SPRFMO SC7-Report
Annex 8. Jack Mackerel Technical Annex Rev1[1]

1. Introduction

This document and content are based on discussions and analyses conducted at the Scientific Committee (SC) meeting in 2019. The analyses updated the model and assumptions from SC6 (the last full assessment in 2018), and a preferred model configuration was agreed upon at the workshop. A summary of discussions during the workshop can be found on the SC7 meeting webpage. The model was updated with new data, and subsequently accepted at the SC7 meeting. Discussions at SC7 focused on the following topics:

- Review and update of data sets;
- Assumptions on selectivity and catchability for the fisheries and surveys;
- The need for safeguards for weight-at-age data templates to reduce the likelihood of erroneous inputs.

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° to 50° 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 hypotheses: 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

[1] Rev1 refers to an update of Table A8.30

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 hypotheses 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 SC to continue the work on evaluating alternative hypotheses on Jack mackerel stock population. Pending more conclusive findings on the stock population structure of Jack mackerel, the 2nd Commission meeting requested the SC to continue and expand the stock assessment work under both stock hypotheses considered in the 11th SWG Meeting, and this continues to be one of the main tasks undertaken at SC7.

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 for fish meal. In Peru, the fishery is variable from year to year. Here the fish are taken by purse seiners that also fish for other pelagic species (e.g., anchovy, mackerel, sardines). 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 (70,000 tons in 2011). Part of the catch is processed into fish meal but recently Jack 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 Belize, 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 Jack mackerel fishery in Chilean and offshore waters is mono-specific. In the offshore fishery, the catch consists for 90 – 98% of Jack mackerel, with minor bycatch of chub mackerel (*Scomber japonicus*) and Pacific bream (*Brama australis*). The available time series of Jack mackerel catches in the south-eastern Pacific by country are shown in Table A8.1 with the catch summarised by fleets in Figure A8.1.

Management

Jack mackerel were managed by coastal states beginning in the mid-1990s. National catch quotas 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 limits for Jack mackerel were established for all countries fishing in the convention area in the south-eastern Pacific.

Information on the environment in relation to the fisheries

Important environmental events (e.g., the 2016 El Niño) affect oceanographic dynamics. During such events, the depth of the 15ºC isotherm and oxycline changed significantly affecting the spatial distribution of Jack mackerel and their availability in different regions. The extent that such changes affect the overall population productivity is unclear.

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 have been used to determine the time of spawning.

2. Data used in the assessment

Fishery Data

The catch data for the model sum values from various countries (Table A8.1), and form four "fleets", which are intended to be consistent with the gear and general areas of fishing (Figure A8.1). The catches from each of these fleets are presented in Table A8.2.

Length data are available from all major fisheries both inside and outside the EEZs. Length distributions from Chile and the older international fleet were converted into age distributions using annual Chilean age-length keys. The more recent length composition data from China and EU were converted to age compositions by applying Chilean age-length keys as compiled by quarter of the year and then aggregated (Table A8.3, Table A8.4, and Table A8.5). In some years, including 2018 and 2019, the EU provided age-length keys which were used to convert EU length distribution data to age. For Peruvian and Ecuadorian fisheries, length frequency data (Table A8.6) were used directly and fit within the model according to the specified growth curve.

Several CPUE data series are used in the model, with some changes introduced during SC6 and SC7. For the Chilean purse seiner fleet, a "Generalized Linear Model" (GLM; McCullagh & Nelder, 1989) approach was used to standardise the CPUE. Here CPUE was modelled as a linear combination of explanatory variables with the goal to estimate a year-effect that is proportional to Jack mackerel density. Factors in the GLM included year, quarter, zone, and vessel hold capacity. Effort units were computed as the number of days spent fishing by each vessel. This CPUE series was revised during SC4 to exclude trips with no Jack mackerel catches. This was preferred because it better reflects changes in management over time (particularly the introduction of vessel-level quotas starting in 2000). To account for changes in fleet behaviour arising from the changes in management, the revised CPUE series from the GLM was modelled to have a catchability change in year 2000.

Up to 2018, Peru had been using a CPUE abundance index derived from the industrial purse seine fleet. This fishery has a strong focus on anchoveta and other stocks such as chub mackerel (*Scomber japonicus*) and bonito (*Sarda chiliensis*). With increasing catch rates in those fisheries, the focus on Jack mackerel shifted, and the CPUE index was deemed no longer indicative of Jack mackerel biomass. This resulted in a lack of CPUE data between 2015 and 2017 for previous assessments. Thus, in 2018, a change was introduced. CPUE indicators were calculated based on artisanal and small-scale fleets. These fleets are and have been targeting the Jack mackerel on a regular basis, operating at a closer distance to the coast than the industrial fleets. Historical data on catch by haul capacity for the artisanal fleets were recovered beginning in 2000. A Generalised Additive Model, in which the dependent variable (catch per trip) is gamma-distributed using a log-link function, was applied by removing the operational (holding capacity) and temporal effects (year, month). The GAM combined data from both artisanal and industrial fleets, although concerns were raised about the accuracy of the historical data (e.g., from missing fleet identifiers) and thus there is a need for continued development.

Until 2017, both the European CPUE index (un-standardised), the Russian CPUE index (un-standardised) and the Chinese CPUE index (standardised with a GLM) were included as separate indices of exploitable biomass for offshore fleet. The Russian data were incorporated into a combined standardised offshore CPUE index in 2018, with the Chinese CPUE kept separate. In 2019, haul-by-haul data of China, EU, Korea, Vanuatu, and Russia were combined and standardised into a single Offshore CPUE time series (SC7-JM06_rev1). The standardisation procedure followed what had previously been done during SCW6. A GAM was fit to catch data with an offset of log(effort) assuming a negative binomial distribution. Vessel, month of the year, year, and El Niño effect (sea surface temperature anomaly) were taken as linear effects while two-dimensional smoothers were applied to correct for spatial effects. The resultant combined Offshore CPUE index included in the 2019 stock assessment was from 2008 to 2018, whereas the 2018 Offshore CPUE index was from 2006 to 2017. It was noted that these fleets share similar temporal and spatial dynamics.

In all standardised CPUE series, no explicit correction for search time has been incorporated. In some products, such as the offshore CPUE, effort in weeks is taken rather than effort by day (of positive registrations) to account for searching time. However, the inability to consistently define and accurately measure searching time remains an issue. Further, the lack of a defined protocol for CPUE standardisation was noted, and it was agreed that the development of CPUE standardisation guidelines should be a priority to improve the quality of the assessment. These guidelines should include some guidance on the best types of models to use (e.g., GLM vs. GAM), and explore how best to define search time. Considerations should also be made to include flexibility for future improvements and revisions.

Fisheries Independent Data

The Chilean Jack mackerel research programme has included conducting surveys using hydro-acoustics and the daily egg production method (DEPM). Acoustic estimates and egg survey results are used as relative abundance indices. For the northern region (N-Chile) data on acoustic biomass and number and weight at age are available annually from 2006 to 2019. For the central-southern regions, these data are available from 1997 to 2009. In previous Jack mackerel assessments, the acoustic survey in northern Chile was assigned the same selection-at-age curve as the northern Chile fishing fleet; however, given the survey age composition data indicate that it catches younger ages than the fishing fleet, the SC6 considered it more appropriate to assign the survey its own selectivity. To estimate the abundance of the spawning stock, egg surveys (through the DEPM) were conducted on an annual basis from 1999 to 2008 along the central zone of the Chilean coast. In addition, there are estimates of abundance and numbers-at-age for the central-southern regions based on DEPM for the years 2001, 2003, 2004, 2005, 2006, 2008. Age composition data for the acoustic and DEPM Chilean surveys are shown in Table A8.7, Table A8.8, and Table A8.9.

The Peruvian Jack mackerel research programme includes egg and larvae surveys and hydro-acoustic 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. During SC3, a new series of acoustic biomass was provided by Peru for years 1986-2013. This series represented 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 target species, the data only covered 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 were being made by using an environmental index describing the potential habitat of this species based on available monthly data on SST, Sea Surface Salinity (SSS), water masses (WM), oxycline depth (OD) and chlorophyll (CHL), since 1983 to the present.

An additional alternative acoustic index for Peru was presented at SC3. This was constructed using backscatter information without converting the information to biomass estimates using length-frequency data. This method was proposed to address the reduced quality of the available length-frequency data in recent years. This alternative series was included in the Jack mackerel assessment in SC4, thus replacing the Peruvian acoustic series used in previous assessments. The last value provided for this series corresponds to 2013. The El Niño conditions in 2014 and 2015 affected the distribution of Jack mackerel making them more dispersed and outside the area covered by the anchovy survey. Further work is needed to standardise and analyse the survey data to develop a reasonable index from these data. This index has been retained in the current assessment.

Acoustic surveys, to estimate the biomass and distribution of Jack mackerel, have also been conducted along the Chilean coast, inside and outside of the EEZ and in the Peruvian EEZ, using scientific vessels. Additionally, comprehensive acoustic surveys have been conducted from the Chilean commercial fleet. The time series of available acoustic estimates extends from 1985 to 2013 (depending on the area). All abundance indices (fishery CPUE and survey) series used in the model are presented in Table A8.10.

Biological Parameters

The maturity-at-age assumed for Jack mackerel was based on a Chilean study (Leal et al. 2012). 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 in the assessment a few years ago. Maturity at length was consistently observed with L50 at about 23 cm fork length (FL). The maturity-at-age values, and those for the far-north stock, are shown in Table A8.11.

To fit the length composition data from the far-north fleet, a growth curve was used to convert age compositions predicted by the model to predicted lengths, with the conversion occurring within the model. The values for the von Bertalanffy growth parameters are given in Table A8.12. Ageing imprecision is acknowledged using an age-error matrix, as shown in Table A8.13. However, because this matrix is based on expert judgement instead of actual data, the discussions during SC4 led to selecting the final assessment model with this ageing error option turned off.

Mean weight-at-age is required for all fishing fleets and biomass indices in order to relate biomass quantities to the underlying model estimates of Jack mackerel abundance (in numbers). The four weight at-age matrices for the fishing fleets correspond to: fleet 1 (northern Chile), fleet 2 (central-south Chile), fleet 3 (the far north fleet) and fleet 4 (the offshore trawl fleet). These values are shown in Table A8.14, Table A8.15, Table A8.16, and Table A8.17.

In Chile, the mean weight-at-age is calculated by year by taking the mean length at age in the catch and a length-weight relationship of the year. Before SC3, the same weight at age matrix was used for the Northern Chilean Fleet (Fleet 1) and Southern Chilean Fleet (Fleet 2). Beginning in SC3, 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 the weight-at-length relationship from IFOP's monitoring programme of the Chilean fisheries. The information was separated into two zones which correspond to fishing areas (and acoustic surveys) that 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 (Table A8.14 and Table A8.15). The information covers the period 1974-2019; for earlier years the weight-at-age from 1974 was used.

In Peru, mean weight-at-age is calculated by year taking the invariant mean length-at-age estimated from the growth function (Table A8.12) and the length-weight relationship of the year. The information covers the period 1970-2019 (Table A8.16).

The weights-at-age for the offshore fleet are derived from EU age-length keys as well as age-length keys from the Chilean South-Central fleet. The EU reported both age, length, and weight data, allowing for weight-at-age to be reported for their catches based on observer programme data compiled in 2018.

For China, Vanuatu, Russia and Korea, length-weight information is transformed using the Chilean fleet-2 quarter-specific age-length keys (Table A8.17). Note that for most countries weight-at-length information is available. In some years however, including 2018, weight-at-length data from the Chinese fleet were missing, which resulted in using the weight-length relationship from the Chilean fleet 2.

It was noted during SC7 that these weight-at-age data showed unusual patterns and warranted further investigation. For example, the reported weights of age-2 and age-3 fish for the Chilean Central-South and Offshore fleets in 2015 were anomalously higher relative to those historically reported. A similar anomaly emerged in the 2018 weight-at-age data for the Offshore fleet. A decision was made to use an average of the previous and the subsequent years for those aforementioned years and fleets. This interim measure was taken in lieu of a more in-depth look at those data, which will be discussed at the next benchmark assessment.

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 (see Table A8.12).

Data Sets

A full description of data sets used for the assessment of Jack mackerel is in Annex 3 of the SC Data workshop 2015. A summary list of all data available for the assessment is provided in Table A8.18.

3. The Assessment Model

A statistical catch-at-age model was used to evaluate the Jack mackerel stocks. The JJM ("Joint Jack Mackerel Model") is implemented in ADMB and considers different types of information, which corresponds to the available data of the Jack mackerel fishery in the South Pacific area from 1970 to 2019 (Table A8.18).

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.

JJM Developments

Since its adoption, the JJM model has been improved by participating scientists. The most noted changes have 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 the use of catch information either at age or size for any fleet, and explicitly incorporates regime shifts in population productivity.

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

Stock dynamics: recruitment is considered to occur in January while the spawning season is considered as an instantaneous process at mid-November. The population's age composition considers individuals from 1 to 12+ years old for the single stock hypothesis (hypothesis 2) as well as for the southern stock in the two-stock hypothesis (hypothesis 1), while for the northern stock (hypothesis 1) 1 to 8+ years old are considered. In all cases a stochastic Beverton-Holt relationship (Beverton & Holt 1957) 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) in the case of the single stock (hypothesis 2) and in the southern stock in the case of the two-stock hypothesis (hypothesis 1), while in the northern stock equilibrium condition occurs in 1962 (8 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 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 index-specific, and there are nine abundance indexes. For some of the indices, time variations in catchability and / or selectivity 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 indices data.

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 mostly constant over years. For the total catch by fishery (4) and abundance indices (9), a log-normal assumption has been assumed with constant CV; the CV for the fisheries is 0.05 whereas the CVs for the abundance indices depend on the index. Beginning in 2018, as discussed in SC4 and agreed upon in SCW6, the Francis T1.8 weighting method (Francis 2011) is used to assign weighted sample sizes for age-frequency data. The same data weights from SC6 were used for the SC7 update.

Parameter estimation: The model parameters are estimated by maximising 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 its characteristics can be consulted in Fournier et al. (2012).

Model Details

Parameters estimated conditionally are listed in Table A8.19. The most numerous of these involve estimates of annual and age-specific components of fishing mortality for each year from 1970-2019 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+ and 1-8+) were the second most numerous type of parameter.

Equations and specifications for the assessment model are given in Table A8.20 and Table A8.21. Table A8.22 contains the initial variance assumptions for the indices and age and length compositions.

The treatment of selectivity and how they are shared among fisheries and indices are given in Table A8.23 and Table A8.24 for the two stocks under the two-stock model configurations, and Table A8.25 for the single-stock hypothesis. Selectivity for the FarNorth fleet was specified with a regime shift in 2002 under the two-stock hypothesis, while annual variations beginning in 1981 were specified under the single-stock hypothesis. Depending on the model configuration, some growth functions were employed inside the model to convert model-predicted age compositions to length compositions, in order to fit the model to the length composition data.

Models for Stock Structure Hypothesis

During SWG 11, two types of population structure were evaluated, and this was continued for subsequent evaluations. Models under the two-stock hypotheses carry the same naming convention but have the letters “N” or “S” appended to designate split-stock model runs (for North and South stock structure hypothesis).

Description of Model Explorations

As SC7 was an update assessment, the only model explorations involved incrementally adding new data components relative to last year's Jack mackerel model (Model 1.5 from SC6). These are labelled "Mod0.x" where x represents the number when a component was added (Table A8.26).

The rationale for the main updates and data revisions occurring through model configurations 0.00 to 0.18 has been explained in the "Data used in the assessment" section, earlier in this Annex. The data exercise concluded with Model 0.18.

Thereafter, Model 0.18 was renamed as Model *1.00*. with an updated control file to reflect changes in selectivity for the current year, as was done in previous years. Given that this was an update assessment, alternate model configurations and sensitivities were not explored at this meeting, and Model *1.00* was adopted. The most salient features of this model configuration, agreed by SC7, are outlined below.

Notably, the final model used the Francis weights agreed upon by SC6 for the multinomial age composition sample sizes, and these weights were not updated in this assessment. Also, the model took a precautionary approach to assessment and advice. It assumed low steepness (h=0.65) based on the most recent recruitment time-series (2000-2015), similar to assessments prior to SC5, proposing a precautionary approach to assessment and advice. Furthermore, the recent strong recruitment estimate for 2016 was found to be greatly different from the previous years, and not confirmed at a population-wide level. As such, for the purposes of a more precautionary projection, the decision was made to use the lower 95% confidence interval for 2016 recruitment value.

4. Results

Results comparing the impact of new data (Models 0.00-0.18) show that updating the fishery composition data in particular resulted in a change of recruitment trends in recent years. Changing the anomalous weights at ages resulted in no change to the perception of stock status. Other major data updates include the incorporation of the Chinese index into the Offshore CPUE index, as mentioned previously, which resulted in a more optimistic outlook on the stock.

The analytical retrospective analysis (which involves running the model multiple times, each time removing the final year of data, done for five years) shows that the time series of recruitment and SSB have a slight tendency to be over-estimated relative to the next year's estimates when more data were added. Further, as more data are accumulated, the magnitude of recruitment estimates can change (Figure A8.2).

An alternative to the analytical retrospective analysis, which is based on the current model formulation, the "historical retrospective analysis" instead compares quantities derived from assessments previously adopted by the SC (raw values for biomass found in Table A8.27; graphically visualised in Figure A8.3 and Figure A8.4). This indicates the year-to-year changes in estimates of stock trends and reference points. Results indicate that the current model formulation is consistent in the most recent years for biomass and fishing mortality. The recruitment comparison shows that high recruitment of the 2016 year class that was estimated in 2017 is no longer evident from the most recent assessment (Figure A8.3). Downward revision of SSB was further driven by an update in the Chinese CPUE and a change in assumption on fleet selectivity, allowing free estimation of F-at-age in recent years compared to more rigid assumptions in the 2017 model configuration.

Assumed fishery mean weight-at-age assumed for all models are shown in Figure A8.5. Estimates of numbers-at-age from the model are given in Table A8.28. The fishery age and length composition fits are shown in Figure A8.6, Figure A8.7, Figure A8.8, and Figure A8.9. The fits to age composition data from the surveys are given in Figure A8.10 and Figure A8.11. This model fit the indices well (Figure A8.12). Fits to the fishery and survey mean age compositions are shown in Figure A8.13 and Figure

A8.14 respectively. Fits to mean length compositions for the Far North fleet are shown in Figure A8.15. Selectivity estimates for the fishery and indices are shown over time in Figure A8.16.

