A5. 2013 jack mackerel stock assessment

Introduction

This document and content is based on discussions analyses conducted at the SC-01 meeting. Changes in the data used compared to the 2012 assessment include new age compositions for the acoustic surveys from the northern area of Chile, updates on the main abundance indices as (CPUE of Chile, China, the EU, Peru) and updates on the acoustic survey from Peru. Model modifications relative to the most recent assessment are presented below and mainly involve how selectivity was allowed to vary over time and how different data sets were weighted in model fitting.

Scientific name and general distribution

The Chilean Jack mackerel (*Trachurus murphyi*, Nichols 1920) is widespread throughout the South Pacific, along the shelf and oceanic waters adjacent to Ecuador, Peru, and Chile, and across the South Pacific along the Subtropical Convergence Zone in what has been described as the “Jack mackerel belt” that goes from the coast of Chile to New Zealand within a 35^o to 50^o S variable band across the South Pacific.

Main management units

At least five management units of *T. murphyi* associated to distinct fisheries are identified in the SE Pacific: the Ecuadorian fishery, which is managed as part of a more general pelagic fishery within the Ecuadorian EEZ; the Peruvian fishery, which is managed as part of a Jack mackerel, mackerel and sardine fishery directed exclusively for direct human consumption taking place almost entirely within the Peruvian EEZ; the northern and the central-southern Chilean fisheries which are managed as separate management units, with the northern fishery being mostly within Chilean EEZ and the central-southern Chilean fishery which straddles the Chilean EEZ and the adjacent high sea; and, the purely high sea fishery which is a multinational fishery being managed entirely within the context of the SPRFMO. At present there is no directed fishery for *T. murphyi* in the central and western South Pacific and around New Zealand, where if any, incidental catches are very small.

Stock structure

There are a number of competing stock structure hypotheses, and up to five and more separate stocks have been suggested: i) a Peruvian stock (northern stock) which is a straddling stock with respect to the high seas; ii) a Chilean stock (southern stock) which is also a straddling stock with respect to the high seas; iii) a central Pacific stock which exists solely in the high seas; iv) a southwest Pacific stock which exist solely in the high seas; v) and, a New Zealand-Australian stock which straddles the high seas and both the New Zealand and Australian EEZs. Regarding specifically the eastern and central South Pacific, the SPRFMO has identified the following four alternative stock structure working hypothesis: 1) Jack mackerel caught off the coasts of Peru and Chile each constitute separate stocks which straddle the high seas; 2) Jack mackerel caught off the coasts of Peru and Chile constitute a single shared stock which straddles the high seas; 3) Jack mackerel caught off the Chilean area constitute a single straddling stock extending from the coast out to about 120°W; and, 4) Jack mackerel caught off the Chilean area constitute separate straddling and high seas stocks.

Accordingly, the Jack Mackerel Sub-group (JMSG) of the Science Working Group (SWG) of the SPRFMO at its 11th Session (SWG-11) carried out parallel assessments of the Jack mackerel stock(s) in the Eastern South Pacific under the two main working hypothesis already identified. That is: that Jack mackerel caught off the coasts of Peru and Chile each constitute separate stocks (Peruvian or northern and Chilean or southern stocks - hypothesis 1) which straddle the high seas; and, that Jack mackerel caught off the coasts of Peru and Chile constitute a single shared stock (hypothesis 2) which straddles the high seas. In following up on the SWG-11 recommendations, the SPRFMO Commission at its 1st Commission Meeting requested the newly established Scientific Committee to continue the work on evaluating alternative hypotheses on Jack mackerel stock population and, pending more conclusive findings on the stock population structure of Jack mackerel, the Commission requested the Scientific Committee (SC) to continue and expand the stock assessment work under both the stock hypotheses considered in the 11th SWG Meeting, and this is one of the main tasks for its 1st Session (SC-01) in La Jolla, 21-27 October 2013.

Fishery

The fishery for jack mackerel in the south-eastern Pacific is conducted by fleets from the coastal states (Chile, Peru and Ecuador), and by distant water fleets from various countries, operating beyond the EEZ of the coastal states.

The fishery by the coastal states is done by purse seiners. The largest fishery exists in Chile, where the fish are used mainly for the production of fish meal. In Peru, the fishery is variable from year to year. Here the fish is taken by purse seiners that also fish for anchovy. According to government regulations, the jack mackerel in Peru may only be used for human consumption. Ecuador constitutes the northern fringe of the distribution of jack mackerel. Here the fish only occur in certain years, when the local purse seiners may take substantial quantities (80 000 tons in 2011). Part of the catch is processed into fish meal but recently horse mackerel has been promoted to be used for human consumption.

The distant water fleets operating for jack mackerel outside the EEZs have been from a number of parties including China, Cook Islands, Cuba, European Union (Netherlands, Germany and Lithuania), Faroe Islands , Korea, , Japan, Russian Federation, Ukraine and Vanuatu,. These fleets consist exclusively of pelagic trawlers that freeze the catch for human consumption. In the 1980s a large fleet from Russia and other Eastern European countries operated as far west as 130° W. After the economic reforms in the communist countries around 1990, the fishery by these countries in the eastern Pacific was halted. It was not until 2003 that foreign trawlers re-appeared in the waters outside the EEZ of the coastal states.

The fishery for jack mackerel is generally a mono-specific fishery. In the offshore fishery the catch consists for 90 – 98% of jack mackerel, with minor by-catches of chub mackerel (*Scomber japonicus*) and Pacific bream (*Brama australis*).

The development of the catches of jack mackerel in the eastern Pacific is shown in Table A5.1.

Management

Jack mackerel were managed by coastal states beginning in the mid-1990s. National catch quota for jack mackerel were introduced by Peru in 1995 and by Chile in 1999. Peru introduced a ban on the use of jack mackerel for fish meal in 2002. For the international waters, the first voluntary agreement on limitation of the number of vessels was introduced in 2010. Starting from 2011, catch quota for jack mackerel were introduced for all countries fishing in eastern Pacific.

Information on the environment in relation to the fisheries

Peru is currently using the Coastal El Niño Index (ICEN, from Indice Costero de El Niño) to describe the short-term variability of the environment. Data to calculate this index on a monthly basis is available from 1950 to date. According to this index, 2013 is a year characterized by the presence of La Niña event.

Large-scale variability has also been observed and analyzed, especially with respect to changes in water masses dynamics and depth of the 15^{o}C isotherm between 1961 and 2013. These variables influence the spatial distribution Jack mackerel, and probably in the long run also influence its availability and abundance. The various environmental and biological signals contribute to explain the drastic decline in abundance towards the end of the 1990s implied by the results of the acoustic estimates, which took place in the absence of a significant fishing pressure and very low catches in the 1980s and 1990s. Long-term changes in the distribution pattern of the Sea Surface Temperature in Peruvian waters have by themselves noticeable impacts on the Peruvian Jack mackerel stock, as suggested by the tight parallelism between the decline of the area covered by warm isotherms (22°C-25°C) and the acoustic biomass estimates since mid-1990s.

Reproductive biology

The main spawning season happens from October to December; however spawning has been described to occur from July to March. Gonadosomatic index and eggs surveys are the source of information to describe the time of spawning

Data used in the assessment

Fishery data

The catch data for the model sums values from Table A5.1 and forms four “fleets” which are intended to be consistent with the gear and general areas of fishing (Figure A5.1). These are presented in Table A5.2.

Length data are available from all major fisheries both inside and outside the EEZs. Length distributions from Chile and the international fleet are converted into age distributions using Chilean age-length keys. These data are shown in Tables A5.3, A5.4, and A5.5. For Peruvian and Ecuadorian catches, catch-at length compositions are used (Table A5.6). There was a compilation of length compositions (partial results 2013) 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.

Several CPUE data series are used in the model. For the Chilean purse seiner fleet, “General Linear Models” (GLM; McCullagh & Nelder, 1989) were used to standardize the CPUE. Following this approach, CPUE is predicted as a linear combination of explanatory variables, and the ultimate objective is to estimate the annual effect. A normal delta and delta gamma models were assessed (Pennington, 1983; Ortiz y Arocha, 2004), which models separately the positive tows from the number of catch successes, where the index is obtained as the product between the proportion of positive tows and the index estimated for the rates of fishing with catch (Lo et al, 1992). A deviance analysis was conducted to assess the importance of each main effect. Factors in the GLM included year, quarter, zone and the vessel hold capacity. Effort units were computed as the number of days of a trip multiplied by the vessel hold capacity. The rationale being that trip duration can serve as a proxy for search time.

The Peruvian CPUE was standardized using a GAM model, allowing the inclusion of non-linear relationships among the explained and explanatory variables. The independent variable (catch by trip) in a monthly scale was previously normalized using the Box-Cox transformation and modeled using time (Gregorian) month, hold capacity, latitude, and distance to the coast as explanatory variables. The standardized CPUE was estimated fixing the hold capacity, latitude, and distance to the coast to the median value and the month to March, assuming the continuous time captures the variability in the abundance of Jack mackerel.

The Chinese CPUE was standardized using a GLM and updated earlier studies. This series was included as an index of exploitable biomass for offshore fleet. As from previous assessments, the Russian time series of CPUE was included but with low weight since it remains unstandardized. Also, for the international trawler fleet, a CPUE series for the EU fleet was used with an updated value for 2013.

Fisheries independent data

China has a system of observers onboard fishing vessels that, among others, collect data on environmental variables (wind direction and speed, SST, etc.) in the fishing grounds. Although this data is not available at the moment, it might be in the future.

In Chile the Jack mackerel research program includes stock assessment surveys using hydroacoustics and the daily egg production method (DEPM). For the northern region (XV-III) data on acoustic biomass and number and weight at age are available from 2006 to 2012 on a yearly basis. For the central-southern regions (V-X), these data are available from 1997 to date. Eggs survey (through the Daily Egg Production Method), to estimate the abundance of the spawning stock, were conducted on an annual basis from 1999 to 2008 along the central zone of the Chilean coast. Acoustic estimates and egg survey results are used as relative abundance indices to fine-tune the stock assessment model. Besides that, for the central-southern regions there are estimates of abundance and numbers at age based on DEPM for the years 2001, 2003, 2004, 2005, 2006, 2008.

In Peru the Jack mackerel research programme includes egg and larvae surveys and hydroacoustic stock assessment surveys. Results of these egg and larvae surveys provide information on the spatial and temporal variability of Jack mackerel larvae along the Peruvian coast from 1966 to-date. A new series of acoustic biomass was provided by Peru for years 1986-2013. This series represents estimations based on the assumption of shifts in habitat area and its impact over traditional estimations. Acoustic biomass estimates of Jack mackerel are available from 1983 to-date. Because these surveys have the Peruvian anchoveta as the main target, data only covers the first 80 miles and eventually 100 miles from the coast. Corrections to compensate for this partial coverage of acoustic biomass estimates of Jack mackerel are being made by using an environmental index describing the potential habitat of this species based available data on Sea Surface Temperature (SST), Sea Surface Salinity (SSS), water masses (WM), oxycline depth (OD) and chlorophyll (CHL), since 1983 to the present on monthly basis.

Acoustic surveys, to estimate the biomass and distribution of Jack Mackerel, have been conducted along the Chilean coast, inside and outside of the EEZ and in the Peruvian EEZ, using scientific vessels and well-equipped vessels from the commercial fleet. The available acoustic estimates time series extends from 1984 to 2012. (depending on the area).

In 2012, the conversion of length composition (to age) from Peru and Ecuador was developed. Fishery length compositions (total length since 1980, converted to fork length) were included.

All CPUE (and fishery-independent) series used in the model are presented in Table A5.7.

Biological parameters

The maturity-at-age was updated based on a Chilean study (SWG-11-JM-07). The application of these results reduced the age at first reproduction by about one year, to 2-3 years from the 3-4 years used previously. Maturity at length was consistently observed with L50 at about 23 cm FL. These values, and those for the far-north stock, are shown in A5.8.

To fit the length composition data from the far-north fleet, a growth curve was used to convert age compositions to predicted lengths in the model. The value for the von Bertalanfy growth parameters are given in Table A5.9.

In Chile the mean weight at age is calculated by year taken the mean length at age in the catch and a length-weight relationship of the year. In previous year the same weight at age matrix was used for the Northern Chilean Fleet (Fleet 1) and Southern Chilean Fleet (Fleet 2). This year a weight at age matrix specific for Northern Chile has been applied. The method uses two information sources: the length-age keys and the parameters of weight-at-length relationship from IFOP's monitoring program of the Chilean fisheries. The information was separated in two zones which correspond to fishing areas (and acoustic surveys) occur in Chile. Annual weight-at-length relationship was fitted to the data by each fleet independently and these relationships were applied to mean length at-age within each zone. The information covers the period 1974-2013; for earlier years the weight at age from 1974 was used. The four weight at-age matrices correspond to: north fleet, central-south fleet, north acoustic survey, and central-south acoustic survey. These are shown in Tables A5.10 - A5.13.

In Peru the mean weight at age is calculated by year taking the invariant mean length at age estimated from the growth function (Table A.5.9) and the length-weight relationship of the year. The information covers the period 1970-2012.

Estimates of natural mortality are derived from Pauly´s method, using the Gili et al (1995) growth function for Chile and the Dioses (2013) growth function for Peru. The estimated M values are assumed to be the same for all ages and all years within the given stock.

Data sets

A summary list of all data available for the assessment is provided in Table A5.14.

Description of assessment model

A statistical catch-at-age model was used to evaluate the jack mackerel stocks. The JJM ("Joint Jack Mackerel Model") is implemented in ADMB and considers different types of information, which corresponds to the available data of the jack mackerel fishery in the South Pacific area since 1970 to 2013.

The JJM model is an explicit age-structured model that uses a forward projection approach and maximum likelihood estimation to solve for model parameters. The operational population dynamics model is defined by the standard catch equation with various modifications such as those described by Fournier and Archibald (1982), Hilborn and Walters (1992) and Schnute and Richards (1995). This model was adopted as assessment method in 2010 after several technical meetings (http://www.southpacificrfmo.org/jack-mackerel-sub-group/).

JJM developments

Since its adoption, the JJM model has been improved by participating scientists. The most noted change has been options to include length composition data (and specifying or estimating growth) and the capability to estimate natural mortality by age and 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.

The model can be considered to consist of several components, (i) the dynamics of the fish population; (ii) the fishery dynamics; (ii) observation models for the data; and (v) parameter estimation procedure.

Population dynamics: the recruitments are considered to occur in January while the spawning season is considered as instantaneous process at mid of November. The population's age comps considers individuals from 1 to 12+ years old, and a stochastic relationship (Beverton & Holt) between stock and recruitment is included. The survivors follow the age-specific mortality composed by fishing mortalities at-age by fleet and the natural mortality, the latest one supposed to be constant over time and ages. The model is spatially aggregated except that the fisheries are geographically distinct. The initial population is based on an equilibrium condition and occurs in 1958 (12 years prior to the model start in 1970).

Fishery dynamics: The interaction of the fisheries with the population occurs through fishing mortality. Fishing mortality is assumed to be a composite of several separable processes – selectivity (by fleets), which describes the age-specific pattern of fishing mortality; catchability, which scales fishing effort to fishing mortality; and effort deviations, which are a random effect in the fishing effort − fishing mortality relationship. The selectivity is non-parametric and assumed to be fishery-specific and time-variant. The catchability is fixed by index and is estimated in nine abundance indexes. However, for some of these, e.g. the acoustic biomass from Peru and Chile (south) and the CPUE of southern area of Chile, time variations have been considered.

Observation models for the data: There are five data components that contribute to the log-likelihood function − the total catch data, the age-frequency data, the length-frequency data and the abundance indexes data. The observed total catch data are assumed to be unbiased and relatively precise, with the CV of residuals being 0.05.

The probability distributions for the age and length-frequency proportions are assumed to be approximated by multinomial distributions. Sample size is specified to be different by gear but constant over years. Total catch data by fishery (4) and abundance indexes (9), a log-normal assumption has been assumed with constant CV but different by fishery.

- Parameter estimation: The model parameters were estimated by maximizing the log-likelihoods of the data plus the log of the probability density functions of the priors and smoothing penalties specified in the model. Estimation was conducted in a series of phases, the first of which used arbitrary starting values for most parameters. The model has been implemented and compiled in ADMB and whose characteristics can be consulted in Fournier et al (2012)

Model details

Parameters estimated conditionally are listed in Table A5.15. 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 A5.16 and A5.17. Table A5.18 contains the initial variance assumptions for the indices and age and length compositions.

The treatment of selectivities and how they are shared among fisheries and indices are given in Table A5.19, A5.20 and A5.21. Also depending on the model configuration, some growth functions were employed inside the model to convert length compositions to age compositions. Initial variance assumptions and

Models for stock structure hypothesis

During SWG 11, two types of population structure were evaluated and this was continued for SC-01 evaluations. The following table summarizes these hypotheses with cross reference to models presented Table A5.22:

Model reference	Stock/Hypothesis	Fleets	Considerations
2.xN	Northern Stock (Hypothesis #1, SPRFMO/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.
2.xS	Southern Stock (Hypothesis #1 and #3, SPRFMO/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.
0.x, 1.x 3.x 4.x	A single stock (Hypothesis #2, SPRFMO/FAO 2008)	All fleets	This considers the hypothesis that the northern and southern stock correspond to a single population unit.

Description of exploratory assessments

Description of key changes from base case assessment to exploratory assessment

As a progression of sensitivities of Model 0.4, there were different approaches to consider catchability (q) changes in 2012 and 2013 in the Chilean CPUE (Model 1.1) and the Peruvian acoustic catchability changes from 1994 (Model 1.2). Then, time-varying selectivity changes were introduce for the South Central Chilean fishery (Model 1.3) and because of the improvement in the adjustments, time- varying selectivity changes were considered for the other fleets. There were exercises, increasing variability in the recruitments (Sigma R=1.0 , Model 1.5) and down weighting indices (Models 1.6, 1.7 and 1.9) and also estimating natural mortality (*M*; Model 1.9). Same model configurations that were used to the single stock hypothesis were implemented as a mirror in Models 2.1 to 2.9 but considering differences in M between areas (M=0.33 and growth function for the Far North model, and M=0.23 for the Southern model). As noted above, these model configurations are summarized in Table A5.22.

Results of exploratory assessments evaluate these, the negative-log likelihood components were presented to evaluate trade-offs between different data components and model assumptions.

Assessment 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 (Table A5.23). 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 with different stock structure hypotheses (i.e., those identified with 2.0-2.9) require consideration of the number of parameters.

For projection purposes, alternative considerations about recruitment regimes and productivity were configured as Models 4.1-4.4. Based on results over all models and sensitivities including ageing error, Model 4.1 (which is identical to 3.1) was selected as the base case for assessment results.

Results comparing the impact of new data (models 0.0-0.4) show that for the starting model configuration, the biomass trend was a bit more gradual and recruitment varied more as all the data were included (Figure A5.2). For the alternative model configurations the range of uncertainty was reasonably broad for the recent trend in spawning biomass but overall the patterns were quite similar (Figure A5.3). The rationale for selecting model 1.4 among these was due to the improved fit to the data and a broader representation of the uncertainty among indices and age compositions. The other alternative configurations (models 1.1-1.9) were largely consistent (except for 1.8 in which an unrealistically high value of M was estimated). Comparing model 1.4 with the alternative stock structure indicated that the "south" model (2.4_S) was very similar to the combined stock-structure model (1.4; Figure A5.4). Comparing the recruitment patterns in this figure, it appears that the far-north model some synchrony in recruitment except for in 1990 and a few other years. This may be due to divergent environmental conditions and may lend some support to the two-stock hypothesis.

Fishery catch fits are shown in Figure A5.5 and mean weight-at-age assumed for this model is shown in Figure A5.6. The model numbers-at-age estimates are given in Table A5.24. The fishery age and length composition fits are shown in Figures A5.7, A5.8, A5.9, and A5.10. The age composition data from the surveys are given in Figures A5.11 and A5.12. This model fit the indices reasonably well (Figure A5.13). Fits to the index and fishery mean age compositions are shown in Figures A5.14, and A5.15.

