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 Jim Ianelli (USA), who welcomed all participants.

2. Adoption of Agenda

The draft agenda (SWG-11-01) was adopted.

3. Administrative Arrangements

3.1 Meeting arrangements

The Chair outlined the meeting arrangements.

3.2 Meeting documents

A list of Jack Mackerel Sub-Group documents was provided in SWG-11-03 (rev 1).

4. Nomination of Rapporteurs

Rapporteurs Andres Chipollini (Peru), Erich Diaz (Peru) and Geoff Tingley (New Zealand) were nominated. Craig Loveridge (Interim Secretariat) offered to support this process.

5. Report on inter-Sessional Assessment Work by Participants

Relative to work on model developments, the Chair noted that two web-based sessions on the JMA stock assessment model development took place over the last two months. Participants acknowledged the work that was undertaken inter-sessionally in model developments and in holding webinars to help coordinate data compilation and preparations for the meeting.

Jack Mackerel Maturity Studies (SWG-11-JM-07).

A study has provided new estimates of the age-at-first reproduction which shifts from 3-4 years used previously to 2-3 years. The Technical Subgroup considered and then applied this updated information in the stock assessment once the new information had been accepted by the SWG. Maturity at length was consistently observed with L_{50} at about 23cm FL.

It was noted that the gonadosomatic index (GSI) data from Chile appear to have a higher peak than similar data from Peru. Macroscopic studies from Chilean samples appear to have over-estimated L_{50} as compared to the results derived from histological techniques applied more recently. Changes in biomass could be responsible for density-dependent changes in maturity-at-length (and age), current low biomass and currently low estimated mean length-at-maturity. This is probably too much for the current model to accommodate but should be explored using the planned management strategy evaluation (MSE) approach.

Reference Points SWG-11-JM-01, 09, 10

The reference point discussion occurred after the stock assessment data and configurations were agreed upon. Three working documents were prepared prior to the meeting dealing with reference point estimation. A document by Mr. Li briefly described the general concepts of reference point estimation while the other two documents performed reference point estimations based on last year's stock assessment results. Among the analyses were estimates of F limit and target reference points as well as biomass target and reference points. Based on analyses performed by Mr. Canales there are indications for biomass targets at around 40% of SSB_0 while F targets are around to 0.15 $year^{-1}$. Canales included variability in the biological parameters of interest into the analyses and therefore was able to generate 'risk' intervals on the reference points estimated. Three different approaches were proposed by Mr. Hintzen with varying assumptions on the amount of variability that was included in the stock-recruitment curve and in biology. These approaches primarily focused on F_{msy} and to a lesser degree to F_{crash}. The first two approaches results indicate that F_{msy} might be estimated at 0.15 year^{-1}. The third option proposed relieves the assumption of a static stock-recruitment and incorporated a time-varying stock-recruitment relationship. Clear trends are visible in the beta parameter of both the Ricker as the Beverton & Holt curve over time, indicating a change in regime. Based on most recent estimates of alpha and beta of both these curves, F_{msy} might be as high as 0.25 year^{-1}.

Stock Structure studies

Two papers dealing with stock structure were presented. One from EU (SWG-11-JM-04) and the other from Peru (SWG-11-JM-03). .

Francois Gerlotto presented SWG-11-JM-04 concerning stock structure related to jack mackerel. The paper describes three major types of population structure, (i) a network of separate closed populations, (ii) a network of linked populations, functioning as a single or metapopulation, and (iii) a single patchy population. Given available evidence, the author expressed preference for a metapopulation hypothesis but some participants had differing opinions based on theoretical grounds. There was discussion on this topic and it was noted that any spatial population structure has potential implications for management.

The need for monitoring of the whole jack mackerel distribution is required to best understand and manage regardless of alternative stock structure hypotheses. The group **recommended** that measures to support monitoring be given high priority.

The group discussed how management of a metapopulation should proceed. It was noted that the EU has a project under development to consider stock structure and how scientific advice for management can be developed. This will likely involve developing models that incorporate immigration and emigration, implying a need to estimate rates of movement between subpopulations. The Working Group **recommended** that all parties cooperate and contribute to research on this topic.

Peru presented a paper on jack mackerel stock structure including environmental variables, eggs and larvae, a 40-year series of size at maturity, growth, feeding preferences etc. The Peruvian ecosystem tends to be highly variable and data presented show that jack mackerel in Peruvian waters grow faster and the various characteristics of jack mackerel biology and distribution off Peru suggests stock differentiation. Peru indicated that a report on age-determination of jack mackerel will become available shortly and distributed to SWG members.

With regard to the document SWG 11-JM-03 presented by the Peruvian delegation, the Working Group agreed that future management of the jack mackerel fishery in the southeast Pacific must be done in accordance with the stock structure of the resource defined and scientifically supported by the SWG of the SPRFMO. However, some participants held that SWG-11-JM-03 does not contain enough information to take a decision on the stock structure hypotheses that were presented and discussed at the 2008 Chilean Jack Mackerel Workshop. At the 2008 workshop it was agreed that multidisciplinary methods/techniques were needed to elucidate the stock structure. They proposed postponing the assessment of a "northern stock" at least until more conclusive information is available from the Stock Structure project. Others participants argued that the information that was presented in the report provided a clear basis for distinguishing a northern stock.

Based on these discussions and some modeling work that had been done during the week (and some beforehand) some members proposed to evaluate running separate models for the "Far North" region separately from the remaining area west of the Chilean coast. This may provide some indication of consistencies between regions and move forward towards achieving a more realistic evaluation of regional differences observed in jack mackerel, in addition to, as done for the single stock option, providing guidance on possible management options under the two separate stocks option.

Otolith workshop report

The main recommendation from the "Chilean Jack Mackerel Otolith Interpretation and Ageing Workshop" (SWG -10-JM-01), held in Lima in July 2011, was to have a standardised otolith interpretation protocol for *Trachurus murphyi* and a work plan was proposed during this meeting (SWG-11-JM-05). The main activity would be to circulate a sample of otolith images among participating experts and conclude with a workshop. The concept behind using images instead of otoliths is to facilitate the circulation of the sample and save time. The SWGJM **recommended** that SPRFMO secretariat request members to nominate scientists for this team prior to the Commission meeting. Obvious candidates might include those that participated in the aging workshop (i.e., the scientists from Ecuador, China, Chile, Peru, Poland (EU), and Russia). The Chilean delegation volunteered to coordinate the work. The WG supports conducting length frequency analysis to evaluate aging as was done by Peru for the far north stock.

6. Recent fishing and environmental conditions

Over the past two years, the spatial and temporal distribution of jack mackerel catches in the south-eastern Pacific appears to have changed drastically. In May 2010, juvenile fish of 20-21 cm fork length were encountered in large numbers in the international waters off central Chile. In 2011, these fish had largely disappeared from this area. In January 2011, however, fish of 28 cm total length (25 cm fork length) were caught in large numbers in the EEZ of Ecuador, and in subsequent months in the EEZ of Peru. Taking into account some growth between May 2010 and January 2011, the fish taken 2011 in Ecuador and Peru were probably of the same generation as those taken in May 2010 off Chile. This suggests a displacement of juvenile fish from the international waters off Chile towards the EEZ of Ecuador and Chile in the second half of 2010, possibly as a result of the cooling of the waters (La Niña) in this period. An alternative explanation is that the strong year-class that appeared in Ecuador and Peru in 2011 originated from Peruvian waters. There were reports from the Japanese[1] and Peruvian fleets that juvenile jack mackerel were taken in the Peruvian zone in 2010 and 2011.

A second change in distribution of catches is shown by the Chilean fishery. Here the catches in 2012 were almost entirely taken within the Chilean EEZ. Only 2% of the catch was taken in international waters. This presents a reversal of the trend towards offshore waters, observed in earlier years, when up to 58% (in 2008) of the catch was taken in international waters. There was also a change in the season of the fishery in 2012, with the main catch during the first three months instead of later in the year.

The eastern Pacific and in particular the waters off of Peru is characterized by the variability of environmental conditions that respond to changing patterns at different time scales. These patterns, which can range from seasonal to secular, can be identified and eventually be monitored through the temporal changes in various environmental variables and indexes. Recent observations also confirm decadal variability patterns. Another decadal pattern can be observed from the analysis of the changes in the 15^{0}C isotherm depth between 1961 and 2011 off Peru (Ref SWG-11-08a). There is a clear deepening of this variable during the decades of the 1980s and 1990s, which is an indicator of favourable sub-surface conditions for the presence and expansion of fish stocks such as hake and jack mackerel, associated with equatorial currents such the Southern Extension of the Sub-superficial

[1] Squid fishing vessels

Cromwell Countercurrent and the Peruvian Subsurface Current.

For the same time period the spatial distribution of salinity and of the depth of the oxygen minimum shows that toward the end of the 1970s and during the1980s and 1990s the prevailing conditions were those determined by the intrusion of Superficial Subtropical Waters, with water masses with temperatures ranging between 15°C and 20ºC, salinities between 35.1 ups and 35.6 ups and oxygen content between 1.0 and 6.0 mL/L, which are the preferred environmental conditions reported for the jack mackerel off Peru.

7. Jack Mackerel Stock Assessments

Details of the models and some of the evaluations of the models performed during the week are provided in Attachment A1 while the total catch estimates by fleet is shown in Fig. 1.

The following request in the 2012 Interim Measures for pelagic fisheries provides guidance for the SWG-11 activities. Specifically, where possible and appropriate, the stock assessment should incorporate:

- The most up to date information on ageing, growth rates and size at maturity, including associated uncertainties ;
- Standardized catch-per-unit-effort data to be used in the model as abundance indices. The standardizations should account for historical changes in vessels, fishing areas and seasons, environmental factors and other relevant factors. Standardised CPUE indices will need to be provided by participants;
- All fishery and biological data available for 2011, and 2012 at the time of the assessment.

Further development of the model should consider:

- Further development of the preliminary analysis conducted in 2011 on biological and management reference points, including the evaluation of a range of alternative and appropriate targets and limits for fishing mortality and biomass levels.
- Evaluation of stock status under alternative stock structure assumptions.
- The explicit modelling of length composition data;
- Evaluation of possible improvements to existing acoustic abundance indices;
- Sensitivity to alternative plausible levels of natural mortality and to age-variable natural mortality;
- Evaluation of the effect of minimum size limits and minimum fishery specific net mesh sizes on jack mackerel stock restoration.
- Investigation of changes in the geographical distribution of catches observed between 2010 and 2011 and the possible causes, such as changing environmental or other conditions, that could influence the distribution of the stock.
- The link between concentrations of juvenile fish observed in 2009 and 2010 by several fleets fishing in the high seas and the higher catches of young fish observed in coastal shelf areas in 2011

Whereas the WG was unable to address each of these topics exhaustively, a number of these have been completed and are reflected in the following sections.

7.1. Updating of data sets for additional stock assessment runs

The SPRFMO Data Manager coordinated with updated data sets that were provided for the stock assessment runs conducted at the meeting. Additionally, participants were asked to present data to improve inputs to the models.

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[2] and updating of preliminary 2012 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; introducing newly standardized CPUE and other indices; and a new matrix of mean weights at age over time for the far north fleet. As before, 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.

It was noted that the time series of weights at age were specified to be the same for all of the fleets and surveys. Given differences in age determinations observed from different areas the group requested that more appropriate weights at ages be applied for each fishery. Peru provided an updated time series for the Far north fleet (which was also used for the region-specific model). This series was developed by assuming a single growth curve for the entire period but with variability due to estimated annual length-weight relationships.

The WG discussed the need for comparing length-weight relationships by season and region and **recommended** that intersessional studies be conducted to refine estimates of mean weight at age data for each fishery and for the population as a whole.

During the meeting, Peruvian scientists presented new results from their work standardizing fishery CPUE and hydro-acoustic survey results. The standardized CPUE corresponds to the purse seine fleet targeting on jack mackerel in its jurisdictional waters. The time series is for the period 2002 – 2012 and corresponds to the total catch per trip of all vessels that landed jack mackerel. At the moment there was no way to estimate the proportion of trips with no catch. Efforts are being made to collect such data in the future to also take into account the trips with no catch if they do occur, as well as the total duration of the trips. The standardization process included the Box-Cox transformation of the dependent variable (tonnes/trip) and used year, month, latitude, distance to the coast and the hold capacity as independent variables. The best model was selected by a stepwise automatic procedure based on AIC. Standardized values of this CPUE series are the predictions of the best model fixing the value of the independent variables but the year.

The standardized acoustic index takes into account the variability of the area covered by the Peruvian surveys between years. The surveys mainly focus on the assessment of anchovy. A niche model for jack mackerel off Peru was built using acoustic presence/absence data from 1985-2008 as the dependent variable and environmental variables (SST, SSS, water masses, depth of the 2mL/L oxycline, chlorophyll, kinetic energy of eddies and vortices) as independent variables. This niche model as indicator of presence/absence of jack mackerel was validated through observation of presence/absence coming from the same acoustic surveys (cross-validation) as well as from other surveys (for squid, egg & larvae surveys) and reports from the commercial fleet. The niche model allows predictions to areas with higher probability of jack mackerel presence given a combination of environmental variables. This model was used to predict the potential habitat of jack mackerel off Peru in a monthly basis from 1985-2008. An index calculated as the ratio between the area covered by the survey with positive jack mackerel observations and the total area of the potential habitat of

[2] The delegation of the Russian Federation stated that the Russian Federation will implement the 2012 Interim Measures and further management measures for the pelagic fisheries according to the data which were provided to the Interim Secretariat.

jack mackerel was used to standardize the acoustic index to the full potential habitat area. Standardized acoustic index is expected to remove the variability related to the area covered by the survey and better represent the trends in the abundance of the jack mackerel population. This method was not able to take into account the possible underestimations of the acoustic estimates due to the too shallow distribution (and avoidance of the surveying vessel) of the jack mackerel schools, effect that can be particularly important under cooler than normal conditions and/or when the thermocline and the minimum oxygen line are too shallow. The Peruvian delegation will submit a technical report on the details of the methodology and ways to improve the method in the future.

The applicability of this index within the assessment model was discussed at length by the WG and it concluded that time was too short to adequately review the analysis (a presentation was made but no working document was presented). Nonetheless, the WG was encouraged by the desire to correct and standardized this index and agreed to allow it for inclusion in some model runs specified below. The WG **recommended** that in the future, new methods are fully documented and adequate time be allowed to review them prior to the SC so that they can be more fully understood.

7.2. Assessment models

Progression of models from last year
To bridge the developments and changes made in the past year, the WG took a stepwise approach. This begins with last year's Model 2 (Annex SWG-10-03) which is compared with the same structure and only updated catch, age composition, Chinese and Chilean CPUE indices and is labeled 0.0. These data were classified as having been "routine" updates of indices considered at SWG-10 and hence were considered as a group for clarity. Model 0.1 is the same as 0.0 but incorporates the maturity work presented in SWG-11-JM-07).

As noted above one request was to develop the ability to use length frequency data within the model and in doing so it was recognized that the model structure would be more appropriate to start accounting from age 1 jack mackerel instead of age 2 (previous models). This change is evaluated in Model 0.2. With the length composition included and based on evidence provided at the meeting (SWG-11-8, SWG-11-8a) an updated growth curve was considered more appropriate to apply to the length frequency data in the Far North fleet and this was the change made in Model 0.3. Similarly, new data provided by Peru were incorporated and shown in Models 0.4 and 0.5. Table 1 lists the set of models intended to bridge the gap between years. Additionally, different model approaches have been considered to cover the two different hypotheses regarding stock structure (single stock and two stocks). In the case of the two stocks hypotheses, one sub-model was built for each stock (south and far north) considering independent recruitments for each one and a split of the data for each region. This way, the addition of far north and south stock sub-models provide estimates for the total population of jack mackerel in the Southeast Pacific. Additionally, since the total data used within the models for the single stock hypothesis is used for the model within the two stock hypothesis is the same, likelihoods can be used to make comparisons between the assessments for the two hypotheses considered during this meeting.

The specifications for the initial base case model is summarised below.

Model	Description
Initial base case Model 1	• Model begin age 1 • All indices assumed proportional to biomass • Fleet 4 length frequency data used with Peruvian growth parameters • Include all index data • Stock-recruitment steepness set to 0.8 • Assume *M* = 0.23

Results from these changes indicate the impact on spawning biomass and fishing mortality estimates with the expected change in spawning biomass increasing with the younger age at maturity assumed and switching to the model which included age one jack mackerel resulted in lower fishing mortality estimates in recent years (Fig. 2). Comparing the recruitment between these models showed the impact of changing the model from beginning with age 2 to age 1 and the other incremental changes (Fig. 3).

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

Results of key stock assessment runs and model description are attached in a technical Appendix. Given the model changes evaluated in the previous section, the WG proceeded to accept a baseline from which to conduct more extensive evaluation of alternative specifications. During the meeting a series of alternatives were examined and the final set are shown in Table 2. To evaluate these, the negative-log likelihood components were presented to evaluate trade-offs between different data components and model assumptions. For comparison purposes, the minimum value over all models for each component was subtracted to ease evaluation (Attachment A2.1 and A2.2). It is important to note that some values in this table for some subsets of models cannot be compared across models because some models introduce new data (i.e., the revised acoustic survey index for Peru). Also, comparison between models 1-7 (single stock hypothesis) and model 8 (two stock hypothesis) can be carried out just when the same data is used. The same restriction applies to the comparisons between sub-models (for far north and south stocks) in the assessment under the “two stock” hypothesis.

Results show that including the revised Peruvian acoustic data improves the fit to other data components compared to the base model which indicates some consistency—e.g., the age composition data. When natural mortality is increased from 0.23 to 0.28 the fit is improved further (Model 4). Model 6 which is the same as Model 4 but recognizes a regime shift for latest 12 years in fitting the stock recruitment relationship results in further improvements. Among the models which use the original acoustic survey data, Model 7 resulted in the best fit. The analysts recognized that even better alternative specifications were likely, but due to time constraints they could not be pursued. The WG **recommended** that intersessional work on this topic continue with the formation of a technical sub-group involving all interested participants.

For the models using the two stock hypothesis, an improvement of the fit of the different data components was observed inside the regional sub-models (south and far north) and also an improvement in the fit when considered the integration of the sub-models (model 8).

The WG decided that Models 6, 7, and 8 should be brought forward for further analysis and summarized in Figs. 4, 5, and 6. Importantly, these provide some contrast in the projected stock-recruitment scenarios useful for projections (Fig. 7).

A major discussion point throughout the week revolved around the extent that jack mackerel can be considered as separate stocks. To this end, data sets for individual models were constructed and considerable time devoted to this activity.

Model 8 (results of two stock hypothesis model, south and far north added together) was run and results are similar (intermediate to Model 6 and 7). The WG was instructed to consider alternative stock structure options. They were encouraged by this investigation and look forward to future developments, including alternative fine-scale modeling approaches. It was noted that this model relies on the revised acoustic survey index which had not been adequately reviewed. Nonetheless, since Model 6 also uses the new acoustic index, it was considered not inappropriate to carry Model 8 forward for advice (since scientific reservations and doubts exist with all models).

For example, Fig. 6 shows that combining the "two stock" models provides generally similar results but with some differences between the N3 and S2 models. Particularly, despite the similar results of Model 6 and 8, the N3 model provides lower estimates of biomass and different trends compared to model S2. They also appear to have different peaks in abundance over time. This results in higher estimates of fishing mortality for Far North fleet in comparison to single stock models 6 and 7.

8. Advice to the Science Working Group on Jack Mackerel Stock Status

The JMSG task is to prepare advice for presentation to the SWG and Commission on the status of the jack mackerel stock in 2012. Similar to last year, the group agreed to present a range of plausible model configurations in order to reflect real concerns over model specification uncertainties. 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 since 2010:

- Jack mackerel catches by all but one of the fleets continued to decline in 2012, with estimated 2012 catches being 69% of 2011 catches. Updated assessment results indicate that current biomass is now estimated to be 8% - 16% of the spawning biomass which would have existed had there been no fishing, which is slightly higher than the range estimated for 2010 (5-10%). The 2012 assessments results indicate a continuing decrease in fishing mortality and an increase in estimated spawning and total biomass since 2010.
- The increase is in part due to some indications of improved recruitment in recent years. Nonetheless the stronger recruitment observed by a number of fleets is still estimated to be below the long-term average (Figure A2.15).
- Projection results under the assumption of recent average recruitment at the levels estimated for the recent period (2000–2012) indicate that effort should be maintained at or below 2012 levels to improve the likelihood of spawning biomass increasing. This results in catches for 2013 on the order of 441 kt or lower. Fishing effort in the next 10 years at or below current (2012) levels are projected to have a high probability of resulting in spawning stock increases under most projections.

For Model 7 the spawning stock was estimated to be at its lowest level in 2010—about 5% of unfished (10% in Model 6)—and increasing to about 8% of unfished in 2012 (16.5% in Model 6; Fig. 8). The Model 8 estimates of spawning stock biomass were slightly higher than that estimated by Model 6 prior to 1998 and a bit lower afterwards. Relative to Model 7, Model 8 spawning biomass was higher during the entire period.

The ratio of the Model 8 estimate of spawning biomass over unfished spawning biomass was intermediate to that of 6 and 7 but showed some different patterns. The estimated degree of stock decline from 1970 to 1998 ranged from 11% to 19% with a slight recovery during 2003 (19% – 33%). Presently the 2012 ratio ranges between 8% and 17%.

Five harvest scenarios were evaluated for models 6, 7, and 8. These scenarios simply carried forward under fishing mortality rates observed in 2012 and multipliers of the 2012 fishing mortality was applied for projection purposes. Figures 9 and 10 show comparisons for the alternative single stock models and Figure 11 shows projection results for Model 8 (separating the south from far north stock).

The WG reiterated that more preparation time is needed to conduct the work of the assessment including that all catch information and data revisions be provided to the Secretariat and members of the SC well in advance of the meeting. Additionally, the WG suggests that the SC support that

1) A stock assessment working group be formed
2) That the duration of the SC be extended by two days. Five days is insufficient to adequately discuss all the issues about jack mackerel, much less the other activities of the SC, and
3) That a protocol for data and information submitted for the assessment be established including a cutoff date.

9. Jack Mackerel Research Programme

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

Members of the Jack Mackerel Research Programme Task Team will be given an opportunity to provide brief overviews of any inter-sessional progress made with projects under the Jack Mackerel Stock Structure Research Programme.

9.2. Future Jack Mackerel Work Programme

The Work Programme for jack mackerel is part of the general Research Programme of the SPRFMO included in Annex 6 of the Science Working Group report. For jack mackerel, the programme considers the following components: 1) Biology and Ecology, 2) Stock Structure, 3) Stock Assessment and 4) Conservation, Rebuilding Plan and Management Procedures.

The intention is that the SPRFMO's Scientific Committee will review this programme, prioritise activities and regularly update its research programme.

9.3. Identification of short term research and assessment requirements

The group considers that for developing scientific advice on the jack mackerel fishery, progress on the following areas is a high priority in the short term:

1) Stock structure studies. Research is in progress on several aspects of jack mackerel stock structure. The proposed simulation studies within a Management Strategy Evaluation (MSE) framework will help to fill the gap between uncertainty in stock structure and management measures (see item 9.4 below).
2) Age determination. The proposed work programme on age determination based on circulation of images is cost effective and could bring important insights into the current uncertainty. The collaboration of Peru would be fundamental due to the age validation work in the northern area of jack mackerel distribution.
3) Acoustic survey standardization. Standardization of survey design and potential habitat modeling should be consider, especially for jack mackerel surveys, where the target fish is highly mobile and not necessarily present every year in the same place and in the same period. These activities should be developed under the supervision of the ICES FAST working group, for ensuring the highest scientific level of the research.
4) It was suggested that the recording of data on non-fish bycatch, specifically including seabirds, was desirable in terms of understanding the wider ecosystem relations of the fishery.

9.4. European project on hydrography and jack mackerel in the Southeast Pacific

Hintzen and EU colleagues gave a short presentation on a new EU project that will start in later 2012. The objectives of the project are: 1) Identify the most likely stock structure hypotheses of Chilean Jack Mackerel, 2) Considering the most likely stock structure, identify management objectives for Chilean Jack Mackerel, 3) Evaluate sustainable management strategies to achieve these objectives. Different partners from the SPRFMO have already been approached to collaborate to ensure that the outcomes become a SPRFMO participant result rather than an EU project result. When the proposal was presented at the PrepCon meeting in 2012, it was well received by many different nations. The project will study Jack Mackerel over the course of 2 years.

10. Revisions to the draft jack mackerel species profile

An updated jack mackerel species profile prepared by Dr Glubokov was tabled at the SWG8 JMSG meeting. Chile and Peru noted that they are planning to provide corrections and updates on the species to the Secretariat .

11. Other Matters

There were no other matters.

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

The report and summary of the jack mackerel sub-group was adopted after inclusion of the final edits.

Tables

Table 1. Incremental changes to the jack mackerel model in an attempt to illustrate the impact of changes relative to the 2011 model.

Model	Description
0.0	Last year's configuration with updated data (catch, SC Chilean age composition, Chinese and Chilean CPUE)
0.1	As 0.0 with new maturity
0.2	As with 0.1 with model starting at age 1 instead of age 2 and Far north length frequency (not cohort-sliced); Gili growth
0.3	As with 0.2 but Peruvian growth curve estimates
0.4	As 0.3 but updated wt-at-age for Peru
0.5	As 0.4 with new Peruvian CPUE (2002-2012)

Table 2. Final model sets to the combined jack mackerel model data (Models 1-7) and split stock tests (Models N0-N3 for Northern stock and models S1 and S2 for the southern stock).

