Annex SWG-10-03

Report of the Jack Mackerel Subgroup

1. Opening of the Meeting

The meeting of the Jack Mackerel Sub-group (JMSG) of the Science Working Group (SWG) was opened by the chair of the SWG, Andrew Penney (New Zealand), who welcomed all participants.

2. Adoption of Agenda

The draft agenda (SWG-10-01) was adopted without amendment (Annex SWG-01).

3. Administrative Arrangements

3.1. Meeting documents

A list of Jack Mackerel Sub-Group documents was provided in SWG-10-03, rev 8.

4. Nomination of Rapporteurs

Dr. Cristian Canales (Chile) and Mr Niels Hintzen (European Union) offered to assist the Chair with rapporteuring the meeting. Dr Ianelli offered to coordinate the preparation of technical annexes summarising the stock assessment methods used and the results obtained.

5. Chairmanship of the Jack Mackerel Sub-Group

No inter-sessional nominations were received for a Chair of the Jack Mackerel Sub-Group. The Sub-Group agreed that this meeting would be Chaired by the Chair of the SWG.

6. Report of the Jack Mackerel Otolith Interpretation & Ageing Workshop

The report of the 9th Science Working Group noted that differences between sensitivity analyses conducted during the 2010 jack mackerel assessment process emphasised the importance of obtaining correct ageing and growth information for the different fleets. It was agreed to hold an Otolith Interpretation and Ageing Workshop during 2011 to develop standardised jack mackerel otolith interpretation protocols

As coordinator of the Jack Mackerel Research Programme Task Team, Rodolfo Serra (Chile) coordinated the workshop, which was hosted by IMARPE in Lima, Peru from 4 – 13 July 2011. Mr Serra presented key points and conclusions from the workshop report (SWG-10-JM-01). The main conclusions of the workshop were:

- The results of the age reading exercises show particularly good agreement when ageing otoliths of juveniles.
- In juveniles it is far easier to identify the 1st and 2nd ring, although it is not always possible to do so.
- For fish up to about age 11 there are reasonably high levels of agreement between readers. However, there are still high CVs on age readings, and statistically significant differences between readers.
- In older fish, and particularly using whole otoliths, it is frequently difficult to identify the first one or two rings, and this then affects age readings for subsequent rings.
- Use of otolith sections results in better ageing of larger fish (> 40cm FL) than using whole otoliths.

- Cooperative training, exchange of otoliths and joint interpretation of otolith images results in substantial improvements in agreement between readers, and better ageing of older fish.
- Annual rings should be well defined and possible to follow around the otolith. This is not always possible, particularly near the edge due to the concave shape of the otolith, and the thickening of otoliths in older (larger) fish. The best approach for large fish is to compare readings of whole and cross-sectioned otoliths. When it is not possible to follow a ring around the otolith, then it may be a false ring or split ring.
- The entire otolith or otolith section should be examined when doing age reading, including the caudal zone and the rostrum. This is particularly important when the caudal zone is difficult to read, in which case it is necessary to examine the rostrum. Identification of false and split rings should also be checked on the rostrum.
- For larger fish (40 cm FL and larger), age readings should be confirmed using otolith cross-sections to avoid under-estimation of age. Ring deposition in larger fish occurs across more by thickening of the otolith, and older rings are particularly difficult to read at the otolith edge, particularly using whole otoliths.

The JMSG recommended that the draft Jack Mackerel Otolith Interpretation Protocol developed by the workshop (Annex SWG-JM-01 to this report) should be adopted by the SWG as the guideline for interpretation of jack mackerel otoliths by all participants, and that this protocol should be improved over time as necessary. To facilitate this improvement, the JMSG also endorsed the recommendations from the workshop for continued collaborative work:

- Collaborative discussions on otolith interpretation should continue. Improvements in agreement between otolith readers will benefit from the regular exchange of images of otoliths between the research institutes involved in jack mackerel ageing.
- Inter-sessional work should continue to improve otolith interpretation by the workshop participants, and to increase the level of experience in reading Chilean jack mackerel otoliths. Photographic images are particularly suitable for this purpose, eliminating the practical difficulties with circulating otolith collections between countries. Images can also be examined simultaneously by all participants.
- Otolith images for exchange should be export in a format and resolution that ensure adequate quality for image interpretation, while still allowing images to be easily exchanged. There may need to be some standardization of image analysis software.
- Participants should continue to work inter-sessionally on validation of jack mackerel ageing and growth.

In discussion of the results of the ageing workshop, JMSG participants noted that, over the course of the workshop, age readings had converged more closely towards age readings by the reference reader (number 5), who was the most experienced jack mackerel age reader at the workshop, and had participated in otolith age readings used to prepare the Chilean age-length keys for jack mackerel.

7. Report on Inter-Sessional Assessment Work by Participants

SWG-10-JM-08: Estimating F_{MSY} Assuming a Variety of Stock Recruit Relationships

Niels Hintzen (EU) gave a presentation on initial work done to investigate the determination of biological reference points for jack mackerel, following the approach used by Simmonds *et al*.

(2011)[1] for Atlantic mackerel. Based on statistical (log-likelihood) selection of a wide range of alternative fits for the stock-recruit relationship, plots of fishing mortality (F) against yield indicated that optimum F (F_{MSY}) for Chilean jack mackerel is approximately 0.15, and that the corresponding optimal spawning biomass (SSB_{MSY}) is approximately 7.4 million tons.

The JMSG noted that this was preliminary work that could serve as a starting point for further work to determine appropriate biological and management reference points for Chilean jack mackerel.

SWG-10-JM-06: Standardisation of CPUE for Chilean Jack Mackerel from the Chinese Trawl Fleet on the High Seas in the Southeast Pacific Ocean (2001-2010)

Dr Gang Li gave a presentation on the work done to standardise CPUE for the Chinese fleet using general linear models (GLM) and general additive models (GAM) to correct for the effects of season, vessel, latitude and a range of environmental variables (Sea Surface Temperature and El Niño effects). GLM modelling determined that Month explained the highest proportion of the deviance (16.58%), followed by Vessel (6.01%) and Year (3.33%), while the deviance explained by El Niño effects and Latitude was less than one percent. GAM modelling accepted eight variables (in addition to the year effect), including three environmental variables, and explained a higher cumulative deviance (30.6%) than the GLM model (27.3%).

The JMSG noted that the three environmental variables were likely to be highly correlated, so that the higher explained deviance by the GLM model was misleading. The JMSG further noted that it was the year effects (Figures 3 or 4) that provided standardised abundance indices for input into the stock assessment models, and that the inter-annual trend in these year effects was highly similar for the GLM and GAM models. It was agreed to use the GAM year effects as a standardised CPUE index for the Chinese fleet in the updated assessment.

8. Jack Mackerel Stock Assessment

8.1. Updating of data sets for additional stock assessment runs

A substantial amount of time was spent updating and revising data inputs for the Joint Jack Mackerel (JJM) stock assessment model. These updates include revisions to many of the catch data series, including: revision of historical catches for some countries and updating of preliminary 2011 catches for all fleets; preparation of an updated table of aggregated catches for the four fleets used in the JJM model; generation of catch-at-age matrices for the four fleets; updating of a number of the CPUE and other indices used; and generation of a new standardised CPUE index for the Chinese fleet.

The four fleets used in the JM assessments are:

- Fleet 1: Chilean northern area within EEZ purse-seine fishery.
- Fleet 2: Chilean southern area within EEZ and high seas purse seine fishery.
- Fleet 3: Far northern area fishery, inside and outside the Peruvian EEZ and inside the Ecuadorian EEZ.
- Fleet 4: International fleet high seas trawl fishery off the Chilean EEZ.

[1] Simmonds, E.J., Campbell, A., Skagen, D., Roel, B.A., Kelly, C., Development of a stock–recruit model for simulating stockdynamics for uncertain situations: the exampleof Northeast Atlantic mackerel (Scomber scombrus), ICES Journal of Marine Science 68(5), 848-859

Details of these data revisions and the final table of catches for the four fleets are provided in Annex SWG-JM-02 and all final data and other inputs to the assessment model are detailed in Annex SWG-JM-03.

Participants expressed concern that the historic time series of catches had been substantially revised for a number of countries. Some participants expressed concern at the possible double-counting of Russian and Peruvian catches in 2010. Participants also noted that much of the above data preparation work could have been conducted by participants prior to the meeting. The JMSG recommended that the process for inter-sessional data preparation of finalised data inputs to the stock assessment model be improved to ensure that participants arrive at future stock assessment meetings with all of the data inputs to the models in the formats required by the model. Data preparation tasks should preferably be allocated to particular individuals to ensure that key data sets are prepared. Updated data sets should be circulated prior to the assessment meeting. Alternately, these tasks could be accomplished at dedicated data workshops, or by extending the duration of SWG meetings.

8.2. Selection and specification of the base-case assessment, and specification of stock assessment sensitivity runs to be conducted

Initially, eight JJM assessment model runs were conducted, with the specifications for Model 1 (the base case) being the same as the final base case model accepted during the 2010 assessment. Models 2 and 3 were the same sensitivity runs as those conducted in 2010, with acoustic indices down-weighted in Model 2 and CPUE indices down-weighted in Model 3. Two models (4 and 5) were run to evaluate the effect of setting the stock-recruit steepness parameter at two alternative lower levels and three models (6, 7 and 8) were run to estimate steepness, Sigma-r (the variability around the stock-recruit relationship) and natural mortality (*M*). The specifications for these initial models are summarised below.

Model	Description
Initial base case Model 1	• All indices assumed proportional to biomass • Fleet 4 age compositions based on Chilean age-length keys • Include all index data • Gili growth parameters to convert length frequencies from the far-north fishery to age compositions • Stock-recruitment steepness set to 0.8 • Assume *M* = 0.23
Initial Sensitivities	
Model 2	Downweight acoustic indices (Double CV)
Model 3	Downweight CPUE data (Double CV)
Model 4	Assume stock-recruit steepness = 0.6
Model 5	Assume stock-recruit steepness = 0.4
Model 6	Estimate M
Model 7	Estimate steepness
Model 8	Estimate steepness and Sigma R and natural mortality (*M*)

Results for these eight assessment model runs were evaluated by participants:

- Setting steepness to lower values (Models 4 and 5) had little effect on estimated trends in biomass and fishing mortality. The model-estimated values of steepness generated by Model 7 was 0.83 , similar to the assumed value of 0.8 in the base case. Participants agreed that the assumed value was appropriate and models 4, 5, and 7 were scrapped.
- The estimate of natural mortality (*M*) generated by Model 6 and 8 was greater than 0.5, which participants considered to be highly unrealistic. During the 2010 assessment, and alternative model run assuming *M* = 0.33 was rejected as being unrealistic, and so Model 8 was rejected for the 2011 assessment.

Models 1 (the base case) 2 and 3 were retained as the basis for conducting stock assessments and providing advice on jack mackerel stock status in 2011. These are essentially the same base case and sensitivity runs as conducted in 2010, bearing in mind that many of the data inputs and abundance indices were either updated or revised.

Following acceptance of these three models, one additional sensitivity run (new Model 4) was conducted to evaluate the effect of iterative re-weighting of effective sample sizes of the input data and indices, to provide improved estimates of variance around the inputs. Detailed specifications of this additional model are provided in Annex SWG-JM-02. Results of this additional sensitivity indicated that use of estimated effective sample sizes produces values of historical (pre-1992) biomass larger than the base case, but that, for recent years, the differences are minor. It was suggested that such tuning of input assumptions should be considered further in future assessments.

Regarding other possible sensitivity runs, there was brief discussion of options for running an assessment or projections varying the selectivity or fishing mortality on young (age 0 – 4) fish, to investigate the potential effect of a minimum size limit on biomass and fishing mortality trends. The Chair gave a brief presentation on some preliminary work done by himself and Dr Ianelli after the 9th SWG meeting to evaluate the potential effect on yield-per-recruit and spawner-biomass-per-recruit for jack mackerel of reducing F on small fish (SWG-JM-07). In view of the limited time at this meeting, it was agreed to defer the evaluation of the potential effects of minimum size limits to a future meeting.

8.3. Conducting of final stock assessment runs

Final assessment runs were conducted using the base case (Model 1) and two remaining sensitivities (Models 2 and 3), detailed specifications of which are provided in Annexes SWG-JM-02 and SWG-JM-03. Details of the data inputs to these models are also provided in Annex SWG-JM-03.

8.4. Synthesis and summary of key results from all stock assessment runs conducted

Dr Ianelli coordinated final JJM model runs using the three agreed models, and prepared technical annexes SWG-JM-02 and SWG-JM-03 containing the main outputs, model fit results and projection results for the final JJM assessment model runs. Based on updated catch information and abundance indices and the results of these assessments the JMSG produced the following jack mackerel stock status summary:

- Over the period 2005 – 2011, the main jack mackerel (*Trachurus murphyi*) fishery of interest to SPRFMO has been the fishery occurring off the south-central coast of Chile, extending from within the Chilean EEZ out onto the high seas. Jack mackerel catches in this area (Fleets 1, 2 and 4) contributed 89% of the total jack mackerel catch reported to SPRFMO over 2005 - 2011. The remaining 11% of jack mackerel catch reported to SPRFMO over that period has been taken by Fleet 3 in the far north, primarily within the Peruvian EEZ.
- There were substantial changes in the relative proportional contribution of catches by the various fleets between 2010 and 2011, with the fleets fishing off Chile (Fleets 1, 2 and 4) making 53% of the 2011 catch, and the Far North (Fleet 3) fishery making 47% of the catch. Expressed as percentages of the 2010 catches, the reported or estimated 2011 catches decreased to 14% for

Fleet 1, 66% for fleet 2 and 21% for Fleet 4. There was a substantial increase in the reported catch by Fleet 3 in 2011 compared to 2010.

- Jack mackerel catches off the south-central Chilean coast over this period have shown a continuous distribution from the coast out to the westwards extent of the high-seas fishery, extending westwards past 120°W in 2009 and to about 108°W in 2010. In 2011 there was a further contraction of the high-seas fishing area towards the Chilean EEZ, with catches extending out as far as about 94°W in 2011. In 2009 the SWG recommended that jack mackerel should be managed as one single management unit for the immediate future. This recommendation is not intended to prejudice any of the stock structure hypotheses adopted by the Jack Mackerel Stock Structure Workshop.
- Reported jack mackerel catches increased steadily from 1970 onwards, reaching a peak of 4.74 million t in 1995. Catches then declined rapidly to 1.37 million t in 1999. Over the period 2000 - 2006 there was a slow increase in total catches to 2 million t. Despite increasing participation and fishing effort in the fishery since then, catches declined steadily from 2007 onwards to 753,761 t in 2010, which was at that time the lowest catch on record since 1976. Catches continued to decline in 2011, with reported or estimated total catches (as at September 2011) of 522,440 t, which is now the lowest catch on record since 1976 (Annex SWG-JM-02 Table 1 and SWG-JM-03 Figure 5).
- Jack mackerel abundance and productivity are strongly driven by annual recruitment. Results of the 2011 JJM assessment base case indicate that high catches in the 1990s resulted from steadily increasing recruitment (age 2) from 1970 to 1982, followed by two exceptionally strong year classes in 1983 and 1984. Resulting strong recruitments in 1985 and 1986 (averaging 48.6 billion fish per year) were more than two and a half times the long-term 1970 – 2010 average annual recruitment of 18.0 billion fish (Annex SWG-JM-03 Figure 17). These estimates of recruitment are slightly higher than those from the 2010 assessment.
- Results of the 2011 JJM stock assessment indicate that recruitments from 1989 – 1996 were slightly below the long-term average, and that increasing catches over 2000 – 2006 resulted from above average recruitment (around 20.8 billion fish) over the years 1997 – 2001. Since 2002, recruitment has remained below the long-term average. Over the period 2000 – 2010, annual recruitment was only 58% (10.4 billion fish) of the long-term average. As a result of weak year classes from 2004 onwards, average recruitment over the period 2006 – 2010 (4.4 billion fish) has only been 24% of the long term average, and lower than estimated in the 2010 assessment (Annex SWG-JM-03 Figure 17).
- Results of the 2011 JJM stock assessment indicate that fishing mortality (*F*) increased slowly over the period from 1970 to reach about 0.18 in 1993, and then increased rapidly to 0.58 in 1997. Estimated *F* declined back down to 1994 levels by 2005 partially as a result of effort reductions in the Chilean fleet, but increased sharply again to about 0.61 in 2009, the highest level over the history of the fishery, before declining to 0.41 in 2011 (Annex SWG-JM-03 Figure 17). These estimates of F are slightly lower than those produced by the 2010 assessment. However, the updated assessment now indicates that the highest level of F in the fishery occurred in 2009, and not in 1997 as indicated by the 2010 assessment.
- Total biomass (B) and spawning biomass (SSB) are both assessed to have increased steadily over the period 1970 to 1987 as a result of the steadily increasing recruitments over that period, and particularly the strong 1985 and 1986 recruitments, reaching a peak total biomass of about 30.1 million t in 1988 (Annex SWG-JM-03 Figure 17).
- As a result of below average recruitment over the following decade coupled with high and increasing fishing mortality, estimated total biomass declined to about 7.0 million t in 1998. Increased recruitment resulted in a slow increase in estimated biomass to about 9.7 million t in 2001. Weak year classes from 2004 onwards, combined with escalating fishing mortality, resulted in a decline in estimated total biomass to about 2.5 million t in 2010, the lowest level

over the history of this fishery. The updated assessment indicates a slight increase in estimated total biomass to 2.8 million t in 2011, but a continuing decrease in spawning biomass from 760,000 t in 2010 to 723,000 t in 2011 (Annex SWG-JM-03 Figure 17).

- The ratio of estimated total biomass to the biomass that would have existed had no fishing occurred has declined steadily throughout most of the history of this fishery. Under the JJM assessment model base case, the 2011 ratio of total biomass relative to the potential unfished biomass is estimated to be 14%, ranging from 10% (model 3) to 19% (model 2) in sensitivity analyses (Annex SWG-JM-03 Figure 21).
- Projections of future spawning biomass (*B*) and fishing mortality (*F*) in 2021 were conducted using the base case and sensitivity models under a future recruitment scenario that estimated recruitment sampled from the distribution around average recruitment over the recent five-year period 2006 - 2010 (24% of the long-term average). Four constant catch scenarios were explored in projections: 520,000, 390,000, 260,000, 130,000 and 5,000, corresponding approximately to current (2011) catches and 75%, 50%, 25%, and 1% of 2011 catches (Annex SWG-JM-03 Figures 24 and 25).
- These projections indicate that, for the base case (Model 1), under future constant catches of 520,000 for the 5-year average recruitment scenario, there is a only a 21% probability of a decrease in spawning biomass, with median predicted biomass in 2021 being 1.23 times current spawning biomass (SWG-JM-03 Figures 24 and 25). Under the sensitivity analyses explored, for model 3 there is a 100% likelihood that spawning biomass will decline under catches at 520,000, whereas under model 2 there is a 0% probability of a decline, with spawning biomass predicted to increase to 1.7 times current levels.
- Projections at catches of 390,000 t show a high probability of an increase in spawning biomass by 2021 under all model runs, with spawning biomass potentially increasing from 1.3 times to 2.2 times current levels (SWG-JM-03 Figures 24 and 25).

Table 1. Summary of probabilities, from the 2011 JJM assessment results of biomass in 2021 being less than current biomass (p $B_{2021}<B_{2012}$) and the predicted ratio of 2021 biomass to current biomass (B_{2021}/B_{2012}) under a recent 5-year average future recruitment scenarios and five alternative future constant catch scenarios levels: 520 kt, 390 kt, 260 kt, 130 kt and 5 kt.

Estimated proportion of simulations where $SSB_{2021}< SSB_{2012}$

2021	5 kt	130 kt	260 kt	390 kt	520 kt
Model 1	0%	0%	0%	0%	21%
Model 2	0%	0%	0%	0%	0%
Model 3	0%	0%	0%	23%	100%

Median ratio (SSB_{2021}/SSB_{2012} from simulations

2021	5 kt	130 kt	260 kt	390 kt	520 kt
Model 1	4.642	3.884	3.057	2.181	1.229
Model 2	3.315	2.947	2.551	2.143	1.720
Model 3	6.425	4.893	3.185	1.298	0.000

8.5. Recommendations for Improving Future Assessments

The sub-group recommended that attention be given to the following work in order to improve future assessments:

- Improve the process for preparation of data inputs to assessment models, either by means of data workshops, extending the duration of the SWG or requiring participants to prepare and exchange data sets prior to assessment meetings.
- Ongoing cooperative work between participants to develop consistent otolith ageing protocols and to resolve apparent differences in growth-rate analyses and maturity schedules for the various regions.
- Further work to investigate the effect of spatial and seasonal patterns to improve existing acoustic indices and to evaluate to what extent they provide indices of abundance for particular areas or stock components.
- If CPUE data are to be used to provide indices of abundance, efforts must be made to develop standardised CPUE indices adjusted for factors such as historical changes in vessels, fishing areas, seasonal fishing patterns and environmental factors.
- Investigate the explicit incorporation of length-composition data within the assessment model, with model estimation of growth parameters.
- Conduct projections of stock status associated with the impact of a range of possible management measures, including minimum size lengths for jack mackerel and minimum fishery specific net mesh sizes.
- Further investigation of the tuning of input assumptions (variances and effective sample sizes) to improve model fits to the input data sets and indices.