Selectivity estimates for the fishery and indices is shown over time in Figs. A5.16 and A5.17 respectively. A summary of the time series stock status (spawning biomass, F, recruitment, total biomass) is shown in Fig. A5.18. The immature component of the stock appears to be increasing since about 2008 and the mature component of the stock has also begun to show signs of stabilization and possibly an increase (Fig. A5.19). As in past years, the biomass can be projected forward based on the estimated recruits (with an adjustment due to the change in spawning biomass through the stock recruitment relationship) to evaluate the impact of fishing. This can be informative to distinguish environmental effects relative to direct fishing impacts. For jack mackerel fishing has appeared to be a major cause of the population trend with the current level at below 20% of what is estimated to have occurred had there been no fishing (Fig. A5.20).

Fishing mortality rates at age (combined fleets) were relatively high starting in about 1992 but has declined in the past few years (Fig. A5.21; Table A5.25.). The stock recruitment relationship appears to be consistent with the fixed value of steepness assumed (0.8; Fig. A5.22). 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. A5.23).

Management advice

Projections and risk analysis

Considering the actual population status of jack mackerel, the subgroup recommended examining constant fishing mortality scenarios with current levels (F_{2013}) and at 125%, 75%, 50%, and 0% (no catch). For evaluation purposes, four recruitment scenarios were developed which reflected hypotheses about the scale of the recruitment (by period or "regime") and the stock recruitment productivity near the origin (stock recruitment "steepness"). The scale of recruitment was affected by the "regime" (2000-2011) and steepness hypotheses were specified at values of 0.8 and 0.65 (Figure A5.23). In addition to these specified sources of uncertainty, uncertainty in all other internally-estimated model parameters along with future recruitment variability were also propagated forward. An evaluation of risk was developed that was conditioned on this uncertainty. Objectives considered included the goal to rebuild the stock to the long-term expected B_{MSY} level using likely recruitment scenarios expected in the near-term.

Projections using the entire time series of recruitment (1970-2011) under the assumption of constant fishing mortality equal to 2013 levels (Models 4.1 and 4.4) indicate that the biomass is expected to increase over the next 10 years, eventually reaching B_{MSY} in about 5 years. Projections using recruitment levels from 2000-2011 (believed be a period of lower productivity compared to that prior to 2000; Models 4.2 and 4.3) indicate that the biomass is expected to increase over the next 5 years but then stabilize at a point below the agreed provisional B_{MSY} (Figure A5.24). The 2014 catch that corresponds to the 2013 estimated effort level is 440,000 t.

Assessment issues

The assessment in 2012 estimated SSB in 2012 at 1.5 million tons. The 2013 assessment however estimates SSB in 2012 at 2.4 million tons, a marked increase. The point estimate for the 2012 fishing mortality went from 0.27 in the 2012 assessment compared to 0.15 from currently accepted model. These differences can be explained by updated data including different mean weights-at-age than assumed in the past as well as catch and index information. Also, the current model fits the available data substantially better than previous assessments and is based on a more rigorous examination of statistical weights placed on different types and sources of data. However, the overall trends between the 2012 assessment and the present one are quite similar.

The quality of the input data improved considerably from 2012 to 2013 with the inclusion of variable weight-at-age matrices for different datasets and standardization of indices. The lack of standardization in the EU and Russian CPUE time series is still a concern but does not seem to affect the assessment results. Potentially, allowing the stock assessment model to fit to length frequency data of these fisheries might improve the offshore fleet fits.

The inability to adequately estimate natural mortality, either internally or from other approaches, continues to be a concern. Estimating natural mortality within the stock assessment model resulted in implausible values. As natural mortality might be related to variable environmental conditions, explorations of time-varying estimation and alternative model configurations should be pursued in future evaluations.

During the discussion of management control rules and reference points the issue of "unfished" biomass was noted as needing clearer descriptions. In fact, there are a variety of definitions which often may have interchangeable symbols or phrases to represent them. The table below provides a summary of some definitions to help clarify considerations of stock depletion levels and other biological reference points:

Symbol	Definition	Notes
B_0	From a stock recruitment relationship it is the point where the equilibrium stock size will generate the recruitment needed to maintain the population at that level	This is the classical age-structured definition. Inversely correlated with stock recruitment steepness it is difficult to reliably estimate. Provides the only theoretical basis for B_{MSY} estimation
Dynamic B_0 or Unfished biomass	Given an age structured model with estimates of recruitment in each year, it is the spawning biomass that would exist had no fishing mortality occurred (i.e., the historical population is projected forward from these recruits with only natural mortality	Has an advantage in that it may show the extent of population declines due to environmental conditions relative to the impact of fishing. Easy to estimate and compute.
$B_{100\%}$	Spawning biomass given some average recruitment level computed as $\bar{R}\varphi$ where φ is the expected life-time contribution of spawning biomass per recruit under no fishing (a function of natural mortality, age-specific maturity and growth)	Sometimes used as a proxy for B_0. Often used in conjunction with the proxy F_{MSY} rate. E.g., $F_{35\%}$ is the fishing mortality that will reduce spawners-per-recruit (SPR) to 35% of their unfished level. Depends on assumed average recruitment but avoids stock recruitment curve estimation.

Management would benefit from having either biomass or fishing mortality targets / limits at hand. Decisions on these targets could be informed results from SC-01-05 and SC-01-17. The assessment appears to be maturing to the point where issues of model specification are diminishing. A next step would be to more fully embrace the work presented SC-01-17, specifically the part that functions as a conditioned operating model (given current assessment configurations) for use to test management procedures (or management strategies). More work is needed to develop transparent control rules that can be tested against this type of operating model (e.g., the three rules covered in SC-01-17). These would need to be evaluated by performance indicators relevant to the objectives of the Commission. This document highlights some of the complexities involved in defining "recovery plans" (i.e., recovery to what?) given recent recruitment estimates and environmental conditions. Management strategies robust to these conditions require further development.

A5. References

Dioses, T. 2013. Edad y crecimiento del jurel *Trachurus murphyi* en el Perú. In: Csirke J., R. Guevara-Carrasco & M. Espino (Eds.). Ecología, pesquería y conservación del jurel (*Trachurus murphyi*) en el Perú. Rev. Peru. biol. número especial 20(1): 045- 052

Fournier, D. & C.P. Archibald. 1982. A general theory for analyzing catch at age data. Can. J. Fish. Aquat. Sci. 39: 1195-1207

Gavaris, S., Ianelli, J. N., 2001. Statistical issues in fisheries stock assessment. Scand. J. Statistics: Theory and Appl., 29, 245-272.

Gang Li, Xiaorong Zou, Yinqi Zhou & Lin Lei. Update Standardization of CPUE for Chilean Jack Mackerel (*Trachurus murphyi*) from Chinese Trawl Fleet. SWG-11-JM-08, 2011. 11th Meeting of the Science Working Group, Lima, Perú.

Gili, R., L. Cid, V. Bocic, V. Alegría, H. Miranda & H. Torres. 1995. Determinación de la estructura de edad del recurso jurel. In: Estudio biológico pesquero sobre el recurso jurel en la zona centro-sur, V a IX Regiones. Informes Técnicos FIP/IT-93-18.

Hilborn, R. & C.J. Walters. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. Chapman and Hall, New York: 570 p.

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

Leal, E., E. Diaz & J.C. Saavedra, 2011. Reproductive Timing and Maturity at Length and Age of Jack Mackerel Trachurus murphyi, in the Chilean Coast SWG-11-JM-07, 2011. 11th Meeting of the Science Working Group, Lima, Perú.

Saavedra J.C, L. Caballero & C. Canales, 2011. Analysis of the CPUE in the Jack Mackerel Fishery in centre-southern Chile. SWG-11-JM-06. 11th Meeting of the Science Working Group, Lima, Perú.

Serra R. and C. Canales 2009. Short review of some biological aspects of the Chilean jack mackerel, *Trachurus murphyi*. Working Paper SP-07-SWG-JM-SA-05. Jack Mackerel Stock Assessment Methods Workshop. Lima, Peru.

Schnute, J.T., & L.J. Richards. 1995. The influence of error on population estimates from catch-age models. Canadian Journal of Fisheries and Aquatic Sciences, 52(10): 2063-2077

SPRFMO/FAO. 2008. Report of the South Pacific Fisheries Management Organization (SPRFMO) Chilean Jack Mackerel Workshop. Chilean Jack Mackerel Workshop, organized and convened jointly by the SPRFMO and the Government of Chile, with Technical Assistance from the Food and Agriculture Organization of the United Nations (FAO). Santiago, Chile, 30 June-4 July 2008: 71pp.

A5. Tables

Table A5.1. Sources and values of catch (t) compiled for the four fleets used for the assessment.

Year	Fleet 1 N Chile	Fleet 2 Chile CS	Fleet 3 (Far North) Cook Islands	Cuba (2)	Ecuador (ANJ)	Peru (ANJ)	USSR	Subtotal	Fleet 4 (Offshore Trawl) Belize	China	Cuba	European Union	Faroe Islands	Japan	Korea	Peru	Russia/ USSR	Ukraine	Vanuatu	Subtotal	Total
1970	101685	10309				4711		4711												0	116705
1971	143454	14988				9189		9189												0	167631
1972	64457	22546				18782		18782									5500			5500	111285
1973	83204	38391				42781		42781												0	164376
1974	164762	28750				129211		129211												0	322723
1975	207327	53878				37899		37899												0	299104
1976	257698	84571				54154		54154						35						35	396458
1977	226234	114572				504992		504992						2273						2273	848071
1978	398414	188267				386793	0	386793						1667	403		49220			51290	1024764
1979	344051	253460		6281		151591	175938	333810			12719	1180		120			356271			370290	1301611
1980	288809	273453		38841		123380	252078	414299			45130	1780					292892			339802	1316363
1981	474817	586092		35783		37875	371981	445638			38444			29			399649			438123	1944670
1982	789912	704771		9589		50013	84122	143724			74292	7136					651776			733204	2371611
1983	301934	563338		2096		76825	31769	110690			52779	39943		1694			799884			894300	1870262
1984	727000	699301		560		184333	15781	200674			33448	80129		3871			942479			1059927	2686902
1985	511150	945839		1067		87466	26089	114622			31191			5229			762903			799323	2370934
1986	55210	1129107		66		49863	1100	51029			46767			6835			783900			837502	2072848
1987	313310	1456727		0		46304	0	46304			35980			8815			818628			863423	2679764
1988	325462	1812793		5676		118076	120476	244229			38533			6871			817812			863215	3245699
1989	338600	2051517		3386	35108	140720	137033	316247			21100			701			854020			875821	3582185
1990	323089	2148786		6904	4144	191139	168636	370823			34293			157			837609			872059	3714757
1991	346245	2674267		1703	45313	136337	30094	213447			29125						514534			543659	3777618
1992	304243	2907817		0	15022	96660	0	111682			3196						32000	2736		37932	3361674
1993	379467	2856777			2673	130681		133354												0	3369598
1994	222254	3819193			36575	196771		233346												0	4274793
1995	230177	4174016			174393	376600		550993												0	4955186
1996	278439	3604887			56782	438736		495518												0	4378844
1997	104198	2812866			30302	649751		680053												0	3597117
1998	30273	1582639			25900	386946		412846												0	2025758
1999	55654	1164035			19072	184679		203751						7						7	1423447
2000	118734	1115565			7121	296579		303700		2318										2318	1540317
2001	248097	1401836			134011	723733		857744		20090										20090	2527767
2002	108727	1410266			604	154219		154823		76261										76261	1750077
2003	143277	1278019			0	217734		217734		94690					2010		7540		53959	158199	1797229
2004	158656	1292943			0	187369		187369		131020					7438		62300		94685	295443	1934411
2005	165626	1264808			0	80663		80663	867	143000		6179			9126		7040		77356	243568	1754665
2006	155256	1224685			0	277568		277568	481	160000		62137			10474		0		129535	362627	2020136
2007	172701	1130083	7		927	254426		255360	12585	140582		123511	38700		10940		0		112501	438818	1996962
2008	167258	728850	0		0	169537		169537	15245	143182		106665	22919		12600		4800		100066	405477	1471122
2009	134022	700905	0		1935	74694		76629	5681	117963		111921	20213	0	13759	13326	9113		79942	371918	1283474
2010	169012	295796	0		4613	17559		22172	2240	63606		67749	11643	0	8183	40516			45908	239845	726825
2011	30825	216470	0		69153	257241		326394	0	32862	8	2248	0	0	9253	674	8229		7672	60946	634635
2012	16208	211252	0		104	168779		168883	0	13012	0	0	0	0	5492	5290	0		16068	39862	436205
2013	31000	211013	0		2477	50000		52477		10000		8992			5054	3772			19412	47230	341720

Underlined figures have been updated; the 2013 figures are the best catch estimates for the entire year.

Table A5.2. Input catch by fleet (combined) for the stock assessment model. Note that 2013 data are preliminary.

	Fleet 1	Fleet 2	Fleet 3	Fleet 4
1970	101,685	10,309	4,711	0
1971	143,454	14,988	9,189	0
1972	64,457	22,546	18,782	5,500
1973	83,204	38,391	42,781	0
1974	164,762	28,750	129,211	0
1975	207,327	53,878	37,899	0
1976	257,698	84,571	54,154	35
1977	226,234	114,572	504,992	2,273
1978	398,414	188,267	386,793	51,290
1979	344,051	253,460	333,810	370,290
1980	288,809	273,453	414,299	339,802
1981	474,817	586,092	445,638	438,123
1982	789,912	704,771	143,724	733,204
1983	301,934	563,338	110,690	894,300
1984	727,000	699,301	200,674	1,059,927
1985	511,150	945,839	114,622	799,323
1986	55,210	1,129,107	51,029	837,502
1987	313,310	1,456,727	46,304	863,423
1988	325,462	1,812,793	244,229	863,215
1989	338,600	2,051,517	316,247	875,821
1990	323,089	2,148,786	370,823	872,059
1991	346,245	2,674,267	213,447	543,659
1992	304,243	2,907,817	111,682	37,932
1993	379,467	2,856,777	133,354	0
1994	222,254	3,819,193	233,346	0
1995	230,177	4,174,016	550,993	0
1996	278,439	3,604,887	495,518	0
1997	104,198	2,812,866	680,053	0
1998	30,273	1,582,639	412,846	0
1999	55,654	1,164,035	203,751	7
2000	118,734	1,115,565	303,700	2,318
2001	248,097	1,401,836	857,744	20,090
2002	108,727	1,410,266	154,823	76,261
2003	143,277	1,278,019	217,734	158,199
2004	158,656	1,292,943	187,369	295,443
2005	165,626	1,264,808	80,663	243,568
2006	155,256	1,224,685	277,568	362,627
2007	172,701	1,130,083	255,360	438,818
2008	167,258	728,850	169,537	405,477
2009	134,022	700,905	76,629	371,918
2010	169,012	295,796	22,172	239,845
2011	30,825	216,470	326,394	60,946
2012	16,208	211,252	168,883	39,862
2013	31,000	211,013	52,477	47,230

Table A5.3. 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 A5.4. 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	7	31	31	18	7	4	1	0	0
2013	0	0	3	21	26	31	16	3	0	0	0	0

Table A5.5. 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
2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	2	15	32	27	14	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	2	2	4	4	11	8	5	2	0	1	1	1	3	12	20	15	4	1	0	0	0	0	0	0	0	0

Table A5.6. 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
2013	0	2	1	7	12	21	27	13	7	6	2	2

Table A5.7. Index values used within the assessment model. Legend:

Chile (1): Acoustics for south-central zone in Chile
Chile (2): Acoustics for northern zone in Chile
Chile (3): Chilean south-central fishery CPUE for fleet 2
Chile (4): Daily Egg Production Method
Peru(1): Peruvian acoustic index in fleet 3
Peru(2): Peruvian fishery CPUE in fleet 3
China: Chinese CPUE for fleet 4
EU_U: CPUE for EU in fleet 4
Rus./USSR: Catch per day from Russian/USSR in fleet 4

Year	Chile (1)	Chile (2)	Chile (3)	Chile (4)	Peru(1)	Peru(2)	China	EU_U	Russia/USSR
1983			0.646						
1984		99	0.569						
1985		324	0.466						
1986		123	0.402		17811				
1987		213	0.481		22955				55.020
1988		134	0.410		9459				58.240
1989			0.419		15034				51.060
1990			0.333		14139				52.570
1991		242	0.409		16486				60.990
1992			0.349		6266				
1993			0.302		19659				
1994			0.359		10768				
1995			0.322		6429				
1996			0.334		7271				
1997	3530		0.293		2561				
1998	3200		0.277		190				
1999	4100		0.329	5724	342				
2000	5600		0.309	4688	2373				
2001	5950		0.397	5627	2052		1.144		
2002	3700		0.331		248	214	2.022		
2003	2640		0.289	1388	1118	245	1.607		
2004	2640		0.316	3287	864	278	1.190		
2005	4110		0.287	1043	1025	195	1.190		
2006	3192	112	0.316	3283	1678	247	0.782	310	
2007	3140	275	0.240	626	522	232	0.873	308	
2008	487	259	0.161	1935	223	221	0.666	256	77.419
2009	328	18	0.134		849	184	0.634	209	59.563
2010		440	0.099				0.499	124	
2011		432	0.057		678	268	0.392	57	45.213
2012		230	0.173		94	267	0.408		
2013			0.148		890			81	

Table A5.8. 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 A5.9. Growth parameters and natural mortality.

Parameter	Far North stock	South Stock	Single stock
L_∞ (cm) (Total length)	80.77	-	80.77
k	0.16	-	0.16
t_0 (year)	-0.356	-	-0.356
M ($year^{-1}$)	0.33	0.23	0.23

Table A5.10. Input mean body mass (kg) at age over time assumed for fleet 1.

Fleet 1	1	2	3	4	5	6	7	8	9	10	11	12+
1975	0.050	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.880	1.115
1976	0.050	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.880	1.115
1977	0.050	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.880	1.115
1978	0.050	0.105	0.124	0.163	0.204	0.314	0.369	0.405	0.434	0.453	0.590	1.115
1979	0.050	0.108	0.163	0.179	0.217	0.274	0.370	0.420	0.474	0.629	0.633	1.115
1980	0.050	0.069	0.118	0.210	0.256	0.324	0.410	0.451	0.511	0.998	0.880	1.115
1981	0.050	0.094	0.139	0.214	0.269	0.331	0.412	0.481	0.580	0.661	1.112	1.115
1982	0.071	0.093	0.168	0.202	0.248	0.305	0.356	0.411	0.446	0.471	0.719	1.115
1983	0.084	0.099	0.119	0.221	0.264	0.314	0.377	0.429	0.475	0.528	0.540	1.115
1984	0.050	0.164	0.186	0.217	0.273	0.345	0.394	0.437	0.497	0.568	0.786	1.115
1985	0.050	0.167	0.173	0.224	0.271	0.340	0.401	0.465	0.536	0.582	0.726	1.115
1986	0.096	0.099	0.143	0.222	0.289	0.332	0.418	0.497	0.550	0.869	0.880	1.115
1987	0.092	0.121	0.146	0.189	0.233	0.336	0.427	0.477	0.513	0.650	0.803	1.115
1988	0.050	0.110	0.167	0.197	0.230	0.298	0.472	0.545	0.586	0.610	0.880	1.115
1989	0.050	0.123	0.167	0.230	0.270	0.310	0.379	0.491	0.541	0.569	0.713	1.115
1990	0.069	0.099	0.160	0.248	0.290	0.338	0.409	0.533	0.651	0.677	0.756	1.115
1991	0.049	0.121	0.143	0.201	0.277	0.366	0.408	0.478	0.637	0.720	0.794	0.883
1992	0.069	0.092	0.127	0.201	0.268	0.300	0.373	0.444	0.512	0.595	0.681	0.786
1993	0.021	0.116	0.152	0.205	0.298	0.364	0.422	0.489	0.528	0.596	0.774	0.889
1994	0.059	0.097	0.107	0.235	0.291	0.330	0.387	0.459	0.565	0.748	0.798	0.898
1995	0.069	0.101	0.137	0.186	0.263	0.321	0.357	0.434	0.561	0.668	0.880	1.115
1996	0.067	0.000	0.140	0.170	0.229	0.295	0.367	0.507	0.657	0.639	0.880	1.115
1997	0.029	0.063	0.125	0.177	0.246	0.357	0.503	0.615	0.584	0.728	0.880	1.115
1998	0.000	0.082	0.104	0.195	0.249	0.290	0.390	0.475	0.634	0.728	0.880	1.115
1999	0.071	0.074	0.089	0.147	0.270	0.315	0.446	0.722	0.584	0.728	0.880	1.115
2000	0.043	0.054	0.138	0.191	0.225	0.251	0.372	0.488	0.584	0.728	0.880	1.115
2001	0.066	0.093	0.112	0.133	0.204	0.286	0.421	0.488	0.584	0.728	0.880	1.115
2002	0.029	0.059	0.092	0.172	0.238	0.327	0.398	0.416	0.628	0.728	0.880	1.115
2003	0.036	0.082	0.102	0.141	0.227	0.309	0.416	0.464	0.534	0.728	0.880	1.115
2004	0.037	0.078	0.164	0.186	0.203	0.257	0.342	0.488	0.584	0.728	0.880	1.115
2005	0.029	0.076	0.111	0.175	0.222	0.268	0.281	0.488	0.584	0.728	0.880	1.115
2006	0.032	0.074	0.114	0.132	0.204	0.374	0.442	0.506	0.606	0.728	0.880	1.115
2007	0.087	0.075	0.122	0.158	0.222	0.296	0.404	0.514	0.614	0.723	0.723	1.115
2008	0.042	0.047	0.066	0.187	0.243	0.291	0.388	0.563	0.616	0.748	0.880	1.115
2009	0.015	0.047	0.106	0.138	0.239	0.285	0.335	0.526	0.584	0.728	0.880	1.115
2010	0.013	0.048	0.101	0.172	0.233	0.301	0.397	0.493	0.639	0.772	0.880	1.115
2011	0.019	0.065	0.095	0.167	0.276	0.314	0.398	0.488	0.584	0.728	0.880	1.115
2012	0.016	0.048	0.088	0.202	0.235	0.269	0.396	0.488	0.584	0.728	0.880	1.115
2013	0.050	0.090	0.129	0.188	0.248	0.312	0.395	0.488	0.565	0.687	0.821	1.086

Table A5.11. Input mean body mass (kg) at age over time assumed for fleet 2.

