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Status of B.C. Pacific Herring (*Clupea pallasii*) in 2017 and forecasts for 2018

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

This document presents a stock assessment for Pacific Herring (*Clupea pallasii*) in British Columbia using data current to 2017. Results of the work are intended to serve as advice over the short term to fishery managers and stakeholders on current stock status and likely impacts of different harvest options. An updated platform of the integrated combined-sex statistical catch-at-age model (ISCAM) was applied independently to each of the 5 major stock areas and tuned to fishery-independent spawn index data, annual estimates of commercial catch since 1951, and age composition data from the commercial fishery and from the test fishery charter program. Comprehensive stock assessments were done for five major stock areas: Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SoG), and West Coast of Vancouver Island (WCVI). Results are summarized as stock reconstructions, status of spawning stock in 2017, and projected spawning biomass in 2018. We also present data for two minor stocks (Area 27; Area 2 West) in Appendix C.

The model estimated stock-recruitment parameters, time-varying natural mortality, catchability coefficients for the survey time series, and selectivity parameters for the commercial fishery and those survey series for which age data are available. Median posterior estimates and 90% credible intervals of spawning biomass, recruitment, time-varying natural mortality, and unfished equilibrium spawning biomass are presented for AM2 and AM1 model parameterizations.

Unfished equilibrium spawning biomass (SB_0) is the main biological reference point used for Pacific Herring and it is estimated from a Beverton-Holt stock-recruitment relationship (parameterized within the assessment model) fitted to longterm average trends in weight-at-age and natural mortality. One-year projections of spawning biomass 2018 were performed for each major stock area over a range of constant catches to estimate probabilities that spawning biomass and harvest rate metrics are below and above control points historically used in the management of Pacific Herring, as specified in the herring harvest control rule. This assessment also includes presentation of current stock status and projected stock status in 2018 relative to a Limit Reference Point (LRP) of $0.3 \cdot SB_0$.

1 INTRODUCTION

1.1 CONTEXT FOR THE 2017 ASSESSMENT

Assessments of Pacific Herring stocks in British Columbia were done for 5 major stock assessment regions (SARs): Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SoG), and West Coast of Vancouver Island (WCVI). We also present data for 2 minor SARs: Area 27 (A27) and Area 2 West (A2W). Assessments for the five major herring stocks areas are reported in the main body of this report, whereas assessments for the two minor stock areas are reported in Appendix C. There are several key components to the management procedures of Pacific Herring (*Clupea pallasii*) in BC. Here we define a management procedure as the suite of activities that leads to catches in any given year. These components include: which, and how much data are collected; what is assumed about stock structure, the stock assessment model used; and the herring harvest control rule (HCR) that mathematically converts some estimate of current stock status to a total allowable catch (TAC) (de la Mare, 1998) and implementation errors. How well a particular management procedure performs depends on what objectives are defined for the management of the stock, including the probability of achieving target biomass level, the probability of avoiding limit biomass levels, the mean catch, the variability in catch and others. Accordingly, the performance of any given management procedure cannot be viewed without understanding management objectives.

Pacific Herring has been managed using a set harvest control rule but according to our definition above, the management procedure applied in practice has been in a constant state of flux. Since it was implemented in 1986 and formally tested (Haist, 1988[1]; Hall et al., 1988), there is no single element that has not changed: the survey data changed in 1988 to the dive survey; the harvest control rule changed from being applied to the current spawning biomass estimate to the projected spawning stock biomass estimate (for minor stocks); and assessment model assumptions have changed on multiple occasions with different discrete and instantaneous formulations, alternative assumptions about q, and others that included empirical weight-at-age and time-varying estimates of natural mortality; plus many others. In addition to operational changes in the application of management procedures, there is some evidence for environmental and ecological changes that resulted in apparent changes in size at age and natural mortality that would have affected management procedure performance even if it had been consistently applied. As a result, it is difficult to attribute departures from the original predictions of management procedure performance (in terms of probability of fisheries closures, average annual variability of catch) to any single cause.

This year's assessment presents two base cases assessments for each of the 5 major stocks: "AM1" denoting the case where surface (1951–1987) and dive (1988–2017) survey catchability parameters (q_1 and q_2) are estimated using a prior distribution, and "AM2" denoting the case where the surface survey catchability (q_1) is estimated and the dive survey catchability is fixed at $q_2 = 1$. The ISCAM modelling code used in 2017 has been updated to the new platform, the details of which are described in the Bridging Analysis (Appendix D).

Sensitivity cases for AM2 and AM1 investigate:

1. Estimation of time-varying vs. constant natural mortality,

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[1] Haist, V. 1988. An evaluation of three harvest strategies based on forecast stock biomass for B.C. herring fisheries. Pacific Stock Assessment Review Committee working paper H88-3, Department of Fisheries and Oceans. Unpublished manuscript.

2. Errors-in-variables parameterization of process and observation error,
3. Sensitivity to broadening of the prior on q, and
4. Juxtaposition of maturity-at-age and selectivity-at-age.

Sensitivity cases are presented for all 5 major stocks.

1.2 LIFE HISTORY

Pacific Herring is a pelagic species migrating between inshore spawning and offshore feeding areas of the North Pacific. In the eastern Pacific, herring distribution ranges from California to the Beaufort Sea. In southern BC, herring recruit to the spawning stock and are sexually mature predominantly at age 3 with some precocious 2 year olds joining the spawning population. In northern BC, herring tend to spawn for the first time at ages 3 and 4 with few or no two year old recruits (Taylor, 1964). It is generally believed that in the Strait of Georgia the young-of-year herring overwinter in their first year before joining the immature and adult populations in the offshore feeding grounds whereas in other areas of the coast young-of-year herring appear to begin migration offshore at the end of their first summer (Hourston and Haegele, 1980). Herring mature and recruit to the spawning stock predominantly at age 3 within BC but age-at-recruitment tends to increase with latitude within this range.

Herring are iteroparous and return to spawn each year once reaching maturity, until they die naturally or are intercepted in fisheries. Based on many years of tagging data it is evident that while herring generally return to the same large geographical region each year they do not home to the same spawning beach or bay each year (Hay et al., 2001; Flostrand et al., 2009). Each female produces about 20–40,000 eggs and quite consistently about 100 eggs/g of female weight, with larger females producing more eggs than smaller and younger fish (Hourston and Haegele, 1980; Hay, 1985).

The age of maturity of herring is difficult to assess since few surveys of maturing fish have been conducted in offshore areas. Indications from histological assessment of developing ovaries suggests that about 25% of Pacific Herring mature at age 2, and at least 90% mature at age 3 (Doug Hay, unpublished data[2]). This is consistent with observations for southern BC stocks, as described above.

The majority of herring in BC appear to occur as large schooling aggregations exhibiting seasonal migratory behaviour. The main Haida Gwaii (HG) and Prince Rupert District (PRD) stocks feed in Hecate Strait during the summer and fall months, remaining in the offshore areas of Hecate Strait prior to inshore spawning migration in February before spawning in March through May. The main Central Coast (CC) stock feeds in southern Hecate Strait and Queen Charlotte Sound during the summer and early fall months, remaining in offshore areas prior to inshore migration in February to the CC before spawning in March and April. The main Strait of Georgia (SOG) stock feeds off the west coast of Vancouver Island during the summer and early fall months, reentering the SOG beginning in October before spawning in March and April. The main West Coast of Vancouver Island (WCVI) stock feeds in offshore areas of southern Vancouver Island during the summer and early fall months (mixing with the migratory SOG stock), returning inshore in late fall before spawning in March and April, with some early spawns occurring January and February.

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1.3 STOCK STRUCTURE

Research examining stock structure of Pacific Herring includes studies using genetics and a variety of tagging methods. Beacham et al. (2008) examined genetic population structure of Pacific Herring in BC and adjacent regions using microsatellite variation. This research identified four stocks of Pacific Herring in BC, as well as stocks in southeast Alaska, Washington, and California. In BC, differences in timing of spawning were identified as the main isolating mechanisms among stocks, although it is also recognized that geographic isolation of spawning populations may also have some effect in maintaining genetic distinctiveness among stocks. The genetic research concludes that the limited genetic differentiation observed among Pacific Herring populations in BC is consistent with among-population straying rates that are sufficient to homogenize allele frequencies over broad areas but Beacham et al. (2008) also caution that while straying among Pacific Herring populations in BC is sufficient to lead to minimal genetic differentiation among Pacific Herring from different areas, the levels of straying may not be sufficient to offset overexploitation of the species in specific regions.

Beginning in the 1930s, BC Pacific Herring have been the subject of three tag-recovery programs. The first study employed internal belly tags (1936–1967), the second external anchor tags (1979–1992), and the third internal coded wire tags (1999–2006). The most recent analysis of data collected from the coded wire tag program indicates a wide range in fidelity across regions, from 53 to 90% (Flostrand et al., 2009), consistent with previous findings by Stevenson (1954), Hourston (1982), Ware et al. (2000), Hay et al. (2001), as well as Ware and Schweigert (2001).

The stock concept for BC herring has changed over time in response to the need for fisheries management. In recent years, migratory stocks have been the target for the roe and food and bait fisheries although some resident stocks, usually found within inlets, are thought to also support bait fisheries. At present, for the purposes of fisheries management, BC Pacific Herring stocks are managed as five major and two minor stock areas (Figure 2). With the terms ‘major’ and ‘minor’ being used to describe relative differences in the geographic and biomass scales being represented by them. Stock boundaries for major and minor stocks attempt to capture the habitat range of relatively discrete migratory herring stocks, and are based on historical records of commercial catch and spawning locations. Each stock assessment region (SAR) is comprised of several to many herring Statistical Areas that are further broken down into herring Sections and then Locations. Maps identifying stock boundaries and Statistical Areas for each SAR can be found on the Fisheries and Oceans Canada Herring Spawn and Catch Records website.

1.4 ECOSYSTEM CONSIDERATIONS

As a forage species, herring play a key role in the marine ecosystem and are a food source for a variety of species (Schweigert et al., 2010). Herring are an important prey species to many piscivores including Pacific Salmon (Coho and Chinook), Pacific Hake, Pacific Halibut, Arrowtooth Flounder, and Spiny Dogfish. They are also believed to be important in the diet of marine mammal predators such as Steller and California sea lions, harbour and northern fur seals, harbour porpoises, Pacific white-sided dolphins, as well as humpback and grey whales. Over the time series depicted in the Pacific Herring assessment (1951-2017), population sizes of seals and sea lions and baleen whales, which forage on herring, have increased (DFO, 2003, 2010;Caretta et al., 2011; Crawford and Irvine, 2011).

DFO is currently compiling data to develop ecosystem modeling approaches in the hope that this endeavor (along with other ecosystem modeling initiatives at the University of British

Columbia) will help explain how environmental and ecological interactions have affected BC Pacific Herring stocks, and how they are likely to be affected in the future.

In the meantime, DFO Pacific Region has committed to a Management Strategy Evaluation (MSE) process for Pacific Herring within which the performance of management procedures in the face of ecosystem impacts on natural mortality and growth will be tested. Testing the performance of management procedures in the face such ecosystem changes for BC Pacific Herring stocks is a priority area of research for DFO.

1.5 HERRING FISHERIES

Herring have been harvested for many years to provide a variety of food products. First Nations have traditionally harvested whole herring and herring spawn for food, social and ceremonial (FSC) purposes. The commercial Pacific Herring fishery started in BC in the 19th century for the local food market, and quickly expanded into a dry salt fishery for the orient. In 1937 a reduction fishery was also established to produce fishmeal and fish oil (Hourston and Haegele, 1980). The average catch of Pacific Herring from 1951 to 1965 was 143 thousand tonnes.

From the early 1930s to the late 1960s, herring were commercially harvested and processed (reduced) into relatively low-value products such as fishmeal and oil. Commercial catches increased dramatically in the early 1960s, but were unsustainable. By 1965, most of the older fish had been removed from the spawning population by a combination of overfishing and by a sequence of weak year-classes attributed to unfavourable environmental conditions and a low spawning biomass. As a result, the commercial fishery collapsed and was closed by the federal government in 1967 to rebuild the resource. During the closure from 1967 to 1971, limited fishing activity occurred at low levels (Hourston, 1980). At this time, there was a growing interest in harvesting roe herring for export to Japan, where herring stocks had been decimated. A small experimental roe harvest began in 1971 and expanded rapidly until 1983, when a fixed harvest rate was introduced to regulate catch. A series of above average year-classes occurred in the early 1970s, rapidly rebuilding stocks and permitting the re-opening of all areas for commercial fishing. In comparison to the average catch from 1951 to 1965, the average catch over the past 35 years (1983 to 2017) is 27 thousand tonnes.

1.6 MANAGEMENT OF MAJOR HERRING STOCKS

The harvest rule for Pacific Herring is described as (Martell et al., 2012):

$$U'_{T+1} = \begin{cases} 0 & SB_{T+1} \leq 0.25 \cdot SB_0 \\ \min\left(\frac{SB_{T+1} - 0.25 \cdot SB_0}{SB_{T+1}},\ 0.2\right) & SB_{T+1} > 0.25 \cdot SB_0 \end{cases} \tag{1}$$

where T is the terminal year for the stock assessment, SB_{T+1} is the prefishery forecast biomass in year T+1, and SB_0 is the unfished equilibrium spawning stock biomass. The output from the harvest control rule is the intended annual harvest rate, which is reduced to zero as the spawning stock is depleted to the level of $0.25 \cdot SB_0$.

For the major stock areas, the harvest control rule is a hybrid that combines both constant escapement and constant harvest rate policies, allowing for a reduced harvest rate in areas where the intended 20% annual harvest rate would bring the forecast pre-fishery mature spawning biomass (i.e., the ‘escapement’) to levels below the cut-off value of $0.25 \cdot SB_0$ (Cleary et al., 2010; Cleary and Schweigert, 2012).

This cut-off value was selected based on simulation work (Hall, 1986; Haist, 1988[1]; Hall et al., 1988; Zheng et al., 1993; Haist et al., 1993) suggesting that for stocks above the $0.25 \cdot SB_0$ level, that the hybrid HCR would produce lower catch variance and fewer fishery closures than a constant escapement rule.

Contrary to the predictions of the analyses done in the late 1980s, some herring stocks appear to have been below cut-off levels relatively frequently. Since 1986 there have been several different stock assessments models used, each of which had different assumptions and new data so that for each assessment, in each year, there were new estimates of current and unfished spawning biomass levels; it is therefore not possible to compare the current stock assessments estimates to what would have been estimated historically. Accordingly, the best approximation that is available to determine if stocks were above or below cut-offs is to examine historical Integrated Fisheries Management Plans. On the basis of this analysis, three of the major herring stocks, WCVI, CC, and HG, were below cut-off for 32%, 21%, and 46% of years, respectively from 1986 to 2013. The relative contribution of harvest, environmental and ecological interactions causing changes in natural mortality and growth, or alternative assessment models (in particular more conservative models applied before 2011), and/or other factors to the stocks having been estimated to be below cut-offs is currently not well understood.

Since the introduction of the HCR for Pacific Herring the policy environment for Canadian fisheries has changed with the introduction of the sustainable fisheries framework in 2009 which includes a fisheries decision-making framework incorporating the precautionary approach, hereafter called the DFO PA Framework. The Framework is one component of the Sustainable Fisheries Framework, the Department's national strategy for moving DFO towards an ecosystem approach to management of Canadian fisheries. The 2017 Request for Scientific Information and Advice (RSIA) submitted by Fisheries Management has requested that advice for Pacific Herring be consistent with the Framework requirement to characterize uncertainty and risk. DFO Pacific Region has committed to Renewal of the Management Framework for Pacific Herring, including updated simulation analyses of harvest control rules. Although the herring HCR was not originally designed to address the intent of the Framework, the form of the rule does meet the requirement to reduce the fishing rate as stock status declines to low levels of abundance, a tactic intended to encourage stock growth towards the target biomass reference point. Simulation analyses of HCR will occur within a Management Strategy Evaluation (MSE) process, focusing on establishing Management Procedures compliant with the DMF policy, including avoiding Limit Reference Points (LRPs) with high probability and establishing Upper Stock Reference (USR) points or target biomass levels.

1.7 BIOLOGICAL REFERENCE POINTS

Unfished equilibrium spawning biomass (SB_0) has been part of the management procedure for Pacific Herring since 1986 when $0.25 \cdot SB_0$ was adopted as a commercial fishing threshold (cut-off) in the harvest control rule. Annual science advice includes presentation of estimated stock status relative to the long-term average unfished spawning biomass, and presentation of probabilistic decision tables with projected pre-fishery biomass relative to fractions of SB_0 (e.g., $0.25 \cdot SB_0$ and $0.30 \cdot SB_0$). Time series estimates of weight-at-age show significant declines in mean weight-at-age for all major stocks between 1980-2010 as well as increasing and decreasing trends in estimated natural mortality. Given these non-stationary dynamics, SB_0 is calculated using on long-term average weight-at-age and average natural mortality and we do not present dynamic estimates of SB_0, i.e., based on shorter time series or during “high” or “low” productivity periods. Regarding the calculation of reference points, the DFO PA Framework recommends “as long as a time series as possible should be used in establishing reference points for a stock”. Many stocks will show substantial variation in productivity over a long time series, and this variation should be taken into account when setting the reference points.

Evidence of non-stationarity as well as modelling of three selectivity types due to concurrent harvesting by multiple gear types limits our ability to calculate and evaluate equilibrium reference points such as B_{MSY} in the management procedure. Previous attempts to estimate B_{MSY} for BC Pacific Herring stocks has resulted in unusually high estimates of F_{MSY} (Martell et al., 2012).

Attempts to estimate F_{MSY} using ISCAM are presented in 2.3.4 of the Sensitivity Analyses, based on a single gear type (roe seine), in order to investigate whether overlap or lack of overlap in maturity and selectivity curves impacts estimates of F_{MSY}.

1.7.1 Limit Reference Point

The recently reviewed and approved CSAS publication “The Selection and Role of Limit Reference Points for Pacific Herring (*Clupea pallasii*) in British Columbia, Canada” (Kronlund et al., 2018) is a significant and new contribution of research to the topic of biological reference points for Pacific Herring and other forage species. The DFO PA Framework specifies that a Limit Reference Point (LRP) should be positioned before a state of serious harm occurs, rather than at the state of serious harm and that it must be avoided with high probability. Kronlund et al. (2018) use an evidence-based production analysis conditional on current data and stock assessment model assumptions, to evaluate whether the major Pacific Herring stocks in British Columbia show stock states consistent with signs of possible serious harm. The production analysis identified recent persistent states of low production and low biomass (LP-LB states) for the Central Coast (CC), Haida Gwaii (HG) and West Coast of Vancouver Island (WCVI) management areas. A spawning biomass-based LRP of $0.30 \cdot SB_0$ for the CC, HG, and WCVI stocks was recommended based on results of the production analysis and consistency with international best practice recommendations. Persistent LP-LB states were not diagnosed for stocks in the Prince Rupert District (PRD) and Strait of Georgia (SOG) management areas, however a LRP of $0.30 \cdot SB_0$ is also recommended for the PRD and SOG stocks as it aligns with best practice recommendations, and because these stocks are geographically adjacent to stocks for which recent low LP-LB states were detected.

The authors recommend the phasing-in of any new management procedure (i.e., changes to data collection, stock assessment models and/or harvest control rules) designed to avoid LRPs and achieve targets in order to mitigate short-term consequences to resource users. Specific recommendations on *how to* apply LRPs in the context of annual advice derived from stock assessment models were beyond the scope of the paper. However as requested in the Terms of Reference, this assessment presents current estimates of spawning biomass for each major stock relative to the LRP.

1.7.2 Upper Stock Reference

A fully specified set of objectives that includes both LRPs and target reference points (TRPs) will be necessary to meet goals for renewal of the Pacific Herring management system and consistency with the DFO PA Framework. The Framework also defines the Upper Stock Reference (USR) point as the boundary between the Cautious and Healthy zones. The Framework presents a special case where the USR and point where the harvest rate is reduced with declining stock status are equivalent (Figure 1). A more general representation distinguishes between biological reference points that represent limits and targets, and the points at which management action is taken to avoid limits and achieve targets, typically represented by a harvest control rule (e.g., Kronlund et al., 2018). The USR and TRP can be equivalent, and the TRP cannot be lower than the USR. The USR must be set at an appropriate distance above the LRP to provide sufficient opportunity for the management system to recognize a declining stock status through feedback in response to management actions. The management actions are expressed by a management procedure that includes a choice of data, the stock assessment model, and catch recommendation generated by the harvest control rule.

While the Framework defines the USR as the boundary between the Cautious and Healthy zones, it does not provide guidance on how to identify an appropriate choice of the breakpoint between these zones.

The hybrid constant escapement/constant harvest rate feature of the herring HCR was intended to maintain a minimum escapement level equal to the commercial fishery cut-off. In this case, the management procedure has treated the LRP as an operational control point (OCP) where management action is taken. In the design of the current HCR (Cleary et al., 2010), this "ramping-down" of the harvest rate is intended to avoid commercial fishery closures and encourage stock growth, however the reduction from $0.31 \cdot SB_0$ to $0.25 \cdot SB_0$ is so steep that there is a very limited range of estimated biomass where reduced harvest rates might arrest stock decline before closure of the commercial fisheries. The effect of this feature of the HCR is the "on or of" behaviour seen in the simulation results of Cox et al. (2015)[3]; DFO (2015). The outcome of which is that for 3 of the stocks, spawning biomass fell below this level far more often than predicted (Section 1.6).

A comprehensive review of approaches to establishing both limit and target reference points for herring stocks worldwide for clupeids is included in Kronlund et al. (2018, Appendix F). Examples for establishing the USR include:

1. Interim USRs were defined at biomass levels to which stocks are expected to grow under average recruitment (DFO, 2005); recommended for Southern Gulf of St. Lawrence Atlantic Herring,
2. The USR, referred to as B_{BUF}, is defined as the lowest observed historical spawning-stock biomass which produced good recruitment; recommended for West coast of Newfoundland (NAFO Div 4R) Atlantic Herring (McQuinn et al., 1999), and
3. The biological limit, B_{lim} is established as the minimum spawning stock biomass that would ensure adequate recruitment based on available stock-recruitment information, and the B_{pa}, the precautionary level for stock biomass, is set at 5.0 million tonnes which is 2x the B_{lim} of 2.5 million tonnes; recommended for Norwegian spring-spawning herring (Tjelmeland and Røttingen, 2009).

In these examples, the biological reference points are implemented as the lower and upper operational control points (OCPs) in a hockey-stick shaped harvest control rule.

For Canadian fisheries in the Maritimes Region, a commonly used approach to defining the USR (and the boundary between the cautious and healthy zones) is to set the USR equal to 2x the LRP. The following model-based approaches are used (DFO, 2012):

4. Set the LRP at 40% of spawning stock biomass at maximum sustainable yield (SSB_{MSY}) and the USR at 80% of (SSB_{MSY}); recommended for 3NOPs4VWX+5 Atlantic Halibut, 4VsW Atlantic Cod, 4X5Y Haddock, 4VWX American Plaice,
5. LRP established based on analysis of stock-recruitment data, with proposed USR equal to 2x the LRP; recommended for 4X5Y Atlantic Cod, and

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[3] Cox, S.P., Benson, A.J., Cleary, J.S., and Taylor, N.G. 2019. Candidate limit reference points as a basis for choosing among alternate harvest control rules for Pacific Herring (*Clupea pallasii*) in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. In press.

6. Reference points based on analysis of carrying capacity: LRP at 25% of carrying capacity and USR at 50% of carrying capacity; recommended for 4VWX Snow Crab.

Where model-based estimates were not available, empirical approaches to approximating B_{MSY} are used, with LRP and USR set at 40% and 80% of B_{MSY} (DFO, 2012). However, estimates of MSY-statistics are not plausible for Pacific Herring in BC for reasons discussed by Kronlund et al. (2018).

Sinclair and Starr (2005) suggest using the long-term average biomass B_{avg} as a proxy USR. This approach of defining a historical target reference point is recommended for Rock Sole (Holt et al., 2016) and for Pacific cod (Forrest et al., 2015). An alternative to using the long-term average biomass is the average biomass during a productive period ($B_{\text{avg-prod}}$).

Proposed candidate USR for Pacific Herring are:

1. USR = long-term average spawning biomass SB_{avg},
2. USR = long-term average biomass during a productive period $SB_{\text{avg-prod}}$,
3. USR = 2x LRP (e.g., $0.60 \cdot SB_0$), and
4. USR = SB_0.

The analysis conducted by Kronlund et al. (2018) looked at a variety of B_{MSY} proxies and they were rejected as implausible, thus we are not including B_{MSY}-based candidates at this time.

Simulation testing of the consequences of the choice of LRP, USR, and TRP relative to candidate management procedures is the recommended procedure for understanding expected performance trade-offs in management outcomes. The management outcomes are related to measurable objectives of avoiding LRPs with high probability and maintaining stocks at TRP levels with the desired probability over a specified time-frame appropriate to life history and current understanding of stock dynamics. The DFO has committed to a management strategy evaluation process for Pacific Herring, with engagement of managers and resource-users, focusing on evaluation of reference points and management procedures to fully align the Pacific Herring management framework with the DFO PA Framework (DFO, 2009).

1.8 ASSESSMENT HISTORY

Annual stock assessments for the BC Pacific Herring major stocks have been conducted using a catch-age model since the early 1980s (Haist and Stocker, 1984; Haist and Schweigert, 2006). Since then, the design of the model has undergone re-structuring various model components, as often as every 2-3 years, to address issues identified during peer-review. One major change introduced in 2011 (Martell et al., 2012) was setting the model to estimate the spawn dive survey scaling parameter q_2, rather than setting it fixed at $q_2 = 1.0$, as was done in some previous assessment models. Another major change introduced in 2011 was to make the fishery cut-offs in the harvest control rule dependent on the model's most recent estimate of unfished spawning biomass SB_0 (i.e., cease fishing when the stock is estimated to be below $0.25 \cdot SB_0$). In previous model iterations, the fishery cut-offs were fixed at absolute biomass levels based on 1996 estimates of $0.25 \cdot SB_0$ (Schweigert et al., 1997). Throughout this document, the term Assessment Model 1 (AM1) describes the more recent management procedure (MP), which estimates the scaling factor for the surface survey q_1 (1951-1987) and dive survey q_2 (1988-2017) using informative priors; and uses estimated fishery cut-offs. Assessment Model 2 (AM2) refers to an approximation of the historical MP, in which the surface survey q_1 (1951-1987) is estimated, the dive survey q_2 (1988-2017) is fixed at 1.0 and the fishery cut-offs are fixed at 1996 levels.

There have been a number of requests to evaluate the potential consequences of applying AM1 vs. AM2 using simulation modelling. This reflects concerns that the consequences of applying AM1 were not simulation-tested prior to its implementation in 2011, which, along with lack of rebuilding in some areas, has led to questioning the performance of AM1. Both MPs have been peer reviewed through CSAS and both have been implemented in the provision of science advice for Pacific Herring in previous years.

To address concerns arising both from previous CSAS processes and from implementation of each approach, the 2016 Science Response (DFO, 2016) includes a table developed by the Herring Technical Working Group (HTWG) that describes the main attributes and limitations of AM1 and AM2, to support short-term decision-making (see DFO, 2016, Table A.1). The status of BC herring stocks in 2017 and forecasts for 2018 are provided in the form of dual stock assessment updates, using the AM1 (Martell et al., 2012) and AM2 (approximation of Cleary and Schweigert, 2012) MPs.

2 STOCK ASSESSMENT MODELLING

We applied a statistical catch-at-age model in a Bayesian estimation framework to assess the coastwide stock of Pacific Herring. The model was fit to catch data, two survey indices of relative spawner biomass, and to age composition data from the commercial fisheries and the herring test fishery. A matrix of average weight-at-age from 1951 to 2017 was also estimated external to the model, using biological samples from the seine caught fish (seine roe, food and bait, seine test). Additional biological parameters such as growth parameters and maturity schedules were taken from external analyses and input to the assessment model as fixed parameters that were assumed to remain constant over time (Section 2.1.5).

Reference points based on estimated long-term average unfished equilibrium spawning biomass (SB_0) and estimates of current stock status relative to estimated unfished spawning biomass (SB_{2017}/SB_0) are presented in Tables 13 to 17. Estimates of SB and depletion levels ($SB2017/SB0$) for the most recent 10 years are presented for models AM2 and AM1 in Tables 18 to 27.

Maximum Sustainable Yield (MSY) and the annual harvest rate producing MSY (U_{MSY}), were presented only within the context of the Sensitivity Analysis investigating interactions between maturity-at-age and selectivity-at-age (Section 2.3.4).

Harvest decision tables were created by projecting the assessment model one year into the future, given range of assumed catch levels (Tables 38 to 47). One year projections of spawning biomass assume recent 5-year average estimates of natural mortality and weight-at-age. For each level of catch, decision tables show the probability that projected spawning biomass in 2018 will be less than the LRP ($0.30 \cdot SB_0$), the fixed cut-off (for AM2), and the probability that the effective harvest rate for each catch level will be greater than target harvest rates of 10% and 20% (Section 3.2).

2.1 INPUT DATA

We use both fishery dependent and fishery independent time series data for stock assessment of Pacific Herring. Tables of all the data inputs are in Appendix B.

This section describes sources of fishery-dependent data: validated catch and biological samples from commercial fisheries, and fishery-independent data: biological samples from the test fishery program and a herring egg deposition survey (aka spawn survey) used to estimate a relative index of spawner biomass herring. Time series of commercial catch, spawn survey data, average weight-at-age data, and proportion-at-age data are used as input for the assessment model.

Observed trends in the data are presented in this section but key observations are interpreted in association with assessment model results (Section 2.4). To help readers view the collective data sets we summarize them by major stock area in Figures 3 to 7.

2.1.1 Catch data

Commercial fishing data are presented in this document from 1951 to 2017 (Figure 3).

Catch information is obtained from landing slips or dockside monitoring. Historically, landing slip data were summed by fishery season with seasons running from July 1 to June 30. Beginning in the 1997/98 season, roe catch data switched to verified plant offload weights, a result of the introduction of the pool quota system for all fisheries except the Strait of Georgia and Prince Rupert gillnet fisheries which remained open fisheries. Beginning in the 1998/99 season, verified plant offload weights became available for all food and roe fisheries coast-wide. Landings from the minor herring fisheries (SU and SOK) are based on landing slip data or more recently also from verified plant offload weights.

For the purposes of stock assessment, catch data are summarized by gear type and fishing category as follows:

Gear 1: other fisheries Commercial catch from the historical reduction fishery (1951–1967), winter seine fishery (FB, 1968–2017), and the SU fishery (up to 2017).

Gear 2: roe seine Commercial catch and test fishery catch from the roe seine fishery (1972–2017)

Gear 3: roe gillnet Commercial catch and test fishery catch from the roe gillnet fishery (1972–2017)

Currently, catch input to the stock assessment model does not include mortality from the commercial SOK fishery, nor any recreational or FSC fisheries. The FSC and recreational catches are minuscule. The commercial SOK fishery is licensed based on pounds of validated SOK product (i.e., eggs adhered to kelp), not tonnes of fish used or spawned. Currently there is no basis for verifying mortality imposed on the population by this fishery, however methods for estimating SOK mortality are being developed.

Commercial catch data are aggregated into three gear types/ fishery periods:

1. historic reduction fishery and FB,
2. seine roe and test, and
3. gillnet roe.

The same aggregation is applied to the biological sampling data to calculate proportions-at-age data input. Note that seine and gillnet roe fisheries catch whole fish, but the product is for the roe.

A summary of recent fishing activity is described below by major SAR. For areas where commercial food and bait, special use and roe fisheries have occurred, catches by fishery are summarized by stock area in Figure 3. Raw catch data for each stock area from 1951 to 2017 are included in Appendix B.

Haida Gwaii

Haida Gwaii was closed to commercial roe fisheries from 2002–2013 and 2015–2017, and commercial spawn-on-kelp (SOK) fisheries from 2004–2013 and 2015–2017. Commercial roe and SOK fishing opportunities were available in 2014, however they were not pursued following an agreement between the commercial sector and local First Nations. First Nations FSC fisheries operate within traditional territories of individual Nations, harvesting wild SOK and through closed-ponding for SOK.

Prince Rupert District

There are currently five commercial fisheries operating in the PRD. They are: the Winter fishery - food and bait herring (FB) that operates November - February; Seine Roe (SN) that operates February - March; Gillnet Roe (GN) that operates February - March; Spawn-on-kelp (SOK) that operates March - May; and Special Use (SU) that uses multiple gear types and operates year round although mainly in fall/winter period. First Nations FSC fisheries operate within traditional territories of individual Nations, fishing both whole herring (year round), SOK, and spawn-on-boughs (March-May).

Central Coast

The Central Coast was closed to commercial roe fisheries and commercial SOK fisheries from 2007-2013. Commercial roe and SOK fishing opportunities were available and pursued in 2014–2016. Commercial roe and SOK fishing opportunities were available in 2017, though only SOK opportunities were pursued. First Nations FSC fisheries operate within traditional territories of individual Nations, fishing spawn-on-boughs (March - April) and SOK (open and closed ponding).

Strait of Georgia

There are currently four commercial fisheries operating in the SOG. They are: the Winter fishery - food and bait herring (FB) that operates November - February; Seine Roe (SN) that operates February - March; Gillnet Roe (GN) that operates February - March; and Special Use (SU) that uses multiple gear types and operates year round although mainly in fall/ winter period. First Nations FSC fisheries operate within traditional territories of individual Nations, fishing both whole herring (year round) and spawn-on-boughs (February - March).

West Coast Vancouver Island

The West Coast Vancouver Island has been closed to commercial roe and spawn-on-kelp (SOK) fisheries since 2006 (with SOK permitted in 2011). First Nations FSC fisheries operate within traditional territories of individual Nations, fishing whole herring (year round), spawn-on-boughs (March - April), and SOK (closed and open ponding). Commercial fishing opportunities were not permitted in 2014 following an interlocutory injunction as a result of a federal court decision.

2.1.2 Biological data

Biological samples are used to provide model inputs of average weight-at-age and proportion-at-age by gear type/ fishery period ($n = 3$) from 1951 to 2017.

Biological samples are collected from the major commercial herring fisheries and through the test fishery program. The test fishery seine charter program began in 1975. The charter vessels collect sounding information, reporting locations and approximate size of pre-spawning aggregations of Pacific Herring on a daily basis, and collects biological samples from pre-spawning aggregations via purse seine. The present-day objective of test fishery biological sampling program is to collect samples in a variety of areas both open and closed to commercial fishing (providing the sole source of biological data for closed areas). Through a dock-side catch sampling contract, attempts are made to collect 15-20 herring samples from each of the roe seine and roe gillnet fisheries (during validation). In addition, catch sampling are collected for the FB fishery, and a small number of samples are collected from the commercial SOK and SU fisheries.

In all sampling events, one “herring sample” (one bucket) is roughly 100 individual herring, from which the following data are collected: fish length, weight, sex, gonad length, gonad weight, and maturity. Table B.29 indicates the number of biological samples by year and SAR.

For the purposes of stock assessment all fish within a “herring sample” are treated as independent observations, that is, there is no weighting of the biological samples by catch or spawn. Proportions-at-age data are aggregated into three gear types/ fishery periods:

1. historic reduction fishery and FB samples,
2. seine roe and test samples, and
3. gillnet roe samples.

The same aggregation is applied to the commercial catch data.

A stock-specific matrix of weight-at-age exists for each of the five major stocks. The matrix of weight-at-age for years 1951 to 2017 is the average weight over all seine-caught fish (Gear 1 and 2, where available) for each age categories 2 to 10+. Gillnet caught fish are excluded from the calculation of average weight-at-age because gillnet gear is size-selective. The number of biological samples used in the calculation of proportions-at-age and weight-at-age by year and SAR is summarized in Appendix B.

Herring are aged at the DFO Sclerochronology Lab at the Pacific Biological Station, Nanaimo, B.C. Since 1985, ageing convention for aged finfish species is to use a January-1 birthday. Prior to this change Pacific Herring were aged with a July-1 birthday coinciding with their biological birthday ranging from mid March (southern stocks) to early June (northern stocks). Herring ageing data arising from catch samples collected July-1 to Dec-31 are “+1 age-incremented”. That is, during data import, +1 ages are added to the ages of fish collected from July-1 to Dec-31 (e.g., age-2 fish become age-3 fish). This protocol has been in place since 1985, recognizing that these summer-fall collected fish would be 1-year older had they been removed from the population during the following roe season (March-April). Herring aged prior to 1985 have been age-adjusted in this way as well for consistency across all years.

Ageing errors are currently analyzed and corrected during the ageing process. Approximately 10% of herring scales in each sample are independently aged by two technicians to determine sample precision and ensure consistency between technicians. Further action is taken if technicians disagree on the age of a scale. The second technician (i.e., the technician doing the precision test) reviews the age; if they agree with the first technician, the age is resolved. If they disagree, the first technician (i.e., the technician that initially aged the scale) reviews the age; if they agree with the second technician, the age is resolved. If they still disagree, the scale is labelled ‘unresolved.’ Unresolved ages are often associated with scales that have unclear or confusing patterns which prevent definitive interpretation. If sample precision is less than 80%, the second technician will double-check more scales to ensure that the first technician is not biased or misinterpreting patterns. The final resolved age is the only source of age data for the assessment model, and data-derived precision estimates are not included as a source of error.

Ageing errors are most common in young fish, for example differentiating between 2 and 3 year old fish, or between 3 and 4 year old fish. This is in part due to faster growth in young fish, and the presence of checks which can be confused with annuli. Fish that are 4 years and older generally have fewer errors because growth patterns are more easily recognized, and growth is slower, more compact, and has less variation. Herring from certain stocks can have growth patterns that are more difficult to interpret, such as fish from Statistical Areas 14, 17, and 23 to25.

Mean weight-at-age data are important to the assessment in several ways (Figure 4). Firstly, using a time series of weight-at-age allows the assessment model to capture the effects of time-varying changes in weight-at-age, which are relevant and significant for Pacific Herring (also referred to as non-stationarity). Second, these data are an important determinant in estimating current biomass because this quantity is given by the sum of the element wise product of numbers-at-age and weight-at-age vectors so that even given fixed numbers-at-age, biomass will change considerably with changes in weight-at-age. Finally, changes in mean weight-at-age affect the estimate of the equilibrium unfished biomass, the key reference point for Pacific Herring.

Proportions-at-age and the number of biological samples by year are presented in Figures 5 & 6.

Measurable declines in weight-at-age are evident for all major herring stocks, from the mid-1980s to 2010 as shown in Figure 4. All stocks show a leveling off or increase in the recent most 5-years. Declining weight-at-age may be attributed to any number of factors, including fishing effects (i.e., gear selectivity) and environmental effects (changes in ocean productivity), or it may be attributed to by changes in sampling protocols (shorter time frame over which samples are collected). Declining weight-at-age is observed in all five of the major stocks, and despite area closures over the last 10-years has continued to occur in the HG and WCVI stocks. This trend has been observed in B.C. and U.S. waters, from California to Alaska (Schweigert et al., 2002). Changes in weight-at-age are not unique to Pacific Herring: they have also been observed in Pacific Hake (Taylor et al., 2014) and Pacific Halibut. The direct cause and influence of this decline should be investigated in the context of the assessment framework because changes in growth patterns will result in different reference point estimates and different estimated optimal harvest rate. Even though the mechanisms behind weight-at-age changes are not well understood, the model does account for observed changes in stock reconstructions and predictions.

2.1.3 Abundance index

Herring egg deposition (spawn) surveys have been conducted throughout the B.C. coast beginning in the 1930s. The time series of spawn survey data used for the assessment of Pacific Herring begins in 1951. Prior to 1988, spawn surveys were conducted from the surface either by walking the beach at low tide or using a drag from a skiff to estimate the shoreline length and width of spawn. In 1988, SCUBA methods were introduced to measure herring spawn along transects and SCUBA methods were implemented coastwide within a couple of years.

Both survey methods (surface or dive) involve collecting information on spawn length (parallel to shore), spawn width (perpendicular to shore), and number of egg layers by vegetation type.

These data are used to calculate egg densities per spawning bed, with the ultimate goal of back-calculating the biomass of mature spawners estimated to have deposited the eggs. Execution of the 2017 spawn survey followed all standard protocols as described in the 2013 version of the herring spawn survey manual. Detailed background, methods, and equations for calculating the spawn index are summarized in the draft spawn index technical report.

For the purposes of stock assessment, spawn survey data are represented as two independent indices:

1. surface survey index from 1951 to 1987, and

2. dive survey index from 1988 to 2017.

Spawn indices are an output of the Herring Stock Assessment Database, in units of metric tonnes of herring spawning biomass. Time series of spawn index by major stock area, from 1951 to 2017 for 1951 to 1987 (surface observations) and 1988 to 2017 (dive observations) are summarized in Figure 7. Surface survey data are processed such that the average width estimates are in a comparable format to those from the dive survey data and these observations are combined with the dive survey estimates into a single survey index.

In 4 of the major stock areas (HG, CC, SOG, WCVI), numeric estimates of spawning biomass (spawn index values) declined from 2016 to 2017. In PRD, numeric estimates of spawning biomass (spawn index values) neither increased nor decreased from 2016 to 2017.

Proportion-at-age and catch-at-age

ISCAM estimates catch-at-age for each of the three gear types using proportions-at-age data. The estimation procedure involves fitting a logistic function with age-specific selectivity coefficients to each gear type.

Estimated proportions-at-age from Gear 2 biological samples (roe seine, seine test, SOK, where available) by stock area are summarized in Figure 5. The matrix of mean weight-at-age data is calculated from the biological samples presented in Figure 5. Tables of numbers-at-age for Gear 1, Gear 2, and Gear 3 are included in Appendix B.

An adjustment is made in analytical procedures for compiling the proportions-at-age and weight-at-age data for Central Coast in 2014 and 2015. Area 08 biological samples are weighted by their average relative contribution over the past 20 years (7%), because the sampling protocol in 2014 and 2015 involved collecting an uncommonly high number of samples from Statistical Area 08. The downweighting of Area 08 samples was deemed necessary because fish sampled in Area 08 are consistently smaller at age than in Area 06 and Area 07 (DFO, 2014, 2016).

Stock specific trends are discussed in the sections below.

2.1.4 Assumed biological parameters

As described in Section 1.2, indications from histological assessment of developing ovaries suggest that about 25% of Pacific Herring mature at age 2, and at least 90% mature at age 3 (Doug. Hay, unpublished data[2]). For the assessment, a fixed maturity schedule is used for all herring stocks: 25% mature for age-2s, 90% mature for age-3s, and 100% mature for ages 4 and older (see description in Section 2.3.4).

Weight and length-at-age are currently analyzed external to the assessment model which requires inputs of asymptotic growth $L_\infty = 27$, alpha, α and beta, β for the length-weight allometry ($\alpha = 4.5e\ 06$, $\beta = 3.127$), and Brody growth coefficient ($k = 0.48$) were taken from FishBase (2017). Age at 50% maturity was estimated at 2.055. A matrix of empirically derived proportion-at-age data is generated from this analysis and required as input into the assessment catch-age model.

2.1.5 Data summaries for major SARs

We provide a brief description of input data to the assessment model for each of the major Pacific Herring SARs from 1951 to 2017. There are 4 timeseries of data for each major SAR: catch by gear type, spawn index, number-at-age, and weight-at-age. We provide tables of these timeseries in Appendix B.

Haida Gwaii

There were no commercial fisheries in 2017 (Figure 3). The spawn index decreased from 6,888 tonnes in 2016 to 3,016 tonnes in 2017 (Figure 7). Generally, mean weight-at-age for age-2 to -10+ has been stable or increasing since 2010 (Figure 4). In 2017, proportion-at-age was dominated by age-3 fish, and older age classes (i.e., age-6+) contributed 33% (Figure 5). There were 8 biological samples used to calculate mean weight-at-age and proportion-at-age data in 2017 (Figure 6). Each sample is approximately 100 fish.

Prince Rupert District

The total commercial catch in 2017 was 2,849 tonnes (Figure 3). The spawn index increased from 18,985 tonnes in 2016 to 19,235 tonnes in 2017 (Figure 7). Generally, mean weight-at-age for age-2 to -10+ has been stable or increasing since 2010 (Figure 4). In 2017, proportion-at-age was dominated by age-5 fish, and older age classes (i.e., age-6+) contributed 28% (Figure 5). There were 51 biological samples used to calculate mean weight-at-age and proportion-at-age data in 2017 (Figure 6). Each sample is approximately 100 fish.

Central Coast

There were no commercial roe fisheries in 2017 (Figure 3), thus the catch input for 2017 is zero. The spawn index decreased from 32,508 tonnes in 2016 to 23,517 tonnes in 2017 (Figure 7). Generally, mean weight-at-age for age-2 to -10+ has been stable or increasing since 2010 (Figure 4). In 2017, proportion-at-age was dominated by age-5 fish, and older age classes (i.e., age-6+) contributed 22% (Figure 5). There were 44 biological samples used to calculate mean weight-at-age and proportion-at-age data in 2017 (Figure 6). Each sample is approximately 100 fish.

Strait of Georgia

The total commercial catch in 2017 was 25,279 tonnes (Figure 3). The spawn index decreased from 129,502 tonnes in 2016 to 81,064 tonnes in 2017 (Figure 7). Generally, mean weight-at-age for age-2 to -10+ has been stable or increasing since 2010 (Figure 4). In 2017, proportion-at-age was relatively even among age-3 to -5 fish, and older age classes (i.e., age-6+) contributed 17% (Figure 5). There were 148 biological samples used to calculate mean weight-at-age and proportion-at-age data in 2017 (Figure 6). Each sample is approximately 100 fish.

West Coast of Vancouver Island

There were no commercial fisheries in 2017 (Figure 3). The spawn index decreased from 20,528 tonnes in 2016 to 15,734 tonnes in 2017 (Figure 7). Generally, mean weight-at-age for age-2 to -10+ has been stable or increasing since 2010 (Figure 4). In 2017, proportion-at-age was dominated by age-4 fish, and older age classes (i.e., age-6+) contributed 10% (Figure 5). There were 19 biological samples used to calculate mean weight-at-age and proportion-at-age data in 2017 (Figure 6). Each sample is approximately 100 fish.

2.2 STATISTICAL CATCH-AT-AGE MODEL

This assessment reports a base case of a catch-age model that is fitted to three sources of data: commercial catch, spawn survey biomass index, and proportions-at-age. The assessment depends primarily upon the spawn survey biomass index (surface: 1951 to 1987, dive: 1988 to 2017) for information on the scale of the major herring stocks.

The assessment uses Bayesian methods to incorporate prior information and integrate over parameter uncertainty to provide results that can be probabilistically interpreted. The exploration of uncertainty is not limited to parameter uncertainty as structural uncertainty is investigated through retrospective analyses (Section 2.6).

The assessment includes presentation of two alternate management procedures for each stock and scenario: AM1 and AM2 (Section 1.8).

2.2.1 Changes from the 2016 assessment

The assessment model was compiled using AD Model Builder (ADMB) version 11.6, released December 20, 2016. There were no changes made to the methods used for compiling model input data (survey indices, catch, biological information). Adjustments were made to some of the analytical procedures within ISCAM as described in the Bridging Analysis (Appendix D). These changes are considered regular year-to-year updates and lead to slight differences in model estimates and projections when comparing 2016 base model runs with results captured in the September 2016 assessment document.

The most significant update was to the estimation of the variance structure. In Martell et al. (2012) the errors-in-variables approach (partitioning of variance between observation and process error) parameterized varphi as the total standard deviation of the process error, rather than the total variance. Given the recommendation of the reviewers in 2011 and to bring the assessment in line with best practices, the current assessment includes updates to the errors-in-variables approach to represent partitioning of the total precision (Appendix A). This change to partitioning of the total variance impacts model estimates of leading parameters and unfished biomass (SB_0). The Bridging Analysis (Appendix D) provides a comparison of these differences.

2.2.2 Model description

A Bayesian statistical catch-at-age model was applied to assess each of the 5 Pacific Herring major SARs separately. The Integrated Statistical Catch Age Model (ISCAM) was first reviewed and implemented for the assessment of Pacific Herring in 2011 (Martell et al., 2012). Updates to ISCAM are explained in the Bridging Analysis (Appendix D) and full model details are provided in Appendix A.

Marginal posterior distributions for estimated model parameters were constructed using the AD Model Builder built-in Metropolis-Hastings algorithm (Fournier et al., 2012). For each major assessment area, a systematic sample of 5,000 points were taken from a chain of length 5 million intended to represent a random sample from the marginal posterior distribution. These analytical steps (Bayesian methods) are the same as were applied annually since September 2011 (Martell et al., 2012), and are consistent with previous years' assessments using Herring Catch Age Model (HCAM and HCAMv2) (Cleary and Schweigert, 2012; Schweigert et al., 2009).

The Bayesian estimation procedure integrates over the full range of uncertainty producing a posterior distribution for each parameter estimated in the model. Then, these samples are used to construct marginal distributions for derived quantities (e.g., SB_0).

2.2.3 Prior probability distributions

Prior probability distributions for leading parameters for each major stock are shown in Tables 1 & 2, and Figures 21 to 30. The form of each distribution remains the same as was implemented in Martell et al. (2012) and as has been implemented in each subsequent assessment. The initial values for each leading parameter were set equal to the MPD estimates from the 2016 assessment for each stock area. Prior values and standard deviations in priors remain the same. We explore sensitivity of model estimates to assumptions about standard deviation on the q prior in Section 2.3.3.

2.3 SENSITIVITY ANALYSES

We tested the sensitivity of the results from the base case assessment model identified in the bridging analysis in Appendix D to the following assumptions:

1. Assumed time varying natural mortality,
2. Assumed initial values for variance parameters ϑ^2 and ρ,
3. The prior probability on the survey catchability parameters (q_1 and q_2), and
4. The assumed fixed values for maturity at age.

Further details and results for each of these sensitivity analyses are presented below.

2.3.1 Natural mortality

The base case for the assessment model assumes that the natural mortality *M* is time varying where instantaneous natural mortality is assumed equal over all ages but varies over time (Fu et al., 2004). Estimating annual deviations in time varying *M* using a random walk process was introduced in 2006 (Haist and Schweigert, 2006), and with the introduction of *ISCAM* (Martell et al., 2012) a more parsimonious cubic spline approach was introduced which reduced the number of estimated *M* parameters to 12, as opposed to estimating 60+ annual deviations.

For this sensitivity analysis we investigated the effects of estimating a single constant M over ages and time. The main motivation for this sensitivity analysis was to further investigate the impact of using time-varying natural mortality in the assessment model given recent increasing trends in model estimates of M for HG, CC, and WCVI. Incidentally, an alternative approach to estimating M is implemented in the assessment of some Pacific Herring stocks in Alaska in which constant M is estimated for pre-specified time blocks defined by changes in the Pacific Decadal Oscillation (PDO). We did not consider such a scenario here as undertaking an analysis to determine how to define time-blocks for estimating M was outside of the scope of this assessment.

The constant estimated natural mortality scenario was applied to all major stocks and both parameterizations of the assessment model (AM2 and AM1) and compared with time varying M model runs. Results are shown in Figures 66 to 89.

Model estimates were influenced by the method used to estimate M. The addition of time varying M appears to improve model and empirical fits to the spawn index for both AM2 and AM1 versions of the assessment model for all stocks (Figures 66 to 75). The biggest difference between estimating time varying M and constant M occurs in the recent 5-years of model fits to the spawn index. For example, for HG (Figure 67), for both AM1 and AM2, the constant M sensitivity runs show a significant lack of fit to declining spawn index from 2014 – 2017. For CC, both AM1 and AM2, the constant M sensitivity runs appear to overestimate the magnitude of increase in the survey data (Figure 71). The lack of fit to the declining survey index also carries through to the estimation of spawning biomass, e.g., HG: Figure 76.

The estimated time-varying natural mortality values do show high variability in some stocks over short time periods (Figures 83 to 87) and this can likely be attributed to either periods of heavy predation, trophic interactions and/or model variance.

When examining estimated spawning biomass between all four model runs (AM1- constant M, AM1- time varying M, AM2- constant M, AM2- time varying M), trends in spawning biomass over time were most similar within the AM1 and AM2 categories. That is, it does not appear that the method used to estimate M is confounded with the choice of q prior. See for example Figure 76 and 77.

For most stocks the resulting spawning biomass and recruitment deviations showed little difference between the models assuming constant M over time varying M for both AM2 and AM1 (Figures 76 to 77 and 78 to 82, respectively). Recruitment deviations showed similar trends to the spawning biomass with HG and WCVI stocks showing the greatest variation between constant M and time varying M (and not between AM1 and AM2). The resulting trends in q_t are similar between stocks with the greatest variations between constant and time varying M models seen in the q_2 estimates for AM1 and AM2. For example, HG (Figure 88) and WCVI (Figure 89) time-varying and constant M AM2 estimates of q_2 are predicted to be higher than those predicted by the AM1 models.

MCMC trace plots, autocorrelation plots, and pairs plots were very similar between constant M and time varying M model runs for PRD, CC, SOG and WCVI. See time varying M , Figure 32 to 60; constant M not shown. The exception was for HG AM2 where trace plots, autocorrelation plots, and pairs plots showed signs of persistent drift and autocorrelation (Figures 90, 91, & 92, respectively).

The total likelihood, Akaike information criterion (AIC) values and the difference in likelihood from the base model were also examined for all models and for each stock group (Table 54). With the exception of SOG the AM1 and AM2 time-vaying M models have higher total likelihoods and lower AIC values indicating that overall the time-varying models provide a better fit to the data.

There is support for continued inclusion of time varying M as the base case for the assessment in this analysis, as well as from the Bridging Analysis (Appendix D) based on the reduction improved coherence between assumed and empirical fits to the spawn survey index and issues of autocorrelation between parameters and model convergence with constant M.

2.3.2 Variance parameters

The key variance parameter in the errors-in-variables approach is the inverse of the total variance $\varphi^{-}2$ (i.e., total precision, varphi). The total variance is partitioned into observation and process error components by the model parameter rho ρ, which is the proportion of the total variance that is due to observation error (Punt and Butterworth, 1993; Deriso et al., 2007).

In ISCAM, standard deviations in process error (tau, τ) and observation error (sigma, σ) are related and modelled using the following equations for kappa κ

$$\kappa = \left(\frac{1}{\sqrt{(\sigma^2 + \tau^2)}} \right)^2 \tag{2}$$

and rho ρ

$$\rho = \sigma^2 \left(\frac{1}{\sqrt{(\sigma^2 + \tau^2)}} \right)^2 . \tag{3}$$

The base case initial values for κ and ρ were set equal to MPD estimated values from the 2016 assessment, which resulted in an observation error term ($\sigma = 0.58$) and a process error term ($\tau = 0.69$). We tested model sensitivity to these initial values ϑ^2 and ρ by varying them, while estimating all leading parameters.

This analysis showed that when both ρ and κ are estimated, the choice of initial value for ρ and κ does not impact estimated model parameters, as shown in Tables 49 & 50 for the Strait of Georgia, models AM2 and AM1. This trend can also be seen in the Bridging Analysis (Appendix D) for AM2 and AM1, both parameterizations of M in the first sensitivity analysis (Section 2.3.1) and all stocks. In the Bridging Analysis we also investigated the effects of fixing either κ or ρ and only estimating one of these parameters at a time. Under these scenarios we found that the estimated results were highly influenced by the initial values of κ and ρ. Because of this observation and because we have no external information to inform the fixing of one of these parameters over the other, the base case estimating both parameters was chosen.

2.3.3 Prior probability distributions for survey catchability

There are two versions of the base stock assessment model that differ in the treatment of spawn survey catchability parameters (q_1 and q_2) for the surface survey period (1951 to 1987) and dive survey period (1988 to 2017), respectively. The two models are labelled AM1 (q_1 and q_2 estimated with prior probability distributions) and AM2 (q_1 estimated, $q_2 = 1$).

There have been concerns that the results from applying the prior probability distributions on q_1 and q_2 in the AM1 model have been too restricting to the resulting estimations. A Bayesian prior for the dive survey q was developed from an analysis of field studies in the 1980s and 1990s, external to the assessment of Pacific Herring, the details of which are included in Appendix C of Martell et al. (2012). Based on this concern and the results of the Bridging Analysis (Appendix D) we conducted sensitivity analyses testing the effects of broadening of the prior distribution on q by changing the standard deviation of this prior while keeping the mean constant. In the base case for AM1 the q prior distributions have the mean set at 0.566 and the standard deviation set to 0.274 for both q_1 and q_2. For the sensitivity scenarios we increased the standard deviation to 0.5, 2.0 and 3.0 for both q_1 and q_2. We did not consider scenarios with alternate mean prior values or distribution type because developing a new prior was beyond the scope of this paper.

Also, Step 9 in the Bridging Analysis (Appendix D) clearly shows the direct relationship between mean prior values and estimated spawning biomass, indicating that with decreasing mean prior values the estimated spawning biomass increases. Model estimates show small increases in spawning biomass, depletion and natural mortality with increasing prior standard deviation on qs and minor decreases in the estimates of q_1 and q_2 for all stock groups (Figures 96 to 110).

Table 53 presents median posterior distribution estimates of SB_{2017}, SB_0, SB_{2017}/SB_0, and both qs for AM1 for the base 3 sensitivity cases where the prior on q is broadened by increasing the standard deviation. These results show that there is no consistent trend in the relationship between the standard deviation on the prior of q and the estimated prior values. For example, for HG and CC, as the standard deviation on the prior is increased, both q_1 and q_2 estimates decrease resulting in slightly higher estimate of SB_{2017}. For PRD, SOG and WCVI, q_2, as the standard deviation on the prior increases, model estimates of q_2 increase. In all cases, overall influence on the estimation of SB_{2017}, SB_0, and SB_{2017}/SB_0 is negligible.

2.3.4 Maturity at age

The base case maturity vector assumes 25% of age-2 fish are mature, 90% of age-3 fish are mature, and 100% maturity for fish ages 4 and older. From these assumptions the age of 50% maturity is estimated to be approximately 2.3 years. These base case values are fixed for all BC Pacific Herring stocks at values indicated from histological assessment of developing ovaries (Hay, 1985; Hay and McCarter, 1999). In the recent analysis identifying limit reference points for BC Pacific Herring stocks, Kronlund et al. (2018) discuss the location of the maturity and fishery selectivity schedules in relation to estimation of F_{MSY}. When the positioning of the maturity curve is to the left of the fishery selectivity curve(s) and thus age at 50% maturity is estimated to occur at a much younger age than 50% selectivity, the model interprets the portion of the population that is mature but not yet selected for by the gear as invulnerable to the fishery.

Kronlund et al. (2018) suspect this phenomena (the juxtaposition of the maturity and selectivity curves) is one of the contributing factors to the high estimates of F_{MSY} coming from ISCAM. High F_{MSY} values subsequently infer high sustainable harvest rates, and the estimates of F_{MSY} reported in Kronlund et al. (2018) and in DFO (2015) were among the highest produced for Herring species worldwide.

The sensitivity analysis considered here involves setting the maturity at age vector equal to the selectivity of the seine roe fishery (gear 2) and then re-estimating equilibrium reference point F_{MSY}. Hay (1985) identify that age specific maturation varies with latitude and that generally, the warmer the water temperature the earlier the maturation of herring should occur. Thus different stocks of BC Pacific Herring may have different maturity schedules as they are distributed throughout different latitudes. In the absence of recent histological studies to provide new estimates of maturity at age, we tested the model sensitivity to the fixed base values by setting the maturity at age vector equal to the selectivity of the seine roe fishery (gear 2; Table 48). The selectivity of the seine roe fishery was chosen because the fishery targets pre-spawning aggregations with seine gear that is non size-selective, providing age composition samples from a mature portion of the population.

The resulting estimates of the leading parameters showed minor differences between the current fixed maturity vector model (base case) and the sensitivity case where the maturity at age is set to the selectivity at age (results not shown). We examined estimates of MSY , F_{MSY}, SB_0, and SB_{2017} for the base case and the maturity schedule sensitivity case (SoG: Tables 51 and 52) and in most cases, estimates of F_{MSY} was numerically lower for the maturity sensitivity case than the base. The exception is HG (AM2) where estimated of F_{MSY} increased for the maturity sensitivity case. Estimates of F_{MSY} under the maturity sensitivity case were still very high and imply that this change alone is insufficient to produced reliable estimates of F_{MSY} estimates for use in a management procedure.

2.4 ASSESSMENT MODEL RESULTS

2.4.1 Base case models

The Base Case models for this years Pacific Herring assessment were chosen based on the results of the Bridging Analysis (Appendix D) and the Sensitivity Analysis (Section 2.3). The 2016 assessment implemented two versions of the base stock assessment model that differ in the treatment of spawn survey catchability parameters (q_1 and q_2) for the surface survey period (1951 to 1987) and dive survey period (1988 to 2017), respectively. The two models are labelled AM1 (q_1 and q_2 estimated with prior probability distributions) and AM2 (q_1 estimated, $q_2 = 1$). Both the Bridging Analysis (Appendix D) and the Sensitivity Analyses (Section 2.3) support continued use of these two base case models for each of the 5 major herring stocks. These analyses alone were insufficient for understanding the complex interplay between q and management parameters, and resolution between AM1 and AM2 parameterization of q will require simulation-evaluation. It would however be possible to pursue alternative sources of data for developing stock-specific Bayesian priors for q, e.g., based on new analyses or expert opinion.

The sensitivity analyses supports continued use of time-varying natural mortality based on the improved coherence in empirical fits to the spawn survey index, and issues of autocorrelation between parameters and model convergence with constant M scenarios.

Because we found the model estimates of spawning biomass and unfished spawning biomass to be highly influenced by the initial values of ρ and κ when either of these parameters is fixed, and because we have no external information to inform the fixing of one of these parameters over the other, the base case of estimating both parameters was chosen.

Table 1 presents parameterization of AM1 and AM2 base case assessment models.

2.4.2 Model diagnostics

The joint posterior distribution was numerically approximated using the Markov Chain Monte Carlo (MCMC) routines built into AD Model Builder (Fournier et al., 2012). For AM2 and AM1 base cases and all sensitivity cases, posterior samples were drawn systematically every 1,000 iterations from a chain of length 5 million, resulting in 5,000 posterior samples. Convergence was diagnosed using visual inspection of the trace plots (Figures 32 to 40) and visual examination of autocorrelation in posterior chains (Figures 42 to 50). Autocorrelation was minor for all parameters in the AM2 and AM1 base model runs and there was no strong evidence for lack of convergence.

2.4.3 Fits to survey and proportions at age data

Figure (a) in each of Figures 8 to 17 show AM2 and AM1 model fits to the spawn survey data for each of the 5 major SARs: Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SoG), and West Coast of Vancouver Island (WCVI). Figures 111 to 125 present model estimated proportions at age for the 5 major SARs.

2.4.4 Parameter estimates

Prior and marginal posterior probability distributions of estimated parameters are shown in Figures 21 to 30. The median, 5th percentile and 95th percentile posterior parameter estimates, and MPDs are given in Tables 3 to 12. Choice of prior and prior distribution is described in Appendix A.

2.4.5 Biomass and stock status

The following section presents posterior distributions characterizing the major Pacific Herring stocks for the following parameters and derived quantities: model fits to the spawn survey index, age-2 recruitment, instantaneous natural mortality, and spawning biomass reconstructions.

To help readers view and interpret trends in results and uncertainty for each stock major stock area, collective sets of figures showing these four sets of model results across the 1951 to 2017 time series are presented by stock area in Figures 8 to 17. We also present median posterior estimates for the spawn survey scaling parameter (q; Table 2), as well as MPD estimates for age-2 recruits versus spawning biomass relationships (Figure 20), and age-specific fishing gear selectivity (Figures 61 to 65).

Estimated spawning biomass relative to the LRP is presented in Figure 19.

Haida Gwaii

Models AM2 and AM1 base case assessments estimate a declining trend in spawning stock biomass since 2013 (Figures 8 & 9, and Tables 18 & 19). In most years since 2000, including 2017, the WCVI stock has been in a low productivity low biomass state (Figure 19). AM2 estimates the median spawning biomass in 2017 (SB_{2017}) at 3,963 t and 17% of SB_0. AM1 estimates the median spawning biomass in 2017 (SB_{2017}) at 7,336 t and 25% of SB_0. Both AM2 and AM1 models estimate SB_{2017} to be below the LRP of $0.30 \cdot SB_0$ (Figure 19) by greater than

50% probability. The pattern of biomass estimates for AM2 is similar to that of AM1, however AM2 estimates of SB_{2017} and stock status relative to SB_0 are lower than the AM1 estimates, due largely to differences in model estimates of q_2 (Table 2).

There is no apparent recruitment predicted to be entering the spawning population in 2017: Figure 20 shows the number of age-2 recruits per number of spawners is near the origin of the Beverton-Holt stock recruit curve and Figure 112 shows a higher proportion of 3-year olds relative to 2-year olds. Although model estimates of current natural mortality remain highly uncertain, there is an increasing trend in the median estimates of natural mortality since 2012 (Figures 8 & 9).

The projected pre-fishery spawning biomass in 2018 is 4,346 t (AM2) or 7,302 t (AM1), similar to SB_{2017} levels, consisting of 34% (median) age-3 fish and 38% (median) age-4 and older fish (Table 13).

Prince Rupert District

Since the mid-1990s, the PRD stock is characterized by two periods of consistent and stable biomass: 1996-2003 and 2006-2017 (Figures 10 & 11, and Tables 20 & 21). AM2 estimates the median spawning biomass in 2017 (SB_{2017}) at 21,738 t and 34% of SB_0. AM1 estimates the median spawning biomass in 2017 (SB_{2017}) at 22,820 t and 36% of SB_0. Based on a comparison of median estimates, both AM2 and AM1 models estimate SB_{2017} to be above the LRP of $0.30 \cdot SB_0$ by greater than 50% probability but less than 95% probability (Figure 19). Numeric estimates of spawning biomass and stock status are very similar between AM2 and AM1, due to similarities in model estimates of q_1 and q_2 (Table 2).

Both AM2 and AM1 estimate a large recruitment of age 2 fish to the population in 2014, relative to the last 10 years, owing largely to the age composition information showing a high proportion of samples consisting of this age class. Figure 20 shows the number of age-2 recruits in 2017 as near average, just below the B-H stock recruit curve. Figure 115 shows a higher proportion of 4 and 5-year old fish relative to ages 2 and 3. Although model estimates of current natural mortality remain highly uncertain, there is an decreasing trend in the median estimates of natural mortality since 2006 (Figures 10 & 11).

Both AM2 and AM1 predict a continued stable trend in spawning biomass, with projected pre-fishery spawning biomass in 2018 of 23,924 t (AM2) and 24,903 t (AM1, Table 14), consisting of 23% (median) age-3 fish and 68% (median) age-4 and older fish (Table 14).

Central Coast

The survey index increased from 2012 - 2016 and declined from 2016 to 2017 (Figures 12 & 13). AM2 and AM1 base case assessments estimate an increasing trend in spawning stock biomass since 2012 (Figures 12 & 13, and Tables 22 & 23).

AM2 estimates the median spawning biomass in 2017 (SB_{2017}) at 30,474 t and 55% of SB_0. AM1 estimates the median spawning biomass in 2017 (SB_{2017}) at 49,620 t and 80% of SB_0. Based on a comparison of median estimates, both AM2 and AM1 models estimate SB_{2017} to be above the LRP of $0.30 \cdot SB_0$ by greater than 95% probability (Figure 19). The pattern of biomass estimates for AM2 is similar to that of AM1, however AM2 estimates of SB_{2017} and stock status relative to SB_0 are lower than the AM1 estimates, due largely to differences in model estimates of q_2 (Table 2).

Figure 20 shows average-to-below-average number of age-2 recruits in 2017 with 5-year old fish comprising the highest estimated proportion of fish, arising from the 2012 cohort (Figure 118).

There is no apparent recruitment entering the spawning population in 2017 (Figure 20).

Model estimates of current natural mortality are highly uncertain in the most recent years. Figures 12 & 13 indicate a declining trend in estimated natural mortality since 2008.

The projected pre-fishery spawning biomass in 2018 is 32,458 t (AM2) or 50,259 t (AM1), similar to SB_{2017} levels, consisting of 25% (median) age-3 fish and 66% (median) age-4 and older fish (Table 15).

Strait of Georgia

The survey index increased from 2013 - 2016 and declined from 2016 to 2017 (Figures 14 & 15). AM2 and AM1 base case assessments estimate an increasing trend in spawning stock biomass since 2010 (Figures 14 & 15, and Tables 24 & 25).

AM2 estimates the median spawning biomass in 2017 (SB_{2017}) at 114,626 t and 81% of SB_0. AM1 estimates the median spawning biomass in 2017 (SB_{2017}) at 175,960 t and 108% of SB_0. Based on a comparison of median estimates, both AM2 and AM1 models estimate SB_{2017} to be above the LRP of $0.30 \cdot SB_0$ by greater than 95% probability (Figure 19). The pattern of biomass estimates for AM2 is similar to that of AM1, however AM2 estimates of SB_{2017} and stock status relative to SB_0 are lower than the AM1 estimates, due largely to differences in model estimates of q_2 (Table 2).

Figure 20 shows above-average number of age-2 recruits in 2017 with 3 and 4-year old fish comprising the highest estimated proportion of fish, which is consistent with the previous 5 years (Figure 121). Although model estimates of current natural mortality are highly uncertain, there is an decreasing trend in the median estimates of natural mortality since 2007 (Figures 14 & 15).

The projected pre-fishery spawning biomass in 2018 is 125,285 t (AM2) or 169,910 t (AM1), declining from 2017, consisting of 25% (median) age-3 fish and 67% (median) age-4 and older fish (Table 16).

West Coast of Vancouver Island

Since 2005 the WCVI stock has been in a prolonged low productivity low biomass state, increasing in 2016 and then declining in 2017. At these low biomass levels, the WCVI stock is characterized by seemingly abrupt differences in year-to-year survey biomass. AM2 and AM1 base case assessments estimate a decline in spawning stock biomass from 2016 to 2017 (Tables 26 and 27). AM2 estimates the median spawning biomass in 2017 (SB_{2017}) at 17,742 t and 37% of SB_0. AM1 estimates the median spawning biomass in 2017 (SB_{2017}) at 32,810 t and 56% of SB_0. Based on a comparison of median estimates, both AM2 and AM1 models estimate SB_{2017} to be above the LRP of $0.30 \cdot SB_0$, by greater than 50% probability but less than 95% probability (Figure 19). The pattern of biomass estimates for AM2 is similar to that of AM1, however AM2 estimates of SB_{2017} and stock status relative to SB_0 are lower than the AM1 estimates, due largely to differences in model estimates of q_2 (Table 2).

There is no apparent recruitment entering the spawning population in 2017: Figure 20 shows the number of age-2 recruits is below-average and Figure 124 shows a higher proportion of 4-year olds relative to ages 2 and 3. Although model estimates of current natural mortality remain highly uncertain, there is an increasing trend in the median estimates of natural mortality since 2014 (Figures 16 & 17).

The projected pre-fishery spawning biomass in 2018 is 20,003 t (AM2) or 34,886 t (AM1), similar to SB_{2017} levels, consisting of 32% (median) age-3 fish and 48% (median) age-4 and older fish (Table 17).

2.4.6 Recruitment

Recruitment is defined as the number of age-2 fish recruiting into the population at the beginning of each year, defined as January 1st based on ageing conventions. This age-2 recruitment is estimated as a free parameter within the model, subject to the constraint that annual estimates vary around a Beverton-Holt stock recruitment relationship with an estimated unknown standard deviation (Figure 20). For HG, PRD, CC and WCVI stocks, age-2 recruitment is estimated to be average-to-below average in 2017. Age-2 recruitment for the SOG stock is estimated to be above average in 2017. Recruitment estimates for the 5 major stocks (AM2 only) are presented in Tables 29 to 37.

2.4.7 Effective harvest rates

The management of Pacific Herring fisheries since 1983 has included implementing a maximum target harvest rate of 20%. For Pacific Herring in the major stock areas, for models AM2 and AM1, the effective harvest rate is calculated as:

$$U_t = \frac{C_t}{SB_t + C_t} \tag{4}$$

where SB_t and C_t are the estimated spawning biomass and catch in year t. Figure 18 presents time series estimates of effective harvest rates for each stock area.

2.4.8 Production analysis

Kronlund et al. (2018) use an analysis of surplus production to evaluate whether the major Pacific Herring stocks in BC show stock states consistent with signs of possible serious harm, the result of which identified recent persistent states of low production and low biomass (LP-LB states) for the Central Coast (CC), Haida Gwaii (HG) and West Coast of Vancouver Island (WCVI) management areas.

The production analysis was updated for the major Pacific Herring stocks with the addition of 2017 catch data and MPD spawning biomass estimates for AM2 and AM1. Figures 8 to 17 show AM2 and AM1 production analyses for the 5 major SARs: Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SoG), and West Coast of Vancouver Island (WCVI), respectively. The updated production analysis was compared to results presented in Kronlund et al. (2018) and the key results are the same and provide continued support to the recommendations of Kronlund et al. (2018). Median posterior distributions of the estimated spawning biomass in 2017 for each major stock, and juxtaposition of the estimated LRP are presented in Figure 19. The following bullets report estimated SB_{2017} relative to the LRP ($0.30 \cdot SB_0$):

1. HG: Spawning biomass production and production rate are negative (AM2 and AM1) and there is greater than a 50% probability the estimated spawning biomass in 2017 is below the LRP of $0.30 \cdot SB_0$ (AM2 and AM1)

2. PRD: Spawning biomass production and production rate are positive (AM2 and AM1) and there is greater than a 50% probability the estimated spawning biomass in 2017 is above the LRP of $0.30 \cdot SB_0$ (AM2 and AM1)
3. CC: Spawning biomass production and production rate are positive (AM2 and AM1) and there is greater than a 95% probability the estimated spawning biomass in 2017 is above the LRP of $0.30 \cdot SB_0$ (AM2 and AM1)
4. SOG:Spawning biomass production and production rate are positive (AM2 and AM1) and there is greater than a 95% probability the estimated spawning biomass in 2017 is above the LRP of $0.30 \cdot SB_0$ (AM2 and AM1)
5. WCVI: Spawning biomass production and production rate are negative (AM2 and AM1). AM1: there is 28% probability estimated spawning biomass in 2017 is above the LRP of $0.30 \cdot SB_0$; AM2: there is a 43% probability the estimated spawning biomass in 2017 is below the LRP of $0.30 \cdot SB_0$.

2.5 ASSUMPTIONS AND UNCERTAINTY

This assessment uses Bayesian methods to incorporate prior information and integrate over parameter uncertainty to provide results that can be probabilistically interpreted. Measures of uncertainty in this assessment underestimate the true uncertainty in current stock status and future projections because they do not account for alternative structural models for Pacific Herring population dynamics (e.g., natural mortality) and fishery processes (e.g., selectivity), the effects of data-weighting schemes, and the scientific basis for prior probability distribution choices. The base case assessment models AM2 and AM1 integrate over the substantial uncertainty associated with several important model parameters including: spawn survey catchability (q), the productivity of the stock (via the steepness parameter, h, of the stock-recruitment relationship), the rate of natural mortality (M), and recruitment deviations. Although the Bayesian results presented include estimation uncertainty, this within-model uncertainty is likely an underestimate of the true uncertainty in current stock status and future projections, since it does not include structural modelling choices, data-weighting uncertainty, assessment errors and scientific uncertainty in selection of prior probability distributions. The only way to develop a management procedure that is robust to the true range of uncertainty in current stock status and future projections is with rigorous testing using feedback simulations.

Estimation bias is explored through retrospective analyses.

2.6 RETROSPECTIVE ANALYSES

Patterns of retrospective bias in estimates of spawning biomass and age-2 recruitment for all major stocks (AM1 and AM2) were examined by successively removing the last 10-years of data. Results are presented in Figures 161 to 165 and Figures 166 to 175, for AM1 and AM2 respectively.

Two categories of retrospective patterns emerge when examining these figures. For HG, CC, and WCVI, the general retrospective patterns are the same between AM1 and AM2 within these stocks. That is, neither AM1 nor AM2 demonstrates a greater pattern of retrospective bias and for these stocks, ISCAM appears to under- and over-estimate stock biomass with equal frequency.

For PRD and SOG, AM1 and AM2, the overestimation of spawning biomass occurs more frequently than underestimation. When comparing between AM1 and AM2 for both PRD and

SOG, AM1 appears to overestimate the spawning biomass to a greater degree than the AM2 model.

3 RECOMMENDATIONS AND YIELD OPTIONS

3.1 PROJECTED BIOMASS IN 2018

Projected pre-fishery spawning biomass estimates (i.e., prior to any harvest in 2018), and the relative contribution of fish aged 3 and aged 4-10 are presented in Tables 13 to 17. Advice to managers for 2018 for each stock area is presented in the stock-specific sections below, as two sets of decision tables, one for each assessment model (AM2 and AM1; Tables 38 to 47). Tables from AM2 provide probabilities of the projected post-harvest spawning biomass in 2018 (SB_{2018}) falling below the LRP of $0.3 \cdot SB_0$ or falling below the historically-used stock-specific fixed cut-off level (calculated as $0.25 \cdot SB_0$ from the 1996 assessment [Schweigert et al. (1997)]); and of the harvest rate exceeding the 10% (as requested by Fisheries Management) and 20% (as per the HCR) target rates over a range of constant catch levels. Tables from AM1 provide probabilities of the projected post-harvest spawning biomass in 2018 (SB_{2018}) falling below the LRP of $0.3 \cdot SB_0$, and of the harvest rate exceeding the 10% and 20% target harvest rates over a range of constant 2018 catch levels.

3.2 DECISION TABLES

Decision tables for 2018 are presented for AM1 and AM2 base case model runs for the 5 major stock areas: HG, PRD, CC, SoG, and WCVI. Below is an example of how to read the tables for PRD:

Under the assumptions of AM2 for PRD (Table 40, row 10), given a 2018 catch of 5,000 t, the estimated probability that the harvest rate (U') exceeds the 20% target rate is 0.503 (50%), and the probability that SB_{2018} < fixed cut-off (12,100 t) is estimated to be 0.144 (14%). At this harvest level, the probability that SB_{2018} < LRP is 0.444 (44%).

3.2.1 Performance metrics

Here we explain performance metrics/column headings to interpret the decision tables:

1. 2018 TAC indicates a range of total allowable catch values in metric tonnes,
2. P($SB_{2018} < \text{LRP} = 0.3 \cdot SB_0$) is the probability that spawning biomass after harvest is below the LRP, $0.3 \cdot SB_0$ in 2018,
3. Med($SB_{2018} / 0.3 \cdot SB_0$) is the median ratio of projected post-harvest spawning biomass to $0.3 \cdot SB_0$ in 2018,
4. P($SB_{2018} <$ [value]) is the probability that spawning biomass after harvest is below the 1996 fixed cut-off value in 2018,
5. Med($SB_{2018} /$[value]) is the median ratio of projected post-harvest biomass to the 1996 fixed cut-off value in 2018,

6. P($U_{2018} > 20\%$) is the probability that the removal rate will be greater than the targe harvest rate of 20% in 2018,
7. P($U_{2018} > 10\%$) is the probability that the removal rate will be greater than the targe harvest rate of 10% in 2018, and
8. Med(U_{2018}) is the median removal rate in 2018.

Note that in the decision tables the fixed cut-offs and the 20% HR are taken from the current harvest control rule.

4 FUTURE RESEARCH AND DATA REQUIREMENTS

1. Continue engagement in the MSE process. Proceed with simulation-testing of management procedures for each major Pacific Herring stock.
2. Quantify all sources of herring mortality, including herring mortality and egg removal from SOK operations, and egg removal from SOB activity.
3. Collect new data to investigate maturity-at-age for individual BC Pacific Herring stocks.

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7 TABLES

Table 1. Estimated and fixed parameters and prior probability distributions used in all SAR models.

Parameter	Number Estimated	Bounds [low, high	Prior (mean, SD) (single value = fixed)
Log recruitment (ln(R_0))	1	[-5, 15]	Uniform
Steepness (h)	1	[0.2, 1]	Beta(α = 10, β = 4.925373)
Log natural mortality (ln(M))	1	[-5, 5]	Normal(ln(0.4), 0.4)
Log mean recruitment (ln(R))	1	[-5, 15]	Uniform
Log initial recruitment (ln(R_{init}))	1	[-5, 15]	Uniform
Variance ratio, rho (ρ)	1	[0.001, 0.999]	Beta(α = 17.08696, β = 39.0559)
Inverse total variance, kappa (κ)	1	[0.01, 5]	Gamma(k = 25), θ = 28.75)
Fishery age at 50% logistic selectivity ($\hat{a}_k$)	3	[0, 1]	None
Fishery SD of logistic selectivity ($\hat{\gamma}_k$)	3	[0, Inf)	None
Log recruitment deviations (ω_t)	67	None	Normal(0, τ)
Initial log recruitment deviations ($\omega_{init,t}$)	8	None	Normal(0, τ)

Table 2. Estimated catchability (q) parameters and prior probability distributions used in all SAR models. Estimated values are medians of the MCMC posteriors

SAR	Model	Survey	Bounds	Estimated q1	Estimated q2	Prior (mean, SD)	SB$_{2017}$	SB$_0$	Depletion SB$_{2017}$/SB$_0$
HG	AM1	Surface	None	0.352	0.582	Normal(0.566, 0.274)	7.336	29.818	0.246
HG	AM1	Dive	None	0.352	0.582	Normal(0.566, 0.274)	7.336	29.818	0.246
HG	AM2	Surface	None	0.410	0.999	Normal(1.000, 1.000)	3.963	23.098	0.171
HG	AM2	Dive	None	0.410	0.999	Normal(1.000, 0.010)	3.963	23.098	0.171
PRD	AM1	Surface	None	0.555	0.972	Normal(0.566, 0.274)	22.821	62.595	0.358
PRD	AM1	Dive	None	0.555	0.972	Normal(0.566, 0.274)	22.821	62.595	0.358
PRD	AM2	Surface	None	0.562	1.001	Normal(1.000, 1.000)	21.738	61.097	0.344
PRD	AM2	Dive	None	0.562	1.001	Normal(1.000, 0.010)	21.738	61.097	0.344
CC	AM1	Surface	None	0.299	0.640	Normal(0.566, 0.274)	49.624	62.063	0.801
CC	AM1	Dive	None	0.299	0.640	Normal(0.566, 0.274)	49.624	62.063	0.801
CC	AM2	Surface	None	0.335	0.999	Normal(1.000, 1.000)	30.474	55.347	0.545
CC	AM2	Dive	None	0.335	0.999	Normal(1.000, 0.010)	30.474	55.347	0.545
SOG	AM1	Surface	None	0.667	0.621	Normal(0.566, 0.274)	175.962	162.050	1.078
SOG	AM1	Dive	None	0.667	0.621	Normal(0.566, 0.274)	175.962	162.050	1.078
SOG	AM2	Surface	None	1.032	0.999	Normal(1.000, 1.000)	114.626	138.795	0.813
SOG	AM2	Dive	None	1.032	0.999	Normal(1.000, 0.010)	114.626	138.795	0.813
WCVI	AM1	Surface	None	0.623	0.547	Normal(0.566, 0.274)	32.805	58.491	0.559
WCVI	AM1	Dive	None	0.623	0.547	Normal(0.566, 0.274)	32.805	58.491	0.559
WCVI	AM2	Surface	None	0.837	0.999	Normal(1.000, 1.000)	17.742	46.890	0.373
WCVI	AM2	Dive	None	0.837	0.999	Normal(1.000, 0.010)	17.742	46.890	0.373

Table 3. Posterior (5^{th} percentile, Median, and 95^{th} percentile) and MPD estimates of key parameters from the Haida Gwaii AM2 model. Subscripts on q (catchability) indicate: 1 = Surface survey, 2 = Dive survey. Tau (τ) and sigma (σ) are calculated values.

Parameter	**5%**	**50%**	**95%**	**MPD**
R_0	203.312	269.439	367.078	274.779
$Steepness(h)$	0.657	0.783	0.895	0.802
M	0.225	0.406	0.707	0.378
$\bar{R}$	140.381	168.819	202.671	178.579
$\bar{R}_{init}$	8.852	30.174	167.867	33.279
ρ	0.217	0.280	0.352	0.266
ϑ	0.788	0.960	1.153	1.030
q_1	0.338	0.410	0.497	1.030
q_2	0.982	0.999	1.016	0.400
τ	0.775	0.865	0.969	0.999
σ	0.470	0.539	0.619	0.844

Table 4. Posterior (5^{th} percentile, Median, and 95^{th} percentile) and MPD estimates of key parameters from the Prince Rupert District AM2 model. Subscripts on q (catchability) indicate: 1 = Surface survey, 2 = Dive survey. Tau (τ) and sigma (σ) are calculated values.

Parameter	**5%**	**50%**	**95%**	**MPD**
R_0	240.142	314.335	468.732	303.776
$Steepness(h)$	0.531	0.689	0.847	0.719
M	0.231	0.442	0.750	0.423
$\bar{R}$	165.540	190.647	218.290	197.632
$\bar{R}_{init}$	59.488	203.137	1,076.189	242.920
ρ	0.228	0.297	0.375	0.296
ϑ	0.973	1.190	1.451	1.266
q_1	0.491	0.562	0.643	1.266
q_2	0.984	1.001	1.017	0.553
τ	0.679	0.766	0.869	1.000
σ	0.433	0.499	0.575	0.746

Table 5. Posterior (5^{th} percentile, Median, and 95^{th} percentile) and MPD estimates of key parameters from the Central Coast AM2 model. Subscripts on q (catchability) indicate: 1 = Surface survey, 2 = Dive survey. Tau (τ) and sigma (σ) are calculated values.

Parameter	**5%**	**50%**	**95%**	**MPD**
R_0	296.607	375.869	492.689	363.272
$Steepness(h)$	0.679	0.805	0.906	0.826
M	0.273	0.483	0.802	0.443
$\bar{R}$	219.256	247.640	282.208	248.300
$\bar{R}_{init}$	55.743	208.721	1,137.437	250.969
ρ	0.177	0.239	0.314	0.220
ϑ	1.013	1.228	1.486	1.307
q_1	0.287	0.335	0.383	1.307
q_2	0.983	0.999	1.015	0.339
τ	0.699	0.786	0.882	0.999
σ	0.378	0.439	0.513	0.773

Table 6. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of key parameters from the Strait of Georgia AM2 model. Subscripts on q (catchability) indicate: 1 = Surface survey, 2 = Dive survey. Tau (τ) and sigma (σ) are calculated values.

Parameter	5%	50%	95%	MPD
R_0	1,259.159	1,574.375	2,106.512	1,513.440
$Steepness(h)$	0.597	0.744	0.872	0.775
M	0.255	0.462	0.772	0.455
$\bar{R}$	897.756	1,038.515	1,199.972	1,068.490
$\bar{R}_{init}$	41.313	154.565	850.954	276.788
ρ	0.209	0.282	0.367	0.273
ϑ	1.234	1.529	1.861	1.643
q_1	0.875	1.032	1.215	1.643
q_2	0.983	0.999	1.016	1.016
τ	0.605	0.683	0.779	0.999
σ	0.368	0.429	0.499	0.665

Table 7. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of key parameters from the WCVI AM2 model. Subscripts on q (catchability) indicate: 1 = Surface survey, 2 = Dive survey. Tau (τ) and sigma (σ) are calculated values.

Parameter	5%	50%	95%	MPD
R_0	431.237	561.851	763.668	552.814
$Steepness(h)$	0.601	0.728	0.854	0.737
M	0.330	0.609	1.041	0.584
$\bar{R}$	315.368	367.836	429.757	372.587
$\bar{R}_{init}$	33.745	165.316	1,375.869	263.372
ρ	0.235	0.308	0.391	0.296
ϑ	1.068	1.305	1.581	1.413
q_1	0.697	0.837	0.992	1.413
q_2	0.983	0.999	1.016	0.841
τ	0.639	0.727	0.825	0.999
σ	0.424	0.484	0.555	0.706

Table 8. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of key parameters from the Haida Gwaii AM1 model. Subscripts on q (catchability) indicate: 1 = Surface survey, 2 = Dive survey. Tau (τ) and sigma (σ) are calculated values.

Parameter	5%	50%	95%	MPD
R_0	274.441	395.526	579.489	428.809
$Steepness(h)$	0.661	0.791	0.895	0.810
M	0.230	0.419	0.715	0.393
$\bar{R}$	185.805	253.962	348.186	285.661
$\bar{R}_{init}$	9.266	33.143	185.100	38.260
ρ	0.212	0.274	0.347	0.260
ϑ	0.818	0.998	1.208	1.085
q_1	0.276	0.352	0.439	1.085
q_2	0.425	0.582	0.789	0.329
τ	0.758	0.851	0.958	0.544
σ	0.456	0.523	0.606	0.826

Table 9. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of key parameters from the Prince Rupert District AM1 model. Subscripts on q (catchability) indicate: 1 = Surface survey, 2 = Dive survey. Tau (τ) and sigma (σ) are calculated values.

Parameter	**5%**	**50%**	**95%**	**MPD**
R_0	226.824	332.403	535.021	348.116
$Steepness(h)$	0.537	0.688	0.842	0.720
M	0.227	0.445	0.787	0.436
$\bar{R}$	144.494	196.334	298.229	230.983
$\bar{R}_{init}$	59.871	206.269	1,289.433	259.552
ρ	0.222	0.297	0.376	0.298
ϑ	0.969	1.188	1.447	1.273
q_1	0.444	0.555	0.658	1.273
q_2	0.726	0.972	1.225	0.516
τ	0.678	0.768	0.870	0.889
σ	0.433	0.498	0.577	0.743

Table 10. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of key parameters from the Central Coast AM1 model. Subscripts on q (catchability) indicate: 1 = Surface survey, 2 = Dive survey. Tau (τ) and sigma (σ) are calculated values.

Parameter	**5%**	**50%**	**95%**	**MPD**
R_0	375.561	516.341	733.568	504.723
$Steepness(h)$	0.672	0.797	0.905	0.820
M	0.283	0.492	0.800	0.463
$\bar{R}$	268.622	349.195	462.475	352.658
$\bar{R}_{init}$	60.618	224.560	1,261.456	296.544
ρ	0.174	0.234	0.314	0.212
ϑ	1.057	1.289	1.558	1.375
q_1	0.249	0.299	0.353	1.375
q_2	0.478	0.640	0.846	0.301
τ	0.686	0.769	0.863	0.641
σ	0.365	0.425	0.499	0.757

Table 11. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of key parameters from the Strait of Georgia AM1 model. Subscripts on q (catchability) indicate: 1 = Surface survey, 2 = Dive survey. Tau (τ) and sigma (σ) are calculated values.

Parameter	**5%**	**50%**	**95%**	**MPD**
R_0	1,965.234	2,967.525	4,614.864	3,109.920
$Steepness(h)$	0.547	0.712	0.858	0.748
M	0.305	0.544	0.896	0.549
$\bar{R}$	1,369.045	2,021.505	3,051.534	2,288.370
$\bar{R}_{init}$	62.609	293.147	2,085.613	595.950
ρ	0.197	0.269	0.354	0.248
ϑ	1.273	1.579	1.925	1.729
q_1	0.475	0.667	0.900	1.729
q_2	0.463	0.621	0.813	0.611
τ	0.598	0.679	0.773	0.587
σ	0.352	0.412	0.481	0.660

Table 12. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of key parameters from the WCVI AM1 model. Subscripts on q (catchability) indicate: 1 = Surface survey, 2 = Dive survey. Tau (τ) and sigma (σ) are calculated values.

Parameter	5%	50%	95%	MPD
R_0	648.416	906.951	1,291.767	899.234
$Steepness(h)$	0.607	0.740	0.866	0.760
M	0.381	0.658	1.052	0.646
$\bar{R}$	471.923	633.105	859.035	652.612
$\bar{R}_{init}$	45.616	241.000	1,744.953	397.812
ρ	0.239	0.313	0.397	0.301
ϑ	1.138	1.385	1.675	1.508
q_1	0.494	0.623	0.770	1.508
q_2	0.405	0.547	0.745	0.625
τ	0.620	0.702	0.795	0.540
σ	0.415	0.475	0.544	0.681

Table 13. Posterior (5th percentile, Median, and 95th percentile) of proposed reference points for the Haida Gwaii models. Biomass numbers are in thousands of tonnes.

	AM2			AM1		
Reference point	5%	50%	95%	5%	50%	95%
SB_0	18.319	23.098	30.163	22.781	29.818	40.026
$0.3SB_0$	5.496	6.929	9.049	6.834	8.945	12.008
SB_{2017}	1.980	3.963	8.005	3.434	7.336	15.433
SB_{2017}/SB_0	0.083	0.171	0.347	0.118	0.246	0.495
SB_{2018}	1.900	4.346	11.326	3.044	7.302	18.483
Proportion aged 3	0.09	0.34	0.70	0.09	0.31	0.67
Proportion aged 4-10	0.15	0.38	0.68	0.17	0.42	0.71

Table 14. Posterior (5th percentile, Median, and 95th percentile) of proposed reference points for the Prince Rupert District models. Biomass numbers are in thousands of tonnes.

	AM2			AM1		
Reference point	5%	50%	95%	5%	50%	95%
SB_0	46.919	61.097	92.122	47.786	62.595	91.271
$0.3SB_0$	14.076	18.329	27.637	14.336	18.779	27.381
SB_{2017}	12.656	21.738	36.537	12.213	22.821	41.708
SB_{2017}/SB_0	0.193	0.344	0.595	0.182	0.358	0.669
SB_{2018}	12.893	23.924	44.818	12.606	24.903	50.081
Proportion aged 3	0.07	0.23	0.55	0.07	0.24	0.54
Proportion aged 4-10	0.39	0.68	0.87	0.39	0.68	0.87

Table 15. Posterior (5th percentile, Median, and 95th percentile) of proposed reference points for the Central Coast models. Biomass numbers are in thousands of tonnes.

	AM2			**AM1**		
Reference point	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
SB_0	44.424	55.347	71.220	49.235	62.063	81.175
$0.3SB_0$	13.327	16.604	21.366	14.770	18.619	24.352
SB_{2017}	18.518	30.474	47.125	27.553	49.624	85.709
SB_{2017}/SB_0	0.328	0.545	0.898	0.449	0.801	1.324
SB_{2018}	17.728	32.458	60.684	25.958	50.259	96.481
Proportion aged 3	0.07	0.25	0.56	0.07	0.22	0.52
Proportion aged 4-10	0.38	0.66	0.85	0.42	0.69	0.87

Table 16. Posterior (5th percentile, Median, and 95th percentile) of proposed reference points for the Strait of Georgia models. Biomass numbers are in thousands of tonnes.

	AM2			**AM1**		
Reference point	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
SB_0	110.088	138.795	199.081	126.823	162.050	229.336
$0.3SB_0$	33.026	41.638	59.724	38.047	48.615	68.801
SB_{2017}	70.478	114.626	176.690	102.598	175.962	304.613
SB_{2017}/SB_0	0.464	0.813	1.313	0.610	1.078	1.796
SB_{2018}	71.847	125.285	216.387	92.908	169.910	323.468
Proportion aged 3	0.09	0.25	0.51	0.10	0.26	0.52
Proportion aged 4-10	0.42	0.67	0.85	0.40	0.64	0.82

Table 17. Posterior (5th percentile, Median, and 95th percentile) of proposed reference points for the WCVI models. Biomass numbers are in thousands of tonnes.

	AM2			**AM1**		
Reference point	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
SB_0	37.870	46.890	61.469	45.961	58.491	76.910
$0.3SB_0$	11.361	14.067	18.441	13.788	17.547	23.073
SB_{2017}	9.719	17.742	30.650	16.877	32.805	62.881
SB_{2017}/SB_0	0.201	0.373	0.654	0.297	0.559	1.021
SB_{2018}	10.183	20.003	41.001	16.914	34.886	73.564
Proportion aged 3	0.11	0.32	0.63	0.11	0.31	0.60
Proportion aged 4-10	0.24	0.48	0.72	0.27	0.51	0.74

Table 18. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of spawning biomass (1000 t) and relative spawning biomass for the Haida Gwaii AM2 model.

	Spawning Biomass				Depletion (SB_t/SB_0)			
Year	**5%**	**50%**	**95%**	**MPD**	**5%**	**50%**	**95%**	**MPD**
2007	4.238	5.556	7.289	5.564	0.162	0.241	0.347	0.249
2008	4.149	5.376	6.949	5.381	0.159	0.233	0.330	0.241
2009	4.818	6.385	8.422	6.421	0.187	0.276	0.400	0.288
2010	5.163	6.825	9.034	6.885	0.201	0.296	0.422	0.309
2011	5.436	7.225	9.610	7.326	0.210	0.313	0.447	0.328
2012	8.076	10.743	14.095	10.928	0.311	0.465	0.659	0.490
2013	11.531	15.683	21.145	16.076	0.450	0.680	0.989	0.721
2014	8.211	11.377	15.778	11.580	0.320	0.493	0.728	0.519
2015	5.368	7.510	10.539	7.488	0.214	0.325	0.480	0.336
2016	3.456	5.067	7.378	4.890	0.139	0.219	0.332	0.219
2017	1.980	3.963	8.005	3.714	0.083	0.171	0.347	0.166

Table 19. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of spawning biomass (1000 t) and relative spawning biomass for the Haida Gwaii AM1 model.

	Spawning Biomass				Depletion (SB_t/SB_0)			
Year	**5%**	**50%**	**95%**	**MPD**	**5%**	**50%**	**95%**	**MPD**
2007	6.590	10.020	15.163	10.688	0.223	0.335	0.495	0.358
2008	6.411	9.743	14.569	10.349	0.217	0.325	0.474	0.347
2009	7.513	11.542	17.630	12.352	0.255	0.387	0.571	0.414
2010	8.068	12.372	18.833	13.215	0.275	0.413	0.607	0.443
2011	8.470	13.040	19.754	14.051	0.290	0.437	0.644	0.471
2012	12.677	19.273	29.456	21.002	0.426	0.646	0.956	0.704
2013	18.173	28.258	44.081	30.878	0.613	0.948	1.425	1.034
2014	12.965	20.425	32.198	22.130	0.436	0.687	1.047	0.741
2015	8.510	13.504	21.355	14.329	0.286	0.452	0.690	0.480
2016	5.611	9.109	15.150	9.479	0.193	0.306	0.481	0.318
2017	3.434	7.336	15.433	7.350	0.118	0.246	0.495	0.246

Table 20. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of spawning biomass (1000 t) and relative spawning biomass for the Prince Rupert District AM2 model.

	Spawning Biomass				Depletion (SB_t/SB_0)			
Year	**5%**	**50%**	**95%**	**MPD**	**5%**	**50%**	**95%**	**MPD**
2007	12.907	15.796	19.389	15.824	0.161	0.256	0.361	0.278
2008	12.899	15.652	18.956	15.757	0.159	0.254	0.358	0.277
2009	12.252	14.926	18.261	15.152	0.151	0.243	0.347	0.266
2010	13.114	16.238	20.199	16.643	0.164	0.264	0.382	0.292
2011	13.721	17.213	21.708	17.715	0.171	0.281	0.407	0.311
2012	12.876	16.201	20.362	16.608	0.161	0.264	0.382	0.292
2013	13.359	16.885	21.429	17.167	0.169	0.275	0.401	0.301
2014	13.501	17.058	22.048	17.150	0.172	0.277	0.404	0.301
2015	17.474	22.434	29.462	22.119	0.230	0.365	0.533	0.388
2016	16.056	22.186	30.874	21.188	0.223	0.358	0.534	0.372
2017	12.656	21.738	36.537	19.950	0.193	0.344	0.595	0.350

Table 21. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of spawning biomass (1000 t) and relative spawning biomass for the Prince Rupert District AM1 model.

	Spawning Biomass				**Depletion (SB_t/SB_0)**			
Year	**5%**	**50%**	**95%**	**MPD**	**5%**	**50%**	**95%**	**MPD**
2007	11.621	16.371	23.886	18.095	0.154	0.260	0.415	0.316
2008	11.552	16.156	23.295	17.925	0.153	0.258	0.406	0.313
2009	10.876	15.485	22.519	17.258	0.145	0.246	0.391	0.302
2010	11.539	16.845	25.171	19.043	0.155	0.269	0.434	0.333
2011	11.878	17.867	27.374	20.338	0.158	0.286	0.470	0.356
2012	11.221	16.758	25.494	19.006	0.148	0.268	0.438	0.332
2013	11.825	17.472	26.532	19.561	0.156	0.280	0.458	0.342
2014	12.180	17.731	27.096	19.568	0.161	0.285	0.462	0.342
2015	15.926	23.386	35.747	25.259	0.213	0.376	0.606	0.442
2016	14.960	23.248	36.587	24.015	0.211	0.370	0.607	0.420
2017	12.213	22.821	41.708	22.465	0.182	0.358	0.669	0.393

Table 22. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of spawning biomass (1000 t) and relative spawning biomass for the Central Coast AM2 model.

	Spawning Biomass				**Depletion (SB_t/SB_0)**			
Year	**5%**	**50%**	**95%**	**MPD**	**5%**	**50%**	**95%**	**MPD**
2007	5.449	7.059	9.122	7.090	0.088	0.128	0.179	0.134
2008	5.153	6.544	8.290	6.579	0.083	0.118	0.166	0.124
2009	6.847	8.821	11.283	8.885	0.111	0.159	0.225	0.168
2010	7.093	9.097	11.616	9.173	0.115	0.164	0.231	0.173
2011	6.917	8.880	11.318	8.990	0.112	0.160	0.226	0.170
2012	6.913	8.766	11.111	8.904	0.111	0.158	0.220	0.168
2013	11.405	14.469	18.373	14.687	0.185	0.262	0.363	0.278
2014	13.099	16.660	21.147	16.811	0.213	0.302	0.415	0.318
2015	17.864	23.166	29.857	23.057	0.292	0.420	0.573	0.436
2016	18.758	25.594	34.909	25.041	0.316	0.462	0.663	0.473
2017	18.518	30.474	47.125	29.068	0.328	0.545	0.898	0.549

Table 23. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of spawning biomass (1000 t) and relative spawning biomass for the Central Coast AM1 model.

	Spawning Biomass				**Depletion (SB_t/SB_0)**			
Year	**5%**	**50%**	**95%**	**MPD**	**5%**	**50%**	**95%**	**MPD**
2007	7.836	11.871	17.873	11.980	0.126	0.191	0.282	0.201
2008	7.257	10.781	15.897	10.826	0.115	0.174	0.255	0.182
2009	9.604	14.295	21.044	14.382	0.152	0.231	0.339	0.242
2010	9.929	14.533	21.533	14.665	0.156	0.234	0.345	0.247
2011	9.692	14.102	20.553	14.269	0.151	0.227	0.333	0.240
2012	9.666	13.956	20.222	14.163	0.151	0.224	0.328	0.238
2013	15.991	23.350	33.881	23.627	0.250	0.374	0.548	0.397
2014	18.531	27.463	40.102	27.574	0.292	0.441	0.642	0.464
2015	25.765	38.288	57.187	38.088	0.409	0.616	0.891	0.640
2016	27.170	42.295	65.236	41.067	0.439	0.679	1.007	0.690
2017	27.553	49.624	85.709	47.245	0.449	0.801	1.324	0.794

Table 24. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of spawning biomass (1000 t) and relative spawning biomass for the Strait of Georgia AM2 model.

	Spawning Biomass				Depletion (SB_t/SB_0)			
Year	**5%**	**50%**	**95%**	**MPD**	**5%**	**50%**	**95%**	**MPD**
2007	51.501	61.301	73.024	61.534	0.294	0.442	0.594	0.472
2008	34.294	40.763	48.769	40.934	0.195	0.293	0.394	0.314
2009	35.968	43.374	52.733	43.772	0.205	0.312	0.426	0.336
2010	30.352	37.181	45.835	37.762	0.173	0.267	0.371	0.290
2011	47.016	57.128	69.512	58.274	0.265	0.411	0.566	0.447
2012	51.043	61.795	74.306	63.017	0.289	0.443	0.606	0.484
2013	49.075	60.294	73.551	61.565	0.282	0.433	0.596	0.473
2014	58.491	72.454	90.433	73.777	0.338	0.521	0.725	0.566
2015	61.861	76.714	95.968	76.745	0.358	0.549	0.769	0.589
2016	72.642	94.623	124.030	91.992	0.438	0.675	0.954	0.706
2017	70.478	114.626	176.690	108.263	0.464	0.813	1.313	0.831

Table 25. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of spawning biomass (1000 t) and relative spawning biomass for the Strait of Georgia AM1 model.

	Spawning Biomass				Depletion (SB_t/SB_0)			
Year	**5%**	**50%**	**95%**	**MPD**	**5%**	**50%**	**95%**	**MPD**
2007	72.203	102.036	148.583	109.193	0.423	0.630	0.881	0.697
2008	47.655	67.150	96.708	71.419	0.276	0.413	0.578	0.456
2009	50.761	72.538	105.194	77.288	0.292	0.445	0.626	0.493
2010	43.960	63.915	93.533	68.793	0.256	0.393	0.557	0.439
2011	67.606	97.506	141.995	105.839	0.390	0.603	0.843	0.675
2012	73.269	105.225	153.117	114.458	0.425	0.649	0.903	0.730
2013	71.934	105.326	155.515	115.224	0.420	0.649	0.921	0.735
2014	87.213	129.233	195.165	141.603	0.514	0.796	1.148	0.903
2015	91.712	135.900	206.825	146.332	0.540	0.838	1.202	0.933
2016	107.939	159.039	243.017	165.401	0.642	0.977	1.425	1.055
2017	102.598	175.962	304.613	174.053	0.610	1.078	1.796	1.110

Table 26. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of spawning biomass (1000 t) and relative spawning biomass for the WCVI AM2 model.

	Spawning Biomass				Depletion (SB_t/SB_0)			
Year	**5%**	**50%**	**95%**	**MPD**	**5%**	**50%**	**95%**	**MPD**
2007	3.693	4.790	6.269	4.762	0.068	0.102	0.147	0.104
2008	3.344	4.361	5.650	4.311	0.062	0.093	0.132	0.095
2009	3.466	4.607	6.063	4.571	0.065	0.098	0.141	0.100
2010	3.956	5.206	6.846	5.205	0.074	0.110	0.159	0.114
2011	4.896	6.460	8.461	6.506	0.092	0.137	0.198	0.143
2012	4.809	6.293	8.152	6.365	0.090	0.133	0.190	0.140
2013	5.900	7.765	10.092	7.883	0.110	0.165	0.234	0.173
2014	8.621	11.571	15.346	11.732	0.164	0.245	0.350	0.257
2015	11.634	15.462	20.542	15.570	0.224	0.329	0.468	0.341
2016	14.870	20.999	29.306	20.674	0.295	0.444	0.657	0.453
2017	9.719	17.742	30.650	16.730	0.201	0.373	0.654	0.367

Table 27. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of spawning biomass (1000 t) and relative spawning biomass for the WCVI AM1 model.

	Spawning Biomass				**Depletion (SB_t/SB_0)**			
Year	**5%**	**50%**	**95%**	**MPD**	**5%**	**50%**	**95%**	**MPD**
2007	6.044	9.334	14.211	9.446	0.104	0.159	0.237	0.167
2008	5.441	8.290	12.541	8.372	0.092	0.142	0.210	0.148
2009	5.624	8.691	13.281	8.797	0.096	0.148	0.223	0.155
2010	6.390	9.827	14.915	10.014	0.107	0.168	0.251	0.177
2011	7.989	12.226	18.486	12.503	0.134	0.209	0.311	0.221
2012	7.798	11.867	17.898	12.191	0.132	0.203	0.299	0.215
2013	9.693	14.754	22.496	15.238	0.166	0.254	0.372	0.269
2014	14.515	22.144	34.033	22.771	0.248	0.379	0.562	0.402
2015	19.512	29.894	46.018	30.338	0.337	0.510	0.755	0.536
2016	25.003	39.983	63.975	39.797	0.441	0.683	1.034	0.703
2017	16.877	32.805	62.881	31.451	0.297	0.559	1.021	0.555

Table 28. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of recruitment (millions) for the Haida Gwaii AM2 model.

Year	**5%**	**50%**	**95%**	**MPD**
2007	45.364	67.715	100.366	69.395
2008	214.571	305.933	427.808	313.902
2009	36.695	55.731	83.631	56.922
2010	151.844	216.903	308.909	223.925
2011	98.928	144.632	214.370	149.881
2012	439.485	619.548	873.784	642.306
2013	39.085	59.838	91.435	62.227
2014	95.218	148.221	222.806	154.405
2015	63.965	102.918	160.281	106.673
2016	164.023	263.481	423.954	274.364
2017	89.968	161.524	293.441	164.264

Table 29. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of recruitment (millions) for the Haida Gwaii AM1 model.

Year	**5%**	**50%**	**95%**	**MPD**
2007	72.330	122.838	205.207	134.841
2008	348.772	560.068	904.803	617.965
2009	59.518	100.715	170.201	110.659
2010	245.868	397.882	648.226	440.453
2011	158.426	263.777	434.052	291.885
2012	707.285	1,137.465	1,839.733	1,262.680
2013	62.886	107.006	183.873	120.037
2014	153.952	265.872	446.896	301.321
2015	105.063	186.791	323.965	209.912
2016	270.934	480.776	871.557	543.612
2017	149.677	299.341	595.936	326.612

Table 30. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of recruitment (millions) for the Prince Rupert District AM2 model.

Year	5%	50%	95%	MPD
2007	104.977	144.976	200.071	146.981
2008	103.405	142.132	192.825	144.736
2009	164.664	225.630	305.527	231.602
2010	197.855	271.965	373.017	283.517
2011	105.391	148.499	206.399	154.810
2012	158.992	224.478	312.115	233.028
2013	54.151	79.339	114.953	82.724
2014	321.590	457.424	644.653	476.964
2015	131.743	200.060	303.238	206.389
2016	70.478	152.191	273.211	157.147
2017	55.692	168.332	419.835	165.248

Table 31. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of recruitment (millions) for the Prince Rupert District AM1 model.

Year	5%	50%	95%	MPD
2007	89.964	152.048	268.686	178.432
2008	86.872	150.743	259.039	176.200
2009	135.779	237.976	415.023	282.585
2010	162.636	287.955	519.352	347.161
2011	85.608	156.285	284.661	190.329
2012	131.204	235.289	423.120	284.539
2013	44.941	82.985	156.847	101.713
2014	269.139	481.378	895.587	585.569
2015	113.419	211.156	409.530	254.488
2016	66.373	157.500	350.715	193.923
2017	55.819	172.399	488.926	197.426

Table 32. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of recruitment (millions) for the Central Coast AM2 model.

Year	5%	50%	95%	MPD
2007	84.202	120.161	168.135	121.315
2008	409.923	545.926	727.587	554.045
2009	135.215	179.088	239.652	182.106
2010	262.587	351.853	472.789	357.336
2011	82.166	110.036	146.957	112.173
2012	255.670	339.626	450.977	346.729
2013	97.566	131.311	176.755	134.573
2014	347.180	462.850	633.525	478.746
2015	79.318	113.912	163.533	114.854
2016	172.311	248.327	356.820	248.047
2017	140.691	227.930	372.651	225.389

Table 33. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of recruitment (millions) for the Central Coast AM1 model.

Year	5%	50%	95%	MPD
2007	130.467	213.586	350.027	217.480
2008	601.983	950.322	1,471.786	966.016
2009	196.938	303.543	467.999	307.190
2010	379.529	582.750	899.986	589.202
2011	117.640	180.812	274.425	184.103
2012	369.049	569.022	861.806	576.013
2013	142.861	219.122	341.129	224.645
2014	504.343	785.986	1,208.346	809.549
2015	118.061	193.175	310.674	194.648
2016	258.826	426.918	685.410	427.971
2017	218.296	390.351	711.013	386.566

Table 34. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of recruitment (millions) for the Strait of Georgia AM2 model.

Year	5%	50%	95%	MPD
2007	420.854	553.045	731.554	562.277
2008	1,496.360	1,928.035	2,492.647	1,961.540
2009	269.436	356.442	470.534	362.262
2010	1,606.186	2,109.830	2,781.046	2,170.870
2011	944.392	1,245.785	1,633.543	1,282.050
2012	515.338	692.891	920.727	718.691
2013	964.150	1,286.695	1,705.967	1,337.900
2014	975.258	1,319.465	1,770.971	1,368.380
2015	966.090	1,310.950	1,805.304	1,355.170
2016	1,130.790	1,544.565	2,128.139	1,568.220
2017	1,275.259	1,908.830	2,868.578	1,902.520

Table 35. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of recruitment (millions) for the Strait of Georgia AM1 model.

Year	5%	50%	95%	MPD
2007	703.122	1,148.915	1,882.181	1,262.980
2008	2,455.043	3,979.880	6,412.505	4,377.240
2009	453.080	743.778	1,215.545	818.666
2010	2,712.752	4,391.960	7,245.316	4,902.680
2011	1,604.539	2,599.425	4,224.158	2,882.080
2012	892.314	1,459.210	2,377.970	1,637.060
2013	1,675.319	2,778.430	4,515.300	3,125.370
2014	1,712.128	2,897.045	4,821.711	3,287.180
2015	1,719.617	2,950.585	5,054.329	3,323.610
2016	1,994.658	3,428.265	5,848.275	3,826.490
2017	2,263.749	4,002.960	7,090.808	4,333.230

Table 36. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of recruitment (millions) for the WCVI AM2 model.

Year	5%	50%	95%	MPD
2007	99.469	144.784	209.079	145.427
2008	194.871	269.663	374.775	271.850
2009	109.496	150.257	208.059	150.932
2010	281.963	387.474	529.938	389.266
2011	69.731	98.472	137.318	98.759
2012	82.231	114.714	159.180	116.458
2013	216.594	304.051	418.850	312.256
2014	150.075	211.678	296.786	218.256
2015	501.407	718.974	1,021.657	745.120
2016	112.790	169.923	254.002	172.534
2017	126.822	210.754	350.694	210.581

Table 37. Posterior (5th percentile, Median, and 95th percentile) and MPD estimates of recruitment (millions) for the WCVI AM1 model.

Year	5%	50%	95%	MPD
2007	178.626	302.884	496.911	311.263
2008	339.621	556.995	884.488	572.949
2009	188.368	299.087	476.590	307.995
2010	477.083	767.273	1,226.877	785.699
2011	119.122	193.029	311.491	198.439
2012	141.246	226.647	361.858	233.837
2013	379.403	602.759	967.530	632.822
2014	260.745	422.615	684.580	442.479
2015	887.202	1,437.735	2,356.512	1,514.200
2016	205.382	346.416	586.115	355.929
2017	231.267	432.178	783.754	432.184

Table 38. Probabilistic decision table for Haida Gwaii, AM2 model.

