SPRFMO SC9-Report
Annex 10. Jack Mackerel Technical Annex

1. Introduction

1. This document and content are based on discussions and analyses conducted at the Scientific Committee (SC) meeting in 2021. The analyses updated the model and assumptions from SC8. Due to the COVID-19 pandemic it was decided that no significant model changes would be made for this assessment and that it would be an update only. A Jack mackerel data workshop (SCW11) was held prior to the SC, and the report can be found on the meeting webpage. A summary of discussions at a series of pre-SC web meetings can be found in document SC9-Doc06_rev1. The model was updated with new data, and subsequently accepted at the SC9 meeting. Discussions at SC9 focused on the following topics:

- Review and update of data sets;
- Corrections to ageing methods and their implications on the assessment;
- Acknowledging uncertainty in the final year of each CPUE series

Scientific Name and General Distribution

2. The Chilean jack mackerel (*Trachurus murphyi*, Nichols 1920) is widespread throughout the South Pacific. It is found 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

3. 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 the 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 incidental catches are very small.

Stock Structure

4. 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 exists 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 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.

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5. 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: Jack mackerel caught off the coasts of Peru and Chile constitute a single shared stock which straddles the high seas (hypothesis 1); or that Jack mackerel caught off the coasts of Peru and Chile each constitute separate stocks (the Peruvian or northern and the Chilean or southern stock) which straddle the high seas (hypothesis 2). In following up on the SWG-11 recommendations, the SPRFMO Commission at its 1st Commission Meeting requested the newly established Scientific Commission (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 SC9.

Fishery

6. 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.

7. The fishery by the coastal states is conducted 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.

8. 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, Poland 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.

9. The Jack mackerel fishery in Chilean and offshore waters is mono-specific. In the offshore fishery, the catch consists of 90 – 98% 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 Member are shown in Table A10.1 with the catch summarised by fleets in Figure A10.1.

Management

10. 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. Catch limits for Jack mackerel were established for the south-eastern Pacific starting from 2011.

Information on the environment in relation to the fisheries

11. Important environmental events such as the El Niño effect of 2016 affect oceanographic dynamics. During such events, the depth of the 15^{o}C isotherm and oxycline change significantly affecting the spatial distribution of Jack mackerel and their availability in different regions (see for example the work of the Habitat Monitoring Working Group of the Scientific Committee as reported in previous meetings of the Scientific Committee). The extent that such changes affect the overall population productivity is unclear.

Reproductive Biology

12. The main spawning season happens from October to December; however, spawning has been described from July to March. Gonadosomatic index and egg surveys have been used to determine the time of spawning.

2. Data used in the assessment

Fishery Data

13. The catch data for the model sum values from various Members (Table A10.1), and form four "fleets", which are intended to be consistent with the gear and general areas of fishing (Figure A10.1). The summarised catches from each of these fleets are presented in Table A10.2.

14. 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 were converted to age compositions by applying Chilean age-length keys as compiled by quarter of the year and then aggregated (Table A10.3, Table A10.4, and Table A10.5). 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 A10.6) were used directly and fit within the model according to the specified growth curve.

15. In the data workshop prior to SC9 (SCW11), a new Chilean ageing method was proposed. This resulted in two datasets being available to SC9: (1) an "antiguo" dataset consisting of minor revisions to the historical age composition data for fleets 1 (Northern Chile) and 2 (South-Central Chile) using the old ageing criteria (these data are being used in the assessment) and (2) a "validacion" dataset based on the validated new ageing criteria. Some detail on the revisions to the historical data and the validation approach can be found in the SCW11 report. During SC9, analysts attempted to test the performance of the new ("validacion") ageing data but were unable to finalize this work given the time limitations and some missing information.

16. Several CPUE data series are used in the model, with changes in methodology to calculate the series introduced during SC4, SC6, SC7, and SC9.

17. For the Chilean purse seiner fleet in the southern-central area, a "Generalized Linear Model" (GLM; McCullagh & Nelder, 1989) approach has been used to standardise the CPUE. Here trip-based CPUE has been modelled as a linear combination of explanatory variables, with the goal of estimating a year-effect that is proportional to Jack mackerel biomass. 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 reflected 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 with a catchability change in year 2000.

18. Prior to the 2018 assessment (SC6), Peru presented 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 to be no longer indicative of Jack mackerel biomass. This resulted in a lack of CPUE data between 2015 and 2017. Thus, for the 2018 assessment 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.

19. Up to the 2017 assessment (SC5), the European Union 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 the offshore fleet. However, it was noted that these fleets shared similar temporal and spatial dynamics and the European Union and Russian data were incorporated into a combined standardised offshore CPUE index in 2018 (SC6), with the Chinese CPUE kept separate. In 2019 (SC7), 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. In SC9, the vessel explanatory variable was replaced by vessel contracting party, which resulted in CPUE indices that were similar in trend (SC9-JM02). Note that the start year of the various offshore CPUE indices has varied over time. Originally, when the European Union CPUE index was separate from the Chinese and Russian CPUE indices (SC5), the index began in 2003. In SC6, when the Russian CPUE data was incorporated into the combined Offshore index, this index was taken as beginning in 2006. From 2019 (SC7), the combined Offshore CPUE index has been included in the stock assessment as an index for the period from 2008 to the present.

20. In all standardised CPUE series (Table A10.7), 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 has been noted, and development of CPUE standardisation guidelines have been identified as a priority to improve the quality of the assessment.

21. It was noted during SC9 that the final years of the CPUE indices should be treated with additional uncertainty in the assessment, due to increasing uncertainty in the index standardization process. In previous assessments, the coefficient of variation was fixed over time for each series.

Fisheries Independent Data

22. The Chilean Jack mackerel research programme has included surveys using hydro-acoustics and the daily egg production method (DEPM). Acoustic estimates have been 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 that 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.

23. Egg surveys (using DEPM) were conducted on an annual basis from 1999 to 2008 along the central zone of the Chilean coast in order to assess the biomass of the spawning stock. 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. Egg survey results have been used as relative abundance indices in the models. Age composition data from the acoustic and DEPM Chilean surveys are shown in Table A10.8, Table A10.9, and Table A10.10.

24. In SC9, as mentioned previously, changes were made to the Chilean ageing methods. These resulted in updated historical age composition data for both Chilean surveys and the commercial catches.

25. 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 beginning in 1966. Acoustic biomass estimates of Jack mackerel were available beginning in 1983. As these surveys had 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 made 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). An 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 the later data. The index has been retained in the current assessment and extends from 1985 to 2013.

26. 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, using scientific vessels. Additionally, comprehensive acoustic surveys have been conducted from the Chilean commercial fleet. The time series of available acoustic estimates extends from 1984 to present day (intermittently, depending on the area). All abundance indices (fishery CPUE and survey) series used in the model are presented in Table A10.7.

Biological Parameters

27. 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 previously. Maturity at length was consistently observed with L_{50} at about 23 cm fork length (FL). The maturity-at-age values, for the single/Southern stock and those for the far-north stock, are shown in Table A10.11.

28. 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 A10.12. Ageing imprecision was previously acknowledged using an age-error matrix, as shown in Table A10.13. 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.

29. 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 A10.14, Table A10.15, Table A10.16, and Table A10.17.

30. For the Chilean fleets, the mean weight-at-age is calculated by year by taking the mean length at age in the catch and a length-weight relationship derived for the year. Before SC3, the same weight at age matrix was used for the Northern Chilean Fleet (Fleet 1) and the 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, resulting in the weights-at-ages seen in Table A10.14 and Table A10.15. The information covers the period 1974-2021; for earlier years the weight-at-age from 1974 was used.

31. For the far north fleet, mean weight-at-age is fixed for all years and was initially calculated from the time-invariant mean length-at-age estimated from the growth function (Table A10.12). The information covers the period from 1970 to present year (Table A10.16).

32. 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 2019. For China, Vanuatu, Russia and Korea, length-weight information is transformed using the Chilean fleet-2 quarter-specific age-length keys (Table A10.17). 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 length-weight relationship from the Chilean fleet 2.

33. 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.

34. 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 A10.12).

35. In SC9, the weights-at-age for both Chilean fleets were revised for both the "antiguo" and "validacion" methods, as part of the update to their ageing methods. The weights-at age for the "antiguo" dataset were adopted for the assessment. Similar to SC7, it was noted that the 2020 and 2021 weights-at age for the Chilean North fleet were anomalously high relative to the entire time series. A decision was made to use the updated 2019 weight at age data from the "antiguo" dataset instead. It was noted that the maturity and natural mortality parameters were to be updated as well. The parameter updates would be made available for investigation at the next benchmark assessment.

Data Sets

36. A full description of data sets used for the assessment of Jack mackerel is in Annex 3 of the SC Data workshop 2015. Summaries of all data available for the assessment are provided in Table A10.18 and *Figure A10.2.*

3. The Assessment Model

37. A statistical catch-at-age model was used to evaluate the Jack mackerel stocks. The JJM ("Joint Jack Mackerel Model") is implemented in AD Model Builder (ADMB) and considers different types of information, which correspond to the available data on the Jack mackerel fishery in the South Pacific area from 1970 to 2021 (Table A10.18).

38. The JJM model is an explicitly 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 & Archibald (1982), Hilborn & Walters (1992) and Schnute & Richards (1995). This model was adopted as the assessment method in 2010 after several technical meetings.

JJM Developments

39. Since its adoption, the JJM model has been improved by participating scientists. The most notable 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 (although this capability is not used). 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.

40. The model consists 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).

41. Stock dynamics: recruitment is assumed to occur in January while the spawning season is assumed to be an instantaneous process occurring in mid-November. The population's age composition considers individuals from 1 to 12+ years old. In all cases a stochastic Beverton-Holt relationship (Beverton & Holt 1957) between stock and recruitment is included. Each cohort survives an age-specific mortality composed of fishing mortalities at-age by fleet and natural mortality (assumed to be constant over time and age). The model is not spatially-explicit, although the fisheries operate in geographically distinct areas. The initial population is based on an equilibrium condition and occurs in 1958 (12 years prior to the model start in 1970).

42. 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 fleet), 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 pattern is non-parametric and assumed to be fishery-specific and time-variant. Catchability is specific to each of the seven abundance indices. For some of the indices, time variations in catchability and / or selectivity have also been considered.

43. Observation models for the data: There are four 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.

44. The probability distributions for the age and length-frequency proportions are assumed to be approximated by multinomial distributions. Sample size is specified to be gear-specific but mostly constant over years. For the total catch by fishery (4) and the abundance indices (7), a log-normal assumption has been assumed with constant CV; the CV for the fisheries being 0.05 whereas the CV for

the abundance indices depends 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 subsequent updates (SC7-9).

45. 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

46. Parameters estimated conditionally are listed in Table A10.19. The most numerous of these involve estimates of annual and age-specific components of fishing mortality for each year and for each of the four fisheries identified in the model. Parameters describing population numbers at age 1 in each year (and years prior to 1970 to estimate the initial population numbers at ages 1-12+) were the second most numerous type of parameter.

47. Equations and specifications for the assessment model are given in Table A10.20 and Table A10.21. Table A10.22 contains the initial variance assumptions for the indices and the age and length compositions.

48. The treatment of selectivity patterns and how they are shared among fisheries and indices are given in Table A10.23 and Table A10.24 for the two stocks under the two-stock model configurations (hypothesis 2), and Table A10.25 for the single-stock hypothesis (hypothesis 1). Selectivity for the Far North fleet was specified with a regime shift in 2002 under the two-stock hypothesis, while annual variations beginning in 1981 were specified for the same fleet 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

49. During SWG 11, two types of population structure were evaluated, and this was continued for subsequent evaluations. Beginning in 2020 (SC8), models under the one-stock hypothesis carry "h1" in front of the model number, models under the two-stock hypotheses carry "h2" in front of the model number.

Description of Model Explorations

50. As SC9 was an update assessment, the main model explorations involved incrementally adding new data components relative to last year's Jack mackerel model (Model 1.00 from SC8). These are labelled "*h1_0.x*" and "*h2_0.x*. where *h1* and *h2* represent the stock structure hypothesis and *x* represents the number when a component was added (Table A10.26).

51. The rationale for the main updates and data revisions occurring through model configurations 0.00 to 0.13 has been explained in the "Data used in the assessment" section, earlier in this Annex. The data exercise concluded with Model 0.13.

52. Thereafter, Model 0.13 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. As agreed upon in SCW11, sensitivities to the updated Chilean ageing methods were conducted. The "antiguo" dataset was accepted as the best available data for 2021. It was noted that there was insufficient data for the results of the "validacion" sensitivity runs (Models 1.02 and 1.03) to be informative. Thus, those models were not run at SC9. Other sensitivity runs included downweighting of the final data point in each CPUE time series (Model 1.04) and a correction of abnormal 2020-2021 weight-at-age data for the Chile North fleet

(Model 1.05). Model *1.05* was adopted, with versions for the one stock hypothesis (h1) and the two stock hypothesis (h2). The most salient features of this model configuration, agreed by SC9, are outlined below.

53. 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) and used the most recent recruitment time-series (2000-2015), similar to assessments prior to SC5. Recruitment used in the forecast was taken directly from the assessment.

54. In SC9, efforts were made to increase the reproducibility and transparency of the assessment process. A centralised repository for data submissions was created on Teams to facilitate ease of access. R scripts were developed to document the assessment update process. These scripts included code to 1) read in, analyse, and raise catch at age/length data, 2) incrementally update data files for the bridging exercise from the previous year's assessment to the new assessment, 3) update model files for model sensitivity runs, 4) conduct projections with the final model, and 5) create an HTML document for result presentation. They can be found on the Github repository, in the assessment folder, under the data (1) and R (2-5) subfolders.

55.

4. Results

56. Results from Models 0.00 to 0.13 in which new data are iteratively introduced into the model show that updating the Peruvian CPUE data to 2021 in particular resulted in an increase in the 2018 estimate of recruitment, leading to a slight increase in biomass for the most recent two years. Overall, the stock (or stocks; depending on the stock structure hypothesis used) shows continued increasing trends in biomass, similar to previous years.

57. An analytical retrospective analysis involves running the model multiple times, each time removing the final year of data (for five years). The retrospective analysis shows that Model h1_1.05 does not suffer from a retrospective bias in SSB estimation with a Mohn's rho of 0.03. Recruitment tended to be under-estimated, with a Mohn's rho of -0.4 (Figure A10.3). The negative bias in recruitment is likely due to the fact that recruitment in recent years has been very high, and estimated recruitment in the final year reverts to a mean. Model h2_1.05 had a slight tendency to over-estimate SSB (Mohn's rho of 0.1 (south) and 0.08 (north)) and under-estimate recruitment (Mohn's rho of -0.14 (south) and -0.1 (north); Figure A10.4).

58. 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. This indicates the year-to-year changes in estimates of stock trends and reference points. This analysis was only conducted on Model h1_1.05 (raw values for biomass found in Table A10.27; graphically visualised in Figure A10.5 and Figure A10.6). The results indicate that the current model formulation is consistent in the most recent years for biomass and fishing mortality. The recruitment comparison shows that the high recruitment of the 2016 year class that was estimated in 2017 is no longer evident in the most recent three assessments (2018-2021; Figure A10.5). Overall, the trends appear consistent over time. Another interesting point to note is that the management reference points (biomass (B) at maximum sustainable yield (MSY) and fishing mortality (F) at MSY; B_{MSY} and F_{MSY} respectively) estimated by Model h1_1.05 appear to be more consistent over time, relative to previous assessments (Figure A10.6). Also, the stock has consistently been estimated as rebuilt since 2018, and not subject to overfishing since 2013, relative to the dynamically-estimated MSY reference points.

59. Fishery mean weights-at-age assumed for all models are shown in Figure A10.7. Estimates of numbers-at-age from Model h1_1.05 are given in Table A10.28, whereas Model h2_1.05 results are in Table A10.29 (southern stock) and (northern stock). Both models show similar fits to the composition data. The fishery age and length composition fits for both Models h1_1.05 and h2_1.05 are shown in Figure A10.8, Figure A10.9, Figure A10.10, Figure A10.11, Figure A10.12, Figure A10.13, Figure A10.14 and Figure A10.15. The fits to age composition data from the surveys are given in Figure A10.16, Figure A10.17, Figure A10.18, Figure A10.19, Figure A10.20, and Figure A10.21. Models h1_1.05 and h2_1.05 fit the indices similarly (Figure A10.22 and Figure A10.23); they both fit well to the Chilean CPUE data and poorly to recent years of the offshore and Peruvian CPUE data, although the relative abundance estimates remained within the uncertainty bounds of the data. Whereas the models predicted higher relative abundance than was shown in the offshore CPUE data, they predicted lower relative abundance than was shown in the Peruvian CPUE data. Fits to the fishery mean age compositions are shown in Figure A10.24 (h1_1.05) and Figure A10.25 (h2_1.05), and survey mean age compositions are shown in Figure A10.26 (h1_1.05) and Figure A10.27 (h2_1.05). Both models fit poorly to data from the Central-South Chilean acoustic survey. Both models seem to fit relatively well to mean length composition data for the Far North fleet, shown in Figure A10.28 and Figure A10.29. Selectivity estimates for the fishery and indices are shown over time in Figure A10.30, Figure A10.31, Figure A10.32, and Figure A10.33.

60. A summary of the time series stock status (spawning biomass, F, recruitment, total biomass) for the single-stock hypothesis (h1_1.05) is shown in Figure A10.34. 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 43% of what is estimated to have occurred had there been no fishing (Figure A10.35).

61. Under the 2-stock hypothesis (h2_1.05), 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 (Figure A10.36). 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 A10.36). Figure A10.37 shows the current total biomass to be approximately 44% and 65% of unfished total biomass for the southern and the far north stocks respectively.

62. Fishing mortality rates at age (combined fleets) were high starting in about 1992 across the entire Jack mackerel population, but have declined in the past years, regardless of stock structure hypothesis or designation (Table A10.31, Table A10.32, Table A10.33, Figure A10.34, and Figure A10.36). It should be noted that the low probability of B_{2031} being greater than B_{MSY} under the F_{MSY} projection for model h1_1.05 is likely due to B_{MSY} being set at the provisional 5.5 million t level, and not the model-estimated B_{MSY}. To evaluate the potential for alternative "regimes", stock recruitment curves were estimated over different periods (as defined in Annex 4 of SC1). Within the 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. This period was used for projections but Model 1.05 uses the period 2001 to 2017 to fit the stock recruitment curve for the Southern/Single stock. Time series of quantities derived by Model h1_1.05 are presented in Table A10.34, whereas those of Model h2_1.05 are in Table A10.35 (southern stock) and Table A10.36 (far north stock). Short, medium and long-term predictions for the stock(s) under different fishing mortalities are found under Table A10.37 (h1_1.05) and Table A10.38 (h2_1.05).

5. Management Advice

63. 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 all fisheries for which data are available, and increase in average age in the Chilean fisheries) drive the increase.

64. Historical fishing mortality rates and patterns relative to the provisional biomass target are shown in Figure A10.34 for Model h1_1.05. Near term spawning biomass is expected to increase from the 2021 estimate of 10.0 million t to 11.2 million t in 2022 (with approximate 90% confidence bounds of 9.1 – 13.7 million t). Under the two-stock hypothesis, historical fishing mortality rates and patterns relative to the model-estimated biomass targets are shown in Figure A10.36. Near term spawning biomass is expected to increase from the 2021 estimate of 7.6 million t to 8.7 million t in 2022 for the southern stock (with approximate 90% confidence bounds of 6.5 – 11.6 million t), and from 2.9 million t to 3.0 million t for the far north stock (with approximate 90% confidence bounds of 2.0 – 4.6 million t).

65. Recent increases in the model-calculated B_{MSY} values (which is different from the constant B_{MSY}) that are likely due to changes in selectivity of all fisheries combined, would imply an estimate of SSB at well over 50% over B_{MSY} for both the single-stock and the two-stock hypotheses.

66. Given current stock status, the third tier of the Jack mackerel rebuilding plan should be applied. This means that F_{MSY} would be used as the basis for catch advice. However, this would result in a potential increase of over twice of last year's recommended catch. In line with the "adjusted Annex K" rebuilding plan, catch advice relative to the previous year can only increase by a maximum of 15%. This results in advice of a 2022 catch level for Jack mackerel within the entire Jack mackerel range to be at or below 900 kt.

67. Projections show a high likelihood of the biomass being above B_{MSY} in 2023 even under the most conservative recruitment productivity scenario evaluated (h1_1.05.ls and h2_1.05.ls; Table A10.37 and Table A10.38). 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

68. Based on results from the 2018 assessment workshop, as noted previously, assessment plans for the next benchmark should be developed several months prior 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.

69. 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 A10.1. Sources and values of catch (t) compiled for the four fleets used for the assessment (note that data for 2020 are not official figures, and 2021 are predictions).

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	101 685	10 309				4 711		4 711												0	116 705
1971	143 454	14 988				9 189		9 189												0	167 631
1972	64 457	22 546				18 782		18 782									5 500			5 500	111 285
1973	83 204	38 391				42 781		42 781												0	164 376
1974	164 762	28 750				129 211		129 211												0	322 723
1975	207 327	53 878				37 899		37 899												0	299 104
1976	257 698	84 571				54 154		54 154						35						35	396 458
1977	226 234	114 572				504 992		504 992						2 273						2 273	848 071
1978	398 414	188 267				386 793	0	386 793						1 667	403		49 220			51 290	1 024 764
1979	344 051	253 460		6 281		151 591	175 938	333 810			12 719	1 180		120			356 271			370 290	1 301 611
1980	288 809	273 453		38 841		123 380	252 078	414 299			45 130	1 780					292 892			339 802	1 316 363
1981	474 817	586 092		35 783		37 875	371 981	445 638			38 444			29			399 649			438 123	1 944 670
1982	789 912	704 771		9 589		50 013	84 122	143 724			74 292	7 136					651 776			733 204	2 371 611
1983	301 934	563 338		2 096		76 825	31 769	110 690			52 779	39 943		1 694			799 884			894 300	1 870 262
1984	727 000	699 301		560		184 333	15 781	200 674			33 448	80 129		3 871			942 479			1 059 927	2 686 902
1985	511 150	945 839		1 067		87 466	26 089	114 622			31 191			5 229			762 903			799 323	2 370 934
1986	55 210	1 129 107		66		49 863	1 100	51 029			46 767			6 835			783 900			837 502	2 072 848
1987	313 310	1 456 727		0		46 304	0	46 304			35 980			8 815			818 628			863 423	2 679 764
1988	325 462	1 812 793		5 676		118 076	120 476	244 229			38 533			6 871			817 812			863 215	3 245 699
1989	338 600	2 051 517		3 386	0	140 720	137 033	281 139			21 100			701			854 020			875 821	3 547 077
1990	323 089	2 148 786		6 904	4 144	191 139	168 636	370 823			34 293			157			837 609			872 059	3 714 757
1991	346 245	2 674 267		1 703	45 313	136 337	30 094	213 447			29 125						514 534			543 659	3 777 618
1992	304 243	2 907 817		0	15 022	96 660	0	111 682			3 196						32 000	2 736		37 932	3 361 674
1993	379 467	2 856 777			2 673	130 681		133 354												0	3 369 598
1994	222 254	3 819 193			36 575	196 771		233 346												0	4 274 793
1995	230 177	4 174 016			174 393	376 600		550 993												0	4 955 186
1996	278 439	3 604 887			56 782	438 736		495 518												0	4 378 844
1997	104 198	2 812 866			30 302	649 751		680 053												0	3 597 117
1998	30 273	1 582 639			25 900	386 946		412 846												0	2 025 758
1999	55 654	1 164 035			19 072	184 679		203 751						7						7	1 423 447
2000	118 734	1 115 565			7 122	296 579		303 701		2 318										2 318	1 540 318
2001	248 097	1 401 836			133 969	723 733		857 702		20 090										20 090	2 527 725
2002	108 727	1 410 266			604	154 219		154 823		76 261										76 261	1 750 077
2003	143 277	1 278 019			0	217 734		217 734		94 690					2 010		7 540		53 959	158 199	1 797 229
2004	158 656	1 292 943			0	187 369		187 369		131 020					7 438		62 300		94 685	295 443	1 934 411
2005	165 626	1 264 808			0	80 663		80 663	867	143 000		6 187			9 126		7 040		77 356	243 576	1 754 673
2006	155 256	1 224 685			0	277 568		277 568	481	160 000		62 137			10 474		0		129 535	362 627	2 020 136
2007	172 701	1 130 083	7		927	254 426		255 360	12 585	140 582		123 523	38 700		10 940		0		112 501	438 831	1 996 975
2008	167 258	728 850	0		0	169 537		169 537	15 245	143 182		108 174	22 919		12 600		4 800		100 066	406 986	1 472 631
2009	134 022	700 905	0		1 934	74 694		76 628	5 681	117 963		111 921	20 213	0	13 759	13 326	9 113		79 942	371 918	1 283 473
2010	169 012	295 796	0		4 613	17 559		22 172	2 240	63 606		67 497	11 643	0	8 183	40 516			45 908	239 593	726 573
2011	30 825	216 470	0		69 373	257 240		326 613	0	32 862	8	2 248	0	0	9 253	674	8 229		7 617	60 891	634 799
2012	13 256	214 204	0		77	187 292		187 369		13 012	0	0	0	0	5 492	5 346	0		16 068	39 917	454 746
2013	16 361	214 999	0		3 563	77 022		80 585		8 329		10 101	0		5 267	2 670			14 809	41 175	353 120
2014	18 219	254 295	0		9	74 528		74 537		21 155		20 539	0		4 078	2 557			15 324	63 652	410 703
2015	34 886	250 327			289	22 158		22 447		29 180		27 955	0		5 749	0	2 561		21 227	86 672	394 332
2016	24 657	295 160			0	15 087		15 087		20 208		11 962	0		6 430	0	0		15 563	54 163	389 067
2017	35 002	311 863			54	8 813		8 867		16 802		27 887	0		1 235	0	3 188		0	49 113	404 845
2018	11 551	415 149			23	57 140		57 163		24 366		9 691	0		3 717	0	4 685		0	42 460	526 323
2019	11 875	432 447			0	135 784		135 784		22 699		11 870	0		7 444	0	9 423		0	51 436	631 542
2020	44 155	517 665			0	140 116		140 116		0		0	0		0	0	4 739		0	4 739	706 675
2021	61 359	567 267			5	130 572		130 577				43 111					12 198			55 309	814 512

Table A10.2. Input catch (kilo tonnes) by fleet (combined) for the stock assessment model. Note that the final year's data are predictions.

Year	Fleet 1	Fleet 2	Fleet 3	Fleet 4
1970	101.69	10.31	4.71	0.00
1971	143.45	14.99	9.19	0.00
1972	64.46	22.55	18.78	5.50
1973	83.20	38.39	42.78	0.00
1974	164.76	28.75	129.21	0.00
1975	207.33	53.88	37.90	0.00
1976	257.70	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	414.30	339.80
1981	474.82	586.09	445.64	438.12
1982	789.91	704.77	143.72	733.20
1983	301.93	563.34	110.69	894.30
1984	727.00	699.30	200.67	1059.93
1985	511.15	945.84	114.62	799.32
1986	55.21	1129.11	51.03	837.50
1987	313.31	1456.73	46.30	863.42
1988	325.46	1812.79	244.23	863.22
1989	338.60	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	0.00
1994	222.25	3819.19	233.35	0.00
1995	230.18	4174.02	550.99	0.00
1996	278.44	3604.89	495.52	0.00
1997	104.20	2812.87	680.05	0.00
1998	30.27	1582.64	412.85	0.00
1999	55.65	1164.04	203.75	0.01
2000	118.73	1115.57	303.70	2.32
2001	248.10	1401.84	857.74	20.09
2002	108.73	1410.27	154.82	76.26
2003	143.28	1278.02	217.73	158.20
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	172.70	1130.08	255.36	438.83
2008	167.26	728.85	169.54	406.99
2009	134.02	700.91	76.63	371.92
2010	169.01	295.80	22.17	239.59
2011	30.83	216.47	326.39	60.89
2012	13.26	214.20	187.40	39.92
2013	16.36	215.00	80.59	41.18
2014	18.22	254.30	74.53	63.65
2015	34.89	250.33	22.45	86.67
2016	24.66	295.16	15.09	54.16
2017	35.00	311.86	8.87	49.11
2018	11.55	415.15	57.16	42.46
2019	11.88	432.45	135.78	51.44
2020	44.16	517.67	140.12	4.74
2021	61.36	567.27	129.32	55.31

Table A10.3. 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, with darker green indicating a stronger cohort.