Fleet 2	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	0.078	0.155	0.214	0.275	0.336	0.394	0.472	0.632	0.714	0.898	1.538
1977	0.055	0.092	0.109	0.236	0.275	0.314	0.375	0.456	0.521	0.732	0.651	1.137
1978	0.052	0.084	0.104	0.147	0.211	0.327	0.394	0.449	0.514	0.583	0.631	1.538
1979	0.052	0.108	0.160	0.199	0.241	0.301	0.388	0.466	0.588	0.871	1.265	1.972
1980	0.026	0.060	0.132	0.231	0.272	0.350	0.447	0.519	0.716	0.820	1.073	1.854
1981	0.052	0.095	0.149	0.242	0.294	0.340	0.407	0.503	0.637	0.765	1.184	1.900
1982	0.055	0.085	0.166	0.207	0.269	0.323	0.378	0.472	0.536	0.644	0.987	1.185
1983	0.070	0.099	0.122	0.230	0.273	0.320	0.374	0.461	0.596	0.709	1.196	1.769
1984	0.035	0.135	0.154	0.185	0.266	0.330	0.383	0.449	0.577	0.685	1.012	1.846
1985	0.058	0.148	0.181	0.223	0.270	0.339	0.398	0.473	0.573	0.796	1.376	1.647
1986	0.073	0.075	0.172	0.247	0.286	0.346	0.427	0.518	0.640	0.844	1.351	2.110
1987	0.076	0.117	0.140	0.191	0.270	0.357	0.434	0.503	0.577	0.689	1.089	1.979
1988	0.100	0.124	0.159	0.197	0.233	0.342	0.444	0.512	0.588	0.750	1.012	1.372
1989	0.052	0.103	0.220	0.241	0.278	0.339	0.467	0.585	0.702	0.779	0.880	1.538
1990	0.064	0.091	0.153	0.264	0.309	0.373	0.461	0.582	0.694	0.835	0.970	1.598
1991	0.037	0.106	0.132	0.186	0.271	0.381	0.451	0.542	0.667	0.787	0.901	1.053
1992	0.063	0.083	0.118	0.177	0.239	0.275	0.409	0.524	0.594	0.709	0.851	1.046
1993	0.011	0.089	0.121	0.181	0.246	0.320	0.408	0.579	0.719	0.853	0.965	1.174
1994	0.041	0.084	0.112	0.224	0.270	0.336	0.462	0.643	0.808	0.868	1.058	1.421
1995	0.070	0.098	0.145	0.192	0.270	0.340	0.429	0.577	0.807	0.965	1.115	1.367
1996	0.061	0.092	0.151	0.191	0.280	0.352	0.524	0.683	0.945	1.216	1.426	1.477
1997	0.104	0.106	0.146	0.201	0.260	0.355	0.495	0.683	0.884	1.088	1.467	1.647
1998	0.084	0.128	0.138	0.178	0.248	0.340	0.545	0.806	1.035	1.246	1.412	1.655
1999	0.090	0.109	0.134	0.174	0.250	0.331	0.465	0.742	1.021	1.258	1.376	1.776
2000	0.043	0.064	0.163	0.196	0.255	0.346	0.466	0.756	0.999	1.141	1.228	1.563
2001	0.066	0.098	0.122	0.179	0.258	0.325	0.461	0.614	0.828	1.074	1.360	1.671
2002	0.031	0.074	0.130	0.200	0.257	0.329	0.445	0.645	0.883	1.102	1.321	1.649
2003	0.036	0.086	0.117	0.186	0.245	0.307	0.400	0.564	0.768	1.005	1.209	1.537
2004	0.034	0.080	0.158	0.193	0.247	0.307	0.387	0.528	0.700	0.897	1.087	1.541
2005	0.029	0.075	0.113	0.196	0.259	0.318	0.399	0.517	0.641	0.767	0.918	1.296
2006	0.033	0.076	0.116	0.141	0.261	0.350	0.419	0.516	0.631	0.752	0.924	1.263
2007	0.086	0.074	0.121	0.172	0.226	0.331	0.431	0.510	0.621	0.756	0.903	1.177
2008	0.036	0.048	0.069	0.186	0.254	0.312	0.416	0.515	0.605	0.719	0.861	1.148
2009	0.014	0.045	0.109	0.142	0.253	0.330	0.411	0.532	0.625	0.764	0.886	1.144
2010	0.014	0.052	0.101	0.175	0.237	0.313	0.415	0.539	0.649	0.787	0.964	1.473
2011	0.019	0.067	0.101	0.190	0.287	0.353	0.466	0.613	0.774	0.923	1.173	1.514
2012	0.007	0.014	0.082	0.202	0.264	0.353	0.476	0.558	0.711	0.912	1.146	1.600
2013	0.052	0.125	0.268	0.263	0.310	0.362	0.431	0.507	0.678	0.726	0.936	1.143

Table A5.12. Input mean body mass (kg) at age over time assumed for fleet 3.

Fleet 3	1	2	3	4	5	6	7	8	9	10	11	12+
1975	0.034	0.136	0.310	0.540	0.808	1.095	1.387	1.674	1.946	2.201	2.434	2.645
1976	0.044	0.160	0.340	0.567	0.822	1.087	1.351	1.606	1.845	2.065	2.266	2.446
1977	0.032	0.130	0.294	0.510	0.760	1.028	1.300	1.566	1.818	2.054	2.270	2.465
1978	0.032	0.129	0.295	0.516	0.774	1.050	1.332	1.608	1.872	2.117	2.343	2.547
1979	0.036	0.138	0.304	0.518	0.762	1.020	1.280	1.532	1.770	1.991	2.193	2.375
1980	0.036	0.136	0.298	0.506	0.743	0.994	1.245	1.490	1.721	1.934	2.130	2.306
1981	0.041	0.148	0.314	0.524	0.758	1.003	1.247	1.481	1.702	1.905	2.089	2.255
1982	0.039	0.144	0.309	0.519	0.755	1.002	1.249	1.488	1.712	1.920	2.108	2.278
1983	0.042	0.138	0.280	0.451	0.638	0.828	1.014	1.191	1.356	1.507	1.643	1.764
1984	0.044	0.156	0.328	0.541	0.778	1.024	1.267	1.501	1.719	1.921	2.103	2.267
1985	0.040	0.149	0.322	0.541	0.789	1.048	1.308	1.558	1.794	2.012	2.211	2.389
1986	0.042	0.151	0.323	0.539	0.781	1.033	1.285	1.527	1.755	1.965	2.156	2.327
1987	0.034	0.132	0.294	0.504	0.745	1.001	1.260	1.512	1.751	1.973	2.176	2.359
1988	0.038	0.145	0.315	0.533	0.780	1.041	1.302	1.554	1.793	2.013	2.215	2.396
1989	0.044	0.158	0.337	0.561	0.812	1.074	1.334	1.585	1.821	2.038	2.236	2.413
1990	0.042	0.150	0.320	0.532	0.769	1.017	1.263	1.499	1.722	1.927	2.113	2.280
1991	0.039	0.142	0.305	0.511	0.743	0.985	1.227	1.461	1.680	1.883	2.068	2.234
1992	0.040	0.148	0.318	0.534	0.776	1.031	1.286	1.531	1.763	1.976	2.171	2.346
1993	0.039	0.147	0.323	0.549	0.807	1.080	1.354	1.620	1.871	2.104	2.317	2.508
1994	0.036	0.147	0.335	0.584	0.874	1.186	1.503	1.813	2.109	2.385	2.638	2.867
1995	0.038	0.146	0.318	0.540	0.792	1.058	1.325	1.583	1.827	2.053	2.260	2.446
1996	0.038	0.145	0.317	0.537	0.788	1.053	1.318	1.576	1.820	2.045	2.251	2.436
1997	0.045	0.152	0.312	0.506	0.720	0.940	1.155	1.361	1.553	1.729	1.889	2.031
1998	0.040	0.140	0.294	0.483	0.693	0.911	1.126	1.333	1.526	1.703	1.864	2.008
1999	0.037	0.146	0.324	0.557	0.824	1.107	1.394	1.673	1.938	2.183	2.408	2.611
2000	0.035	0.145	0.336	0.592	0.893	1.218	1.550	1.877	2.189	2.481	2.750	2.994
2001	0.033	0.139	0.324	0.572	0.864	1.180	1.504	1.822	2.127	2.412	2.674	2.912
2002	0.036	0.145	0.330	0.576	0.861	1.167	1.478	1.783	2.074	2.344	2.593	2.817
2003	0.040	0.154	0.341	0.584	0.862	1.157	1.454	1.743	2.017	2.272	2.504	2.714
2004	0.038	0.149	0.333	0.574	0.852	1.148	1.447	1.740	2.017	2.275	2.511	2.724
2005	0.037	0.150	0.341	0.595	0.890	1.206	1.527	1.842	2.142	2.422	2.678	2.911
2006	0.038	0.152	0.347	0.606	0.907	1.230	1.558	1.880	2.187	2.473	2.735	2.973
2007	0.038	0.149	0.335	0.579	0.861	1.161	1.465	1.762	2.044	2.306	2.546	2.763
2008	0.036	0.146	0.334	0.585	0.876	1.190	1.510	1.823	2.122	2.400	2.656	2.888
2009	0.038	0.150	0.337	0.582	0.865	1.167	1.474	1.773	2.057	2.321	2.563	2.782
2010	0.039	0.150	0.332	0.567	0.837	1.123	1.411	1.691	1.956	2.203	2.428	2.631
2011	0.031	0.143	0.351	0.644	1.000	1.395	1.806	2.217	2.614	2.990	3.337	3.655
2012	0.032	0.145	0.349	0.632	0.971	1.344	1.731	2.115	2.485	2.834	3.156	3.449
2013	0.032	0.145	0.349	0.632	0.971	1.344	1.731	2.115	2.485	2.834	3.156	3.449

Table A5.13. Input mean body mass (kg) at age over time assumed for fleet 4.

Fleet 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	0.078	0.155	0.214	0.275	0.336	0.394	0.472	0.632	0.714	0.898	1.538
1977	0.055	0.092	0.109	0.236	0.275	0.314	0.375	0.456	0.521	0.732	0.651	1.137
1978	0.052	0.084	0.104	0.147	0.211	0.327	0.394	0.449	0.514	0.583	0.631	1.538
1979	0.052	0.108	0.160	0.199	0.241	0.301	0.388	0.466	0.588	0.871	1.265	1.972
1980	0.026	0.060	0.132	0.231	0.272	0.350	0.447	0.519	0.716	0.820	1.073	1.854
1981	0.052	0.095	0.149	0.242	0.294	0.340	0.407	0.503	0.637	0.765	1.184	1.900
1982	0.055	0.085	0.166	0.207	0.269	0.323	0.378	0.472	0.536	0.644	0.987	1.185
1983	0.070	0.099	0.122	0.230	0.273	0.320	0.374	0.461	0.596	0.709	1.196	1.769
1984	0.035	0.135	0.154	0.185	0.266	0.330	0.383	0.449	0.577	0.685	1.012	1.846
1985	0.058	0.148	0.181	0.223	0.270	0.339	0.398	0.473	0.573	0.796	1.376	1.647
1986	0.073	0.075	0.172	0.247	0.286	0.346	0.427	0.518	0.640	0.844	1.351	2.110
1987	0.076	0.117	0.140	0.191	0.270	0.357	0.434	0.503	0.577	0.689	1.089	1.979
1988	0.100	0.124	0.159	0.197	0.233	0.342	0.444	0.512	0.588	0.750	1.012	1.372
1989	0.052	0.103	0.220	0.241	0.278	0.339	0.467	0.585	0.702	0.779	0.880	1.538
1990	0.064	0.091	0.153	0.264	0.309	0.373	0.461	0.582	0.694	0.835	0.970	1.598
1991	0.037	0.106	0.132	0.186	0.271	0.381	0.451	0.542	0.667	0.787	0.901	1.053
1992	0.063	0.083	0.118	0.177	0.239	0.275	0.409	0.524	0.594	0.709	0.851	1.046
1993	0.011	0.089	0.121	0.181	0.246	0.320	0.408	0.579	0.719	0.853	0.965	1.174
1994	0.041	0.084	0.112	0.224	0.270	0.336	0.462	0.643	0.808	0.868	1.058	1.421
1995	0.070	0.098	0.145	0.192	0.270	0.340	0.429	0.577	0.807	0.965	1.115	1.367
1996	0.061	0.092	0.151	0.191	0.280	0.352	0.524	0.683	0.945	1.216	1.426	1.477
1997	0.104	0.106	0.146	0.201	0.260	0.355	0.495	0.683	0.884	1.088	1.467	1.647
1998	0.084	0.128	0.138	0.178	0.248	0.340	0.545	0.806	1.035	1.246	1.412	1.655
1999	0.090	0.109	0.134	0.174	0.250	0.331	0.465	0.742	1.021	1.258	1.376	1.776
2000	0.043	0.064	0.163	0.196	0.255	0.346	0.466	0.756	0.999	1.141	1.228	1.563
2001	0.066	0.098	0.122	0.179	0.258	0.325	0.461	0.614	0.828	1.074	1.360	1.671
2002	0.031	0.074	0.130	0.200	0.257	0.329	0.445	0.645	0.883	1.102	1.321	1.649
2003	0.036	0.086	0.117	0.186	0.245	0.307	0.400	0.564	0.768	1.005	1.209	1.537
2004	0.034	0.080	0.158	0.193	0.247	0.307	0.387	0.528	0.700	0.897	1.087	1.541
2005	0.029	0.075	0.113	0.196	0.259	0.318	0.399	0.517	0.641	0.767	0.918	1.296
2006	0.033	0.076	0.116	0.141	0.261	0.350	0.419	0.516	0.631	0.752	0.924	1.263
2007	0.086	0.074	0.121	0.172	0.226	0.331	0.431	0.510	0.621	0.756	0.903	1.177
2008	0.036	0.048	0.069	0.186	0.254	0.312	0.416	0.515	0.605	0.719	0.861	1.148
2009	0.014	0.045	0.109	0.142	0.253	0.330	0.411	0.532	0.625	0.764	0.886	1.144
2010	0.014	0.052	0.101	0.175	0.237	0.313	0.415	0.539	0.649	0.787	0.964	1.473
2011	0.019	0.067	0.101	0.190	0.287	0.353	0.466	0.613	0.774	0.923	1.173	1.514
2012	0.007	0.014	0.082	0.202	0.264	0.353	0.476	0.558	0.711	0.912	1.146	1.600
2013	0.052	0.125	0.268	0.263	0.310	0.362	0.431	0.507	0.678	0.726	0.936	1.143

Table A5.14. 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	-	1970-2013	-	Index: 1984-1988; 1991; 2006-2012 Age comps: 2006-2012	Index: 1999-2008 Age comps: 2001-2008
South-central Chile purse seine	1975-2013	-	1970-2013	1983-2013	1997-2009 Age comps: 1997-2009	-
FarNorth	-	1980-2012	1970-2013	2002-2009, 2011-2012	1983-2013	-
International trawl off Chile	1979-1991	2007-2013*	1978-2013	China (2001-2012); EU & Vanuatu (2006-2013); Russian (1987-1991, 2008-09, 2011)	-	-

(*)Are converted to age using age-length keys of central-southern area off Chile

Table A5.15. Symbols and definitions used for model equations.

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: i = {1970, …., 2013}	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 A5.16. 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, …, 2013	$\varepsilon_i, \sum_{i=1958}^{2013} \varepsilon_i = 0$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
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	$\eta^s{}_j, \sum_{j=1958}^{2013} \eta^s{}_j = 0$	$s_j^s = e^{\eta_{\text{maxage}}^s}$ $j > \text{maxage}$

Table A5.16. (continued) Variables and equations describing implementation of the joint jack mackerel assessment model (JJM).

Eq	Description	Symbol/Constraints	Key Equation(s)
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	$\varphi_i, \sum_{i=1970}^{2013} \varphi_i = 0$	
15)	age effect of fishing (regularized) In year time variation allowed	$\eta^{f}{}_{j}, \sum_{j=1958}^{2013} \eta^{f}{}_{j} = 0$	$s_{ij}^{f} = e^{\eta_{j}^{f}}$ $j \le \text{maxage}$ $s_{ij}^{f} = e^{\eta_{\text{maxage}}^{f}}$ $j > \text{maxage}$
	In years where selectivity is constant over time	$\eta_{i,j}^{f} = \eta_{i-1,j}^{f}$	$i \neq \text{change year}$
16)	Natural Mortality	M	fixed
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 1.	$\tilde{R}_i$	$\tilde{R}_i = \frac{\alpha B_t}{\beta + B_i},$ $\alpha = \frac{4hR_0}{5h-1} \text{and}\, \beta = \frac{B_0(1-h)}{5h-1}$ 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 A5.17. Specification of objective function that is minimized (i.e., the penalized negative of the log-likelihood).

	Likelihood /penalty component		Description / notes
19)	Abundance indices	$L_1 = 0.5\sum_s \frac{1}{cv_s^2}\sum_j log\left(\frac{I_j}{\hat{I}_j}\right)^2$	Surveys / CPUE indexes
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	$L_3 = \lambda_3 \sum_{j=1958}^{2013} \varepsilon^2{}_j$	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	$L_4 = 0.5\sum_f \frac{1}{cv_f^2}\sum_{j=1970}^{2013} log\left(\frac{C^f{}_j}{\hat{C}^f{}_j}\right)^2$	Fit to catch biomass in each year
23)	Proportion at age/length likelihood	$L_5 = -\sum_{v,i,j} n^v P_{i,j/l}^v \log(\hat{P}_{i,j/l}^v)$	*v={s, f}* for survey and fishery age composition observations $P_{i,j/l}$ are the catch-at-age/length proportions n effective sample size
24)	Fishing mortality regularity	F values constrained between 0 and 5	(relaxed in final phases of estimation)
25)	Recruitment curve fit	$L_6 = \frac{0.5}{cv_r^2}\sum_{j=1970}^{2013} log\left(\frac{N_{i,1}}{\tilde{R}_i}\right)^2$	Conditioning on stock-recruitment curve over period 1977-2012.
26)	Priors or assumptions	R_0 non-informative	(Explored alternative values of σ_R^2)
27)	Overall objective function to be minimized	$\dot{L} = \sum_k L_k$	

Table A5.18. Coefficients of variation and sample sizes used in likelihood functions.