2018 TAC (t)	**P($SB_{2018} < 0.3SB_0$)**	**Med($SB_{2018}/0.3SB_0$)**	**P($SB_{2018} <$ 10, 700 t)**	**Med($SB_{2018}/$ 10, 700 t)**	**P($U_{2018} >$ 20%)**	**P($U_{2018} >$ 10%)**	**Med(U_{2018})**
0	0.808	0.630	0.938	0.406	0.000	0.000	0.000
400	0.821	0.598	0.943	0.387	0.041	0.399	0.088
457	0.824	0.593	0.944	0.384	0.068	0.501	0.100
500	0.825	0.589	0.944	0.382	0.096	0.570	0.109
600	0.829	0.581	0.945	0.377	0.177	0.697	0.129
770	0.835	0.569	0.946	0.369	0.332	0.829	0.163
800	0.836	0.566	0.946	0.368	0.359	0.847	0.169
965	0.842	0.553	0.948	0.360	0.501	0.905	0.200
1,000	0.843	0.550	0.948	0.358	0.529	0.915	0.207
1,500	0.857	0.515	0.952	0.335	0.791	0.978	0.295
1,620	0.860	0.508	0.953	0.329	0.830	0.982	0.315
1,700	0.862	0.502	0.954	0.325	0.851	0.986	0.328

Table 39. Probabilistic decision table for Haida Gwaii, AM1 model.

2018 TAC (t)	**P($SB_{2018} < 0.3SB_0$)**	**Med($SB_{2018}/0.3SB_0$)**	**P($U_{2018} >$ 20%)**	**P($U_{2018} >$ 10%)**	**Med(U_{2018})**
0	0.654	0.808	0.000	0.000	0.000
400	0.669	0.785	0.002	0.116	0.053
457	0.671	0.781	0.006	0.170	0.061
500	0.673	0.778	0.013	0.212	0.066
600	0.676	0.772	0.032	0.324	0.079
770	0.682	0.762	0.086	0.504	0.101
800	0.684	0.760	0.096	0.537	0.104
965	0.689	0.749	0.170	0.660	0.125
1,000	0.690	0.748	0.184	0.683	0.129
1,500	0.710	0.718	0.446	0.878	0.188
1,620	0.715	0.711	0.504	0.908	0.201
1,700	0.718	0.706	0.542	0.920	0.210

Table 40. Probabilistic decision table for the Prince Rupert District, AM2 model.

2018 TAC (t)	P(SB_{2018} < $0.3SB_0$)	Med(SB_{2018}/ $0.3SB_0$)	P(SB_{2018} < 10, 700 t)	Med(SB_{2018}/ 10, 700 t)	P(U_{2018} > 20%)	P(U_{2018} > 10%)	Med(U_{2018})
0	0.265	1.271	0.034	1.977	0.000	0.000	0.000
2,400	0.361	1.169	0.077	1.817	0.025	0.483	0.098
2,440	0.362	1.167	0.077	1.814	0.027	0.500	0.100
2,545	0.367	1.163	0.079	1.808	0.034	0.548	0.104
3,000	0.382	1.144	0.090	1.778	0.087	0.705	0.122
3,500	0.400	1.122	0.103	1.745	0.171	0.822	0.142
4,000	0.419	1.099	0.116	1.711	0.277	0.902	0.162
4,500	0.436	1.078	0.130	1.678	0.385	0.946	0.181
5,000	0.451	1.057	0.144	1.646	0.503	0.970	0.201
5,200	0.460	1.049	0.147	1.633	0.546	0.977	0.208
5,500	0.469	1.037	0.156	1.613	0.605	0.983	0.220
6,000	0.485	1.016	0.168	1.580	0.687	0.989	0.239
7,000	0.522	0.976	0.198	1.517	0.807	0.995	0.276

Table 41. Probabilistic decision table for the Prince Rupert District, AM1 model.

2018 TAC (t)	P(SB_{2018} < $0.3SB_0$)	Med(SB_{2018}/ $0.3SB_0$)	P(U_{2018} > 20%)	P(U_{2018} > 10%)	Med(U_{2018})
0	0.264	1.311	0.000	0.000	0.000
2,400	0.339	1.208	0.029	0.443	0.095
2,440	0.340	1.206	0.033	0.459	0.096
2,545	0.343	1.202	0.041	0.502	0.100
3,000	0.356	1.184	0.094	0.651	0.118
3,500	0.374	1.163	0.168	0.778	0.137
4,000	0.392	1.143	0.258	0.858	0.155
4,500	0.408	1.121	0.358	0.913	0.174
5,000	0.425	1.101	0.462	0.945	0.193
5,200	0.432	1.092	0.501	0.956	0.200
5,500	0.441	1.079	0.553	0.967	0.211
6,000	0.456	1.059	0.633	0.979	0.229
7,000	0.486	1.017	0.763	0.992	0.265

Table 42. Probabilistic decision table for the Central Coast, AM2 model.

2018 TAC (t)	$P(SB_{2018} < 0.3SB_0)$	$Med(SB_{2018}/0.3SB_0)$	$P(SB_{2018} < 10,700\ t)$	$Med(SB_{2018}/10,700\ t)$	$P(U_{2018} > 20\%)$	$P(U_{2018} > 10\%)$	$Med(U_{2018})$
0	0.034	1.933	0.047	1.844	0.000	0.000	0.000
3,000	0.069	1.791	0.087	1.712	0.011	0.386	0.091
3,320	0.074	1.776	0.092	1.697	0.021	0.500	0.100
4,000	0.083	1.744	0.102	1.667	0.069	0.709	0.120
4,500	0.090	1.721	0.111	1.645	0.121	0.810	0.135
5,150	0.100	1.690	0.124	1.616	0.215	0.893	0.153
6,000	0.115	1.649	0.142	1.578	0.360	0.942	0.178
6,800	0.133	1.612	0.159	1.543	0.502	0.968	0.200
6,900	0.135	1.608	0.162	1.538	0.522	0.970	0.203
7,000	0.137	1.603	0.165	1.534	0.540	0.973	0.206
9,000	0.184	1.511	0.212	1.445	0.791	0.992	0.261
10,550	0.221	1.440	0.250	1.378	0.894	0.997	0.303
12,000	0.259	1.372	0.286	1.315	0.936	0.999	0.341

Table 43. Probabilistic decision table for the Central Coast, AM1 model.

2018 TAC (t)	$P(SB_{2018} < 0.3SB_0)$	$Med(SB_{2018}/0.3SB_0)$	$P(U_{2018} > 20\%)$	$P(U_{2018} > 10\%)$	$Med(U_{2018})$
0	0.007	2.675	0.000	0.000	0.000
3,000	0.014	2.545	0.001	0.088	0.059
3,320	0.015	2.530	0.002	0.133	0.065
4,000	0.016	2.501	0.009	0.260	0.078
4,500	0.018	2.481	0.018	0.372	0.088
5,150	0.021	2.455	0.037	0.502	0.100
6,000	0.024	2.421	0.079	0.657	0.116
6,800	0.027	2.387	0.132	0.766	0.132
6,900	0.028	2.383	0.139	0.777	0.133
7,000	0.028	2.379	0.147	0.788	0.135
9,000	0.037	2.299	0.347	0.922	0.172
10,550	0.045	2.234	0.502	0.964	0.201
12,000	0.056	2.173	0.635	0.982	0.227

Table 44. Probabilistic decision table for the Strait of Georgia, AM2 model.

2018 TAC (t)	P(SB_{2018} < 0.3SB_0)	Med(SB_{2018}/ 0.3SB_0)	P(SB_{2018} < 10, 700 t)	Med(SB_{2018}/ 10, 700 t)	P(U_{2018} > 20%)	P(U_{2018} > 10%)	Med(U_{2018})
0	0.003	2.951	0.000	5.910	0.000	0.000	0.000
12,000	0.008	2.729	0.000	5.466	0.010	0.422	0.094
12,800	0.009	2.714	0.000	5.436	0.016	0.500	0.100
14,000	0.010	2.692	0.000	5.391	0.030	0.616	0.109
15,000	0.011	2.671	0.000	5.353	0.047	0.695	0.117
17,500	0.013	2.623	0.000	5.259	0.116	0.842	0.136
20,000	0.015	2.573	0.000	5.166	0.210	0.918	0.154
26,200	0.025	2.453	0.000	4.937	0.501	0.983	0.200
30,000	0.031	2.382	0.001	4.798	0.671	0.992	0.228
35,000	0.041	2.291	0.002	4.617	0.824	0.997	0.263
36,000	0.044	2.273	0.003	4.582	0.848	0.997	0.270
38,000	0.049	2.236	0.003	4.508	0.883	0.998	0.285

Table 45. Probabilistic decision table for the Strait of Georgia, AM1 model

2018 TAC (t)	P(SB_{2018} < 0.3SB_0)	Med(SB_{2018}/ 0.3SB_0)	P(U_{2018} > 20%)	P(U_{2018} > 10%)	Med(U_{2018})
0	0.001	3.452	0.000	0.000	0.000
12,000	0.002	3.275	0.002	0.151	0.069
12,800	0.003	3.264	0.003	0.197	0.074
14,000	0.003	3.247	0.005	0.277	0.081
15,000	0.003	3.232	0.009	0.342	0.086
17,500	0.004	3.193	0.025	0.501	0.100
20,000	0.004	3.156	0.054	0.641	0.114
26,200	0.006	3.066	0.189	0.851	0.148
30,000	0.009	3.008	0.316	0.922	0.168
35,000	0.011	2.935	0.472	0.961	0.195
36,000	0.012	2.919	0.501	0.968	0.200
38,000	0.015	2.890	0.559	0.977	0.211

Table 46. Probabilistic decision table for the WCVI, AM2 model.

2018 TAC (t)	$P(SB_{2018} < 0.3SB_0)$	$Med(SB_{2018}/0.3SB_0)$	$P(SB_{2018} < 10,700\ t)$	$Med(SB_{2018}/10,700\ t)$	$P(U_{2018} > 20\%)$	$P(U_{2018} > 10\%)$	$Med(U_{2018})$
0	0.203	1.413	0.447	1.064	0.000	0.000	0.000
2,000	0.272	1.315	0.505	0.993	0.033	0.476	0.097
2,075	0.276	1.311	0.508	0.990	0.040	0.503	0.100
3,000	0.310	1.267	0.537	0.957	0.193	0.812	0.143
3,610	0.330	1.239	0.553	0.936	0.342	0.905	0.170
4,300	0.354	1.208	0.576	0.912	0.502	0.955	0.200
5,000	0.380	1.175	0.596	0.888	0.644	0.978	0.231
6,000	0.410	1.130	0.623	0.854	0.790	0.990	0.272
7,500	0.459	1.063	0.662	0.801	0.906	0.997	0.332
8,000	0.476	1.041	0.675	0.784	0.928	0.999	0.352
9,000	0.503	0.996	0.698	0.751	0.957	1.000	0.389
10,000	0.533	0.952	0.717	0.718	0.974	1.000	0.426

Table 47. Probabilistic decision table for the WCVI, AM1 model.

2018 TAC (t)	$P(SB_{2018} < 0.3SB_0)$	$Med(SB_{2018}/0.3SB_0)$	$P(U_{2018} > 20\%)$	$P(U_{2018} > 10\%)$	$Med(U_{2018})$
0	0.050	1.980	0.000	0.000	0.000
2,000	0.070	1.904	0.002	0.091	0.056
2,075	0.071	1.901	0.003	0.103	0.058
3,000	0.085	1.866	0.018	0.343	0.084
3,610	0.092	1.843	0.046	0.500	0.100
4,300	0.102	1.817	0.101	0.656	0.118
5,000	0.110	1.791	0.180	0.771	0.137
6,000	0.124	1.753	0.309	0.873	0.163
7,500	0.146	1.698	0.501	0.947	0.200
8,000	0.154	1.680	0.563	0.957	0.213
9,000	0.169	1.644	0.665	0.975	0.237
10,000	0.185	1.608	0.746	0.986	0.261

Table 48. Assumed maturity schedule for the sensitivity case: maturity at age equal to selectivity of the roe seine fishery.

		Maturity at age								
Stock	**Model**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
HG	AM1	0.0377	0.1565	0.4680	0.8066	0.9519	1.0	1.0	1.0	1.0
HG	AM2	0.0407	0.1644	0.4767	0.8084	0.9513	1.0	1.0	1.0	1.0
PRD	AM1	0.0439	0.2736	0.7556	0.9621	0.9952	1.0	1.0	1.0	1.0
PRD	AM2	0.0455	0.3020	0.7970	0.9727	0.9969	1.0	1.0	1.0	1.0
CC	AM1	0.0393	0.4822	0.9550	0.9979	1.0000	1.0	1.0	1.0	1.0
CC	AM2	0.0430	0.5087	0.9597	0.9982	1.0000	1.0	1.0	1.0	1.0
SOG	AM1	0.0503	0.5025	0.9506	0.9973	1.0000	1.0	1.0	1.0	1.0
SOG	AM2	0.0627	0.5657	0.9620	0.9980	1.0000	1.0	1.0	1.0	1.0
WCVI	AM1	0.0393	0.4822	0.9550	0.9979	1.0000	1.0	1.0	1.0	1.0
WCVI	AM2	0.0430	0.5087	0.9597	0.9982	1.0000	1.0	1.0	1.0	1.0

Table 49. Variance parameter sensitivities: leading parameter estimates for AM1, SoG

	Base		**1**		**2**		**3**		**4**		**5**	
Leading Parameters	**Initial**	**Estimated**	**Initial**	**Estimated**	**Initial**	**Estimated**	**Initial**	**Estimated**	**Initial**	**Estimated**	**Initial**	**Estimated**
Log recruitment ($ln(R_0)$)	7.28	8.04	7.28	8.04	7.28	8.04	7.28	8.04	7.28	8.04	7.28	8.04
Steepness (h)	0.80	0.70	0.80	0.70	0.80	0.70	0.80	0.70	0.80	0.70	0.80	0.70
Log natural mortality ($ln(M)$)	-0.69	-0.60	-0.69	-0.60	-0.69	-0.60	-0.69	-0.60	-0.69	-0.60	-0.69	-0.60
Log mean recruitment (ln($\bar{R}$))	7.09	7.74	7.09	7.74	7.09	7.74	7.09	7.74	7.09	7.74	7.09	7.74
Log initial recruitment (ln($\bar{R}_{init}$))	5.97	6.39	5.97	6.39	5.97	6.39	5.97	6.39	5.97	6.39	5.97	6.39
Variance ratio, rho (ρ)	0.41	0.25	0.50	0.25	0.06	0.25	0.33	0.25	0.41	0.25	0.80	0.25
Inverse total variance, kappa (κ)	1.22	1.73	0.50	1.73	1.47	1.73	2.89	1.73	1.22	1.73	0.80	1.73
Sigma (σ)	0.58	0.38	1.00	0.38	0.20	0.38	0.34	0.38	0.58	0.38	1.00	0.38
Tau (τ)	0.69	0.66	1.00	0.66	0.80	0.66	0.48	0.66	0.69	0.66	0.50	0.66

Table 50. Variance parameter sensitivities: leading parameter estimates for AM2, SoG

	Base		**1**		**2**		**3**		**4**		**5**	
Leading Parameters	**Initial**	**Estimated**	**Initial**	**Estimated**	**Initial**	**Estimated**	**Initial**	**Estimated**	**Initial**	**Estimated**	**Initial**	**Estimated**
Log recruitment ($ln(R_0)$)	7.28	7.32	7.28	7.32	7.28	7.32	7.28	7.32	7.28	7.32	7.28	7.32
Steepness (h)	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Log natural mortality ($ln(M)$)	-0.69	-0.79	-0.69	-0.79	-0.69	-0.79	-0.69	-0.79	-0.69	-0.79	-0.69	-0.79
Log mean recruitment (ln($\bar{R}$))	7.09	6.97	7.09	6.97	7.09	6.97	7.09	6.97	7.09	6.97	7.09	6.97
Log initial recruitment (ln($\bar{R}_{init}$))	5.97	5.62	5.97	5.62	5.97	5.62	5.97	5.62	5.97	5.62	5.97	5.62
Variance ratio, rho (ρ)	0.41	0.27	0.50	0.27	0.06	0.27	0.33	0.27	0.41	0.27	0.80	0.27
Inverse total variance, kappa (κ)	1.22	1.64	0.50	1.64	1.47	1.64	2.89	1.64	1.22	1.64	0.80	1.64
Sigma (σ)	0.58	0.41	1.00	0.41	0.20	0.41	0.34	0.41	0.58	0.41	1.00	0.41
Tau (τ)	0.69	0.67	1.00	0.67	0.80	0.67	0.48	0.67	0.69	0.67	0.50	0.67

Table 51. Maturity sensitivity reference points for the Strait of Georgia AM1 model.

	Base Case				**Sensitivity Case maturity set to selectivity**			
Stock	**SB_0**	**SB_{2017}**	**F_{MSY}**	**MSY**	**SB_0**	**SB_{2017}**	**F_{MSY}**	**MSY**
HG	29.85	7.35	4.80	5.21	20.80	5.39	5.44	8.23
PRD	57.18	22.46	2.11	7.13	46.29	21.80	1.97	8.73
CC	59.48	47.25	1.02	13.39	49.16	43.49	0.77	15.51
SOG	156.76	174.05	1.01	60.26	138.02	157.84	0.87	77.74
WCVI	56.64	31.45	1.44	18.17	48.95	32.77	0.97	20.86

Table 52. Maturity sensitivity reference points for the Strait of Georgia AM2 model.

	Base Case				**Sensitivity Case maturity set to selectivity**			
Stock	**SB_0**	**SB_{2017}**	**F_{MSY}**	**MSY**	**SB_0**	**SB_{2017}**	**F_{MSY}**	**MSY**
HG	22.31	3.71	5.44	8.23	16.87	3.56	4.12	13.55
PRD	56.95	19.95	2.11	7.13	46.86	20.76	1.83	8.00
CC	52.92	29.07	1.02	13.39	43.61	29.16	0.79	11.67
SOG	130.24	108.26	1.01	60.26	114.81	103.93	0.69	44.49
WCVI	45.62	16.73	1.44	18.17	38.42	18.36	0.92	12.24

Table 53. Estimated catchability (q) parameters and prior probability distributions used in AM1 models investigating the sensitivity to the q parameter. Estimated values are medians of the MCMC posteriors.

SAR	**Model**	**Bounds**	**Estimated q1**	**Estimated q2**	**Prior (mean, SD)**	**SB2017**	**SB0**	**Depletion SB2017/SB0**
HG	AM1	None	0.272	0.436	Normal(0.566, 3.000)	9.900	35.578	0.276
HG	AM1	None	0.280	0.451	Normal(0.566, 2.000)	9.443	34.915	0.268
HG	AM1	None	0.307	0.511	Normal(0.566, 0.500)	8.404	32.093	0.263
PRD	AM1	None	0.662	1.316	Normal(0.566, 3.000)	16.605	70.550	0.230
PRD	AM1	None	0.629	1.224	Normal(0.566, 2.000)	17.687	66.088	0.262
PRD	AM1	None	0.614	1.159	Normal(0.566, 0.500)	18.699	65.569	0.279
CC	AM1	None	0.259	0.558	Normal(0.566, 3.000)	57.564	65.190	0.886
CC	AM1	None	0.263	0.568	Normal(0.566, 2.000)	55.987	64.549	0.865
CC	AM1	None	0.281	0.617	Normal(0.566, 0.500)	51.345	62.587	0.820
SOG	AM1	None	0.775	0.716	Normal(0.566, 3.000)	157.944	158.276	1.005
SOG	AM1	None	0.813	0.740	Normal(0.566, 2.000)	152.897	154.692	0.979
SOG	AM1	None	0.725	0.672	Normal(0.566, 0.500)	166.909	158.442	1.052
WCVI	AM1	None	0.646	0.561	Normal(0.566, 3.000)	32.694	57.959	0.561
WCVI	AM1	None	0.649	0.563	Normal(0.566, 2.000)	31.926	57.906	0.553
WCVI	AM1	None	0.641	0.559	Normal(0.566, 0.500)	32.757	58.282	0.563

Table 54. Log-likelihood components, totals, and AIC for models testing the sensitivity to M.

Area	Model parameterization	Model sensitivity	Catch data likelihood	Survey Index 1 likelihood	Survey Index 2 likelihood	Age comp data gear 1 likelihood	Age comp data gear 2 likelihood	Age comp data gear 3 likelihood	S-R relation likelihood	Total likelihood	Difference in total likelihood from AM2 TVM	Number of total estimated parameters	AIC
HG	AM2	Time-varying M	129.12	-29.52	-17.14	60.30	371.52	67.66	-79.10	502.84	0.00	174.00	-657.69
HG	AM2	Constant M	129.58	-32.51	-30.85	43.66	345.43	61.05	-99.34	417.01	85.83	162.00	-510.02
PRD	AM2	Time-varying M	229.35	-33.00	-9.80	135.62	316.56	312.53	-64.35	886.92	0.00	232.00	-1309.84
PRD	AM2	Constant M	229.15	-26.49	-12.83	131.23	310.49	307.04	-73.76	864.83	22.09	220.00	-1289.66
CC	AM2	Time-varying M	170.74	-22.36	-6.01	93.55	540.21	248.12	-69.45	954.79	0.00	198.00	-1513.58
CC	AM2	Constant M	170.69	-29.30	-35.66	95.10	545.32	241.86	-80.49	907.51	47.28	186.00	-1443.02
SOG	AM2	Time-varying M	151.85	-22.89	-14.98	96.45	483.57	142.60	-57.91	778.69	0.00	187.00	-1183.37
SOG	AM2	Constant M	267.18	-23.39	-11.85	387.41	493.27	368.23	-57.10	1423.75	-645.07	242.00	-2363.50
WCVI	AM2	Time-varying M	151.85	-22.89	-14.98	96.45	483.57	142.60	-57.91	778.69	0.00	187.00	-1183.37
WCVI	AM2	Constant M	151.87	-32.06	-32.53	96.16	462.36	149.98	-79.02	716.77	61.91	175.00	-1083.55
HG	AM1	Time-varying M	129.27	-27.78	-15.81	61.91	368.90	67.21	-76.79	506.91	0.00	174.00	-665.82
HG	AM1	Constant M	129.36	-32.78	-34.12	65.15	335.42	65.25	-97.57	430.72	76.19	162.00	-537.43
PRD	AM1	Time-varying M	229.41	-33.22	-9.67	135.56	313.60	314.07	-63.83	885.92	0.00	232.00	-1307.84
PRD	AM1	Constant M	229.28	-26.31	-12.24	130.66	305.62	309.10	-72.01	864.09	21.83	220.00	-1288.18
CC	AM1	Time-varying M	170.89	-21.25	-3.52	93.57	536.84	247.68	-66.85	957.36	0.00	198.00	-1518.73
CC	AM1	Constant M	170.64	-29.18	-35.17	95.09	541.70	243.09	-78.71	907.47	49.90	186.00	-1442.94
SOG	AM1	Time-varying M	152.00	-20.12	-15.51	96.26	479.93	142.46	-53.53	781.49	0.00	187.00	-1188.97
SOG	AM1	Constant M	267.80	-23.05	-11.67	391.35	493.37	372.14	-54.20	1435.73	-654.25	242.00	-2387.47
WCVI	AM1	Time-varying M	152.00	-20.12	-15.51	96.26	479.93	142.46	-53.53	781.49	0.00	187.00	-1188.97
WCVI	AM1	Constant M	151.85	-32.16	-33.15	96.25	462.06	150.26	-78.86	716.25	65.23	175.00	-1082.51

8 FIGURES

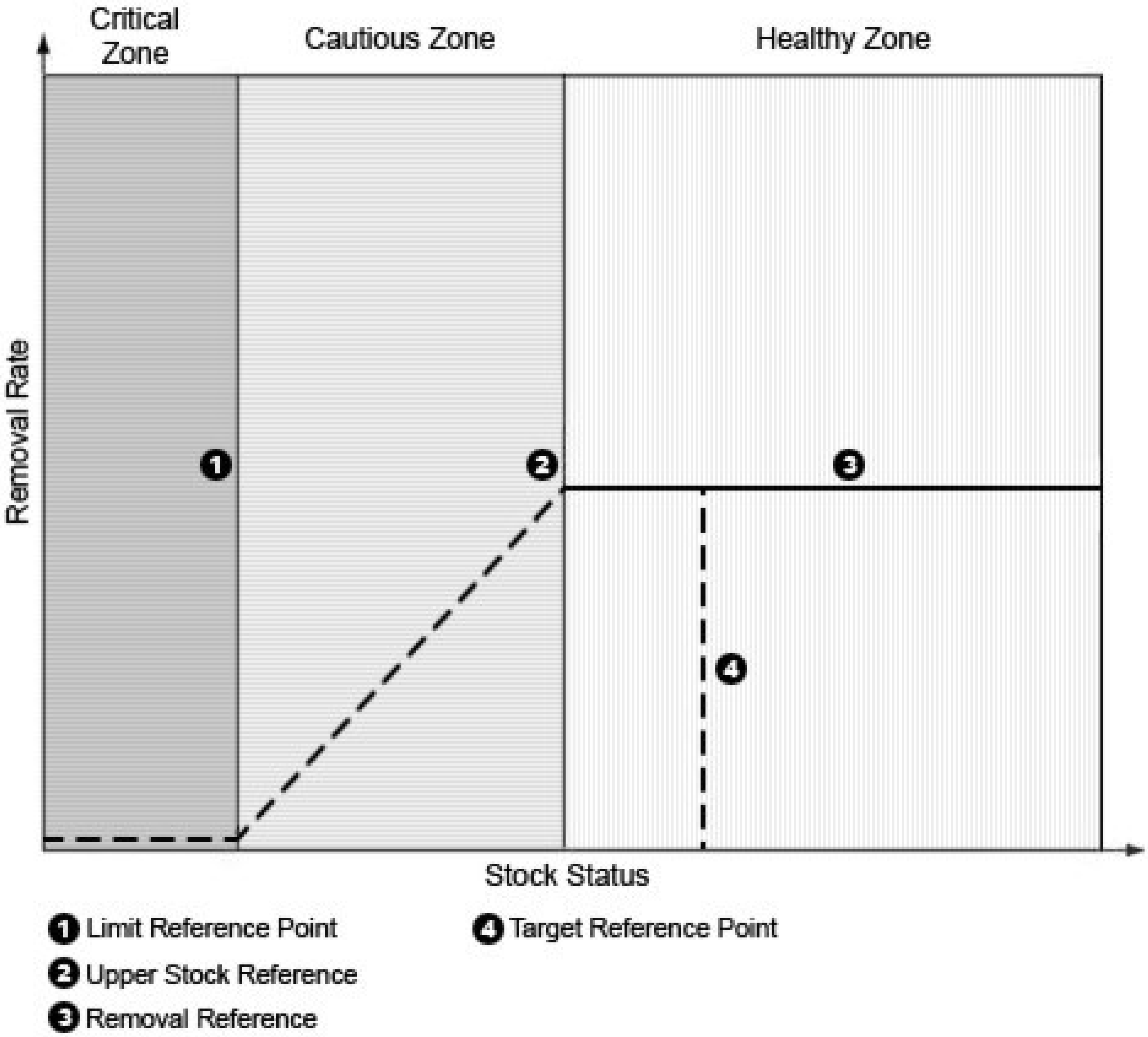


Figure 1. Zones in the Fisheries and Oceans Canada's precautionary approach paradigm.

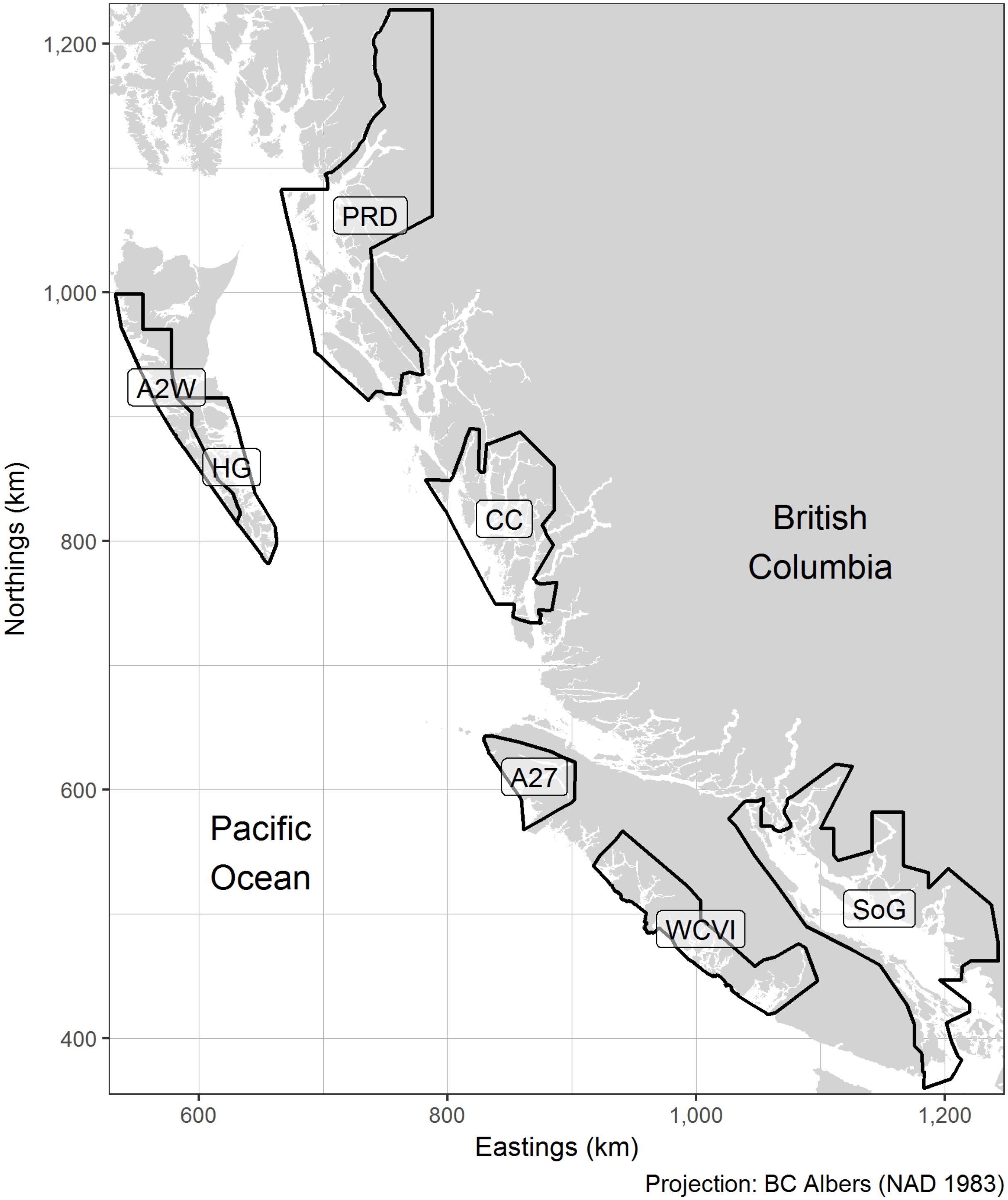


Figure 2. Boundaries for the Pacific Herring stock assessment regions (SARs) in British Columbia. The major SARs are Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SoG), and West Coast of Vancouver Island (WCVI). The minor SARs are Area 27 (A27) and Area 2 West (A2W). Units: kilometres (km).

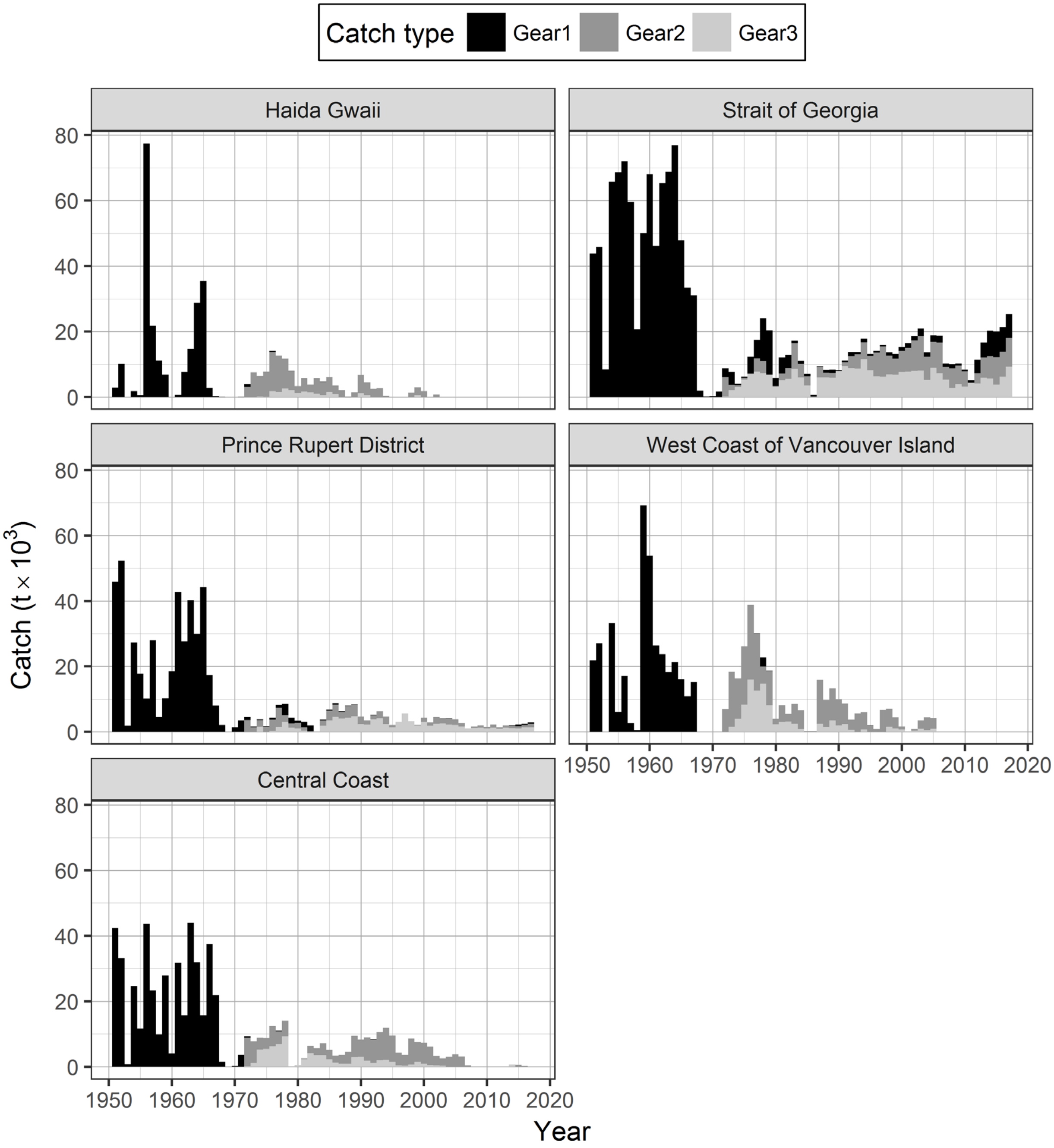


Figure 3. Time series of total landed catch in thousands of metric tonnes (t x 10^3) of Pacific Herring from 1951 to 2017 in the major stock assessment regions (SARs). Legend: 'Gear1' represents the reduction, the food and bait, as well as the special use fishery; 'Gear2' represents the roe seine fishery; and 'Gear3' represents the roe gillnet fishery.

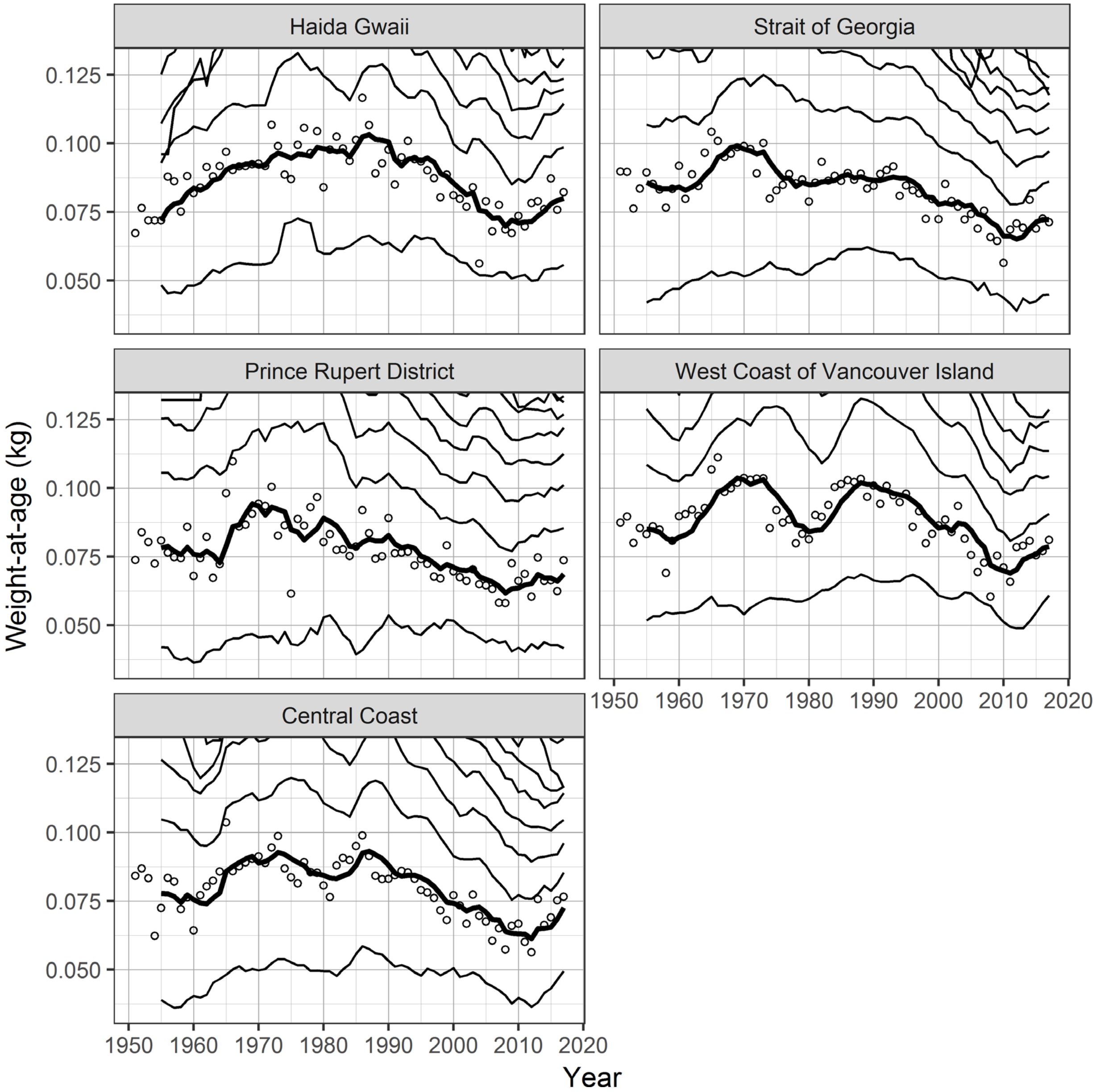


Figure 4. Time series of weight-at-age in kilograms (kg) for age-3 (circles) and 5-year running mean weight-at-age (lines) for Pacific Herring from 1951 to 2017 in the major stock assessment regions (SARs). Lines show 5-year running means for age-2 to age-10 herring (incrementing higher from the lowest line); the thick black line highlights age-3 herring. Missing weight-at-age values (i.e., years where there are no biological samples) are imputed using one of two methods: missing values at the beginning of the time series are imputed by extending the first non-missing value backwards; other missing values are imputed as the mean of the previous 5 years. Biological summaries only include samples collected using seine nets (commercial and test) due to size-selectivity of other gear types such as gillnet. The age-10 class is a 'plus group' which includes fish ages 10 and older.

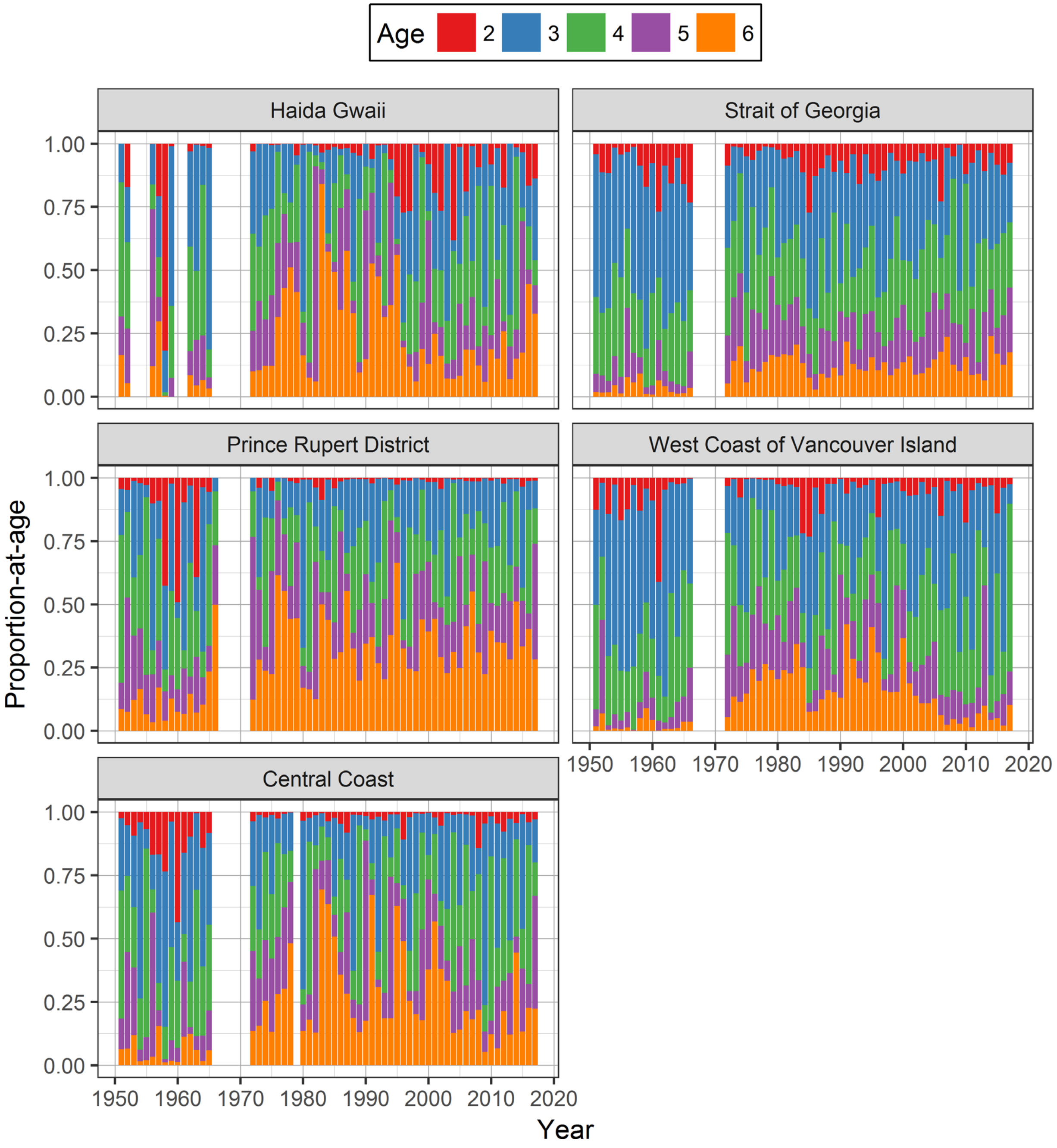


Figure 5. Time series of proportion-at-age for Pacific Herring from 1951 to 2017 in the major stock assessment regions (SARs). Biological summaries only include samples collected using seine nets (commercial and test) due to size-selectivity of other gear types such as gillnet. The age-6 class is a 'plus group' which includes fish ages 6 and older.

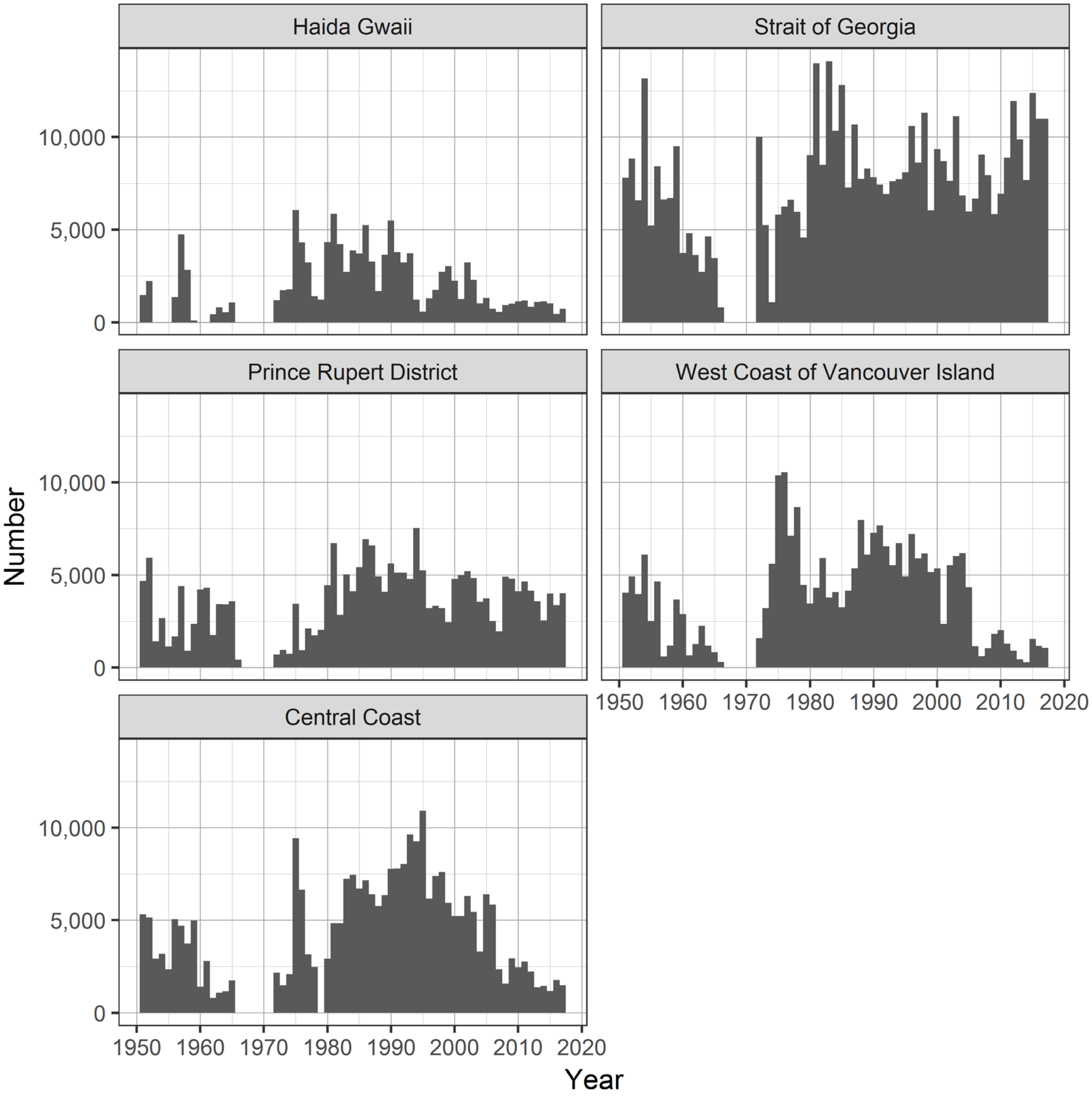


Figure 6. Number of biological samples by year for Pacific Herring from 1951 to 2017 in the major stock assessment regions (SARs). Biological summaries only include samples collected using seine nets (commercial and test) due to size-selectivity of other gear types such as gillnet.

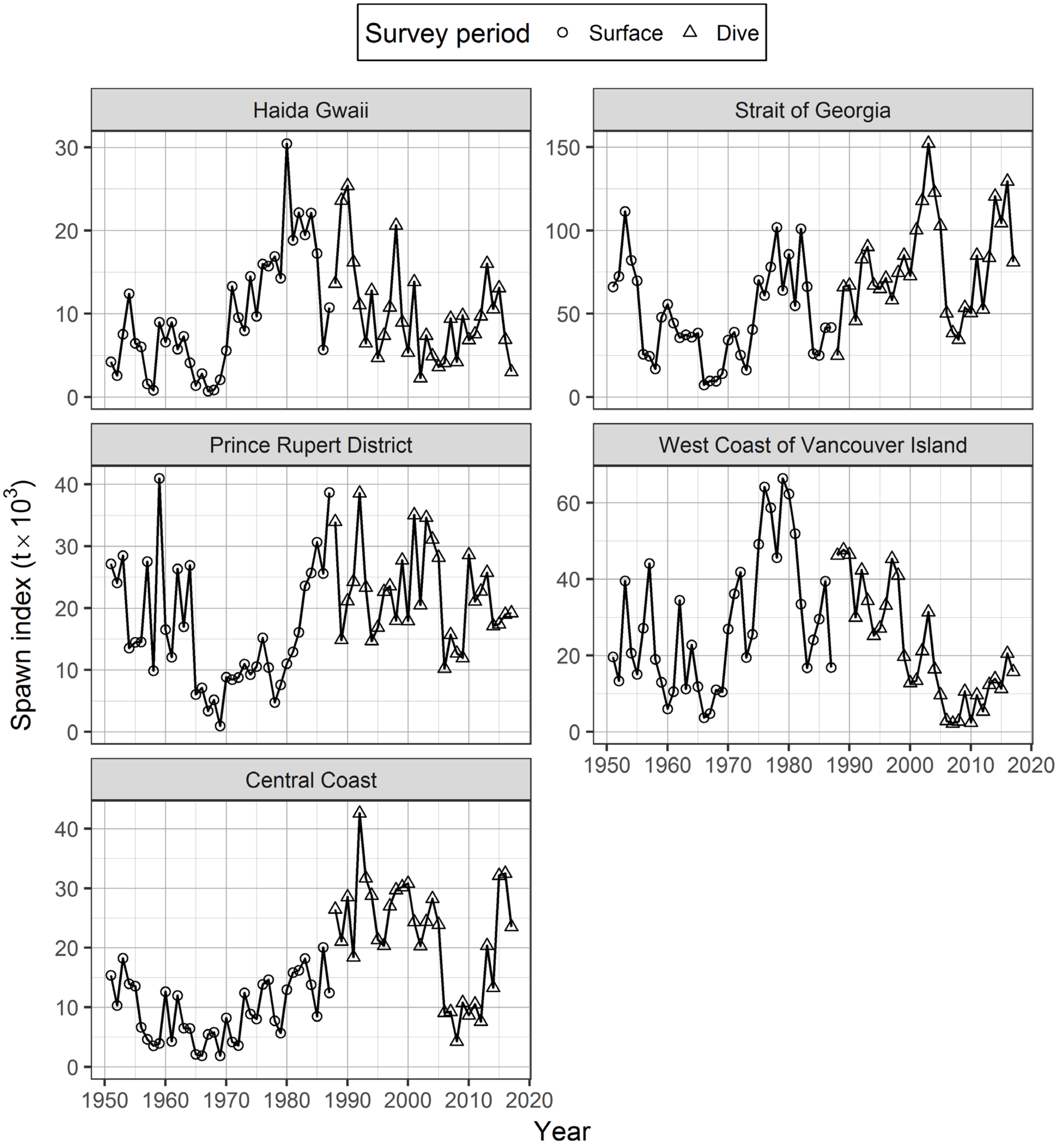


Figure 7. Time series of spawn index in thousands of metric tonnes (t x 10^3) for Pacific Herring from 1951 to 2017 in the major stock assessment regions (SARs). The spawn ix has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The 'spawn index' represents the raw survey data only, and is not scaled by the spawn survey scaling parameter, q.

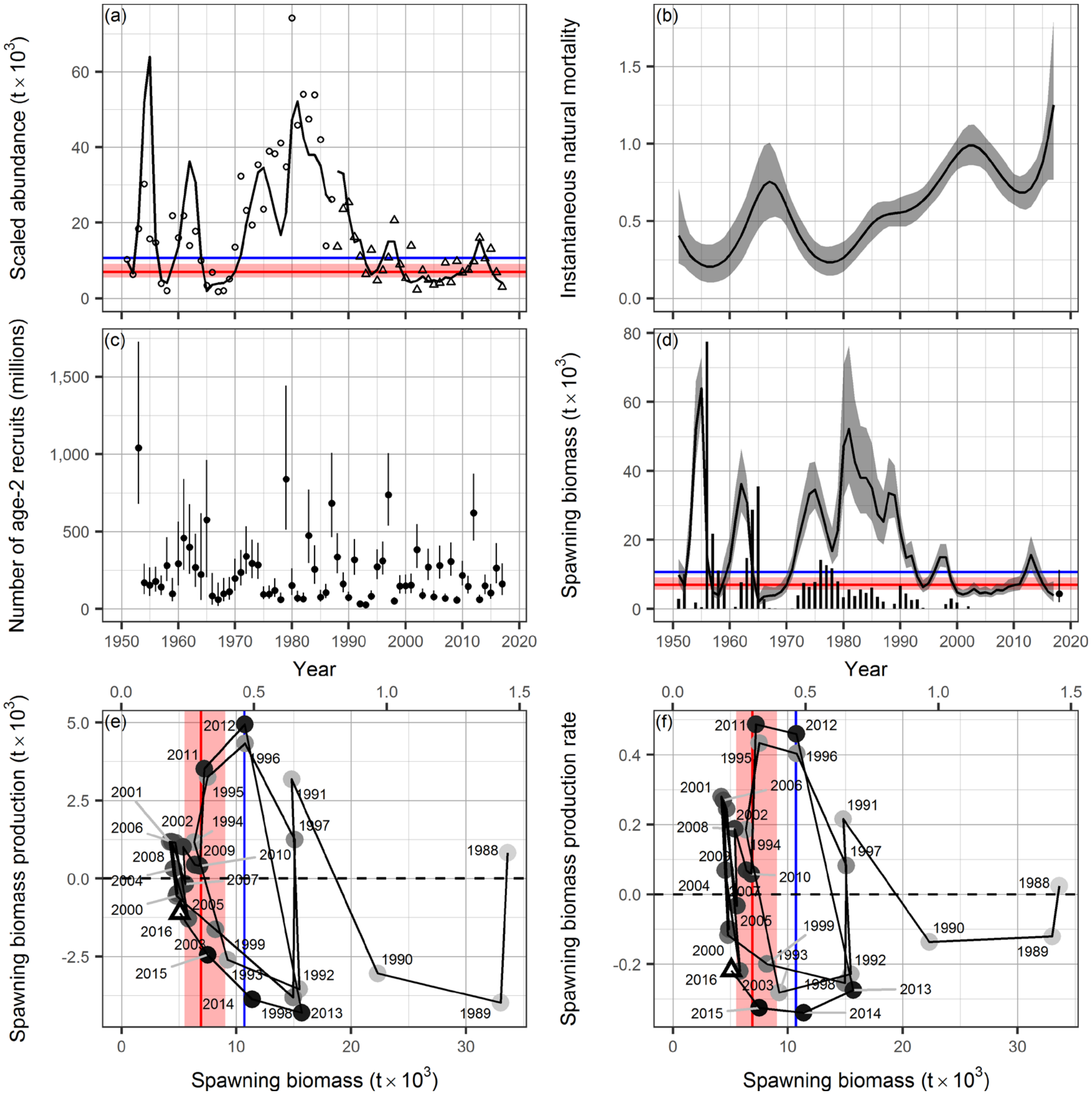


Figure 8. Model output for Pacific Herring in the HG major stock assessment region (SAR) for AM2. Panel (a): model fit to time series of scaled spawn survey data in thousands of metric tonnes (t x 10^3). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The spawn survey data (i.e., spawn index) is scaled to abundance via the spawn survey scaling parameter q. Panel (b): posterior estimates of instantaneous natural mortality. Line and shaded area indicate the median and 90% credible interval, respectively. Panel (c): reconstructed number of age-2 recruits in millions. Circles with vertical lines indicate medians and 90% credible intervals, respectively. Panel (d): posterior estimate of spawning biomass (SB_t) for each year t in thousands of metric tonnes. Line and shaded area indicates the median and 90% credible interval, respectively. Also shown is projected spawning biomass assuming no fishing (SB_{2018}): circle and vertical line indicates the median and 90% credible interval, respectively. Vertical bars indicate commercial catch, excluding spawn on kelp (SOK). Panels (e & f): phase plots of spawning biomass production and spawning biomass production rate against spawning biomass, respectively, for the dive survey period (MPD estimates). Grey shading becomes darker in chronological order. The triangle indicates 2016. The axis scale at the top of panels (e & f) is spawning biomass depletion, SB/SB_0. Panels (a, d, e, & f): red lines indicate medians, and red shading indicate 90% confidence intervals for the limit reference point (LRP), $0.3SB_0$, where SB_0 is estimated unfished biomass; if present, the blue lines indicates the 1996 fixed cutoffs. Scales are different between AM2 and AM1 (show in separate figures).

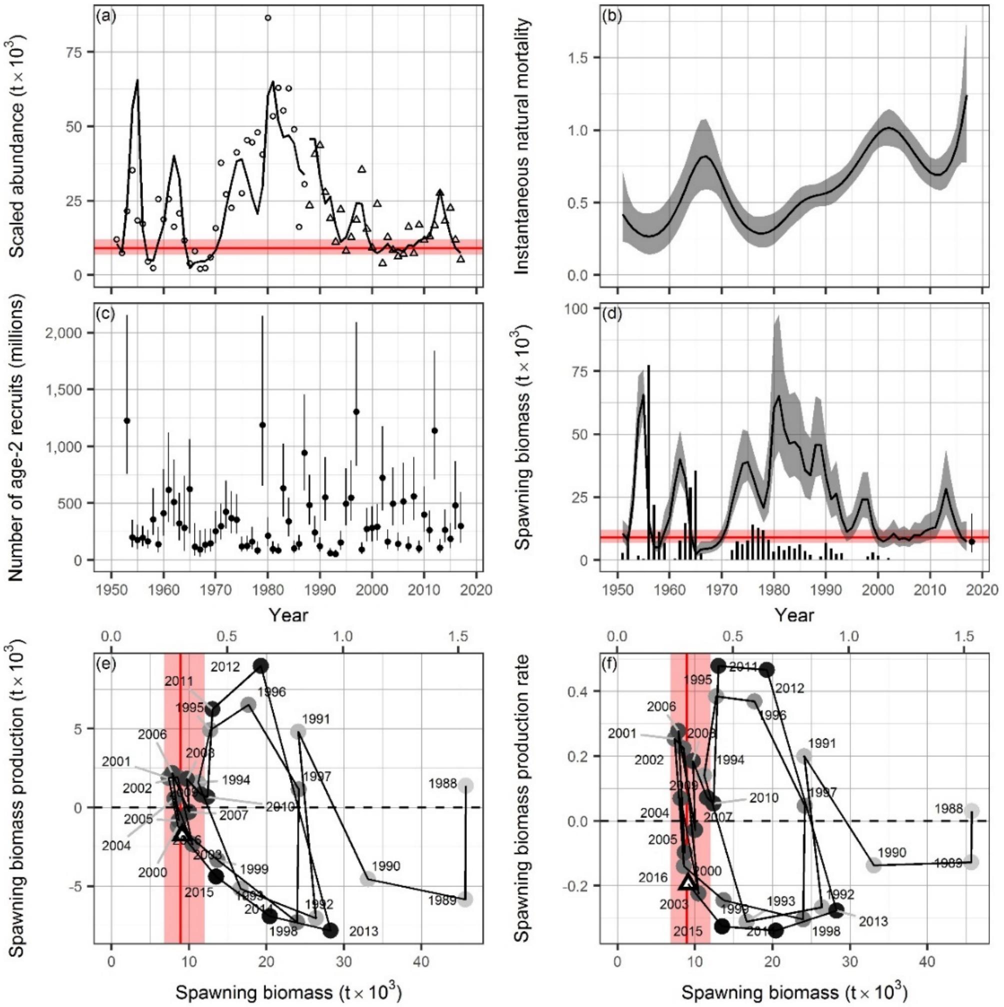


Figure 9. Model output for Pacific Herring in the HG major stock assessment region (SAR) for AM1. Panel (a): model fit to time series of scaled spawn survey data in thousands of metric tonnes (t x 10^3). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The spawn survey data (i.e., spawn index) is scaled to abundance via the spawn survey scaling parameter q. Panel (b): posterior estimates of instantaneous natural mortality. Line and shaded area indicate the median and 90% credible interval, respectively. Panel (c): reconstructed number of age-2 recruits in millions. Circles with vertical lines indicate medians and 90% credible intervals, respectively. Panel (d): posterior estimate of spawning biomass (SB_t) for each year t in thousands of metric tonnes. Line and shaded area indicates the median and 90% credible interval, respectively. Also shown is projected spawning biomass assuming no fishing (SB_{2018}): circle and vertical line indicates the median and 90% credible interval, respectively. Vertical bars indicate commercial catch, excluding spawn on kelp (SOK). Panels (e & f): phase plots of spawning biomass production and spawning biomass production rate against spawning biomass, respectively, for the dive survey period (MPD estimates). Grey shading becomes darker in chronological order. The triangle indicates 2016. The axis scale at the top of panels (e & f) is spawning biomass depletion, SB/SB_0. Panels (a, d, e, & f): red lines indicate medians, and red shading indicate 90% confidence intervals for the limit reference point (LRP), $0.3SB_0$, where SB_0 is estimated unfished biomass; if present, the blue lines indicates the 1996 fixed cutoffs. Scales are different between AM2 and AM1 (show in separate figures).

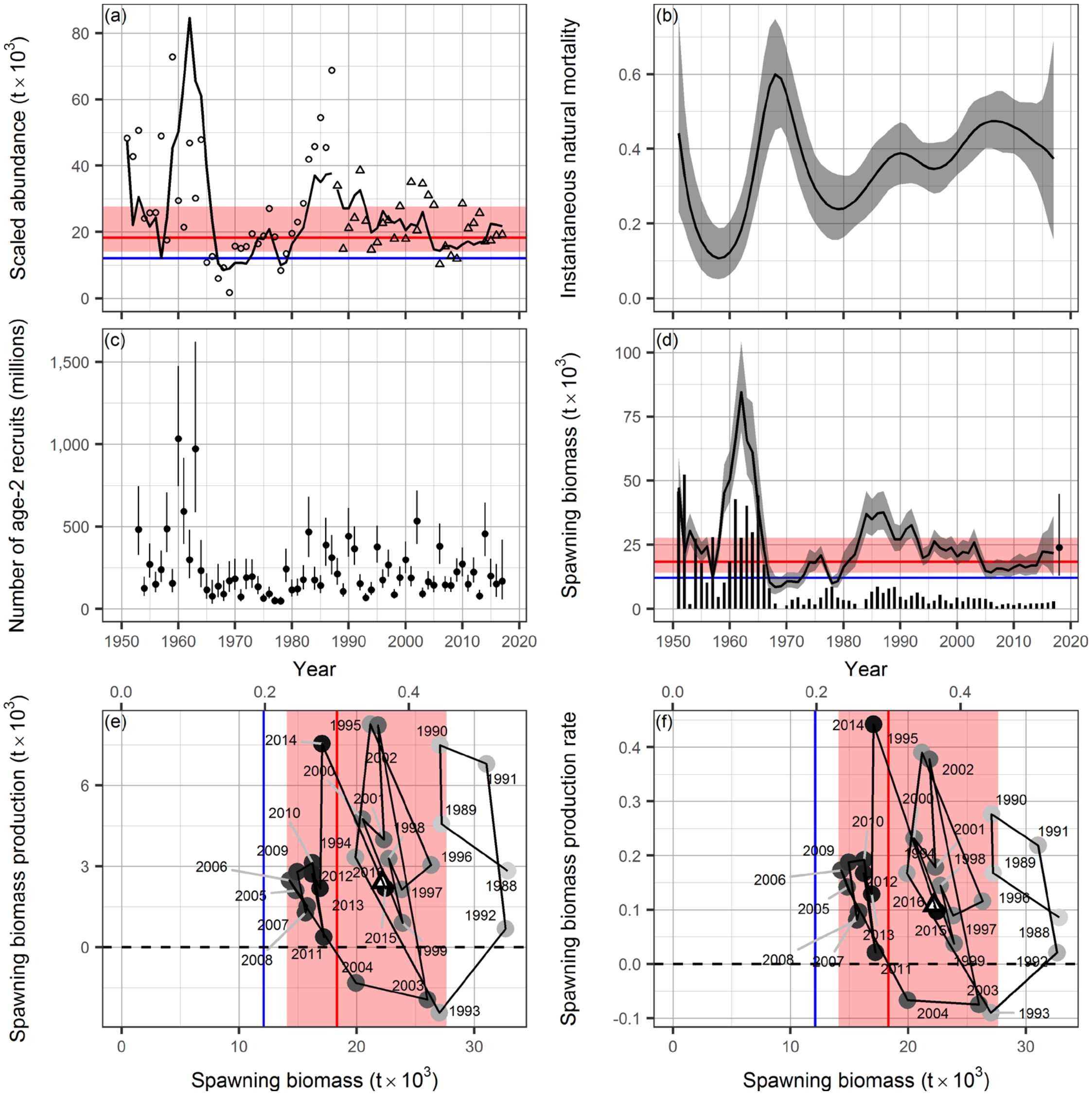


Figure 10. Model output for Pacific Herring in the PRD major stock assessment region (SAR) for AM2. Panel (a): model fit to time series of scaled spawn survey data in thousands of metric tonnes (t x 10^3). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The spawn survey data (i.e., spawn index) is scaled to abundance via the spawn survey scaling parameter q. Panel (b): posterior estimates of instantaneous natural mortality. Line and shaded area indicate the median and 90% credible interval, respectively. Panel (c): reconstructed number of age-2 recruits in millions. Circles with vertical lines indicate medians and 90% credible intervals, respectively. Panel (d): posterior estimate of spawning biomass (SB_t) for each year t in thousands of metric tonnes. Line and shaded area indicates the median and 90% credible interval, respectively. Also shown is projected spawning biomass assuming no fishing (SB_{2018}): circle and vertical line indicates the median and 90% credible interval, respectively. Vertical bars indicate commercial catch, excluding spawn on kelp (SOK). Panels (e & f): phase plots of spawning biomass production and spawning biomass production rate against spawning biomass, respectively, for the dive survey period (MPD estimates). Grey shading becomes darker in chronological order. The triangle indicates 2016. The axis scale at the top of panels (e & f) is spawning biomass depletion, SB/SB_0. Panels (a, d, e, & f): red lines indicate medians, and red shading indicate 90% confidence intervals for the limit reference point (LRP), $0.3SB_0$, where SB_0 is estimated unfished biomass; if present, the blue lines indicates the 1996 fixed cutoffs. Scales are different between AM2 and AM1 (show in separate figures).

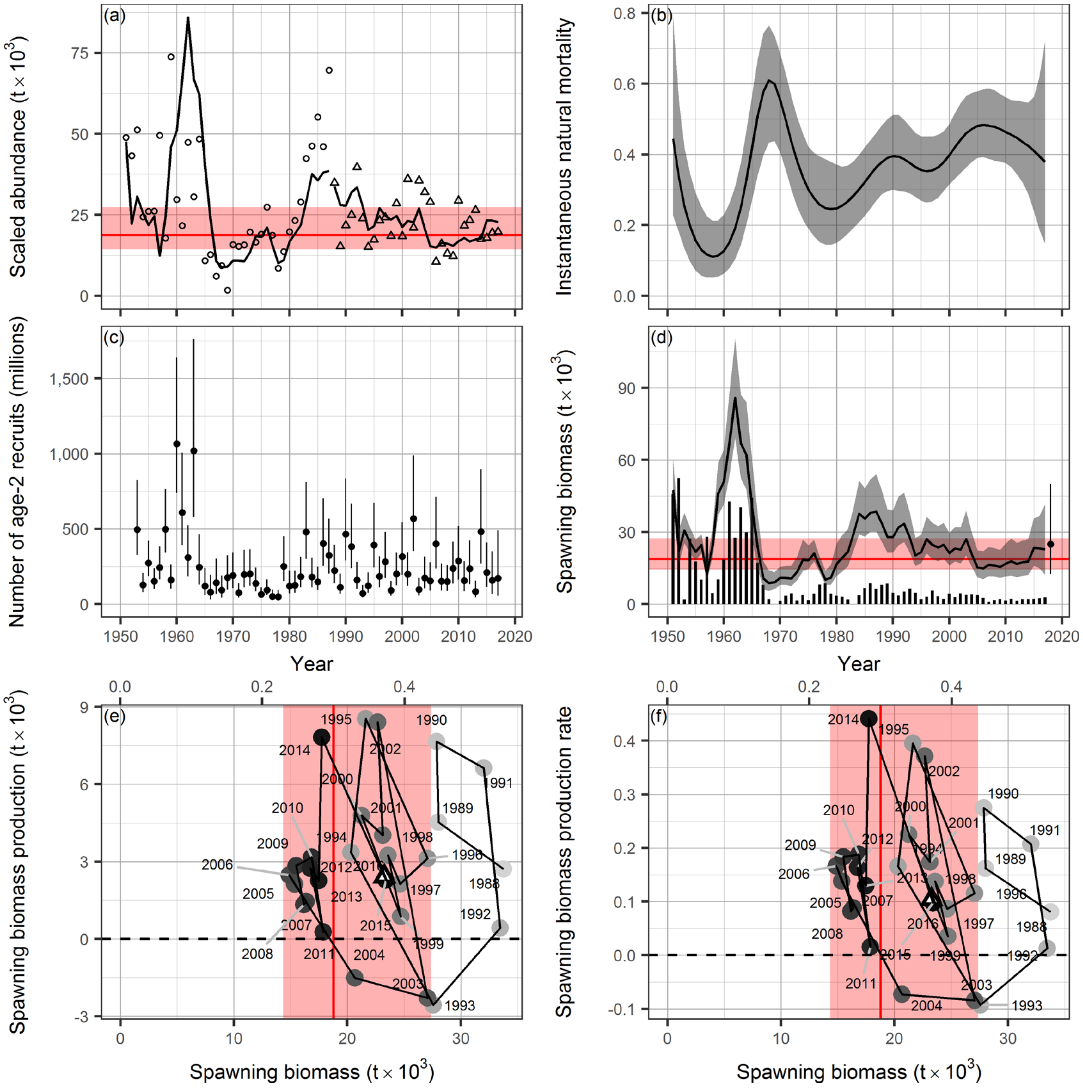


Figure 11. Model output for Pacific Herring in the PRD major stock assessment region (SAR) for AM1. Panel (a): model fit to time series of scaled spawn survey data in thousands of metric tonnes (t x 10^3). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The spawn survey data (i.e., spawn index) is scaled to abundance via the spawn survey scaling parameter q. Panel (b): posterior estimates of instantaneous natural mortality. Line and shaded area indicate the median and 90% credible interval, respectively. Panel (c): reconstructed number of age-2 recruits in millions. Circles with vertical lines indicate medians and 90% credible intervals, respectively. Panel (d): posterior estimate of spawning biomass (SB_t) for each year t in thousands of metric tonnes. Line and shaded area indicates the median and 90% credible interval, respectively. Also shown is projected spawning biomass assuming no fishing (SB_{2018}): circle and vertical line indicates the median and 90% credible interval, respectively. Vertical bars indicate commercial catch, excluding spawn on kelp (SOK). Panels (e & f): phase plots of spawning biomass production and spawning biomass production rate against spawning biomass, respectively, for the dive survey period (MPD estimates). Grey shading becomes darker in chronological order. The triangle indicates 2016. The axis scale at the top of panels (e & f) is spawning biomass depletion, SB/SB_0. Panels (a, d, e, & f): red lines indicate medians, and red shading indicate 90% confidence intervals for the limit reference point (LRP), $0.3SB_0$, where SB_0 is estimated unfished biomass; if present, the blue lines indicates the 1996 fixed cutoffs. Scales are different between AM2 and AM1 (show in separate figures).

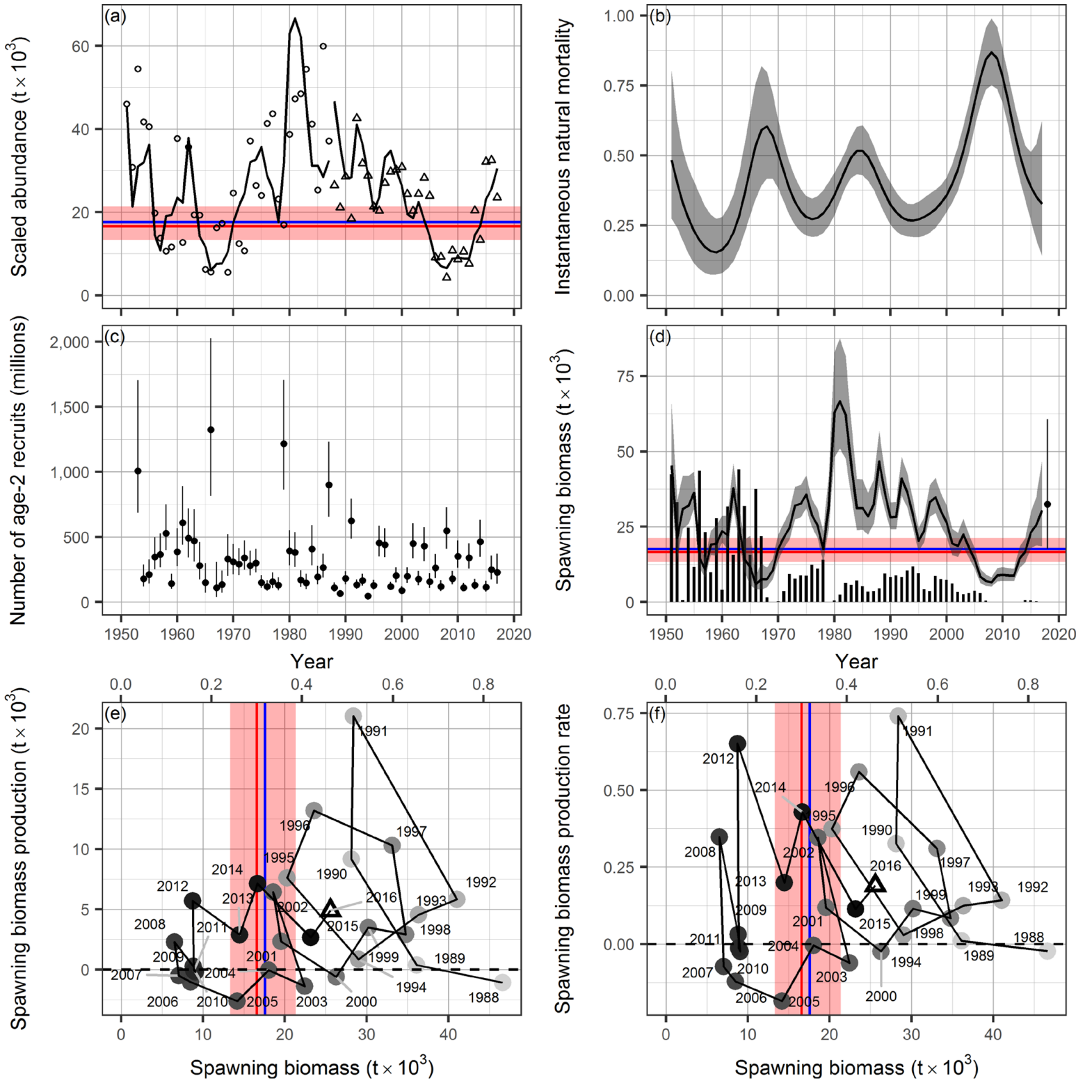


Figure 12. Model output for Pacific Herring in the CC major stock assessment region (SAR) for AM2. Panel (a): model fit to time series of scaled spawn survey data in thousands of metric tonnes (t x 10^3). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The spawn survey data (i.e., spawn index) is scaled to abundance via the spawn survey scaling parameter q. Panel (b): posterior estimates of instantaneous natural mortality. Line and shaded area indicate the median and 90% credible interval, respectively. Panel (c): reconstructed number of age-2 recruits in millions. Circles with vertical lines indicate medians and 90% credible intervals, respectively. Panel (d): posterior estimate of spawning biomass (SB_t) for each year t in thousands of metric tonnes. Line and shaded area indicates the median and 90% credible interval, respectively. Also shown is projected spawning biomass assuming no fishing (SB_{2018}): circle and vertical line indicates the median and 90% credible interval, respectively. Vertical bars indicate commercial catch, excluding spawn on kelp (SOK). Panels (e & f): phase plots of spawning biomass production and spawning biomass production rate against spawning biomass, respectively, for the dive survey period (MPD estimates). Grey shading becomes darker in chronological order. The triangle indicates 2016. The axis scale at the top of panels (e & f) is spawning biomass depletion, SB/SB_0. Panels (a, d, e, & f): red lines indicate medians, and red shading indicate 90% confidence intervals for the limit reference point (LRP), $0.3SB_0$, where SB_0 is estimated unfished biomass; if present, the blue lines indicates the 1996 fixed cutoffs. Scales are different between AM2 and AM1 (show in separate figures).

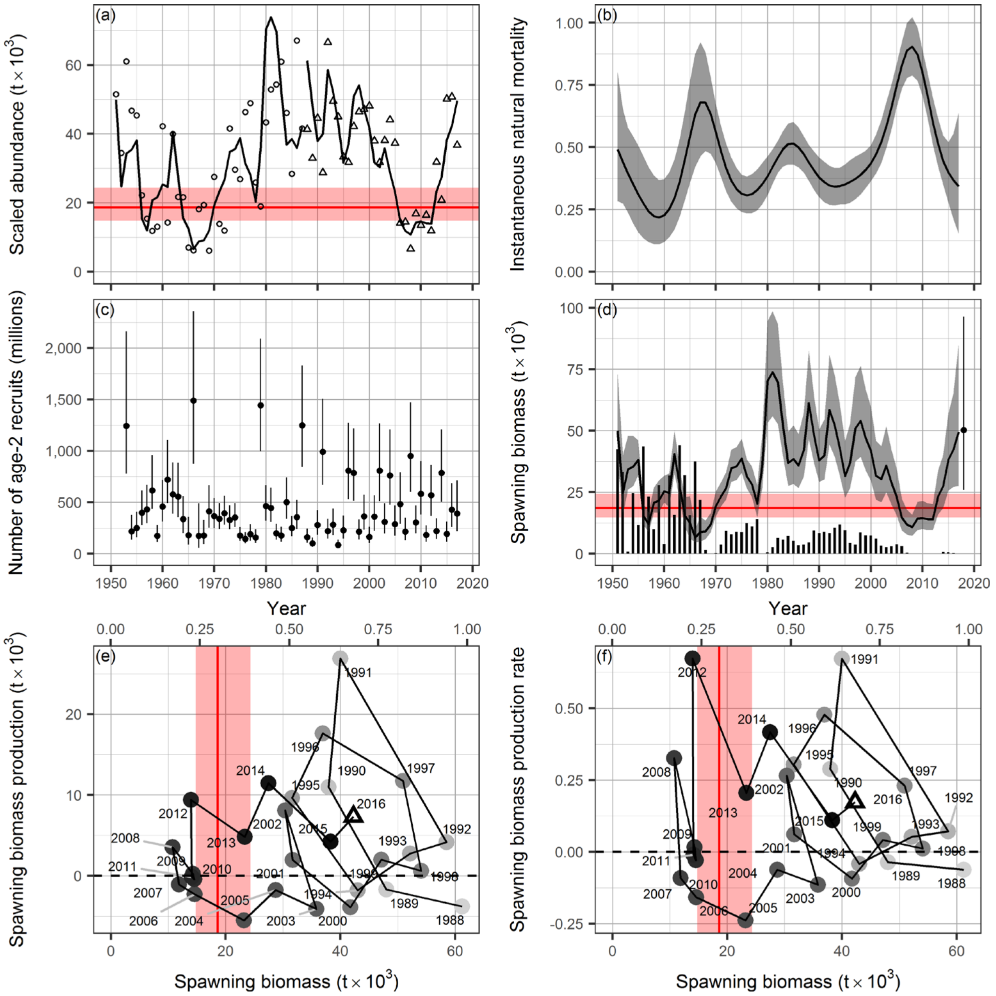


Figure 13. Model output for Pacific Herring in the CC major stock assessment region (SAR) for AM1. Panel (a): model fit to time series of scaled spawn survey data in thousands of metric tonnes ($t \times 10^3$). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The spawn survey data (i.e., spawn index) is scaled to abundance via the spawn survey scaling parameter q. Panel (b): posterior estimates of instantaneous natural mortality. Line and shaded area indicate the median and 90% credible interval, respectively. Panel (c): reconstructed number of age-2 recruits in millions. Circles with vertical lines indicate medians and 90% credible intervals, respectively. Panel (d): posterior estimate of spawning biomass (SB_t) for each year t in thousands of metric tonnes. Line and shaded area indicates the median and 90% credible interval, respectively. Also shown is projected spawning biomass assuming no fishing (SB_{2018}): circle and vertical line indicates the median and 90% credible interval, respectively. Vertical bars indicate commercial catch, excluding spawn on kelp (SOK). Panels (e & f): phase plots of spawning biomass production and spawning biomass production rate against spawning biomass, respectively, for the dive survey period (MPD estimates). Grey shading becomes darker in chronological order. The triangle indicates 2016. The axis scale at the top of panels (e & f) is spawning biomass depletion, SB/SB_0. Panels (a, d, e, & f): red lines indicate medians, and red shading indicate 90% confidence intervals for the limit reference point (LRP), $0.3SB_0$, where SB_0 is estimated unfished biomass; if present, the blue lines indicates the 1996 fixed cutoffs. Scales are different between AM2 and AM1 (show in separate figures).

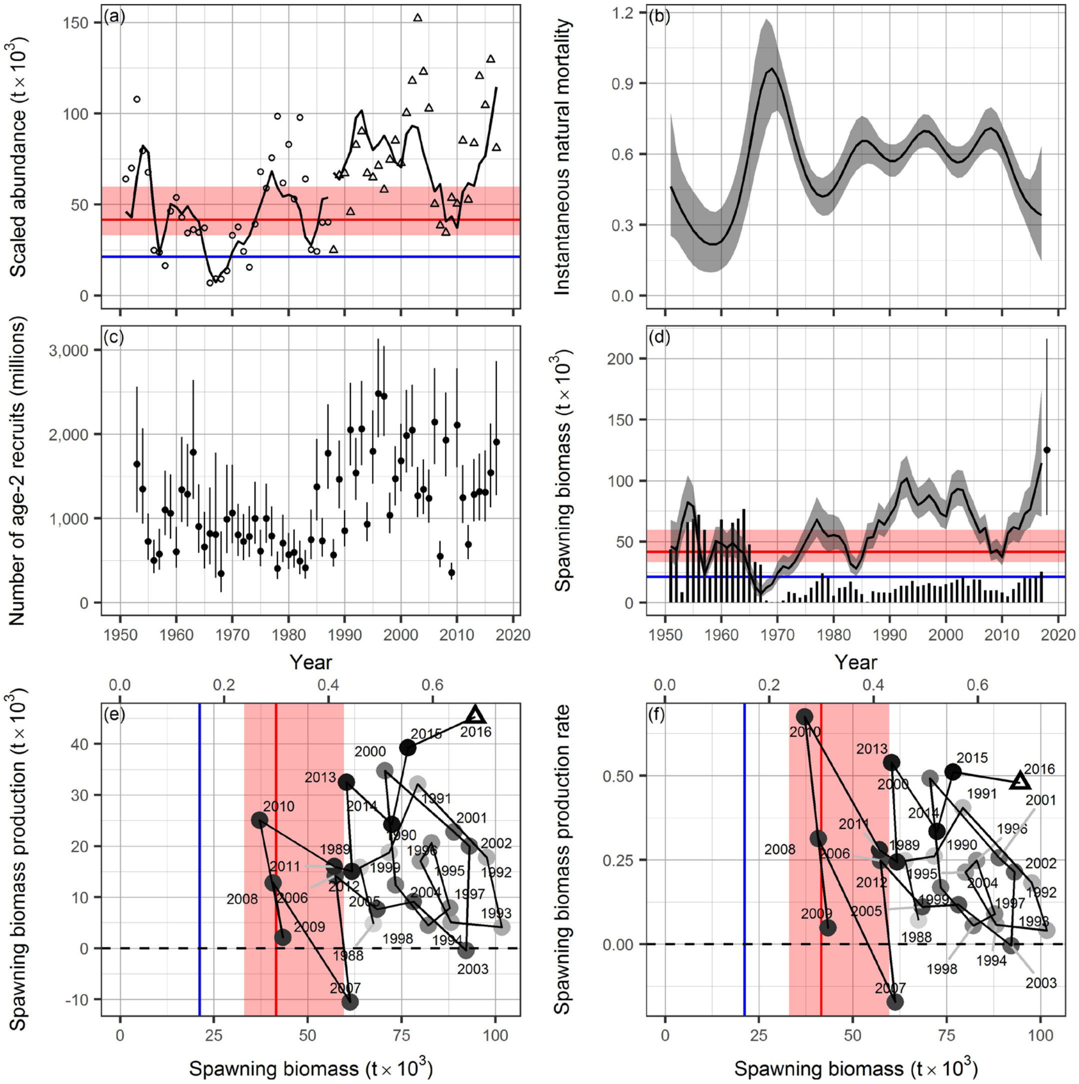


Figure 14. Model output for Pacific Herring in the SoG major stock assessment region (SAR) for AM2. Panel (a): model fit to time series of scaled spawn survey data in thousands of metric tonnes (t x 10^3). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The spawn survey data (i.e., spawn index) is scaled to abundance via the spawn survey scaling parameter q. Panel (b): posterior estimates of instantaneous natural mortality. Line and shaded area indicate the median and 90% credible interval, respectively. Panel (c): reconstructed number of age-2 recruits in millions. Circles with vertical lines indicate medians and 90% credible intervals, respectively. Panel (d): posterior estimate of spawning biomass (SB_t) for each year t in thousands of metric tonnes. Line and shaded area indicates the median and 90% credible interval, respectively. Also shown is projected spawning biomass assuming no fishing (SB_{2018}): circle and vertical line indicates the median and 90% credible interval, respectively. Vertical bars indicate commercial catch, excluding spawn on kelp (SOK). Panels (e & f): phase plots of spawning biomass production and spawning biomass production rate against spawning biomass, respectively, for the dive survey period (MPD estimates). Grey shading becomes darker in chronological order. The triangle indicates 2016. The axis scale at the top of panels (e & f) is spawning biomass depletion, SB/SB_0. Panels (a, d, e, & f): red lines indicate medians, and red shading indicate 90% confidence intervals for the limit reference point (LRP), $0.3SB_0$, where SB_0 is estimated unfished biomass; if present, the blue lines indicates the 1996 fixed cutoffs. Scales are different between AM2 and AM1 (show in separate figures).

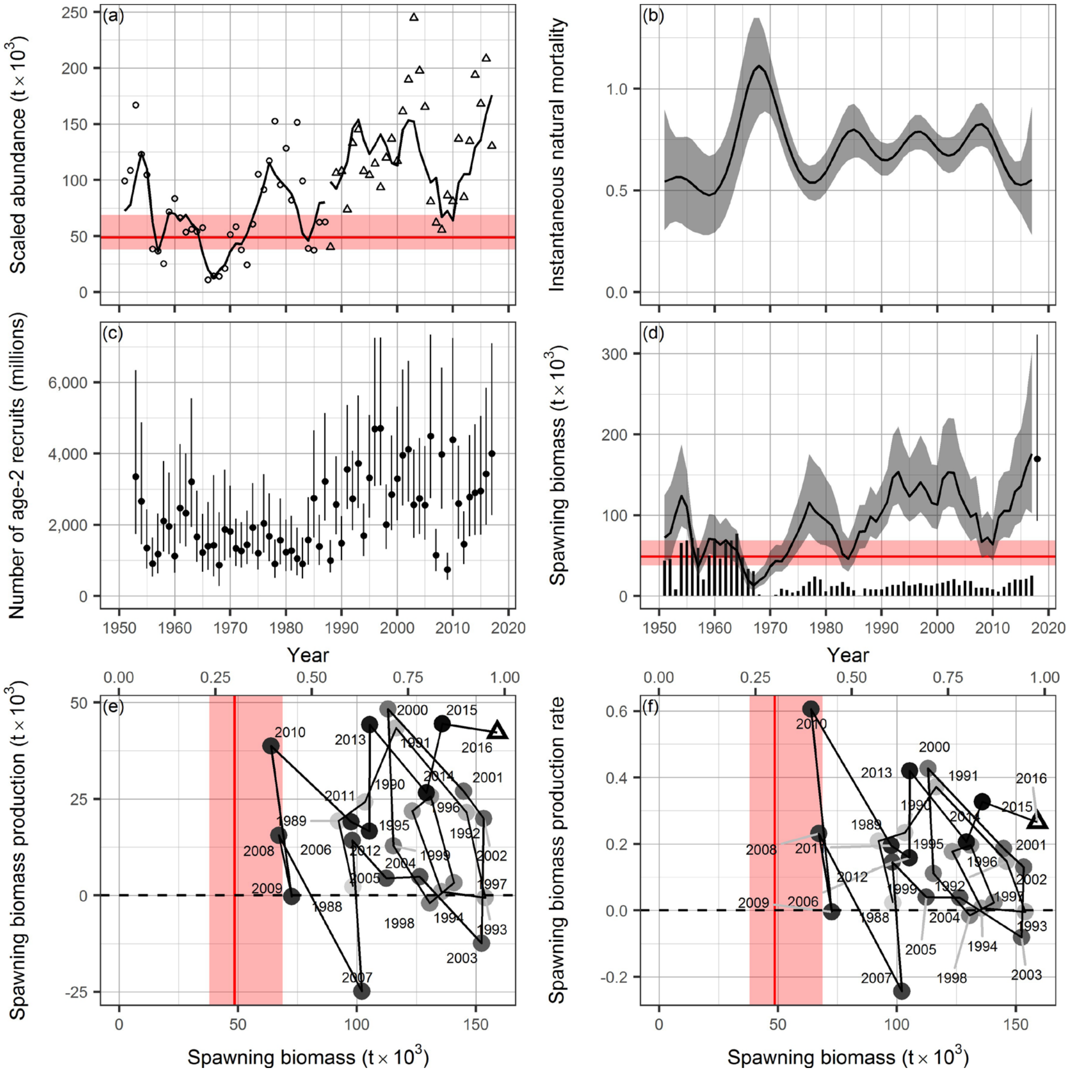


Figure 15. Model output for Pacific Herring in the SoG major stock assessment region (SAR) for AM1. Panel (a): model fit to time series of scaled spawn survey data in thousands of metric tonnes (t x 10^3). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The spawn survey data (i.e., spawn index) is scaled to abundance via the spawn survey scaling parameter q. Panel (b): posterior estimates of instantaneous natural mortality. Line and shaded area indicate the median and 90% credible interval, respectively. Panel (c): reconstructed number of age-2 recruits in millions. Circles with vertical lines indicate medians and 90% credible intervals, respectively. Panel (d): posterior estimate of spawning biomass (SB_t) for each year t in thousands of metric tonnes. Line and shaded area indicates the median and 90% credible interval, respectively. Also shown is projected spawning biomass assuming no fishing (SB_{2018}): circle and vertical line indicates the median and 90% credible interval, respectively. Vertical bars indicate commercial catch, excluding spawn on kelp (SOK). Panels (e & f): phase plots of spawning biomass production and spawning biomass production rate against spawning biomass, respectively, for the dive survey period (MPD estimates). Grey shading becomes darker in chronological order. The triangle indicates 2016. The axis scale at the top of panels (e & f) is spawning biomass depletion, SB/SB_0. Panels (a, d, e, & f): red lines indicate medians, and red shading indicate 90% confidence intervals for the limit reference point (LRP), $0.3SB_0$, where SB_0 is estimated unfished biomass; if present, the blue lines indicates the 1996 fixed cutoffs. Scales are different between AM2 and AM1 (show in separate figures).

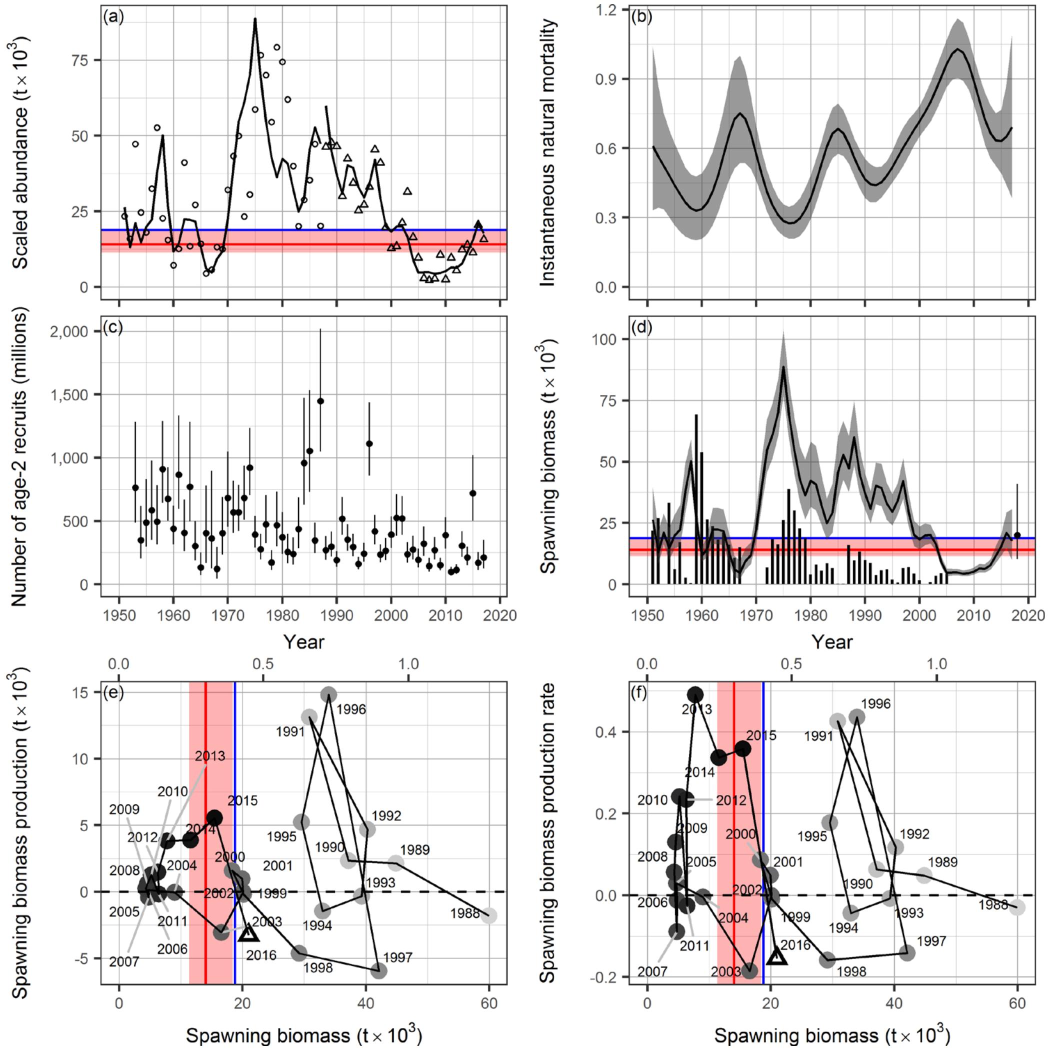


Figure 16. Model output for Pacific Herring in the WCVI major stock assessment region (SAR) for AM2. Panel (a): model fit to time series of scaled spawn survey data in thousands of metric tonnes (t x 10^3). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The spawn survey data (i.e., spawn index) is scaled to abundance via the spawn survey scaling parameter q. Panel (b): posterior estimates of instantaneous natural mortality. Line and shaded area indicate the median and 90% credible interval, respectively. Panel (c): reconstructed number of age-2 recruits in millions. Circles with vertical lines indicate medians and 90% credible intervals, respectively. Panel (d): posterior estimate of spawning biomass (SB_t) for each year t in thousands of metric tonnes. Line and shaded area indicates the median and 90% credible interval, respectively. Also shown is projected spawning biomass assuming no fishing (SB_{2018}): circle and vertical line indicates the median and 90% credible interval, respectively. Vertical bars indicate commercial catch, excluding spawn on kelp (SOK). Panels (e & f): phase plots of spawning biomass production and spawning biomass production rate against spawning biomass, respectively, for the dive survey period (MPD estimates). Grey shading becomes darker in chronological order. The triangle indicates 2016. The axis scale at the top of panels (e & f) is spawning biomass depletion, SB/SB_0. Panels (a, d, e, & f): red lines indicate medians, and red shading indicate 90% confidence intervals for the limit reference point (LRP), $0.3SB_0$, where SB_0 is estimated unfished biomass; if present, the blue lines indicates the 1996 fixed cutoffs. Scales are different between AM2 and AM1 (show in separate figures).

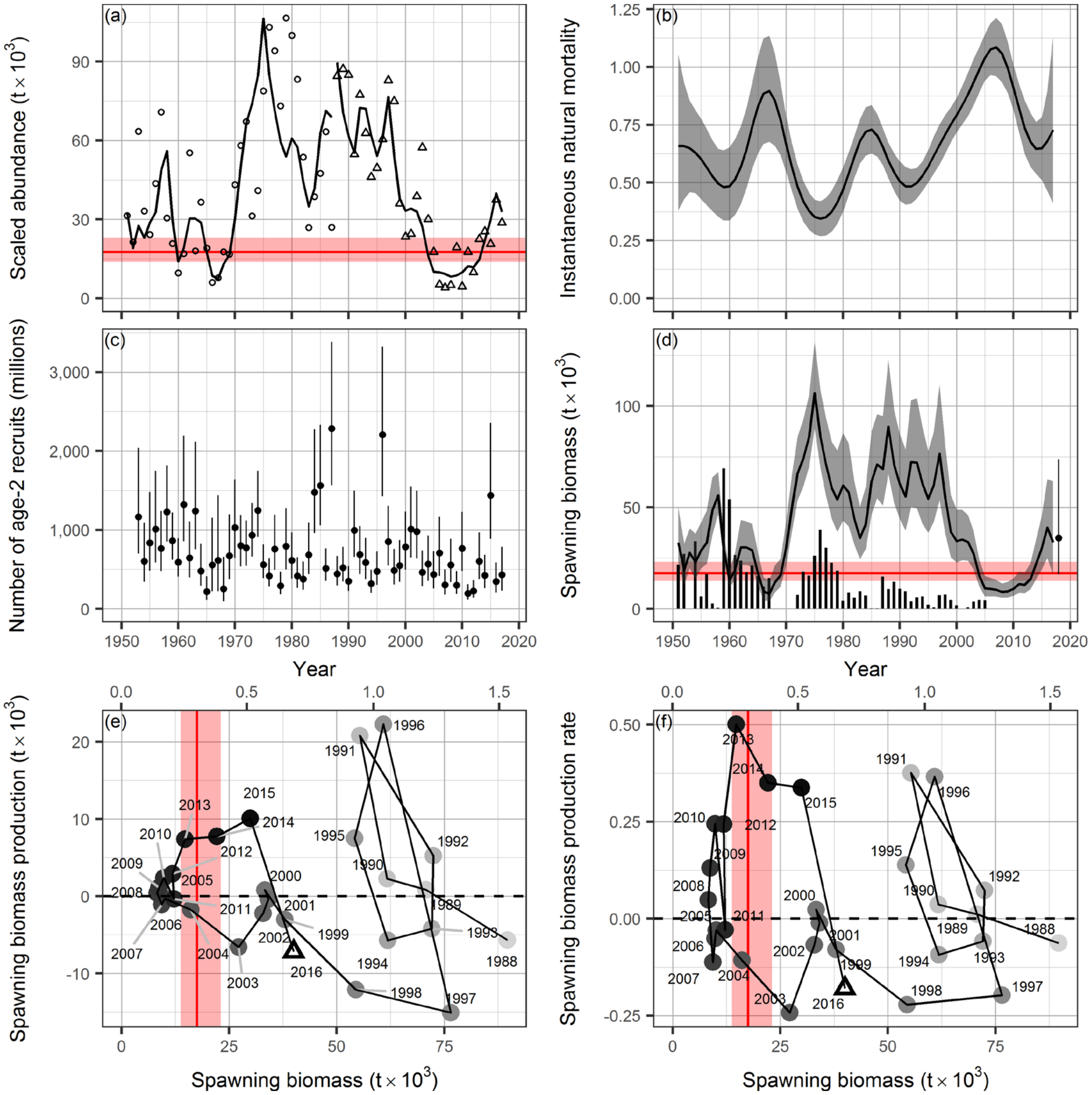


Figure 17. Model output for Pacific Herring in the WCVI major stock assessment region (SAR) for AM1. Panel (a): model fit to time series of scaled spawn survey data in thousands of metric tonnes (t x 10^3). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The spawn survey data (i.e., spawn index) is scaled to abundance via the spawn survey scaling parameter q. Panel (b): posterior estimates of instantaneous natural mortality. Line and shaded area indicate the median and 90% credible interval, respectively. Panel (c): reconstructed number of age-2 recruits in millions. Circles with vertical lines indicate medians and 90% credible intervals, respectively. Panel (d): posterior estimate of spawning biomass (SB_t) for each year t in thousands of metric tonnes. Line and shaded area indicates the median and 90% credible interval, respectively. Also shown is projected spawning biomass assuming no fishing (SB_{2018}): circle and vertical line indicates the median and 90% credible interval, respectively. Vertical bars indicate commercial catch, excluding spawn on kelp (SOK). Panels (e & f): phase plots of spawning biomass production and spawning biomass production rate against spawning biomass, respectively, for the dive survey period (MPD estimates). Grey shading becomes darker in chronological order. The triangle indicates 2016. The axis scale at the top of panels (e & f) is spawning biomass depletion, SB/SB_0. Panels (a, d, e, & f): red lines indicate medians, and red shading indicate 90% confidence intervals for the limit reference point (LRP), $0.3SB_0$, where SB_0 is estimated unfished biomass; if present, the blue lines indicates the 1996 fixed cutoffs. Scales are different between AM2 and AM1 (show in separate figures).

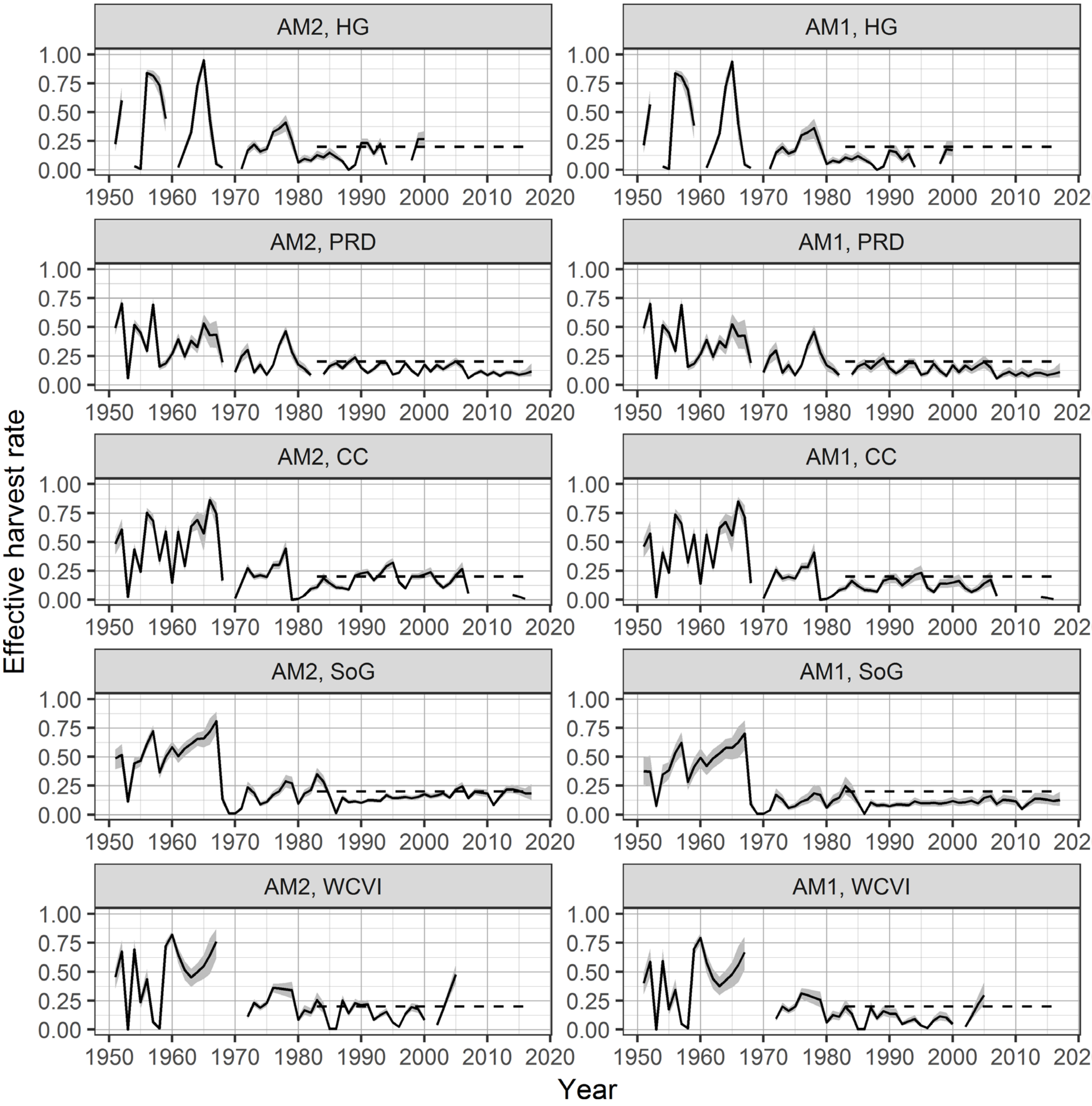


Figure 18. Effective harvest rate for Pacific Herring in the major stock assessment regions (SARs) for models AM2 and AM1. Effective harvest rate in year t, U_t is calculated as $U_t = \frac{C_t}{SB_t + C_t}$ where C_t is catch in year t, and SB_t is estimated spawning biomass in year t. Black lines indicate medians and shaded ribbons indicate 90% confidence intervals for spawning biomass, SB_t. Horizontal dashed lines indicate $U_t = 0.2$.

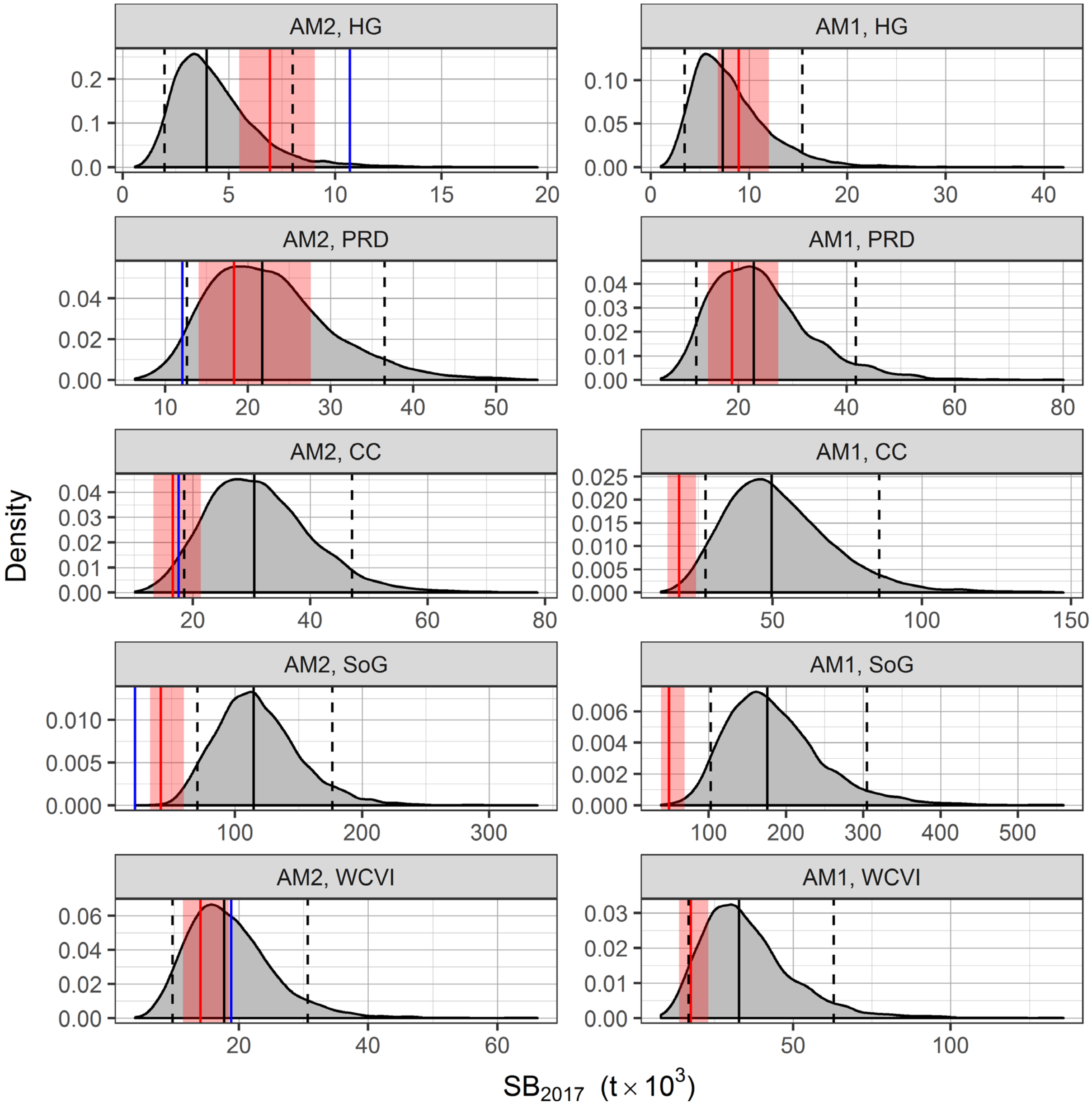


Figure 19. Estimated spawning biomass in 2017, SB_{2017} in thousands of tonnes, t for Pacific Herring in the major stock assessment regions (SARs) for models AM2 and AM1. Vertical black lines indicate medians (solid) and 90% confidence intervals (dashed) for SB_{2017}. Vertical red lines indicate medians, and shaded red rectangles indicate 90% confidence intervals for the limit reference point (LRP), $0.3SB_0$, where SB_0 is estimated unfished biomass. Vertical blue lines indicate 1996 fixed cutoffs.

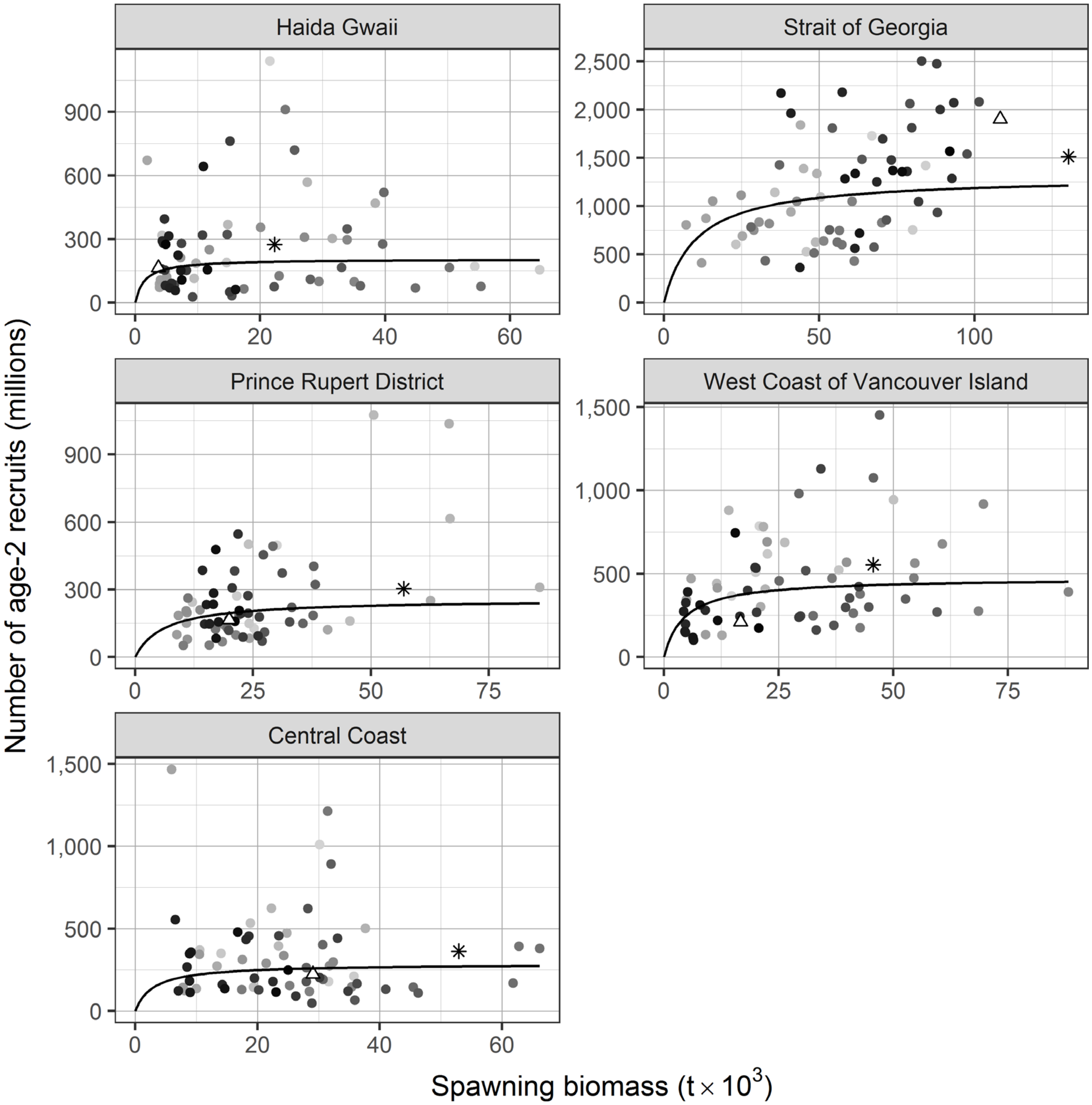


Figure 20. Beverton-Holt stock-recruitment relationship using MPD estimates for Pacific Herring in the major stock assessment regions (SARs) for model AM2. Lines indicate MPD Beverton-Holtstock-recruitment relationships. Stars indicate MPD estimates of unfished spawning biomass, SB_0, and unfished age-2 recruitment, R_0. Grey shading becomes darker in chronological order. Triangles indicate the current year, 2017. Legend: tonnes (t).