A summary of the time series stock status (spawning biomass, F, recruitment, total biomass) for the single-stock hypothesis is shown in Figure A8.17. As in past years, the biomass can be projected forward based on the estimated recruits to evaluate the impact of fishing under four scenarios with different recruitment (and hence productivity) assumptions. This can be informative to distinguish environmental effects relative to direct fishing impacts. For the Jack mackerel stock, fishing appears to be a major cause of the population trend, with the current level at around 48% of what is estimated to have occurred had there been no fishing (Figure A8.18).

Fishing mortality rates at age (combined fleets) were high starting in about 1992 but have declined in the past years (Table A8.29 and Figure A8.17). To evaluate the potential for alternative “regimes”, stock recruitment curves were estimated over different periods (as defined in Annex 4 of SC1). Within the current period (2001-2015), the level of expected recruitment was lower than the alternatives although recruitment has increased in recent years to about the long-term average mean. Time series of quantities derived by the model are presented in Table A8.30. Short, medium and long-term SSB predictions using Model *1.00* (single-stock hypothesis) are presented in Table A8.31.

The JJM assessment model was also run under the 2-stock hypothesis, and a summary figure of the northern (far-north) and southern stocks can be found in Figure A8.19. Conditions of the Jack mackerel stock in its entire distribution range in the southeast Pacific shows a continued recovery since the time-series low in 2010. It is noted that under the two-stock model, the northern unit shows stable and relatively low biomass over the last decade, while the southern unit shows an increasing trend. The southern unit showed similar results to that of the single-stock hypothesis, although SSB was estimated slightly higher under the former scenario. Estimates of stock size and exploitation rate for the Northern stock were comparable to previous years and show a small increase in stock size in the last year while fishing mortality is low (Figure A8.19).

5. Management Advice

New data and indicators on the status of the Jack mackerel stock suggest that conditions evaluated in detail from the last benchmark assessment (completed in 2018) are relatively unchanged. The population trend is estimated to be increasing. The indications of stock improvement (higher abundance observed in the acoustic survey in the northern part of Chile, better catch rates apparent in some fisheries, and increase in average age in the Chilean fisheries) drive the increase.

Historical fishing mortality rates and patterns relative to the provisional biomass target are shown in Figure A8.17. Near term spawning biomass is expected to increase from the 2019 estimate of 6.2 million t to 7.5.1 million t in 2020 (with approximate 90% confidence bounds of 6.0 – 9.2 million t).

Given current stock status, the third tier of the Jack mackerel rebuilding plan should be applied. However as this would result in a potential increase in the catch of over 480 kt a maximum increase of 15% needs to be applied in line with the “adjusted Annex K” rebuilding plan. This would result in a 2020 catch level for Jack mackerel within the entire Jack mackerel range to be at or below 680 kt. Note that this stock status is based on an assessment configuration that assumes a constant 5.5 million t B_{MSY} level. Recent increases in the theoretical B_{MSY} values (estimated in the model; likely due to changes in selectivity of all fisheries combined; different from the constant B_{MSY}) would imply an estimate of SSB at about 40% over B_{MSY}. Under the current harvest control rule, a 15% increase results in recommended catch levels at or below 680 kt.

Projections show a high likelihood of the biomass being rebuilt to B_{MSY} in 2019 under the most conservative recruitment productivity scenario evaluated. As such, a re-evaluation of the rebuilding plan is recommended to analyse sustainable exploitation rates of a re-built Jack mackerel stock.

6. Assessment Issues

Based on results from the 2018 assessment workshop, as noted previously, assessment plans for 2020 should be developed several months prior to SC8 (or the next benchmark) so that data coordinators can configure alternatives and conduct a careful evaluation of all available information to best guide the Commission. One of the higher priority items for consideration continues to be the catch-at-age estimates (based on age-determinations being conducted from different labs) and mean body weights at age assumed in the model. Another priority for consideration is the development of guidelines for standardisation of CPUE indices and the collection of relevant data. Results of the data weighting and the retrospective pattern analysis also warrant further investigation.

The issue of evaluating sensitivities to the early fishery age composition data was raised. The SC noted that this might be a fruitful avenue for investigation in subsequent assessments, particularly since these data (pre-1990) are less well-documented.

7. References

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8. Tables

Table A8.1. Sources and values of catch (t) complied for the four fleets used for the assessment (data for 2018 are preliminary, and 2019 are provisional).

Assigned Fleet	Fleet 1	Fleet 2	Fleet 3 (Far North)						Fleet 4 (Offshore Trawl)												Grand Total
Year	N Chile	Chile CS	Cook Islands	Cuba	Ecuador (ANJ)	Peru (ANJ)	USSR	Subtotal	Belize	China	Cuba	European Union	Faroe Islands	Japan	Korea	Peru	Russia / USSR	Ukraine	Vanuatu	Subtotal	
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	0	140720	137033	281139			21100			701			854020			875821	3547077
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			7122	296579		303701		2318										2318	1540318
2001	248097	1401836			133969	723733		857702		20090										20090	2527725
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		6187			9126		7040		77356	243576	1754673
2006	155256	1224685			0	277568		277568	481	160000		62137			10474		0		129535	362627	2020136
2007	172701	1130083	7		927	254426		255360	12585	140582		123523	38700		10940		0		112501	438831	1996975
2008	167258	728850	0		0	169537		169537	15245	143182		108174	22919		12600		4800		100066	406986	1472631
2009	134022	700905	0		1934	74694		76628	5681	117963		111921	20213	0	13759	13326	9113		79942	371918	1283473
2010	169012	295796	0		4613	17559		22172	2240	63606		67497	11643	0	8183	40516			45908	239593	726573
2011	30825	216470	0		69373	257241		326614	0	32862	8	2248	0	0	9253	674	8229		7617	60891	634800
2012	13256	214204	0		77	187292		187369		13012	0	0	0	0	5492	5346	0		16068	39917	454746
2013	16361	214999	0		3563	77022		80585		8329		10101	0		5267	2670			14809	41175	353120
2014	18219	254295	0		9	74528		74537		21155		20539	0		4078	2557			15324	63652	410703
2015	34886	250327			289	22158		22447		29180		27955	0		5749	0	2561		21227	86672	394332
2016	24657	295160			0	15087		15087		20208		11962	0		6430	0	0		15563	54163	389067
2017	35002	311863			54	8813		8867		16802		27887	0		1235	0	3188		0	49113	404845
2018	11551	415149			23	57140		57163		24366		9691	0		3717	0	4685		0	42460	526323
2019	12000	437000			0	140000		140000		22699		11963	0		6965	0	7184		0	48811	637811

Table A8.2. Input catch (kilo tonnes) by fleet (combined) for the stock assessment model. Note that 2019 data are preliminary.

Year	Fleet 1	Fleet 2	Fleet 3	Fleet 4
1970	101.69	10.31	4.71	0
1971	143.45	14.99	9.19	0
1972	64.46	22.55	18.78	5.5
1973	83.2	38.39	42.78	0
1974	164.76	28.75	129.21	0
1975	207.33	53.88	37.9	0
1976	257.7	84.57	54.15	0.04
1977	226.23	114.57	504.99	2.27
1978	398.41	188.27	386.79	51.29
1979	344.05	253.46	333.81	370.29
1980	288.81	273.45	414.3	339.8
1981	474.82	586.09	445.64	438.12
1982	789.91	704.77	143.72	733.2
1983	301.93	563.34	110.69	894.3
1984	727	699.3	200.67	1059.93
1985	511.15	945.84	114.62	799.32
1986	55.21	1129.11	51.03	837.5
1987	313.31	1456.73	46.3	863.42
1988	325.46	1812.79	244.23	863.22
1989	338.6	2051.52	316.25	875.82
1990	323.09	2148.79	370.82	872.06
1991	346.25	2674.27	213.45	543.66
1992	304.24	2907.82	111.68	37.93
1993	379.47	2856.78	133.35	0
1994	222.25	3819.19	233.35	0
1995	230.18	4174.02	550.99	0
1996	278.44	3604.89	495.52	0
1997	104.2	2812.87	680.05	0
1998	30.27	1582.64	412.85	0
1999	55.65	1164.04	203.75	0.01
2000	118.73	1115.57	303.7	2.32
2001	248.1	1401.84	857.74	20.09
2002	108.73	1410.27	154.82	76.26
2003	143.28	1278.02	217.73	158.2
2004	158.66	1292.94	187.37	295.44
2005	165.63	1264.81	80.66	243.58
2006	155.26	1224.69	277.57	362.63
2007	172.7	1130.08	255.36	438.83
2008	167.26	728.85	169.54	406.99
2009	134.02	700.9	76.63	371.92
2010	169.01	295.8	22.17	239.59
2011	30.82	216.47	326.39	60.89
2012	13.26	214.2	187.4	39.92
2013	16.36	215	80.59	41.18
2014	18.22	254.29	74.53	63.65
2015	34.89	250.33	22.45	86.67
2016	24.66	295.16	15.09	54.16
2017	35	311.86	8.87	49.11
2018	11.55	415.15	57.16	42.46
2019	12	437	140	48.81

Table A8.3. Catch at age for fleet 1. Units are relative value (they are normalised to sum to 100 for each year in the model). Green shading reflects relative level.

Age group (years)

Year	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
2013	4	68	26	1	0	0	0	0	0	0	0	0
2014	6	93	1	0	0	0	0	0	0	0	0	0
2015	11	3	11	49	20	6	1	0	0	0	0	0
2016	0	0	12	19	13	21	15	8	8	3	1	1
2017	0	18	15	45	16	4	1	0	0	0	0	0
2018	25	75	0	0	0	0	0	0	0	0	0	0
2019	65	34	0	0	0	0	0	0	0	0	0	0

Table A8.4. Catch at age for fleet 2. Units are relative value (they are normalised to sum to 100 in the model). Green shading reflects relative level.

Age group (years)

Year	1	2	3	4	5	6	7	8	9	10	11	12
1975	0	0	1	2	6	18	28	25	#	5	2	0
1976	0	1	0	0	1	14	36	31	#	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	#	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	#	2	0	0
1991	0	1	2	2	1	7	28	31	#	8	3	1
1992	0	0	1	4	6	7	8	24	#	18	8	3
1993	0	0	4	12	15	14	13	12	#	12	4	1
1994	0	0	1	11	17	18	11	10	#	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	#	7	4	3
2007	0	0	1	13	15	11	15	15	#	9	5	4
2008	1	2	0	1	7	21	19	15	#	9	5	9
2009	0	0	4	9	2	19	22	17	#	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	#	5	1	1
2012	0	0	0	7	31	31	18	7	4	1	0	0
2013	0	0	2	18	29	33	14	3	0	0	0	0
2014	0	0	4	17	38	24	14	2	0	0	0	0
2015	0	0	11	40	17	11	10	7	2	1	0	0
2016	0	0	3	20	26	22	14	8	4	2	1	1
2017	0	0	8	19	15	18	15	10	5	4	3	3
2018	0	1	1	17	24	20	17	9	5	3	1	1
2019	0	0	0	11	21	23	21	16	5	3	0	0

Table A8.5. Catch at age for fleet 4. Units are relative value (they are normalised to sum to 100 for each year in the model). Green shading reflects relative level. Catch-at-age 1979-2013 were calculated considering Age-Length Key from fleet 2. Catch-at-age 2017 was calculated with an Age-Length Key from Chile from the EU.

Age group (years)

Year	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	0	1	18	21	25	17	8	3	4	1	1
2014	0	2	28	21	14	14	12	5	2	1	1	1
2015	0	0	10	19	14	15	16	14	5	3	2	2
2016	0	2	13	21	24	17	11	6	3	2	0	1
2017	30	31	15	11	5	3	3	2	1	0	0	0
2018	0	3	31	32	20	7	4	2	1	0	0	0

Table A8.6. Catch at length for fleet 3. Units are relative value (they are normalised to sum to 100 for each year in the model). Green shading represents the relative level.

	Total length (cm)																																								
Year	**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
2014	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	2	5	20	31	19	8	3	2	2	1	1	0	0	0	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0	0	0	0	1	1	3	10	13	12	14	14	9	5	4	4	3	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
2016	0	0	0	0	0	0	0	0	0	0	0	1	2	5	6	6	7	8	7	8	8	8	8	7	6	5	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0
2017	0	0	0	0	0	0	1	2	3	4	5	6	8	8	7	7	8	8	7	5	5	3	3	3	3	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0
2018	0	0	0	0	0	0	0	0	1	1	1	1	2	3	7	11	15	18	15	7	5	4	3	2	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	3	4	6	9	11	14	15	12	8	5	3	2	1	1	1	0	0	0	0	0	0	0

Table A8.7. Catch at age for acoustic surveys at southern of Chile. Units are relative value (they are normalised to sum to 100 for each year in the model). Green shading reflects relative level.

Age group (years)

Year	1	2	3	4	5	6	7	8	9	10	11	12
1997	0	1	39	42	12	3	1	1	1	0	0	0
1998	0	1	48	44	4	1	1	1	1	0	0	0
1999	0	2	29	43	11	6	2	1	3	2	1	0
2000	0	0	10	45	31	11	2	0	0	0	0	0
2001	0	1	21	46	23	6	1	1	1	0	0	0
2002	0	0	6	28	23	30	7	4	1	0	0	0
2003	0	0	3	23	34	26	7	2	2	1	1	0
2004	0	0	1	7	18	23	17	11	9	9	3	1
2005	0	0	0	9	21	41	18	5	2	0	1	1
2006	0	0	0	0	18	43	27	5	3	2	1	1
2007	0	0	0	0	0	7	21	20	19	17	8	8
2008	0	0	0	0	0	10	33	27	12	9	4	5
2009	0	0	0	0	0	0	1	33	21	18	16	12

Table A8.8. Catch at age for acoustic surveys at northern of Chile. Units are relative value (they are normalised to sum to 100 for each year in the model). Green shading reflects relative level.

Age group (years)

Year	1	2	3	4	5	6	7	8	9	10	11	12
2006	12	42	28	16	2	0	0	0	0	0	0	0
2007	0	5	17	55	21	1	0	0	0	0	0	0
2008	0	49	48	1	1	0	0	0	0	0	0	0
2009	0	41	42	16	0	1	0	0	0	0	0	0
2010	0	0	7	71	17	3	1	0	0	0	0	0
2011	0	27	12	50	4	5	1	0	0	0	0	0
2012	0	43	5	17	25	9	1	0	0	0	0	0
2013	11	35	2	17	16	15	4	1	0	0	0	0
2014	30	66	1	1	0	1	1	0	0	0	0	0
2015	62	10	5	15	4	2	1	0	0	0	0	0
2016	70	4	10	10	4	1	0	0	0	0	0	0
2017	19	57	7	10	5	1	0	0	0	0	0	0
2018	78	15	2	3	1	0	0	0	0	0	0	0
2019	4	12	20	39	20	4	1	0	0	0	0	0

Table A8.9. Catch at age for DEPM surveys at southern of Chile. Units are relative value (they are normalised to sum to one for each year in the model). Green shading reflects relative level.

	Age group (years)											
Year	1	2	3	4	5	6	7	8	9	10	11	12+
2001	15	36	37	6	3	2	2	1	0	0	0	0
2003	2	15	24	10	16	11	12	6	2	1	0	0
2004	2	15	35	19	9	5	7	5	2	1	0	0
2005	0	0	1	38	24	16	11	5	3	2	0	0
2006	0	0	4	20	31	24	14	5	2	1	0	0
2008	0	0	4	12	22	27	20	9	5	0	0	0

Table A8.10. Index values used within the assessment model.

Year	Chile (1)	Chile (2)	Chile (3)	Chile (4)	Peru (2)	Peru (3)	China	Offshore
1983			0.582					
1984		99	0.532					
1985		324	0.46		94.316			
1986		123	0.379		108.116			
1987		213	0.462		109.789			
1988		134	0.406		114.18			
1989			0.391		157.394			
1990			0.322		229.757			
1991		242	0.368		231.672			
1992			0.353		180.355			
1993			0.299		145.726			
1994			0.332		95.245			
1995			0.297		54.257			
1996			0.284		29.967			
1997	3530		0.215		31.664			
1998	3200		0.207		43.994			
1999	4100		0.216	5724	52.681			
2000	5600		0.21	4688	105.784			
2001	5950		0.265	5627	131.586		1.34	
2002	3700		0.213		96.661	4.016	1.9	
2003	2640		0.207	1388	67.471	4.859	1.92	
2004	2640		0.239	3287	51.853	5.316	1.45	
2005	4110		0.224	1043	75.171	4.206	1.51	
2006	3192	112	0.233	3283	111.259	5.572	1.05	1788
2007	3140	275	0.166	626	79.75	7.986	1.19	1595
2008	487	259	0.102	1935	24.251	3.904	0.91	1099
2009	328	18	0.083			1.45	0.81	873
2010		440	0.052		7.247	2.678	0.58	543
2011		432	0.034		35.283	6.79	0.35	497
2012		230	0.132		50.332	6.033	0.4	476
2013		144	0.111		64.504	2.599	0.58	580
2014		87	0.086			3.678	0.53	468
2015		459	0.068			3.076	1.35	589
2016		587.244	0.133			2.685	0.77	551
2017		610.47	0.162			3.545	1.28	775
2018		375.639	0.169					
2019		1487.07	0.356			11.13		

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 1
Chile (4): Daily Egg Production Method
Peru(1): Peruvian acoustic index in fleet 3
Peru(2): Peruvian echo-abundance index in fleet 3 (alternative)
Peru(3): Peruvian fishery CPUE in fleet 3
China: Chinese CPUE for fleet 4 (down weighted)
Offshore: Combined CPUE for China, EU, South Korea, Russia, and Vanuatu in fleet 4

Table A8.11. Jack mackerel sexual maturity by age used in the JJM models.

Age (yr)	1	2	3	4	5	6	7	8	9	10	11	12
Single Stock	0.070	0.310	0.720	0.930	0.980	0.990	1.000	1.000	1.000	1.000	1.000	1.000
Far North Stock	0.000	0.370	0.980	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table A8.12. Jack mackerel growth and natural mortality parameters used in JJM models.

