



## SPRFMO SC8-Report

### Annex 8. Jack Mackerel Technical Annex

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#### 1. Introduction

1. This document and content are based on discussions and analyses conducted at the Scientific Committee (SC) meeting in 2020. The analyses updated the model and assumptions from SC7. 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 summary of discussions at a series of pre-SC web meetings can be found in document [SC8-Doc06 rev1](#). The model was updated with new data, and subsequently accepted at the [SC8 meeting](#). Discussions at SC8 focused on the following topics:

- Review and update of data sets;
- The weighting of age composition data based on recorded sample sizes

#### *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.
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 SC8.

#### *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 A8.1 with the catch summarised by fleets in Figure A8.1.

#### *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°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 A8.1), and form four “fleets”, which are intended to be consistent with the gear and general areas of fishing (Figure A8.1). The summarised catches from each of these fleets are presented in Table A8.2.
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 and EU were converted to age compositions by applying Chilean age-length keys as compiled by quarter of the year and then aggregated (Table A8.3, Table A8.4, and Table A8.5). In some years, including 2018 and 2019, the EU provided age-length keys which were used to convert EU length distribution data to age. For Peruvian and Ecuadorian fisheries, length frequency data (Table A8.6) were used directly and fit within the model according to the specified growth curve. In SC8, the 2020 age composition data for the northern Chilean fleet were found to be unusual, and as they were derived from a very small sample size there was discussion about the need in future to include the sample sizes of composition data in the model to inform the data weighting process. For the SC8 assessment the 2020 age composition data from North Chile were entirely downweighted.
15. Several CPUE data series are used in the model, with changes introduced during SC4, SC6 and SC7.
16. 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.
17. In SC8, a new set-based standardisation method for the Chilean CPUE was tabled. Given that SC8 was an update assessment only, this new index was not included for advice to the Commission. The impact of including it in the assessment will be assessed at the next benchmark assessment.
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. 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 A8.7), 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.

#### *Fisheries Independent Data*

21. 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.
22. 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 A8.8, Table A8.9, and Table A8.10.
23. 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.

24. 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 A8.7.

#### *Biological Parameters*

25. 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 A8.11.
26. To fit the length composition data from the far-north fleet, a growth curve was used to convert age compositions predicted by the model to predicted lengths, with the conversion occurring within the model. The values for the von Bertalanffy growth parameters are given in Table A8.12. Ageing imprecision was previously acknowledged using an age-error matrix, as shown in Table A8.13. However, because this matrix is based on expert judgement instead of actual data, the discussions during SC4 led to selecting the final assessment model with this ageing error option turned off.
27. Mean weight-at-age is required for all fishing fleets and biomass indices in order to relate biomass quantities to the underlying model estimates of Jack mackerel abundance (in numbers). The four weight-at-age matrices for the fishing fleets correspond to: Fleet 1 (northern Chile), Fleet 2 (central-south Chile), Fleet 3 (the far north fleet) and Fleet 4 (the offshore trawl fleet). These values are shown in Table A8.14, Table A8.15, Table A8.16, and Table A8.17.
28. 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 A8.14 and Table A8.15. The information covers the period 1974-2019; for earlier years the weight-at-age from 1974 was used.

29. 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 A8.12). The information covers the period from 1970 to present year (Table A8.16).
30. 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 A8.17). Note that for most countries weight-at-length information is available. In some years however, including 2018, weight-at-length data from the Chinese fleet were missing, which resulted in using the length-weight relationship from the Chilean fleet 2.
31. 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.
32. Estimates of natural mortality are derived from Pauly's method, using the Gili et al. (1995) growth function for Chile and the Díoses (2013) growth function for Peru. The estimated M values are assumed to be the same for all ages and all years within the given stock (see Table A8.12).

#### *Data Sets*

33. 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 A8.18 and Figure A8.2.

### **3. The Assessment Model**

34. 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 2020 (Table A8.18).
35. 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*

36. 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.
37. The model consists of several components, (i) the dynamics of the stock; (ii) the fishery dynamics; (iii) observation models for the data; and (iv) the procedure used for parameter estimation (including uncertainties).

38. 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).
39. 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.
40. 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.
41. 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 SC7 and SC8 updates.
42. 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*

43. Parameters estimated conditionally are listed in Table A8.19. The most numerous of these involve estimates of annual and age-specific components of fishing mortality for each year 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.
44. Equations and specifications for the assessment model are given in Table A8.20 and Table A8.21. Table A8.22 contains the initial variance assumptions for the indices and the age and length compositions.
45. The treatment of selectivities and how they are shared among fisheries and indices are given in Table A8.23 and Table A8.24 for the two stocks under the two-stock model configurations (hypothesis 2), and Table A8.25 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*

46. 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*

47. As SC8 was an update assessment, the only model explorations involved incrementally adding new data components relative to last year’s Jack mackerel model (Model 1.00 from SC7). 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 A8.26).
48. 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.
49. 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. Given that this was an update assessment, alternate model configurations and sensitivities were not explored at this meeting, and Model 1.00 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 SC8, are outlined below.
50. 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.

## **4. Results**

51. 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 2020 in particular resulted in an increase in the 2016 estimates of recruitment, leading to a slight increase in biomass for the most recent two years. The historical Chinese index was completely removed from the data and the model in SC8, with no impact to the assessment. Overall, the stock (or stocks; depending on the stock structure hypothesis used) shows continued increasing trends in biomass, similar to previous years.
52. 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\_1.00 does not suffer from a retrospective bias with a Mohn’s rho on SSB of 0.06 and on recruitment of -0.03 (Figure A8.3). Model h2\_1.00 has a somewhat higher tendency to over-estimate SSB (Mohn’s rho 0.17) and recruitment (Mohn’s rho 0.15) for the southern stock relative to those for the northern stock and those for the Model h1\_1.00 (Figure A8.4).
53. 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\_1.00 (raw values for biomass found in Table A8.27; graphically visualised in Figure A8.5 and Figure A8.6). These 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 (2018-2020; Figure A8.5). 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\_1.00 appear to be more consistent over time, relative to previous assessments (Figure A8.6). Also, the stock has consistently been estimated as rebuilt since 2018, and not overfished since 2013, relative to the dynamically-estimated MSY reference points.

54. Fishery mean weights-at-age assumed for all models are shown in Figure A8.7. Estimates of numbers-at-age from Model h1\_1.00 are given in Table A8.28, whereas Model h2\_1.00 results are in Table A8.29 (southern stock) and Table A8.30 (northern stock). Both models show similar fits to the composition data. The fishery age and length composition fits for both Models h1\_1.00 and h2\_1.00 are shown in Figure A8.8, Figure A8.9, Figure A8.10, Figure A8.11, Figure A8.12, Figure A8.13, Figure A8.14 and Figure A8.15. The fits to age composition data from the surveys are given in Figure A8.16, Figure A8.17, Figure A8.18, Figure A8.19, Figure A8.20, and Figure A8.21. Both models fit the indices similarly (Figure A8.22 and Figure A8.23), with good fits to the Chilean CPUE data and poor fits to recent years of the offshore CPUE data, where the models predicted higher relative abundance than was shown in the offshore data. Fits to the fishery mean age compositions are shown in Figure A8.24 (h1\_1.00) and Figure A8.25 (h2\_1.00), whereas survey mean age compositions are shown in Figure A8.26(h1\_1.00) and Figure A8.27 (h2\_1.00). 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 A8.28 and Figure A8.29. Selectivity estimates for the fishery and indices are shown over time in Figure A8.30, Figure A8.31, Figure A8.32, and Figure A8.33.
55. A summary of the time series stock status (spawning biomass, F, recruitment, total biomass) for the single-stock hypothesis is shown in Figure A8.34. 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 41% of what is estimated to have occurred had there been no fishing (Figure A8.35).
56. Under the 2-stock hypothesis (h2 1.00), 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 A8.36). 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 A8.36). Figure A8.37 shows the current total biomass to be approximately 42% and 65% of unfished total biomass for the southern and the far north stocks respectively.
57. 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 A8.31, Table A8.32,

59. Table A8.33, Figure A8.34, and Figure A8.36). It should be noted that the low probability of  $B_{2030}$  being greater than  $B_{MSY}$  under the  $F_{MSY}$  projection for model h1\_1.00 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 1.00 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\_1.00 are presented in Table A8.34, whereas those of Model h2\_1.00 are in Table A8.35 (southern stock) and Table A8.36 (far north stock). Short, medium and long-term predictions for the stock(s) under different fishing mortalities are found under Table A8.37 (h1\_1.00) and Table A8.38 (h2\_1.00).

## 5. Management Advice

60. New data and indicators on the status of the Jack mackerel stock suggest that conditions evaluated in detail from the last benchmark assessment (completed in 2018) are relatively unchanged. The population trend is estimated to be increasing. The indications of stock improvement (higher abundance observed in the acoustic survey in the northern part of Chile, better catch rates apparent in some fisheries, and increase in average age in the Chilean fisheries) drive the increase.
61. Historical fishing mortality rates and patterns relative to the provisional biomass target are shown in Figure A8.34 for Model h1\_1.00. Near term spawning biomass is expected to increase from the 2020 estimate of 8.3 million t to 9.3 million t in 2021 (with approximate 90% confidence bounds of 7.5 – 11.4 million t). Under the two-stock hypothesis, historical fishing mortality rates and patterns relative to the model-estimated biomass targets are shown in Figure A8.36. Near term spawning biomass is expected to increase from the 2020 estimate of 6.9 million t to 7.7 million t in 2021 for the southern stock, and from 2.6 million t to 2.8 million t for the far north stock.
62. 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 60% over  $B_{MSY}$  for both the single-stock and the two-stock hypotheses.
63. 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 2021 catch level for Jack mackerel within the entire Jack mackerel range to be at or below 782 kt.
64. Projections show a high likelihood of the biomass being above  $B_{MSY}$  in 2021 even under the most conservative recruitment productivity scenario evaluated. As such, a re-evaluation of the rebuilding plan is recommended to analyse sustainable exploitation rates of a re-built Jack mackerel stock.

## 6. Assessment Issues

65. 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.

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

## 7. References

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## 8. Tables

Table A8.1. Sources and values of catch (t) compiled for the four fleets used for the assessment (note that data for 2019 are not official figures, and 2020 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 (ANU)	Peru (ANU)	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	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	396,458	
1977	226,234	114,572				504,992		504,992												2,273	848,071	
1978	398,414	188,267				386,793	0	386,793												51,290	1,024,764	
1979	344,051	253,460	6,281			151,591	175,938	333,810	12,719	1,180										356,271	370,290	
1980	288,809	273,453	38,841			123,380	252,078	414,299	45,130	1,780										292,892	339,802	
1981	474,817	586,092	35,783			37,875	371,981	445,638	38,444											399,649	438,123	
1982	789,912	704,771	9,589			50,013	84,122	143,724	74,292	7,136										651,776	733,204	
1983	301,934	563,338	2,096			76,825	31,769	110,690	52,779	39,943	1,694									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	
1985	511,150	945,839	1,067			87,466	26,089	114,622	31,191		5,229									762,903	799,323	
1986	55,210	1,129,107	66			49,863	1,100	51,029	46,767		6,835									783,900	837,502	
1987	313,310	1,456,727	0			46,304	0	46,304	35,980		8,815									818,628	863,423	
1988	325,462	1,812,793	5,676			118,076	120,476	244,229	38,533		6,871									817,812	863,215	
1989	338,600	2,051,517	3,386	0		140,720	137,033	281,139	21,100		701									854,020	875,821	
1990	323,089	2,148,786	6,904	4,144		191,139	168,636	370,823	34,293		157									837,609	872,050	
1991	346,245	2,674,267	1,703	45,313		136,337	30,094	213,447	29,125											514,534	543,659	
1992	364,243	2,907,817	0	15,022		96,660	0	111,682	3,196										32,000	2,736	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	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	
2004	158,656	1,292,943				0	187,369	187,369	131,020										7,438	62,300		
2005	165,626	1,264,808				0	80,663	80,663	867	143,000	6,187								9,126	7,040		
2006	155,256	1,224,685				0	277,568	277,568	481	160,000	62,137	10,474							0	129,535		
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		
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		
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		
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		
2011	30,825	216,470	0			69,373	257,241	326,614	0	32,862	8	2,248	0	0	9,253	674			8,229	7,617		
2012	13,256	214,204	0			77	187,292	187,369	13,012	0	0	0	0	0	5,492	5,346	0		16,068	39,917		
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	
2014	18,219	254,295	0			9	74,528	74,537	21,155		20,539	0	4,078	2,557					15,324	63,652		
2015	34,886	250,327				289	22,158	22,447		29,180	27,955	0	5,749	0	2,561				21,227	86,672		
2016	24,657	295,160				0	15,087	15,087		20,208	11,962	0	6,430	0	0				15,563	54,163		
2017	35,002	311,863				54	8,813	8,867		16,802	27,887	0	1,235	0	3,188				0	49,113		
2018	11,551	415,149				23	57,140	57,163		24,366	9,691	0	3,717	0	4,685				0	42,460		
2019	11,875	432,447				0	135,784	135,784		22,699	11,870	0	7,444	0	9,426				0	51,439		
2020	45,049	465,000				0	137,000	137,000	0	0	0	0	0	0	0	2,867	0		2,867	649,915		

Table A8.2. Input catch (kilo tonnes) by fleet (combined) for the stock assessment model. Note that the final year's data are predictions.

<b>Year</b>	<b>Fleet 1</b>	<b>Fleet 2</b>	<b>Fleet 3</b>	<b>Fleet 4</b>
1970	101.69	10.31	4.71	0
1971	143.45	14.99	9.19	0
1972	64.46	22.55	18.78	5.5
1973	83.2	38.39	42.78	0
1974	164.76	28.75	129.21	0
1975	207.33	53.88	37.9	0
1976	257.7	84.57	54.15	0.04
1977	226.23	114.57	504.99	2.27
1978	398.41	188.27	386.79	51.29
1979	344.05	253.46	333.81	370.29
1980	288.81	273.45	414.3	339.8
1981	474.82	586.09	445.64	438.12
1982	789.91	704.77	143.72	733.2
1983	301.93	563.34	110.69	894.3
1984	727	699.3	200.67	1059.93
1985	511.15	945.84	114.62	799.32
1986	55.21	1129.11	51.03	837.5
1987	313.31	1456.73	46.3	863.42
1988	325.46	1812.79	244.23	863.22
1989	338.6	2051.52	316.25	875.82
1990	323.09	2148.79	370.82	872.06
1991	346.25	2674.27	213.45	543.66
1992	304.24	2907.82	111.68	37.93
1993	379.47	2856.78	133.35	0
1994	222.25	3819.19	233.35	0
1995	230.18	4174.02	550.99	0
1996	278.44	3604.89	495.52	0
1997	104.2	2812.87	680.05	0
1998	30.27	1582.64	412.85	0
1999	55.65	1164.04	203.75	0.01
2000	118.73	1115.57	303.7	2.32
2001	248.1	1401.84	857.74	20.09
2002	108.73	1410.27	154.82	76.26
2003	143.28	1278.02	217.73	158.2
2004	158.66	1292.94	187.37	295.44
2005	165.63	1264.81	80.66	243.58
2006	155.26	1224.69	277.57	362.63
2007	172.7	1130.08	255.36	438.83
2008	167.26	728.85	169.54	406.99
2009	134.02	700.9	76.63	371.92
2010	169.01	295.8	22.17	239.59
2011	30.82	216.47	326.39	60.89
2012	13.26	214.2	187.4	39.92
2013	16.36	215	80.59	41.18
2014	18.22	254.29	74.53	63.65
2015	34.89	250.33	22.45	86.67
2016	24.66	295.16	15.09	54.16
2017	35	311.86	8.87	49.11
2018	11.55	415.15	57.16	42.46
2019	11.88	432.45	135.78	51.44
2020	45.05	465	137	2.87

Table A8.3. Catch at age for Fleet 1. Units are relative value (they are normalised to sum to 100 for each year in the model). Green shading reflects relative level, with darker green indicating a stronger cohort.

Year	Age group (years)											
	1	2	3	4	5	6	7	8	9	10	11	12
1975	0	1	2	8	10	28	29	14	5	1	1	0
1976	0	0	0	2	10	30	37	17	3	1	0	0
1977	0	2	3	7	20	33	25	9	1	0	0	0
1978	0	1	8	15	14	9	25	20	7	1	0	0
1979	0	0	4	9	18	22	23	18	6	1	0	0
1980	0	1	3	6	17	23	27	19	4	0	0	0
1981	0	0	2	9	20	24	29	14	3	0	0	0
1982	0	0	1	14	15	20	27	16	5	1	0	0
1983	0	0	0	7	20	29	27	14	3	0	0	0
1984	0	0	11	28	13	13	17	15	3	0	0	0
1985	0	0	4	17	27	29	17	5	1	0	0	0
1986	4	13	12	7	8	15	22	13	5	1	0	0
1987	0	5	40	41	10	2	2	1	0	0	0	0
1988	0	0	11	41	38	9	0	0	0	0	0	0
1989	0	1	1	6	45	38	8	1	0	0	0	0
1990	1	9	1	3	28	48	10	1	0	0	0	0
1991	0	2	20	20	11	17	24	6	0	1	0	0
1992	0	3	21	12	23	23	13	5	1	0	0	0
1993	0	3	62	25	5	4	1	0	0	0	0	0
1994	0	14	34	10	26	13	2	0	0	0	0	0
1995	0	16	32	28	14	8	2	0	0	0	0	0
1996	8	16	31	34	9	2	0	0	0	0	0	0
1997	0	5	55	36	4	0	0	0	0	0	0	0
1998	0	2	57	24	12	4	0	0	0	0	0	0
1999	0	6	72	17	4	1	0	0	0	0	0	0
2000	7	30	17	30	14	2	0	0	0	0	0	0
2001	0	12	63	23	1	0	0	0	0	0	0	0
2002	6	12	47	21	11	2	1	0	0	0	0	0
2003	1	14	55	22	5	2	1	0	0	0	0	0
2004	0	2	13	59	24	1	0	0	0	0	0	0
2005	4	26	38	16	12	4	0	0	0	0	0	0
2006	2	3	33	52	6	2	1	0	0	0	0	0
2007	0	9	32	44	10	3	2	1	0	0	0	0
2008	1	49	24	8	9	8	1	0	0	0	0	0
2009	0	7	29	51	4	8	0	0	0	0	0	0
2010	0	46	5	32	12	3	1	0	0	0	0	0
2011	6	59	28	3	1	2	0	0	0	0	0	0
2012	4	12	15	61	8	0	0	0	0	0	0	0
2013	4	68	26	1	0	0	0	0	0	0	0	0
2014	6	93	1	0	0	0	0	0	0	0	0	0
2015	11	3	11	49	20	6	1	0	0	0	0	0
2016	0	0	12	19	13	21	15	8	8	3	1	1
2017	0	18	15	45	16	4	1	0	0	0	0	0
2018	25	75	0	0	0	0	0	0	0	0	0	0
2019	30	6	0	13	4	14	11	5	6	3	2	4
2020	0	0	0	16	12	21	35	12	3	0	0	0

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

Year	Age group (years)											
	1	2	3	4	5	6	7	8	9	10	11	12
1975	0	0	1	2	6	18	28	25	14	5	2	0
1976	0	1	0	0	1	14	36	31	14	2	0	0
1977	0	0	0	3	11	19	35	27	4	0	0	0
1978	0	0	1	6	19	31	26	12	3	0	0	0
1979	0	0	1	13	18	18	18	16	11	4	0	0
1980	0	0	1	9	23	25	22	12	6	1	0	0
1981	0	0	0	4	17	31	28	14	4	1	0	0
1982	0	0	0	3	18	24	26	18	7	2	0	0
1983	0	2	4	7	17	25	26	13	5	1	0	0
1984	0	0	4	8	10	23	27	20	7	1	0	0
1985	0	0	1	8	14	25	31	16	4	0	0	0
1986	0	1	1	5	15	24	33	18	3	0	0	0
1987	0	4	9	8	5	15	32	22	4	1	0	0
1988	0	0	3	21	24	10	17	18	6	1	0	0
1989	0	0	0	4	23	32	19	15	6	1	0	0
1990	0	0	0	1	8	26	33	19	11	2	0	0
1991	0	1	2	2	1	7	28	31	16	8	3	1
1992	0	0	1	4	6	7	8	24	21	18	8	3
1993	0	0	4	12	15	14	13	12	14	12	4	1
1994	0	0	1	11	17	18	11	10	15	12	4	0
1995	0	0	4	18	14	25	18	9	6	4	2	0
1996	0	1	11	14	20	18	16	11	5	2	1	0
1997	0	2	17	31	22	11	6	4	4	2	1	0
1998	0	4	28	35	14	6	3	3	3	1	1	0
1999	0	4	37	34	14	5	2	1	1	1	1	1
2000	0	1	15	40	25	10	3	1	1	1	1	1
2001	0	1	10	26	34	16	5	2	2	2	1	2
2002	0	1	12	26	26	16	6	3	2	2	2	3
2003	0	0	6	25	30	20	8	3	2	2	1	1
2004	0	0	4	14	29	29	13	5	3	2	1	1
2005	1	1	1	5	17	39	19	8	5	2	1	1
2006	0	0	1	4	8	21	27	14	10	7	4	3
2007	0	0	1	13	15	11	15	15	13	9	5	4
2008	1	2	0	1	7	21	19	15	11	9	5	9
2009	0	0	4	9	2	19	22	17	11	7	5	4
2010	0	0	4	29	20	10	10	6	9	7	2	2
2011	0	0	1	16	13	35	10	6	13	5	1	1
2012	0	0	0	7	31	31	18	7	4	1	0	0
2013	0	0	2	18	29	33	14	3	0	0	0	0
2014	0	0	4	17	38	24	14	2	0	0	0	0
2015	0	0	11	40	17	11	10	7	2	1	0	0
2016	0	0	3	20	26	22	14	8	4	2	1	1
2017	0	0	8	19	15	18	15	10	5	4	3	3
2018	0	1	1	17	24	20	17	9	5	3	1	1
2019	0	0	0	9	18	22	23	14	8	4	1	0
2020	0	0	0	9	11	15	21	18	13	8	3	1

Table A8.5. Catch at age for Fleet 4. Units are relative value (they are normalised to sum to 100 for each year in the model). Green shading reflects relative level 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.

Year	Age group (years)											
	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

Table A8.6. Catch at length for Fleet 3. Units are relative value (they are normalised to sum to 100 for each year in the model). Green shading represents the relative level with a darker green indicating a stronger cohort.

Table A8.7. Abundance indices used within the assessment model.

Year	Chile (1)	Chile (2)	Chile (3)	Chile (4)	Peru (1)	Peru (2)	Offshore
1970	-	-	-	-	-	-	-
1971	-	-	-	-	-	-	-
1972	-	-	-	-	-	-	-
1973	-	-	-	-	-	-	-
1974	-	-	-	-	-	-	-
1975	-	-	-	-	-	-	-
1976	-	-	-	-	-	-	-
1977	-	-	-	-	-	-	-
1978	-	-	-	-	-	-	-
1979	-	-	-	-	-	-	-
1980	-	-	-	-	-	-	-
1981	-	-	-	-	-	-	-
1982	-	-	-	-	-	-	-
1983	-	-	0.854	-	-	-	-
1984	-	99	0.783	-	-	-	-
1985	-	324	0.694	-	94.316	-	-
1986	-	123	0.586	-	108.116	-	-
1987	-	213	0.7	-	109.789	-	-
1988	-	134	0.621	-	114.18	-	-
1989	-	-	0.613	-	157.394	-	-
1990	-	-	0.528	-	229.757	-	-
1991	-	242	0.595	-	231.672	-	-
1992	-	-	0.56	-	180.355	-	-
1993	-	-	0.499	-	145.726	-	-
1994	-	-	0.541	-	95.245	-	-
1995	-	-	0.488	-	54.257	-	-
1996	-	-	0.49	-	29.967	-	-
1997	3530	-	0.404	-	31.664	-	-
1998	3200	-	0.342	-	43.994	-	-
1999	4100	-	0.35	5724	52.681	-	-
2000	5600	-	0.342	4688	105.784	-	-
2001	5950	-	0.414	5627	131.586	-	-
2002	3700	-	0.365	-	96.661	4.193	-
2003	2640	-	0.322	1388	67.471	5.044	-
2004	2640	-	0.347	3287	51.853	5.552	-
2005	4110	-	0.316	1043	75.171	4.368	-
2006	3192	112	0.358	3283	111.259	5.82	-
2007	3140	275	0.262	626	79.75	8.254	-
2008	487	259	0.183	1935	24.251	4.106	1584.95
2009	328	18	0.153	-	-	1.506	1417.35
2010	-	440	0.115	-	7.247	2.78	867.244
2011	-	432	0.064	-	35.283	7.143	712.387
2012	-	230	0.197	-	50.332	6.333	623.957
2013	-	144	0.175	-	64.504	2.815	762.383
2014	-	87	0.139	-	-	3.947	737.48
2015	-	459	0.117	-	-	3.198	1184.33
2016	-	587.244	0.214	-	-	2.769	781.825
2017	-	610.47	0.254	-	-	3.653	950.503
2018	-	374.11	0.25	-	-	10.05	873.474
2019	-	1487.07	0.287	-	-	17.912	1107.18
2020	-	1728.27	0.366	-	-	11.756	-

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 A8.8. 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.

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

Table A8.9. 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.

Year	Age group (years)											
	1	2	3	4	5	6	7	8	9	10	11	12
2006	12	42	28	16	2	0	0	0	0	0	0	0
2007	0	5	17	55	21	1	0	0	0	0	0	0
2008	0	49	48	1	1	0	0	0	0	0	0	0
2009	0	41	42	16	0	1	0	0	0	0	0	0
2010	0	0	7	71	17	3	1	0	0	0	0	0
2011	0	27	12	50	4	5	1	0	0	0	0	0
2012	0	43	5	17	25	9	1	0	0	0	0	0
2013	11	35	2	17	16	15	4	1	0	0	0	0
2014	30	66	1	1	0	1	1	0	0	0	0	0
2015	62	10	5	15	4	2	1	0	0	0	0	0
2016	70	4	10	10	4	1	0	0	0	0	0	0
2017	19	57	7	10	5	1	0	0	0	0	0	0
2018	78	15	2	3	1	0	0	0	0	0	0	0
2019	4	12	20	39	20	4	1	0	0	0	0	0
2020	19	4	1	7	25	31	11	2	0	0	0	0

Table A8.10. 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.

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

Table A8.11. 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 A8.12. Jack mackerel growth (von Bertalanffy) and natural mortality parameters used in JJM models.

Parameter	Far North stock	Single / South stock
$L_\infty$ (cm) (Total length)	80.4	74.4
k	0.16	0.16
$L_0$ (cm)	18.0	18.0
M (year-1)	0.33	0.23

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

Table A8.13. Ageing error matrix of Jack mackerel. 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 A8.14. Input mean body mass (kg) at age over time assumed for Fleet 1 (northern Chile).