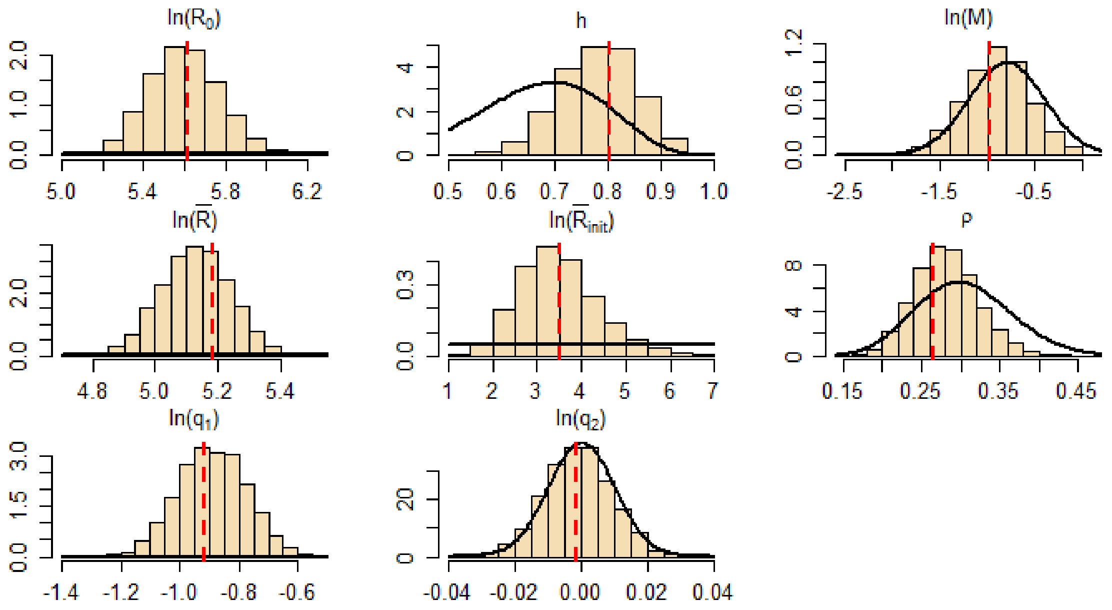


Figure 21. Prior probability distributions (lines) with comparative posterior histograms (bars) used in the Haida Gwaii AM2 model. Parameters q_k represent gears where: $k = 1$ is the surface survey and $k = 2$ is the dive survey. The dotted red lines are the MPD estimates.

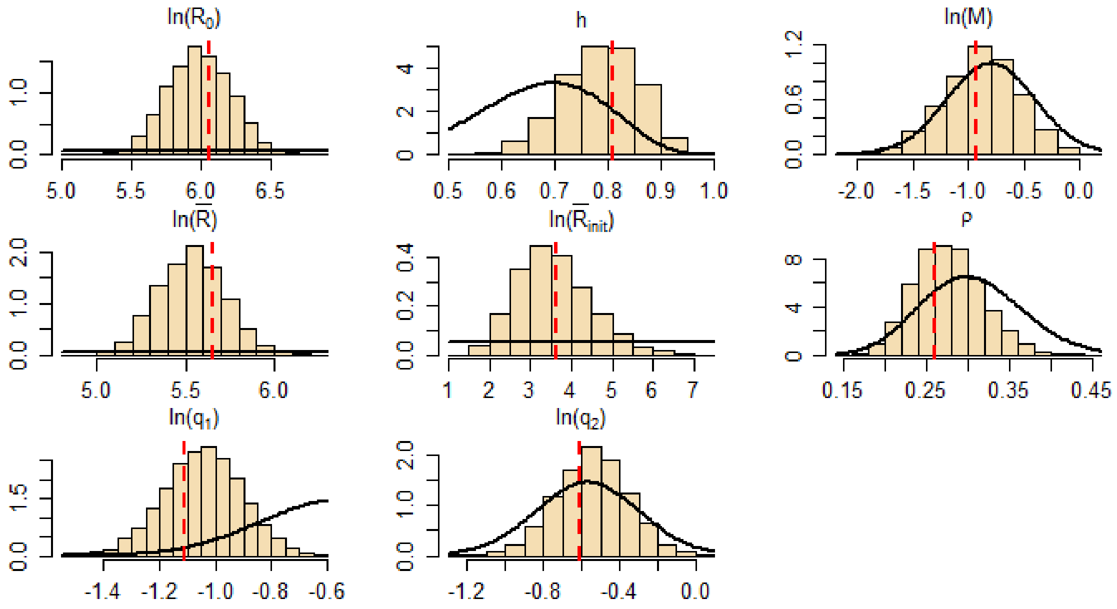


Figure 22. Prior probability distributions (lines) with comparative posterior histograms (bars) used in the Haida Gwaii AM1 model. Parameters q_k represent gears where: $k = 1$ is the surface survey and $k = 2$ is the dive survey. The dotted red lines are the MPD estimates.

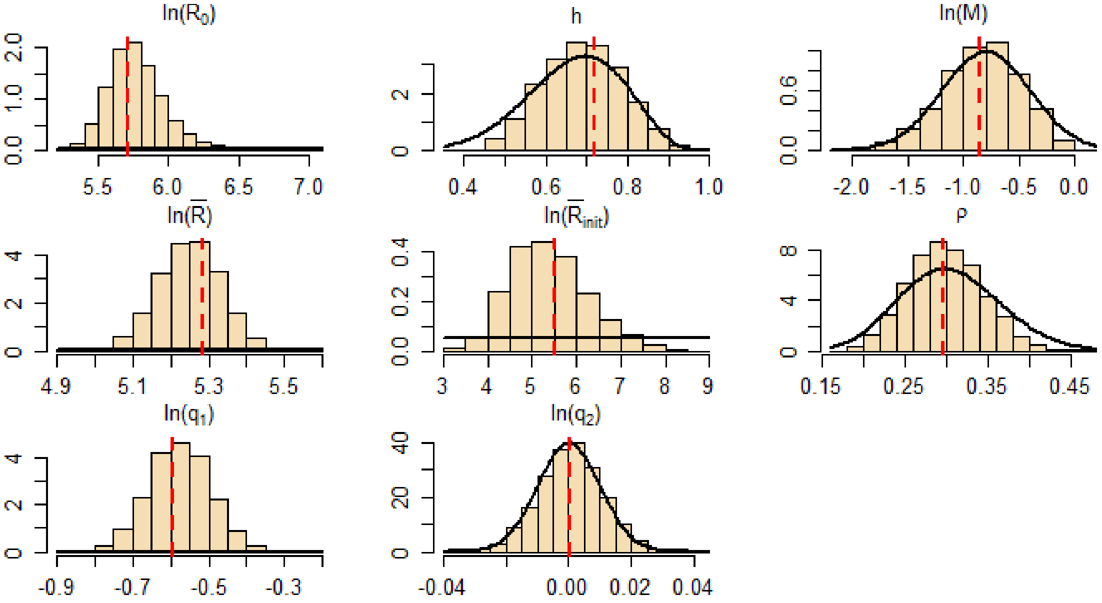


Figure 23. Prior probability distributions (lines) with comparative posterior histograms (bars) used in the Prince Rupert District AM2 model. Parameters q_k represent gears where: $k = 1$ is the surface survey and $k = 2$ is the dive survey. The dotted red lines are the MPD estimates.

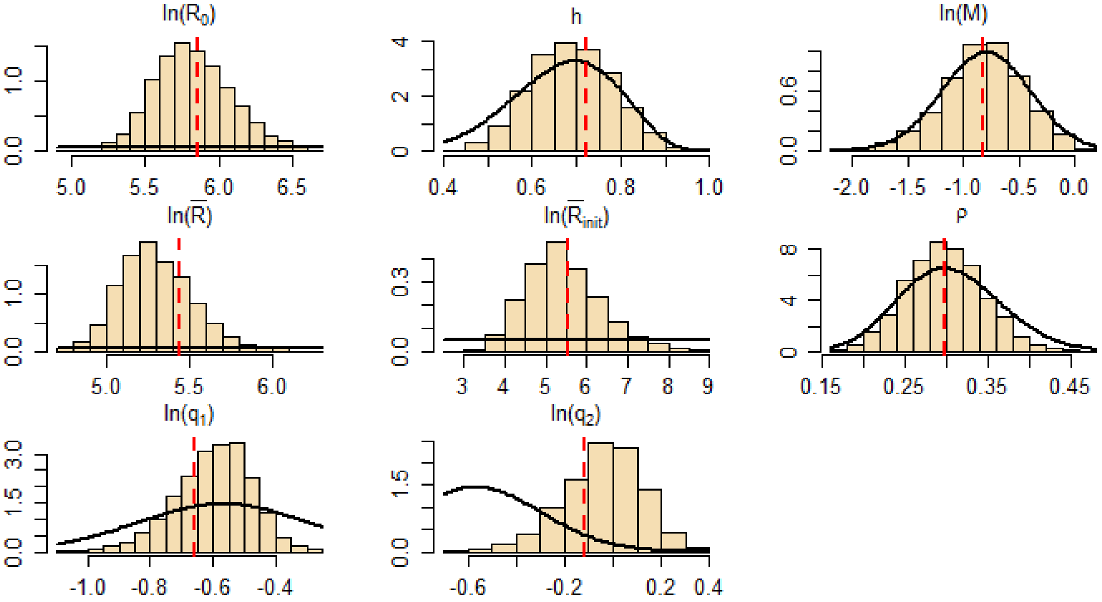


Figure 24. Prior probability distributions (lines) with comparative posterior histograms (bars) used in the Prince Rupert District AM1 model. Parameters q_k represent gears where: $k = 1$ is the surface survey and $k = 2$ is the dive survey. The dotted red lines are the MPD estimates.

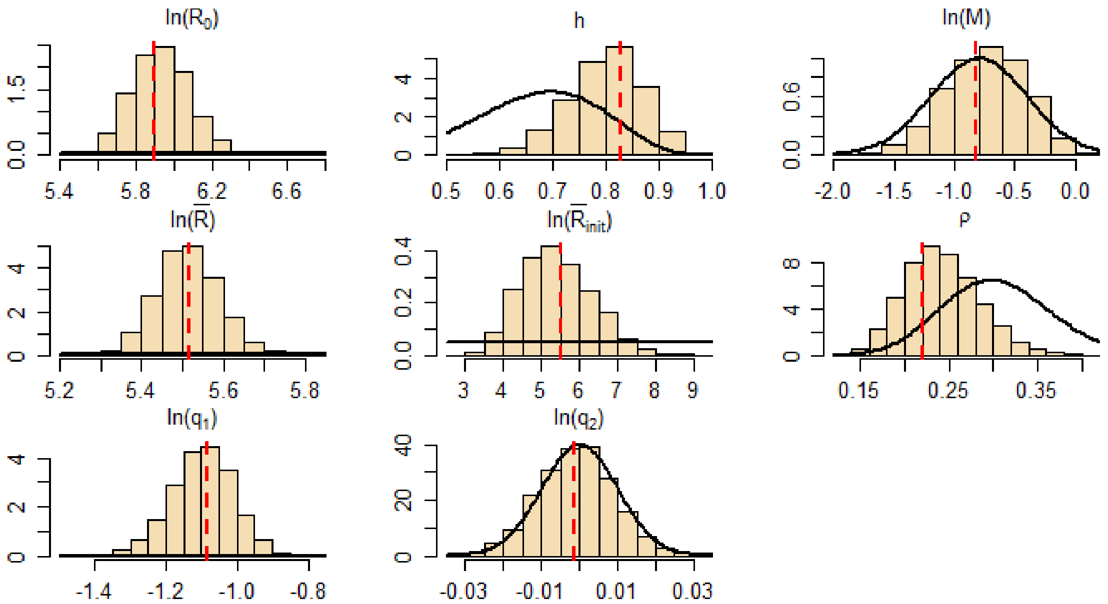


Figure 25. Prior probability distributions (lines) with comparative posterior histograms (bars) used in the Central Coast AM2 model. Parameters q_k represent gears where: $k = 1$ is the surface survey and $k = 2$ is the dive survey. The dotted red lines are the MPD estimates.

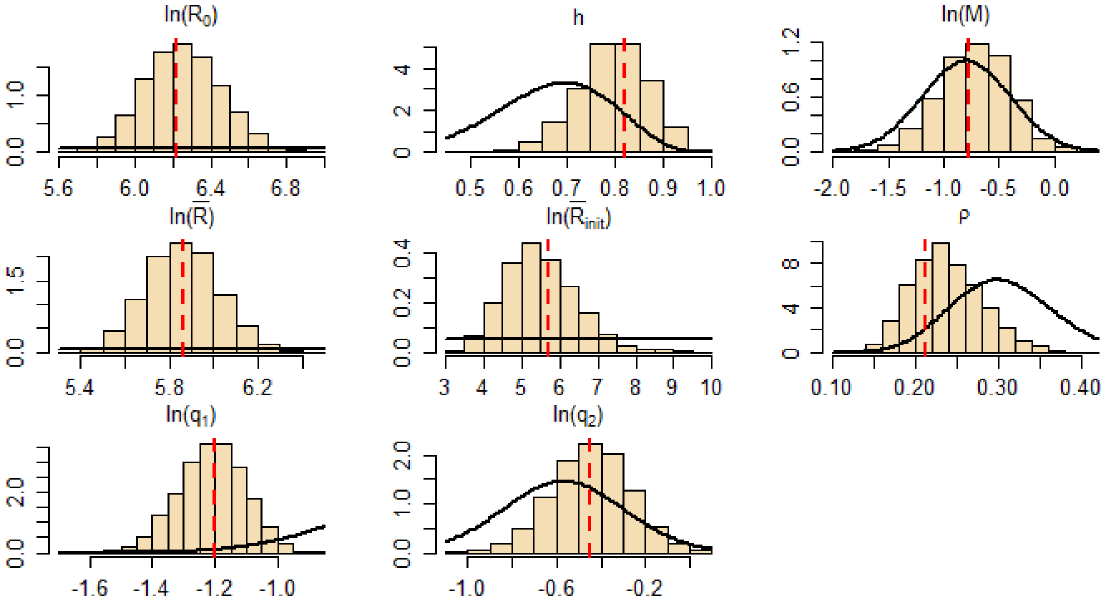


Figure 26. Prior probability distributions (lines) with comparative posterior histograms (bars) used in the Central Coast AM1 model. Parameters q_k represent gears where: $k = 1$ is the surface survey and $k = 2$ is the dive survey. The dotted red lines are the MPD estimates.

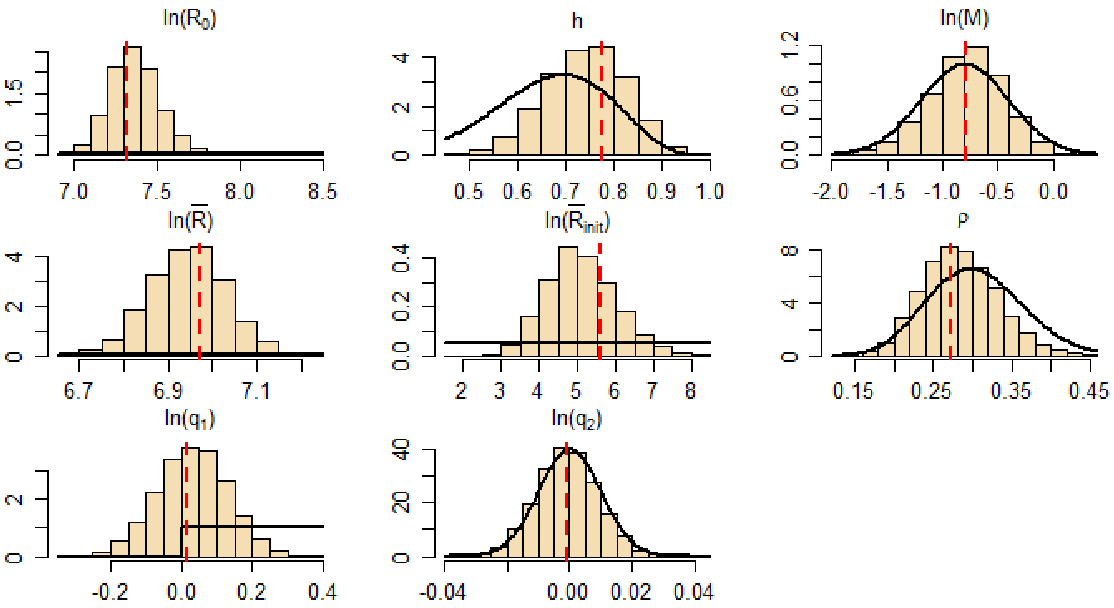


Figure 27. Prior probability distributions (lines) with comparative posterior histograms (bars) used in the Strait of Georgia AM2 model. Parameters q_k represent gears where: $k = 1$ is the surface survey and $k = 2$ is the dive survey. The dotted red lines are the MPD estimates.

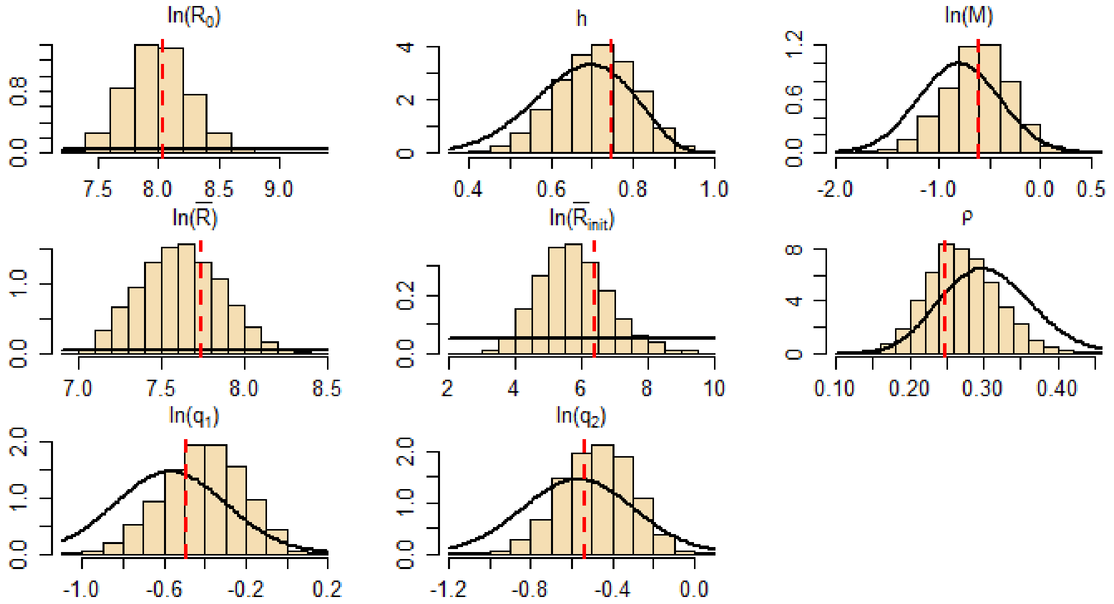


Figure 28. Prior probability distributions (lines) with comparative posterior histograms (bars) used in the Strait of Georgia AM1 model. Parameters q_k represent gears where: $k = 1$ is the surface survey and $k = 2$ is the dive survey. The dotted red lines are the MPD estimates.

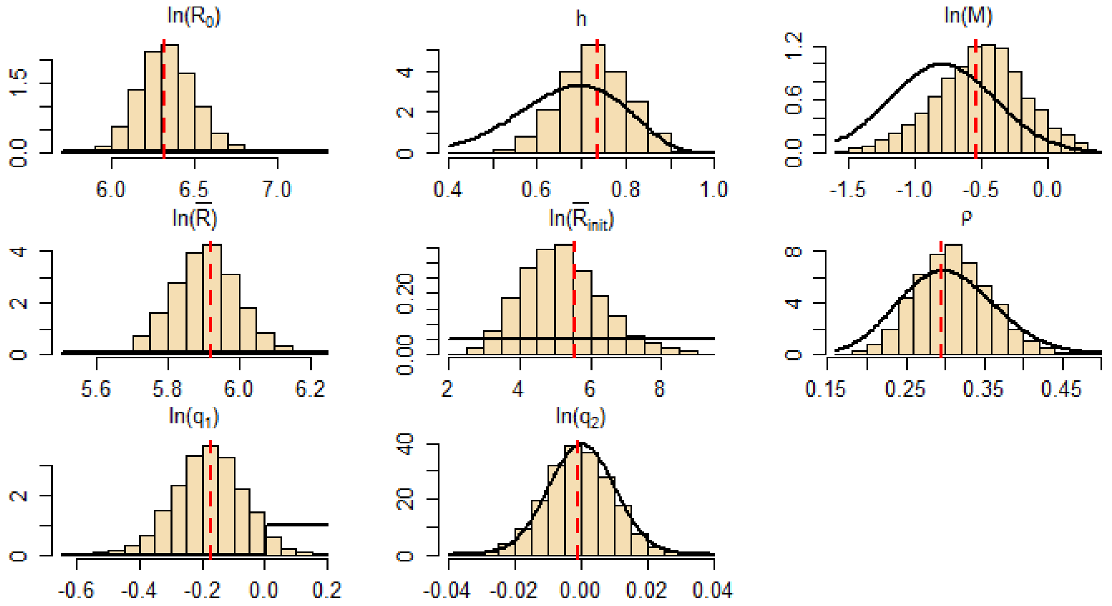


Figure 29. Prior probability distributions (lines) with comparative posterior histograms (bars) used in the WCVI AM2 model. Parameters q_k represent gears where: $k = 1$ is the surface survey and $k = 2$ is the dive survey. The dotted red lines are the MPD estimates.

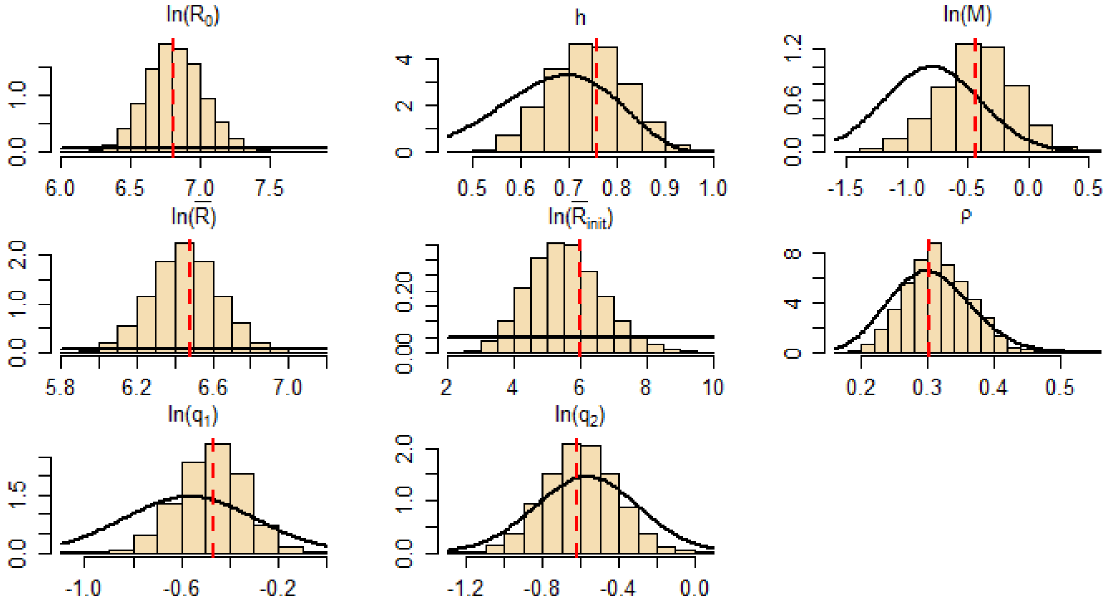


Figure 30. Prior probability distributions (lines) with comparative posterior histograms (bars) used in the WCVI AM1 model. Parameters q_k represent gears where: $k = 1$ is the surface survey and $k = 2$ is the dive survey. The dotted red lines are the MPD estimates.

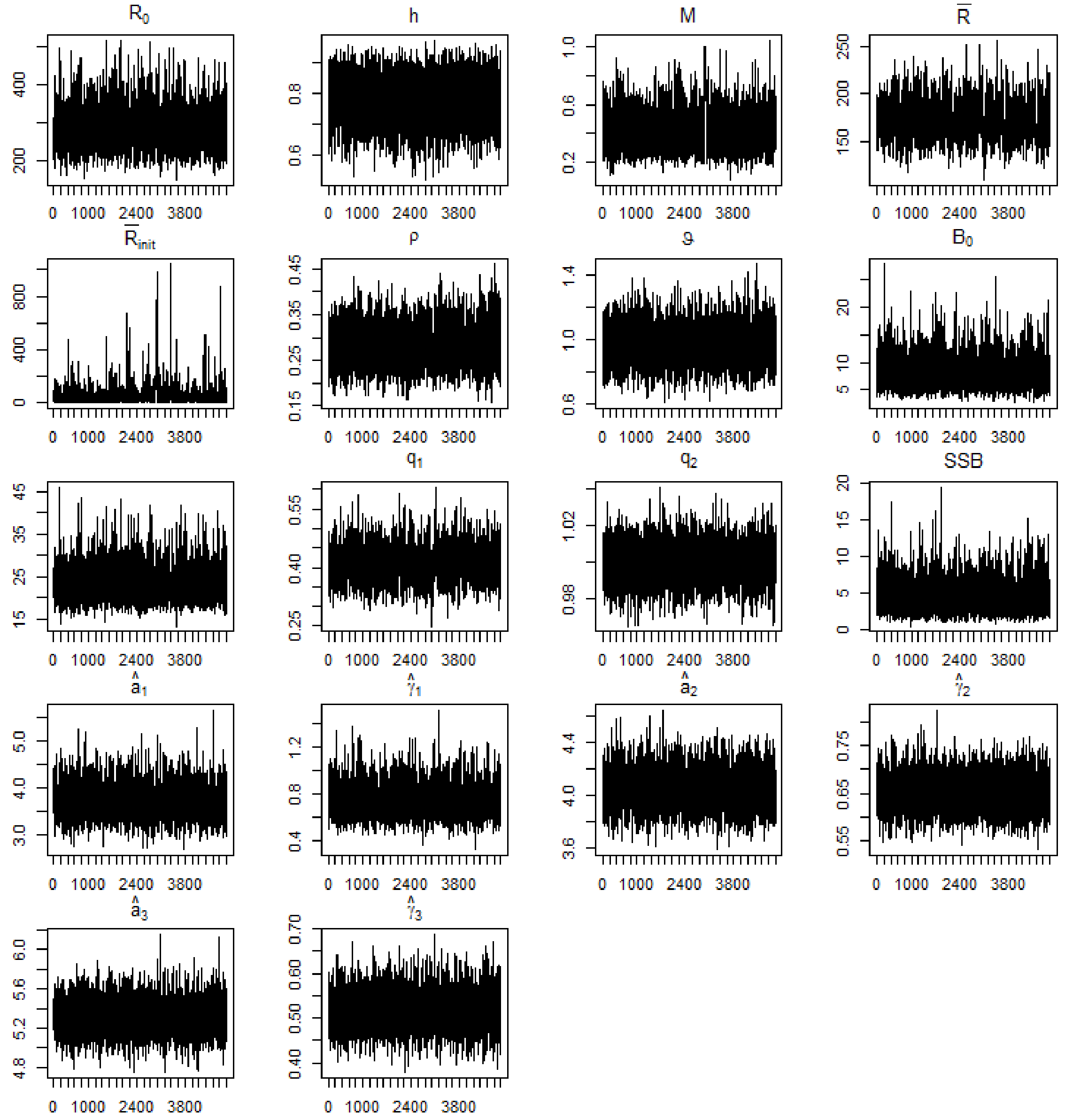


Figure 31. Trace plots for MCMC output of estimated parameters for the Haida Gwaii AM2 model. The MCMC run had chain length 5 million, with a sample taken at every 1,000th iteration. The catchability parameter q_1 represents the surface survey and q_2 the dive survey. Parameters $\hat{a}_k$ (selectivity-at-age-50%), and $\hat{\gamma}_k$ (selectivity standard deviation-at-50%) represent gears as follows: k = 1: Other fisheries, k = 2: Roe seine, k = 3: Gillnet roe.

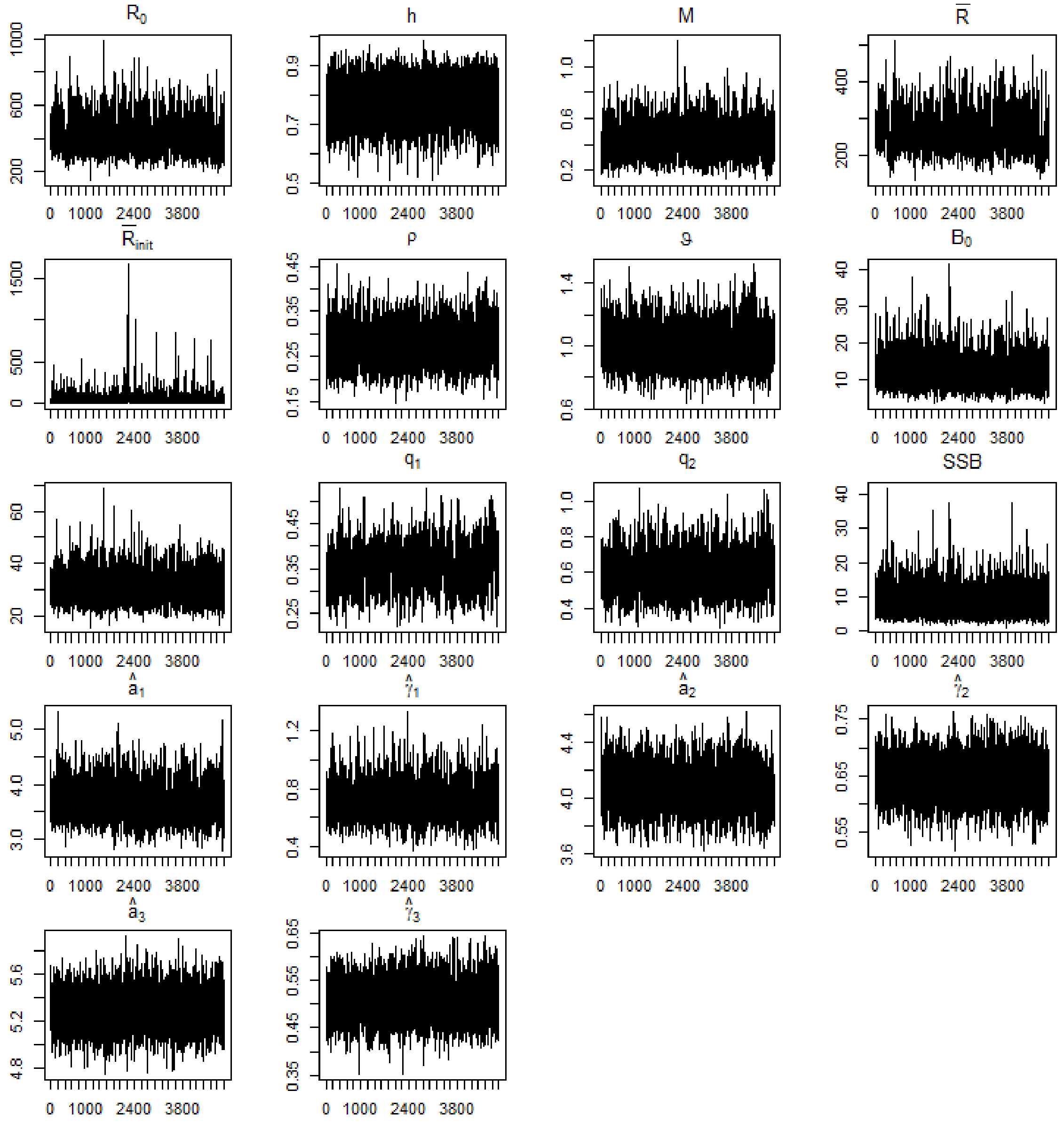


Figure 32. Trace plots for MCMC output of estimated parameters for the Haida Gwaii AM1 model. The MCMC run had chain length 5 million, with a sample taken at every 1,000th iteration. The catchability parameter q_1 represents the surface survey and q_2 the dive survey. Parameters $\hat{a}_k$ (selectivity-at-age-50%), and $\hat{\gamma}_k$ (selectivity standard deviation-at-50%) represent gears as follows: k = 1: Other fisheries, k = 2: Roe seine, k = 3: Gillnet roe.

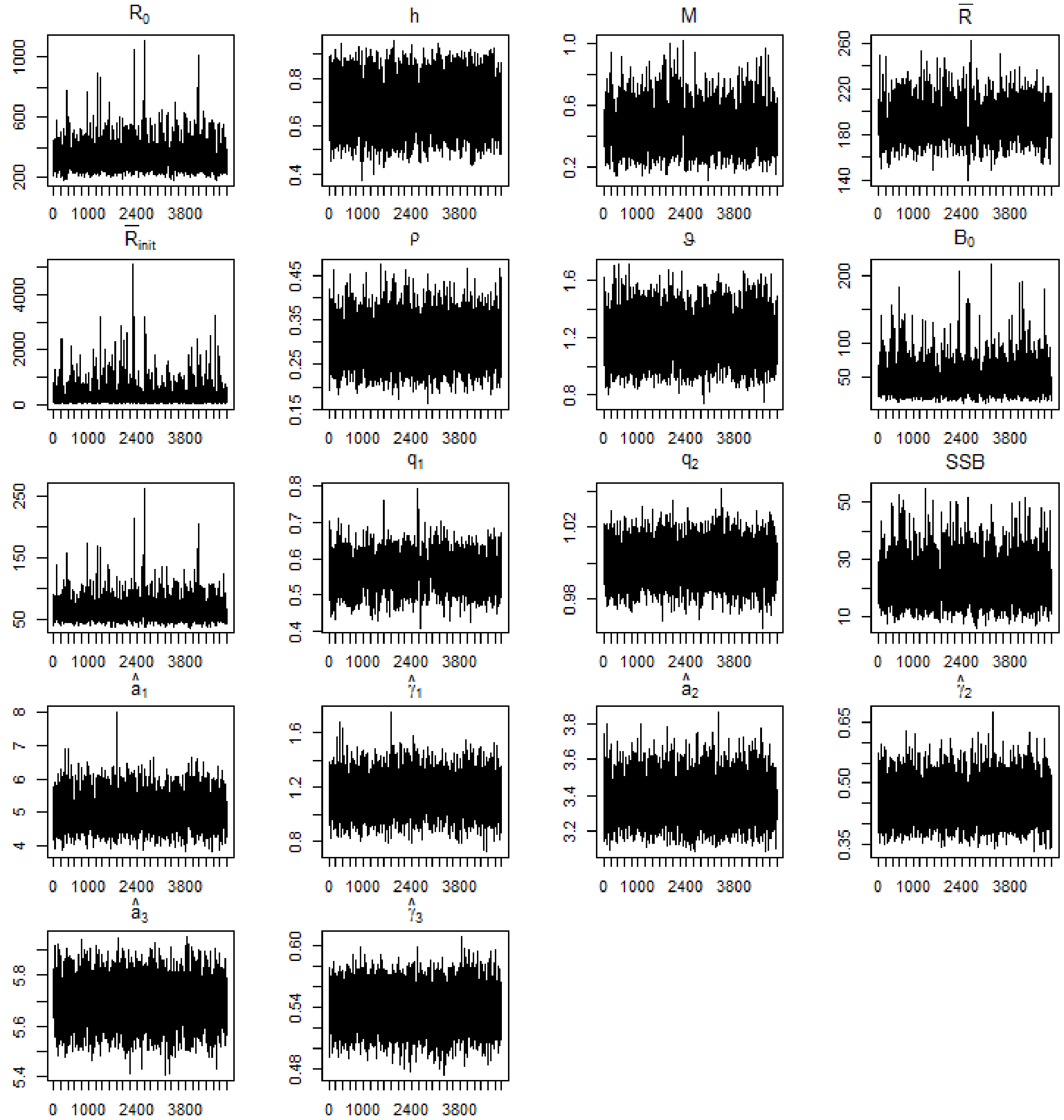


Figure 33. Trace plots for MCMC output of estimated parameters for the Prince Rupert District AM2 model. The MCMC run had chain length 5 million, with a sample taken at every 1,000th iteration. The catchability parameter q_1 represents the surface survey and q_2 the dive survey. Parameters $\hat{a}_k$ (selectivity-at-age-50%), and $\hat{\gamma}_k$ (selectivity standard deviation-at-50%) represent gears as follows: k = 1: Other fisheries, k = 2: Roe seine, k = 3: Gillnet roe.

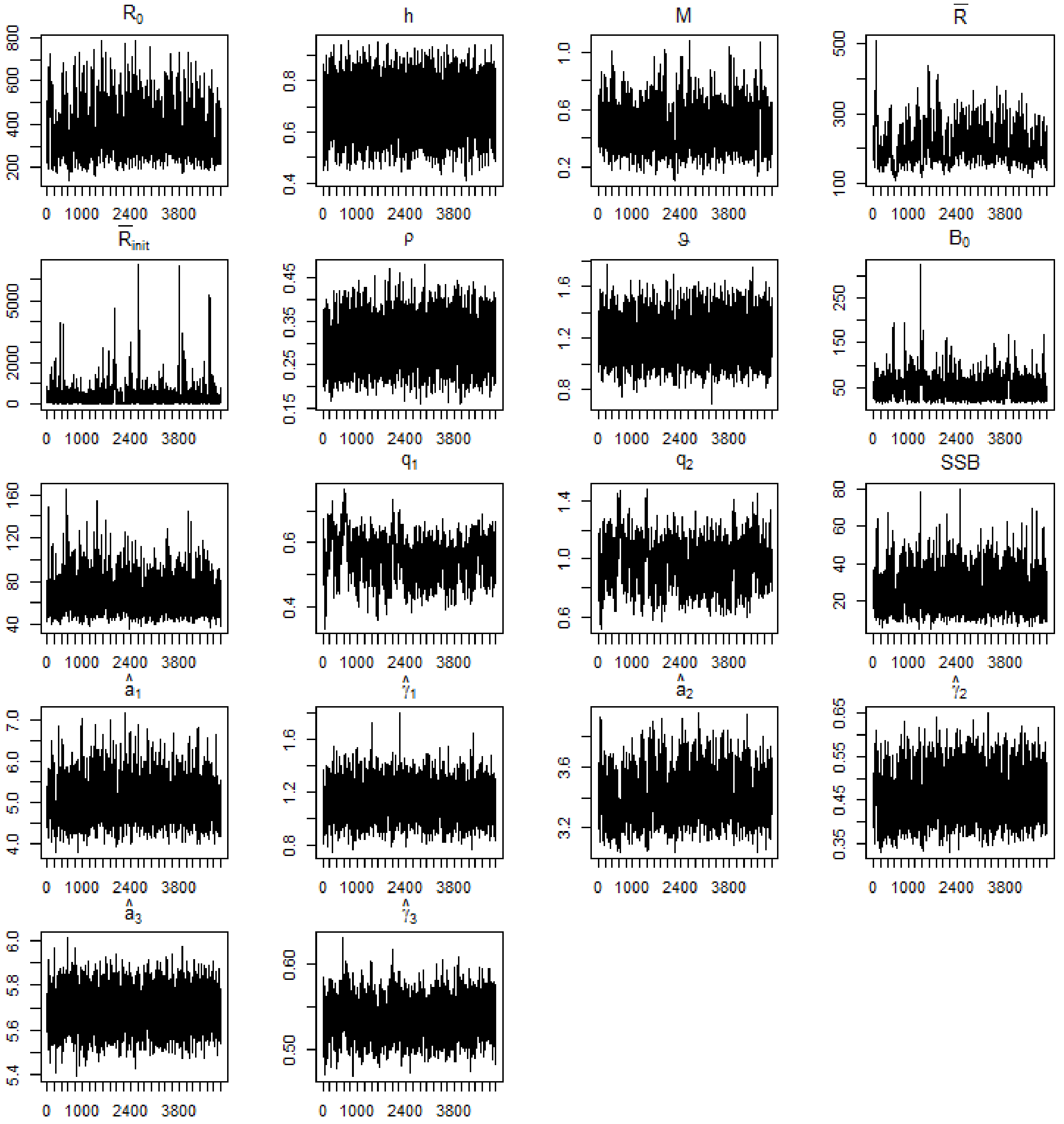


Figure 34. Trace plots for MCMC output of estimated parameters for the Prince Rupert District AM1 model. The MCMC run had chain length 5 million, with a sample taken at every 1,000th iteration. The catchability parameter q_1 represents the surface survey and q_2 the dive survey. Parameters $\hat{a}_k$ (selectivity-at-age-50%), and $\hat{\gamma}_k$ (selectivity standard deviation-at-50%) represent gears as follows: k = 1: Other fisheries, k = 2: Roe seine, k = 3: Gillnet roe.

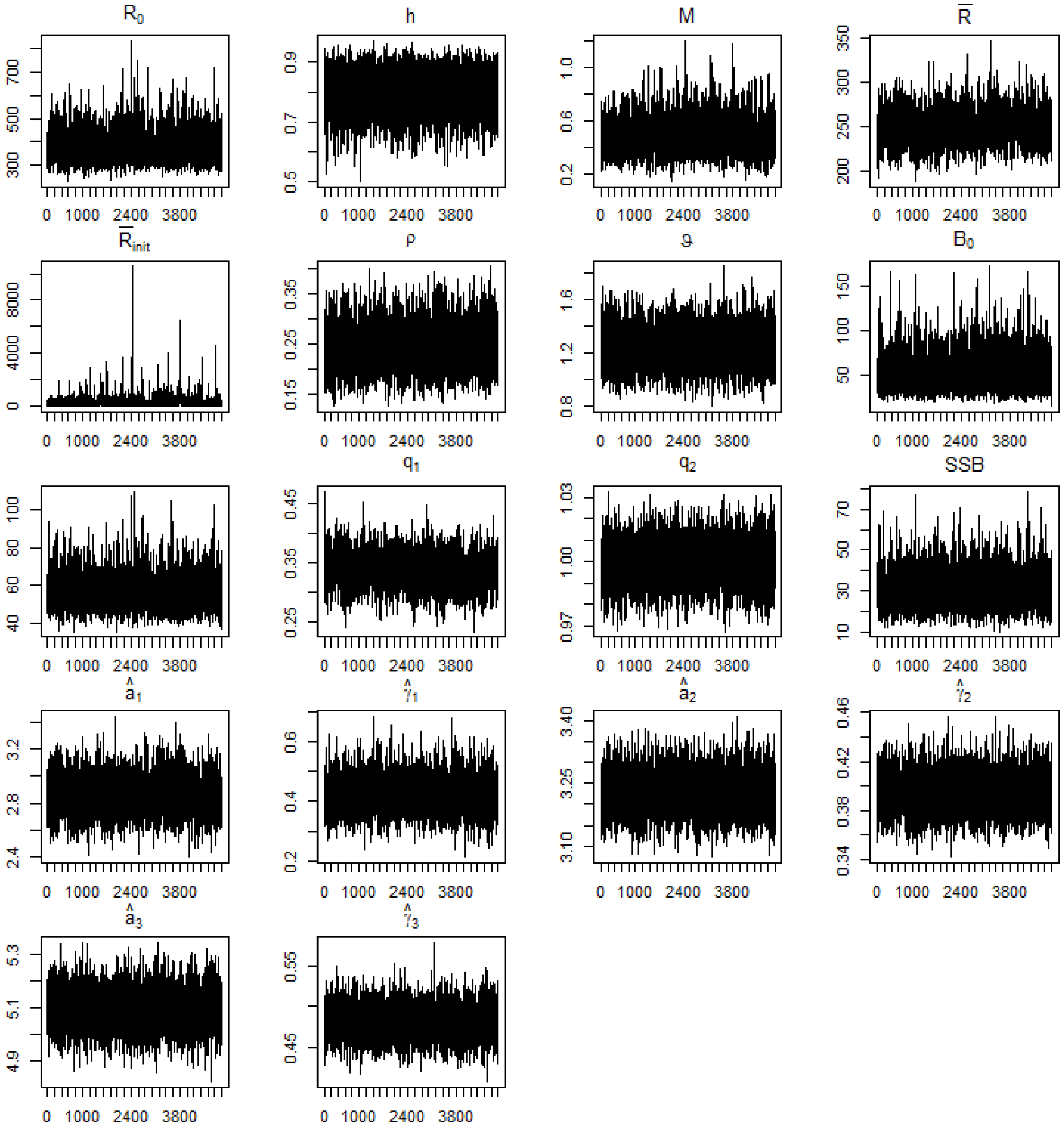


Figure 35. Trace plots for MCMC output of estimated parameters for the Central Coast AM2 model. The MCMC run had chain length 5 million, with a sample taken at every 1,000th iteration. The catchability parameter q_1 represents the surface survey and q_2 the dive survey. Parameters $\hat{a}_k$ (selectivity-at-age-50%), and $\hat{\gamma}_k$ (selectivity standard deviation-at-50%) represent gears as follows: k = 1: Other fisheries, k = 2: Roe seine, k = 3: Gillnet roe.

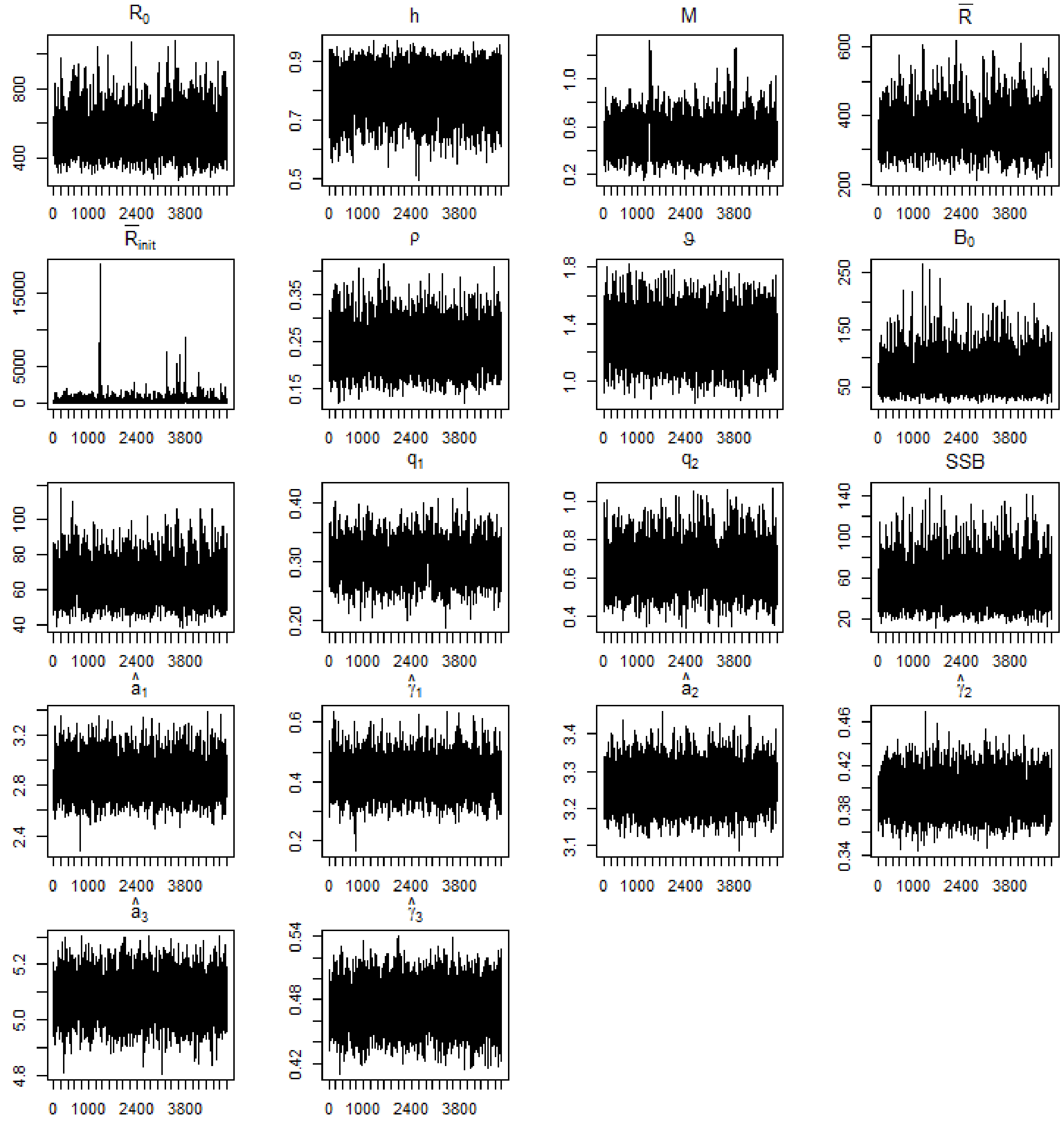


Figure 36. Trace plots for MCMC output of estimated parameters for the Central Coast AM1 model. The MCMC run had chain length 5 million, with a sample taken at every 1,000th iteration. The catchability parameter q_1 represents the surface survey and q_2 the dive survey. Parameters $\hat{a}_k$ (selectivity-at-age-50%), and $\hat{\gamma}_k$ (selectivity standard deviation-at-50%) represent gears as follows: k = 1: Other fisheries, k = 2: Roe seine, k = 3: Gillnet roe.

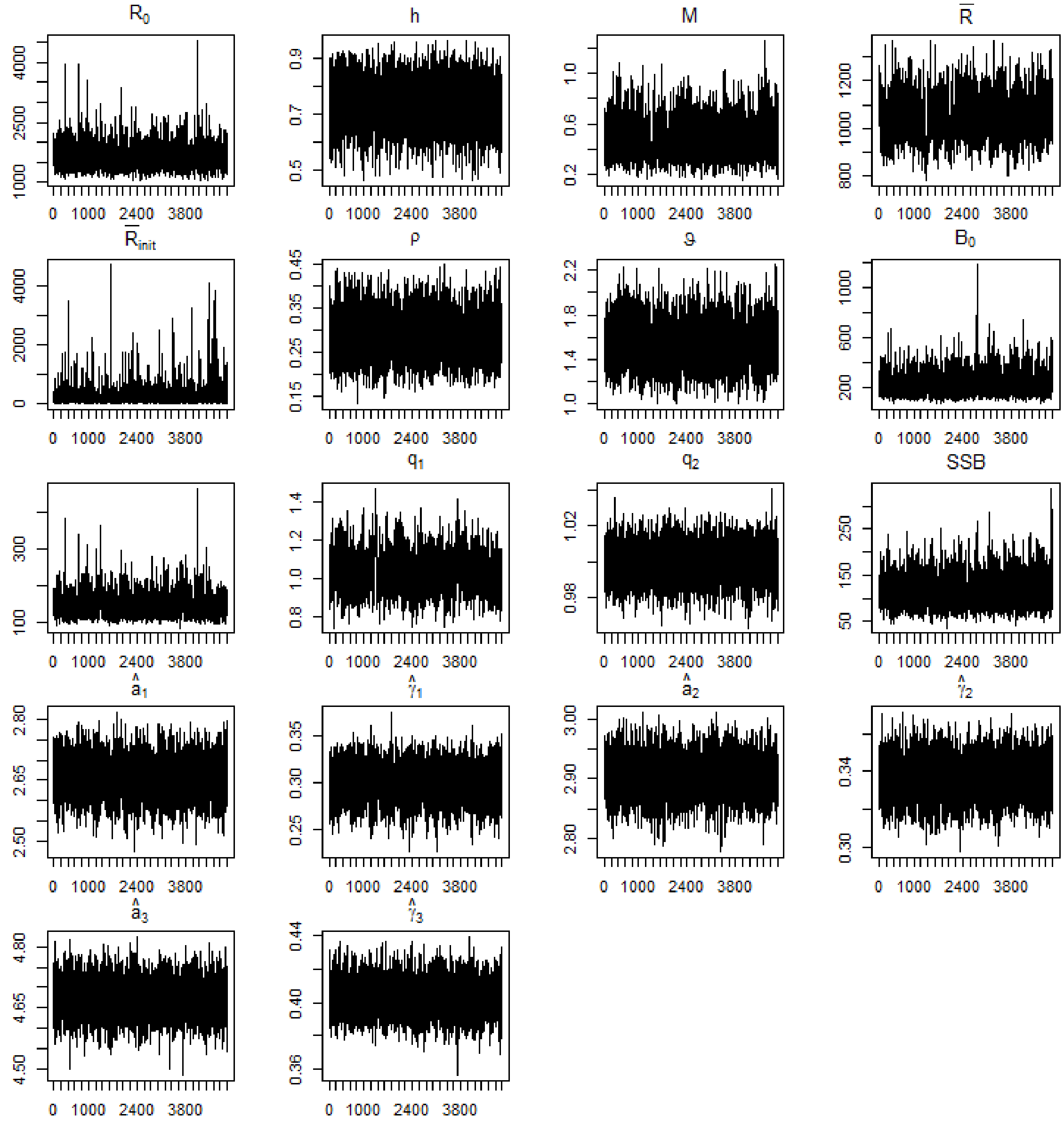


Figure 37. Trace plots for MCMC output of estimated parameters for the Strait of Georgia AM2 model. The MCMC run had chain length 5 million, with a sample taken at every 1,000th iteration. The catchability parameter q_1 represents the surface survey and q_2 the dive survey. Parameters $\hat{a}_k$ (selectivity-at-age-50%), and $\hat{\gamma}_k$ (selectivity standard deviation-at-50%) represent gears as follows: k = 1: Other fisheries, k = 2: Roe seine, k = 3: Gillnet roe.

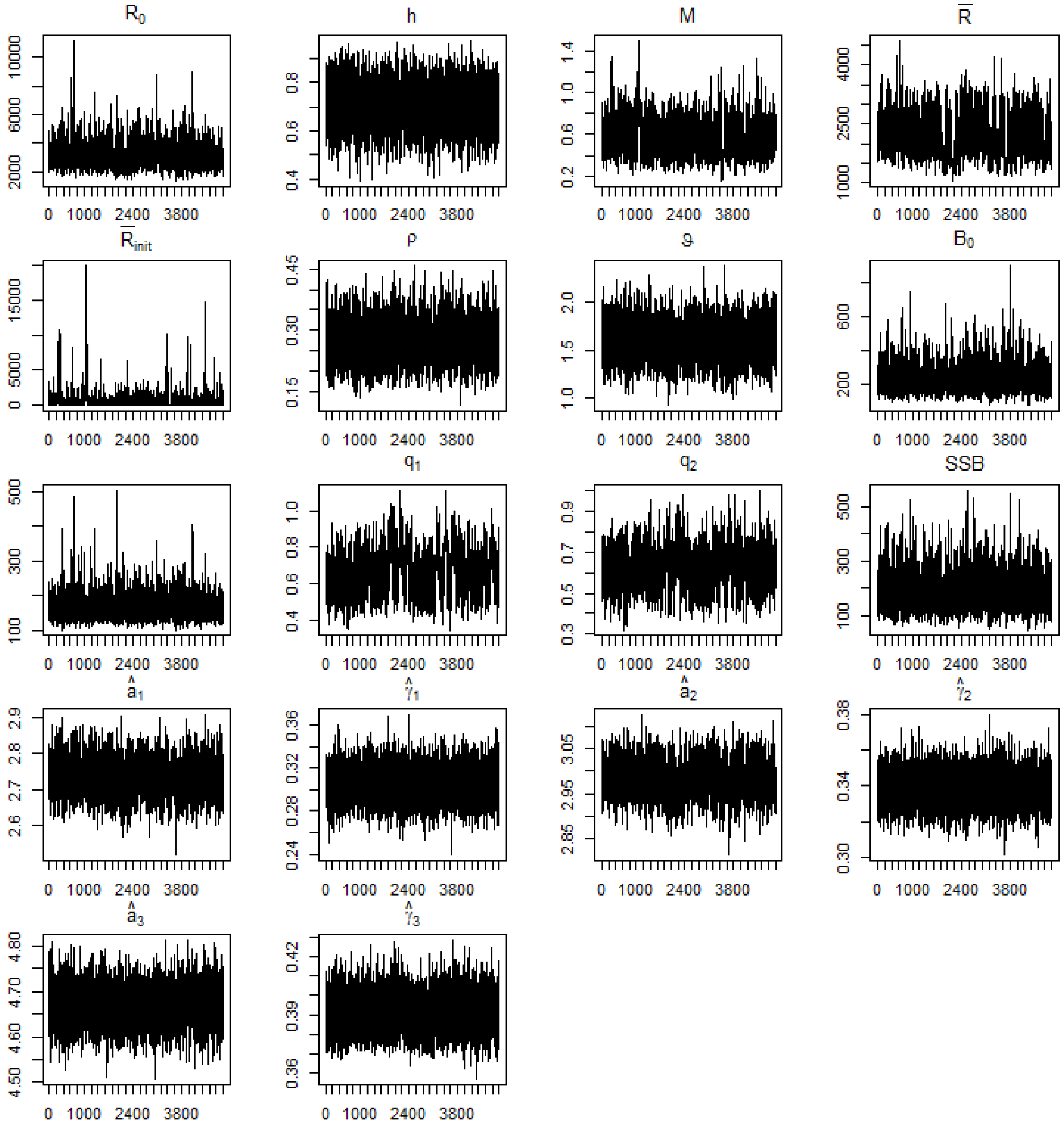


Figure 38. Trace plots for MCMC output of estimated parameters for the Strait of Georgia AM1 model. The MCMC run had chain length 5 million, with a sample taken at every 1,000th iteration. The catchability parameter q_1 represents the surface survey and q_2 the dive survey. Parameters $\hat{a}_k$ (selectivity-at-age-50%), and $\hat{\gamma}_k$ (selectivity standard deviation-at-50%) represent gears as follows: k = 1: Other fisheries, k = 2: Roe seine, k = 3: Gillnet roe.

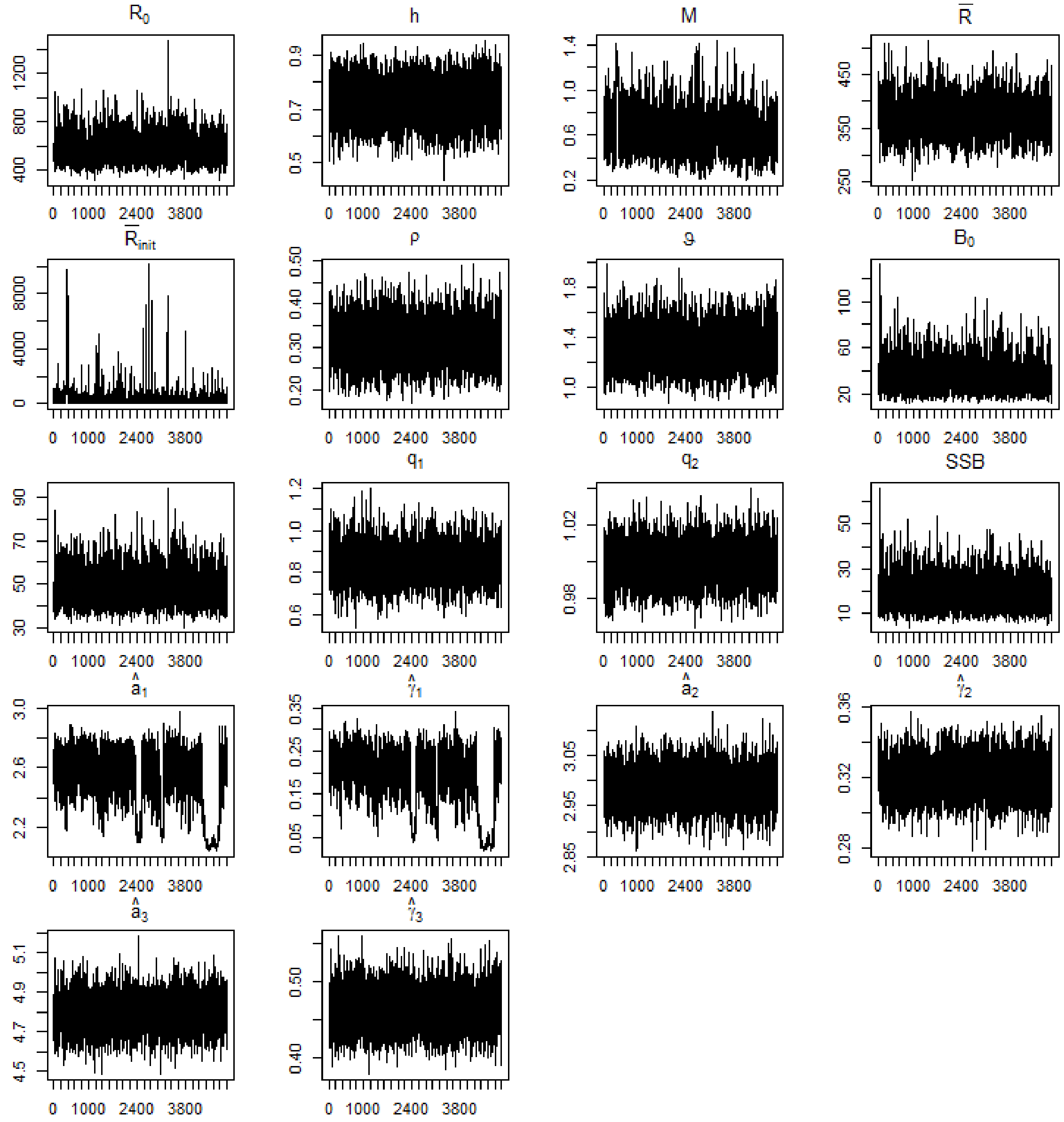


Figure 39. Trace plots for MCMC output of estimated parameters for the WCVI AM2 model. The MCMC run had chain length 5 million, with a sample taken at every 1,000th iteration. The catchability parameter q_1 represents the surface survey and q_2 the dive survey. Parameters $\hat{a}_k$ (selectivity-at-age-50%), and $\hat{\gamma}_k$ (selectivity standard deviation-at-50%) represent gears as follows: k = 1: Other fisheries, k = 2: Roe seine, k = 3: Gillnet roe.

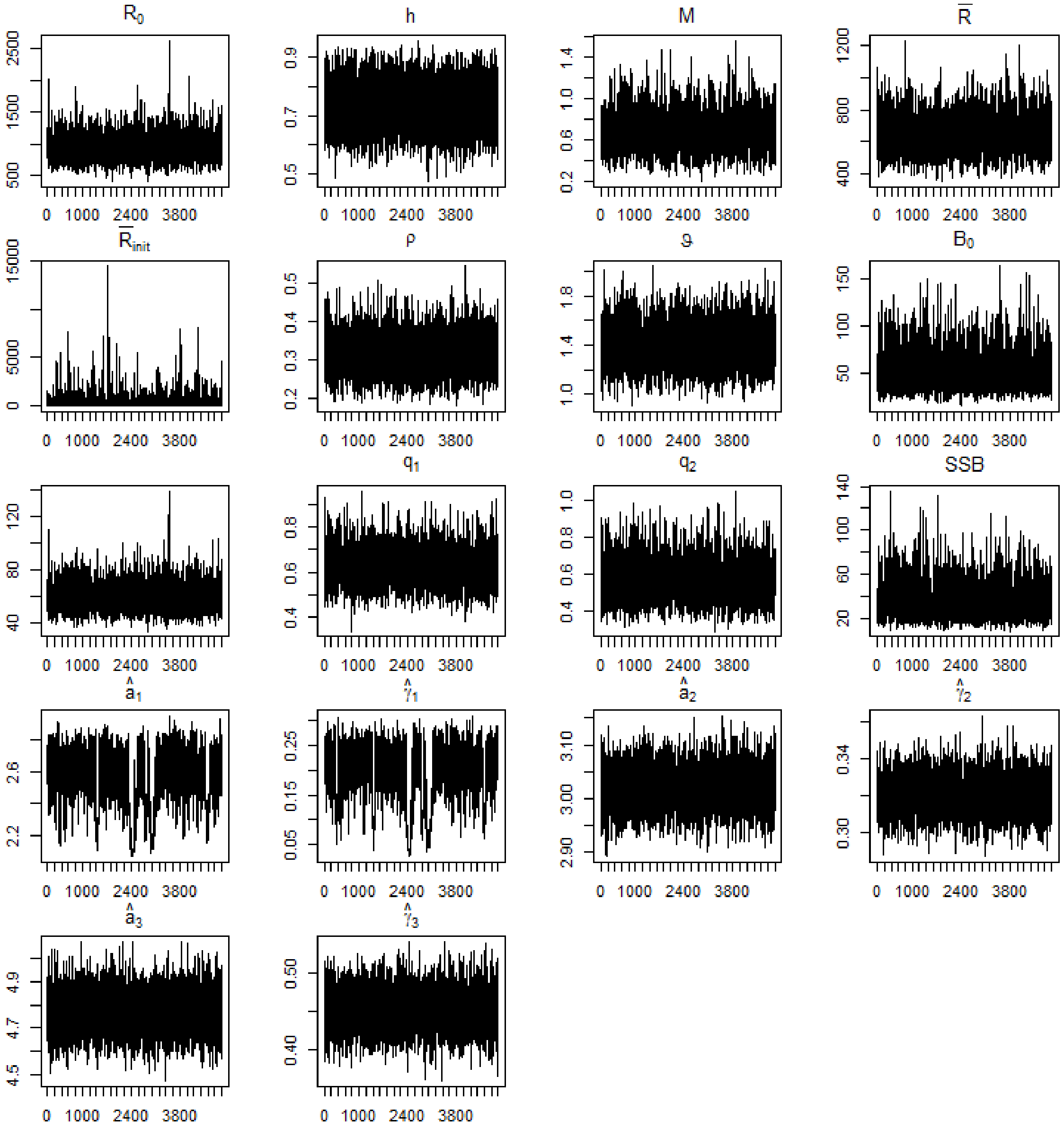


Figure 40. Trace plots for MCMC output of estimated parameters for the WCVI AM1 model. The MCMC run had chain length 5 million, with a sample taken at every 1,000th iteration. The catchability parameter q_1 represents the surface survey and q_2 the dive survey. Parameters $\hat{a}_k$ (selectivity-at-age-50%), and $\hat{\gamma}_k$ (selectivity standard deviation-at-50%) represent gears as follows: k = 1: Other fisheries, k = 2: Roe seine, k = 3: Gillnet roe.

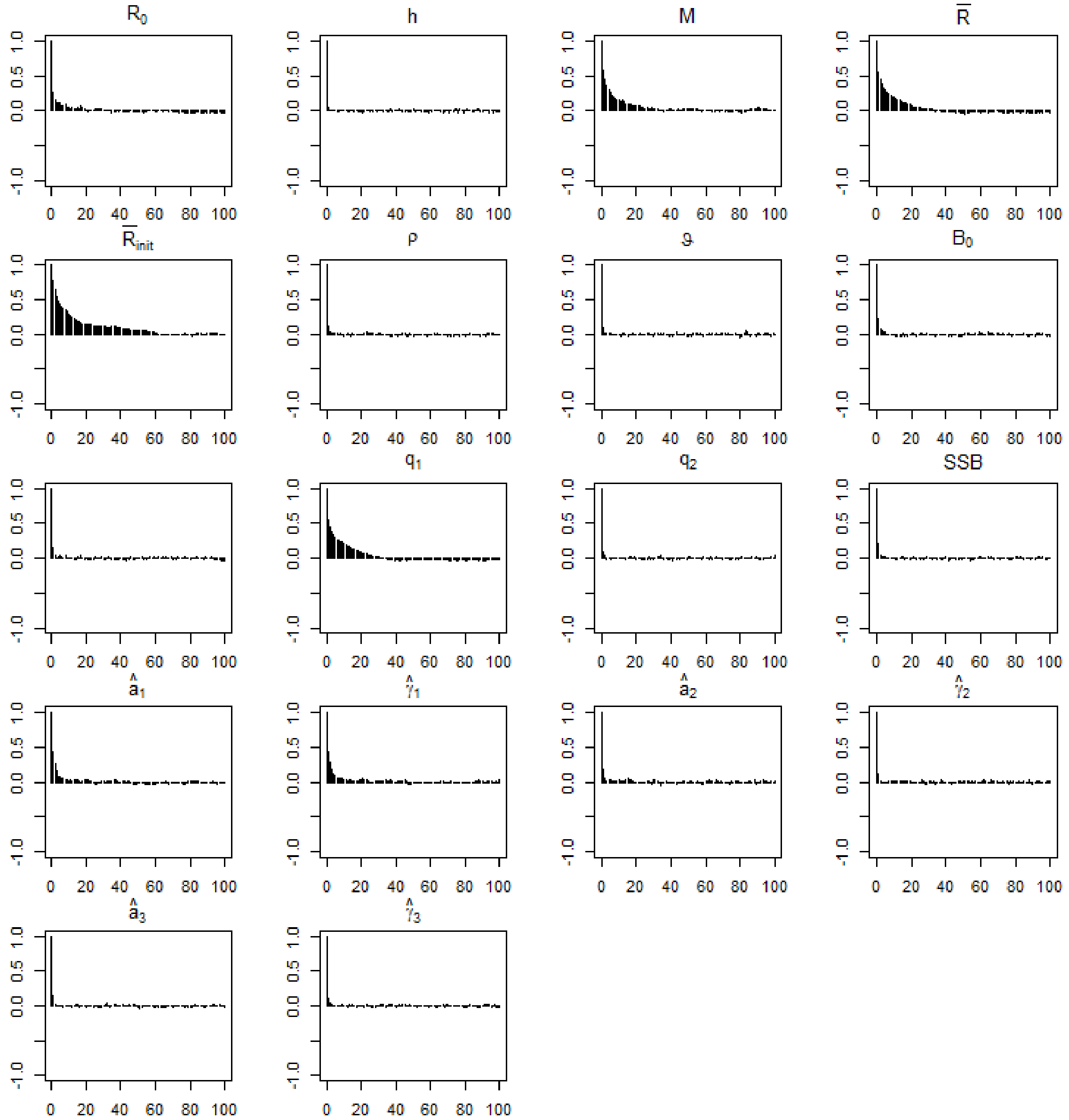


Figure 41. Autocorrelation plots for MCMC output of estimated parameters for the Haida Gwaii AM2 model. See Figure 32 for parameter descriptions.

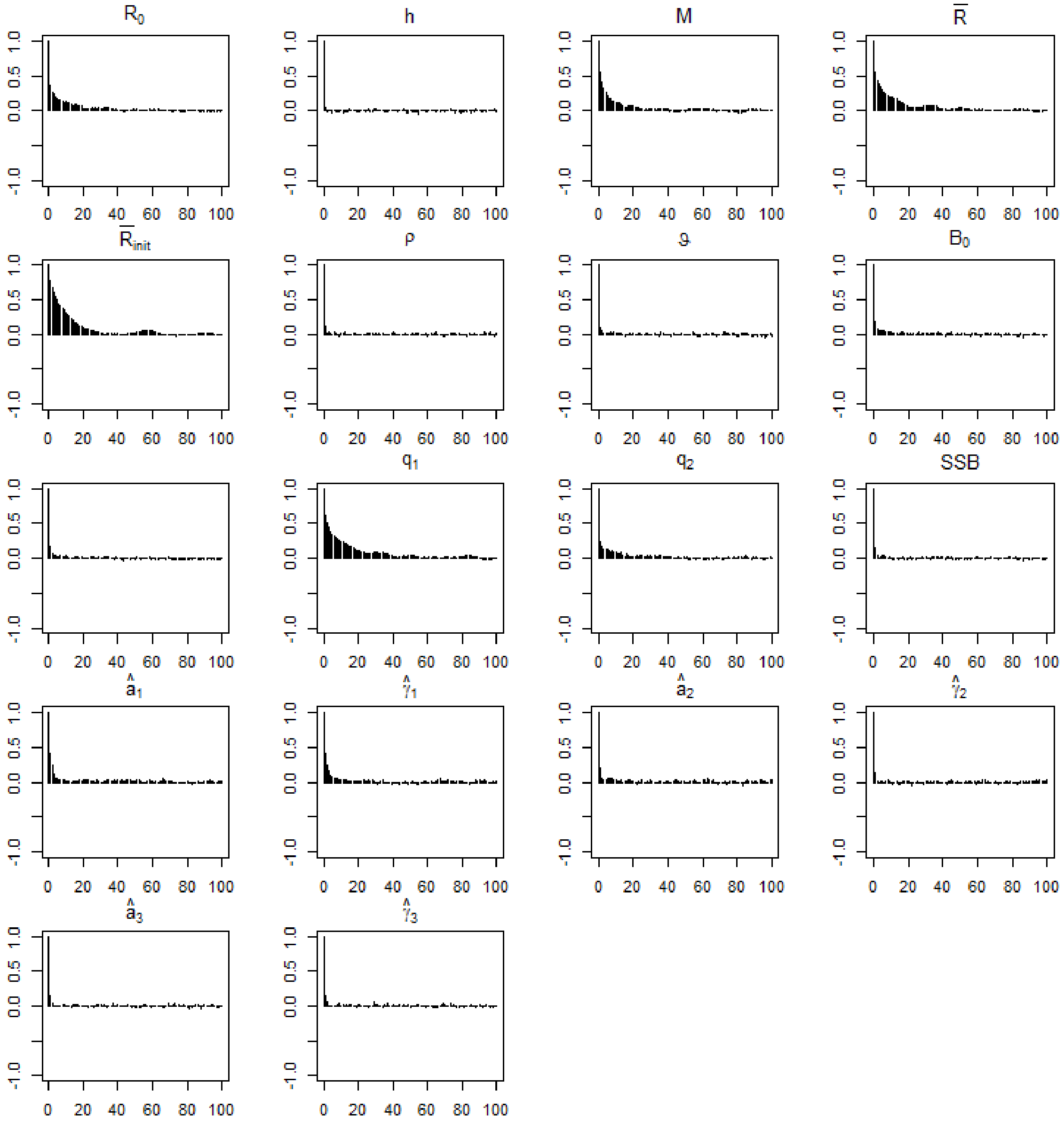


Figure 42. Autocorrelation plots for MCMC output of estimated parameters for the Haida Gwaii AM1 model. See Figure 32 for parameter descriptions.

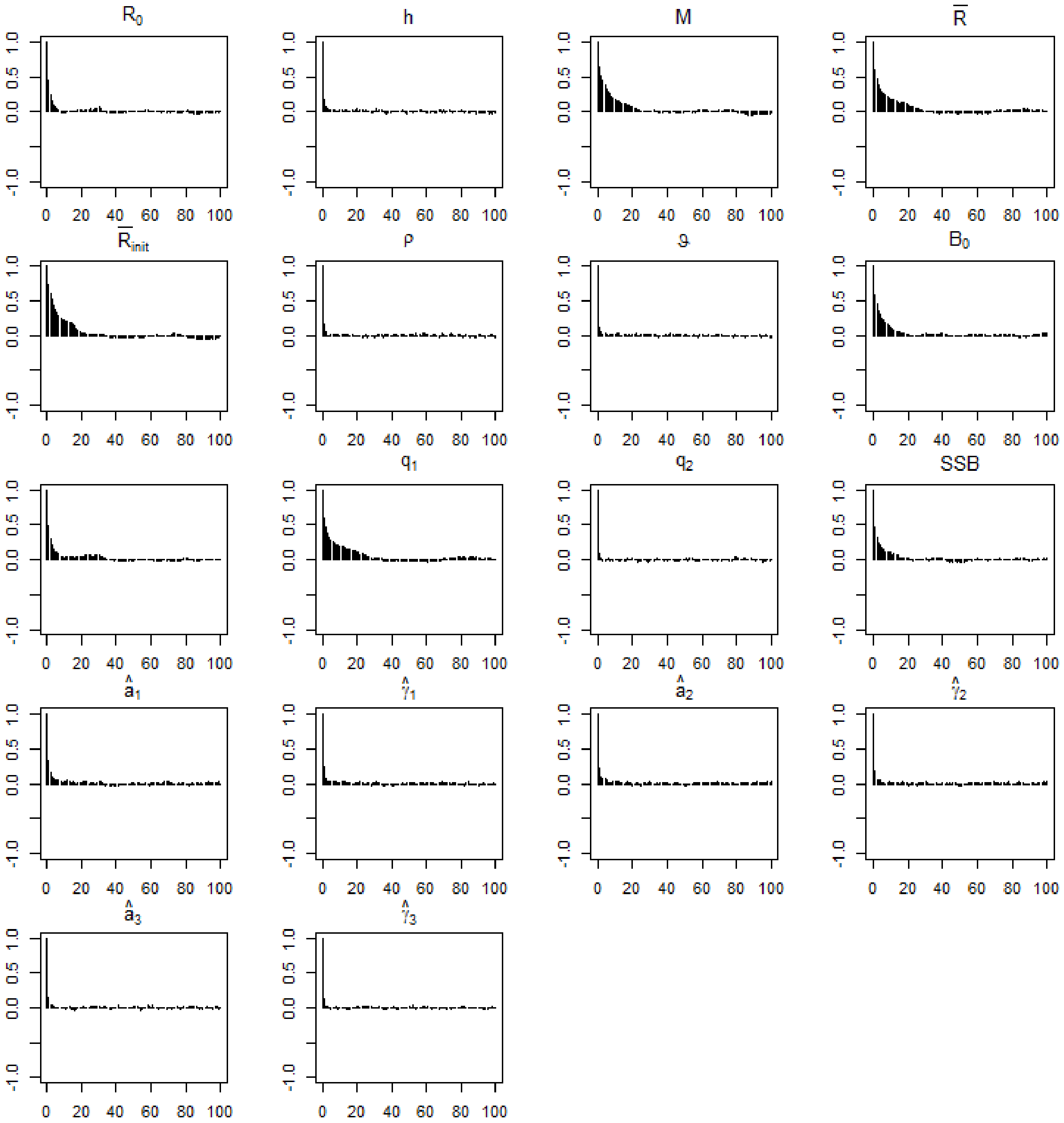


Figure 43. Autocorrelation plots for MCMC output of estimated parameters for the Prince Rupert District AM2 model. See Figure 34 for parameter descriptions.

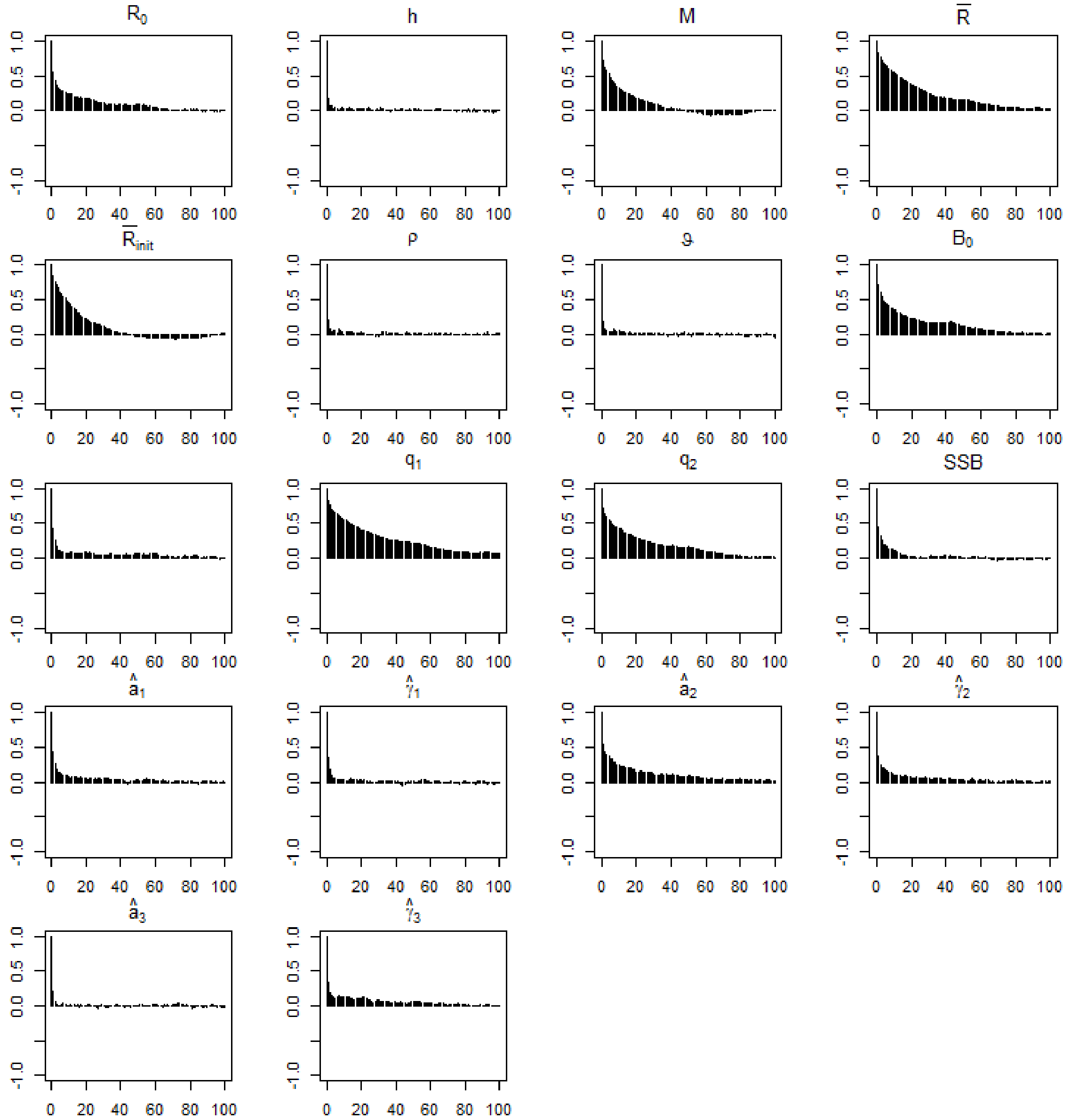


Figure 44. Autocorrelation plots for MCMC output of estimated parameters for the Prince Rupert District AM1 model. See Figure 34 for parameter descriptions.

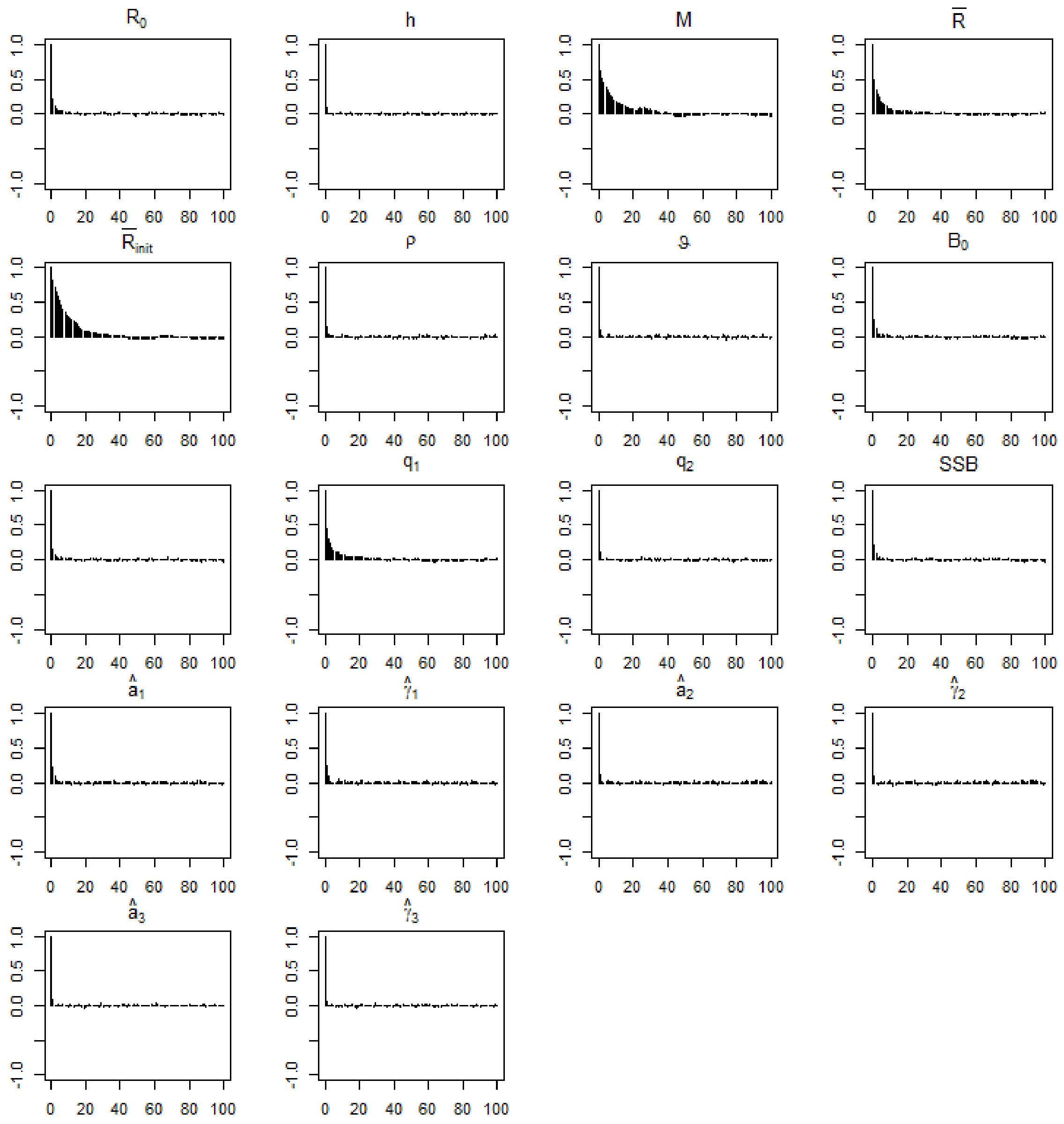


Figure 45. Autocorrelation plots for MCMC output of estimated parameters for the Central Coast AM2 model. See Figure 36 for parameter descriptions.

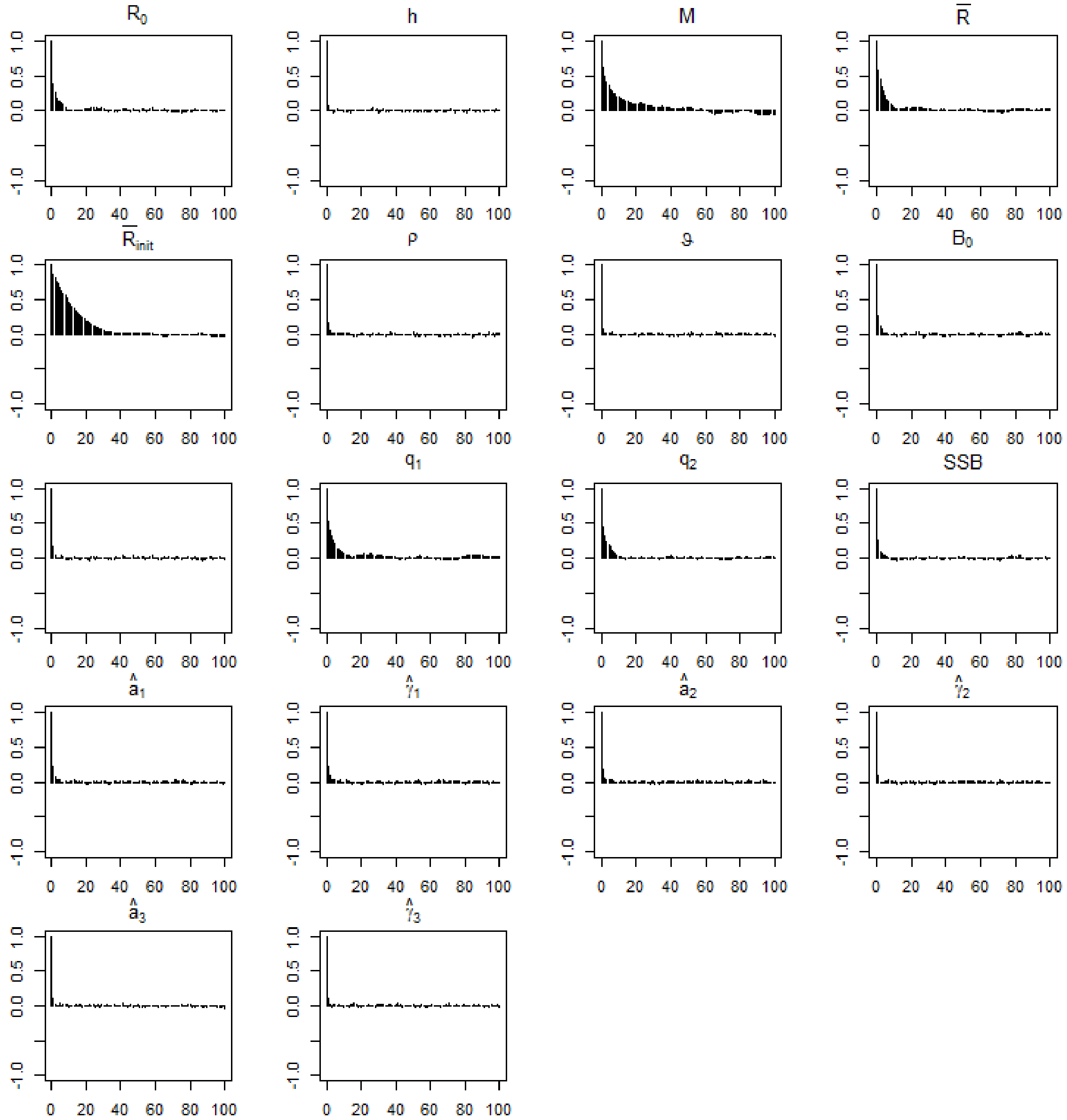


Figure 46. Autocorrelation plots for MCMC output of estimated parameters for the Central Coast AM1 model. See Figure 36 for parameter descriptions.

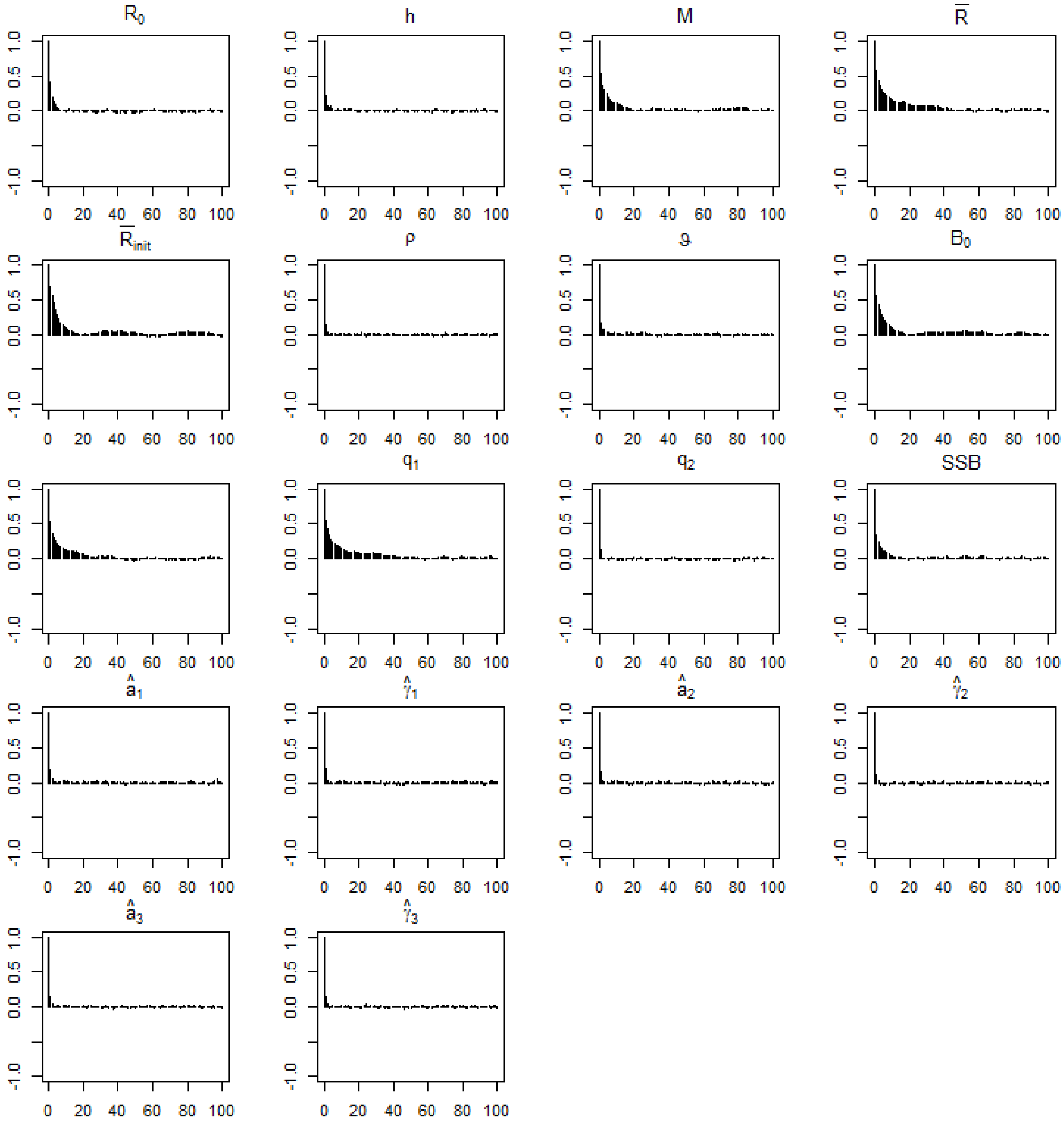


Figure 47. Autocorrelation plots for MCMC output of estimated parameters for the Strait of Georgia AM2 model. See Figure 38 for parameter descriptions.

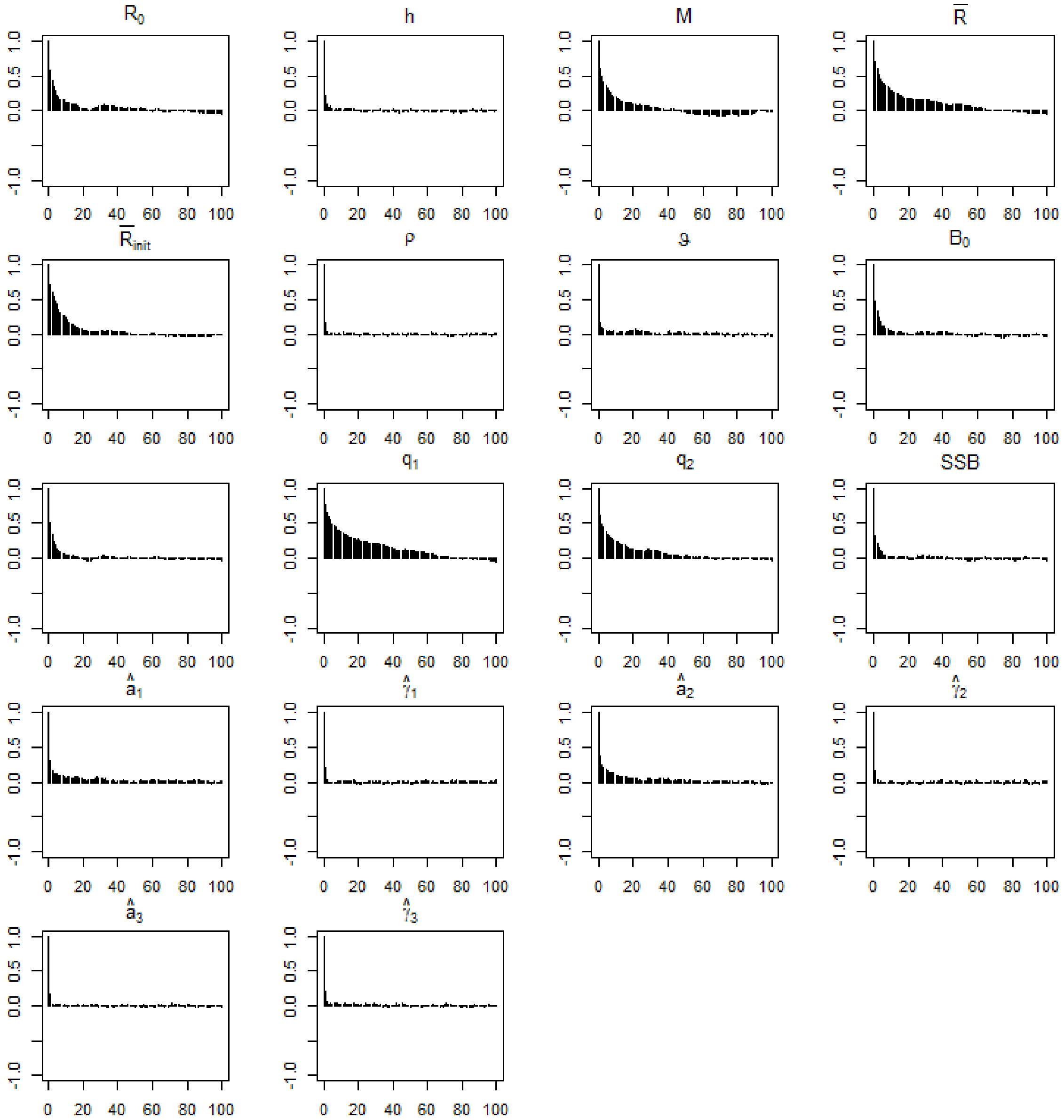


Figure 48. Autocorrelation plots for MCMC output of estimated parameters for the Strait of Georgia AM1 model. See Figure 38 for parameter descriptions.

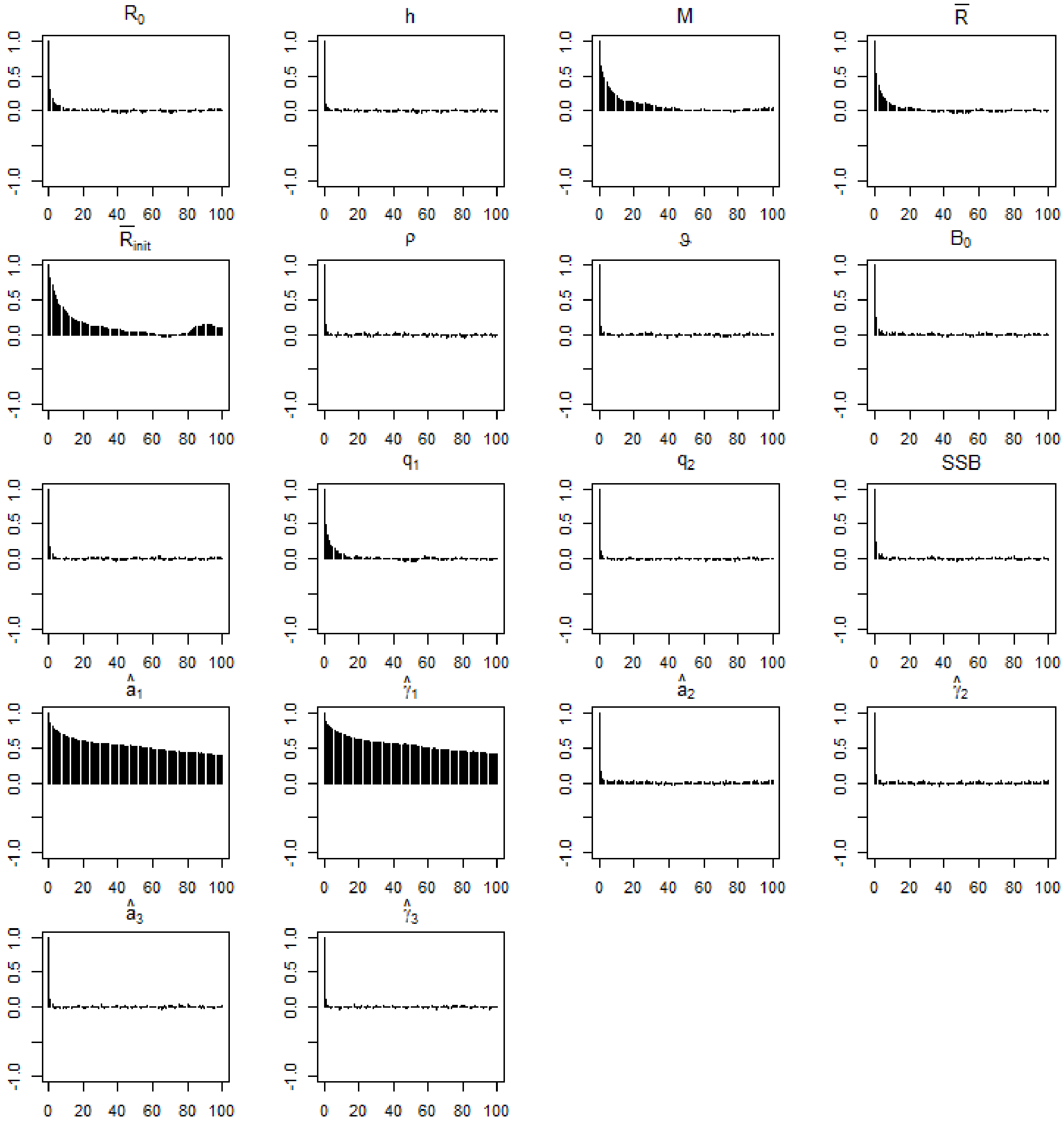


Figure 49. Autocorrelation plots for MCMC output of estimated parameters for the WCVI AM2 model. See Figure 40 for parameter descriptions.

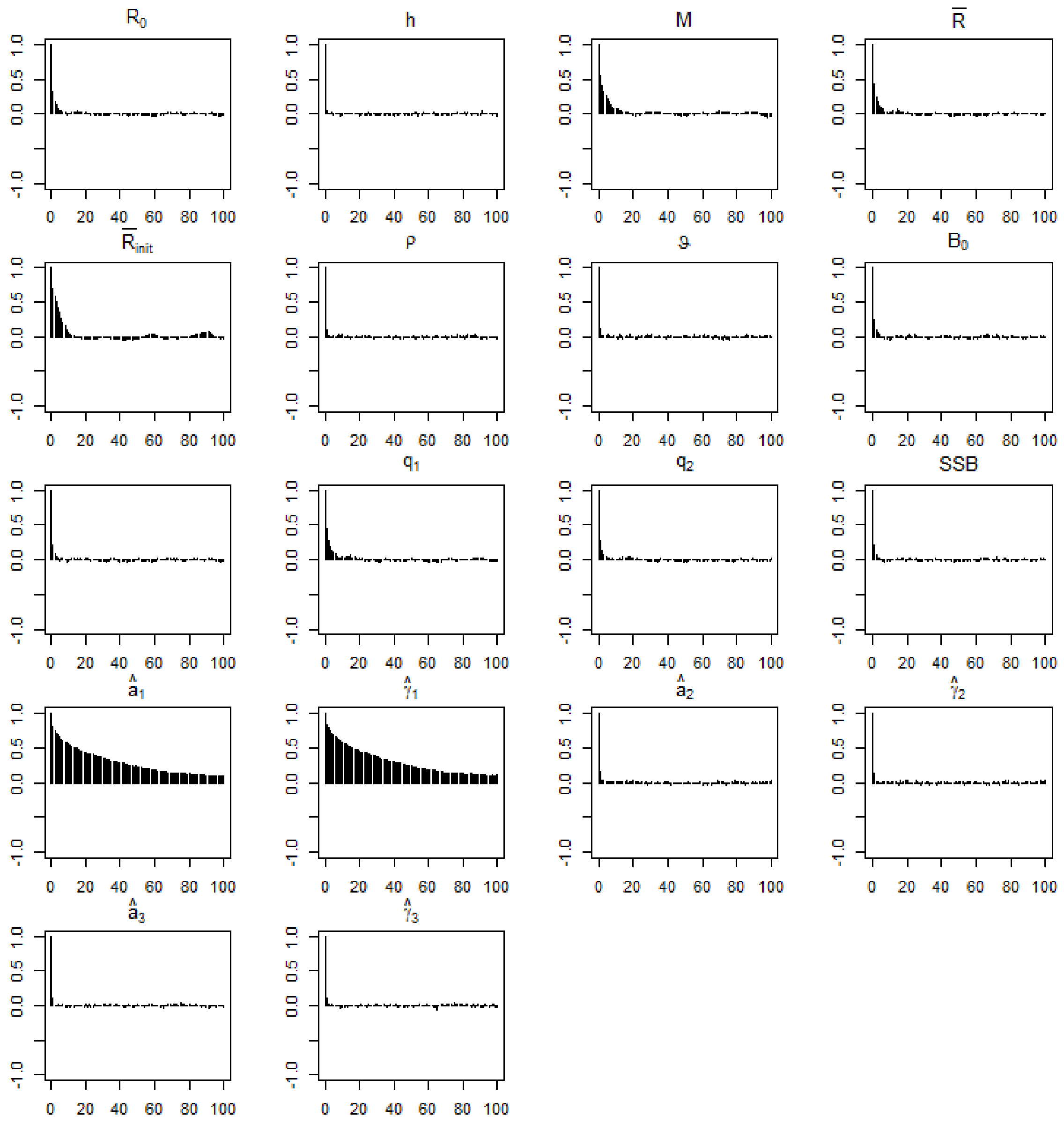


Figure 50. Autocorrelation plots for MCMC output of estimated parameters for the WCVI AM1 model. See Figure 40 for parameter descriptions.

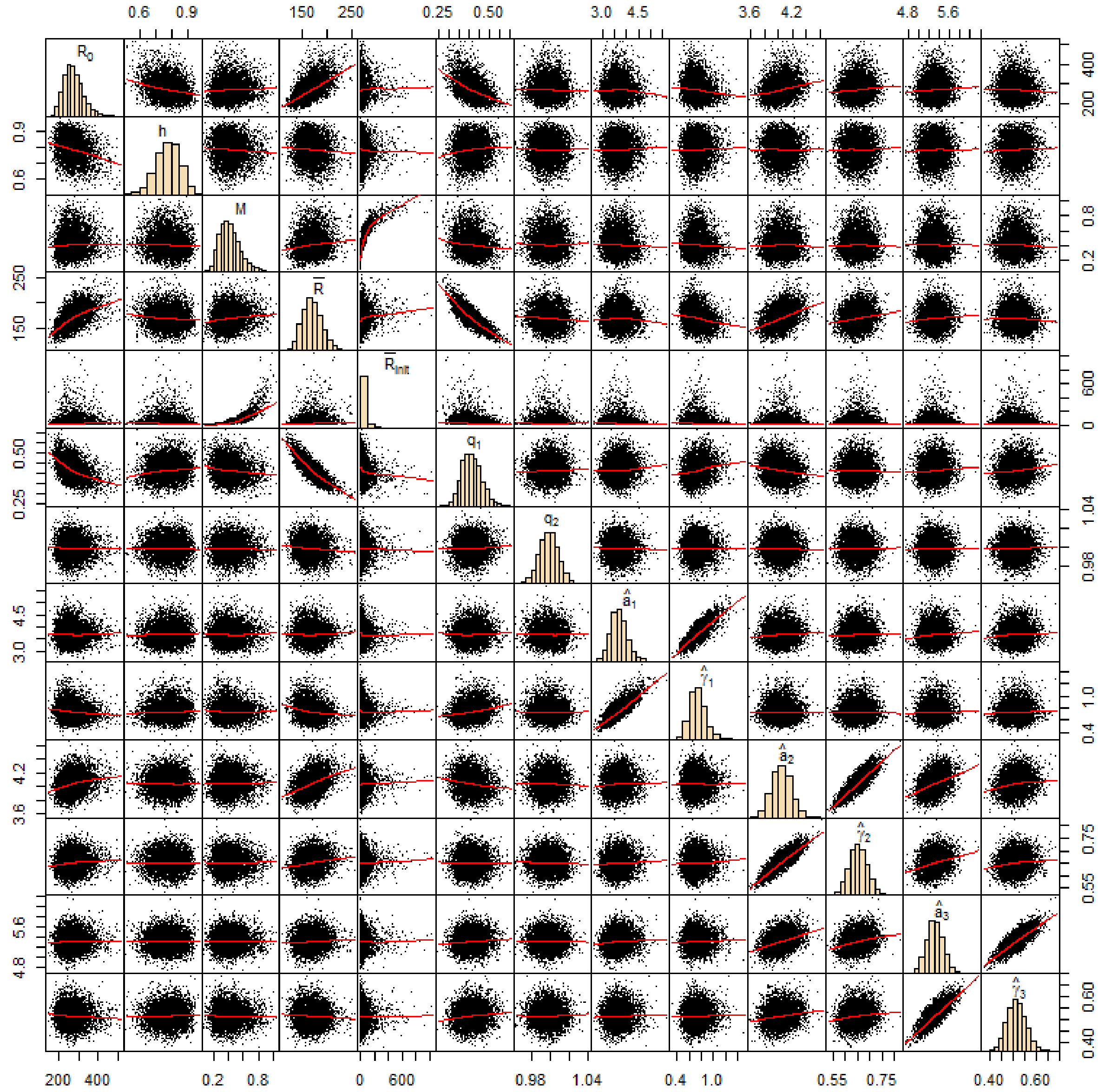


Figure 51. Pairs plots for MCMC output of estimated parameters in for the Haida Gwaii AM2 model. See Figure 32 for parameter descriptions.

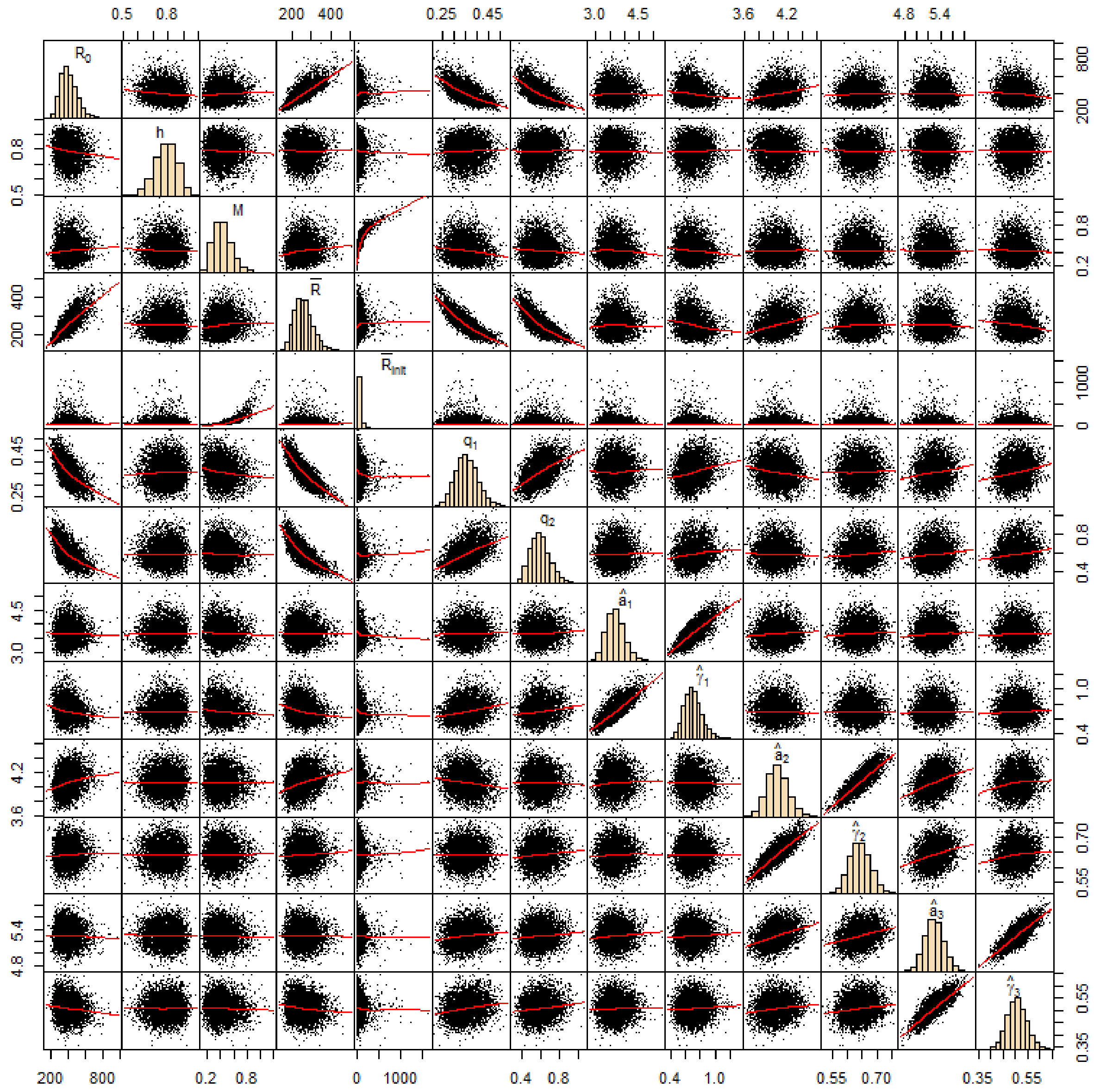


Figure 52. Pairs plots for MCMC output of estimated parameters in for the Haida Gwaii AM1 model. See Figure 32 for parameter descriptions.

