INTER-BENCHMARK WORKSHOP ON WEST OF SCOTLAND COD (6.a) (IBPCOD6.a)

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INTER-BENCHMARK WORKSHOP ON WEST OF SCOTLAND COD (6.a) (IBP-COD6.a)

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i Executive summary

The Inter-benchmark Process for West of Scotland Cod in Division 6.a (IBPCod.6.a 2019), chaired by Poul Degnbol (Denmark) took place by correspondence during seven WebEx meetings spread over several weeks (18 February–29 March 2019). Participants included scientists from the UK and Ireland, and external reviewers from Denmark. The main focus of the IBP was to remedy the poor diagnostics in the TSA assessment and to identify the reasons for differences between the 2018 WG TSA assessment and an alternative peer-reviewed assessment which shows markedly different trends to the 2018 WG assessment, modifying the TSA configuration as necessary.

This IBP investigated the possible reasons for this discrepancy including exploring the sensitivity of the TSA assessment to selectivity parameter assumptions, weighting of different data sources and inclusion of another surveys in the assessment. The IBP has agreed on that configuration of the TSA assessment which in the opinion of the group, within the options in the TSA assessment, best reflects the developments which may have taken place in the stock and the fisheries. Reference points have been updated on the basis of this final agreed assessment.

The revised TSA shows a significant improvement in the model diagnostics: the tendency of the model to over-estimate terminal F (as apparent in the 2018 WG assessment retrospective) has been resolved and the heterogeneity observed in model residuals is now also much less of an issue. However, during the work it became clear that there were some issues which could either not be addressed or not be resolved in the current process. The main issue which could not be addressed was the possibility for other assessment models or the use of multiple models as basis for the assessment. This limitation was a given in the ToRs and would also not have been practically possible within a brief IBP by correspondence as the present. It appears that this stock assessment may be particularly sensitive to model bias or model error as different models produce quite different perspectives, an issue which does not occur when the same models are applied to similar stocks in the region or neighbouring regions. As a result there was an extensive discussion in the IBP regarding the need for independent evidence to support various interpretations which may emerge from different models. The question of process uncertainty (along with other unresolved issues) is discussed in the report in the context of future benchmark planning.

ii Expert group information

Expert group name	Inter-benchmark Process for West of Scotland Cod in Division 6.a
Expert group cycle	Annual
Year cycle started	2019
Reporting year in cycle	1/1
Chair	Poul Degnbol, Denmark
Meeting venue and dates	18 February–29 March 2019, By correspondence, 11 participants

1 Introduction

1.1 Terms of reference

The IBP6a worked by correspondence to address the following terms of reference:

IBP6a–Inter-benchmark Workshop on West of Scotland Cod (IBPCod6.a)

2018/xx/xx An inter-benchmark workshop on West of Scotland cod (6.a), chaired by Poul Degnbol, Denmark, and with Marie Storr-Paulsen and Poul Degnbol as external reviewers, will be established and will meet by correspondence from February to March 2019 to:

1. Consider the inclusion of new survey indices in the current TSA assessment;
2. Evaluate selectivity parameter settings in the current TSA assessment;
3. Sensitivity analysis of the weighting of different data sources in the assessment;
4. Re-examine and update (if necessary) limit & precautionary F and SSB reference points and MSY reference points;
5. Describe the resulting data analysis procedure and assessment methodology in the stock annex;
6. Review and agree on the resulting stock annex.

IBP6a will report by 31st March 2019 for the attention of the ACOM and WGCSE.

1.2 Working modus and report

The IBP worked by correspondence and WebEx.

Prior to this IBP, West of Scotland cod (6a) was last benchmarked in 2012 (ICES, 2012) and subject to an inter-benchmark process in 2015 (ICES, 2015a). The outcomes of these processes are documented in the stock annex (latest update prior to this IBP was at the assessment WG in 2016).

The latest assessment of West of Scotland cod carried out by ICES indicates that the stock is being fished above F_{MSY} with F declining only slowly. The spawning–stock biomass (SSB) shows no increase and remains well below B_{lim}. These trends differ markedly from stocks of other species in the same area and from other adjacent cod stocks, which show significant declines in F and increasing SSB. Although there may be plausible explanations for these differences, an alternative assessment with different underlying fishery selectivity assumptions (Cook, 2019) indicates a recovering 6.a cod stock with F close to F_{MSY}. This latter assessment is more in line with other stocks and with reductions in effort that have occurred in the fisheries.

As the ToRs state that the IBP is to work on basis of the current TSA assessment, the IBP has not ventured into an investigation of further potential assessment models.

This IBP thus started out investigating the possible reasons for this discrepancy including the sensitivity of the TSA assessment to selectivity parameters and weighting of different data sources and inclusion of other surveys in the assessment. The IBP has on this basis agreed on that configuration of the TSA assessment which in the opinion of the group, within the options in the TSA assessment, best reflects the developments which may have taken place in the stock and the fisheries. That configuration will then be reflected in an updated stock annex.

During the work, it became clear that there were some issues, which could either not be addressed or not be resolved in the current process.

The main issue, which could not be addressed, was the possibilities for other assessment models or the use of multiple models as basis for the assessment. This limitation was a given in the ToRs, and would also not have been practically possible within a brief IBP by correspondence as the present. It has become clear that this stock assessment may be especially sensitive to model bias or model error as different models produces quite different perspectives, which do not appear when the same models are used on data regarding similar stock in the region or neighbouring regions. There has in this situation been an extensive discussion in the IBP regarding the need for independent evidence to support various interpretations, which may emerge from different models, and ultimately regarding the legitimacy (or not) of some extent of model twisting to produce outcomes which may be more in line with expectations emerging from observations of other similar stocks exploited by the same fisheries.

The issues, which could not be resolved numerically within the present process, includes use of spatial data, seal predation and alternative approaches to modelling discards Alternative assessment methods, stock–recruitment modelling, stock structure, fleet disaggregated catch-at-age data and misreporting estimates. These are discussed in the Section 4.

The TSA assessment, which was agreed and proposals for reference points emerging from that, are documented in the main report. Various other analysis were carried out including sensitivity analysis to a range of alternative TSA configurations, some of which are documented in the IBP report and some in the working document by Helen Dobby and Rob Fryer (WD 1, Annex 4). For completeness, Annex 5 includes full model results and diagnostic plots from the sensitivity runs described in the report. Detailed outputs from the reference point calculation and a sensitivity analysis to some of the assumptions, can be found in the working document by Helen Dobby (WD 2, Annex 4). During the process, Robin Cook also contributed with input regarding the discrepancies between the present ICES assessment and what may emerge from other assessment models and with a discussion of some issues to be addressed. This is documented in a working document (WD 3, Annex 4).

2 TSA Stock Assessment

2.1 Issues

The West of Scotland cod stock assessment was last benchmarked by WKROUND in 2012 (ICES, 2012) with an inter-benchmark following in 2015 (ICES, 2015a). For a number of years, the TSA assessment (Gudmundson, 1994; Fryer, 2001 and 2011) agreed at these meetings was applied with no apparent issues. However, diagnostic plots presented at the latest assessment WG (ICES, 2018) highlighted a number of potential problems with the current TSA model configuration and in addition, published work by Cook (2019) calls into question the results of the current assessment.

Concerns were raised at the 2018 WG about the retrospective for mean F from the 2018 assessment (Figure 2.1.1). There appears to be a persistent over estimation of mean F in the final assessment year, which is particularly obvious in the final year estimates for 2015–2017. In TSA, the year component of the fishing mortality is modelled as a random walk, allowing for both transitory and persistent changes (with standard deviations estimated as part of the fitting process). In the 2018 WG assessment (and associated retrospective fits), the TSA explains the decline in F as a transitory change with no persistent change, resulting in the final year F at around the long-term average.

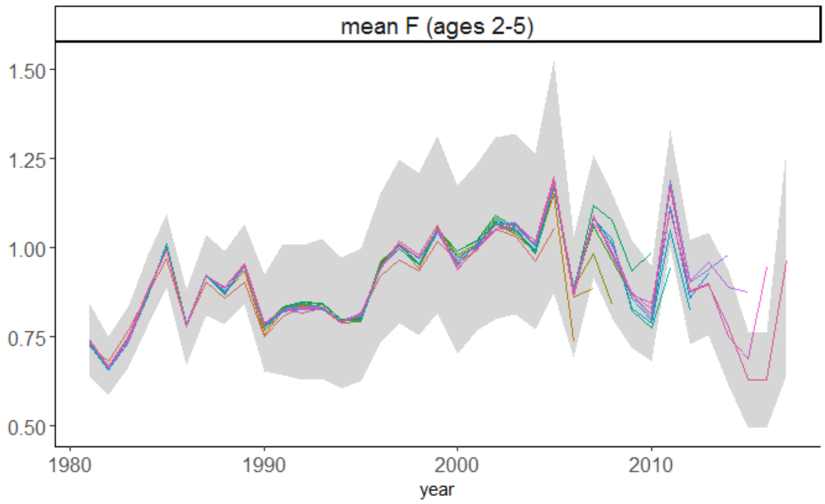


Figure 2.1.1. Cod.27.6a. Mean F retrospective analysis from final assessment from 2018 assessment WG.

Secondly, the latest assessment shows clear heterogeneity in the residuals, particularly of the landings data (Figure 2.1.2) indicating problems with the model fit (and assumptions). The current assessment assumes landings measurement error to have constant age-specific CV over time (see later for fuller explanation), while these residual plots tend to indicate an increased variability for ages 1 and 2 from around 2007 onwards. These diagnostics, therefore suggested the need to reconsider the assumptions associated with age-specific measurement error.

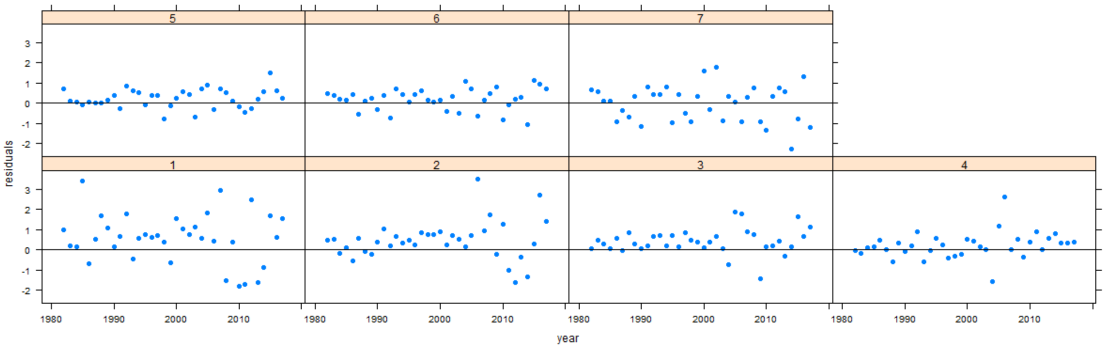


Figure 2.1.2. Cod.27.6a. Landings residuals by age from final assessment from 2018 WGCSE.

In addition to these issues identified through diagnostic plots, recently published work disputes the results of the current assessment. Cook (2019) demonstrates that a similar stock assessment model with different fishery selectivity assumptions could result in a quite different perception of the state of the stock: one which has seen a dramatic reduction in F and an increase in SSB to levels similar to those of the early 1990s. The paper argues that these results are consistent with wider evidence such as estimated trends in other demersal stocks in the region, trends in neighbouring cod stocks and fishery effort data, while arguing that in contrast, the results from the TSA (as presented at the 2018 WG) are not.

One feature of this model (Cook, 2019) which could account for the different perception is that the fishery selectivity is estimated to be extremely low for ages 5 and 6 in comparison to younger ages for most of the time-series. In contrast, the current ICES assessment estimates selectivity to be relatively flat topped (with the constraint that for ages 4 and above selectivity is assumed constant). In addition, the alternative assessment also includes additional survey data: both Scottish and Irish quarter 4 survey indices.

The assessment WG therefore agreed that a number of issues should be explored in the current TSA assessment including: i) greater flexibility in the estimation of fishery selectivity, ii) age-specific measurement error of the commercial catch data, and iii) the inclusion of additional survey indices. A number of TSA assessments are presented here which address these issues.

2.2 Improving model diagnostics

The first of the new assessments (A1) presented at this IBP attempts to address the poor model diagnostics (including both the retrospective pattern in mean F and the residual patterns) by using external data to provide better weights for the landings and discards data. In addition, it also uses a more flexible fishery selectivity pattern. The modifications to the 2018 WG implementation of TSA are described as follows:

1. **Fishery Selectivity**: In TSA, the fishing mortality selection pattern is allowed to evolve stochastically over time, but is assumed fixed above a certain age (specified in the model) with only transitory departures from this. In previous assessments, selectivity has been assumed to be equal for ages 4 and above. A recently published alternative assessment of this stock estimates a dome-shaped fishery selection pattern (Cook, 2019) which it is acknowledged could potentially result from differential exploitation of different components of the stock (spatial difference in fisheries and stock distribution). Therefore, model A1 assumes that the selection pattern is flat for ages 6 and above (age 7+) which allows greater flexibility for the selectivity at ages 4, 5 and 6 than in the 2018 WG assessment.

2. **Age-specific measurement error**: In general in TSA, the landings and discards are estimated with constant CVs: CV_L and CV_D respectively, parameters which are estimated by maximum likelihood. However, the data for some age classes is typically more variable than others, which can be apparent in the prediction error and residual plots[1]. Based on these plots, age-specific weighting factors are chosen. In the 2018 WG assessment (and all assessments since the benchmark in 2012 and possibly earlier), the landings were assumed to have CVs of (1,1,1,1,1,2,2)CV_L i.e. ages 6 and 7+ had CV twice that of the other age groups. (Individual datapoints, which appear to be outliers based on residual plots were also been down-weighted in this manner).

In model A1, these age-specific CV multipliers have been re-evaluated in 3 stages:

i. The first stage makes use of a subset of the full dataset: including commercial data up to 2005 and survey data to 2006, i.e. covering the time period before the change in discarding practices. The 2018 WG configuration of TSA (i.e. landings CVs as above) was initially fitted to this subset of data. The resulting landings residuals were greater for ages 1 and 6 and 7+. Based on the relative magnitude of the median of these landings residuals (text table below), the landings CV multiplier on age 1 was increased from 1 to 2 and that on age 7+ from 2 to 3. The landings-at-age CVs for this period were therefore assumed to be (2,1,1,1,1,2,3)CV_L..

Age	1	2	3	4	5	6	7+
Median landings residuals (2018 WG configuration with data to 2005/2006)	0.61	0.30	0.28	0.28	0.32	0.42	0.91

In addition, the down-weighting of all age 7+ landings outliers was removed and WCIBTS.Q1 1987 age 1 and landings 2004 age 4 were down-weighted based on residual/prediction error plots.

ii. Step 2 uses the model configuration from step 1 and additionally includes commercial data from 2007 to 2009 and survey data to 2010 (the final year of the old survey index, WCIBTS.Q1) with all down-weighting of outliers from these additional years initially removed. Commercial data from 2006 have been completely excluded from the model fit as this year appears to be a transition year between the low discard and high discard fisheries. (The legislation that ended the potential for underreporting of landings occurred midway through 2006).
External estimates of the CVs of the Scottish landings and discards data are available from 2012 to 2017 (derived from market and observer sampling data as part of the assessment input data estimation process). The median CVs by age over these years are given below. (Note that discards at age 5 and above are included in landings i.e. discard proportion not modelled).

[1] PREDICTION ERRORS ARE THE SCALED DIFFERENCES BETWEEN THE OBSERVATIONS (LANDINGS, DISCARDS AND SURVEY INDICES) AND THE ONE-STEP-AHEAD PREDICTIONS (FROM THE FORWARD PASS OF THE KALMAN FILTER). RESIDUALS ARE THE MORE TYPICAL SCALED DIFFERENCES BETWEEN THE OBSERVATIONS AND THE FITTED VALUES (FOLLOWING BOTH THE FORWARD AND THE BACKWARDS PASS).

Age	1	2	3	4	5	6	7+
Median landings CV	1.56	0.91	0.36	0.12	0.19	0.38	0.75
Median discards CV	0.51	0.33	0.48	0.46			

These CVs are assumed to apply to the commercial data for 2007 onwards i.e. the period of high discarding. The age-specific CV multipliers for landings and discards were calculated as (1.56, 0.91, 0.36, 0.12, 0.19, 0.39, 0.75) / CV_L and (0.51, 0.33, 0.48, 0.46) / CV_D where CV_L=0.1 and CV_D=0.53 are the estimated landings and discards CVs from the analysis up to 2006.

Finally a number of additional datapoints were down-weighted based on residual/prediction error plots: WCIBTS.Q1 2007 age 2, 2008 age 3, 2008 age 4, 2010 age 2.

iii. Step 3 adds in the remaining years of data (still excluding 2006).

The final model specification for assessment A1 including data up to 2017 (2018 survey) is given in Table 2 and the parameter estimates in Table 1 of the working document (See WD 1, Annex 4). The stock summary is shown in Figure 2.2.1 (below).

In terms of results, the model estimates a persistent trend in F (unlike the 2018 WG assessment) which results in an F in recent years of just below 0.5, a reduction of over 50% compared to the pre-2007 level (and more consistent with the decline in effort that has occurred in the main fisheries since the early 2000s).

Despite allowing greater flexibility in the fishery selectivity, only in a few years in the assessment does fishing mortality at intermediate ages exceed that at older ages (See WD 1, Annex 4). There is no evidence of age 1 fishing mortality being higher than that at ages 5 and 6 as estimated by Cook (2019). Residual plots are shown in Figures 2.2.2 and 2.2.3 and although there are still a few patterns in the residuals, the heterogeneity in the commercial catch data residuals is greatly reduced compared to the assessment presented at WGCSE in 2018. (See working document in Annex 4 for full diagnostic plots and model outputs).

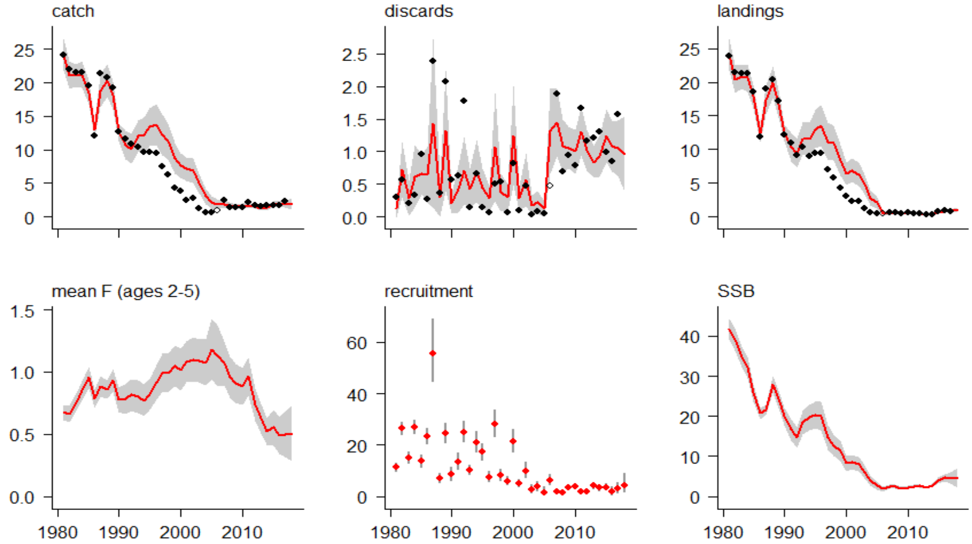
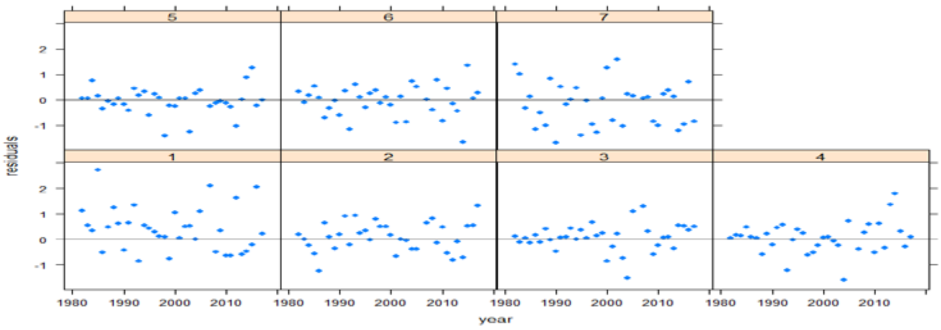


Figure 2.2.1. Cod.27.6a. Stock summary. Assessment A1: flexible fishery selectivity, re-evaluated age-specific CVs. Red lines (or points) give best estimates, grey bands (or lines) give approximate 95% confidence intervals, and black points give observed values. Note that final value in the mean F plot is a projection.



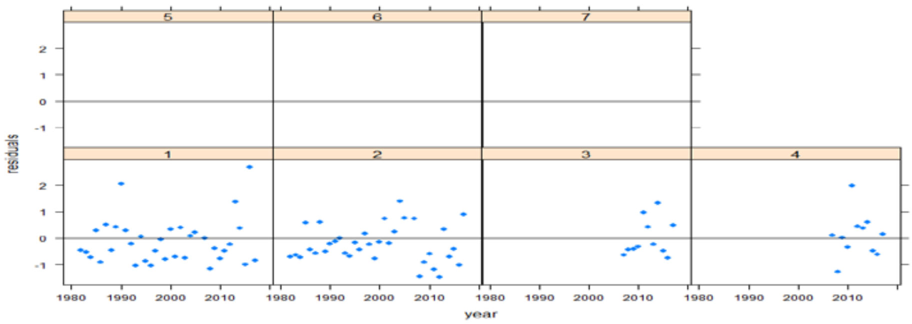


Figure 2.2.2. Cod.27.6a. Assessment A1: Residual plots by age class for landings (upper plot) and discards (lower plot). Assessment A1: flexible fishery selectivity, re-evaluated age-specific CVs.

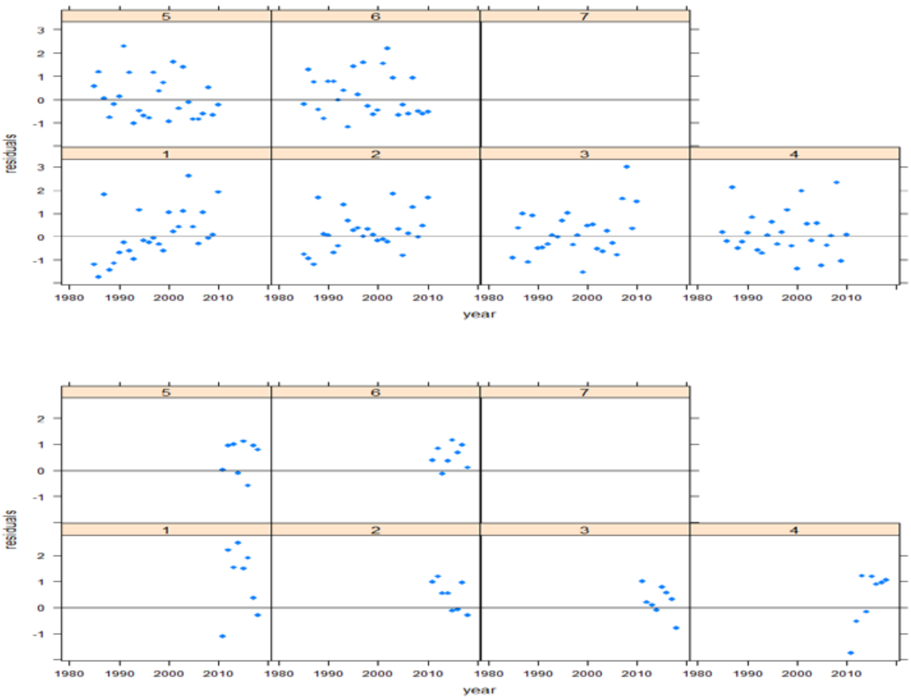


Figure 2.2.3. Cod.27.6a. Assessment A1: Survey residual plots by age class for WCIBTS.Q1 (upper plot) and SCO.Q1 (lower plot). Assessment A1: flexible fishery selectivity, re-evaluated age-specific CVs.

2.3 Additional survey indices

The 2018 WG assessment included only the Scottish Q1 indices, one running until 2010 and a second from 2011 onwards. Based on exploratory assessment runs, the 2012 benchmark concluded that the Scottish Q4 survey (WCIBTS.Q4 (1996–2009)) survey had little influence on assessment results or diagnostics, and there was little benefit to including this index in the assessment. In addition, they concluded that it was doubtful that the Irish Q4 survey (IGFS-WIBTS-Q4) index could be considered representative of the whole stock, given that the survey extends only to 56°30′N, while most of the stock is in the far north of Division 6a. These surveys (and the new Scottish Q4 survey index) were reconsidered for inclusion in the assessment at this IBP.

The old Scottish Q4 index (WCIBTS.Q4) shows reasonable internal consistency, particularly for ages 1 to 3, and shows little evidence of year effects (Figures 2.3.1 and 2.3.2). In addition, the index shows consistency, in terms of interannual fluctuations, with the Scottish Q1 index during the same period (although the longer term trends differ, particularly at the start of the time-series). (Figure 2.3.7). Since 2011, there has been a new Scottish survey index (SCO.Q4), which uses the same design and gear as the SCO.Q1 index. The index (and variance) are given in Table 2.3.1. Mean standardised indices and correlation plots are shown in Figures 2.3.3 and 2.3.4. The combination of few very large hauls and a large proportion of zero hauls results in high variance estimates (See Table 2.3.1 lower) although in general it is a more precise index than the SCO.Q1 index (which has been used in the assessment since the IBP in 2015). The plots do not suggest particularly good internal consistency (and there is evidence of year effects in the data), but the fact that the time-series remains relatively short with a missing year also makes the data difficult to interpret. Despite the clear limitations with the latter survey (short and noisy index), it shows some consistency with the other current surveys, and therefore it was agreed that both of the Scottish Q4 indices could provide additional useful information to the assessment.

The Irish Q4 survey (IRGFS.Q4) which runs from 2003 onwards was also considered again at this IBP meeting. This survey catches very few fish at older ages (See Table 2.3.1) and therefore further analysis is limited to ages 1 to 3. There appears to be reasonable internal consistency, particularly between ages 1 and 2 during the middle of the time-series (Figures 2.3.5 and 2.3.6). In addition, there is some consistency with the Scottish surveys (particularly Q4) as shown in Figure 2.3.7. It was therefore considered that this survey could provide an additional indicator of year-class strength, and could be useful as it covers the period during which there is a break in the Scottish survey indices. The lack of spatial coverage was deemed less important given the index is only being used to provide information on the younger ages.

Note that work is also ongoing at ICES WGISDAA on methods for combining the Irish and Scottish quarter 4 surveys to provide a combined index, which may prove useful for use in future assessments.

The data from the three additional indices span the following years and age ranges (note that a vessel breakdown resulted in a lack of quarter 4 survey data in 2013):

Survey	TSA survey acronym	Years	Ages	Variance	Catchability
Scottish western IBTS survey Q4 (old)	WCIBTS.Q4	1996-2009	1–4	Estimated in the model	No persistent or transitory
Scottish west-ern IBTS sur-vey Q4 (new)	SCO.Q4	2011-2017 (excl 2013)	1–6	Calculated externally	Transitory changes estimated
Irish western IBTS survey Q4	IRGFS.Q4	2003-2017	1–3	Estimated in the model	Transitory changes estimated

This assessment (S1), including the additional survey indices, is configured in the same manner as assessment A1 in terms of landings and discards uncertainty. The recent Scottish Q4 survey and the Irish Q4 survey are modelled in the same way as the recent Scottish Q1 survey in that transitory changes in survey catchability are estimated (to account for potential year effects in the survey). The full model specification is given in Table 2.3.3 (below).

Estimated model parameters from the assessment are given in Table 2.3.3 and the stock summary is shown in Figure 2.3.8.

Other model outputs are shown in Figures 2.3.9–2.3.10. Despite allowing greater flexibility in the fishery selectivity (compared to the 2018 WG configuration of TSA), only in a few years in the assessment does fishing mortality at intermediate ages exceed that at older ages (Figure 2.3.9).

TSA has an optional feature which allows for between-year changes in survey catchability (common across ages), which could arise because of between-year differences in e.g. the timing of the survey or in weather conditions (either affecting the survey itself, or the availability of cod). This feature is used in this assessment for three of the surveys: the new Scottish surveys (where year effects are particularly apparent in the index for Q1) and also for the Irish survey, although for the latter they are estimated to be almost zero (Figure 2.3.10). (Further details of the approach to modelling survey catchability within TSA can be found in Section 3.5.4, ICES, 2015a).

Figure 2.3.11 shows the estimated survey catchability by age. The SCO.Q1 and SCO.Q4 (post-2010 Scottish surveys) show a pattern of increasing survey catchability to age 5 with a decrease at age 6 (although with substantial uncertainty across these older ages). For the early Scottish Q1 survey (WCIBTS.Q1), survey catchability at age is estimated to increase over all age classes. The early Scottish Q4 survey (WCIBTS.Q4) and the Irish survey (IRGFS.Q4) show somewhat different patterns with a dome-shaped survey catchability for the former and declining catchability with age estimated for the latter.

In terms of results, this model (S1) estimates a persistent trend in F (Table 2.3.3, unlike the 2018 WG assessment, but consistent with model A1 above) which results in an F in recent years of just below 0.6, a reduction of around 50% compared to the pre 2007 level (and more consistent with the decline in effort that has occurred in the main fisheries since the early 2000s). With this model configuration the retrospective pattern in mean F in the recent years is markedly reduced (no upturn in final year F), however there appears to be some underestimation of F in the assessments ending in years 2009–2011; the years just before the break in the Scottish surveys (Figure 2.3.13).

Modelled discard proportions are compared to observations in Figure 2.3.12. The model can reproduce the general features of the data (including general trends and step change), but does not model the interannual variability in discard proportions particularly well. Such variability has become a feature of the data particularly at ages 3 and 4 since the change in discarding practices in 2006.

The standardised residuals are shown in Figures 2.3.14 and 2.3.15. The model fit looks reasonable with no obvious patterns or significant outliers in the residuals (most lying within ±2) or prediction errors. Note that a large outlier in the age 1 discards in 2016 was identified in an earlier model run and down-weighted in the run presented here. (An intermediate model run including the four Scottish surveys, but excluding the Irish survey can be found in the WD 1 in Annex 4, model A2).

SCO.Q4 (index)

2011	2017									
1	1	0.75	1.0							
0	8									
10	0.60	9.71	31.54	10.88	0.93	1.70	2.38	0.00	0.00	2011
10	0.75	19.78	7.12	15.43	13.60	1.02	0.68	0.34	0.00	2012
Survey not completed due to mechanical issues										2013
10	1.67	23.65	28.06	15.63	5.57	6.63	1.37	0.00	0.00	2014
10	3.64	28.17	52.53	34.22	10.58	4.24	5.27	1.18	0.59	2015
10	0.374	6.162	34.941	45.443	118.92	14.893	5.773	3.176	0	2016
10	2.127	10.024	6.221	24.427	10.881	8.538	0.767	0.511	0	2017

SCO.Q4 (variance)

2011	**2017**									
1	1	0.75	1.0							
0	8									
10	0.21	31.08	38.07	5.78	0.19	1.56	4.79	0.00	0.00	2011
10	0.14	41.72	2.79	11.37	48.79	1.05	0.46	0.12	0.00	2012
Survey not completed due to mechanical issues										2013
10	0.68	132.97	56.62	44.17	3.87	4.79	0.39	0.00	0.00	2014
10	5.55	98.78	316.23	51.22	8.60	4.43	4.61	0.34	0.12	2015
10	0.14	7.394	419.36	716.38	7654.82	118.64	24.30	6.08	0	2016
10	3.215	11.252	3.816	76.154	14.262	8.928	0.207	0.063	0	2017

Table 2.3.1. Cod.27.6a. Current Scottish Q (SCO.Q4) survey index (upper) and variance (lower) by age (columns) and year (rows). Numbers are standardised to 10 hours fishing (as indicated by 1st column).

2003	**2017**			
1	1	0.79	0.92	
1	4			
10	5.3	5.9	0.0	0.0
10	12.0	5.0	0.5	0.0
10	8.1	4.4	0.0	1.3
10	37.7	4.8	0.0	0.0
10	82.4	6.1	0.0	0.5
10	12.2	12.7	2.1	0.0
10	32.7	1.7	2.2	0.0
10	32.5	14.4	1.9	1.4
10	12.1	12.1	1.9	0.0
10	36.1	3.4	1.5	0.0
10	42.6	5.1	0.0	0.0
10	56.5	10.0	1.0	0.0
10	7.4	5.4	1.5	0.0
10	16.8	14.3	1.2	0.0
10	1.0	8.5	3.5	1.0

Table 2.3.2. Cod.27.6a. Irish Q4 (IRGFS.Q4) survey index by age (columns) and year (rows). Numbers are standardised to 10 hours fishing (as indicated by 1st column).

Parameter	Setting	Justification
Age of full selection.	$a_m = 6$	To allow flexibility when estimating fishery selectivity.
Multipliers on variance matrices of measurements.	$B_{landings}$(a, 1981-2005) = 2 for ages 1, 6 $B_{landings}$(a, 1981-2005) = 3 for ages 7+ $B_{landings}$(1-7+, 2007 onwards) = (15.6,9.1,3.6,1.2,1.9,3.8,7.5) $B_{discards}$(1-4, 2007 onwards) = (0.96,0.62,0.91,0.87)	Allows extra measurement variability for poorly-sampled ages (based on relative size of residuals). Allows extra measurement error post Buyers & Sellers legislation (based on external estimates of CV).
Multipliers on variances for fishing mortality estimates.	H(1) = 2 v.cvmult (1986) = 3	Allows for more variable fishing mortalities for age 1 fish. Allows for greater transitory change in fishing mortality year component.
Downweighting of particular datapoints.	Landings: Age 2 in 1987 age 6 in 1982 age 4 in 2004 Discards: age 1 in 1988, 1992 and 2016 age 2 in 1988, 1992,1998,2002. Survey (WCIBTS.Q1): Age 1 in 1987 age 2 in 2007 and 2010, age 3 in 2008, age 4 in 2001 and 2008, age 5 in 2001. Survey IRGFS.Q4: age 1	CV multiplier set to 3 or 5 as necessary. Large values indicated by exploratory prediction error plots. Survey downweighting in 2001 resulted from a single large haul, 24 fish >75 cm in 30 minutes. In 2008 due to v large haul near 4 degrees W line.
Discards	Discards are allowed to evolve over time constrained by a trend. Ages 1 to 4 are modelled independently. A step function is specified with the step occurring in 2006.	
Recruitment.	Modelled by a Ricker model, with numbers-at-age 1 assumed to be independent and normally distributed with mean $\eta 1$ S exp($-\eta 2$ S), where S is the spawning–stock biomass at the start of the previous year. To allow recruitment variability to increase with mean recruitment, a constant coefficient of variation is assumed.	
Large year classes.	The 1986 year class was large, and recruitment at-age 1 in 1987 is not well modelled by the Ricker recruitment model. Instead, N(1, 1987) is taken to be normally distributed with mean 5$\eta 1$ S exp($-\eta 2$ S). The factor of 5 was chosen by comparing maximum recruitment to median recruitment from 1966–1996 for 6.a cod, haddock, and whiting in turn using previous XSA runs. The coefficient of variation is again assumed to be constant.	

Table 2.3.3. Cod.27.6a. Comparison of TSA parameter estimates from 2018 WG and model S1 (final IBP assessment).

Parameter	*Notation*	Description	2018 WG	S1
Initial fishing mortality	*F* (1, 1981)	Fishing mortality-at-age *a* in year *y*	0.323	0.2507
	F (2, 1981)		0.668	0.5698
	F (a_m, 1981)		1.032	0.7805
Fishing mortality standard deviations	σ_F	Transitory changes in overall fishing mortality	0.152	0.1304
	σ_U	Persistent changes in selection (age effect in F)	0.009	0.0299
	σ_V	Transitory changes in the year effect in fishing mortality	0.178	0.0398
	σ_Y	Persistent changes in the year effect in fishing mortality	0.000	0.0989
Measurement CVs	$CV_{landings}$	CV of landings-at-age data	0.125	0.0881
	$CV_{discards}$	CV of discards-at-age data	0.445	0.5776
Recruitment	η_1	Ricker parameter (slope at the origin)	1.282	1.1145
	η_2	Ricker parameter (curve dome occurs at $1/\eta_2$)	0.024	0.0203
	cv_{rec}	Coefficient of variation of recruitment data	0.407	0.4213
Discards	$\sigma_{logit\ p}$	Transitory trends in discarding	0.788	0.7766
	$\sigma_{persistent}$	Persistent trends in discarding	0.296	0.2428
	Step fn age 1	Amount by which discards increase in 2006	4.058	5.9209
	Step fn age 2		5.895	6.2889
	Step fn age 3		0.985	1.1065
	Step fn age 4		-0.436	-0.1026
Survey selectivities WCIBTS.Q1	$\Phi(1)$	Survey selectivity-at-age *a*	0.561	0.4805
	$\Phi(2)$		2.897	2.8158
	$\Phi(3)$		6.950	6.4213
	$\Phi(4)$		10.666	9.9981
	$\Phi(5)$		15.379	12.9927
	$\Phi(6)$		20.789	15.1818

Parameter	*Notation*	Description	2018 WG	S1
Survey CVs	σ_{survey}	CV parameter controlling gamma type dispersion	0.258	0.0393
	η_{survey}	CV parameter controlling poisson type dispersion	1.142	1.5815
Survey catchability standard deviations	σ_{Ω}	Transitory changes in survey catchability	NA	NA
	σ_{β}	Persistent changes in survey catchability	NA	NA
Survey selectivities UK-SCO.Q1	$\Phi(1)$	Survey selectivity-at-age *a*	0.841	0.6911
	$\Phi(2)$		20.677	23.4037
	$\Phi(3)$		40.604	37.077
	$\Phi(4)$		49.005	48.9306
	$\Phi(5)$		84.270	71.0896
	$\Phi(6)$		63.453	48.8489
Survey catchability standard deviations	σ_{Ω}	Transitory changes in survey catchability	0.388	0.3794
	σ_{β}	Persistent changes in survey catchability	NA	NA
Survey selectivities WCIBTS.Q4	$\Phi(1)$	Survey selectivity-at-age *a*	NA	3.1029
	$\Phi(2)$		NA	6.2709
	$\Phi(3)$		NA	5.1223
	$\Phi(4)$		NA	1.9957
Survey CVs	σ_{survey}	CV parameter controlling gamma type dispersion	NA	0.0498
	η_{survey}	CV parameter controlling poisson type dispersion	NA	2.643
Survey catchability standard deviations	σ_{Ω}	Transitory changes in survey catchability	NA	NA
	σ_{β}	Persistent changes in survey catchability	NA	NA
Survey selectivities UK-SCO.Q4	$\Phi(1)$	Survey selectivity-at-age *a*	NA	12.2388
	$\Phi(2)$		NA	23.3137
	$\Phi(3)$		NA	61.3276
	$\Phi(4)$		NA	99.2573
	$\Phi(5)$		NA	149.2903
	$\Phi(6)$		NA	125.1986

Parameter	***Notation***	**Description**	**2018 WG**	**S1**
Survey catchability standard deviations	σ_{Ω}	Transitory changes in survey catchability	NA	0.142
	σ_{β}	Persistent changes in survey catchability	NA	NA
Survey selectivities IRGFS.Q4	$\Phi(1)$	Survey selectivity-at-age	NA	15.3431
	$\Phi(2)$		NA	12.0422
	$\Phi(3)$		NA	3.4018
Survey CVs	σ_{survey}	CV parameter controlling gamma type dispersion	NA	0.0393
	η_{survey}	CV parameter controlling poisson type dispersion	NA	1.6476
Survey catchability standard deviations	σ_{Ω}	Transitory changes in survey catchability	NA	0.0197
	σ_{β}	Persistent changes in survey catchability	NA	NA
Misreporting		Transitory changes in misreporting	0.002	0.0185
		Persistent changes in misreporting	0.258	0.1498

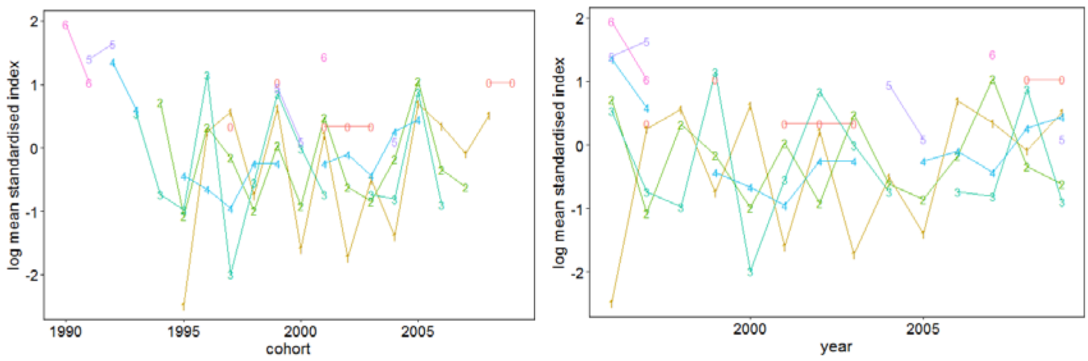


Figure 2.3.1. Cod.27.6a. Log mean standardised index values by cohort (left) and year (right) from WCIBTS.Q4.

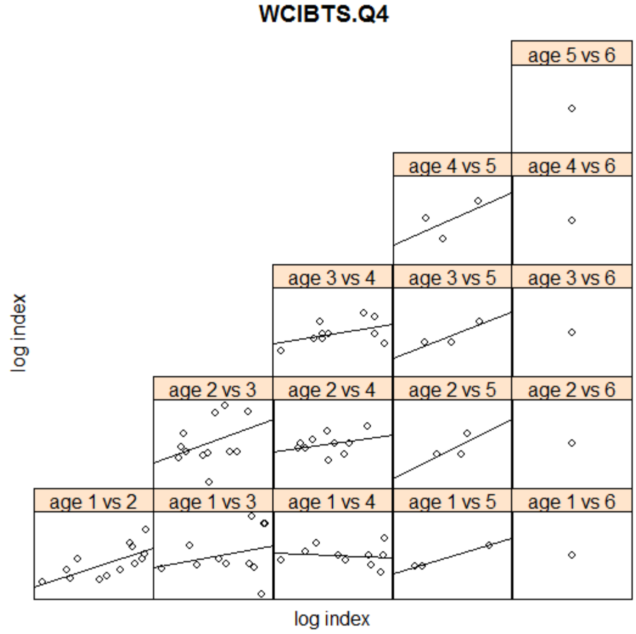


Figure 2.3.2. Cod.27.6a. Within survey correlations for WCIBTS.Q4 survey, comparing index values at different ages for the same cohorts. The solid line is a linear regression.

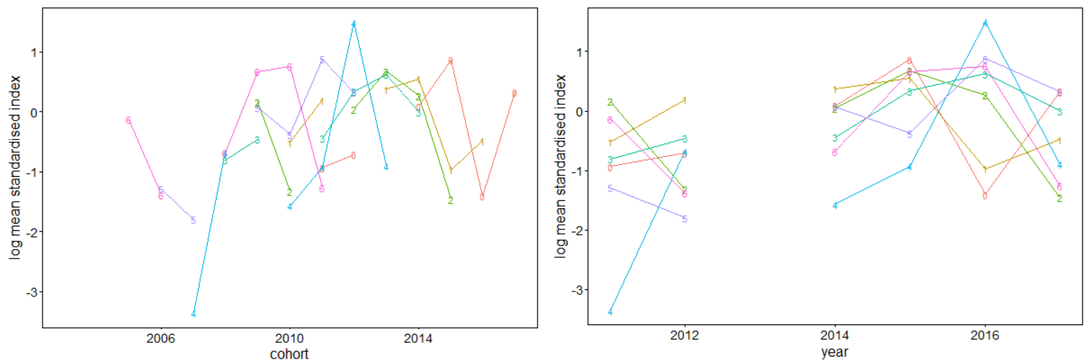


Figure 2.3.3. Cod.27.6a. Log mean standardised index values by cohort (left) and year (right) from SCO.Q4.

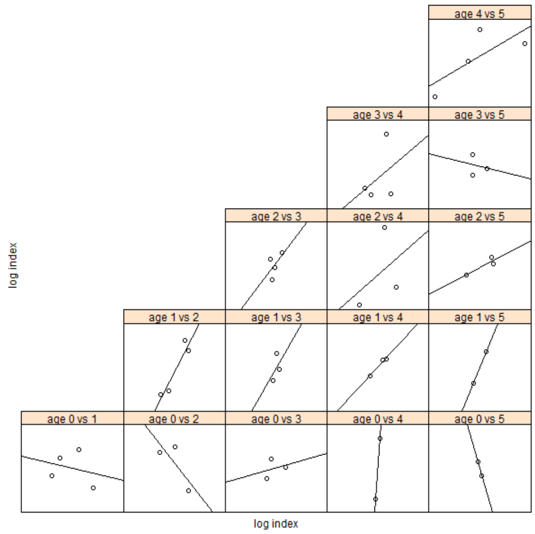


Figure 2.3.4. Cod.27.6a. Within survey correlations for SCO.Q4 survey, comparing index values at different ages for the same cohorts. The solid line is a linear regression.

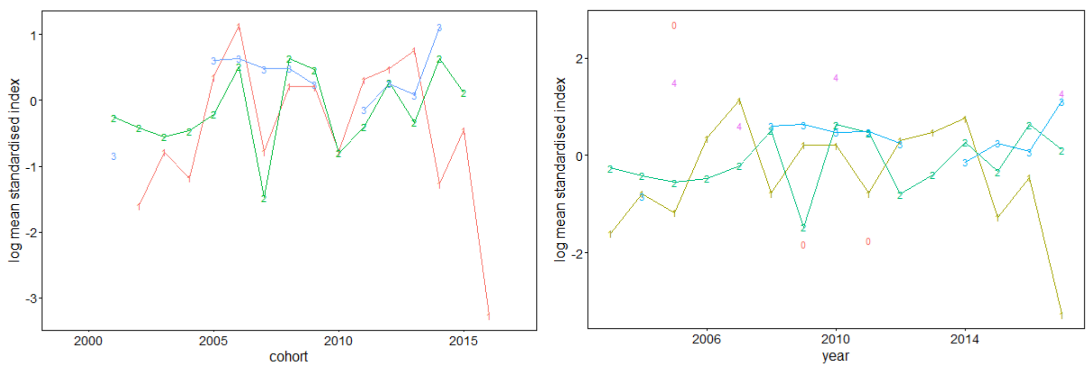


Figure 2.3.5. Cod.27.6a. Log mean standardised index values by cohort (left) and year (right) from IRGFS.Q4.

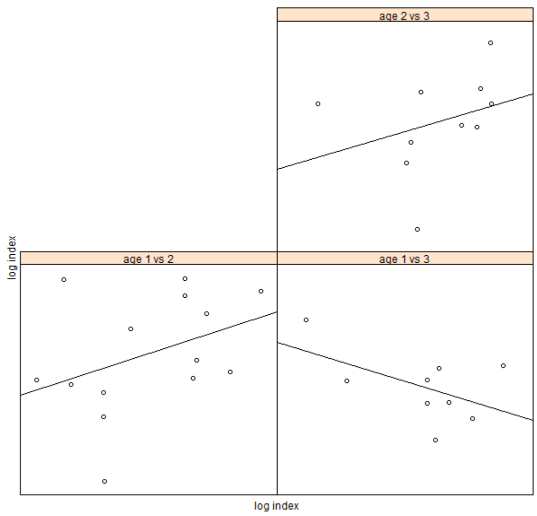


Figure 2.3.6. Cod.27.6a. Within survey correlations for IRGFS.Q4 survey, comparing index values at different ages for the same cohorts. The solid line is a linear regression.

Figure 2.3.7. Cod.27.6a. Comparison of survey indices by age. Irish Q4 survey (IRGFS.Q4) is compared to the early Scottish surveys in the upper plot and to the later Scottish surveys in the lower plot. Values are mean standardised over the time period in common (upper: 2003–2009, lower: 2011–2017).

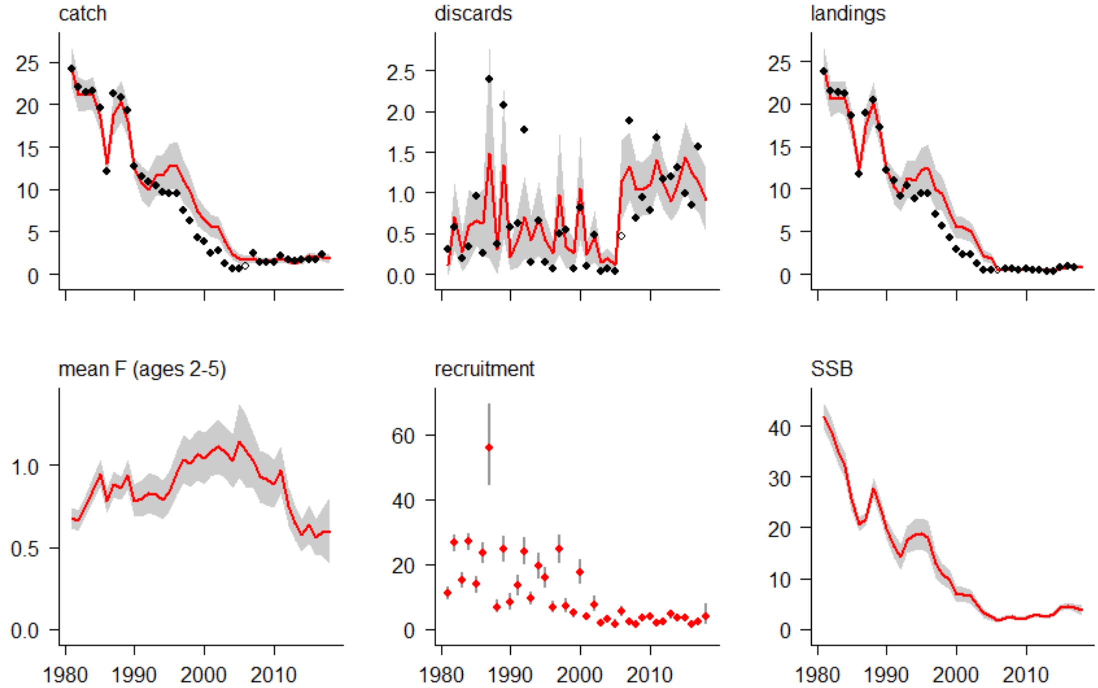


Figure 2.3.8 Cod.27.6a. Stock summary. Assessment S1: flexible fishery selectivity, re-evaluated age-specific CVs & five surveys. Red lines (or points) give best estimates, grey bands (or lines) give approximate 95% confidence intervals, and black points give observed values. Note that final value in the mean F plot is a projection.

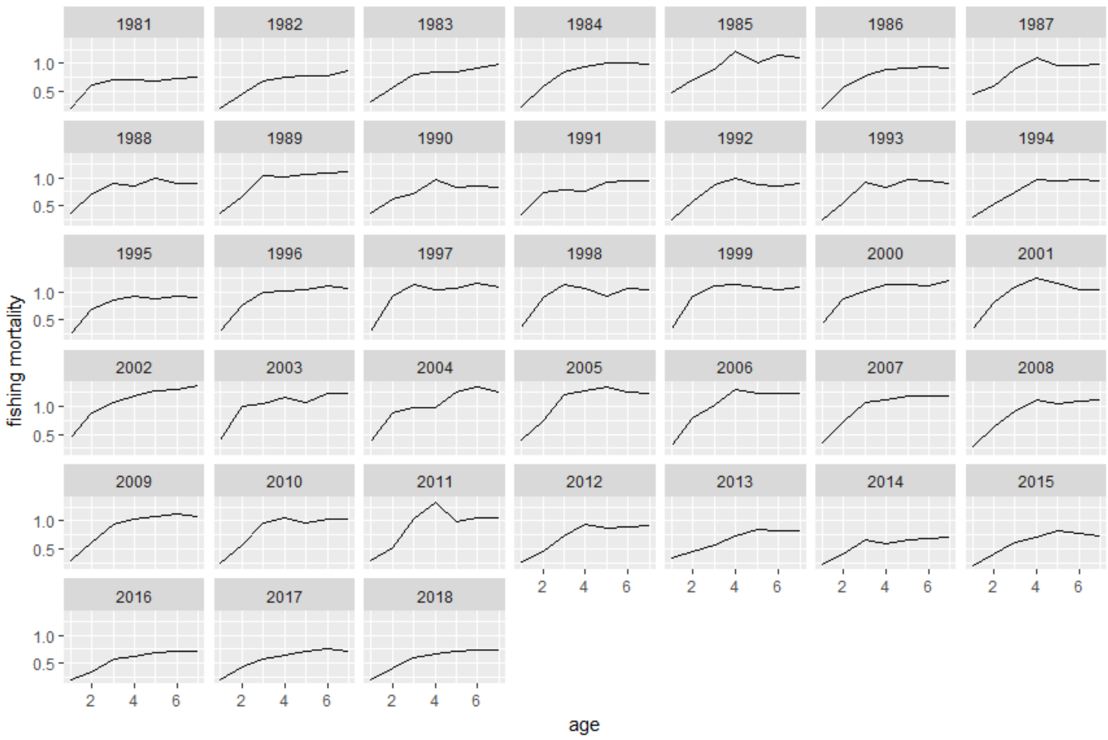


Figure 2.3.9. Cod.27.6a. Estimated fishing mortality by age and year. Assessment S1.

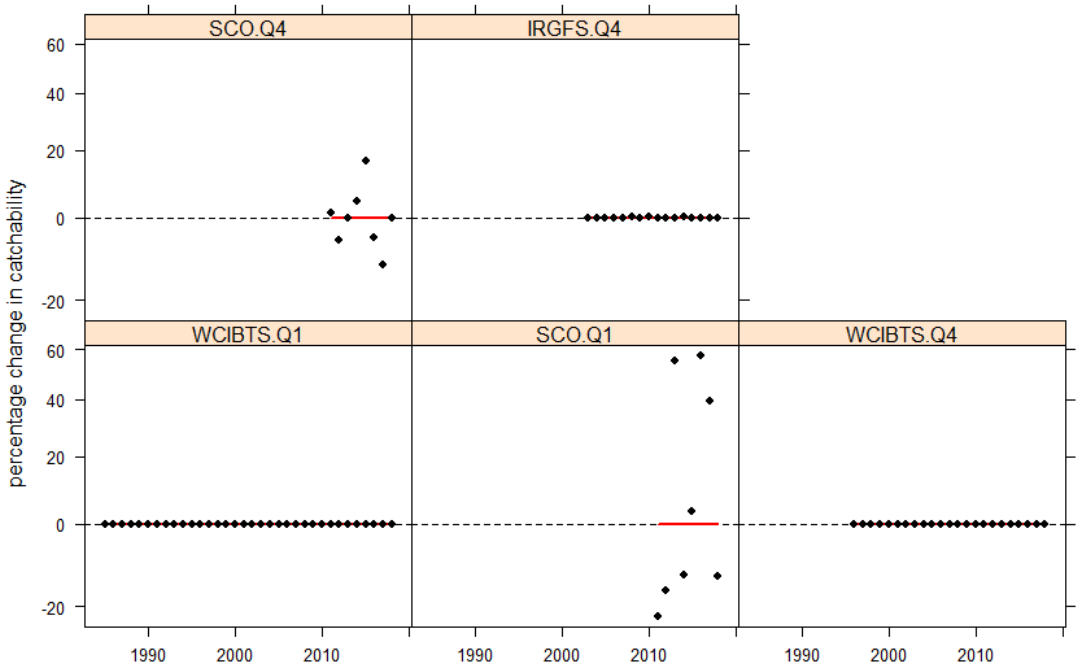


Figure 2.3.10. Cod.27.6a. Estimated survey catchability. Assessment S1.

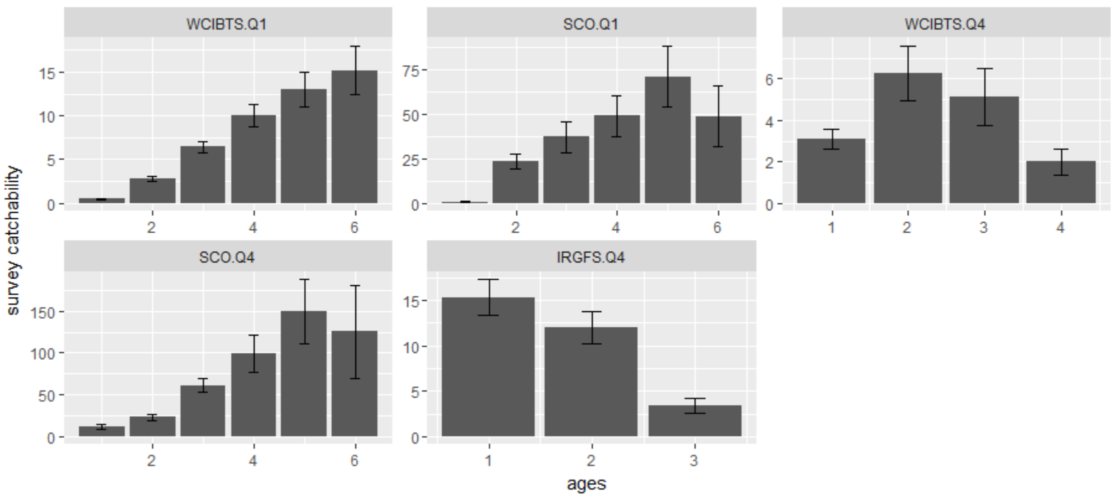


Figure 2.3.11. Cod.27.6a. Estimated survey catchability by age. Error bars are ± 1 standard error. Assessment S1.

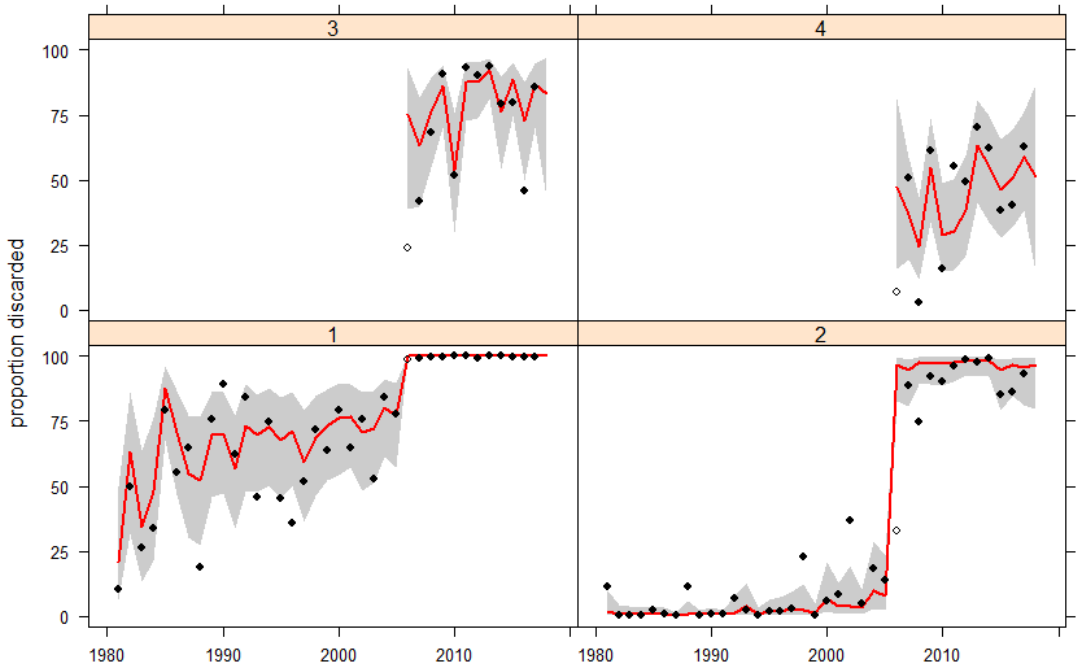


Figure 2.3.12. Cod.27.6a. Modelled discard proportions (solid line) and observations (circles). Open circles indicate years where data are not included in the assessment model. Assessment S1.

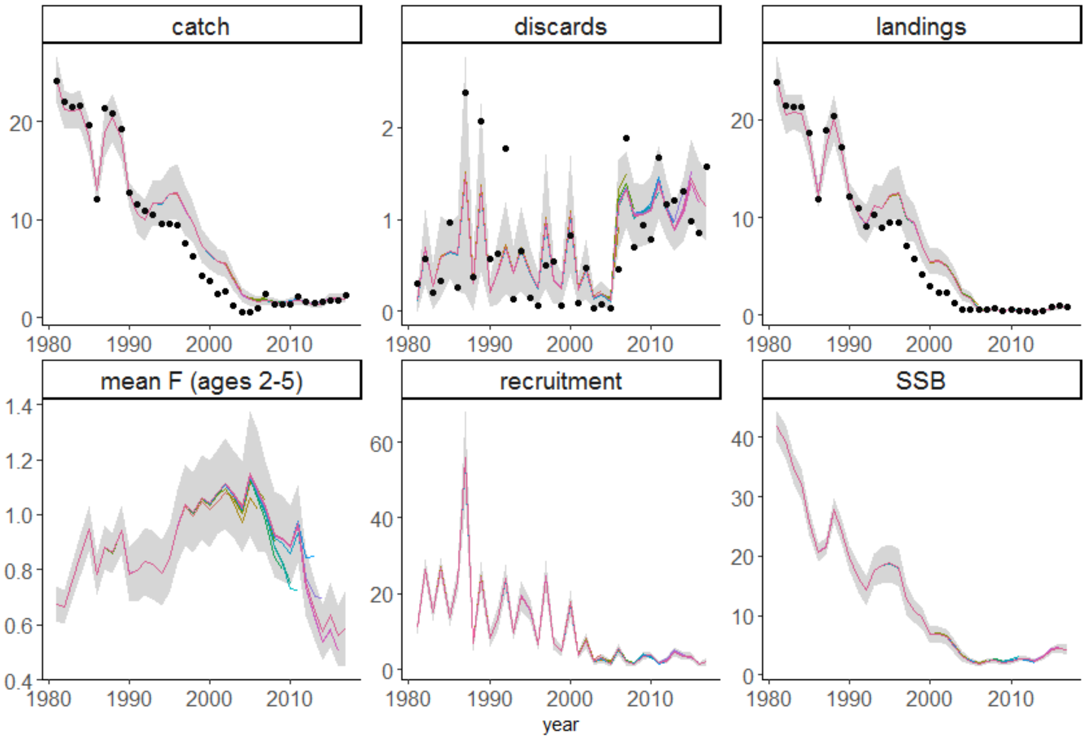


Figure 2.3.13. Cod.27.6a. Assessment S1: Retrospective analysis.