Abundance index	cv	Catch biomass likelihood	cv
Acoustic CS- Chile	0.20	N-Chile	0.05
Acoustic N-Chile	0.50	CS- Chile	0.05
CPUE – Chile	0.15	Farnorth	0.05
DEPM – Chile	0.50	Offshore	0.05
Acoustic-Peru	0.20		
CPUE – Peru	0.20		
CPUE- China	0.20		
CPUE-EU	0.20		
CPUE- ex USSR	0.40		
Smoothness for selectivities (indexes)	**λ**	**Proportion at age likelihood (indexes)**	**n**
Acoustic CS- Chile	100	Acoustic CS- Chile	30
Acoustic N-Chile	100	Acoustic N- Chile	30
CPUE – Chile	100	DEPM – Chile	20
CPUE- China	100		
CPUE-EU	100		
CPUE ex-USSR	100		
Smoothness for selectivities (fleets)	**λ**	**Proportion at age likelihood**	**n**
N-Chile	1	N-Chile	20
CS- Chile	25	CS- Chile	50
Farnorth	12.5	Farnorth	30
Offshore	12.5	Offshore	30
Recruitment regularity	**λ**	**S-Recruitment curve fit**	**cv**
	1.4		0.7

Table A5.19. 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	Completely available since 3 yrs old.
3)	Peruvian fishery CPUE	Assumed to be the same as 1)

Table A5.20. 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. Annual variations were considered since 1984
2)	Chilean central and southern area fishery	Estimated from age composition data. Annual variations were considered since 1984.
3)	Offshore trawl fishery	Estimated from age composition data. Annual variations were considered since 1984.
Index series		
4)	Acoustic survey in central and southern Chile	Estimated from age composition data. Two time-blocks were considered 1970-2004; 2005-2013.
5)	Acoustic survey in northern Chile	Estimated from age composition data. Annual variations were considered since 1984.
6)	Central and southern fishery CPUE	Assumed to be the same as 2)
7)	Egg production survey	Estimated from age composition data. Two time-blocks were considered 1970-2002; 2003-2012.
8)	Chinese fleet CPUE (from FAO workshop)	Assumed to be the same as 3)
9)	Vanuatu & EU fleets CPUE	Assumed to be the same as 3)
10)	ex-USSR CPUE	Assumed to be the same as 3) but for earlier period

Table A5.21. 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. Annual variations were considered since 1984
2)	Chilean central and southern area fishery	Estimated from age composition data. Annual variations were considered since 1984.
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)	Offshore trawl fishery	Estimated from age composition data. Annual variations were considered since 1984.
Index series		
5)	Acoustic survey in central and southern Chile	Estimated from age composition data. Two time-blocks were considered 1970-2004; 2005-2013.
6)	Acoustic survey in northern Chile	Estimated from age composition data. Annual variations were considered since 1984.
7)	Central and southern fishery CPUE	Assumed to be the same as 2)
8)	Egg production survey	Estimated from age composition data. Two time-blocks were considered 1970-2002; 2003-2012.
9)	Acoustic survey in Peru	Completely available since 3 yrs old.
10)	Peruvian fishery CPUE	Assumed to be the same as 3)
11)	Chinese fleet CPUE (from FAO workshop)	Assumed to be the same as 4)
12)	Vanuatu & EU fleets CPUE	Assumed to be the same as 4)
13)	ex-USSR CPUE	Assumed to be the same as 4) but for earlier period

Table A5.22. Systematic model progression from the 2012 assessment data to the agreed revised datasets for 2013. Note that the data file names corresponding to each model follow the convention e.g., “Mod0.1.dat” and “Mod0.1.ctl”.

Model	Description
0.0	2012 configuration and data (Model 7c from the 2012 assessment)
0.1	As in Model 0.0 but with the updated catch time series (through 2012 only)
0.2	As in Model 0.1 but with the revised mean weights-at-age provided by Chile
0.3	As in Model 0.2 but extended to 2013 (estimated end-year catches) and with the updated Chilean indices and age compositions
0.4	As in Model 0.3 but with the all other updated indices and age compositions
1.1	As in 0.4 Chilean SC CPUE q change in 2012 and SC Acoustic q step 2002+
1.2	As in 1.1 Peruvian acoustic q change from 1994, and again in 1997
1.3	As in 1.2 but with time-varying selectivity for the SC Chilean fleet
1.4	As 1.3 add time-varying for other fleets
1.5	As 1.4 but SigmaR = 1.0
1.6	As 1.2 but down weight offshore trawl composition data by a factor of 10
1.7	As 1.2 but down weight all indices (and their age or length comps) except Chinese CPUE, SC Chilean CPUE, and SC Acoustics, and downweight offshore age compositions
1.8	As 1.2 w/ M estimated (but constant w/ age and time)
1.9	As 1.2 with all age composition data downweighted by 10
2.1-2.9	Mirrors all of 1.1-1.9 but with split area assessments into north and south components
3.1	As 1.4 but with age-error option turned on
3.2	As 3.1, age-error on, sigmaR=1.0, with downweight all indices (and their age or length comps) except Chinese CPUE, SC Chilean CPUE, and SC Acoustics, and downweight offshore age compositions
3.3	As 3.2 but downweight SC Chile Acoustic Age compositions
4.1	As 3.1; uses recruits from 1970-2011 to scale stock recruitment relationship
4.2	As 3.1 but for projections, use recruits from 2000-2011
4.3	As 3.1 but for projections, fix steepness at 0.65, recent period (2000-2011)
4.4	As 3.1 but for projections, fix steepness at 0.65, using recruits from 1970-2011

Table A5.23. Comparison of jack mackerel models by contributions from negative log-likelihood components based on data and model conditioned priors for one stock hypothesis model (0.0-1.9) and the two-stock hypothesis (2.1-2.9). Some rows are not comparable across all models due to different input data and model assumptions.

Model	Number of parameters	Fishery age	Fishery length	Indices	Index ages	Data sub-total	Fishery selectivity	Index selectivity	Recruit	Prior	Prior sub-total	Total
0.0	378	614	467	522	133	1,737	75	25	25	0	125	1,863
0.1	378	614	467	518	132	1,732	75	25	26	0	125	1,859
0.2	378	616	466	534	132	1,750	74	26	25	0	125	1,877
0.3	383	634	471	571	229	1,907	76	27	21	0	124	2,032
0.4	383	645	534	702	236	2,119	74	28	30	0	131	2,251
1.1	385	630	534	678	233	2,078	74	24	32	0	130	2,208
1.2	387	611	528	405	224	1,772	71	23	17	0	112	1,885
1.3	657	521	525	374	219	1,640	100	22	18	0	140	1,781
1.4	**1,333**	**384**	**422**	**296**	**184**	**1,286**	**271**	**21**	**27**	**0**	**320**	**1,607**
1.5	1,333	365	421	294	183	1,264	268	21	52	0	341	1,606
1.6	387	430	522	385	227	1,568	65	25	2	0	93	1,662
1.7	387	410	508	133	112	1,165	67	20	4	0	90	1,257
1.8	388	574	532	398	227	1,734	68	25	3	15	110	1,845
1.9	387	119	61	229	43	454	34	4	-2	0	36	491
2.1	449	583	417	359	221	1,587	84	22	53	0	159	1,745
2.2	451	583	400	362	221	1,571	84	22	41	0	147	1,732
2.3	721	496	400	328	215	1,441	111	21	42	0	174	1,629
2.4	1383	368	424	270	188	1,253	255	21	48	0	324	1,597
2.5	1383	349	417	261	187	1,217	251	21	94	0	366	1,602
2.6	451	408	400	342	225	1,379	78	23	22	0	123	1,516
2.7	451	391	400	290	113	1,198	79	19	19	0	117	1,328
2.8	453	542	405	321	225	1,497	79	24	31	28	162	1,679
2.9	451	583	59	324	221	1,193	73	22	24	0	119	1,327

Table A5.24. Estimated begin-year numbers at age (Model 4.1), 1970-2013.

	1	2	3	4	5	6	7	8	9	10	11	12+
1970	8,168	5,357	3,437	1,941	1,467	1,237	1,046	915	801	699	607	5,516
1971	5,538	6,488	4,254	2,725	1,537	1,156	957	784	700	629	550	4,819
1972	10,264	4,398	5,150	3,368	2,153	1,204	880	692	587	547	493	4,203
1973	9,007	8,150	3,488	4,068	2,663	1,695	930	656	523	460	430	3,697
1974	9,176	7,145	6,451	2,737	3,202	2,086	1,295	678	487	408	361	3,241
1975	20,605	7,260	5,621	4,957	2,128	2,487	1,565	909	496	377	318	2,806
1976	22,311	16,350	5,750	4,418	3,894	1,651	1,840	1,063	648	382	293	2,425
1977	19,023	17,698	12,940	4,507	3,461	3,003	1,200	1,201	736	495	295	2,098
1978	25,202	14,953	13,708	9,439	3,407	2,636	2,162	773	812	558	381	1,841
1979	18,760	19,885	11,684	10,294	7,196	2,550	1,767	1,170	456	595	419	1,666
1980	23,647	14,819	15,579	8,852	7,880	5,364	1,650	821	567	320	431	1,511
1981	29,275	18,665	11,590	11,737	6,781	5,943	3,606	858	453	408	237	1,435
1982	32,636	23,134	14,596	8,664	8,940	5,017	3,747	1,612	409	312	295	1,210
1983	21,399	25,842	18,266	11,330	6,631	6,363	2,723	1,120	533	251	204	984
1984	59,365	16,983	20,452	14,261	8,782	4,872	3,798	1,013	413	327	163	770
1985	65,161	47,103	13,404	15,811	10,796	6,147	2,626	1,082	294	210	179	512
1986	18,032	51,720	37,273	10,465	12,035	7,622	3,387	823	327	141	114	374
1987	21,390	14,321	41,016	29,399	8,135	8,933	4,800	1,343	270	152	76	263
1988	28,051	16,979	11,327	32,082	22,441	5,940	5,699	1,938	398	100	66	148
1989	15,902	22,234	13,266	8,718	24,153	15,925	3,742	2,636	568	112	32	69
1990	29,905	12,601	17,387	10,150	6,581	17,291	10,110	1,934	1,008	171	32	29
1991	19,766	23,699	9,893	13,269	7,589	4,767	11,514	5,751	846	333	45	16
1992	26,053	15,671	18,647	7,593	9,878	5,484	3,232	6,746	2,529	268	85	16
1993	16,993	20,659	12,331	14,311	5,613	7,000	3,691	1,979	3,245	687	55	21
1994	19,189	13,467	16,145	9,252	10,184	3,775	4,465	2,204	1,017	1,227	128	14
1995	31,913	15,202	10,512	11,978	6,349	6,152	2,068	2,252	896	271	196	23
1996	19,726	25,199	11,607	7,129	6,897	2,748	2,334	740	685	188	39	32
1997	30,763	15,532	18,925	7,492	3,312	1,992	782	718	224	175	43	16
1998	24,150	24,223	11,592	11,721	2,147	563	492	263	247	69	49	17
1999	33,815	18,938	18,079	8,056	4,931	752	249	251	137	122	32	31
2000	40,793	26,694	14,491	13,066	4,279	2,415	420	151	155	81	69	35
2001	11,633	32,129	20,234	10,680	8,204	2,290	1,408	263	96	94	47	59
2002	20,966	9,021	22,789	14,080	6,717	4,121	1,228	831	158	54	48	54
2003	5,005	16,534	6,953	17,137	9,545	3,788	2,352	739	494	84	25	47
2004	7,813	3,931	12,606	5,127	11,972	5,823	2,200	1,438	444	259	36	30
2005	4,962	6,146	3,022	9,272	3,566	7,700	3,359	1,288	835	221	106	27
2006	10,241	3,903	4,705	2,186	6,469	2,387	4,627	1,937	730	421	92	56
2007	6,070	8,020	2,868	3,158	1,436	4,317	1,455	2,505	994	322	164	58
2008	3,970	4,767	6,018	1,885	1,890	875	2,568	773	1,128	359	102	71
2009	10,609	3,128	3,627	3,986	1,129	1,155	500	1,368	351	436	114	55
2010	10,823	8,388	2,420	2,608	2,495	630	565	229	482	110	111	43
2011	5,493	8,564	6,482	1,790	1,730	1,379	357	316	107	168	34	48
2012	7,750	4,328	6,380	4,635	1,310	1,211	915	231	198	58	84	41
2013	8,619	6,138	3,371	4,818	3,526	937	780	611	157	126	36	76
Mean	19,771	15,599	12,053	8,981	6,260	4,122	2,525	1,309	628	313	175	921

Table A5.25. Estimated total fishing mortality at age, 1970-2013.

	1	2	3	4	5	6	7	8	9	10	11	12+
1970	0.000	0.001	0.002	0.003	0.009	0.027	0.059	0.037	0.011	0.009	0.009	0.009
1971	0.000	0.001	0.004	0.006	0.014	0.043	0.095	0.059	0.018	0.015	0.015	0.015
1972	0.001	0.002	0.006	0.005	0.009	0.028	0.063	0.049	0.013	0.009	0.009	0.009
1973	0.002	0.004	0.013	0.009	0.014	0.039	0.086	0.068	0.019	0.012	0.012	0.012
1974	0.004	0.010	0.033	0.021	0.023	0.057	0.123	0.082	0.025	0.020	0.020	0.020
1975	0.001	0.003	0.011	0.011	0.024	0.071	0.157	0.109	0.031	0.023	0.023	0.023
1976	0.002	0.004	0.013	0.014	0.030	0.089	0.196	0.137	0.039	0.029	0.029	0.029
1977	0.011	0.025	0.085	0.050	0.042	0.098	0.210	0.161	0.047	0.032	0.032	0.032
1978	0.007	0.017	0.056	0.041	0.060	0.170	0.385	0.298	0.082	0.058	0.058	0.058
1979	0.006	0.014	0.047	0.037	0.064	0.205	0.536	0.494	0.123	0.092	0.092	0.092
1980	0.007	0.016	0.053	0.037	0.052	0.167	0.424	0.366	0.099	0.072	0.072	0.072
1981	0.005	0.016	0.061	0.042	0.071	0.231	0.575	0.510	0.141	0.094	0.094	0.094
1982	0.003	0.006	0.023	0.037	0.110	0.381	0.978	0.877	0.258	0.195	0.195	0.195
1983	0.001	0.004	0.017	0.025	0.078	0.286	0.759	0.768	0.259	0.204	0.204	0.204
1984	0.001	0.007	0.027	0.048	0.127	0.388	1.026	1.006	0.445	0.371	0.371	0.371
1985	0.001	0.004	0.017	0.043	0.118	0.366	0.931	0.965	0.505	0.385	0.385	0.385
1986	0.000	0.002	0.007	0.022	0.068	0.232	0.695	0.885	0.540	0.389	0.389	0.389
1987	0.001	0.005	0.016	0.040	0.084	0.219	0.677	0.986	0.759	0.596	0.596	0.596
1988	0.002	0.017	0.032	0.054	0.113	0.232	0.541	0.997	1.036	0.901	0.901	0.901
1989	0.003	0.016	0.038	0.051	0.104	0.224	0.430	0.731	0.969	1.011	1.011	1.011
1990	0.003	0.012	0.040	0.061	0.092	0.177	0.334	0.597	0.878	1.100	1.100	1.100
1991	0.002	0.010	0.035	0.065	0.095	0.159	0.305	0.592	0.918	1.136	1.136	1.136
1992	0.002	0.010	0.035	0.072	0.114	0.166	0.261	0.502	1.074	1.359	1.359	1.359
1993	0.003	0.017	0.057	0.110	0.167	0.220	0.285	0.436	0.742	1.452	1.452	1.452
1994	0.003	0.018	0.069	0.147	0.274	0.372	0.454	0.671	1.094	1.603	1.603	1.603
1995	0.006	0.040	0.158	0.322	0.607	0.739	0.797	0.961	1.333	1.699	1.699	1.699
1996	0.009	0.056	0.208	0.537	1.012	1.027	0.949	0.967	1.136	1.247	1.247	1.247
1997	0.009	0.063	0.249	1.020	1.542	1.168	0.859	0.836	0.949	1.035	1.035	1.035
1998	0.013	0.063	0.134	0.636	0.819	0.586	0.445	0.423	0.475	0.534	0.534	0.534
1999	0.006	0.038	0.095	0.403	0.484	0.353	0.269	0.252	0.290	0.345	0.345	0.345
2000	0.009	0.047	0.075	0.235	0.395	0.310	0.237	0.224	0.265	0.330	0.330	0.330
2001	0.024	0.113	0.133	0.234	0.458	0.393	0.297	0.280	0.342	0.436	0.436	0.436
2002	0.007	0.030	0.055	0.159	0.343	0.331	0.278	0.290	0.399	0.559	0.559	0.559
2003	0.012	0.041	0.075	0.129	0.264	0.313	0.262	0.280	0.414	0.621	0.621	0.621
2004	0.010	0.033	0.077	0.133	0.211	0.320	0.305	0.314	0.468	0.664	0.664	0.664
2005	0.010	0.037	0.094	0.130	0.171	0.279	0.321	0.337	0.456	0.643	0.643	0.643
2006	0.014	0.078	0.169	0.190	0.174	0.266	0.383	0.437	0.589	0.710	0.710	0.710
2007	0.012	0.057	0.190	0.284	0.266	0.289	0.402	0.568	0.787	0.915	0.915	0.915
2008	0.008	0.043	0.182	0.282	0.263	0.329	0.400	0.560	0.722	0.918	0.918	0.918
2009	0.005	0.027	0.100	0.239	0.353	0.485	0.553	0.813	0.928	1.135	1.135	1.135
2010	0.004	0.028	0.072	0.180	0.363	0.339	0.351	0.525	0.826	0.949	0.949	0.949
2011	0.008	0.064	0.105	0.082	0.127	0.180	0.206	0.238	0.379	0.464	0.464	0.464
2012	0.003	0.020	0.051	0.044	0.105	0.210	0.173	0.154	0.223	0.263	0.263	0.263
2013	0.002	0.009	0.024	0.035	0.094	0.175	0.134	0.121	0.197	0.242	0.242	0.242

Figures

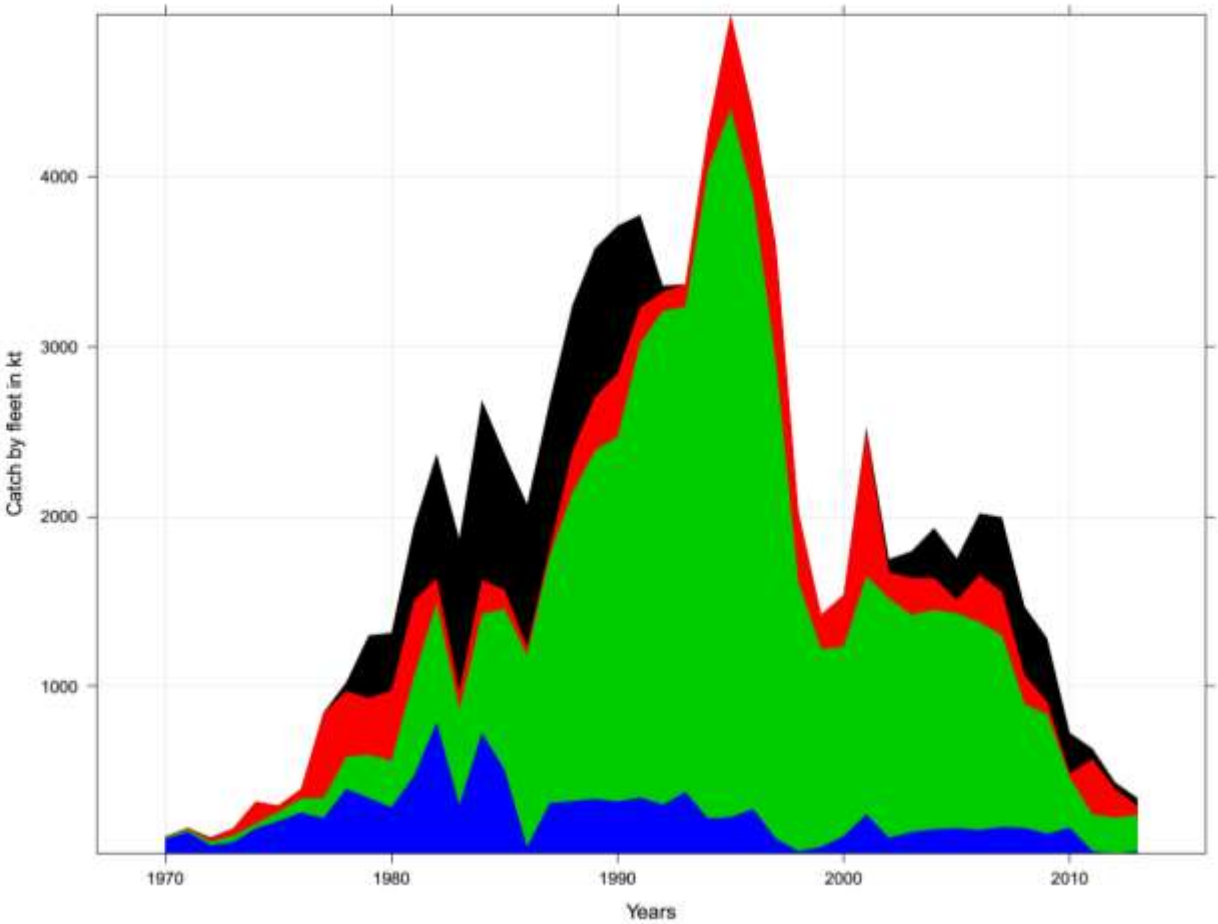


Figure A5.1. Catch of jack mackerel by fleet. Green is the SC Chilean fleet, black is the offshore trawl fleet, red is the far-north fleet, and blue in the northern Chilean fleet.