Year	Age group (years)											
	1	2	3	4	5	6	7	8	9	10	11	12
1970	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1971	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1972	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1973	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1974	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1975	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1976	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1977	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1978	0.05	0.105	0.124	0.163	0.204	0.314	0.369	0.405	0.434	0.453	0.59	1.115
1979	0.05	0.108	0.163	0.179	0.217	0.274	0.37	0.42	0.474	0.629	0.633	1.115
1980	0.05	0.069	0.118	0.210	0.256	0.324	0.41	0.451	0.511	0.998	0.880	1.115
1981	0.05	0.094	0.139	0.214	0.269	0.331	0.412	0.481	0.58	0.661	1.112	1.115
1982	0.071	0.093	0.168	0.202	0.248	0.305	0.356	0.411	0.446	0.471	0.719	1.115
1983	0.084	0.099	0.119	0.221	0.264	0.314	0.377	0.429	0.475	0.528	0.54	1.115
1984	0.05	0.164	0.186	0.217	0.273	0.345	0.394	0.437	0.497	0.568	0.786	1.115
1985	0.05	0.167	0.173	0.224	0.271	0.34	0.401	0.465	0.536	0.582	0.726	1.115
1986	0.096	0.099	0.143	0.222	0.289	0.332	0.418	0.497	0.55	0.869	0.88	1.115
1987	0.092	0.121	0.146	0.189	0.233	0.336	0.427	0.477	0.513	0.65	0.803	1.115
1988	0.05	0.11	0.167	0.197	0.23	0.298	0.472	0.545	0.586	0.61	0.88	1.115
1989	0.05	0.123	0.167	0.23	0.27	0.31	0.379	0.491	0.541	0.569	0.713	1.115
1990	0.069	0.099	0.16	0.248	0.29	0.338	0.409	0.533	0.651	0.677	0.756	1.115
1991	0.049	0.121	0.143	0.201	0.277	0.366	0.408	0.478	0.637	0.72	0.794	0.883
1992	0.069	0.092	0.127	0.201	0.268	0.3	0.373	0.444	0.512	0.595	0.681	0.786
1993	0.021	0.116	0.152	0.205	0.298	0.364	0.422	0.489	0.528	0.596	0.774	0.889
1994	0.059	0.097	0.107	0.235	0.291	0.33	0.387	0.459	0.565	0.748	0.798	0.898
1995	0.069	0.101	0.137	0.186	0.263	0.321	0.357	0.434	0.561	0.668	0.88	1.115
1996	0.067	0	0.14	0.17	0.229	0.295	0.367	0.507	0.657	0.639	0.88	1.115
1997	0.029	0.063	0.125	0.177	0.246	0.357	0.503	0.615	0.584	0.728	0.88	1.115
1998	0	0.082	0.104	0.195	0.249	0.29	0.39	0.475	0.634	0.728	0.88	1.115
1999	0.071	0.074	0.089	0.147	0.27	0.315	0.446	0.722	0.584	0.728	0.88	1.115
2000	0.043	0.054	0.138	0.191	0.225	0.251	0.372	0.488	0.584	0.728	0.88	1.115
2001	0.066	0.093	0.112	0.133	0.204	0.286	0.421	0.488	0.584	0.728	0.88	1.115
2002	0.029	0.059	0.092	0.172	0.238	0.327	0.398	0.416	0.628	0.728	0.88	1.115
2003	0.036	0.082	0.102	0.141	0.227	0.309	0.416	0.464	0.534	0.728	0.88	1.115
2004	0.037	0.078	0.164	0.186	0.203	0.257	0.342	0.488	0.584	0.728	0.88	1.115
2005	0.029	0.076	0.111	0.175	0.222	0.268	0.281	0.488	0.584	0.728	0.88	1.115
2006	0.032	0.074	0.114	0.132	0.204	0.374	0.442	0.506	0.606	0.728	0.88	1.115
2007	0.087	0.075	0.122	0.158	0.222	0.296	0.404	0.514	0.614	0.723	0.723	1.115
2008	0.042	0.047	0.066	0.187	0.243	0.291	0.388	0.563	0.616	0.748	0.88	1.115
2009	0.015	0.047	0.106	0.138	0.239	0.285	0.335	0.526	0.584	0.728	0.88	1.115
2010	0.013	0.048	0.101	0.172	0.233	0.301	0.397	0.493	0.639	0.772	0.88	1.115
2011	0.019	0.065	0.095	0.167	0.276	0.314	0.398	0.488	0.584	0.728	0.88	1.115
2012	0.016	0.048	0.088	0.202	0.235	0.269	0.396	0.488	0.584	0.728	0.88	1.115
2013	0.038	0.052	0.069	0.151	0.255	0.43	0.495	0.664	0.525	0.687	0.821	1.086
2014	0.018	0.04	0.082	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
2015	0.027	0.058	0.177	0.183	0.298	0.442	0.621	0.52	0.583	0.729	0.868	1.109
2016	0.027	0.058	0.158	0.195	0.235	0.3	0.353	0.535	0.692	0.742	0.859	0.974
2017	0.024	0.063	0.14	0.164	0.181	0.223	0.299	0.4	0.6	0.528	0.88	1.115
2018	0.016	0.041	0.093	0.199	0.235	0.259	0.272	0.323	0.323	0.528	0.88	1.115
2019	0.013	0.033	0.128	0.18	0.28	0.444	0.501	0.528	0.732	0.853	0.888	1.512
2020	0.013	0.033	0.128	0.231	0.283	0.365	0.486	0.622	0.777	1.079	0.888	1.512

Table A8.15. Input mean body mass (kg) at age over time assumed for Fleet 2 (central-south Chile).

Year	Age group (years)											
	1	2	3	4	5	6	7	8	9	10	11	12
1970	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1971	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1972	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1973	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1974	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1975	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1976	0.052	0.078	0.155	0.214	0.275	0.336	0.394	0.472	0.632	0.714	0.898	1.538
1977	0.055	0.092	0.109	0.236	0.275	0.314	0.375	0.456	0.521	0.732	0.651	1.137
1978	0.052	0.084	0.104	0.147	0.211	0.327	0.394	0.449	0.514	0.583	0.631	1.538
1979	0.052	0.108	0.16	0.199	0.241	0.301	0.388	0.466	0.588	0.871	1.265	1.972
1980	0.026	0.06	0.132	0.231	0.272	0.35	0.447	0.519	0.716	0.82	1.073	1.854
1981	0.052	0.095	0.149	0.242	0.294	0.34	0.407	0.503	0.637	0.765	1.184	1.9
1982	0.055	0.085	0.166	0.207	0.269	0.323	0.378	0.472	0.536	0.644	0.987	1.185
1983	0.07	0.099	0.122	0.23	0.273	0.32	0.374	0.461	0.596	0.709	1.196	1.769
1984	0.035	0.135	0.154	0.185	0.266	0.33	0.383	0.449	0.577	0.685	1.012	1.846
1985	0.058	0.148	0.181	0.223	0.27	0.339	0.398	0.473	0.573	0.796	1.376	1.647
1986	0.073	0.075	0.172	0.247	0.286	0.346	0.427	0.518	0.64	0.844	1.351	2.11
1987	0.076	0.117	0.14	0.191	0.27	0.357	0.434	0.503	0.577	0.689	1.089	1.979
1988	0.1	0.124	0.159	0.197	0.233	0.342	0.444	0.512	0.588	0.75	1.012	1.372
1989	0.052	0.103	0.22	0.241	0.278	0.339	0.467	0.585	0.702	0.779	0.88	1.538
1990	0.064	0.091	0.153	0.264	0.309	0.373	0.461	0.582	0.694	0.835	0.97	1.598
1991	0.037	0.106	0.132	0.186	0.271	0.381	0.451	0.542	0.667	0.787	0.901	1.053
1992	0.063	0.083	0.118	0.177	0.239	0.275	0.409	0.524	0.594	0.709	0.851	1.046
1993	0.011	0.089	0.121	0.181	0.246	0.32	0.408	0.579	0.719	0.853	0.965	1.174
1994	0.041	0.084	0.112	0.224	0.27	0.336	0.462	0.643	0.808	0.868	1.058	1.421
1995	0.07	0.098	0.145	0.192	0.27	0.34	0.429	0.577	0.807	0.965	1.115	1.367
1996	0.061	0.092	0.151	0.191	0.28	0.352	0.524	0.683	0.945	1.216	1.426	1.477
1997	0.104	0.106	0.146	0.201	0.26	0.355	0.495	0.683	0.884	1.088	1.467	1.647
1998	0.084	0.128	0.138	0.178	0.248	0.34	0.545	0.806	1.035	1.246	1.412	1.655
1999	0.09	0.109	0.134	0.174	0.25	0.331	0.465	0.742	1.021	1.258	1.376	1.776
2000	0.043	0.064	0.163	0.196	0.255	0.346	0.466	0.756	0.999	1.141	1.228	1.563
2001	0.066	0.098	0.122	0.179	0.258	0.325	0.461	0.614	0.828	1.074	1.36	1.671
2002	0.031	0.074	0.13	0.2	0.257	0.329	0.445	0.645	0.883	1.102	1.321	1.649
2003	0.036	0.086	0.117	0.186	0.245	0.307	0.4	0.564	0.768	1.005	1.209	1.537
2004	0.034	0.08	0.158	0.193	0.247	0.307	0.387	0.528	0.7	0.897	1.087	1.541
2005	0.029	0.075	0.113	0.196	0.259	0.318	0.399	0.517	0.641	0.767	0.918	1.296
2006	0.033	0.076	0.116	0.141	0.261	0.35	0.419	0.516	0.631	0.752	0.924	1.263
2007	0.086	0.074	0.121	0.172	0.226	0.331	0.431	0.51	0.621	0.756	0.903	1.177
2008	0.036	0.048	0.069	0.186	0.254	0.312	0.416	0.515	0.605	0.719	0.861	1.148
2009	0.014	0.045	0.109	0.142	0.253	0.33	0.411	0.532	0.625	0.764	0.886	1.144
2010	0.014	0.052	0.101	0.175	0.237	0.313	0.415	0.539	0.649	0.787	0.964	1.473
2011	0.019	0.067	0.101	0.19	0.287	0.353	0.466	0.613	0.774	0.923	1.173	1.514
2012	0.007	0.014	0.082	0.202	0.264	0.353	0.476	0.558	0.711	0.912	1.146	1.6
2013	0.054	0.158	0.251	0.26	0.318	0.385	0.45	0.553	0.705	0.829	1.117	1.977
2014	0.052	0.093	0.182	0.247	0.375	0.485	0.534	0.682	1.094	1.281	1.302	1.656
2015	0.051	0.112	0.191	0.256	0.345	0.429	0.504	0.627	0.935	1.069	1.206	1.447
2016	0.05	0.131	0.2	0.265	0.316	0.372	0.475	0.572	0.777	0.858	1.11	1.237
2017	0.017	0.058	0.201	0.24	0.303	0.382	0.468	0.562	0.721	0.953	1.096	1.616
2018	0.016	0.031	0.212	0.241	0.305	0.378	0.494	0.594	0.78	0.916	1.346	1.824
2019	0.015	0.025	0.187	0.27	0.305	0.391	0.481	0.579	0.685	0.761	0.898	1.628
2020	0.015	0.025	0.232	0.23	0.309	0.404	0.532	0.613	0.788	0.984	1.271	1.658

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

Year	Age group (years)											
	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

Table A8.17. 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.

Year	Age group (years)											
	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	0.125	0.131	0.193	0.416	0.451	0.617	0.74	0.804	0.968	1.034	1.132	1.164

Table A8.18. Years and types of information used in the JJM assessment models.

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

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

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

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: $i = \{1970, \dots, 2019\}$	$i$	
Fleets (f) and surveys (s)	$f, s$	Identification of information source
Age index: $j = \{1, 2, \dots, 12^+\}$	$j$	
length index: $l = \{10, 11, \dots, 50\}$	$l$	
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	$\Gamma$	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( $\mu_q^s, \sigma_q^2$ )
Stock-recruitment parameters	$R_0$	Unfished equilibrium recruitment
	$h$	Stock-recruitment steepness
	$\sigma_R^2$	Recruitment variance
Unfished biomass	$\phi$	Spawning biomass per recruit when there is no fishing
Estimated parameters		
$\phi(\#), R_0, h, \varepsilon_i(\#), \mu^f, \mu^s, M, \eta_j^s(\#), \eta_j^f(\#), q^s(\#)$		

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

Table A8.20. Variables and equations describing implementation of the Joint Jack Mackerel assessment model (JJM).

Eq	Description	Symbol/Constraints	Key Equation(s)
1)	Survey abundance index (s) by year. The symbol $\Delta^s$ represents the fraction of the year when the survey occurs.	$I_i^s$	$I_i^s = q^s \sum_{j=1}^{12} N_{ij} W_{ij} S_j^s e^{-\Delta^s Z_{ij}}$
2)	Catch biomass by fleet (f=1,2,3,4), year(i) and age (j) /length (l)  (transformation from age to length composition. Fleet 3, FarNorth)	$\hat{C}_{il}, \hat{C}_{ij}, \hat{Y}_i$	$\hat{C}_{i,j}^f = N_{i,j} \frac{F_{i,j}^f}{Z_{i,j}^f} (1 - e^{-Z_{i,j}^f})$ $\hat{Y}_i^f = \sum_{j=1}^{12+} \hat{C}_{i,j}^f w_{i,j}^f$ $\hat{C}_{il} = \Gamma_{lj} \hat{C}_{ij}$
3)	Proportion at age j, in year i  Proportion at length l, in year i		$\Gamma_{l,j} = \int_j^{j+1} e^{-\frac{1}{2\sigma_j^2}(l-L_j)^2} dl$ $L_j = L_{00} (1 - e^{-k}) + e^{-k} L_{j-1}$ $\sigma_j = cv L_j$ $P_{ij}^f = \frac{\hat{C}_{ij}^f}{\sum_j \hat{C}_{ij}^f} \quad P_{ij}^s = \frac{N_{ij} S_j^s e^{-\Delta^s Z_{ij}}}{\sum_j N_{ij} S_j^s e^{-\Delta^s Z_{ij}}}$ $P_{il} = \frac{C_{il}}{\sum_{l=10}^{50} C_{il}}$
4)	Initial numbers at age	$j = 1$	$N_{1970,j} = e^{\mu_R + \varepsilon_{1970}}$
5)	$1 < j < 11$		$N_{1970,j} = e^{\mu_R + \varepsilon_{1971-j}} \prod_{j=1}^j e^{-M}$
6)	$j = 12+$		$N_{1970,12+} = N_{1970,11} e^{-M} (1 - e^{-M})^{-1}$
7)	Subsequent years (i > 1970)	$j = 1$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$
8)	$1 < j < 11$		$N_{i,j} = N_{i-1,j-1} e^{-Z_{i-1,j-1}}$
9)	$j = 12+$		$N_{i,12+} = N_{i-1,11} e^{-Z_{i-1,10}} + N_{i-1,12} e^{-Z_{i-1,11}}$
10)	Year effect and individuals at age 1 and i = 1958, ..., 2020	$\varepsilon_i, \sum_{i=1958}^{2020} \varepsilon_i = 0$	$N_{i,1} = e^{\mu_R + \varepsilon_i}$

Eq	Description	Symbol/Constraints	Key Equation(s)
11)	Index catchability		$q_i^s = e^{\mu^s}$
	Mean effect	$\mu^s, \mu^f$	$s_j^s = e^{\eta_j^s} \quad j \leq \text{maxage}$
	Age effect	$\eta^s_j, \sum_{j=1958}^{2020} \eta^s_j = 0$	$s_j^s = e^{\eta_{\text{maxage}}^s} \quad j > \text{maxage}$
12)	Instantaneous fishing mortality		$F_{ij}^f = e^{\mu^f + \eta_j^f + \phi}$
13)	Mean fishing effect	$\mu^f$	
14)	Annual effect of fishing mortality in year i	$\varphi_i, \sum_{i=1970}^{2020} \varphi_i = 0$	
15)	age effect of fishing (regularised) In year time variation allowed	$\eta^f_j, \sum_{j=1958}^{2020} \eta^f_j = 0$	$s_{ij}^f = e^{\eta_j^f} \quad j \leq \text{maxage}$ $s_{ij}^f = e^{\eta_{\text{maxage}}^f} \quad j > \text{maxage}$
	In years where selectivity is constant over time	$\eta_{i,j}^f = \eta_{i-1,j}^f$	$i \neq \text{change year}$
16)	Natural Mortality	M	fixed
17)	Total mortality		$Z_{ij} = \sum_f F_{ij}^f + M$
17)	Spawning biomass (note spawning taken to occur at mid of November)	$B_i$	$B_i = \sum_{j=2}^{12} N_{ij} e^{-\frac{10.5}{12} Z_{ij}} W_{ij} p_j$
18)	Recruits (Beverton-Holt form) at age 1.	$\tilde{R}_i$	$\tilde{R}_i = \frac{\alpha B_i}{\beta + B_i},$ $\alpha = \frac{4hR_0}{5h-1}$ and $\beta = \frac{B_0(1-h)}{5h-1}$ where $B_0 = R_0 \varphi$ $\varphi = \sum_{j=1}^{12} e^{-M(j-1)} W_j p_j + \frac{e^{-12M} W_{12} p_{12}}{1 - e^{-M}}$ $h=0.8$

Table A8.21 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	$L_1 = 0.5 \sum_s \frac{1}{cv_s^2} \sum_l \log \left( \frac{I_l}{\hat{I}_l} \right)^2$ Surveys / CPUE indexes
20)	Prior on smoothness for selectivities	$L_2 = \sum_l \lambda_2 \sum_{j=1}^{12} (\eta_{j+2}^l + \eta_j^l - 2\eta_{j+1}^l)^2$ Smoothness (second differencing), Note: $l=\{s, f\}$ for survey and fishery selectivity
21)	Prior on recruitment regularity	$L_3 = \lambda_3 \sum_{i=1958}^{2020} \varepsilon_i^2$ $\lambda_3 = \frac{0.5}{\sigma_R^2}$ 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	$L_4 = 0.5 \sum_f \frac{1}{cv_f^2} \sum_{i=1970}^{2020} \log \left( \frac{Y_{f,i}^f}{\hat{Y}_{f,i}^f} \right)^2$ 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 $P_{i,j/l}^v$ are the catch-at-age/length proportions $n$ effective sample size
24)	Dome-shaped selectivity	$L_6 = \lambda_4 \sum_{j=6}^{12} (lnS_{j-1} - lnS_j)^2$ $S_{j-1} > S_j$ (relaxed in final phases of estimation)
25)	Fishing mortality regularity	F values constrained between 0 and 5 (relaxed in final phases of estimation)
26)	Recruitment curve fit	$L_7 = \lambda_5 \sum_{j=1970}^{2015} \log \left( \frac{N_{i,1}}{\tilde{R}_i} \right)^2$ $\lambda_5 = \frac{0.5}{\sigma_R^2}$ Conditioning on stock-recruitment curve over period 1970-2015. (Model 1.00 used the period 2000-2017)
27)	Priors or assumptions	$R_0$ non-informative $\sigma_R = 0.6$
28)	Overall objective function to be minimised	$\dot{L} = \sum_k L_k$

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

<b>Abundance index</b>	<b>CV</b>	<b>Catch biomass likelihood</b>	<b>CV</b>
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)	$\Lambda$	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)	$\lambda$	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	$\lambda$	S – Recruitment curve fit	cv
	1.4		0.6

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

<b>Item</b>	<b>Description</b>	<b>Selectivity assumption</b>
<b>Fisheries</b>		
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 2019.
<b>Index series</b>		
2)	Acoustic survey in Peru	Assumed to be the same as in fishery 1)
3)	Peruvian fishery CPUE	Assumed to be the same as in fishery 1)

Table A8.24. Description of JJM model components and how selectivity was treated (two-stock hypothesis; Southern Stock).

Item	Description	Selectivity assumption
<b>Fisheries</b>		
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.
<b>Index series</b>		
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 A8.25. Description of JJM model components and how selectivity was treated under the single-stock hypothesis.

Item	Description	Selectivity assumption
<b>Fisheries</b>		
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.
<b>Index series</b>		
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 A8.26. Systematic model progression from the 2019 assessment data to the agreed revised datasets for 2020. Note that the data file names corresponding to each model follow the same naming convention, albeit 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”).

<b>Model</b>	<b>Description</b>
<b>Models 0.x</b>	<b>Data introductions</b>
0.00	Exact 2019 (single stock h1 and two-stock h2) model and data set through 2019 (mod1.0 from SC07)
0.01	As 0.00 with revised catches through to 2019
0.02	As 0.01 but with updated 2019 fishery age composition and weight-at-age for N_Chile, SC_Chile (+CPUE), and Offshore_Trawl (+CPUE)
0.03	As 0.02 but with updated 2019 fishery length composition for FarNorth
0.04	As 0.03 but with updated Offshore CPUE Index to 2019
0.05	As 0.04 but with updated catches to projected 2020 estimates; 2019 CTL file
0.06	As 0.05 but with updated 2020 fishery age composition and weight-at-age for N_Chile and SC_Chile (+CPUE); downweighted
0.07	As 0.06 but with updated 2020 fishery length composition for FarNorth
0.08	As 0.07 but with updated 2020 Chile_AcouSN index, age composition, and weight-at- age
0.09	As 0.08 but with replaced SC_Chile_CPUE index (traditional absolute scaled CPUE by trip)
0.10	As 0.09 but with replaced Peru_CPUE index
0.11	As 0.10 but with correct Chile_AcouSN 2018 data point
0.12	As 0.11 but with 2019/2020 N_Chile weight-at-age set to mean(2016,2017,2018)
0.13	As 0.11 but removed Chinese CPUE (as opposed to completely downweight) from both data and control files
<hr/>	
<b>Models 1.x</b>	<b>Updated Model and Sensitivities</b>
1.00	Update model (selectivity changes, recruitment) to 2020; 0.13 data file

Table A8.27.Spawning biomass of Jack mackerel (Model *h1\_1.00*; single-stock) estimated in previous SPRFMO SC meetings.

Year	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8
1970	8761	6726	10082	9770	9928	10319	10289	10629
1971	8112	6384	9164	8872	9037	10015	9964	10214
1972	7818	6173	8527	8289	8457	9854	9783	9964
1973	7726	6015	8042	7911	8079	9756	9666	9794
1974	7676	5910	7673	7633	7800	9646	9538	9625
1975	7763	5894	7446	7511	7675	9604	9480	9534
1976	8141	6075	7454	7638	7799	9752	9610	9638
1977	8810	6589	7808	8027	8186	10113	9948	9955
1978	9551	7151	8224	8445	8603	10459	10267	10256
1979	10189	7613	8553	8810	8965	10717	10497	10473
1980	10854	8276	9085	9349	9494	11124	10881	10847
1981	11171	8521	9213	9561	9693	11174	10920	10878
1982	10806	8122	8679	9137	9252	10513	10263	10217
1983	11092	8503	8926	9487	9578	10584	10358	10310
1984	11122	8635	8942	9653	9722	10502	10310	10264
1985	11554	9342	9557	10297	10351	10869	10721	10679
1986	13159	11355	11531	11890	11936	12177	12075	12039
1987	14919	13284	13459	13371	13411	13402	13344	13314
1988	15496	13717	13895	13801	13830	13717	13702	13679
1989	15050	13082	13256	13389	13406	13455	13472	13454
1990	14228	12207	12371	12701	12699	13076	13116	13101
1991	13098	11032	11197	11792	11763	12408	12467	12455
1992	11909	9856	10018	10772	10716	11542	11610	11602
1993	10802	8942	9082	9800	9722	10658	10726	10720
1994	9271	7518	7634	8165	8070	9061	9127	9123
1995	7154	5448	5532	5901	5794	6696	6761	6758
1996	5819	3820	3862	4174	4073	4775	4832	4831
1997	4950	2991	2965	3254	3181	3609	3655	3657
1998	4985	3158	3074	3539	3498	3677	3724	3730
1999	5668	3937	3795	4475	4457	4434	4499	4511
2000	6671	5018	4834	5616	5624	5463	5556	5574
2001	7481	5892	5690	6368	6404	6172	6298	6323
2002	8083	6699	6544	7010	7073	6805	6965	6997
2003	8201	6952	6848	7274	7349	7080	7270	7309
2004	7641	6564	6475	6908	6979	6725	6935	6980
2005	6708	5763	5676	6159	6225	5997	6213	6262
2006	5486	4682	4595	5102	5160	4979	5195	5248
2007	4119	3430	3324	3846	3890	3754	3973	4029
2008	3067	2545	2382	2890	2915	2779	2998	3055
2009	2130	1850	1598	2070	2074	1893	2103	2159
2010	1709	1647	1291	1775	1758	1538	1728	1778
2011	1855	1861	1382	1868	1832	1667	1817	1855
2012	2304	2115	1552	2065	2015	1980	2068	2090
2013	3085	2383	1814	2308	2248	2339	2362	2370
2014		2738	2222	2667	2572	2725	2687	2691
2015			2720	3273	3103	3176	3019	3042
2016				4116	3885	3606	3390	3456
2017					5294	4097	3915	4047
2018						4777	4821	5078
2019							6188	6673
2020								8273

Table A8.28. Estimated begin-year numbers at age (Model  $h_{-1.00}$ ; single-stock hypothesis), 1970-2020. Green shading reflects relative level with darker green indicating a stronger cohort.

Year	Age group (years)											
	1	2	3	4	5	6	7	8	9	10	11	12
1970	9996.41	6719.33	4903.88	3674.91	2508.11	2003.14	1541.75	1343.78	1169.97	1013.78	872.133	4281.24
1971	9664.94	7940.81	5335.73	3888.52	2908.15	1973.83	1558.62	1180.2	1034.55	919.72	798.433	4058.69
1972	10151.2	7676.35	6303.31	4225.27	3070.69	2277.94	1520.28	1171.72	894.726	808.987	721.267	3809.07
1973	10642.9	8060.88	6090.84	4983.87	3341.26	2418.98	1776.98	1168.48	902.987	702.227	637.74	3571.35
1974	13025.3	8446.24	6387.14	4792.14	3928.78	2622.91	1874.54	1350.03	890.516	705.299	552.529	3311.82
1975	18314.2	10313.6	6657.97	4933.2	3736.7	3057.15	2003.84	1391.14	1010.8	692.12	551.078	3019.37
1976	21770.9	14534.6	8171.79	5237.68	3874.22	2900.65	2310.26	1455.49	1020.64	779.479	538.883	2779.94
1977	21068.8	17274.1	11509.9	6415.89	4102.91	2991.13	2166.17	1642.61	1047.35	781.15	604.069	2571.97
1978	21911.8	16572.7	13413.4	8423.25	4862.4	3133.12	2220.53	1530.61	1170.01	794.17	603.3	2452.93
1979	21998.8	17290.4	12958.6	10064	6410.84	3638.12	2201.78	1414.69	990.887	854.409	597.54	2299.53
1980	22944.6	17380.7	13557.9	9821.47	7693.74	4784.82	2514.45	1341.37	861.165	695.032	622.025	2109.12
1981	27961.3	18108.8	13597.6	10191.5	7506.26	5797.29	3389.45	1610.75	858.279	614.654	513.251	2016.84
1982	32551.1	22094.3	14163.4	10185.6	7721.59	5502.19	3842.14	1913.43	902.401	573.387	439.669	1809.8
1983	26779	25766.4	17426.3	10961.1	7710.12	5400.68	3218.73	1697.12	832.484	528.886	369.453	1449.41
1984	43545.2	21247	20376.3	13574.7	8441.12	5624.27	3462.88	1680.44	849.488	503.838	345.703	1188.89
1985	52645	34532.5	16745.1	15689	10175.7	5920.38	3335.06	1542.63	692.29	449.886	290.22	883.953
1986	29003.3	41767.3	27285.9	13029.5	11873.6	7239.61	3631.03	1577.57	664.453	363.17	261.291	681.954
1987	27143.9	23025.9	33090.3	21469.9	10084.3	8824.94	4862.4	1952.29	728.514	351.974	212.996	553.205
1988	32363.2	21536.5	18178.4	25774.4	16299	7342.9	5824.45	2531.12	825.543	338.393	181.738	395.62
1989	28118.2	25643.4	16846.4	13989.4	19249.4	11515.1	4782.63	3157.18	1066.98	331.635	146.305	249.621
1990	30578.1	22275	20069.2	12914.7	10500.9	13608.8	7382.58	2710.15	1523.91	454.272	135.577	161.86
1991	21169.5	24223.9	17496.8	15361.1	9647.81	7521.95	8916.89	4271.2	1380.09	685.745	182.657	119.596
1992	21830.8	16771.9	19037.3	13425.7	11452.7	6933.56	4977.23	5074.86	2016.77	572.926	245.244	108.095
1993	15401.4	17294.3	13166.7	14549.8	9963.08	8116.31	4579.42	2948	2386.46	745.013	165.244	101.91
1994	14442.5	12189.1	13451.3	9776.69	10493.6	6879.74	5294.66	2751.18	1552.36	991.567	219.103	78.5681
1995	18938.6	11419.4	9439.93	9832.77	6730.83	6734.79	4103.73	2937.23	1313.07	532.237	241.58	72.523
1996	21075.8	14890.4	8551.08	6183.19	5832.67	3608.46	3263.15	1881.26	1221.34	407.95	111.38	65.7317
1997	28539.9	16502.2	10830.8	5314.34	3283.72	2638.76	1563.65	1433.74	785.296	429.367	110.774	48.0925
1998	27080.7	22303.2	11808	6490.82	2484.56	1255.61	1049.37	683.534	606.978	280.571	126.538	46.8191
1999	31975.8	21219.8	16248.7	7968.69	3590.1	1263.89	654.681	573.017	367.526	299.058	124.604	76.9894
2000	33055	25216.4	16107	11516	4943.65	2090.83	744.756	400.985	351.081	214.079	162.522	109.555
2001	21902.2	25965.4	18991.7	11735.3	7461.51	2971.44	1283.94	480.619	261.75	222.296	129.75	164.902
2002	14943.3	16929.1	18158.9	12886.5	7451.58	4151.38	1690.88	786.155	300.283	158.259	127.493	168.991
2003	8428.18	11777.6	13075.4	13425.8	8797.84	4557.27	2465.98	1047.07	490.618	178.733	88.1103	165.067
2004	8621.21	6604.32	8898.39	9569.1	9333.42	5573.24	2736.32	1515.37	650.528	289.953	98.4491	139.455
2005	6707.36	6764.2	5054.68	6479.98	6655.45	6031.54	3288.08	1613.99	904.323	369.403	154.987	127.166
2006	6858.66	5262.07	5151.5	3661.02	4521.89	4433.56	3580.12	1924.23	952.462	511.028	198.859	151.89
2007	4667.06	5349.14	3842.67	3511.57	2422.39	2967.33	2648.76	1954.6	1052.87	498.751	259.09	177.829
2008	4168.17	3642.1	3919.46	2439.14	2158.13	1489.14	1731.16	1405.55	949.009	483.109	216.53	189.686
2009	7479.52	3247.91	2622.34	2487.62	1502.35	1319.39	845.154	919.625	694.214	447.166	214.323	180.211
2010	9337.17	5845.47	2402.77	1758.95	1463.66	844.905	654.72	389.864	390.615	284.356	174.402	153.875
2011	5158.33	7269.88	4216.06	1637.15	1057.54	854.796	474.672	362.912	207.84	189.497	137.933	159.238
2012	8708.09	4046.1	5241.67	2791.96	1158.94	728.145	538.27	305.622	238.692	132.255	123.794	194.134
2013	7309.98	6885.65	3137.5	3787.69	2061.66	798.093	454.774	342.739	205.273	162.072	91.315	219.512
2014	9659.29	5786.02	5368.54	2389.29	2831.92	1466.57	524.754	301.02	236.352	143.789	114.686	219.948
2015	9467.33	7644.13	4504.06	4080.79	1799.54	2058.22	1031.76	357.062	206.592	164.438	101.076	235.231
2016	14963.5	7497.47	5989.92	3495.18	3055.62	1314.77	1488.67	719.52	239.796	138.836	112.323	229.723
2017	36368.7	11864.8	5908.18	4679.32	2651.11	2236.05	933.156	1041.84	493.422	162.966	95.6258	235.591
2018	24830.1	28826.4	9355.05	4623.16	3570.11	1964.41	1610.33	651.534	721.186	338.897	112.736	229.128
2019	11066.3	19679.7	22668.3	7331.03	3564.17	2654.2	1406.05	1118.14	445.861	495.81	235.435	237.497
2020	12492.8	8768.61	15511.5	17674.5	5696.95	2681.72	1911.47	966.211	766.025	306.898	349.425	333.301

Table A8.29. Estimated begin-year numbers at age (Model  $h_{-2.00}$ ; two-stock hypothesis; southern stock), 1970-2020. Green shading reflects relative level with darker green indicating a stronger cohort.