	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	0	0	4	15	24	31	22	4	0	0	0
1981	0	0	0	6	15	21	33	19	5	1	0	0
1982	0	0	1	12	16	21	26	16	6	1	0	0
1983	0	0	1	7	18	27	28	15	3	0	0	0
1984	0	0	11	23	14	14	18	16	4	0	0	0
1985	0	0	4	16	26	30	18	5	1	0	0	0
1986	1	8	5	6	9	18	32	18	4	0	0	0
1987	0	3	33	47	12	3	2	1	0	0	0	0
1988	0	0	0	16	55	26	2	0	0	0	0	0
1989	0	0	2	5	44	39	8	1	0	0	0	0
1990	0	9	1	3	28	48	10	1	0	0	0	0
1991	0	3	19	20	11	18	24	6	1	0	0	0
1992	0	3	21	13	24	21	12	5	1	0	0	0
1993	0	3	59	25	8	4	1	0	0	0	0	0
1994	0	16	31	11	26	13	2	1	0	0	0	0
1995	0	5	32	36	18	6	2	0	0	0	0	0
1996	9	16	30	32	10	3	0	0	0	0	0	0
1997	0	9	54	33	4	0	0	0	0	0	0	0
1998	0	2	53	30	12	3	0	0	0	0	0	0
1999	0	5	72	16	5	2	0	0	0	0	0	0
2000	7	29	16	31	15	1	0	0	0	0	0	0
2001	0	11	64	23	1	0	0	0	0	0	0	0
2002	2	10	39	27	17	3	1	0	0	0	0	0
2003	0	11	57	24	5	2	1	0	0	0	0	0
2004	0	4	13	58	23	1	0	0	0	0	0	0
2005	3	27	37	17	11	4	1	0	0	0	0	0
2006	0	6	33	51	6	2	1	0	0	0	0	0
2007	0	7	29	45	13	3	2	0	0	0	0	0
2008	7	45	25	7	8	7	1	0	0	0	0	0
2009	0	12	29	46	4	8	0	0	0	0	0	0
2010	0	4	47	32	13	3	1	0	0	0	0	0
2011	6	67	21	3	2	1	0	0	0	0	0	0
2012	3	31	16	42	7	0	0	0	0	0	0	0
2013	0	31	63	3	1	1	1	0	0	0	0	0
2014	2	43	48	4	2	0	0	0	0	0	0	0
2015	6	7	9	51	15	6	4	1	0	0	0	0
2016	0	0	12	18	13	19	19	7	10	1	0	0
2017	0	30	15	46	6	1	1	0	0	0	0	0
2018	27	72	0	0	0	0	0	0	0	0	0	0
2019	12	8	0	19	9	14	13	6	7	4	3	5
2020	0	0	1	26	25	23	15	8	2	0	0	0
2021	2	8	0	0	3	9	15	37	13	11	1	0

Table A10.4. 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 with darker green indicating a stronger cohort.

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	14	5	2	0
1976	0	1	0	0	1	14	36	31	14	2	0	0
1977	0	0	0	3	11	19	35	27	4	0	0	0
1978	0	0	1	6	19	31	26	12	3	0	0	0
1979	0	0	1	13	18	18	18	16	11	4	0	0
1980	0	0	3	20	42	26	8	1	0	0	0	0
1981	0	1	5	13	35	31	12	3	0	0	0	0
1982	0	0	3	22	41	25	8	1	0	0	0	0
1983	0	7	18	16	26	20	11	2	0	0	0	0
1984	0	1	24	32	9	14	12	6	2	0	0	0
1985	0	0	3	24	28	20	17	7	2	0	0	0
1986	1	2	4	6	26	27	21	12	2	0	0	0
1987	0	4	22	28	7	10	17	10	2	0	0	0
1988	0	0	7	34	37	7	8	6	1	0	0	0
1989	0	0	1	8	46	30	9	5	2	0	0	0
1990	0	0	0	0	7	26	33	18	12	3	0	0
1991	0	0	2	1	0	6	27	29	18	10	4	1
1992	0	0	1	5	8	6	8	21	22	16	9	4
1993	0	0	4	12	18	14	12	10	14	12	4	1
1994	0	0	0	6	17	18	13	11	17	13	4	1
1995	0	0	2	17	17	22	20	8	7	4	1	0
1996	0	1	10	15	20	17	15	10	6	3	1	0
1997	0	1	13	34	22	10	6	5	5	2	1	1
1998	0	3	25	38	15	6	3	3	4	2	1	0
1999	0	2	30	38	17	6	2	1	1	1	0	0
2000	0	0	15	43	25	10	3	1	1	1	1	1
2001	0	1	10	35	30	12	4	2	2	2	1	2
2002	0	1	10	29	24	16	6	4	3	2	2	3
2003	0	0	7	25	31	21	8	3	2	2	1	1
2004	0	0	3	18	30	26	11	5	3	2	1	1
2005	0	1	1	7	21	33	19	9	5	2	1	1
2006	0	1	1	5	9	20	25	14	11	7	3	3
2007	0	0	1	12	17	11	15	15	12	9	4	4
2008	0	2	0	1	6	22	20	16	11	9	5	7
2009	0	1	5	11	2	19	21	16	10	7	4	4
2010	0	0	4	29	20	10	11	6	9	6	2	2
2011	0	0	1	11	15	36	11	8	13	2	1	1
2012	0	0	0	8	25	27	29	7	3	1	0	0
2013	0	0	2	17	32	33	14	2	0	0	0	0
2014	0	0	2	11	24	26	21	12	3	1	0	0
2015	0	0	13	40	15	10	10	7	3	1	0	0
2016	0	0	3	20	26	22	14	8	4	2	1	1
2017	0	0	2	20	17	16	16	11	7	4	3	3
2018	0	1	1	17	24	20	17	9	5	3	1	1
2019	0	0	0	9	17	22	24	14	8	4	1	0
2020	0	0	0	9	10	15	22	20	14	8	3	1
2021	0	0	0	3	22	23	25	15	8	3	1	0

Table A10.5. 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 with a darker green indicating a stronger cohort. Catches-at-age 1979-2013 were calculated using Age-Length Keys from fleet 2. Catches-at-age 2017-present were calculated with Age-Length Keys from Chile and 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
2019	9	27	10	9	12	7	6	5	7	6	2	0
2020	14	53	24	4	1	1	1	0	0	0	0	0

Table A10.6. 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 with a darker green indicating a stronger cohort.

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	1	1	1	2	3	5	8	12	16	17	13	8	5	3	2	1	1	0	0	0	0	0	0	0	0	0	0	0
2020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	3	4	6	9	13	16	15	11	7	4	2	1	1	0	0	0	0	0	0	0	0	0
2021	0	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	2	2	2	3	3	3	4	6	7	7	8	9	9	9	9	6	4	2	1	1	0	0	0	0

Table A10.7. Abundance indices used within the assessment model.

Year	Chile (1)	Chile (2)	Chile (3)	Chile (4)	Peru(2)	Peru(3)	Offshore
1970	-	-	-	-	-	-	-
1971	-	-	-	-	-	-	-
1972	-	-	-	-	-	-	-
1973	-	-	-	-	-	-	-
1974	-	-	-	-	-	-	-
1975	-	-	-	-	-	-	-
1976	-	-	-	-	-	-	-
1977	-	-	-	-	-	-	-
1978	-	-	-	-	-	-	-
1979	-	-	-	-	-	-	-
1980	-	-	-	-	-	-	-
1981	-	-	-	-	-	-	-
1982	-	-	-	-	-	-	-
1983	-	-	0.858	-	-	-	-
1984	-	99	0.792	-	-	-	-
1985	-	324	0.703	-	94.316	-	-
1986	-	123	0.591	-	108.116	-	-
1987	-	213	0.706	-	109.789	-	-
1988	-	134	0.626	-	114.18	-	-
1989	-	-	0.616	-	157.394	-	-
1990	-	-	0.529	-	229.757	-	-
1991	-	242	0.596	-	231.672	-	-
1992	-	-	0.561	-	180.355	-	-
1993	-	-	0.5	-	145.726	-	-
1994	-	-	0.543	-	95.245	-	-
1995	-	-	0.491	-	54.257	-	-
1996	-	-	0.492	-	29.967	-	-
1997	3530	-	0.405	-	31.664	-	-
1998	3200	-	0.344	-	43.994	-	-
1999	4100	-	0.352	5724	52.681	-	-
2000	5600	-	0.343	4688	105.784	-	-
2001	5950	-	0.417	5627	131.586	-	-
2002	3700	-	0.367	-	96.661	4.146	-
2003	2640	-	0.324	1388	67.471	4.976	-
2004	2640	-	0.349	3287	51.853	5.462	-
2005	4110	-	0.319	1043	75.171	4.348	-
2006	3192	112	0.361	3283	111.259	5.778	-
2007	3140	275	0.263	626	79.75	8.056	-
2008	487	259	0.184	1935	24.251	4.099	1749.79
2009	328	18	0.153	-	-	1.482	1278.03
2010	-	440	0.116	-	7.247	2.8	913.461
2011	-	432	0.065	-	35.283	7.057	829.268
2012	-	230	0.199	-	50.332	6.269	733.962
2013	-	144	0.176	-	64.504	2.773	855.072
2014	-	87	0.14	-	-	3.865	908.79
2015	-	459	0.115	-	-	3.136	1311.44
2016	-	587.244	0.21	-	-	2.706	942.706
2017	-	610.47	0.253	-	-	3.512	1220.59
2018	-	374.11	0.257	-	-	9.756	1214.57
2019	-	1487.07	0.285	-	-	16.687	1424.29
2020	-	1728.27	0.376	-	-	18.474	2367.2
2021	-	1886.27	0.371	-	-	22.862	-

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 fishery CPUE in Fleet 3
Offshore: Combined CPUE for China, EU, South Korea, Russia, and Vanuatu in Fleet 4

Table A10.8. Catch at age for acoustic surveys in southern Chile. Units are relative value (they are normalised to sum to 100 for each year in the model). Green shading reflects relative level with a darker green indicating a stronger cohort.

	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	38	17	11	17	6	4	2	1	1	1
2002	0	0	9	36	29	13	5	5	2	1	0	0
2003	0	0	0	27	34	22	7	4	2	1	1	1
2004	0	0	0	11	21	25	17	10	9	4	1	1
2005	0	0	0	10	22	41	16	5	2	1	1	1
2006	0	0	0	0	13	34	32	8	6	4	2	2
2007	0	0	0	0	2	14	19	21	18	13	8	4
2008	0	0	0	0	0	12	33	25	13	9	4	5
2009	0	0	0	0	0	0	1	30	24	16	17	13

Table A10.9. Catch at age for acoustic surveys in northern Chile. Units are relative value (they are normalised to sum to 100 for each year in the model). Green shading reflects relative level with a darker green indicating a stronger cohort.

	Age group (years)											
Year	1	2	3	4	5	6	7	8	9	10	11	12
2006	0	20	49	30	1	0	0	0	0	0	0	0
2007	0	4	17	46	23	8	2	0	0	0	0	0
2008	0	49	48	1	1	0	0	0	0	0	0	0
2009	0	43	40	16	1	0	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	0	39	1	13	23	17	6	1	0	0	0	0
2014	0	93	1	2	0	2	1	0	0	0	0	0
2015	0	26	14	41	11	6	2	0	0	0	0	0
2016	0	28	22	30	11	5	2	1	1	0	0	0
2017	0	62	10	16	9	2	1	0	0	0	0	0
2018	0	67	8	17	5	1	1	0	0	0	0	0
2019	0	13	20	41	21	4	1	0	0	0	0	0
2020	0	5	2	8	31	39	13	2	0	0	0	0
2021	32	30	1	0	13	14	5	3	2	0	0	0

Table A10.10. Catch at age for DEPM surveys in the southern area of Chile. Units are relative value (they are normalised to sum to one for each year in the model). Green shading reflects relative level with a darker green indicating a stronger cohort.

	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 A10.11. 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 / Southern 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 A10.12. Jack mackerel growth (von Bertalanffy) and natural mortality parameters used in JJM models.

Parameter	Far North stock	Single / South stock
L∞ (cm) (Total length)	80 .4	74.4
k	0.16	0.16
L0 (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 A10.13. Ageing error matrix of Jack mackerel. Columns represent the observed ages, while the rows represent the true age. These data are not used in the stock assessment.

	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 A10.14. Input mean body mass (kg) at age over time assumed for Fleet 1 (northern Chile).

	Age group (years)											
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	0.136	0.134	0.209	0.261	0.338	0.434	0.462	0.499	1.062	0.88	1.115
1981	0.05	0.168	0.189	0.228	0.284	0.353	0.424	0.5	0.601	0.735	1.112	1.115
1982	0.057	0.092	0.158	0.192	0.235	0.301	0.354	0.422	0.46	0.49	0.739	1.115
1983	0.084	0.095	0.113	0.192	0.242	0.309	0.376	0.429	0.485	0.486	0.529	1.115
1984	0.05	0.138	0.151	0.18	0.238	0.323	0.387	0.443	0.51	0.559	0.786	1.115
1985	0.05	0.146	0.174	0.212	0.274	0.344	0.406	0.482	0.553	0.595	0.726	1.115
1986	0.092	0.083	0.123	0.201	0.279	0.358	0.432	0.523	0.559	0.716	0.88	1.115
1987	0.079	0.104	0.138	0.183	0.235	0.335	0.432	0.491	0.542	0.545	0.803	1.115
1988	0.05	0.109	0.178	0.213	0.251	0.296	0.382	0.581	0.69	0.61	0.88	1.115
1989	0.05	0.068	0.121	0.208	0.251	0.297	0.354	0.496	0.579	0.547	0.701	1.115
1990	0.102	0.114	0.17	0.249	0.293	0.338	0.386	0.49	0.688	0.677	0.95	1.115
1991	0.049	0.103	0.126	0.188	0.266	0.344	0.388	0.44	0.739	0.855	0.775	0.883
1992	0.079	0.089	0.115	0.189	0.257	0.285	0.342	0.394	0.471	0.673	0.681	0.786
1993	0.013	0.081	0.114	0.175	0.258	0.334	0.379	0.432	0.52	0.638	0.815	0.935
1994	0.037	0.08	0.101	0.229	0.281	0.322	0.379	0.436	0.508	0.584	0.798	0.898
1995	0.069	0.072	0.117	0.174	0.27	0.34	0.394	0.394	0.632	0.668	0.88	1.115
1996	0.067	0.089	0.141	0.164	0.203	0.23	0.284	0.388	1.32	0.639	0.88	1.115
1997	0.029	0.123	0.147	0.175	0.225	0.291	0.425	0.615	0.584	0.728	0.88	1.115
1998	0.061	0.076	0.094	0.19	0.246	0.285	0.339	0.411	0.634	0.728	0.88	1.115
1999	0.068	0.068	0.086	0.154	0.266	0.306	0.37	0.612	0.584	0.728	0.88	1.115
2000	0.047	0.057	0.137	0.189	0.232	0.256	0.456	0.488	0.584	0.728	0.88	1.115
2001	0.069	0.094	0.113	0.137	0.206	0.289	0.4	0.488	0.584	0.728	0.88	1.115
2002	0.027	0.072	0.101	0.181	0.24	0.324	0.389	0.483	0.628	0.728	0.88	1.115
2003	0.052	0.073	0.102	0.139	0.234	0.314	0.422	0.478	0.51	0.728	0.88	1.115
2004	0.043	0.07	0.171	0.184	0.199	0.246	0.36	0.488	0.584	0.728	0.88	1.115
2005	0.033	0.077	0.109	0.178	0.223	0.265	0.294	0.66	0.739	0.728	0.88	1.115
2006	0.035	0.06	0.117	0.133	0.202	0.386	0.457	0.529	0.636	0.728	0.88	1.115
2007	0.071	0.087	0.117	0.155	0.216	0.296	0.401	0.539	0.658	0.723	0.723	1.115
2008	0.038	0.048	0.069	0.188	0.246	0.29	0.389	0.592	0.629	0.761	0.88	1.115
2009	0.03	0.059	0.112	0.136	0.244	0.286	0.334	0.534	0.584	0.728	0.88	1.115
2010	0.013	0.035	0.053	0.17	0.231	0.287	0.401	0.602	0.701	0.772	0.88	1.115
2011	0.016	0.064	0.102	0.164	0.275	0.325	0.382	0.488	0.584	0.728	0.88	1.115
2012	0.015	0.05	0.107	0.207	0.252	0.349	0.361	0.488	0.584	0.728	0.88	1.115
2013	0.017	0.063	0.06	0.167	0.284	0.39	0.441	0.657	0.52	0.687	0.821	1.086
2014	0.019	0.046	0.09	0.164	0.218	0.283	0.43	0.553	0.584	0.728	0.88	1.115
2015	0.033	0.04	0.177	0.186	0.279	0.369	0.437	0.608	0.779	0.729	0.868	1.109
2016	0.027	0.068	0.149	0.189	0.233	0.294	0.366	0.499	0.718	0.86	0.658	0.974
2017	0.024	0.049	0.13	0.167	0.192	0.259	0.332	0.451	0.6	0.528	0.88	1.115
2018	0.017	0.04	0.1	0.222	0.248	0.277	0.279	0.323	0.323	0.528	0.88	1.115
2019	0.018	0.033	0.128	0.18	0.284	0.471	0.501	0.528	0.732	0.853	0.888	1.512
2020	0.018	0.033	0.128	0.18	0.284	0.471	0.501	0.528	0.732	0.853	0.888	1.512
2021	0.018	0.033	0.128	0.18	0.284	0.471	0.501	0.528	0.732	0.853	0.888	1.512

Table A10.15. Input mean body mass (kg) at age over time assumed for Fleet 2 (central-south Chile).

	Age group (years)											
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	0.098	0.138	0.207	0.236	0.275	0.328	0.375	0.504	0.82	1.073	1.854
1981	0.105	0.114	0.123	0.204	0.236	0.268	0.308	0.368	0.464	0.796	1.184	1.9
1982	0.07	0.095	0.178	0.199	0.232	0.261	0.295	0.344	0.402	0.447	0.987	1.185
1983	0.071	0.095	0.118	0.196	0.246	0.284	0.33	0.418	0.497	0.606	1.196	1.769
1984	0.106	0.122	0.135	0.158	0.242	0.289	0.342	0.421	0.499	0.567	1.012	1.846
1985	0.058	0.149	0.18	0.203	0.233	0.299	0.366	0.452	0.537	0.627	0.695	1.647
1986	0.075	0.106	0.138	0.233	0.271	0.313	0.408	0.475	0.55	0.687	1	2.11
1987	0.111	0.106	0.12	0.149	0.215	0.335	0.407	0.455	0.492	0.564	0.824	1.979
1988	0.112	0.142	0.176	0.195	0.217	0.34	0.444	0.49	0.539	0.801	1.108	1.372
1989	0.052	0.091	0.135	0.216	0.258	0.31	0.436	0.536	0.579	0.625	0.948	1.538
1990	0.064	0.097	0.132	0.263	0.316	0.38	0.457	0.572	0.675	0.752	0.797	1.485
1991	0.037	0.109	0.126	0.167	0.283	0.418	0.469	0.538	0.657	0.761	0.829	0.93
1992	0.063	0.083	0.127	0.184	0.228	0.296	0.47	0.545	0.605	0.712	0.844	0.983
1993	0.011	0.099	0.134	0.189	0.246	0.32	0.389	0.533	0.684	0.82	0.925	1.143
1994	0.041	0.107	0.166	0.223	0.288	0.347	0.454	0.614	0.783	0.884	1.014	1.186
1995	0.02	0.084	0.152	0.193	0.266	0.339	0.425	0.563	0.797	1.012	1.187	1.432
1996	0.074	0.146	0.166	0.209	0.281	0.362	0.512	0.704	0.954	1.182	1.356	1.534
1997	0.071	0.126	0.156	0.207	0.264	0.36	0.518	0.699	0.887	1.084	1.287	1.594
1998	0.087	0.123	0.139	0.18	0.25	0.343	0.539	0.794	1.025	1.218	1.404	1.661
1999	0.087	0.116	0.147	0.179	0.257	0.338	0.494	0.789	1.039	1.235	1.397	1.733
2000	0.044	0.144	0.178	0.203	0.26	0.357	0.486	0.801	1.058	1.159	1.31	1.615
2001	0.066	0.152	0.158	0.211	0.265	0.336	0.455	0.614	0.868	1.119	1.395	1.703
2002	0.082	0.134	0.172	0.207	0.265	0.33	0.449	0.638	0.86	1.093	1.312	1.627
2003	0.067	0.122	0.157	0.196	0.248	0.305	0.403	0.588	0.786	1.026	1.261	1.604
2004	0.034	0.119	0.151	0.209	0.258	0.311	0.396	0.52	0.685	0.857	1.065	1.546
2005	0.023	0.039	0.165	0.235	0.279	0.318	0.396	0.506	0.642	0.751	0.92	1.317
2006	0.062	0.066	0.134	0.197	0.288	0.349	0.413	0.512	0.618	0.76	0.938	1.251
2007	0.086	0.051	0.125	0.195	0.23	0.333	0.431	0.513	0.625	0.777	0.909	1.198
2008	0.022	0.031	0.144	0.225	0.287	0.336	0.421	0.525	0.62	0.726	0.88	1.181
2009	0.014	0.067	0.132	0.148	0.273	0.346	0.418	0.539	0.624	0.759	0.892	1.142
2010	0.014	0.047	0.131	0.188	0.236	0.321	0.414	0.539	0.651	0.796	1.056	1.512
2011	0.019	0.062	0.187	0.203	0.295	0.36	0.478	0.64	0.806	1.025	1.261	1.65
2012	0.007	0.014	0.189	0.213	0.297	0.349	0.491	0.65	0.827	1.062	0.968	2.153
2013	0.054	0.116	0.213	0.242	0.313	0.381	0.448	0.58	0.714	0.926	1.292	2.28
2014	0.016	0.119	0.217	0.269	0.418	0.544	0.643	0.785	0.913	1.002	1.345	2.068
2015	0.062	0.175	0.203	0.217	0.281	0.48	0.61	0.746	0.884	0.99	1.049	1.232
2016	0.017	0.137	0.199	0.264	0.317	0.377	0.483	0.584	0.791	0.872	1.132	1.522
2017	0.017	0.058	0.188	0.225	0.292	0.368	0.444	0.549	0.676	0.922	1.096	1.52
2018	0.016	0.034	0.214	0.241	0.305	0.376	0.493	0.594	0.771	0.922	1.342	1.821
2019	0.015	0.025	0.187	0.27	0.305	0.393	0.482	0.578	0.683	0.759	0.888	1.621
2020	0.015	0.025	0.232	0.229	0.302	0.424	0.56	0.686	0.813	1.014	1.204	1.451
2021	0.015	0.025	0.095	0.272	0.303	0.347	0.427	0.604	0.713	0.809	1.106	2.128

Table A10.16. Input mean body mass (kg) at age over time assumed for Fleet 3 (far north).

	Age group (years)											
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
2020	0.033	0.146	0.346	0.621	0.95	1.31	1.682	2.051	2.405	2.739	3.047	3.327
2021	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 A10.17. Input mean body mass (kg) at age over time assumed for Fleet 4 (offshore trawl). Weight-at-age 1970-2013 were assumed to be the same as Fleet 2.

	Age group (years)											
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	0.125	0.131	0.193	0.416	0.451	0.617	0.74	0.804	0.968	1.034	1.132	1.164
2020	0.132	0.196	0.212	0.223	0.501	0.675	0.706	0.902	1.067	1.09	1.224	1.164
2021	0.132	0.196	0.212	0.223	0.501	0.675	0.706	0.902	1.067	1.09	1.224	1.164

Table A10.18. Years and types of information used in the JJM assessment models.

Fleet	Catch-at-age	Catch-at-length	Landings	CPUE	Acoustic	DEPM
1 North Chile purse seine	1975-2021	-	1970-2021	-	Index: 1984-1988; 1991; 2006-2021 Age comps: 2006-2021	Index: 1999-2008 Age comps: 2001-2008
2 South-central Chile purse seine	1975-2021	-	1970-2021	1983-2021	1997-2009 Age comps: 1997-2009	-
3 FarNorth	-	1980-2020	1970-2021	2002-2021	1985-2013	-
4 International trawl off Chile	1979-1991; 2000-2004; 2006-2020	2007-2019*	1970-2021	China, EU, Korea, Russia, & Vanuatu (2008-2020)	-	-

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

Table A10.19. 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}	l	
Mean length at age	L_j	
Variation coefficient of the length at age	cv	
Mean weight in year t by age j	$W_{t,j}$	
Maximum age beyond which selectivity is constant	*Maxage*	Selectivity 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	Γ	Transform from age to length
Sample size for proportion in year i	T_i	Scales multinomial assumption about estimates of proportion at age
Survey catchability coefficient	q^s	Prior distribution lognormal(μ_q^s , σ_q^2)
Stock-recruitment parameters	R_0	Unfished equilibrium recruitment
	h	Stock-recruitment steepness
	σ_R^2	Recruitment variance
Unfished biomass	φ	Spawning biomass per recruit when there is no 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 A10.20. 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)	$\hat{C}_{il}, \hat{C}_{ij}, \hat{Y}_i$	$\hat{C}^f_{i,j}, = N_{i,j} \frac{F^f{}_{i,j}}{Z^f{}_{i,j}} \left(1 - e^{-Z^f{}_{i,j}}\right)$ $\hat{Y}^f{}_i = \sum_{j=1}^{12+} \hat{C}^f_{i,j} w^f_{i,j}$
	(transformation from age to length composition. Fleet 3, FarNorth)		$\hat{C}_{il} = \Gamma_{lj} \hat{C}_{ij}$ $\Gamma_{l,j} = \int_j^{j+1} e^{-\frac{1}{2\sigma_j^2}(l-L_j)^2} dl$ $L_j = L_{00}(1-e^{-k}) + e^{-k} L_{j-1}$ $\sigma_j = cv L_j$
3)	Proportion at age j, in year i		$p_{ij}^f = \frac{\hat{C}_{ij}^f}{\sum_j \hat{C}_{ij}^f} \quad p_{ij}^s = \frac{N_{ij} S_j^s e^{-\Delta^s Z_{ij}}}{\sum_j N_{ij} S_j^s e^{-\Delta^s Z_{ij}}}$
	Proportion at length l, in year i		$P_{il} = \frac{C_{il}}{\sum_{l=10}^{50} C_{il}}$
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, …, 2020	$\varepsilon_i, \sum_{i=1958}^{final\ year} \varepsilon_i = 0$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$

Eq	Description	Symbol/Constraints	Key Equation(s)	
11)	Index catchability	μ^s, μ^f	$q_i^s = e^{\mu^s}$	
	Mean effect		$s_j^s = e^{\eta_j^s}$	$j \le \text{maxage}$
	Age effect	$\eta^s{}_j, \sum_{j=1958}^{final\ year} \eta^s{}_j = 0$	$s_j^s = e^{\eta_{\text{maxage}}^s}$	$j > \text{maxage}$
12)	Instantaneous fishing mortality		$F_{ij}^f = e^{\mu^f + \eta_j^f + \phi_i}$	
13)	Mean fishing effect	μ^f		
14)	Annual effect of fishing mortality in year i	$\varphi_i, \sum_{i=1970}^{final\ year} \varphi_i = 0$		
15)	age effect of fishing (regularised) In year time variation allowed	$\eta^f{}_j, \sum_{j=1958}^{final\ year} \eta^f{}_j = 0$	$s_{ij}^f = e^{\eta_j^f}$	$j \le \text{maxage}$
			$s_{ij}^f = e^{\eta_{\text{maxage}}^f}$	$j > \text{maxage}$
	In years where selectivity is constant over time	$\eta_{i,j}^f = \eta_{i-1,j}^f$	$i \ne \text{change year}$	
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.	$\tilde{R}_i$	$\tilde{R}_i = \frac{\alpha B_t}{\beta + B_i}$, $\alpha = \frac{4hR_0}{5h-1}$ and $\beta = \frac{B_0(1-h)}{5h-1}$ where $B_0 = R_0\varphi$ $\varphi = \sum_{j=1}^{12} e^{-M(j-1)} W_j p_j + \frac{e^{-12M} W_{12} p_{12}}{1-e^{-M}}$ h=0.8	

Table A10.21 Specification of objective function that is minimised (i.e., the penalised negative of the log-likelihood).

Eq	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	$L_3 = \lambda_3 \sum_{i=1958}^{final\ year} \varepsilon^2{}_i$ $\lambda_3 = \frac{0.5}{\sigma_R^2}$	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	$L_4 = 0.5 \sum_f \frac{1}{cv_f^2} \sum_{i=1970}^{final\ year} log\left(\frac{Y^f{}_i}{\hat{Y}^f{}_i}\right)^2$	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. (Assessment models use the period 1970 to (present year – 3))
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 A10.22. 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 – 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 – 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 A10.23. 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 regimes were considered – before and after 2002. This is a different assumption from the single-stock hypothesis, which has annual variations in selectivity between 1981 and 2020.
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 A10.24. Description of JJM model components and how selectivity was treated (two-stock hypothesis; Southern 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)	Offshore fleet (China, EU, Korea, Russia, Vanuatu) CPUE	Assumed to be the same as 3)

Table A10.25.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)	Offshore fleet (Vanuatu, Russia, Korea, EU & China) CPUE	Assumed to be the same as 4)

Table A10.26. Systematic model progression from the 2020 assessment data to the agreed revised datasets for 2021. Note that the data file names corresponding to each model follow the same naming convention, but with the stock-structure hypothesis denoted as h1 for the single-stock and h2 for the two-stock (e.g., “0.01.dat” with “h1_0.01.ctl” and “h2_0.01.ctl).

