currently used in the assessment runs from 2002–2012 and uses ages 2–5. Extensive work was conducted on the survey time-series in preparation for the previous benchmark. The only main consideration is the choice of age range in the survey. The choice of 2–5 was based on the need to exclude 0 and 1 ringers which are not well selected by the survey, and ages older than 5 which encompassed the plus group and were poorly represented in the population in recent years owing to high F. The acoustic time-series is presented in Table 4.5.2.

Details of other surveys which have been investigated as possible tuning series for this stock are presented in the stock annex. However none offered sufficient year range, data quality or ability to track cohorts.

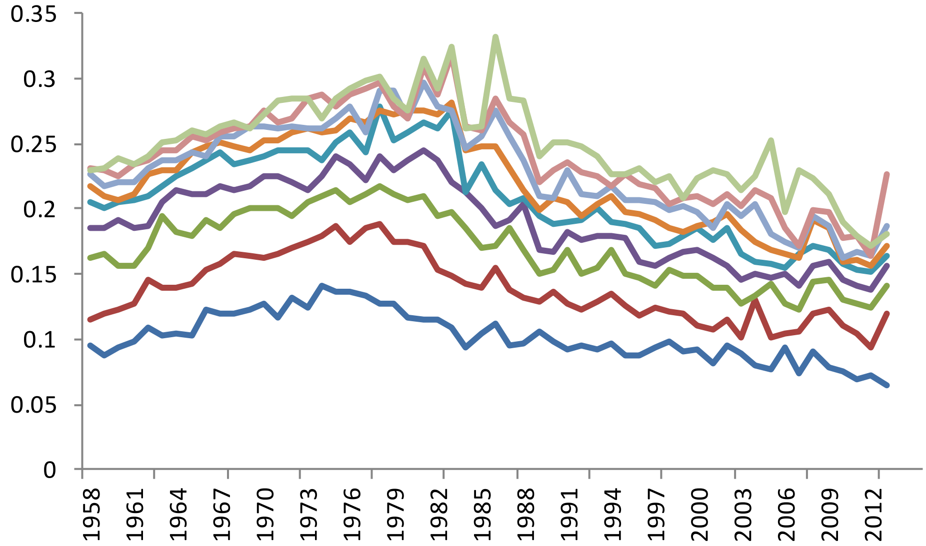
Table 4.5.2. Abundance (thousands) and biomass (thousands of tonnes) with C.V. (%) for acoustic time-series 2002–2013. Ages (winter rings) 2–5 are currently used in tuning in ICA.

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Rings	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
0	0	24	-	2	-	1	99	239	5	0	31	4
1	42	13	-	65	21	106	64	381	346	342	270	698
2	**185**	**62**	**-**	**137**	**211**	**70**	**295**	**112**	**549**	**479**	**856**	**291**
3	**151**	**60**	**-**	**28**	**48**	**220**	**111**	**210**	**156**	**299**	**615**	**197**
4	**30**	**17**	**-**	**54**	**14**	**31**	**162**	**57**	**193**	**47**	**330**	**44**
5	**7**	**5**	**-**	**22**	**11**	**9**	**27**	**125**	**65**	**71**	**49**	**38**
6	7	1	-	5	1	13	6	12	91	24	121	10
7	3	0	-	1	-	4	5	4	7	33	25	5
8	0	0	-	0	-	1		6	3	4	23	0
9	0	0	-	0	-	0		1		2	3	2
							-					
Abundance	423	183	-	312	305	454	769	1,147	1,414	1,300	2,322	1,286
SSB	41	20	-	33	36	46	90	91	122	122	246	71
CV	49	34	-	48	35	25	20	24	20	28	25	28
Design	AR	AR		R	R	R	R	R	R	AR	AR	AR

4.5.3 Weights, maturities, growth

Weights in the catch and in the stock at spawning time have shown dramatic fluctuations over time (Figure 4.5.3). Similar trends in mean length-at-age have been documented by Harma (2013) and Lynch (2011). Both authors showed that single s-species density-dependence is not a factor in these cycles. Lynch reported that increased SST and was associated with reduced size/weight-at-age and condition factor. Also, abundance of Calanus copepods is positively correlated with size and weight-at-age (Lynch, 2011). Strong non-linear correlations between herring growth and environmental parameters; particularly with zooplankton abundance (positive) and AMO and phytoplankton indices (negative). These factors explained more than 80% in variability of size of three year old fish (Harma, 2013).

Maturity at 1-ring is considered to be 50% with 100% at subsequent ages. Lynch (2011) investigated trends over time in maturity-at-age, in commercial sampling. Earlier maturity at 1-ring began to increase in the early 1970s and has remained high ever since.



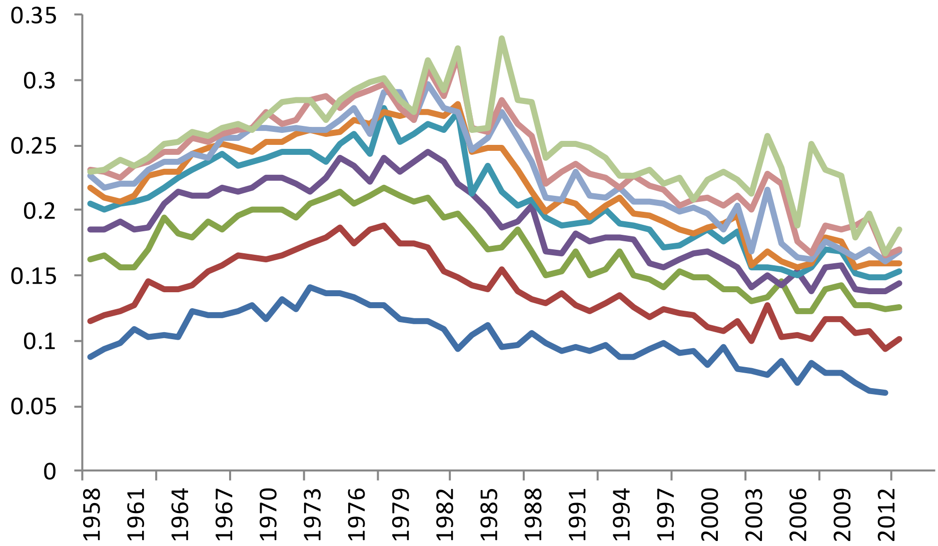


Figure 4.5.3. Trends over time in mean weights in the catch (above) and in the stock at spawning time (below).

4.5.4 Assessment models

The use of state–space models for stock assessment has become increasingly common in recent years. In the past the reason state–space models have not been more frequently used in stock assessment is that software to handle these models has not been available (Nielsen and Berg, 2013). This is no longer the case. In a state–space model the underlying process is considered a random variable that is not observed. A derived variable is observed and is subject to measurement noise (Nielsen, 2009). SAM is a state–space stock assessment model that is currently used to assess several fish stocks including many herring stocks such as North Sea, Irish Sea and Western Baltic Spring-spawning herring. The SAM model uses the standard exponential decay equations to carry forward the N's (with appropriate treatment of the plus-group), and the Baranov catch equation to calculate catch-at-age based on the F's (ICES, 2013). The assessment of Celtic Sea herring was carried out using FLSAM which is an R-platform to run SAM.

Given the choice of SAM as a model framework, the approach to further parameterization was as follows:

1) Data Selection;

2) Model refinement;

3) Data refinement;

4) Sensitivity analyses to various alternative data sources.

Data selection

Catch-at-age data

The Celtic Sea Herring catch data time-series has been run with ages 1–6+ in recent years. The plus group was 9 until 2007; and 7 until 2009 At that point it was reduced to 6, which led to much improved model fitting. This reduced plus group accorded with the attenuation of older ages in the catch-at-age matrix, owing to high mortality at that time. Attempts to increase the plus group at the 2012 and 2103 herring assessment working group never yielded better diagnostics, and it has remained at 6 since. Mean standardized catch numbers at 9+ are presented in Figure 4.5.4, with position of lower possible plus groups indicated/. The catch data used in the assessment include data from Ireland only.

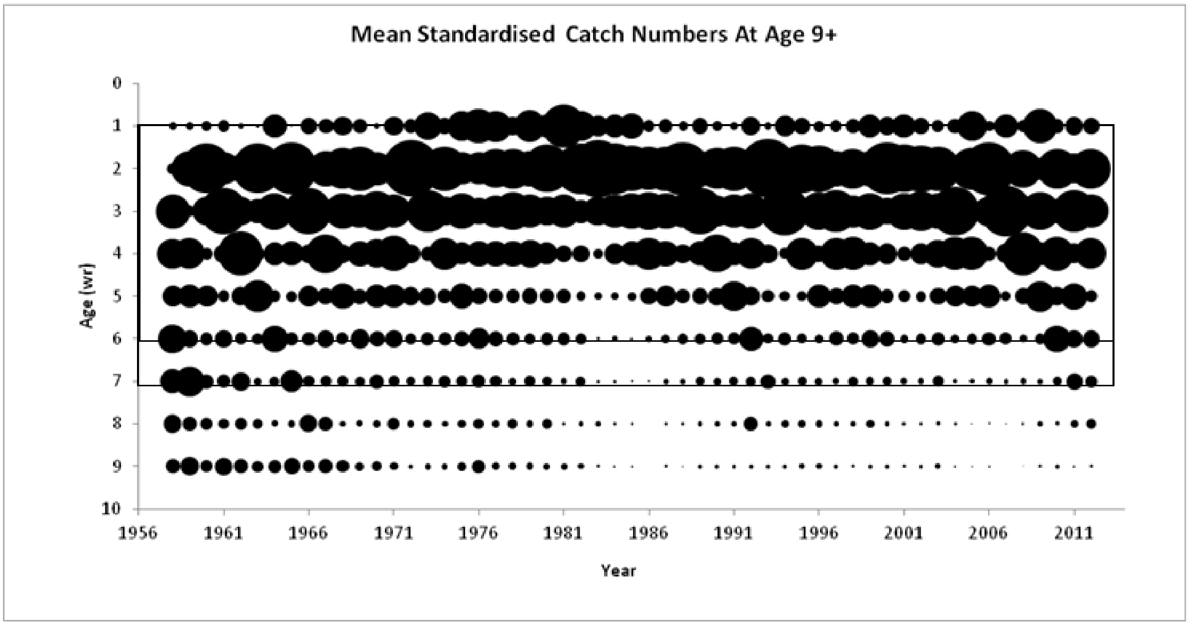


Figure 4.5.4. Mean Standardized catch numbers-at-age for 9% showing also position of 6 and 7 plus groups.

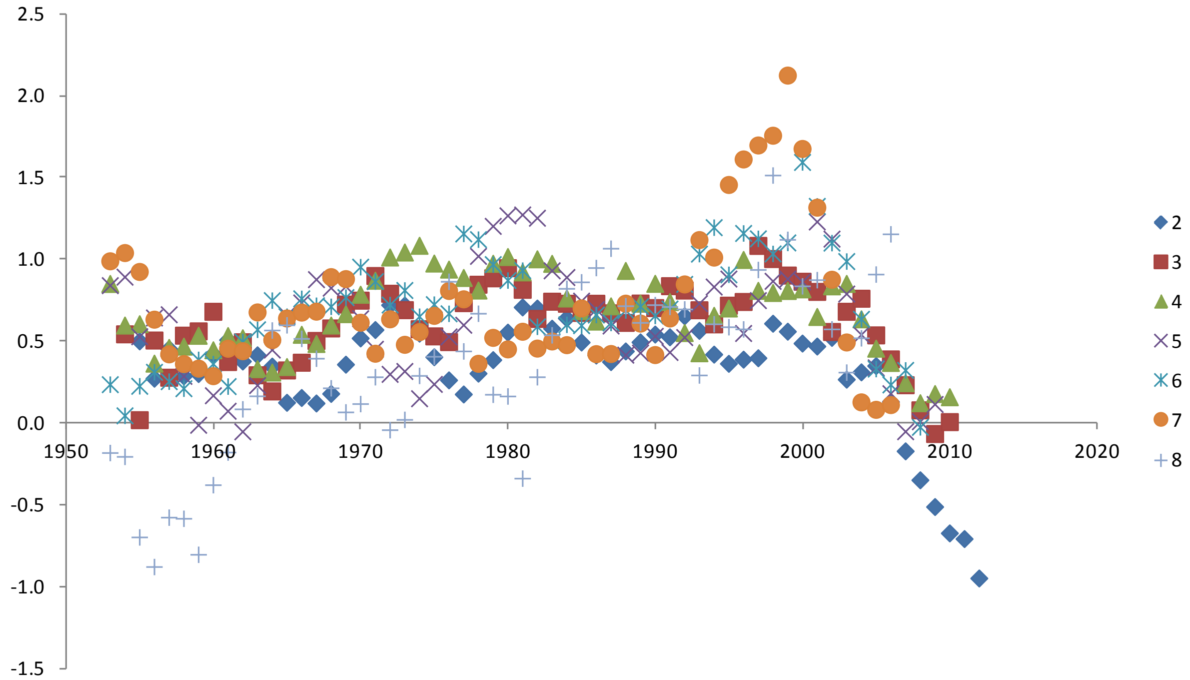


Figure 4.5.5. Log catch ratios [ln ($catch_{a,y}$ / $catch_{a+1,y+1}$) over time-series by cohort hatching year. 1-ring excluded as if exhibits mainly negative mortality.

Figure 4.5.5 shows long catch ratios over time, exhibiting a raw total mortality signal. Mortality was variable over time, but reached a peak for cohorts hatched in late 1990s and early 2000s. Cohorts hatched since the mid-2000s have enjoyed much lower total mortality. This effect can also be seen in cohort catch curve estimates of total mortality (Table 4.5.3). Though information on the most recent cohorts is not complete there is some evidence of either negative mortality, or a switch towards full selection at older ages in the fishery. This would invalidate the constant selection period of eight years used in recent ICA assessments.

Model refinement

The overall approach began with the existing input data files as used in the current ICA assessment. Then experimentation was performed to find which of the plus groups were most appropriate and also which survey age range was most appropriate. Optimum fitting was considered, where appropriate, taking into account AIK, negative log-likelihood and variance/covariance matrices. When optimum fitting was obtained, changes to input data such as M, catches and natural mortality were considered.

Base run settings

Settings were chosen for an initial run of the SAM model called the base run. Similar to the other herring stock assessments all fishing mortality states are free except the oldest ages to ensure stability. It was assumed that the random walks for fishing mortality were correlated. In the base run the survey catchability parameters were all free. Variance in fishing mortality random walk by age from FLICA is calculated over the whole time-series using the var function and in R (Figure 2). The results showed markedly different variance for age 1 compared to the other ages. The variance for age 1 was left unbounded and the variance for all other ages was bound to improve stability.

As a starting point the observation variance on the catch data 1 was left free, 2:3 and 4:6 were bound. The observation variances on the survey ages 2:5 were all bound. The settings are presented in Table 4.1.

Table 4.5.3. Total mortality (Z) estimates over two age ranges (winter rings) with sample size (n) derived from the commercial landings, and from the acoustic survey. Incompletely represented cohorts shown in grey.

Cohort	Z 2-5	n2-5	Z 2-8	n2-8	Cohort	Z2-5	n2-5	Z2-8	n2-8	Z survey 2-5	n survey 2-5
1953	-0.8	2	-0.5	5	1982	-0.7	4	-0.7	7		
1954	-0.4	3	-0.5	6	1983	-0.7	4	-0.5	7		
1955	-0.1	4	-0.2	7	1984	-0.7	4	-0.7	7		
1956	-0.5	4	-0.6	7	1985	-0.4	4	-0.6	7		
1957	-0.3	4	-0.4	7	1986	-0.5	4	-0.6	7		
1958	-0.8	4	-0.2	7	1987	-0.7	4	-0.6	7		
1959	-0.6	4	-0.4	7	1988	-1.0	4	-0.7	7		
1960	-0.4	4	-0.5	7	1989	-0.7	4	-0.6	7		
1961	-0.1	4	-0.3	7	1990	-0.6	4	-0.7	7		
1962	-0.4	4	-0.5	7	1991	-0.5	4	-0.6	7		
1963	-0.2	4	-0.4	7	1992	-0.6	4	-0.8	7		
1964	-0.2	4	-0.5	7	1993	-0.5	4	-1.0	7		
1965	-0.4	4	-0.7	7	1994	-0.7	4	-0.9	7		
1966	-0.6	4	-0.7	7	1995	-0.8	4	-0.9	7		
1967	-0.5	4	-0.6	7	1996	-1.1	4	-0.9	7		
1968	-0.6	4	-0.6	7	1997	-1.0	4	-1.1	7	-1.7	2
1969	-0.9	4	-0.9	7	1998	-0.6	4	-1.1	7	-2.2	2
1970	-0.9	4	-0.7	7	1999	-0.4	4	-1.0	7	-0.7	3
1971	-1.1	4	-0.6	7	2000	-0.6	4	-1.0	7	-0.5	3
1972	-0.7	4	-0.6	7	2001	-0.7	4	-0.7	7	-0.6	3
1973	-0.4	4	-0.6	7	2002	-0.8	4	-0.6	7	-0.5	4
1974	-0.5	4	-0.5	7	2003	-0.5	4	-0.4	7	-0.2	4
1975	-0.4	4	-0.7	7	2004	-0.3	4	-0.2	7	-0.1	4
1976	-0.7	4	-0.8	7	2005	0.0	4	-0.1	6	-0.4	4
1977	-1.0	4	-1.2	7	2006	0.1	4	-0.1	5	-0.4	4
1978	-0.7	4	-0.9	7	2007	-0.1	4	-0.1	4	-0.8	4
1979	-0.9	4	-0.9	7	2008	0.1	3	0.1	3	-1.2	3
1980	-0.8	4	-0.9	7	2009	0.0	2	0.0		-1.5	2
1981	-0.6	4	-0.8	7							

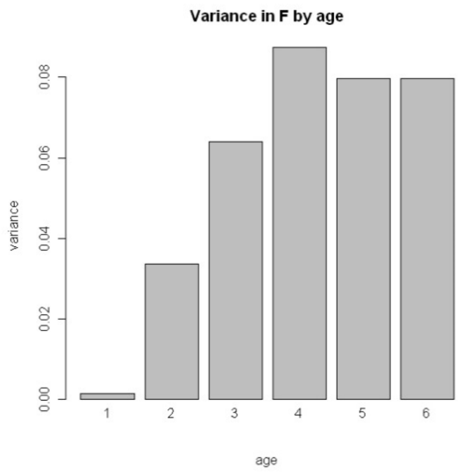


Figure 4.5.5. Variance in F by age from FLICA.

Table 4.5.5. SAM settings for the base run, 6+.

	SAM Settings	Base Run
1	Coupling of fishing mortality states	1,2,3,4,5,5
2	Correlated random walks for F	correlated (TRUE)
3	Coupling of catchability parameters	all free 1,2,3,4
4	Variances in F random walk	1,2,2,2,2,2 (1 free rest bound)
5	Coupling of logN RW Variances	All free
6	Coupling of observation variances - Catch	1,2,2,3,3,3 - 1 free 2:3 and 4:6 bound
7	Coupling of observation variances - Survey	4,4,4,4 - all bound

Comparison FLICA 2013 and the FLSAM base run

ICA and SAM are both implemented in the FLR framework and both models are compared. It is difficult to compare the outputs from FLICA and FLSAM directly because ICA is a partially stochastic model with elements of a deterministic VPA and elements of a statistical model (Payne and Hintzen, 2012). Comparison of the stock trajectories of SSB, Recruitment and Mean F show a similar pattern in the historic period with some divergence in recent years. In the FLICA assessment the recruitment is adjusted in the final year. The geometric mean recruitment from 1981–2010 is used because this represents the current perceived recruitment regime where recruitment has been fluctuating around the mean (ICES, 2013). In SAM the recruitment in the final year is equal to the previous year before the random walk. Figure 3 shows the stock trajectories with the recruitment. Diagnostics and retrospective patterns for the base case run are presented in Appendix 1.

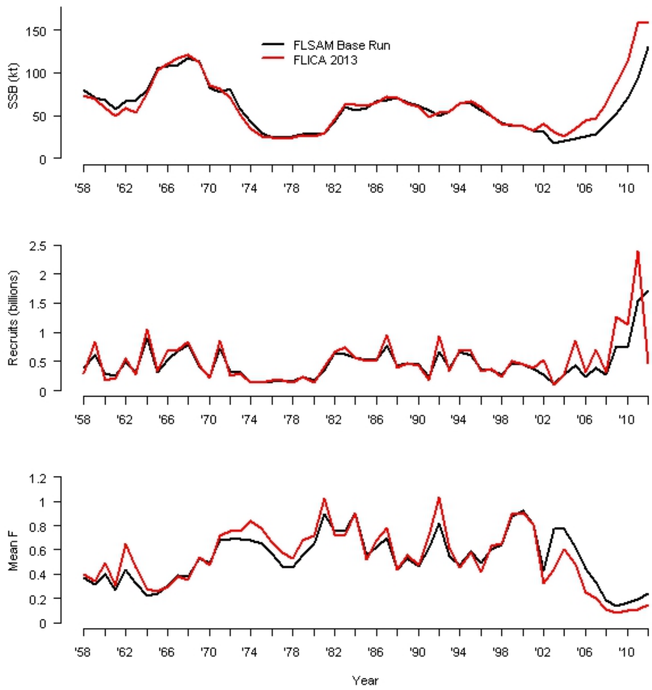


Figure 4.5.6. Stock trajectories from final FLICA 2013 with the recruitment adjustment in the terminal year and base run FLSAM. SSSB (top), Recruitment (middle), Mean F (bottom).

Plus group choice

The assessment was run using each of the plus group options 6+, 7+ and 9+ and the base run settings. A comparison of the precisions of the parameter estimation between the three options showed that 9+ offered the best precision (Table 3). Furthermore, the correlation matrices for the three runs demonstrate an improvement (lower correlations in general especially in the lower left part of the figure) when 9 + is used (Figure 4.1).

Choice of plus group should aim to make the model as simple as possible while avoiding oversimplification. The plus group was 9 in assessments conducted prior to 2008, though these were not used as an analytical basis for advice for some preceding years. In 2008 the plus group was reduced to 7 and in 2009 to 6, to reduce the error in the assessment and simplifying the model. This choice was supported by the attenuation of the age structure in the preceding years. The age structure has since extended again, and is comparable to the earlier part of the time-series. While a plus group of 6 mimics the recent ICA assessment, 9+ offers slightly better diagnostics. To investigate further, two runs where the catch observation variance was unbound (each catch observation having its own estimation) were compared viz. runs 11 (6+) and 55 (9+) in Figure 4.2. At the expense of parsimony, the choice of 9+ is strengthened by the observation that variance of 9+ age is high, but not higher than for 1 ring. Retrospective upward bias with successive estimations (Figure 4.3) are better than for the current assessment (ICES, HAWG 2013), and the bias in SSB is less with 9+ than with 6+. These considerations are important when giving management advice.

Table 4.5.6. Value, standard deviation and absolute value of the standard deviation / value of parameter estimation across 6, 7 and 9+ base case runs.

	6			7			9		
parameter	**value**	**std.dev**	**CV**	**value**	**std.dev**	**CV**	**value**	**std.dev**	**CV**
logFpar	0.789	0.168	0.21	0.829	0.155	0.19	0.860	0.150	0.17
logFpar	1.186	0.174	0.15	1.263	0.153	0.12	1.324	0.150	0.11
logFpar	0.974	0.199	0.20	1.088	0.160	0.15	1.188	0.150	0.13
logFpar	0.979	0.251	0.26	1.182	0.188	0.16	1.478	0.154	0.10
logSdLogFsta	-0.840	0.252	0.30	-0.791	0.227	0.29	-0.745	0.206	0.28
logSdLogFsta	-1.204	0.121	0.10	-1.221	0.120	0.10	-1.247	0.123	0.10
logSdLogN	-0.476	0.158	0.33	-0.472	0.156	0.33	-0.465	0.149	0.32
logSdLogN	-1.441	0.152	0.11	-1.484	0.171	0.12	-1.591	0.198	0.12
logSdLogObs	-0.056	0.128	2.28	-0.102	0.132	1.30	-0.185	0.128	0.69
logSdLogObs	-2.128	0.410	0.19	-2.052	0.390	0.19	-1.861	0.304	0.16
logSdLogObs	-1.815	0.269	0.15	-1.436	0.140	0.10	-0.980	0.079	0.08
logSdLogObs	-1.185	0.150	0.13	-1.209	0.158	0.13	-1.173	0.162	0.14
rho	0.981	0.020	0.02	0.965	0.028	0.03	0.923	0.043	0.05

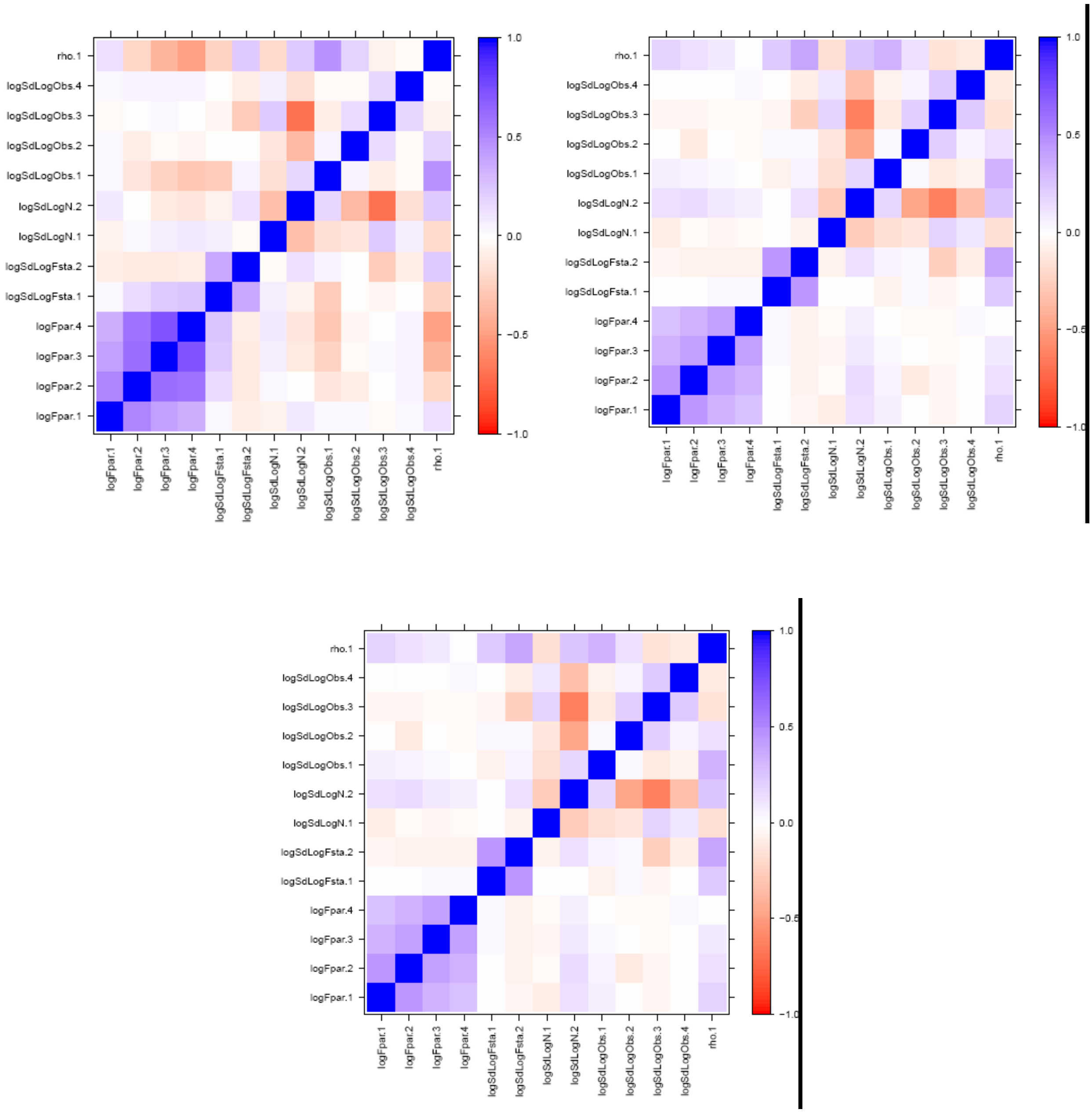


Figure 4.5.7. Correlation matrices for base case runs at 6+ (top left). 7+ (top right) and 9+ (bottom).

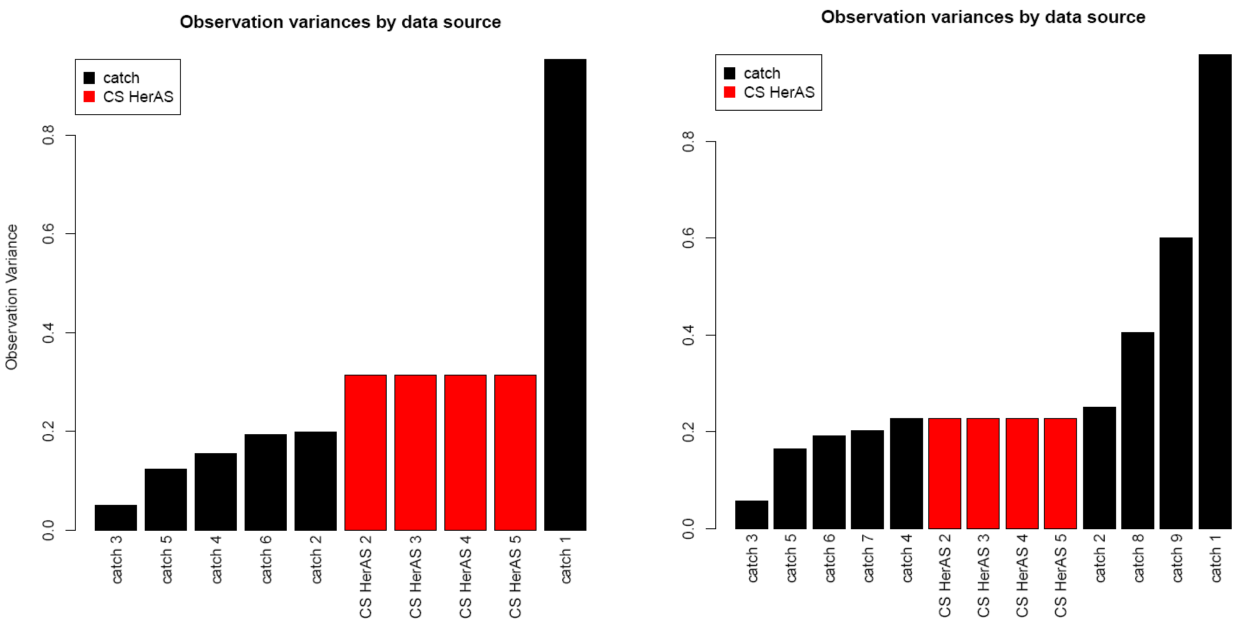


Figure 4.5.8. Catch observation variances for unbound runs at 6+ (left) and 9+ (right).

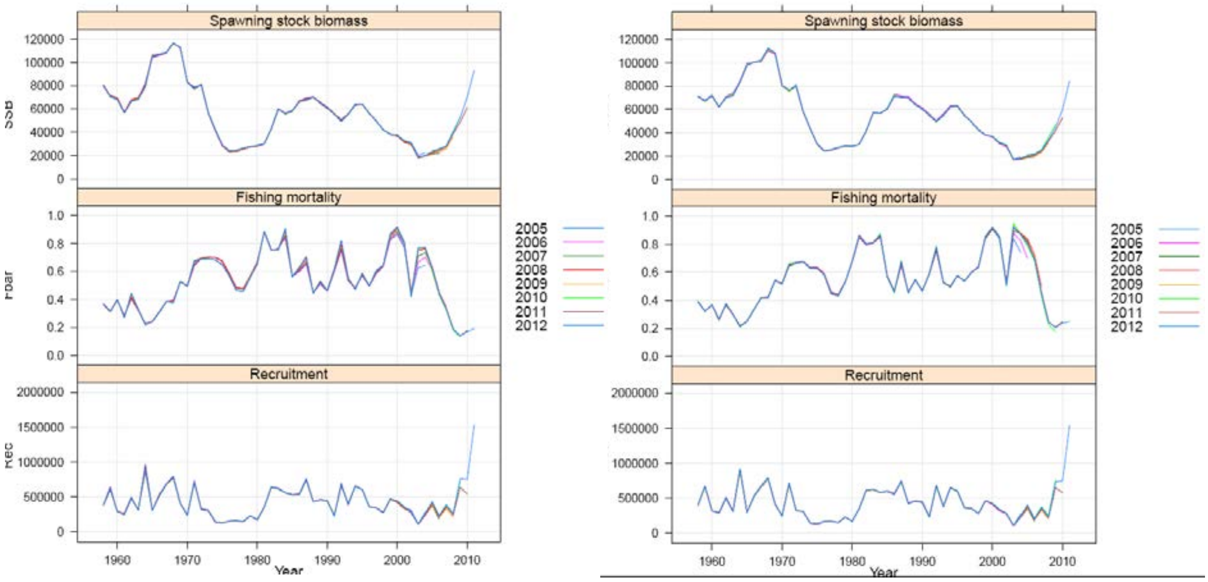


Figure 4.5.9. Analytical retrospective estimations of SSB, F and recruitment from 6+ and 9+ assessments.

Acoustic Survey age range

As there is only one time-series available the only factor to examine was the age range to be used. Currently only ages 2–5 are utilized. Including additional ages 1–6, 1–9, 2–8 and 2–6 in the assessment was examined. The most complete tuning series (1–9) was favoured by WKPELA because it contained the best information. However it should be noted that the residual pattern for 1 and for 9 in the survey was very unbalanced.

SAM model settings

The objective of refining the model was to reduce the effective number of free parameters in the model by binding selected parameters together. This refinement uses one fitted parameter to represent more than one variable in the model i.e. binding ages together. The reduction in the number of parameters can lead to a poorer quality fit but it has the benefit of producing a simpler model that is quicker to run and easier to interpret (ICES, 2012). The Akaike Information Criteria or AIC value is used to assess the model performance with a lower value indicating an improved fit. In the following text, binding is represented in the following notation:

1,2,2,2,2,3

which means that the first age is free, the next set of ages (2,3,4,5) are bound and the last age (6) is also free.

Screening over a range of options was performed, in order to obtain an optimum range of settings. This screening was performed in FLSAM, with additional settings in www.stockassesment.org.

Optimum model refinement

Based on the AIC values the optimum model refinement incorporates the settings in the text table below.

	SAM Settings	Best combination
1	Coupling of fishing mortality states	1,2,3,4,5,6,7,8,8
2	Correlated random walks for F	correlated (TRUE)
3	Coupling of catchability parameters	1,2,3,3,3,3,3,3,3
4	Variances in F random walk	1,2,2,2,2,2,2,2,2
5	Coupling of logN RW Variances	1,2,2,2,2,2,2,2,2
6	Coupling of observation variances - Catch	1,2,3,3,3,4,4,5,5
7	Coupling of observation variances - Survey	6,6,6,6,6,6,6,6,6

The diagnostics of this run are presented in Appendix 2a and 3a (without and with the 2013 data). Residuals in catch-at-age show little trend over time, and display a well-balanced pattern. The exception to this is at the beginning of the time-series at 1-ring, and this manifests itself in poor fitted catch at that age in the earlier years. Magnitude of residuals is highest at 1 and 2-ring and 6 ring onwards, though there is no trend over time in the magnitude of residuals within age. Model fitting to the survey is good, with well-balanced residual patterns, except at 1, 8 and 9-ring where there is large bias. Year effects in the survey are manifest in the years 2010–2012, with 2012 the highest in the series of observations by 200%. Notwithstanding this, there is good cohort tracking in the survey with strong positive correlations between most ages. Catch at 1 ring contributes by far the most variance in the observation, followed by catches at 8- and 9-ring. Selection patterns are quite different to those displayed in the previous ICES assessments. They increase to about 1.5 at oldest age throughout the series, with an increasing trend towards higher selection at oldest ages in recent years. There is no *a priori* reason to believe that the fishery has increasingly targeted older fish, though of course the age structure was attenuated in the 1970s and 1990s–2000s. Estimation of SSB and F is reasonably precise. Comparison of stock trends over time (Figure 4.5.10) shows strong agreement across the three parameters over the time-series. Both frameworks predict full stock recover, with F being low. Retrospective bias is small in this run (Appendix 2b and 3b (without and with the 2013 data)).

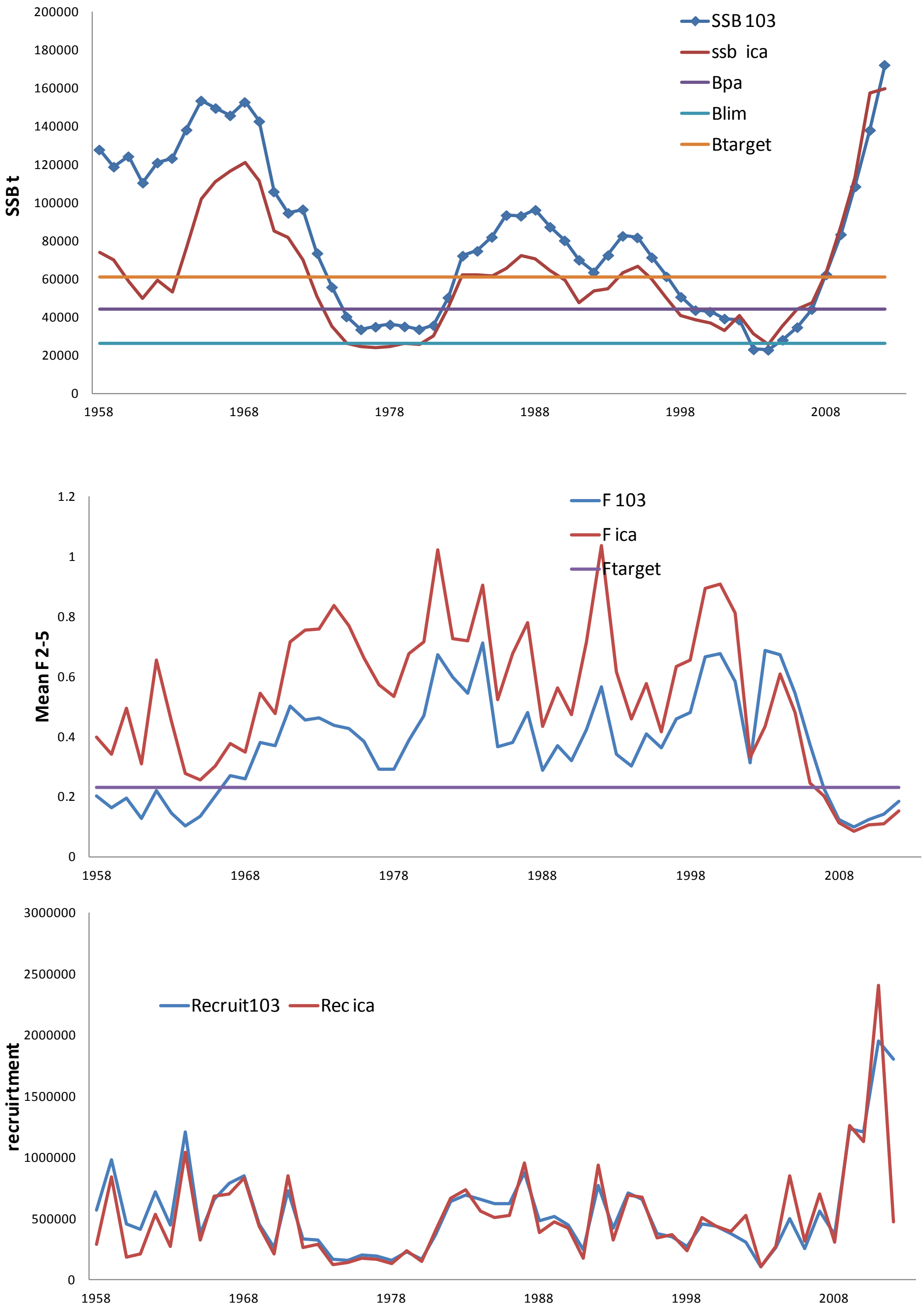


Figure 4.5.10. SSB, F and recruitment from best case SAM run compared with ICA SPALY assessment 2013.

Data refinement

Catch data

The current assessment of Celtic Sea herring largely includes data from Ireland only in recent years. Continental fleets stopped fishing the stock in earlier years, though there is evidence that they have begun to target it again now that the stock has become much more abundant. An analysis of the catch data submitted by countries other than Ireland to the working group from 2005–2012 was carried out. The purpose of this analysis was to investigate if any changes should be made to the catch data. Information, including anecdotal reports and analyses of fleet behaviour and fleet capacity were used to inform decisions on the input data. In the end, no substantial changes were made to the catch data on the basis of these investigations. Anecdotal reports suggest that a certain amount of herring was being caught and processed by freezer trawlers in VIIj in recent years, though these catches were not reported to the WG. It is likely that there are additional catches, including discarded catches, from freezer trawlers that are missing from the dataseries.

Natural mortality

The natural mortality which has been used in the assessment is based on the results of a multispecies VPA for North Sea herring which was calculated by the ICES multispecies working group in 1987 and were applied to herring stocks in adjacent areas (Anon, 1987). Natural mortality was fixed by age and assumed to be as follows: These values were used in the assessment in subsequent years, and are as follows:

Rings	My^{-1}	M%
1	1	63
2	0.3	26
3	0.2	18
4	0.1	10
5	0.1	10
6	0.1	10

The above values seem rather low, at 2-ringer and older, given that herring in this area are forage for other fish, sharks, cetaceans, seals and seabirds. At the North Sea herring benchmark meeting in 2012 (ICES, 2012) the multispecies stock assessment model for the North Sea (SMS key-run 2010) was used to inform a variable natural mortality pattern. Annual total predation and background mortality estimates from the SMS model, were considered as a natural mortality estimation method (North Sea stock annex).

These values are higher than the values in current use, for 2-ring and older, and may be more realistic for a forage species such as herring. Figure 12 shows various estimations of natural mortality. The estimates in current use are the lowest at ages less than 2 rings, and also the lowest (except at 1-ring) of the age-variant methods. No attempt was made to estimate M using von Bertalanffy growth parameters because t_0 is thought to be poorly estimated in the absence of 0 and 1 year old (0-ring) fish. The basis of the methods used is presented in Table 4. Figure 13 shows two time-variant estimations of M, based on mean weight in the stock at spawning time.

Choice of M is more a matter of *a priori* biological decision than model fitting. The following methods were investigated:

- Hoenig 1983 maximum age
- Hewitt and Hoenig 2005, updating Hoenig 1983 maximum age
- Tanaka, 1960; Sekharan, 1975; Alagaraja, 1984 maximum age
- "Rule of thumb" 3 / maximum age
- Richter and Efanov, 1977 age-at-maturity
- Gundersen and Dygert, 1989 gonadosomatic index
- NS from SMS, time invariant mean of current North Sea multispecies estimates
- Anon. 1987 North Sea multispecies estimates
- ICES standard = 0.2 unknown source
- Lorenzen, 1986 (mean of time variant values) mean weight
- Peterson and Wroblewski, 1984 Mean weight

The methods based on maximum age offer a mathematically plausible basis. However assuming fixed values across ages is an over simplification. However these methods can be used as comparisons for the age-invariant methods. Of the latter methods, Lorenzen produces considerably higher estimates across all ages compared to the others. Interestingly, Peterson and Wrobleski and the North Sea multispecies values are in close agreement from age 2 onwards, though the basis of their derivation is not comparable. All the age variant methods start very high, just as the current method does. There is broad scale agreement between the North Sea, Peterson and Worbleski and the maximum age methods, the latter of which enjoy wide usage in stock assessments worldwide. The maximum age methods offer a means to compare the estimates for the oldest ages, and these are broadly similar to the North Sea and the Peterson/Wroblewski methods. This provides some basis to support the choice of either of these. It should be noted from Figure 9 that the literature-based time variant methods differ in the trends over time with respect to the North Sea estimates. Though no attempt is made to hypothesize why there should be differences of this kind, the North Sea herring underwent similar stock trajectories over time to this stock, and this may provide a basis for choosing these values. Another reason for preferring the NS estimates is that they are high at 1-ring, which is biologically more reasonable. The overall choice was based on the following preferences:

- age variant rather than age invariant;
- time invariant rather than time variant;
- North Sea derived averages rather than literature derived age-variant methods.

Based on the a priori considerations, the decision was made to use averages of the North Sea derived M values.

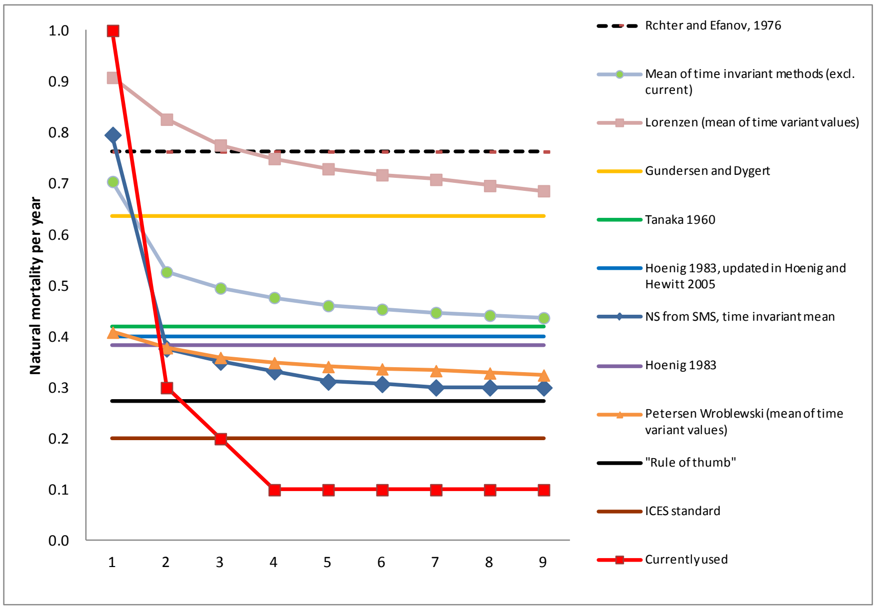


Figure 4.5.11. Comparison of % natural mortality estimates currently in use and averages derived from NS data.

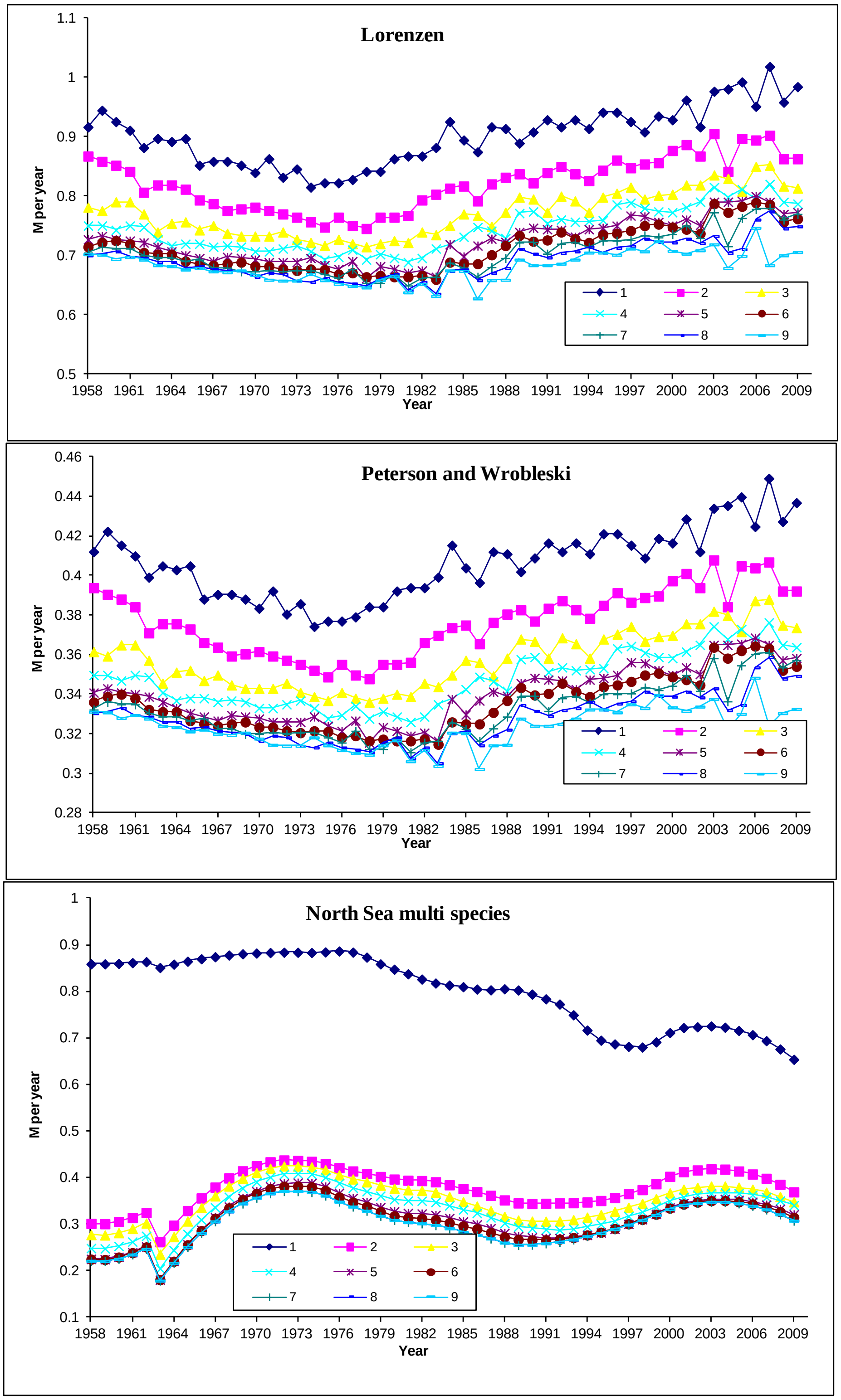


Figure 4.5.12. Three estimations of M over time, based on methods of Peterson and Wrobleski (1984) and Lorenzen (1996) and as derived from the North Sea SMS model.

Survey data

One of the features of this assessment is the very high acoustic survey estimates for 2012. Concerns have been raised (HAWG 2012) that double counting was occurring in the acoustic survey. The effect of possible double counting in the inshore stratum of VIIaS, have inflated the population estimate. Owing to tight transect spacing and the high risk of double counting, the survey design was changed in 2013. Though this is expected to lead to better estimation into the future, it remains a matter of concern how to handle the 2012 estimate. In order to test this, two scenarios were considered. The best case run, using the new natural mortality estimates was re-run without the 2012 survey. This was both to test the effect of removal, and also the robustness of a new model to missing survey in the terminal year. The latter is a consideration of importance because a survey may not always be available as happened in 2004. Figure 4.5.13 shows little difference between the runs in terms of stock trajectories. There is no diagnostic that can be used to judge whether the 2012 survey should be included. Its use is an a priori decision based on whether it is considered useful or not. Certainly the stock could not have grown by that amount from 2011 to 2012 and this alone suggests that it should not be included. To further test the effect of the abnormally high 2012 survey, the 2013 survey and catch-at-age data were added and the above analysis re-run. Results of this analysis are shown in Figure 4.5.14. It can be seen that a very large retrospective revision emerges when the 2013 data are included.

Another approach to dealing with abnormally high survey points is provided for in the stock assessment.org formulation of SAM. This formulation allows the surveys to be modelled with a Fat tail distribution that can be adjusted to be robust to extreme outliers. Three runs were performed using a value of 0.1, 0.5 and 0.9, for the proportion of the distribution about the surveys that is assumed to be fat-tailed (Figure 4.5.15). The remainder is considered to be normal. No appreciable difference in stock trajectories was found between these runs, though negative log likelihood increased with increasing proportion of the fat tailed distribution.

Auditing of code

The code used in FLSAM was audited by means of comparison with the configuration used in stockassessment.org (Nielsen, personal communication) to achieve the same couplings. An error was found in the screening runs used for 9+ in FLSAM. The result of this was that the stock–recruitment variance was being set as the same as that around the stock equation down the cohorts. Therefore it is not clear if the final best case run from FLSAM is indeed the optimum in terms of model fit. However it does provide a lower negative log-likelihood and AIC value than any of these runs. A matter of more concern is that FLSAM and stockassessment.org do not agree when the 2012 survey is removed (Figures 4.5.16 and 4.5.17). There may be some adjustment required to FLSAM to make it robust to missing years in the tuning file.

Final data

Data (1-9+ in all cases)	Year range	Notes
Catch tonnes	1958–2013	Catch in tonnes incl. discards
Catch numbers	II	Catch in numbers
Mean weight catch	II	Weighted by catch numbers
Mean weight stock	II	Unweighted, from commercial sampling October–February
Natural mortality	II	From North Sea herring multispecies, time-invariant means
Maturity ogive	II	50% at 1-ring, 100% subsequently
Proportion of F before spawning	II	0.5
Proportion of M before spawning	II	Changed in recent years as fishery began earlier
Survey	2002–2013	2004 excluded

Conclusions

The work conducted by WKPELA attempted to achieve an optimal formulation of the SAM approach. It is not entirely clear if the optimum formulation was achieved, owing to some errors that we subsequently spotted in the initial screening. However the formulation that was achieved offers good diagnostics (except for youngest and oldest ages in the survey) and reasonable precision. However the retrospective pattern in the new assessment is worse than in the old one (Figures 4.5.17 and 4.5.18). Therefore the main aim of the benchmark process has not been achieved, namely to achieve a model with less retrospective year-on-year revision than the previous model. The SAM model is rather sensitive to the final year survey data, particularly the abnormally high 2012 survey estimates. Further work, either through another benchmark in the future, or through the inter-benchmark process may be required to find the most suitable model that is robust to survey outliers and delivers better retrospective patterns.

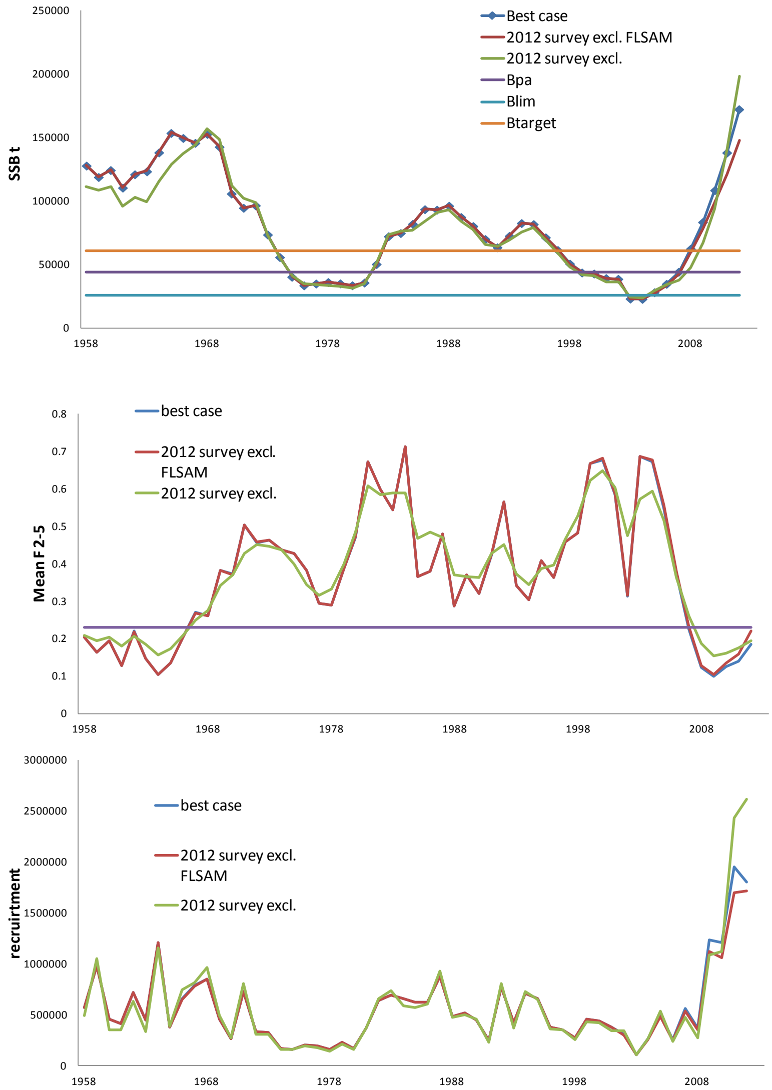


Figure 4.5.13. Comparison of stock trajectories including and excluding the 2012 survey in tuning, using FLSAM, and for comparison also using stockassessment.org without the 2012 survey.

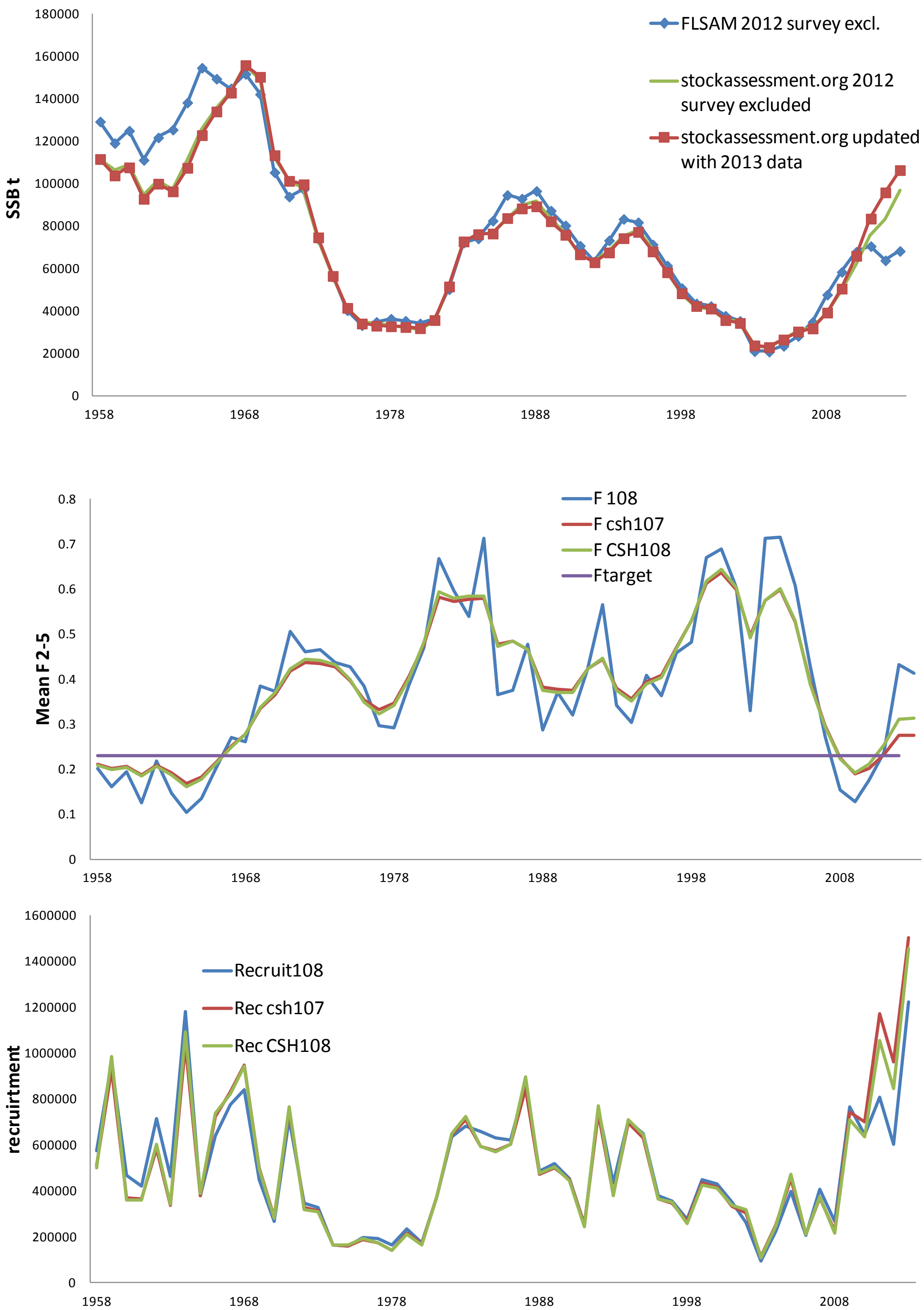


Figure 4.5.14. Comparison of stock trajectories for best case SAM run, updated with 2013 survey and catch-at-age, excluding (108) and including (107) 2012 survey. Stockassessment.org run with 2013 data, but excluding 2012 survey included (CSH 108).

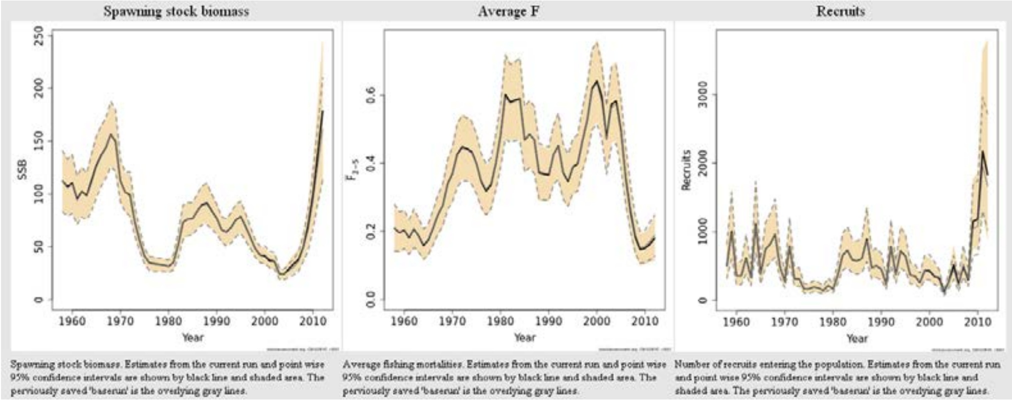


Figure 4.5.15. Comparison of stock trajectories using a fat tail proportion of 0.9 (base case) and 0.1, in stockassessment.org.

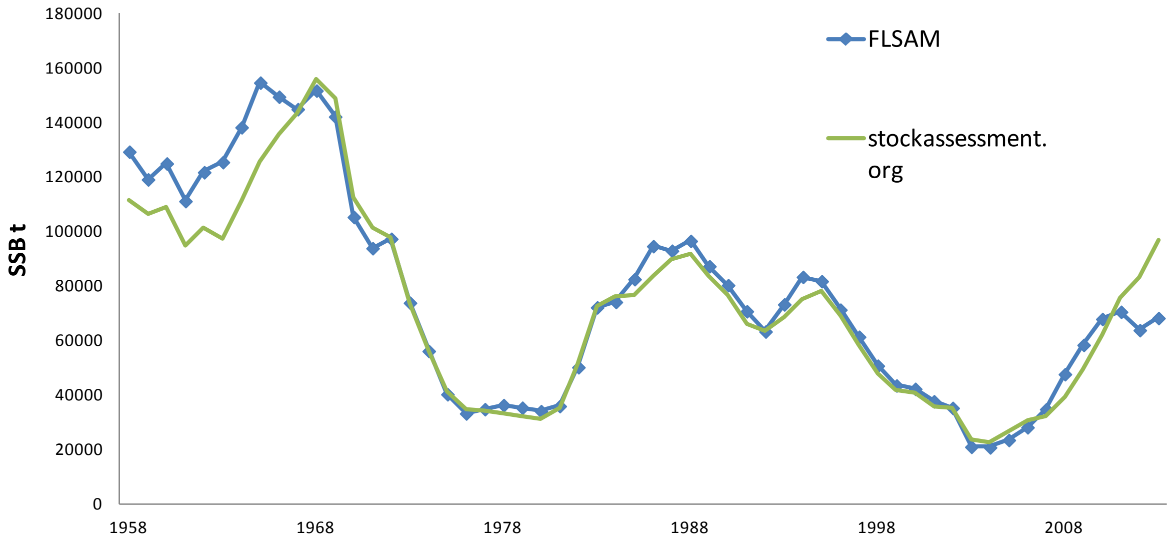


Figure 4.5.16. Comparison of stock trajectories for best case SAM run, updated with 2013 survey and catch-at-age, and excluding 2012 survey, in both FLSAM and in stockassessment.org.

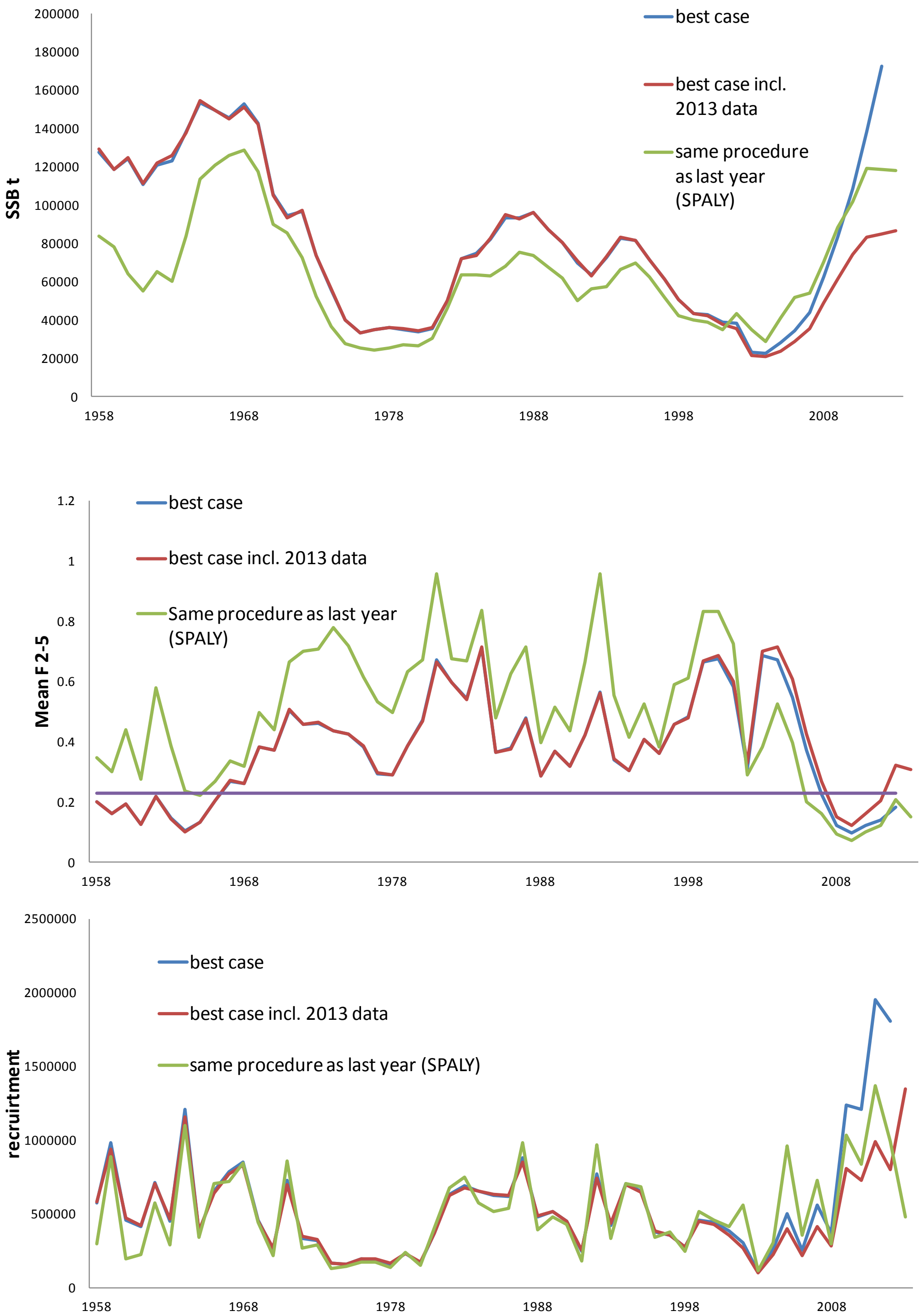


Figure 4.5.17. Comparison of best case run, also with 2013 catch and survey data, and by way of comparison the old assessment method updated with 2013 data.

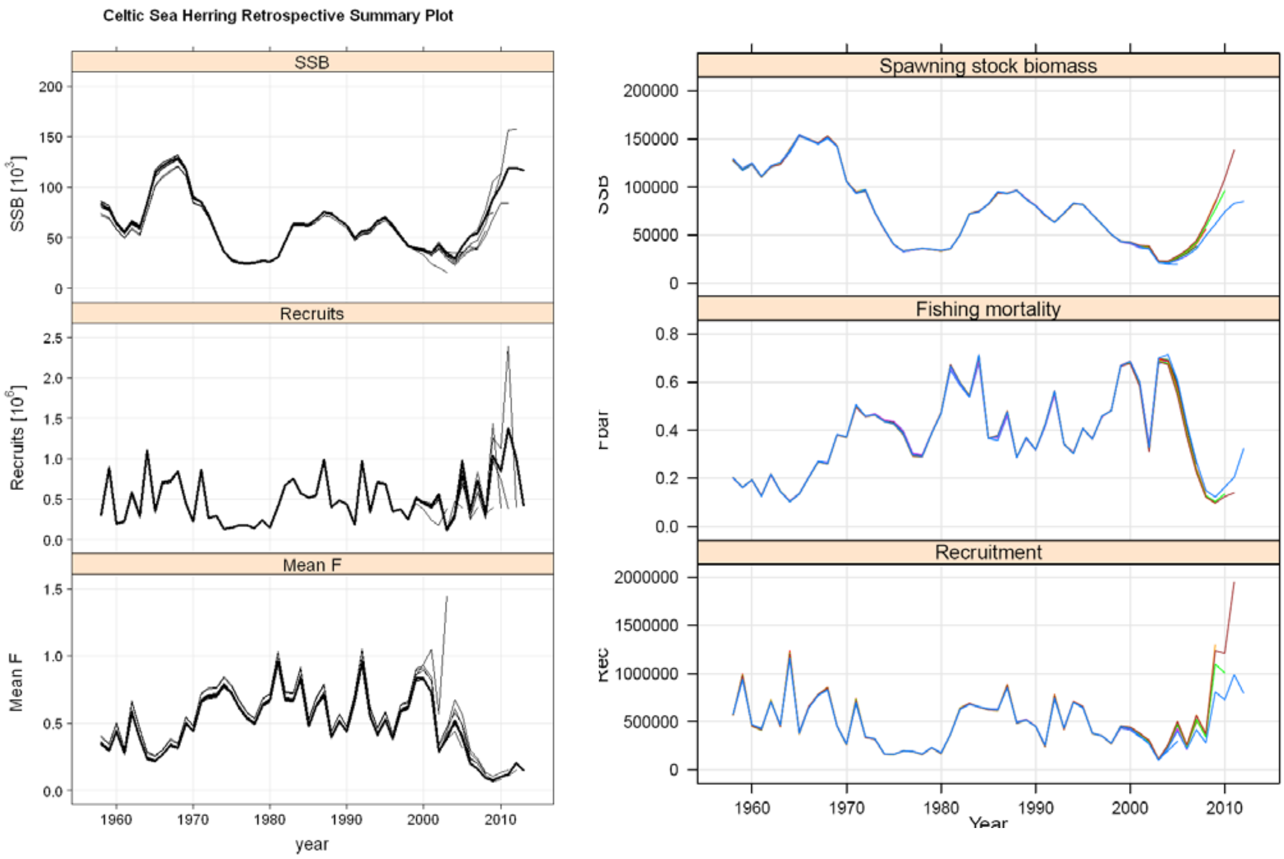


Figure 4.5.18. Comparison of retrospective patterns from old assessment using ICA (left) and the benchmark final SAM assessment (right) both with updated data for 2013 included.

4.6 Short-term projections

An updated procedure for STF is proposed, based on the FLSAM configuration. Recruitment (final year, interim year and advice year) in the short-term forecast is to be set to the same value based on the segmented stock recruit relationship (Figure 1.7.1), based on the SSB in the final year–2 years.

Interim year catch is calculated as follows:

Irish quota in assessment year – quarter 1 catch in assessment year

+ Estimated catch in quarter 1 advice year (may require iteration)

Population numbers at 2-ring in the interim year should be adjusted as follows:

$N_{2,\ int.\ year} = N_{1,final\ year} * (exp(-F_{1,\ final\ year} = M_{1,\ final\ year})$

4.7 Appropriate reference points (MSY)

The current reference points for this stock are as follows:

	Type	Value	Technical basis
MSY	MSY $B_{trigger}$	61 000 t.	Stochastic simulations on segmented regression stock–recruitment relationship.
Approach	F_{MSY}	0.25	Stochastic simulations on segmented regression stock–recruitment relationship.
Management Plan	SSB_{MGT}	61 000 t.	A trigger reference point based on stochastic HCR simulations on segmented regression stock recruit relationship using the HCS software (Skagen, 2010).
	F_{MGT}	0.23	If SSB in TAC year >61 000.
Precautionary approach	B_{lim}	26 000 t.	The lowest stock observed.
	B_{pa}	44 000 t.	Low probability of low recruitment.
	F_{lim}	Not defined.	
	F_{pa}	Not defined.	

Reference point considerations were referred to the ICES Herring assessment working group. See report of this group for further details.

4.8 Future research and data requirements

A key feature of this assessment is the large revision in stock perception from 2012 to 2013. There is concern that the acoustic survey may have been biased in the years before 2013. Work conducted by HAWG in 2013 to test for double counting due to tight transect spacing in the inshore strata, and results suggested that this was not a problem. However this analysis only considered the potential for parallel-to shore double counting bias. The effect of inshore-offshore and *vice-versa* double counting was not investigated. In the period 2005–2012 (eight years) there was a temporal mismatch in when an inshore stratum, containing high abundance, was done relative to the neighbouring offshore transect (see Figure 1.8.1). This could lead to an aggregation of fish being registered in one stratum and again in another, thus biasing the abundance estimate. This practice was discontinued from 2013 onwards due concerns that it was not a suitable design. Further work is required to investigate the potential for bias during the period 2005–2012.

The survey time-series and how it is used in the assessment is a matter that is being referred to the ICES Working Group on Pelagic Ecosystem Surveys (WGIPS) and the Herring Assessment Working Group. The main matter to resolve is not a re-working of the survey grid, but rather an improved incorporation of the data into the assessment.

Notwithstanding a re-working of the acoustic time-series to account for potential bias, more work may be required to find an optimal assessment method that has better historical retrospective patterns than SAM, and is not so sensitive to outlying survey values.

Further work is required to understand the change in productivity that has been experienced since 2003, and its implications for the management of the stock.

The reference points need to be updated in the next ICES Herring assessment working group.

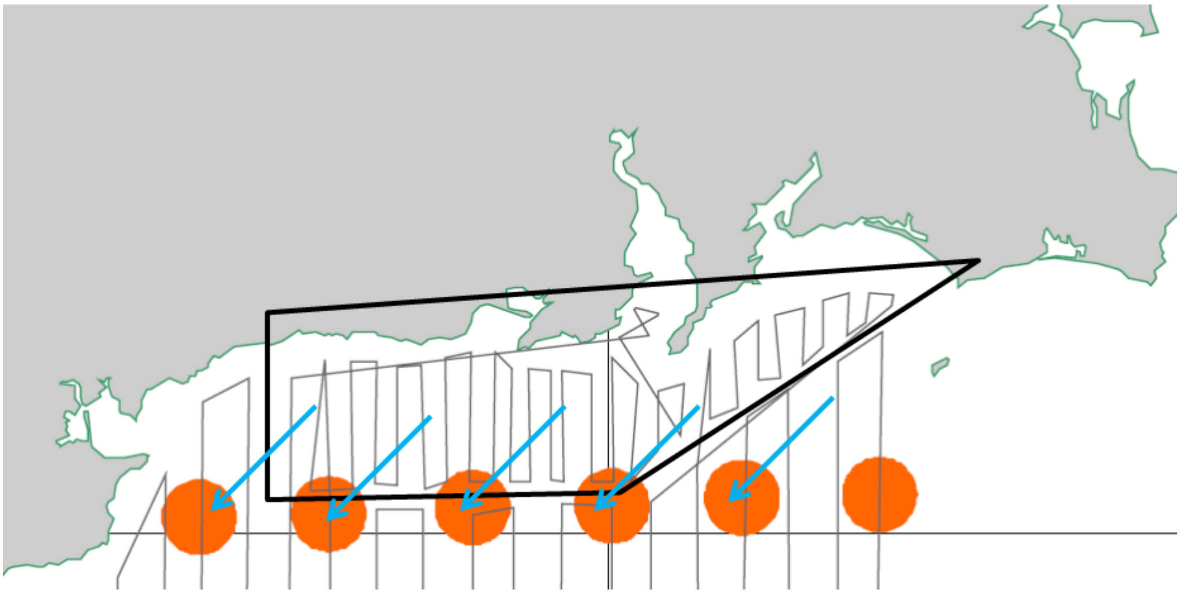


Figure 1.8.1. Hypothesized effect double counting leading to a biased abundance estimate. Inshore stratum (black polygon) surveyed at a time-lag of up to two days. Therefore schools could straddle the line and be counted twice, leading to bias.

4.9 External reviewers comments

The meeting was well prepared. The document available allowed the reviewers to see a summary of what was done and which conclusions were drawn. This made making suggestions easy.

However, many things were not presented so certain decisions could not be evaluated. For example, the details of the HERAS survey.

Similar to mackerel, we recommend conducting research on how stock migrations interact with survey coverage. More specifically, a better understanding of how recruitment is supplemented in some years by other components (from the Irish Sea) and how this affects size at age would be beneficial.