Year	Age group (years)											
	1	2	3	4	5	6	7	8	9	10	11	12
1970	9422.19	6324.58	4584.99	3413.09	2324.47	1853.76	1424.21	1239.76	1078.44	933.852	802.883	3648.74
1971	9078.01	7485.5	5023.5	3638.91	2701.51	1828.37	1440.14	1086.84	951.393	846.621	734.632	3501.96
1972	9497.01	7211.73	5944.71	3984.84	2875.02	2114.7	1405.16	1077.87	820.153	742.514	662.848	3316.97
1973	10079	7545.15	5728.62	4719.36	3156.69	2265.16	1648.07	1077.51	828.456	642.91	584.885	3134.94
1974	12130.5	8007.39	5993.07	4546.7	3735.01	2479.91	1753.72	1248.72	818.572	646.182	505.514	2924.86
1975	16340.5	9636.48	6358.77	4752.84	3589.09	2915.97	1894.19	1297.68	931.778	635.695	504.729	2679.44
1976	19904.2	12980.4	7651.37	5040.33	3744.84	2786.69	2199.19	1369.25	946.721	716.683	494.072	2474.79
1977	19738	15810.6	10304.9	6061.77	3963.92	2892.33	2076.62	1555.33	978.967	722.374	554.26	2296.02
1978	18897.8	15678.9	12552.6	8165.79	4769.64	3062.49	2155.11	1466.63	1105.7	742.974	559.116	2206.11
1979	19947.8	15008.2	12439.3	9922.12	6368.38	3594.12	2153.44	1366.62	942.187	804.709	558.124	2077.25
1980	22512	15842.1	11907.1	9832.6	7736.28	4781.01	2485.36	1305.5	823.53	656.44	583.04	1909.42
1981	27970	17880.7	12573.4	9424.24	7700.58	5875.95	3396.82	1591.11	831.284	585.613	483.622	1836.28
1982	27888	22212.2	14183.4	9931.07	7320.63	5694.01	3911.16	1919.64	886.669	552.321	417.424	1653.62
1983	26474	22137.3	17594.2	11147.5	7580.96	5142.69	3343.4	1729.74	827.161	513.323	352.244	1320.82
1984	50829.3	21022.5	17555.1	13884.6	8635.73	5544.68	3302.4	1743.3	856.983	494.071	331.82	1081.49
1985	62133.6	40338.3	16635.2	13739.1	10490.2	6073.65	3286.24	1457.84	704.334	443.633	278.904	797.815
1986	27353	49311.7	31924.4	13036.9	10452.2	7471.18	3723.46	1543.78	615.41	361.261	252.725	613.376
1987	15308.3	21718.9	39091.7	25176.5	10115.4	7762.76	5012.17	1996.71	702.222	318.784	207.757	498.084
1988	18733.8	12147.9	17173.2	30526.8	19166.5	7372.83	5105.56	2595.96	833.648	318.508	160.633	355.667
1989	25692.6	14862.9	9599.85	13390.6	22994.4	13643	4818.16	2753.42	1079.74	325.679	132.835	215.325
1990	29430.5	20382.5	11745.6	7499.16	10166.8	16439.3	8884.91	2765.26	1332.09	452.498	128.417	137.282
1991	23264.2	23345.9	16102.3	9175.51	5709.05	7348.02	11011.6	5313.87	1441.5	597.352	175.914	103.294
1992	18497.7	18445.7	18410	12485.3	6897.22	4102.04	4931.61	6568.05	2658	611.189	207.34	96.9123
1993	16941	14659.8	14513.1	14168.4	9296.15	4865.53	2708.95	3007.23	3347.6	1054.48	175.876	87.5518
1994	18200	13420.5	11489.7	10909.9	10294.9	6429.35	3138.4	1615.9	1637.38	1508.43	319.541	79.8268
1995	18868.4	14415.8	10500	8627.85	7618.62	6601.85	3748.45	1651.64	733.867	559.522	378.049	100.091
1996	21994.6	14924.1	11182	7557.78	5224.75	3963.5	2939.97	1510.6	585.723	200.648	115.926	99.0647
1997	26361	17363.4	11453.3	7592.03	4022.1	2180.41	1494.13	1079.82	521.984	175.883	52.1027	55.8271
1998	23856.9	20861	13426.8	7645.37	3474.56	1416.58	784.045	585.46	410.934	172.377	50.9865	31.2877
1999	27431.4	18916.1	16298.1	9408.16	4208.58	1734.24	720.615	416.127	306.748	198.899	76.0737	36.3094
2000	26999.4	21752.7	14818	11721.2	5893.57	2478.78	1028.27	440.552	253.616	177.441	106.762	60.3233
2001	22239.7	21392.1	17026.1	11036.7	7738.4	3626.01	1544.35	665.641	286.45	158.634	104.961	98.8353
2002	11812.8	17571.3	16582.2	12316.9	7216.31	4446.19	2104.41	952.772	414.326	169.861	87.5281	112.447
2003	8470.74	9351.55	13752.5	12445.1	8488.18	4489.01	2686.93	1315.07	593.349	240.675	89.352	105.193
2004	6327.33	6696.91	7285.3	10276.1	8726.99	5446.83	2743.22	1675.47	821.189	344.394	125.059	101.089
2005	3060.17	4998.34	5214.09	5462.03	7214.8	5699.26	3273.9	1649.77	1010.49	459.695	174.039	114.284
2006	4837.64	2408.88	3829.01	3794.94	3833	4832.92	3435.45	1950.63	984.011	563.776	234.603	147.144
2007	5745.49	3804.04	1841.77	2738.4	2578.96	2562.75	2936.31	1919.59	1083.48	510.531	273.109	184.929
2008	4861.59	4503.76	2865.28	1251.36	1739.09	1617.82	1524.72	1585.05	948.55	492.761	211.152	189.441
2009	4712.58	3791.81	3281.3	1918.65	782.307	1075.72	926.358	818.327	785.952	435.988	207.056	168.327
2010	4501.95	3677.97	2826.05	2238.51	1148.2	447.307	532.592	417.725	337.944	300.939	154.391	132.93
2011	4915.44	3485.51	2608.33	1905.96	1341.96	670.525	243.03	281.337	211.304	151.058	132.819	126.809
2012	8091.37	3883.93	2698.34	1990.22	1408.07	935.478	406.181	147.023	178.288	129.636	94.6688	162.71
2013	9967.52	6414.91	3061.02	2103.65	1498.37	968.342	574.688	252.316	96.9608	118.678	87.5604	173.842
2014	10183.9	7900.03	5036.43	2384.15	1587.09	1042	623.391	374.899	171.088	66.3868	81.9263	180.453
2015	11971.3	8070.59	6201.93	3933.08	1798.69	1111.33	700.672	414.705	253.557	115.776	45.1267	178.353
2016	16389.7	9486.31	6370.55	4840.88	2940.59	1294.07	772.151	467.752	271.31	165.71	76.0475	146.793
2017	18609.9	12999.4	7505.14	4996.59	3682.41	2137.45	895.244	515.331	307.278	178.294	110.383	148.439
2018	17266.3	14745	10265.2	5883.5	3821.05	2738.06	1526.76	608.338	340.88	201.986	118.887	172.584
2019	13553.1	13693	11669.2	8094.19	4554.09	2858.22	1978.41	1052.29	403.983	223.068	134.55	194.159
2020	13675.1	10750.1	10852.5	9221.83	6321.21	3458.17	2086.28	1382.28	713.229	268.54	151.442	223.163

Table A8.30. Estimated begin-year numbers at age (Model *h2\_1.00*; two-stock hypothesis; far north stock), 1970-2020. Green shading reflects relative level with darker green indicating higher mortality.

Year	Age group (years)											
	1	2	3	4	5	6	7	8	9	10	11	12
1970	4386.89	3077.94	2209.85	1587.22	1140.44	819.499	589.023	423.421	304.4	218.843	157.336	416.695
1971	4389.86	3153.54	2209.89	1581.87	1139.92	819.791	589.145	423.459	304.405	218.838	157.33	412.681
1972	4392.1	3155.4	2261.34	1575.42	1134.98	819.332	589.344	423.544	304.43	218.841	157.326	409.788
1973	4392.82	3156.15	2254.06	1592.1	1127.01	815.498	588.98	423.677	304.485	218.854	157.324	407.697
1974	4385.92	3155.03	2238.26	1549.64	1132.54	809.254	586.159	423.398	304.568	218.884	157.327	406.174
1975	4357.39	3143.36	2171.53	1395.21	1077.04	811.062	581.405	421.296	304.313	218.905	157.321	405.012
1976	4307.31	3129.61	2229.48	1493.54	992.577	773.377	582.971	417.953	302.856	218.761	157.364	404.242
1977	4091.6	3092.82	2211.5	1514.85	1059.47	712.495	555.853	419.07	300.446	217.709	157.257	403.711
1978	6125.02	2893.08	1761.52	741.555	908.986	746.079	510.412	399.074	300.871	215.705	156.304	402.746
1979	4214.13	4330.02	1643.31	585.463	444.037	639.952	534.449	366.444	286.51	216.006	154.863	401.363
1980	3818.55	2989.18	2578.36	637.442	363.646	313.928	458.755	383.806	263.156	205.753	155.122	399.445
1981	4285.01	2708.5	1779.09	998.582	395.785	257.082	225.041	329.447	275.624	188.981	147.758	398.253
1982	6495.71	3025.22	1510.05	556.289	589.355	278.183	184.107	161.548	236.497	197.859	135.662	391.959
1983	4109.27	4642.76	2004.18	830.646	375.346	420.635	199.743	132.296	116.085	169.942	142.178	379.138
1984	3346.81	2944.01	3179.17	1228.51	575.028	268.68	302.18	143.559	95.0835	83.4327	122.141	374.68
1985	2505.03	2396.38	1999.78	1898.06	845.159	411.323	192.993	217.172	103.174	68.3352	59.9619	357.059
1986	4070.38	1795.54	1651.89	1252.79	1320.76	605.339	295.52	138.713	156.092	74.156	49.1158	299.732
1987	6152.5	2921.49	1261.44	1101.24	884.692	947.582	435.04	212.428	99.711	112.203	53.3053	250.762
1988	432.9	4414.91	2045.97	832.26	775.762	634.546	680.967	312.712	152.696	71.6737	80.6533	218.568
1989	5636.3	7446.98	2871.27	1059.34	553.555	552.768	455.493	489.277	224.685	109.713	51.4978	214.991
1990	5444.4	4028.12	4926.97	1572.53	714.03	395.036	396.895	327.306	351.583	161.453	78.8369	191.493
1991	2701.6	3893.73	2691.62	2787.55	1068.14	510.007	283.684	285.215	235.208	252.653	116.023	194.263
1992	4266.46	1933.95	2636.28	1589.89	1912.86	763.825	366.321	203.876	204.976	169.037	181.575	222.994
1993	2721.86	3059.52	1341.97	1687.68	1112.02	1370.88	548.835	263.302	146.541	147.332	121.5	290.795
1994	2175.45	1948.27	2068.75	789.28	1156.94	795.11	984.636	394.429	189.227	105.314	105.883	296.302
1995	4226.82	1552.64	1264.87	1065.05	524.259	824.246	570.735	707.458	283.396	135.959	75.6679	288.969
1996	4562.87	2935.02	685.962	184.629	524.755	360.942	588.183	409.153	507.168	203.163	97.467	261.403
1997	4390.85	3091.6	919.465	32.4824	69.6666	350.414	256.221	420.817	292.729	362.854	145.354	256.755
1998	3769.72	2822.78	463.754	3.90483	6.92119	43.5741	245.968	182.529	299.786	208.537	258.493	286.458
1999	3981.6	2456.94	513.171	3.69589	0.96587	4.40355	30.676	175.421	130.178	213.803	148.726	388.652
2000	7221.29	2787.81	1219.57	109.689	1.99325	0.6719	3.14797	22.0062	125.843	93.386	153.377	385.501
2001	1642.46	5092.91	1531.64	363.457	64.005	1.39916	0.48107	2.25961	15.796	90.3295	67.0323	386.806
2002	4169.54	1111	1558.59	67.1804	134.677	42.6516	0.99286	0.34413	1.61642	11.2997	64.6177	324.655
2003	1215.9	2971.49	644.691	806.944	45.212	96.0056	30.6098	0.71329	0.24723	1.16127	8.11798	279.662
2004	1875.91	863.056	1562.42	286.987	526.819	32.1043	68.8452	21.9837	0.51228	0.17756	0.83401	206.681
2005	4606.22	1334.67	480.74	759.78	190.721	374.94	23.0326	49.4532	15.7914	0.36798	0.12755	149.063
2006	2220.45	3288.84	810.786	266.998	518.597	136.203	269.184	16.5496	35.5336	11.3466	0.26441	107.198
2007	693.19	1570.32	1580.76	314.529	169.555	366.941	97.5996	193.269	11.8823	25.5124	8.14662	77.1555
2008	304.935	491.655	810.387	683.813	204.163	120.309	263.092	70.0908	138.795	8.53321	18.3216	61.2594
2009	1386.23	215.748	238.89	319.646	435.704	144.521	86.2176	188.901	50.3255	99.6555	6.12688	57.1395
2010	5022.11	977.386	96.2694	82.6963	198.391	307.384	103.497	61.8874	135.594	36.1239	71.5332	45.413
2011	1332.31	3592.96	623.539	57.6328	57.3034	141.956	220.771	74.3774	44.475	97.444	25.9602	84.0426
2012	1857.53	934.998	1429.93	181.148	34.5315	40.2444	101.565	158.411	53.3685	31.9125	69.9197	78.9311
2013	485.767	1320.5	510.412	674.19	119.638	24.5566	28.8679	72.9522	113.783	38.3334	22.922	106.916
2014	1425.03	346.817	801.039	282.861	459.975	85.4349	17.6299	20.7423	52.418	81.7561	27.5435	93.292
2015	1099.77	1017.22	209.412	440.778	192.71	328.412	61.334	12.6674	14.9037	37.6631	58.743	86.8221
2016	1797.84	788.193	677.578	133.94	309.522	138.126	235.957	44.0835	9.1046	10.7119	27.0701	104.624
2017	7429.68	1290.67	547.193	461.732	95.2611	222.215	99.2739	169.616	31.6891	6.54477	7.70018	94.6673
2018	5151.16	5337.46	911.383	382.716	330.119	68.4368	159.733	71.3662	121.934	22.7807	4.70491	73.5901
2019	1301.61	3695.62	3647.06	606.122	270.868	236.854	49.1805	114.817	51.2983	87.6464	16.3749	56.2788
2020	2160.98	933.329	2492.84	2378.04	427.282	194.243	170.191	35.3497	82.5272	36.8719	62.998	52.2216

Table A8.31. Estimated total fishing mortality at age (Model *h1\_1.00*; single-stock hypothesis), 1970-2020. Green shading reflects relative level with darker green indicating higher mortality.

Year	Age group (years)											
	1	2	3	4	5	6	7	8	9	10	11	12
1970	0	0.001	0.002	0.004	0.01	0.021	0.037	0.032	0.011	0.009	0.009	0.009
1971	0	0.001	0.003	0.006	0.014	0.031	0.055	0.047	0.016	0.013	0.013	0.013
1972	0.001	0.001	0.005	0.005	0.009	0.018	0.033	0.031	0.012	0.008	0.008	0.008
1973	0.001	0.003	0.01	0.008	0.012	0.025	0.045	0.042	0.017	0.01	0.01	0.01
1974	0.003	0.008	0.028	0.019	0.021	0.039	0.068	0.059	0.022	0.017	0.017	0.017
1975	0.001	0.003	0.01	0.012	0.023	0.05	0.09	0.08	0.03	0.02	0.02	0.02
1976	0.001	0.003	0.012	0.014	0.029	0.062	0.111	0.099	0.037	0.025	0.025	0.025
1977	0.01	0.023	0.082	0.047	0.04	0.068	0.117	0.109	0.047	0.028	0.028	0.028
1978	0.007	0.016	0.057	0.043	0.06	0.123	0.221	0.205	0.084	0.054	0.054	0.054
1979	0.006	0.013	0.047	0.039	0.063	0.139	0.266	0.266	0.125	0.087	0.087	0.087
1980	0.007	0.015	0.055	0.039	0.053	0.115	0.215	0.217	0.107	0.073	0.073	0.073
1981	0.005	0.016	0.059	0.048	0.081	0.181	0.342	0.349	0.173	0.105	0.105	0.105
1982	0.004	0.007	0.026	0.048	0.127	0.306	0.587	0.602	0.304	0.21	0.21	0.21
1983	0.001	0.005	0.02	0.031	0.085	0.214	0.42	0.462	0.272	0.195	0.195	0.195
1984	0.002	0.008	0.031	0.058	0.125	0.293	0.579	0.657	0.406	0.322	0.322	0.322
1985	0.001	0.006	0.021	0.049	0.11	0.259	0.519	0.612	0.415	0.313	0.313	0.313
1986	0.001	0.003	0.01	0.026	0.067	0.168	0.391	0.543	0.405	0.304	0.304	0.304
1987	0.001	0.006	0.02	0.046	0.087	0.186	0.423	0.631	0.537	0.431	0.431	0.431
1988	0.003	0.016	0.032	0.062	0.117	0.199	0.382	0.634	0.682	0.609	0.609	0.609
1989	0.003	0.015	0.036	0.057	0.117	0.215	0.338	0.498	0.624	0.664	0.664	0.664
1990	0.003	0.011	0.037	0.062	0.104	0.193	0.317	0.445	0.569	0.681	0.681	0.681
1991	0.003	0.011	0.035	0.064	0.1	0.183	0.334	0.52	0.649	0.798	0.798	0.798
1992	0.003	0.012	0.039	0.068	0.114	0.185	0.294	0.524	0.766	1.013	1.013	1.013
1993	0.004	0.021	0.068	0.097	0.14	0.197	0.28	0.411	0.648	0.994	0.994	0.994
1994	0.005	0.026	0.083	0.143	0.213	0.287	0.359	0.51	0.84	1.182	1.182	1.182
1995	0.01	0.059	0.193	0.292	0.393	0.495	0.55	0.648	0.939	1.334	1.334	1.334
1996	0.015	0.088	0.246	0.403	0.563	0.606	0.592	0.644	0.815	1.074	1.074	1.074
1997	0.017	0.105	0.282	0.53	0.731	0.692	0.598	0.63	0.799	0.992	0.992	0.992
1998	0.014	0.087	0.163	0.362	0.446	0.421	0.375	0.39	0.478	0.582	0.582	0.582
1999	0.007	0.046	0.114	0.247	0.311	0.299	0.26	0.26	0.31	0.38	0.38	0.38
2000	0.011	0.053	0.087	0.204	0.279	0.258	0.208	0.197	0.227	0.271	0.271	0.271
2001	0.028	0.128	0.158	0.224	0.356	0.334	0.261	0.24	0.273	0.326	0.326	0.326
2002	0.008	0.028	0.072	0.152	0.262	0.291	0.249	0.241	0.289	0.356	0.356	0.356
2003	0.014	0.05	0.082	0.134	0.227	0.28	0.257	0.246	0.296	0.366	0.366	0.366
2004	0.013	0.037	0.087	0.133	0.207	0.298	0.298	0.286	0.336	0.396	0.396	0.396
2005	0.013	0.042	0.093	0.13	0.176	0.292	0.306	0.297	0.341	0.389	0.389	0.389
2006	0.019	0.084	0.153	0.183	0.191	0.285	0.375	0.373	0.417	0.449	0.449	0.449
2007	0.018	0.081	0.225	0.257	0.257	0.309	0.404	0.493	0.549	0.604	0.604	0.604
2008	0.019	0.098	0.225	0.255	0.262	0.336	0.403	0.475	0.522	0.583	0.583	0.583
2009	0.017	0.071	0.169	0.3	0.346	0.471	0.544	0.626	0.663	0.712	0.712	0.712
2010	0.02	0.097	0.154	0.279	0.308	0.347	0.36	0.399	0.493	0.493	0.493	0.493
2011	0.013	0.097	0.182	0.115	0.143	0.233	0.21	0.189	0.222	0.196	0.196	0.196
2012	0.005	0.024	0.095	0.073	0.143	0.241	0.221	0.168	0.157	0.14	0.14	0.14
2013	0.004	0.019	0.042	0.061	0.111	0.189	0.183	0.142	0.126	0.116	0.116	0.116
2014	0.004	0.02	0.044	0.053	0.089	0.122	0.155	0.146	0.133	0.122	0.122	0.122
2015	0.003	0.014	0.024	0.059	0.084	0.094	0.13	0.168	0.167	0.151	0.151	0.151
2016	0.002	0.008	0.017	0.046	0.082	0.113	0.127	0.147	0.156	0.143	0.143	0.143
2017	0.002	0.008	0.015	0.041	0.07	0.098	0.129	0.138	0.146	0.138	0.138	0.138
2018	0.002	0.01	0.014	0.03	0.066	0.104	0.135	0.149	0.145	0.134	0.134	0.134
2019	0.003	0.008	0.019	0.022	0.054	0.098	0.145	0.148	0.143	0.12	0.12	0.12
2020	0.004	0.008	0.021	0.019	0.042	0.081	0.116	0.122	0.106	0.089	0.089	0.089

Table A8.32. Estimated total fishing mortality at age (Model *h2\_1.00*; two-stock hypothesis; southern stock), 1970-2020. Green shading reflects relative level with darker green indicating higher mortality.

Year	Age group (years)											
	1	2	3	4	5	6	7	8	9	10	11	12
1970	9.91E-05	0.00032	0.0011	0.00381	0.01007	0.02247	0.04035	0.03474	0.01202	0.00995	0.00995	0.00995
1971	1.46E-04	0.00047	0.00163	0.00563	0.0149	0.03327	0.05976	0.05154	0.01789	0.01471	0.01471	0.01471
1972	7.18E-05	0.00023	0.00083	0.00297	0.00841	0.01931	0.0355	0.03318	0.01349	0.00863	0.00863	0.00863
1973	9.17E-05	0.0003	0.00107	0.00392	0.0113	0.02591	0.04748	0.04485	0.01848	0.01043	0.01043	0.01043
1974	1.65E-04	0.00053	0.00186	0.0065	0.01755	0.03943	0.07116	0.06278	0.02284	0.01706	0.01706	0.01706
1975	2.07E-04	0.00067	0.00236	0.00836	0.02305	0.05211	0.09453	0.08533	0.03246	0.02204	0.02204	0.02204
1976	2.53E-04	0.00082	0.00288	0.01024	0.02832	0.06411	0.1164	0.10552	0.04046	0.027	0.027	0.027
1977	2.28E-04	0.00075	0.00267	0.00973	0.02801	0.06422	0.11778	0.11121	0.04584	0.02619	0.02619	0.02619
1978	4.48E-04	0.00146	0.00517	0.01861	0.05297	0.12216	0.2255	0.21252	0.08775	0.05608	0.05608	0.05608
1979	4.47E-04	0.00146	0.00516	0.01885	0.05669	0.13888	0.27048	0.2765	0.13137	0.09223	0.09223	0.09223
1980	3.29E-04	0.00108	0.00385	0.01441	0.04505	0.11181	0.21598	0.22137	0.11094	0.07553	0.07553	0.07553
1981	4.91E-04	0.00164	0.00592	0.02259	0.07188	0.17703	0.3407	0.35472	0.17884	0.10856	0.10856	0.10856
1982	9.30E-04	0.00307	0.01086	0.04003	0.12312	0.30243	0.58586	0.6119	0.31657	0.21981	0.21981	0.21981
1983	5.67E-04	0.00192	0.00679	0.02531	0.0828	0.21293	0.42121	0.47231	0.28532	0.20632	0.20632	0.20632
1984	1.17E-03	0.00407	0.0151	0.05034	0.12195	0.2931	0.58769	0.67628	0.42842	0.34181	0.34181	0.34181
1985	1.13E-03	0.00393	0.01374	0.04343	0.10939	0.25931	0.52551	0.63243	0.43765	0.3327	0.3327	0.3327
1986	6.40E-04	0.00225	0.00746	0.02372	0.06747	0.16919	0.39315	0.55774	0.42778	0.32323	0.32323	0.32323
1987	1.23E-03	0.00483	0.0173	0.04275	0.08626	0.18901	0.42791	0.64345	0.5606	0.45539	0.45539	0.45539
1988	1.46E-03	0.00541	0.0188	0.05335	0.10994	0.19541	0.38749	0.64724	0.7099	0.64454	0.64454	0.64454
1989	1.53E-03	0.00539	0.01696	0.04543	0.10558	0.19887	0.32526	0.49609	0.63969	0.70063	0.70063	0.70063
1990	1.61E-03	0.00571	0.01694	0.04274	0.09469	0.17073	0.28403	0.42145	0.572	0.71479	0.71479	0.71479
1991	2.08E-03	0.00753	0.02441	0.05542	0.10057	0.16877	0.28673	0.46275	0.62803	0.82815	0.82815	0.82815
1992	2.53E-03	0.00978	0.03188	0.06495	0.11894	0.18492	0.26465	0.44397	0.69452	1.01563	1.01563	1.01563
1993	2.95E-03	0.01366	0.05538	0.08937	0.13873	0.20846	0.28667	0.37792	0.56718	0.96392	0.96392	0.96392
1994	3.10E-03	0.01541	0.05645	0.12908	0.2143	0.30953	0.41195	0.55932	0.84377	1.1538	1.1538	1.1538
1995	4.51E-03	0.02401	0.0988	0.27159	0.42347	0.57895	0.67884	0.80668	1.06678	1.34413	1.34413	1.34413
1996	6.43E-03	0.0347	0.15721	0.40077	0.64389	0.74558	0.77161	0.83263	0.97303	1.11833	1.11833	1.11833
1997	4.00E-03	0.02711	0.17418	0.55163	0.81356	0.7928	0.7069	0.73612	0.87795	1.00826	1.00826	1.00826
1998	2.06E-03	0.01684	0.12568	0.36698	0.46469	0.44589	0.40348	0.41637	0.49564	0.58798	0.58798	0.58798
1999	1.95E-03	0.01417	0.09965	0.23772	0.29936	0.29269	0.26208	0.26517	0.31739	0.3922	0.3922	0.3922
2000	2.79E-03	0.01499	0.06461	0.18521	0.25573	0.24317	0.20488	0.20046	0.23922	0.29505	0.29505	0.29505
2001	5.61E-03	0.02469	0.09377	0.19489	0.32415	0.3141	0.25298	0.2441	0.29259	0.36464	0.36464	0.36464
2002	3.64E-03	0.01504	0.05701	0.1423	0.24471	0.27365	0.24014	0.24359	0.31321	0.4124	0.4124	0.4124
2003	4.97E-03	0.01968	0.06141	0.12491	0.21364	0.2625	0.2423	0.2409	0.314	0.42466	0.42466	0.42466
2004	5.77E-03	0.02028	0.05804	0.12368	0.19608	0.27905	0.2785	0.27566	0.35019	0.45251	0.45251	0.45251
2005	9.31E-03	0.0365	0.0877	0.12417	0.17068	0.27619	0.28783	0.28675	0.35353	0.44267	0.44267	0.44267
2006	1.04E-02	0.03843	0.10523	0.15628	0.17257	0.2683	0.35204	0.35798	0.42619	0.49479	0.49479	0.49479
2007	1.35E-02	0.0534	0.1565	0.22401	0.23631	0.28927	0.38654	0.47493	0.55791	0.65287	0.65287	0.65287
2008	1.85E-02	0.08667	0.17104	0.23974	0.25037	0.32758	0.3923	0.47148	0.54732	0.63704	0.63704	0.63704
2009	1.79E-02	0.06396	0.15243	0.28343	0.329	0.47299	0.56644	0.65438	0.72999	0.80812	0.80812	0.80812
2010	2.59E-02	0.11365	0.16389	0.28168	0.30789	0.38006	0.4082	0.45153	0.57521	0.58792	0.58792	0.58792
2011	5.53E-03	0.02598	0.04046	0.07277	0.13083	0.27126	0.2726	0.22616	0.25857	0.23728	0.23728	0.23728
2012	2.17E-03	0.00881	0.01896	0.05387	0.14439	0.25723	0.24612	0.18628	0.17699	0.1624	0.1624	0.1624
2013	2.46E-03	0.01193	0.01991	0.05177	0.13323	0.21041	0.19717	0.1585	0.14881	0.14059	0.14059	0.14059
2014	2.58E-03	0.01201	0.01727	0.05178	0.12635	0.16686	0.17761	0.16107	0.16052	0.15602	0.15602	0.15602
2015	2.66E-03	0.00654	0.01777	0.06081	0.09927	0.13413	0.1741	0.1943	0.19535	0.1903	0.1903	0.1903
2016	1.75E-03	0.00426	0.01293	0.04353	0.089	0.13845	0.17437	0.19019	0.18983	0.17628	0.17628	0.17628
2017	2.79E-03	0.00614	0.01344	0.03823	0.06632	0.10647	0.15637	0.18328	0.18955	0.17526	0.17526	0.17526
2018	1.87E-03	0.00395	0.00762	0.02613	0.06033	0.09496	0.14217	0.17936	0.19406	0.17626	0.17626	0.17626
2019	1.69E-03	0.00249	0.00538	0.01724	0.04529	0.08481	0.12856	0.15893	0.17837	0.15727	0.15727	0.15727
2020	3.38E-03	0.00323	0.00511	0.01437	0.03558	0.06912	0.1056	0.12759	0.12879	0.1156	0.1156	0.1156

Table A8.33. Estimated total fishing mortality at age (Model *h2\_1.00*; two-stock hypothesis; far north stock), 1970-2020. Green shading reflects relative level with darker green indicating higher mortality.