Model	Description
Models 0.x	Data introductions
0.00	Exact 2020 (single stock h1 and two-stock h2) model and data set through 2020 (mod1.0 from SC08)
0.01	As 0.00 but with revised catches through 2020 (currently still estimates)
0.02	As 0.01 but with updated 2020 fishery age composition data for N_Chile, SC_Chile, and Offshore_Trawl, and updated 2020 fishery length composition data for FarNorth
0.03	As 0.02 but with updated 2020 weight at age data for all fisheries and their associated CPUE indices
0.04	As 0.03 but replaced offshore CPUE up to 2020
0.05	As 0.04 but with 2021 catch projections
0.06	As 0.05 but with updated 2021 fishery age composition data for N_Chile, SC_Chile, and Offshore_Trawl, and updated 2020 fishery length composition data for FarNorth
0.07	As 0.06 but but with updated 2021 weight at age data for N_Chile, SC_Chile, and FarNorth fleets, and for their associated CPUE indices
0.08	As 0.07 but replaced SC_Chile_CPUE index (traditional absolute scaled CPUE by trip)
0.09	As 0.08 but replaced Peru_CPUE index
0.10	As 0.09 but with updated AcousN 2021 index, with associated age composition and weight at age
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Models 1.x	Updated Model and Sensitivities
1.00	Update model (selectivity changes, recruitment) to 2021; 0.10 data file
1.01	As 1.00 but use revised data series "antiguo" of age composition and weight at age data for both Chilean fisheries and both Chilean acoustic surveys (assessment/NewAgeData/AgeDataInAssessment.csv)
1.02	As 1.01 but incorporate revised (validated) age data for surveys and fleets with M and maturity updated (M=0.35) (NOT RUN)
1.03	As 1.02 but M=0.45 (NOT RUN)
1.04	As 1.01 but with increased uncertainty (CV=0.4) for final year CPUE indices
1.05	As 1.04 but replacing 2020/2021 weight at age with 2019 revised "antiguo" data for N_Chile
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Models 1.xx.yy	Base Model Projections
1.05	Base model
1.05.ll	As 1.05 but low steepness and long recruitment time series (1970-2015)
1.05.ls	As 1.05 but low steepness and short recruitment time series (2000-2015)
1.05.hl	As 1.05 (i.e., high steepness and long recruitment time series (1970-2015)
1.05.hs	As 1.05 but high steepness and short recruitment time series (2000-2015)

Table A10.27. Spawning biomass of Jack mackerel (base model under the single-stock hypothesis) estimated in previous SPRFMO SC meetings.

Year	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9
1970	8761	6726	10082	9770	9928	10319	10289	10629	11383
1971	8112	6384	9164	8872	9037	10015	9964	10214	10979
1972	7818	6173	8527	8289	8457	9854	9783	9964	10731
1973	7726	6015	8042	7911	8079	9756	9666	9794	10521
1974	7676	5910	7673	7633	7800	9646	9538	9625	10249
1975	7763	5894	7446	7511	7675	9604	9480	9534	9984
1976	8141	6075	7454	7638	7799	9752	9610	9638	9822
1977	8810	6589	7808	8027	8186	10112	9948	9955	9808
1978	9551	7151	8224	8445	8603	10458	10267	10256	9810
1979	10188	7613	8553	8810	8965	10717	10497	10473	9832
1980	10854	8276	9085	9349	9494	11124	10881	10847	10069
1981	11170	8521	9213	9561	9693	11174	10920	10878	9982
1982	10806	8122	8679	9137	9252	10513	10263	10217	9192
1983	11092	8503	8926	9487	9578	10584	10358	10310	9344
1984	11122	8635	8942	9653	9722	10502	10310	10264	9434
1985	11554	9342	9557	10297	10351	10869	10721	10679	10077
1986	13159	11355	11531	11890	11936	12177	12075	12039	11772
1987	14919	13284	13459	13371	13411	13402	13344	13314	13297
1988	15496	13716	13894	13801	13830	13717	13702	13679	13828
1989	15050	13082	13256	13389	13406	13455	13472	13454	13502
1990	14228	12207	12371	12701	12699	13076	13116	13101	13136
1991	13098	11032	11197	11792	11763	12408	12466	12455	12537
1992	11909	9856	10018	10772	10716	11542	11610	11602	11763
1993	10802	8942	9082	9800	9722	10658	10726	10720	10743
1994	9271	7518	7634	8165	8070	9061	9127	9123	9074
1995	7154	5448	5532	5901	5794	6696	6761	6758	6666
1996	5819	3820	3862	4174	4073	4775	4832	4831	4740
1997	4950	2990	2965	3254	3181	3609	3655	3657	3564
1998	4985	3158	3074	3539	3498	3677	3724	3730	3573
1999	5668	3937	3795	4475	4457	4434	4499	4511	4278
2000	6671	5018	4834	5616	5624	5463	5556	5574	5312
2001	7481	5892	5690	6368	6404	6172	6298	6323	6095
2002	8083	6699	6544	7010	7073	6805	6965	6997	6770
2003	8201	6952	6848	7274	7349	7080	7270	7309	7078
2004	7641	6564	6475	6908	6979	6725	6935	6980	6751
2005	6708	5763	5676	6159	6225	5997	6213	6262	6056
2006	5486	4682	4595	5102	5160	4979	5195	5248	5061
2007	4119	3430	3324	3846	3890	3754	3973	4029	3857
2008	3067	2545	2382	2890	2915	2779	2998	3055	2926
2009	2130	1850	1598	2070	2074	1893	2103	2159	2076
2010	1709	1647	1291	1775	1758	1538	1728	1778	1703
2011	1855	1861	1382	1868	1832	1667	1817	1855	1782
2012	2304	2115	1552	2065	2015	1980	2068	2090	2038
2013	3085	2383	1814	2308	2248	2339	2362	2370	2348
2014	-	2738	2222	2667	2572	2725	2687	2691	2719
2015	-	3206	2720	3273	3103	3176	3019	3042	3107
2016	-	-	3174	4116	3885	3606	3390	3456	3567
2017	-	-	-	-	5294	4097	3915	4047	4190
2018	-	-	-	-	-	4777	4821	5078	5264
2019	-	-	-	-	-	-	6188	6673	6956
2020	-	-	-	-	-	-	-	8273	8740
2021	-	-	-	-	-	-	-	-	9960

Table A10.28. Estimated begin-year numbers at age (Model *h_1.05*; single-stock hypothesis). Green shading reflects relative level with darker green indicating a stronger cohort.

Age group (years)

Year	1	2	3	4	5	6	7	8	9	10	11	12
1970	11019.4	7883.8	5827.44	4063.67	2562.12	2049.01	1579.55	1376.15	1197.39	1036.65	890.97	4684.13
1971	9755.73	8753.89	6261.24	4622.48	3216.93	2016.96	1594.83	1209.52	1060.46	942.42	816.92	4393.41
1972	9357.24	7749.2	6950.26	4961.19	3652.34	2521.08	1554.4	1199.77	918.45	830.84	739.73	4089.77
1973	9002.66	7431.36	6150.36	5499.79	3923.34	2875.21	1966.54	1196.66	927.51	722.5	655.39	3809.66
1974	9955.21	7146.09	5891.09	4845.37	4335.31	3076.34	2228.9	1499.91	917.6	727.23	569.02	3516.53
1975	13864.1	7886.42	5639.26	4564.58	3783.14	3375.97	2355.49	1662.37	1129.89	715.77	569.07	3197.01
1976	18531.9	11004.4	6250.46	4438.84	3585.22	2936.61	2558	1724.25	1232.09	876.72	558.63	2939.24
1977	19747.2	14704.6	8714.84	4905.51	3474.52	2764.25	2195.69	1830.72	1253.43	949.46	680.93	2716.72
1978	21791.5	15522.2	11399.9	6325.14	3688.33	2631.01	2040.54	1552.42	1313.15	955.16	732.33	2620.65
1979	22831.6	17190.2	12127.3	8508.99	4775.88	2720.61	1818.94	1281.26	1004.14	965.42	717.27	2517.9
1980	21983.4	18038.5	13476.1	9163.81	6447.49	3493.16	1828.98	1074.35	773.31	710.57	701.66	2351.32
1981	30613.6	17354.4	14115.8	10115.1	6930.81	4730.41	2381.19	1117.1	668.8	550.34	521.33	2239.93
1982	35933.6	24200.1	13573.5	10543.2	7512.22	4821.5	2924.25	1240.31	596.1	443.19	388.21	1947.81
1983	27505.2	28450.1	19072.9	10433.4	7754.14	4869.58	2519.03	1105.18	479.7	339.2	274.6	1447.41
1984	51042.7	21824	22487.4	14796.6	7881.11	5387.68	2928.13	1212.99	519.45	283.6	213.28	1082.76
1985	57806.6	40481.8	17191.7	17172.3	10722.3	5260.84	2975.51	1173.09	457.08	257.95	150.14	686.12
1986	28970.5	45864.3	31968.9	13294.9	12606.6	7200.91	3030.89	1364.85	500.92	229.02	138.54	449.15
1987	27441.3	22996.6	36293.1	24994	10073.6	8965.78	4586.16	1599.9	643.24	257.74	125.02	320.8
1988	32855.8	21770.5	18133.2	27987	18363.2	7003.75	5635.35	2338.78	695.72	289.81	119.98	207.52
1989	29732.7	26034.5	17022.4	13867.9	20322.3	12322.8	4447.27	3171.33	1121.03	302.64	118.49	133.9
1990	29695.4	23553.8	20367.2	12996.8	10201.3	13539.6	7682.24	2601.56	1665.34	505.36	115.92	96.68
1991	20923.4	23525.3	18499.5	15567.8	9651.45	7208.28	8781.22	4489.43	1369.49	769.35	197.55	83.11
1992	21523.8	16576.7	18483.2	14178.4	11560.2	6884.88	4751.01	5054.88	2197.54	567.12	267.35	97.53
1993	14913	17051.1	13010.9	14108	10477	8144.75	4579.96	2878.81	2527.3	838.31	161.74	104.06
1994	13724.8	11800.9	13251	9618.16	10083.1	7120.89	5267.96	2766.32	1544.61	1046.73	232.33	73.67
1995	18688.3	10852.5	9144.35	9713.38	6685.04	6433.85	4248.17	2924.86	1341.19	532.59	247.84	72.45
1996	20185.3	14695	8141.45	6019.6	5786.45	3512.14	3103.46	1930.5	1241.79	413.26	105.27	63.31
1997	26330.2	15807.4	10708.6	5110.82	3199.84	2574.76	1525.43	1382.98	822.61	432.95	106.16	43.31
1998	26638.6	20574.6	11311.8	6534.53	2380.68	1205.17	1023.9	668.99	584.71	286.65	121.33	41.88
1999	32001.5	20869.1	14949.6	7689.96	3528.2	1176.21	619.1	554.99	354.86	278.85	121.98	69.45
2000	31568.8	25239.4	15854	10682	4688.26	2004.85	688.08	379.53	339.12	204.66	149.4	102.57
2001	21826.8	24801.5	19025.4	11578.6	6820.26	2799.39	1241.94	447.34	247.95	213.87	123.3	151.8
2002	14544.8	16880.2	17343.8	12918.7	7195	3847.2	1647.35	772.55	279.89	148.97	121.86	156.75
2003	8584.26	11471.4	13062.5	12860.5	8729.3	4414.75	2301.51	1021.73	477.95	164.01	81.79	152.97
2004	8705.4	6731.63	8677.67	9558.53	8885.59	5499.25	2657.88	1419.24	631.13	278.78	89.03	127.44
2005	6594.79	6833.76	5154.93	6311.47	6583.25	5664.02	3272.31	1580.89	838.06	351.09	145.89	113.28
2006	7018.54	5177.61	5210.3	3738.61	4375.03	4332.11	3398.94	1913.44	917.75	462.4	184.69	136.34
2007	4796.84	5477.77	3782.65	3553.85	2463.57	2842.61	2582.01	1848.59	1026.36	466.84	228.09	158.36
2008	4757.16	3744.3	4022.15	2408.92	2170.07	1496.43	1640.45	1347.95	873.84	455.79	195.62	161.93
2009	6739.52	3706.65	2712.04	2565.68	1486.89	1328.1	844.67	855.6	652	402.4	197.55	154.98
2010	9306.07	5273.78	2756.54	1818.57	1523.12	837.37	652.21	381.43	350.41	255.3	149.8	131.24
2011	5781.39	7259.03	3866.77	1778.41	1068.58	886.64	463.38	351.4	195.83	161.15	118.5	130.45
2012	9121.26	4536.64	5200.26	2555.49	1263.78	741.58	564.54	294.11	226.72	122.6	104.39	161.27
2013	7246.27	7215.46	3518.01	3754.8	1901.06	895.88	481.02	353.08	196.22	153.61	84.54	183.18
2014	10458.2	5741.04	5648.26	2673.45	2819.57	1362.83	594.46	315.39	239.59	135.46	107.49	187.34
2015	9660.62	8285.79	4494.39	4292.63	2030.69	2095.79	971.43	403.52	211.79	163.88	94.26	205.16
2016	15190.3	7655.85	6499.73	3487.86	3225.08	1499.92	1528.17	679.39	269.24	139.45	109.45	199.98
2017	36776	12047.8	6035.92	5085.15	2657.62	2382.84	1079.77	1079.55	466.07	181.13	94.55	209.8
2018	28423.5	29159.8	9502.6	4731.41	3894.04	1978.64	1729.78	757.59	743.04	315.11	123.02	206.71
2019	16140.3	22538	22951.1	7455.6	3663.55	2922.02	1433.56	1213.9	520.23	506.5	215.43	225.43
2020	12496.3	12797.7	17781.4	17924.6	5814.79	2787.94	2138.01	995.2	828.32	353.28	351.12	305.61
2021	16292.7	9913.03	10119.5	13910.3	14025.3	4478.5	2066.91	1507.73	675.72	570.54	250.31	465.31

Table A10.29. Estimated begin-year numbers at age (Model *h_2.05*; two-stock hypothesis; southern stock). Green shading reflects relative level with darker green indicating a stronger cohort.

Age group (years)

Year	1	2	3	4	5	6	7	8	9	10	11	12
1970	10436.8	7450.03	5469.67	3788.56	2378.3	1897.85	1459.07	1268.95	1102.57	953.38	818.43	3837.33
1971	9215.71	8291.79	5917.83	4341.62	2999.4	1871.07	1474.52	1113.32	974.42	866.62	750.4	3664.51
1972	8809	7321.45	6585.7	4695.2	3431.46	2348.71	1438.45	1103.87	841.28	761.99	679.1	3459.58
1973	8558.04	6998.68	5815.91	5227.95	3718.17	2701.28	1830.14	1104.79	851.23	661.13	600.64	3262.34
1974	9284.32	6799.19	5559.14	4615.41	4135.05	2917.21	2092.17	1392.48	844.91	666.81	520.43	3040.86
1975	12365.5	7375.89	5399.99	4409.75	3645.08	3231.06	2234.16	1557	1046.37	659.08	521.94	2787.56
1976	17004.3	9823.42	5857.23	4280.98	3474.83	2830.35	2444.11	1628.76	1148.66	810.44	513.67	2579.33
1977	18633.4	13508.1	7799.69	4640.61	3365.59	2680.9	2112.69	1741.46	1177.81	883.3	628.47	2398.53
1978	19013.9	14802.2	10724.8	6177.69	3643.68	2587.09	1991.98	1497.99	1251.33	901.4	684.73	2346.53
1979	21003.2	15101.6	11743.7	8468.79	4795.74	2712.62	1793.48	1248.46	964.46	919.28	677.08	2276.89
1980	21353.2	16681.2	11979.4	9266.77	6556.02	3534.06	1828.45	1057.37	748.37	679.75	666.09	2140.37
1981	30955.5	16960.3	13235	9458.72	7188.75	4857.02	2422.25	1119.81	656.97	531.79	498.33	2057.45
1982	31377.4	24582.3	13443.1	10400.5	7204.51	5057.06	3027.45	1269.89	596.98	434.11	374.37	1799.22
1983	26629.3	24906.2	19450.9	10490.2	7719.56	4704.53	2666.69	1155.55	489.36	336.29	266.52	1334.48
1984	58782.4	21144.8	19735.4	15272.2	7972.61	5385.82	2840.73	1288.43	539.78	286.06	209.28	996.33
1985	67417.9	46650	16716.6	15291.6	11153	5343.56	2982.64	1135.91	479.2	262.76	148.57	626.15
1986	26892.4	53506.1	36892.2	13010.2	11269.6	7501.28	3083.61	1367.06	480.21	236.16	138.82	409.28
1987	15593	21349.8	42363.7	28904.9	9877.03	7996.24	4775.8	1627.58	639.98	243.5	126.86	294.42
1988	19688.8	12372.5	16858.2	32749.1	21310.6	6874.56	5018.3	2436.66	705.55	284.32	111.16	192.31
1989	27845.3	15620.5	9768.97	13053.1	24018	14467.5	4403.68	2844.8	1175	304.92	113.83	121.49
1990	28406	22089.3	12335.4	7593.92	9713.17	16291.2	9224.16	2629.74	1519.43	531.81	114.48	88.35
1991	22862.3	22533.2	17446	9616.55	5739.98	6927.87	10824	5579.38	1421	705.71	203.15	77.48
1992	18173	18126.6	17763.4	13507.5	7193.89	4090.01	4627.34	6513.7	2882.14	603.74	240.99	95.83
1993	16176.9	14402.5	14258.6	13649.6	10010.2	5037.75	2714.4	2871.46	3490.85	1182.67	173.88	97
1994	17030.2	12813.5	11278.8	10669.6	9825.94	6816.47	3226.33	1632.25	1591.8	1574.32	344.12	78.82
1995	18541.2	13490.6	10031.8	8493.88	7521.87	6271.55	3992.64	1714.04	763.27	555.69	392.39	105.41
1996	21058.6	14669.3	10493.1	7275.59	5185.03	3853.77	2807.68	1619.53	639.9	213.55	111.93	100.27
1997	24215.6	16631.9	11294	7223.23	3889.58	2142.35	1475.08	1067.78	584.39	193.83	53.47	53.13
1998	23558.3	19172.9	12909.7	7729.67	3324.92	1363.41	778.86	587.03	410.4	190.08	54.22	29.82
1999	27548.7	18684.5	15018.1	9158.16	4180.1	1623.54	688.59	413.67	305.93	194.26	81.43	36
2000	25717.8	21850.8	14668.2	10922.1	5672.25	2422.62	962.65	424.28	253.38	176.89	103.99	62.86
2001	22239.5	20383.3	17130.9	10964.3	7122.28	3478.07	1528.23	630.74	277.76	159.18	105.18	99.21
2002	11521.4	17585	15837.8	12431.4	7026.83	4139.58	2088.02	960.9	395.41	165.18	88.47	113.61
2003	8647.53	9128.08	13793.9	11936.1	8490.55	4387.27	2522.69	1311.35	596.92	228.66	87.39	106.91
2004	6421.74	6842	7125.27	10315.7	8330.46	5428.84	2693.71	1583.42	819.02	345.92	119.62	101.64
2005	3015.32	5075.95	5330.83	5340.51	7180.65	5380.5	3297.73	1637.91	950.05	453.9	174.56	111.65
2006	5074.08	2376.1	3894.75	3888.06	3728	4763.59	3287.6	1970.55	966.72	522.67	230.45	145.32
2007	5919.23	3994.05	1818.74	2791.58	2636.76	2474.34	2896.26	1838.51	1080.74	492.76	250.6	180.17
2008	5581.01	4642.36	3018.18	1242.88	1766.56	1639.56	1463.38	1549.66	895.63	484.36	201.83	176.44
2009	4130.1	4353.32	3404.03	2031.01	780.03	1096.59	938.43	777.28	761.15	410.4	204.46	159.67
2010	4524.35	3230.54	3265.28	2322.24	1233.07	450.84	544.78	420.75	315.99	287.72	144.78	128.46
2011	5686.09	3514.77	2351.68	2064.98	1365.25	727.61	246.38	285.32	209.72	138.71	126.72	120.34
2012	8737.45	4497.86	2722.56	1792.19	1537.2	963.85	452.95	148.2	178.97	128.63	87.85	156.48
2013	9683.21	6930.81	3545.74	2123.3	1360.77	1092.26	621.14	277.24	97.49	119.77	87.52	166.24
2014	11292.2	7681.16	5463.41	2753.22	1610.45	959.76	716.4	405.13	186.46	66.36	82.53	174.85
2015	11783.3	8958.07	6060.5	4260.4	2100.65	1173.13	662.91	480.74	271.38	125.7	45.29	175.64
2016	15994.8	9343.05	7075.71	4730.09	3200.18	1535.37	828.92	447.18	315.96	176.55	81.95	144.03
2017	20203.9	12688.3	7393.16	5555.14	3612.7	2353.76	1084.97	564.17	297.3	208.62	117.42	150.3
2018	12273	16011.4	10018.4	5802.35	4259.56	2696.23	1698.46	746.12	375.34	195.09	138.46	177.68
2019	14347.7	9734.26	12675.4	7904.58	4503.94	3209.01	1967.38	1188.01	503.44	247.38	129.6	210.01
2020	12694.8	11382.3	7711.39	10019.3	6187.29	3444.3	2372.65	1389.08	811.6	335.24	166.64	228.78
2021	16635.1	10075.4	9026.82	6101.94	7863.31	4775.69	2579.04	1700.72	958.37	553.6	231.53	273.1

Table A10.30. Estimated begin-year numbers at age (Model *h2_1.05*; two-stock hypothesis; far north stock). Green shading reflects relative level with darker green indicating higher mortality.

	Age group (years)											
Year	1	2	3	4	5	6	7	8	9	10	11	12
1970	4012.7	2810.2	2018.45	1450.27	1042.36	749.21	538.62	387.25	278.44	200.2	143.94	381.97
1971	4013.8	2884.55	2017.62	1444.37	1041.37	749.27	538.61	387.22	278.4	200.17	143.93	378.08
1972	4014	2885.1	2068.38	1437.41	1035.95	748.45	538.64	387.21	278.38	200.15	143.91	375.28
1973	4011.83	2884.46	2060.82	1453.94	1027.36	744.24	538.02	387.22	278.36	200.12	143.88	373.24
1974	3997.24	2881.42	2045.21	1411.84	1032.25	737.47	534.91	386.75	278.36	200.1	143.86	371.73
1975	3961.25	2864.86	1981.72	1259.94	975.07	738.49	529.74	384.44	277.96	200.05	143.81	370.55
1976	3906.23	2845.11	2031.44	1357.94	894.57	699.93	530.78	380.8	276.35	199.81	143.81	369.76
1977	3702.17	2804.84	2009.75	1373.62	960.82	641.88	503.03	381.54	273.74	198.65	143.63	369.17
1978	5532.05	2617.04	1582.28	620.66	792.8	672.52	459.36	361.02	273.83	196.46	142.57	368.03
1979	3819.24	3907.15	1457.88	467.69	354.16	554.14	481.16	329.64	259.07	196.5	140.98	366.42
1980	3386.44	2706.26	2281.16	507.49	278.46	248.83	396.82	345.41	236.64	185.98	141.06	364.24
1981	3765.5	2399.34	1577.77	790.12	301.77	195.62	178.18	284.86	247.95	169.87	133.5	362.73
1982	5718.58	2653.58	1294.64	417.29	438.02	210.18	139.87	127.84	204.37	177.9	121.88	356.03
1983	3639.94	4084.91	1739.59	674.85	275.95	311.71	150.84	100.49	91.85	146.83	127.81	343.35
1984	2947.63	2607.09	2783.37	1037.42	462.16	197.22	223.87	108.4	72.22	66.01	105.52	338.6
1985	2223.37	2110.08	1762.67	1615.56	705.48	330.01	141.62	160.88	77.9	51.9	47.43	319.15
1986	3611.14	1593.47	1450.75	1084.64	1115.43	504.69	237.05	101.78	115.62	55.99	37.3	263.46
1987	5552.07	2591.74	1118.01	958.08	762.75	799.76	362.67	170.39	73.16	83.11	40.24	216.18
1988	9407.58	3983.84	1812.47	729.96	671.76	546.69	574.66	260.68	122.48	52.59	59.74	184.32
1989	4979.08	6712.89	2571.97	895.67	476.06	477.24	392.23	412.82	187.26	87.98	37.78	175.32
1990	4780.58	3557.47	4414.96	1355.84	594.03	338.91	342.52	281.8	296.6	134.54	63.21	153.1
1991	2375.37	3418.35	2366.46	2421.53	908.54	423.42	243.29	246.11	202.49	213.12	96.67	155.43
1992	3818.8	1700.17	2306.04	1362.98	1643.4	648.6	304.04	174.83	176.86	145.5	153.15	181.16
1993	2538.53	2738.23	1177.04	1453.64	946.96	1176.57	465.96	218.52	125.65	127.11	104.58	240.28
1994	2088.34	1816.78	1844.87	674.91	985.39	675.93	844.83	334.84	157.03	90.29	91.34	247.81
1995	4167.35	1490.11	1172.37	910.19	439.98	700.02	484.95	606.9	240.54	112.8	64.86	243.64
1996	4678.38	2890.31	639.37	139.52	410	298.8	498.38	347.37	434.71	172.29	80.8	220.98
1997	4347.52	3160.69	850.59	20.45	44.66	267.09	211.22	356.03	248.15	310.55	123.08	215.58
1998	3503.94	2783.3	429.31	1.84	3.25	26.72	186.06	150.06	252.94	176.3	220.63	240.6
1999	3824.1	2271.53	452.64	1.74	0.34	1.98	18.67	132.36	106.75	179.93	125.41	328.1
2000	7056.61	2669.9	1072.17	75.1	0.85	0.24	1.41	13.39	94.87	76.51	128.97	325.07
2001	1477	4967.56	1418.75	268.84	41.06	0.59	0.17	1.01	9.6	68.06	54.89	325.72
2002	3852.74	992.04	1344.14	33.86	79.76	26.5	0.42	0.12	0.72	6.86	48.59	271.73
2003	998.52	2743.3	561.46	650.91	21.81	56.62	19.01	0.3	0.09	0.52	4.92	230.06
2004	1674.06	708.51	1423.37	235.54	402.93	15.42	40.57	13.65	0.22	0.06	0.37	168.71
2005	4056.56	1190.69	390.17	658.84	149.84	285.63	11.05	29.13	9.8	0.16	0.04	121.43
2006	2027.85	2896.16	720.18	210.86	437.56	106.75	204.98	7.94	20.93	7.04	0.11	87.27
2007	592.36	1431.93	1332.45	247.71	123.52	307.25	76.39	147.1	5.7	15.02	5.05	62.71
2008	280.12	419.51	708.31	516.57	150.01	87.07	220.04	54.84	105.59	4.09	10.78	48.64
2009	1299.88	198.05	199.12	256.51	306.97	105.51	62.33	157.93	39.36	75.78	2.94	42.65
2010	4726.26	916.02	86.62	62.99	146.81	214.98	75.47	44.72	113.31	28.24	54.37	32.7
2011	1084.34	3380.73	580.94	50.62	42.76	104.85	154.35	54.23	32.13	81.42	20.29	62.57
2012	1602.93	760.11	1296.76	147.97	27.28	29.74	74.9	110.68	38.89	23.04	58.38	59.42
2013	414.02	1138.89	407.73	574.73	93.01	19.31	21.31	53.78	79.48	27.92	16.55	84.59
2014	1219.73	295.51	684.13	217.86	380.5	66.23	13.86	15.31	38.64	57.1	20.06	72.65
2015	955.26	870.29	176.04	360.56	143.68	270.85	47.52	9.96	11	27.75	41.02	66.6
2016	1589.72	684.57	577.82	110.97	249.92	102.86	194.56	34.16	7.16	7.91	19.95	77.35
2017	6743.41	1141.15	473.89	390.26	78.41	179.32	73.92	139.85	24.55	5.14	5.68	69.94
2018	7114.79	4844.38	805.31	330.4	278.19	56.32	128.89	53.14	100.54	17.65	3.7	54.36
2019	2564.48	5103.95	3300.57	529.79	231.75	199.43	40.46	92.64	38.2	72.26	12.69	41.73
2020	1200.45	1839.29	3458.72	2152.12	370.69	166.09	143.29	29.08	66.59	27.45	51.94	39.11
2021	2053.51	860.98	1246.48	2255.48	1505.86	265.67	119.33	102.99	20.9	47.86	19.73	65.44

Table A10.31. Estimated total fishing mortality at age (Model h1_1.05; single-stock hypothesis). Green shading reflects relative level with darker green indicating higher mortality.