Alternative explanations for the drop in mean weight-at-age should be investigated. For example, during the meeting oral information was provided on changes in the proportion of individuals spawning at different times of the year (autumn or winter), and this should be investigated for its effect on mean weight-at-age, as well as other aspects of herring biology and assessment (e.g. effect on recruitment dynamics).

Recent herring recruitment estimates are the highest on record. Recruitment estimates at the end of time-series are often poorly determined because the cohorts have not been observed in the population for more than a few years. In some instances, subsequent data collection has reduced the size of cohorts previously estimated to be relatively high. Caution should be used in interpreting these recent high recruitment estimates, management should use caution, and industry planning should consider uncertainty.

4.10 References

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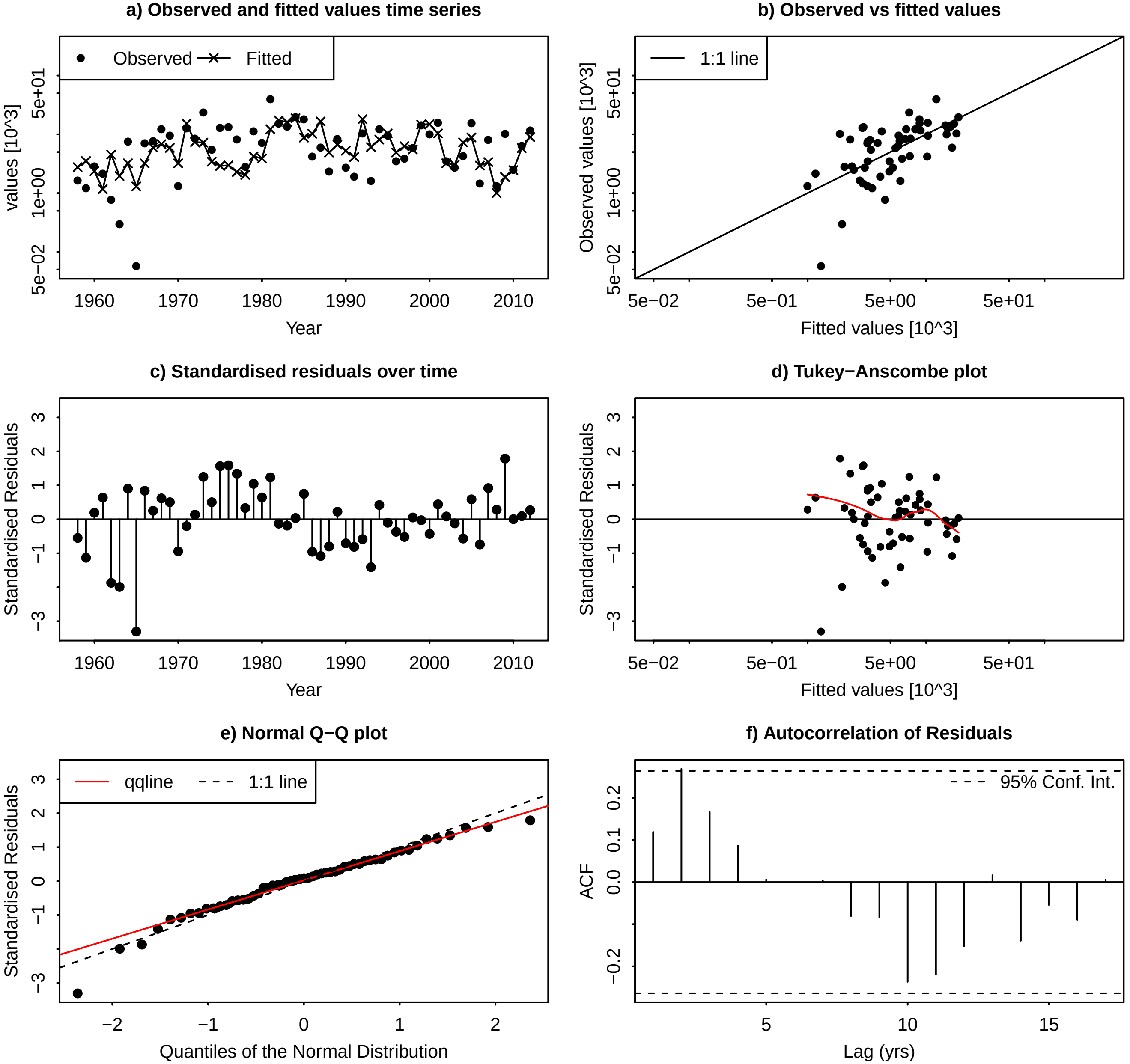
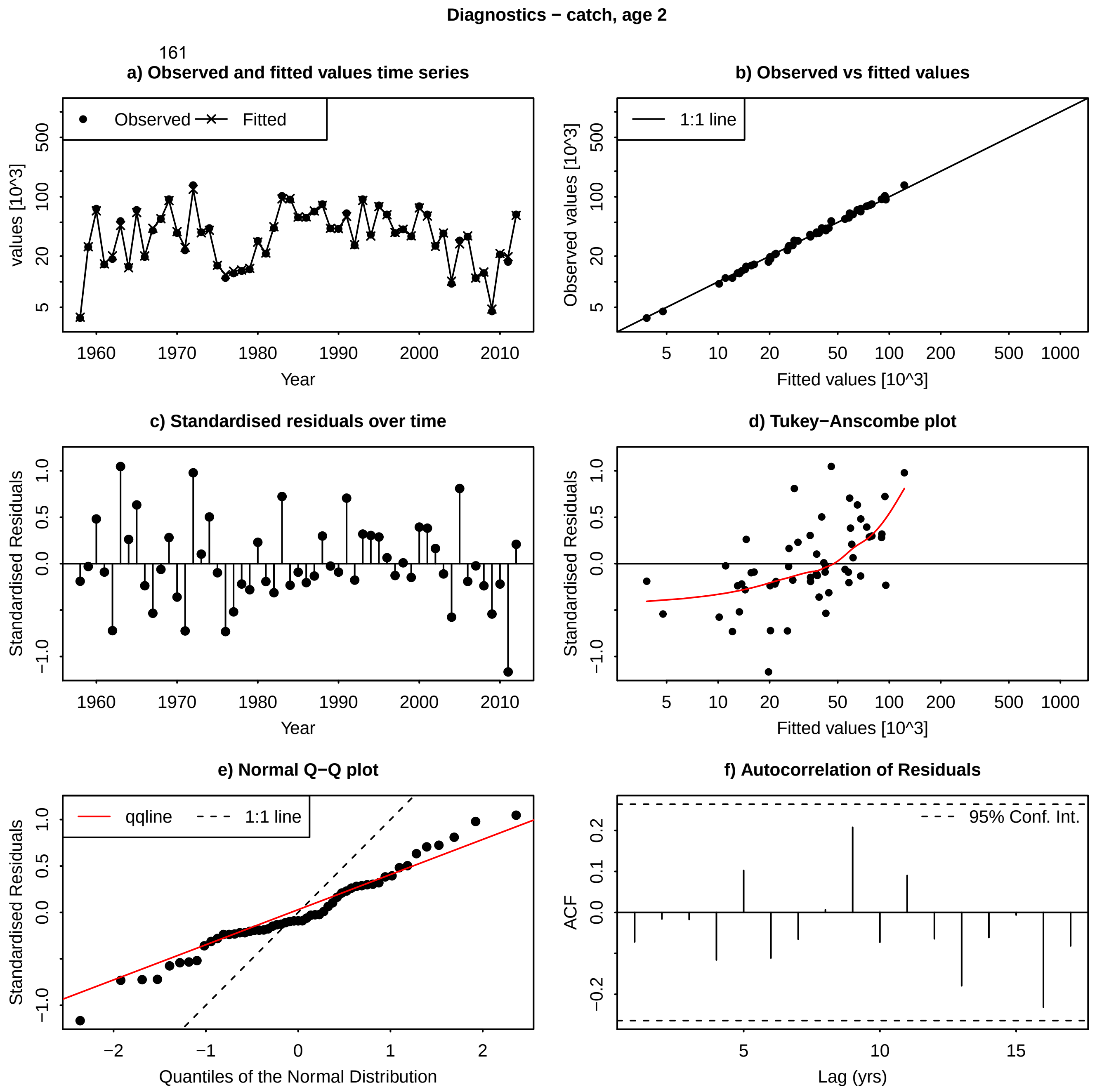
4.11 Appendixes

Appendix 1	a. Diagnostics from base case run.
	b. Retrospective pattern from base case run
Appendix 2	a. Diagnostics from best case run.
	b. Retrospective pattern from best. case run.
Appendix 3	a. Diagnostics from best case run updated with 2013 data.
	b. Retrospective pattern from best case run updated with 2013 data.

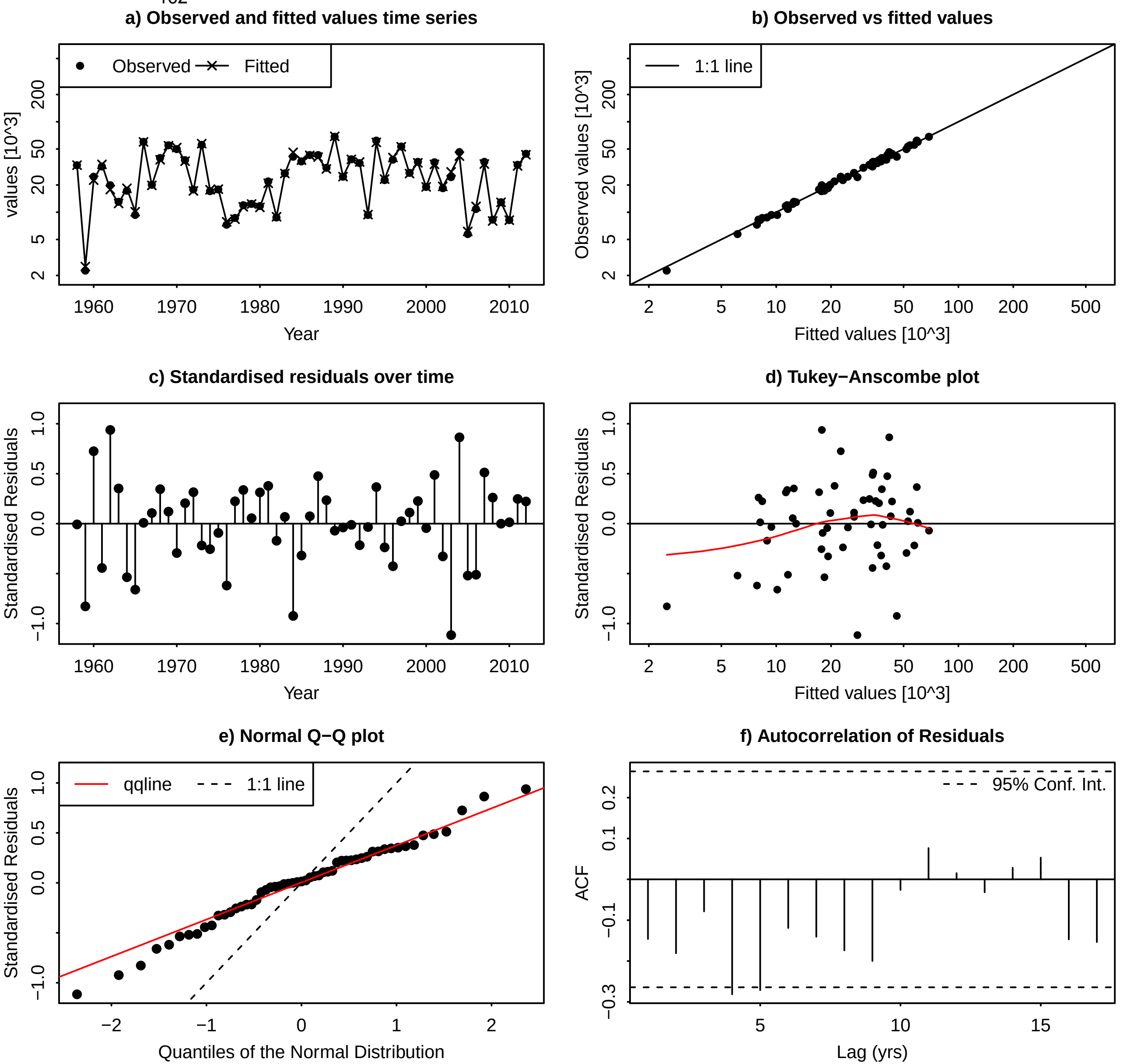
Diagnostics − catch, age 1



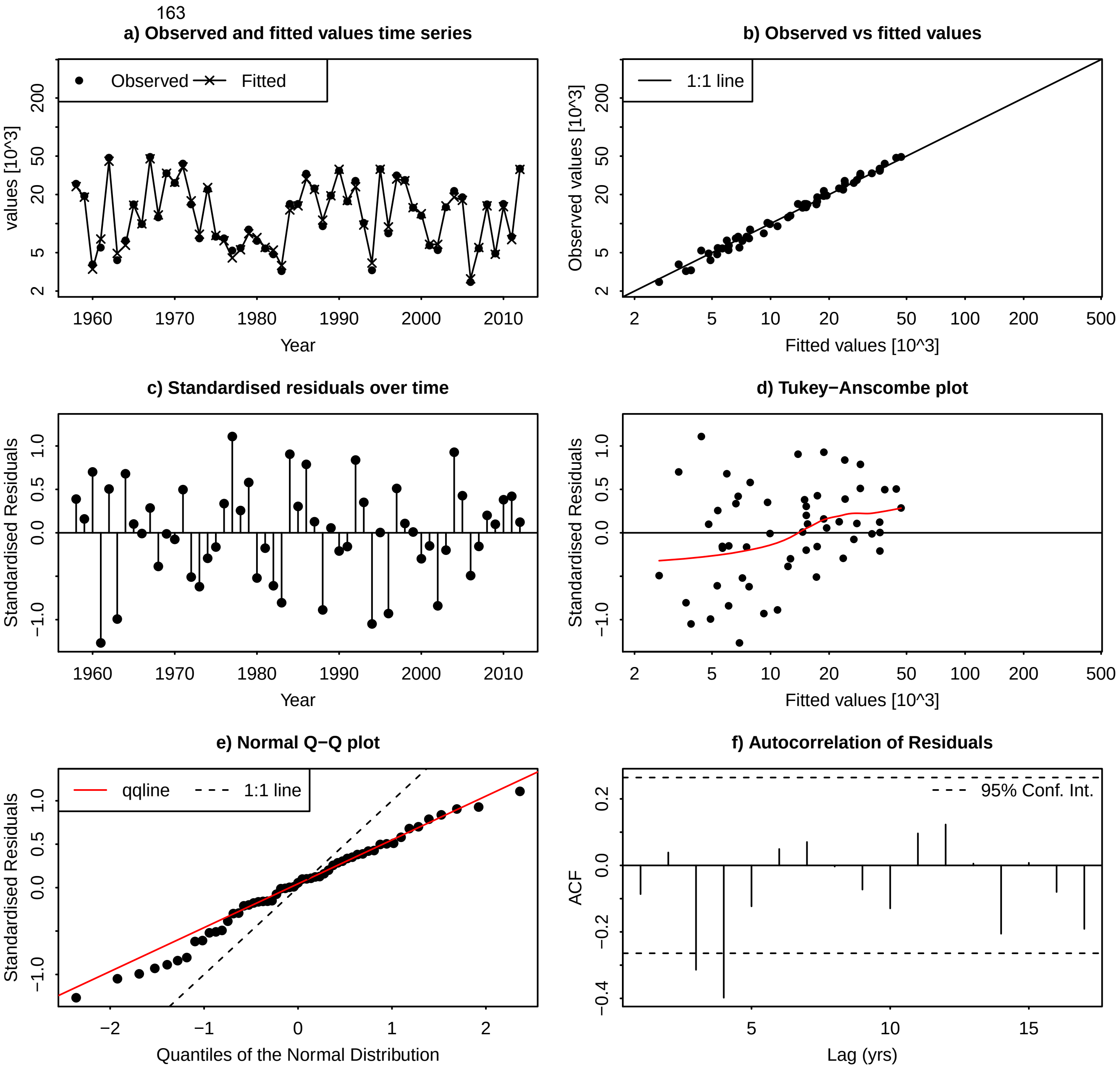

Diagnostics − catch, age 2
161
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)

Diagnostics − catch, age 3

162

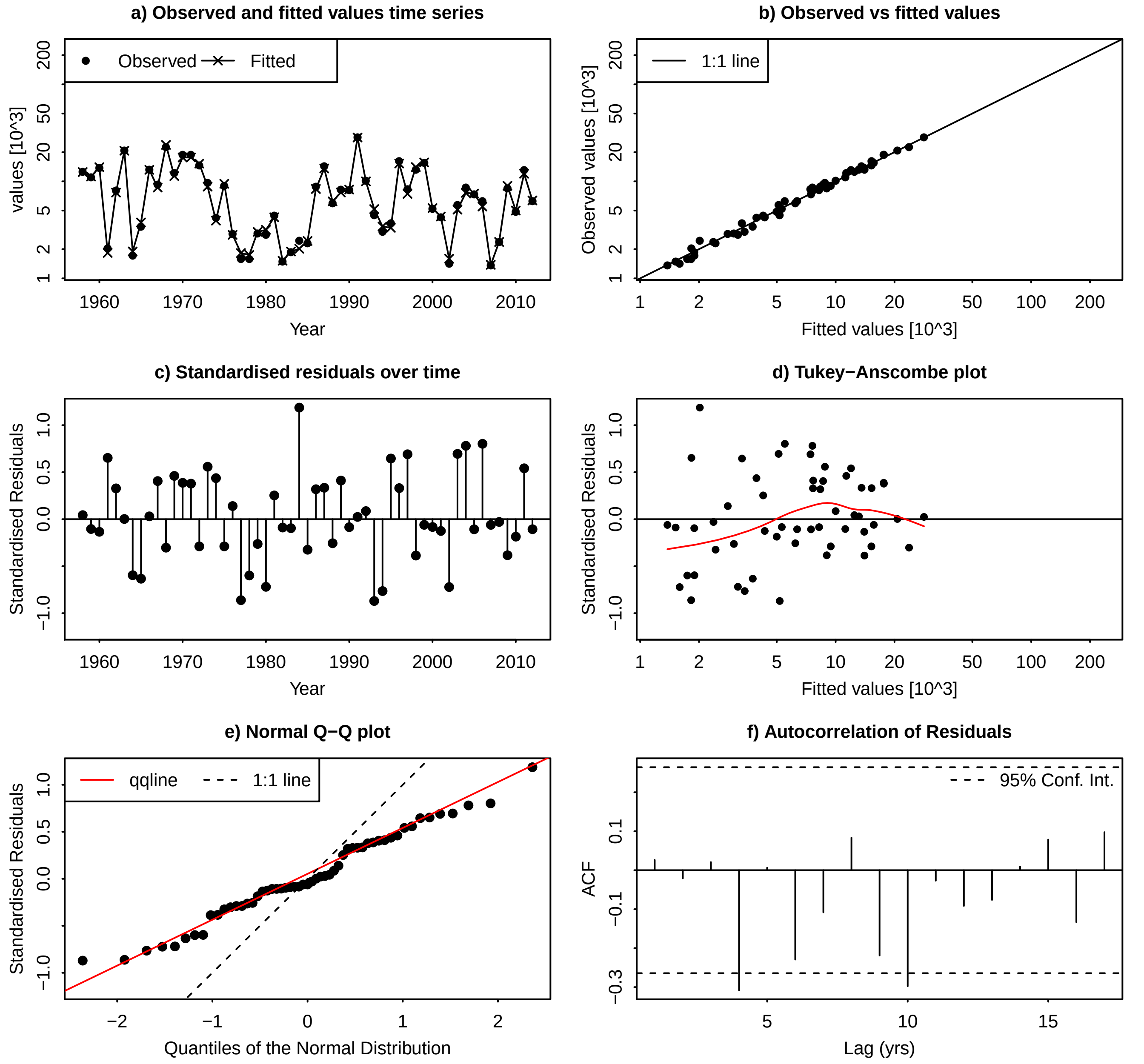


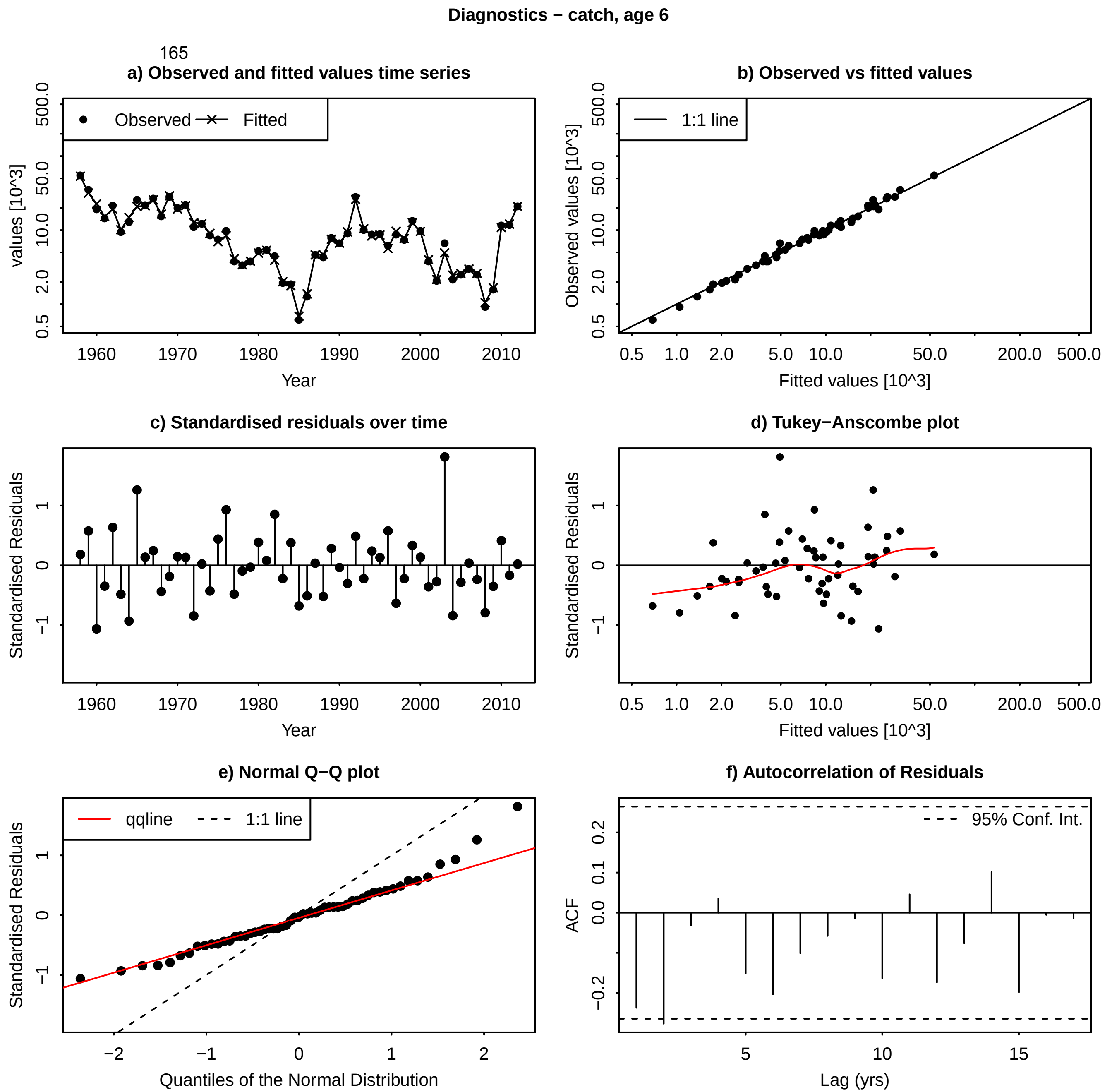
Diagnostics − catch, age 4



Diagnostics − catch, age 5

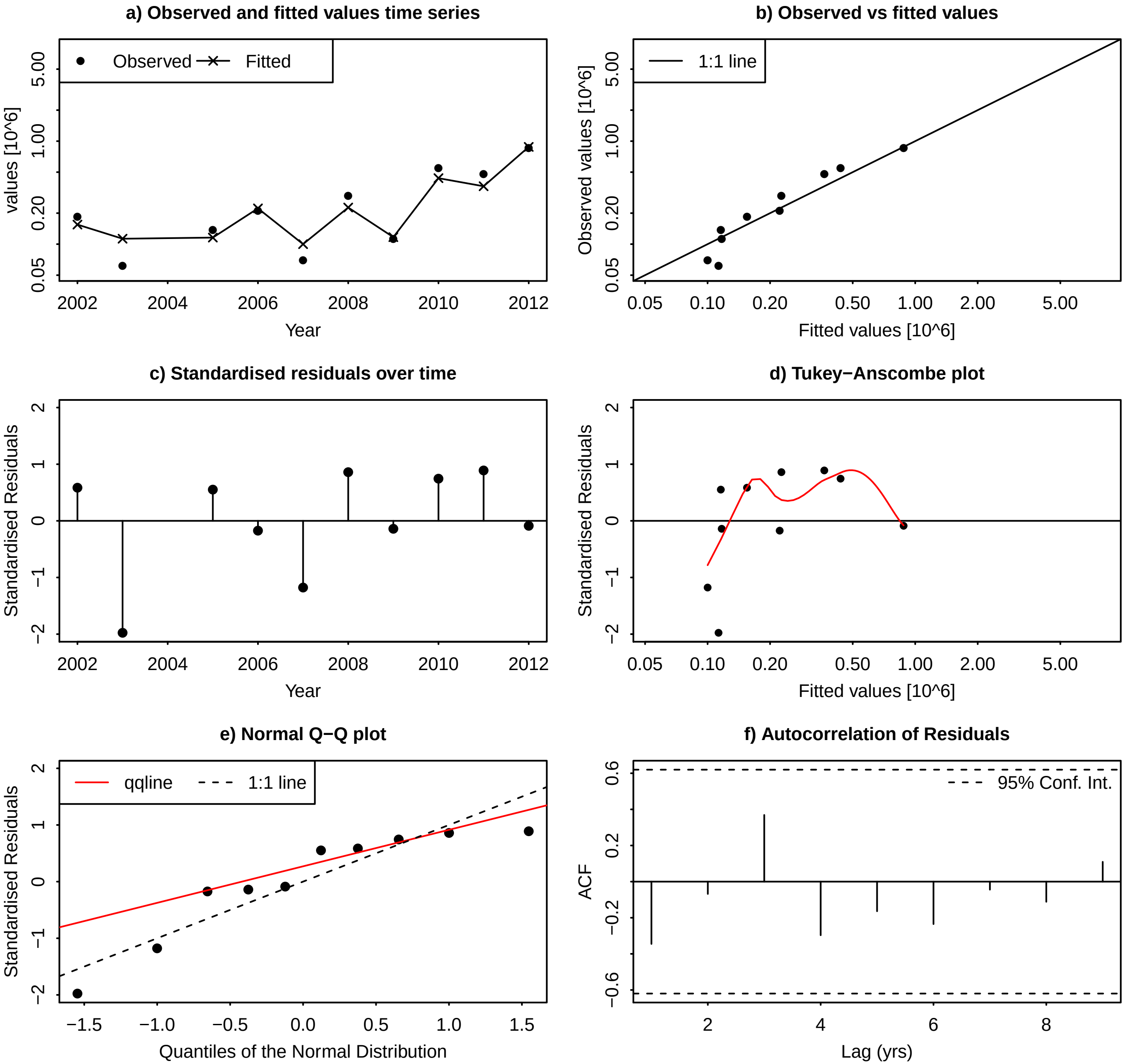
164

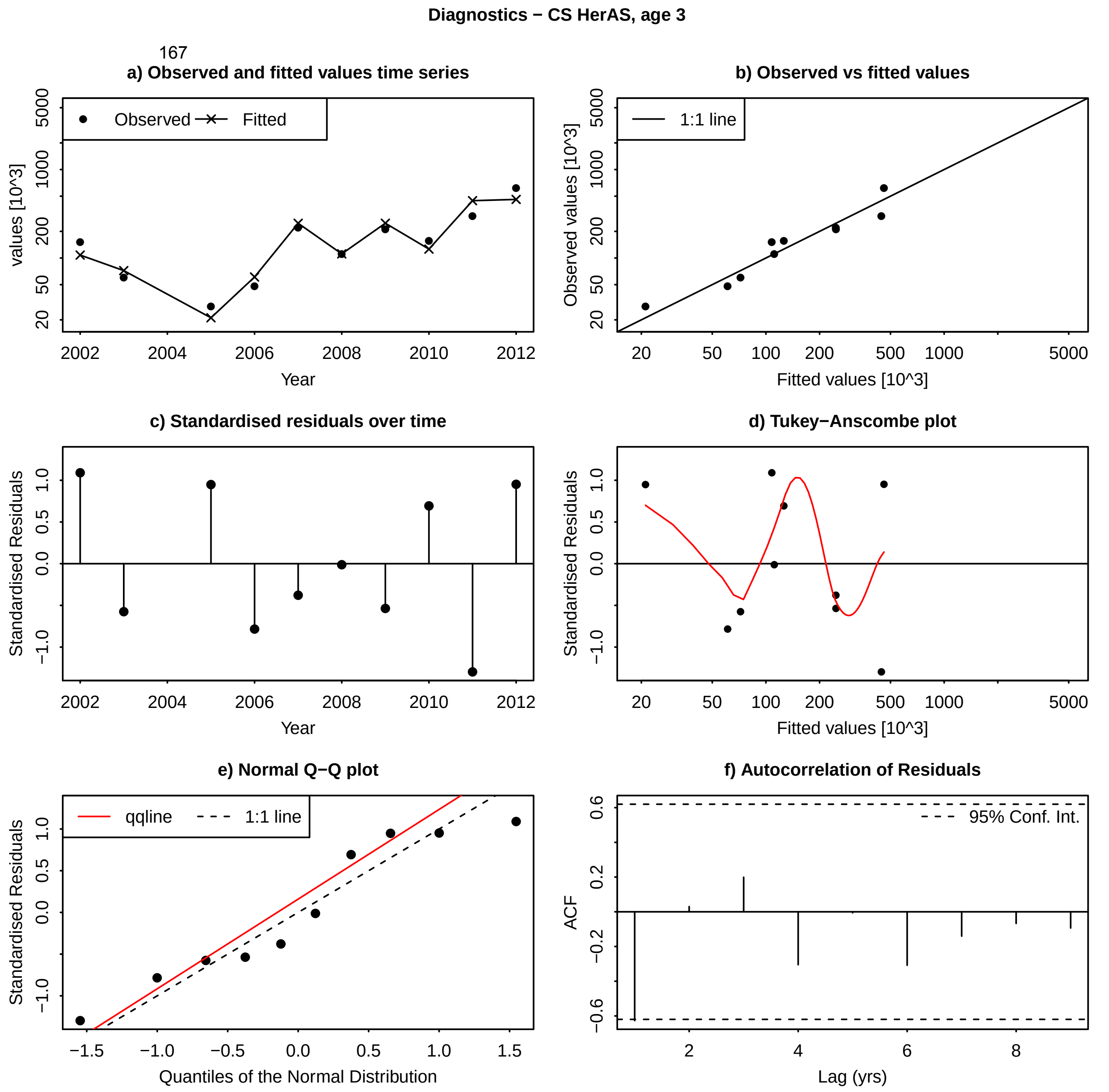


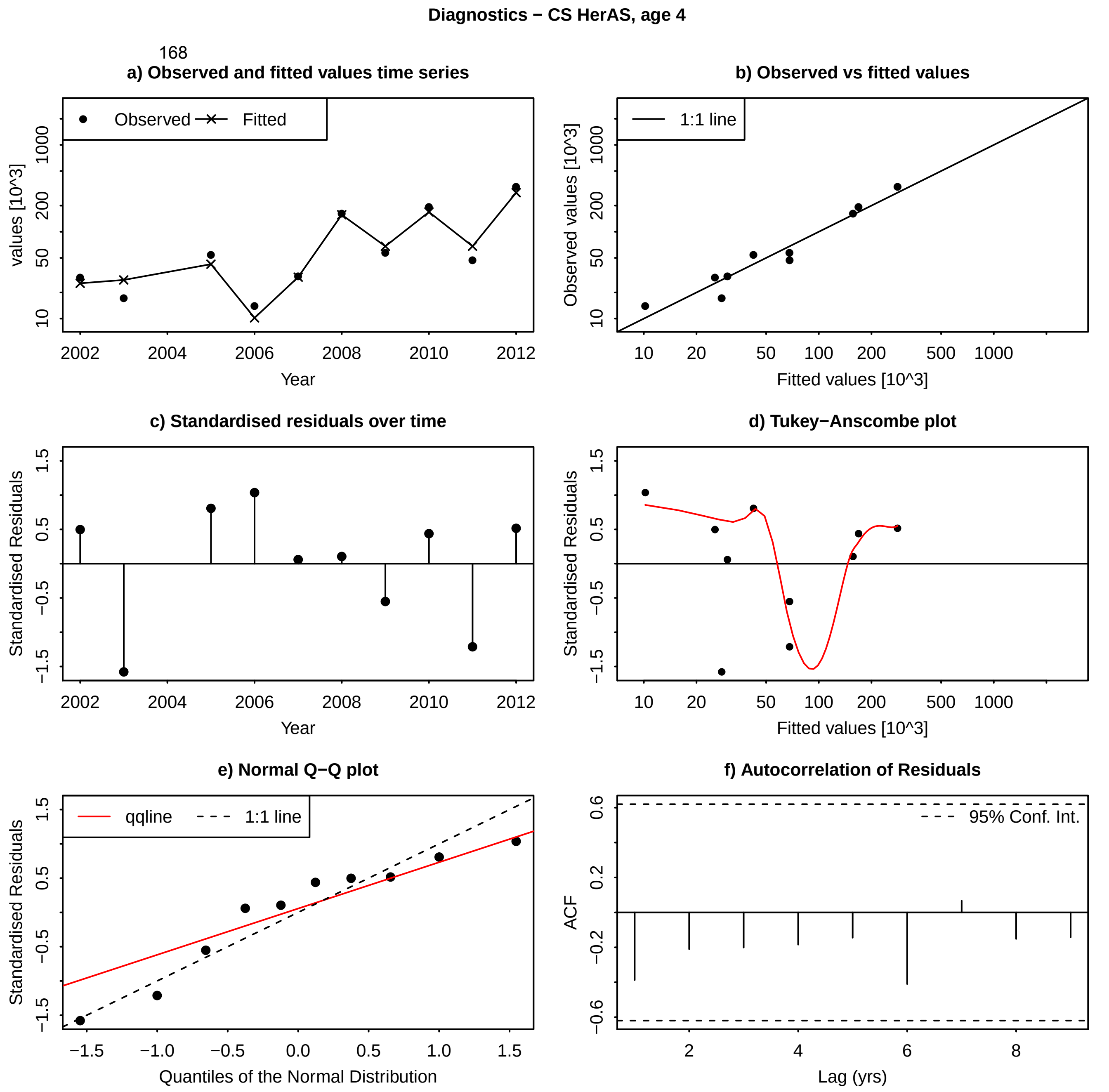


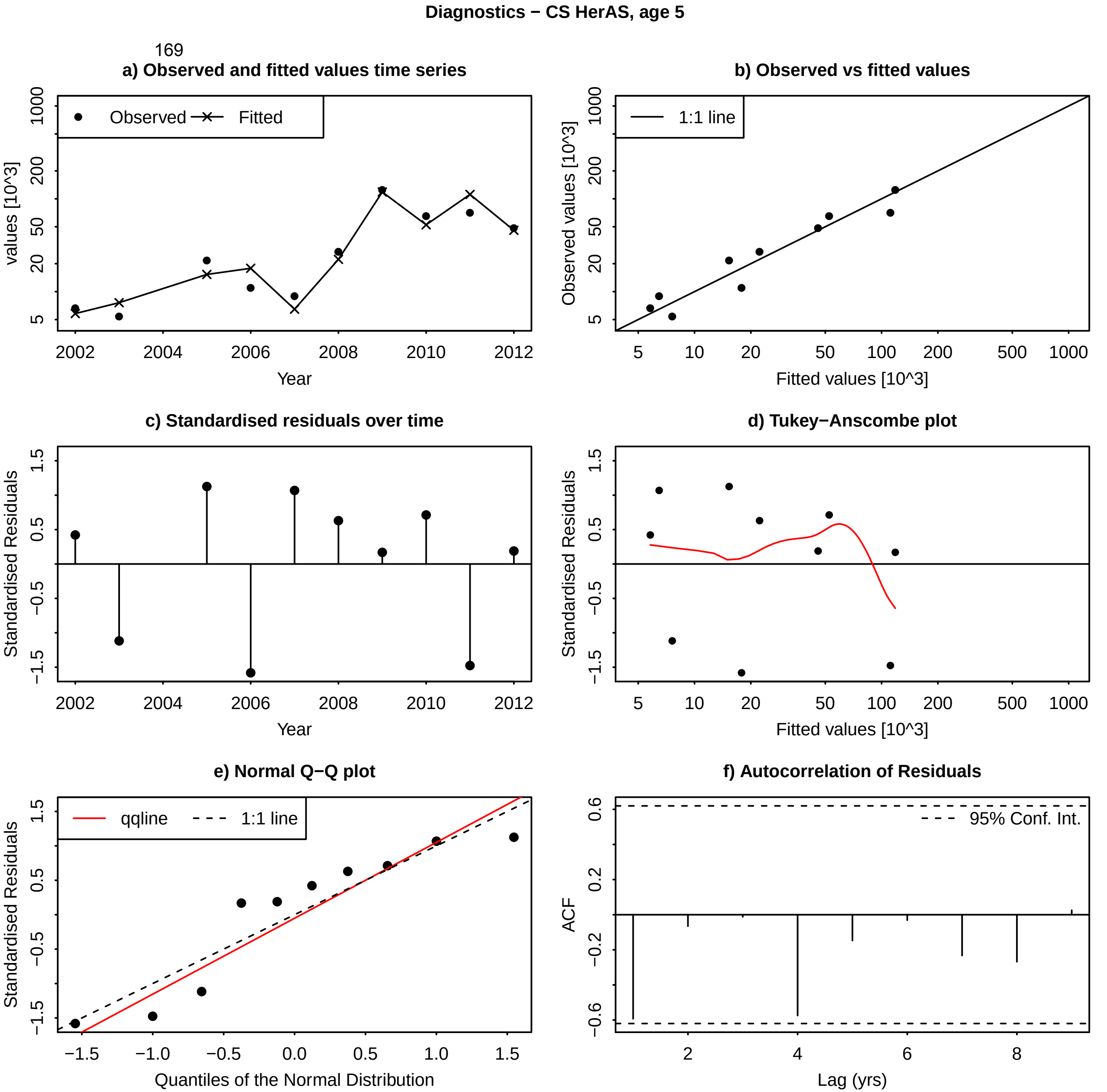
Diagnostics − catch, age 6
165
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)

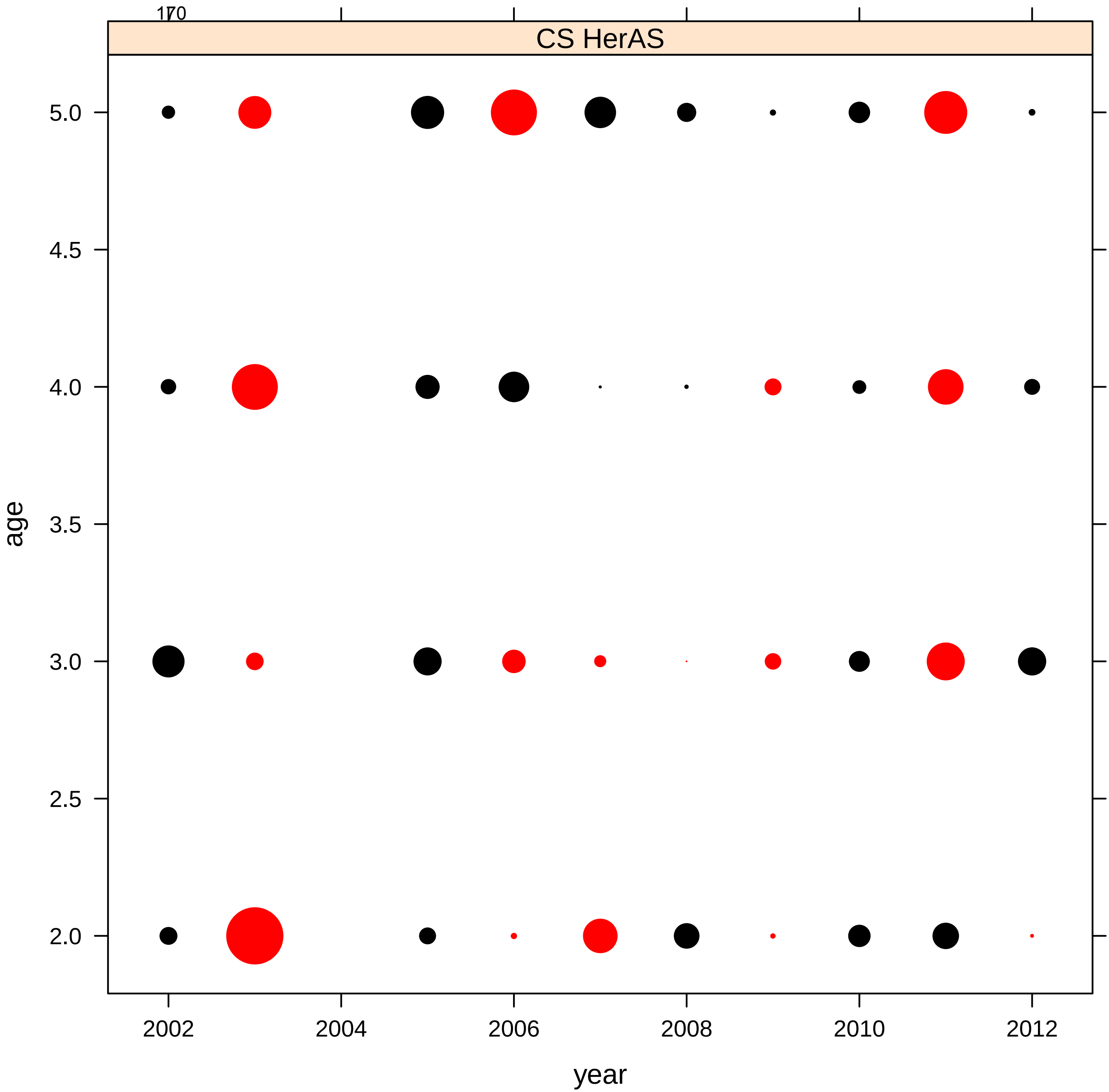
Diagnostics − CS HerAS, age 2

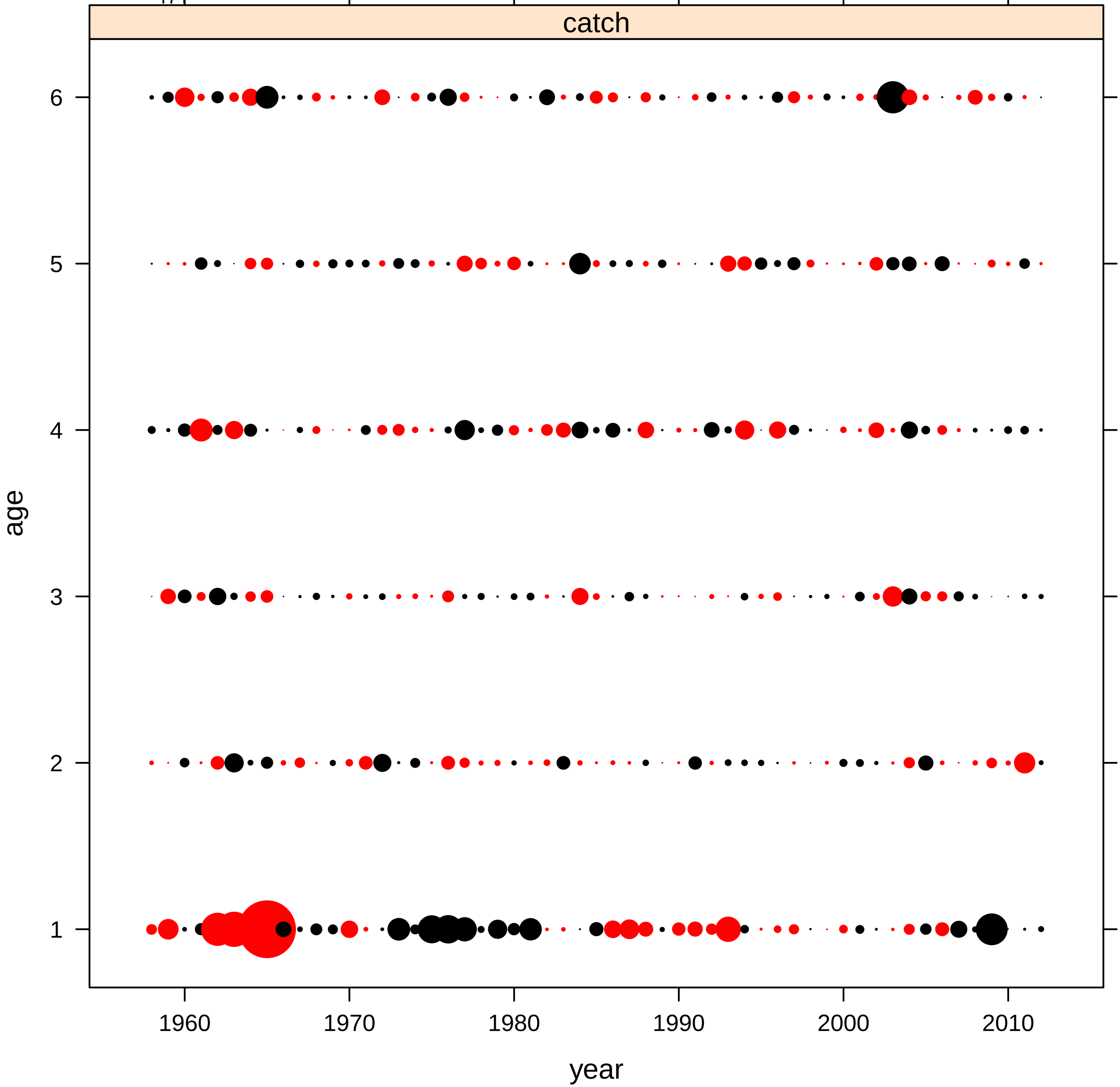


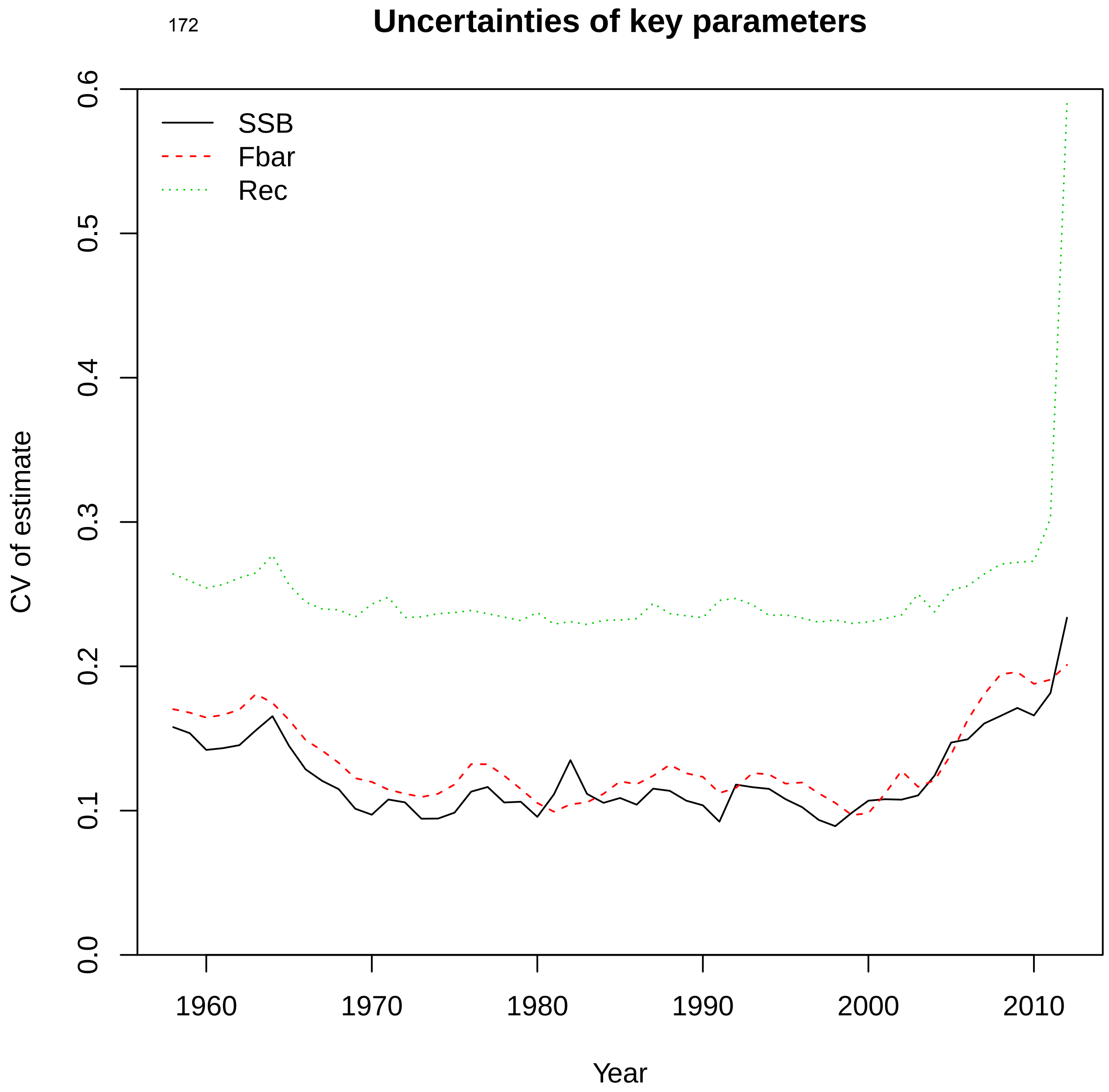

Diagnostics − CS HerAS, age 3
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)

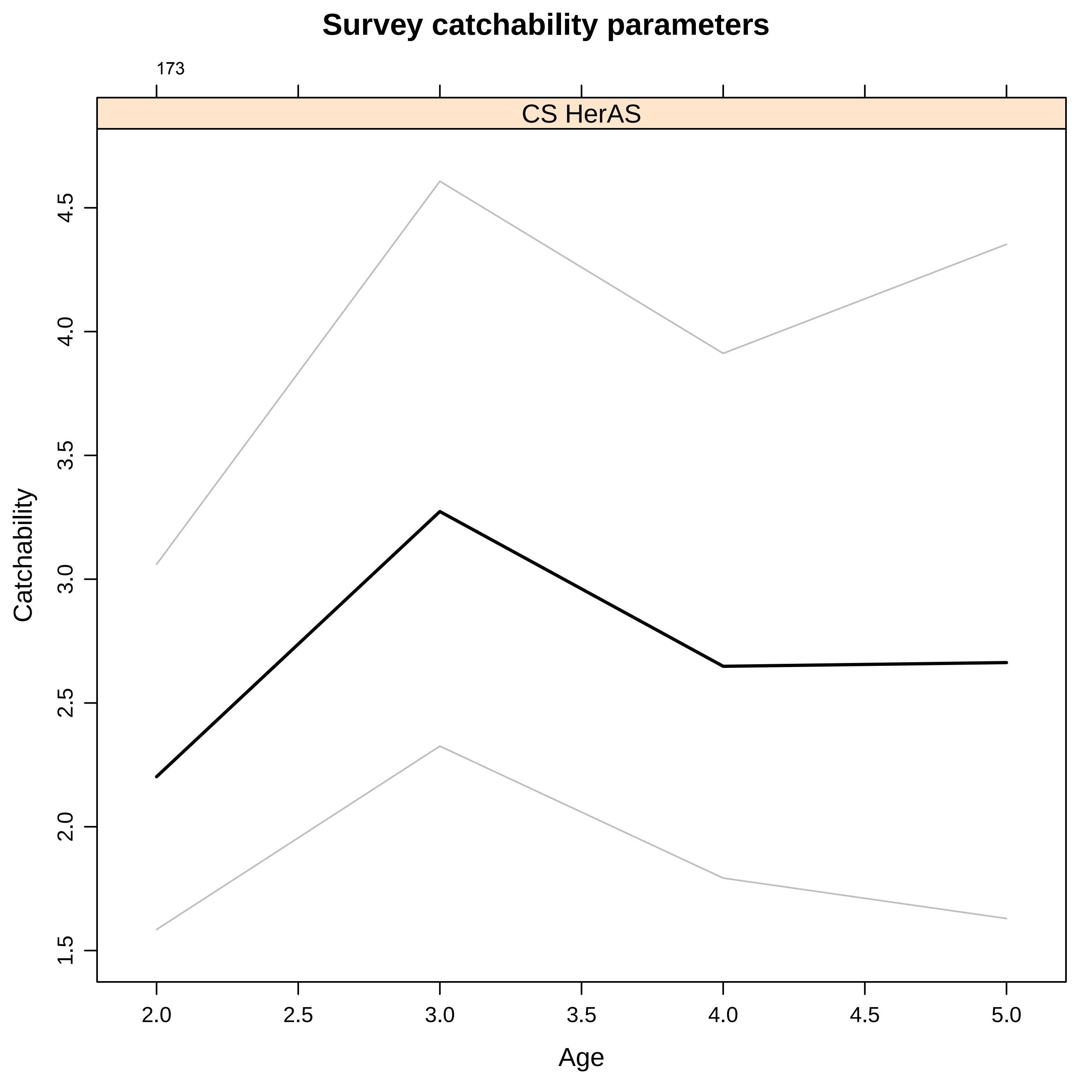

Diagnostics − CS HerAS, age 4
168
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
10
50
200
1000
2002
2004
2006
2008
2010
2012
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
10
50
200
1000
10
20
50
100
200
500
1000
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
−1.5
−0.5
0.5
1.5
2002
2004
2006
2008
2010
2012
Year
d) Tukey−Anscombe plot
Standardised Residuals
−1.5
−0.5
0.5
1.5
10
20
50
100
200
500
1000
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
−1.5
−0.5
0.5
1.5
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
−0.6
−0.2
0.2
0.6
2
4
6
8
Lag (yrs)

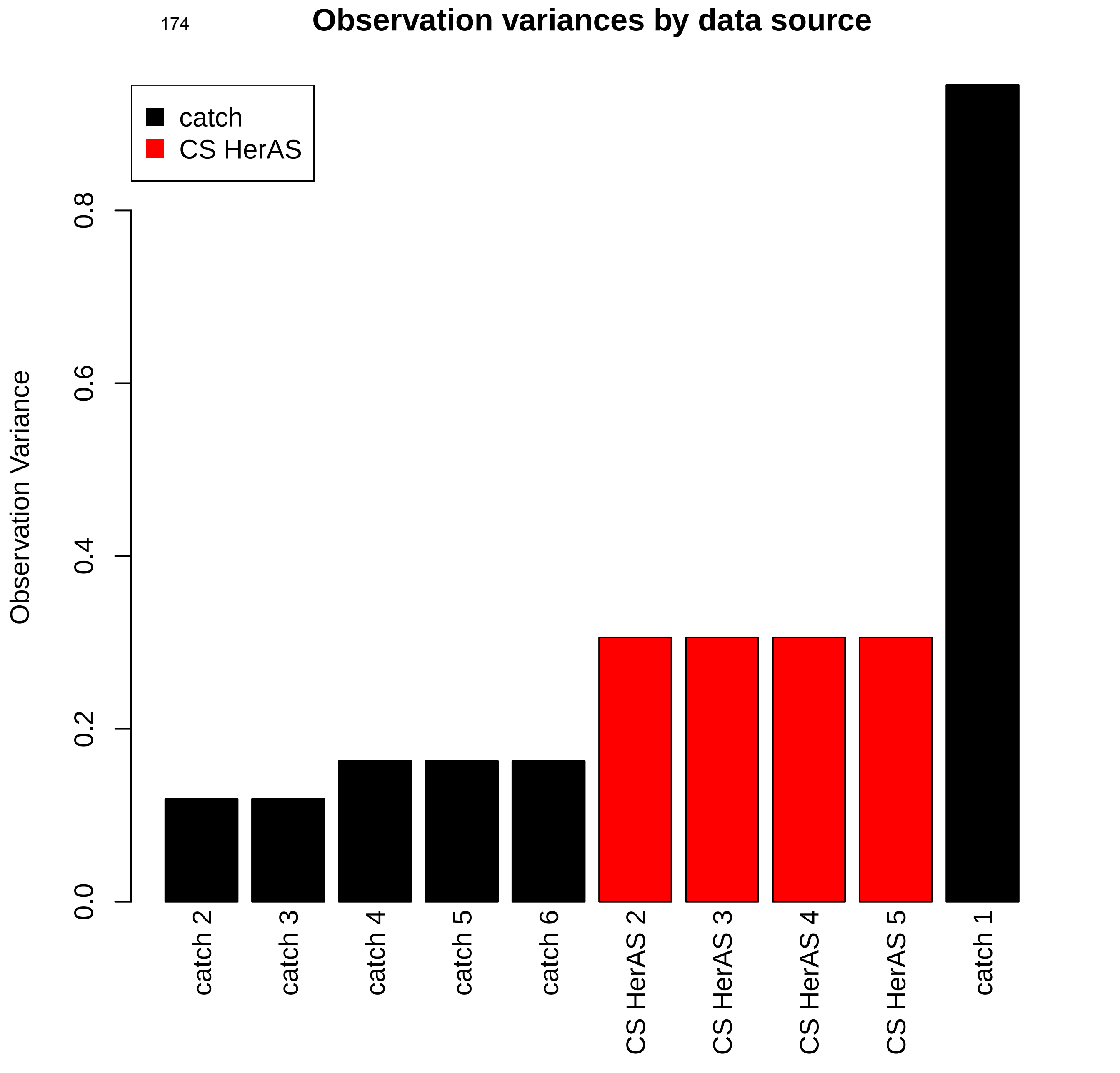

Diagnostics − CS HerAS, age 5
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)

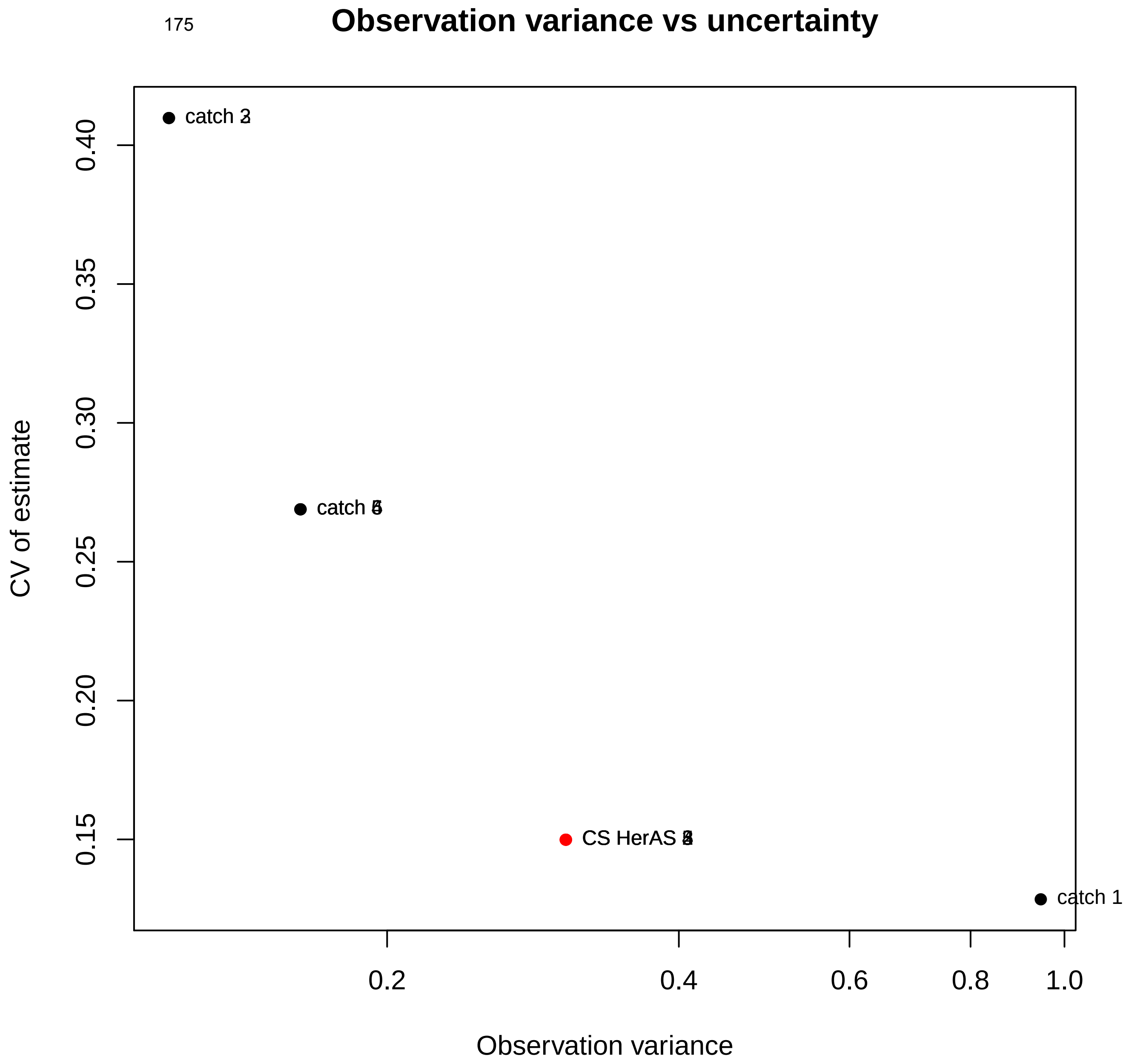

170
CS HerAS
age
5.0
4.5
4.0
3.5
3.0
2.5
2.0
2002
2004
2006
2008
2010
2012
year


catch
age
6
5
4
3
2
1
1960
1970
1980
1990
2000
2010
year

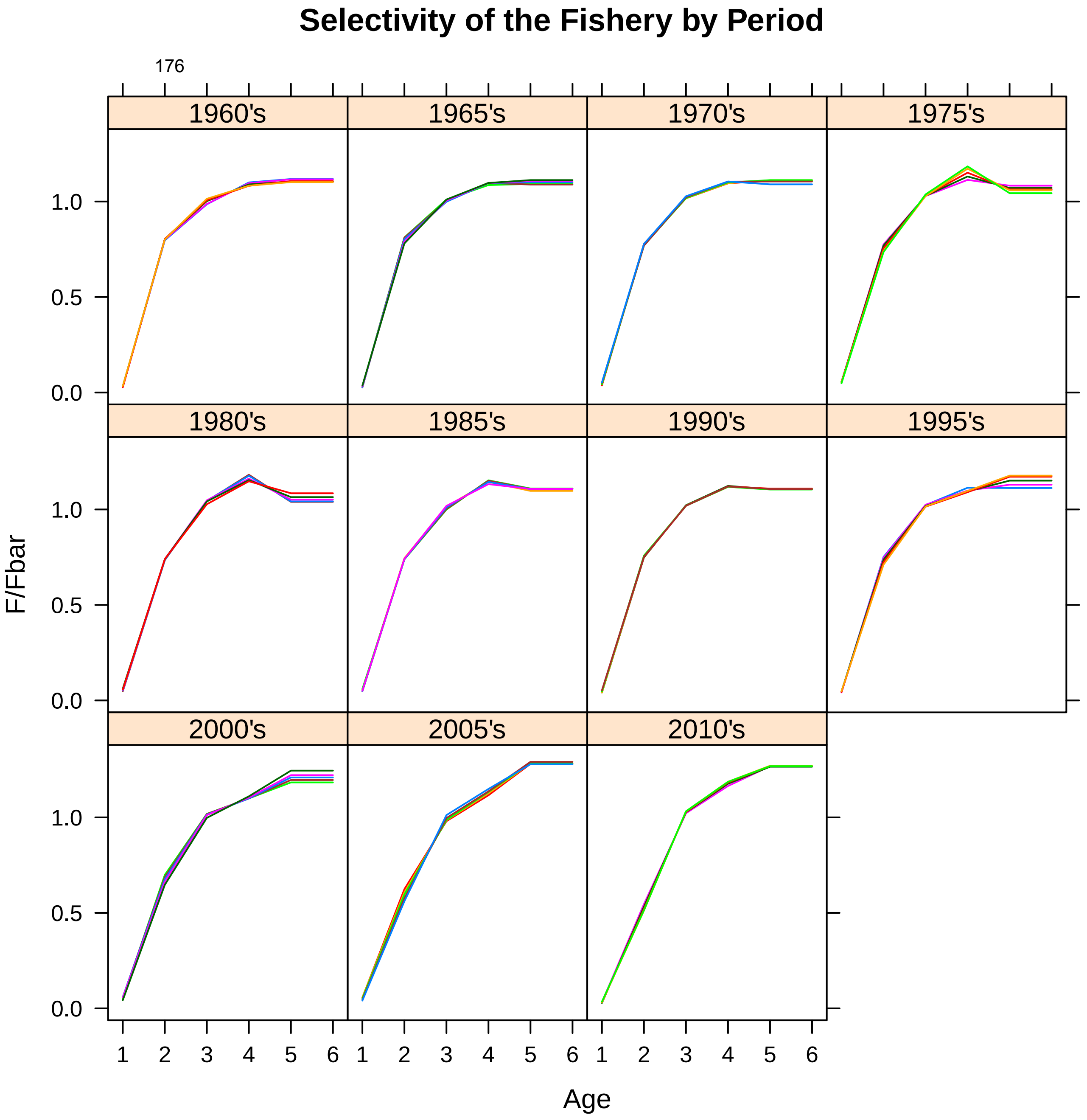

Uncertainties of key parameters
SSB
Fbar
Rec
CV of estimate
0.0
0.1
0.2
0.3
0.4
0.5
0.6
1960
1970
1980
1990
2000
2010
Year


Survey catchability parameters
173
CS HerAS
Catchability
4.5
4.0
3.5
3.0
2.5
2.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Age

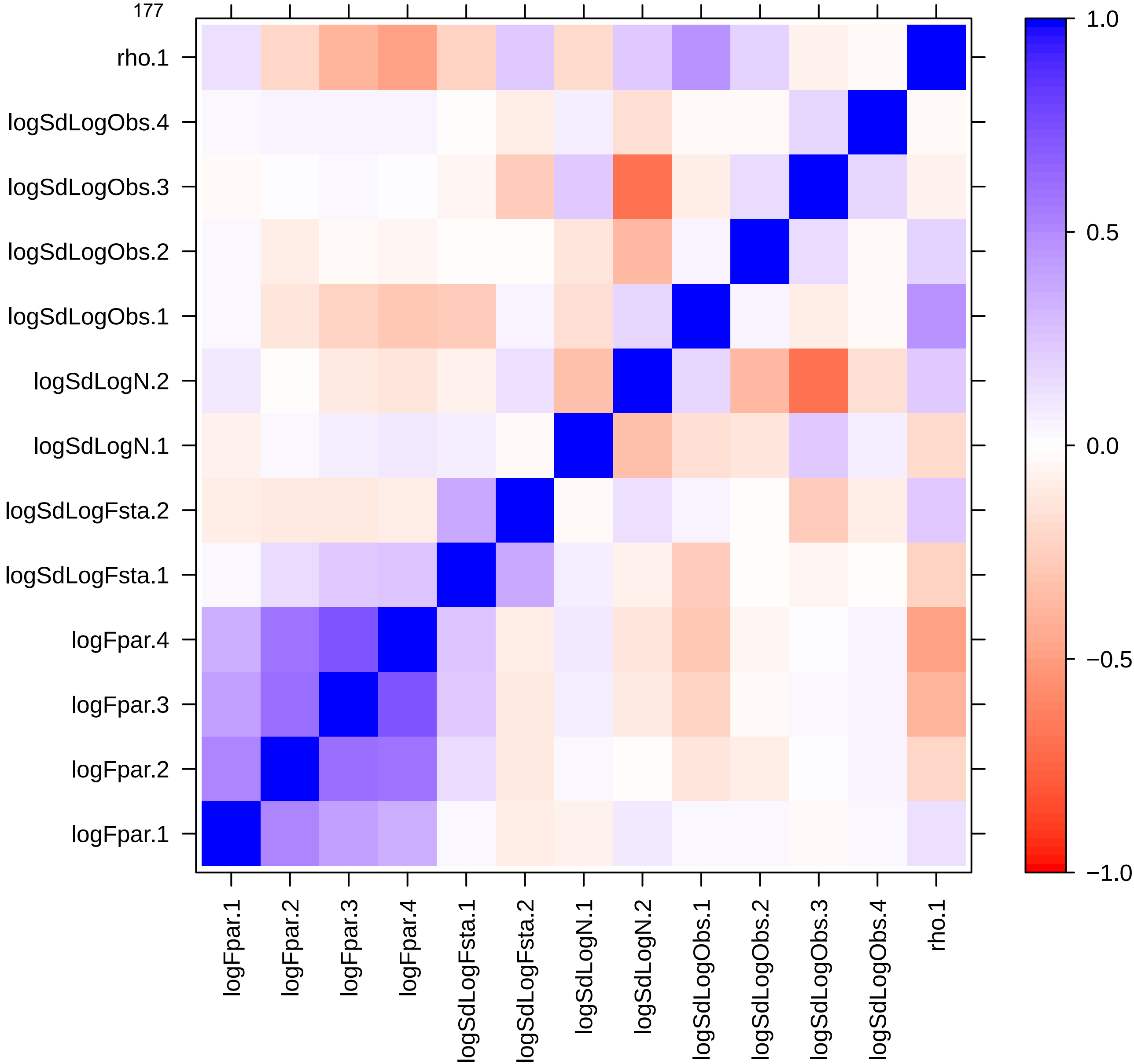

Observation variances by data source
catch
CS HerAS
Observation Variance
0.0
0.2
0.4
0.6
0.8
catch 2
catch 3
catch 4
catch 5
catch 6
CS HerAS 2
CS HerAS 3
CS HerAS 4
CS HerAS 5
catch 1

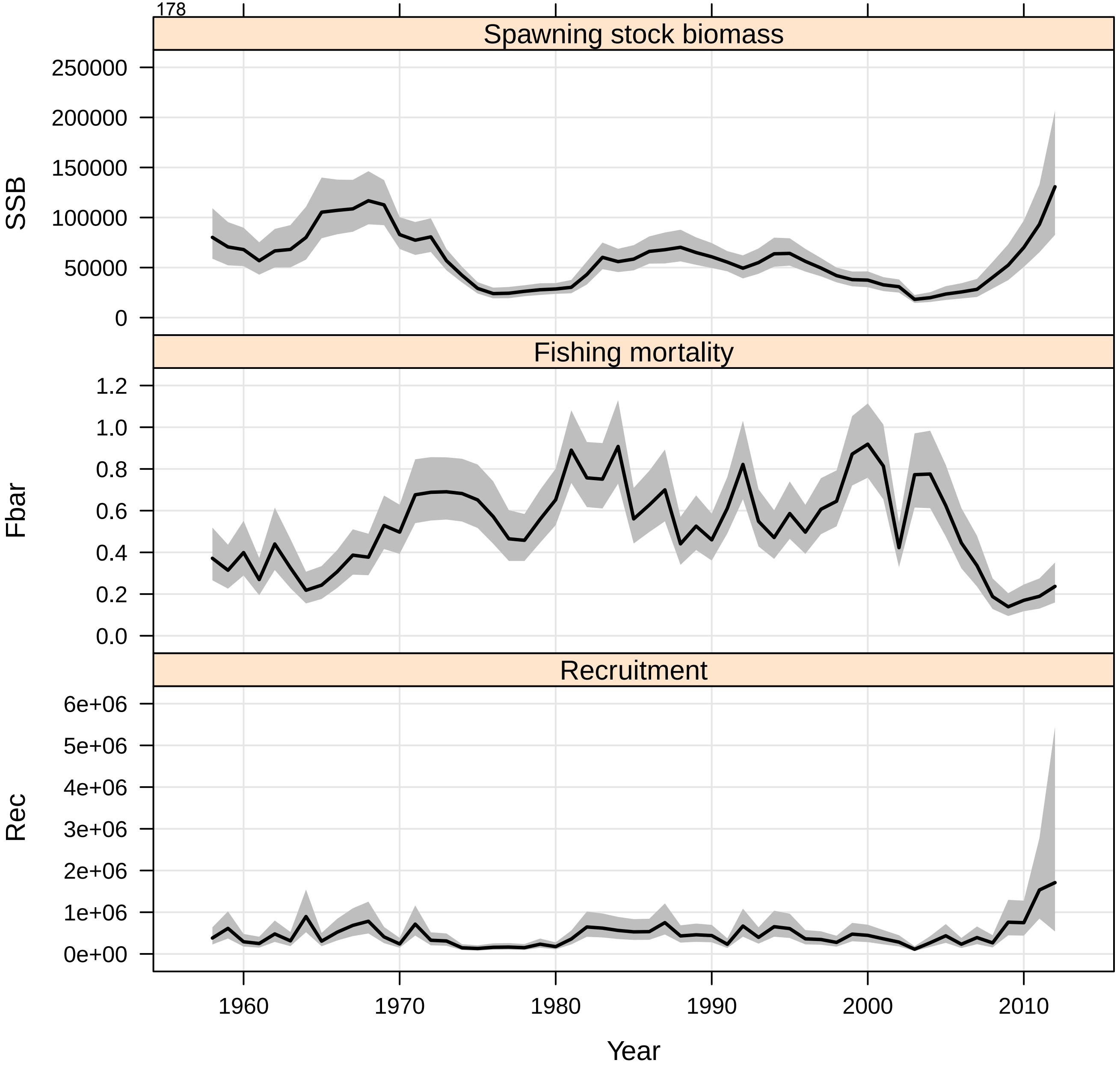

175
Observation variance vs uncertainty
CV of estimate
0.15
0.20
0.25
0.30
0.35
0.40
catch 1
0.2
0.4
0.6
0.8
1.0
Observation variance