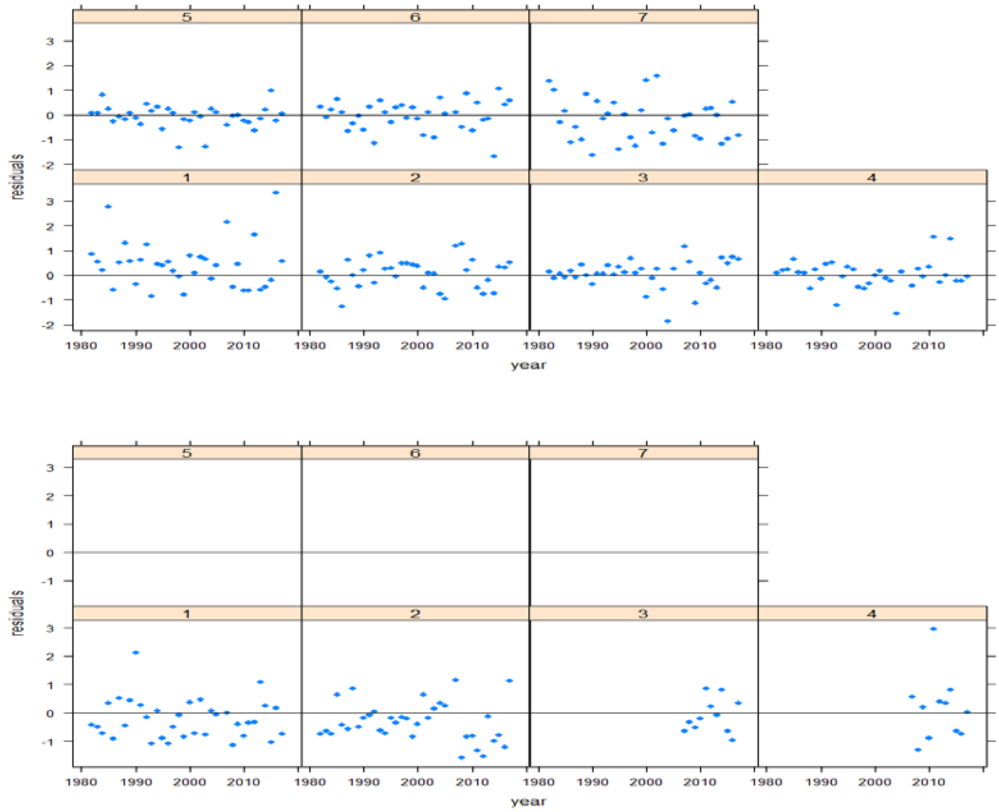


Figure 2.3.14. Cod.27.6a. Assessment S1: Residual plots by age class for landings (upper plot) and discards (lower plot).

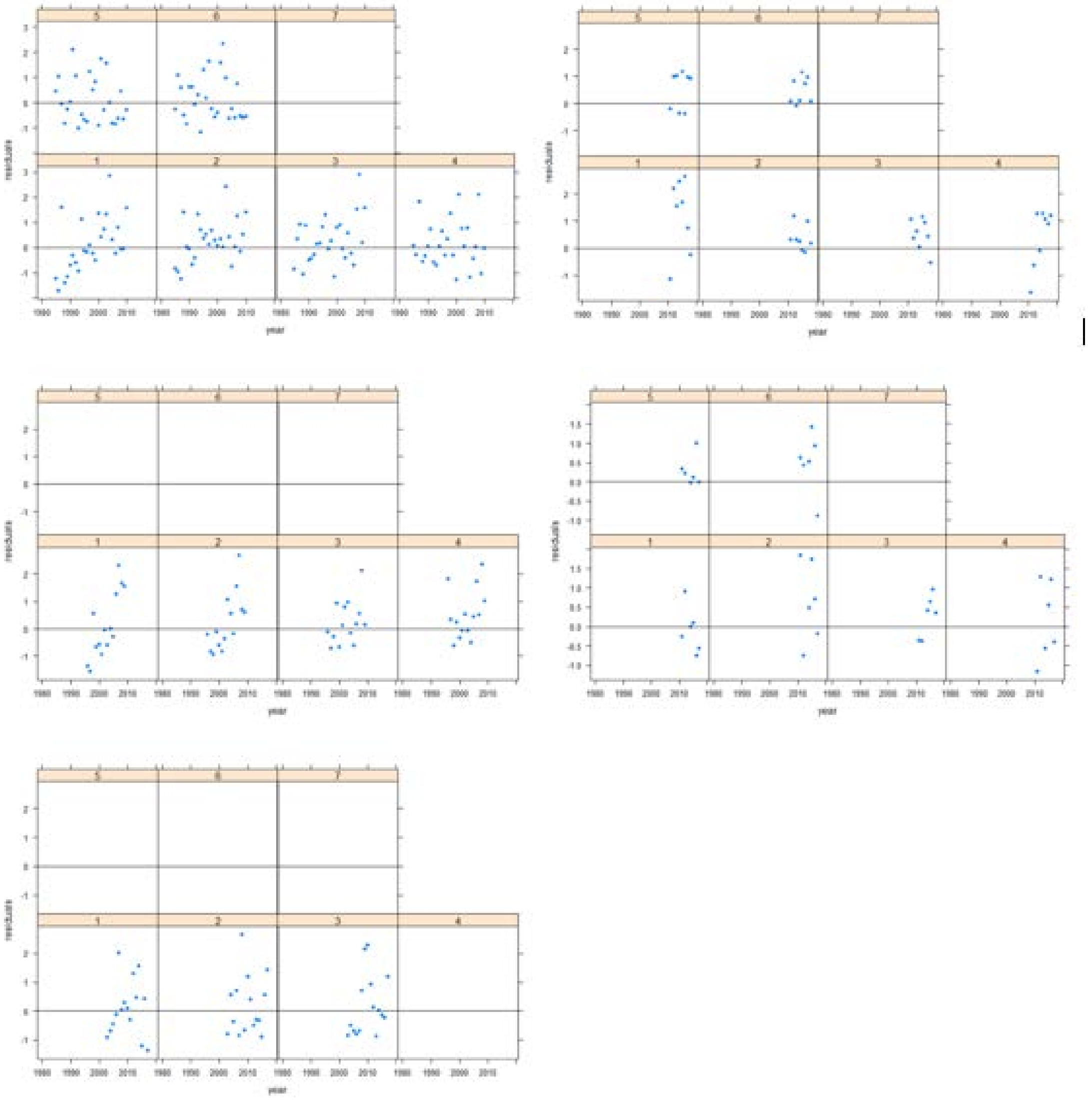


Figure 2.3.15. Cod.27.6a. Assessment S1: Residual plots by age class for WCIBTS.Q1 (upper left), SCO.Q1 (upper right), WCIBTS.Q4 (middle left), SCO.Q4 (middle right), and IRGFS.Q4 (lower left).

2.4 Fishery selectivity and further sensitivity analysis

Despite allowing greater flexibility in the fishery selectivity (flat topped for age 6 and above rather than age 4 and above), neither of the assessments presented above (A1 or S1) show evidence of a dome-shaped selectivity pattern or any particular changes in selectivity in recent years (Figure 2.3.7). This is in stark contrast to the fishery selectivity estimated in Cook (2019) which estimates fishing mortality-at-age 1 to be higher than that at ages 6 for full time-series (and age 5 for most of the time-series). To further explore and attempt to explain these differences a number of additional configurations of TSA were explored:

1. In TSA, the age component of the fishing mortality is modelled as a random walk, and hence current selectivity estimates may be influenced by historical data. Therefore to remove any influence of data from the period before Buyers & Sellers legislation (the low discarding period), an assessment (model A3 in WD 1, Annex 4) is carried out based on only a subset of the full dataset:

- Landings and discards, 2007–2017, ages 1–7+
- SCO.Q1, 2010–2018, ages 1–6
- SCO.Q4, 2011–2017, ages 1–6

   Parameter estimates from this model fit can be found in the WD with full model diagnostics and outputs to be found in Annex 5 (Assessment A3). Although the fishery selectivity shows significant between year variability over this time period, there is still little evidence of a dome-shaped selectivity pattern. So even in this shortened time period, the TSA finds evidence in the data for higher fishery selectivity at older ages.

2. Some concern was expressed at the IBP regarding the credibility of the estimates of survey catchability from the TSA assessments presented at this IBP, which show an increase with increasing age for both Scottish Q1 surveys (WCIBTS.Q1 and SCO.Q1) and the more recent Scottish Q4 survey (SCO.Q4). In addition, there is a substantial change in the pattern of catchability at age between the old and new Scottish Q4 surveys. Although the recent Scottish survey data, particularly at older ages, are characterised by a small number of large hauls and many zeros, which would be consistent with aggregating behaviour (and hence increased survey catchability), the more usual expectation would be for a decline in survey catchability at older ages (as big fish may out-swim a short survey tow).

   To explore the sensitivity of the results to the survey catchability estimates, a further model run (S2) was conducted which included constant survey selectivities at ages four and above for both Scottish Q1 surveys and the more recent Scottish Q4 survey. The model results (other parameter estimates and stock summary) appear relatively insensitive to these changes in survey catchability and this assumption does not noticeably affect the estimated fishery selection pattern. The stock summary from this assessment is compared to that from assessment S1 in Figure 2.4.1. Full results and model diagnostic plots can be found in Annex 5 (Assessment S2).

3. A final sensitivity test was performed (model S3) in which the weight given to the recent landings data was reduced (in addition to including the survey catchability plateau described in assessment S2 above). This was in order to include additional uncertainty associated with the estimates of misreported landings during this period and give more weight to the survey data. This was implemented by making the cv multiplier on the landings age compositions twice the value suggested by the market sampling estimation variance and at the same time keeping the ‘cv landings’ parameter (See Section 2.2 for explanation) fixed at the value estimated when only considering the data up to 2006.

(Without fixing the 'cv landings' parameter, its estimate drops by half to account for the imposed doubling in cvmult – essentially, the model wants to track the landings). There are a number of minor differences in the results of this assessment (S3), compared to S1: i) the mean F does not reduce as much because the landings have less weight, and ii) the fishery selection pattern shows a slight reduction in F at older ages, but nowhere near to the extent that it could be classed as dome-shaped. The stock summary from this assessment is also compared in Figure 2.4.1. Full results and model diagnostic plots can be found in Annex 5 (Assessment S3).

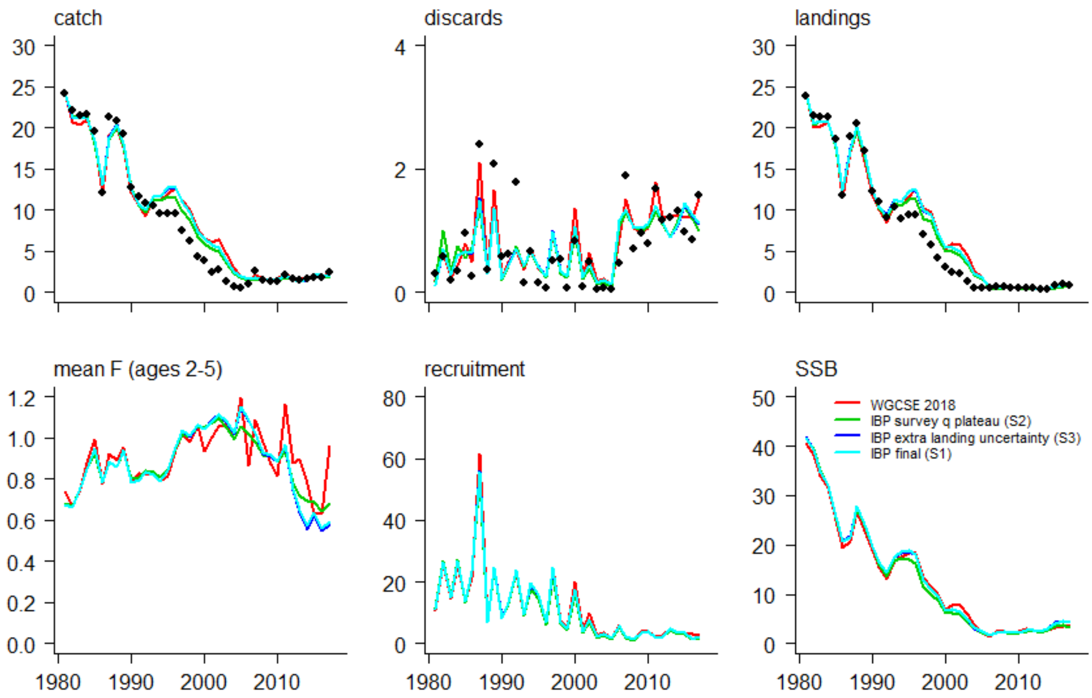


Figure 2.4.1. Cod.27.6a. Comparison of stock summaries from WGCSE 2018 (red), IBP S1: 5 surveys (light blue), IBP S2: as S1 plus constrained survey catchability (green), IBP S3: as S2 with greater landings uncertainty (dark blue). All IBP runs shown here include 5 surveys.

2.5 Final assessment

The final assessment model was chosen as model S1. This is the TSA run that includes all five research vessel surveys (described in Section 2.3 above), in addition to modifications to the age-specific measurement error assumptions in the commercial data and allowing greater flexibility in the estimation of fishery selectivity parameters.

The model has better diagnostics than that presented at the WG in 2018 in terms of both residuals and retrospective pattern. The previous assessment assumed landings measurement error to have a constant age-specific cv over time, so the low recent landings had a low variance. Making use of the external estimates of uncertainty associated with the landings and discards-at-age, (as derived from the market and observer sampling data as part of the input data preparation process) results in less weight being given to landings at age 3 and 6, and significantly less weight being given to landings at ages 1, 2 and 7 (post-2006). The signal in the fishing mortality comes from the ages where we have the 'best' data and is not diluted by the noise in the other age classes, which is now accounted for in the increased measurement error in the landings data. Previously, TSA (2018 WG configuration) accounted for this noise in the estimate of transitory changes in F, giving rise to the retrospective pattern in the 2018 WG assessment–the penultimate year F showed a decline (transient effect) followed by the final year F estimated at around the long-term average–a feature which was repeated with each retrospective peel, resulting in a tendency to significantly over-estimate terminal F. The model now estimates a persistent change in the year effect in the fishing mortality with a comparatively small transitory effect. (Table 2.3.3 gives a comparison of TSA parameter estimates between 2018 WG and final IBP assessment, S1).

The final assessment (S1) results in a reduction in mean F during the period 2011–2014, and also in the final year compared to the assessment presented at WGCSE in 2018. The estimated trend in mean F is now more consistent with the decline in fishing effort that has occurred in the region. Figure 2.5.1 provides a comparison of the estimated mean F from the final assessment with the effort from the main fleets operating in the fishery (TR1 + TR2 effort from both regulated and unregulated fleets, STECF effort database). Mean F is estimated to be very high for most of the historical time-series (which is consistent with the other cod stocks across the region) and shows a decline since 2005. The reported effort has declined by approximately 50% since the start of the time-series (2003), and while the fishing mortality decline is proportionately similar, the decline does not occur until several years later. In contrast to the TSA assessment, Cook (2019) estimates the decline in mean F to be proportionately greater than the reduction in effort. Note that the comparison presented here is between officially reported effort (i.e. EU logbook data) and mean F from an assessment, which accounts for underreported and area misreported landings. Given the known issues with officially reported landings, it is clear that the associated reported effort may not be completely representative of actual effort in the fisheries in Division 6a.

As described in the WD by Cook submitted to this IBP (WD 3, Annex 4), the area of the main demersal trawl fishery (catching cod) has contracted, and operates largely in the northern part of Division 6a. The research vessel survey data indicate that cod in Division 6a is now largely confined to the same area and that very large hauls of cod still do occur in this area, suggesting that there are still small areas with a high density of cod. This could potentially explain why the estimated mean F does not decline at the same rate as fishing effort. This feature is not unique to West of Scotland cod with the same type of relationship between decline in reported effort and estimated mean F being observed in Irish Sea cod. Effort in the Irish Sea declined over the same period as in Division 6a (2003–2010) and while the estimated fishing mortality on Irish Sea cod has declined dramatically, this decline did not occur until after 2010.

While the estimated mean F from the revised TSA assessment has been revised downwards for recent years, the estimated SSB has been revised upwards (~25% greater than the estimate from the 2018 WG for 2015–2018 SSB). The total stock biomass (TSB) has also been revised upwards, but to a lesser degree. SSB in 2018 from the revised assessment is estimated to be 3698 tonnes and TSB to be 5380 tonnes. Biomass shows a generally increasing trend since 2006, although still remains extremely low.

Cod consumption by seals (derived from diet composition studies and seal abundance estimates) is estimated to be 7632 tonnes (95% CI: 3542–13 937) in 2010 (Hammond and Wilson, 2016) compared to a TSB estimate of 4377 tonnes from the TSA assessment. Seal foraging mostly occurs on the continental shelf (Russell *et al*., 2017) including areas which are unsuitable for trawl fishing while most of the cod landings are taken along the continental shelf edge (STECF, 2016) and thus the seals and fishery are largely operating in different areas and could be exploiting different substocks. Knowledge of the extent of the cod population estimated by the stock assessment and of the movements of cod found off the shelf (seasonal or otherwise) is incomplete, although there is genetic evidence for more than a single population including some coastal subpopulations. The high spatial separation of the fishery (and surveys), and areas heavily used by seals for foraging, is at least a partial explanation for how the estimated consumption by seals can be so large relative to the size of the assessed stock. The assessment presented in Cook (2019) estimates much greater stock biomass and the discussion in the working document (Annex 4) suggests these results to be consistent with an estimate of the stock exploited by both seals and fishery.

The final TSA assessment (S1) estimates increasing survey catchability at-age for both Scottish Q1 surveys and the more recent Scottish Q4 survey. In addition, there is a substantial change in the pattern of catchability at-age between the old and new Scottish Q4 surveys. Although the recent Scottish survey data, particularly at older ages, are characterised by a small number of large hauls and many zeros, which would be consistent with aggregating behaviour (and hence increased survey catchability), the more usual expectation would be for a decline in survey catchability at older ages (as big fish may out-swim a short survey tow). In contrast, to this configuration of TSA, Cook (2019) estimates dome-shaped survey catchability and the working document suggests this is the reason for the low estimate of stock biomass in TSA (compared to Cook, 2019). However, a TSA model run in which survey catchability is held constant at ages four and above (assessment S2 presented in Section 2.4 above) shows little difference to the final agreed assessment in terms of both estimated fishery selectivity and stock biomass. In fact, none of the sensitivity runs suggested evidence of dome-shaped selectivity.

The differences in estimated fishery selection pattern between the final TSA assessment and Cook (2019) are central to the differences in the perception of stock status from the two approaches. Flat-topped and dome-shaped fishery selectivity patterns are both plausible options and both occur across a range of stocks as shown in Figure 3 of WD 3 in Annex 4. However, with the data currently available it is difficult to establish which is more plausible in this case. In other implementations of TSA (e.g. for Northern Shelf haddock and West of Scotland whiting), the estimated selection pattern shows either some doming or increased F at younger ages (WD 3, Annex 4), so asymptotic selectivity is not a particular feature of TSA and must be associated with the 6.a cod data.

The IBP agreed on the final configuration of the TSA assessment, which in the opinion of the group, gives the best assessment of the stock within the limitations of the current TSA assessment method. The sensitivity testing shows that the results are robust to assumptions about selectivity, survey catchability, the time-series of data included and the relative weight of survey and landings data. However, it is clear from the discussion above (and in WD 3, Annex 4) that significant uncertainties remain. The input data for this cod assessment are particularly uncertain (both survey indices and commercial data) and as a result, the data can be interpreted in different ways by different assessment methods. There is clearly significant process uncertainty associated with this stock and the uncertainty estimate from the final TSA run is unlikely to adequately reflect the overall uncertainty in the estimates of stock biomass and fishing mortality for this stock.

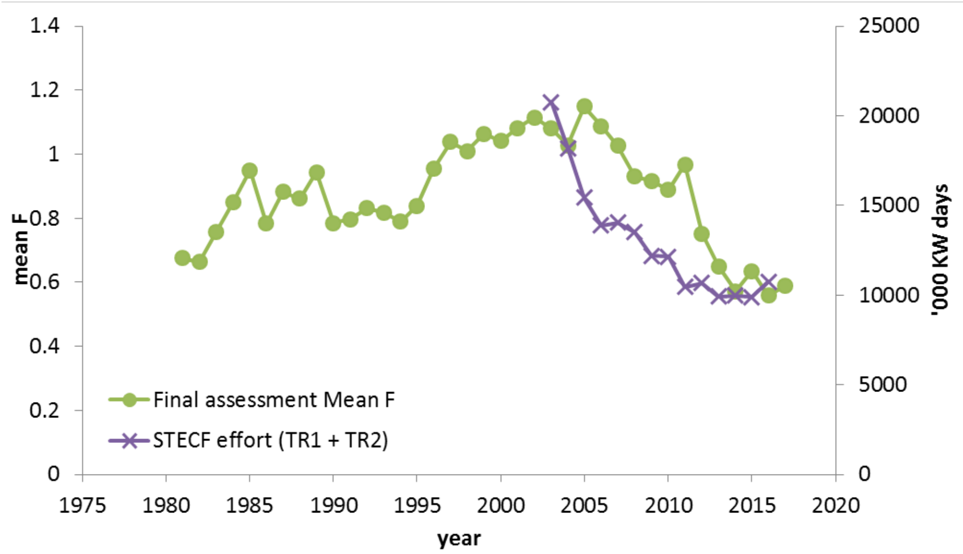


Figure 2.5.1. Cod.27.6a. Comparison between estimated mean F from the final assessment and effort data from the main fleets catching cod (2003–2016, TR1 + TR2 effort from both regulated and unregulated fleets, STECF effort database).

3 Reference points

3.1 Background

In deriving F_{MSY}, a decision has to be taken about the definition of yield; ICES defines this as catch above MCRS. The current reference points for this stock date back to WKMSYREF4 (ICES, 2015b) and were based on an assessment that included data up to 2014. At that time, when selection at MCRS was not known, yield was taken to be the landings, maintaining current discarding practices (WKMSYREF3 and ICES, 2016). More recent F_{MSY} evaluations for other stocks, where above MCRS discarding is known to occur, have approximated this selectivity by including a proportion of the discards in the yield calculation (in addition to the landings). The IBP therefore agreed that there was a need to revise the MSY reference points for this stock using an appropriate definition of yield in line with current approaches.

By considering mean sizes in the Scottish catches, it appears that a significant proportion of age 1 catches are greater than MCRS (at least in some years) and historically there were some landings from this age class. Therefore, yield was taken to be total catch less discards, with the discard proportion-at-age taken to be the average of the historical discards calculated from the period before the change in discarding practices (1981–2000). As part of the process of evaluating MSY reference points, the PA reference points were also reconsidered. The pre-IBP reference points are shown below.

Reference Point	Value	Technical Basis
F_{MSY}	0.17	F that provides maximum yield (Based on simulation, EqSim)
MSY Btrigger	20 000 t	B_{PA}
B_{lim}	14 000 t	Bloss from which the stock has increased (SSB in 1992 as estimated in 2015)
B_{PA}	20 000 t	B_{lim} x 1.4
F_{lim}	0.82	Based on simulation using segmented regression with Blim as the breakpoint (EqSim): F such that 50% probability of SSB < Blim
F_{PA}	0.59	Flim/1.4

3.2 Input data

The first step in defining reference points is to agree the data to be used in the calculations. The IBP agreed that there was no evidence of a regime change and therefore the full time-series of stock and recruitment data (excluding the final year which depends only on a single datapoint) was used in the estimation of biomass and F reference points (both MSY & PA). (See working document 2 in Annex 4 for further details).

Eqsim provides MSY reference points based on the equilibrium distribution of stochastic projections. Stochasticity is included in biological and fishery parameters by resampling at random from the recent stock assessment. Consideration of biological and fishery data suggested no reason to deviate from the default year range for these data (most recent 10 years), with the exception of i) using 1981–2000 discard proportions to approximate above MCRS yield and ii) the use of catch mean weights instead of landings mean weights for ages 2 and above to avoid the use of mean landings weight affected by high grading.

3.3 Defining PA reference points

Following the ICES guidance, the stock is Type 2: a stock with a wide dynamic range of SSB, and evidence that recruitment is or has been impaired. In such cases the ICES guidance suggests B_{lim} is set at the segmented regression change point. The estimated breakpoint has very wide confidence intervals and the range includes the current estimate of B_{lim}. Given this, and the uncertainty associated with this assessment in general, there is considered to be limited basis for revising the current value of B_{lim}. (Additionally, a benchmark in the near future ought to provide a sounder basis for updating biomass reference points). The current value of B_{pa} (=20 000 t) which is 1.4 x B_{lim} or B_{lim} x exp(1.645sigma) where sigma=0.2 (rounded to the nearest 1000 t) is also retained. The estimate of uncertainty from the assessment is less than this.

F_{lim} estimation was performed using Eqsim (without assessment/advice error) to derive the F that has 50 % probability of SSB falling below B_{lim} using a segmented regression stock–recruitment relationship with the breakpoint fixed at B_{lim}. F_{lim} was estimated as 0.77. F_{pa} was calculated using the default value of σF (0.2) resulting in F_{pa}=0.55.

3.4 Calculating F_{MSY}

F_{MSY} calculations require the use of a stock–recruitment relationship. In situations where the stock–recruitment relationship is uncertain, the ICES guidance suggests using the model averaging approach. The model averaged fit of the Beverton–Holt, Ricker and segmented regression relationships gives the greatest weight to the Beverton–Holt (i.e. is statistically the best fit) although the fit is visually very similar to the Ricker, which takes very little weight. However, further exploration shows that the Beverton–Holt plateau occurs well outside the range of historical data and therefore this relationship is excluded from the calculation of F_{MSY} (See Annex 4). The stock–recruitment relationships (and fit to the data) used in the EqSim analysis are shown in Figure 3.4.1.

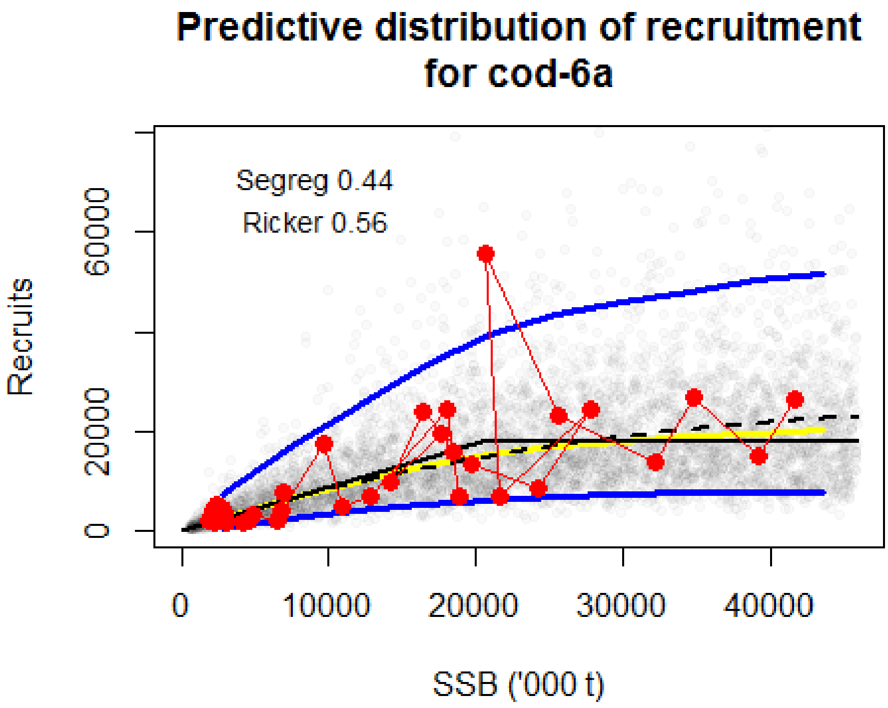


Figure 3.4.1. Cod.27.6a. Stock–recruitment data (red points) with fitted relationship using Ricker (dashed black line) and segmented regression (solid black line). Blue lines are 5th and 95th percentiles. Yellow line: 50th percentile.

F_{MSY} is initially calculated by running EqSim with assessment/advice error, but without application of the ICES advice rule (MSY $B_{trigger}$). To include assessment and advice error, the values F_{cv}=0.212 and F_{phi}=0.423 (default values suggested by WKMSYREF4 (ICES, 2016)) were used. The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was 0.29. The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was 0.41 and the lower bound 0.2. Note that the associated SSB is above the historically observed values, although recruitment and landings are within the range of historical values (Figures 3.4.2. and 3.4.3).

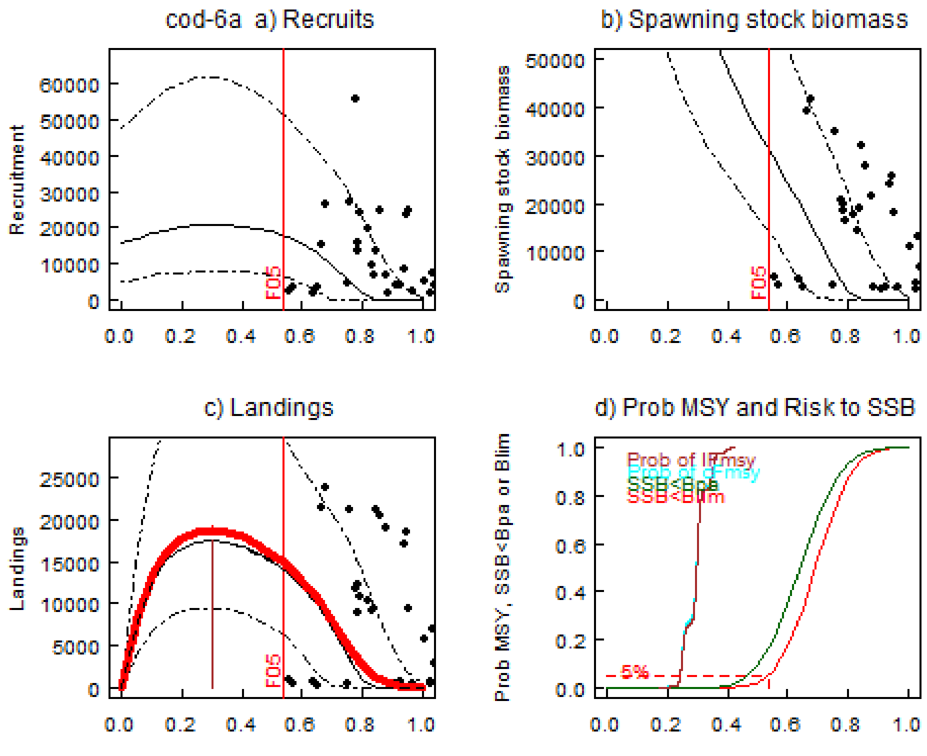


Figure 3.4.2. Cod.27.6a. Eqsim summary plot. Panels a–c: historic values(dots), median (solid black) and 90% intervals (dotted) for recruitment, SSB and yield for exploitation at fixed values of F. Panel c also shows mean yield (red). Panel d shows the probability of SSB less than B_{lim} (red), less than B_{pa}(green) and the cumulative distribution of F_{MSY} based on > MCRS yield (brown) and catch (cyan).

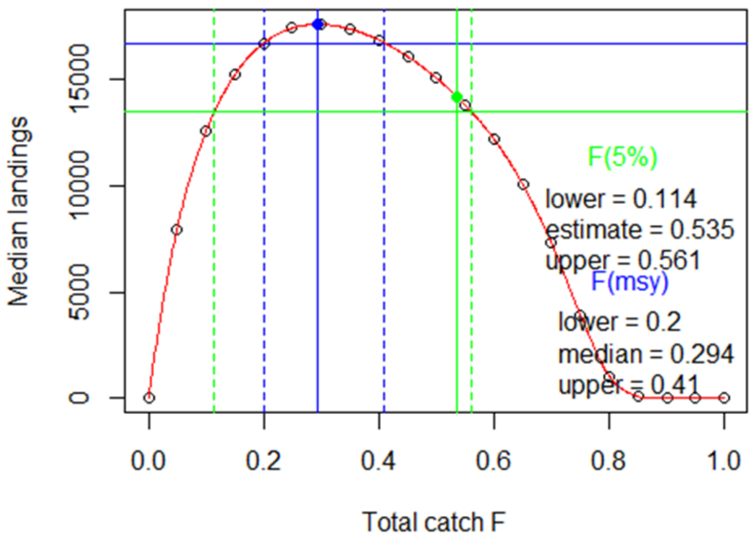


Figure 3.4.3. Cod.27.6a. Median yield curve with estimated reference points for fixed F. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: Fp.05 estimate (solid line) and range at 95% of yield at Fp.05 (dotted line).

The next step is to set MSY $B_{trigger}$. According to ICES guidelines, MSY $B_{trigger}$ is set equal to B_{pa} unless the stock has been fished below F_{MSY} for the last five years. The ICES MSY advice rule is then evaluated to check that the F_{MSY} and MSY $B_{trigger}$ combination fulfils the precautionary criterion of having a less than 5% annual probability of SSB <B_{lim} in the long term. (The evaluation includes assessment/advice error). The Fp.05 is calculated as 0.64 (see Figure 3.4.4 below) which is greater than the F_{MSY} (and F_{MSY} upper) without the advice rule and therefore the F_{MSY} reference points are not limited by Fp.05.

Further outputs from the final EqSim runs and sensitivity testing can be found in WD 2. (Annex 4).

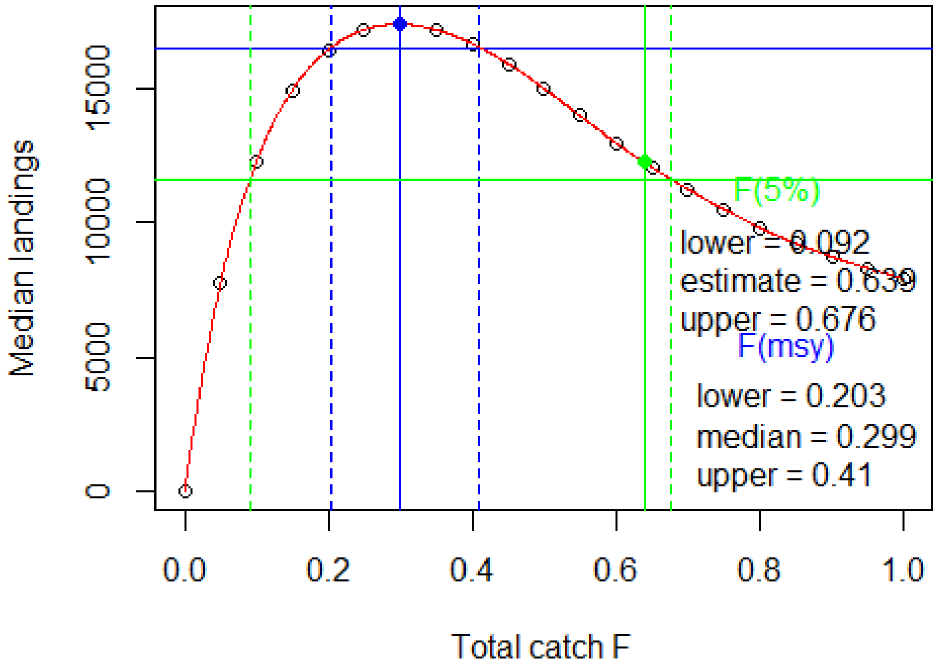


Figure 3.4.4. Cod.27.6a. Median yield curve with estimated reference points when applying the ICES advice rule with $B_{trigger}$=20 000 tonnes. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: Fp.05 estimate (solid line) and range at 95% of yield at Fp.05 (dotted line).

3.5 Proposed final reference points

The final proposed reference points are shown below. The F_{MSY} estimate has increased substantially since it was last estimated at WKMSYREF4. This is in part due to the change in definition of yield (which now uses an approximation for catch above MCRS) and also, due to the exclusion of the Beverton–Holt stock–recruitment relationship from the simulations (as this results in a lower F_{MSY} with much higher SSB and recruitment).

Table 3.5.1. Cod.27.6a. Final proposed reference points (previous values in brackets).

Reference Point	Value (previous value in brackets)	Technical Basis
F_{MSY}	0.29 (0.17)	F that provides maximum yield (calculated from EqSim using Segmented regression & Ricker stock recruitment relationships including full time-series of stock recruit data minus the final datapoint)
MSY Btrigger	20 000 t (20 000 t)	B_{PA}
B_{lim}	14 000 t (14 000t)	Bloss from which the stock has increased (SSB in 1992 as estimated in 2015)
B_{PA}	20 000 t (20 000 t)	B_{lim} x 1.4
F_{lim}	0.77 (0.82)	Based on simulation using segmented regression with Blim as the breakpoint (EqSim): F such that 50% probability of SSB < Blim
F_{PA}	0.55 (0.59)	Flim/1.4
$F_{MSY\ lower}$ (without ICES AR)	0.20 (0.11)	F at 95% MSY (below FMSY)
$F_{MSY\ upper}$ (without ICES AR)	0.41 (0.25)	F at 95 % MSY (above FMSY)
$F_{p.05\ (}$with ICES AR)	0.64 (0.65)	F that gives a 5 % probability of SSB < Blim when the ICES advice rule is applied

4 Issues for a future benchmark

A number of issues were identified for addressing at a future benchmark:

- Alternative assessment methods

The input data for this cod assessment are particularly uncertain (both survey indices and commercial data) and as a result, the data can be interpreted in different ways by different assessment methods. It is recommended that at a future benchmark additional assessment models such as SAM (Nielsen and Berg, 2014), a4a (Jardim *et al*., 2015) and the model described in Cook (2019) should be applied which may help to identify where the particular uncertainties lie. There may, in addition, be further advantages to the use of SAM or a4a in that they can (and have) been used in management strategy evaluations. The current implementation of TSA does not allow for this.

Stock assessment results generally only report model fit and uncertainty of estimated quantities for the 'agreed' model, ignoring other potential plausible models and hence ignoring (or not fully quantifying) uncertainty in the results. For stocks such as West of Scotland cod, with significant uncertainty across a range of assumptions (e.g. fishery selectivity, survey catchability) it may in future be appropriate to consider a multiple model approach to stock assessment. Such an approach accounts for process uncertainty in particular aspects of the model by fitting multiple models and integrating across model results (Millar *et al*., 2015; Scott *et al*., 2015).

- Discard modelling

Approaches to discard modelling were discussed at length at this IBP. In the current TSA implementation (final IBP and recent assessment WGs), the proportions discarded at-age are modelled as a random walk (with transitory and persistent changes controlled by estimated standard deviations), with a step change in 2006. While this approach can reproduce the general trends in the data, it does not model the interannual variability in discard proportions particularly well. It is also unable to model the transitional year between the period of low and high discarding, the data from which are included from the final IBP assessment. Consideration of the processes contributing to the proportion discarded at-age (which could be size related or quota related) may allow for improved modelling of these data. The use of alternative stock assessment methods will, inevitably necessitate the consideration of alternative approaches to modelling discards. A future benchmark will also potentially have to deal with further major changes in discarding practices due to the full implementation of the landing obligation.

- Stock–recruitment modelling

The TSA assessment (IBP configuration) assumes that recruitment follows a Ricker curve and estimates the parameters of the relationship and deviations around it. As part of the process for estimating reference points, a stock–recruitment relationship must be chosen and concern was expressed at this IBP when it became apparent that the best fitting model (from EqSim) was not consistent with the assumptions of the current TSA configuration. Given the strong signal in the recruitment data, it seems unlikely that the Ricker assumption has a significant impact on the results of the assessment. However, it would be informative in a future TSA assessment to consider the sensitivity of the assessment results to this assumption.

- Stock structure

Cod to the west of Scotland are believed to comprise of at least two subpopulations of cod that remain geographically separated throughout the year with the latitudinal boundary of these groups between 57° and 58°30′N. The southern component is characterised by coastal groups with a tendency towards year-round residency, although tagging data show that there is some exchange with the Irish Sea (7.a) (Neat *et al*., 2014). The northern component appears to intermix with cod in the northern North Sea (4.a) at all stages of the life history (See ICES 2012, WD 4). More recently, Doyle *et al*. (2016) identified finer scale population structure between resident inshore and offshore migratory cod populations around Shetland (4a) and westwards into 6.a and suggested that inshore cod to the west of Scotland (6.aN) may be genetically distinct from other groups sampled.

WKROUND (ICES, 2012) concluded that based on the evidence available at the time there was no need for changes in assessment units given that most fish can be expected to remain within their respective assessment areas (although recent publications appear to dispute this). They also acknowledged a need to consider local stock components to avoid depletion of potentially isolated substocks. Such dynamics can be masked when considering assessments of 'stock' units which consist of multiple substocks and Holmes *et al*. (2014) identified differing trends in SSB (derived from survey data) for putative substocks of cod (with stock definitions based on genetic, tagging, and otolith microchemistry studies) in the Division 6.a.

The situation is clearly complex and the currently agreed stock assessment units require further consideration. This would need to be carried out across the Celtic Seas and North Sea Ecoregions, drawing on the results of the most recent studies (including a recently concluded Irish Sea cod tagging project, EASME/EMFF/2015/010). There are further relevant projects on cod stock structure currently in proposal stage.

- Fleet disaggregated catch-at-age data

One of the critical issues identified at the current IBP is the choice of fishery selectivity pattern with both flat-topped and dome-shaped both being considered plausible options. The application of a stock assessment in which the main fleets (demersal fish target and *Nephrops* target fisheries) are modelled separately may help to sort out these selectivity issues. However, fleet disaggregated catch-at-age composition data are currently only available for a relatively short time period. A data call would therefore be required to obtain a more complete time-series of such data.

- Misreporting estimates

Scottish landings (from 2006) are adjusted to include estimates of area misreporting (cod actually caught in Division 6.a are declared as being caught in Subarea 4) in an attempt to reduce bias in the assessment. In recent years, area misreported landings account for over half of the total landings. The misreporting estimates are provided by Marine Scotland Compliance based on intelligence and consideration of VMS data. Estimates based on provisional analysis of VMS data linked to landings at a trip level (conducted at the 2015 inter-benchmark (ICES, 2015a)) gave somewhat higher estimates. Finalising this analysis would validate the current area misreporting corrections.

- Seals

The contribution of seal predation to total cod mortality is likely to be significant and this may impair the ability of the stock to recover (Cook *et al*., 2015). Weight dependent natural mortalities-at-age were adopted at the benchmark meeting in 2012 to take account of increased mortality at younger ages. And while it would be worth reviewing the appropriateness of these natural mortality estimates, given the sparsity of the data, it is unlikely that seal consumption estimates could be incorporated into a robust annual stock assessment. Furthermore, there are no new/recent seal consumption data.

5 Comments from External Reviewers

The WebExes and the documentation provided through the process have given a transparent and well-documented investigation for issues relevant within the Terms of Reference. The discussions have focused on the pertinent issues, which have been addressed and, to the extent possible within the ToRs, been resolved and incorporated in the decision on future stock assessment methodology and Stock annex. The comments and questions from the external reviewers have also been addressed and answered in the process and are incorporated in this report and in the updated Stock Annex.

Some of the comments from members of the groups were discussed, but not incorporated within this IBP, as the issues were outside the scope of the ToRs for this IBP.

It is apparent from the process that the assessment of this stock poses an extra challenge by the data inputs being more uncertain than for other stocks in the same fisheries, and by the overall perspectives on the development of the stock and its exploitation being very sensitive to not only model configuration but also to model choice. It has been beyond the ToRs for the present process to investigate model choices further but, as discussed in Section 4, this is obviously an issue to be looked into at a future benchmark for this stock. In the meantime, there is a need for ICES, when using data from this assessment regarding this stock, to emphasise that uncertainties relate not only to the available input data, but for this stock also, more than usual, to the choice of methodology to analyse the data.

There were some discussions during the IBP on fishing selectivity. The former model used a fixed selectivity for age 4 and above; this was questioned by an alternative model showing a dome shape fishing selectivity curve presented during the IBP. Exploratory runs were presented for the IBP were selectivity were estimated within the model and the group decided on selectivity settings fixed for ages 6 and above, which allows greater flexibility for the selectivity at ages <6. The new settings within the model resulted, in F estimates just below 0.6, a reduction of approximately 50% compared to the pre-2007 level and an F development more in line with the effort reduction seen since the early 2000. Further, the large retrospective pattern in F seen in the former assessment has been much improved.

The inclusion of more surveys within the model was investigated. In the present assessment only one survey (Scottish Q1 in two divided time periods) have been included. Several exploratory runs were conducted with the inclusions of both the Scottish Q4 survey and the Irish Q4 survey. In the former benchmark, it was concluded that the Irish survey was not relevant do to a limited spatial overlap. This IBP group argued that there is an advantage of having a survey covering both time periods (where the gap appeared in the Q1 survey), although the spatial coverage was more limited as there were a reasonable internal consistency as well as some external consistency with the Scottish surveys.

The need to update the reference points was discussed during the WebEx meetings, and it was agreed to use the full time-series for calculating the reference point, as there was no clear evidence for regime shift within the current assessment period (1981–present time). The stock–recruitment relationship was characterised as a type 2, with clear evidence that recruitment is or has been impaired at lower spawning stock levels. The present B_{lim} was defined as B_{loss}, from which the stock has increased. It was during the IBP tested if the new proposed assessment would change the perspective of B_{lim}. The estimated breakpoint had very wide confidence intervals and the range included the current estimate of B_{lim}. It was concluded by the group, that the basis for revising the current value of B_{lim} was limited given the general uncertainty associated with this assessment and as the former B_{lim} was within the confident intervals, it was decided to keep the B_{lim} at 14 000. However, it was further recommended that this issue would be investigated in a future benchmark process. There were some discussions within the group on the stock–recruitment relationship used for the F_{MSY} calculations within EqSim. The ICES guidelines suggest using a segmented regression however, as the assessment model is using a Ricker relationship this was, for consistency reasons, suggested as an alternative option. The Beverton–Holt stock–recruitment relationship was excluded from the simulations due the plateau and peak well outside the observed range of stock–recruit pairs. It was decided to use a combined Richer and segmented regression relationship given equal weight. The final F_{MSY} was calculated to be 0.29.

As the external reviewers' concerns have been addressed in the process the reviewers have no further comments.

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Annex 2: Stock Annex: Cod (*Gadus morhua*) in Division 6.a (West of Scotland)

The table below provides information regarding the stock annex for the Cod (*Gadus morhua*) in Division 6.a (West of Scotland). Stock Annexes for other stocks are available on the ICES website Library under the Publication Type "Stock Annexes". Use the search facility to find a particular Stock Annex, refining your search in the left-hand column to include the *year*, *ecoregion*, *species*, and *acronym* of the relevant ICES expert group.

Stock ID	Stock name	Last updated	Link
cod.27.6a	Cod (*Gadus morhua*) in Division 6.a (West of Scotland)	March 2019	West of Scotland cod

Annex 3: Working Documents

WD 1: Dobby, H. and Fryer, R. Working Document for IBPCod.6.a: TSA stock assessment.

Working Document for IBP Cod.6a: TSA stock assessment

Helen Dobby & Rob Fryer (Marine Scotland Science)

Feb, 2019

Background

The West of Scotland cod stock assessment was last benchmarked by WKROUND in 2012 (ICES, 2012) with an interbenchmark following in 2015 (ICES, 2015). Prior to 2012, ICES had been unable to provide an assessment in which mortality could be partitioned into fishing and natural mortality (although total mortality was estimated to be high). Although stock biomass was very low and hence precautionary advice was for zero catch, ICES were unable to provide an indication of fishing mortality relative to reference points. These difficulties in estimating fishing mortality were largely associated with unknown total landings (due to underreporting in the fishery), but also uncertainty in natural mortality due to potentially significant predation by seals. Therefore at the 2012 benchmark, considerable effort was put into deriving an assessment which could cope with such a situation and provide an estimate of fishing mortality. This included allowing the TSA (Gumundson, 1994; Fryer, 2001 & 2011) to estimate misreporting during the period 1991 to 2005 (while still making use of the commercial age composition data during this period), making use of area misreporting estimates (provided by Marine Scotland Compliance) to adjust the reported landings for 2006 onwards and deriving age (weight) dependent natural mortality estimates (Lorenzen, 1996). Note that legislation introduced in the UK during 2006 ('Buyers & Sellers') meant that it became much harder for the fishing industry to underreport landings (although area misreporting is still known to occur) which resulted in major changes in discarding practices at that time (a significant increase in discarding and discarding older ages) and hence the TSA also had to be adapted to account for this change. Discards have typically been estimated as between 60 and 80 % of the total catch by weight since then.

The assessment is further complicated by the fact that there was a change in design and gear of the Scottish surveys (both Q1 and Q4) between 2010 and 2011, meaning that the surveys have had to be treated as two separate indices in the stock assessment. The recent surveys have a high proportion of zero hauls which coupled with a small number of very large hauls results in very high variance estimates (particularly for the older ages).

In addition, there are likely to be a number of sub-stocks of cod within ICES Subarea 6a with cod in the north, potentially more closely associated with the North Sea stock of cod than with cod in the south of 6a (WD to ICES 2012, Wright et al, XXXX).

The data and main features of the final assessment presented at WGCSE in 2018 (following ICES, 2012 & 2015) were as follows:

- Landings & discards at age 1981 – 2017, ages 1-7+
    - 1991-2005 use age compositions only

- Landings adjusted for area misreporting 2006 onwards (MS-Compliance estimates)
- Q1 Scottish trawl survey 1985 – 2010, ages 1-6 (WIBTS.Q1)
    - Constant catchability year component
- Q1 Scottish trawl survey 2011 onwards + variance estimates, ages 1-6 (SCO.Q1, IBP 2015)
    - Known variance
    - Transitory changes in catchability year component
- Lorenzen natural mortality (weight dependent)
- Log F separated into age and year component
    - follow a random walk with persistent & transitory changes (variances estimated by maximum likelihood)
    - Am=4 age above which F is assumed constant (except for local transitory variability)
- Discards proportions modelled as random walk
    - Ages 1-4 (only 1-2 pre 2006)
    - Step change in proportion in 2006
- Ricker stock-recruitment relationship
    - Parameters and CV estimated

The stock summary from the stock assessment conducted at WGCSE in 2018 is shown in Figure 1 (and parameter estimates given in Table 1). It illustrates a stock in which fishing mortality is declining only slowly (and is still well above F_{MSY}) despite management measures which include significant reductions in effort. Furthermore, SSB shows no sign of increase and ICES advice has been for zero catches for over 15 years.

Issues

Diagnostic plots presented at the latest assessment WG (ICES, 2018) highlighted a number of potential problems with the current TSA model configuration.

Figure 2 shows the retrospective analysis for mean F from the 2018 assessment. There appears to be a persistent over estimation of mean F in the final assessment year which is particularly obvious in the final year estimates for 2015-2017. In TSA, the year component of the fishing mortality is modelled as a random walk, allowing for both transitory and persistent changes (with standard deviations estimated as part of the fitting process). In these assessments, the TSA explains the decline in F as a transitory change with no persistent change (see parameter estimates in Table 1), resulting in the final year F at around the long term average.

Secondly, the latest assessment shows clear heterogeneity in the residuals, particularly of the landings data (Figure 3) indicating problems with the model fit (and assumptions). The current assessment assumes landings measurement error to have constant age-specific CV over time (see later for fuller explanation) while these plots tend to indicate an increased variability for ages 1 and 2 from around 2007 onwards. These diagnostics, therefore suggested the need to reconsider the assumptions associated with age-specific measurement error.

In addition, recently published work (Cook, 2019) demonstrates that a similar stock assessment model with different fishery selectivity assumptions could result in a quite different perception of the state of the stock: one which has seen a dramatic reduction in F and an increase in SSB to levels similar to those of the early 1990s. One feature of this model which could account for the different perception is that the fishery selectivity is estimated to be extremely low for ages 5 and 6 in comparison to younger ages. In contrast the current ICES assessment estimates selectivity to be relatively flat topped (with the constraint that for ages 4 and above selectivity is assumed constant). In addition, the alternative assessment also includes additional survey data: both Scottish and Irish quarter 4 survey indices.

Therefore the assessment WG agreed that a number of issues should be explored in the current TSA assessment: i) greater flexibility in the estimation of fishery selectivity, ii) age-specific measurement error of the commercial catch data, and iii) the inclusion of additional survey indices. A number of exploratory TSA assessments are presented here which address these issues.

Assessment 1

The first of the new assessments (A1) considers two aspects of the 2018 WG TSA specification (and addresses i) and ii) above):

1) **Fishery Selectivity**: In TSA, the fishing mortality selection pattern is allowed to evolve stochastically over time, but is assumed fixed above a certain age (specified in the model) with only transitory departures from this. In previous assessments, selectivity has been assumed to be equal for ages 4 and above. Recently published alternative assessments of this stock estimate a dome shaped selection pattern (Cook, 2019) and it is acknowledged that dome-shaped selectivity could potentially result from differential exploitation of different components of the stock (spatial difference in fisheries and stock distribution). Therefore, model A1 assumes that the selection pattern is flat for ages 6 and above (age 7+) which allows greater flexibility for the selectivity at ages 4, 5 and 6.

2) **Age-specific measurement error**: In TSA, the landings and discards are estimated with constant CVs: CV_L and CV_D respectively, parameters which are estimated by maximum likelihood. However, the data for some age classes is typically more variable than others which can be apparent in the prediction error and residual plots[1]. Based on these plots age-specific weighting factors are chosen. In the 2018 WG assessment (and all assessments since the benchmark in 2012 and possibly earlier), the landings were assumed to have CVs of $(1,1,1,1,1,2,2)CV_L$ i.e. ages 6 and 7+ had CV twice that of the other age groups. (Individual data points which appear to be outliers based on residual plots have also been down-weighted in this manner).

   In A1, these age-specific CV multipliers have been re-evaluated in 3 stages:

[1] Prediction errors are the scaled differences between the observations (landings, discards and survey indices) and the step-one-ahead predictions (from the forward pass of the Kalman Filter). Residuals are the more typical scaled differences between the observations and the fitted values (following both the forward and the backwards pass).

i) The first stage made use of a subset of the full data set: including commercial data up to 2005 and survey data to 2006, i.e. covering the time period before the change in discarding practices. The current configuration of TSA (CVs as above) was initially fitted to this subset of data. The resulting landings residuals were greater for age1 and 6 and 7+, and based on the median of these landings residuals (text table below), the landings CV multiplier on age 1 was increased from 1 to 2 and that on age 7+ from 2 to 3.

Age	1	2	3	4	5	6	7+
Median landings residual	0.61	0.30	0.28	0.28	0.32	0.42	0.91

In addition, the down-weighting of all age 7+ landings outliers was removed and WCIBTS 1987 age 1 and landings 2004 age 4 were down-weighted based on residual/prediction error plots.

ii) Step 2 uses the model configuration from step 1 and additionally includes commercial data from 2007 to 2009 and survey data to 2010 (the final year of the old survey index, WCIBTS Q1) with all down-weighting of outliers from these additional years initially removed. Commercial data from 2006 have been completely excluded from the model fit as this year appears to be a transition year between the low discard and high discard fisheries. (The legislation that ended the potential for underreporting of landings occurred midway through 2006).

External estimates of the CVs of the Scottish landings and discards data are available from 2012 to 2017 (derived from market and observer sampling data as part of the assessment input data estimation process). The median CVs by age over these years are given below. (Note that discards at age 5 and above are included in landings i.e. discard proportion not modelled).

Age	1	2	3	4	5	6	7+
Median landings CV	1.56	0.91	0.36	0.12	0.19	0.38	0.75
Median discards CV	0.51	0.33	0.48	0.46			

These CVs are assumed to apply to the commercial data for 2007 onwards i.e. the period of high discarding. The age specific CV multipliers for landings and discards were calculated as (1.56, 0.91, 0.36, 0.12, 0.19, 0.39, 0.75) / CV_L and (0.51, 0.33, 0.48, 0.46) / CV_D where CV_L=0.1 and CV_D=0.53 are the estimated landings and discards CVs from the analysis up to 2006.

Finally a number of additional data points were down-weighted based on residual/prediction error plots: WCIBTS 2007 age 2, 2008 age 3, 2008 age 4, 2010 age 2.

iii) Step 3 adds in the remaining years of data (still excluding 2006).

The final model specification for assessment A1 including data up to 2017 (2018 survey) is given in Table 2. The stock summary is shown in Figure 4, parameters estimates in Table 1 and other results and full diagnostic plots in Figures 5-13. Full results from steps 1 and 2 of the process can be found on the IBP Sharepoint.

Assessment 2

The 2018 WG assessment includes only the Scottish Q1 indices as concluded by ICES (2012). Based on exploratory assessment runs, the 2012 benchmark concluded that the WIBTS Q1 (1996-2009) survey had little influence on assessment results or diagnostics and there was little benefit to including this index in the assessment.

Since 2011, there has been a new Scottish survey index (SCO Q4) which uses the same design and gear as the SCO Q1 index. The index (and variance) are given in Table 3. Mean standardised indices and correlation plots are shown in Figures 14-16. The combination of few very large hauls and a large proportion of zero hauls results in high variance estimates and the plots do not suggest particularly good internal consistency. The fact that the time series remains relatively short with a missing year also makes the data difficult to interpret.

The Irish Q4 survey (IGFS-WIBTS-Q4) which runs from 2003 onwards was also considered at the 2012 meeting. This survey only extends to 56°30'N and given the (distribution of the stock in 6a, with most of the stock in the north), it was considered doubtful as to whether this index could be considered representative of the whole stock (although age 1 at lease appears relatively consistent with the Scottish survey data). This index has not been considered further in the work presented here. Work is, however, ongoing at ICES WGISDAA on methods for combining the Irish and Scottish quarter 4 surveys to provide a combined index.

Despite the limitations of SCO-Q4 and previous benchmark conclusions regarding WIBTS Q1, in assessment model A2, these two survey indices are also included in the assessment (in addition to the quarter 1). The data from the two indices span the following years and age ranges (note that a vessel breakdown resulted in a lack of quarter 4 survey data in 2013):

Survey	Years	Ages	Variance	Catchability

WCIBTS Q4	1996-2009	1-4	Estimated in the model	No persistent or transitory
SCO Q4	2011-2017 (excl 2013)	1-6	Calculated externally	Transitory changes allowed

The model is configured in the same manner as A1 and the quarter four survey indices are modelled in the same way as the quarter one indices. Parameter estimates are given in Table 1 and the stock summary is shown in Figure 17. Full diagnostic plots can be found on the IBP sharepoint.

Assessment 3

Despite allowing greater flexibility in the fishery selectivity, neither of the assessments presented above show evidence of a dome-shaped selectivity pattern or any particular changes in selectivity in recent years. In TSA, the age component of the fishing mortality is modelled as a random walk and hence current selectivity estimates may be influenced by historical data. Therefore to remove any influence of data from the period before Buyers & Sellers legislation (the low discarding period), assessment A3 is fitted to only a subset of the full data set:

- Landings and discards, 2007-2017, ages 1-7+
- SCO Q1, 2010-2018, ages 1-6
- SCO Q4, 2011-2017, ages 1-6

Parameter estimates from this model fit can be found in Table 2 and the stock summary in Figure 18. Full model diagnostics and outputs can be found on the IBP sharepoint.

Discussion

The model fit presented in A1 appears reasonable. Although there are still some patterns apparent in the residuals, the heterogeneity in the commercial catch data residuals is greatly reduced compared to the assessment presented at WGCSE 2018. There are some outliers which could potentially be down-weighted, but they do not appear to be particularly influential, and there are no exceptionally large residual/prediction errors.

In terms of results, the model estimates a persistent trend in F (unlike the 2018 WG assessment) which results in an F in recent years of just below 0.5, a reduction of over 50 % compared to the pre 2007 level. This reduction in F is more consistent (than the 2018 WG assessment) with the decline in effort which has occurred in the main fisheries since the early 2000s. (Note that a retrospective analysis has not yet been carried out). Despite allowing greater flexibility in the fishery selectivity, only in a few years in assessment A1 does fishing mortality at intermediate ages exceed that at older ages (e.g. 1998, 2001, Figure 9). There is no evidence of age 1 fishing mortality being higher than that at ages 5 and 6 as estimated by Cook (2019).

The trend in SSB in assessment A1 remains similar to that from the 2018 WG assessment, with little increase in recent years.

There are only limited differences in model diagnostics and precision of results between A2 and A1. The main difference is that the inclusion of the quarter 4 surveys results in a slightly higher mean F in recent years.

Model A3 which excludes commercial data pre 2007 and focuses on an assessment of the stock since discarding patterns changed shows a similar picture to the 2 full time series assessments. Estimated fishery selectivity shows significant between year variability over this time period, but as in the other two assessments there is little evidence of a dome-shaped selectivity pattern.

Assessment A3 does, however, suggest that a lot of the transitory variation in discarding (in the fit to the full data set is due to the age 1's (from 2007 onwards), where the proportions discarded get extreme (and the variation is amplified on the logistic scale). Potentially a better fit to the full data set could be obtained by regarding all the age 1 catch as discards (from 2007), although this would require some (bespoke) changes to the TSA dll.

A comparison of results of assessments A1 to A3 and the 2018 WG assessment is shown in Figure 20. All assessments show similar trends with the main differences apparent in the more recent estimates of mean F with the models which include the SCO Q4 survey indicating higher recent mean F.

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Tables

Table 1. Comparison of final parameter estimates from 2018 WG assessment and the IBP assessments A1:A3.

Parameter	Notation	Description	2018 WG	A1	A2	A3
Initial fishing mortality	F (1, 1981)	Fishing mortality-at-age a in year y	0.323	0.254	0.253	0.379
	F (2, 1981)		0.668	0.568	0.570	0.406
	F (Am, 1981)		1.032	0.785	0.774	1.563
Fishing mortality standard deviations	σ_F	Transitory changes in overall fishing mortality	0.152	0.126	0.136	0.303
	σ_U	Persistent changes in selection (age effect in F)	0.009	0.037	0.032	0.0000
	σ_V	Transitory changes in the year effect in fishing mortality	0.178	0.032	0.040	0.069
	σ_Y	Persistent changes in the year effect in fishing mortality	0.000	0.107	0.094	0.040
Measurement CVs	$CV_{landings}$	CV of landings-at-age data	0.125	0.088	0.084	0.100
	$CV_{discards}$	CV of discards-at-age data	0.445	0.611	0.578	0.500
Recruitment	η_1	Ricker parameter (slope at the origin)	1.282	1.166	1.119	0.906
	η_2	Ricker parameter (curve dome occurs at $1/\eta_2$)	0.024	0.023	0.021	0.000
	cv_{rec}	Coefficient of variation of recruitment data	0.407	0.412	0.430	0.452
Discards	$\sigma_{logit\ p}$	Transitory trends in discarding	0.788	0.835	0.775	0.445
	$\sigma_{persistent}$	Persistent trends in discarding	0.296	0.202	0.196	0.097
	Step fn age 1	Amount by which discards increase in 2006	4.058	6.142	6.060	NA
	Step fn age 2		5.895	6.538	6.498	NA
	Step fn age 3		0.985	1.372	1.372	NA
	Step fn age 4		-0.436	-0.159	-0.183	NA

Parameter	Notation	Description	2018 WG	A1	A2	A3
Survey selectivities SCOWIBTS.Q1	$\Phi(1)$	Survey selectivity-at-age *a*	0.561	0.454	0.479	NA
	$\Phi(2)$		2.897	2.688	2.821	NA
	$\Phi(3)$		6.950	6.341	6.387	NA
	$\Phi(4)$		10.666	9.462	9.922	NA
	$\Phi(5)$		15.379	12.155	12.982	NA
	$\Phi(6)$		20.789	13.791	15.163	NA
Survey CVs	σ_{survey}	CV parameter controlling gamma type dispersion	0.258	0.004	0.034	NA
	η_{survey}	CV parameter controlling poisson type dispersion	1.142	1.512	1.515	NA
Survey catchability standard deviations	σ_{Ω}	Transitory changes in survey catchability	NA	NA	NA	NA
	σ_{β}	Persistent changes in survey catchability	NA	NA	NA	NA
Survey selectivities UK-SCOWCGFS-Q1	$\Phi(1)$	Survey selectivity-at-age *a*	0.841	0.728	0.708	0.133
	$\Phi(2)$		20.677	22.314	23.320	2.908
	$\Phi(3)$		40.604	44.432	38.808	4.003
	$\Phi(4)$		49.005	50.494	48.070	4.819
	$\Phi(5)$		84.270	68.555	71.722	9.707
	$\Phi(6)$		63.453	42.833	48.092	7.631
Survey catchability standard deviations	σ_{Ω}	Transitory changes in survey catchability	0.388	0.433	0.402	0.354
	σ_{β}	Persistent changes in survey catchability	NA	NA	NA	NA
Survey selectivities SCOWIBTS.Q4	$\Phi(1)$	Survey selectivity-at-age *a*	NA	NA	2.845	NA
	$\Phi(2)$		NA	NA	5.899	NA
	$\Phi(3)$		NA	NA	4.670	NA
	$\Phi(4)$		NA	NA	1.725	NA
Survey CVs	σ_{survey}	CV parameter controlling gamma type dispersion	NA	NA	0.046	NA
	η_{survey}	CV parameter controlling poisson type dispersion	NA	NA	2.645	NA
Survey catchability standard deviations	σ_{Ω}	Transitory changes in survey catchability	NA	NA	NA	NA

PARAMETER	NOTATION	DESCRIPTION	2018 WG	A1	A2	A3
	σ_β	Persistent changes in survey catchability	NA	NA	NA	NA
Survey selectivities UK-SCOWCGFS-Q4	$\Phi(1)$	Survey selectivity-at-age *a*	NA	NA	12.158	1.269
	$\Phi(2)$		NA	NA	23.496	2.937
	$\Phi(3)$		NA	NA	63.050	6.684
	$\Phi(4)$		NA	NA	101.684	11.694
	$\Phi(5)$		NA	NA	154.680	20.476
	$\Phi(6)$		NA	NA	134.062	32.682
Survey catchability standard deviations	σ_Ω	Transitory changes in survey catchability	NA	NA	0.136	0.2011
	σ_β	Persistent changes in survey catchability	NA	NA	NA	NA
Misreporting		Transitory changes in misreporting	0.002	0.0000	0.0000	NA
		Persistent changes in misreporting	0.258	0.176	0.164	NA

Table 2. TSA configuration for assessment model A1 (2 survey index model).

