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Pacific Ocean Perch (*Sebastes alutus*) Stock Assessment for British Columbia in 2023

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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

Pacific Ocean Perch (*Sebastes alutus*, POP) ranges from Honshu in Japan to Baja California in Mexico. In British Columbia (BC), POP occurrence is almost continuous, with apparent breaks in upper Hecate Strait (probably too shallow) and off the SW coast of Haida Gwaii (steep terrain unsuitable for trawling). Hotspots (high catch per unit effort [CPUE] density) occur in Moresby Gully, around Anthony Island, off Rennell Sound, off the NW coast of Haida Gwaii, and in Dixon Entrance near Langara Island.

This stock assessment evaluated a BC coastwide population with three subareas, each with separate fisheries in 5ABC (Queen Charlotte Sound), 3CD (west coast Vancouver Island), and 5DE (west coast Haida Gwaii). The fisheries were dominated by trawl gear (>99%) with minor removals by other gear types (e.g., longline). Midwater trawl catches of POP were most prevalent in 3CD, but only after 2007. Midwater trawl activity in 5ABC was moderate to low, and in 5DE was minimal. For this stock assessment, bottom and midwater trawl records were combined.

The assessment used an annual catch-at-age model tuned to six fishery-independent trawl survey series, annual estimates of commercial catch since 1935, and age composition data from survey series (29 years of data from five surveys) and the commercial fishery (43 years of data from three fisheries). The model started from an assumed equilibrium state in 1935; the survey index data covered the period 1967 to 2022 (although not all years were represented).

A two-sex model, which estimated M for each sex and the stock-recruitment steepness parameter h, was implemented in a Bayesian framework using the Markov Chain Monte Carlo (MCMC) ‘No U-Turn Sampling’ (NUTS) procedure. In addition to natural mortality and steepness, the parameters estimated by this model included average recruitment over the period 1935–2014, recruitment distribution parameters to allocate coastwide recruitment, and selectivity for the 5ABC commercial fleet (shared with 3CD and 5DE) and for the five surveys using age frequency (AF) data. The survey scaling coefficients (q) were determined analytically. Single-area models assuming three independent stocks were also run to compare with the subarea results from the multi-area base run model. Ten primary sensitivity analyses, evaluated with ‘Markov Chain Monte Carlo’, were conducted relative to the base run to test the effect of alternative model assumptions. A further three sensitivity runs were made only to the level of the ‘mode of the posterior distribution’ (MPD) because the results differed little from the base run.

The base run estimated the POP spawning population biomass at the start of 2024 (median with 0.05 and 0.95 quantiles) to be 0.58 (0.42, 0.81) relative to B_0 and 2.3 (1.4, 3.9) relative to B_{MSY}. This latter result suggested that the 2024 POP spawning population was positioned well in the Healthy zone coastwide and by subarea.

The median MCMC estimates by the 10 primary sensitivity runs for B_{2024}/B_0 ranged from 0.54 to 0.64 and for $B_{2023}/B_{\mathrm{MSY}}$ ranged from 2.08 to 2.53, indicating that all 10 sensitivity runs lay well in the Healthy zone. These analyses included: parameterising the weighting of AFs, higher and lower pre-1996 catch histories, higher and lower recruitment standard deviation (σ_{R}) assumptions, omitting ageing error, and using two alternative ageing error vectors.

The greatest uncertainty in this stock assessment was the relative size of the three subareas, an issue that was demonstrated by varying the choice of the recruitment reference area in two of the sensitivity runs compared to the base run. This uncertainty centred on the size of the 3CD subarea, which varied between 14% and 22% of the total B_0 biomass over the two sensitivity runs and the base run. The larger 5ABC subarea varied between 52% and 60% of the total B_0 biomass for the same three models while the 5DE biomass was relatively constant near 20% of

the total B_0 biomass over all three runs. The total B_0 biomass was similar for the two sensitivity runs and the base run. This result implies that, while the overall yield from this population is reasonably well understood, the 3CD subarea should be managed with caution in conjunction with the other two subareas.

The impact of environmental covariates was not modelled in this stock assessment because of inconclusive results obtained in previous stock assessments (POP in 2017, Canary Rockfish in 2022). Instead, a projection run was made after arbitrarily reducing the mean recruitment by 50% to represent a “worst case” scenario in terms of recruitment over the next 10 years.

1. INTRODUCTION

Fisheries and Oceans Canada (DFO) Fisheries Management requested that DFO Science Branch provide advice regarding the assessment of the three Pacific Ocean Perch (POP, *Sebastes alutus*) stocks relative to reference points consistent with the DFO's Fishery Decision-Making Framework Incorporating the Precautionary Approach (PA; DFO 2009), including the implications of various harvest strategies on expected stock status. In 2019, Bill C-68 was enacted to amend the *Fisheries Act* (now ss. 6.1-6.3) with the Fish Stocks Provisions (FSP). The FSP came into force through amendments to the Fishery (General) Regulations on April 4, 2022. The FSP established binding obligations on the Minister of Fisheries and Oceans to (1) maintain major fish stocks at levels necessary to promote sustainability (s. 6.1); and (2) develop and implement rebuilding plans for stocks that have declined to or below their limit reference point (s. 6.2). An initial list of 30 major stocks (for all of Canada) was identified (Batch 1) out of 62 proposed major stocks. The three POP stocks appeared on the second list and will likely be included in Batch 2.

Pacific Ocean Perch is a long-lived, commercially important species of rockfish found along the rim of the North Pacific. Its commercial attractiveness stems from the bright red colour and long shelf life when properly processed. It is also one of the most abundant rockfish species on Canada's west coast and has been the mainstay of the shelf/slope trawl fishery for decades. A distinguishing feature of POP is a prominent forward-thrusting knob on the lower jaw (Love et al. 2002).

The life history of POP follows similar patterns to other *Sebastes* species, with the live release of larvae that spend periods, likely ranging from three to twelve months, as free-swimming pelagic larvae before settling to the bottom as juveniles. POP reproduction appears to follow onshore-offshore migration patterns where females move onshore for insemination and then migrate deeper to the entrances of submarine gullies where they release larvae from February to May (Love et al. 2002). The larvae depend on vertical upwelling to bring them into the upper pelagic zone to facilitate growth and dispersal. The larvae can spend up to a year in the water column before settling into benthic habitat (Kendall and Lenarz 1987). Juvenile benthic habitat is shallow (100–200 m), compared to the depths occupied by adult POP, and comprises either rough rocky bottoms or high relief features such as boulders, anemones, sponges, and corals (Carlson and Straty 1981; Rooper et al. 2007).

The maximum reported age in the literature for POP is 98 years for a specimen from the Aleutian Islands (Munk 2001); however, the DFO database GFBio reports one specimen older than 98 y (age 103 y: female specimen from Moresby Gully at 362 m in 2002). Values used for the natural mortality rate of POP in other published stock assessments were usually close to 0.06 (e.g., Schnute et al. 2001; Hanselman et al. 2007, 2009). The 5ABC 2017 POP stock assessment estimated female M to be 0.060 (0.055, 0.066) and male M to be 0.065 (0.060, 0.071), where values in parentheses represent the 0.05 and 0.95 quantiles from the MCMC posterior (Haigh et al. 2018).

Pacific Ocean Perch supports the second largest rockfish fishery (after Yellowtail Rockfish, *S. flavidus*) in British Columbia (BC), with an annual coastwide TAC (total allowable catch) in 2023 of 5,192 t and an average annual catch of 3,306 t from 2018 to 2022. In areas 5ABC, 3CD, and 5DE, the 2023 annual TACs were 3,242 t, 750 t, and 1,200 t, respectively, and the 5-year average catches were1,618 t, 840 t, and 848 t, respectively. The trawl fishery accounts for 99.98% of the coastwide TAC, with the remainder allocated to the hook and line fishery. Since 2006, the annual TACs have included the catches from the groundfish research programs, primarily from the synoptic surveys.

Before the 2010 assessment (Edwards et al. 2012a), POP was assessed using a set of "slope rockfish areas" (SRFA: 3C, 3D, 5AB, 5CD, 5ES, 5EN), derived from locality codes (fishing grounds) that are recorded in the DFO catch databases. Additionally, three main gullies (slope rockfish subareas: Goose Island, Mitchell's, and Moresby) in Queen Charlotte Sound (QCS) constitute the primary fishing grounds for this species and were analysed as separate stocks. However, early POP population modelling focused on Goose Island Gully (GIG) because it held the most complete set of otolith data, and early surveys focused on this area. A detailed history of the POP fishery before the implementation of the observer trawl program in 1996 can be found in Richards and Olsen (1996). The catch-age model used to assess the stock status for GIG POP (Schnute and Richards 1995) related process error in recruitments with measurement error in the abundance index. This concept was carried forward in subsequent POP stock assessments (e.g., Richards and Schnute 1998), including the 2001 assessment (Schnute et al. 2001).