Model	Description
1	Same as 0.5
2	Use new Peruvian acoustic index
3	Model 1 but M average between regions (0.28)
4	Model 2 but M average between regions (0.28)
5	Model 4 but early stock recruitment period (1970-1999)
6	Model 4 but recent stock recruitment period (2000-2012)
7	Model 1 but with changes in selectivity to better match mean ages observed (more variability in selectivity)
8	Addition of model N3 + S2.
Far North stock	
N0	Original acoustic
N1	Original acoustic, lognormal prior on q=1, sigma=0.15
N2	As N1 but new acoustic
N3	Fix q=1 for new Peru acoustic survey and shift in M to reflect natural mortality change in 2000.
South stock	
S1	As Model 1
S2	As with Model 7

Figures

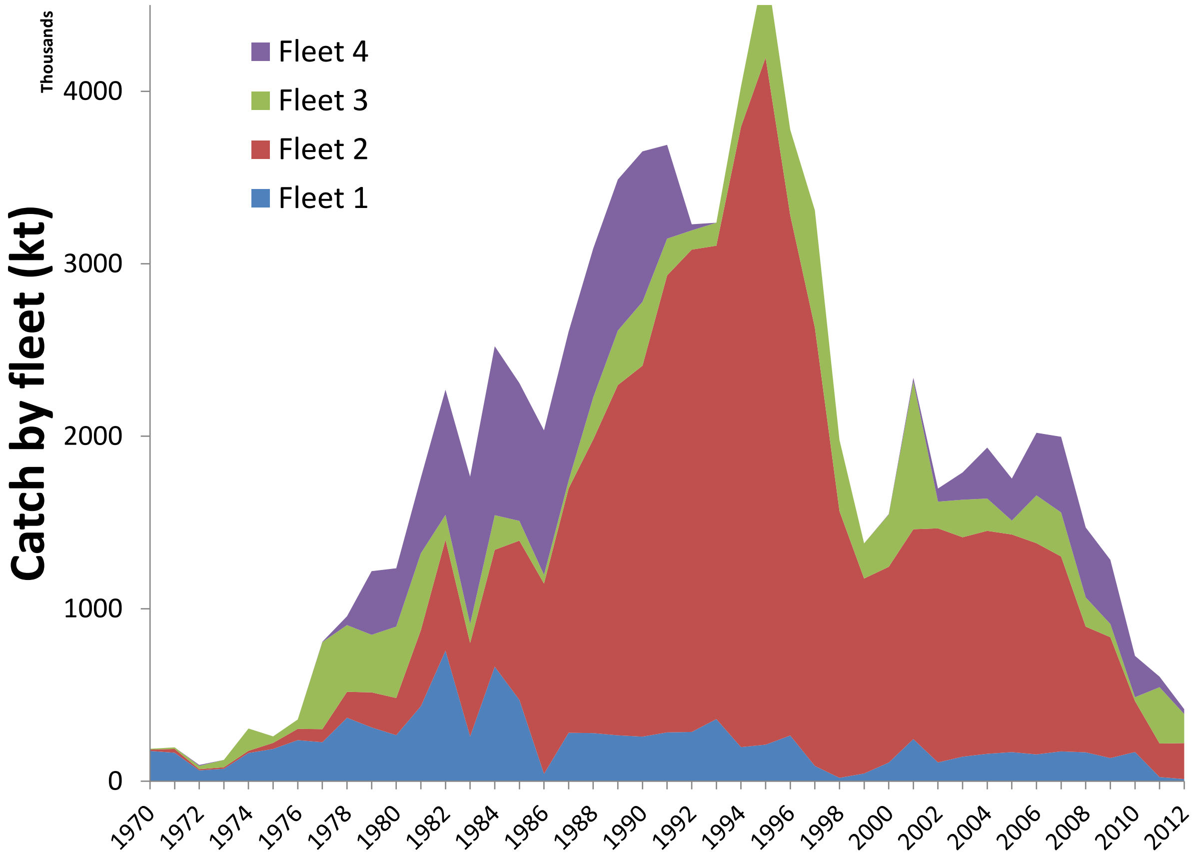


Figure 1. Jack mackerel estimated catch by fleet used for the stock assessment models.

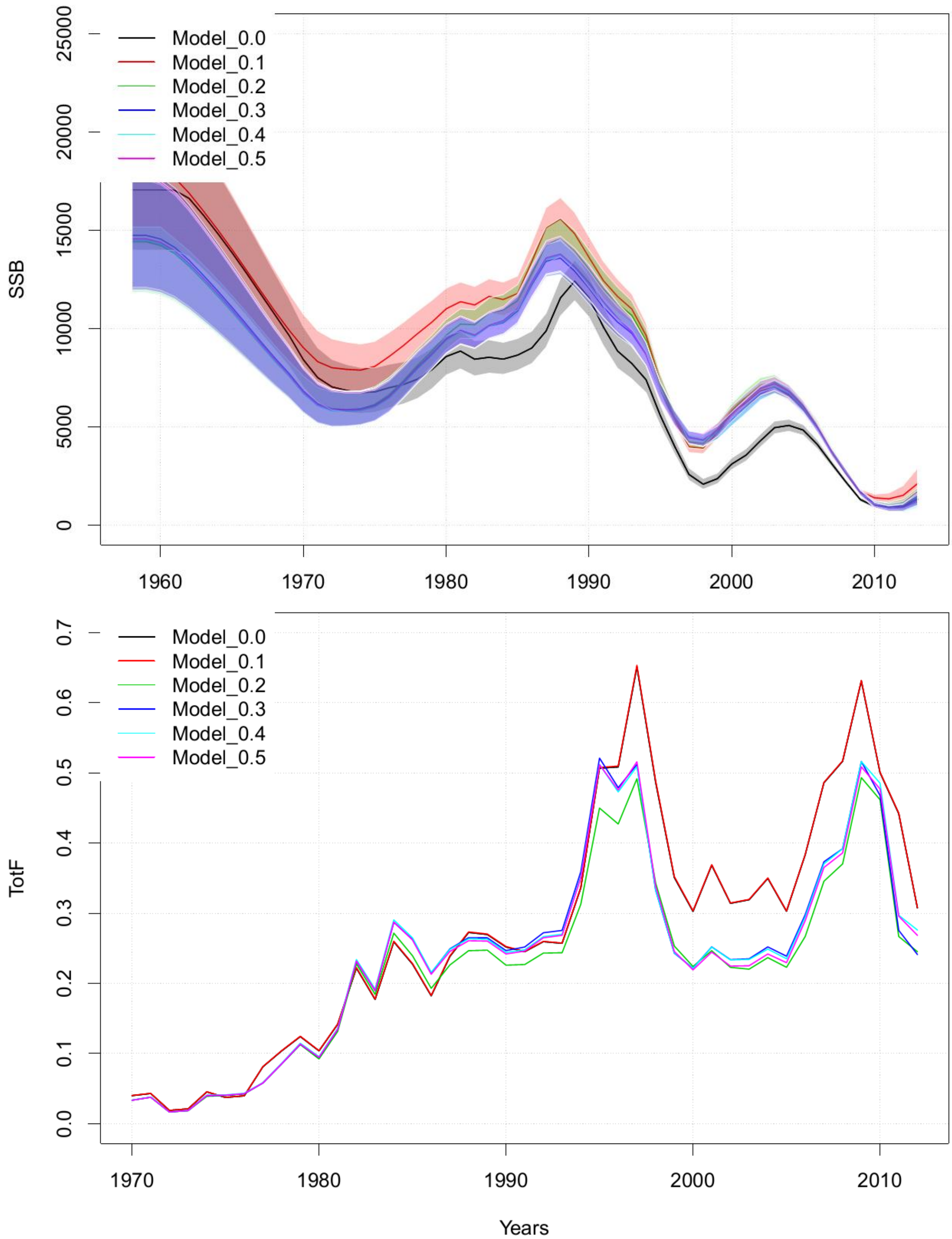


Figure 2. Jack mackerel spawning biomass (top in kt) and fishing mortality (bottom) estimates for the different model modifications reflecting modifications (structural and data based) relative to the model from 2011 (Model_0.0). Shadings represent approximate 90% confidence intervals.

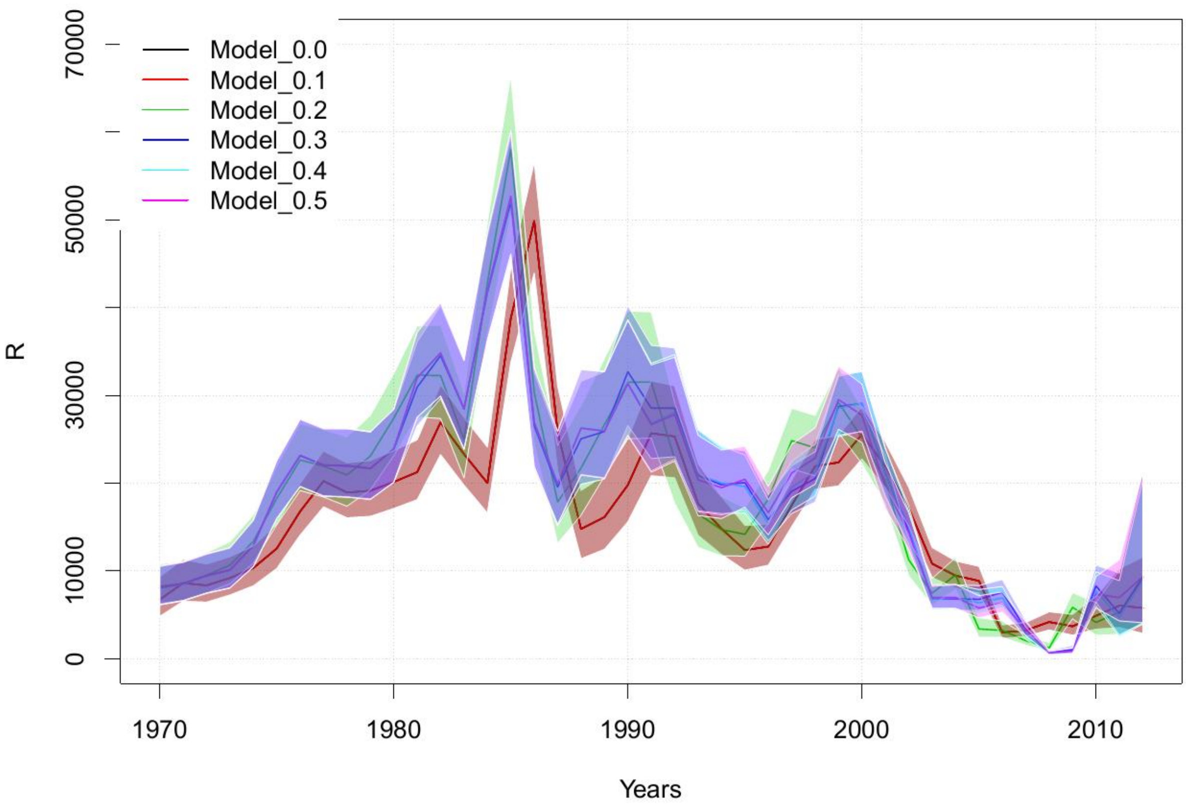
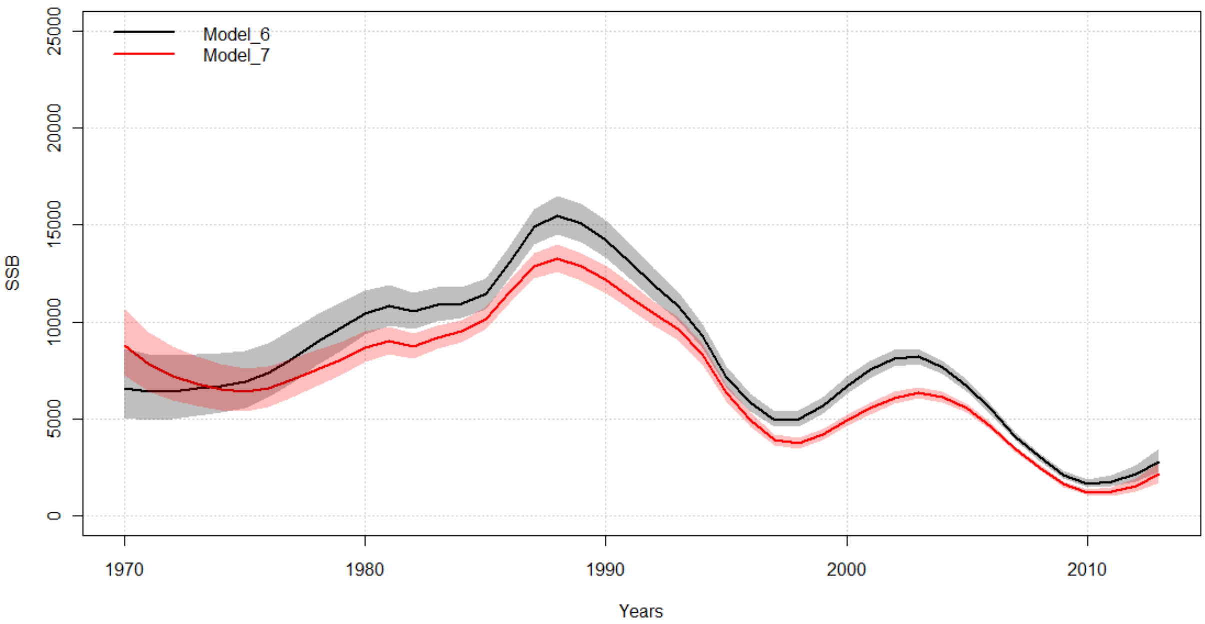


Figure 3. Jack mackerel recruitment estimates (millions) for the different model modifications reflecting modifications (structural and data based) relative to the model from 2011 (Model_0.0). Shadings represent approximate 90% confidence intervals.



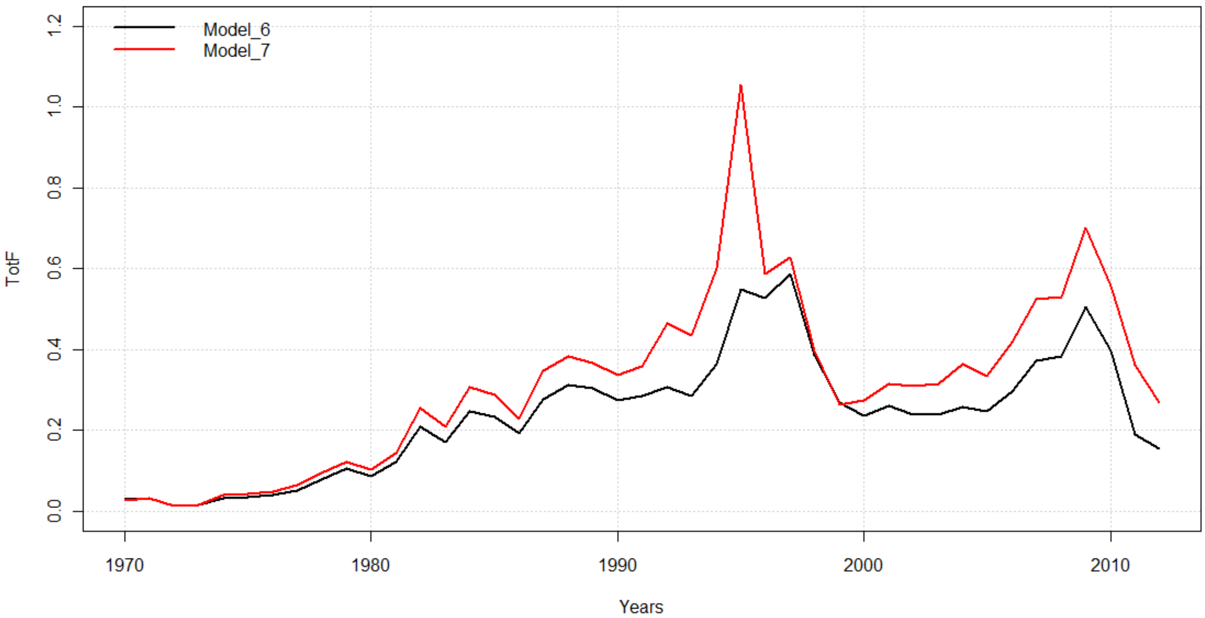


Figure 4. Jack mackerel spawning biomass (top in kt) and fishing mortality (bottom) estimates for models 6 and 7. Shadings represent approximate 90% confidence intervals.

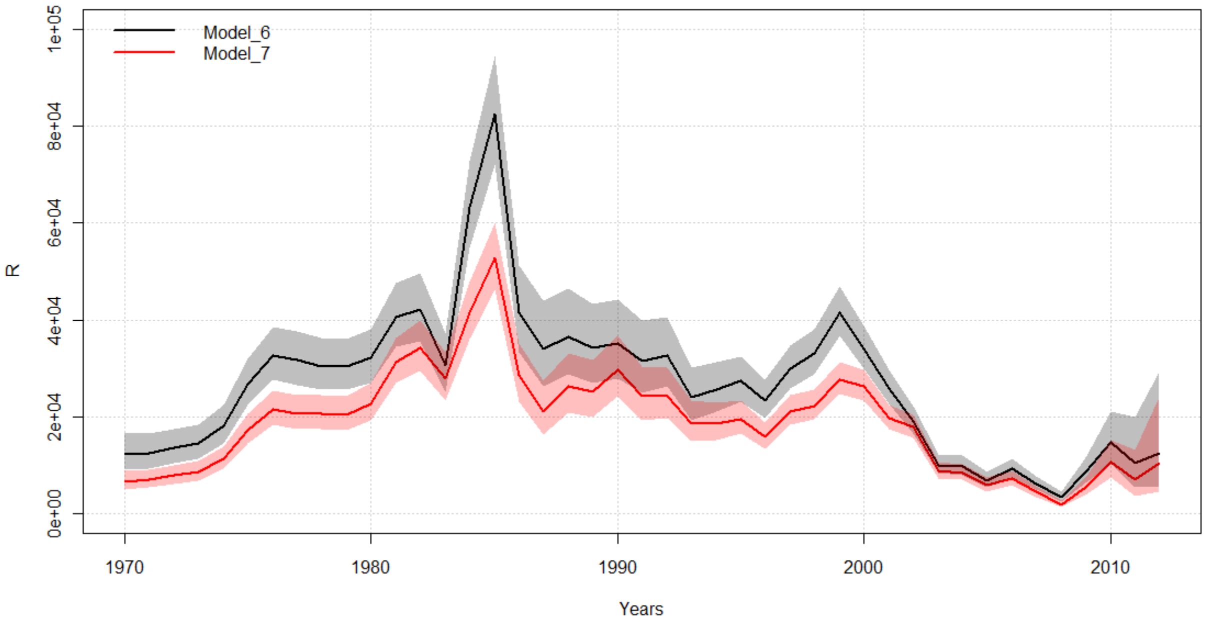


Figure 5. Jack mackerel recruitment estimates (millions) for Models 6 and 7. Shadings represent approximate 90% confidence intervals.

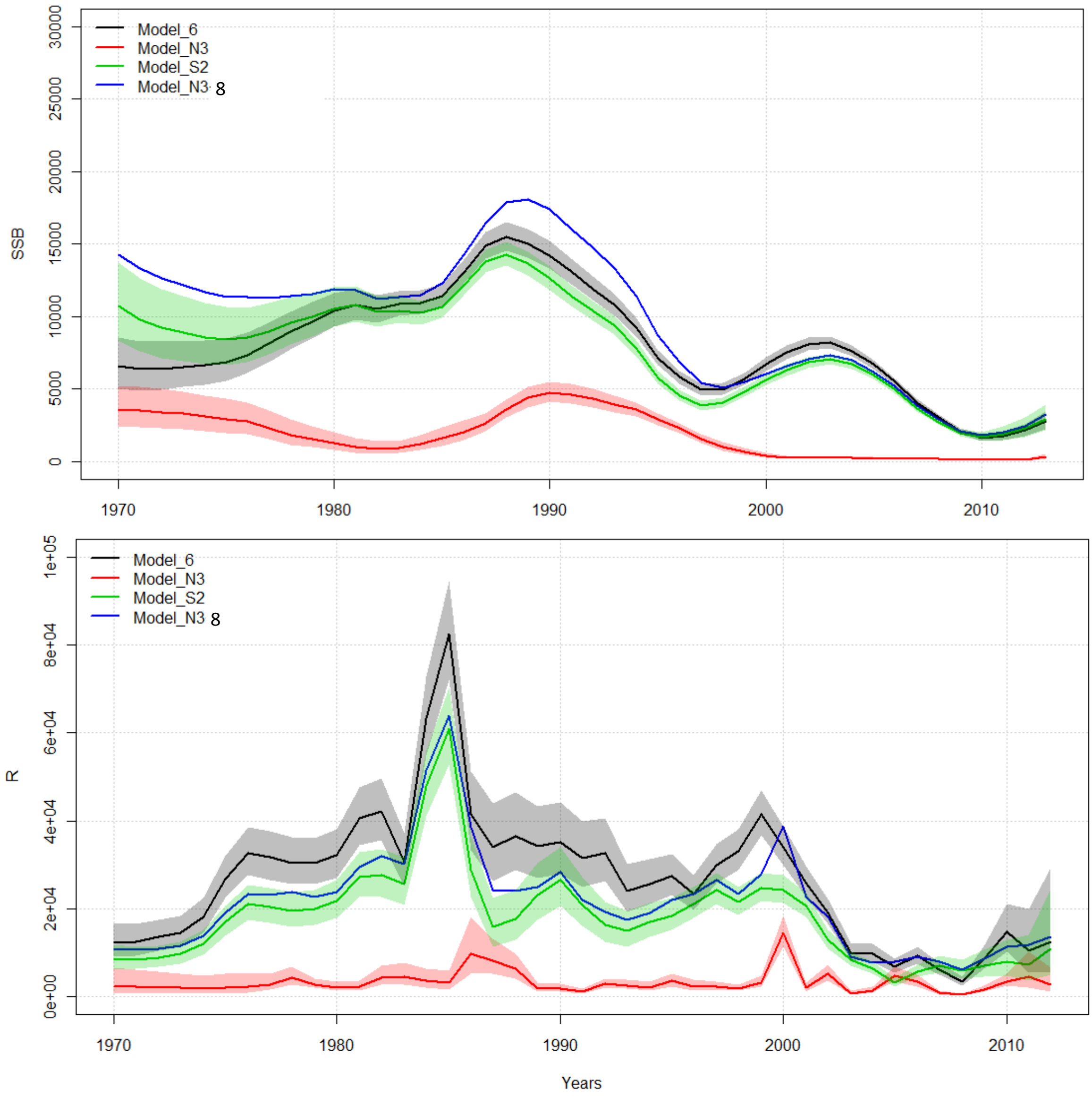


Figure 6. Jack mackerel spawning biomass (top, in kt) and recruitment (bottom in millions) estimates for the combined area (Model 6) and regional models (N2 and S2) along with the sum of N2 and S2 (Model 8). Shadings represent approximate 90% confidence intervals.

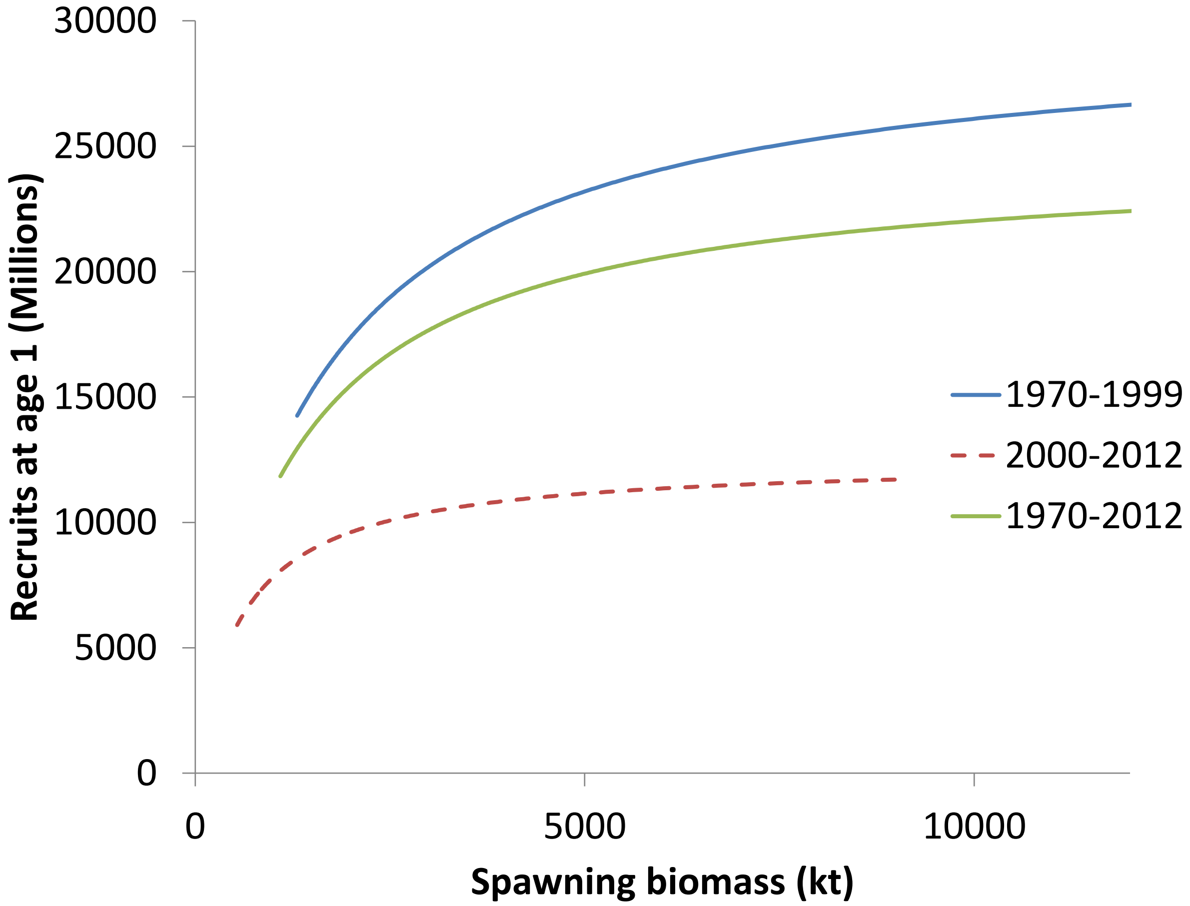


Figure 7. Jack mackerel stock recruitment estimates (with steepness fixed at 0.8) estimated for different regimes. For near-term projection purposes the regime specified from 2000-2012 was used.