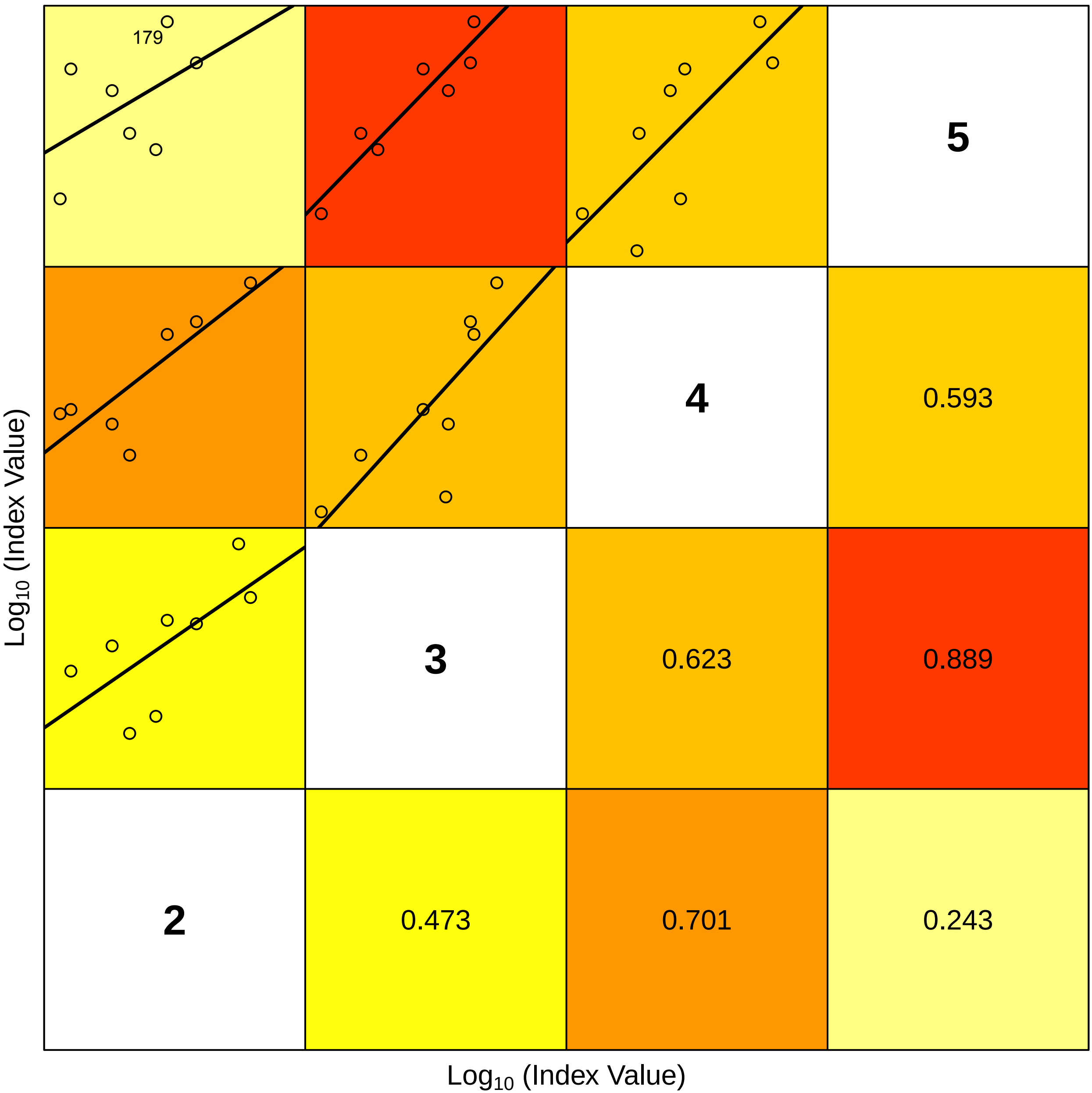
176



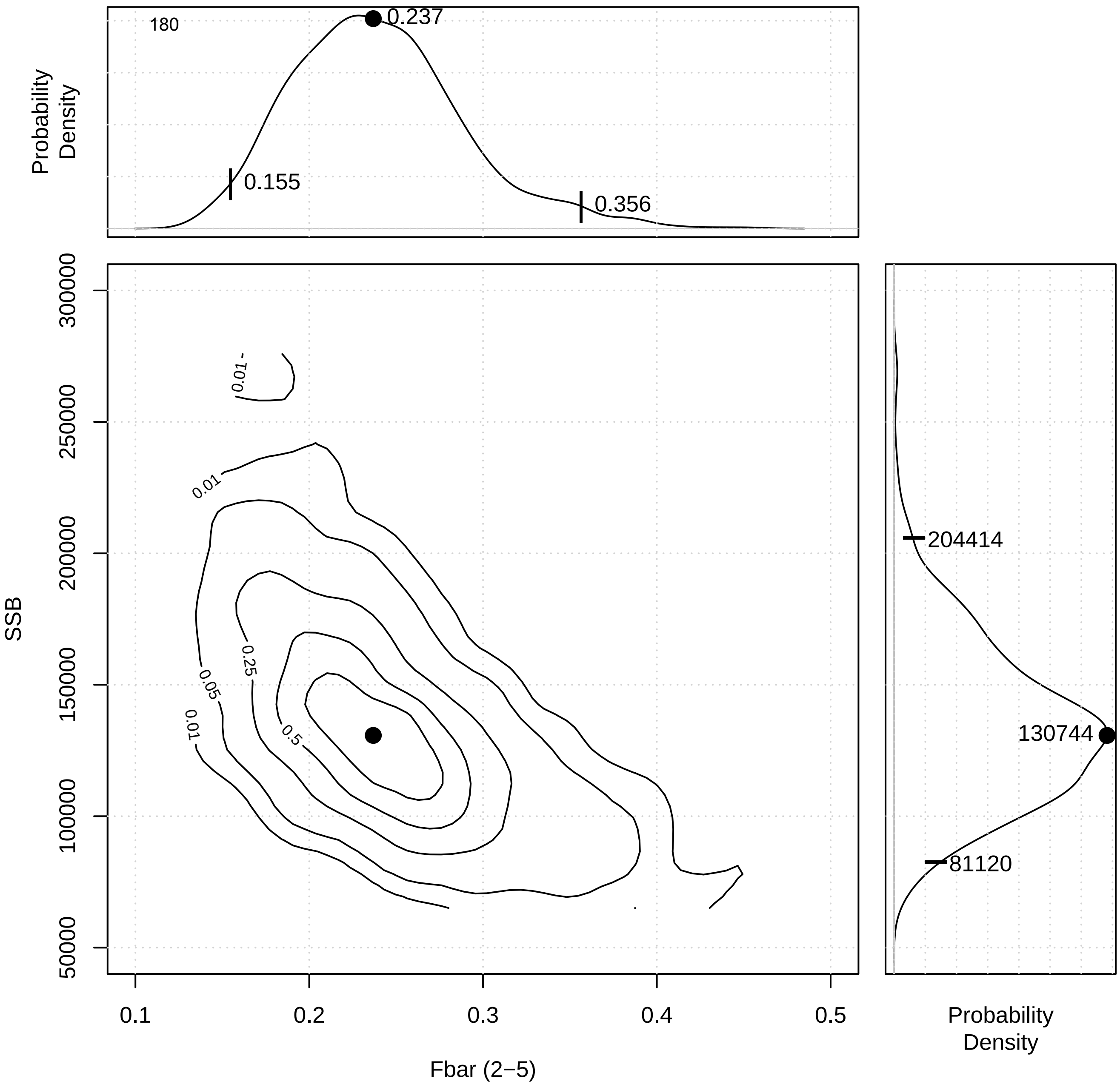
Selectivity of the Fishery by Period
1960's
1965's
1970's
1975's
1980's
1985's
1990's
1995's
2000's
2005's
2010's
F/Fbar
0.0
0.5
1.0
1
2
3
4
5
6
Age


rho.1
logSdLogObs.4
logSdLogObs.3
logSdLogObs.2
logSdLogObs.1
logSdLogN.2
logSdLogN.1
logSdLogFsta.2
logSdLogFsta.1
logFpar.4
logFpar.3
logFpar.2
logFpar.1
1.0
0.5
0.0
−0.5
−1.0


Spawning stock biomass
SSB
250000
200000
150000
100000
50000
0
Fishing mortality
Fbar
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Recruitment
Rec
6e+06
5e+06
4e+06
3e+06
2e+06
1e+06
0e+00
1960
1970
1980
1990
2000
2010
Year

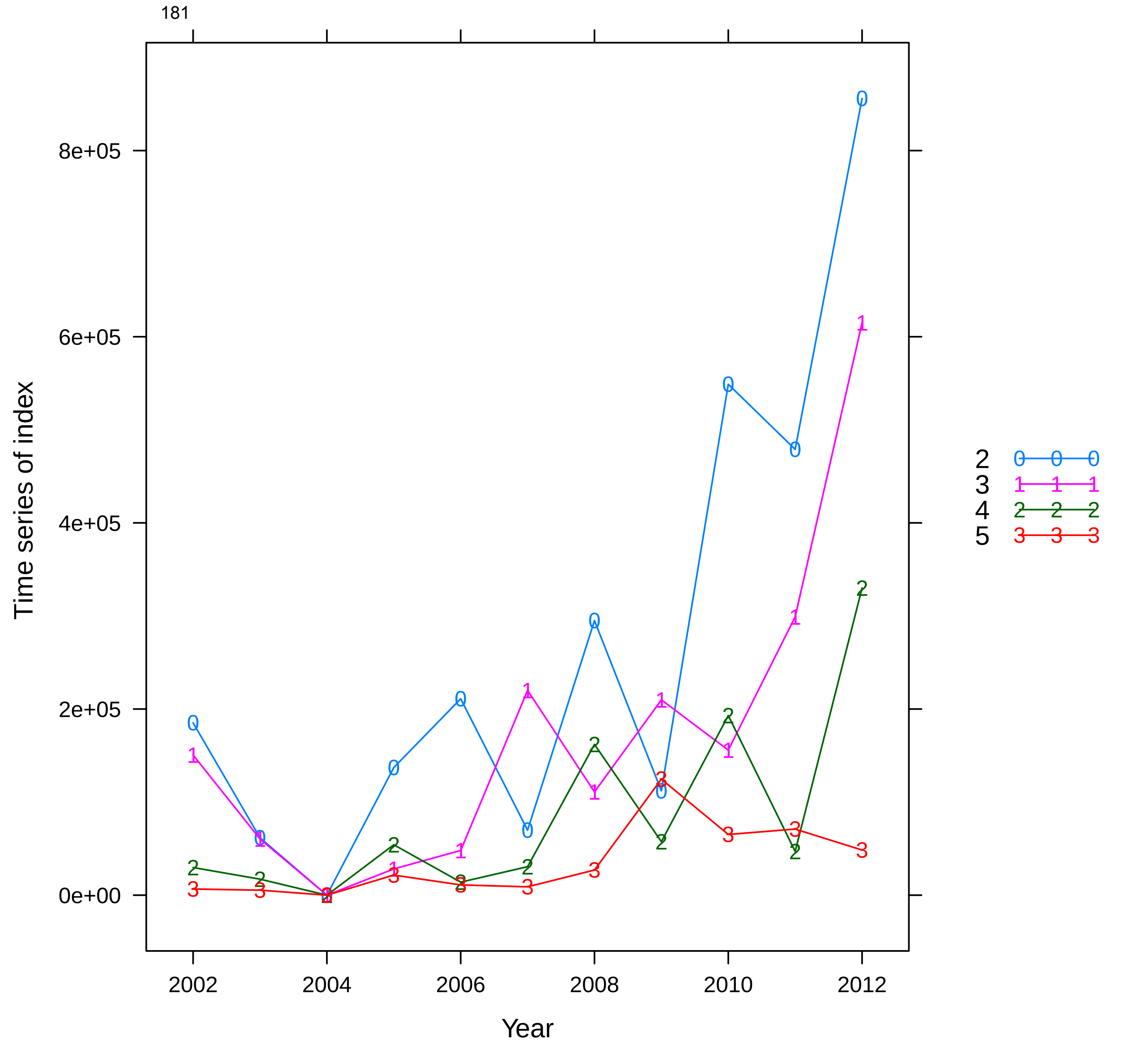


Lower right panels show the Coefficient of Determination (r^2)



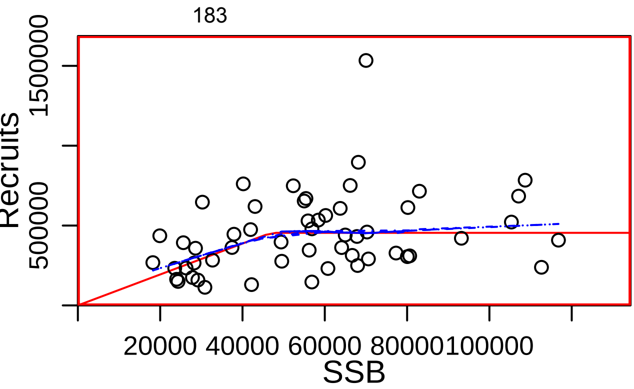
180
0.237
0.155
0.356
Probability Density
0.01
0.01
0.05
0.25
0.5
0.01
SSB
300000
250000
200000
150000
100000
50000
0.1
0.2
0.3
0.4
0.5
Fbar (2−5)
204414
130744
81120
Probability Density

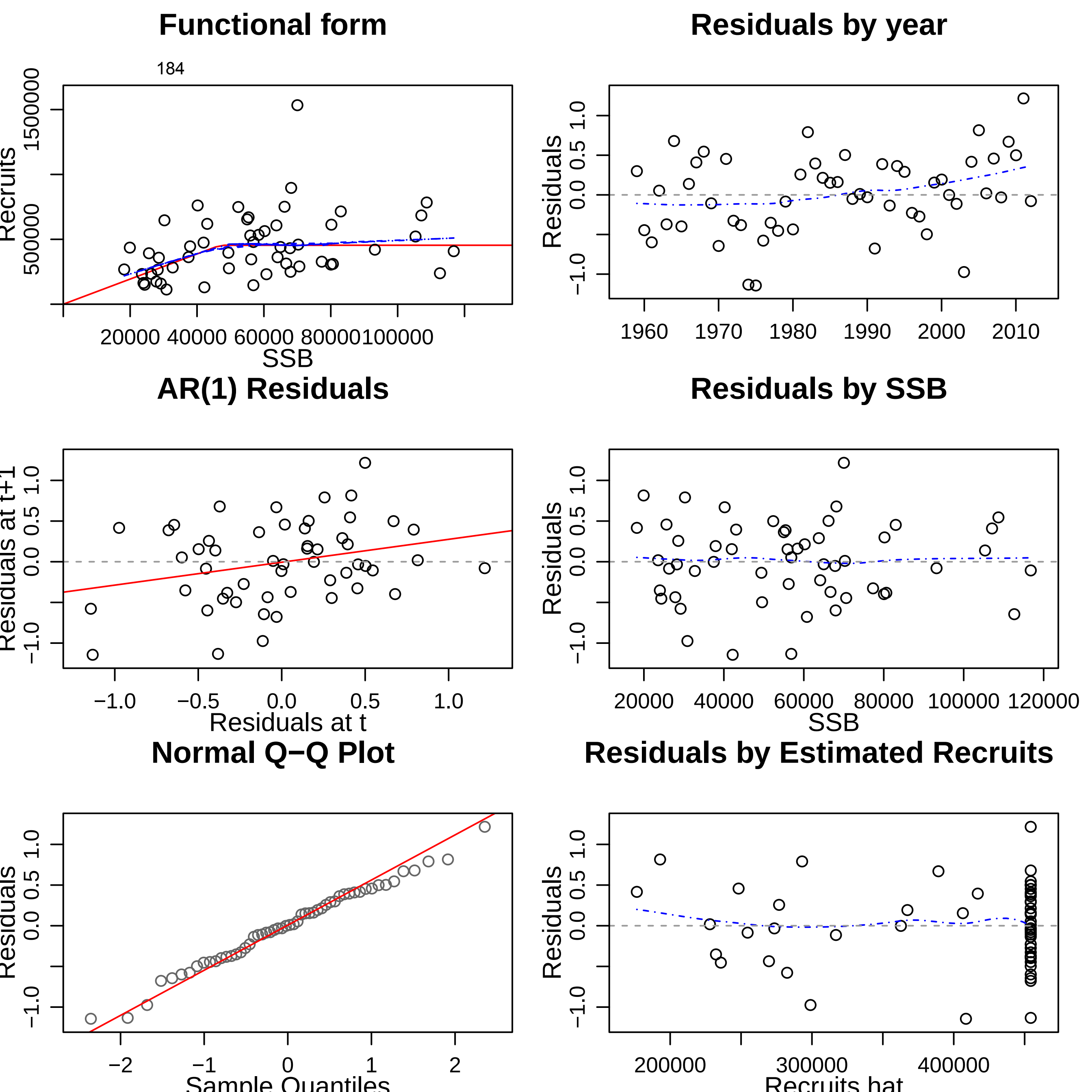
Celtic Sea Herring acoustic survey timeseries of index



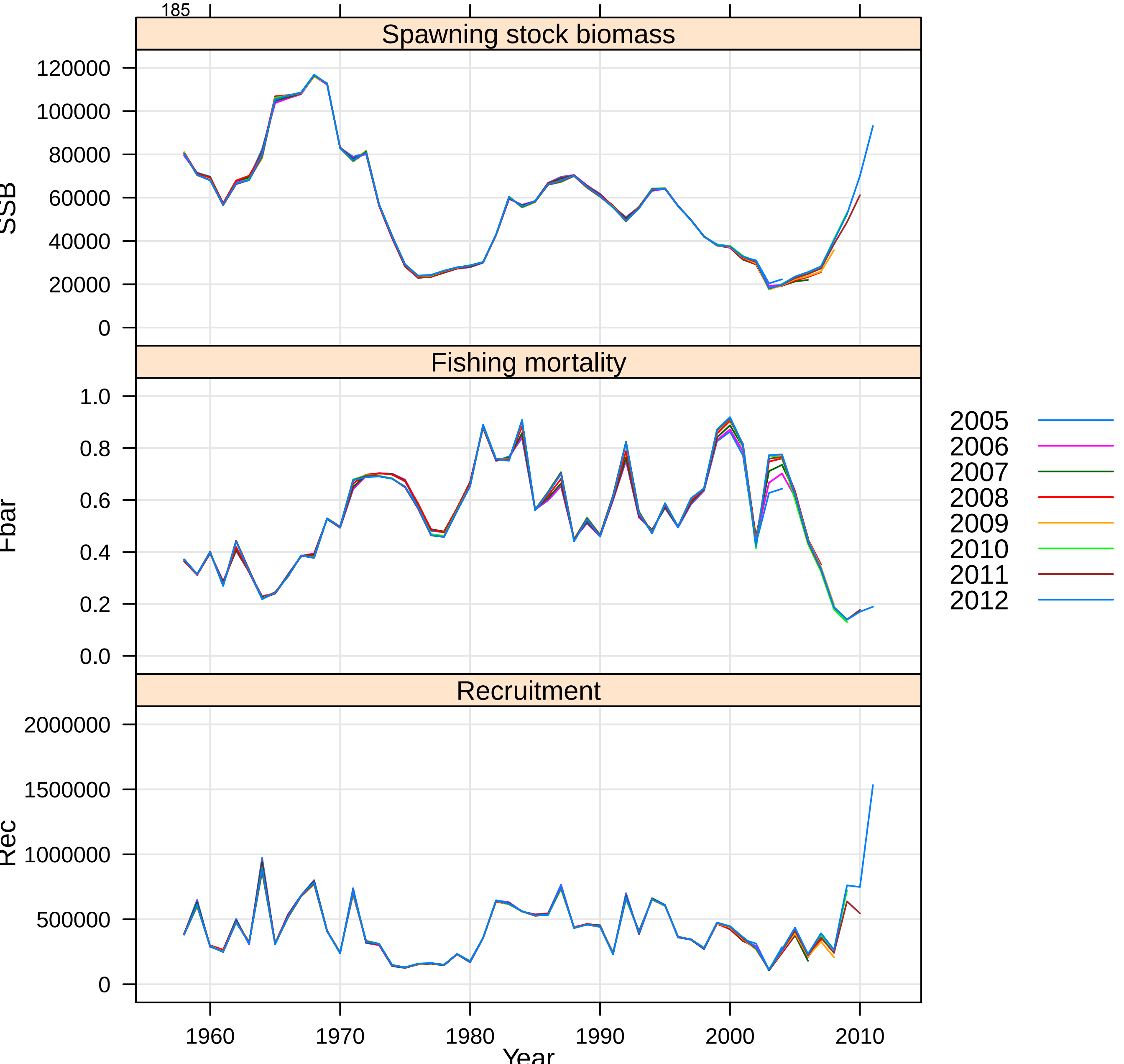

Celtic Sea Herring Weight in the stock by cohort
Weight in the stock (kg)
0.30
0.25
0.20
0.15
0.10
0.05
1980
1990
2000
2010
Year
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011

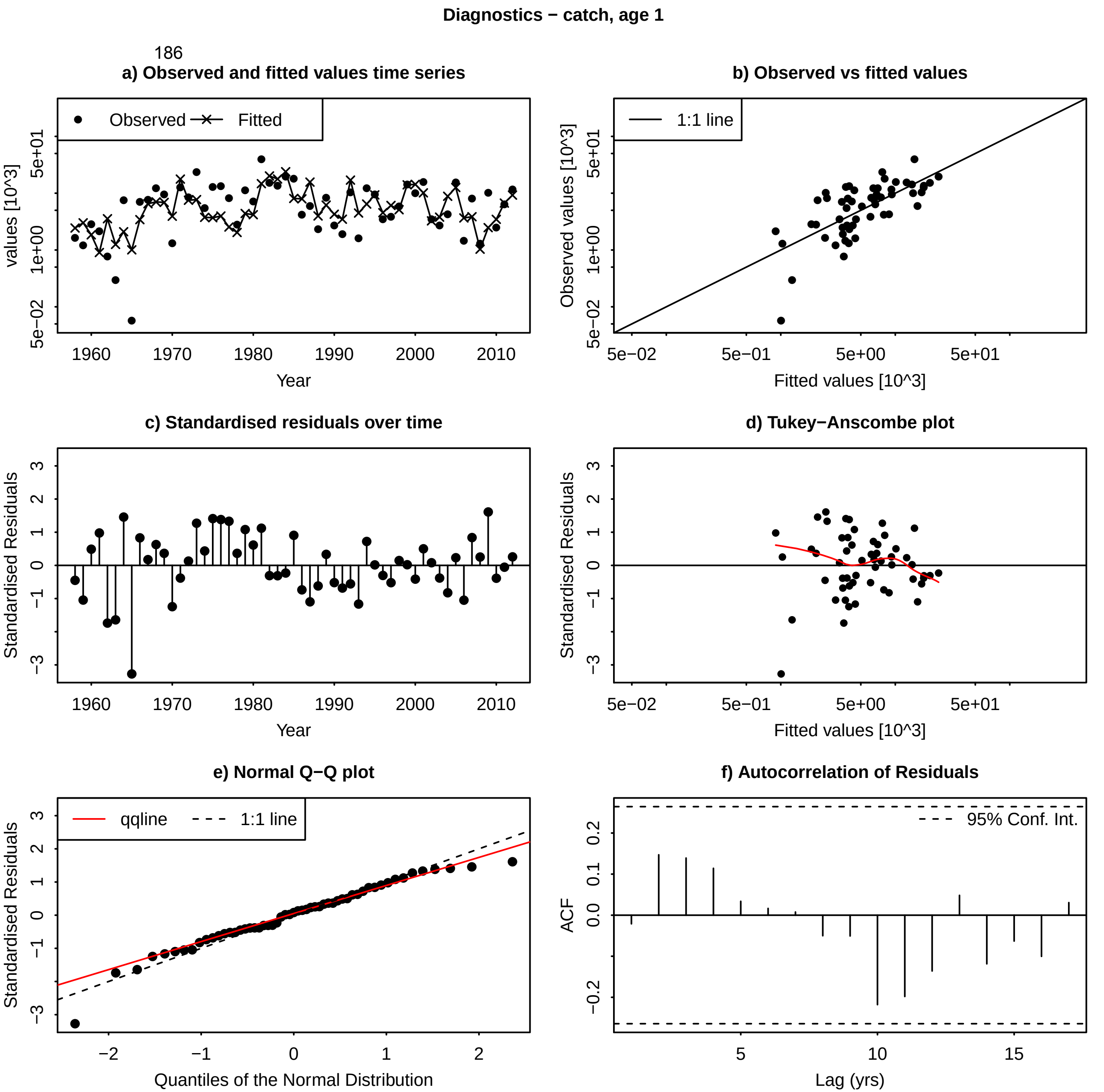
Functional form



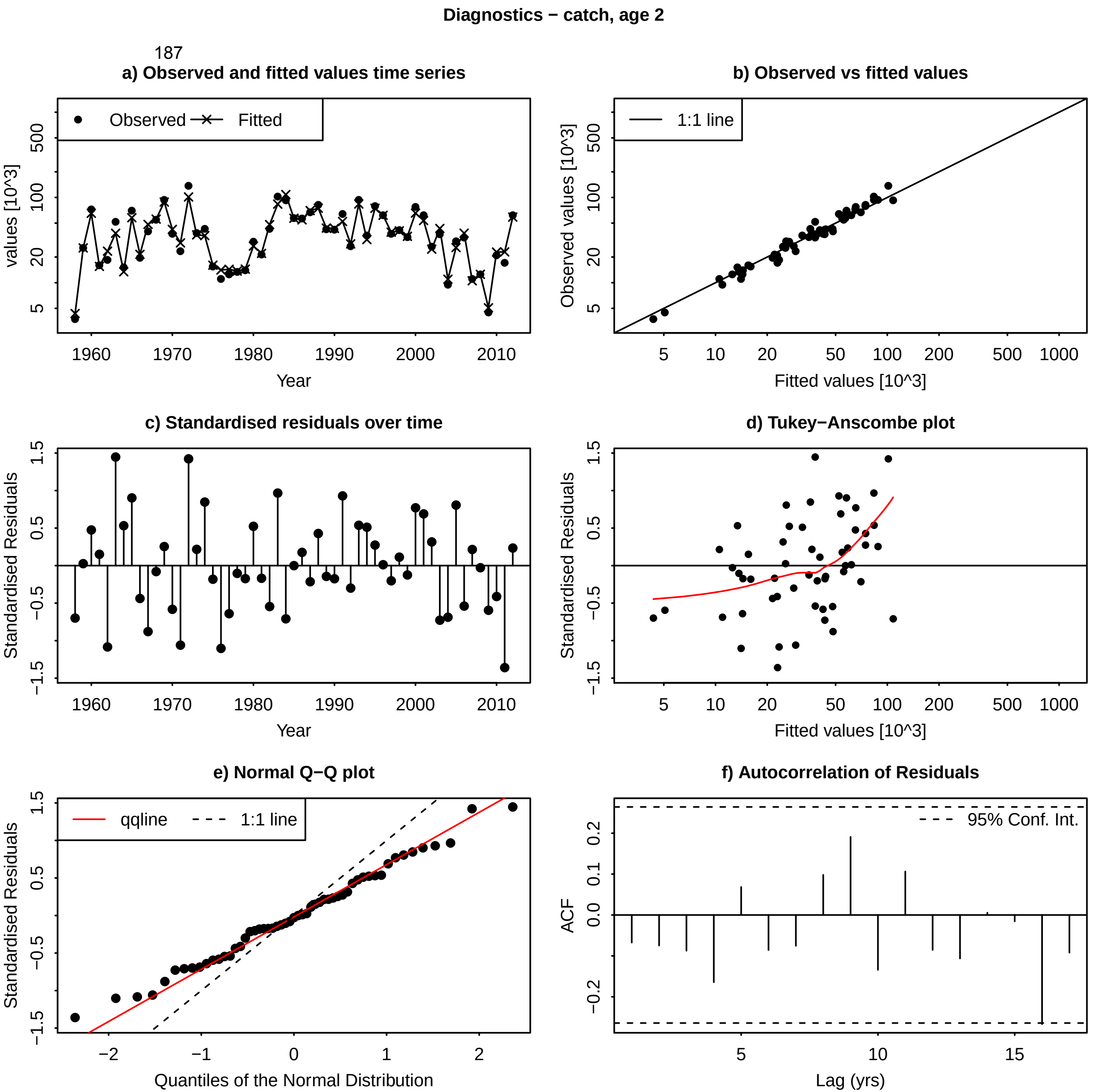


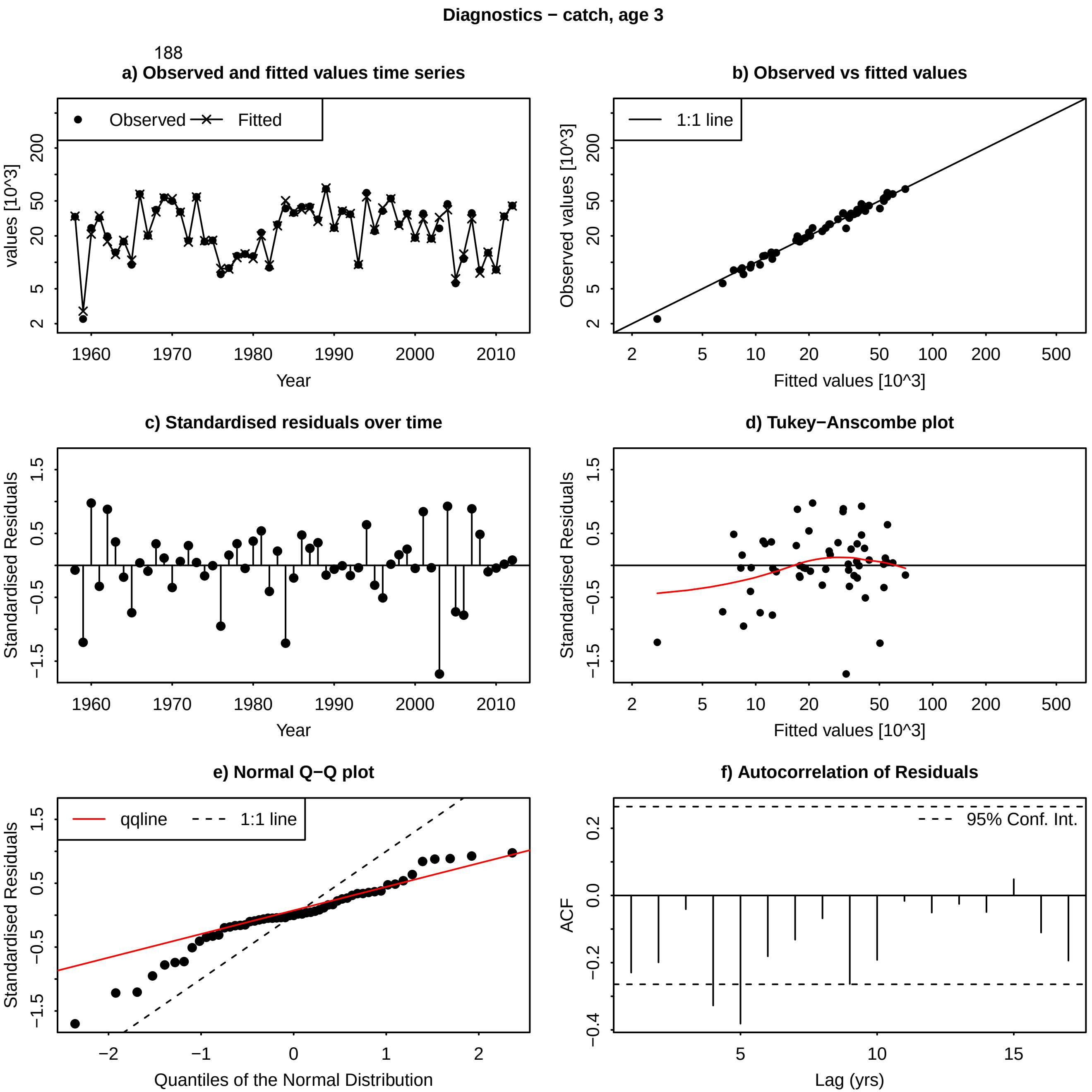
Functional form
184
Recruits
SSB
Residuals by year
Residuals
AR(1) Residuals
Residuals at t+1
Residuals at t
Residuals by SSB
Residuals
SSB
Normal Q−Q Plot
Residuals
Sample Quantiles
Residuals by Estimated Recruits
Residuals
Recruits hat


Spawning stock biomass
SSB
120000
100000
80000
60000
40000
20000
0
Fishing mortality
Fbar
1.0
0.8
0.6
0.4
0.2
0.0
Recruitment
Rec
2000000
1500000
1000000
500000
0
1960
1970
1980
1990
2000
2010
Year
2005
2006
2007
2008
2009
2010
2011
2012

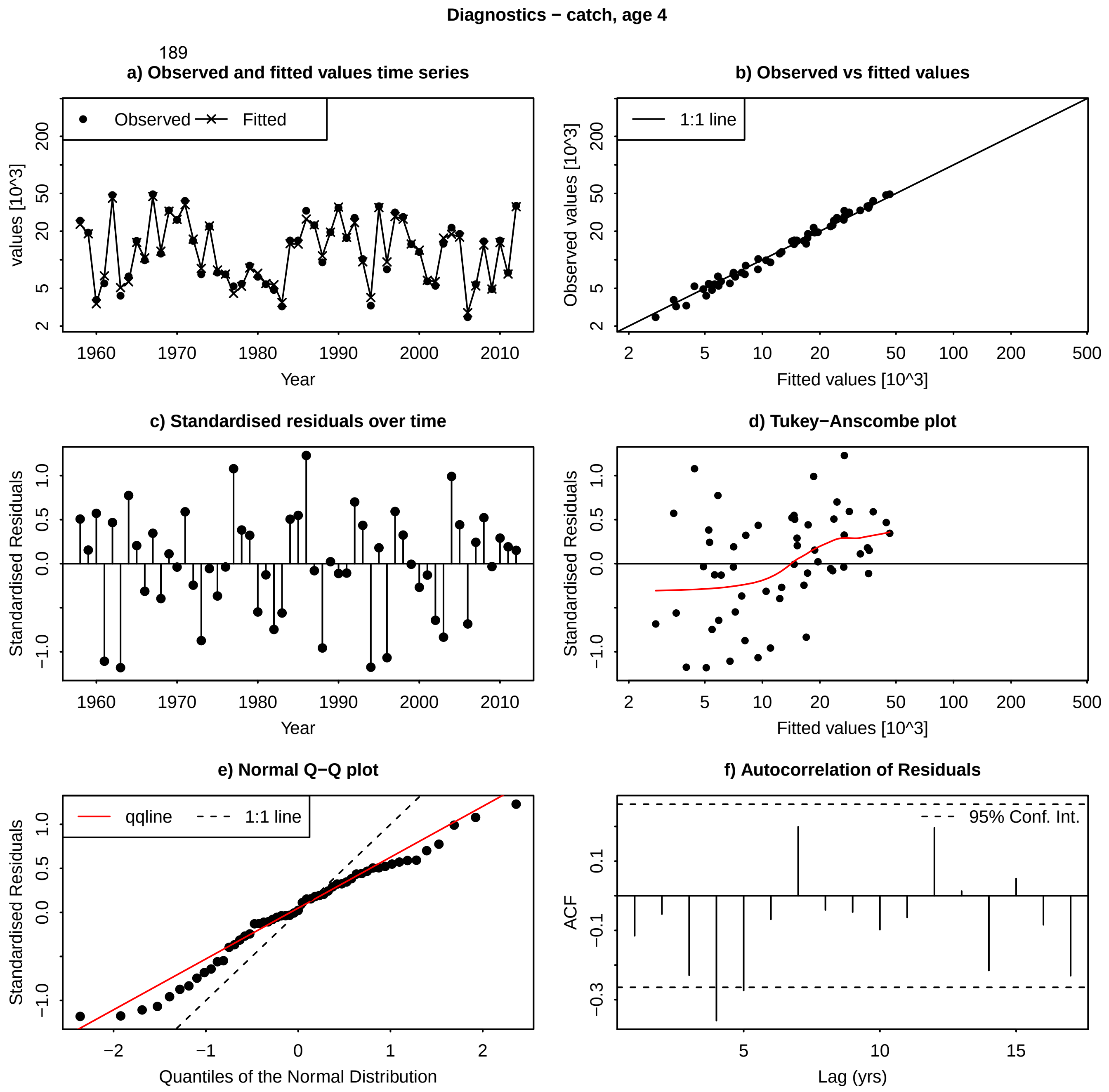


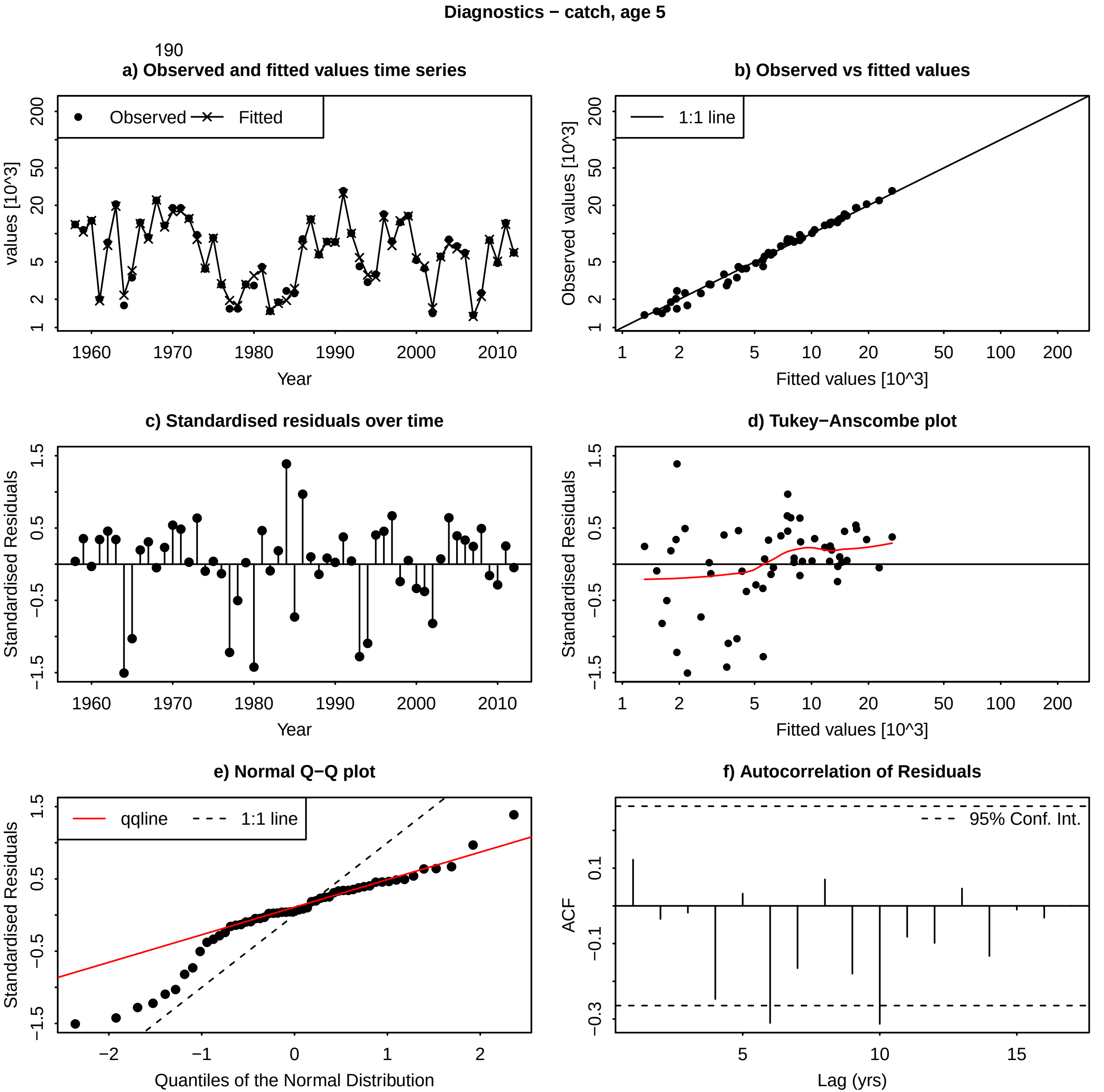
Diagnostics − catch, age 1
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)

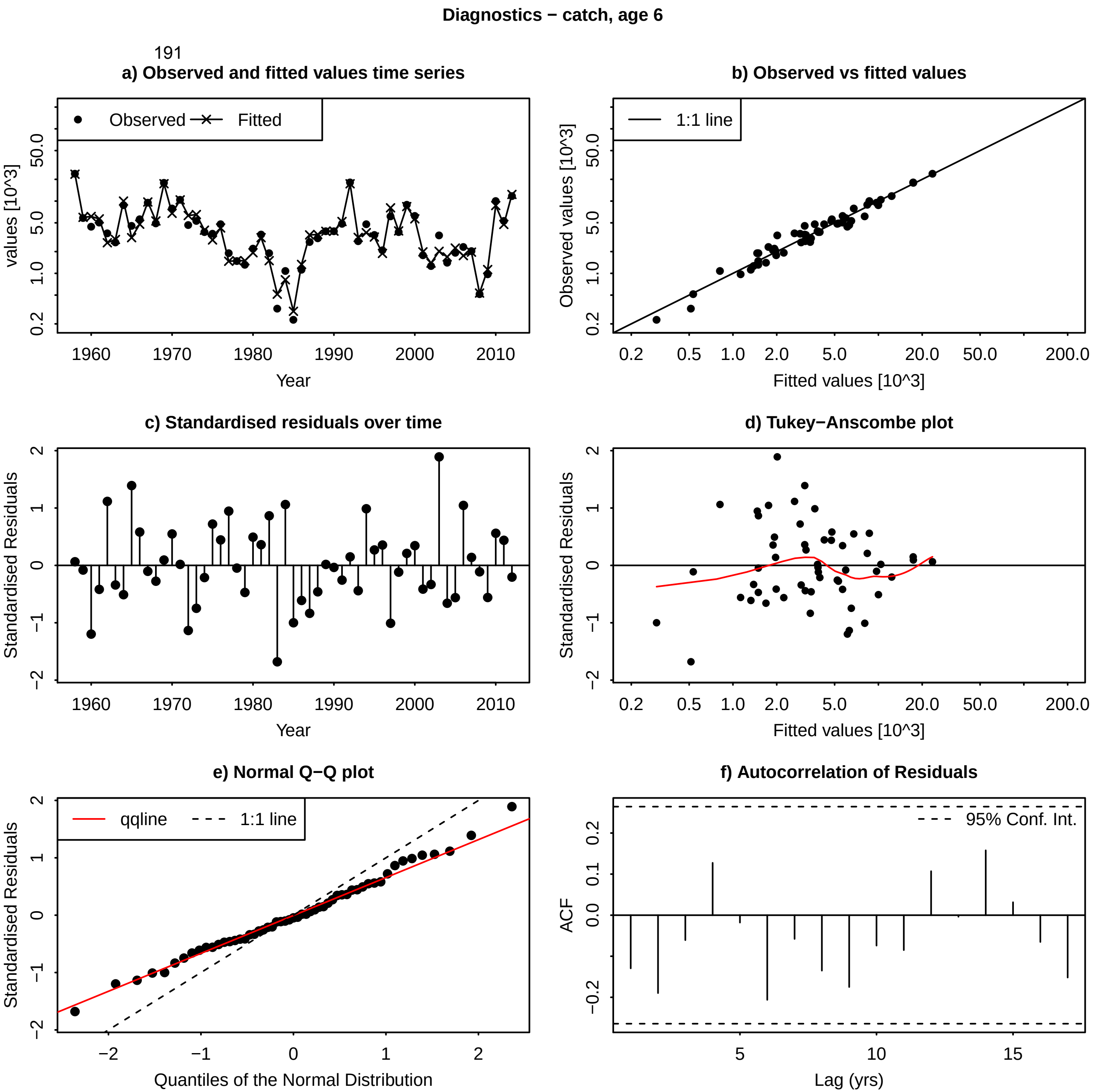

Diagnostics − catch, age 2
187
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)



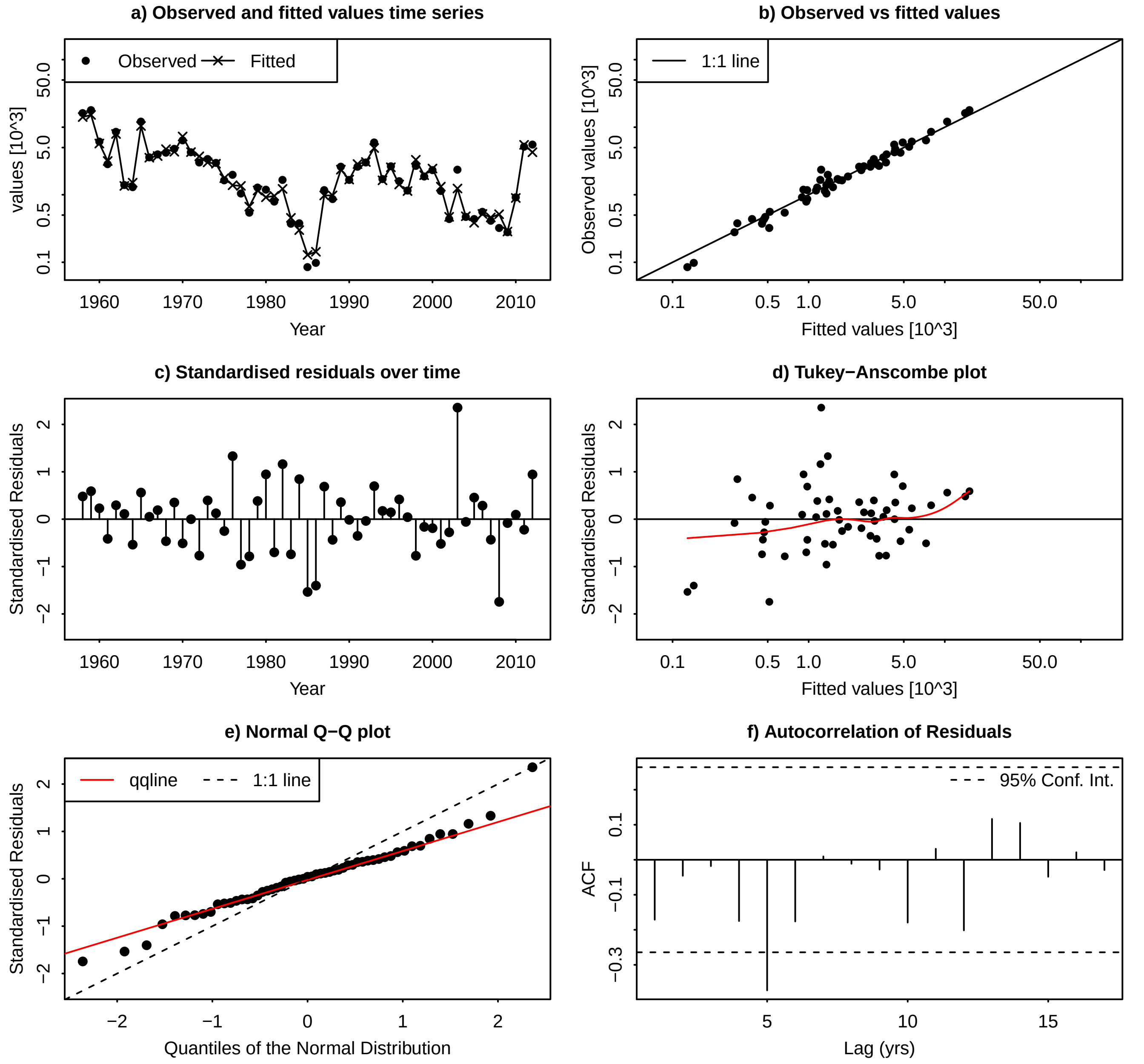
Diagnostics − catch, age 3
188
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)


Diagnostics − catch, age 4
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)


Diagnostics − catch, age 5
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)

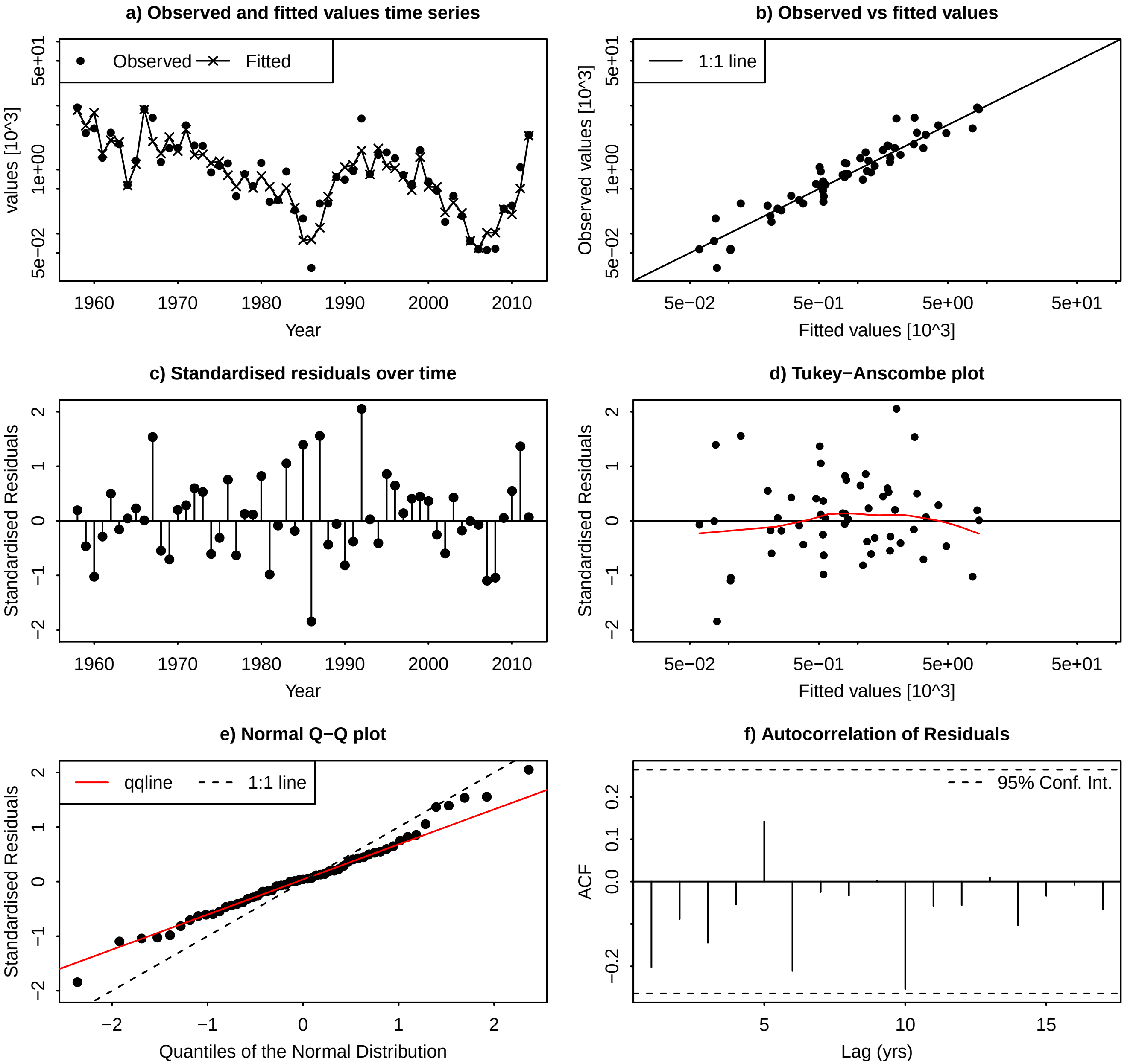

Diagnostics − catch, age 6
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)

Diagnostics − catch, age 7

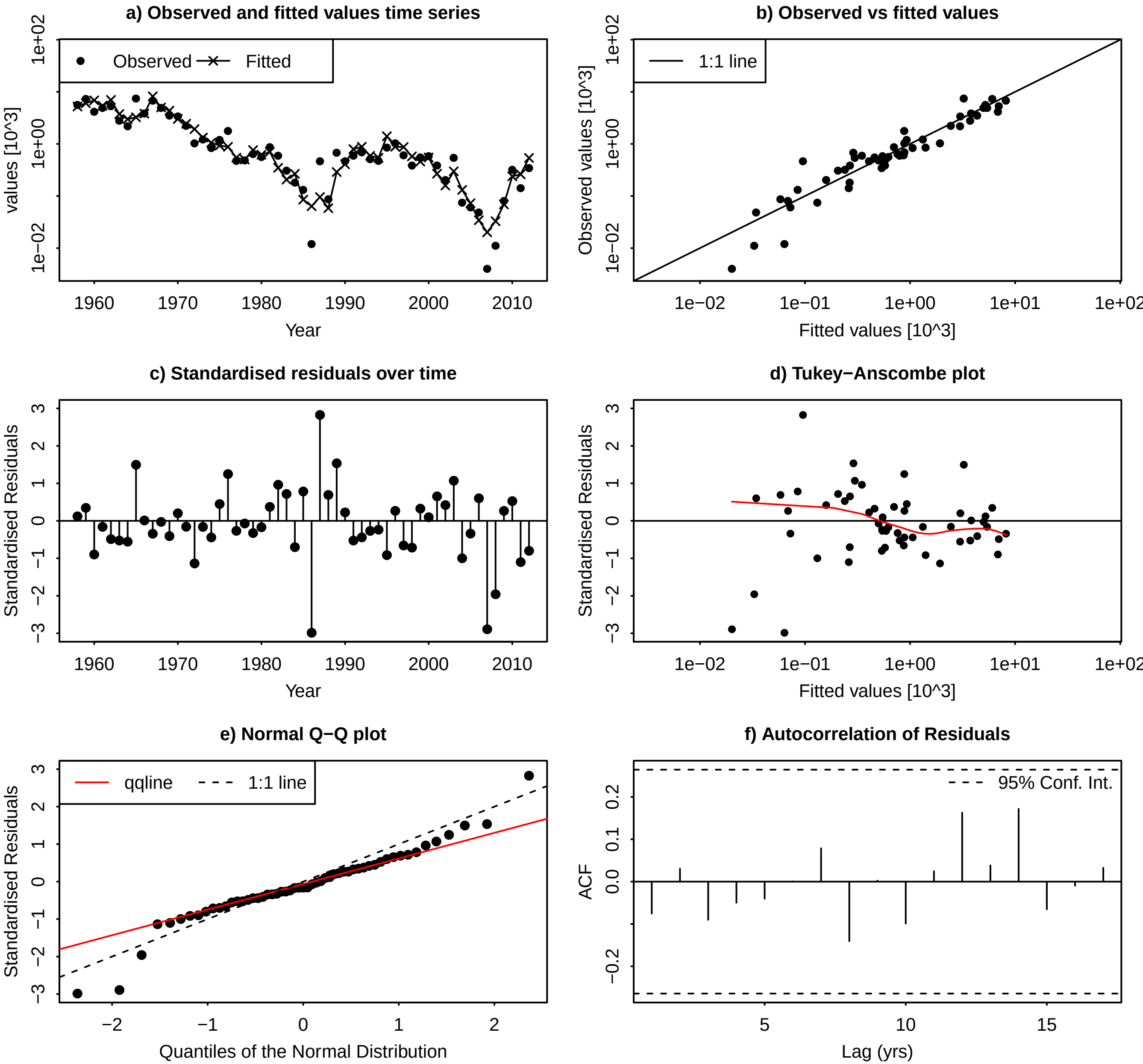


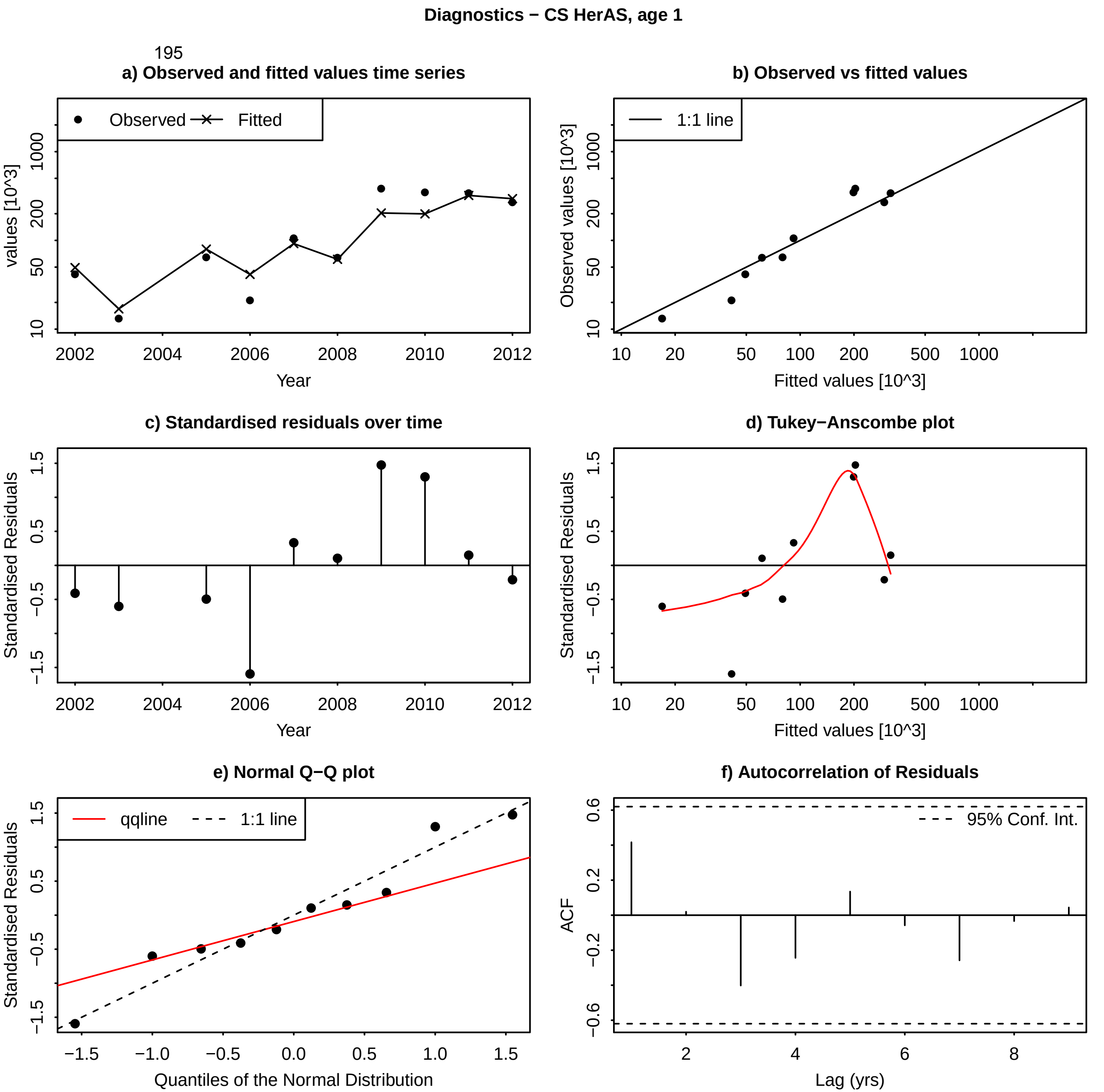
Diagnostics − catch, age 8

193

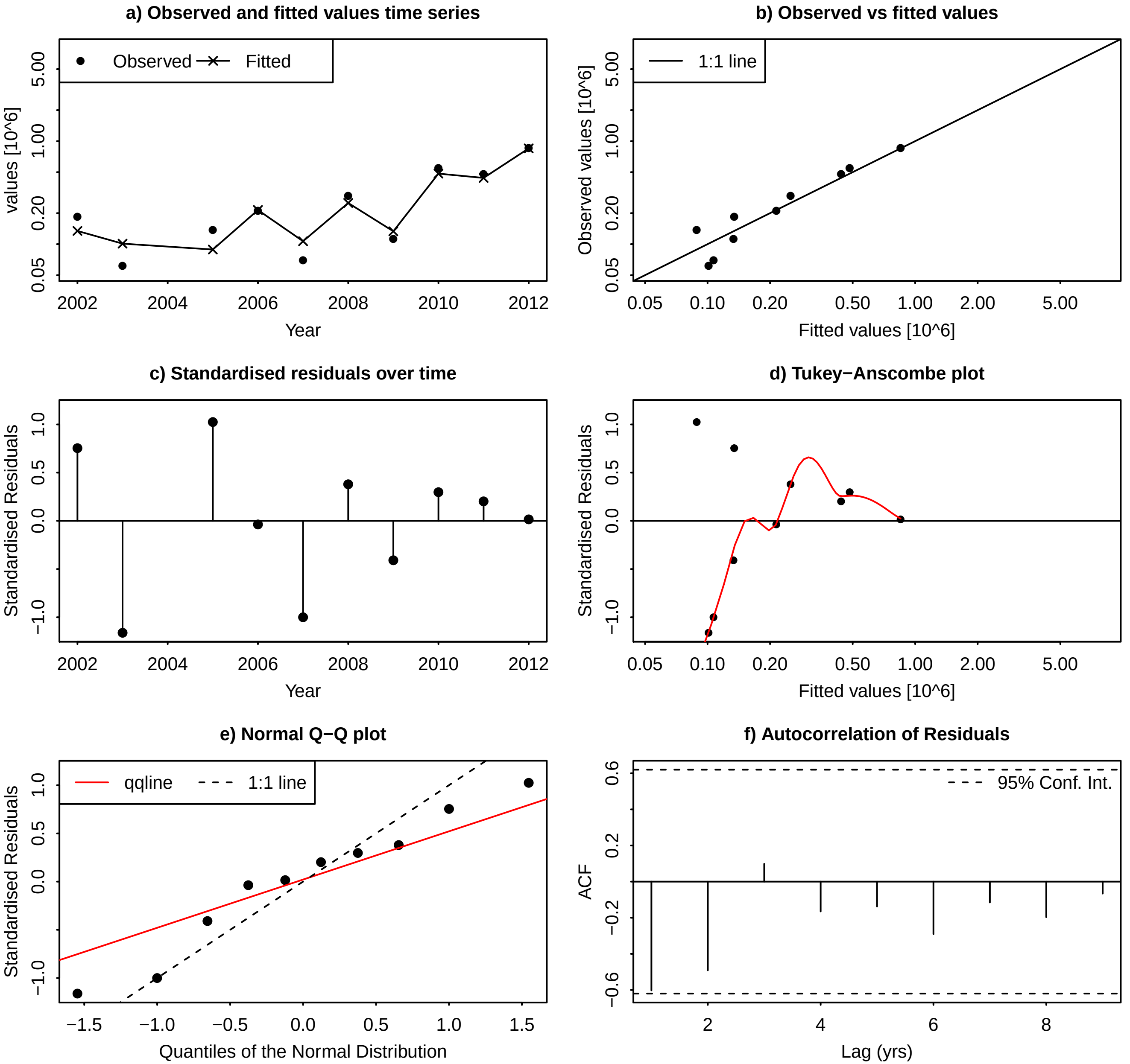


Diagnostics − catch, age 9

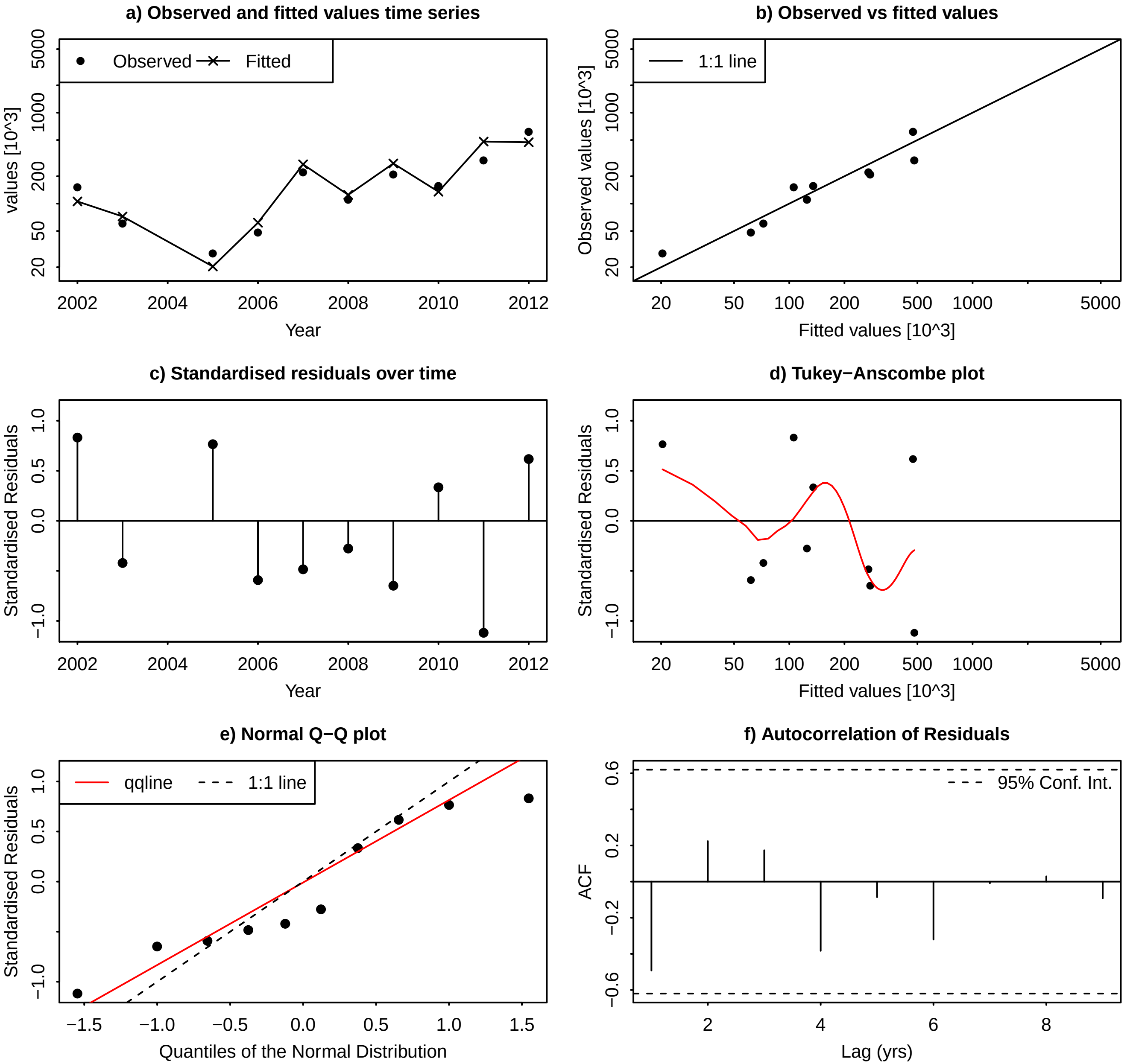


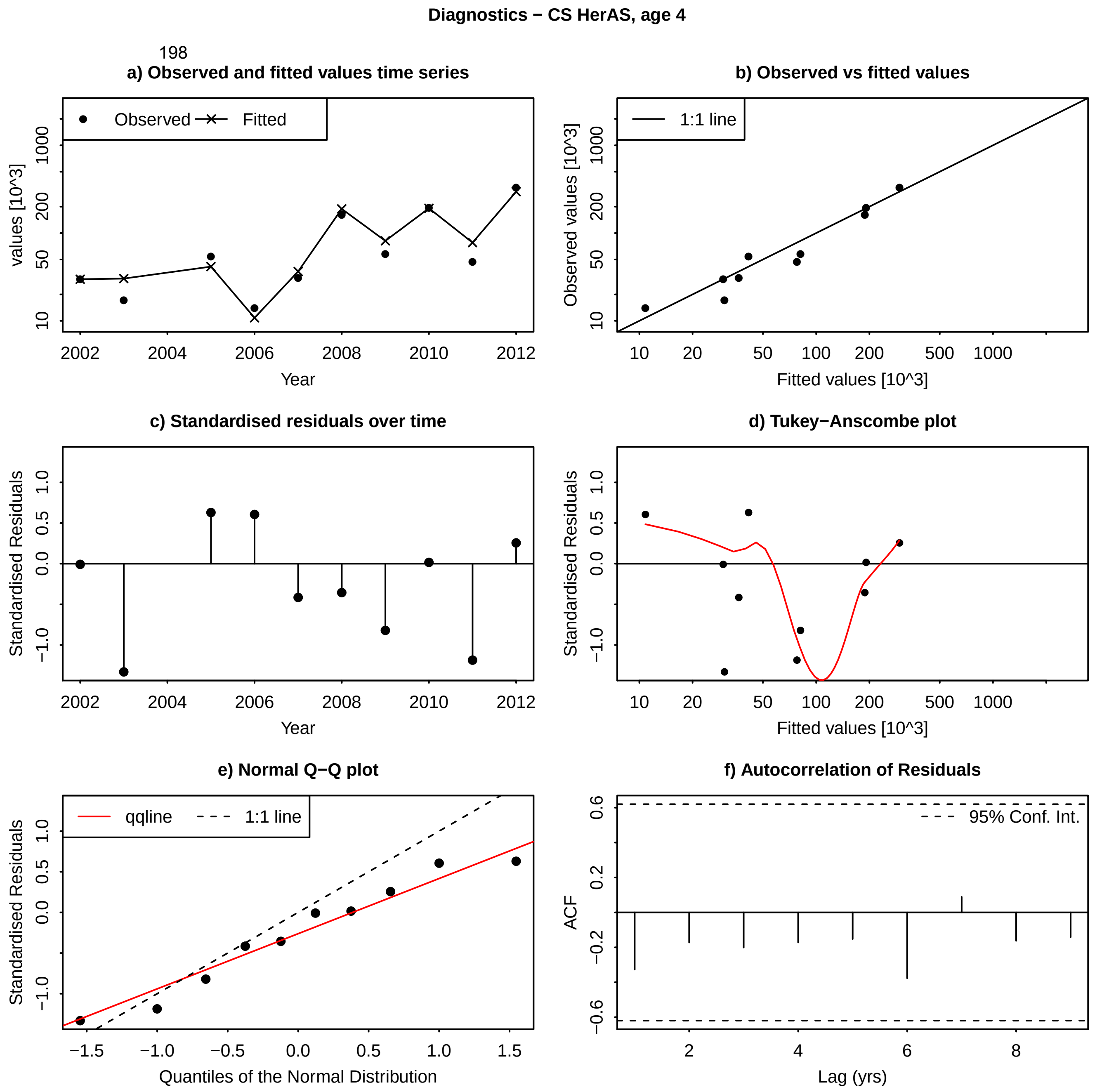

Diagnostics − CS HerAS, age 1
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
10
50
200
1000
2002
2004
2006
2008
2010
2012
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
10
50
200
1000
10
20
50
100
200
500
1000
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
−1.5
−0.5
0.5
1.5
2002
2004
2006
2008
2010
2012
Year
d) Tukey−Anscombe plot
Standardised Residuals
−1.5
−0.5
0.5
1.5
10
20
50
100
200
500
1000
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
−1.5
−0.5
0.5
1.5
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
−0.6
−0.2
0.2
0.6
2
4
6
8
Lag (yrs)

Diagnostics − CS HerAS, age 2

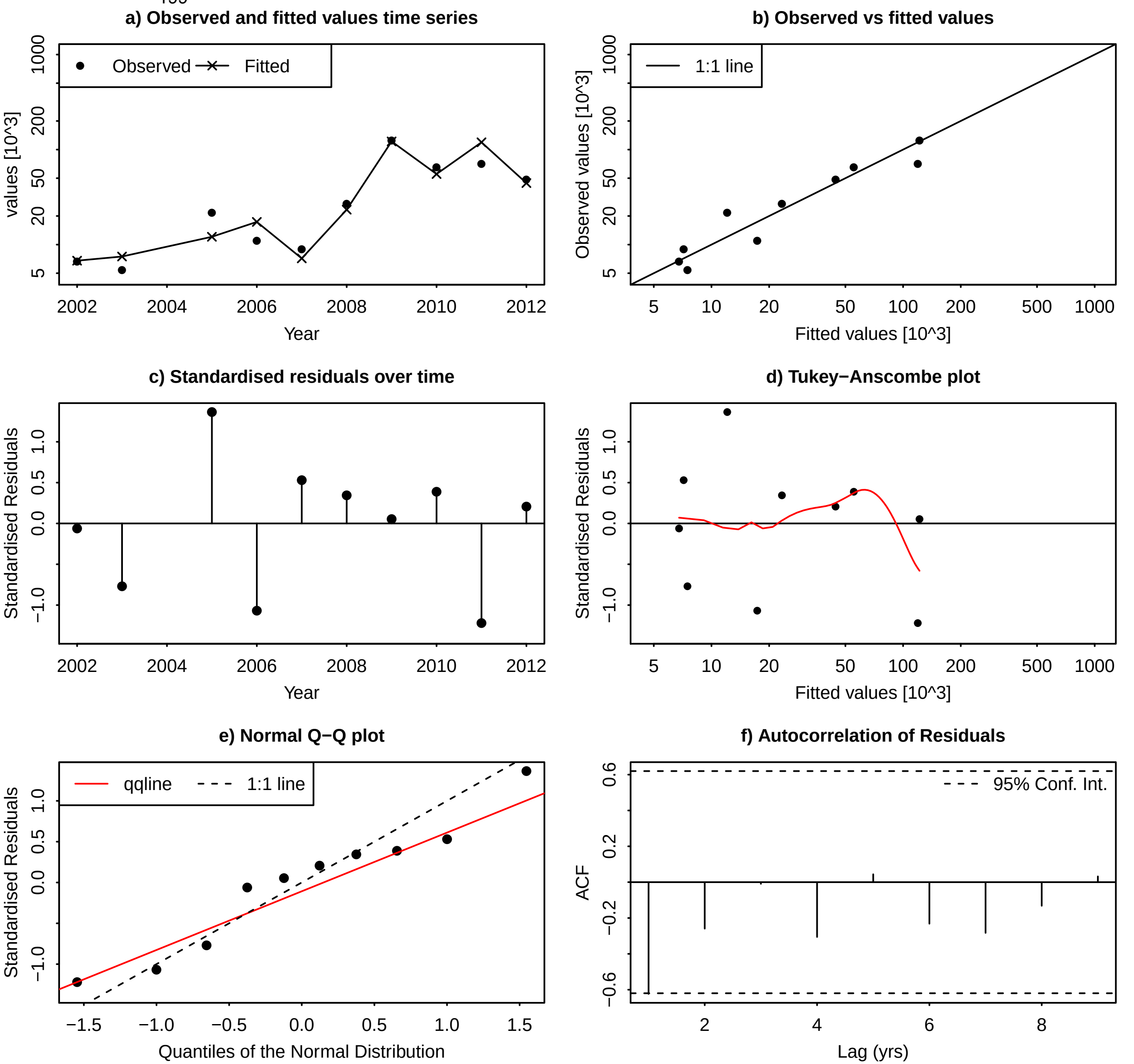


Diagnostics − CS HerAS, age 3



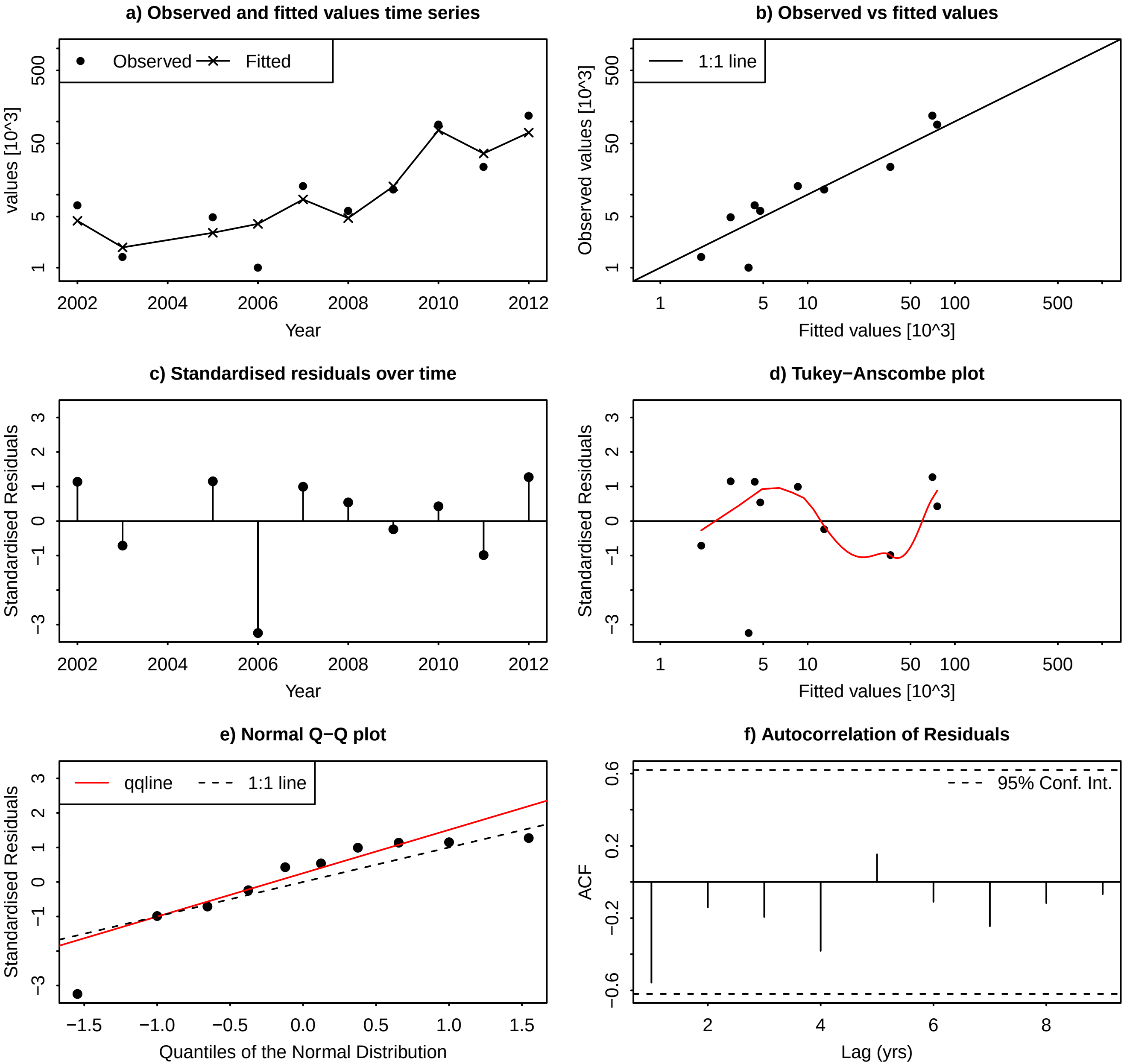

Diagnostics − CS HerAS, age 4
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)