Parameter	Setting	Justification
Age of full selection.	$a_m = 6$	To allow flexibility when estimating fishery selectivity.
Multipliers on variance matrices of measurements.	$B_{landings}$(a, 1981-2005) = 2 for ages 1, 6 $B_{landings}$(a, 1981-2005) = 3 for ages 7+ $B_{landings}$(1-7+, 2007 onwards) = (15.6,9.1,3.6,1.2,1.9,3.8,7.5) $B_{discards}$(1-4, 2007 onwards) = (0.96,0.62,0.91,0.87)	Allows extra measurement variability for poorly-sampled ages (based on relative size of residuals). Allows extra measurement post Buyers & Sellers legislation (based on external estimates of CV).
Multipliers on variances for fishing mortality estimates.	H(1) = 2	Allows for more variable fishing mortalities for age 1 fish.
Downweighting of particular datapoints.	Landings: Age 2 in 1987 age 6 in 1982 age 4 in 2004 Discards: age 1 in 1988 and 1992, age 2 in 1988, 1992,1998,2002. Survey (WIBTS Q1): Age 1 in 1987 age 2 in 2007 and 2010, age 3 in 2008, age 4 in 2001 and 2008, age 5 in 2001.	CV multiplier set to 3 or 5 as necessary. Large values indicated by exploratory prediction error plots. Survey downweighting in 2001 resulted from a single large haul, 24 fish >75 cm in 30 minutes. In 2008 due to v large haul near 4 degrees W line.
Discards	Discards are allowed to evolve over time constrained by a trend. Ages 1 to 4 are modelled independently. A step function is specified with the step occurring in 2006.	
Recruitment.	Modelled by a Ricker model, with numbers-at-age 1 assumed to be independent and normally distributed with mean η1 S exp(−η2 S), where S is the spawning–stock biomass at the start of the previous year. To allow recruitment variability to increase with mean recruitment, a constant coefficient of variation is assumed.	
Large year classes.	The 1986 year class was large, and recruitment at-age 1 in 1987 is not well modelled by the Ricker recruitment model. Instead, N(1, 1987) is taken to be normally distributed with mean 5η1 S exp(−η2 S). The factor of 5 was chosen by comparing maximum recruitment to median recruitment from 1966–1996 for 6.a cod, haddock, and whiting in turn using previous XSA runs. The coefficient of variation is again assumed to be constant.	

Table 3. Cod.27.6a. SCO-Q4 survey index (upper) and variance (lower) by age (columns) and year (rows). Numbers are standardised to 10 hours fishing (as indicated by 1st column).

UK-SCO-Q4 (index)

2011	2017									
1	1	0.75	1.0							
0	8									
10	0.60	9.71	31.54	10.88	0.93	1.70	2.38	0.00	0.00	2011
10	0.75	19.78	7.12	15.43	13.60	1.02	0.68	0.34	0.00	2012
Survey not completed due to mechanical issues										2013
10	1.67	23.65	28.06	15.63	5.57	6.63	1.37	0.00	0.00	2014
10	3.64	28.17	52.53	34.22	10.58	4.24	5.27	1.18	0.59	2015
10	0.374	6.162	34.941	45.443	118.92	14.893	5.773	3.176	0	2016
10	2.127	10.024	6.221	24.427	10.881	8.538	0.767	0.511	0	2017

UK-SCO-Q4 (variance)

2011	2017									
1	1	0.75	1.0							
0	8									
10	0.21	31.08	38.07	5.78	0.19	1.56	4.79	0.00	0.00	2011
10	0.14	41.72	2.79	11.37	48.79	1.05	0.46	0.12	0.00	2012
Survey not completed due to mechanical issues										2013
10	0.68	132.97	56.62	44.17	3.87	4.79	0.39	0.00	0.00	2014
10	5.55	98.78	316.23	51.22	8.60	4.43	4.61	0.34	0.12	2015
10	0.14	7.394	419.36	716.38	7654.82	118.64	24.30	6.08	0	2016
10	3.215	11.252	3.816	76.154	14.262	8.928	0.207	0.063	0	2017

Figures

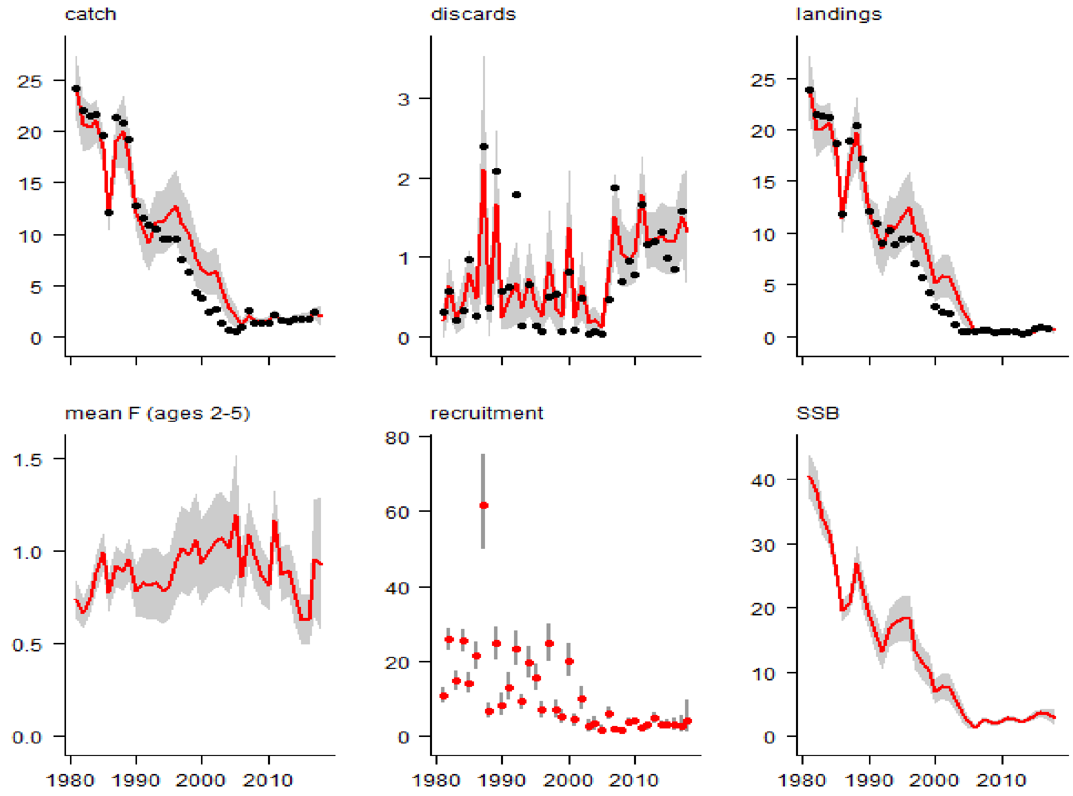


Figure 1. Cod.27.6a. Stock summary from final assessment from 2018 WGCSE. Red lines (or points) give best estimates, grey bands (or lines) give approximate 95% confidence intervals , and black points give observed values. Note that final value in the mean F plot is a projection.

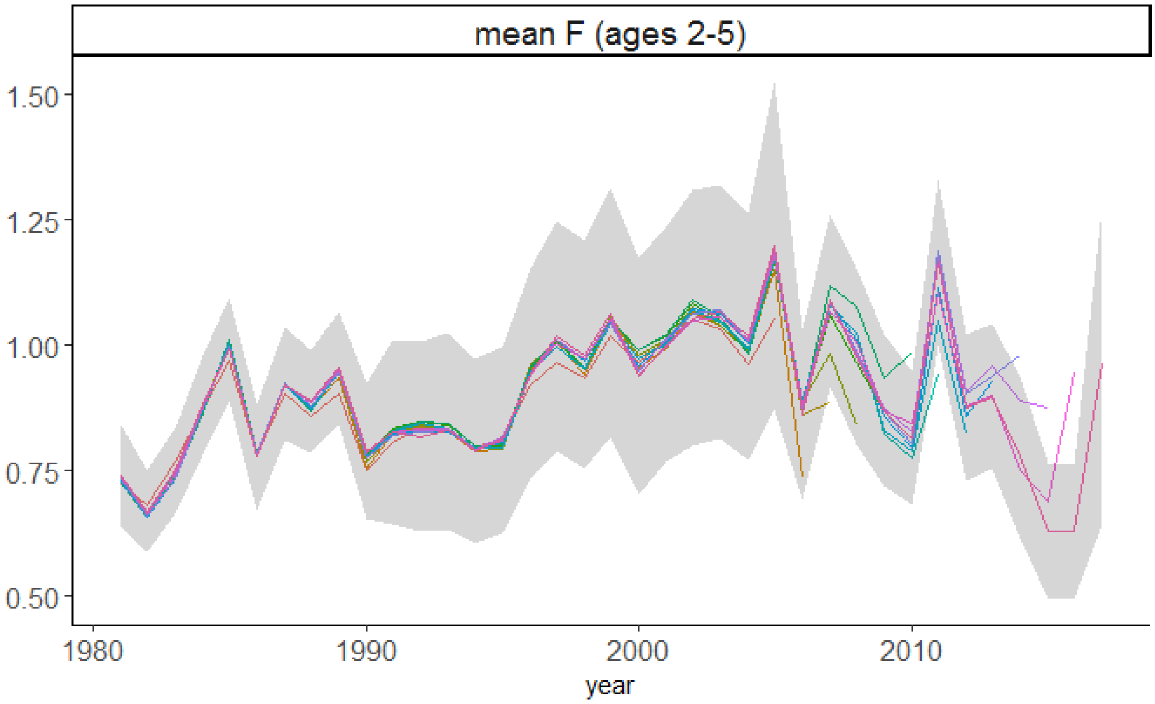


Figure 2. Cod.27.6a. Mean F retrospective analysis from final assessment from 2018 assessment WG.

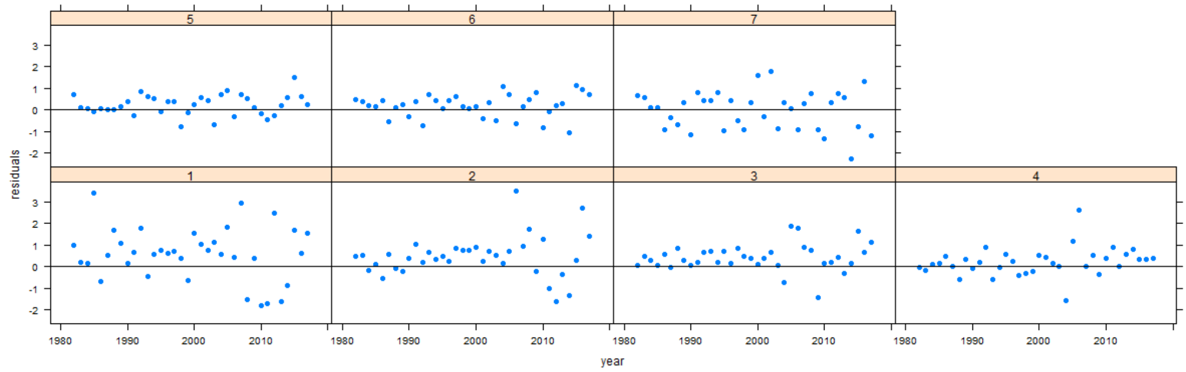


Figure 3. Cod.27.6a. Landings residuals by age from final assessment from 2018 WGCSE.

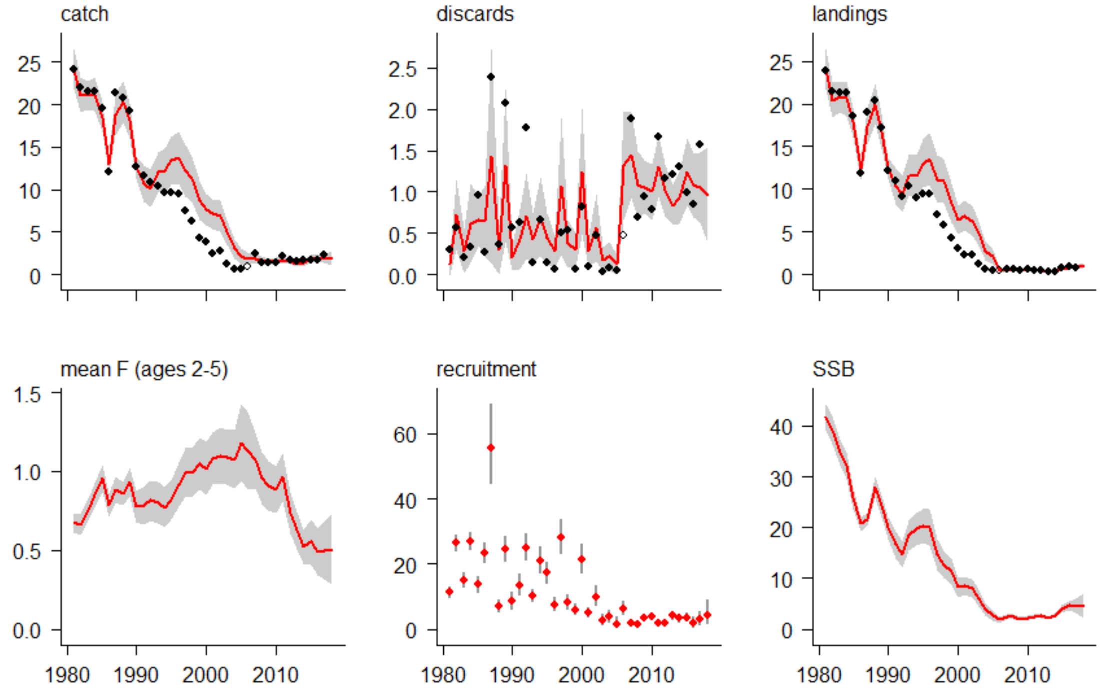


Figure 4. Cod.27.6a. Stock summary. Assessment A1: flexible fishery selectivity, re-evaluated age-specific CVs. Red lines (or points) give best estimates, grey bands (or lines) give approximate 95% confidence intervals , and black points give observed values. Note that final value in the mean F plot is a projection.

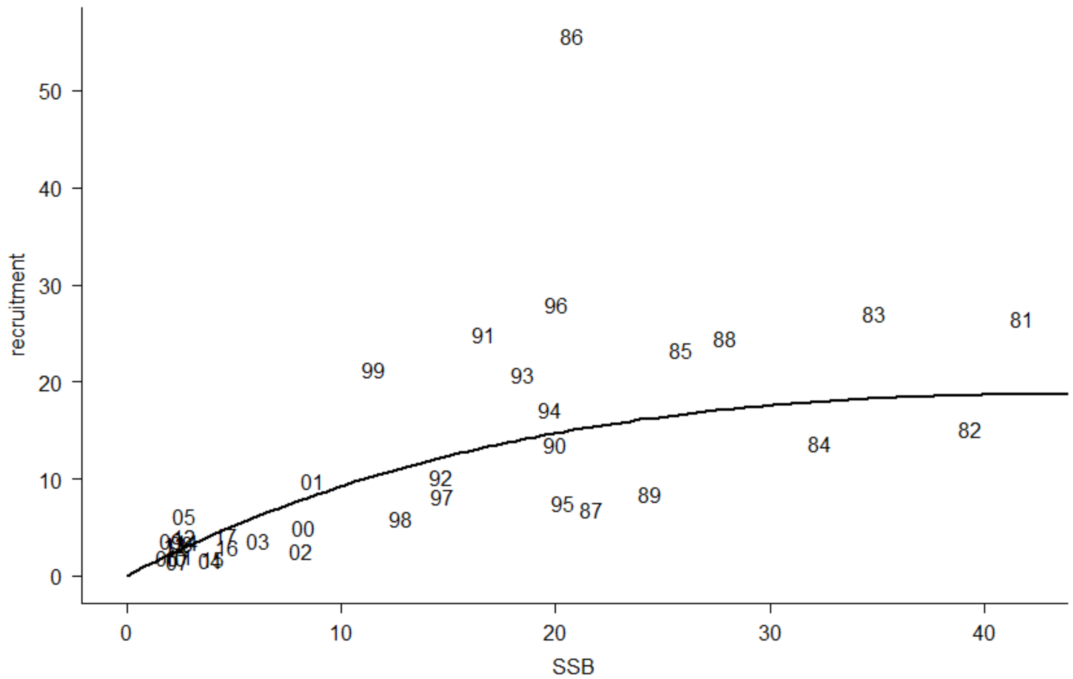


Figure 5. Cod.27.6a. Estimated stock recruit relationship (numbers indicate year class). Assessment A1: flexible fishery selectivity, re-evaluated age-specific CVs.

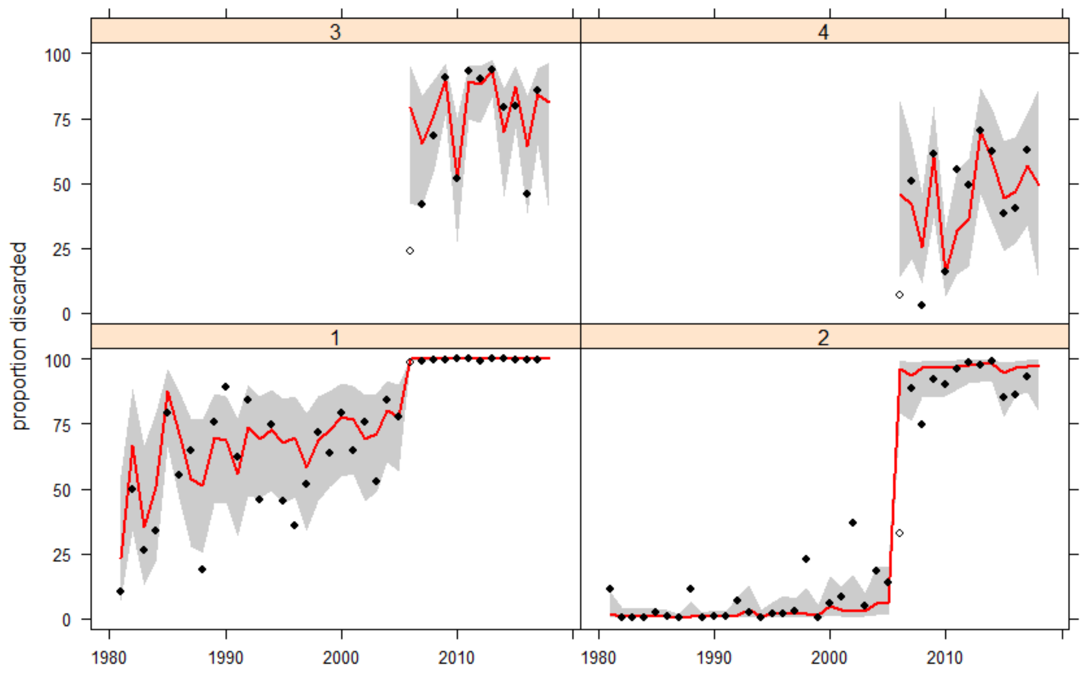


Figure 6. Cod.27.6a. Observed (points) and fitted (red lines with 95% CI indicated by grey bands) for the proportion discarded by age. Note that the plot also shows the TSA projection of discards for 2018. Assessment A1: flexible fishery selectivity, re-evaluated age-specific CVs.

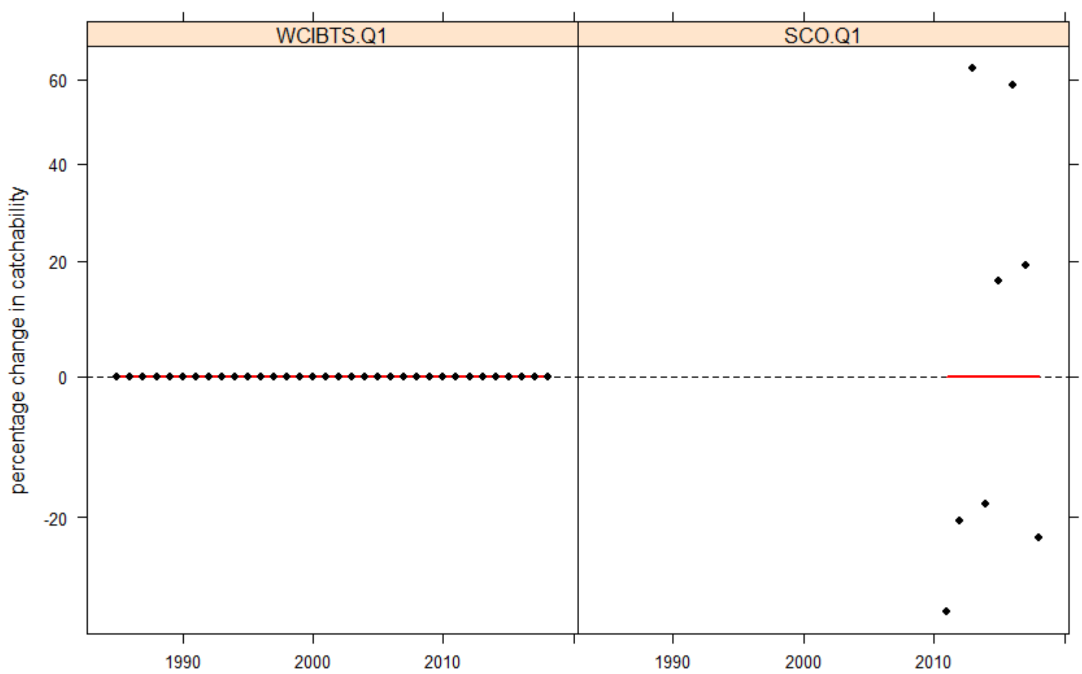
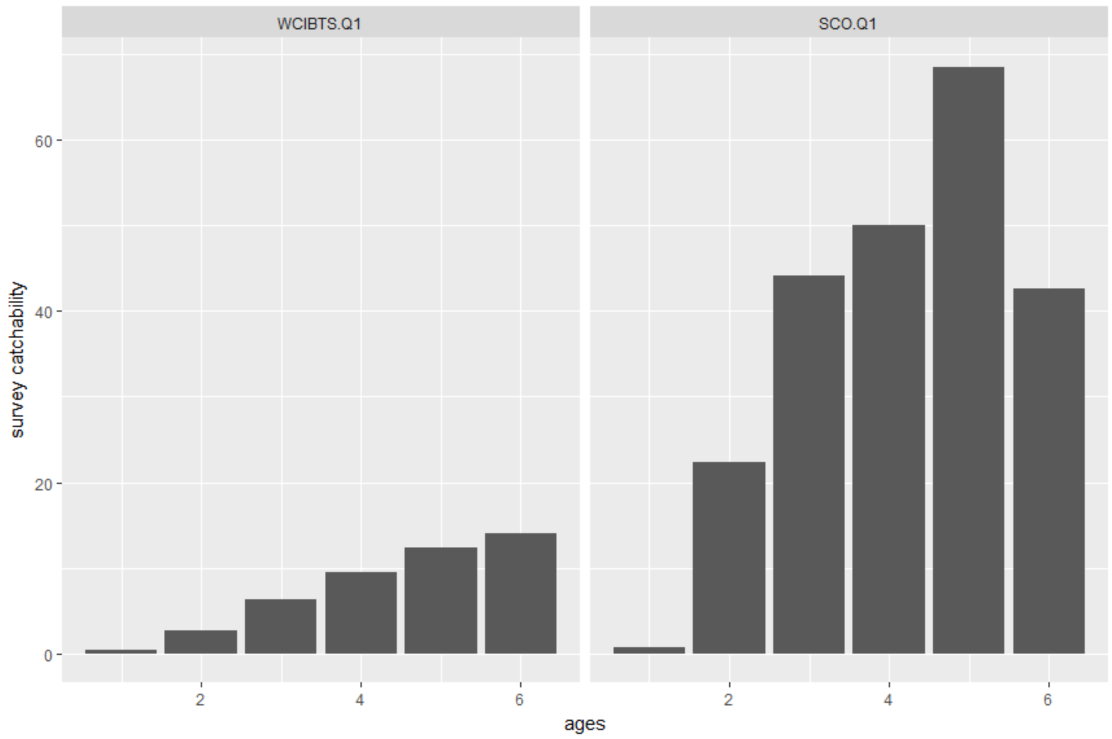


Figure 7. Cod.27.6a. Survey catchability. Assessment A1: flexible fishery selectivity, re-evaluated age-specific CVs.



Figure

Figure 8. Cod.27.6a. Survey catchability by age. Assessment A1: flexible fishery selectivity, re-evaluated age-specific CVs.

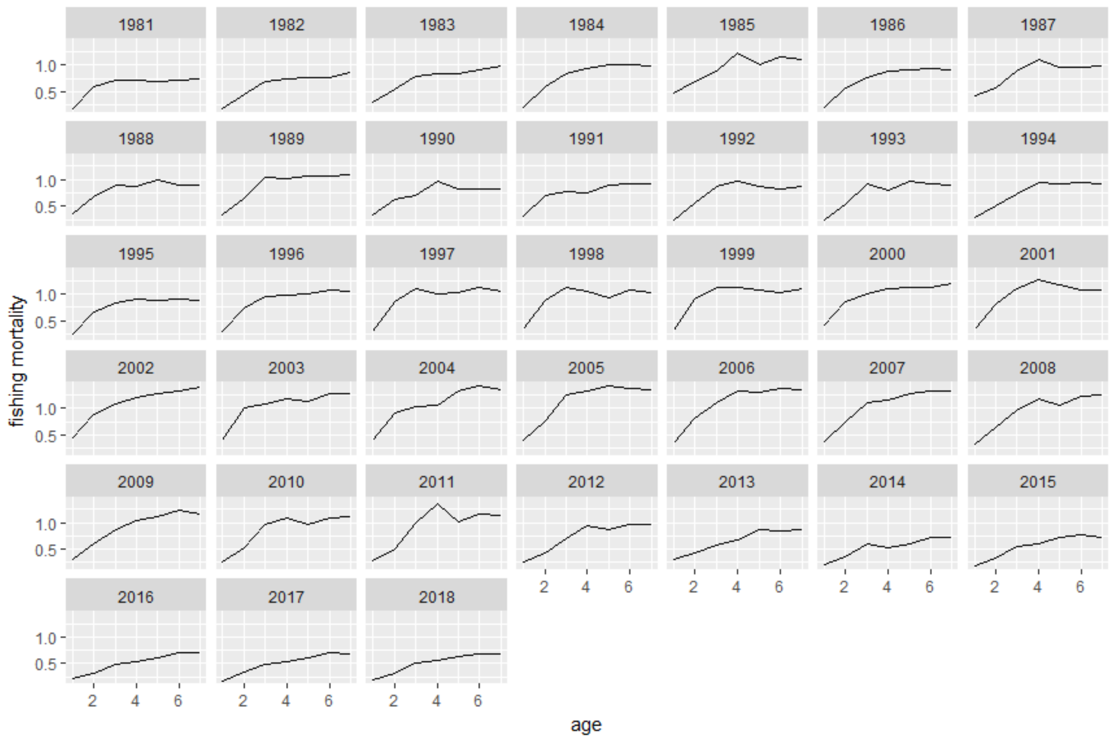
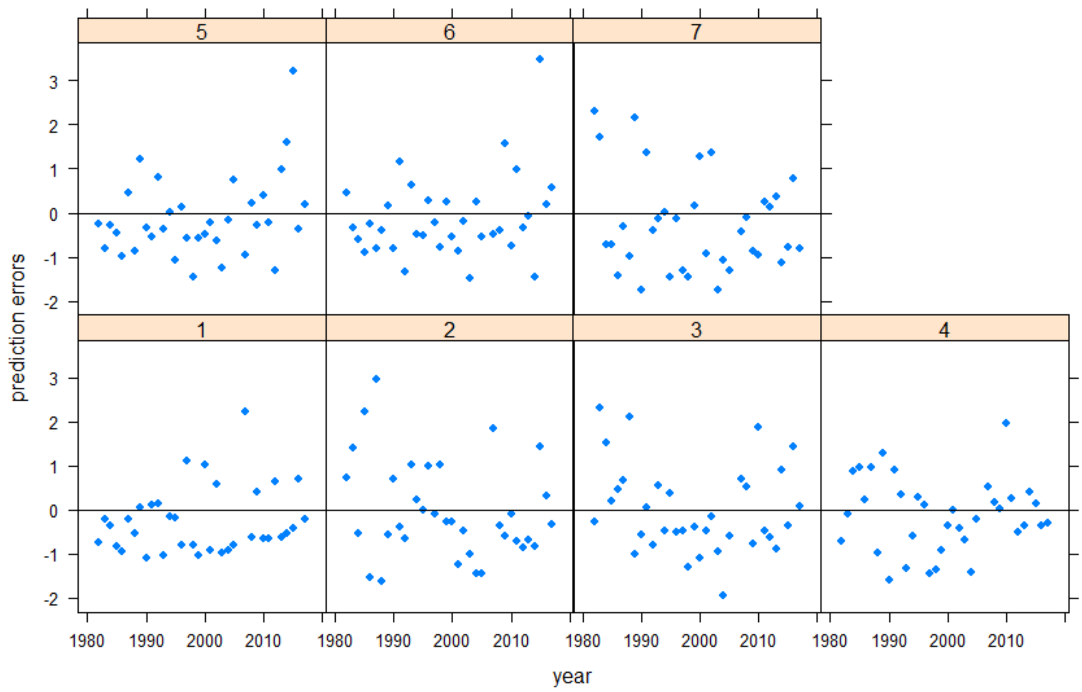


Figure 9. Cod.27.6a. Estimated fishing mortality by age and year. Assessment A1: flexible fishery selectivity, re-evaluated age-specific CVs.



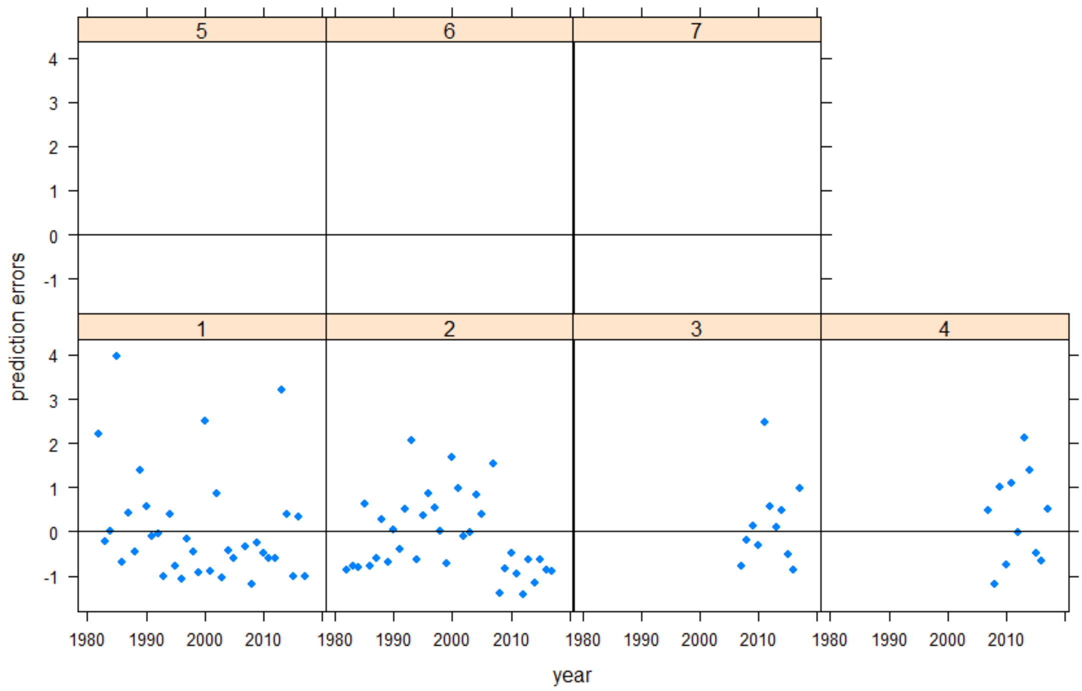


Figure 10. Cod.27.6a. Prediction errors by age class for landings (upper plot) and discards (lower plot). Assessment A1: flexible fishery selectivity, re-evaluated age-specific CVs.

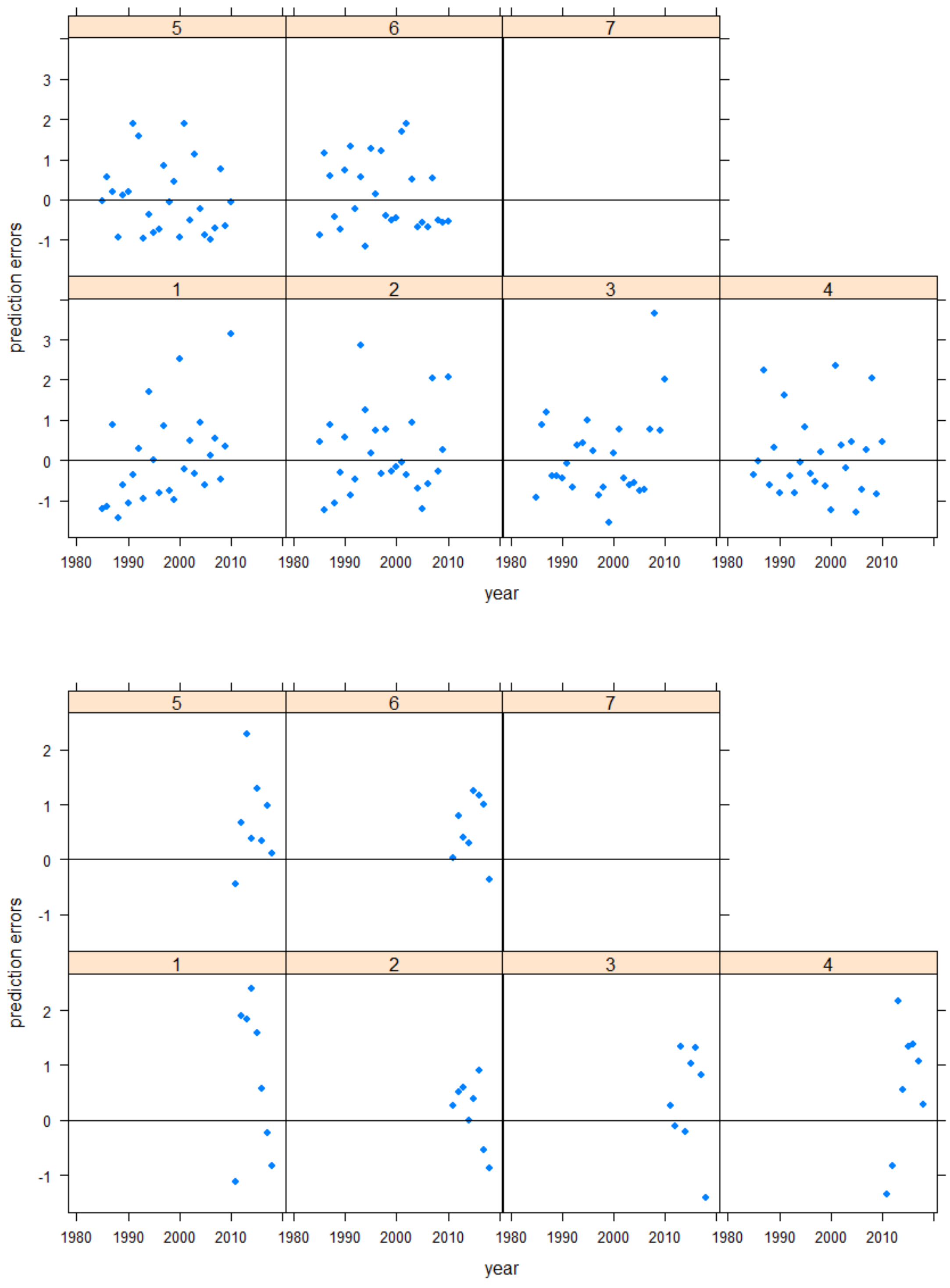
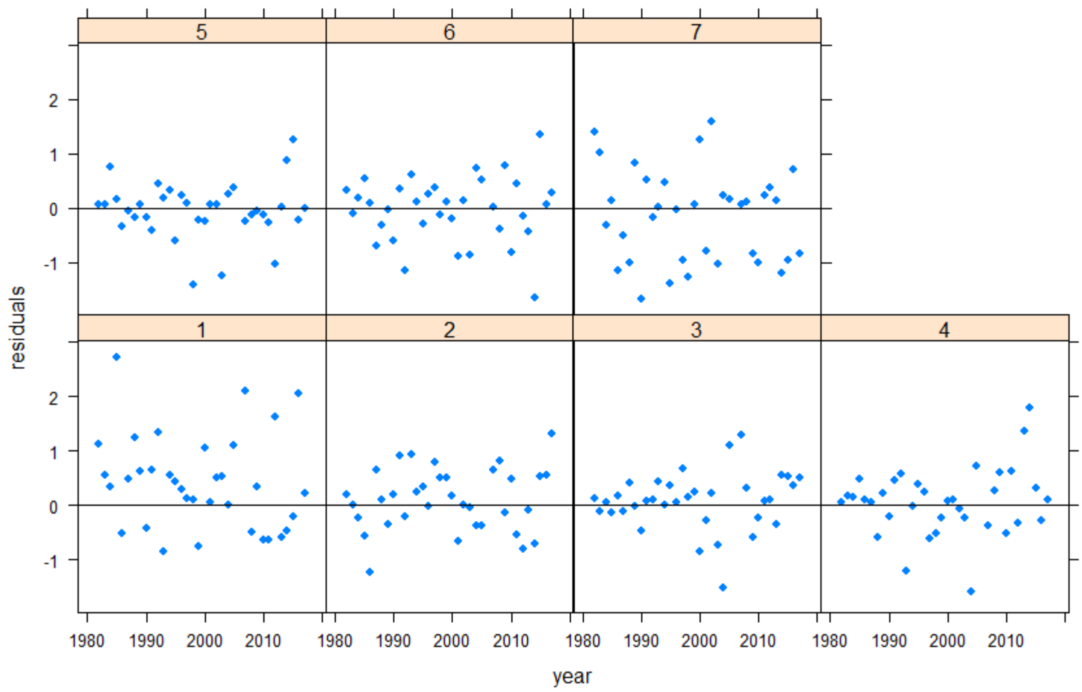


Figure 11. Cod.27.6a. Survey prediction errors by age class for WIBTS Q1 (upper plot) and SCO Q1 (lower plot). Assessment A1: flexible fishery selectivity, re-evaluated age-specific CVs.



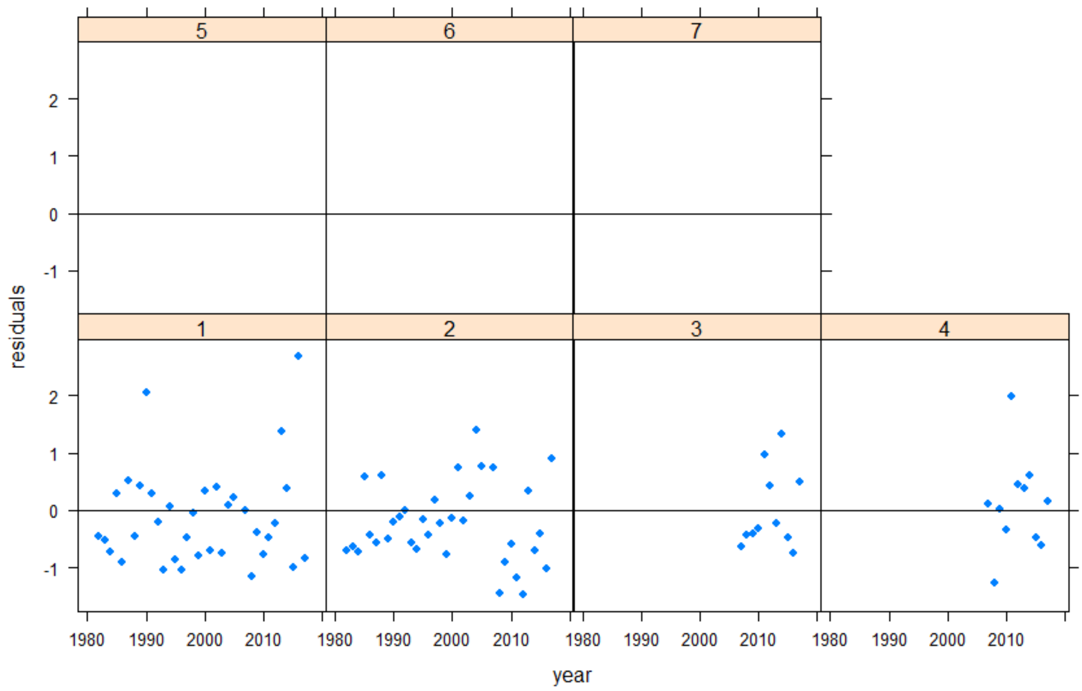
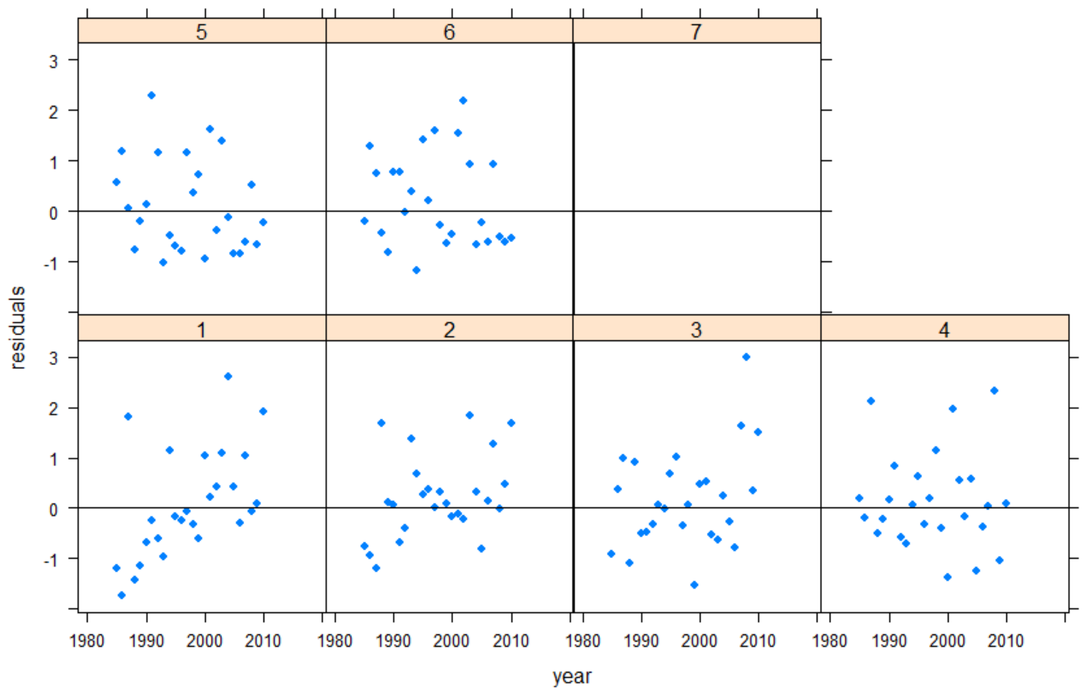


Figure 12. Cod.27.6a. Residual plots by age class for landings (upper plot) and discards (lower plot). Assessment A1: flexible fishery selectivity, re-evaluated age-specific CVs.



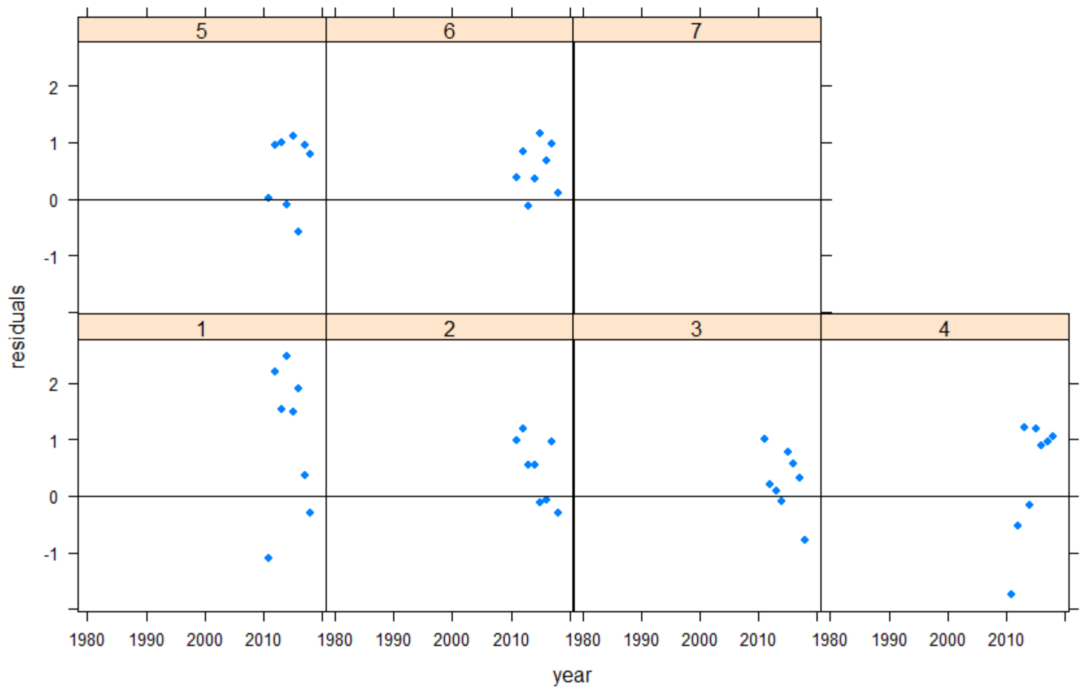


Figure 13. Cod.27.6a. Survey residual plots by age class for WIBTS Q1 (upper plot) and SCO Q1 (lower plot). Assessment A1: flexible fishery selectivity, re-evaluated age-specific CVs.

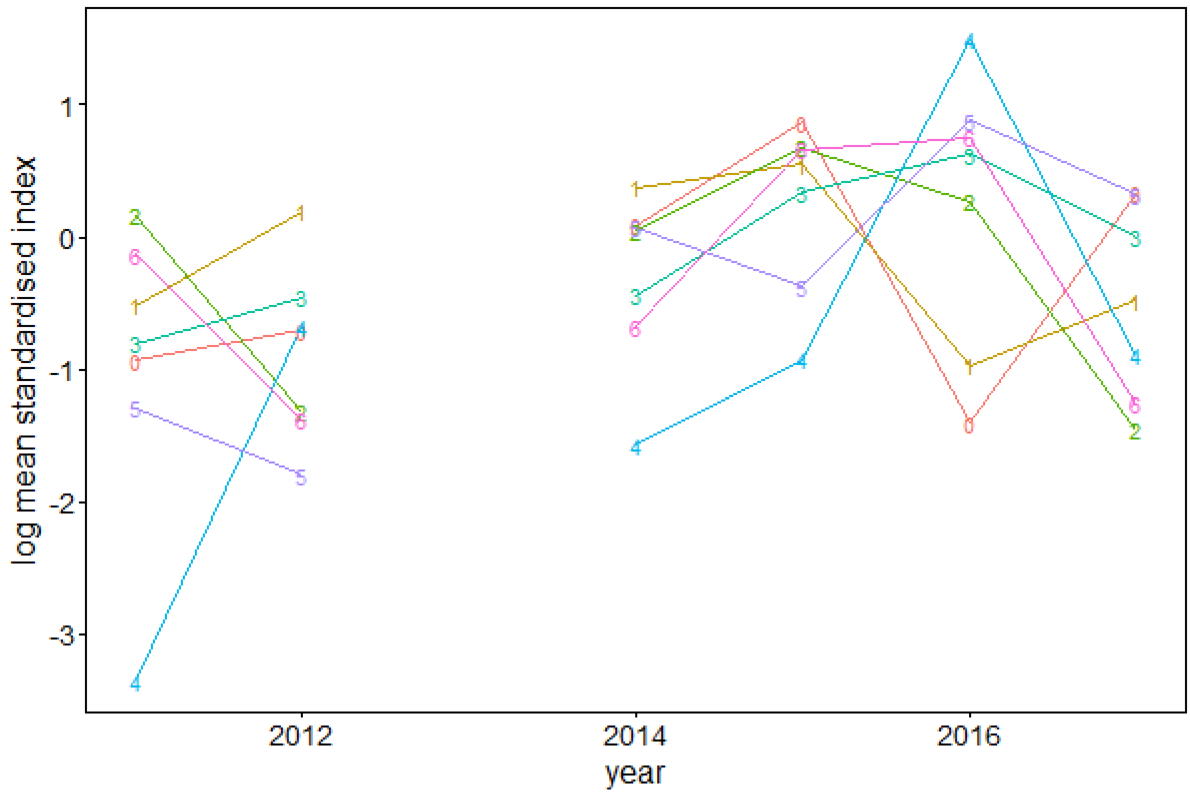


Figure 14. Cod.27.6a. Log mean standardised index values by year from SCO Q4.

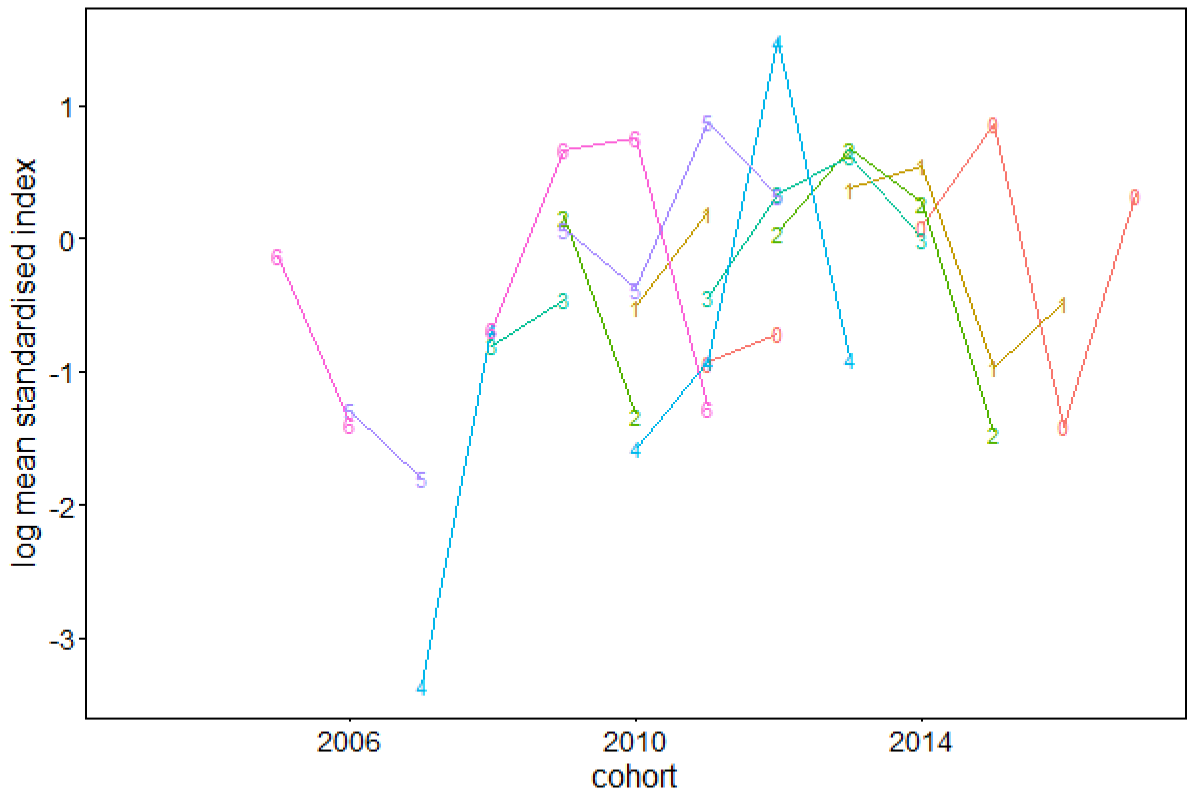


Figure 15. Cod.27.6a. Log mean standardised index values by cohort from SCO Q4.

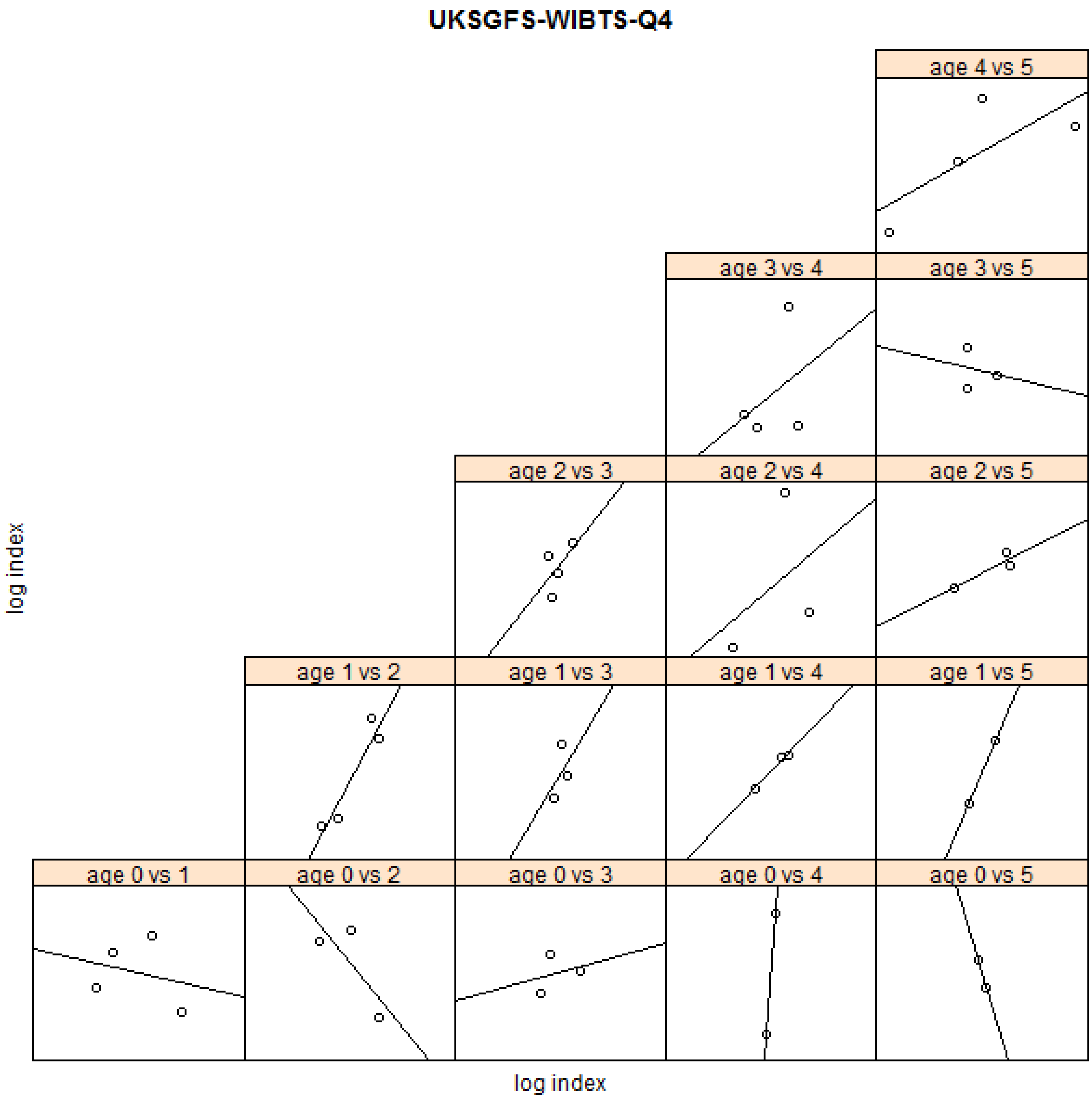


Figure 16. Cod.27.6a. Within survey correlations for SCO Q4 survey, comparing index values at different ages for the same cohorts. The solid line is a linear regression.

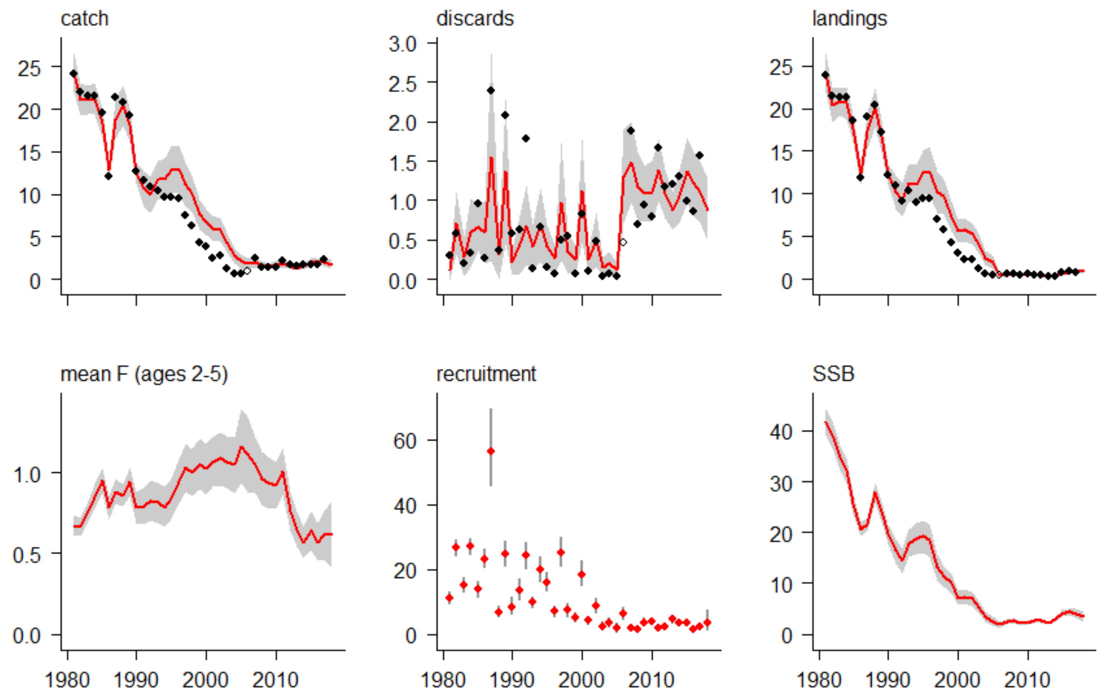


Figure 17. Cod.27.6a. Stock summary. Assessment A2: including two additional survey indices (WIBTS-Q4 and SCO Q4). Red lines (or points) give best estimates, grey bands (or lines) give approximate 95% confidence intervals , and black points give observed values. Note that final value in the mean F plot is a projection.

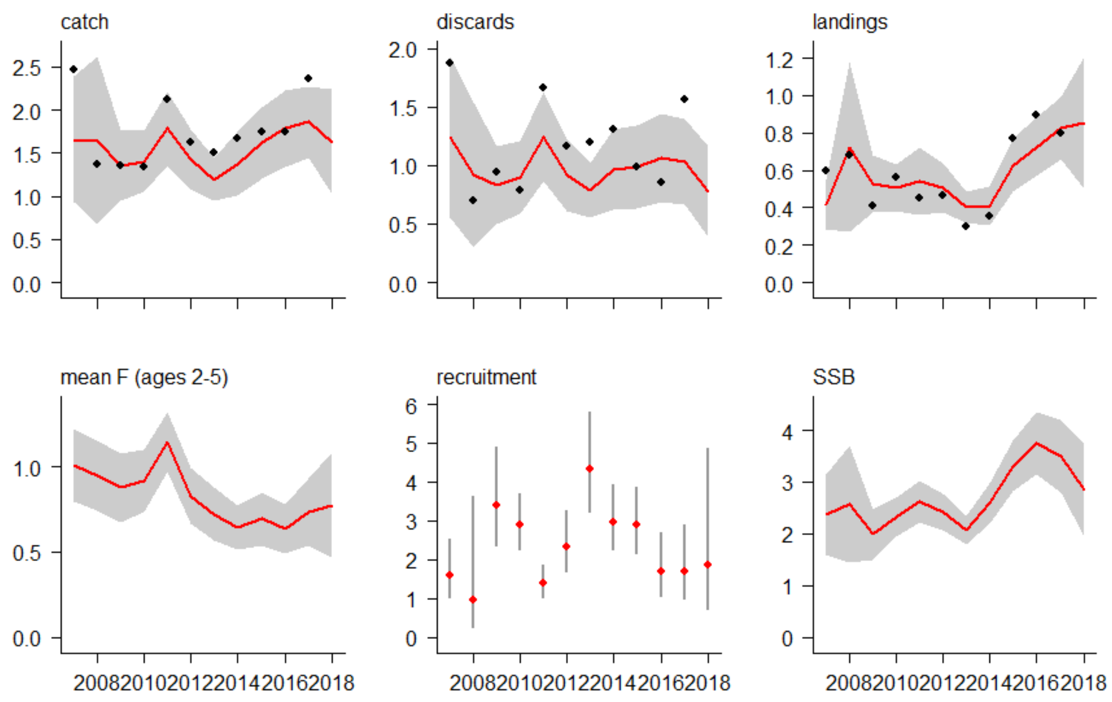


Figure 18. Cod.27.6a. Stock summary. Assessment A3: shortened input data series with commercial data from 2007 and SCO Q1 and Q4. Red lines (or points) give best estimates, grey bands (or lines) give approximate 95% confidence intervals , and black points give observed values. Note that final value in the mean F plot is a projection.