	Age group (years)											
Year	1	2	3	4	5	6	7	8	9	10	11	12
1970	0	0	0.002	0.004	0.009	0.021	0.037	0.031	0.009	0.008	0.008	0.008
1971	0	0.001	0.003	0.006	0.014	0.031	0.055	0.045	0.014	0.012	0.012	0.012
1972	0	0.001	0.004	0.005	0.009	0.018	0.032	0.027	0.01	0.007	0.007	0.007
1973	0.001	0.002	0.008	0.008	0.013	0.025	0.041	0.036	0.013	0.009	0.009	0.009
1974	0.003	0.007	0.025	0.017	0.02	0.037	0.063	0.053	0.018	0.015	0.015	0.015
1975	0.001	0.002	0.009	0.012	0.023	0.047	0.082	0.07	0.024	0.018	0.018	0.018
1976	0.001	0.003	0.012	0.015	0.03	0.061	0.105	0.089	0.031	0.023	0.023	0.023
1977	0.011	0.025	0.09	0.055	0.048	0.074	0.117	0.102	0.042	0.03	0.03	0.03
1978	0.007	0.017	0.062	0.051	0.074	0.139	0.235	0.206	0.078	0.056	0.056	0.056
1979	0.006	0.013	0.05	0.047	0.083	0.167	0.297	0.275	0.116	0.089	0.089	0.089
1980	0.006	0.015	0.057	0.049	0.08	0.153	0.263	0.244	0.11	0.08	0.08	0.08
1981	0.005	0.016	0.062	0.067	0.133	0.251	0.422	0.398	0.181	0.119	0.119	0.119
1982	0.004	0.008	0.033	0.077	0.204	0.419	0.743	0.72	0.334	0.249	0.249	0.249
1983	0.001	0.005	0.024	0.051	0.134	0.279	0.501	0.525	0.296	0.234	0.234	0.234
1984	0.002	0.009	0.04	0.092	0.174	0.364	0.685	0.746	0.47	0.406	0.406	0.406
1985	0.001	0.006	0.027	0.079	0.168	0.321	0.549	0.621	0.461	0.392	0.392	0.392
1986	0.001	0.004	0.016	0.047	0.111	0.221	0.409	0.522	0.434	0.375	0.375	0.375
1987	0.001	0.008	0.03	0.078	0.133	0.234	0.443	0.603	0.567	0.535	0.535	0.535
1988	0.003	0.016	0.038	0.09	0.169	0.224	0.345	0.505	0.602	0.664	0.664	0.664
1989	0.003	0.015	0.04	0.077	0.176	0.243	0.306	0.414	0.567	0.73	0.73	0.73
1990	0.003	0.012	0.039	0.068	0.117	0.203	0.307	0.412	0.542	0.709	0.709	0.709
1991	0.003	0.011	0.036	0.068	0.108	0.187	0.322	0.484	0.652	0.827	0.827	0.827
1992	0.003	0.012	0.04	0.073	0.12	0.178	0.271	0.463	0.734	1.025	1.025	1.025
1993	0.004	0.022	0.072	0.106	0.156	0.206	0.274	0.393	0.651	1.053	1.053	1.053
1994	0.005	0.025	0.081	0.134	0.219	0.287	0.358	0.494	0.835	1.211	1.211	1.211
1995	0.01	0.057	0.188	0.288	0.414	0.499	0.559	0.627	0.947	1.391	1.391	1.391
1996	0.014	0.086	0.236	0.402	0.58	0.604	0.578	0.623	0.824	1.129	1.129	1.129
1997	0.017	0.105	0.264	0.534	0.746	0.692	0.594	0.631	0.824	1.042	1.042	1.042
1998	0.014	0.089	0.156	0.386	0.475	0.436	0.382	0.404	0.51	0.624	0.624	0.624
1999	0.007	0.045	0.106	0.265	0.335	0.306	0.259	0.263	0.32	0.394	0.394	0.394
2000	0.011	0.053	0.084	0.219	0.286	0.249	0.201	0.196	0.231	0.277	0.277	0.277
2001	0.027	0.128	0.157	0.246	0.343	0.3	0.245	0.239	0.279	0.333	0.333	0.333
2002	0.007	0.026	0.069	0.162	0.258	0.284	0.248	0.25	0.304	0.37	0.37	0.37
2003	0.013	0.049	0.082	0.14	0.232	0.277	0.253	0.252	0.309	0.381	0.381	0.381
2004	0.012	0.037	0.088	0.143	0.22	0.289	0.29	0.297	0.356	0.418	0.418	0.418
2005	0.012	0.041	0.091	0.136	0.188	0.281	0.307	0.314	0.365	0.412	0.412	0.412
2006	0.018	0.084	0.153	0.187	0.201	0.287	0.379	0.393	0.446	0.477	0.477	0.477
2007	0.018	0.079	0.221	0.263	0.269	0.32	0.42	0.519	0.582	0.64	0.64	0.64
2008	0.02	0.093	0.22	0.252	0.261	0.342	0.421	0.496	0.545	0.606	0.606	0.606
2009	0.015	0.066	0.17	0.291	0.344	0.481	0.565	0.663	0.708	0.758	0.758	0.758
2010	0.018	0.08	0.208	0.302	0.311	0.362	0.388	0.437	0.547	0.537	0.537	0.537
2011	0.012	0.104	0.184	0.112	0.135	0.221	0.225	0.208	0.238	0.204	0.204	0.204
2012	0.004	0.024	0.096	0.066	0.114	0.203	0.239	0.175	0.159	0.142	0.142	0.142
2013	0.003	0.015	0.045	0.056	0.103	0.18	0.192	0.158	0.141	0.127	0.127	0.127
2014	0.003	0.015	0.044	0.045	0.067	0.109	0.157	0.168	0.15	0.133	0.133	0.133
2015	0.003	0.013	0.024	0.056	0.073	0.086	0.128	0.175	0.188	0.174	0.174	0.174
2016	0.002	0.008	0.015	0.042	0.073	0.099	0.118	0.147	0.166	0.159	0.159	0.159
2017	0.002	0.007	0.014	0.037	0.065	0.09	0.124	0.144	0.161	0.157	0.157	0.157
2018	0.002	0.009	0.013	0.026	0.057	0.092	0.124	0.146	0.153	0.15	0.15	0.15
2019	0.002	0.007	0.017	0.019	0.043	0.082	0.135	0.152	0.157	0.136	0.136	0.136
2020	0.002	0.005	0.016	0.015	0.031	0.069	0.119	0.157	0.143	0.115	0.115	0.115
2021	0.002	0.005	0.013	0.019	0.03	0.067	0.118	0.149	0.145	0.122	0.122	0.122

Table A10.32. Estimated total fishing mortality at age (Model *h2_1.05*; two-stock hypothesis; southern stock). Green shading reflects relative level with darker green indicating higher mortality.

	Age group (years)											
Year	1	2	3	4	5	6	7	8	9	10	11	12
1970	6.94E-05	0.000249	0.00097	0.00357	0.00988	0.0224	0.0405	0.0341	0.0108	0.00941	0.00941	0.00941
1971	0.000102	0.000366	0.00143	0.00526	0.0145	0.0329	0.0595	0.0502	0.0159	0.0138	0.0138	0.0138
1972	5.30E-05	0.00021	0.000882	0.00331	0.00926	0.0195	0.0339	0.0299	0.011	0.00793	0.00793	0.00793
1973	6.75E-05	0.000278	0.0012	0.00452	0.0126	0.0255	0.0433	0.0382	0.0142	0.0093	0.0093	0.0093
1974	0.00011	0.000406	0.00162	0.00602	0.0167	0.0368	0.0654	0.0558	0.0184	0.015	0.015	0.015
1975	0.000141	0.00054	0.00222	0.00827	0.023	0.0491	0.086	0.0742	0.0255	0.0193	0.0193	0.0193
1976	0.000178	0.000686	0.00283	0.0106	0.0294	0.0624	0.109	0.0942	0.0327	0.0243	0.0243	0.0243
1977	0.000177	0.000728	0.00314	0.0119	0.0331	0.067	0.114	0.101	0.0375	0.0246	0.0246	0.0246
1978	0.000366	0.00146	0.00617	0.0232	0.0651	0.136	0.237	0.21	0.0784	0.0562	0.0562	0.0562
1979	0.000396	0.00162	0.00688	0.026	0.0753	0.164	0.298	0.282	0.12	0.0922	0.0922	0.0922
1980	0.000325	0.00141	0.00625	0.0239	0.07	0.148	0.26	0.246	0.112	0.0805	0.0805	0.0805
1981	0.000524	0.00241	0.011	0.0422	0.122	0.243	0.416	0.399	0.184	0.121	0.121	0.121
1982	0.000969	0.00413	0.018	0.0681	0.196	0.41	0.733	0.724	0.344	0.258	0.258	0.258
1983	0.000615	0.0027	0.0119	0.0444	0.13	0.274	0.497	0.531	0.307	0.244	0.244	0.244
1984	0.00117	0.00499	0.0251	0.0843	0.17	0.361	0.687	0.759	0.49	0.425	0.425	0.425
1985	0.00111	0.00467	0.0207	0.0752	0.167	0.32	0.55	0.631	0.478	0.408	0.408	0.408
1986	0.000802	0.00351	0.014	0.0455	0.113	0.222	0.409	0.529	0.449	0.391	0.391	0.391
1987	0.00134	0.00621	0.0274	0.0748	0.132	0.236	0.443	0.606	0.581	0.554	0.554	0.554
1988	0.00147	0.00627	0.0258	0.0801	0.157	0.215	0.338	0.499	0.609	0.685	0.685	0.685
1989	0.00157	0.00611	0.0219	0.0655	0.158	0.22	0.286	0.397	0.563	0.75	0.75	0.75
1990	0.00161	0.00598	0.019	0.0499	0.108	0.179	0.273	0.386	0.537	0.732	0.732	0.732
1991	0.00211	0.00785	0.0259	0.0603	0.109	0.174	0.278	0.431	0.626	0.844	0.844	0.844
1992	0.00253	0.01	0.0334	0.0696	0.126	0.18	0.247	0.394	0.661	1.01	1.01	1.01
1993	0.00309	0.0145	0.06	0.0987	0.154	0.216	0.279	0.36	0.566	1	1	1
1994	0.003	0.0147	0.0536	0.12	0.219	0.305	0.402	0.53	0.822	1.16	1.16	1.16
1995	0.00424	0.0213	0.0912	0.264	0.439	0.574	0.672	0.755	1.04	1.37	1.37	1.37
1996	0.00599	0.0315	0.143	0.396	0.654	0.73	0.737	0.789	0.964	1.15	1.15	1.15
1997	0.0035	0.0233	0.149	0.546	0.818	0.782	0.691	0.726	0.893	1.04	1.04	1.04
1998	0.00178	0.0142	0.113	0.385	0.487	0.453	0.403	0.422	0.518	0.618	0.618	0.618
1999	0.00172	0.012	0.0885	0.249	0.315	0.293	0.254	0.26	0.318	0.395	0.395	0.395
2000	0.00247	0.0134	0.061	0.198	0.259	0.231	0.193	0.194	0.235	0.29	0.29	0.29
2001	0.00483	0.0223	0.0907	0.215	0.313	0.28	0.234	0.237	0.29	0.357	0.357	0.357
2002	0.00285	0.0128	0.0528	0.151	0.241	0.265	0.235	0.246	0.318	0.407	0.407	0.407
2003	0.00419	0.0177	0.0606	0.13	0.217	0.258	0.236	0.241	0.316	0.418	0.418	0.418
2004	0.00517	0.0196	0.0583	0.132	0.207	0.268	0.267	0.281	0.36	0.454	0.454	0.454
2005	0.00825	0.0349	0.0856	0.129	0.18	0.263	0.285	0.297	0.368	0.448	0.448	0.448
2006	0.00934	0.0373	0.103	0.158	0.18	0.268	0.351	0.371	0.444	0.505	0.505	0.505
2007	0.013	0.0502	0.151	0.228	0.245	0.295	0.395	0.489	0.573	0.663	0.663	0.663
2008	0.0184	0.0803	0.166	0.236	0.247	0.328	0.403	0.481	0.55	0.632	0.632	0.632
2009	0.0157	0.0576	0.152	0.269	0.318	0.47	0.572	0.67	0.743	0.812	0.812	0.812
2010	0.0225	0.0875	0.228	0.301	0.297	0.374	0.417	0.466	0.593	0.59	0.59	0.59
2011	0.00442	0.0254	0.0417	0.0652	0.118	0.244	0.278	0.236	0.259	0.227	0.227	0.227
2012	0.00164	0.00785	0.0186	0.0454	0.112	0.209	0.261	0.189	0.172	0.155	0.155	0.155
2013	0.00162	0.0079	0.023	0.0465	0.119	0.192	0.197	0.167	0.155	0.142	0.142	0.142
2014	0.00156	0.00698	0.0187	0.0405	0.0868	0.14	0.169	0.171	0.164	0.152	0.152	0.152
2015	0.00205	0.00589	0.0178	0.0562	0.0835	0.117	0.164	0.19	0.2	0.198	0.198	0.198
2016	0.00158	0.00408	0.0119	0.0395	0.0772	0.117	0.155	0.178	0.185	0.178	0.178	0.178
2017	0.00258	0.00626	0.0123	0.0356	0.0626	0.0963	0.144	0.178	0.191	0.18	0.18	0.18
2018	0.00175	0.00363	0.00698	0.0233	0.0532	0.0852	0.127	0.163	0.187	0.179	0.179	0.179
2019	0.00152	0.00295	0.00516	0.0149	0.0382	0.072	0.118	0.151	0.177	0.165	0.165	0.165
2020	0.0011	0.00186	0.00409	0.0123	0.029	0.0593	0.103	0.141	0.153	0.14	0.14	0.14
2021	0.00225	0.00352	0.00578	0.0135	0.0315	0.0634	0.107	0.144	0.163	0.157	0.157	0.157

Table A10.33. Estimated total fishing mortality at age (Model *h2_1.05*; two-stock hypothesis; far north stock), 1970-2020. Green shading reflects relative level with darker green indicating higher mortality.

Age group (years)

Year	1	2	3	4	5	6	7	8	9	10	11	12
1970	9.30E-05	0.00134	0.00466	0.00121	0.000147	2.53E-05	9.51E-06	9.51E-06	9.51E-06	9.51E-06	9.51E-06	9.51E-06
1971	0.000181	0.00261	0.00908	0.00236	0.000288	4.92E-05	1.85E-05	1.85E-05	1.85E-05	1.85E-05	1.85E-05	1.85E-05
1972	0.000449	0.00645	0.0225	0.00585	0.000712	0.000122	4.59E-05	4.59E-05	4.59E-05	4.59E-05	4.59E-05	4.59E-05
1973	0.000963	0.0138	0.0482	0.0125	0.00153	0.000261	9.84E-05	9.84E-05	9.84E-05	9.84E-05	9.84E-05	9.84E-05
1974	0.00308	0.0443	0.154	0.0401	0.00489	0.000838	0.000315	0.000315	0.000315	0.000315	0.000315	0.000315
1975	0.000959	0.0138	0.048	0.0125	0.00152	0.00026	9.80E-05	9.80E-05	9.80E-05	9.80E-05	9.80E-05	9.80E-05
1976	0.00122	0.0176	0.0613	0.0159	0.00194	0.000332	0.000125	0.000125	0.000125	0.000125	0.000125	0.000125
1977	0.0169	0.242	0.845	0.22	0.0268	0.00458	0.00172	0.00172	0.00172	0.00172	0.00172	0.00172
1978	0.0178	0.255	0.889	0.231	0.0281	0.00482	0.00181	0.00181	0.00181	0.00181	0.00181	0.00181
1979	0.0145	0.208	0.725	0.189	0.023	0.00393	0.00148	0.00148	0.00148	0.00148	0.00148	0.00148
1980	0.0146	0.21	0.73	0.19	0.0231	0.00396	0.00149	0.00149	0.00149	0.00149	0.00149	0.00149
1981	0.02	0.287	1	0.26	0.0317	0.00542	0.00204	0.00204	0.00204	0.00204	0.00204	0.00204
1982	0.00642	0.0923	0.321	0.0836	0.0102	0.00174	0.000656	0.000656	0.000656	0.000656	0.000656	0.000656
1983	0.00373	0.0536	0.187	0.0486	0.00592	0.00101	0.000382	0.000382	0.000382	0.000382	0.000382	0.000382
1984	0.00427	0.0614	0.214	0.0556	0.00678	0.00116	0.000437	0.000437	0.000437	0.000437	0.000437	0.000437
1985	0.00311	0.0446	0.156	0.0404	0.00493	0.000844	0.000318	0.000318	0.000318	0.000318	0.000318	0.000318
1986	0.0017	0.0244	0.0849	0.0221	0.00269	0.000461	0.000173	0.000173	0.000173	0.000173	0.000173	0.000173
1987	0.00192	0.0276	0.0963	0.025	0.00305	0.000522	0.000197	0.000197	0.000197	0.000197	0.000197	0.000197
1988	0.00749	0.108	0.375	0.0974	0.0119	0.00203	0.000765	0.000765	0.000765	0.000765	0.000765	0.000765
1989	0.0062	0.089	0.31	0.0806	0.00983	0.00168	0.000633	0.000633	0.000633	0.000633	0.000633	0.000633
1990	0.0054	0.0777	0.271	0.0703	0.00857	0.00147	0.000552	0.000552	0.000552	0.000552	0.000552	0.000552
1991	0.00443	0.0636	0.222	0.0576	0.00702	0.0012	0.000453	0.000453	0.000453	0.000453	0.000453	0.000453
1992	0.00263	0.0377	0.131	0.0342	0.00416	0.000713	0.000268	0.000268	0.000268	0.000268	0.000268	0.000268
1993	0.00452	0.0649	0.226	0.0588	0.00716	0.00123	0.000462	0.000462	0.000462	0.000462	0.000462	0.000462
1994	0.00752	0.108	0.377	0.0979	0.0119	0.00204	0.000769	0.000769	0.000769	0.000769	0.000769	0.000769
1995	0.0359	0.516	1.8	0.468	0.057	0.00976	0.00367	0.00367	0.00367	0.00367	0.00367	0.00367
1996	0.0622	0.893	3.11	0.809	0.0986	0.0169	0.00635	0.00635	0.00635	0.00635	0.00635	0.00635
1997	0.116	1.67	5.81	1.51	0.184	0.0315	0.0119	0.0119	0.0119	0.0119	0.0119	0.0119
1998	0.103	1.49	5.18	1.35	0.164	0.0281	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106
1999	0.0293	0.421	1.47	0.381	0.0464	0.00795	0.00299	0.00299	0.00299	0.00299	0.00299	0.00299
2000	0.021	0.302	1.05	0.274	0.0334	0.00571	0.00215	0.00215	0.00215	0.00215	0.00215	0.00215
2001	0.068	0.977	3.41	0.885	0.108	0.0185	0.00695	0.00695	0.00695	0.00695	0.00695	0.00695
2002	0.00962	0.239	0.395	0.11	0.0126	0.00246	0.000975	0.000975	0.000975	0.000975	0.000975	0.000975
2003	0.0131	0.326	0.539	0.15	0.0172	0.00335	0.00133	0.00133	0.00133	0.00133	0.00133	0.00133
2004	0.0107	0.267	0.44	0.122	0.0141	0.00274	0.00109	0.00109	0.00109	0.00109	0.00109	0.00109
2005	0.00695	0.173	0.285	0.0793	0.00912	0.00178	0.000704	0.000704	0.000704	0.000704	0.000704	0.000704
2006	0.018	0.446	0.737	0.205	0.0236	0.00459	0.00182	0.00182	0.00182	0.00182	0.00182	0.00182
2007	0.015	0.374	0.618	0.172	0.0197	0.00385	0.00152	0.00152	0.00152	0.00152	0.00152	0.00152
2008	0.0167	0.415	0.686	0.19	0.0219	0.00427	0.00169	0.00169	0.00169	0.00169	0.00169	0.00169
2009	0.02	0.497	0.821	0.228	0.0262	0.00511	0.00202	0.00202	0.00202	0.00202	0.00202	0.00202
2010	0.00504	0.125	0.207	0.0575	0.00662	0.00129	0.000511	0.000511	0.000511	0.000511	0.000511	0.000511
2011	0.0253	0.628	1.04	0.288	0.0332	0.00646	0.00256	0.00256	0.00256	0.00256	0.00256	0.00256
2012	0.0118	0.293	0.484	0.134	0.0155	0.00301	0.00119	0.00119	0.00119	0.00119	0.00119	0.00119
2013	0.00723	0.18	0.297	0.0824	0.00948	0.00185	0.000732	0.000732	0.000732	0.000732	0.000732	0.000732
2014	0.00756	0.188	0.31	0.0862	0.00992	0.00193	0.000766	0.000766	0.000766	0.000766	0.000766	0.000766
2015	0.0032	0.0796	0.131	0.0365	0.0042	0.000818	0.000324	0.000324	0.000324	0.000324	0.000324	0.000324
2016	0.00152	0.0378	0.0624	0.0173	0.002	0.000389	0.000154	0.000154	0.000154	0.000154	0.000154	0.000154
2017	0.000747	0.0186	0.0307	0.00852	0.00098	0.000191	7.57E-05	7.57E-05	7.57E-05	7.57E-05	7.57E-05	7.57E-05
2018	0.00216	0.0537	0.0887	0.0246	0.00284	0.000553	0.000219	0.000219	0.000219	0.000219	0.000219	0.000219
2019	0.00238	0.0591	0.0976	0.0271	0.00312	0.000608	0.000241	0.000241	0.000241	0.000241	0.000241	0.000241
2020	0.00238	0.0591	0.0975	0.0271	0.00312	0.000607	0.000241	0.000241	0.000241	0.000241	0.000241	0.000241
2021	0.00409	0.102	0.168	0.0467	0.00537	0.00105	0.000414	0.000414	0.000414	0.000414	0.000414	0.000414

Table A10.34. Summary of results for Model *h1_1.05* (single-stock hypothesis). Note that MSY values are a function of time-varying selectivity and average weight.

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	11383	11019	0.01	0.13	4644
1971	168	10979	9756	0.02	0.14	4621
1972	111	10731	9357	0.01	0.13	4498
1973	164	10521	9003	0.01	0.13	4369
1974	323	10249	9955	0.02	0.12	4343
1975	299	9984	13864	0.03	0.13	4509
1976	396	9822	18532	0.03	0.13	4480
1977	848	9808	19747	0.05	0.11	4443
1978	1025	9810	21792	0.09	0.13	4405
1979	1302	9832	22832	0.11	0.13	4762
1980	1316	10069	21983	0.1	0.13	4686
1981	1945	9982	30614	0.16	0.13	4725
1982	2372	9192	35934	0.27	0.14	4769
1983	1870	9344	27505	0.21	0.13	5340
1984	2687	9434	51043	0.32	0.13	5415
1985	2371	10077	57807	0.28	0.13	5380
1986	2073	11772	28970	0.24	0.12	5975
1987	2680	13297	27441	0.31	0.12	6064
1988	3246	13828	32856	0.33	0.14	5570
1989	3582	13502	29733	0.34	0.14	5675
1990	3715	13136	29695	0.32	0.16	5378
1991	3778	12537	20923	0.36	0.19	4870
1992	3362	11763	21524	0.41	0.19	5233
1993	3370	10743	14913	0.42	0.16	5572
1994	4275	9074	13725	0.51	0.16	5311
1995	4955	6666	18688	0.65	0.13	5547
1996	4379	4740	20185	0.61	0.12	5429
1997	3597	3564	26330	0.63	0.12	5340
1998	2026	3573	26639	0.39	0.11	5498
1999	1423	4278	32002	0.26	0.11	5556
2000	1540	5312	31569	0.2	0.11	5311
2001	2528	6095	21827	0.25	0.11	5289
2002	1750	6770	14545	0.23	0.12	5521
2003	1797	7078	8584	0.23	0.11	5572
2004	1934	6751	8705	0.25	0.12	5449
2005	1755	6056	6595	0.25	0.12	5297
2006	2020	5061	7019	0.3	0.13	5045
2007	1997	3857	4797	0.38	0.13	5030
2008	1473	2926	4757	0.37	0.13	5071
2009	1283	2076	6740	0.46	0.13	5162
2010	727	1703	9306	0.36	0.11	5648
2011	635	1782	5781	0.17	0.12	4814
2012	455	2038	9121	0.13	0.12	4926
2013	353	2348	7246	0.11	0.12	5041
2014	411	2719	10458	0.1	0.13	5063
2015	394	3107	9661	0.11	0.14	5034
2016	389	3567	15190	0.1	0.14	5201
2017	405	4190	36776	0.09	0.13	5346
2018	526	5264	28424	0.09	0.13	5476
2019	632	6956	16140	0.09	0.15	5034
2020	707	8740	12496	0.08	0.15	4960
2021	813	9960	16293	0.08	0.13	5495

Table A10.35. Summary of results for Model *h2_1.05* (two-stock hypothesis; southern stock). Note that MSY values are a function of time-varying selectivity and average weight.

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	9924	10437	0.01	0.13	3807
1971	168	9679	9216	0.02	0.13	3806
1972	111	9564	8809	0.01	0.13	3795
1973	164	9471	8558	0.01	0.13	3774
1974	323	9322	9284	0.02	0.13	3799
1975	299	9148	12366	0.03	0.13	3791
1976	396	9041	17004	0.03	0.13	3796
1977	848	9157	18633	0.04	0.13	3745
1978	1025	9295	19014	0.08	0.13	3818
1979	1302	9419	21003	0.1	0.13	4167
1980	1316	9739	21353	0.09	0.13	4087
1981	1945	9753	30956	0.15	0.13	4069
1982	2372	9036	31377	0.27	0.14	3899
1983	1870	9203	26629	0.21	0.13	4369
1984	2687	9257	58782	0.32	0.13	4441
1985	2371	9990	67418	0.29	0.13	4376
1986	2073	12063	26892	0.25	0.12	4828
1987	2680	14041	15593	0.31	0.12	4892
1988	3246	14632	19689	0.33	0.14	4568
1989	3582	13824	27845	0.33	0.14	4731
1990	3715	12815	28406	0.31	0.16	4527
1991	3778	11833	22862	0.35	0.19	4024
1992	3362	10950	18173	0.4	0.18	4282
1993	3370	9957	16177	0.4	0.16	4526
1994	4275	8310	17030	0.5	0.16	4319
1995	4955	6121	18541	0.67	0.13	4569
1996	4379	4469	21059	0.66	0.12	4423
1997	3597	3569	24216	0.65	0.12	4381
1998	2026	3754	23558	0.39	0.11	4488
1999	1423	4511	27549	0.25	0.11	4529
2000	1540	5482	25718	0.19	0.11	4375
2001	2528	6236	22240	0.23	0.11	4486
2002	1750	6887	11521	0.23	0.12	4537
2003	1797	7199	8648	0.23	0.11	4648
2004	1934	6868	6422	0.25	0.12	4565
2005	1755	6120	3015	0.25	0.12	4370
2006	2020	5042	5074	0.29	0.13	4350
2007	1997	3746	5919	0.37	0.13	4338
2008	1473	2764	5581	0.37	0.12	4321
2009	1283	1941	4130	0.48	0.13	4275
2010	727	1568	4524	0.38	0.11	4597
2011	635	1581	5686	0.16	0.12	4356
2012	455	1728	8737	0.12	0.12	4375
2013	353	1973	9683	0.11	0.12	4288
2014	411	2376	11292	0.1	0.13	4174
2015	394	2874	11783	0.12	0.14	4047
2016	389	3468	15995	0.11	0.14	4186
2017	405	4182	20204	0.11	0.14	4317
2018	526	5073	12273	0.1	0.13	4542
2019	632	6071	14348	0.09	0.15	4279
2020	707	6953	12695	0.08	0.15	4223
2021	813	7621	16635	0.08	0.13	4798

Table A10.36. Summary of results for Model *h2_1.05* (two-stock hypothesis; far north stock). Note that MSY values are a function of time-varying selectivity and average weight.

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	5361	4013	0	0.09	1588
1971	168	5350	4014	0	0.09	1588
1972	111	5342	4014	0	0.09	1601
1973	164	5319	4012	0.01	0.09	1591
1974	323	5230	3997	0.02	0.09	1589
1975	299	5161	3961	0.01	0.09	1594
1976	396	5115	3906	0.01	0.09	1581
1977	848	4733	3702	0.11	0.09	1593
1978	1025	4233	5532	0.12	0.09	1595
1979	1302	3830	3819	0.1	0.09	1588
1980	1316	3485	3386	0.1	0.09	1587
1981	1945	3049	3766	0.13	0.09	1581
1982	2372	2811	5719	0.04	0.09	1583
1983	1870	2833	3640	0.03	0.09	1572
1984	2687	3021	2948	0.03	0.09	1579
1985	2371	3138	2223	0.02	0.09	1584
1986	2073	3222	3611	0.01	0.09	1582
1987	2680	3273	5552	0.01	0.09	1590
1988	3246	3343	9408	0.05	0.09	1585
1989	3582	3601	4979	0.04	0.09	1582
1990	3715	4027	4781	0.04	0.09	1581
1991	3778	4253	2375	0.03	0.09	1583
1992	3362	4420	3819	0.02	0.09	1583
1993	3370	4376	2539	0.03	0.09	1587
1994	4275	4230	2088	0.05	0.09	1594
1995	4955	3667	4167	0.24	0.09	1586
1996	4379	3075	4678	0.42	0.09	1586
1997	3597	2485	4348	0.78	0.09	1574
1998	2026	1989	3504	0.7	0.09	1578
1999	1423	1633	3824	0.2	0.09	589
2000	1540	1397	7057	0.14	0.09	592
2001	2528	1074	1477	0.46	0.09	592
2002	1750	1003	3853	0.06	0.09	599
2003	1797	975	999	0.09	0.09	596
2004	1934	1023	1674	0.07	0.09	597
2005	1755	1025	4057	0.05	0.09	599
2006	2020	1065	2028	0.12	0.09	599
2007	1997	1109	592	0.1	0.09	598
2008	1473	1053	280	0.11	0.09	599
2009	1283	944	1300	0.13	0.09	598
2010	727	870	4726	0.03	0.09	596
2011	635	858	1084	0.17	0.09	606
2012	455	883	1603	0.08	0.09	604
2013	353	879	414	0.05	0.09	604
2014	411	891	1220	0.05	0.09	604
2015	394	876	955	0.02	0.09	603
2016	389	919	1590	0.01	0.09	603
2017	405	979	6743	0.01	0.09	603
2018	526	1236	7115	0.01	0.09	603
2019	632	1931	2564	0.02	0.09	603
2020	707	2638	1200	0.02	0.09	603
2021	813	2936	2054	0.03	0.09	603

Table A10.37. Summary results for the short, medium and long-term predictions for Model *h1_1.05.ls* (single-stock hypothesis, low steepness, short timeseries). Note that "B" in all cases represents thousands of tonnes of spawning stock biomass, "P" represents probability as a percentage and B_{MSY} is taken to be 5.5 million tonnes of spawning biomass in all cases.