After 2001, stock assessments for POP adopted a modified version of the Coleraine statistical catch-at-age software (Hilborn et al. 2003) called 'Awatea' to assess three separate stocks – Queen Charlotte Sound (QCS) in Pacific Marine Fisheries Commission (PMFC[1]) areas 5ABC (Edwards et al. 2012a, Haigh et al. 2018), west coast Vancouver Island (WCVI) in PMFC areas 3CD (Edwards et al. 2014a), and west coast Haida Gwaii (WCHG) in PMFC areas 5DE (Edwards et al. 2014b).

This stock assessment adopted the National Oceanic and Atmospheric Administration's (NOAA's) Stock Synthesis 3 (SS3, version 3.30.20) software platform (Methot and Wetzel 2013, Methot et al. 2022; also see Appendix E for more details). Stock Synthesis has been used in many United States (US) stock assessments in the Pacific region, and in BC, it was used to assess Yellowmouth Rockfish (Starr and Haigh 2022c) and Canary Rockfish (Starr and Haigh 2023). The SS3 platform has more flexibility in fitting data and provides some useful diagnostics (e.g., retrospective analysis) that were not available in the previously used model platform, Awatea.

Commercial catch per unit effort (CPUE) indices were not used in the stock assessment as POP remains a highly targeted species by the trawl fishery. The age frequency (AF) weightings were established using the Francis (2011) procedure (Section E.6.2.2).

1.1. ASSESSMENT BOUNDARIES

This assessment included modified PMFC major areas (5ABC, 3CD, 5DE) along the BC coast (Figure 1). The modification expanded PMFC 5C at the expense of 5E and 5B. The area reallocation relied on georeferenced fishing events or recorded fishing localities. Events either located in a 5C expansion polygon[2] or in localities Anthony Island (codes: major 9, minor 34, locality 1), Flamingo Inlet (major 9, minor 34, locality 5), E Cape St. James (codes: major 6, minor 8, locality 6),or Outside Cape St. James (major 6, minor 8, locality 12) were assigned to 5C (major 7). The reallocation increased the stock area 5ABC by the 5E area south of 52°20′ North, which reduced the 5DE area by the same amount; the 3CD area did not change.

PMFC areas are similar but not identical to the management areas used by the Groundfish Management Unit (GMU), which uses combinations of DFO Pacific Fishery Management Areas. This stock assessment did not use GMU management areas for catch reconstruction because catch reporting from these areas was only available since 1996. In 1997, GMU changed its

[1]See Appendix A for historical background on the PMFC.

[2] X=c(-131.5, -132, -131, -130, -130, -131.2), Y=c(52.33333, 52.33333, 51.5, 51.8, 52.16667, 52.16667)

management areas for POP and Yellowmouth Rockfish (YMR) to include the Cape St. James wraparound, which extended 5C to include lower Moresby Gully and Anthony Island to facilitate the execution of the POP/YMR fishery. This assessment mimics the GMU POP/YMR boundaries using the above modifications to PMFC areas, and subsequent stock area delineation. However, these modified boundaries do not greatly affect the POP stock areas (e.g., 5ABC changes to 5ABC + Anthony Island). Although the modified PMFC areas are still slightly different than the GMU POP/YMR areas, managers can prorate any catch policy using historical catch ratios as outlined in Appendix A, Section A.3.

As the three POP stock delineations were previously identified by DFO sustainability managers, there was no need to search for potential stock delineation. Regardless, Appendix D presents biological differences (size, growth, etc.) among the three areas.

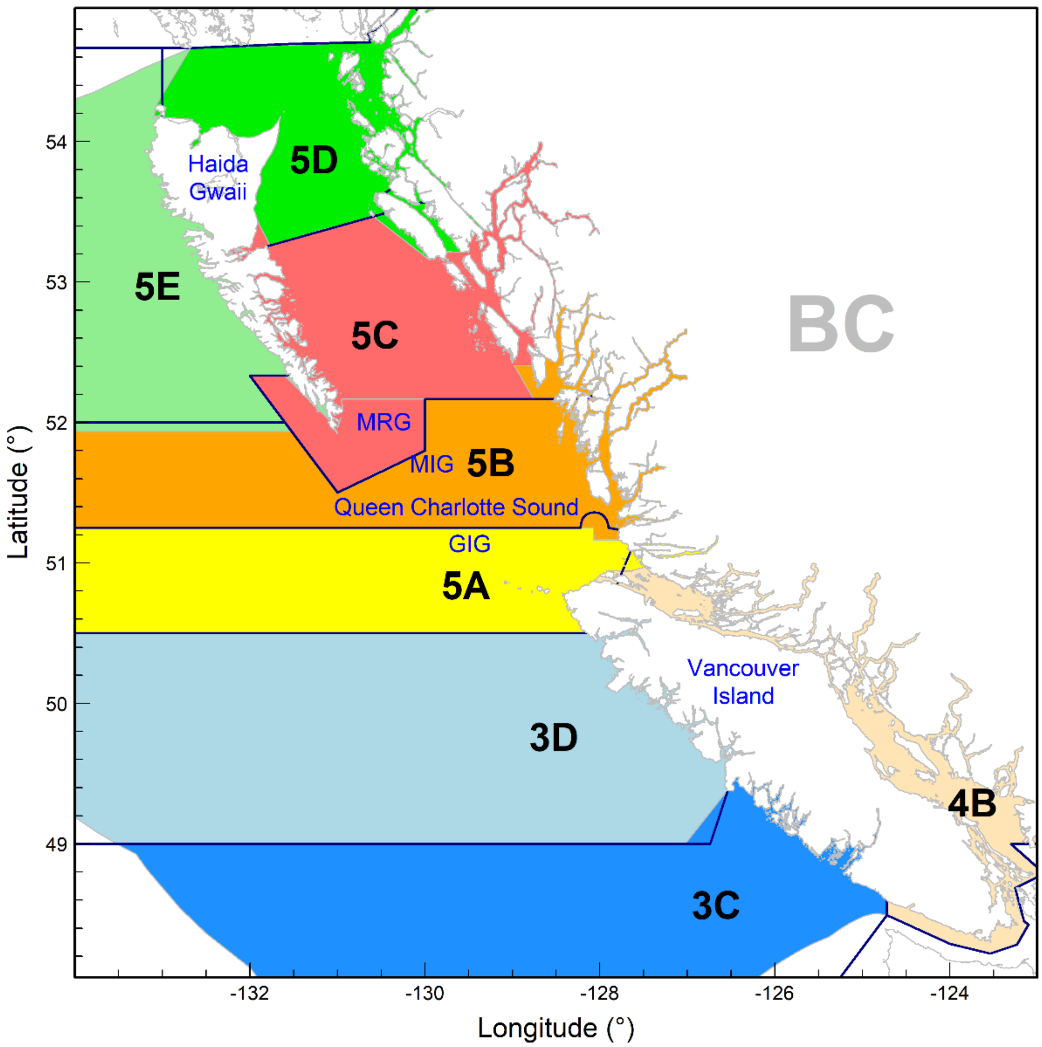

Figure 1. Modified Pacific Marine Fisheries Commission (PMFC) major areas (outlined in dark blue) compared with Groundfish Management Unit areas for POP (shaded). For reference, the map indicates Moresby Gully (MRG), Mitchell's Gully (MIG), and Goose Island Gully (GIG). This assessment estimates coastwide recruitment which is apportioned to three stocks: 5ABC, 3CD, and 5DE.