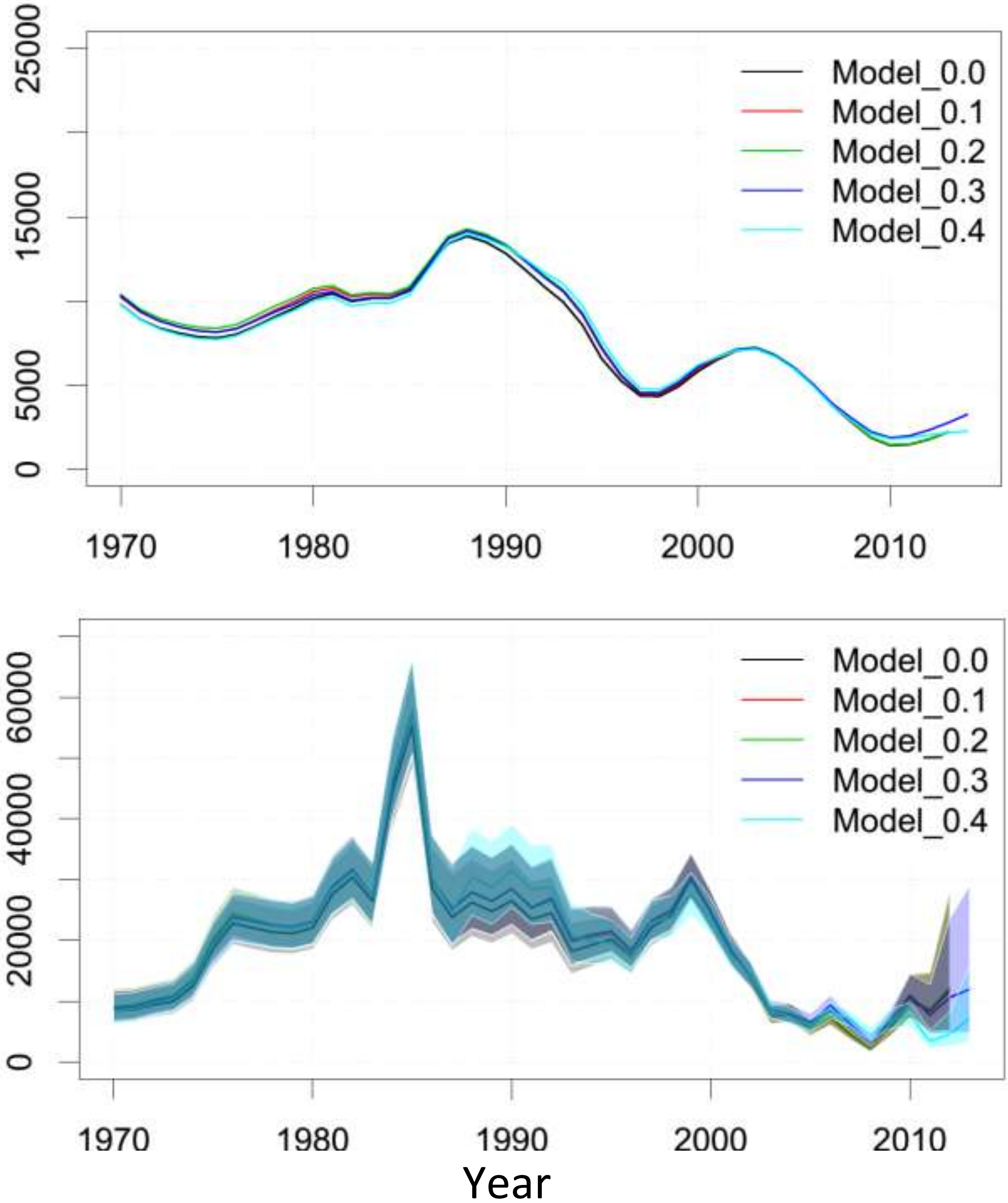
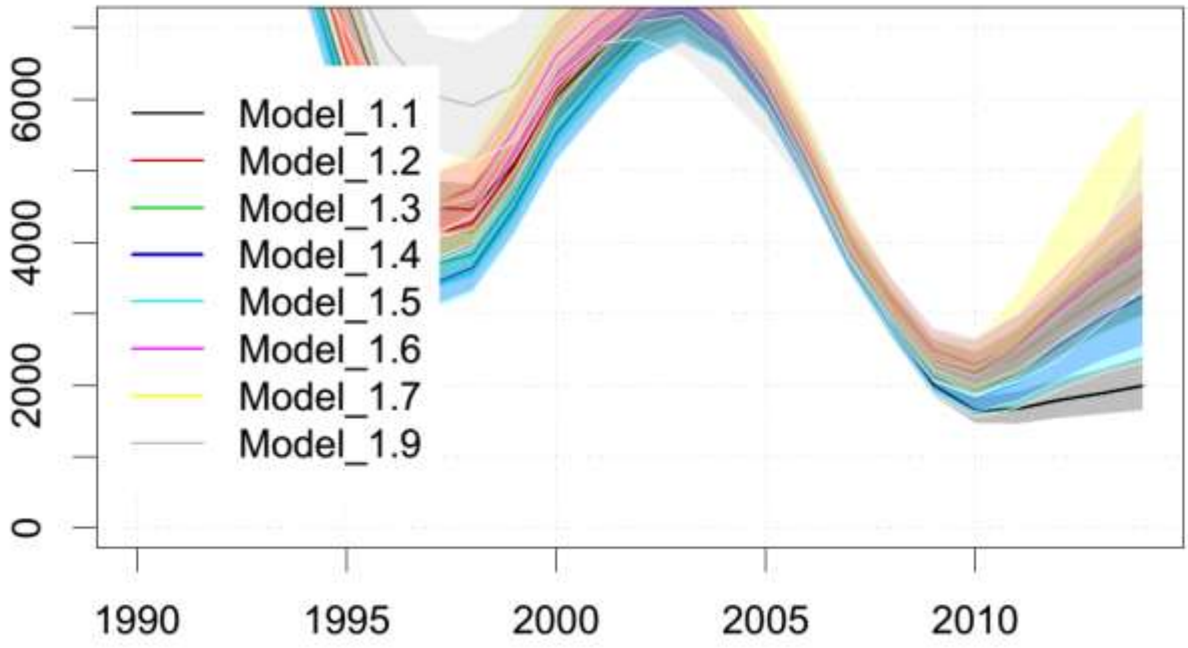


Figure A5.2. Spawning biomass (top; in kt) and age one recruitment estimates (in millions) comparing model configurations 0.0 - 0.4.



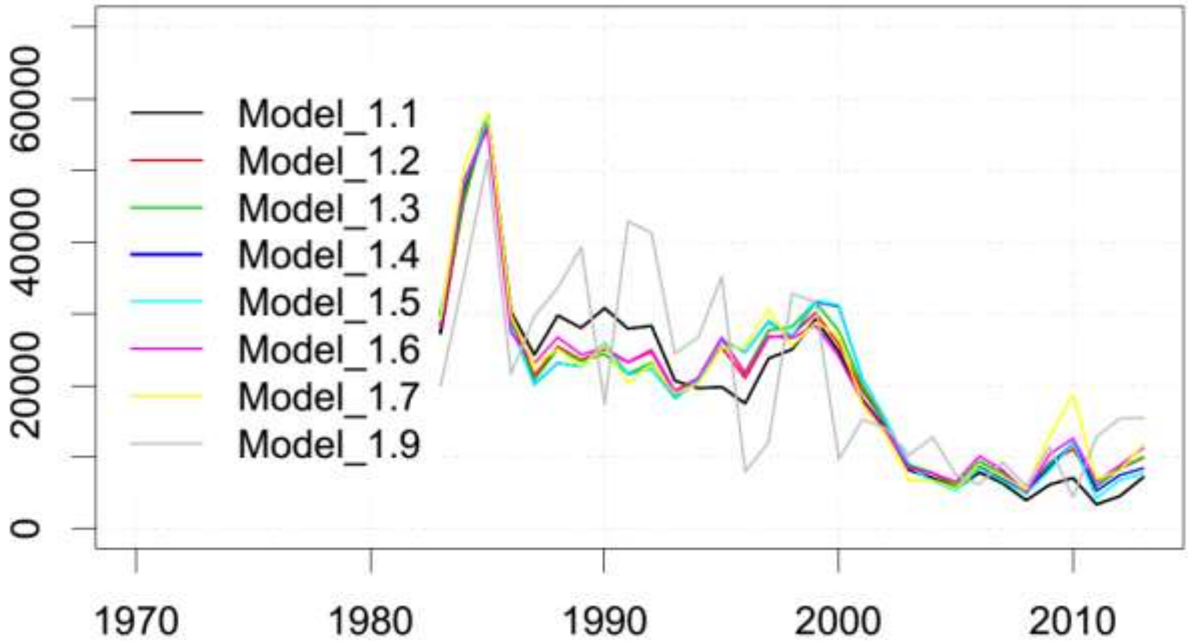


Figure A5.3. Spawning biomass (top; in kt) and age one recruitment estimates (in millions) comparing model configurations 1.1 - 1.9 (model 1.8 is omitted since it was off the scale).

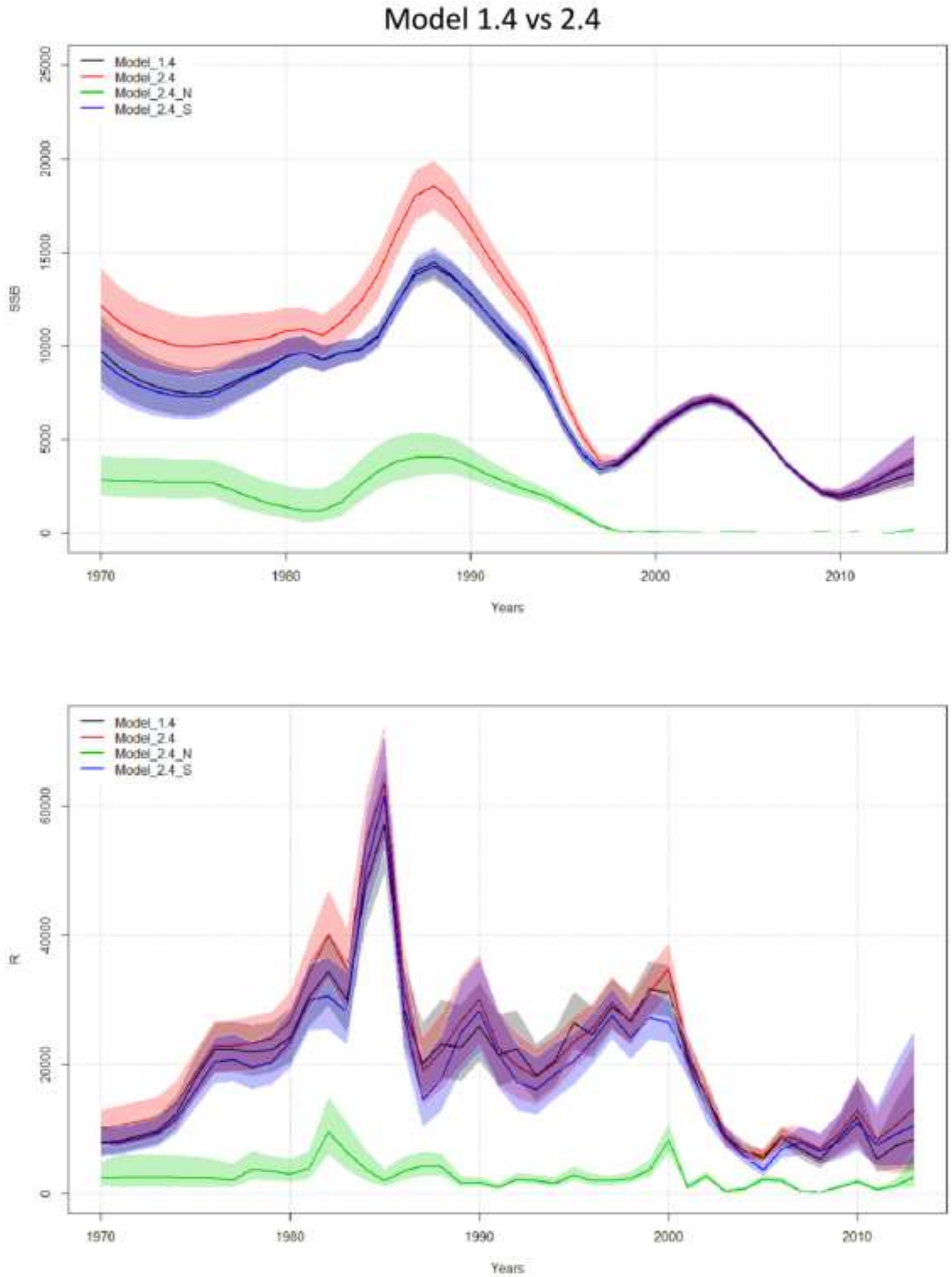


Figure A5.4. Spawning biomass (top; in kt) and age one recruitment estimates (in millions) comparing model configurations 1.4 and 2.4 (and the component models of 2.4).

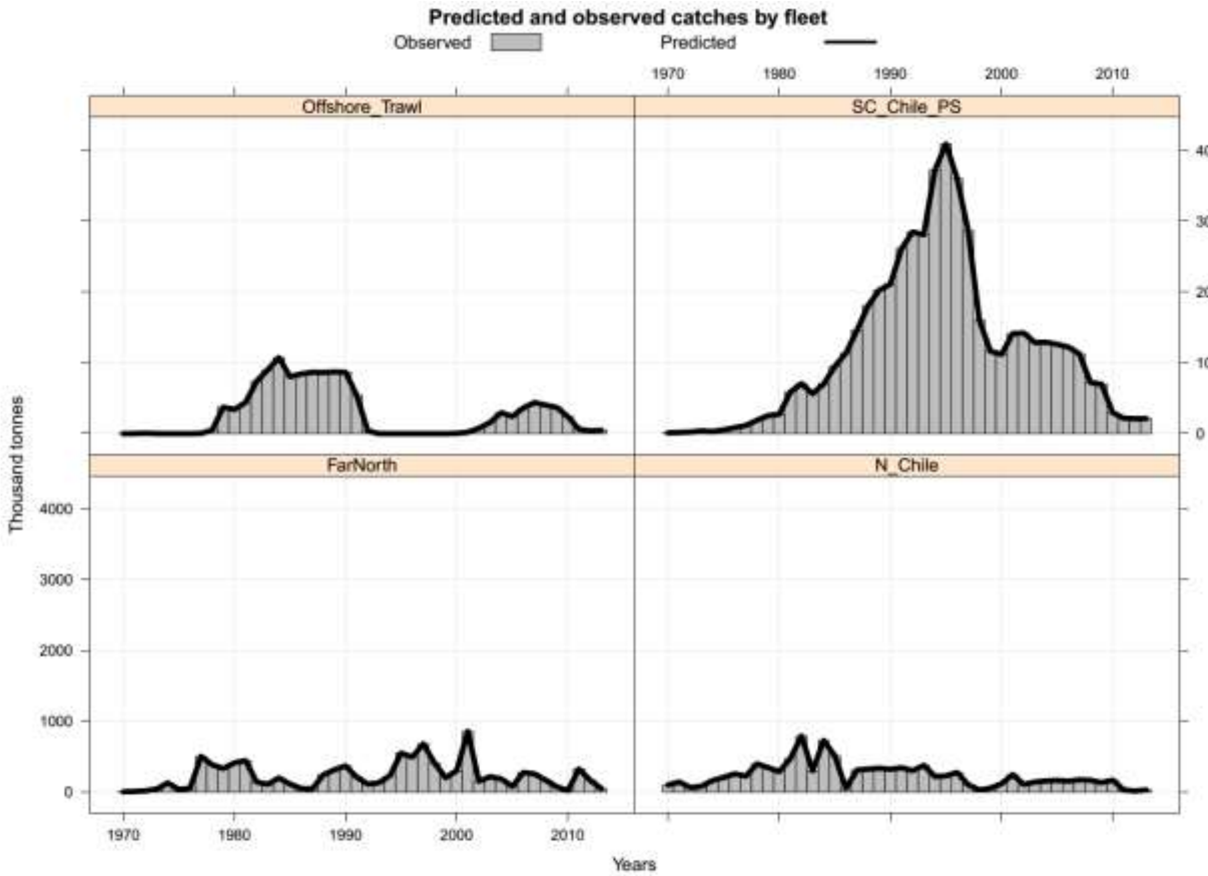


Figure A5.5. JJM Model fit to the total catches (‘000 tonnes) by fleet for Fleet 1 (N_Chile_PS), Fleet 2 (SC_Chile_PS), Fleet 3 (Far_North) and Fleet 4 (Offshore_Trawl). The bars represent the observations and the line represents the predicted values.

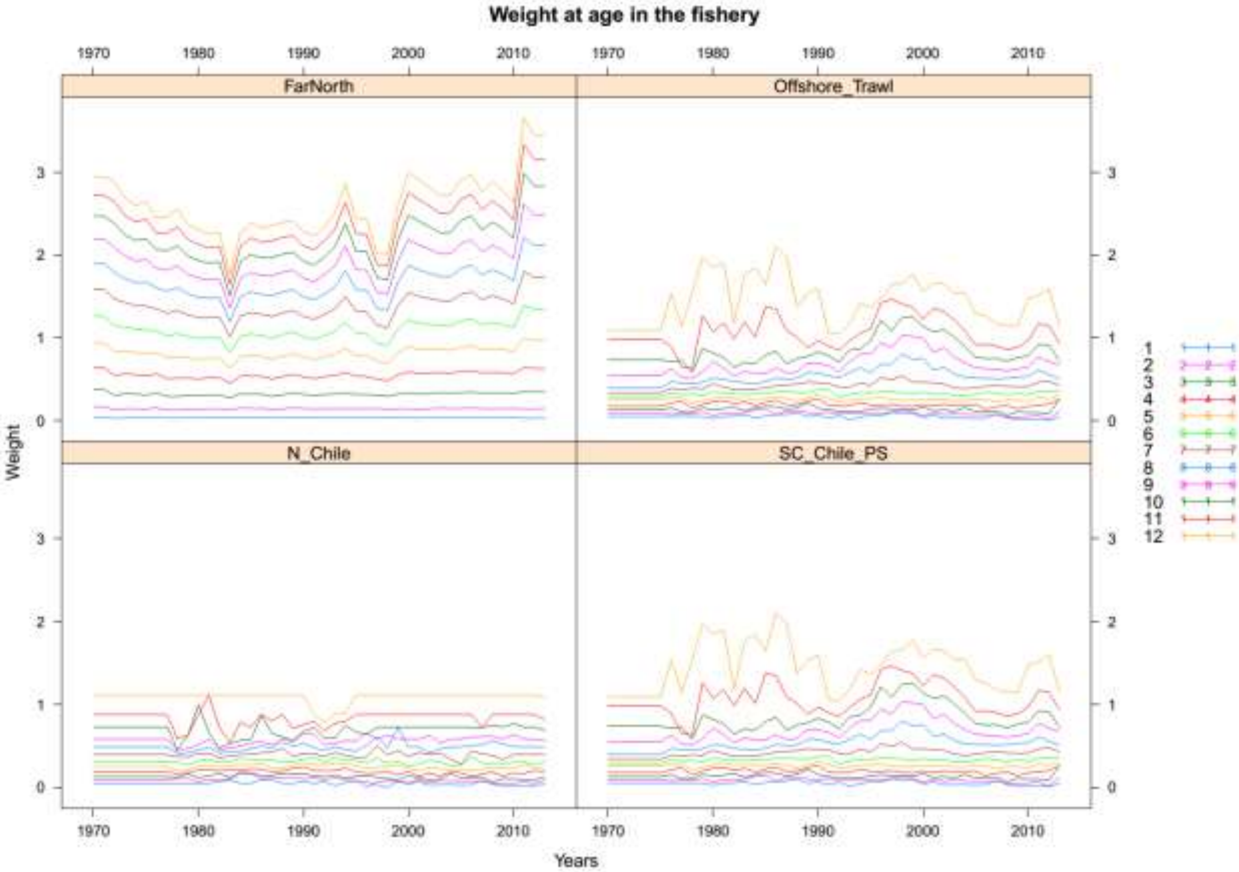


Figure A5.6. Mean weights-at-age (kg) over time used for all data types in the JJM models. Different lines represent ages 1 to 12.