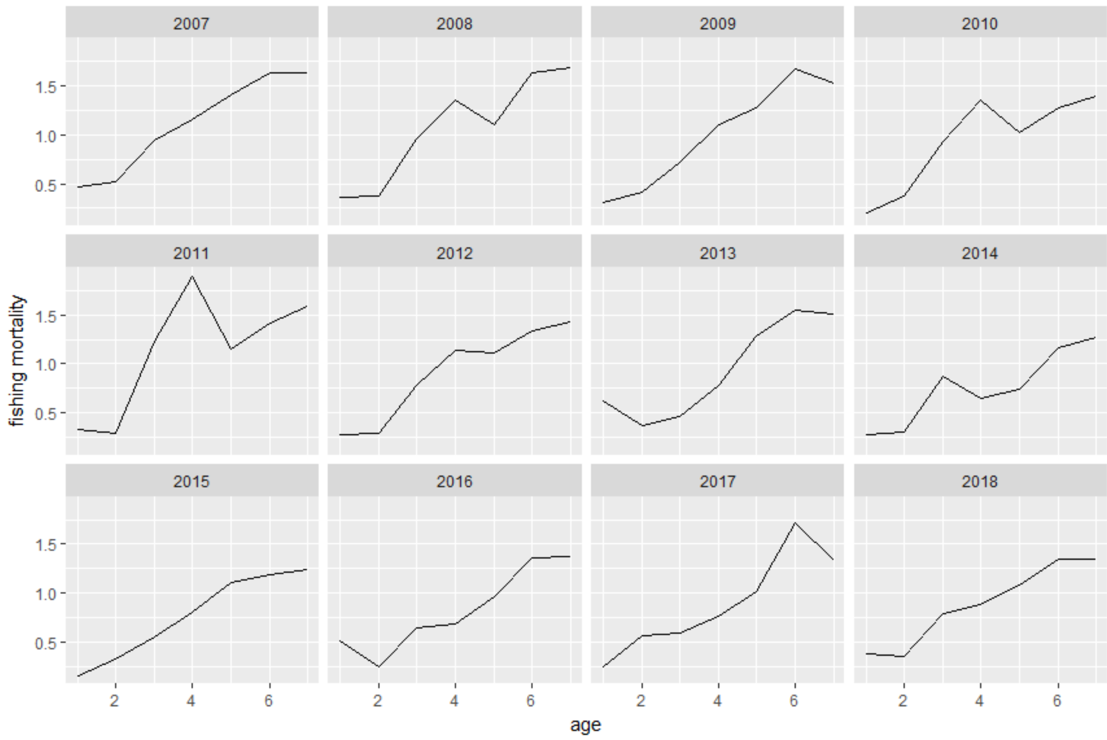


Figure 19. Cod.27.6a. Estimated fishing mortality by age and year. Assessment A3: shortened input data series with commercial data from 2007 and SCO Q1 and Q4.

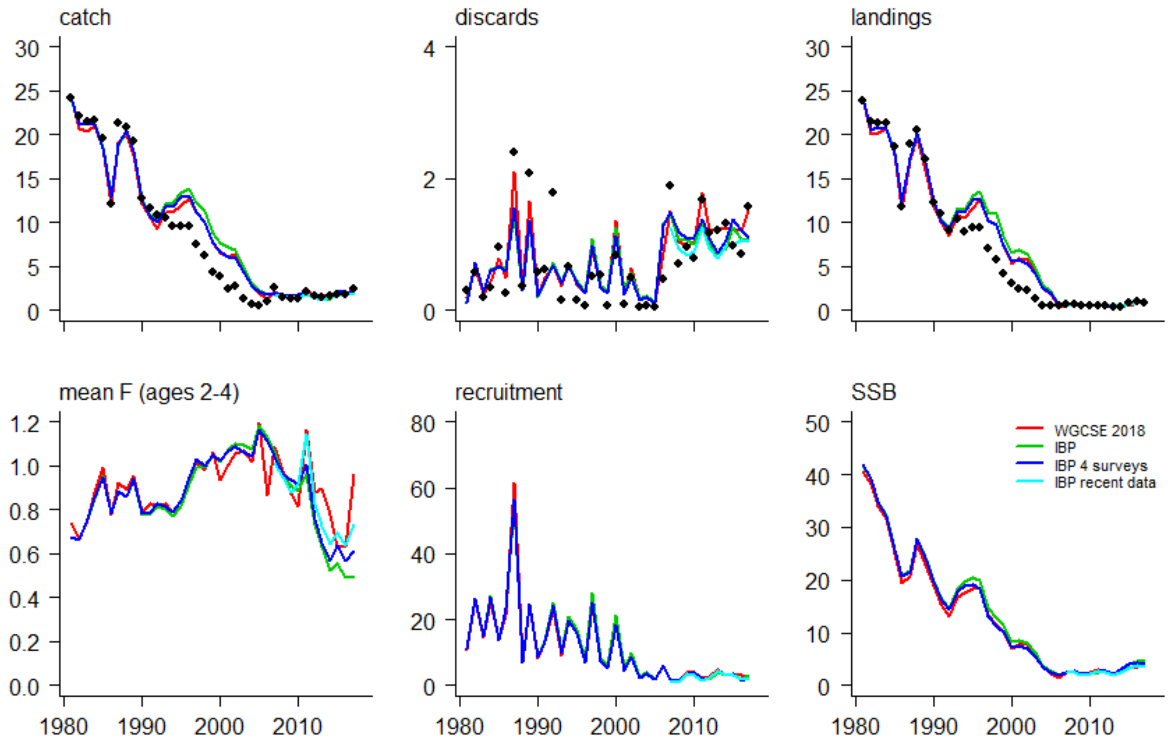


Figure 20. Comparison of stock summaries from models A1 (green), A2 (dark blue) and A3 (light blue) and the 2018 WG assessment (red).

WD 2: Dobby, H. Cod in 6.a: Reference points.

Cod in 6a: Reference Points (WD for IBP cod 6a)

Helen Dobby

Executive Summary

This is an extensive document which contains all the EqSim R code, figures and many of the tables for estimating PA and MSY reference points. The main assumptions and results are summarized here:

- Yield is catch minus an approximation of below MCRS discards.
- Fishery selectivity and mean weights are resampled from the last 10 years (default assumption).
- The breakpoint in the segmented regression fit has confidence intervals [13334,35094] and hence includes the current Blim (just). We therefore retain Blim = 14000 t.
- We also retain the current value of Bpa (=20000 t) which is 1.4 x Blim or Blim x exp(1.645sigma) where sigma=0.2 (rounded to the nearest 1000 t). The estimate of uncertainty from the assessment is less than this.
- Flim is calculated as the F that has 50% probability of SSB falling below Blim using a segmented regression SR relationship with the breakpoint fixed at Blim. Fpa is derived from Flim/1.4. (Uncertainty from the assessment is also lower for mean F). See table below for values.

PA reference point	Value	Basis
Blim	14000 t	Bloss from which the stock has increased (1992 SSB from 2015 assessment).
Bpa	20000 t	Blim x 1.4
Flim	0.77	F that has 50 % probability of SSB falling below Blim (Derived using EqSim analysis with the full time series of stock and recruit pairs and a segmented regression with breakpoint fixed at Blim).
Fpa	0.55	Flim/1.4

- All calculations include the full time series of stock and recruit pairs (with the exception of 2018 recruitment)
- Assessment/advice error are default values.
- The sensitivity of the Fmsy estimate to the use of different stock recruitment relationships has been explored. Unsurprisingly the Beverton Holt gives a much lower estimate than the other models due to R being an ever increasing function of SSB beyond the range of current values. See table below for values.

MSY Reference point	Ricker	Beverton Holt	Ricker/Beverton Holt	Segmented Regression	Ricker/Segmented Regression	All
Fmsy (no AR)	0.31	0.18	0.22	0.27	0.29	0.22
MSY Btrigger	20000	20000	20000	20000	20000	20000
Fmsy lower (no AR)	0.22	0.12	0.15	0.17	0.20	0.15
Fmsy upper (no AR)	0.40	0.26	0.31	0.44	0.41	0.32
Fp.05 (with AR)	0.63	0.62	0.63	0.67	0.64	0.63

Introduction

This is an R markdown document which uses the EqSim package to explore potential MSY reference points for West of Scotland cod based on the output of the TSA stock assessment agreed at the IBP cod 6a, including landings data up to 2017 and survey data to 2018.

Eqsim (stochastic equilibrium reference point software) provides MSY reference points based on the equilibrium distribution of stochastic projections. Productivity parameters (i.e. year vectors for natural mortality, weights-at-age, maturities, and selectivity) are resampled at random from the last few years of the assessment (although there may be no variability of these values). Recruitments are resampled from their predictive distribution which is based on parametric models fitted to the full time-series provided. The software also allows the incorporation of assessment/advice error. Random deviations from S-R are the same for each target F. Uncertainty in the stock-recruitment model is taken into account by applying model averaging using smooth AIC weights (Buckland et al. 1997) although often the SR is taken to be just a single one function (most commonly segmented regression). A Btrigger can optionally be specified - in such cases F is reduced when the stock biomass is below Btrigger (although results are still main F target i.e. the value of F intended to be applied when stock biomass is above Btrigger).

	value
Blim	1.4e+04
Bpa	2.0e+04
Btrigger	2.0e+04
Flim	8.2e-01
Fpa	5.9e-01
Fmsy	1.7e-01

Definition of yield

In deriving Fmsy, it is necessary to define the yield from the fishery (to be maximised). ICES defines yield to be catch above MCRS. The current Fmsy reference point for West of Scotland cod was calculated at WKMSYREF4 based on an assessment which included data up to 2014. Contrary to current approaches, the guidance at the time was to take yield as equivalent to landings in cases where the selection pattern corresponding to catch above MCRS is unknown. Hence the Fmsy was based on maximising landings only (although a sensitivity to other assumptions was presented). In contrast, more recent FMSY evaluations for other stocks where above MCRS discarding is known to occur, have approximated this selectivity using either e.g. historical discard proportions (before high grading became an issue) or by assuming yield is equivalent to all catch age 2+. In this case we choose the former, but consider the sensitivity to this assumption (see Sensitivity section).

Input data

The parameters describing the population biology and the fishery, such as weight-at-age, in stock and catch, maturity, natural mortality and fishery selection in EqSim are by default derived from the last ten years of data unless there are clearly documented persistent trends. Additionally there is a requirement to choose an appropriate stock recruitment relationship. These data are presented below.

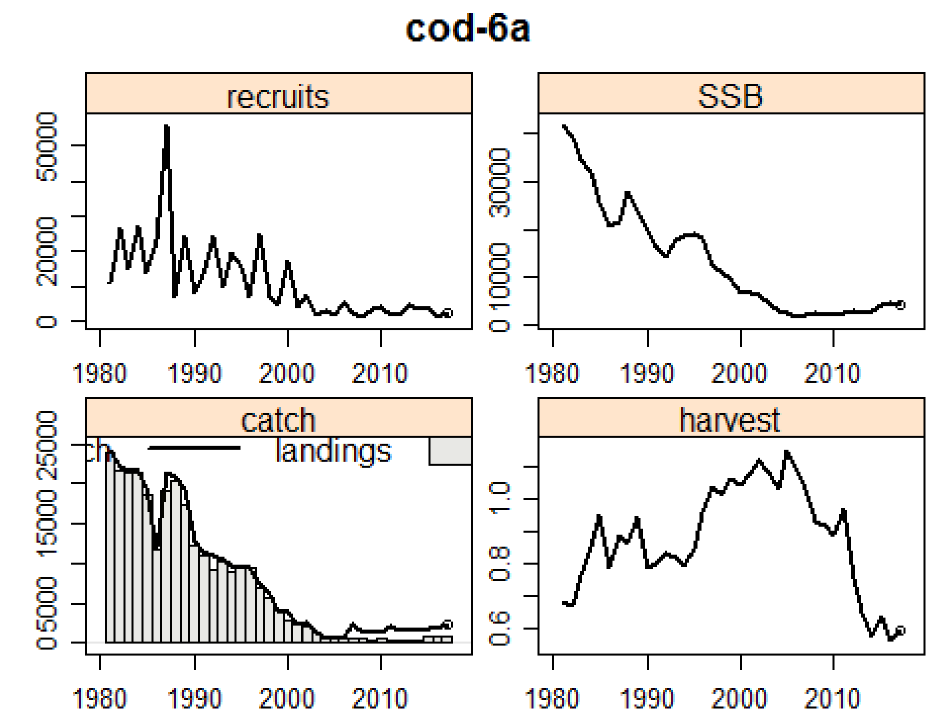


Figure 1: cod-6a. Stock assessment summary.

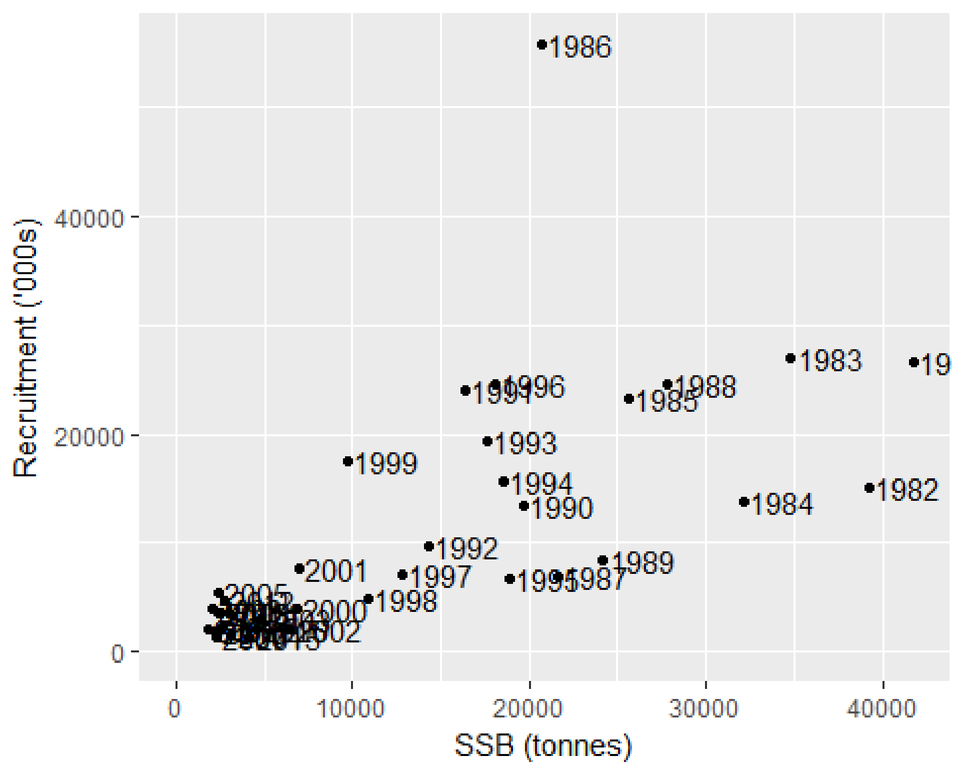


Figure 2: cod-6a. Stock-recruit relationship with points labelled by year class (or SSB year).

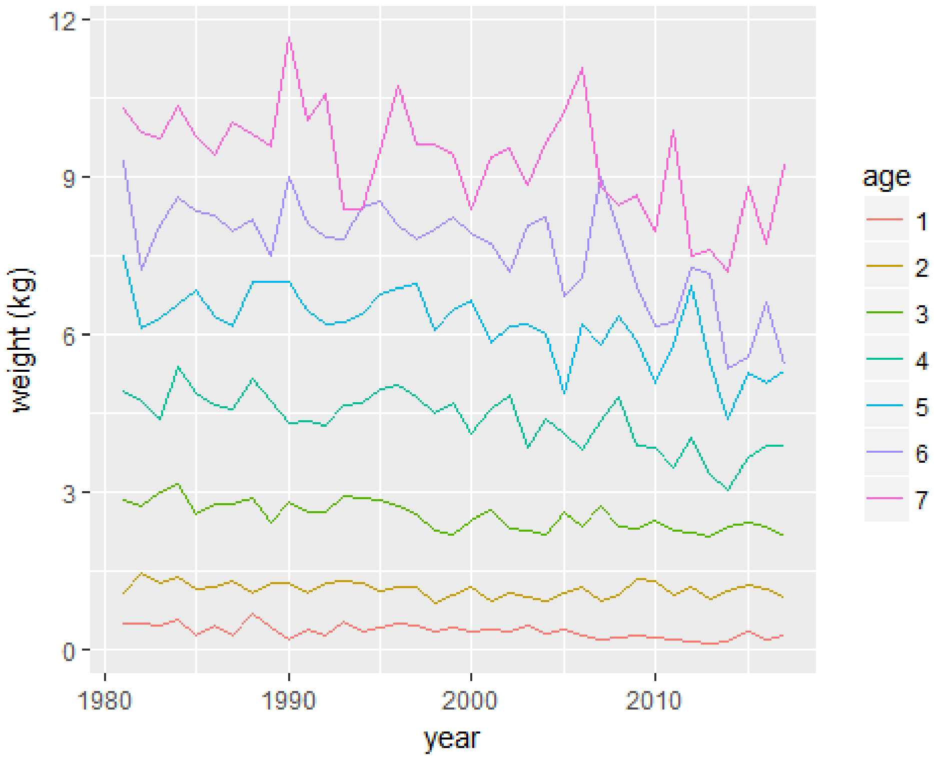


Figure 3: cod-6a. Mean weights at age in the stock/catch.

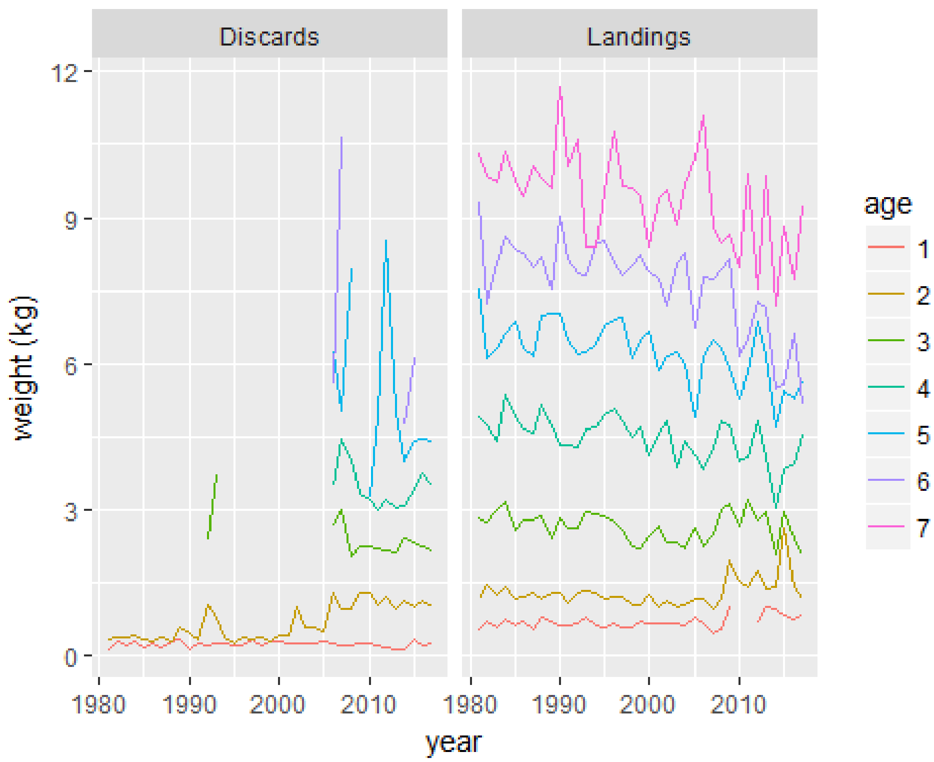


Figure 4: cod-6a. Mean weights at age in the discards and landings.

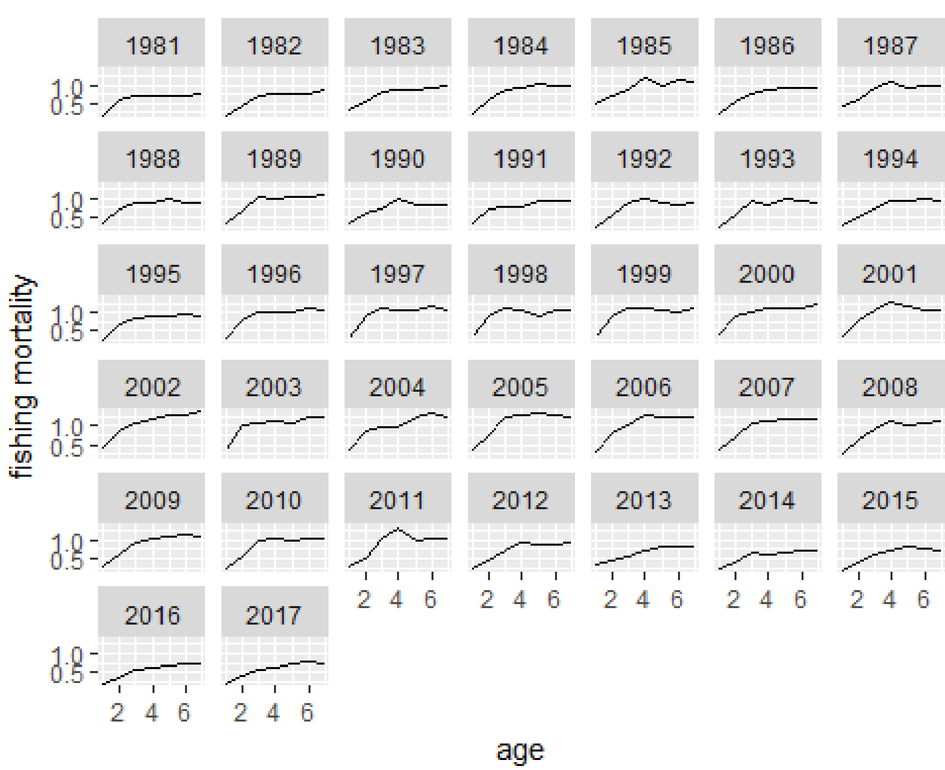


Figure 5: cod-6a. Changes in selection pattern over time.

There is a small amount of variability in the fishery selection pattern over time, but no systematic changes. Therefore the default 10 year window is used for resampling within EqSim.

In recent years, mean weights at age are very noisy (most likely due to low sampling levels). Since the start of the time series there has been a substantial decline in the mean weights in the stock/catch, particularly at older ages although they are more stable over the most recent 10 years. We therefore also use the default 10 year window for biological parameters, but with a check of the sensitivity of the results to this assumption (see Sensitivity section).

Also noticeable in the mean weights in the landings is an increase at age 2 and 3 in the late 2000s, potentially associated with the change in discarding practices around this time i.e. high grading at ages 2 and 3.

EqSim internally uses the landings and catch numbers at age provided in the FLStock object to calculate a discard ratio at age, which is then used to split the catch between landings and discards. Therefore to ensure that the appropriate (above MCRS) yield is maximised, a new stock object has to be derived. We use the average discard proportions between 1981 and 2000 (well before the change in discarding practicies occurred) as a proxy for below MCRS discarding and apply this discard propotion to total catches for the whole time series.

```
stk <-stk.out

disc.rate <-stk.out@discards.n/stk.out@catch.n
disc.rat <-as.numeric(yearMeans(window(disc.rate,start=1981,end=2000)))

stk@discards.n <-stk.out@catch.n*disc.rat
stk@landings.n <-stk.out@catch.n*(1-disc.rat)
print(round(disc.rat,2))

## [1] 0.56 0.04 0.00 0.00 0.00 0.00 0.00
```

Using the historical discard proportions results in just over 50 % of age 1 cod being discarded, and negligible discard rates at ages 2 and above. Given these discard proportions are assumed to apply in the calculations of Fmsy, we use mean weights in the catches instead of mean weights in the landings (for ages 2+) when maximising yield above MCRS.

```
stk@landings.wt[2:7,,,,,] <-stk@catch.wt[2:7,,,,,]
```

Deriving PA reference points

Options for Blim

The first step is to define Blim, the biomass limit below which a stock is considered to have reduced reproductive capacity.

The current Blim is tonnes and was defined on the basis of the Bloss from which the stock has increased (SSB in 1992 as estimated in the 2015 assessment). The currently preferred basis (ICES, 2017a) for defining Blim is the biomass below which recruitment reduces with SSB e.g. the change point in segmented regression. According to the ICES guidelines, when estimating Blim, the full time series of stock and recruitment pairs should be used unless there is very strong evidence to do otherwise, although any points which are considered poorly estimated should be excluded. (In this case we exclude the 2018 recruitment estimate).

Using the full time series, the stock would be characterised as Type 2: a stock with a wide dynamic range of SSB, and evidence that recruitment is or has been impaired. In such cases the ICES guidance suggests Blim is set at the segmented regression change point.

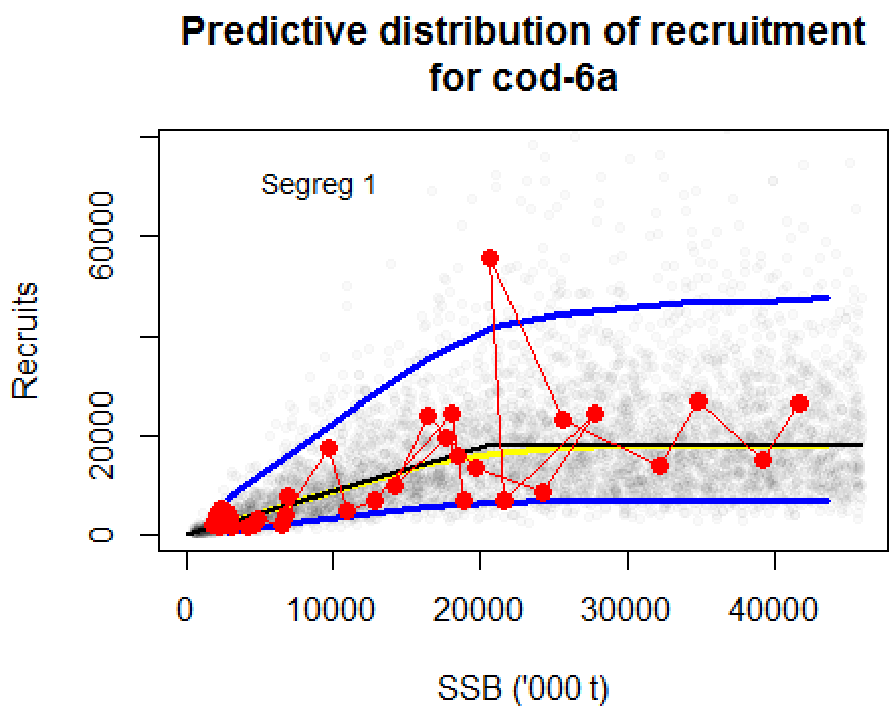


Figure 6: cod-6a. Stock recruitment relationship - fitted segmented regression.

The estimated breakpoint has very wide confidence intervals (shown below) and the range includes the current estimate of Blim. Given this, and the uncertainty associated with this assessment in general, there is considered to be limited basis for revising the current value of Blim. (Additionally, a benchmark in the near future ought to provide a sounder basis for updating biomass reference points).

```
round(quantile(fit$sr.sto$b.b,c(0.025,0.5,0.975)))

##  2.5%   50% 97.5%
## 13334 20667 35094
```

Bpa is also retained at its current value of 14000. This is equal to 1.4 x Blim (rounded to the nearest 1000 t) or Blim x exp(1.645sigma) where sigma = 0.2. Note that assessment uncertainty in SSB in the final year as estimated by the TSA assessment is 0.14 (estimated standard deviation of ln(SSB)). ICES guidance suggests that if sigma is unknown or the estimated value is less than 0.2 and is considered to be unrealistically low, the default value can be used.

```
print(blim)

## [1] 14000

print(bpa)

## [1] 20000
```

Deriving Flim and Fpa

Flim estimation was performed using Eqsim to derive the F that has 50 % probability of SSB falling below Blim using a segmented regression stock recruitment relationship with the breakpoint fixed at Blim.

Other cod stocks (North Sea and Irish Sea) make use of a truncated time series of stock and recruit pairs in the derivation of reference points based on possible changes in reproductive potential, possibly related to environmental factors. For West of Scotland cod, although recruitment has been very low since 2003, SSB has also been very low and there is no suggestion from the plot of recruitment per SSB (below) that there has been a systematic reduction in stock productivity. Therefore for the baseline model run we use the full time series of stock and recruitment data.

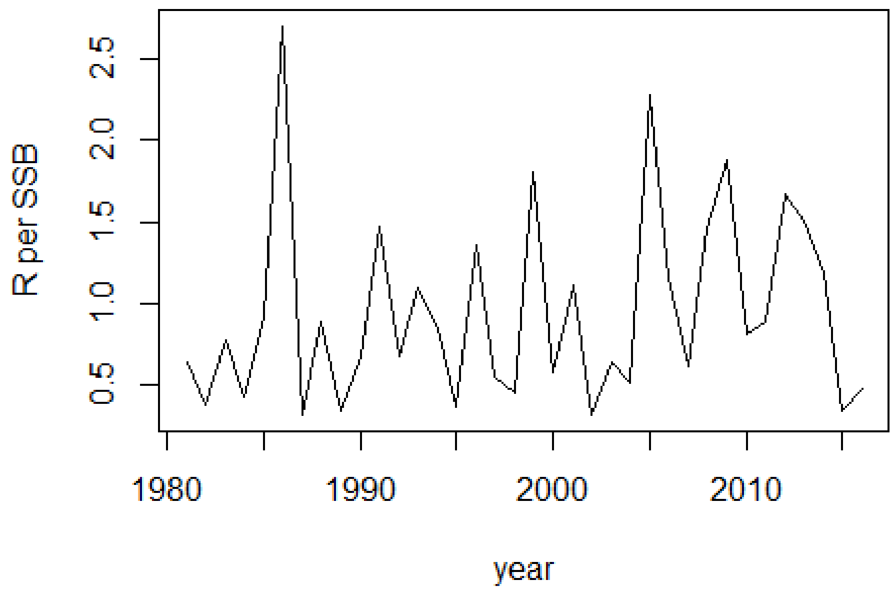


Figure 7: cod-6a. Recruitment per SSB over time.

```
B <-blim
SegregFixed <- function (ab, ssb) {
  log(ifelse (ssb>=B, ab$a*B, ab$a*ssb))
}

cod.indat <-list(data=stk,
                 bio.yrs=c(2008,2017),
                 sel.yrs=c(2008,2017),
                 Fscan=seq(0,1.0,by=0.05),
                 Fcv=0,
                 Fphi=0,
                 Blim=blim,
                 Bpa=bpa,
                 Btrigger = 0,
                 extreme.trim=c(0.05,0.95)
                 )

cod.res <-within(cod.indat,
{
  fit <-eqsr_fit(data,nsamp=1000,models= "SegregFixed")
  sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
                  Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
                  Blim=Blim, Bpa=Bpa, Btrigger=Btrigger)
})
save(cod.res,file=file.path(paste("eqsim.flim.all.rec.rdata",sep="")))
```

	catF	lanF	catch	landings	catB	lanB
F05	0.567	NA	10993	NA	23291	NA
F10	0.613	NA	10660	NA	21184	NA
F50	0.769	NA	8416	NA	13863	NA
medianMSY	NA	0.274	NA	12409	NA	48526
meanMSY	0.300	0.300	12354	12389	44791	44791
Medlower	NA	0.171	NA	11773	NA	70294
Meanlower	NA	0.176	NA	12286	NA	NA
Medupper	NA	0.451	NA	11772	NA	29938
Meanupper	NA	0.465	NA	12279	NA	NA

Table 1: cod-6a. Summary of eqsim run without assessment/advice error, to determine Flim using segmented regression with Blim as breakpoint and full recruitment time series.

Flim	Fpa
0.769	0.549

Table 2: cod-6a. Summary of F reference points.

Calculating Fmsy

Fmsy is initially calculated by running EqSim with assessment/advice error, but without application of the ICES advice rule (MSY Btrigger). To include assessment and advice error, the values Fcv=0.212 and Fphi=0.423 which are the default values suggested by WKMSYREF4(ICES, 2016) were used.

The ICES guidance notes that while the segmented regression stock-recruitment may be required to provide the best estimate of a change point for Blim, other stock-recruitment functions may better characterise the whole stock dynamics and hence should be used in the calculation of Fmsy. Figure 8 shows the model averaged fit of the Beverton Holt, Ricker and segmented regression relationships to the full time series of stock recruit data. The Beverton Holt takes greatest weight, although looks almost identical to the Ricker (which takes very little weight). The Beverton Holt and Ricker appear to have plateau and peak well outside the observed range of stock recruit pairs (i.e. continuous increasing curves).

Initially, we calculate the Fmsy reference points using the Ricker model (which would be consistent with the stock assessment model assumptions) and then consider the sensitivity to other stock recruitment relationship assumptions (individually and combinations of multiple relationships).

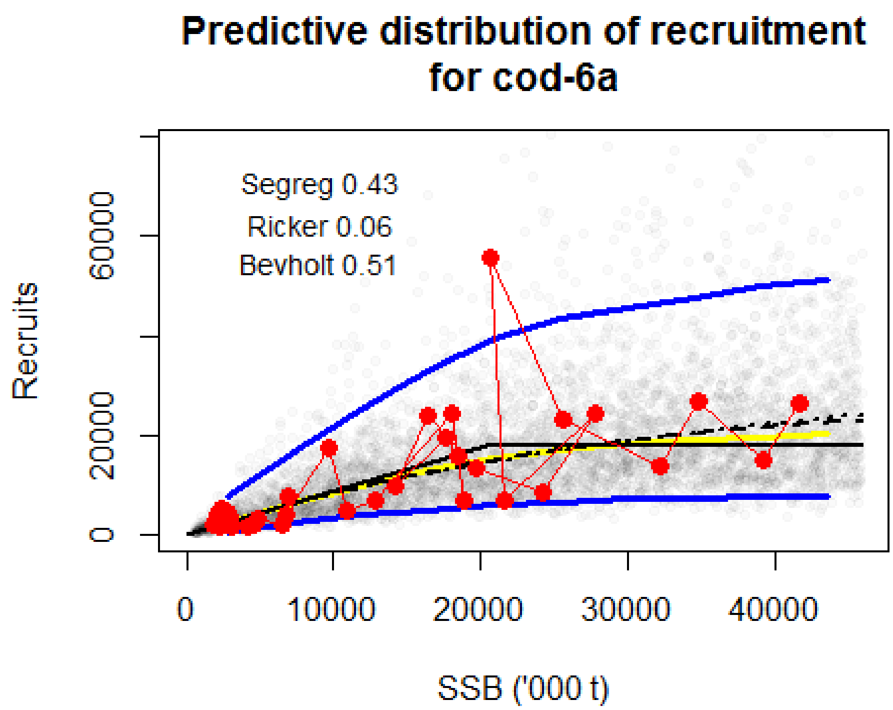


Figure 8: cod-6a. Stock recruitment relationship - model averaged.

Ricker & no advice rule (AR)

The first run includes assessment and advice error, but not Btrigger.

```
cod.indat <-list(data=stk,
                 bio.yrs=c(2008,2017),
                 sel.yrs=c(2008,2017),
                 Fscan=seq(0,1.0,by=0.05),
                 Fcv=0.212,
                 Fphi=0.423,
                 Blim=blim,
                 Bpa=bpa,
                 Btrigger = 0,
                 extreme.trim=c(0.05,0.95)
                 )

cod.res <-within(cod.indat,
{
  fit <-eqsr_fit(data,nsamp=1000,models= "Ricker")
  sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
                  Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
                  Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
                  extreme.trim=extreme.trim,
                  verbose=FALSE)
```

```
})
save(cod.res,file=file.path(paste("eqsim.fmsy.no.ar.ricker.rdata",sep="")))
```

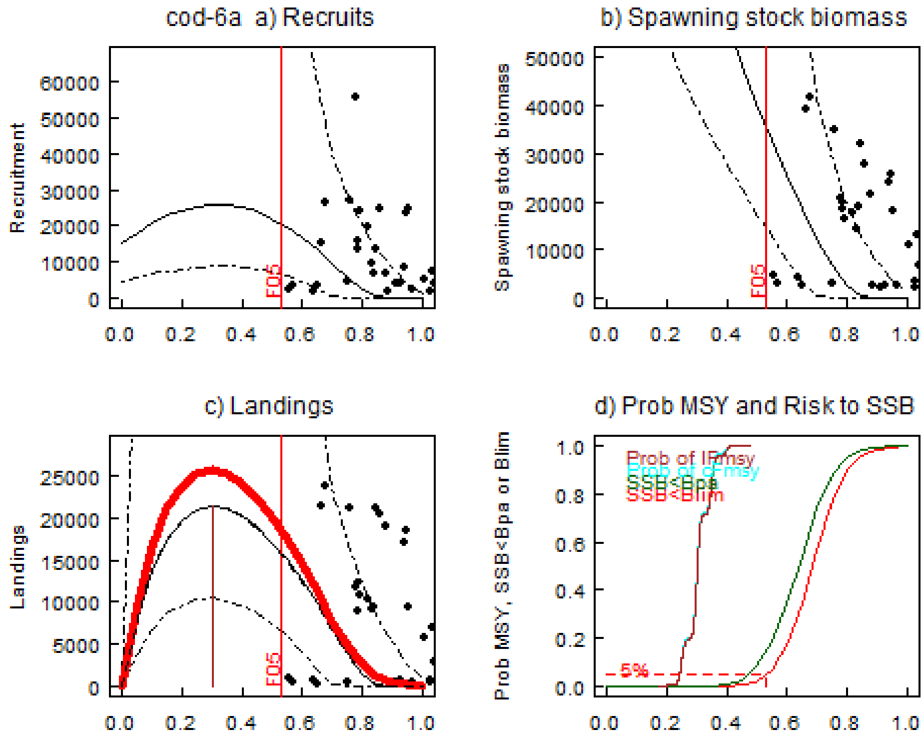


Figure 9: cod-6a. Eqsim summary plot. Panels a-c: historic values(dots), median (solid black) and 90% intervals (dotted) for recruitment, SSB and yield for exploitation at fixed values of F. Panel c also shows mean yield (red). Panel d shows the probablility of SSB less than Blim (red), less than Bpa(green) and the cumulative distribution of Fmsy based on > MCRS yield (brown) and catch (cyan).

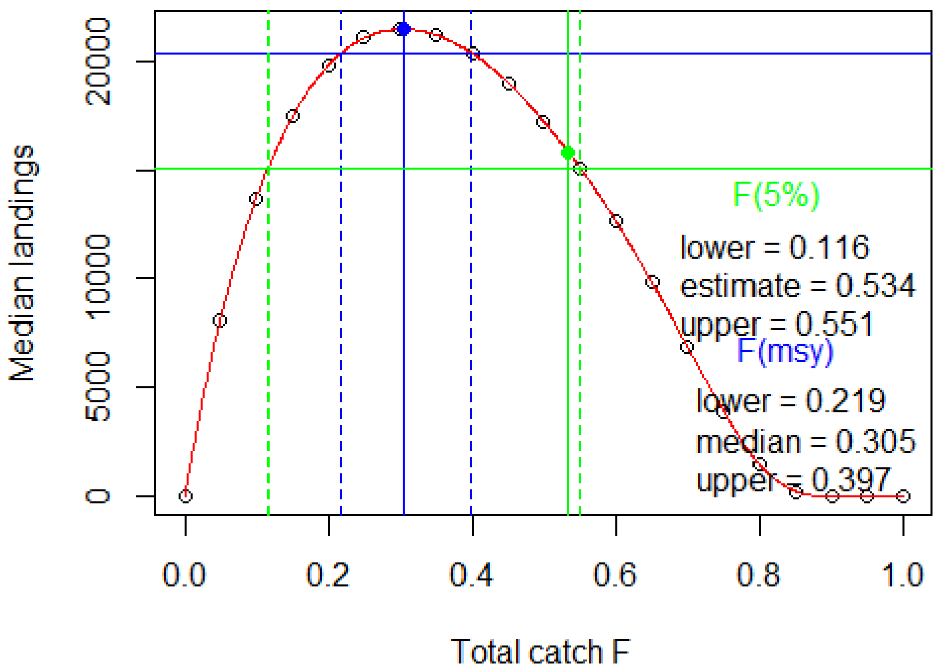


Figure 10: cod-6a. Yield (>MCRS) with median Fmsy (and 5th and 95th percentiles), blue vertical lines..

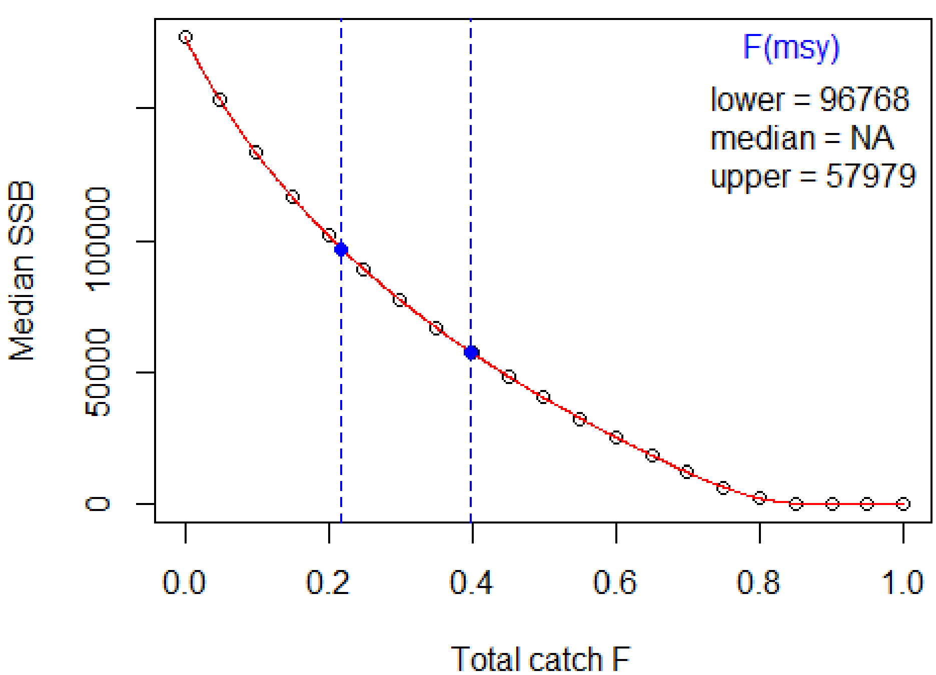


Figure 11: cod-6a. Median SSB curve over a range of target F values. Blue line corresponds to Fmsy range (Note that the 'NA' at median Fmsy is a persistent feature of EqSim).

The median Fmsy estimated by Eqsim applying a fixed F harvest strategy was 0.31. The upper bound of the Fmsy range giving at least 95 % of the maximum yield was 0.4 and the lower bound 0.22. Note that the associated SSB is well above the historically observed values (Figure 1).

Ricker with advice rule

The next step is to set MSY Btrigger. According to ICES guidelines MSY Btrigger is set equal to Bpa unless the stock has been fished below Fmsy for the last 5 years. The ICES MSY advice rule is then evaluated to check that the Fmsy and MSY Btrigger combination fulfils the precautionary criterion of having a less than 5 % annual probability of SSB < Blim in the long term. (The evaluation includes assessment/advice error).

```
cod.indat <-list(data=stk,
                 bio.yrs=c(2008,2017),
                 sel.yrs=c(2008,2017),
                 Fscan=seq(0,1.0,by=0.05),
                 Fcv=0.212,
                 Fphi=0.423,
                 Blim=blim,
                 Bpa=bpa,
                 Btrigger = bpa,
                 extreme.trim=c(0.05,0.95)
)

cod.res <-within(cod.indat,
                 {
                   fit <-eqsr_fit(data,nsamp=1000,models= "Ricker")
                   sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
                                   Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
                                   Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
                                   extreme.trim=extreme.trim,
                                   verbose=FALSE)
                 })
save(cod.res,file=file.path(paste("eqsim.fmsy.with.ar.ricker.rdata",sep="")))
```

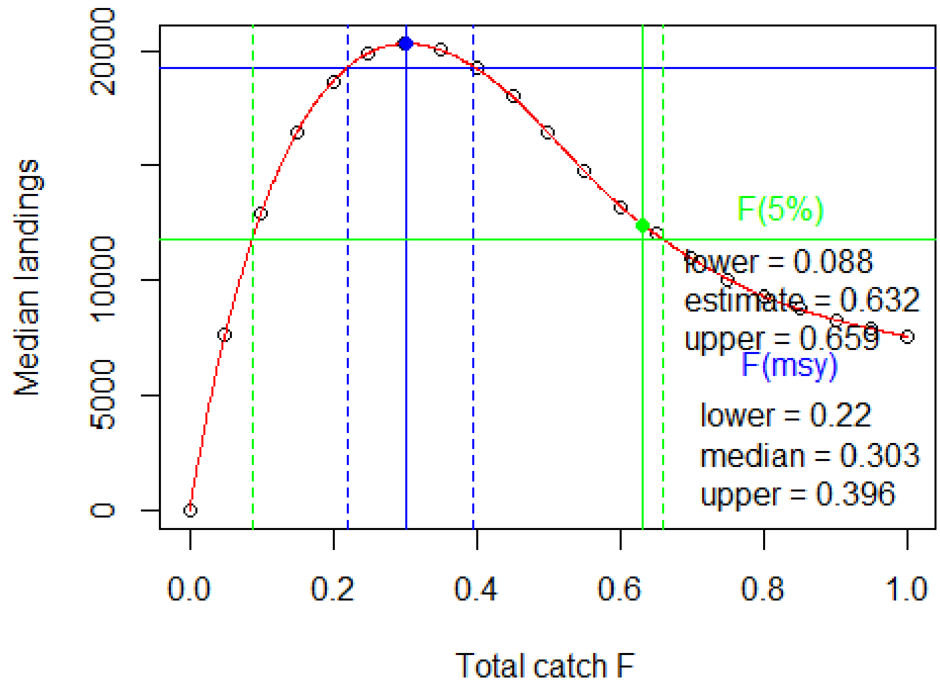


Figure 12: cod-6a. Yield (>MCRS) with median Fmsy (and 5th and 95th percentiles), blue vertical lines..

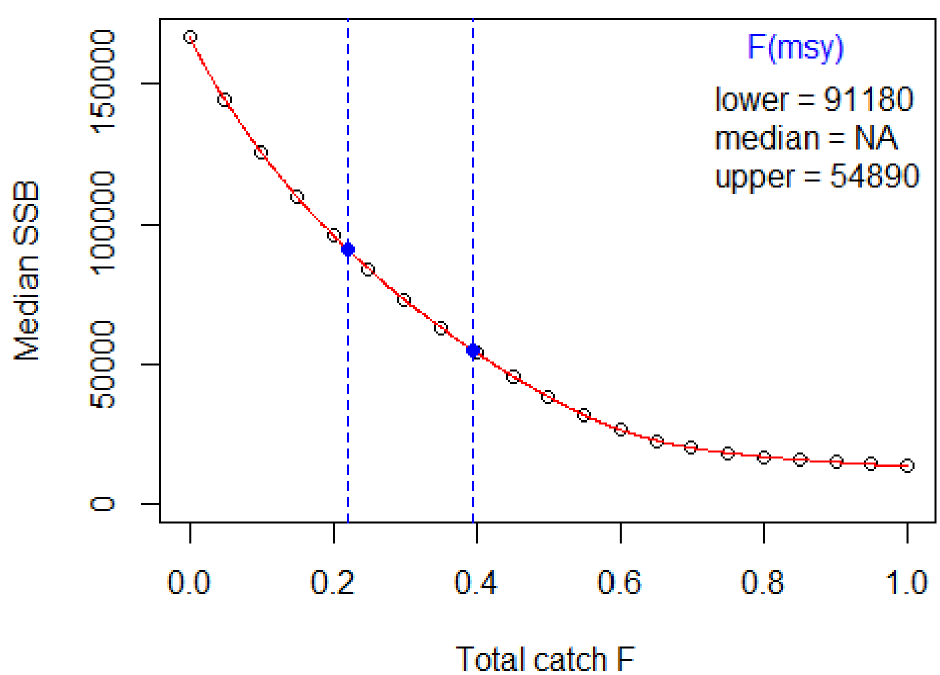


Figure 13: cod-6a. Median SSB curve over a range of target F values. Blue line corresponds to Fmsy range (Note that the 'NA' at median Fmsy is a persistent feature of EqSim).

	catF	lanF	catch	landings	catB	lanB
F05	0.632	NA	12366	NA	24299	NA
F10	0.691	NA	11076	NA	20751	NA
F50	0.976	NA	7668	NA	13996	NA
medianMSY	NA	0.303	NA	20301	NA	72475
meanMSY	0.300	0.300	20228	20299	73160	73160
Medlower	NA	0.220	NA	19285	NA	91180
Meanlower	NA	0.215	NA	22598	NA	NA
Medupper	NA	0.396	NA	19302	NA	54890
Meanupper	NA	0.389	NA	22604	NA	NA

Table 3: cod-6a. Summary of eqsim run including assessment/advice error and the ICES MSY advice rule.

The Fp.05 (the F at which there is a 5 % probability of falling below Blim) is calculated as 0.632 which greater than the Fmsy (and Fmsy upper) without the advice rule and therefore the Fmsy reference points are not limited by Fp.05.

Beverton Holt without ICES AR

```
cod.indat <-list(data=stk,
                 bio.yrs=c(2008,2017),
                 sel.yrs=c(2008,2017),
                 Fscan=seq(0,1.0,by=0.05),
                 Fcv=0.212,
                 Fphi=0.423,
                 Blim=blim,
                 Bpa=bpa,
                 Btrigger = 0,
                 extreme.trim=c(0.01,0.99)
                 )

cod.res <-within(cod.indat,
{
  fit <-eqsr_fit(data,nsamp=1000,models= "Bevholt")
  sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
                  Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
                  Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
                  extreme.trim=extreme.trim,
                  verbose=FALSE)
})
save(cod.res,file=file.path(paste("eqsim.fmsy.no.ar.beverton.rdata",sep="")))
```

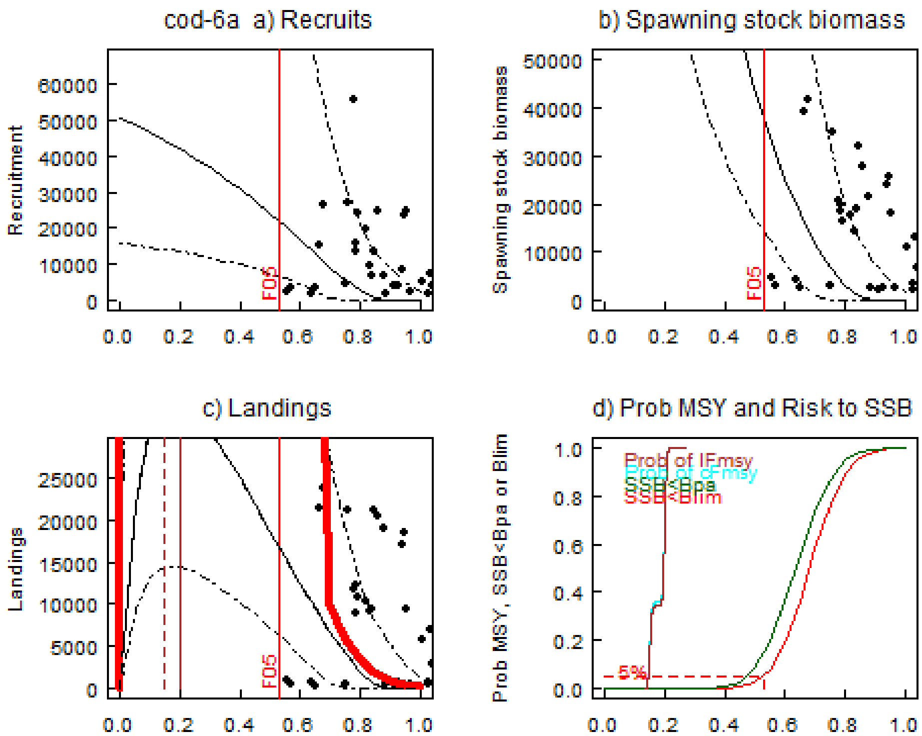


Figure 14: cod-6a. Eqsim summary plot. Panels a-c: historic values(dots), median (solid black) and 90% intervals (dotted) for recruitment, SSB and yield for exploitation at fixed values of F. Panel c also shows mean yield (red). Panel d shows the probablility of SSB less than Blim (red), less than Bpa(green) and the cumulative distribution of Fmsy based on > MCRS yield (brown) and catch (cyan).

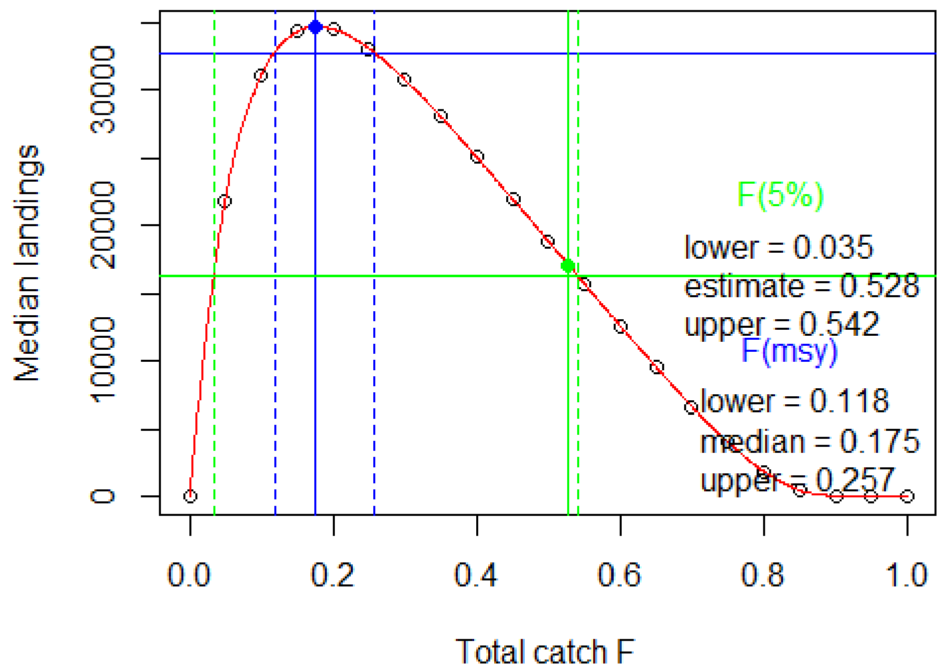


Figure 15: cod-6a. Yield (>MCRS) with median Fmsy (and 5th and 95th percentiles), blue vertical lines..

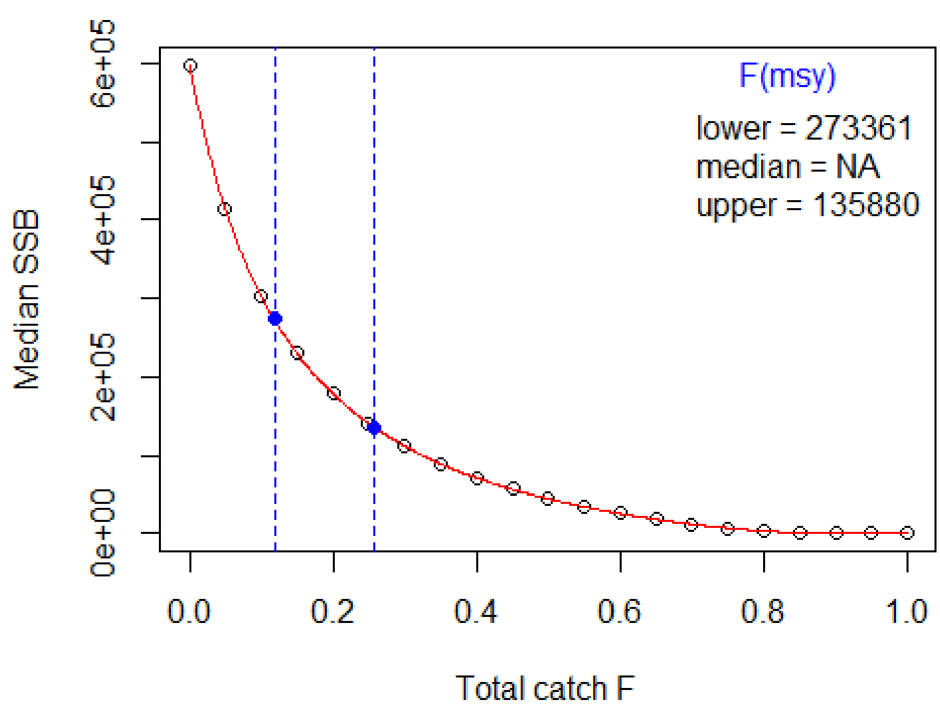


Figure 16: cod-6a. Median SSB curve over a range of target F values. Blue line corresponds to Fmsy range (Note that the 'NA' at median Fmsy is a persistent feature of EqSim).

The median Fmsy estimated by Eqsim applying a fixed F harvest strategy was 0.18. The upper bound of the Fmsy range giving at least 95 % of the maximum yield was 0.26 and the lower bound 0.12. Note that the associated SSB is well above the historically observed values (Figure 1).

Beverton Holt with ICES AR

The next step is to set MSY Btrigger. According to ICES guidelines MSY Btrigger is set equal to Bpa unless the stock has been fished below Fmsy for the last 5 years. The ICES MSY advice rule is then evaluated to check that the Fmsy and MSY Btrigger combination fulfils the precautionary criterion of having a less than 5 % annual probability of SSB < Blim in the long term. (The evaluation includes assessment/advice error).

```
cod.indat <-list(data=stk,
                 bio.yrs=c(2008,2017),
                 sel.yrs=c(2008,2017),
                 Fscan=seq(0,1.0,by=0.05),
                 Fcv=0.212,
                 Fphi=0.423,
                 Blim=blim,
                 Bpa=bpa,
                 Btrigger = bpa,
                 extreme.trim=c(0.05,0.95)
)

cod.res <-within(cod.indat,
                 {
                   fit <-eqsr_fit(data,nsamp=1000,models= "Bevholt")
                   sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
                                   Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
                                   Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
                                   extreme.trim=extreme.trim,
                                   verbose=FALSE)
                 })
save(cod.res,file=file.path(paste("eqsim.fmsy.with.ar.beverton.rdata",sep="")
))
```

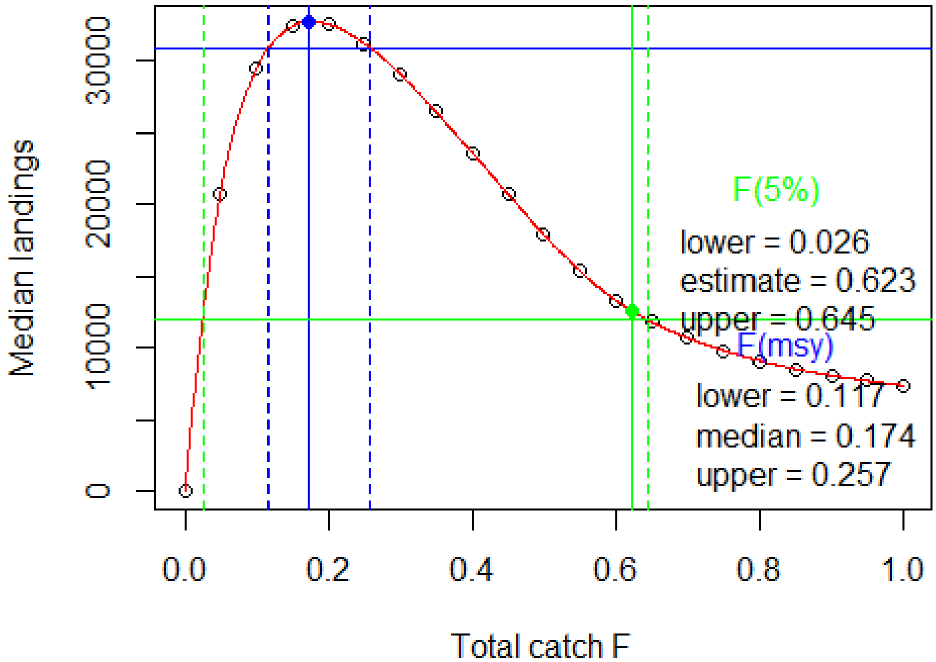


Figure 17: cod-6a. Yield (>MCRS) with median Fmsy (and 5th and 95th percentiles), blue vertical lines..

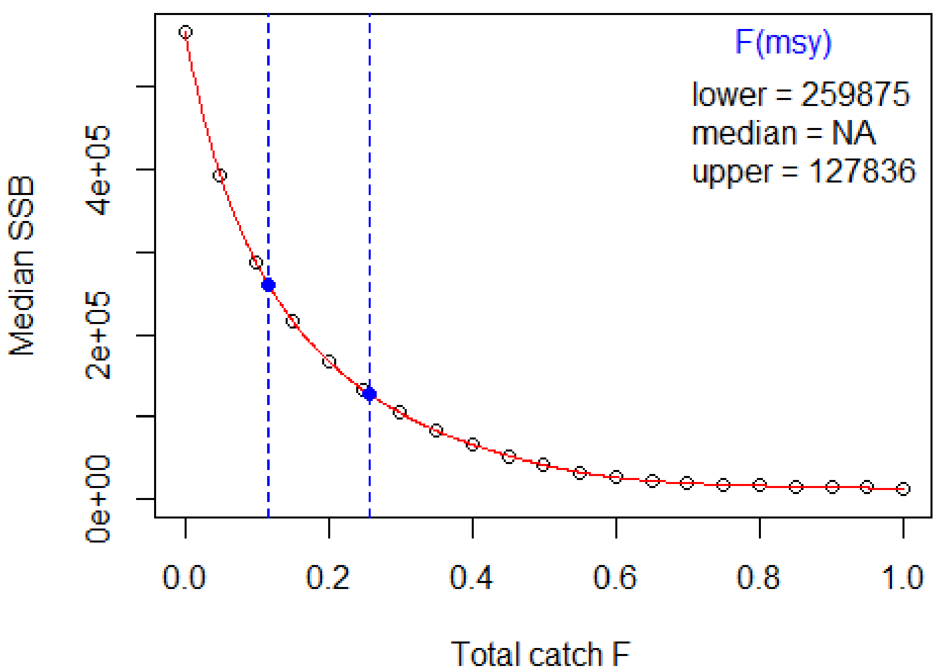


Figure 18: cod-6a. Median SSB curve over a range of target F values. Blue line corresponds to Fmsy range (Note that the 'NA' at median Fmsy is a persistent feature of EqSim).

	catF	lanF	catch	landings	catB	lanB
F05	0.623	NA	12560	NA	24955	NA
F10	0.682	NA	11044	NA	20922	NA
F50	0.962	NA	7595	NA	14003	NA
medianMSY	NA	0.174	NA	32789	NA	191479
meanMSY	0.200	0.200	32562	32588	168381	168381
Medlower	NA	0.117	NA	31004	NA	259875
Meanlower	NA	0.116	NA	38264	NA	NA
Medupper	NA	0.257	NA	30990	NA	127836
Meanupper	NA	0.254	NA	38296	NA	NA

Table 4: cod-6a. Summary of eqsim run including assessment/advice error and the ICES MSY advice rule.