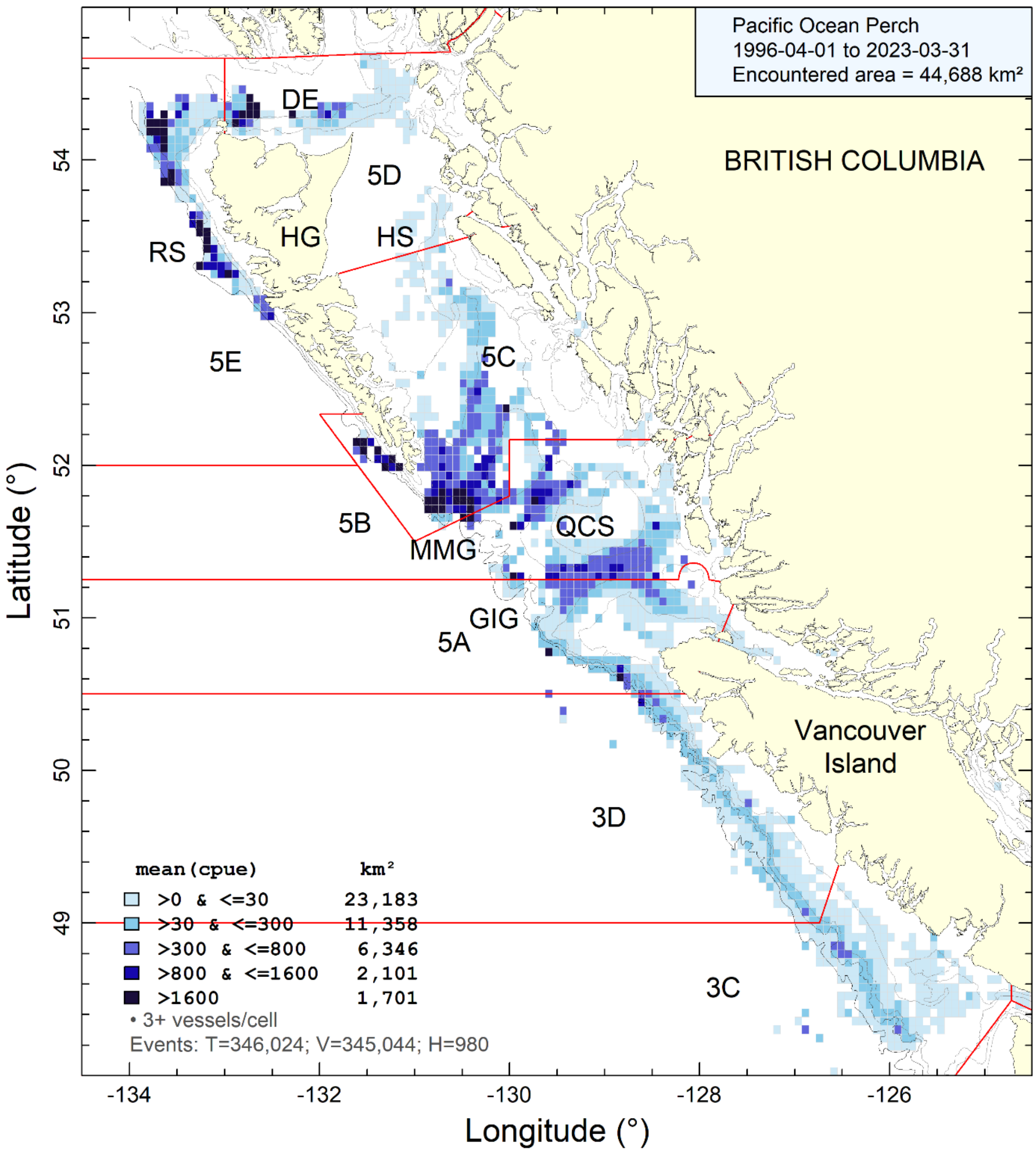

Figure 2. CPUE density of POP from trawl tows (bottom and midwater) occurring from 1996 to 2023 in grid cells 0.075° longitude by 0.055° latitude (roughly 32 km² each). Isobaths show the 100, 200, 500, and 1,000 m depth contours. Cells with <3 fishing vessels are not displayed. DE=Dixon Entrance, GIG=Goose Island Gully, HG=Haida Gwaii, HS=Hecate Strait, MMG=Moresby and Mitchell's Gullies, QCS=Queen Charlottes Sound, RS=Rennell Sound.

1.2. RANGE AND DISTRIBUTION

The range of Pacific Ocean Perch forms an arc along the North Pacific rim from Honshu in Japan to Baja California in Mexico; however, the species is most abundant from the northern Kuril Islands in Russia to northern California in the USA (Love et al. 2002). Along the BC coast, POP occurrence is almost continuous, with apparent breaks in upper Hecate Strait (probably too shallow) and off the SW coast of Haida Gwaii (steep terrain unsuitable for trawling). Hotspots (high CPUE density) occur in Moresby Gully, around Anthony Island, off Rennell Sound, off the NW coast of Haida Gwaii, and in Dixon Entrance near Langara Island (Figure 2). Goose Island Gully, the historical focus of stock assessments, appears to offer moderate densities when averaged over the last 28 years.

Pacific Ocean Perch was encountered by the BC bottom trawl fleet over an estimated 44,688 km^2 (Figure 2 top right, based on a roughly 32-km^2 grid size and tow start positions in the commercial fishery, see Appendix G for alternative estimates of occupancy and occurrence), and the bulk of the BC population was captured by the trawl fleet between depths of 100 m and 528 m coastwide (see Appendix G, Table G.1). The map of trawl catch hotspots (defined as the sum of catch) by fishing locality (Figure G.9) indicates that the top three localities from 1996 to 2023 were 'SE Cape St. James' (QCS), 'SE Goose' (QCS), and 'Frederick Island' (WCHG).

2. CATCH DATA

This stock assessment recognised three commercial trawl fisheries: QCS (5ABC), WCVI (3CD), and WCHG (5DE). Catch from other fisheries (halibut longline, sablefish trap/longline, lingcod and dogfish troll, ZN hook and line) was minor (~0.015% from 1996 to 2022), and so it was added to the commercial trawl fishery catch. Recreational and First Nations POP catches were assumed to be non-existent or negligible. Prior to COVID-19 lockdowns in 2020, the observer-recorded released catch of POP (total released catch from 2015 to 2019 in tonnes) and its proportion to total catch during these years varied by PMFC area:

- 3C : 173 t (10.1%)   3D : 477 t (16.2%)
- 5A : 135 t (7.7%)   5B : 14 t (0.4%)   5C : 228 t (4.0%)
- 5D : 1.4 t (32.3%)   5E : 24 t (0.5%)

The methods used to reconstruct a catch history for this POP assessment, along with the full catch history, are presented in detail in Appendix A. Information about species caught concurrently with POP commercial catches is presented in Appendix G. The mean annual POP catch for the trawl fishery over the most recent five years (2018–2022) was 3,306 metric tonnes (t) coastwide. The equivalent mean catch for the non-trawl fisheries was 0.49 t/y (i.e., negligible). Mean trawl (and all-gear) catch by area over the same period was 1,618 t/y in 5ABC, 840 t/y in 3CD, and 848 t/y in 5DE. Reconstructed trawl and non-trawl catches are presented in Figure 3 for three fisheries (by area). The catch for 2023 was incomplete (at 275 t by May 12, 2023) so the model used the 2022 catches for 2023, which was endorsed by the technical working group. Using the current-year catch, the model provided managers with advice that started at the end of 2023 (i.e., the beginning of 2024).

The 5ABC catch trajectory presented in Figure 3 was very similar to that used in the 2017 POP stock assessment (Figure 4, top panel). However, the catch trajectory used in the 2012 3CD stock assessment was similar to the 2023 reconstruction but the 2012 5DE catch trajectory differed substantially with the 2023 reconstruction for various periods (Figure 4, bottom panel), primarily during foreign fleet activity (1965–1976) and early domestic fleet activity prior to onboard observers (1977–1995). We note that some of the larger differences were due to relatively small catches which get magnified when expressed as simple ratios. These differences are not too surprising given the extensive changes made to the catch reconstruction algorithm since 2012 (see Appendix A, Section A.2.2). Sensitivity runs that decreased and increased POP catch by 30% and 50%, respectively, during this period (1965–1995) are explored in Appendix F and Section 8.3.