9. Advice to the Scientific Working Group on Jack Mackerel Stock Status

In October 2010, based on the Joint Jack Mackerel model and TISVPA stock assessments conducted, the 9th meeting of the Scientific Working Group advised, *inter alia*, that:

- *"Jack mackerel catches have declined steadily since 2006, and continued to decline in 2010, with provisional (to September) 2010 catches being at the lowest level since 1976. … Assessment results indicate that total biomass has declined by 79% since 2001 to 2.1 million t, the lowest level in the history of the fishery. Current total biomass levels are estimated to be 9% - 14% of the biomass which would have existed if there had been no fishing.*
- *Estimated average recruitment over 2005 – 2009 has only been 30% of long-term average recruitment. …*
- *Under 5-year average recruitment, for the base case assessment, there is a 100% probability that biomass will continue to decline at … 2010 catch levels (711,783 t), with projected biomass in 2020 of 10% of current biomass. At 75% of current catches, there is a 54% chance that biomass will continue to decline, with projected biomass in 2020 of 97% of current biomass. At 50% of current catches, all models indicate that biomass will increase …"*

(Report of the 9th SWG Meeting, 2010)

Advice on jack mackerel stock status at this meeting was based on stock assessments conducted using the Joint Jack Mackerel (JJM) statistical catch-at-age model developed collaboratively by participants during 2010, advised and assisted by Dr Ianelli of NOAA:

- Jack mackerel catches by all but one of the fleets continued to decline in 2011, with overall 2011 catches being 69% of 2010 catches. Updated assessment results indicate that current biomass is now estimated to be 10% - 19% of the total biomass which would have existed if there had been no fishing, which is slightly higher than the estimated range from the 2010 assessment. The 2011 assessments results indicate a continuing decrease in fishing mortality and a slight increase in estimated total biomass over 2010, but a continuing decrease in spawning biomass.

- There continue to be indications of slightly improved recruitment in recent years, although the updated assessment indicates that the apparently strong recruitment observed by a number of fleets in 2010 was actually lower than the recruitment in 2009, and well below long-term average levels. Significant catches of 2 year old recruits were only made by the North Chilean (Fleet 1) fleet in 2011 and the resulting estimate of higher recruitment in 2011 is highly uncertain, and still well below long-term average levels (Annex SWG-JM-03 Figure 17).
- Projection results under the assumption of average recruitment at the levels estimated for the recent five-year period 2006 – 2010 indicate that catches should be maintained below 520,000 t to maintain spawning biomass at least at current levels. Catches below 390,000 t are projected to have a high probability of resulting in spawning stock rebuilding under most projections.

10. Jack Mackerel Research Programme

10.1. Inter-Sessional Progress with the Jack Mackerel Stock Structure Research Programme

SWG-10-JM-04: Report of 2011 SNP Workshops on Acoustic and Geo-statistical Assessment of abundance, distribution changes and size structure of Jack Mackerel (*Trachurus murphyi*)

Dr Mariano Gutiérrez presented an overview of acoustic survey work conducted in jack mackerel fishing areas in Peruvian waters. Substantial shifts in distribution and changes in availability of jack mackerel between 2010 and 2011 were correlated with shifts in distribution of water masses, with jack mackerel aggregating in narrow areas of preferred water temperature between coastal waters and oceanic or equatorial water. The thermocline depth in this suitable temperature area increased from 30m - 40m in 2010 to 70m in 2011. These oceanographic changes increased the availability of a number of species in this area.

There was some discussion of the substantial and rapid increase in modal size of jack mackerel caught over the 2011 fishing season. This appeared to result from a combination of growth and changes in the distribution / mixing of a number of separate age classes through the season.

SWG-10-JM-02: Acoustic data from fishing vessels

Dr Francois Gerlotto presented an overview of the use of commercial fishing vessels to collect standardised acoustic data during fishing trips, the use that could be made of such data and the statistical challenges associated with correcting for the bias and high CVs that result from concentration of fishing effort in areas where fish density exceeds some "fisher threshold" for commercially viable fish aggregations.

Commercial fishing vessels provided over 150,000 acoustic data records in the first quarter of 2011, covering almost the entire extent of the Peruvian jack mackerel fishing area. Most of these data records were concentrated in the main fishing areas and there are challenges with correcting for the bias introduced by this concentration of acoustic data in areas of highest jack mackerel abundance. However, commercial vessels can provide large quantities of acoustic data at low cost, compared to structured surveys. Dr Gerlotto concluded by recommending the establishment of a working group on fisheries acoustics to develop a common methodology for data collection, extraction, processing and analysis of acoustic data from commercial vessels, and to work towards a programme to collect standardised acoustic data using a number of vessels from each of the major jack mackerel fishing countries.

SWG-10-JM-03: Bio-acoustics: Minutes of ICES-FAST meeting held in Rejkavik, Iceland on 12 May 2011

Dr Rudy Kloser presented a summary of the outcomes of the 2011 ICES FAST working group meeting, at which initial results of acoustic work in the SPRFMO area were presented and discussed. Much of the work of this acoustics coordinating group has related to use of commercial vessels to conduct structured surveys, but there has been a recent trend towards use of acoustic information collected during unstructured fishing activities. Such information has primarily been used for spatial and ecological studies, as high CVs presents challenges in using the information in stock assessments. The FAST meeting proposed the development of a work plan for a pilot collaborative acoustic programme in the SPRFMO area, using one vessel from each of the active jack mackerel fishing countries to participate in unstructured and structured surveys. Initial requirements would include vessel selection, echo-sounder calibration, target strength determination and species identification.

JMSG participants considered that it was premature to establish an acoustics subgroup or to hold a dedicated acoustics workshop, but expressed interest in continuing discussion of collaborative acoustics work. The potential costs of participating in such an acoustics project remain a concern. Dr Kloser (Australia) agreed to act as coordinator of an inter-sessional process to develop draft terms of reference for a possible acoustics group, and to communicate with participants regarding a workshop to discuss the design of a pilot acoustics project. It was noted that such a workshop could be linked to the next ICES FAST working group meeting, to be held in Brest in 2012.

Francois Gerlotto, Ad Corten (EU), Jorge Castillo and Aquiles Sepulveda (Chile) were proposed as initial contact persons for inter-sessional communication with Dr Kloser. Peru and Russia undertook to identify suitable contact persons and the Secretariat was requested to write to these countries after the meeting requesting nomination of contact persons for this work.

SWG-10-JM-05: Russian population genetics study of jack mackerel in the South Pacific

Dr Alexander Glubokov presented a summary of the results of an initial study of the genetic polymorphism of South Pacific jack mackerel using selected microsatellite loci, comparing samples taken from 110°W (high-seas) and from 170°W (New Zealand EEZ) in the South Pacific Ocean. Of the four microsatellite loci investigated, two showed no differences between samples from the two locations, whereas the other two loci showed significant differences in allele frequencies between the two sampling locations. It was noted that this study is the first phase of a genetics study to compare samples from different regions, and that future work will include the investigation of a number of other microsatellite loci and the inclusions of samples from a third sampling area.

10.2. Future Jack Mackerel Work Programme

Annex D to the report of the 2nd session of the SPRFMO Preparatory Conference held in Cali, Colombia, in January 2011, includes a request that the SWG prepare a draft scientific work programme, taking into account the components listed in that Annex. In view of limited time at this meeting, it was agreed that this should be conducted as an inter-sessional process. Dr Rafael Duarte agreed to prepare a draft SWG scientific work plan combining the key elements of the Jack Mackerel Stock Structure work programme, the components listed in Annex D and the proposals at this meeting regarding collaborative acoustic surveys, and to coordinate an inter-sessional exchange of correspondence with all SWG participants to finalise a draft work plan for consideration by the SWG and Preparatory Conference.

10.3. Identification of short term research and assessment requirements

The following were identified as the most important jack mackerel research activities to conduct over the next year:

- Stock assessment: Implement the recommended improvements to the jack mackerel stock assessment process and jack mackerel stock assessments.
- Jack Mackerel Research Programme:
    - Continued work to standardise interpretation and ageing of jack mackerel otoliths through exchange of otolith images and improvement of the otolith interpretation protocol.
    - Development of draft terms of reference for a possible jack mackerel acoustics task team or group, and consideration of options for holding a workshop to discuss design of a pilot collaborative acoustics project (inter-sessional exchange to be coordinated by Dr Rudy Kloser).

11. Revisions to the Jack Mackerel Species Profile

Discussion of the draft revised jack mackerel species profile was again deferred to the next meeting. Participants were again requested to send comments and revisions on the revised profile prepared by Dr Glubokov.

12. Other Matters

No other matters were discussed.

13. Adoption of Jack-Mackerel Sub-Group Report and Summary

The report and summary of the jack Mackerel Sub-Group meeting was adopted after inclusion of agreed final edits.

Recommended Standardised Otolith Interpretation Protocol for *Trachurus murphyi*

The criteria and rules identified by 2011 SPRFMO Otolith Interpretation and Ageing Workshop are recommended as a starting point for a standardised jack mackerel otolith interpretation protocol that can be improved later. The main purpose of this protocol is to reduce bias in future age readings by participants in the jack mackerel fishery.

Recommended Otolith Interpretation Rules:

- From previous investigations of daily growth, the radius of the first annulus may be between 1.5 and 2.5 mm. This criterion should be used to identify the first annual ring. Large serrations in the shape of rings are an indication that they may be false rings.
- Consistency and a regular decrease in the width of subsequent rings is a second important criterion for identifying annual rings. Split rings were often observed in the first three years. The steady decrease in spacing between annual rings can be used to recognize split rings.
- Many additional false rings (minor growth checks) may be visible and make it difficult to identify true annual rings in the central part of otolith when magnification is more than 20x. Higher magnification may be needed to distinguish closely spaced rings near the edge of otoliths for larger fish, so it is recommended that different magnifications be used for the central and marginal zones of larger otoliths.
- Annual rings should be well defined and possible to follow around the otolith. This is not always possible, particularly near the edge due to the concave shape of the otolith, and the thickening of otoliths in older (larger) fish. The best approach for large fish is to compare readings of whole and cross-sectioned otoliths. When it is not possible to follow a ring around the otolith, then it may be a false ring or split ring.
- The entire otolith or otolith section should be examined when doing age reading, including the caudal zone and the rostrum. This is particularly important when the caudal zone is difficult to read, in which case it is necessary to examine the rostrum. Identification of false and split rings should also be checked on the rostrum.
- For larger fish (40 cm FL and larger), age readings should be confirmed using otolith cross-sections to avoid under-estimation of age. Ring deposition in larger fish occurs across more by thickening of the otolith, and older rings are particularly difficult to read at the otolith edge, particularly using whole otoliths.

Data

During the meeting, several new pieces of information were presented. The meeting agreed on data sets going forward for catch (Table 1). The detailed catch-at-age and index data are provided in Annex SWG-JM-03. The mean weights-at-age over time used for all gear types and indices, as decided by the ASTT, is shown in Fig. 1 and maturity-at-age is shown in Table 2. The final datasets evaluated by the subgroup are available to members upon request.

Data revisions

During the beginning of the SWG meeting, the following data were compiled for the assessment report:

- Chile
    - Catches by region
    - Catch age
- Peru
    - Length composition
    - CPUE
    - Acoustic index
- EU
    - Length frequency
    - CPUE (with Vanuatu) Added on year to end of time series
- China
    - CPUE (year effect coefficients)
    - Catch at length (in cm)
- Russian
    - CPUE data (2008-2011 (different catchability from USSR but this was not yet implemented due to time constraints)
    - 2008, 2009, and 2011 length frequency data

For the Chinese analyses, the year-effect coefficients on CPUE results were compiled from the figure in their report:

Year	Coefficients	Values for index
2001	0.180	1.197
2002	0.558	1.748
2003	0.417	1.517
2004	0.293	1.340
2005	0.234	1.263
2006	-0.068	0.934
2007	0.156	1.169
2008	-0.299	0.741
2009	-0.326	0.722
2010	-0.503	0.605

The Russian time series for jack mackerel covering the years 2008, 2009, and 2011 catch per day was 10.06, 7.94, and 5.45. The suggestion is to include these as either a new time series or an extension from previous years. Until standardizations can be completed, this time series was kept together and given relatively low weight.

Correspondence with Cuban colleagues resulted in revised total catch estimates (Fig. 2). These were adopted as the official estimates and incorporated into the estimate. Additionally, draft estimates of 2009-2011 catch levels occurring off Ecuadorian waters (80,000 t in 2011) were obtained from the following report: Condiciones Ocenográficas y Pesqueras Frente al Litoral Ecuatoriano. Comite ERFEN Agosto 2011. Instituto Nacional de Pesca del Ecuador (INP_agosto_201_ERFN). 2011. Other re-aggregations of fleet by members involved catches in the Far North region (Peru) and their activities in the more southern offshore international waters. This involved revising the Peruvian catches to reflect statistics submitted by the Peruvian Ministry of Production (1984-2011).

Assessment

Joint jack mackerel model

A statistical catch-at-age model was used to evaluate the jack mackerel stock. The JJM ("Joint Jack Mackerel Model") considered different types of information, which corresponds to the available data of the jack mackerel fishery developed on the South Pacific area since 1970 to 2011. A list of this information is listed in Table 3.

Parameters estimated conditionally are listed in Table 4. The most numerous of these involve estimates of annual and age-specific components of fishing mortality for each year from 1970-2011 and each of the four fisheries identified in the model. Parameters describing population numbers at age 2 in each year (and years prior to 1970 to estimate the initial population numbers at ages 2-12+) were the second most numerous type of parameter.

The table of equations for the assessment model is given in Tables 5, 6 and 7.

The treatment of selectivities and how they are shared among fisheries and indices is given in Table 8. The numbers of parameters for different model configurations were around 350. Also depending on the model configuration, some growth functions were employed to convert length compositions to age compositions (see Table 9).

Model evaluation

A set of 9 exploratory models were proposed and run for evaluation purposes. After preliminary evaluations, a subset of 3 models was carried forward for presentation and these are detailed in Table 10. Models 2 and 3 were based on model 1 correspond to sensitivity analysis, which focused on evaluating the model response when the variance assumption about the different types of abundance indexes is changed (Table 11). The subgroup evaluated the impact of different configurations for sensitivity but selected Model 1 as the "base case" similar to the configuration used in 2010. Likelihood values are shown in Table 12.

Effective sample size (Model 4)

An iterative process to estimate the effective sample size for each age composition used in the assessment was adopted as a sensitivity run. The estimator proposed by Gavaris and Ianelli (2002) was used to estimate the sample size by year and updating input values with the harmonic mean for each age composition data set. The sample sizes converged after four iterations (Fig. 3) and were adopted as input sample sizes as specified in Table 13.

The general results indicate that the input sample sizes were appropriate for the Northern Chile fishery and DEPM survey. For other data components, there were indications that the best fit of the age compositions occur in the Offshore fleet and that these input sample sizes could be increased. Results on the age composition data from Chilean Acoustic and FarNorth Fishery indicated that the sample size could be reduced for consistency. The implications of this analysis is that, for the years without abundance indices (before 1992), the estimated sample sizes produces values of biomass larger than the basecase, while for the most recent years, the differences are minor (Fig. 4). This suggests that model assumptions combined with the magnitude of catches has an important influence on assessment results and historical stock estimates. The subgroup appreciated the extra work that went into estimating these terms and as further improvements to the data and modelling are made, that such tuning of input assumptions should be considered in the future.

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Kochkin, P.N., 1994. Age determination and estimate of growth rate for the Peruvian jack mackerels, Trachurus symmetricus murphyi. J. of Ichthyol. 34(3): 39-50.

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Figures

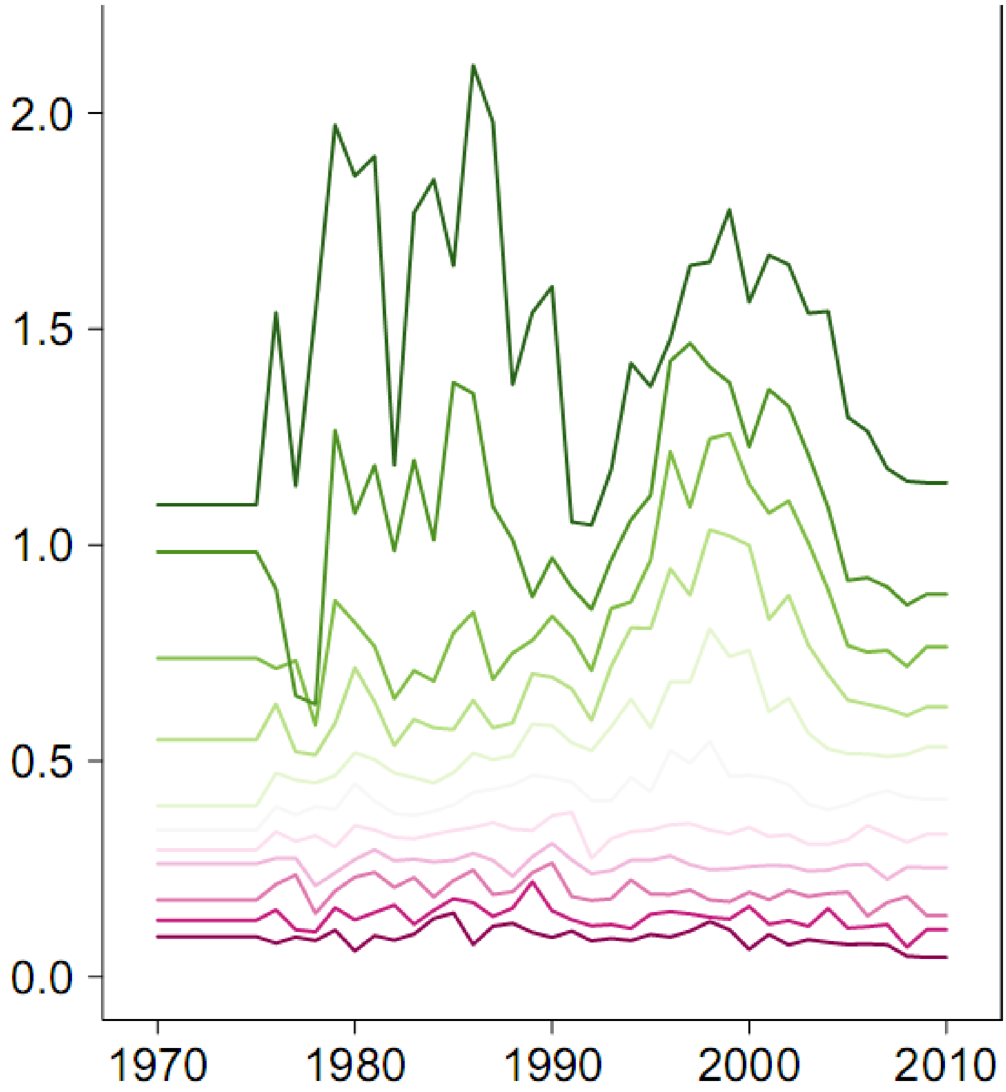


Figure 1. Mean weights-at-age (kg) over time used for all data types in the JJM models. Different lines represent ages 2 to 12.

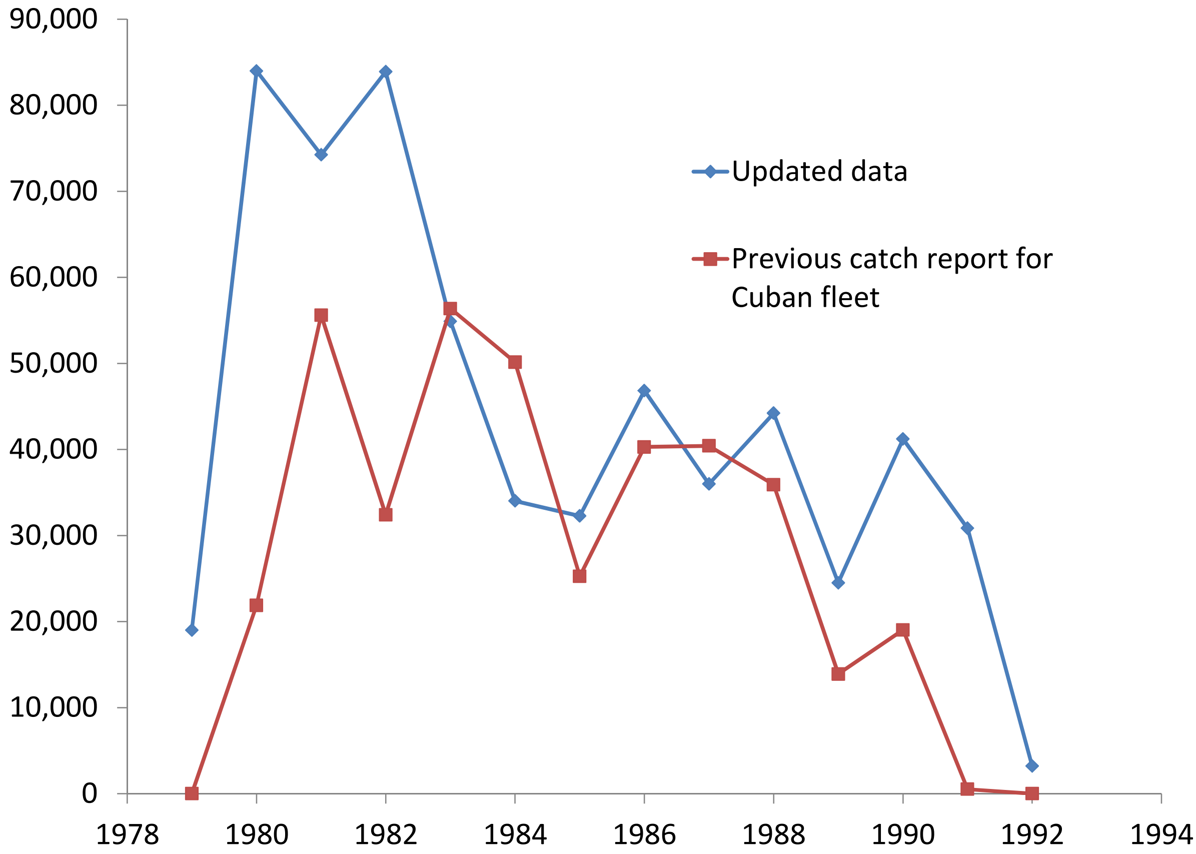


Figure 2. Change in catch reported from Cuba. The updated values were included in the assessment model.