Year	Age group (years)											
	1	2	3	4	5	6	7	8	9	10	11	12
1970	9.41E-05	0.00132	0.00432	0.00102	0.00012	2.01E-05	7.69E-06	7.69E-06	7.69E-06	7.69E-06	7.69E-06	7.69E-06
1971	1.83E-04	0.00257	0.00842	0.00199	0.00023	3.92E-05	1.50E-05	1.50E-05	1.50E-05	1.50E-05	1.50E-05	1.50E-05
1972	4.55E-04	0.00638	0.0209	0.00495	0.00057	9.74E-05	3.72E-05	3.72E-05	3.72E-05	3.72E-05	3.72E-05	3.72E-05
1973	9.74E-04	0.01365	0.04471	0.0106	0.00121	2.08E-04	7.96E-05	7.96E-05	7.96E-05	7.96E-05	7.96E-05	7.96E-05
1974	3.11E-03	0.04356	0.14266	0.03381	0.00387	6.65E-04	2.54E-04	2.54E-04	2.54E-04	2.54E-04	2.54E-04	2.54E-04
1975	9.65E-04	0.01352	0.04428	0.01049	0.0012	2.06E-04	7.88E-05	7.88E-05	7.88E-05	7.88E-05	7.88E-05	7.88E-05
1976	1.23E-03	0.01724	0.05645	0.01338	0.00153	2.63E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04
1977	1.66E-02	0.23291	0.76268	0.18074	0.0207	3.55E-03	1.36E-03	1.36E-03	1.36E-03	1.36E-03	1.36E-03	1.36E-03
1978	1.68E-02	0.23561	0.77153	0.18284	0.02094	3.60E-03	1.37E-03	1.37E-03	1.37E-03	1.37E-03	1.37E-03	1.37E-03
1979	1.34E-02	0.18842	0.617	0.14622	0.01674	2.88E-03	1.10E-03	1.10E-03	1.10E-03	1.10E-03	1.10E-03	1.10E-03
1980	1.35E-02	0.1889	0.61857	0.14659	0.01679	2.88E-03	1.10E-03	1.10E-03	1.10E-03	1.10E-03	1.10E-03	1.10E-03
1981	1.81E-02	0.25425	0.83257	0.19731	0.02259	3.88E-03	1.48E-03	1.48E-03	1.48E-03	1.48E-03	1.48E-03	1.48E-03
1982	5.83E-03	0.08175	0.26769	0.06344	0.00726	1.25E-03	4.76E-04	4.76E-04	4.76E-04	4.76E-04	4.76E-04	4.76E-04
1983	3.47E-03	0.04869	0.15944	0.03778	0.00433	7.43E-04	2.84E-04	2.84E-04	2.84E-04	2.84E-04	2.84E-04	2.84E-04
1984	4.05E-03	0.05674	0.18579	0.04403	0.00504	8.66E-04	3.31E-04	3.31E-04	3.31E-04	3.31E-04	3.31E-04	3.31E-04
1985	3.00E-03	0.04204	0.13766	0.03262	0.00374	6.42E-04	2.45E-04	2.45E-04	2.45E-04	2.45E-04	2.45E-04	2.45E-04
1986	1.64E-03	0.02305	0.07548	0.01789	0.00205	3.52E-04	1.34E-04	1.34E-04	1.34E-04	1.34E-04	1.34E-04	1.34E-04
1987	1.87E-03	0.02622	0.08586	0.02035	0.00233	4.00E-04	1.53E-04	1.53E-04	1.53E-04	1.53E-04	1.53E-04	1.53E-04
1988	7.15E-03	0.10023	0.32823	0.07778	0.00891	1.53E-03	5.84E-04	5.84E-04	5.84E-04	5.84E-04	5.84E-04	5.84E-04
1989	5.93E-03	0.08308	0.27207	0.06448	0.00738	1.27E-03	4.84E-04	4.84E-04	4.84E-04	4.84E-04	4.84E-04	4.84E-04
1990	5.22E-03	0.07316	0.23956	0.05677	0.0065	1.12E-03	4.26E-04	4.26E-04	4.26E-04	4.26E-04	4.26E-04	4.26E-04
1991	4.28E-03	0.06	0.19647	0.04656	0.00533	9.16E-04	3.50E-04	3.50E-04	3.50E-04	3.50E-04	3.50E-04	3.50E-04
1992	2.53E-03	0.03543	0.11601	0.02749	0.00315	5.41E-04	2.06E-04	2.06E-04	2.06E-04	2.06E-04	2.06E-04	2.06E-04
1993	4.37E-03	0.06131	0.20077	0.04758	0.00545	9.36E-04	3.57E-04	3.57E-04	3.57E-04	3.57E-04	3.57E-04	3.57E-04
1994	7.28E-03	0.10198	0.33393	0.07914	0.00906	1.56E-03	5.94E-04	5.94E-04	5.94E-04	5.94E-04	5.94E-04	5.94E-04
1995	3.47E-02	0.48689	1.59437	0.37784	0.04327	7.43E-03	2.84E-03	2.84E-03	2.84E-03	2.84E-03	2.84E-03	2.84E-03
1996	5.93E-02	0.83068	2.72012	0.64643	0.07382	1.27E-02	4.84E-03	4.84E-03	4.84E-03	4.84E-03	4.84E-03	4.84E-03
1997	1.12E-01	1.56709	5.13158	1.21611	0.13926	2.39E-02	9.13E-03	9.13E-03	9.13E-03	9.13E-03	9.13E-03	9.13E-03
1998	9.81E-02	1.37487	4.50213	1.06694	0.12218	2.10E-02	8.01E-03	8.01E-03	8.01E-03	8.01E-03	8.01E-03	8.01E-03
1999	2.64E-02	0.37042	1.21296	0.28745	0.03292	5.65E-03	2.16E-03	2.16E-03	2.16E-03	2.16E-03	2.16E-03	2.16E-03
2000	1.92E-02	0.26892	0.88059	0.20869	0.0239	4.10E-03	1.57E-03	1.57E-03	1.57E-03	1.57E-03	1.57E-03	1.57E-03
2001	6.09E-02	0.85407	2.79671	0.66278	0.0759	1.30E-02	4.98E-03	4.98E-03	4.98E-03	4.98E-03	4.98E-03	4.98E-03
2002	8.74E-03	0.21425	0.32828	0.06602	0.00847	1.74E-03	6.99E-04	6.99E-04	6.99E-04	6.99E-04	6.99E-04	6.99E-04
2003	1.28E-02	0.31283	0.47934	0.0964	0.01237	2.55E-03	1.02E-03	1.02E-03	1.02E-03	1.02E-03	1.02E-03	1.02E-03
2004	1.04E-02	0.25515	0.39096	0.07862	0.01009	2.08E-03	8.33E-04	8.33E-04	8.33E-04	8.33E-04	8.33E-04	8.33E-04
2005	6.87E-03	0.16843	0.25808	0.0519	0.00666	1.37E-03	5.50E-04	5.50E-04	5.50E-04	5.50E-04	5.50E-04	5.50E-04
2006	1.64E-02	0.40263	0.61693	0.12407	0.01592	3.28E-03	1.31E-03	1.31E-03	1.31E-03	1.31E-03	1.31E-03	1.31E-03
2007	1.35E-02	0.33152	0.50798	0.10216	0.01311	2.70E-03	1.08E-03	1.08E-03	1.08E-03	1.08E-03	1.08E-03	1.08E-03
2008	1.60E-02	0.39177	0.6003	0.12072	0.0155	3.19E-03	1.28E-03	1.28E-03	1.28E-03	1.28E-03	1.28E-03	1.28E-03
2009	1.95E-02	0.47696	0.73083	0.14697	0.01886	3.88E-03	1.56E-03	1.56E-03	1.56E-03	1.56E-03	1.56E-03	1.56E-03
2010	4.87E-03	0.11947	0.18306	0.03681	0.00473	9.72E-04	3.90E-04	3.90E-04	3.90E-04	3.90E-04	3.90E-04	3.90E-04
2011	2.41E-02	0.59135	0.9061	0.18222	0.02339	4.81E-03	1.93E-03	1.93E-03	1.93E-03	1.93E-03	1.93E-03	1.93E-03
2012	1.12E-02	0.27533	0.42187	0.08484	0.01089	2.24E-03	8.99E-04	8.99E-04	8.99E-04	8.99E-04	8.99E-04	8.99E-04
2013	6.93E-03	0.16986	0.26026	0.05234	0.00672	1.38E-03	5.55E-04	5.55E-04	5.55E-04	5.55E-04	5.55E-04	5.55E-04
2014	7.12E-03	0.17449	0.26737	0.05377	0.0069	1.42E-03	5.70E-04	5.70E-04	5.70E-04	5.70E-04	5.70E-04	5.70E-04
2015	3.11E-03	0.0763	0.11692	0.02351	0.00302	6.21E-04	2.49E-04	2.49E-04	2.49E-04	2.49E-04	2.49E-04	2.49E-04
2016	1.43E-03	0.03494	0.05354	0.01077	0.00138	2.84E-04	1.14E-04	1.14E-04	1.14E-04	1.14E-04	1.14E-04	1.14E-04
2017	7.33E-04	0.01795	0.02751	0.00553	0.00071	1.46E-04	5.86E-05	5.86E-05	5.86E-05	5.86E-05	5.86E-05	5.86E-05
2018	2.07E-03	0.05083	0.07788	0.01566	0.00201	4.14E-04	1.66E-04	1.66E-04	1.66E-04	1.66E-04	1.66E-04	1.66E-04
2019	2.60E-03	0.06373	0.09765	0.01964	0.00252	5.19E-04	2.08E-04	2.08E-04	2.08E-04	2.08E-04	2.08E-04	2.08E-04
2020	3.55E-03	0.08708	0.13342	0.02683	0.00344	7.09E-04	2.84E-04	2.84E-04	2.84E-04	2.84E-04	2.84E-04	2.84E-04

Table A8.34. Summary of results for Model *h1\_1.00* (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	10629	9996	0.01	0.13	4178
1971	168	10214	9665	0.02	0.14	4153
1972	111	9964	10151	0.01	0.13	4024
1973	164	9794	10643	0.02	0.13	3903
1974	323	9625	13025	0.03	0.12	3889
1975	299	9534	18314	0.03	0.13	4068
1976	396	9638	21771	0.04	0.14	4066
1977	848	9955	21069	0.05	0.12	3954
1978	1025	10256	21912	0.08	0.13	3953
1979	1302	10473	21999	0.1	0.13	4332
1980	1316	10847	22945	0.09	0.13	4231
1981	1945	10878	27961	0.13	0.13	4230
1982	2372	10217	32551	0.22	0.14	4261
1983	1870	10310	26779	0.17	0.13	4752
1984	2687	10264	43545	0.26	0.13	4732
1985	2371	10679	52645	0.24	0.14	4763
1986	2073	12039	29003	0.21	0.13	5293
1987	2680	13314	27144	0.27	0.13	5287
1988	3246	13679	32363	0.33	0.15	4891
1989	3582	13454	28118	0.32	0.15	4923
1990	3715	13101	30578	0.32	0.15	4982
1991	3778	12455	21170	0.36	0.18	4555
1992	3362	11602	21831	0.42	0.18	4858
1993	3370	10720	15401	0.4	0.16	4961
1994	4275	9123	14442	0.5	0.15	5052
1995	4955	6758	18939	0.63	0.14	4894
1996	4379	4831	21076	0.6	0.12	4885
1997	3597	3657	28540	0.61	0.11	4876
1998	2026	3730	27081	0.37	0.11	4947
1999	1423	4511	31976	0.25	0.11	5062
2000	1540	5574	33055	0.19	0.11	4780
2001	2528	6323	21902	0.25	0.11	4780
2002	1750	6997	14943	0.22	0.11	5025
2003	1797	7309	8428	0.22	0.11	4993
2004	1934	6980	8621	0.24	0.12	4925
2005	1755	6262	6707	0.24	0.12	4797
2006	2020	5248	6859	0.29	0.13	4571
2007	1997	4029	4667	0.37	0.13	4517
2008	1473	3055	4168	0.36	0.12	4598
2009	1283	2159	7480	0.45	0.13	4687
2010	727	1778	9337	0.33	0.11	5001
2011	635	1855	5158	0.17	0.12	4295
2012	455	2090	8708	0.13	0.12	4302
2013	353	2370	7310	0.1	0.12	4359
2014	411	2691	9659	0.09	0.12	4518
2015	394	3042	9467	0.1	0.13	4593
2016	389	3456	14964	0.09	0.14	4476
2017	405	4047	36369	0.09	0.13	4757
2018	526	5078	24830	0.09	0.13	4839
2019	632	6673	11066	0.08	0.14	4491
2020	650	8273	12493	0.07	0.13	4583

Table A8.35. Summary of results for Model *h2\_1.00* (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 <sub>MSY</sub> ('000 t)
1970	117	9447	9422	0.01	0.13	3603
1971	168	9141	9078	0.02	0.13	3602
1972	111	8982	9497	0.01	0.14	3592
1973	164	8892	10079	0.02	0.14	3569
1974	323	8811	12130	0.02	0.13	3594
1975	299	8781	16340	0.03	0.14	3586
1976	396	8903	19904	0.04	0.13	3605
1977	848	9306	19738	0.04	0.14	3554
1978	1025	9711	18898	0.07	0.14	3609
1979	1302	10005	19948	0.1	0.13	4007
1980	1316	10438	22512	0.08	0.13	3880
1981	1945	10555	27970	0.12	0.13	3838
1982	2372	9960	27888	0.22	0.14	3657
1983	1870	10066	26474	0.18	0.13	4085
1984	2687	9985	50829	0.27	0.13	4085
1985	2371	10504	62134	0.25	0.13	4072
1986	2073	12246	27353	0.22	0.13	4492
1987	2680	13983	15308	0.28	0.13	4474
1988	3246	14430	18734	0.34	0.15	4203
1989	3582	13738	25693	0.33	0.15	4283
1990	3715	12729	29430	0.31	0.15	4394
1991	3778	11677	23264	0.35	0.18	3947
1992	3362	10711	18498	0.41	0.17	4161
1993	3370	9871	16941	0.39	0.16	4218
1994	4275	8305	18200	0.5	0.15	4293
1995	4955	6169	18868	0.67	0.13	4220
1996	4379	4525	21995	0.66	0.12	4168
1997	3597	3622	26361	0.64	0.11	4192
1998	2026	3865	23857	0.38	0.11	4229
1999	1423	4688	27431	0.25	0.11	4326
2000	1540	5680	26999	0.19	0.11	4137
2001	2528	6393	22240	0.24	0.11	4270
2002	1750	7037	11813	0.23	0.11	4341
2003	1797	7346	8471	0.23	0.12	4380
2004	1934	7010	6327	0.25	0.12	4340
2005	1755	6240	3060	0.25	0.12	4157
2006	2020	5142	4838	0.28	0.12	4147
2007	1997	3830	5745	0.36	0.13	4091
2008	1473	2807	4862	0.37	0.12	4121
2009	1283	1939	4713	0.47	0.12	4083
2010	727	1556	4502	0.37	0.11	4275
2011	635	1566	4915	0.17	0.12	4089
2012	455	1688	8091	0.13	0.12	4010
2013	353	1896	9968	0.11	0.12	3877
2014	411	2242	10184	0.11	0.12	3916
2015	394	2705	11971	0.12	0.13	3884
2016	389	3260	16390	0.11	0.14	3787
2017	405	3961	18610	0.11	0.13	4044
2018	526	4849	17266	0.1	0.13	4229
2019	632	5879	13553	0.09	0.15	3994
2020	650	6906	13675	0.07	0.14	4128

Table A8.36. Summary of results for Model *h2\_1.00* (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 <sub>MSY</sub> ('000 t)
1970	117	5862	4387	0	0.1	1731
1971	168	5852	4390	0	0.1	1731
1972	111	5846	4392	0	0.1	1745
1973	164	5824	4393	0.01	0.1	1735
1974	323	5738	4386	0.02	0.1	1733
1975	299	5669	4357	0.01	0.1	1738
1976	396	5625	4307	0.01	0.1	1724
1977	848	5249	4092	0.1	0.1	1737
1978	1025	4748	6125	0.1	0.1	1739
1979	1302	4346	4214	0.08	0.1	1731
1980	1316	4019	3819	0.08	0.1	1730
1981	1945	3591	4285	0.11	0.1	1724
1982	2372	3360	6496	0.04	0.1	1726
1983	1870	3408	4109	0.02	0.1	1715
1984	2687	3640	3347	0.02	0.1	1722
1985	2371	3777	2505	0.02	0.1	1727
1986	2073	3860	4070	0.01	0.1	1725
1987	2680	3897	6152	0.01	0.1	1733
1988	3246	3967	10433	0.04	0.1	1729
1989	3582	4250	5636	0.04	0.1	1725
1990	3715	4736	5444	0.03	0.1	1724
1991	3778	5005	2702	0.03	0.1	1726
1992	3362	5196	4266	0.02	0.1	1727
1993	3370	5141	2722	0.03	0.1	1731
1994	4275	4970	2175	0.04	0.1	1738
1995	4955	4350	4227	0.21	0.1	1730
1996	4379	3673	4563	0.36	0.1	1730
1997	3597	2986	4391	0.69	0.1	1717
1998	2026	2402	3770	0.6	0.1	1721
1999	1423	1981	3982	0.16	0.1	667
2000	1540	1706	7221	0.12	0.1	670
2001	2528	1347	1642	0.37	0.1	670
2002	1750	1269	4170	0.05	0.1	676
2003	1797	1241	1216	0.08	0.1	673
2004	1934	1297	1876	0.06	0.1	674
2005	1755	1302	4606	0.04	0.1	676
2006	2020	1356	2220	0.1	0.1	676
2007	1997	1428	693	0.08	0.1	674
2008	1473	1377	305	0.1	0.1	676
2009	1283	1252	1386	0.12	0.1	674
2010	727	1149	5022	0.03	0.1	673
2011	635	1117	1332	0.15	0.1	683
2012	455	1138	1858	0.07	0.1	681
2013	353	1133	486	0.04	0.1	681
2014	411	1143	1425	0.04	0.1	681
2015	394	1118	1100	0.02	0.1	680
2016	389	1157	1798	0.01	0.1	680
2017	405	1212	7430	0	0.1	680
2018	526	1485	5151	0.01	0.1	680
2019	632	2161	1302	0.02	0.1	680
2020	650	2643	2161	0.02	0.1	680

Table A8.37. Summary results for the short, medium and long-term predictions for Model *h1\_1.00* (single-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 taken to be 5.5 million tonnes of spawning biomass in all cases.

F	B <sub>2022</sub>	P(B <sub>2022&gt;B<sub>MSY</sub></sub> )	B <sub>2025</sub>	P(B <sub>2065&gt;B<sub>MSY</sub></sub> )	B <sub>2030</sub>	P(B <sub>2030&gt;B<sub>MSY</sub></sub> )	Catch 2021 (kt)	Catch 2022 (kt)
0	10905	100	13900	100	14467	100	0	0
0.75 × F <sub>2020</sub>	10043	100	10381	100	9570	100	582	750
F <sub>2020</sub>	9775	100	9463	100	8436	99	769	974
1.25 × F <sub>2020</sub>	9517	100	8648	100	7480	95	953	1186
F <sub>MSY</sub>	8798	100	6707	95	5397	44	1483	1757

Table A8.38. Summary results for the short, medium and long-term predictions for Model *h2\_1.00* (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 <sub>2022</sub>	P(B <sub>2022&gt;B<sub>MSY</sub></sub> )	B <sub>2025</sub>	P(B <sub>2065&gt;B<sub>MSY</sub></sub> )	B <sub>2030</sub>	P(B <sub>2030&gt;B<sub>MSY</sub></sub> )	Catch 2021 (kt)	Catch 2022(kt)
0	9851	100	12612	100	12888	100	0	0
0.75 × F <sub>2020</sub>	9075	100	9393	100	8376	100	496	627
F <sub>2020</sub>	8837	100	8574	100	7382	100	655	811
1.25 × F <sub>2020</sub>	8609	100	7855	100	6559	99	809	983
F <sub>MSY</sub>	8007	100	6239	100	4885	97	1232	1416

#### Far North Stock:

F	B <sub>2022</sub>	P(B <sub>2022&gt;B<sub>MSY</sub></sub> )	B <sub>2025</sub>	P(B <sub>2065&gt;B<sub>MSY</sub></sub> )	B <sub>2030</sub>	P(B <sub>2030&gt;B<sub>MSY</sub></sub> )	Catch 2021 (kt)	Catch 2022 (kt)
0	2996	100	2862	100	2568	100	0	0
0.75 × F <sub>2020</sub>	2917	100	2594	99	2195	98	50	47
F <sub>2020</sub>	2893	99	2515	99	2086	97	66	60
1.25 × F <sub>2020</sub>	2869	99	2440	99	1983	95	82	73
F <sub>MSY</sub>	2659	99	1855	94	1210	39	233	171

## 9. Figures

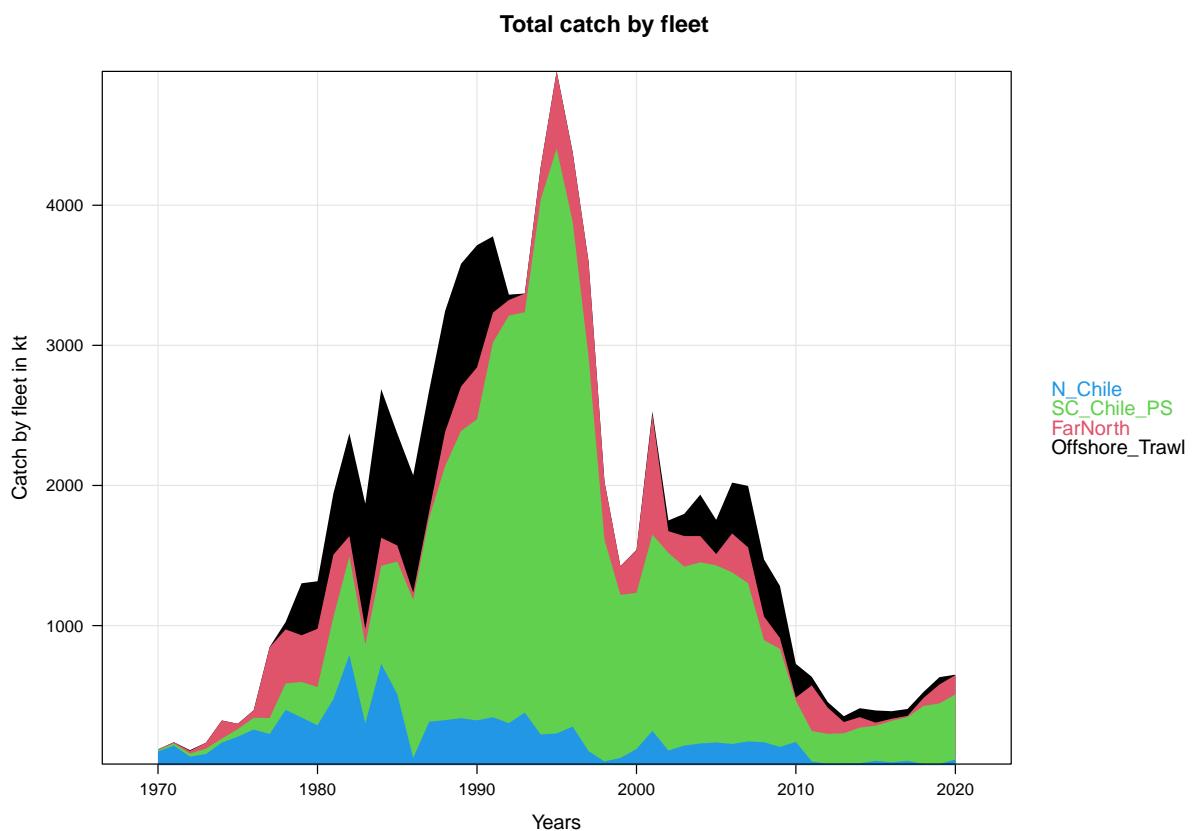


Figure A8.1. Catch of Jack mackerel by fleet. Blue is the northern Chilean fleet, green is the south-central Chilean fleet, red is the far north fleet, and black is the offshore trawl fleet.

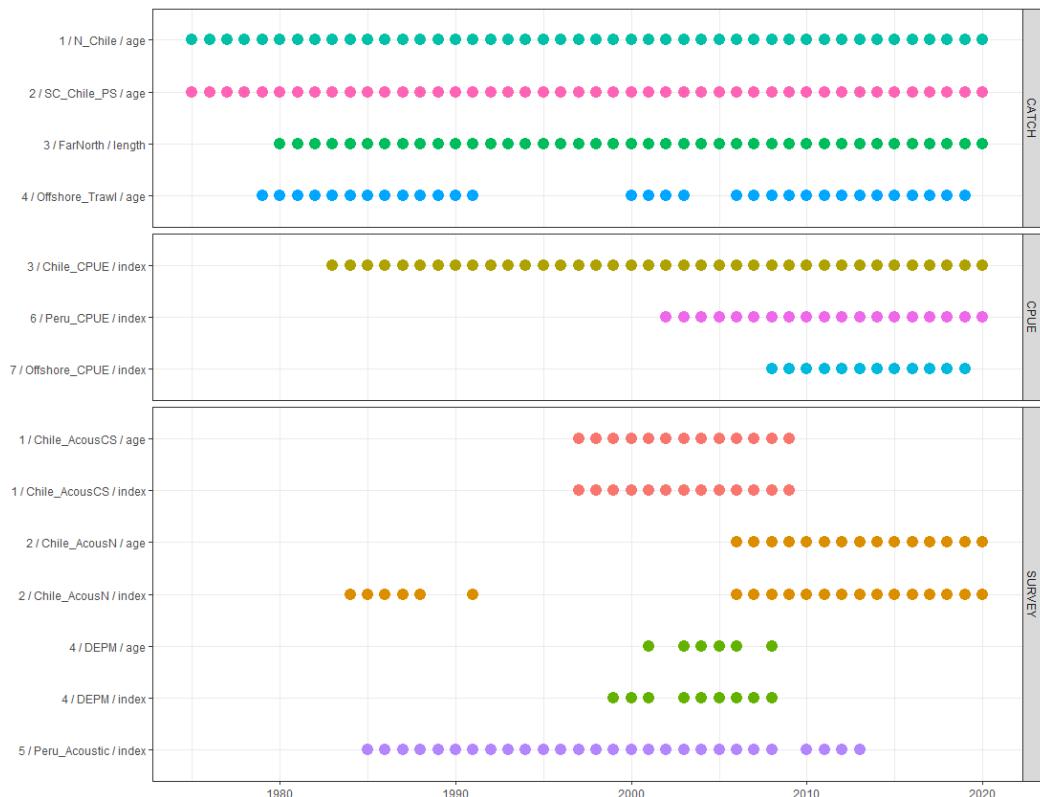


Figure A8.2. Years and types of information used in the JJM assessment models.