Parameter	Far North stock	Single stock
L_∞ (cm) (Total length)	80 .4	74.4
k	0.16	0.16
L_0 (cm)	18.0	18.0
M (year^{-1})	0.33	0.23

L_o is the mean length at the recruitment age (1 yrs).

Table A8.13. Ageing error matrix of Jack mackerel.

	1	2	3	4	5	6	7	8	9	10	11	12+
1	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.76	0.22	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.24	0.51	0.23	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.02	0.23	0.50	0.23	0.02	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.02	0.23	0.49	0.23	0.02	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.03	0.23	0.48	0.23	0.03	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.03	0.24	0.46	0.24	0.03	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.03	0.24	0.45	0.24	0.03	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.24	0.44	0.24	0.04	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.24	0.43	0.24	0.04
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.24	0.42	0.29
12+	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.24	0.71

Table A8.14. Input mean body mass (kg) at age over time assumed for fleet 1.

Year	1	2	3	4	5	6	7	8	9	10	11	12
1970	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1971	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1972	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1973	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1974	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1975	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1976	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1977	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1978	0.05	0.105	0.124	0.163	0.204	0.314	0.369	0.405	0.434	0.453	0.59	1.115
1979	0.05	0.108	0.163	0.179	0.217	0.274	0.37	0.42	0.474	0.629	0.633	1.115
1980	0.05	0.069	0.118	0.21	0.256	0.324	0.41	0.451	0.511	0.998	0.88	1.115
1981	0.05	0.094	0.139	0.214	0.269	0.331	0.412	0.481	0.58	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	0.54	1.115
1984	0.05	0.164	0.186	0.217	0.273	0.345	0.394	0.437	0.497	0.568	0.786	1.115
1985	0.05	0.167	0.173	0.224	0.271	0.34	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	0.55	0.869	0.88	1.115
1987	0.092	0.121	0.146	0.189	0.233	0.336	0.427	0.477	0.513	0.65	0.803	1.115
1988	0.05	0.11	0.167	0.197	0.23	0.298	0.472	0.545	0.586	0.61	0.88	1.115
1989	0.05	0.123	0.167	0.23	0.27	0.31	0.379	0.491	0.541	0.569	0.713	1.115
1990	0.069	0.099	0.16	0.248	0.29	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	0.72	0.794	0.883
1992	0.069	0.092	0.127	0.201	0.268	0.3	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	0.33	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	0.88	1.115
1996	0.067	0	0.14	0.17	0.229	0.295	0.367	0.507	0.657	0.639	0.88	1.115
1997	0.029	0.063	0.125	0.177	0.246	0.357	0.503	0.615	0.584	0.728	0.88	1.115
1998	0	0.082	0.104	0.195	0.249	0.29	0.39	0.475	0.634	0.728	0.88	1.115
1999	0.071	0.074	0.089	0.147	0.27	0.315	0.446	0.722	0.584	0.728	0.88	1.115
2000	0.043	0.054	0.138	0.191	0.225	0.251	0.372	0.488	0.584	0.728	0.88	1.115
2001	0.066	0.093	0.112	0.133	0.204	0.286	0.421	0.488	0.584	0.728	0.88	1.115
2002	0.029	0.059	0.092	0.172	0.238	0.327	0.398	0.416	0.628	0.728	0.88	1.115
2003	0.036	0.082	0.102	0.141	0.227	0.309	0.416	0.464	0.534	0.728	0.88	1.115
2004	0.037	0.078	0.164	0.186	0.203	0.257	0.342	0.488	0.584	0.728	0.88	1.115
2005	0.029	0.076	0.111	0.175	0.222	0.268	0.281	0.488	0.584	0.728	0.88	1.115
2006	0.032	0.074	0.114	0.132	0.204	0.374	0.442	0.506	0.606	0.728	0.88	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	0.88	1.115
2009	0.015	0.047	0.106	0.138	0.239	0.285	0.335	0.526	0.584	0.728	0.88	1.115
2010	0.013	0.048	0.101	0.172	0.233	0.301	0.397	0.493	0.639	0.772	0.88	1.115
2011	0.019	0.065	0.095	0.167	0.276	0.314	0.398	0.488	0.584	0.728	0.88	1.115
2012	0.016	0.048	0.088	0.202	0.235	0.269	0.396	0.488	0.584	0.728	0.88	1.115
2013	0.038	0.052	0.069	0.151	0.255	0.43	0.495	0.664	0.525	0.687	0.821	1.086
2014	0.018	0.04	0.082	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
2015	0.027	0.058	0.177	0.183	0.298	0.442	0.621	0.52	0.583	0.729	0.868	1.109
2016	0.027	0.058	0.158	0.195	0.235	0.3	0.353	0.535	0.692	0.742	0.859	0.974
2017	0.024	0.063	0.14	0.164	0.181	0.223	0.299	0.4	0.6	0.528	0.88	1.115
2018	0.016	0.041	0.093	0.199	0.235	0.259	0.272	0.323	0.323	0.528	0.88	1.115
2019	0.011	0.022	0.179	0.179	0.201	0.232	0.266	0.323	0.323	0.528	0.88	1.115

Table A8.15. Input mean body mass (kg) at age over time assumed for fleet 2.

Year	1	2	3	4	5	6	7	8	9	10	11	12
1970	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1971	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1972	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1973	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1974	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1975	0.052	0.093	0.131	0.178	0.262	0.294	0.34	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	0.16	0.199	0.241	0.301	0.388	0.466	0.588	0.871	1.265	1.972
1980	0.026	0.06	0.132	0.231	0.272	0.35	0.447	0.519	0.716	0.82	1.073	1.854
1981	0.052	0.095	0.149	0.242	0.294	0.34	0.407	0.503	0.637	0.765	1.184	1.9
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	0.07	0.099	0.122	0.23	0.273	0.32	0.374	0.461	0.596	0.709	1.196	1.769
1984	0.035	0.135	0.154	0.185	0.266	0.33	0.383	0.449	0.577	0.685	1.012	1.846
1985	0.058	0.148	0.181	0.223	0.27	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	0.64	0.844	1.351	2.11
1987	0.076	0.117	0.14	0.191	0.27	0.357	0.434	0.503	0.577	0.689	1.089	1.979
1988	0.1	0.124	0.159	0.197	0.233	0.342	0.444	0.512	0.588	0.75	1.012	1.372
1989	0.052	0.103	0.22	0.241	0.278	0.339	0.467	0.585	0.702	0.779	0.88	1.538
1990	0.064	0.091	0.153	0.264	0.309	0.373	0.461	0.582	0.694	0.835	0.97	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	0.32	0.408	0.579	0.719	0.853	0.965	1.174
1994	0.041	0.084	0.112	0.224	0.27	0.336	0.462	0.643	0.808	0.868	1.058	1.421
1995	0.07	0.098	0.145	0.192	0.27	0.34	0.429	0.577	0.807	0.965	1.115	1.367
1996	0.061	0.092	0.151	0.191	0.28	0.352	0.524	0.683	0.945	1.216	1.426	1.477
1997	0.104	0.106	0.146	0.201	0.26	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	0.34	0.545	0.806	1.035	1.246	1.412	1.655
1999	0.09	0.109	0.134	0.174	0.25	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	1.36	1.671
2002	0.031	0.074	0.13	0.2	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	0.4	0.564	0.768	1.005	1.209	1.537
2004	0.034	0.08	0.158	0.193	0.247	0.307	0.387	0.528	0.7	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	0.35	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	0.51	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	0.33	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	0.19	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	1.6
2013	0.054	0.158	0.251	0.26	0.318	0.385	0.45	0.553	0.705	0.829	1.117	1.977
2014	0.052	0.093	0.182	0.247	0.375	0.485	0.534	0.682	1.094	1.281	1.302	1.656
2015	0.051	0.112	0.191	0.256	0.345	0.429	0.504	0.627	0.935	1.069	1.206	1.447
2016	0.05	0.131	0.2	0.265	0.316	0.372	0.475	0.572	0.777	0.858	1.11	1.237
2017	0.017	0.058	0.201	0.24	0.303	0.382	0.468	0.562	0.721	0.953	1.096	1.616
2018	0.016	0.031	0.212	0.241	0.305	0.378	0.494	0.594	0.78	0.916	1.346	1.824
2019	0.012	0.034	0.192	0.269	0.304	0.396	0.482	0.587	0.754	0.766	1.149	2.175

Table A8.16. Input mean body mass (kg) at age over time assumed for fleet 3.

Year	1	2	3	4	5	6	7	8	9	10	11	12
1970	0.045	0.171	0.377	0.642	0.945	1.265	1.587	1.9	2.196	2.47	2.721	2.946
1971	0.045	0.171	0.377	0.643	0.946	1.266	1.588	1.902	2.198	2.472	2.723	2.949
1972	0.03	0.13	0.306	0.548	0.835	1.148	1.47	1.789	2.095	2.382	2.647	2.887
1973	0.037	0.147	0.33	0.568	0.842	1.134	1.43	1.718	1.991	2.246	2.478	2.688
1974	0.038	0.147	0.326	0.558	0.825	1.108	1.393	1.671	1.934	2.178	2.402	2.603
1975	0.034	0.136	0.31	0.54	0.808	1.095	1.387	1.674	1.946	2.201	2.434	2.645
1976	0.044	0.16	0.34	0.567	0.822	1.087	1.351	1.606	1.845	2.065	2.266	2.446
1977	0.032	0.13	0.294	0.51	0.76	1.028	1.3	1.566	1.818	2.054	2.27	2.465
1978	0.032	0.129	0.295	0.516	0.774	1.05	1.332	1.608	1.872	2.117	2.343	2.547
1979	0.036	0.138	0.304	0.518	0.762	1.02	1.28	1.532	1.77	1.991	2.193	2.375
1980	0.036	0.136	0.298	0.506	0.743	0.994	1.245	1.49	1.721	1.934	2.13	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	1.92	2.108	2.278
1983	0.042	0.138	0.28	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	0.04	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	1.26	1.512	1.751	1.973	2.176	2.359
1988	0.038	0.145	0.315	0.533	0.78	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	0.15	0.32	0.532	0.769	1.017	1.263	1.499	1.722	1.927	2.113	2.28
1991	0.039	0.142	0.305	0.511	0.743	0.985	1.227	1.461	1.68	1.883	2.068	2.234
1992	0.04	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	1.08	1.354	1.62	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	0.54	0.792	1.058	1.325	1.583	1.827	2.053	2.26	2.446
1996	0.038	0.145	0.317	0.537	0.788	1.053	1.318	1.576	1.82	2.045	2.251	2.436
1997	0.045	0.152	0.312	0.506	0.72	0.94	1.155	1.361	1.553	1.729	1.889	2.031
1998	0.04	0.14	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	1.55	1.877	2.189	2.481	2.75	2.994
2001	0.033	0.139	0.324	0.572	0.864	1.18	1.504	1.822	2.127	2.412	2.674	2.912
2002	0.036	0.145	0.33	0.576	0.861	1.167	1.478	1.783	2.074	2.344	2.593	2.817
2003	0.04	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	1.74	2.017	2.275	2.511	2.724
2005	0.037	0.15	0.341	0.595	0.89	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	1.23	1.558	1.88	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	1.19	1.51	1.823	2.122	2.4	2.656	2.888
2009	0.038	0.15	0.337	0.582	0.865	1.167	1.474	1.773	2.057	2.321	2.563	2.782
2010	0.039	0.15	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	1.395	1.806	2.217	2.614	2.99	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
2014	0.032	0.145	0.349	0.632	0.971	1.344	1.731	2.115	2.485	2.834	3.156	3.449
2015	0.033	0.146	0.346	0.621	0.95	1.31	1.682	2.051	2.405	2.739	3.047	3.327
2016	0.033	0.146	0.346	0.621	0.95	1.31	1.682	2.051	2.405	2.739	3.047	3.327
2017	0.033	0.146	0.346	0.621	0.95	1.31	1.682	2.051	2.405	2.739	3.047	3.327
2018	0.033	0.146	0.346	0.621	0.95	1.31	1.682	2.051	2.405	2.739	3.047	3.327
2019	0.033	0.146	0.346	0.621	0.95	1.31	1.682	2.051	2.405	2.739	3.047	3.327

Table A8.17. Input mean body mass (kg) at age over time assumed for fleet 4. Weight-at-age 1970-2013 were assumed to be the same as fleet 2.

Year	1	2	3	4	5	6	7	8	9	10	11	12
1970	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1971	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1972	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1973	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1974	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1975	0.052	0.093	0.131	0.178	0.262	0.294	0.34	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	0.16	0.199	0.241	0.301	0.388	0.466	0.588	0.871	1.265	1.972
1980	0.026	0.06	0.132	0.231	0.272	0.35	0.447	0.519	0.716	0.82	1.073	1.854
1981	0.052	0.095	0.149	0.242	0.294	0.34	0.407	0.503	0.637	0.765	1.184	1.9
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	0.07	0.099	0.122	0.23	0.273	0.32	0.374	0.461	0.596	0.709	1.196	1.769
1984	0.035	0.135	0.154	0.185	0.266	0.33	0.383	0.449	0.577	0.685	1.012	1.846
1985	0.058	0.148	0.181	0.223	0.27	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	0.64	0.844	1.351	2.11
1987	0.076	0.117	0.14	0.191	0.27	0.357	0.434	0.503	0.577	0.689	1.089	1.979
1988	0.1	0.124	0.159	0.197	0.233	0.342	0.444	0.512	0.588	0.75	1.012	1.372
1989	0.052	0.103	0.22	0.241	0.278	0.339	0.467	0.585	0.702	0.779	0.88	1.538
1990	0.064	0.091	0.153	0.264	0.309	0.373	0.461	0.582	0.694	0.835	0.97	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	0.32	0.408	0.579	0.719	0.853	0.965	1.174
1994	0.041	0.084	0.112	0.224	0.27	0.336	0.462	0.643	0.808	0.868	1.058	1.421
1995	0.07	0.098	0.145	0.192	0.27	0.34	0.429	0.577	0.807	0.965	1.115	1.367
1996	0.061	0.092	0.151	0.191	0.28	0.352	0.524	0.683	0.945	1.216	1.426	1.477
1997	0.104	0.106	0.146	0.201	0.26	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	0.34	0.545	0.806	1.035	1.246	1.412	1.655
1999	0.09	0.109	0.134	0.174	0.25	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	1.36	1.671
2002	0.031	0.074	0.13	0.2	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	0.4	0.564	0.768	1.005	1.209	1.537
2004	0.034	0.08	0.158	0.193	0.247	0.307	0.387	0.528	0.7	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	0.35	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	0.51	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	0.33	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	0.19	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	1.6
2013	0.052	0.125	0.268	0.263	0.31	0.362	0.431	0.507	0.678	0.726	0.936	1.143
2014	0.052	0.093	0.217	0.266	0.372	0.47	0.603	0.65	0.747	0.753	1.636	1.72
2015	0.051	0.113	0.216	0.277	0.359	0.428	0.544	0.632	0.777	0.833	1.365	1.458
2016	0.05	0.132	0.214	0.287	0.346	0.385	0.486	0.615	0.806	0.914	1.094	1.195
2017	0.056	0.094	0.445	0.353	0.369	0.437	0.525	0.616	0.653	0.837	1.071	1.11
2018	0.053	0.106	0.292	0.302	0.362	0.431	0.538	0.627	0.736	0.835	1.267	1.342
2019	0.053	0.106	0.292	0.302	0.362	0.431	0.538	0.627	0.736	0.835	1.267	1.342

Table A8.18. 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	1975-2019	-	1970-2019	-	Index: 1984-1988; 1991; 2006-2019 Age comps: 2006-2019	Index: 1999-2008 Age comps: 2001-2008
South-central Chile purse seine	1975-2019	-	1970-2019	1983-2019	1997-2009 Age comps: 1997-2009	-
FarNorth	-	1980-2019	1970-2019	2002-2019	1985-2013	-
International trawl off Chile	1979-1991; 2000-2004; 2006-2018	2007-2015*	1970-2019	China, EU, Korea, Russia, & Vanuatu (2008-2018)	-	-

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

Table A8.19. Symbols and definitions used for model equations.

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: i = {1970, …., 2019}	I	
Fleets (f) and surveys (s)	f,s	Identification of information source
Age index: j = { 1,2,…, 12^+}	J	
length index: l = { 10,11,…, 50} Mean length at age Variation coefficient the length at age Mean weight in year t by age j	l L_j cv $W_{t,j}$	
Maximum age beyond which selectivity is constant	*Maxage*	Selectivity parameterisation
Instantaneous Natural Mortality	M	Constant over all ages
Proportion females mature at age j	p_j	Definition of spawning biomass
Ageing error matrix	T	
Proportion of length at some age Sample size for proportion in year i	Γ T_i	Transform from age to length 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 A8.20. 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. The symbol 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 fleet (f=1,2,3,4), year(i) and age (j) /length (l) (transformation from age to length composition. Fleet 3, FarNorth)	$\hat{C}_{il}, \hat{C}_{ij}, \hat{Y}_i$	$\hat{C}^f_{i,j}, = N_{i,j} \frac{F^f{}_{i,j}}{Z^f{}_{i,j}} \left(1 - e^{-Z^f{}_{i,j}}\right)$ $\hat{Y}^f{}_i = \sum_{j=1}^{12+} \hat{C}^f_{i,j} w^f_{i,j}$ $\hat{C}_{il} = \Gamma \ \hat{C}_{ij}$ $\Gamma_{l,j} = \int_j^{j+1} e^{-\frac{1}{2\sigma_j^2}(l-L_j)^2} dl$ $L_j = L_{00}(1-e^{-k}) + e^{-k} L_{j-1}$ $\sigma_j = cv L_j$
3)	Proportion at age j, in year i Proportion at length l, in year i		$p_{ij}^f = \frac{\hat{C}_{ij}^f}{\sum_j \hat{C}_{ij}^f} \quad p_{ij}^s = \frac{N_{ij} S_j^s e^{-\Delta^s Z_{ij}}}{\sum_j N_{ij} S_j^s e^{-\Delta^s Z_{ij}}}$ $P_{il} = \frac{C_{il}}{\sum_{l=10}^{50} C_{il}}$
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+	$N_{1970,12+} = N_{1970,11} e^{-M} (1 - e^{-M})^{-1}$
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, ..., 2019	$\varepsilon_i, \sum_{i=1958}^{2018} \varepsilon_i = 0$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$

Eq	Description	Symbol/Constraints	Key Equation(s)
11)	Index catchability Mean effect Age effect	μ^s, μ^f $\eta^s{}_j, \sum_{j=1958}^{2018} \eta^s{}_j = 0$	$q_i^s = e^{\mu^s}$ $s_j^s = e^{\eta_j^s}$ $j \le \text{maxage}$ $s_j^s = e^{\eta_{\text{maxage}}^s}$ $j > \text{maxage}$
12)	Instantaneous fishing mortality		$F_{ij}^f = e^{\mu^f + \eta_j^f + \phi_i}$
13)	Mean fishing effect	μ^f	
14)	Annual effect of fishing mortality in year i	$\varphi_i, \sum_{i=1970}^{2018} \varphi_i = 0$	
15)	age effect of fishing (regularised) In year time variation allowed In years where selectivity is constant over time	$\eta^f{}_j, \sum_{j=1958}^{2018} \eta^f{}_j = 0$ $\eta_{i,j}^f = \eta_{i-1,j}^f$	$s_{ij}^f = e^{\eta_j^f}$ $j \le \text{maxage}$ $s_{ij}^f = e^{\eta_{\text{maxage}}^f}$ $j > \text{maxage}$ $i \ne \text{change year}$
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)	Recruits (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 A8.21 Specification of objective function that is minimised (i.e., the penalised negative of the log-likelihood).