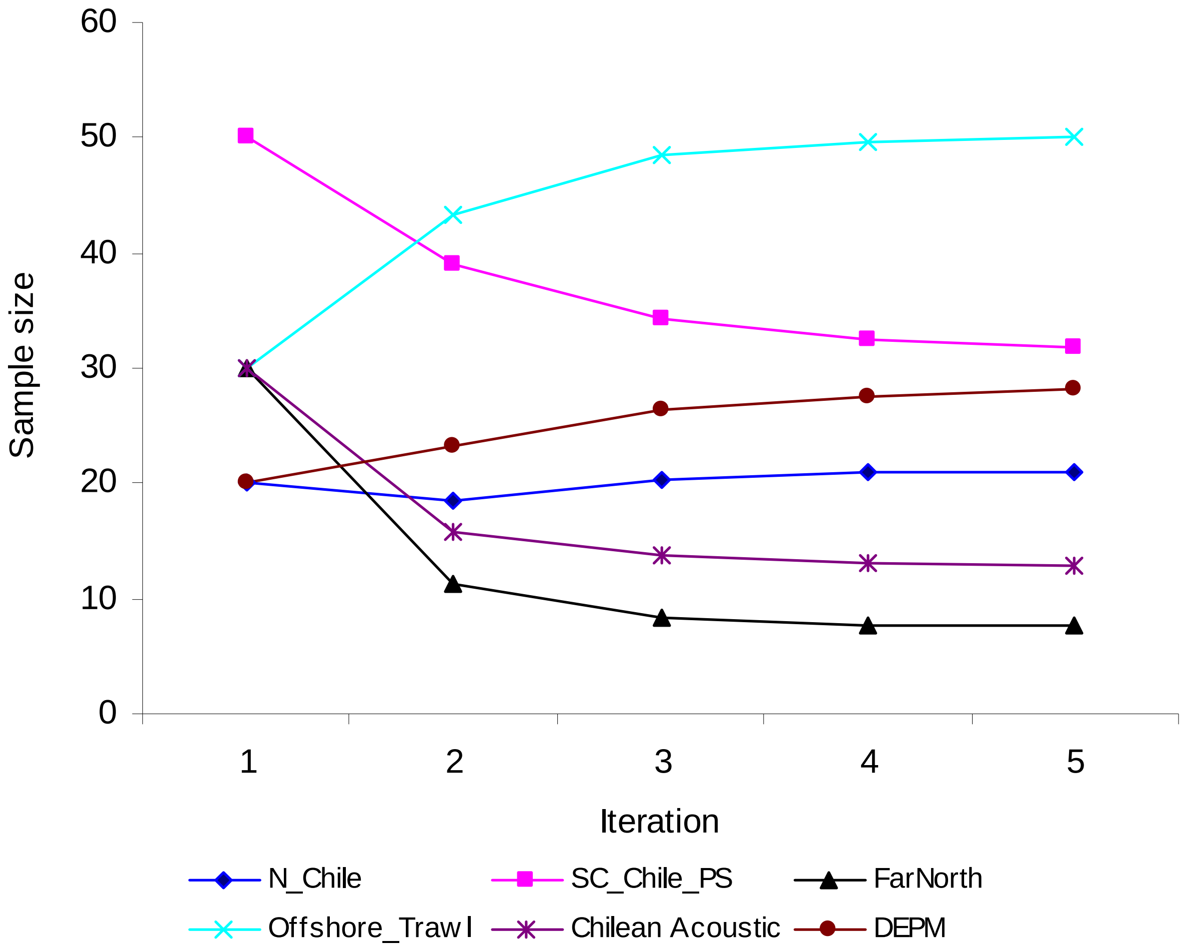


Figure 3. Effective sample size estimates by iteration for the main age composition gear types. The resulting value was used for Model 4.

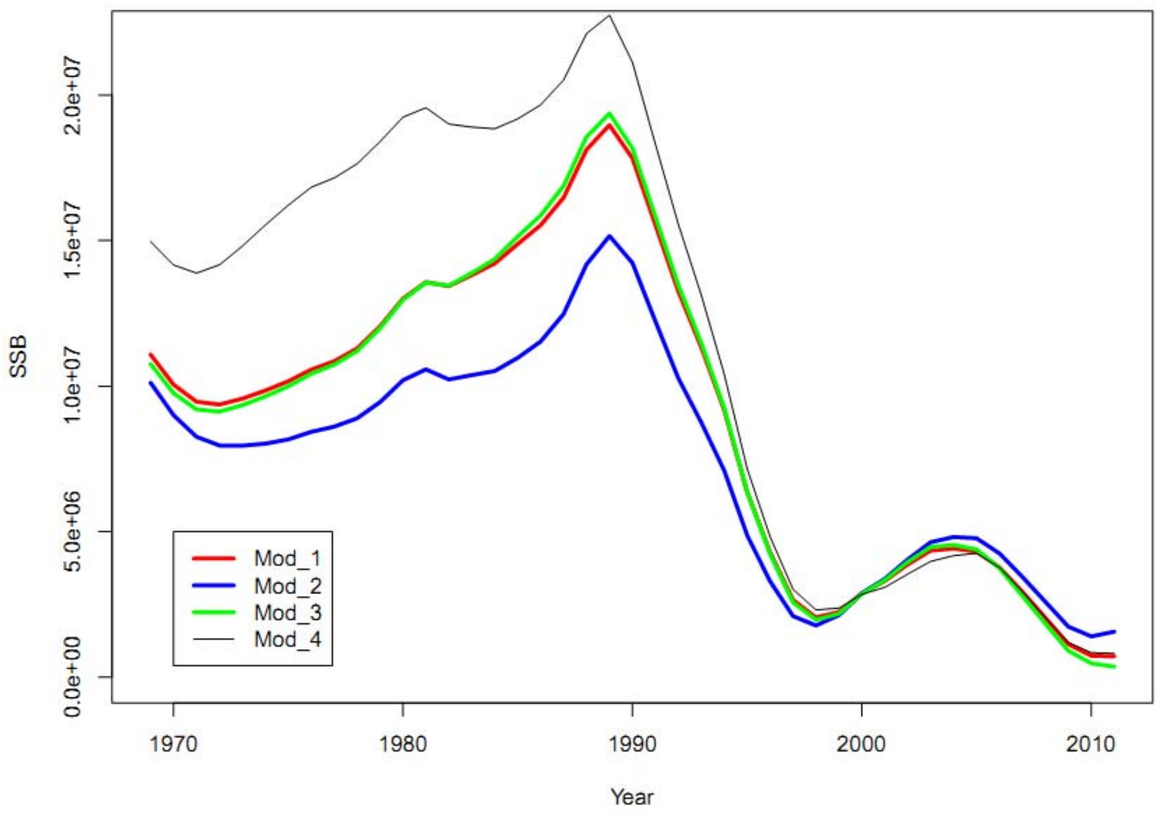


Figure 4. Spawning biomass estimates (t) comparing model configurations 1 – 4.

Table 1. Sources and values of catch (t) compiled for the four fleets used for the assessment.

	Fleet 1	Fleet 2	Fleet 3 (Far north)					Fleet 4 Trawler fleet off Chile (outside EEZ)											
Year	N Chile (1)	Chile CS (1)	Peru(1)	Ecuador (2)	USSR	Cuba (2)	Subtotal	Belize	Peru	Japan	China	EU	Faroe I.	Korea	Russia /USSR 1)	Cuba	Vanuatu	Subtotal	Total
1970	175208	7938	4711				4711											0	187857
1971	164838	21934	9189				9189											0	195961
1972	62634	7100	18782				18782								5500			5500	94016
1973	71762	8904	42781				42781											0	123447
1974	163396	12678	129211				129211											0	305285
1975	186890	34951	37899				37899											0	259740
1976	237876	65570	54154				54154			35								35	357635
1977	225907	75585	504992				504992			2273								2273	808757
1978	367762	150319	386793				386793			1667					49220			50887	955761
1979	311682	203269	151591		175938	6281	333810			120					356271	12719		369110	1217871
1980	266697	215528	123380		252078	38841	414299			0					292892	45130		338022	1234546
1981	435061	440935	37875		371981	35783	445639			29					399649	38444		438122	1759757
1982	756484	643821	50013		84122	9589	143724			0					651776	74292		726068	2270097
1983	259128	541696	76825		31769	2096	110690			1694					799884	52779		854357	1765871
1984	663695	677910	184333		15781	560	200674			3871					942479	33448		979798	2522077
1985	471599	923042	87466		26089	1067	114622			5229					762903	31191		799323	2308586
1986	42536	1103200	49863		1100	66	51029			6835					783900	46767		837502	2034267
1987	280594	1416781	46304			0	46304			8815					818628	35980		863423	2607102
1988	278701	1703037	118076		120476	5676	244228			6871					817812	38533		863216	3089182
1989	265861	2031058	140720		137033	3386	281139			701					854020	21100		875821	3453879
1990	258233	2150956	191139	4144	168636	6904	370823			157					837609	34293		872059	3652071
1991	282817	2649828	136337	45313	30094	1703	213447								514534	29125		543659	3689751
1992	285387	2796812	96660	15022		0	111682								32000	3196		35196	3229077
1993	359947	2745099	130681	2673			133354											0	3238400
1994	197414	3596904	196771	36575			233346											0	4027664
1995	211594	3984244	376600	174393			550993											0	4746831
1996	264631	3017165	438736	56782			495518											0	3777314
1997	88276	2541981	649751	30302			680053											0	3310310
1998	19278	1546704	386946	25900			412846											0	1978828

Year	Fleet 1 N Chile (1)	Fleet 2 Chile CS (1)	Fleet 3 (Far north) Peru(1)	Ecuador (2)	USSR	Cuba (2)	Subtotal	Fleet 4 Trawler fleet off Chile (outside EEZ) Belize	Peru	Japan	China	EU	Faroe I.	Korea	Russia /USSR 1)	Cuba	Vanuatu	Subtotal	Total
1999	44582	1130488	184679	19072			203751			7								7	1378828
2000	107769	1135082	296579	7122			303701				2318							2318	1548870
2001	244019	1216754	723733	133969			857702				20090							20090	2338565
2002	108727	1357185	154219	604			154823				76261							76261	1696996
2003	142016	1272302	217734				217734				94690			2010	7540		53959	158199	1790251
2004	158656	1292943	187369				187369				131020			7438	62300		94685	295443	1934411
2005	168383	1262051	80663				80663	867			143000	6179		9126	7040		77356	243568	1754665
2006	155256	1224685	277568				277568	481			160000	62137		10474			129535	362627	2020136
2007	172701	1130083	254426	927			255353	12585			140582	123511	38700	10940			112501	438819	1996956
2008	167258	728850	169537				169537	15245			143182	106665	22919	12600	4800		100066	405477	1471122
2009	134022	700905	25912	19834			45746	5681	13326		117963	111921	20213	13759	9113		79942	371918	1252591
2010	169010	295681	300	5000			5300	2240	40516		63606	67749	13674	8183	41315		46487	283770	753761
2011	23945	194532	164589	80000			244589		662		27936	2261		9254	8229	3360	7672	59374	522440

See text for changes in the Peruvian, Cuban, and Equadorian estimates.
2011 data are preliminary and reflect the best estimates for the year.

Table 2. Jack mackerel sexual maturity by age used in the JMM models (Serra and Canales 2009).

Age (yr)	2	3	4	5	6	7	8	9	10	11	12
Proportion mature	0.00	0.04	0.50	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 3. Years and types of information used in the JJM assessment models.

Fleet	Catch at age	Catch at length	Landings	CPUE	Acoustic	DEPM
North Chile purse seine	1975-2011	-	1970-2011	-	1984-1988; 1991; 2006-2009	1999-2008
South-central Chile purse seine	1975-2011	-	1970-2011	1995-2002	1997-2009	-
FarNorth	-	1980-2011	1970-2011	1996-2009, 2011	1983-2011	-
International trawl off Chile	1979-1991	2007-2011	1978-2011	China (2001-2010); EU & Vanuatu (2003-2011); Russian (1987-1991, 2008-09, 2011)	-	-

Table 4. Symbols and definitions used for model equations.

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: i = {1970, …., 2011}	i	
Age index: j = { 2, 3, …, 12^+}	j	
Mean weight in year t by age j	$W_{t,j}$	
Maximum age beyond which selectivity is constant	*Maxage*	Selectivity parameterization
Instantaneous Natural Mortality	M	Fixed M=0.23, constant over all ages
Proportion females mature at age j	p_j	Definition of spawning biomass
Sample size for proportion in year i	T_i	Scales multinomial assumption about estimates of proportion at age
Survey catchability coefficient	q^s	Prior distribution = lognormal(μ_q^s , σ_q^2)
Stock-recruitment parameters	R_0	Unfished equilibrium recruitment
	h	Stock-recruitment steepness
	σ_R^2	Recruitment variance
Unfished biomass	φ	Spawning biomass per recruit when there is not fishing
Estimated parameters		
$\phi_i(\#), R_0, h, \varepsilon_i(\#), \mu^f, \mu^s, M, \eta_j^s(\#), \eta_j^f(\#), q^s(\#)$		

Note that the number of selectivity parameters estimated depends on the model configuration.

Table 5. Variables and equations describing implementation of the joint jack mackerel assessment model (JJM).

Eq	Description	Symbol/Constraints	Key Equation(s)
1)	Survey abundance index (s) by year (Δ^s represents the fraction of the year when the survey occurs)	I_i^s	$I_i^s = q^s \sum_{j=2}^{12} N_{ij} W_{ij} S_j^s e^{-\Delta^s Z_{ij}}$
2)	Catch biomass by year	C_i	$\hat{C}_{ij}^f = \sum_{j=2}^{12} N_{ij} W_{ij} \frac{F_{ij}^f}{Z_{ij}} (1-e^{-Z_{ij}})$
3)	Proportion at age j, in year i	P_{ij}, $\sum_{j=2}^{12} P_{ij} = 1.0$	$p_{ij}^f = \frac{\hat{C}_{ij}^f}{\sum_j \hat{C}_{ij}^f}$ $p_{ij}^s = \frac{N_{ij} S_j^s e^{-\Delta^s Z_{ij}}}{\sum_j N_{ij} S_j^s e^{-\Delta^s Z_{ij}}}$
4)	Initial numbers at age	j = 2	$N_{1970,j} = e^{\mu_R + \varepsilon_{1970}}$
5)		2 < j < 11	$N_{1970,j} = e^{\mu_R + \varepsilon_{1971-j}} \prod_{j=1}^{j} e^{-M}$
6)		j = 12+	$N_{1970,12} = N_{1970,11} \left(1-e^{-M}\right)^{-1}$
7)	Subsequent years (i >1970)	j = 2	$N_{i,2} = e^{\mu_R + \varepsilon_i}$
8)		2 < j < 11	$N_{i,j} = N_{i-1,j-1} e^{-Z_{i-1,j-1}}$
9)		j = 12+	$N_{i,12^+} = N_{i-1,11} e^{-Z_{i-1,10}} + N_{i-1,12} e^{-Z_{i-1,11}}$
10)	Year effect and individuals at age 2 and i = 1958, …, 2011	$\varepsilon_i, \sum_{i=1958}^{2011} \varepsilon_i = 0$	$N_{i,2} = e^{\mu_R + \varepsilon_i}$
11)	Index catchability		$q_i^s = e^{\mu^s}$
	Mean effect	μ^s, μ^f	$s_j^s = e^{\eta_j^s}$ $j \le \text{maxage}$
	Age effect	$\eta_j^s, \sum_{j=2}^{12^+} \eta_j^s = 0$	$s_j^s = e^{\eta_{maxage}^s}$ $j > \text{maxage}$
12)	Instantaneous fishing mortality		$F_{ij}^f = e^{\mu^f + \eta_j^f + \phi_i}$
13)	Mean fishing effect	μ^f	
14)	Annual effect of fishing mortality in year i	$\phi_i, \sum_{i=1970}^{2011} \phi_i = 0$	
15)	age effect of fishing (regularized) In year time variation allowed	η_{ij}^f, $\sum_{j=2}^{12^+} \eta_{ij} = 0$	$s_{ij}^f = e^{\eta_j^f}$, $j \le \text{maxage}$; $s_{ij}^f = e^{\eta_{maxage}^f}$ $j > \text{maxage}$
	In years where selectivity is constant over time	$\eta_{i,j}^f = \eta_{i-1,j}^f$	$i \ne \text{change year}$
16)	Natural Mortality	M	Set fixed at 0.23 in basecase
17)	Total mortality		$Z_{ij} = \sum_f F_{ij}^f + M$
17)	Spawning biomass (note spawning taken to occur at mid of November)	B_i	$B_i = \sum_{j=2}^{12} N_{ij} e^{-\frac{10,5}{12} Z_{ij}} W_{ij} p_j$

Eq	Description	Symbol/Constraints	Key Equation(s)
18)	Recruitments (Beverton-Holt form) at age 2.	$\tilde{R}_i$	$\tilde{R}_i = \frac{\alpha B_i}{\beta + B_i}$, $\alpha = \frac{4hR_0}{5h-1}$ and $\beta = \frac{B_0(1-h)}{5h-1}$ where $B_0 = R_0\varphi$ $\varphi = \sum_{j=2}^{12} e^{-M(j-1)} W_j p_j + \frac{e^{-12M} W_{12} p_{12}}{1-e^{-M}}$ h=0.8

Table 6. Specification of objective function that is minimized (i.e., the penalized negative of the log-likelihood).

	Likelihood /penalty component		Description / notes
19)	Abundance indices	$L_1 = \sum_s \lambda_1^s \sum_i \log\left(\frac{I_i^s}{\hat{I}_i^s}\right)^2$	Survey abundances
20)	Prior on smoothness for selectivities	$L_2 = \sum_l \lambda_2^l \sum_{j=2}^{12^+} \left(\eta_{j+2}^l + \eta_j^l - 2\eta_{j+1}^l\right)^2$	Smoothness (second differencing), Note: *l={s,* or *f}* for survey and fishery selectivity
21)	Prior on recruitment regularity	$L_3 = \lambda_3 \sum_{i=1958}^{2011} \varepsilon_i^2$	Influences estimates where data are lacking (e.g., if no signal of recruitment strength is available, then the recruitment estimate will converge to median value).
22)	Catch biomass likelihood	$L_4 = \sum_f \lambda_4^f \sum_{i=1970}^{2011} \log\left(\frac{C_i^f}{\hat{C}_i^f}\right)^2$	Fit to catch biomass in each year
23)	Proportion at age likelihood	$L_5 = -\sum_{l,i,j} T^l P_{i,j}^l \log(\hat{P}_{i,j}^l)$	*l={s, f}* for survey and fishery age composition observations P_{ij} are the catch-at-age proportions
24)	Fishing mortality regularity	F values constrained between 0 and 5	(relaxed in final phases of estimation)
25)	Recruitment curve fit	$L_6 = \lambda_6 \sum_{i=1977}^{2010} \log\left(\frac{N_{i,2}}{\tilde{R}_i}\right)^2$	Conditioning on stock-recruitment curve over period 1977-2011.
26)	Priors or assumptions	R_0 non-informative σ_R^2 fixed at 0.6	(Explored alternative values of σ_R^2
27)	Overall objective function to be minimized	$\dot{L} = \sum_k L_k$	

Table 7. Lambda values used on log-likelihood functions in the base model.

L	s	Abundance index	$\lambda^{s\ (1)}$	L	f	Catch biomass likelihood	$\lambda^{f\ (1)}$
1	1	Acoustic CS- Chile	5.6	4	1	N-Chile	200
	2	Acoustic N-Chile	2		2	CS- Chile	200
	3	CPUE – Chile	12.5		3	Peru	200
	4	DEPM – Chile	3.1		4	International	200
	5	Acoustic-Peru	5.6		5	ex USSR	200
	6	CPUE – Peru	12.5				
	7	CPUE- China	3.1				
	8	CPUE-EU	12.5				
	9	CPUE- ex USSR	3.1				
2	s	Smoothness for selectivities	$\lambda^{s\ (1)}$	5	s	Proportion at age likelihood	T^s
	1	Acoustic CS- Chile	100		1	Acoustic CS- Chile	30
	2	Acoustic N-Chile	100		2	DEPM – Chile	20
	3	CPUE – Chile	100				
	7	CPUE- China	100				
	8	CPUE-EU	100				
	9	CPUE ex-USSR	100				
	f	Smoothness for selectivities	$\lambda^{f\ (1)}$	6	f	Proportion at age likelihood	T^f
	1	N-Chile	1		1	N-Chile	20
	2	CS- Chile	25		2	CS- Chile	50
	3	Peru	12.5		3	Peru	30
	4	Internacional	12.5		4	Internacional	30
	5	ex – USSR	12.5		5	ex - USSR	30
3		Recruitment regularity	$\lambda^{s\ (1)}$			S-Recruitment curve fit	$\lambda^{(1)}$
			1.4				1.4

(1) λ corresponds to $0.5/\sigma^2$:

σ	λ
0.05	200
0.10	50
0.20	12.5
0.30	5.6
0.40	3.1
0.50	2.0
0.60	1.4

Table 8. Description of JJM model components and how selectivity was treated.

Item	Description	Selectivity assumption
Fisheries		
1)	Chilean northern area fishery	Estimated from age composition data. Two time-blocks were considered 1970-1987; 1988-2011.
2)	Chilean central and southern area fishery	Estimated from age composition data. Four time-blocks were considered 1970-1987; 1988-1991;1992-2004;2005-2011.
3)	Peruvian fishery	Estimated from transformed length data to age.
4)	Recent offshore trawl fishery and	Estimated from recent age composition data (post 1992)
	Ex-USSR trawl fishery	Estimated from historical age composition data.
Index series		
5)	Acoustic survey in central and southern Chile	Estimated from age composition data. Two time-blocks were considered 1970-2005; 2006-2011.
6)	Acoustic survey in northern Chile	Assumed to be the same as 1)
7)	Central and southern fishery CPUE	Assumed to be the same as 2)
8)	Egg production survey	Estimated from age composition data
9)	Acoustic survey in Peru	Assumed to be the same as 3)
10)	Peruvian fishery CPUE	Assumed to be the same as 3)
11)	Chinese fleet CPUE (from FAO workshop)	Assumed to be the same as 4)
12)	Vanuatu & EU fleets CPUE	Assumed to be the same as 4)
13)	ex-USSR CPUE	Assumed to be the same as 4) but for earlier period

Table 9. Growth parameters employed to convert the length compositions (Peru) to age compositions for the Fleet 3 far north fishery. A conversion factor of 1.0822was used to convert total length to fork length (the Peruvian data were measured as total length).