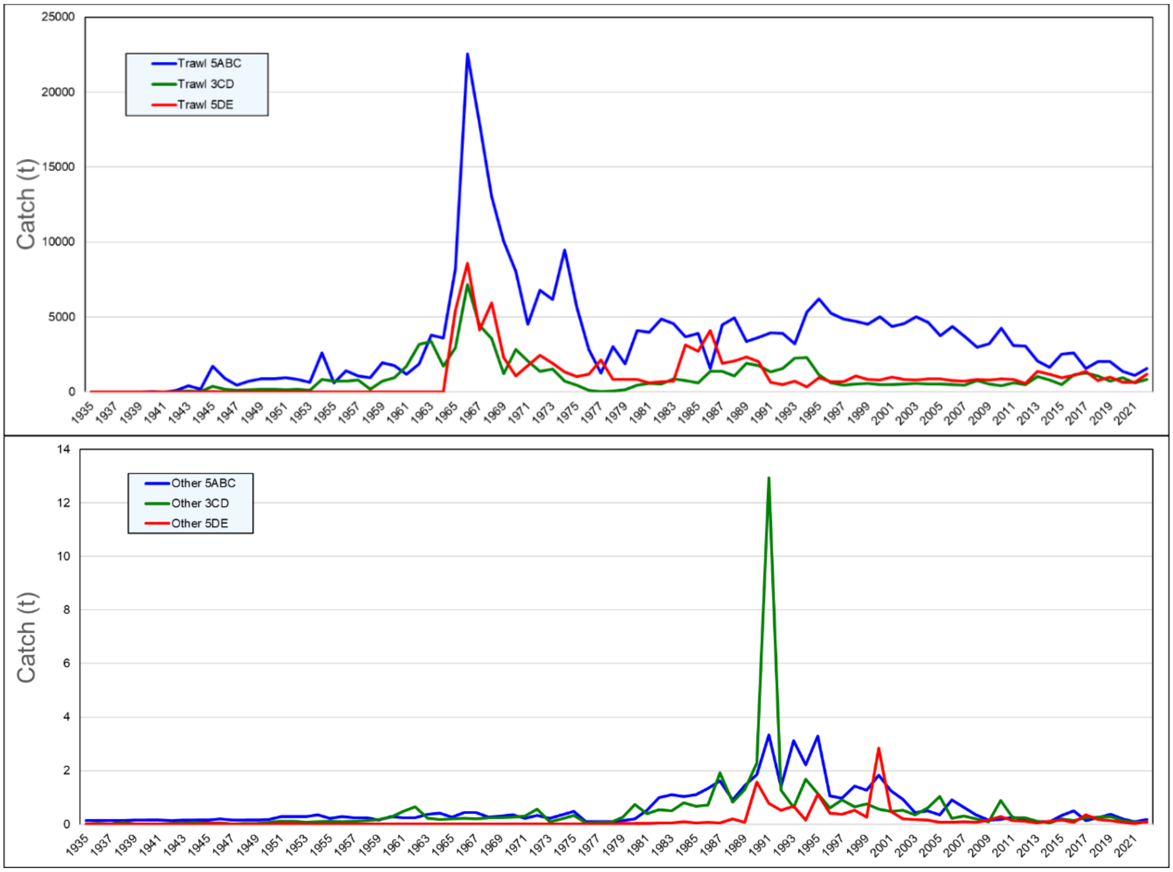

Figure 3. Plots of catch by fishery (area) and gear type (top: trawl, bottom: other) for POP from 1935 to 2022 (gears were combined for use in the population model). Data values provided in Table A.4.

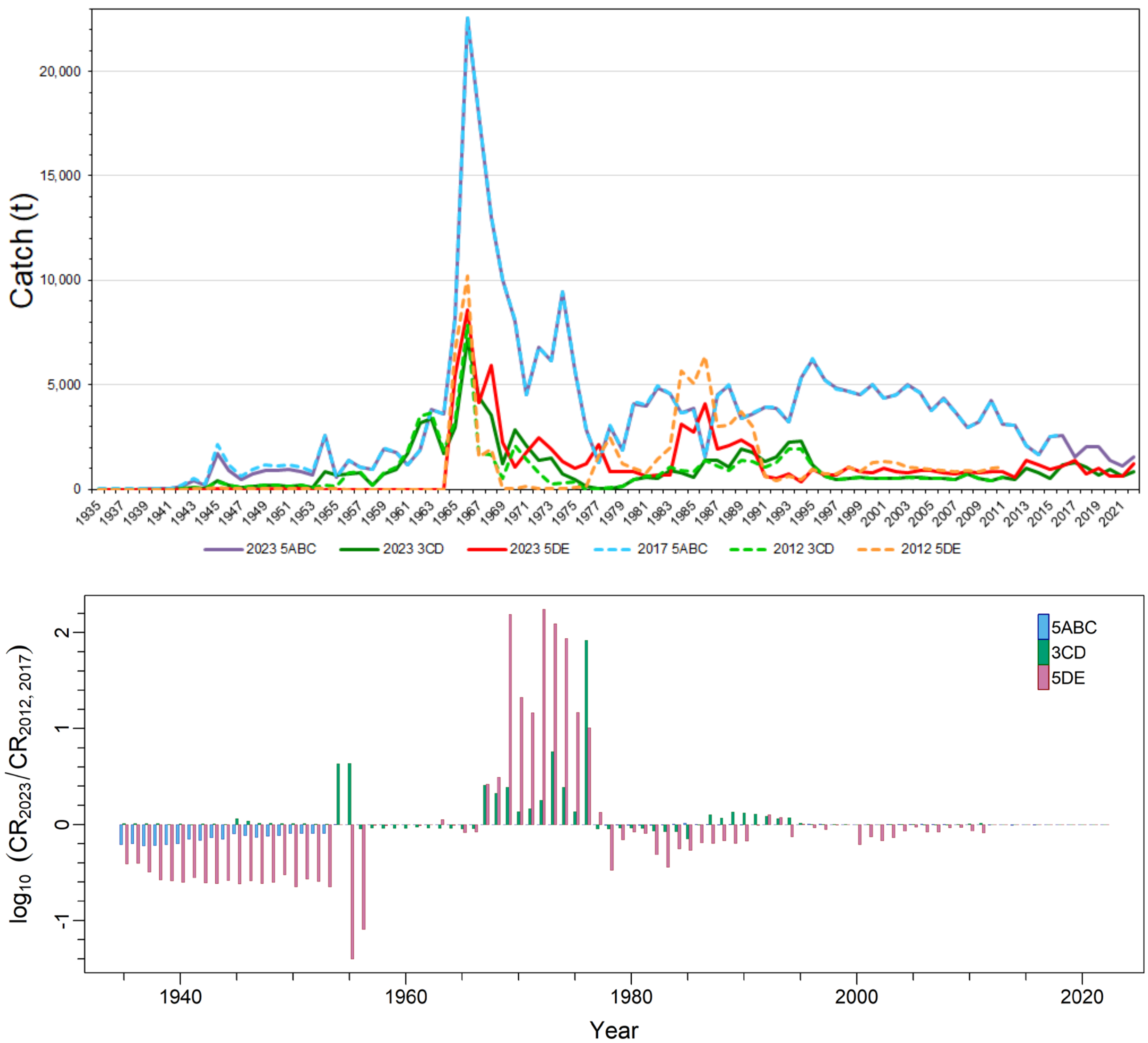

Figure 4. Top: comparison of the trawl catch trajectory used in the 2012 and 2017 assessments with the reconstructed trawl catch trajectory presented in Figure 3; bottom: ratio (in log_{10} space) of annual reconstructed catch in 2023 to earlier reconstructions (in 2012 or 2017).

3. FISHERIES MANAGEMENT

The early history of the British Columbia (BC) trawl fleet is discussed by Forrester and Smith (1972). A trawl fishery for continental slope/shelf rockfish has existed in BC since the 1940s. Aside from Canadian trawlers, foreign fleets targeted Pacific Ocean Perch in BC waters for approximately two decades. These fleets came from the USA (1959–1980), the USSR (1965–1968), and Japan (1966–1976). The foreign vessels removed large amounts of rockfish biomass (POP included), particularly in Queen Charlotte Sound (5ABC). Canadian effort escalated in the mid-1980s but the catch never reached the levels of those by the combined foreign vessels.

Before 1977, no quotas were in effect for slope/shelf rockfish species. Since then, the groundfish management unit (GMU) at DFO imposed a combination of species/area quotas, area/time closures, and trip limits on the major species. Quotas were first introduced for POP (and Yellowmouth Rockfish, YMR, *Sebastes reedi*) in 1979 for GMU area 5AB (Appendix A). On April 18, 1997 (one month into the individual vessel quota [IVQ] program) the boundaries of GMU areas 5AB, 5CD, and 5E were adjusted to extend 5CD southwest around Cape St. James for these two species only (Barry Ackerman, GMU, pers. comm. 2010).

In the 1980s, experimental over-harvesting of POP stocks was attempted in two regions along the BC coast (Leaman and Stanley 1993; Leaman 1998). The objectives of the experiments included (i) ground-truthing trawl survey biomass estimates, (ii) estimating fishing mortality, (iii) validating ageing techniques by introducing a large negative anomaly in the age composition, (iv) exploring stock-recruitment relationships, and (v) involving industry in research and management. See Appendix A for more details.

After the 2010 assessment (Edwards et al 2012a), management implemented a conservation measure: a TAC reduction in 5AB+5CD of 258 t per year over a three year period (for a 774 t total reduction). In 2017, the 5ABC POP assessment showed that the median spawning biomass was close to B_{MSY}, and had been there for the past decade, with fairly consistent reductions below u_{MSY}. The spawning biomass was estimated to be above the limit reference point (LRP = $0.4B_{\text{MSY}}$) with a probability of 0.99 and above the upper stock reference (USR = $0.8B_{\text{MSY}}$) with a probability of 0.74. The probability of being in DFO's three zones, Critical, Cautious, and Healthy, was 0.01, 0.25, and 0.74, respectively.

In 2023, POP had an annual coastwide TAC of 5,192 t, which was split among four management subunits: 3CD = 750 t, 5AB = 1,687 t, 5C = 1,555 t, and 5DE =1,200 t (Appendix A). The ZN Outside fishery was allocated 1 t coastwide.