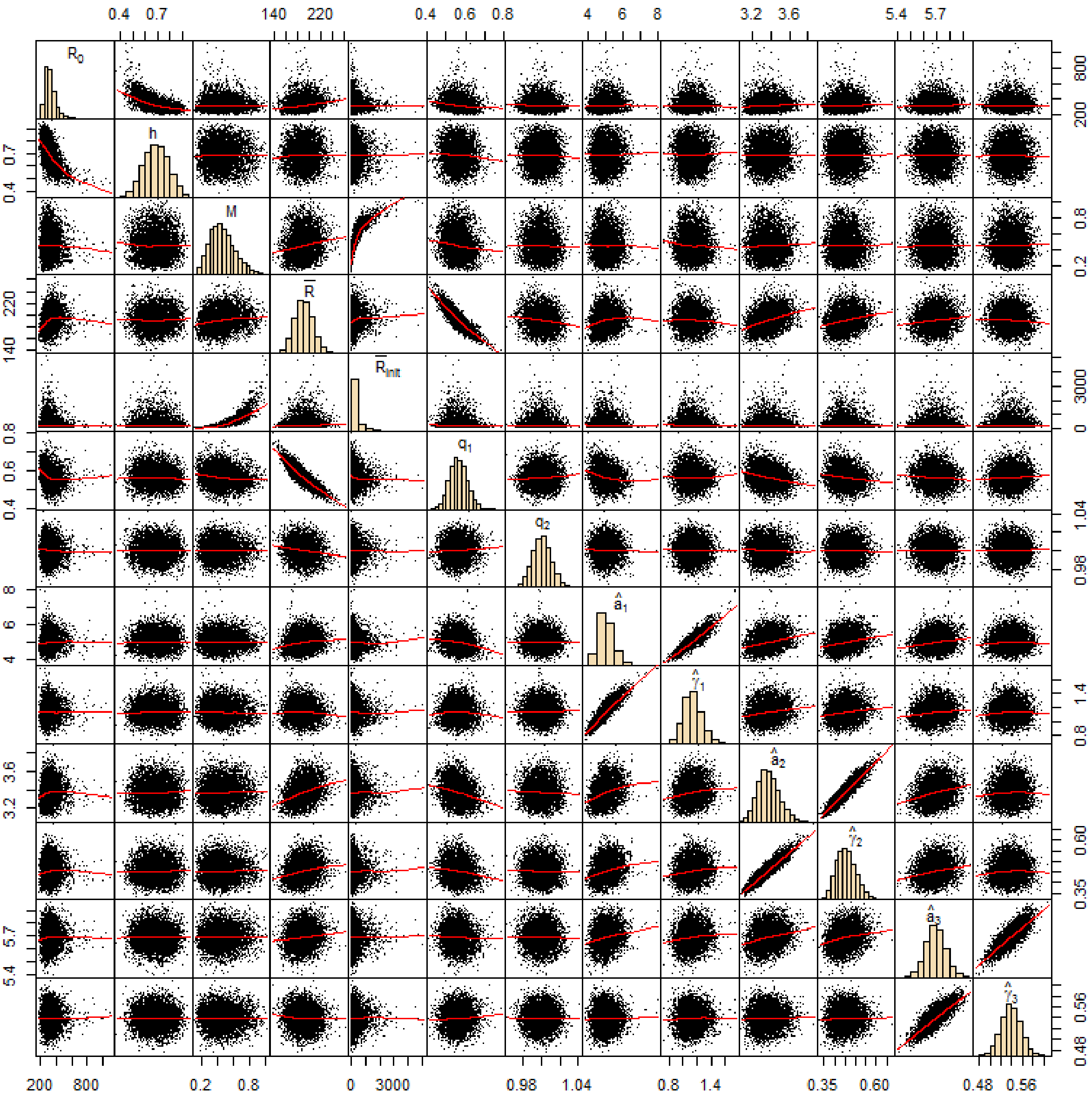


Figure 53. Pairs plots for MCMC output of estimated parameters in for the Prince Rupert AM2 model. See Figure 34 for parameter descriptions.

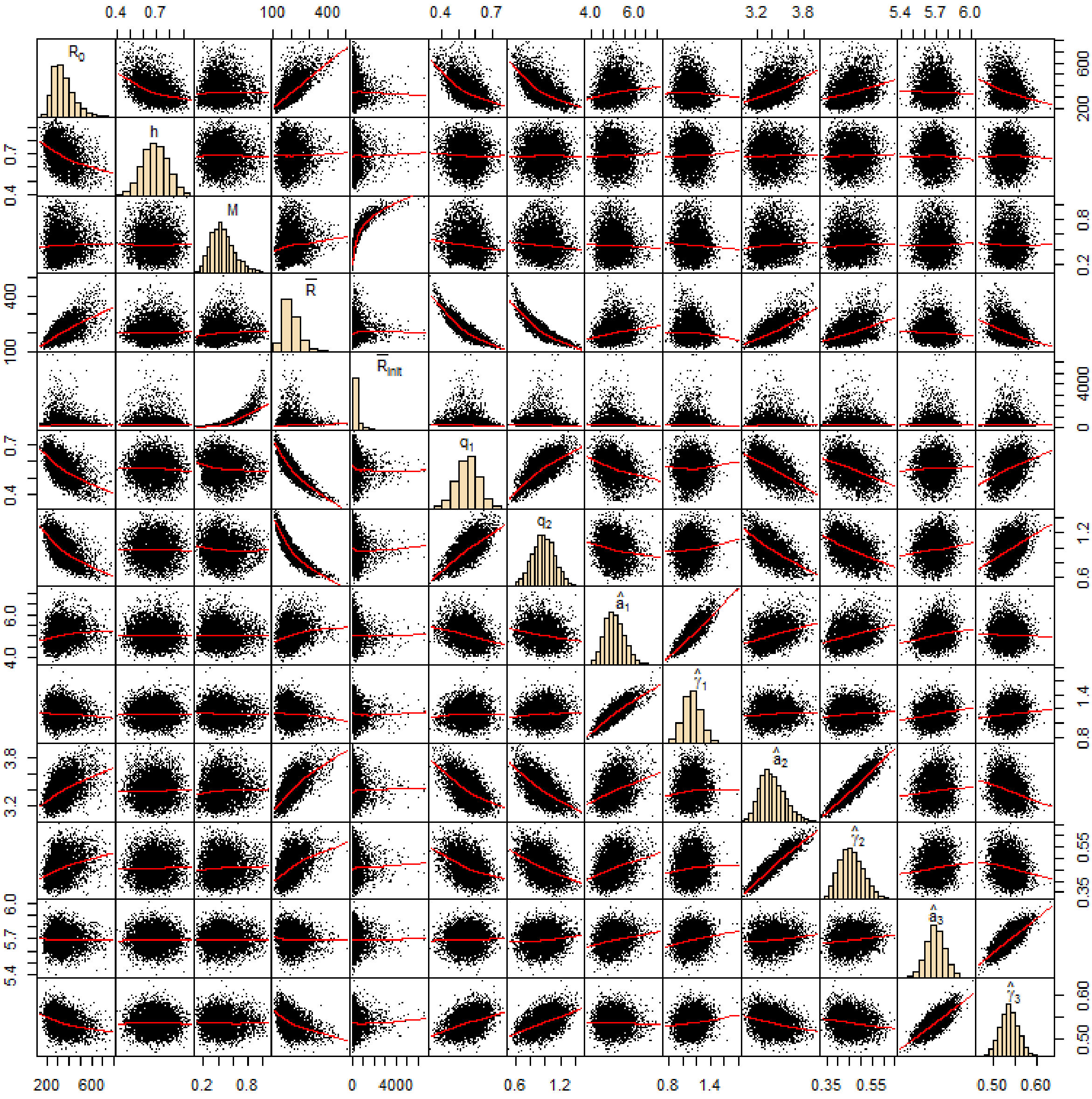


Figure 54. Pairs plots for MCMC output of estimated parameters in for the Prince Rupert AM1 model. See Figure 34 for parameter descriptions.

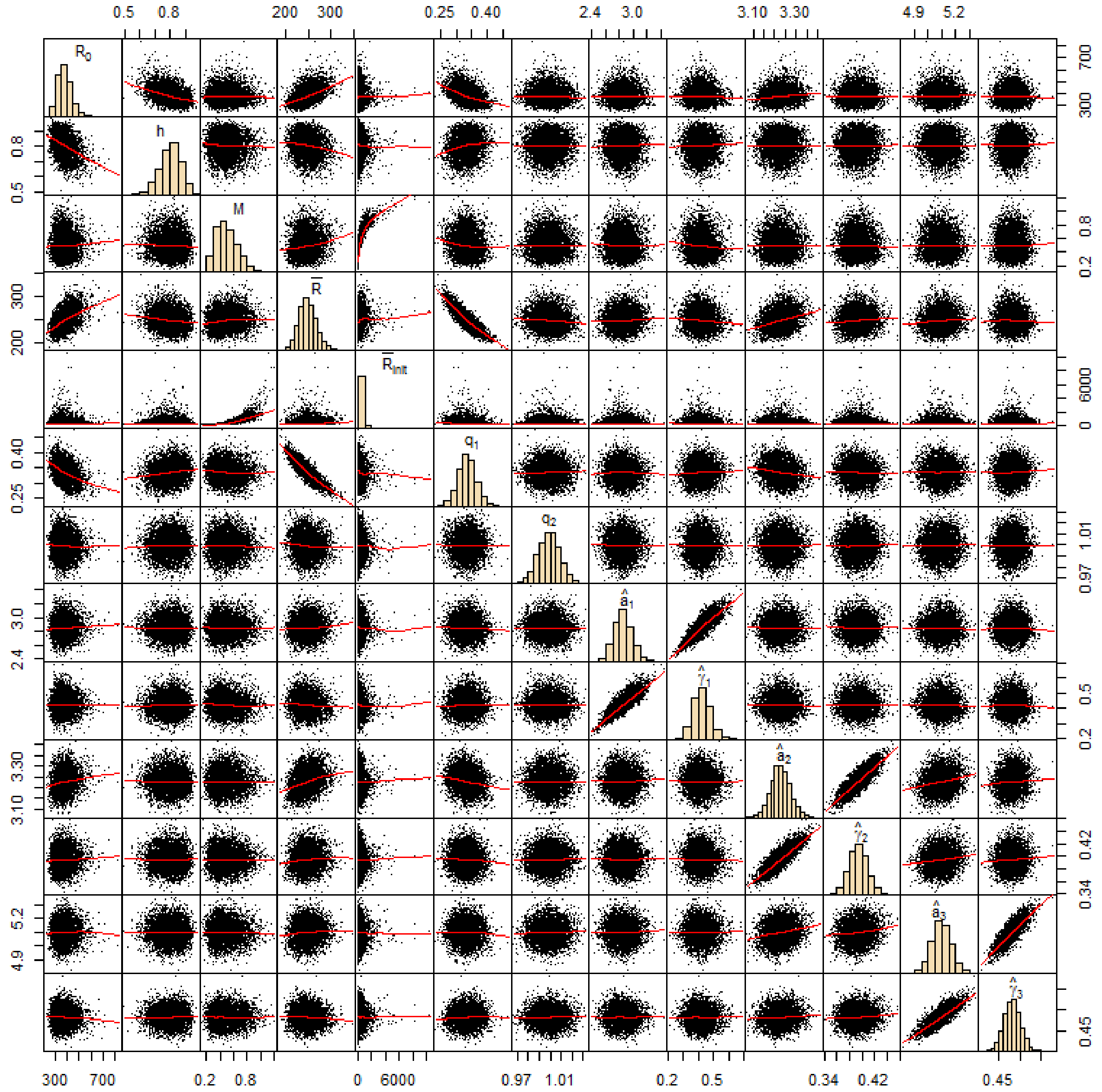


Figure 55. Pairs plots for MCMC output of estimated parameters in for the Central Coast AM2 model. See Figure 36 for parameter descriptions.

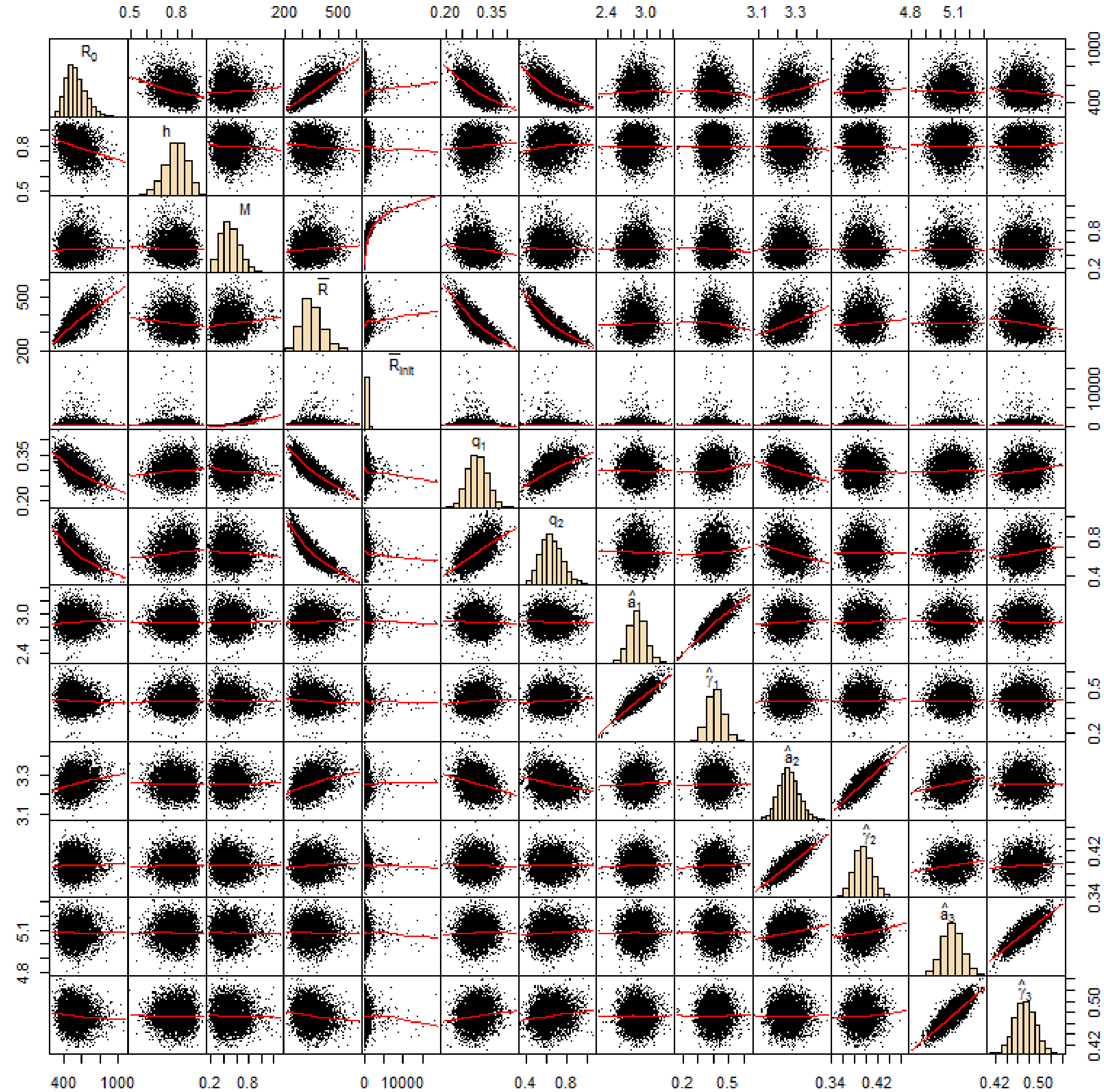


Figure 56. Pairs plots for MCMC output of estimated parameters in for the Central Coast AM1 model. See Figure 36 for parameter descriptions.

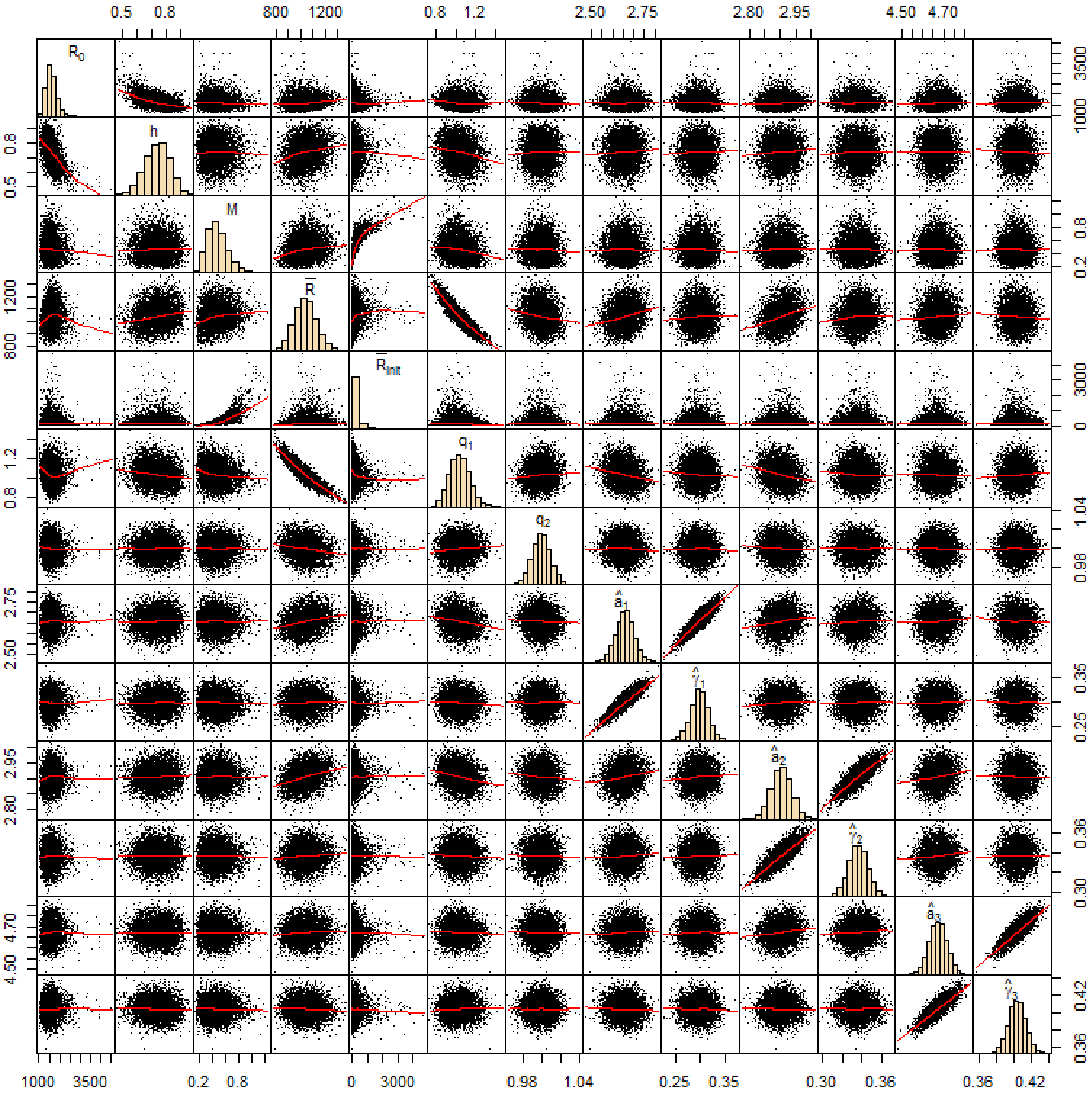


Figure 57. Pairs plots for MCMC output of estimated parameters in for the Strait of Georgia AM2 model. See Figure 38 for parameter descriptions.

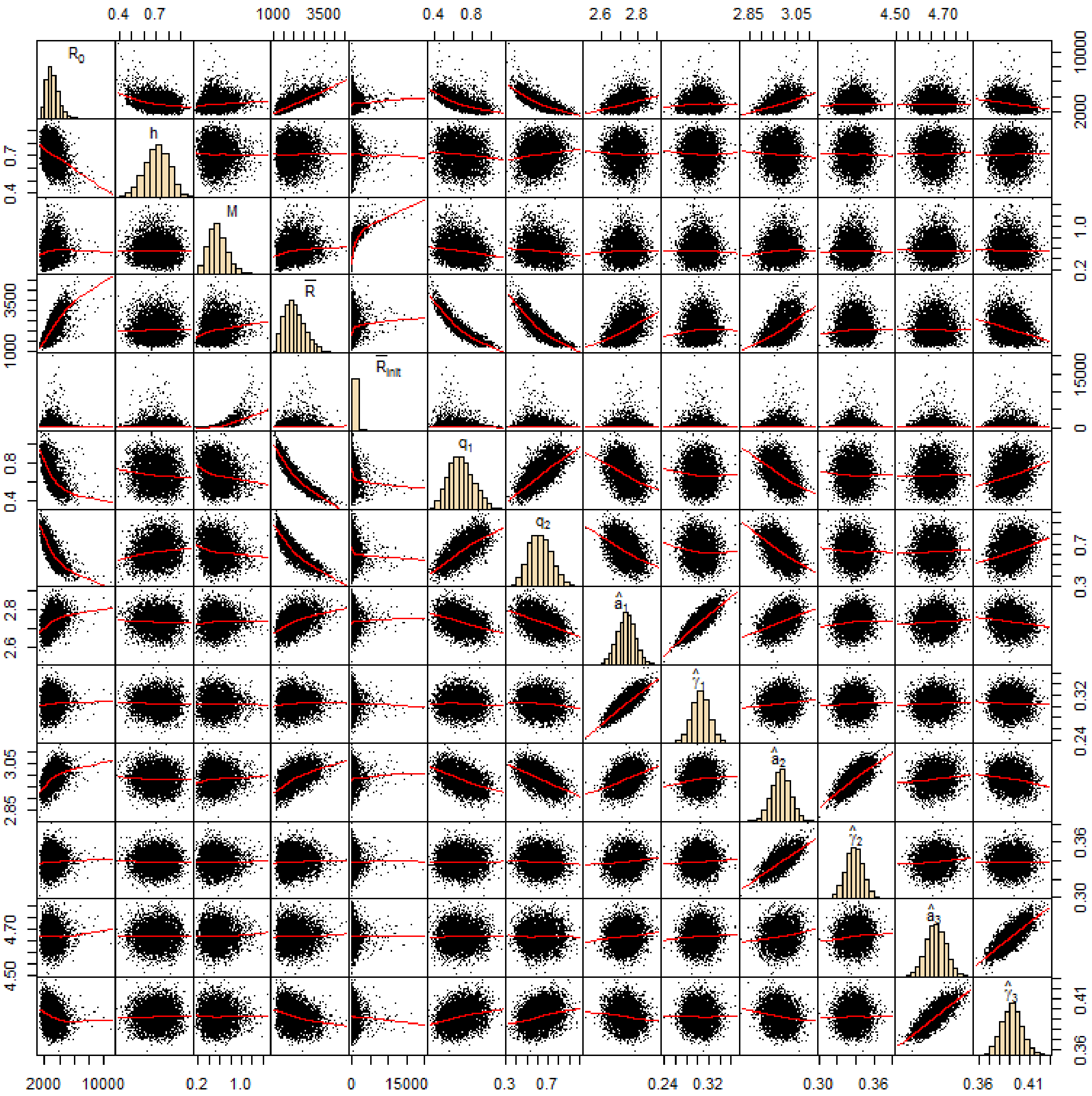


Figure 58. Pairs plots for MCMC output of estimated parameters in for the Strait of Georgia AM1 model. See Figure 38 for parameter descriptions.

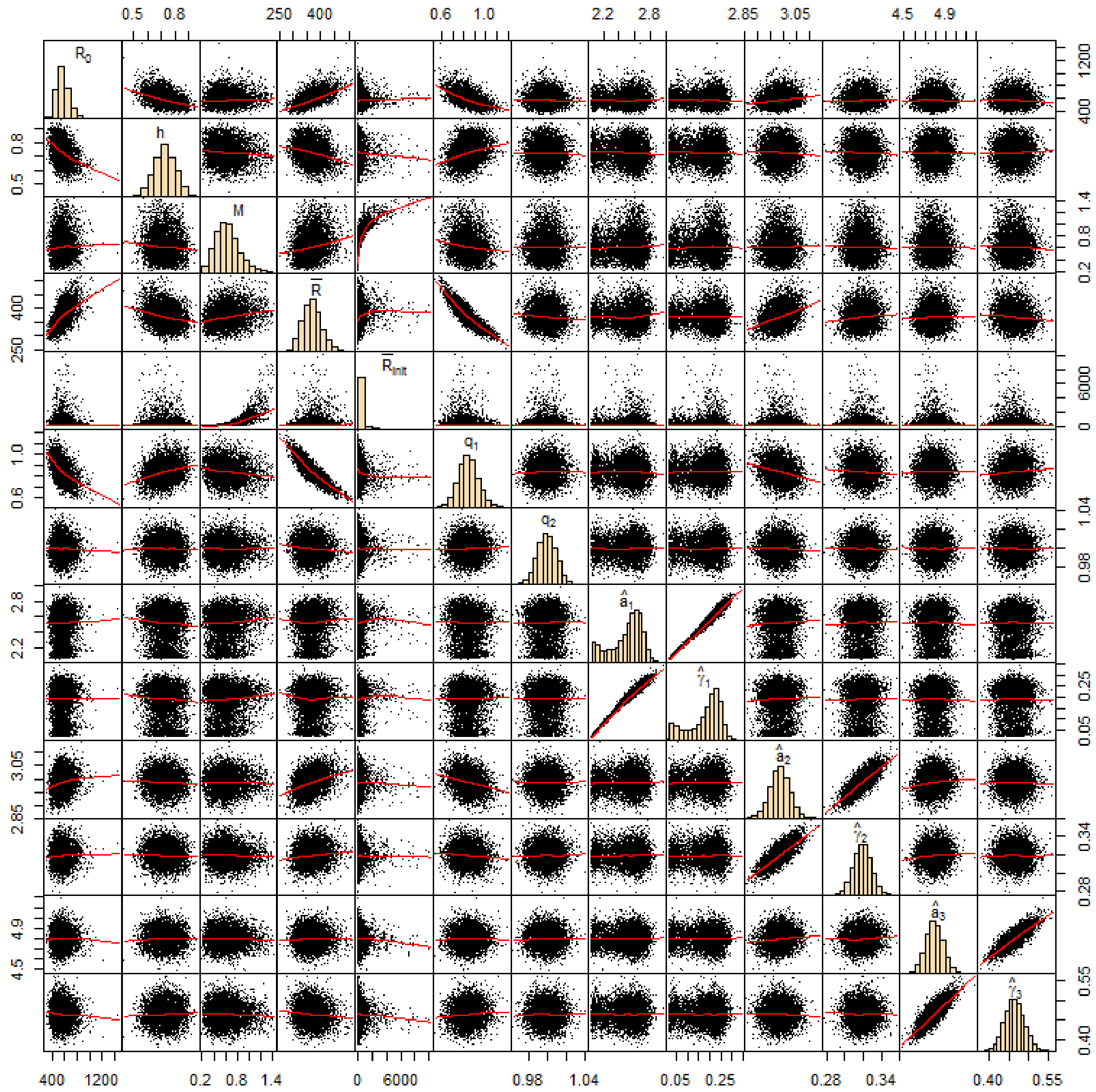


Figure 59. Pairs plots for MCMC output of estimated parameters in for the WCVI AM2 model. See Figure 40 for parameter descriptions.

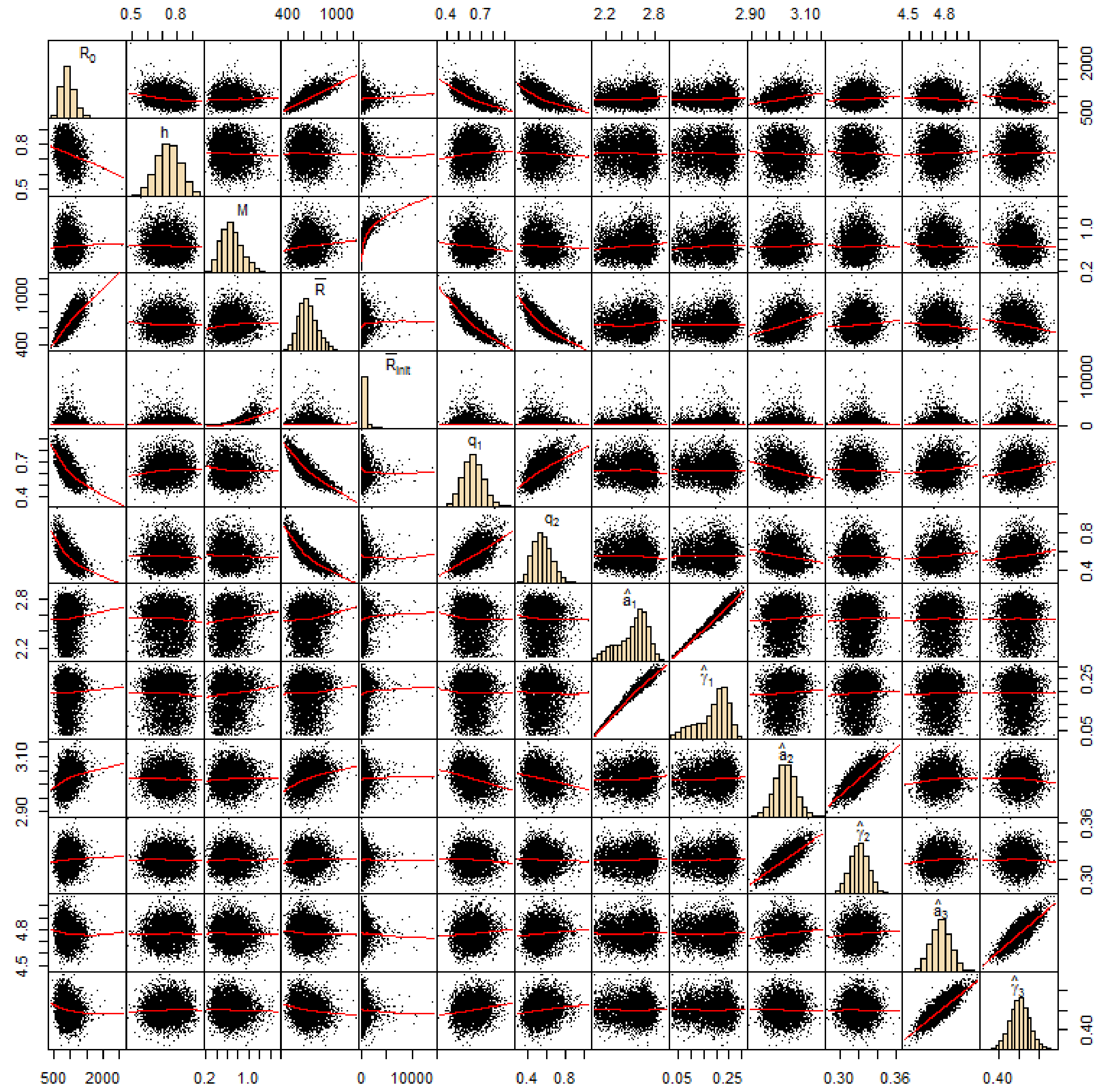


Figure 60. Pairs plots for MCMC output of estimated parameters in for the WCVI AM1 model. See Figure 40 for parameter descriptions.

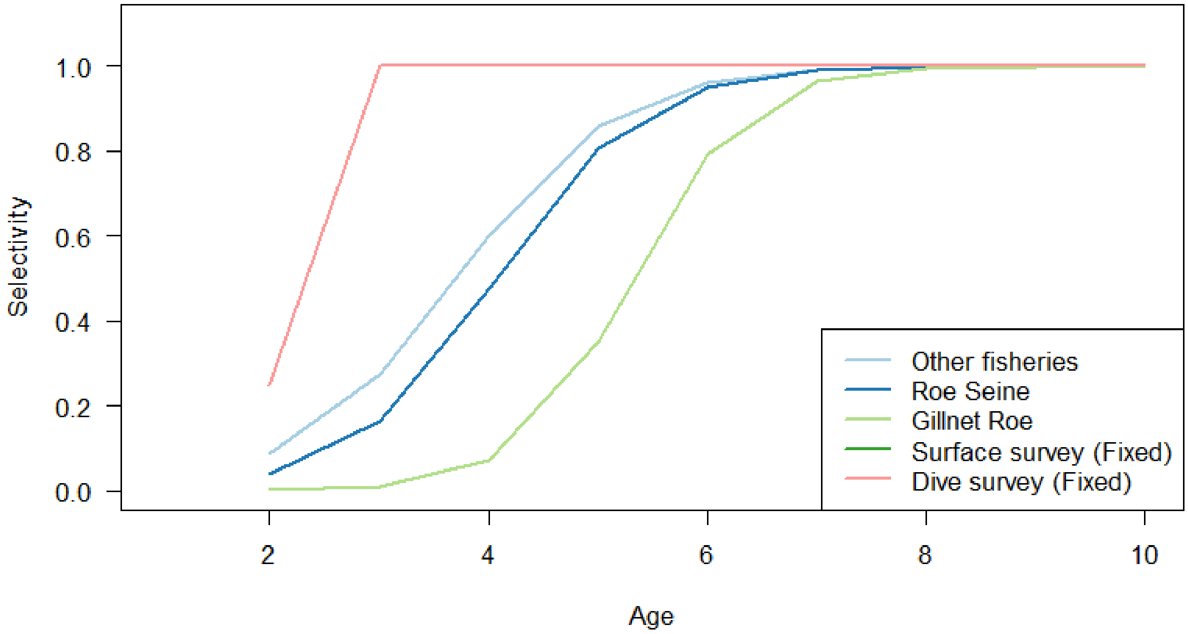


Figure 61. Estimated and Fixed selectivities for the Haida Gwaii AM2 model.

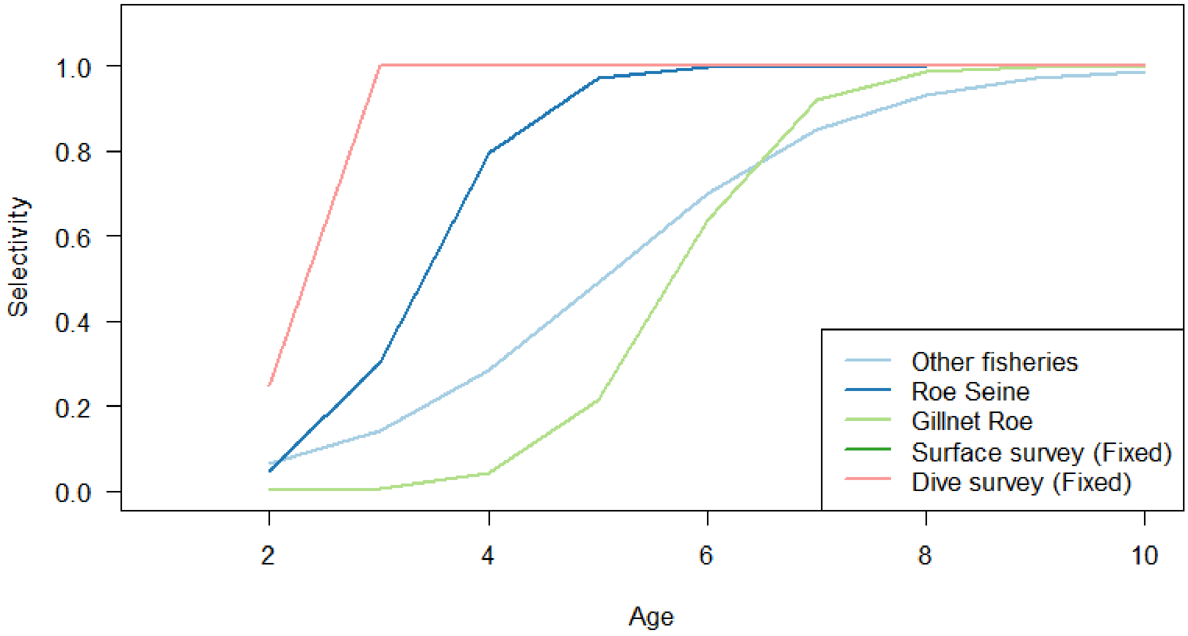


Figure 62. Estimated and Fixed selectivities for the Prince Rupert District AM2 model.

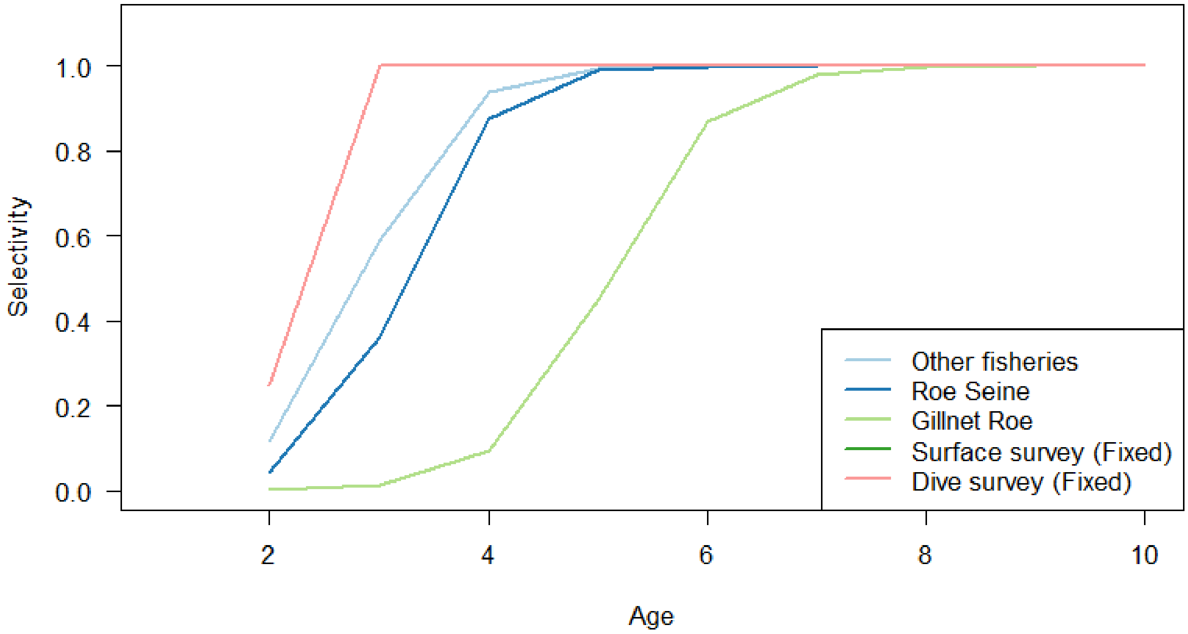


Figure 63. Estimated and Fixed selectivities for the Central Coast AM2 model.

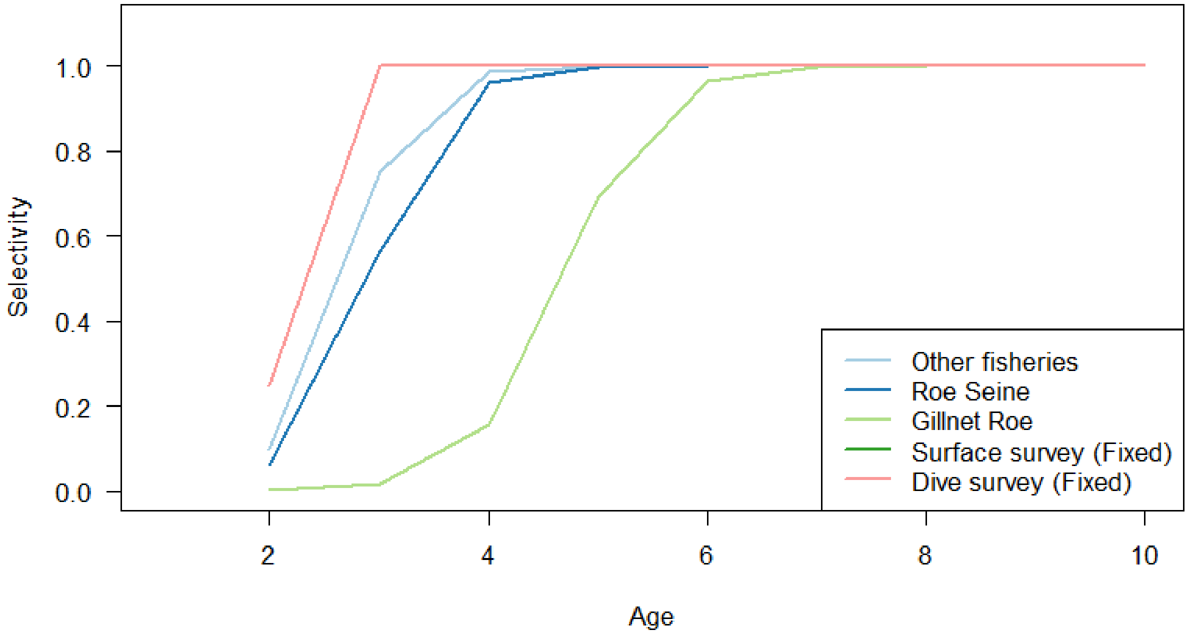


Figure 64. Estimated and Fixed selectivities for the Strait of Georgia AM2 model.

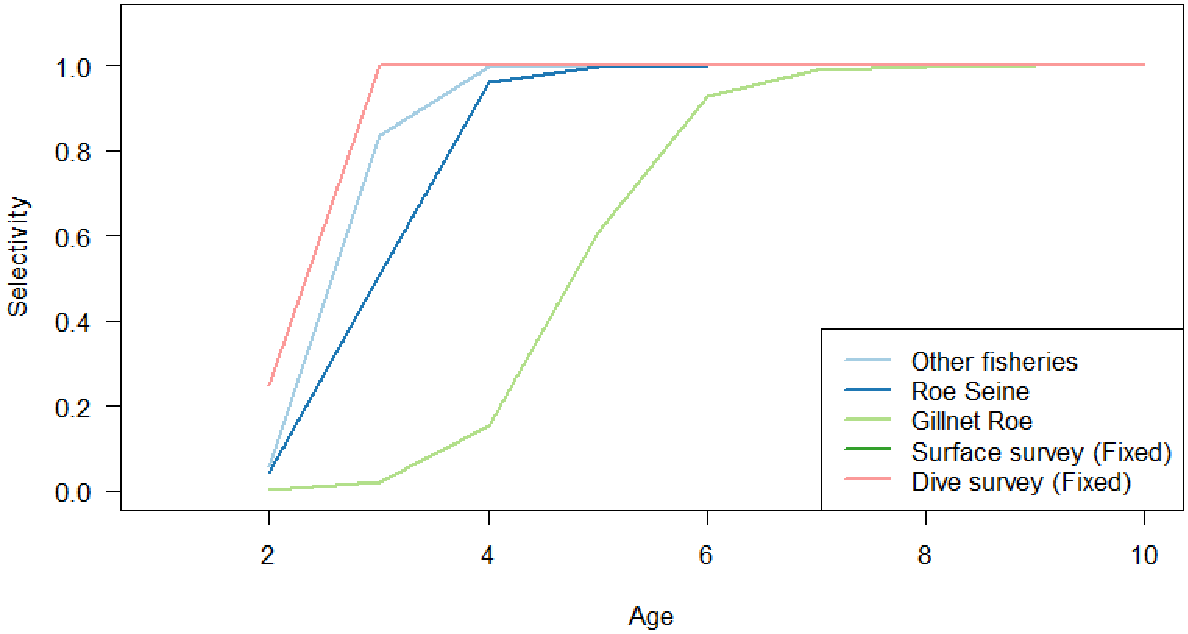


Figure 65. Estimated and Fixed selectivities for the WCVI AM2 model.

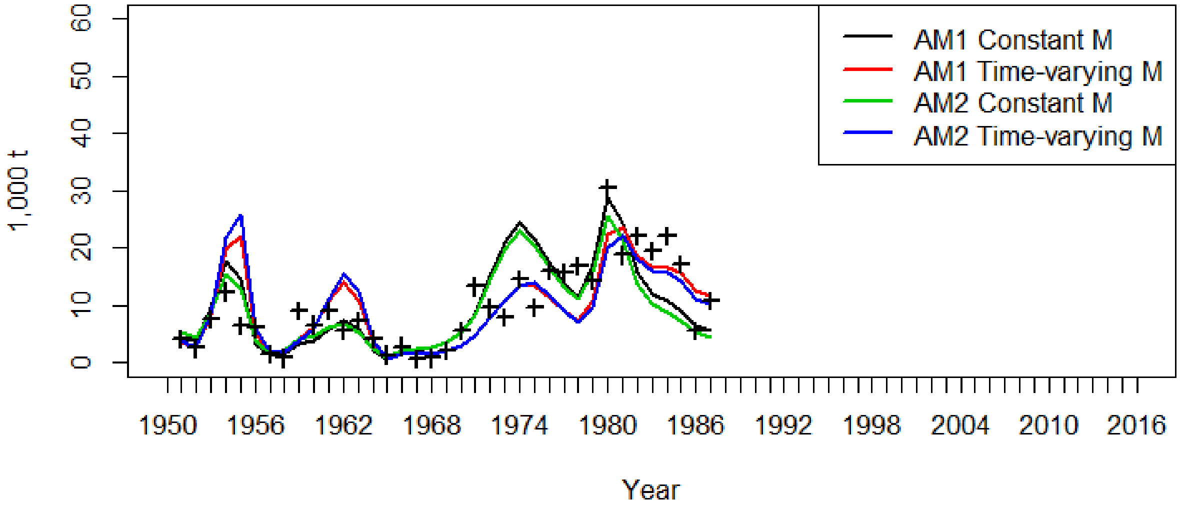


Figure 66. Natural Mortality Sensitivity Case: Natural mortality sensitivity model index fits (lines) and inputs (points) for the Haida Gwaii surface survey.

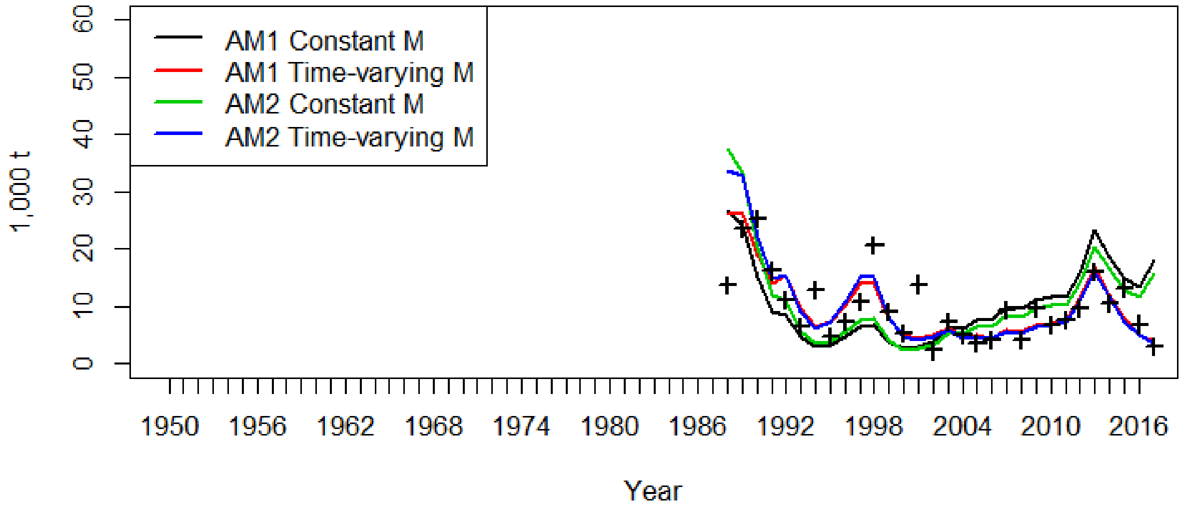


Figure 67. Natural Mortality Sensitivity Case: Natural mortality sensitivity model index fits (lines) and inputs (points) for the Haida Gwaii dive survey.

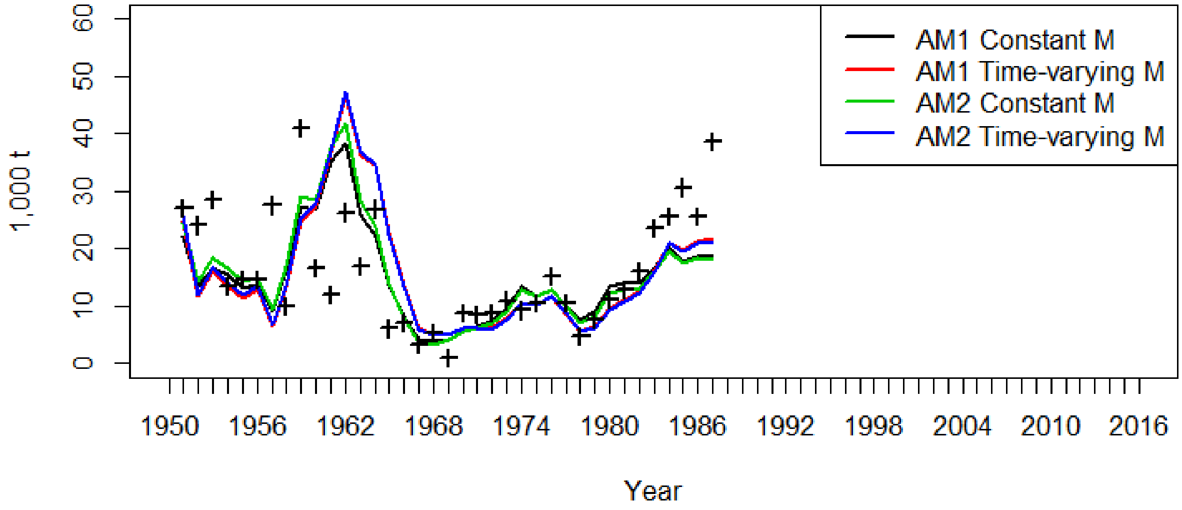


Figure 68. Natural Mortality Sensitivity Case: Natural mortality sensitivity model index fits (lines) and inputs (points) for the Prince Rupert District surface survey.

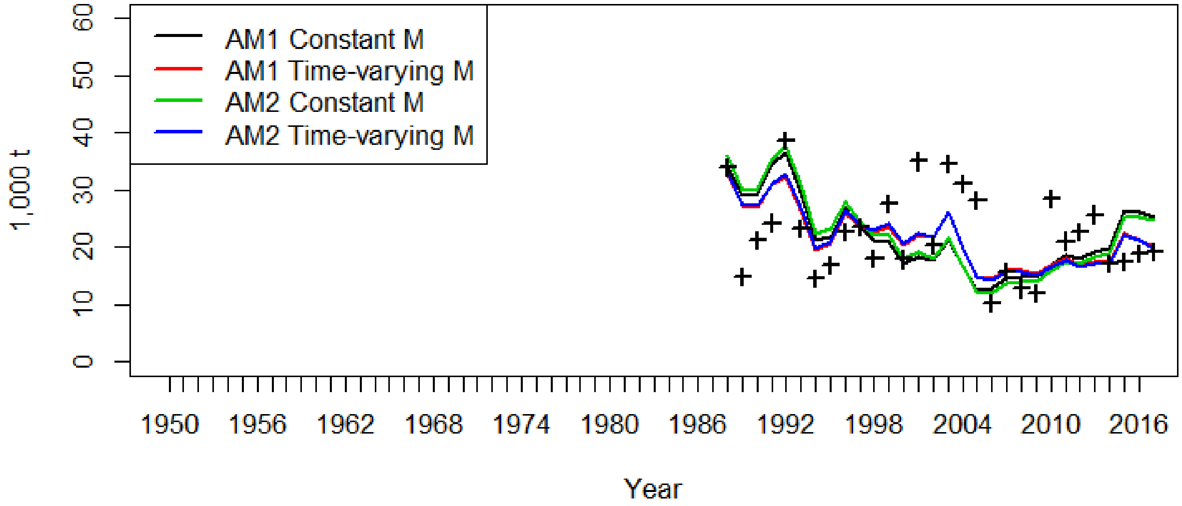


Figure 69. Natural Mortality Sensitivity Case: Natural mortality sensitivity model index fits (lines) and inputs (points) for the Prince Rupert District dive survey.

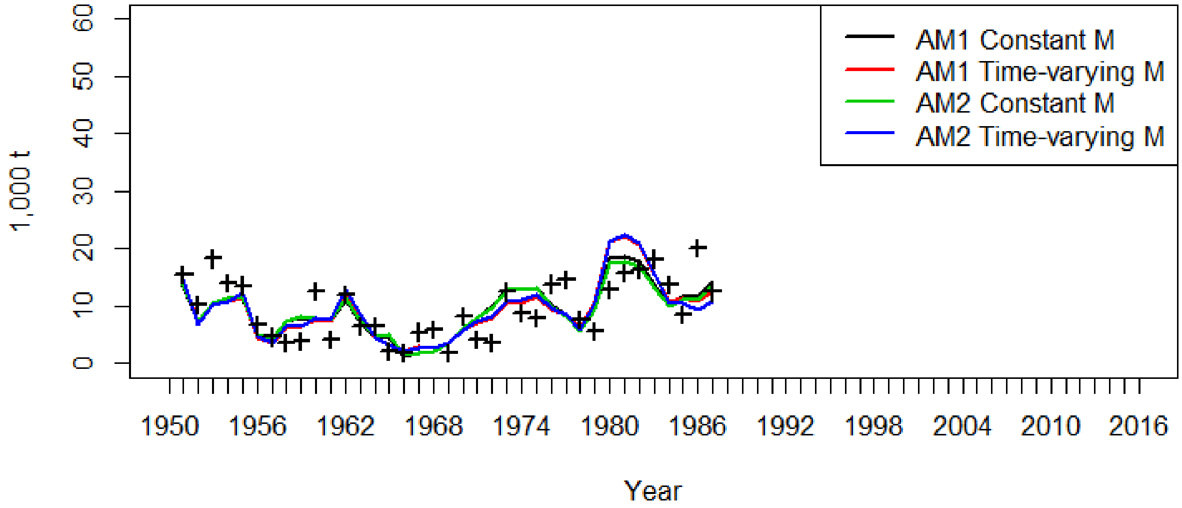


Figure 70. Natural Mortality Sensitivity Case: Natural mortality sensitivity model index fits (lines) and inputs (points) for the Central Coast surface survey.

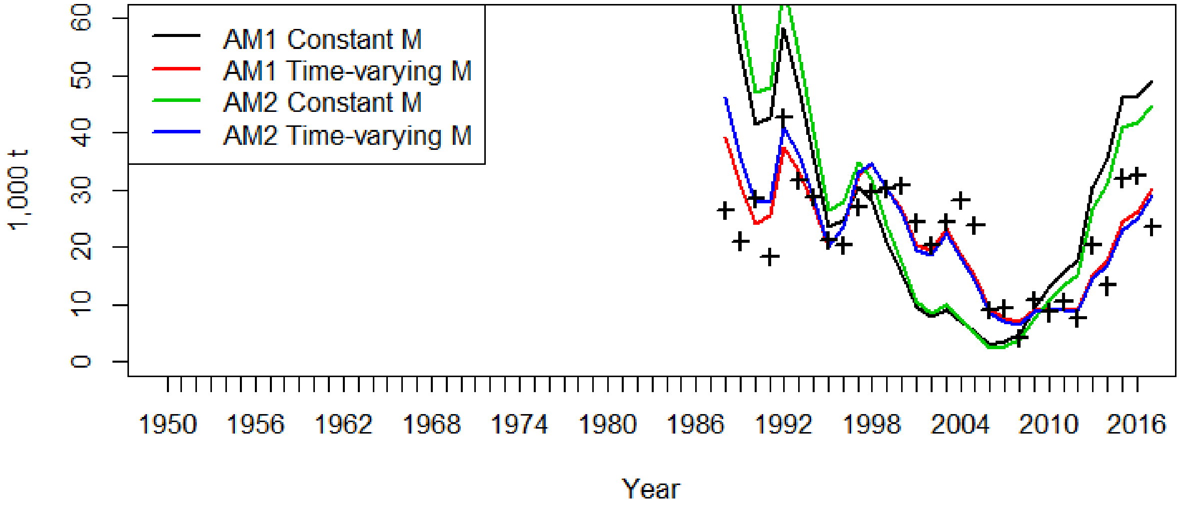


Figure 71. Natural Mortality Sensitivity Case: Natural mortality sensitivity model index fits (lines) and inputs (points) for the Central Coast dive survey.

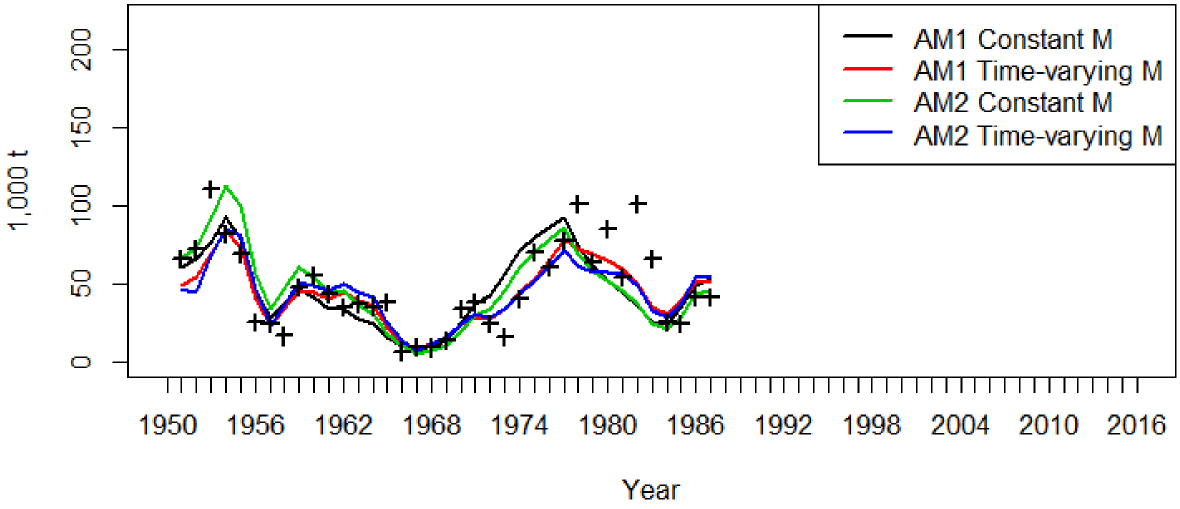


Figure 72. Natural Mortality Sensitivity Case: Natural mortality sensitivity model index fits (lines) and inputs (points) for the Strait of Georgia surface survey.

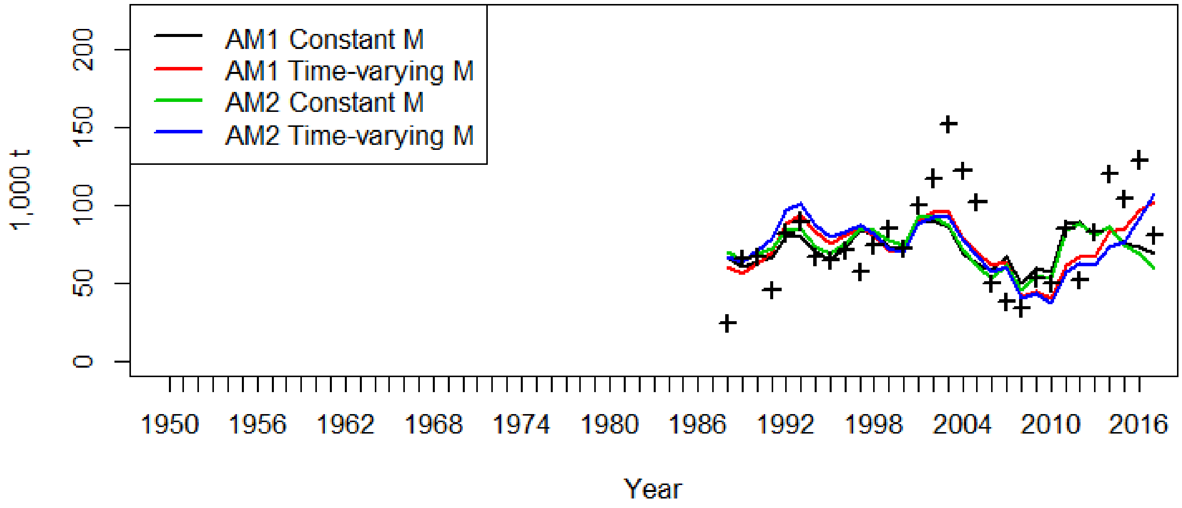


Figure 73. Natural Mortality Sensitivity Case: Natural mortality sensitivity model index fits (lines) and inputs (points) for the Strait of Georgia dive survey.

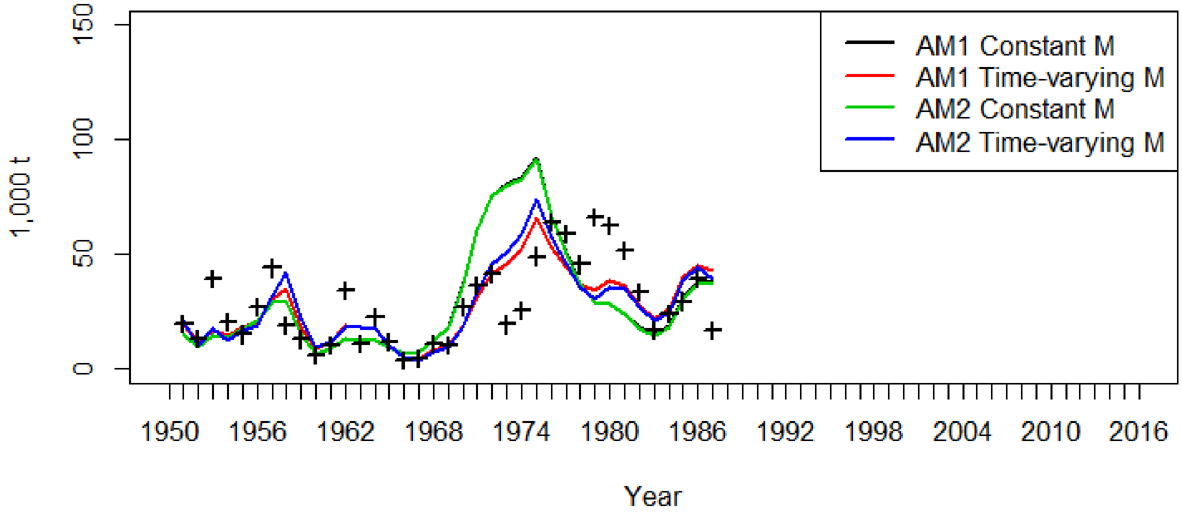


Figure 74. Natural Mortality Sensitivity Case: Natural mortality sensitivity model index fits (lines) and inputs (points) for the WCVI surface survey.

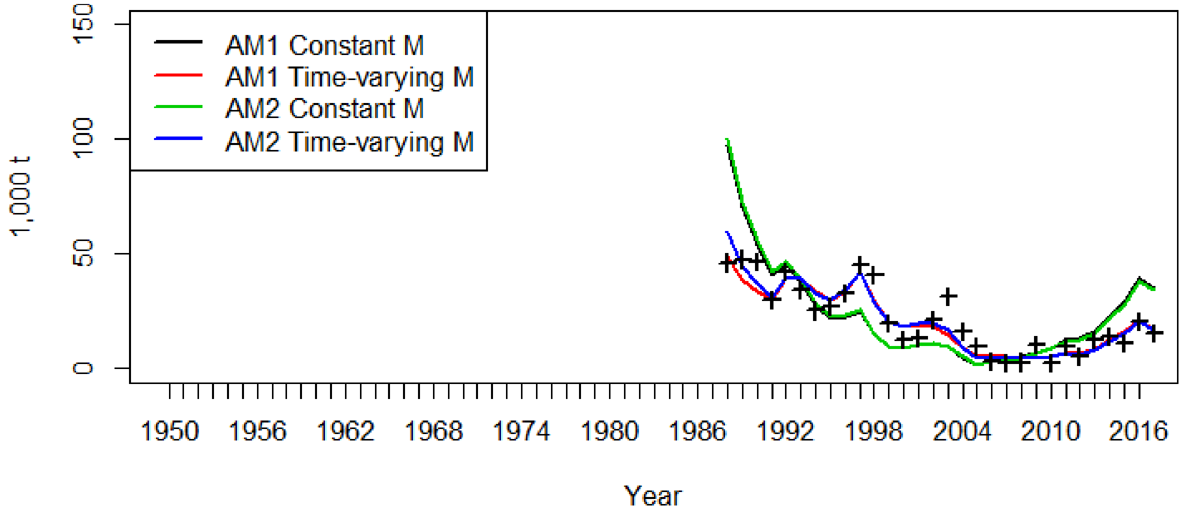


Figure 75. Natural Mortality Sensitivity Case: Natural mortality sensitivity model index fits (lines) and inputs (points) for the WCVI dive survey.

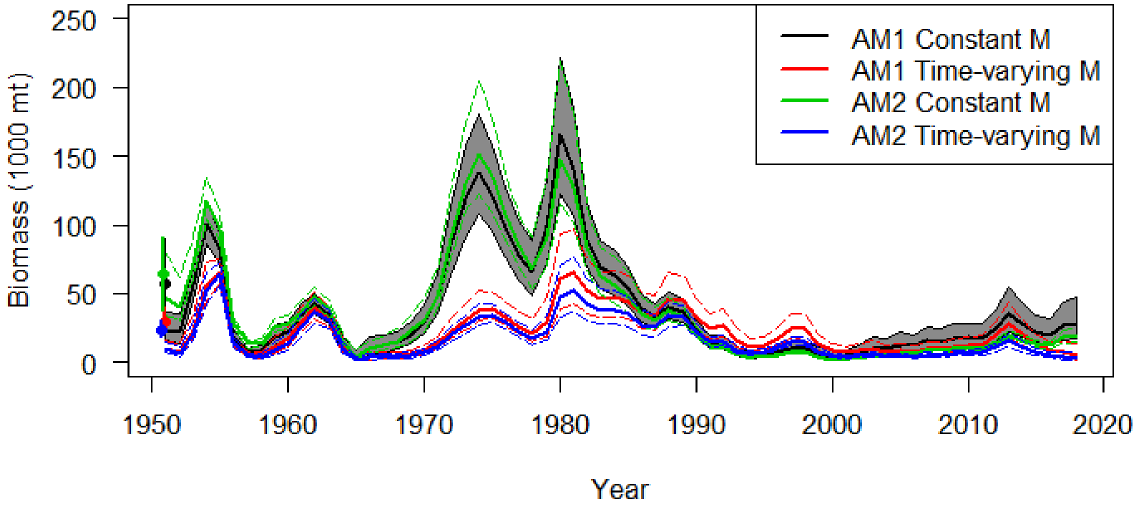


Figure 76. Natural Mortality Sensitivity Case: Natural mortality sensitivity model biomass trajectories for the Haida Gwaii stock.

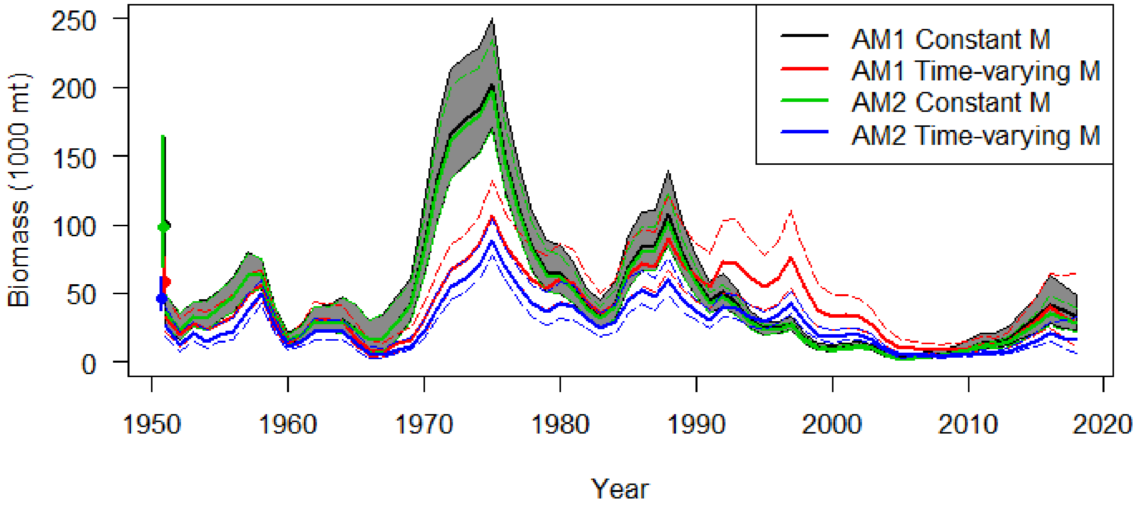


Figure 77. Natural Mortality Sensitivity Case: Natural mortality sensitivity model biomass trajectories for the WCVI stock.

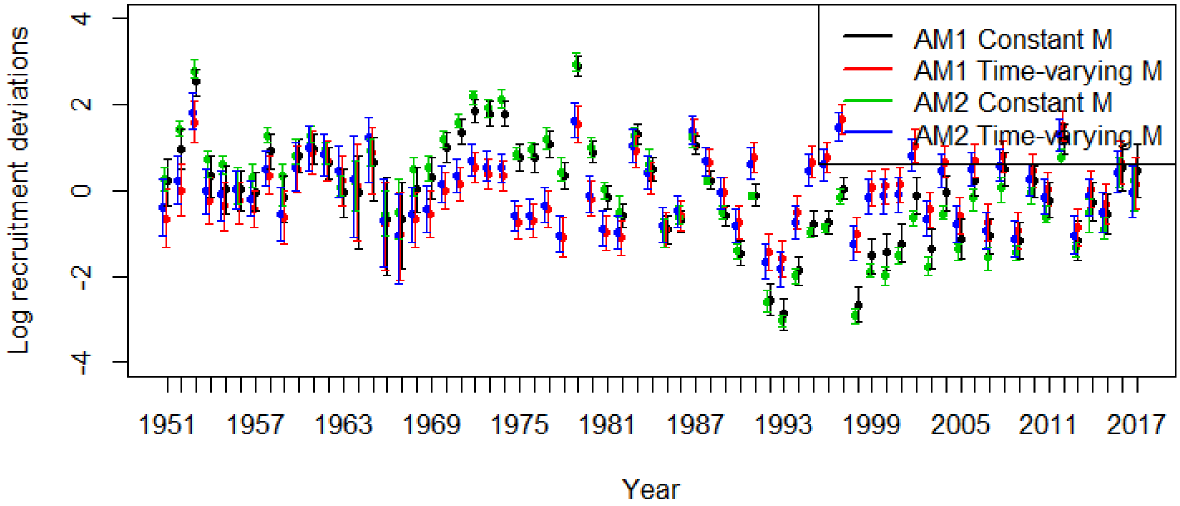


Figure 78. Natural Mortality Sensitivity Case: Natural mortality sensitivity model recruitment deviations for the Haida Gwaii stock.

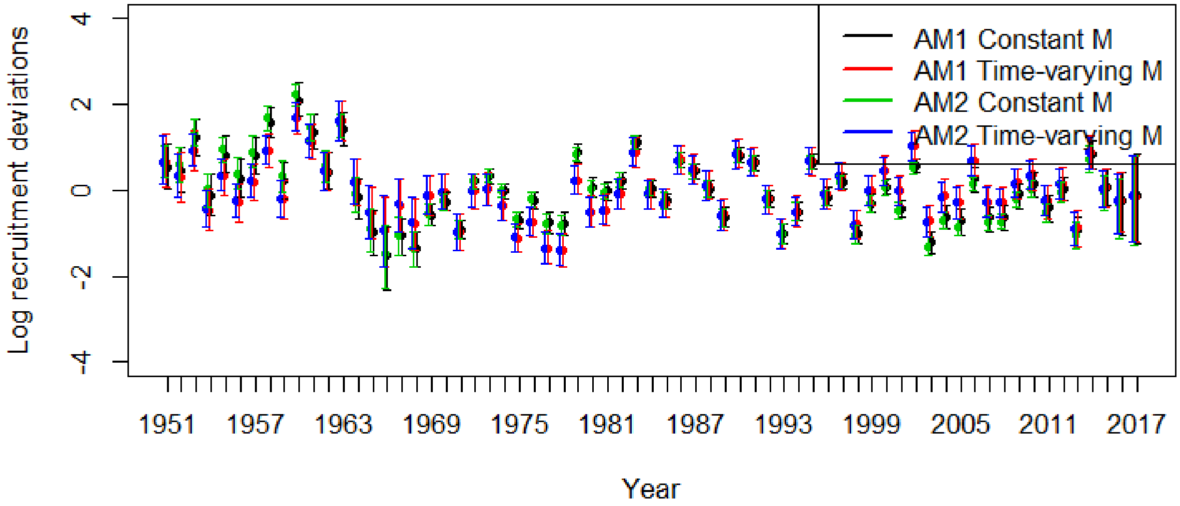


Figure 79. Natural Mortality Sensitivity Case: Natural mortality sensitivity model recruitment deviations for the Prince Rupert District stock.

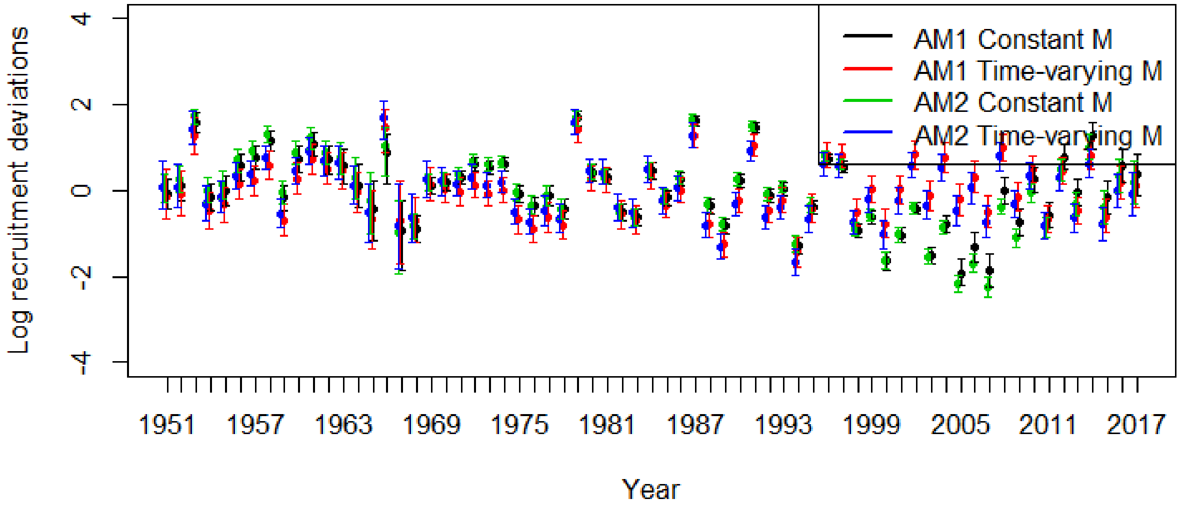


Figure 80. Natural Mortality Sensitivity Case: Natural mortality sensitivity model recruitment deviations for the Central Coast stock.

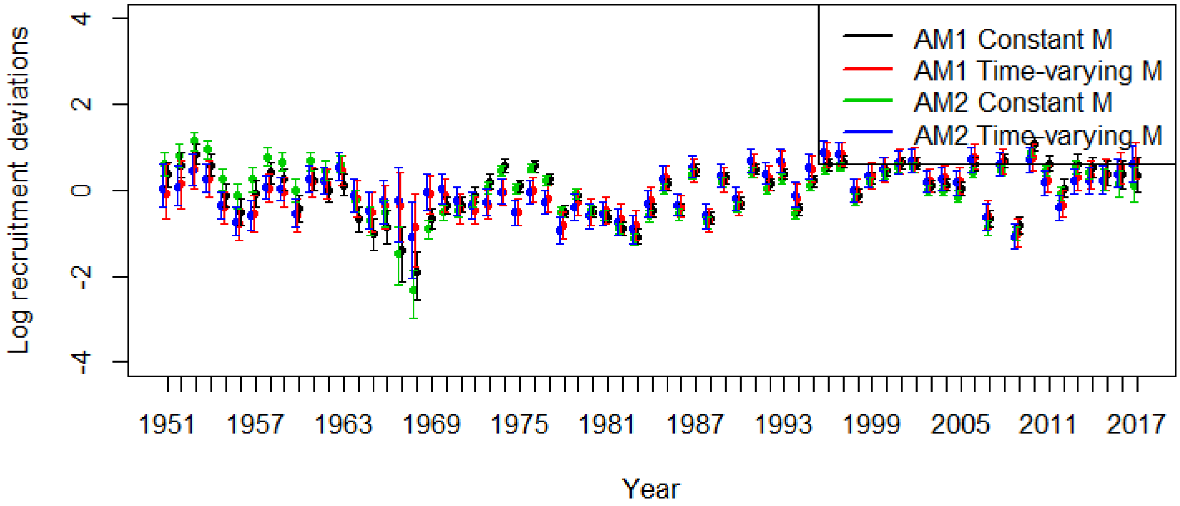


Figure 81. Natural Mortality Sensitivity Case: Natural mortality sensitivity model recruitment deviations for the Strait of Georgia stock.

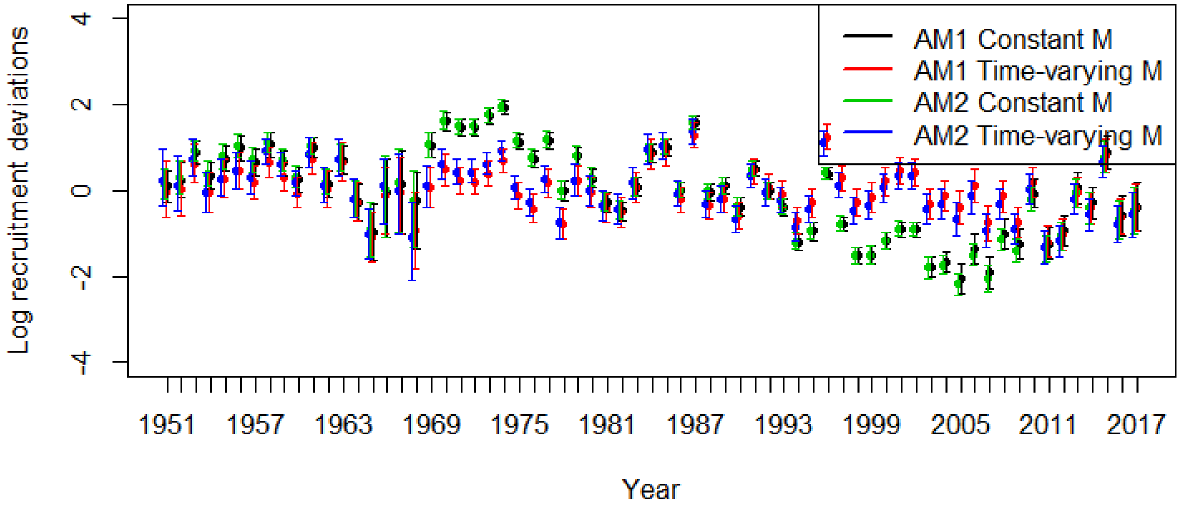


Figure 82. Natural Mortality Sensitivity Case: Natural mortality sensitivity model recruitment deviations for the WCVI stock.

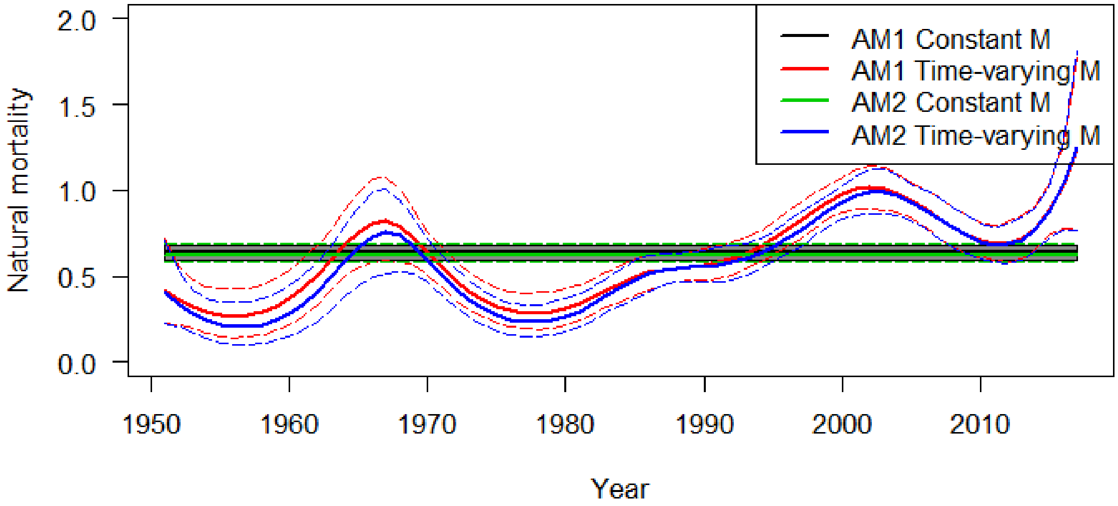


Figure 83. Natural Mortality Sensitivity Case: Natural mortality for the sensitivity to the natural mortality parameter for the Haida Gwaii stock.

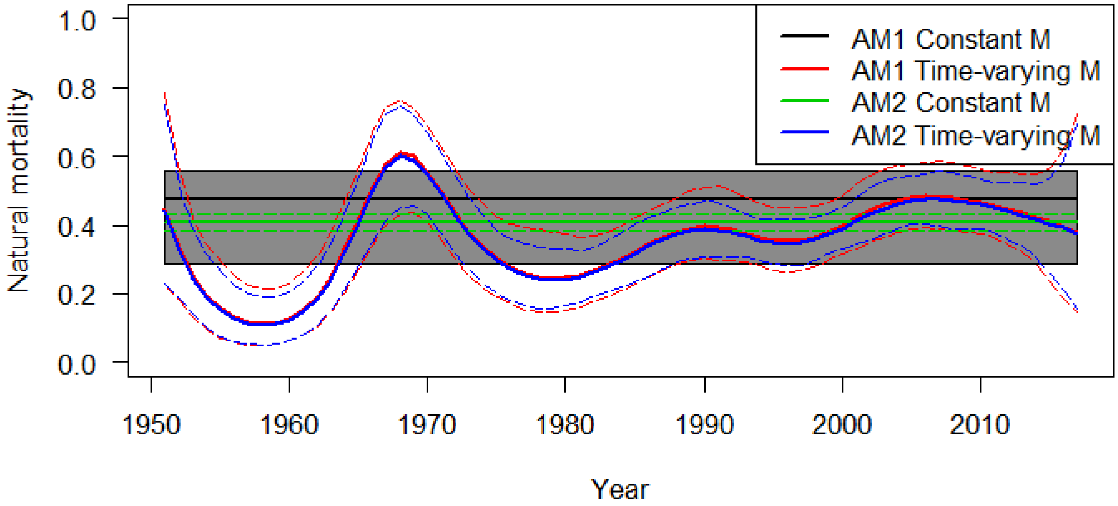


Figure 84. Natural Mortality Sensitivity Case: Natural mortality for the sensitivity to the natural mortality parameter for the Prince Rupert District stock.

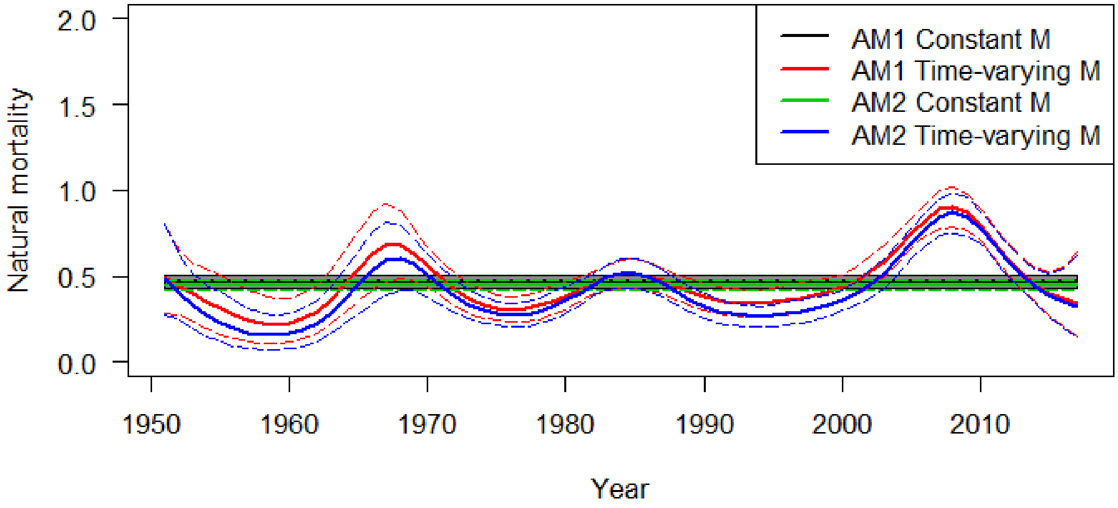


Figure 85. Natural Mortality Sensitivity Case: Natural mortality for the sensitivity to the natural mortality parameter for the Central Coast stock.

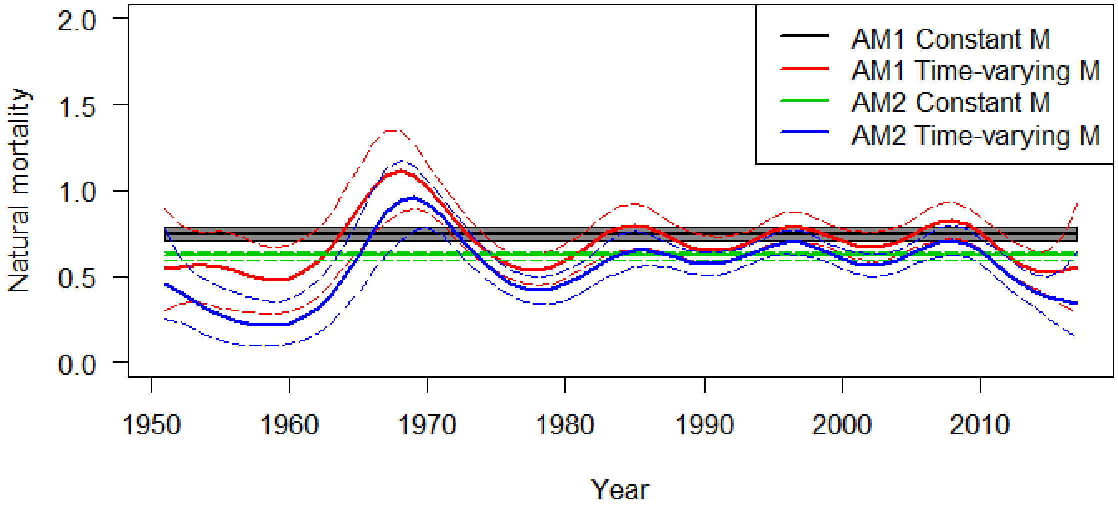


Figure 86. Natural Mortality Sensitivity Case: Natural mortality for the sensitivity to the natural mortality parameter for the Strait of Georgia stock.

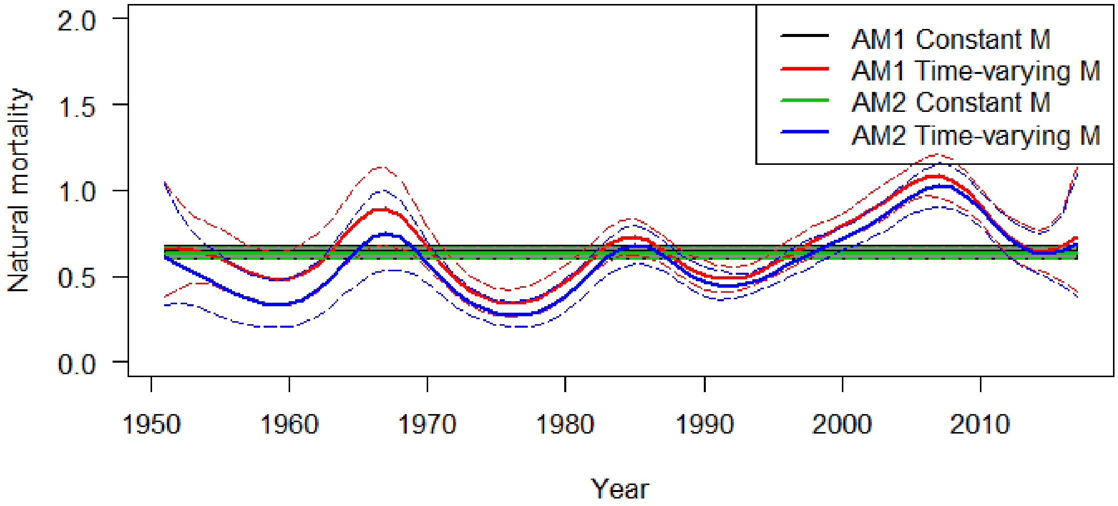


Figure 87. Natural Mortality Sensitivity Case: Natural mortality for the sensitivity to the natural mortality parameter for the WCVI stock.

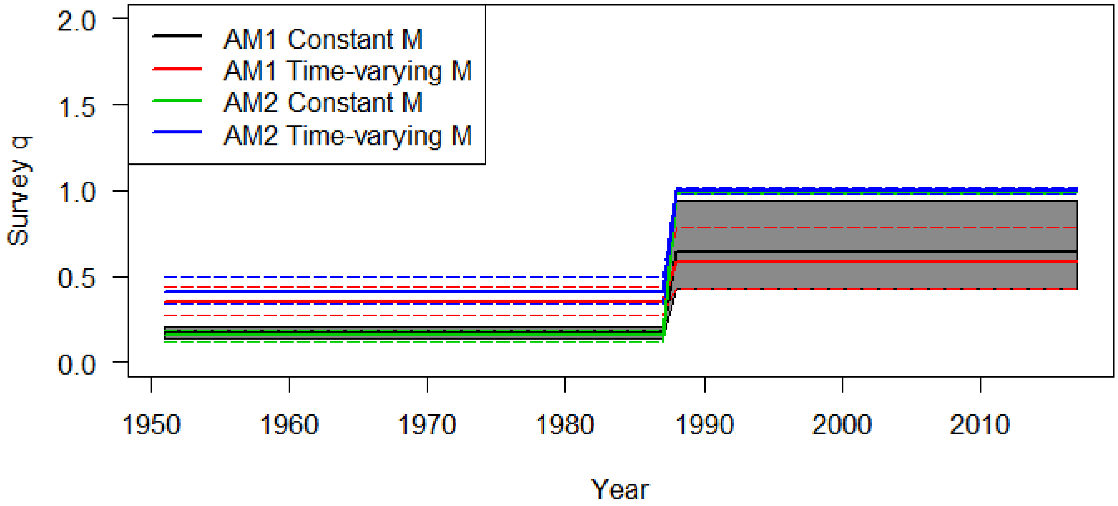


Figure 88. Natural Mortality Sensitivity Case: Natural mortality sensitivity models survey q for the Haida Gwaii stock.

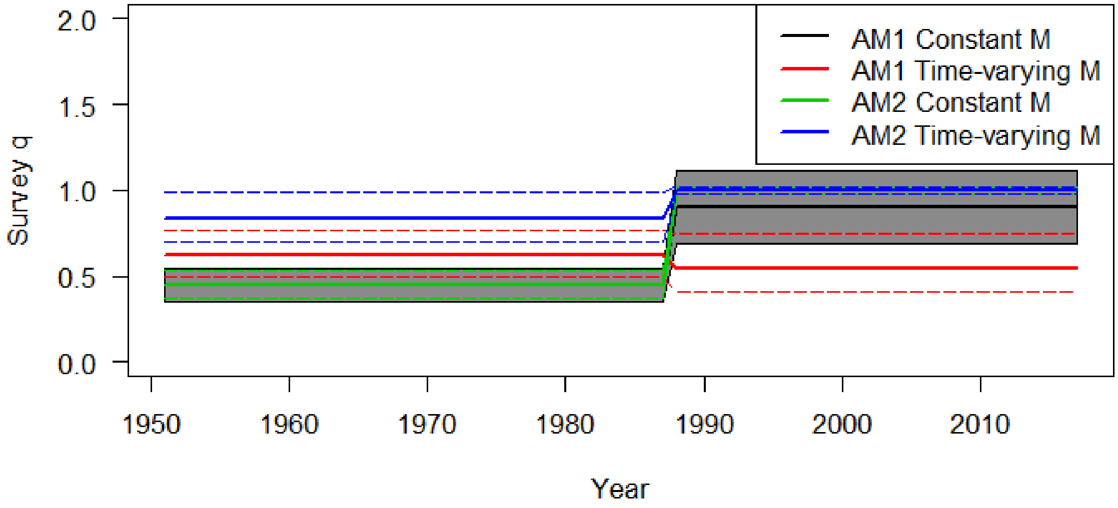


Figure 89. Natural Mortality Sensitivity Case: Natural mortality sensitivity models survey q for the WCVI stock.

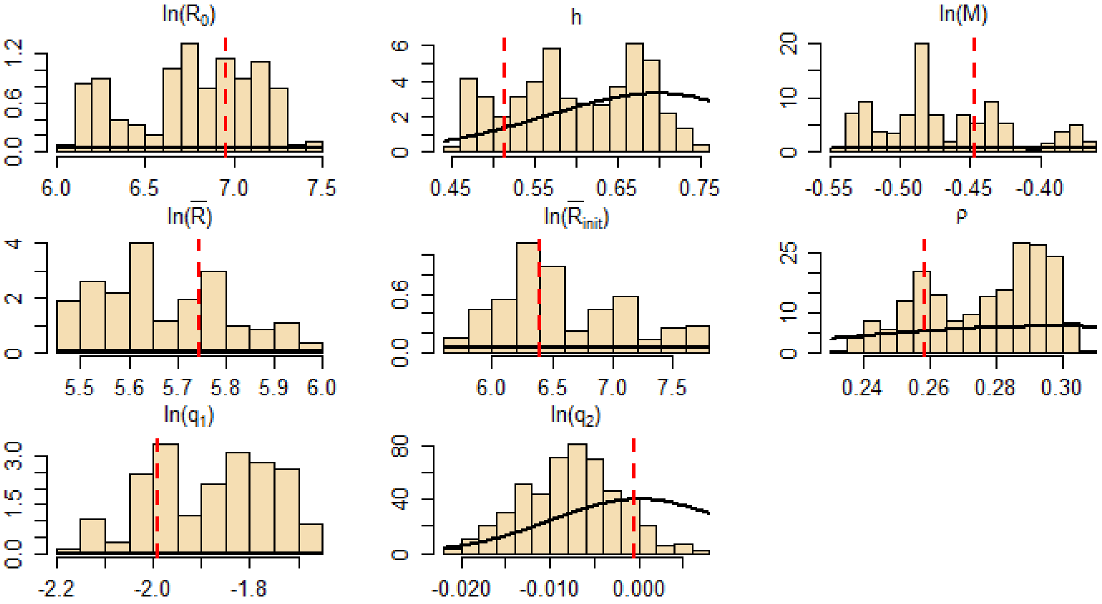


Figure 90. Prior probability distributions (lines) with comparative posterior histograms (bars) used in the Haida Gwaii AM2 model with constant natural mortality. Parameters q_k represent gears where: $k = 1$ is the surface survey and $k = 2$ is the dive survey. The dotted red lines are the MPD estimates.

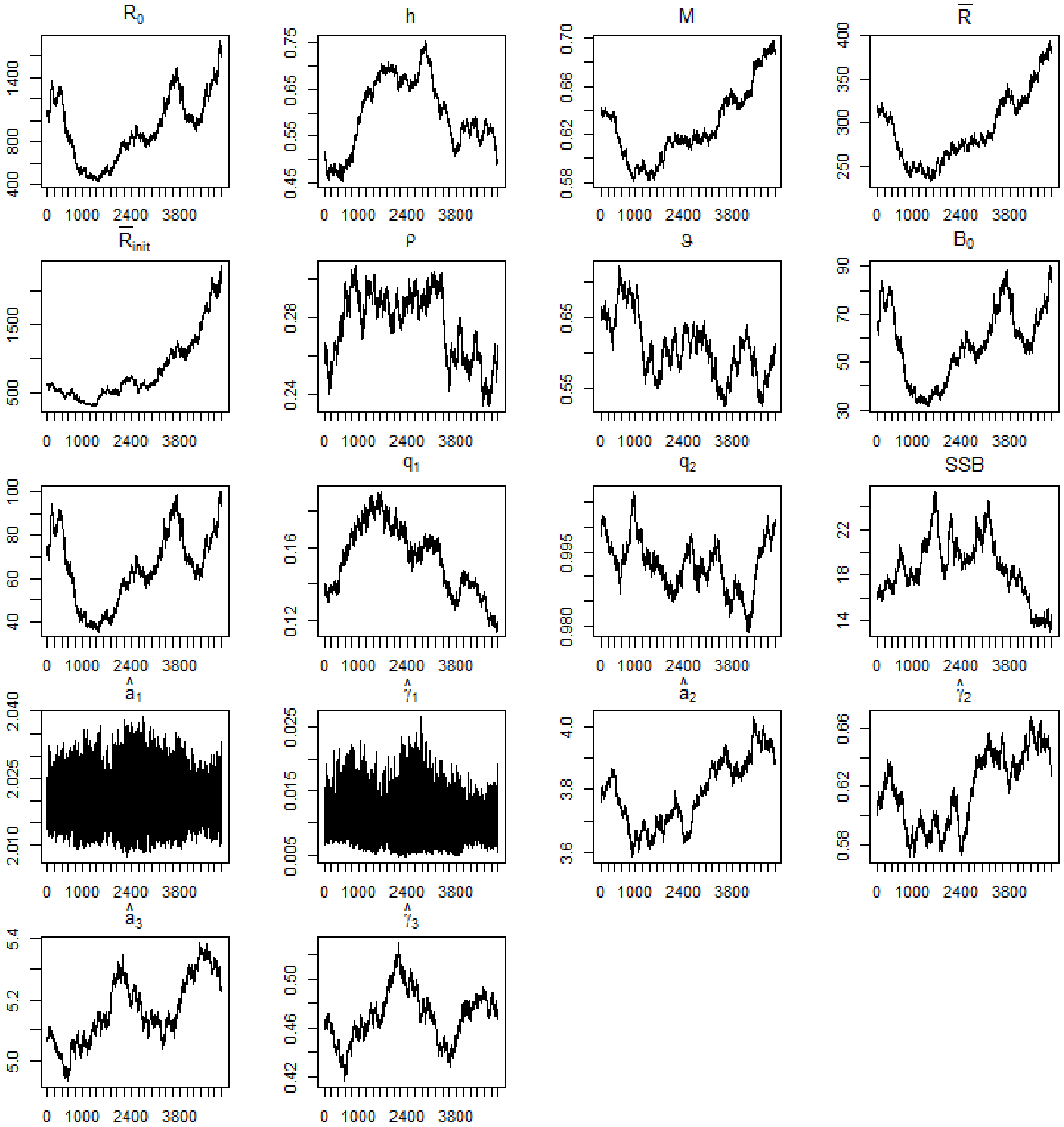


Figure 91. Trace plots for MCMC output of estimated parameters for the Haida Gwaii AM2 model with constant natural mortality. The MCMC run had chain length 5 million, with a sample taken at every 1,000th iteration. The catchability parameter q_1 represents the surface survey and q_2 the dive survey. Parameters $\hat{a}_k$ (selectivity-at-age-50%), and $\hat{\gamma}_k$ (selectivity standard deviation-at-50%) represent gears as follows: k = 1: Other fisheries, k = 2: Roe seine, k = 3: Gillnet roe.

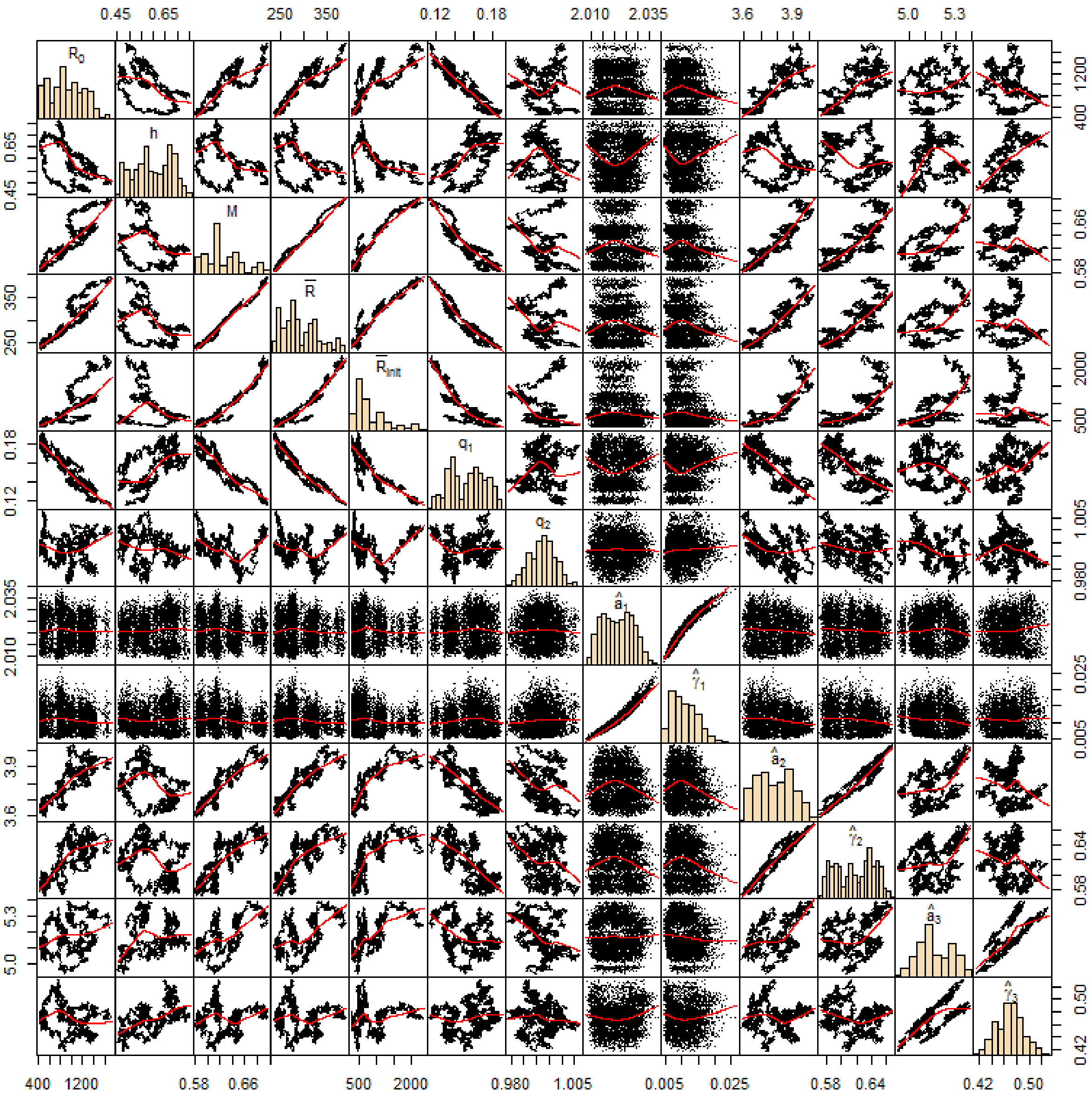


Figure 92. Pairs plots for MCMC output of estimated parameters in for the Haida Gwaii AM2 model with constant natural mortality. See Figure 32 for parameter descriptions.

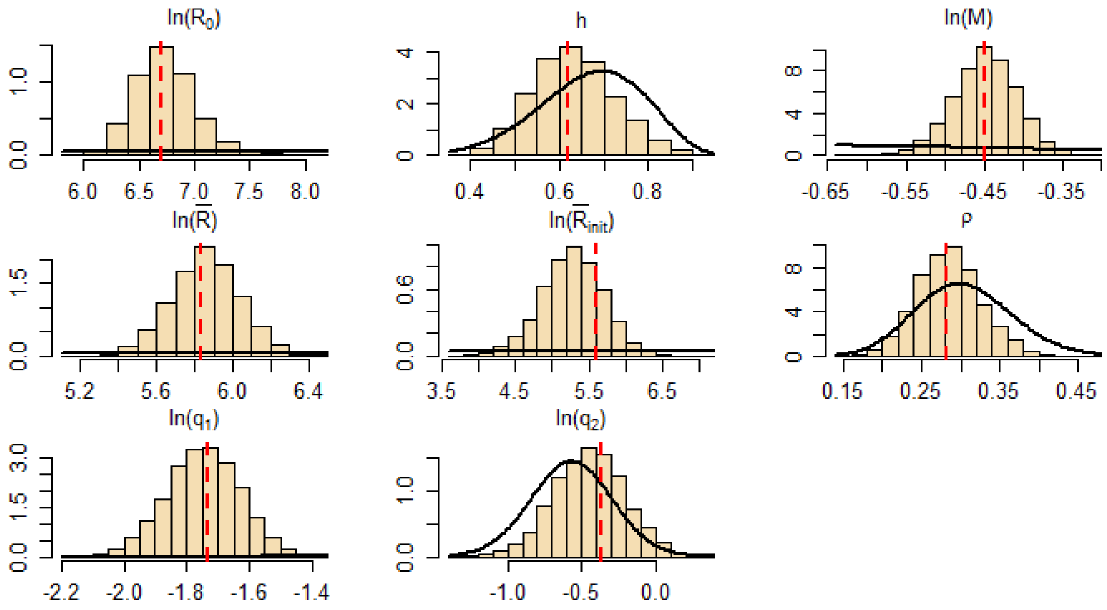


Figure 93. Prior probability distributions (lines) with comparative posterior histograms (bars) used in the Haida Gwaii AM1 model with constant natural mortality. Parameters q_k *represent gears where:* $k = 1$ *is the surface survey and* $k = 2$ *is the dive survey. The dotted red lines are the MPD estimates.*

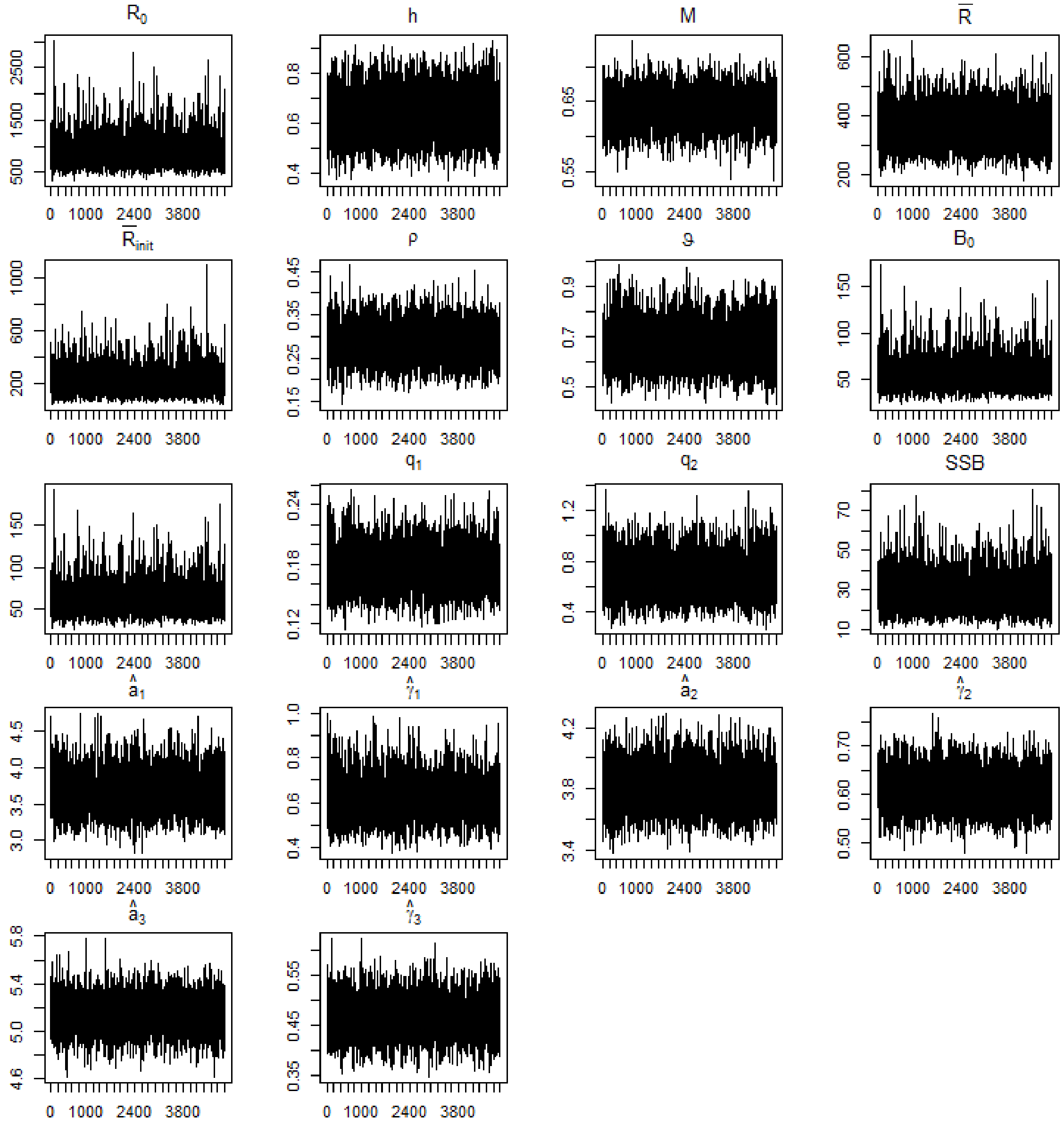


Figure 94. Trace plots for MCMC output of estimated parameters for the Haida Gwaii AM1 model with constant natural mortality. The MCMC run had chain length 5 million, with a sample taken at every 1,000th iteration. The catchability parameter q_1 represents the surface survey and q_2 the dive survey. Parameters $\hat{a}_k$ (selectivity-at-age-50%), and $\hat{\gamma}_k$ (selectivity standard deviation-at-50%) represent gears as follows:k = 1: Other fisheries, k = 2: Roe seine, k = 3: Gillnet roe.

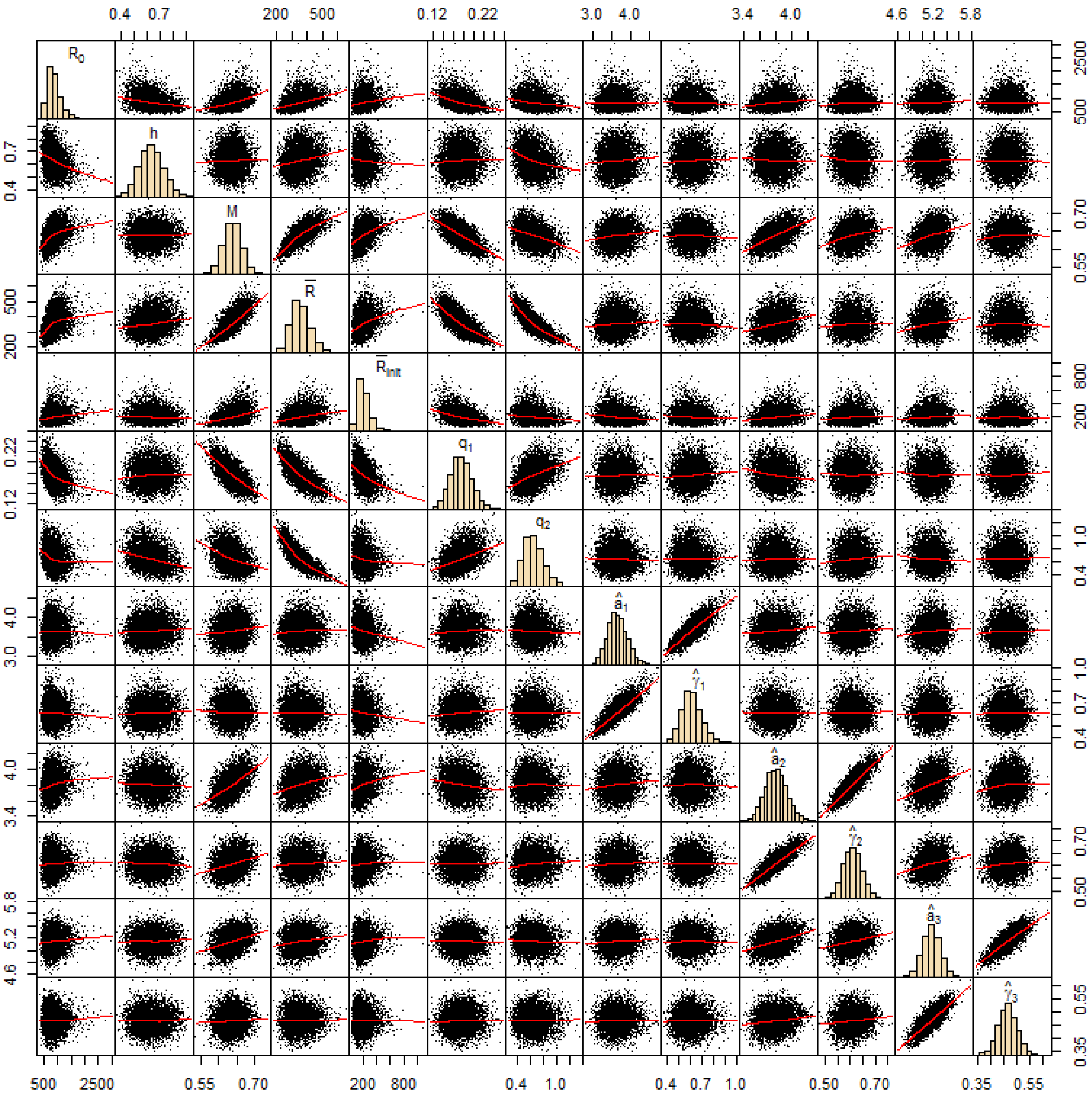


Figure 95. Pairs plots for MCMC output of estimated parameters in for the Haida Gwaii AM1 model with constant natural mortality. See Figure 32 for parameter descriptions.

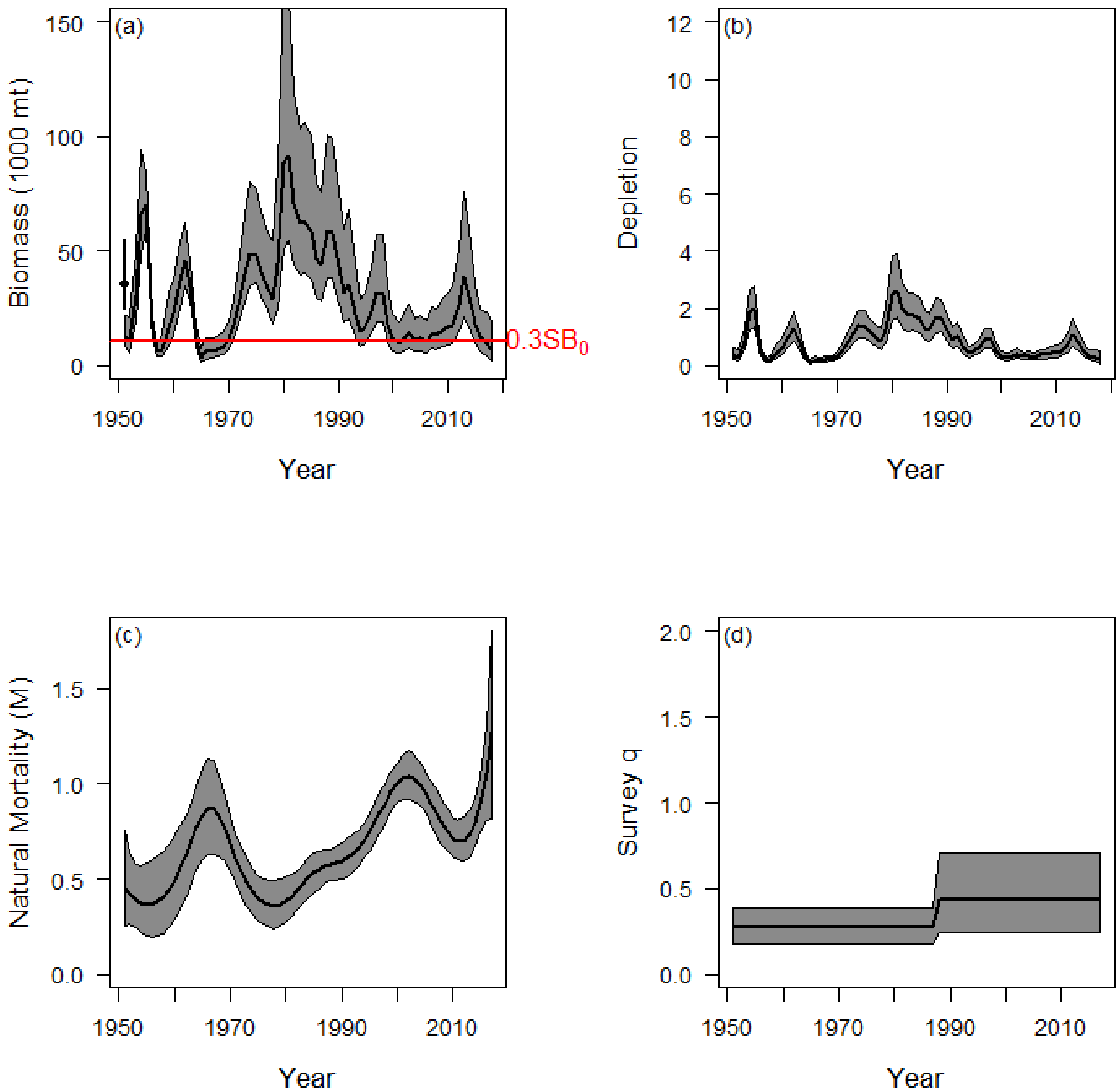


Figure 96. q Prior Sensitivity Case: Biomass (a), Depletion (b), Natural Mortality (c) and Survey Q (d) for the sensitivity model where the survey q standard deviation prior is set to 3 for the Haida Gwaii stock.