	Likelihood /penalty component		Description / noted
19)	Abundance indices	$L_1 = 0.5 \sum_s \frac{1}{cv_s^2} \sum_i log\left(\frac{I_i}{\hat{I}_i}\right)^2$	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	$L_3 = \lambda_3 \sum_{i=1958}^{2018} \varepsilon^2{}_i$ $\lambda_3 = \frac{0.5}{\sigma_R^2}$	Influences estimates where data are lacking (e.g., if no signal of recruitment strength is available, then the recruitment estimate will converge to median value).
22)	Catch biomass likelihood	$L_4 = 0.5 \sum_f \frac{1}{cv_f^2} \sum_{i=1970}^{2018} log\left(\frac{Y^f{}_i}{\hat{Y}^f{}_i}\right)^2$	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)	Dome-shaped selectivity	$L_6 = \lambda_4 \sum_{j=6}^{12} (lnS_{j-1} - lnS_j)^2$ $S_{j-1} > S_j$	(relaxed in final phases of estimation)
25)	Fishing mortality regularity	F values constrained between 0 and 5	(relaxed in final phases of estimation)
26)	Recruitment curve fit	$L_7 = \lambda_5 \sum_{j=1970}^{2015} log\left(\frac{N_{i,1}}{\tilde{R}_i}\right)^2$ $\lambda_5 = \frac{0.5}{\sigma_R^2}$	Conditioning on stock-recruitment curve over period 1970-2015. (Model 1.00 used the period 2000-2016)
27)	Priors or assumptions	R_0 non-informative	$\sigma_R = 0.6$
28)	Overall objective function to be minimised	$\dot{L} = \sum_k L_k$	

Table A8.22. Coefficients of variation and sample sizes used in likelihood functions, with adjustments based on calculated Francis weights. Initial sample sizes are in parentheses.

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	0.10		
CPUE – Offshore	0.20		
Smoothness for selectivities (indexes)	Λ	Proportion at age likelihood (indexes)	n
Acoustic CS-Chile	100	Acoustic CS-Chile	15.4 (30)
Acoustic N-Chile	100	Acoustic N-Chile	27.1 (30)
CPUE – Chile	100	DEPM – Chile	13.1 (20)
CPUE – China	100		
CPUE – Offshore	100		
Smoothness for selectivities (fleets)	λ	Proportion at age (or length) likelihood	n
N -Chile	1	N-Chile	5.37 (20)
CS-Chile	25	CS-Chile	4.07 (50)
Farnorth	12.5	Farnorth (length)	30
Offshore	12.5	Offshore	26.1 (30)
Recruitment regularity	λ	S – Recruitment curve fit	cv
	1.4		0.6

Table A8.23. Description of JJM model components and how selectivity was treated (two-stock hypothesis; Far North Stock).

Item	Description	Selectivity assumption
Fisheries		
1)	Peruvian and Ecuadorian area fishery	Selectivity in the model under the two-stock hypothesis was estimated from length composition data (converted to age inside the model). Two time blocks were considered – before and after 2002. This is a different assumption than mod1.00 (one-stock), which has annual variations in selectivity between 1981 and 2019.
Index series		
2)	Acoustic survey in Peru	Assumed to be the same as in fishery 1)
3)	Peruvian fishery CPUE	Assumed to be the same as in fishery 1)

Table A8.24. Description of JJM model components and how selectivity was treated (two-stock hypothesis; 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 1980.
Index series		
4)	Acoustic survey in central and southern Chile	Estimated from age composition data. Two time-blocks were considered 1970-2004; 2005-2009.
5)	Acoustic survey in northern Chile	Estimated from age composition data. Selectivity changes were implemented in 2012 and 2016.
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; 2003-2008.
8)	Chinese fleet CPUE (from FAO workshop; down-weighted in SC7 after incorporation into the Offshore CPUE)	Assumed to be the same as 3)
9)	Offshore fleet (China, EU, Korea, Russia, Vanuatu) CPUE	Assumed to be the same as 3)

Table A8.25. Description of JJM model components and how selectivity was treated under the single stock hypothesis.

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). Annual variations were considered since 1981
4)	Offshore trawl fishery	Estimated from age composition data. Annual variations were considered since 1980.
Index series		
5)	Acoustic survey in central and southern Chile	Estimated from age composition data. Two time-blocks were considered 1970-2004; 2005-2009.
6)	Acoustic survey in northern Chile	Estimated from age composition data 2006-2016. Selectivity changes were implemented in 2015 and 2016
7)	Central and southern fishery CPUE	Assumed to be the same as 2)
8)	Egg production survey	Estimated from age composition data 2001, 2003-2006, 2008. Two time-blocks were considered around 2003.
9)	Acoustic survey in Peru	Assumed to be the same as 3)
10)	Peruvian fishery CPUE	Assumed to be the same as 3)
11)	Chinese fleet CPUE	Assumed to be the same as 4)
12)	Offshore fleet (Vanuatu, Russia, Korea, EU & China) CPUE	Assumed to be the same as 4)

Table A8.26. Systematic model progression from the 2019 assessment data to the agreed revised datasets for 2019. Note that the data file names corresponding to each model follow the convention e.g., "Mod0.01.dat" and "Mod0.01.ctl". The same process was repeated for the model under the 2-stock hypothesis.

Model	Description
Models 0.x	**Data introductions**
mod0.00	Exact 2018 model and data set through 2018 (mod1.4 from SC06)
mod0.01	Data file as 0.0 with revised catches through 2018; 2018 model
mod0.02	As 0.01 but with updated fishery age compositions and weight-at-age for N_Chile, SC_Chile, and Offshore_Trawl to 2018
mod0.03	As 0.02 but with updated fishery length compositions for FarNorth to 2018
mod0.04	As 0.03 but with updated FarNorth (Peru) CPUE index to 2018
mod0.05	As 0.04 but with updated Offshore CPUE index to 2018; removed 2006-2007; downweighted Chinese_CPUE (CV=10; now combined into Offshore CPUE)
mod0.06	As 0.05 but with updated age comps and weight-at-age for Chile_AcousN to 2018
mod0.07	As 0.06 but with projected 2019 catch estimates
mod0.08	As 0.07 but with updated fishery age composition and weight-at-age for N_Chile and SC_Chile to 2019
mod0.09	As 0.08 but with updated FarNorth CPUE to 2019
mod0.10	As 0.09 but with updated Acous_N survey index to 2019
mod0.11	As 0.10 but with updated age composition data from Acous_N to 2019
mod0.12	As 0.11 but with updated Chile CPUE (cpue_abs)
mod0.13	As 0.12 but with updated Chile CPUE weight-at-age
mod0.14	As 0.13 but with updated Peru CPUE weight-at-age
mod0.15	As 0.14 but with updated Offshore CPUE weight-at-age
mod0.16	As 0.15 but with updated FarNorth length composition data (to 2019)
mod0.17	As 0.16 but with averaged weight-at-age data for 2015 SC_Chile (avg(2014,2016)), and 2015 (avg(2014,2016)) and 2018/2018 (avg(2014,2016,2017)) Offshore
mod0.18	As 0.17 but with downweighted (/10) age composition data for 2015 SC_Chile, and 2015+2018 Offshore
Models 1.x	**Configuration sensitivities**
mod1.00	As mod0.17 data file but model (i.e., selectivity changes) updated to 2019
mod1.00.ll	As mod1.00 but low steepness and long recruitment time series (1970-2015)
mod1.00.ls	As mod1.00 but low steepness and short recruitment time series (2000-2015)
mod1.00.hl	As mod1.00 (i.e., high steepness and long recruitment time series (1970-2015))
mod1.00.hs	As mod1.00 but high steepness and short recruitment time series (2000-2015)

Table A8.27. Spawning biomass of Jack mackerel (Mod 1.00; single-stock) obtained in previous SPRFMO SC meetings.

Year	SC1	SC2	SC3	SC4	SC5	SC6	SC7
1970	8761	6726	10082	9770	9928	10319	10289
1971	8112	6384	9164	8872	9037	10015	9964
1972	7818	6173	8527	8289	8457	9854	9783
1973	7726	6015	8042	7911	8079	9756	9666
1974	7676	5910	7673	7633	7800	9646	9538
1975	7763	5894	7446	7511	7675	9604	9480
1976	8141	6075	7454	7638	7799	9752	9610
1977	8810	6589	7808	8027	8186	10113	9948
1978	9551	7151	8224	8445	8603	10459	10267
1979	10189	7613	8553	8810	8965	10717	10497
1980	10854	8276	9085	9349	9494	11124	10881
1981	11171	8521	9213	9561	9693	11174	10920
1982	10806	8122	8679	9137	9252	10513	10263
1983	11092	8503	8926	9487	9578	10584	10358
1984	11122	8635	8942	9653	9722	10502	10310
1985	11554	9342	9557	10297	10351	10869	10721
1986	13159	11355	11531	11890	11936	12177	12075
1987	14919	13284	13459	13371	13411	13402	13344
1988	15496	13717	13895	13801	13830	13717	13702
1989	15050	13082	13256	13389	13406	13455	13472
1990	14228	12207	12371	12701	12699	13076	13116
1991	13098	11032	11197	11792	11763	12408	12467
1992	11909	9856	10018	10772	10716	11542	11610
1993	10802	8942	9082	9800	9722	10658	10726
1994	9271	7518	7634	8165	8070	9061	9127
1995	7154	5448	5532	5901	5794	6696	6761
1996	5819	3820	3862	4174	4073	4775	4832
1997	4950	2991	2965	3254	3181	3609	3655
1998	4985	3158	3074	3539	3498	3677	3724
1999	5668	3937	3795	4475	4457	4434	4499
2000	6671	5018	4834	5616	5624	5463	5556
2001	7481	5892	5690	6368	6404	6172	6298
2002	8083	6699	6544	7010	7073	6805	6965
2003	8201	6952	6848	7274	7349	7080	7270
2004	7641	6564	6475	6908	6979	6725	6935
2005	6708	5763	5676	6159	6225	5997	6213
2006	5486	4682	4595	5102	5160	4979	5195
2007	4119	3430	3324	3846	3890	3754	3973
2008	3067	2545	2382	2890	2915	2779	2998
2009	2130	1850	1598	2070	2074	1893	2103
2010	1709	1647	1291	1775	1758	1538	1728
2011	1855	1861	1382	1868	1832	1667	1817
2012	2304	2115	1552	2065	2015	1980	2068
2013	3085	2383	1814	2308	2248	2339	2362
2014		2738	2222	2667	2572	2725	2687
2015		3206	2720	3273	3103	3176	3019
2016			3174	4116	3885	3606	3390
2017					5294	4097	3915
2018						4777	4821
2019							6188

Table A8.28. Estimated begin-year numbers at age (Model *1.00*; single-stock hypothesis), 1970-2019. Green shading reflects relative level.

Year	1	2	3	4	5	6	7	8	9	10	11	12
1970	10059.40	6766.38	4943.06	3707.52	2533.70	2025.02	1560.03	1360.30	1184.94	1027.23	884.12	3949.82
1971	9722.75	7990.81	5373.05	3919.48	2933.75	1993.61	1575.07	1193.47	1046.76	931.32	808.88	3806.44
1972	10209.30	7722.25	6342.95	4254.69	3094.88	2297.54	1534.89	1183.32	904.33	818.37	730.22	3618.74
1973	10702.60	8106.97	6127.21	5015.11	3364.42	2437.86	1792.01	1179.44	911.77	709.71	645.08	3428.08
1974	13093.00	8493.58	6423.62	4820.70	3953.32	2640.96	1888.99	1361.28	898.83	712.14	558.39	3204.68
1975	18395.40	10367.20	6695.24	4961.36	3758.93	3076.12	2017.48	1401.78	1019.23	698.56	556.39	2940.08
1976	21856.70	14599.00	8214.21	5266.99	3896.29	2917.84	2324.57	1465.53	1028.62	786.00	543.87	2722.23
1977	21147.20	17342.10	11560.90	6449.29	4125.89	3008.20	2179.14	1653.19	1054.91	787.30	609.11	2531.06
1978	21983.10	16634.40	13466.60	8461.98	4888.31	3151.00	2233.65	1540.48	1178.18	800.06	608.08	2425.35
1979	22053.20	17346.60	13007.10	10105.00	6440.96	3658.03	2215.14	1424.31	998.28	860.63	602.00	2282.51
1980	22983.80	17423.70	13602.30	9859.17	7725.86	4808.13	2529.40	1351.09	868.17	700.51	626.62	2100.17
1981	27982.40	18139.80	13631.40	10225.90	7535.88	5822.56	3407.57	1622.16	865.63	619.98	517.40	2014.03
1982	32548.80	22111.00	14187.70	10211.90	7748.65	5525.56	3862.02	1927.37	910.94	578.91	443.65	1811.47
1983	26763.40	25764.60	17439.50	10980.40	7731.21	5422.44	3237.20	1712.02	842.33	535.09	373.48	1454.89
1984	43489.50	21234.60	20374.90	13585.30	8456.74	5641.47	3480.10	1694.18	860.06	511.06	350.34	1197.08
1985	52564.40	34488.40	16735.50	15688.50	10185.00	5933.55	3349.10	1555.73	701.98	457.48	295.39	894.40
1986	28975.20	41703.50	27251.30	13022.40	11874.60	7248.82	3643.03	1589.40	674.03	370.11	266.74	693.72
1987	27140.80	23003.70	33040.10	21443.30	10079.70	8827.99	4872.32	1963.56	737.84	358.93	217.99	565.69
1988	32353.00	21534.20	18161.10	25736.30	16280.70	7341.81	5831.66	2543.15	834.86	344.80	186.31	406.79
1989	28107.20	25635.40	16844.70	13976.40	19223.40	11506.30	4785.97	3168.30	1077.18	337.49	149.98	257.98
1990	30558.30	22266.40	20063.10	12913.50	10492.00	13594.30	7382.35	2716.18	1533.81	460.69	138.69	167.65
1991	21167.90	24208.30	17490.10	15356.50	9647.24	7516.82	8911.64	4275.62	1385.76	692.38	186.07	123.74
1992	21831.10	16770.60	19025.10	13420.50	11449.40	6933.77	4975.20	5075.67	2021.95	576.68	248.64	111.26
1993	15407.20	17294.50	13165.70	14540.30	9959.23	8114.40	4580.36	2948.27	2390.04	748.73	167.09	104.28
1994	14445.10	12193.70	13451.40	9775.68	10486.50	6877.18	5293.89	2752.53	1553.68	995.09	221.25	80.19
1995	18921.70	11421.40	9443.44	9832.60	6729.84	6729.81	4101.96	2937.08	1314.58	534.02	243.89	73.88
1996	21024.70	14877.00	8552.43	6185.24	5831.85	3607.30	3259.92	1880.16	1221.91	409.61	112.59	67.00
1997	28443.80	16461.90	10820.10	5314.43	3283.83	2637.03	1562.37	1431.86	785.04	430.53	111.91	49.06
1998	27010.50	22227.50	11776.70	6481.52	2482.65	1254.54	1048.09	682.88	606.37	280.97	127.45	47.65
1999	31906.90	21164.30	16189.70	7944.12	3581.63	1262.20	654.08	572.32	367.19	298.85	124.92	77.85
2000	32926.00	25161.80	16063.40	11470.90	4925.90	2085.35	743.84	400.57	350.46	213.65	162.15	110.02
2001	21803.50	25863.90	18948.80	11701.30	7433.34	2961.16	1279.92	479.46	260.99	221.21	128.87	164.17
2002	14867.00	16853.40	18086.00	12850.20	7428.85	4136.43	1683.89	782.48	298.76	157.05	125.92	166.81
2003	8379.04	11717.60	13016.10	13368.30	8771.78	4543.33	2456.30	1041.59	487.12	176.88	86.62	161.46
2004	8572.74	6566.21	8852.89	9521.94	9289.69	5554.54	2726.57	1507.98	645.74	286.41	96.48	135.32
2005	6658.81	6726.33	5025.29	6444.59	6618.56	5999.00	3273.95	1606.27	897.89	364.76	151.62	122.71
2006	6838.55	5223.94	5121.87	3637.79	4493.61	4404.82	3556.03	1913.07	945.76	504.92	194.61	146.36
2007	4674.51	5333.47	3814.58	3489.14	2403.96	2944.65	2626.13	1936.31	1043.13	492.10	253.53	171.21
2008	4203.70	3647.80	3907.19	2418.34	2139.32	1474.52	1712.62	1387.34	933.75	473.61	210.60	181.77
2009	7626.44	3275.30	2625.21	2476.01	1484.18	1303.30	833.21	905.03	679.76	433.63	206.39	170.98
2010	9643.55	5959.33	2422.04	1758.20	1450.60	829.40	640.23	379.89	378.13	271.77	164.30	142.98
2011	5211.90	7505.43	4294.67	1647.06	1051.75	841.66	461.87	351.24	199.75	179.11	128.39	145.17
2012	8851.69	4087.76	5415.84	2853.45	1166.28	723.43	527.55	295.40	229.28	125.60	115.50	176.41
2013	6843.10	6998.45	3169.81	3922.35	2109.22	803.50	450.41	333.88	197.15	154.38	85.95	199.77
2014	9051.86	5414.88	5453.13	2413.93	2936.11	1504.36	529.27	297.79	229.42	137.21	108.42	200.66
2015	8497.72	7159.86	4208.15	4143.44	1818.28	2140.17	1062.95	361.41	204.24	158.64	95.62	215.39
2016	14008.00	6725.23	5602.94	3259.16	3097.53	1329.91	1554.61	746.23	243.74	136.66	107.41	210.57
2017	33982.20	11101.10	5293.17	4366.66	2461.28	2263.23	946.24	1096.13	516.03	165.99	93.83	218.32
2018	14692.40	26899.20	8731.14	4127.09	3308.93	1812.43	1629.84	665.56	768.27	357.86	115.23	216.69
2019	20171.60	11618.50	21101.80	6823.05	3153.09	2430.62	1287.35	1141.79	463.04	536.66	250.14	232.00

Table A8.29. Estimated total fishing mortality at age (Model *1.00*; single-stock hypothesis), 1970-2019. Green shading reflects relative level.