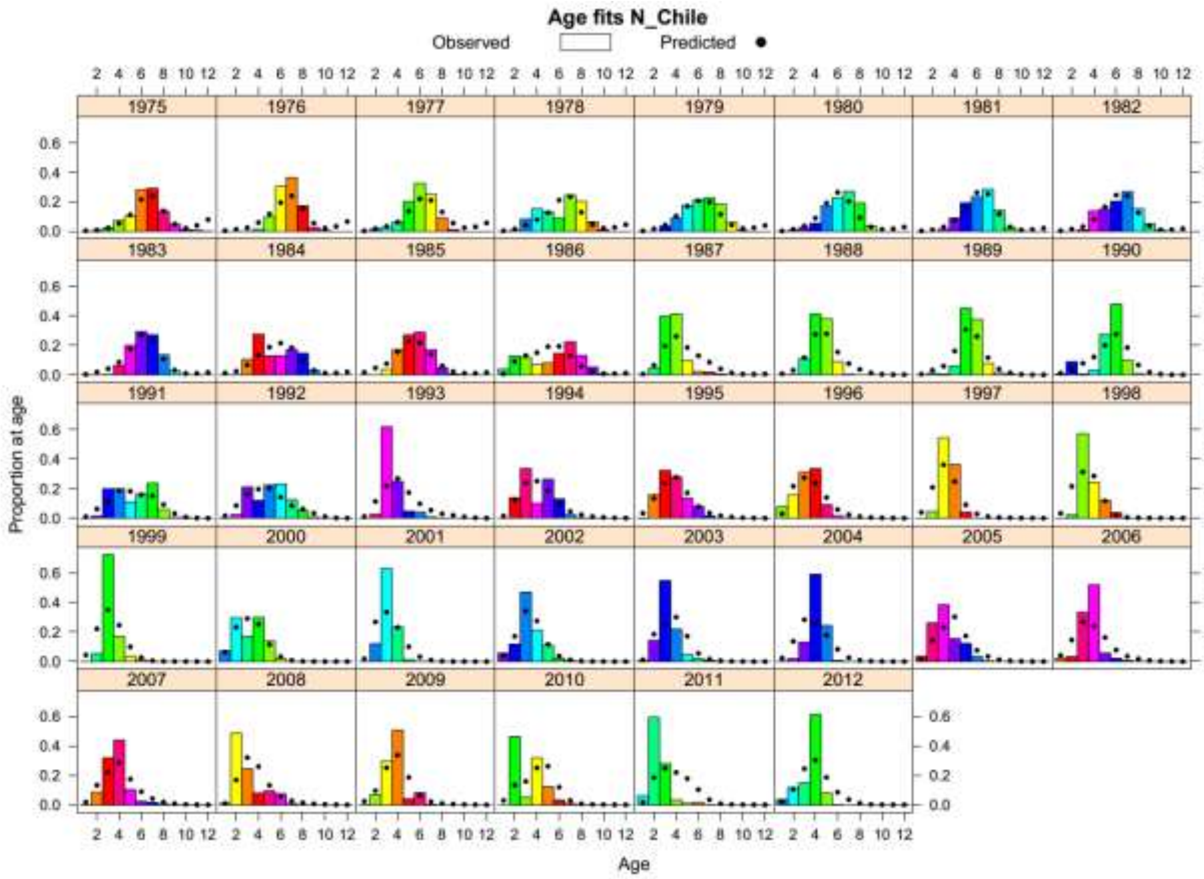


Figure A5.7. Model fit (Model 4.1) to the age compositions for the **Chilean northern zone fishery (Fleet 1)**. Bars represent the observed data and dots represent the model fit and color codes correspond to cohorts.

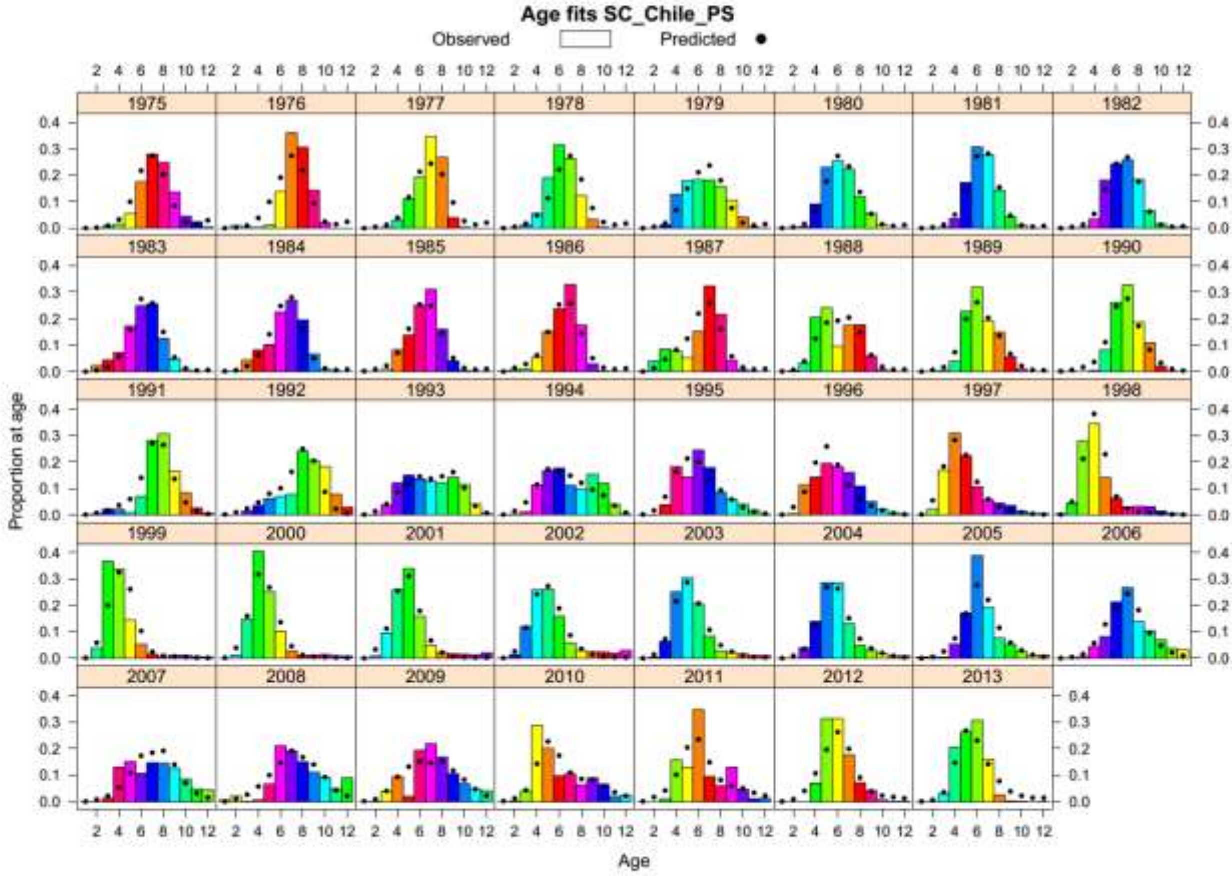


Figure A5.8. Model fit (Model 4.1) to the age compositions for the **South-Central Chilean purse seine** fishery (Fleet 2). Bars represent the observed data and dots represent the model fit and color codes correspond to cohorts.

To Come

Figure A5.9. Model fit (Model 4.1) 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.

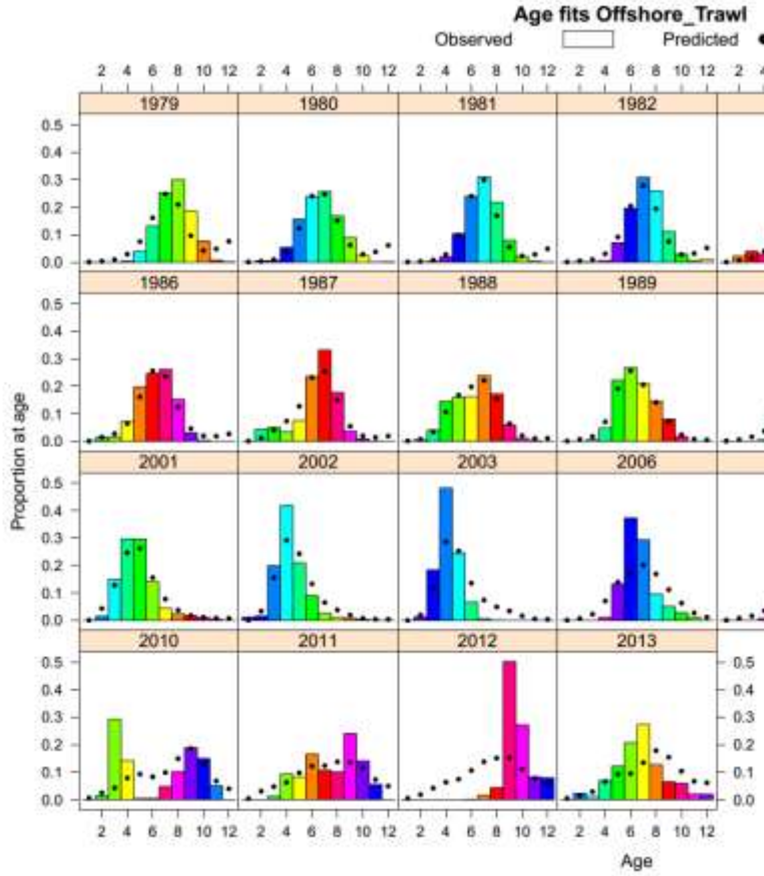


Figure A5.10. Model fit (Model 4.1) to the age compositions for the **offshore trawl** fishery (Fleet 4). Bars represent the observed data and dots represent the model fit and color codes correspond to cohorts.

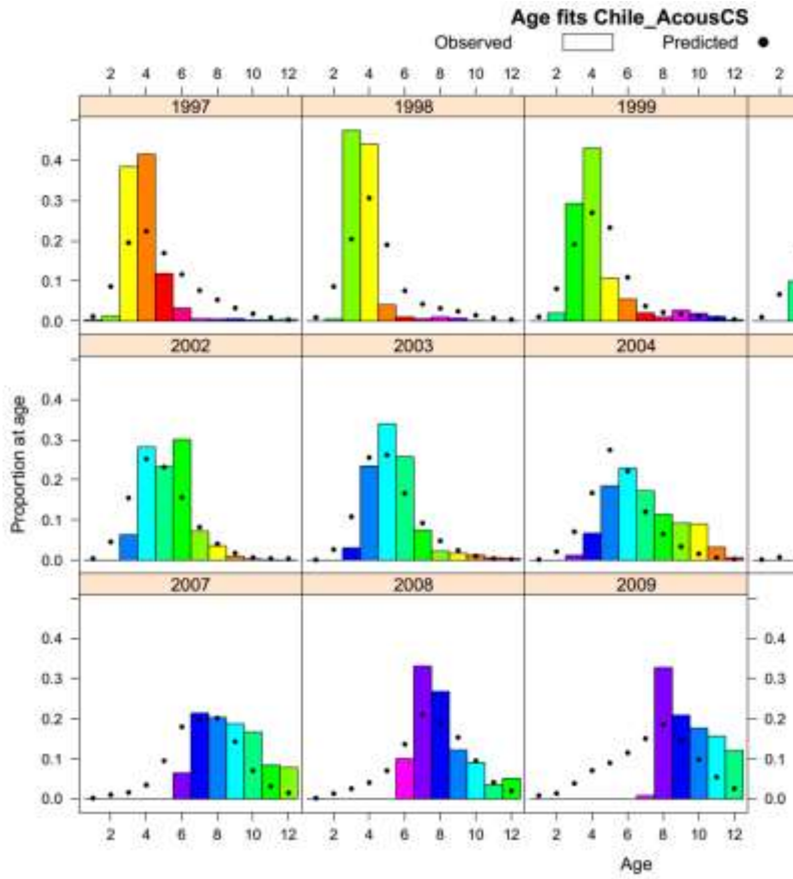


Figure A5.11. Model fit (Model 4.1) to the age compositions for the **SC Chilean acoustic survey**. Bars represent the observed data and dots represent the model fit and color codes correspond to cohorts.

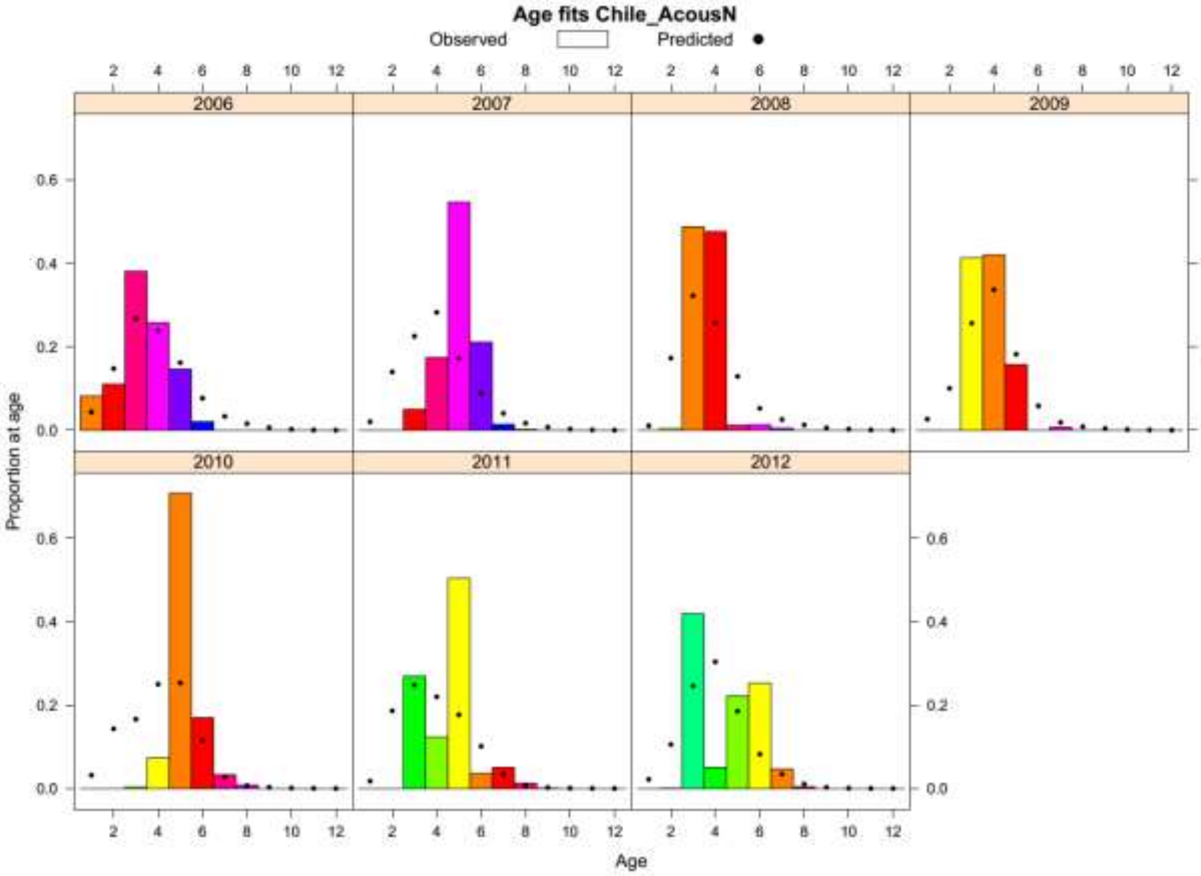


Figure A5.12. Model fit (Model 4.1) to the age compositions for the **N Chilean acoustic survey**. Bars represent the observed data and dots represent the model fit and color codes correspond to cohorts.

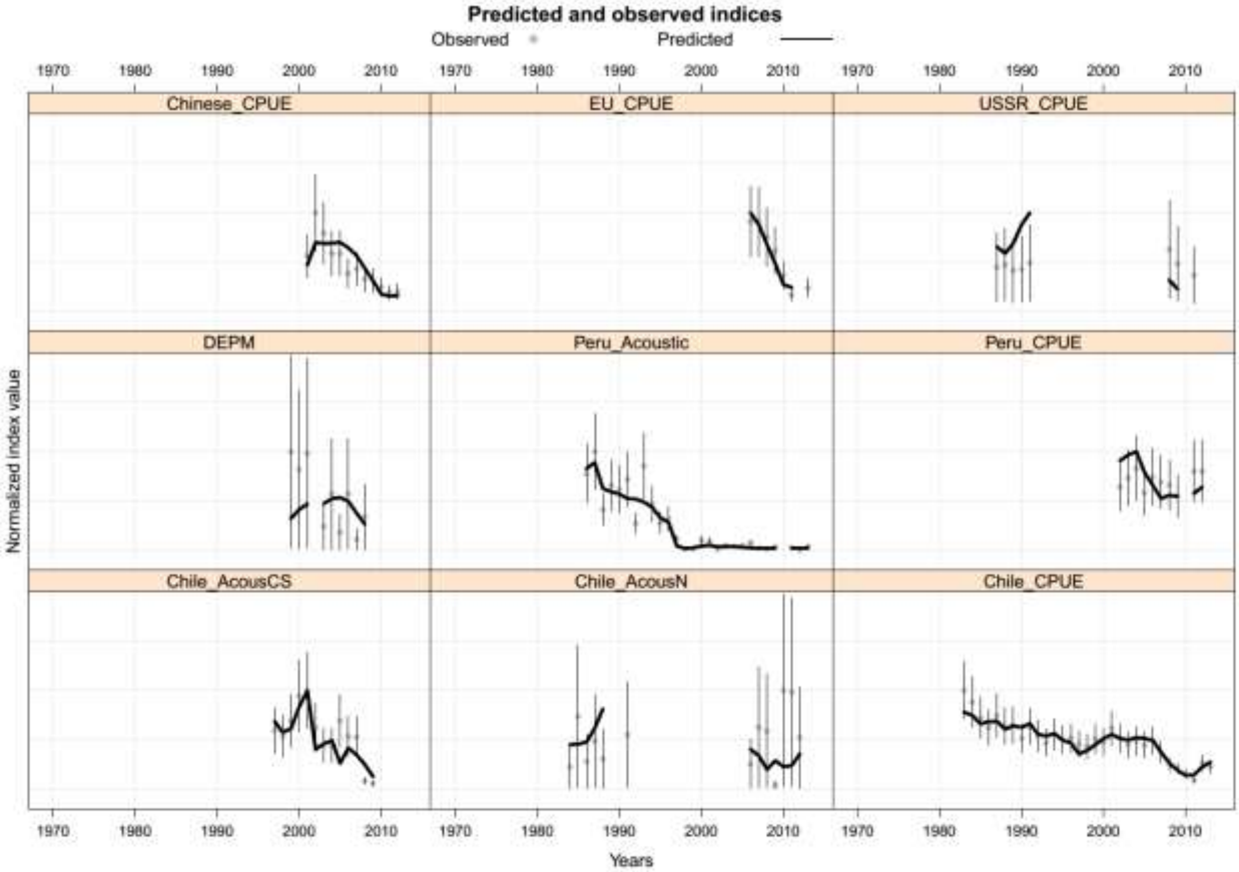


Figure A5.13. Model fit (Model 4.1) to different indices. Vertical bars represent 2 standard deviations around the observations.