4. SURVEY DESCRIPTIONS

Six sets of fishery independent survey indices were used to track changes in the biomass of this population coastwide (Appendix B):

1. **QCS Synoptic** – a random-stratified synoptic (species comprehensive snapshot) trawl survey covering all of Queen Charlotte Sound (QCS) and targeting a wide range of finfish species. This survey has been repeated 11 times from 2003 to 2021, using three different commercial vessels (Table B.5) but with a consistent design, including the same net.
2. **WCVI Synoptic** – a random-stratified synoptic trawl survey covering the west coast of Vancouver Island (WCVI). This survey has been repeated 10 times from 2004 to 2022 using the Canadian Coast Guard Ship (CCGS) *W.E. Ricker* up to 2016, and was conducted in 2018 and 2021 using the commercial fishing vessel (FV) *Nordic Pearl* after the retirement of the *W.E. Ricker*. The tenth survey was conducted in 2022 by the newly commissioned CCGS *Sir John Franklin*. The scheduled 2020 WCVI synoptic survey was delayed until 2021 due to concerns caused by the COVID-19 pandemic. This survey employs a consistent design, including the same net, and targets a wide range of finfish species.
3. **WCHG Synoptic** – a random-stratified synoptic trawl survey covering the west coast (WC) of Graham Island in Haida Gwaii (HG) and the western part of Dixon Entrance. This survey has been repeated 10 times from 2006 to 2022 using four commercial vessels (Table B.11) and a consistent design, including the same net and targeting a wide range of finfish species. A random stratified WCHG trawl survey that operated in 1997 was also included in this series because it caught POP in sufficient numbers under a very similar design to the subsequent synoptic survey. In 2020, during the COVID-19 pandemic, this survey was conducted without any DFO personnel on board, but the data from this survey have been included in this stock assessment. The 2014 survey was omitted from the series because less than ½ of the tows were completed.

4. **GIG Historical** – a composite series of eight indices extending from 1967 to 1994 in Goose Island Gully (see Appendix B.3 and Appendix C of Edwards et al. 2012a). Most of these surveys were performed by the CCGS *G.B. Reed*, but two commercial vessels (FV *Eastward Ho* and FV *Ocean Selector*) were used in 1984 and 1994 respectively. Only tows located in Goose Island Gully have been used to ensure comparability across all surveys.
5. **NMFS Triennial** – this survey, operated by the U.S. National Marine Fisheries Service every three years, was operated seven times in Canadian waters over the period 1980 to 2001 (Table B.3), extending variable distances up the west coast of Vancouver Island but never going further north than 49º42′[3]. The survey used a transect design, repeating the transects at 25-nm intervals with a randomised start position in California. Tow locations were selected randomly along the transect. Initially the survey depth ended at 366 m (200 fathoms) but was extended to 500 m in 1995. Ten vessels were used to conduct this survey in Canadian waters, but the information on vessel names was not available. The stratum boundaries changed between the 1983 and 1989 surveys, but the early surveys have been adjusted to ensure a consistent survey index series.
6. **WCVI Historical** – a composite series of four surveys that were considered comparable were conducted by the research vessel *G.B. Reed* off the west coast of Vancouver Island from 1967 to 1970 (see Appendix B.4 and Appendix C.5 of Edwards et al. 2014a).
7. **HS Synoptic** – a random-stratified synoptic trawl survey covering Hecate Strait, beginning where the QCS survey ends (at its northern boundary), and targeting a wide range of finfish species. This survey has been repeated nine times between 2005 to 2021, using a consistent design and including the same net. Four vessels (Table B.14) have conducted this survey, with commercial vessels in 2005, 2017 and 2019. The research vessel *W.E. Ricker* was used five times from 2007 to 2015 until it was retired. The replacement research vessel *Sir John Franklin* conducted this survey in 2021.The Hecate Strait (HS) synoptic survey was not used in the base run because the occurrence of POP in this survey was considered too sporadic to provide a reliable index series. The HS synoptic survey was assigned to 5DE in a sensitivity run because most of the tows which caught POP were from the western sections of Dixon Entrance (see Figures B.51 to B.59).

The Hecate Strait (HS) Multi-species Assemblage bottom trawl survey and the two shrimp trawl surveys (WCVI and QCS) were omitted from this stock assessment, following the reasoning presented in Haigh et al. (2018). Either the presence of POP in these surveys was sporadic or the surveys' coverage, spatial or by depth, was incomplete, rendering these surveys poor candidates to provide reliable abundance series for this species. Rockfish stock assessments, beginning with Yellowtail Rockfish (DFO 2015), have explicitly omitted using the WCVI and QCS shrimp surveys because of the truncated depth coverage, which ends at 160 m for the WCVI shrimp survey and at 231 m for the QCS survey. Both shrimp surveys have constrained spatial coverage with the WCVI survey confined to the latitudinal centre of WCVI and the QCS survey only covering the inshore (head) end of Goose Island Gully.

Two hard-bottom longline (HBLL, outside of PMFC area 4B) surveys were examined for inclusion to the POP stock assessment. These are depth-stratified, random-design, research longline surveys conducted with chartered commercial fishing vessels, which employ standardised longline gear and fishing methods and alternate annually between the northern and southern portions of BC. These surveys are meant to be complementary to the synoptic trawl surveys by covering habitat that is not available to trawl gear (Doherty et al. 2019) and

[3] approximately the latitude of the southern tip of Nootka Island

have been conducted eight times in the North (2006–2021) and seven times in the South (2007–2020). However, these longline survey series rarely caught POP (one or two positive sets out of 194 each year, when any were caught at all).

The relative biomass survey indices were used as data in the models along with the associated relative error for each index value. No process error was added to the survey relative errors because the observation errors provided enough leeway to achieve sensible model fits, and it was felt necessary to maximise the information content from these surveys because they were the primary source of biomass information in the model.

5. COMMERCIAL CPUE

Commercial catch per unit effort (CPUE) data were not used in this stock assessment because (i) POP is a highly targeted species, (ii) the survey relative indices provided sufficient signal on abundance, and (iii) a fishery-based CPUE index series might be contaminated by fisher behaviour responses to economic considerations.

6. BIOLOGICAL INFORMATION

6.1. AGE FREQUENCIES

For the POP stocks, sampled age frequencies (AF) from the trawl fisheries (bottom, midwater, unknown) were combined; shrimp trawl data were discarded. No age data were available from the hook and line fisheries. The commercial trawl AF dataset spanned years 1977 to 2019, but dropped years 1993 and 1996 for 3CD and 1981, 1983, 2010–2012, and 2019 for 5DE because these years were only represented by one sample each or had fewer than 75 aged specimens (Appendix D). The remaining trawl AF dataset included 43 years in 5ABC, 27 years in 3CD, and 33 years in 5DE. Note that samples originally in 5DE were reallocated to 5ABC if they occurred in Flamingo Inlet or Anthony Island localities immediately NW of Cape St. James.

Only otoliths aged using the 'break and burn' (B&B) method were included in age samples for this assessment because an earlier surface ageing method was shown to be biased, especially with increasing age (Stanley 1987). However, surface ageing is currently the preferred method for ageing very young rockfish (≤ 3y) by the ageing lab (DFO 2022a). Commercial fishery age frequency data were summarised for each quarter year, weighted by the POP catch weight for the sampled trip. The total quarterly samples were scaled up to the entire year using the quarterly landed commercial catch weights of POP. See Appendix D (Section D.2.1) for details.

The POP AF data included both sorted and unsorted samples for reasons provided in Starr and Haigh (2021a). Sorted samples generally occur earlier in the time series than do unsorted samples. Consequently, dropping sorted samples loses information about early recruitment strength. This is also a species where there is relatively little discarding, minimising the difference between the two sample types.

Lengths and ages for POP caught by midwater trawls appeared to be larger/older than those from bottom trawls (Appendix D, Section D.3.2); however, sampled AFs from bottom and midwater trawl were combined because there were insufficient data to support area-specific midwater fleets in the assessment model. Consequently, the model was run assuming a joint selectivity for these two trawl methods by combining the AFs and the catch data into a area-specific trawl fisheries. A sensitivity run added midwater fleets for 3CD and 5ABC (see Section 8.3.2).

Age data for POP from the surveys cover years from 1984 to 2022. Age cohort patterns are typically less evident in survey data compared to commercial data. The coastwide POP stock is covered by six surveys, but only five surveys had usable AF: QCS synoptic (11y AF), WCVI synoptic (11y AF), WCHG synoptic (10y AF), GIG historical (3y AF), and NMFS triennial (5y AF). The Hecate Strait synoptic survey, although it was included as a sensitivity run for the coastwide model, had too little AF data to be usable in the model.