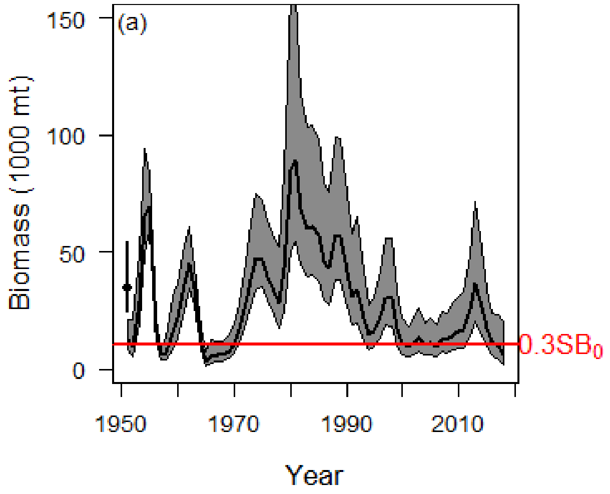


Figure 97. q Prior Sensitivity Case: Biomass (a), Depletion (b), Natural Mortality (c) and Survey Q (d) for the sensitivity model where the survey q standard deviation prior is set to 2 for the Haida Gwaii stock.

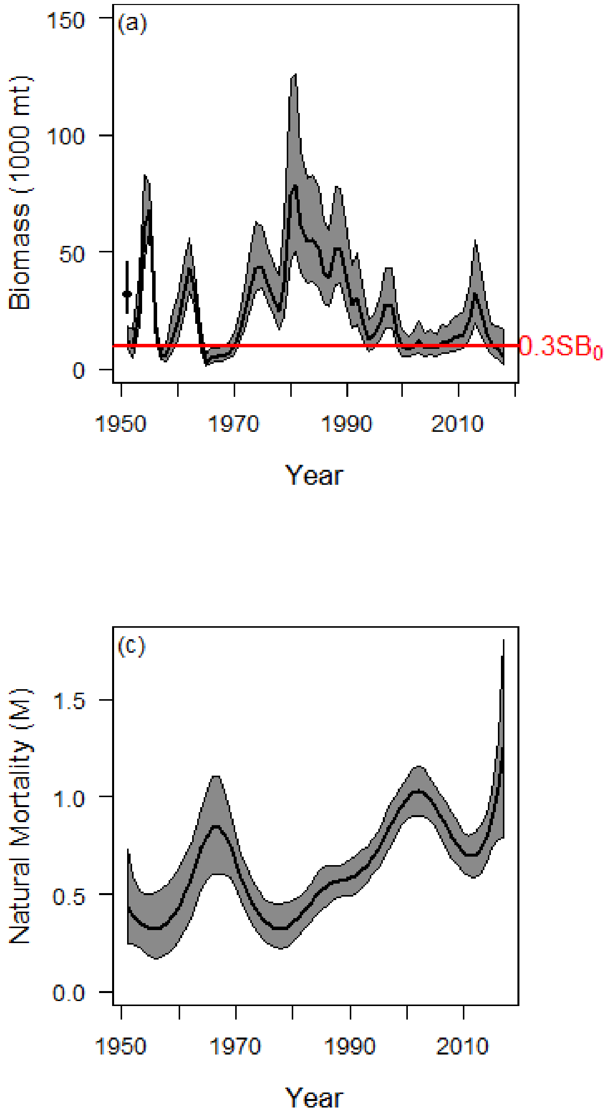


Figure 98. q Prior Sensitivity Case: Biomass (a), Depletion (b), Natural Mortality (c) and Survey Q (d) for the sensitivity model where the survey q standard deviation prior is set to 0.5 for the Haida Gwaii stock.

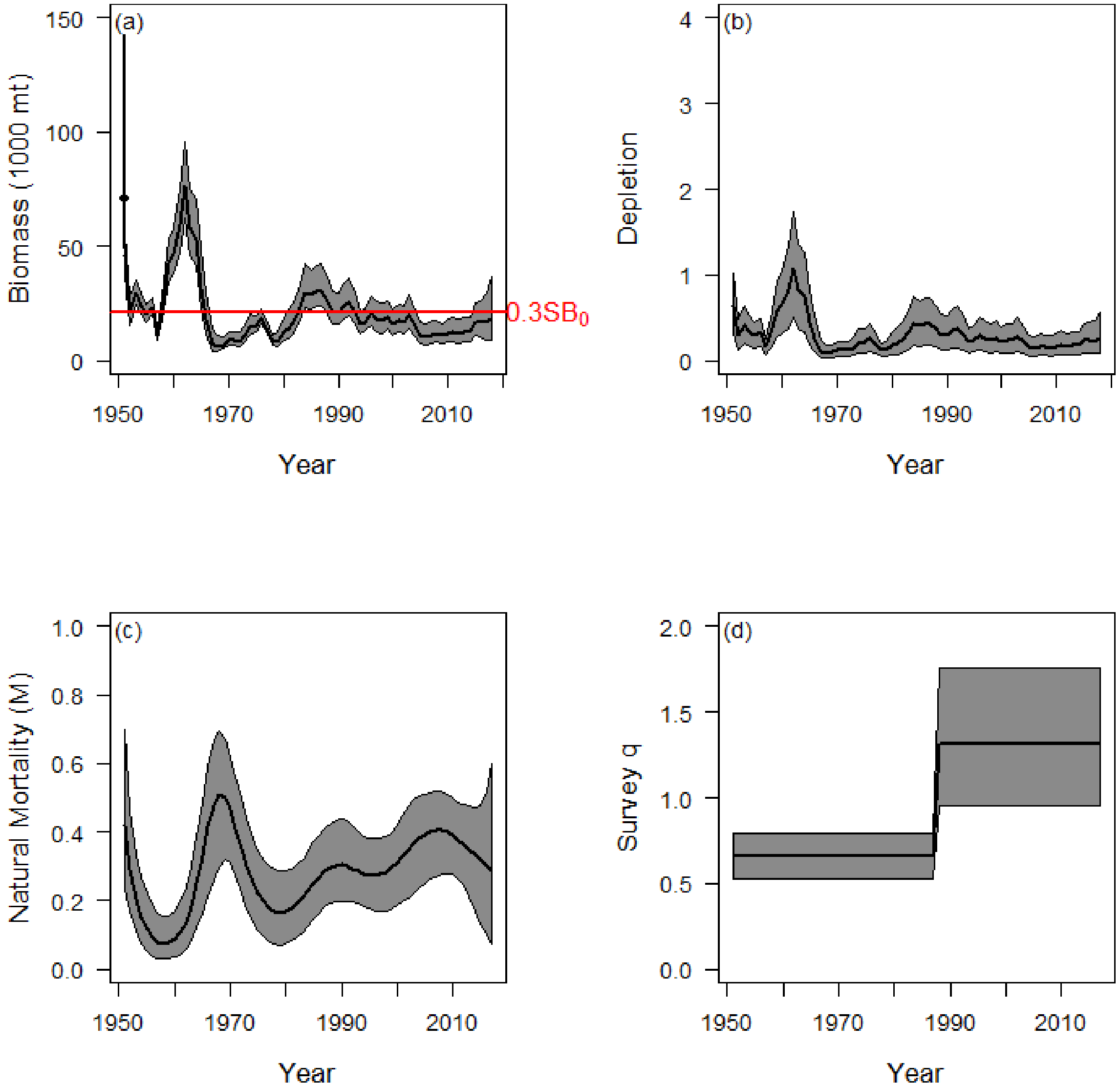


Figure 99. q Prior Sensitivity Case: Biomass (a), Depletion (b), Natural Mortality (c) and Survey Q (d) for the sensitivity model where the survey q standard deviation prior is set to 3 for the Prince Rupert District stock.

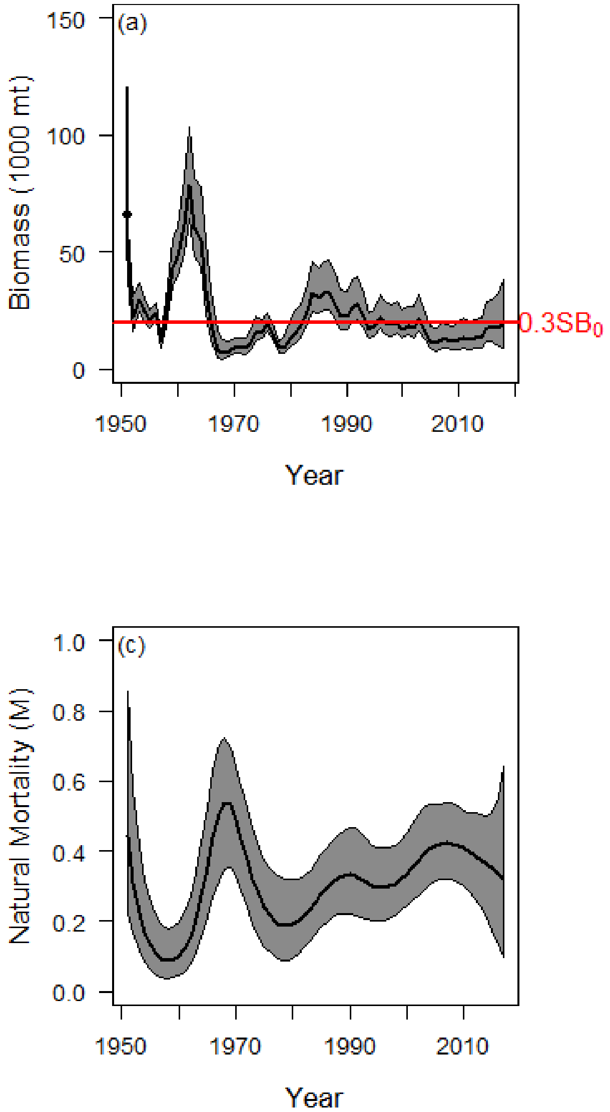


Figure 100. q Prior Sensitivity Case: Biomass (a), Depletion (b), Natural Mortality (c) and Survey Q (d) for the sensitivity model where the survey q standard deviation prior is set to 2 for the Prince Rupert District stock.

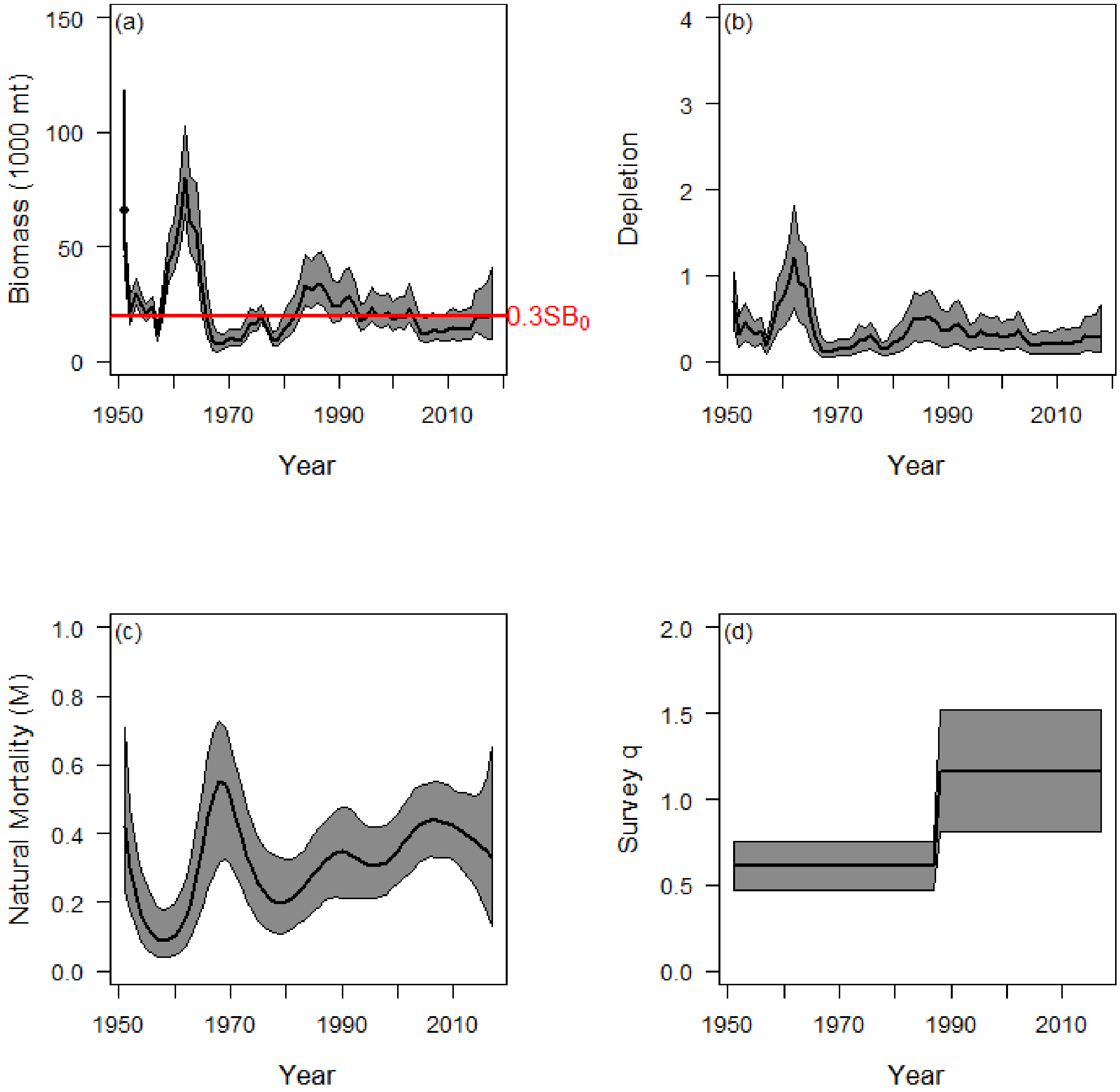


Figure 101. q Prior Sensitivity Case: Biomass (a), Depletion (b), Natural Mortality (c) and Survey Q (d) for the sensitivity model where the survey q standard deviation prior is set to 0.5 for the Prince Rupert District stock.

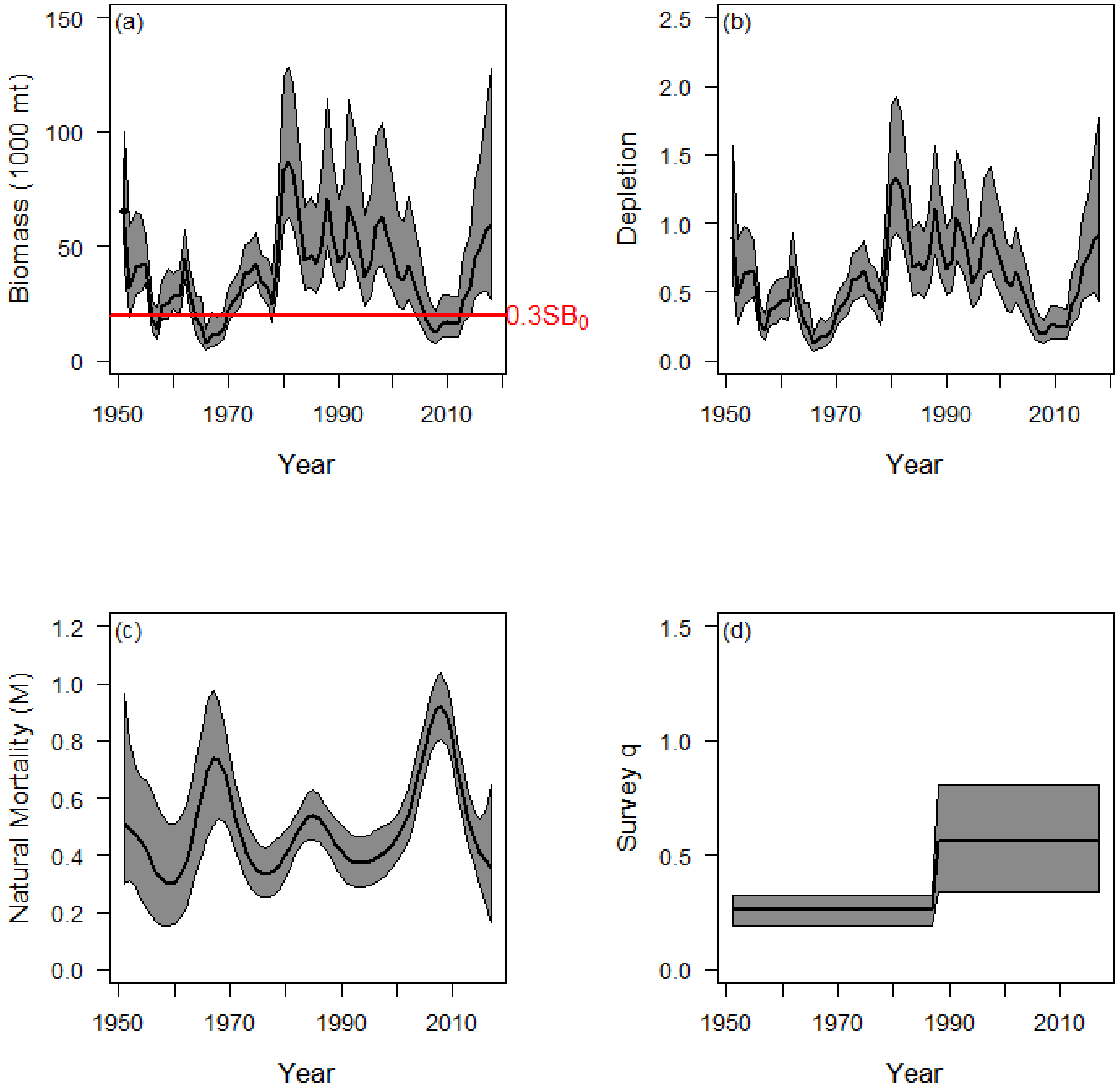


Figure 102. q Prior Sensitivity Case: Biomass (a), Depletion (b), Natural Mortality (c) and Survey Q (d) for the sensitivity model where the survey q standard deviation prior is set to 3 for the Central Coast stock.

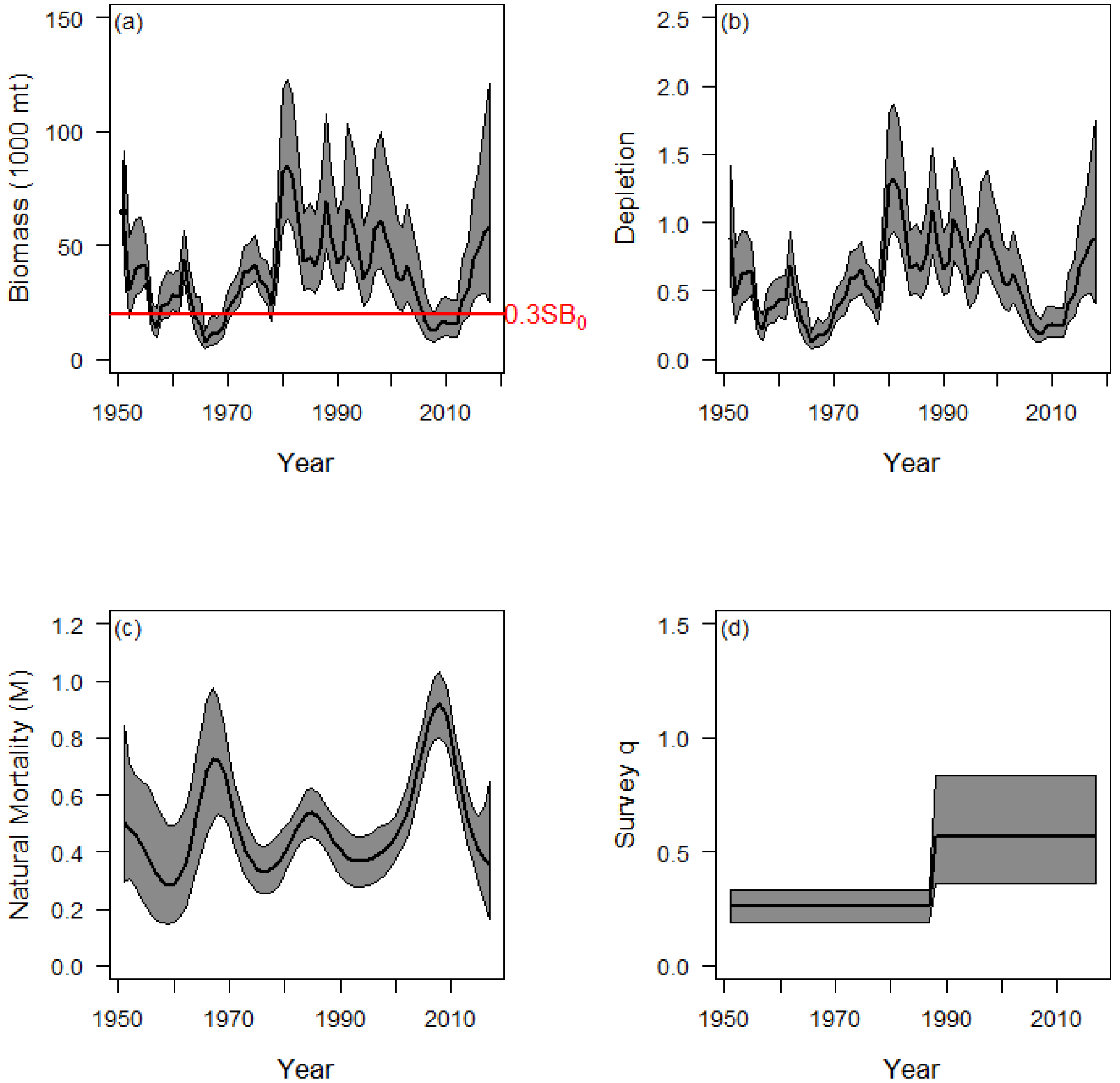


Figure 103. q Prior Sensitivity Case: Biomass (a), Depletion (b), Natural Mortality (c) and Survey Q (d) for the sensitivity model where the survey q standard deviation prior is set to 2 for the Central Coast stock.

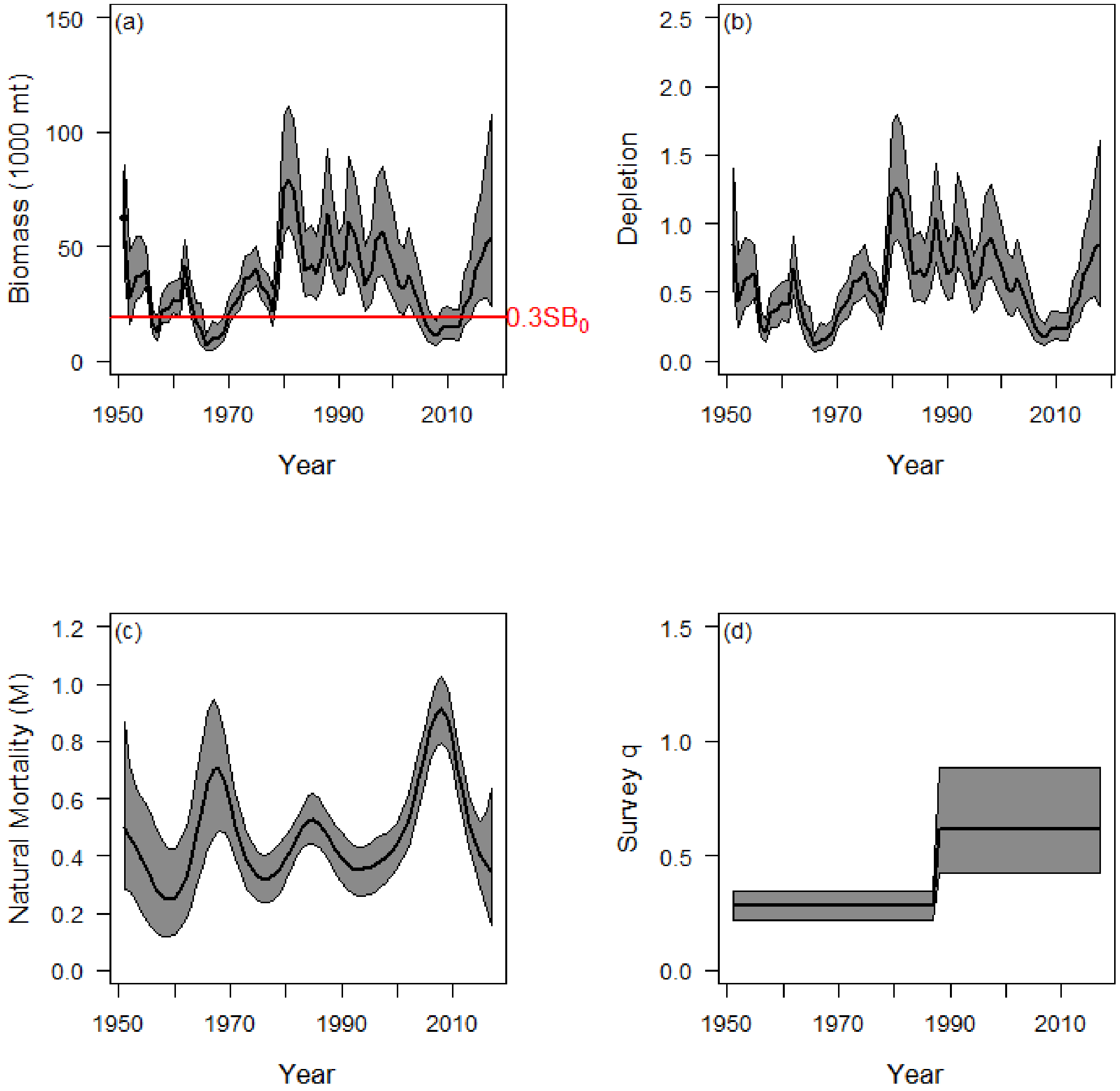


Figure 104. q Prior Sensitivity Case: Biomass (a), Depletion (b), Natural Mortality (c) and Survey Q (d) for the sensitivity model where the survey q standard deviation prior is set to 0.5 for the Central Coast stock.

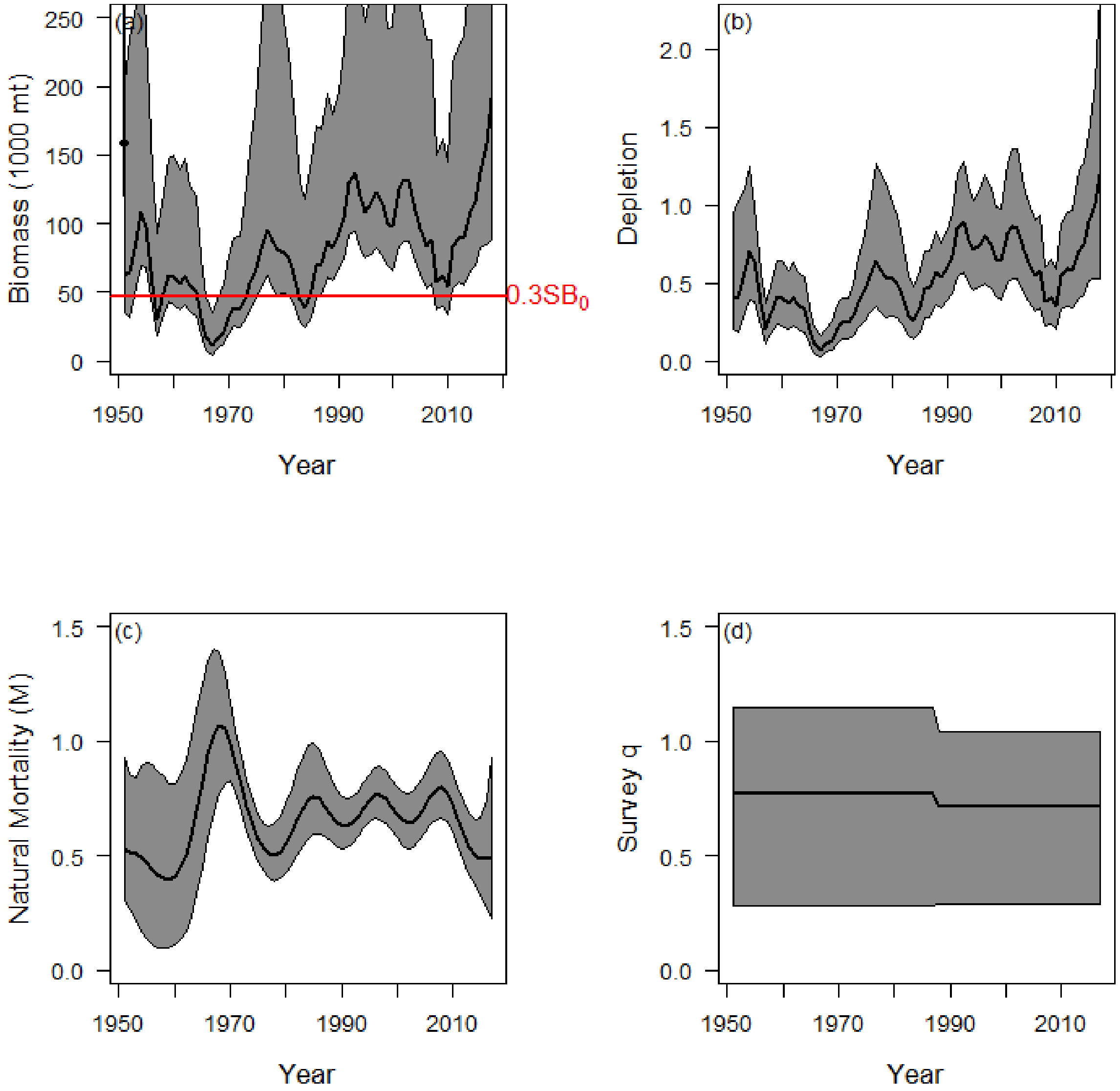


Figure 105. q Prior Sensitivity Case: Biomass (a), Depletion (b), Natural Mortality (c) and Survey Q (d) for the sensitivity model where the survey q standard deviation prior is set to 3 for the Strait of Georgia stock.

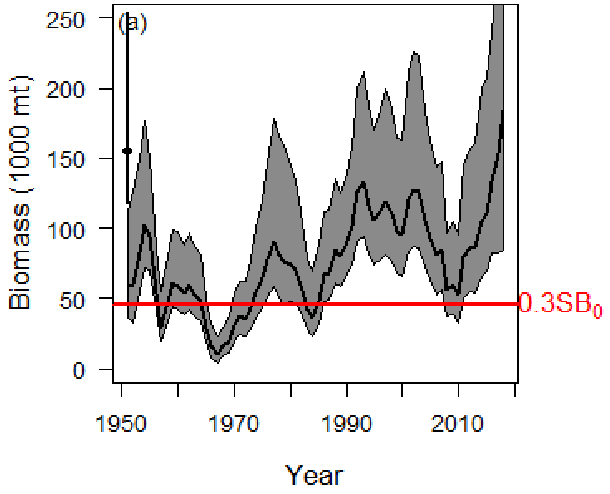


Figure 106. q Prior Sensitivity Case: Biomass (a), Depletion (b), Natural Mortality (c) and Survey Q (d) for the sensitivity model where the survey q standard deviation prior is set to 2 for the Strait of Georgia stock.

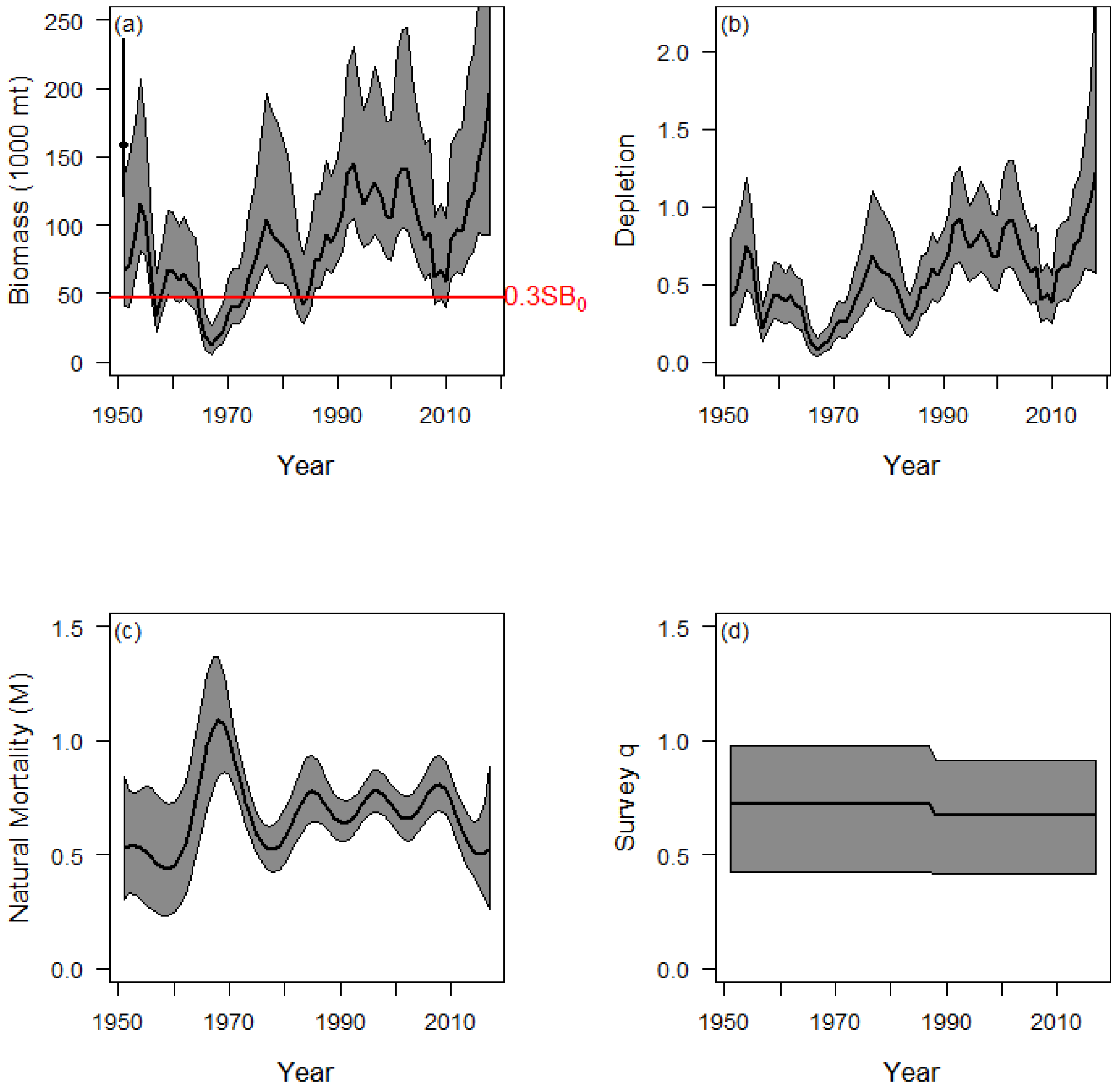


Figure 107. q Prior Sensitivity Case: Biomass (a), Depletion (b), Natural Mortality (c) and Survey Q (d) for the sensitivity model where the survey q standard deviation prior is set to 0.5 for the Strait of Georgia stock.

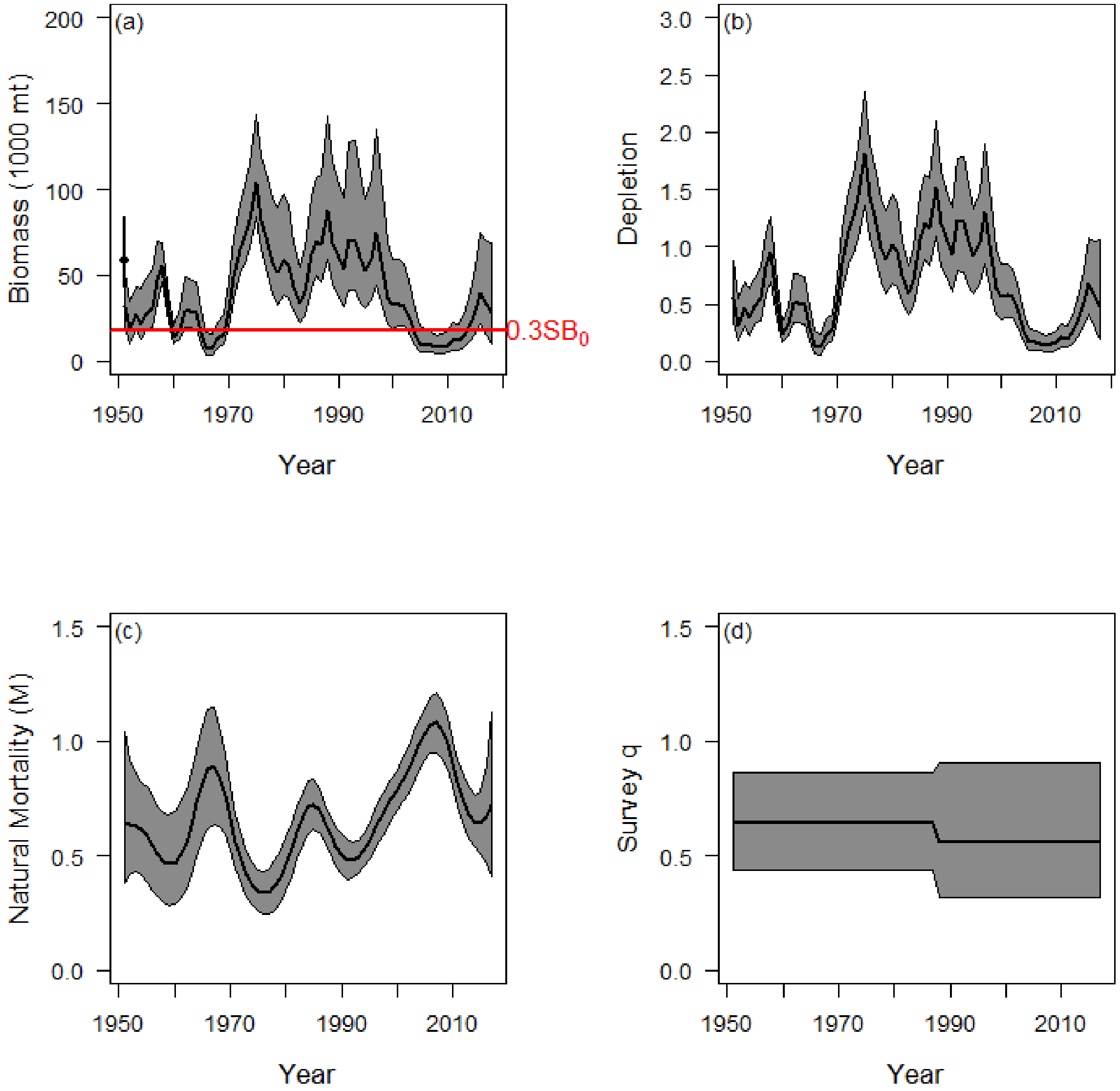


Figure 108. q Prior Sensitivity Case: Biomass (a), Depletion (b), Natural Mortality (c) and Survey Q (d) for the sensitivity model where the survey q standard deviation prior is set to 3 for the WCVI stock.

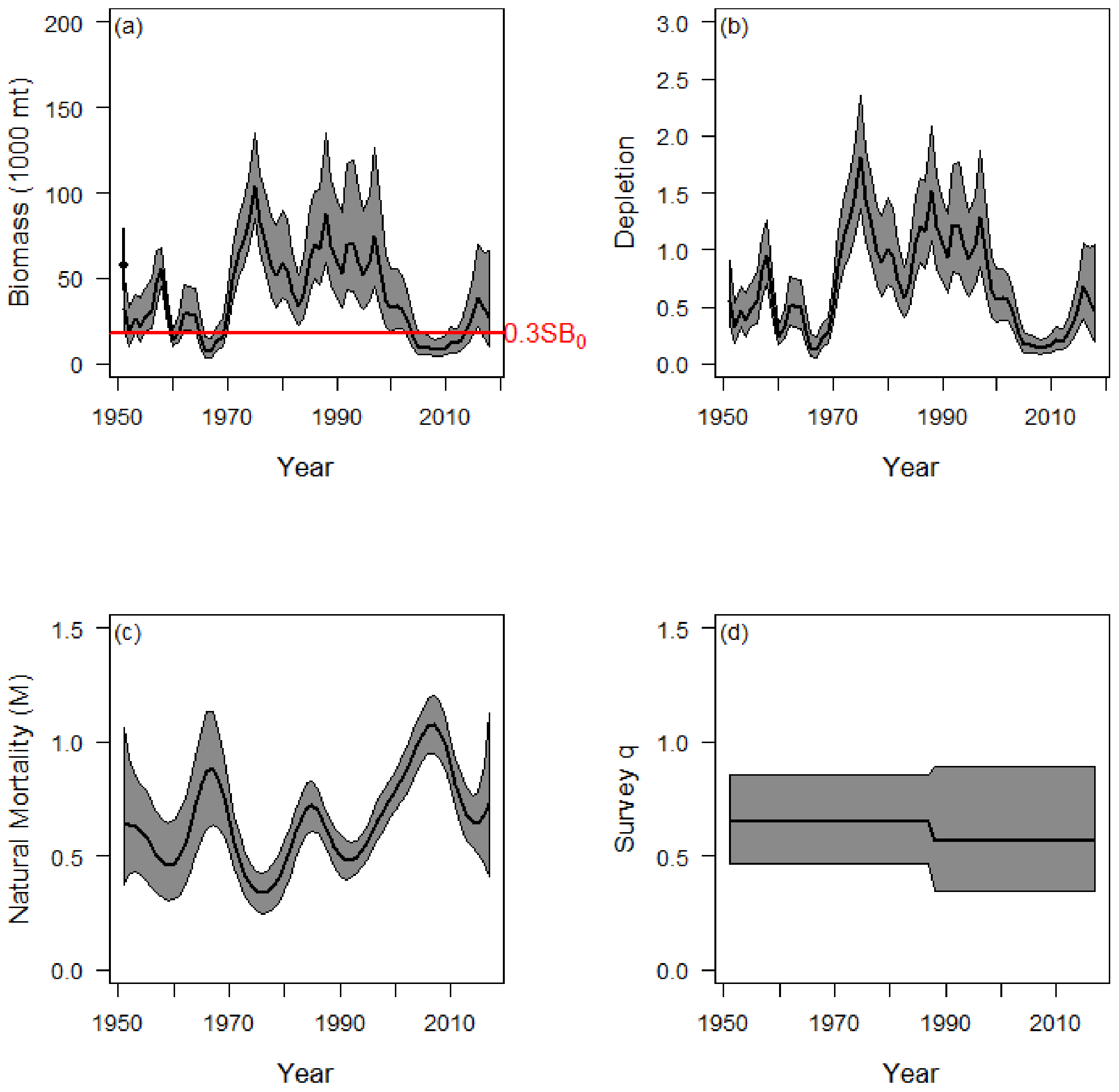


Figure 109. q Prior Sensitivity Case: Biomass (a), Depletion (b), Natural Mortality (c) and Survey Q (d) for the sensitivity model where the survey q standard deviation prior is set to 2 for the WCVI stock.

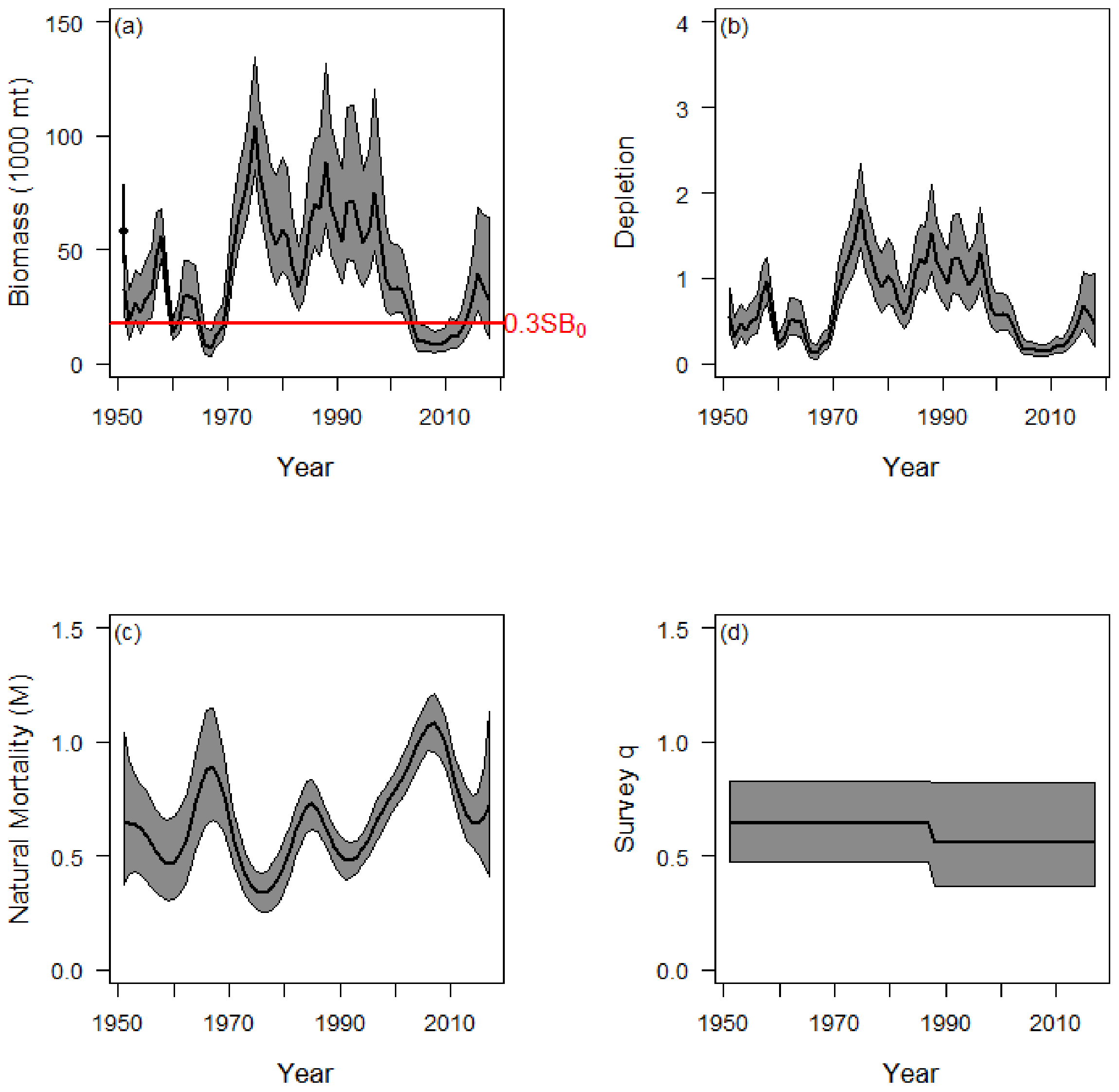


Figure 110. q Prior Sensitivity Case: Biomass (a), Depletion (b), Natural Mortality (c) and Survey Q (d) for the sensitivity model where the survey q standard deviation prior is set to 0.5 for the WCVI stock.

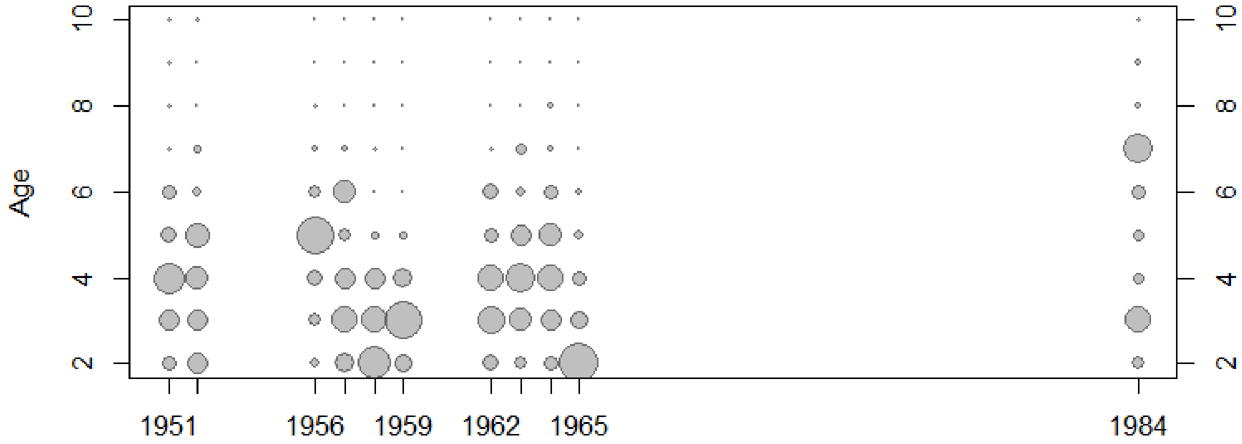


Figure 111. Estimated proportion-at-age versus time for Gear 1 (other fisheries), for Haida Gwaii. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10.

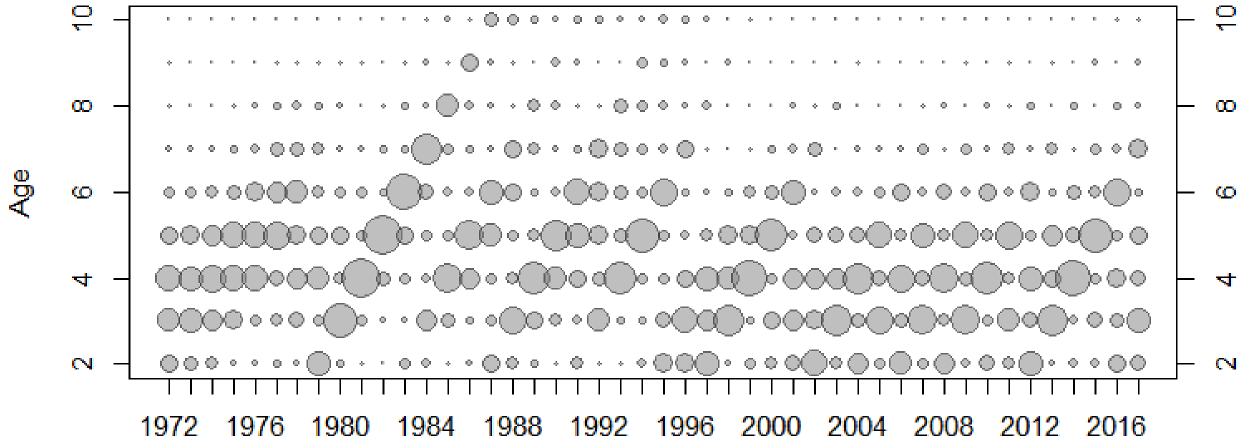


Figure 112. Estimated proportion-at-age versus time for Gear 2 (roe seine), for Haida Gwaii. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10.

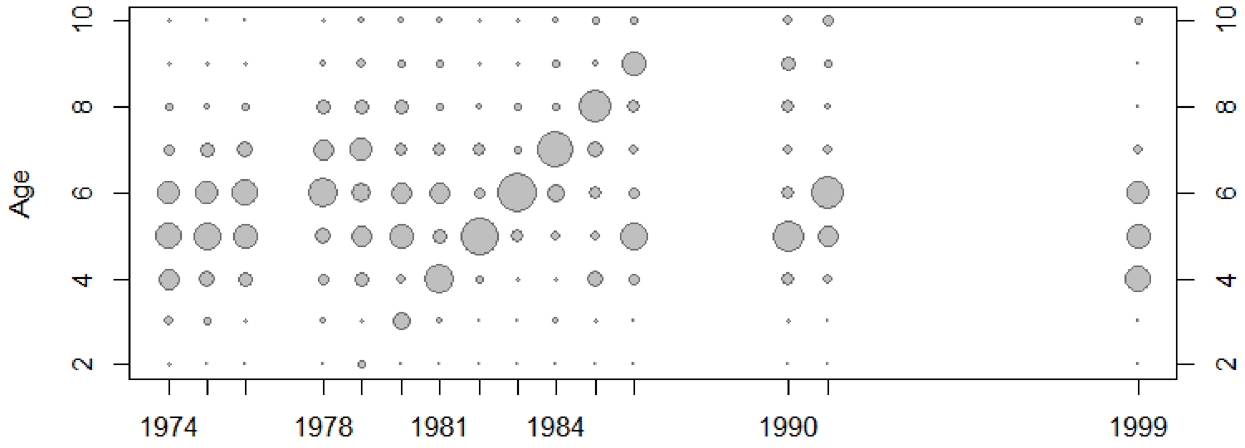


Figure 113. Estimated proportion-at-age versus time for Gear 3 (row gillnet), for Haida Gwaii. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10.

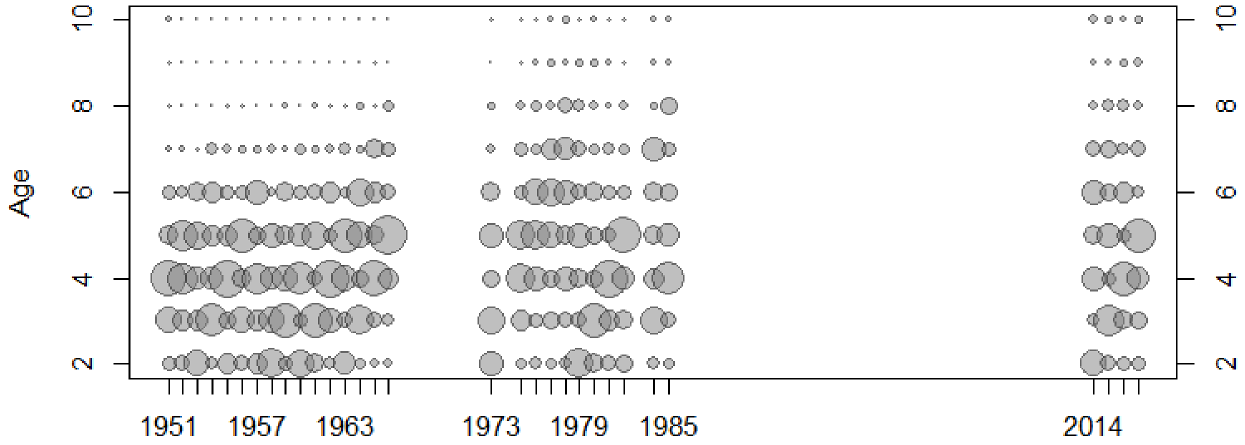


Figure 114. Estimated proportion-at-age versus time for Gear 1 (other fisheries), for the Prince Rupert District. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10.

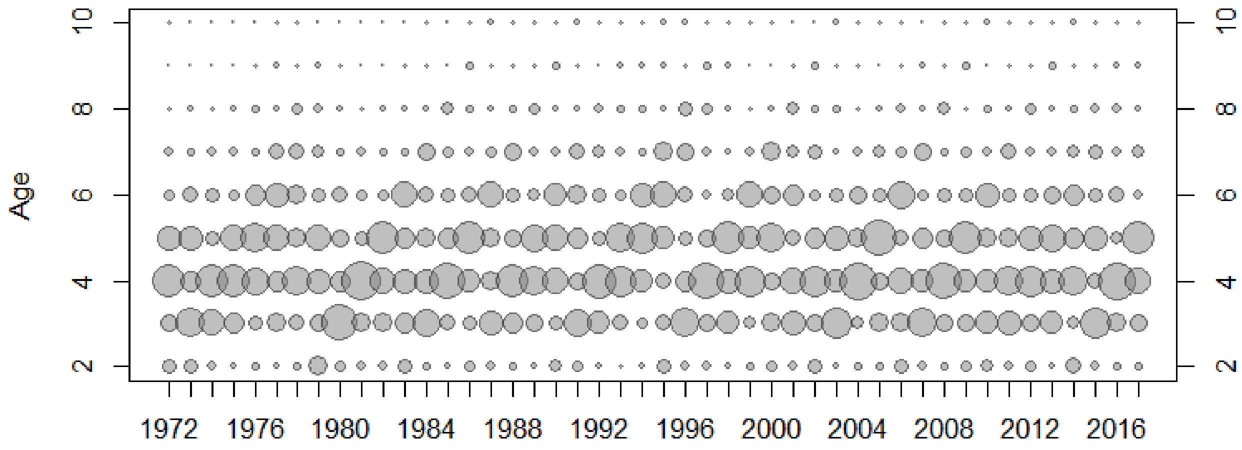


Figure 115. Estimated proportion-at-age versus time for Gear 2 (roe seine), for the Prince Rupert District. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10.

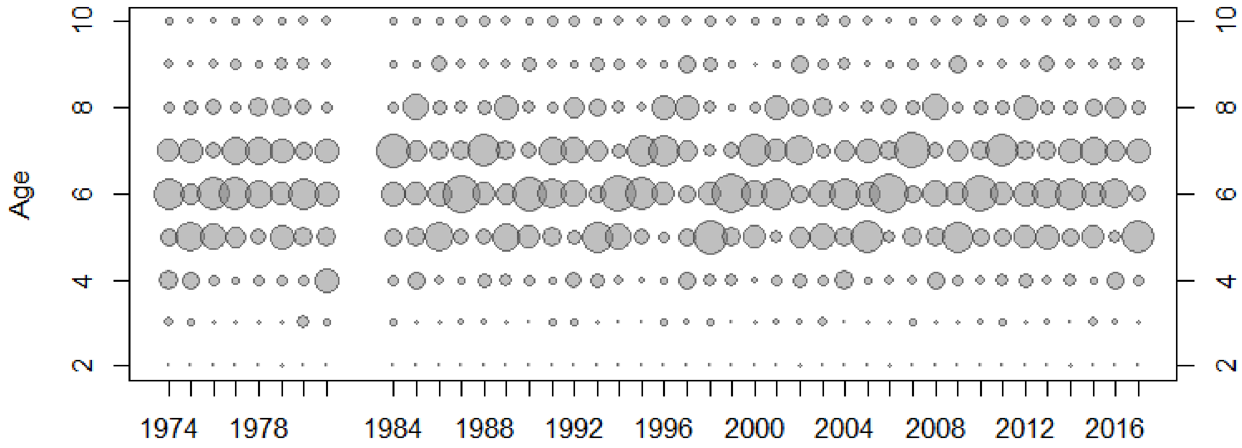


Figure 116. Estimated proportion-at-age versus time for Gear 3 (roe gillnet), for the Prince Rupert District. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10.

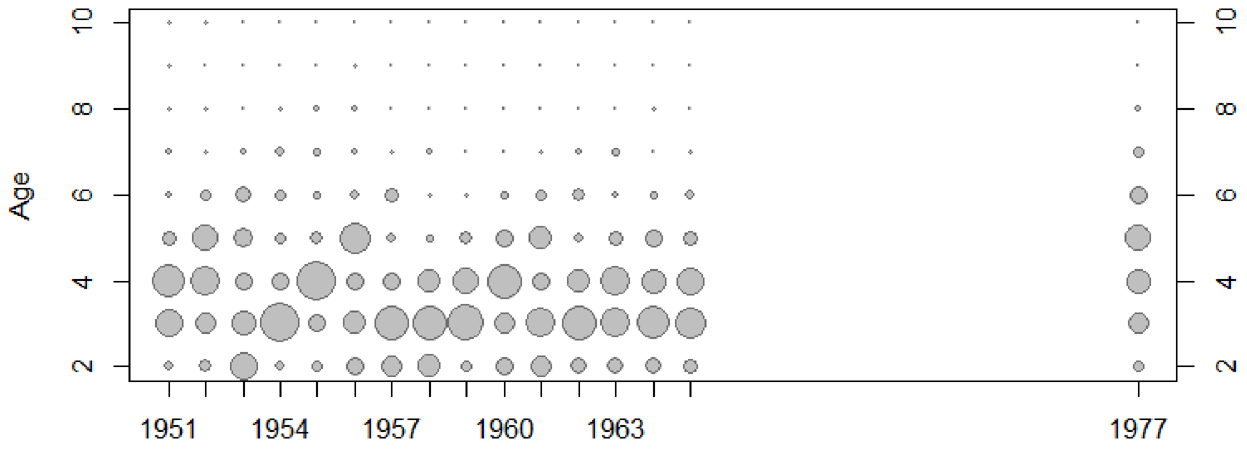


Figure 117. Estimated proportion-at-age versus time for Gear 1 (other fisheries), for the Central Coast. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10.

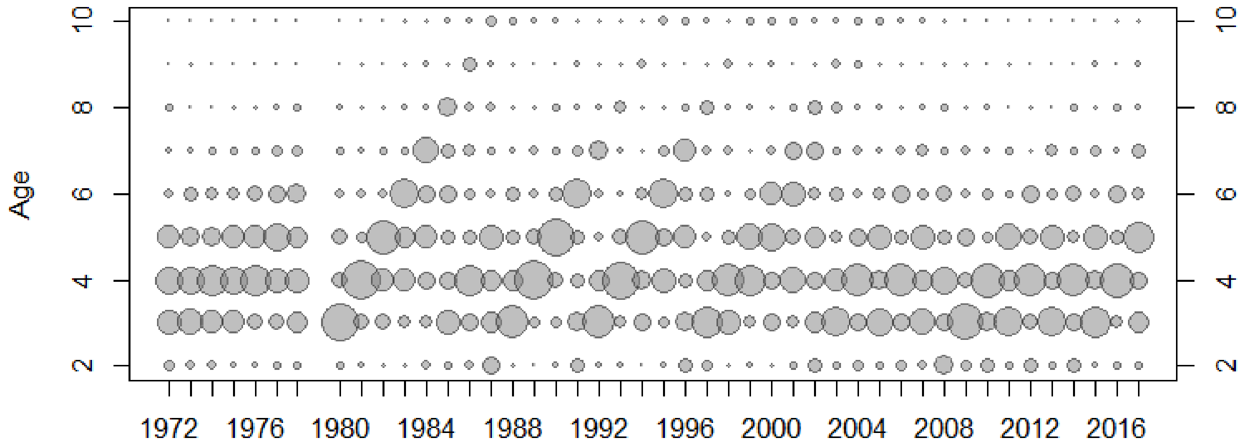


Figure 118. Estimated proportion-at-age versus time for Gear 2 (roe seine), for the Central Coast. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10.

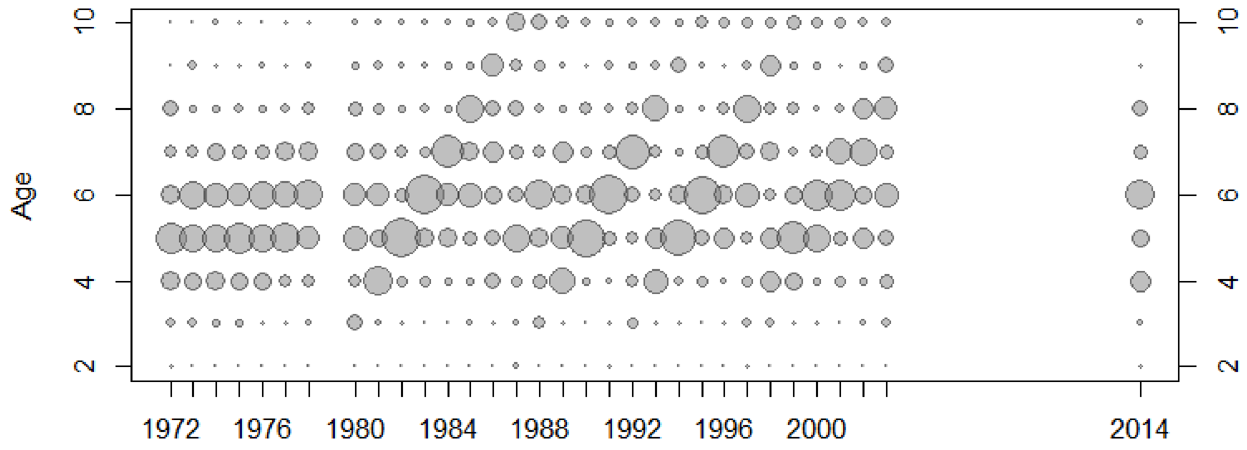


Figure 119. Estimated proportion-at-age versus time for Gear 3 (roe gillnet), for the Central Coast. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10.

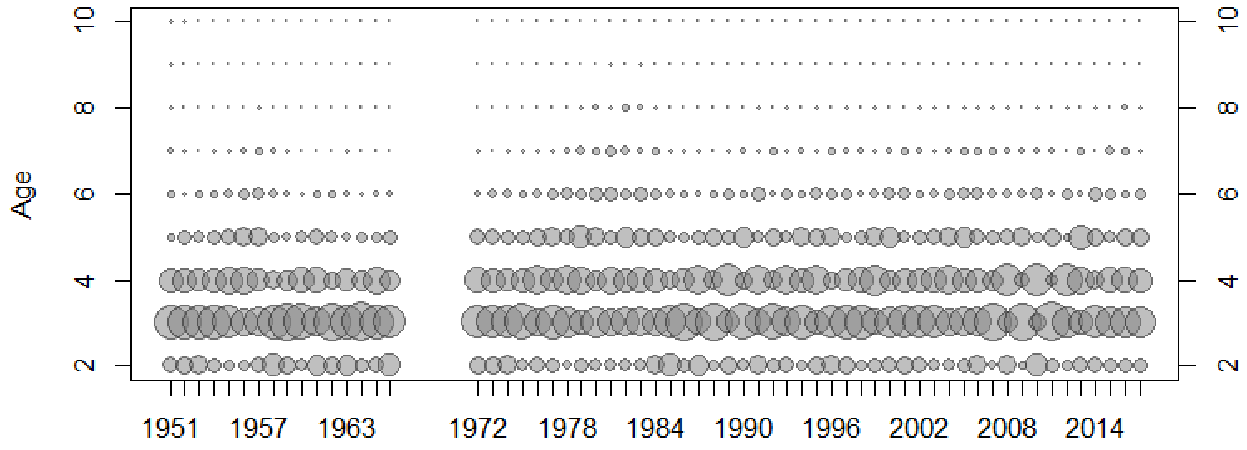


Figure 120. Estimated proportion-at-age versus time for Gear 1 (other fisheries), for the Strait of Georgia. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10.

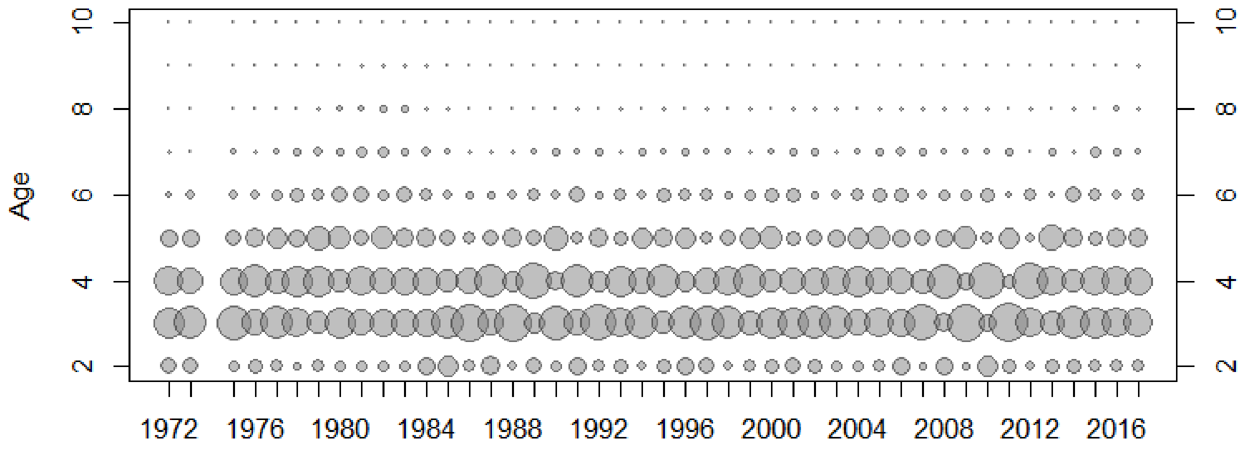


Figure 121. Estimated proportion-at-age versus time for Gear 2 (roe seine), for the Strait of Georgia. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10.

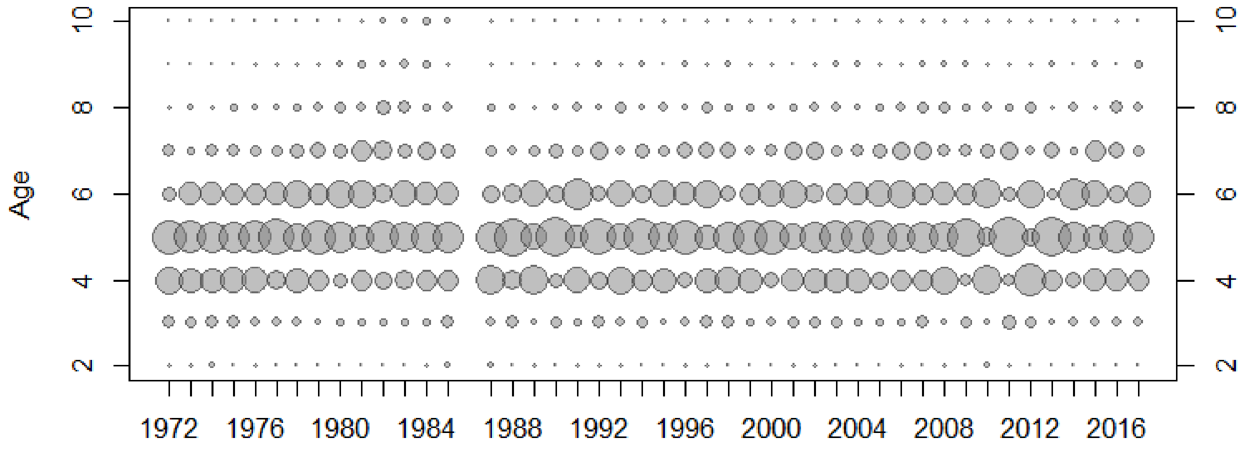


Figure 122. Estimated proportion-at-age versus time for Gear 3 (roe gillnet), for the Strait of Georgia. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10.

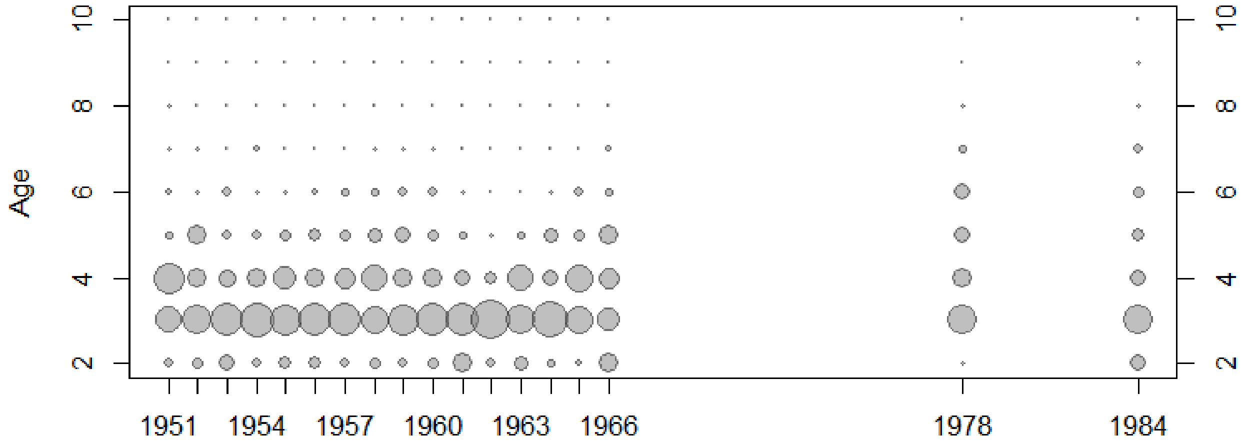


Figure 123. Estimated proportion-at-age versus time for Gear 1 (other fisheries), for the WCVI. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10.

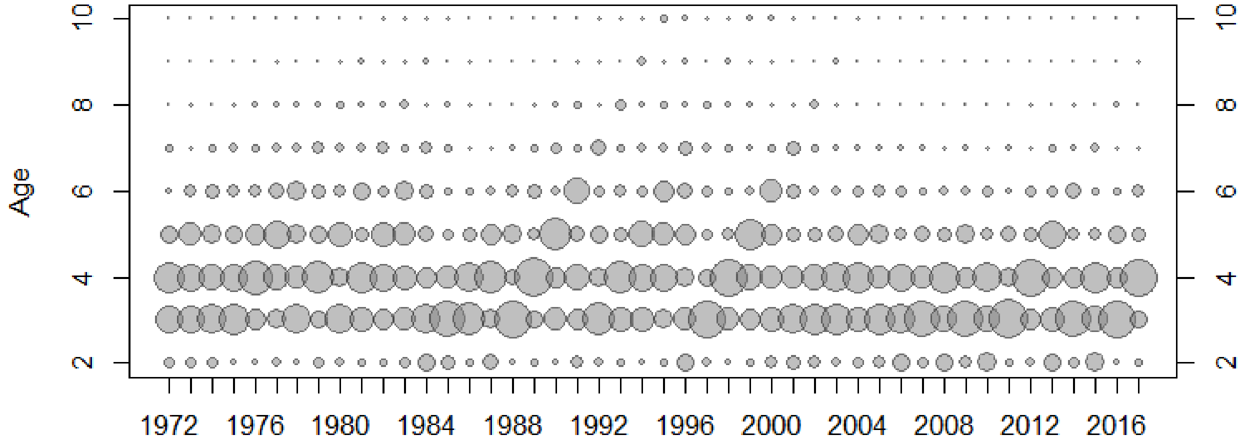


Figure 124. Estimated proportion-at-age versus time for Gear 2 (roe seine), for the WCVI. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10.

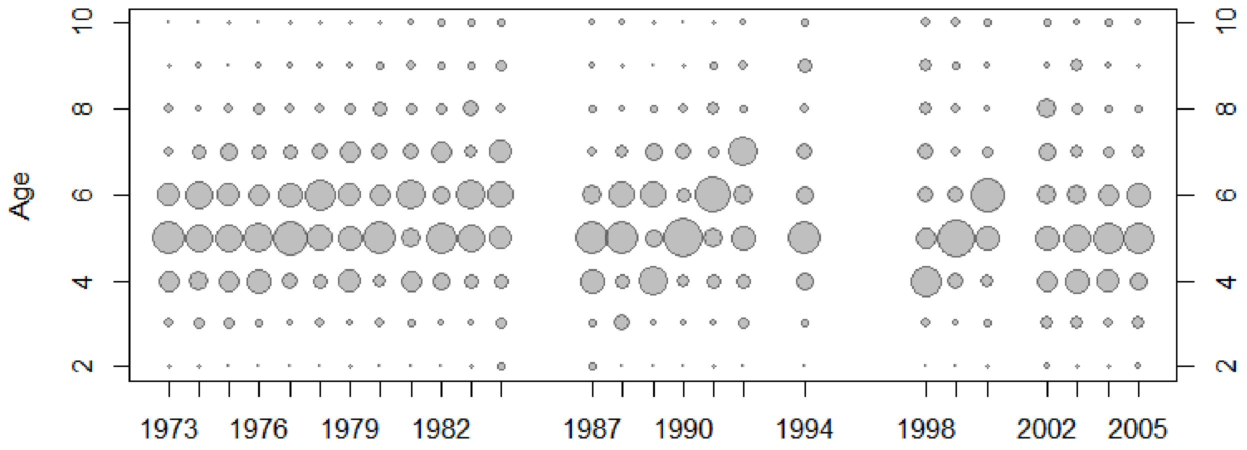


Figure 125. Estimated proportion-at-age versus time for Gear 3 (roe gillnet), for the WCVI. The area of each circle reflects the proportion-at-age, each column sums to 1, zeros are not shown. Plus group is age-10.

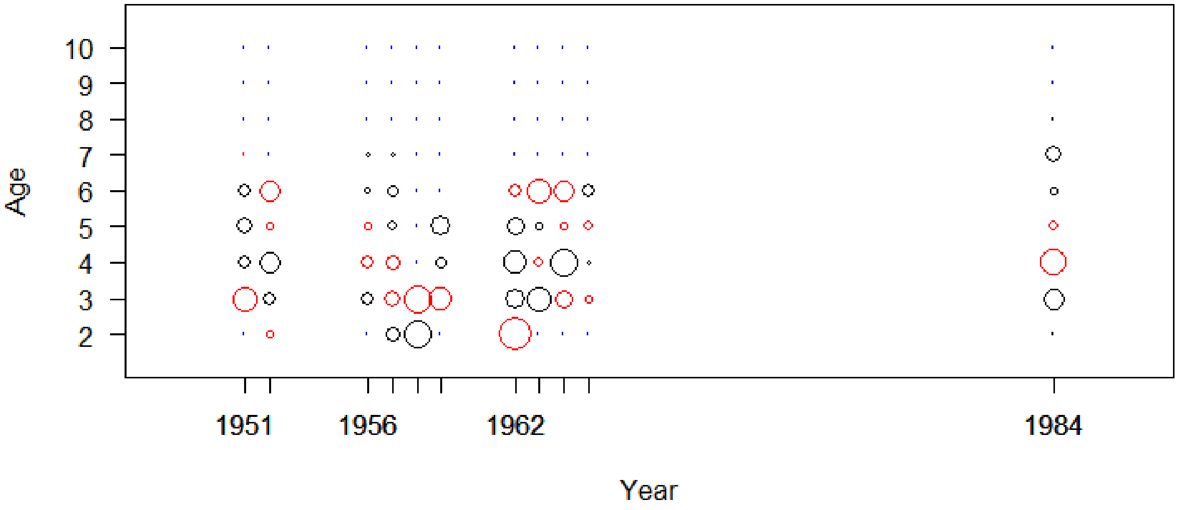


Figure 126. HG - gear 1 age fit residuals.

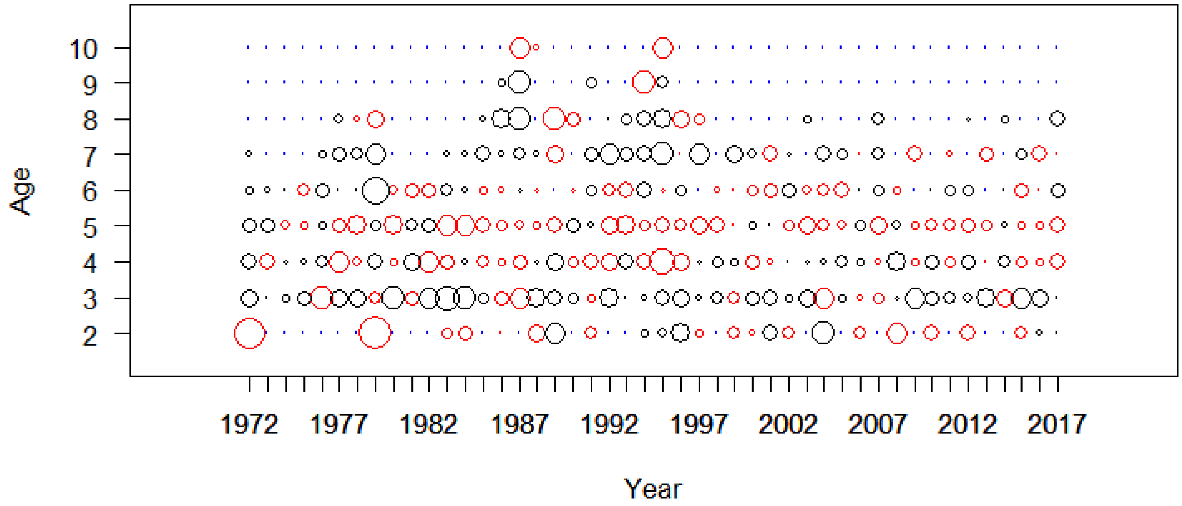


Figure 127. HG - gear 2 age fit residuals.

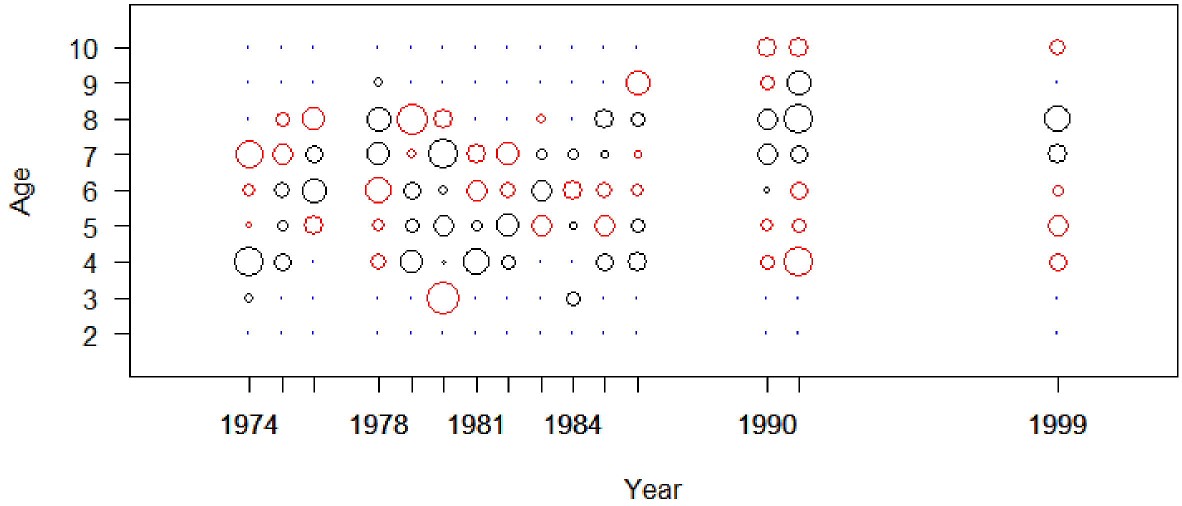


Figure 128. HG - gear 3 age fit residuals.

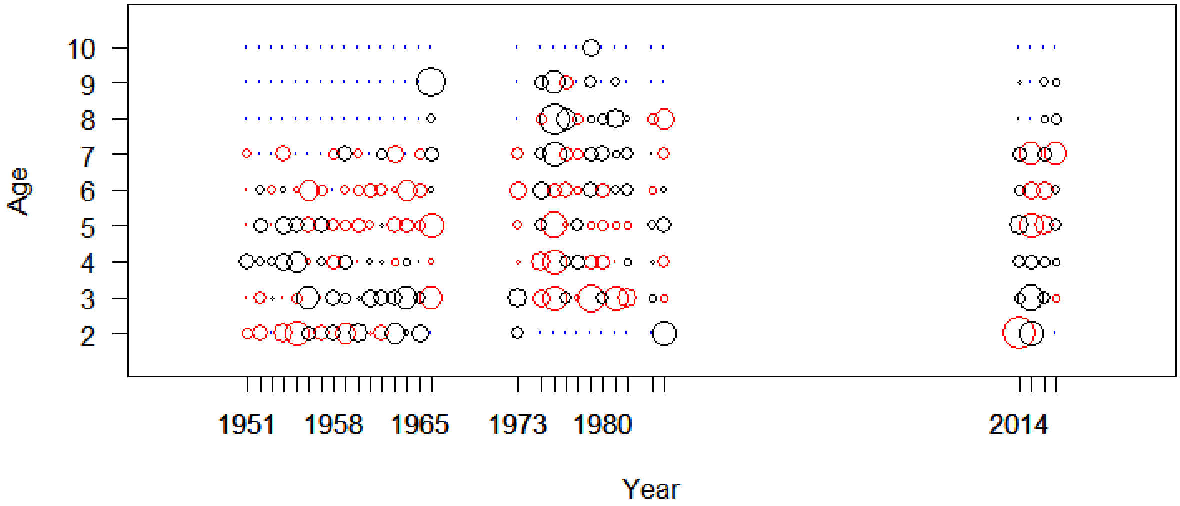


Figure 129. PRD - gear 1 age fit residuals.

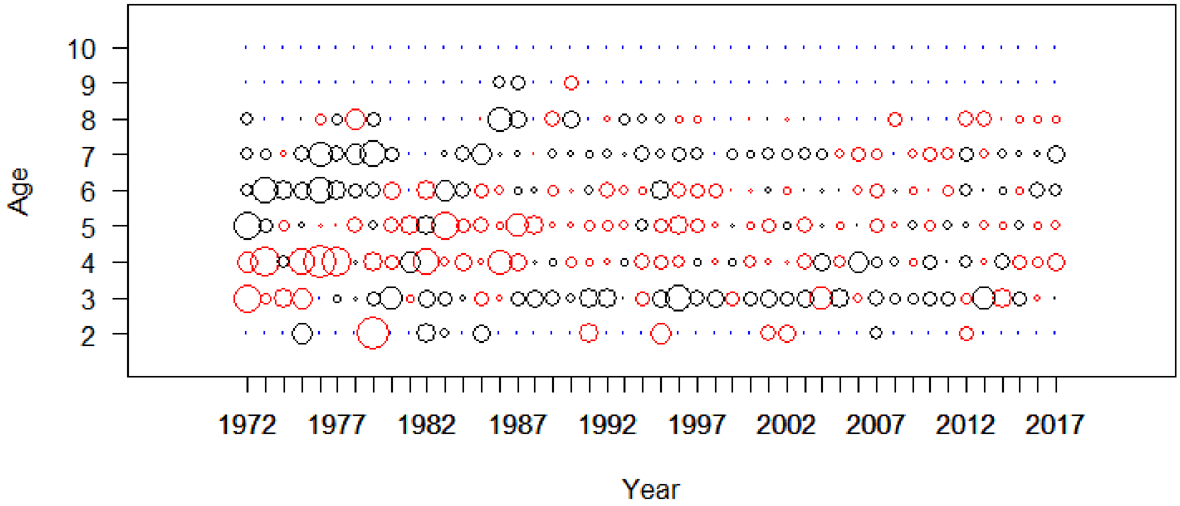


Figure 130. PRD - gear 2 age fit residuals.

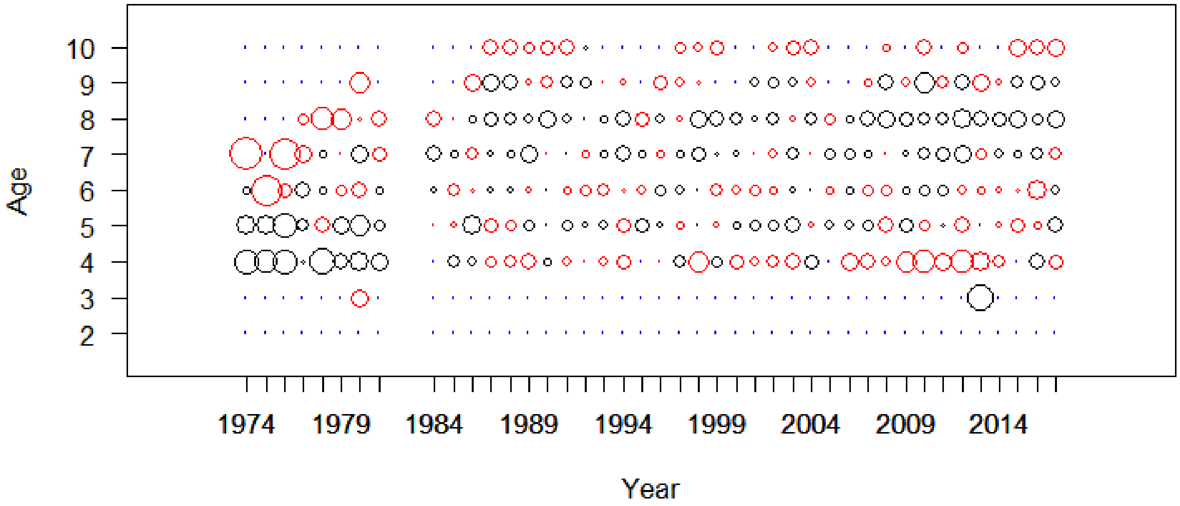


Figure 131. PRD - gear 3 age fit residuals.

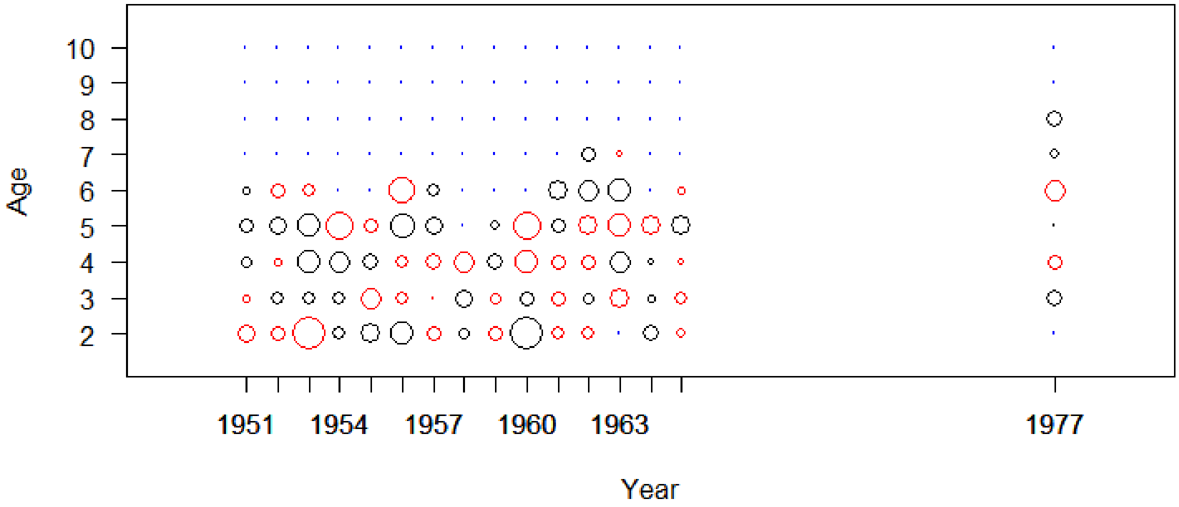


Figure 132. CC - gear 1 age fit residuals.

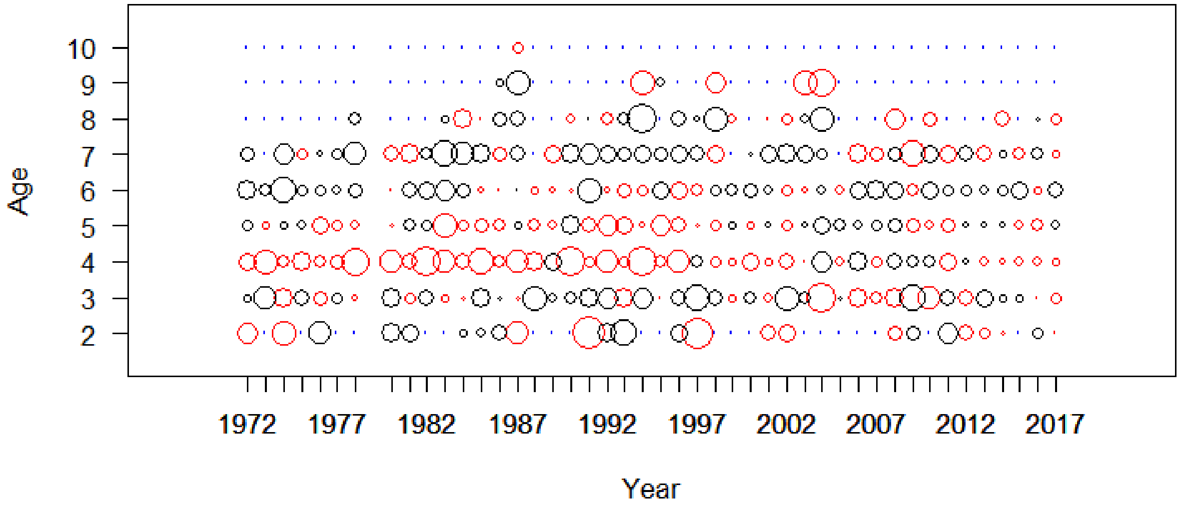


Figure 133. CC - gear 2 age fit residuals.

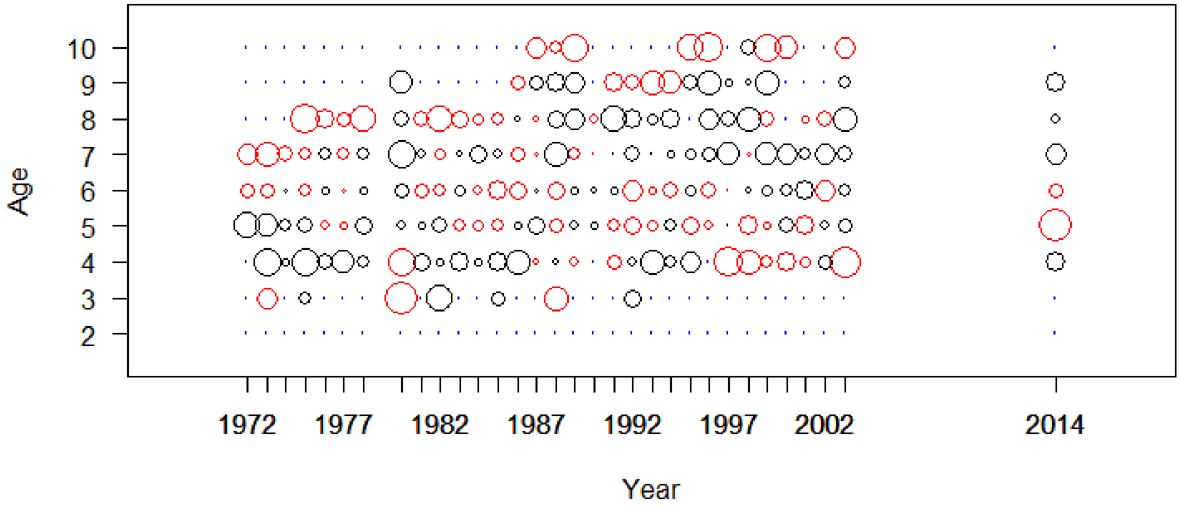


Figure 134. CC - gear 3 age fit residuals.

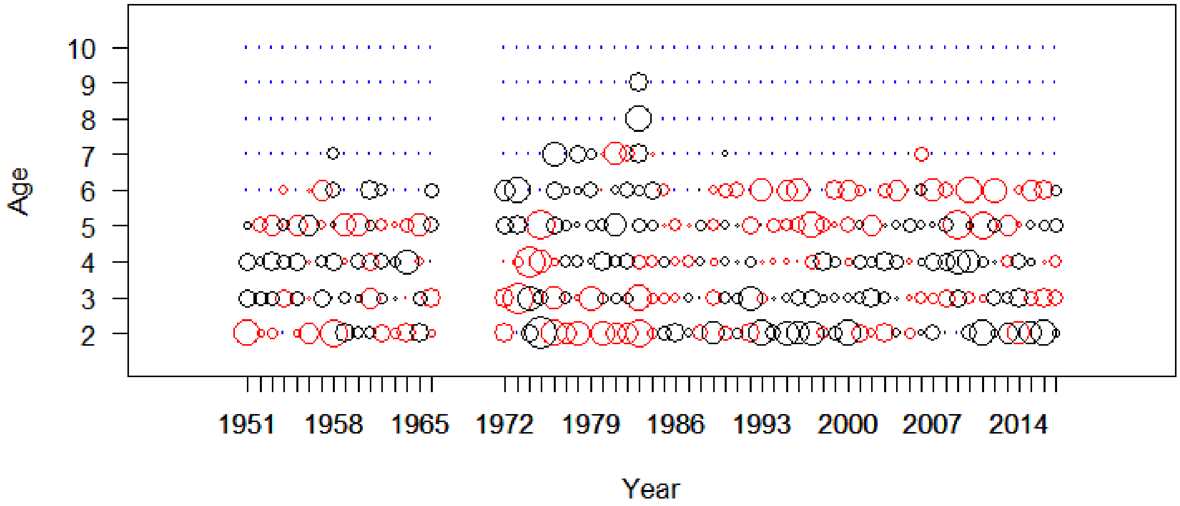


Figure 135. SOG - gear 1 age fit residuals.

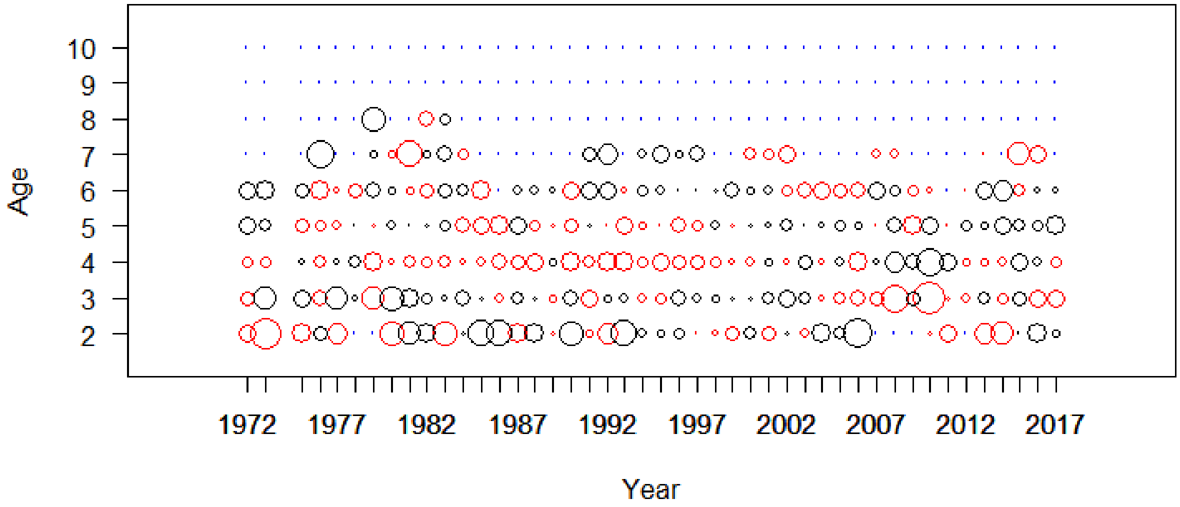


Figure 136. SOG - gear 2 age fit residuals.

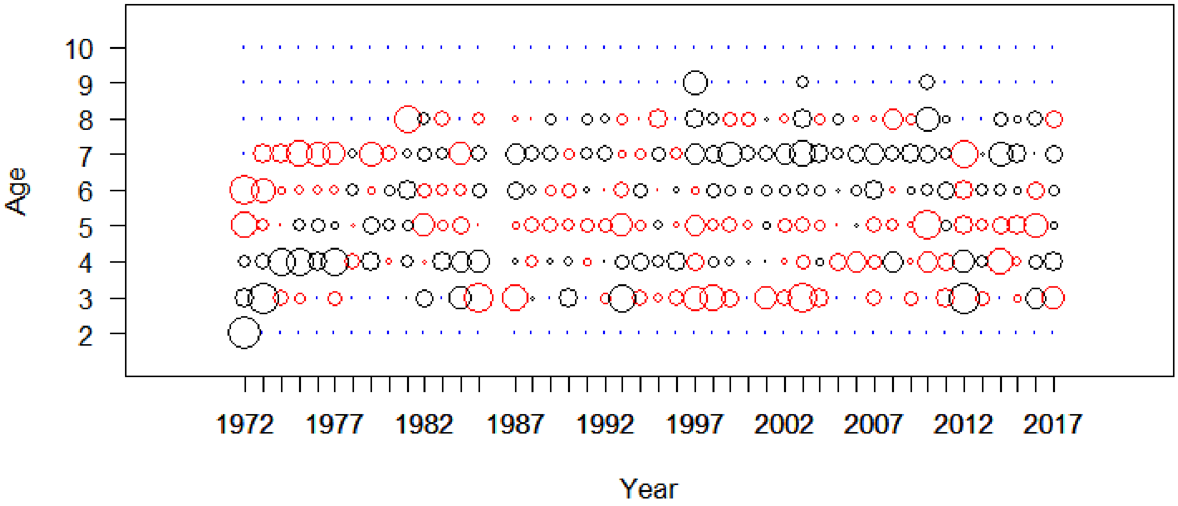


Figure 137. SOG - gear 3 age fit residuals.

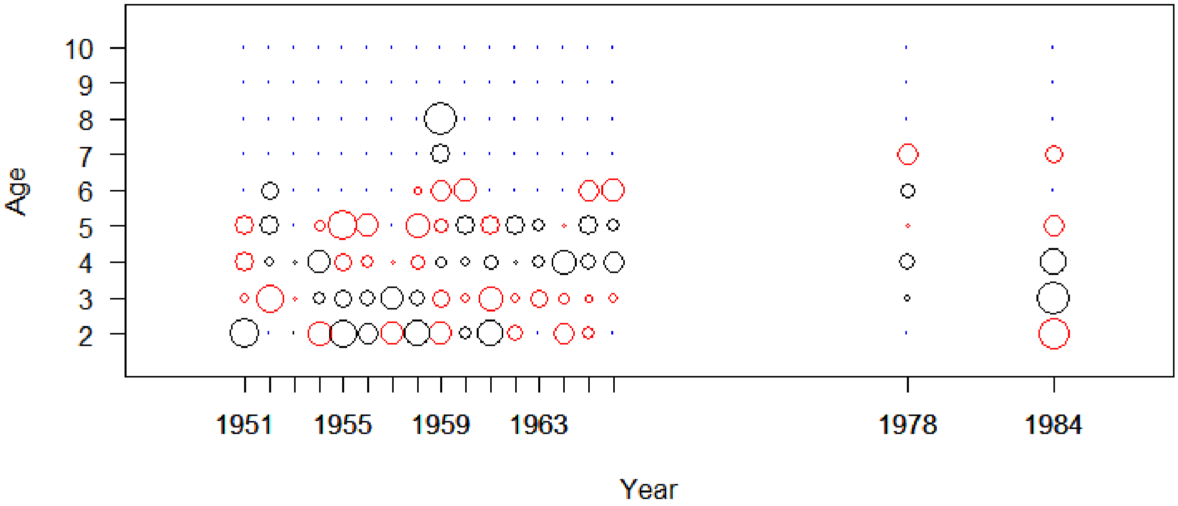


Figure 138. WCVI - gear 1 age fit residuals.

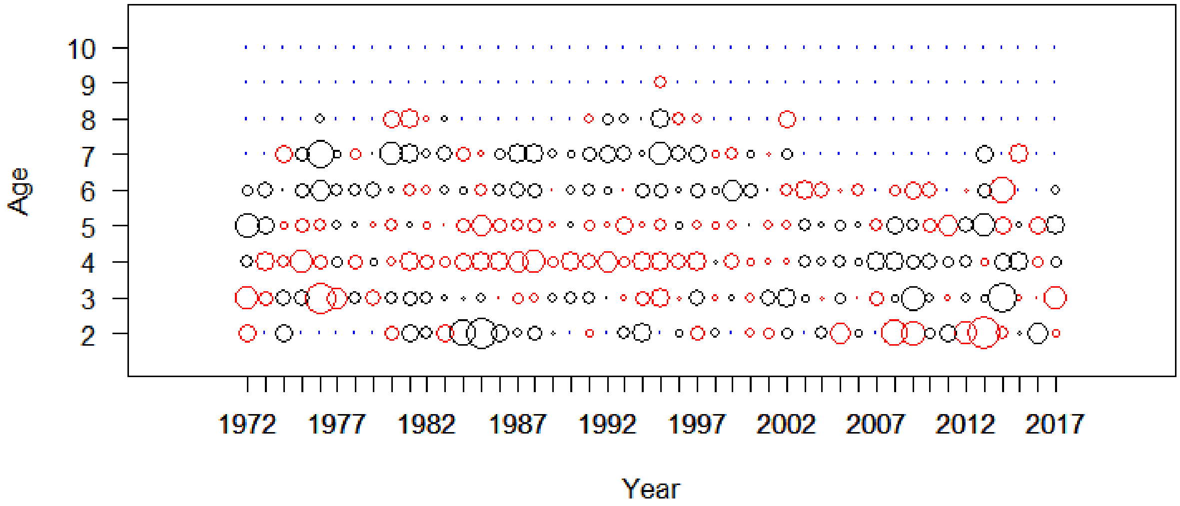


Figure 139. WCVI - gear 2 age fit residuals.

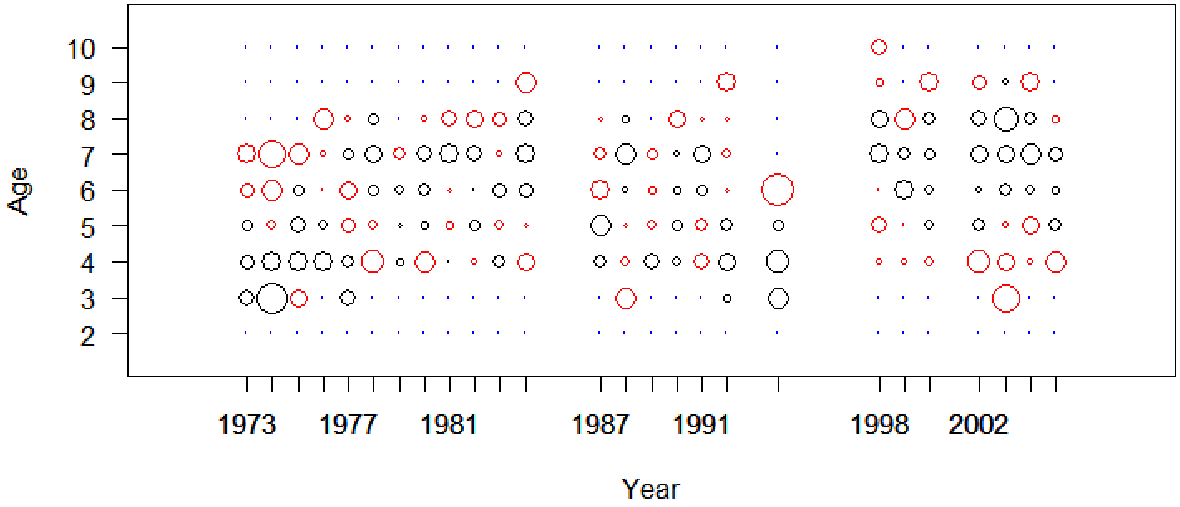


Figure 140. WCVI - gear 3 age fit residuals.

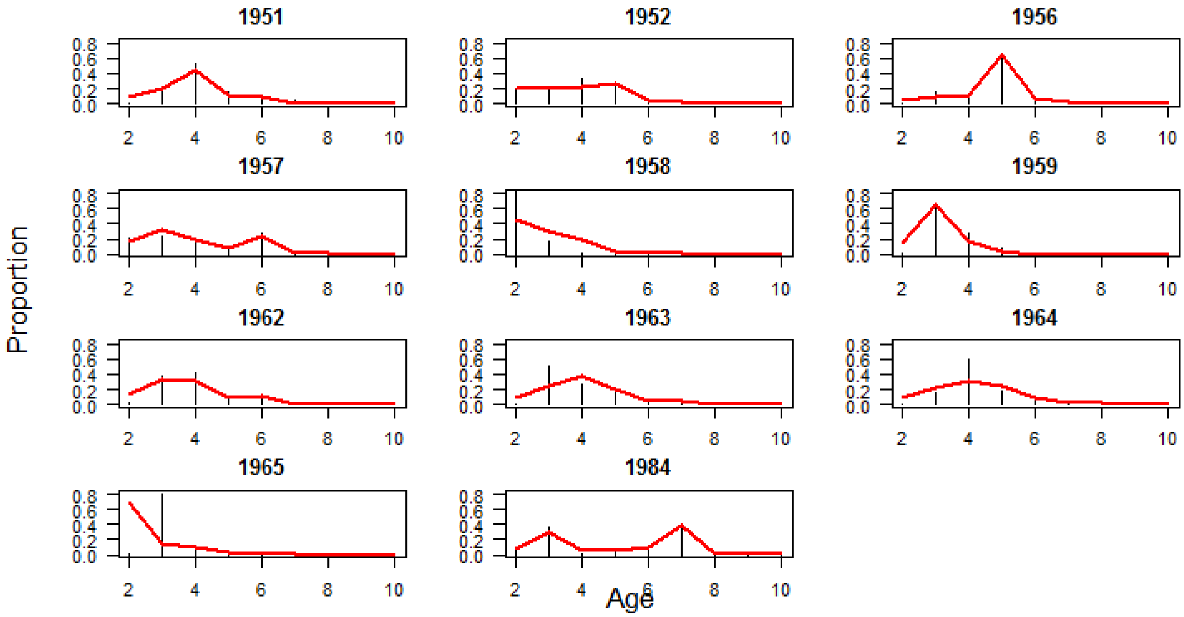


Figure 141. HG - gear 1 age fits.

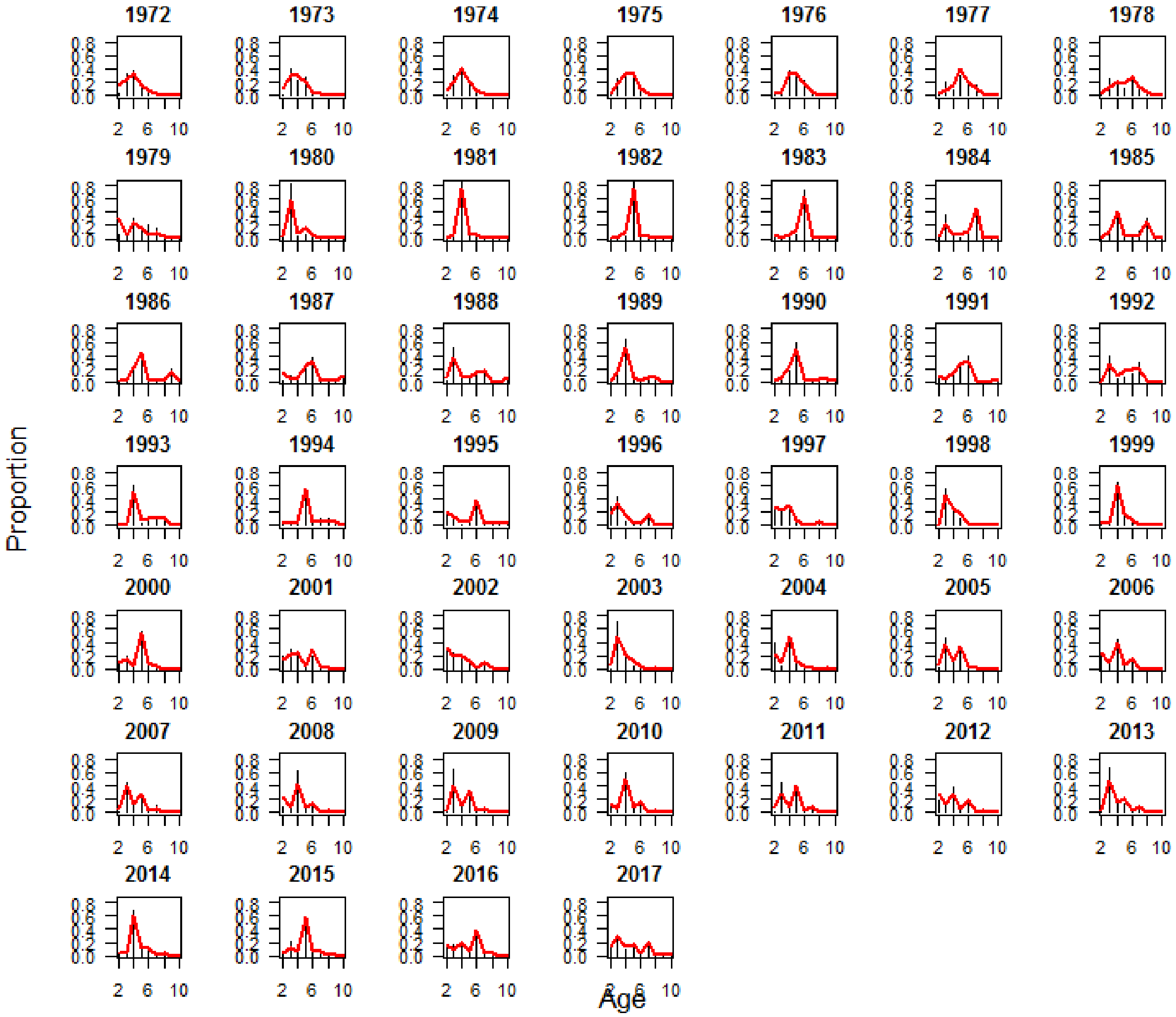


Figure 142. HG - gear 2 age fits.