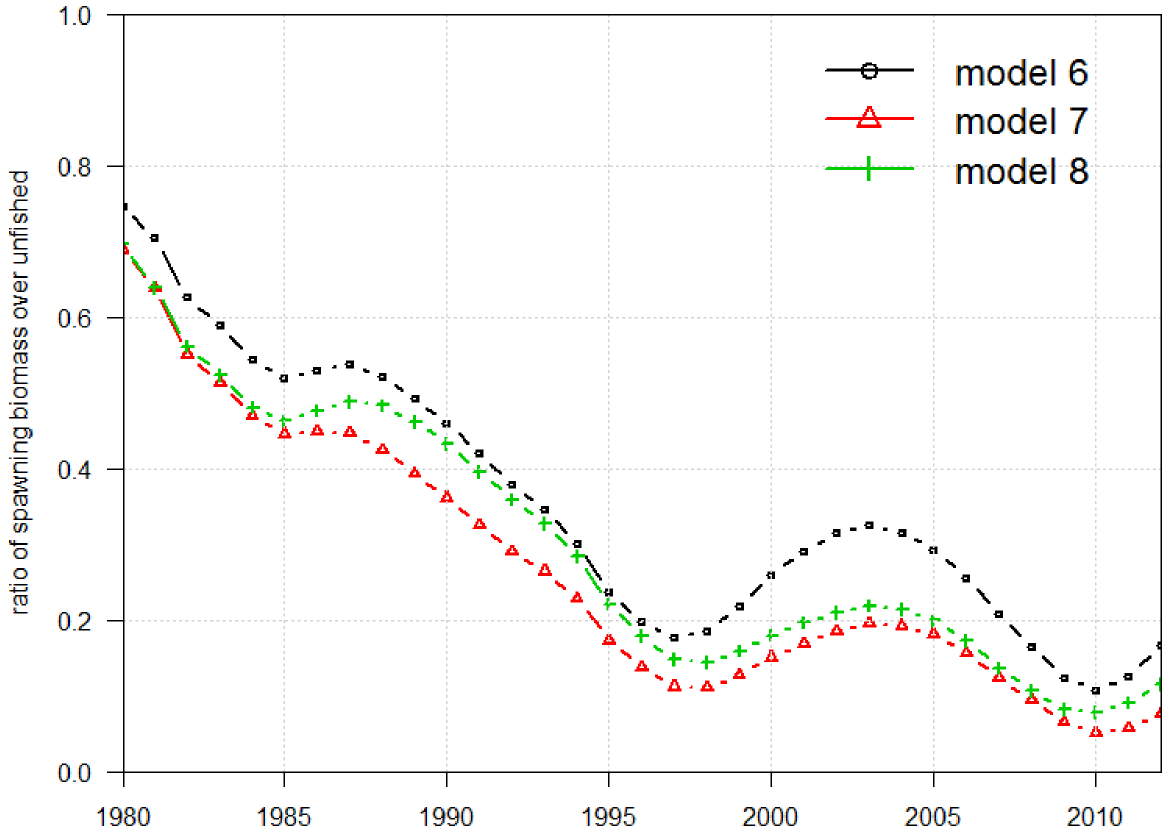
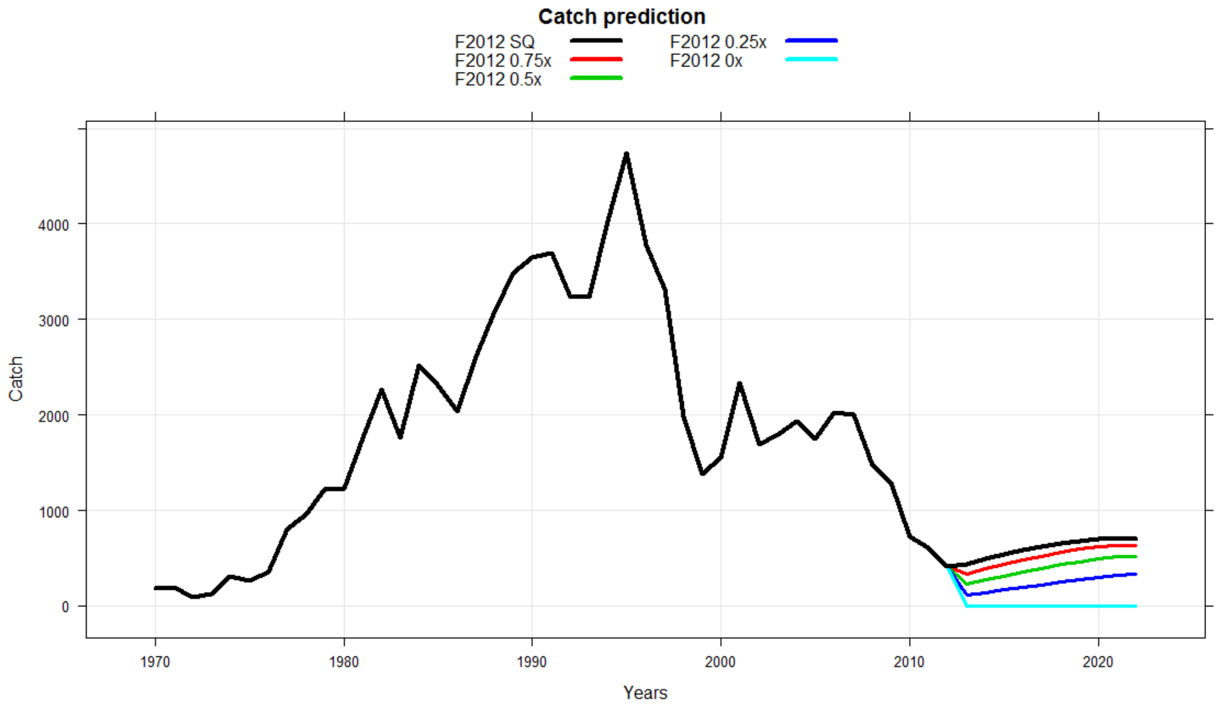


Figure 8. Jack mackerel spawning biomass expressed as a ratio of estimated over "unfished" where unfished is computed based on projecting estimated numbers at age 1 forward with natural mortality only for Models 6, 7, and 8.

Model 6



Model 7

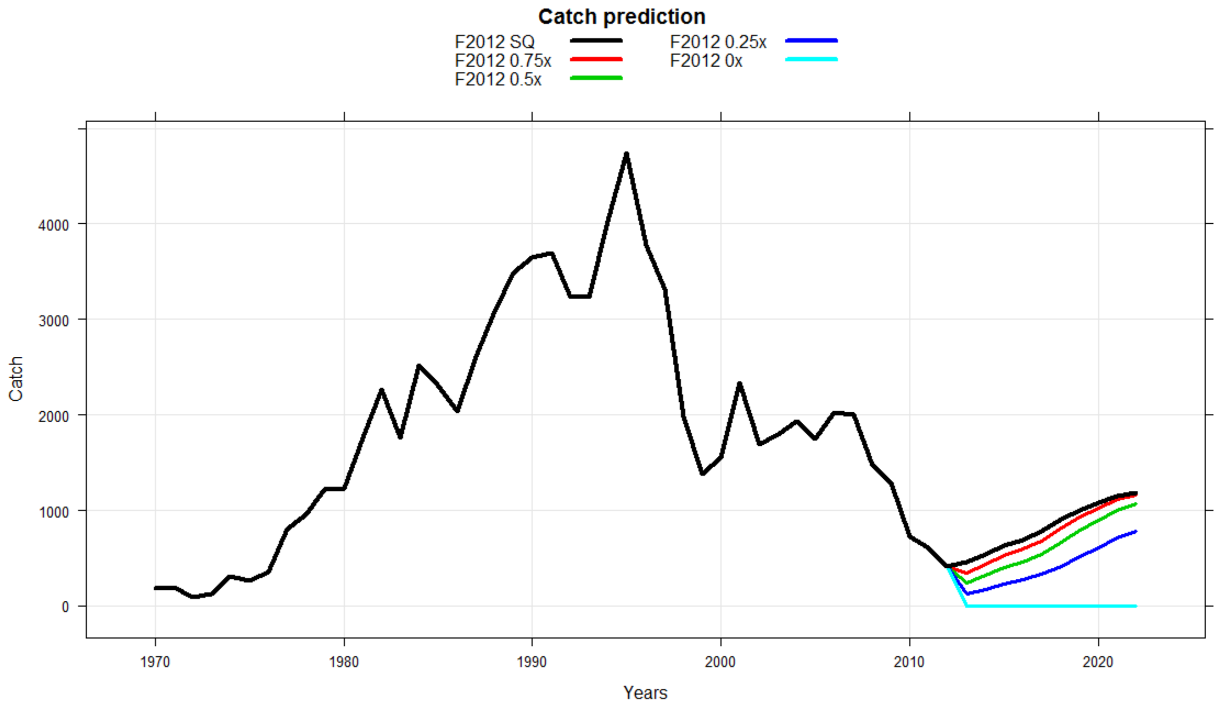
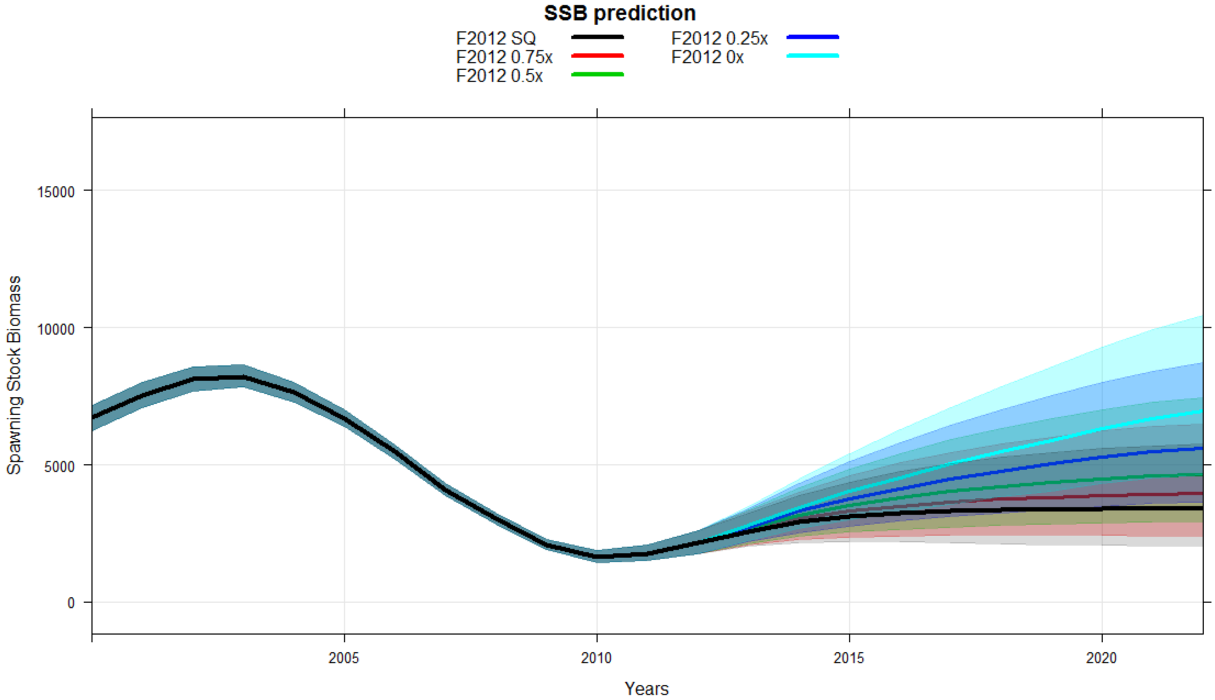


Figure 9. Jack mackerel historical and projected catch scenarios for Model 6 (top) and Model 7 (bottom). Units are kt.

Model 6



Model 7

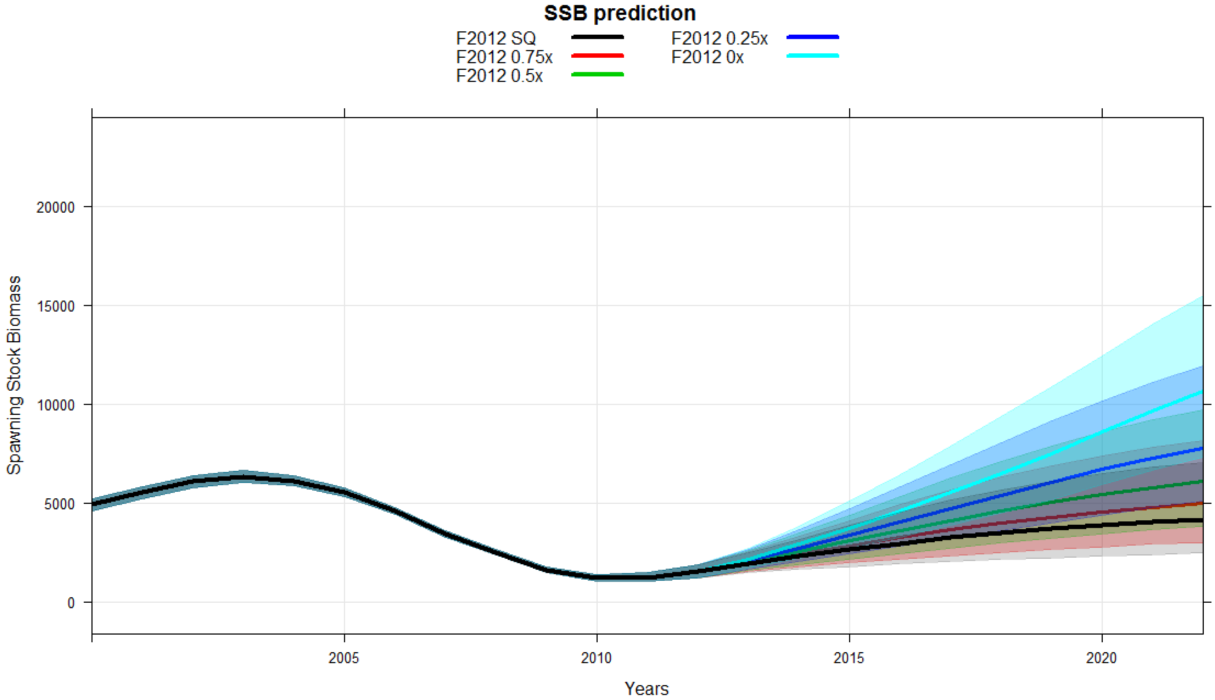
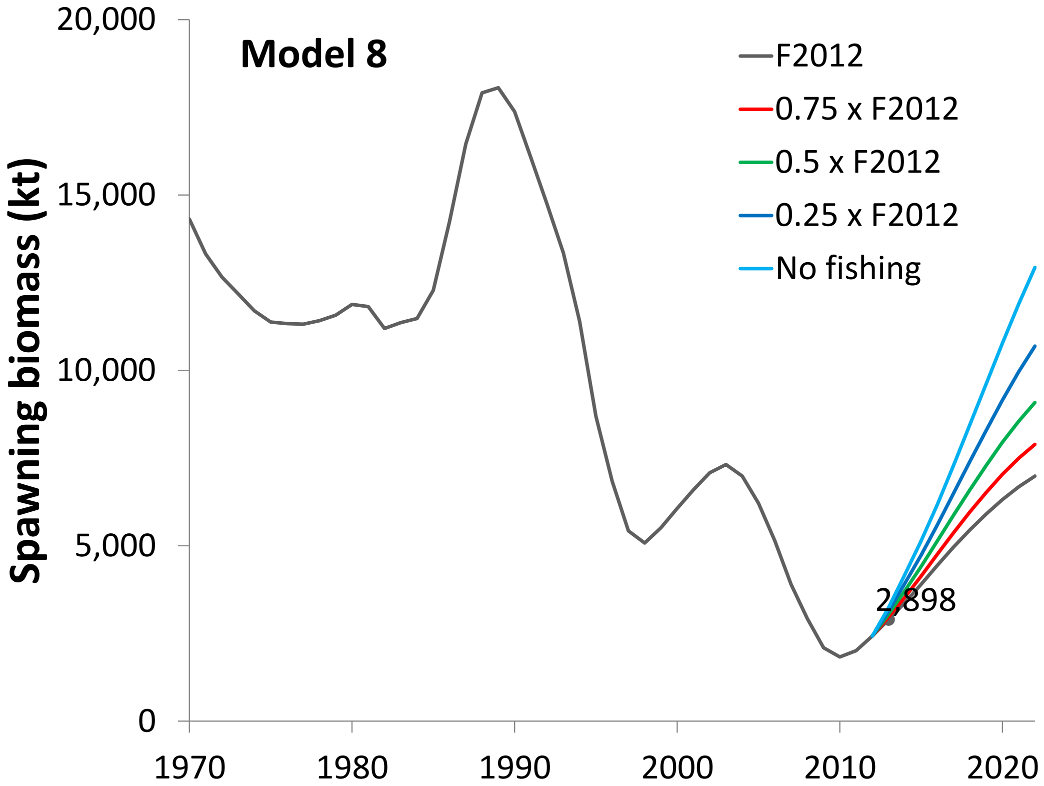


Figure 10. Jack mackerel historical and projected spawning stock estimates for Model 6 (top) and Model 7 (bottom) under different harvest scenarios. Units are kt.



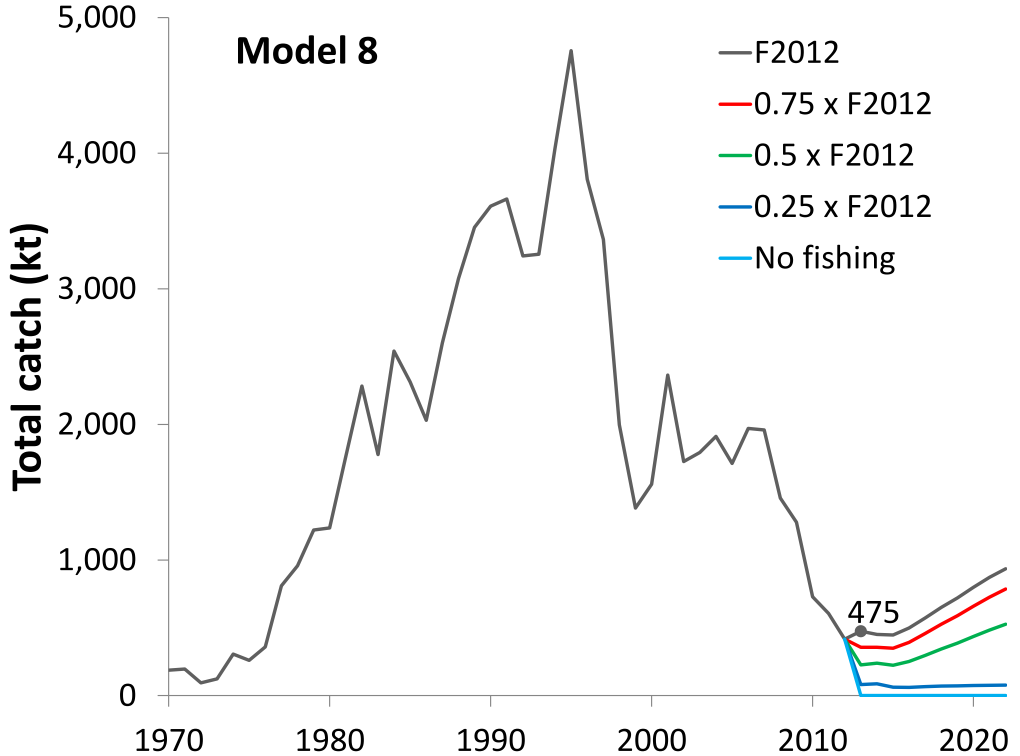


Figure 11. Jack mackerel historical and projected spawning stock estimates (top) and catch (bottom) for Model 8 under different harvest scenarios.

A1. Attachment to SWG-03: Assessment models developed and evaluated during the Jack Mackerel Subgroup Meeting

A1. Data

During the meeting, several new pieces of information were presented. The meeting agreed on data sets going forward for catch (Table A1.3). The detailed catch-at-age and index data are provided in Attachment A2. The mean weights-at-age over time used for all gear types and indices of central-south and offshore fleets were the same as used in the 2011 assessment except for the Far North fleet (see Attachment A2). The maturity-at-age was updated based on new studies and the growth parameters are given in Table A1.4 and Table A1.5). 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
  - Standardized CPUE
- Peru
  - Length composition
  - Standardized CPUE
  - Acoustic index
- EU
  - Length frequency
  - Nominal CPUE (with Vanuatu) Added on year to end of time series
- China
  - CPUE (year effect coefficients)
  - Catch at length (in cm)
- Russian
  - Nominal CPUE data 2008-2011
  - 2008, 2009, and 2011 length frequency data

CPUE series

The Chinese CPUE was presented at the document SWG-11-JM-08, where the series standardized considered a GAM approach. In this work the year effects suppose represents the changes on exploitable biomass for offshore fleet. A similar approach analysis (GLM) was conducted in order to standardize the Chilean CPUE for the central-south area, whose details were informed in document SWG-11-JM-06. For the Peruvian CPUE, the abundance index was based on a GLM approach for two periods, since 1970 - 2001, and 2002-2012 (not documented). However and considering the fishery orientation, the first part was excluded from the analysis for assessment purposes.

As was recommended at SWG10, the Russian time series of CPUE was included but with low weight since it remains unstandardized.

Age and length compositions

There was a compilation of length compositions (partial results 2012) for countries that don't have age compositions (China, Vanuatu and Korea). A weighted frequency was done as a representative of offshore fleet. The age conversion for these fleets was done considering age-length keys of central-south area of Chile. A similar procedure was applied considering the information since 2000 for all offshore fleets that have operated off Chile.

The conversion of length composition (to age) from Peru and Ecuador was done within the model considering an approach length-based which was implemented for these purposes. In this context, a new series of length comps (total length since 1980) was provided by Ecuador, which was added to Peruvian comps based on its landings and an isometric weight-length relationship.

Acoustic biomass

A new series of acoustic biomass was provided by Peru for years 1985-2011. This series represents estimations based on the assumption of shifts in habitat area and its impact over traditional estimations. There were some discussion related to the criterion employed in this correction and if its value can be used as abundance index. Both series were used in stock assessment work. The long of this series is shorter than other series that were provided before (three years less), because for some of these years were not available environmental data to do the corrections before mentioned

Biological parameters

A new biological parameters set were updated, such as sexual maturity, growth and natural mortality. This update is based on differences of growth function between Peru and Chile. An average of natural mortality was used for combined model scenario (M=0.28). A weight-at-age matrix was included as well to describe the weight variation (by age and year) in the Peruvian fishery, which values were included in some model scenarios.

A1. The assessment model

A statistical catch-at-age model was used to evaluate the jack mackerel stocks. The JJM (“Joint Jack Mackerel Model”) is implemented on ADMB and considered different types of information, which corresponds to the available data of the jack mackerel fishery in the South Pacific area since 1970 to 2012. The extent and type of information is listed in Table A1.6.

JJM developments

As requested at the Third Session of Preparatory Conference (Santiago, January 2012), some model improvements were included, as the explicit modeling of length comps for Far north fishery, and the incorporation of some routines related to stock projections, retrospective analysis and variations on stock- recruitment relationship over time. The model is now more flexible and permits to use catch information either at age or size for any fleet, and incorporate explicitly regime shifts in population productivity.

Models for stock structure hypothesis

The Third Session of Preparatory Conference also requested alternative stock structure hypotheses. During the meeting, three variants related to population structure were developed:

	Stock/Hypothesis	Fleets	Considerations
N0-N3	Northern Stock (Hypothesis #1, FAO 2008)	Far north	This considers the hypothesis that the Peruvian and Ecuadorian fishery information come from the same population and it's independent of the southern stock, principally fished by the Chilean fleet.
S1-S2	Southern Stock (Hypothesis #1 and #3, FAO 2008)	Northern Central-South Offshore fleet	This considers the hypothesis that the fishery information from Chile and those international fleets that operate offshore off EEZ Chile come from the same population, whose it's independent of the northern stock, principally fished by the Peruvian fleet.
1-7	A single stock (Hypothesis #2, FAO 2008)	All fleets	This considers the hypothesis that the northern and southern stock correspond to a single population unit.
8	Northern + Southern Stocks (Hypothesis #1 and #3, FAO 2008)	All fleets	This hypothesis considers the northern and southern stocks as separate population units, which are added together to provide estimates for the whole area that are comparable with those of the single stock hypothesis.

Model details

Parameters estimated conditionally are listed in Table A1.7. The most numerous of these involve estimates of annual and age-specific components of fishing mortality for each year from 1970-2012 and each of the four fisheries identified in the model. Parameters describing population numbers at age 1 in each year (and years prior to 1970 to estimate the initial population numbers at ages 1-12+) were the second most numerous type of parameter.

The table of equations for the assessment model is given in Tables A1.8, A1.9 and A1.10.

The treatment of selectivities and how they are shared among fisheries and indices are given in Table A1.11, A1.12 and A1.13. The numbers of parameters for different model configurations were around 350. Also depending on the model configuration, some growth functions were employed inside the model to convert length compositions to age compositions.

Model evaluation

A number of 14 exploratory models were proposed and run for evaluation purposes. After preliminary evaluations, a subset of 3 models (models 6, 7 and 8) was carried forward for presentation. Details of all these models are given in Table A1.14. The coefficient of variation for abundance indices are shown in Table A1.15.

Models 6 and 7 consider the single stock hypothesis and were based on model 1 (new sexual maturity and Peruvian information) and correspond to sensitivity analysis, which focused on evaluating the model response when the stock-recruitment relationship considers the period 2000-2012 (model 6) and when more variability in selectivity is considered (model 7). Model 8 considers the far north and the southern stocks as separate units (the two separate stocks hypothesis) added together. This provides estimates for the whole area under the two stocks hypothesis which are comparable with those of the single stock hypothesis.

A1. References

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A1. Tables

Table A1.3. 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				403	49220			51290	956164
1979	311682	203269	151591		175938	6281	333810			120					356271	12719		369110	1217871
1980	266697	215528	123380		252078	38841	414299								292892	45130		338022	1234546
1981	435061	440935	37875		371981	35783	445639			29					399649	38444		438122	1759757
1982	756484	643821	50013		84122	9589	143724								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	35108	137033	3386	316247			701					854020	21100		875821	3488987
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
1999	44582	1130488	184679	19072			203751			7								7	1378828
2000	107769	1135082	296579	7122			303701				2318							2318	1548870

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
2001	244019	1216754	723733	134011			857744				20090							20090	2338607
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	74694	19834			94528	5681	13326	0	117963	111921	20213	13759	9113		79942	371918	1301373
2010	169010	295681	17559	4613			22172	2240	40516	0	63606	67749	11643	8183	0		45908	239845	726708
2011	23945	194532	257241	69153			326394	0	674	0	32862	2248	0	9253	8229	8	7672	60946	605817
2012	12000	208403	168779	104			168883	0	2996	0	10797	0	0	5492	0	0	8746	28031	417317

Underlined figures have been updated.