Diagnostics − CS HerAS, age 5

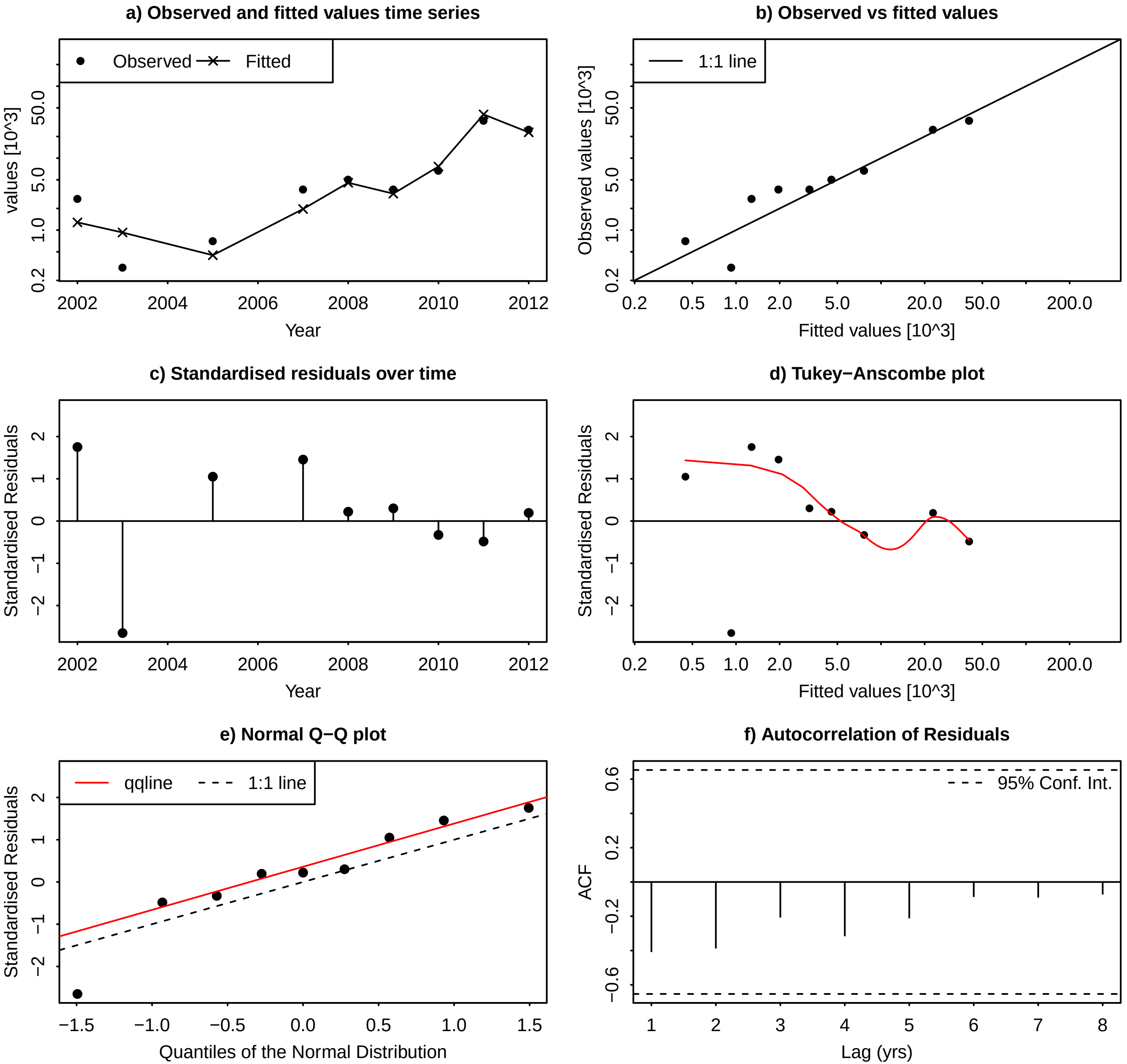


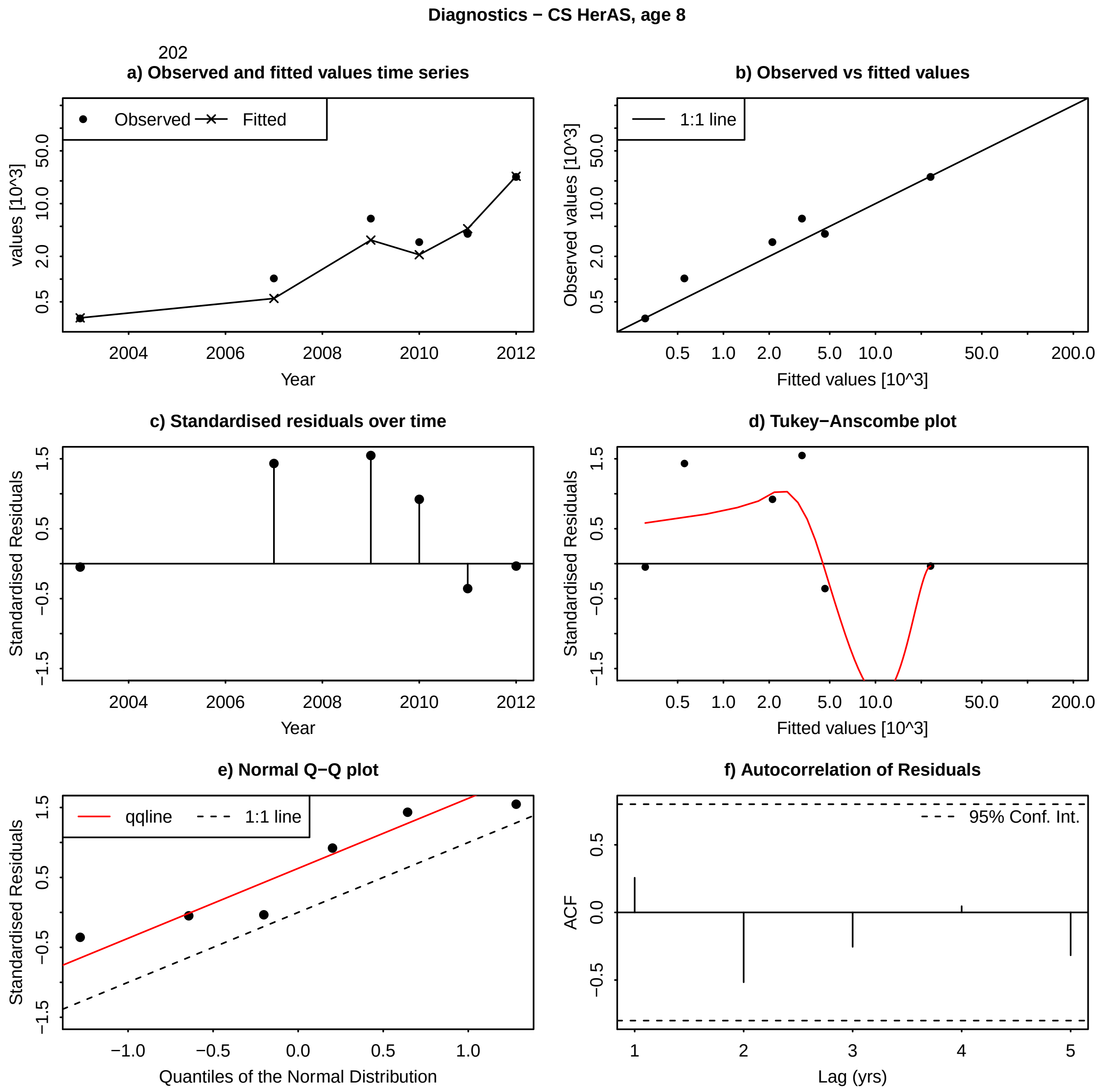
Diagnostics − CS HerAS, age 6

200

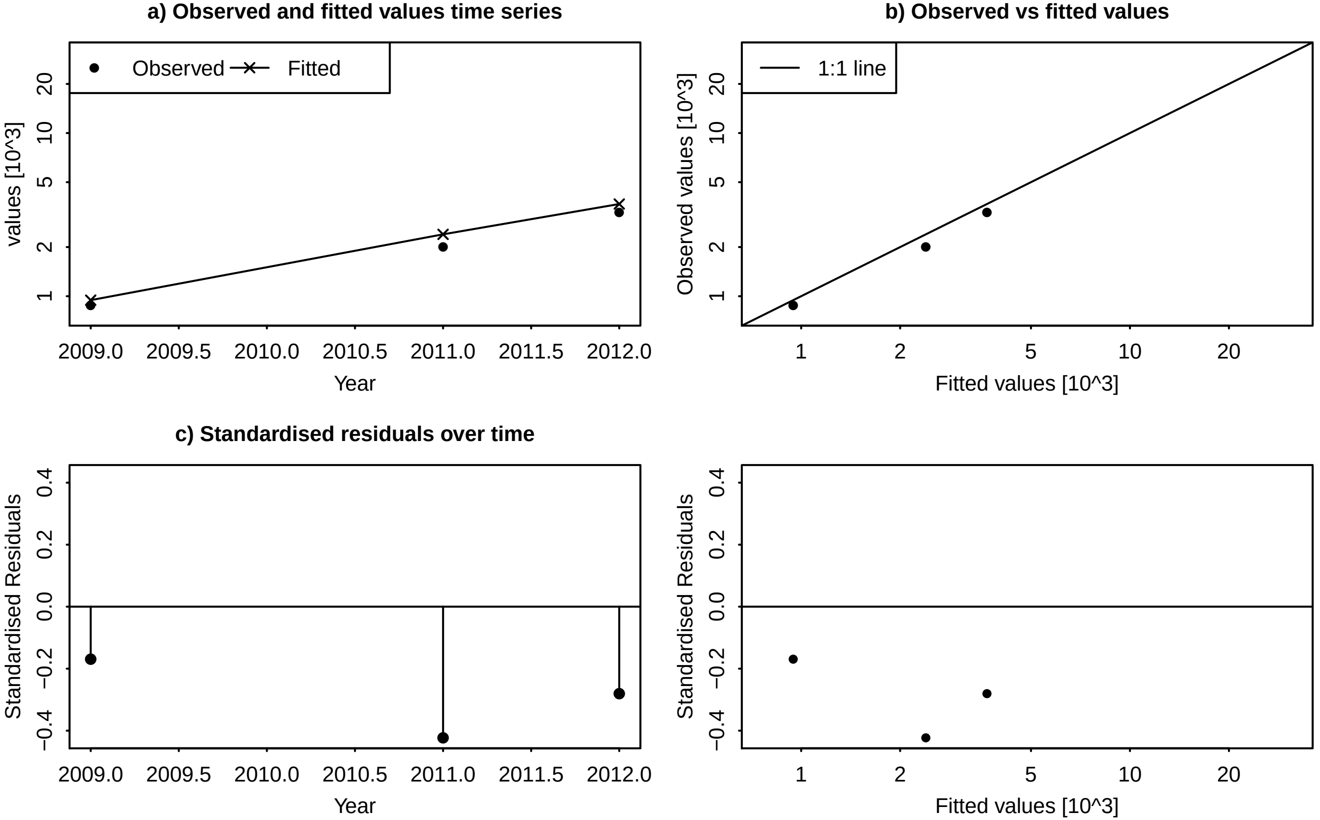


Diagnostics − CS HerAS, age 7

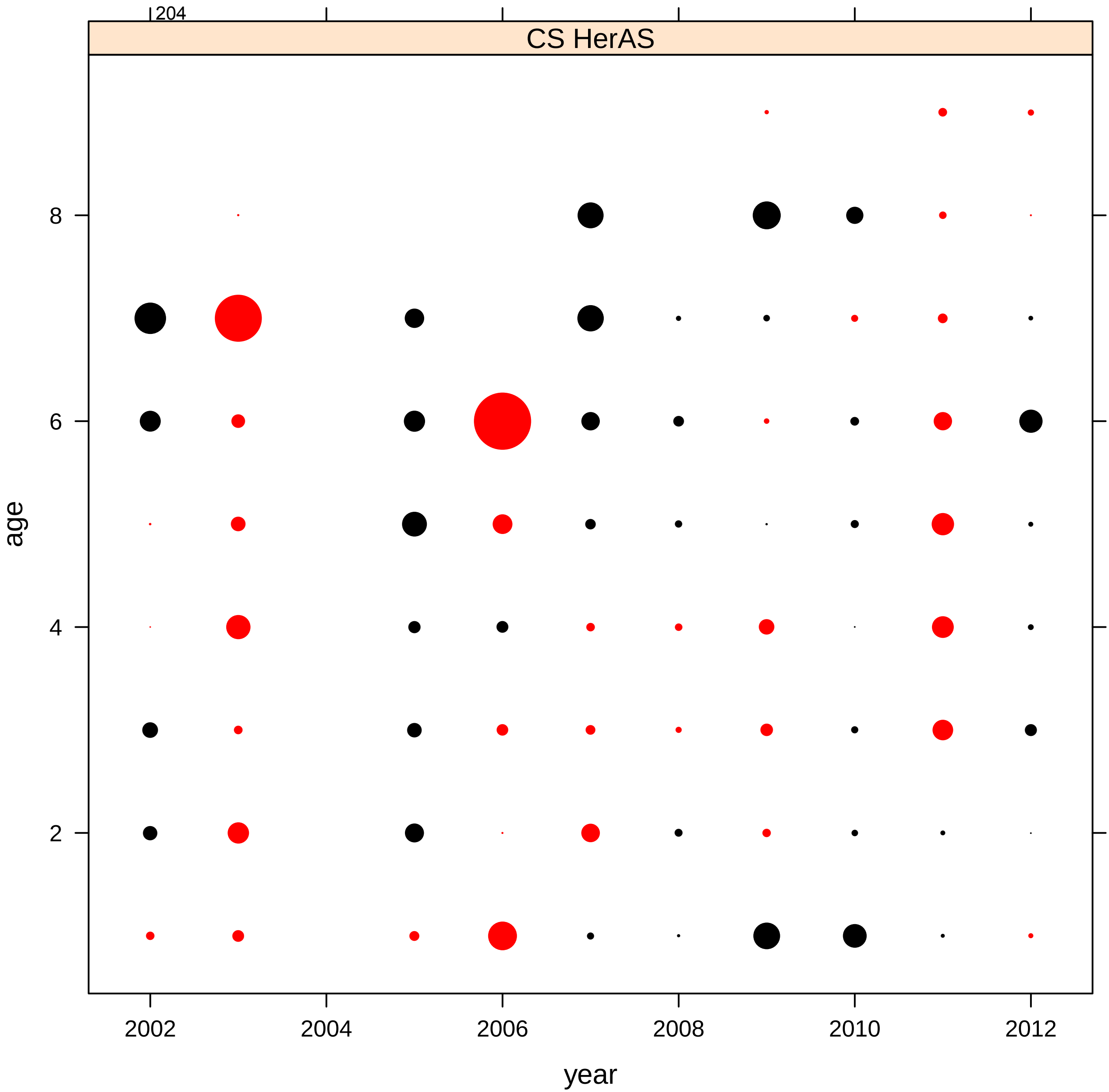



Diagnostics − CS HerAS, age 8
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
0.5
2.0
10.0
50.0
2004
2006
2008
2010
2012
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
0.5
1.0
2.0
5.0
10.0
50.0
200.0
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
−1.5
−0.5
0.5
1.5
d) Tukey−Anscombe plot
e) Normal Q−Q plot
qqline
1:1 line
−1.0
−0.5
0.0
0.5
1.0
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
1
2
3
4
5
Lag (yrs)

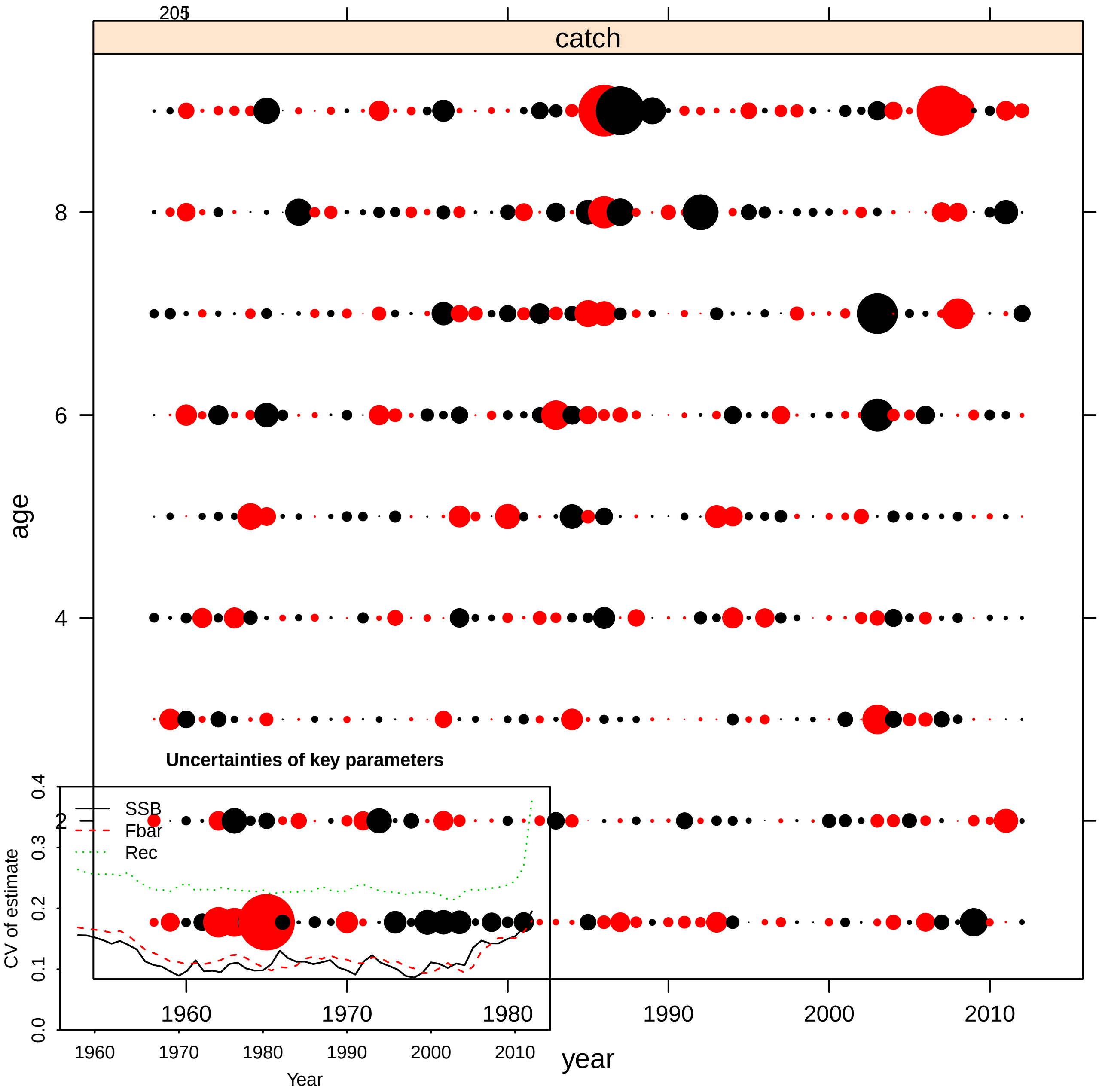
203

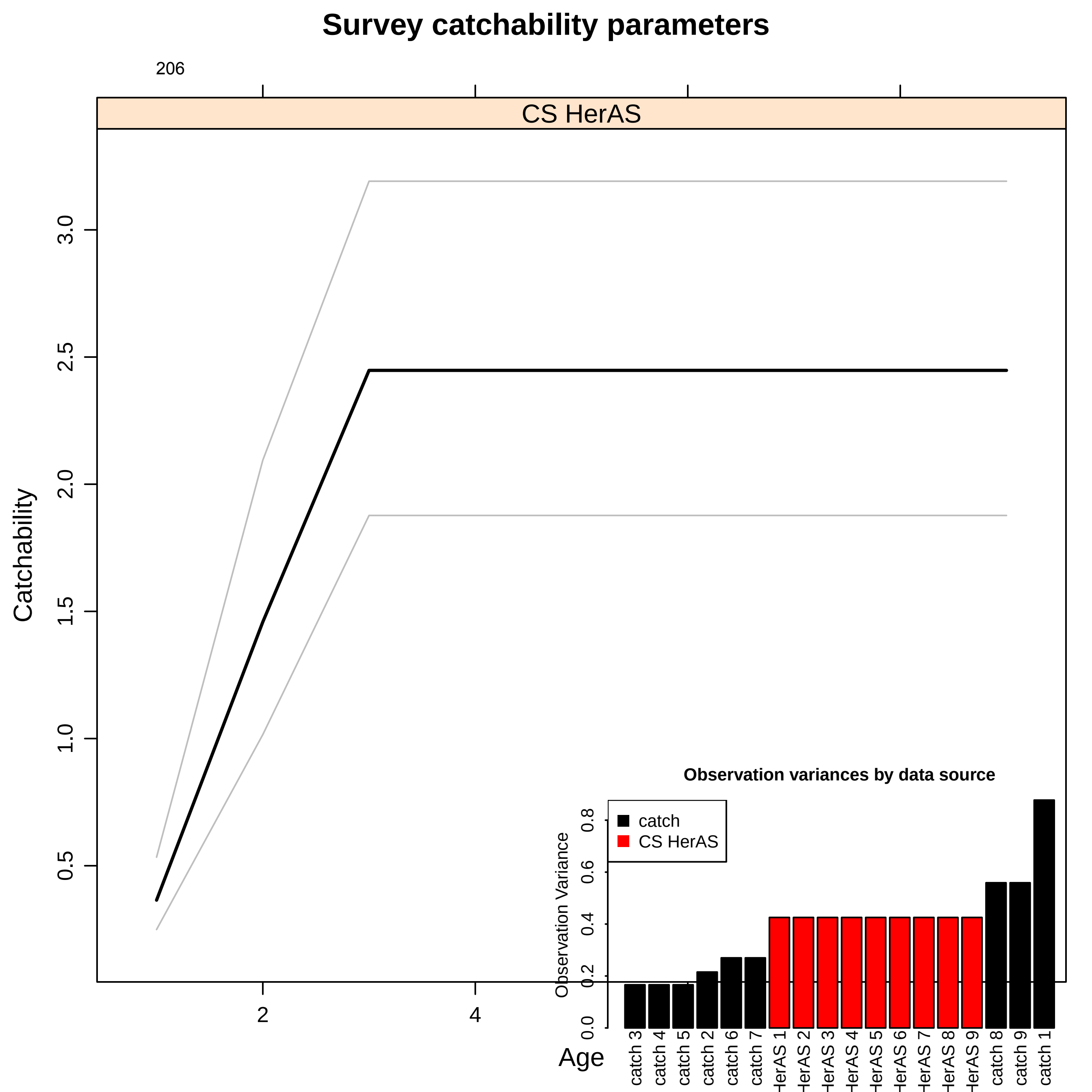


a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
Standardised Residuals
Fitted values [10^3]



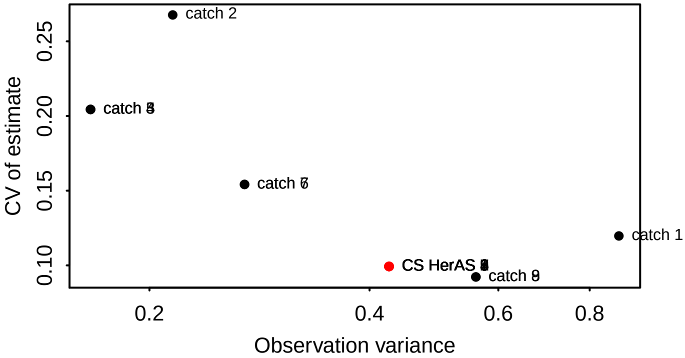
204
CS HerAS
age
year
2
4
6
8
2002
2004
2006
2008
2010
2012

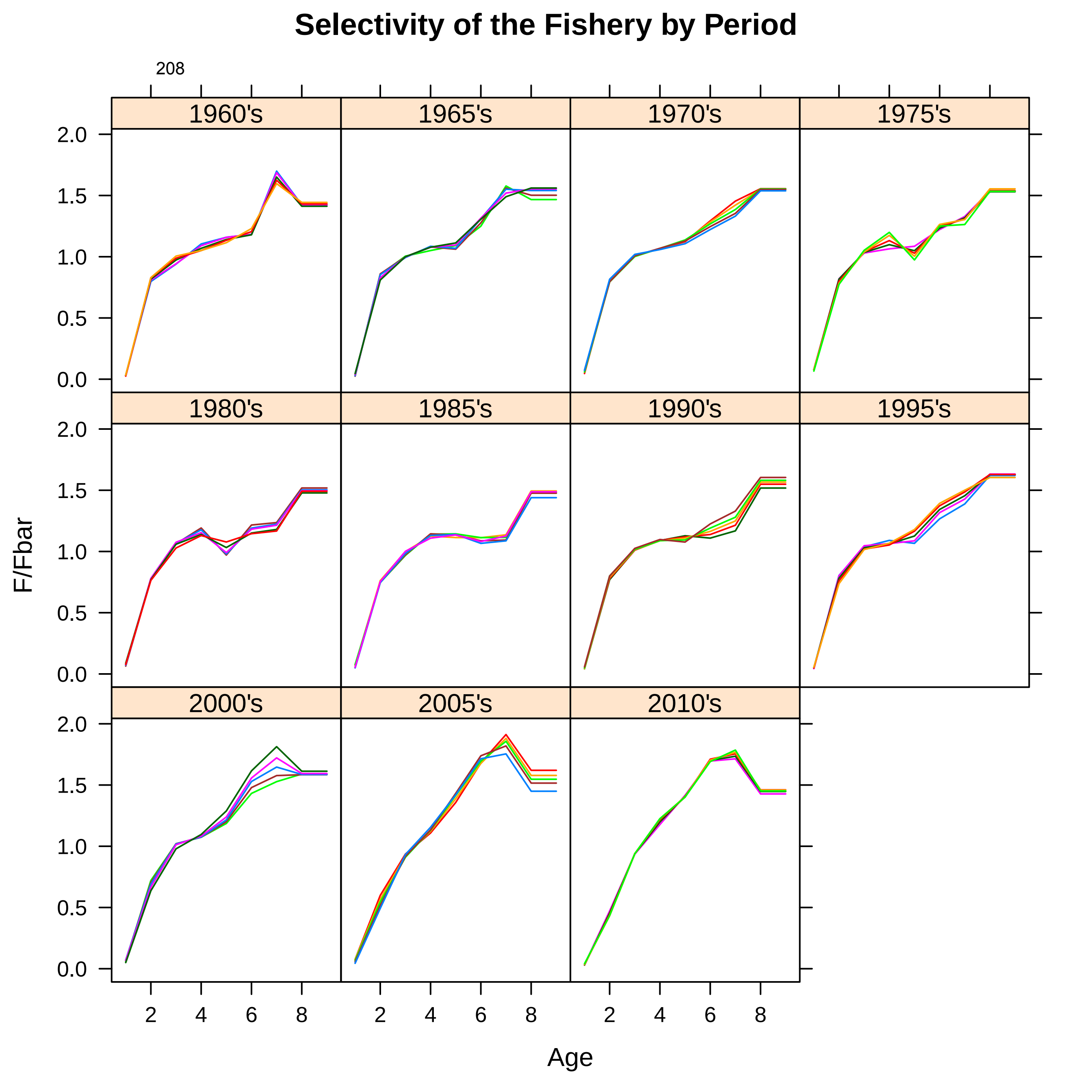

205
catch
age
8
6
4
2
year
1960
1970
1980
1990
2000
2010
Uncertainties of key parameters
SSB
Fbar
Rec
CV of estimate
0.0
0.1
0.2
0.3
0.4
Year


Survey catchability parameters
206
CS HerAS
Catchability
3.0
2.5
2.0
1.5
1.0
0.5
2
4
Age
Observation variances by data source
catch
CS HerAS
Observation Variance
0.0
0.2
0.4
0.6
0.8
catch 3
catch 4
catch 5
catch 2
catch 6
catch 7
HerAS 1
HerAS 2
HerAS 3
HerAS 4
HerAS 5
HerAS 6
HerAS 7
HerAS 8
HerAS 9
catch 8
catch 9
catch 1

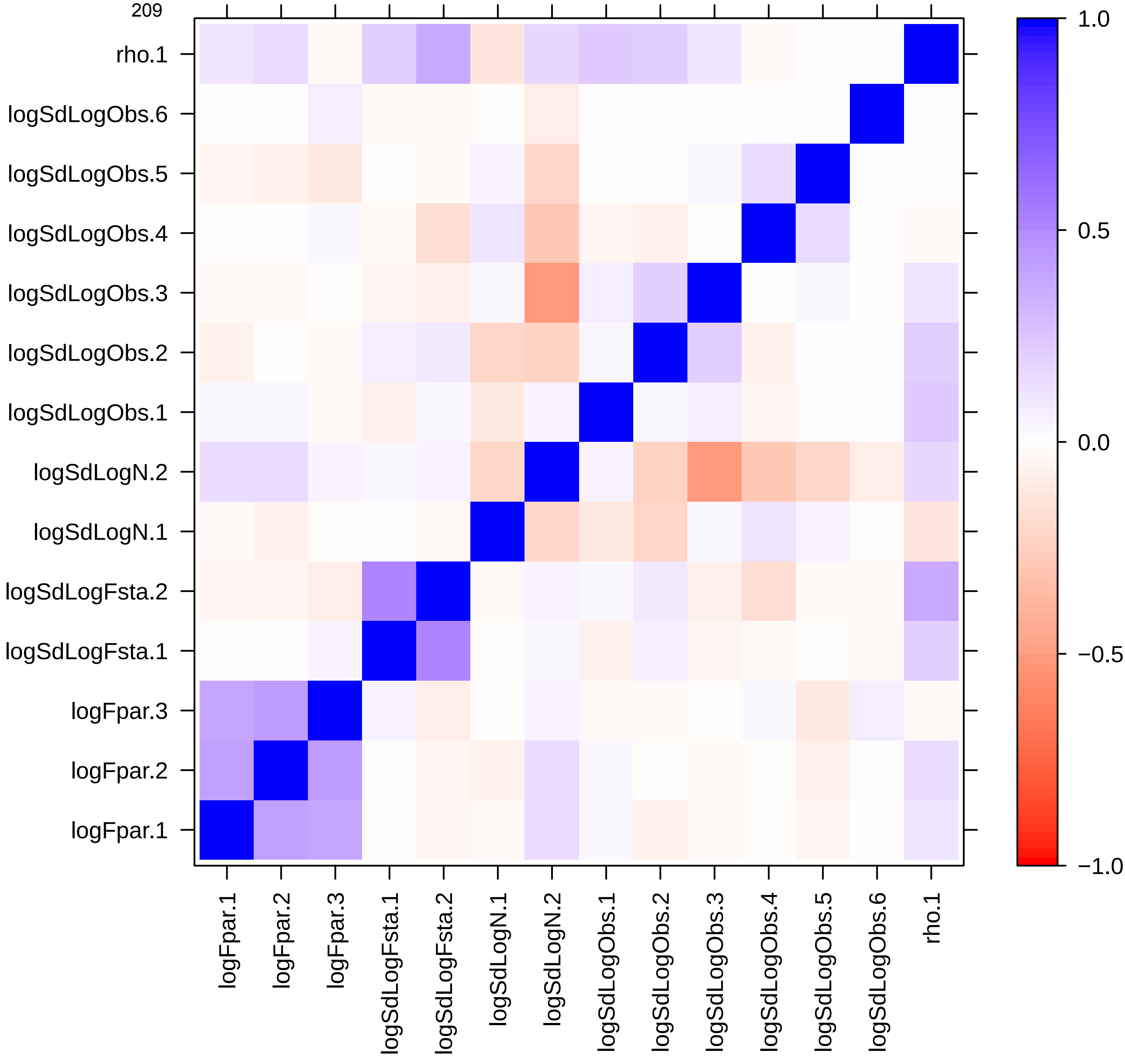
207

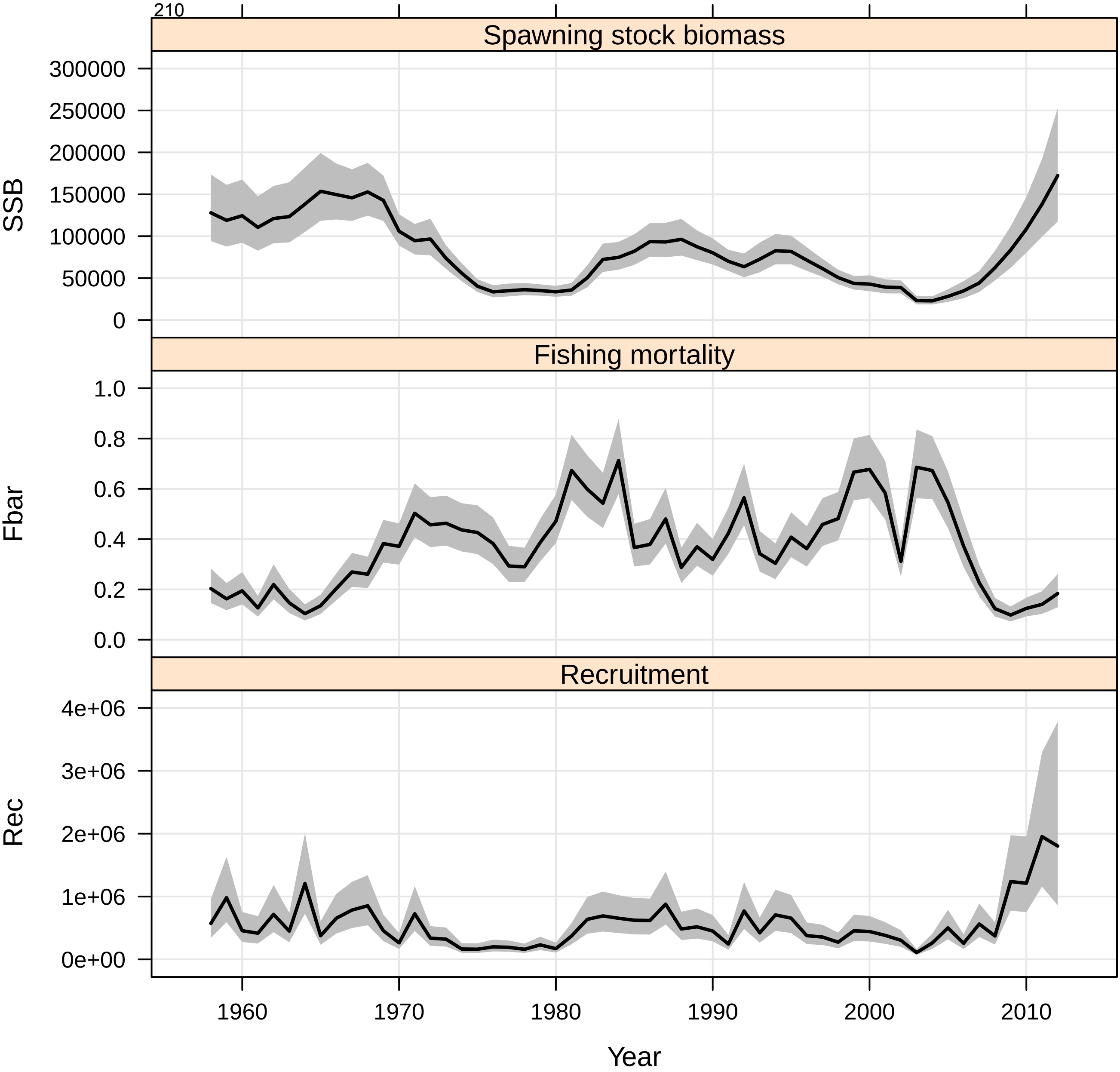
Observation variance vs uncertainty

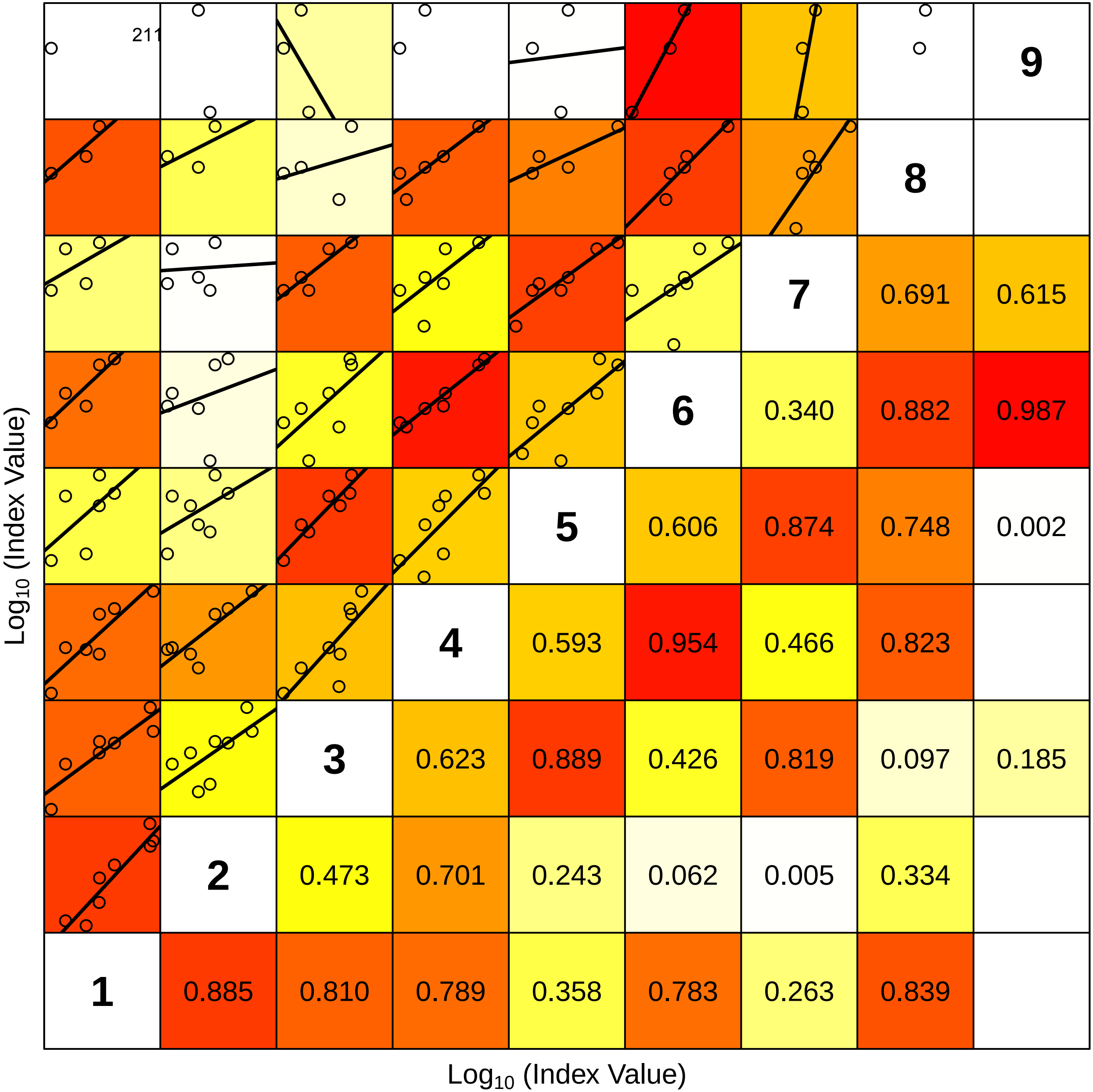




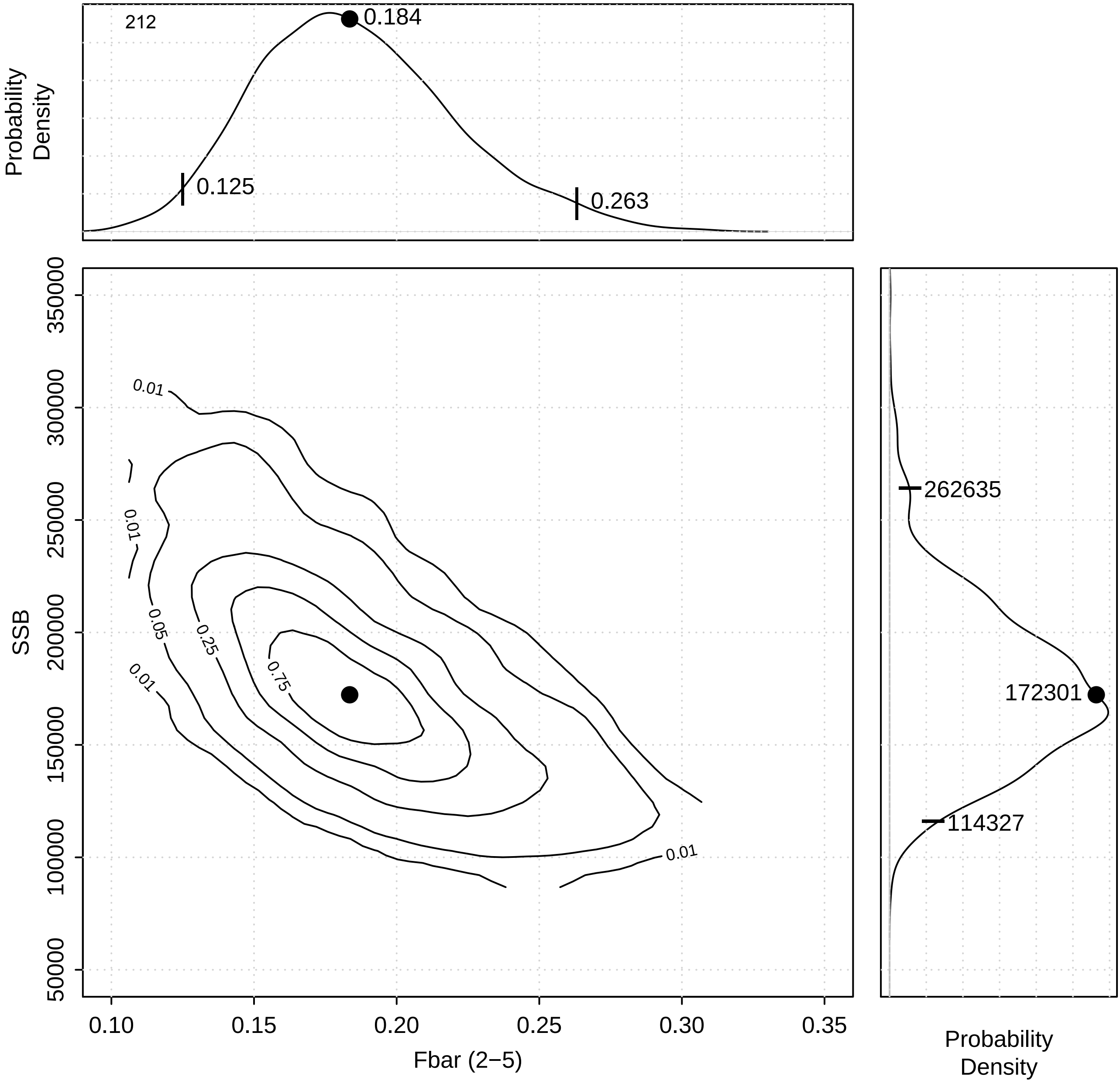
Selectivity of the Fishery by Period
208
1960's
1965's
1970's
1975's
1980's
1985's
1990's
1995's
2000's
2005's
2010's
F/Fbar
0.0
0.5
1.0
1.5
2.0
2
4
6
8
Age


rho.1
logSdLogObs.6
logSdLogObs.5
logSdLogObs.4
logSdLogObs.3
logSdLogObs.2
logSdLogObs.1
logSdLogN.2
logSdLogN.1
logSdLogFsta.2
logSdLogFsta.1
logFpar.3
logFpar.2
logFpar.1
1.0
0.5
0.0
−0.5
−1.0

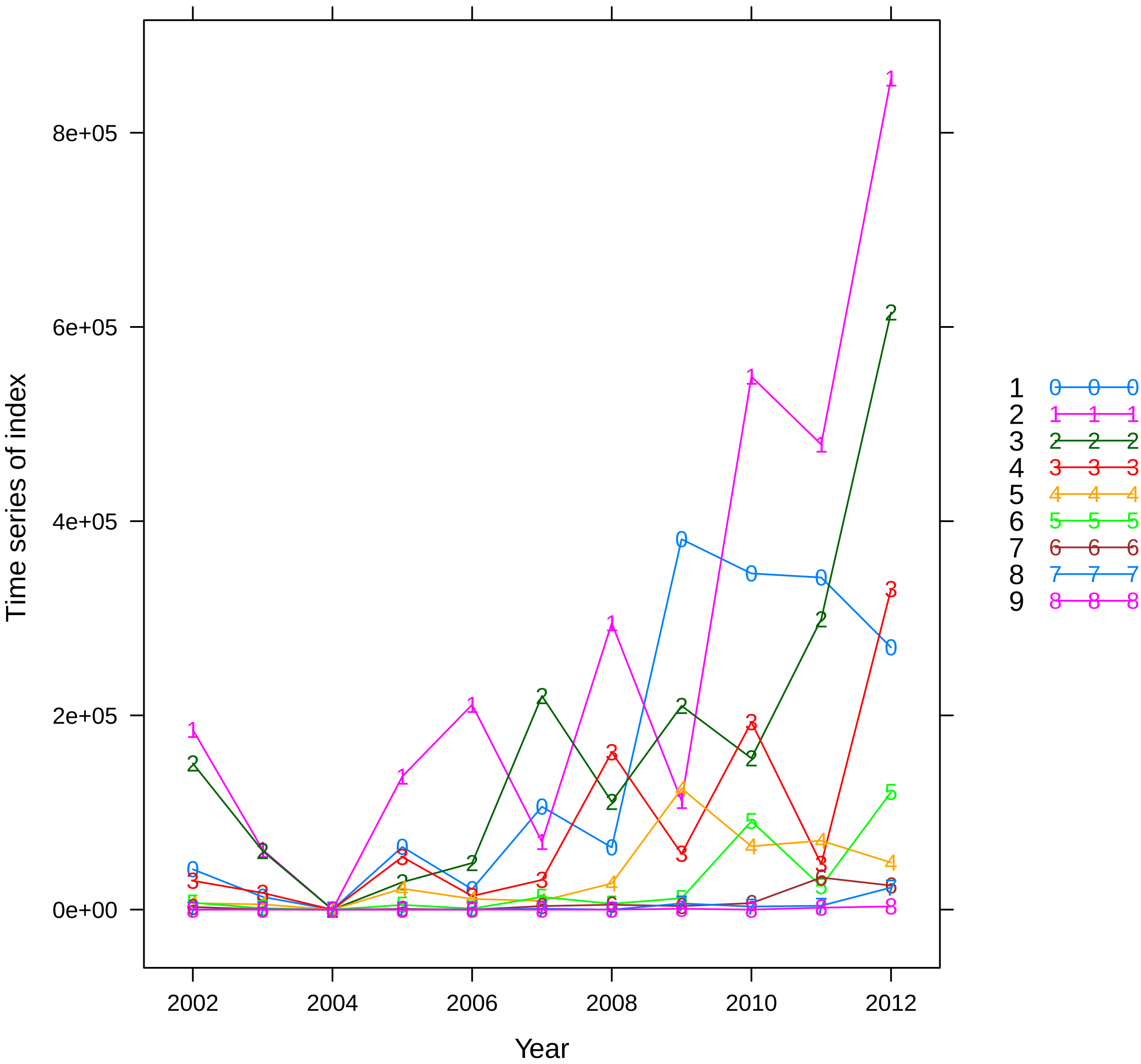

Spawning stock biomass
SSB
300000
250000
200000
150000
100000
50000
0
Fishing mortality
Fbar
1.0
0.8
0.6
0.4
0.2
0.0
Recruitment
Rec
4e+06
3e+06
2e+06
1e+06
0e+00
1960
1970
1980
1990
2000
2010
Year



Lower right panels show the Coefficient of Determination (r^2)

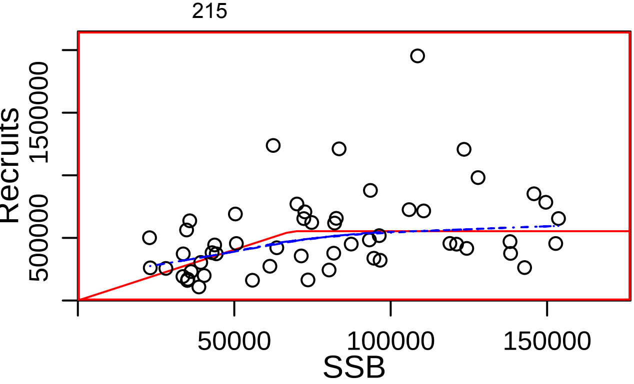

212
0.184
0.125
0.263
Probability Density
0.01
0.05
0.25
0.75
SSB
Fbar (2−5)
262635
172301
114327
Probability Density
0.10
0.15
0.20
0.25
0.30
0.35
50000
100000
150000
200000
250000
300000
350000

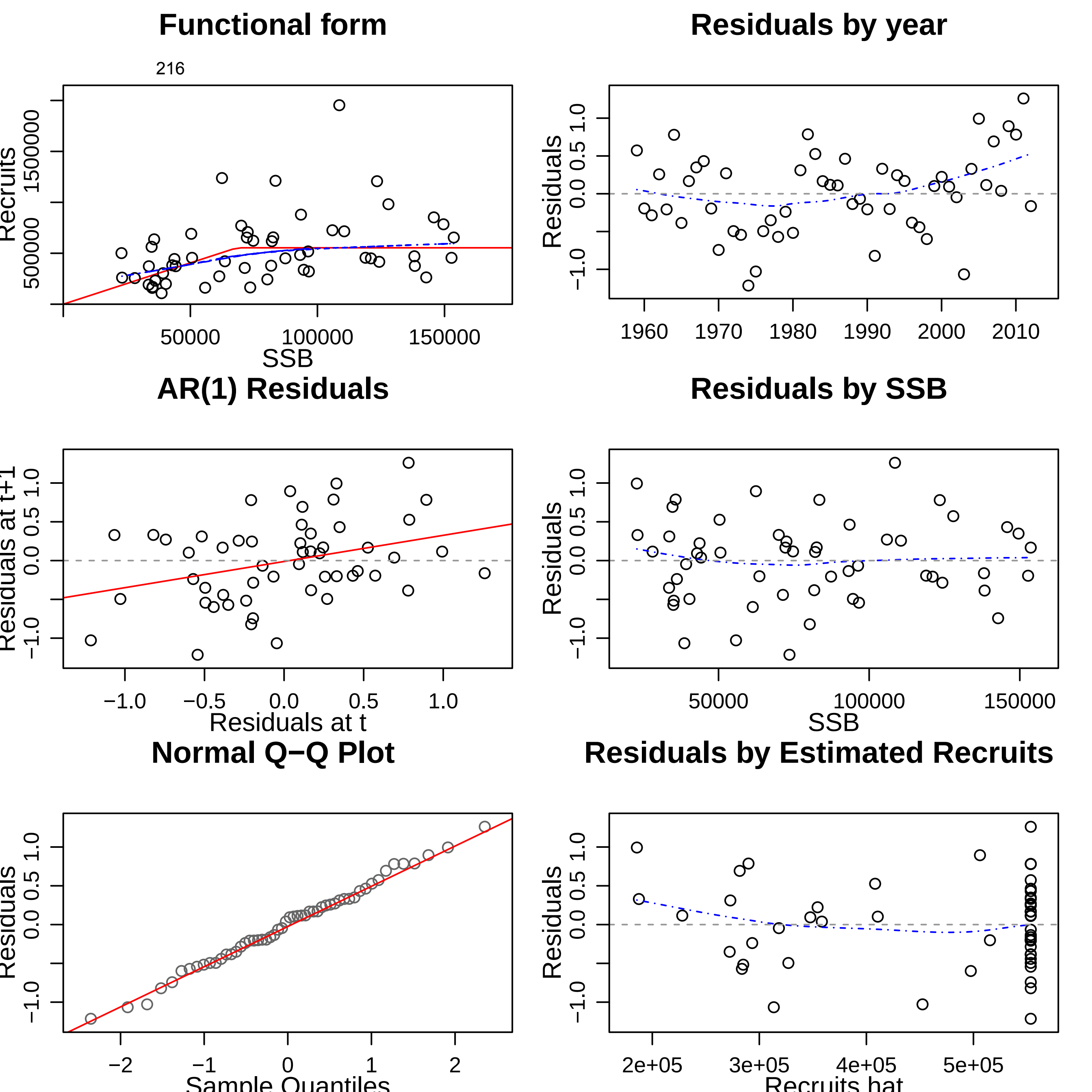
Celtic Sea Herring acoustic survey timeseries of index

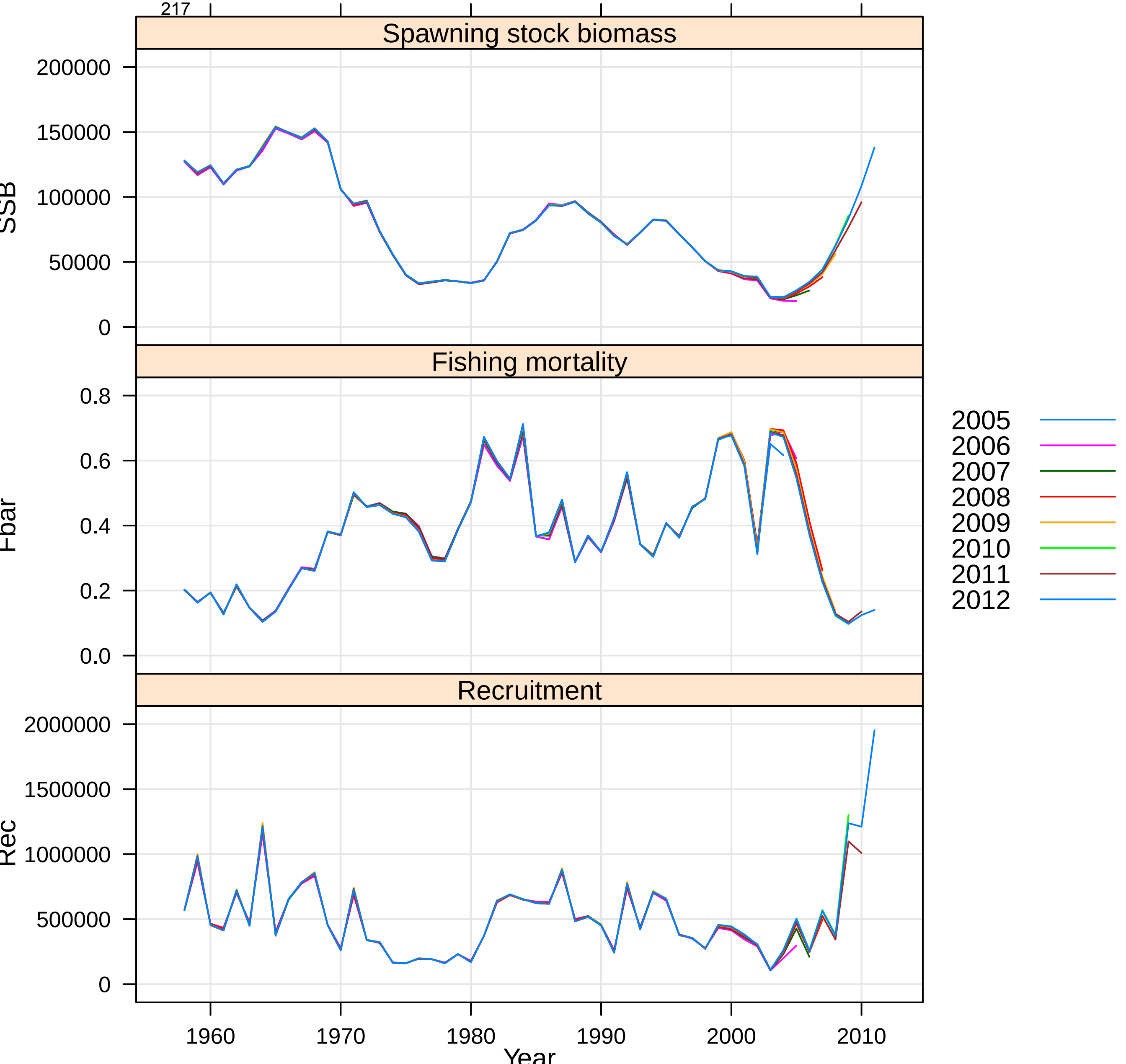


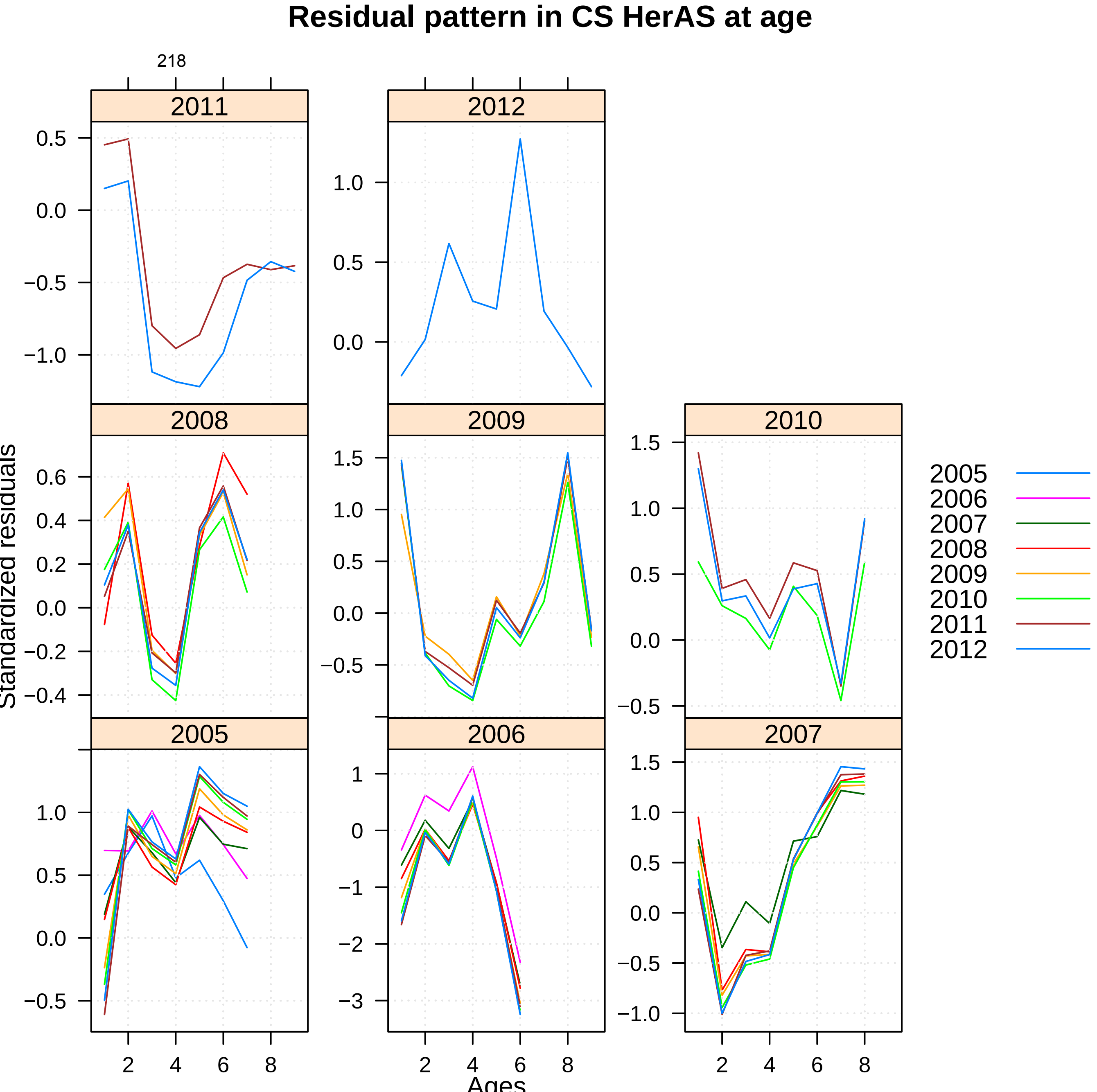
Celtic Sea Herring Weight in the stock by cohort
214
Weight in the stock (kg)
Year
0.05
0.10
0.15
0.20
0.25
0.30
1980
1990
2000
2010
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011

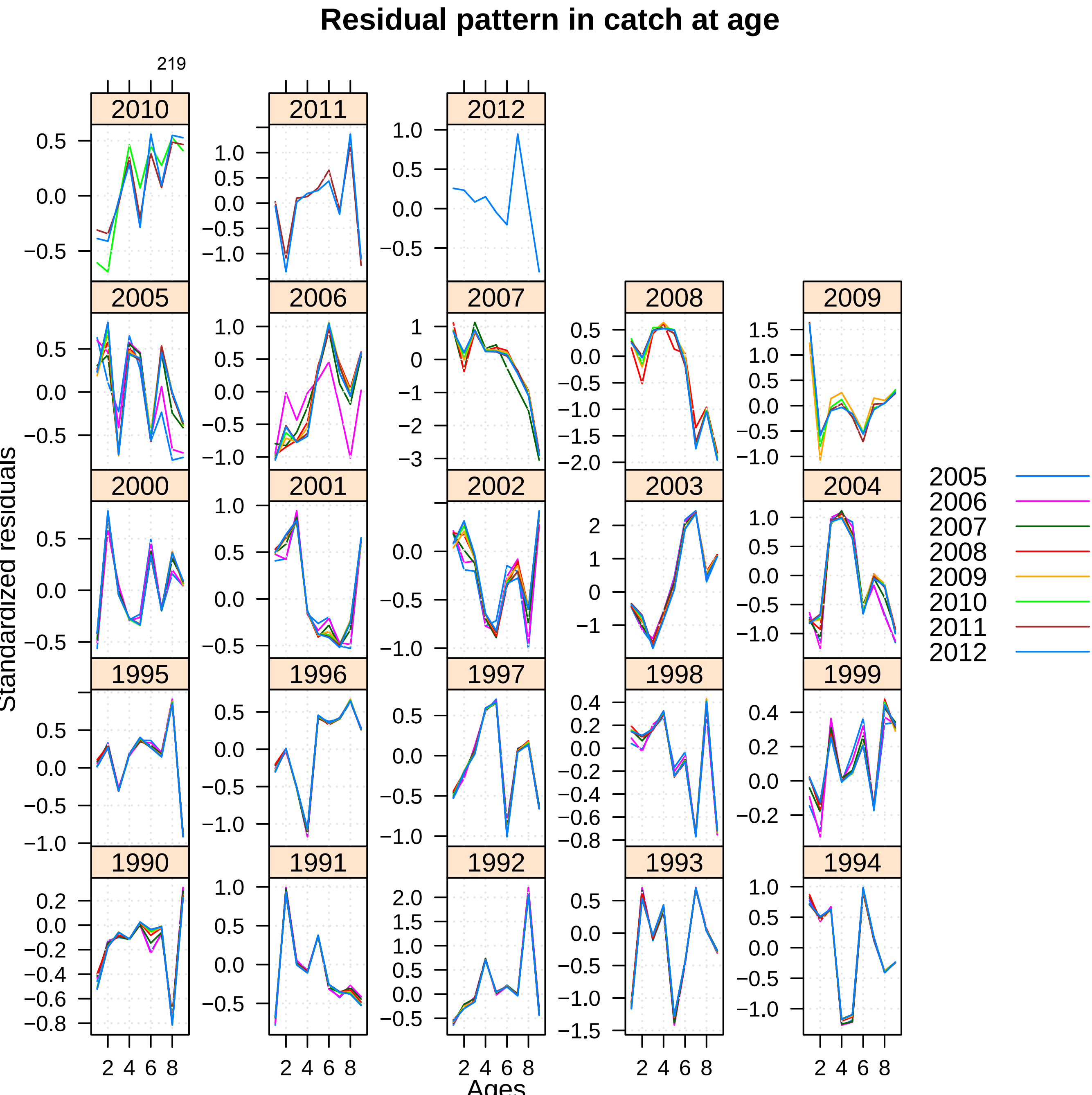
Functional form



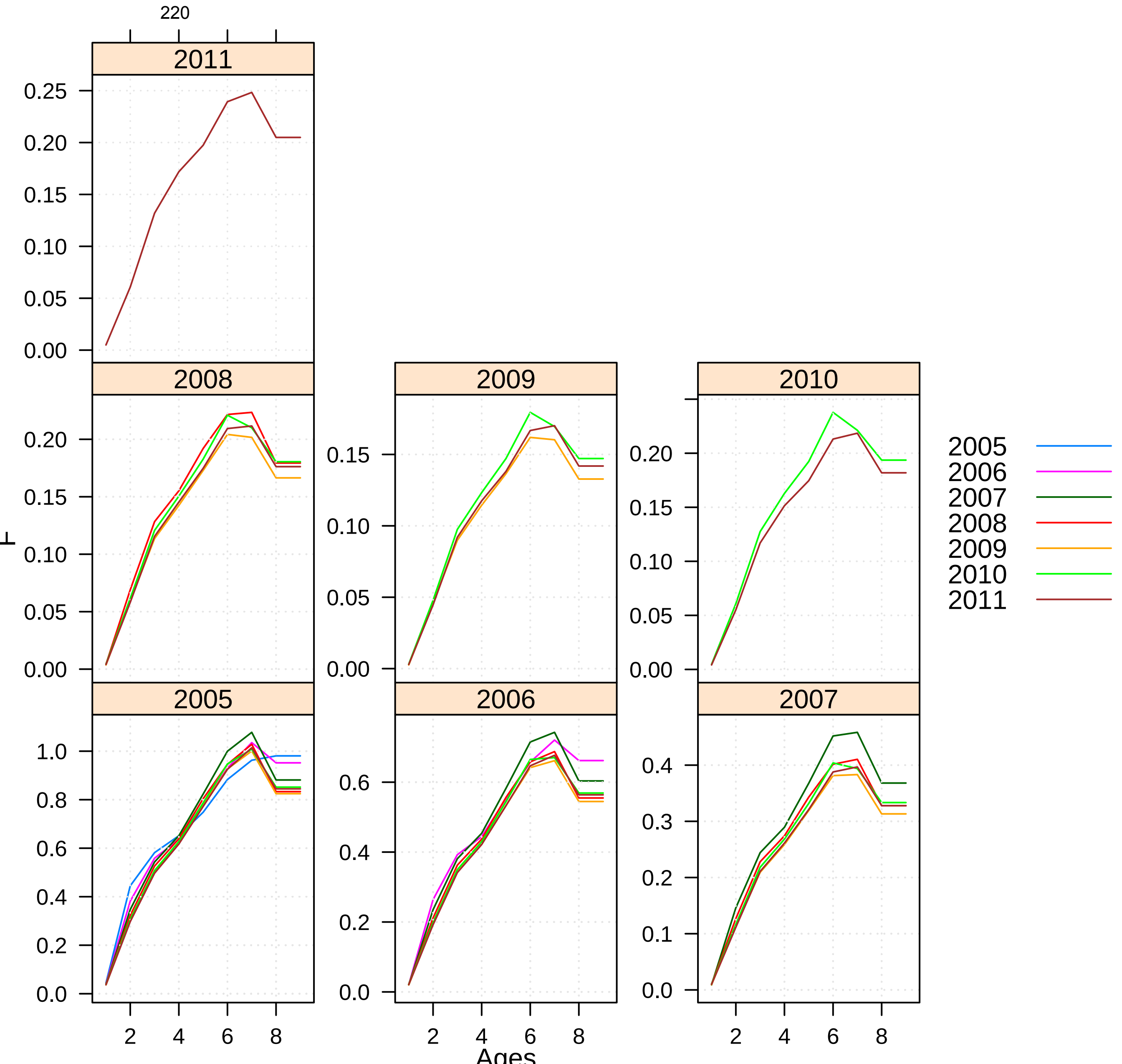

Functional form
216
Recruits
500000
1500000
50000
100000
150000
SSB
Residuals by year
Residuals
−1.0
0.0 0.5 1.0
1960
1970
1980
1990
2000
2010
AR(1) Residuals
Residuals at t+1
−1.0
0.0 0.5 1.0
−1.0
−0.5
0.0
0.5
1.0
Residuals at t
Residuals by SSB
Residuals
−1.0
0.0 0.5 1.0
50000
100000
150000
SSB
Normal Q−Q Plot
Residuals
−1.0
0.0 0.5 1.0
−2
−1
0
1
2
Sample Quantiles
Residuals by Estimated Recruits
Residuals
−1.0
0.0 0.5 1.0
2e+05
3e+05
4e+05
5e+05
Recruits hat

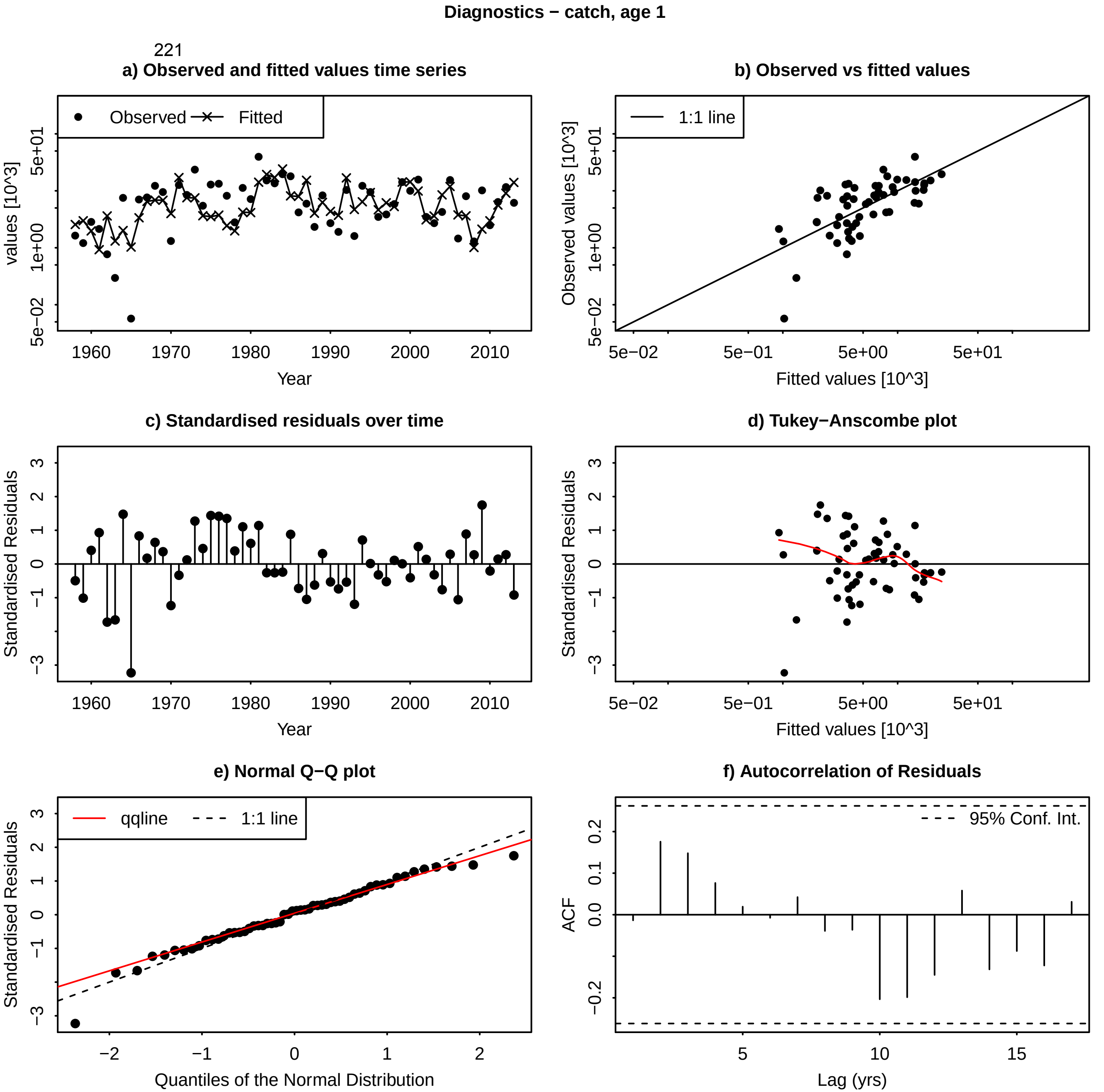

Spawning stock biomass
SSB
200000
150000
100000
50000
0
Fishing mortality
Fbar
0.8
0.6
0.4
0.2
0.0
Recruitment
Rec
2000000
1500000
1000000
500000
0
1960
1970
1980
1990
2000
2010
Year
2005
2006
2007
2008
2009
2010
2011
2012


Residual pattern in CS HerAS at age
2011
2012
2008
2009
2010
2005
2006
2007
Standardized residuals
Ages
2005
2006
2007
2008
2009
2010
2011
2012

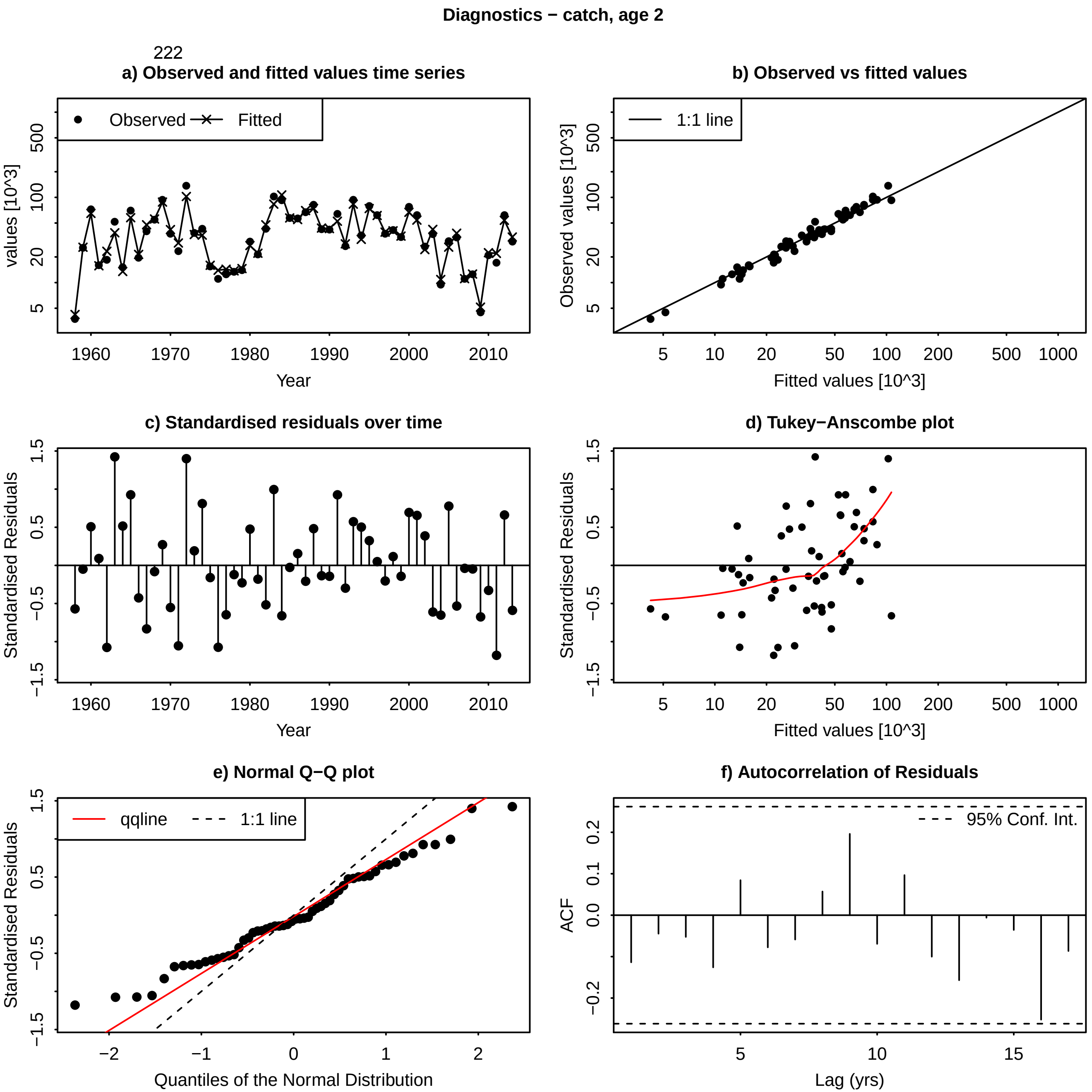

Residual pattern in catch at age
219
2010
2011
2012
2005
2006
2007
2008
2009
2000
2001
2002
2003
2004
1995
1996
1997
1998
1999
1990
1991
1992
1993
1994
Standardized residuals
Ages
2005
2006
2007
2008
2009
2010
2011
2012