6.2. AGEING ERROR

Accounting for ageing error in stock assessments helps to identify episodic recruitment events. Figure D.19 (Appendix D) suggests that POP ages determined by primary readers are reproduced fairly consistently by secondary readers. Larger deviations become more extreme at older ages. The population model for POP used an ageing error (AE) vector based on smoothing the standard deviations calculated from the coefficient of variation (CV) of observed lengths-at-age (Figure D.20). This ageing error vector has been used with good effect in previous rockfish stock assessments (Starr and Haigh 2022c, 2023) because this metric is typically better represented at all ages than that using age-reader CVs. However, the sensitivity to which AE vector is chosen can be very small (Starr and Haigh 2023), at least for standard deviations that increase with age. Alternate ageing error vectors representing smoothed age-reader CVs or constant CVs were used in sensitivity runs for the coastwide model (see Section 8.3.1).

6.3. GROWTH PARAMETERS

Growth and allometric function parameters were estimated from POP length-age and length-weight data, respectively, using biological samples collected from research/survey trips conducted between 1953 and 2022 (Section D.1.1, Appendix D). While length and weight data can be used from earlier years, age data are typically restricted to dates after 1977, when the break and burn protocol was implemented. The parametric fits used standard maximum likelihood estimation (MLE).

Research survey data are preferred over commercial data when estimating allometric and growth parameters because surveys generally capture a wider range of sizes and ages due to the use of smaller size mesh in the cod ends of the trawl net. Commercial data lack information on smaller fish because the cod ends deliberately exclude small, less marketable fish, while a survey attempts to capture a wide range of sizes. Consequently the growth functions derived from commercial data will be poorly determined at the lower end. There are usually sufficient aged otoliths for this species from the research data alone that there is no need to include commercial data. The stock assessment assumes that POP has a time invariant set of biological parameters which exist regardless of the gear used to collect the data.

Allometric function parameters were similar for females and males coastwide: (log α, β) = ♀ (-11.54, 3.10), ♂ (-11.55, 3.11). Estimated parameters by area were similar.

Growth function parameter fits showed that females were larger than males coastwide (L_∞: ♀=43.9 cm, ♂=40.7 cm). Additionally, with respect to L_∞, female estimates were very similar among the three stocks; male estimates exhibited a small but steady decrease from north (5DE) to south (3CD), and coastwide estimates were very similar to those for 5ABC (Section D.3.3).

6.4. MATURITY AND FECUNDITY

Many offshore rockfish species in BC spawn in the winter or early spring months, a period not covered by research surveys (which occur from May to September). Although it is preferable to use research data to estimate biological functions, maturity analysis necessitates the use of combined commercial and research/survey data to properly cover all stages, especially spawning.

Maturity stage was determined macroscopically by either the research technicians on the survey vessels or the commercial fishery observers, partitioning the samples into one of seven maturity stages (Stanley and Kronlund 2000). Fish assigned to stages 1 or 2 were considered immature while those assigned to stages 3–7 were considered mature. Mature (stage 3) POP females start appearing in July and were most abundant during the months of November and December, with fertilised females appearing in January through March followed by embryo-bearing fish in February through April (Figure D.7).

Maturity ogives (cumulative frequency curves) were fit using data representing staged and aged females (using the B&B method), pooled from research and commercial trips, to derive observed proportions mature at each age. A monotonic increasing maturity-at-age vector was constructed by fitting a half-Gaussian function (Equation D.3) to the observed maturity-at-age values (Section D.1.3). Although the fit to empirical data appeared to be poor (Figure D.8), the 2-parameter model was designed to force 100% maturity at an age earlier than that indicated by data observations which approach unity but never reach it. The ages used in the function fit excluded ages greater than 30 to avoid potentially influential proportions caused by spurious values (due to sparse data). The maturity ogive used in the main model assigned proportions mature to zero for ages 1 to 4, then switched to the fitted monotonic function for ages 5 to 30, all forced to 1.0 (fully mature) from age 16 to age 60 (for the coastwide population, Table D.6). This strategy follows previous BC rockfish stock assessments where it was recognised that younger ages are not well sampled, and those that are, tend to be larger and more likely to be mature (e.g., Stanley et al. 2009). Females older than age 9.5 were estimated to be at least 50% mature.

Fecundity was assumed to be proportional to the female body weight (approximately length cubed); however, researchers have demonstrated that this assumption may have consequences for sustainability. Specifically, if larger and older females produce more eggs of higher quality, the removal of these productive females by fishing will have a disproportionate effect on recruitment (He et al. 2015). Dick et al. (2017) concluded that relative fecundity (eggs per gram body weight) increased with size in *Sebastes*, and estimated the length-fecundity relationship median exponent for POP to be 4.97, which is considerably larger than the cubic length-weight exponents typically used for BC rockfish stock assessments. Another issue affecting reproductive output is ‘skip spawning’ where some species do not spawn in every year (Rideout and Tomkiewicz 2011). Conrath (2017) found varying rates of skipped spawning in three deepwater rockfish species. It is not known if POP exhibits skipped spawning.

6.5. NATURAL MORTALITY

Using the natural mortality estimators of Hoenig (1983) and Gertseva (NOAA, pers. comm. 2018, see Starr and Haigh 2021a), Table D.7 calculates the *M* estimate associated with the upper tail of the POP age distribution (Figure D.9). For ages 50 and above (at 10-y increments), estimates of *M* spanned 0.045 to 0.108. The *M* prior used in the base run was N(0.06, 0.018)[4], adopting a CV of 30%. The prior mean was informed by previous POP stock assessments in BC (Edwards et al. 2012a; Haigh et al. 2018) and in the USA (Hanselman et al. 2012; Hulson et al. 2021; Spencer and Ianelli 2022), and was the value approximated by the Gertseva/Hamel estimator at age 90.

[4] In SS3, model priors comprise a distribution (N=normal), a mean, and a standard deviation.

6.6. STEEPNESS

A Beverton-Holt (BH) stock-recruitment function was used to generate average recruitment estimates in each year based on the biomass of female spawners (Equation E.33). Recruitments were allowed to deviate from this average (Equations E.39 and E.40) in order to improve the fit of the model to the data. The BH function was parameterised using a ‘steepness’ parameter, *h,* which specified the proportion of the maximum recruitment that was available at 0.2 B_0, where B_0 is the unfished equilibrium spawning biomass (mature females). This parameter was previously estimated in POP stock assessments in BC but appears to be fixed in many US stock assessments (e.g., h=0.5 for POP off the northwest coast of the contiguous USA, Wetzel et al. 2017). The parameter h was estimated in this stock assessment, constrained by a prior developed for west coast rockfish by Forrest et al. (2010) after removing all information for QCS POP (Edwards et al. 2012a). This prior took the form of a beta distribution with equivalent of mean 0.674 and standard deviation 0.168.

Although some research indicates that steepness might change over time (Miller and Brooks 2021), we have no basis for making such an assumption. We also note that the stock reconstructions that are presented in Section 8 indicate that none of these stocks were reduced to a level where recruitment would have been impaired. Consequently changes in h over time are unlikely to have had an impact in this stock assessment.

7. AGE-STRUCTURED MODEL

A two-sex, age-structured, stochastic model was used to reconstruct the population trajectory of POP from 1935 to the end of 2023 using NOAA’s Stock Synthesis 3 model platform (Methot and Wetzel 2013). Ages were tracked from 1 to 60, where 60 acted as an accumulator age category. The population was assumed to be in equilibrium with average recruitment and with no fishing at the beginning of the reconstruction. Female selectivities for surveys and commercial fisheries (collectively called ‘fleets’ in SS3) were determined by a flexible selectivity function, parameterised in SS3 using six β parameters (described in Appendix E). For this assessment, only three β parameters were estimated: β_1, equivalent to the μ parameter in Awatea (age at which selectivity first reaches maximum selectivity), β_3, equivalent to the log v_L parameter in Awatea (variance that determines the width of the ascending limb of a double normal curve), and Δ_1, equivalent to Δ in Awatea (male offset parameter for μ). The right-hand (descending limb log v_R) parameter β_4 was fixed at a large value (500) to achieve maximum selectivity for all fleets to avoid the creation of a cryptic population. The remaining three β parameters were fixed (β_2=0, $\beta_{5,6}$=-999, see Appendix E, Section E.4.10 for details).

The Dirichlet-Multinomial (D-M) distribution, implemented in SS3 as a model-based method for estimating effective sample size (Thorson et al. 2017), was not used in this assessment for the base run and most sensitivities. It was found that model fits using the D-M distribution were sensitive to the magnitude of sample sizes placed on the AF data (see Appendix E.6.2.3 for details). In contrast, using the Francis (2011) mean-age method of reweighting showed no such sensitivity, and estimated similar model fits for the two contrasting sample size options presented. The use of the McAllister-Ianelli (1997) harmonic-mean method of reweighting was not explored.

The abundance data (six surveys, with no commercial CPUE indices) were not reweighted in this stock assessment as the observation errors provided enough range for credible model fits. In general, adding process error downweights the abundance data.