The Fp.05 (the F at which there is a 5 % probability of falling below Blim) is calculated as 0.623 which greater than the Fmsy (and Fmsy upper) without the advice rule and therefore the Fmsy reference points are not limited by Fp.05.

Ricker/Beverton Holt without AR

```
cod.indat <-list(data=stk,
                 bio.yrs=c(2008,2017),
                 sel.yrs=c(2008,2017),
                 Fscan=seq(0,1.0,by=0.05),
                 Fcv=0.212,
                 Fphi=0.423,
                 Blim=blim,
                 Bpa=bpa,
                 Btrigger = 0,
                 extreme.trim=c(0.05,0.95)
                 )

cod.res <-within(cod.indat,
{
  fit <-eqsr_fit(data,nsamp=1000,models= c("Ricker","Bevholt"))
  sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
                  Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
                  Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
                  extreme.trim=extreme.trim,
                  verbose=FALSE)
})
save(cod.res,file=file.path(paste("eqsim.fmsy.no.ar.ricker.and.beverton.rdata
",sep="")))
```

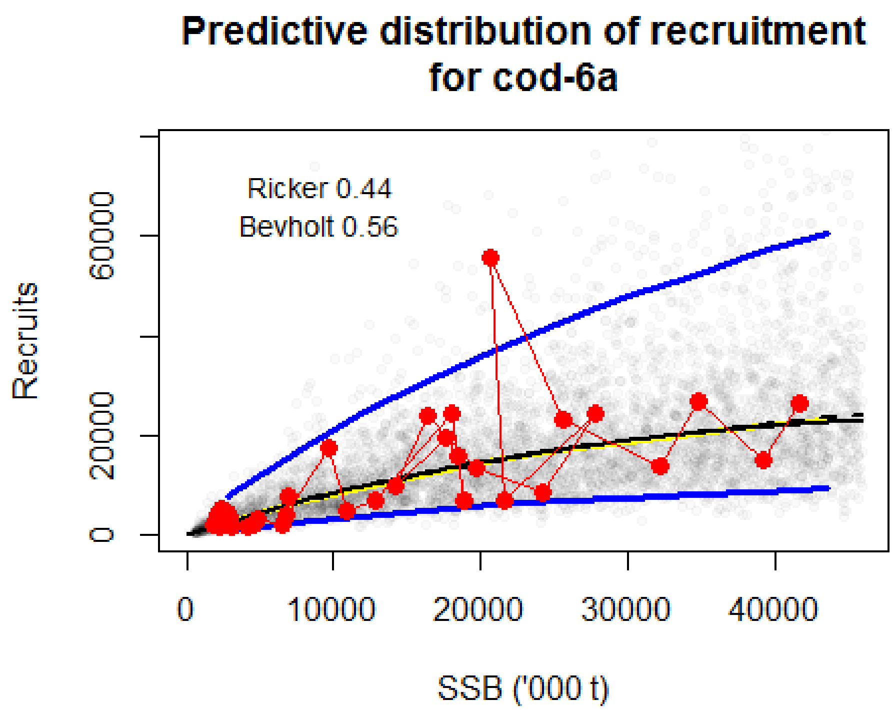


Figure 19: cod-6a. Stock recruitment fit - Ricker & Beverton Holt.

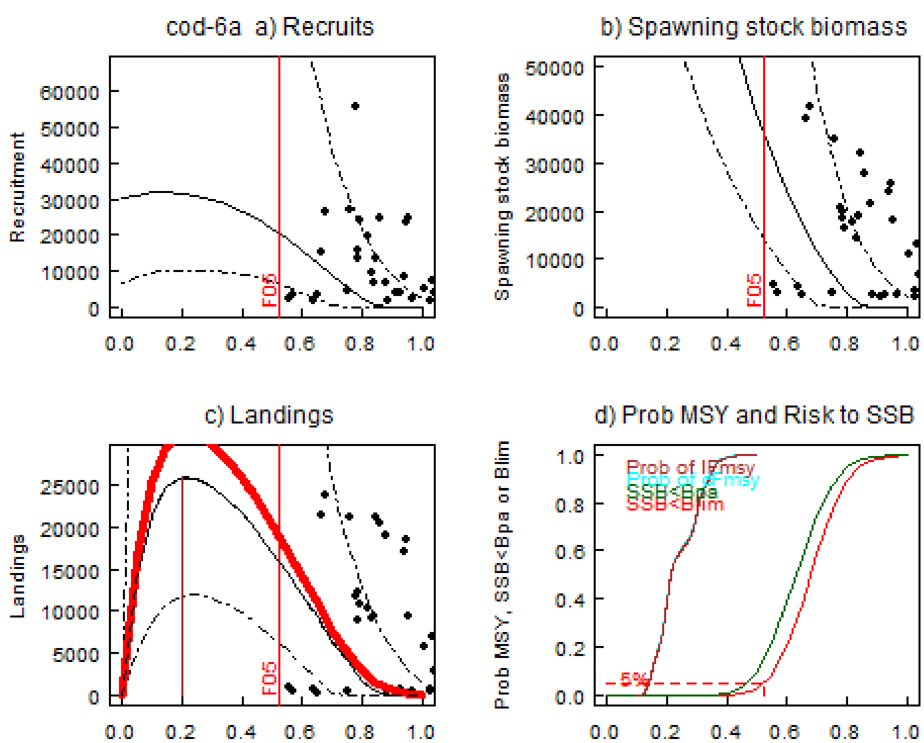


Figure 20: cod-6a. Eqsim summary plot. Panels a-c: historic values(dots), median (solid black) and 90% intervals (dotted) for recruitment, SSB and yield for exploitation at fixed values of F. Panel c also shows mean yield (red). Panel d shows the probablility of SSB less than Blim (red), less than Bpa(green) and the cumulative distribution of Fmsy based on > MCRS yield (brown) and catch (cyan).

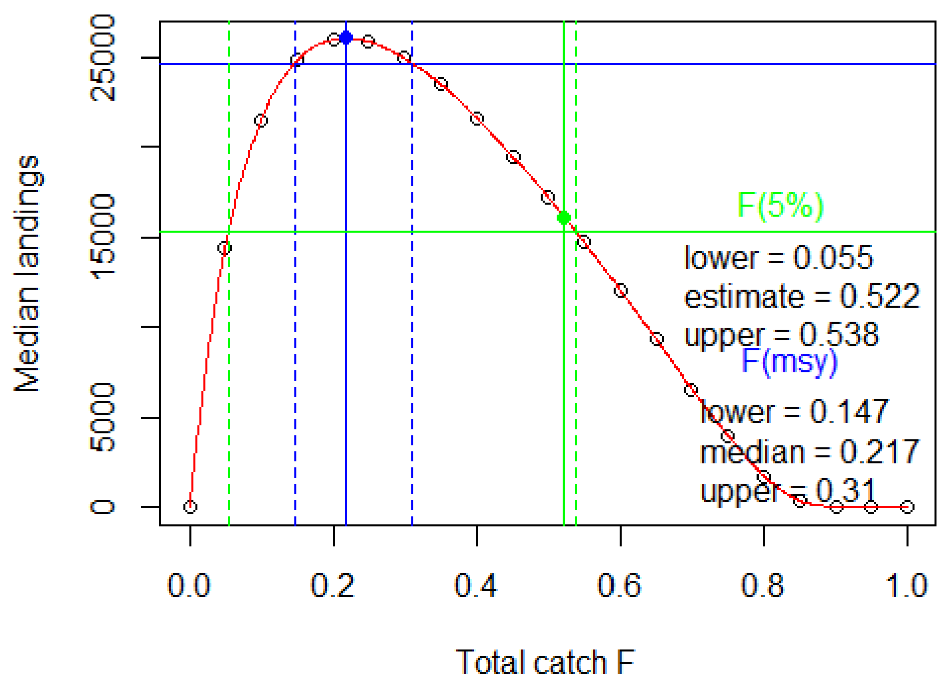


Figure 21: cod-6a. Yield (>MCRS) with median Fmsy (and 5th and 95th percentiles), blue vertical lines..

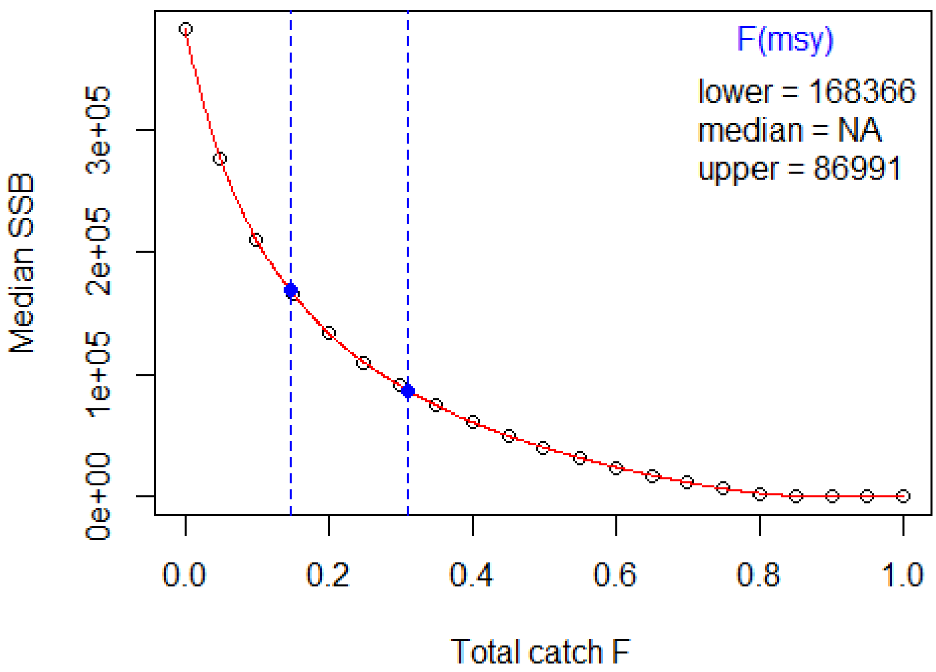


Figure 22: cod-6a. Median SSB curve over a range of target F values. Blue line corresponds to Fmsy range (Note that the 'NA' at median Fmsy is a persistent feature of EqSim).

The median Fmsy estimated by Eqsim applying a fixed F harvest strategy was 0.22. The upper bound of the Fmsy range giving at least 95 % of the maximum yield was 0.31 and the lower bound 0.15. Note that the associated SSB is well above the historically observed values (Figure 1).

Ricker/Beverton Holt with ICES AR

The next step is to set MSY Btrigger. According to ICES guidelines MSY Btrigger is set equal to Bpa unless the stock has been fished below Fmsy for the last 5 years. The ICES MSY advice rule is then evaluated to check that the Fmsy and MSY Btrigger combination fulfils the precautionary criterion of having a less than 5 % annual probability of SSB < Blim in the long term. (The evaluation includes assessment/advice error).

```
cod.indat <-list(data=stk,
                 bio.yrs=c(2008,2017),
                 sel.yrs=c(2008,2017),
                 Fscan=seq(0,1.0,by=0.05),
                 Fcv=0.212,
                 Fphi=0.423,
                 Blim=blim,
                 Bpa=bpa,
                 Btrigger = bpa,
```

```
                  extreme.trim=c(0.05,0.95)
)

cod.res <-within(cod.indat,
                 {
                   fit <-eqsr_fit(data,nsamp=1000,models=
c("Ricker","Bevholt"))
                   sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
                                   Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
                                   Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
                                   extreme.trim=extreme.trim,
                                   verbose=FALSE)
                 })
save(cod.res,file=file.path(paste("eqsim.fmsy.with.ar.ricker.and.beverton.rda
ta",sep="")))
```

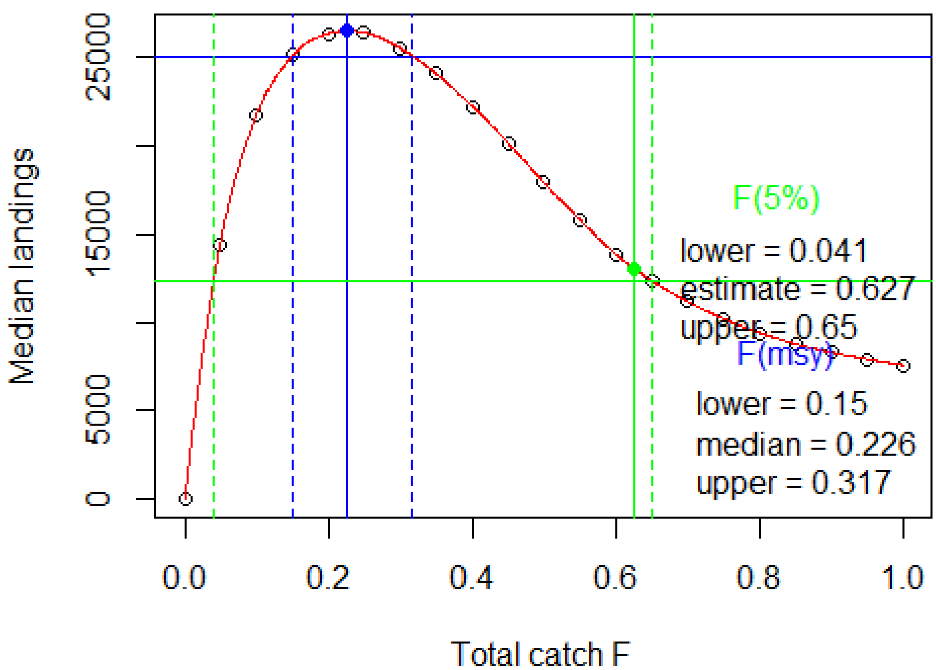


Figure 23: cod-6a. Yield (>MCRS) with median Fmsy (and 5th and 95th percentiles), blue vertical lines..

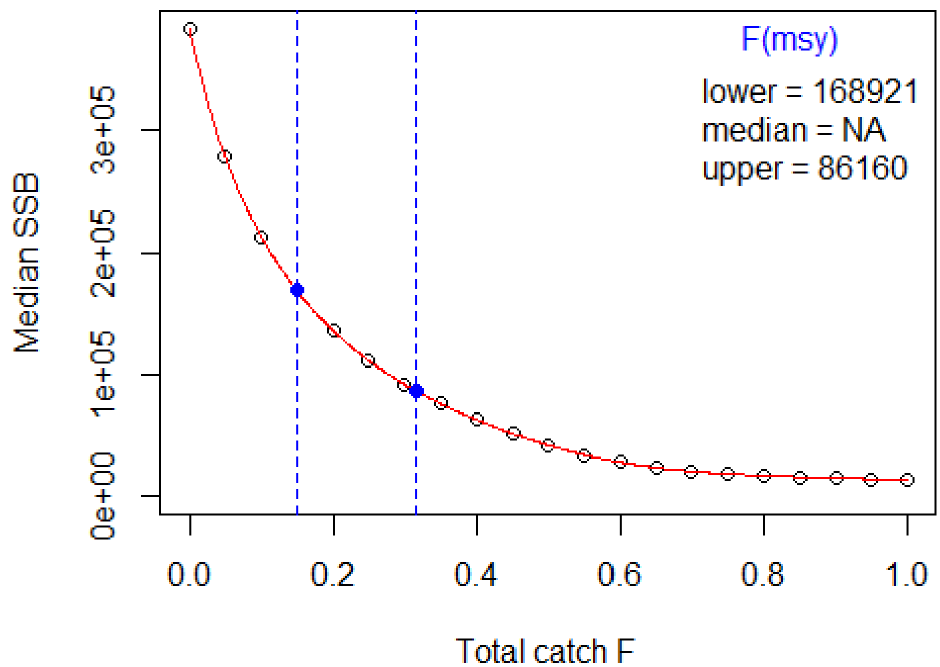


Figure 24: cod-6a. Median SSB curve over a range of target F values. Blue line corresponds to Fmsy range (Note that the 'NA' at median Fmsy is a persistent feature of EqSim).

	catF	lanF	catch	landings	catB	lanB
F05	0.627	NA	12975	NA	25692	NA
F10	0.690	NA	11337	NA	21221	NA
F50	0.977	NA	7682	NA	14008	NA
medianMSY	NA	0.226	NA	26510	NA	122565
meanMSY	0.200	0.200	26343	26348	136331	136331
Medlower	NA	0.150	NA	25118	NA	168921
Meanlower	NA	0.150	NA	30856	NA	NA
Medupper	NA	0.317	NA	25095	NA	86160
Meanupper	NA	0.313	NA	30830	NA	NA

Table 5: cod-6a. Summary of eqsim run including assessment/advice error and the ICES MSY advice rule.

The Fp.05 (the F at which there is a 5 % probability of falling below Blim) is calculated as 0.627 which greater than the Fmsy (and Fmsy upper) without the advice rule and therefore the Fmsy reference points are not limited by Fp.05.

Segreg without AR

```
cod.indat <-list(data=stk,
                 bio.yrs=c(2008,2017),
                 sel.yrs=c(2008,2017),
                 Fscan=seq(0,1.0,by=0.05),
                 Fcv=0.212,
                 Fphi=0.423,
                 Blim=blim,
                 Bpa=bpa,
                 Btrigger = 0,
                 extreme.trim=c(0.05,0.95)
                 )

cod.res <-within(cod.indat,
{
  fit <-eqsr_fit(data,nsamp=1000,models= c("Segreg"))
  sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
                  Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
                  Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
                  extreme.trim=extreme.trim,
                  verbose=FALSE)
})
save(cod.res,file=file.path(paste("eqsim.fmsy.no.ar.segreg.rdata",sep="")))
```

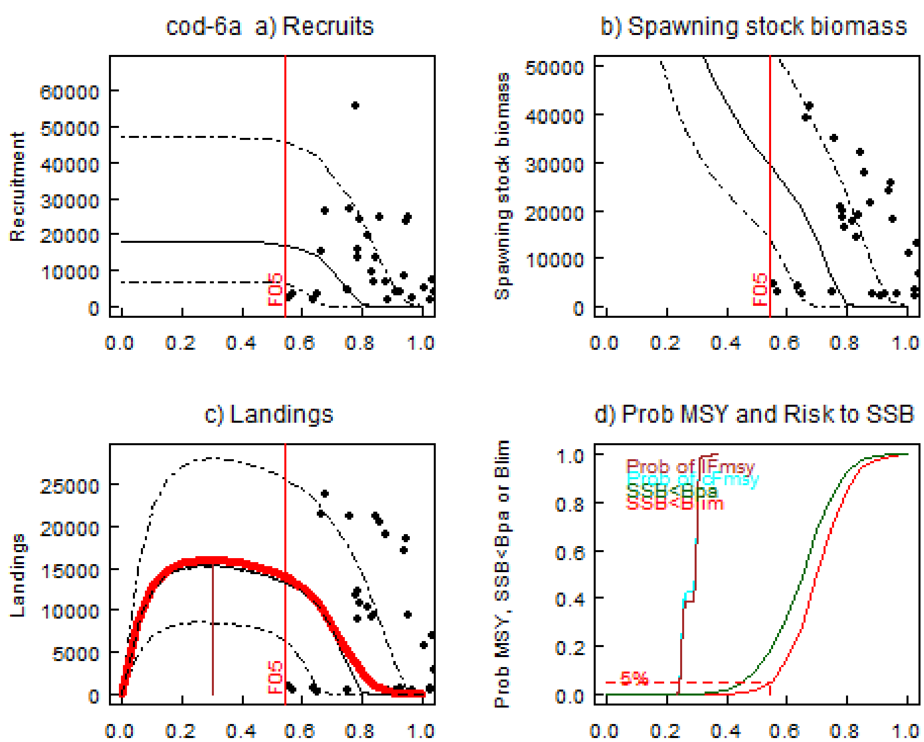


Figure 25: cod-6a. Eqsim summary plot. Panels a-c: historic values(dots), median (solid black) and 90% intervals (dotted) for recruitment, SSB and yield for

exploitation at fixed values of F. Panel c also shows mean yield (red). Panel d shows the probablility of SSB less than Blim (red), less than Bpa(green) and the cumulative distribution of Fmsy based on > MCRS yield (brown) and catch (cyan).

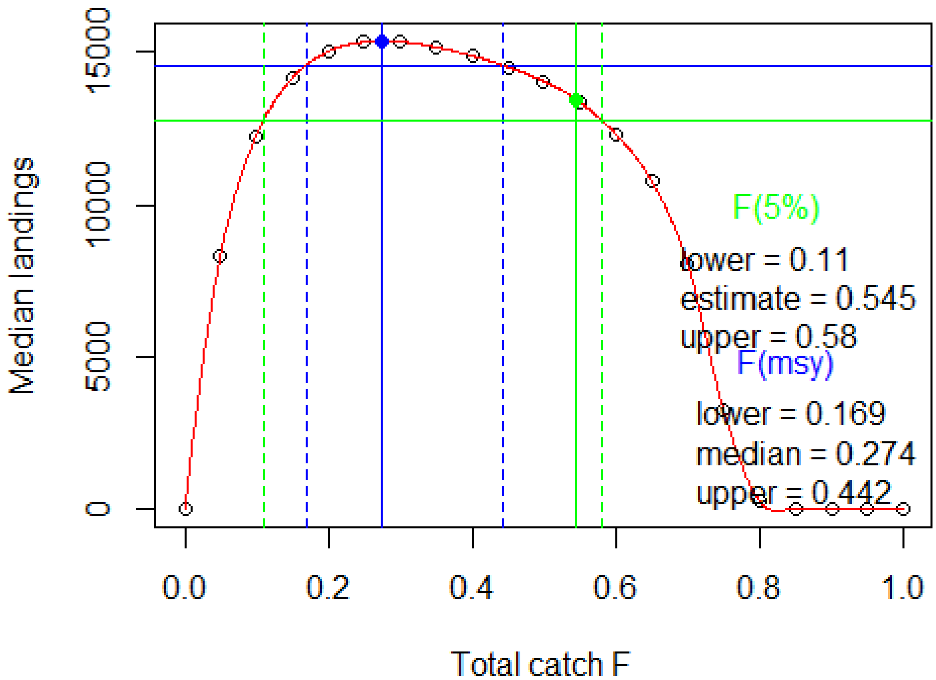


Figure 26: cod-6a. Yield (>MCRS) with median Fmsy (and 5th and 95th percentiles), blue vertical lines..

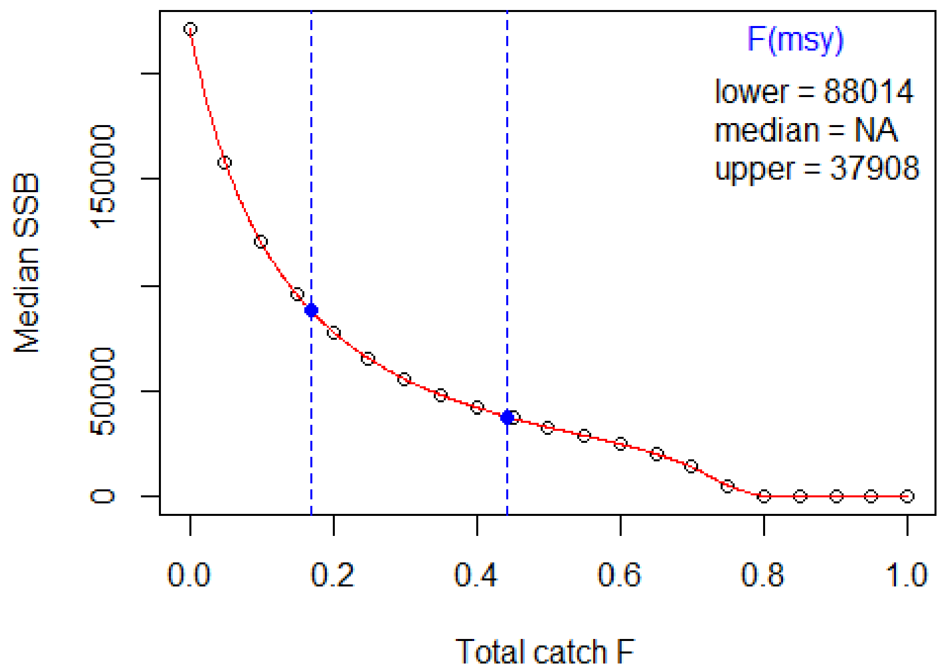


Figure 27: cod-6a. Median SSB curve over a range of target F values. Blue line corresponds to Fmsy range (Note that the 'NA' at median Fmsy is a persistent feature of EqSim).

The median Fmsy estimated by Eqsim applying a fixed F harvest strategy was 0.27. The upper bound of the Fmsy range giving at least 95 % of the maximum yield was 0.44 and the lower bound 0.17. Note that the associated SSB is well above the historically observed values (Figure 1).

Segreg with ICES AR

The next step is to set MSY Btrigger. According to ICES guidelines MSY Btrigger is set equal to Bpa unless the stock has been fished below Fmsy for the last 5 years. The ICES MSY advice rule is then evaluated to check that the Fmsy and MSY Btrigger combination fulfils the precautionary criterion of having a less than 5 % annual probability of SSB < Blim in the long term. (The evaluation includes assessment/advice error).

```
cod.indat <-list(data=stk,
                 bio.yrs=c(2008,2017),
                 sel.yrs=c(2008,2017),
                 Fscan=seq(0,1.0,by=0.05),
                 Fcv=0.212,
                 Fphi=0.423,
                 Blim=blim,
                 Bpa=bpa,
                 Btrigger = bpa,
```

```
                   extreme.trim=c(0.05,0.95)
)

cod.res <-within(cod.indat,
                   {
                     fit <-eqsr_fit(data,nsamp=1000,models= c("Segreg"))
                     sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
                                     Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
                                     Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
                                     extreme.trim=extreme.trim,
                                     verbose=FALSE)
                   })
save(cod.res,file=file.path(paste("eqsim.fmsy.with.ar.segreg.rdata",sep="")))
```

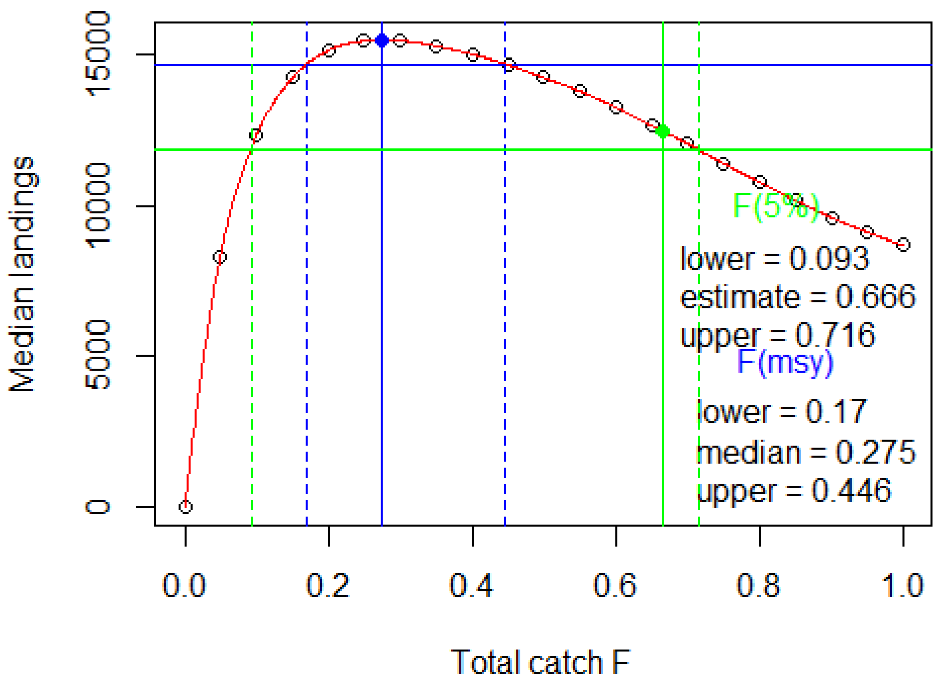


Figure 28: cod-6a. Yield (>MCRS) with median Fmsy (and 5th and 95th percentiles), blue vertical lines..

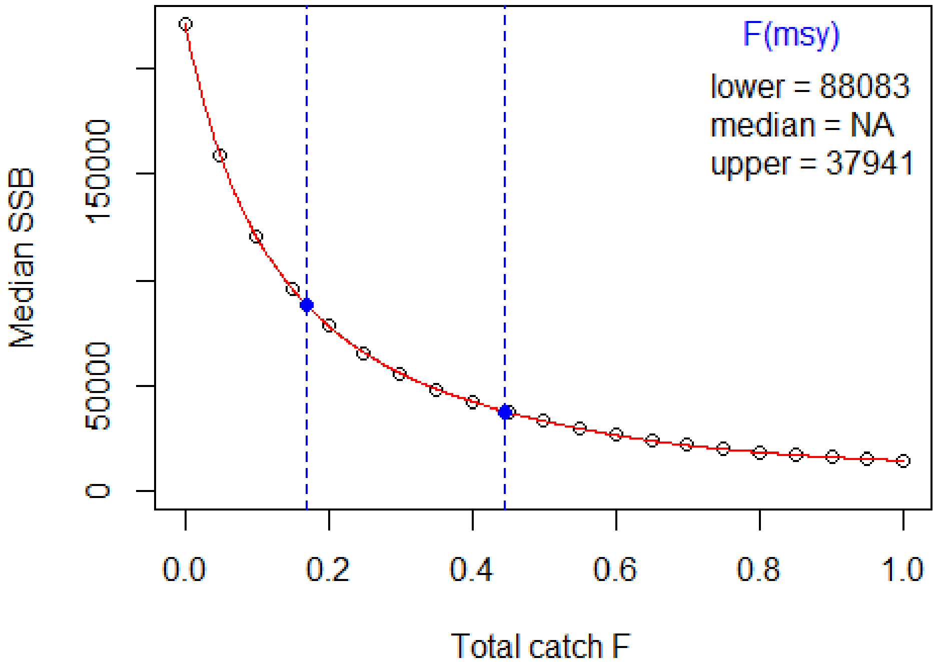


Figure 29: cod-6a. Median SSB curve over a range of target F values. Blue line corresponds to Fmsy range (Note that the 'NA' at median Fmsy is a persistent feature of EqSim).

	catF	lanF	catch	landings	catB	lanB
F05	0.666	NA	12347	NA	23334	NA
F10	0.735	NA	11480	NA	20593	NA
F50	NA	NA	NA	NA	NA	NA
medianMSY	NA	0.275	NA	15470	NA	60500
meanMSY	0.300	0.300	15410	15446	56037	56037
Medlower	NA	0.170	NA	14689	NA	88083
Meanlower	NA	0.172	NA	15304	NA	NA
Medupper	NA	0.446	NA	14679	NA	37941
Meanupper	NA	0.451	NA	15296	NA	NA

Table 6: cod-6a. Summary of eqsim run including assessment/advice error and the ICES MSY advice rule.

The Fp.05 (the F at which there is a 5 % probability of falling below Blim) is calculated as 0.666 which greater than the Fmsy (and Fmsy upper) without the advice rule and therefore the Fmsy reference points are not limited by Fp.05.

Ricker/Segreg without AR

```
cod.indat <-list(data=stk,
                 bio.yrs=c(2008,2017),
                 sel.yrs=c(2008,2017),
                 Fscan=seq(0,1.0,by=0.05),
                 Fcv=0.212,
                 Fphi=0.423,
                 Blim=blim,
                 Bpa=bpa,
                 Btrigger = 0,
                 extreme.trim=c(0.05,0.95)
                 )

cod.res <-within(cod.indat,
{
  fit <-eqsr_fit(data,nsamp=1000,models= c("Segreg","Ricker"))
  sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
                  Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
                  Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
                  extreme.trim=extreme.trim,
                  verbose=FALSE)
})
save(cod.res,file=file.path(paste("eqsim.fmsy.no.ar.ricker.and.segreg.rdata",
sep="")))
```

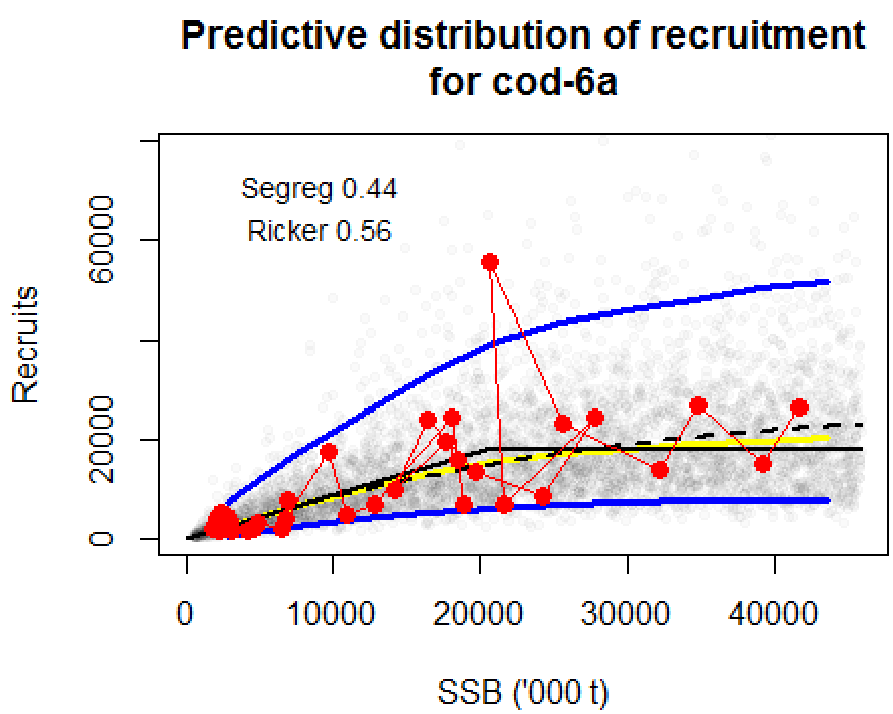


Figure 30: cod-6a. Stock recruitment fit - Ricker & Segmented regression.

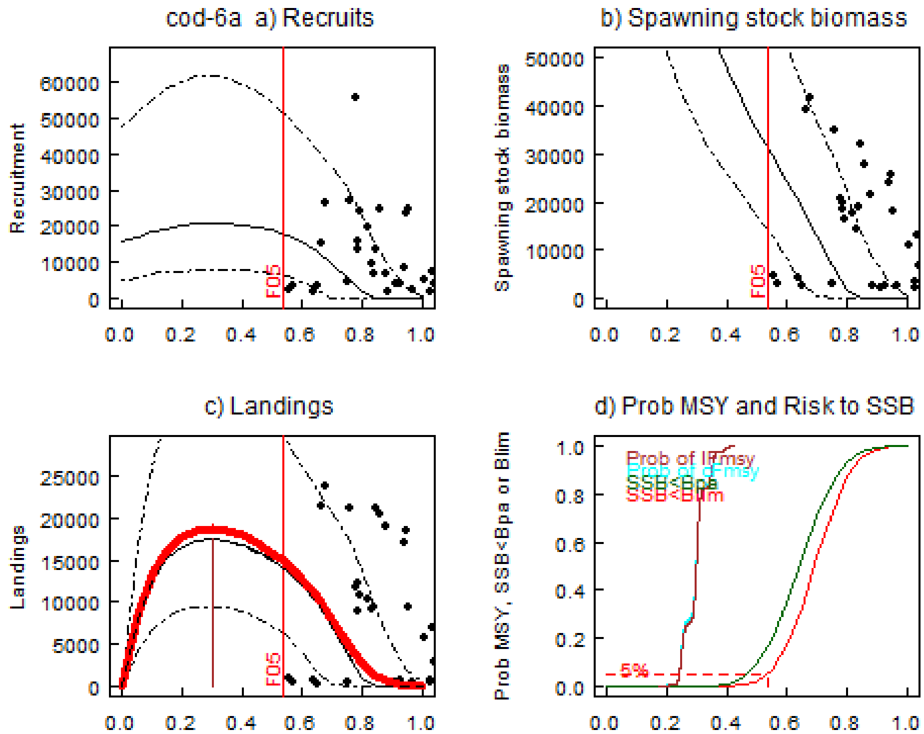


Figure 31: cod-6a. Eqsim summary plot. Panels a-c: historic values(dots), median (solid black) and 90% intervals (dotted) for recruitment, SSB and yield for exploitation at fixed values of F. Panel c also shows mean yield (red). Panel d shows the probablility of SSB less than Blim (red), less than Bpa(green) and the cumulative distribution of Fmsy based on > MCRS yield (brown) and catch (cyan).

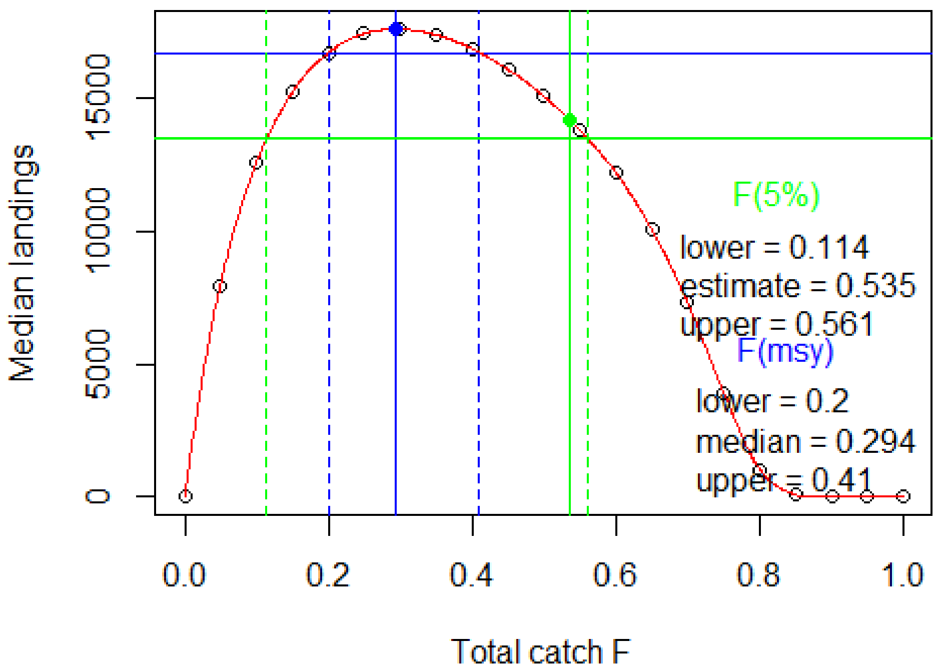


Figure 32: cod-6a. Yield (>MCRS) with median Fmsy (and 5th and 95th percentiles), blue vertical lines..

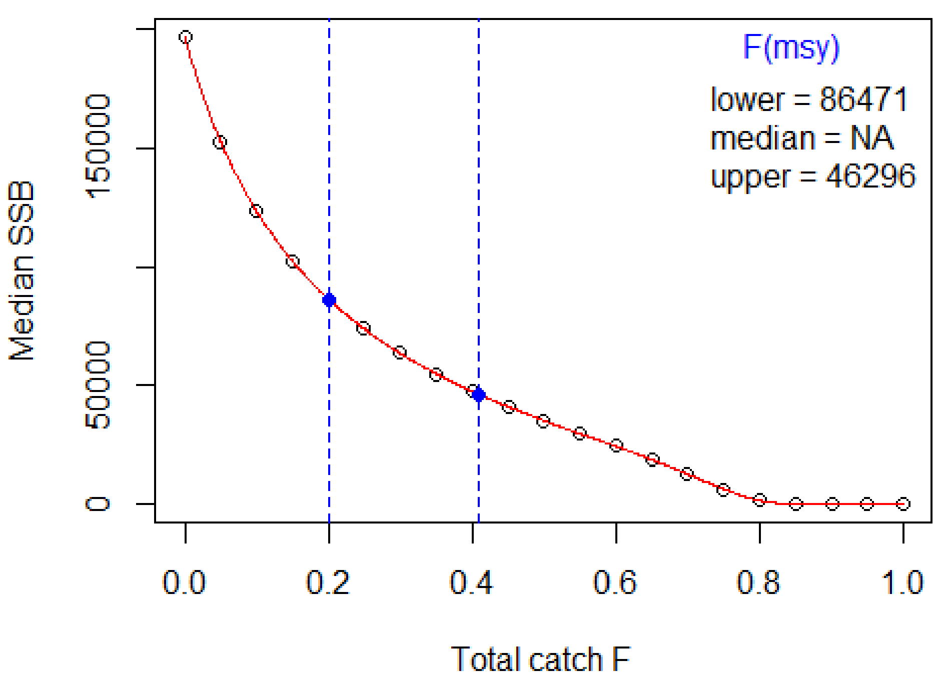


Figure 33: cod-6a. Median SSB curve over a range of target F values. Blue line corresponds to Fmsy range (Note that the 'NA' at median Fmsy is a persistent feature of EqSim).

The median Fmsy estimated by Eqsim applying a fixed F harvest strategy was 0.29. The upper bound of the Fmsy range giving at least 95 % of the maximum yield was 0.41 and the lower bound 0.2. Note that the associated SSB is well above the historically observed values (Figure 1).

Ricker/Segreg with ICES AR

The next step is to set MSY Btrigger. According to ICES guidelines MSY Btrigger is set equal to Bpa unless the stock has been fished below Fmsy for the last 5 years. The ICES MSY advice rule is then evaluated to check that the Fmsy and MSY Btrigger combination fulfils the precautionary criterion of having a less than 5 % annual probability of SSB < Blim in the long term. (The evaluation includes assessment/advice error).

```
cod.indat <-list(data=stk,
                 bio.yrs=c(2008,2017),
                 sel.yrs=c(2008,2017),
                 Fscan=seq(0,1.0,by=0.05),
                 Fcv=0.212,
                 Fphi=0.423,
                 Blim=blim,
                 Bpa=bpa,
                 Btrigger = bpa,
                 extreme.trim=c(0.05,0.95)
)

cod.res <-within(cod.indat,
                 {
                   fit <-eqsr_fit(data,nsamp=1000,models=
c("Ricker","Segreg"))
                   sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
                                   Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
                                   Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
                                   extreme.trim=extreme.trim,
                                   verbose=FALSE)
                 })
save(cod.res,file=file.path(paste("eqsim.fmsy.with.ar.ricker.and.segreg.rdata
",sep="")))
```

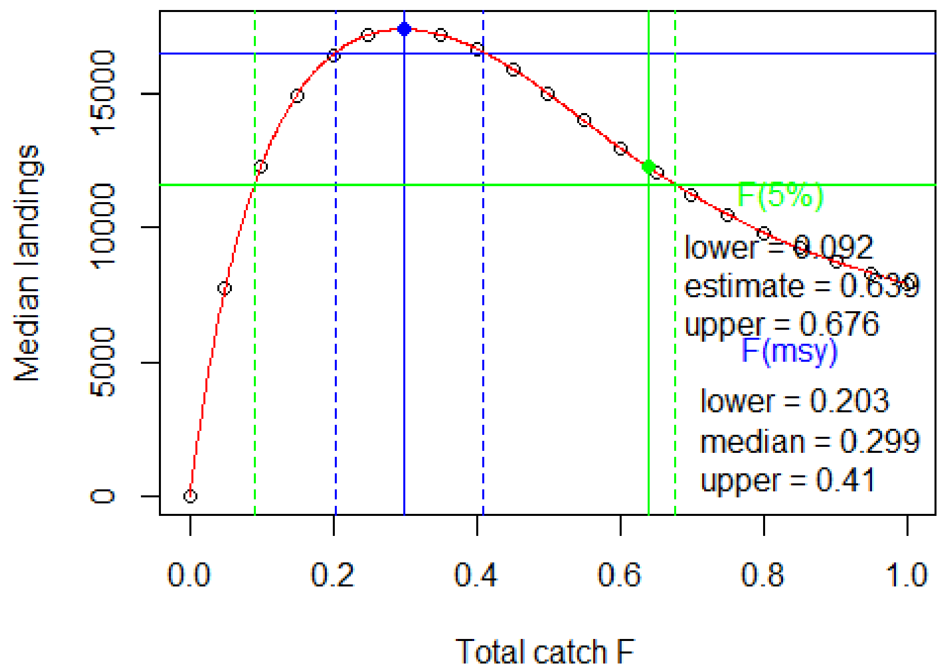


Figure 34: cod-6a. Yield (>MCRS) with median Fmsy (and 5th and 95th percentiles), blue vertical lines..

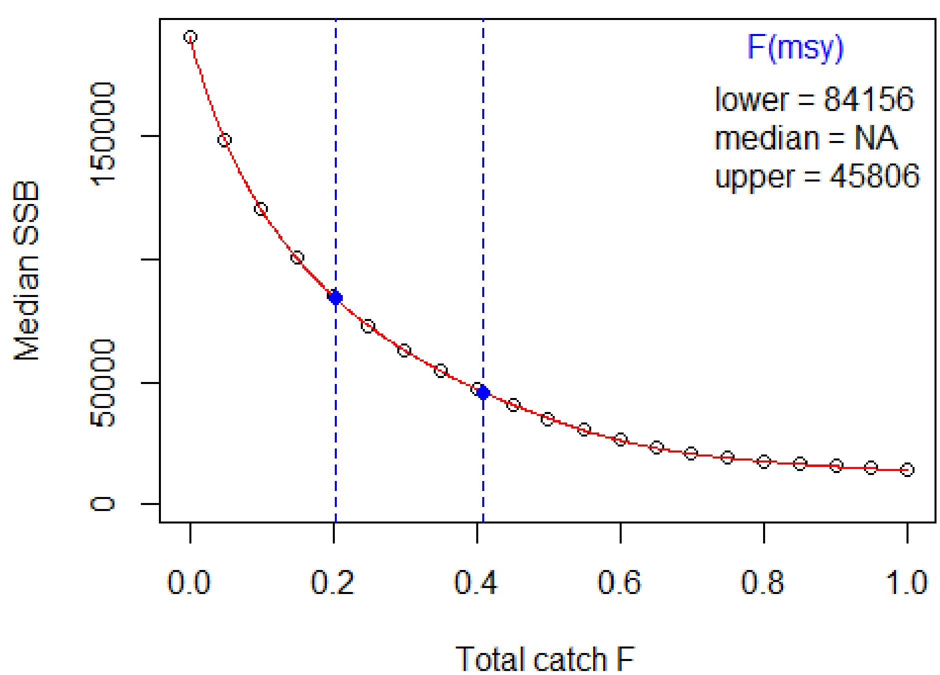


Figure 35: cod-6a. Median SSB curve over a range of target F values. Blue line corresponds to Fmsy range (Note that the 'NA' at median Fmsy is a persistent feature of EqSim).

	catF	lanF	catch	landings	catB	lanB
F05	0.639	NA	12156	NA	23690	NA
F10	0.704	NA	11090	NA	20515	NA
F50	NA	NA	NA	NA	NA	NA
medianMSY	NA	0.299	NA	17361	NA	63031
meanMSY	0.300	0.300	17307	17361	62901	62901
Medlower	NA	0.203	NA	16493	NA	84156
Meanlower	NA	0.204	NA	17653	NA	NA
Medupper	NA	0.410	NA	16505	NA	45806
Meanupper	NA	0.408	NA	17653	NA	NA

Table 7: cod-6a. Summary of eqsim run including assessment/advice error and the ICES MSY advice rule.

The Fp.05 (the F at which there is a 5 % probability of falling below Blim) is calculated as 0.639 which greater than the Fmsy (and Fmsy upper) without the advice rule and therefore the Fmsy reference points are not limited by Fp.05.

All SR relationship without ICES AR

```
cod.indat <-list(data=stk,
                 bio.yrs=c(2008,2017),
                 sel.yrs=c(2008,2017),
                 Fscan=seq(0,1.0,by=0.05),
                 Fcv=0.212,
                 Fphi=0.423,
                 Blim=blim,
                 Bpa=bpa,
                 Btrigger = 0,
                 extreme.trim=c(0.05,0.95)
                 )

cod.res <-within(cod.indat,
{
  fit <-eqsr_fit(data,nsamp=1000,models= c("Ricker","Bevholt","Segreg"))
  sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
                  Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
                  Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
                  extreme.trim=extreme.trim,
                  verbose=FALSE)
})
save(cod.res,file=file.path(paste("eqsim.fmsy.no.ar.all.rdata",sep="")))
```

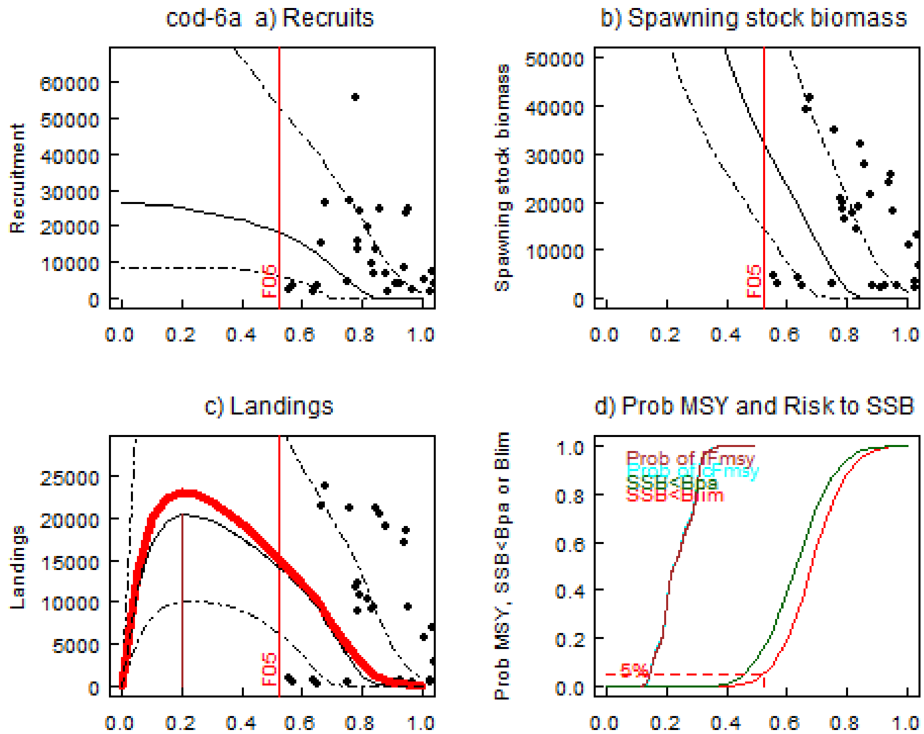


Figure 36: cod-6a. Eqsim summary plot. Panels a-c: historic values(dots), median (solid black) and 90% intervals (dotted) for recruitment, SSB and yield for exploitation at fixed values of F. Panel c also shows mean yield (red). Panel d shows the probablility of SSB less than Blim (red), less than Bpa(green) and the cumulative distribution of Fmsy based on > MCRS yield (brown) and catch (cyan).

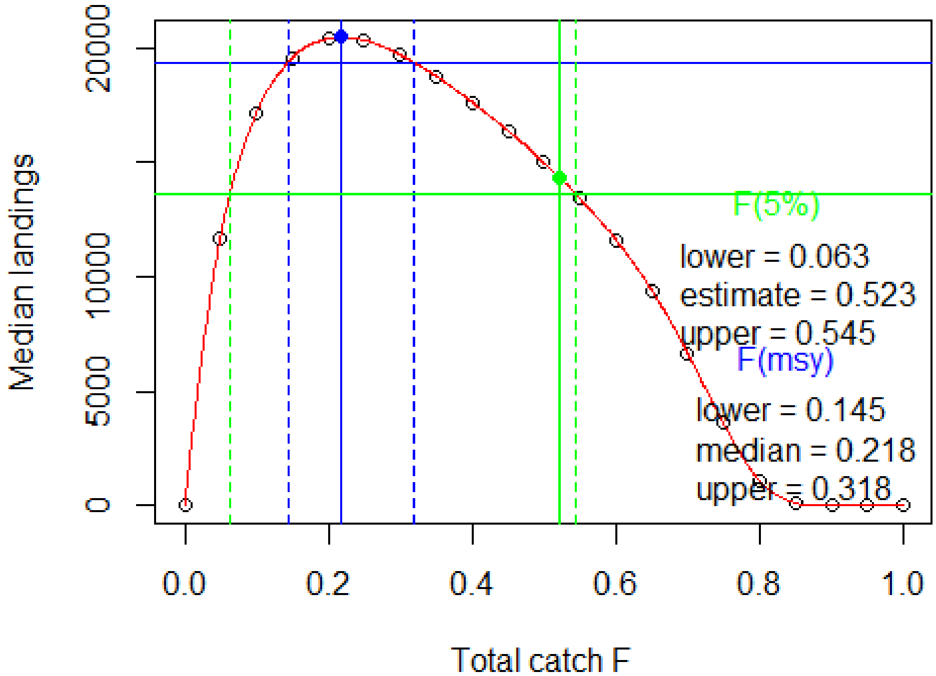


Figure 37: cod-6a. Yield (>MCRS) with median Fmsy (and 5th and 95th percentiles), blue vertical lines..

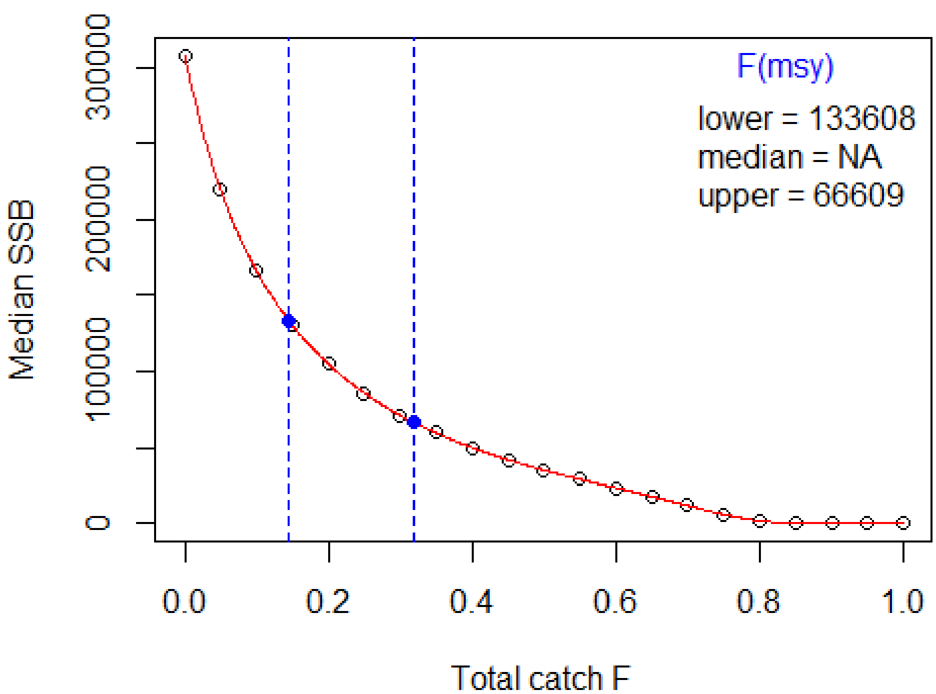


Figure 38: cod-6a. Median SSB curve over a range of target F values. Blue line corresponds to Fmsy range (Note that the 'NA' at median Fmsy is a persistent feature of EqSim).

The median Fmsy estimated by Eqsim applying a fixed F harvest strategy was 0.22. The upper bound of the Fmsy range giving at least 95 % of the maximum yield was 0.32 and the lower bound 0.15. Note that the associated SSB is well above the historically observed values (Figure 1).

All SR relationships with ICES AR

The next step is to set MSY Btrigger. According to ICES guidelines MSY Btrigger is set equal to Bpa unless the stock has been fished below Fmsy for the last 5 years. The ICES MSY advice rule is then evaluated to check that the Fmsy and MSY Btrigger combination fulfils the precautionary criterion of having a less than 5 % annual probability of SSB < Blim in the long term. (The evaluation includes assessment/advice error).

```
cod.indat <-list(data=stk,
                 bio.yrs=c(2008,2017),
                 sel.yrs=c(2008,2017),
                 Fscan=seq(0,1.0,by=0.05),
                 Fcv=0.212,
                 Fphi=0.423,
                 Blim=blim,
                 Bpa=bpa,
                 Btrigger = bpa,
                 extreme.trim=c(0.05,0.95)
)

cod.res <-within(cod.indat,
                 {
                   fit <-eqsr_fit(data,nsamp=1000,models=
c("Ricker","Bevholt","Segreg"))
                   sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
                                   Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
                                   Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
                                   extreme.trim=extreme.trim,
                                   verbose=FALSE)
                 })
save(cod.res,file=file.path(paste("eqsim.fmsy.with.ar.all.rdata",sep="")))
```

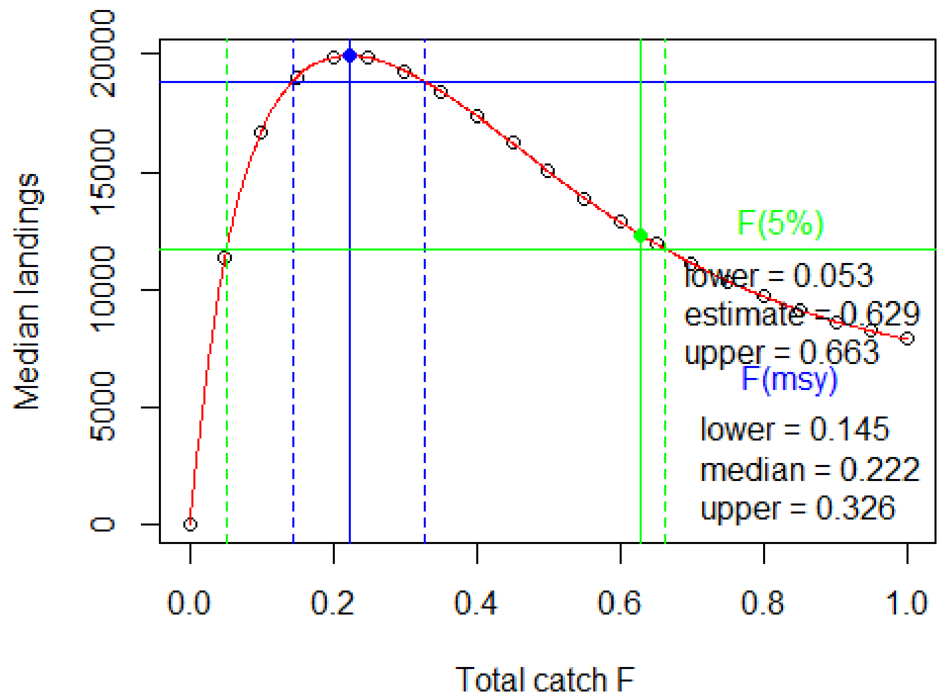


Figure 39: cod-6a. Yield (>MCRS) with median Fmsy (and 5th and 95th percentiles), blue vertical lines..

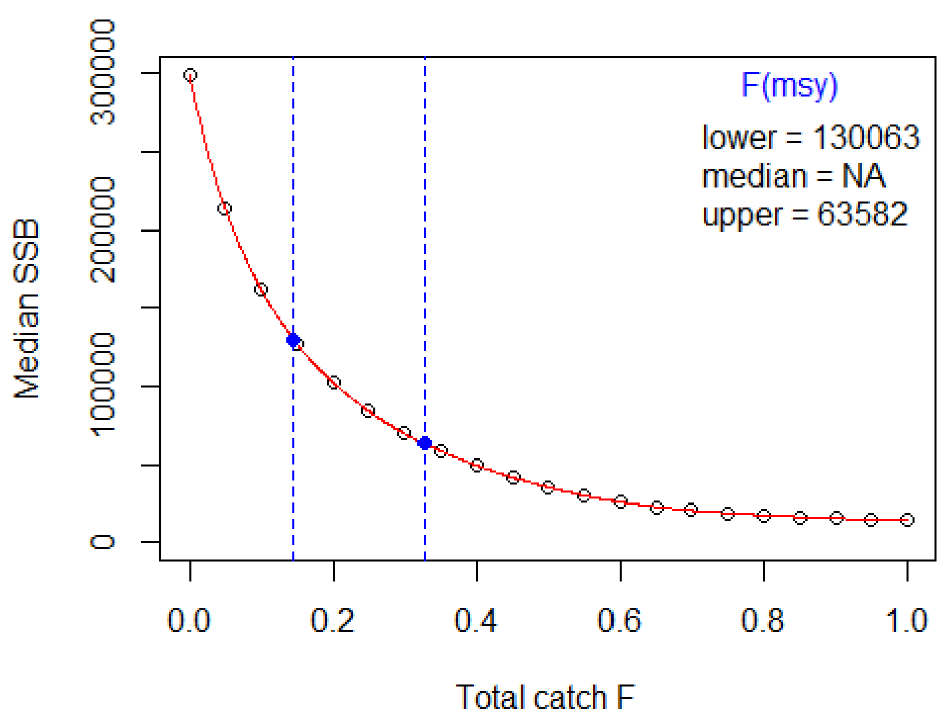


Figure 40: cod-6a. Median SSB curve over a range of target F values. Blue line corresponds to Fmsy range (Note that the 'NA' at median Fmsy is a persistent feature of EqSim).

	catF	lanF	catch	landings	catB	lanB
F05	0.629	NA	12254	NA	24185	NA
F10	0.694	NA	11135	NA	20777	NA
F50	0.997	NA	7826	NA	14000	NA
medianMSY	NA	0.222	NA	19933	NA	93590
meanMSY	0.200	0.200	19816	19850	102451	102451
Medlower	NA	0.145	NA	18876	NA	130063
Meanlower	NA	0.138	NA	21279	NA	NA
Medupper	NA	0.326	NA	18870	NA	63582
Meanupper	NA	0.302	NA	21279	NA	NA

Table 8: cod-6a. Summary of eqsim run including assessment/advice error and the ICES MSY advice rule.

The Fp.05 (the F at which there is a 5 % probability of falling below Blim) is calculated as 0.629 which greater than the Fmsy (and Fmsy upper) without the advice rule and therefore the Fmsy reference points are not limited by Fp.05.

References

WD 3: Cook, R. Issues arising from the revised 6.a cod assessment.

Issues arising from the revised 6a cod assessment

Robin Cook
University of Strathclyde, Glasgow, UK

Introduction

The scientific justification for the current IBP as set out by ICES is:

"The latest assessment of West of Scotland cod carried out by ICES indicates that the stock is being fished above FMSY with F declining only slowly. The spawning stock biomass (SSB) shows no increase and remains well below Blim. These trends differ markedly from stocks of other species in the same area and from other adjacent cod stocks which show significant declines in F and increasing SSB. Although there may be plausible explanations for these differences, an alternative assessment with different underlying fishery selectivity assumptions indicates a recovering 6a cod stock with F close to FMSY. This latter assessment is more in line with other stocks and with reductions in effort that have occurred in the fisheries."

This outlines the context in which the TSA assessment has been reviewed; basically to consider whether a revision would resolve any of these apparent differences. The important point to note is that the alternative assessment referred to (in Cook, 2019) offers a contrasting interpretation of the data not a "better" interpretation of the data. The paper points to the need to explore the full range of uncertainty rather than to identify a single best model. In the discussion here we review the extent to which the new TSA assessment changes our understanding of uncertainty surrounding the assessment. We briefly summarise the model output from the Cook (2019) model, which for convenience we refer to as the "ALD model", then consider the wider fishery context in the North Sea and West of Scotland, consider the various hypothesis that may explain the characteristics of the TSA and ALD results and finally outline the need for a multiple modelling approach.