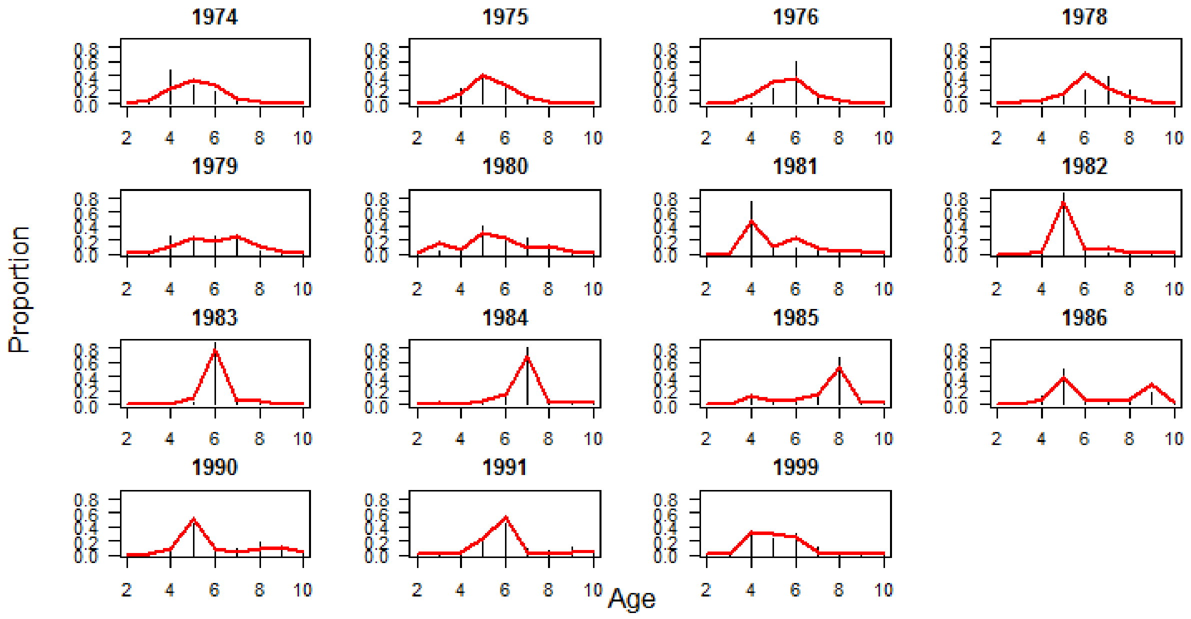


Figure 143. HG - gear 3 age fits.

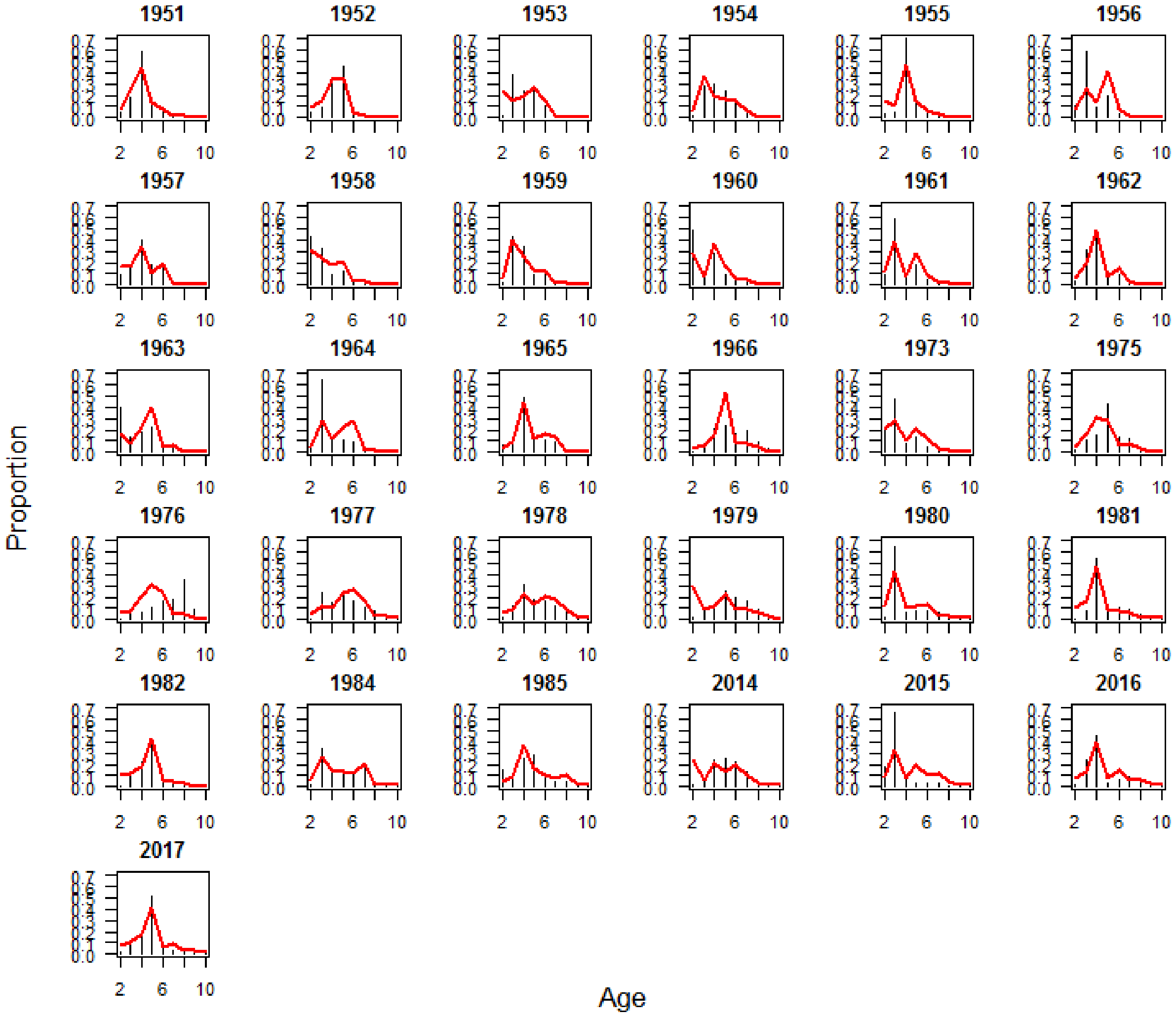
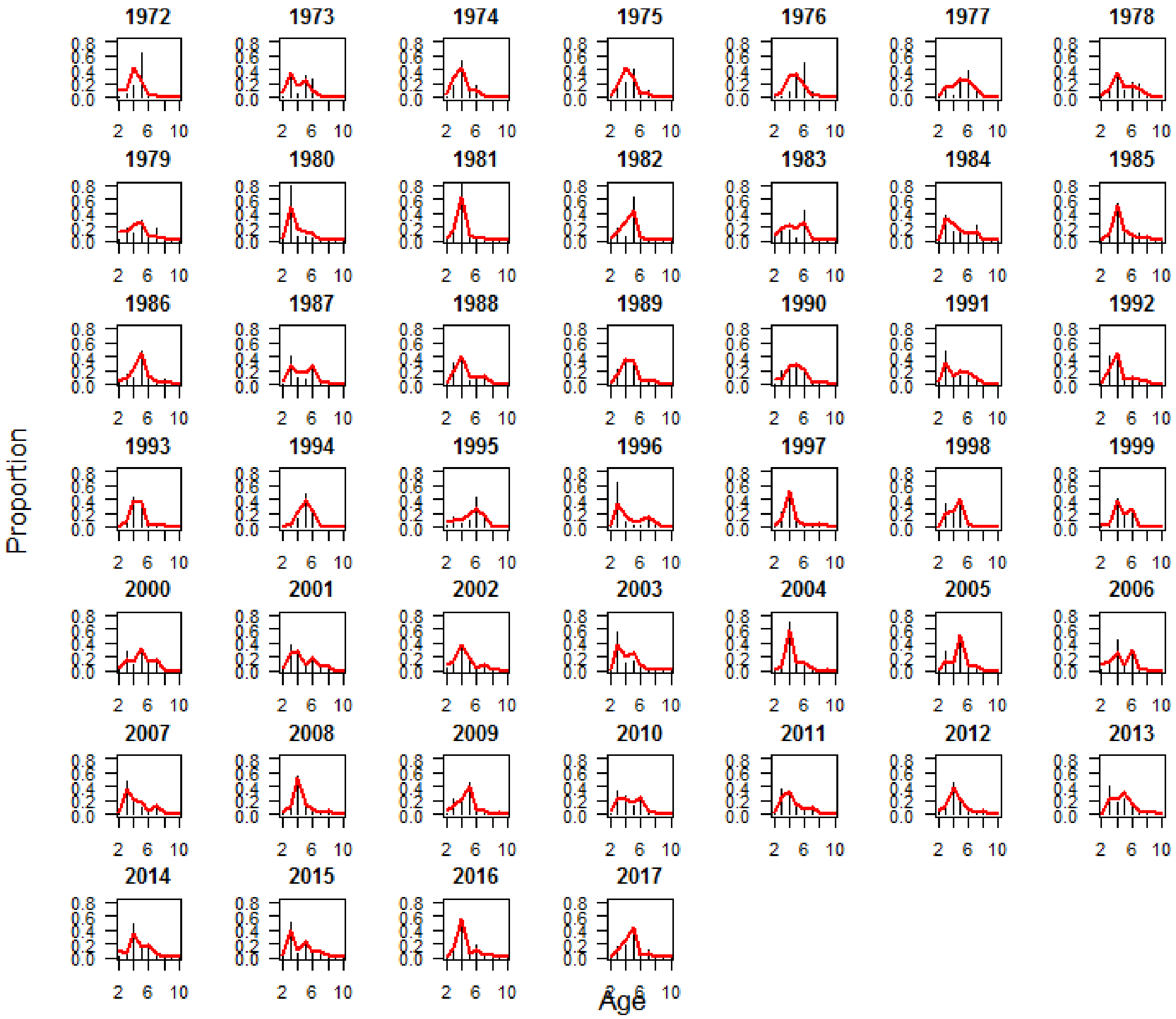


Figure 144. PRD - gear 1 age fits.



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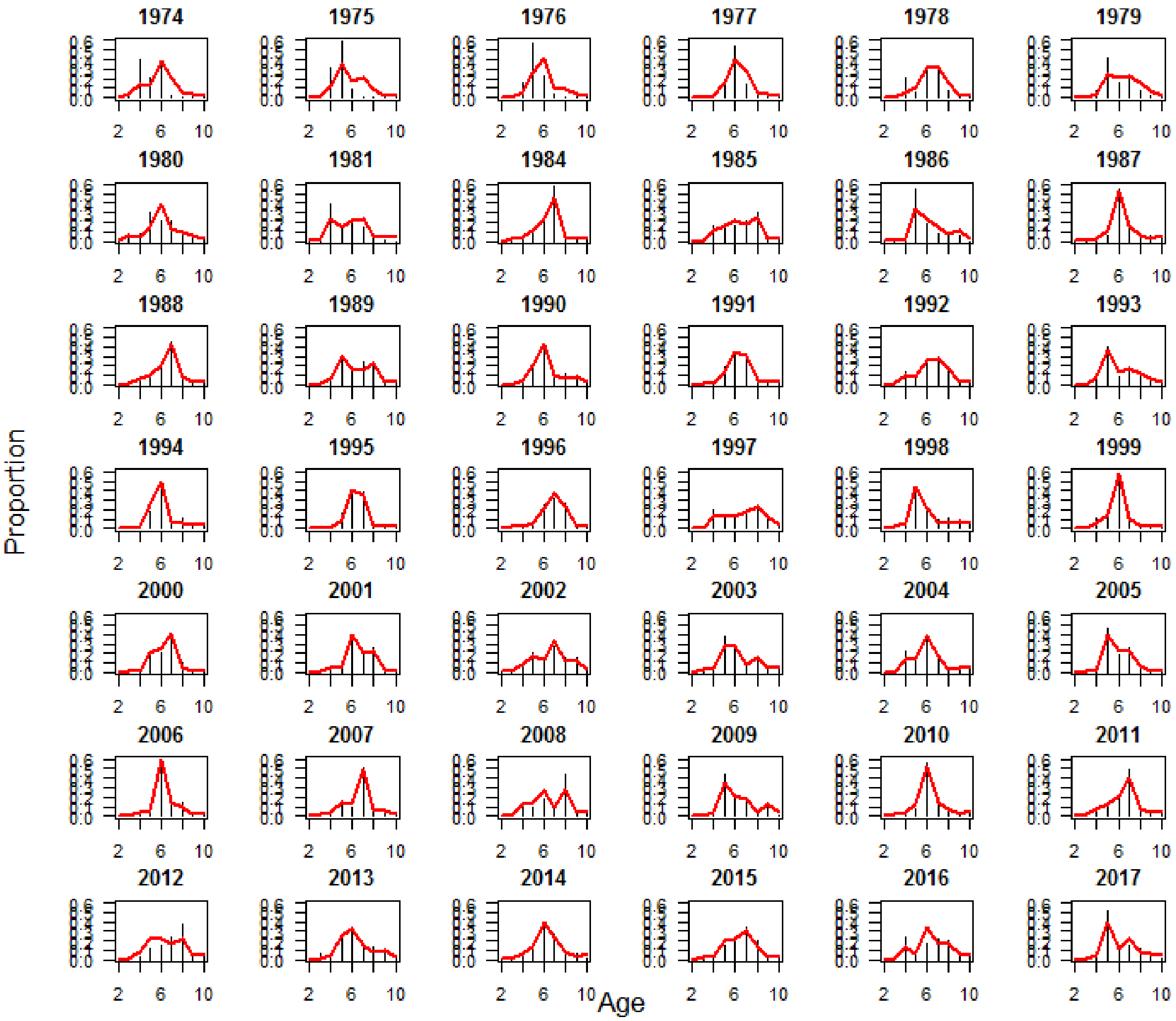


Figure 146. PRD - gear 3 age fits.

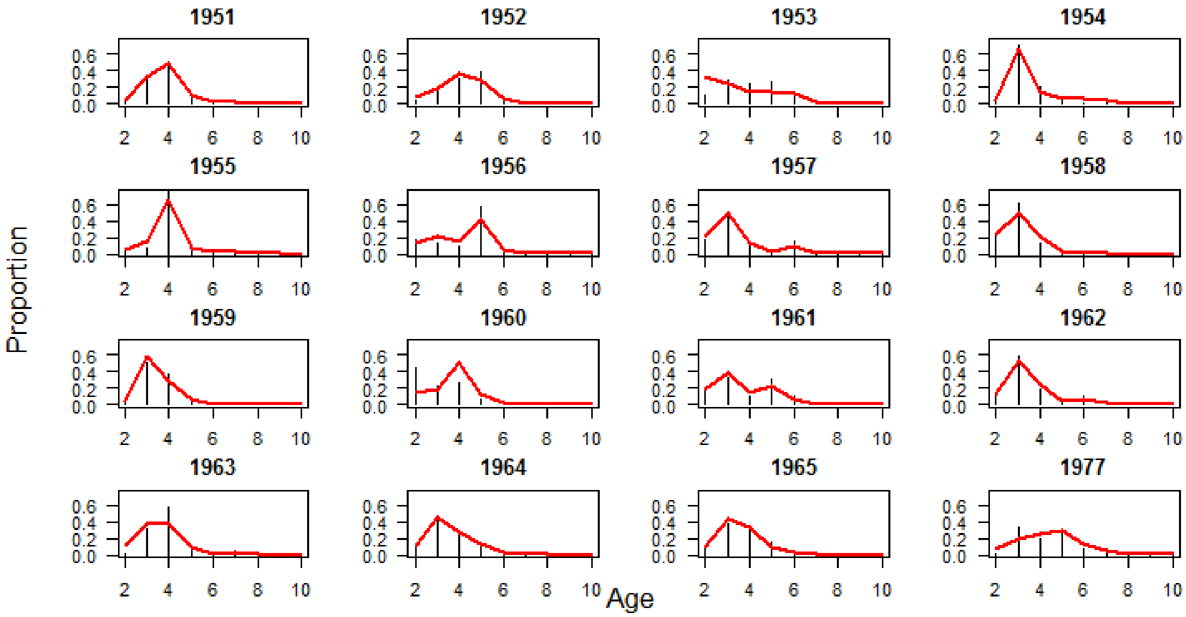


Figure 147. CC - gear 1 age fits.

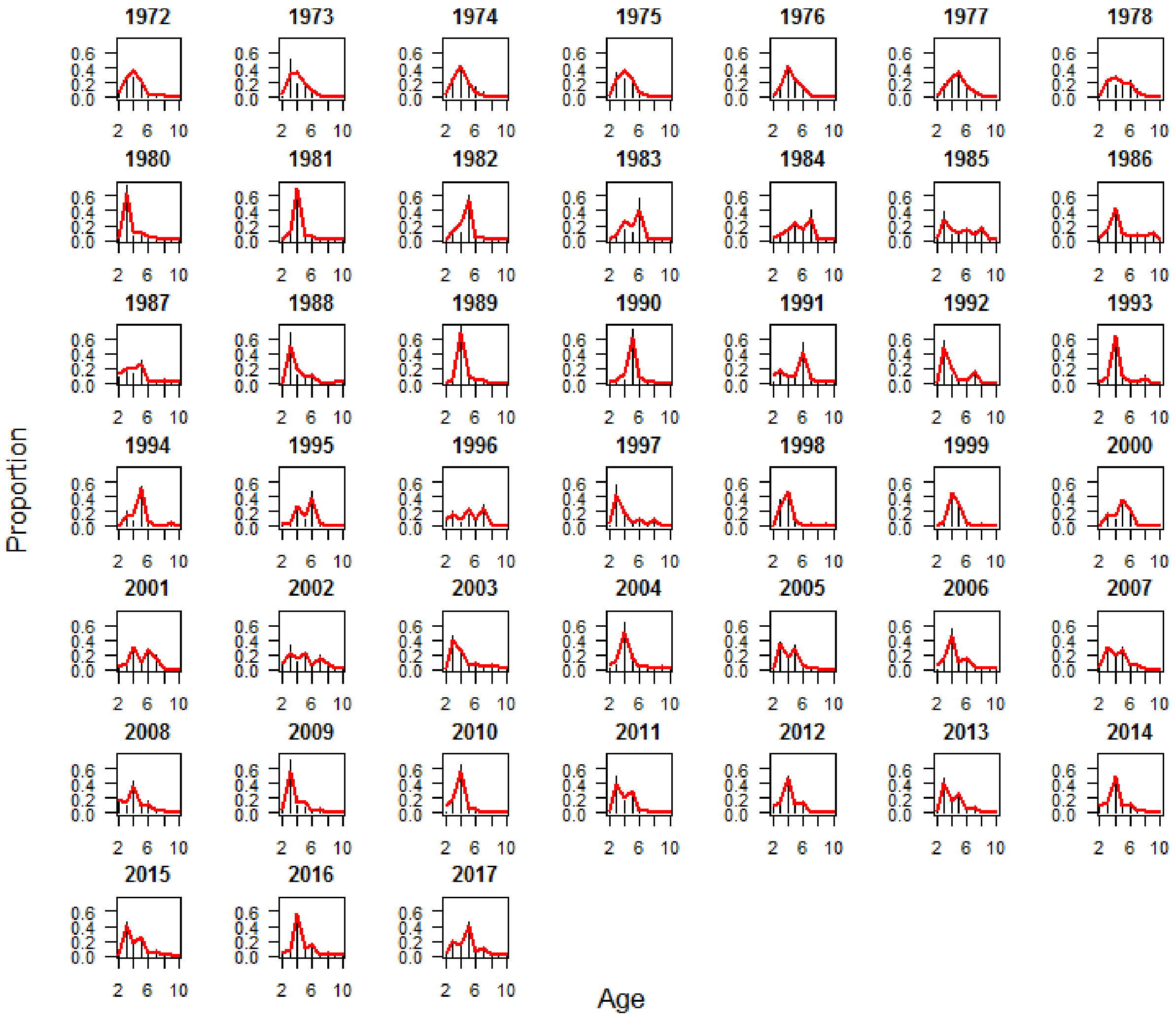


Figure 148. CC - gear 2 age fits.

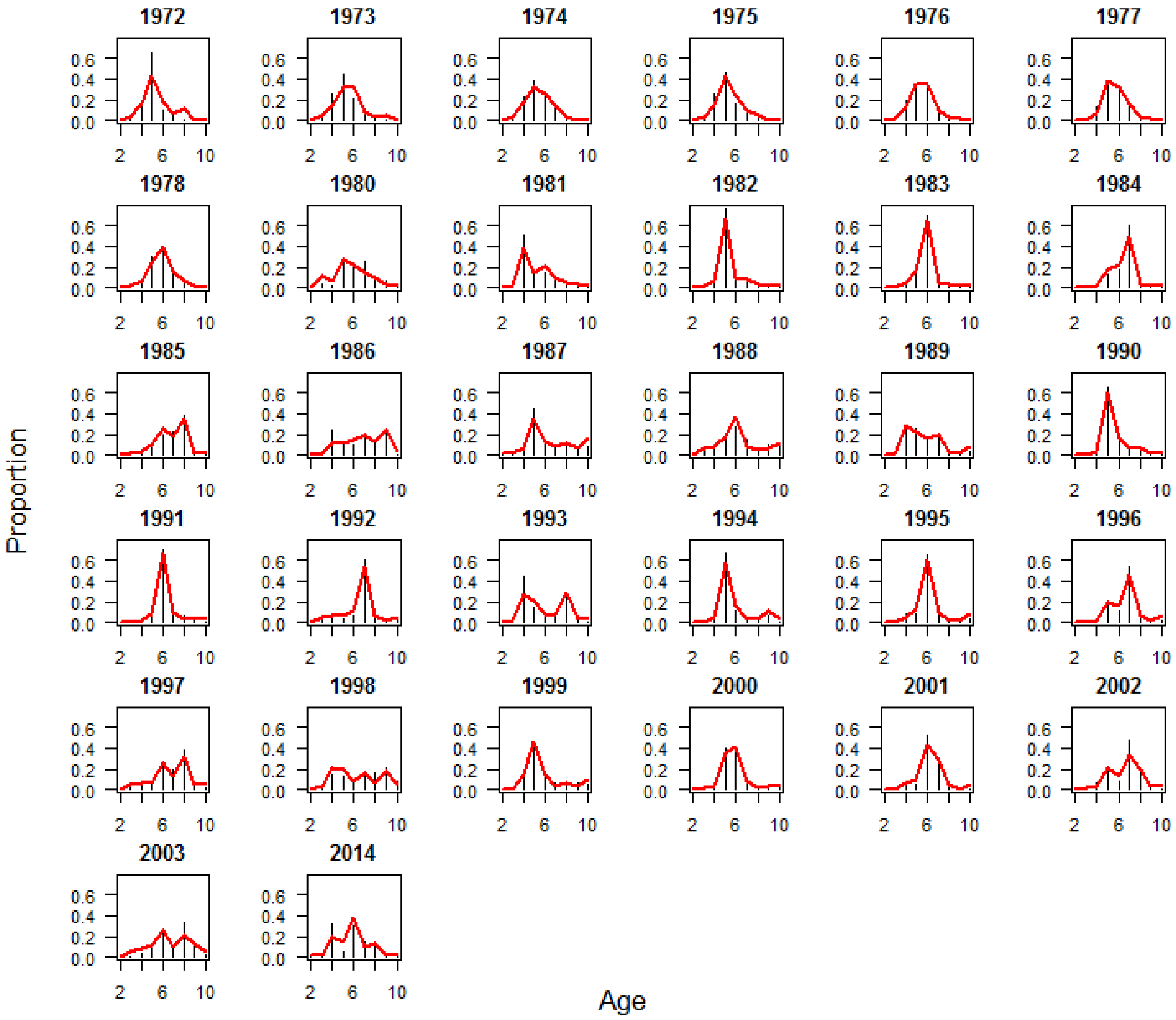


Figure 149. CC - gear 3 age fits.

Figure 150. SOG - gear 1 age fits.

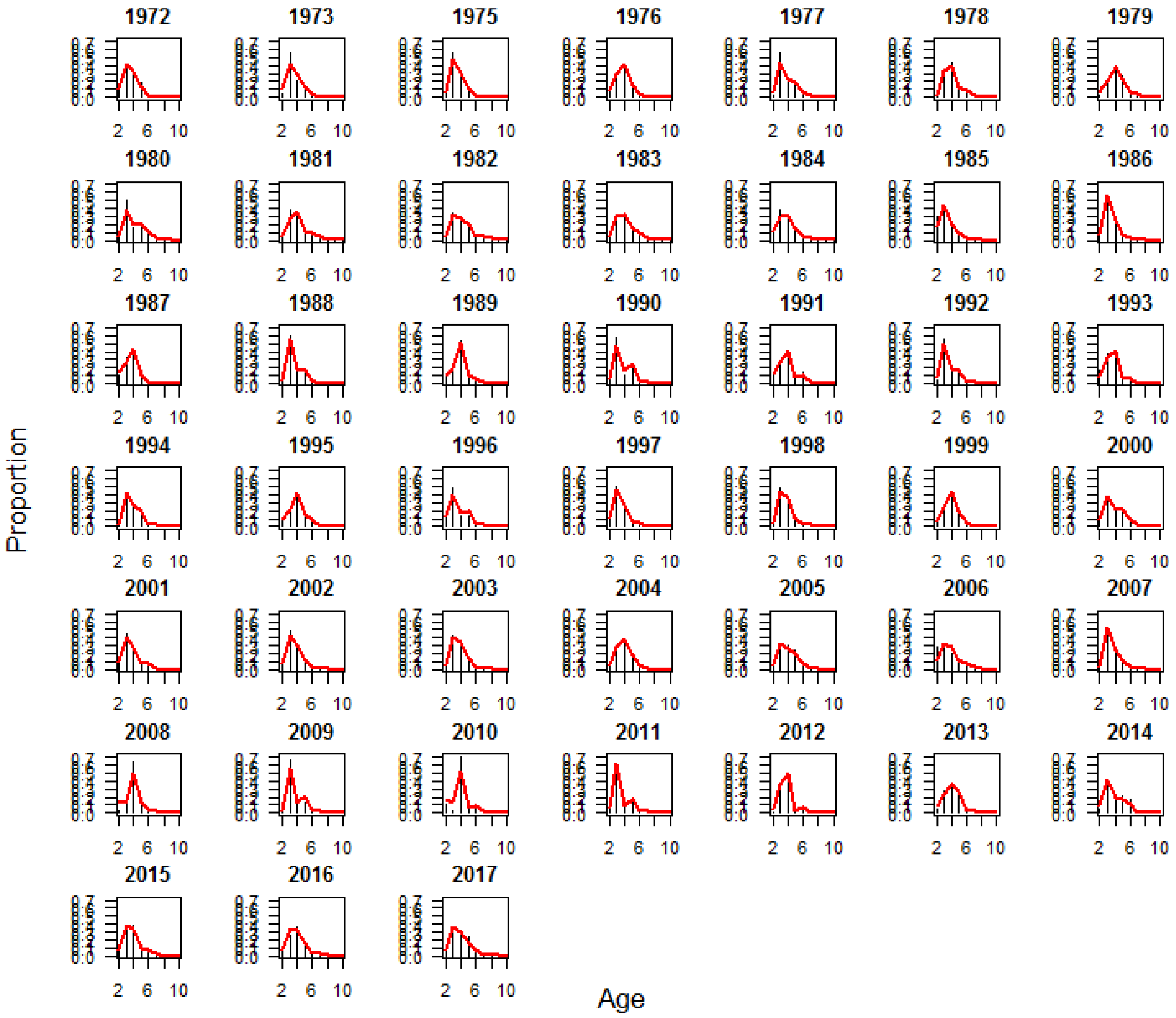
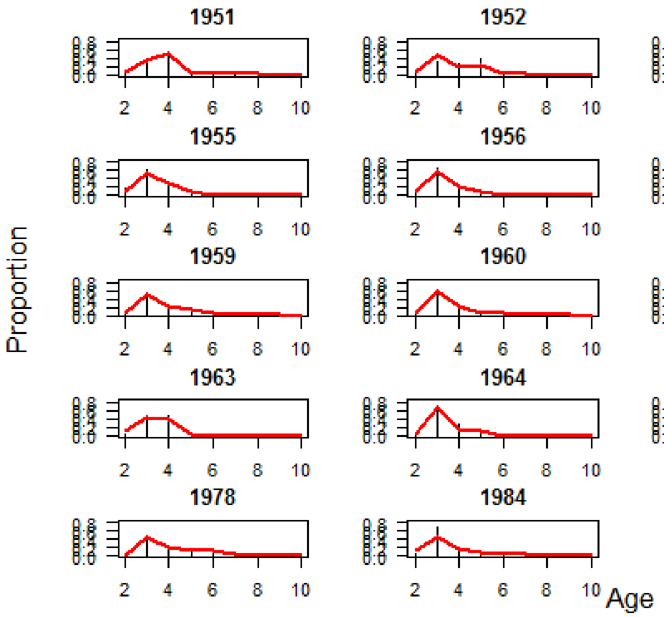


Figure 151. SOG - gear 2 age fits.

Figure 152. SOG - gear 3 age fits.



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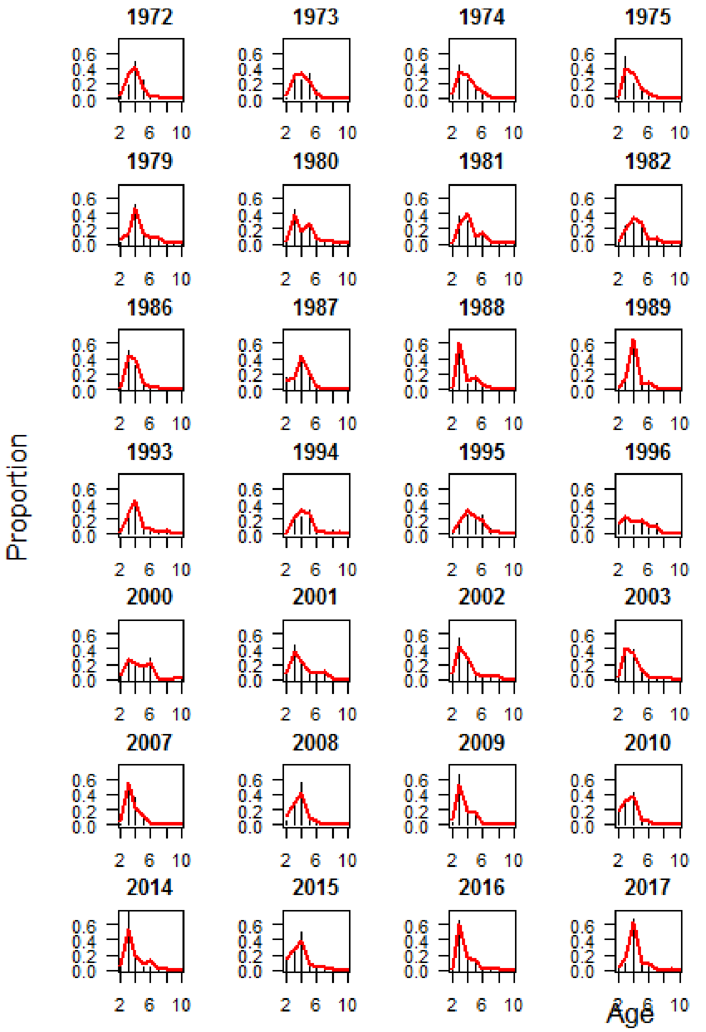


Figure 154. WCVI - gear 2 age fits.

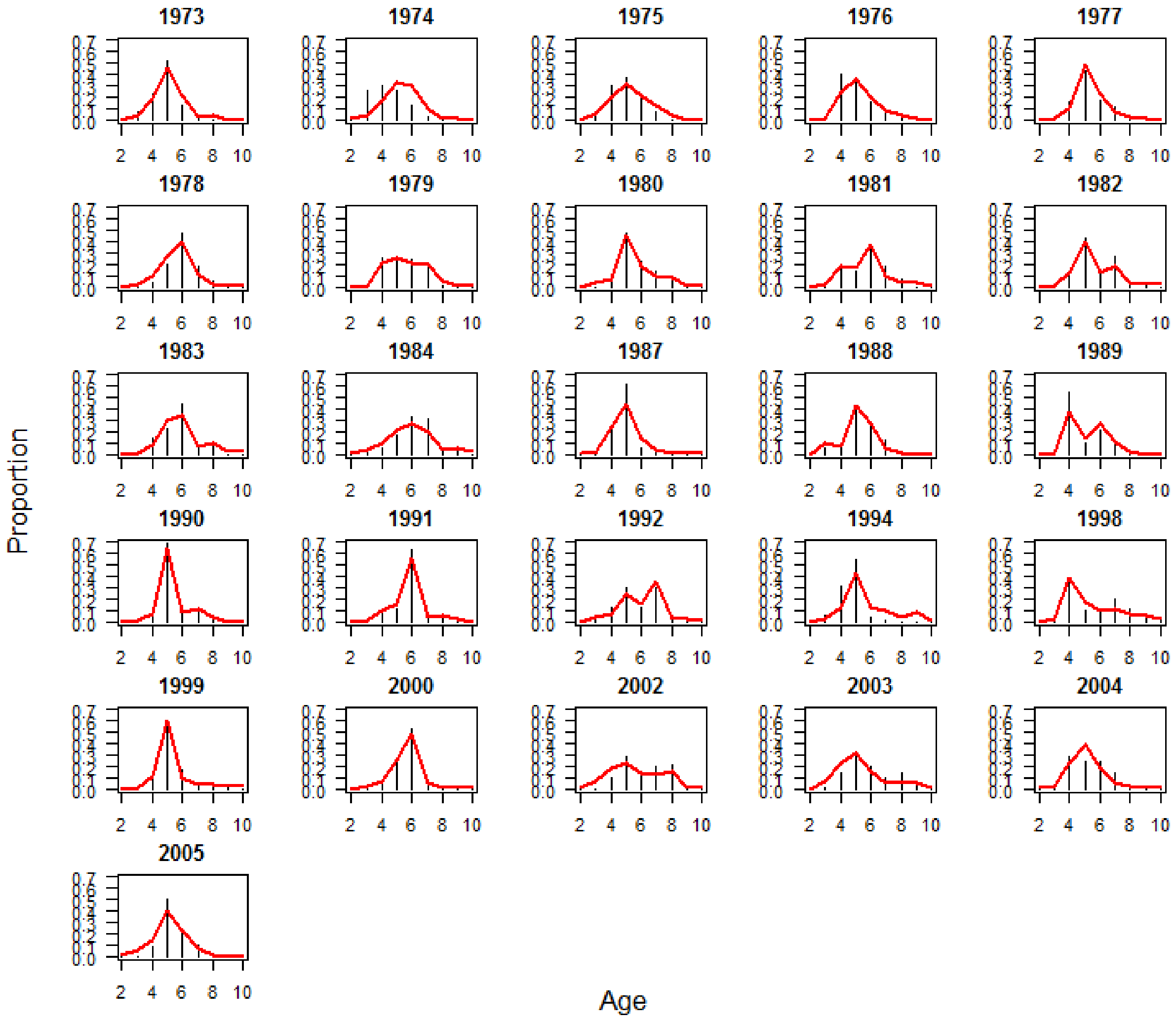


Figure 155. WCVI - gear 3 age fits.

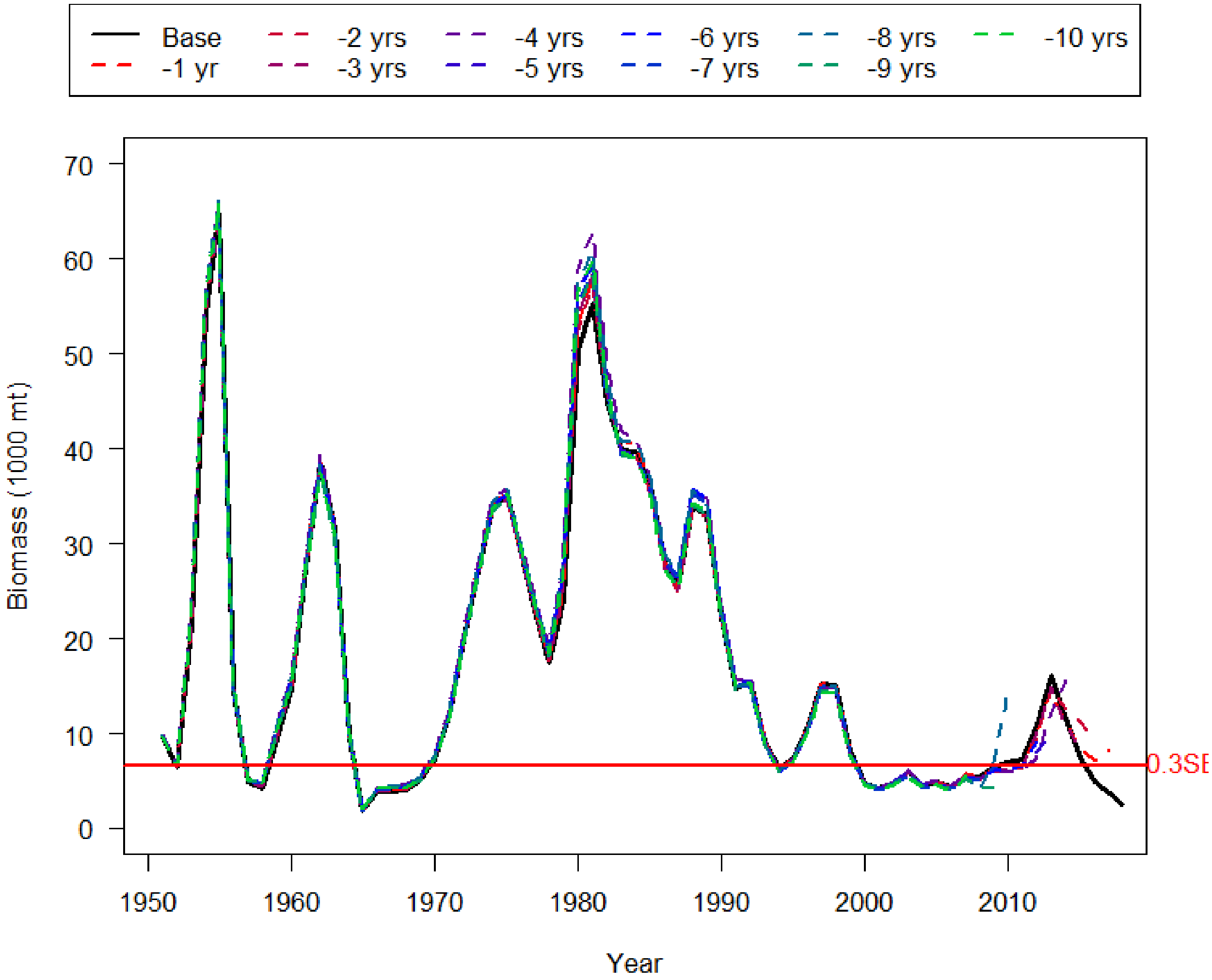


Figure 156. Retrospective spawning biomass for the Haida Gwaii AM2 model.

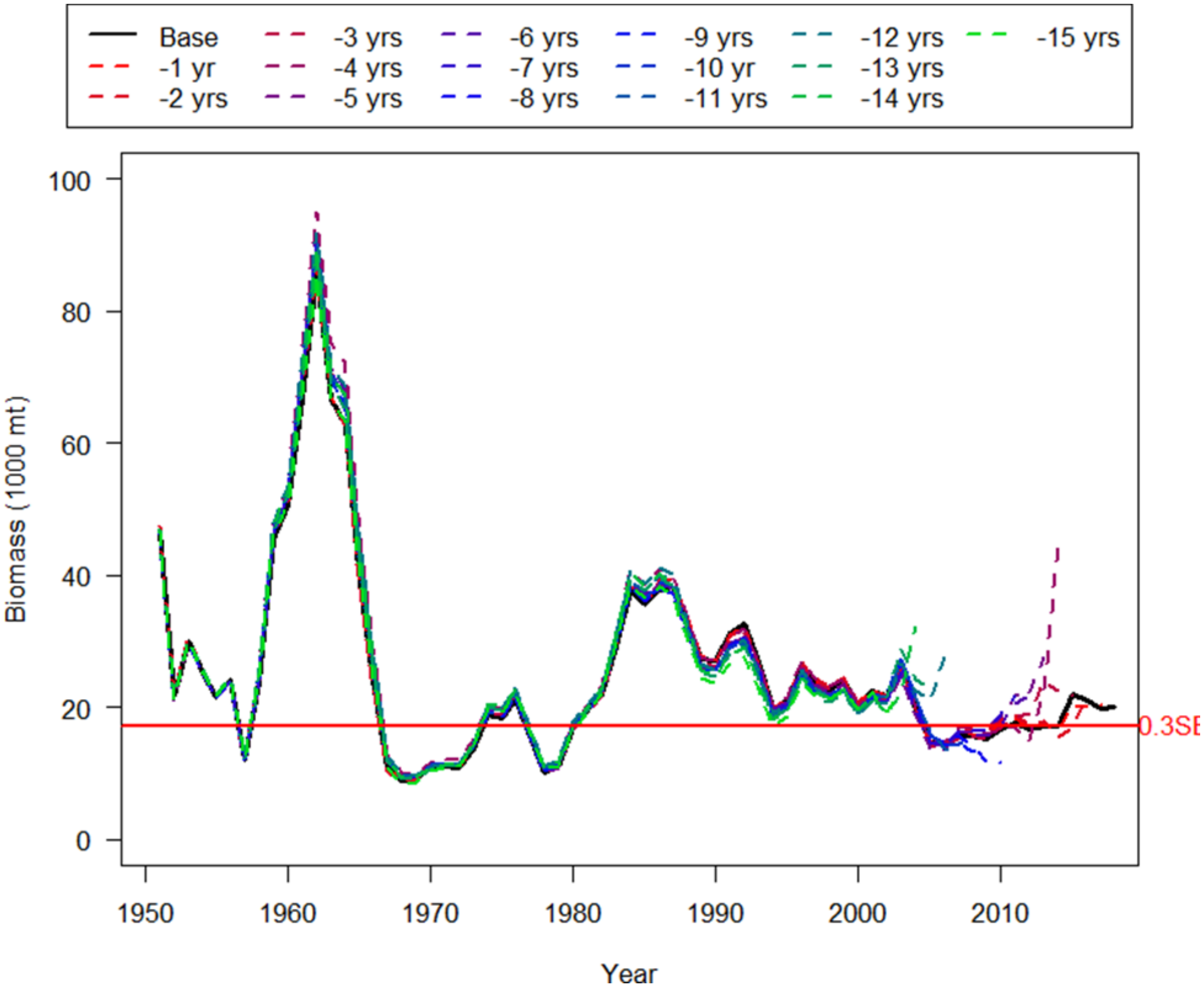


Figure 157. Retrospective spawning biomass for the Prince Rupert District AM2 model.

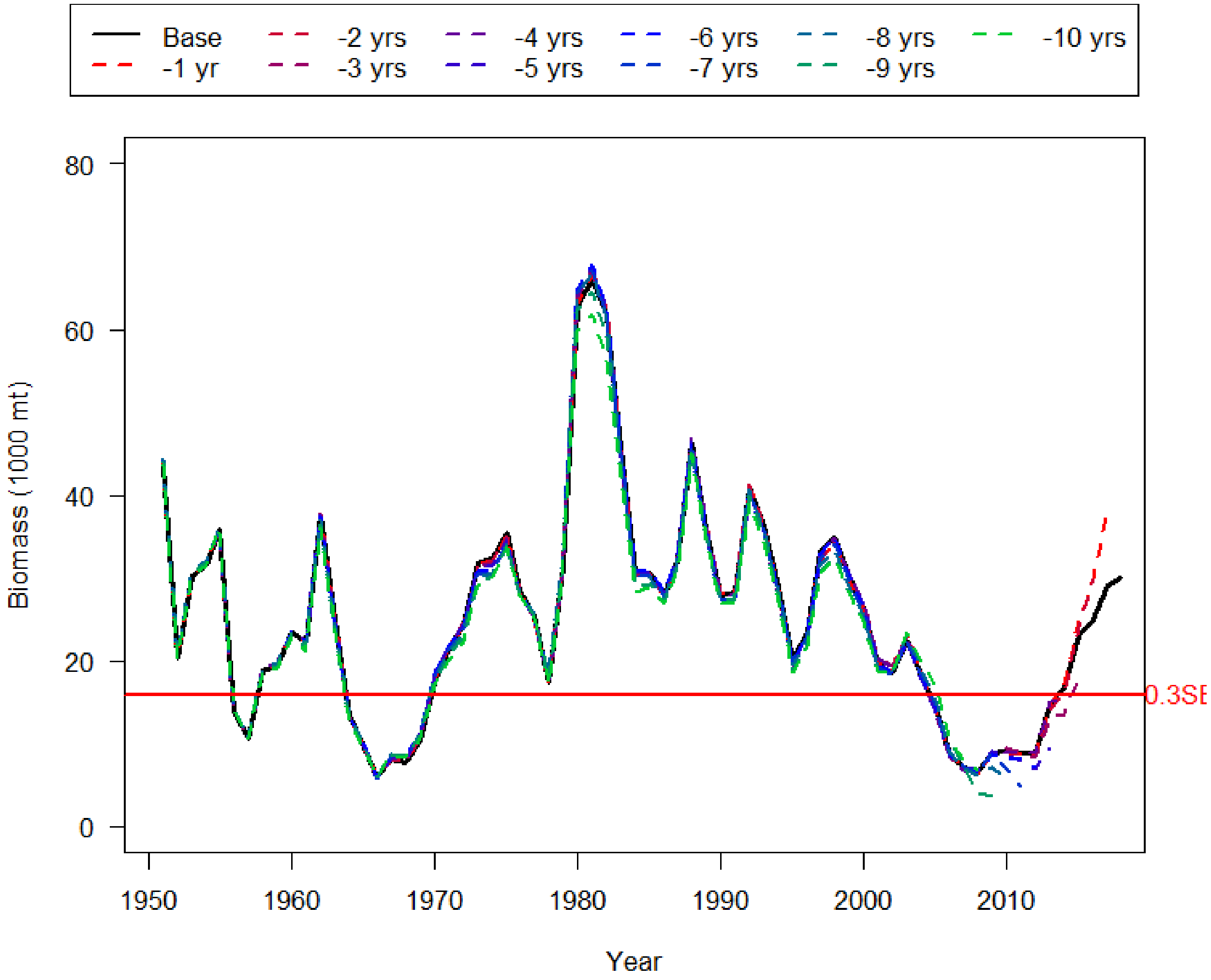


Figure 158. Retrospective spawning biomass for the Central Coast AM2 model.

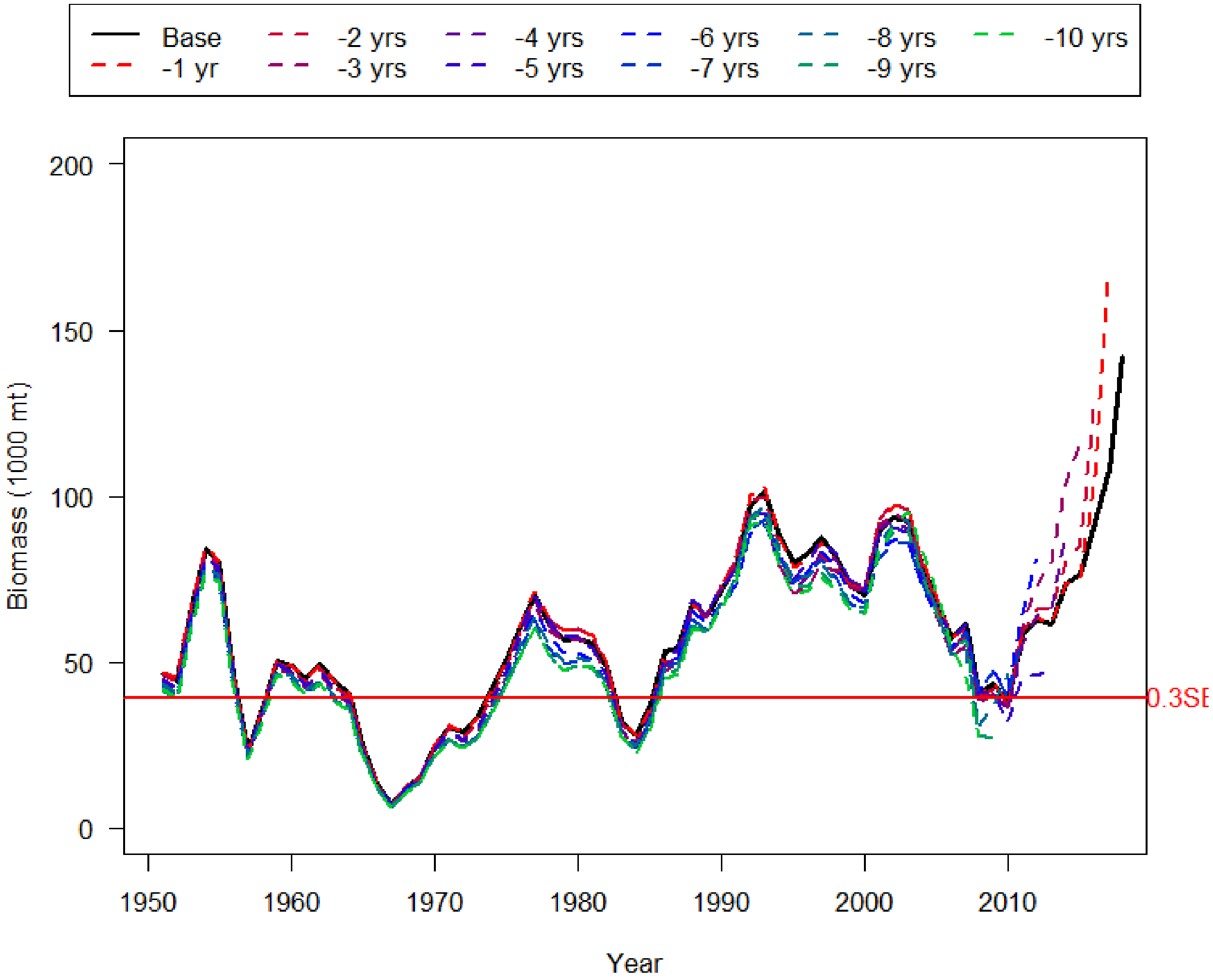


Figure 159. Retrospective spawning biomass for the Strait of Georgia AM2 model.

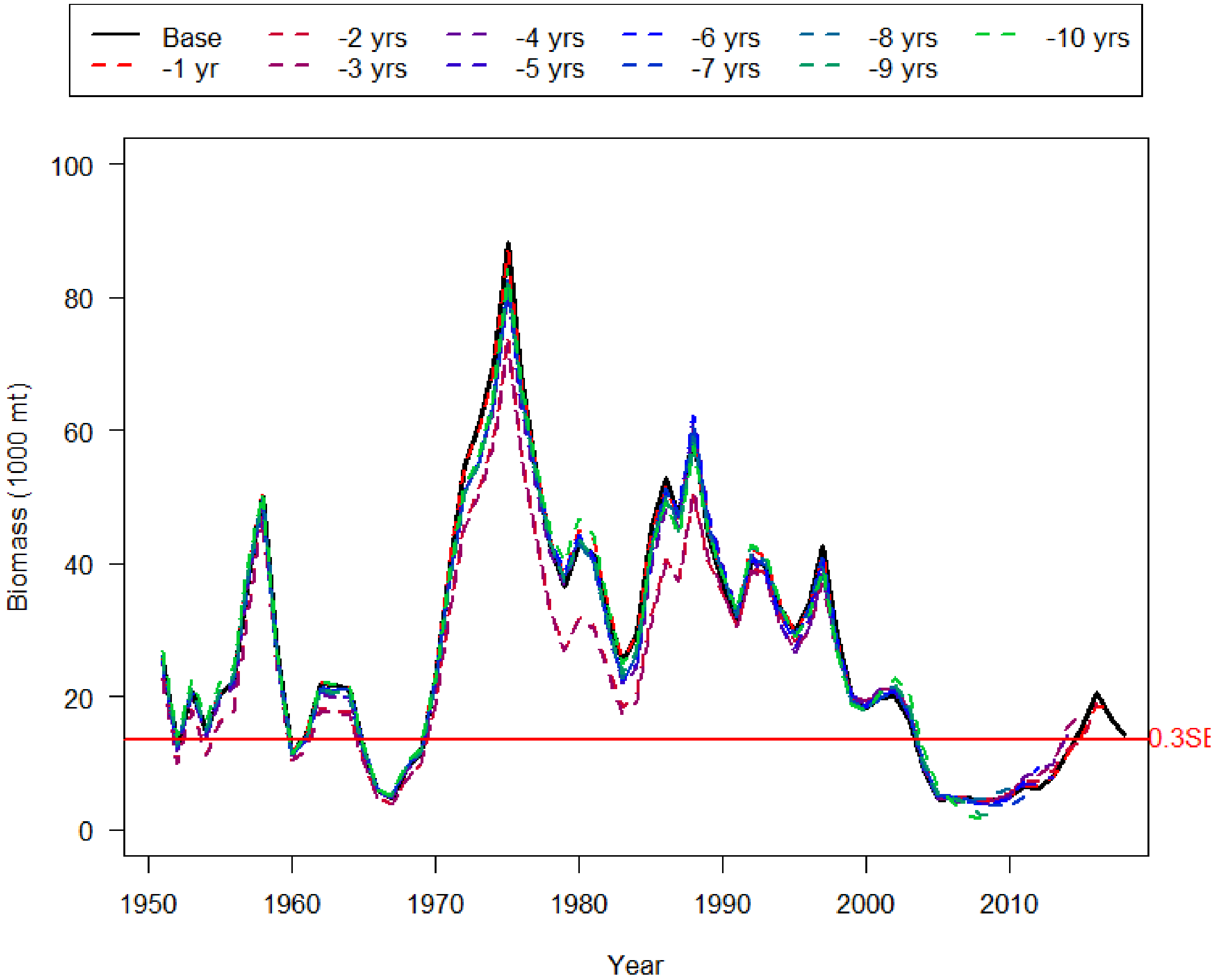


Figure 160. Retrospective spawning biomass for the WCVI AM2 model.

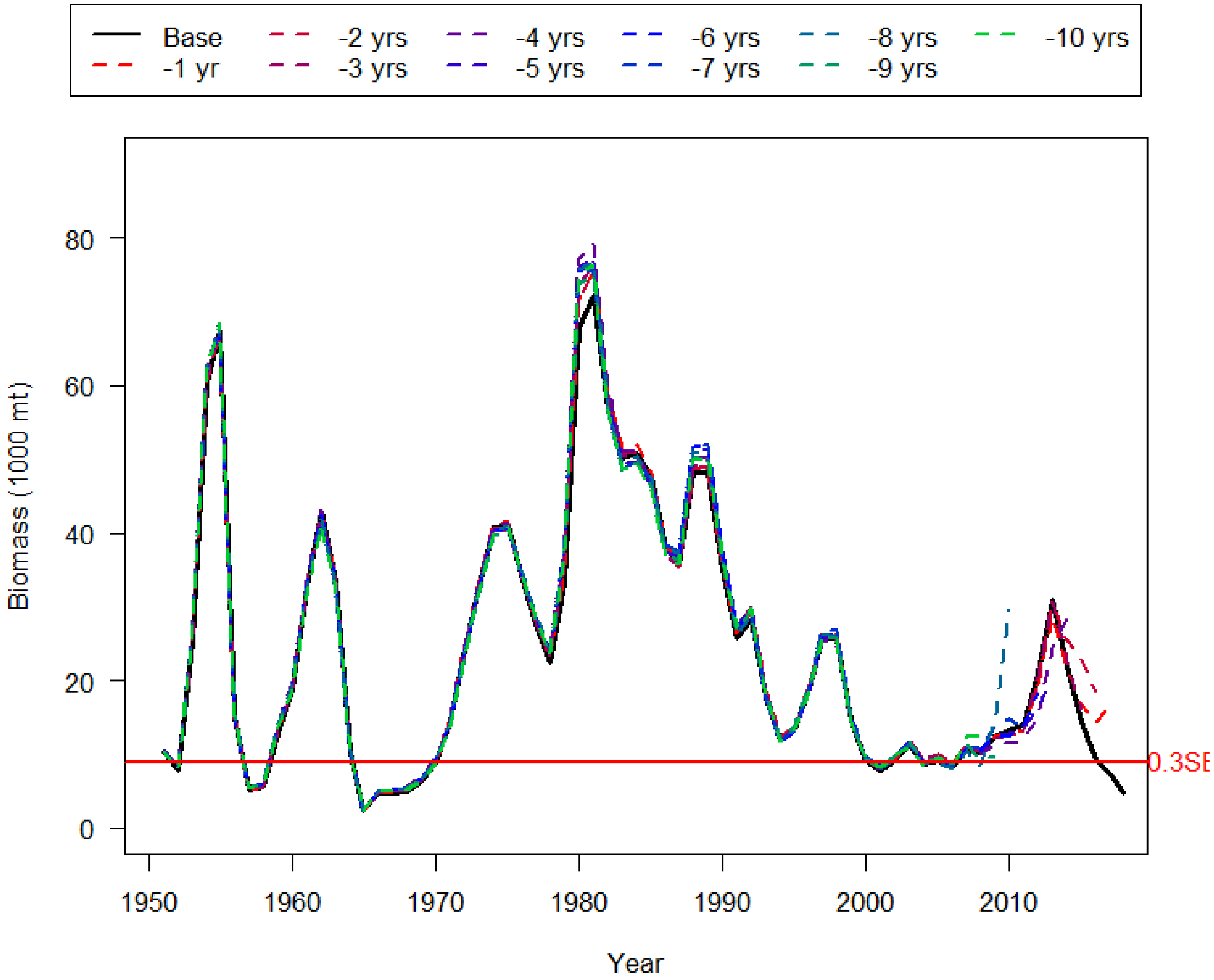


Figure 161. Retrospective spawning biomass for the Haida Gwaii AM1 model.

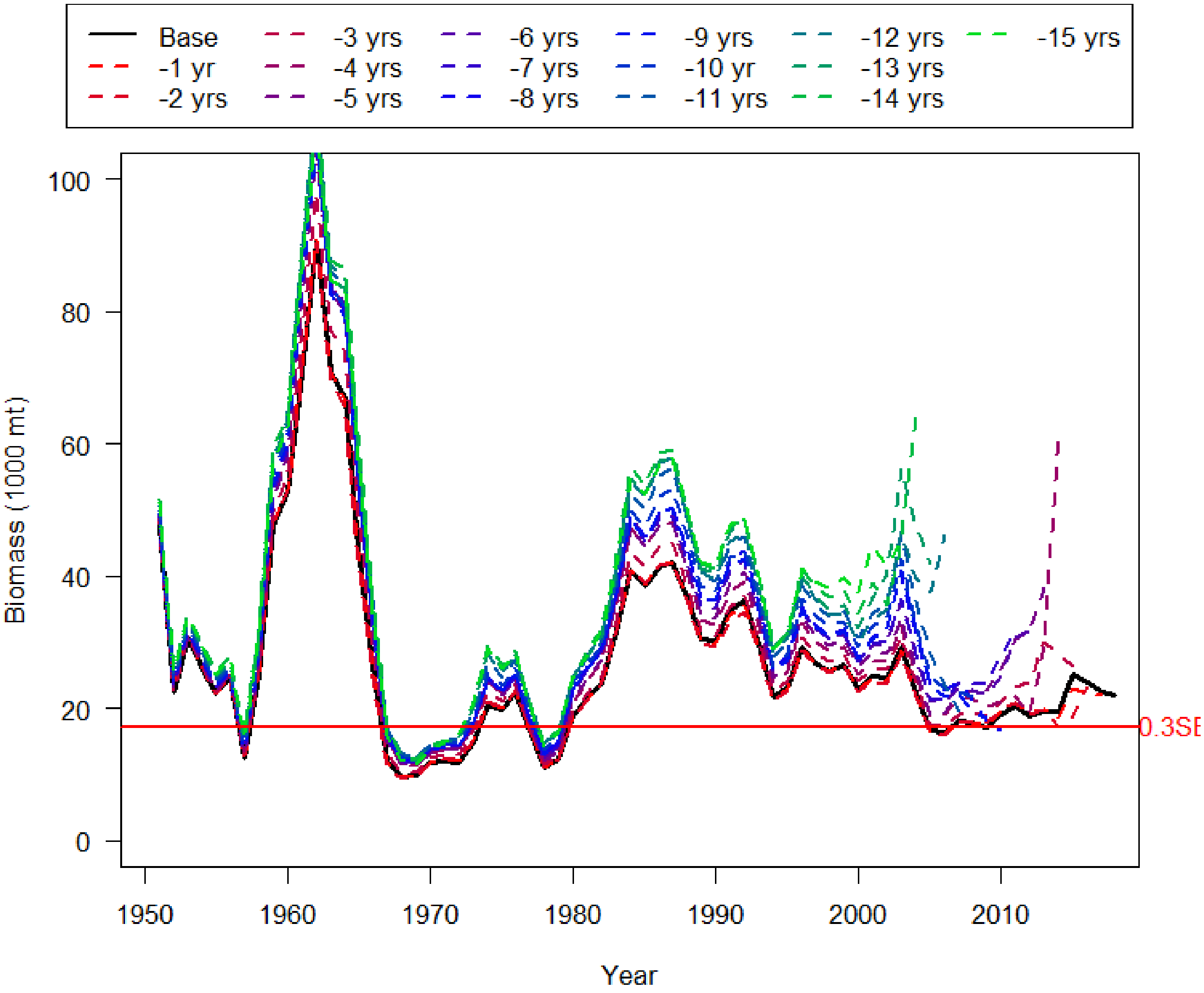


Figure 162. Retrospective spawning biomass for the Prince Rupert District AM1 model.

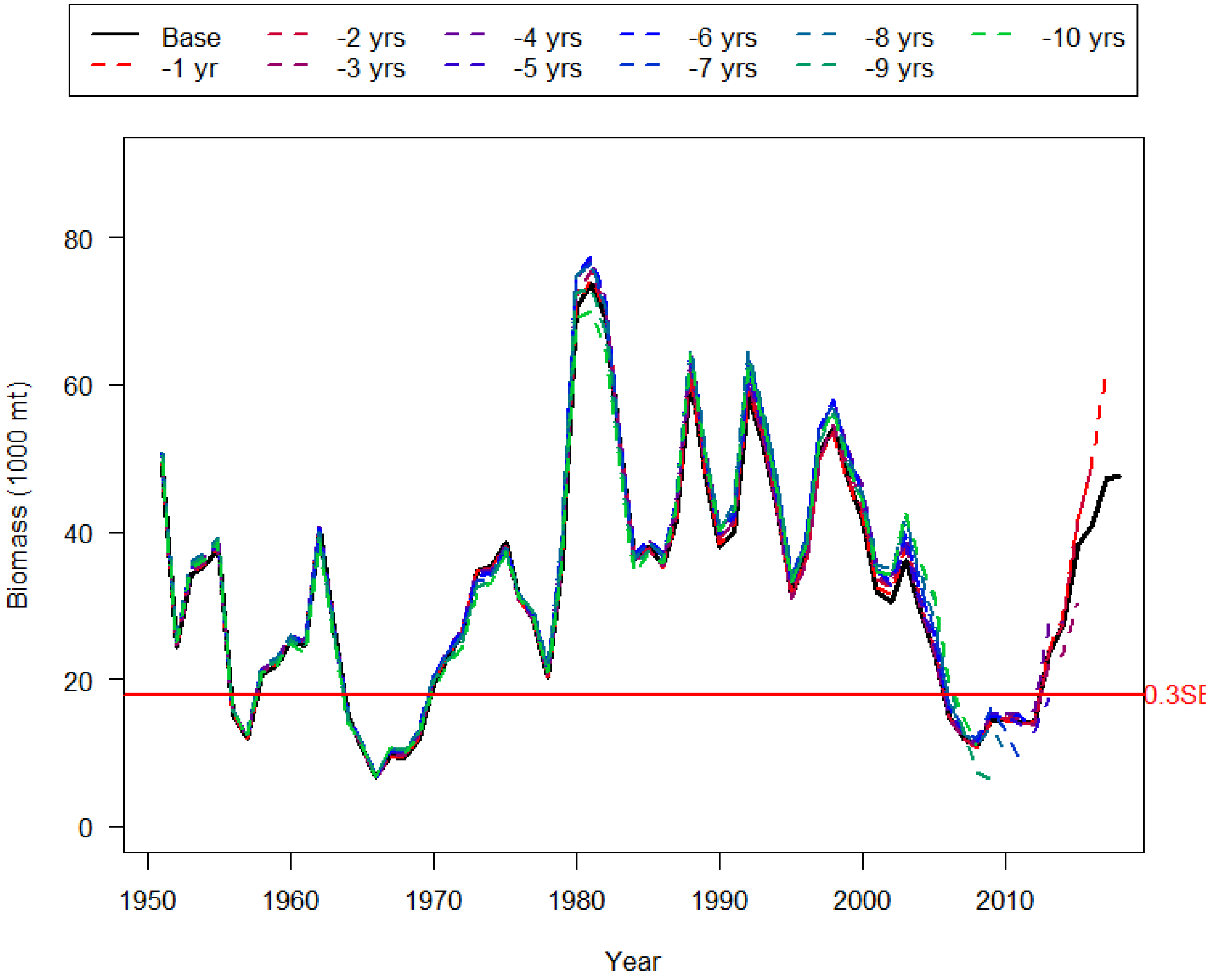


Figure 163. Retrospective spawning biomass for the Central Coast AM1 model.

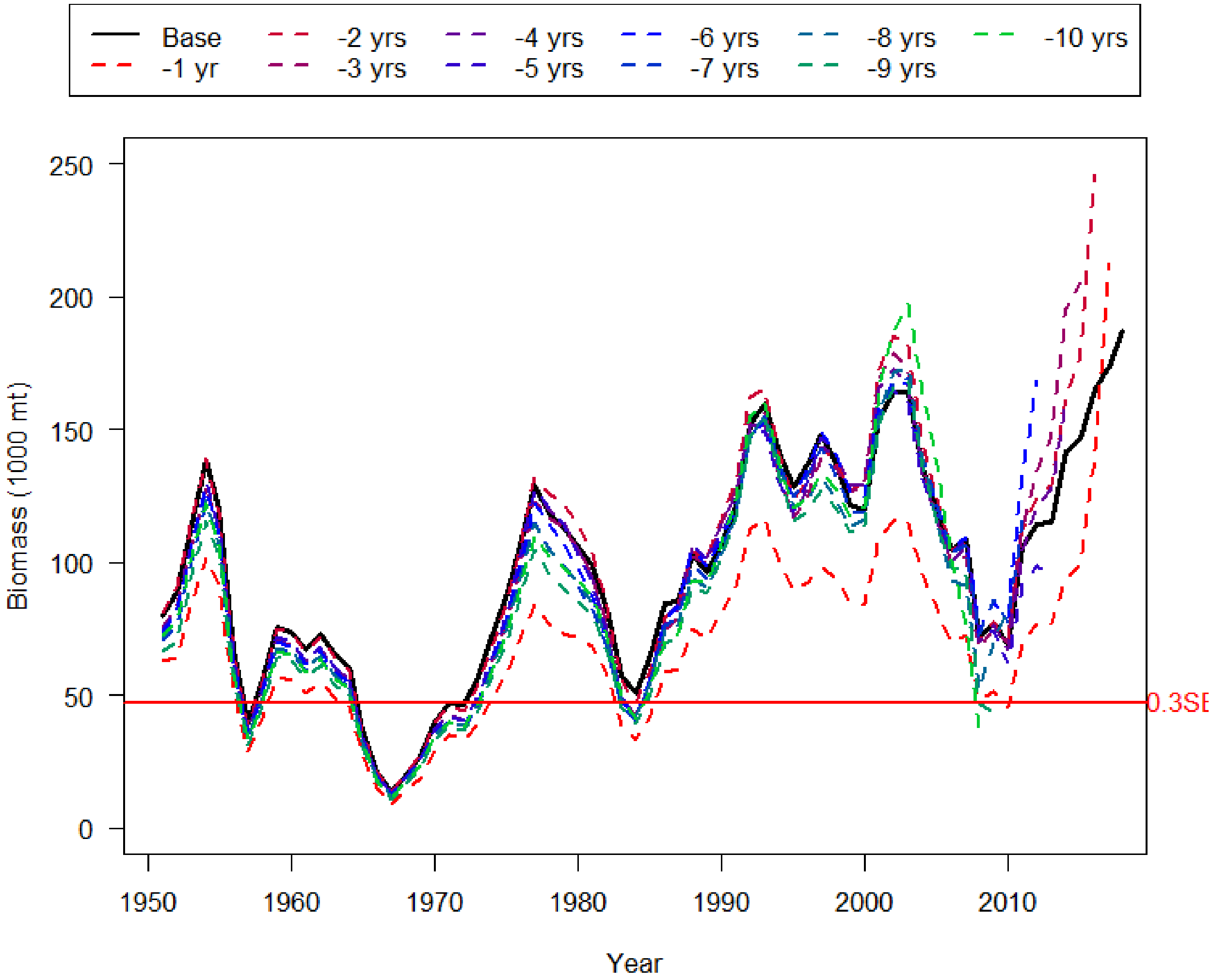


Figure 164. Retrospective spawning biomass for the Strait of Georgia AM1 model.

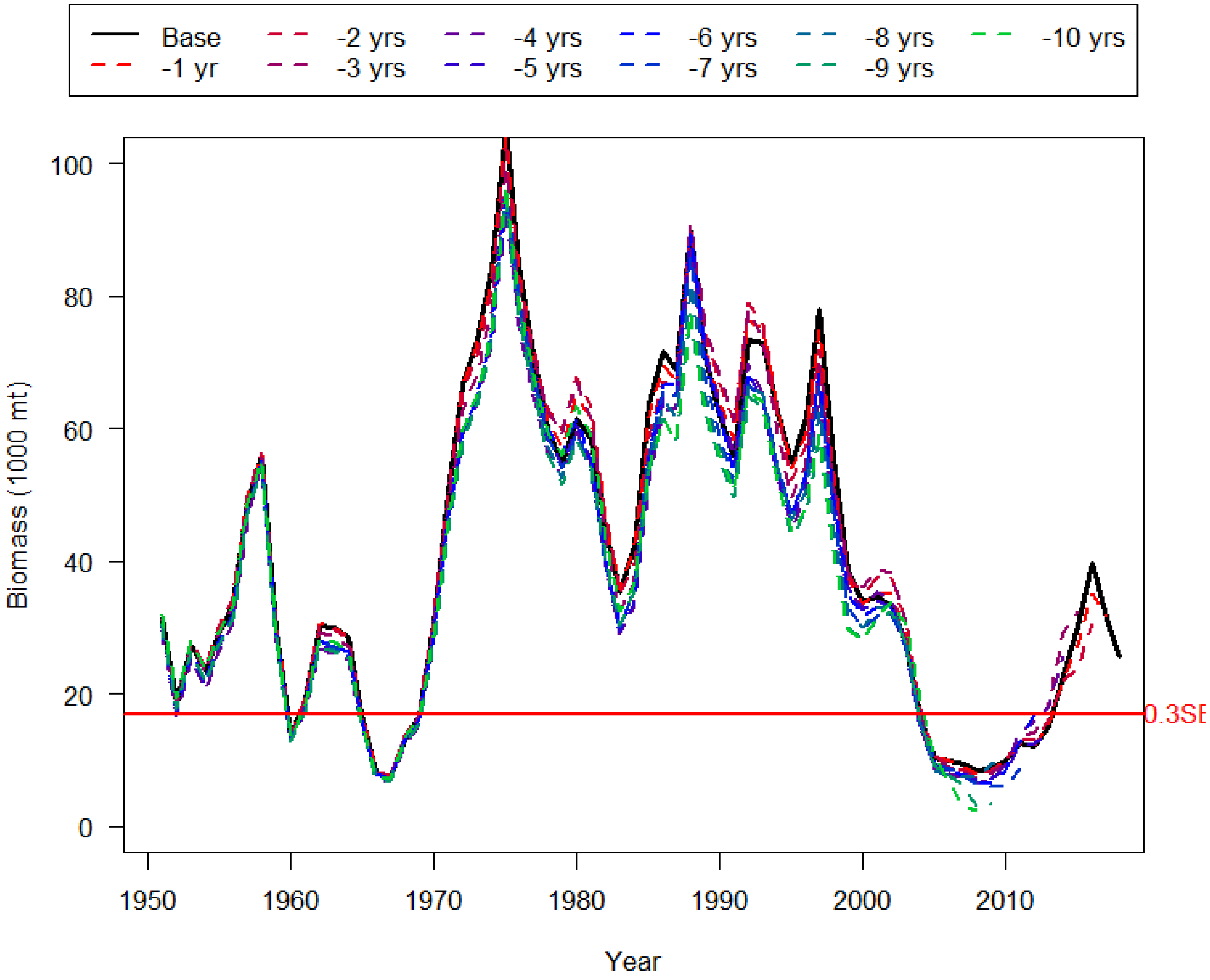


Figure 165. Retrospective spawning biomass for the WCVI AM1 model.

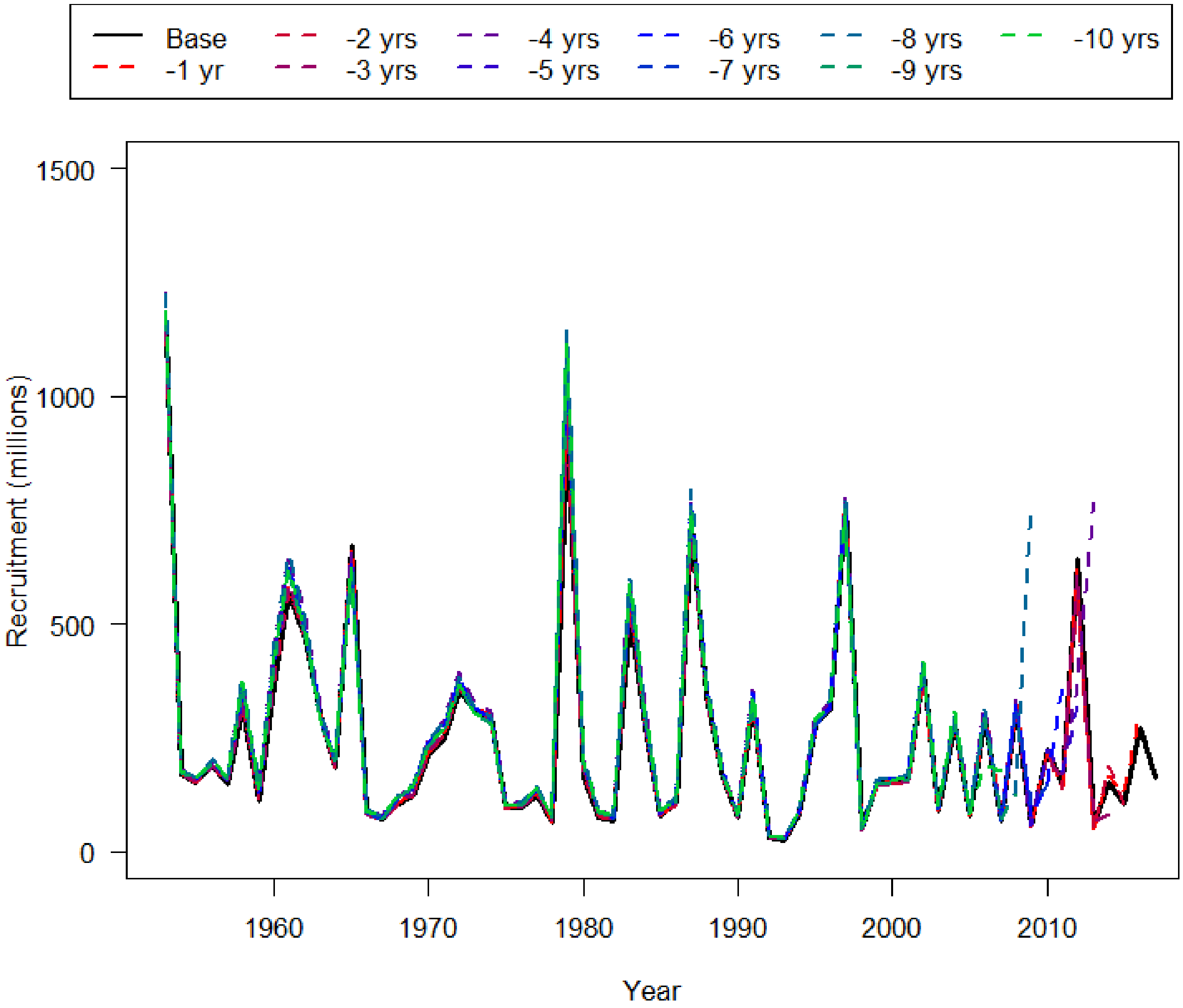


Figure 166. Retrospective recruitment for the Haida Gwaii AM2 model.

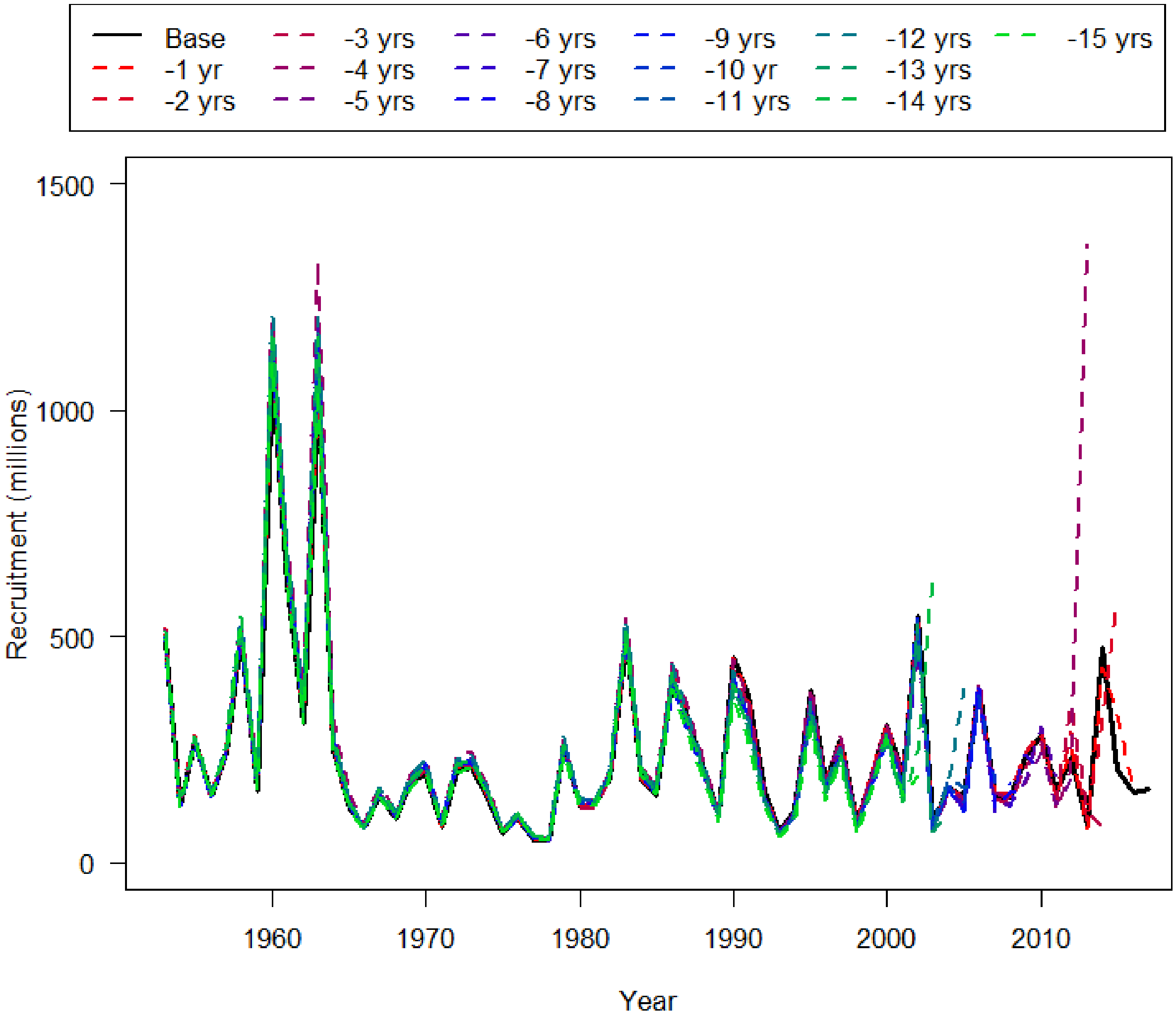


Figure 167. Retrospective recruitment for the Prince Rupert District AM2 model.

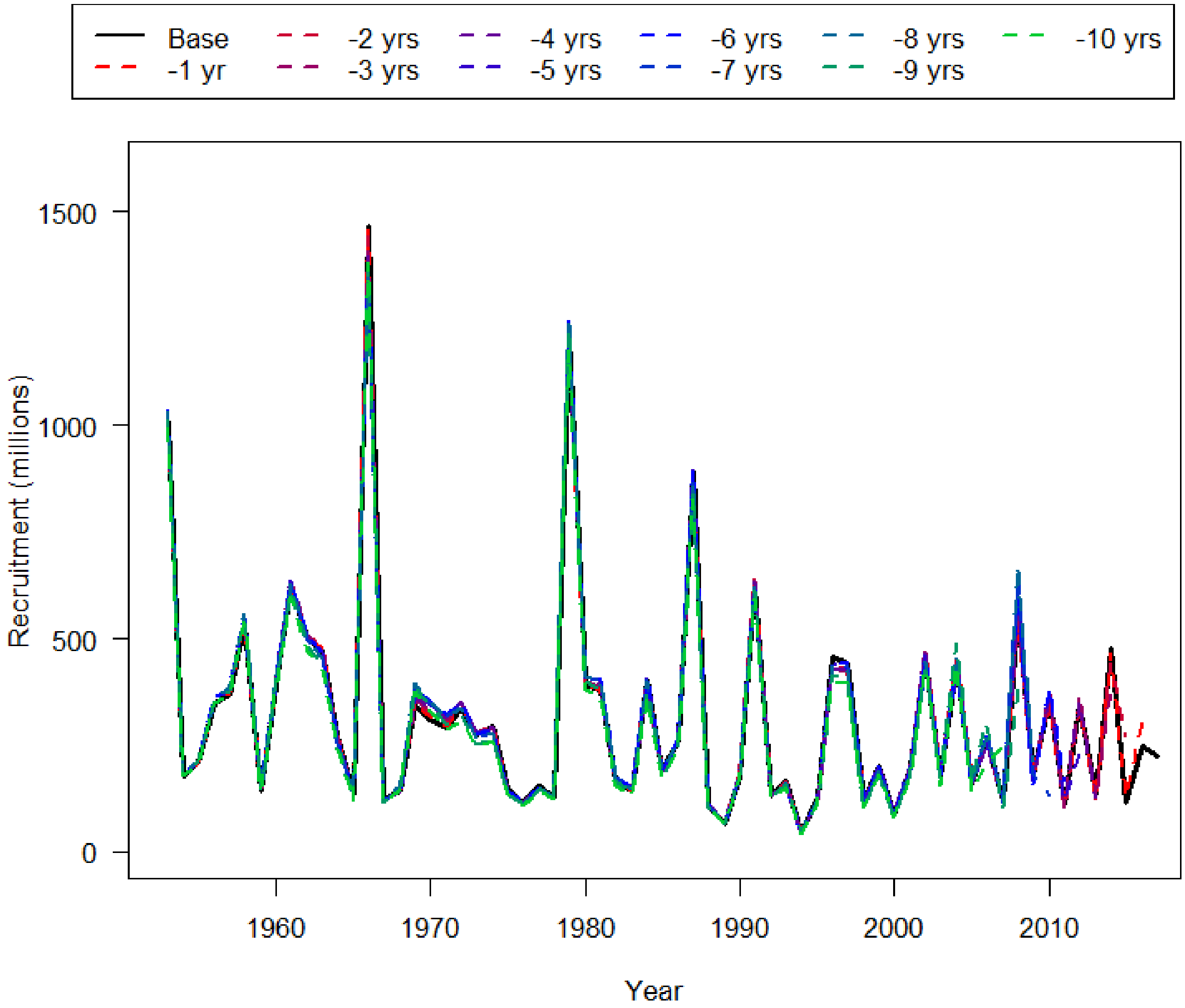


Figure 168. Retrospective recruitment for the Central Coast AM2 model.

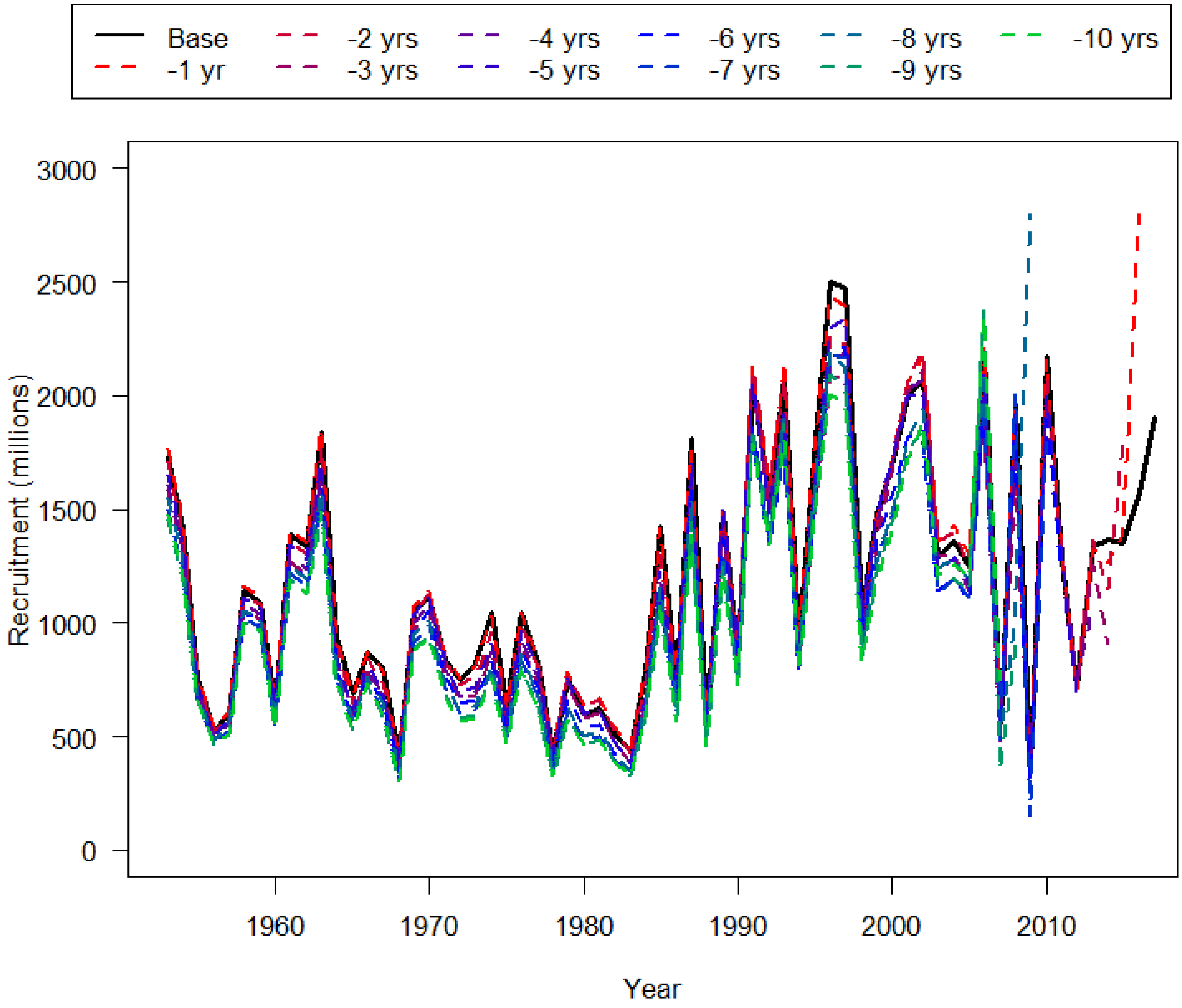


Figure 169. Retrospective recruitment for the Strait of Georgia AM2 model.

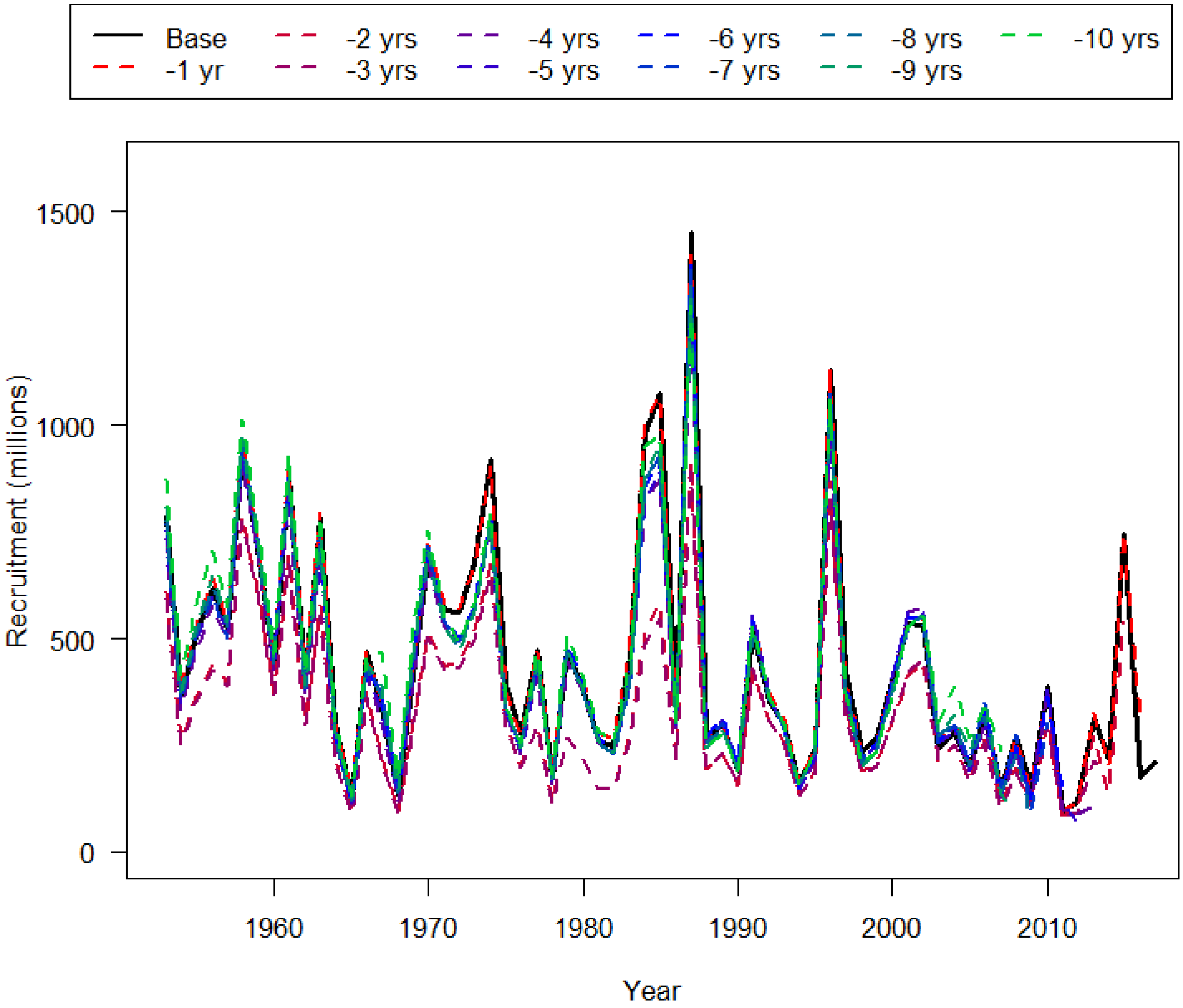


Figure 170. Retrospective recruitment for the WCVI AM2 model.

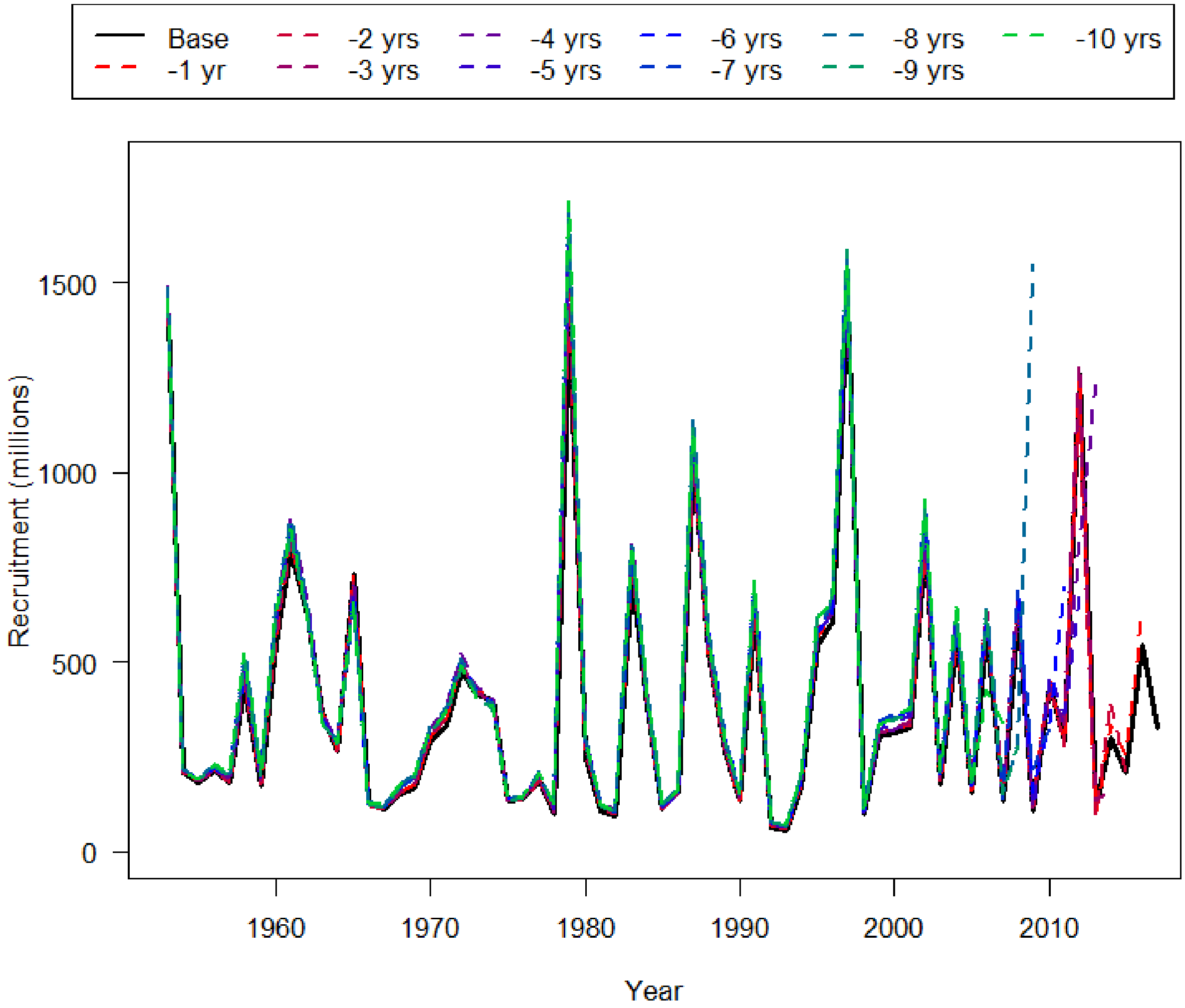


Figure 171. Retrospective recruitment for the Haida Gwaii AM1 model.

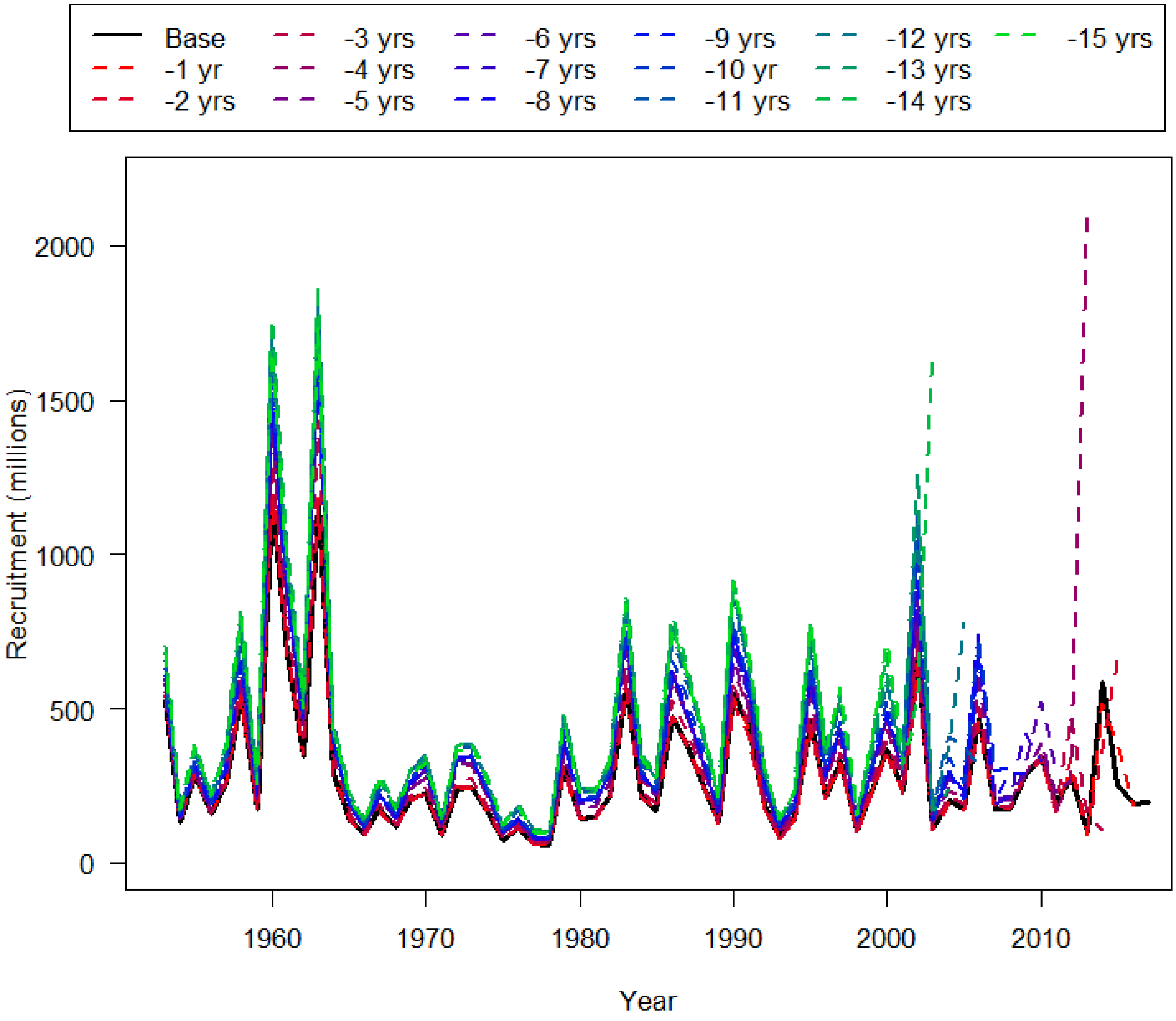


Figure 172. Retrospective recruitment for the Prince Rupert District AM1 model.

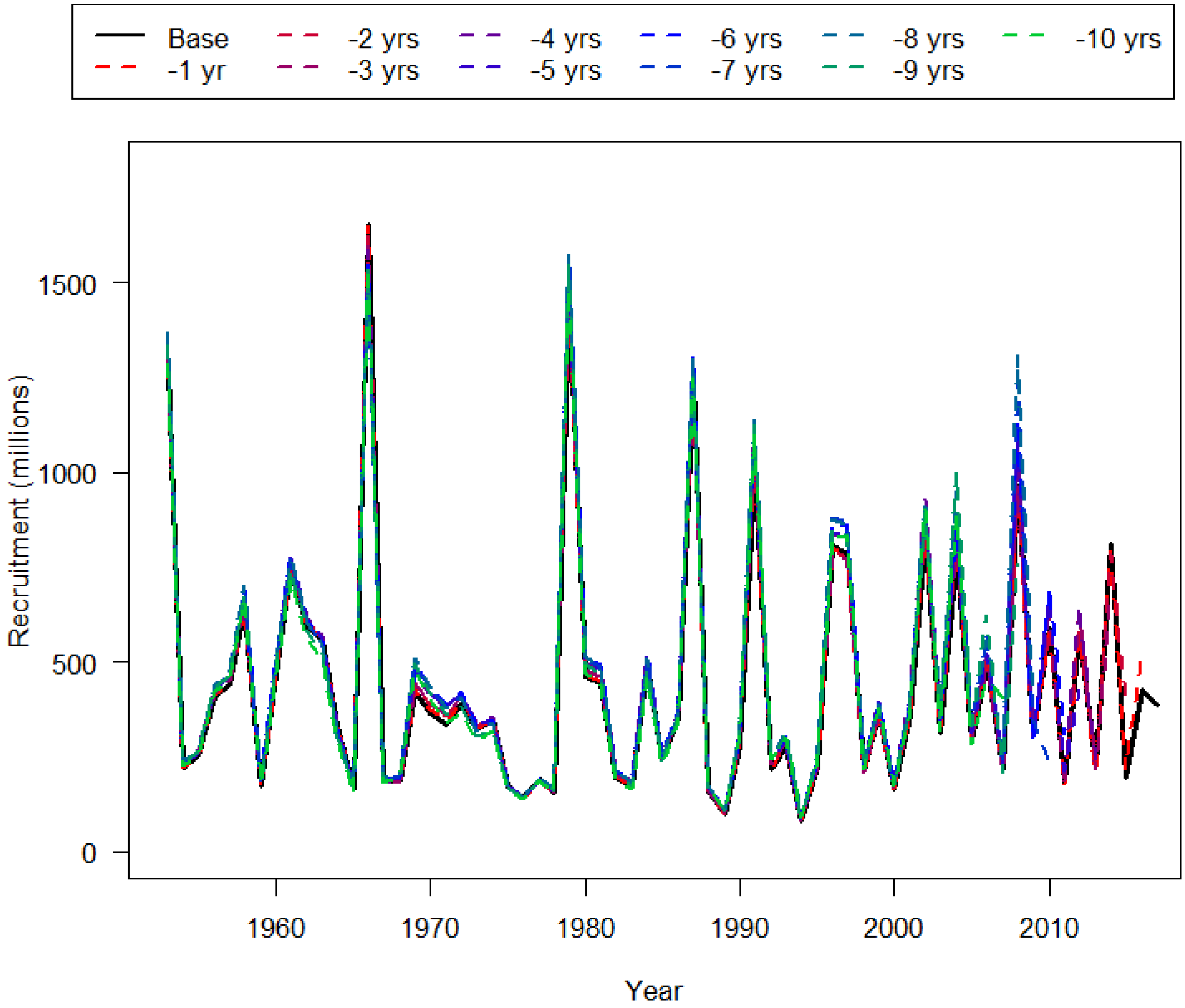


Figure 173. Retrospective recruitment for the Central Coast AM1 model.

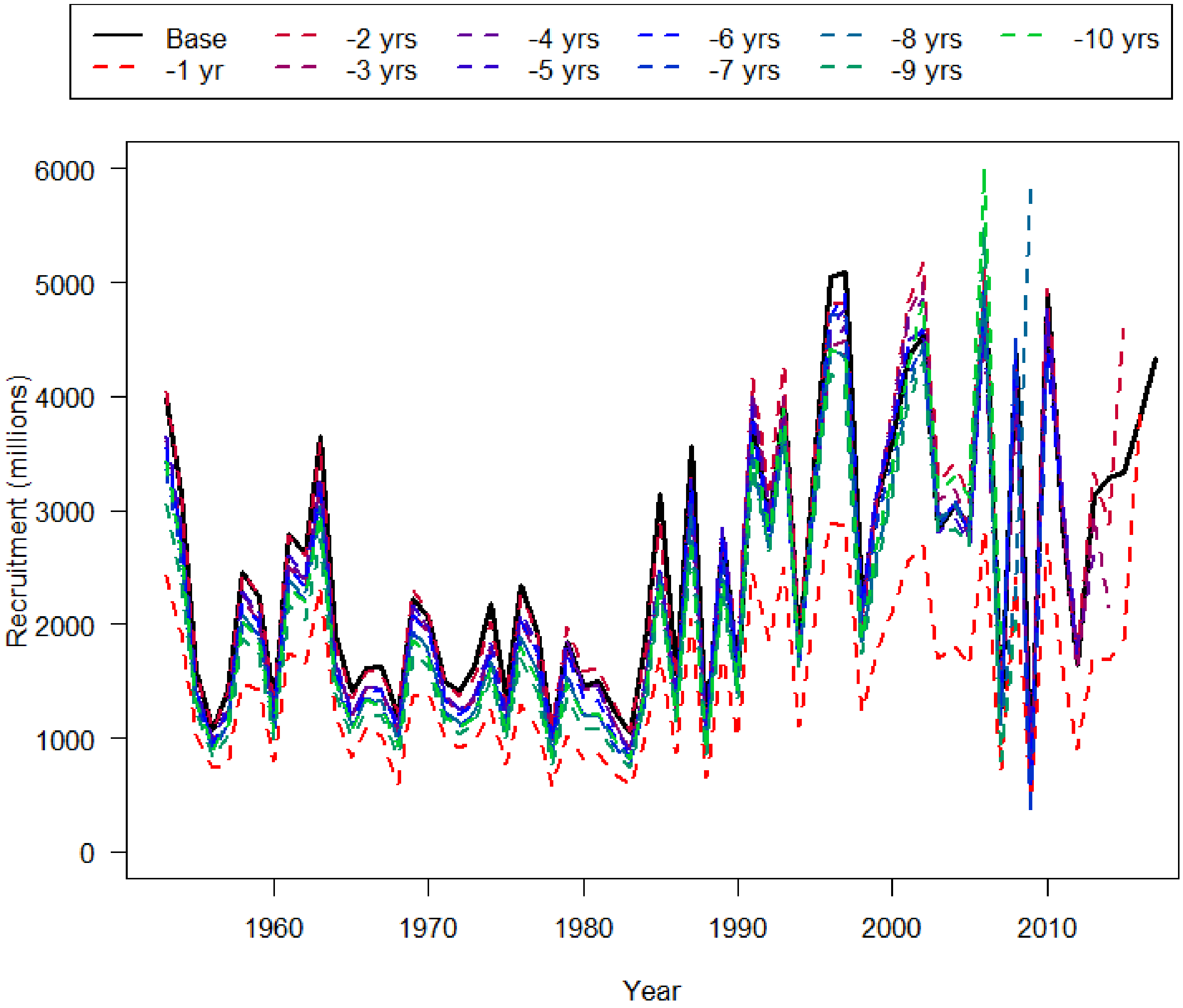


Figure 174. Retrospective recruitment for the Strait of Georgia AM1 model.

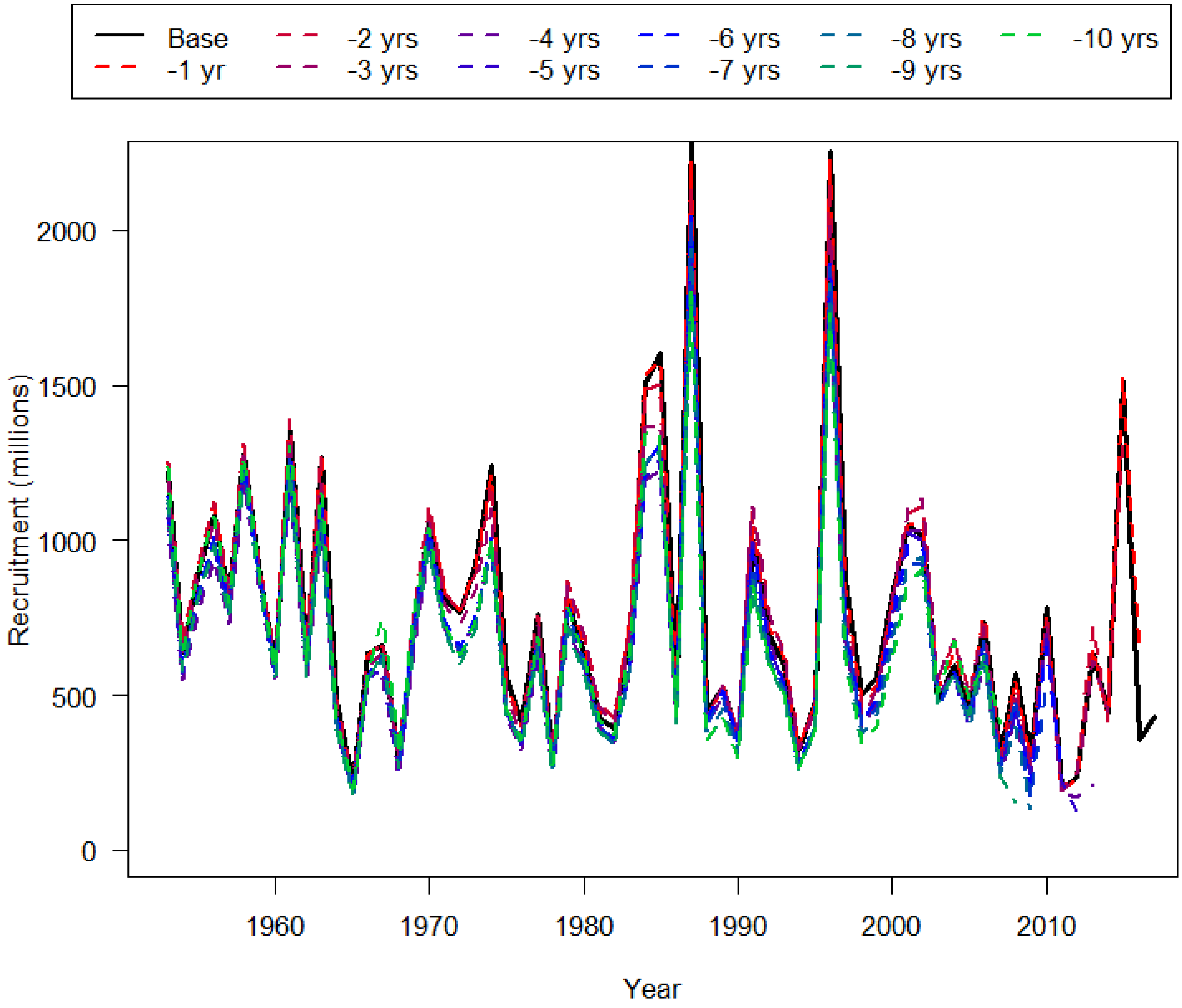


Figure 175. Retrospective recruitment for the WCVI AM1 model.

APPENDIX A. MODEL DESCRIPTION

A.1 INTRODUCTION

Stock Assessment modelling was done using the Integrated Statistical Catch Age Model (ISCAM), developed by S. Martell (Martell et al., 2012). ISCAM is written in AD Model Builder and the source code and documentation for both are available online. ISCAM uses a statistical catch-at-age model implemented in a Bayesian estimation framework.

Running of ISCAM and compilation of results figures was streamlined using the ISCAM-gui software package developed at the Pacific Biological Station. ISCAM-gui is written in the statistical language R, and provides a graphical user interface that allows users to run and show output of multiple ISCAM model scenarios in a comparative fashion.

A.2 MODEL DESCRIPTION

This section contains the documentation in mathematical form of the underlying ISCAM age-structured model, its steady state version that is used to calculate reference points, the observation models used in predicting observations, and the components of the objective function that formulate the statistical criterion used to estimate model parameters. A documented list of symbols used in model equations is given in Table A.1. The documentation presented here is a revised version of the ISCAM user guide available online. Much of the text and many of the equations have been taken directly from the original ISCAM user guide.

Note that all the model equations are presented for a sex structured model with S sexes. Models can therefore be constructed with data for females only, for males and females, or with combined sex data.

The model documentation describes all features of the ISCAM catch-age model, some of which are not implemented for Pacific Herring. The following list describes modifications specific to the assessment of Pacific Herring.

1. Data are unsexed, $S = 1$
2. Total mortality is constant across ages, $Z_{t,a}=Z_t$
3. Fecundity and maturity are synonymous and used interchangeably
4. 100% of Z_t occurs prior to spawning
5. Unfished spawning biomass is represented as B_0 in the Model Description, and as SB_0 in the main text.

A.3 ANALYTIC METHODS: EQUILIBRIUM CONSIDERATIONS

A.3.1 A STEADY-STATE AGE-STRUCTURED MODEL

For the steady-state conditions represented in Table A.2, we assume the parameter vector Θ in Eq. A.13 is unknown and would be estimated by fitting ISCAM to data. For a given set of growth parameters and maturity-at-age parameters defined by Eq. A.14, growth is assumed to follow von Bertalanffy (Eq. A.15), mean weight-at-age is given by the allometric relationship in Eq. A.16, and the age-specific vulnerability is given by an age-based logistic function (Eq. A.17). The terms vulnerability and selectivity are used interchangeably throughout this document, although, technically, selectivity refers to the fishing gear, while vulnerability refers to all processes affecting the availability of fish to the fishery. Selectivity parameters can be fixed or estimated.

Survivorship for unfished and fished populations is defined by Eqns. A.19 and A.20, respectively. It is assumed that all individuals ages A and older (i.e., the plus group) have the same total mortality rate. The incidence functions refer to the life-time or per-recruit quantities such as spawning biomass per recruit (ϕ_E , Eq. A.21) or vulnerable biomass per recruit (ϕ_B, Eq. A.22).

Note that upper and lower case subscripts denote unfished and fished conditions, respectively. Unfished spawning biomass is given by Eq. A.24 and the recruitment compensation ratio (Myers et al., 1999) is given by Eq. A.25. The steady-state equilibrium recruitment for a given fishing mortality rate F_e is given by Eq. A.26. Note that we assume that recruitment follows a Beverton-Holt stock recruitment model of the form shown in Eq. A.39, where the maximum juvenile survival rate s_o is given by:

$$s_o = \frac{\kappa}{\phi_E},$$

and the density-dependent term is given by:

$$\beta = \frac{\kappa - 1}{R_o \phi_E}$$

which simplifies to Eq. A.26.

The equilibrium yield C_e for a given fishing mortality rate is given by Eq. A.27. These steady-state conditions are critical for determining various reference points such as F_{MSY} and B_{MSY}.

A.3.2. MSY-BASED REFERENCE POINTS

ISCAM calculates F_{MSY} by finding the value of F_e that results in the zero derivative of Eq. A.27. This is accomplished numerically using a Newton-Raphson method where an initial guess for F_{MSY} is set equal to M. Given an estimate of F_{MSY}, other reference points such as MSY and B_{MSY} are calculated using the equations in Table A.2.

A.4 ANALYTIC METHODS: STATE DYNAMICS

The estimated parameter vector in ISCAM is defined in Eq. A.28 of Table A.3. The estimated parameters R_0, h, and M, are the leading population parameters that define the overall scale and productivity of the population.

Variance components of the model were partitioned using an errors in variables approach. The key variance parameter is the inverse of the total variance ϑ^2 (i.e., total precision). This parameter can be fixed or estimated, and was estimated for this model. The total variance is partitioned into observation and process error components by the model parameter ρ, which represents the proportion of the total variance that is due to observation error (Eq. A.29, Punt and Butterworth (1993); Deriso et al. (2007)).