F	B_{2023}	$P(B_{2023}>B_{MSY})$	B_{2027}	$P(B_{2027}>B_{MSY})$	B_{2031}	$P(B_{2031}>B_{MSY})$	Catch 2022 (kt)	Catch 2023 (kt)
0	12675	100	15884	100	15594	100	0	0
0.75 × F_{2021}	10191	100	7669	96	5925	63	1654	1911
F_{2021}	11502	100	11282	100	9654	99	748	941
1.25 × F_{2021}	11145	100	10156	100	8404	95	987	1214
F_{MSY}	10805	100	9184	99	7390	87	1220	1469

Table A10.38. Summary results for the short, medium and long-term predictions for Model *h2_1.05.ls* (two-stock hypothesis). Note that "B" in all cases represents thousands of tonnes of spawning stock biomass, "P" represents probability as a percentage, and B_{MSY} is estimated dynamically within the model.

Southern Stock:

F	B_{2023}	$P(B_{2023}>B_{MSY})$	B_{2027}	$P(B_{2027}>B_{MSY})$	B_{2031}	$P(B_{2031}>B_{MSY})$	Catch 2022 (kt)	Catch 2023 (kt)
0	10702	100	13425	100	13267	100	0	0
0.75 × F_{2021}	9674	100	9533	100	8106	100	631	763
F_{2021}	9367	100	8610	100	7072	100	830	978
1.25 × F_{2021}	9075	100	7823	100	6247	100	1023	1175
F_{MSY}	8722	100	6977	100	5418	100	1264	1404

Far North Stock:

F	B_{2023}	$P(B_{2023}>B_{MSY})$	B_{2027}	$P(B_{2027}>B_{MSY})$	B_{2031}	$P(B_{2031}>B_{MSY})$	Catch 2022 (kt)	Catch 2023 (kt)
0	3101	99	2746	98	2371	91	0	0
0.75 × F_{2021}	3014	99	2441	94	1949	76	53	55
F_{2021}	2987	98	2353	92	1830	68	70	70
1.25 × F_{2021}	2962	98	2271	90	1719	59	87	85
F_{MSY}	2798	98	1806	69	1108	2	202	164

9. Figures

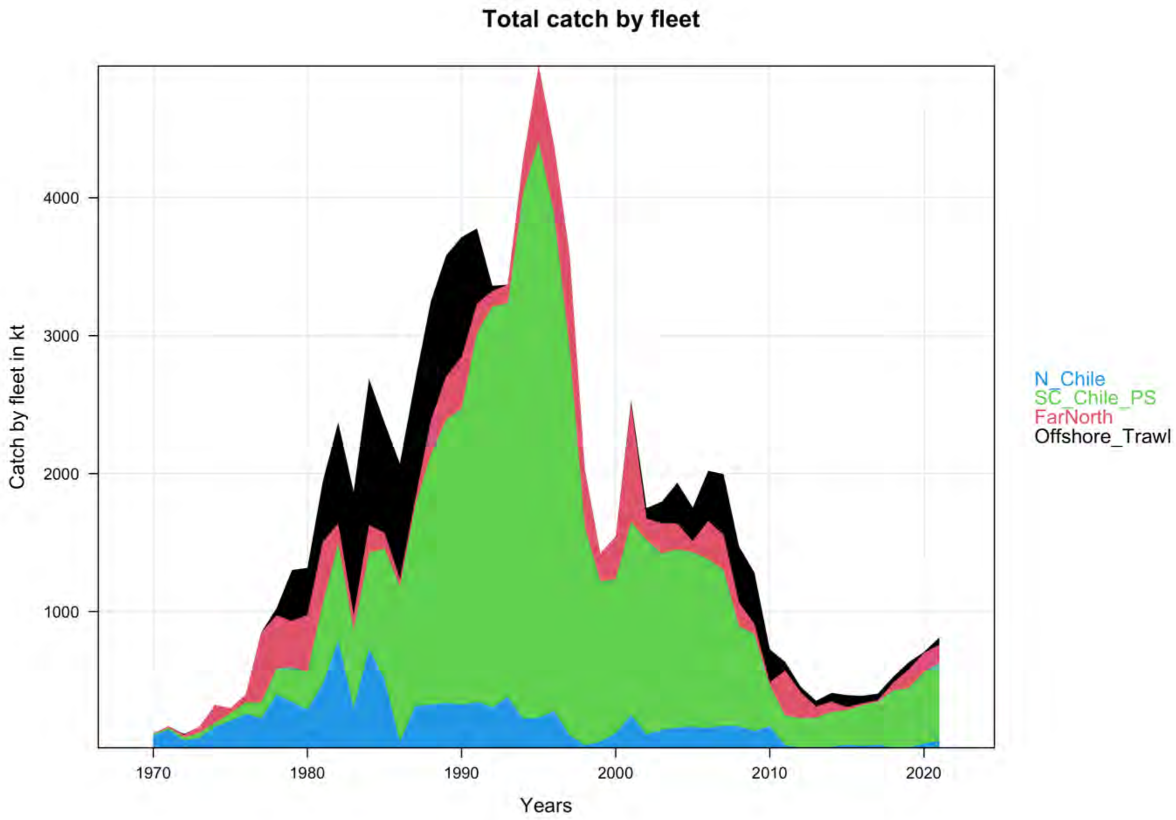


Figure A10.1. Catch of Jack mackerel by fleet. Blue is the northern Chilean fleet, green is the south-central Chilean fleet, red is the far north fleet, and black is the offshore trawl fleet.

Figure *A10.2.Years and types of information used in the JJM assessment models.*

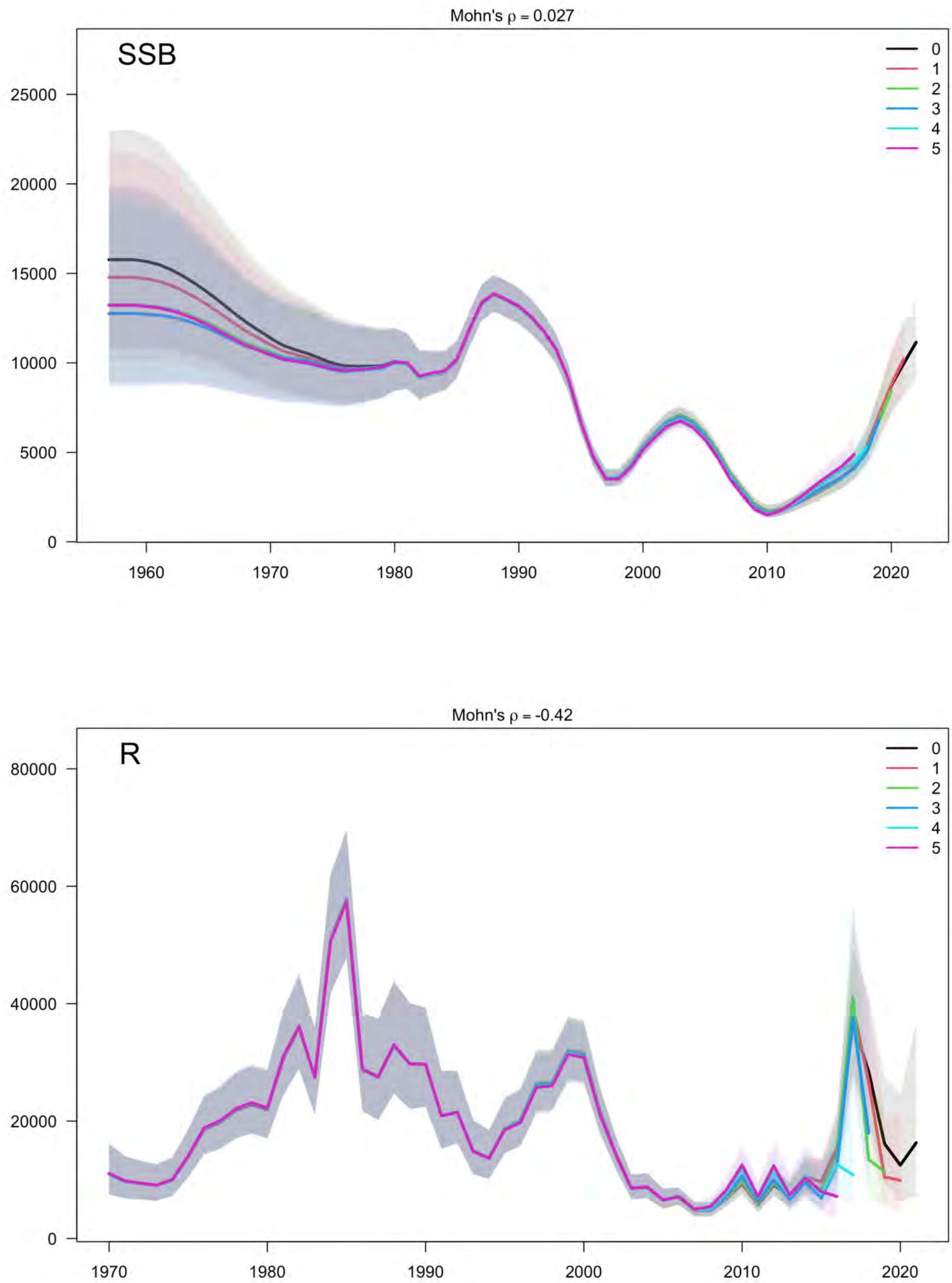


Figure A10.3. Model retrospective of spawning biomass (top) and recruitment (bottom) from 5 separate model runs, based on Model *h1_1.05* (single-stock hypothesis).

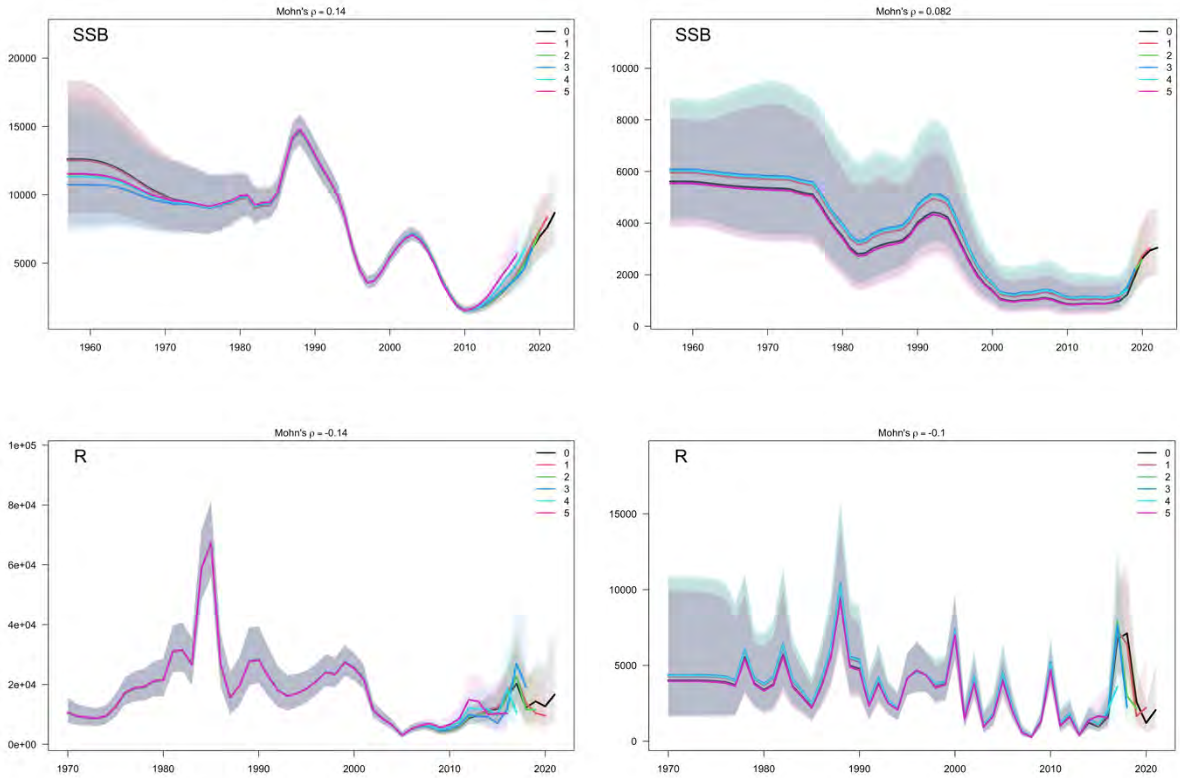


Figure A10.4. Model retrospective of spawning biomass (top) and recruitment (bottom) from 5 separate model runs, based on Model *h2_1.05* (two-stock hypothesis). The southern stock is represented on the left, while the far north stock is represented on the right.

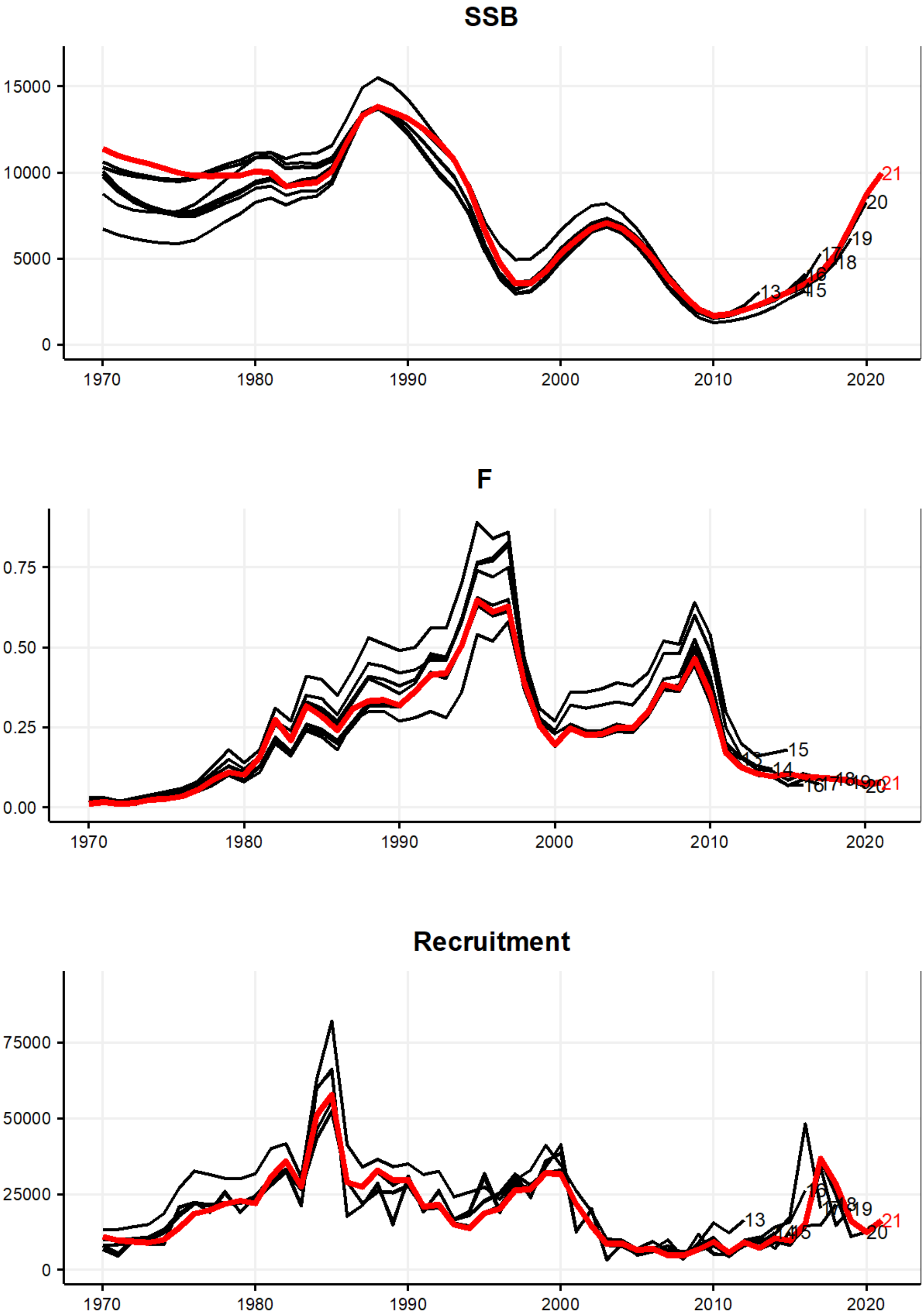


Figure A10.5. Historical retrospective of spawning stock biomass, fishing mortality, and recruitment estimated from Model *h1_1.05* (single-stock hypothesis), as estimated and used for advice from SPFRMO Scientific Committees 2013-2021.

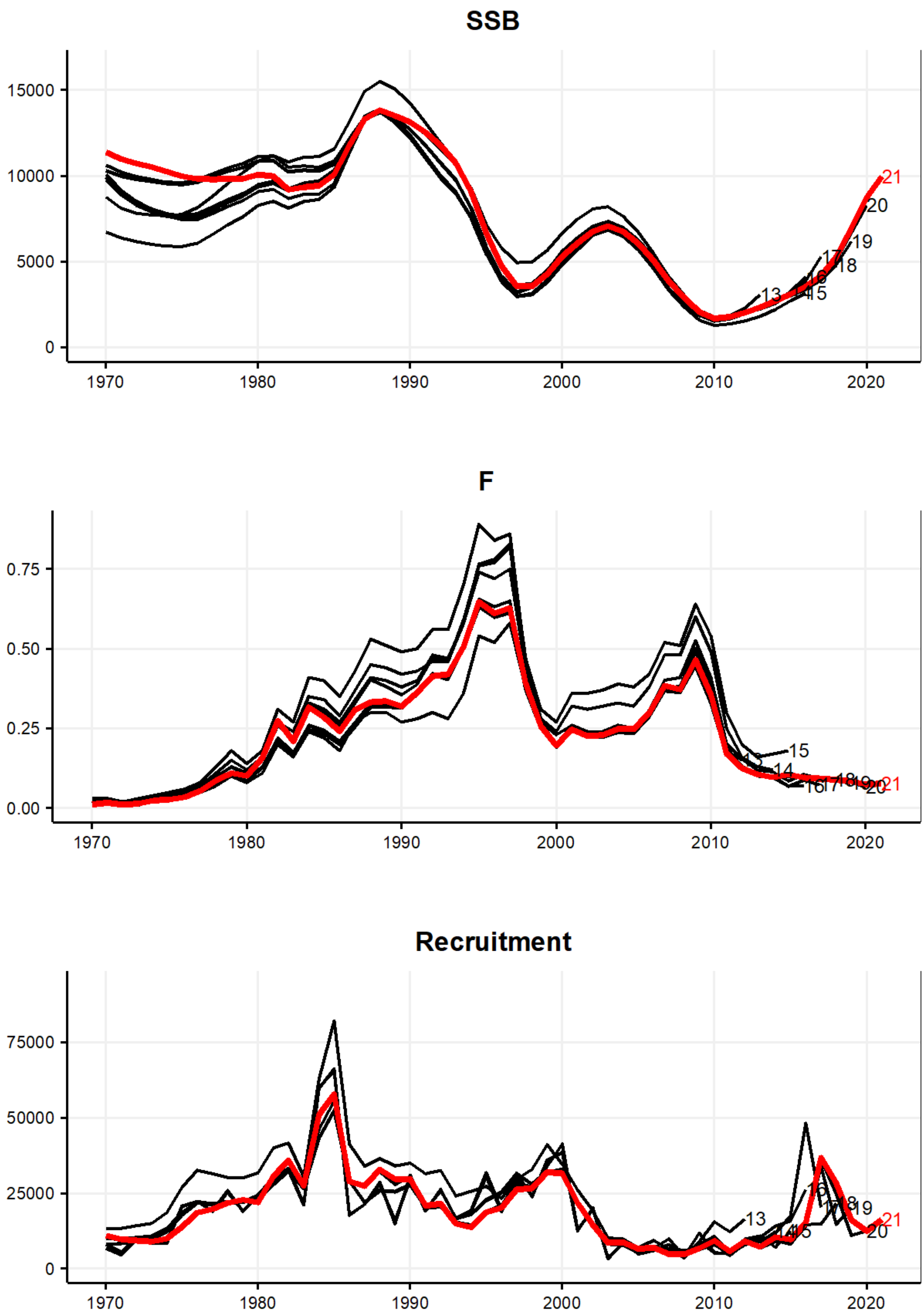


Figure A10.6. Historical retrospective of management reference points estimated from Model *h1_1.05* (single-stock hypothesis), as estimated and used for advice from past (and present) SPRFMO scientific committees. It is to be noted that the B_{MSY} in this figure is dynamically estimated within the model, and hence is not fixed at the provisional 5.5 million tonnes.

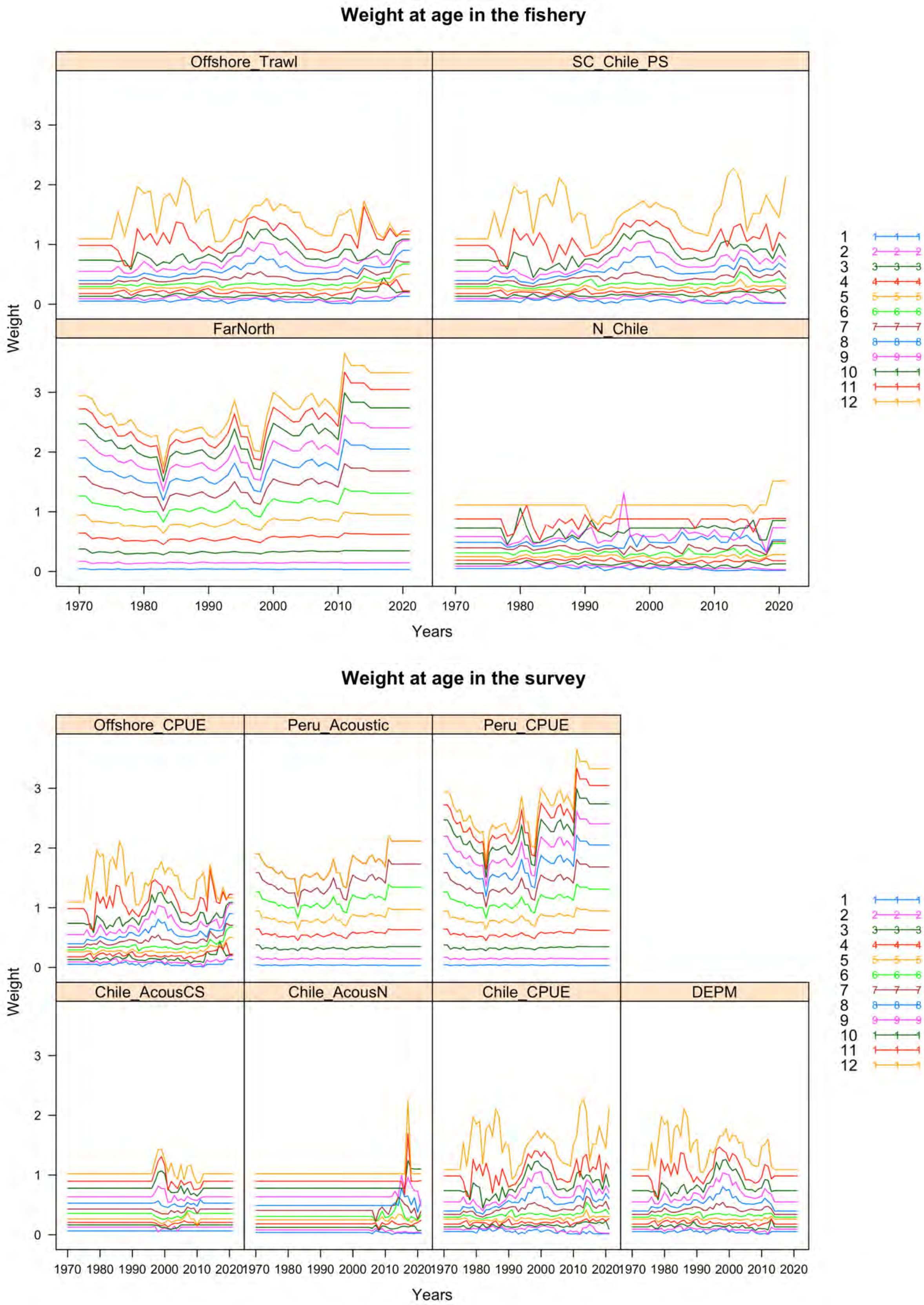


Figure A10.7. Mean weights-at-age (kg) over time used for all data types in the JJM models. Each line represents an age from 1 to 12.

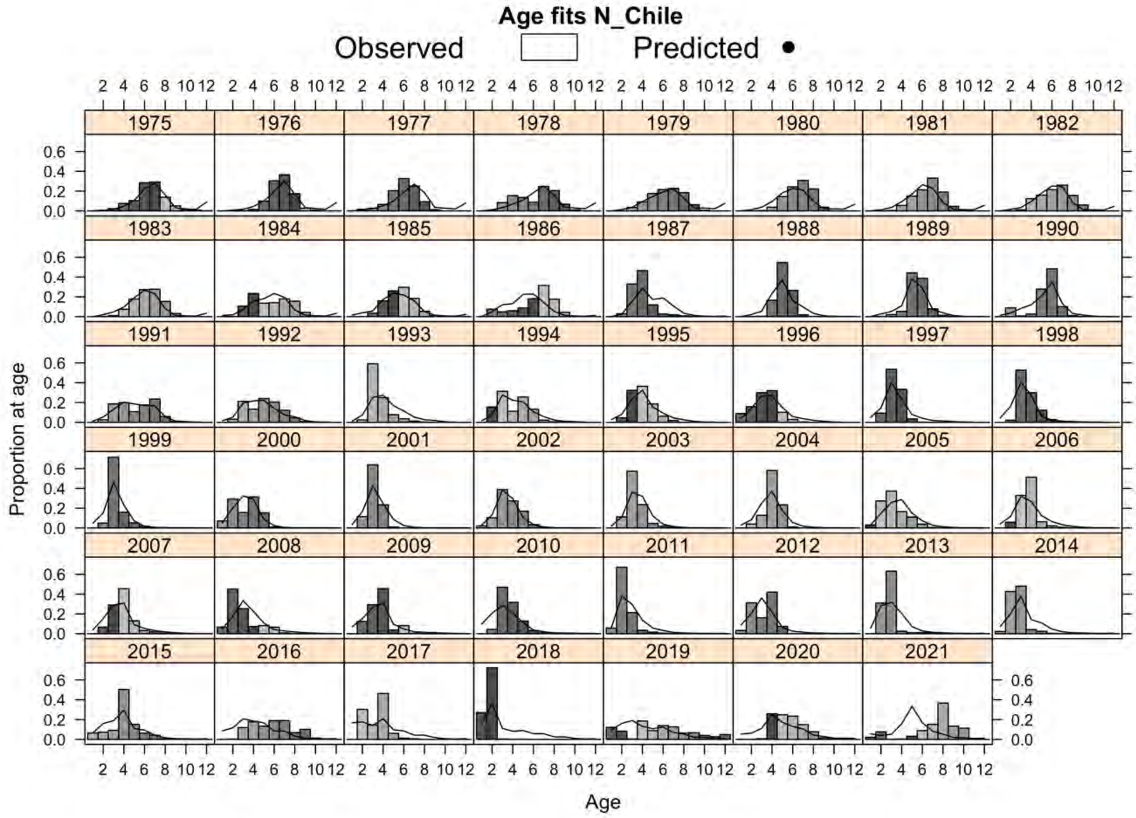


Figure A10.8. Model *h1_1.05* (single-stock hypothesis) fit to the age compositions for the Chilean northern zone fishery (Fleet 1). Bars represent the observed data and lines represent the model predictions.