The modelling procedure determined the best fit (mode of the posterior distribution or maximum posterior density [MPD], which is synonymous with maximum likelihood estimate [MLE], but includes a likelihood component from priors), to the unweighted set of abundance and composition data by minimising the negative log likelihood. Each MPD run was used as the respective starting point for the Markov Chain Monte Carlo (MCMC) simulations. Each run was evaluated using a "No U-Turn Sampling" (NUTS) algorithm (Monnahan and Kristensen 2018; Monnahan et al. 2019). As described in the Yellowmouth Rockfish stock assessment (Starr and Haigh 2022c), the NUTS procedure reduces evaluation time from days to hours because it employs a more efficient search algorithm than that of the random-walk Metropolis. For the base run in this assessment, 20,000 NUTS iterations were evaluated by parsing the workload into eight parallel chains (using the R package `'snowfall'`, Knaus 2015) of 5,000 iterations each, discarding the first 2,500 iterations and saving the last 2,500 samples per chain. The parallel chains were then merged for a total of 20,000 iterations, which were saved in the binary `.psv` file. The `-mecal` phase then looped through the saved iterations and extracted every 10th sample to yield 2,000 posterior samples for use in the analysis.

The key model assumptions/inputs for the base run of the stock assessment model are:

- delineated three stocks by area, corresponding to PMFC boundaries[5] 5ABC, 3CD, and 5DE (Figure 1), with shared coastwide recruitment;
- used sex-specific (female, male) parameters;
- used survey series abundance indices by year (y):
  - three synoptic bottom trawl surveys:
    QCS = Queen Charlotte Sound (11y, spanning 2003 to 2021),
    WCVI = west coast Vancouver Island (10y, spanning 2004 to 2022),
    WCHG = west coast Haida Gwaii (10y, spanning 1997 to 2022);
  - three historical bottom trawl surveys:
    GIG = Goose Island Gully (8y, spanning 1967 to 1994);
    NMFS = U.S. National Marine Fisheries Service Triennial (7y, spanning 1980 to 2001),
    WCVI = west coast Vancouver Island (4y, spanning 1967 to 1970);
- used proportions-at-age data (also called age frequencies or 'AF') by year (y), eight fleets:
  - 5ABC commercial trawl catch (43y, spanning 1977 to 2019),
  - 3CD commercial trawl catch (27y, spanning 1980 to 2019),
  - 5DE commercial trawl catch (33y, spanning 1978 to 2017),
  - QCS synoptic (11y, spanning 2003 to 2021),
  - WCVI synoptic (11y, spanning 1996 to 2022),
  - WCHG synoptic (10y, spanning 1997 to 2022),
  - GIG historical (3y, spanning 1984 to 1995),
  - NMFS triennial (5y, spanning 1989 to 2001);
- set accumulator age A = 60 (pooled age for ages $a \geq 60$);
- used an ageing error vector of smoothed standard deviations derived from CVs of observed lengths-at-age;
- used the Francis (2011) mean-age reweighting method for adjusting sample sizes in the composition (age frequency) data;

[5] PMFC 5C was modified to include a portion of 5E south of 52°20′ (Anthony Island) and Moresby Gully from 5B to accommodate the management of POP (and Yellowmouth Rockfish) only. The net effect on the 5ABC area is the inclusion of Anthony Island at the expense of 5DE.

- used a model-derived analytical solution for the abundance series scaling parameters (q_g), where q values were not estimated as active parameters (Methot et al. 2022); and
- fixed the standard deviation of recruitment residuals (σ_R) to 0.9.

The estimated parameters for the base run of the stock assessment model included:

- unfished, equilibrium recruitment of age-0 fish, LN(R_0);
- natural mortality rate (M) per sex to represent all ages over time;
- steepness parameter (h) for Beverton-Holt recruitment;
- selectivity parameters ($\beta_1 \equiv \mu$, $\beta_3 \equiv \log v_L$, $\Delta_1 \equiv \Delta$) for the 5ABC commercial fishery (3CD and 5DE adopted 5ABC selectivity) and for each of the survey series (WCVI historical adopted GIG historical selectivity);
- main recruitment deviations from 1935 to 2014 (using simple deviations without the sum-to-zero constraint) and late recruitment deviations (2015–2023); and
- Rdist_area(1) and Rdist_area(2): proportion recruitment (in natural log space) allocated to area 1 (5ABC) and 2 (3CD) relative to fixed area 3 (5DE).

Four base models were run (with MCMC sampling) to compare a multi-area model (B1, R21v3a) with three single-area models: 5ABC (A1: R24v1a), 3CD (A2: R25v1a), and 5DE (A3: R26v1a). The three single-area base runs were sampled using the same protocol used for B1. AF data were fit using the Multinomial distribution, and AF sample sizes were reweighted using the Francis (2011) mean-age method.

Ten primary sensitivity analyses were run (with MCMC sampling) relative to the base stock assessment run (B1) to test the sensitivity of the outputs to alternative key model assumptions. The first sensitivity (using the D-M method) was sampled at the same intensity as the base runs, but the remainder of the sensitivities (Multinomial, Francis reweight) were sampled less (10,000 NUTS iterations over 8 chains, 1,250 burn-in samples per chain, 1,250 samples saved per chain, and the merged chains thinned every 5th sample).

- S01 (R17v18a) – use Dirichlet-Multinomial parameterisation (label: “D-M parameterisation”)
- S02 (R27v1a) – fix recruitment distribution parameter for area 5ABC
  (label: “Rdist 5ABC fixed”)
- S03 (R28v1a) – fix recruitment distribution parameter for area 3CD
  (label: “Rdist 3CD fixed”)
- S04 (R29v1a) – remove ageing error (label: “AE1 no age error”)
- S05 (R30v1a) – use ageing error from age-reader CVs (label: “AE5 age reader CV”)
- S06 (R31v1a) – use CASAL ageing error (label: “AE6 CASAL CV=0.1”)
- S07 (R32v1a) – reduce commercial catch (1965-95) by 30% (label: “reduce catch 30%”)
- S08 (R33v1a) – increase commercial catch (1965-95) by 50% (label: “increase catch 50%”)
- S09 (R34v1a) – reduce σ_R to 0.6 (label: “sigmaR=0.6”)
- S10 (R35v1a) – increase σ_R to 1.2 (label: “sigmaR=1.2”)

A further three secondary sensitivity runs were made to the MPD level only:

- S11 (R22v2) add midwater trawl fisheries for 3CD and 5ABC
  (label: “add 3CD 5ABC midwater”)
- S12 (R36v2) add HS synoptic survey to 5DE (label: “add HS synoptic”)
- S13 (R37v1) use empirical proportions mature (label: “empirical proportions mature”)

These latter runs were made because they represented potential issues or questions regarding this stock assessment, based on concerns that have been brought up in past stock assessment reviews. They were not pursued further than these MPD runs because it was felt that the best-fit results were sufficient to settle the issues raised.

The “Terms of Reference” for this POP stock assessment included the task to “7. Explore environmental effects, including climate change, on the stock assessment with the understanding that their incorporation at this point is preliminary.” In the 2022 Canary Rockfish stock assessment (Starr and Haigh 2023), an attempt was made to incorporate an environmental index series (winter Pacific Decadal Oscillation); however, it was found that its influence on the model results was entirely dependent on how much relative weight was assigned to the series (through added process error). This analysis was not repeated for POP. Instead, the recruitment strength in the forecasts was reduced by 50% for the base run as a ‘worst-case’ scenario (see Section 9.2.2).

8. MODEL RESULTS

8.1. MULTI-AREA MODEL

Both natural mortality (M) and steepness (h) were estimated without difficulty, there being only weak correlation between these two parameters (ρ = 0.15). This eliminated the requirement used in some previous stock assessments where multiple runs using fixed M values were needed to build a composite base case that covered a plausible range of values for this parameter. The MPD estimate (in Table F.1) for female natural mortality (M = 0.046) shifted lower than the prior mean value (M = 0.06), as did the male MPD (M = 0.053). However, the median values from the posterior (Table 1) shifted higher than the MPD values: M_1 =0.053 (0.044, 0.061) and M_2 =0.059 (0.051, 0.069), expressed as median and 0.05, 0.95 quantiles in parentheses. Steepness was estimated to be higher at 0.75 (0.47, 0.94) than the prior mean (h=0.67), but lower than the MPD (h=0.82).

The selectivity parameter age-at-full selectivity (β_{1g} or μ_g) for the trawl fisheries, all represented by the 5ABC trawl fishery: 11.3 (10.9, 11.7), was lower than that for the synoptic surveys (Table 1), which was surprising given that the latter employs smaller mesh codends but examination of the age distributions show there were more older POP in the survey AFs than observed in the commercial fishery AFs, accounting for the shift to the right in the survey selectivities. The estimated μ_g values for the historical surveys were estimated quite low: GIG at 8.5 (5.4, 12.9) and NMFS at 5.2 (2.8, 9.8), which was attributable to the lack of older POP in the age distributions.