Retrospective pattern in F at age

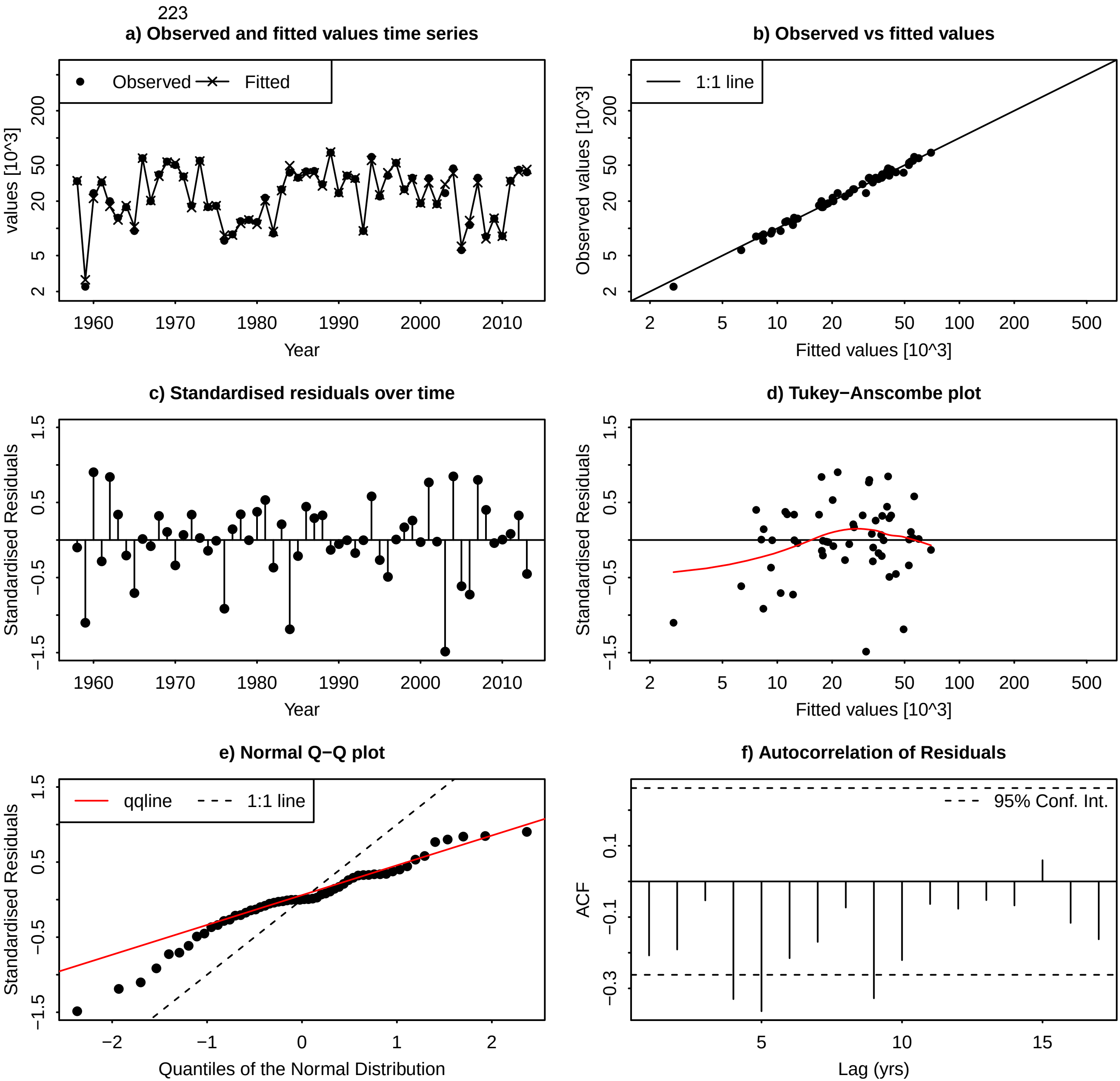


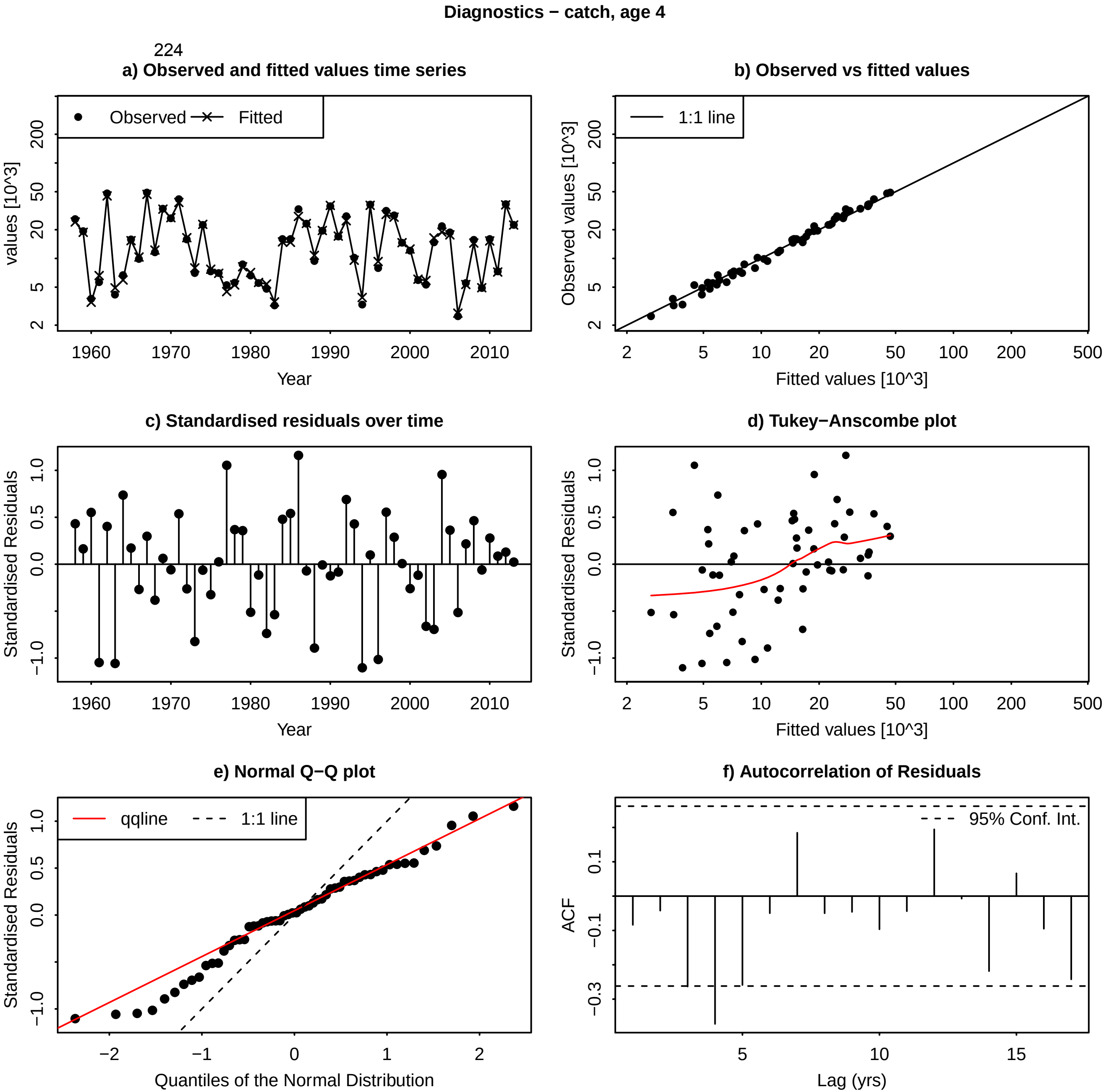

Diagnostics − catch, age 1
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
5e−02
1e+00
5e+01
1960
1970
1980
1990
2000
2010
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
5e−02
5e−01
5e+00
5e+01
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)

222

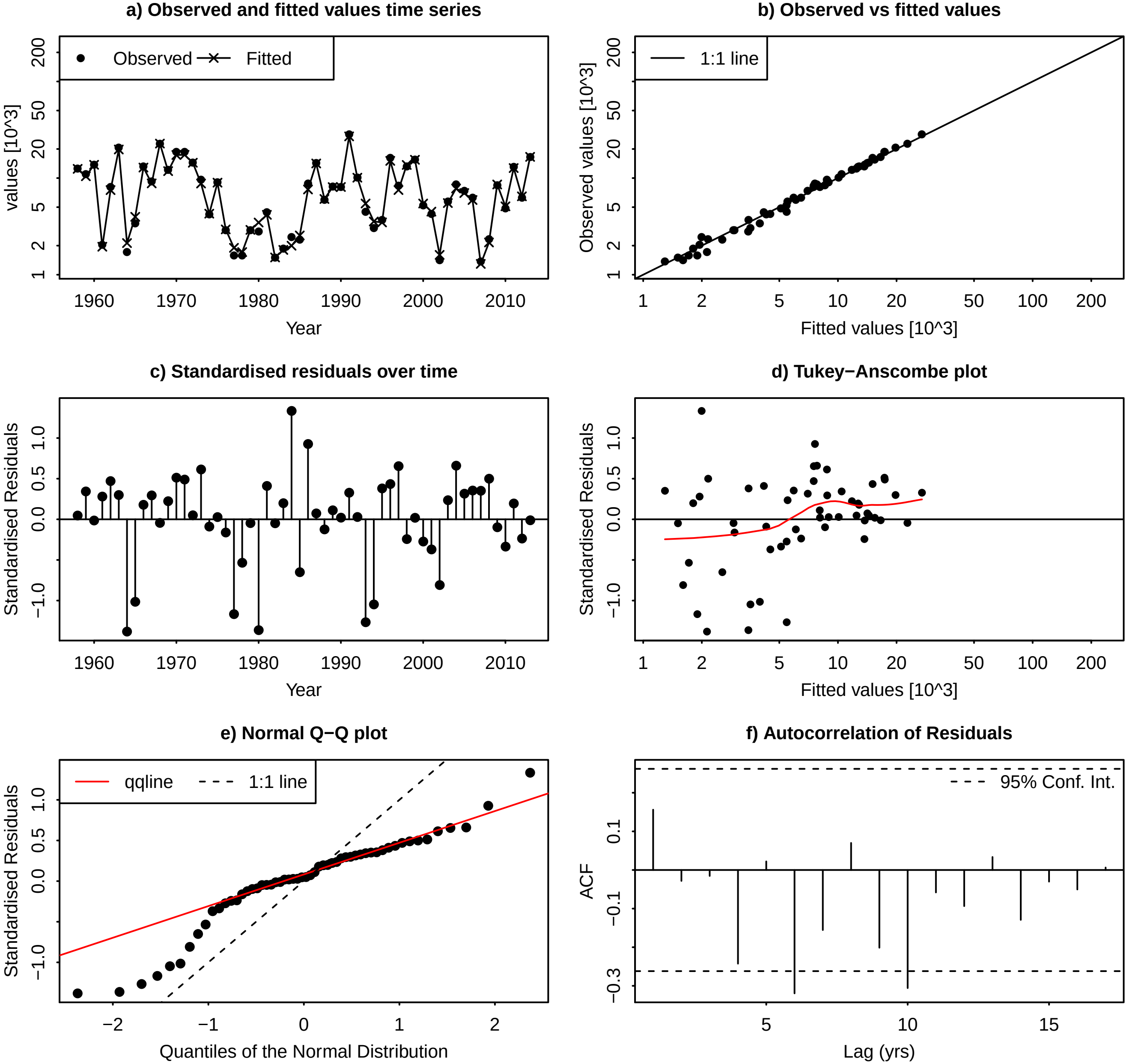

Diagnostics − catch, age 2
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
500
100
20
5
1960
1970
1980
1990
2000
2010
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
5
10
20
50
100
200
500
1000
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
1.5
0.5
−0.5
−1.5
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
−2
−1
0
1
2
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
0.2
0.1
0.0
−0.2
5
10
15
Lag (yrs)

Diagnostics − catch, age 3



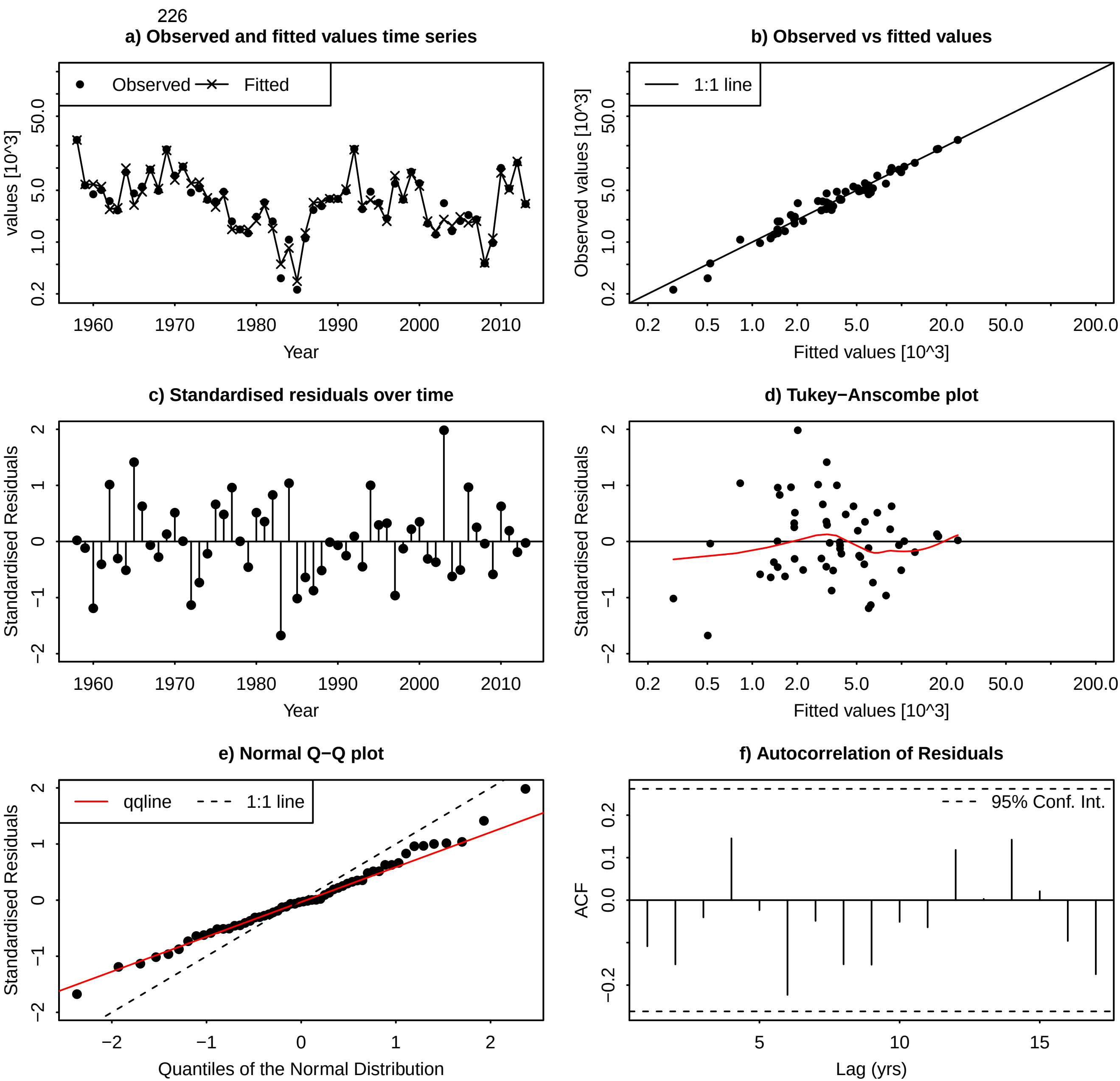

Diagnostics − catch, age 4
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)

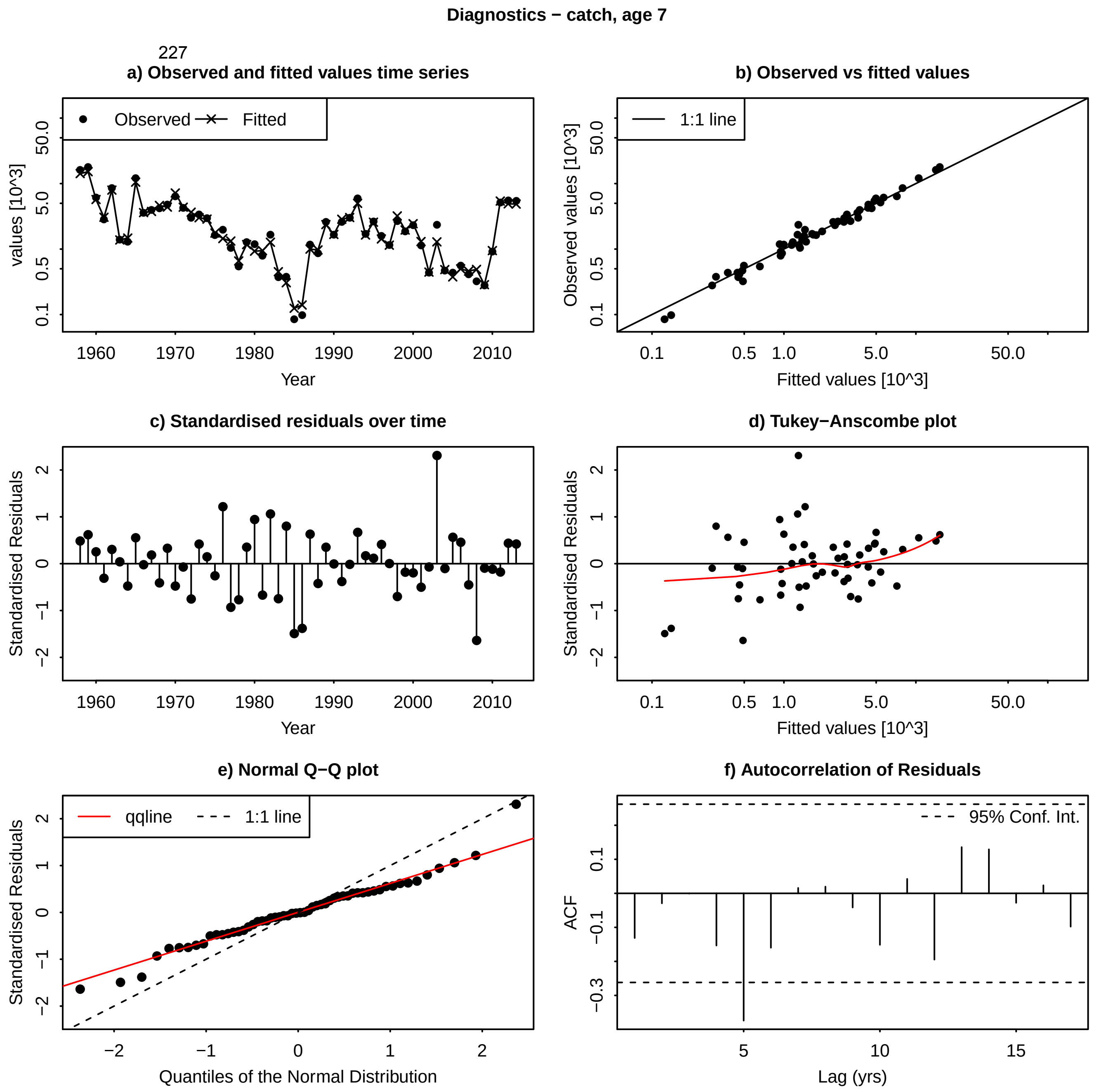
Diagnostics − catch, age 5



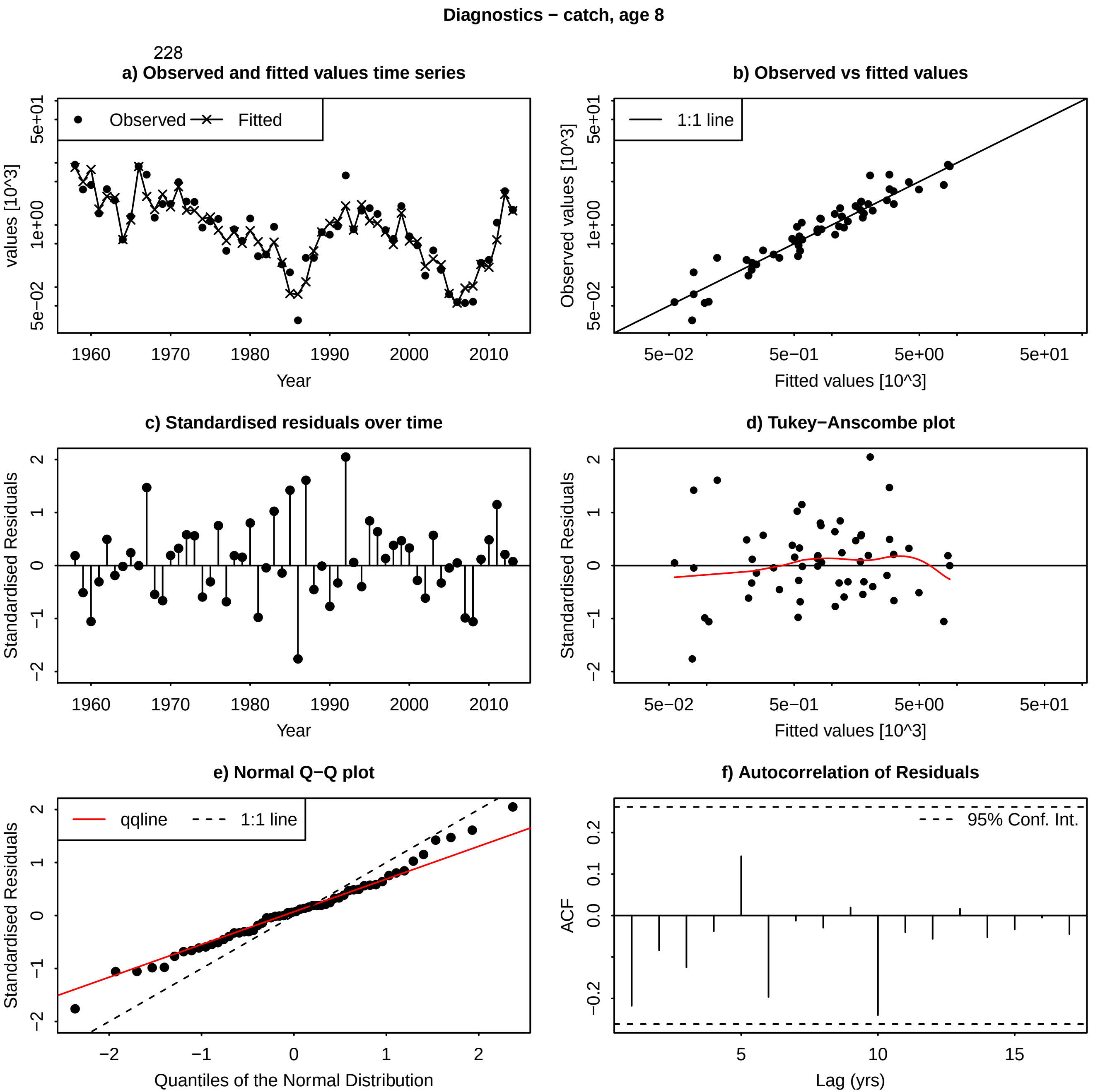
Diagnostics − catch, age 6

226

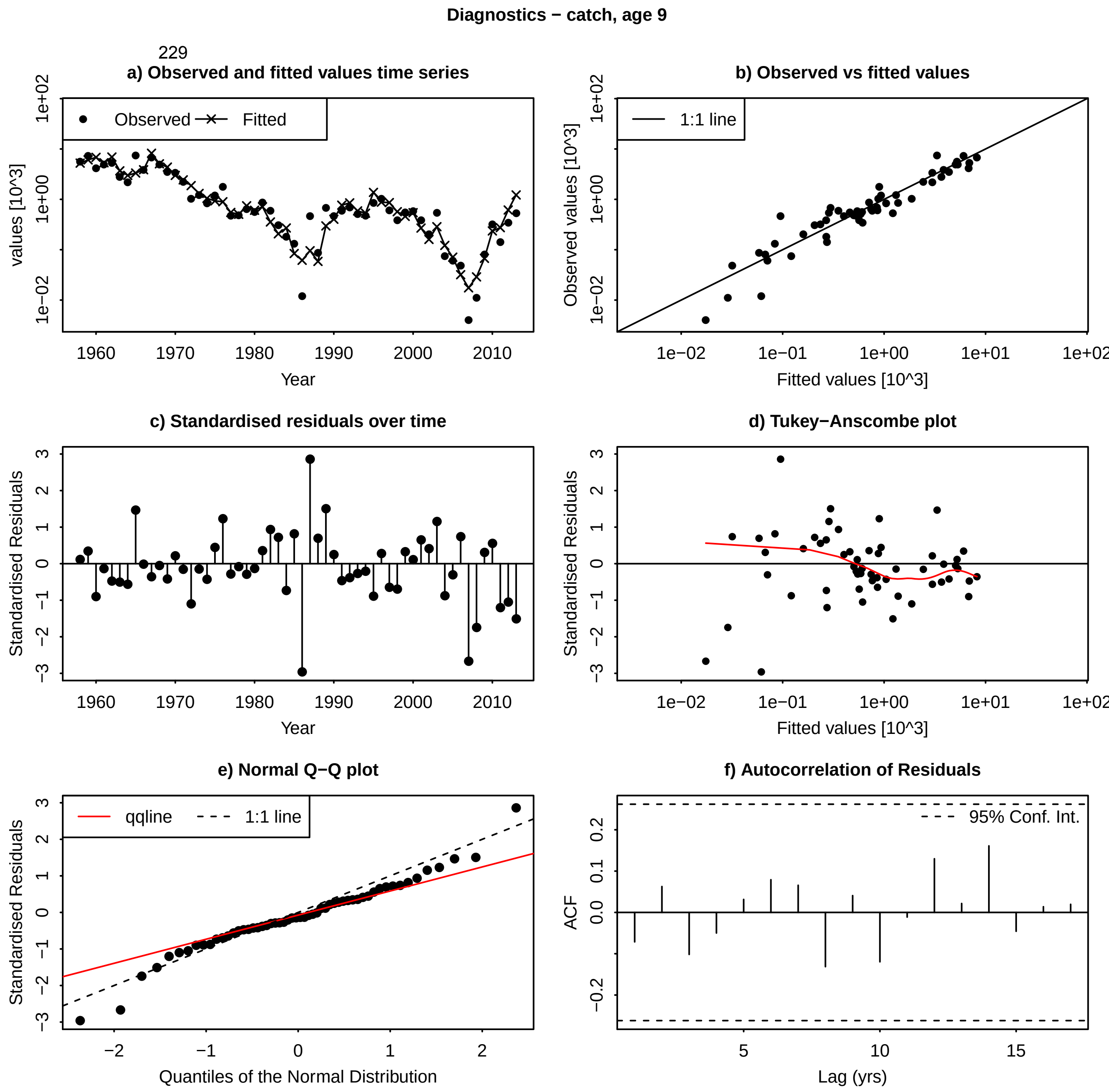



Diagnostics − catch, age 7
227
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
0.1
0.5
5.0
50.0
1960
1970
1980
1990
2000
2010
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
0.1
0.5
1.0
5.0
50.0
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)

228

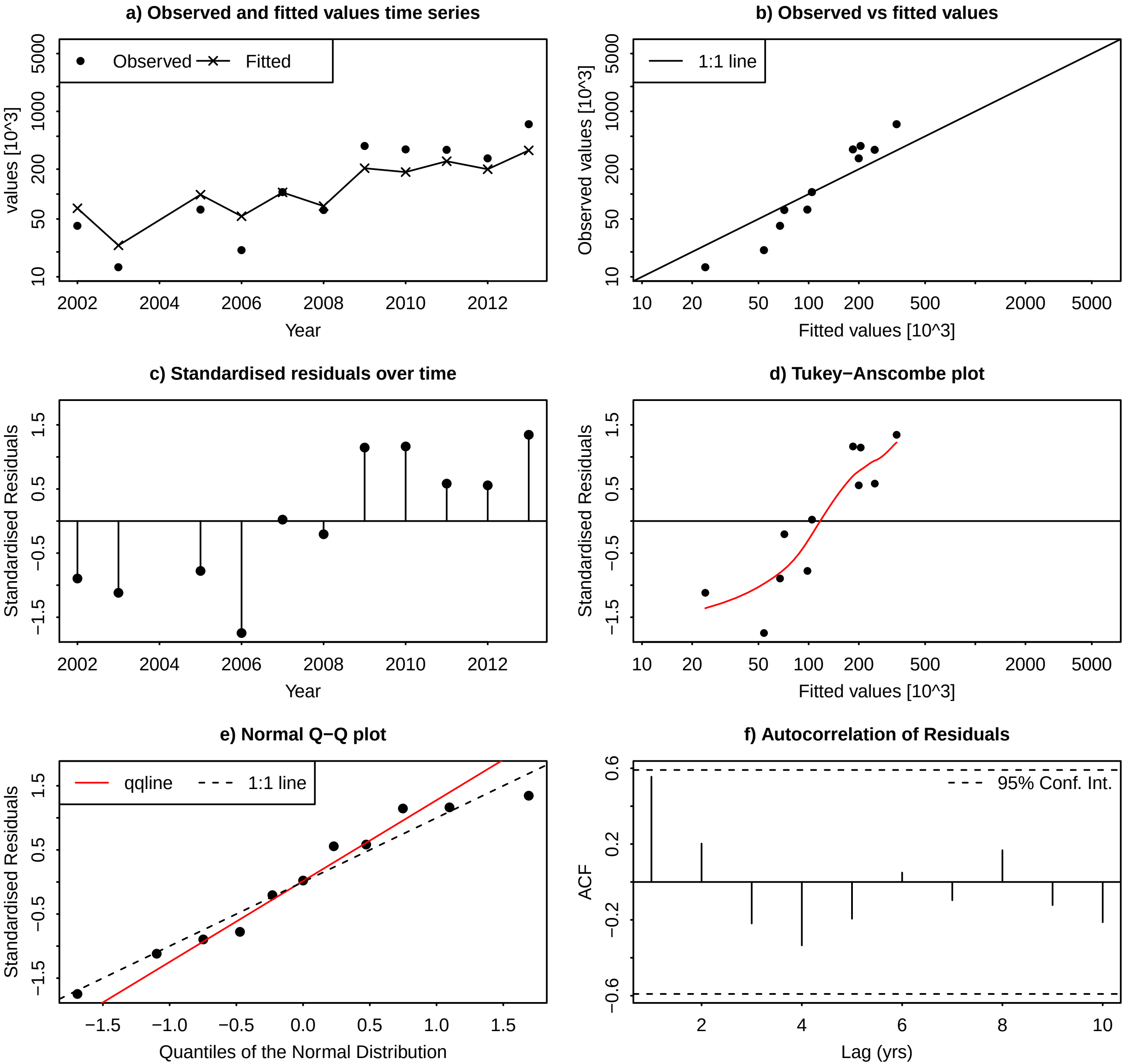


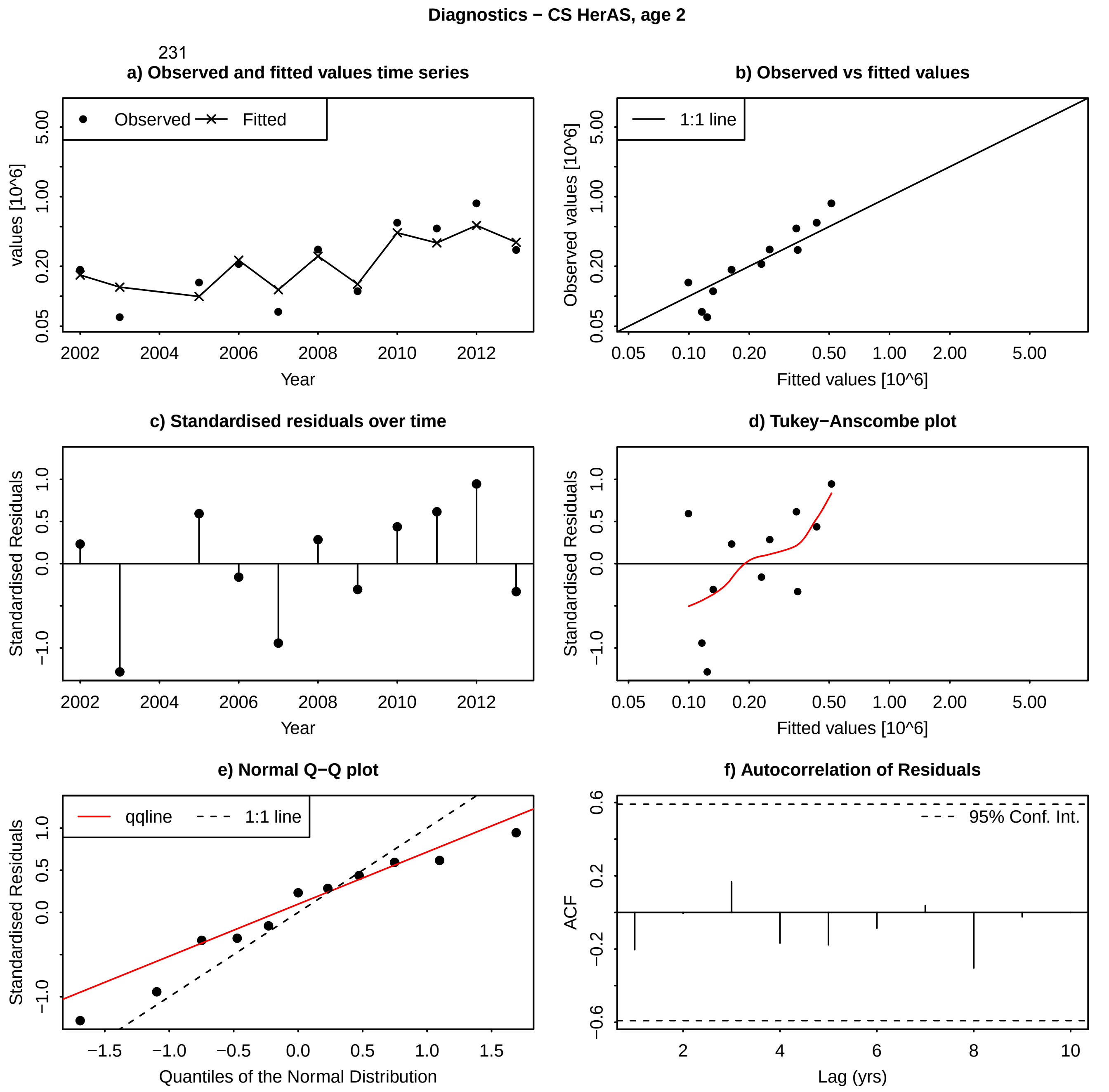
Diagnostics − catch, age 8
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)

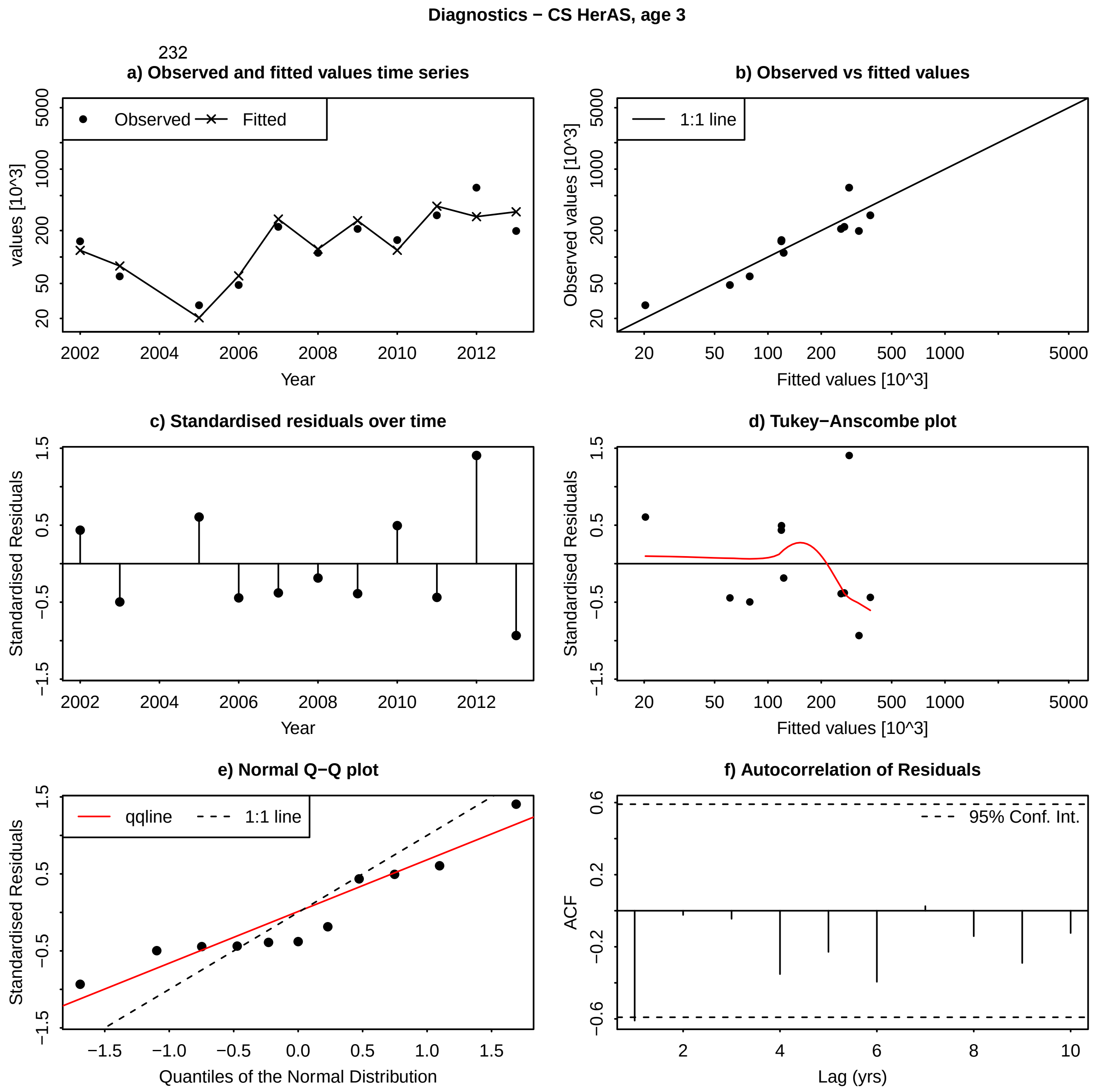


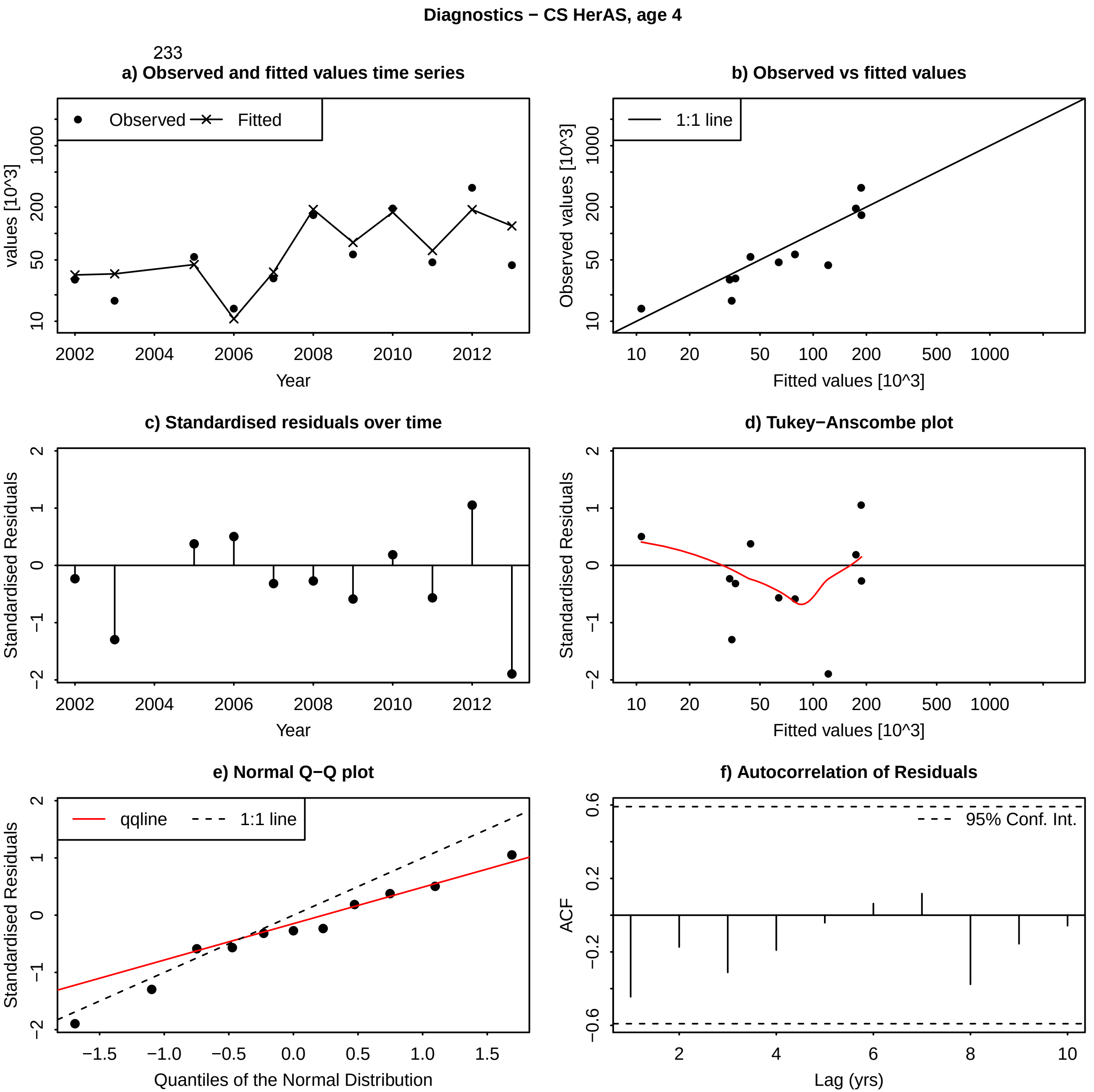
Diagnostics − catch, age 9
229
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)

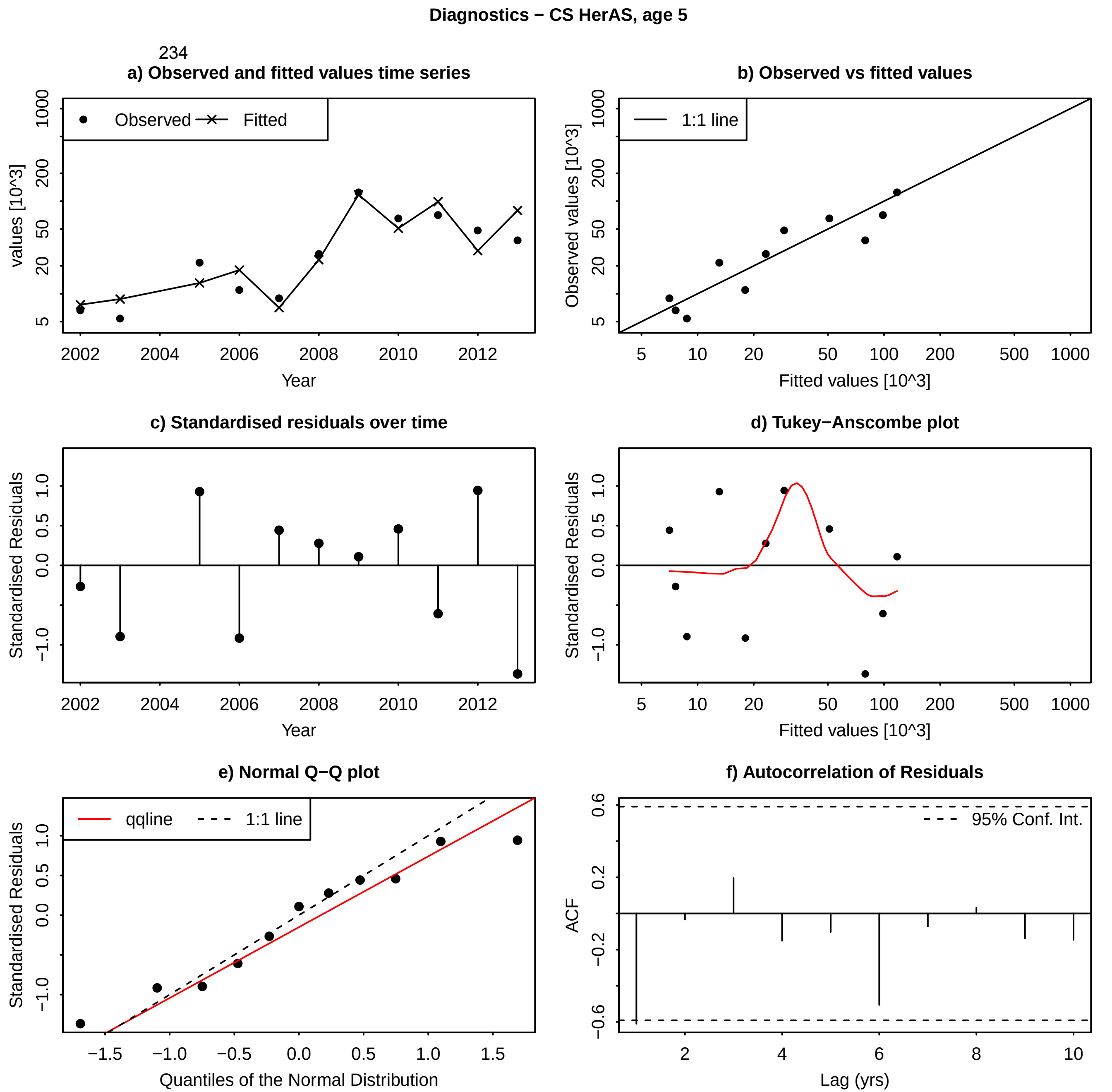
Diagnostics − CS HerAS, age 1

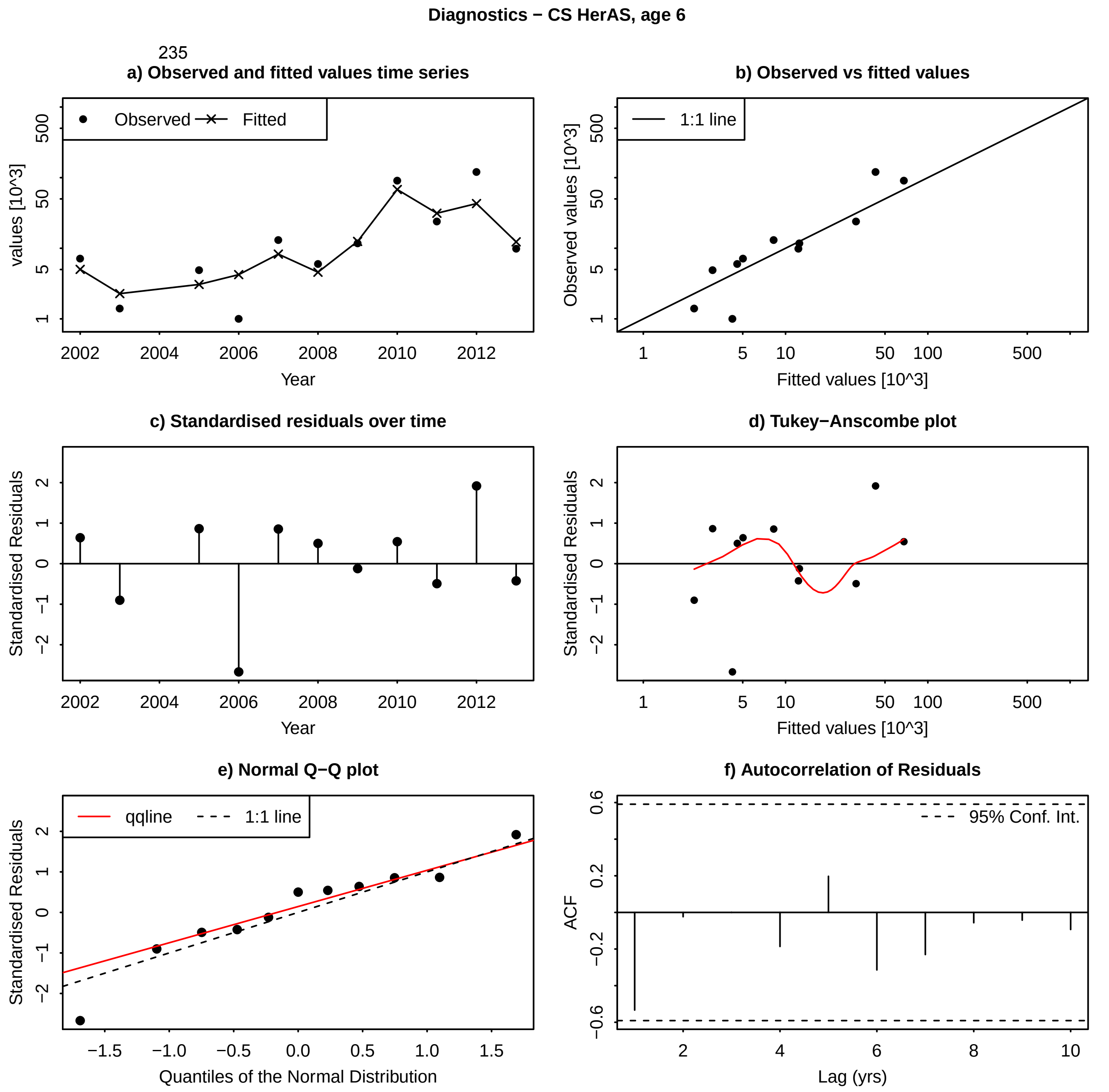



Diagnostics − CS HerAS, age 2
231
a) Observed and fitted values time series
Observed
Fitted
values [10^6]
0.05
0.20
1.00
5.00
2002
2004
2006
2008
2010
2012
Year
b) Observed vs fitted values
1:1 line
Observed values [10^6]
0.05
0.10
0.20
0.50
1.00
2.00
5.00
Fitted values [10^6]
c) Standardised residuals over time
Standardised Residuals
−1.0
0.0
0.5
1.0
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^6]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
−0.6
−0.2
0.2
0.6
2
4
6
8
10
Lag (yrs)


Diagnostics − CS HerAS, age 3
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)

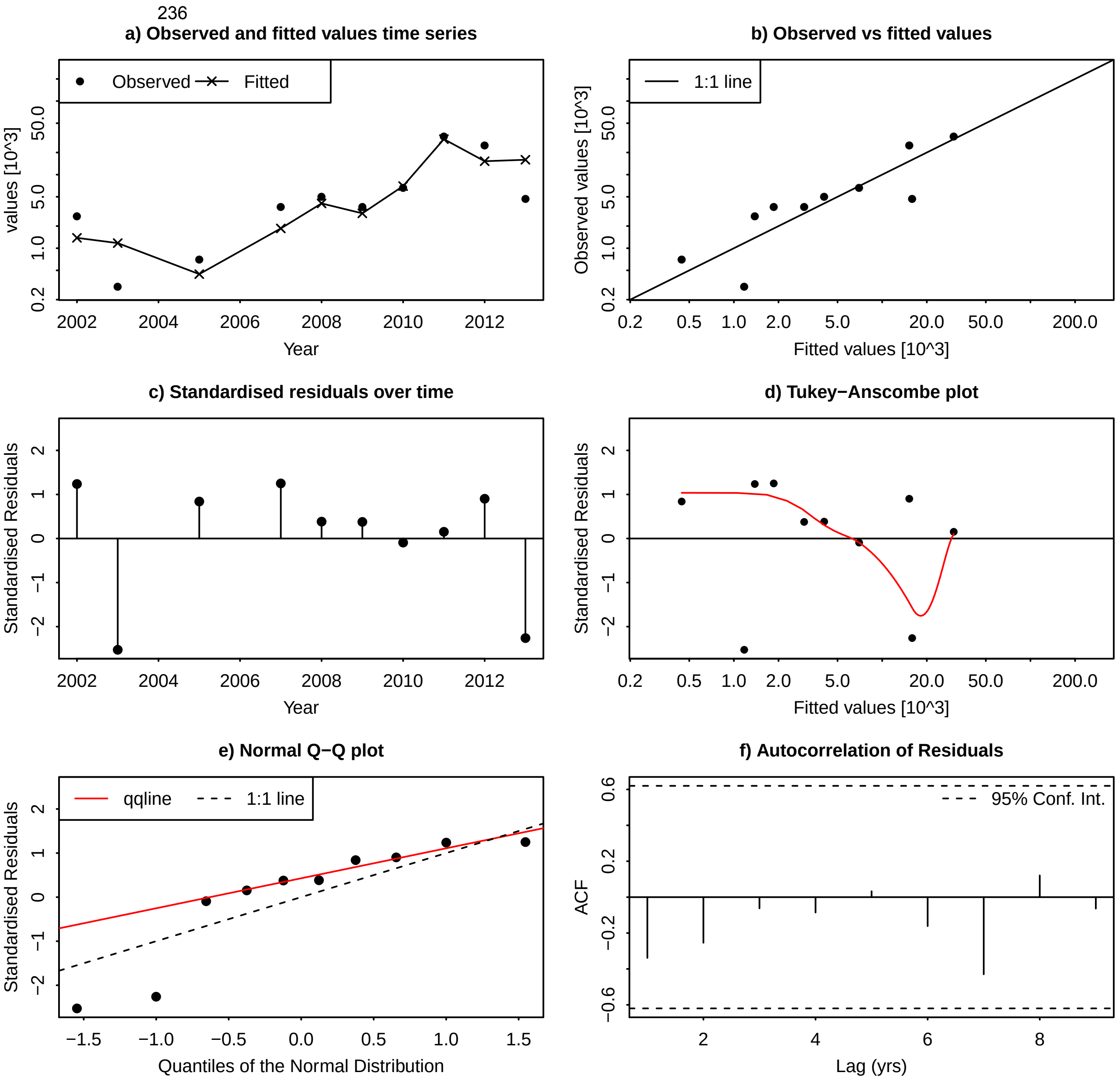

Diagnostics − CS HerAS, age 4
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
10
50
200
1000
2002
2004
2006
2008
2010
2012
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
10
20
50
100
200
500
1000
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
−2
−1
0
1
2
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
−0.6
−0.2
0.2
0.6
2
4
6
8
10
Lag (yrs)


Diagnostics − CS HerAS, age 5
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)



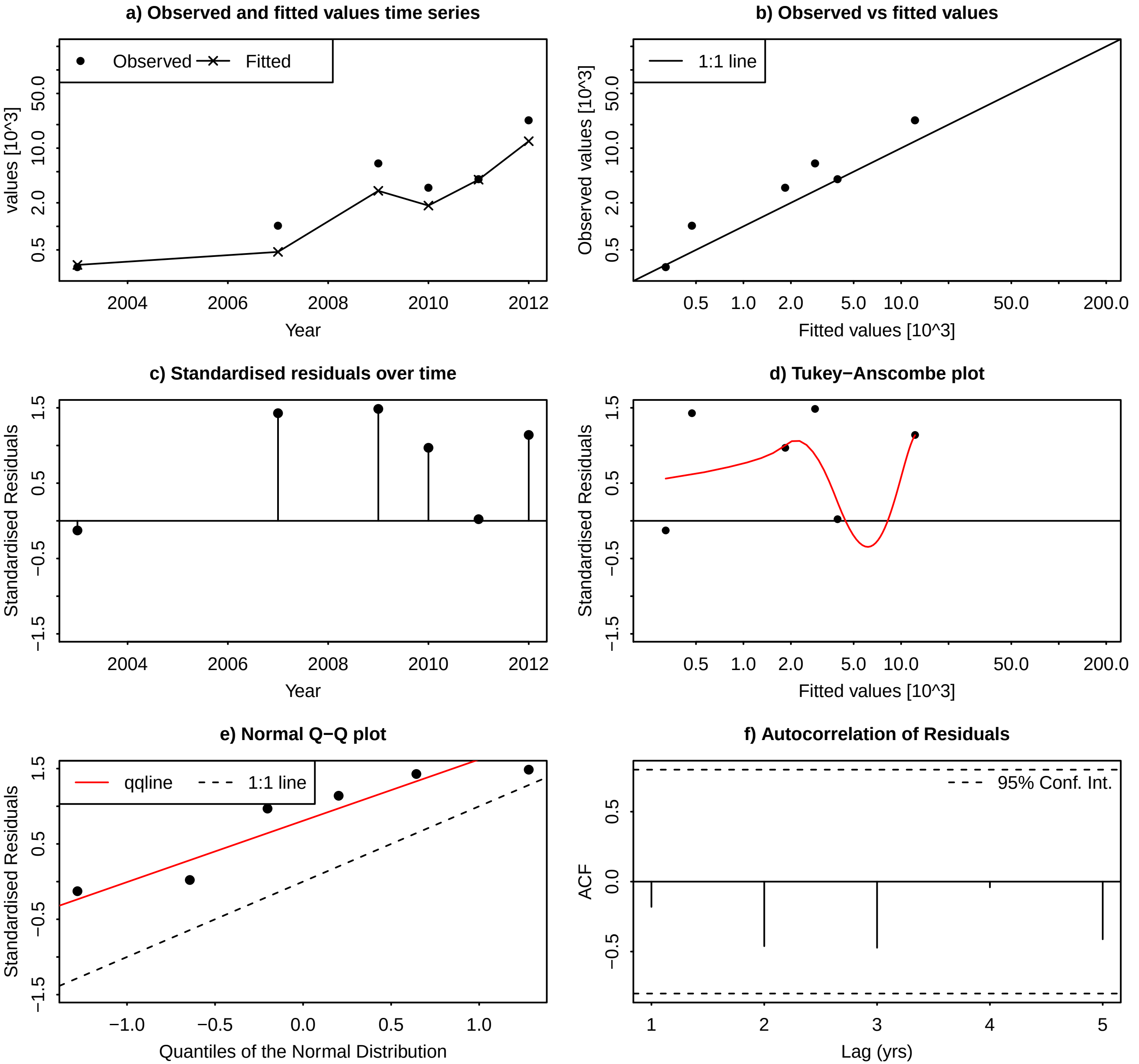
Diagnostics − CS HerAS, age 6
235
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
d) Tukey−Anscombe plot
Standardised Residuals
Fitted values [10^3]
e) Normal Q−Q plot
qqline
1:1 line
Standardised Residuals
Quantiles of the Normal Distribution
f) Autocorrelation of Residuals
95% Conf. Int.
ACF
Lag (yrs)

Diagnostics − CS HerAS, age 7

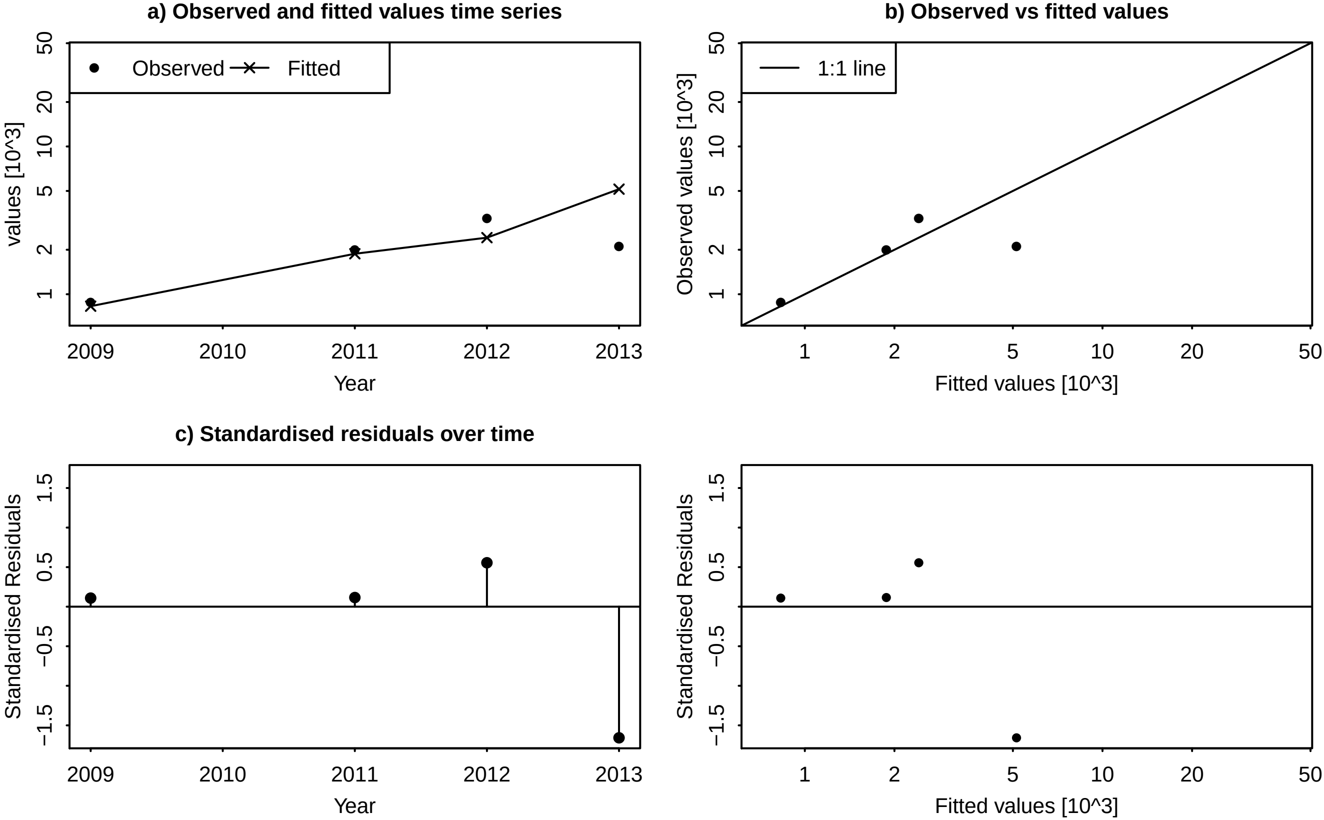


Diagnostics − CS HerAS, age 8

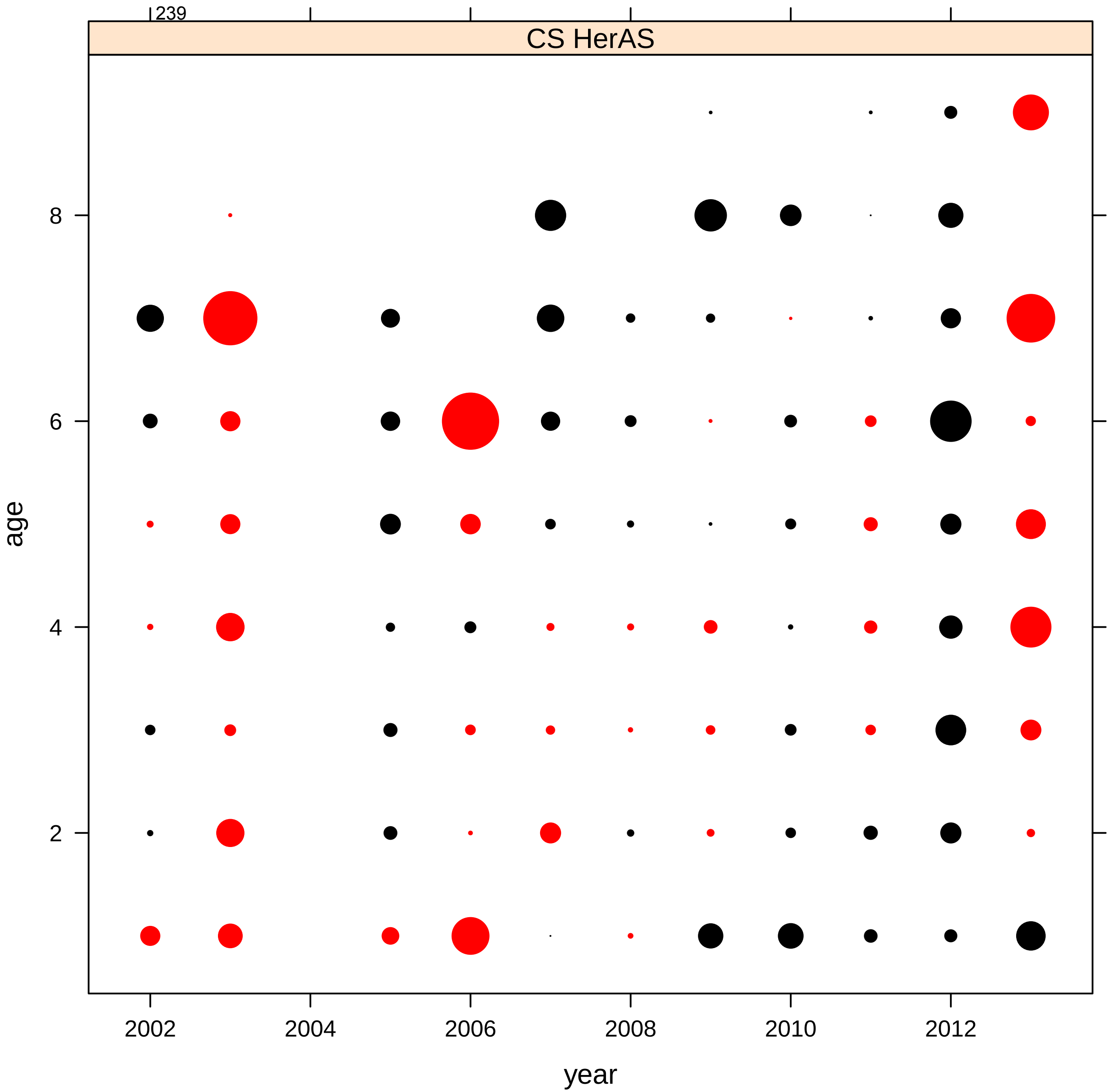
237

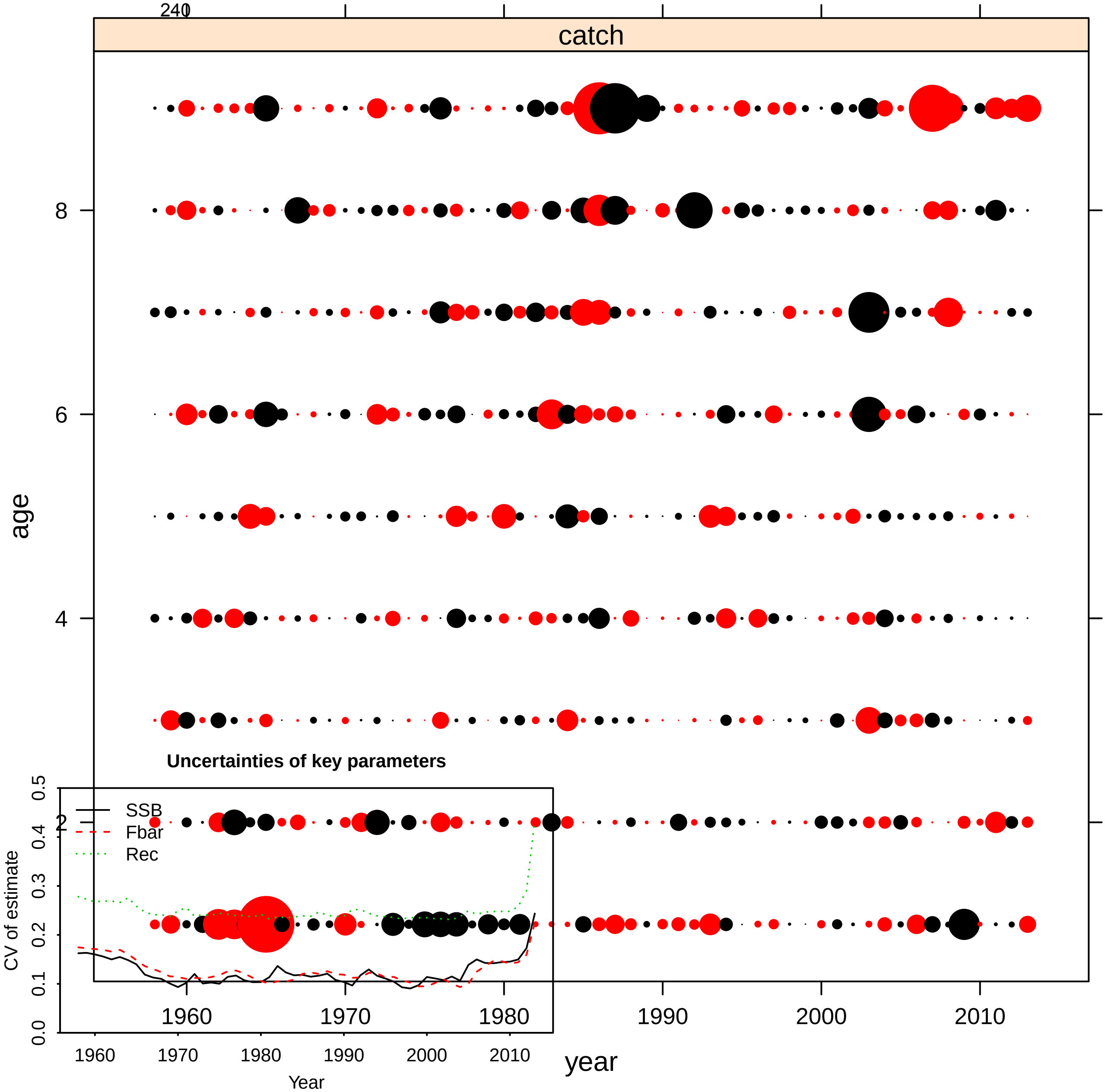


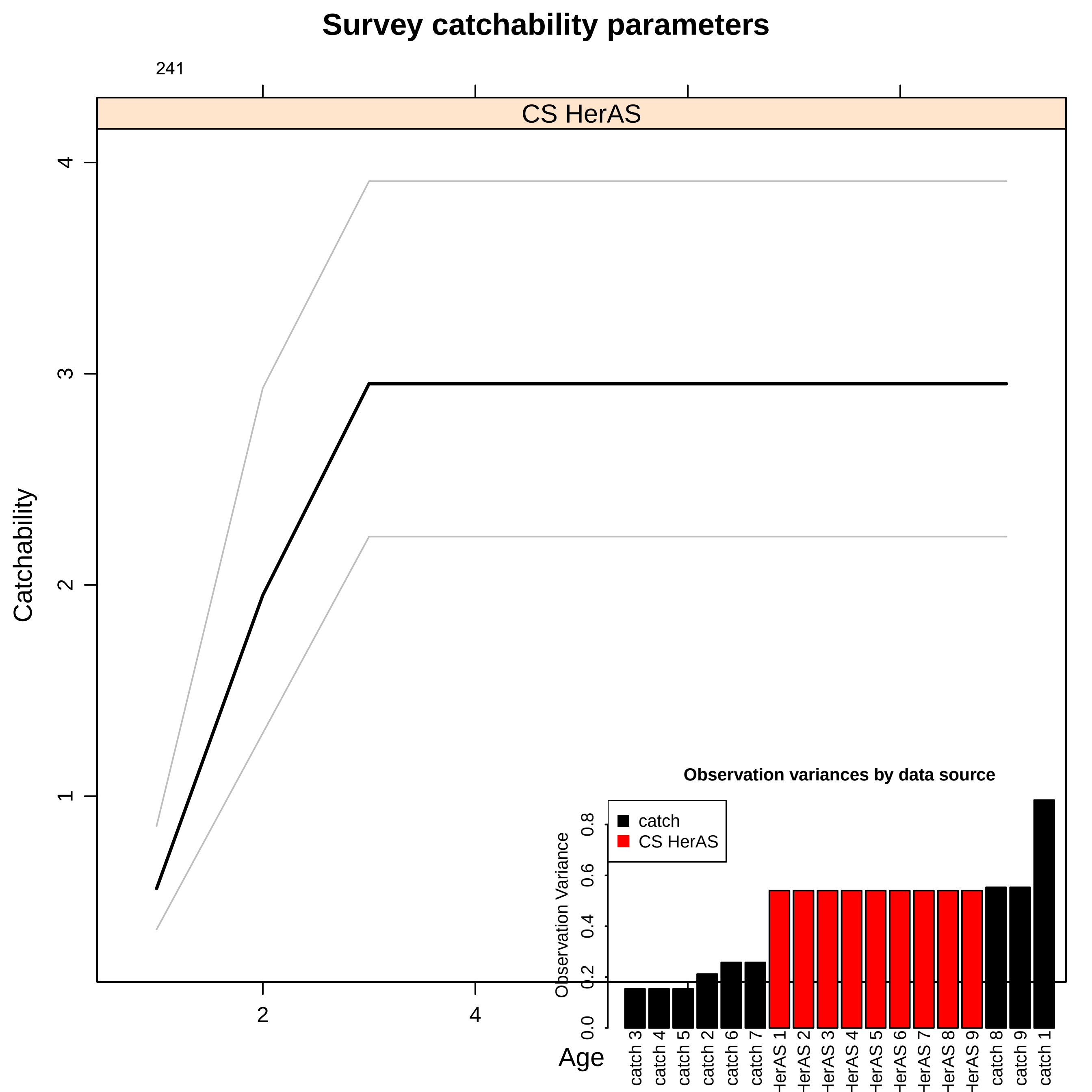
238



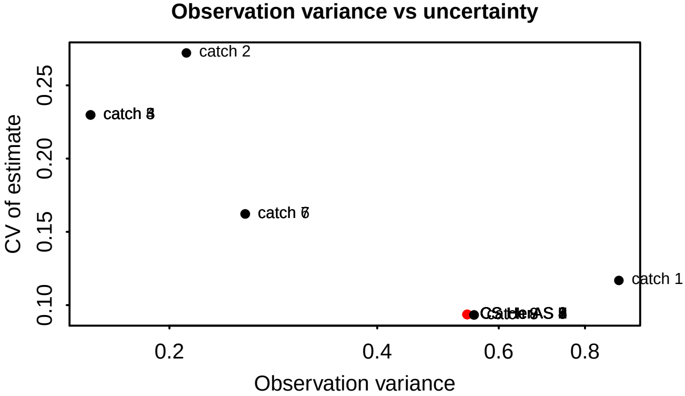
a) Observed and fitted values time series
Observed
Fitted
values [10^3]
Year
b) Observed vs fitted values
1:1 line
Observed values [10^3]
Fitted values [10^3]
c) Standardised residuals over time
Standardised Residuals
Year
Standardised Residuals
Fitted values [10^3]

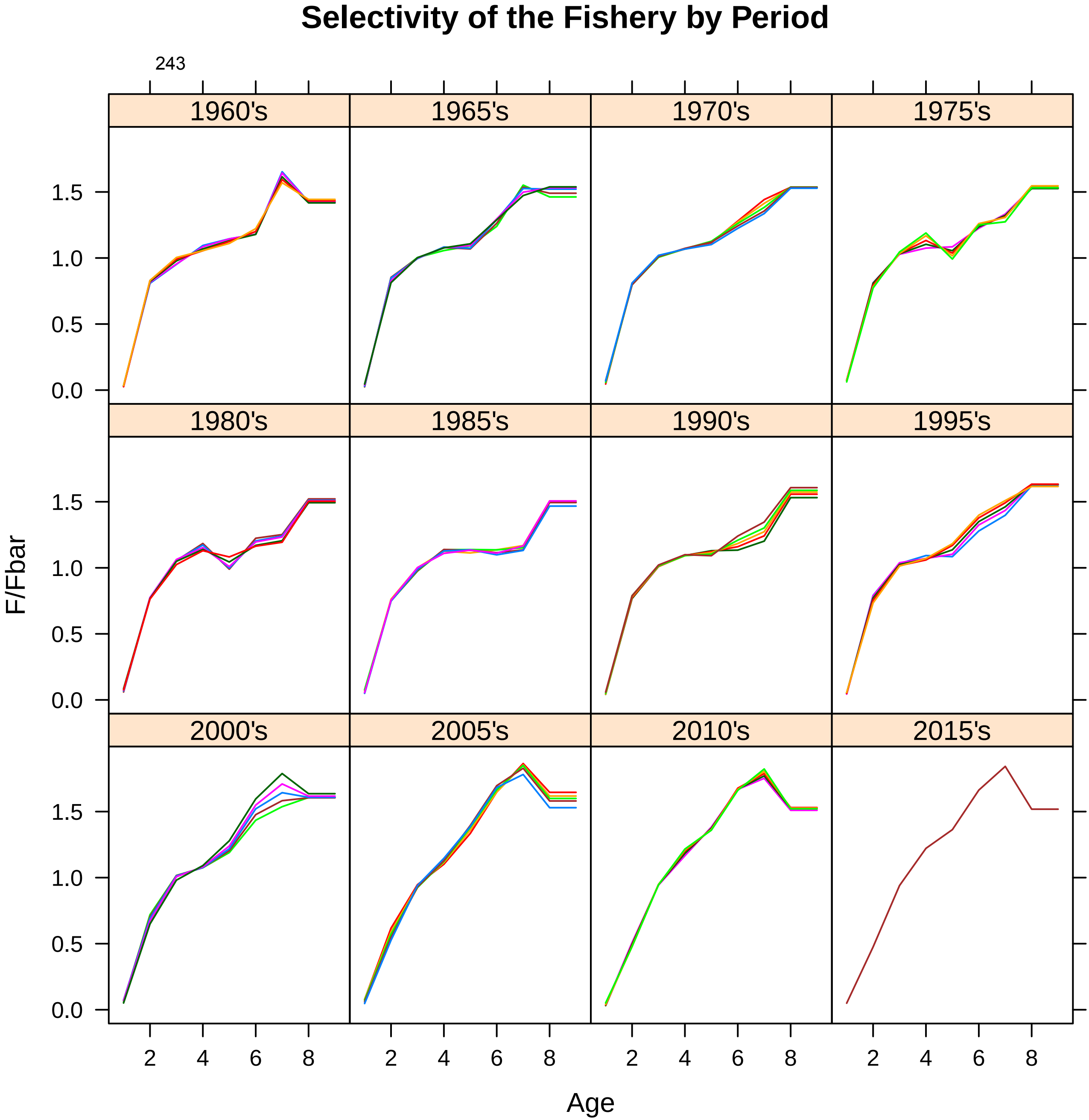

239
CS HerAS
8
6
4
2
age
2002
2004
2006
2008
2010
2012
year

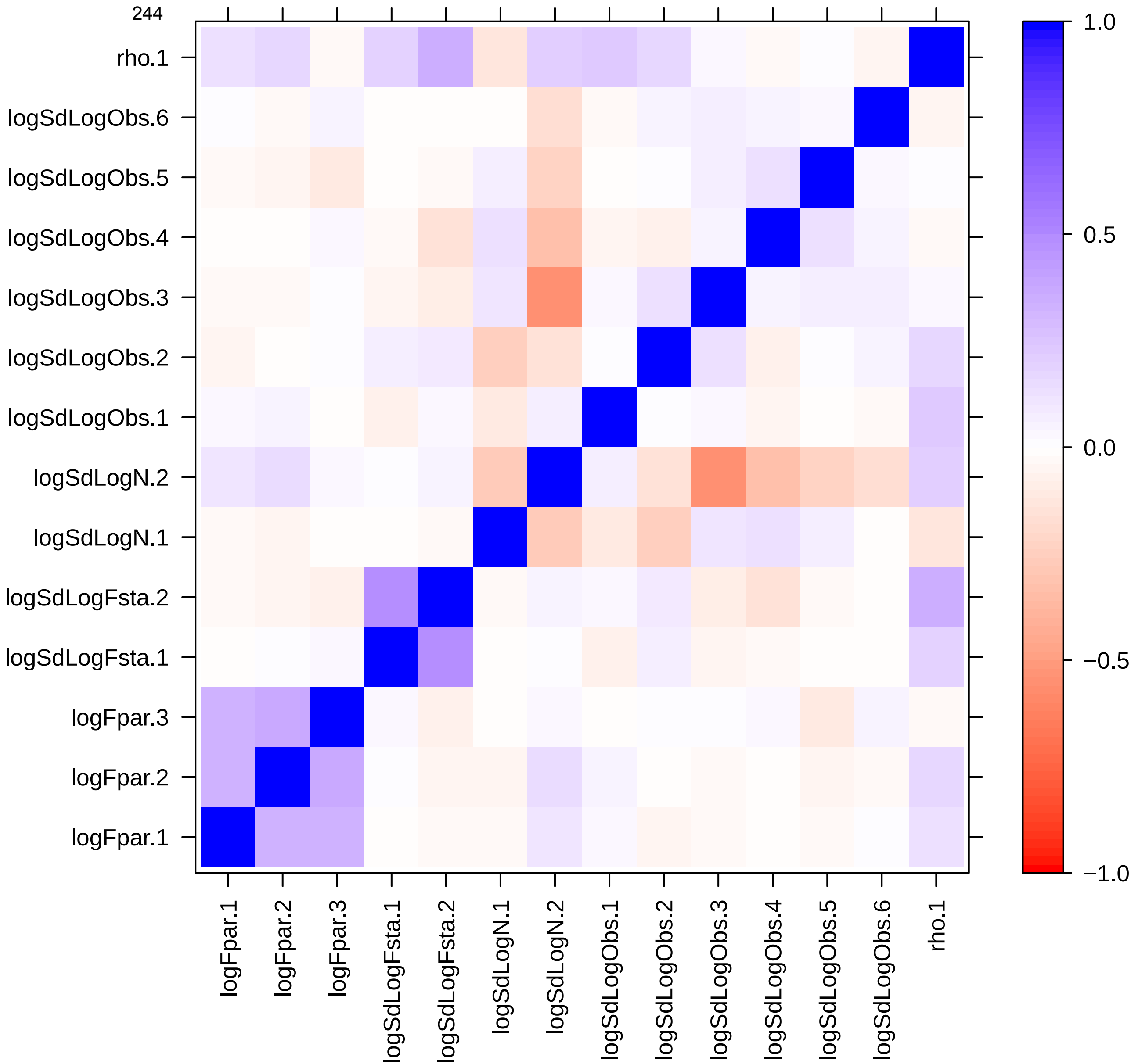

catch
age
8
6
4
2
1960
1970
1980
1990
2000
2010
year
Uncertainties of key parameters
SSB
Fbar
Rec
CV of estimate
0.0
0.1
0.2
0.3
0.4
0.5
Year