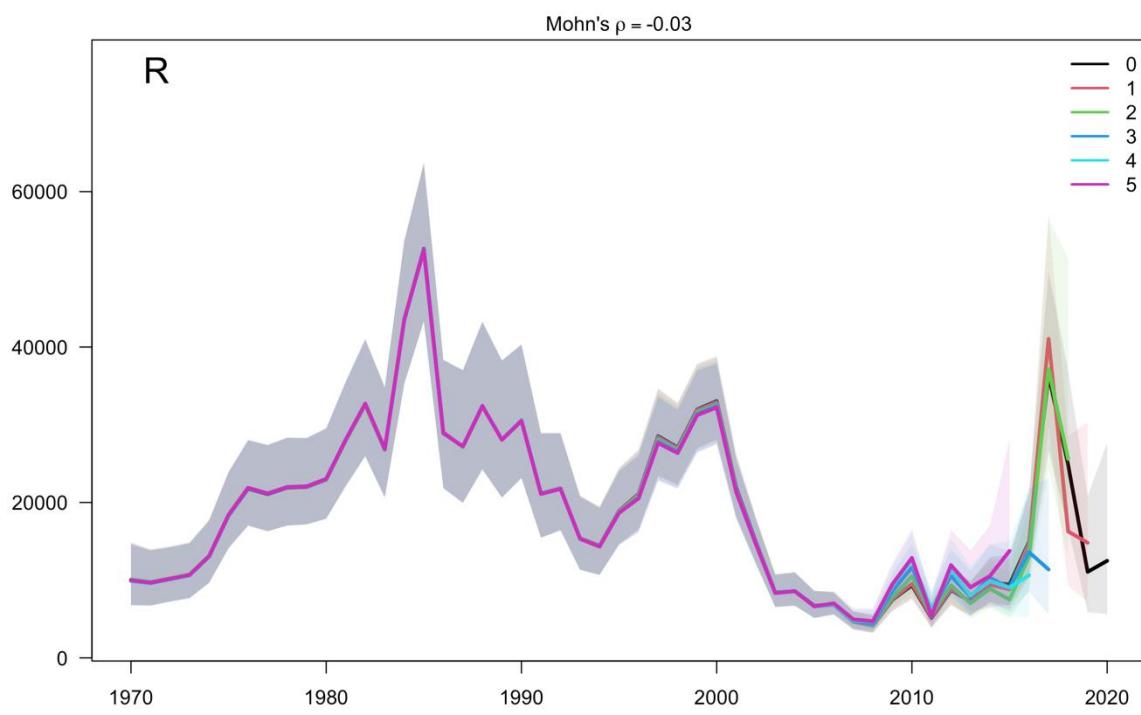
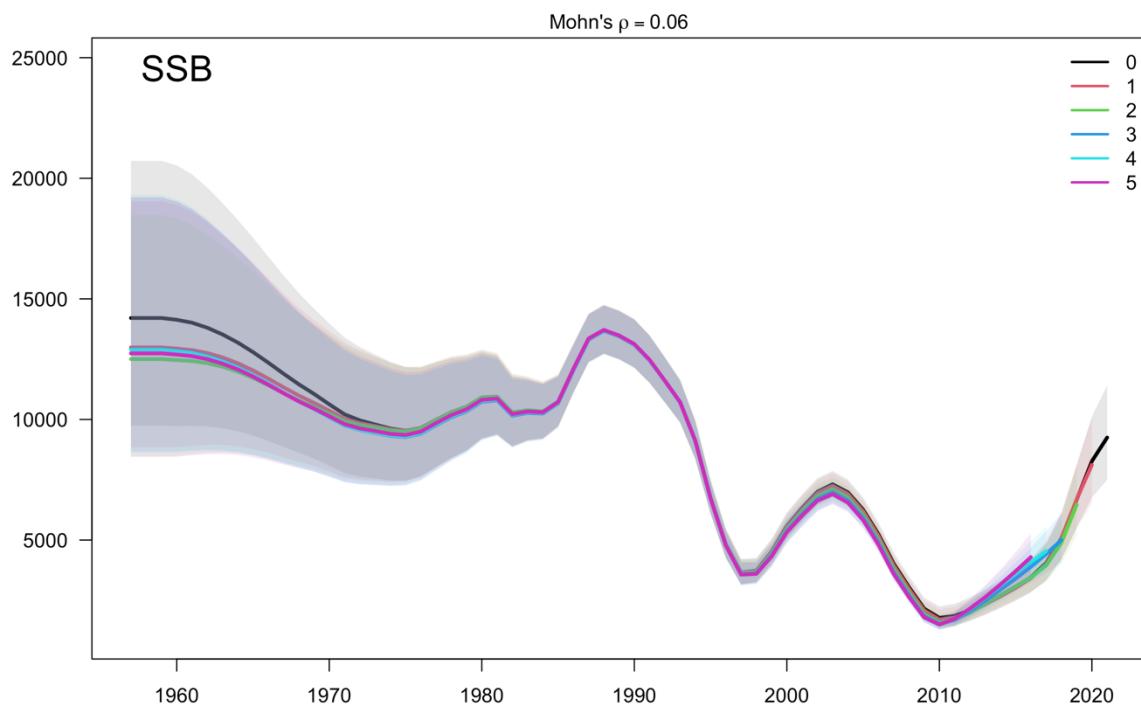


Figure A8.3. Model retrospective of spawning biomass (top) and recruitment (bottom) from 5 separate model runs, based on Model *h1\_1.00* (single-stock hypothesis).

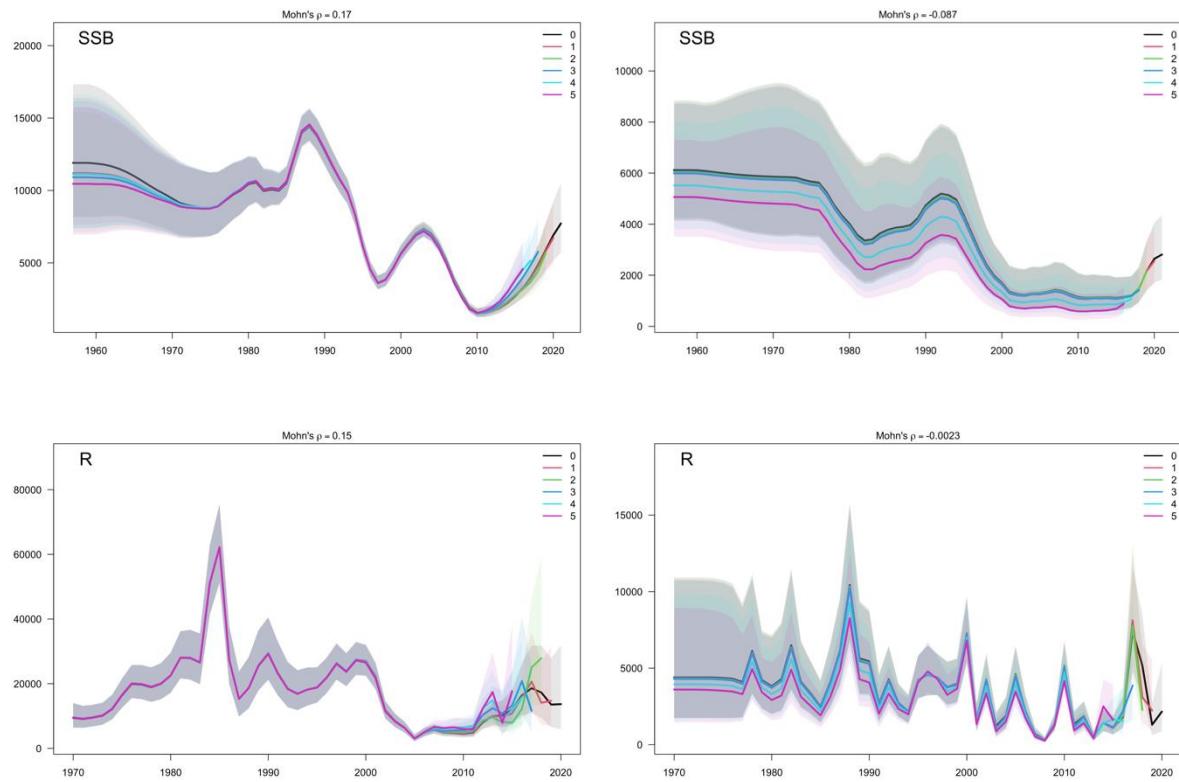


Figure A8.4. Model retrospective of spawning biomass (top) and recruitment (bottom) from 5 separate model runs, based on Model *h2\_1.00* (two-stock hypothesis). The southern stock is represented on the left, while the far north stock is represented on the right.

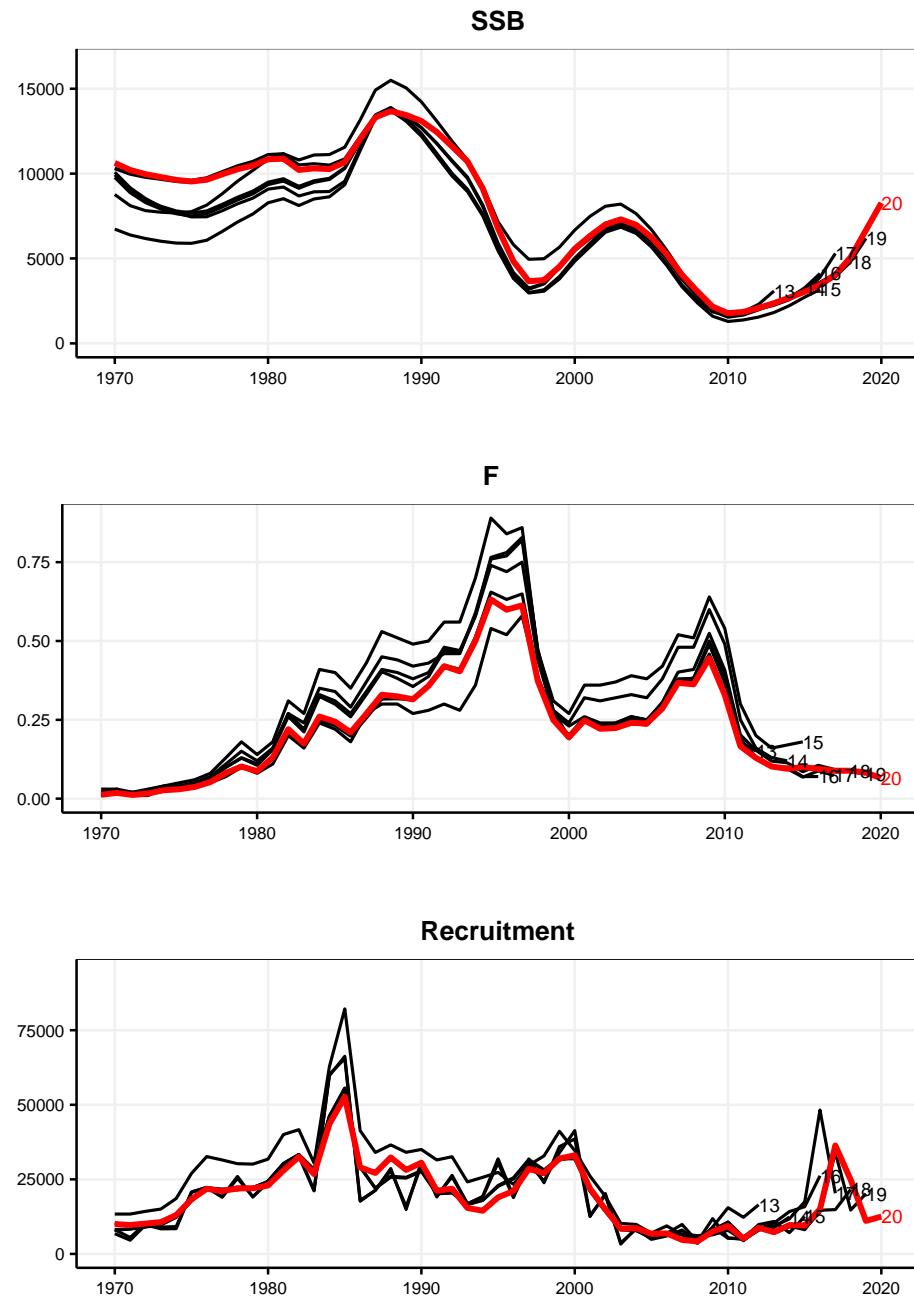


Figure A8.5. Historical retrospective of spawning stock biomass, fishing mortality, and recruitment estimated from Model *h1\_1.00* (single-stock hypothesis), as estimated and used for advice from SPRFMO Scientific Committees 2013–2020.

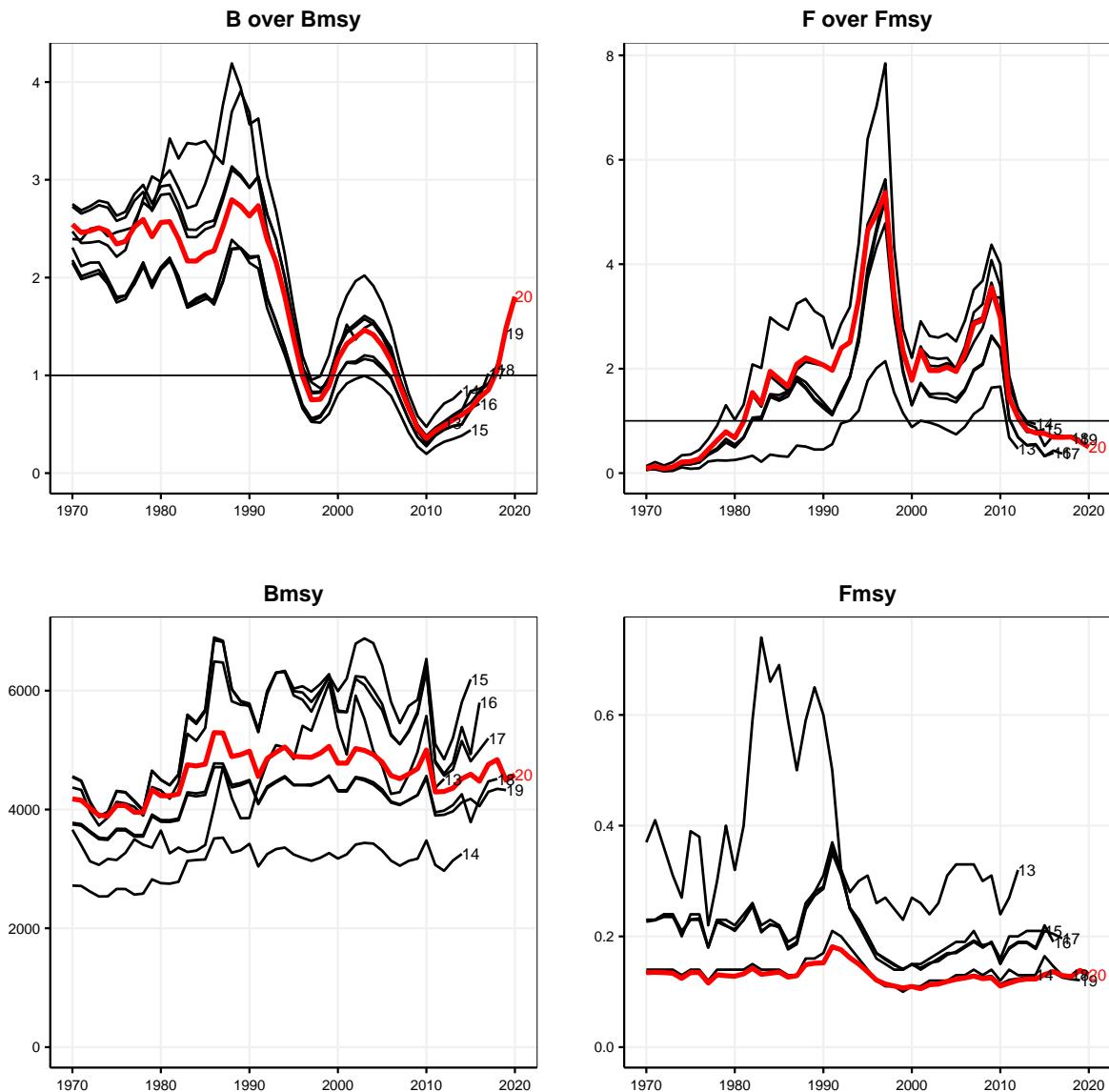
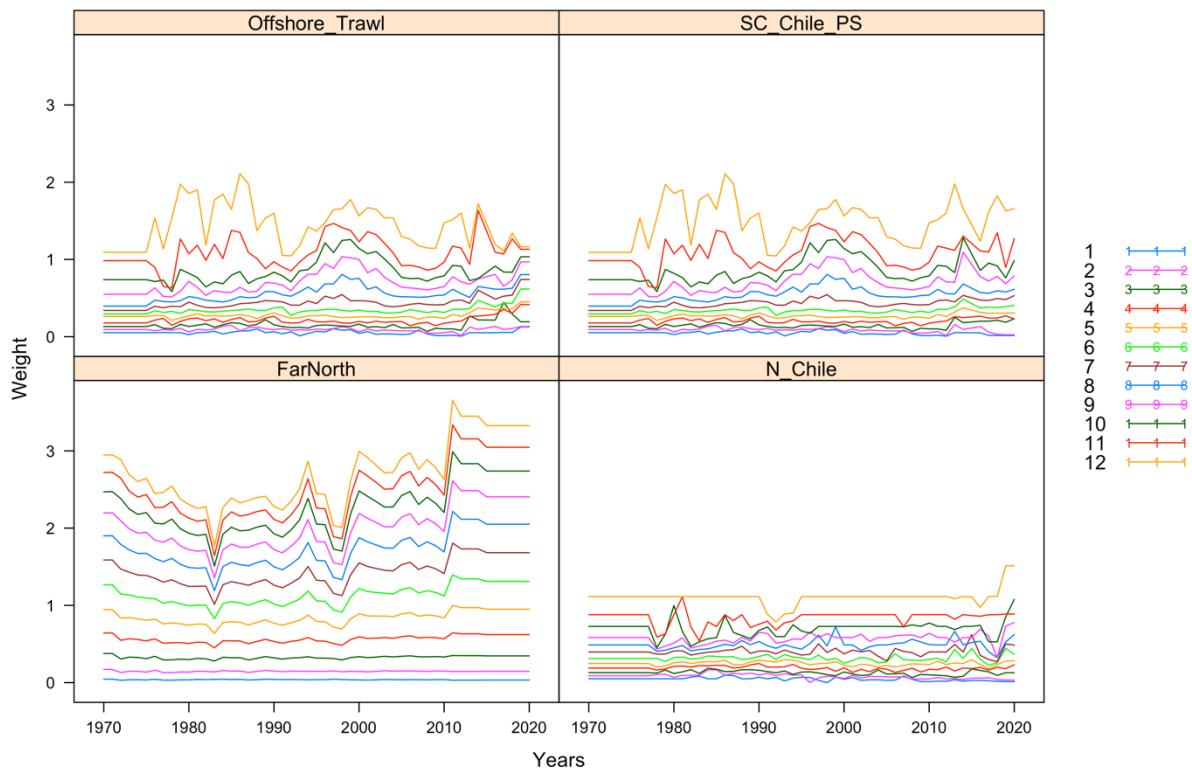


Figure A8.6. Historical retrospective of management reference points estimated from Model *h1\_1.00* (single-stock hypothesis), as estimated and used for advice from past (and present) SPRFMO scientific committees. It is to be noted that the  $B_{MSY}$  in this figure is dynamically estimated within the model, and hence is not fixed at the provisional 5.5 million tonnes.

### Weight at age in the fishery



### Weight at age in the survey

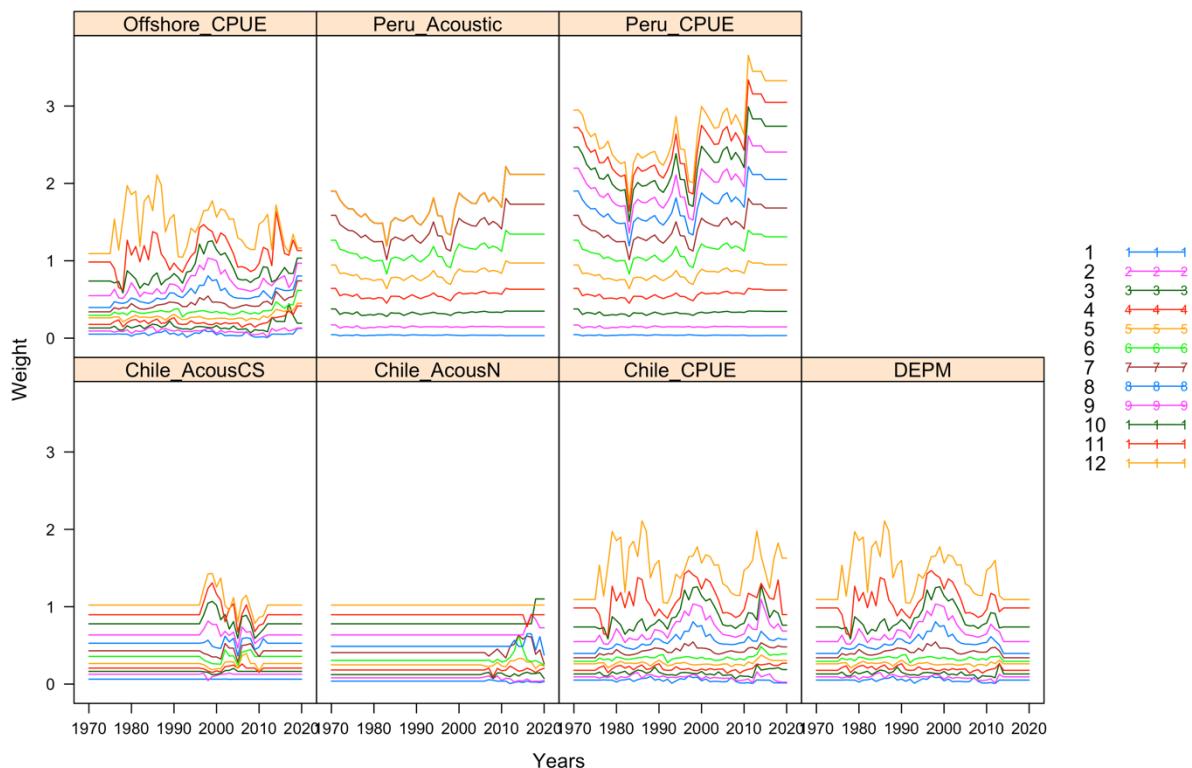


Figure A8.7. Mean weights-at-age (kg) over time used for all data types in the JJM models. Each line represents an age from 1 to 12.

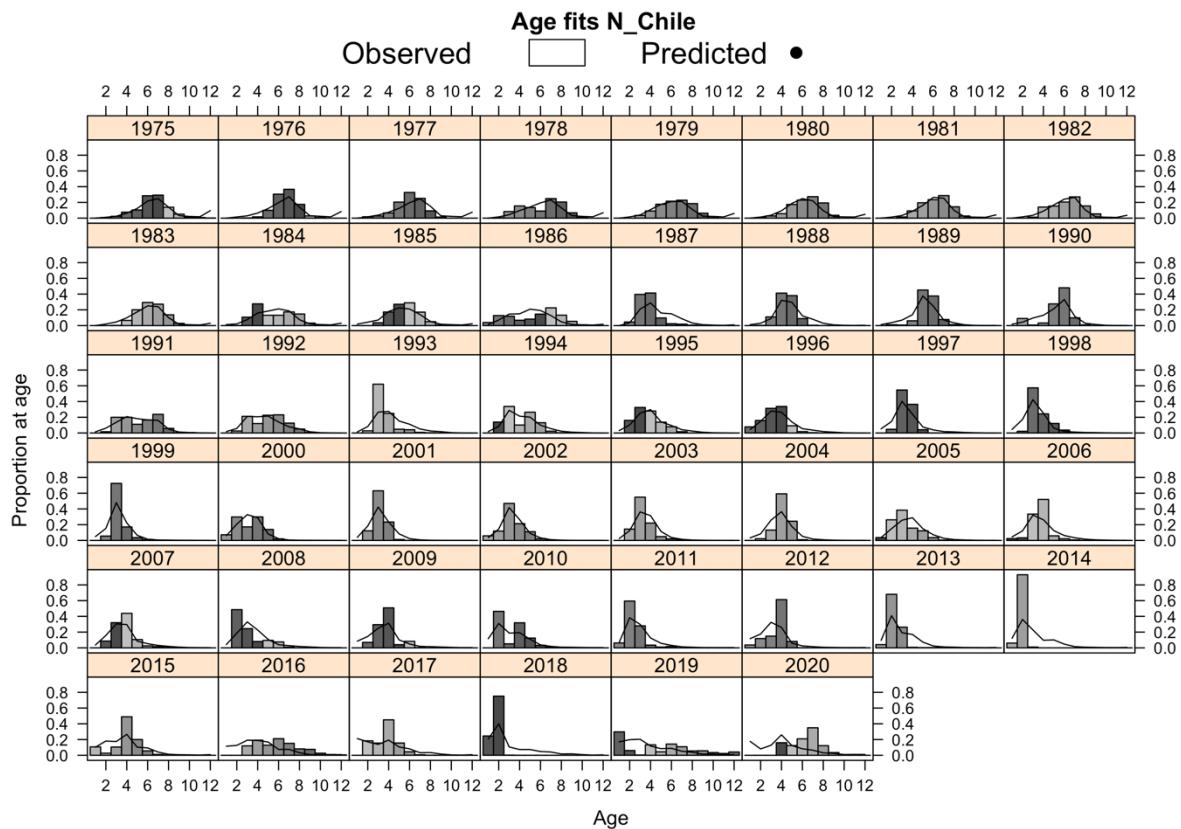


Figure A8.8. Model h1\_1.00 (single-stock hypothesis) fit to the age compositions for the Chilean northern zone fishery (Fleet 1). Bars represent the observed data and lines represent the model predictions.

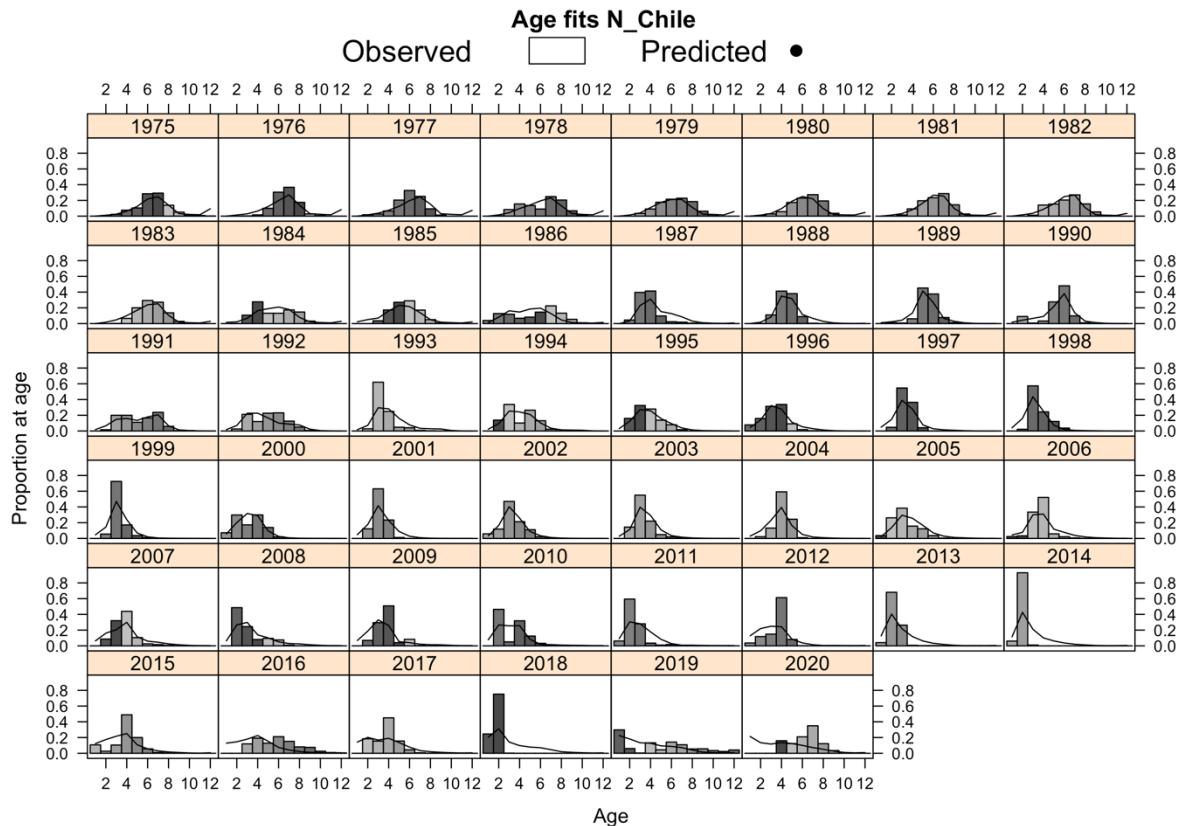


Figure A8.9. Model h2\_1.00 (two-stock hypothesis) fit to the age compositions for the Chilean northern zone fishery (Fleet 1). Bars represent the observed data and lines represent the model predictions.