Parameter	Chile (Gili et al, 1995)
Loo (cm)	70.8
k (year-1)	0.094
to (year)	-0.896

Table 10. Particular specifications for the different models applied.

Model	Description
Initial base case Model 1	• All indices assumed proportional to biomass • Fleet 4 age compositions based on Chilean age-length keys • Include all index data • Gili growth parameters to convert length frequencies from the far-north fishery to age compositions • Stock-recruitment steepness set to 0.8
Sensitivities	
Model 2	Downweight acoustic indices (Double CV)
Model 3	Downweight CPUE data (Double CV)
Model 4	Iteratively re-weight input sample sizes

Table 11. Different cases (coefficients of variation) considered on the sensitivity analysis

Index	n *	Model 1 Basecase	Model 2	Model 3	Model 4
Acoustic Chile CS	13	0.2	0.4	0.2	0.2
Acoustic Chile N	10	0.5	1.0	0.5	0.5
CPUE Chile	8	0.2	0.2	0.4	0.2
DEPM Chile	9	0.5	0.5	0.5	0.5
Acoustic Peru	27	0.2	0.4	0.2	0.2
CPUE Peru	14	0.2	0.2	0.4	0.2
CPUE China	10	0.2	0.2	0.4	0.2
CPUE Vanuatu & EU	8	0.25	0.25	0.25	0.25
CPUE USSR	5	0.25	0.25	0.5	0.25
M		0.23	0.23	0.23	0.23

Notes:

* number of observations

Table 12. Values of components of the objective function for the 3 different JJM models. Note that Models 2 - 4 values use different variance assumptions are not strictly comparable (but within categories can be compared).

	Model 1	Model 2	Model 3	Model 4
Data				
Indices likelihoods	889.5	377.4	750.5	796.1
Fishery Age compositions	941.4	898.3	941.1	721.2
Survey age compositions	130.9	121.2	127.7	85.1
Catch biomass	9.2	1.6	9.4	5.2
Priors				
Fishery selectivity	50.0	47.6	50.6	52.4
Indices selectivity	23.8	21.2	22.6	16.6
Stock-recruitment	20.7	17.6	28.4	9.6
Total	2065.7	1485.2	1930.4	1686.4

Table 13. Effective sample sizes estimated for the catch-at-age compositions used on the jack mackerel assessment.

Source	Original	Re-estimated
Chilean Northern fishery	20	21
Chilean Southern fishery	50	32
Far North fishery	30	8
Offshore Trawl fishery	30	50
Chilean (Southern) Acoustic survey	30	13
Chilean DEPM survey	20	28

Results from final selected models for the 2011 Jack mackerel stock assessment

This annex contains the main results from the final models specified at the subgroup meeting.

Assessment model results

Total catch used for this assessment is shown in Fig. 5 and basecase model fit to these is in Fig. 6. Other data in the model is shown in the fit figures below or in Annex SWG-JM-02. For the purposes of this section the three models presented represent the base case (Model 1 from Annex SWG-JM-02) and alternatives that seem to bracket model uncertainty (Models 2 and 3 from Annex SWG-JM-02).

The base case fit (Model 1) to the fishery age composition data is shown in Figures 7, 8, 9, and 10. This model fit to the indices is shown in Figure 11 while the fit to the index age compositions are shown in Figures 12, and 13. Selectivity estimates for the fishery and indices is shown over time in Figs. 14 and 15 respectively. Residuals to the indices and age compositions are presented in Fig. 16. A summary of the time series stock status (spawning biomass, F, recruitment, total biomass) is shown in Fig. 17. Noticeably, the 2011 recruitment estimates suggest an increase which based on the age composition fits, appears to be coming primarily from Fleet number 1 (Northern Chile). The immature component of the stock seems increasing in recent years whereas the estimated mature component of the stock is near an all-time low (Fig. 18). Fishing mortality rates have been relatively high since 1992 but has apparently shifted towards older ages (Fig. 19). The stock recruitment relationship appears to be consistent with the fixed value of steepness assumed (0.8; Fig. 20). In alternative runs where steepness was estimated, the estimates tended towards higher values. As with last year, the group requested a presentation of the stock trend as estimated compared to an estimate had no historical fishing occurred (Fig. 21).

Model sensitivities

As an initial model evaluation, the impact of downweighting different types of indices was selected to illustrate potential structural errors in model assumptions and the influence it may have on trends and current abundance levels. For fishing mortality, the comparison of the base case and model sensitivities indicate higher levels for Model 3 (which downweighted CPUE data) relative to the base case and the model which downweights the acoustic indices (Model 2). In terms of the effect on stock status relative to "unfished", the differences were relatively minor and in all cases, the 2011 total biomass is estimated to be between 10 – 19% of the unfished level.

Projections

The following recruitment scenarios were proposed for projections during the subgroup meeting it was decided to use average recruitment as estimated from 2006-2010. For this period, 100 stochastic simulations (in recruitment) were conducted assuming the same mean and variance *without regard to a stock recruitment relationship.* These (low) recruitments are assumed to be independent of spawning biomass levels.

As with last year, the subgroup recommended examining constant catch scenarios with current levels (520 kt) and at 75%, 50%, 25%, and 1% (corresponding roughly to 390, 260, 130, and 5 kt. Constant catch solutions were obtained by iterating F's (assuming ratios among the 4 fleets to be similar to that observed in 2011) within the Baranov catch equation. The 3 models and 5 constant catch strategies result in 15 unique projection configurations. Each of these were projected for 10 years (to 2021) and simulated 100 times. These simulations show that for the for example, base case, example future constant catches of 260 kt using the 5-year average recruitment scenario should result in stock increases and lower fishing mortality rates (Fig. 22). At current catch levels (520 kt) the stock is projected to increase but with a 21% chance of declines by 2021 (Fig. 23).

For the 5-year average recruitment scenario, examination of mean values from projections indicates that, for the stock to show signs of increase, a reduction in catch by about 50% would be required regardless of the model (Fig. 24). The more optimistic recruitment scenario based on the 10-year average recruitment projection indicates that even at the current catch level (520 kt) the stock is likely to increase (Fig. 25).

Estimated proportion of simulations where $SSB_{2016} < SSB_{2012}$

2016	5 kt	130 kt	260 kt	390 kt	520 kt
Model 1	0%	0%	0%	0%	0%
Model 2	0%	0%	0%	0%	0%
Model 3	0%	0%	0%	1%	86%

Estimated proportion of simulations where $SSB_{2021} < SSB_{2012}$

2021	5 kt	130 kt	260 kt	390 kt	520 kt
Model 1	0%	0%	0%	0%	21%
Model 2	0%	0%	0%	0%	0%
Model 3	0%	0%	0%	23%	100%

Median ratio (SSB_{2016}/SSB_{2012} from simulations

2016	5 kt	130 kt	260 kt	390 kt	520 kt
Model 1	3.279	2.861	2.421	1.976	1.527
Model 2	2.484	2.278	2.062	1.846	1.627
Model 3	4.196	3.366	2.488	1.598	0.691

Median ratio (SSB_{2021}/SSB_{2012} from simulations

2021	5 kt	130 kt	260 kt	390 kt	520 kt
Model 1	4.642	3.884	3.057	2.181	1.229
Model 2	3.315	2.947	2.551	2.143	1.720
Model 3	6.425	4.893	3.185	1.298	0.000

Figures

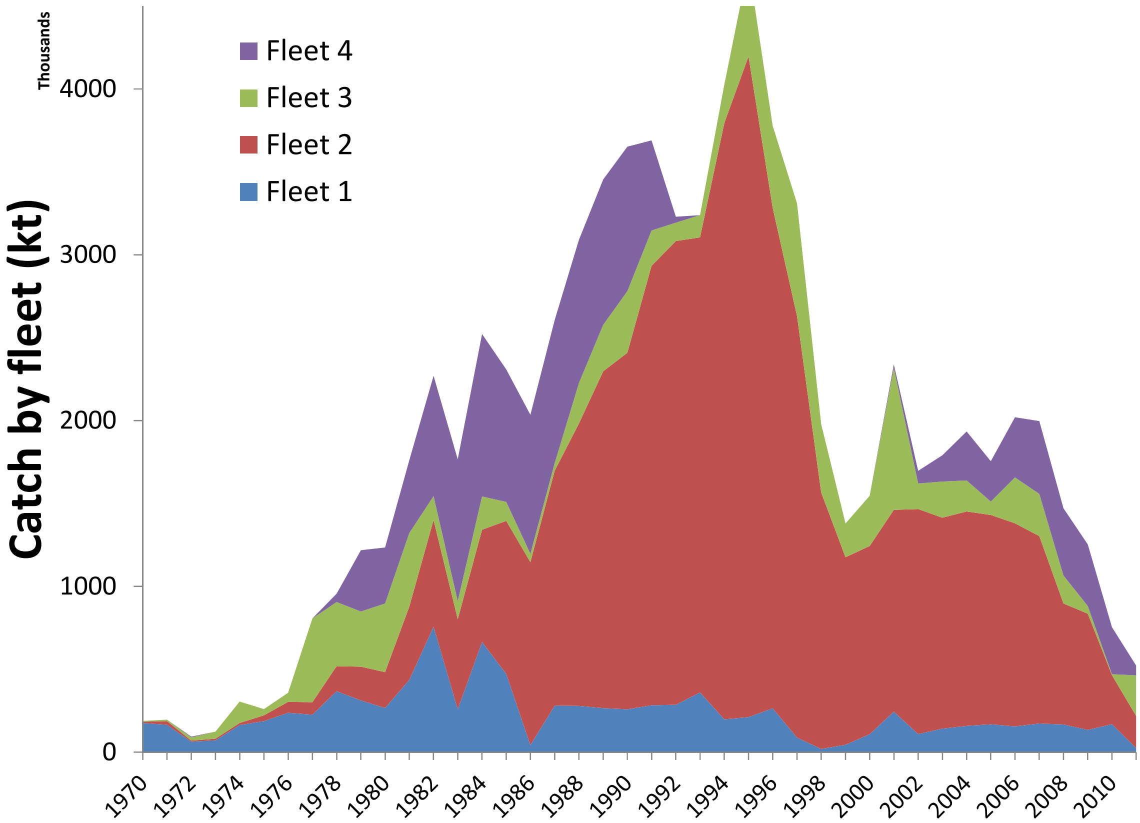


Figure 5. Total catch and catch components used for the joint jack mackerel assessment, 1970-2011. Fleet 1 corresponds to the N Chile purse seine, Fleet 2 the SC Chilean purse seine, Fleet 3 the far north fishery, and Fleet 4 the Offshore trawl fishery.

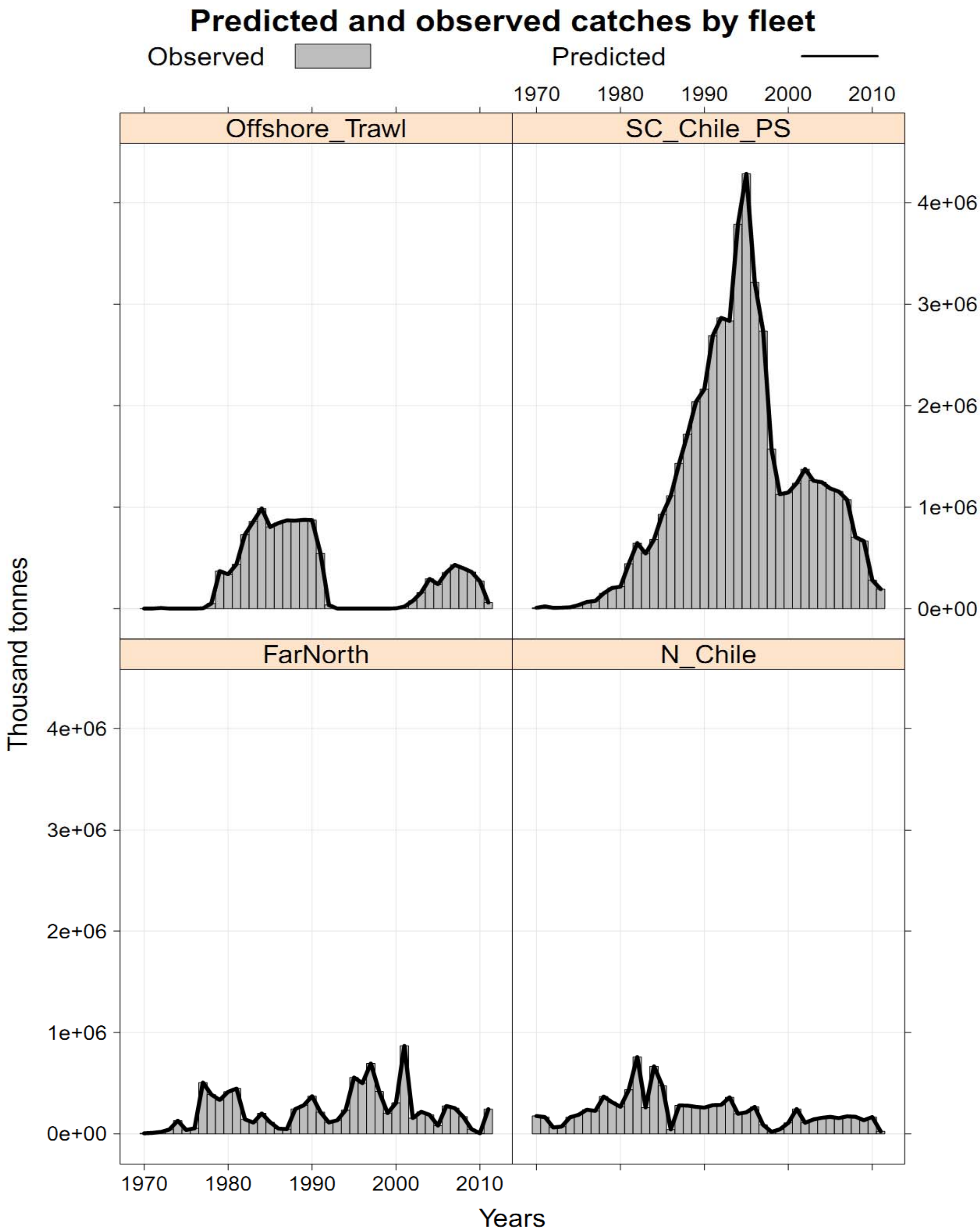


Figure 6. JJM Model fit to the total catches ('000 tonnes) by fleet for Fleet 1 (N_Chile_PS), Fleet 2 (SC_Chile_PS), Fleet 3 (Far_North) and Fleet 4 (Offshore_Trawl). The bars represent the observations and the line represents the predicted values.

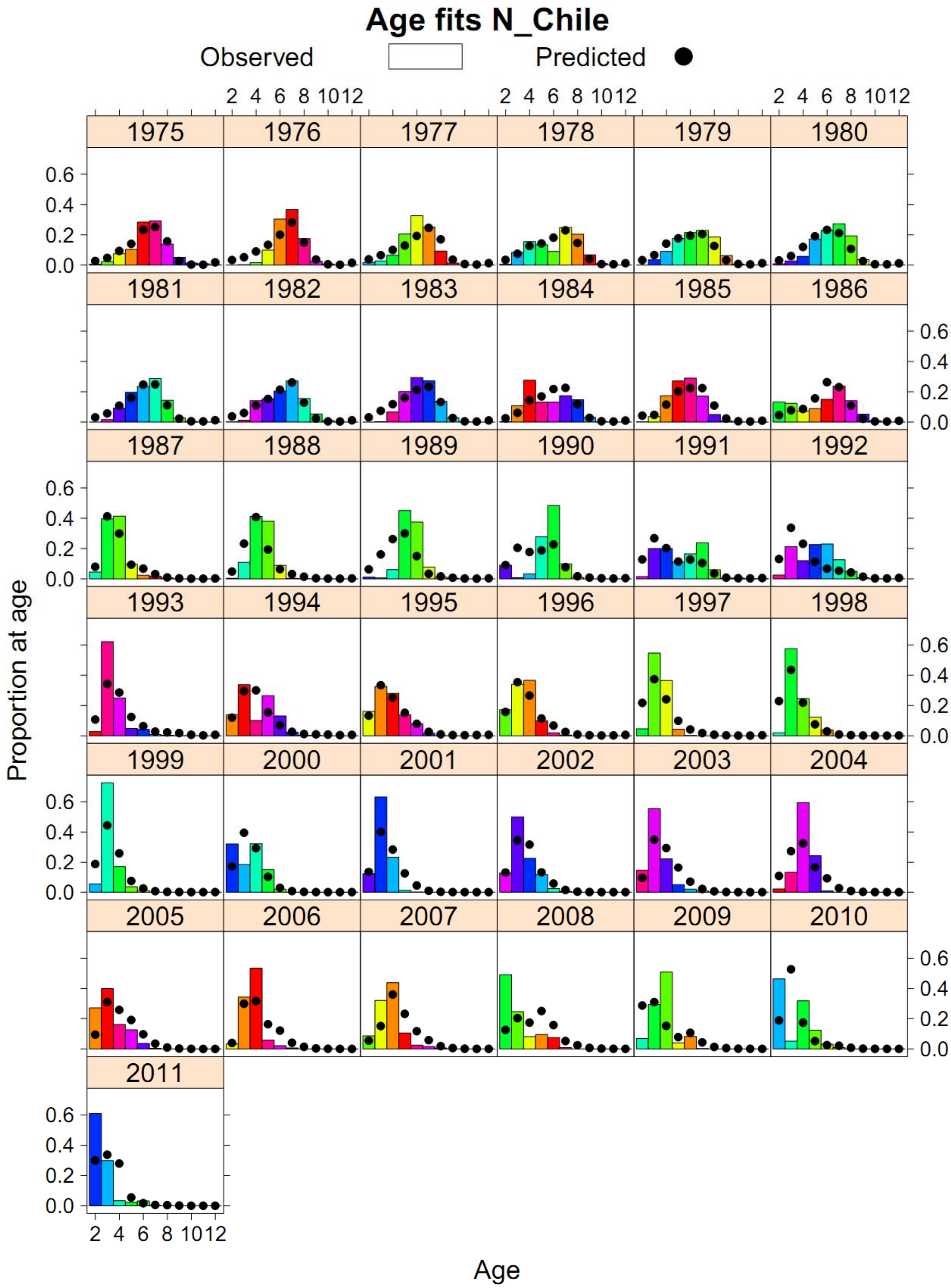


Figure 7. Base case (model 1) fit to the age compositions for the **Chilean northern zone fishery (Fleet 1)**. Bars represent the observed data and dots represent the model fit and color codes correspond to cohorts.

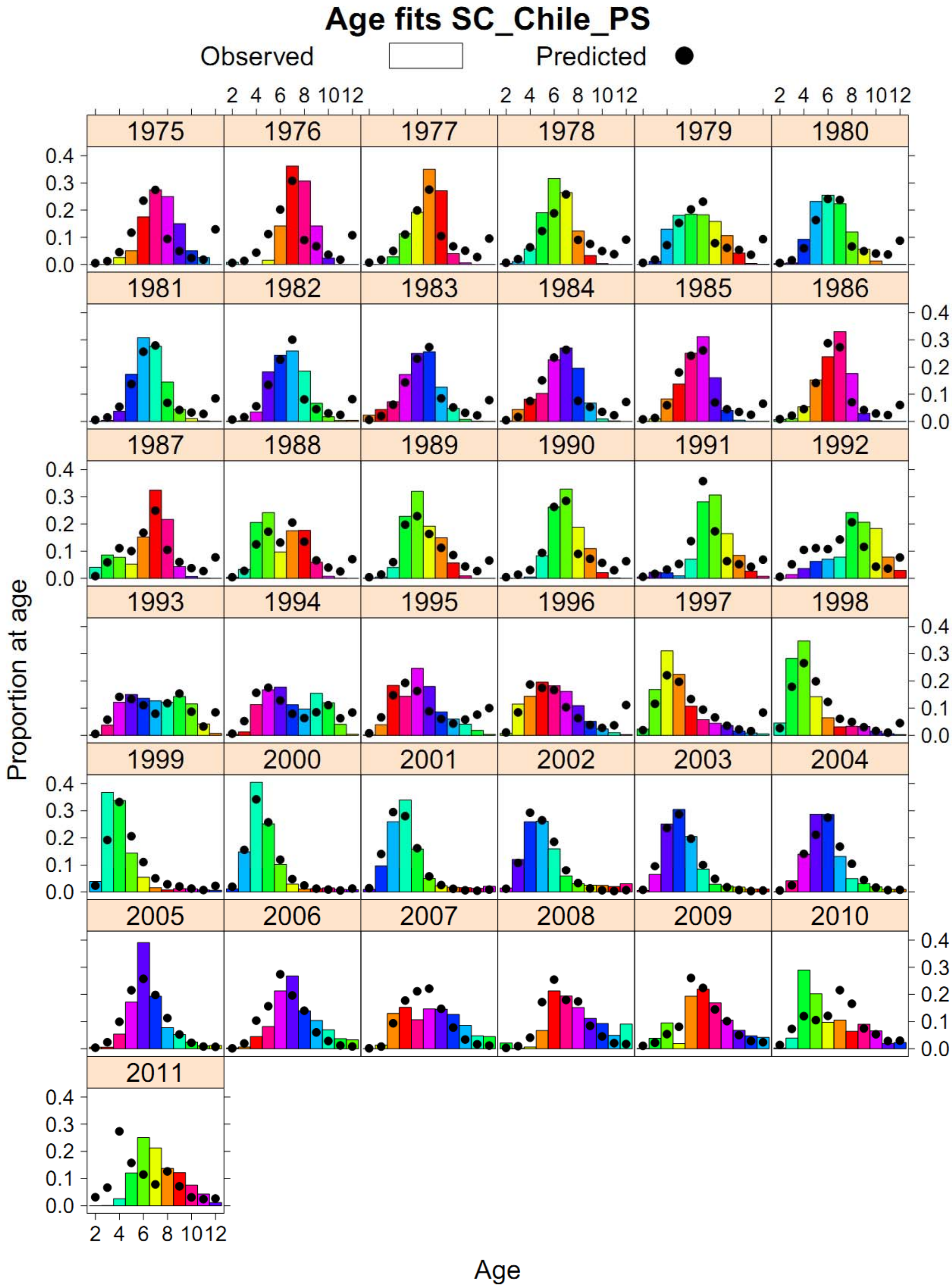


Figure 8. Base case (model 1) fit to the age compositions for the **South-Central Chilean purse seine** fishery (Fleet 2). Bars represent the observed data and dots represent the model fit and color codes correspond to cohorts.