Year	1	2	3	4	5	6	7	8	9	10	11	12
1970	0.0002	0.0006	0.0020	0.0041	0.0097	0.0213	0.0378	0.0320	0.0108	0.0090	0.0090	0.0090
1971	0.0004	0.0009	0.0034	0.0062	0.0144	0.0315	0.0560	0.0474	0.0161	0.0133	0.0133	0.0133
1972	0.0006	0.0014	0.0049	0.0048	0.0086	0.0185	0.0334	0.0307	0.0123	0.0079	0.0079	0.0079
1973	0.0012	0.0027	0.0098	0.0079	0.0121	0.0251	0.0449	0.0417	0.0171	0.0098	0.0098	0.0098
1974	0.0034	0.0079	0.0283	0.0188	0.0209	0.0393	0.0683	0.0594	0.0221	0.0168	0.0168	0.0168
1975	0.0011	0.0028	0.0099	0.0117	0.0233	0.0501	0.0896	0.0795	0.0299	0.0203	0.0203	0.0203
1976	0.0014	0.0033	0.0119	0.0142	0.0287	0.0619	0.1108	0.0988	0.0374	0.0250	0.0250	0.0250
1977	0.0100	0.0229	0.0820	0.0471	0.0396	0.0677	0.1168	0.1087	0.0465	0.0283	0.0283	0.0283
1978	0.0069	0.0160	0.0572	0.0429	0.0599	0.1224	0.2199	0.2038	0.0841	0.0544	0.0544	0.0544
1979	0.0056	0.0132	0.0471	0.0385	0.0624	0.1389	0.2644	0.2651	0.1242	0.0873	0.0873	0.0873
1980	0.0067	0.0155	0.0553	0.0387	0.0528	0.1143	0.2142	0.2152	0.1067	0.0730	0.0730	0.0730
1981	0.0055	0.0157	0.0588	0.0474	0.0803	0.1806	0.3398	0.3470	0.1723	0.1046	0.1046	0.1046
1982	0.0037	0.0073	0.0263	0.0483	0.1270	0.3047	0.5835	0.5977	0.3020	0.2083	0.2083	0.2083
1983	0.0014	0.0047	0.0198	0.0311	0.0851	0.2135	0.4175	0.4584	0.2697	0.1935	0.1935	0.1935
1984	0.0019	0.0081	0.0314	0.0581	0.1243	0.2915	0.5751	0.6511	0.4013	0.3182	0.3182	0.3182
1985	0.0015	0.0055	0.0209	0.0485	0.1101	0.2578	0.5153	0.6064	0.4101	0.3095	0.3095	0.3095
1986	0.0008	0.0029	0.0097	0.0261	0.0665	0.1673	0.3881	0.5374	0.4002	0.2994	0.2994	0.2994
1987	0.0014	0.0064	0.0198	0.0454	0.0869	0.1846	0.4202	0.6253	0.5308	0.4257	0.4257	0.4257
1988	0.0027	0.0156	0.0319	0.0618	0.1171	0.1979	0.3801	0.6291	0.6757	0.6025	0.6025	0.6025
1989	0.0029	0.0151	0.0358	0.0568	0.1165	0.2138	0.3365	0.4954	0.6194	0.6593	0.6593	0.6593
1990	0.0029	0.0114	0.0373	0.0616	0.1035	0.1923	0.3162	0.4430	0.5654	0.6766	0.6766	0.6766
1991	0.0029	0.0109	0.0348	0.0636	0.1003	0.1827	0.3329	0.5189	0.6467	0.7941	0.7941	0.7941
1992	0.0029	0.0120	0.0388	0.0683	0.1143	0.1846	0.2932	0.5231	0.7634	1.0087	1.0087	1.0087
1993	0.0039	0.0213	0.0677	0.0968	0.1403	0.1971	0.2793	0.4106	0.6462	0.9891	0.9891	0.9891
1994	0.0049	0.0256	0.0834	0.1433	0.2135	0.2867	0.3591	0.5090	0.8379	1.1761	1.1761	1.1761
1995	0.0105	0.0593	0.1932	0.2924	0.3936	0.4948	0.5501	0.6470	0.9361	1.3267	1.3267	1.3267
1996	0.0146	0.0884	0.2458	0.4032	0.5637	0.6068	0.5927	0.6434	0.8132	1.0676	1.0676	1.0676
1997	0.0166	0.1049	0.2824	0.5311	0.7322	0.6927	0.5976	0.6292	0.7975	0.9873	0.9873	0.9873
1998	0.0139	0.0870	0.1637	0.3631	0.4465	0.4213	0.3750	0.3905	0.4776	0.5806	0.5806	0.5806
1999	0.0075	0.0458	0.1146	0.2479	0.3109	0.2988	0.2603	0.2605	0.3115	0.3814	0.3814	0.3814
2000	0.0114	0.0536	0.0868	0.2038	0.2789	0.2581	0.2092	0.1984	0.2301	0.2755	0.2755	0.2755
2001	0.0275	0.1277	0.1584	0.2243	0.3561	0.3345	0.2621	0.2430	0.2779	0.3335	0.3335	0.3335
2002	0.0081	0.0284	0.0722	0.1518	0.2617	0.2912	0.2504	0.2440	0.2942	0.3650	0.3650	0.3650
2003	0.0138	0.0503	0.0826	0.1340	0.2269	0.2806	0.2579	0.2481	0.3011	0.3761	0.3761	0.3761
2004	0.0126	0.0375	0.0875	0.1337	0.2073	0.2986	0.2991	0.2885	0.3412	0.4061	0.4061	0.4061
2005	0.0127	0.0425	0.0931	0.1306	0.1772	0.2929	0.3073	0.2997	0.3457	0.3982	0.3982	0.3982
2006	0.0186	0.0844	0.1539	0.1843	0.1927	0.2872	0.3779	0.3765	0.4233	0.4589	0.4589	0.4589
2007	0.0180	0.0812	0.2258	0.2592	0.2588	0.3120	0.4081	0.4993	0.5596	0.6187	0.6187	0.6187
2008	0.0196	0.0990	0.2262	0.2582	0.2656	0.3408	0.4078	0.4834	0.5370	0.6006	0.6006	0.6006
2009	0.0167	0.0718	0.1709	0.3047	0.3519	0.4808	0.5554	0.6427	0.6868	0.7405	0.7405	0.7405
2010	0.0207	0.0976	0.1556	0.2838	0.3144	0.3554	0.3704	0.4128	0.5172	0.5199	0.5199	0.5199
2011	0.0129	0.0963	0.1788	0.1152	0.1442	0.2371	0.2170	0.1965	0.2340	0.2087	0.2087	0.2087
2012	0.0049	0.0243	0.0926	0.0722	0.1426	0.2438	0.2275	0.1744	0.1656	0.1493	0.1493	0.1493
2013	0.0041	0.0195	0.0424	0.0596	0.1080	0.1875	0.1838	0.1452	0.1325	0.1234	0.1234	0.1234
2014	0.0045	0.0221	0.0447	0.0534	0.0862	0.1173	0.1515	0.1471	0.1389	0.1311	0.1311	0.1311
2015	0.0039	0.0152	0.0256	0.0609	0.0828	0.0897	0.1238	0.1639	0.1718	0.1600	0.1600	0.1600
2016	0.0026	0.0094	0.0193	0.0508	0.0838	0.1104	0.1194	0.1389	0.1542	0.1460	0.1460	0.1460
2017	0.0037	0.0101	0.0188	0.0474	0.0760	0.0983	0.1219	0.1254	0.1360	0.1350	0.1350	0.1350
2018	0.0047	0.0127	0.0166	0.0392	0.0785	0.1121	0.1259	0.1328	0.1288	0.1281	0.1281	0.1281
2019	0.0045	0.0112	0.0237	0.0351	0.0709	0.1053	0.1196	0.1203	0.1156	0.1105	0.1105	0.1105

Table A8.30. Summary of results for Model 1.00 (single-stock hypothesis). Note that MSY values are a function of time-varying selectivity and average weight. Also note that the 2019 landings value is preliminary.

Year	Landings ('000 t)	SSB ('000 t)	Recruitment (age 1, millions)	Fishing Mortality (Mean over ages 1-12)	F_{MSY}	SSB_{MSY} ('000 t)
1970	117	10289	10059	0.01	0.13	3776
1971	168	9964	9723	0.02	0.14	3753
1972	111	9783	10209	0.01	0.13	3636
1973	164	9666	10703	0.02	0.13	3526
1974	323	9538	13093	0.03	0.12	3513
1975	299	9480	18395	0.03	0.13	3675
1976	396	9610	21857	0.04	0.14	3674
1977	848	9948	21147	0.05	0.12	3571
1978	1025	10267	21983	0.08	0.13	3571
1979	1302	10497	22053	0.1	0.13	3914
1980	1316	10881	22984	0.09	0.13	3822
1981	1945	10920	27982	0.13	0.13	3821
1982	2372	10263	32549	0.22	0.14	3848
1983	1870	10358	26763	0.17	0.13	4290
1984	2687	10310	43490	0.26	0.13	4271
1985	2371	10721	52564	0.24	0.14	4299
1986	2073	12075	28975	0.21	0.13	4776
1987	2680	13344	27141	0.27	0.13	4772
1988	3246	13702	32353	0.33	0.15	4416
1989	3547	13472	28107	0.32	0.15	4445
1990	3715	13116	30558	0.31	0.15	4498
1991	3778	12466	21168	0.36	0.18	4113
1992	3362	11610	21831	0.42	0.18	4388
1993	3370	10726	15407	0.4	0.16	4480
1994	4275	9127	14445	0.5	0.15	4561
1995	4955	6761	18922	0.63	0.14	4419
1996	4379	4832	21025	0.6	0.12	4410
1997	3597	3655	28444	0.61	0.11	4402
1998	2026	3724	27010	0.37	0.11	4468
1999	1423	4499	31907	0.25	0.11	4574
2000	1540	5556	32926	0.2	0.11	4322
2001	2528	6298	21804	0.25	0.11	4325
2002	1750	6965	14867	0.22	0.11	4548
2003	1797	7270	8379	0.23	0.11	4519
2004	1934	6935	8573	0.24	0.12	4458
2005	1755	6213	6659	0.24	0.12	4339
2006	2020	5195	6839	0.29	0.13	4134
2007	1997	3973	4675	0.37	0.13	4085
2008	1473	2998	4204	0.37	0.12	4159
2009	1283	2103	7626	0.46	0.13	4240
2010	727	1728	9644	0.34	0.11	4530
2011	635	1817	5212	0.17	0.12	3898
2012	455	2068	8852	0.13	0.12	3912
2013	353	2362	6843	0.1	0.12	3970
2014	411	2687	9052	0.1	0.12	4120
2015	394	3019	8498	0.1	0.13	4180
2016	389	3390	14008	0.09	0.14	4056
2017	405	3915	33982	0.09	0.13	4298
2018	526	4821	14692	0.09	0.12	4348
2019	638	6188	20172	0.08	0.12	4328

Table A8.31. Summary results for the short, medium and long-term predictions for Model *1.00* (single-stock hypothesis). Note that "B" in all cases represents thousands of t of spawning stock biomass and B_{MSY} is taken to be 5.5 million tonnes of spawning biomass in all cases.

Multiplier of F_{2019}	B_{2021}	$P(B_{2021}>B_{MSY})$	B_{2025}	$P(B_{2025}>B_{MSY})$	B_{2029}	$P(B_{2029}>B_{MSY})$	Catch 2020 (kt)	Catch 2021 (kt)
0	8 549	98	11 695	100	13 285	100	0	0
0.5	8 033	96	9 484	98	9 680	97	360	445
0.75	7 790	94	8 575	95	8 349	92	535	648
1	7 556	92	7 773	90	7 251	83	706	840
F_{MSY}	7 074	88	6 320	72	5 439	48	1 072	1 225

9. Figures

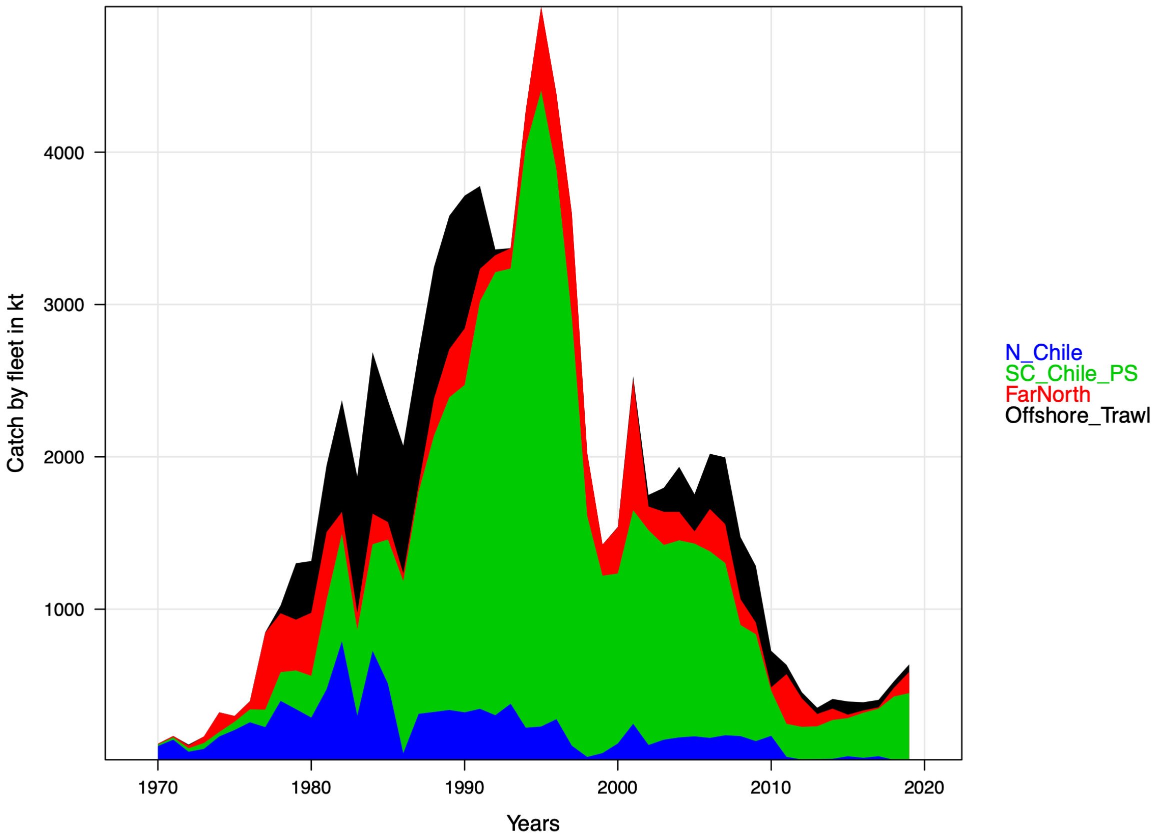


Figure A8.1. Catch of Jack mackerel by fleet. Green is the SC Chilean fleet, black is the offshore trawl fleet, red is the far-north fleet, and blue in the northern Chilean fleet.

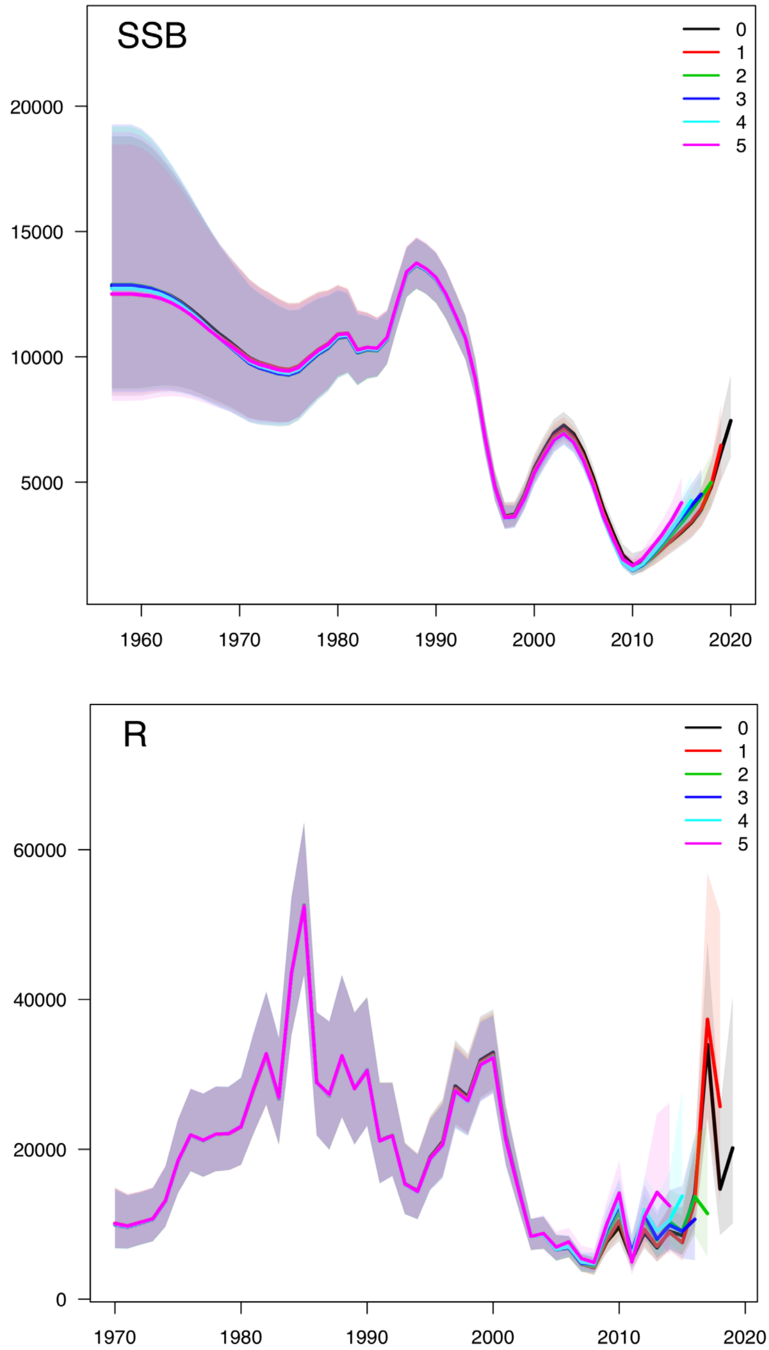


Figure A8.2. Model retrospective of spawning biomass (top) and recruitment (bottom) from 5 separate model runs, based on Model *1.00* (single-stock hypothesis).