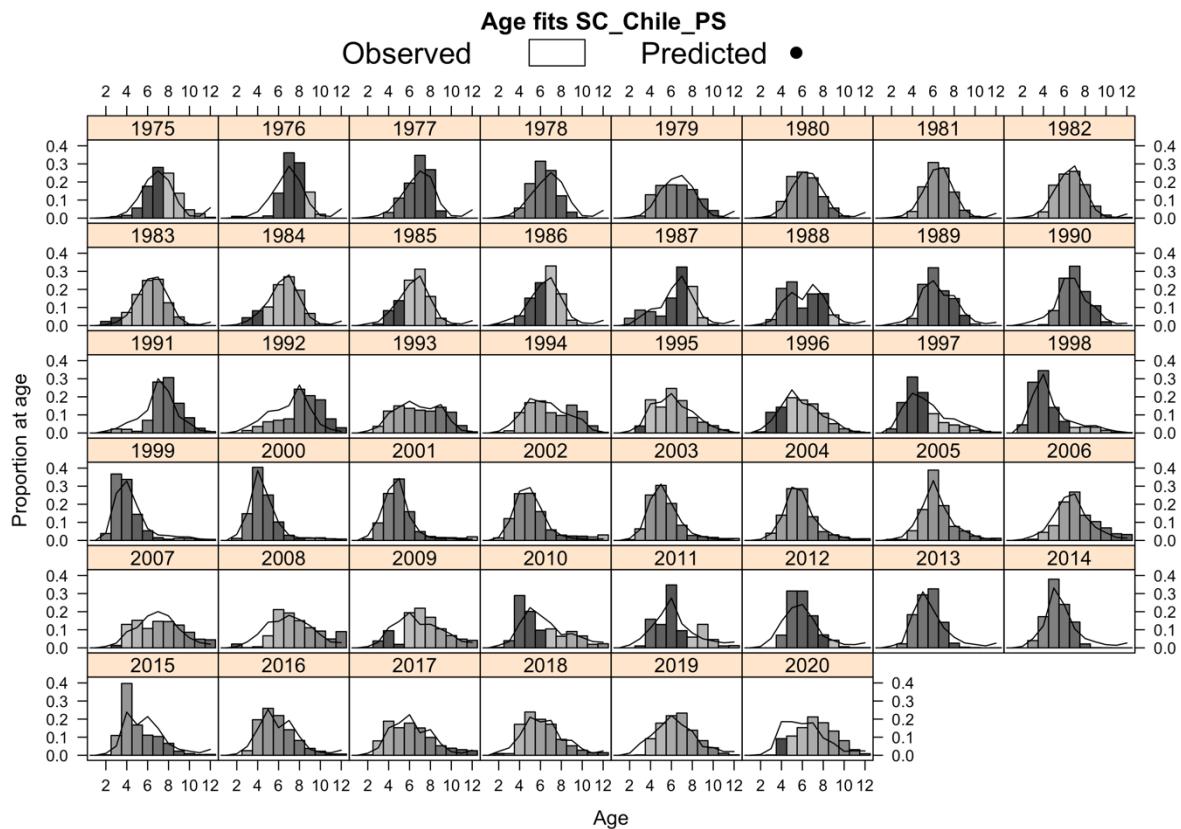


Figure A8.10. Model h1\_1.00 (single-stock hypothesis) fit to the age compositions for the South-Central Chilean purse seine fishery (Fleet 2). Bars represent the observed data and lines represent the model predictions.

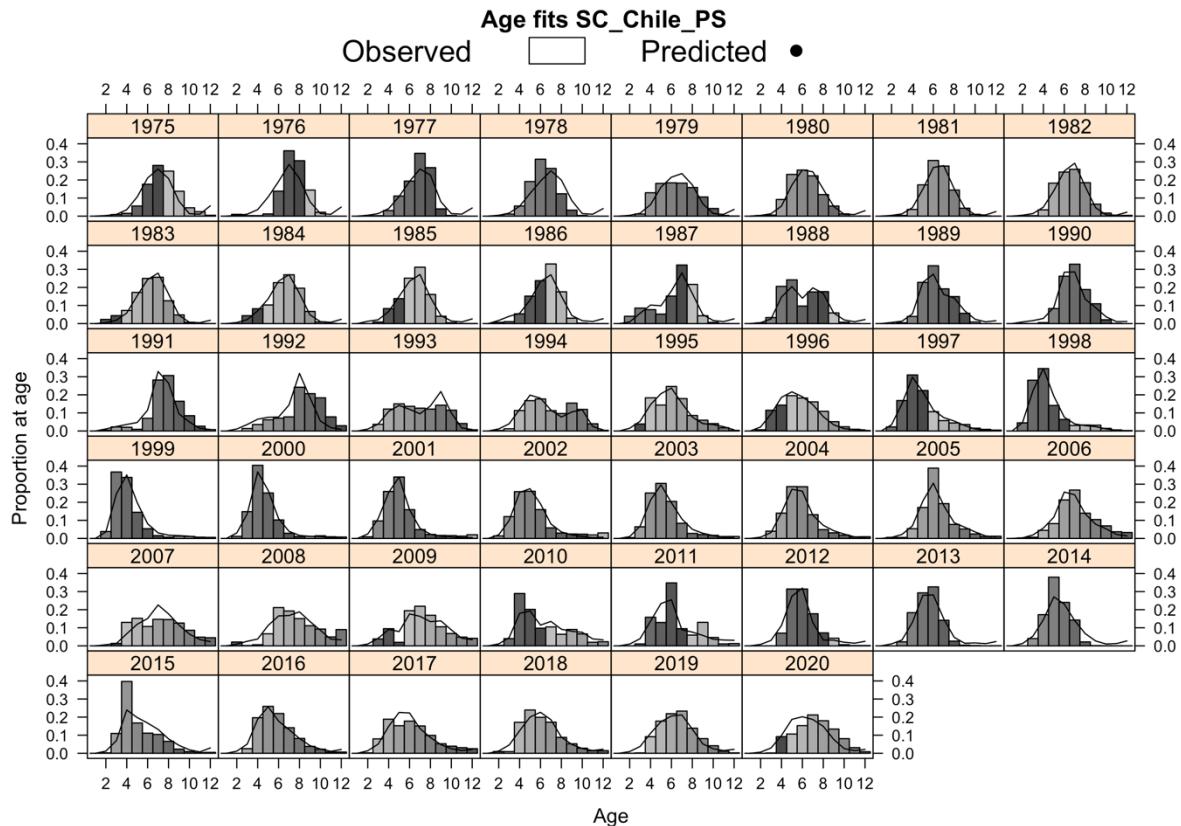


Figure A8.11. Model h2\_1.00 (two-stock hypothesis) fit to the age compositions for the South-Central Chilean purse seine fishery (Fleet 2). Bars represent the observed data and lines represent the model predictions.

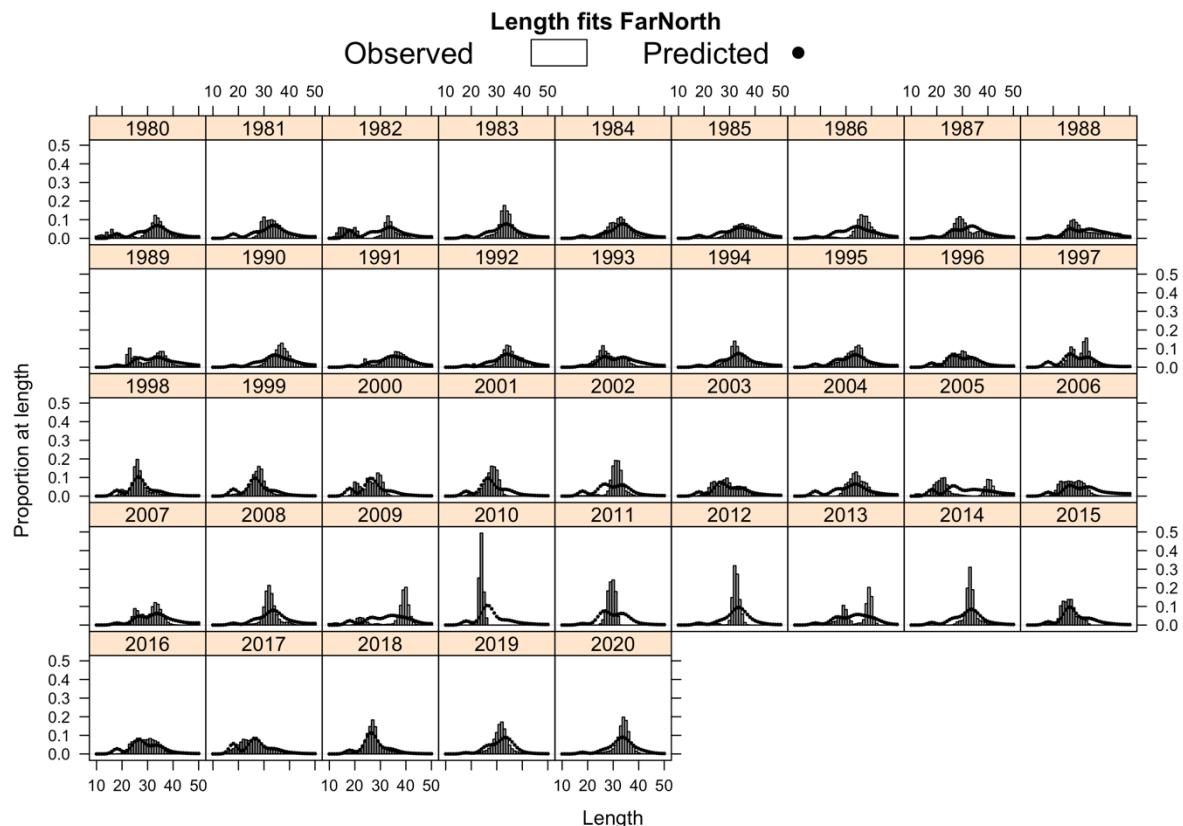


Figure A8.12. Model h1\_1.00 (single-stock hypothesis) fit to the length compositions for the far north fishery (Fleet 3). Bars represent the observed data and lines represent the model predictions.

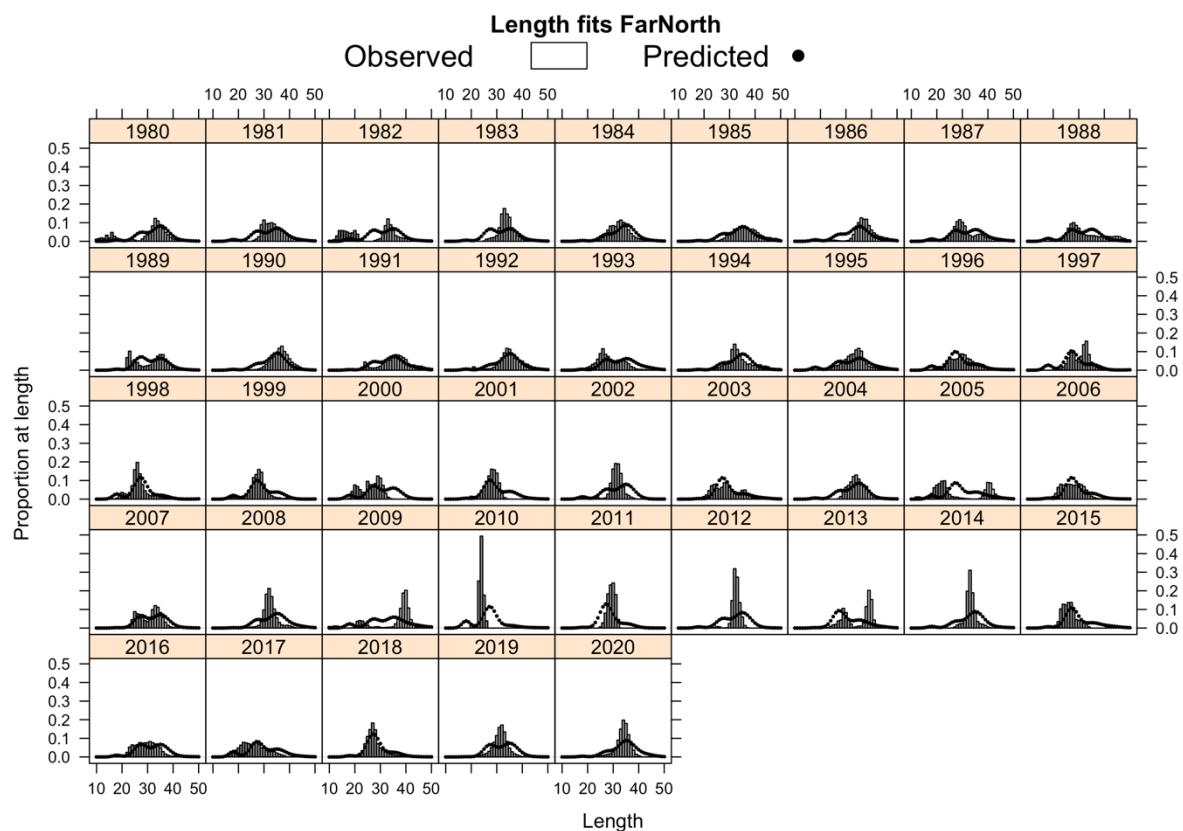


Figure A8.13. Model h2\_1.00 (two-stock hypothesis) fit to the length compositions for the far north fishery (Fleet 3). Bars represent the observed data and lines represent the model predictions.

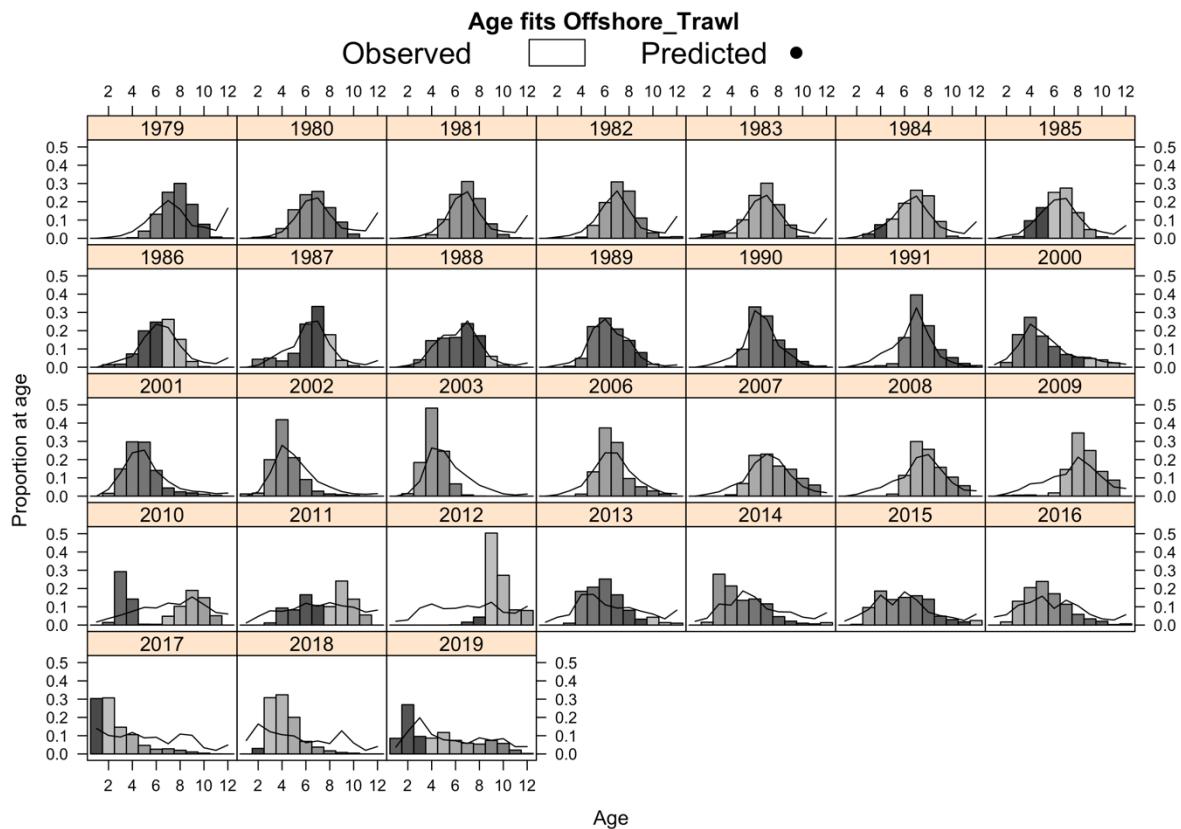


Figure A8.14. Model h1\_1.00 (single-stock hypothesis) fit to the age compositions for the offshore trawl fishery (Fleet 4). Bars represent the observed data and lines represent the model predictions.

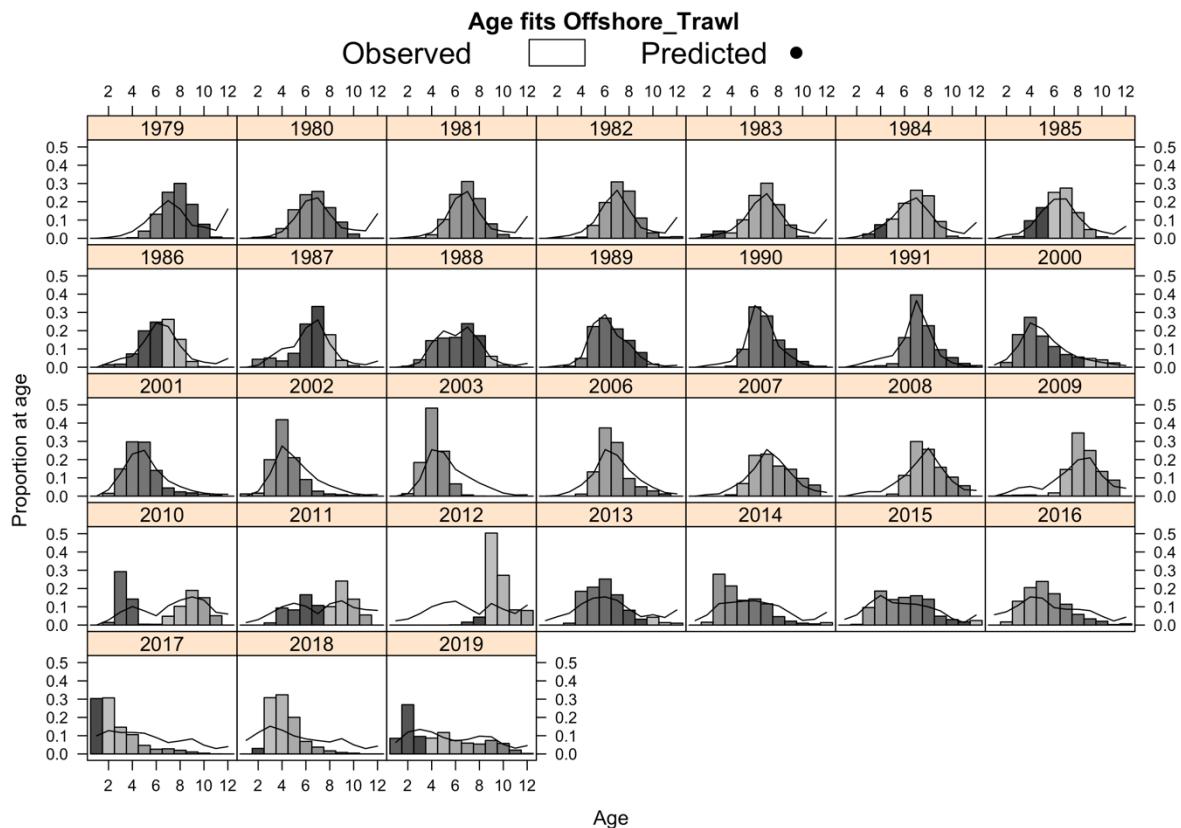


Figure A8.15. Model h2\_1.00 (two-stock hypothesis) fit to the age compositions for the offshore trawl fishery (Fleet 4). Bars represent the observed data and lines represent the model predictions.

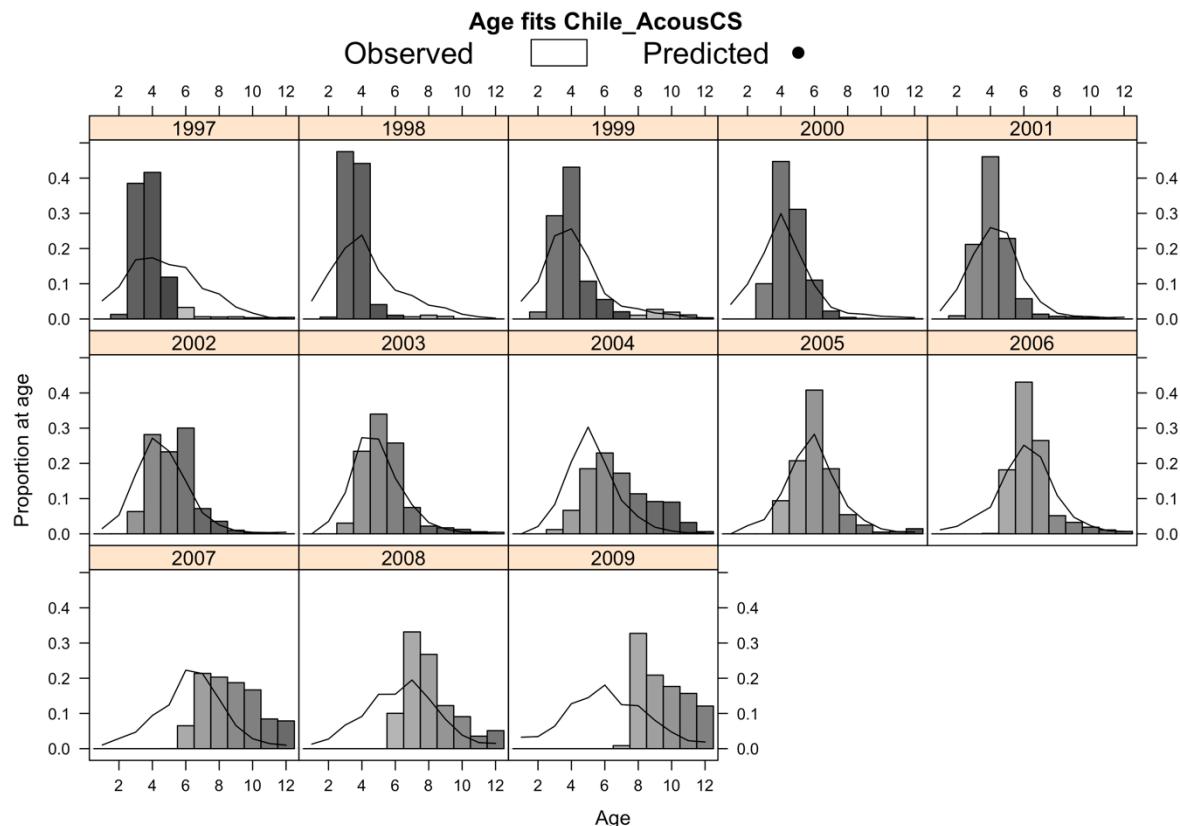


Figure A8.16. Model *h1\_1.00* (single-stock hypothesis) fit to the age compositions for the South-Central Acoustic survey. Bars represent the observed data and lines represent the model predictions.

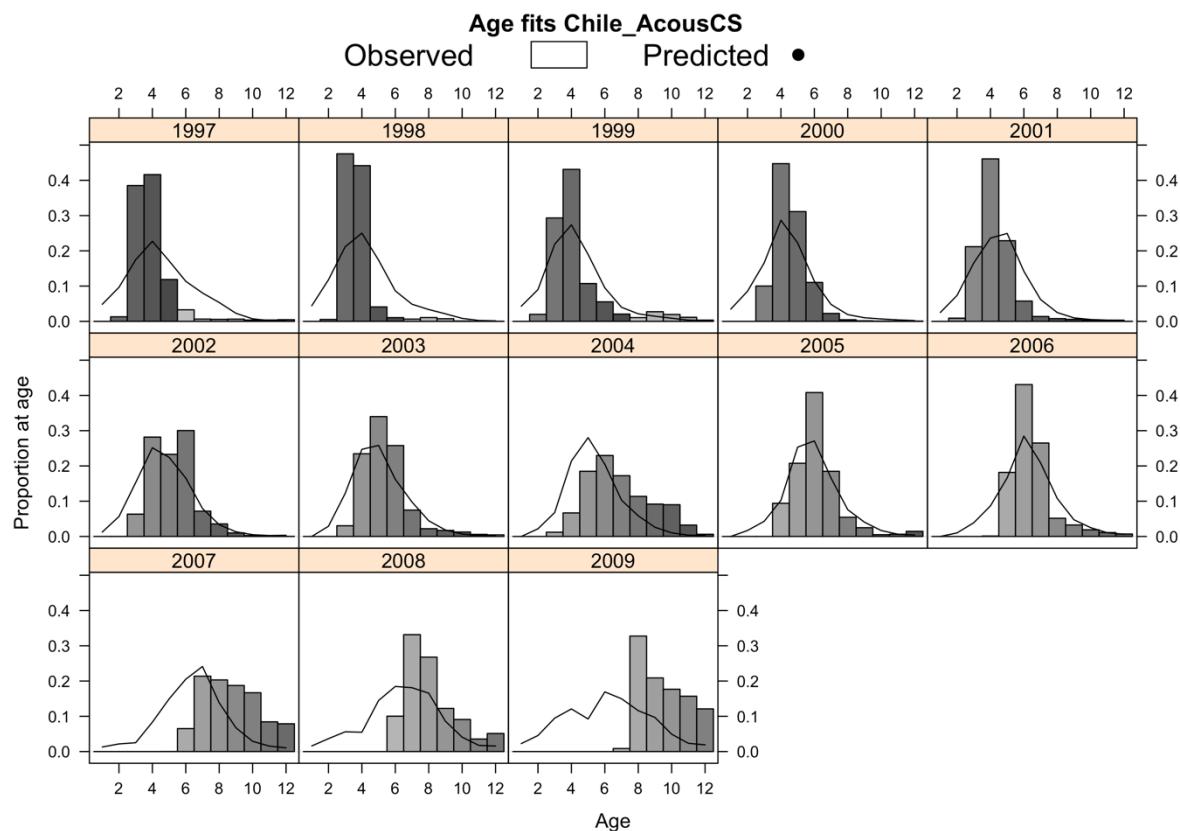


Figure A8.17. Model *h2\_1.00* (two-stock hypothesis) fit to the age compositions for the South-Central Acoustic survey. Bars represent the observed data and lines represent the model predictions.

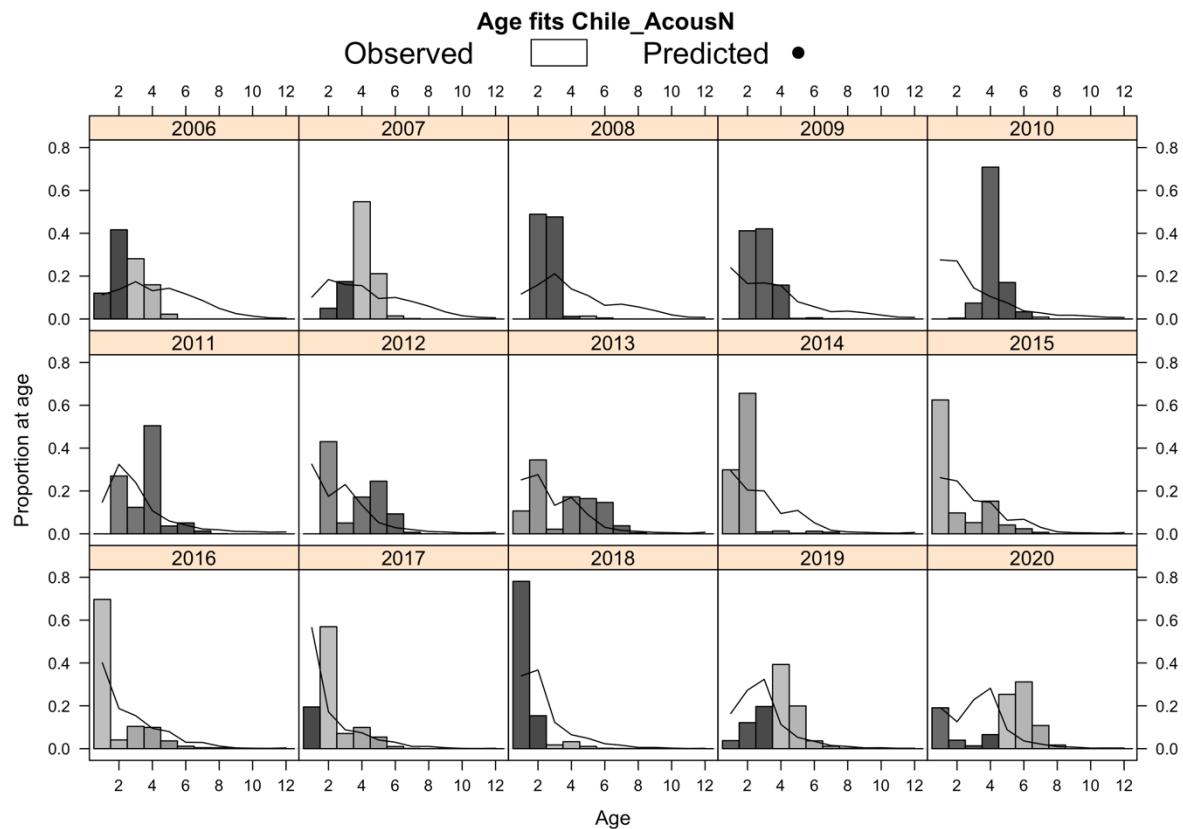


Figure A8.18. Model  $h1\_1.00$  (single-stock hypothesis) fit to the age compositions for the North Chilean acoustic survey. Bars represent the observed data and lines represent the model predictions.