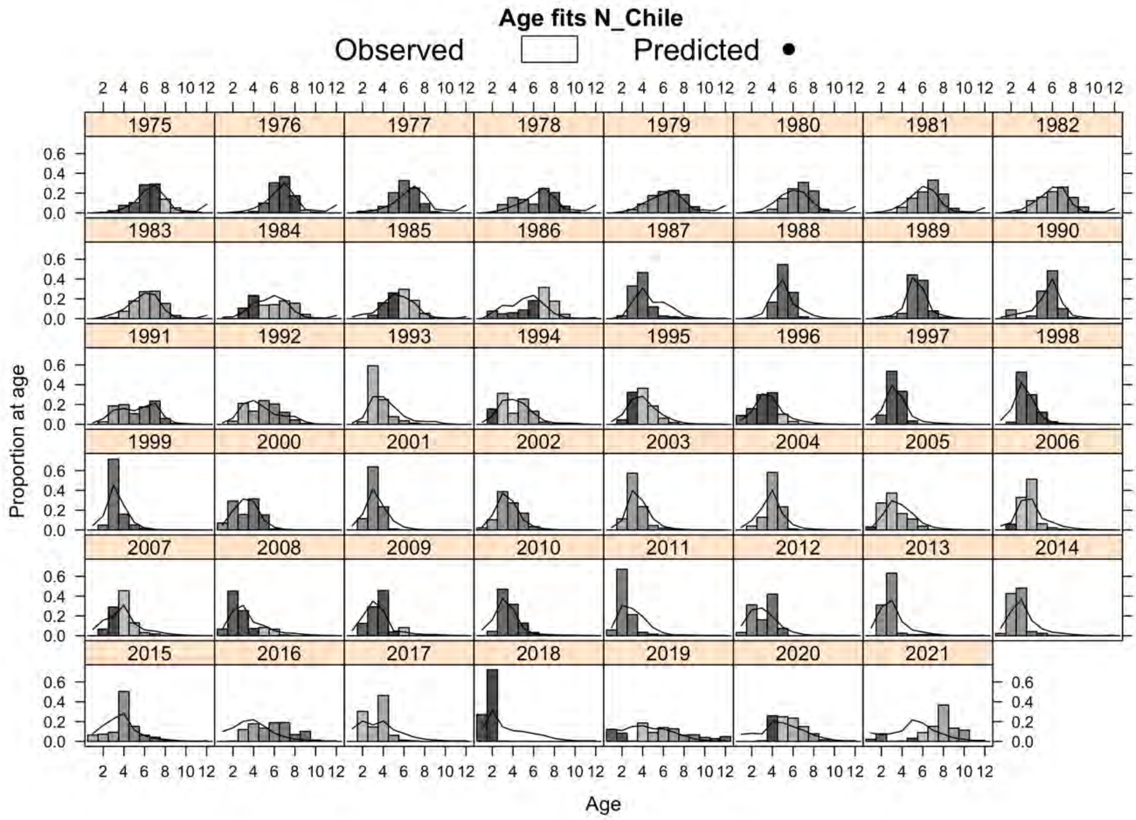


Figure A10.9. Model *h2_1.05* (two-stock hypothesis) fit to the age compositions for the Chilean northern zone fishery (Fleet 1). Bars represent the observed data and lines represent the model predictions.

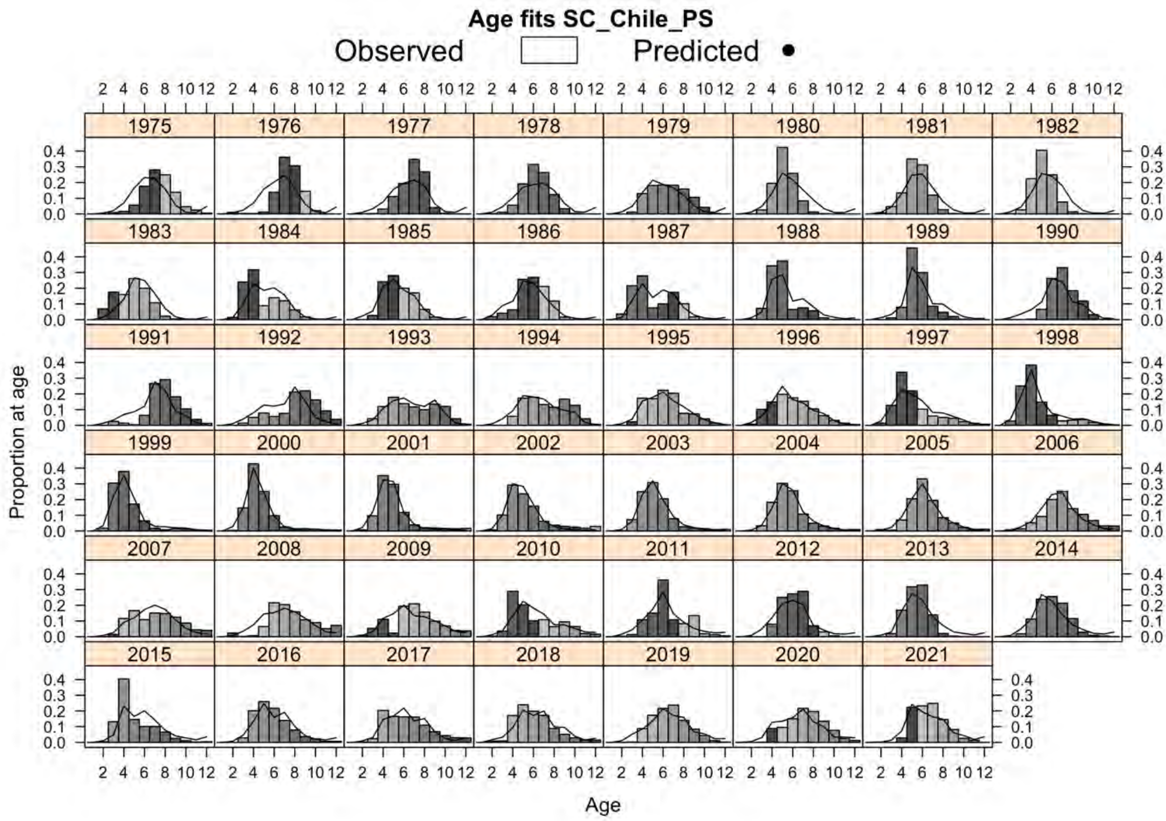


Figure A10.10. Model *h1_1.05* (single-stock hypothesis) fit to the age compositions for the South-Central Chilean purse seine fishery (Fleet 2). Bars represent the observed data and lines represent the model predictions.

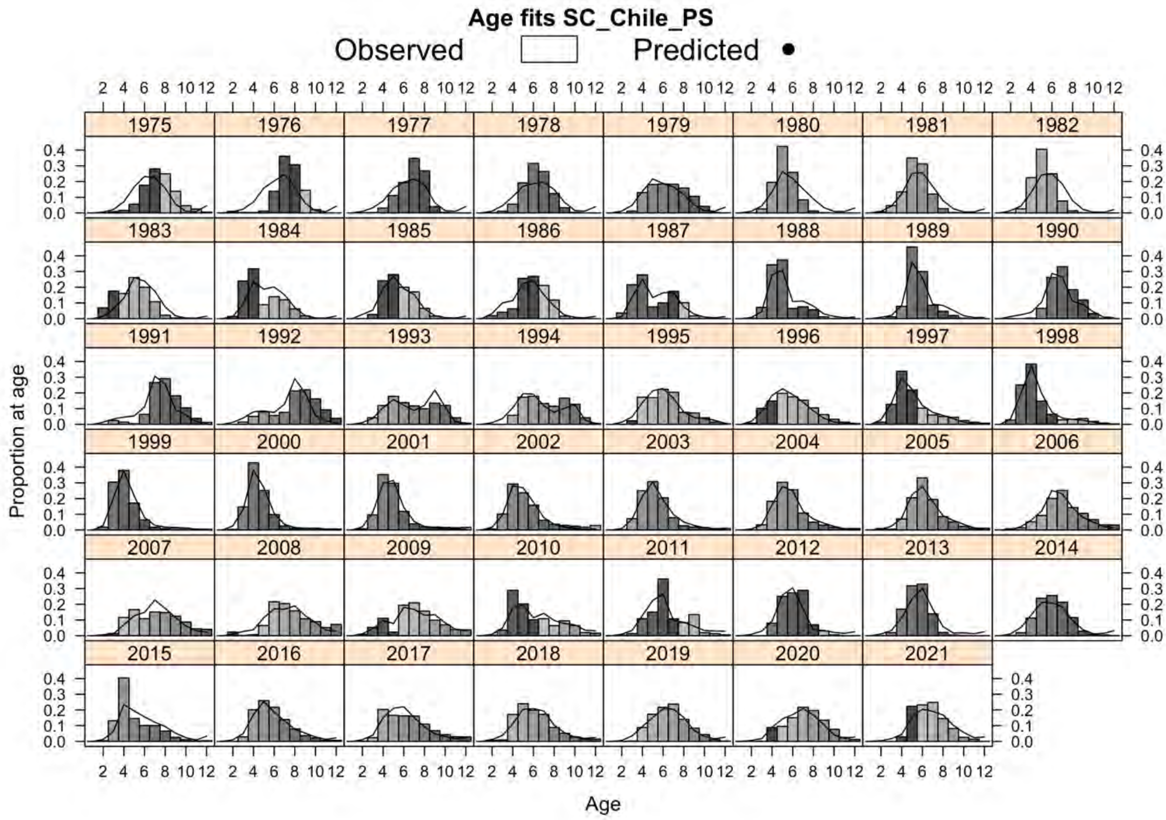


Figure A10.11. Model *h2_1.05* (two-stock hypothesis) fit to the age compositions for the South-Central Chilean purse seine fishery (Fleet 2). Bars represent the observed data and lines represent the model predictions.

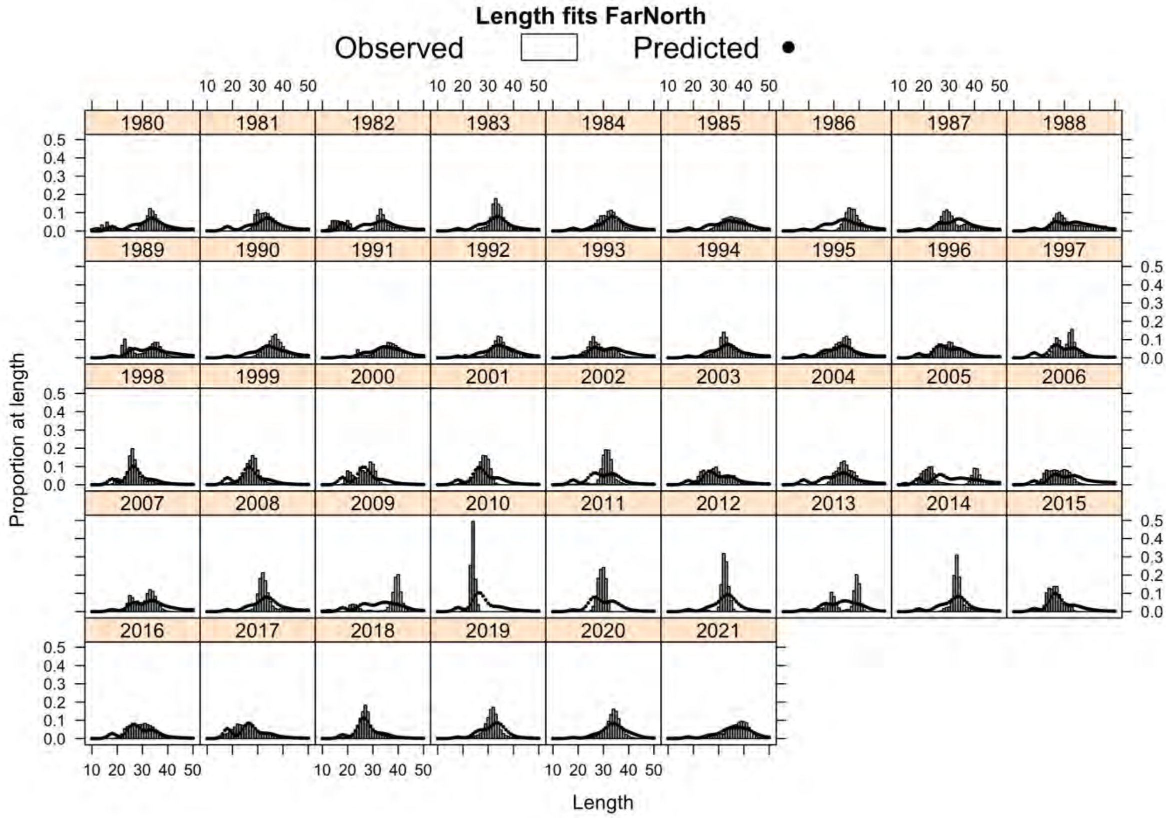


Figure A10.12. Model *h1_1.05* (single-stock hypothesis) fit to the length compositions for the far north fishery (Fleet 3). Bars represent the observed data and lines represent the model predictions.

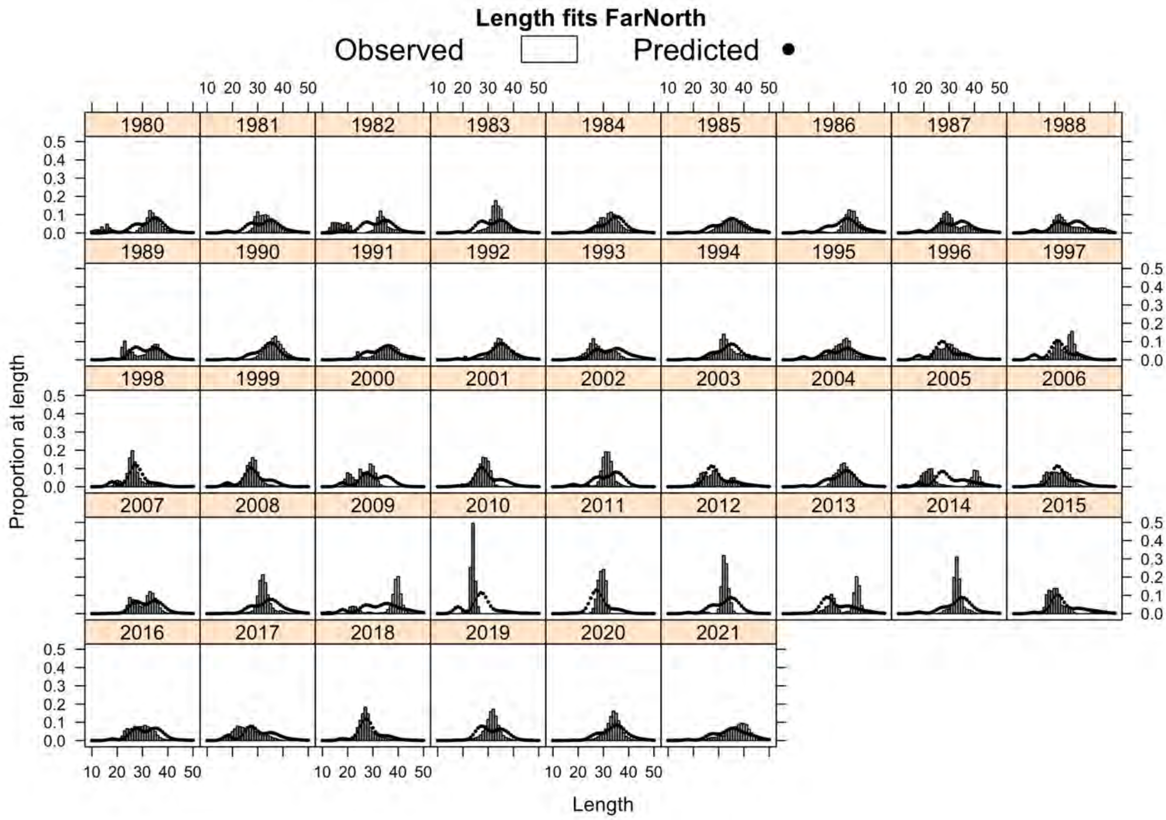


Figure A10.13. Model h2_*1.05* (two-stock hypothesis) fit to the length compositions for the far north fishery (Fleet 3). Bars represent the observed data and lines represent the model predictions.

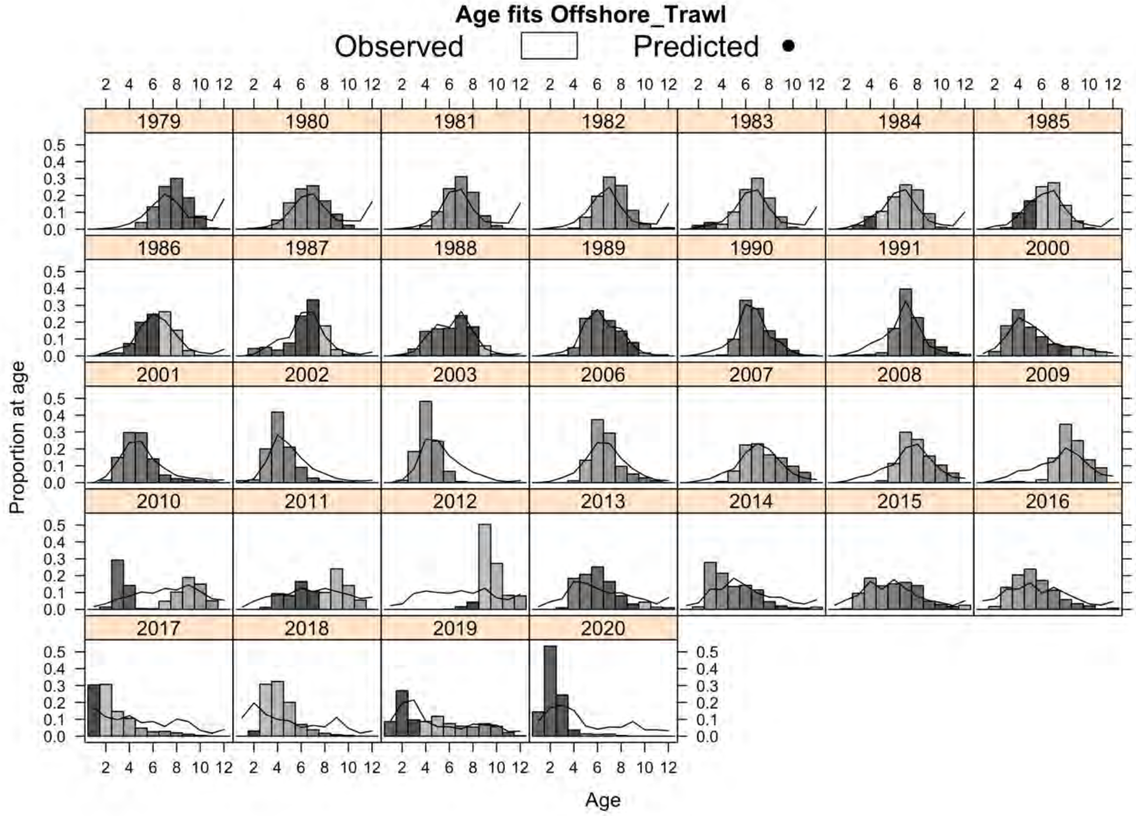


Figure A10.14. Model *h1_1.05* (single-stock hypothesis) fit to the age compositions for the offshore trawl fishery (Fleet 4). Bars represent the observed data and lines represent the model predictions.

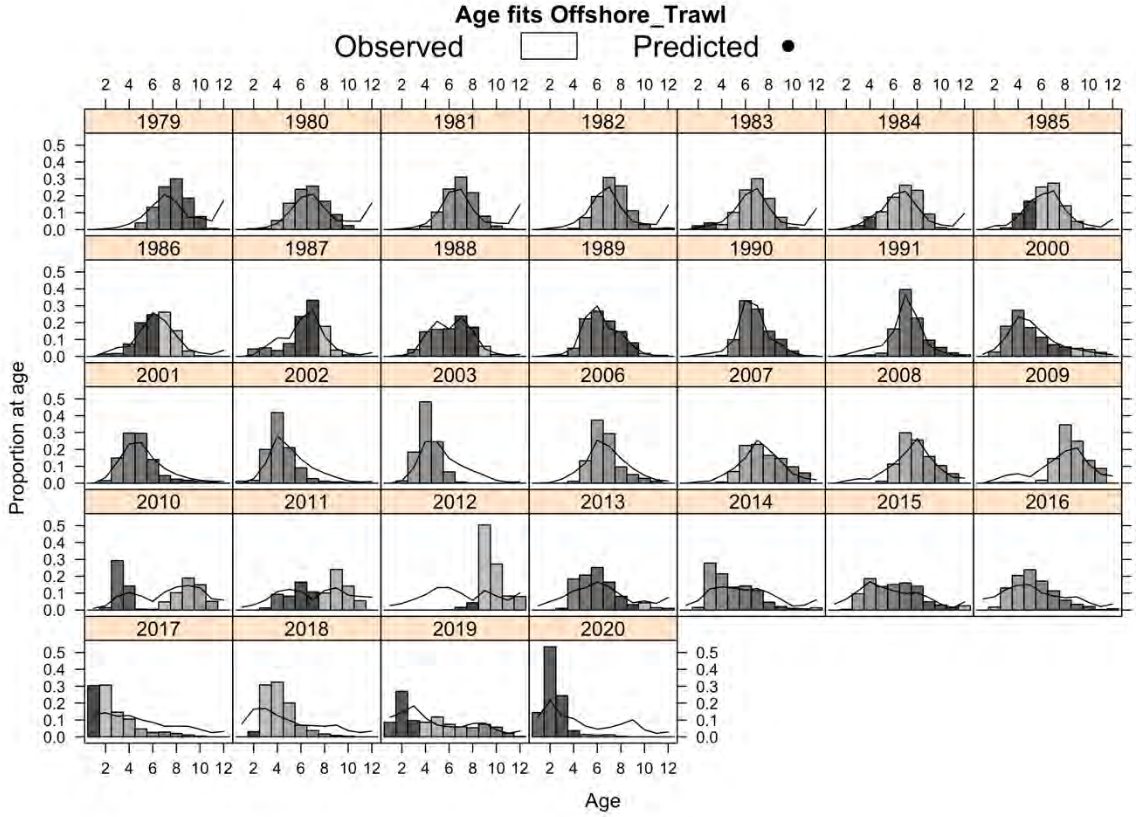


Figure A10.15. Model *h2_1.05* (two-stock hypothesis) fit to the age compositions for the offshore trawl fishery (Fleet 4). Bars represent the observed data and lines represent the model predictions.

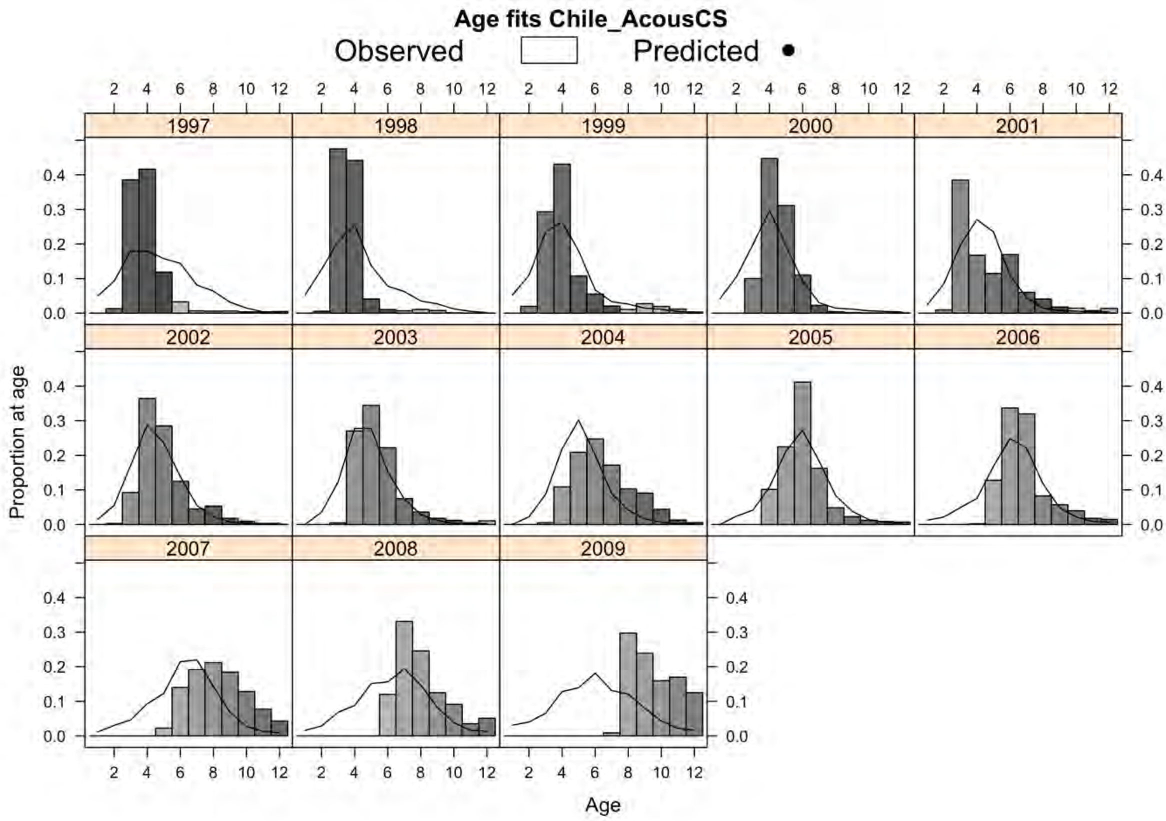


Figure A10.16. Model *h1_1.05* (single-stock hypothesis) fit to the age compositions for the South-Central Acoustic survey. Bars represent the observed data and lines represent the model predictions.

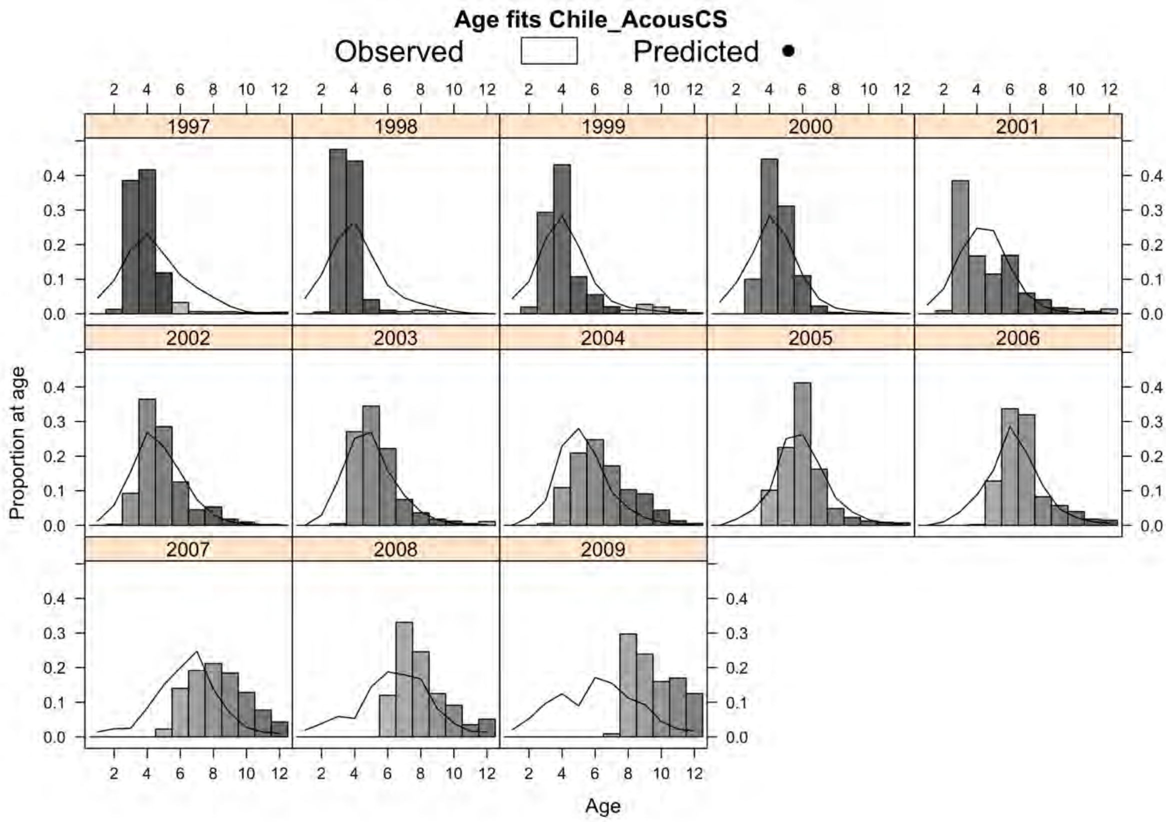


Figure A10.17. Model *h2_1.05* (two-stock hypothesis) fit to the age compositions for the South-Central Acoustic survey. Bars represent the observed data and lines represent the model predictions.