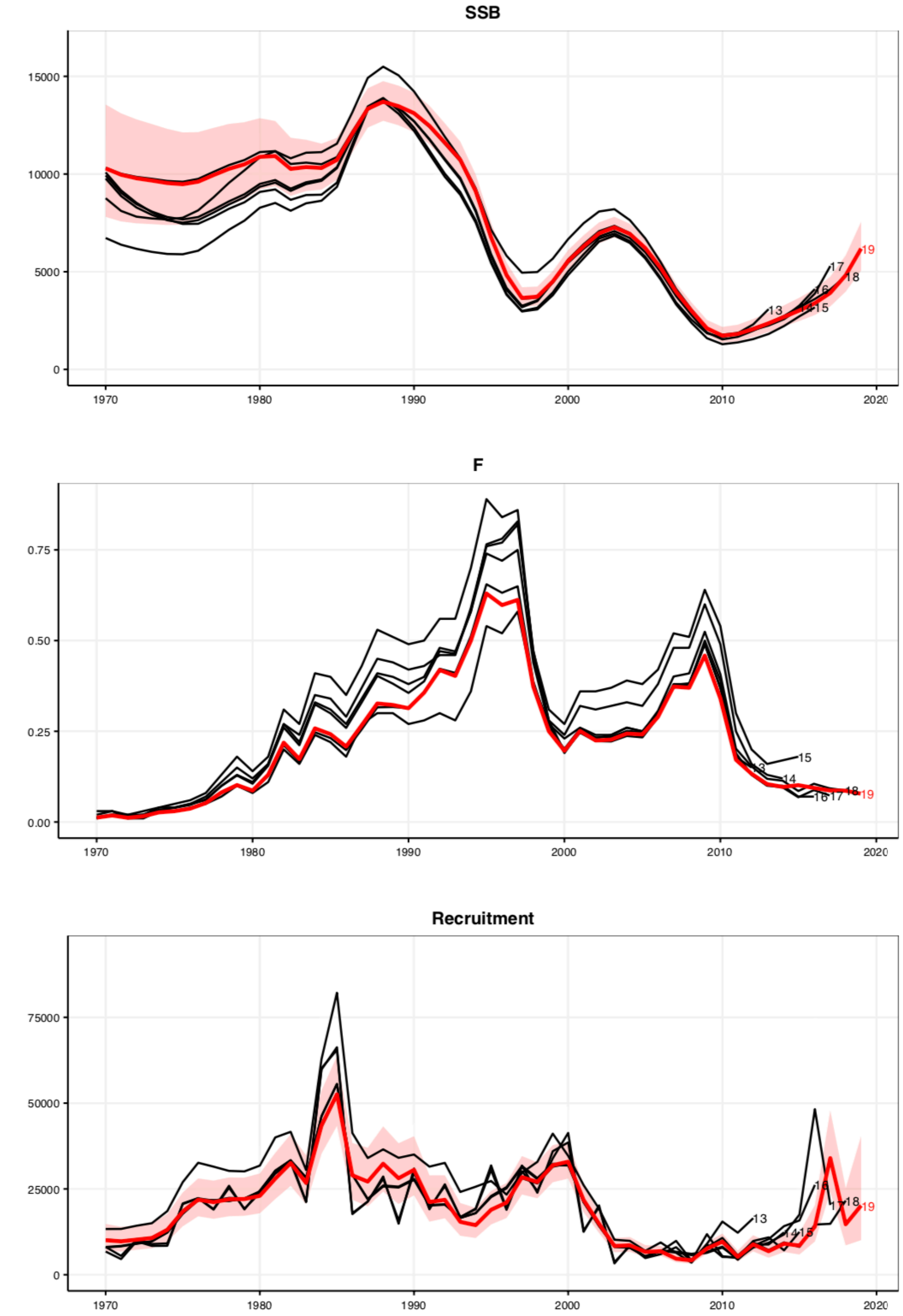


Figure A8.3. Historical retrospective of spawning stock biomass, fishing mortality, and recruitment (2019 estimates from Model *1.00* (single-stock hypothesis)), as estimated and used for advice from past (and present) SPFRMO scientific committees.

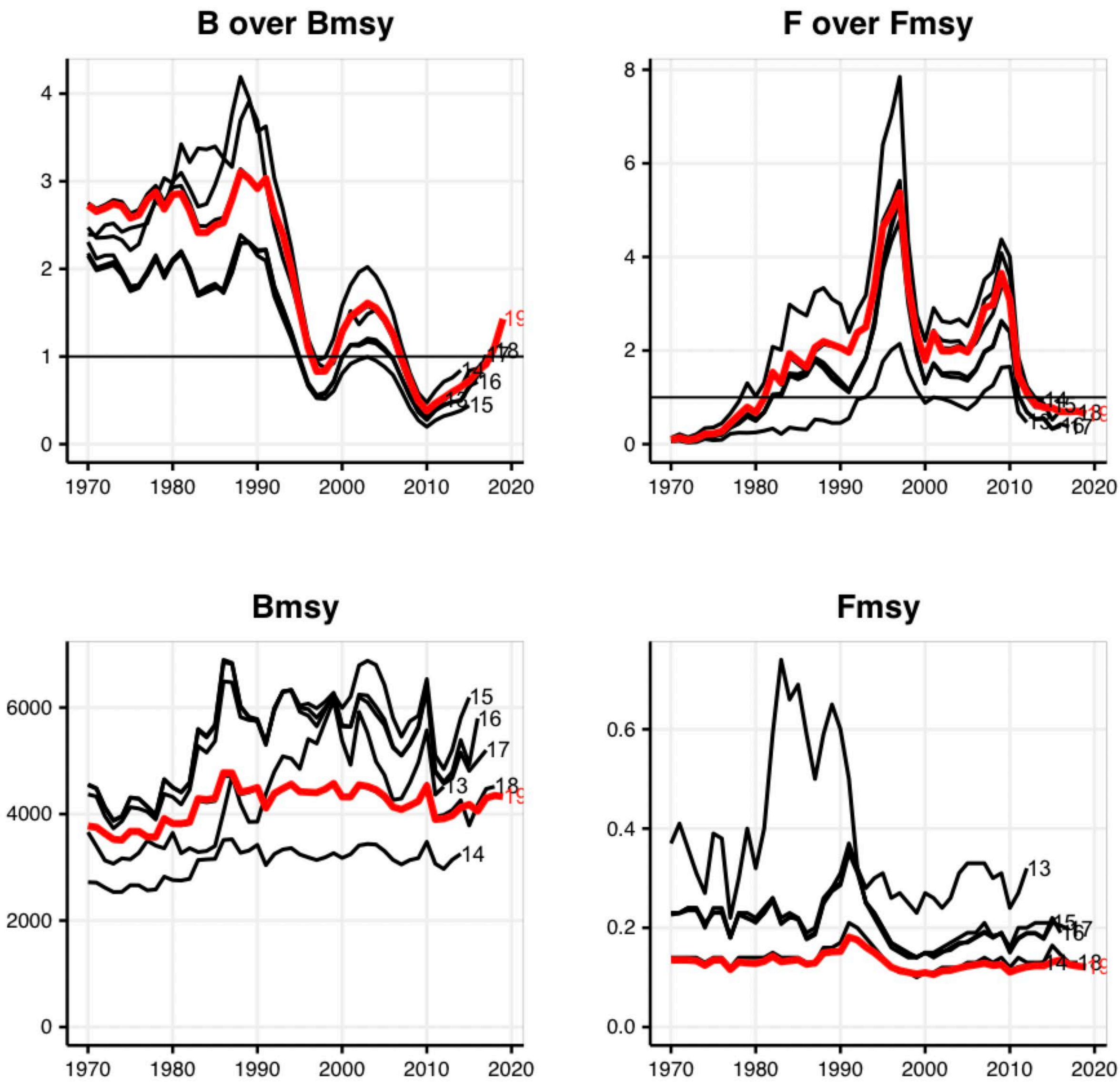


Figure A8.4. Historical retrospective of management reference points (2019 estimates from Model *1.00* (single-stock hypothesis)), as estimated and used for advice from past (and present) SPRFMO scientific committees. It is to be noted that the B_{MSY} in this figure is dynamically estimated within the model, and hence is not fixed at the provisional 5.5 million tons.

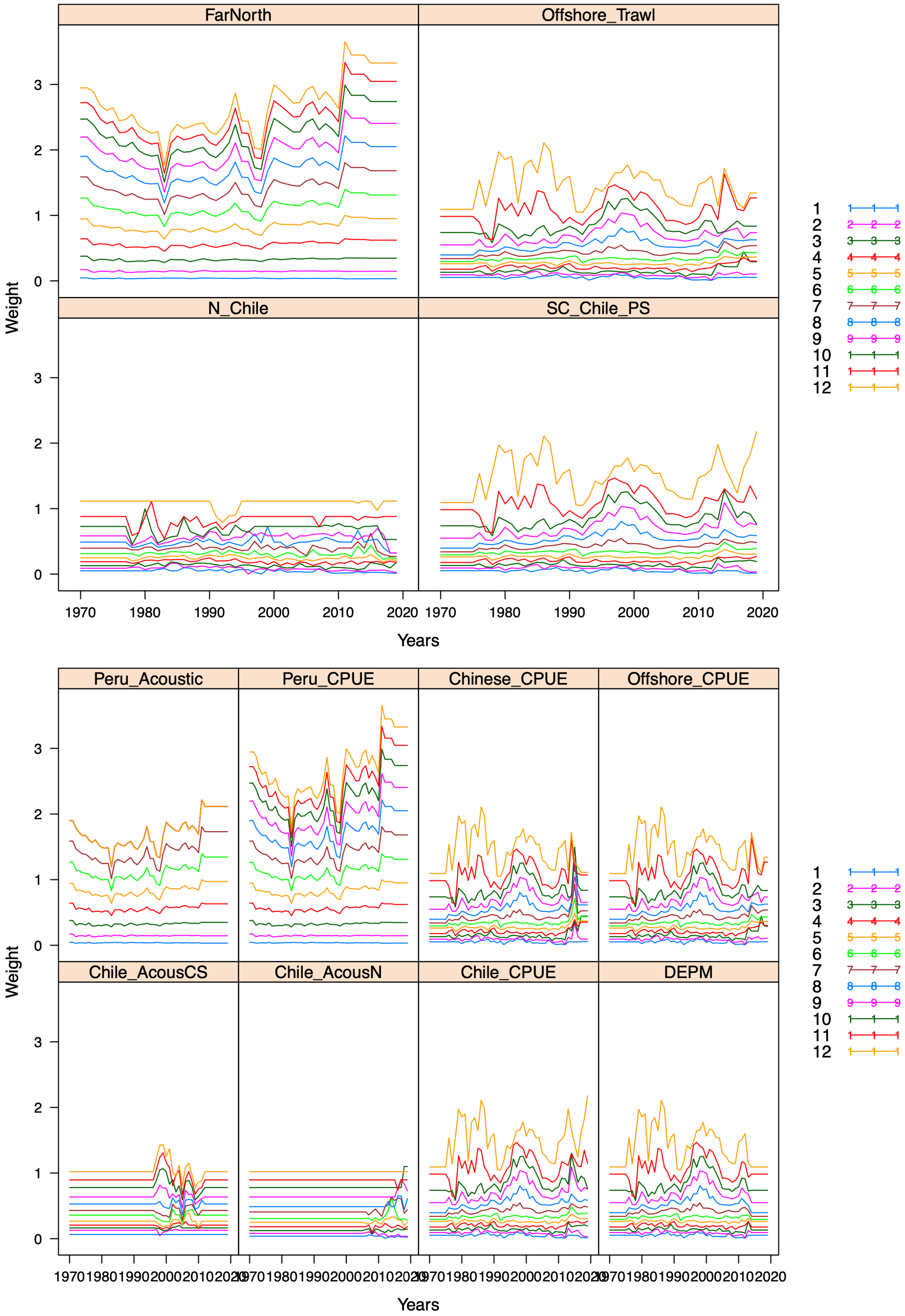


Figure A8.5. Mean weights-at-age (kg) over time used for all data types in the JJM models. Different lines represent ages 1 to 12.

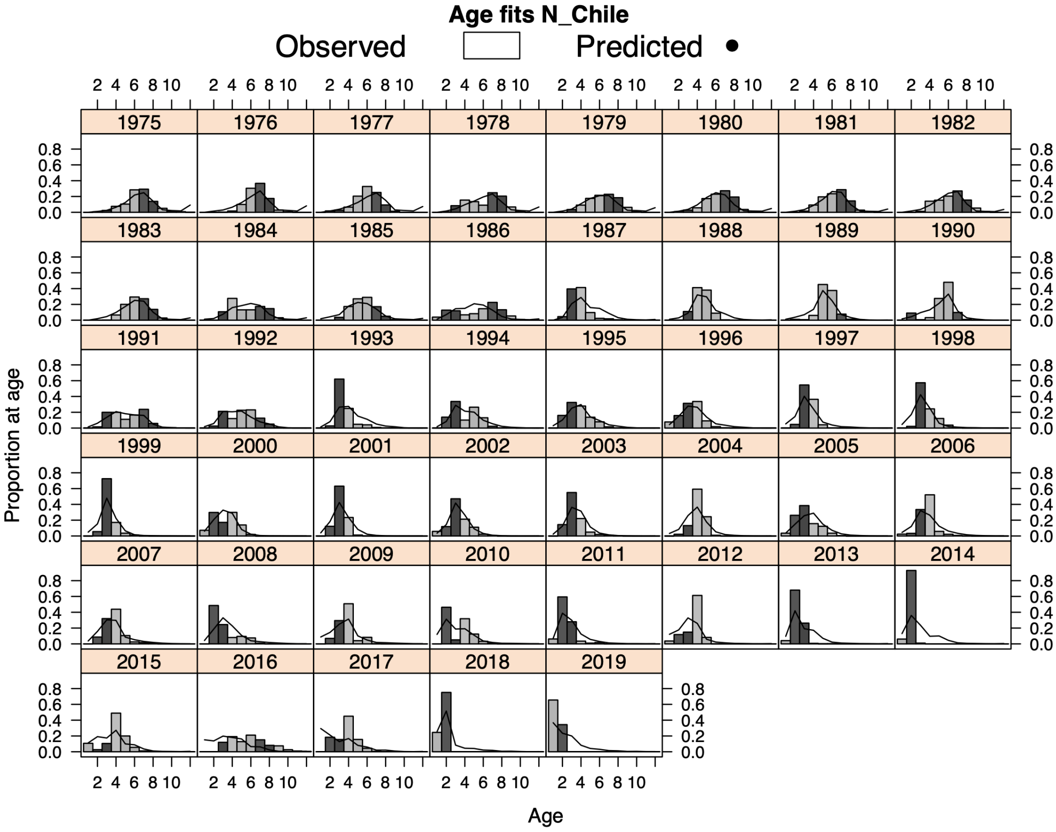


Figure A8.6. Model *1.00* (single-stock hypothesis) fit to the age compositions for the Chilean northern zone fishery (Fleet 1). Bars represent the observed data and lines represent the model predictions.

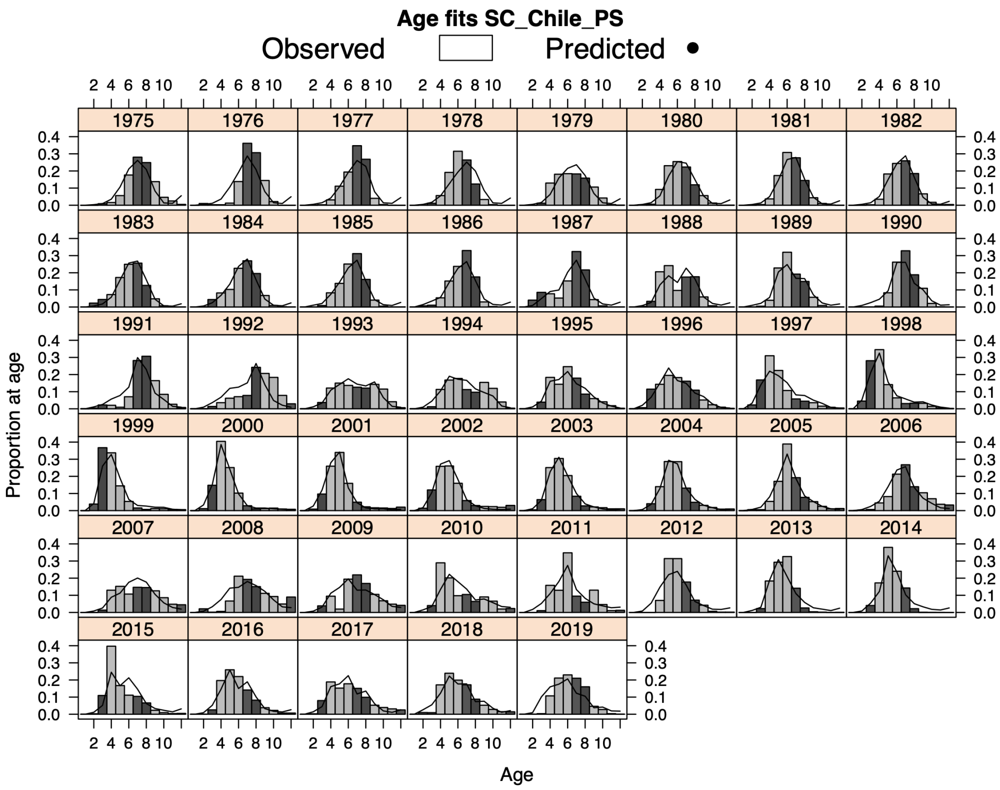


Figure A8.7. Model *1.00* (single-stock hypothesis) fit to the age compositions for the South-Central Chilean purse seine fishery (Fleet 2). Bars represent the observed data and lines represent the model predictions.