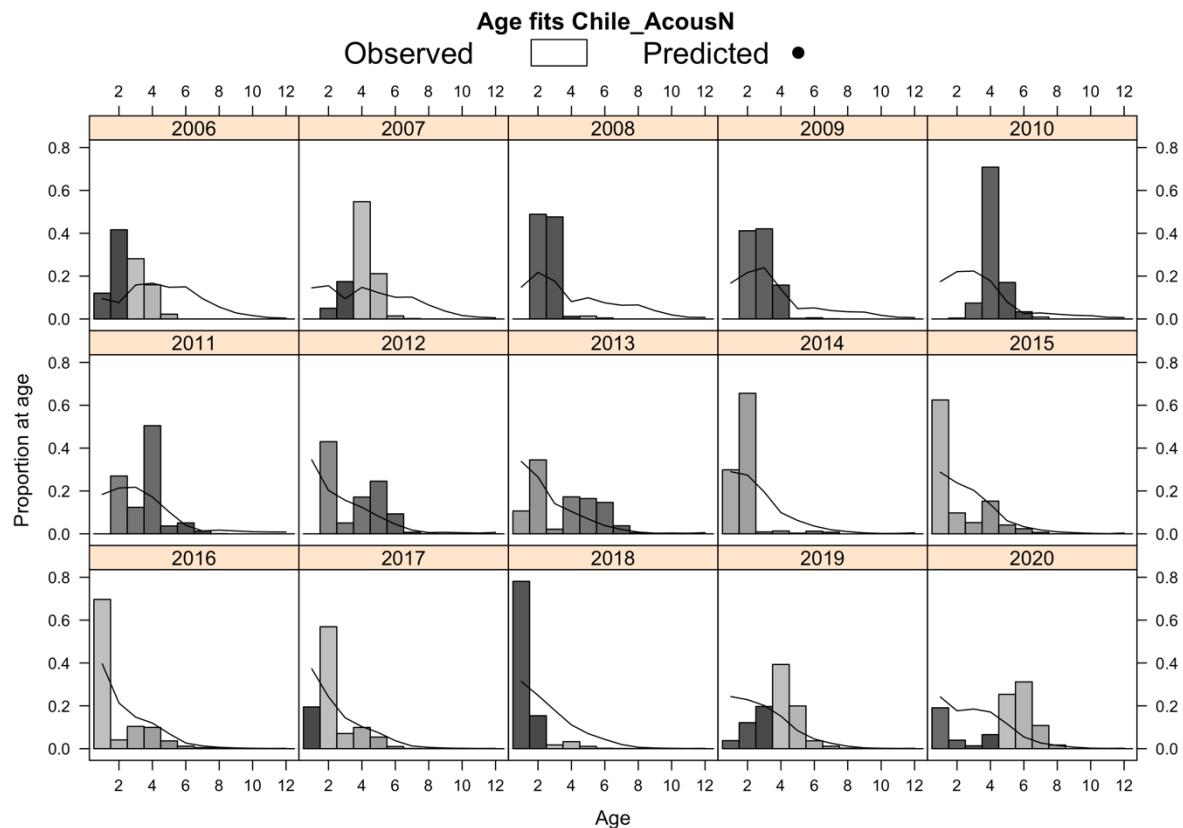


Figure A8.19. Model  $h2\_1.00$  (two-stock hypothesis) fit to the age compositions for the North Chilean acoustic survey. Bars represent the observed data and lines represent the model predictions.

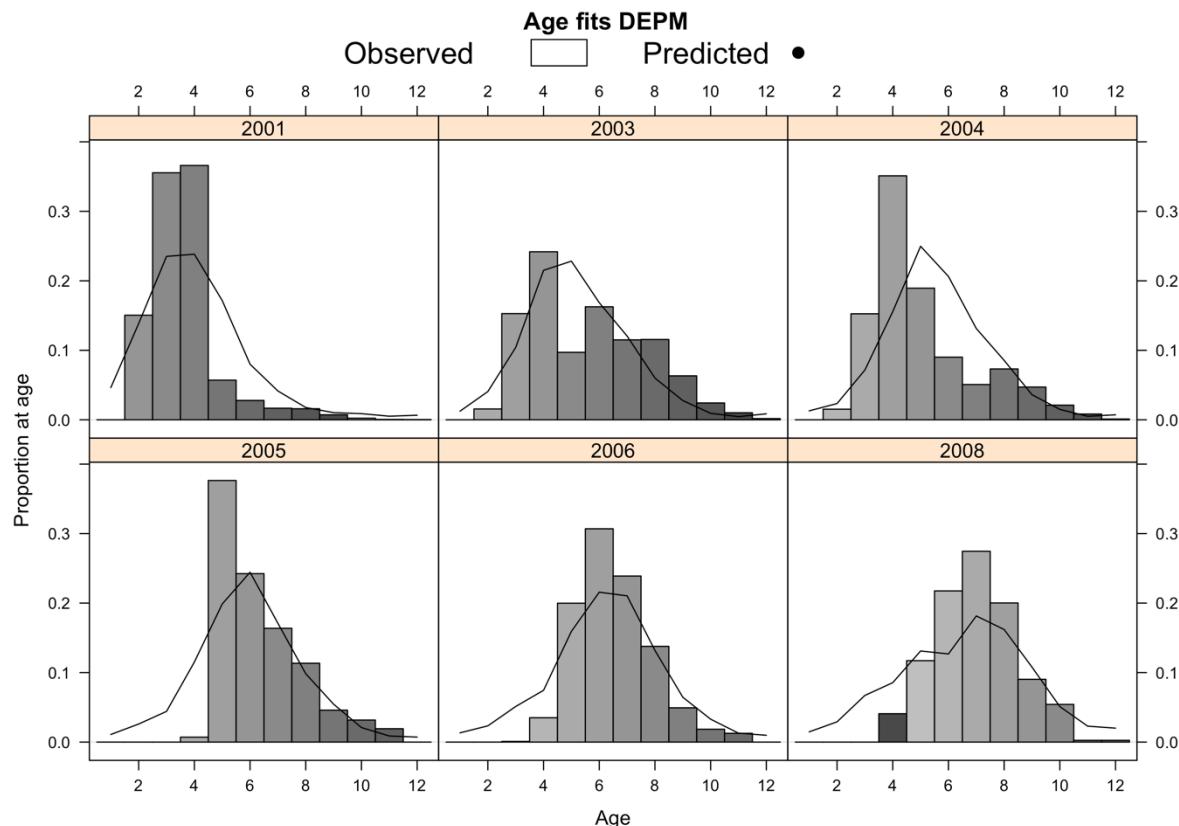


Figure A8.20. Model  $h1\_1.00$  (single-stock hypothesis) fit to the age compositions for the Daily Egg Production Method (DEPM) survey. Bars represent the observed data and lines represent the model predictions.

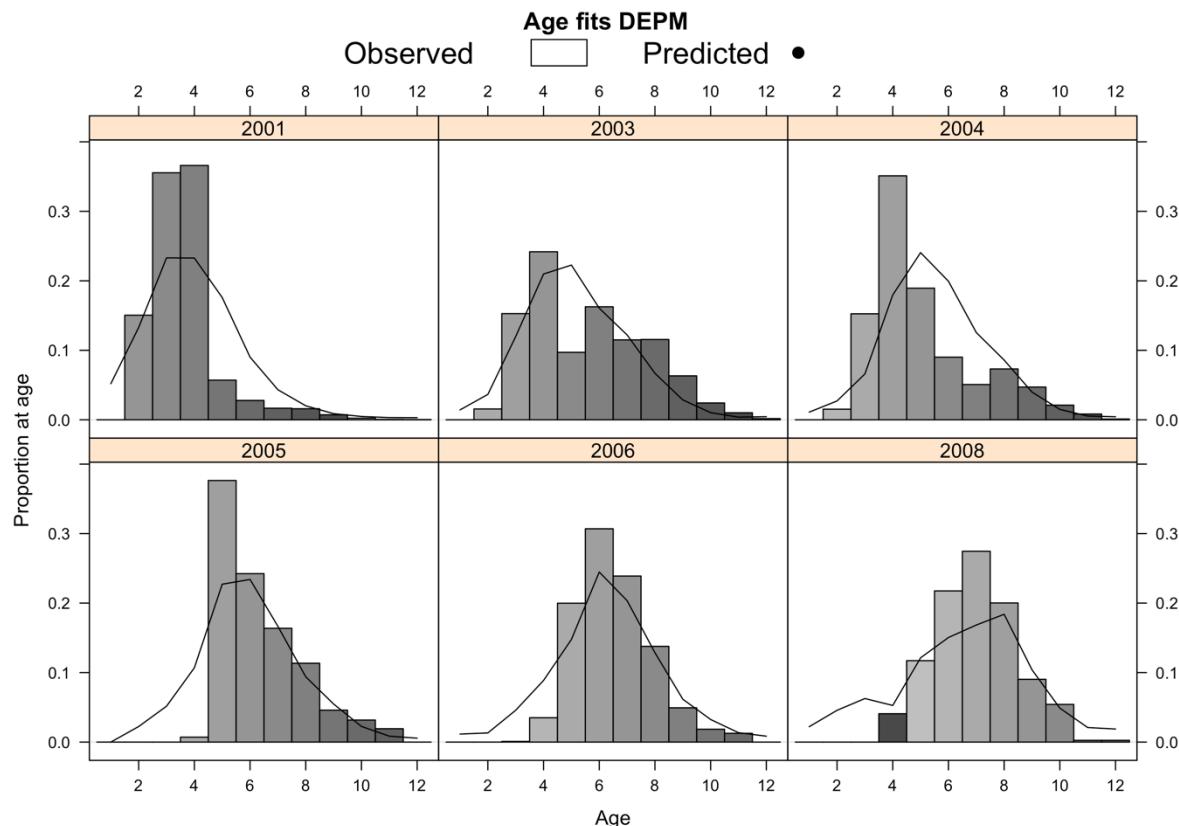


Figure A8.21. Model  $h2\_1.00$  (two-stock hypothesis) fit to the age compositions for the Daily Egg Production Method (DEPM) survey. Bars represent the observed data and lines represent the model predictions.

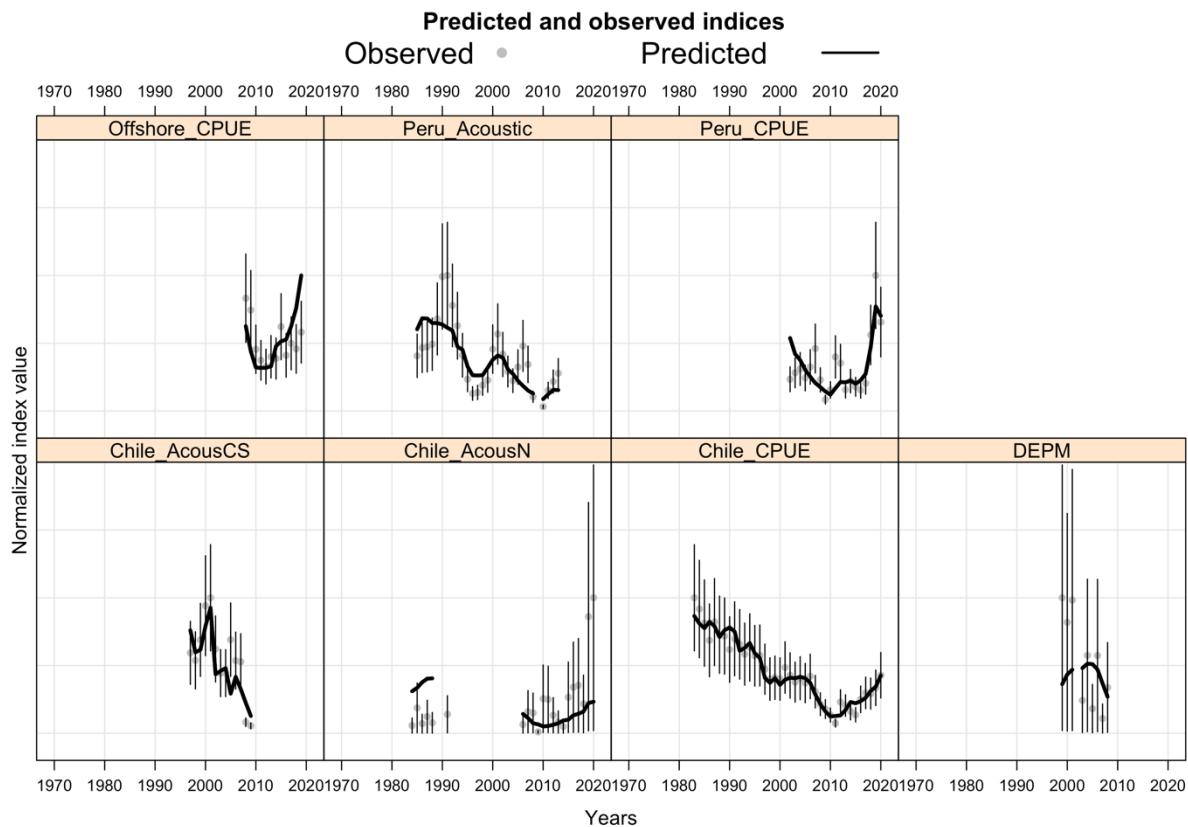


Figure A8.22. Model *h1\_1.00* (single-stock hypothesis) fit to different indices. Vertical bars represent 2 standard deviations around the observations.

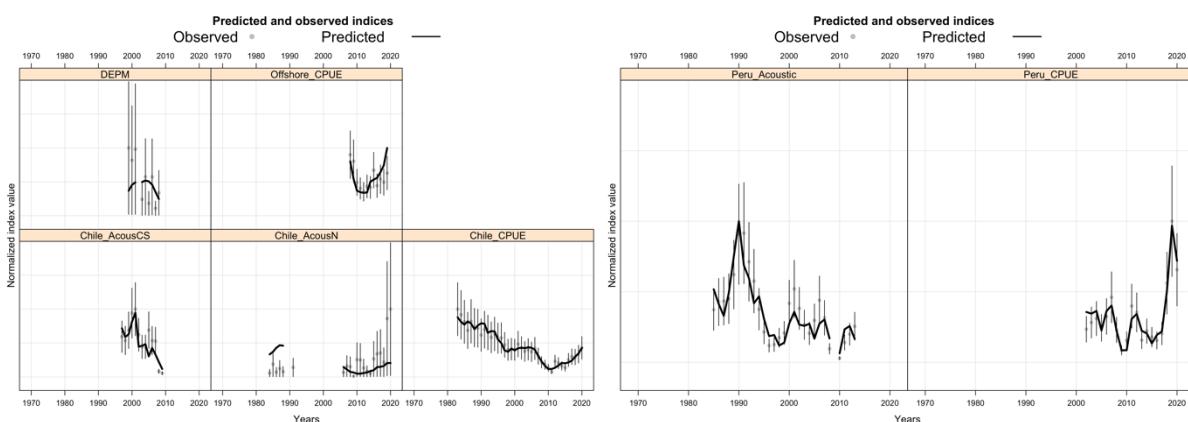


Figure A8.23. Model *h2\_1.00* (two-stock hypothesis) fit to different indices. Vertical bars represent 2 standard deviations around the observations.

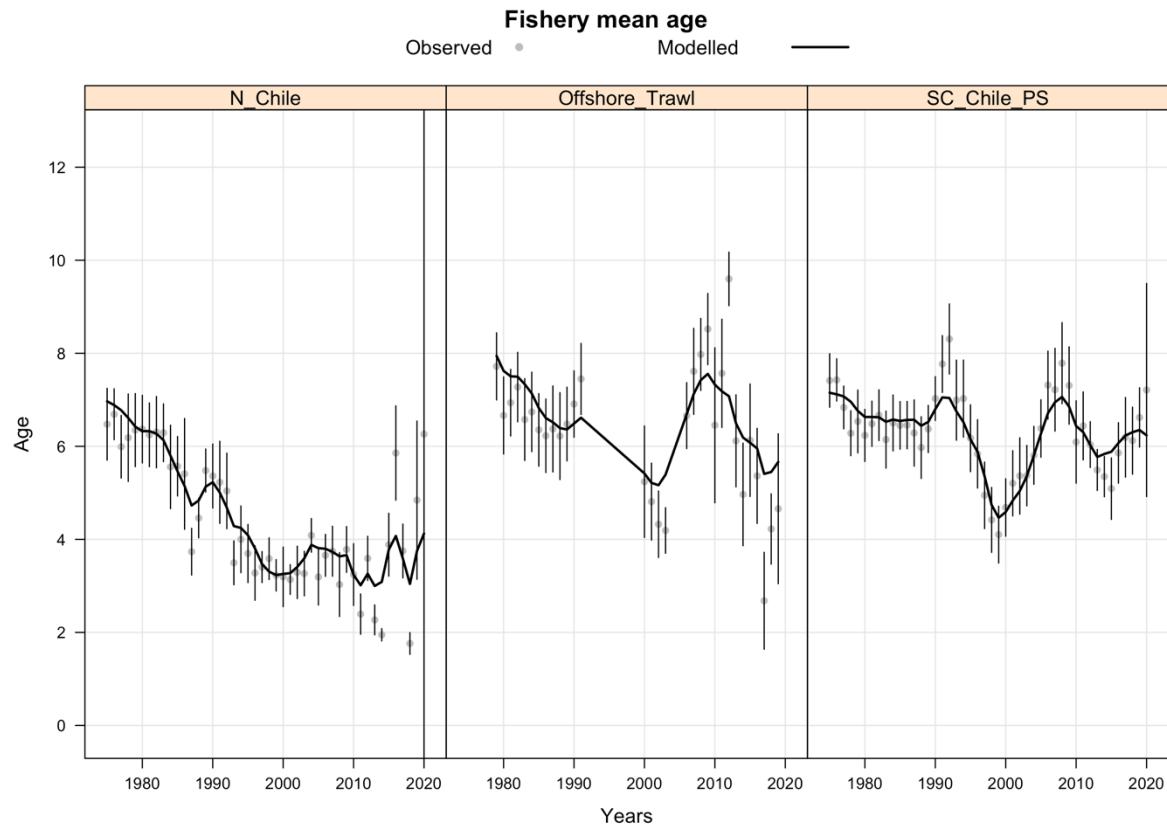


Figure A8.24. Mean age by year and fishery. Line represents the Model *h1\_1.00* (single-stock hypothesis) predictions and dots observed values with implied input error bars.

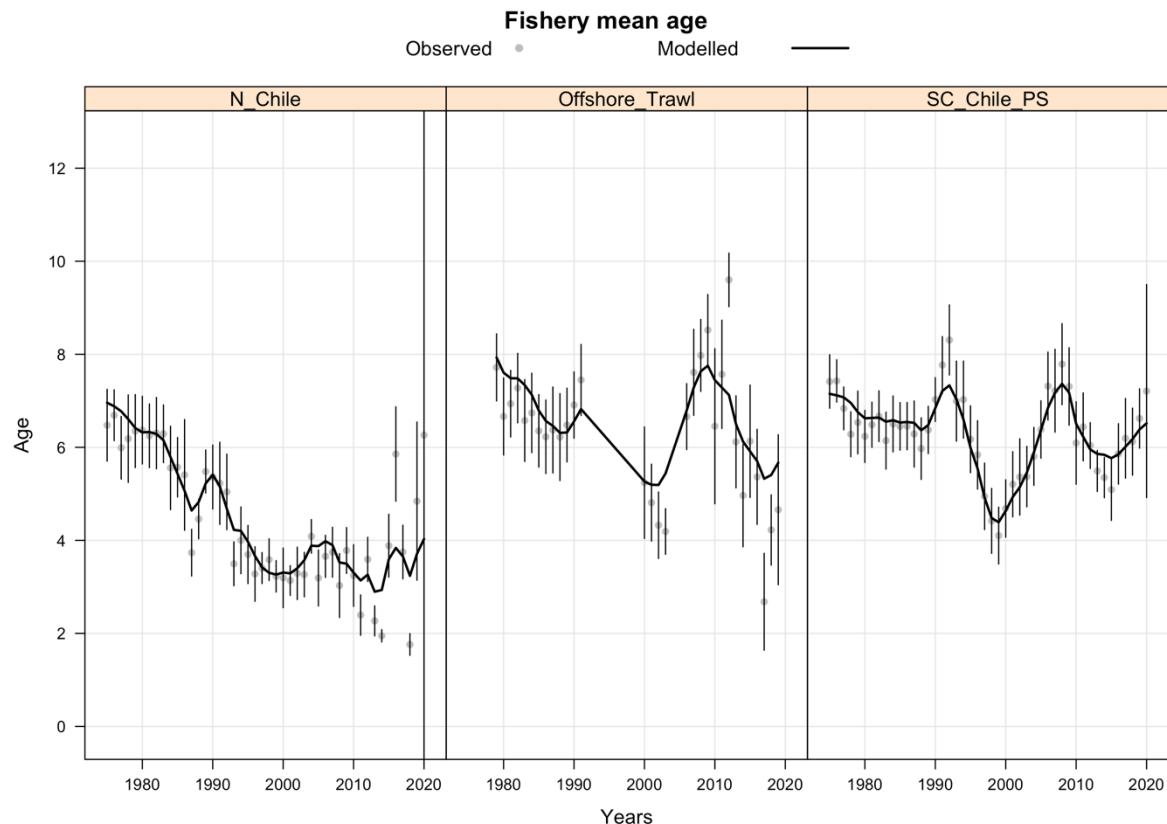


Figure A8.25. Mean age by year and fishery. Line represents the Model *h2\_1.00* (two-stock hypothesis) predictions and dots observed values with implied input error bars.

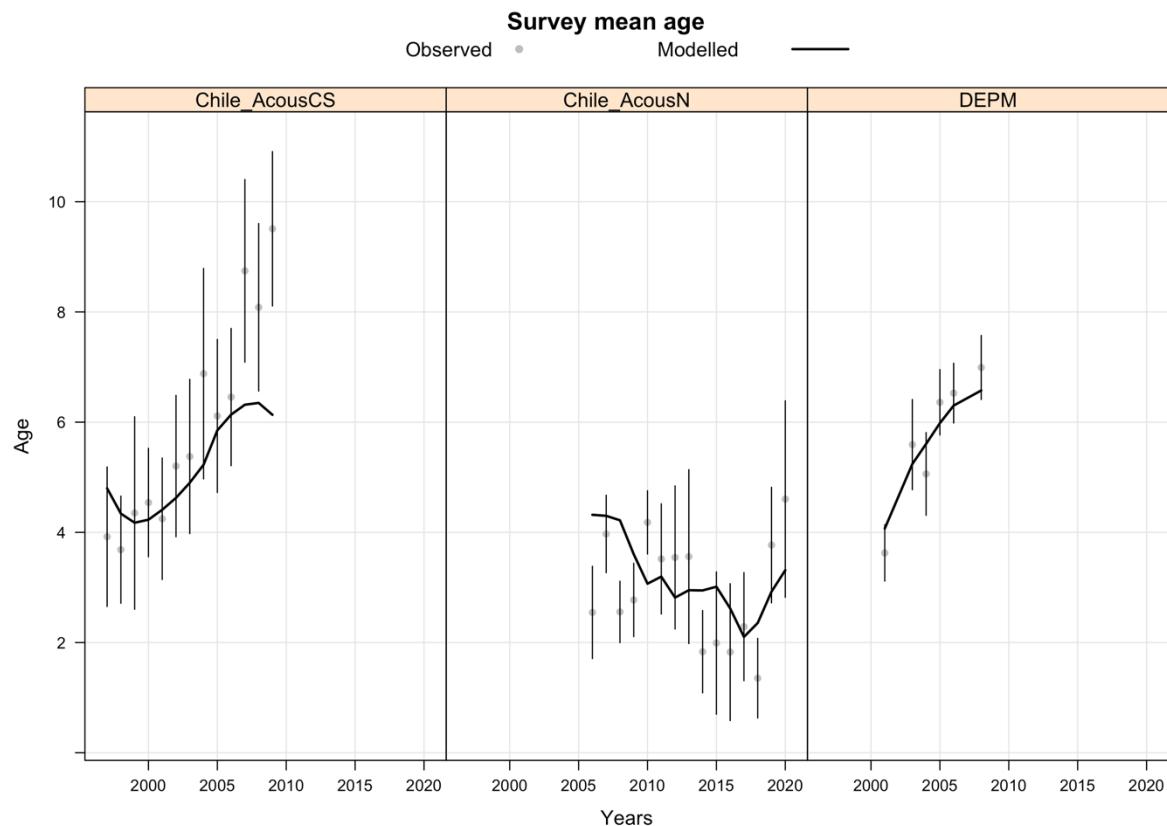


Figure A8.26. Mean age by year and survey. Line represents the Model *h1\_1.00* (single-stock hypothesis) predictions and dots observed values with implied input error bars.

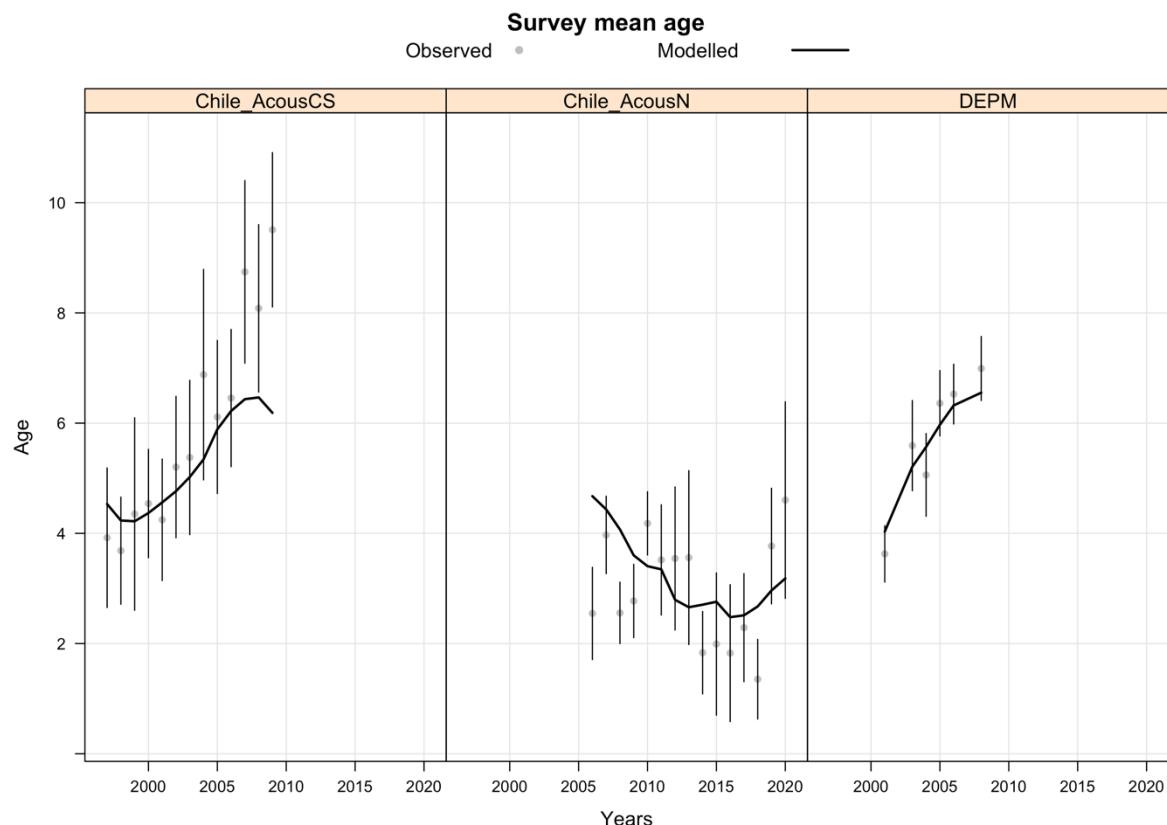


Figure A8.27. Mean age by year and survey. Line represents the Model *h2\_1.00* (two-stock hypothesis) predictions and dots observed values with implied input error bars.