2012 data are preliminary and reflect the best estimates for the year.

Table A1.4. Jack mackerel sexual maturity by age used in the JMM models.

Age (yr)	1	2	3	4	5	6	7	8	9	10	11	12
Southern Stock	0.07	0.31	0.72	0.93	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
Far North Stock	0.00	0.37	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table A1.5. Growth parameters and natural mortality.

Parameter	Far North stock	South Stock
L_∞ (cm) (Total length)	80.77	n/e
k	0.16	n/e
to (year)	-0.356	n/e
M (year-1)	0.33	0.23

n/e: not employed

Table A1.6. 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	1975-2012	-	1970-2012	-	1984-1988; 1991; 2006-2009	1999-2008
South-central Chile purse seine	1975-2012	-	1970-2012	1982-2011	1997-2009	-
FarNorth	-	1980-2011	1970-2012	1996-2009, 2011	1983-2011	-
International trawl off Chile	1979-1991	2007-2011	1978-2012	China (2001-2012); EU & Vanuatu (2003-2011); Russian (1987-1991, 2008-09, 2011)	-	-

Table A1.7. Symbols and definitions used for model equations.

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: i = {1970, …., 2012}	i	
Age index: j = { 1,2,…, 12$^+$}	j	
length index: l = { 10,11,…, 50}	l	
Mean length at age	L_j	
Variation coefficient the length at age	cv	
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
Proportion of length at some age	Γ	Transform from age to length
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 A1.8. 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	$I_i^s = q^s \sum_{j=1}^{12} N_{ij} W_{ij} S_j^s e^{-\Delta^s Z_{ij}}$
2)	Catch biomass by year and age/length	$\hat{C}_{il}, \hat{C}_{ij}$	$\hat{C}_{ij}^f = \sum_{j=1}^{12} N_{ij} W_{ij} \frac{F_{ij}^f}{Z_{ij}} (1 - e^{-Z_{ij}})$ $\hat{C}_{il} = \Gamma_{l,j} \hat{C}_{ij}$ $\Gamma_{l,j} = \int_j^{j+1} e^{-\frac{1}{2\sigma_j^2}(l - L_j)^2} dl$ $L_j = L_{00}(1 - e^{-k}) + e^{-k} L_{j-1}$ $\sigma_j = cv\, L_j$
3)	Proportion at age j, in year i	$P_{ij}, \sum_{j=1}^{12} P_{ij} = 1.0$	$p_{ij}^f = \frac{\hat{C}_{ij}^f}{\sum_j \hat{C}_{ij}^f}$ $p_{ij}^s = \frac{N_{ij} S_j^s e^{-\Delta^s Z_{ij}}}{\sum_j N_{ij} S_j^s e^{-\Delta^s Z_{ij}}}$
	Proportion at length l, in year i	$P_{il}, \sum_{l=10}^{50} P_{il} = 1.0$	$P_{il} = \frac{C_{il}}{\sum_{l=10}^{50} C_{il}}$
4)	Initial numbers at age	j = 1	$N_{1970,j} = e^{\mu_R + \varepsilon_{1970}}$
5)		1 < 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 = 1	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
8)		1 < 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 1 and i = 1958, …, 2012	$\varepsilon_i, \sum_{i=1958}^{2012} \varepsilon_i = 0$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
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	$\eta_j^s, \sum_{i=1958}^{2012} \eta_j^s = 0$	$s_j^s = e^{\eta_{\text{maxage}}^s}$ $j > \text{maxage}$
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	$\varphi_i, \sum_{i=1970}^{2012} \varphi_i = 0$	
15)	age effect of fishing (regularized) In year time variation allowed	$\eta_j^f, \sum_{i=1958}^{2012} \eta_j^f = 0$	$s_{ij}^f = e^{\eta_j^f}$, $j \le \text{maxage}$ $s_{ij}^f = e^{\eta_{\text{maxage}}^f}$ $j > \text{maxage}$
	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	fixed

Eq	Description	Symbol/Constraints	Key Equation(s)
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	$B_i=\sum_{j=2}^{12} N_{ij}e^{-\frac{10,5}{12}Z_{ij}}W_{ij}p_j$
18)	Recruitments (Beverton-Holt form) at age 2.	$\tilde{R}_i$	$\tilde{R}_i=\frac{\alpha B_t}{\beta+B_i}$, $\alpha=\frac{4hR_0}{5h-1}$ and $\beta=\frac{B_0(1-h)}{5h-1}$ where h=0.8 $B_0=R_0\varphi$ $\varphi=\sum_{j=1}^{12}e^{-M(j-1)}W_j p_j+\frac{e^{-12M}W_{12}p_{12}}{1-e^{-M}}$

Table A1.9. 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	$L_2=\sum_l \lambda_2^l \sum_{j=1}^{12}\left(\eta_{j+2}^l+\eta_j^l-2\eta_{j+1}^l\right)^2$	Smoothness (second differencing), Note: *l={s,* or *f}* for survey and fishery selectivity
21)	Prior on recruitment regularity	$L_3=\lambda_3\sum_{i=1958}^{2012}\varepsilon_i^2$	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	$L_4=\sum_f \lambda_4^f \sum_{i=1970}^{2012}\log\left(\frac{C_i^f}{\hat{C}_i^f}\right)^2$	Fit to catch biomass in each year
23)	Proportion at age/length likelihood	$L_5=-\sum_{v,i,j} T^v P_{i,j/l}^v \log(\hat{P}_{i,j/l}^v)$	*v={s, f}* for survey and fishery age composition observations $P_{i,j/l}$ are the catch-at-age/length proportions
24)	Fishing mortality regularity	F values constrained between 0 and 5	(relaxed in final phases of estimation)
25)	Recruitment curve fit	$L_6=\lambda_6\sum_{i=1977}^{2012}\log\left(\frac{N_{i,1}}{\tilde{R}_i}\right)^2$	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 A1.10. Lambda values used on log-likelihood functions in the base model.

s	Abundance index	$\lambda^{s\ (1)}$	*f*	Catch biomass likelihood	$\lambda^{f\ (1)}$
1	Acoustic CS- Chile	12.5	1	N-Chile	200
2	Acoustic N-Chile	2	2	CS- Chile	200
3	CPUE – Chile	21.9	3	Peru	200
4	DEPM – Chile	2.0	4	International	200
5	Acoustic-Peru	12.5	5	ex USSR	200
6	CPUE – Peru	12.5			
7	CPUE- China	12.5			
8	CPUE-EU	12.5			
9	CPUE- ex USSR	3.1			

s	Smoothness for selectivities	$\lambda^{s\ (1)}$	*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	$\lambda^{f\ (1)}$	*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

	Recruitment regularity	$\lambda^{(1)}$		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 A1.11. Description of JJM model components and how selectivity was treated (Far North Stock).

Item	Description	Selectivity assumption
Fisheries		
1)	Peruvian and Ecuadorian area fishery	Estimated from length composition data (converted to age inside the model). Two time-blocks were considered, before and after 2002.
Index series		
2)	Acoustic survey in Peru	All age groups are available (without selectivity)
3)	Peruvian fishery CPUE	Assumed to be the same as 1)

Table A1.12. Description of JJM model components and how selectivity was treated (South stock).

Item	Description	Selectivity assumption
Fisheries		
1)	Chilean northern area fishery	Estimated from age composition data. Two time-blocks were considered 1970-1986; 1987-2012.
2)	Chilean central and southern area fishery	Estimated from age composition data. Four time-blocks were considered 1970-1987; 1988-1992; 1993-2003; 2004-2012.
3)	Recent offshore trawl fishery and	Estimated from age composition data. Two time-blocks were considered 1970-1995; 1996-2012.
4)	Ex-USSR trawl fishery	Estimated from historical age composition data as 3)
Index series		
6)	Acoustic survey in central and southern Chile	Estimated from age composition data. Two time-blocks were considered 1970-2004; 2005-2012.
7)	Acoustic survey in northern Chile	Assumed to be the same as 1)
8)	Central and southern fishery CPUE	Assumed to be the same as 2)
9)	Egg production survey	Estimated from age composition data. Two time-blocks were considered 1970-2002; 2003-2012.
10)	Chinese fleet CPUE (from FAO workshop)	Assumed to be the same as 3)
11)	Vanuatu & EU fleets CPUE	Assumed to be the same as 3)
12)	ex-USSR CPUE	Assumed to be the same as 3) but for earlier period

Table A1.13. Description of JJM model components and how selectivity was treated for the single stock cases.

Item	Description	Selectivity assumption
Fisheries		
1)	Chilean northern area fishery	Estimated from age composition data. Two time-blocks were considered 1970-1986; 1987-2012.
2)	Chilean central and southern area fishery	Estimated from age composition data. Four time-blocks were considered 1970-1987; 1988-1992; 1993-2003; 2004-2012.
3)	Peruvian and Ecuadorian area fishery	Estimated from length composition data (converted to age inside the model). Two time-blocks were considered, before and after 2002.
4)	Recent offshore trawl fishery and	Estimated from age composition data. Two time-blocks were considered 1970-1995; 1996-2012.
5)	Ex-USSR trawl fishery	Estimated from historical age composition data as 2)
Index series		
6)	Acoustic survey in central and southern Chile	Estimated from age composition data. Two time-blocks were considered 1970-2005; 2006-2012.
7)	Acoustic survey in northern Chile	Assumed to be the same as 1)
8)	Central and southern fishery CPUE	Assumed to be the same as 2)
9)	Egg production survey	Estimated from age composition data. Two time-blocks were considered 1970-2004; 2005-2012.
10)	Acoustic survey in Peru	All age groups are available (without selectivity)
11)	Peruvian fishery CPUE	Assumed to be the same as 3)
12)	Chinese fleet CPUE (from FAO workshop)	Assumed to be the same as 4)
13)	Vanuatu & EU fleets CPUE	Assumed to be the same as 4)
14)	ex-USSR CPUE	Assumed to be the same as 4) but for earlier period

Table A1.14. Particular specifications for the different models applied.

Model	Description
1	New maturity, new Peruvian CPUE, wt-at-age for Peru and Peruvian growth curve estimates
2	Use new Peruvian acoustic index
3	Model 1 but M average between regions (0.28)
4	Model 2 but M average between regions (0.28)
5	Model 4 but early stock recruitment period (1970-1999)
6	Model 4 but recent stock recruitment period (2000-2012)
7	Model 1 but with changes in selectivity to better match mean ages observed (more variability in selectivity)
8	Addition of model N3 + S2.
Far North stock	
N0	Original acoustic
N1	Original acoustic, lognormal prior on q=1, sigma=0.15
N2	As N1 but new acoustic
N3	Fix q=1 for new Peru acoustic survey and shift in M to reflect natural mortality change in 2000.
South stock	
S1	As Model 1
S2	As with Model 7

Table A1.15. Coefficients of variations considered on the base case

Index	No. years	cv
Acoustic Chile CS	13	0.2
Acoustic Chile N	10	0.5
CPUE Chile	30	0.2
DEPM Chile	9	0.5
Acoustic Peru	26	0.2
CPUE Peru	10	0.2
CPUE China	11	0.2
CPUE Vanuatu & EU	9	0.2
CPUE USSR	8	0.4

A2. Attachment to SWG-03: Results from final selected models for the 2012 Jack mackerel stock assessment

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

Assessment model results

During the meeting a series of alternatives were examined. To evaluate these, the negative-log likelihood components were presented to evaluate trade-offs between different data components and model assumptions. For comparison purposes, the minimum value over all models for each component was subtracted to ease evaluation (Table A2.1 and A2.2). It is important to note that some values in this table for some subsets of models cannot be compared across models because some models introduce new data (i.e., the revised acoustic survey index for Peru). Also, comparison between models 1-7 (single stock hypothesis) and model 8 (two stock hypothesis) can be carried out just when the same data is used. The same restriction applies to the comparisons between sub-models (for far north and south stocks) in the assessment under the “two stock” hypothesis.

Results show that including the revised Peruvian acoustic data improves the fit to other data components compared to the base model which indicates some consistency—e.g., the age composition data. When natural mortality is increased from 0.23 to 0.28 the fit is improved further (Model 4). Model 6 which is the same as Model 4 but recognizes a regime shift for latest 12 years in fitting the stock recruitment relationship results in further improvements. Among the models which use the original acoustic survey data, Model 7 resulted in the best fit. The analysts recognized that even better alternative specifications were likely, but due to time constraints they could not be pursued.

For the models using the two stock hypothesis, an improvement of the fit of the different data components was observed inside the regional sub-models (south and far north) and also an improvement in the fit when considered the integration of the sub-models (Model 8).

Model 8 (results of two stock hypothesis model, south and far north added together) was run and results are similar (intermediate to Model 6 and 7). The WG was instructed to consider alternative stock structure options. They were encouraged by this investigation and look forward to future developments, including alternative fine-scale modelling approaches. It was noted that this model relies on the revised acoustic survey index which had not been adequately reviewed. Nonetheless, since Model 6 also uses the new acoustic index, it was considered not inappropriate to carry Model 8 forward for advice (since scientific reservations and doubts exist with all models). Data for these models are shown in Tables A2.3-A2.10

For an example of fitting performance, Model 7 was used (noting the differences in these estimates for spawning biomass, Fig. A2.12). Based on this, the fishery catch fits are shown in Figure A2.13 and mean weight-at-age assumed for this model is shown in Figure A2.14. The model numbers-at-age estimates are given in Table A2.11. The fishery age and length composition fits are shown in Figures A2.15, A2.16, A2.17, and A2.18. This (and all other) models fit some indices better than others (Figure A2.19). Fits to the index and fishery mean age compositions are shown in Figures A2.20, and A2.21. Selectivity estimates for the fishery and indices is shown over time in Figs. A2.22 and A2.23 respectively. Residuals to the indices and age compositions are presented in Fig. A2.24 and to length composition fits (in Fig. A2.25). A summary of the time series stock status (spawning biomass, F, recruitment, total biomass) is shown in Fig. A2.26. The immature component of the stock appears to be increasing in since about 2008 and the mature component of the stock has also begun to show signs of stabilization and possibly an increase (Fig. A2.27). Fishing mortality rates have remained relatively high since about 1992 but shows some declines in the past few years (Fig. A2.28; Table A2.12.). The stock recruitment relationship appears to be consistent with the fixed value of steepness assumed (0.8; Fig. A2.29). In order to evaluate the potential for alternative "regimes", stock recruitment curves were estimated over different periods and found that within the current period (2000-2012) the level of expected recruitment was considerably lower than the alternatives (Fig. A2.30).

Projections and risk analysis

Considering the actual population status of jack mackerel, the subgroup recommended examining constant fishing mortality scenarios with current levels (F_{2012}) and at 75%, 50%, 25%, and 0% (no catch). The recruitments were projected considering a stock-recruitment relationship adjusted from 2000 to 2012, which represents a low productivity period that has characterized the population condition in the most recent years (Figure A2.30). The uncertainty was measured considering the probability to reduce the spawning biomass in the next 10 yrs (approximated by propagating process—i.e., recruitment variability) and parameter errors forward within the assessment model). As a tentative risk criterion, the sub-group selected an acceptable fishing level that would be robust over the alternative models evaluated while ensuring with high probability (>90%) that future spawning biomass would rebuild from 2012 levels.

Projection results indicate that effort should be maintained at or below 2012 levels to improve the likelihood of spawning biomass increasing. This results in catches for 2013 on the order of 441 kt or lower. Fishing effort in the next 10 years at or below current (2012) levels are projected to have a high probability of resulting in spawning stock increases under most projections (Figure A2.31).

A2. Figures

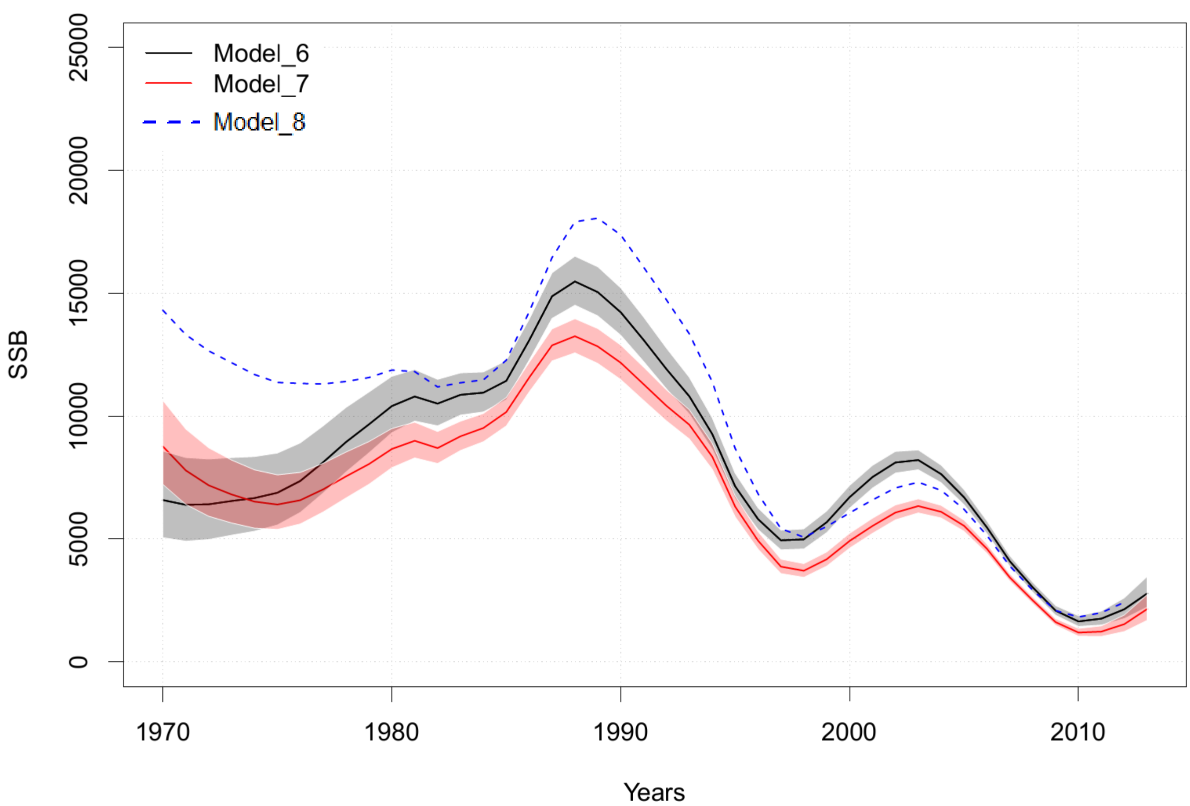

Figure A2.1. Spawning biomass estimates (t) comparing model configurations 6, 7, and 8.

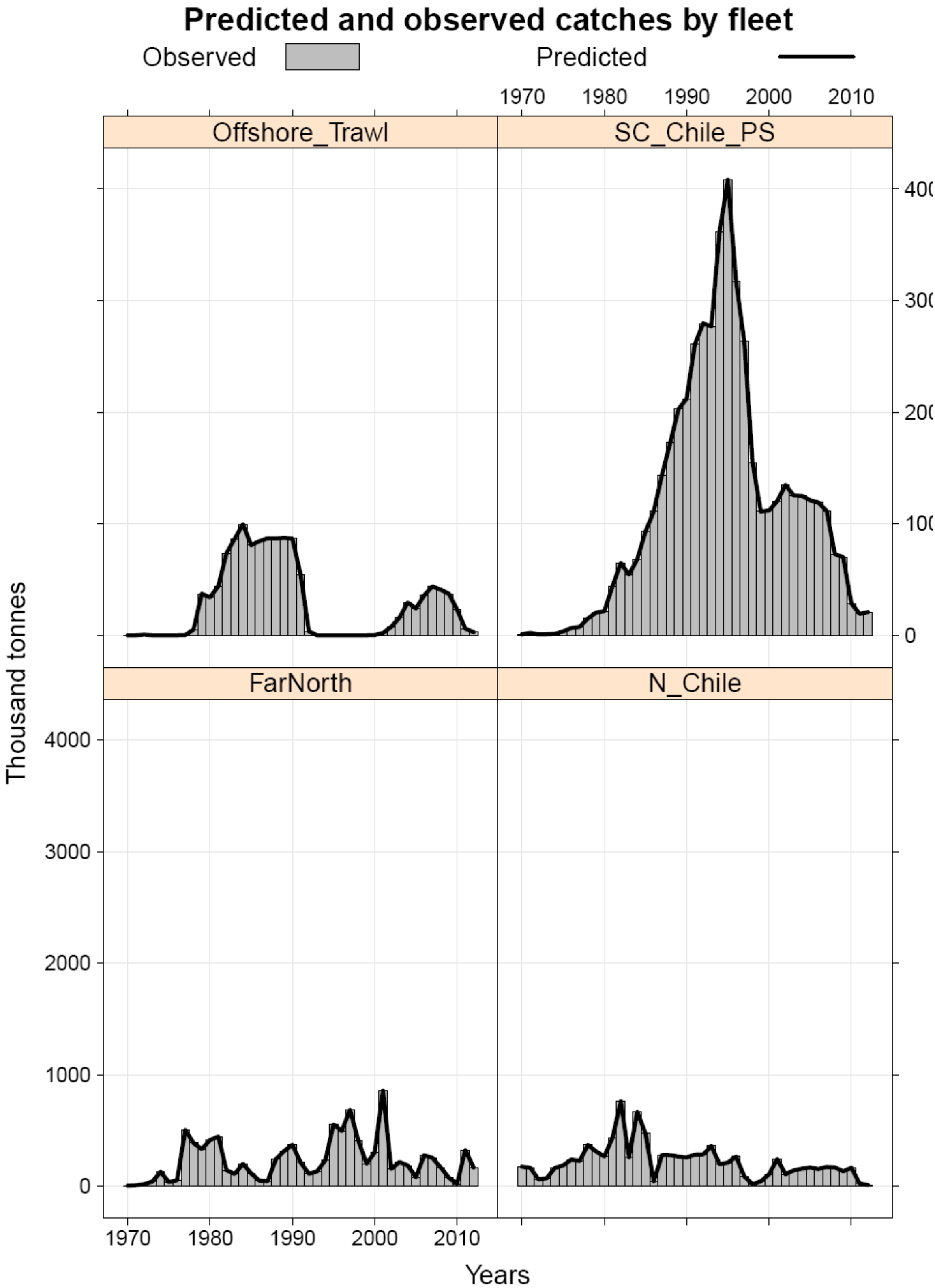

Figure A2.2. JJM Model fit to the total catches ('000 tonnes) by fleet for Fleet 1 (N_Chile_PS), Fleet 2 (SC_Chile_PS), Fleet 3 (Far_North) and Fleet 4 (Offshore_Trawl). The bars represent the observations and the line represents the predicted values.

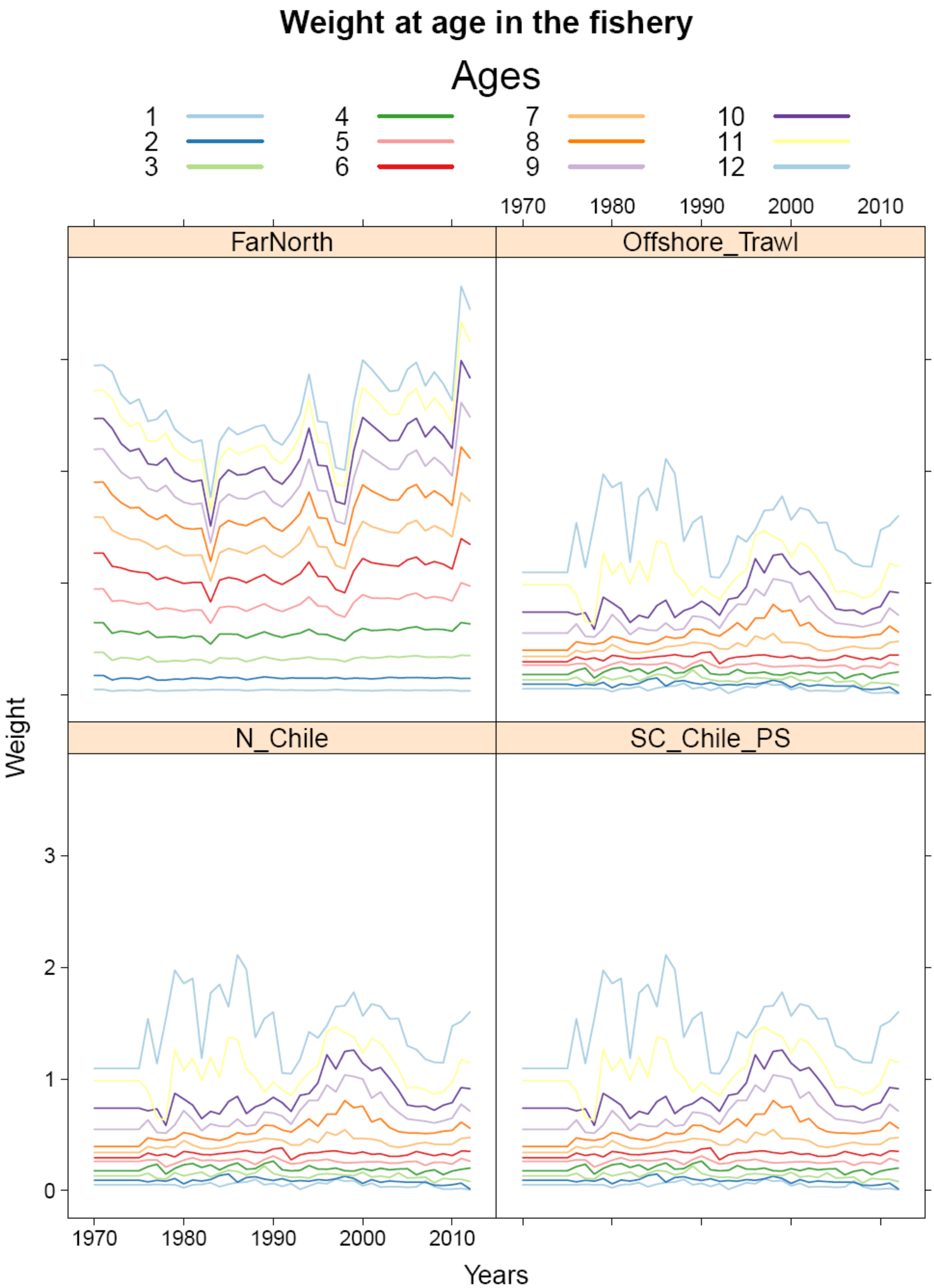

Figure A2.3. Mean weights-at-age (kg) over time used for all data types in the JJM models. Different lines represent ages 1 to 12. Note that the values provided for the “FarNorth” fleet were developed during SWG-11 and used for all of the models (including those for which far north was treated as a separate stock.