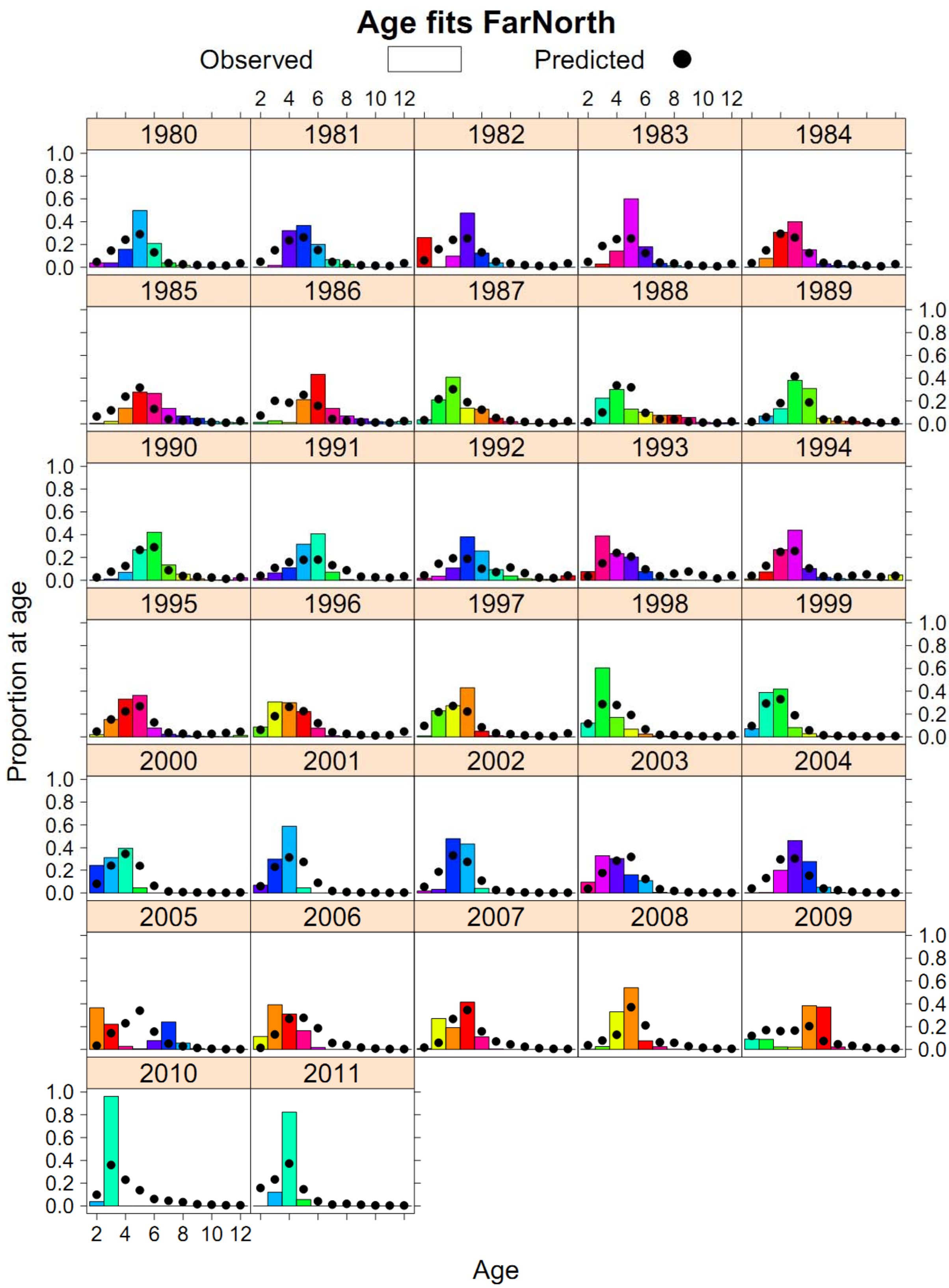


Figure 9. Base case (model 1) fit to the age compositions for the far north fishery (Fleet 3). Bars represent the observed data and dots represent the model fit and color codes correspond to cohorts.

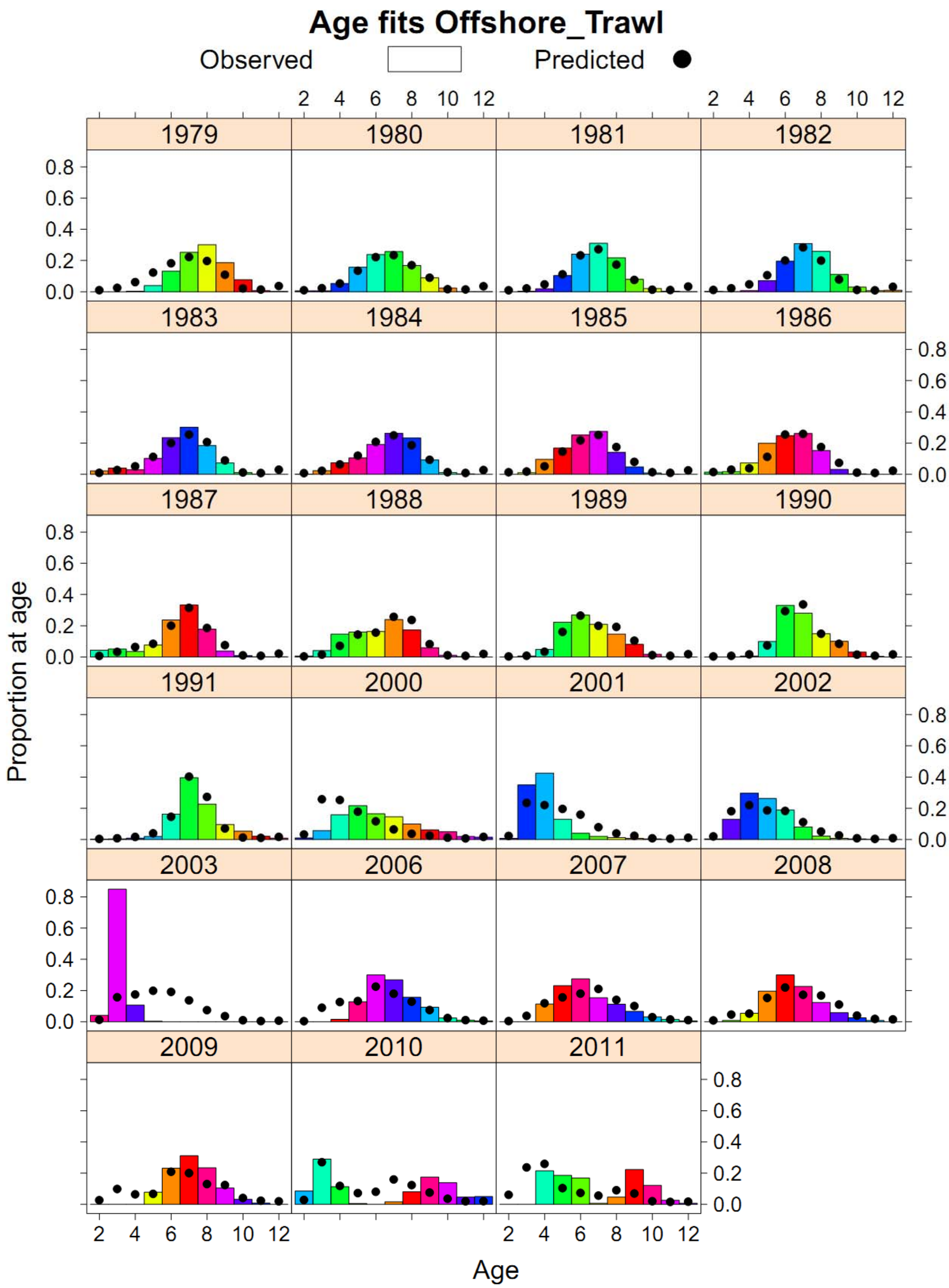


Figure 10. Base case (model 1) fit to the age compositions for the **offshore trawl** fishery (Fleet 4). Bars represent the observed data and dots represent the model fit and color codes correspond to cohorts.

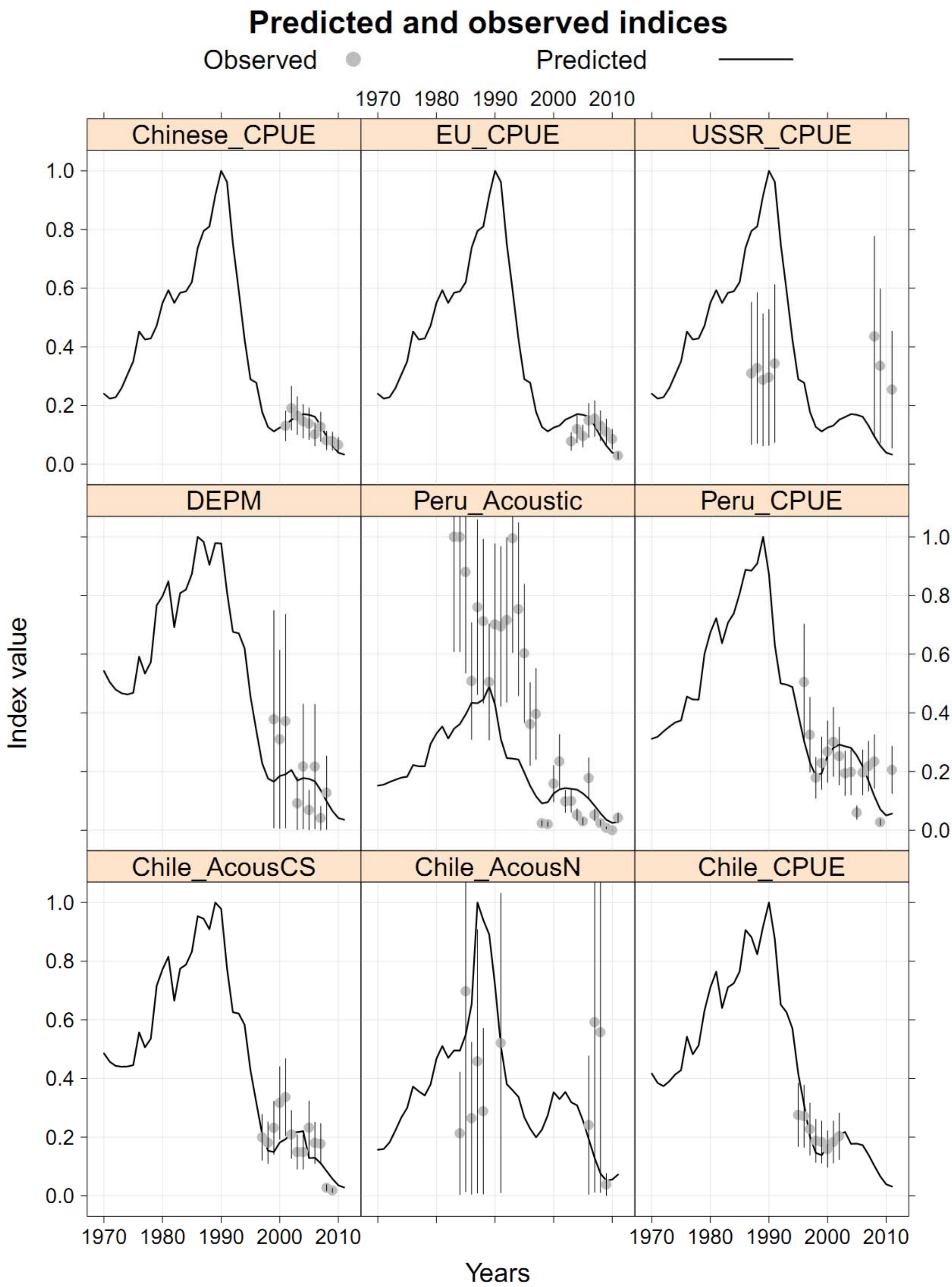


Figure 11. Base case (model 1) fit to different indices. Vertical bars represent 2 standard deviations around the observations.

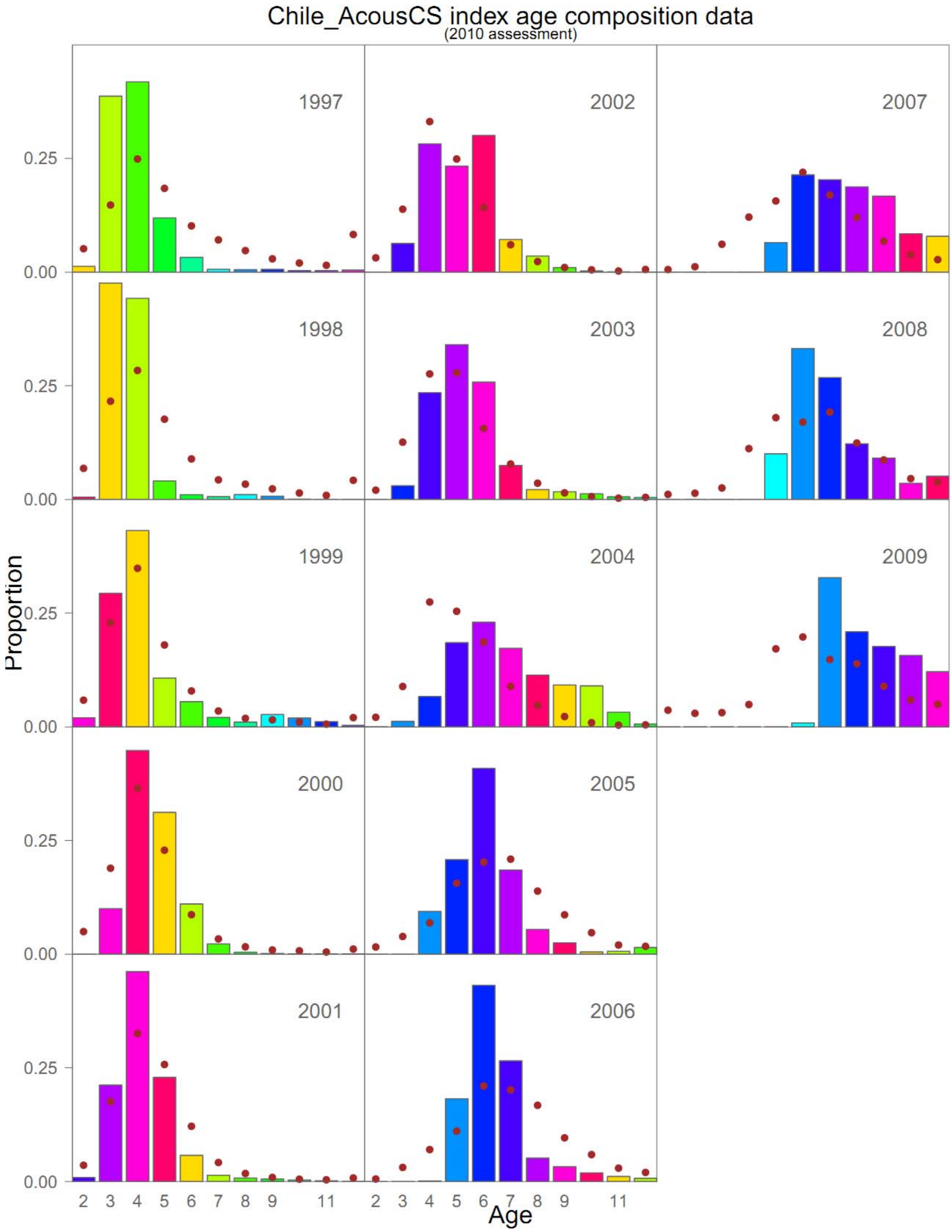


Figure 12. Base case model fit (x's) to age composition data (columns) for age samples collected during the CS Chilean region acoustic surveys.

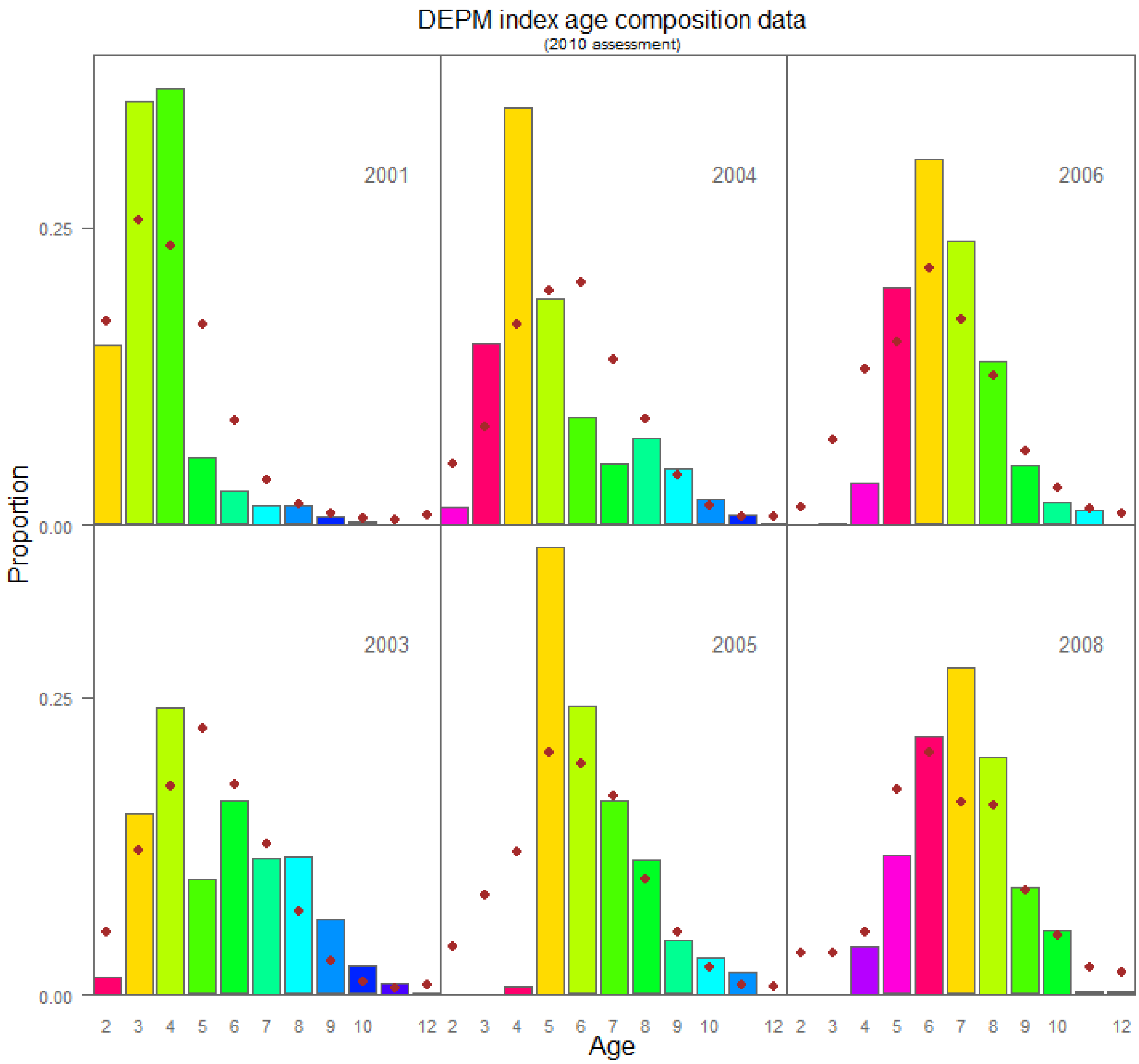


Figure 13. Base case (model 4) fit (dots) to age composition data (columns) for age samples collected during the daily egg production surveys.

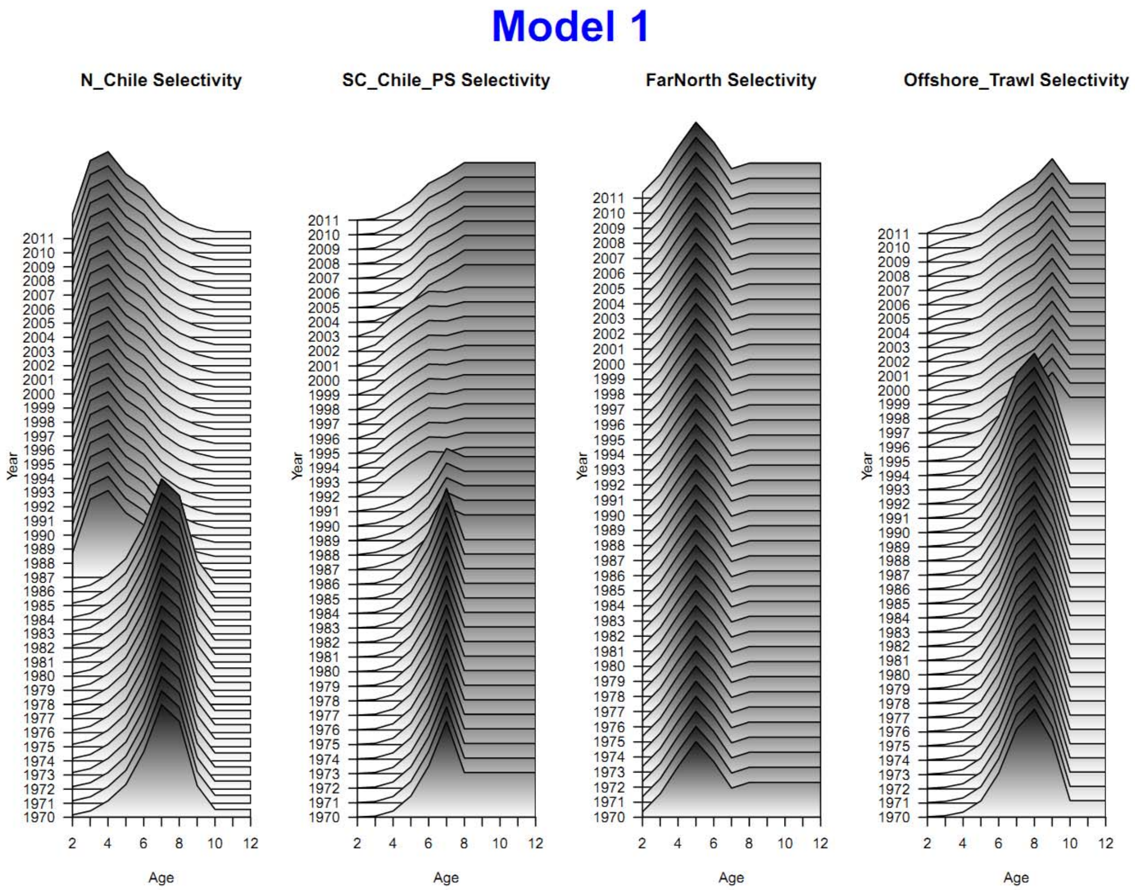


Figure 14. Base case (model 1) estimates of selectivity by fishery over time.