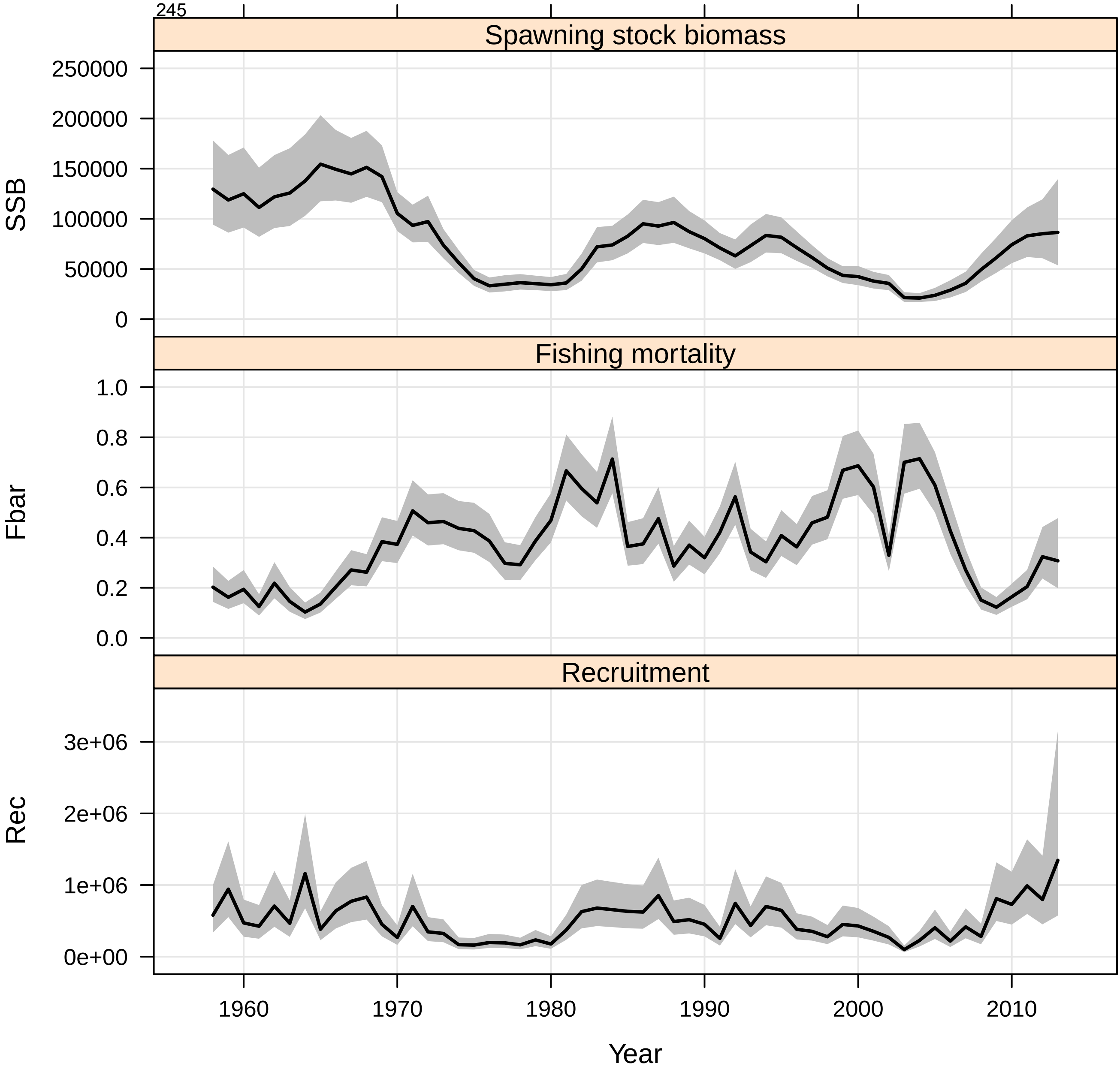


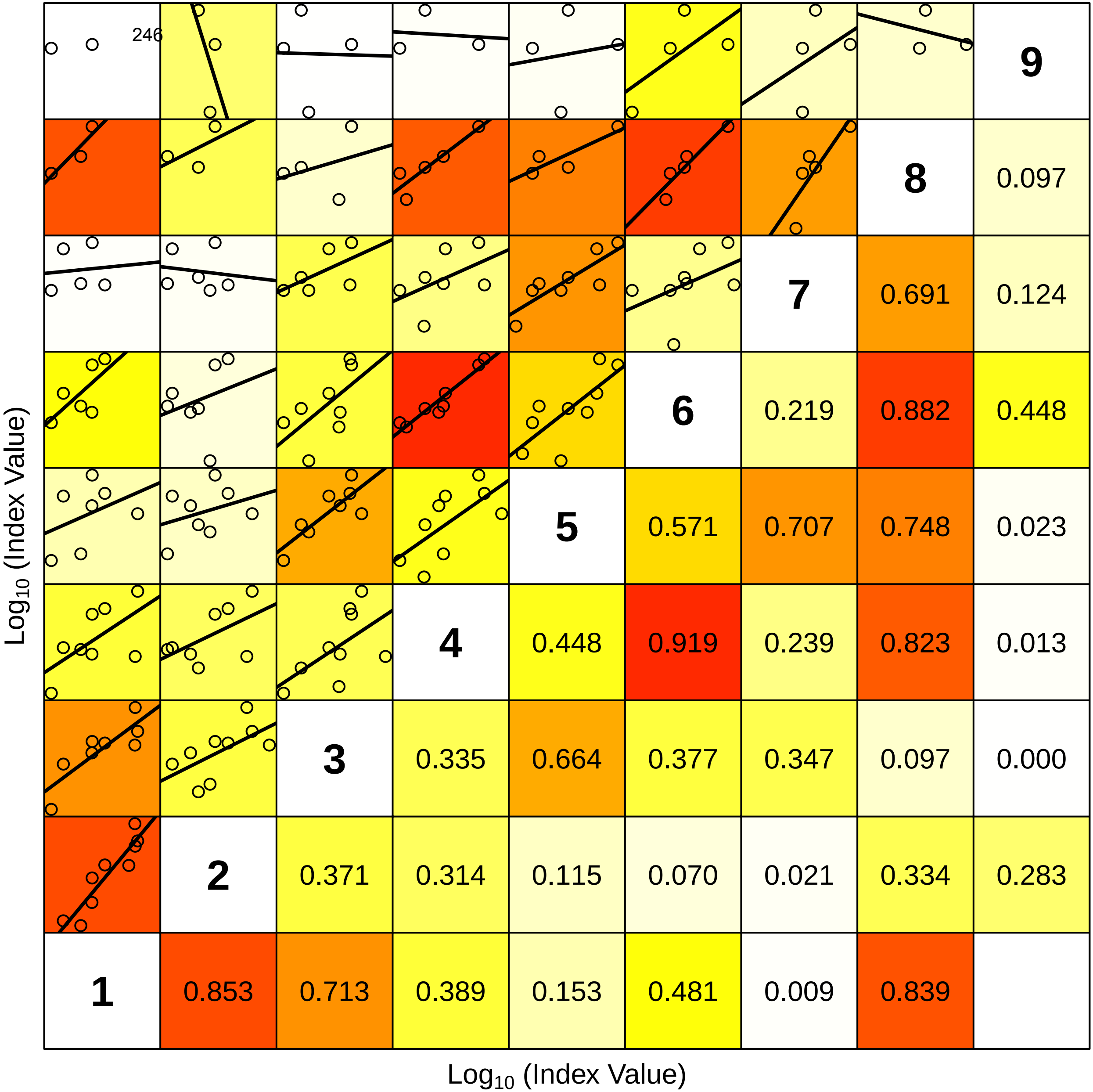
Survey catchability parameters
241
CS HerAS
Catchability
Age
Observation variances by data source
Observation Variance
catch
CS HerAS
catch 3
catch 4
catch 5
catch 2
catch 6
catch 7
catch 8
catch 9
catch 1


Observation variance vs uncertainty
catch 2
catch 3
catch 4
catch 6
catch 7
catch 1
CS-HerAS 1
catch 9
0.10
0.15
0.20
0.25
CV of estimate
0.2
0.4
0.6
0.8
Observation variance

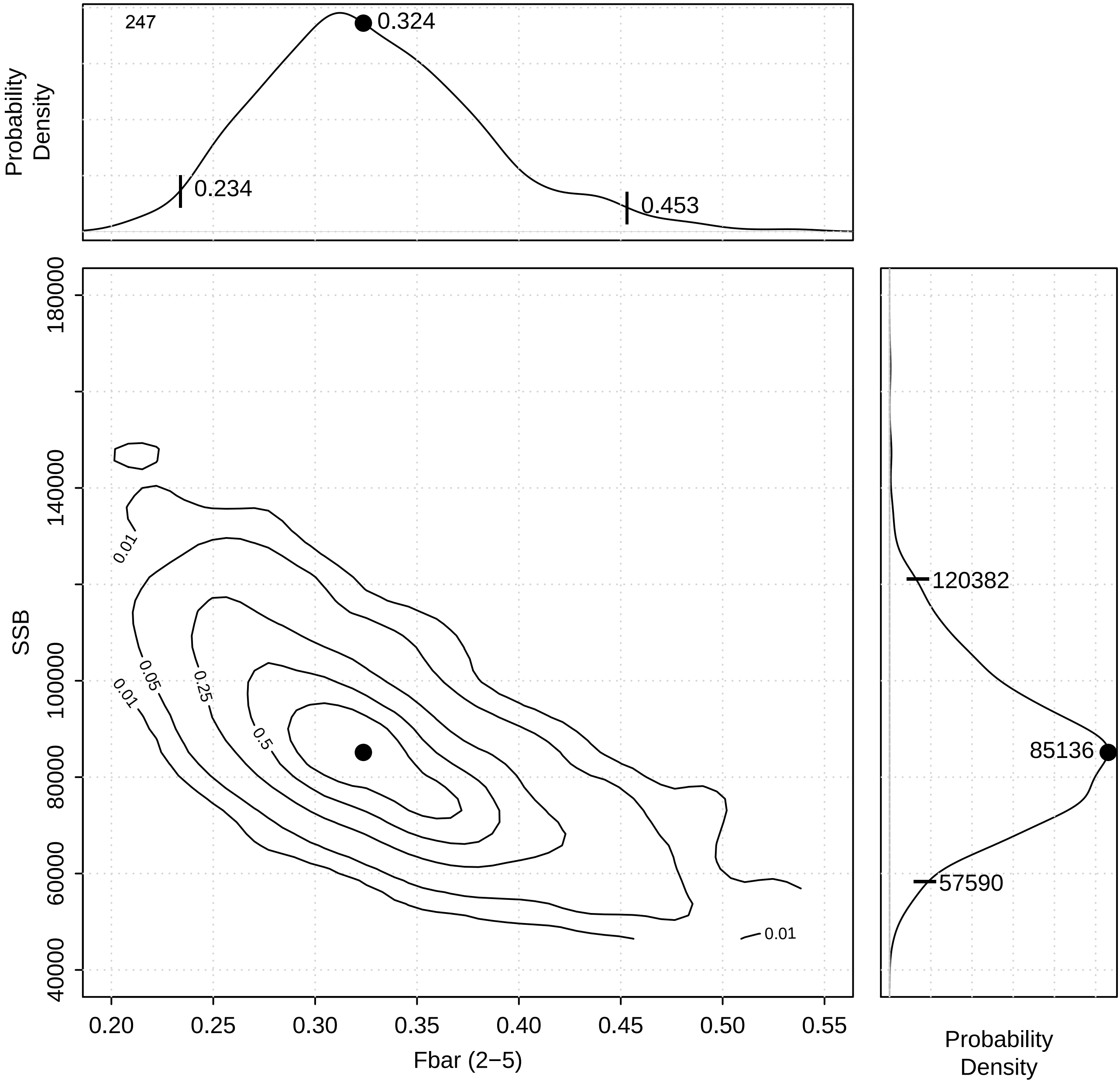

Selectivity of the Fishery by Period
1960's
1965's
1970's
1975's
1980's
1985's
1990's
1995's
2000's
2005's
2010's
2015's
F/Fbar
0.0
0.5
1.0
1.5
Age
2
4
6
8


244
rho.1
logSdLogObs.6
logSdLogObs.5
logSdLogObs.4
logSdLogObs.3
logSdLogObs.2
logSdLogObs.1
logSdLogN.2
logSdLogN.1
logSdLogFsta.2
logSdLogFsta.1
logFpar.3
logFpar.2
logFpar.1
logFpar.1
logFpar.2
logFpar.3
logSdLogFsta.1
logSdLogFsta.2
logSdLogN.1
logSdLogN.2
logSdLogObs.1
logSdLogObs.2
logSdLogObs.3
logSdLogObs.4
logSdLogObs.5
logSdLogObs.6
rho.1
1.0
0.5
0.0
−0.5
−1.0

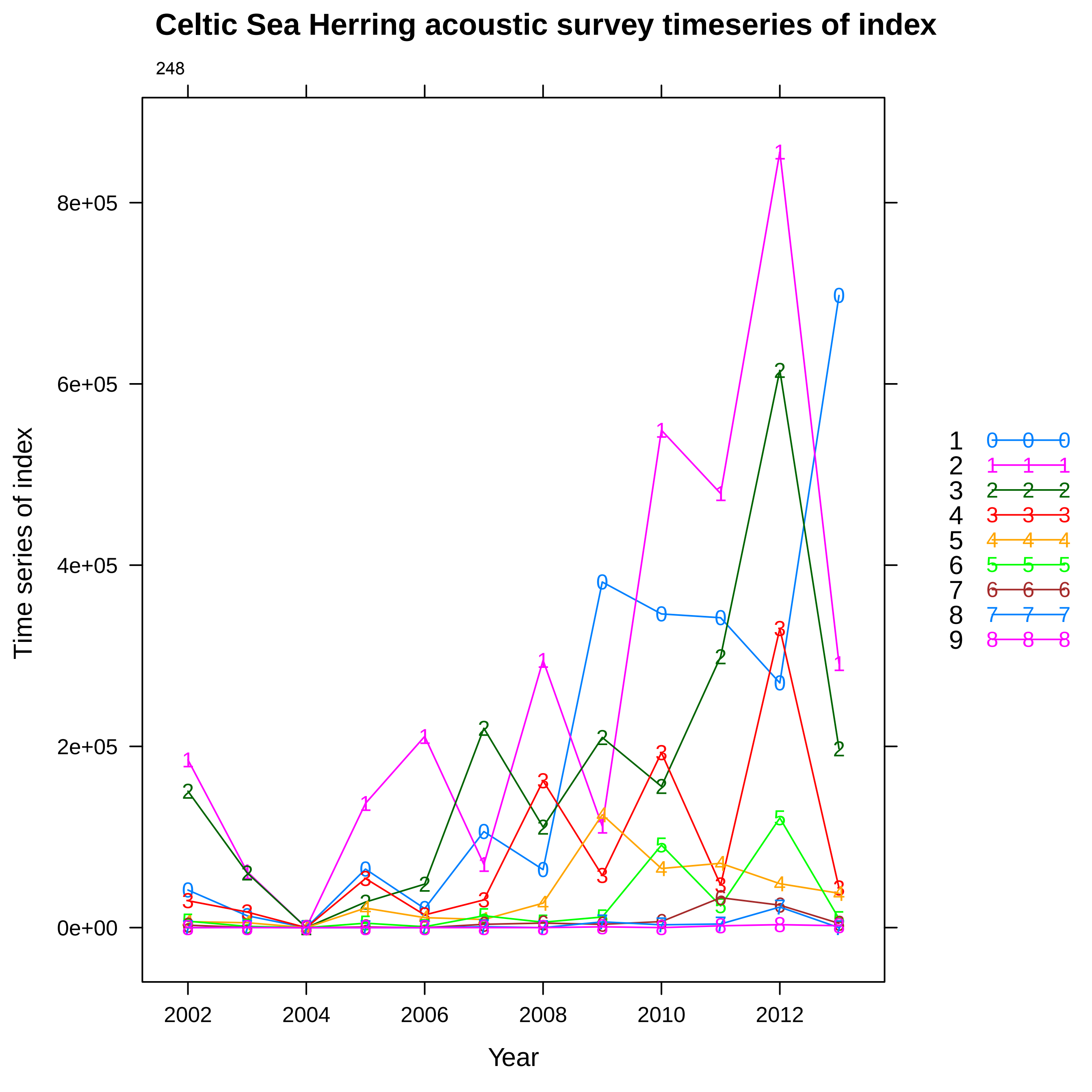

Spawning stock biomass
SSB
250000
200000
150000
100000
50000
0
Fishing mortality
Fbar
1.0
0.8
0.6
0.4
0.2
0.0
Recruitment
Rec
3e+06
2e+06
1e+06
0e+00
1960
1970
1980
1990
2000
2010
Year



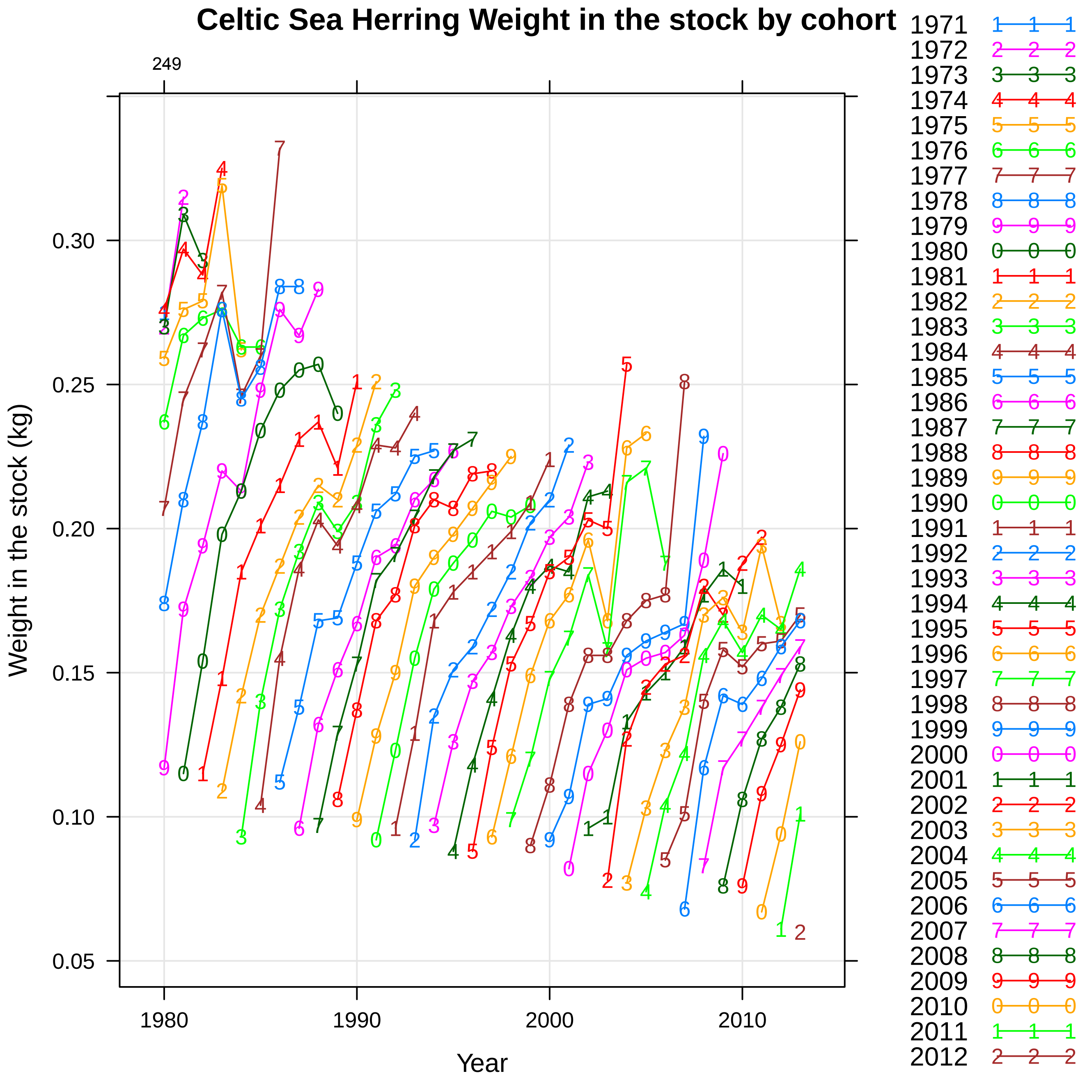
Lower right panels show the Coefficient of Determination (r^2)



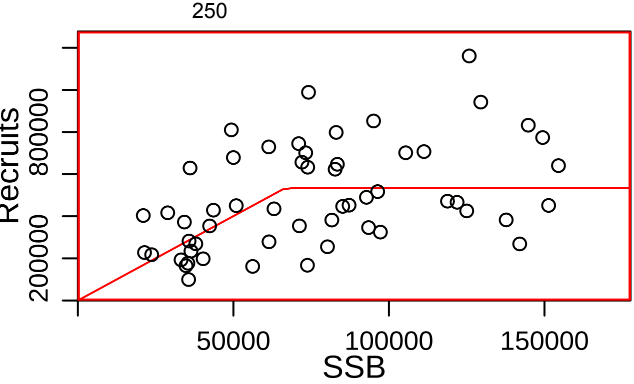
247
0.324
0.234
0.453
Probability Density
SSB
180000
140000
100000
80000
60000
40000
0.01
0.05
0.25
0.5
0.01
0.01
120382
85136
57590
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
Fbar (2−5)
Probability Density

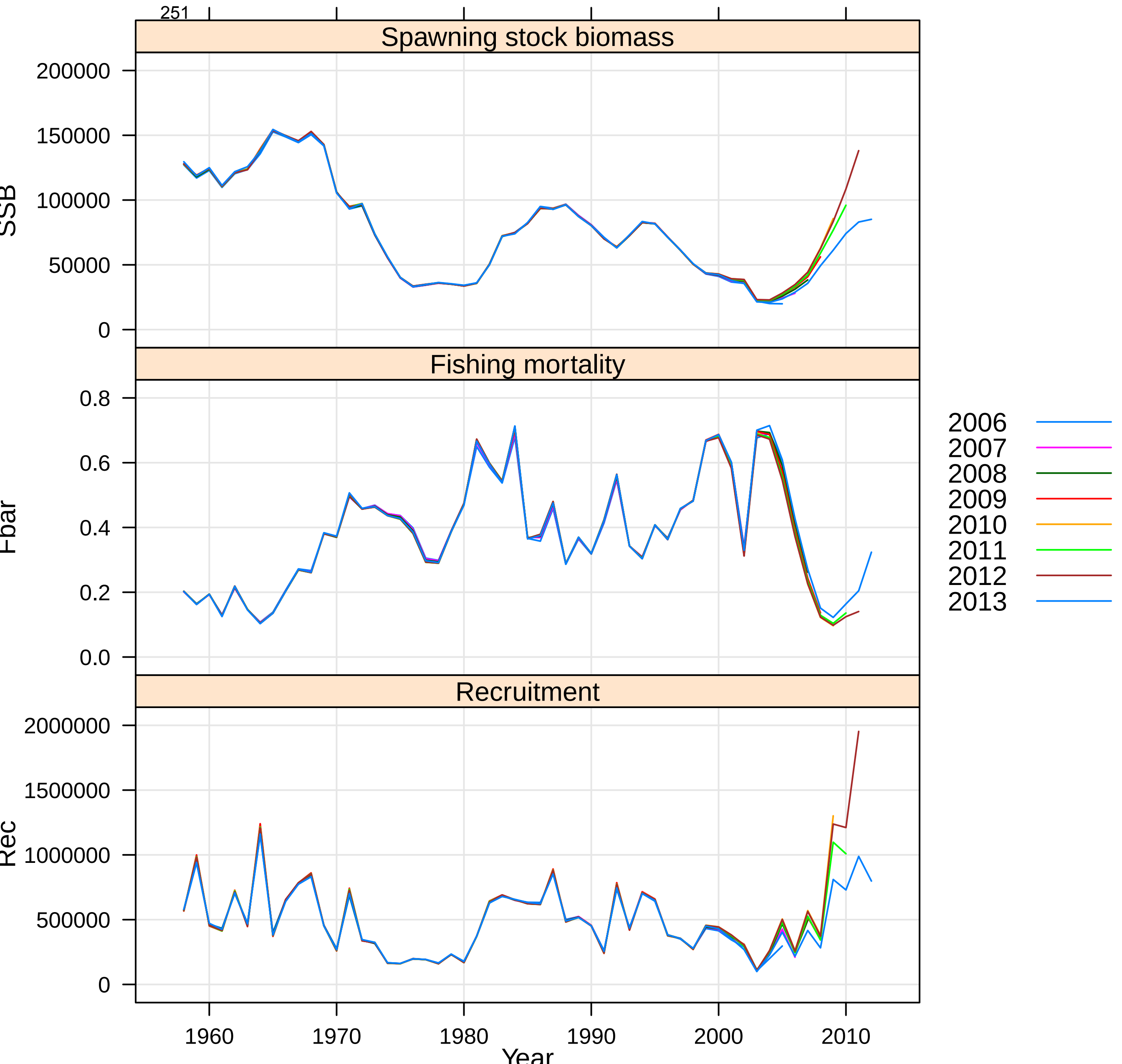


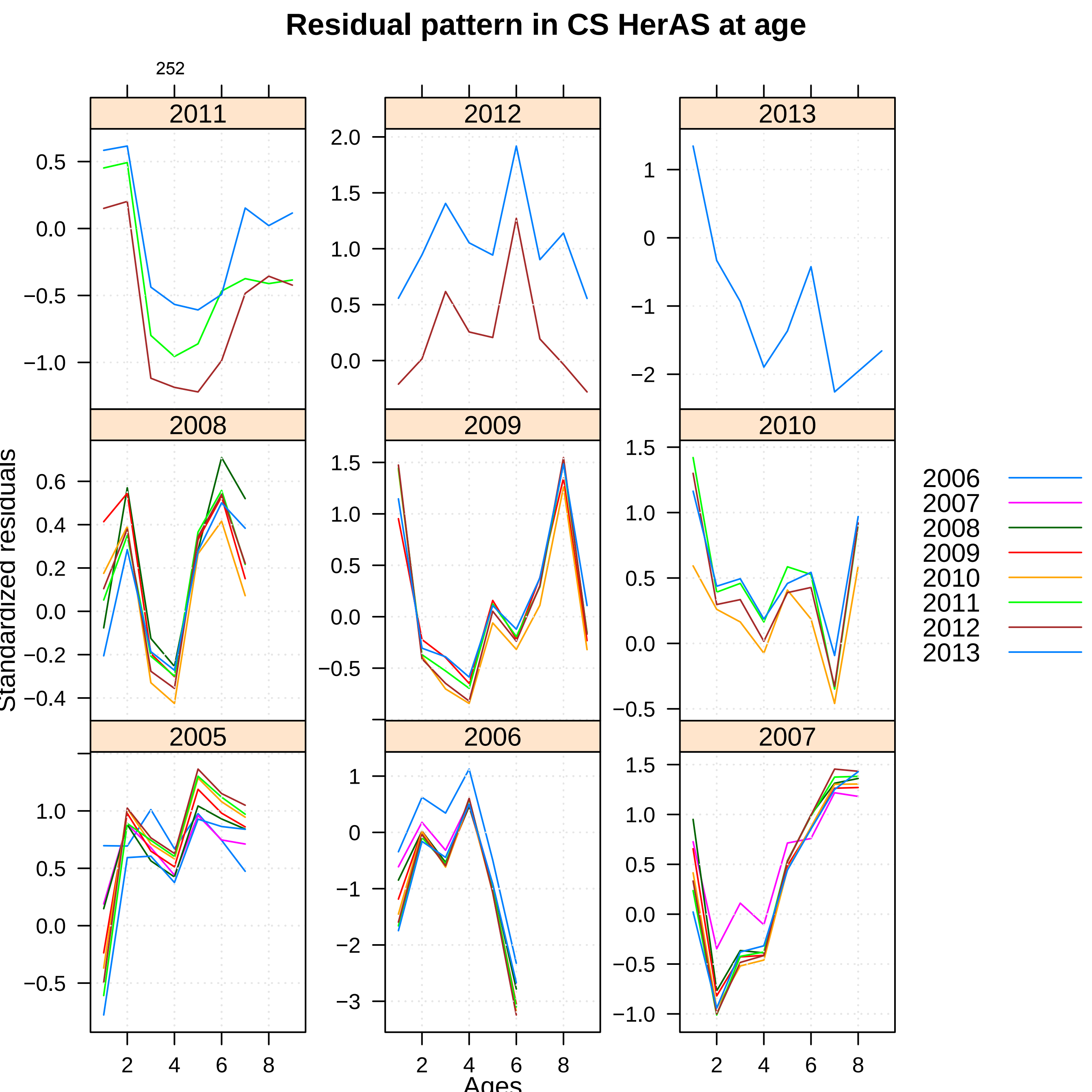
Celtic Sea Herring acoustic survey timeseries of index
248
Time series of index
8e+05
6e+05
4e+05
2e+05
0e+00
2002
2004
2006
2008
2010
2012
Year
1
2
3
4
5
6
7
8
9

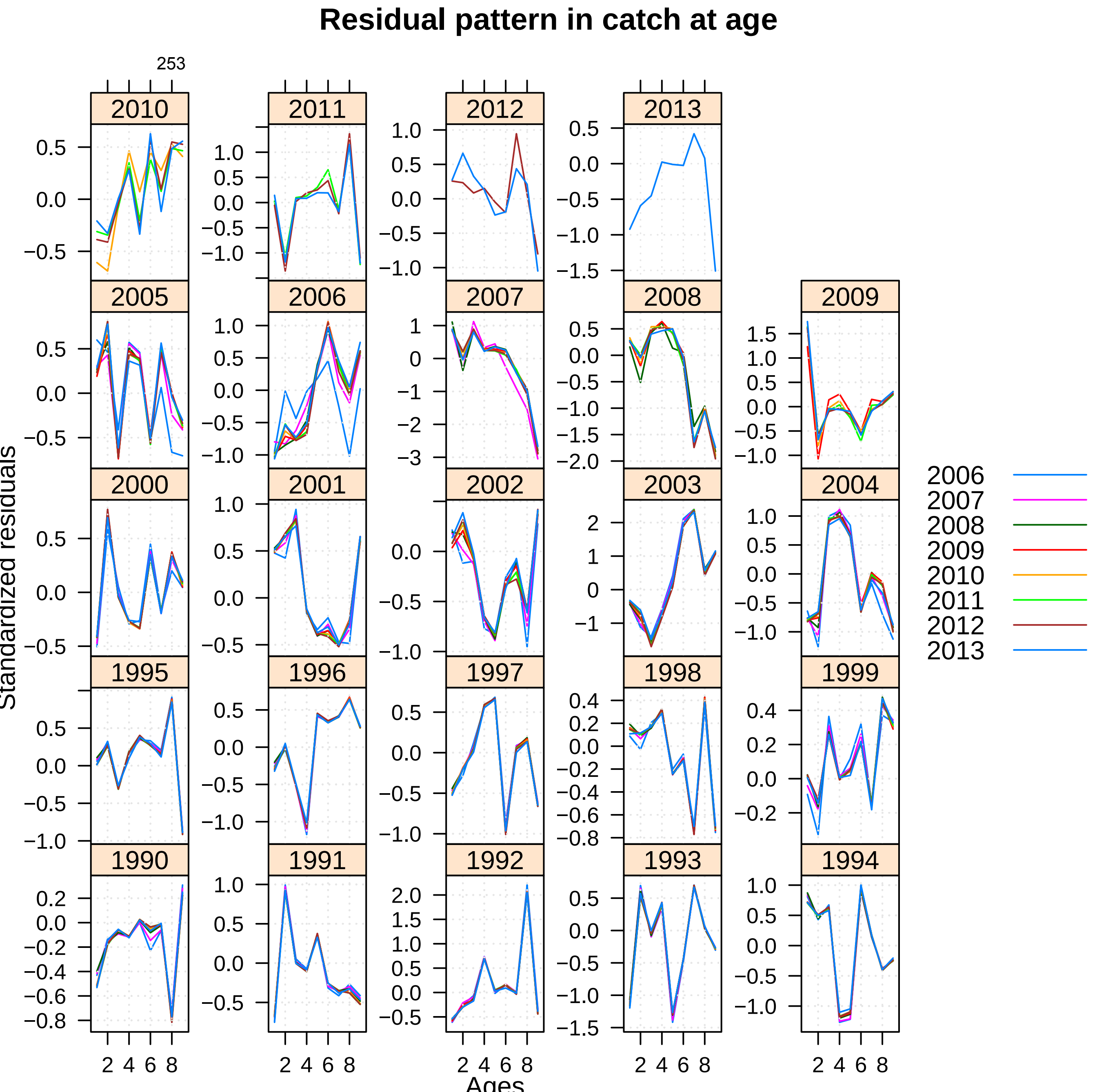

Celtic Sea Herring Weight in the stock by cohort
249
Weight in the stock (kg)
0.05
0.10
0.15
0.20
0.25
0.30
Year
1980
1990
2000
2010
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012

Functional form

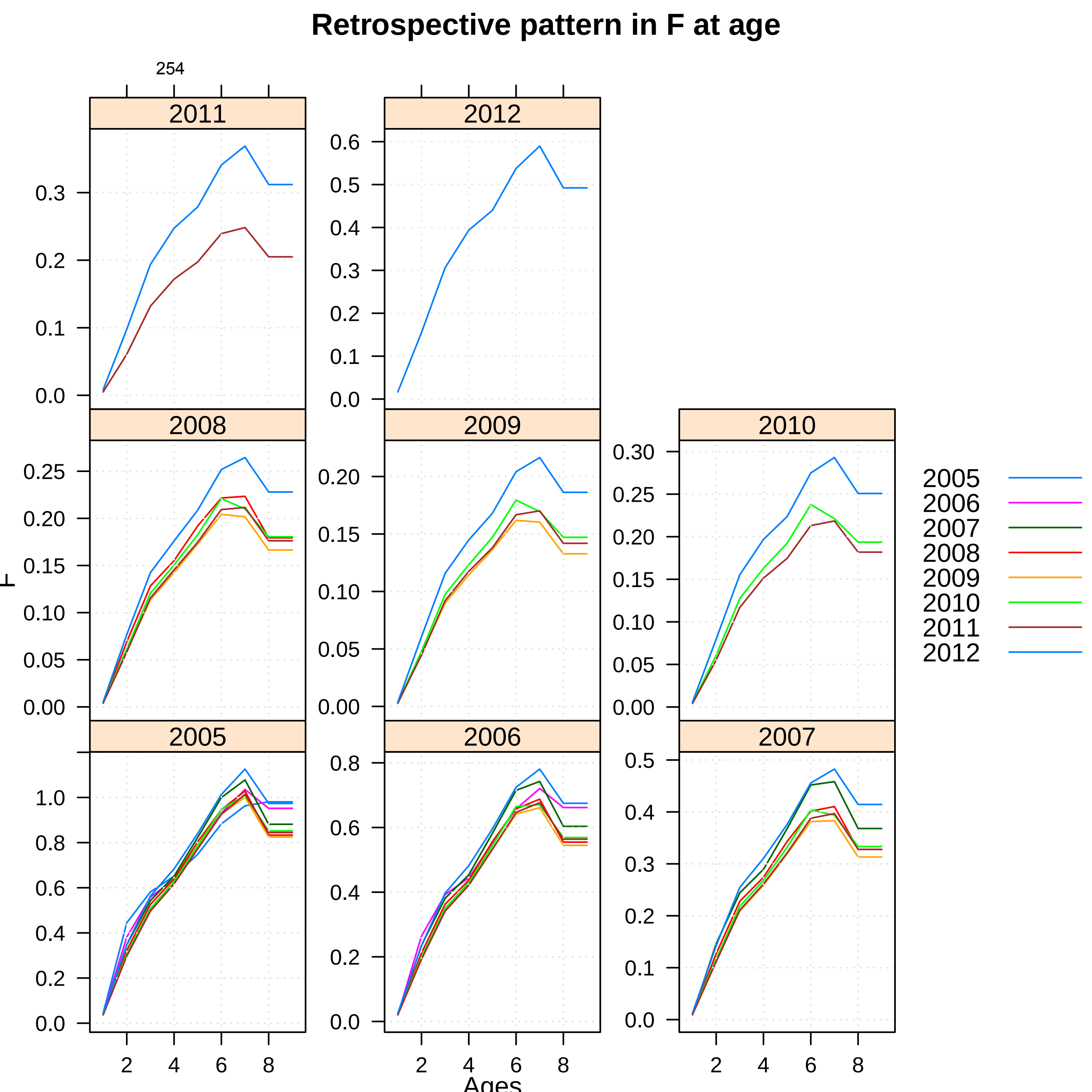



251
Spawning stock biomass
SSB
200000
150000
100000
50000
0
Fishing mortality
Fbar
0.8
0.6
0.4
0.2
0.0
Recruitment
Rec
2000000
1500000
1000000
500000
0
1960
1970
1980
1990
2000
2010
Year
2006
2007
2008
2009
2010
2011
2012
2013


Residual pattern in CS HerAS at age
252
2011
2012
2013
2008
2009
2010
2005
2006
2007
Standardized residuals
Ages
2006
2007
2008
2009
2010
2011
2012
2013



Residual pattern in catch at age
253
2010
2011
2012
2013
2005
2006
2007
2008
2009
2000
2001
2002
2003
2004
1995
1996
1997
1998
1999
1990
1991
1992
1993
1994
Standardized residuals
Ages
2006
2007
2008
2009
2010
2011
2012
2013



Retrospective pattern in F at age
254
2011
2012
2008
2009
2010
2005
2006
2007
F
Ages
2005
2006
2007
2008
2009
2010
2011
2012

Annex 1: Participants list

NAME	ADDRESS	PHONE/FAX	E-MAIL
Thomas Brunel	Wageningen IMARES PO Box 68 1970 AB IJmuiden Netherlands	Phone +31 317 487 161 Fax +31	thomas.brunel@wur.nl
Finlay Burns	Marine Scotland Science 375 Victoria Road Aberdeen AB11 9DB United Kingdom	Phone +44 1 224 29 5376	f.burns@marlab.ac.uk
Andrew Campbell	Marine Institute Rinville Oranmore Co. Galway Ireland	Phone +353 91 387 301 Fax +353 91 387 400	andrew.campbell@marine.ie
Pablo Carrera	Instituto Español de Oceanografía Centro Oceanográfico de Vigo PO Box 1552 36200 Vigo (Pontevedra) Spain		pablo.carrera@vi.ieo.es
Maurice Clarke	Marine Institute Rinville Oranmore Co. Galway Ireland	Phone +353 91387494 Fax +353 91387201	maurice.clarke@marine.ie
Cindy van Damme	Wageningen IMARES PO Box 68 1970 AB IJmuiden Netherlands		cindy.vandamme@wur.nl
Chris Darby	Centre for Environment, Fisheries and Aquaculture Science (Cefas) Lowestoft Laboratory Pakefield Road Lowestoft Suffolk NR33 0HT United Kingdom	Phone +44 1502 524329 /+44 7909 885 157 Fax +44 1502 513865	chris.darby@cefas.co.uk
Jonathan Deroba External Chair	National Marine Fisheries Services Northeast Fisheries Science Center Woods Hole Laboratory 7 M B L St Woods Hole MA 02543 United States	Phone +1 508 495 2310 Fax +1	jonathan.deroba@noaa.gov

Name	Address	Phone/Fax	E-mail
Katja Enberg	Institute of Marine Research PO Box 1870 Nordnes 5817 Bergen Norway	Phone +47 410 06368 Fax +47 5558 4246	katja.enberg@imr.no
Sascha Fassler	Wageningen IMARES PO Box 68 1970 AB IJmuiden Netherlands	Phone +31 317 48 7474	sascha.fassler@wur.nl
Michael Frisk Invited Expert	Stony Brook University 165 Discovery Hall Stony Brook New York 11794-5000 United States	Phone 631 632 3750	Michael.Frisk@stonybrook.edu
Ian Gatt	Scottish Pelagic Fishermen's Association 1 Frithside Street Fraserburgh AB43 9AR United Kingdom		ian.gatt@scottishpelagic.co.uk
Emma Hatfield	Marine Scotland Science 375 Victoria Road Aberdeen AB11 9DB United Kingdom	Phone +44 1 224 295 434 Fax +44 1 224 295511	e.hatfield@marlab.ac.uk
Jan Arge Jacobsen	Faroe Marine Research Institute PO Box 3051 110 Tórshavn Faroe Islands	Phone +298 353900 Fax +298 353901	Janarge@hav.fo
Teunis Jansen	Greenland Institute of Natural Resources Department of Fish and Shellfish Kivioq 2 3900 Nuuk Greenland	Phone +45 33 96 33 00	tej@aqua.dtu.dk
Ciaran Kelly ICES Chair	Marine Institute Rinville Oranmore Co. Galway Ireland	Phone +353 91 387 397 Fax +353 91 387 400	ciaran.kelly@marine.ie
Jeroen van der Kooij	Centre for Environment, Fisheries and Aquaculture Science (Cefas) Pakefield Road Lowestoft Suffolk NR33 0HT United Kingdom	Phone +44 1502 524416 Fax +44 1502 513865	jeroen.vanderkooij@cefas.co.uk

Name	Address	Phone/Fax	E-mail
Alexander Krysov	Knipovich Polar Research Institute of Marine Fisheries and Oceanography(PINRO) 6 Knipovitch Street 183038 Murmansk Russian Federation	Phone +7 (8152) 47 34 24 Fax +47 789 10 518	A_krysov@pinro.ru
Anders Nielsen	DTU Aqua - National Institute of Aquatic Resources Jægersborg Allé 1 2920 Charlottenlund Denmark	Phone +45 35 88 34 54 Fax +45	an@aqua.dtu.dk
Leif Nøttestad	Institute of Marine Research PO Box 1870 Nordnes 5817 Bergen Norway	Phone +47 00 227025 Fax +47 55236809	leif.noettestad@imr.no
Sean O'Donoghue	Killybegs Fishermen's Organisation Ltd. Bruach na Mara St Catherine's Road Killybegs, Co. Donegal Ireland	Phone +353 749 731089	kfo@kfo.ie
Anna Ólafsdóttir	Faroe Marine Research Institute PO Box 3051 110 Tórshavn Faroe Islands	Phone +298-353900 Fax +298	annao@hav.fo
Gudmundur Johann Oskarsson	Marine Research Institute PO Box 1390 121 Reykjavík Iceland	Phone 354 5752000 Fax 354 5752001	gjos@hafro.is
Ken Patterson	European Commission Directorate for Maritime Affairs and Fisheries 200 rue de la Loi B-1049 Brussels Belgium	Phone +32 22 998 227	Kenneth.Patterson@ec.europa.eu
Mark Payne	DTU Aqua - National Institute of Aquatic Resources Section for Fisheries Advice Charlottenlund Slot Jægersborg Alle 1 2920 Charlottenlund Denmark	Phone +45 35 88 34 25 Fax +45 3396 3333	mpa@aqua.dtu.dk

Name	Address	Phone/Fax	E-mail
Søren Lorenzen Post	Greenland Institute of Natural Resources Department of Fish and Shellfish Kivioq 2 3900 Nuuk, Greenland	Phone +45 Fax +45	Sopo@natur.gl
Dave Reid	Marine Institute Rinville Oranmore Co. Galway Ireland	Phone +353 91 387431 Fax +353 91 387201	david.reid@marine.ie
Norbert Rohlf	Thünen Institute Institute for Sea Fisheries Palmaille 9 22767 Hamburg Germany	Phone +49 40 38905 166 Fax +49 40 38905 263	norbert.rohlf@ti.bund.de
Barbara Schoute	ICES H.C. Andersens Blvd. 44–46 1553 Copenhagen V Denmark		barbara@ices.dk
Rob Scott	Centre for Environment, Fisheries and Aquaculture Science (Cefas) Pakefield Road Lowestoft Suffolk NR33 0HT United Kingdom	Phone general +44 (0) 1502 562244	robert.scott@cefas.co.uk
John Simmonds	Netherby West End Kirkbymoorside N Yorkshire YO62 6AD United Kingdom	Phone +44 1751 430695	simmonds@ices.dk
Aril Slotte	Institute of Marine Research PO Box 1870 Nordnes 5817 Bergen Norway	Mobile +47 995 19782	aril.slotte@imr.no
Claus Reedtz Sparrevohn	Danish Pelagic Producers' Organisation Willemoesvej 2 9850 Hirtshals Denmark	Phone +45 Fax +45	crs@pelagisk.dk
Verena Trenkel Invited Expert	Ifremer Nantes Centre PO Box 21105 44311 Nantes Cédex 03 France	Phone +33 240 374157	verena.trenkel@ifremer.fr

NAME	ADDRESS	PHONE/FAX	E-MAIL
Ivan Tretyakov	Knipovich Polar Research Institute of Marine Fisheries and Oceanography(PINRO) 6 Knipovitch Street 183038 Murmansk Russian Federation	Phone +7 8152472469 Fax +7	tis@pinro.ru
Kjell Rong Utne	Institute of Marine Research PO Box 1870 Nordnes 5817 Bergen Norway	Phone +47 Fax +47	kjell.rong.utne@imr.no

Annex 2: WKPELA Terms of Reference

2013/2/ACOM43 A **Benchmark Workshop on Pelagic stocks** (WKPELA), chaired by External Chair Jon Deroba, US and ICES Chair Ciaran Kelly, Ireland, and attended by three invited external experts Kiersti Curti, US, Michael Frisk, US and Verena Trenkel, France will be established and will meet in Copenhagen for a data compilation meeting 30 October–1 November 2013 and in Copenhagen for a five day Benchmark meeting 17–21 February 2014 to:

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

i) Stock identity and migration issues;

ii) Life-history data;

iii) Fishery-dependent and fishery-independent data;

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

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

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

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

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

a) As part of the evaluation:

i) Conduct a 3 day data compilation workshop (DCWK). Stakeholders are invited to contribute data (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality. As part of the data compilation workshop consider the quality of data including discard and estimates of misreporting of landings;

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

	Stock	Assessment Lead	WG
mac-nea	Mackerel in the Northeast Atlantic (combined Southern, Western and North Sea spawning components)	Emma Hatfield	WGWIDE
her-irls	Herring in Division VIIa South of 52° 30′ N and VIIg,h,j,k (Celtic Sea and South of Ireland)	Afra Egan	HAWG

The Benchmark Workshop will report by 1 April 2014 for the attention of ACOM.

Annex 3: Stock Annexes

Stock Annex Northeast Atlantic mackerel

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Mackerel in the Northeast Atlantic
Working Group	Working Group on Widely Distributed Stocks
Date	February 2014
Revised by	WKPELA 2014. T. Brunel, E.M.C. Hatfield, T. Jansen, L. Nottestad, A. Campbell

A. General

A.1. Stock definition

Atlantic mackerel (*Scomber scombrus*) occurs on both sides of the North Atlantic and has traditionally been grouped into five spawning components, some of which have been thought to be isolated natal homing populations. Previous studies have provided no evidence of cross-Atlantic migration and no, or weak, support for isolated spawning components within either side of the North Atlantic (Jansen and Gislason, 2013).

ICES currently uses the term "Northeast Atlantic (NEA) mackerel" to define the mackerel present in the area extending from the Iberian peninsula in the south to the northern Norwegian Sea in the north, and Iceland in the west to the western Baltic Sea in east.

In the Northeast Atlantic, mackerel spawn from the Portuguese waters in the south to Iceland in the north and from Hatton Bank in the west to Kattegat in the east. Spawning starts in January/February in Iberian Peninsula waters and ends in July to the northwest of Scotland and in the North Sea (ICES, 2013a). While spawning varies locally from day to day (Bakken, 1977; Iversen, 1981), it seems to form one large spatio-temporal continuum on the larger scale. However, relatively low levels of spawning in the English and Fair Isle channels separates the main spawning areas in the North Sea from the western areas along the continental shelf edge (Johnston, 1977). Recent studies on distribution, eggs distribution and abundance and mark–recapture experiments (Reid, 1997; Uriarte and Lucio, 2001; Uriarte *et al*., 2001) have questioned the limits of previously established stocks and proposed to consider NEA mackerel as one single stock divided into three spawning components. These components are not completely independent but reproductive exchanges occur, and no differences were observed between these components outside the spawning season. Despite this lack of complete spatial or temporal separation, NEA mackerel is divided into three distinct entities, namely the Southern, Western and North Sea spawning components (ICES 1977; 2013a). Catches cannot be allocated specifically to spawning area components on biological grounds, but by convention; catches from the Southern and Western components are separated according to the areas in which these are taken:

Mackerel in the Northeast Atlantic			
Mainly distributed and fished in ICES Subareas and Divisions IIa, IIIa, IV, V, VI, VII, VIII, and IXa			
Spawning component	**Western**	**Southern**	**North Sea**
Main spawning areas	VI, VII, VIIIa,b,d,e,	VIIIc, IXa	IV, IIIa

The Western component is defined as mackerel spawning in the western area (ICES Divisions and Subareas VI, VII, and VIII a,b,d,e). This component currently accounts for ~75% of the entire Northeast Atlantic stock. Similarly, the Southern component (~22%) is defined as mackerel spawning in the southern area (ICES Divisions VIIIc and IXa). Although the North Sea component has been at an extremely low level since the early 1970s, ICES considers that the North Sea component still exists as a discrete unit (~3%). This component spawns in the North Sea and Skagerrak (ICES Subarea IV and Division IIIaN).

Jansen and Gislason (2013) recently reviewed the concept of spawning components on the basis of spawning and age distribution data. Spawning intensities, proxied by larval abundances, were found to be negatively correlated between the North Sea and Celtic Sea, which indicates that the two spawning components may be connected by substantial straying. This finding was based on unique larvae samples collected before the collapse of North Sea component, thus showing that the exchange is not a recent phenomenon due to the collapse. Furthermore, analyses of old as well as more recent age distributions showed that strong year classes spread into other areas where they spawn as adults (i.e. "twinning"). The authors found that this was in accordance with the lack of solid evidence of stock separation from previous analyses of tagging data, genetics, ectoparasite infections, otolith shapes, and blood phenotypes. Because no method has been able to identify the origin of spawning mackerel unequivocally from any of the traditional spawning components, and in the light of their results, they concluded that straying outweighs spatial segregation. Jansen and Gislason (2013) therefore proposed a new model where the population structure of mackerel was described as a dynamic cline, rather than as connected contingents. Temporal changes in hydrography and mackerel behaviour may affect the steepness of the cline at various locations (Jansen *et al.*, 2013; Jansen and Gislason, 2013; Jansen *et al.*, 2013).

A.2. Fishery

As a widely distributed and migratory species, NEA Mackerel is exploited over a wide geographic range throughout the year. Significant fisheries extend from the Gulf of Cadiz, along the western and northern Iberian costs, through the Bay of Biscay, S, W and N of the United Kingdom and Ireland, into the northern North Sea and the Norwegian Sea and, in more recent years as far north as 72°N and west into Icelandic and east Greenland waters.

The fishery is international and, as such it is exploited by several nations using a variety of techniques determined by both the national fleet structure and the behaviour of the mackerel. At the onset of the spawning migration, large mackerel shoals move out of the northern North Sea initially to the west before moving south down the west coast of Scotland and Ireland. The timing of this migration is variable but generally occurs around the end of quarter 4 and the start of quarter 1. During this time, they are targeted primarily by Scottish and Irish pelagic trawlers with RSW tanks and also freezer (factory) vessels (primarily Dutch and German). Prior to the onset of this migration the mackerel are overwintering, relatively static and are targeted by a large

Norwegian purse-seine fleet. During summer the mackerel are more widely dispersed as they feed in Northern waters. At this time Russian pelagic freezer trawlers and in more recent times Icelandic, Faroese and Greenlandic pelagic vessels are active. The southern fishery takes place at the start of the spawning season upon completion of the spawning migration. The Spanish fleet is comprised of both bottom and pelagic trawlers and also a large artisanal fleet. There are other smaller scale fisheries such as a Norwegian gillnet fleet and an English handline fleet that operates in the otherwise restricted area known as the Cornwall box.

There exists a number of national and international agreements to control the exploitation of the NEA Mackerel stock. Targeted fishing is prohibited in the North Sea with the purpose of protecting the North Sea stock component which has failed to recover from extremely heavy exploitation during the 1970s. The Cornwall box is an area off the SW coat of England that is a known juvenile area. It supported a very large fishery prior to its introduction in the early 1980s after which the only permitted fishing in this area is by handliners. A number of countries have discard prohibition. Unfortunately, there has been no overarching agreement in the most recent period which would permit control of the overall exploitation and catches have exceeded advice.

A.3. Ecosystem and behavioural aspects

A.3.1. Feeding

Post larval mackerel feed on a variety of zooplankton and small fish. They prefer larger prey species over smaller prey (Pepin *et al.*, 1987; Langoy *et al.*, 2006). Feeding patterns vary seasonally, spatially and with size. Mackerel stops feeding almost completely during winter. Main zooplankton prey species in the North Sea are: Copepods (mainly *Calanus finmarchicus*), euphausiids (mainly *Meganyctiphanes norvegica*), while primary fish prey species are: sandeel, herring, sprat, and Norway pout (Walsh and Rankine, 1979; Mehl and Westgård, 1983; ICES, 1989; ICES, 1997a). In the Norwegian Sea euphausiids, copepods (mainly *Calanus finmarchicus* and *Oithona*), *Limacina retroversa, Maurolicus muelleri,* amphipods, Appendicularia and capelin are the main diet during the summer feeding migration (Langoy *et al.*, 2006; Prokopchuk, 2006; Langoy *et al.*, 2010).

In the North Sea, mackerel and horse mackerel are responsible for virtually all of the predation on 0-group herring as well as a large part of the consumption of 0-group Norway pout and of all ages of sandeel (ICES, 2008b). Mackerel has also fed opportunistically on available NSS herring larvae along the continental shelf coast of Norway (Skaret *et al.*, 2014). This may have a significant impact on the herring larval survival rate, and largely depends upon the degree of overlap in time and space, which can vary from year to year.

Spatial and temporal overlap between NEA mackerel and Norwegian spring-spawning herring particularly in the outskirts or periphery of mackerel distribution (northern Faroese, Icelandic and Jan Mayen waters) may cause increased interspecific competition between mackerel and herring for preferred food such as *Calanus finmarchicus* (Debes *et al.*, 2012; Langøy *et al.*, 2012; Óskarsson *et al.*, 2012). Mackerel may partly outcompete herring during summer because mackerel are generally larger, faster, more enduring when migrating and more effective plankton eaters, including a wider food niche (wider diet breadth) than herring (Nøttestad *et al.*, 2012). Mackerel may thus both compete better for preferred zooplankton species and size fractions as well as better utilize smaller plankton species available in the northern part of the Northeast Atlantic Ocean compared with herring.

The mackerel seems to be very opportunistic, and from one year to the next they may exploit any available oceanic areas for feeding purposes (Langøy *et al.*, 2012). A westwards and northwards expansion has been observed in the Nordic Seas in recent years (since 2007), as far as Icelandic and south Greenlandic waters in the west and as far north as Spitzbergen (Nøttestad, 2014). Historically, expansions into Icelandic waters are known to coincide with periods of warm waters (Astthorsson *et al.*, 2012).

The dynamics and environmental drivers of the mackerel summer distribution are not yet uncovered. Surveys in recent years indicate substantial interannual variation and provides hypothesis on relations to temperature and food (Holst and Iversen, 1992; Holst and Iversen, 1999; Gill, *et al.*, 2004; ICES, 2006b; ICES, 2007b; ICES, 2009; ICES, 2009). When the mackerel stock is large (as in the recent years) and plankton abundance is low, mackerel has to spread out further to the north and to the west to forage on suitable plankton aggregations. The record high surface temperatures observed in the Nordic Seas during summer in recent years (Hughes *et al.*, 2011; Nøttestad *et al.*, 2012) made this expansion possible and has resulted in an increase in the potential feeding habitat for mackerel (as defined by water temperatures above 6°C).

A.3.2. Spawning

Even though spawning occurs widely on the shelf and shelf edge from the Bay of Biscay to the southern Norwegian Sea, most of the egg production is concentrated in two core spawning areas (Figure A.3.2.1). One elongated area along the shelf break from Spanish and Portuguese waters in January to March, and one around southwest Ireland to the west of Scotland where spawning peaked in April (Beare and Reid, 2002; Iversen, 2002) but the spawning peak has shifted to March in the most recent years. In the central North Sea spawning takes place in May–July.

Spawning activity along the shelf edge has varied to the north and to the south at various times over the decades since the 1980s although the centre of gravity of spawning has remained relatively stable off the southwest of Ireland over this period (Hughes, 2013; Beare and Reid, 2002) In the North Sea there is a westward shift in the main spawning area from the central part of the North Sea in the early 1980s to the western part in recent years (2005 and 2008) (Anon, 2009).

In the recent period (since the 2007 survey) an expansion of the spawning distribution for the western spawning component has been observed (ICES, 2013b). Spawning occurs now further to the west (up to 20° of latitude west) and to the north (up to the southern Norwegian Sea) (ICES, 2013b; Nøttestad *et al.*, 2012; 2013). However, most of the egg production of the western component remains in the traditional spawning grounds, located on the shelf edge in the southwest of Ireland to the west of Scotland. The egg production in the new areas remains marginal. The causes of this geographical expansion of spawning remain unclear, but are suspected to be triggered by the increase in the stock size (i.e. density-dependent space occupation) coupled with changes in the potential spawning habitat linked to environmental conditions (ICES, 2013b). As a consequence of this expansion of spawning to the North, juveniles 0-group mackerel are now found in the Nordic seas (Iceland, Barents sea, ICES 2013a).

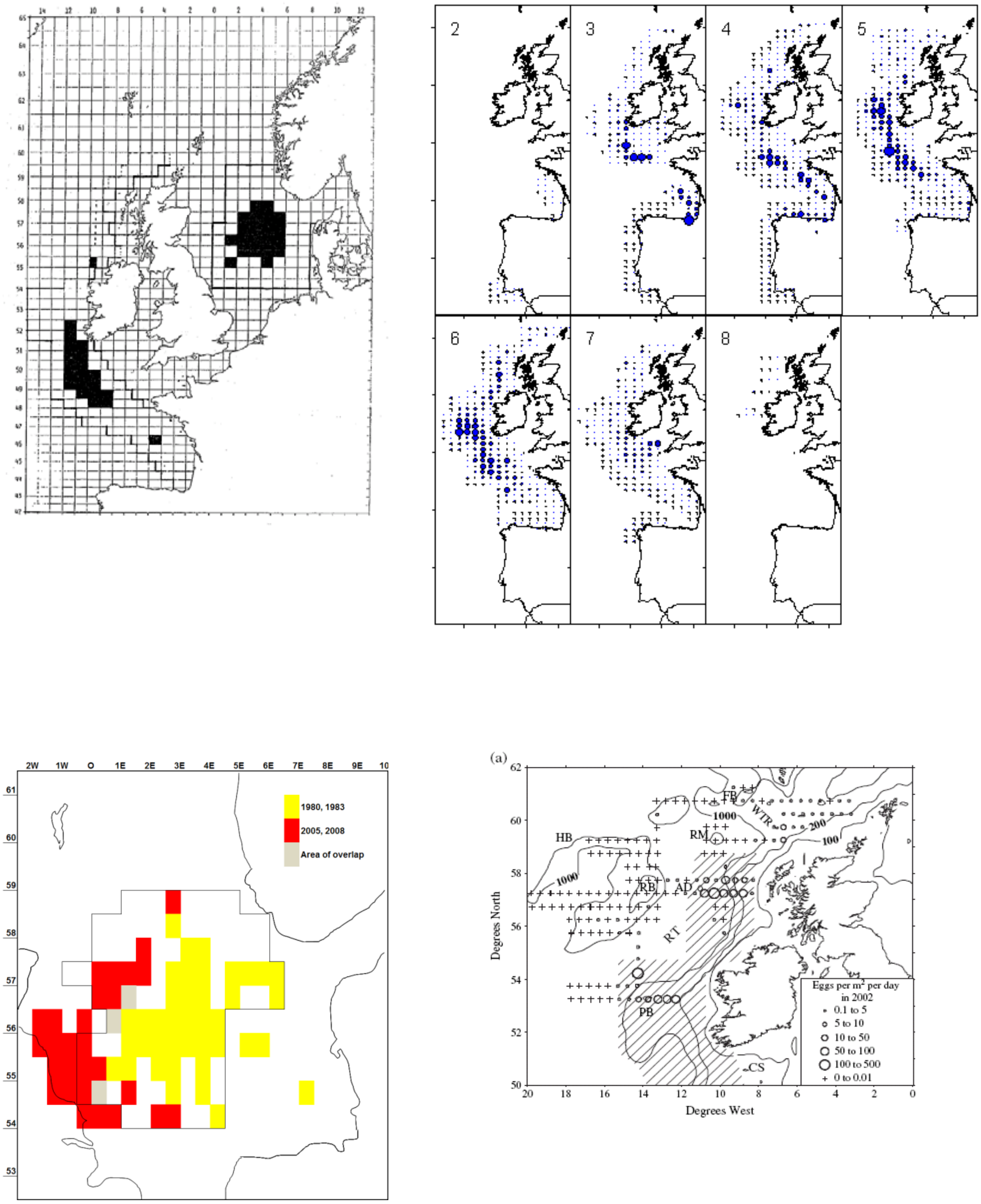


Figure A.3.2.1. NEA mackerel spawning areas. Upper left: Shaded areas indicate 100 eggs/m^2 in at least two of the years in the period 1977–1988 (from (ICES, 1990)). Upper right: Average distribution of mackerel eggs by ICES statistical rectangle in 1992–2007, each map represents a survey between February and August (from (Anon, 2009)). Lower left: North sea spawning area defined by a daily egg production of at least 50 mackerel eggs per m^2 of sea surface in any of the years 1980, 1983, 2005 and 2008 (from (Anon, 2009)). Lower right: Experimental survey in May 2002 (from (Dransfeld *et al.*, 2005)).

A.3.3. Migration

Mackerel performs extensive migrations between spawning grounds, feeding grounds and overwintering areas. The migration pattern has changed substantially through time.

Tagging studies (Uriarte and Lucio, 1996; Belikov *et al*., 1998; Uriarte *et al*., 2001) have demonstrated that mackerel travel from both the western and southern spawning ground north up into the North Sea and Nordic Seas. The migration can be considered as having two elements;

1) A post-spawning migration from the spawning areas along the western European shelf edge (Uriarte *et al*., 2001);

2) A prespawning migration from feeding grounds in the North and Norwegian Seas (Walsh *et al*., 1995; Reid *et al*., 1997). This prespawning migration includes shorter or longer halts that sometimes are referred to as overwintering.

Studies of the timing and the routes for the post-spawning feeding migration are limited. Patterns of food and temperature related distributions in the Norwegian Sea in summer are emerging from summer surveys in the Norwegian Sea in 1992 and 2002–2009. However, the big picture of when and where is the thermal preference dominating/subordinate in relation to other activities like feeding, spawning and predator avoidance remains to be drawn.

Swimming speed during migration is related to fish length (Pepin *et al*., 1988). Tagging has shown that juveniles of the southern/western component do not migrate as far as the adults (Uriarte *et al*., 2001). The larger fish reaches furthest to the north and west during the feeding migration in summer (Holst and Iversen, 1992; Nøttestad *et al*., 1999; Anon 2009; ICES, 2009). This effectively results in a spatial gradient in the mean length of the fish measured during the IESSNS (Nøttestad *et al*., 2012; 2013), with larger mean length in the north and west, and smaller mean length to the southeast. Similarly, the large mackerel also arrive to the feeding areas (observed in eastern Danish waters) before and leave later than small mackerel (Jansen and Gislason, 2011).

When the NEA mackerel return in late summer and autumn from the feeding areas on the European shelf and in the Nordic Seas, they aggregate through autumn and early winter along the continental shelf edge, where they are targeted by commercial trawlers and purse-seiners. Later in winter the commercial fleets and the fisheries-independent bottom-trawl survey find the mackerel further towards the southwest. The path of the migration, as suggested by the location of commercial and survey catches coincides with the location of the relatively warm high saline eastern Atlantic water flowing northeastwards on and along the continental shelf edge, flanked by cooler water masses. The mackerel population is found further upstream in warmer waters as the current cools through winter and this process is associated via climatic variability, with large impacts on the mackerel migration and fisheries (Jansen *et al*., 2012; Walsh and Martin, 1986; Reid *et al*., 2003; Walsh *et al*., 1995; Reid *et al*., 1997; Reid *et al*., 2001). However, other factors than temperature preferences are affecting the mackerel behaviour and can in different scenarios have different weights. D'Amours and Castonguay (1992) showed that mackerel from the northern component of the West Atlantic mackerel migrated into Cabot Straight with approximately 4ºC in order to get to their spawning grounds. They argued that the fish’s thermal preferences could be subordinate to their reproductive requirements, a point supported by the fact that this stock always enter the Cabot Straight around the same date (Anonymous, 1896; Castonguay and Beaulieu, 1993).

There are also indications of variation in spawning time: The Spanish spring fishery in the Bay of Biscay has been occurring earlier each year, and since this fishery is targeting spawning mackerel, this indicates that the spawning in the southern component occurs earlier each year (Punzon and Villamor, 2009). In winter 2011–2012 the timing of the spawning migration was even more pronounced in the Cantabrian Sea from early January to February compared to March and April just some years ago. However, the triennial egg survey in 2013 showed that the peak of spawning in the Cantabrian Sea was later than in both 2007 and 2010. Mackerel egg surveys also gave indication of earlier spawning for 2010 and 2013 in the western spawning component with a peak in egg production early in March compared to the earlier years when peak production was in centred on May.

Timing of overwintering, spawning migration and spawning of the NEA mackerel has previously been linked to temperature, with, e.g. earlier overwintering and spawning related to increased temperatures (Reid *et al*., 1997; Jansen *et al.*, 2012; Punzón and Villamor, 2009; Jansen and Gislason, 2011). In spring and summer 2012 the measurements of plankton concentrations were among the lowest in the entire time-series since 1996 in the northern and western parts of the Northeast Atlantic.

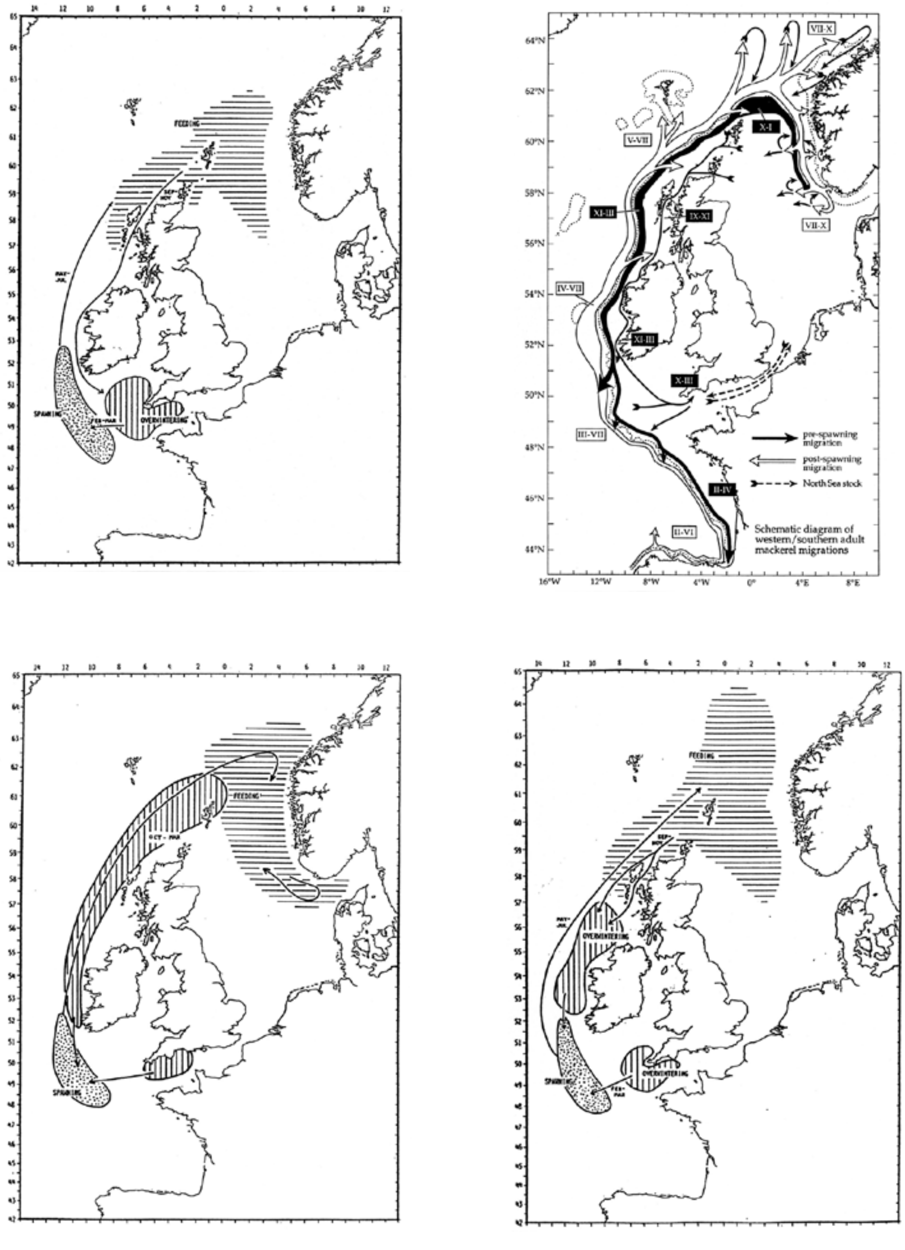


Figure A.3.3.1. Schematic outline of the migration of the western (+ southern in top right map) adult mackerel through time. From left: late 1970s (ICES, 1990), early 1980s (ICES, 1990), latter half of 1980s (ICES, 1990), mid-1990 (Anon, 1997).

B. Data

B.1. Commercial catch

Data Compilation and Archiving

Prior to the annual assessment WG, national data submitters are responsible for submitting details of commercial catch and the associated sampling (carried out under the DCF in EU countries) to the stock coordinator. This information is supplied aggregated to ICES subarea and quarter. The data are usually detailed in an Excel spreadsheet (known as the 'exchange format'). Information on misreported catches, unallocated catches and discards can also be included on the spreadsheet. An up to date fleet description and a breakdown of catch by ICES statistical rectangle are also requested. For nations with minor (and generally unsampled) catches, the stock co-ordinator will retrieve the data from the Statlant database, hosted by ICES.

Upon completion of error checking, the stock coordinator will compile the data in order that it can be used in the assessment. A key step in this process is the allocation of samples to unsampled catches. The stock coordinator will choose appropriate samples (and their relative weightings) on the basis of fleet type, quarter and geographic area. Once the samples have been assigned the stock coordinator will produce a vector of catch numbers, weights and lengths in addition to the total catch. This was traditionally done using a bespoke software application known as *sallocl* (Patterson, 1998). Presently, a web-based data portal known as InterCatch is used which is hosted by ICES and has the advantage of acting as a central repository for the data. Frequent comparisons are made using both approaches as a quality check.

Discards

The working group has estimated the level of discards since 1978. However, this is based on estimates provided by only a few countries and is routinely identified as being an underestimate. The level of underestimation is variable and unknown.

The primary reason for the discarding or slipping (where the entire catch is released prior to being brought on board) of mackerel is on the basis of size. The discarding of high proportions of the total catch resulted in the establishment of the Cornwall box catch restrictions around the SW coat of England. Small mackerel is also often caught in the horse mackerel directed fishery, primarily in the English Channel, and is subsequently discarded either because of quota restrictions or unfavourable market conditions. Widespread discarding of fish weighing under 600 g also occurred in the early 1990s in response to the high prices paid for large fish which has been proposed as a possible reason for the low abundance of some year classes.

Data quality

If they are in possession of supplementary information, national data submitters can identify misreported catches. Often, catches will be transferred from one ICES area to another to account for information on misreporting. While not considered to be an issue in recent years, there is evidence of large-scale misreporting between ICES Subareas IVa and VIa and IVa and IIa in the past.

A significant proportion of the complete catch time-series is considered to be of relatively poor quality in that it is believed that there is a significant underreporting of catch. A study into unaccounted mortality (Simmonds, 2007) suggested significant unaccounted mortality equivalent to 1.6 to 3.4 times the reported catch. This unaccounted mortality could be the result of unreported discards and slipping, fish that escape but subsequently die or unreported catch. Improved monitoring and stricter reporting requirements have resulted in improved confidence in recent years.

B.2. Biological

B.2.1. Weighting of spawning components

The SSB estimates from the egg surveys in the North Sea and the western/southern area are used to compute the proportion of the NEA mackerel represented by each of the three spawning components. For a complete time-series of proportion of each component, see the report of the 2014 Benchmark Workshop on Pelagic Fish (ICES, 2014) and the WGWIDE reports since then.

B.2.2. Weight-at-age in stock

The mean weights-at-age in the stock are based on available samples from the area and season of spawning of each of the spawning components.

For the southern component, stock weights are based on the samples from the Portuguese and Spanish catch taken in VIIIc and IXa in the 2nd quarter of the year, complemented by egg survey samples when available. For the Western spawning component, samples come from commercial catches, and when available, the egg survey for the areas and months corresponding to spawning (Table 2.2.1). In addition, fish sampled during the May tagging experiments by Norway in the northwest of Ireland are also included. For the North Sea spawning component, mean weights-at-age were calculated from samples of commercial catches collected from Area IVa in June combined with data collected during the North Sea egg survey in May–June when available.

The mean weights-at-age for the total stock are then calculated as weighted mean of the weights in each component, where the weighting is the egg survey based estimate of SSB in the three components. For a complete time-series on mean weights-at-age in the three components see the report of the 2014 Benchmark Workshop on Pelagic Fish (ICES, 2014) and the WGWIDE reports since then.

Table 2.2.1. Areas and month corresponding to the core spawning used for the selection of samples to compute mean stock weights-at-age in the western component. Establish based on egg survey results (see ICES, 2014).

MONTHS	ICES SUBDIVISION
March	VIIb,j,h,VIIIa,b
April	VIa,VIIb,c,j,h VIIIa
May	VIa,VIIb,c,j,k,VIIIa,d

B.2.3. proportions of individuals mature at age

The proportions of individuals mature at age are based on the following information:

North Sea component: The present proportions mature were calculated in 1984 on the basis of analysis of Norwegian biological samples from June–August 1960–1981. This revealed that 74% of the two year old mackerel, which appeared in the catches, were sexually mature. By comparing fishing mortalities for II-group mackerel with the fishing mortalities for the III-group the year after, when they are fully recruited to the spawning stock, it seems that about 50% of the II-group mackerel are available to the fishery. Assuming that only the spawning component of the stock is available in the fishery, maturity ogive for the North Sea stock was estimated (ICES, 1984).

Western component: Since the 2014 mackerel benchmark (ICES, 2014) time varying proportions of individuals mature at age are calculated based on samples from the Dutch, Irish, German and UK commercial catches collected from February to July. Proportions of mature fish at age were calculated grouping the data in blocks of five years, and moving this five year window from 1980 to the terminal year in the assessment. Due to the scarcity of samples for age 1 fish, the time varying estimate for this age is replaced by the mean across all years.