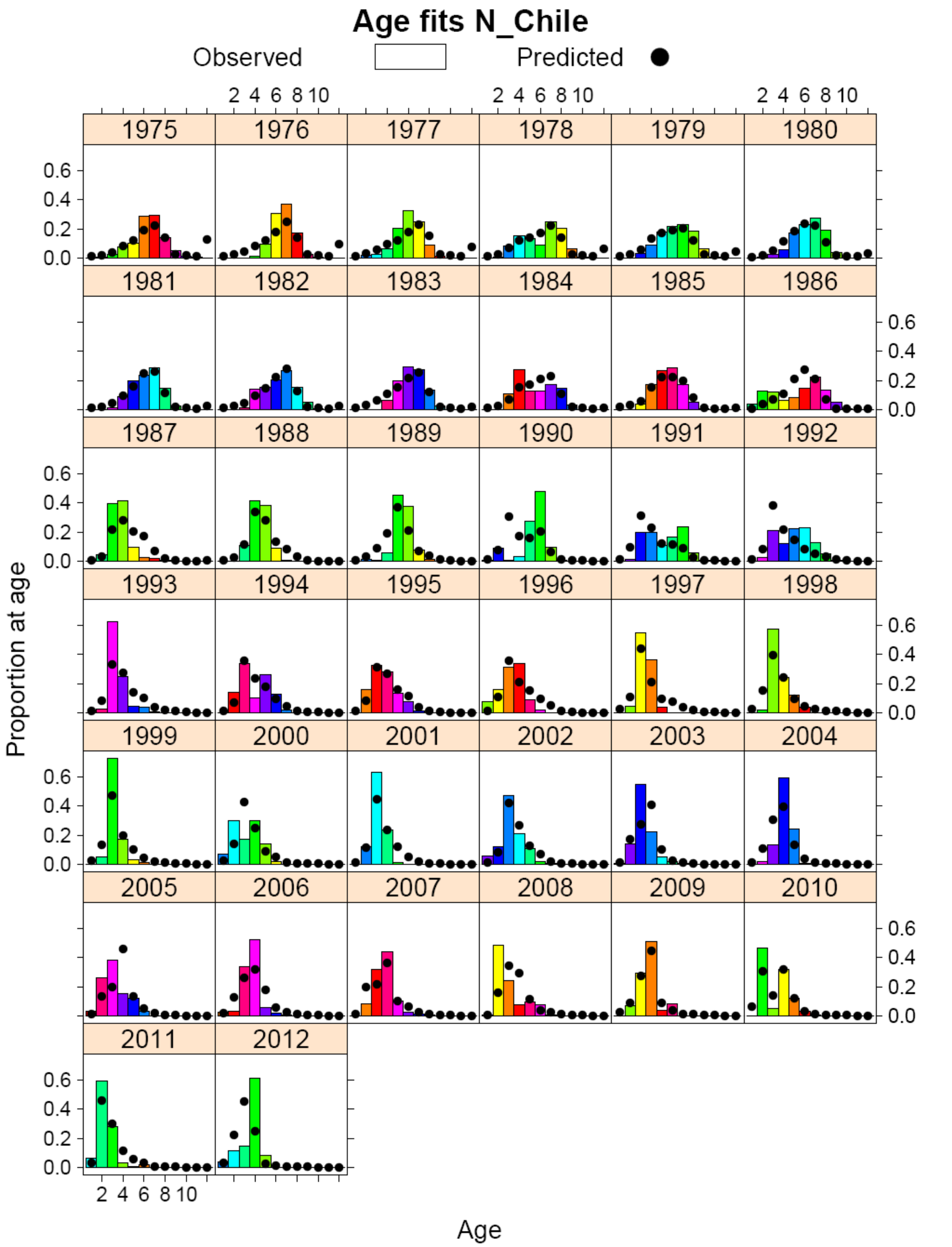

Figure A2.4. Model fit (model 7) to the age compositions for the **Chilean northern zone fishery (Fleet 1)**. Bars represent the observed data and dots represent the model fit and color codes correspond to cohorts.

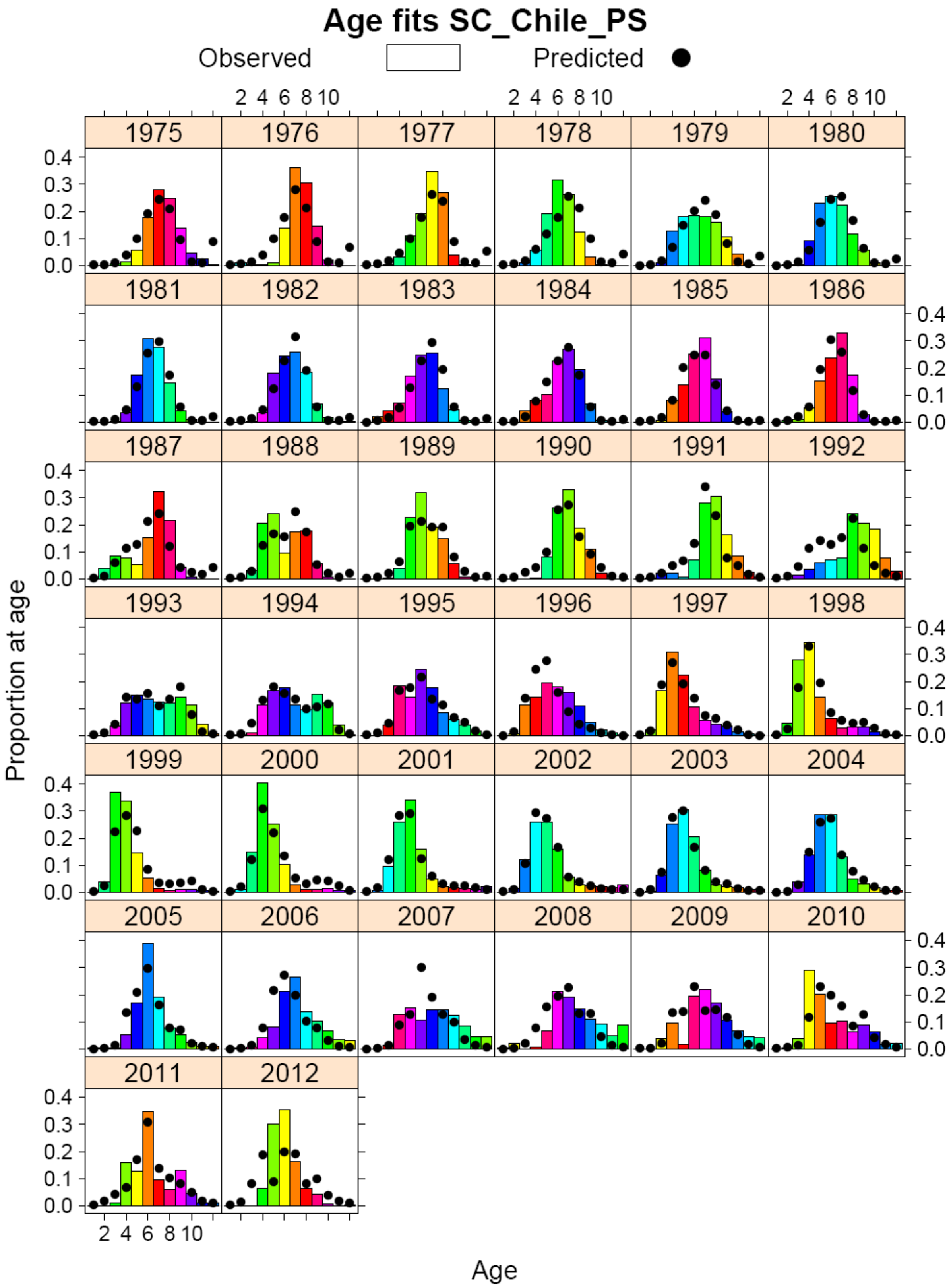

Figure A2.5. Model fit (model 7) to the age compositions for the **South-Central Chilean purse seine** fishery (Fleet 2). Bars represent the observed data and dots represent the model dfit and color codes correspond to cohorts.

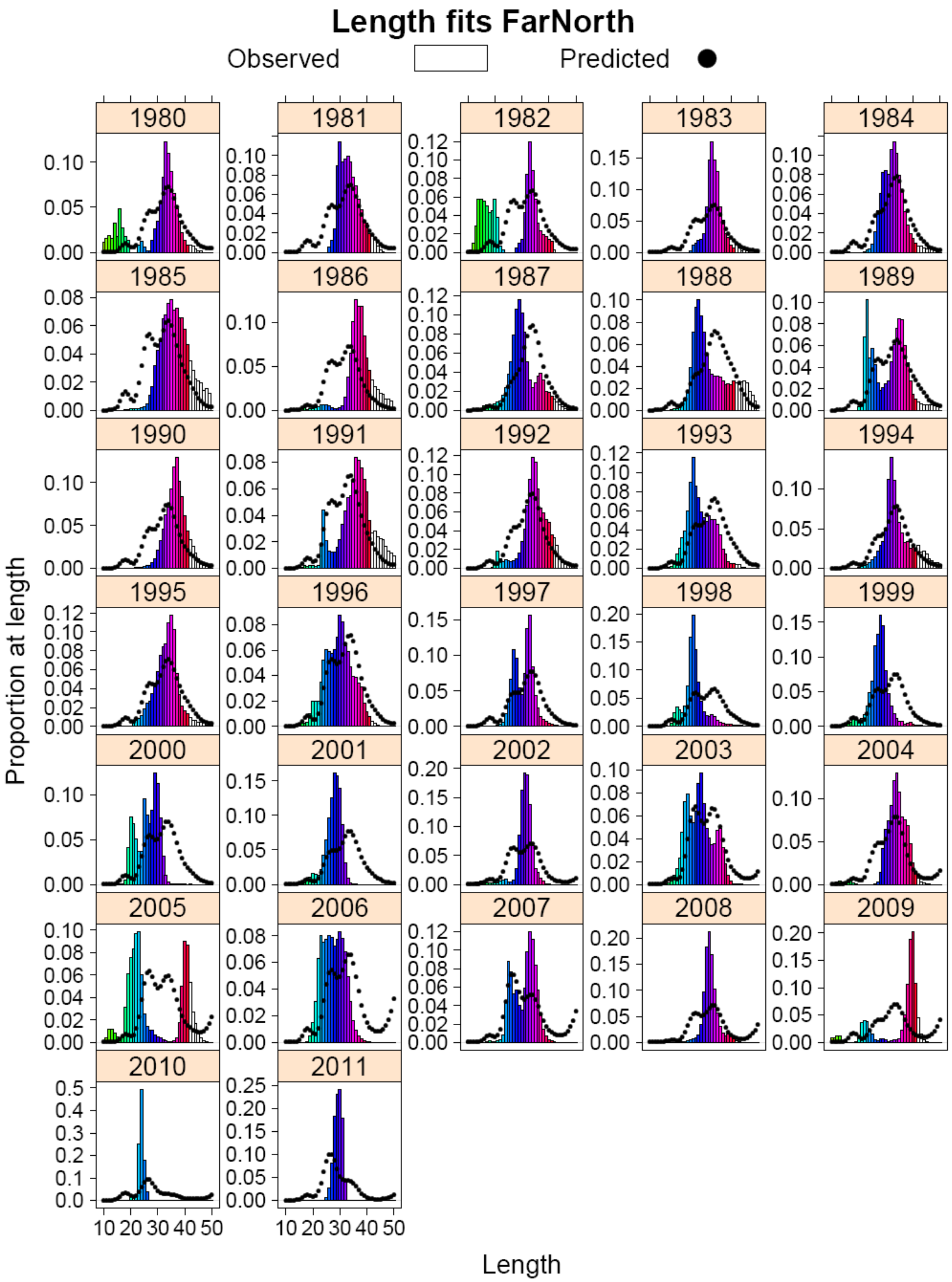

Figure A2.6. Model fit (model 7) to the length compositions for the far north fishery (Fleet 3). Bars represent the observed data and dots represent the model fit and color codes correspond to cohorts.

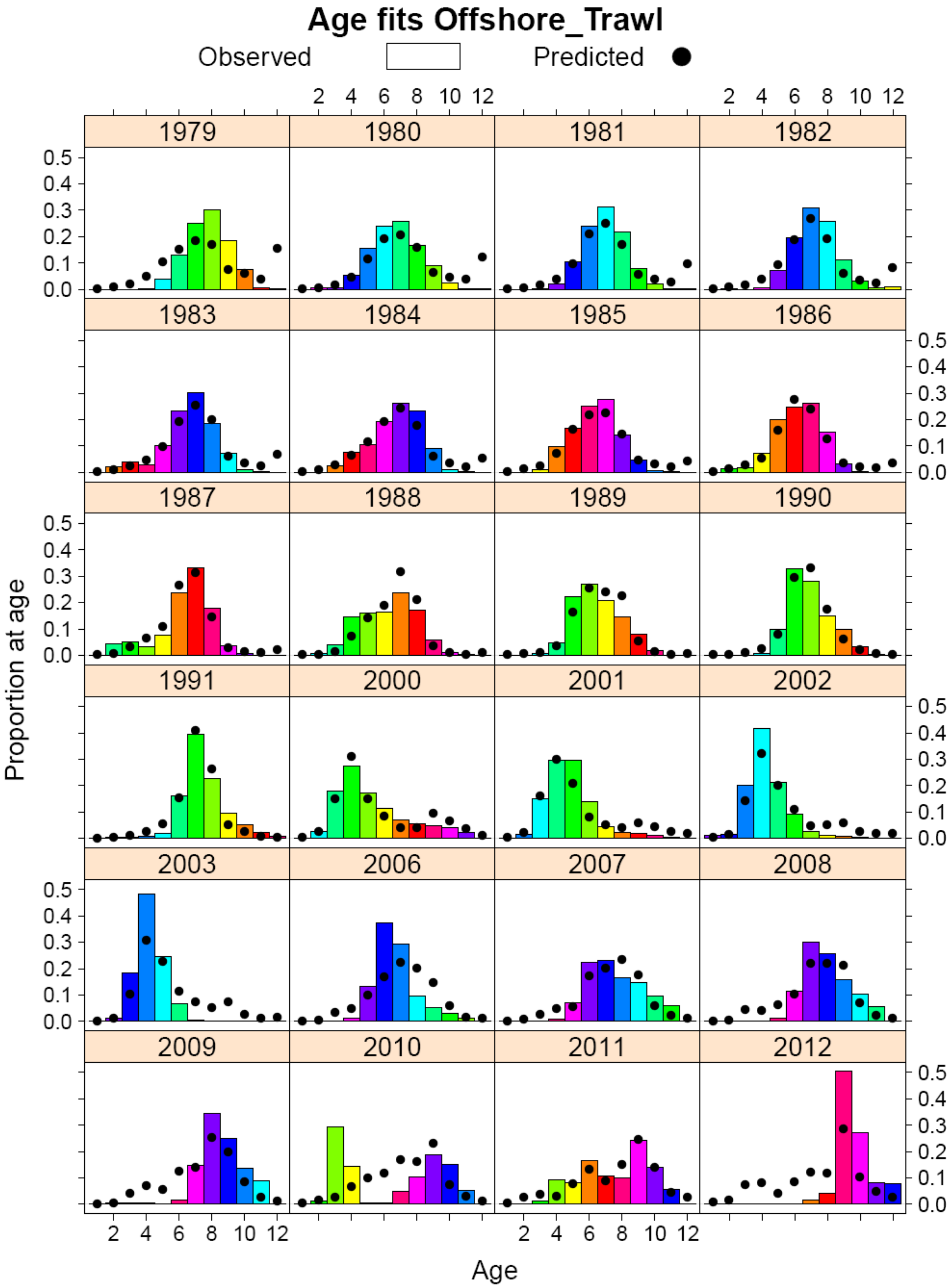

Figure A2.7. Model fit (model 7) to the age compositions for the **offshore trawl** fishery (Fleet 4). Bars represent the observed data and dots represent the model fit and color codes correspond to cohorts.

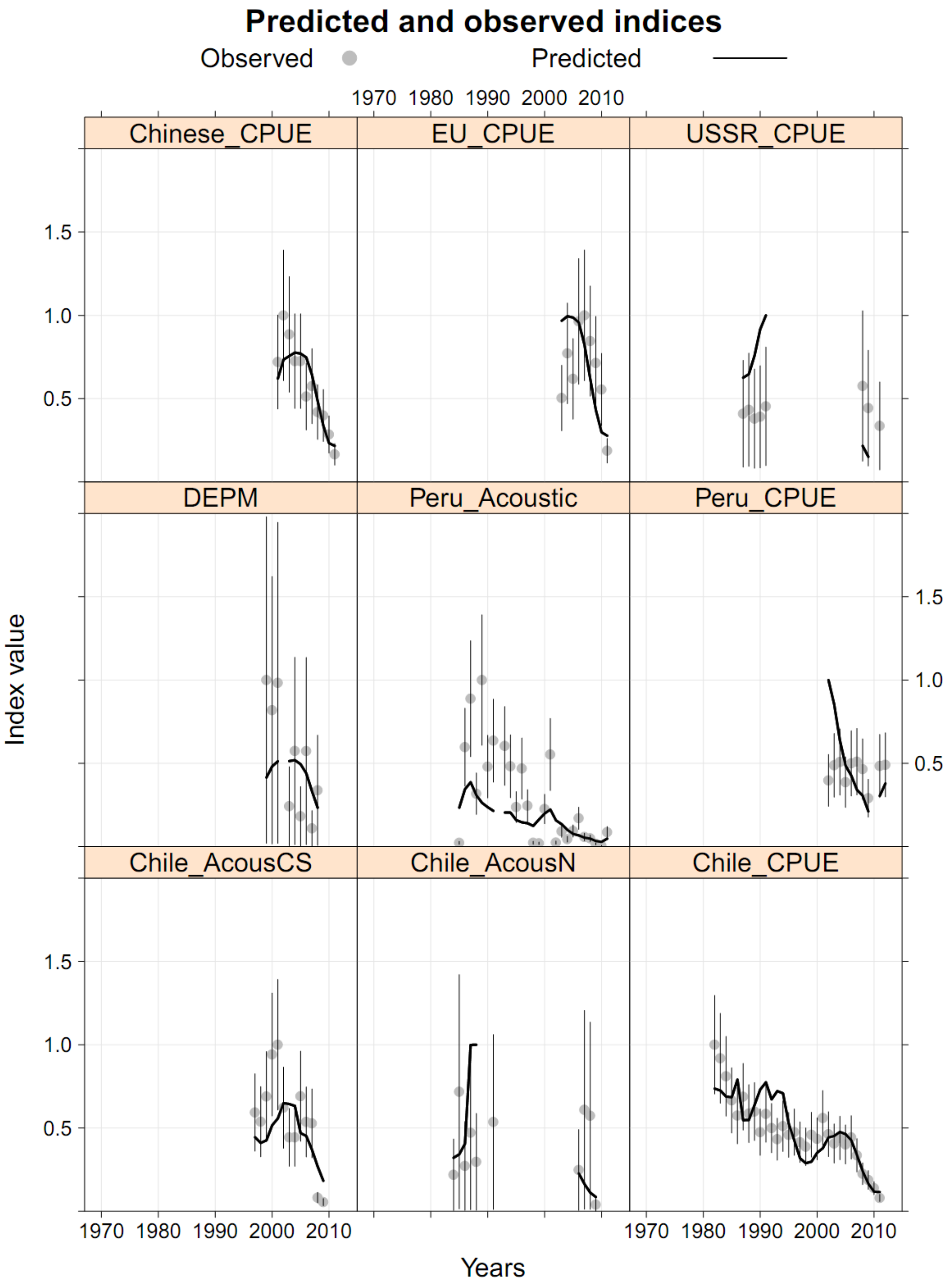

Figure A2.8a. Model fit (model 6) to different indices. Vertical bars represent 2 standard deviations around the observations.

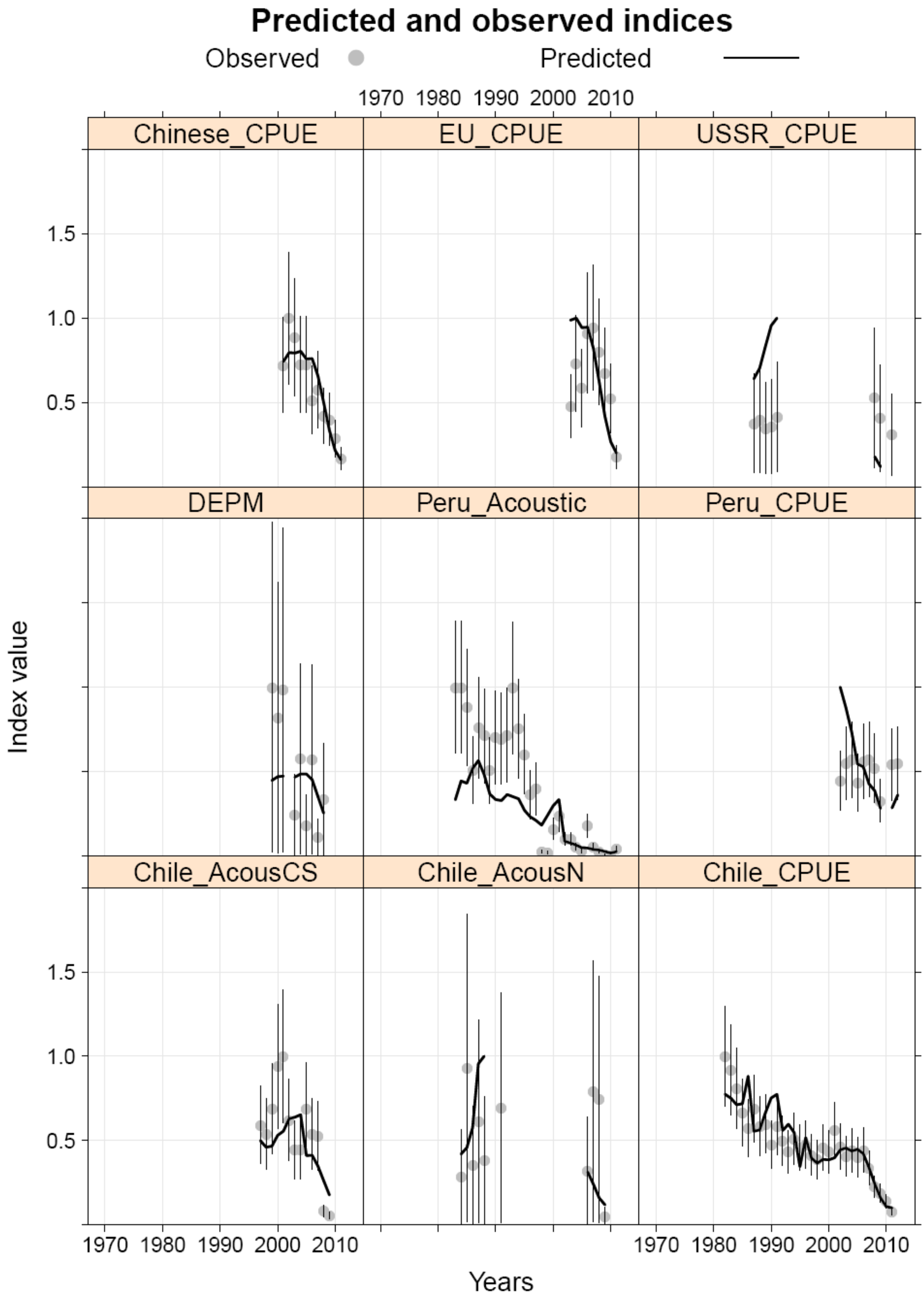

Figure A2.8b. Model fit (model 7) to different indices. Vertical bars represent 2 standard deviations around the observations.