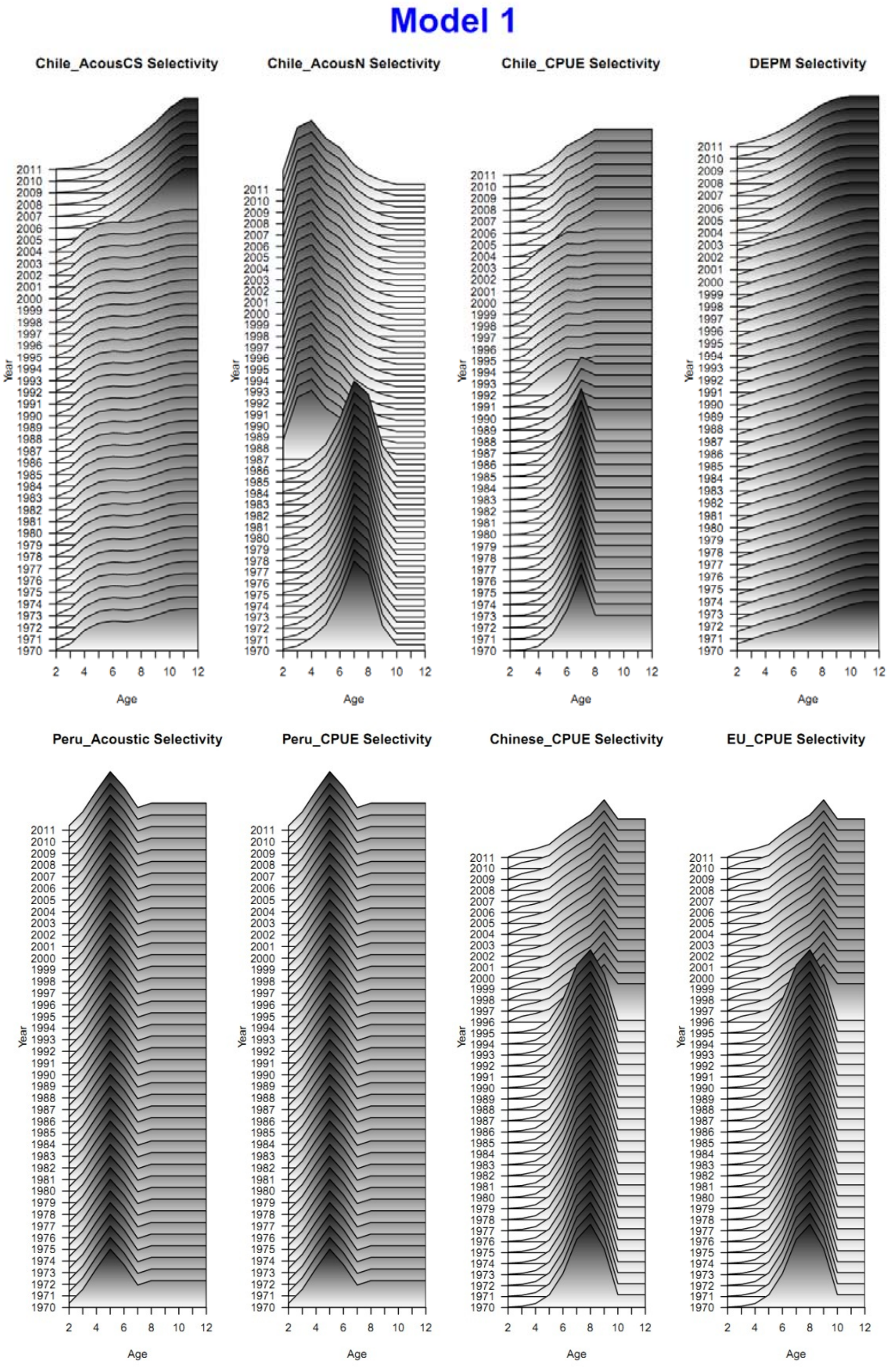


Figure 15. Base case (model 1) estimates of selectivity for each index over time.

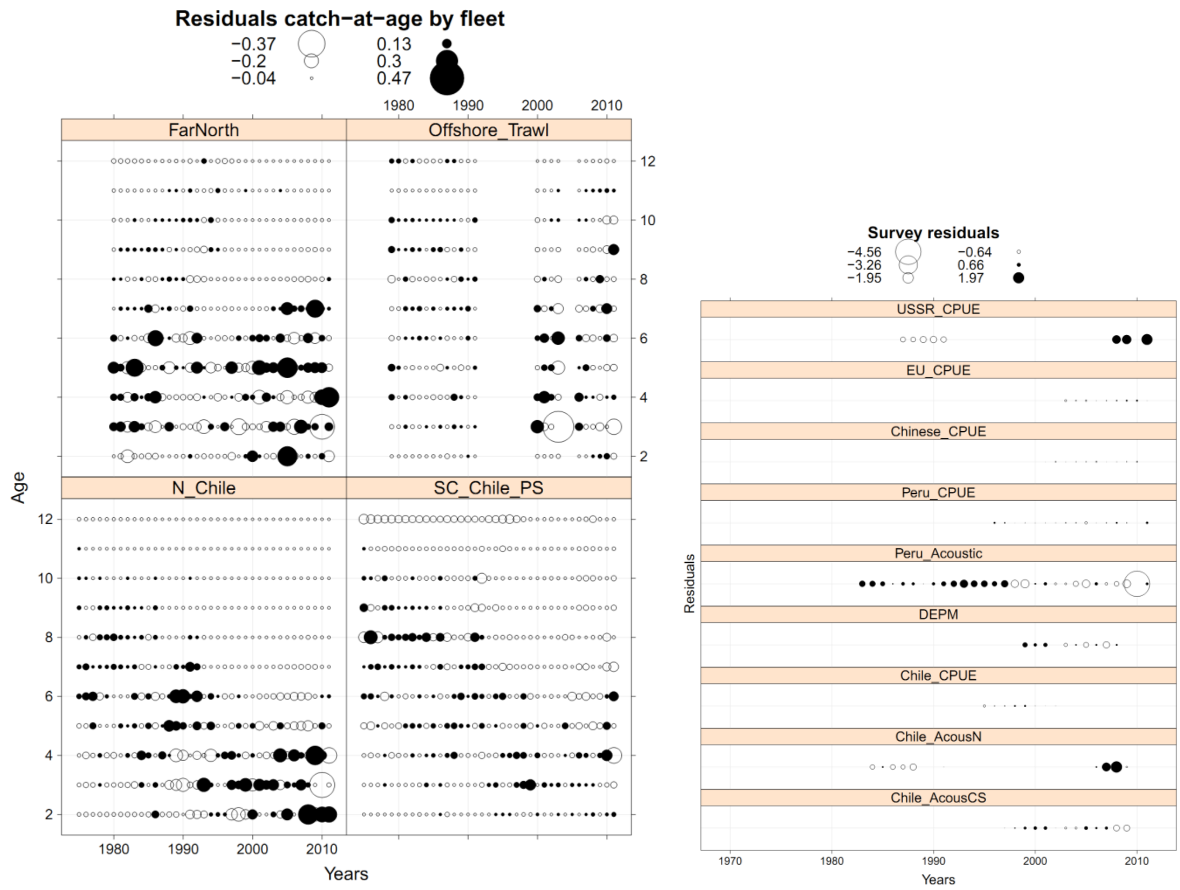


Figure 16. Logged residuals of observed and predicted catch-at-age proportions for the different fleets (left) and residuals for each of the indices (right) from JJM model 1.

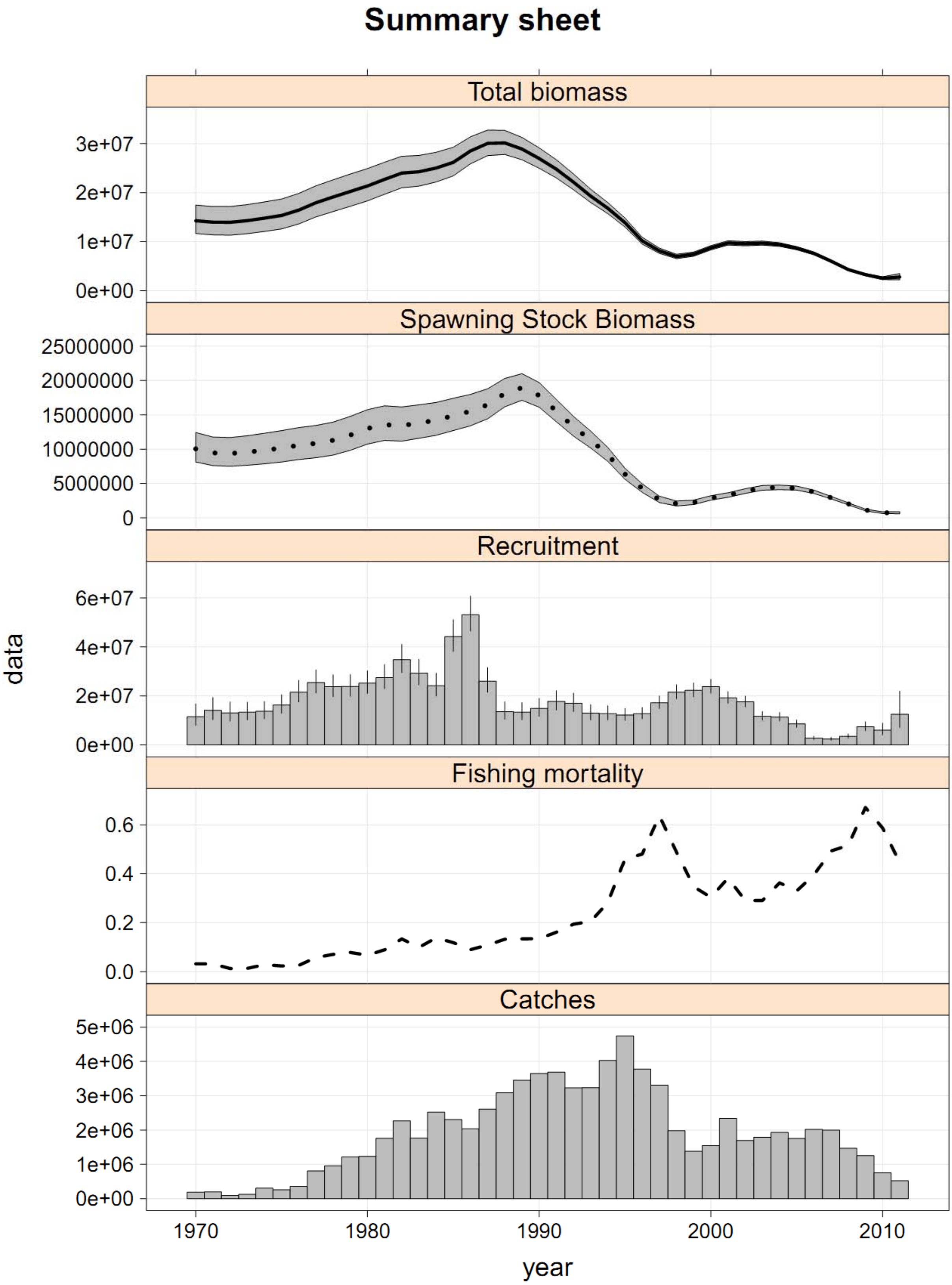


Figure 17. Base case (model 1) summary estimates over time showing total and spawning biomass (t; top), recruitment at age 2 (millions; 3rd from top) total fishing mortality (4th) and total catch biomass (t; bottom). Shaded areas and vertical bars represent the approximate 95% confidence bands.

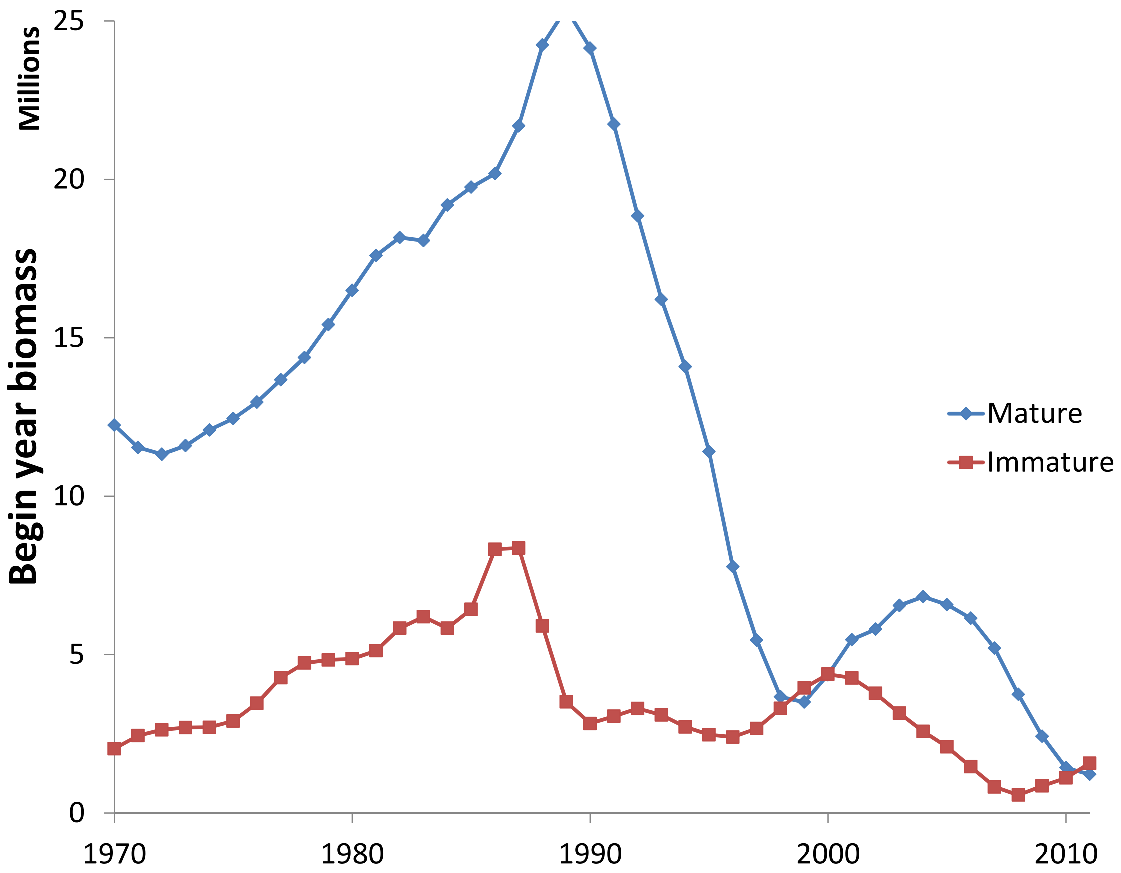


Figure 18. Base case (model 1) results showing mature and immature estimated components of the jack mackerel stock, 1970-2011.

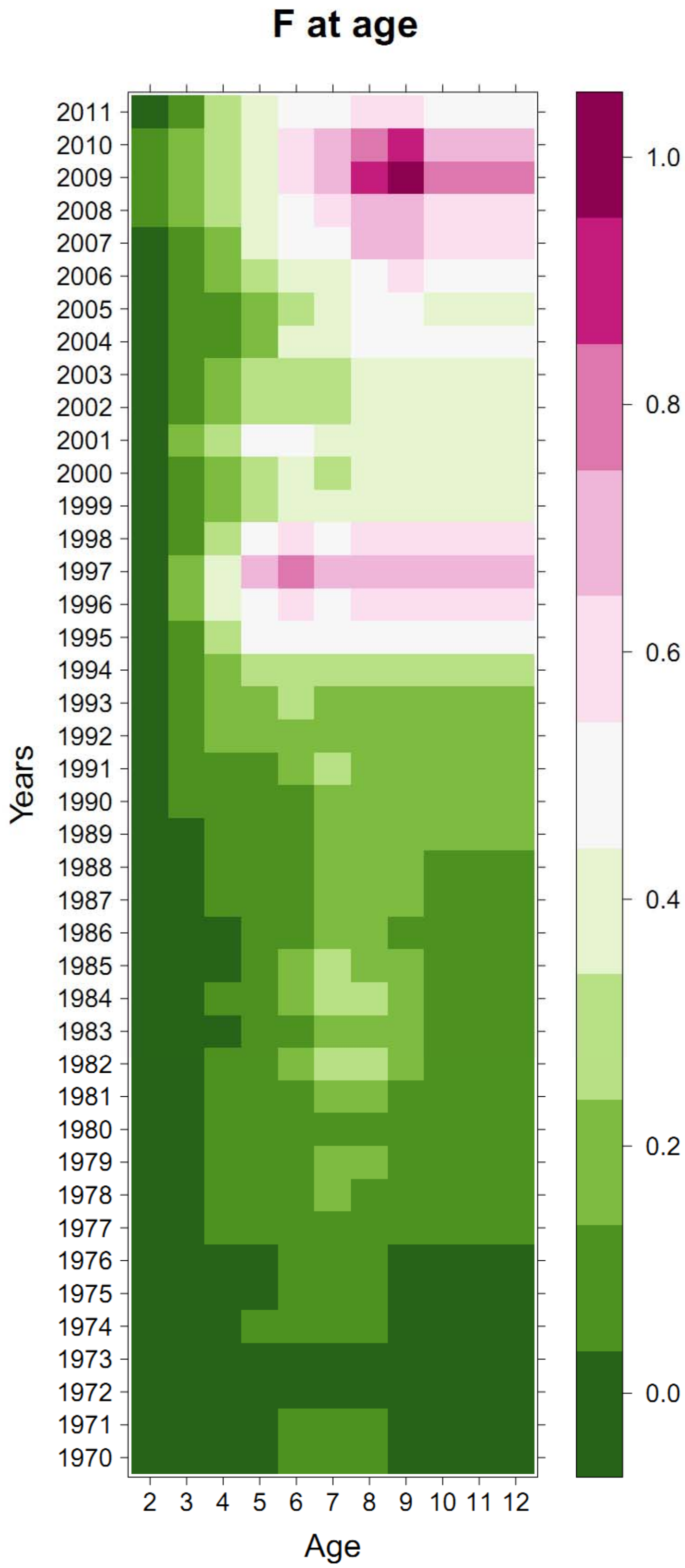


Figure 19. Historical fishing mortality at age for the base casel (Model 1).

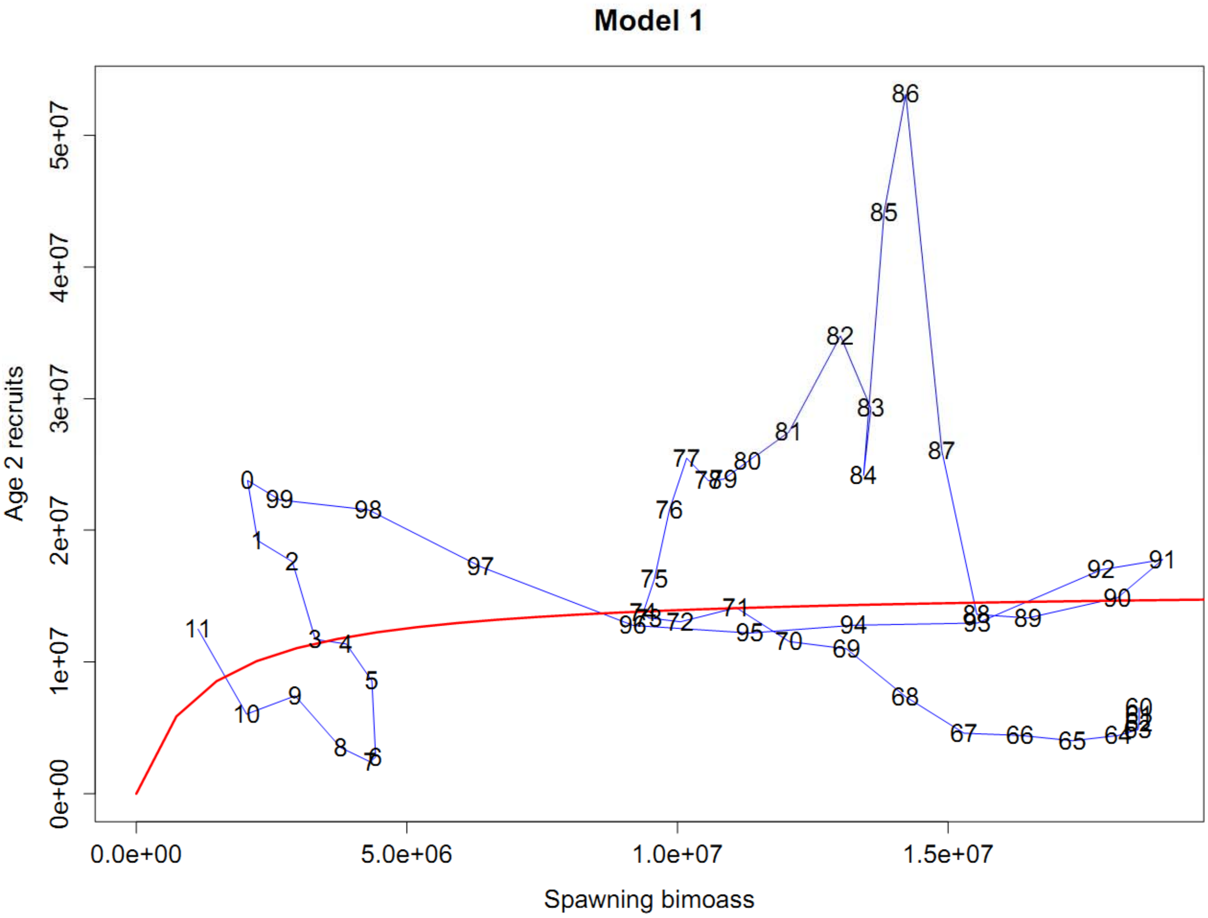


Figure 20. Stock recruitment curve relative to model estimates of biomass and recruitment for Model 1.