The unobserved state variables in Eq. A.30 include the numbers-at-age in year t ($N_{t,a}$), the total biomass in year t (B_t), the spawning stock biomass (SB_t) and the total age-specific total mortality rate ($Z_{t,a}$). The initial numbers-at-age in the first year (Eq. A.31) and the annual recruits (Eq. A.32) are treated as estimated parameters and used to initialize the numbers-at-age array.

Vulnerability-at-age is here assumed time-invariant and is modelled using a two-parameter logistic function (Eq. A.33). The annual fishing mortality for each gear k in year t is the exponent of the estimated vector $\Gamma_{k,t}$ (Eq. A.34). The vector of log fishing mortality rate parameters $\Gamma_{k,t}$ is a bounded vector with a minimum value of -30.0 and an upper bound of 3.0. In arithmetic space this corresponds to a minimum value of $9.36e^{-14}$ and a maximum value of 20.01 for annual fishing mortality rates. In years where there are zero reported catches for a given fleet, no corresponding fishing mortality rate parameter is estimated and the implicit assumption is there was no fishery in that year.

State variables in each year are updated using Eqns. A.35–A.38, where the spawning biomass is the product of the numbers-at-age and the mature biomass-at-age (Eq. A.35). The total mortality rate is given by Eq. A.36, and the total catch (in weight) for each gear is given by Eq. A.37, assuming that both natural and fishing mortality occur simultaneously throughout the year.

Numbers-at-age are propagated over time using Eq. A.38, where members of the plus group (age A) are all assumed to have the same total mortality rate.

Recruitment to age k is assumed to follow a Beverton-Holt model for Pacific Herring (Eq. A.39) where the maximum juvenile survival rate (s_o) is defined by $s_o = \kappa/\phi_E$. For the Beverton-Holt model, β is derived by solving Eq. A.39 for β conditional on estimates of h and R_o.

A.5 RESIDUALS, LIKELIHOODS, AND OBJECTIVE FUNCTION VALUE COMPONENTS

The objective function contains five major components:

1. The negative log-likelihood for the catch data
2. The negative log-likelihood for the relative abundance data
3. The negative log-likelihood for the age composition data
4. The prior distributions for model parameters
5. Three penalty functions that are invoked to regularize the solution during intermediate phases of the non-linear parameter estimation. The penalty functions:
    a. constrain the estimates of annual recruitment to conform to a Beverton-Holt stock-recruit function
    b. weakly constrain the log recruitment deviations to a normal distribution
    c. weakly constrain estimates of log fishing mortality to a normal distribution (~ *N*(ln(0.2), 4.0)) to prevent estimates of catch from exceeding estimated biomass.

Tests showed the model was insensitive to changes in the penalty function parameters, indicating that the other likelihood components and prior probability distributions were the most important contributors to the objective function.

The objective function components are discussed in more detail in the following sections.

A.5.1 CATCH DATA

It is assumed that the measurement errors in the catch observations are log-normally distributed, and the residuals given by:

$$\eta_{k,t} = \ln(C_{k,t} + o) - \ln(\ddot{C}_{k,t} + o) \tag{A.1}$$

where o is a small constant (e^{-10}) to ensure the residual is defined in the case of a zero catch observation. The residuals are assumed to be normally distributed with a user-specified standard deviation σ_C . At present, it is assumed that observed catches for each gear k have the same standard deviation. The negative loglikelihood (ignoring the scaling constant) for the catch data is given by:

$$\ell_C = \sum_k [T_k \ln(\sigma_C) + \frac{\sum_t(\eta_{k,t})^2}{2\sigma_C^2}] \tag{A.2}$$

where T_k is the total number of catch observations for gear type k.

A.5.2 RELATIVE ABUNDANCE DATA

For Pacific herring the relative abundance data are assumed to be proportional to spawning biomass so the kth survey the vulnerable biomass available to the survey sampling gear:

$$V_{k,t} = \sum_a SB_{t,a} e^{-\lambda_{k,t} M_{t,a}} f_{a,t} \tag{A.3}$$

where $v_{k,a}$ is the age-specific selectivity of gear k, and w_a is the mean-weight-at-age. A user specified fraction of the total mortality $\lambda_{k,t}$ adjusts the numbers-at-age to correct for survey timing. The residuals between the observed and predicted relative abundance index is given by:

$$\epsilon_{k,t} = \ln(I_{k,t}) - \ln(q_k) + \ln(V_{k,t}) \tag{A.4}$$

where $I_{k,t}$ is the observed relative abundance index, q_k is the catchability coefficient for index k, and $V_{k,t}$ is the predicted vulnerable biomass at the time of sampling. The catchability coefficient q_k is evaluated at its conditional maximum likelihood estimate:

$$q_k = \frac{1}{N_k} \sum_{t \in I_{k,t}} \ln(I_{k,t}) - \ln(V_{k,t})$$

where N_k is the number of relative abundance observations for index k (see Walters and Ludwig, 1994, for more information). The negative loglikelihood for relative abundance data is given by:

$$\ell_I = \sum_k \sum_{t \in I_{k,t}} \ln(\sigma_{k,t}) + \frac{\epsilon_{k,t}^2}{2\sigma_{k,t}^2} \tag{A.5}$$

where

$$\sigma_{k,t} = \frac{\rho\varphi^2}{\omega_{k,t}}$$

where $\rho\varphi^2$ is the proportion of the total error that is associated with observation errors, and $\omega_{k,t}$ is a user specified relative weight for observation t from gear k.

The $\omega_{k,t}$ terms allow each observation to be weighted relative to the total error $\rho\varphi^2$; for example, to omit a particular observation, set $\omega_{k,t} = 0$, or to give 2 times the weight, then set $\omega_{k,t} = 2.0$. To assume all observations have the same variance then simply set $\omega_{k,t} = 1$. Note that if $\omega_{k,t} = 0$ then Eq. A.5 is undefined; therefore, ISCAM adds a small constant to $\omega_{k,t}$ (e^{-10}, which is equivalent to assuming an extremely large variance) to ensure the likelihood can be evaluated.

In the case of the Pacific Herring assessment, the spawn survey data post 1988 were assumed to be 1.166 times as precise as the pre-dive survey data (1951-1987). To implement this, objective function weights for the 1951-1987 data were set equal to unity and the contemporary data was assigned a relative weight of 1.166. The standard deviation in the observation errors is conditional on estimated values of ρ and φ^2.

A.5.3 AGE COMPOSITION DATA

Sampling theory suggest that age composition data are derived from a multinomial distribution (Fournier and Archibald, 1982). However, ISCAM assumes that age-proportions are obtained from a multivariate logistic distribution (Schnute and Richards, 1995; Richards et al., 1997). ISCAM departs from the traditional multinomial model due to choices regarding weighting of the age-composition data in the objective function. First, the multinomial distribution requires the specification of an effective sample size. This weighting may be done arbitrarily or through iterative re-weighting (McAllister and Ianelli, 1997; Gavaris and Ianelli, 2002), and in the case of multiple and potentially conflicting age-proportions this procedure may fail to converge properly. The assumed effective sample size can have a large impact on the overall model results.

A feature of the multivariate logistic distribution is that the age-proportion data can be weighted based on the conditional maximum likelihood estimate of the variance in the age-proportions.

Therefore, the contribution of the age-composition data to the overall objective function is “self-weighting” and is conditional on other components in the model. Ignoring the subscript for gear type for clarity, the observed and predicted proportions-at-age must satisfy the constraint:

$$\sum_{a=1}^{A} p_{t,a} = 1$$

for each year. The residuals between the observed ($p_{t,a}$) and predicted proportions ($\hat{p}_{t,a}$) is given by:

$$\eta_{t,a} = \ln(p_{t,a}) - \ln(\hat{p}_{t,a}) - \frac{1}{A}\sum_{a=1}^{A}\left[\ln(p_{t,a}) - \ln(\hat{p}_{t,a})\right] \tag{A.6}$$

The conditional maximum likelihood estimate of the variance is given by

$$\hat{\tau}^2 = \frac{1}{(A-1)T}\sum_{t=1}^{T}\sum_{a=1}^{A}\eta_{t,a}^2$$

and the negative loglikelihood evaluated at the conditional maximum likelihood estimate of the variance is given by:

$$\ell_A = (A-1)T\ln(\hat{\tau}^2). \tag{A.7}$$

In short, the multivariate logistic likelihood for age-composition data is just the log of the residual variance weighted by the number observations over years and ages.

A.5.4 STOCK RECRUITMENT

This stock assessment assumes Beverton-Holt recruitment. Annual recruitment and the initial age-composition are treated as latent variables in ISCAM, and residuals between estimated recruits and the deterministic stock-recruitment models are used to estimate unfished spawning stock biomass and recruitment compensation. The residuals between the estimated and predicted recruits is given by:

$$\delta_t = \ln(\bar{R}e^{w_t}) - R_t) \tag{A.8}$$

where R_t is given by Eq. A.39, and k is the age at recruitment. Note that a bias correction term for the lognormal process errors is included in Eq. A.39.

The negative log likelihood for the recruitment deviations is given by the normal density (ignoring the scaling constant):

$$\ell_\delta = n\ln(\tau) + \frac{\sum_{t=1+k}^{T}\delta_t^2}{2\tau^2} \tag{A.9}$$

Eqs. A.8 and A.9 are key for estimating unfished spawning stock biomass and recruitment compensation via the recruitment models. The relationship between (s_o, β) and (B_o, κ) is defined as:

$$s_o = \frac{\kappa}{\phi_E} \tag{A.10}$$

$$\beta = \frac{\kappa - 1}{B_o} \quad (Beverton - Holt) \tag{A.11}$$

where s_o is the maximum juvenile survival rate, and β is the density effect on recruitment, and B_o is the unfished spawning stock biomass. Unfished steady-state spawning stock biomass per recruit is given by ϕ_E, which is the sum of products between age-specific survivorship and relative fecundity. In the cases where the natural mortality rate is allowed to vary over time, the calculation of ϕ_E, and the corresponding unfished spawning stock biomass (B_o) is based on the average natural mortality rate over the entire time period. This subtle calculation has implications for reference point calculations in cases where there are increasing or decreasing trends in natural mortality rates trend upwards, estimates of B_o decrease.

A.5.5 PARAMETER ESTIMATION AND UNCERTAINTY

Parameter estimation and quantifying uncertainty was carried out using the tools available in AD Model Builder. AD Model Builder (ADMB) is a software for creating computer programs to estimate the parameters and associated probability distributions for nonlinear statistical models. The software is freely available from the ADMB project. This software was used to develop ISCAM, and the source code and documentation for the original version of ISCAM (on which ISCAM is based) is freely available from the ISCAM project, or from a subversion repository on GitHub.

There are actually five distinct components that make up the objective function that ADMB is minimizing:

f = negative loglikelihoods + constraints + priors for parameters + survey priors + convergence penalties.

The purpose of this section is to completely document all of the components that make up the objective function.

Negative loglikelihoods The negative loglikelihoods pertain specifically elements that deal with the data and variance partitioning and have already been described in detail in earlier portions of Section A.5. There are four specific elements that make up the vector of the objective function:

$$\vec{\ell} = \ell_C, \ell_I, \ell_A, \ell_\delta. \tag{A.12}$$

To reiterate, these are the likelihood of the catch data R_C , likelihood of the survey data R_I, the likelihood of the age-composition data R_A and the likelihood of the stock-recruitment residuals R_δ. Each of these elements are expressed in negative log-space, and ADMB attempts to estimate model parameters by minimizing the sum of these elements.

Constraints There are two specific constraints that are described here:

1. parameter bounds, and
2. constraints to ensure that a parameter vector sums to 0.

In ISCAM the user must specify the lower and upper bounds for the leading parameters defined in the control file ($\ln(R_o), h, \ln(M), \ln(\overline{R}), \ln(\ddot{R}), \rho, \vartheta$). All estimated selectivity parameters $\vec{\gamma}_k$ are estimated in log space and have a minimum and maximum values of -5.0 and 5.0, respectively. These values are hard-wired into the code, but should be sufficiently large/small enough to capture a wide range of selectivities. Estimated fishing mortality rates are also constrained (in log space) to have a minimum value of -30, and a maximum value of 3.0, also hard-wired. Log annual recruitment deviations are also constrained to have minimum and maximum values of -15.0 and 15.0 and there is an additional constraint to ensure the vector of deviations sums to 0. This is necessary in order to be able to estimate the average recruitment $\bar{R}$. Finally, the annual log deviations in natural mortality rates are constrained to lie between -5.0 and 5.0.

Priors for parameters Each of the seven leading parameters specified in the control file ($\ln(R_o), h, \ln(M), \ln(\overline{R}), \ln(\ddot{R}), \rho, \vartheta$) are declared as bounded parameters and in addition the user can also specify an informative prior distribution for each of these parameters. Five distinct prior distributions can be implemented: uniform, normal, lognormal, beta and a gamma distribution. For the Pacific herring, a bounded recruitment uniform prior was specified for the log of unfished recruitment U(-5,15), a beta prior was assumed for steepness Beta(10.0,4.92), a normal prior was specified for the log of natural mortality rate N(-0.79,0.4), a bounded uniform prior for both the log of initial recruitment and average recruitment U(-5.0,15.0), a beta prior for the variance partitioning parameter $\rho\tilde{\beta}$(17.086, 39.0559), and a gamma prior for the inverse total standard deviation parameter $\vartheta\tilde{T}$(25, 28.75). The scaling parameter q for each of the surveys is not treated as an unknown parameter within the code; rather, the maximum posterior density estimate for *ln(q)* conditional on all other parameters is used to scale the predicted spawning biomass to the observed acoustic biomass index. The priors for the log of both survey q's are assumed to be informative N(0.569, 0.276) for the AM1. For AM2 the prior on q_1 was assumed uninformative N(0, 1) and informative for q_2 N(1, 0.01).

A.6 TABLES

Table A.1. A list of symbols, constants and description for variables used in ISCAM.

Indices

Symbol	Value	Description
s	-	Index for sex
a	-	Index for age
t	-	Index for year
k	-	Index for gear

Model dimensions

Symbol	Value	Description
S	1	Number of sexes
$\acute{a}, A$	2, 10	Youngest and oldest age class (A is a plus group)
$\acute{t}, T$	1951, 2017	First and last year of catch data
K	5	Number of gears including survey gears

Observations (data)

Symbol	Value	Description
$C_{k,t}$	-	catch in weight by gear k in year t
$I_{k,t}$	-	relative abundance index for gear k in year t

Estimated parameters

Symbol	Value	Description
R_0	-	Age-$\acute{a}$ recruits in unfished conditions
h	-	Steepness of the stock-recruitment relationship
$\bar{R}$	-	Average age-$\acute{a}$ recruitment from year $\acute{t}$ to T
$\bar{R}_{init}$	-	Average age-$\acute{a}$ recruitment in year $\acute{t}$
M_s	-	Instantaneous natural mortality rate
$\hat{a}_k, \hat{\gamma}_k$	-	Selectivity parameters for gear k
$\Gamma_{k,t}$	-	Logarithm of the instantaneous fishing mortality for gear k in year t
ω_t	-	Age-$\acute{a}$ deviates from $\bar{R}$ for years $\acute{t}$ to T
$\omega_{init,t}$	-	Age-$\acute{a}$ deviates from $\bar{R}_{init}$ for year $\acute{t}$
q_s	-	Catchability parameter for survey k
ρ	-	Fraction of the total variance associated with observation error
ϑ^2	-	Total precision (inverse of variance) of the total error

Standard deviations

Symbol	Value	Description
o	-	Standard deviation for observation errors in survey index
τ	-	Standard deviation in process errors (recruitment deviations)
σ_C	-	Standard deviation in observed catch by gear

Residuals

Symbol	Value	Description
δ_t	-	Annual recruitment residual
η_t	-	Residual error in predicted catch

Fixed Growth & maturity parameters

Symbol	Value	Description
$l_{\infty s}$	-	Asymptotic length in mm sex s
$\acute{k}_s$	-	Brody growth coefficient sex s
t_{os}	-	Theoretical age at zero length sex s
$\acute{a}_s$	-	Scalar in length-weight allometry for sex s
$\acute{b}_s$	-	Power parameter in length-weight allometry for sex s
$\dot{a}_s$	-	Age at 50% maturity for sex s
$\dot{\gamma}_s$		Standard deviation at 50% maturity for sex s

Table A.2. Steady-state age-structured model assuming unequal vulnerability-at-age, age-specific fecundity and Ricker type recruitment.

Parameters

$$\Theta = (R_o, h, M); \quad R_o > 0; \quad 0.2 \leq h < 1.0; \quad M > 0 \tag{A.13}$$

$$\Phi = (l_{\infty,s}, \acute{k}S, t_{0,s}, \acute{a}_s, \acute{b}_s, \dot{a}_s, \dot{\gamma}_s, \hat{a}_k, \hat{\gamma}_k) \tag{A.14}$$

Age-schedule information

$$l_{a,s} = l(1 - e^{\left(-k_s\left(a-t_{0,s}\right)\right)}) \tag{A.15}$$

$$w_{a,s} = \acute{a}_s\left(l_{a,s}\right)^{\acute{b}_s} \tag{A.16}$$

$$v_a = (1 + e^{\left(\frac{-(\hat{a}-a)}{\hat{y}}\right)})^{-1} \tag{A.17}$$

$$f_{a,s} = w_{a,s}(1 + e^{\left(\frac{-(\dot{a}_s-a_s)}{\dot{y}_s}\right)})^{-1} \tag{A.18}$$

Survivorship

$$\iota_a = \begin{cases} \frac{1}{S}, & a = 1 \\ \iota_{a-1}e^{-M}, & a > 1 \\ \frac{\iota_{a-1}}{(1-e^{-M})}, & a = A \end{cases} \tag{A.19}$$

$$\iota_a = \begin{cases} \frac{1}{S}, & a = 1 \\ \hat{\iota}_{a-1,s}e^{-M-F_e v_{a-1,s}}, & a > 1 \\ \frac{\hat{\iota}_{a-1,s}e^{-M-F_e v_{a-1,s}}}{(1-e^{-M-F_e v_{a,s}})}, & a = A \end{cases} \tag{A.20}$$

Incidence Functions

$$\Phi\mathrm{E} = \sum_{s=1}^{S}\sum_{a=1}^{\infty} l_a f_{a,s}, \ \Phi\mathrm{e} = \sum_{s=1}^{S}\sum_{a=1}^{\infty} \hat{l}_a f_{a,s} \tag{A.21}$$

$$\Phi\mathrm{B} = \sum_{s=1}^{S}\sum_{a=1}^{\infty} l_a w_{a,s} v_{a,s}, \ \Phi\mathrm{b} = \sum_{s=1}^{S}\sum_{a=1}^{\infty} \hat{l}_a w_{a,s} v_{a,s} \tag{A.22}$$

$$\Phi\mathrm{q} = \sum_{s=1}^{S}\sum_{a=1}^{\infty} \frac{\hat{l}_a w_{a,s} v_{a,s}}{M + F_e v_{a,s}}\left(1 - e^{\left(-M-F_e v_{a,s}\right)}\right) \tag{A.23}$$

Steady-state conditions

$$B_o = R_o\varphi_B \tag{A.24}$$

$$k = \frac{4h}{1-h} \tag{A.25}$$

$$k = R_e = R_o\frac{k-\frac{\Phi\mathrm{E}}{\Phi\mathrm{e}}}{k-1} \ \textit{(Beverton- Holt)} \tag{A.26}$$

$$C_e = F_e R_e \varphi_q \tag{A.27}$$

Table A.3. Statistical catch-age model using Baranov catch.

Estimated parameters

$$\Theta = (R_0, h, M, \overline{R}, \overline{R}_{init}, \vartheta^2, \rho, \Gamma_{k,t}, \{w_t\}_{\acute{t}=1-A}^{\acute{t}=T}, \{w_{init,t}\}_{t=\acute{t}-A}^{t=\acute{t}-1}) \quad \text{(A.28)}$$

$$\sigma = \sqrt{p\vartheta}, \tau = \sqrt{(1-p)\vartheta} \quad \text{(A.29)}$$

Unobserved states

$$N_{t,a,s}, B_t, s, Z_{t,a,s} \quad \text{(A.30)}$$

Initial states

$$N_{t,a,s} = \frac{1}{S}\overline{R}_{init} e^{w_{init,t}} e^{-M(a-1)}; \ (\acute{t} - A) < t < 1; 2 \le a \le A \quad \text{(A.31)}$$

$$N_{t,a,s} = \frac{1}{S}\overline{R} e^{w_t}; 1 \le t \le T; a = 1 \quad \text{(A.32)}$$

$$v_{k,a} = \frac{1}{1 + e^{-\frac{(a-\hat{a}_k)}{\hat{\gamma}_k}}} \quad \text{(A.33)}$$

$$F_{k,t} = e^{T_{k,t}} \quad \text{(A.34)}$$

State dynamics (t>1)

$$B_{t,s,} = \sum_a N_{t,a,s} f_{a,s} \quad \text{(A.35)}$$

$$Z_{t,a,s} = M + \sum_k F_{k,t} v_{k,t,a,s} \quad \text{(A.36)}$$

$$\hat{C}_{k,t} = \sum_s \sum_a \frac{N_{t,a,s} w_{a,s} F_{k,t} v_{k,t,a,s} (1 - e^{-Z_{t,a,s}})^{nt}}{Z_{t,a,s}} \quad \text{(A.37)}$$

$$N_{t,a,s} = \begin{cases} \frac{s_o E_{t-1}}{1+\beta E_{t-1}} e^{(\omega_t - 0.5\tau^2)} & a = 1 \\ N_{t-1,a-1,s} e^{(-Z_{t-1,a-1,s})} & a > 1 \\ N_{t-1,a,s} e^{(-Z_{t-1,a,s})} & a = A \end{cases} \quad \text{(A.38)}$$

Recruitment model

$$R_t = \frac{s_O B_{t-k}}{1+\beta B_{t-k}} e^{\delta_t - 0.5\tau^2} \ \textit{(Beverton- Holt)} \quad \text{(A.39)}$$

APPENDIX B. INPUT DATA

We provide stock assessment input data for the 5 major stock assessment regions (SARs): Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SoG), and West Coast of Vancouver Island (WCVI). In addition, we provide the same data for the 2 minor SARs which are not assessed: Area 27 (A27) and Area 2 West (A2W). Tables B.1 to B.7 have time series of catch in thousands of metric tonnes (t x 10^3) for Haida Gwaii, Prince Rupert District, Central Coast, Strait of Georgia, West Coast of Vancouver Island, Area 27, and Area 2 West, respectively. Tables B.8 to B.14 have time series of spawn index in thousands of metric tonnes (t x 10^3) for the aforementioned SARs, respectively. Tables B.15 to B.21 have time series of number-at-age for the aforementioned SARs, respectively. Tables B.22 to B.28 have time series of weight-at-age for the aforementioned SARs, respectively. Table B.29 has the number of biological samples by year and SAR.

Table B.1. Pacific Herring catch in thousands of metric tonnes (t x 10^3) by Period from 1951 to 2017 in the HG stock assessment region (SAR). Legend: 'Gear1' represents the reduction, the food and bait, as well as the special use fishery; 'Gear2' represents the roe seine fishery; and 'Gear3' represents the roe gillnet fishery.

	Catch (t x 10^3) by Period		
Year	Gear1	Gear2	Gear3
1951	2.847	0.000	0.000
1952	10.147	0.000	0.000
1953	0.000	0.000	0.000
1954	1.786	0.000	0.000
1955	0.498	0.000	0.000
1956	77.461	0.000	0.000
1957	21.803	0.000	0.000
1958	11.147	0.000	0.000
1959	6.828	0.000	0.000
1960	0.000	0.000	0.000
1961	0.576	0.000	0.000
1962	7.632	0.000	0.000
1963	14.705	0.000	0.000
1964	28.772	0.000	0.000
1965	35.448	0.000	0.000
1966	2.746	0.000	0.000
1967	0.213	0.000	0.000
1968	0.080	0.000	0.000
1969	0.000	0.000	0.000
1970	0.000	0.000	0.000
1971	0.102	0.000	0.000
1972	0.849	3.124	0.000
1973	0.000	7.520	0.000
1974	0.000	6.191	0.127
1975	0.017	7.602	0.105
1976	0.374	11.939	1.802

Year	Catch ($t \times 10^3$) by Period		
	Gear1	Gear2	Gear3
1977	0.021	11.125	1.489
1978	0.000	9.172	2.553
1979	0.050	5.817	2.086
1980	0.000	2.106	1.210
1981	0.043	3.884	1.705
1982	0.018	2.353	1.407
1983	0.067	4.601	0.929
1984	0.096	4.016	0.535
1985	0.044	4.571	1.493
1986	0.000	2.613	0.890
1987	0.033	2.028	0.000
1988	0.032	0.000	0.000
1989	0.042	1.419	0.000
1990	0.008	5.534	1.170
1991	0.001	3.898	0.543
1992	0.000	2.524	0.000
1993	0.000	2.699	0.000
1994	0.000	0.299	0.000
1995	0.000	0.000	0.000
1996	0.000	0.000	0.000
1997	0.000	0.000	0.000
1998	0.000	1.371	0.000
1999	0.000	2.493	0.485
2000	0.000	1.765	0.000
2001	0.000	0.000	0.000
2002	0.000	0.706	0.000
2003	0.000	0.000	0.000
2004	0.000	0.000	0.000
2005	0.000	0.000	0.000
2006	0.000	0.000	0.000
2007	0.000	0.000	0.000
2008	0.000	0.000	0.000
2009	0.000	0.000	0.000
2010	0.000	0.000	0.000
2011	0.000	0.000	0.000
2012	0.000	0.000	0.000
2013	0.000	0.000	0.000
2014	0.000	0.000	0.000
2015	0.000	0.000	0.000
2016	0.000	0.000	0.000
2017	0.000	0.000	0.000

Table B.2. Pacific Herring catch in thousands of metric tonnes (t x 10^3) by Period from 1951 to 2017 in the PRD stock assessment region (SAR). Legend: ‘Gear1’ represents the reduction, the food and bait, as well as the special use fishery; ‘Gear2’ represents the roe seine fishery; and ‘Gear3’ represents the roe gillnet fishery.

	Catch (t x 10^3) by Period		
Year	Gear1	Gear2	Gear3
1951	45.865	0.000	0.000
1952	52.379	0.000	0.000
1953	1.865	0.000	0.000
1954	27.277	0.000	0.000
1955	17.806	0.000	0.000
1956	10.182	0.000	0.000
1957	28.035	0.000	0.000
1958	4.523	0.000	0.000
1959	10.224	0.000	0.000
1960	18.476	0.000	0.000
1961	42.746	0.000	0.000
1962	27.660	0.000	0.000
1963	40.228	0.000	0.000
1964	29.930	0.000	0.000
1965	44.211	0.000	0.000
1966	17.295	0.000	0.000
1967	7.998	0.000	0.000
1968	2.068	0.000	0.000
1969	0.000	0.000	0.000
1970	1.330	0.000	0.000
1971	3.500	0.000	0.000
1972	0.877	3.613	0.004
1973	0.218	1.388	0.000
1974	0.182	2.122	1.515
1975	0.155	1.536	0.011
1976	0.564	3.466	0.276
1977	0.792	5.856	1.494
1978	3.519	2.038	3.031
1979	1.810	1.271	1.236
1980	0.738	1.641	1.046
1981	1.682	1.051	0.356
1982	1.815	0.170	0.000
1983	0.000	0.000	0.000
1984	0.173	1.653	1.880
1985	0.253	3.018	3.476
1986	0.375	3.732	4.573
1987	0.122	2.077	4.071
1988	0.079	3.550	4.340
1989	0.071	3.657	4.745
1990	0.043	2.285	2.361

	Catch (t x 10^3) by Period		
Year	Gear1	Gear2	Gear3
1991	0.019	1.348	2.143
1992	0.142	1.238	3.797
1993	0.008	2.200	4.112
1994	0.001	2.363	2.324
1995	0.000	0.706	1.355
1996	0.000	0.000	3.086
1997	0.000	0.000	5.541
1998	0.000	0.000	3.217
1999	0.000	0.256	1.859
2000	0.000	1.239	3.076
2001	0.000	1.012	1.906
2002	0.001	2.061	2.432
2003	0.005	1.446	2.562
2004	0.011	1.909	2.192
2005	0.000	1.750	2.050
2006	0.000	0.957	1.661
2007	0.000	0.000	0.969
2008	0.000	0.513	1.148
2009	0.000	0.713	1.286
2010	0.000	0.475	1.010
2011	0.000	0.883	1.264
2012	0.000	0.466	0.917
2013	0.000	0.743	1.284
2014	0.169	0.718	1.116
2015	0.435	0.737	0.991
2016	0.316	0.729	1.380
2017	0.432	1.019	1.398

Table B.3. Pacific Herring catch in thousands of metric tonnes (t x 10^3) by Period from 1951 to 2017 in the CC stock assessment region (SAR). Legend: 'Gear1' represents the reduction, the food and bait, as well as the special use fishery; 'Gear2' represents the roe seine fishery; and 'Gear3' represents the roe gillnet fishery.

	Catch (t x 10^3) by Period		
Year	Gear1	Gear2	Gear3
1951	42.458	0.000	0.000
1952	33.195	0.000	0.000
1953	0.768	0.000	0.000
1954	24.616	0.000	0.000
1955	11.594	0.000	0.000
1956	43.627	0.000	0.000
1957	23.261	0.000	0.000
1958	9.849	0.000	0.000
1959	27.870	0.000	0.000
1960	4.037	0.000	0.000

	Catch (t x 10^3) by Period		
Year	Gear1	Gear2	Gear3
1961	31.704	0.000	0.000
1962	15.709	0.000	0.000
1963	44.054	0.000	0.000
1964	31.895	0.000	0.000
1965	15.670	0.000	0.000
1966	37.482	0.000	0.000
1967	21.890	0.000	0.000
1968	1.528	0.000	0.000
1969	0.000	0.000	0.000
1970	0.209	0.000	0.000
1971	3.614	0.000	0.000
1972	0.388	8.755	0.137
1973	0.035	6.653	1.112
1974	0.000	3.621	5.267
1975	0.000	3.343	5.395
1976	0.000	6.198	6.213
1977	0.320	3.881	6.904
1978	0.000	4.769	9.277
1979	0.005	0.000	0.000
1980	0.010	0.000	0.528
1981	0.006	0.263	2.304
1982	0.041	2.258	4.071
1983	0.000	2.061	3.579
1984	0.002	3.588	3.582
1985	0.000	2.915	2.294
1986	0.038	2.173	1.176
1987	0.000	2.695	0.920
1988	0.028	3.529	0.970
1989	0.000	6.531	2.911
1990	0.000	5.305	3.046
1991	0.000	7.097	1.806
1992	0.088	7.163	1.111
1993	0.000	8.478	2.038
1994	0.000	9.757	2.122
1995	0.000	8.131	1.451
1996	0.000	3.897	0.402
1997	0.000	3.276	0.344
1998	0.000	7.976	0.646
1999	0.000	6.013	1.511
2000	0.000	6.394	0.972
2001	0.000	5.613	0.517
2002	0.000	2.894	0.399
2003	0.000	2.299	0.289
2004	0.000	2.988	0.000
2005	0.000	3.778	0.000

	Catch (t x 10^3) by Period		
Year	Gear1	Gear2	Gear3
2006	0.000	3.072	0.000
2007	0.000	0.398	0.000
2008	0.000	0.000	0.000
2009	0.000	0.000	0.000
2010	0.000	0.000	0.000
2011	0.000	0.000	0.000
2012	0.000	0.000	0.000
2013	0.000	0.000	0.000
2014	0.000	0.000	0.687
2015	0.000	0.626	0.000
2016	0.000	0.213	0.000
2017	0.000	0.000	0.000

Table B.4. Pacific Herring catch in thousands of metric tonnes (t x 10^3) by Period from 1951 to 2017 in the SoG stock assessment region (SAR). Legend: 'Gear1' represents the reduction, the food and bait, as well as the special use fishery; 'Gear2' represents the roe seine fishery; and 'Gear3' represents the roe gillnet fishery.

	Catch (t x 10^3) by Period		
Year	Gear1	Gear2	Gear3
1951	43.798	0.000	0.000
1952	45.885	0.000	0.000
1953	8.425	0.000	0.000
1954	65.767	0.000	0.000
1955	68.641	0.000	0.000
1956	72.062	0.000	0.000
1957	59.608	0.000	0.000
1958	20.628	0.000	0.000
1959	50.025	0.000	0.000
1960	68.037	0.000	0.000
1961	46.215	0.000	0.000
1962	65.303	0.000	0.000
1963	68.847	0.000	0.000
1964	76.881	0.000	0.000
1965	47.819	0.000	0.000
1966	33.338	0.000	0.000
1967	31.043	0.000	0.000
1968	1.893	0.000	0.000
1969	0.194	0.000	0.000
1970	0.244	0.000	0.000
1971	1.700	0.000	0.000
1972	2.753	5.921	0.137
1973	4.005	1.604	2.040
1974	0.485	0.439	3.093
1975	0.405	0.469	5.305

	Catch (t x 10^3) by Period		
Year	Gear1	Gear2	Gear3
1976	5.069	0.202	6.966
1977	5.676	4.098	7.735
1978	13.049	3.723	7.230
1979	13.576	0.000	6.762
1980	2.472	0.169	3.177
1981	4.907	2.081	5.065
1982	3.938	3.312	5.583
1983	0.824	7.780	8.613
1984	0.870	4.126	6.039
1985	0.773	2.762	3.495
1986	0.432	0.162	0.000
1987	0.244	3.111	5.998
1988	0.756	1.471	5.988
1989	1.033	1.417	5.919
1990	0.233	0.000	7.886
1991	0.562	1.131	9.410
1992	1.216	3.610	8.870
1993	0.617	4.391	8.733
1994	1.032	5.134	11.572
1995	0.643	4.359	8.190
1996	0.541	7.338	6.233
1997	0.402	9.274	6.148
1998	0.954	5.754	6.896
1999	1.471	4.887	6.838
2000	1.156	6.454	7.594
2001	1.423	7.276	7.683
2002	1.328	9.299	7.986
2003	2.194	10.600	8.083
2004	1.356	7.019	5.226
2005	1.988	7.929	8.954
2006	2.177	9.308	7.277
2007	1.071	3.865	5.286
2008	1.201	6.046	2.752
2009	0.547	5.685	3.937
2010	0.539	4.540	3.244
2011	0.713	0.000	4.415
2012	4.090	3.170	4.079
2013	4.543	6.099	5.905
2014	7.835	6.880	5.595
2015	7.825	8.417	3.726
2016	7.550	7.627	6.133
2017	7.260	8.796	9.223

Table B.5. Pacific Herring catch in thousands of metric tonnes (t x 10^3) by Period from 1951 to 2017 in the WCVI stock assessment region (SAR). Legend: 'Gear1' represents the reduction, the food and bait, as well as the special use fishery; 'Gear2' represents the roe seine fishery; and 'Gear3' represents the roe gillnet fishery.

	Catch (t x 10^3) by Period		
Year	Gear1	Gear2	Gear3
1951	21.821	0.000	0.000
1952	27.008	0.000	0.000
1953	0.020	0.000	0.000
1954	33.209	0.000	0.000
1955	6.123	0.000	0.000
1956	17.098	0.000	0.000
1957	2.612	0.000	0.000
1958	0.556	0.000	0.000
1959	69.223	0.000	0.000
1960	53.911	0.000	0.000
1961	26.435	0.000	0.000
1962	23.684	0.000	0.000
1963	18.206	0.000	0.000
1964	21.266	0.000	0.000
1965	16.046	0.000	0.000
1966	10.843	0.000	0.000
1967	15.145	0.000	0.000
1968	0.000	0.000	0.000
1969	0.000	0.000	0.000
1970	0.000	0.000	0.000
1971	0.000	0.000	0.000
1972	0.000	6.894	0.000
1973	0.000	16.766	1.537
1974	0.000	12.394	3.940
1975	0.001	17.798	8.309
1976	0.000	22.820	16.005
1977	0.029	17.458	12.556
1978	2.839	5.151	14.755
1979	0.084	10.472	8.138
1980	0.000	1.682	2.300
1981	0.002	5.008	3.079
1982	0.002	2.370	3.115
1983	0.000	6.141	2.434
1984	0.000	5.718	0.858
1985	0.001	0.177	0.000
1986	0.001	0.203	0.000
1987	0.000	13.463	2.471
1988	0.000	8.276	1.448
1989	0.000	9.774	3.515
1990	0.000	7.890	1.959

Year	Catch (t x 10^3) by Period		
	Gear1	Gear2	Gear3
1991	0.000	6.299	2.336
1992	0.000	3.086	0.627
1993	0.000	5.612	0.000
1994	0.001	5.332	0.706
1995	0.004	1.947	0.000
1996	0.001	0.790	0.000
1997	0.000	6.656	0.000
1998	0.000	5.450	1.534
1999	0.000	3.405	0.968
2000	0.000	0.926	0.700
2001	0.000	0.000	0.000
2002	0.000	0.433	0.388
2003	0.000	2.571	0.945
2004	0.000	3.861	0.593
2005	0.000	3.373	0.896
2006	0.000	0.000	0.000
2007	0.000	0.000	0.000
2008	0.000	0.000	0.000
2009	0.000	0.000	0.000
2010	0.000	0.000	0.000
2011	0.000	0.000	0.000
2012	0.000	0.000	0.000
2013	0.000	0.000	0.000
2014	0.000	0.000	0.000
2015	0.000	0.000	0.000
2016	0.000	0.000	0.000
2017	0.000	0.000	0.000

Table B.6. Pacific Herring catch in thousands of metric tonnes (t x 10^3) by Period from 1951 to 2017 in the A27 stock assessment region (SAR). Legend: 'Gear1' represents the reduction, the food and bait, as well as the special use fishery; 'Gear2' represents the roe seine fishery; and 'Gear3' represents the roe gillnet fishery.

Year	Catch (t x 10^3) by Period		
	Gear1	Gear2	Gear3
1951	0.000	0.000	0.000
1952	0.000	0.000	0.000
1953	0.000	0.000	0.000
1954	1.920	0.000	0.000
1955	5.939	0.000	0.000
1956	0.000	0.000	0.000
1957	0.000	0.000	0.000
1958	0.000	0.000	0.000
1959	0.407	0.000	0.000

Year	Catch (t x 10^3) by Period		
	Gear1	Gear2	Gear3
1960	0.000	0.000	0.000
1961	1.149	0.000	0.000
1962	0.173	0.000	0.000
1963	0.031	0.000	0.000
1964	0.323	0.000	0.000
1965	0.769	0.000	0.000
1966	0.951	0.000	0.000
1967	0.051	0.000	0.000
1968	0.000	0.000	0.000
1969	0.000	0.000	0.000
1970	0.000	0.000	0.000
1971	0.000	0.000	0.000
1972	0.000	0.000	0.000
1973	0.000	0.000	0.000
1974	0.000	0.508	0.018
1975	0.000	0.000	0.000
1976	0.000	0.000	0.079
1977	0.000	0.000	0.000
1978	0.075	0.000	0.075
1979	0.000	0.422	0.270
1980	0.000	0.000	0.519
1981	0.000	0.000	0.671
1982	0.000	0.238	0.332
1983	0.000	0.000	0.163
1984	0.000	0.000	0.171
1985	0.000	0.000	0.000
1986	0.000	0.000	0.000
1987	0.000	0.000	0.000
1988	0.000	0.000	0.000
1989	0.000	0.000	0.000
1990	0.000	0.000	0.000
1991	0.000	0.000	0.000
1992	0.000	0.335	0.000
1993	0.000	0.000	0.367
1994	0.000	0.000	0.345
1995	0.000	0.088	0.000
1996	0.000	0.000	0.000
1997	0.000	0.000	0.000
1998	0.000	0.000	0.000
1999	0.000	0.000	0.000
2000	0.000	0.000	0.000
2001	0.000	0.000	0.000
2002	0.000	0.000	0.000
2003	0.000	0.000	0.000

	Catch (t x 10^3) by Period		
Year	Gear1	Gear2	Gear3
2004	0.000	0.000	0.000
2005	0.000	0.000	0.000
2006	0.000	0.000	0.000
2007	0.000	0.000	0.000
2008	0.000	0.000	0.000
2009	0.000	0.000	0.000
2010	0.000	0.000	0.000
2011	0.000	0.000	0.000
2012	0.000	0.000	0.000
2013	0.000	0.000	0.000
2014	0.000	0.000	0.000
2015	0.000	0.000	0.000
2016	0.000	0.000	0.000
2017	0.000	0.000	0.000

Table B.7. Pacific Herring catch in thousands of metric tonnes (t x 10^3) by Period from 1951 to 2017 in the A2W stock assessment region (SAR). Legend: 'Gear1' represents the reduction, the food and bait, as well as the special use fishery; 'Gear2' represents the roe seine fishery; and 'Gear3' represents the roe gillnet fishery.

	Catch (t x 10^3) by Period		
Year	Gear1	Gear2	Gear3
1951	0.000	0.000	0.000
1952	0.000	0.000	0.000
1953	0.000	0.000	0.000
1954	0.000	0.000	0.000
1955	0.000	0.000	0.000
1956	0.000	0.000	0.000
1957	0.106	0.000	0.000
1958	0.000	0.000	0.000
1959	0.000	0.000	0.000
1960	0.000	0.000	0.000
1961	0.000	0.000	0.000
1962	0.000	0.000	0.000
1963	0.000	0.000	0.000
1964	0.312	0.000	0.000
1965	1.251	0.000	0.000
1966	0.172	0.000	0.000
1967	0.000	0.000	0.000
1968	0.000	0.000	0.000
1969	0.000	0.000	0.000
1970	0.000	0.000	0.000
1971	0.000	0.000	0.000
1972	0.000	0.000	0.000

Year	Catch (t x 10^3) by Period		
	Gear1	Gear2	Gear3
1973	0.000	0.706	0.000
1974	0.000	0.403	0.000
1975	0.000	0.449	0.000
1976	0.000	0.000	0.000
1977	0.000	0.000	0.000
1978	0.000	0.575	0.000
1979	0.048	0.643	0.000
1980	0.000	0.000	0.000
1981	0.000	0.770	0.000
1982	0.000	1.225	0.000
1983	0.000	2.518	0.000
1984	0.000	0.000	0.000
1985	0.000	0.199	0.000
1986	0.000	0.000	0.000
1987	0.000	0.000	0.000
1988	0.000	0.000	0.000
1989	0.000	0.000	0.000
1990	0.000	2.272	0.000
1991	0.000	2.558	0.000
1992	0.000	1.284	0.000
1993	0.000	1.306	0.000
1994	0.000	0.000	0.000
1995	0.000	0.000	0.000
1996	0.000	0.000	0.000
1997	0.000	0.000	0.000
1998	0.000	0.179	0.000
1999	0.000	0.000	0.000
2000	0.000	0.000	0.000
2001	0.000	0.000	0.000
2002	0.000	0.000	0.000
2003	0.000	0.000	0.000
2004	0.000	0.000	0.000
2005	0.000	0.000	0.000
2006	0.000	0.000	0.000
2007	0.000	0.000	0.000
2008	0.000	0.000	0.000
2009	0.000	0.000	0.000
2010	0.000	0.000	0.000
2011	0.000	0.000	0.000
2012	0.000	0.000	0.000
2013	0.000	0.000	0.000
2014	0.000	0.000	0.000
2015	0.000	0.000	0.000
2016	0.000	0.000	0.000

	Catch ($t \times 10^3$) by Period		
Year	Gear1	Gear2	Gear3
2017	0.000	0.000	0.000

Table B.8. Pacific Herring spawn index in thousands of metric tonnes ($t \times 10^3$) from 1951 to 2017 in the HG stock assessment region (SAR). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The 'spawn index' represents the raw survey data only, and is not scaled by the spawn survey scaling parameter, q.

Year	Spawn index ($t \times 10^3$)	Survey
1951	4.213	Surface
1952	2.578	Surface
1953	7.555	Surface
1954	12.408	Surface
1955	6.437	Surface
1956	6.042	Surface
1957	1.592	Surface
1958	0.815	Surface
1959	8.981	Surface
1960	6.599	Surface
1961	8.981	Surface
1962	5.730	Surface
1963	7.297	Surface
1964	4.104	Surface
1965	1.378	Surface
1966	2.824	Surface
1967	0.710	Surface
1968	0.833	Surface
1969	2.075	Surface
1970	5.552	Surface
1971	13.291	Surface
1972	9.542	Surface
1973	7.960	Surface
1974	14.510	Surface
1975	9.686	Surface
1976	15.986	Surface
1977	15.717	Surface
1978	16.885	Surface
1979	14.289	Surface
1980	30.455	Surface
1981	18.823	Surface
1982	22.159	Surface
1983	19.470	Surface
1984	22.120	Surface
1985	17.232	Surface
1986	5.679	Surface
1987	10.750	Surface
1988	13.631	Dive

Year	Spawn index (t $\times 10^3$)	Survey
1989	23.638	Dive
1990	25.404	Dive
1991	16.204	Dive
1992	11.068	Dive
1993	6.462	Dive
1994	12.806	Dive
1995	4.701	Dive
1996	7.374	Dive
1997	10.778	Dive
1998	20.622	Dive
1999	8.971	Dive
2000	5.341	Dive
2001	13.859	Dive
2002	2.286	Dive
2003	7.398	Dive
2004	4.906	Dive
2005	3.614	Dive
2006	4.097	Dive
2007	9.436	Dive
2008	4.213	Dive
2009	9.794	Dive
2010	6.845	Dive
2011	7.554	Dive
2012	9.720	Dive
2013	16.025	Dive
2014	10.566	Dive
2015	13.102	Dive
2016	6.888	Dive
2017	3.016	Dive

Table B.9. Pacific Herring spawn index in thousands of metric tonnes (t x 10^3) from 1951 to 2017 in the PRD stock assessment region (SAR). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The 'spawn index' represents the raw survey data only, and is not scaled by the spawn survey scaling parameter, q.

Year	Spawn index (t $\times 10^3$)	Survey
1951	27.149	Surface
1952	24.047	Surface
1953	28.468	Surface
1954	13.535	Surface
1955	14.482	Surface
1956	14.533	Surface
1957	27.518	Surface
1958	9.882	Surface
1959	40.961	Surface
1960	16.545	Surface
1961	12.059	Surface

Year	Spawn index (t $\times 10^3$)	Survey
1962	26.329	Surface
1963	16.981	Surface
1964	26.919	Surface
1965	6.055	Surface
1966	7.105	Surface
1967	3.386	Surface
1968	5.197	Surface
1969	0.965	Surface
1970	8.814	Surface
1971	8.480	Surface
1972	8.774	Surface
1973	10.959	Surface
1974	9.244	Surface
1975	10.565	Surface
1976	15.199	Surface
1977	10.425	Surface
1978	4.734	Surface
1979	7.600	Surface
1980	11.001	Surface
1981	12.939	Surface
1982	16.108	Surface
1983	23.575	Surface
1984	25.702	Surface
1985	30.675	Surface
1986	25.580	Surface
1987	38.673	Surface
1988	33.957	Dive
1989	14.876	Dive
1990	21.177	Dive
1991	24.305	Dive
1992	38.585	Dive
1993	23.328	Dive
1994	14.683	Dive
1995	16.879	Dive
1996	22.664	Dive
1997	23.565	Dive
1998	17.997	Dive
1999	27.742	Dive
2000	17.943	Dive
2001	35.070	Dive
2002	20.503	Dive
2003	34.630	Dive
2004	31.104	Dive
2005	28.172	Dive
2006	10.255	Dive
2007	15.700	Dive
2008	12.728	Dive
2009	11.961	Dive
2010	28.607	Dive

Year	Spawn index (t $\times 10^3$)	Survey
2011	21.097	Dive
2012	22.716	Dive
2013	25.755	Dive
2014	17.125	Dive
2015	17.407	Dive
2016	18.985	Dive
2017	19.235	Dive

Table B.10. Pacific Herring spawn index in thousands of metric tonnes (t x 10^3) from 1951 to 2017 in the CC stock assessment region (SAR). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The 'spawn index' represents the raw survey data only, and is not scaled by the spawn survey scaling parameter, q.

Year	Spawn index (t×103)	Survey
1951	15.390	Surface
1952	10.295	Surface
1953	18.237	Surface
1954	13.967	Surface
1955	13.564	Surface
1956	6.626	Surface
1957	4.607	Surface
1958	3.549	Surface
1959	3.904	Surface
1960	12.615	Surface
1961	4.265	Surface
1962	11.948	Surface
1963	6.485	Surface
1964	6.464	Surface
1965	2.097	Surface
1966	1.863	Surface
1967	5.434	Surface
1968	5.790	Surface
1969	1.837	Surface
1970	8.230	Surface
1971	4.156	Surface
1972	3.572	Surface
1973	12.434	Surface
1974	8.852	Surface
1975	8.037	Surface
1976	13.849	Surface
1977	14.613	Surface
1978	7.747	Surface
1979	5.669	Surface
1980	12.957	Surface
1981	15.811	Surface
1982	16.239	Surface

Year	Spawn index (t×103)	Survey
1983	18.214	Surface
1984	13.788	Surface
1985	8.483	Surface
1986	20.056	Surface
1987	12.431	Surface
1988	26.467	Dive
1989	21.098	Dive
1990	28.551	Dive
1991	18.429	Dive
1992	42.594	Dive
1993	31.717	Dive
1994	28.790	Dive
1995	21.343	Dive
1996	20.344	Dive
1997	27.016	Dive
1998	29.736	Dive
1999	30.208	Dive
2000	30.810	Dive
2001	24.334	Dive
2002	20.318	Dive
2003	24.401	Dive
2004	28.245	Dive
2005	23.903	Dive
2006	9.081	Dive
2007	9.264	Dive
2008	4.255	Dive
2009	10.771	Dive
2010	8.671	Dive
2011	10.534	Dive
2012	7.592	Dive
2013	20.369	Dive
2014	13.309	Dive
2015	32.146	Dive
2016	32.508	Dive
2017	23.517	Dive

Table B.11. Pacific Herring spawn index in thousands of metric tonnes (t x 10^3) from 1951 to 2017 in the SoG stock assessment region (SAR). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The 'spawn index' represents the raw survey data only, and is not scaled by the spawn survey scaling parameter, q.

Year	Spawn index (t $\times 10^3$)	Survey
1951	66.143	Surface
1952	72.376	Surface
1953	111.307	Surface
1954	82.141	Surface

Year	Spawn index (t $\times 10^3$)	Survey
1955	69.854	Surface
1956	25.667	Surface
1957	24.465	Surface
1958	16.911	Surface
1959	47.864	Surface
1960	55.709	Surface
1961	44.326	Surface
1962	35.596	Surface
1963	37.381	Surface
1964	35.954	Surface
1965	38.390	Surface
1966	7.211	Surface
1967	9.647	Surface
1968	9.442	Surface
1969	14.039	Surface
1970	34.163	Surface
1971	38.921	Surface
1972	25.139	Surface
1973	16.191	Surface
1974	40.571	Surface
1975	70.208	Surface
1976	60.996	Surface
1977	78.113	Surface
1978	101.784	Surface
1979	63.973	Surface
1980	85.679	Surface
1981	54.754	Surface
1982	101.025	Surface
1983	66.201	Surface
1984	26.054	Surface
1985	25.024	Surface
1986	41.575	Surface
1987	41.737	Surface
1988	24.976	Dive
1989	66.052	Dive
1990	67.150	Dive
1991	45.827	Dive
1992	82.710	Dive
1993	90.197	Dive
1994	67.138	Dive
1995	64.898	Dive
1996	71.325	Dive
1997	58.181	Dive
1998	74.616	Dive
1999	85.094	Dive

Year	Spawn index (t $\times 10^3$)	Survey
2000	72.688	Dive
2001	100.248	Dive
2002	117.862	Dive
2003	152.150	Dive
2004	122.839	Dive
2005	102.764	Dive
2006	50.258	Dive
2007	38.524	Dive
2008	34.507	Dive
2009	53.652	Dive
2010	50.454	Dive
2011	85.001	Dive
2012	52.636	Dive
2013	83.693	Dive
2014	120.468	Dive
2015	104.481	Dive
2016	129.502	Dive
2017	81.064	Dive

Table B.12. Pacific Herring spawn index in thousands of metric tonnes (t x 10^3) from 1951 to 2017 in the WCVI stock assessment region (SAR). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The 'spawn index' represents the raw survey data only, and is not scaled by the spawn survey scaling parameter, q.

Year	Spawn index (t $\times 10^3$)	Survey
1951	19.597	Surface
1952	13.310	Surface
1953	39.571	Surface
1954	20.648	Surface
1955	15.112	Surface
1956	27.183	Surface
1957	44.114	Surface
1958	18.986	Surface
1959	12.979	Surface
1960	6.015	Surface
1961	10.556	Surface
1962	34.470	Surface
1963	11.245	Surface
1964	22.761	Surface
1965	11.891	Surface
1966	3.722	Surface
1967	4.813	Surface
1968	11.029	Surface
1969	10.465	Surface
1970	26.912	Surface
1971	36.206	Surface

Year	Spawn index (t $\times 10^3$)	Survey
1972	41.857	Surface
1973	19.481	Surface
1974	25.540	Surface
1975	49.149	Surface
1976	64.200	Surface
1977	58.679	Surface
1978	45.607	Surface
1979	66.397	Surface
1980	62.308	Surface
1981	51.929	Surface
1982	33.483	Surface
1983	16.771	Surface
1984	24.087	Surface
1985	29.590	Surface
1986	39.514	Surface
1987	16.858	Surface
1988	46.242	Dive
1989	47.718	Dive
1990	46.464	Dive
1991	29.996	Dive
1992	42.366	Dive
1993	34.392	Dive
1994	25.249	Dive
1995	27.128	Dive
1996	33.121	Dive
1997	45.362	Dive
1998	41.011	Dive
1999	19.734	Dive
2000	12.799	Dive
2001	13.414	Dive
2002	21.242	Dive
2003	31.397	Dive
2004	16.432	Dive
2005	9.664	Dive
2006	2.875	Dive
2007	2.246	Dive
2008	2.739	Dive
2009	10.607	Dive
2010	2.464	Dive
2011	9.663	Dive
2012	5.407	Dive
2013	12.342	Dive
2014	13.937	Dive
2015	11.323	Dive
2016	20.528	Dive
2017	15.734	Dive

Table B.13. Pacific Herring spawn index in thousands of metric tonnes (t x 10^3) from 1951 to 2017 in the A27 stock assessment region (SAR). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The 'spawn index' represents the raw survey data only, and is not scaled by the spawn survey scaling parameter, q.

Year	Spawn index (t $\times 10^3$)	Survey
1951	1.955	Surface
1952	0.484	Surface
1953	4.618	Surface
1954	2.646	Surface
1955	0.575	Surface
1956	0.001	Surface
1957	0.184	Surface
1958	0.039	Surface
1959	0.060	Surface
1960	0.224	Surface
1961	0.169	Surface
1962	0.102	Surface
1963	0.407	Surface
1964	NA	Surface
1965	2.517	Surface
1966	0.082	Surface
1967	0.046	Surface
1968	0.142	Surface
1969	2.198	Surface
1970	2.434	Surface
1971	0.290	Surface
1972	0.250	Surface
1973	2.578	Surface
1974	NA	Surface
1975	1.606	Surface
1976	0.210	Surface
1977	0.638	Surface
1978	3.595	Surface
1979	6.909	Surface
1980	14.419	Surface
1981	1.828	Surface
1982	1.468	Surface
1983	2.500	Surface
1984	3.004	Surface
1985	1.382	Surface
1986	3.495	Surface
1987	0.952	Surface
1988	1.612	Dive
1989	4.612	Dive
1990	5.212	Dive
1991	3.213	Dive
1992	2.779	Dive
1993	5.576	Dive

Year	Spawn index (t $\times 10^3$)	Survey
1994	5.229	Dive
1995	2.484	Dive
1996	1.332	Dive
1997	1.963	Dive
1998	2.156	Dive
1999	0.657	Dive
2000	1.301	Dive
2001	0.220	Dive
2002	0.917	Dive
2003	0.963	Dive
2004	1.223	Dive
2005	1.918	Dive
2006	2.044	Dive
2007	2.248	Dive
2008	0.796	Dive
2009	1.201	Dive
2010	0.846	Dive
2011	0.547	Dive
2012	0.744	Dive
2013	0.914	Dive
2014	1.307	Dive
2015	2.169	Dive
2016	0.814	Dive
2017	0.026	Dive

Table B.14. Pacific Herring spawn index in thousands of metric tonnes (t x 10^3) from 1951 to 2017 in the A2W stock assessment region (SAR). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The 'spawn index' represents the raw survey data only, and is not scaled by the spawn survey scaling parameter, q.

Year	Spawn index (t $\times 10^3$)	Survey
1951	NA	Surface
1952	NA	Surface
1953	0.203	Surface
1954	NA	Surface
1955	NA	Surface
1956	NA	Surface
1957	0.004	Surface
1958	0.157	Surface
1959	1.916	Surface
1960	1.569	Surface
1961	0.558	Surface
1962	1.715	Surface
1963	1.436	Surface
1964	0.969	Surface
1965	0.439	Surface
1966	0.024	Surface

Year	Spawn index (t $\times 10^3$)	Survey
1967	0.262	Surface
1968	0.073	Surface
1969	0.593	Surface
1970	0.577	Surface
1971	0.604	Surface
1972	1.011	Surface
1973	1.604	Surface
1974	1.675	Surface
1975	1.154	Surface
1976	0.826	Surface
1977	1.174	Surface
1978	0.832	Surface
1979	0.494	Surface
1980	2.114	Surface
1981	1.811	Surface
1982	4.781	Surface
1983	4.869	Surface
1984	2.522	Surface
1985	1.719	Surface
1986	0.684	Surface
1987	0.989	Surface
1988	3.380	Dive
1989	2.719	Dive
1990	9.057	Dive
1991	2.985	Dive
1992	3.909	Dive
1993	0.089	Dive
1994	0.248	Dive
1995	NA	Dive
1996	NA	Dive
1997	NA	Dive
1998	0.469	Dive
1999	NA	Dive
2000	0.288	Dive
2001	0.035	Dive
2002	0.149	Dive
2003	1.462	Dive
2004	2.996	Dive
2005	0.575	Dive
2006	1.828	Dive
2007	1.469	Dive
2008	2.000	Dive
2009	2.871	Dive
2010	2.725	Dive
2011	2.641	Dive
2012	2.416	Dive
2013	2.076	Dive
2014	1.368	Dive

Year	Spawn index (t $\times 10^3$)	Survey
2015	NA	Dive
2016	3.001	Dive
2017	NA	Dive

Table B.15. Pacific Herring number-at-age from 1951 to 2017 in the HG stock assessment region (SAR). Legend: 'Gear1' represents the reduction, the food and bait, as well as the special use fishery; 'Gear2' represents the roe seine fishery; and 'Gear3' represents the roe gillnet fishery. The age-10 class is a 'plus group' which includes fish ages 10 and older.

		Number-at-age								
Year	Gear	2	3	4	5	6	7	8	9	10
1951	1	1	226	781	226	170	62	9	1	0
1952	1	381	485	760	479	92	25	2	0	0
1956	1	2	216	130	838	113	37	10	0	2
1957	1	983	1142	746	454	1265	116	21	6	0
1958	1	2324	466	35	5	4	4	0	0	0
1959	1	1	60	27	7	0	0	0	0	0
1962	1	13	161	177	41	28	7	1	0	0
1963	1	3	402	218	146	17	16	0	1	1
1964	1	5	81	314	94	28	6	0	0	0
1965	1	17	840	116	46	22	10	2	0	0
1984	1	11	68	4	8	16	73	4	1	1
1972	2	36	386	454	190	72	29	11	5	1
1973	2	3	700	372	471	138	29	13	0	0
1974	2	2	493	653	286	147	30	5	1	0
1975	2	38	1521	2056	1677	573	117	22	6	0
1976	2	18	116	1557	1225	948	263	40	3	0
1977	2	3	630	258	947	739	486	144	13	0
1978	2	2	323	214	117	323	174	65	12	4
1979	2	57	45	322	191	217	154	29	4	1
1980	2	17	2819	151	182	94	64	39	19	3
1981	2	9	175	4201	267	151	90	35	9	6
1982	2	30	167	163	3117	88	60	36	19	5
1983	2	96	103	69	135	1434	77	31	18	5
1984	2	83	1200	154	92	336	1382	35	11	5
1985	2	47	531	1132	144	160	404	1119	16	3
1986	2	109	135	1041	1902	191	155	380	905	15
1987	2	57	342	192	799	1239	126	142	190	194
1988	2	61	855	126	80	197	249	23	28	57
1989	2	175	625	2364	143	56	139	99	22	37
1990	2	11	487	918	3033	199	93	193	86	33
1991	2	227	140	361	972	1303	125	61	135	63
1992	2	23	1243	159	270	402	992	77	19	43
1993	2	12	128	2240	165	225	448	436	43	15
1994	2	75	52	61	590	129	133	132	39	8

		Number-at-age								
Year	Gear	2	3	4	5	6	7	8	9	10
1995	2	119	96	12	24	193	49	40	26	12
1996	2	351	560	92	35	43	165	26	12	4
1997	2	465	435	550	86	25	73	88	14	6
1998	2	10	1470	758	315	73	18	33	30	9
1999	2	101	57	1557	419	195	62	16	10	13
2000	2	183	415	85	1271	171	97	9	10	4
2001	2	243	375	264	58	252	37	16	3	1
2002	2	859	758	728	367	87	374	42	14	3
2003	2	2	1597	387	134	75	25	51	10	3
2004	2	394	43	442	77	32	22	11	5	3
2005	2	17	606	205	374	51	31	16	6	3
2006	2	139	72	318	70	111	21	3	0	2
2007	2	6	247	78	114	32	56	12	1	0
2008	2	86	68	583	70	79	17	15	0	2
2009	2	1	645	76	222	20	29	4	5	1
2010	2	92	95	658	62	171	19	15	3	2
2011	2	21	521	90	370	65	100	9	4	0
2012	2	144	122	314	33	168	15	25	2	3
2013	2	0	739	136	140	21	45	6	4	0
2014	2	16	41	767	129	106	16	38	6	3
2015	2	35	224	56	533	61	81	18	14	4
2016	2	75	73	77	26	170	20	9	1	1
2017	2	102	238	74	83	37	148	36	11	10
1974	3	0	9	76	40	26	5	0	0	1
1975	3	0	0	9	16	12	2	1	0	0
1976	3	0	0	1	29	81	19	3	0	0
1978	3	0	1	8	19	32	65	33	6	1
1979	3	0	0	50	50	50	40	7	1	1
1980	3	0	35	42	376	195	209	65	15	1
1981	3	0	2	677	75	85	44	17	5	0
1982	3	0	1	18	464	18	14	6	4	1
1983	3	0	0	10	21	665	23	19	5	4
1984	3	0	11	5	18	35	313	7	1	1
1985	3	0	0	22	3	6	16	96	1	0
1986	3	0	0	48	205	22	21	42	65	2
1990	3	0	2	36	189	44	37	74	37	14
1991	3	0	0	10	85	175	36	27	41	20
1999	3	0	4	185	137	175	60	16	8	16

Table B.16. Pacific Herring number-at-age from 1951 to 2017 in the PRD stock assessment region (SAR). Legend: 'Gear1' represents the reduction, the food and bait, as well as the special use fishery; 'Gear2' represents the roe seine fishery; and 'Gear3' represents the roe gillnet fishery. The age-10 class is a 'plus group' which includes fish ages 10 and older.

		Number-at-age								
Year	Gear	2	3	4	5	6	7	8	9	10
1951	1	203	852	2739	486	263	124	12	2	1
1952	1	282	522	1994	2679	364	61	18	2	0
1953	1	17	541	327	361	158	14	1	0	0
1954	1	56	753	772	638	351	69	16	1	0
1955	1	31	55	795	177	59	12	2	0	0
1956	1	169	978	160	319	43	9	3	2	0
1957	1	397	666	1767	817	658	78	19	2	0
1958	1	388	302	78	106	17	20	0	0	0
1959	1	54	1000	785	216	205	53	39	5	0
1960	1	2067	263	1186	374	174	106	28	8	0
1961	1	419	2508	313	774	187	69	25	5	0
1962	1	53	535	789	119	171	55	17	8	5
1963	1	1342	454	621	753	123	101	17	2	2
1964	1	126	2208	344	372	301	24	20	4	1
1965	1	201	457	1723	365	401	345	70	18	7
1966	1	0	23	93	102	71	83	42	14	7
1973	1	35	73	12	20	7	4	2	0	0
1975	1	1	9	13	37	12	10	2	2	0
1976	1	0	8	11	16	27	29	57	14	0
1977	1	2	120	80	117	85	55	38	12	2
1978	1	12	90	247	140	130	101	48	15	9
1979	1	11	72	76	182	144	121	62	34	17
1980	1	13	672	67	82	77	61	44	20	11
1981	1	30	238	1623	294	302	260	123	64	33
1982	1	7	144	280	520	130	78	44	22	7
1984	1	9	168	76	75	50	97	15	1	2
1985	1	97	52	163	178	74	34	26	5	2
2014	1	4	11	41	45	40	23	5	5	2
2015	1	98	373	32	18	17	15	4	3	0
2016	1	6	80	158	10	23	30	22	11	5
2017	1	7	57	79	237	28	14	18	16	8
1972	2	0	38	128	460	42	27	17	1	1
1973	2	2	263	35	242	212	27	10	6	0
1974	2	1	113	336	47	104	28	2	1	0
1975	2	172	366	690	1329	345	299	77	18	5
1976	2	0	6	49	226	357	52	17	6	0
1977	2	1	210	49	297	495	197	43	12	6
1978	2	9	93	261	76	168	162	19	5	2
1979	2	27	182	123	319	123	189	65	15	8
1980	2	18	2262	208	147	113	100	37	11	3
1981	2	15	370	2710	110	56	49	13	5	2

Year	Gear	Number-at-age 2	3	4	5	6	7	8	9	10
1982	2	100	296	115	1025	44	21	6	3	0
1983	2	437	1016	822	242	2256	171	52	27	10
1984	2	17	1138	436	314	448	721	31	9	4
1985	2	130	328	2237	516	263	429	327	8	6
1986	2	99	778	534	2616	611	298	401	313	5
1987	2	42	1904	490	327	1423	281	165	136	60
1988	2	19	1306	1646	251	352	488	82	61	16
1989	2	22	784	1307	1001	178	162	129	23	10
1990	2	33	920	1143	1431	1040	203	168	109	21
1991	2	113	1990	391	519	649	391	68	36	48
1992	2	15	1699	1587	251	228	287	146	26	26
1993	2	5	432	1783	1216	162	177	175	63	14
1994	2	44	325	885	3246	1487	276	248	96	36
1995	2	140	673	297	495	1898	692	107	56	35
1996	2	29	1763	241	76	115	316	140	10	7
1997	2	35	615	1447	216	68	133	128	50	6
1998	2	4	702	465	768	94	30	23	27	3
1999	2	17	95	706	350	425	76	18	15	18
2000	2	77	1111	381	1132	498	646	89	20	18
2001	2	79	1430	875	235	702	315	260	39	6
2002	2	228	849	1526	846	186	430	167	82	13
2003	2	11	2253	502	593	312	90	131	47	22
2004	2	23	50	1700	273	238	98	19	28	3
2005	2	21	856	268	1297	279	166	59	13	13
2006	2	29	327	887	176	460	78	32	9	3
2007	2	27	355	161	78	22	72	9	7	1
2008	2	69	578	2062	448	310	65	135	29	10
2009	2	11	847	703	1723	286	197	45	59	3
2010	2	41	1095	888	377	676	108	54	10	13
2011	2	17	1230	1058	527	208	294	49	19	6
2012	2	97	301	1452	717	312	164	123	13	4
2013	2	20	1167	490	609	328	89	62	25	1
2014	2	9	110	663	186	230	102	41	15	4
2015	2	41	1206	168	549	162	185	71	23	9
2016	2	34	303	987	132	366	87	71	26	10
2017	2	33	382	441	1035	154	274	66	43	11
1974	3	0	1	41	22	36	3	1	0	0
1975	3	0	0	15	28	4	0	0	0	0
1976	3	0	0	9	33	13	2	0	0	0
1977	3	0	3	6	56	152	41	19	4	0
1978	3	0	0	31	9	49	50	10	2	0
1979	3	3	3	21	108	41	58	21	5	1
1980	3	0	17	43	154	110	104	45	17	3
1981	3	0	2	166	66	98	63	24	8	0

		Number-at-age								
Year	Gear	2	3	4	5	6	7	8	9	10
1984	3	0	5	10	65	108	290	17	6	4
1985	3	0	2	90	82	87	120	164	2	3
1986	3	0	5	55	686	242	111	99	73	3
1987	3	0	10	53	122	973	283	155	105	60
1988	3	0	3	46	51	153	318	83	36	20
1989	3	0	0	22	145	65	112	104	16	12
1990	3	0	0	34	116	231	56	63	33	11
1991	3	0	0	39	171	288	287	61	40	30
1992	3	0	3	112	80	195	225	164	34	43
1993	3	0	0	62	302	71	138	99	61	12
1994	3	0	0	24	160	434	110	101	54	16
1995	3	0	1	10	144	295	334	35	16	13
1996	3	0	4	21	29	132	167	135	16	7
1997	3	0	1	123	73	88	128	130	70	18
1998	3	0	7	33	466	222	107	122	76	49
1999	3	0	0	78	119	357	97	33	14	23
2000	3	0	1	17	187	166	342	76	9	13
2001	3	0	3	58	97	337	215	266	55	9
2002	3	0	1	62	178	103	241	139	135	20
2003	3	0	3	40	323	226	92	107	46	33
2004	3	0	1	244	151	412	172	55	53	29
2005	3	0	0	6	350	136	195	44	10	13
2006	3	0	0	14	36	303	77	69	7	0
2007	3	1	11	40	208	108	630	150	65	15
2008	3	0	1	126	102	224	108	519	77	40
2009	3	0	1	20	406	187	144	53	92	11
2010	3	0	0	19	72	492	145	78	31	30
2011	3	0	2	49	138	282	601	108	45	19
2012	3	0	0	35	110	150	225	370	54	28
2013	3	1	47	18	209	242	100	102	54	9
2014	3	0	1	55	120	363	277	105	72	19
2015	3	0	18	10	150	209	342	213	52	30
2016	3	0	2	234	65	172	216	198	88	26
2017	3	0	2	40	557	119	158	122	76	23

Table B.17. Pacific Herring number-at-age from 1951 to 2017 in the CC stock assessment region (SAR). Legend: 'Gear1' represents the reduction, the food and bait, as well as the special use fishery; 'Gear2' represents the roe seine fishery; and 'Gear3' represents the roe gillnet fishery. The age-10 class is a 'plus group' which includes fish ages 10 and older.

		Number-at-age								
Year	Gear	2	3	4	5	6	7	8	9	10
1951	1	129	1518	2693	638	269	66	3	0	0
1952	1	267	1035	1551	1966	232	79	23	2	1
1953	1	274	822	702	779	297	39	13	0	0

		Number-at-age								
Year	Gear	2	3	4	5	6	7	8	9	10
1954	1	126	2222	646	147	41	5	0	2	0
1955	1	156	181	1749	213	36	9	0	0	0
1956	1	853	688	465	2880	146	17	2	0	1
1957	1	785	2377	506	292	693	34	1	0	0
1958	1	880	2298	474	48	22	21	0	0	0
1959	1	189	2463	1835	403	40	22	21	1	0
1960	1	616	328	375	79	16	1	1	0	0
1961	1	450	902	302	831	282	26	3	2	1
1962	1	78	464	145	21	80	19	1	0	0
1963	1	4	329	630	59	31	32	2	0	0
1964	1	164	549	320	118	17	1	0	0	0
1965	1	143	637	591	277	95	6	1	0	0
1977	1	2	65	37	59	16	13	6	0	0
1972	2	80	548	508	472	127	80	21	1	0
1973	2	16	670	247	206	156	25	6	2	0
1974	2	44	281	613	313	212	105	15	4	0
1975	2	103	2932	2269	2477	764	283	60	6	2
1976	2	163	637	2234	1132	912	246	80	13	1
1977	2	17	435	565	793	414	213	48	10	1
1978	2	3	359	212	278	323	152	49	15	5
1980	2	99	1933	170	235	106	67	18	10	3
1981	2	105	431	2147	263	230	88	20	11	3
1982	2	59	548	376	2112	182	160	51	17	3
1983	2	29	381	840	589	3109	274	169	40	14
1984	2	274	460	637	1143	1016	2563	142	52	6
1985	2	149	2052	410	457	698	638	987	24	7
1986	2	330	973	2379	516	384	404	367	697	37
1987	2	518	1181	748	1629	295	231	294	236	291
1988	2	59	3528	606	326	370	87	76	78	64
1989	2	72	260	4300	517	202	158	42	45	46
1990	2	121	403	347	4985	511	260	202	51	53
1991	2	226	1348	480	440	3947	453	166	105	33
1992	2	146	4241	828	199	250	1362	155	44	39
1993	2	318	597	5621	851	177	225	916	99	41
1994	2	85	1538	620	3888	549	148	199	257	24
1995	2	101	592	2254	897	4615	609	193	221	168
1996	2	667	1114	323	926	388	1698	325	83	77
1997	2	146	3892	1161	249	422	274	583	106	38
1998	2	34	2393	2793	553	155	202	198	192	51
1999	2	39	440	2141	1709	326	81	106	97	66
2000	2	16	865	490	1572	1186	263	53	41	41
2001	2	112	340	1194	517	1173	831	181	38	28
2002	2	337	1875	581	971	338	1124	475	78	15
2003	2	21	2060	1079	333	388	180	317	120	25

		Number-at-age								
Year	Gear	2	3	4	5	6	7	8	9	10
2004	2	37	225	2085	542	112	147	75	70	18
2005	2	42	2311	1037	2101	566	125	112	60	40
2006	2	53	702	3246	585	967	199	44	31	8
2007	2	32	700	444	739	190	185	37	10	3
2008	2	224	162	659	184	246	44	43	8	2
2009	2	130	2104	308	238	67	63	8	10	2
2010	2	41	387	1597	133	189	51	52	2	6
2011	2	124	1359	427	671	85	63	18	16	4
2012	2	171	236	1082	267	373	53	35	11	7
2013	2	36	659	177	333	77	78	6	4	2
2014	2	61	94	299	57	90	18	19	3	0
2015	2	9	532	183	291	65	75	10	5	1
2016	2	70	161	971	166	258	50	69	19	5
2017	2	43	252	196	662	132	137	35	18	10
1972	3	0	3	49	214	35	26	2	0	0
1973	3	0	4	40	71	33	7	2	1	0
1974	3	0	2	113	187	123	61	9	1	0
1975	3	0	17	133	240	85	33	11	0	0
1976	3	0	10	230	364	431	144	37	5	1
1977	3	0	5	59	161	143	61	18	6	0
1978	3	0	14	96	318	410	190	41	5	1
1980	3	0	9	7	68	65	72	31	18	4
1981	3	4	23	779	209	236	163	84	28	10
1982	3	0	32	79	1016	89	79	31	10	1
1983	3	0	9	129	234	1245	90	70	11	5
1984	3	0	3	34	152	200	696	55	13	6
1985	3	0	41	70	121	251	290	492	13	10
1986	3	0	19	256	128	107	171	141	238	9
1987	3	0	8	76	440	115	77	97	80	88
1988	3	0	24	58	84	154	86	42	57	61
1989	3	0	2	196	178	123	117	41	26	27
1990	3	0	0	10	551	143	53	66	9	15
1991	3	0	3	14	41	417	60	44	19	5
1992	3	0	54	54	33	51	475	76	26	11
1993	3	0	2	342	112	44	45	211	17	8
1994	3	0	30	94	1287	237	69	83	135	16
1995	3	0	3	112	101	823	135	23	29	41
1996	3	0	2	8	102	65	306	59	12	12
1997	3	0	7	15	32	117	99	197	37	10
1998	3	0	5	149	142	90	183	164	217	81
1999	3	0	1	132	416	166	62	51	57	42
2000	3	0	3	14	277	285	71	11	6	18
2001	3	0	0	39	46	422	225	57	9	2
2002	3	0	3	30	105	38	237	83	7	1

Year	Gear	Number-at-age 2	3	4	5	6	7	8	9	10
2003	3	0	4	33	103	238	104	306	114	23
2014	3	0	1	261	36	248	122	109	22	15

Table B.18. Pacific Herring number-at-age from 1951 to 2017 in the SoG stock assessment region (SAR). Legend: 'Gear1' represents the reduction, the food and bait, as well as the special use fishery; 'Gear2' represents the roe seine fishery; and 'Gear3' represents the roe gillnet fishery. The age-10 class is a 'plus group' which includes fish ages 10 and older.

Year	Gear	Number-at-age 2	3	4	5	6	7	8	9	10
1951	1	326	4413	2371	556	110	27	8	2	0
1952	1	1008	4900	2191	589	114	23	6	1	0
1953	1	763	3509	1897	285	96	15	4	0	0
1954	1	200	6011	4845	1520	432	124	27	3	0
1955	1	227	2533	2048	350	57	6	0	0	0
1956	1	280	2550	2628	2307	529	86	26	5	3
1957	1	84	3829	1566	761	333	38	3	1	1
1958	1	588	3548	1528	428	363	212	29	5	0
1959	1	1616	6073	1455	251	55	24	12	2	1
1960	1	288	1921	1368	135	20	6	3	0	1
1961	1	1292	1252	1191	765	263	39	4	0	0
1962	1	317	2348	608	212	114	30	9	0	0
1963	1	427	1388	734	113	33	14	2	0	0
1964	1	259	2650	1507	172	36	11	5	0	0
1965	1	555	1870	891	95	36	8	5	0	0
1966	1	184	274	191	114	18	9	0	0	0
1972	1	394	1313	1337	696	143	51	5	1	0
1973	1	47	1294	1432	1188	585	82	14	2	0
1974	1	15	63	7	1	0	0	0	0	0
1975	1	97	265	54	9	6	2	0	1	0
1976	1	272	872	1723	914	272	117	41	18	2
1977	1	110	1349	584	439	118	33	13	4	3
1978	1	42	695	815	207	145	59	10	7	2
1979	1	44	437	1002	703	213	121	30	7	3
1980	1	121	1753	969	773	345	91	52	15	4
1981	1	176	1521	1554	715	391	135	21	5	0
1982	1	80	839	711	349	133	92	19	2	1
1983	1	60	336	507	392	211	77	91	44	9
1984	1	279	598	435	321	153	63	19	8	6
1985	1	681	993	464	188	77	25	8	2	0
1986	1	116	501	177	50	15	3	1	0	0
1987	1	192	306	273	88	17	4	2	0	0
1988	1	32	550	158	140	25	6	2	1	0
1989	1	278	174	450	74	62	9	2	0	0
1990	1	37	427	102	144	16	19	0	0	0

		Number-at-age								
Year	Gear	2	3	4	5	6	7	8	9	10
1991	1	162	286	313	57	56	7	2	0	0
1992	1	31	526	92	56	4	1	1	0	0
1993	1	253	302	316	67	26	3	6	1	0
1994	1	42	287	134	81	9	5	0	0	0
1995	1	294	329	413	125	54	8	2	0	1
1996	1	421	821	199	157	41	18	3	0	0
1997	1	112	304	70	16	4	1	2	1	0
1998	1	60	699	596	99	19	8	2	0	0
1999	1	175	416	619	217	46	9	2	0	0
2000	1	422	736	259	210	65	18	2	2	0
2001	1	91	560	326	85	56	22	6	2	0
2002	1	131	949	369	93	16	5	2	0	1
2003	1	28	377	303	75	21	5	2	2	0
2004	1	80	288	402	153	30	9	0	1	0
2005	1	42	207	134	134	43	17	3	1	0
2006	1	87	154	142	64	46	14	2	1	0
2007	1	57	510	309	104	25	14	2	0	0
2008	1	320	234	1134	276	69	22	15	1	0
2009	1	8	692	150	52	10	2	0	0	0
2010	1	272	103	705	50	29	10	2	3	0
2011	1	354	1011	126	114	10	6	0	0	0
2012	1	246	2382	1917	172	143	9	4	0	0
2013	1	823	1429	1116	674	51	39	4	0	0
2014	1	148	1940	618	350	241	18	18	3	0
2015	1	671	1365	1292	345	151	75	12	2	0
2016	1	842	1025	1153	656	152	36	8	2	1
2017	1	439	1216	900	722	341	68	11	2	0
1972	2	428	1819	1655	903	174	50	6	1	0
1973	2	16	208	81	49	23	2	0	0	0
1975	2	191	2852	1452	408	174	83	25	9	0
1976	2	135	279	456	166	38	26	17	5	1
1977	2	79	1315	474	341	91	30	18	6	3
1978	2	29	1209	1477	396	253	47	10	1	2
1979	2	23	282	461	394	132	73	29	9	6
1980	2	103	2061	656	733	408	107	51	11	5
1981	2	660	3111	2493	903	774	297	52	23	2
1982	2	371	1875	1354	1127	253	282	135	30	4
1983	2	358	3759	3407	2134	1372	381	366	150	35
1984	2	894	2869	2101	935	515	242	81	35	11
1985	2	2818	3815	1558	651	276	108	47	5	1
1986	2	818	3603	1423	396	123	48	9	5	0
1987	2	855	2584	2861	1176	273	82	29	10	5
1988	2	327	3568	883	900	242	61	13	4	0
1989	2	643	1157	3435	607	456	102	20	2	1

		Number-at-age								
Year	Gear	2	3	4	5	6	7	8	9	10
1990	2	496	3251	607	1070	170	97	23	3	1
1991	2	701	1191	2125	473	770	118	74	10	1
1992	2	260	2762	691	843	176	260	30	16	1
1993	2	963	2138	1747	379	326	76	84	8	2
1994	2	279	2518	1594	1120	238	168	42	9	0
1995	2	664	1317	2080	1010	627	155	62	20	6
1996	2	1125	4051	1170	1198	481	280	57	19	7
1997	2	805	3810	1667	428	464	185	107	9	5
1998	2	349	3992	2608	1005	216	166	62	16	2
1999	2	231	898	1553	687	245	67	26	6	2
2000	2	692	2444	1237	1432	570	137	19	13	1
2001	2	499	2856	1847	564	531	169	39	6	2
2002	2	413	2536	1325	607	127	108	21	4	0
2003	2	387	3835	3248	1060	310	77	33	7	0
2004	2	398	1274	1805	902	225	67	14	8	1
2005	2	337	1313	1390	1093	362	85	30	10	4
2006	2	1438	1334	1095	734	442	98	35	8	1
2007	2	89	2469	1384	647	324	174	40	10	1
2008	2	75	445	2531	562	215	89	27	8	2
2009	2	16	2644	564	559	173	58	25	10	1
2010	2	566	164	3428	269	300	70	26	7	4
2011	2	319	3243	576	1031	105	57	22	4	1
2012	2	82	1757	2391	208	391	36	11	4	0
2013	2	245	1190	1457	1311	102	160	13	2	2
2014	2	134	973	482	577	472	45	45	4	1
2015	2	363	2399	2350	541	308	160	13	9	0
2016	2	512	1342	1808	923	202	110	70	7	4
2017	2	392	1312	1319	1071	398	85	36	12	2
1972	3	46	119	481	300	71	15	2	1	0
1973	3	0	39	68	84	25	7	1	0	0
1974	3	0	48	418	310	165	40	9	0	0
1975	3	0	9	78	65	22	6	1	0	0
1976	3	0	5	349	385	112	26	6	1	0
1977	3	0	54	456	755	263	60	8	2	0
1978	3	0	4	115	170	202	65	8	2	0
1979	3	0	7	141	332	82	35	9	0	1
1980	3	0	15	69	336	252	66	14	2	0
1981	3	1	25	207	262	426	183	32	3	1
1982	3	0	37	128	237	123	173	118	14	3
1983	3	0	2	113	120	96	38	30	7	1
1984	3	0	54	231	238	147	71	13	5	7
1985	3	1	34	286	356	259	101	41	9	9
1987	3	0	48	684	642	317	163	50	11	5
1988	3	0	75	122	395	160	45	19	3	2

Year	Gear	Number-at-age 2	3	4	5	6	7	8	9	10
1989	3	0	13	331	181	213	64	18	3	0
1990	3	0	115	160	771	167	133	20	4	1
1991	3	0	14	306	187	436	79	51	13	1
1992	3	0	74	174	510	137	221	31	17	5
1993	3	0	104	363	154	196	37	49	2	2
1994	3	1	45	300	537	183	95	30	8	2
1995	3	0	21	243	341	242	52	22	4	2
1996	3	0	21	86	247	119	56	10	4	1
1997	3	0	30	113	104	202	108	54	16	6
1998	3	0	45	450	438	185	191	57	26	6
1999	3	0	18	245	307	176	56	28	5	1
2000	3	0	12	161	488	309	99	24	4	0
2001	3	0	31	190	263	345	154	34	7	3
2002	3	0	45	206	285	149	178	45	5	2
2003	3	0	32	293	452	316	139	87	29	6
2004	3	0	25	278	451	276	116	25	13	1
2005	3	0	5	91	352	207	80	28	9	1
2006	3	0	7	119	315	322	160	40	11	1
2007	3	0	144	397	801	802	551	146	42	7
2008	3	1	32	857	468	318	159	56	18	1
2009	3	0	42	63	466	166	99	29	11	1
2010	3	0	1	222	67	428	114	60	23	8
2011	3	0	103	77	1171	205	260	61	18	8
2012	3	1	247	1306	154	398	50	28	4	2
2013	3	0	27	286	689	84	160	8	4	2
2014	3	0	23	110	489	799	75	106	9	2
2015	3	0	100	456	386	645	634	55	29	3
2016	3	2	159	618	564	252	263	229	27	18
2017	3	1	56	622	1022	645	187	86	39	3

Table B.19. Pacific Herring number-at-age from 1951 to 2017 in the WCVI stock assessment region (SAR). Legend: 'Gear1' represents the reduction, the food and bait, as well as the special use fishery; 'Gear2' represents the roe seine fishery; and 'Gear3' represents the roe gillnet fishery. The age-10 class is a 'plus group' which includes fish ages 10 and older.

Year	Gear	Number-at-age 2	3	4	5	6	7	8	9	10
1951	1	508	1519	1666	272	58	12	1	1	0
1952	1	97	1435	1230	1824	245	72	16	2	0
1953	1	565	2220	1086	65	19	2	0	0	0
1954	1	163	3852	1681	338	42	9	5	1	1
1955	1	422	1490	494	86	16	1	0	0	0
1956	1	575	2990	743	282	52	7	2	2	0
1957	1	16	423	146	2	1	0	0	0	0

		Number-at-age								
Year	Gear	2	3	4	5	6	7	8	9	10
1958	1	154	579	322	75	34	20	5	1	0
1959	1	155	1650	1004	528	141	88	74	21	4
1960	1	255	1575	671	252	81	27	10	4	2
1961	1	274	248	118	26	1	0	0	0	0
1962	1	59	1031	130	31	10	0	0	0	0
1963	1	39	985	1110	106	14	4	0	0	0
1964	1	30	713	305	123	10	3	0	0	0
1965	1	18	283	411	82	27	3	0	0	0
1966	1	1	124	100	64	8	3	0	0	0
1978	1	29	935	479	259	311	45	19	7	5
1984	1	2	42	10	2	1	3	0	0	0
1972	2	51	291	756	387	55	18	12	1	0
1973	2	18	784	625	823	277	40	7	2	0
1974	2	436	2333	1298	738	480	120	12	2	1
1975	2	60	5437	2005	1153	806	505	130	17	1
1976	2	19	818	4332	1828	1196	746	251	40	0
1977	2	35	838	2097	2507	834	301	112	19	3
1978	2	41	2396	1066	1000	1104	264	77	11	4
1979	2	30	530	1966	554	414	306	60	20	5
1980	2	86	1317	448	661	218	182	73	14	3
1981	2	138	1415	1173	433	512	231	94	21	0
1982	2	160	1210	1401	1316	275	466	132	71	15
1983	2	135	723	701	702	566	142	173	34	29
1984	2	888	1231	425	286	316	191	35	33	8
1985	2	753	1695	446	114	83	99	53	4	7
1986	2	157	2094	1233	344	130	93	73	24	3
1987	2	760	803	1624	1011	346	120	65	51	18
1988	2	191	4548	571	1100	736	209	55	33	16
1989	2	146	903	3482	376	495	259	39	10	2
1990	2	33	1856	849	3233	307	406	125	16	6
1991	2	482	1565	1543	780	2420	220	251	48	2
1992	2	97	2860	630	803	360	1017	126	73	13
1993	2	214	1528	2255	380	416	226	423	51	31
1994	2	182	1361	1449	1862	491	311	330	97	15
1995	2	40	646	1200	1023	1277	334	220	155	35
1996	2	1122	1537	907	1412	928	955	203	84	60
1997	2	144	4068	478	268	395	293	197	32	20
1998	2	119	1149	3155	336	149	172	98	59	16
1999	2	70	961	1044	1641	325	112	63	31	16
2000	2	278	1110	929	849	1286	177	60	30	10
2001	2	165	1074	475	197	178	222	31	5	5
2002	2	368	2662	1136	371	140	157	131	15	1
2003	2	96	2191	2042	705	135	62	42	33	4
2004	2	391	1316	2450	1004	286	64	21	11	1

		Number-at-age								
Year	Gear	2	3	4	5	6	7	8	9	10
2005	2	157	1655	939	680	237	71	12	2	3
2006	2	174	430	387	91	62	9	1	0	0
2007	2	7	303	211	66	11	4	0	0	0
2008	2	54	255	559	119	32	8	6	1	1
2009	2	44	1204	284	230	41	10	0	0	0
2010	2	356	597	859	105	91	14	2	0	0
2011	2	62	806	270	123	12	6	0	0	0
2012	2	19	168	561	93	53	6	3	0	0
2013	2	15	106	66	209	22	20	2	0	0
2014	2	8	209	41	8	9	2	0	1	0
2015	2	217	368	781	105	27	43	6	0	1
2016	2	46	754	195	144	16	3	5	1	0
2017	2	27	81	703	140	87	17	2	2	0
1973	3	0	49	143	323	84	18	6	1	0
1974	3	0	46	54	46	24	6	0	0	0
1975	3	0	8	82	102	57	19	1	0	0
1976	3	0	9	529	445	206	87	33	4	1
1977	3	2	12	59	153	63	44	19	5	1
1978	3	0	7	27	125	284	116	40	4	2
1979	3	0	7	148	152	143	108	11	2	0
1980	3	0	0	24	213	102	65	44	3	1
1981	3	0	5	59	42	102	53	20	0	0
1982	3	0	5	103	374	101	234	35	10	1
1983	3	0	2	81	136	256	37	56	2	1
1984	3	0	10	40	107	194	190	32	20	2
1987	3	0	10	135	340	30	12	16	5	2
1988	3	0	27	35	204	147	64	15	6	2
1989	3	0	1	208	42	85	36	6	4	0
1990	3	0	6	35	307	37	46	11	3	0
1991	3	0	1	25	41	223	28	28	2	1
1992	3	0	35	75	171	77	166	16	14	2
1994	3	1	35	199	340	33	7	4	1	0
1998	3	0	5	344	99	87	181	111	51	21
1999	3	0	8	106	527	159	44	31	12	1
2000	3	0	8	47	169	330	39	16	14	2
2002	3	0	0	55	154	82	110	120	12	2
2003	3	0	15	99	203	142	77	103	57	4
2004	3	0	5	179	154	158	92	24	14	5
2005	3	0	4	54	294	143	61	22	1	2

Table B.20. Pacific Herring number-at-age from 1951 to 2017 in the A27 stock assessment region (SAR). Legend: 'Gear1' represents the reduction, the food and bait, as well as the special use fishery; 'Gear2' represents the roe seine fishery; and 'Gear3' represents the roe gillnet fishery. The age-10 class is a 'plus group' which includes fish ages 10 and older.

		Number-at-age								
Year	Gear	2	3	4	5	6	7	8	9	10
1954	1	0	127	108	27	2	3	0	0	0
1955	1	96	491	702	98	20	4	1	0	0
1964	1	0	44	29	21	1	0	0	0	0
1965	1	2	26	52	47	10	1	2	2	0
1978	1	1	38	4	14	12	2	0	0	0
1979	2	1	10	55	10	2	1	1	0	0
1981	2	17	103	467	63	101	12	0	0	0
1982	2	7	370	105	439	43	84	8	1	0
1983	2	4	21	32	11	29	0	4	0	0
1986	2	6	64	172	7	4	5	7	6	0
1987	2	48	78	45	100	3	0	3	1	4
1988	2	8	232	41	23	57	6	3	0	1
1989	2	1	59	268	38	39	53	6	2	0
1990	2	17	210	132	367	54	66	72	6	2
1991	2	33	145	33	38	83	10	18	8	0
1992	2	49	1004	158	48	41	71	14	18	7
1993	2	72	228	248	32	10	9	32	2	4
1994	2	14	300	232	292	52	20	27	5	3
1995	2	24	91	504	348	352	59	19	23	8
1996	2	107	172	49	123	104	86	18	2	2
1997	2	23	441	42	9	23	27	9	0	0
1998	2	4	112	140	14	1	8	7	2	0
1999	2	59	213	257	189	31	4	4	2	1
2000	2	15	355	158	63	49	8	1	3	1
2001	2	13	41	70	25	24	19	2	1	1
2002	2	35	293	73	47	3	11	4	1	0
2003	2	3	295	214	36	23	1	4	1	0
2004	2	5	83	209	76	4	6	3	0	0
2005	2	1	97	43	23	13	1	1	0	0
2007	2	5	209	140	72	16	10	1	0	0
2008	2	6	12	218	80	44	5	1	0	0
2009	2	9	448	73	143	23	18	0	1	0
2010	2	15	35	154	25	36	6	7	0	0
2011	2	6	105	64	74	8	10	2	1	0
2012	2	25	109	318	76	85	10	8	0	1
2013	2	42	255	51	127	29	35	1	0	1
1976	3	0	7	77	51	33	12	7	0	0
1979	3	0	1	46	16	19	11	1	0	0
1980	3	0	3	7	53	9	2	1	0	0
1982	3	0	1	7	60	10	28	3	0	0

Year	Gear	Number-at-age 2	3	4	5	6	7	8	9	10
1983	3	0	0	7	12	50	2	9	0	0
1984	3	0	0	18	182	72	144	11	5	0
1993	3	0	17	276	73	41	39	60	5	7
1994	3	0	6	91	287	46	16	18	2	3

Table B.21. Pacific Herring number-at-age from 1951 to 2017 in the A2W stock assessment region (SAR). Legend: 'Gear1' represents the reduction, the food and bait, as well as the special use fishery; 'Gear2' represents the roe seine fishery; and 'Gear3' represents the roe gillnet fishery. The age-10 class is a 'plus group' which includes fish ages 10 and older.

Year	Gear	Number-at-age 2	3	4	5	6	7	8	9	10
1957	1	0	26	13	1	1	0	0	0	0
1965	1	0	23	4	14	4	3	2	0	0
1981	1	2	4	52	1	1	0	0	0	0
1973	2	0	11	28	26	66	7	2	1	0
1974	2	16	54	49	46	17	24	4	0	0
1975	2	2	171	123	47	13	14	4	0	0
1976	2	46	13	80	46	9	0	0	0	0
1978	2	0	15	53	21	86	13	12	6	0
1979	2	8	101	123	87	123	74	10	6	4
1980	2	0	119	26	11	8	5	0	1	0
1981	2	107	50	837	143	86	56	20	5	0
1982	2	31	648	25	887	71	37	20	6	1
1983	2	23	45	1893	101	1111	98	42	25	18
1984	2	32	8	3	175	12	253	9	3	1
1985	2	5	29	52	28	218	28	631	7	1
1986	2	3	1	42	43	20	76	27	152	2
1987	2	152	273	2	5	5	6	32	4	14
1988	2	27	1119	292	4	8	10	12	25	15
1989	2	6	42	934	195	6	6	12	10	17
1990	2	5	36	42	1901	412	11	5	14	21
1991	2	17	415	54	80	2163	501	26	15	17
1992	2	179	197	270	32	55	1198	243	11	19
1993	2	27	367	449	386	55	125	1097	140	20
1994	2	10	23	82	28	18	4	11	10	2
1998	2	252	407	269	212	32	7	18	2	0
1999	2	120	249	216	110	56	12	4	2	0
2000	2	13	56	16	0	2	0	1	0	0
2001	2	17	33	158	95	47	27	8	2	2
2002	2	448	281	53	236	104	73	30	16	3
2003	2	7	879	95	11	45	12	14	5	4
2004	2	139	76	555	58	13	12	2	0	2
2005	2	4	297	96	654	45	6	9	0	2

Year	Gear	Number-at-age 2	3	4	5	6	7	8	9	10
2006	2	50	65	82	32	209	16	8	3	0
2007	2	2	374	73	42	21	120	10	3	1
2008	2	61	3	75	15	5	4	15	0	1
2009	2	21	590	20	99	18	20	18	24	4
2010	2	55	210	240	18	63	14	36	17	12
2011	2	20	455	167	212	15	32	6	4	1
2012	2	34	91	176	70	75	7	14	2	4
2013	2	2	412	57	123	42	32	0	4	1
2014	2	14	1	116	18	55	28	25	3	5
2015	2	14	266	11	47	4	27	10	6	1
2016	2	17	46	342	13	50	8	2	0	0
2017	2	37	70	48	340	17	36	13	4	0
1974	3	78	17	9	24	9	14	2	0	0

Table B.22. Pacific Herring weight-at-age in kilograms (kg) from 1951 to 2017 in the HG stock assessment region (SAR). Biological summaries only include samples collected using seine nets (commercial and test) due to size-selectivity of other gear types such as gillnet. The age-10 class is a 'plus group' which includes fish ages 10 and older.

Year	Weight-at-age (kg) 2	3	4	5	6	7	8	9	10
1951	0.058	0.067	0.085	0.099	0.114	0.126	0.142	0.096	0.158
1952	0.039	0.076	0.101	0.116	0.136	0.152	0.143	0.096	0.158
1953	0.048	0.072	0.093	0.107	0.125	0.139	0.142	0.096	0.158
1954	0.048	0.072	0.093	0.107	0.125	0.139	0.142	0.096	0.158
1955	0.048	0.072	0.093	0.107	0.125	0.139	0.142	0.096	0.158
1956	0.043	0.088	0.110	0.121	0.147	0.160	0.166	0.096	0.158
1957	0.041	0.086	0.119	0.135	0.143	0.165	0.166	0.180	0.158
1958	0.046	0.075	0.100	0.122	0.147	0.161	0.152	0.113	0.158
1959	0.062	0.088	0.098	0.117	0.138	0.153	0.154	0.116	0.158
1960	0.048	0.082	0.104	0.120	0.140	0.156	0.156	0.120	0.158
1961	0.048	0.084	0.106	0.123	0.143	0.159	0.159	0.125	0.158
1962	0.053	0.091	0.116	0.136	0.157	0.150	0.168	0.131	0.158
1963	0.058	0.088	0.118	0.144	0.166	0.162	0.158	0.173	0.184
1964	0.057	0.092	0.110	0.136	0.162	0.183	0.159	0.133	0.164
1965	0.056	0.097	0.115	0.150	0.184	0.184	0.257	0.137	0.165
1966	0.055	0.090	0.113	0.138	0.163	0.168	0.180	0.140	0.166
1967	0.056	0.092	0.114	0.141	0.166	0.169	0.184	0.143	0.167
1968	0.056	0.092	0.114	0.142	0.168	0.173	0.188	0.145	0.169
1969	0.056	0.092	0.113	0.141	0.169	0.175	0.193	0.139	0.166
1970	0.056	0.093	0.114	0.142	0.170	0.174	0.200	0.141	0.167
1971	0.056	0.092	0.114	0.141	0.167	0.172	0.189	0.141	0.167
1972	0.059	0.107	0.150	0.171	0.212	0.231	0.242	0.250	0.250
1973	0.073	0.099	0.145	0.180	0.213	0.236	0.239	0.163	0.184

	Weight-at-age (kg)								
Year	2	3	4	5	6	7	8	9	10
1974	0.110	0.089	0.126	0.157	0.194	0.213	0.244	0.254	0.187
1975	0.059	0.087	0.120	0.156	0.188	0.206	0.209	0.230	0.191
1976	0.063	0.099	0.124	0.152	0.184	0.207	0.236	0.240	0.196
1977	0.054	0.106	0.134	0.150	0.177	0.203	0.218	0.243	0.201
1978	0.070	0.096	0.131	0.155	0.170	0.189	0.207	0.235	0.254
1979	0.059	0.104	0.130	0.160	0.173	0.189	0.208	0.203	0.222
1980	0.054	0.084	0.104	0.148	0.173	0.186	0.194	0.230	0.226
1981	0.062	0.098	0.114	0.136	0.160	0.177	0.182	0.208	0.206
1982	0.064	0.102	0.119	0.128	0.142	0.164	0.174	0.193	0.203
1983	0.069	0.098	0.125	0.141	0.155	0.167	0.179	0.200	0.208
1984	0.064	0.094	0.116	0.136	0.141	0.152	0.172	0.184	0.195
1985	0.062	0.101	0.128	0.147	0.161	0.166	0.186	0.206	0.204
1986	0.070	0.117	0.141	0.159	0.171	0.180	0.188	0.202	0.226
1987	0.067	0.107	0.132	0.151	0.168	0.174	0.180	0.188	0.200
1988	0.061	0.089	0.125	0.150	0.166	0.182	0.192	0.203	0.202
1989	0.055	0.093	0.119	0.145	0.159	0.178	0.192	0.193	0.205
1990	0.066	0.098	0.116	0.139	0.154	0.167	0.184	0.193	0.198
1991	0.061	0.085	0.113	0.127	0.142	0.156	0.163	0.176	0.182
1992	0.059	0.095	0.120	0.143	0.148	0.174	0.179	0.174	0.197
1993	0.077	0.101	0.116	0.128	0.148	0.153	0.161	0.183	0.194
1994	0.069	0.094	0.119	0.125	0.138	0.148	0.147	0.155	0.183
1995	0.060	0.093	0.129	0.139	0.150	0.159	0.181	0.175	0.186
1996	0.062	0.090	0.110	0.133	0.145	0.153	0.155	0.159	0.151
1997	0.056	0.087	0.105	0.122	0.151	0.152	0.160	0.163	0.171
1998	0.062	0.080	0.084	0.109	0.120	0.136	0.140	0.148	0.149
1999	0.058	0.089	0.103	0.111	0.128	0.137	0.148	0.141	0.169
2000	0.055	0.081	0.096	0.114	0.129	0.137	0.144	0.143	0.162
2001	0.052	0.080	0.100	0.115	0.131	0.143	0.160	0.167	0.211
2002	0.054	0.077	0.099	0.117	0.127	0.139	0.148	0.162	0.159
2003	0.048	0.084	0.110	0.120	0.142	0.148	0.167	0.155	0.179
2004	0.050	0.056	0.102	0.115	0.135	0.137	0.146	0.166	0.166
2005	0.055	0.079	0.082	0.115	0.122	0.144	0.147	0.162	0.146
2006	0.051	0.068	0.086	0.096	0.112	0.116	0.139	0.162	0.141
2007	0.061	0.077	0.083	0.107	0.114	0.134	0.131	0.105	0.158
2008	0.048	0.069	0.089	0.095	0.112	0.114	0.137	0.150	0.132
2009	0.039	0.067	0.085	0.102	0.099	0.118	0.115	0.134	0.144
2010	0.059	0.074	0.092	0.110	0.125	0.131	0.160	0.139	0.166
2011	0.054	0.070	0.080	0.098	0.112	0.121	0.129	0.129	0.148
2012	0.050	0.078	0.092	0.103	0.116	0.125	0.120	0.160	0.131
2013	0.050	0.079	0.110	0.116	0.116	0.126	0.143	0.135	0.144
2014	0.057	0.076	0.102	0.126	0.130	0.128	0.133	0.138	0.123
2015	0.061	0.087	0.091	0.109	0.117	0.114	0.125	0.130	0.139
2016	0.054	0.076	0.094	0.104	0.115	0.121	0.117	0.124	0.148
2017	0.057	0.082	0.096	0.117	0.120	0.129	0.135	0.144	0.140

Table B.23. Pacific Herring weight-at-age in kilograms (kg) from 1951 to 2017 in the PRD stock assessment region (SAR). Biological summaries only include samples collected using seine nets (commercial and test) due to size-selectivity of other gear types such as gillnet. The age-10 class is a 'plus group' which includes fish ages 10 and older.

	Weight-at-age (kg)								
Year	2	3	4	5	6	7	8	9	10
1951	0.038	0.074	0.094	0.113	0.123	0.132	0.142	0.138	0.132
1952	0.047	0.084	0.116	0.131	0.150	0.166	0.167	0.222	0.132
1953	0.039	0.080	0.111	0.131	0.143	0.157	0.155	0.180	0.132
1954	0.040	0.072	0.106	0.131	0.145	0.162	0.183	0.193	0.132
1955	0.046	0.081	0.101	0.121	0.143	0.159	0.154	0.183	0.132
1956	0.037	0.076	0.094	0.114	0.141	0.152	0.170	0.199	0.132
1957	0.029	0.075	0.104	0.117	0.136	0.157	0.166	0.168	0.132
1958	0.034	0.074	0.112	0.132	0.140	0.163	0.165	0.184	0.132
1959	0.044	0.086	0.104	0.120	0.146	0.151	0.164	0.151	0.132
1960	0.038	0.068	0.106	0.122	0.148	0.160	0.182	0.176	0.132
1961	0.040	0.074	0.108	0.131	0.145	0.160	0.161	0.193	0.132
1962	0.045	0.082	0.110	0.141	0.168	0.176	0.196	0.200	0.265
1963	0.039	0.067	0.106	0.130	0.155	0.166	0.189	0.225	0.224
1964	0.044	0.072	0.093	0.122	0.133	0.156	0.152	0.156	0.148
1965	0.053	0.098	0.116	0.144	0.157	0.169	0.187	0.195	0.216
1966	0.044	0.110	0.143	0.155	0.170	0.175	0.189	0.196	0.183
1967	0.045	0.086	0.114	0.138	0.157	0.169	0.182	0.194	0.207
1968	0.045	0.087	0.114	0.138	0.154	0.167	0.180	0.193	0.196
1969	0.046	0.090	0.116	0.140	0.154	0.167	0.178	0.187	0.190
1970	0.047	0.094	0.120	0.143	0.158	0.169	0.183	0.193	0.199
1971	0.045	0.093	0.121	0.143	0.159	0.169	0.182	0.193	0.195
1972	0.046	0.100	0.137	0.163	0.199	0.225	0.233	0.249	0.259
1973	0.033	0.083	0.117	0.164	0.179	0.198	0.210	0.216	0.208
1974	0.067	0.086	0.121	0.166	0.184	0.195	0.204	0.175	0.210
1975	0.025	0.061	0.113	0.137	0.165	0.167	0.182	0.179	0.199
1976	0.043	0.089	0.133	0.158	0.173	0.203	0.211	0.227	0.214
1977	0.054	0.086	0.118	0.151	0.169	0.184	0.196	0.196	0.223
1978	0.055	0.093	0.123	0.143	0.166	0.182	0.196	0.231	0.240
1979	0.057	0.097	0.129	0.148	0.167	0.184	0.191	0.214	0.216
1980	0.055	0.080	0.116	0.146	0.169	0.179	0.188	0.207	0.221
1981	0.047	0.083	0.101	0.133	0.156	0.170	0.182	0.202	0.215
1982	0.038	0.077	0.109	0.117	0.151	0.172	0.178	0.185	0.207
1983	0.035	0.078	0.104	0.122	0.135	0.154	0.170	0.191	0.199
1984	0.046	0.075	0.090	0.111	0.124	0.135	0.157	0.177	0.187
1985	0.030	0.079	0.098	0.110	0.122	0.134	0.149	0.177	0.176
1986	0.056	0.092	0.118	0.137	0.147	0.158	0.169	0.179	0.204
1987	0.055	0.084	0.107	0.128	0.142	0.153	0.160	0.172	0.175
1988	0.051	0.074	0.097	0.117	0.135	0.151	0.152	0.164	0.185
1989	0.056	0.075	0.096	0.116	0.136	0.147	0.166	0.160	0.195
1990	0.050	0.089	0.108	0.122	0.138	0.152	0.166	0.176	0.192

	Weight-at-age (kg)								
Year	2	3	4	5	6	7	8	9	10
1991	0.041	0.076	0.106	0.120	0.129	0.141	0.148	0.160	0.173
1992	0.047	0.076	0.093	0.120	0.133	0.141	0.149	0.167	0.178
1993	0.054	0.077	0.096	0.109	0.126	0.137	0.142	0.151	0.156
1994	0.042	0.072	0.093	0.106	0.116	0.134	0.138	0.141	0.157
1995	0.048	0.074	0.092	0.112	0.121	0.131	0.149	0.158	0.162
1996	0.052	0.072	0.095	0.111	0.129	0.134	0.143	0.148	0.172
1997	0.056	0.068	0.084	0.104	0.119	0.131	0.138	0.145	0.150
1998	0.045	0.067	0.080	0.092	0.102	0.120	0.130	0.146	0.152
1999	0.058	0.079	0.096	0.104	0.116	0.119	0.136	0.139	0.152
2000	0.046	0.070	0.085	0.104	0.110	0.118	0.130	0.131	0.145
2001	0.042	0.067	0.092	0.105	0.124	0.126	0.137	0.138	0.153
2002	0.046	0.066	0.085	0.105	0.118	0.128	0.133	0.148	0.156
2003	0.042	0.070	0.086	0.110	0.126	0.140	0.146	0.152	0.160
2004	0.050	0.065	0.086	0.100	0.115	0.131	0.143	0.152	0.144
2005	0.038	0.064	0.071	0.100	0.106	0.119	0.138	0.139	0.152
2006	0.048	0.063	0.080	0.091	0.110	0.121	0.131	0.143	0.120
2007	0.040	0.058	0.070	0.090	0.107	0.110	0.120	0.127	0.144
2008	0.044	0.058	0.082	0.095	0.108	0.117	0.132	0.132	0.153
2009	0.032	0.072	0.082	0.102	0.113	0.120	0.129	0.137	0.152
2010	0.045	0.066	0.087	0.098	0.112	0.118	0.127	0.107	0.150
2011	0.040	0.069	0.082	0.102	0.111	0.125	0.138	0.145	0.141
2012	0.054	0.060	0.081	0.091	0.102	0.113	0.118	0.137	0.125
2013	0.036	0.075	0.080	0.098	0.109	0.124	0.130	0.139	0.153
2014	0.044	0.066	0.097	0.095	0.109	0.116	0.127	0.129	0.136
2015	0.039	0.066	0.080	0.114	0.112	0.124	0.131	0.130	0.122
2016	0.041	0.062	0.085	0.097	0.119	0.118	0.120	0.131	0.123
2017	0.048	0.074	0.085	0.101	0.113	0.128	0.126	0.128	0.133

Table B.24. Pacific Herring weight-at-age in kilograms (kg) from 1951 to 2017 in the CC stock assessment region (SAR). Biological summaries only include samples collected using seine nets (commercial and test) due to size-selectivity of other gear types such as gillnet. The age-10 class is a 'plus group' which includes fish ages 10 and older.