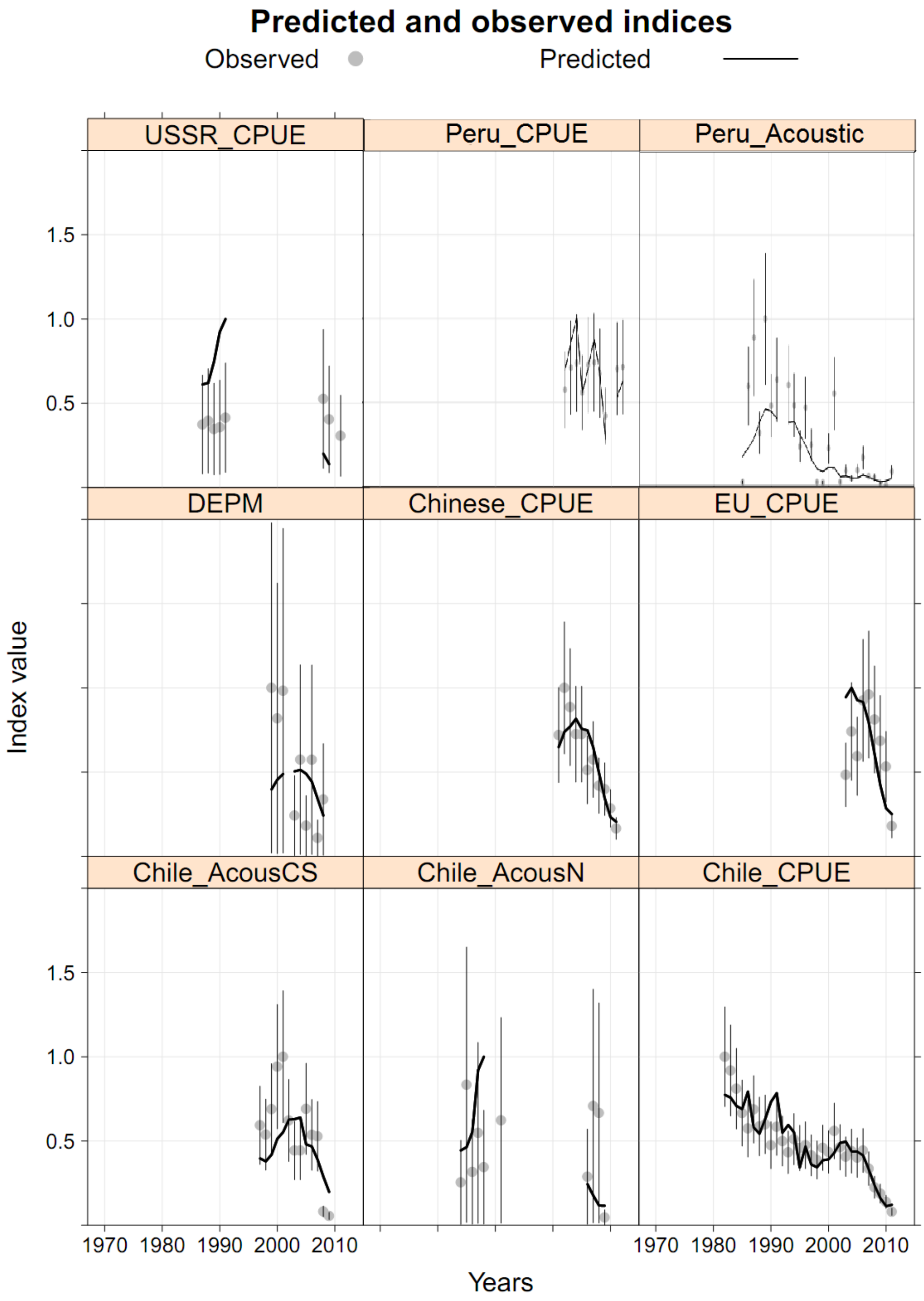

Figure A2. 8c. Model fit (models N3 and S2) to different indices . Vertical bars represent 2 standard deviations around the observations. This scenario represents the named "Model 8"

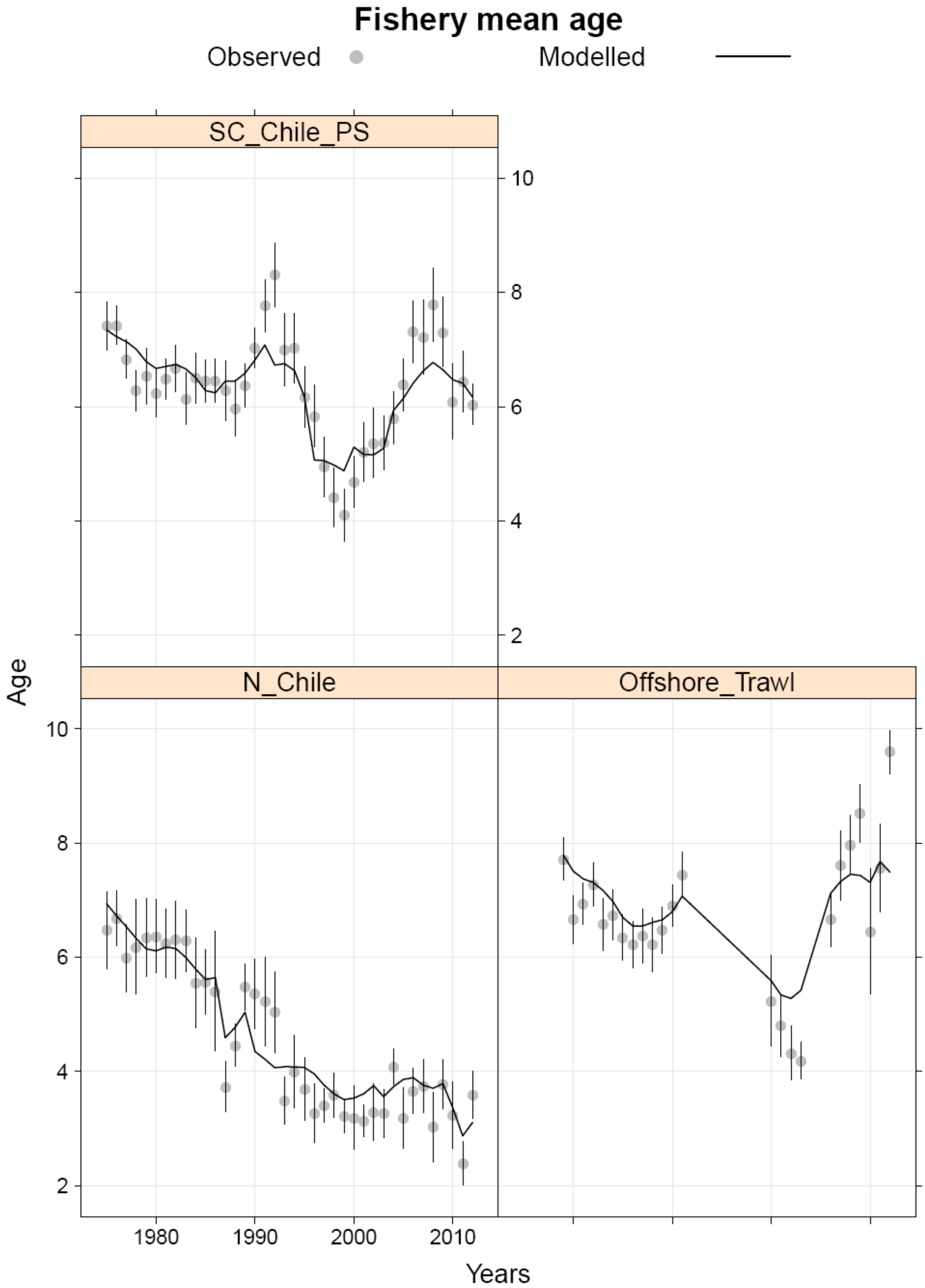

Figure A2.9. Mean age by year and fishery. Line represents the model and dots the observed values.

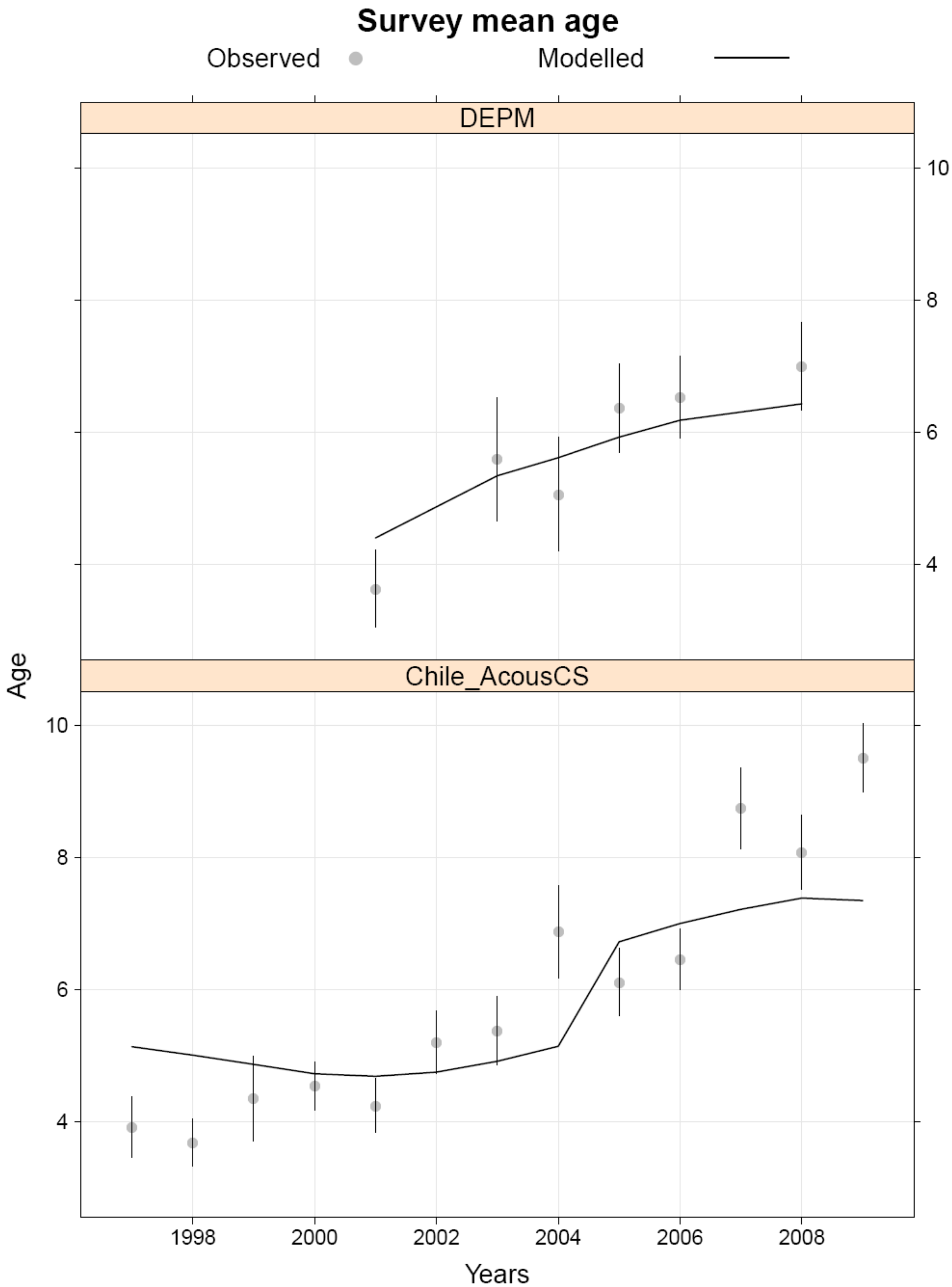

Figure A2.10. Mean age by year and survey. Line represents the model and dots the observed values.

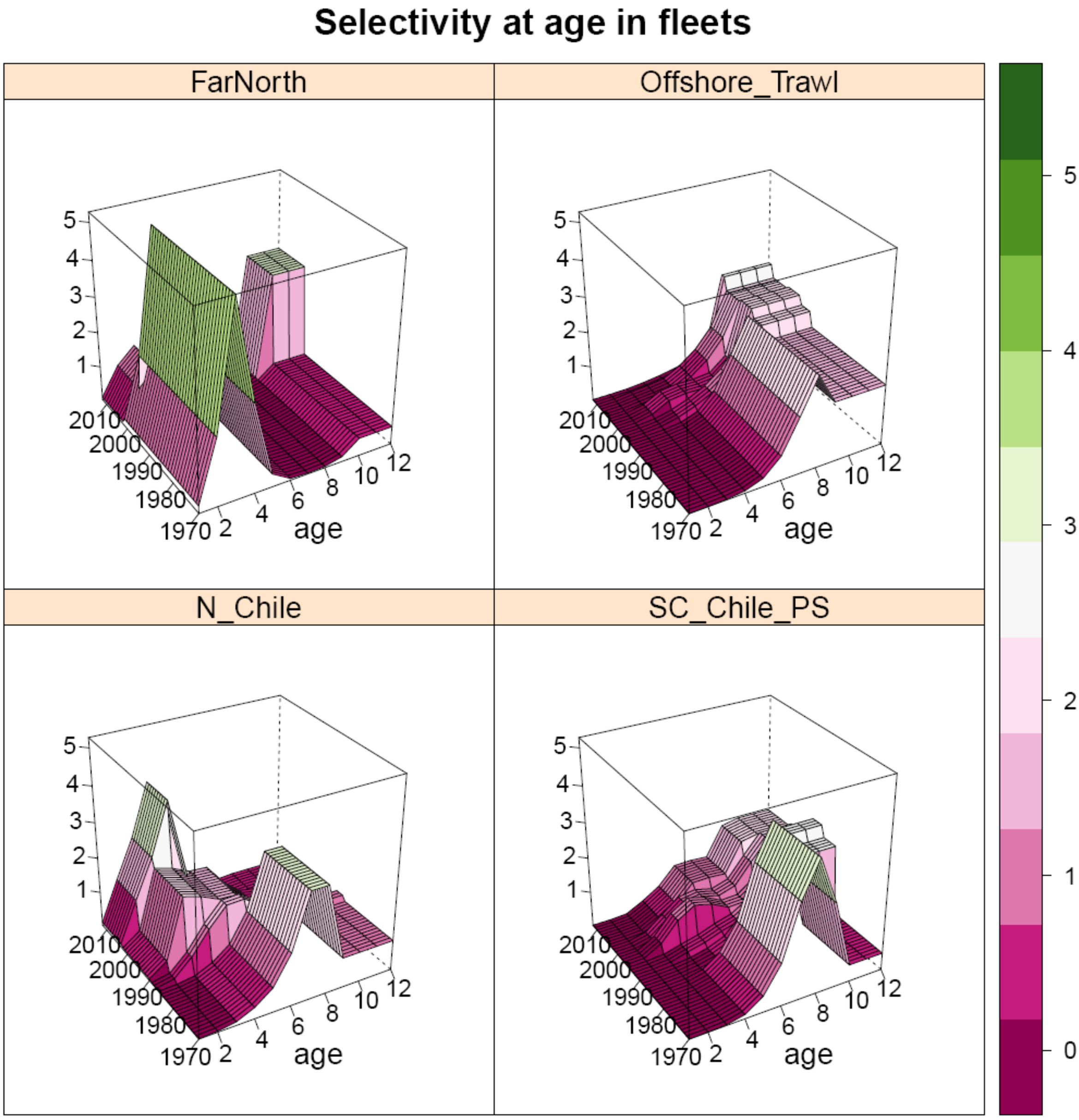

Figure A2.11. Estimates of selectivity by fishery over time.

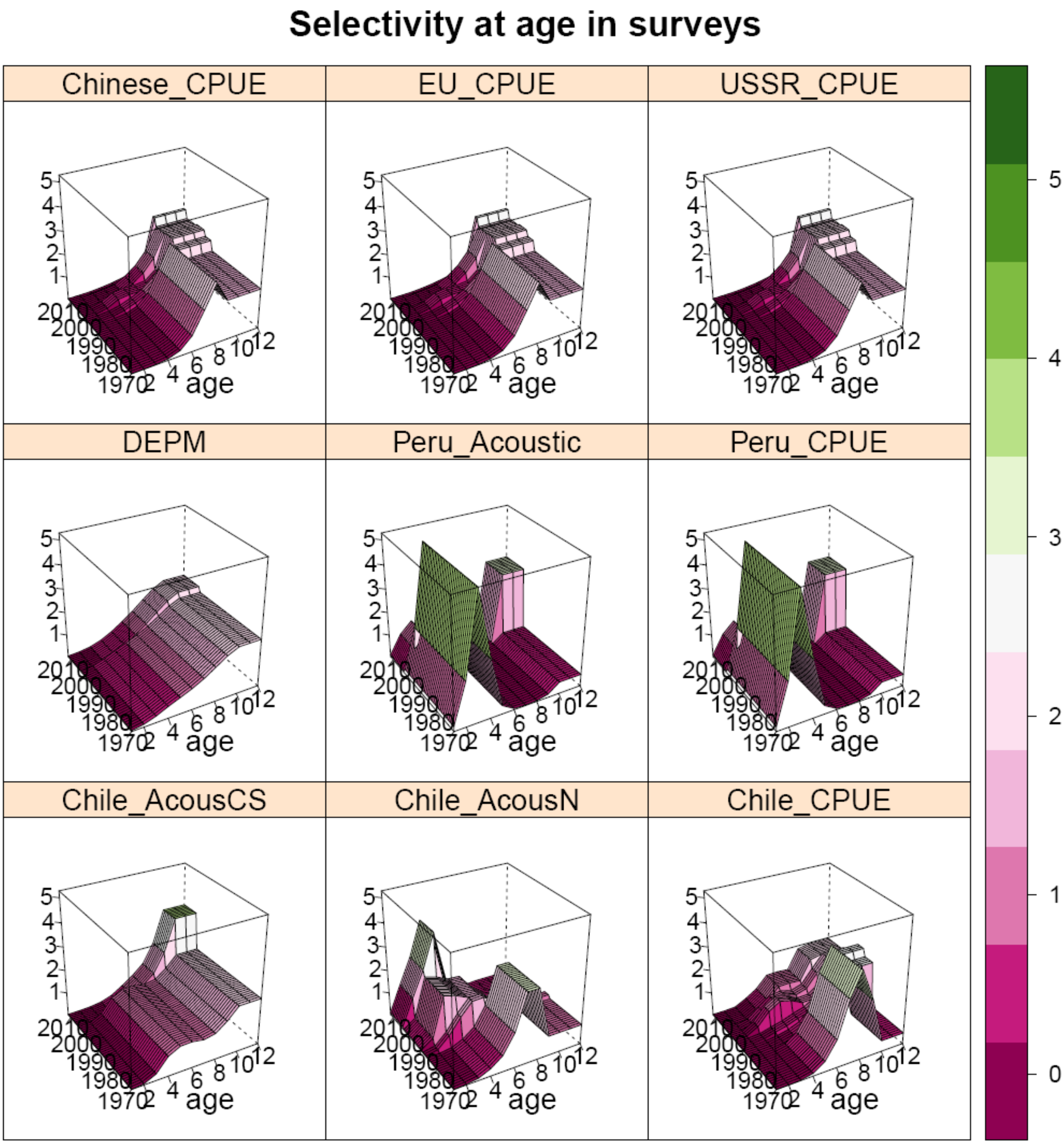

Figure A2.12. Base case (model 1) estimates of selectivity for each index over time.

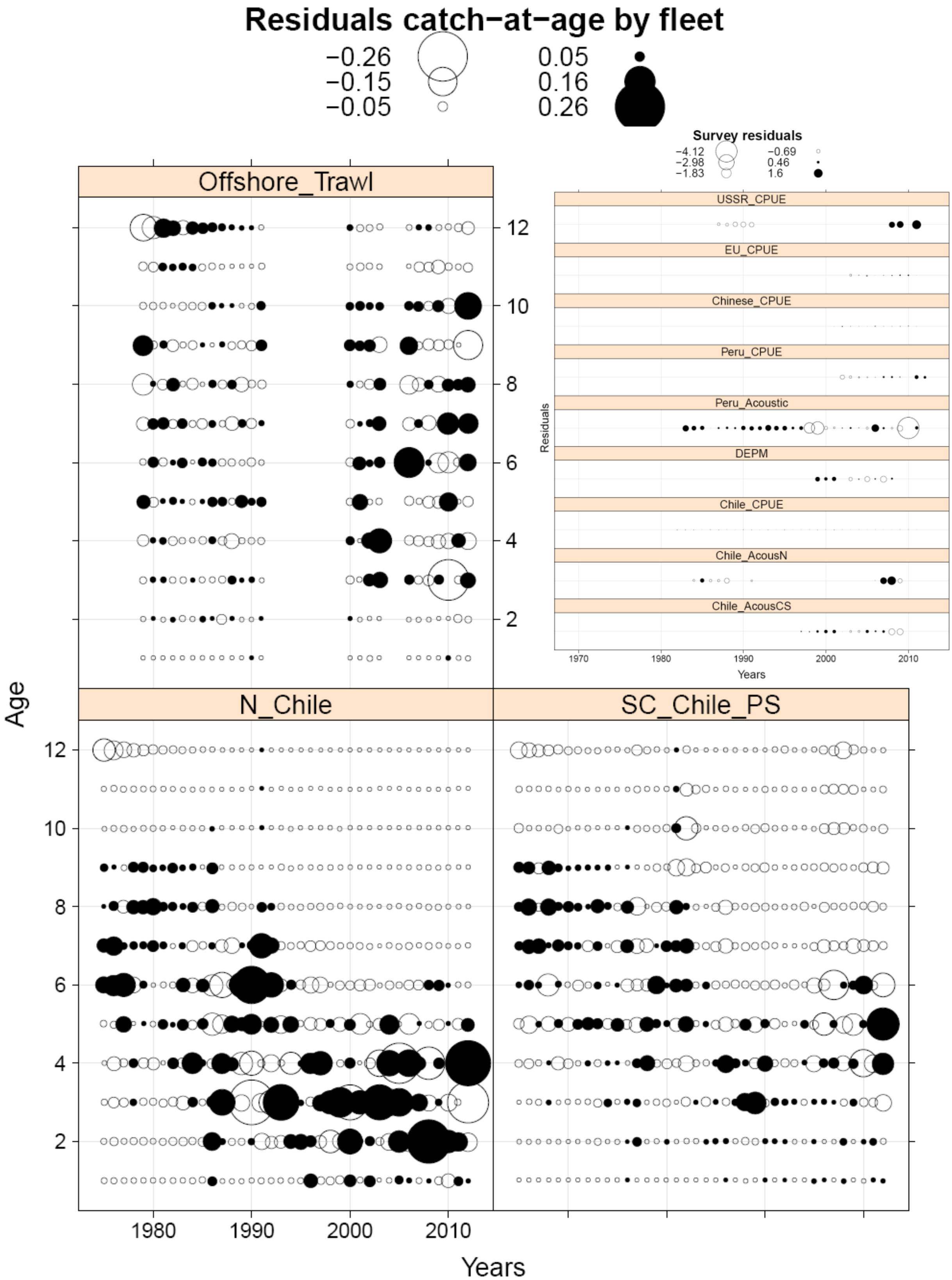

Figure A2.13. Logged residuals of observed and predicted catch-at-age proportions for the different fleets (left) and residuals for each of the indices (upper right).

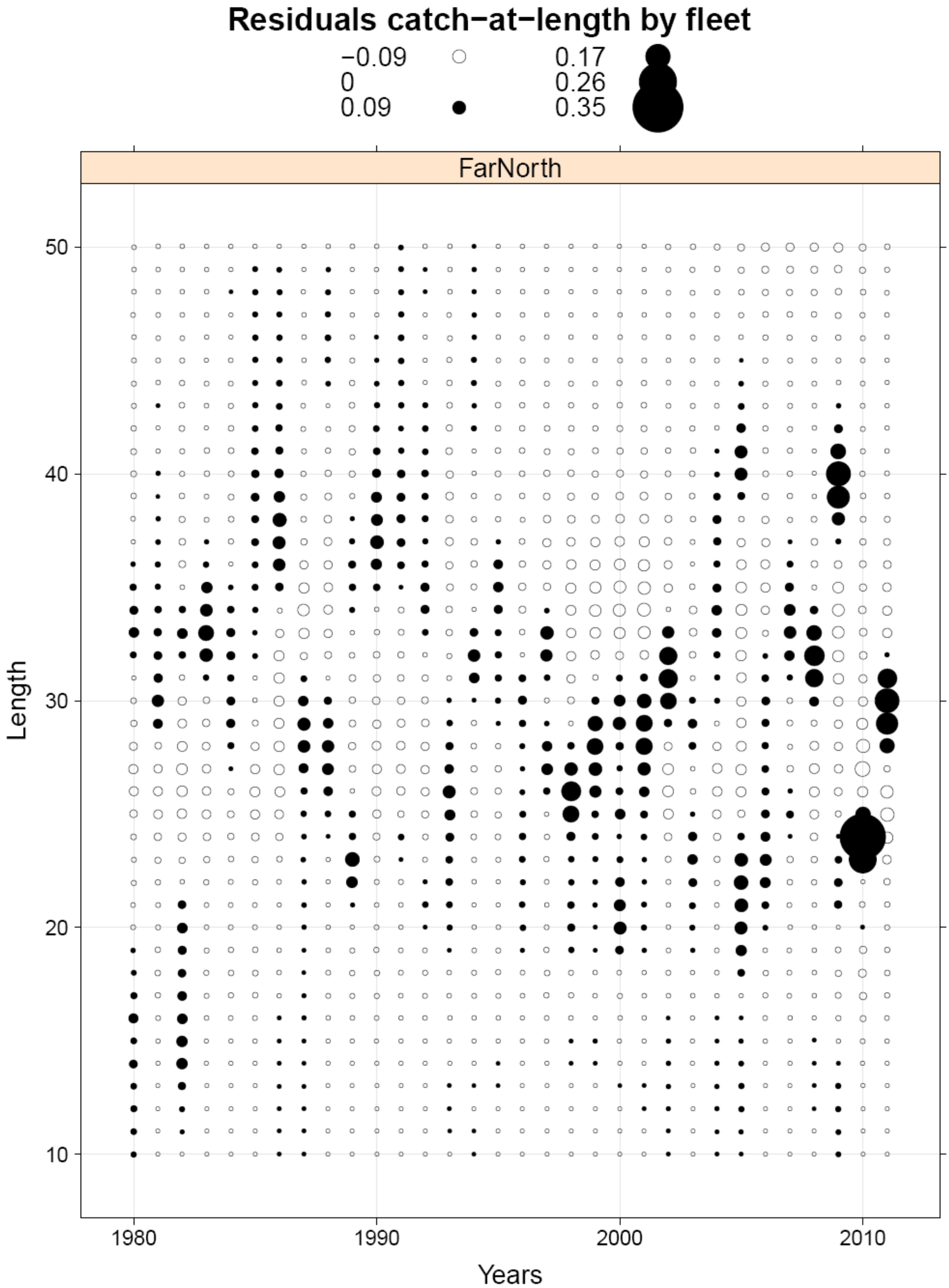

Figure A2.14. Logged residuals of observed and predicted catch-at-length proportions for FarNorth fleet

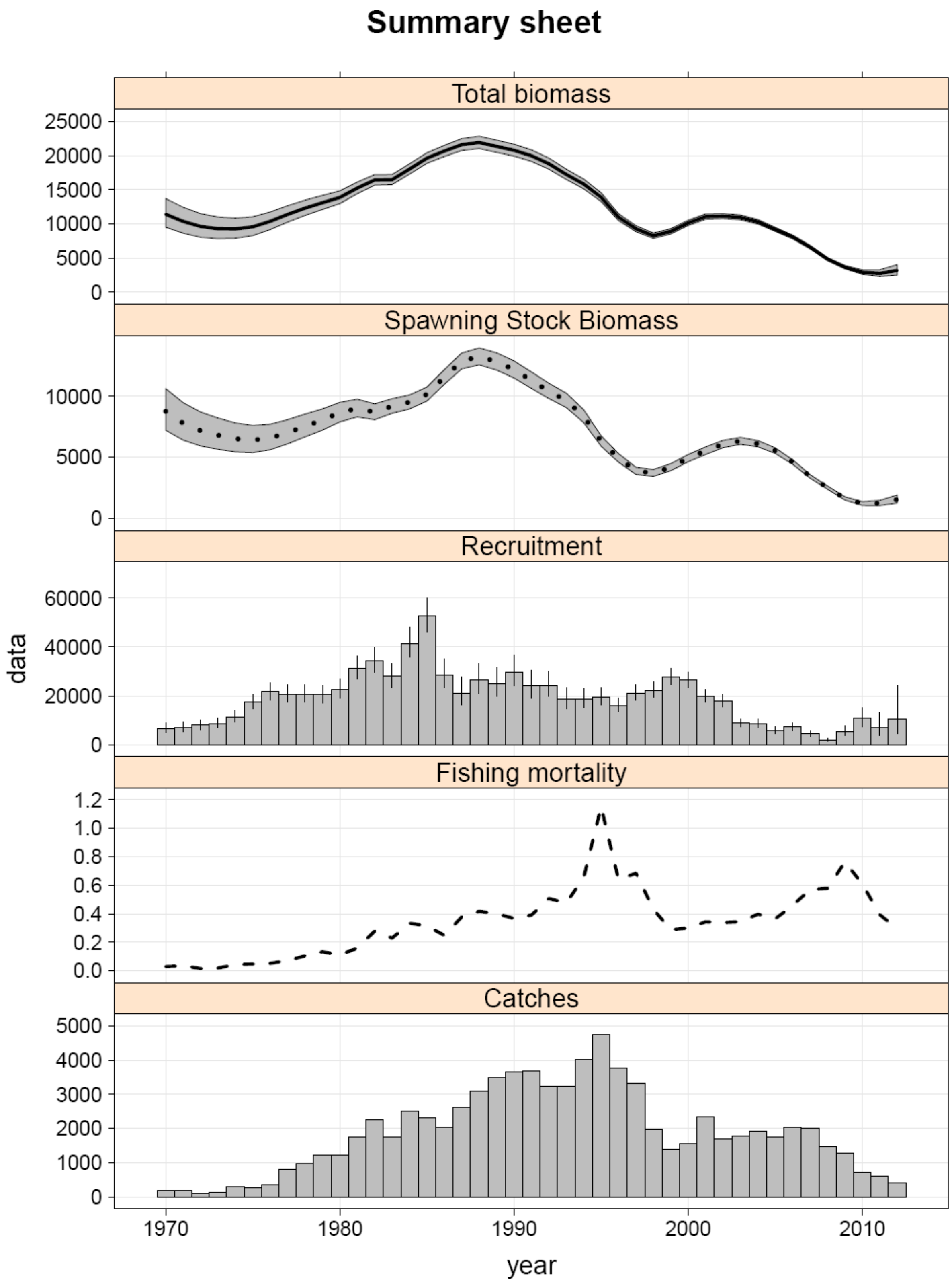

Figure A2.15. Summary estimates over time showing total and spawning biomass (kt; top two panels), recruitment at age 1 (millions; third from top) total fishing mortality (fourth panel) and total catch (kt; bottom). Shaded areas represent the approximate 90% confidence bands.