ALD model

The peer reviewed model is fully described in Cook (2019) and details are not presented here. It has been discussed by the MASTS Fishery Forum to produce a policy brief (Fernandes et al, 2019). Figure 1 shows the summary output and retrospective pattern from ALD for mean F and SSB for the years 2005-2017. Also shown on the mean F plot is the scaled fishing effort for the Scottish TR1 fleet. Over the range of years considered ALD shows no systematic revisions in either F or SSB. It is noticeable that for the period 1997-2004 the mean F shows wide variation in scale corresponding the years when the model tries to estimate unreported catch. However, the terminal F and terminal SSB are consistent across years and the overall trends are very similar.

Comparison with other demersal stocks

Figure 2 shows the mean F estimated from the ALD model when fitted to a range of demersal stocks in the North Sea and West of Scotland. These results can be compared to the standard ICES assessments for the same stocks. In general, the results from ALD and the ICES assessments are very similar both in scale and trend. Some differences are to be expected when applying different models of this class (Deroba *et al* 2015) but the 6a cod assessment stands out as an exception. It is noticeable that for both haddock (Northern Shelf) and whiting in 6a, TSA and ALD give very similar results which suggests there is no systematic tendency in the models that might explain the 6a cod results.

There are, perhaps, two points to note regarding the stocks in Figure 2. Firstly, in nearly all cases the current fishing mortality is below 0.4. Secondly, for some roundfish stocks (North Sea cod, haddock and 6a whiting) fishing mortality starts to decline fairly rapidly around the year 2000 and is likely to be associated with a period when a substantial number of active fishing vessels were decommissioned. An indication of the decline in effort can be seen in Figure 1. Fernandes and Cook (2013) show that at this time there was a significant decline in the EU fleet which is correlated with reductions in harvest rate. The TSA assessment of 6a cod, however, does not reflect this trend to the same degree with only a modest decline occurring mostly from around 2010.

The exploitation patterns for the stocks are shown in Figure 3 where the ALD model is compared to the standard ICES assessments. With the exception of cod in 6a, the models estimate similar selectivity.

Survey catchability

Most age structured models using survey indices make the assumption that survey abundance is proportional to population abundance. The proportionality constant is usually referred to as "catchability" and is typically assumed to be time invariant but age specific. Both ALD and TSA make this assumption but TSA can be configured to estimate time varying catchability and this variant is used to model the Scottish quarter 1 and quarter 4 surveys post 2010 in the cod assessment.

Figure 4 shows the estimated survey catchabilities for the Scottish surveys from ALD and TSA. For the early series quarter 4 survey (pre 2010, wcsgfs.q1) both models estimate a somewhat anomalous selection pattern compared with the other surveys. The TSA estimate is particularly different indicating a very large change in the post 2010 survey. For the other surveys ALD catchability is fairly flat over ages 3-5 and lower at the youngest and oldest age. By contrast TSA estimates catchability for the same surveys to increase linearly at least up to age 5 so that fish aged 5 are three times more "catchable" than age 3. These differences are important in interpreting the shape of commercial selectivity. Relative to survey catchability, both models estimate dome shaped commercial selection. This can be seen in Figure 5 which shows the ratio of the number of fish at age in the catch to the number of fish in the index averaged over the years of the survey. The figure suggests peak relative selection to be at ages 3-4. TSA "sees" a flat topped selection because survey catchability increases with age. ALD sees commercial selectivity as dome shaped because survey catchability is mostly flat. If one was to over-simplify, the proportion of old fish in the surveys is estimated by ALD to reflect the proportion of older fish in the sea. TSA considers the proportion in the survey to be higher than in the sea. This leads to the low estimate of stock biomass in from TSA and high biomass from ALD.

Fishing effort in 6a

The cod recovery plan (EU 2008) instigated effort control measures in order to try to reduce fishing mortality on cod and covered the 6a area. It is indicative of a belief that effort influences fishing mortality rate. The largest single fleet catching cod in the area is based in Scotland and TR1 effort has reduced substantially from around 2003 following a number of major decommissioning schemes (Figure 6). TR2 effort has also reduced but to a lesser degree. A simple multiple regression of mean F on TR1 and TR2 effort gives an R-squared value for ALD of 90% and TSA 52% (Table 1). In the TSA case the coefficient for TR1 is not significant. A similar percentage of variance explained can be obtained using total EU regulated gear effort.

In the TSA assessment the reduction in mean F is proportionately much lower than the reduction in effort and means that cod catchability must have increased to compensate for reduced effort. There is evidence that the area operated by the fishery is now more limited and high catchability could be explained if the remnant cod population has reduced to occupy the same area, i.e. that the density of fish has remained high but is confined a smaller area. Given that most cod caught are discarded this must mean that the main target species for the fleet, haddock, is also abundant in this area.

For the ALD assessment the reduction in F is approximately the same as the reduction in effort and spatial effects are not required to explain the change in F.

Seals

Predation by seals on cod has long been a source of controversy. The Sea Mammal Research Unit (SMRU) at St Andrews University, UK, has undertaken diet studies of grey and harbour seals for a number of years. For Division 6a estimates of grey seal consumption of cod are available for 1985, 2002 and 2010/11. The estimates for these years are fairly similar and range between 5000-8000 tonnes. Hence the range for seal consumption in 2010 is higher than the estimate of total stock biomass emerging from the TSA assessment for this year (4377t). It has been suggested that seals exploit a different cod population, i.e. that there are distinct populations of cod, one exploited by seals and another by the fishery. If the seal consumption in 2010 was approximately 7600t (Hammond and Wilson, 2016) and we assume that they can exploit up to 30% of the biomass, this would suggest a biomass of cod of approximately 25000t that is currently unavailable to the fishery. Studies of seal movements show that they appear to forage in areas where the fishery does not operate (Matthiopoulos et al 2004) and this satisfies one condition for the two stock hypothesis. A further requirement is that the population exploited by seals does not mix with the fished stock. If it did the assessment would estimate a higher biomass and lower F as is seen in the ALD assessment. Tagging studies that can only access the fished stock show that cod in 6a can move large distances (Figure 7). This shows the potential for stock mixing but clearly cannot explicitly identify mixing with the hypothesised second stock. The results do show, however, that 6a cod mix with the North Sea.

The ALD assessment is consistent with the two stock hypothesis but does not require it to explain the scale of seal consumption. In effect the seal exploited stock is added to the fished stock and this shows up in the biomass estimates that are much higher and Fs that are lower. For 2010, ALD estimates the SSB to be around 11000t which would correspond to a total biomass of around 15000t. Assessments that assume stock mixing have been performed that explicitly include seal predation as a dynamic component (Cook and Trijoulet, 2015) and these produce estimates of SSB and F that are similar to the ALD assessment. These models allocate more of the unreported catch to seal predation than assessments that do not include seals.

Retrospective analysis

The new TSA assessment is little changed from the 2018 ICES assessment apart from the significant downward revision of F in 2017 from 0.96 to 0.59 (Figure 8). A similar revision occurred when the 2017 ICES assessment was updated where the 2016 F was revised from 0.94 to 0.63. It shows that the model previously had a tendency to significantly over-estimate terminal F. The new TSA settings still give a retrospective pattern that shows major shifts in terminal F most notably around 2010 (Figure 9). This has been attributed to the effect of introducing new survey series but the anomaly is absent from the ALD retrospective analysis (Figure 1) which uses the same survey series.

The need for more than one stock assessment model

When configured to estimate fishing selectivity without constraints on shape, TSA and ALD estimate quite different patterns and this difference cascades through the assessment. The shape of the selection pattern from ALD may be producing unrealistically low values for the older ages. This is quite possible but is not unprecedented. Irish Sea cod have even lower selectivity at the oldest age and North Sea cod has a dome shaped pattern. TSA estimates an asymptotic pattern which is quite plausible especially for homogeneous trawl fisheries exploiting a well-mixed population. However, the increasing proportion of TR2 effort might be expected to favour a higher selectivity at younger ages. Explanations can be proposed for either form of selection but none are conclusive without further investigation. On other stocks to which the two models have been applied, they produce reasonably similar selection patterns (haddock and 6a whiting, Figure 3) suggesting there is no strong inherent bias toward a particular shape in either model. When the exploitation pattern is constrained to asymptotic in ALD, it will produce very similar results to TSA (Cook, 2019).

The analysis discussed at the IBP shows that the TSA results are robust to model assumptions on selectivity and the inclusion/exclusion of data. This is a good thing. On the other hand, the ALD model has a more consistent retrospective pattern for F and shows a closer association with changes in fishing effort that are also evident in other stocks taken in the fishery.

Unfortunately, the perception of stock status from the two approaches is quite different. TSA suggests the stock is well below B_{lim} and F well above F_{MSY}. ALD suggests the SSB is close to B_{lim} but with F below F_{MSY}. These differences have management consequences. At this stage the models represent a range of uncertainty that needs to be taken into account in formulating management advice. If the emergent stock status was similar, matters of detail would be much less important and choosing a preferred model to base specific catch options would not be critical. At present it is necessary to characterise the range of uncertainty which means applying a range of models. To that end additional models such as SAM (Nielsen and Berg, 2014) and AAP (Aarts and Poos, 2009) may well make a useful addition to understanding where the principal issues with the assessment lie.

It is not difficult to see the problems of reliance on a single model. In 6a cod alone, minor changes to the model settings result in a significant downward estimate of terminal F with no change in the available data. For North Sea cod a single year update has resulted in a major change in the perceived status of the stock in relation to $B_{trigger}$. Even more dramatic is the change in the assessment for Irish Sea cod where F_{2015} was revised downward in 2017 from 1.077 to 0.07 as a result both of data revisions and a change in assessment model. These problems arise because neither model nor data uncertainty are characterised in annual assessments and ultimately reliance is placed on variance estimates derived from a single model configuration. It might be argued that the place to investigate uncertainty comprehensively is at benchmarks but the failure to characterise the robustness of annual assessments gives the impression of much greater certainty than is merited. While the assessments have passed the ICES quality procedures, all too often erratic management advice is the result.

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Table 1. Multiple regression of mean F from ALD and TSA assessments on Scottish fishing effort.

ALD model

	Estimate	SE	t value	p
Intercept	-5.03E-01	1.11E-01	-4.526	0.000475
TR1	4.01E-05	8.22E-06	4.878	0.000244
TR2	1.42E-04	2.83E-05	5.015	0.000189

R-squared=0.90

TSA model

	Estimate	SE	t value	p
Intercept	1.030E-02	2.774E-01	0.037	0.9709
TR1	9.846E-06	2.052E-05	0.480	0.6388
TR2	1.952E-08	7.064E-09	2.764	0.0152

R-squared=0.517

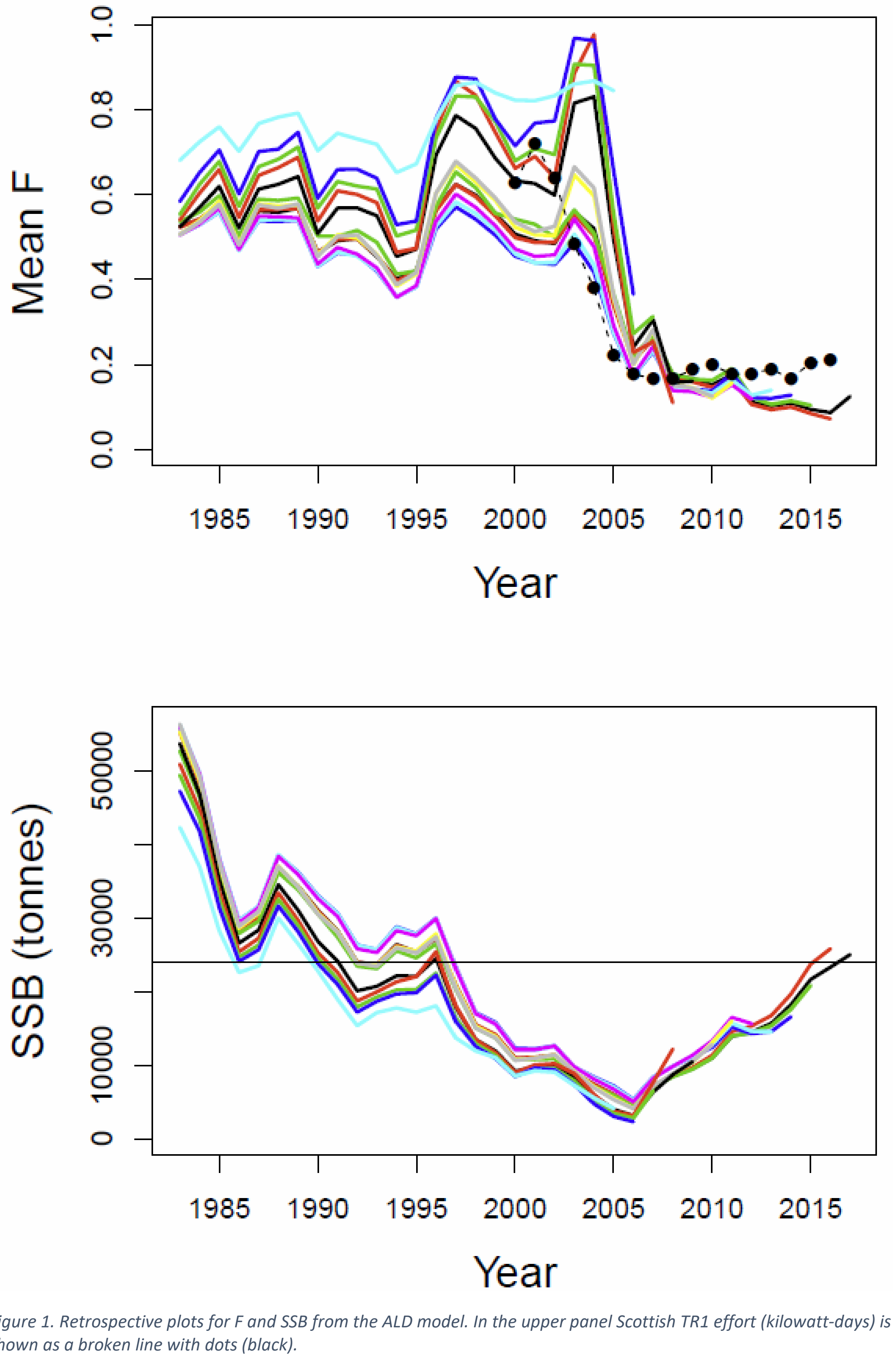


Figure 1. Retrospective plots for F and SSB from the ALD model. In the upper panel Scottish TR1 effort (kilowatt-days) is shown as a broken line with dots (black).

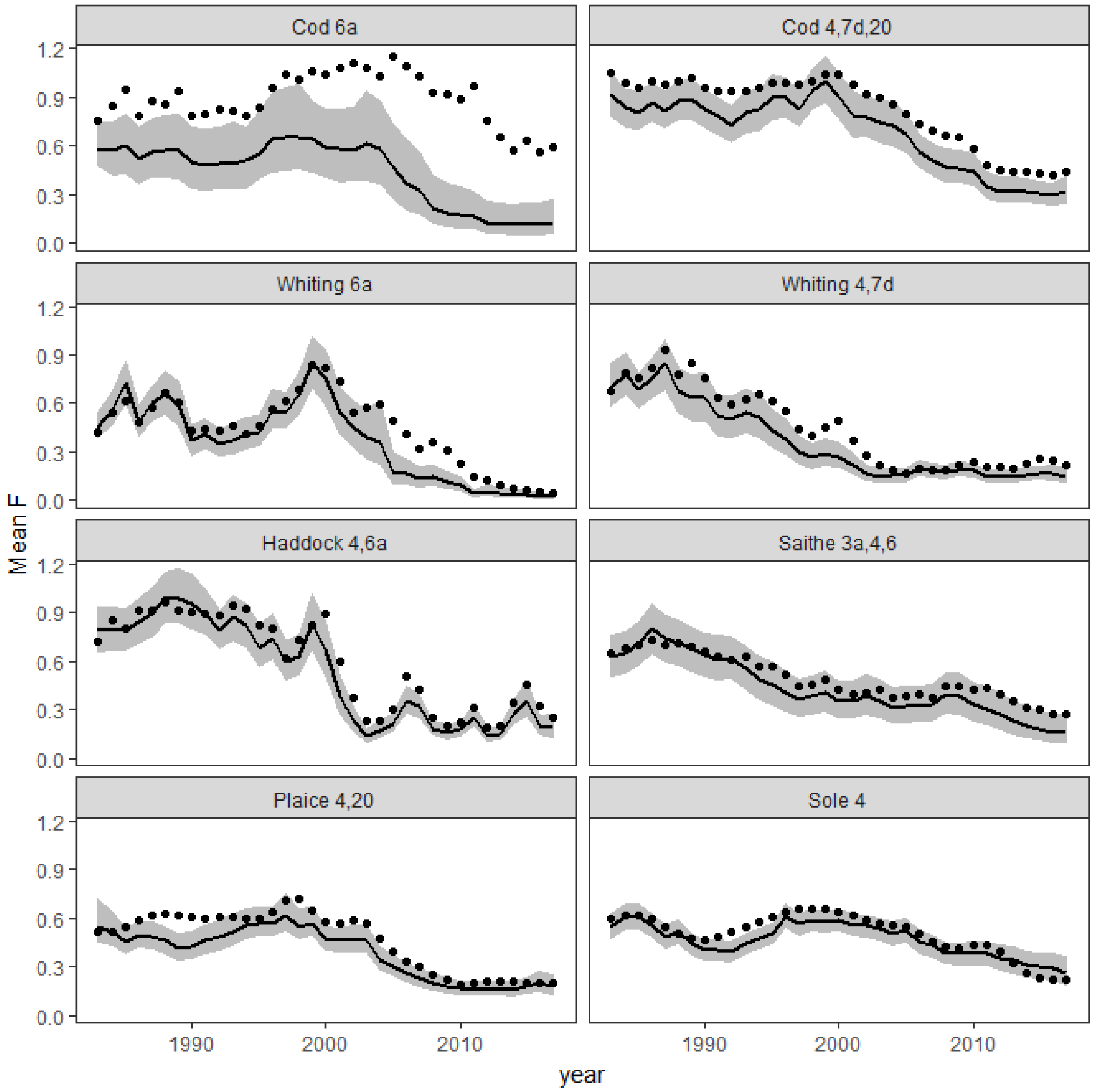


Figure 2. Mean F for demersal stocks in the North Sea and West of Scotland estimated from the ALD model (solid line) and ICES assessments (dots). Shading shows the 95% CI from the ALD model. For cod in 6a, the values are from the new TSA settings.

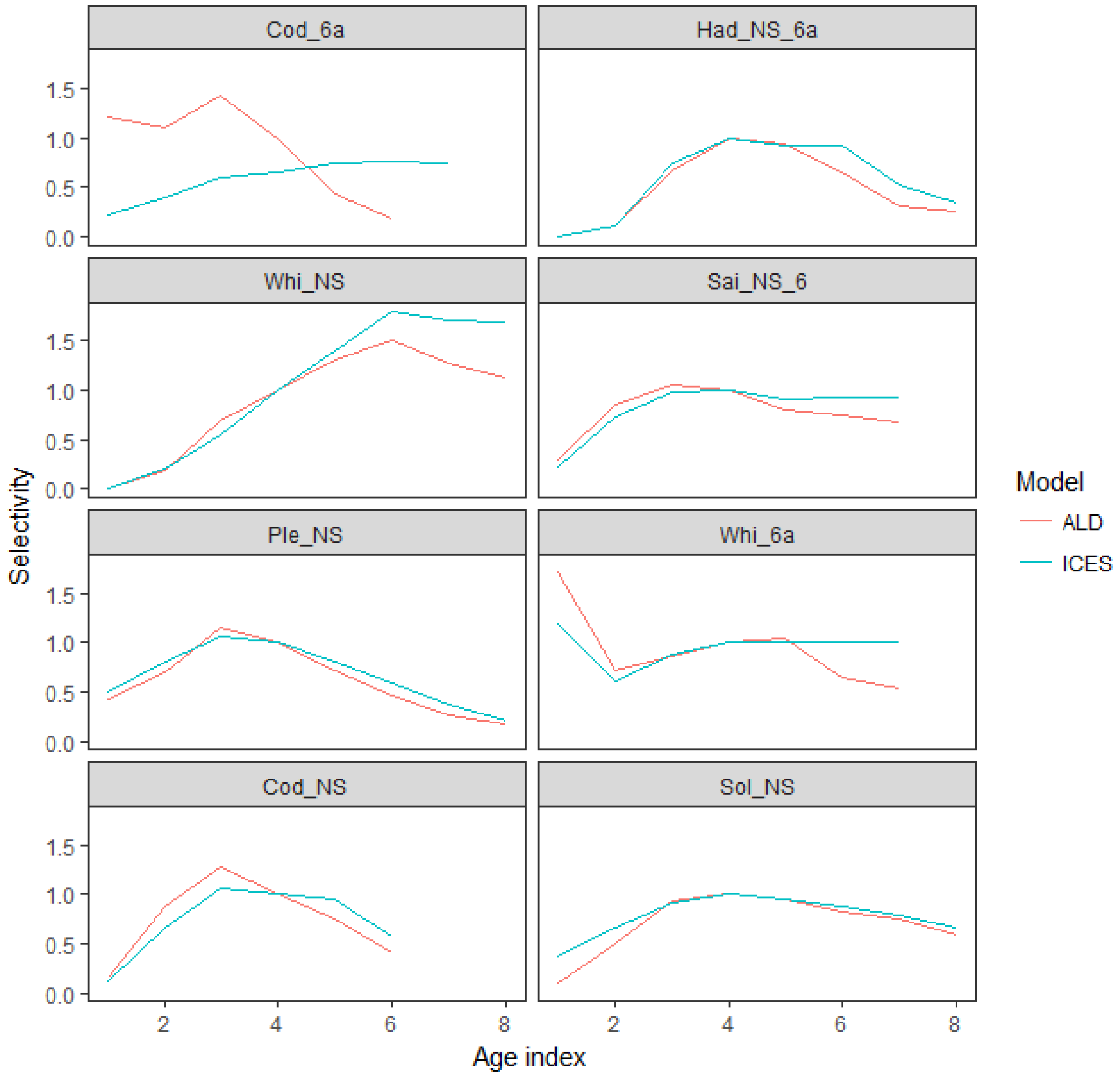


Figure 3. Selection pattern for a range of demersal stocks in the North Sea and West of Scotland as estimated from ALD (red) and ICES assessments (blue). The patterns are all scaled to index age 4. For most stocks index age 1=1. For haddock it is 0 and saithe 3.

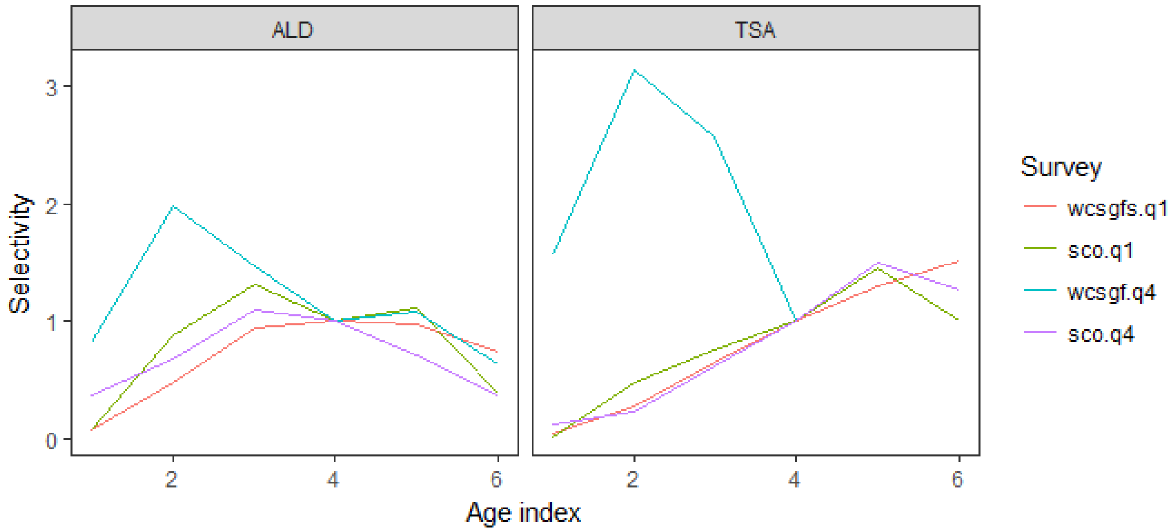


Figure 4. Selection pattern for quarter 1 and quarter 4 surveys (Irish survey excluded) relative to age 4.

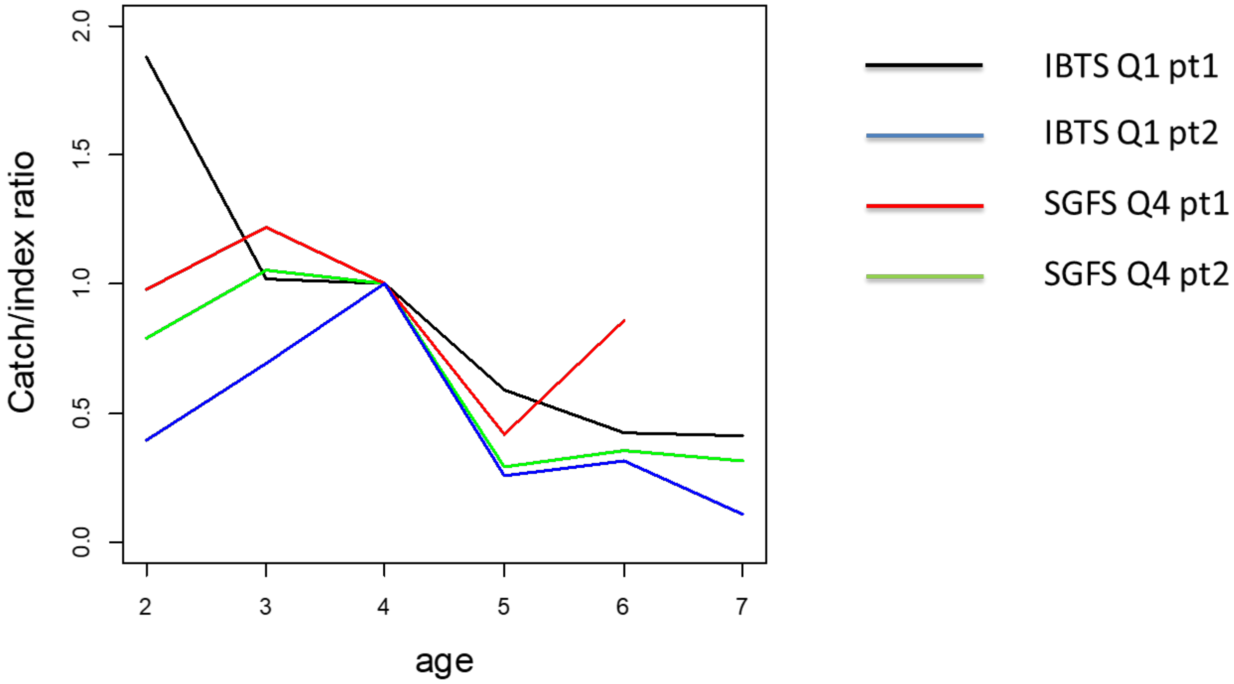
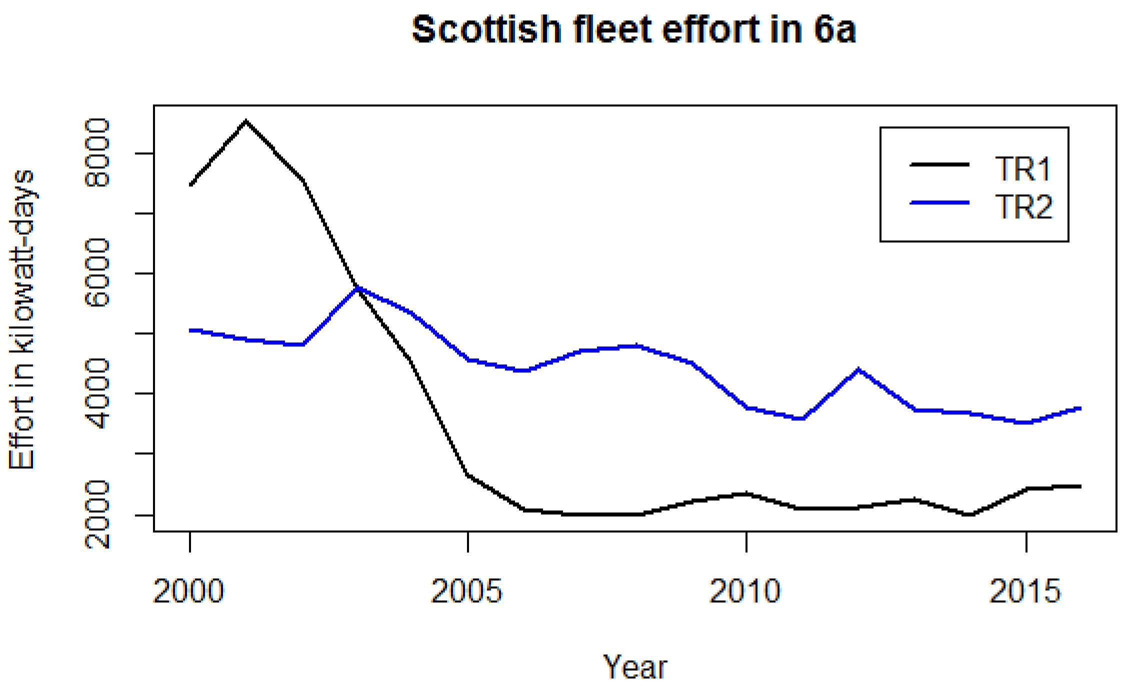


Figure 5. The ratio of mean number at age in the commercial catch to the mean number at age in the various surveys. Values are expressed relative to age 4. Part 2 surveys refer to surveys starting in 2011. Part 1 surveys were discontinued after 2009 or 2010..



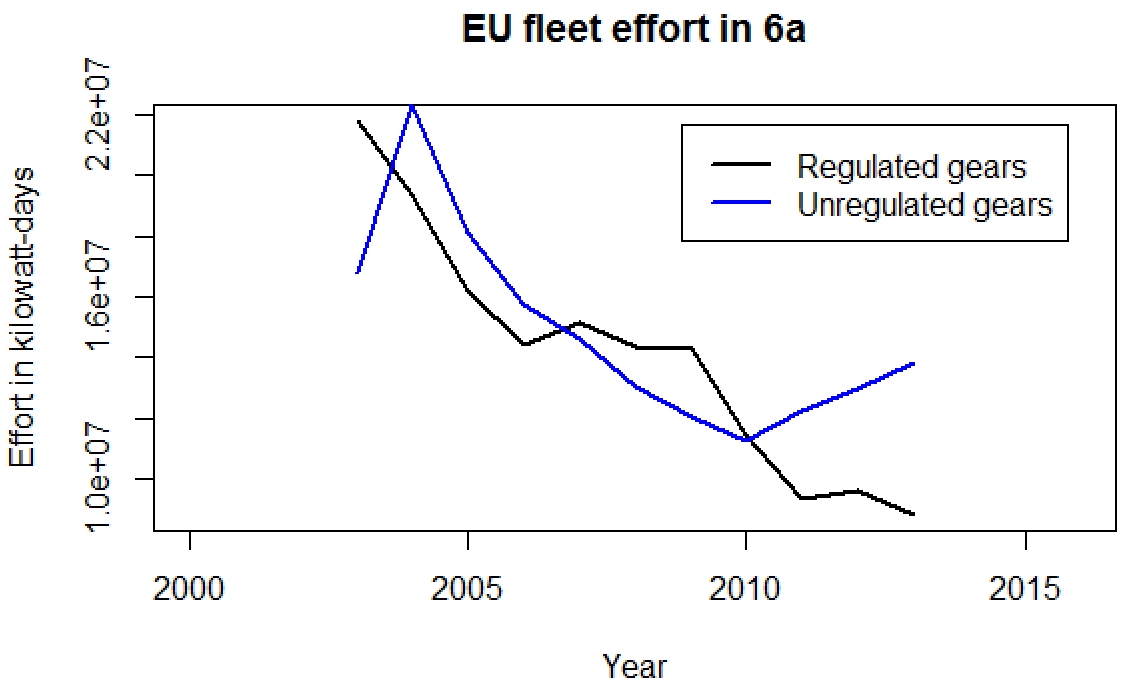


Figure 6. Fishing effort in 6a for gears regulated as part of the cod recovery plan. Scottish effort data are included in the EU effort data.

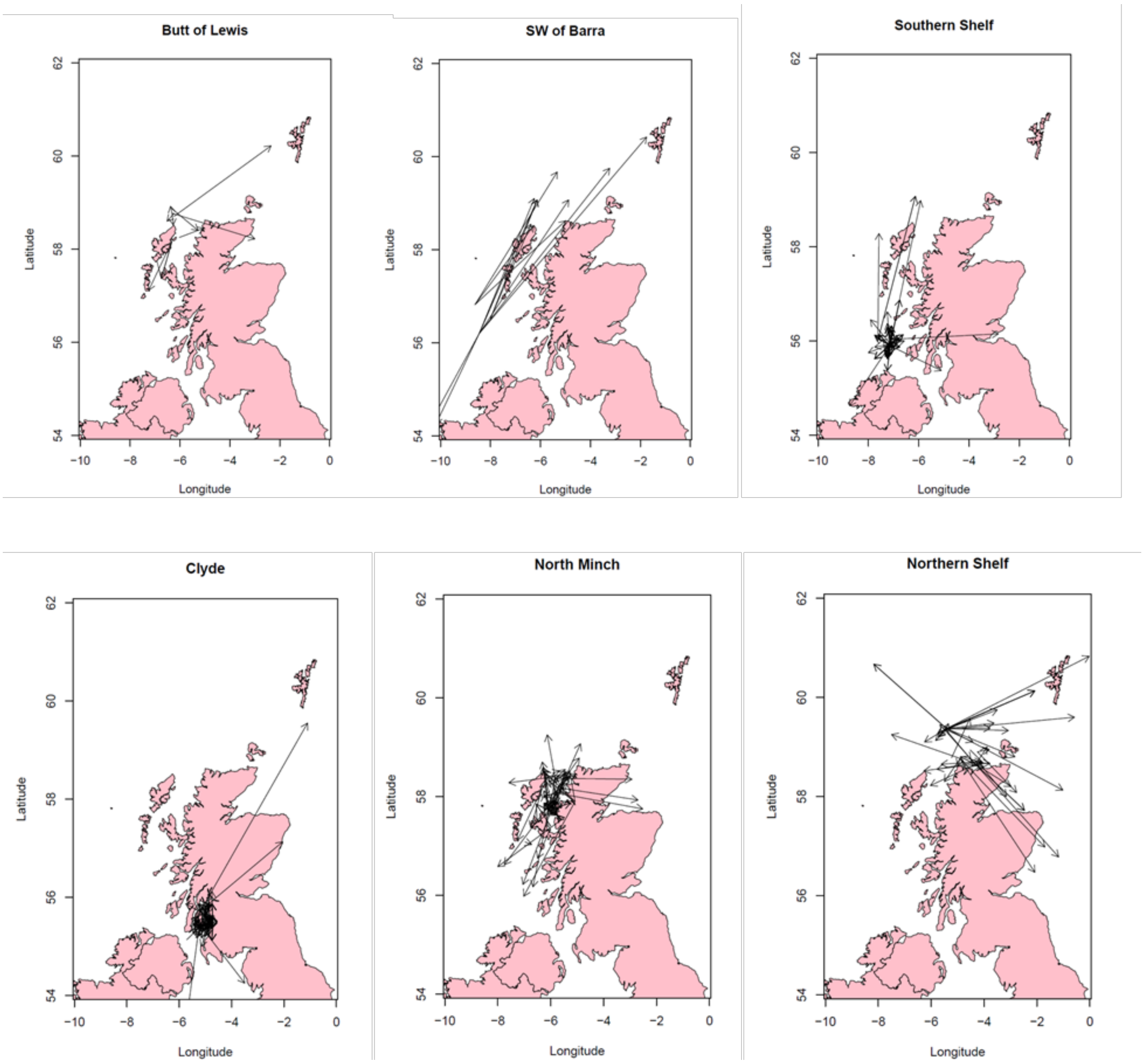


Figure 7. Results of cod tagging experiments conducted by Marine Scotland Science for fish tagged in 6a. The arrow base is the point of release, and the arrow head the point of recapture.

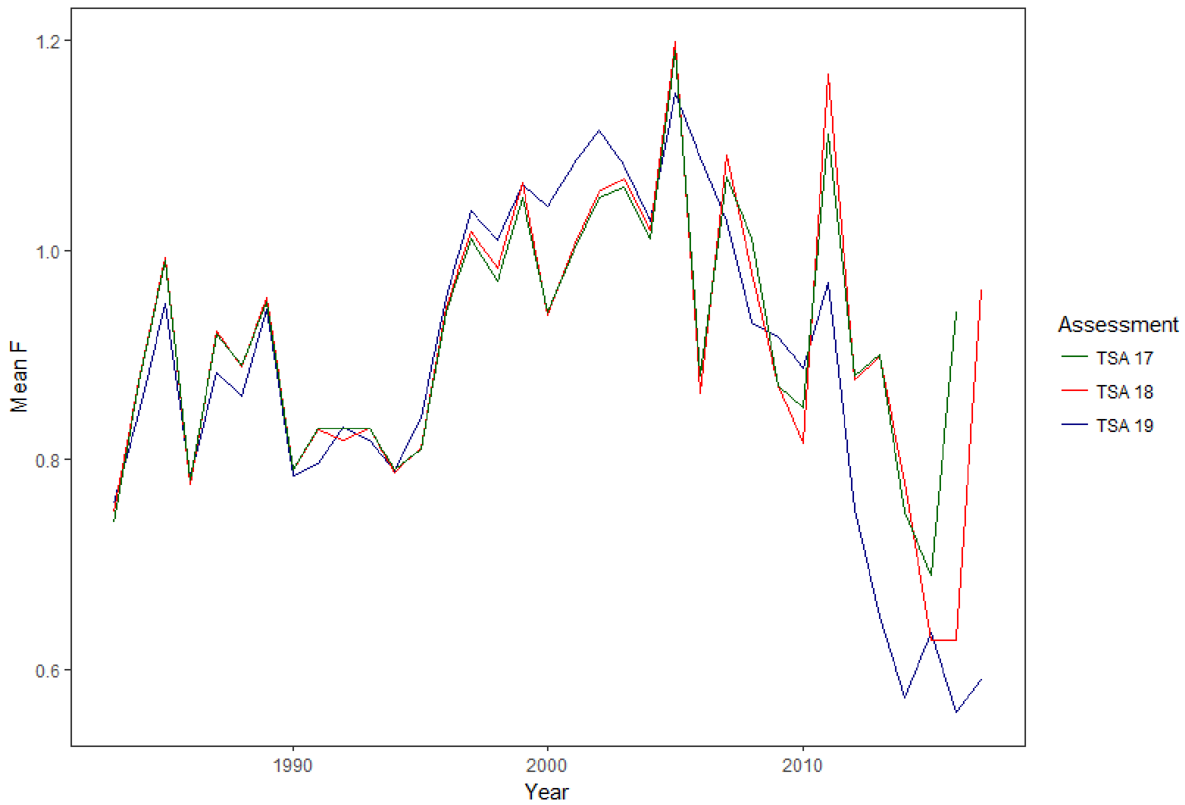


Figure 8. Comparison of mean F from recent TSA assessments for cod in 6a. The main change to the assessment presented at the IBP is the large downward revision of the 2017 estimate.

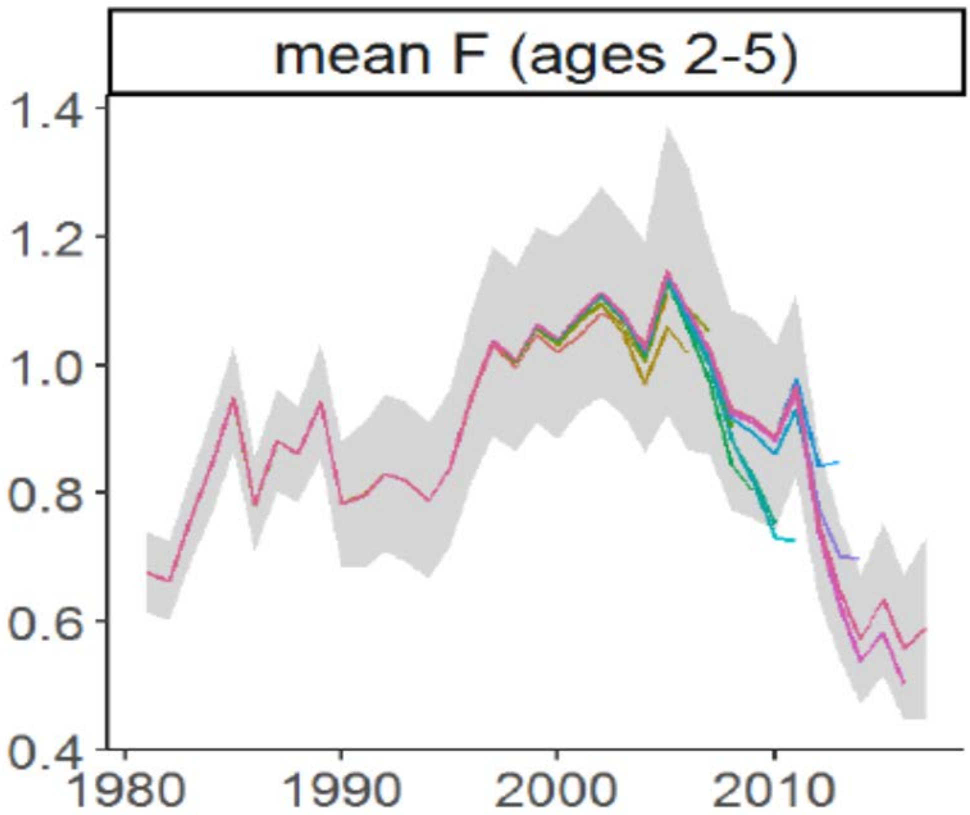


Figure 9. Retrospective analysis for the current TSA assessment.

Annex 4: Outputs and diagnostics from TSA sensitivity runs

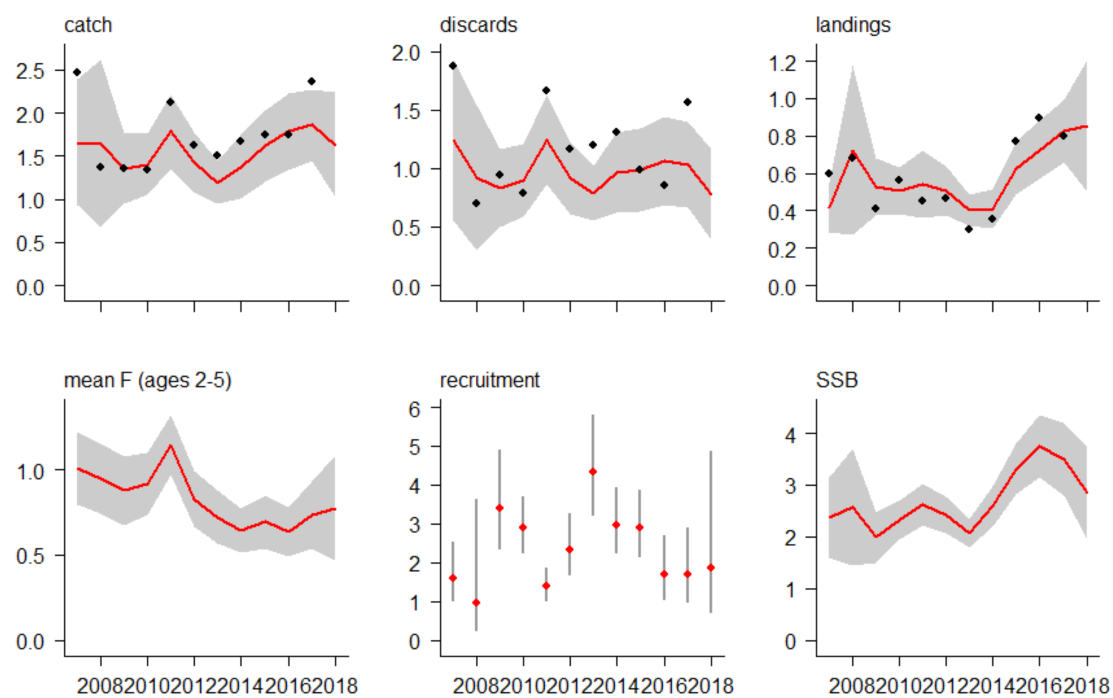
Assessment A3

The following plots show the results and diagnostics from TSA sensitivity run A3, which is described in the WD (Annex 3) and also in the IBP report (Section 2.4 (1)).

Sensitivity Run A3: TSA model output and diagnostic plots

Results

Stock summary

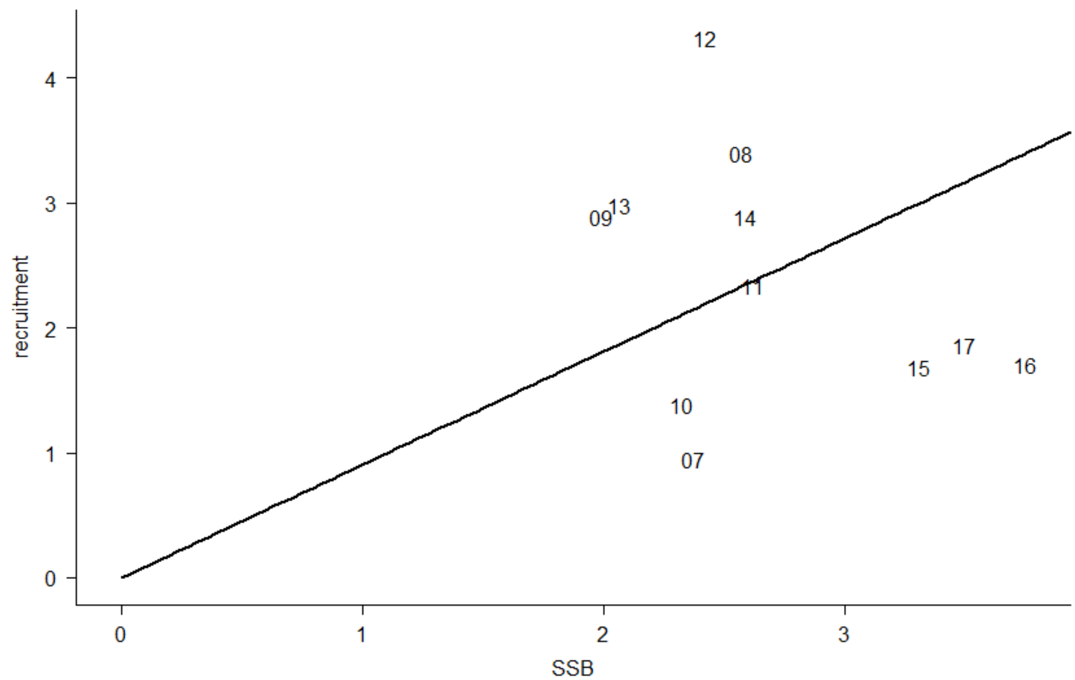


Parameter estimates

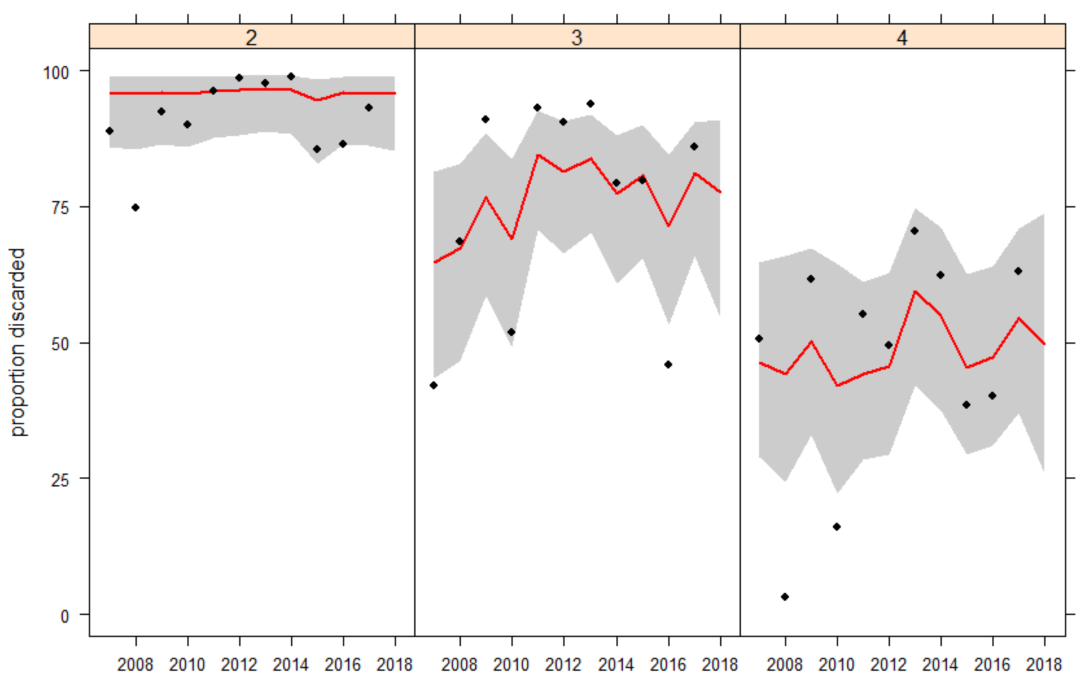
	estimate	lower.bound	upper.bound	active	on.bound
F age 1	0.3791	0.10	0.50	TRUE	FALSE
F age 2	0.4065	0.30	1.00	TRUE	FALSE
F age 3	0.8775	0.30	1.00	TRUE	FALSE
F age 6	1.5628	0.60	2.00	TRUE	FALSE
sd F	0.3028	0.00	0.40	TRUE	FALSE
sd U	0.0000	0.00	0.20	TRUE	TRUE
sd V	0.0690	0.00	0.20	TRUE	FALSE
sd Y	0.0405	0.00	0.20	TRUE	FALSE
cv landings	0.1000	0.05	0.30	FALSE	FALSE
cv discards	0.5000	0.20	0.80	FALSE	FALSE

recruitment alpha (slope at origin)	0.9055	0.50	1.50	TRUE	FALSE
recruitment beta (density dependence)	0.0000	0.00	0.06	FALSE	TRUE
recruitment cv	0.4521	0.25	0.70	TRUE	FALSE
discards sd transitory	0.4454	0.00	1.00	TRUE	FALSE
discards sd persistent	0.0968	0.00	1.00	TRUE	FALSE
SCO.Q1 selection age 1	0.1329	0.05	1.00	TRUE	FALSE
SCO.Q1 selection age 2	2.9075	1.00	10.00	TRUE	FALSE
SCO.Q1 selection age 3	4.0034	1.00	10.00	TRUE	FALSE
SCO.Q1 selection age 4	4.8187	2.00	20.00	TRUE	FALSE
SCO.Q1 selection age 5	9.7073	2.00	20.00	TRUE	FALSE
SCO.Q1 selection age 6	7.6313	2.00	20.00	TRUE	FALSE
SCO.Q1 omega	0.3542	0.00	2.00	TRUE	FALSE
SCO.Q1 beta	0.0000	0.00	0.20	FALSE	TRUE
SCO.Q4 selection age 1	1.2689	0.50	10.00	TRUE	FALSE
SCO.Q4 selection age 2	2.9369	1.00	10.00	TRUE	FALSE
SCO.Q4 selection age 3	6.6845	2.00	20.00	TRUE	FALSE
SCO.Q4 selection age 4	11.6943	2.00	20.00	TRUE	FALSE
SCO.Q4 selection age 5	20.4764	5.00	30.00	TRUE	FALSE
SCO.Q4 selection age 6	32.6821	10.00	40.00	TRUE	FALSE
SCO.Q4 omega	0.2011	0.00	2.00	TRUE	FALSE
SCO.Q4 beta	0.0000	0.00	0.20	FALSE	TRUE