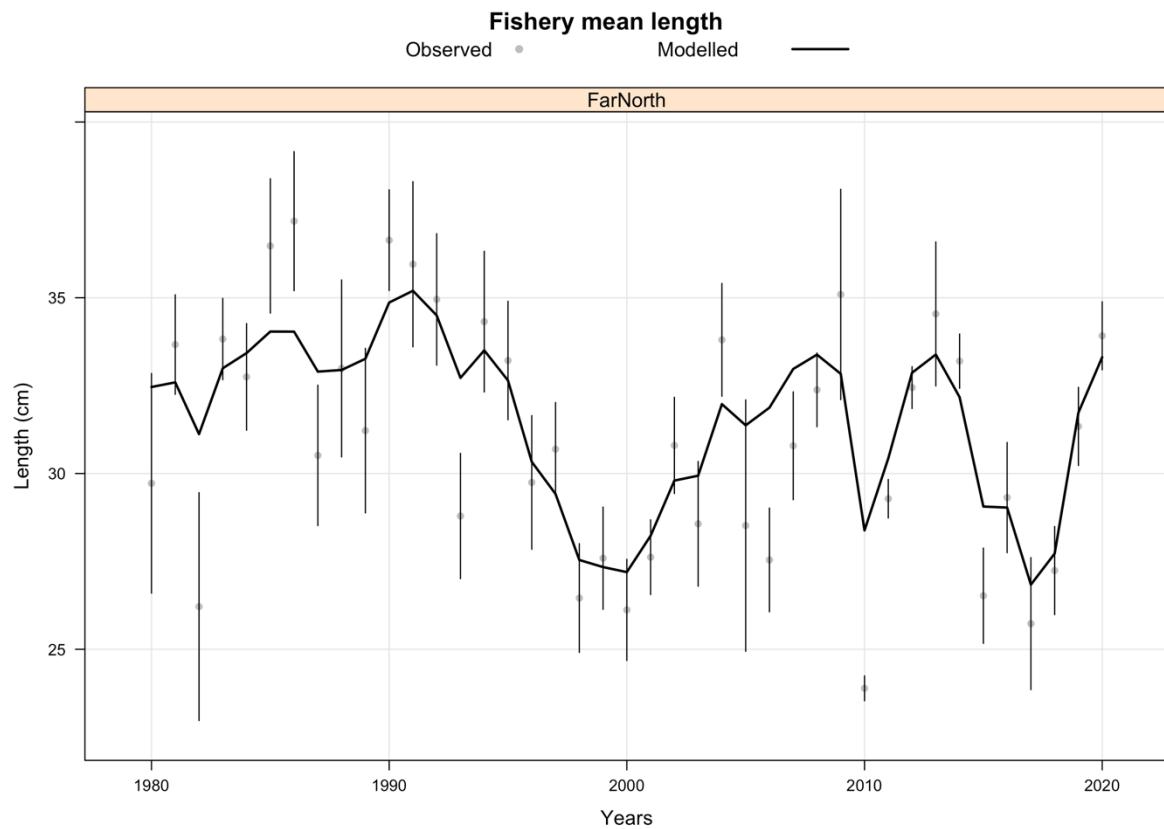


Figure A8.28. Mean length by year in Fleet 3 (Far North). Line represents the Model  $h1\_1.00$  (single-stock hypothesis) predictions and dots observed values with implied input error bars.

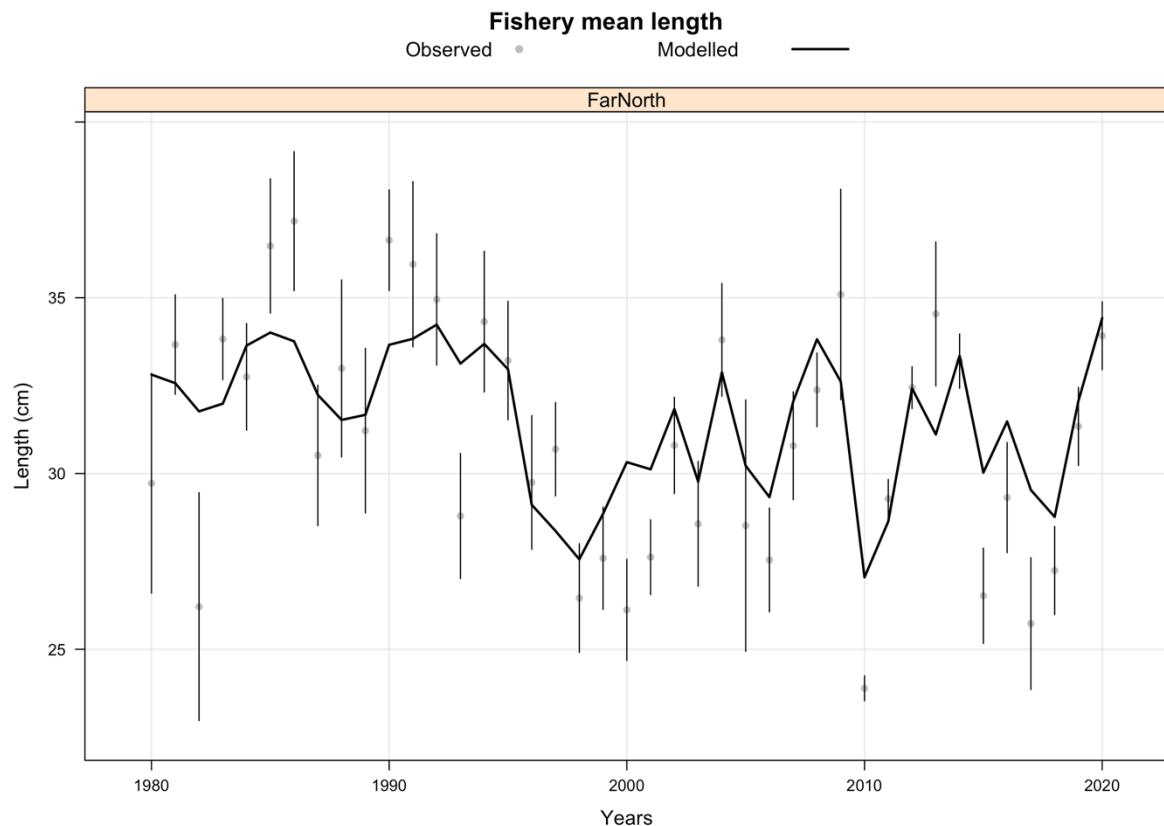


Figure A8.29. Mean length by year in Fleet 3 (Far North). Line represents the Model  $h2\_1.00$  (two-stock hypothesis) predictions and dots observed values with implied input error bars.

### Selectivity of the Fishery by Pentad

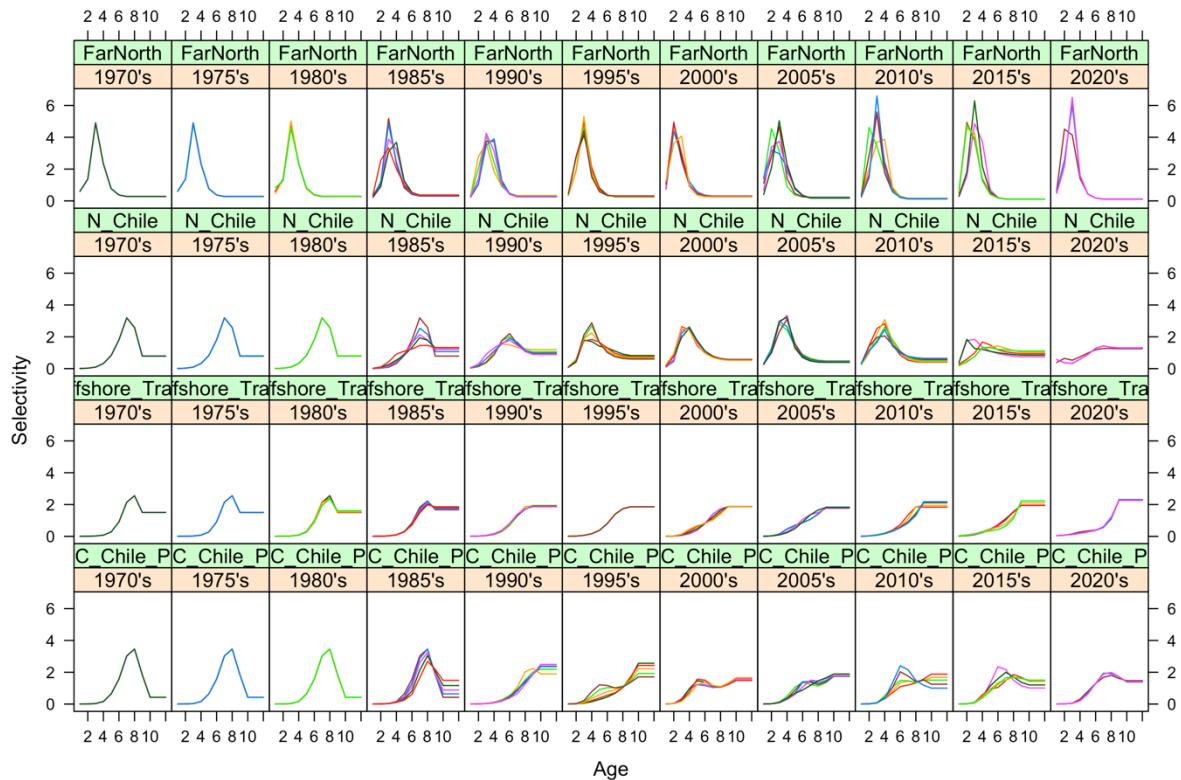


Figure A8.30. Estimates of selectivity by fishery over time for Model *h1\_1.00* (single-stock hypothesis). Each cell represents a 5-year period. The years denote the middle of the 5-year period (pentad).

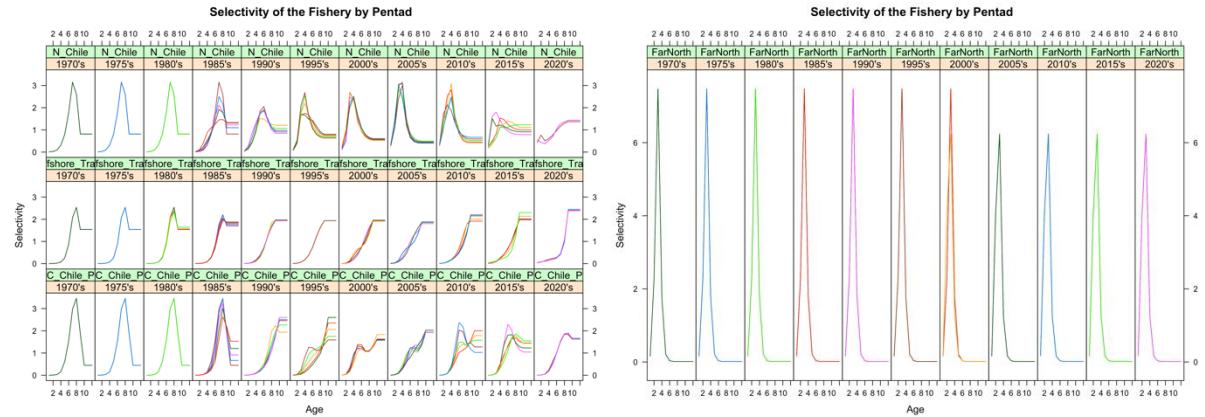


Figure A8.31. Estimates of selectivity by fishery over time for Model *h2\_1.00* (two-stock hypothesis). Each cell represents a 5-year period. The years denote the middle of the 5-year period (pentad).

### Selectivity of the survey by Pentad

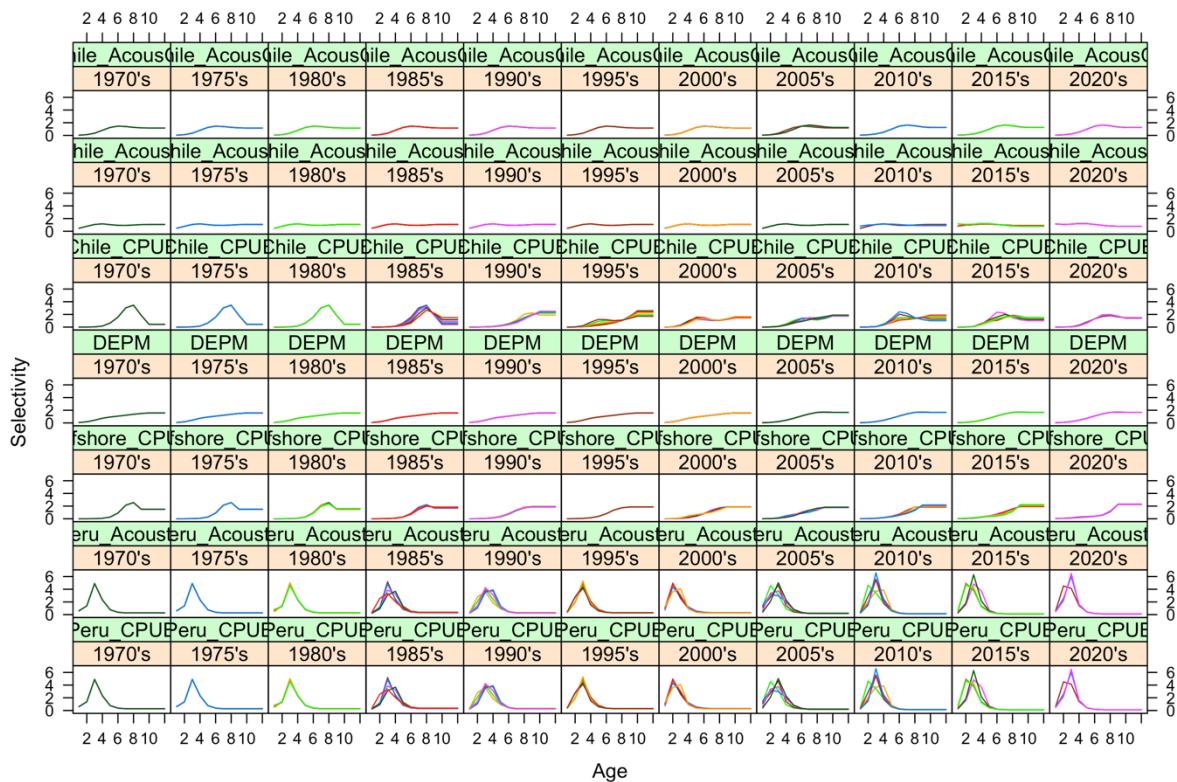


Figure A8.32. Estimates of selectivity by index over time for Model  $h1\_1.00$  (single-stock hypothesis). Each cell represents a 5-year period. The years denote the middle of the 5-year period (pentad).

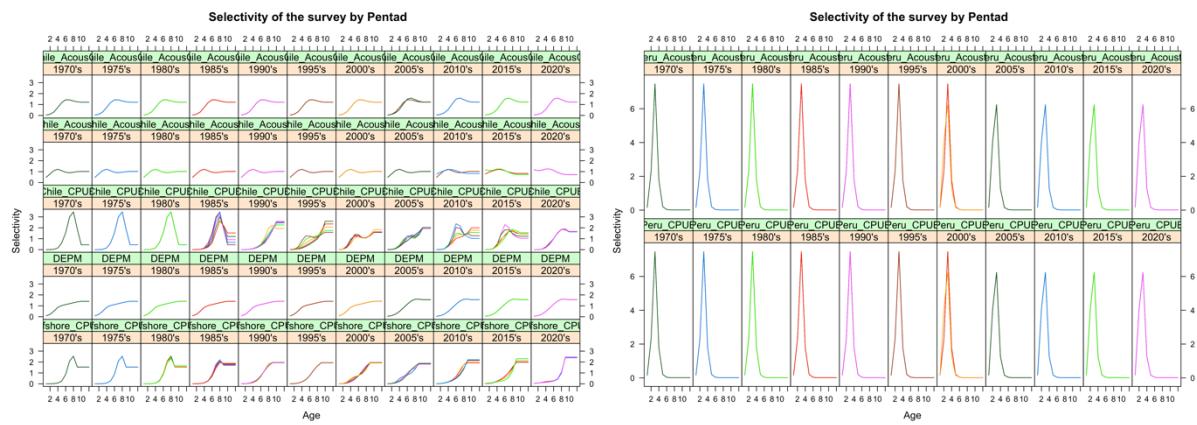


Figure A8.33. Estimates of selectivity by index over time for Model  $h2\_1.00$  (two-stock hypothesis). Each cell represents a 5-year period. The years denote the middle of the 5-year period (pentad).

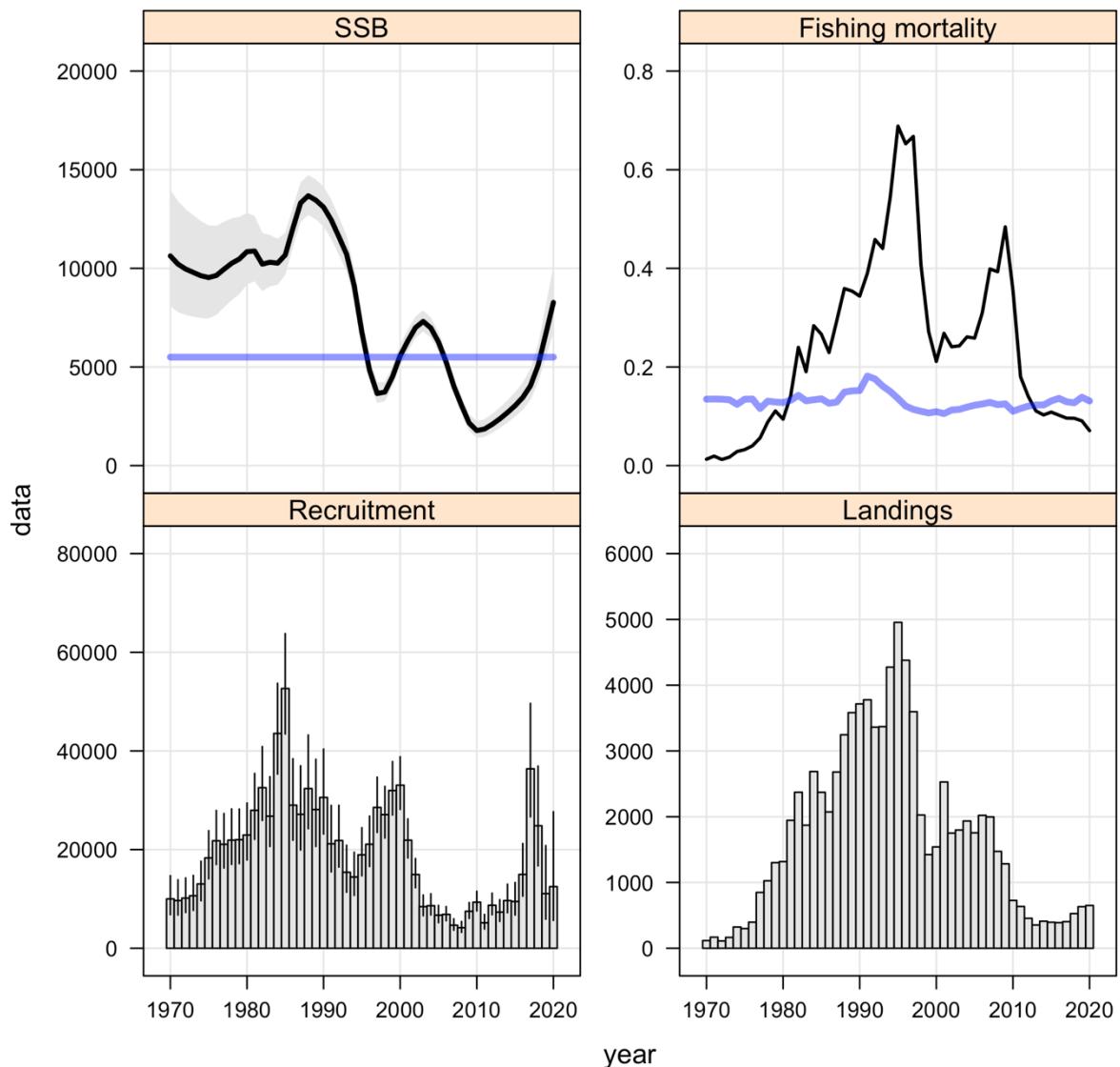


Figure A8.34. Model h1\_1.00 (single-stock hypothesis) summary estimates over time showing spawning biomass (kt; top left), recruitment at age 1 (millions; lower left), total fishing mortality (top right), and total catch (kt; bottom right). Blue lines represent the provisional  $B_{MSY}$  (upper left) and dynamic estimates of  $F_{MSY}$  (upper right).

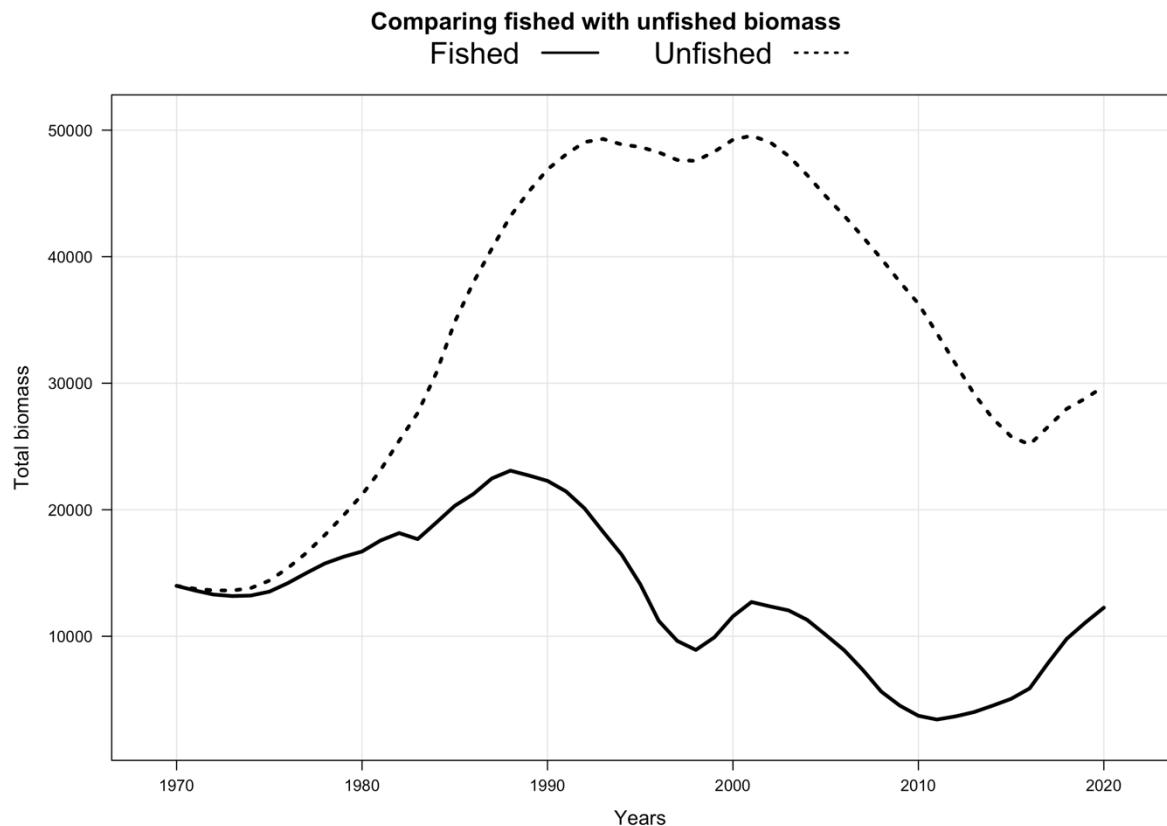
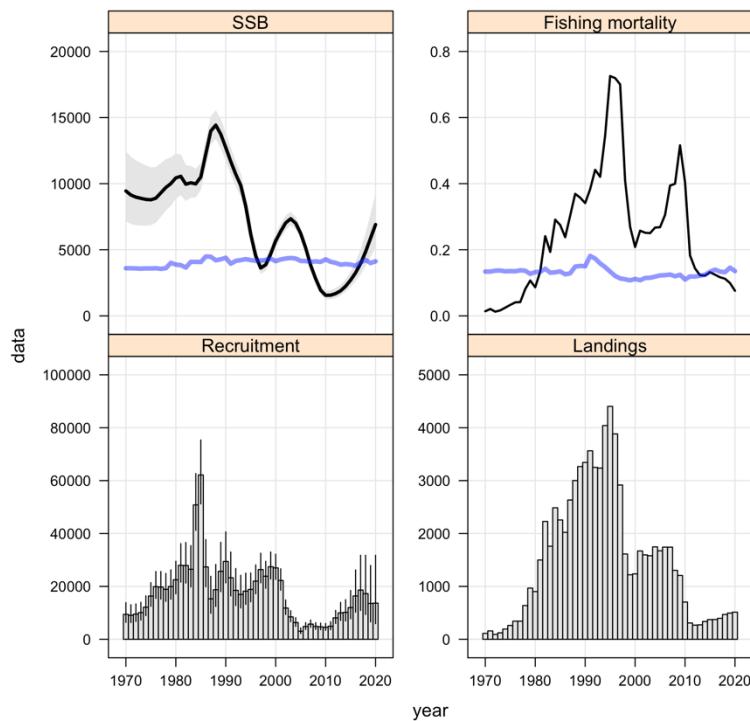


Figure A8.35. Model *h1\_1.00* (single-stock hypothesis) results for the estimated total biomass (solid line) and the estimated total biomass that would have occurred if no fishing had taken place (dotted line), beginning in 1970.

### Southern stock



### Far North stock

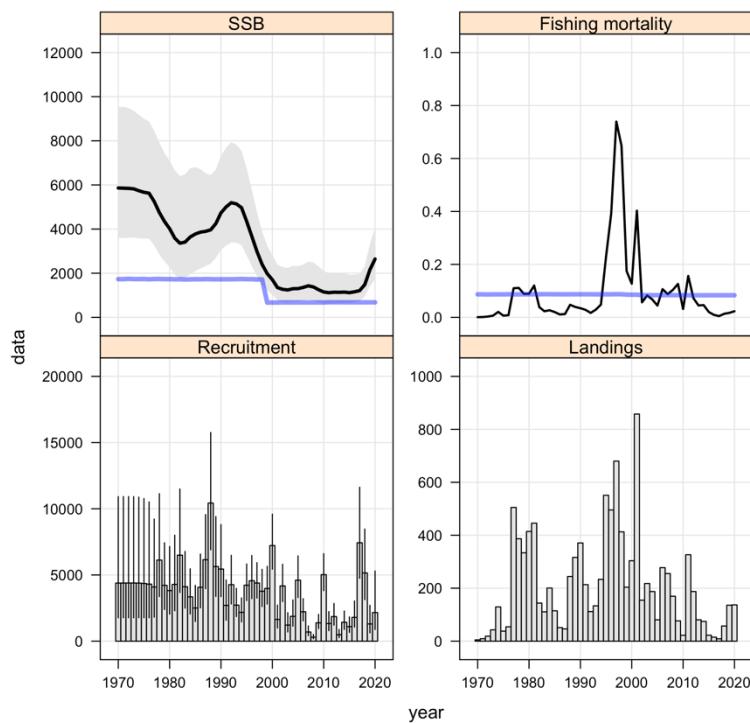


Figure A8.36. Model h2\_1.00 (two-stock hypothesis) summary estimates over time showing spawning biomass (kt; top left), recruitment at age 1 (millions; lower left), total fishing mortality (top right) and total catch (kt; bottom right) for the “Far North” stock (top set) and for the “Southern” stock (bottom set). Blue lines represent the dynamic estimates of  $B_{MSY}$  (upper left) and the dynamic estimates of  $F_{MSY}$  (upper right).

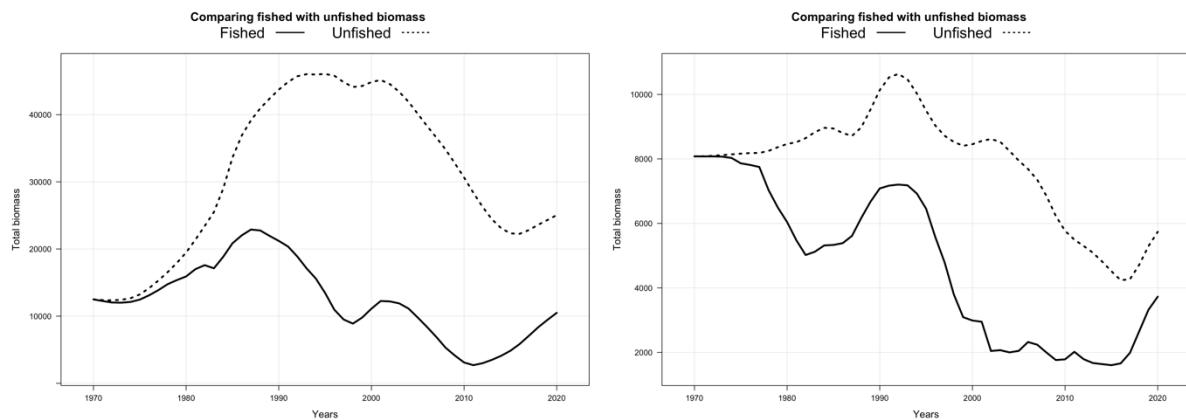


Figure A8.37. Model h2\_1.00 (two-stock hypothesis) results for the estimated total biomass (solid line) and the estimated total biomass that would have occurred if no fishing had taken place (dotted line), beginning in 1970. The plot on the left shows results for the southern stock, and the one on the right the far north stock.