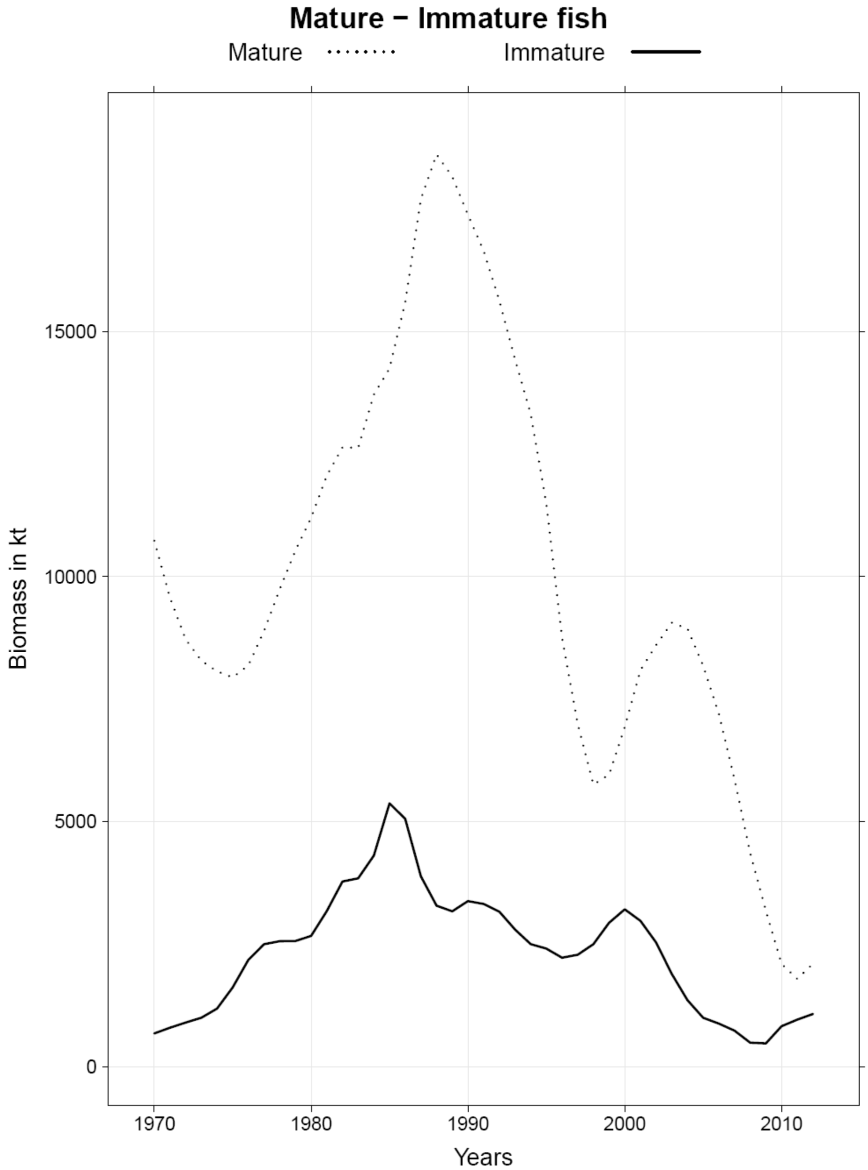

Figure A2.16. Model 7 results showing mature and immature estimated components of the jack mackerel stock, 1970-2012.

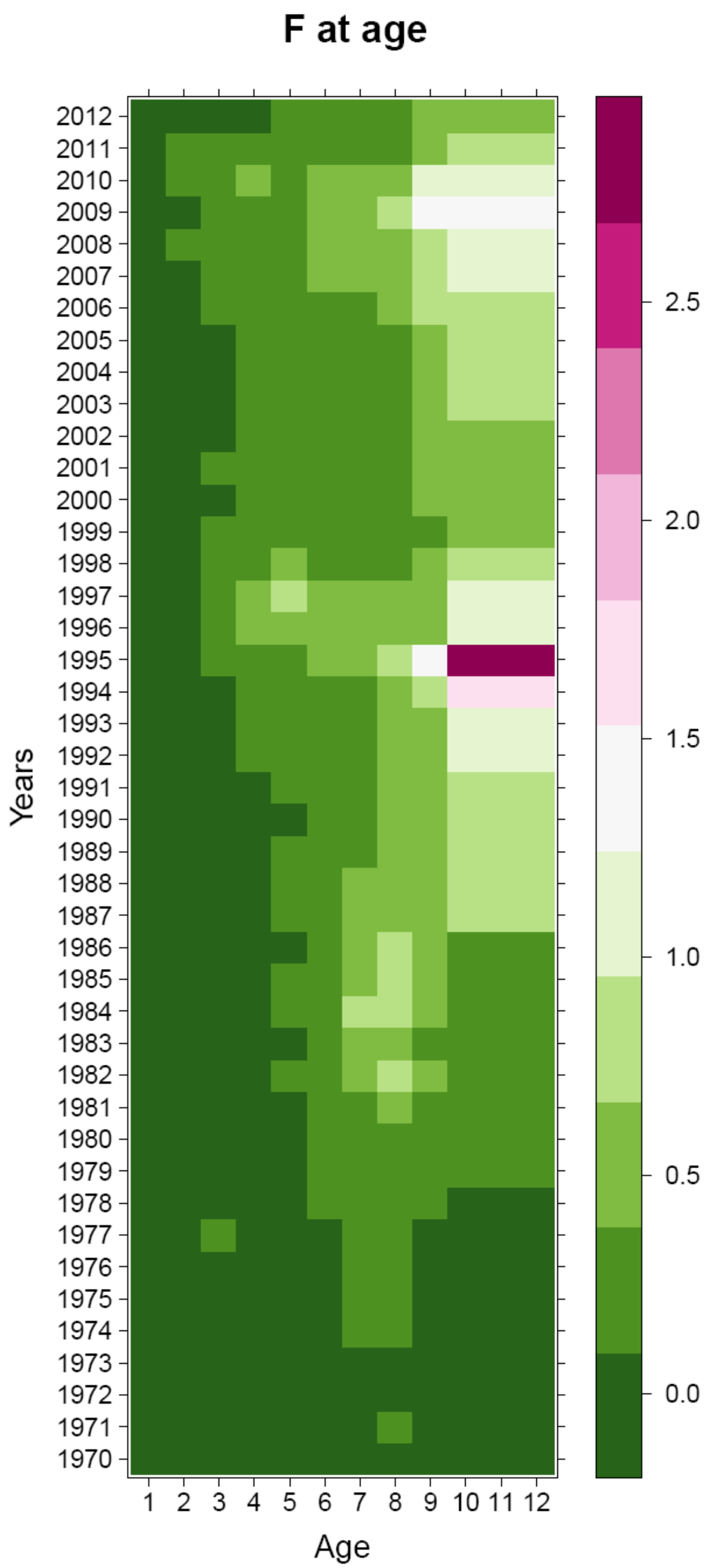

Figure A2.17. Historical fishing mortality at age.

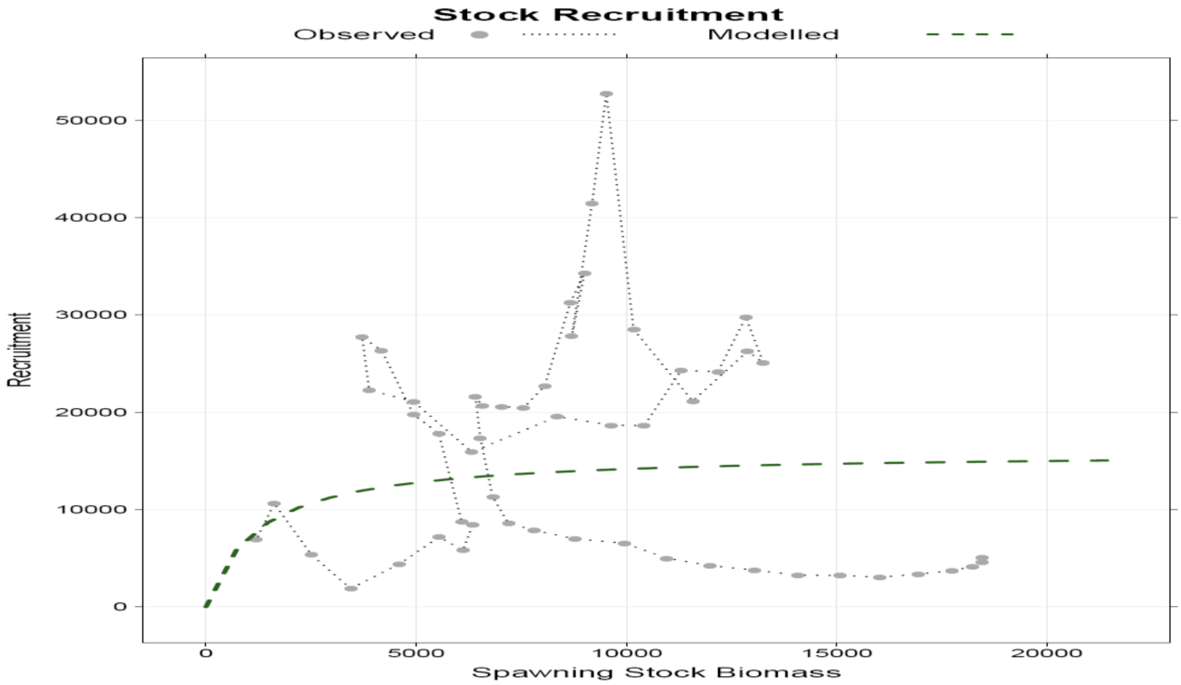

Figure A2.18. Stock recruitment curve relative to model estimates of biomass and recruitment.

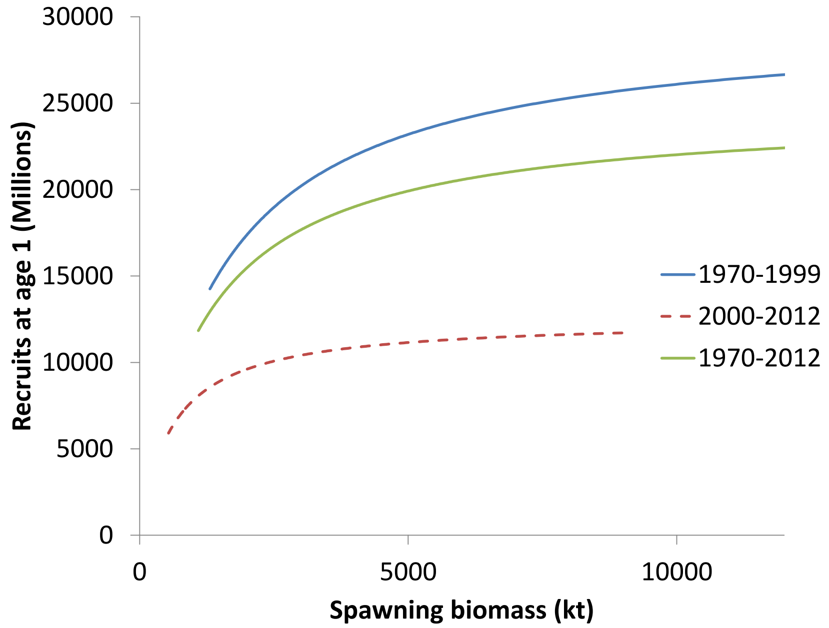

Figure A2.19. Jack mackerel stock recruitment estimates (with steepness fixed at 0.8) estimated for different regimes. For near-term projection purposes the regime specified from 2000-2012 was used.

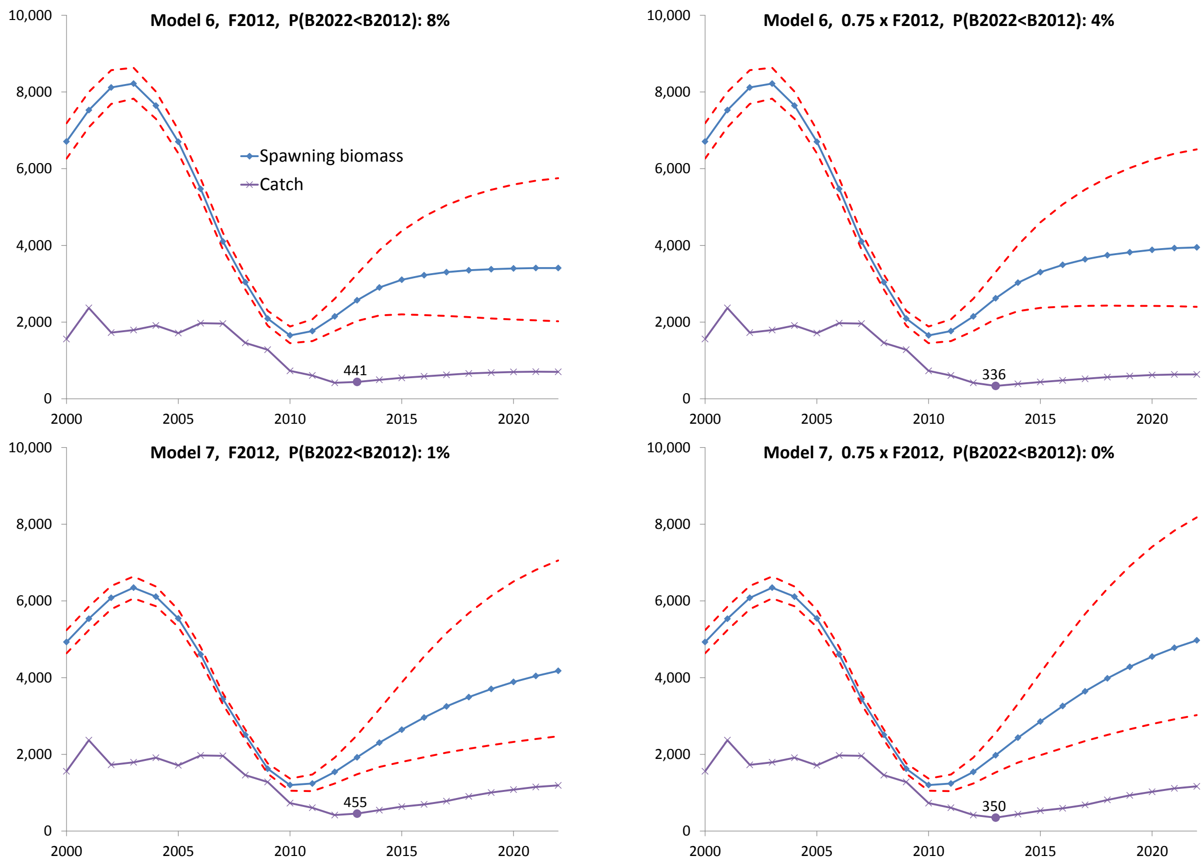

Figure A2.20. Jack mackerel projections showing catch (lower line) and spawning biomass (dash lines represent 90% confidence bands) for Models 6 (top row) and 7 (bottom row) assuming the same fishing mortality as in 2012 (left column) and at 75% of that level (right column).

A2 Tables

Table A2.1. Comparison of jack mackerel models by contributions from negative log-likelihood components based on data and model conditioned priors for one stock hypothesis model. Some rows are not comparable across all models due to different input data and model assumptions.

Data components	Model_1	Model_2	Model_3	Model_4	Model_5	Model_6	Model_7
Catch biomass	1	0	2	0	0	0	2
Fishery age composition	122	108	130	86	88	81	0
Fishery length composition	1	0	11	6	6	5	0
Index likelihoods*	183	3	153	0	0	1	162
Index age compositions	11	0	2	1	0	0	11
Subtotal*	317	111	298	93	94	87	175
Priors / penalties							
Fishery selectivities	29	1	13	1	1	0	47
Index selectivities	5	2	0	2	2	2	5
Recruitment likelihood+	26	12	46	7	5	0	25
Subtotal*	60	15	60	11	8	2	77
Total*	2,223	1,972	2,204	1,949	1,947	1,935	2,098

* Note that Models 1, 3, 7 include the original Peruvian acoustic data and are thus only comparable with eachother.
+ Note that Models 5 and 6 have different time frames over which selectivity is estimated

Table A2.2. Comparison of models by contributions from likelihood components based on data and model conditioned priors for two stocks hypothesis model.

Data components	Model 6	Model 7	S2+N3	S1	S2	N0	N1	N2	N3
Catch biomass	0	2	2	3	1	2	1	1	0
Fishery age composition	594	512	420	531	420				
Fishery length composition	475	469	361			375	375	364	361
Index likelihoods*	420	581	277	23	0	58	51	66	110
Index age compositions	132	143	120	120	120	0	0	0	0
Sub-total*	1621	1709	1179	677	540	434	428	431	471
Priors / penalties									
Fishery selectivities	56	102	81	43	61	4	4	0	2
Index selectivities	25	28	24	24	24				
Recruitment likelihood+	0	25	15	9	4	23	24	14	2
Sub-total*	81	156	121	77	89	27	28	14	4
Total	1702	1865	1300	754	629	461	456	445	475

Table A2.3. Input catch by fleet (combined) for the stock assessment model. Note that 2012 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	51,290
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	316,247	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	857,744	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	76,629	371,918
2010	169,010	295,681	22,172	239,845
2011	23,945	194,532	326,394	60,946
2012	12,000	208,403	168,883	28,031

Table A2.4. Input catch at age for fleet 1. Units are relative value (they are normalized to sum to one for each year in the model).

	1	2	3	4	5	6	7	8	9	10	11	12+
1975	0	1	2	8	10	28	29	14	5	1	1	0
1976	0	0	0	2	10	30	37	17	3	1	0	0
1977	0	2	3	7	20	33	25	9	1	0	0	0
1978	0	1	8	15	14	9	25	20	7	1	0	0
1979	0	0	4	9	18	22	23	18	6	1	0	0
1980	0	1	3	6	17	23	27	19	4	0	0	0
1981	0	0	2	9	20	24	29	14	3	0	0	0
1982	0	0	1	14	15	20	27	16	5	1	0	0
1983	0	0	0	7	20	29	27	14	3	0	0	0
1984	0	0	11	28	13	13	17	15	3	0	0	0
1985	0	0	4	17	27	29	17	5	1	0	0	0
1986	4	13	12	7	8	15	22	13	5	1	0	0
1987	0	5	40	41	10	2	2	1	0	0	0	0
1988	0	0	11	41	38	9	0	0	0	0	0	0
1989	0	1	1	6	45	38	8	1	0	0	0	0
1990	1	9	1	3	28	48	10	1	0	0	0	0
1991	0	2	20	20	11	17	24	6	0	1	0	0
1992	0	3	21	12	23	23	13	5	1	0	0	0
1993	0	3	62	25	5	4	1	0	0	0	0	0
1994	0	14	34	10	26	13	2	0	0	0	0	0
1995	0	16	32	28	14	8	2	0	0	0	0	0
1996	8	16	31	34	9	2	0	0	0	0	0	0
1997	0	5	55	36	4	0	0	0	0	0	0	0
1998	0	2	57	24	12	4	0	0	0	0	0	0
1999	0	6	72	17	4	1	0	0	0	0	0	0
2000	7	30	17	30	14	2	0	0	0	0	0	0
2001	0	12	63	23	1	0	0	0	0	0	0	0
2002	6	12	47	21	11	2	1	0	0	0	0	0
2003	1	14	55	22	5	2	1	0	0	0	0	0
2004	0	2	13	59	24	1	0	0	0	0	0	0
2005	4	26	38	16	12	4	0	0	0	0	0	0
2006	2	3	33	52	6	2	1	0	0	0	0	0
2007	0	9	32	44	10	3	2	1	0	0	0	0
2008	1	49	24	8	9	8	1	0	0	0	0	0
2009	0	7	29	51	4	8	0	0	0	0	0	0
2010	0	46	5	32	12	3	1	0	0	0	0	0
2011	6	59	28	3	1	2	0	0	0	0	0	0
2012	4	12	15	61	8	0	0	0	0	0	0	0

Table A2.5. Input catch at age for fleet 2. Units are relative value (they are normalized to sum to one in the model)

	1	2	3	4	5	6	7	8	9	10	11	12+
1975	0	0	1	2	6	18	28	25	14	5	2	0
1976	0	1	0	0	1	14	36	31	14	2	0	0
1977	0	0	0	3	11	19	35	27	4	0	0	0
1978	0	0	1	6	19	31	26	12	3	0	0	0
1979	0	0	1	13	18	18	18	16	11	4	0	0
1980	0	0	1	9	23	25	22	12	6	1	0	0
1981	0	0	0	4	17	31	28	14	4	1	0	0
1982	0	0	0	3	18	24	26	18	7	2	0	0
1983	0	2	4	7	17	25	26	13	5	1	0	0
1984	0	0	4	8	10	23	27	20	7	1	0	0
1985	0	0	1	8	14	25	31	16	4	0	0	0
1986	0	1	1	5	15	24	33	18	3	0	0	0
1987	0	4	9	8	5	15	32	22	4	1	0	0
1988	0	0	3	21	24	10	17	18	6	1	0	0
1989	0	0	0	4	23	32	19	15	6	1	0	0
1990	0	0	0	1	8	26	33	19	11	2	0	0
1991	0	1	2	2	1	7	28	31	16	8	3	1
1992	0	0	1	4	6	7	8	24	21	18	8	3
1993	0	0	4	12	15	14	13	12	14	12	4	1
1994	0	0	1	11	17	18	11	10	15	12	4	0
1995	0	0	4	18	14	25	18	9	6	4	2	0
1996	0	1	11	14	20	18	16	11	5	2	1	0
1997	0	2	17	31	22	11	6	4	4	2	1	0
1998	0	4	28	35	14	6	3	3	3	1	1	0
1999	0	4	37	34	14	5	2	1	1	1	1	1
2000	0	1	15	40	25	10	3	1	1	1	1	1
2001	0	1	10	26	34	16	5	2	2	2	1	2
2002	0	1	12	26	26	16	6	3	2	2	2	3
2003	0	0	6	25	30	20	8	3	2	2	1	1
2004	0	0	4	14	29	29	13	5	3	2	1	1
2005	1	1	1	5	17	39	19	8	5	2	1	1
2006	0	0	1	4	8	21	27	14	10	7	4	3
2007	0	0	1	13	15	11	15	15	13	9	5	4
2008	1	2	0	1	7	21	19	15	11	9	5	9
2009	0	0	4	9	2	19	22	17	11	7	5	4
2010	0	0	4	29	20	10	10	6	9	7	2	2
2011	0	0	1	16	13	35	10	6	13	5	1	1
2012	0	0	0	6	30	36	16	6	4	1	0	0

Table A2.6. Input catch at length for fleet 3. Units are relative value (they are normalized to sum to one for each year in the model).