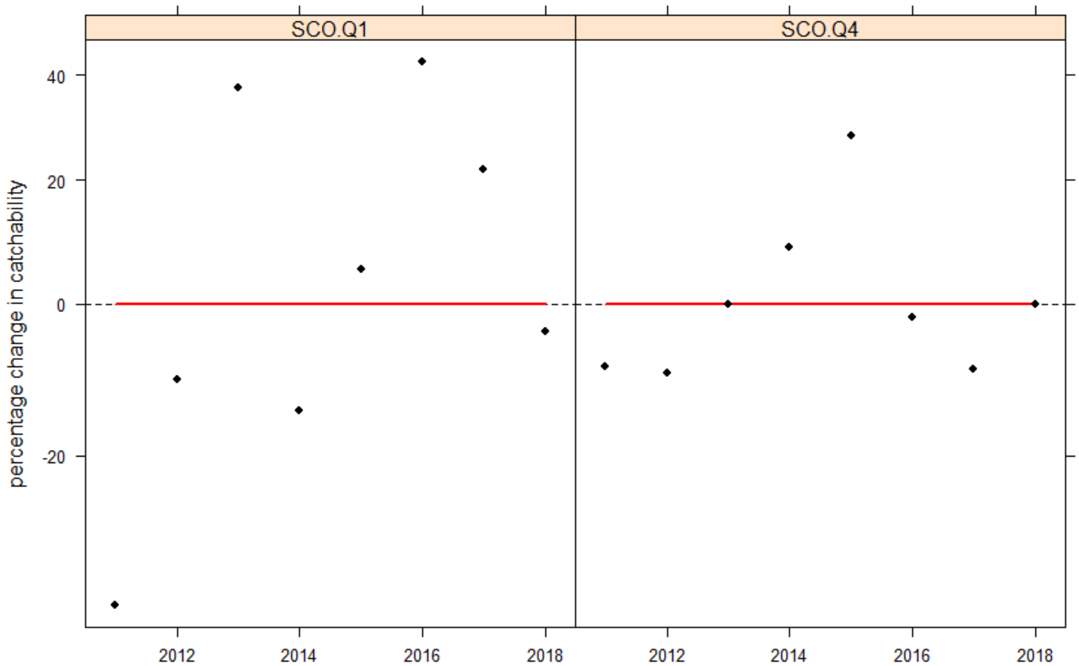
Stock recruit curve



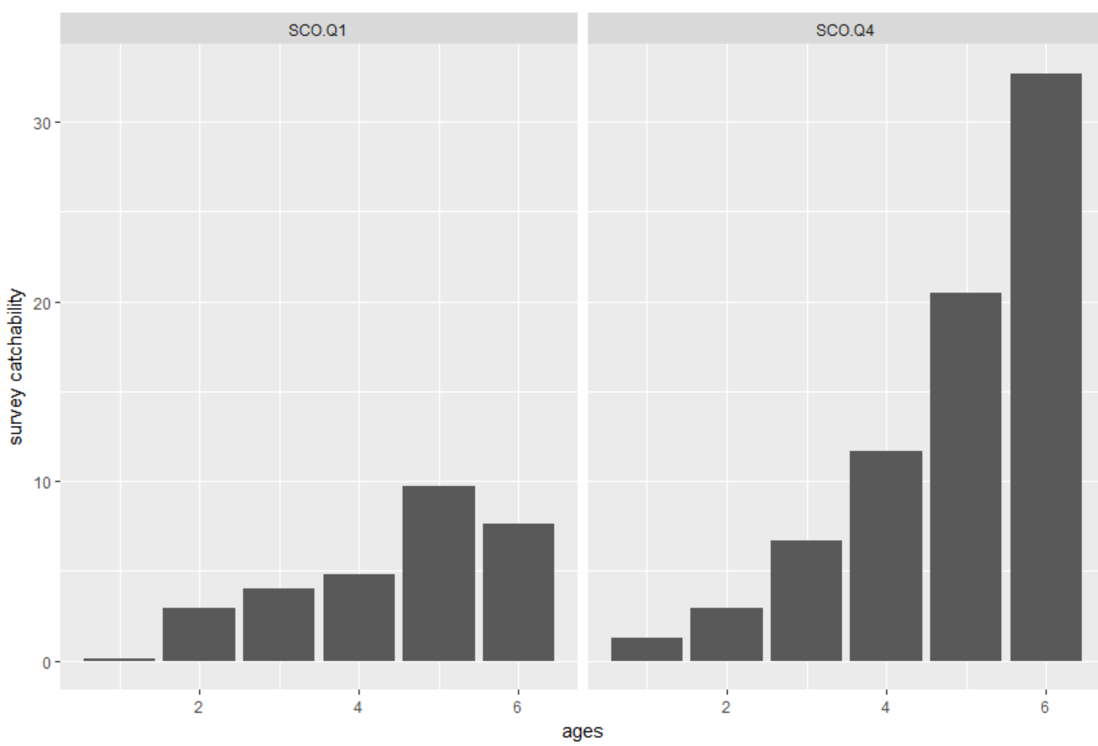
Discards



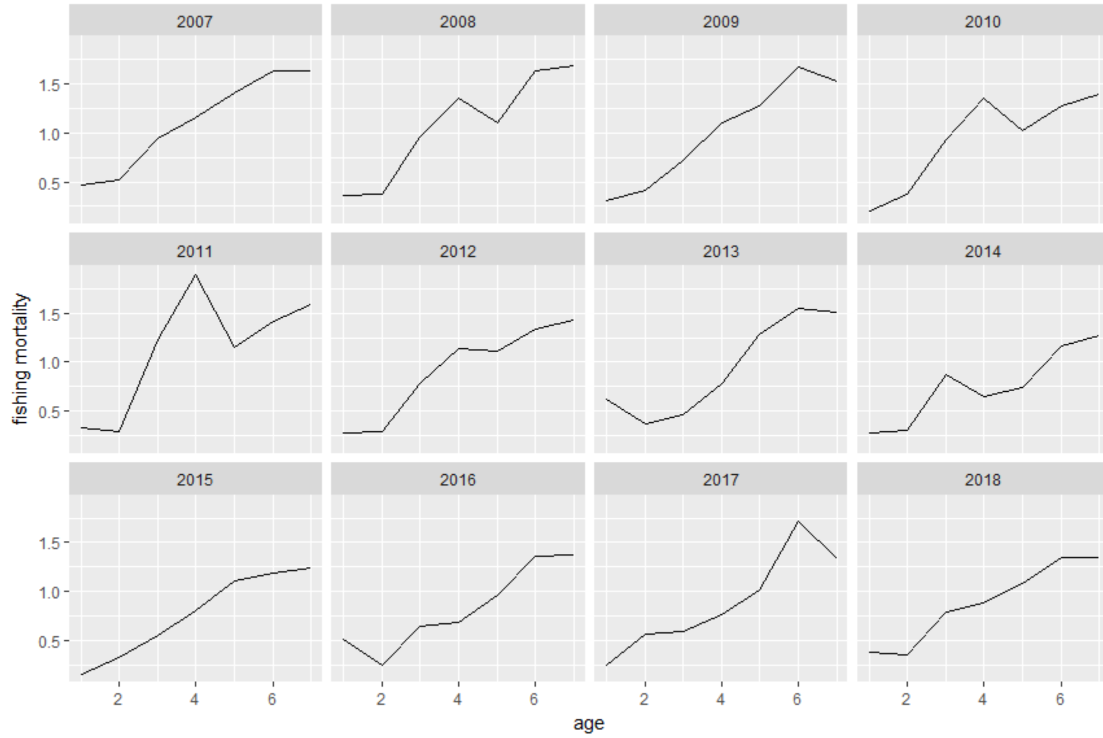
Survey catchability



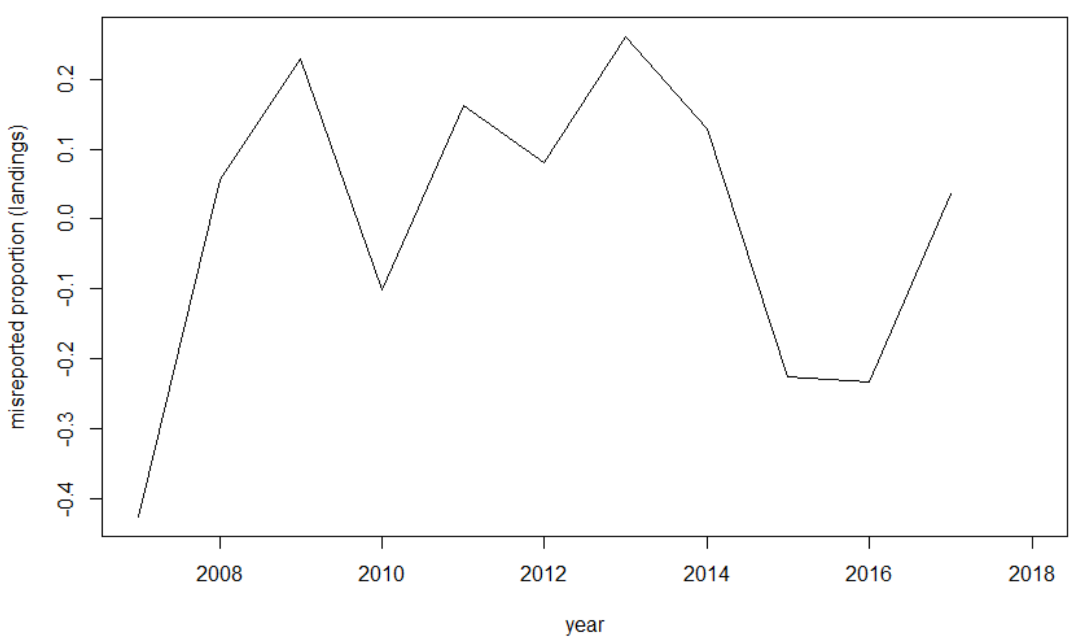
Survey catchability by age



Fishing mortality at age

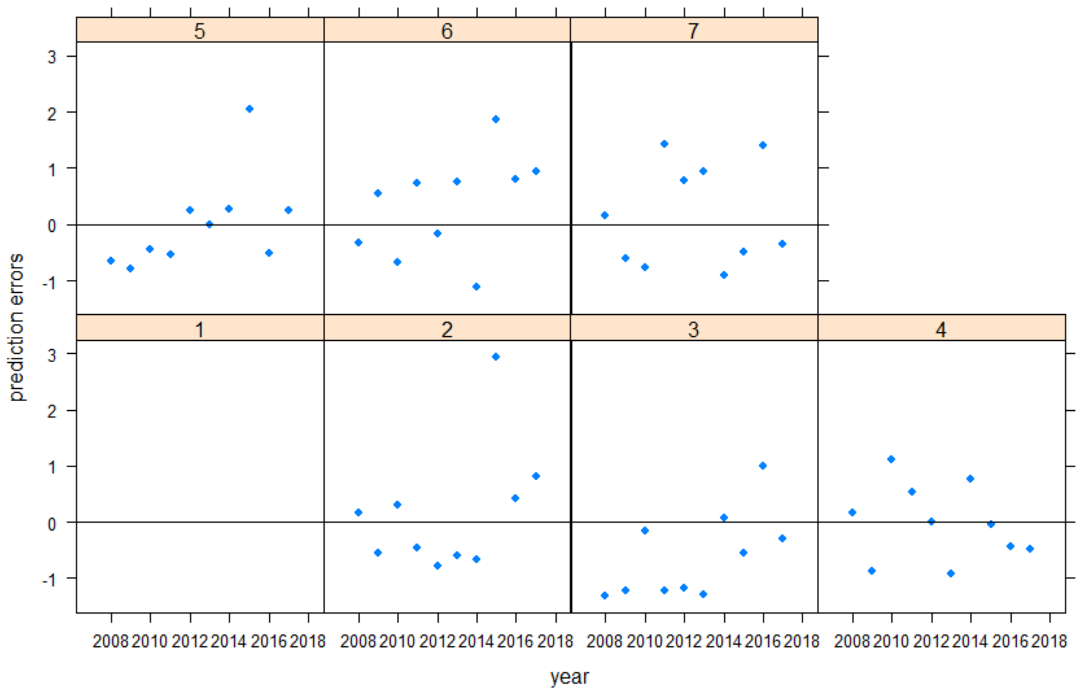


Misreporting estimate

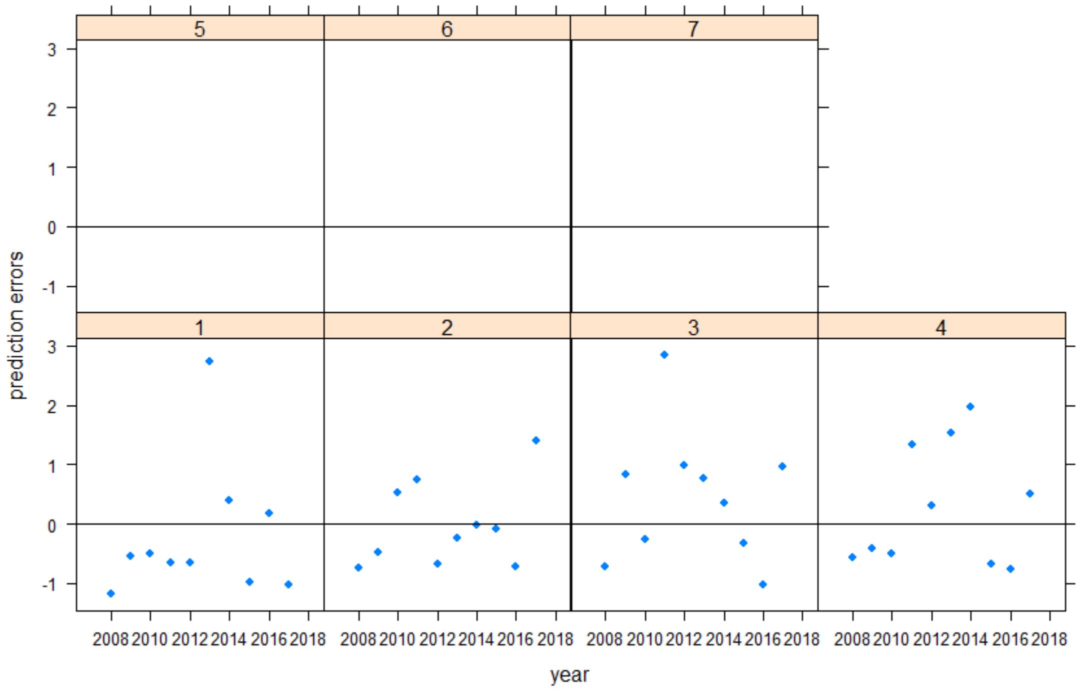


Prediction errors

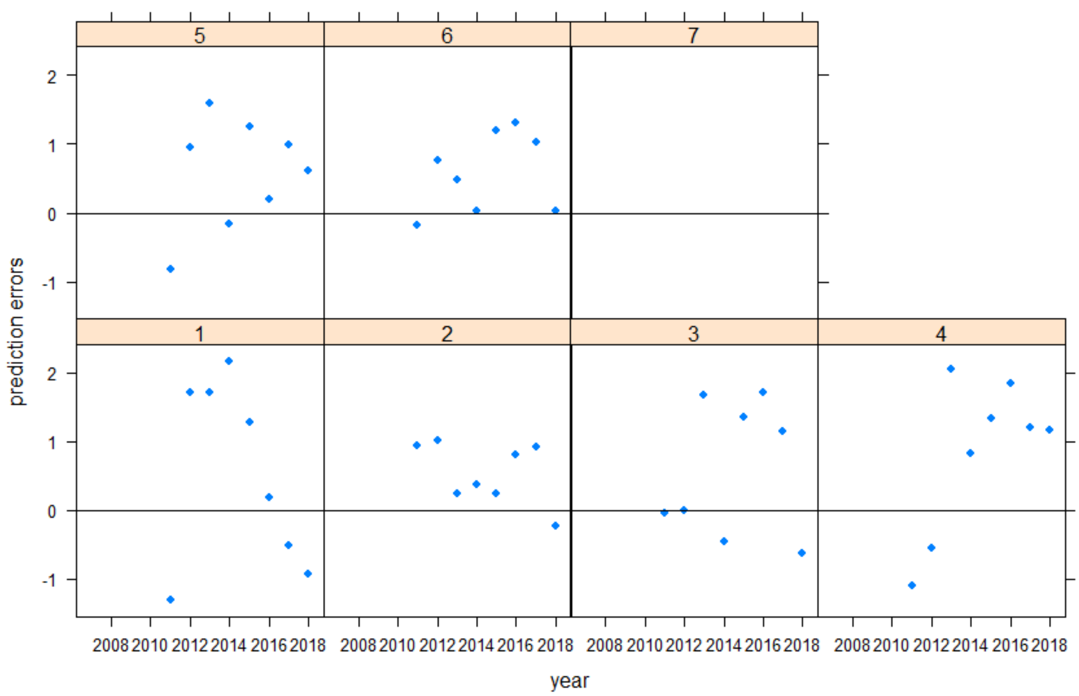
Landings



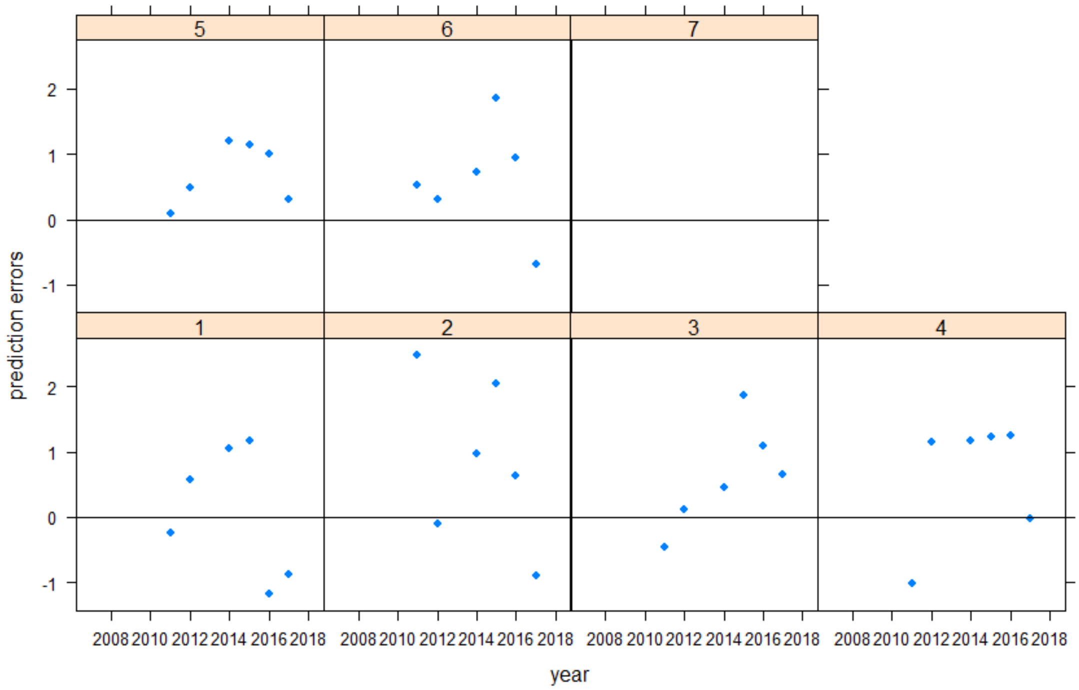
Discards



SCO Q1

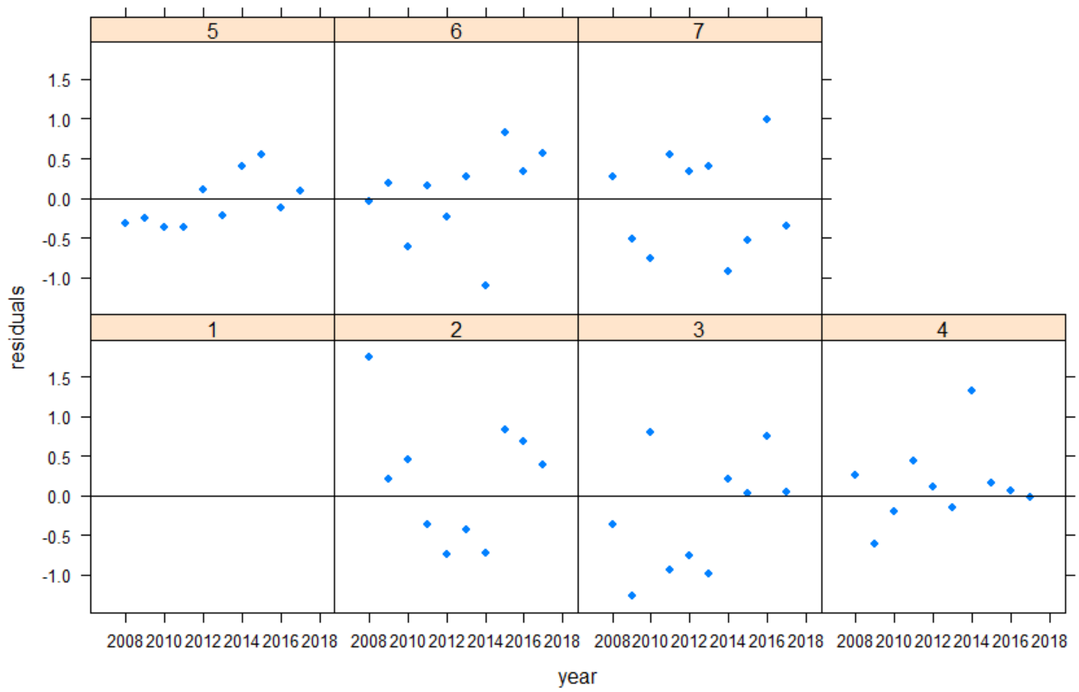


SCO Q4

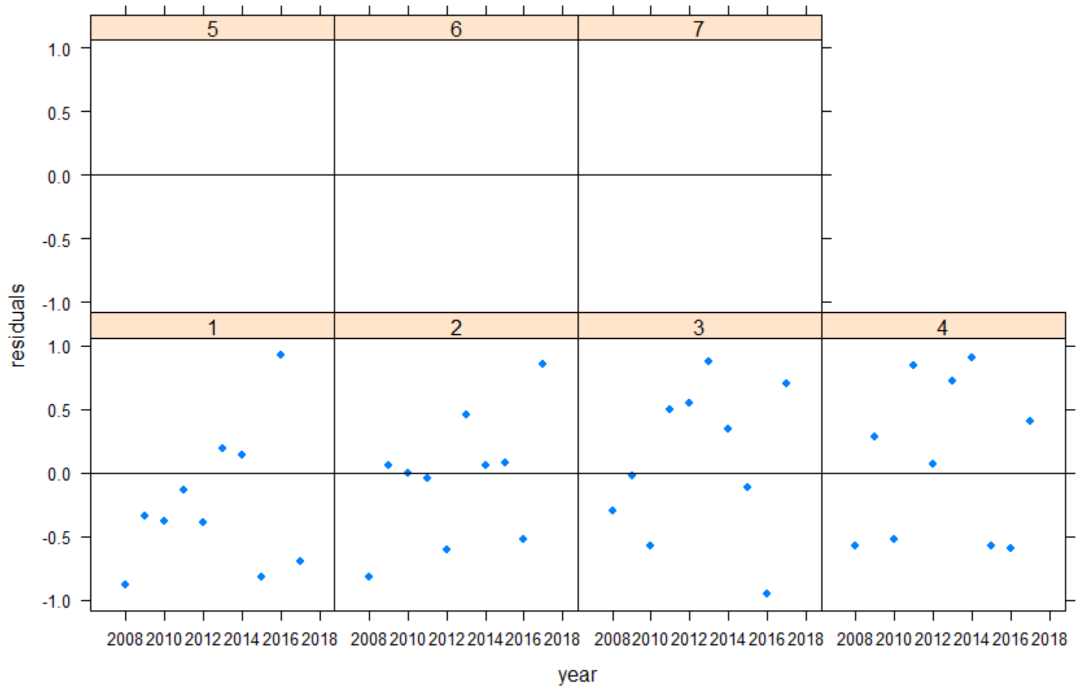

5
6
7
1
2
3
4
prediction errors
2
1
0
-1
2008 2010 2012 2014 2016 2018
year

Residuals

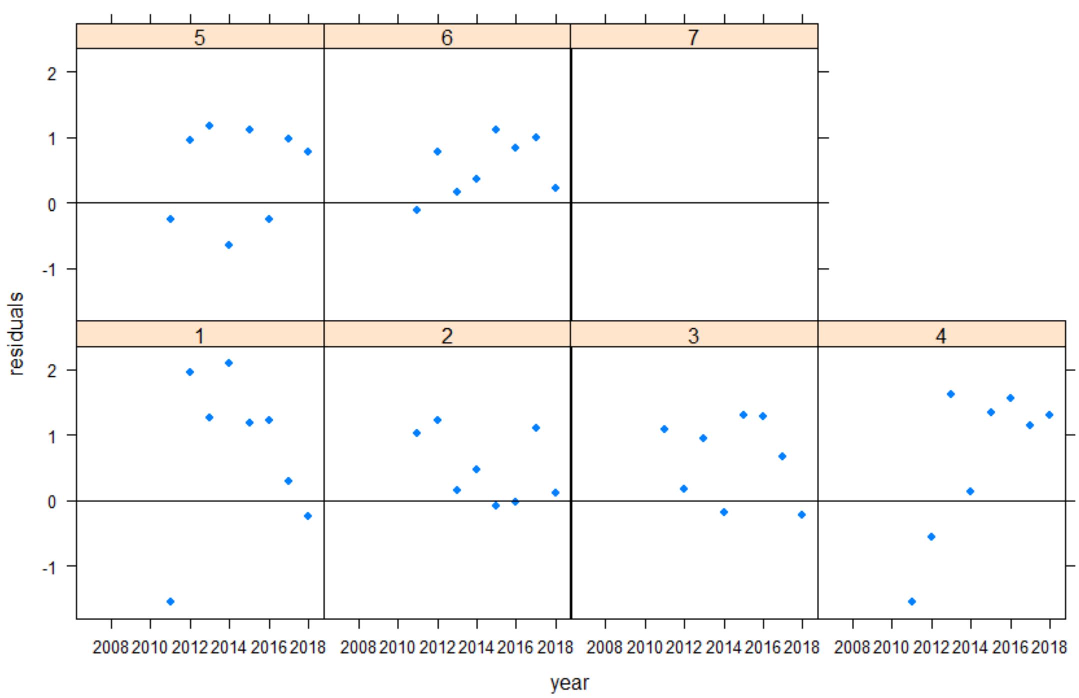
Landings



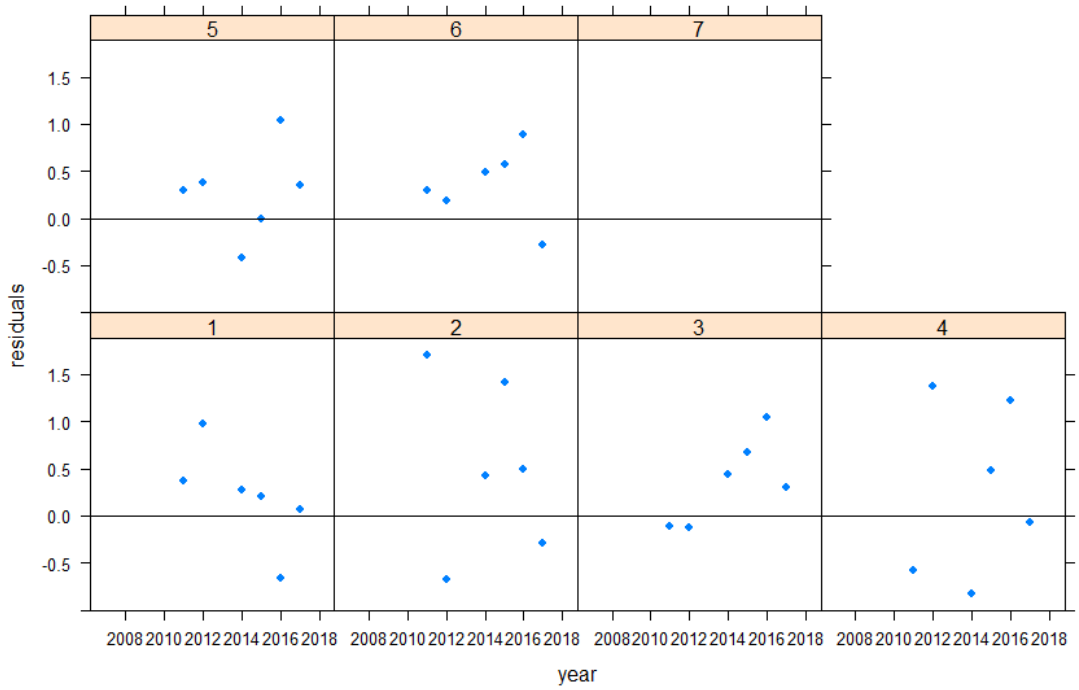
Discards



SCO Q1



SCO Q4


5
6
7
1
2
3
4
1.5
1.0
0.5
0.0
-0.5
residuals
2008 2010 2012 2014 2016 2018
year

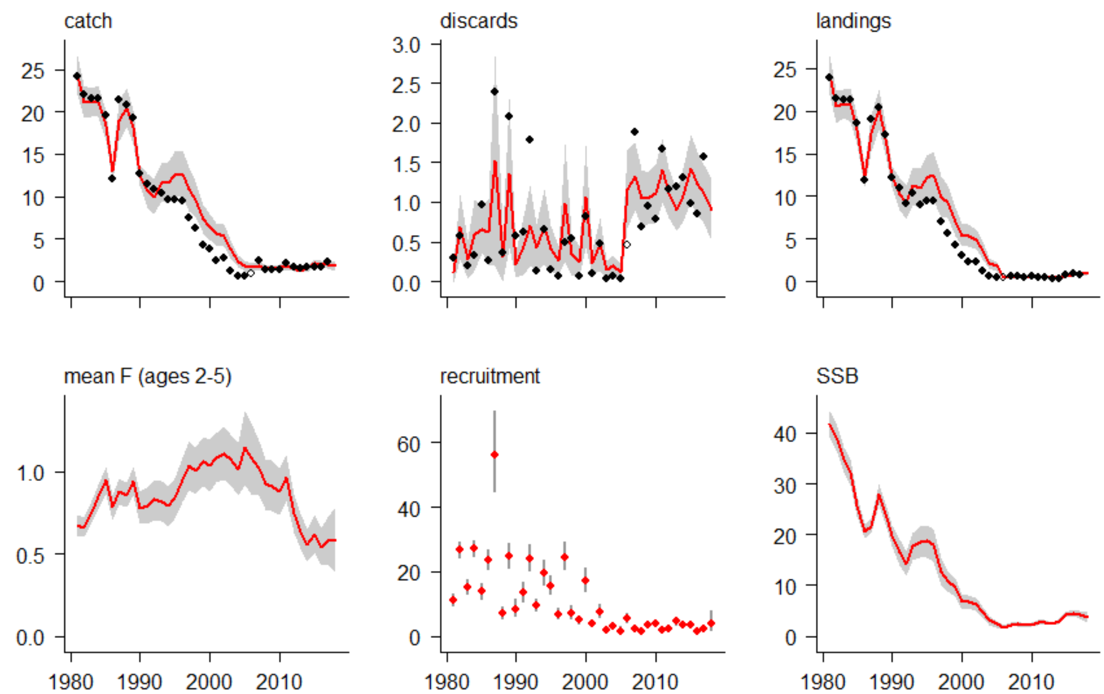
Assessment S2

The following plots show the results and diagnostics from TSA sensitivity run S2, which is described in the IBP report (Section 2.4 (2)).

Sensitivity Run S2: TSA model outputs and diagnostic plots

Results

Stock summary



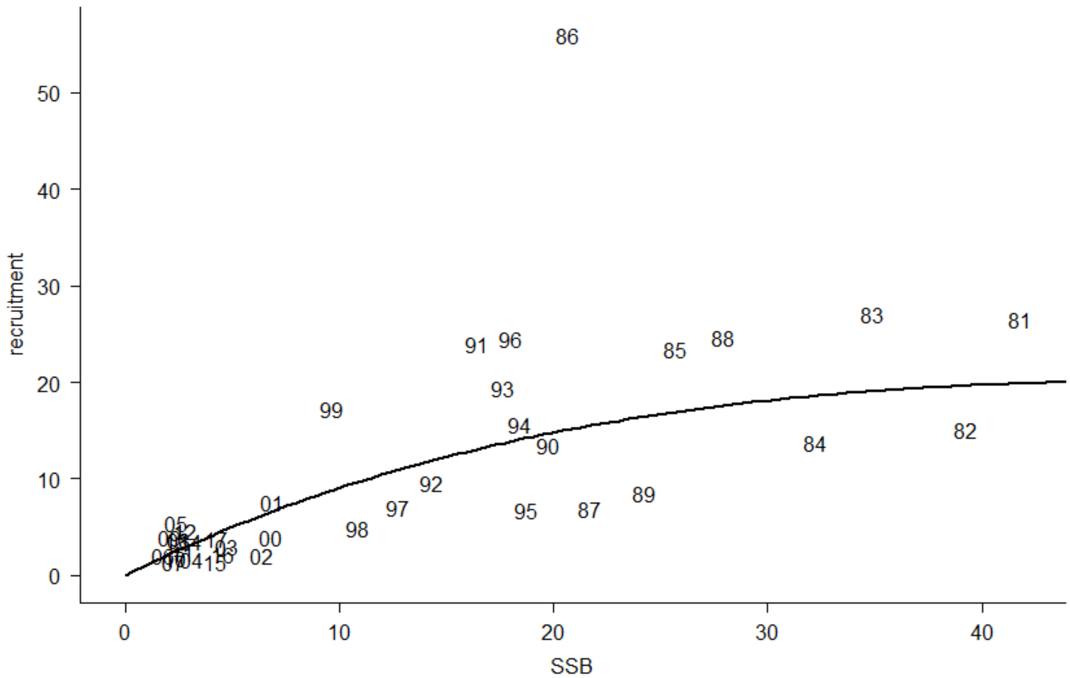
Parameter estimates

	estimate	lower.bound	upper.bound	active	on.bound
F age 1	0.2538	0.10	0.50	TRUE	FALSE
F age 2	0.5708	0.30	1.00	TRUE	FALSE
F age 6	0.7708	0.40	1.50	TRUE	FALSE
sd F	0.1350	0.00	0.20	TRUE	FALSE
sd U	0.0285	0.00	0.20	TRUE	FALSE
sd V	0.0400	0.00	0.20	TRUE	FALSE
sd Y	0.0967	0.00	0.20	TRUE	FALSE
cv landings	0.0838	0.05	0.30	TRUE	FALSE
cv discards	0.5776	0.20	0.80	TRUE	FALSE
recruitment alpha (slope at origin)	1.1105	0.70	1.60	TRUE	FALSE
recruitment beta (density dependence)	0.0203	0.00	0.06	TRUE	FALSE

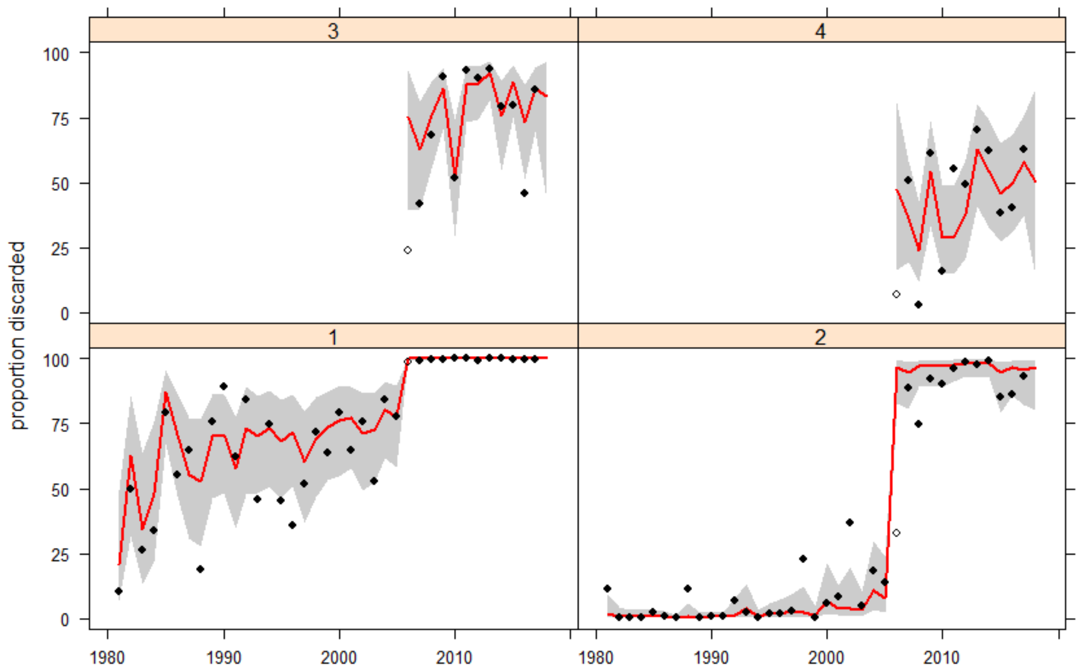
recruitment cv	0.4248	0.25	0.70	TRUE	FALSE
discards sd transitory	0.7705	0.00	1.00	TRUE	FALSE
discards sd persistent	0.2432	0.00	1.00	TRUE	FALSE
step age 1	5.8789	3.00	7.00	TRUE	FALSE
step age 2	6.2127	3.00	8.00	TRUE	FALSE
step age 3	1.1191	-1.00	2.00	TRUE	FALSE
step age 4	-0.1006	-1.50	1.00	TRUE	FALSE
WCIBTS.Q1 selection age 1	0.4766	0.20	1.00	TRUE	FALSE
WCIBTS.Q1 selection age 2	2.7951	1.50	5.00	TRUE	FALSE
WCIBTS.Q1 selection age 3	6.3531	2.00	10.00	TRUE	FALSE
WCIBTS.Q1 selection age 4	11.3780	5.00	15.00	TRUE	FALSE
WCIBTS.Q1 sigma	0.0353	0.00	1.00	TRUE	FALSE
WCIBTS.Q1 eta	1.6514	0.00	2.00	TRUE	FALSE
SCO.Q1 selection age 1	0.6837	0.20	5.00	TRUE	FALSE
SCO.Q1 selection age 2	22.9382	10.00	30.00	TRUE	FALSE
SCO.Q1 selection age 3	38.1650	20.00	70.00	TRUE	FALSE
SCO.Q1 selection age 4	52.2675	20.00	70.00	TRUE	FALSE
SCO.Q1 omega	0.3922	0.00	2.00	TRUE	FALSE
WCIBTS.Q4 selection age 1	3.0622	1.00	5.00	TRUE	FALSE
WCIBTS.Q4 selection age 2	6.3471	2.00	10.00	TRUE	FALSE
WCIBTS.Q4 selection age 3	5.1205	2.00	10.00	TRUE	FALSE
WCIBTS.Q4 selection age 4	1.9802	1.00	10.00	TRUE	FALSE
WCIBTS.Q4 sigma	0.0493	0.00	1.00	TRUE	FALSE
WCIBTS.Q4 eta	2.6170	0.00	3.00	TRUE	FALSE
SCO.Q4 selection age 1	12.1259	5.00	30.00	TRUE	FALSE
SCO.Q4 selection age 2	23.1599	10.00	30.00	TRUE	FALSE
SCO.Q4 selection age 3	59.9209	40.00	80.00	TRUE	FALSE
SCO.Q4 selection age 4	108.0909	50.00	150.00	TRUE	FALSE
SCO.Q4 omega	0.1398	0.00	2.00	TRUE	FALSE
IRGFS.Q4 selection age 1	15.3200	5.00	30.00	TRUE	FALSE
IRGFS.Q4 selection age 2	11.9778	5.00	20.00	TRUE	FALSE
IRGFS.Q4 selection age 3	3.4012	1.00	10.00	TRUE	FALSE
IRGFS.Q4 sigma	0.0358	0.00	2.00	TRUE	FALSE
IRGFS.Q4 eta	1.6228	0.00	4.00	TRUE	FALSE
IRGFS.Q4 omega	0.0184	0.00	2.00	TRUE	FALSE
misrep transitory	0.0097	0.00	0.20	TRUE	FALSE

misrep persistent	0.1508	0.00	0.30	TRUE	FALSE

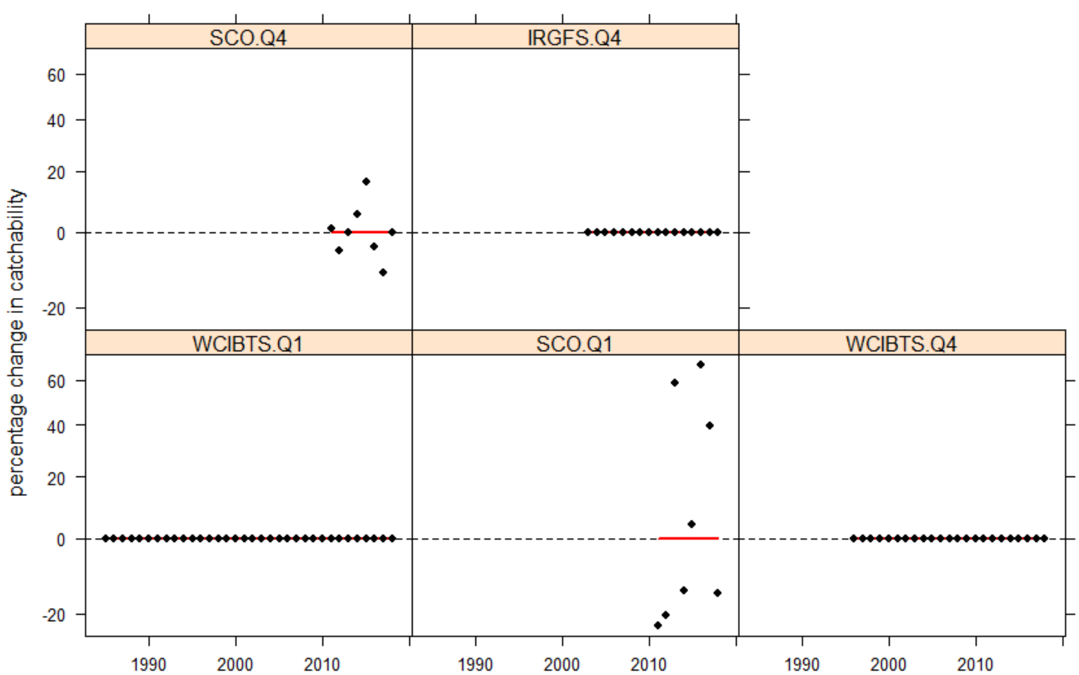
Stock recruit curve



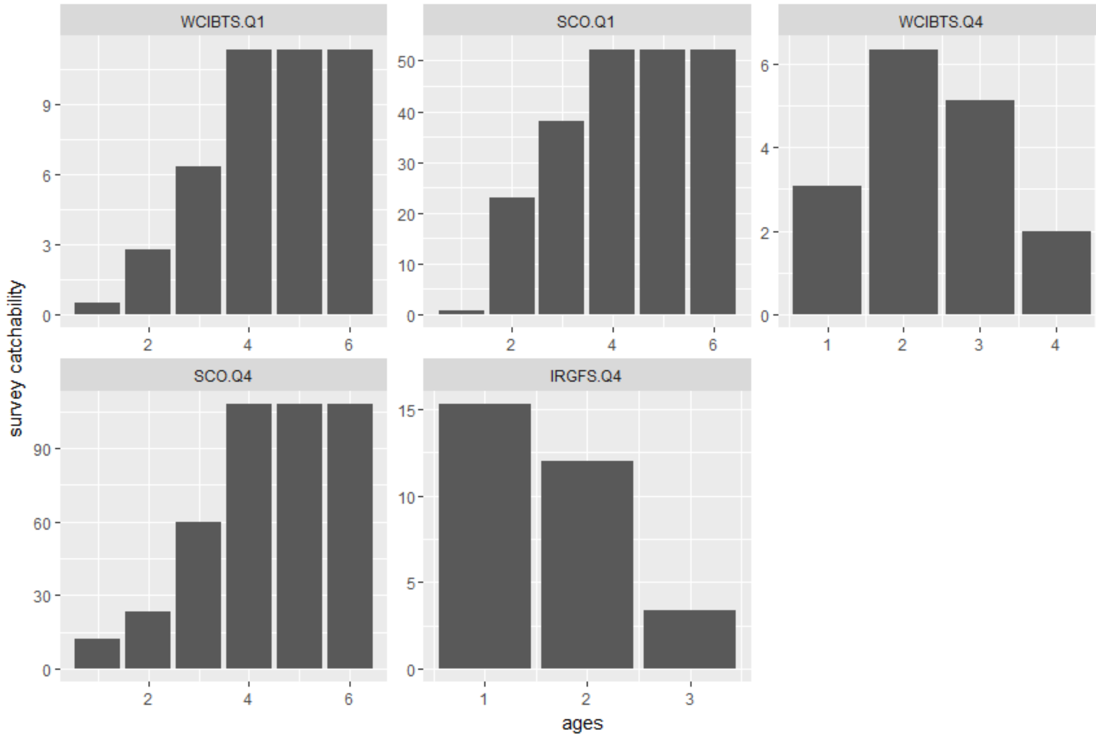
Discards



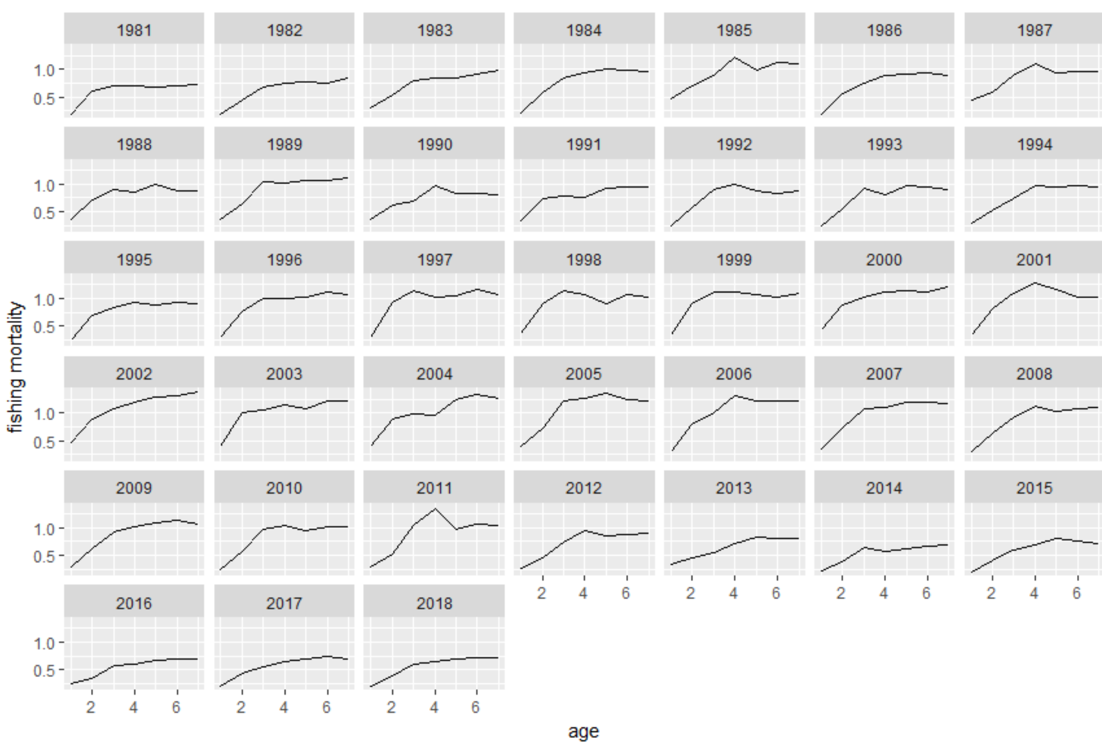
Survey catchability



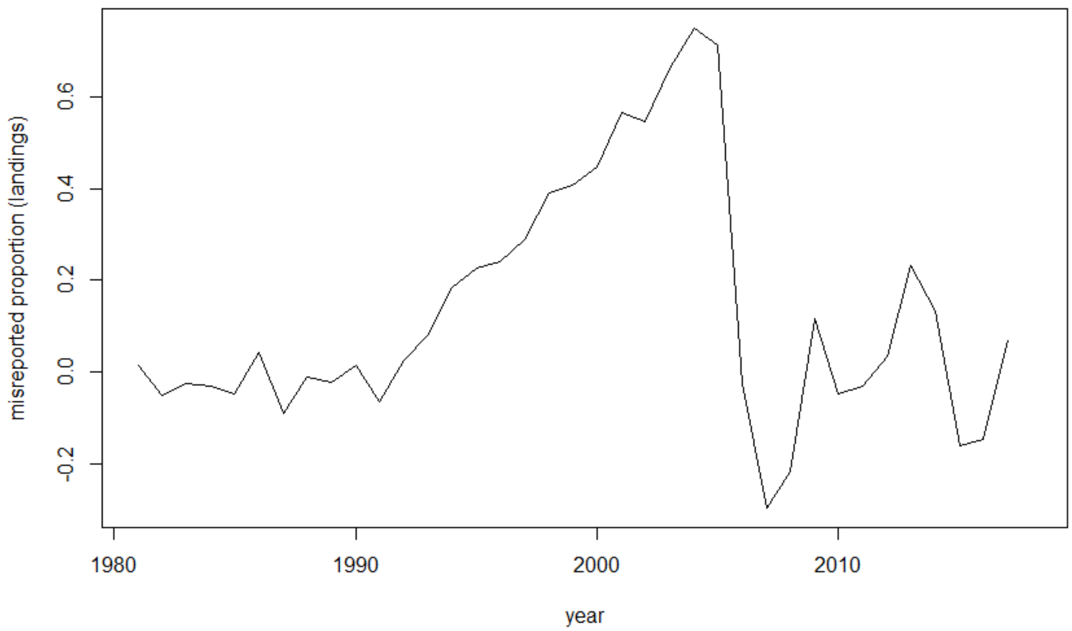
Survey catchability by age



Fishing mortality at age

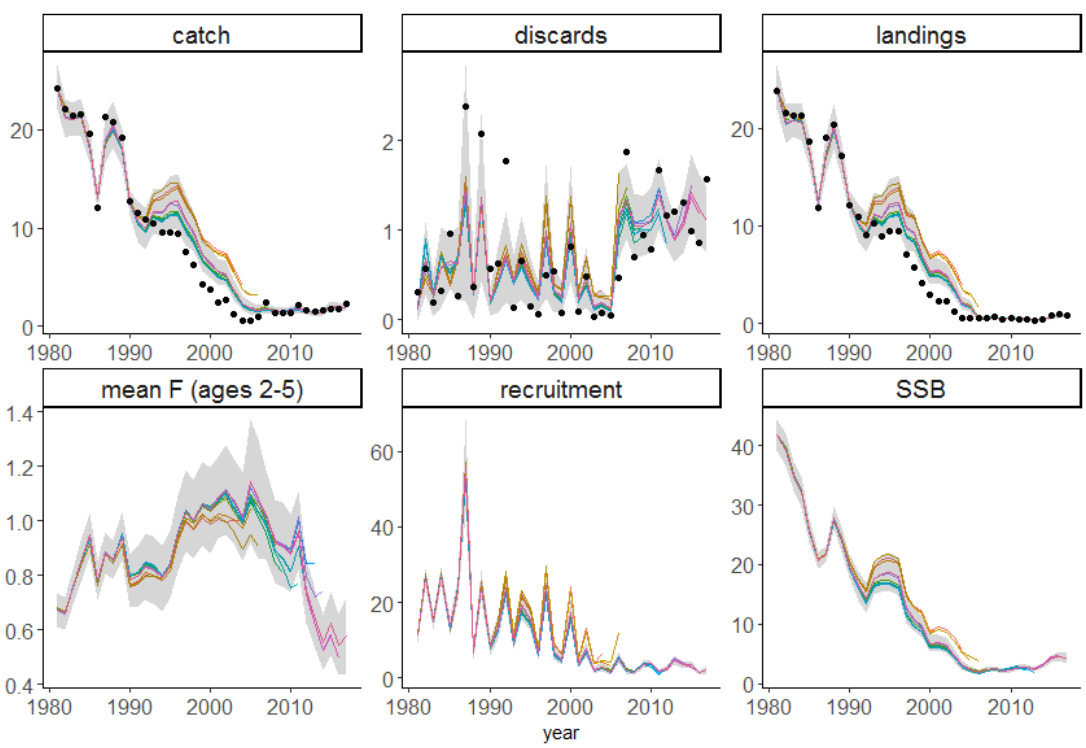


Misreporting estimate



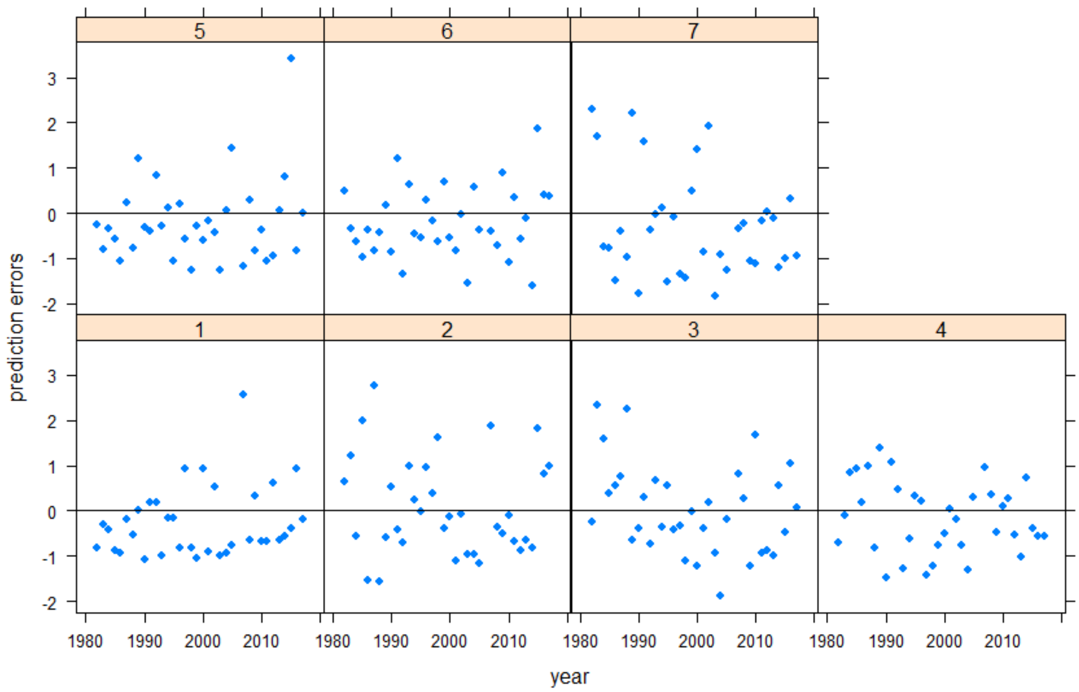
Retro

```
tsa.retro.plot.stock.summary.hd(wk.retro)
```