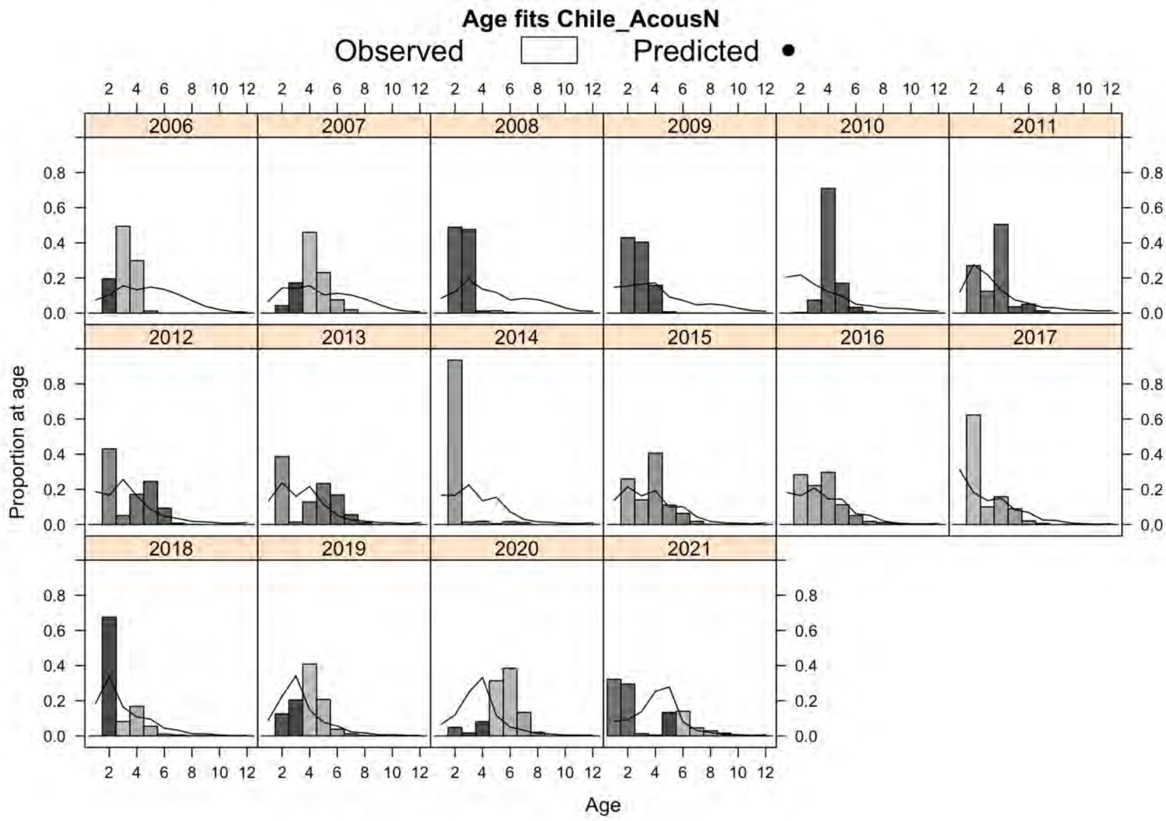


Figure A10.18. Model *h1_1.05* (single-stock hypothesis) fit to the age compositions for the North Chilean acoustic survey. Bars represent the observed data and lines represent the model predictions.

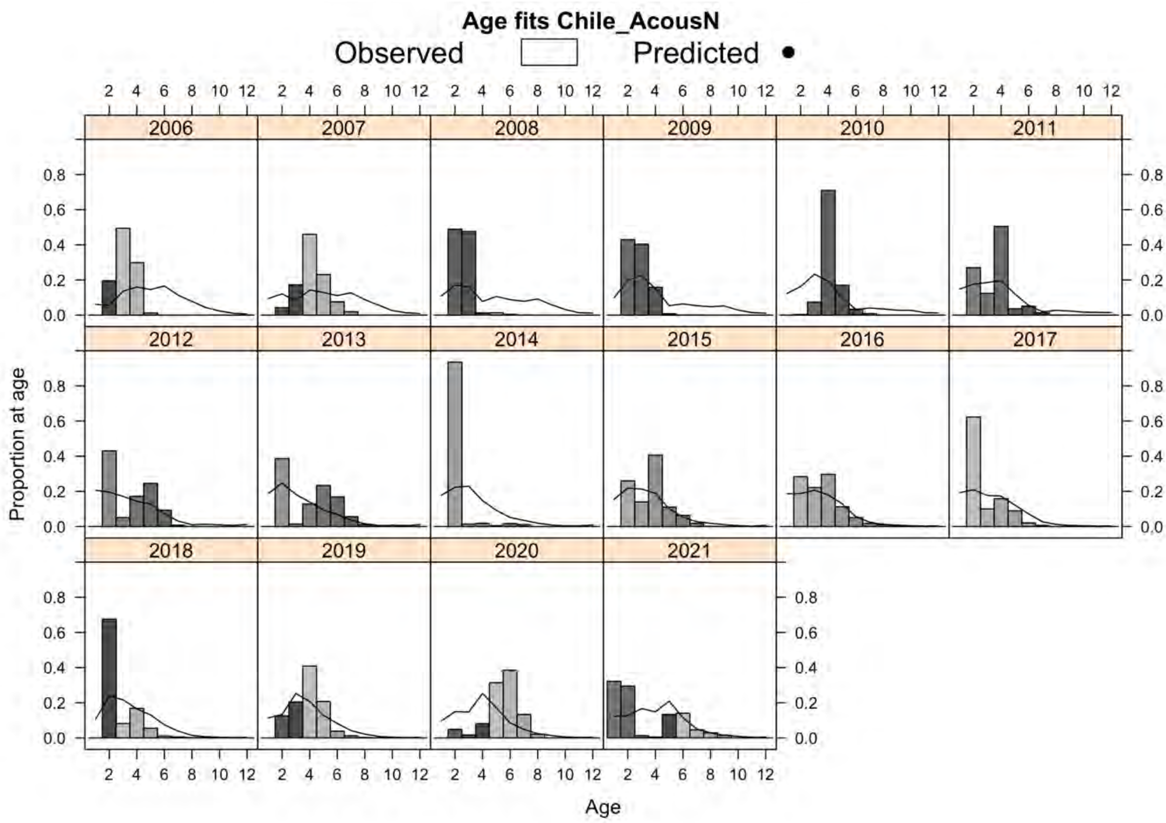


Figure A10.19. Model *h2_1.05* (two-stock hypothesis) fit to the age compositions for the North Chilean acoustic survey. Bars represent the observed data and lines represent the model predictions.

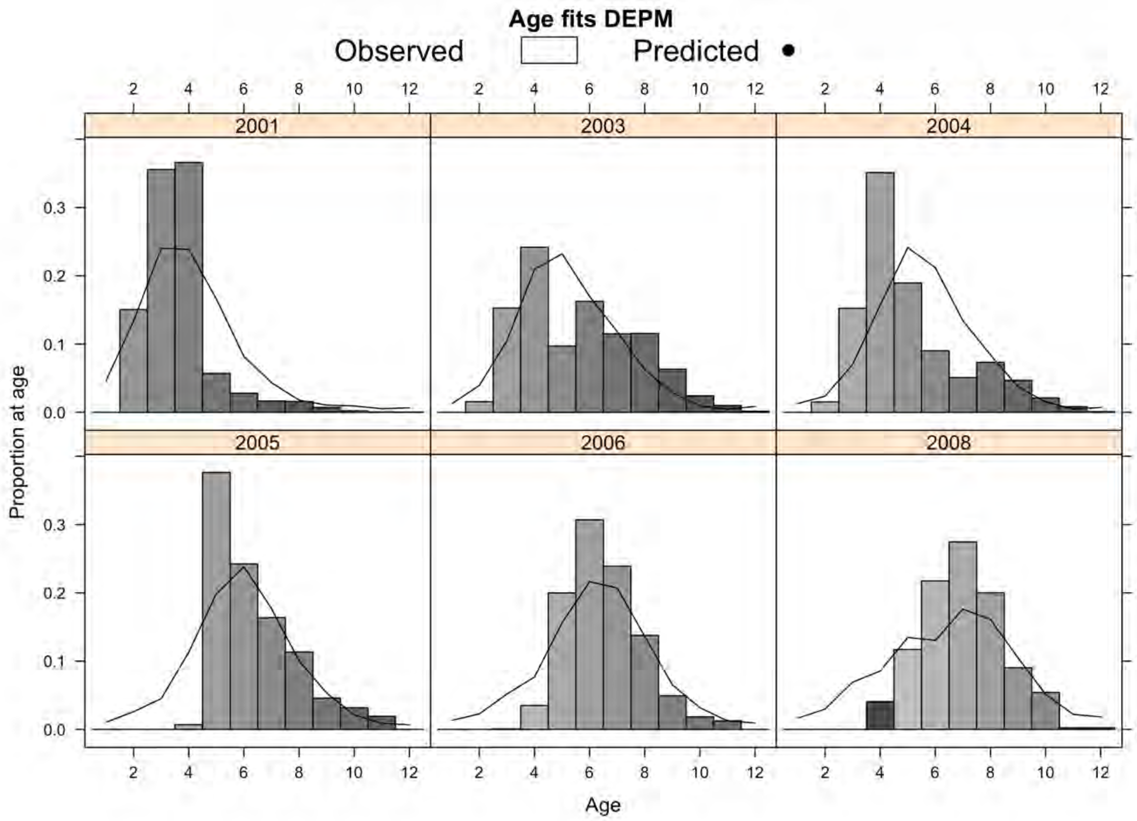


Figure A10.20. Model *h1_1.05* (single-stock hypothesis) fit to the age compositions for the Daily Egg Production Method (DEPM) survey. Bars represent the observed data and lines represent the model predictions.

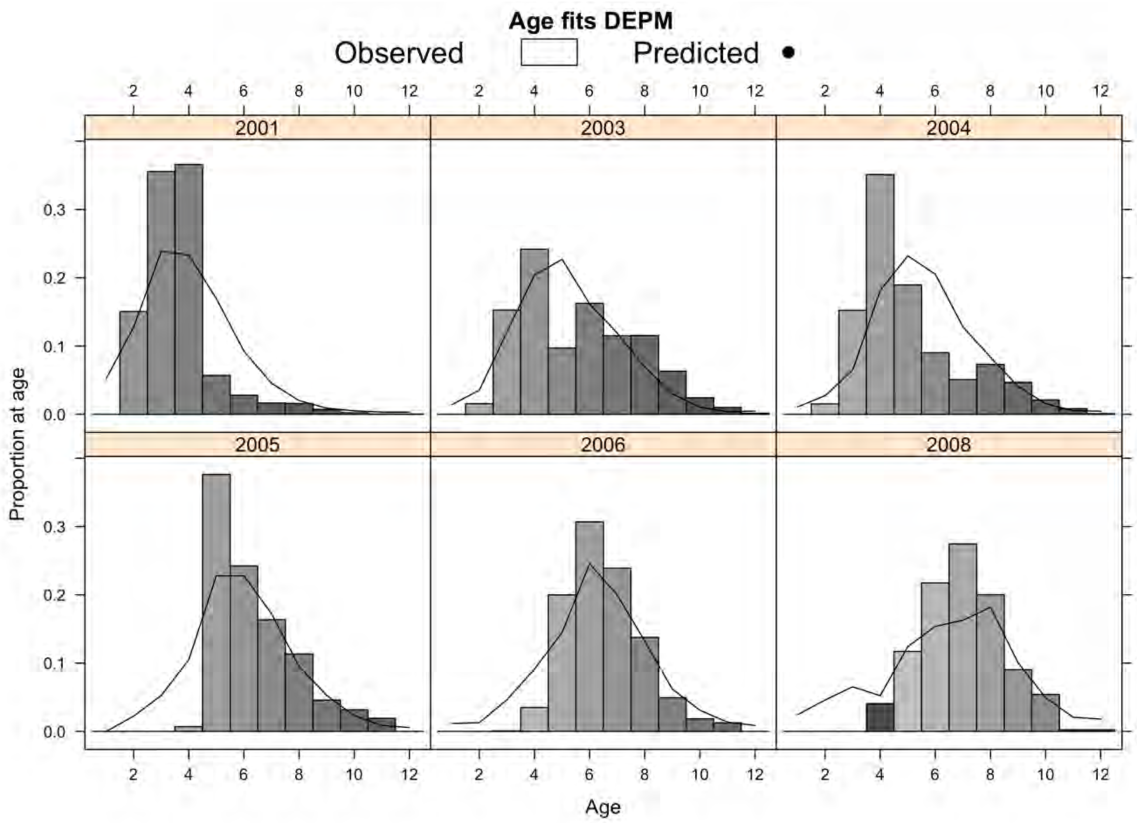


Figure A10.21. Model *h2_1.05* (two-stock hypothesis) fit to the age compositions for the Daily Egg Production Method (DEPM) survey. Bars represent the observed data and lines represent the model predictions.

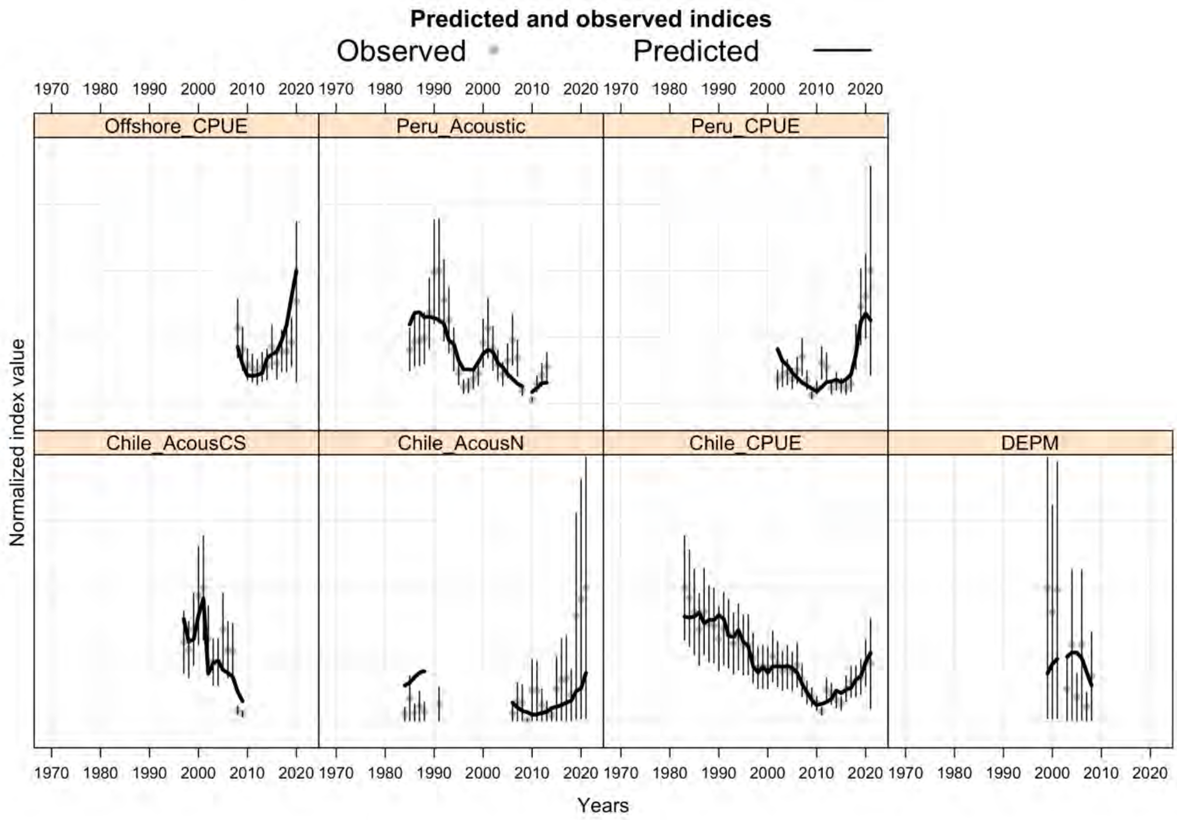


Figure A10.22. Model *h1_1.05* (single-stock hypothesis) fit to different indices. Vertical bars represent 2 standard deviations around the observations.

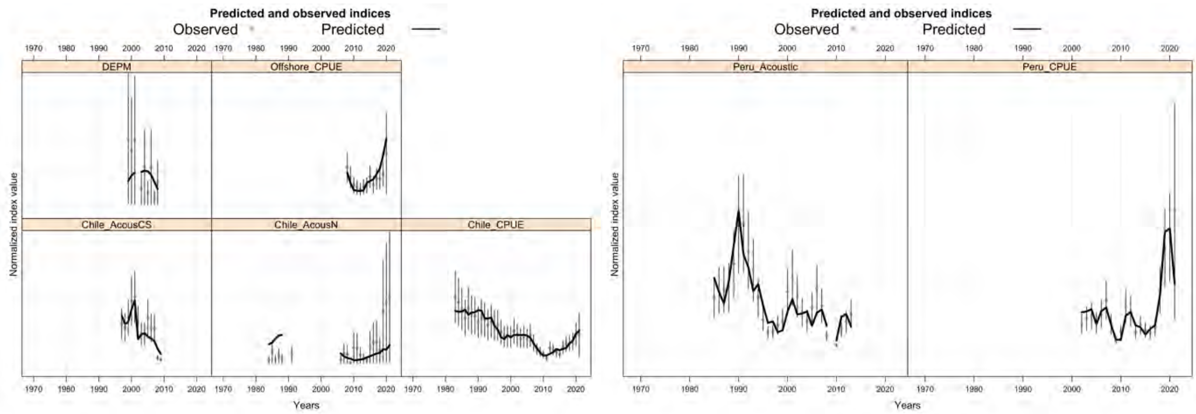


Figure A10.23. Model *h2_1.05* (two-stock hypothesis) fit to different indices. Vertical bars represent 2 standard deviations around the observations.

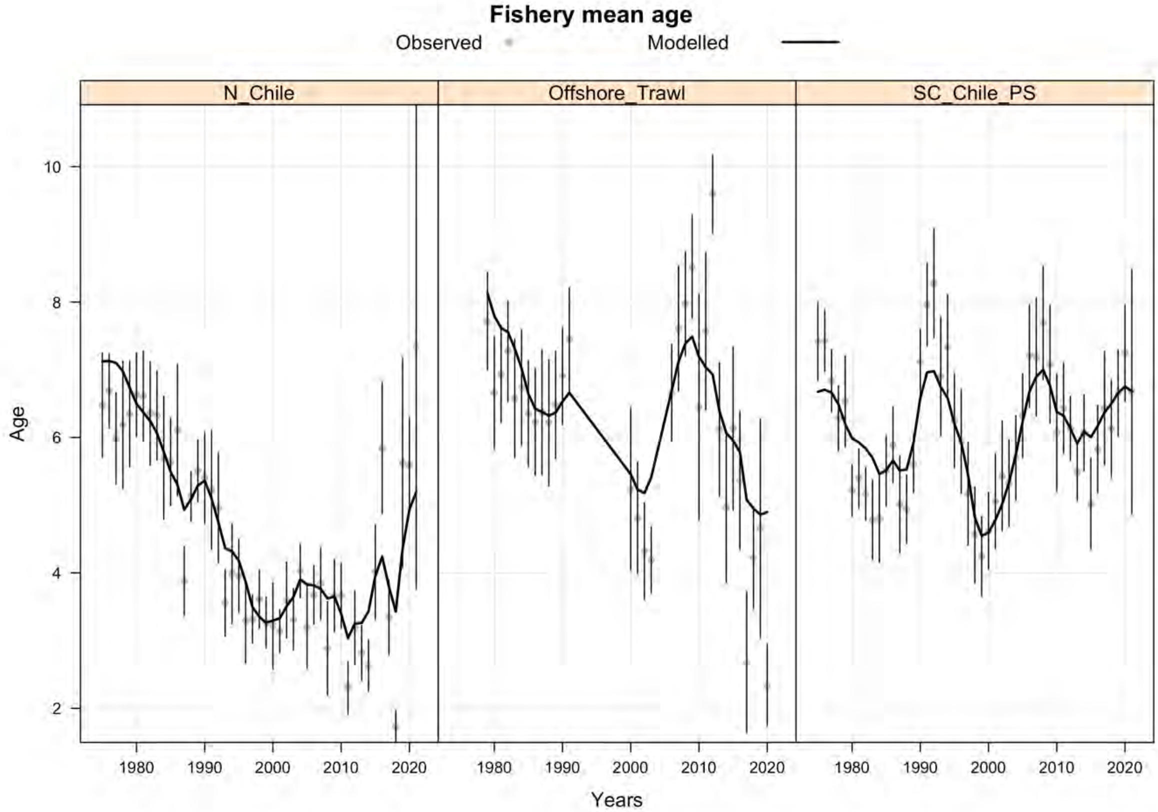


Figure A10.24. Mean age by year and fishery. Line represents the Model *h1_1.05* (single-stock hypothesis) predictions and dots observed values with implied input error bars.

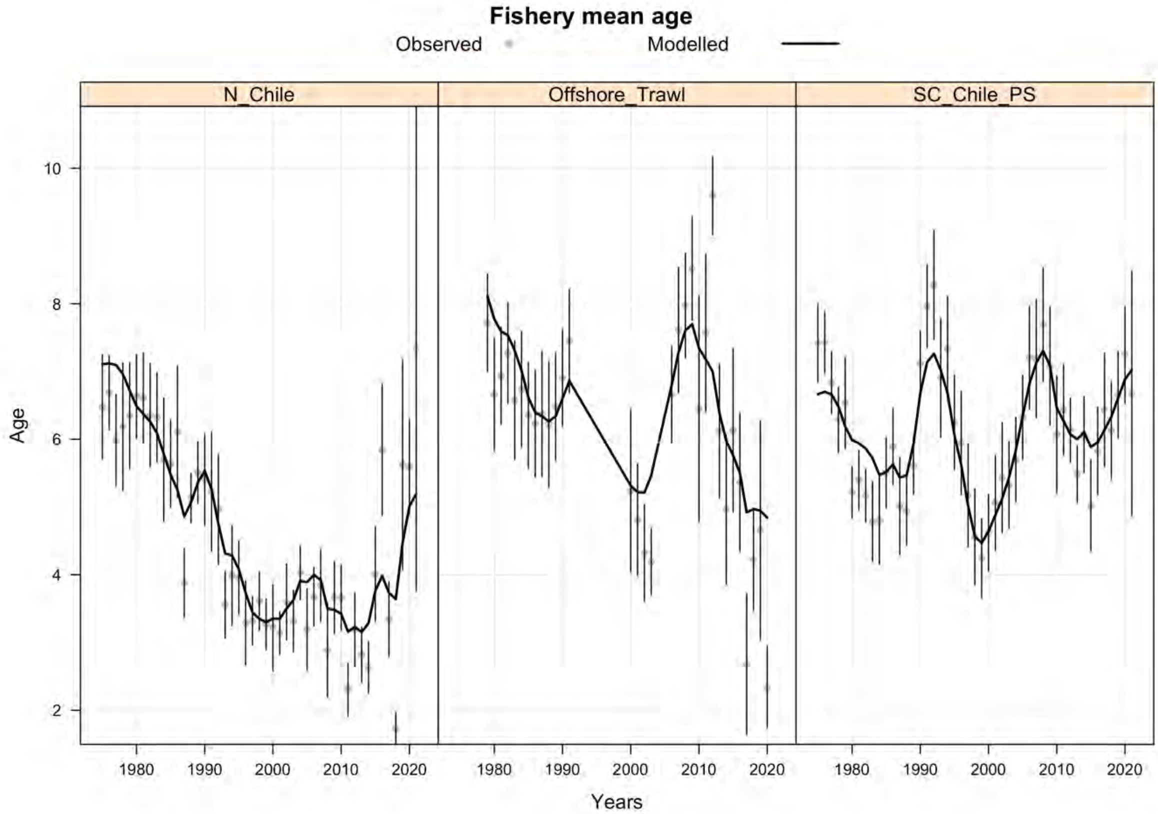


Figure A10.25. Mean age by year and fishery. Line represents the Model *h2_1.05* (two-stock hypothesis) predictions and dots observed values with implied input error bars.

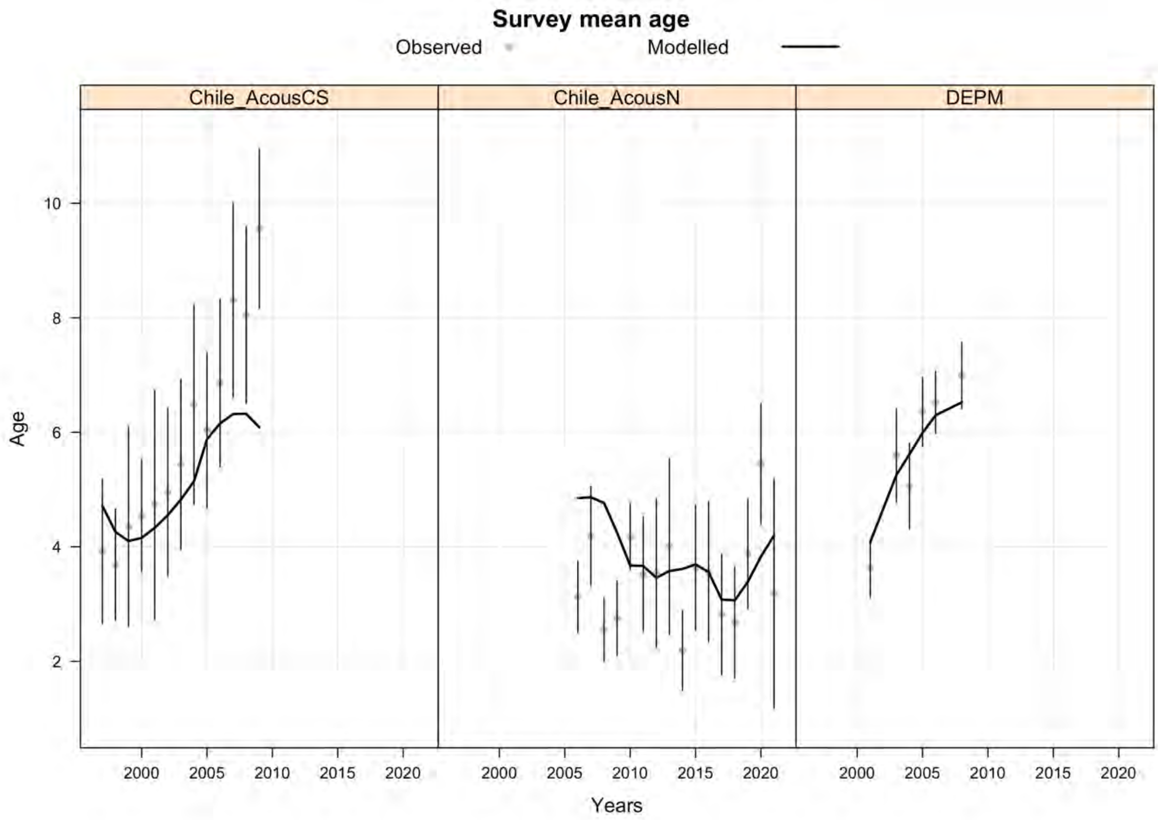


Figure A10.26. Mean age by year and survey. Line represents the Model *h1_1.05* (single-stock hypothesis) predictions and dots observed values with implied input error bars.

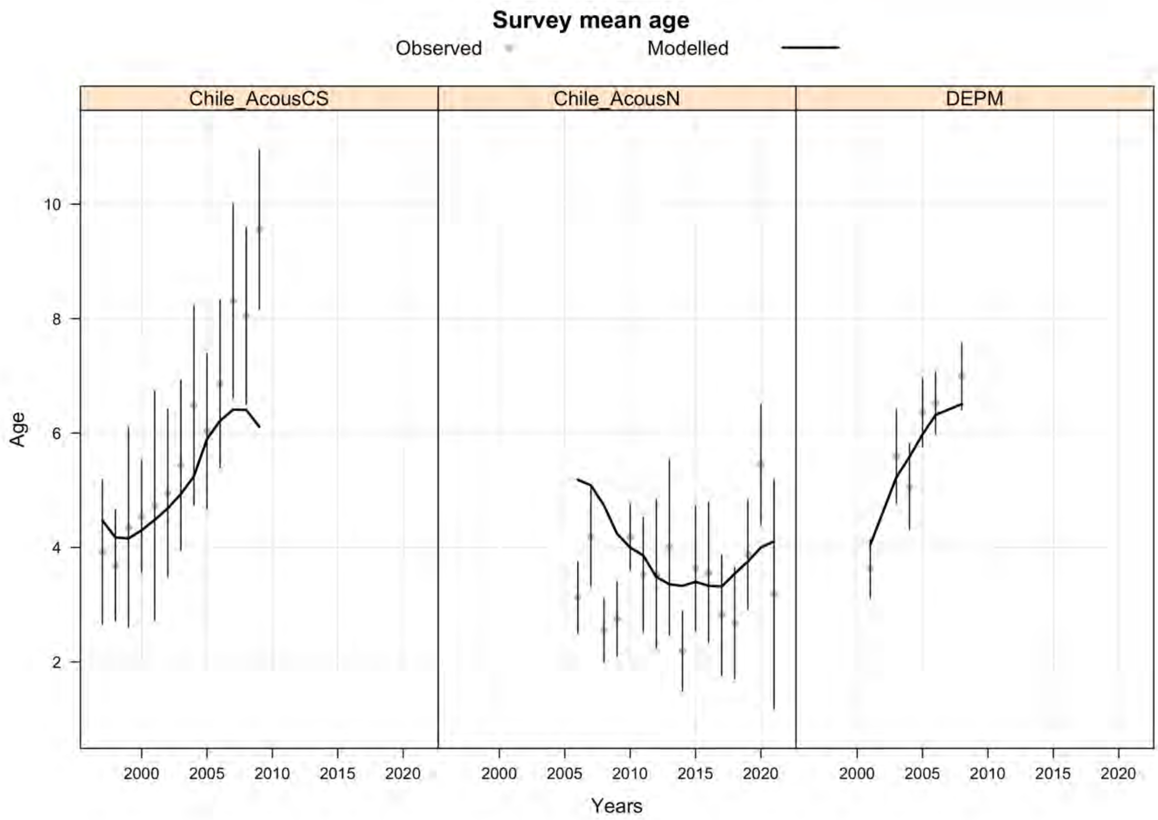


Figure A10.27. Mean age by year and survey. Line represents the Model *h2_1.05* (two-stock hypothesis) predictions and dots observed values with implied input error bars.