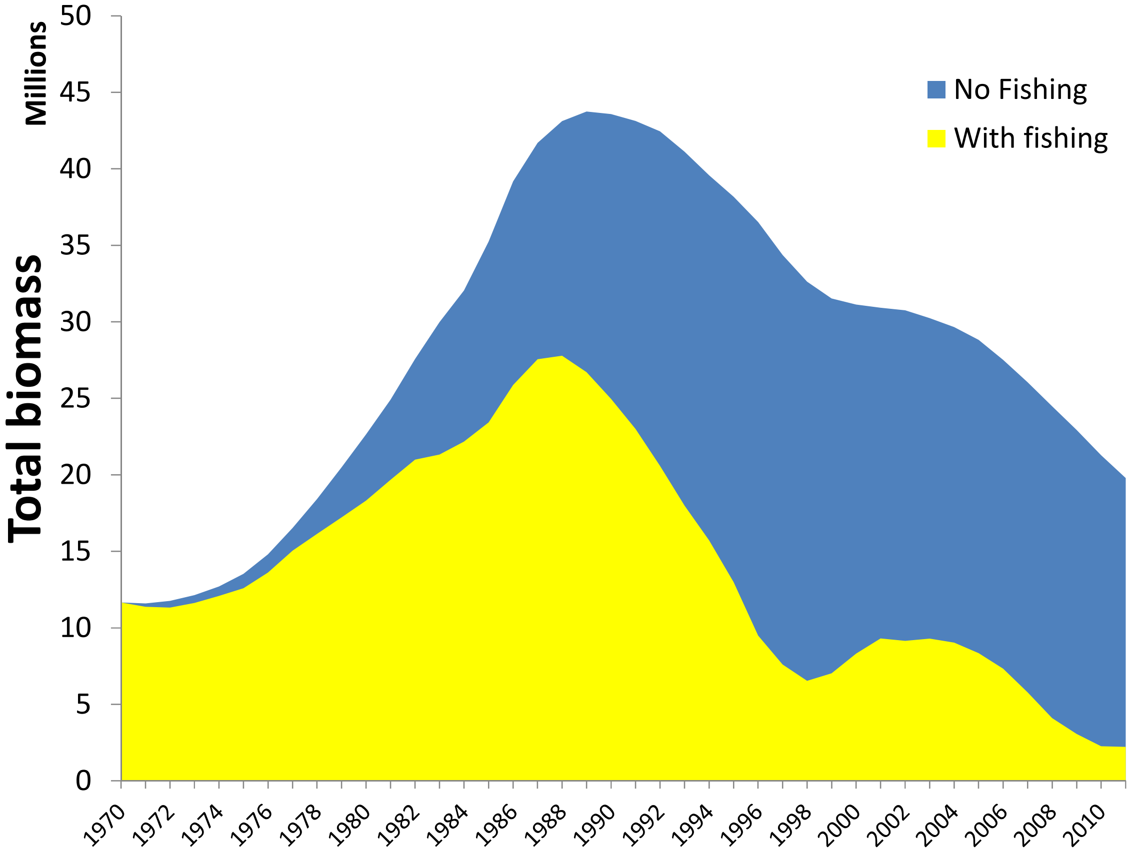
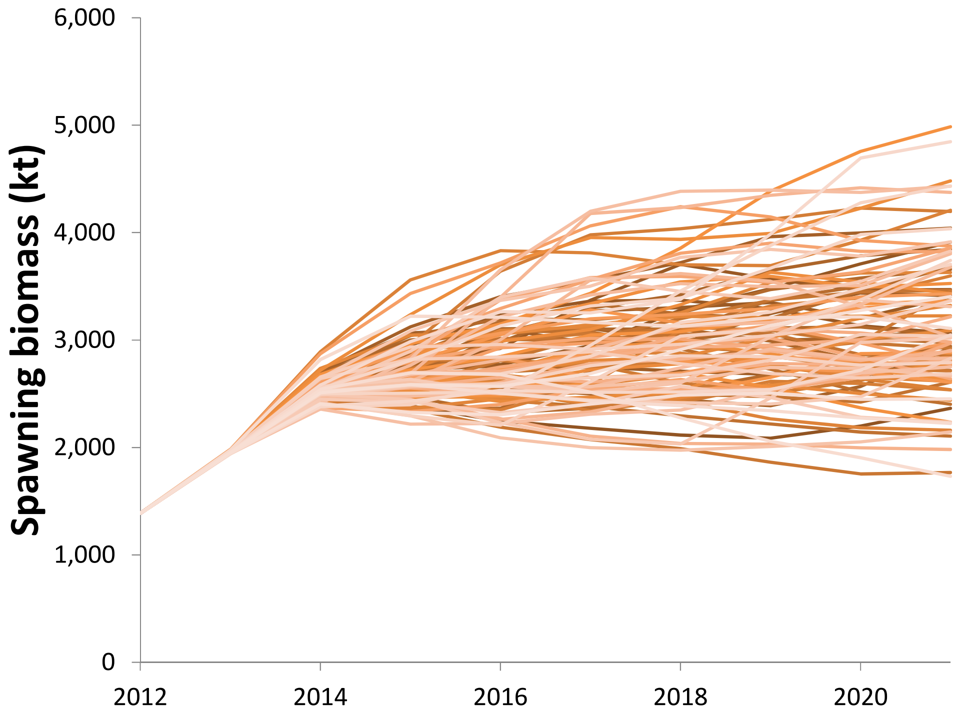


Figure 21. Total biomass trajectories for the base case (Model 1) under a hypothetical scenario of no fishing relative to the total biomass as estimated in the assessment. The 2011 ratio of estimated total biomass relative to the unfished is 14%. The values for the sensitivities (model 2 and 3) were 19% and 10%, respectively.



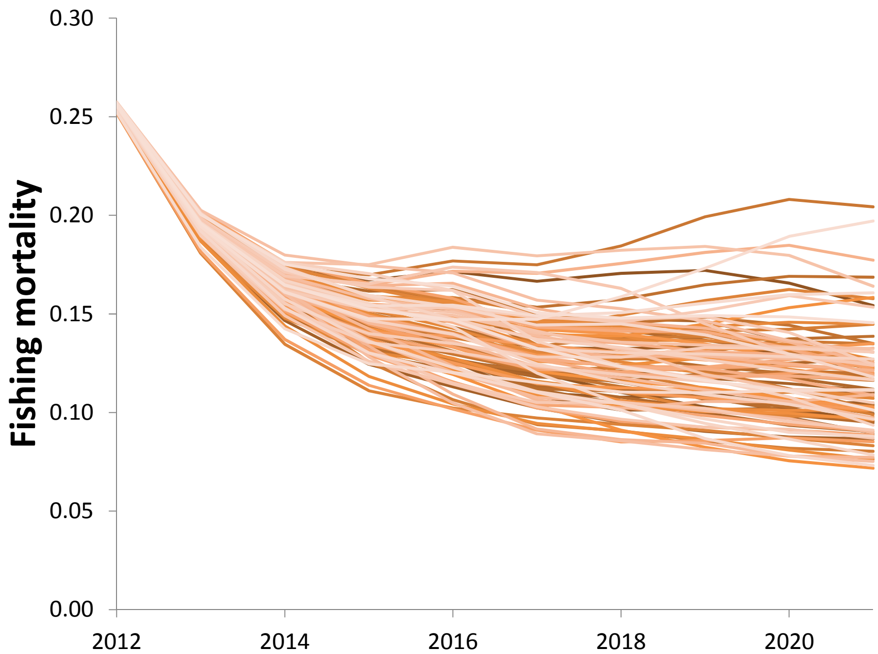


Figure 22. Stochastic projections of biomass (kt; top panel) and fishing mortality (average ages 2-12; bottom panel) for the base case model (Model 1) under the assumption that future recruitment has the same mean and variance as the **5-year** period 2006-2010 and assuming constant catch of 390 kt (75% of 2011 catch).

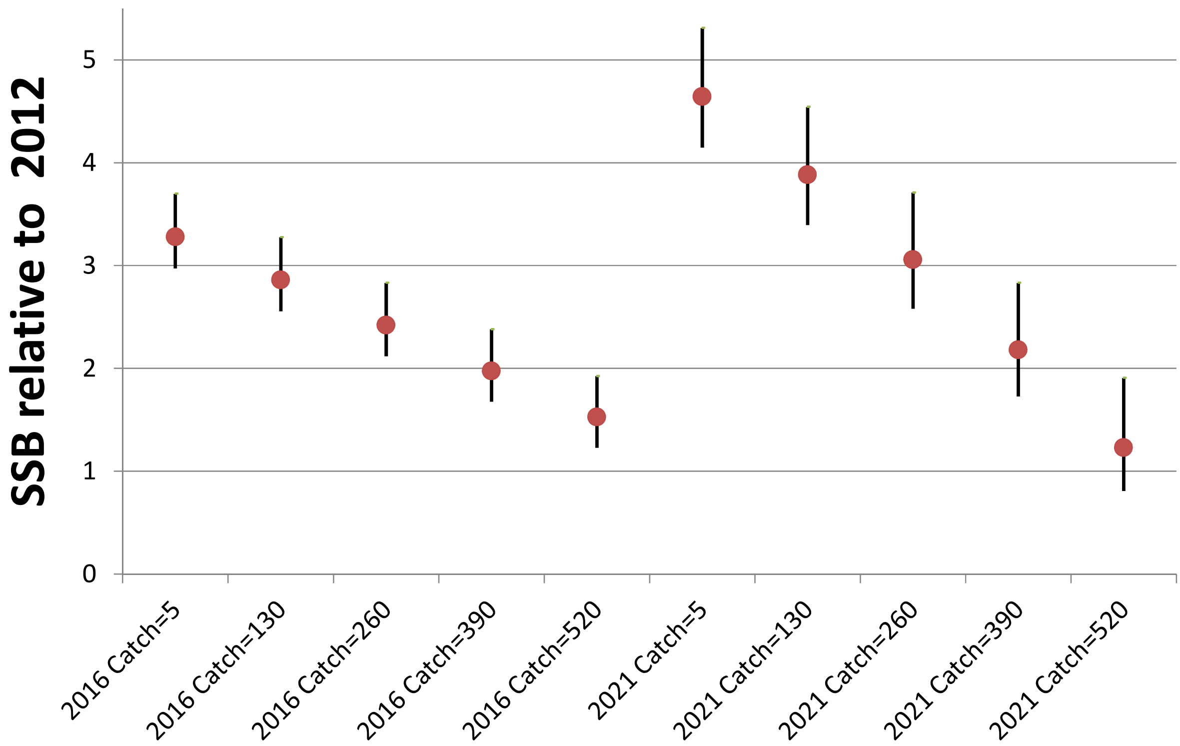


Figure 23. Projections of spawning biomass for the base case model (Model 1) relative to 2011 estimated spawning biomass under the assumption that future recruitment has the same mean and variance as the **5-year** period 2006-2010 (which is different for each model). Total biomass is on the left, and future catch is on the right. The different harvest levels are based on 1%, 25%, 50%, 75%, and 100% of the status quo catch.

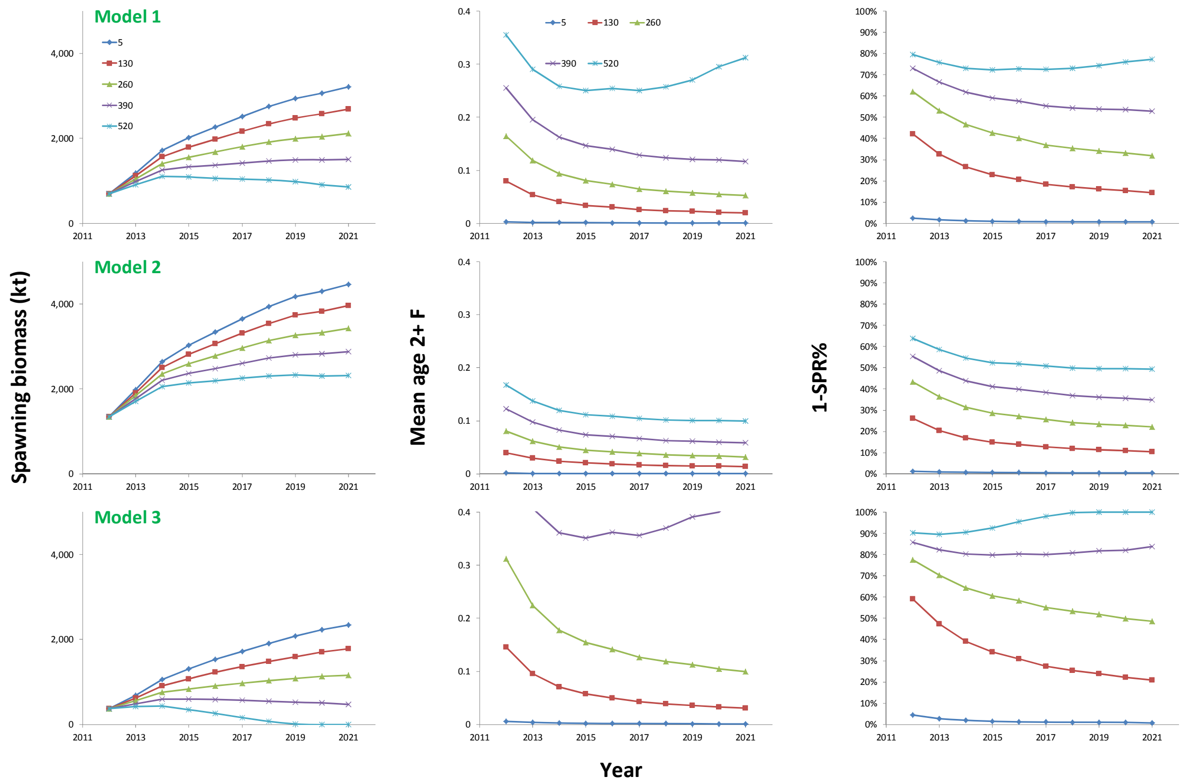


Figure 24. Projections of median spawning biomass (kt, left panels) and fishing mortality (over ages 2-12; right panels) for the base case model (Model 1; top row) and the 2 sensitivities (Models 2 and 3) under the assumption that future recruitment has the same mean and variance as the **5-year** period 2006-2010 (which is different for each model). Total biomass is on the left, and future catch is on the right. The different harvest levels are based on 1%, 25%, 50%, 75%, and 100% of the status quo catch.

Tables

Table 14. Input catch by fleet (combined) for the stock assessment model. Note that 2011 data are preliminary.

	Fleet 1	Fleet 2	Fleet 3	Fleet 4
1970	175,208	7,938	4,711	0
1971	164,838	21,934	9,189	0
1972	62,634	7,100	18,782	5,500
1973	71,762	8,904	42,781	0
1974	163,396	12,678	129,211	0
1975	186,890	34,951	37,899	0
1976	237,876	65,570	54,154	35
1977	225,907	75,585	504,992	2,273
1978	367,762	150,319	386,793	50,887
1979	311,682	203,269	333,810	369,110
1980	266,697	215,528	414,299	338,022
1981	435,061	440,935	445,639	438,122
1982	756,484	643,821	143,724	726,068
1983	259,128	541,696	110,690	854,357
1984	663,695	677,910	200,674	979,798
1985	471,599	923,042	114,622	799,323
1986	42,536	1,103,200	51,029	837,502
1987	280,594	1,416,781	46,304	863,423
1988	278,701	1,703,037	244,228	863,216
1989	265,861	2,031,058	281,139	875,821
1990	258,233	2,150,956	370,823	872,059
1991	282,817	2,649,828	213,447	543,659
1992	285,387	2,796,812	111,682	35,196
1993	359,947	2,745,099	133,354	0
1994	197,414	3,596,904	233,346	0
1995	211,594	3,984,244	550,993	0
1996	264,631	3,017,165	495,518	0
1997	88,276	2,541,981	680,053	0
1998	19,278	1,546,704	412,846	0
1999	44,582	1,130,488	203,751	7
2000	107,769	1,135,082	303,701	2,318
2001	244,019	1,216,754	857,702	20,090
2002	108,727	1,357,185	154,823	76,261
2003	142,016	1,272,302	217,734	158,199
2004	158,656	1,292,943	187,369	295,443
2005	168,383	1,262,051	80,663	243,568
2006	155,256	1,224,685	277,568	362,627
2007	172,701	1,130,083	255,353	438,819
2008	167,258	728,850	169,537	405,477
2009	134,022	700,905	45,746	371,918
2010	169,010	295,681	5,300	283,770
2011	23,945	194,532	244,589	59,374

Table 15. Input catch at age for fleet 1. Units are relative value (they are normalized to sum to one for each year in the model).

	2	3	4	5	6	7	8	9	10	11	12
1975	4	14	44	61	166	171	81	30	8	5	1
1976	0	2	10	62	191	230	110	17	5	0	0
1977	13	20	48	150	239	184	68	10	0	0	0
1978	6	93	172	150	100	275	227	75	12	0	0
1979	0	40	104	202	247	262	212	72	8	0	0
1980	6	19	40	120	159	189	134	25	1	0	0
1981	0	18	107	227	273	333	167	32	4	0	0
1982	2	29	333	363	485	640	367	127	22	0	0
1983	0	2	50	152	222	206	103	21	1	0	0
1984	4	232	600	285	285	377	319	68	4	0	0
1985	1	53	255	400	427	253	74	12	1	0	0
1986	15	14	8	10	17	27	16	6	1	0	0
1987	70	612	639	150	36	27	9	0	0	0	0
1988	4	130	490	452	106	5	1	0	0	0	0
1989	8	5	44	327	272	56	9	3	0	0	0
1990	77	6	28	237	412	84	8	0	0	0	0
1991	17	218	218	121	181	259	65	5	6	1	1
1992	30	252	143	269	274	150	60	9	1	0	0
1993	66	1486	597	115	99	19	7	2	1	0	0
1994	140	339	102	266	132	23	3	2	0	0	0
1995	171	345	297	146	84	17	1	0	0	0	0
1996	270	533	573	155	31	7	0	0	0	0	0
1997	26	307	205	24	1	0	0	0	0	0	0
1998	3	89	38	19	6	0	0	0	0	0	0
1999	24	320	76	16	5	0	0	0	0	0	0
2000	236	136	237	110	15	0	0	0	0	0	0
2001	257	1326	492	25	2	0	0	0	0	0	0
2002	99	391	177	92	19	4	0	0	0	0	0
2003	158	605	243	54	22	9	2	0	0	0	0
2004	17	103	465	191	7	0	0	0	0	0	0
2005	324	476	193	151	44	5	0	0	0	0	0
2006	38	390	608	68	25	8	1	0	0	0	0
2007	94	347	475	114	27	18	7	1	0	0	0
2008	713	359	118	139	110	13	1	0	0	0	0
2009	59	251	433	35	71	3	0	0	0	0	0
2010	524	58	360	141	36	10	1	1	0	0	0
2011	144	71	8	6	8	0	0	0	0	0	0

Table 16. Input catch at age for fleet 2. Units are relative value (they are normalized to sum to one in the model)

	2	3	4	5	6	7	8	9	10	11	12
1975	0	0	1	2	7	11	10	6	2	1	0
1976	1	0	0	2	18	46	39	18	3	0	0
1977	0	0	5	20	34	62	48	7	1	0	0
1978	1	4	21	70	116	97	45	12	1	0	0
1979	0	13	148	206	210	208	180	121	48	4	1
1980	4	8	129	323	356	312	167	78	18	1	1
1981	2	9	84	392	697	627	327	99	23	4	1
1982	4	9	118	618	826	878	627	225	57	10	14
1983	99	191	315	749	1,085	1,113	548	208	31	4	1
1984	8	190	358	447	985	1,175	852	292	39	8	0
1985	1	40	373	622	1,131	1,405	726	182	22	3	2
1986	33	50	254	720	1,125	1,564	833	141	13	1	1
1987	240	510	460	312	907	1,930	1,291	258	40	4	1
1988	24	228	1,416	1,663	666	1,204	1,216	406	51	7	0
1989	6	35	284	1,634	2,293	1,377	1,071	407	64	1	0
1990	5	2	32	507	1,599	2,003	1,148	668	128	9	0
1991	30	134	123	56	420	1,683	1,832	982	505	159	46
1992	0	71	187	322	367	405	1,258	1,072	953	407	152
1993	11	232	760	940	855	791	759	894	721	259	42
1994	22	87	808	1,200	1,266	803	692	1,103	854	285	27
1995	9	366	1,728	1,351	2,319	1,688	808	563	385	171	32
1996	49	835	1,042	1,422	1,327	1,173	793	375	171	70	20
1997	191	1,429	2,628	1,899	906	488	377	303	132	76	42
1998	243	1,517	1,864	763	345	166	178	173	79	32	13
1999	190	1,825	1,676	718	267	77	35	59	55	35	29
2000	46	598	1,633	1,015	413	115	43	47	59	37	31
2001	33	362	970	1,270	595	184	83	62	57	47	76
2002	45	395	847	854	522	191	97	80	77	63	99
2003	17	232	909	1,101	741	303	100	78	62	38	38
2004	2	129	449	920	918	422	156	99	59	28	30
2005	16	15	145	461	1,048	518	209	141	67	28	33
2006	5	12	82	150	390	491	256	191	128	68	60
2007	0	26	250	293	206	283	280	243	166	92	86
2008	24	2	7	75	237	216	169	125	104	55	101
2009	2	44	109	22	222	251	194	121	78	55	48
2010	2	24	176	123	59	64	39	55	40	12	14
2011	0	0	16	74	153	129	84	74	46	26	7

Table 17. Input catch at age for fleet 3. Units are relative value (they are normalized to sum to one for each year in the model).