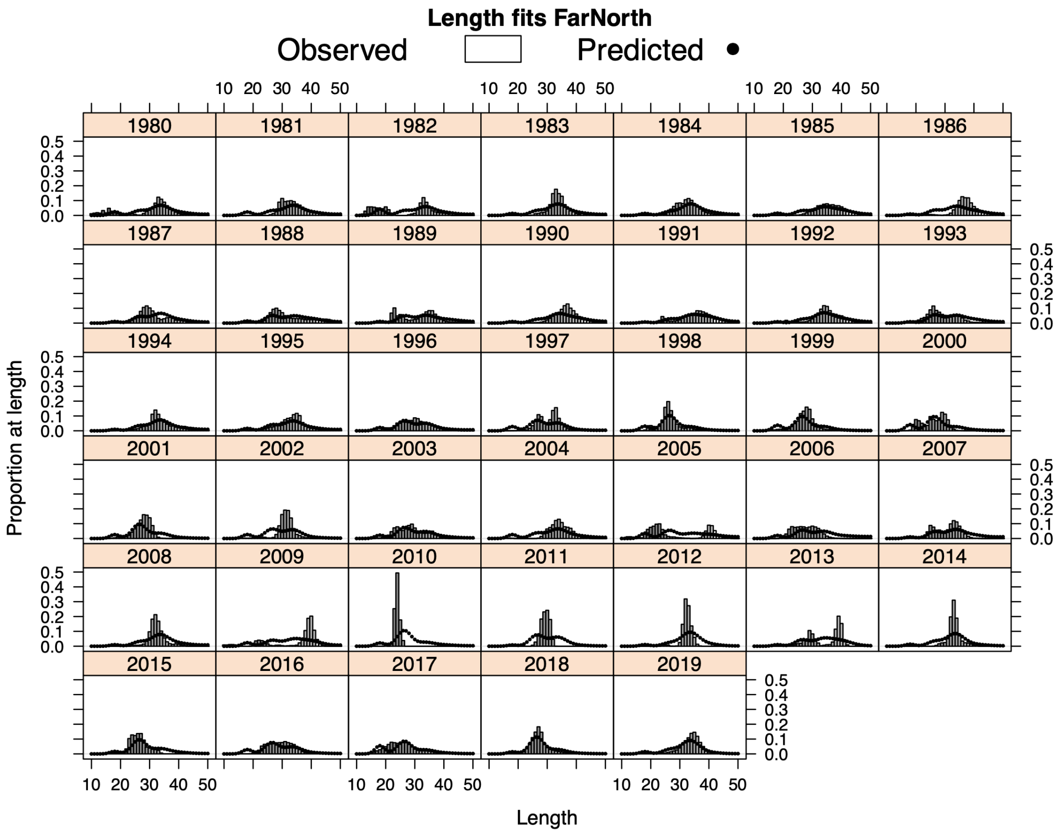


Figure A8.8. Model *1.00* (single-stock hypothesis) fit to the length compositions for the far north fishery (Fleet 3). Bars represent the observed data and lines represent the model predictions.

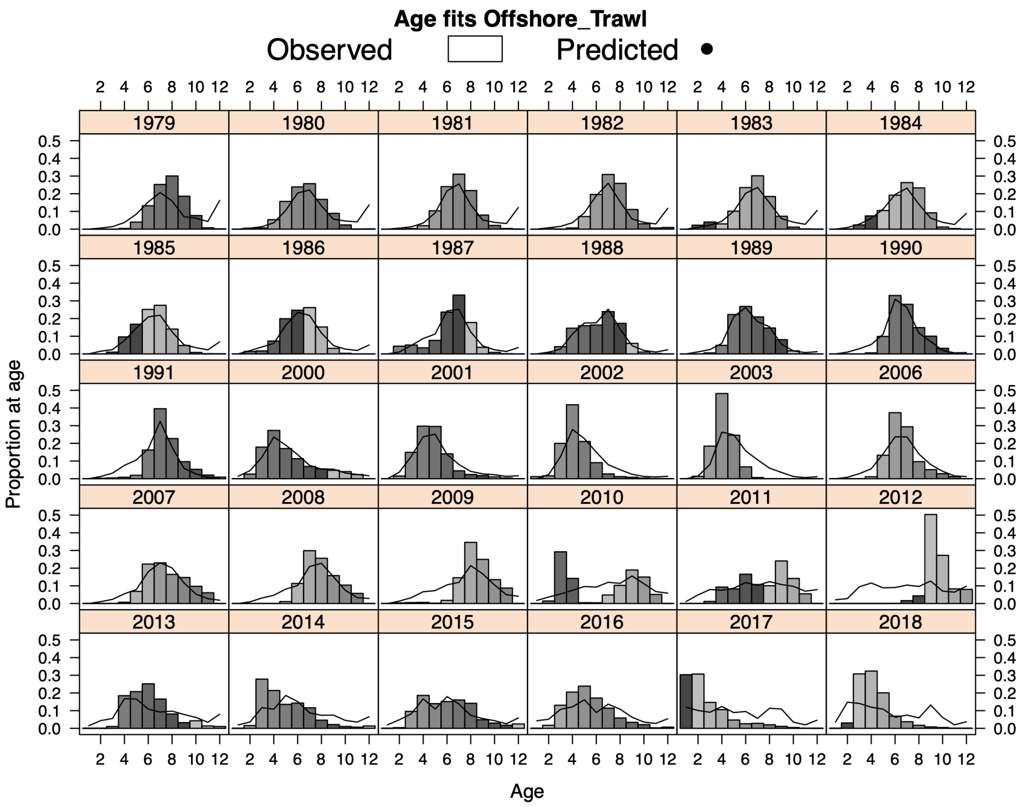


Figure A8.9. Model *1.00* (single-stock hypothesis) fit to the age compositions for the offshore trawl fishery (Fleet 4). Bars represent the observed data and lines represent the model predictions.

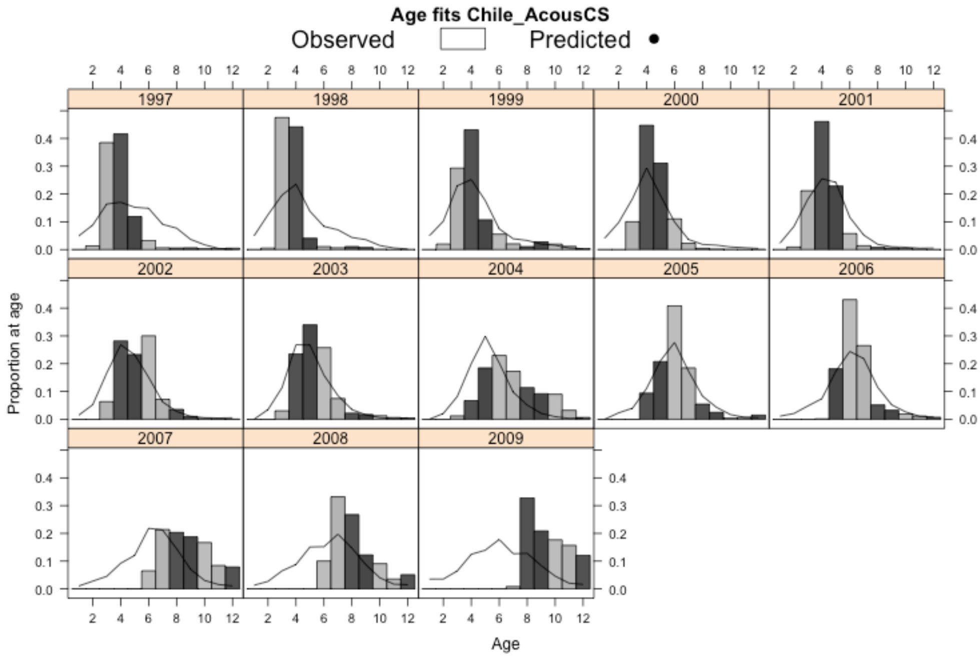


Figure A8.10. Model *1.00* (single-stock hypothesis) fit to the age compositions for the S-Central Acoustic survey. Bars represent the observed data and lines represent the model predictions.

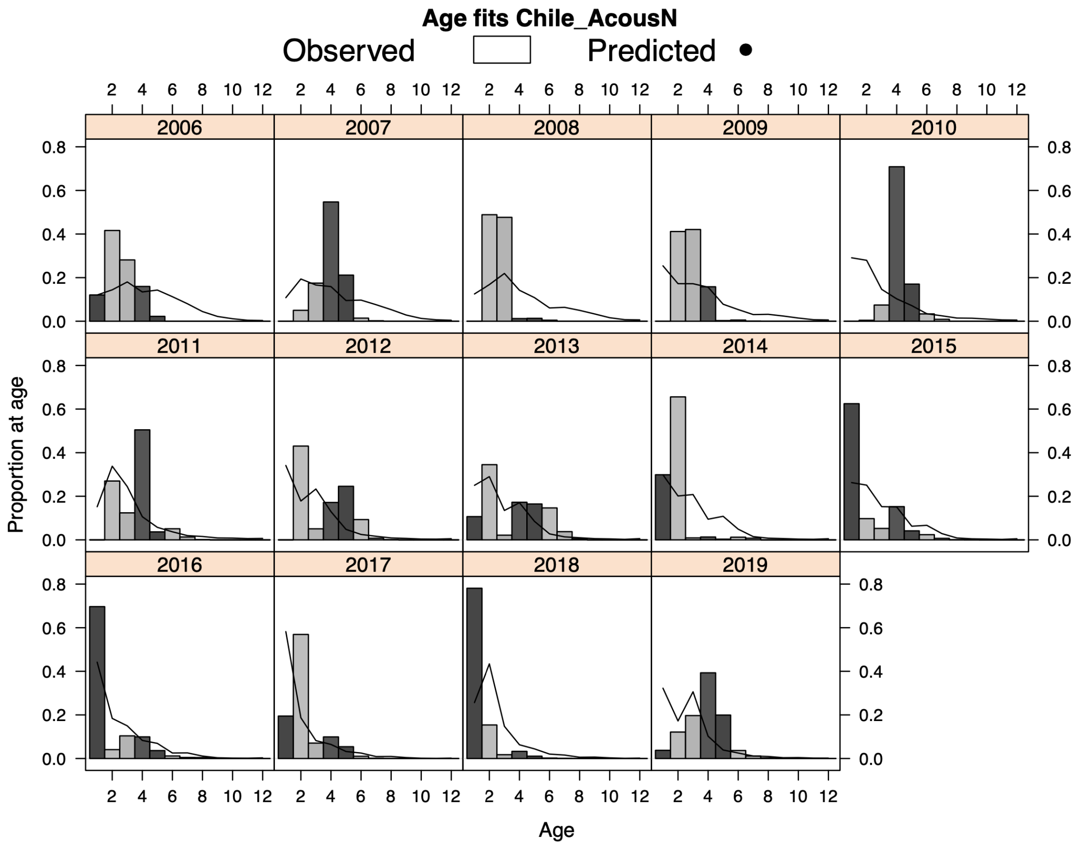


Figure A8.11. Model *1.00* (single-stock hypothesis) fit to the age compositions for the N Chilean acoustic survey (bottom). Bars represent the observed data and lines represent the model predictions.

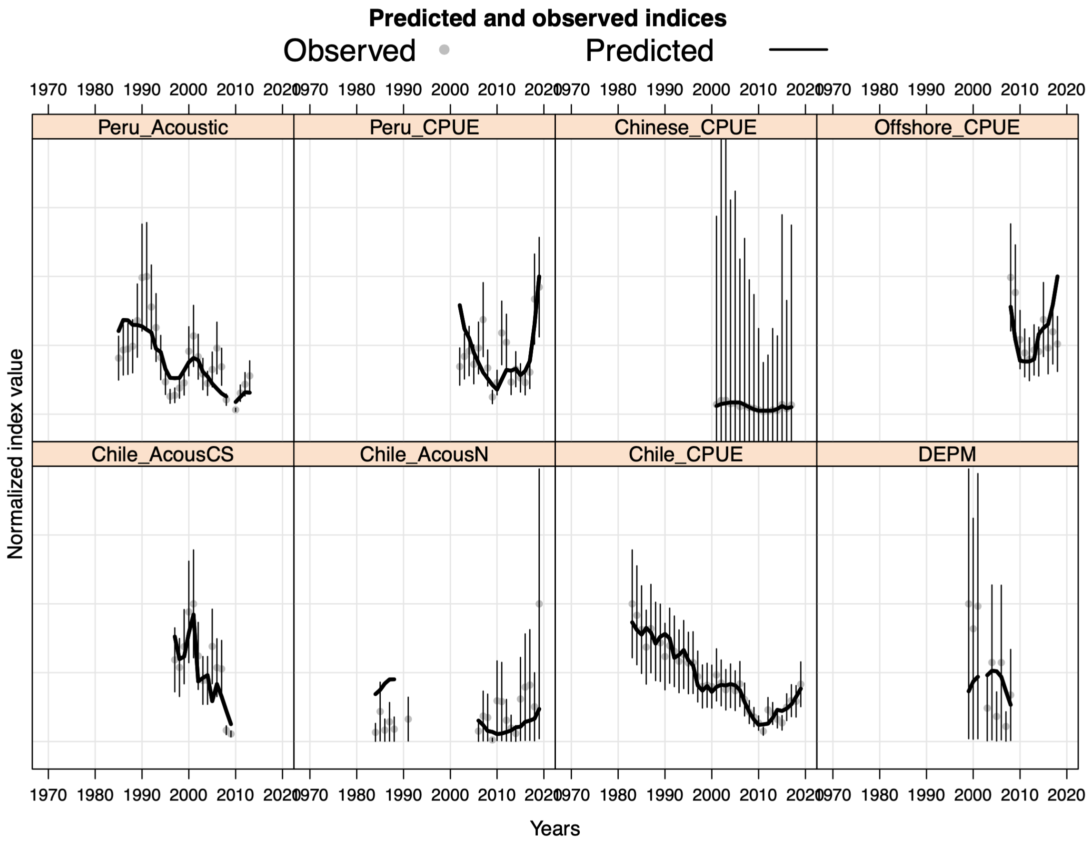


Figure A8.12. Model *1.00* (single-stock hypothesis) fit to different indices. Vertical bars represent 2 standard deviations around the observations.

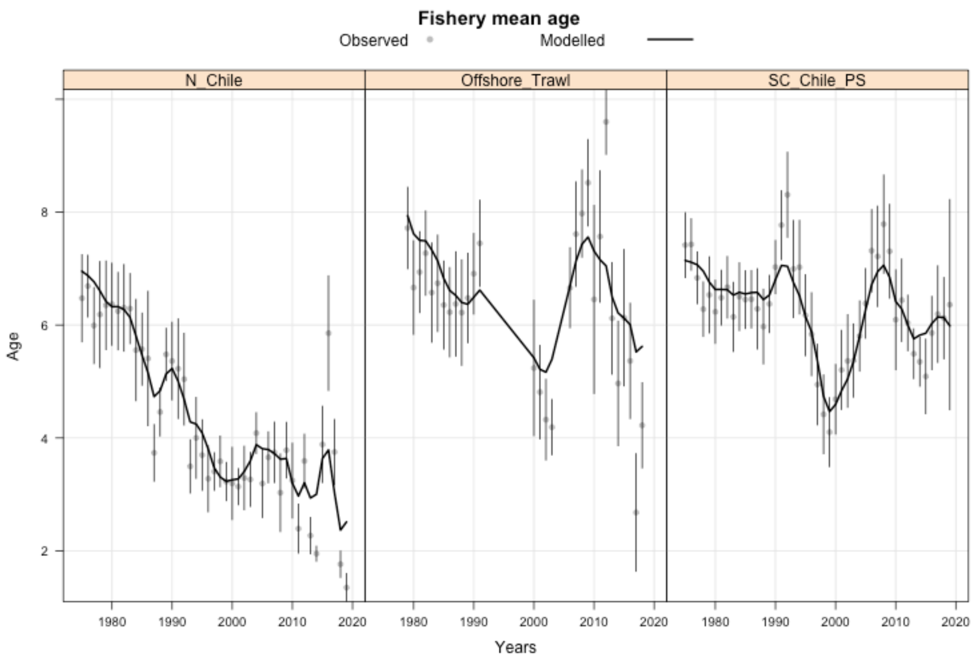


Figure A8.13. Mean age by year and fishery. Line represents the Model *1.00* (single-stock hypothesis) predictions and dots observed values with implied input error bars.