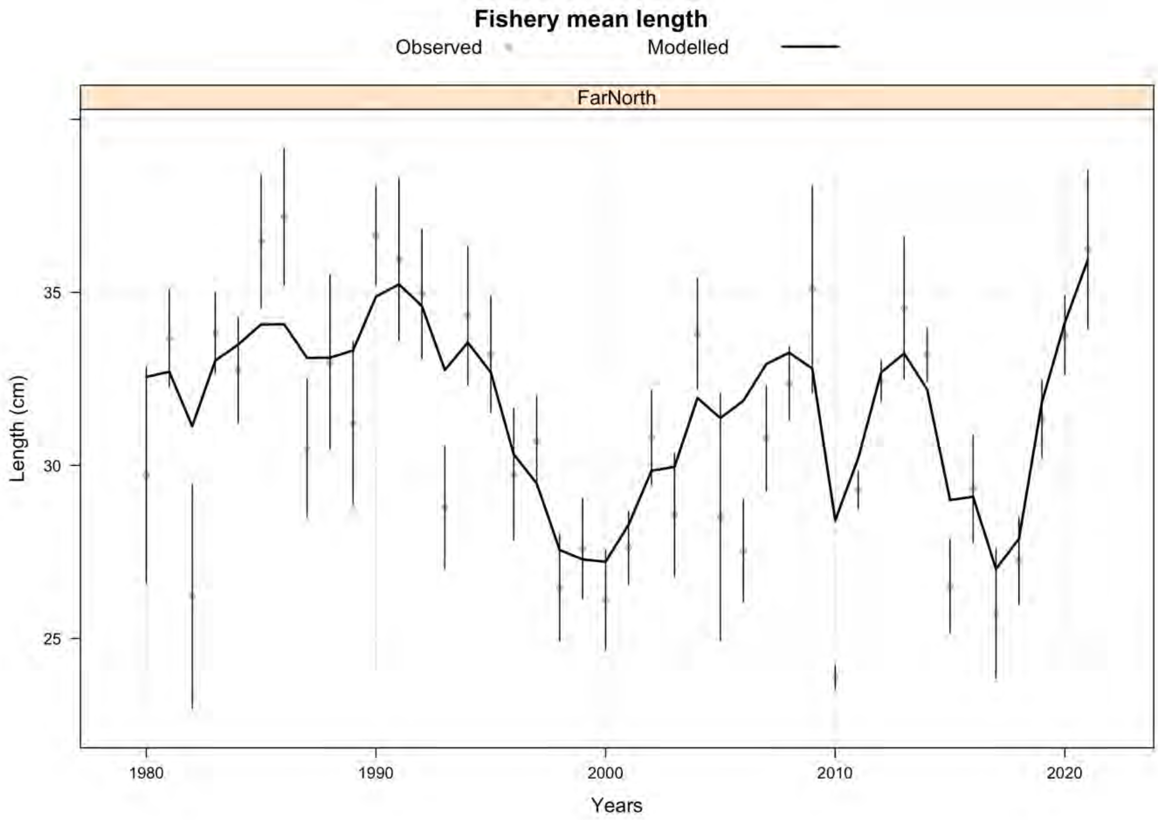


Figure A10.28. Mean length by year in Fleet 3 (Far North). Line represents the Model *h1_1.05* (single-stock hypothesis) predictions and dots observed values with implied input error bars.

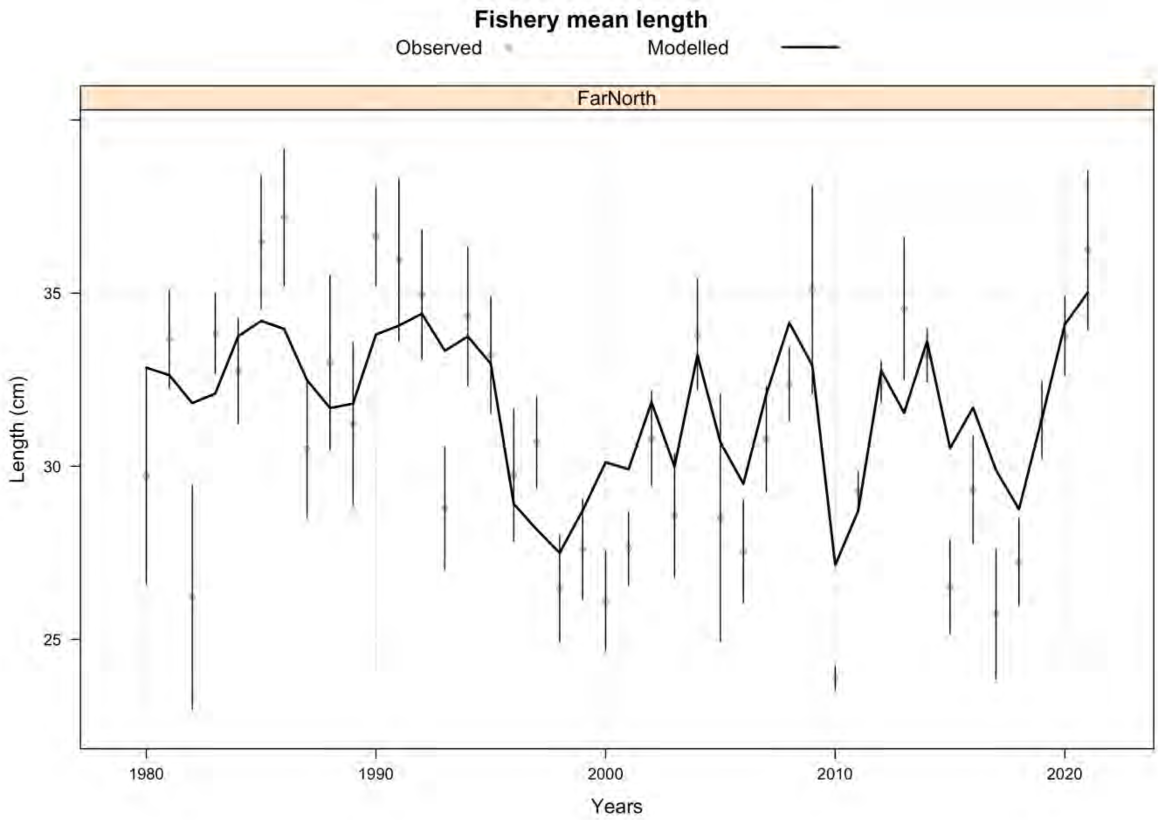


Figure A10.29. Mean length by year in Fleet 3 (Far North). Line represents the Model *h2_1.05* (two-stock hypothesis) predictions and dots observed values with implied input error bars.

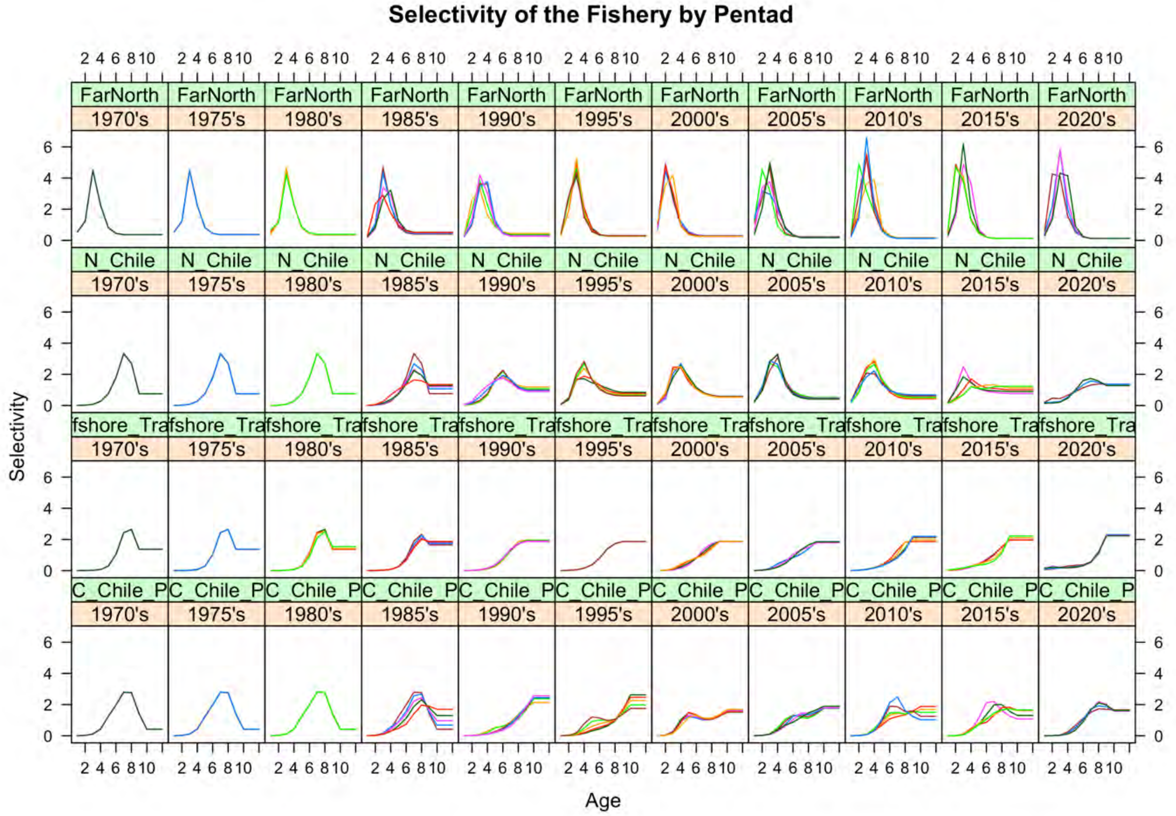


Figure A10.30. Estimates of selectivity by fishery over time for Model *h1_1.05* (single-stock hypothesis). Each cell represents a 5-year period. The years denote the middle of the 5-year period (pentad).

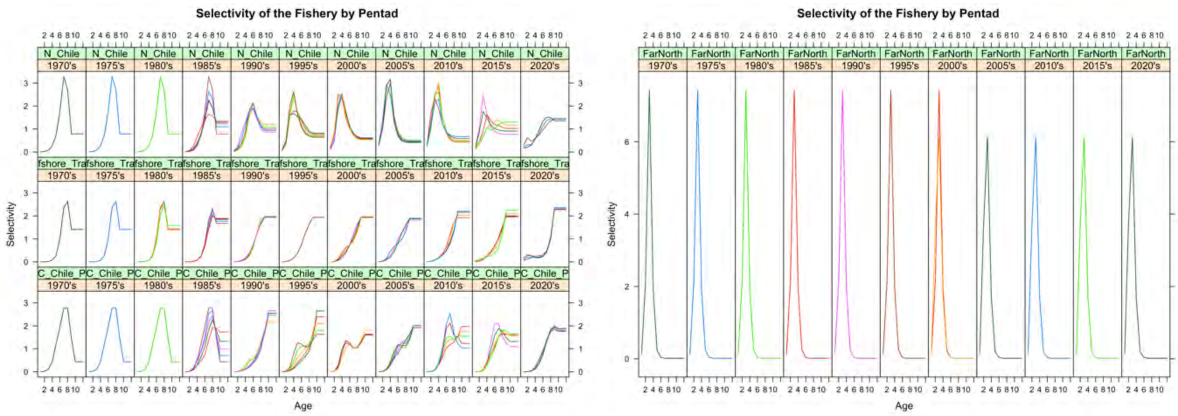


Figure A10.31. Estimates of selectivity by fishery over time for Model *h2_1.05* (two-stock hypothesis). Each cell represents a 5-year period. The years denote the middle of the 5-year period (pentad).

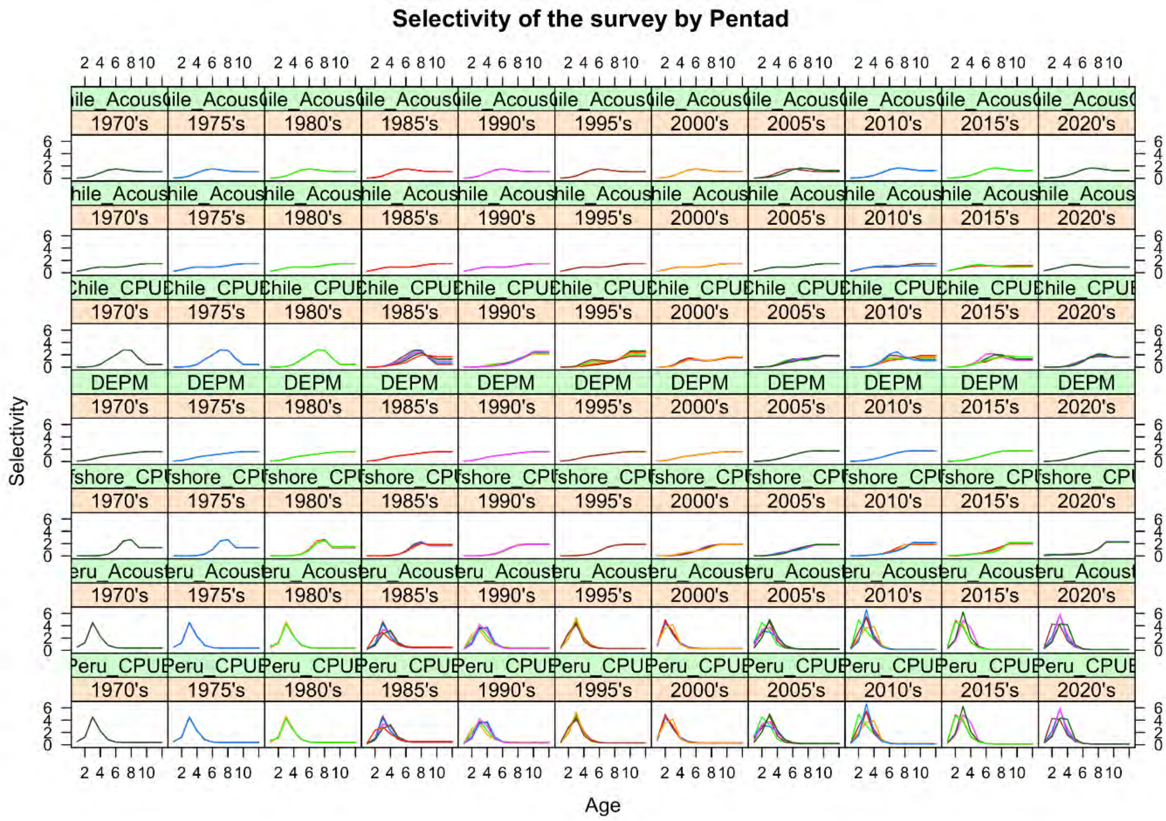


Figure A10.32. Estimates of selectivity by index over time for Model *h1_1.05* (single-stock hypothesis). Each cell represents a 5-year period. The years denote the middle of the 5-year period (pentad).

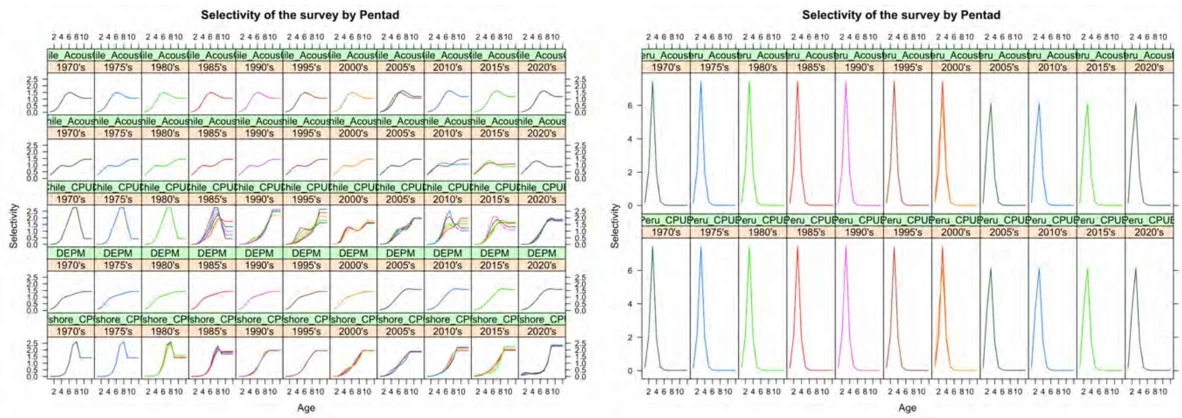


Figure A10.33. Estimates of selectivity by index over time for Model *h2_1.05* (two-stock hypothesis). Each cell represents a 5-year period. The years denote the middle of the 5-year period (pentad).

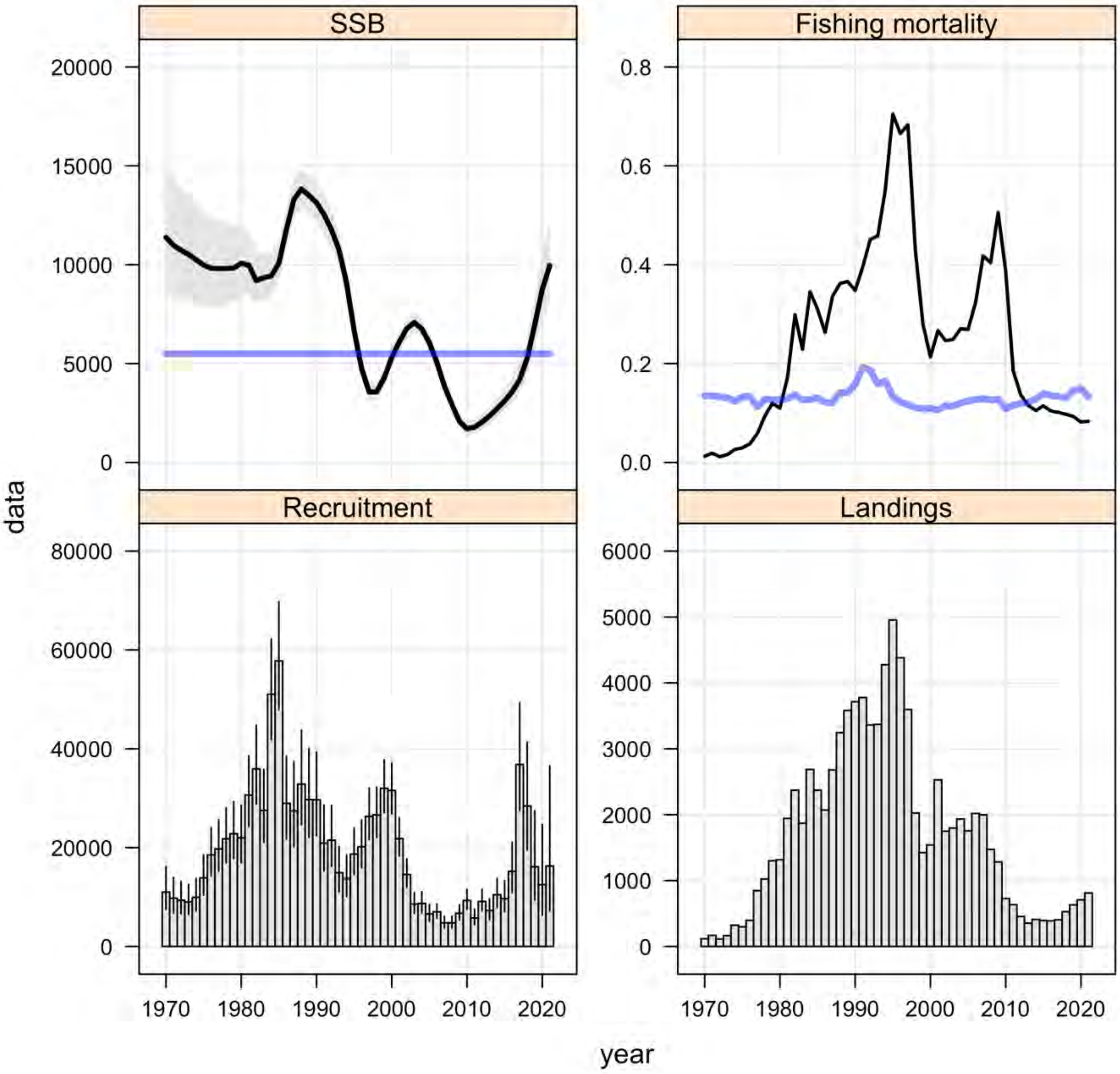


Figure A10.34. Model *h1_1.05* (single-stock hypothesis) summary estimates over time showing spawning biomass (kt; top left), recruitment at age 1 (millions; lower left), total fishing mortality (top right), and total catch (kt; bottom right). Blue lines represent the provisional B_{MSY} (upper left) and dynamic estimates of F_{MSY} (upper right).

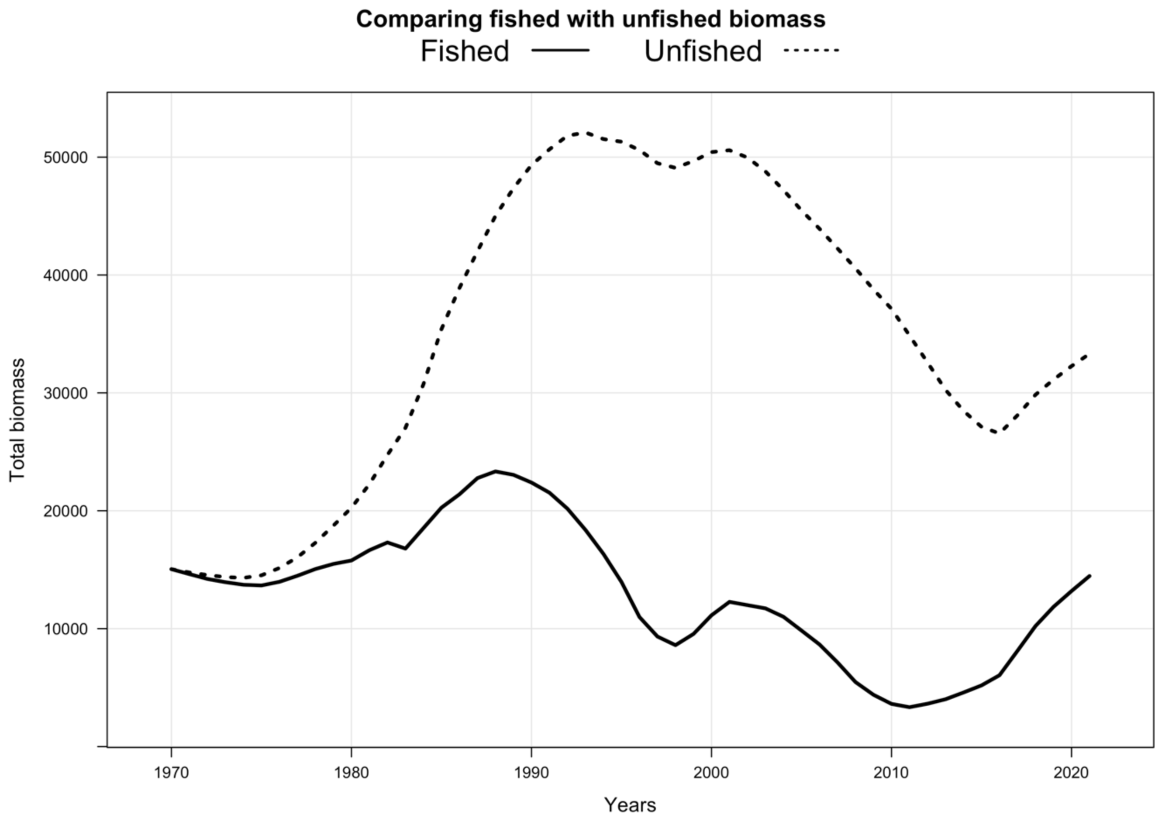
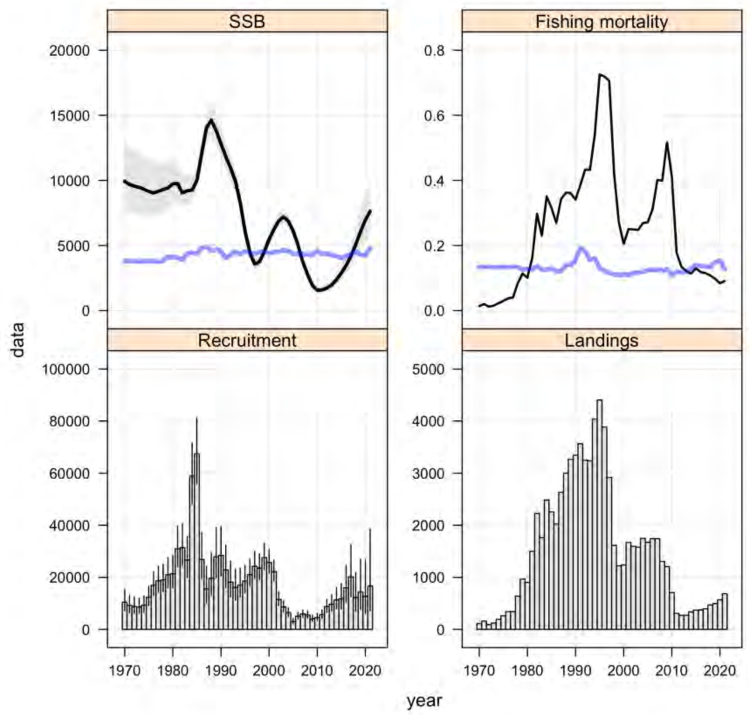


Figure A10.35. Model *h1_1.05* (single-stock hypothesis) results for the estimated total biomass (solid line) and the estimated total biomass that would have occurred if no fishing had taken place (dotted line), beginning in 1970.

Southern stock



Far North stock

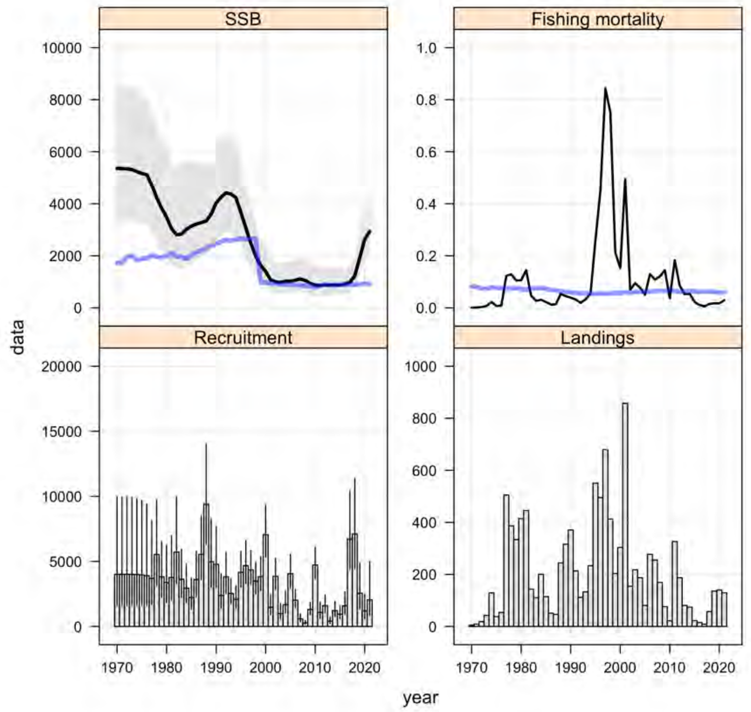


Figure A10.36. Model *h2_1.05* (two-stock hypothesis) summary estimates over time showing spawning biomass (kt; top left), recruitment at age 1 (millions; lower left), total fishing mortality (top right) and total catch (kt; bottom right) for the "Far North" stock (top set) and for the "Southern" stock (bottom set). Blue lines represent the dynamic estimates of B_{MSY} (upper left) and the dynamic estimates of F_{MSY} (upper right).

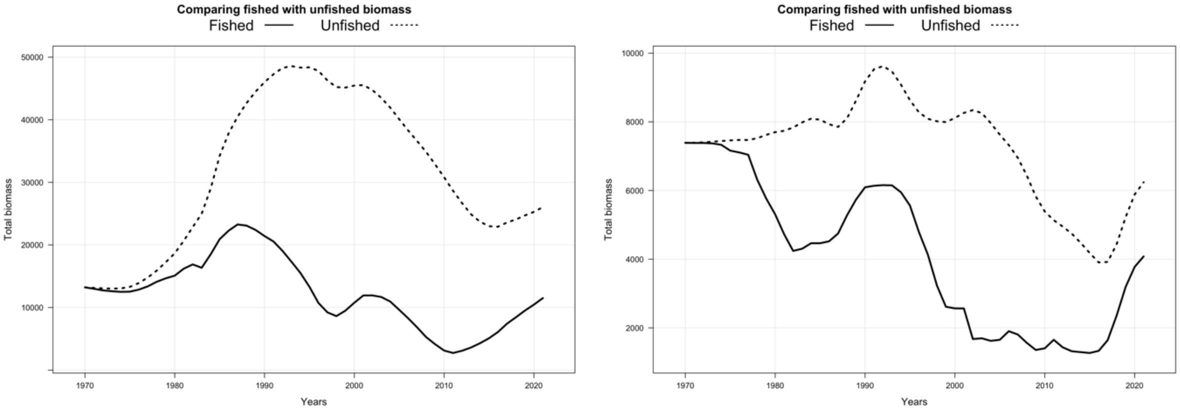


Figure A10.37. Model *h2_1.05* (two-stock hypothesis) results for the estimated total biomass (solid line) and the estimated total biomass that would have occurred if no fishing had taken place (dotted line), beginning in 1970. The plot on the left shows results for the southern stock, and the one on the right the far north stock.