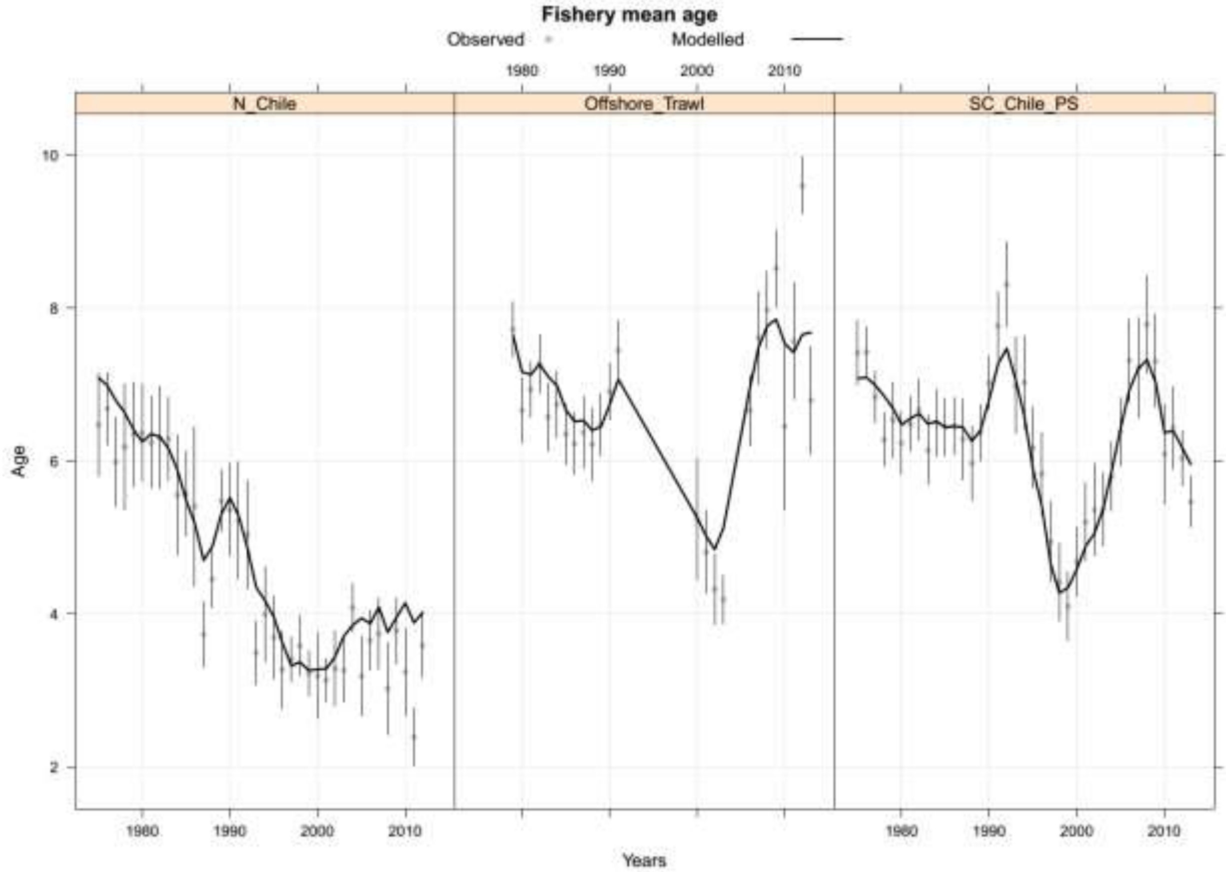


Figure A5.14. Mean age by year and fishery. Line represents the model and dots the observed values.

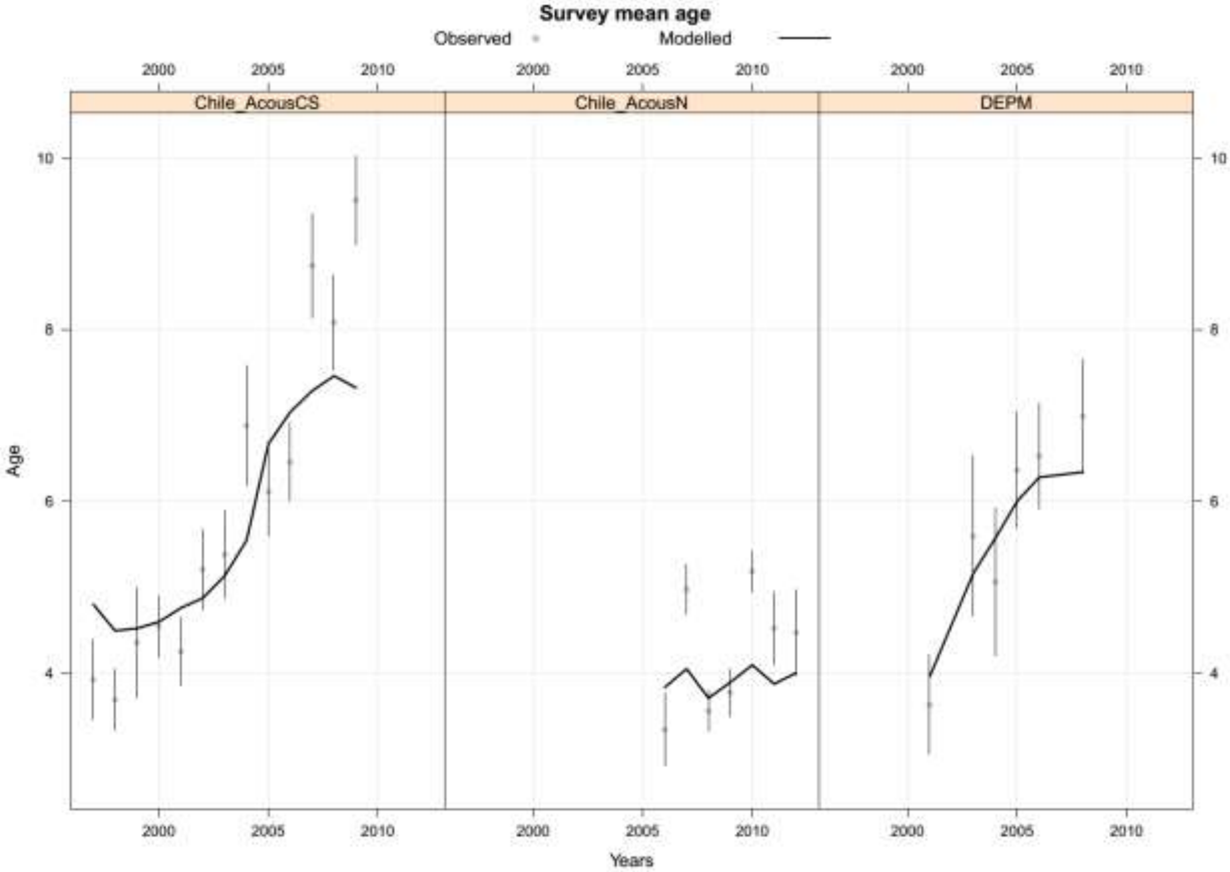


Figure A5.15. Mean age by year and survey. Line represents the model and dots the observed values.

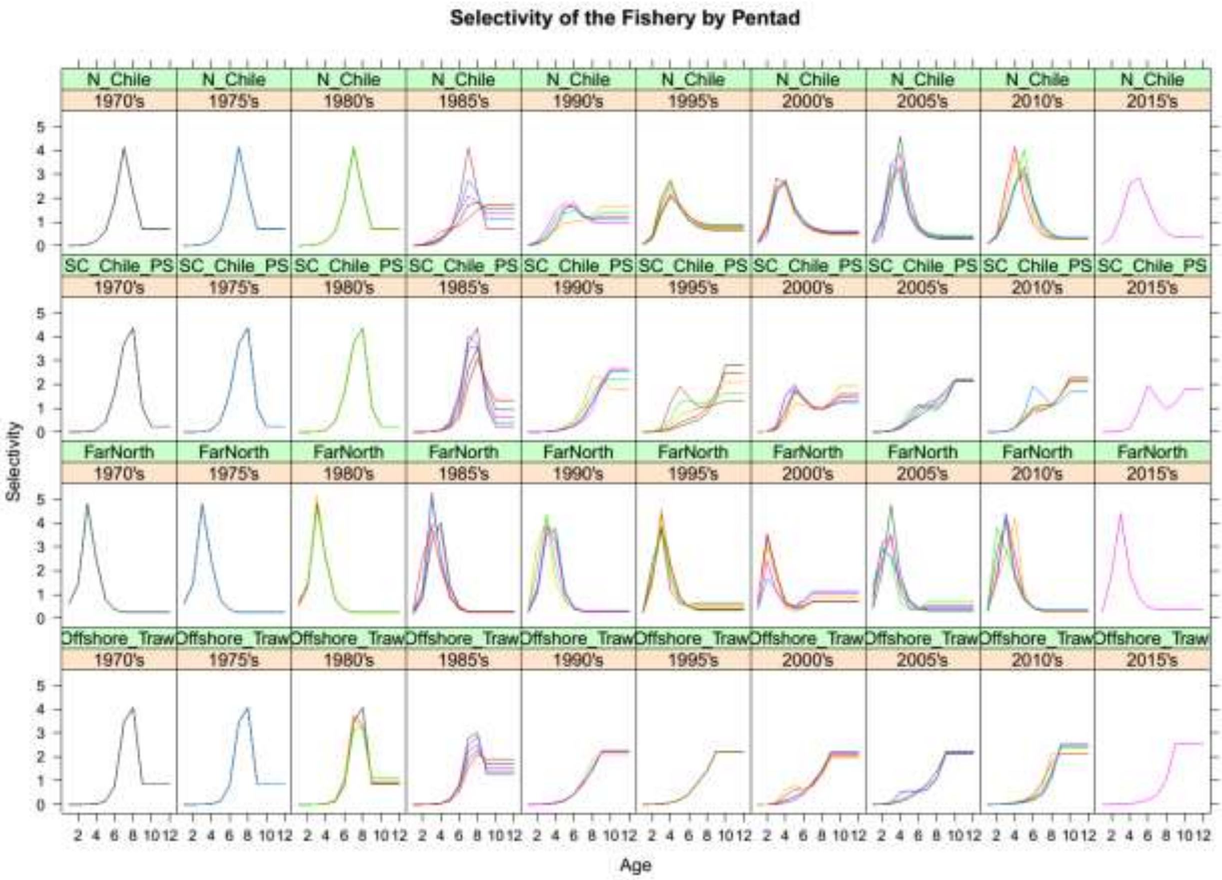


Figure A5.16. Estimates of selectivity by fishery over time for Model 4.1.

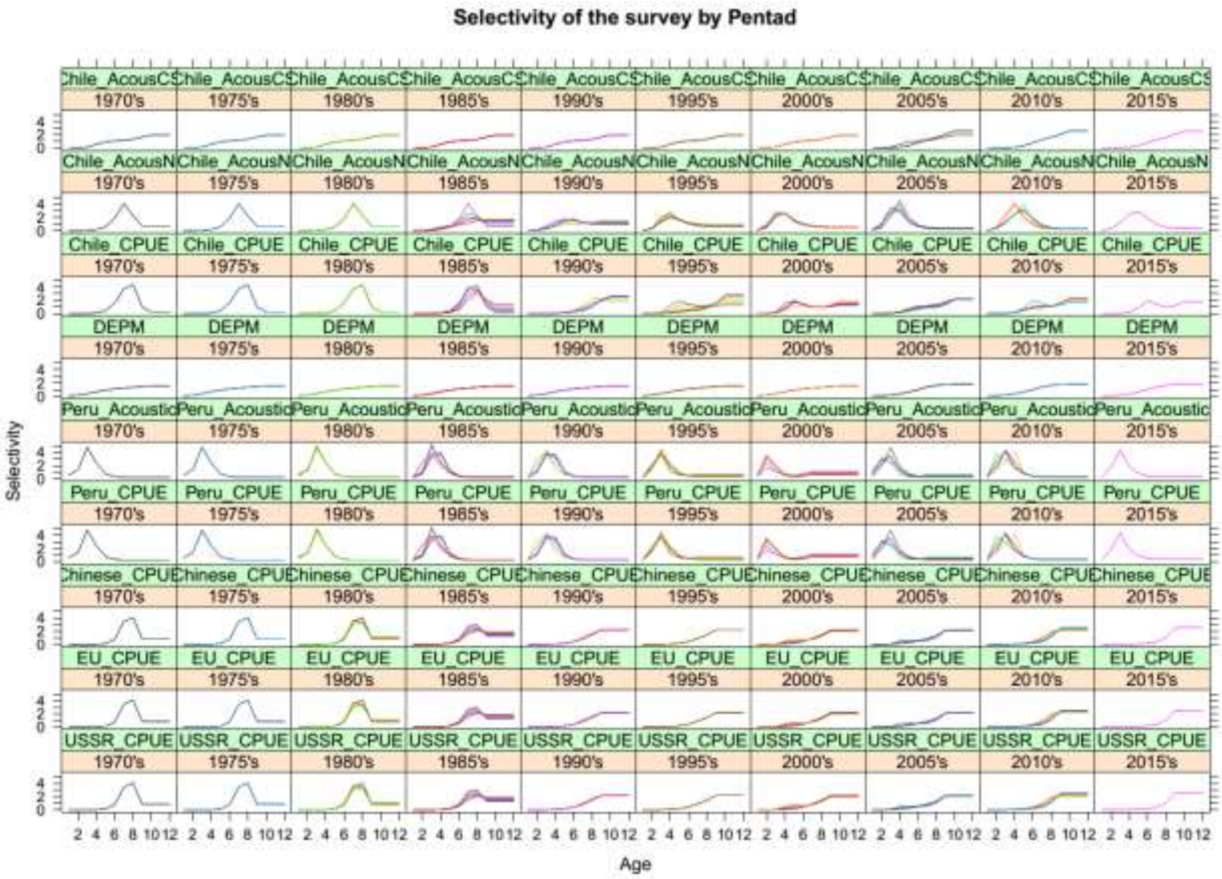


Figure A5.17. Model 4.1) estimates of selectivity for each index over time.

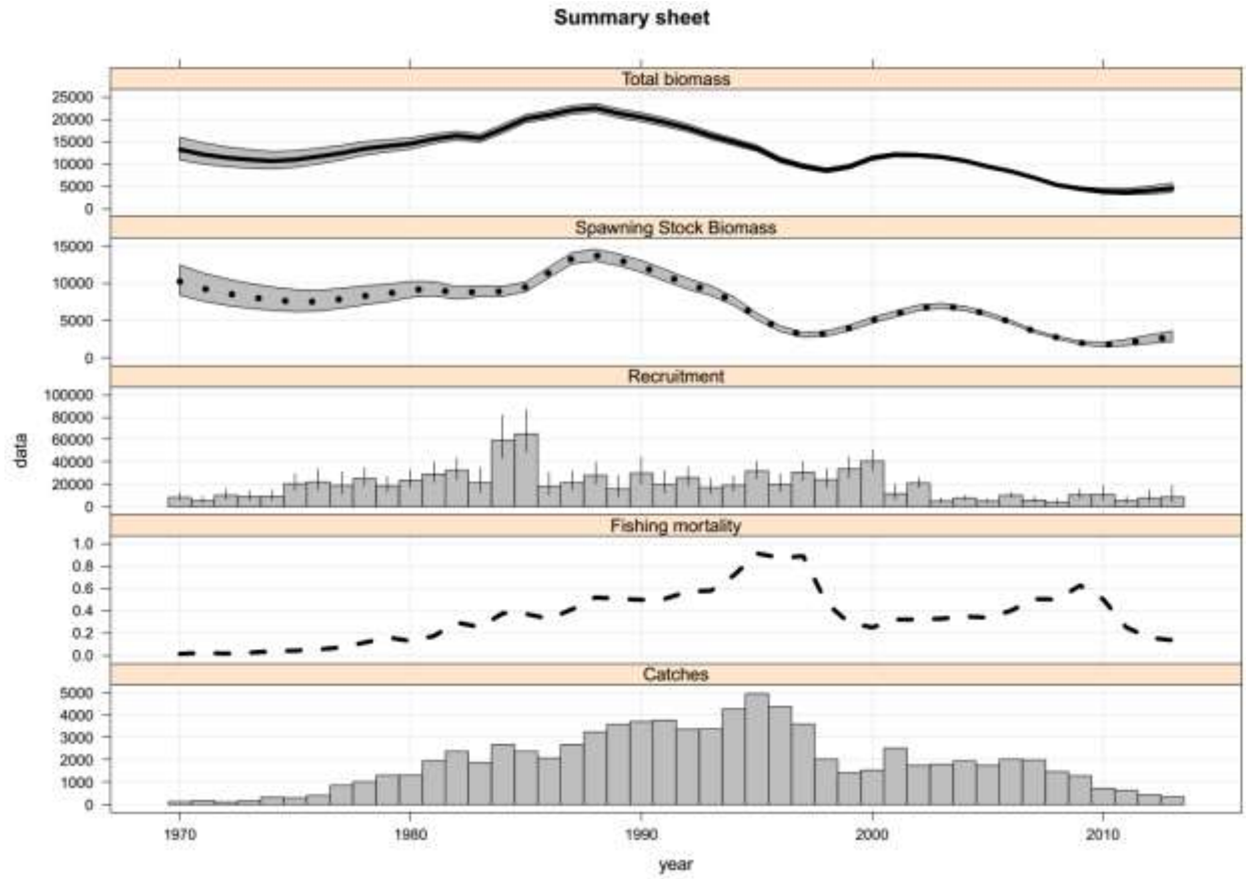


Figure A5.18. Summary estimates over time showing total and spawning biomass (kt; top two panels), recruitment at age 1 (millions; third from top) total fishing mortality (fourth panel) and total catch (kt; bottom). Shaded areas represent the approximate 90% confidence bands.

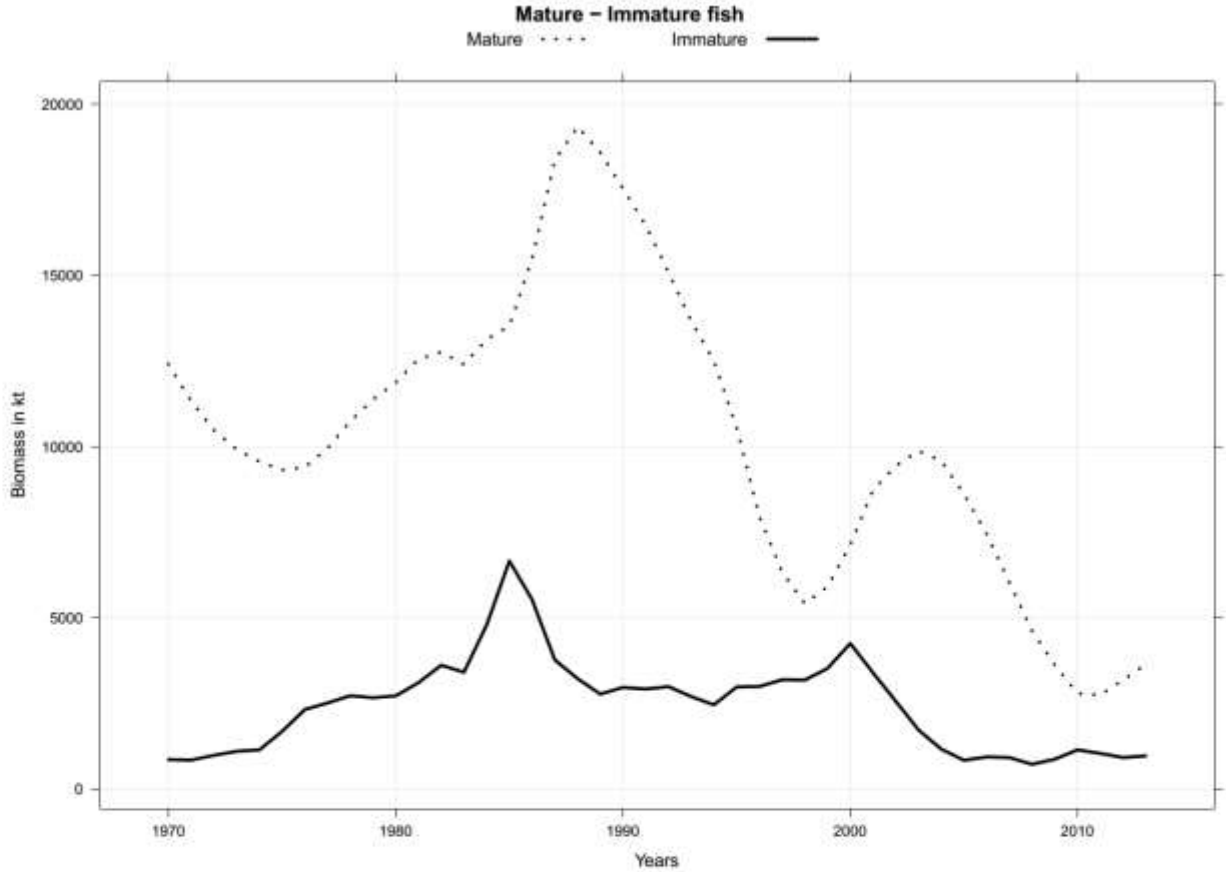


Figure A5.19. Model 4.1 results showing mature and immature estimated components of the jack mackerel stock, 1970-2013.