Southern component: Based on a histological analysis of mackerel samples collected during the 1998 Egg Survey (ICES, 2000; Perez *et al.*, 2000).

The proportions of mature mackerel-at-age for the total stock are calculated as the mean of the proportions in the three spawning components weighted by the respective size of each component (as estimated by the egg surveys).

B.2.4. Natural mortality and proportion of F and M before spawning

Natural mortality (M) has been fixed at 0.15 for decades. This value was calculated based on estimates of total mortality derived from tagging data combined with catch data (Hamre, 1980). The first mackerel working group report where this value was given in was 1983 (ICES, 1984).

Given the variability of the time of spawning, time varying proportions of F and M before spawning are used. The time of spawning is calculated for both the western and southern spawning component in each egg survey year as the Julian day where 50% of the total egg production has occurred. The time of spawning for the whole stock is then taken as the average of the time in these two components (weighted by their respective size). Assuming that natural mortality is constant through the year, the proportion of M occurring before spawning is equal to the proportion of the year before spawning time.

The proportion (per age group) of the catches taken before spawning time are calculated for each survey year as the sum of the quarter 1 catches plus the necessary proportion of the quarter 2 catches (if spawning time occurs in the second quarter) or as the necessary proportion of the catches in the first quarter (if spawning time occurs in the first quarter). Proportions of fishing mortality before spawning (F_{prop}) per age group are then estimated using an optimizer to find the F_{prop} value which minimizes the (square of the) difference between the observed proportion of catches before spawning, and the proportion of catches before spawning calculated based on the M_{prop} value and F at age values from the last available assessment. In order to reduce the effect of the noise in the data, average F_{prop} values are calculated by groups of age-classes: ages 1–2, ages 3–4 and ages 5 and older. F_{prop} for age 0 is by convention set to 0.

Time-series of M_{prop} and of F_{prop} at age based on linear interpolation between survey years are used as input to the assessment model. The M_{prop} and F_{prop} values of the latest survey are used for the most recent years, but these values are updated using linear interpolation when a new survey is carried out.

B.3. Surveys

B.3.1. Mackerel Egg surveys (MEGS)

Two mackerel egg surveys have been performed since 1968. Both are triennial survey and are presently only adding new information to the time-series every third year. The Atlantic survey that started in 1977 covers the western–southern spawning grounds in the Northeast Atlantic while the other survey covers the spawning in the North Sea and Skagerrak (Figure A.3.2.1).

Each survey is split into several sampling periods covering the whole spawning area in order to get an egg production curve covering the whole spawning season. Plankton samplers currently used are Gulf VII high speed plankton samplers or Bongo plankton nets with a mesh size of 280 μm. The Gulf samplers are open torpedoshaped frames with a flowmeter mounted in the nosecone to measure the volume of water sampled. The Bongo's are ringnets with 280 µm mesh size. All samplers are towed in double oblique hauls at a speed of approximately 5 knots. Next to the plankton samples pelagic trawl samples of adult fish are collected in order to determine the sex ratio and collect ovary samples to estimate fecundity and atresia of female fish.

All eggs are sorted out from plankton samples and identified to species. The mackerel eggs in the samples are staged according to development (Lockwood *et al*., 1981). The stage 1 eggs are used to estimate the daily egg production per sampling period. The total annual egg production is then calculated by integrating all periods in the egg production curve. Spatio-temporal coefficient of variation (CV) of the egg production is estimated. The mackerel SSB is estimated by dividing the total annual egg production by the realized fecundity of the females and multiplying by the sex ratio. The coordination of the surveys and SSB estimation are the responsibility of the working group for mackerel and horse mackerel egg surveys (WGMEGS). Preliminary results are reported by WGMEGS to WGWIDE in the year of the survey, the results of the survey are finalized and reported in the year after the survey.

B.3.2. International Bottom Trawl Surveys (IBTS)

A recruitment index derived from catch data from the International Bottom Trawl Surveys (IBTS) was evaluated during the benchmark process (WKPELA, 2014). The cpue time-series was found to be consistent between first and fourth quarter surveys in the overlapping area. It is therefore used as a relative index of abundance at age 0. Full documentation can be found in Jansen *et al*. (2014. WKPELA WD).

Trawling was done by research vessels from Scotland, Ireland, England, France and Spain collectively known as the international bottom-trawl surveys in October–December (IBTS Q4). The surveys sample the fish community on the continental shelf and upper shelf slope. IBTS Q4 covers the shelf from Spain to Scotland, excluding the North Sea. Trawling was done at 3.5–4.0 knots. Two trawls deviated substantially from the GOV-type, namely the Spanish BAKA trawl and the Irish trawl that was used from 1998 to 2002. The BAKA trawl had a vertical opening of only 2.1–2.2 m and was fished at only 3 knots. This was substantially less suitable for catching juvenile mackerel and therefore excluded from the analysis. The Irish trawl used in 1998 to 2002 was a GOV trawl in reduced dimensions. The reduced wingspread and trawl speed was accounted for in the model.

A geostatistical log-Gaussian Cox process mode model (LGC) with spatio-temporal correlations was used to describe the catch rates of mackerel recruits through space and time.

These catch rates were then averaged by year and expressed in relation to the mean of the time-series as a relative catch rate index.

The information value was examined by fitting similar models to the mackerel catch data in Q4 and Q1 (January–March), in the area where the two surveys overlapped (55–60°N, 4–10°W). The time-series from Q4 and Q1 were compared and found to be strongly positively correlated ($p<0.001$, $R^2=0.66$). The simplest explanation for this correlation is that catch rates in both surveys reflect the same recruitment signal from the mackerel population. It furthermore suggests that the applied method was appropriate to modelling the catch rates and the associated sampling noise.

Field observations during acoustic and trawl surveys in October in the mackerel box (Celtic Sea, Peltic survey) suggested that mackerel catchability may increase exponentially with school size. Although the underlying mechanisms are likely to be complex there are several factors that appear likely. Fish in schools may not be able to successfully avoid an approaching trawl due to high fish densities limited movement; another possibility is that vessel avoidance may propagate through the school from fish in top of the school to those nearer the seabed. Visual exploration of echograms showed that an important contributing factor was density-dependent depth behaviour: small mackerel schools were generally observed in midwater whereas large and high density mackerel schools were consistently associated with the seabed. Schooling mackerel could therefore more easily out-manoeuvre the trawl, given the fact that they can escape in multiple directions. The proximity of larger schools to the seabed would make them more accessible to the bottom-trawl gear. This effect may be further amplified by the reported diving behaviour of the mackerel at the top of the school, in response to an approaching vessel (Slotte *et al*., 2007). Although catchability is a complex process affected by many factors, the above observations suggest that the index should be transformated to account for the density effect.

In conclusion:

- The strong correlation between the independent sampled and modelled catch rate in Q1 and Q4 suggests that catch rates in both surveys reflect the same recruitment signal from the mackerel population. It furthermore suggests that the applied method was appropriate to modelling the catch rates and the associated sampling noise.
- A hypothesis of positive density-dependant catchability was suggested and acoustic observations supporting the hypothesis were presented. Log transformation of the cpue index as well as modification of the index calculation was done to reduce the density effect. Correlations with the assessment recruitment time-series improved substantially in both cases, further supporting the hypothesis.
- Further work on extending the Q4-model with data from IBTS Q1 in the North Sea and other northern areas is recommended.

B.3.3. IESSNS swept-area surveys

The main objective of the IESSNS survey in relation to quantitative assessment purposes is to provide reliable and consistent age-disaggregated abundance indices of NEA mackerel. Research vessels and chartered commercial fishing vessels from Norway (two vessels), Faroe Islands and Iceland (one from each country) were used in the Norwegian Sea and adjacent waters in July–August 2007 and from 2010 to 2013 (Nøttestad *et al*., 2014). In 2007, the surveys were conducted by two Norwegian vessels only. The survey aimed at covering the outer borders (zero lines) of the mackerel distribution each year from 2007 in all directions except in the southern region (south of 62°N in the North Sea). Due to the spatial expansion and increased geographical distribution of mackerel in the Nordic Seas from 2007 to 2013, the survey coverage differed from year to year in an effort to cover an expanding stock and at the same time a dynamically moving zero border lines (Figure A.3.3.1). The temporal coverage was limited to 5–6 weeks period, in order to avoid any double or zero counting during the survey. In 2011 short ship time limited the coverage in both the northern and southern part of the eastern Norwegian Sea. The swept-area survey was designed with predominantly parallel east–west survey lines, and fixed sampling stations approximately 60 nautical miles apart at predetermined geographical positions (ICES, 2013b, c; Nøttestad *et al*., 2014). The methodology of the survey is detailed in ICES (2013c) and Valdemarsen *et al*. (2014).

The catch of the different species was weighed on board and a total of 100 mackerel individuals were sampled from the catch randomly and total length (±1 cm) and whole body weight (±0.1 g) recorded from each trawl haul. The otoliths from the first 25 individuals were retrieved for age reading. On basis of the catch data and operation of the trawling hauls, swept-area estimates of age-disaggregated indices and biomass are calculated for rectangles of 2° longitude and 1° latitude across the survey area (Nøttestad *et al*., 2014). The results from the IESSNS surveys (Figure A.3.3.2) are reported at the working group for widely distributed stocks (WGWIDE) and working group for international pelagic surveys (WGIPS).

The decision of indices constructed and used from this survey took into account issues raised at WKPELA (ICES, 2014) regarding apparent lower catchability of fish at age <6, variable and expanding coverage of the annual surveys, uncertainty in catch efficiency with respect to vertical distribution of the stock in the North Sea, and the fact that the survey is only covering the oceanic part of the stock leaving out mackerel further south. Thus the age-disaggregated indices constructed for analytical assessment purpose was spatially restricted to Nordic Seas, leaving out North Sea south of 62°N, delimited to age 6+ and scaled by the total area covered each year (number per square km; equivalent to cpue).

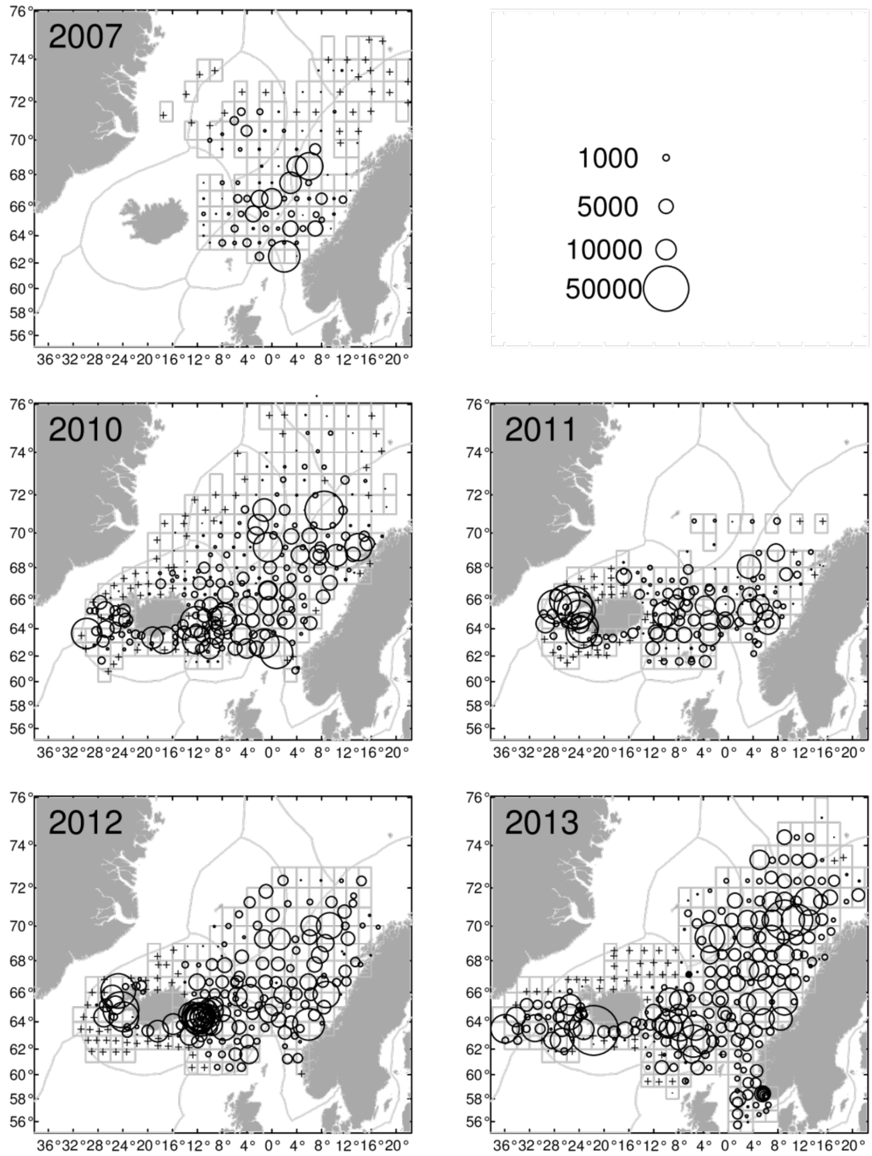


Figure A.3.3.1a–e. Average catch index (kg/km²) presented as circles ranging from no catch (a +), >1000 kg/km² to >50 000 kg/km² for NEA mackerel in July–August 2007, 2010–2013. The spatial coverage varied from 0.926 million km² in 2007 to 2.410 million kg/km² in 2013.

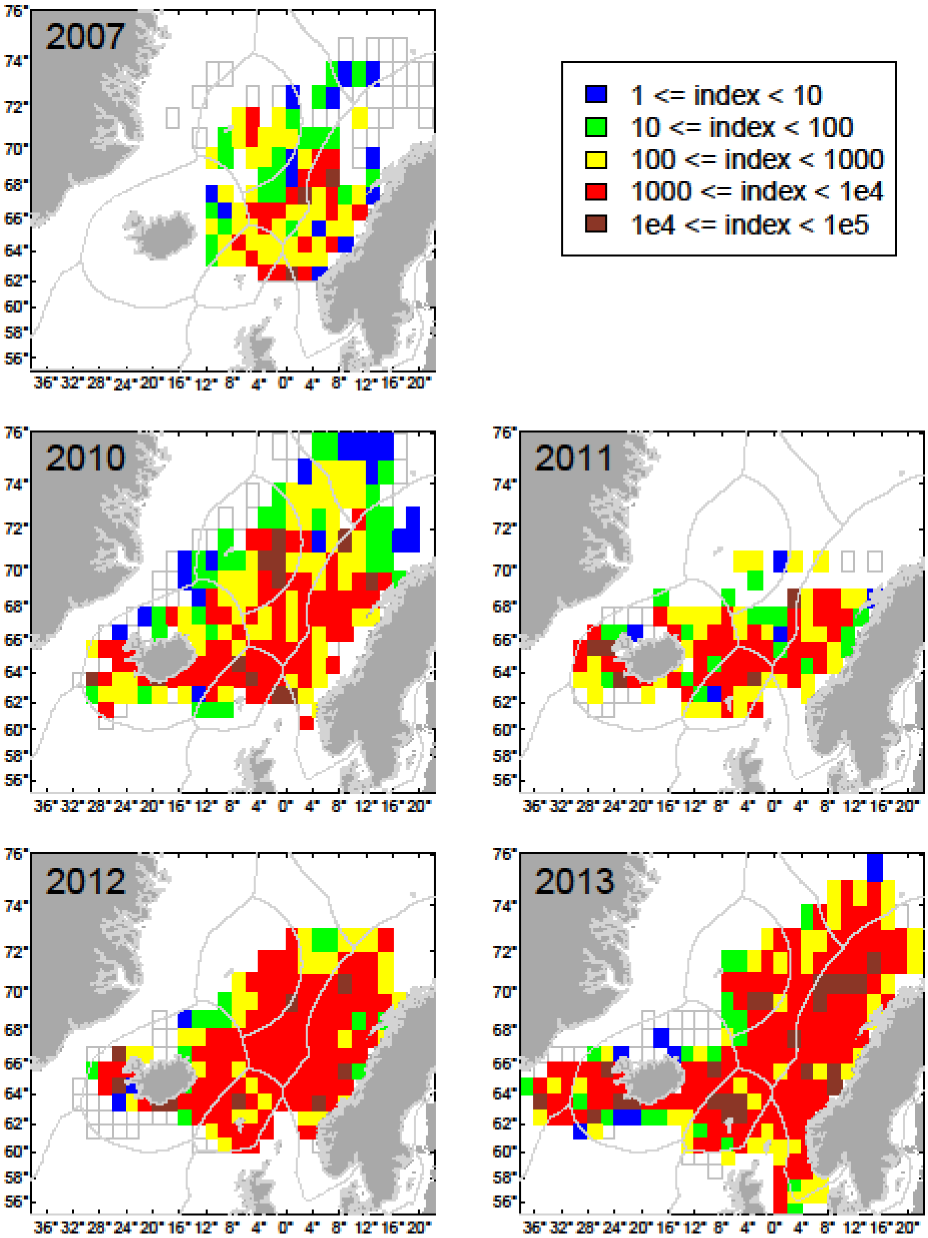


Figure A.3.3.2a–e. Graphical representation of average catch index (kg/km²) for NEA mackerel in July–August in 2007 and 2010–2013. The spatial coverage varied from 0.926 million km² in 2007 to 2.410 million kg/km² in 2013. No catch is represented as open squares.

B.4. Commercial cpue

None.

B.5. Other relevant data: Tagging data

Institute of Marine Research in Bergen has conducted tagging experiments with internal steel tags on mackerel since 1969, both in the North Sea and west of Ireland and the British Isles during the spawning season May–June. In the present assessment the tagging time-series was restricted to releases of the western component during the years 1977–2004 and from screening of commercial catches at factories with metal detectors from 1986–2006. During this period the same methodology was used during both the tagging process and screening, and it was hence suggested to be a very consistent time-series. Tagging with the steel tags continued until 2009 with screening until 2010. However, a change in the fishing process from manual jigging to automatic tagging machines, which could have induced differences in post tagging mortality, as well as some uncertainty regarding screening efficiency at the factories, led to the conclusion that this part of the time-series should be excluded from the assessment. Furthermore, the new effort with tagging using RFID-technology starting in 2011 was considered to be too short, and it is expected that this time-series could be included in the assessment after further evaluation in about three years' time.

The actual format of the tagging data used in the assessment is as numbers tagged of a year class in a specific year, the numbers recovered of this year class from that release year in all successive years, as well as the numbers screened by year class in all years.

C. Historical stock development

The assessment model

SAM

A benchmark assessment for NEA Mackerel was carried out in 2014 during the Benchmark Workshop for Pelagic Stocks (WKPELA, ICES 2014). Following this benchmark investigation, the tool chosen for the assessment is SAM, the state–space assessment model (Nielsen and Berg, 2014). Since 2014, this method has been implemented using the online webpage interface on www.stokassessment.org.

In SAM, the "states" (fishing mortalities and abundances-at-age) are constrained by the survival equation and follow a random walk process. The variances of the random-walk processes on abundances and fishing mortalities are parameters estimated by the model.

SAM is a fully statistical model in which all data sources (including catches) are treated as observations, assuming a lognormal observation model. The corresponding variances, so-called observation variances, are also parameters estimated by the model. Observations variances can be used to describe how well each data source is fitted in the model and effectively correspond to the internal weight given by the model to the difference data sources.

The other parameters estimated are the catchabilities of the surveys.

Uncertainties (standard errors) are estimated for all parameters and for all states (Fs and Ns).

Modifications to SAM for the NEA mackerel assessment

In the SAM mackerel assessment, tagging–recapture data from the Norwegian tagging programme are used as input data. In order to incorporate the tagging–recapture information, tag recoveries (per year and for each year class) were predicted from the model, based on the number of fish screened in the processing factories, the amount of tagged fish of the same year class released in the previous years, and the corresponding abundances of this year class in each release year estimated by the model, conditional to a post-release survival rate (time invariant and for all ages) which is a parameter estimated by the model. Given the nature of these data (count data with overdispersion) a negative binomial observation model is used.

Assessment model configuration

Catches for NEA mackerel for the period prior to 2000 are considered highly unreliable, due to a massive underreporting in the historical period. However, valuable information is available from other data sources (tags, egg survey) for the years before 2000. Instead of discarding all data prior to 2000, it was decided during the 2014 benchmark mackerel assessment to start the assessment in 1980, and reduce as much as possible the influence of the catches until 2000. This was done by arbitrarily down weight the catches for the years prior to 2000, by imposing a high observation variance of these catches (equal to 1.35).

Furthermore, the model incorporates tagging–recapture data until the recovery year 2006, and three survey indices: the IBTS recruitment index, the mackerel egg survey SSB index and abundances indices from the IESSNS.

More details on the input and on the survey indices incorporated in the assessment are given in the tables below (Y being the current year in which the assessment is carried out).

INPUT DATA TYPES AND CHARACTERISTICS:

Name	Year range	Age range	Variable from year to year
Catch in tonnes	1980–(Y-1)		Yes
Catch-at-age in numbers	1980*–(Y-1)	0–12+	Yes
Weight-at-age in the commercial catch	1980–(Y-1)	0–12+	Yes
Weight-at-age of the spawning stock at spawning time.	1980–(Y-1)	0–12+	Yes
Proportion of natural mortality before spawning	1980–(Y-1)	0–12+	Yes
Proportion of fishing mortality before spawning	1980–(Y-1)	0–12+	Yes (constant before 1989)
Proportion mature-at-age	1980–(Y-1)	0–12+	Yes
Natural mortality	1980–(Y-1)	0–12+	No, fixed at 0.15

*** catches-at-age before 2000 are heavily down weighted which makes that in practice, they have little influence on the assessment.**

TUNING DATA:

Type	Name	Year range	Age range
Survey (SSB)	ICES Triennial Mackerel and Horse Mackerel Egg Survey	1992, 1995, 1998, 2001, 2004, 2007, 2010, 2013.	Not applicable (gives SSB)
Survey (abundance index)	IBTS Recruitment index (log transformed)	1998–(Y-1)	Age 0
Survey (abundance index)	International Ecosystem Summer Survey in the Nordic Seas (IESSNS)	2007, 2010–Y	Ages 6-11
Tagging/recapture	Norwegian tagging program	1980–2006 (recapture years)	Ages 2 and older

Model configuration as defined during the 2014 benchmark is given in the table below. In addition, the model has an age range from 0 to 12 and a plus group is set at 12 years. The reference fishing mortality, F_{BAR}, is calculated over the ages 4 to 8.

SAM PARAMETER CONFIGURATION:

Setting	Value	Description
Coupling of fishing mortality states	1/2/3/4/5/6/7/8/8/8/8/8/8	Different F states for ages 0 to 6, one same F state for ages 7 and older
Correlated random walks for the fishing mortalities	0	F random walk of different ages are independent
Coupling of catchability parameters	0/0/0/0/0/0/0/0/0/0/0/0/0 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 0/0/0/0/0/0/2/2/2/2/2/2/0	No catchability parameter for the catches One catchability parameter estimated for the egg One catchability parameter estimated for the recruitment index One catchability parameter estimated for the IESSNS (same for age 6 to11)
Power law model	0	No power law model used for any of the surveys
Coupling of fishing mortality random walk variances	1/1/1/1/1/1/1/1/1/1/1/1/1	Same variance used for the F random walk of all ages
Coupling of log abundance random walk variances	1/2/2/2/2/2/2/2/2/2/2/2/2	Same variance used for the log abundance random walk of all ages except for the recruits (age 0)
Coupling of the observation variances	1/1/1/1/1/1/1/1/1/1/1/1/1 0/0/0/0/0/0/0/0/0/0/0/0/0 2/0/0/0/0/0/0/0/0/0/0/0/0 0/0/0/0/0/0/3/3/3/3/3/3/0	Same observation variance for all ages in the catches One observation variance for the egg survey One observation variance for the recruitment index One observation variance for the IESSNS (all ages)
Stock–recruitment model	0	No stock–recruiment model

Due to the high uncertainty in the recruitment estimates for the terminal year, Y-1, for the NEA Mackerel, the value estimated by SAM is arbitrarily replaced by the output of RCT 3 (see short-term prediction section).

D. Short-term projection

In a given assessment year Y, advice is given on catches for the following year Y+1 based on deterministic projections three years ahead (Y to Y+2). These projections are based on an assumption of the current year's (also called intermediate year) catch (see section below "Assumptions for the intermediate year catch") from which fishing mortality in the current year Y is inferred, and a range of management options for the advice year, Y+1 (fishing mortality in Y+2 being the same as Y+1), are provided.

Initial abundances at age

The survivors at the 1st of January of year Y estimated by SAM are used as starting abundances at age in the first year of the short-term forecast. The recruitment estimate at age 0 from the assessment in the terminal assessment year (Y-1) is considered too uncertain to be used, because this year class has not yet fully recruited into the fishery. The last (Y-1) SAM recruitment estimate is therefore replaced by predictions from the RCT3 software (Shepherd, 1997). The RCT3 software performs a linear regression between the IBTS recruitment index and the SAM estimates over the period 1998 toY-2, and, based on this regression, predicts the Y-1 recruitment from the Y-1

IBTS index value. The final Y-1 recruitment is the average between the prediction from this regression and a time tapered geometric mean of the SAM recruitments up to Y-2, weighted by the inverse of their respective prediction standard errors. The historic performance of the IBTS index thus determines the influence of the Y-1 index value on the Y-1 recruitment produced by RCT3. A weak correlation of the survey index with the SAM estimates brings the RCT3 estimate close to the SAM geometric mean, while a strong correlation brings it close to recruitment predicted from the IBTS index for the year Y-1. The "time tapered geometric mean" is a weighted geometric mean, where the most recent years are given the highest weights.

The abundance of the survivors-at-age 1 (in Y) used as starting values for the short-term forecast is then estimated by bringing forward recruitment-at-age 0 (in Y-1) applying the total mortality-at-age 0 in year Y-1 estimated by SAM.

Conditioning of the short-term forecast

Recruitment

The recruits at age 0 in year Y, Y+1 and Y+2 are set to the geometric mean.

Exploitation pattern

The exploitation pattern (relative selection pattern) used in the predictions from Y to Y+2 is defined as the average of the exploitation pattern of the last three years in the assessment (Y-3 to Y-1), obtained by dividing the fishing mortalities-at-age of those three years by the value of F_{BAR}4–8 in the corresponding years.

Maturity-at-age, weight-at-age in the catch and weight-at-age in the stock

The three year average of Y-3 to Y-1 is used for the proportion mature-at-age as well as stock and catch weights-at-age.

Proportion of natural and fishing mortality occurring before spawning

The three year average of Y-3 to Y-1 is used for the proportions F_{prop} and M_{prop}.

Assumptions for the intermediate year (Y)

The catch in the intermediate year (Y) is taken as a TAC constraint. The catch is estimated from declared quotas modified by e.g. paybacks (e.g. EU COMMISSION REGULATION (EC) No 147/2007), discards (assumed to be equal to the last reported discards in year Y-1), interannual transfers and expected overcatch. Scientists from the relevant countries present at the WGWIDE each year provide the information on interannual transfers and expected overcatch.

Management Option Tables for the TAC year

The different management options for the catch in Y+1 are tested, covering both the ICES approach to MSY and the management plan implemented for NEA Mackerel in 2009:

- $Catch_{Y+1}$ = zero
- $Catch_{Y+1}$ = TAC_{Y} – 20%
- $Catch_{Y+1}$ = TAC_{Y}
- $Catch_{Y+1}$ = TAC_{Y} + 20%
- $Fbar_{Y+1}$ = 0.20

- $Fbar_{Y+1}$ = 0.21
- $Fbar_{Y+1}$ = 0.22
- $Fbar_{Y+1}$ = 0.25 (Fmsy)
- $Fbar_{Y+1}$ = Fmsy transition

Software implementation

The short-term forecast will be calculated in MFDP, FLR or StockAssessment.org. Testing and decision will be done during the preparation of the advice for May 2014.

E. Medium-term projections

No medium-term projections.

F. Long-term projections

No long-term projections.

G. Biological reference points

Precautionary reference points.

Blim **-** There is no evidence of significant reduction in recruitment at low SSB within the time-series (ICES, 2014) hence the previous basis for B_{lim} is retained. B_{lim} is taken as B_{loss}, the lowest estimate of spawning–stock biomass from the revised assessment. This was estimated to have occurred in 2002; B_{loss} = 1 840 000 t.

Flim **-** F_{lim} is derived from B_{lim} and is determined as the F that on average would bring the stock to B_{lim}; F_{lim} = 0.39.

B_{pa} - The ICES basis for advice requires that a precautionary safety margin incorporating the uncertainty in actual stock estimates leads to a precautionary reference point B_{PA}, which is a biomass reference point designed to avoid reaching B_{lim}. Consequently, B_{PA} was calculated as B_{lim} * exp(1.645σ) where σ = 0.15 was taken as the assessment estimate of spawning biomass uncertainty in the most recent year; B_{PA} = 2 350 000t.

FPA **-** F_{PA} is derived from B_{PA} and is determined as the F that on average would bring the stock to B_{PA}; F_{PA} = 0.26.

MSY reference points

MSY reference points were evaluated using equilibrium stochastic simulations (ICES, 2014 WKMSYREF2). Yield was considered as total catch, which is considered relevant to the situation from 2015 onwards when the fishery will be conducted under a discard ban for almost all participants.

F_{MSY} - Applying the WKMSYREF2 simulation approach the median value of F_{MSY} was F=0.31, above F_{PA}, and resulted in a greater than 5% probability of SSB<B_{lim}. Fulfilling the precautionary requirement of SSB having 5% or less probability of being reduced to below B_{lim} results in F_{MSY} = F <= 0.26.

Maximum mean and median catches both occurred at a lower exploitation rate of F=0.25. Following the ICES guidelines (ICES, 2013d WKMSYREF), F=0.25 is an appropriate F_{MSY} target as on average it resulted in the highest mean yields with a low risk of reducing the spawning biomass below B_{lim}.

TYPE		VALUE	TECHNICAL BASIS
Management Plan	$SSB_{trigger}$	N/A	Revision required
	F target	N/A	Revision required
MSY Approach	MSY $B_{trigger}$	2.36 million t	Proxy based on Bpa WKPELA 2014
	MSY target	0.25	Stochastic simulation conducted at WKPELA 2014
Precautionary Approach	B_{lim}	1.84 million t	B_{loss} in 2002 from WKPELA 2014 benchmark assessment
	B_{pa}	2.36 million t	$\exp(1.654*\sigma)*B_{im}$, σ=0.15
	F_{lim}	0.39	F_{loss}, the F that on average leads to B_{lim}
	F_{pa}	0.32	F that on average leads to B_{pa}

H. Other Issues

H.1. Management plans and evaluations

During 2007 and 2008 ICES provided a report on NEA mackerel long-term management (ICES, 2008). The content of the study was developed through a request from the European Commission and a series of meetings with representatives of Pelagic Regional Advisory Council (PRAC). The report was used by ICES to give advice in June 2008, which was presented to the PRAC in July 2008. Following this a request was made by the PRAC to provide information on trade-offs between different management criteria, particularly concentrating on average catch, interannual change in catch and proportion of older fish. More runs were carried out with the software HCM with the same model conditioning and setting used to give ICES advice. These were used to give more detail in the region of greatest interest. The information on the methods used was given in (ICES, 2008).

An agreed management plan for NE Atlantic mackerel was finalized in October 2008. The management plan is as follows:

"The agreed record of negotiations between Norway, Faroe Islands, and EU in 2008 states that the long-term management plan shall consist of the following elements:

1) For the purpose of this long-term management plan, "SSB" means the estimate according to ICES of the spawning–stock biomass at spawning time in the year in which the TAC applies, taking account of the expected catch.

2) When the SSB is above 2 200 000 tonnes, the TAC shall be fixed according to the expected landings, as advised by ICES, on fishing the stock consistent with a fishing mortality rate in the range of 0.20 to 0.22 for appropriate age groups as defined by ICES.

3) When the SSB is lower than 2 200 000 tonnes, the TAC shall be fixed according to the expected landings as advised by ICES, on fishing the stock at a fishing mortality rate determined by the following:

Fishing mortality F=0.22* SSB/ 2 200 000

4) Notwithstanding paragraph 2, the TAC shall not be changed by more than 20% from one year to the next, including from 2009 to 2010.

5) In the event that the ICES estimate of SSB is less than 1 670 000 tonnes, the Parties shall decide on a TAC which is less than that arising from the application of paragraphs 2 to 4.

6) The Parties may decide on a TAC that is lower than that determined by paragraphs 2 to 4.

7) The Parties shall, as appropriate, review and revise these management measures and strategies on the basis of any new advice provided by ICES."

From (NEAFC, 2008).

ICES consider the agreement to be consistent with the precautionary approach. However, the management plan does not specify measures that would apply under poor stock conditions that preclude further evaluation.

The updated assessment from 2014 (WKPELA 2014) resulted in higher recruitment and fishing mortality estimates that are in historical time similar compared to the old assessment, but lower in recent years. As a consequence, the perception of the level of spawning biomass has changed. Consequently, the current management plan fishing mortality target range is still considered to be precautionary, and ICES can continue to provide advice under this plan if requested to do so. However, the current management plan $B_{trigger}$ is below the revised B_{PA} and consequently the management plan should be re-evaluated prior to the release of advice for 2015 in order to determine the appropriate combination of $B_{trigger}$ and fishing mortality range that are consistent with the precautionary approach.

H.2. Data limited approach for NEA mackerel

Context

In 2013 ICES was required to provide advice for the mackerel stock on the basis of no agreed quantitative assessment and corresponding management target and reference points, an exploitation rate which was potentially above the previous reference levels and no international agreement on catches.

For other stocks for which no quantitative assessment was available ICES had previously employed the WKLIFE Data Limited Stocks (DLS) approach (ICES 2012, CM 2012/ACOM 68) to provide precautionary management advice. ICES considered the DLS Method 3.2 approach, which uses survey trend based scaling of catches, applicable to the NEA mackerel. WKLIFE3 (ICES, 2013e) had evaluated the method using a simulated gadoid stock and concluded that for overexploited stocks without a defined management target, a precautionary buffer which reduced catch levels by 20% would be required to prevent increasing risk to the stock when the control rule was applied over the longer term; however caveat scenarios in which the precautionary buffer might not be required were also discussed.

ICES ACOM eventually gave advice on NEA mackerel based on a recent catch, citing the preliminary nature of the most recent egg survey, the lack of good uncertainty estimates and the lack of agreement on whether a precautionary buffer (20% reduction in catches in the first year of application) should be applied. WKLIFE3 later examined the ICES NEA mackerel advice in 2013 and made the following comment:

"Mackerel in the Northeast Atlantic: In the 2013 advice season, ACOM treated this stock in an *ad hoc* way rather than as a data-limited stock proposed by their own ADG. The rationale for this is neither adequately nor clearly explained in any ICES document. On balance, WKLIFE do not understand the rejection of the DLS guidance and support the ADG's recommendation to treat this stock with a Category 3 method incorporating the *precautionary buffer*."

As a result of the uncertainty in the application of the ICES DLS Method 3.2 to mackerel, WKPELA (2014) agreed that a more detailed, stock-specific evaluation of the ICES DLS Method 3.2 application to the NEA mackerel should be conducted in order to provide guidance for management advice in the event that a quantitative assessment was not available.

NEA mackerel simulations

WKPELA (2014) used a MSE simulation framework in FLR, R version 2.10.1 (2009-12-14), Core package of FLR, fisheries modelling in R. Version: 2.3-644. Flash Version: 0.7.0. Evaluations were carried out based on a simulated mackerel stock with stock dynamics (growth, recruitment, etc.), single fleet exploitation and a single fishery-independent survey index.

Fishery-independent time-series

WKPELA considered that the triennial egg survey index of SSB with a CV of the order of 24% gave the only, more or less complete, index of SSB (the egg survey does not include egg mortality and so it is not considered an absolute SSB estimate).

Harvest control rule

As the survey is carried out triennially setting the catch for three years as multi-annual advice (y+1 to y+3) is appropriate and the DLS Method 3.2 becomes:

$$C_{(y+1,y+2,y+3)} = C_{(y)} * Fac \qquad \text{Equ. H.2.1}$$

where Fac is derived from DLS Method 3.2 such that with S(y) the survey index in year y

$$Fac = ((S_{(y)} + S_{(y-1)}) /2) / ((S_{(y-2)} + S_{(y-3)} + S_{(y-4)}) /3) \qquad \text{Equ. H.2.2}$$

Mackerel egg survey indices are available every three years so that $S_{(y-1)}$, $S_{(y-2)}$ and $S_{(y-4)}$ are derived by linear interpolation from the surveys in $S_{(y)}$, $S_{(y-3)}$ and $S_{(y-6)}$ such that after simplification:

$$Fac = 3/2 * (5*S_{(y)} + S_{(y-3)}) / (S_{(y)} + 7*S_{(y-3)} + S_{(y-6)}) \qquad \text{Equ. H.2.3}$$

Interannual variability, which could result from noise in the survey index series, is damped by the use of an uncertainty cap, such that:

$$Fac > 1.2 \Rightarrow Fac = 1.2 \qquad \text{Equ H.2.4a}$$

$$Fac < 0.8 \Rightarrow Fac = 0.8 \qquad \text{Equ H.2.4b}$$

In addition to the uncertainty cap, the application of ICES precautionary buffer margin of -20% for the first application of the rule was evaluated.

$C_{(y+1,y+2,y+3)} = C_{(y)} * 0.8 * Fac$ at the first application and Equ H.2.5a

$C_{(y+1,y+2,y+3)} = C_{(y)} * Fac$ for subsequent iterations Equ H.2.6b

DLS simulation results

Twelve scenarios were evaluated, four rule implementation options (with and without the PA buffer and the uncertainty cap) under three different stock starting conditions: historic fishing mortalities, F=0.22 (~F_{MSY}) and F=0.45 (~2*F_{MSY}). In all cases the stock was conditioned from 1981 to 2009 and DLS management simulated to start in 2009 with first year of catch under this regime in 2010.

The performance of the DLS method was considered in the context of ICES precautionary criteria by comparing the lower 5th percentile of SSB in each forecast year with a B_{lim} proxy (B_{loss}, Figure H.2.1). The inclusion of the precautionary buffer had a major influence on the likelihood that SSB had a greater than 5% probability of falling below B_{lim}. In all cases in which the precautionary buffer was not applied a substantially higher percentage than 5% of the stocks fall below B_{lim} and a significant proportion collapse; the inclusion of the PA buffer appears to prevent collapse in the medium term, independent of the starting conditions in the scenarios examined. This suggests that the application of the ICES DLS Method 3.2 as simulated, using triennial egg surveys to calibrate catch set for a period of three years is precautionary when the buffer is applied; it is not without the application of the buffer.

DLS method conclusions

WKPELA (2014) concluded that the simulations provided very clear guidance that exploitation using the ICES DLS Method 3.2 using the triennial egg survey based on equation H.2.3 would provide precautionary management advice for the provision of triennial multiannual TAC (three years) for the NEA mackerel stock in the absence of an agreed assessment.

The application of the ICES DLS Method 3.2 to the NEA mackerel requires the inclusion of the precautionary buffer at 20% in the first year of implementation (Equation H.2.4ab) and risk of SSB<B_{lim} is also reduced by the application of the uncertainty cap at 20% in each change of three year TAC (Equ H.2.5ab).

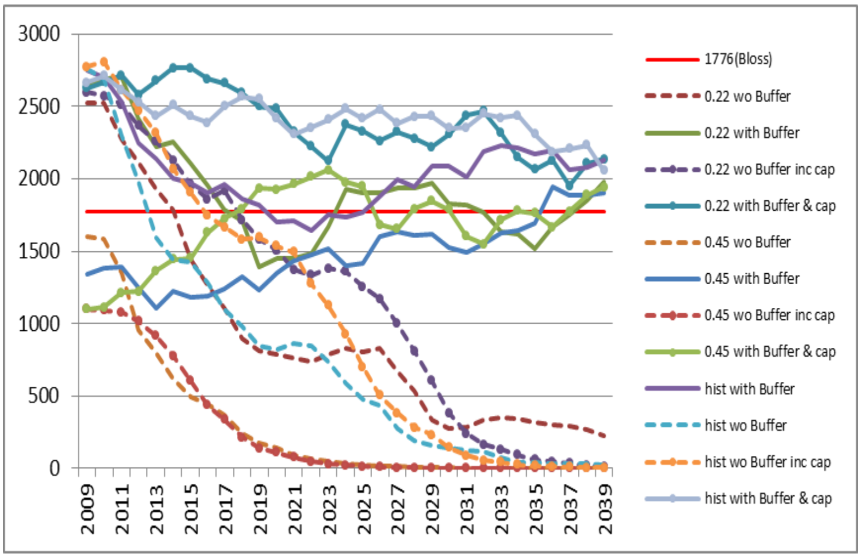


Figure H.2.1. Summary of NEA mackerel DLS Method 3.2 simulations in terms of ICES precautionary criteria. Three starting options 1) stable F=0.22, 2) stable F=0.45 and 3) historic state in 2009. Two options for calculating future catch are tested 1) PA Buffer included (solid lines) or not (dotted lines) 2) +/-20%cap on TAC change included (symbol on the line) or not (no symbol). These results demonstrate that it is essential to include the precautionary buffer if the lower 5% on SSB is to be kept above the assumed B_{lim}.

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Stock Annex Herring in the Celtic Sea and VIIj

Stock specific documentation of standard assessment procedures used by ICES

Stock	Herring in the Celtic Sea and VIIj
Working Group	WKPELA 2014
Date	February 2014
Authors	Afra Egan, Cormac Nolan and Maurice Clarke

This annex was updated in 2014 based on WKPELA.

A. General

The herring (*Clupea harengus*) to the south of Ireland in the Celtic Sea and in Division VIIj comprise both autumn and winter spawning components. For the purpose of stock assessment and management, these areas have been combined since 1982. The inclusion of VIIj was to deal with misreporting of catches from VIIg. The same fleet exploited these stocks and it was considered more realistic to assess and manage the two areas together. This decision was backed up by the work of the ICES Herring Assessment Working Group (HAWG) in 1982 that showed similarities in age profiles between the two areas. In addition, larvae from the spawning grounds in the western part of the Celtic Sea were considered to be transported into VIIj (ICES, 1982). Also it was concluded that Bantry Bay which is in VIIj, was a nursery ground for fish of south coast (VIIg) origin (Molloy, 1968).

A study group examined stock boundaries in 1994 and recommended that the boundary line separating this stock from the herring stock of VIaS and VIIb,c be moved southwards from latitude 52°30′N to 52°00′N (ICES, 1994). However, a recent study (Hatfield, *et al.*, 2007) examined the stock identity of this and other stocks around Ireland. It concluded that the Celtic Sea stock area should remain unchanged.

Some juveniles of this stock are present in the Irish Sea for the first year or two of their life. Juveniles, which are believed to have originated in the Celtic Sea move to nursery areas in the Irish Sea before returning to spawn in the Celtic Sea. This has been verified through herring tagging studies, conducted in the early 1990s, (Molloy, *et al.*, 1993) and studies examining otolith microstructure (Brophy and Danilowicz, 2002). Recent work carried out also used microstructure techniques and found that mixing at 1 winter ring is extensive but also suggests mixing at older ages such as 2 and 3 ring fish. The majority of winter spawning fish found in adult aggregations in the Irish Sea are considered to be fish that were spawned in the Celtic sea (Beggs *et al.*, 2008).

Age distribution of the stock suggests that recruitment in the Celtic Sea occurs first in the eastern area and follows a westward movement. After spawning herring move to the feeding grounds offshore (ICES, 1994). In VIIj herring congregate for spawning in autumn but little is known about where they reside in winter (ICES, 1994). A schematic representation of the movements and migrations is presented in Figure 1. Figure 2 shows the oceanographic conditions that will influence these migrations.

The management area for this stock comprises VIIaS, VIIg, VIIj, VIIk and VIIh. Catches in VIIk and VIIh have been negligible in recent years. The linkages between this stock and herring populations in VIIe and VIIf are unknown. The latter are managed by a separate precautionary TAC. A small herring spawning component exists in VIIIa, though its linkage with the Celtic Sea herring stock area is also unknown.

A.2. Fishery

Historical fishery development

Coastal herring fisheries off the south coast of Ireland have been in existence since at least the seventeenth century (Burd and Bracken, 1965). These fisheries have been an important source of income for many coastal communities in Ireland. There have been considerable fluctuations in herring landings since the early 1900s.

In the Celtic Sea, historically, the main fishery was the early summer driftnet fishery and the Smalls fishery which also took place in summer. In 1933 several British vessels, mainly from Milford Haven, began to fish off the coast of Dunmore East and the winter fishery gained importance. The occurrence of the world war changed the pattern of the herring fishery further with little effort spent exploiting herring in the immediate post-war years (Burd and Bracken, 1965). Landings of herring off the southwest coast increased during the 1950s.

In 1956 Dunmore East was considered as the top herring port in Ireland with over 3000 t landed. This herring was mainly sold to the UK or cured and sent to the Netherlands (Molloy, 2006). During this time many boats from other European countries began to exploit herring in this area during the spawning period. This continued until the 1960s when catches began to fall. In 1961 the Irish fishery limits changed whereby non-Irish vessels were prohibited from fishing in the inshore spawning grounds (Molloy, 1980). Consequently, continental fleets could no longer exploit herring on the Irish spawning grounds. They had to purchase herring from Irish vessels in order to meet requirements (Molloy, 2006).

During the period from 1950–1968 the fleet exploiting the stock changed from mainly drift and ringnets to trawls. Further fluctuations in the landings were evident during this time with high quantities of herring landed from 1966–1971 (Molloy, 1972). In the mid-sixties, the introduction of midwater pair trawling led to greater efficiency in catching herring and this method is still employed today. Overall the 1960s saw a rise in herring landings with 1969 seeing a rise to 48 000 t. The North Sea herring fisheries were becoming depleted and several countries were turning to Ireland to supply their markets. Prices also increased and additional vessels entered the fleet (Molloy, 1995). Increases in effort led to increased catches initially but this did not continue and this combined with poor recruitment began the decline of the fishery. It was eventually closed in April 1977 and remained closed until November 1982 (Molloy, 2006). When the fishery reopened the management area now included VIIj also. In 1983 a new management committee was formed.

Fishery in recent years

In the past, fleets from the UK, Belgium, The Netherlands and Germany as well as Ireland exploited Celtic Sea herring. In recent years however this fishery has been prosecuted entirely by Ireland. This fishery is managed by the Irish "Celtic Sea Herring Management Advisory Committee", established in 2000 and constituted in law in 2005.

The Irish quota is managed by allocating individual quotas to vessels on a weekly basis. Participation in the fishery is restricted to licensed vessels and these licensing requirements have been changed. Previously, vessels had to participate in the fishery each year to maintain their licence. Since 2004 this requirement has been lifted. This has been one of the contributing factors to the reduction in number of vessels participating in the fishery in recent seasons (ICES, 2005b). Fishing is restricted to the period Monday to Friday each week, and vessels must apply a week in advance before they are allowed to fish in the following week. Triennial spawning box closures are enshrined in EU legislation (Figure 3).

The stock is exploited by two types of vessels, larger boats with RSW storage and smaller dry hold vessels. The smaller vessels are confined to the spawning grounds (VIIaS and VIIg) during the winter period. The refrigerated seawater (RSW) tank vessels target the stock inshore in winter and offshore during the summer feeding phase (VIIg). There has been less fishing in VIIj in recent seasons.

The fleet can be classified into four categories of vessels:

Category 1: "Pelagic Segment".	Refrigerated seawater trawlers
Category 2: "Polyvalent RSW Segment".	Refrigerated seawater or slush ice trawlers
Category 3: "Polyvalent Segment".	Varying number of dry hold pair trawlers,
Category 4: Driftnetters.	A negligible component in recent years, very small vessels

The term "Polyvalent" refers to a segment of the Irish fleet, entitled to fish for any species to catch a variety of species, under Irish law. Since 2002 fishing has taken place in quarter 3, targeting fish during the feeding phase on the offshore grounds around the Kinsale Gas Fields. These fish tend to be fatter and in better condition than winter-caught fish. In 2003 the fishery opened in July on the Labadie Bank and caught large fish. In 2004–2006 it opened in August and in 2007 and in 2008 began in September. Only RSW and bulk storage vessels can prosecute this fishery. Traditional dry-hold boats are unable to participate.

In recent years, the targeting fleet has changed. The fleet size has reduced but an increasing proportion of the catch is taken by RSW and bulk storage vessels and less by dry-hold vessels. There has been considerable efficiency creep in the fishery since the 1980s with greater ability to locate fish.

Since 2009, VIIaS has been closed to larger vessels, and only vessels of less than 50 feet length are allowed up to 11% of the Irish quota (lower percentage during rebuilding plan). The effect of this may have been to shift exploitation to slightly older fish, and also to reduce the efficiency of the fleet, thus reducing fishing mortality on spawning shoals.

Non-Irish vessels had ceased to participate in this fishery. However anecdotal reports of freezer trawlers fishing herring off the SW coast of Ireland occur from time to time. Reported catches from continental freezer trawlers have increased in the most recent years. Much of the freezer trawler catch comes from VIIh. This division is part of the management unit, but fish in this area may belong to another stock.

A.3. Ecosystem aspects

The ecosystem of the Celtic Sea is described in ICES WGRED (2007b). The main hydrographical features of this area as they pertain to herring are presented in Figure 2.

Temperatures in this area have been increasing over the last number of decades. There are indications that salinity is also increasing (ICES, 2006a). Herring are found to be more abundant when the water is cooler while pilchards favour warmer water and tend to extend further east under these conditions (Pinnegar *et al*., 2002). However, studies have been unable to demonstrate that changes in the environmental regime in the Celtic Sea have had any effect on productivity of this stock.

Herring larval drift occurs between the Celtic Sea and the Irish Sea. The larvae remain in the Irish Sea for a period as juveniles before returning to the Celtic Sea. Catches of herring in the Irish Sea may therefore impact on recruitment into the Celtic Sea stock (Molloy, 1989). Distinct patterns were evident in the microstructure and it is thought that this is caused by environmental variations. Variations in growth rates between the two areas were found with Celtic Sea fish displaying fastest growth in the first year of life. These variations in growth rates between nursery areas are likely to impact recruitment (Brophy and Danilowicz, 2002). Larval dispersal can further influence maturity-at-age. In the Celtic Sea faster growing individuals mature in their second year (1 winter ring) while slower growing individuals spawn for the first time in their third year (2 winter ring). The dispersal into the Irish Sea which occurs before recruitment and subsequent decrease in growth rates could thus determine whether juveniles are recruited to the adult population in the second or third year (Brophy and Danilowicz, 2003).

The spawning grounds for herring in the Celtic Sea are well known and are located inshore close to the coast (O'Sullivan *et al*., 2013). These spawning grounds may contain one or more spawning beds on which herring deposit their eggs. Individual spawning beds within the spawning grounds have been mapped and consist of either gravel or flat stone (Breslin, 1998). Spawning grounds tend to be vulnerable to anthropogenic influences such as dredging and sand and gravel extraction. The main spawning grounds are displayed in Figure 4, whilst the distributions of spawning and non-spawning fish are presented in Figure 5. Nursery grounds are also thought to be quite discrete and several areas of importance are known, including the western coast of the Irish Sea, Dungarvan Bay, and the bays and rias of SW Ireland (Clarke *et al*., 2010.)

Herring are an important component of the Celtic Sea ecosystem. There is little information on the specific diet of this stock. Farran (1927) highlighted the importance of *Calanus* spp. copepods and noted that they peaked in abundance in April/May. Fat reserves peak in June to August (Molloy and Cullen, 1981). Herring form part of the food source for larger gadoids such as hake. A study was carried out which looked at the diet of hake in the Celtic Sea. This study found that the main species consumed by hake are blue whiting, poor cod and Norway pout. Quantities of herring and sprat were also found in fish caught in the northern part of the Celtic Sea close to the Irish coast. Large hake, >50 cm tended to have more herring in their stomachs than smaller hake (Du Buit, 1996).

Cetaceans are important predators of herring in this area. A preliminary estimate of annual consumption of herring by cetaceans is 3300 t (Berrow, personal communication) This estimate is based on the estimated abundance of the species, their annual consumption of herring, the time spent eating herring and the estimated percentage of herring in their diets (Ryan *et al*., 2013).

Recent work by Whooley *et al*. (2011) shows that fin whales *Balaenoptera physalus* are an important component of the Celtic Sea ecosystem, with a high re-sighting rate indicating fidelity to the area. There is a strong peak in sightings in November, and fin whales were observed actively feeding on many occasions, seeming to associate with sprat and herring shoals. These authors go on to suggest that the peak in fin whale sightings in November may coincide with the inshore spawning migration of herring. Fin whales tend to be distributed off the south coast in VIIg in November, but further east, in VIIaS by February (Berrow, personal communication). This suggests that their occurrence coincides with peak spawning time in these areas.

Bycatch

Bycatch is defined as the incidental catch of non-target species. There are few documented reports of by catch in the Celtic Sea herring fishery. A European study was undertaken to quantify incidental catches of marine mammals from a number of fisheries including the Celtic Sea herring fishery. Small quantities of non-target whitefish species were caught in the nets. Of the non-target species caught whiting was most frequent (84% of tows) followed by mackerel (32%) and cod (30%). The only marine mammals recorded were grey seals (*Halichoerus grypus*). The seals were observed on a number of occasions feeding on herring when the net was being hauled and during towing. They appear to be able to avoid becoming entangled in the nets. It was considered unlikely by Berrow *et al*., 1998, that this rate of incidental catch in the Celtic Sea would cause any decline in the Irish grey seal population. Results from this project also suggested that there was little interaction between the fishing vessels and the cetaceans in this area. Occasional entanglement may occur but overall incidental catches of cetaceans are thought to be minimal (Berrow *et al*., 1998). The absence of any other bycaught mammals does not imply that bycatch is not a problem only that it did not occur during this study period (Morizur *et al*., 1999).

Recent work by the Irish Whale and Dolphin Group (McKeogh and Berrow, 2014) suggest that bycatch of non-target species in this fishery is very low, consisting of blue shark, whiting and haddock.

Discards

Catch is divided into landings (retained catch) and discards (rejected catch). Discards are the portion of the catch returned to the sea as a result of economic, legal, or personal considerations (Alverson *et al*., 1994). In the 1980s a roe (ovary) market developed in Japan and the Irish fishery became dependent on this market. This market required a specific type of herring whose ovaries were just at the point of spawning. A process developed whereby large quantities of herring were slipped at sea. This type of discarding usually took place in the early stages of spawning and was reduced by the introduction of experimental fishing (Molloy, 1995). This market peaked in 1997 and has been in decline since with no roe exported in recent years. Markets have changed with the majority of herring going to the European fillet market.

Discarding was high during 1980s until late 1990s, though available estimates may be too low. Since then the main reason to discard has been unwanted catch. Like all pelagic fisheries, discarding is known to occur but estimates are unavailable at present. Measures taken in 2012 have reduced the risk of discarding through more flexible individual boat quota regulations.

Some information on discards is available from independent work conducted by the Irish Whale and Dolphin Group, and from the Irish national pelagic observer programme. The latter programme did not record any instances of discarding though coverage is very low. The IWDG programme achieved 5% coverage of the Irish fishery in 2013 and recorded a rate of discarding of 0.8% of observed catch indicates that discarding was very small and was not a significant issue in this fishery (McKeogh and Berrow, 2014). The vast majority of herring discarding observed were due to faulty equipment or blue sharks blocking the pump causing overflow. A similar study in the previous year (Lyne and Berrow, 2012) also found that discarding was less than 1% of catch. Boyd *et al*. (2012) recorded some slippage been in the fishery where errors in targeting and fishing on inconclusive marks lead to discarding of mixed catches of mackerel, sprat and herring. A discard rate of <1% was also reported by Lyne and Berrow (2012) during ten trips surveyed in 2012/2013 season. It is not clear how representative these estimates are of total discarding, as they are taken from low observer coverage.

Previously, Berrow *et al*., 1998 also looked at the issue of discarding during the study on bycatch. The discard rate was found to be 4.7% and this compares favourably with other trawl fisheries. Possible reasons for discarding were thought to be the market requirements for high roe content and high proportions of small herring in the catch. Overall this study indicated that the Celtic Sea herring fishery is very selective and that discard rates are well within the figures estimated for fishery models.

B. Data

B.1. Commercial catch

The commercial catch data are provided by national laboratories belonging to the nations that have quota/fisheries for this stock. In recent years, only Ireland has been catching herring in this area, and the data are derived entirely from Irish logbook data. Figure 6 shows the trends in catches over the time-series. Ireland acts as stock coordinator for this stock. Commercial catch-at-age data are submitted in Exchange sheet v 1.6.4. These data are processed either using SALLOCL (Patterson, 1998b), or using *ad hoc* spreadsheets, usually the latter. The relevant files are placed on the ICES archive each year.

InterCatch

Since 2007, InterCatch, which is a web-based system for handling fish stock assessment data, was also used. National fish stock catches are imported into InterCatch. Stock coordinators then allocate sampled catches to unsampled catches, aggregate them to stock level and download the output. The InterCatch stock output can then be used as input for the assessment models. The comparisons to date have been very good and it is envisaged that this system will replace SALLOCL and other previously used systems. InterCatch cannot deal with catches from two calendar years therefore for example data from the 2008/2009 season are uploaded to InterCatch as 2008 figures. Catches from quarter 1 2009 are entered as being from quarter 1 2008.

B.2 Biological

Sampling Protocol

Sampling is performed as part of commitments under the EU Council Regulation 1639/2001.Sampling (of the Irish catches) is conducted using the following protocol:

- Collect a sample from each pair of boats that lands. Depending on the size range, a half to a full fish box is sufficient. If collecting from a processor make sure sample is ungraded and random.

- Record the boat name, ICES area, fishing ground, date landed for each sample.
- Randomly take 75 fish for ageing. Record length in 0.5 cm, weight, sex, maturity (use maturity scale for guideline). Extract the otolith taking care not to break the tip and store it in an otolith tray. Make sure the tray is clean and dry.
- Record a tally for the 75 aged fish under "Aged Tally" on the datasheet.
- Measure the remaining fish and record a tally on the measured component of the datasheet.

Ageing protocol

Celtic Sea herring otoliths are read using a stereoscopic microscope, using reflected light. The minimum level of magnification (15x) is used initially and is then increased to resolve the features of the otolith. Herring otoliths are read within the range of 20x–25x. The pattern of opaque (summer) and translucent (winter) zones is viewed. The winter (translucent) ring at the otolith edge is counted only in otoliths from fish caught after the 1st April. This "birth date" is used because the assessment year for Celtic Sea and Division VIIj herring runs from this date to the 31st March of the following year (ICES, 2007). This ageing and assessment procedure is unique in ICES. A fish of 2 winter rings is a three year old. This naming convention applies to all ICES herring stocks where autumn spawning is a significant feature.

Age composition in the catch

In recent years there is a decreasing proportion of older fish present in the catch. Figure 7 shows the age composition of the catches over the time-series. It is clear that there is a truncation of older age classes with low amounts caught in recent years.

Precision in ageing

Precision estimates from the ageing data were carried out in the HAWG in 2007, for the 2006/2007 season (ICES, 2007). Results found that CVs are highest on youngest and oldest ages that are poorly represented in the fishery. The main ages present in the fishery had low CVs, of between 5% and 13%, which is considered a very good level of precision. In the third and the fourth quarter, estimates of 1 wr on CS herring were also remarkably precise. An overall precision level of 5% was reached in Q1 and Q4 in the 2007/2008 season.

Mean weights and mean lengths

An extensive dataset on landings is available from 1958. Mean weights-at-age in the catch in the 4th and 1st quarter are used as stock weights. Trends in mean weights-at-age in the catches are presented in Figure 8, and for weights in the spawning stock in Figure 9. Clearly there has been a decline in mean weights since the early 1980s, to the lowest values observed. The same trends are apparent in Figure 10.

Similar trends in mean length-at-age have been documented by Harma (2013) and Lynch (2011). Both authors showed that single s-species density-dependence is not a factor in these cycles. Lynch reported that increased SST and was associated with reduced size/weight-at-age and condition factor. Also, abundance of Calanus copepods is positively correlated with size and weight-at-age (Lynch, 2011). Strong non-linear correlations between herring growth and environmental parameters; particularly with zooplankton abundance (positive) and AMO and phytoplankton indices (negative). These factors explained more than 80% in variability of size of three year old fish (Harma, 2013).

Natural mortality

The natural mortality is based on time invariant averages of yearly estimates by age for herring in the North Sea. These estimates are taken from the SMS multispecies model. These are as follows in instantaneous rates by age (winter rings).

1	2	3	4	5	6	7	8	9
0.793	0.377	0.351	0.322	0.312	0.307	0.301	0.301	0.301

Maturity ogive

Clupea harengus is a determinate one-batch spawner. In this stock, the assessment considers that 50% of 1 ringers are mature and 100% of two ringers mature. The percentage of males and females at 1 winter ring are presented in Figure 11. It shows wide fluctuations in percentage maturity from year to year (Lynch, 2011).

It is to be noted that the fish that recruit to the fishery as 1-ringers are probably precocious early maturing fish. Late maturing 1-ringers may not be recruited. Thus maturity at 1-ringer in the population as a whole may be different from that observed in the fishery. Late maturing 1-, 2- and even 3-ringers may recruit from the Irish Sea. Brophy and Danilowicz (2002) showed that late maturing 1-ringers leave the Irish Sea and appear as 2-ringers in the Celtic Sea catches. Beggs, 2008 WD indicated that some older fish also stay in the Irish Sea and return as 3- or even 4-ringers to the Celtic Sea. It is possible that when stock size was low, the relative proportion of late maturing fish from the Irish Sea was greater. This may explain why observed maturity in the catches was later in those years.

Maturity at 1-ring is considered to be 50% with 100% at subsequent ages. Lynch (2011) investigated trends over time in maturity-at-age, in commercial sampling. Earlier maturity at 1-ring began to increase in the early 1970s and has remained high ever since.

B.3. Surveys

Acoustic

Acoustic surveys have been carried out on this stock from 1990–1996, and again from 1998–2010. During the first period, two surveys were carried out each year designed to estimate the size of the autumn and winter spawning components. The series was interrupted in 1997 due to the non-availability of a survey vessel. Since 2005, a uniform design, randomized survey track, uniform timing and the same research vessel have been employed. A summary of the acoustic surveys is presented in Table 1.

Revision of acoustic time-series

A review of the acoustic survey programme was conducted to check the internal consistency of the previous surveys and produce a new refined series for tuning the assessment (Doonan, 2006, unpublished). The old survey abundance at age series is presented in Table 2 and the revised survey time-series is shown in the Table 3 (ICES, 2006).

The surveys were divided into two series, early and late, based on how far from the south coast of Ireland the transects extended. The early group, 1990–1991 to 1994–1995, extended to about 15 nautical miles offshore with two surveys, one in autumn and another in winter. This design aimed to survey spawning fish close inshore with two surveys, the results of which could be added, the two legs covering the two main spawning seasons. The off shore limits were extended in 1995 and some of these surveys had more fish off shore than close inshore. This changed the catchability, suggesting the later series should be separated from the earlier one. Consequently the years before 1995 were removed. This is not considered to be a problem because the earlier series would contribute little to the assessment anyway.

The autumn surveys did not cover the southwest Irish coast of VIIj in all years (three years missing). In order to correct for this, the missing values were substituted with the mean of the available western bays SSB estimates, 7800 t (eleven values, range from 0 to 16 000 t). Numbers-at-age in these surveys were adjusted upwards by the ratio of the adjusted SSB in the SW to the south coast SSB. The current time-series included autumn surveys only.

Analysis errors were found in the surveys from 1998 onwards. The 2003 biomass (SSB, 85 500 t) was re-analysed after the discovery of errors in the spreadsheets used to estimate biomass. The errors affected the calculation of the weighted mean of the integrated backscatter when positive samples had lengths shorter than the base one (here, 15 minutes) and the partitioning of the backscatter for a mixture of species. Also, no account was taken of different sampling frequencies within a 10x20 minute cell (the analysis unit). The 2003 SSB came mainly from two cells that included an intensive survey in Waterford Harbour and these cells had an SSB of about 68 000 t, which was reduced to 7300 t when all errors were corrected. There were some minor corrections in three other cells. The revised total biomass was 24 000 t and the revised spawning biomass was 22 700 t.

In addition, the cell means took no account of the implicit sampling area of transects so that the biomass coming from a large sample value depended on the number of transects passing through the cell. The data were re-analysed using mean herring density by transect as the sample unit and dividing the area into strata based on transect spacing. Areas with no positive samples were excluded from the analysis (since they have zero estimates). Zigzags in bays were analysed as before. For each stratum, a mean density was obtained from the transect data (weighted by transect length) and this was multiplied by the stratum area to obtain a biomass and numbers-at-age. The overall total was the sum of the strata estimates. The same haul assignments as in the original analysis were used. At the same time, a CV was obtained based on transect mean densities, i.e. a survey sample error. For surveys before 1998 and the western part survey in 2002, a CV was estimated using;

$$\sqrt{\log(1.3^2)/n}$$

where n is the number of positive sample values (15 minutes of survey track) from Definite and Probably Herring categories. This was based on the data from the autumn surveys in 1998, 2000, 2001, 2002, and 2005.

In 2013 a change was introduced to the survey design. This was in response to concerns of bias in the survey. From 2005–2012, the inshore stratum in VIIaS was conducted at a time of up to two days from the neighbouring stratum. This has the potential for aggregations being counted more than once, in each stratum. Such an effect would bias the abundance estimate in a positive direction, and was of such concern that the survey design was changed for 2013 onwards. Owing to this change, the surveys from 2013 onwards may not be directly comparable with the earlier ones, and may have a differing catchability.

Current acoustic survey implementation

The acoustic data are collected using the Simrad ER60 scientific echosounder. The Simrad ES-38B (38 KHz) split-beam transducer is mounted within the vessels drop keel or in the case of a commercial vessel mounted within a towed body. The survey area is selected to cover Area VIIj, and the Celtic Sea (Areas VIIg and VIIaS). Transect spacing in these surveys has varied between 1 to 4 nmi. For bays and inlets in the southwest region (VIIj) a combined zigzag and parallel transect approach was used to best optimize coverage. Offshore transect extension reached a maximum of 12 nmi, with further extension where necessary to contain fish echotraces within the survey area.

The data collected is scrutinised using Echoview® post-processing software. The allocated echo integrator counts (S_a values) from these categories were used to estimate the herring numbers according to the method of Dalen and Nakken (1983). The following target strength to fish length relationships is used for herring.

TS = 20logL – 71.2 dB per individual (L = length in cm)

Acoustic survey time-series

The acoustic survey design has been standardized and the timing has been consistent each year since 2005. The 2002 and 2003 surveys had similar timing and are comparable to the uniform time-series. In the benchmark assessment (2007) the time-series used was from 1995–2006. At the time of the benchmark, there were not enough comparable consistent surveys available for tuning. In 2009, four consistent surveys (2005–2008) and two additional fairly consistent surveys (2002–2003) were available. The 2010 assessment also used the 2009 survey.

Irish groundfish survey

The IGFS is part of the western IBTS survey and has been carried out on the RV Celtic Explorer since 2003. The utility of the IGFS as a tuning series was investigated (Johnston and Clarke, 2005 WD). Strong year effects were evident in the data. Herring were either caught in large aggregations or not at all. The signals from this survey were very noisy, but when a longer time-series is developed, it will at least provide qualitative information. The absence of the 2001 year class was supported in the survey data in 2004. The survey is thought to be too uncertain, with poor cohort tracking, to be useful as a tuning series. However it has proved useful as a qualitative index from time to time.

French EVHOE Survey

The Herring Assessment Working group in 2006 had access to data from the French EVHOE quarter 4 western IBTS survey (GOV trawl). The French survey series is from 1997 to 2005 and displayed very variable observed numbers-at-age between years. Consequently, further exploration of the series was not performed. The survey is thought to be too uncertain, with poor cohort tracking, to be useful as a tuning series.

UK Quarter 1 survey

The UK quarter 1 survey was also explored and strong year and age effects, particularly at 2- and 5-ringers were found. Due to strong year and age effects and because it was discontinued in 2002 this survey is considered unsuitable as a recruit index (ICES 2006:ACFM 20).

While these data are useful for comparisons between surveys, as with the Irish data, at the moment it is difficult to see how these data can be used in an assessment. The data, particularly towards the end of the time-series are very noisy and the absence of very small (juvenile) fish, particularly 1 ringers for the majority of time-series is not encouraging (Johnston and Clarke, 2005).

Irish and Dutch juvenile herring trawl surveys

Juvenile herring surveys were carried out from 1972–1974 by Dutch and Irish scientists. These surveys aimed to get information on the location and distribution of young herring. They were also used to examine if young herring surveys in the Irish Sea could provide abundance indices for either the Irish Sea or Celtic Sea stocks. Further young fish surveys were carried out in the Irish Sea from 1979–1988. They were discontinued when it was decided that it was not possible to use the information as recruitment indices for the Celtic Sea or Irish Sea stocks despite earlier beliefs (Molloy, 2006). This was because it was not known what proportion of the catches should be assigned to each stock.

Northern Ireland GFS surveys

These surveys take place in quarters 1 and 3 each year. Armstrong *et al*. (2004) presented a review of these surveys. They are likely to be useful if the natal origin can be established. Further work in this area is required to examine if this survey can be used as a recruit index for Celtic Sea Herring.

Larval Surveys

Herring larval surveys were conducted in the Celtic Sea between October and February from 1978 to 1985 with further surveys carried out in 1989 and 1990. These surveys provided information on the timing of spawning and on the location of the main spawning events as well as on the size of autumn and winter spawning components of the stock. The larval surveys carried out after the fishery reopened in 1982 showed an increase in the spawning stock (Molloy, 1995).

The surveys covered the south coast and stations were positioned 8 nautical miles apart in a grid formation. A Gulf III sampler, with 275 µm mesh was used to collect the samples. The total abundance of <10 mm larvae (prior to December 15th) or <11 mm (after December 15th) was calculated by raising the numbers per m^2 by the area represented by each station. The mean abundance of <11 mm larvae in December–February gave the winter index which when multiplied by 1.465 and added to the Autumn index to give a single index of the whole series (Grainger *et al*., 1982). Larval surveys have not been undertaken in this area since 1989 and until the acoustic survey became established, no survey was available to tune the assessment.

B.4. Commercial cpue

In the 1960s and 1970s cpue (Catch per unit of effort) data from commercial herring vessels were used as indices of stock abundance because there were no survey data available. These data provided an index of changes that were occurring in the fishery at the time. Cpue data were used to tune the assessment (Molloy, 2006). However it is likely that the decline in the stock in the 1970s was not picked up in the cpue until it was at an advanced stage. It is now demonstrated that cpue data do not provide an accurate index of herring abundance, as they are a shoaling fish.

C. Historical stock development

Time periods in the fishery

This fishery can be divided into time periods. A number of factors have changed in this fishery overtime such as the markets, discards and the water allowance. These changes have implications for the trustworthiness of the catch data used in the assessment. The time periods are presented in the Table 4. The recent biological history of the stock is presented in Table 5. It is clear that growth rate has changed over time. Mean length and mean weight-at-age have declined by about 15% and 30% respectively since the late 1970s. Fish are shorter and lighter at age now than at any time in the series. Trends in mean weights in the catch and in the stock are presented in Figures 8 and 9.

Exploration of basic data

Data exploration consisted of examining a number of features of the basic data. These analyses included log catch ratios, cohort catch curves in survey and catch-at-age series. Log catch ratios were constructed for the time-series of catch-at-age data, as follows:

$$\log[C(a,y)/C(a+1,y+1)]$$

These are presented in Figure 12, bu cohort. Mortality was variable over time, but reached a peak for cohorts hatched in late 1990s and early 2000s. There was an increase in ratios in 1998 that seems quite abrupt. Cohorts hatched since the mid-2000s have enjoyed much lower total mortality. This effect can also be seen in cohort catch curve estimates of total mortality (Table 6). Though information on the most recent cohorts is not complete there is some evidence of either negative mortality, or a switch towards full selection at older ages in the fishery. This would invalidate the constant selection period of eight years used in recent ICA assessments. The increased mortality visible in the older ages corresponded to a truncation in oldest ages in the catch-at-age profile at that time.

Assessments 2007–2013

In 2007, a benchmark assessment used a variety of models including ICA (Patterson, 1998) separable VPA, XSA, CSA and Bayesian catch-at-age methods. In addition an analysis of long-term dynamics of recruitment was conducted. Simulations of various fishing mortalities were conducted based on stock productivity. Though no final model formulation was settled upon, the assessment provided information on trends. ICA was preferred to XSA because it is more influenced by younger ages that dominate the stock and fishery, and because of consistency. The settings that had been used before 2007 were found to produce the most reasonable diagnostics.

In 2007 it was considered that the assumption that a constant separable pattern could be used may not have been valid and it was recommended that future benchmark work should consider models that allow for changes in selection pattern.

Also in 2007 a reduction of the plus group to 7+ was recommended. This change did not achieve better diagnostics in 2007, but exploratory assessments in 2008 did find that this change improved the diagnostics.

In 2008 and 2009, the working group continued to explore different assessment settings in ICA. The working group treated these explorations as extensions of the benchmark of 2007. In 2008 ICA was replaced by FLICA and the same stock trajectories were found in each.

In 2009 a final analytical assessment was proposed and was conducted using FLICA (flr-project.org). This assessment was based on exploratory work done in 2008 and 2009. The refinements to the benchmark assessment of 2007 were as follows:

- Further reduction of plus group to 6+;
- Exclusion of acoustic surveys before 2002, because a sufficient series of comparable surveys was now available.

The assessment showed improved precision and coherence between the catch-at-age and the survey data. The survey residuals were lower since 2002 which is reflected in better tuning diagnostics.

The model formulation used for ICA in the 2007 benchmark and the final assessment carried out in 2009–2013 are presented in the table below. The stock trajectory, based on the most recent assessment is presented in Figure 13.

ICA Settings	2007 Benchmark	Final Assessments in 2009 – 2013
Separable period	six years (weighting = 1.0 for each year)	Six years (weighting = 1.0 for each year)
Reference ages for separable constraint	3	3
Selectivity on oldest age	1.0	1.0
First age for calculation of mean F	2	2
Last age for calculation of mean F	6	5
Weighting on 1 ringers	0.1	0.1
Weighting on other age classes	1.0	1.0
Ages for acoustic abundance estimates	2–5	2–5
Plus group	9	6

Benchmark assessments

In 2014 a new assessment method was introduced see Figure 13. This s described in; ICES WKPELA (2014), using the SAM model (Nielsen and Berg, 2014). Settings (coupling of parameter estimation or variance) are as per the text table below.

	SAM Settings	Best combination
1	Coupling of fishing mortality states	1,2,3,4,5,6,7,8,8
2	Correlated random walks for F	correlated (TRUE)
3	Coupling of catchability parameters	1,2,3,3,3,3,3,3,3
4	Variances in F random walk	1,2,2,2,2,2,2,2,2
5	Coupling of logN RW Variances	1,2,2,2,2,2,2,2,2
6	Coupling of observation variances – Catch	1,2,3,3,3,4,4,5,5
7	Coupling of observation variances – Survey	6,6,6,6,6,6,6,6,6

Estimation of terminal year recruitment

Recruitment is considered to be well estimated in SAM, in contrast to the previous model, ICA. This is partly due to the way SAM treats recruitment and to the inclusion of fisheries-independent observations from the acoustic survey, in tuning.

Input data types and characteristics

Data (1-9+ in all cases)	Year range	Notes
Catch tonnes	1958–2013	Catch in tonnes incl. discards
Catch numbers	as above	Catch in numbers
Mean weight catch	as above	Weighted by catch numbers
Mean weight stock	as above	Unweighted, from commercial sampling Oct-Feb
Natural mortality	as above	From North Sea herring multi species, time invariant means
Maturity ogive	as above	50% at 1-ring, 100% subsequently
Proportion of F before spawning	as above	0.5
Proportion of M before spawning	as above	Changed in recent years as fishery began earlier
Survey	2002-2013	2004 excluded

D. Short-term projection

An updated procedure for STF is proposed, based on the FLSAM configuration. Recruitment (final year, interim year and advice year) in the short-term forecast is to be set to the same value based on the segmented stock–recruit relationship (Figure 14), based on the SSB in the final year–2 years.

Interim year catch is calculated as follows:

Irish quota in assessment year – quarter 1 catch in assessment year

+ Estimated catch in quarter 1 advice year (may require iteration)

Population numbers at 2-ring in the interim year should be adjusted as follows:

$N_{2,\text{ int. year}} = N_{1,\text{final year}} * (\exp(-F_{1,\text{ final year}} = M_{1,\text{ final year}})$

Short-term forecasts were routinely performed until 2004. There was no final assessment from 2005–2008 and therefore no short-term forecast was conducted. A forecast was again carried out in 2009–2013. The method used in 2009 and 2010 was the "Multi fleet Deterministic Projection" software (Smith, 2000). From 2011–2013 the forecast was carried out using FLR. A short-term projection is carried out under the following assumptions. From 2009–2011, recruitment was set at geometric mean, from 1995; minus the most recent two years. In 2012 HAWG changed the period for calculation of geometric mean to 1981–2009 (excluding the two most recent years).

E. Medium-term projections

Yield-per-recruit analyses have been conducted for this stock since the mid-1960s, though not necessarily every year. Recent analyses have used the "Multi Fleet Yield-per-recruit" software and using FLR. Based on the most recent yield-per-recruit $F_{0.1}$ is estimated to be 0.412 (Figure 15). Thus, yield-per-recruit is not a basis for estimating F_{MSY}.