	Weight-at-age (kg)								
Year	2	3	4	5	6	7	8	9	10
1951	0.048	0.084	0.114	0.137	0.146	0.156	0.161	0.173	0.148
1952	0.047	0.087	0.112	0.131	0.148	0.158	0.164	0.173	0.148
1953	0.036	0.083	0.108	0.127	0.147	0.162	0.170	0.173	0.148
1954	0.026	0.062	0.093	0.117	0.138	0.133	0.165	0.131	0.148
1955	0.038	0.072	0.097	0.120	0.143	0.135	0.165	0.159	0.148
1956	0.041	0.083	0.111	0.127	0.143	0.158	0.122	0.159	0.180
1957	0.040	0.082	0.108	0.122	0.132	0.149	0.173	0.159	0.154
1958	0.037	0.072	0.096	0.115	0.131	0.142	0.159	0.156	0.156
1959	0.039	0.076	0.093	0.110	0.104	0.129	0.135	0.127	0.157

	Weight-at-age (kg)								
Year	2	3	4	5	6	7	8	9	10
1960	0.045	0.064	0.081	0.104	0.108	0.147	0.124	0.152	0.159
1961	0.038	0.077	0.098	0.121	0.125	0.135	0.122	0.158	0.209
1962	0.045	0.080	0.107	0.136	0.143	0.155	0.122	0.150	0.167
1963	0.060	0.082	0.103	0.123	0.142	0.154	0.166	0.149	0.170
1964	0.046	0.086	0.108	0.127	0.128	0.154	0.134	0.147	0.172
1965	0.052	0.104	0.127	0.147	0.168	0.176	0.242	0.151	0.175
1966	0.048	0.086	0.109	0.131	0.141	0.155	0.157	0.151	0.179
1967	0.050	0.088	0.111	0.133	0.145	0.159	0.164	0.150	0.173
1968	0.051	0.089	0.112	0.132	0.145	0.160	0.172	0.150	0.174
1969	0.050	0.090	0.113	0.134	0.145	0.161	0.174	0.150	0.175
1970	0.050	0.091	0.114	0.136	0.149	0.162	0.182	0.150	0.175
1971	0.050	0.089	0.112	0.133	0.145	0.159	0.170	0.150	0.175
1972	0.061	0.094	0.117	0.141	0.157	0.165	0.195	0.193	0.174
1973	0.059	0.099	0.130	0.156	0.173	0.183	0.197	0.234	0.174
1974	0.049	0.087	0.121	0.143	0.165	0.178	0.194	0.214	0.175
1975	0.045	0.084	0.119	0.144	0.166	0.186	0.199	0.204	0.220
1976	0.044	0.081	0.108	0.136	0.155	0.175	0.191	0.200	0.210
1977	0.060	0.089	0.117	0.139	0.166	0.184	0.199	0.222	0.225
1978	0.049	0.086	0.114	0.134	0.161	0.186	0.216	0.227	0.244
1979	0.050	0.085	0.116	0.139	0.163	0.182	0.200	0.213	0.215
1980	0.043	0.081	0.099	0.123	0.144	0.163	0.167	0.201	0.226
1981	0.044	0.076	0.102	0.119	0.135	0.154	0.177	0.181	0.234
1982	0.052	0.088	0.109	0.130	0.139	0.152	0.168	0.182	0.156
1983	0.061	0.091	0.111	0.129	0.142	0.149	0.157	0.173	0.187
1984	0.059	0.090	0.108	0.122	0.135	0.142	0.156	0.176	0.178
1985	0.062	0.095	0.123	0.140	0.150	0.165	0.173	0.175	0.203
1986	0.058	0.099	0.127	0.142	0.155	0.167	0.173	0.180	0.203
1987	0.047	0.091	0.122	0.149	0.167	0.179	0.184	0.196	0.208
1988	0.054	0.084	0.114	0.139	0.171	0.184	0.189	0.196	0.209
1989	0.056	0.083	0.103	0.130	0.146	0.173	0.180	0.180	0.194
1990	0.050	0.083	0.106	0.126	0.148	0.168	0.179	0.188	0.198
1991	0.048	0.084	0.106	0.129	0.145	0.165	0.178	0.187	0.202
1992	0.050	0.086	0.105	0.124	0.136	0.151	0.168	0.187	0.196
1993	0.049	0.085	0.105	0.120	0.133	0.140	0.154	0.167	0.177
1994	0.048	0.083	0.107	0.122	0.134	0.148	0.158	0.163	0.171
1995	0.044	0.079	0.106	0.123	0.135	0.144	0.152	0.156	0.163
1996	0.061	0.078	0.102	0.126	0.140	0.148	0.158	0.166	0.170
1997	0.046	0.076	0.089	0.105	0.132	0.143	0.149	0.160	0.162
1998	0.042	0.072	0.087	0.101	0.117	0.140	0.146	0.154	0.162
1999	0.054	0.068	0.090	0.105	0.114	0.129	0.148	0.154	0.160
2000	0.051	0.077	0.088	0.113	0.127	0.138	0.145	0.166	0.175
2001	0.044	0.073	0.097	0.106	0.126	0.136	0.147	0.157	0.171
2002	0.048	0.067	0.088	0.108	0.119	0.130	0.137	0.141	0.157
2003	0.047	0.077	0.088	0.112	0.126	0.137	0.143	0.151	0.162

	Weight-at-age (kg)								
Year	2	3	4	5	6	7	8	9	10
2004	0.048	0.070	0.091	0.096	0.112	0.125	0.136	0.137	0.148
2005	0.038	0.068	0.075	0.106	0.109	0.126	0.136	0.140	0.148
2006	0.039	0.060	0.079	0.092	0.111	0.115	0.128	0.135	0.134
2007	0.041	0.065	0.075	0.096	0.102	0.118	0.120	0.140	0.109
2008	0.038	0.057	0.076	0.087	0.103	0.115	0.126	0.134	0.147
2009	0.033	0.066	0.073	0.092	0.103	0.122	0.135	0.132	0.135
2010	0.048	0.067	0.084	0.093	0.105	0.103	0.123	0.154	0.132
2011	0.032	0.060	0.072	0.091	0.100	0.118	0.118	0.134	0.156
2012	0.031	0.056	0.074	0.083	0.099	0.103	0.112	0.135	0.130
2013	0.046	0.076	0.085	0.095	0.104	0.113	0.118	0.128	0.140
2014	0.050	0.066	0.087	0.094	0.101	0.107	0.111	0.107	0.139
2015	0.056	0.069	0.075	0.096	0.100	0.111	0.116	0.111	0.105
2016	0.049	0.075	0.086	0.093	0.111	0.121	0.119	0.125	0.150
2017	0.046	0.077	0.094	0.103	0.107	0.120	0.119	0.111	0.138

Table B.25. Pacific Herring weight-at-age in kilograms (kg) from 1951 to 2017 in the SoG stock assessment region (SAR). Biological summaries only include samples collected using seine nets (commercial and test) due to size-selectivity of other gear types such as gillnet. The age-10 class is a 'plus group' which includes fish ages 10 and older.

	Weight-at-age (kg)								
Year	2	3	4	5	6	7	8	9	10
1951	0.042	0.090	0.113	0.138	0.159	0.171	0.200	0.186	0.201
1952	0.043	0.090	0.113	0.139	0.160	0.176	0.168	0.178	0.201
1953	0.032	0.076	0.097	0.127	0.151	0.160	0.134	0.182	0.201
1954	0.043	0.084	0.107	0.139	0.165	0.182	0.196	0.185	0.201
1955	0.050	0.089	0.105	0.128	0.150	0.172	0.174	0.183	0.201
1956	0.047	0.085	0.108	0.122	0.144	0.161	0.178	0.176	0.201
1957	0.043	0.083	0.114	0.141	0.155	0.172	0.212	0.194	0.192
1958	0.045	0.076	0.111	0.145	0.159	0.166	0.181	0.191	0.197
1959	0.049	0.083	0.101	0.133	0.158	0.176	0.176	0.180	0.144
1960	0.050	0.092	0.114	0.126	0.157	0.134	0.177	0.185	0.143
1961	0.057	0.080	0.110	0.126	0.150	0.171	0.181	0.185	0.175
1962	0.049	0.089	0.104	0.140	0.153	0.167	0.184	0.187	0.170
1963	0.047	0.084	0.106	0.123	0.145	0.182	0.179	0.186	0.166
1964	0.055	0.097	0.115	0.136	0.160	0.190	0.163	0.185	0.160
1965	0.058	0.104	0.121	0.142	0.145	0.150	0.117	0.186	0.163
1966	0.048	0.101	0.137	0.162	0.169	0.194	0.165	0.186	0.167
1967	0.052	0.095	0.117	0.141	0.155	0.177	0.161	0.186	0.165
1968	0.052	0.096	0.119	0.141	0.155	0.179	0.157	0.185	0.164
1969	0.053	0.099	0.122	0.144	0.157	0.178	0.152	0.185	0.164
1970	0.053	0.099	0.123	0.146	0.156	0.175	0.150	0.186	0.164
1971	0.052	0.098	0.124	0.147	0.158	0.180	0.157	0.186	0.165
1972	0.058	0.089	0.127	0.145	0.165	0.175	0.199	0.185	0.164
1973	0.057	0.100	0.129	0.160	0.175	0.193	0.198	0.201	0.164

	Weight-at-age (kg)								
Year	2	3	4	5	6	7	8	9	10
1974	0.064	0.080	0.114	0.199	0.162	0.180	0.172	0.188	0.164
1975	0.042	0.083	0.112	0.142	0.169	0.193	0.200	0.212	0.164
1976	0.050	0.085	0.124	0.146	0.174	0.192	0.206	0.225	0.219
1977	0.057	0.089	0.117	0.139	0.162	0.191	0.201	0.203	0.242
1978	0.050	0.085	0.110	0.132	0.151	0.166	0.168	0.199	0.209
1979	0.062	0.087	0.119	0.141	0.161	0.175	0.199	0.205	0.221
1980	0.050	0.079	0.107	0.132	0.155	0.167	0.181	0.190	0.216
1981	0.060	0.086	0.109	0.135	0.155	0.171	0.183	0.180	0.192
1982	0.061	0.093	0.113	0.126	0.150	0.160	0.167	0.167	0.192
1983	0.057	0.086	0.114	0.133	0.141	0.155	0.169	0.183	0.198
1984	0.061	0.088	0.115	0.140	0.156	0.160	0.167	0.176	0.202
1985	0.062	0.086	0.114	0.135	0.157	0.170	0.187	0.193	0.232
1986	0.066	0.089	0.111	0.132	0.149	0.172	0.197	0.195	0.203
1987	0.061	0.087	0.105	0.122	0.137	0.151	0.166	0.155	0.175
1988	0.058	0.089	0.113	0.130	0.141	0.155	0.164	0.201	0.202
1989	0.064	0.084	0.106	0.127	0.139	0.147	0.156	0.158	0.182
1990	0.058	0.085	0.106	0.128	0.147	0.157	0.161	0.146	0.226
1991	0.062	0.089	0.110	0.128	0.143	0.155	0.163	0.151	0.185
1992	0.059	0.090	0.112	0.132	0.149	0.159	0.175	0.174	0.198
1993	0.056	0.092	0.112	0.129	0.141	0.153	0.156	0.160	0.147
1994	0.052	0.081	0.105	0.121	0.135	0.141	0.151	0.161	0.188
1995	0.060	0.085	0.110	0.131	0.145	0.162	0.163	0.179	0.175
1996	0.062	0.083	0.106	0.126	0.146	0.156	0.172	0.169	0.177
1997	0.046	0.082	0.101	0.119	0.137	0.146	0.154	0.167	0.176
1998	0.050	0.072	0.094	0.108	0.119	0.133	0.144	0.156	0.148
1999	0.045	0.080	0.099	0.114	0.126	0.134	0.143	0.151	0.139
2000	0.052	0.072	0.095	0.111	0.129	0.139	0.153	0.160	0.163
2001	0.060	0.085	0.099	0.120	0.133	0.148	0.155	0.145	0.144
2002	0.049	0.079	0.096	0.107	0.125	0.132	0.141	0.164	0.059
2003	0.047	0.077	0.093	0.105	0.111	0.128	0.140	0.128	0.131
2004	0.043	0.072	0.089	0.099	0.109	0.112	0.124	0.122	0.132
2005	0.048	0.074	0.091	0.106	0.117	0.126	0.130	0.121	0.137
2006	0.045	0.069	0.087	0.102	0.111	0.119	0.127	0.139	0.178
2007	0.062	0.075	0.083	0.100	0.115	0.123	0.130	0.143	0.134
2008	0.026	0.066	0.086	0.094	0.103	0.110	0.116	0.133	0.124
2009	0.045	0.064	0.069	0.103	0.116	0.125	0.135	0.154	0.178
2010	0.040	0.056	0.079	0.085	0.112	0.119	0.114	0.112	0.141
2011	0.035	0.069	0.072	0.091	0.095	0.108	0.119	0.143	0.122
2012	0.048	0.071	0.083	0.086	0.095	0.101	0.111	0.124	0.140
2013	0.049	0.069	0.089	0.102	0.107	0.116	0.118	0.128	0.122
2014	0.037	0.079	0.091	0.108	0.119	0.122	0.126	0.146	0.111
2015	0.043	0.069	0.080	0.089	0.102	0.111	0.117	0.106	0.127
2016	0.046	0.073	0.084	0.091	0.099	0.115	0.129	0.125	0.110
2017	0.049	0.071	0.087	0.095	0.103	0.110	0.110	0.116	0.117

Table B.26. Pacific Herring weight-at-age in kilograms (kg) from 1951 to 2017 in the WCVI stock assessment region (SAR). Biological summaries only include samples collected using seine nets (commercial and test) due to size-selectivity of other gear types such as gillnet. The age-10 class is a 'plus group' which includes fish ages 10 and older.

	Weight-at-age (kg)								
Year	2	3	4	5	6	7	8	9	10
1951	0.050	0.087	0.114	0.134	0.149	0.160	0.205	0.196	0.149
1952	0.054	0.090	0.114	0.139	0.157	0.170	0.178	0.190	0.149
1953	0.043	0.080	0.100	0.121	0.147	0.145	0.192	0.193	0.149
1954	0.054	0.085	0.106	0.126	0.147	0.166	0.155	0.193	0.149
1955	0.058	0.083	0.108	0.125	0.151	0.131	0.182	0.193	0.149
1956	0.058	0.086	0.106	0.119	0.139	0.144	0.182	0.140	0.149
1957	0.053	0.085	0.107	0.126	0.148	0.151	0.178	0.182	0.149
1958	0.051	0.069	0.097	0.108	0.125	0.128	0.138	0.169	0.149
1959	0.051	0.081	0.097	0.113	0.124	0.133	0.137	0.150	0.149
1960	0.059	0.090	0.106	0.121	0.134	0.145	0.160	0.174	0.165
1961	0.058	0.090	0.117	0.141	0.173	0.140	0.159	0.163	0.157
1962	0.057	0.092	0.107	0.125	0.128	0.140	0.155	0.168	0.157
1963	0.056	0.090	0.112	0.123	0.137	0.145	0.150	0.165	0.157
1964	0.061	0.093	0.114	0.135	0.145	0.130	0.152	0.164	0.157
1965	0.069	0.107	0.129	0.147	0.171	0.159	0.155	0.167	0.158
1966	0.042	0.111	0.133	0.149	0.162	0.179	0.154	0.165	0.157
1967	0.057	0.098	0.119	0.136	0.149	0.150	0.153	0.166	0.157
1968	0.057	0.100	0.121	0.138	0.153	0.153	0.153	0.165	0.157
1969	0.057	0.102	0.123	0.141	0.156	0.154	0.154	0.165	0.157
1970	0.056	0.104	0.125	0.142	0.158	0.159	0.154	0.166	0.157
1971	0.054	0.103	0.124	0.141	0.156	0.159	0.154	0.166	0.157
1972	0.064	0.103	0.138	0.160	0.173	0.181	0.202	0.160	0.157
1973	0.063	0.103	0.135	0.160	0.184	0.192	0.190	0.254	0.157
1974	0.062	0.085	0.123	0.149	0.172	0.186	0.184	0.217	0.231
1975	0.055	0.092	0.128	0.165	0.189	0.207	0.220	0.241	0.207
1976	0.054	0.087	0.120	0.152	0.181	0.195	0.211	0.222	0.182
1977	0.063	0.088	0.125	0.143	0.169	0.183	0.192	0.195	0.215
1978	0.060	0.080	0.108	0.134	0.154	0.174	0.188	0.204	0.228
1979	0.062	0.083	0.110	0.141	0.166	0.184	0.200	0.201	0.192
1980	0.059	0.081	0.107	0.131	0.160	0.178	0.192	0.208	0.209
1981	0.061	0.090	0.110	0.137	0.151	0.175	0.180	0.186	0.205
1982	0.071	0.089	0.110	0.126	0.142	0.150	0.171	0.180	0.186
1983	0.061	0.094	0.119	0.141	0.155	0.166	0.174	0.195	0.192
1984	0.068	0.100	0.130	0.153	0.166	0.175	0.185	0.189	0.203
1985	0.069	0.101	0.135	0.161	0.182	0.186	0.207	0.185	0.204
1986	0.068	0.103	0.131	0.160	0.181	0.192	0.198	0.204	0.222
1987	0.069	0.102	0.137	0.163	0.181	0.200	0.203	0.205	0.210
1988	0.068	0.103	0.130	0.160	0.177	0.195	0.202	0.206	0.214
1989	0.064	0.097	0.127	0.149	0.171	0.188	0.193	0.197	0.212
1990	0.062	0.101	0.130	0.154	0.172	0.188	0.199	0.215	0.197

	Weight-at-age (kg)								
Year	2	3	4	5	6	7	8	9	10
1991	0.066	0.094	0.123	0.141	0.161	0.177	0.186	0.198	0.206
1992	0.069	0.101	0.126	0.149	0.164	0.177	0.188	0.197	0.205
1993	0.068	0.097	0.122	0.141	0.159	0.169	0.178	0.187	0.198
1994	0.065	0.095	0.119	0.136	0.150	0.160	0.164	0.175	0.178
1995	0.070	0.098	0.122	0.144	0.160	0.175	0.182	0.189	0.186
1996	0.070	0.086	0.116	0.136	0.151	0.164	0.176	0.181	0.190
1997	0.064	0.091	0.105	0.132	0.149	0.161	0.176	0.173	0.179
1998	0.059	0.080	0.104	0.113	0.132	0.143	0.150	0.156	0.155
1999	0.054	0.083	0.099	0.119	0.126	0.144	0.152	0.163	0.157
2000	0.058	0.086	0.107	0.130	0.147	0.159	0.162	0.171	0.178
2001	0.066	0.088	0.107	0.124	0.141	0.156	0.156	0.148	0.186
2002	0.062	0.084	0.103	0.125	0.144	0.157	0.170	0.187	0.218
2003	0.061	0.093	0.103	0.121	0.139	0.154	0.176	0.167	0.192
2004	0.064	0.082	0.103	0.110	0.124	0.134	0.156	0.166	0.127
2005	0.056	0.075	0.091	0.112	0.120	0.133	0.138	0.152	0.137
2006	0.055	0.069	0.088	0.102	0.117	0.110	0.128	0.164	0.172
2007	0.055	0.073	0.080	0.092	0.098	0.131	0.154	0.167	0.169
2008	0.056	0.060	0.088	0.103	0.116	0.132	0.145	0.139	0.162
2009	0.046	0.075	0.078	0.104	0.110	0.114	0.144	0.158	0.153
2010	0.044	0.071	0.085	0.092	0.106	0.117	0.110	0.156	0.159
2011	0.046	0.066	0.072	0.096	0.099	0.112	0.136	0.157	0.163
2012	0.052	0.078	0.087	0.099	0.110	0.117	0.122	0.155	0.161
2013	0.056	0.079	0.094	0.105	0.121	0.122	0.134	0.153	0.160
2014	0.059	0.081	0.096	0.124	0.140	0.150	0.129	0.164	0.159
2015	0.060	0.075	0.086	0.098	0.102	0.109	0.108	0.157	0.130
2016	0.063	0.077	0.082	0.092	0.094	0.121	0.135	0.146	0.155
2017	0.065	0.081	0.095	0.102	0.110	0.119	0.137	0.121	0.153

Table B.27. Pacific Herring weight-at-age in kilograms (kg) from 1951 to 2017 in the A27 stock assessment region (SAR). Biological summaries only include samples collected using seine nets (commercial and test) due to size-selectivity of other gear types such as gillnet. The age-10 class is a 'plus group' which includes fish ages 10 and older.

	Weight-at-age (kg)								
Year	2	3	4	5	6	7	8	9	10
1951	0.046	0.077	0.101	0.125	0.134	0.145	0.174	0.184	0.196
1952	0.046	0.077	0.101	0.125	0.134	0.145	0.174	0.184	0.196
1953	0.046	0.077	0.101	0.125	0.134	0.145	0.174	0.184	0.196
1954	0.046	0.077	0.101	0.125	0.134	0.145	0.174	0.184	0.196
1955	0.046	0.085	0.105	0.135	0.142	0.181	0.174	0.184	0.196
1956	0.046	0.081	0.103	0.130	0.138	0.163	0.174	0.184	0.196
1957	0.046	0.081	0.103	0.130	0.138	0.163	0.174	0.184	0.196
1958	0.046	0.081	0.103	0.130	0.138	0.163	0.174	0.184	0.196
1959	0.046	0.081	0.103	0.130	0.138	0.163	0.174	0.184	0.196

	Weight-at-age (kg)								
Year	2	3	4	5	6	7	8	9	10
1960	0.046	0.082	0.103	0.131	0.139	0.166	0.174	0.184	0.196
1961	0.046	0.081	0.103	0.130	0.138	0.164	0.174	0.184	0.196
1962	0.046	0.081	0.103	0.130	0.138	0.164	0.174	0.184	0.196
1963	0.046	0.081	0.103	0.130	0.138	0.164	0.174	0.184	0.196
1964	0.046	0.093	0.110	0.136	0.158	0.164	0.174	0.184	0.196
1965	0.110	0.109	0.135	0.151	0.170	0.172	0.187	0.184	0.196
1966	0.059	0.089	0.111	0.135	0.149	0.165	0.177	0.184	0.196
1967	0.062	0.091	0.112	0.137	0.151	0.166	0.177	0.184	0.196
1968	0.065	0.093	0.114	0.138	0.153	0.166	0.178	0.184	0.196
1969	0.068	0.095	0.117	0.139	0.156	0.167	0.178	0.184	0.196
1970	0.073	0.095	0.118	0.140	0.156	0.167	0.179	0.184	0.196
1971	0.065	0.093	0.114	0.138	0.153	0.166	0.178	0.184	0.196
1972	0.067	0.093	0.115	0.138	0.154	0.167	0.178	0.184	0.196
1973	0.068	0.094	0.116	0.139	0.154	0.167	0.178	0.184	0.196
1974	0.068	0.094	0.116	0.139	0.155	0.167	0.178	0.184	0.196
1975	0.068	0.094	0.116	0.139	0.154	0.167	0.178	0.184	0.196
1976	0.067	0.094	0.115	0.138	0.154	0.167	0.178	0.184	0.196
1977	0.068	0.094	0.116	0.139	0.154	0.167	0.178	0.184	0.196
1978	0.055	0.078	0.103	0.131	0.154	0.152	0.178	0.184	0.196
1979	0.035	0.083	0.103	0.125	0.136	0.151	0.178	0.184	0.196
1980	0.059	0.088	0.110	0.134	0.150	0.160	0.178	0.184	0.196
1981	0.062	0.092	0.111	0.129	0.138	0.148	0.178	0.184	0.196
1982	0.056	0.093	0.110	0.126	0.136	0.147	0.166	0.145	0.196
1983	0.051	0.088	0.106	0.114	0.128	0.152	0.137	0.177	0.196
1984	0.053	0.089	0.108	0.126	0.138	0.152	0.167	0.175	0.196
1985	0.056	0.090	0.109	0.126	0.138	0.152	0.165	0.173	0.196
1986	0.068	0.114	0.138	0.156	0.196	0.205	0.199	0.227	0.196
1987	0.067	0.107	0.151	0.165	0.183	0.161	0.211	0.233	0.196
1988	0.062	0.100	0.137	0.154	0.178	0.190	0.186	0.197	0.262
1989	0.043	0.104	0.138	0.177	0.199	0.213	0.198	0.249	0.229
1990	0.063	0.101	0.138	0.171	0.197	0.216	0.226	0.242	0.234
1991	0.065	0.094	0.119	0.153	0.174	0.201	0.206	0.204	0.230
1992	0.060	0.102	0.133	0.154	0.182	0.203	0.221	0.234	0.251
1993	0.058	0.089	0.119	0.128	0.175	0.185	0.197	0.156	0.221
1994	0.070	0.095	0.111	0.136	0.155	0.168	0.186	0.188	0.194
1995	0.060	0.100	0.117	0.131	0.151	0.168	0.175	0.201	0.183
1996	0.056	0.089	0.111	0.135	0.144	0.165	0.169	0.191	0.183
1997	0.048	0.082	0.109	0.133	0.134	0.149	0.158	0.194	0.207
1998	0.043	0.075	0.097	0.099	0.124	0.133	0.153	0.149	0.198
1999	0.049	0.072	0.089	0.106	0.105	0.139	0.124	0.175	0.173
2000	0.053	0.080	0.089	0.113	0.134	0.136	0.150	0.134	0.185
2001	0.051	0.074	0.091	0.102	0.111	0.114	0.114	0.121	0.163
2002	0.085	0.092	0.099	0.123	0.096	0.119	0.145	0.165	0.185
2003	0.057	0.100	0.107	0.115	0.133	0.149	0.163	0.149	0.181

	Weight-at-age (kg)								
Year	2	3	4	5	6	7	8	9	10
2004	0.055	0.082	0.101	0.105	0.129	0.128	0.116	0.149	0.177
2005	0.034	0.068	0.077	0.108	0.134	0.130	0.154	0.144	0.178
2006	0.056	0.083	0.095	0.111	0.120	0.128	0.138	0.145	0.177
2007	0.056	0.068	0.074	0.090	0.100	0.117	0.129	0.150	0.180
2008	0.047	0.066	0.079	0.088	0.096	0.111	0.106	0.147	0.179
2009	0.045	0.073	0.073	0.101	0.113	0.114	0.129	0.154	0.178
2010	0.051	0.068	0.082	0.088	0.092	0.104	0.100	0.148	0.178
2011	0.045	0.064	0.074	0.092	0.100	0.102	0.123	0.058	0.178
2012	0.046	0.068	0.081	0.084	0.091	0.099	0.104	0.132	0.114
2013	0.055	0.076	0.086	0.106	0.119	0.115	0.147	0.128	0.121
2014	0.048	0.070	0.079	0.094	0.103	0.107	0.121	0.124	0.154
2015	0.049	0.069	0.080	0.093	0.101	0.105	0.119	0.118	0.149
2016	0.049	0.070	0.080	0.094	0.103	0.105	0.123	0.112	0.143
2017	0.050	0.071	0.081	0.094	0.103	0.106	0.123	0.123	0.136

Table B.28. Pacific Herring weight-at-age in kilograms (kg) from 1951 to 2017 in the A2W stock assessment region (SAR). Biological summaries only include samples collected using seine nets (commercial and test) due to size-selectivity of other gear types such as gillnet. The age-10 class is a 'plus group' which includes fish ages 10 and older.

	Weight-at-age (kg)								
Year	2	3	4	5	6	7	8	9	10
1951	0.057	0.078	0.101	0.104	0.129	0.196	0.216	0.171	0.195
1952	0.057	0.078	0.101	0.104	0.129	0.196	0.216	0.171	0.195
1953	0.057	0.078	0.101	0.104	0.129	0.196	0.216	0.171	0.195
1954	0.057	0.078	0.101	0.104	0.129	0.196	0.216	0.171	0.195
1955	0.057	0.078	0.101	0.104	0.129	0.196	0.216	0.171	0.195
1956	0.057	0.078	0.101	0.104	0.129	0.196	0.216	0.171	0.195
1957	0.057	0.078	0.101	0.104	0.129	0.196	0.216	0.171	0.195
1958	0.057	0.078	0.101	0.104	0.129	0.196	0.216	0.171	0.195
1959	0.057	0.078	0.101	0.104	0.129	0.196	0.216	0.171	0.195
1960	0.057	0.078	0.101	0.104	0.129	0.196	0.216	0.171	0.195
1961	0.057	0.078	0.101	0.104	0.129	0.196	0.216	0.171	0.195
1962	0.057	0.078	0.101	0.104	0.129	0.196	0.216	0.171	0.195
1963	0.057	0.078	0.101	0.104	0.129	0.196	0.216	0.171	0.195
1964	0.057	0.078	0.101	0.104	0.129	0.196	0.216	0.171	0.195
1965	0.057	0.105	0.163	0.170	0.199	0.196	0.216	0.171	0.195
1966	0.057	0.084	0.113	0.117	0.143	0.196	0.216	0.171	0.195
1967	0.057	0.085	0.116	0.120	0.146	0.196	0.216	0.171	0.195
1968	0.057	0.086	0.119	0.123	0.149	0.196	0.216	0.171	0.195
1969	0.057	0.088	0.122	0.127	0.153	0.196	0.216	0.171	0.195
1970	0.057	0.090	0.126	0.132	0.158	0.196	0.216	0.171	0.195
1971	0.057	0.086	0.119	0.124	0.150	0.196	0.216	0.171	0.195
1972	0.057	0.087	0.120	0.125	0.151	0.196	0.216	0.171	0.195
1973	0.057	0.107	0.124	0.165	0.178	0.189	0.216	0.171	0.195
1974	0.057	0.094	0.118	0.146	0.164	0.178	0.210	0.171	0.195

	Weight-at-age (kg)								
Year	2	3	4	5	6	7	8	9	10
1975	0.070	0.110	0.163	0.187	0.227	0.235	0.269	0.171	0.195
1976	0.058	0.125	0.153	0.191	0.198	0.199	0.226	0.171	0.195
1977	0.062	0.104	0.136	0.163	0.184	0.199	0.227	0.171	0.195
1978	0.062	0.101	0.142	0.168	0.182	0.195	0.222	0.230	0.195
1979	0.053	0.100	0.137	0.156	0.181	0.190	0.211	0.203	0.195
1980	0.061	0.098	0.122	0.169	0.200	0.220	0.231	0.282	0.195
1981	0.066	0.092	0.126	0.155	0.178	0.185	0.188	0.193	0.195
1982	0.066	0.113	0.123	0.156	0.181	0.189	0.214	0.210	0.222
1983	0.075	0.108	0.141	0.158	0.178	0.195	0.203	0.196	0.217
1984	0.073	0.107	0.131	0.156	0.189	0.185	0.184	0.187	0.214
1985	0.085	0.118	0.153	0.179	0.204	0.210	0.219	0.219	0.226
1986	0.080	0.116	0.149	0.162	0.184	0.212	0.227	0.232	0.207
1987	0.063	0.103	0.132	0.170	0.202	0.187	0.223	0.196	0.229
1988	0.071	0.101	0.143	0.158	0.182	0.207	0.221	0.239	0.241
1989	0.062	0.101	0.132	0.158	0.181	0.191	0.203	0.216	0.216
1990	0.058	0.094	0.141	0.164	0.187	0.192	0.230	0.207	0.227
1991	0.062	0.096	0.127	0.168	0.176	0.189	0.200	0.212	0.207
1992	0.056	0.105	0.134	0.145	0.178	0.196	0.210	0.207	0.218
1993	0.068	0.104	0.128	0.146	0.169	0.177	0.189	0.198	0.195
1994	0.075	0.115	0.139	0.151	0.174	0.153	0.200	0.199	0.196
1995	0.064	0.103	0.134	0.155	0.177	0.181	0.206	0.204	0.209
1996	0.065	0.105	0.133	0.153	0.175	0.179	0.201	0.204	0.205
1997	0.066	0.106	0.134	0.150	0.174	0.177	0.201	0.202	0.205
1998	0.069	0.105	0.132	0.168	0.174	0.171	0.198	0.194	0.202
1999	0.071	0.107	0.121	0.148	0.168	0.166	0.134	0.187	0.203
2000	0.069	0.083	0.088	0.155	0.204	0.175	0.111	0.198	0.205
2001	0.070	0.104	0.148	0.172	0.177	0.177	0.178	0.215	0.185
2002	0.062	0.106	0.124	0.174	0.197	0.204	0.203	0.204	0.205
2003	0.065	0.103	0.124	0.140	0.182	0.198	0.194	0.185	0.186
2004	0.057	0.095	0.129	0.143	0.162	0.199	0.246	0.198	0.224
2005	0.059	0.084	0.109	0.139	0.155	0.148	0.174	0.200	0.190
2006	0.059	0.077	0.104	0.137	0.169	0.184	0.210	0.211	0.198
2007	0.080	0.082	0.088	0.117	0.141	0.158	0.155	0.175	0.200
2008	0.056	0.075	0.110	0.129	0.156	0.145	0.164	0.194	0.198
2009	0.056	0.088	0.101	0.139	0.156	0.161	0.192	0.190	0.192
2010	0.056	0.092	0.123	0.135	0.168	0.169	0.172	0.185	0.206
2011	0.056	0.094	0.117	0.141	0.128	0.155	0.161	0.157	0.200
2012	0.057	0.092	0.123	0.145	0.172	0.178	0.179	0.180	0.181
2013	0.074	0.085	0.114	0.156	0.180	0.185	0.174	0.196	0.156
2014	0.059	0.055	0.114	0.134	0.176	0.170	0.195	0.163	0.190
2015	0.061	0.093	0.100	0.143	0.131	0.186	0.190	0.210	0.199
2016	0.065	0.087	0.113	0.124	0.140	0.155	0.181	0.181	0.185
2017	0.062	0.097	0.122	0.138	0.132	0.154	0.167	0.174	0.182

Table B.29. Number of Pacific Herring biosamples from 1951 to 2017 in each stock assessment region (SAR). Each sample is approximately 100 fish.

	Number of biosamples						
Year	A27	A2W	CC	HG	PRD	SoG	WCVI
1951	0	0	60	16	53	83	42
1952	0	0	55	24	70	95	54
1953	0	0	31	0	19	113	40
1954	3	0	36	0	30	142	67
1955	16	0	27	0	14	60	30
1956	0	0	69	23	21	135	49
1957	0	1	99	103	103	158	12
1958	0	0	77	58	17	186	32
1959	0	0	103	2	55	223	78
1960	0	0	30	0	92	95	59
1961	0	0	59	0	92	134	15
1962	0	0	20	12	59	90	27
1963	0	0	23	17	74	65	51
1964	2	0	24	11	71	109	25
1965	3	1	36	22	77	83	18
1966	0	0	0	0	10	21	7
1971	2	0	16	0	11	28	11
1972	0	0	41	16	10	148	25
1973	0	2	22	22	11	75	42
1974	0	6	34	26	11	30	77
1975	0	6	116	75	41	69	127
1976	4	3	79	52	12	84	128
1977	0	0	42	44	28	82	87
1978	1	3	36	21	41	80	116
1979	3	9	0	22	52	110	66
1980	5	3	49	70	70	163	56
1981	10	23	91	97	169	273	92
1982	15	21	65	57	59	170	90
1983	3	37	85	38	55	231	46
1984	7	6	90	46	49	163	49
1985	0	13	80	46	63	155	36
1986	3	5	82	67	101	93	46
1987	3	5	70	36	73	129	69
1988	4	17	70	24	65	109	107
1989	5	13	75	40	49	105	89
1990	10	28	89	61	62	98	89
1991	5	36	89	44	60	88	97
1992	15	24	92	36	61	83	87
1993	14	29	103	41	54	90	71
1994	16	2	101	18	82	85	85
1995	15	0	122	6	57	89	86
1996	7	0	68	14	34	121	99

	Number of biosamples						
Year	A27	A2W	CC	HG	PRD	SoG	WCVI
1997	6	0	78	18	35	95	94
1998	8	13	82	30	38	132	92
1999	8	8	66	34	26	86	78
2000	7	1	56	24	51	109	89
2001	2	4	57	15	69	95	38
2002	5	13	76	36	72	99	83
2003	6	14	69	25	65	137	79
2004	4	9	56	13	40	94	79
2005	2	12	69	14	53	70	52
2006	0	5	64	9	29	79	23
2007	5	7	26	6	24	119	10
2008	4	2	17	10	57	98	22
2009	8	9	34	12	55	71	29
2010	3	7	26	12	47	84	27
2011	3	10	30	13	56	108	28
2012	7	5	24	9	48	144	10
2013	6	7	15	12	44	122	5
2014	0	3	26	12	32	93	4
2015	0	4	20	11	56	158	20
2016	0	5	20	5	44	161	25
2017	0	6	44	8	51	148	19

APPENDIX C. TIME SERIES DATA FOR MINOR STOCKS

The Terms of Reference states:

1. For the minor stock areas, present stock status updates using available spawn survey data and biological samples.

There was insufficient time to conduct a formal analysis of stock trend information for the Pacific Herring minor stocks, Area 27 (A27) and Area 2 West (A2W). However, catch data, spawn index data, and biological sampling information are presented in Appendix B. In addition, we provide timeseries of catch and spawn index (Figures C.1 & C.2, respectively).

C.1 FIGURES

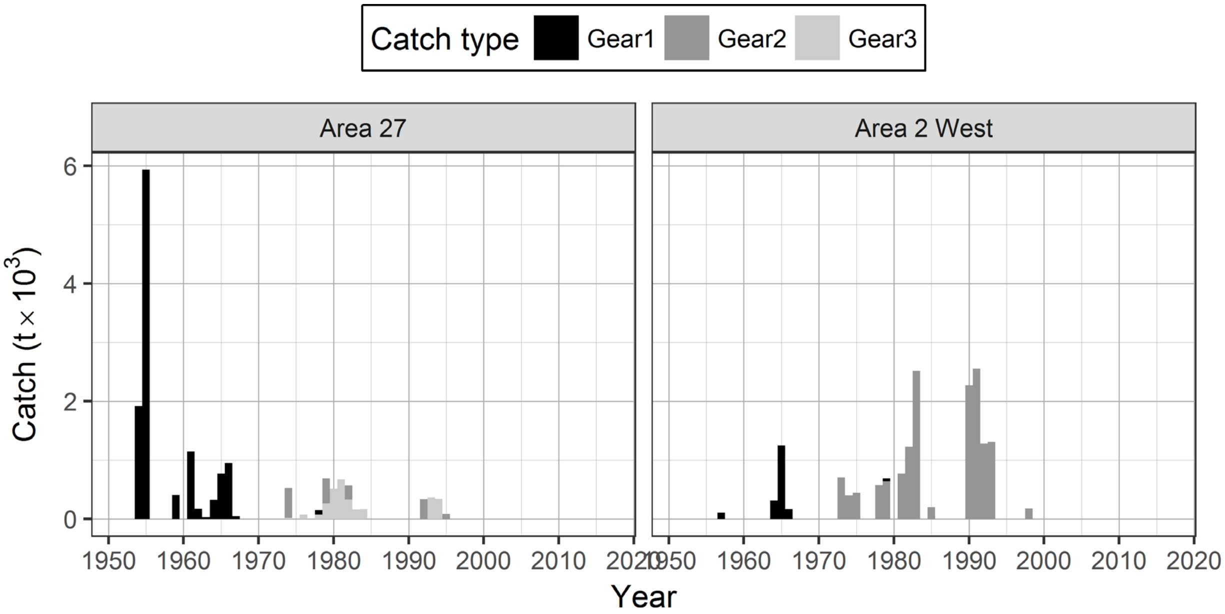


Figure C.1. Time series of total landed catch in thousands of metric tonnes (t x 10^3) of Pacific Herring from 1951 to 2017 in the minor stock assessment regions (SARs). Legend: 'Gear1' represents the reduction, the food and bait, as well as the special use fishery; 'Gear2' represents the roe seine fishery; and 'Gear3' represents the roe gillnet fishery.

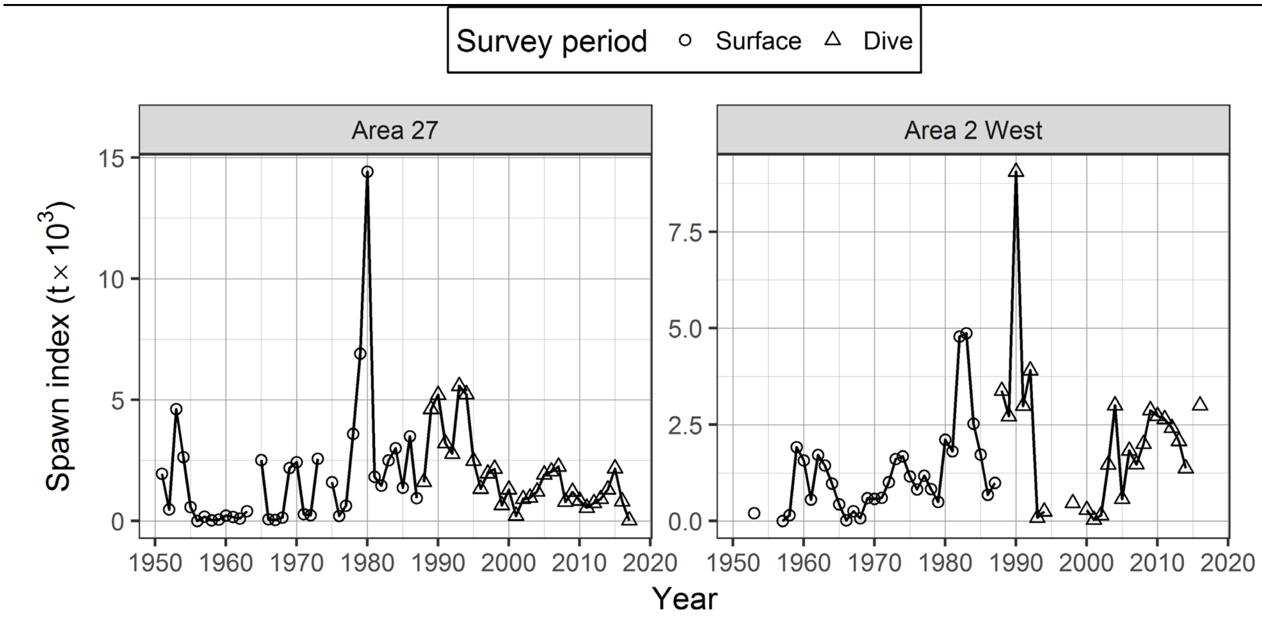


Figure C.2. Time series of spawn index in thousands of metric tonnes (t x 10^3) for Pacific Herring from 1951 to 2017 in the minor stock assessment regions (SARs). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2017). The 'spawn index' represents the raw survey data only, and is not scaled by the spawn survey scaling parameter, q.

APPENDIX D. BRIDGING ANALYSIS

D.1 ANALYSIS

This bridging analysis provides documentation of the transition from the catch-age model code and assessment approach developed in 2011 (Martell et al. 2012) and used from 2011-2016, to an updated version of the assessment model platform used for the current Herring assessment (V2). The new platform has been used in recent stock assessments (e.g., Grandin and Forrest 2017). The detailed bridging analysis is presented for the Strait of Georgia stock only, as the relative results did not differ among stocks areas. Summary results for all five stocks are included where informative.

Sensitivity analyses included in this bridging analysis are limited to the key steps used to develop the base case for the 2017 assessment. We refer to the original 2011 model platform as V0, modifications to V0 as V1, and the new updated platform as V2.

Results presented for each bridging step are maximum posterior density (MPD) estimates. The first step (1A and 1B) was to re-run the 2016 assessment model code (V0) to reproduce results from 2016 (DFO 2016). Before proceeding, the estimation phases for the variance parameters rho (ρ) and kappa (κ) were modified to estimation phases 3 and 4, respectively. These parameters were estimated in phases 3 and 3, respectively, in 2016. Steps 7 and 8 below include descriptions and equations for rho and kappa.

The V1 model code also includes the following update to the estimation of the variance structure. Variance components of the model implemented within the *ISCAM* modelling framework (e.g., Grandin and Forrest 2017) were partitioned using an errors-in- variables approach. The key variance parameter is the inverse of the total variance φ^{-2} (i.e., total precision, *varphi*). The total variance is partitioned into observation and process error components by the model parameter ρ (*rho*), which represents the proportion of the total variance that is due to observation error (Punt and Butterworth 1993, Deriso et al. 2007).

In the 2011 stock assessment (Martell et al., 2011), varphi was parameterized as the total standard deviation of the process error, rather than the total variance, i.e., V0 model code (2011-2016)

$$\tau = \frac{1 - rho}{varphi}$$

$$\sigma = \frac{rho}{varphi}$$

In the review of the 2011 stock assessment (DFO 2012), reviewers noted that the errors-in-variables approach should have been parameterized as a function of total variance (or its inverse precision). This change was made in subsequent versions of the software (e.g., Forrest et al., 2015; Grandin and Forrest 2017). However, the change was not implemented for the Pacific Herring assessment at the time, and for consistency has not been implemented in subsequent iterations of the assessment.

Given the recommendation of the reviewers in 2011 and to bring the assessment in line with best practices, the current assessment will update the errors-in-variables approach to represent partitioning of the total precision, i.e.,

$$\tau = \sqrt{1 - rho} * varphi$$

$$\sigma = \sqrt{rho} * varphi$$

where varphi now represents the inverse of the total variance, not total standard deviation. Therefore, to be able to compare results from model V0 to model V2, a hybrid version of V1 was developed, which used the above definition of tau (τ), sigma (σ) and varphi (φ^{-2}).

Of relevance to the bridging analysis is that this change to partitioning of the total variance impacts model estimates of leading parameters and unfished biomass (SB_0). Table D.1 and D.2 summarizes MPD estimates of relevant leading parameters and SB_0 from V0 model code used from 2011-2016, the updated V1 model code and V2 for AM1 (Table D.1) and AM2 (Table D.2). After making this one change, results from models V1 and V2 are nearly identical (Table D.1), indicating that any differences between V0 and V2 can largely be explained by the update to the errors in variables approach.

For all stocks, MPD estimates of SB_0 using the updated model equations (V1 and V2) are numerically larger than those calculated using the previous equation (V0), with the largest differences occurring for SOG and PRD stocks. V0, V1 and V2 estimates of SB_0 for HG are within 160 tonnes of each other. Trends are similar between AM1 and AM2 parameterizations of q.

Each bridging analysis step is described in Table D.3 and is carried out for both AM1 and AM2 model configurations. Following the convention of DFO 2016, the model cases are denoted AM1 for the case where surface (1951-1987) and dive (1988+) survey catchability parameters are estimated using a prior distribution and AM2 for the case where the surface survey catchability is estimated and the dive survey catchability is fixed at $q_2 = 1$.

Steps 1 and 2: Reconstruction of previous assessment with fixed parameters.

The first step was to ensure that both V1 and V2 models produce output values that are identical to input values when all estimation procedures are turned off. Leading parameter initial values for V1 and V2 were set equal to MPD estimated values from the 2016 assessment (DFO 2016). With the estimation of all leading parameters turned off, both V1 and V2 produced model estimates identical to the initial leading parameters indicating that both models are working correctly and not estimating parameters when estimation procedures have been turned off (Table D.4).

Steps 3 and 4: All parameters estimated except *M*

In Steps 3A, 3B, 4A, and 4B, parameter estimation is turned on for both V1 and V2, and model estimates are compared to examine similarities between estimated parameters and time series trends. Here, estimated natural mortality is assumed to be constant over time. Estimated values differ from initial leading parameter values, as expected, however they vary minimally between V1 and V2 (Table D.5). Model fits to the survey data and time series estimates of spawning biomass, recruitment deviations, depletion, and estimated natural mortality show near-identical trends (Figure D.1). Comparisons using AM2 (Steps 3B and 4B) show the same results thus these figures are not included for this step.

Steps 5 and 6: All parameters estimated, including *M*

The estimation of time varying natural mortality within the age-structured model was first introduced to the herring stock assessment model in 2004, where instantaneous natural mortality is assumed equal over all ages but varies over time (Fu et al. 2004). The current parameterization of natural mortality (M), where annual deviations in M are estimated using a random walk process was introduced in 2006 (Haist and Schweigert 2006). Support for inclusion of time varying M includes reduction in the magnitude of retrospective patterns and improved coherence between assumed and empirical fits to the spawn survey index. This parameterization of *M* has continued to be implemented in annual stock assessment of BC Pacific Herring.

Steps 5A, 5B, 6A, and 6B reexamine model outputs and time series trends described in Steps 3 and 4, with the addition of estimated time varying natural mortality. Model fits to the survey data and time series estimates of spawning biomass, recruitment deviations, depletion, and estimated natural mortality show near-identical trends when comparing V1 and V2 (Figure D.2). Comparisons using AM2 (Steps 5B and 6B) show the same trends as AM1 thus these figures are not included. Figure D.3 compares V2 constant *M* and time varying *M* model runs for AM1 (Steps 4A vs. 6A). The addition of time varying *M* results in improved model fits to the spawn index, particularly from 2010-2016 (Figure D.3b). Differences in the parameterization of *M* also impact estimates of SB_0 where

SB_0_constant*M* is numerically larger than SB_0_timevarying*M* (Figure D.3c- see dots on far left side of the figure), and in deviations in recruitment (Figure D.3d). Steps 4B and 6B compare constant *M* and time varying *M* model runs for AM2, showing similar improvements to model fits in the spawn index (Figure D.4b). With AM2, differences in estimated values of SB_0 are less pronounced than with AM1 (Figure D.4c vs. D.3c), likely attributed to more pronounced differences in q_1 (Figure D.4g vs. D.3g).

Steps 7 and 8: Process and observation error: Investigating sensitivities to variance parameters for rho and kappa.

The key variance parameter in the errors-in-variables approach is the inverse of the total variance φ^{-2} (i.e., total precision, *varphi*). The total variance is partitioned into observation and process error components by the model parameter ρ (*rho*), which is the proportion of the total variance that is due to observation error (Punt and Butterworth 1993, Deriso et al. 2007). In *ISCAM*, standard deviations in process error (tau, τ) and observation error (sigma, σ) are related and modelled using the following equations for kappa (κ) and rho (ρ):

$$kappa = \left(\frac{1}{\sqrt{\sigma^2 + \tau^2}}\right)^2$$

$$rho = \sigma^2\left(\frac{1}{\sqrt{\sigma^2 + \tau^2}}\right)^2$$

Since the introduction of ISCAM V1 in 2011, the model has been parameterized to estimate both kappa and rho. Steps 7 and 8 investigate the sensitivity of V2 (AM1 and AM2) to different fixed kappa values while estimating rho with constant *M* (Step 7A) and time varying *M* (Step 8A), and to different fixed rho values while estimating kappa with constant *M* (Step 7B) and time varying *M* (Step 8B). All combinations are described in Table D.6. Steps 7C and 8C present the status quo to date: estimating both kappa and rho, under constant *M* (Step 7C) and time varying *M* (Step 8C). When both rho and kappa are estimated (Steps 7C, 8C), the choice of initial value for rho and kappa does not impact estimated model parameters. This is the same for AM1, AM2 and both parameterizations of *M*. Figure D.5 shows model estimates of spawning biomass (SB_t), demonstrating there are no changes in SB_t regardless of initial values when both rho and kappa are estimated (figures of model fits to spawn index, recruitment deviations, depletion, natural mortality and *q* are not shown). For all scenarios that include estimating rho while fixing kappa and estimating kappa while fixing rho, for AM1, AM2, and both parameterizations of *M*, the largest difference is in model estimates of SB_0 and hence estimated depletion (SBt/SB_0). Figure D.6 presents (a) through (g) for Step 7A, Figure D.7 summarizes differences in SB_t and SBt/$SB_0$for Step 7A (AM1 and AM2), and

Figure D.8 summarizes differences in SB_t and SB_t/SB_0 for Step 7B (AM1 and AM2). Figures D.9 and D.10 present AM1 results only.

Step 9: Sensitivity to prior on *q*

Estimates of current spawning biomass and one-year projections were presented for both AM1 and AM2 parameterizations of spawn survey *q* in 2014, 2015 and 2016 due to concerns around the choice of *q* prior and interactions with the harvest control rule. In the 2016 Science Response, the Herring Technical Working Group described in detail analytical concerns with both AM1 and AM2 parameterizations of *q* (Table A.1, DFO 2016). The bridging analysis considers 6 *q* prior scenarios, differing by distribution (informative or uninformative) and mean prior *q* value, described in Table D.7, as well as additional scenarios to explore tightening and broadening of *q* prior by changing the standard deviation of the *q* prior while keeping the mean constant (Table D.8).

Under the constant *M* scenario, model estimates of q_1 and q_2 estimated using an uninformative prior (scenario 1) were near-identical to values estimated by AM1 (scenario 3, Figure D.11g). These scenarios produced near-identical estimates of SB_0 and time series of spawning biomass (Figure D.11c). Further investigation of the sensitivity of model estimates to tightening and broadening of the standard deviation of the uninformative prior is presented in Figure D.12. With an uninformative *q* prior and standard deviation between 0.5 and 3.0, model estimates of q_1, q_2, *M*, and model estimates of spawning biomass are very similar (Figure D.12). In contrast, when the standard deviation on *q* prior is reduced to 0.1 (scenario 1d), q_1 and q_2 estimated to be considerably larger than scenarios 1, 1a – 1c, estimated *M* is numerically lower, and the time series of *SB* for all years after 1965 is numerically lower.

Figures D.13 and D.14 explore the same scenarios for time varying *M*. Interactions between estimating time varying *M* and estimating *q* are such that the lowest *q* prior value (scenario 2) results in the highest overall estimates of time varying *M* (Figure D.13f) and the highest estimates of spawning biomass (Figure D.13c). The uninformative prior (scenario 1) produced estimates similar to the mean *q* prior of 0.75 (scenario 4), and the highest *q* values and lowest biomass values occur with scenario 6 (AM2). As was the case with the constant *M* scenario, tightening and broadening the *q* prior by changing the standard deviation for the uninformative prior, scenario 1, estimates *q* values in the range of 0.75 for standard deviations between 0.5 and 3.0.

The uninformative prior with a standard deviation of 0.1 results in lower estimates of time varying *M* and lower spawning biomass estimates relative to the other scenarios.

Step 11: Test V2 model with 2016 input data for remaining 4 major stocks

V2 model successfully reproduced V1 model estimates from 2016 input data for AM1 and AM2 under scenarios of estimated constant *M* and estimated time varying *M* (Steps 3 – 6). Steps 3, 4, 5 and 6 were repeated for the remaining 4 stocks, AM1 and AM2, to ensure V2 would run for all stocks and to diagnose any issues related to model convergence or local minimas. Results from these model runs are not included in the bridging analysis.

Step 12: Summarize conclusions and determine base parameterization for V2

1. 2016 V2 model estimates of SB_0 differ from 2016 V1 estimates due to changes to the model code describing variance structure for process and observation error.
2. Parameter estimates and biomass trajectories compared between V1 and V2 were near identical, supporting the adoption of V2 model code for the 2017 herring assessment.
3. Based on the results from the sensitivity analyses presented in Steps 7, 8 (for rho and kappa for AM1, AM2 and constant and time varying *M*) and Steps 9, 10 (for *q* prior and

standard deviation in *q* prior), we recommend continuing with 2016 parameterization of rho, kappa, and natural mortality (*M*) for AM1 and AM2 model runs. The sensitivity analysis was inconclusive with respect to supporting or eliminating a particular *q* parameterization over another. Resolution between AM1 and AM2 parameterization of *q* will require simulation-evaluation. Sensitivity analyses alone are insufficient for understanding the complex interplay between estimating rho, kappa, *q*, steepness (h), and time varying processes such as *M* and selectivity and the implications for estimating biological references points such as unfished biomass.

We recommend defining two Base cases for each of the 5 major herring stocks: AM1 and AM2, and we recommend using V2 with the same assumptions and parameter settings as were used in 2016.

Step 13: Add 2017 data to V2 base for each stock area

V2 model successfully fitted to the 2017 input data for AM1 and AM2 for all 5 major herring stocks.

D.2 TABLES

Table D.1. Comparison of MPD estimates of leading parameters and unfished biomass, SB_0, given changes to the estimation of the variance structure for process and observation error (AM1).

AM1						
Parameters	***Model Version***	***SOG***	***PRD***	***HG***	***CC***	***WCVI***
SB_0	V0	146.46	53.47	32.17	57.89	54.53
	V1	160.90	57.82	32.33	60.69	57.69
	V2	160.81	57.83	32.15	60.71	57.60
R_0	V0	3215.71	328.34	453.88	504.45	903.93
	V1	3226.89	348.43	450.05	511.89	927.31
	V2	3208.58	350.83	446.51	510.40	921.13
steepness, h	V0	0.76	0.73	0.81	0.82	0.75
	V1	0.74	0.72	0.81	0.82	0.76
	V2	0.74	0.72	0.81	0.82	0.76
M (average)	V0	0.57	0.45	0.40	0.47	0.65
	V1	0.56	0.44	0.40	0.47	0.65
	V2	0.56	0.44	0.40	0.46	0.65
rbar	V0	2731.60	235.92	306.18	372.23	724.75
	V1	2356.01	229.35	296.02	355.45	672.04
	V2	2336.29	231.15	294.38	354.40	666.99
rinit	V0	813.05	286.36	40.82	324.64	415.03
	V1	649.46	265.54	39.40	302.57	409.04
	V2	628.30	262.62	39.06	298.70	404.87
tau	V0	0.48	0.66	0.81	0.69	0.54
	V1	0.67	0.75	0.83	0.76	0.68
	V2	0.67	0.75	0.83	0.76	0.68
sigma	V0	0.32	0.45	0.47	0.35	0.40
	V1	0.39	0.51	0.51	0.41	0.46
	V2	0.37	0.49	0.49	0.39	0.44

Table D.2. Comparison of MPD estimates of leading parameters and unfished biomass, SB_0, given changes to the estimation of the variance structure for process and observation error (AM2).

AM2						
Parameters	**Model Version**	**SOG**	**PRD**	**HG**	**CC**	**WCVI**
SB_0	V0	110.71	53.24	23.90	51.35	42.76
	V1	130.38	57.55	24.10	54.12	46.50
	V2	130.84	57.83	23.99	54.18	46.51
R_0	V0	1453.11	285.63	285.87	346.47	529.33
	V1	1535.98	310.20	286.15	367.04	573.06
	V2	1537.69	350.83	284.25	367.10	569.73
steepness, h	V0	0.80	0.73	0.80	0.83	0.73
	V1	0.77	0.72	0.80	0.83	0.74
	V2	0.77	0.72	0.80	0.83	0.74
M (average)	V0	0.50	0.44	0.38	0.45	0.59
	V1	0.46	0.43	0.38	0.45	0.59
	V2	0.46	0.44	0.38	0.44	0.59
rbar	V0	1206.88	201.61	185.27	247.32	389.91
	V1	1082.17	201.04	182.97	249.08	387.38
	V2	1079.78	231.15	182.38	249.25	385.18
rinit	V0	393.27	263.67	34.43	269.29	272.43
	V1	294.20	250.58	33.99	255.38	273.78
	V2	285.98	262.62	33.82	252.29	270.02
tau	V0	0.48	0.67	0.84	0.72	0.58
	V1	0.67	0.75	0.85	0.78	0.70
	V2	0.67	0.75	0.85	0.78	0.70
sigma	V0	0.34	0.45	0.49	0.37	0.42
	V1	0.42	0.51	0.53	0.43	0.47
	V2	0.40	0.49	0.51	0.41	0.45

Table D.3. Bridging analysis steps.

Bridging Step	Description
1A	V1 (AM1): Set leading parameter initial values equal to the estimated MPD values from 2016 AM1 assessment. All estimation OFF.
1B	V1 (AM2): Set leading parameter initial values equal to the estimated MPD values from 2016 AM2 assessment. All estimation OFF.
2A	**V2** (AM1): Set leading parameter initial values equal to the estimated MPD values from 2016 AM1 assessment. All estimation OFF.
2B	**V2** (AM2): Set leading parameter initial values equal to the estimated MPD values from 2016 AM2 assessment. All estimation OFF.

All subsequent steps include parameter estimation.

Steps 3A-4B estimate natural mortality as constant over time.

Bridging Step	Description
3A	V1 (AM1): Set leading parameter initial values equal to the estimated MPD values from 2016 AM1 assessment. Estimate all parameters.
3B	V1 (AM2): Set leading parameter initial values equal to the estimated MPD values from 2016 AM2 assessment. Estimate all parameters.
4A	**V2** (AM1): Set leading parameter initial values equal to the estimated MPD values from 2016 AM1 assessment. Estimate all parameters.
4B	**V2** (AM2): Set leading parameter initial values equal to the estimated MPD values from 2016 AM2 assessment. Estimate all parameters.

Steps 5A-6B estimate time varying natural mortality.

Bridging Step	Description
5A	V1 (AM1): As per 3A, with time varying *M*.
5B	V1 (AM2): As per 3B, with time varying *M*.

Bridging Step	Description
6A	**V2** (AM1): As per 4A, with time varying *M*.
6B	**V2** (AM2): As per 4B, with time varying *M*.

*All subsequent steps involve **V2** model only.*

Bridging Step	Description
7A	Sensitivity analysis (**V2**, AM1 and AM2): Investigate model sensitivity to different fixed values of kappa while estimating rho (constant *M*)
7B	Sensitivity analysis (**V2**, AM1 and AM2): Investigate model sensitivity to different fixed values of rho while estimating kappa (constant *M*)
7C	Sensitivity analysis (**V2**, AM1 and AM2): Investigate model sensitivity when both kappa and rho are estimated (constant *M*)
8A	Sensitivity analysis (**V2**, AM1 and AM2): As per 7A, with time varying *M*.
8B	Sensitivity analysis (**V2**, AM1 and AM2): As per 7B, with time varying *M*.
8C	Sensitivity analysis (**V2**, AM1 and AM2): As per 7C, with time varying *M*.
9A	Sensitivity analysis (**V2**, AM1 and AM2): Investigate model sensitivity to prior on MEAN *q* (including uninformative and informative priors), with constant *M*.
9B	Sensitivity analysis (**V2**, AM1 and AM2): Investigate model sensitivity to standard deviation of prior distribution on *q*, with constant *M*.
10A	Sensitivity analysis (**V2**, AM1 and AM2): Investigate model sensitivity to prior on MEAN *q* (including uninformative and informative priors), with time varying *M*.
10B	Sensitivity analysis (**V2**, AM1 and AM2): Investigate model sensitivity to standard deviation of prior distribution on *q*, with time varying *M*.

Bridging Step	**Description**
11	**V2**: Test V2 model with 2016 input data for remaining 4 major stocks.
12	Summarize conclusions and determine base parameterization of **V2**
13	Add 2017 data to **V2** base for each stock area

Table D.4. Initial and estimated leading parameters for Steps 1A, 1B, 2A, and 2B.

	All parameters fixed							
	1A		*1B*		*2A*		*2B*	
Leading Parameters	*Initial*	*Estimated*	*Initial*	*Estimated*	*Initial*	*Estimated*	*Initial*	*Estimated*
log_ro	7.28	7.28	7.28	7.28	7.28	7.28	7.28	7.28
steepness,h	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
log.m	-0.69186	-0.69186	-0.69186	-0.69186	-0.69186	-0.69186	-0.69186	-0.69186
log_avgrec	7.09	7.09	7.09	7.09	7.09	7.09	7.09	7.09
log_recinit	5.97	5.97	5.97	5.97	5.97	5.97	5.97	5.97
rho	0.413297	0.413297	0.413297	0.413297	0.413297	0.413297	0.413297	0.413297
kappa	1.22062	1.22062	1.22062	1.22062	1.22062	1.22062	1.22062	1.22062
sig	0.58189	0.58189	0.58189	0.58189	0.58189	0.58189	0.58189	0.58189
tau	0.69330	0.69330	0.69330	0.69330	0.69330	0.69330	0.69330	0.69330

Table D.5. Initial and estimated leading parameters for Steps 3A, 3B, 4A, and 4B.

	Estimate all parameters; estimated natural mortality is assumed constant over time							
	3A		*3B*		*4A*		*4B*	
Leading Parameters	*Initial*	*Estimated*	*Initial*	*Estimated*	*Initial*	*Estimated*	*Initial*	*Estimated*
log_ro	7.28	8.27	7.28	7.61	7.28	8.27	7.28	7.59
steepness,h	0.8	0.7	0.8	0.7	0.8	0.7	0.8	0.7
log.m	-0.69186	-0.29550	-0.69186	-0.46059	-0.69186	-0.29431	-0.69186	-0.45374
log_avgrec	7.09	7.89	7.09	7.19	7.09	7.89	7.09	7.21
log_recinit	5.97	7.56	5.97	6.84	5.97	7.56	5.97	6.87
rho	0.413297	0.318488	0.413297	0.319655	0.413297	0.298097	0.413297	0.324913
kappa	1.22062	1.43411	1.22062	1.37875	1.22062	1.47583	1.22062	1.41208

Leading Parameters	**Estimate all parameters; estimated natural mortality is assumed constant over time**							
	3A		*3B*		*4A*		*4B*	
	Initial	*Estimated*	*Initial*	*Estimated*	*Initial*	*Estimated*	*Initial*	*Estimated*
sig	0.58189	0.47125	0.58189	0.48150	0.58189	0.44943	0.58189	0.47968
tau	0.69330	0.68936	0.69330	0.70246	0.69330	0.68964	0.69330	0.69143

Table D.6. Description of rho and kappa scenarios, including initial values for rho (ρ), kappa (κ), sigma (σ), tau (τ) and the total variance.

rho and kappa scenarios	rho	kappa	σ	τ	total variance
1	0.50000	0.50000	1.00	1.00	1.41421
2	0.05882	1.47059	0.20	0.80	0.82462
3	0.33166	2.89287	0.34	0.48	0.58794
4	0.41330	1.22062	0.58	0.69	0.90513
5	0.80000	0.80000	1.00	0.50	1.11803

Table D.7. Description of each q prior scenario, including prior type, mean, and standard deviation. The uninformative prior is modelled as a uniform distribution (mean, SD) and the informative prior is modeled as a normal distribution (mean, SD).

q prior scenario	q1			q2		
	Type	**Mean**	**SD**	**Type**	**Mean**	**SD**
1	Uninformative	1	1	Uninformative	1	1
2	Informative	0.25	0.274	Informative	0.25	0.274
3 (AM1)	Informative	0.566	0.274	Informative	0.566	0.274
4	Informative	0.75	0.274	Informative	0.75	0.274
5	Informative	1	0.274	Informative	1	0.274
6 (AM2)	Uninformative	1	1	Informative	1	0.01

Table D.8. Description of each q prior scenarios, including prior type, mean and standard deviation. This table differs from Table x.7 in that additional different standard deviation levels are explored.

q prior scenario	q1			q2		
	Type	**Mean**	**SD**	**Type**	**Mean**	**SD**
1	Uninformative	1	1	Uninformative	1	1
1a	Uninformative	1	3	Uninformative	1	3
1b	Uninformative	1	2	Uninformative	1	2
1c	Uninformative	1	0.5	Uninformative	1	0.5

q prior scenario	q1			q2		
	Type	Mean	SD	Type	Mean	SD
1d	Uninformative	1	0.1	Uninformative	1	0.1

D.3 FIGURES

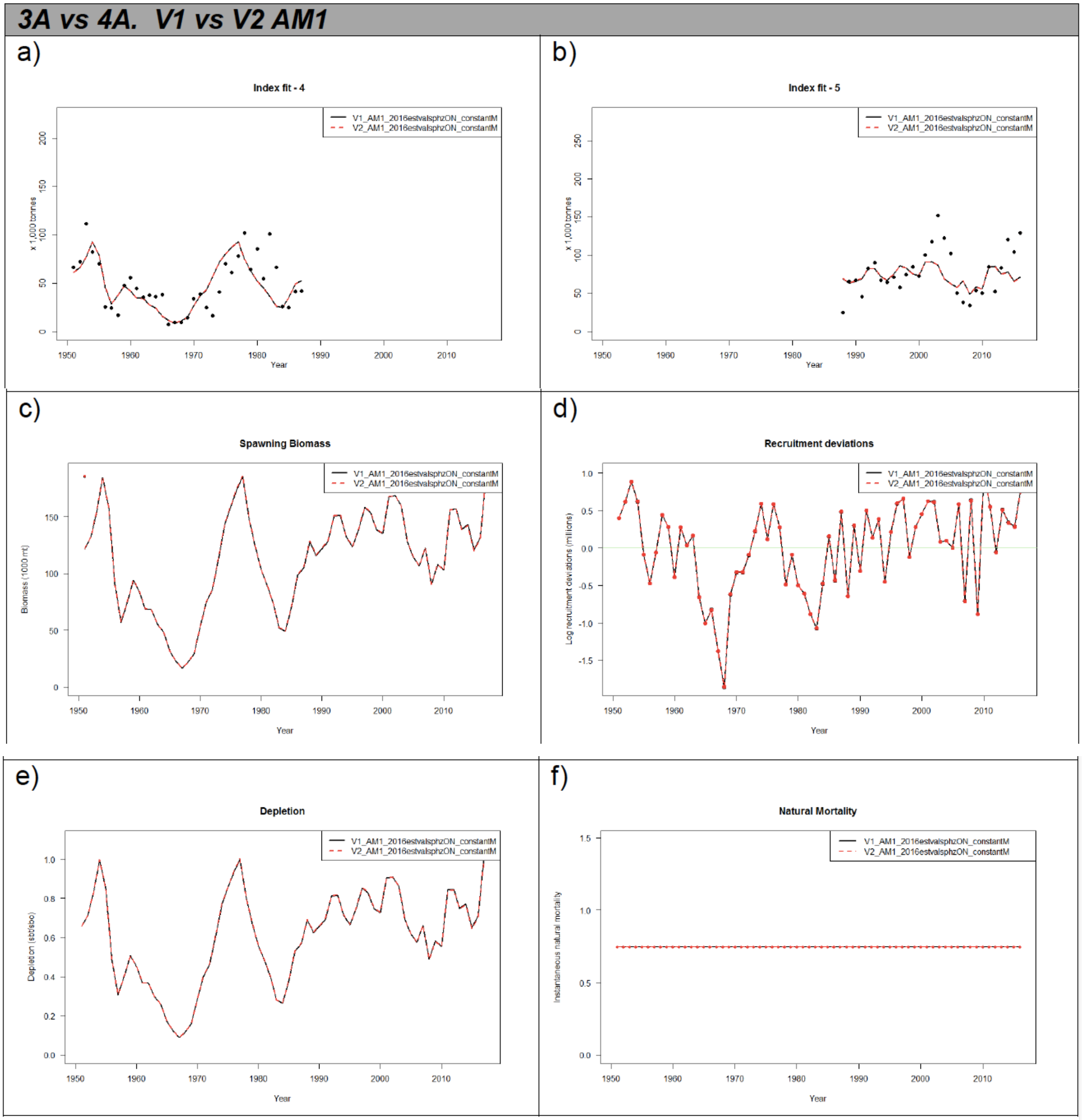


Figure D1. Comparison of V1 and V2 model outputs for Steps 3A and 4A: (a, b) model fits to the survey index, scaled by q, for the surface (a) and dive (b) survey time series;(c) time series of estimates spawning biomass, with unfished spawning biomass (SB_0) shown as a circle at 1951; (d) time series of estimated log recruitment deviations; (e) depletion (SB_t/SB_0); and (f) natural mortality. AM1 results only.

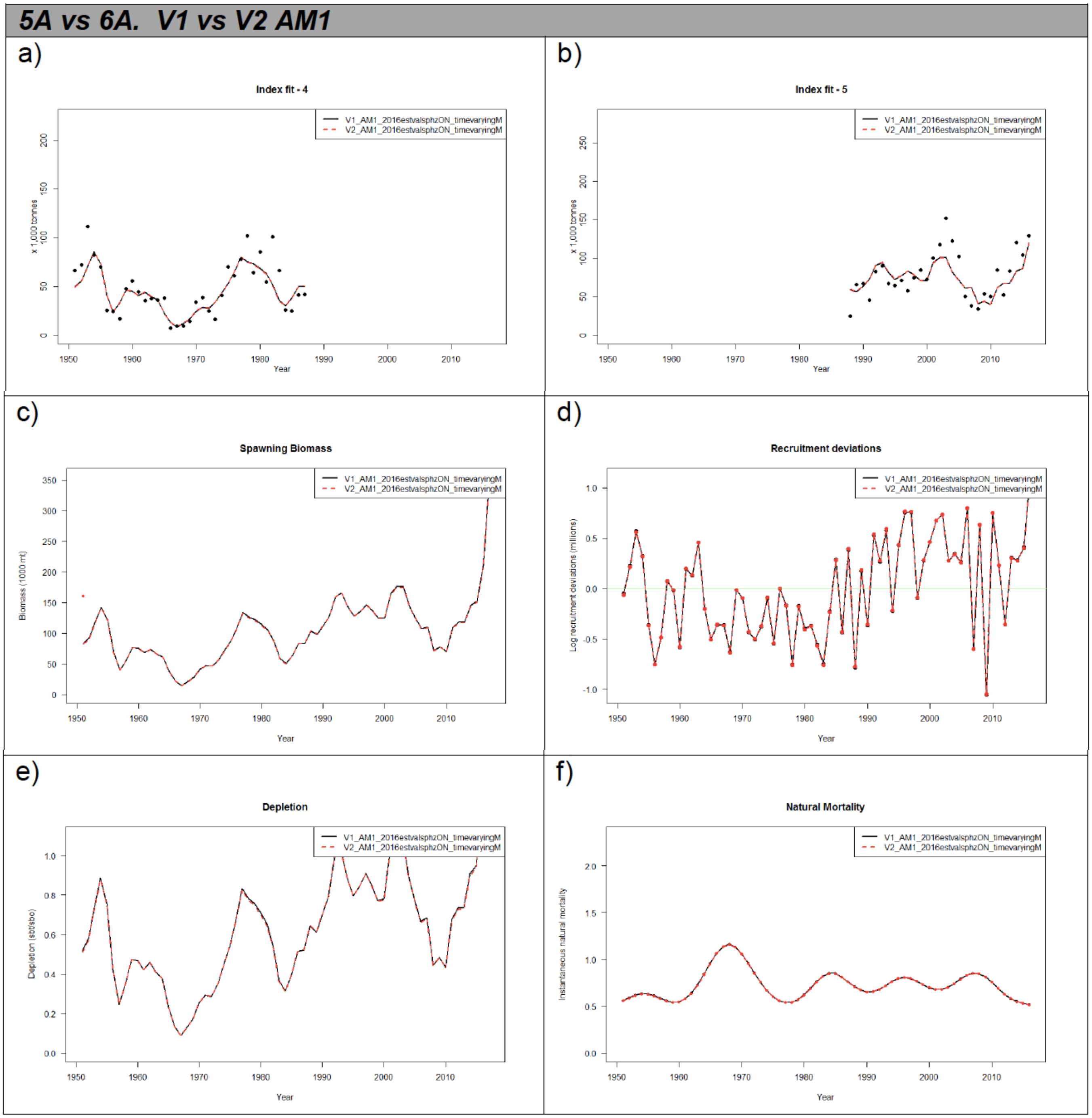


Figure D2. Comparison of V1 and V2 model outputs for Steps 5A and 6A: (a, b) model fits to the survey index, scaled by q, for the surface (a) and dive (b) survey time series;(c) time series of estimates spawning biomass, with unfished spawning biomass (SB_0) shown as a circle at 1951; (d) time series of estimated log recruitment deviations; (e) depletion (SB_t/SB_0); and (f) natural mortality. AM1 results only.

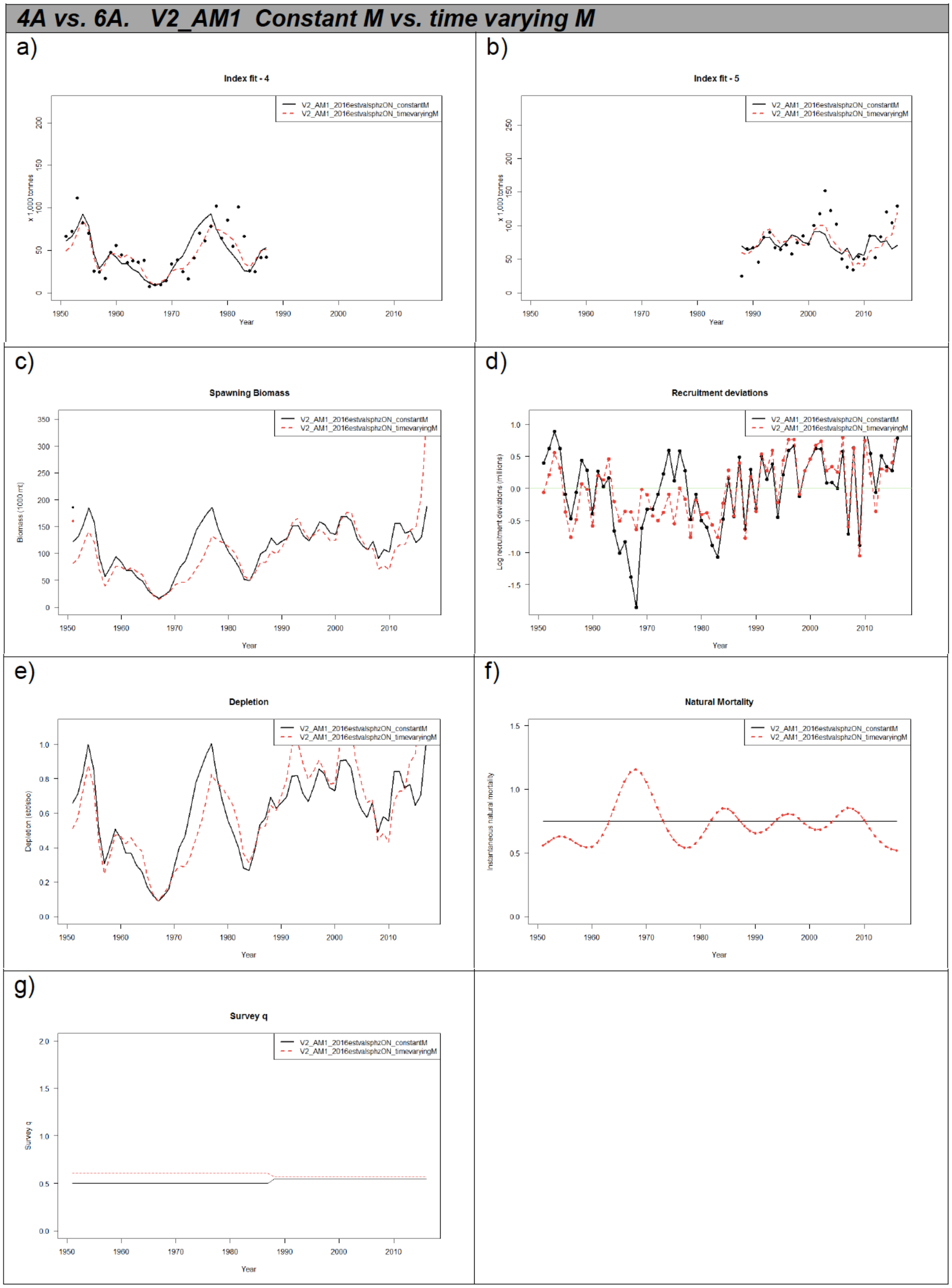


Figure D3. Comparison of V2 model outputs for Steps 4A (constant M) and 6A (time varying M): (a, b) model fits to the survey index, scaled by q, for the surface (a) and dive(b) survey time series; (c) time series of estimates spawning biomass, with unfished spawning biomass (SB_0) shown as a circle at 1951; (d) time series of estimated log recruitment deviations; (e) depletion (SB_t/SB_0); (f) natural mortality, and (g) survey q. AM1 results only.

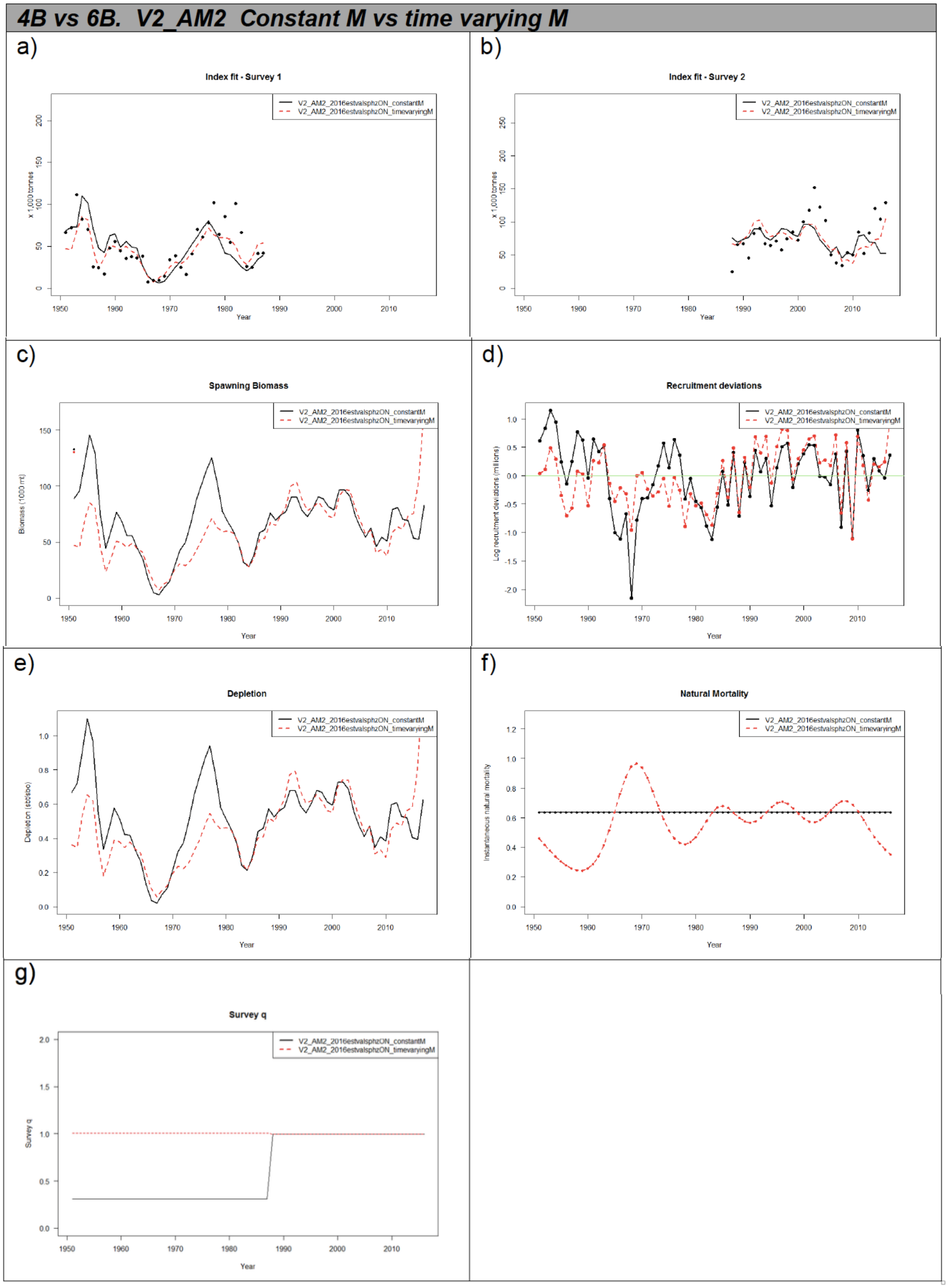
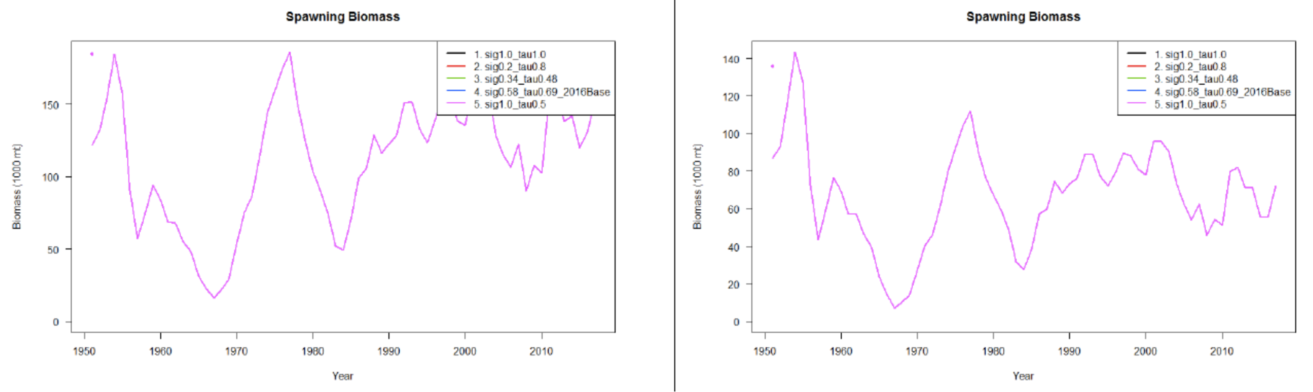


Figure D4. Comparison of V2 model outputs for Steps 4B (constant M) and 6B (time varying M): (a, b) model fits to the survey index, scaled by q, for the surface (a) and dive(b) survey time series; (c) time series of estimates spawning biomass, with unfished spawning biomass (SB_0) shown as circles at 1951; (d) time series of estimated log recruitment deviations; (e) depletion (SB_t/SB_0); (f) natural mortality, and (g) survey q. AM2 results only.

7C and 8C (AM1 and AM2): V2_kappaestimated_rhoestimated with constant M and time varying M.

a) 7C_AM1_constantM

b) 7C_AM2_constantM



c) 8C_AM1_timevaryingM

d) 8C_AM2_timevaryingM

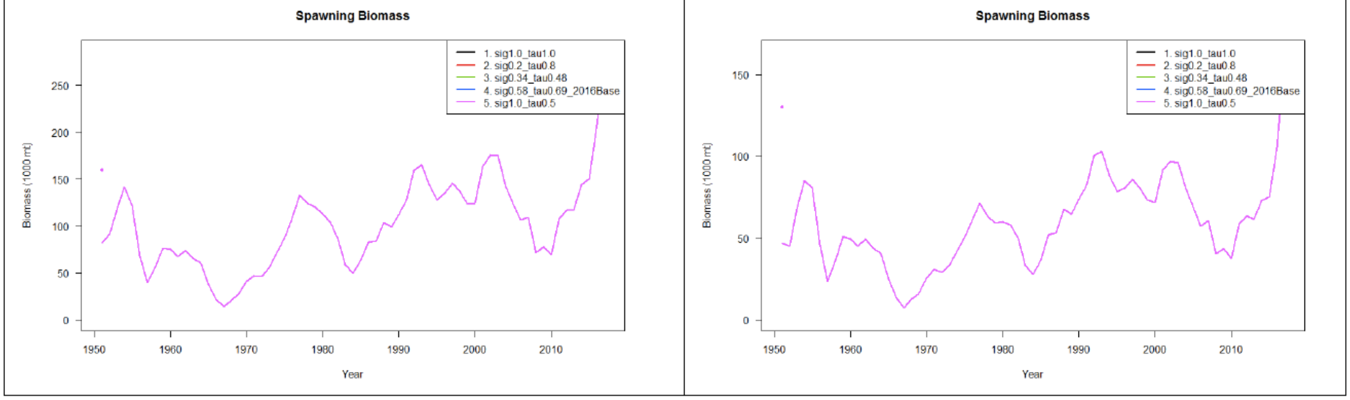


Figure D5. Comparison of V2 estimated spawning biomass (SB_t) when estimating both rho and kappa under constant M, Step 7C: AM1 (a) and AM2 (b), and time varying M, Step 8C: AM1 (c) and AM2 (d). Note y-axis scales differ for (a) – (d).

7A-AM1. V2_AM1_kappafixed_rhoestimated with constant M

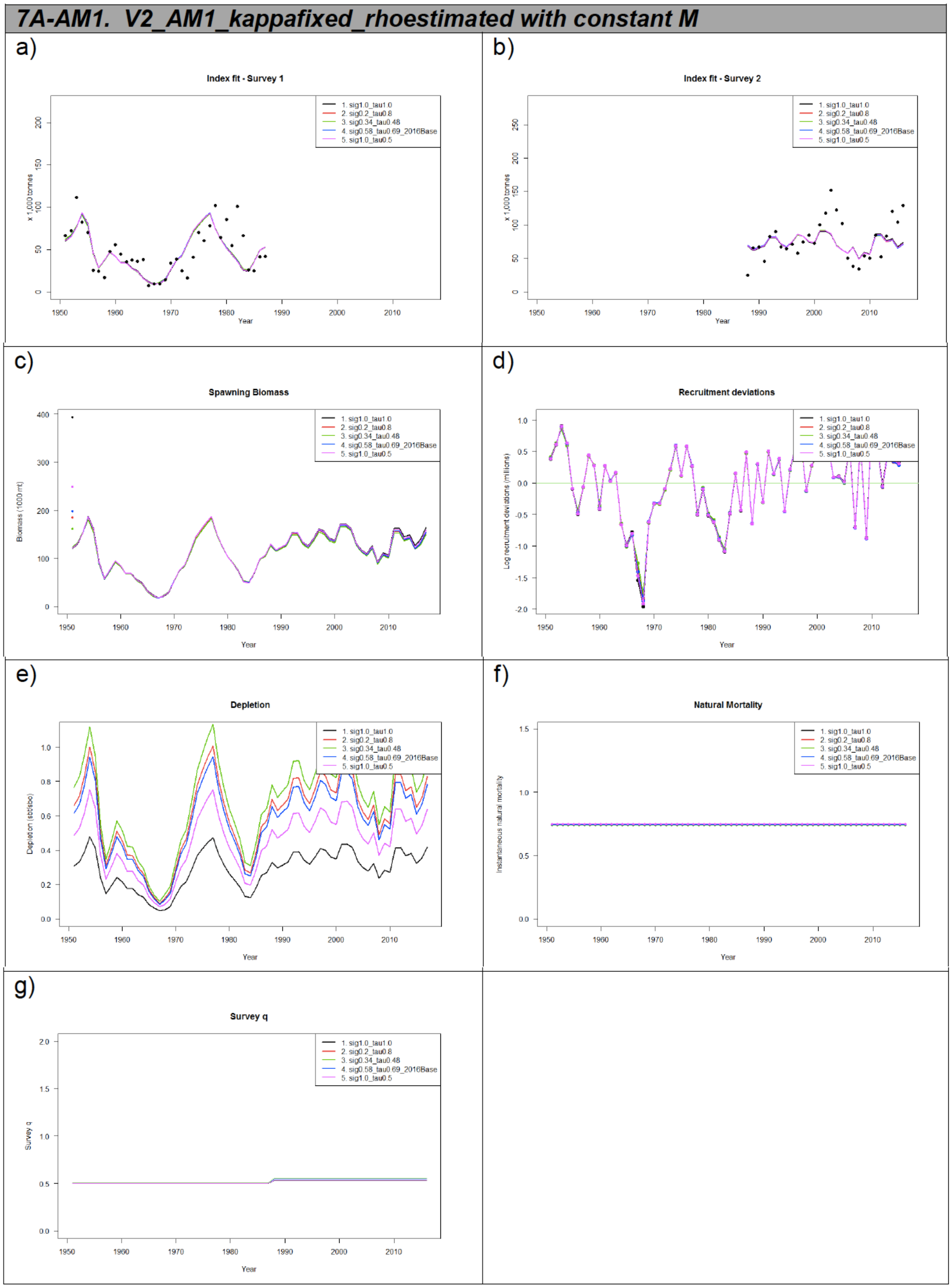
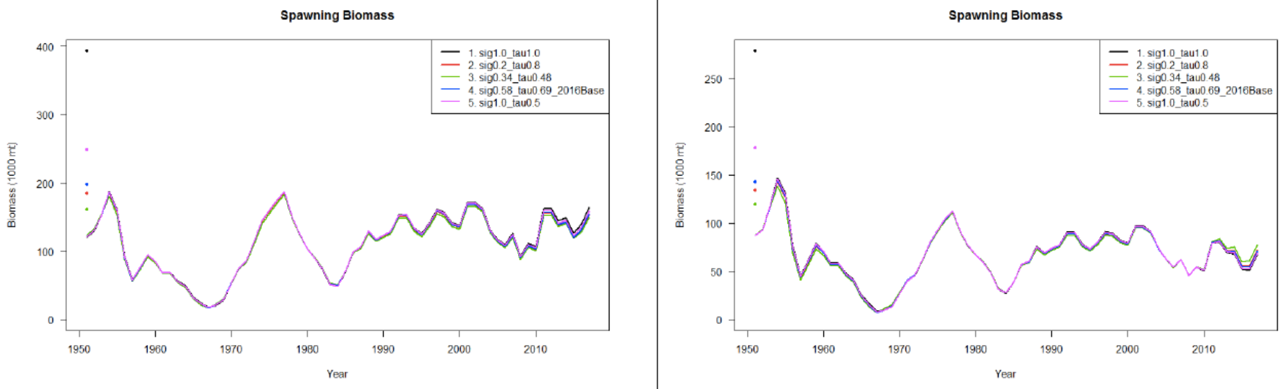


Figure D6. V2 model outputs for Step 7A_AM1 for 5 different fixed kappa values (estimating rho, constant M): (a, b) model fits to the survey index, scaled by q, for the surface (a) and dive (b) survey time series; (c) time series of estimates spawning biomass, with unfished spawning biomass (SB_0) shown as circles at 1951; (d) time series of estimated log recruitment deviations; (e) depletion (SB_t/SB_0); (f) natural mortality, and (g) survey q. AM1 results only.

V2_AM1_AM2_kappafixed_rhoestimated with constant M

a) 7A_AM1_constantM - *SB_t*
kappa-fixed, rho-estimated

b) 7A_AM2_constantM - *SB_t*
kappa-fixed, rho-estimated



c) 7A_AM1_constantM - *SB_t/SB_0*
kappa-fixed, rho-estimated

d) 7A_AM2_constantM - *SB_t/SB_0*
kappa-fixed, rho-estimated

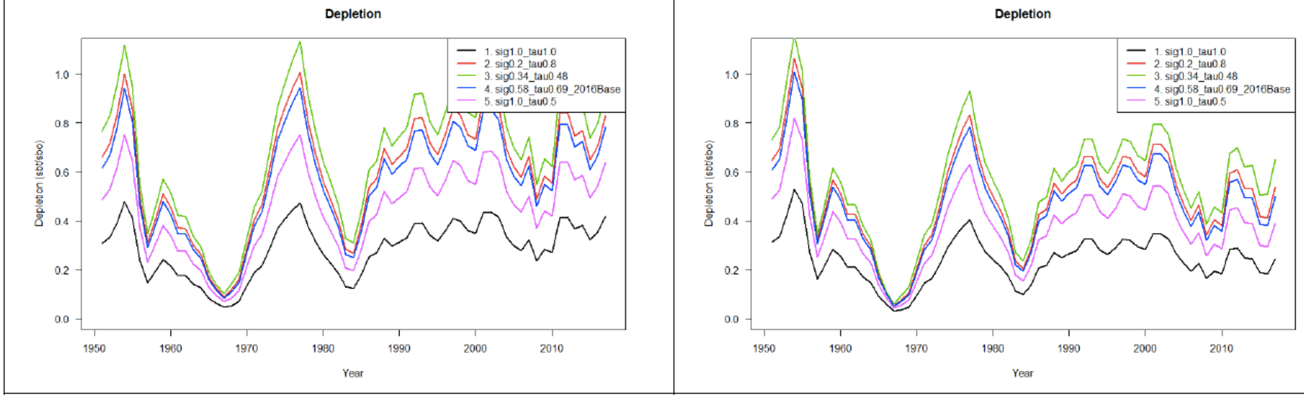
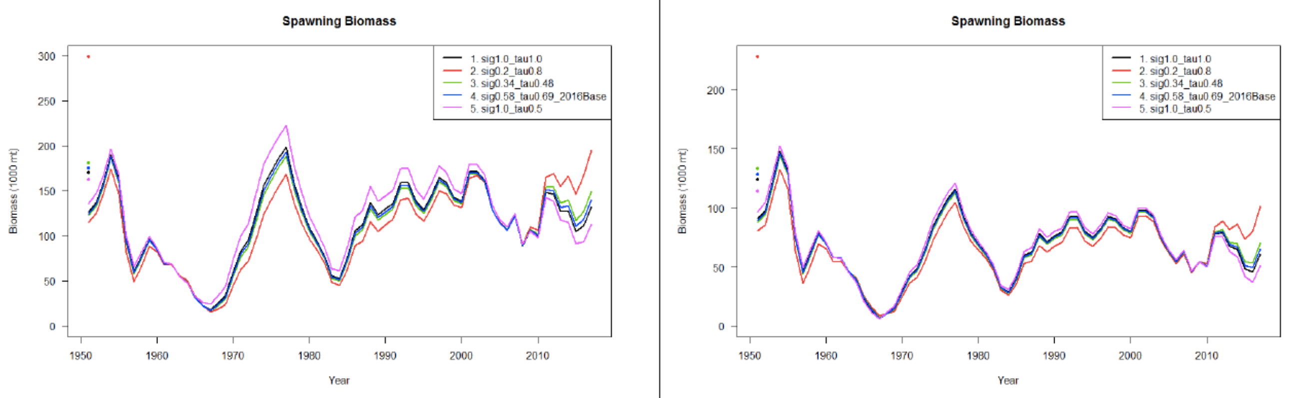


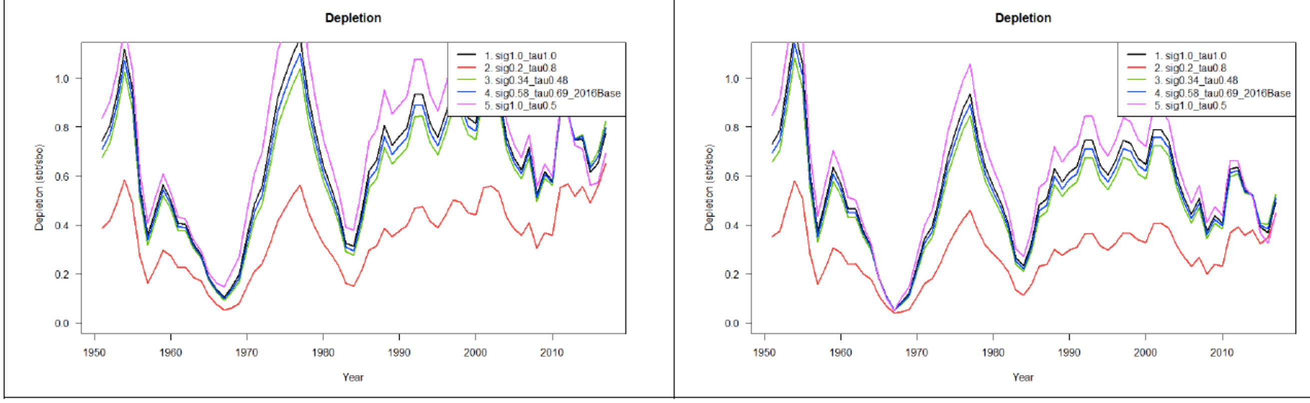
Figure D7. V2 estimates of spawning biomass (SB_t) and depletion (SB_0/SB_t) for Step 7A (fix kappa, estimate rho), AM1 and AM2. Constant M only.

_V2_AM1_AM2_rhofixed_kappaestimated with constant M_



a) 7B_AM1_constantM - *SB*$_t$
rho-fixed, kappa-estimated

b) 7B_AM2_constantM - *SB*$_t$
rho-fixed, kappa-estimated



c) 7B_AM1_constantM - *SB*$_t$/*SB*$_0$
rho-fixed, kappa-estimated

d) 7B_AM2_constantM - *SB*$_t$/*SB*$_0$
rho-fixed, kappa-estimated

Figure D8. V2 estimates of spawning biomass (SB$_t$*) and depletion (SB*$_0$*/SB*$_t$*) for Step 7B (fix rho, estimate kappa), AM1 and AM2. Constant M only.*

8A-AM1. V2_AM1_kappafixed_rhoestimated with time varying M

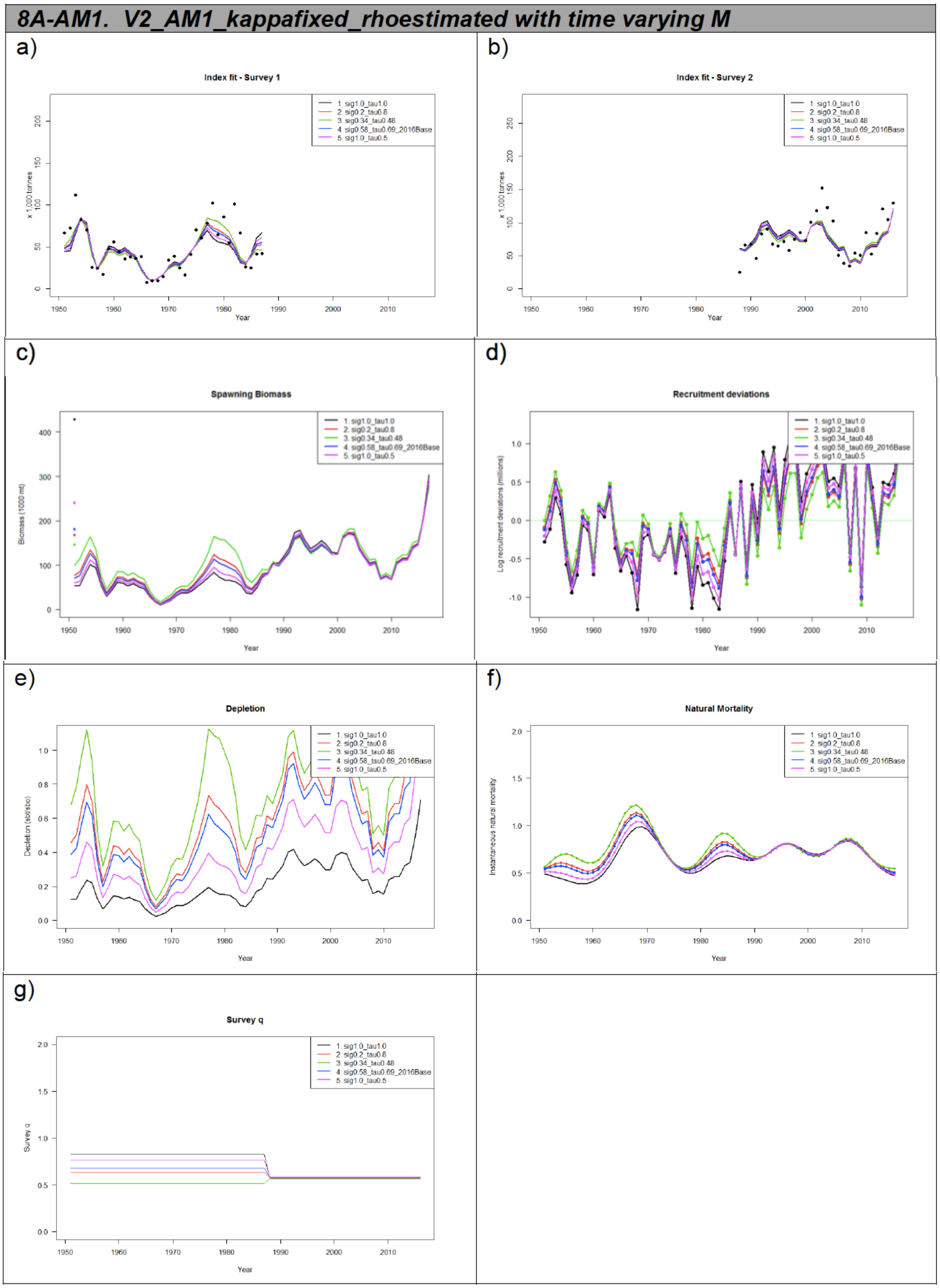


Figure D9. V2 model outputs for Step 8A_AM1 for 5 different fixed kappa values (estimating rho, time varying M): (a, b) model fits to the survey index, scaled by q, for the surface (a) and dive (b) survey time series; (c) time series of estimates spawning biomass, with unfished spawning biomass (SB_0) shown as circles at 1951; (d) time series of estimated log recruitment deviations; (e) depletion (SB_t/SB_0); (f) natural mortality, and (g) survey q. AM1 results only.

8B-AM1. V2_AM1_rhofixed_kappaestimated with time varying M

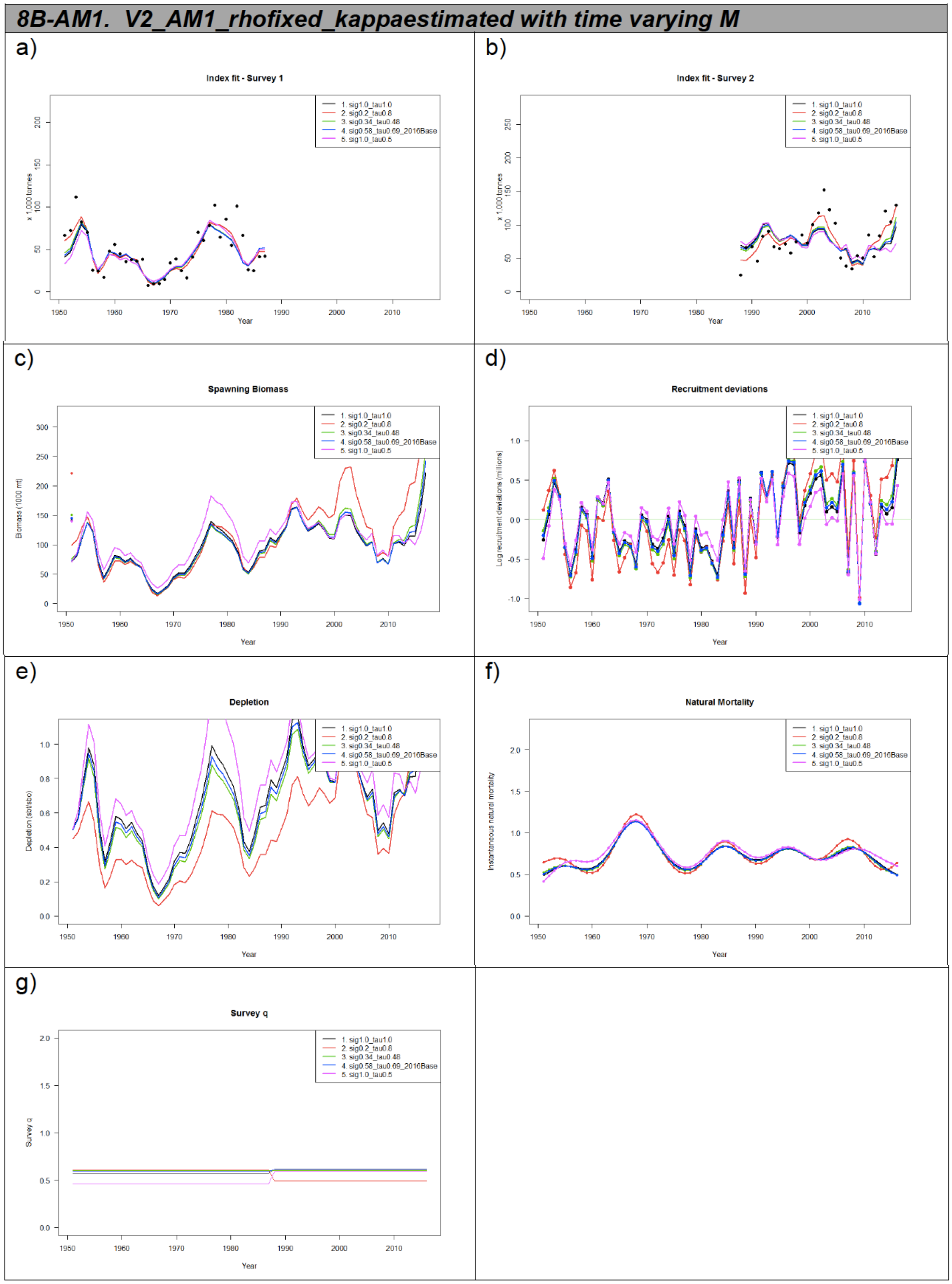


Figure D10. V2 model outputs for Step 8A_AM1 for 5 different fixed rho values (estimating kappa, time varying M): (a, b) model fits to the survey index, scaled by q, for the surface (a) and dive (b) survey time series; (c) time series of estimates spawning biomass, with unfished spawning biomass (SB_0) shown as circles at 1951; (d) time series of estimated log recruitment deviations; (e) depletion (SB_t/SB_0); (f) natural mortality, and (g) survey q. AM1 results only.

9A. Sensitivity to prior on MEAN q, including uninformative and informative priors (constant M)

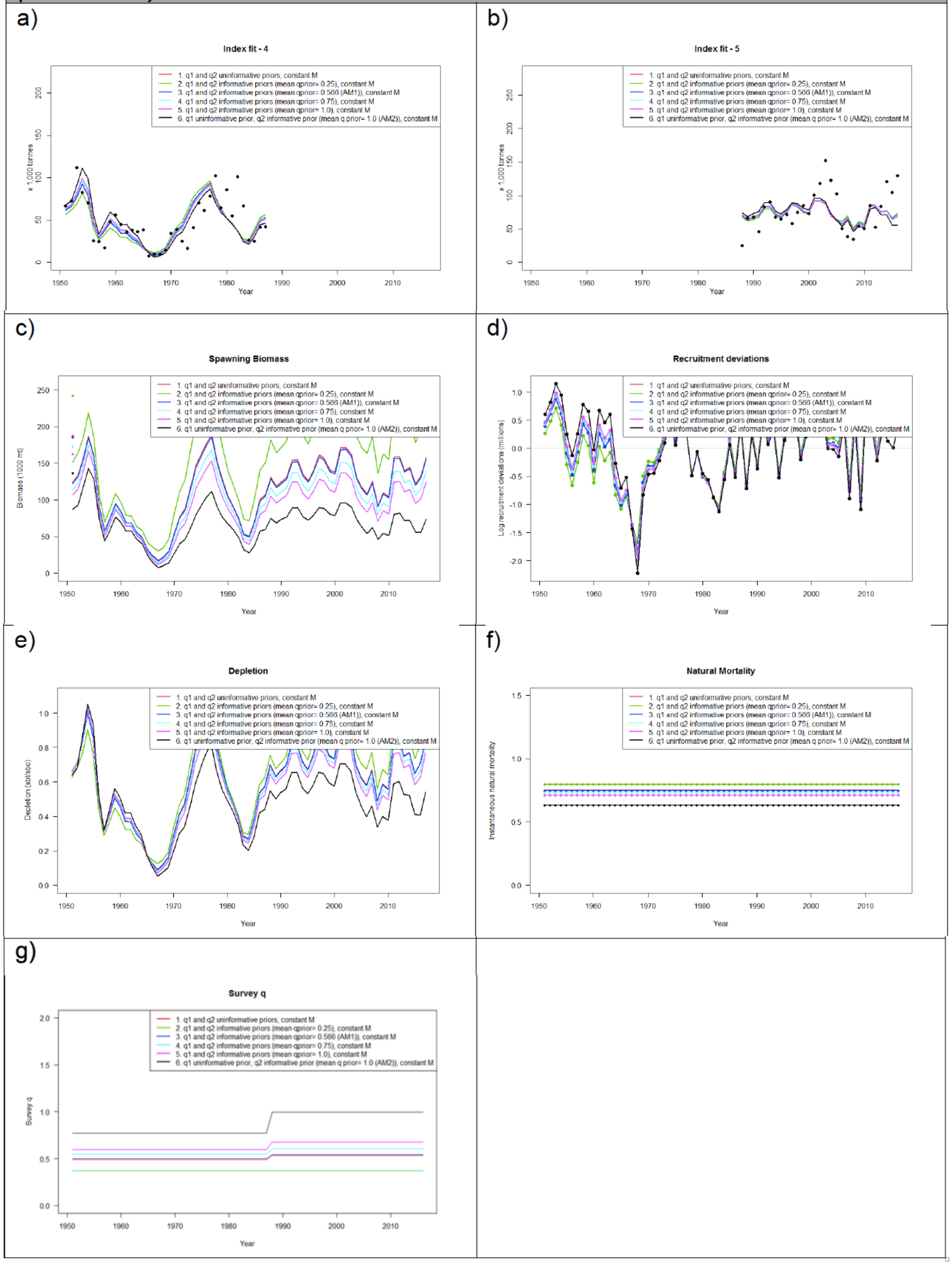


Figure D11. V2 model outputs for Step 9A for 6 different .q prior scenarios as described in Table D.7 with constant natural mortality: (a, b) model fits to the survey index, scaled by q, for the surface (a) and dive (b) survey time series; (c) time series of estimates spawning biomass, with unfished spawning biomass (SB_0) shown as circles at 1951; (d) time series of estimated log recruitment deviations; (e) depletion (SB_t/SB_0); (f) natural mortality, and (g) survey q.

9B. Sensitivity to standard deviation of prior distribution with constant M

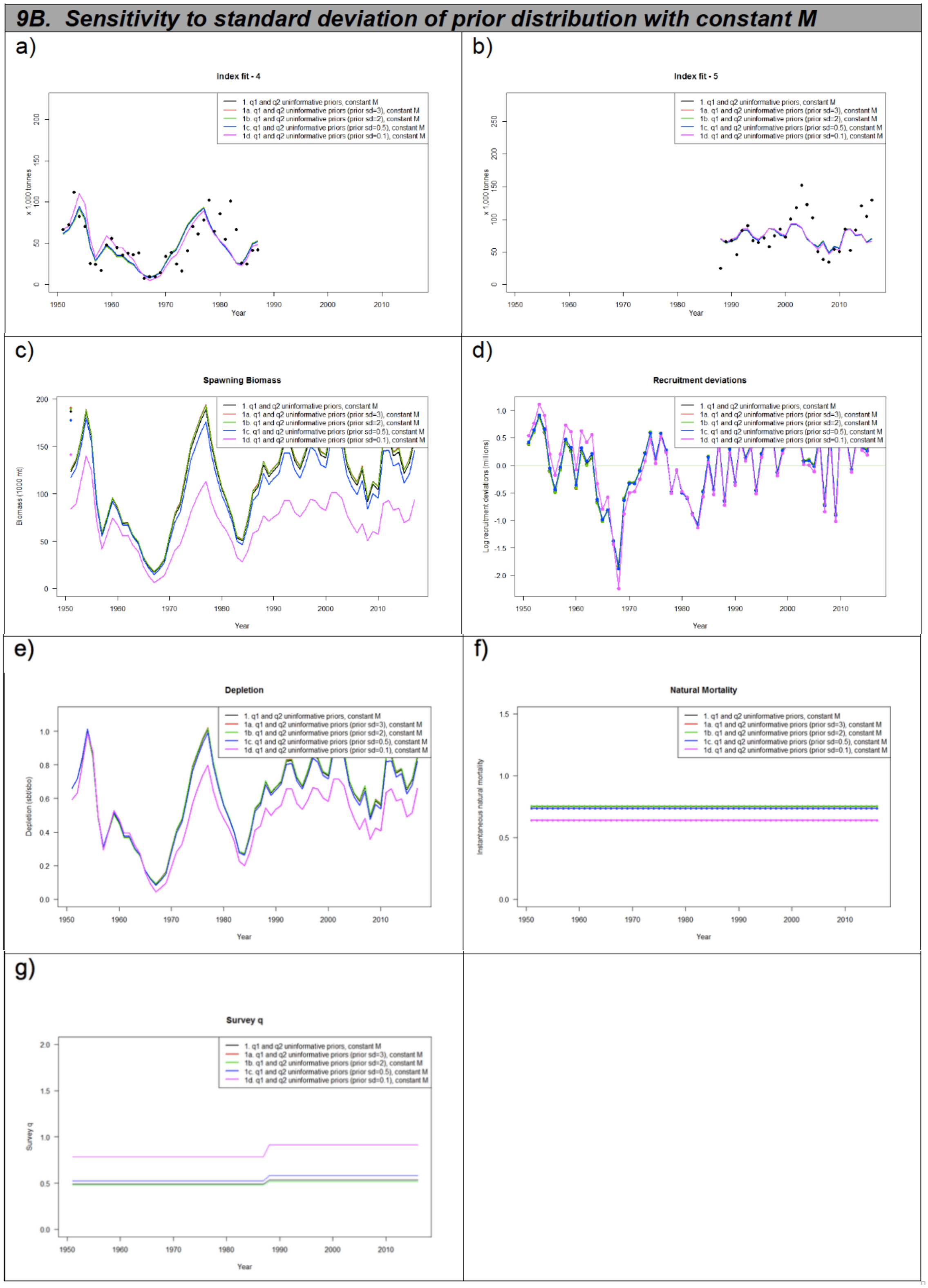


Figure D12. V2 model outputs for Step 9B for q prior scenario 1 with 5 different prior standard deviations as described in Table D.8. with constant natural mortality: (a, b) model fits to the survey index, scaled by q, for the surface (a) and dive (b) survey time series; (c) time series of estimates spawning biomass, with unfished spawning biomass (SB_0) shown as circles at 1951; (d) time series of estimated log recruitment deviations;depletion (SB_t/SB_0); (f) natural mortality, and (g) survey q.

10A. Sensitivity to prior on MEAN q, including uninformative and informative priors (with time varying M)

Figure D13. V2 model outputs for Step 10A for 6 different .q prior scenarios as described in Table D.7 with time varying natural mortality: (a, b) model fits to the survey index, scaled by q, for the surface (a) and dive (b) survey time series; (c) time series of estimates spawning biomass, with unfished spawning biomass (SB_0) shown as circles at 1951; (d) time series of estimated log recruitment deviations; (e) depletion (SB_t/SB_0);natural mortality, and (g) survey q.

Figure D14. V2 model outputs for Step 10B for q prior scenario 1 with 5 different prior standard deviations as described in Table D.8. with time varying natural mortality: (a, b) model fits to the survey index, scaled by q, for the surface (a) and dive (b) survey time series; (c) time series of estimates spawning biomass, with unfished spawning biomass (SB_0) shown as circles at 1951; (d) time series of estimated log recruitment deviations;(e) depletion (SB_t/SB_0); (f) natural mortality, and (g) survey q.

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