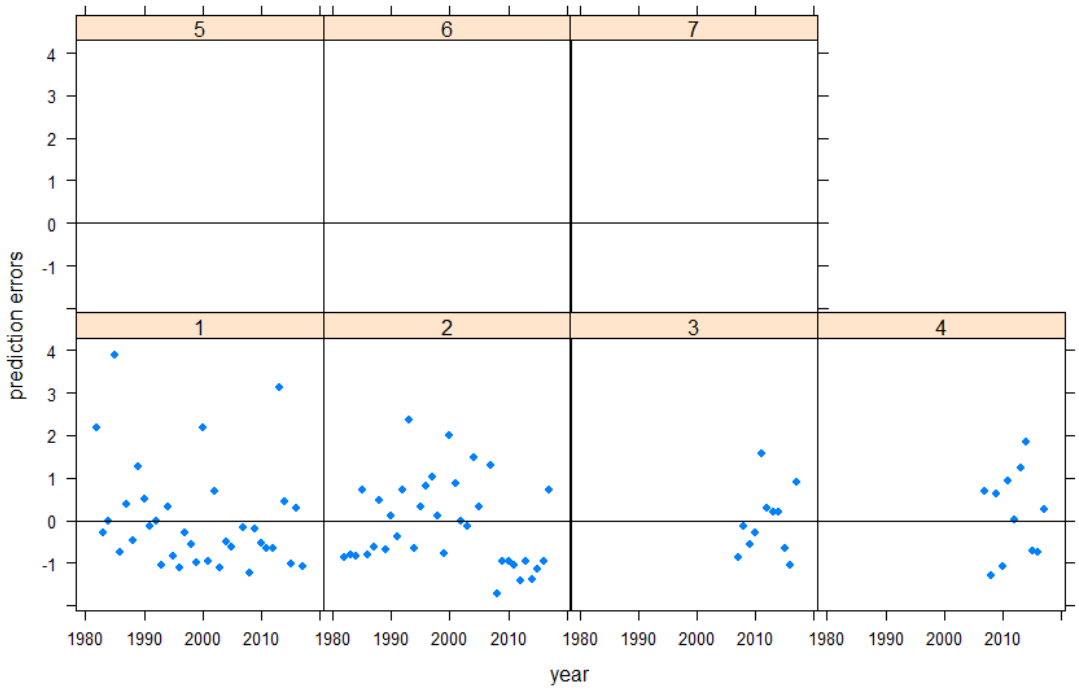


Prediction errors

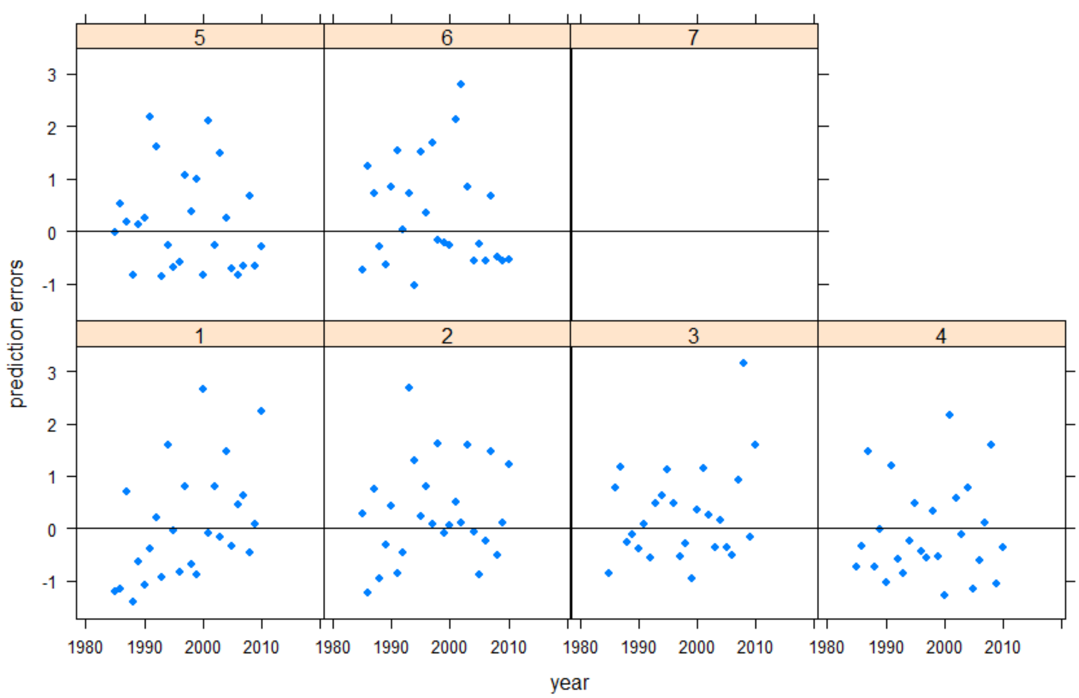
Landings



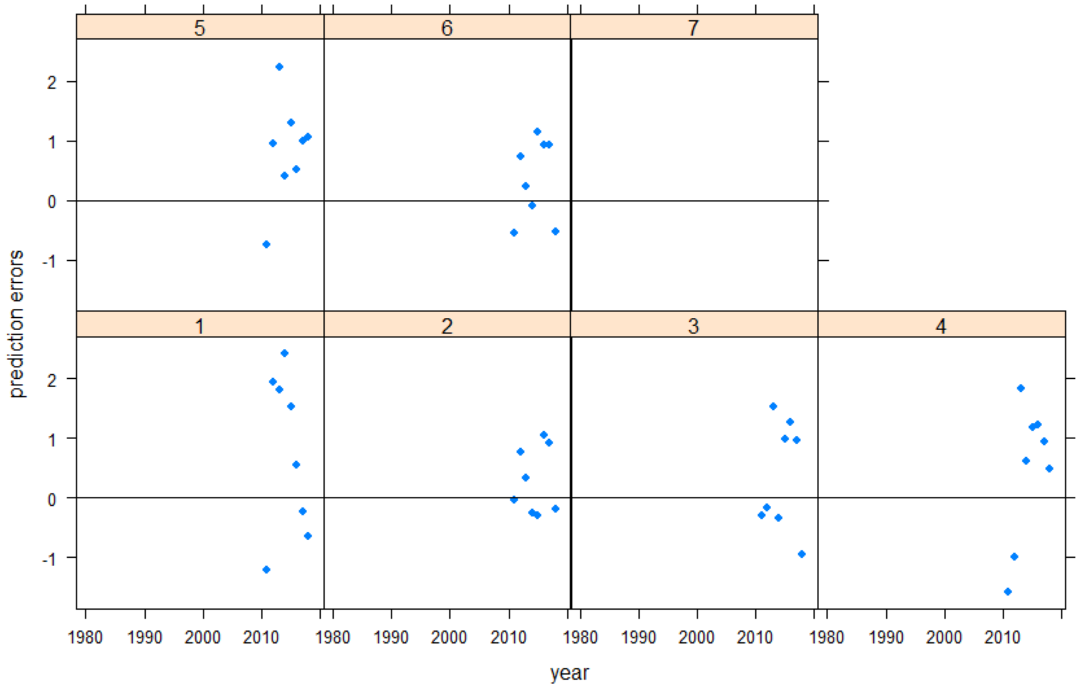
Discards



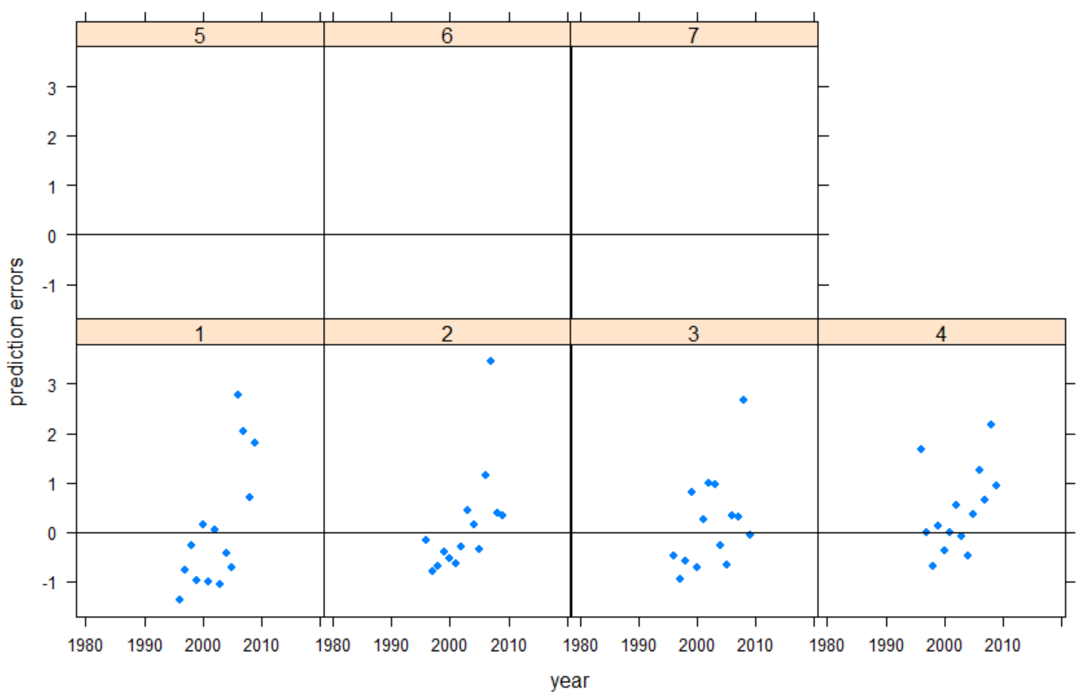
WIBTS Q1



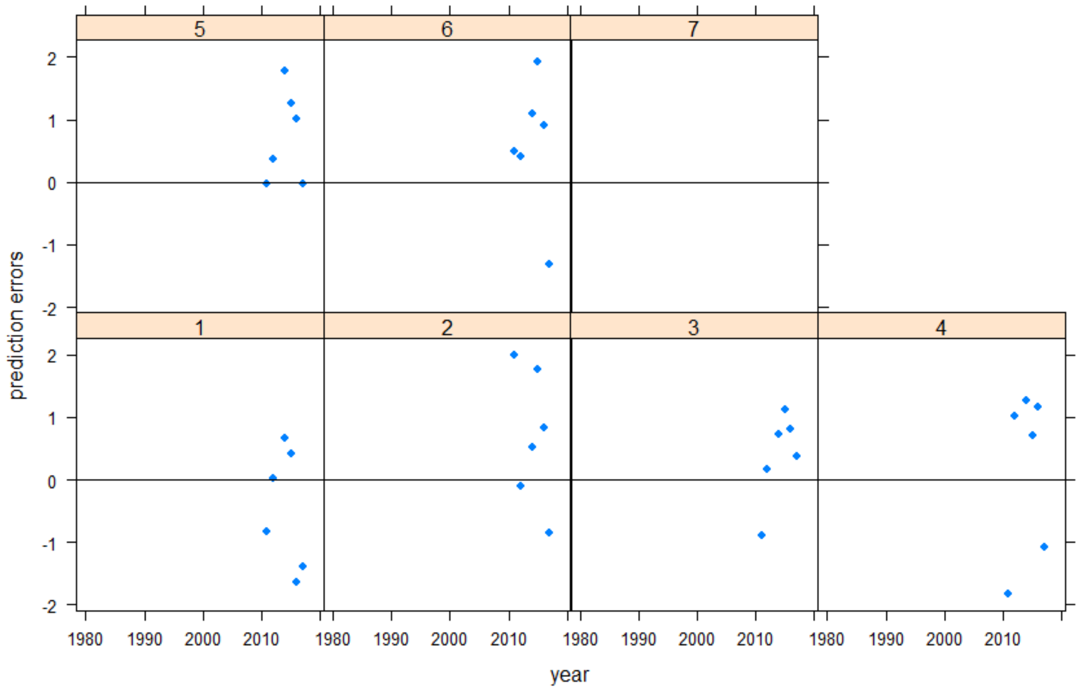
SCO Q1



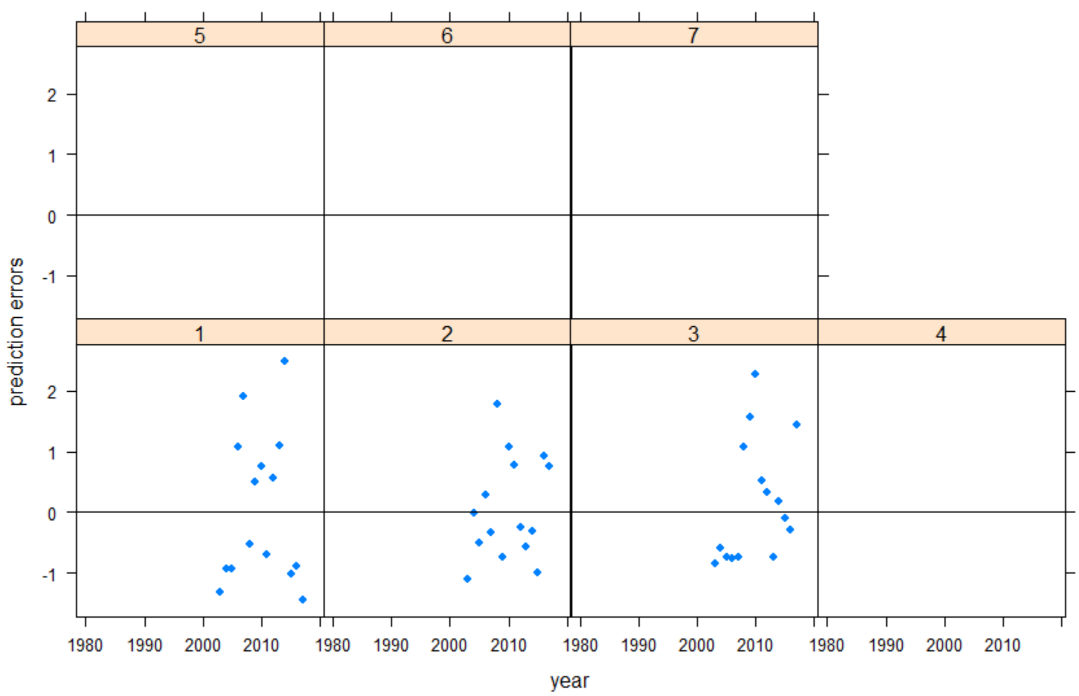
WIBTS Q4



SCO Q4

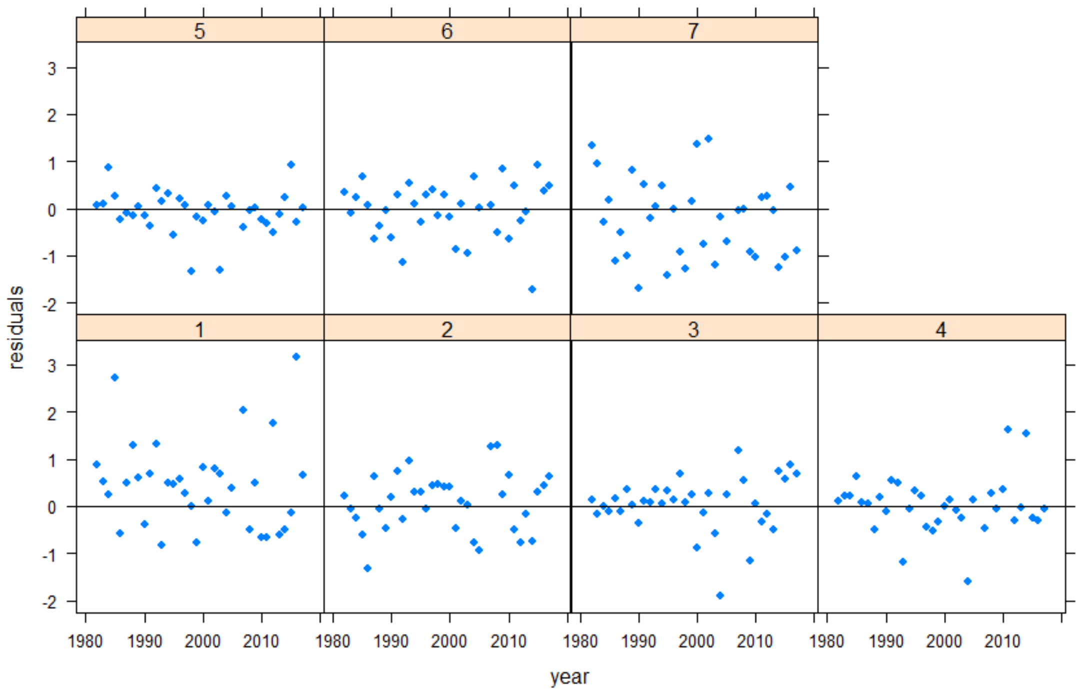


IRGFS.Q4

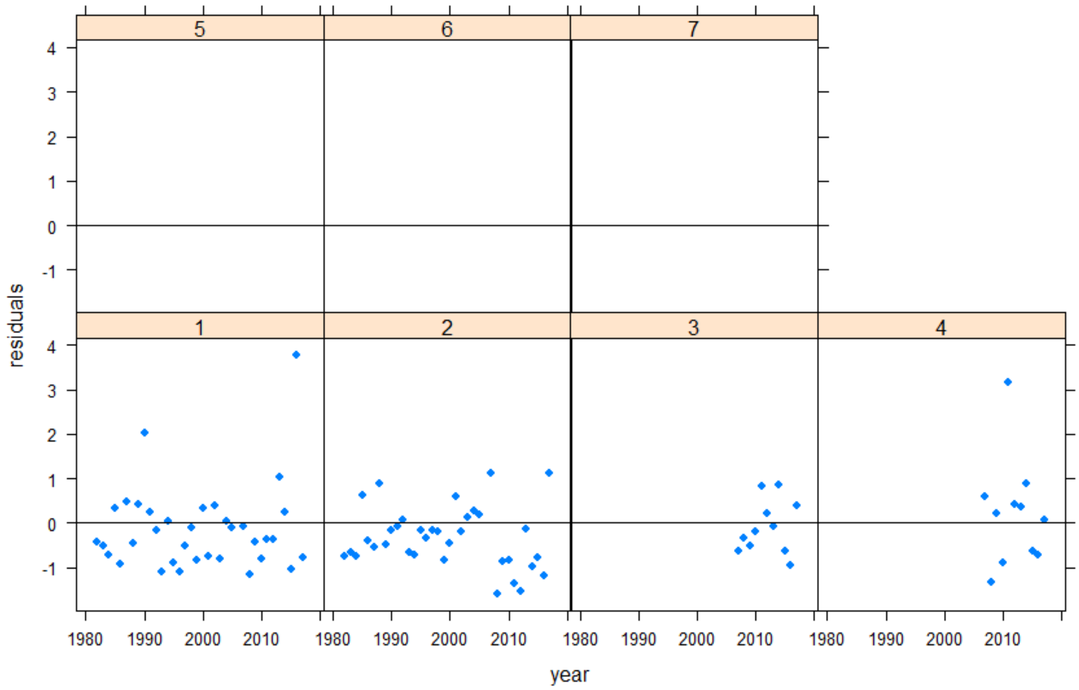


Residuals

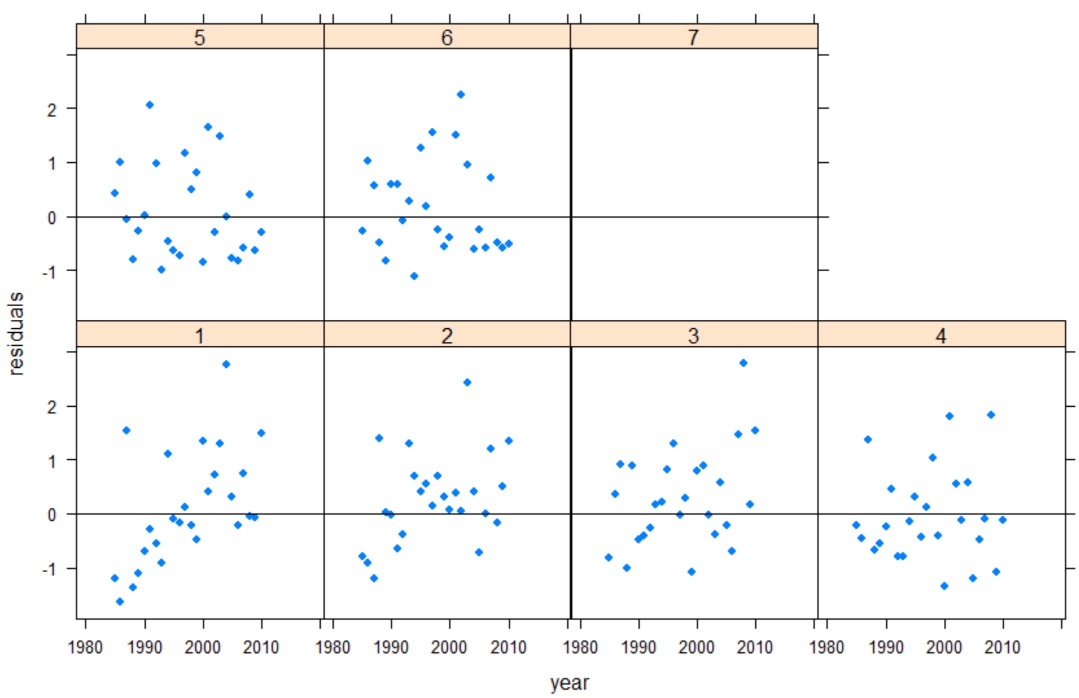
Landings



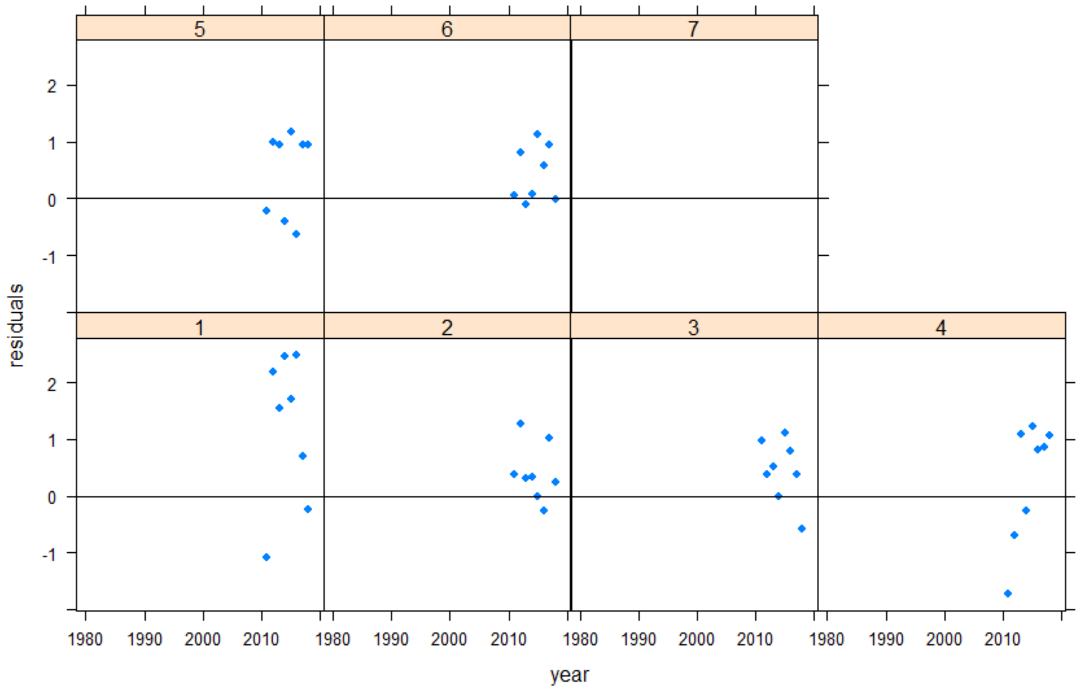
Discards



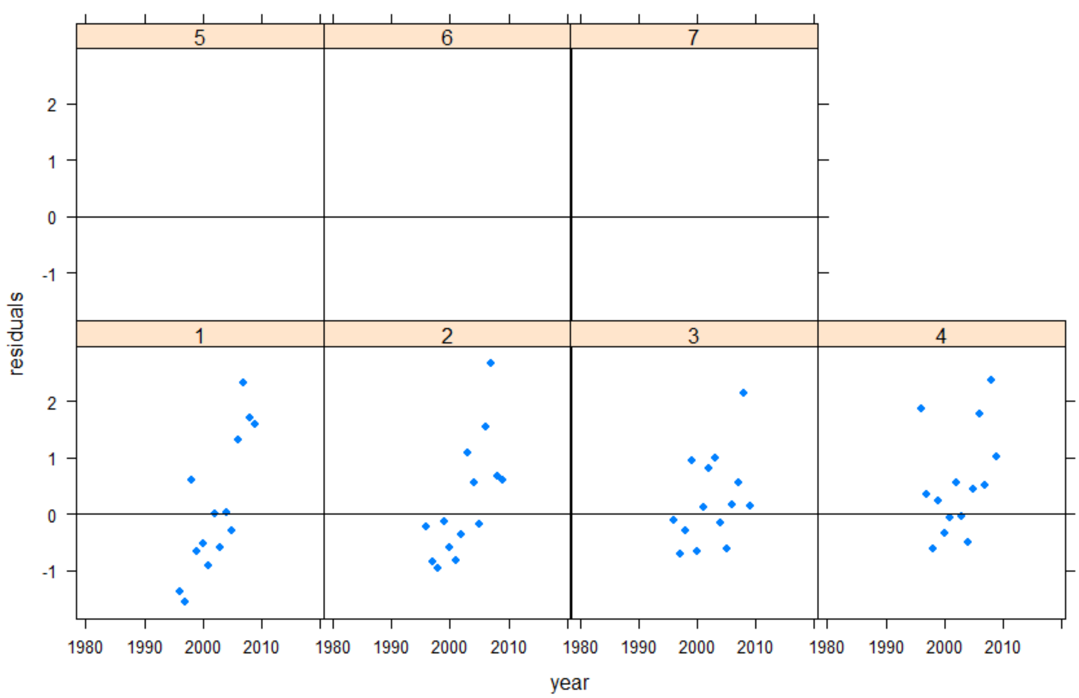
WIBTS Q1



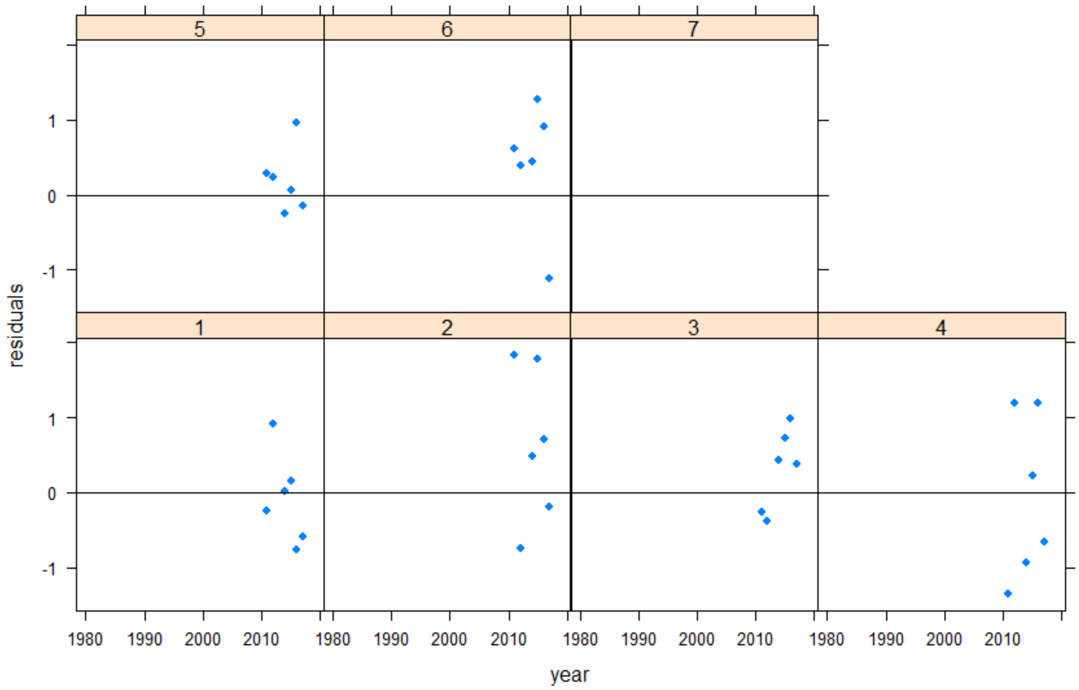
SCO Q1



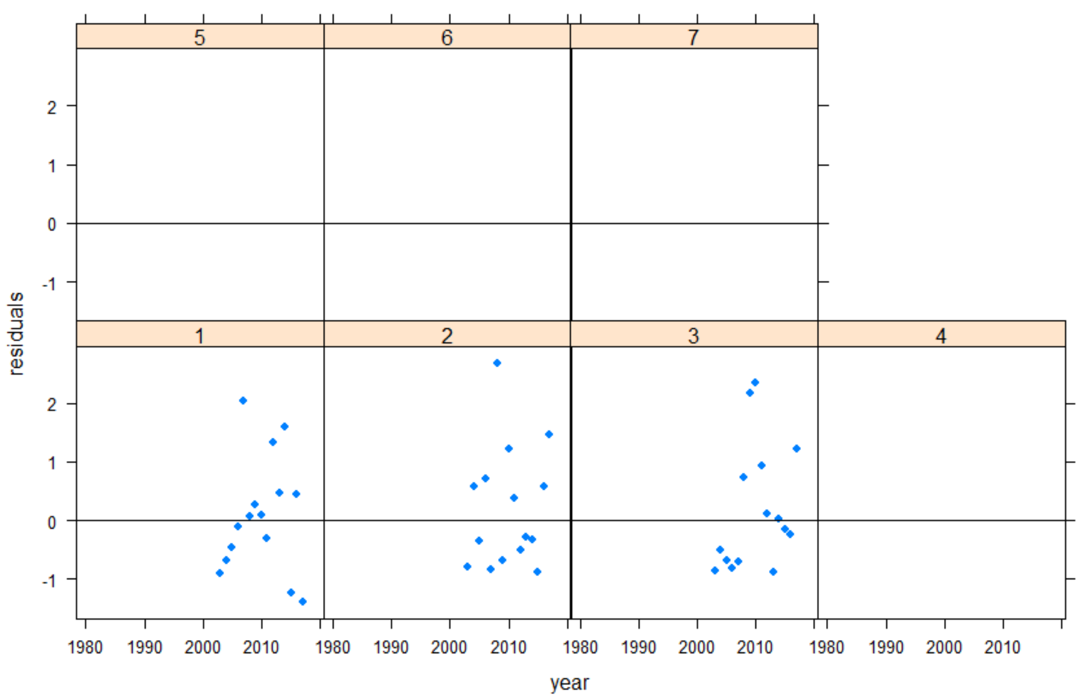
WIBTS Q4



SCO Q4



IRGFS.Q4



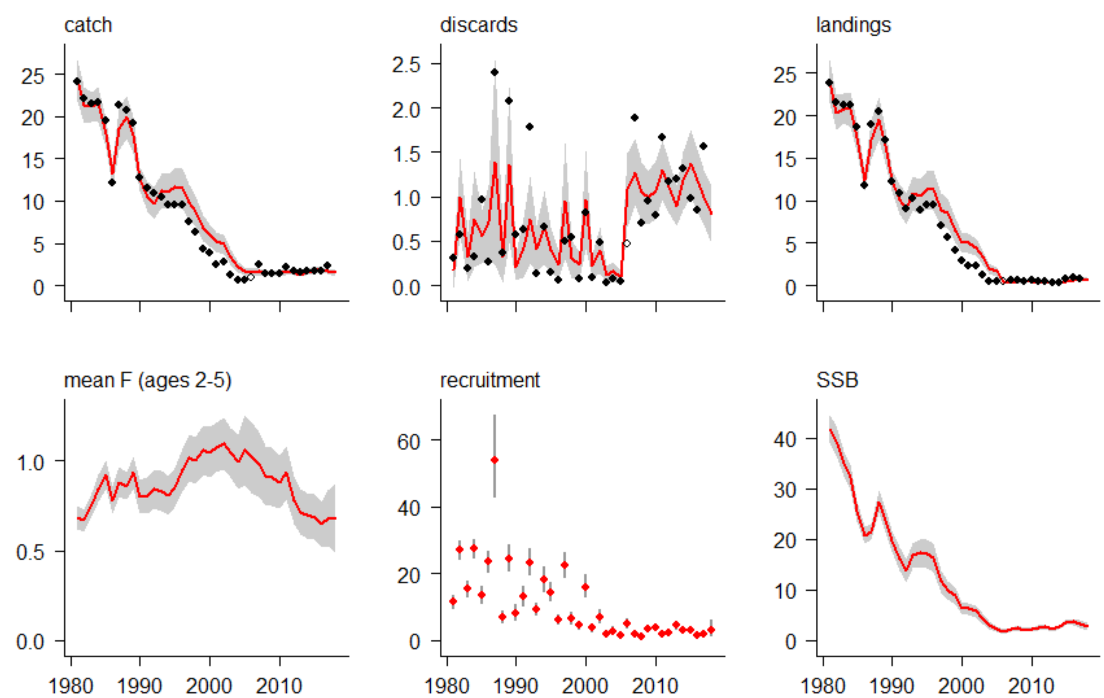
Assessment S3

The following plots show the results and diagnostics from TSA sensitivity run S3, which is described in the IBP report (Section 2.4 (3)).

Sensitivity Run S3: TSA model outputs and diagnostic plots

Results

Stock summary



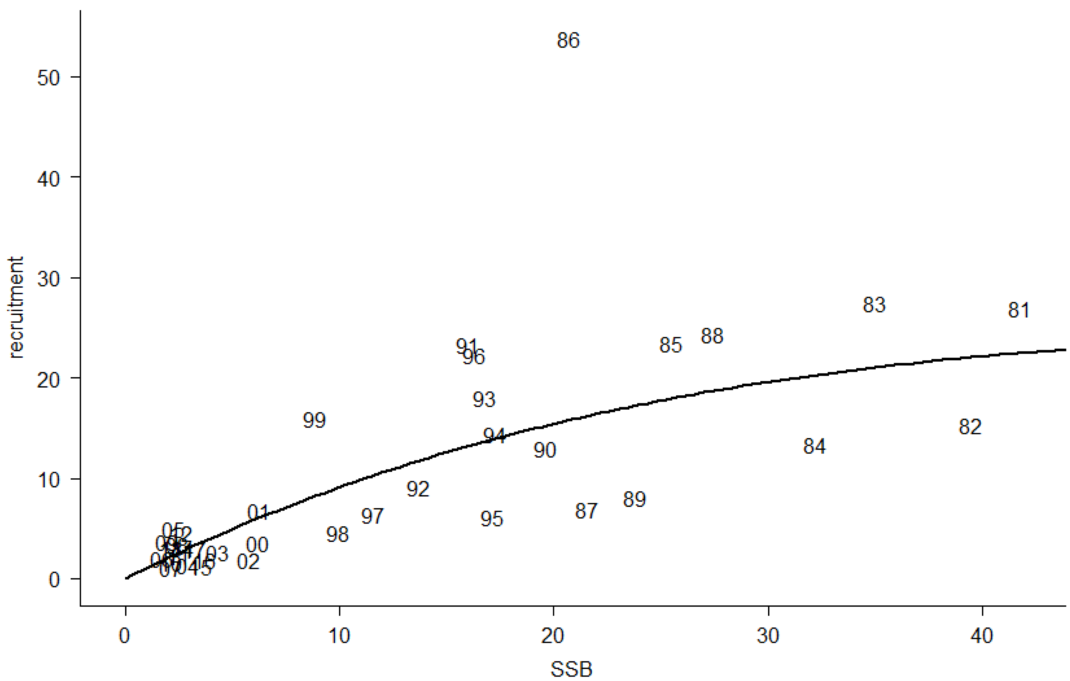
Parameter estimates

	estimate	lower.bound	upper.bound	active	on.bound
F age 1	0.2664	0.10	0.50	TRUE	FALSE
F age 2	0.5881	0.30	1.00	TRUE	FALSE
F age 6	0.8087	0.40	1.50	TRUE	FALSE
sd F	0.1123	0.00	0.20	TRUE	FALSE
sd U	0.0371	0.00	0.20	TRUE	FALSE
sd V	0.0333	0.00	0.20	TRUE	FALSE
sd Y	0.0669	0.00	0.20	TRUE	FALSE
cv discards	0.5685	0.20	0.80	TRUE	FALSE
recruitment alpha (slope at origin)	1.0755	0.70	1.60	TRUE	FALSE

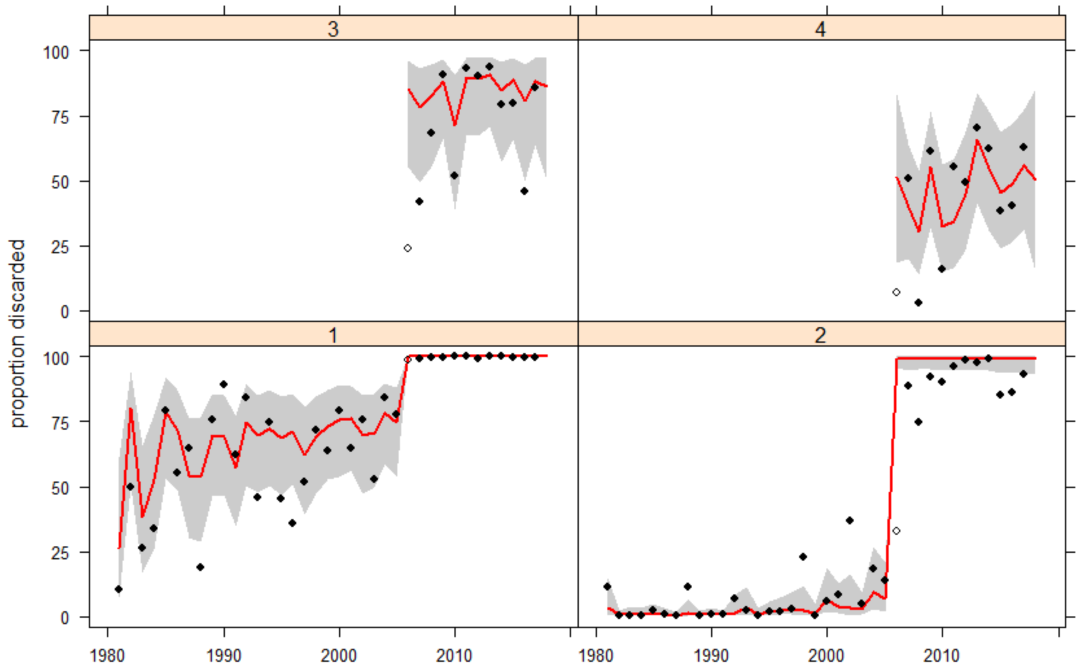
recruitment beta (density dependence)	0.0166	0.00	0.06	TRUE	FALSE
recruitment cv	0.4163	0.25	0.70	TRUE	FALSE
discards sd transitory	0.7673	0.00	1.00	TRUE	FALSE
discards sd persistent	0.1817	0.00	1.00	TRUE	FALSE
step age 1	9.1078	3.00	10.00	TRUE	FALSE
step age 2	8.1402	3.00	10.00	TRUE	FALSE
step age 3	1.7446	-1.00	2.00	TRUE	FALSE
step age 4	0.0520	-1.50	1.00	TRUE	FALSE
WCIBTS.Q1 selection age 1	0.5035	0.20	1.00	TRUE	FALSE
WCIBTS.Q1 selection age 2	3.0094	1.50	5.00	TRUE	FALSE
WCIBTS.Q1 selection age 3	6.7423	2.00	10.00	TRUE	FALSE
WCIBTS.Q1 selection age 4	11.9451	5.00	15.00	TRUE	FALSE
WCIBTS.Q1 sigma	0.0000	0.00	1.00	TRUE	TRUE
WCIBTS.Q1 eta	1.6866	0.00	2.00	TRUE	FALSE
SCO.Q1 selection age 1	0.8823	0.20	5.00	TRUE	FALSE
SCO.Q1 selection age 2	27.3728	10.00	30.00	TRUE	FALSE
SCO.Q1 selection age 3	47.3242	20.00	70.00	TRUE	FALSE
SCO.Q1 selection age 4	72.2720	20.00	100.00	TRUE	FALSE
SCO.Q1 omega	0.4262	0.00	2.00	TRUE	FALSE
WCIBTS.Q4 selection age 1	3.4852	1.00	5.00	TRUE	FALSE
WCIBTS.Q4 selection age 2	7.4210	2.00	10.00	TRUE	FALSE
WCIBTS.Q4 selection age 3	5.8672	2.00	10.00	TRUE	FALSE
WCIBTS.Q4 selection age 4	2.3433	1.00	10.00	TRUE	FALSE
WCIBTS.Q4 sigma	0.0370	0.00	1.00	TRUE	FALSE
WCIBTS.Q4 eta	2.5498	0.00	3.00	TRUE	FALSE
SCO.Q4 selection age 1	15.6283	5.00	30.00	TRUE	FALSE
SCO.Q4 selection age 2	28.7182	10.00	30.00	TRUE	FALSE
SCO.Q4 selection age 3	73.7801	40.00	80.00	TRUE	FALSE
SCO.Q4 selection age 4	160.6210	50.00	200.00	TRUE	FALSE
SCO.Q4 omega	0.1878	0.00	2.00	TRUE	FALSE
IRGFS.Q4 selection age 1	15.8097	5.00	30.00	TRUE	FALSE
IRGFS.Q4 selection age 2	12.5450	5.00	20.00	TRUE	FALSE
IRGFS.Q4 selection age 3	3.2246	1.00	10.00	TRUE	FALSE
IRGFS.Q4 sigma	0.0050	0.00	2.00	TRUE	FALSE
IRGFS.Q4 eta	2.0509	0.00	4.00	TRUE	FALSE

IRGFS.Q4 omega	0.0029	0.00	2.00	TRUE	FALSE
misrep transitory	0.0000	0.00	0.20	TRUE	TRUE
misrep persistent	0.1410	0.00	0.30	TRUE	FALSE

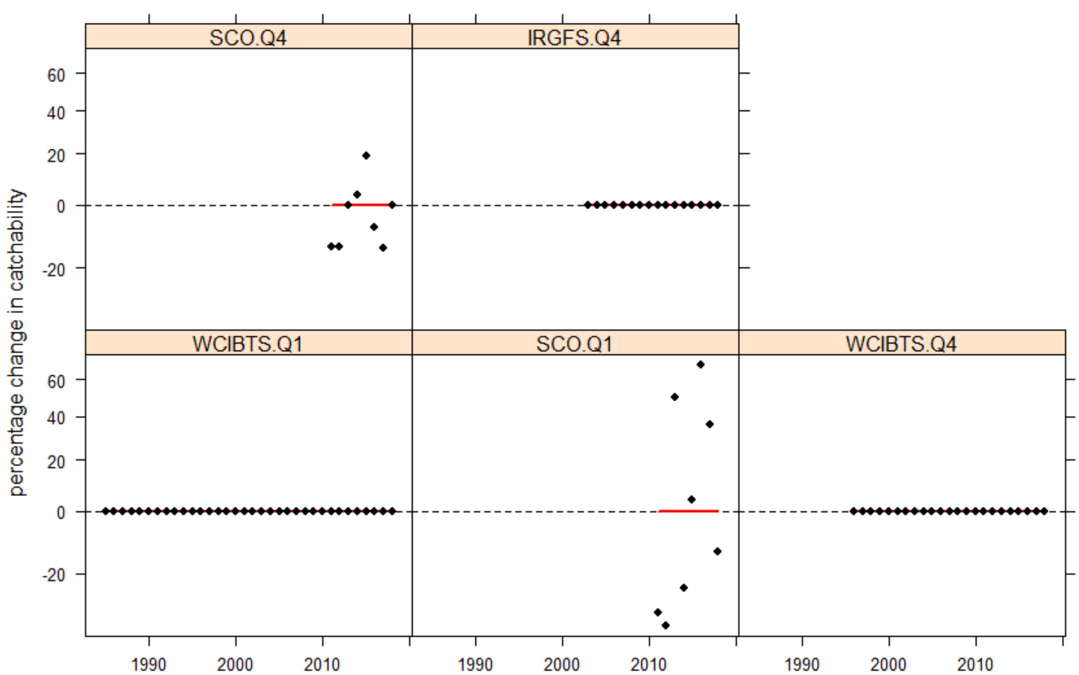
Stock recruit curve



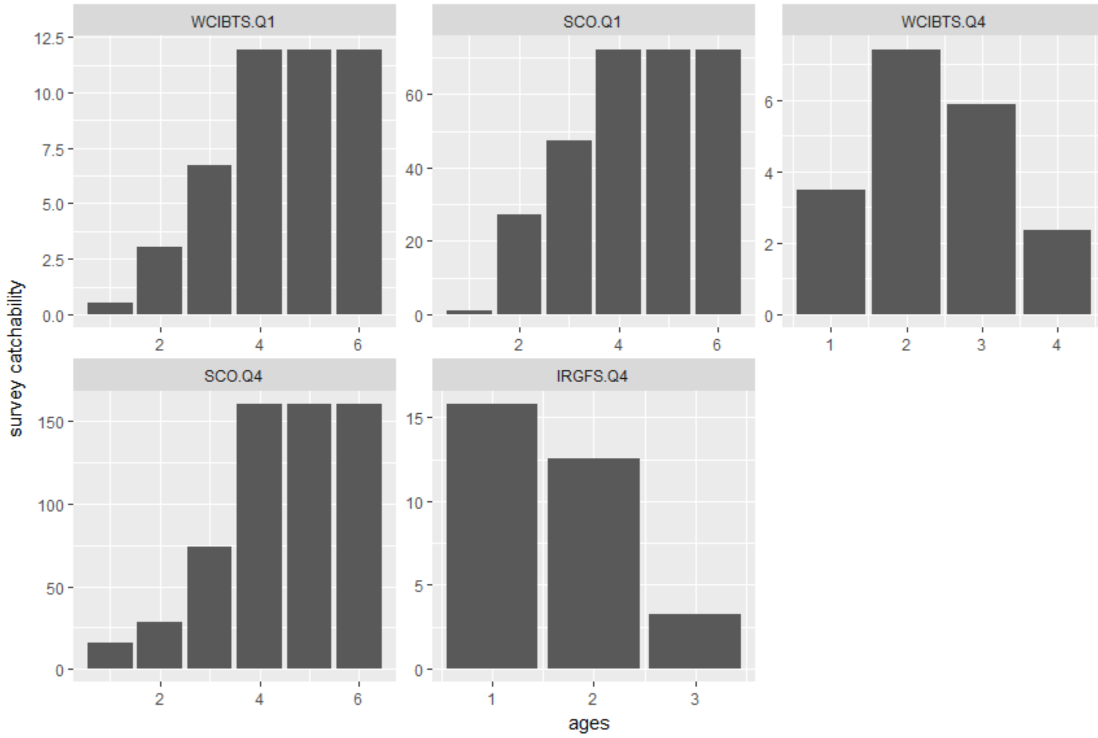
Discards



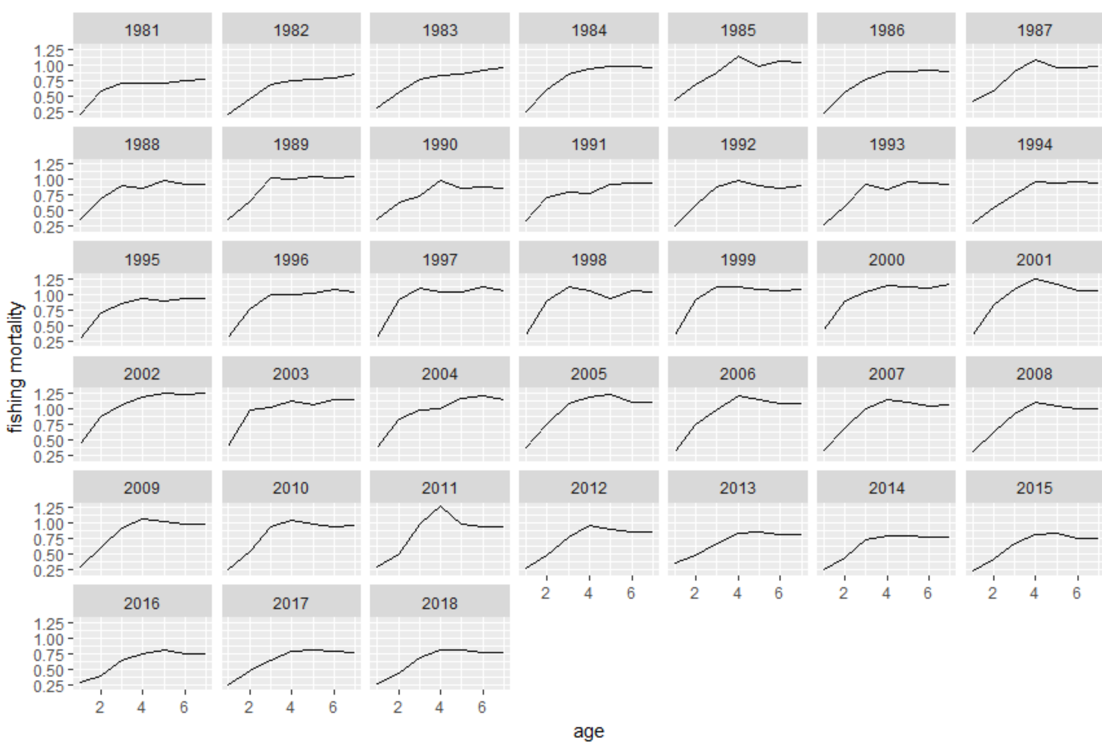
Survey catchability



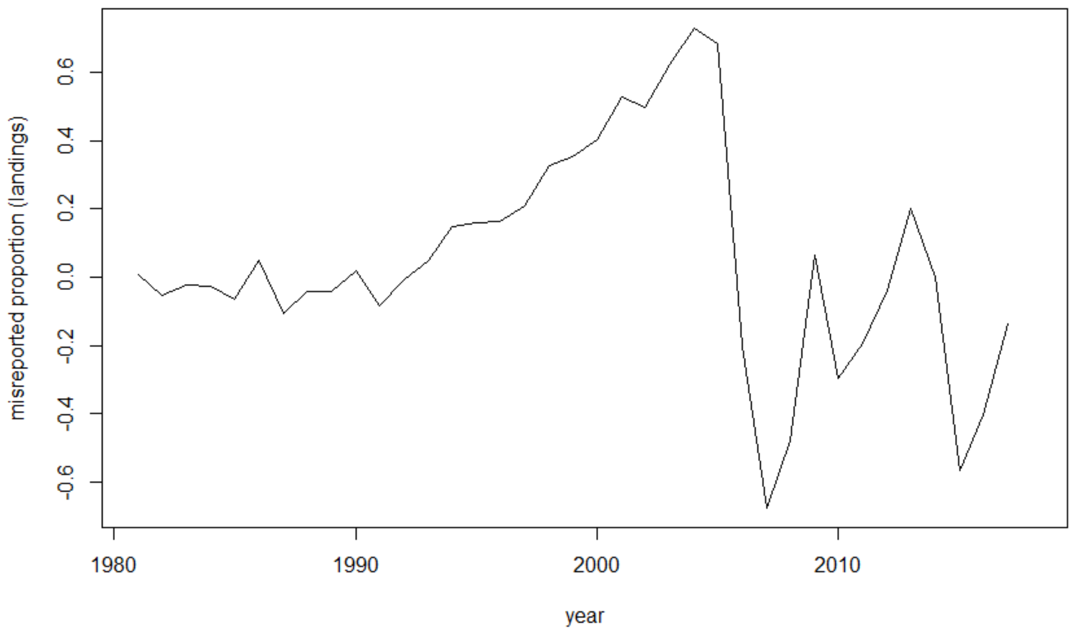
Survey catchability by age



Fishing mortality at age

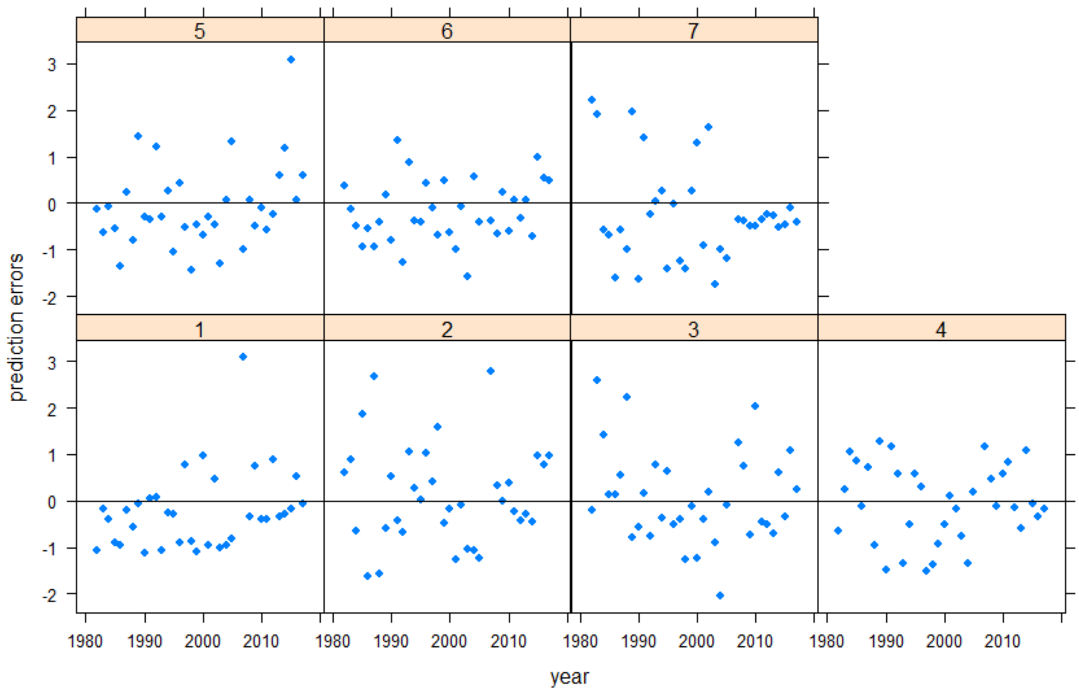


Misreporting estimate

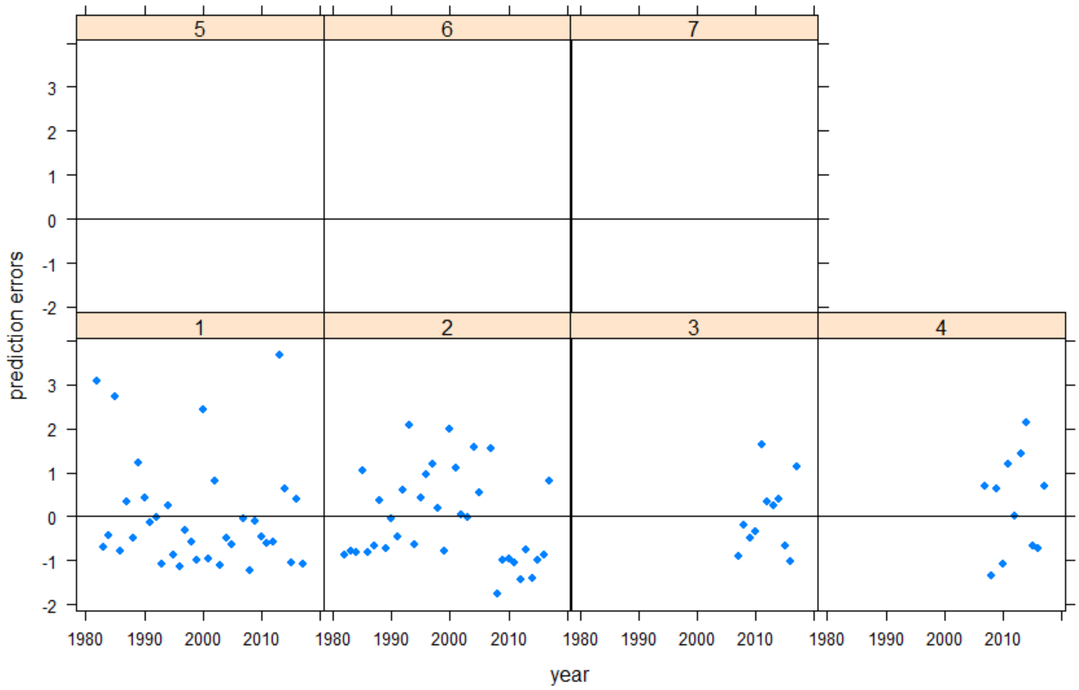


Prediction errors

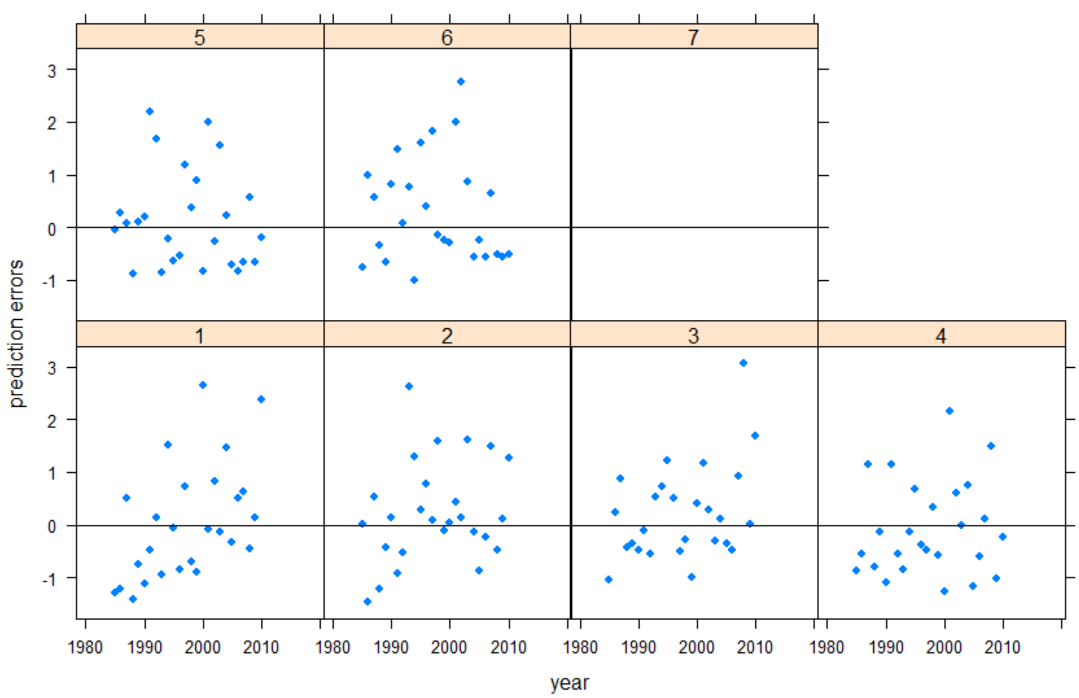
Landings



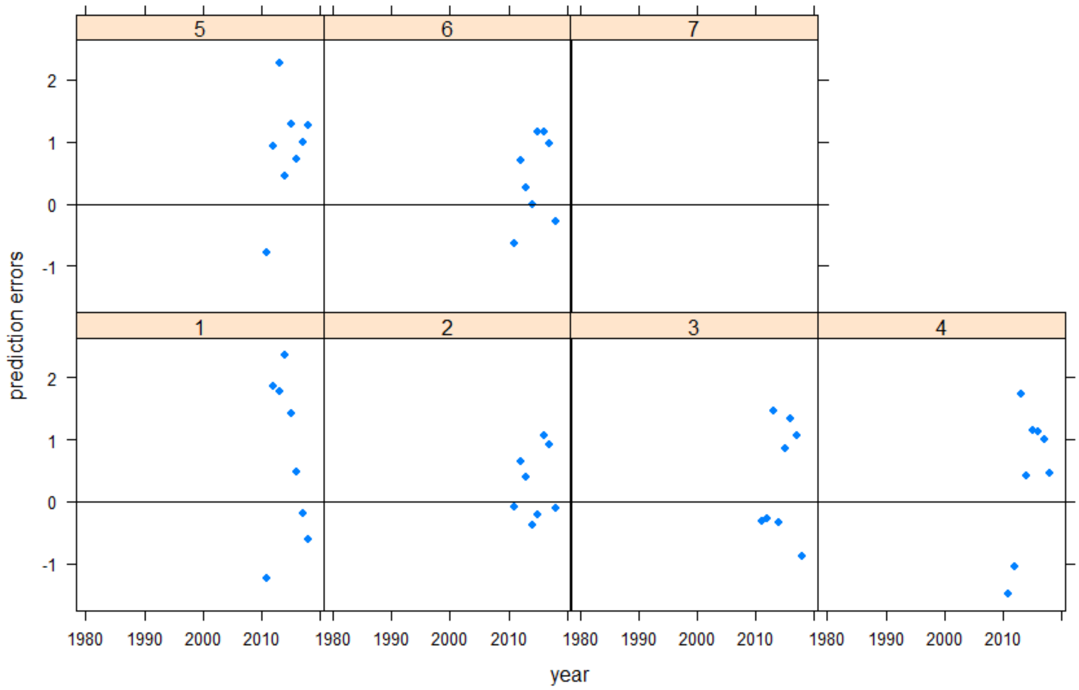
Discards



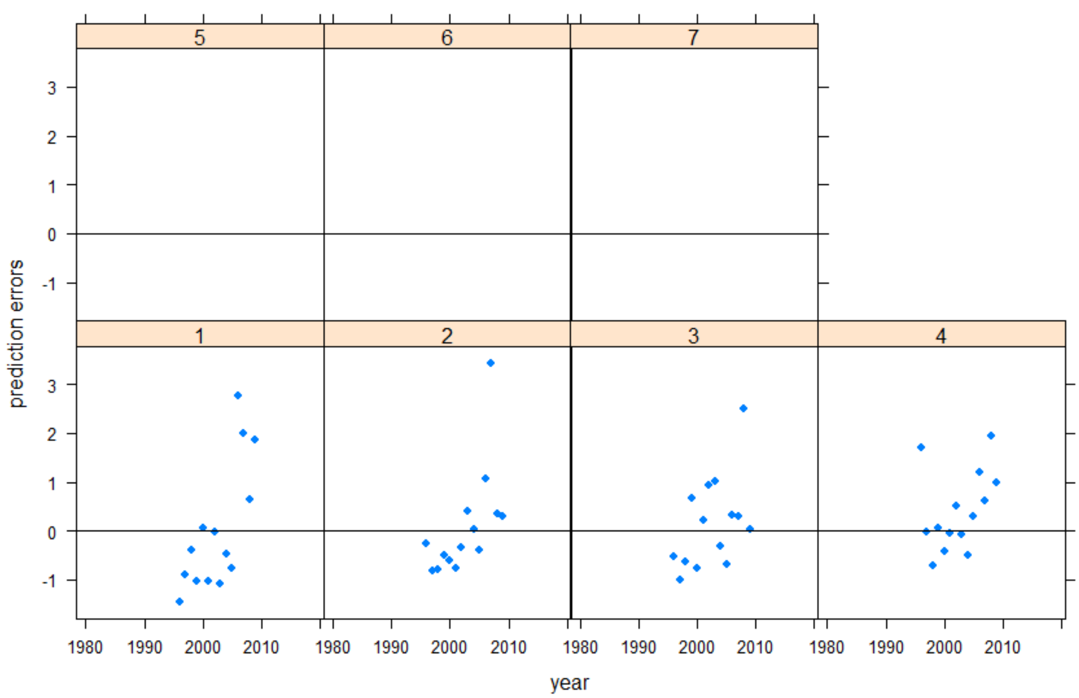
WIBTS Q1



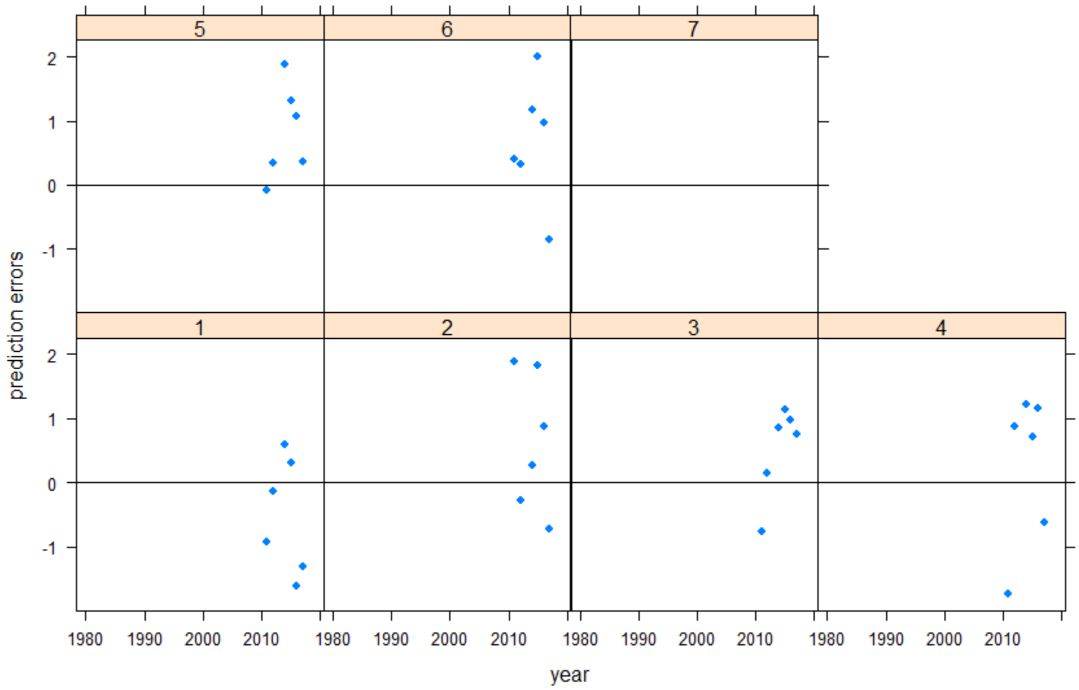
SCO Q1



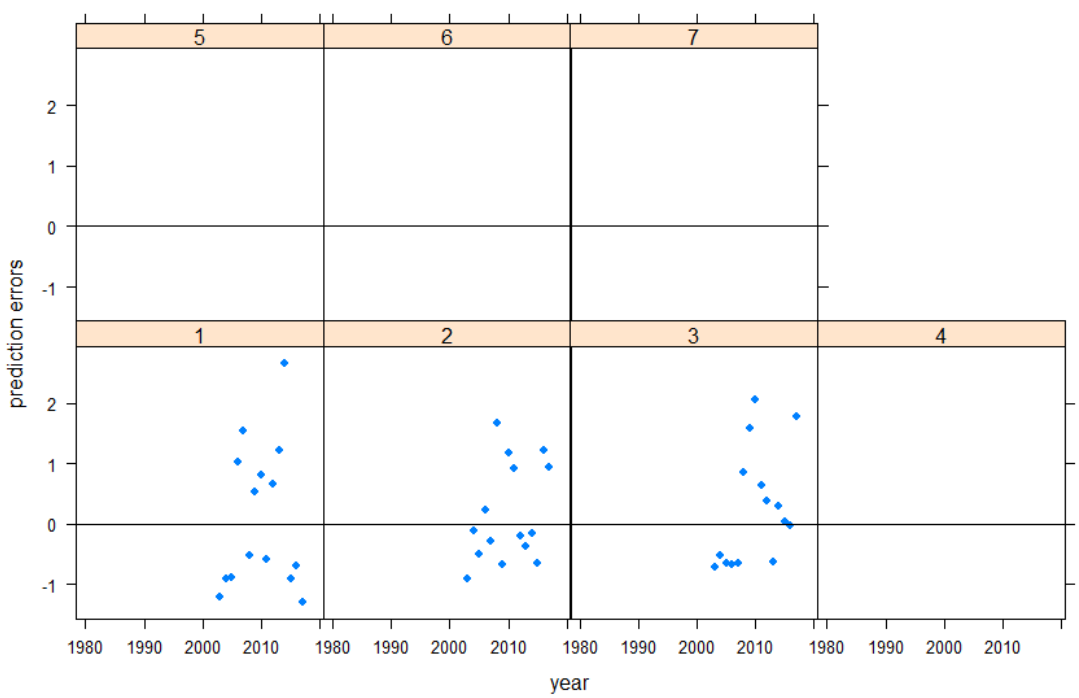
WIBTS Q4



SCO Q4

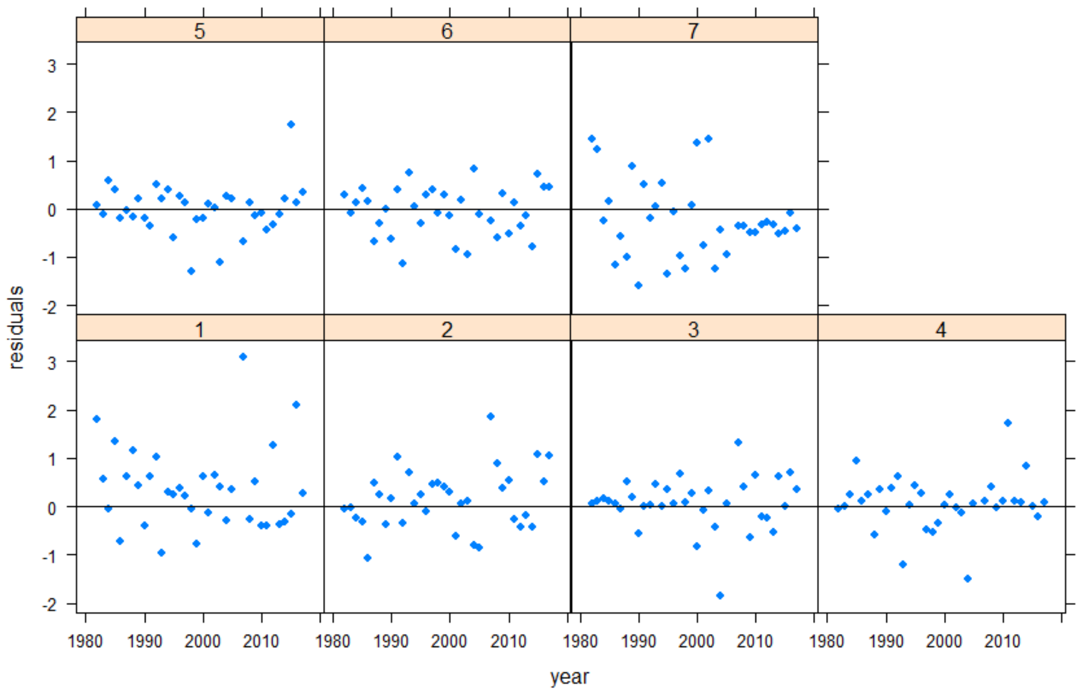


IRGFS.Q4

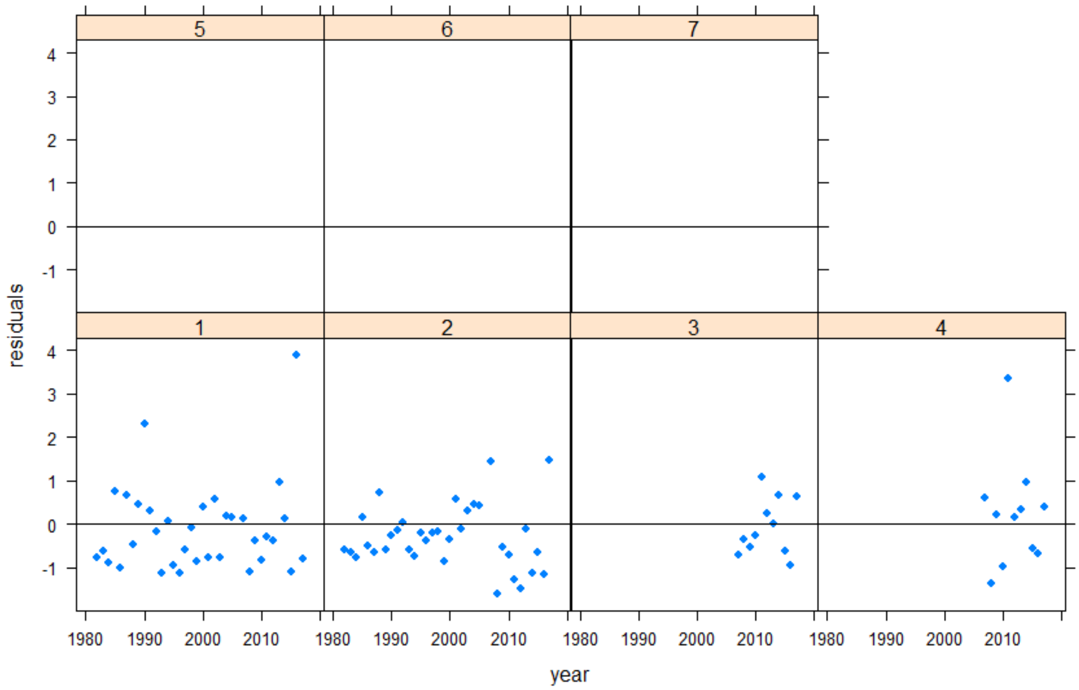


Residuals

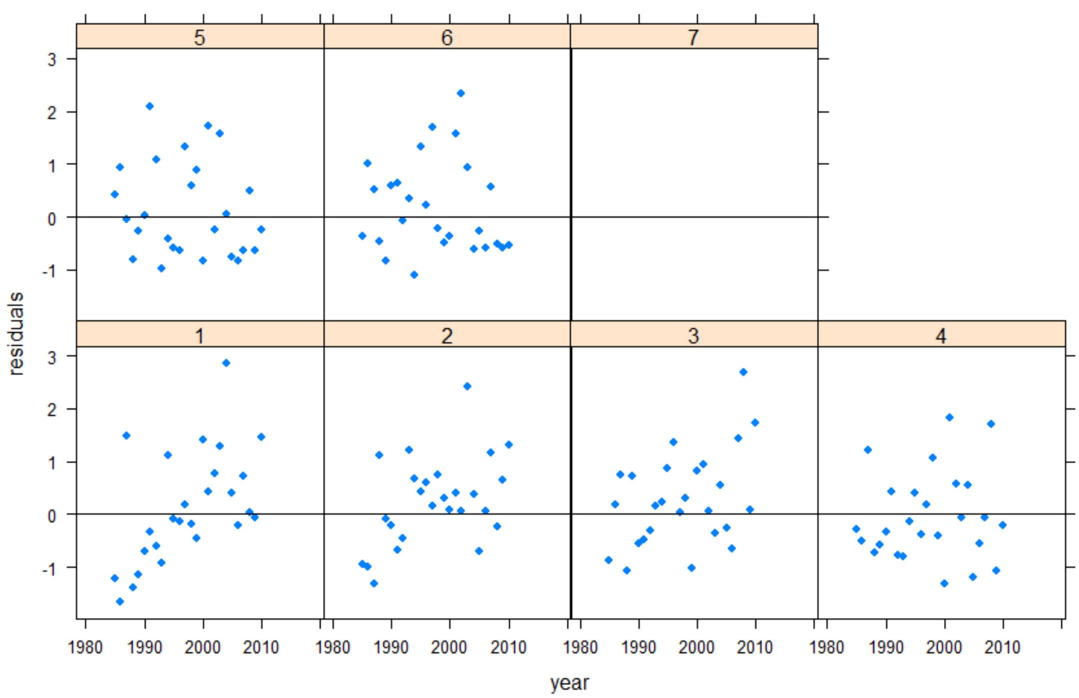
Landings



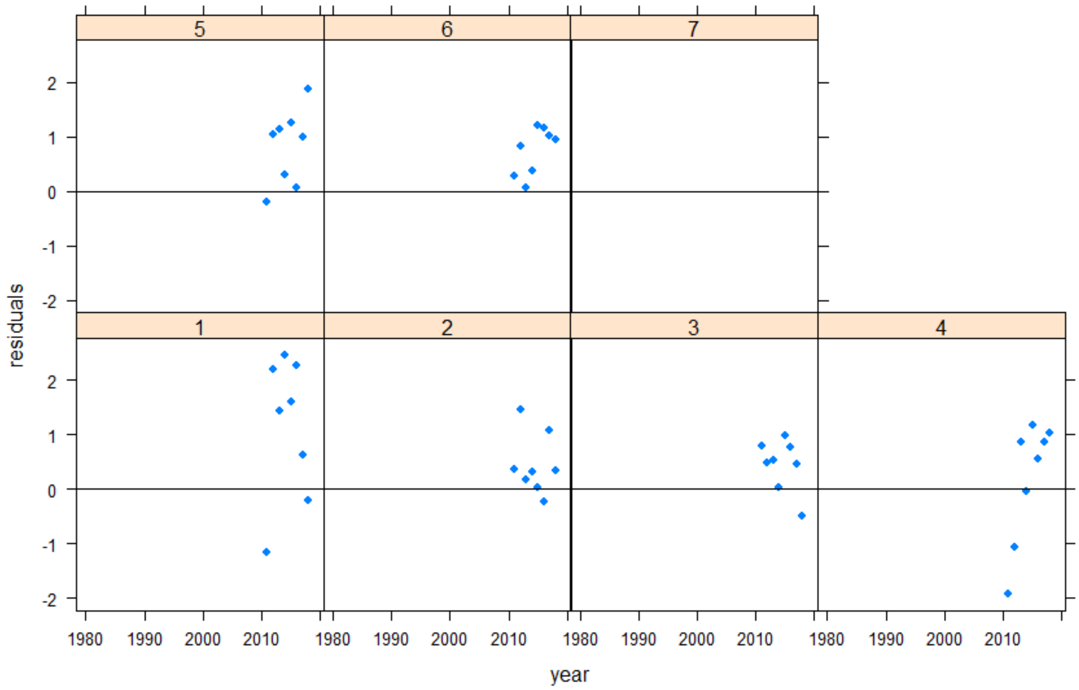
Discards



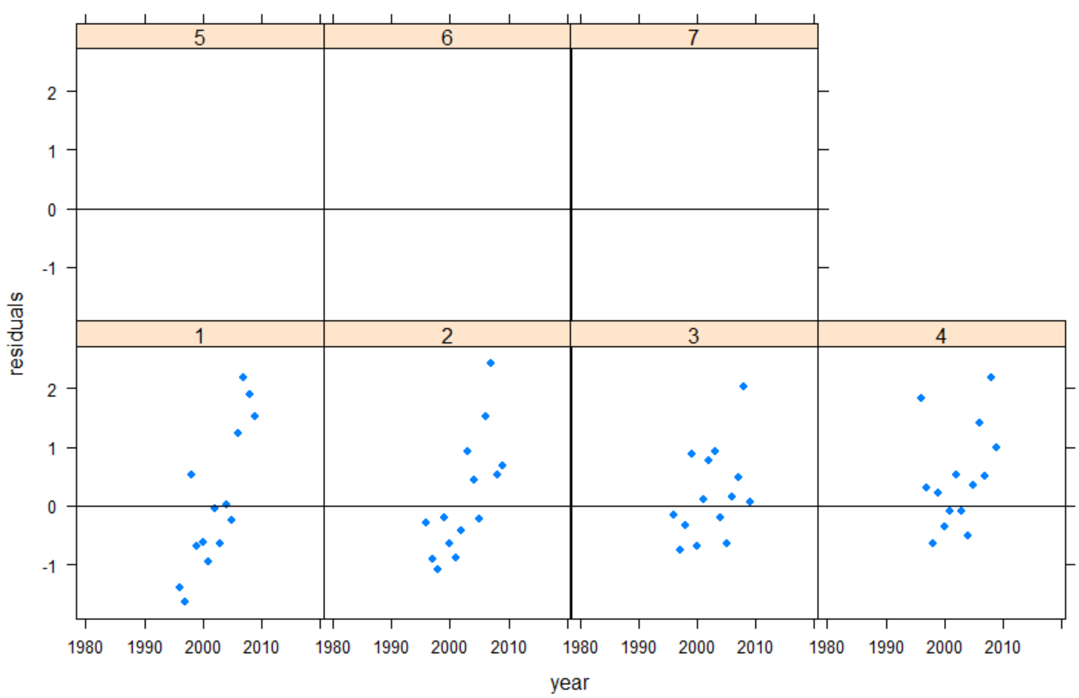
WIBTS Q1



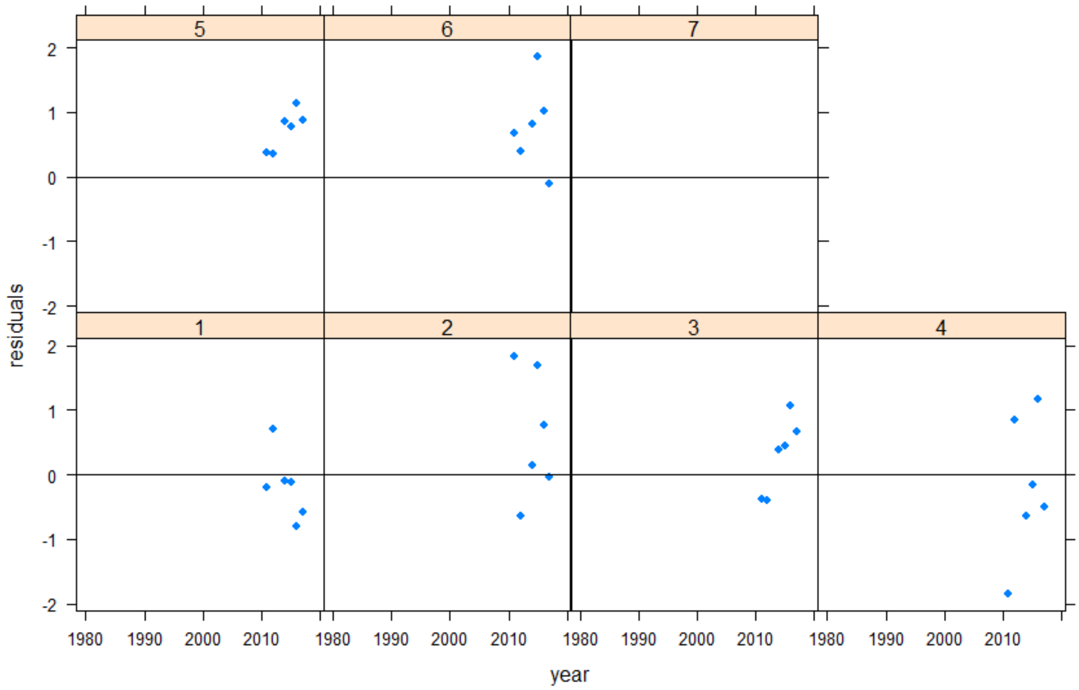
SCO Q1



WIBTS Q4



SCO Q4



IRGFS.Q4