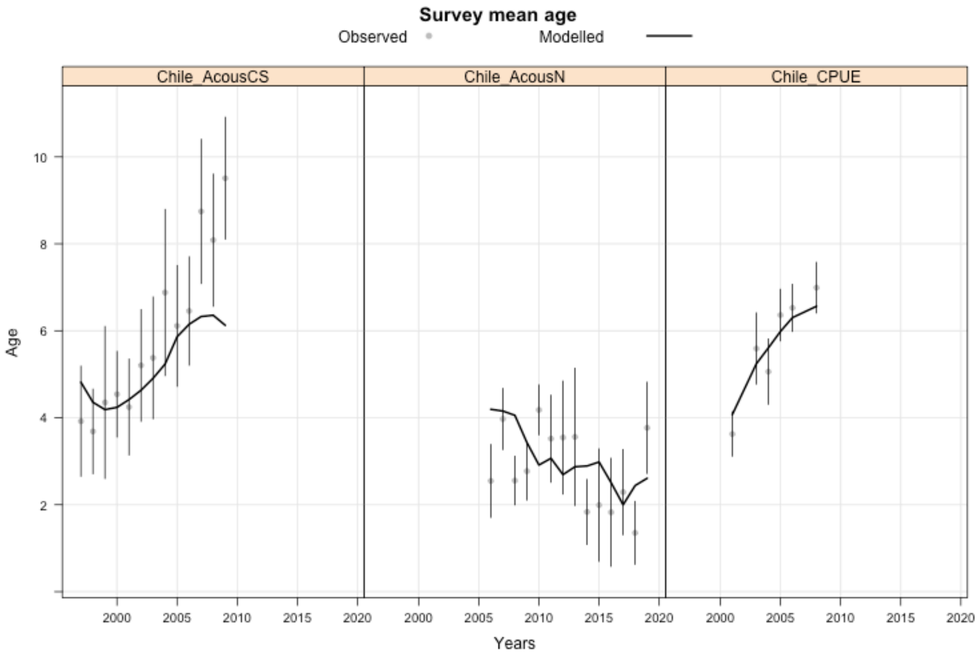


Figure A8.14. Mean age by year and survey. Line represents the Model *1.00* (single-stock hypothesis) predictions and dots observed values with implied input error bars.

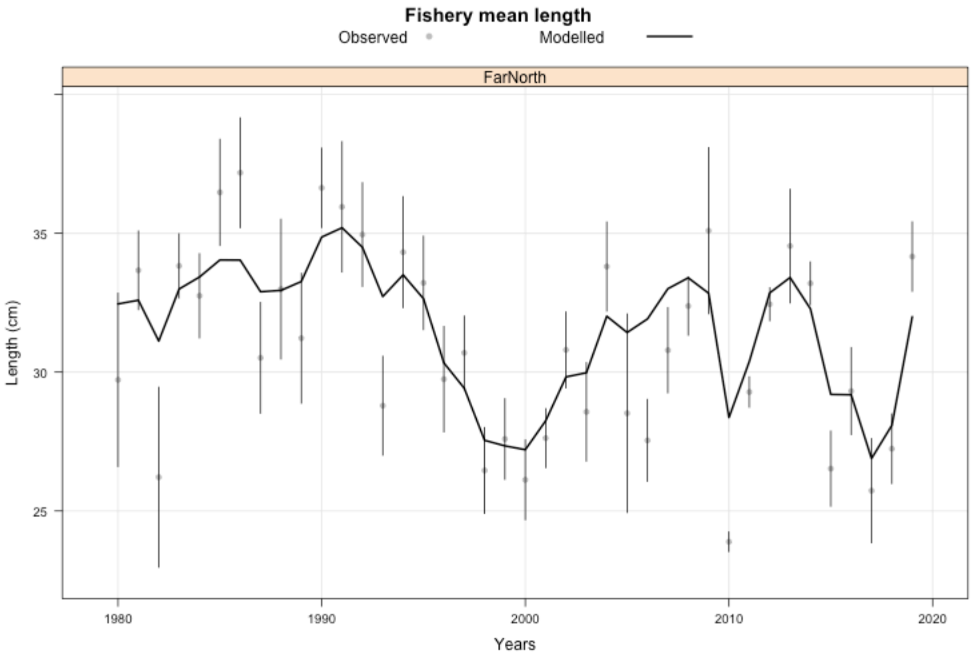


Figure A8.15. Mean length by year in fleet 3 (Far North). Line represents the Model *1.00* (single-stock hypothesis) predictions and dots observed values with implied input error bars.

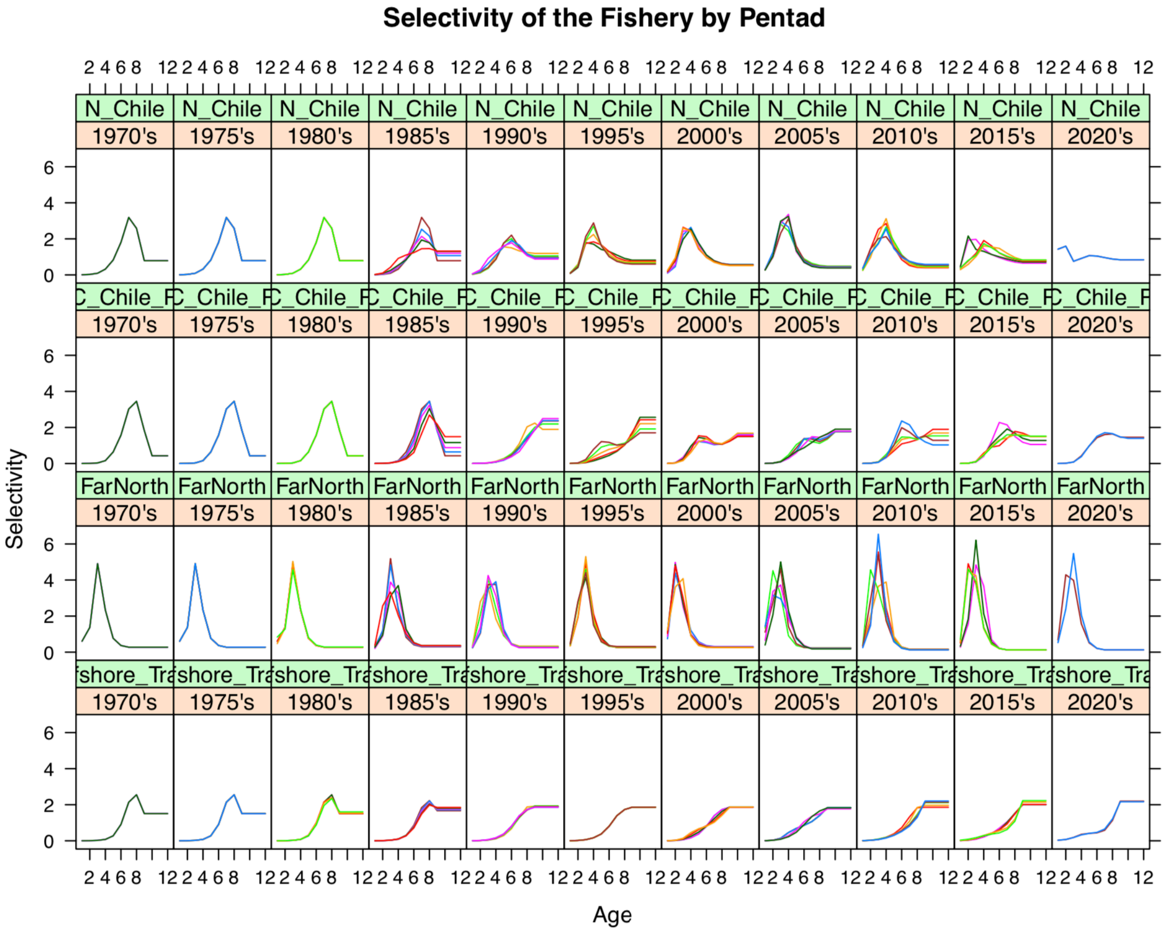


Figure A8.16. Estimates of selectivity by fishery over time for Model *1.00* (single-stock hypothesis) Each cell represents a 5-year period.

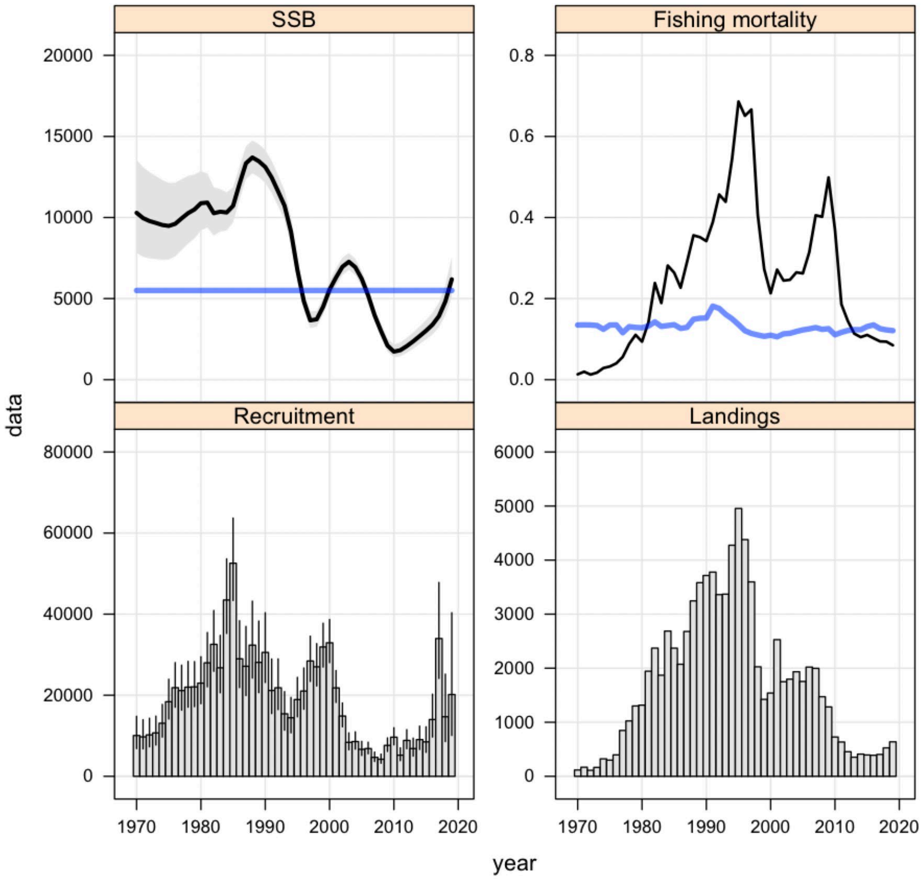


Figure A8.17. Model *1.00*—single-stock hypothesis—summary estimates over time showing spawning biomass (kt; top left), recruitment at age 1 (millions; lower left) total fishing mortality (top right) and total catch (kt; bottom right). Blue lines represent the provisional B_{MSY} (upper left) and dynamic estimates of F_{MSY} (upper right).

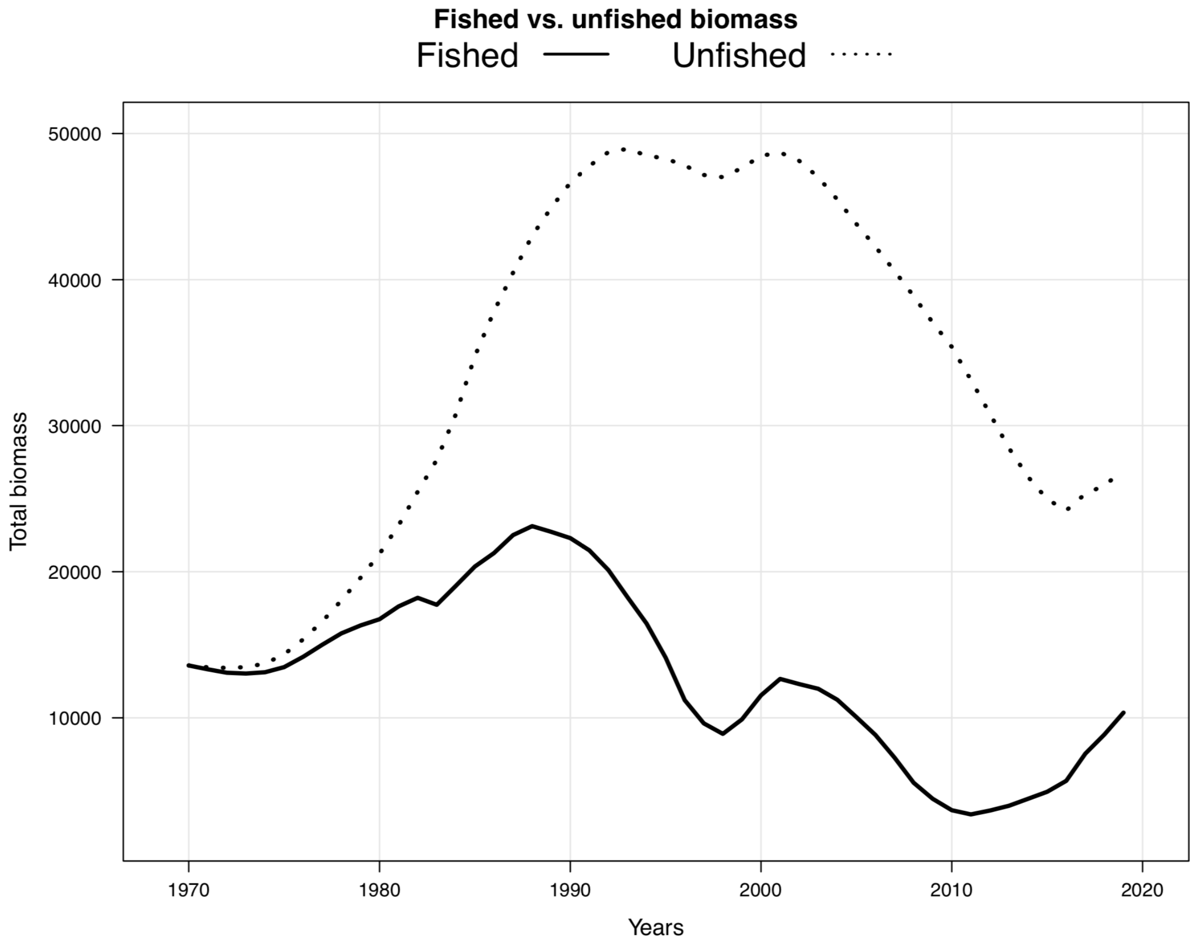
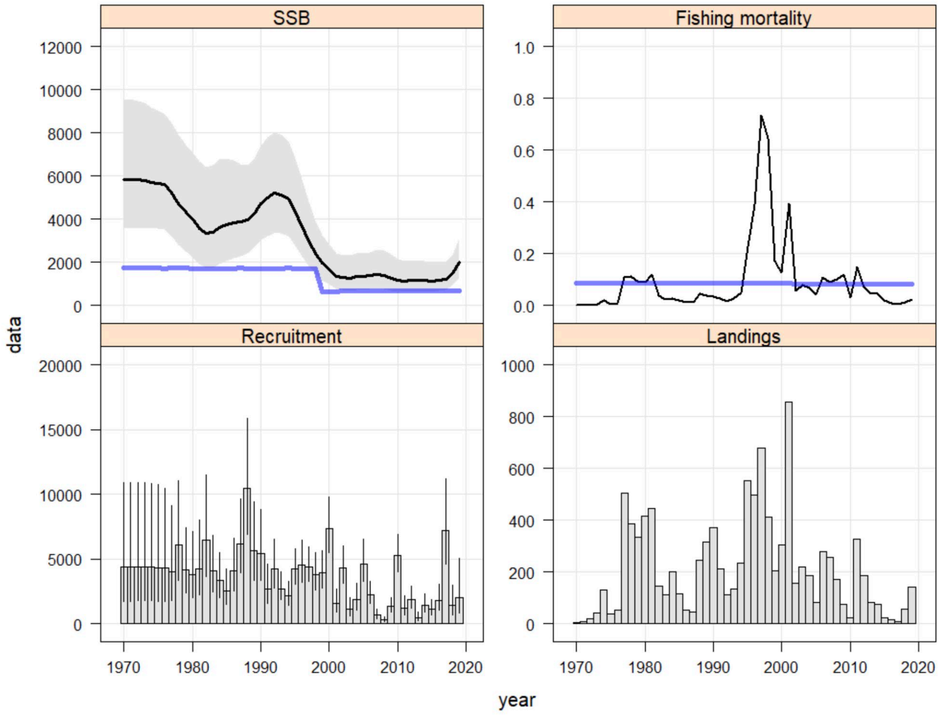


Figure A8.18. Model *1.00* (single-stock hypothesis) results for the estimated total biomass (solid line) and the estimated total biomass that would have occurred if no fishing had taken place, 1970-2019.

Far North



Southern stock

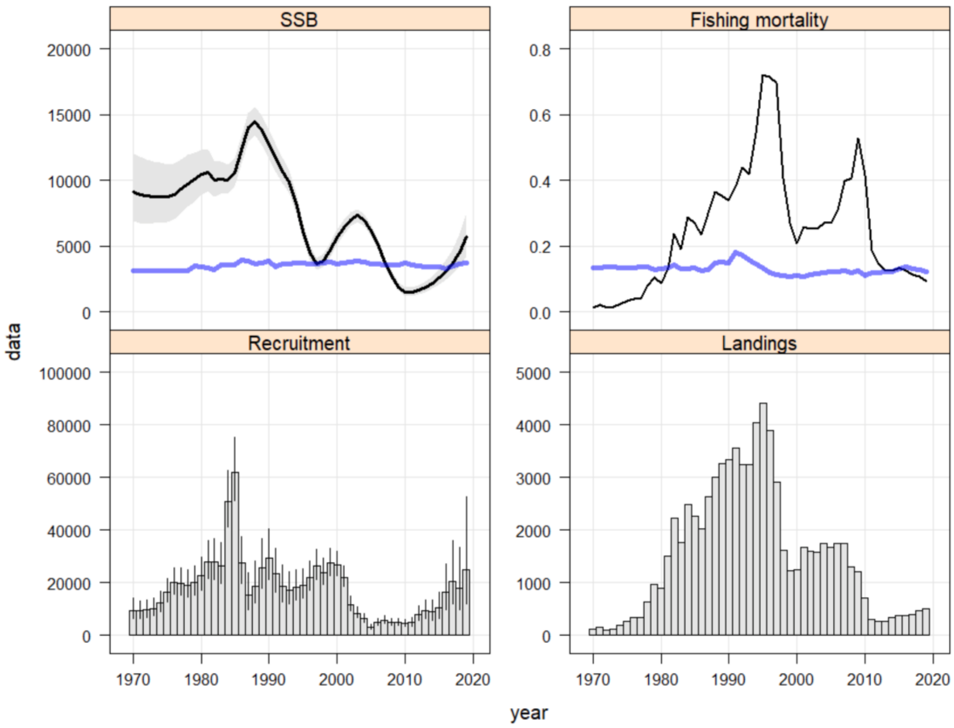


Figure A8.19. Model *1.00* —two-stock hypothesis— summary estimates over time showing spawning biomass (kt; top left), recruitment at age 1 (millions; lower left) total fishing mortality (top right) and total catch (kt; bottom right) for the “Far North” stock (top set) and for the “Southern” stock (bottom set).