Table 7 presents estimates of $F_{0.1}$ from the literature and from yield-per-recruit analyses conducted over time. $F_{0.1}$ estimates from the YPR analysis have been in the range 0.16–0.19, until the benchmark in 2014, when it was re-estimated as 0.412 (due to changing natural mortality. F_{MAX} has been undefined in recent studies but earlier work suggested values of around 0.45, based on the good recruitment regime of the 1960s.

F. Long-term projections

A long-term plan has been proposed for Celtic Sea herring and simulations have been carried out in conjunction with this work. HCS10 (Skagen, 2010) was used to project the stock forward twenty years and screen over a range of possible trigger points, F values and % constraints on TAC change. It was agreed by the Irish industry that a target F of 0.23 would be proposed and that 61 000 t would be used as a trigger biomass. Once the stock falls to this level, reductions in F would be implemented. A 30% constraint in TAC change would also apply. Simulations have shown that this combination of options shows that the risk of falling below the breakpoint which is 41 000 t is less than 5% over the simulation period (ICES, ADGCSHER 2012).

Stochastic simulations were conducted in 2014 by the working group as part of the re-evaluation of reference point Term of Reference from WKPELA 2014. Simulations followed the procedure used to evaluate the present proposed management plan (ICES, HAWG 2013; ICES CM 2012/ACOM:75). The software used was HCS 10-3 (Skagen, 2010; 2013). Errors and biases were as per the final configuration from the long-term management plan (LTMP) evaluation of 2012 (ICES AGDCSHER, 2012), with updated inputs from the benchmark SAM assessment conducted in 2014. Inputs to these simulations are presented in Table 8, using the stock–recruit relationship presented in Figure 14. A number of scenarios were tested as follows:

1) Current LTMP HCR with 10% implementation bias;

2) As above adjusted to have interannual TAC constraint of 10%;

3) As above adjusted to have interannual TAC constraint of 25%;

4) As above adjusted to have a higher target F;

5) As above but considering a range of retrospective revisions of SSB.

Risk profiles follow ICES guidelines (Risk <5% to B_{lim} in any simulation year, "ICES Risk 2"). Scenario 1 predicts that the current HCR has very low risk (<2.5%) in any year, and hence can be considered to continue to conform to the PA approach (Table 9). Scenario 2 predicts that if the TAC constraint is reduced from 30% to 10%, the highest target F that is low risk is F = 0.11 (Table 10). Results of scenario 3 predict for the TAC constraint is reduced to 25%, the target F cannot exceed the current value of F=0.23 (Table 11). Adjustments to target F in the LTMP (Scenario 4) cannot exceed F=0.26 with low risk (Table 12). Finally, Scenario 5 predicted that the current HCR does not remain low risk if retrospective overestimation throughout the series are greater than + 8% (Table 13). TAC constraints in the range 5–20% are not associated with low risk, but values of 0%, or more than 25% are low risk. Table 14 shows that F_{MSY} is calculated as 0.3, without any constraint of a harvest control rule. However, if the ICES generic HCR is applied (Linear decrease to origin when SSB<MSY $B_{trigger}$) then F_{MSY} is calculated as 0.37 with MSY $B_{trigger}$ set at 61 000 t (Table 15).

All simulations predict that yield will tail off from current levels around 20 000 t to about 10 000 t, after about six years. This is assuming that the current low mean weights remain a feature of the stock.

G. Biological reference points

The latest reference points for this stock were:

	Type	Value	Technical basis
MSY	MSY $B_{trigger}$	61 000 t.	Stochastic simulations on segmented regression stock–recruitment relationship.
Approach	F_{MSY}	0.25	Stochastic simulations on segmented regression stock–recruitment relationship.
Precautionary approach	B_{lim}	26 000 t.	The lowest stock observed.
	B_{pa}	44 000 t.	Low probability of low recruitment.
	F_{lim}	Not defined.	
	F_{pa}	Not defined.	
Management Plan	SSB_{MGT}	61 000 t.	A trigger reference point based on stochastic HCR simulations on segmented regression stock–recruit relationship using the HCS software (Skagen, 2010).
	F_{MGT}	0.23	If SSB in TAC year >61 000 t.

Reference points were not updated during WKPELA 2014. The ICES Herring assessment working group will take up the possible revision of these reference points in the light of the new assessment method.

H.1. Biology of the species in the distribution area

Herring shoals migrate to inshore waters to spawn. Their spawning grounds are located in shallow waters close to the coast and are well known and well defined. This stock can be divided into autumn and winter spawning components. Spawning begins in October and can continue until February. A number of spawning grounds are located along the South coast, extending from the Saltee Islands to the Old Head of Kinsale. These grounds include Baginbun Bay, Dunmore East Co Waterford, around Capel and Ballycotton Islands and around the entrance to Cork Harbour (Molloy, 2006). The areas surrounding the Daunt Rock and old Head of Kinsale have also been recognized as spawning grounds (Breslin, 1998; O'Sullivan *et al.*, 2013). These spawning grounds are shown in Figures 4–5.

When referring to spawning locations the following terminology is used (Molloy, 2006).

- A spawning bed is the area over which the eggs are deposited;
- A spawning ground consists of one or more spawning beds located in a small area;
- A spawning area is comprised of a number of spawning grounds in a larger area.

Spawning grounds are typically located in high energy environments such as the mouth of large rivers and areas where the tidal currents are strong. Herring shoals return to the same spawning grounds each year (Molloy, 2006).

Herring produce benthic eggs that are adhered to the bottom substratum where they remain until hatching. Fertilized eggs hatch into larvae in 7–10 days depending on the water temperature[2]. The size of the egg determines the size of the larvae. Larger eggs have a greater chance of survival but this must be balanced against environmental conditions and the inverse relationship between fecundity and egg size (Blaxter and Hunter, 1982).

A study on fecundity of Celtic Sea herring, conducted in the 1920s found that the eggs produced by spring spawners were 25% bigger than those autumn spawners but were less numerous (Farran, 1938). The relationship between fecundity and length has been calculated for both spawning components of Celtic Sea herring. The regression equations are as shown in Molloy (1979), are as follows:

Autumn spawning component: Fecundity = 5.1173 L – 56.69 (n=53)

Winter spawning component: Fecundity = 3.485 L – 35.90 (n=37)

The larval phase is an important period in the herring life cycle. Larvae use their oil globule for food and to provide buoyancy. Currents transport the newly hatched larvae to areas in the Celtic Sea or to the Irish Sea (Molloy, 2006). The conditions experienced during the larval phase as well as during juvenile phase are likely to have some influence on the maturation of Celtic Sea herring. Fast growing juveniles can recruit to the population a year earlier than slow growing juveniles. Faster growth may also lead to increased fecundity (Brophy and Danilowich, 2003). Fluctuating environmental conditions play an important role in the growth and survival of herring in this area.

Celtic Sea herring consist of a mixture of autumn and winter spawners, with spawning occurring between late September and February (Breslin, 1998; Molloy, 1980; 2006; O'Sullivan, 2013). The occurrence of spawning in spring has occasionally been reported by fishermen, but appears restricted to very exceptional events. The fishery at Dunmore East targets winter spawners (Molloy, 2006). There are no reports of autumn spawning in the Celtic Sea prior to 1974 (Molloy, 1980; Molloy and Cullen, 1981). Subsequently, peak spawning period in the Celtic Sea occurred in January off

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[2] http://www.gma.org/herring/biology/life_cycle/default.asp

the southeast and in October–November off the southwest Irish coast (Molloy, 1989; Breslin, 1998). More recently although some spawning occurs in autumn, winter spawning appears to dominate (Brophy and Danilowicz, 2002). Spawning grounds are well defined along the south and southwest of the Irish coast. At a smaller spatial-scale, a few individual spawning beds within the spawning grounds have also been mapped (Breslin, 1998).

Herring larvae are found between October and March in close proximity to spawning grounds. Larvae are transported by currents, mainly wind-driven, either into the Irish Sea (Brophy and Danilowicz, 2002; 2003) or westwards (Molloy and Corten, 1975; ICES, 1994) along the south coast. Nursery areas are located in the bays and estuaries of the south and southwest coast and in the western and eastern Irish Sea (Clarke *et al.*, 2010). A recent survey found large concentrations of juvenile herring in the bays southwest of Ireland: Kinsale and Cork harbours, and Roaringwater Bay; and to the east of Ireland: NE of Dublin (Clarke *et al.*, 2010). Juveniles off the west and southwest spend time close to the south coast but have also been found to migrate northwards to the west coast, following the main residual currents (Molloy, 2006). Evidence shows that winter spawned herring from the Celtic Sea disperse to nursery grounds in the Irish Sea during the first year of life (Brophy and Danilowicz, 2002). The abundance of these juveniles relative to the resident autumn spawned population varies considerably from year to year (Brophy and Danilowicz, 2002; 2003; Burke *et al.*, 2009). This probably reflects both biological parameters such as the yearly spawning potential and physical conditions such as the current strength and residual direction. Tagging experiments (Molloy *et al.*, 1993) and otolith studies (Brophy *et al.*, 2006) suggest that juveniles migrate from the Irish Sea to the Celtic Sea at the time of first spawning. In one year class examined, otoliths shape analyses revealed that 42% of adults spawning in the Celtic Sea had spent their juvenile period in the Irish Sea (Burke, 2008).

After they congregate for spawning in inshore waters, adult herring shoals quickly disperse (Molloy, 2006). It is then assumed that small shoals move back offshore to deeper waters where they overwinter. Feeding occurs predominantly in offshore grounds over summer-time (ICES, 1994; Parrish and Saville, 1965). Such areas include the Smalls, the area around the Kinsale Gas Field and off SW Ireland. Herring fat reserves reach a maximum during June to August, (Molloy and Cullen, 1981). Prerecruit herring are absent from offshore feeding grounds (Burd and Bracken, 1965), assuming they use nursery areas for optimal growth at this stage.

Celtic Sea herring have undergone changes in growth patterns and a declining trend in mean weights and lengths can be seen over time (Figures 8–10). The declines in mean weight reversed around 2008, but since then have declined to the lowest in the series. A scoping exercise by Lynch (2011) suggested that positive NAO and increased SST was associated with declining weight-at-age. Harma (2014) also found temperature (SST or expressed as AMO) to negatively influence weight-at-age. A positive relationship was found between abundance of *Calanus finmarchicus* and weight-at-age (Lynch, 2011). Work by Harma (2013) found that changes in localized environmental parameters such as windspeed rather than global climatic indices like NAO explained cycles in growth over time.

Researchers have agreed that intraspecific density-dependence does not explain declining size, weight or growth (Brunel and Dickey-Collas, 2010; Harma, 2013; Lynch *et al.*, 2011; Molloy, 1984).

The stock seems to have entered a new phase of much higher recruits per SSB than previously (Figure 16).

H.2. Management and ICES Advice

The assessment year is from 1st April to 31st March. However for management purposes, the TAC year is from 1st January to 31st December.

The first time that management measures were applied to this fishery was during the late 1960s. This was in response to the increasing catches particularly off Dunmore East. The industry became concerned and certain restrictions were put in place in order to prevent a glut of herring in the market and a reduction in prices. Boat quotas were introduced restricting the nightly catches and the number of boats fishing. Fishing times were specified with no weekend fishing and herring could not be landed for the production of fishmeal. A minimum landing size was also introduced (Molloy, 1995).

The TAC (total allowable catch) system was introduced in 1972, which meant that yearly quotas were allocated. This continued until 1977 when the fishery was closed. During the closure a precautionary TAC was set for Division VIIj. This division was not assessed analytically (ICES, 1994). After the closure of this fishery a new management structure was implemented with catches controlled on a seasonal basis and individual boat quotas were put in place (Molloy, 1995).

Table 16 shows the history of the ICES advice, implemented TACs and ICES estimates of removals from the stock. It can be seen that the implemented TAC has been set higher than the advice in about 50% of years since the reopening of the fishery in 1983. The tendency for the TAC to be set higher than the advice has also increased in recent years. It can also be seen that ICES catch estimates have been lower than the agreed TAC in most years.

This fishery is still managed by a TAC system with quotas allocated to boats on a weekly basis. Participation in the fishery is restricted to licensed vessels. A series of closed areas have been implemented to protect the spawning grounds, when herring are particularly vulnerable. These spawning box closures were implemented under EU legislation.

The committee set up to manage the Irish fishery for the stock has the following objectives.

- To build the stock to a level whereby it can sustain annual catches of around 20 000 t.
- In the event of the stock falling below the level at which these catches can be sustained the Committee will take appropriate rebuilding measures.
- To introduce measures to prevent landings of small and juvenile herring, including closed areas and/or appropriate time closures.
- To ensure that all landings of herring should contain at least 50% of individual fish above 23 cm.
- To maintain, and if necessary expand the spawning box closures in time and area.
- To ensure that adequate scientific resources are available to assess the state of the stock.
- To participate in the collection of data and to play an active part in the stock assessment procedure.

The Irish Celtic Sea Herring Management Advisory Committee developed a rebuilding plan for this stock, that was used as the *de facto* management plan from 2009–2011 inclusive. The plan incorporated scientific advice with the main elements of the EU "policy statement "on fishing opportunities for 2009, local stakeholder initiatives and Irish legislation. The proposed rebuilding plan for Celtic Sea and Division VIIj herring was deemed to be in accordance with the precautionary approach by ICES in 2009.

Rebuilding plan

1) For 2009, the TAC shall be reduced by 25% relative to the current year (2008).
2) In 2010 and subsequent years, the TAC shall be set equal to a fishing mortality of $F_{0.1}$.
3) If, in the opinion of ICES and STECF, the catch should be reduced to the lowest possible level, the TAC for the following year will be reduced by 25%.
4) Division VIIaS will be closed to herring fishing for 2009, 2010 and 2011.
5) A small-scale sentinel fishery will be permitted in the closed area, Division VIIaS. This fishery shall be confined to vessels, of no more than 65 feet in length. A maximum catch limitation of 8% of the Irish quota shall be exclusively allocated to this sentinel fishery.
6) Every three years from the date of entry into force of this Regulation, the Commission shall request ICES and STECF to evaluate the progress of this rebuilding plan.
7) When the SSB is deemed to have recovered to a size equal to or greater than B_{PA} in three consecutive years, the rebuilding plan will be superseded by a long-term management plan.

Long-term management plan

The rebuilding plan is due to end in 2011 and was replaced by a long-term management plan. In early 2011 the Irish industry agreed a long-term management plan. The plan was evaluated by ICES in 2012 and judged to be in accordance with the PAFM (ICES, ADGCSHER 2012).

<u>Text of the proposed long-term management plan Herring in the Celtic Sea and Division VIIj</u>.

1) Every effort shall be made to maintain a minimum level of spawning–stock biomass (SSB) greater than 41 000 t, the level below which recruitment becomes impaired.
2) Where the SSB, in the year for which the TAC is to be fixed, is estimated to be above 61 000 t ($B_{trigger}$) the TAC will be set consistent with a fishing morality, for appropriate age groups, of 0.23 (F_{target}).
3) Where the SSB is estimated to be below 61 000 tonnes, the TAC will be set consistent with a fishing mortality of:

   SSB * 0.23/61 000

4) Where the rules in paragraphs 2 and 3 would lead to a TAC which deviates by more than 30% from the TAC of the preceding year, the TAC will be

fixed such that it is not more than 30% greater or 30% less than the TAC of the preceding year.

5) Where the SSB is estimated to be below 41 000 tonnes, Subdivision VIIaS will be closed until the SSB has recovered to above 41 000 tonnes.

6) Where the SSB is estimated to be below 41 000 tonnes, and Subdivision VIIaS is closed, a small-scale sentinel fishery will be permitted in the closed area. This fishery will be confined to vessels, of no more than 50 feet in registered length. A maximum catch limitation of 8% of the Irish quota will be exclusively allocated to this sentinel fishery.

7) Notwithstanding paragraphs 2, 3 and 4, if the SSB is estimated to be at or below the level consistent with recruitment impairment (41 000 t), then the TAC will be set at a lower level than that provided for in those paragraphs.

8) No vessels participating in the fishery, if requested, will refuse to take on board any observer for the purposes of improving the knowledge of the state of the stock. All vessels will, upon request, provide samples of catches for scientific analyses.

9) Every three years from the date of entry into force of this Regulation, the Commission will request ICES and STECF to review and evaluate the plan.

10) This arrangement enters into force on 1st January, 2012.

This plan has been the *de-facto* management plan for the stock for 2012 and subsequent years. It is not enshrined in law because it has yet to be considered for approval by the European Parliament.

H.4. Terminology

The WG uses "rings" rather than "age" or "winter rings" throughout the report to denominate the age of herring, with the intention to avoid confusion. It should be observed that, for autumn spawning stocks, there is a difference of one year between "age" and "rings". HAWG in 1992 (ICES 1992/Assess:11) stated that:

"The convention of defining herring age rings instead of years was introduced in various ICES working groups around 1970. The main argument to do so was the uncertainty about the racial identity of the herring in some areas. A herring with one winter ring is classified as 2-years-old if it is an autumn spawner, and one-year-old if it is a spring spawner. Recording the age of the herring in rings instead of in years allowed scientists to postpone the decision on year of birth until a later date when they might have obtained more information on the racial identity of the herring.

The use of winter rings in ICES working groups has introduced a certain amount of confusion and errors. In specifying the age of the herring, people always have to state explicitly whether they are talking about rings or years, and whether the herring are autumn- or spring spawners. These details tend to get lost in working group reports, which can make these reports confusion for outsiders, and even for herring experts themselves. As the age of all other fish species (and of herring in other parts of the world) is expressed in years, one could question the justification of treating West European herring in a special way. Especially with the present trend towards multi-species assessment and integration of ICES working groups, there might be a case for a uniform system of age definition throughout all ICES working groups.

However, the change from rings to years would create a number of practical problems. Data files in national laboratories and at ICES would have to be adapted, which would involve extra costs and manpower. People that had not been aware of the change might be confused when comparing new data with data from old working group reports. Finally, in some areas (notably Division IIIa), the distinction between spring- and autumn spawners is still hard to make, and scientists preferred to continue using rings instead of years.

The Working Group discussed at length the various consequences of a change from rings to years. The majority of the Group felt that the advantages of such a change did not outweigh the disadvantages, and it was decided to stick to the present system for the time being."

The text table below gives an example for the correlation between age, rings and year class for the different spawning types in late 2002:

YEAR CLASS (AUTUMN SPAWNERS)	2001/2002	2000/2001	1999/2000	1998/1999
Rings	0	1	2	3
Age (autumn spawners)	1	2	3	4
Year class (spring spawners)	2002	2001	2000	1999
Rings	0	1	2	3
Age (spring spawners)	0	1	2	3

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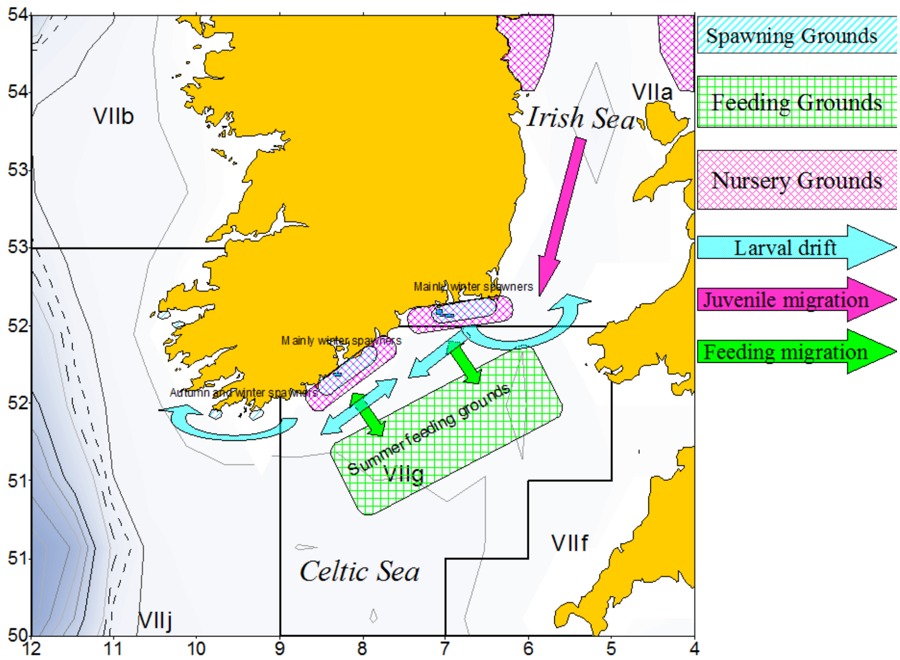

Figure 1. Herring in the Celtic Sea. Schematic presentation of the life cycle of Celtic Sea and VIIj Herring (ICES, 2005c, SGRESP).

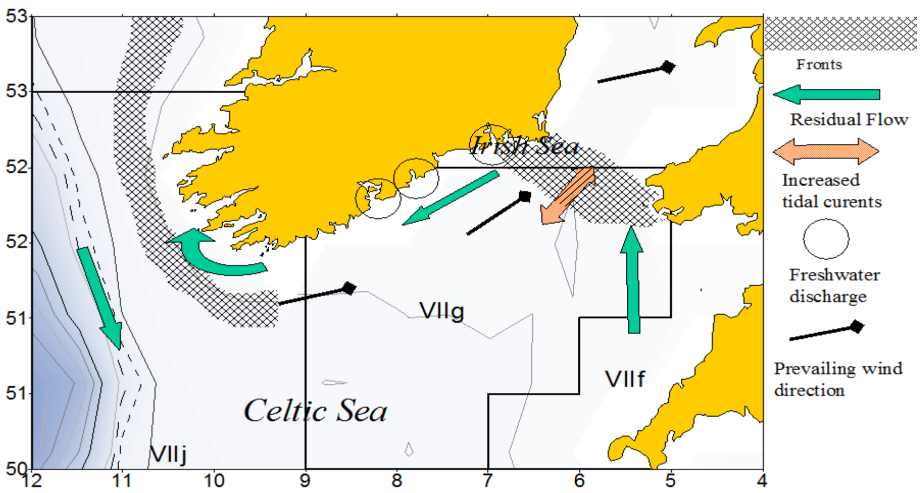

Figure 2. Herring in the Celtic Sea. Schematic presentation of prevailing oceanographic conditions in the Celtic Sea and VIIj (ICES, 2005c, SGRESP).

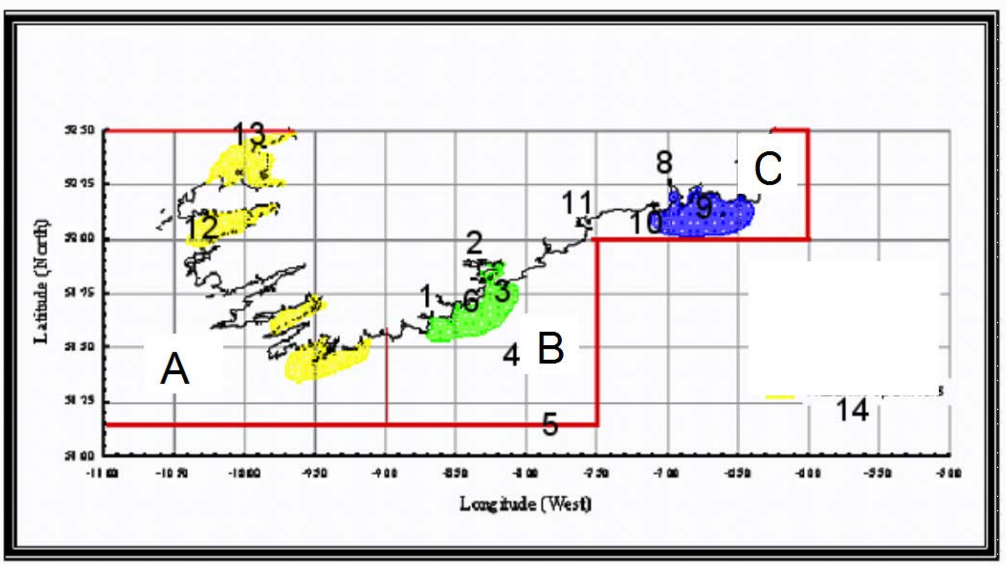

Figure 3. Herring in the Celtic Sea. Areas mentioned in the text and spawning boxes A, B and C, south of Ireland. One of these boxes is closed each season, under EU legislation. 1 Courtmacsherry, 2 Cork Harbour, 3 Daunt Rock, 4 Kinsale Gas Field (Rigs), 5 Labadie Bank, 6 Kinsale, 8 Waterford Harbour, 9, Baginbun Bay, 10, Tramore Bay/ Dunmore East, 11, Ballycotton Bay, 12, Valentia Island, 13 Kerry Head to Loop Head, 14, The Smalls. The spawning boxes A–C correspond to ICES Divisions VIIj, VIIg and VIIaS respectively.

Figure 4. Herring in the Celtic Sea. Spawning grounds (some are named in red text) and general spawning areas (blue text) of herring along the south coast of Ireland, inferred from information on the Irish herring fishery (O'Sullivan *et al.*, 2013).

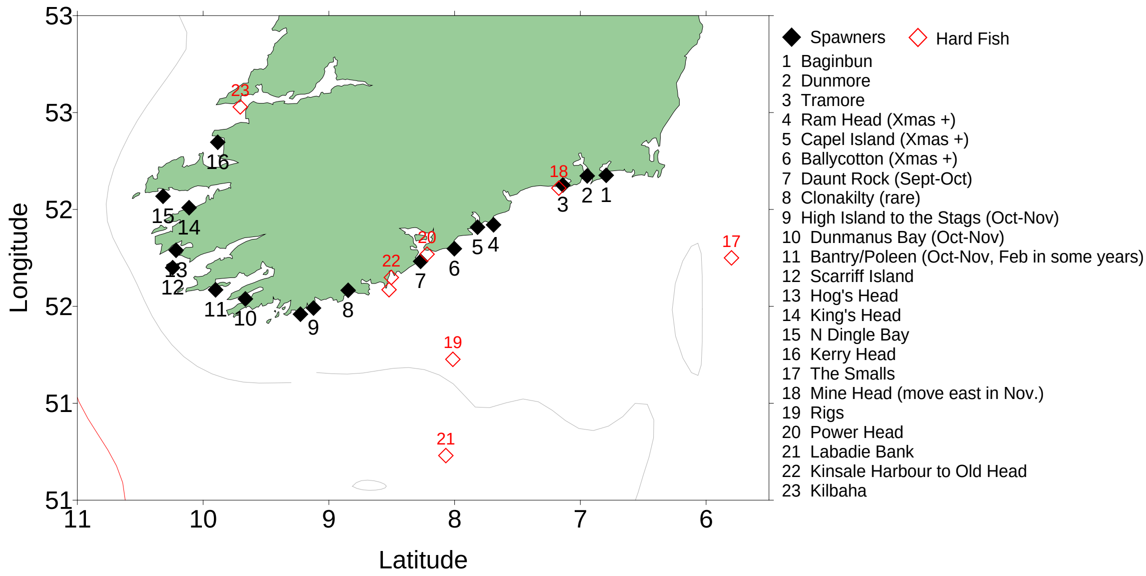

Figure 5. Herring in the Celtic Sea. Location of spawning (closed symbol) and non-spawning (open symbol) herring in the Celtic Sea and SW of Ireland, based on expert fishermen's knowledge.

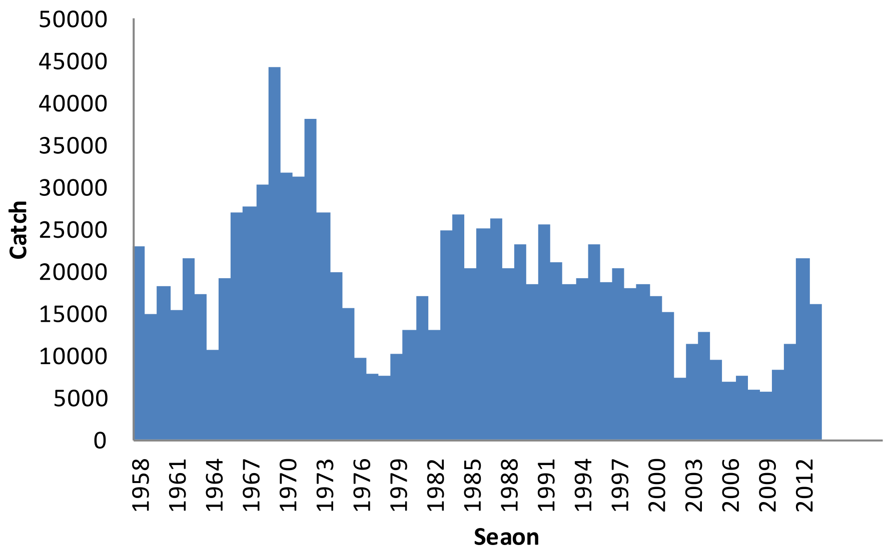

Figure .6. Herring in the Celtic Sea. ICES estimates of herring catches (tonnes) per season 1958/1959 to 2013/2014, indicated by first year on the figure.

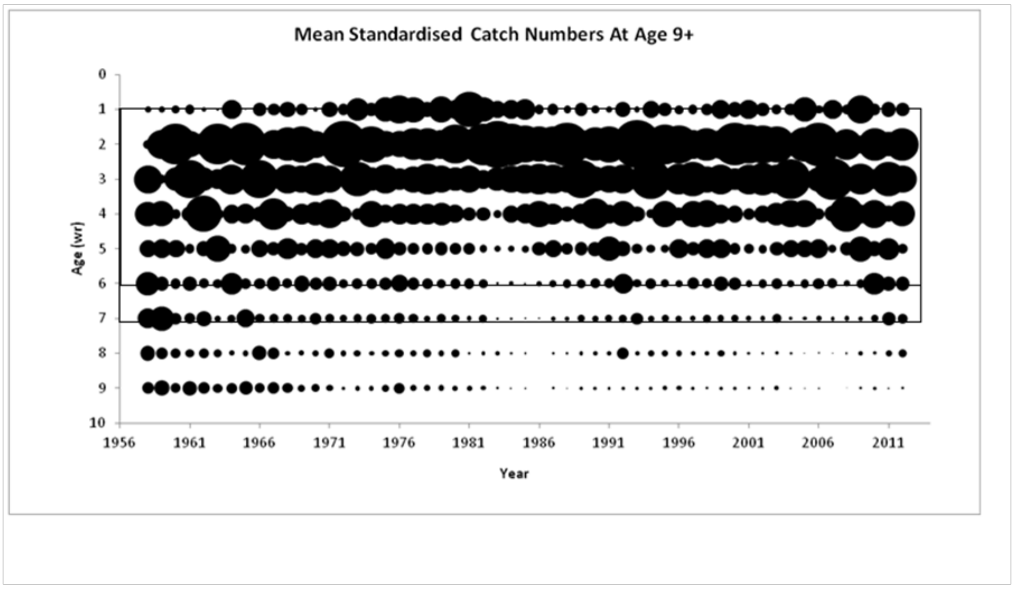

Figure 7. Herring in the Celtic Sea. Catch numbers-at-age standardized by yearly mean 9+.

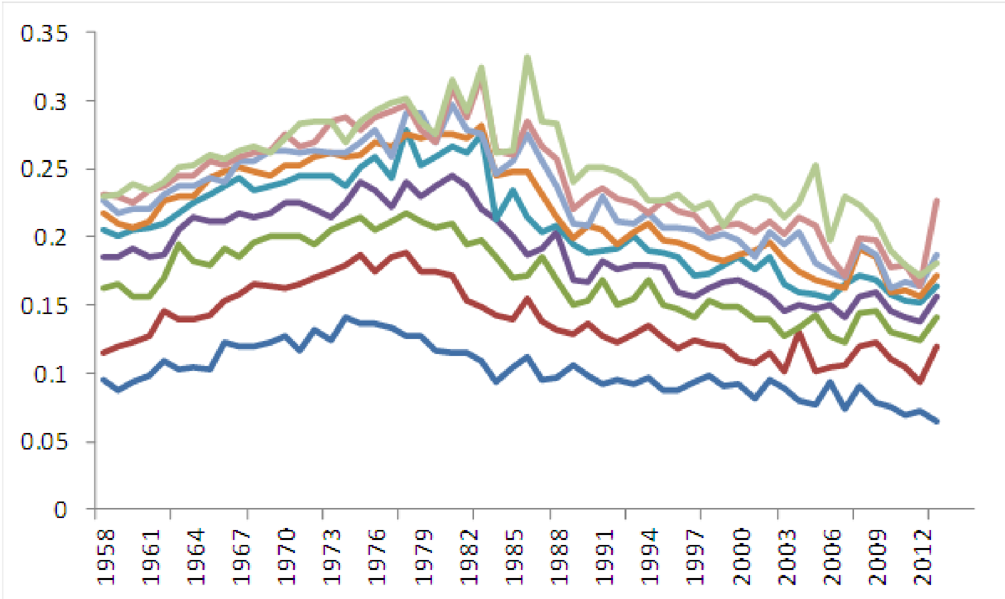

Figure 8. Herring in the Celtic Sea. Trends over time in mean weights in the catch.

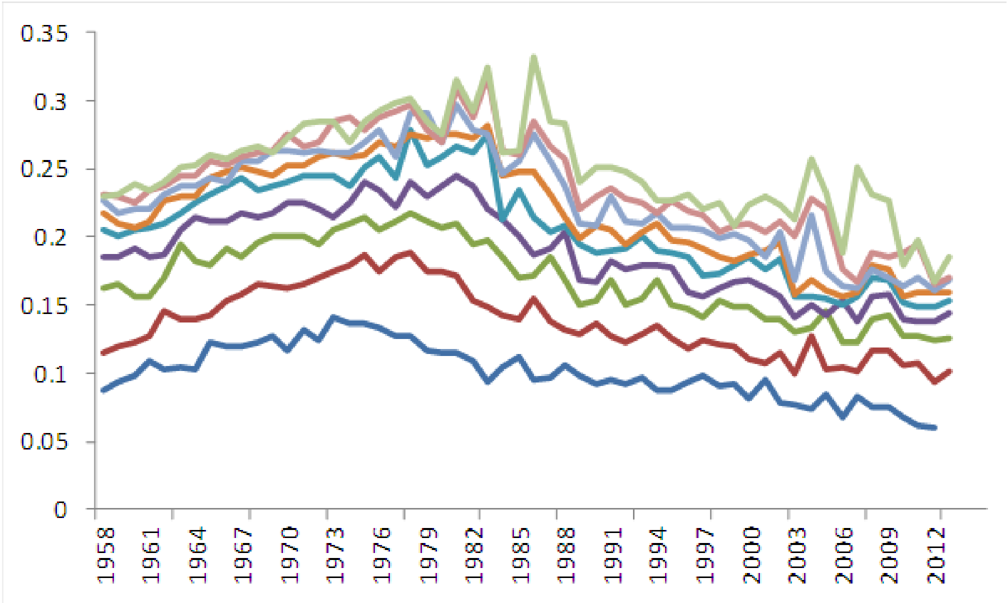

Figure 9. Herring in the Celtic Sea. Trends over time in mean weights in the stock at spawning time.

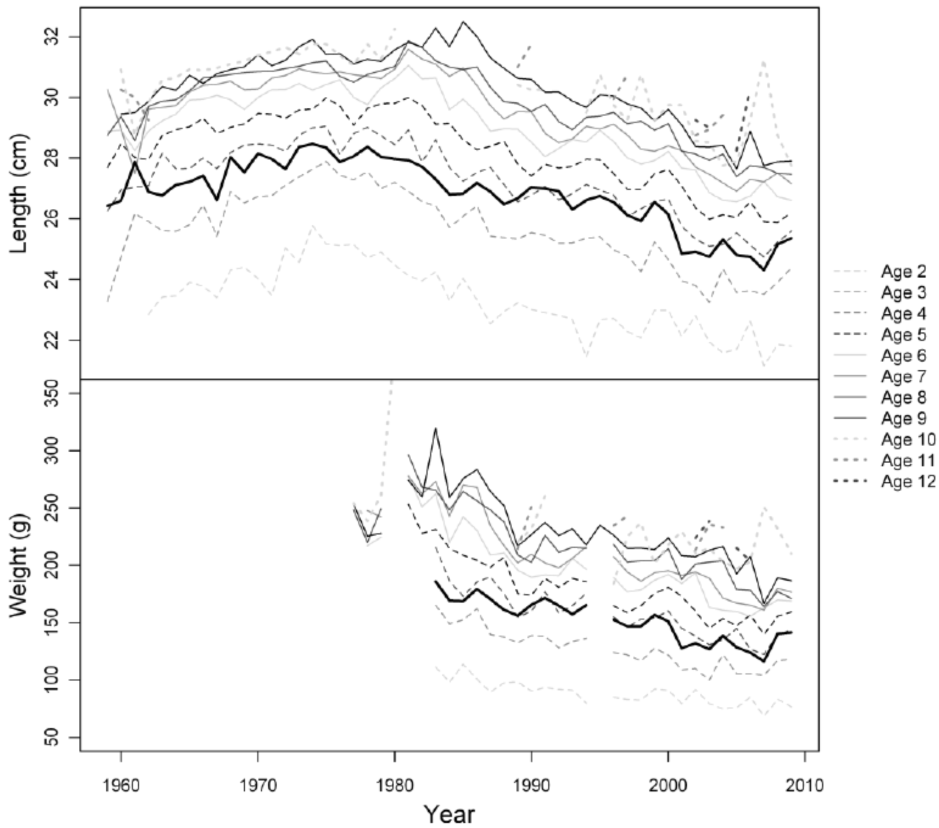

Figure 10. Herring in the Celtic Sea. Mean length and weight-at-age from 1958 to present from Irish commercial sampling (Harma, 2014).

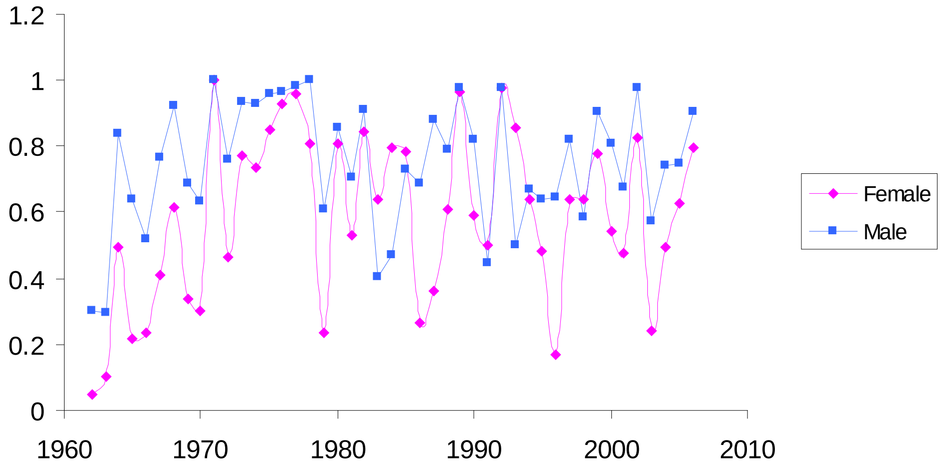

Figure 11. Herring in the Celtic Sea. Percentage maturity in males and females at 1 winter ring (Lynch, 2011).

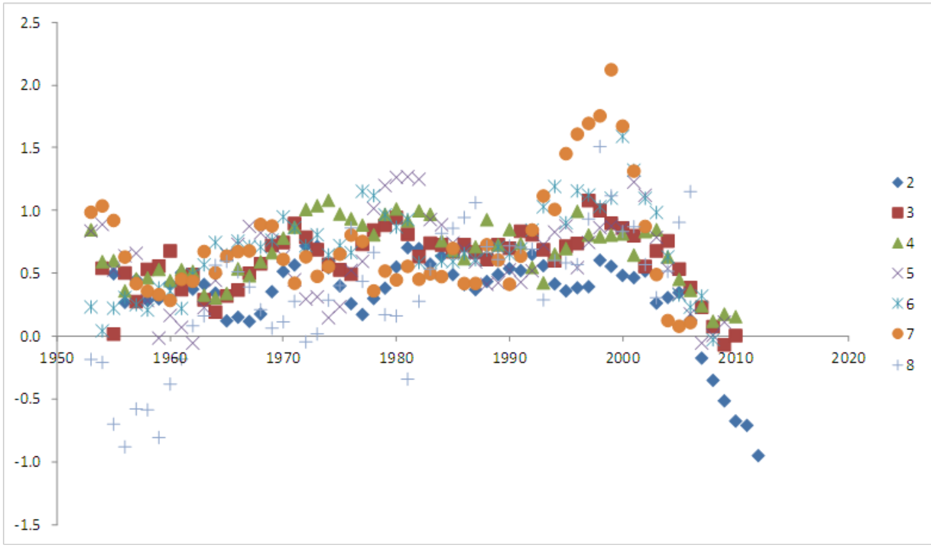

Figure 12. Herring in the Celtic Sea. Log catch ratios (above) and log catch ratios by cohort over time, excluding 1-ringer.

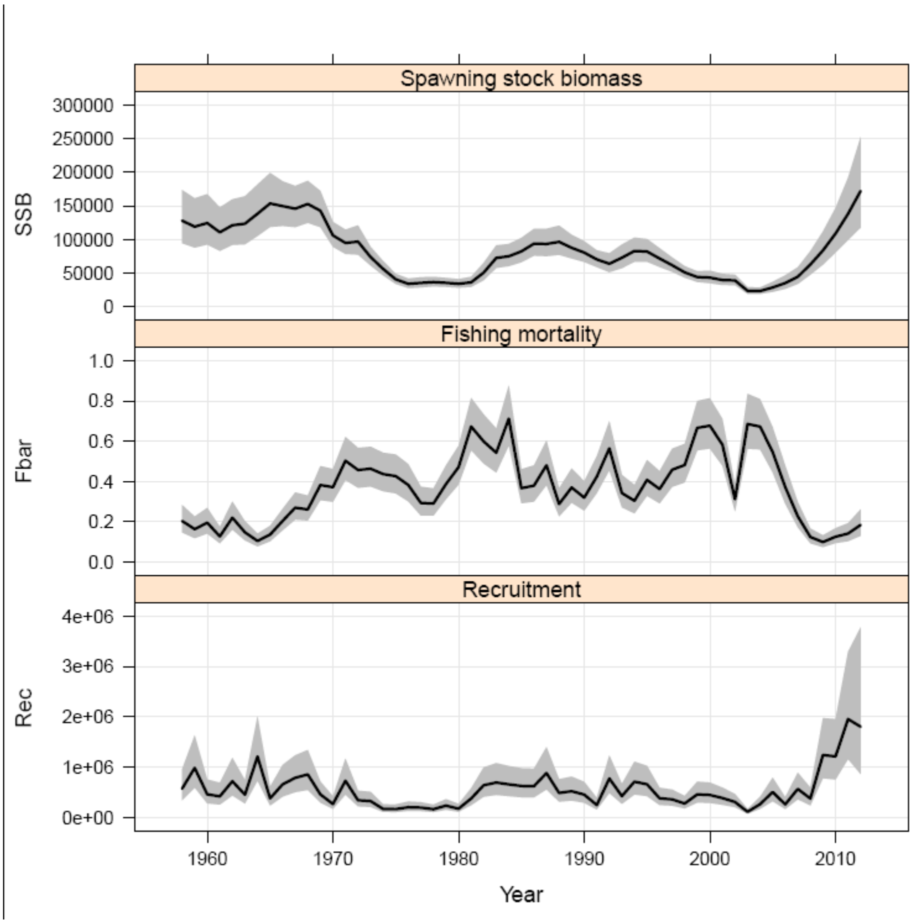

Figure 13. Herring in the Celtic Sea. SSB, F and recruitment (1-ringer) from the final SAM assessment in 2014.

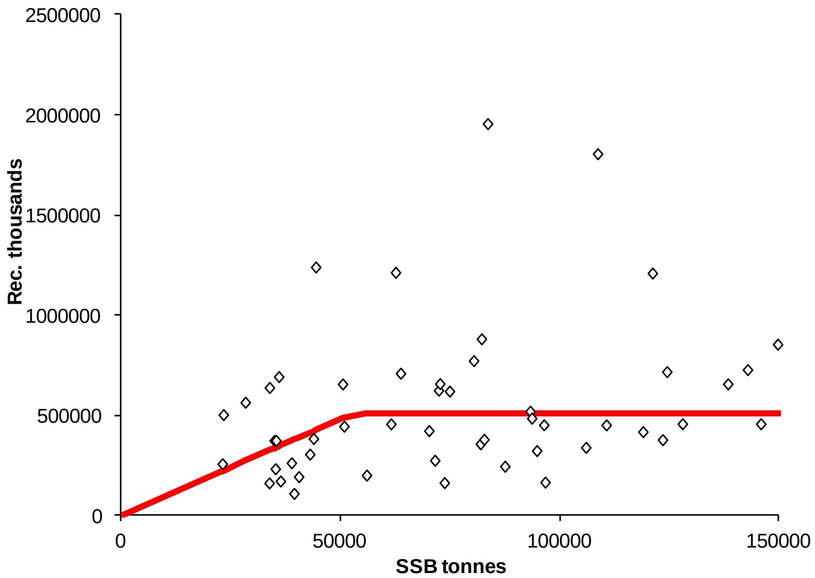

Figure 14. Herring in the Celtic Sea. Stock–recruit relationship from benchmark assessment, and using segmented regression.

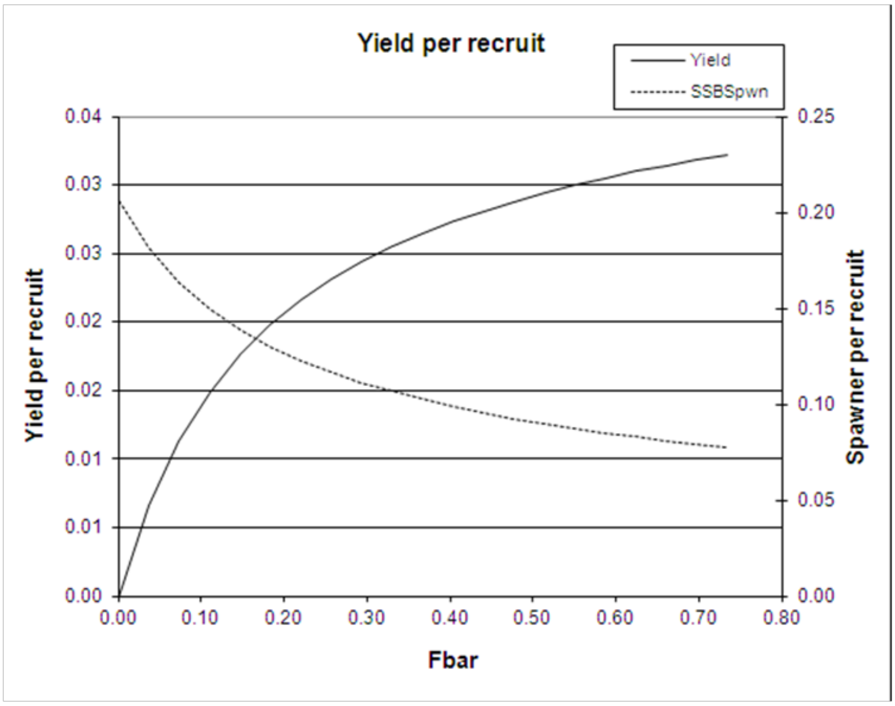

Figure 15. Herring in the Celtic Sea. Yield-per-recruit carried out in benchmark 2014.

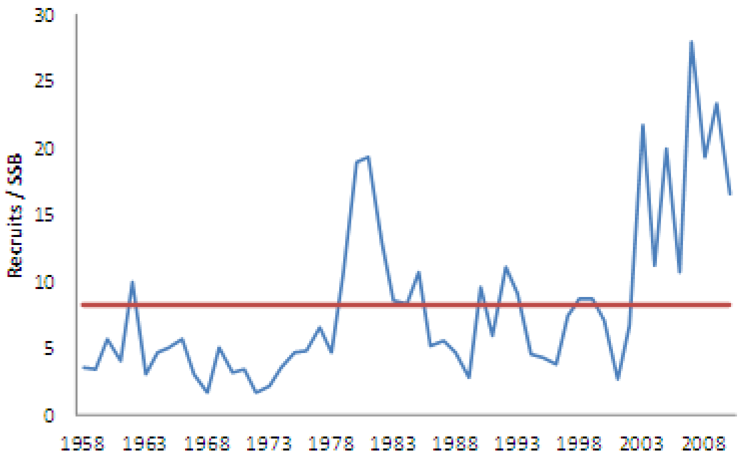

Figure 16. Herring in the Celtic Sea. Recruits per spawner, with long-term mean indicated.

Table 1. Herring in the Celtic Sea. Acoustic surveys of Celtic Sea and VIIj herring, by season. Number of surveys per season and type indicated along with biomass and SSB estimates. Shaded sections show surveys not used in tuning.

Season	No.	Type	Survey Timing	SSB
1990/1991	2	Autumn and winter spawners	Oct and Jan/Feb	-
1991/1992	2	Autumn and winter spawners	Nov/Dec and Jan	-
1992/1993	2	Autumn and winter spawners	Nov and Jan	-
1993/1994	2	Autumn and winter spawners	Nov and Jan	-
1994/1995	2	Autumn and winter spawners	Nov and Jan	-
1995/1996	2	Autumn and winter spawners	Nov and Jan	36
1996/1997	1	Autumn and winter spawners	Oct/Nov and Jan	151
1997/1998	-	No survey		-
1998/1999	1	Autumn spawners	Nov and Jan	100
1999/2000	1	Feeding phase	July	-
1999/2000	1	Winter spawners	Nov and Jan	-
2000/2001	2	Autumn and winter spawners	Oct and Jan	20
2001/2002	2	Prespawning	Sept and Oct	95
2002/2003	1	Prespawning	Sept/Oct	41
2003/2004	1	Prespawning	Oct/Nov	20
2004/2005	1	Prespawning	Nov/Dec	-
2005/2006	1	Prespawning	Oct	33
2006/2007	1	Prespawning	Oct	36
2007/2008	1	Prespawning	Oct	46
2008/2009	1	Prespawning	Oct	90
2009/2010	1	Prespawning	Oct	91
2010/2011	1	Prespawning	Oct	122
2011/2012	1	Prespawning	Oct	122
2012/2013	1	Prespawning	Oct	264
2013/2014	1	Prespawning	Oct	71

Table 2. Herring in the Celtic Sea. Original acoustic survey abundance-at-age as used by ICES until HAWG 2006.

	1990	1991	1992	1993	1994	1995	1996*	1997	1998*	1999**	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2005**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
0	**205**	**214**	**142**	**259**	**41**	**5**	**3**	**-**	**-**	**13**	**-**	**23**	**19**	**0**	**25**	**26**	**13**	**-**	**1**	**99**	**239**	**5**	**0**	**31**	**4**
1	**132**	**63**	**427**	**217**	**38**	**280**	**134**	**-**	**21**	**398**	**23**	**18**	**30**	**41**	**73**	**13**	**54**	**21**	**106**	**64**	**381**	**346**	**342**	**270**	**698**
2	**249**	**195**	**117**	**438**	**127**	**551**	**757**	**-**	**157**	**208**	**97**	**143**	**160**	**176**	**323**	**29**	**125**	**211**	**70**	**295**	**112**	**549**	**479**	**856**	**291**
3	**109**	**95**	**88**	**59**	**160**	**138**	**250**	**-**	**150**	**48**	**85**	**36**	**176**	**142**	**253**	**32**	**26**	**48**	**220**	**111**	**210**	**156**	**299**	**615**	**197**
4	**153**	**54**	**50**	**63**	**11**	**94**	**51**	**-**	**201**	**8**	**16**	**19**	**40**	**27**	**61**	**16**	**50**	**14**	**31**	**162**	**57**	**193**	**47**	**330**	**44**
5	**32**	**85**	**22**	**26**	**11**	**8**	**42**	**-**	**109**	**1**	**21**	**7**	**44**	**6**	**16**	**3**	**20**	**11**	**9**	**27**	**125**	**65**	**71**	**49**	**38**
6	**15**	**22**	**24**	**16**	**7**	**9**	**1**	**-**	**32**	**1**	**8**	**3**	**23**	**8**	**5**	**1**	**5**	**1**	**13**	**6**	**12**	**91**	**24**	**121**	**10**
7	**6**	**5**	**10**	**25**	**2**	**8**	**14**	**-**	**30**	**0**	**2**	**2**	**17**	**3**	**2**	**0**	**1**	**-**	**4**	**5**	**4**	**7**	**33**	**25**	**5**
8	**3**	**6**	**2**	**2**	**3**	**9**	**1**	**-**	**4**	**0**	**1**	**0**	**11**	**0**	**0**	**0**	**-**	**-**	**1**		**6**	**3**	**4**	**23**	**0**
9+	**2**	**-**	**1**	**2**	**1**	**5**	**2**	**-**	**1**	**0**	**0**	**1**	**23**	**0**	**0**	**0**	**-**	**-**	**0**		**1**		**2**	**3**	**2**
																				-					
Total	**904**	**739**	**882**	**1107**	**399**	**1107**	**1253**		**705**	**677**	**252**	**250**	**542**	**404**	**758**	**119**	**292**	**305**	**454**	**769**	**1147**	**1414**	**1300**	**2322**	**1286**
																			46	**90**	**91**	**122**	**122**	**246**	**71**
Biomass (000't)	**103**	**84**	**89**	**104**	**52**	**135**	**151**		**111**	**58**	**30**	**33**	**80**	**49**	**89**	**13**	**33**	**37**	**25**	**20**	**24**	**20**	**28**	**25**	**28**
SSB (000't)	**91**	**77**	**71**	**90**	**51**	**114**	**146**		**111**	**23**	**26**	**32**	**74**	**39**	**86**	**10**	**30**	**36**	**R**	**R**	**R**	**R**	**AR**	**AR**	**AR**

*** Autumn survey.**

**** Summer survey.**

Table 3. Herring in the Celtic Sea. Revised acoustic series as used in tuning.

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Rings	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
0	0	24	-	2	-	1	99	239	5	0	31	4
1	42	13	-	65	21	106	64	381	346	342	270	698
2	**185**	**62**	**-**	**137**	**211**	**70**	**295**	**112**	**549**	**479**	**856**	**291**
3	**151**	**60**	**-**	**28**	**48**	**220**	**111**	**210**	**156**	**299**	**615**	**197**
4	**30**	**17**	**-**	**54**	**14**	**31**	**162**	**57**	**193**	**47**	**330**	**44**
5	**7**	**5**	**-**	**22**	**11**	**9**	**27**	**125**	**65**	**71**	**49**	**38**
6	7	1	-	5	1	13	6	12	91	24	121	10
7	3	0	-	1	-	4	5	4	7	33	25	5
8	0	0	-	0	-	1		6	3	4	23	0
9	0	0	-	0	-	0		1		2	3	2
Abundance	423	183	-	312	305	454	769	1,147	1,414	1,300	2,322	1,286
SSB	41	20	-	33	36	46	90	91	122	122	246	71
CV	49	34	-	48	35	25	20	24	20	28	25	28
Design	AR	AR		R	R	R	R	R	R	AR	AR	AR

Table 4. Herring in the Celtic Sea. Rudimentary history of the Irish fishery since 1958.

Time period	1958-1977	1977-1983	1983-1997	1998-2004	2004-present
Type of fishery	Cured fish	Closure	Herring roe	Fillet/whole fish	Fillet/whole fish
Quality of catch data	High	Medium	Low	High/medium	High/medium
Source of landings data	Auction data	Auction data	Skipper EC logbook estimate	Skipper logbook EC estimate	Weighbridge verifications
Discard Risk Levels	Low	Low	High	Medium	Medium*
Incentive to discard	None	None	Maturity stage		Size grade, market vs. quota, insufficient storage
Allowance for water (RSW tanks)	na	na	na	20%	2%

*** Change to quota allocations per vessel in 2012 reduced risk thenceforward.**

Table 5. Herring in the Celtic Sea. Biological history of the stock.

	1958–1972	1973–1977	1978–1980	1981–1983	1984–1995	1996–2008	2009–2013
MW 2-ring (kg) median	**0.146**	**0.181**	**0.179**	**0.158**	**0.135**	**0.115**	
ML 2-ring (cm) median	**26.4**	**27.5**	**27.1**	**26.3**	**25.2**	**24.4**	
Z (cohort catch curve)	**0.22–0.93**	**0.42–1.12**	**0.74–0.93**	**0.62–0.74**	**0.49–0.89**	**0.48–1.01**	
GM recruitment 10^6	**448**	**167**	**168**	**587**	**514**	**340**	
Recruitment anomaly	**positive**	**negative**	**negative**	**positive**	**positive**	**both**	
SSB (000 t)	**53–126**	**27 to 52**	**25–26**	**30–63**	**49–68**	**24–70**	
F (2-5 r)	**0.23–0.71**	**0.55–0.80**	**0.50–0.68**	**0.68–0.87**	**0.40–0.98**	**0.12–0.88**	

Table 6. Celtic Sea and VIIj herring. Total mortality Z estimated from cohort catch curves in the commercial fishery and the acoustic survey.

Cohort	Z 2-5	n2-5	Z 2-8	n2-8	Cohort	Z2-5	n2-5	Z2-8	n2-8	Z survey 2-5	n survey 2-5
1953	-0.8	2	-0.5	5	1982	-0.7	4	-0.7	7		
1954	-0.4	3	-0.5	6	1983	-0.7	4	-0.5	7		
1955	-0.1	4	-0.2	7	1984	-0.7	4	-0.7	7		
1956	-0.5	4	-0.6	7	1985	-0.4	4	-0.6	7		
1957	-0.3	4	-0.4	7	1986	-0.5	4	-0.6	7		
1958	-0.8	4	-0.2	7	1987	-0.7	4	-0.6	7		
1959	-0.6	4	-0.4	7	1988	-1.0	4	-0.7	7		
1960	-0.4	4	-0.5	7	1989	-0.7	4	-0.6	7		
1961	-0.1	4	-0.3	7	1990	-0.6	4	-0.7	7		
1962	-0.4	4	-0.5	7	1991	-0.5	4	-0.6	7		
1963	-0.2	4	-0.4	7	1992	-0.6	4	-0.8	7		
1964	-0.2	4	-0.5	7	1993	-0.5	4	-1.0	7		
1965	-0.4	4	-0.7	7	1994	-0.7	4	-0.9	7		
1966	-0.6	4	-0.7	7	1995	-0.8	4	-0.9	7		
1967	-0.5	4	-0.6	7	1996	-1.1	4	-0.9	7		
1968	-0.6	4	-0.6	7	1997	-1.0	4	-1.1	7	-1.7	2
1969	-0.9	4	-0.9	7	1998	-0.6	4	-1.1	7	-2.2	2
1970	-0.9	4	-0.7	7	1999	-0.4	4	-1.0	7	-0.7	3
1971	-1.1	4	-0.6	7	2000	-0.6	4	-1.0	7	-0.5	3
1972	-0.7	4	-0.6	7	2001	-0.7	4	-0.7	7	-0.6	3
1973	-0.4	4	-0.6	7	2002	-0.8	4	-0.6	7	-0.5	4
1974	-0.5	4	-0.5	7	2003	-0.5	4	-0.4	7	-0.2	4
1975	-0.4	4	-0.7	7	2004	-0.3	4	-0.2	7	-0.1	4
1976	-0.7	4	-0.8	7	2005	0.0	4	-0.1	6	-0.4	4
1977	-1.0	4	-1.2	7	2006	0.1	4	-0.1	5	-0.4	4
1978	-0.7	4	-0.9	7	2007	-0.1	4	-0.1	4	-0.8	4
1979	-0.9	4	-0.9	7	2008	0.1	3	0.1	3	-1.2	3
1980	-0.8	4	-0.9	7	2009	0.0	2	0.0		-1.5	2
1981	-0.6	4	-0.8	7							

Table 7. Celtic Sea and VIIj herring. Estimates of estimates of $F_{0.1}$, F_{max} and F_{msy} from the literature and HAWG work.

	$F_{0.1}$	F_{MAX}	F_{MSY}	MSY	Comments	Reference
1965	-	>0.5		12–15 k t	Years for calculation had lower recruitment	Burd and Bracken, 1965
1969	-	~0.45		22 K t	Years for calculation had higher recruitment	Molloy, 1969
1974	-	>0.5		14 K *	Fmsy calculated for periods of high and low recruitment	Corten, 1974
1983	0.16				Yield/Biomass ratio	HAWG, 1983
1990	0.16					HAWG, 1990
1994	0.16					HAWG, 1994
1995	0.16					HAWG, 1995
1996	0.16					HAWG, 1996
1997	0.1					HAWG, 1997
1999	<0.2					HAWG, 1999
2000	<0.2					HAWG, 2000
2002	0.17				MFYPR software	HAWG, 2002
2003	0.17				MFYPR software	HAWG, 2003
2004	0.17				MFYPR software	HAWG, 2004
2007	0.19				MFYPR software	HAWG, 2007
2009	0.17				MFYPR software	HAWG 2009
2010	0.18		0.25		MFYPR software (YPR) HCS 10 Software	HAWG 2010
2011	0.17				FLR	HAWG 2011
2014	0.41		0.37		MFYPR software (YPR) HCS 10 Software	HAWG 2014

*endorses Molloy (1969) provided that recruitment is at level 1966–1969.

Table 8. Herring in the Celtic Sea. Input data to stochastic projections.

INPUT	NOTES
Stock–recruitment relationship	Segmented regression, ICES WKPELA, 2014 (Figure 4.7.1)
Observation error (CV)	24%
Onservation bias	0
Implememntation CV	0
Implementation bias	as per ICES ADGCSHER (2012), 10%
Initial numbers	Benchmark assessment, WKPELA, 2014
Weights-at-age	as above
Selection pattern	as above
B_{lim}	B_{loss} 23 000 t (ICES, HAWG 2014)

Table 9. Herring in the Celtic Sea. Results of stochastic simulations of the current LTMP HCR, with 10% implementation bias, showing trajectories of F, SSB, Catch, TAC and interannual TAV variation (AbsIAV). Percentage risk of SSB<Blim indicated (Plim) and risk of there not being enough fish in the population to deliver a catch (Pcrash).

YEAR	F	SSB	CATCH	TAC	ABSIAV	PLIM	PCRASH
2013	0.175	21000	21000	0	0	0	
2014	0.235	25589	23263	22	0	0	
2015	0.285	96475	25313	23011	22.8	0	0
2016	0.321	81377	23044	20949	24.3	0	0
2017	0.353	70579	19707	17915	25.6	0.4	0
2018	0.361	65710	16872	15338	26.4	0.7	0
2019	0.351	62096	14699	13363	26.9	0.8	0
2020	0.325	61059	13411	12192	25.4	0.9	0
2021	0.302	60735	12464	11331	25.9	1.6	0
2022	0.285	61045	12146	11042	25	1.9	0
2023	0.271	61614	11884	10803	24.8	2.1	0
2024	0.263	61916	11853	10776	24.9	2.3	0.1
2025	0.262	62316	11832	10757	24.2	1.9	0.2
2026	0.258	62484	11824	10749	24.7	1.7	0.2
2027	0.256	63173	11869	10790	24.7	1.6	0.2
2028	0.254	63558	11794	10722	24.9	1.7	0.2
2029	0.251	63633	11795	10723	24.9	1.4	0.2
2030	0.249	63843	11883	10803	24.4	1.3	0.2
2031	0.25	63831	11930	10845	24.7	1.3	0.2
2032	0.254	63542	12101	11001	24.2	1.1	0.2
2033	0.254	63241	12080	10981	24.4	1.3	0.2

Table 10. Herring in the Celtic Sea. Herring in the Celtic Sea. Results of stochastic simulations of the current LTMP HCR, as in Table 9, but adjusted to have interannual TAC constraint of 10%, showing trajectories of F, SSB, Catch, TAC and interannual TAV variation (AbsIAV) for highest possible target F (F = 0.11) consistent with low risk. Percentage risk of SSB<Blim indicated (Plim) and risk of there not being enough fish in the population to deliver a catch (Pcrash).

Year	F	SSB	Catch	TAC	AbsIAV	Plim	Pcrash
2013	0.174	21000	21000	0	0	0	
2014	0.201	21563	19603	9.9	0	0	
2015	0.230	20003	18184	9.9	0.2	0	
2016	0.251	89962	18426	16751	10	0.4	0
2017	0.278	80213	16792	15265	10.2	1	0
2018	0.291	75372	15332	13938	10.2	1.3	0
2019	0.302	69682	13950	12681	10.3	1.6	0
2020	0.293	68370	12735	11577	10.3	1.9	0.1
2021	0.284	67843	11729	10663	10.2	2.6	0.3
2022	0.27	67776	10910	9919	10	2.7	0.6
2023	0.254	67825	10200	9272	10	3.4	0.8
2024	0.243	68365	9648	8771	9.8	4	0.9
2025	0.235	69246	9225	8387	9.8	4.1	1
2026	0.231	70420	8896	8088	9.7	4.3	1.3
2027	0.227	71597	8657	7870	9.5	4.6	1.7
2028	0.218	72968	8464	7695	10	4.4	1.9
2029	0.21	74103	8333	7575	9.7	4.4	2.3
2030	0.203	75224	8326	7569	9.5	4.3	2.4
2031	0.199	75985	8279	7526	9.6	4.1	2.5
2032	0.2	76970	8251	7501	10.2	3.9	2.7
2033	0.194	77488	8262	7511	9.7	3.9	2.8

Table 11. Herring in the Celtic Sea. Results of stochastic simulations of the current LTMP HCR, adjusted to have interannual TAC constraint of 25%, showing trajectories of F, SSB, Catch, TAC and interannual TAV variation (AbsIAV), for highest possible target F (F = 0.23) consistent with low risk. Percentage risk of SSB<Blim indicated (Plim) and risk of there not being enough fish in the population to deliver a catch (Pcrash).

Year	F	SSB	Catch	TAC	AbsIAV	Plim	Pcrash
2013	0.172	21000	21000	0	0	0	
2014	0.232	25323	23021	19.3	0	0	
2015	0.288	96206	25357	23052	19.8	0	0
2016	0.338	80651	23379	21253	21	0.2	0
2017	0.393	69343	20477	18615	22.3	0.6	0
2018	0.418	63766	17696	16088	22.7	1.5	0
2019	0.414	59482	15384	13985	23.2	2.3	0
2020	0.388	58909	13787	12533	22.4	3.2	0
2021	0.356	58741	12850	11682	22.1	3.6	0
2022	0.325	58815	12121	11019	21.9	4	0
2023	0.306	58522	11850	10773	21.5	4.2	0.2
2024	0.294	58736	11624	10567	21.8	4.3	0.3
2025	0.282	59101	11355	10322	21.6	4.5	0.4
2026	0.279	59077	11371	10337	21.3	4.1	0.5
2027	0.275	59247	11243	10221	21.6	4.5	0.5
2028	0.269	59770	11086	10078	21.3	4.3	0.5
2029	0.263	60177	11248	10226	21.1	4.2	0.5
2030	0.261	60142	11259	10235	21.2	3.7	0.5
2031	0.255	60528	11190	10173	21.1	4.1	0.5
2032	0.256	61107	11327	10297	21	3.9	0.5
2033	0.253	61531	11368	10335	21.3	3.4	0.6

Table 12. Herring in the Celtic Sea. Herring in the Celtic Sea. Results of stochastic simulations of the current LTMP HCR, adjusted to have a higher target F, showing trajectories of F, SSB, Catch, TAC and interannual TAV variation (AbsIAV) for highest possible target F (F = 0.26) consistent with low risk. Percentage risk of SSB<Blim indicated (Plim) and risk of there not being enough fish in the population to deliver a catch (Pcrash).

Year	F	SSB	Catch	TAC	AbsIAV	Plim	Pcrash
2013	0.175	21000	21000	0	0	0	
2014	0.248	26668	24244	22.5	0.1	0	
2015	0.323	93786	27429	24935	22.5	0.1	0
2016	0.376	77523	24382	22165	24.7	0.2	0
2017	0.426	66684	20776	18887	26.9	1.1	0
2018	0.444	61321	17625	16024	27	1.9	0.1
2019	0.442	57451	15334	13940	27	2.9	0.2
2020	0.399	56381	13566	12333	27.2	3.8	0.2
2021	0.359	55970	12642	11493	26.5	4.3	0.3
2022	0.33	56160	12009	10917	26	4.7	0.3
2023	0.31	56642	11683	10620	25.7	4.4	0.3
2024	0.297	57161	11573	10521	25.1	4.5	0.3
2025	0.288	57665	11617	10561	24.4	4.5	0.3
2026	0.284	57852	11596	10542	24.6	4.4	0.3
2027	0.284	58176	11751	10682	25.2	4.1	0.4
2028	0.28	58419	11744	10676	25	3.4	0.4
2029	0.278	58555	11786	10715	25.2	2.9	0.4
2030	0.278	58492	11776	10705	25.4	3.1	0.5
2031	0.281	58306	11819	10745	25	3.1	0.5
2032	0.28	58137	11742	10675	24.9	3.4	0.5
2033	0.278	58112	11660	10600	25.4	3.3	0.5

Table 13. Herring in the Celtic Sea. Results of stochastic simulations of the current LTMP HCR, showing trajectories of F, SSB, Catch, TAC and interannual TAV variation (AbsIAV) considering a range of retrospective revisions of SSB. Percentage risk of SSB<Blim indicated (Plim) and risk of there not being enough fish in the population to deliver a catch (Pcrash) for highest retrospective bias (+8%) over time that is consistent with low risk.

Year	F	SSB	Catch	TAC	AbsIAV	Plim	Pcrash
2013	0.160	21000	21000	0	0	0	
2014	0.230	27315	24832	22.9	0	0	
2015	0.306	28797	26179	22.5	0	0	
2016	0.365	82040	25981	23619	23.9	0.2	0
2017	0.426	68968	21997	19997	26.8	1	0
2018	0.454	62361	18480	16800	26.8	1.7	0
2019	0.46	57705	15854	14413	26.9	2.7	0.3
2020	0.415	56361	13905	12641	26.8	3.7	0.3
2021	0.372	55786	12835	11668	26.2	4.5	0.4
2022	0.342	55879	12171	11064	25.6	4.4	0.4
2023	0.319	56293	11802	10729	25.4	5	0.5
2024	0.306	56752	11684	10622	24.8	4.7	0.5
2025	0.296	57179	11708	10643	23.9	4.7	0.5
2026	0.289	57270	11673	10611	24.3	4.8	0.5
2027	0.289	57508	11827	10752	24.8	4.8	0.5
2028	0.284	57713	11787	10715	24.7	4.2	0.5
2029	0.281	57834	11819	10744	24.9	3.5	0.5
2030	0.28	57784	11786	10714	25	3.6	0.5
2031	0.282	57651	11795	10723	24.6	3.3	0.5
2032	0.28	57516	11721	10655	24.5	4.1	0.5
2033	0.279	57517	11643	10584	24.9	3.9	0.5

Table 14. Herring in the Celtic Sea. Results of stochastic simulations to evaluate F_{msy}, showing trajectories of F, SSB, Catch, TAC and interannual TAV variation (AbsIAV). Percentage risk of SSB<Blim indicated (Plim) and risk of there not being enough fish in the population to deliver a catch (Pcrash) for highest possible target F (F=0.30) consistent with low risk to Blim.

Year	F	SSB	Catch	TAC	AbsIAV	Plim	Pcrash
2013	0.177	21000	21000	0	0	0	
2014	0.350	37046	37046	50.9	0	0	
2015	0.355	86970	26871	26871	50.4	0.1	0
2016	0.365	74015	21813	21813	51.9	0.3	0
2017	0.354	66681	17455	17455	53.3	0.3	0
2018	0.368	63109	16191	16191	50.1	0.3	0
2019	0.361	60175	14802	14802	51.9	0.6	0
2020	0.366	59432	14583	14583	48.5	1	0
2021	0.376	58354	14473	14473	47.4	0.8	0
2022	0.38	57265	14383	14383	49	1.1	0
2023	0.382	56909	14066	14066	50.7	1.6	0
2024	0.366	56863	13780	13780	50.4	1.8	0
2025	0.381	55789	14086	14086	50.1	2.2	0
2026	0.353	54931	13021	13021	49.6	2	0
2027	0.381	54148	13646	13646	48.7	2.3	0
2028	0.373	53483	13125	13125	48.6	3.1	0
2029	0.359	53259	12721	12721	50.6	2.9	0
2030	0.395	52494	13416	13416	48.6	3.7	0
2031	0.371	51814	12653	12653	51.7	4.1	0
2032	0.358	51389	12226	12226	50.1	4.3	0
2033	0.363	51461	12384	12384	50.1	4.5	0

Table 15. Herring in the Celtic Sea. Results of stochastic simulations of the ICES generic HCR (Btrigger = 61 000 t) , showing trajectories of F, SSB, Catch, TAC and interannual TAV variation (AbsIAV). Percentage risk of SSB<Blim indicated (Plim) and risk of there not being enough fish in the population to deliver a catch (Pcrash). MSY Btrigger is set at 61 000 t, with highest F consistent with low risk (0.37).

Year	F	SSB	Catch	TAC	AbsIAV	Plim	Pcrash
2013	0.172	21000	21000	0	0	0	
2014	0.428	43942	43942	64.7	0	0	
2015	0.456	80212	31305	31305	58.9	0	0
2016	0.442	67223	22568	22579	68.7	0.6	0.1
2017	0.425	61159	18292	18292	69.1	0.3	0.1
2018	0.434	58053	16596	16600	70.3	0.9	0.2
2019	0.423	54943	15361	15361	69.6	1.3	0.2
2020	0.405	53449	14584	14584	70.1	1.4	0.2
2021	0.408	52486	14238	14238	72	1.6	0.2
2022	0.4	51792	13945	13945	76.6	2.2	0.2
2023	0.4	51169	13570	13570	73.2	2.1	0.2
2024	0.397	50420	13599	13599	72.6	2.7	0.2
2025	0.394	49715	13177	13177	71.3	3.2	0.2
2026	0.391	49419	12863	12863	72.8	2.9	0.2
2027	0.386	49660	12712	12712	73.1	2.9	0.2
2028	0.393	49218	13052	13052	74.8	2.3	0.2
2029	0.387	48810	12649	12649	73.1	3.1	0.2
2030	0.399	48505	12851	12854	74.9	3.4	0.4
2031	0.381	48369	12376	12376	71.3	4.5	0.4
2032	0.39	48108	12598	12598	72.2	3.9	0.4
2033	0.385	47683	12447	12447	75.9	4	0.4

Table 16. Celtic Sea and VIIj herring. Advice history. TAC is calendar year, Catch by ass. year/.

Year	ICES Advice	Advised catch	Agreed TAC	Official Landings	Discards	Estimated Catch[1]
1974	NEAFC TAC		32	20	-	19.74
1975	Reduce F, TAC ≤25 000		25	16	-	15.13
1976	TAC between 10 000 and 12 000		10.8	10	-	8.2
1977	No Fishing	0	0	8	-	7.1
1978	No Fishing	0	0	8	-	15.5
1979	TAC set for VIIj only, No fishing in Celtic Sea	0	6	10	-	12.1
1980	TAC set for VIIj only, No fishing in Celtic Sea		6	9	-	9.2
1981	TAC set for VIIj only, No fishing in Celtic Sea		6	17	-	16.8
1982	TAC		8*	10	-	9.5
1983	TAC		8*	22	4	22.18
1984	TAC	13	13	20	3.6	19.7
1985	TAC	13	13	16	3.1	16.23
1986	No specific TAC, preferred overall catch 17,000t		17	13	3.9	23.3
1987	Precautionary TAC	18	18	18	4.2	27.3
1988	TAC	13	18	17	2.4	19.2
1989	TAC	20	20	18	3.5	22.7
1990	TAC	15	17.5	17	2.5	20.2
1991	TAC (TAC excluding discards)	15 (12.5)	21	21	1.9	23.6
1992	TAC	27	21	19	2.1	23
1993	Precautionary TAC (including discards)	20–24	21	20	1.9	21.1
1994	Precautionary TAC (including discards)	20–24	21	19	1.7	19.1
1995	No specific advice	-	21	18	0.7	19
1996	TAC	9.8	16.5–21	21	3	21.8
1997	If required, precautionary TAC	< 25	22	20.7	0.7	18.8
1998	Catches below 25	< 25	22	20.5	0	20.3
1999	F = 0.4	19	21	19.4	0	18.1
2000	F < 0.3	20	21	18.8	0	18.3
2001	F < 0.34	17.9	20	19	0	17.7
2002	F<0.35	11	11	11.5	0	10.5
2003	Substantially less than recent catches	-	13	12	0	11
2004	60% of average catch 1997–2000	11	13	12	n.a.	11
2005	60% of average catch 1997–2000	11	13	10	n.a.	8
2006	Further reduction 60% avg catch 2002–2004	6.7	11	9	n.a.	8.5
2007	No fishing without rebuilding plan	--	9.4	9.6	n.a.	8.3
2008	No targeted fishing without rebuilding plan	--	7.9	7.8	n.a.	6.9
2009	No targeted fishing without rebuilding plan		5.9	6.2	n.a.	5.8
2010	Fmgt 0.19	10.15	10.15	9.6	n.a.	8.3

YEAR	ICES ADVICE	ADVISED CATCH	AGREED TAC	OFFICIAL LANDINGS	DISCARDS	ESTIMATED CATCH[1]
2011	various	16.8 (MSY optn.)	13.2	11.7	n.a.	11.4
2012	MSY approach	26.9	21.1	21.6	0.1	21.6
2013	MSY approach	18.5	17.2	16.2	0.1	16.1
2014	MSY approach	35.9	22.3			
2015	MSY approach	15.4				

Annex 4: Working documents