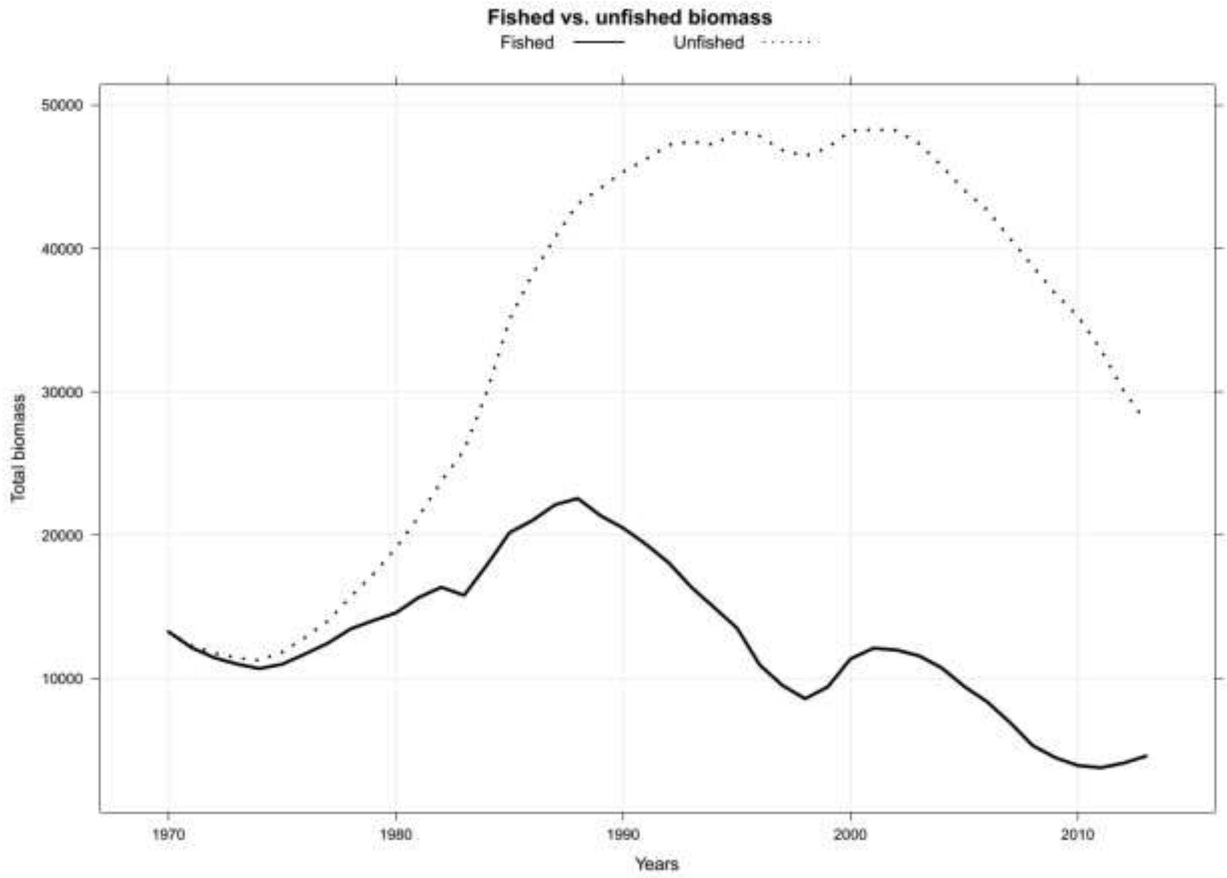


Figure A5.20. Model 4.1 results the estimated total biomass (solid line) and the estimated total biomass that would have occurred if no fishing had taken place, 1970-2013.

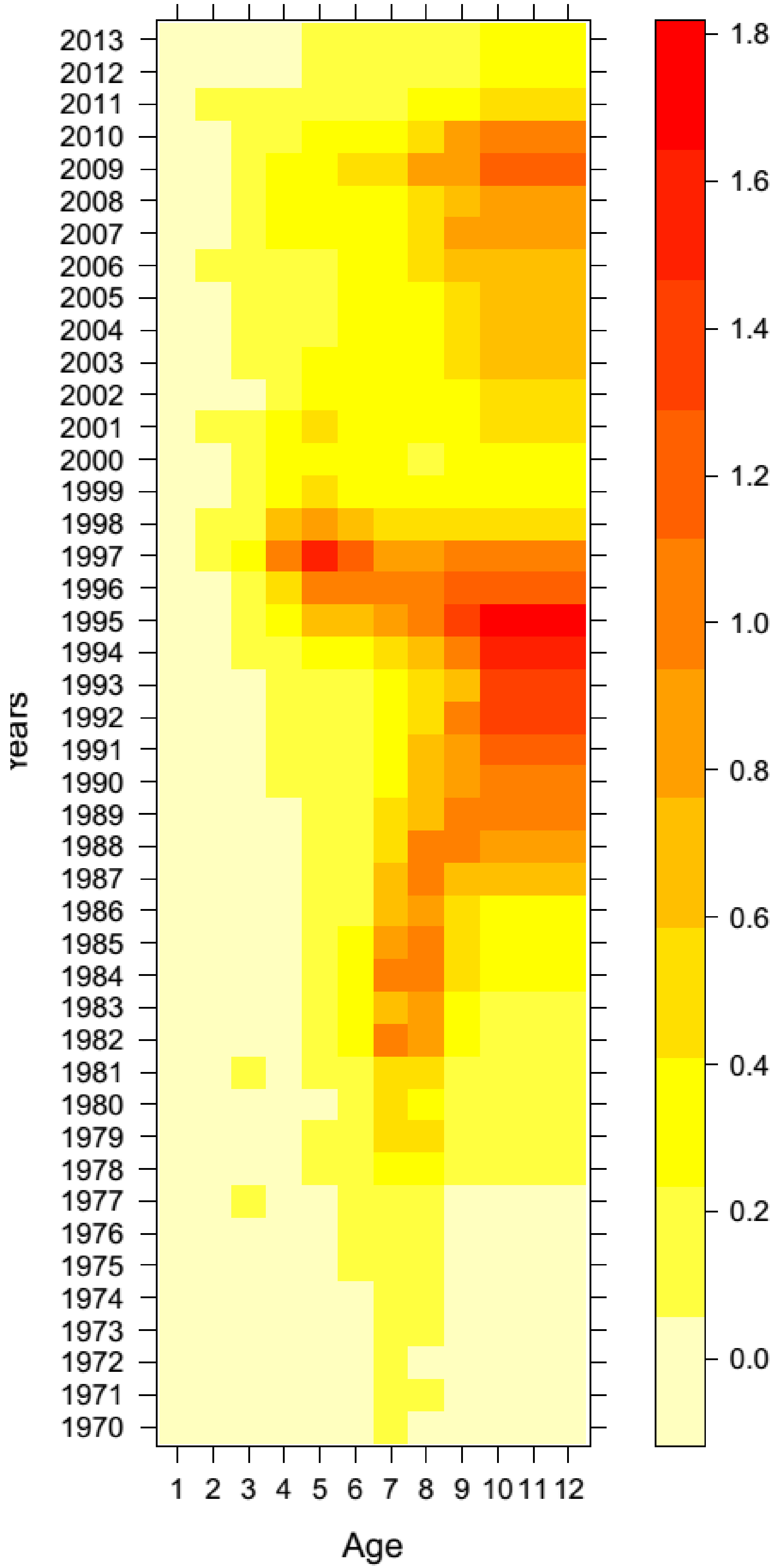


Figure A5.21. Jack mackerel estimated fishing mortality at age for Model 1.4.

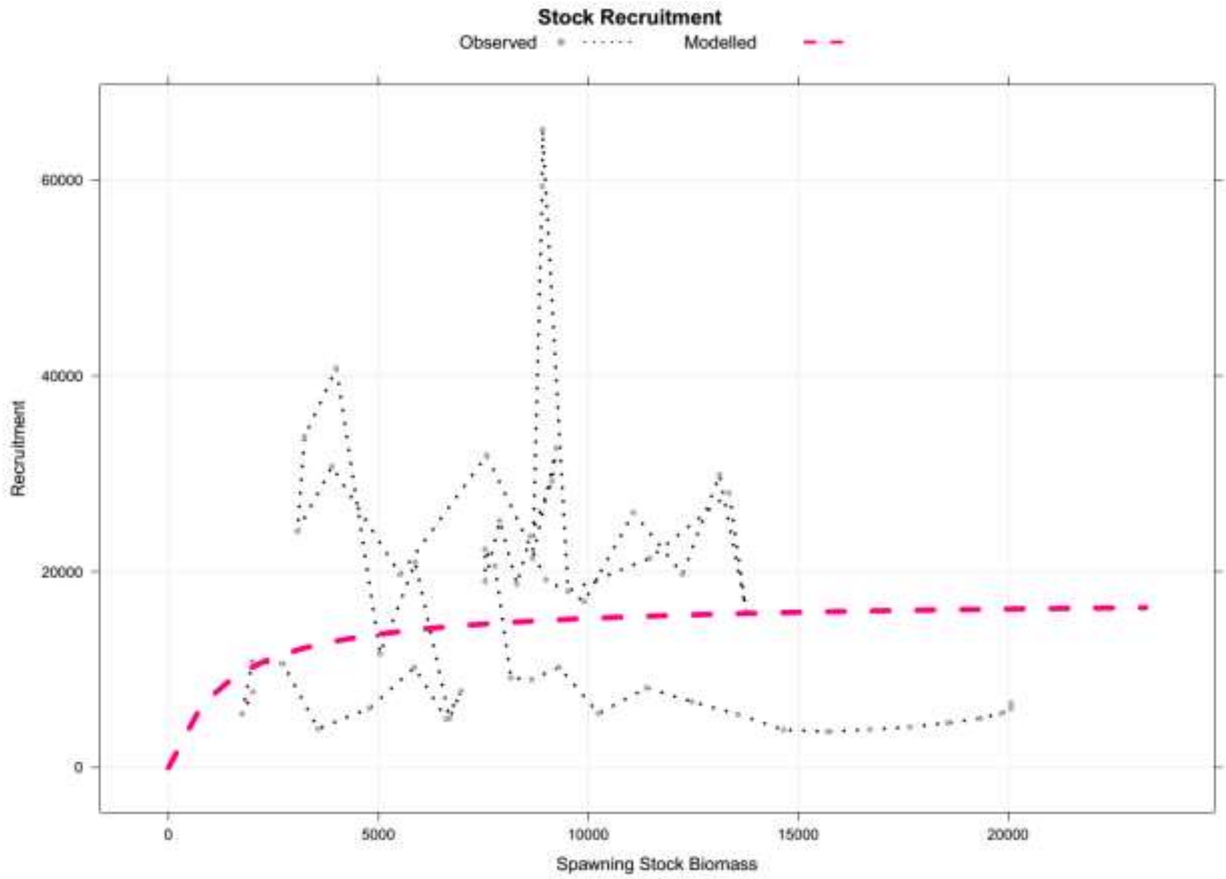


Figure A5.22. Model 4.1 stock recruitment curve relative to model estimates of biomass and recruitment.

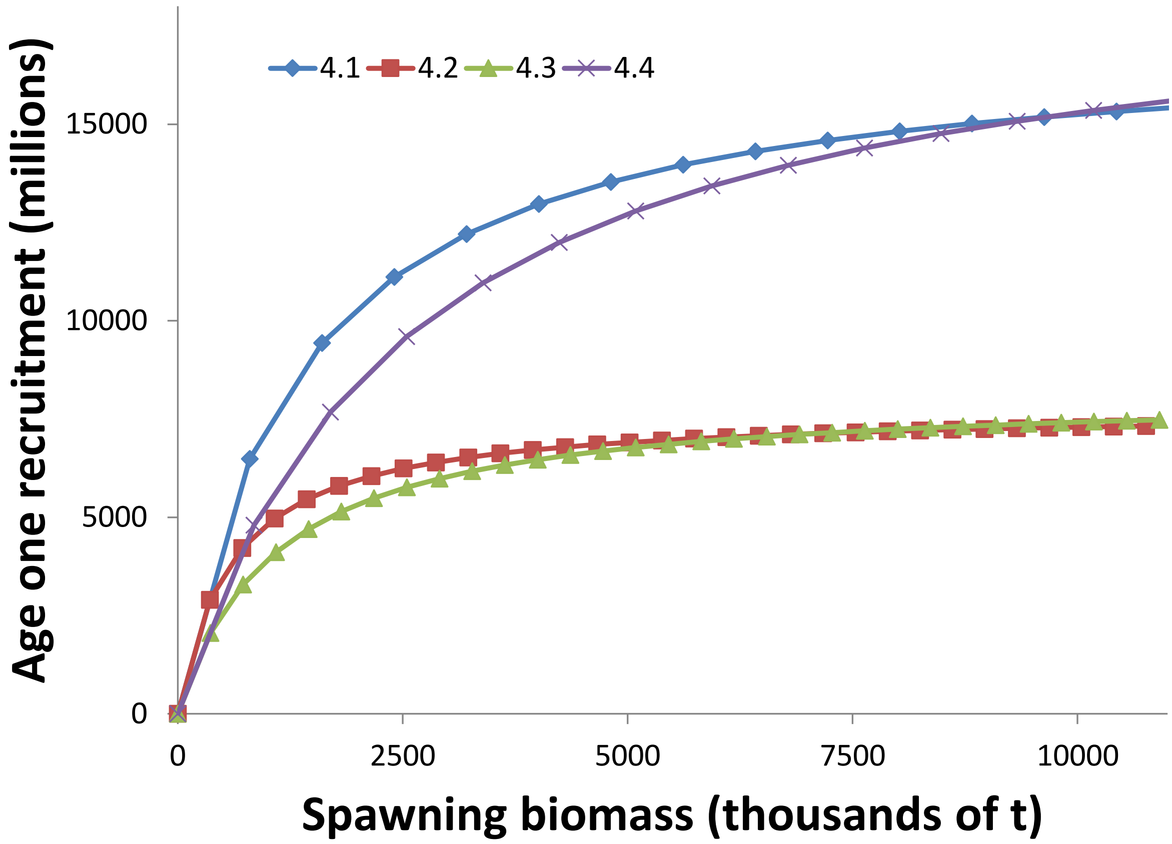


Figure A5.23. Jack mackerel stock recruitment estimates with two alternative steepness values and for models 4.1-4.4. Models 4.1 and 4.4 are estimated based on the whole time series whereas the other two are based on recruits and spawning levels from 2000-2011.

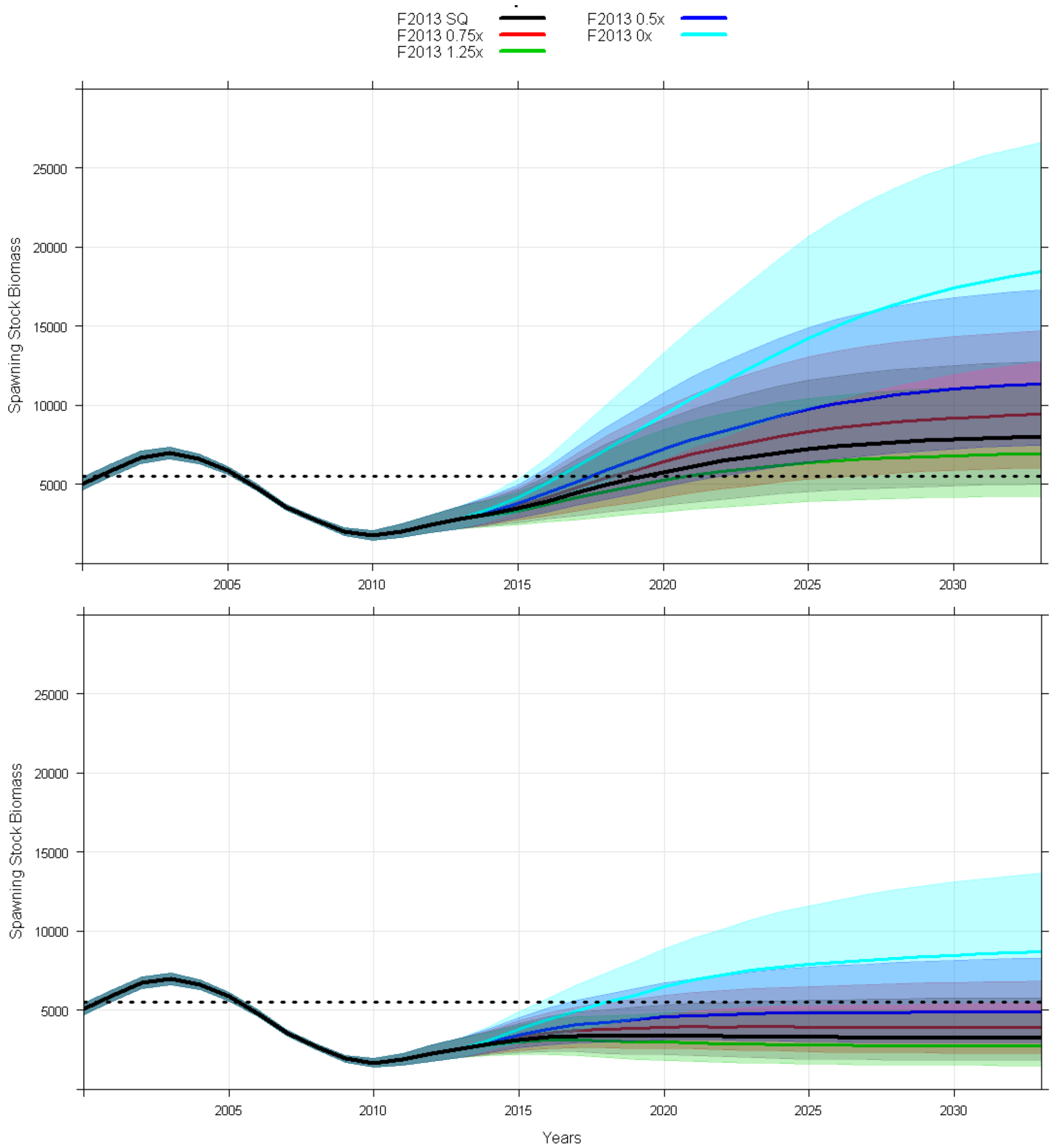


Figure A5.24. Jack mackerel population trajectories for different multipliers of the estimated 2013 fishing mortality rate under models 4.1 (top; stock recruitment steepness = 0.8, recruitment from 1970-2011) and 4.3 (bottom; steepness = 0.65, recruitment from 2000-2011). The horizontal line represents B_{MSY} (provisional target reference point).