	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
1980	1	2	2	2	3	2	5	3	2	1	0	0	0	1	1	1	0	0	1	3	3	5	8	12	11	9	7	5	3	2	1	1	1	1	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	9	11	9	10	10	9	8	7	6	4	3	3	2	2	2	1	0	0	0	0	0	0
1982	0	0	1	3	6	6	6	5	4	5	6	4	1	0	0	0	0	0	0	1	1	4	8	12	9	6	3	2	2	2	1	1	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	3	7	15	18	15	13	7	5	3	2	1	1	1	1	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	4	6	8	8	8	11	11	10	8	6	4	3	2	1	1	1	1	1	0	1	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	4	5	7	7	8	8	7	7	7	7	6	5	3	3	2	2	2	1	2	1	0
1986	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	2	4	7	10	13	12	12	8	6	5	3	3	2	2	2	1	1	1	0
1987	0	0	0	0	0	0	0	1	0	0	1	1	1	2	2	4	5	8	11	12	10	8	5	3	2	3	4	4	3	2	2	2	1	1	1	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	4	7	9	10	9	7	5	4	3	3	3	3	3	2	2	2	3	3	2	3	3	2	2	1	1	0
1989	0	0	0	0	0	0	0	0	0	0	0	1	7	10	5	6	4	3	2	2	2	3	4	6	8	8	8	6	4	3	1	1	1	1	1	1	1	1	0	0	0
1990	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	3	5	6	7	9	12	13	10	8	6	4	3	3	2	1	1	0	0	0	0
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	2	1	1	1	2	2	3	4	5	5	7	8	8	8	7	6	4	3	3	2	2	2	2	1	1	1
1992	0	0	0	0	0	0	0	0	0	0	1	2	1	1	1	1	1	1	1	2	3	4	7	9	12	11	8	6	6	5	5	4	3	2	1	1	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	1	2	2	3	4	6	9	12	9	7	6	5	5	6	5	5	5	4	2	1	1	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	3	3	5	11	14	11	8	6	4	3	3	3	3	2	3	2	2	2	1	1	1	1	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	3	4	5	6	7	8	9	11	12	10	6	3	2	2	1	1	1	1	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0	0	1	2	2	2	3	5	6	6	6	6	7	9	8	6	6	5	4	4	3	3	2	1	1	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	7	11	10	5	4	8	14	16	8	4	3	1	1	1	0	0	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	1	2	4	3	2	4	7	16	20	14	8	4	3	2	2	2	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	1	1	1	1	1	1	1	2	3	5	7	12	13	16	15	8	5	3	2	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	4	8	7	5	4	4	10	8	7	8	12	11	7	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0	1	2	1	1	2	4	7	10	12	16	16	14	9	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0	1	3	9	16	19	19	14	7	3	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0	1	1	2	5	7	8	6	5	6	9	10	7	5	4	3	4	5	5	3	2	1	0	0	0	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	6	7	9	12	13	11	8	8	7	5	3	2	1	0	0	0	0	0	0	0	0
2005	0	0	1	1	1	0	0	1	3	6	8	8	10	10	6	3	1	1	1	1	1	0	0	0	0	0	0	0	2	5	9	9	5	3	2	1	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	2	3	6	8	7	8	8	8	7	8	8	8	7	5	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	9	8	5	6	4	3	6	10	12	11	8	6	3	1	1	0	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	3	10	18	21	17	10	6	3	2	1	2	1	1	0	0	0	0	0	0	0	0	0
2009	1	1	1	1	0	0	0	0	0	0	1	4	4	4	2	2	1	0	1	1	0	0	0	0	0	1	2	5	11	19	20	11	5	1	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	0	0	0	2	0	2	25	49	18	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	8	18	23	24	18	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A2.7. Input catch at age for fleet 4. Units are relative value (they are normalized to sum to one for each year in the model).

	1	2	3	4	5	6	7	8	9	10	11	12+
1979	0	0	0	0	4	13	25	30	19	8	1	0
1980	0	1	1	5	16	24	26	17	9	2	0	0
1981	0	0	0	2	10	24	31	22	8	2	0	0
1982	0	0	0	1	7	20	31	26	11	3	1	1
1983	0	2	4	3	10	23	30	18	7	1	0	0
1984	0	0	2	7	11	19	26	23	9	1	0	0
1985	0	0	1	10	17	25	28	14	5	1	0	0
1986	0	1	2	7	20	25	26	15	3	0	0	0
1987	0	4	5	3	8	24	33	18	4	1	0	0
1988	0	1	4	15	16	16	24	17	6	1	0	0
1989	0	0	1	5	22	27	21	15	8	2	0	0
1990	0	0	0	1	10	33	28	15	10	3	0	0
1991	0	0	0	1	2	16	40	23	10	5	2	1
2000	0	3	18	27	17	11	7	6	5	4	2	0
2001	0	2	15	30	30	14	4	2	2	1	0	0
2002	1	2	20	42	21	9	3	1	1	0	0	0
2003	0	1	18	48	25	7	1	0	0	0	0	0
2006	0	0	0	1	13	37	29	10	5	3	1	0
2007	0	0	0	1	7	22	23	16	15	10	6	0
2008	0	0	0	0	1	11	30	26	16	10	6	0
2009	0	0	1	1	0	2	15	35	25	14	9	0
2010	0	1	29	14	0	0	5	10	19	15	5	0
2011	0	0	1	9	8	17	11	10	24	14	6	0
2012	0	0	0	0	0	0	2	4	50	27	8	8

Table A2.8. Input mean body mass (kg) at age over time assumed for fleets 1,2 and 4.

	1	2	3	4	5	6	7	8	9	10	11	12+
1975	0.052	0.093	0.131	0.178	0.262	0.294	0.340	0.396	0.549	0.738	0.984	1.093
1976	0.052	0.093	0.131	0.178	0.262	0.294	0.340	0.396	0.549	0.738	0.984	1.093
1977	0.052	0.093	0.131	0.178	0.262	0.294	0.340	0.396	0.549	0.738	0.984	1.093
1978	0.052	0.093	0.131	0.178	0.262	0.294	0.340	0.396	0.549	0.738	0.984	1.093
1979	0.052	0.093	0.131	0.178	0.262	0.294	0.340	0.396	0.549	0.738	0.984	1.093
1980	0.052	0.093	0.131	0.178	0.262	0.294	0.340	0.396	0.549	0.738	0.984	1.093
1981	0.052	0.078	0.155	0.214	0.275	0.336	0.394	0.472	0.632	0.714	0.898	1.538
1982	0.055	0.092	0.109	0.236	0.275	0.314	0.375	0.456	0.521	0.732	0.651	1.137
1983	0.052	0.084	0.104	0.147	0.211	0.327	0.394	0.449	0.514	0.583	0.631	1.538
1984	0.052	0.108	0.160	0.199	0.241	0.301	0.388	0.466	0.588	0.871	1.265	1.972
1985	0.026	0.060	0.132	0.231	0.272	0.350	0.447	0.519	0.716	0.820	1.073	1.854
1986	0.052	0.095	0.149	0.242	0.294	0.340	0.407	0.503	0.637	0.765	1.184	1.900
1987	0.055	0.085	0.166	0.207	0.269	0.323	0.378	0.472	0.536	0.644	0.987	1.185
1988	0.070	0.099	0.122	0.230	0.273	0.320	0.374	0.461	0.596	0.709	1.196	1.769
1989	0.035	0.135	0.154	0.185	0.266	0.330	0.383	0.449	0.577	0.685	1.012	1.846
1990	0.058	0.148	0.181	0.223	0.270	0.339	0.398	0.473	0.573	0.796	1.376	1.647
1991	0.073	0.075	0.172	0.247	0.286	0.346	0.427	0.518	0.640	0.844	1.351	2.110
1992	0.076	0.117	0.140	0.191	0.270	0.357	0.434	0.503	0.577	0.689	1.089	1.979
1993	0.100	0.124	0.159	0.197	0.233	0.342	0.444	0.512	0.588	0.750	1.012	1.372
1994	0.052	0.103	0.220	0.241	0.278	0.339	0.467	0.585	0.702	0.779	0.880	1.538
1995	0.064	0.091	0.153	0.264	0.309	0.373	0.461	0.582	0.694	0.835	0.970	1.598
1996	0.037	0.106	0.132	0.186	0.271	0.381	0.451	0.542	0.667	0.787	0.901	1.053
1997	0.063	0.083	0.118	0.177	0.239	0.275	0.409	0.524	0.594	0.709	0.851	1.046
1998	0.011	0.089	0.121	0.181	0.246	0.320	0.408	0.579	0.719	0.853	0.965	1.174
1999	0.041	0.084	0.112	0.224	0.270	0.336	0.462	0.643	0.808	0.868	1.058	1.421
2000	0.070	0.098	0.145	0.192	0.270	0.340	0.429	0.577	0.807	0.965	1.115	1.367
2001	0.061	0.092	0.151	0.191	0.280	0.352	0.524	0.683	0.945	1.216	1.426	1.477
2002	0.104	0.106	0.146	0.201	0.260	0.355	0.495	0.683	0.884	1.088	1.467	1.647
2003	0.084	0.128	0.138	0.178	0.248	0.340	0.545	0.806	1.035	1.246	1.412	1.655
2004	0.090	0.109	0.134	0.174	0.250	0.331	0.465	0.742	1.021	1.258	1.376	1.776
2005	0.043	0.064	0.163	0.196	0.255	0.346	0.466	0.756	0.999	1.141	1.228	1.563
2006	0.066	0.098	0.122	0.179	0.258	0.325	0.461	0.614	0.828	1.074	1.360	1.671
2007	0.031	0.074	0.130	0.200	0.257	0.329	0.445	0.645	0.883	1.102	1.321	1.649
2008	0.036	0.086	0.117	0.186	0.245	0.307	0.400	0.564	0.768	1.005	1.209	1.537
2009	0.034	0.080	0.158	0.193	0.247	0.307	0.387	0.528	0.700	0.897	1.087	1.541
2010	0.029	0.075	0.113	0.196	0.259	0.318	0.399	0.517	0.641	0.767	0.918	1.296
2011	0.033	0.076	0.116	0.141	0.261	0.350	0.419	0.516	0.631	0.752	0.924	1.263
2012	0.086	0.074	0.121	0.172	0.226	0.331	0.431	0.510	0.621	0.756	0.903	1.177

Table A2.9. Input mean body mass (kg) at age over time assumed for fleet 3.

	1	2	3	4	5	6	7	8	9	10	11	12+
1975	0.045	0.171	0.377	0.642	0.945	1.265	1.587	1.900	2.196	2.470	2.721	2.946
1976	0.045	0.171	0.377	0.643	0.946	1.266	1.588	1.902	2.198	2.472	2.723	2.949
1977	0.030	0.130	0.306	0.548	0.835	1.148	1.470	1.789	2.095	2.382	2.647	2.887
1978	0.037	0.147	0.330	0.568	0.842	1.134	1.430	1.718	1.991	2.246	2.478	2.688
1979	0.038	0.147	0.326	0.558	0.825	1.108	1.393	1.671	1.934	2.178	2.402	2.603
1980	0.034	0.136	0.310	0.540	0.808	1.095	1.387	1.674	1.946	2.201	2.434	2.645
1981	0.044	0.160	0.340	0.567	0.822	1.087	1.351	1.606	1.845	2.065	2.266	2.446
1982	0.032	0.130	0.294	0.510	0.760	1.028	1.300	1.566	1.818	2.054	2.270	2.465
1983	0.032	0.129	0.295	0.516	0.774	1.050	1.332	1.608	1.872	2.117	2.343	2.547
1984	0.036	0.138	0.304	0.518	0.762	1.020	1.280	1.532	1.770	1.991	2.193	2.375
1985	0.036	0.136	0.298	0.506	0.743	0.994	1.245	1.490	1.721	1.934	2.130	2.306
1986	0.041	0.148	0.314	0.524	0.758	1.003	1.247	1.481	1.702	1.905	2.089	2.255
1987	0.039	0.144	0.309	0.519	0.755	1.002	1.249	1.488	1.712	1.920	2.108	2.278
1988	0.042	0.138	0.280	0.451	0.638	0.828	1.014	1.191	1.356	1.507	1.643	1.764
1989	0.044	0.156	0.328	0.541	0.778	1.024	1.267	1.501	1.719	1.921	2.103	2.267
1990	0.040	0.149	0.322	0.541	0.789	1.048	1.308	1.558	1.794	2.012	2.211	2.389
1991	0.042	0.151	0.323	0.539	0.781	1.033	1.285	1.527	1.755	1.965	2.156	2.327
1992	0.034	0.132	0.294	0.504	0.745	1.001	1.260	1.512	1.751	1.973	2.176	2.359
1993	0.038	0.145	0.315	0.533	0.780	1.041	1.302	1.554	1.793	2.013	2.215	2.396
1994	0.044	0.158	0.337	0.561	0.812	1.074	1.334	1.585	1.821	2.038	2.236	2.413
1995	0.042	0.150	0.320	0.532	0.769	1.017	1.263	1.499	1.722	1.927	2.113	2.280
1996	0.039	0.142	0.305	0.511	0.743	0.985	1.227	1.461	1.680	1.883	2.068	2.234
1997	0.040	0.148	0.318	0.534	0.776	1.031	1.286	1.531	1.763	1.976	2.171	2.346
1998	0.039	0.147	0.323	0.549	0.807	1.080	1.354	1.620	1.871	2.104	2.317	2.508
1999	0.036	0.147	0.335	0.584	0.874	1.186	1.503	1.813	2.109	2.385	2.638	2.867
2000	0.038	0.146	0.318	0.540	0.792	1.058	1.325	1.583	1.827	2.053	2.260	2.446
2001	0.038	0.145	0.317	0.537	0.788	1.053	1.318	1.576	1.820	2.045	2.251	2.436
2002	0.045	0.152	0.312	0.506	0.720	0.940	1.155	1.361	1.553	1.729	1.889	2.031
2003	0.040	0.140	0.294	0.483	0.693	0.911	1.126	1.333	1.526	1.703	1.864	2.008
2004	0.037	0.146	0.324	0.557	0.824	1.107	1.394	1.673	1.938	2.183	2.408	2.611
2005	0.035	0.145	0.336	0.592	0.893	1.218	1.550	1.877	2.189	2.481	2.750	2.994
2006	0.033	0.139	0.324	0.572	0.864	1.180	1.504	1.822	2.127	2.412	2.674	2.912
2007	0.036	0.145	0.330	0.576	0.861	1.167	1.478	1.783	2.074	2.344	2.593	2.817
2008	0.040	0.154	0.341	0.584	0.862	1.157	1.454	1.743	2.017	2.272	2.504	2.714
2009	0.038	0.149	0.333	0.574	0.852	1.148	1.447	1.740	2.017	2.275	2.511	2.724
2010	0.037	0.150	0.341	0.595	0.890	1.206	1.527	1.842	2.142	2.422	2.678	2.911
2011	0.038	0.152	0.347	0.606	0.907	1.230	1.558	1.880	2.187	2.473	2.735	2.973
2012	0.038	0.149	0.335	0.579	0.861	1.161	1.465	1.762	2.044	2.306	2.546	2.763

Table A2.10. 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			0.450						
1983			0.414						
1984		99	0.365						
1985		324	0.300		319				
1986		123	0.259		8,371				
1987		213	0.310		12,449				55.02
1988		134	0.264		4,455				58.24
1989			0.270		14,018				51.06
1990			0.214		6,733				52.57
1991		242	0.263		8,919				60.99
1992			0.225		0				
1993			0.195		8,471				
1994			0.230		6,761				
1995			0.207		3,329				
1996			0.214		6,570				
1997	3,530		0.187		3,446				
1998	3,200		0.174		323				
1999	4,100		0.207	5,724	279				
2000	5,600		0.196	4,688	3,167				
2001	5,950		0.252	5,627	7,754		1.39		
2002	3,700		0.208	1,388	341	197.2	1.93		
2003	2,640		0.183	3,287	1,284	242.3	1.71	0.72	
2004	2,640		0.198	1,043	628	252.0	1.40	1.11	
2005	4,110		0.181	3,283	1,319	192.0	1.40	0.89	
2006	3,192	112	0.200	626	2,388	248.0	0.99	1.38	
2007	3,140	275	0.151	1,935	812	253.1	1.11	1.43	
2008	487	259	0.102		697	230.9	0.81	1.21	77.42
2009	328	18	0.085		233	144.3	0.77	1.02	59.56
2010			0.063		78		0.55	0.79	
2011			0.036		1,216	240.3	0.32	0.27	45.21
2012						243.7			

Table A2.11. Estimated begin-year numbers at age (Model 7), 1970-2012.

	1	2	3	4	5	6	7	8	9	10	11	12+
1970	6,537	3,965	2,682	1,898	1,299	1,027	767	674	592	524	462	5,002
1971	7,001	5,192	3,146	2,122	1,494	1,013	785	563	494	459	407	4,248
1972	7,889	5,560	4,118	2,486	1,669	1,163	770	569	407	380	356	3,608
1973	8,622	6,266	4,406	3,248	1,962	1,314	907	589	434	318	298	3,113
1974	11,302	6,846	4,953	3,452	2,554	1,542	1,022	690	447	339	250	2,675
1975	17,322	8,963	5,360	3,778	2,668	1,980	1,168	737	496	344	262	2,255
1976	21,590	13,752	7,086	4,198	2,951	2,063	1,483	823	516	376	264	1,935
1977	20,662	17,140	10,868	5,543	3,276	2,277	1,537	1,033	566	387	289	1,687
1978	20,577	16,347	13,140	7,818	4,158	2,509	1,689	1,061	703	422	294	1,501
1979	20,462	16,300	12,684	9,767	5,915	3,130	1,779	1,059	644	497	311	1,324
1980	22,702	16,218	12,706	9,549	7,443	4,452	2,197	1,082	599	427	348	1,144
1981	31,259	17,986	12,588	9,454	7,266	5,659	3,206	1,412	653	409	305	1,064
1982	34,279	24,761	13,944	9,333	7,138	5,415	3,881	1,853	744	414	282	943
1983	27,870	27,190	19,474	10,745	7,055	5,068	3,276	1,709	688	392	250	741
1984	41,466	22,122	21,464	15,174	8,278	5,191	3,305	1,678	734	377	242	612
1985	52,751	32,893	17,404	16,550	11,446	5,808	3,029	1,337	541	350	210	477
1986	28,523	41,866	25,965	13,548	12,595	8,099	3,439	1,256	439	254	204	401
1987	21,155	22,654	33,175	20,446	10,502	9,231	5,183	1,674	492	221	158	376
1988	26,281	16,795	17,910	25,831	15,508	7,584	6,083	2,798	713	217	84	203
1989	25,087	20,850	13,196	13,706	19,400	11,132	4,952	3,215	1,146	296	76	100
1990	29,760	19,893	16,304	9,972	10,264	14,015	7,371	2,689	1,372	490	106	63
1991	24,174	23,583	15,460	12,034	7,410	7,478	9,454	4,169	1,226	622	189	65
1992	24,304	19,166	18,419	11,521	8,931	5,354	5,012	5,331	1,891	533	223	91
1993	18,641	19,274	15,002	13,665	8,120	6,027	3,344	2,971	2,791	795	127	75
1994	18,665	14,778	15,046	11,005	9,586	5,488	3,798	2,020	1,607	1,228	206	52
1995	19,561	14,794	11,513	11,032	7,578	6,251	3,239	2,087	942	558	201	42
1996	15,917	15,457	11,229	7,746	6,774	4,286	2,972	1,355	652	175	28	12
1997	21,105	12,574	11,622	6,581	3,599	2,797	1,904	1,531	696	278	45	10
1998	22,287	16,648	9,324	6,570	2,952	1,440	1,214	962	766	283	65	13
1999	27,743	17,628	12,669	6,002	3,655	1,527	784	727	571	399	103	28
2000	26,336	21,999	13,733	8,934	3,778	2,167	936	513	474	341	188	62
2001	19,809	20,873	17,099	9,938	6,004	2,354	1,329	596	316	252	158	115
2002	17,831	15,648	15,766	11,292	6,287	3,607	1,396	826	358	161	111	120
2003	8,778	14,142	12,202	11,671	7,635	3,864	2,176	875	495	179	67	96
2004	8,454	6,954	10,854	8,894	7,751	4,748	2,381	1,384	528	243	72	66
2005	5,835	6,695	5,324	7,987	6,075	5,035	2,756	1,376	782	215	91	52
2006	7,190	4,623	5,144	3,948	5,512	4,040	2,967	1,586	770	337	87	58
2007	4,418	5,677	3,416	3,578	2,615	3,579	2,307	1,639	836	299	112	48
2008	1,884	3,483	4,109	2,284	2,238	1,618	1,903	1,171	778	271	80	43
2009	5,359	1,485	2,507	2,703	1,360	1,369	863	963	544	244	74	34
2010	10,614	4,227	1,078	1,658	1,538	764	623	364	362	118	47	21
2011	6,938	8,357	2,996	681	880	905	403	309	161	106	33	19
2012	10,463	5,462	5,984	2,012	481	613	582	257	192	74	35	17
Mean	18,823	14,816	11,467	8,380	5,944	4,069	2,562	1,430	725	363	181	805

Table A2.12. Estimated total fishing mortality at age, 1970-2012.

	1	2	3	4	5	6	7	8	9	10	11	12+
1970	0.000	0.001	0.004	0.009	0.018	0.039	0.079	0.080	0.025	0.022	0.022	0.022
1971	0.000	0.002	0.006	0.010	0.021	0.045	0.092	0.096	0.034	0.025	0.025	0.025
1972	0.000	0.003	0.007	0.007	0.009	0.019	0.038	0.040	0.014	0.012	0.012	0.012
1973	0.001	0.005	0.014	0.010	0.011	0.022	0.044	0.046	0.016	0.013	0.013	0.013
1974	0.002	0.015	0.041	0.028	0.024	0.048	0.096	0.099	0.033	0.030	0.030	0.030
1975	0.001	0.005	0.014	0.017	0.027	0.059	0.121	0.128	0.046	0.033	0.033	0.033
1976	0.001	0.005	0.016	0.018	0.030	0.064	0.132	0.143	0.056	0.035	0.035	0.035
1977	0.004	0.036	0.099	0.057	0.037	0.069	0.141	0.154	0.064	0.045	0.045	0.045
1978	0.003	0.024	0.067	0.049	0.054	0.114	0.237	0.269	0.118	0.074	0.074	0.074
1979	0.002	0.019	0.054	0.042	0.054	0.124	0.267	0.340	0.181	0.127	0.127	0.127
1980	0.003	0.023	0.066	0.043	0.044	0.098	0.212	0.275	0.151	0.107	0.107	0.107
1981	0.003	0.025	0.069	0.051	0.064	0.147	0.318	0.410	0.226	0.143	0.143	0.143
1982	0.002	0.010	0.031	0.050	0.113	0.273	0.590	0.761	0.412	0.273	0.273	0.273
1983	0.001	0.006	0.020	0.031	0.077	0.197	0.439	0.616	0.373	0.253	0.253	0.253
1984	0.002	0.010	0.030	0.052	0.124	0.309	0.675	0.902	0.512	0.352	0.352	0.352
1985	0.001	0.007	0.020	0.043	0.116	0.294	0.650	0.884	0.524	0.308	0.308	0.308
1986	0.000	0.003	0.009	0.025	0.081	0.216	0.490	0.708	0.456	0.246	0.246	0.246
1987	0.001	0.005	0.020	0.046	0.096	0.187	0.386	0.623	0.589	0.736	0.736	0.736
1988	0.001	0.011	0.038	0.056	0.102	0.196	0.408	0.663	0.648	0.823	0.823	0.823
1989	0.002	0.016	0.050	0.059	0.095	0.182	0.381	0.621	0.620	0.795	0.795	0.795
1990	0.003	0.022	0.074	0.067	0.087	0.164	0.340	0.556	0.561	0.723	0.723	0.723
1991	0.002	0.017	0.064	0.068	0.095	0.170	0.343	0.561	0.602	0.794	0.794	0.794
1992	0.002	0.015	0.069	0.120	0.163	0.241	0.293	0.417	0.637	1.205	1.205	1.205
1993	0.002	0.018	0.080	0.125	0.162	0.232	0.274	0.385	0.591	1.120	1.120	1.120
1994	0.002	0.020	0.080	0.143	0.198	0.297	0.369	0.533	0.827	1.579	1.579	1.579
1995	0.005	0.046	0.166	0.258	0.340	0.513	0.642	0.933	1.452	2.776	2.776	2.776
1996	0.006	0.055	0.304	0.537	0.655	0.581	0.433	0.436	0.624	1.137	1.137	1.137
1997	0.007	0.069	0.340	0.572	0.686	0.605	0.453	0.463	0.669	1.228	1.228	1.228
1998	0.004	0.043	0.211	0.356	0.429	0.377	0.283	0.291	0.422	0.777	0.777	0.777
1999	0.002	0.020	0.119	0.233	0.293	0.260	0.194	0.198	0.285	0.522	0.522	0.522
2000	0.002	0.022	0.093	0.167	0.243	0.259	0.221	0.256	0.402	0.543	0.543	0.543
2001	0.006	0.051	0.185	0.228	0.280	0.292	0.246	0.280	0.441	0.592	0.592	0.592
2002	0.002	0.019	0.071	0.161	0.257	0.275	0.238	0.282	0.466	0.648	0.648	0.648
2003	0.003	0.035	0.086	0.179	0.245	0.254	0.223	0.275	0.479	0.673	0.673	0.673
2004	0.003	0.037	0.077	0.151	0.201	0.314	0.319	0.340	0.666	0.755	0.755	0.755
2005	0.003	0.033	0.069	0.141	0.178	0.299	0.322	0.351	0.613	0.672	0.672	0.672
2006	0.006	0.073	0.133	0.182	0.202	0.330	0.364	0.410	0.716	0.875	0.875	0.875
2007	0.008	0.093	0.173	0.239	0.250	0.402	0.448	0.515	0.898	1.086	1.086	1.086
2008	0.008	0.099	0.189	0.288	0.262	0.398	0.451	0.536	0.928	1.071	1.071	1.071
2009	0.007	0.090	0.183	0.334	0.346	0.557	0.634	0.749	1.297	1.411	1.411	1.411
2010	0.009	0.114	0.229	0.404	0.300	0.411	0.473	0.586	1.001	1.056	1.056	1.056
2011	0.009	0.104	0.168	0.117	0.132	0.211	0.219	0.247	0.553	0.861	0.861	0.861
2012	0.004	0.042	0.072	0.082	0.124	0.215	0.221	0.230	0.461	0.595	0.595	0.595