	2	3	4	5	6	7	8	9	10	11	12
1979	0.0	0.0	1.9	20.7	69.1	132.2	157.5	97.4	40.3	3.8	0.9
1980	3.8	4.6	38.8	114.1	174.0	187.2	122.4	64.8	17.1	0.7	1.0
1981	0.2	2.9	18.5	99.1	229.5	297.0	208.3	75.8	19.9	3.2	0.8
1982	2.8	1.1	9.9	108.4	299.5	472.4	395.2	169.9	46.0	10.1	13.8
1983	55.4	99.5	73.8	253.7	586.5	753.8	461.2	181.6	28.0	3.8	1.3
1984	2.4	53.5	168.7	238.2	433.4	594.5	526.6	208.1	26.8	7.2	0.4
1985	0.5	20.1	194.7	339.6	508.6	556.2	284.2	96.6	16.9	2.7	1.8
1986	27.5	33.4	143.6	392.1	486.8	515.8	300.1	62.2	6.6	0.7	0.7
1987	93.1	107.5	73.7	162.8	504.5	709.6	379.6	79.5	18.3	3.0	0.9
1988	12.9	89.1	315.6	346.0	354.1	518.0	374.6	129.1	23.0	5.2	0.1
1989	0.3	12.4	100.2	462.4	557.0	434.8	304.7	167.2	35.9	1.3	0.0
1990	0.5	0.3	10.9	176.6	590.0	501.5	266.0	179.3	56.5	5.5	0.1
1991	3.2	5.0	9.1	21.2	176.8	431.5	247.6	104.9	57.9	22.6	9.8
2007	0.0	0.0	137.0	277.0	313.2	142.1	84.8	30.7	11.3	3.4	0.0
2008	0.0	6.0	38.5	139.5	213.4	160.9	87.7	41.3	18.4	5.7	0.0
2009	0.0	0.0	0.4	39.2	117.1	157.6	118.3	52.9	16.4	4.2	0.0
2010	25.2	85.7	33.4	1.5	0.1	4.9	23.9	51.7	41.2	13.8	14.7
2011	0.0	2.4	927.0	800.4	731.2	26.4	201.7	961.6	526.7	114.2	29.9

Table 18. Input catch at age for fleet 4. Units are relative value (they are normalized to sum to one for each year in the model).

	2	3	4	5	6	7	8	9	10	11	12
1979	0.0	0.0	1.9	20.7	69.1	132.2	157.5	97.4	40.3	3.8	0.9
1980	3.8	4.6	38.8	114.1	174.0	187.2	122.4	64.8	17.1	0.7	1.0
1981	0.2	2.9	18.5	99.1	229.5	297.0	208.3	75.8	19.9	3.2	0.8
1982	2.8	1.1	9.9	108.4	299.5	472.4	395.2	169.9	46.0	10.1	13.8
1983	55.4	99.5	73.8	253.7	586.5	753.8	461.2	181.6	28.0	3.8	1.3
1984	2.4	53.5	168.7	238.2	433.4	594.5	526.6	208.1	26.8	7.2	0.4
1985	0.5	20.1	194.7	339.6	508.6	556.2	284.2	96.6	16.9	2.7	1.8
1986	27.5	33.4	143.6	392.1	486.8	515.8	300.1	62.2	6.6	0.7	0.7
1987	93.1	107.5	73.7	162.8	504.5	709.6	379.6	79.5	18.3	3.0	0.9
1988	12.9	89.1	315.6	346.0	354.1	518.0	374.6	129.1	23.0	5.2	0.1
1989	0.3	12.4	100.2	462.4	557.0	434.8	304.7	167.2	35.9	1.3	0.0
1990	0.5	0.3	10.9	176.6	590.0	501.5	266.0	179.3	56.5	5.5	0.1
1991	3.2	5.0	9.1	21.2	176.8	431.5	247.6	104.9	57.9	22.6	9.8
2000	0.1	0.3	0.4	0.3	0.3	0.2	0.1	0.1	0.1	0.0	0.0
2001	0.0	0.3	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2002	26.3	21.8	29.4	28.0	20.1	8.2	1.8	0.6	0.3	0.2	0.1
2003	0.0	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	0.0	0.0	16.6	36.8	39.8	31.6	17.5	9.2	2.2	1.1	0.9
2007	0.0	0.0	137.0	279.2	319.8	153.4	99.1	42.8	17.6	7.2	2.1
2008	0.0	6.2	41.8	147.0	228.3	177.3	101.0	48.9	23.0	8.4	2.4
2009	0.1	0.2	0.6	40.4	124.1	167.5	131.0	62.7	22.3	7.0	1.4
2010	32.1	90.8	34.8	2.0	1.7	9.1	30.2	56.3	42.7	14.6	15.0
2011	0.0	0.0	0.9	0.8	0.7	0.0	0.2	1.0	0.5	0.1	0.0

Table 19. Input mean body mass at age over time assumed for all fleets.

	2	3	4	5	6	7	8	9	10	11	12
1970	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1971	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1972	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1973	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1974	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1975	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1976	0.078	0.155	0.214	0.275	0.336	0.394	0.472	0.632	0.714	0.898	1.538
1977	0.092	0.109	0.236	0.275	0.314	0.375	0.456	0.521	0.732	0.651	1.137
1978	0.084	0.104	0.147	0.211	0.327	0.394	0.449	0.514	0.583	0.631	1.538
1979	0.108	0.16	0.199	0.241	0.301	0.388	0.466	0.588	0.871	1.265	1.972
1980	0.06	0.132	0.231	0.272	0.35	0.447	0.519	0.716	0.82	1.073	1.854
1981	0.095	0.149	0.242	0.294	0.34	0.407	0.503	0.637	0.765	1.184	1.9
1982	0.085	0.166	0.207	0.269	0.323	0.378	0.472	0.536	0.644	0.987	1.185
1983	0.099	0.122	0.23	0.273	0.32	0.374	0.461	0.596	0.709	1.196	1.769
1984	0.135	0.154	0.185	0.266	0.33	0.383	0.449	0.577	0.685	1.012	1.846
1985	0.148	0.181	0.223	0.27	0.339	0.398	0.473	0.573	0.796	1.376	1.647
1986	0.075	0.172	0.247	0.286	0.346	0.427	0.518	0.64	0.844	1.351	2.11
1987	0.117	0.14	0.191	0.27	0.357	0.434	0.503	0.577	0.689	1.089	1.979
1988	0.124	0.159	0.197	0.233	0.342	0.444	0.512	0.588	0.75	1.012	1.372
1989	0.103	0.22	0.241	0.278	0.339	0.467	0.585	0.702	0.779	0.88	1.538
1990	0.091	0.153	0.264	0.309	0.373	0.461	0.582	0.694	0.835	0.97	1.598
1991	0.106	0.132	0.186	0.271	0.381	0.451	0.542	0.667	0.787	0.901	1.053
1992	0.083	0.118	0.177	0.239	0.275	0.409	0.524	0.594	0.709	0.851	1.046
1993	0.089	0.121	0.181	0.246	0.32	0.408	0.579	0.719	0.853	0.965	1.174
1994	0.084	0.112	0.224	0.27	0.336	0.462	0.643	0.808	0.868	1.058	1.421
1995	0.098	0.145	0.192	0.27	0.34	0.429	0.577	0.807	0.965	1.115	1.367
1996	0.092	0.151	0.191	0.28	0.352	0.524	0.683	0.945	1.216	1.426	1.477
1997	0.106	0.146	0.201	0.26	0.355	0.495	0.683	0.884	1.088	1.467	1.647
1998	0.128	0.138	0.178	0.248	0.34	0.545	0.806	1.035	1.246	1.412	1.655
1999	0.109	0.134	0.174	0.25	0.331	0.465	0.742	1.021	1.258	1.376	1.776
2000	0.064	0.163	0.196	0.255	0.346	0.466	0.756	0.999	1.141	1.228	1.563
2001	0.098	0.122	0.179	0.258	0.325	0.461	0.614	0.828	1.074	1.36	1.671
2002	0.074	0.13	0.2	0.257	0.329	0.445	0.645	0.883	1.102	1.321	1.649
2003	0.086	0.117	0.186	0.245	0.307	0.4	0.564	0.768	1.005	1.209	1.537
2004	0.08	0.158	0.193	0.247	0.307	0.387	0.528	0.7	0.897	1.087	1.541
2005	0.075	0.113	0.196	0.259	0.318	0.399	0.517	0.641	0.767	0.918	1.296
2006	0.076	0.116	0.141	0.261	0.35	0.419	0.516	0.631	0.752	0.924	1.263
2007	0.074	0.121	0.172	0.226	0.331	0.431	0.51	0.621	0.756	0.903	1.177
2008	0.048	0.069	0.186	0.254	0.312	0.416	0.515	0.605	0.719	0.861	1.148
2009	0.045	0.109	0.142	0.253	0.33	0.411	0.532	0.625	0.764	0.886	1.144
2010	0.045	0.109	0.142	0.253	0.33	0.411	0.532	0.625	0.764	0.886	1.144
2011	0.052	0.101	0.175	0.236	0.313	0.415	0.539	0.649	0.787	0.963	1.473

Table 20. Index values used as input to the assessment model. ACS=Acoustics for southern – central zone in Chile, ACN=Acoustics for northern zone in Chile, C-U = Chilean fleet 1 CPUE, DEPM= Daily Egg Production Method, ACP = Acoustics in Fleet 3, Ch-U = Chinese CPUE for fleet 4, EU-U – CPUE for EU and Vanuatu (combined) in fleet 4, USSR-U = Catch per day (nominal CPUE for Fleet 4.

	ACS	ACN	C-U	DEPM	ACP	P-U	Ch_U	EU_U	USSR_U
1970									
1971									
1972									
1973									
1974									
1975									
1976									
1977									
1978									
1979									
1980									
1981									
1982									
1983					8,513				
1984		99			8,511				
1985		324			7,493				
1986		123			4,330				
1987		213			6,472				55.02
1988		134			6,066				58.24
1989					4,303				51.06
1990					5,972				52.57
1991		242			5,915				60.99
1992					6,099				
1993					8,471				
1994					6,415				
1995			467		5,131				
1996			460		3,081	1.77			
1997	3,530		385		3,376	1.14			
1998	3,200		318		201	0.63			
1999	4,100		311	5,724.00	177	0.80			
2000	5,600		270	4,688.00	1,351	0.94			
2001	5,950		311	5,627.00	1,999	1.05	1.20		
2002	3,700		344	1,388.00	837	0.88	1.75		
2003	2,640			3,287.00	850	0.68	1.52	0.72	
2004	2,640			1,043.00	449	0.69	1.34	1.11	
2005	4,110			3,283.00	261	0.21	1.26	0.89	
2006	3,192	112		626.00	1,512	0.69	0.93	1.38	
2007	3,140	275		1,935.00	443	0.76	1.17	1.43	
2008	487	259			207	0.82	0.74	1.21	77.42
2009	328	18			70	0.10	0.72	1.02	59.56
2010					1		0.60	0.79	
2011					363	0.72		0.27	45.21

Table 21. Estimated begin-year numbers at age for Model 1 (base case), 1970-2011.

	2	3	4	5	6	7	8	9	10	11	12
1970	11,548	8,735	4,650	2,304	1,765	1,274	1,113	975	858	751	6,341
1971	14,107	9,156	6,903	3,644	1,781	1,329	923	818	754	677	5,593
1972	13,045	11,187	7,237	5,410	2,818	1,343	966	681	633	594	4,937
1973	13,338	10,356	8,865	5,713	4,248	2,194	1,033	746	535	501	4,374
1974	13,782	10,586	8,199	6,984	4,473	3,305	1,691	800	586	423	3,851
1975	16,269	10,922	8,337	6,382	5,362	3,400	2,474	1,275	620	460	3,349
1976	21,514	12,907	8,638	6,547	4,961	4,105	2,545	1,872	993	488	2,997
1977	25,458	17,065	10,203	6,776	5,079	3,786	3,057	1,920	1,455	780	2,737
1978	23,753	20,110	13,254	7,705	4,965	3,713	2,752	2,246	1,452	1,111	2,686
1979	23,872	18,768	15,654	10,043	5,646	3,556	2,567	1,943	1,669	1,105	2,892
1980	25,200	18,888	14,691	11,999	7,456	4,031	2,390	1,741	1,397	1,269	3,038
1981	27,483	19,944	14,790	11,279	8,956	5,412	2,801	1,674	1,272	1,066	3,285
1982	34,776	21,737	15,588	11,291	8,301	6,302	3,554	1,880	1,191	956	3,268
1983	29,277	27,504	17,027	11,913	8,211	5,496	3,622	2,131	1,255	876	3,106
1984	24,143	23,204	21,674	13,217	8,934	5,754	3,470	2,324	1,459	938	2,976
1985	44,171	19,097	18,173	16,564	9,606	5,909	3,298	2,049	1,525	1,071	2,872
1986	53,128	34,989	15,026	14,035	12,258	6,536	3,541	2,067	1,383	1,120	2,894
1987	26,018	42,158	27,674	11,755	10,646	8,722	4,218	2,377	1,437	1,024	2,971
1988	13,607	20,538	32,751	21,191	8,804	7,597	5,726	2,757	1,605	1,030	2,862
1989	13,336	10,726	15,863	24,764	15,551	6,138	4,836	3,640	1,809	1,116	2,708
1990	14,866	10,512	8,281	11,982	18,150	10,840	3,911	3,086	2,390	1,251	2,646
1991	17,763	11,699	8,070	6,202	8,704	12,610	6,944	2,511	2,035	1,653	2,696
1992	16,992	13,934	8,885	5,961	4,440	5,926	7,819	4,379	1,614	1,350	2,886
1993	12,949	13,291	10,313	6,127	3,918	2,811	3,812	4,955	2,789	1,033	2,711
1994	12,782	10,084	9,691	6,976	3,957	2,443	1,793	2,401	3,137	1,770	2,377
1995	12,191	10,004	7,394	6,385	4,228	2,264	1,429	1,021	1,371	1,795	2,373
1996	12,768	9,452	6,969	4,292	3,197	1,956	1,100	663	475	639	1,943
1997	17,219	9,833	6,431	3,916	2,078	1,439	934	502	304	219	1,189
1998	21,527	13,291	6,599	3,306	1,599	778	586	354	191	116	535
1999	22,282	16,807	9,413	3,815	1,596	716	369	262	159	85	291
2000	23,766	17,500	12,350	6,028	2,168	848	391	194	138	83	198
2001	19,210	18,624	12,838	8,018	3,530	1,208	488	218	108	77	157
2002	17,604	14,819	12,863	7,495	4,083	1,769	656	255	114	57	123
2003	11,714	13,833	10,983	8,570	4,566	2,332	1,024	367	141	64	101
2004	11,365	9,175	10,147	7,265	5,205	2,616	1,355	575	203	80	93
2005	8,563	8,903	6,851	7,057	4,647	2,935	1,390	656	271	99	85
2006	2,786	6,705	6,660	4,823	4,634	2,706	1,613	703	325	138	94
2007	2,424	2,166	4,864	4,434	2,930	2,510	1,402	760	320	155	112
2008	3,502	1,866	1,510	3,049	2,499	1,439	1,170	583	300	136	114
2009	7,428	2,661	1,242	902	1,662	1,195	658	479	224	127	106
2010	6,044	5,627	1,743	723	471	699	453	214	142	76	80
2011	12,489	4,555	3,626	1,026	398	216	291	166	71	55	60
Mean	18,001	14,141	10,784	7,806	5,440	3,623	2,290	1,458	969	677	2,160

Table 22. Estimated total fishing mortality at age for Model 1 (base case), 1970-2011.

	2	3	4	5	6	7	8	9	10	11	12
1970	0.0020	0.0054	0.0139	0.0274	0.0537	0.0916	0.0775	0.0264	0.0076	0.0076	0.0076
1971	0.0020	0.0053	0.0137	0.0269	0.0521	0.0886	0.0737	0.0264	0.0090	0.0090	0.0090
1972	0.0009	0.0026	0.0064	0.0119	0.0203	0.0326	0.0282	0.0117	0.0045	0.0045	0.0045
1973	0.0011	0.0036	0.0084	0.0147	0.0211	0.0306	0.0262	0.0113	0.0059	0.0059	0.0059
1974	0.0025	0.0089	0.0204	0.0343	0.0443	0.0594	0.0521	0.0240	0.0137	0.0137	0.0137
1975	0.0015	0.0047	0.0116	0.0218	0.0372	0.0596	0.0487	0.0201	0.0096	0.0096	0.0096
1976	0.0016	0.0051	0.0127	0.0239	0.0405	0.0646	0.0517	0.0225	0.0117	0.0117	0.0117
1977	0.0058	0.0228	0.0508	0.0810	0.0833	0.0888	0.0786	0.0499	0.0393	0.0393	0.0393
1978	0.0056	0.0205	0.0474	0.0809	0.1037	0.1390	0.1181	0.0666	0.0426	0.0426	0.0426
1979	0.0042	0.0149	0.0359	0.0678	0.1069	0.1673	0.1584	0.0997	0.0442	0.0442	0.0442
1980	0.0039	0.0146	0.0343	0.0625	0.0905	0.1343	0.1264	0.0834	0.0410	0.0410	0.0410
1981	0.0045	0.0164	0.0399	0.0765	0.1215	0.1906	0.1685	0.1098	0.0562	0.0562	0.0562
1982	0.0046	0.0142	0.0389	0.0885	0.1824	0.3239	0.2815	0.1744	0.0773	0.0773	0.0773
1983	0.0025	0.0082	0.0233	0.0578	0.1257	0.2297	0.2135	0.1489	0.0613	0.0613	0.0613
1984	0.0045	0.0144	0.0389	0.0891	0.1834	0.3266	0.2969	0.1913	0.0795	0.0795	0.0795
1985	0.0031	0.0097	0.0284	0.0711	0.1550	0.2821	0.2372	0.1629	0.0793	0.0793	0.0793
1986	0.0013	0.0045	0.0155	0.0464	0.1104	0.2079	0.1685	0.1333	0.0708	0.0708	0.0708
1987	0.0065	0.0225	0.0369	0.0591	0.1074	0.1907	0.1954	0.1630	0.1033	0.1033	0.1033
1988	0.0079	0.0283	0.0496	0.0795	0.1307	0.2217	0.2232	0.1914	0.1329	0.1329	0.1329
1989	0.0080	0.0288	0.0506	0.0807	0.1309	0.2207	0.2193	0.1907	0.1384	0.1384	0.1384
1990	0.0096	0.0344	0.0590	0.0896	0.1342	0.2154	0.2130	0.1864	0.1384	0.1384	0.1384
1991	0.0128	0.0451	0.0729	0.1041	0.1544	0.2479	0.2311	0.2123	0.1801	0.1801	0.1801
1992	0.0157	0.0710	0.1418	0.1897	0.2274	0.2112	0.2261	0.2210	0.2163	0.2163	0.2163
1993	0.0200	0.0858	0.1608	0.2071	0.2423	0.2196	0.2324	0.2273	0.2245	0.2245	0.2245
1994	0.0151	0.0803	0.1873	0.2709	0.3284	0.3062	0.3329	0.3300	0.3284	0.3284	0.3284
1995	0.0244	0.1314	0.3140	0.4618	0.5407	0.4922	0.5388	0.5350	0.5329	0.5329	0.5329
1996	0.0313	0.1551	0.3465	0.4952	0.5679	0.5088	0.5540	0.5485	0.5454	0.5454	0.5454
1997	0.0289	0.1688	0.4356	0.6660	0.7525	0.6680	0.7402	0.7381	0.7370	0.7370	0.7370
1998	0.0175	0.1150	0.3181	0.4980	0.5734	0.5164	0.5742	0.5738	0.5736	0.5736	0.5736
1999	0.0116	0.0781	0.2157	0.3351	0.4027	0.3738	0.4132	0.4124	0.4119	0.4119	0.4119
2000	0.0138	0.0798	0.2020	0.3050	0.3548	0.3218	0.3545	0.3529	0.3521	0.3521	0.3521
2001	0.0295	0.1401	0.3081	0.4447	0.4607	0.3811	0.4208	0.4199	0.4145	0.4145	0.4145
2002	0.0111	0.0696	0.1760	0.2657	0.3303	0.3168	0.3506	0.3580	0.3458	0.3458	0.3458
2003	0.0143	0.0798	0.1832	0.2687	0.3270	0.3125	0.3478	0.3630	0.3397	0.3397	0.3397
2004	0.0142	0.0621	0.1332	0.2169	0.3427	0.4022	0.4951	0.5230	0.4830	0.4830	0.4830
2005	0.0146	0.0603	0.1212	0.1906	0.3106	0.3688	0.4518	0.4739	0.4400	0.4400	0.4400
2006	0.0215	0.0909	0.1767	0.2683	0.3829	0.4279	0.5228	0.5581	0.5063	0.5063	0.5063
2007	0.0317	0.1312	0.2372	0.3435	0.4807	0.5333	0.6478	0.7002	0.6224	0.6224	0.6224
2008	0.0447	0.1772	0.2852	0.3769	0.5077	0.5533	0.6624	0.7278	0.6265	0.6265	0.6265
2009	0.0477	0.1927	0.3106	0.4200	0.6353	0.7396	0.8924	0.9838	0.8468	0.8468	0.8468
2010	0.0528	0.2094	0.2999	0.3659	0.5514	0.6476	0.7720	0.8798	0.7176	0.7176	0.7176
2011	0.0275	0.1217	0.2665	0.4181	0.4708	0.4469	0.5486	0.5791	0.5375	0.5375	0.5375