Model fits to the survey abundance indices were generally satisfactory (Figure F.2), although various indices were missed entirely (e.g., 2004 and 2010 in the WCVI synoptic; 2010 in the WCHG synoptic; 1973, 1977, and 1994 in the GIG historical; 1980 and 1983 in the NMFS triennial; 1968 and 1969 in the WCVI historical).

Fits to the commercial trawl fishery age frequency data were good, with the model tracking year classes consistently across the 43 year time span represented by the commercial 5ABC AF data (Figure F.4). Standardised residuals were generally below 2 for most age classes

(Figure F.5), although there were some positive residuals that exceeded this threshold. The fits to the commercial 3CD AF data were generally poorer than for the 5ABC AF (Figure F.6), with one large residual greater than 6 for females and greater than 12 for males (Figure F.7). This lack of fit to the 3CD AF data resulted in greater uncertainty in the 3CD stock assessment than for the other two POP stocks. The fits to the commercial 5DE AF data were generally quite good (Figure F.8), with most residuals less than 1 and with only a few extending past the threshold of 2 (Figure F.9). While the 3CD and 5DE commercial AF fits show a pattern of small negative residuals for ages less than 8 or 9, this is not the case for the 5ABC AF residuals. This may be the result of using the 5ABC selectivity function to fit the 3CD and 5DE age data, but appears to be corrected once the age classes are fully recruited to the fishery. Negative residuals imply overestimation of the size of the younger age classes which may have implications for long-term predictions.

Fits to the survey AFs from the three synoptic surveys were generally good, with most residuals less than 2 (Figures F.10–F.15). There were no consistent patterns in the residuals among these three surveys, with the QCS survey showing a wave of negative residuals from about age 10 to age 25, while the WCVI and WCHG surveys fit these age classes quite well (compare Figures F.11 with F.13 and F.15). In general, the fits to the survey AF data were not as good as for the commercial AF data, an observation consistent with other recent *Sebastes* stock assessments (e.g., Starr and Haigh 2022a,b,c). The fits to the two sets of historic AF data (GIG survey: Figures F.16 and F.17; NMFS Triennial: F.18 and F.19) were generally poor, reflecting the uncertain provenance of these data which were used primarily to estimate appropriate selectivity functions for these surveys.

Mean ages appeared to be well tracked for the commercial data and generally well tracked for the survey data with the exception of a few years (Figure F.20), suggesting that the reweighting procedure generated appropriate weights. The female maturity ogive, generated from an externally fitted model (see Appendix D), was situated to the left of the commercial selectivity fits for ages from about 7 to 15, indicating that the commercial fishery is harvesting immature POP (Figure F.21). On the other hand, the QCS survey selectivity function sits almost perfectly on top of the maturity function, and the WCVI survey selectivity lies to the right of the female maturity function. These two selectivity functions reflect the prevalence of older POP (mainly between ages 30 and 50) in the age distribution data from these two surveys (see Figures F.10 and F.12), particularly in the earlier years of the surveys.

MCMC diagnostics for the base run were good, with stable traces for all the leading parameters (Figure F.25) and only a small amount of fraying among the eight subarea chains in a few of the leading parameters (e.g., `mu(5)_WCVI`; Figure F.26). The `Rdist_area(1)` and `Rdist_area(2)` parameters were well behaved, indicating that the model was able to reliably separate out the three subarea stocks (Figure F.26). There was no evidence of autocorrelation in any of the leading parameters (Figure F.27).

The base run was used to calculate a set of parameter estimates (Table 1) and derived quantities at equilibrium and those associated with MSY (Table 2), all based on the distributions from MCMC posteriors. Recruitment of age-0 fish was dominated by the enormous recruitment by the 1952 year class, which sustained the early fisheries by the foreign fleets in the late 1960s and the 1970s (Figure 5). All three stocks showed above average recruitment in 2006, 2008 and 2013. A feature of the multi-area stock assessment is that both the 3CD and 5DE stocks “borrow” recruitment information from the 5ABC longer data set. Consequently both of these stocks show good recruitment from the 1952 year class, even though the AFs from these stocks do not extend that far back. Figure 7 indicates that the median spawning stock biomass will remain above the USR in each of the stock subareas for the next 10 years at annual catches equal to all catches used in catch projections. Exploitation (harvest) rates largely stayed below u_{MSY} for much of the history of the fishery (Figure F.32).

A phase plot of the time-evolution of spawning biomass and exploitation rate by the modelled fishery in MSY space (Figure 8) suggests that the stock is firmly in the Healthy zone, with a current position at B_{2024}/B_{MSY} = 2.33 (1.41, 3.88) and u_{2023}/u_{MSY} = 0.31 (0.14, 0.72). The current-year stock status figure (Figure 8) shows the position of the base run in DFO's Healthy zone.

Table 1. Quantiles of the posterior distribution based on 2,000 MCMC samples for the main estimated model parameters for the base run POP stock assessment. Selectivity parameters are expressed in terms compatible with Awatea; SS counterparts: $\mu_g = \beta_{1g}$, $\log v_{Lg} = \beta_{3g}$, $\Delta_g = \Delta_{1g}$ (see Appendix E).

Parameter	5%	25%	50%	75%	95%
log R_0	9.448	9.680	9.845	10.01	10.26
Rdist area 1 (5ABC)	0.8684	1.049	1.173	1.299	1.486
Rdist area 2 (3CD)	-0.09547	-0.04481	-0.008557	0.0276	0.08419
M_1 (female)	0.04365	0.04847	0.05229	0.05575	0.06146
M_2 (male)	0.0505	0.05572	0.05939	0.06306	0.06902
BH (h)	0.4736	0.6379	0.7544	0.8482	0.9431
μ_1 (TRAWL)	10.93	11.17	11.33	11.49	11.72
log v_{L1} (TRAWL)	1.996	2.112	2.193	2.265	2.374
Δ_1 (TRAWL)	-0.3206	-0.1700	-0.05945	0.05119	0.2221
μ_4 (QCS)	13.50	15.69	17.74	20.32	24.91
log v_{L4} (QCS)	3.561	3.987	4.315	4.671	5.172
Δ_4 (QCS)	-1.188	-0.4484	-0.003651	0.4669	1.138
μ_5 (WCVI)	17.00	18.84	20.49	22.35	25.74
log v_{L5} (WCVI)	4.290	4.544	4.741	4.935	5.259
Δ_5 (WCVI)	-0.8162	-0.2012	0.2744	0.7112	1.403
μ_6 (WCHG)	11.08	11.80	12.29	12.89	13.81
log v_{L6} (WCHG)	1.597	1.988	2.235	2.484	2.816
Δ_6 (WCHG)	-0.7172	-0.2951	-0.01605	0.2739	0.6846
μ_7 (GIG)	5.398	7.072	8.473	10.16	12.91
log v_{L7} (GIG)	1.801	2.544	3.034	3.523	4.135
Δ_7 (GIG)	-1.682	-0.9182	-0.3249	0.3004	1.150
μ_8 (NMFS)	2.820	4.180	5.222	6.774	9.789
log v_{L8} (NMFS)	1.748	2.408	2.955	3.535	4.348
Δ_8 (NMFS)	-1.666	-0.8098	-0.2313	0.3689	1.240

Table 2. Derived parameter quantiles from the 2,000 samples[6] of the MCMC posterior of the base run coastwide and by subarea. Definitions: B_0 – unfished equilibrium spawning biomass, B_{2024} – spawning biomass at the start of 2024, u_{2023} – exploitation rate (ratio of total catch to vulnerable biomass) in the middle of 2023, u_{max} – maximum exploitation rate (calculated for each sample as the maximum exploitation rate from 1935–2023), B_{MSY} – equilibrium spawning biomass at MSY (maximum sustainable yield), u_{MSY} – equilibrium exploitation rate at MSY. All biomass values (including MSY) are in tonnes. The average catch over the last 5 years (2018–2022) was 3,306 t coastwide, 1,618 t in 5ABC, 840 t in 3CD, and 848 t in 5DE.

Area	Quantity	5%	25%	50%	75%	95%
Coast	B_0	84,811	96,679	106,054	117,619	140,309
	B_{2024}	44,390	53,822	61,965	71,222	90,825
	B_{2024} / B_0	0.4239	0.5114	0.5816	0.6621	0.8116
	u_{2023}	0.01892	0.02389	0.02749	0.03166	0.03813

[6] 35 MCMC samples yielded anomalous (non-finite) MSY-based and harvest-based quantities. B_0 and B_{2024} were available for all 2,000 samples.

Area	Quantity	5%	25%	50%	75%	95%
	u_{max}	0.1051	0.1162	0.1231	0.1300	0.1380
	MSY	3,090	4,073	4,865	5,795	7,262
	B_{MSY}	16,692	22,127	26,798	32,466	42,658
	$0.4B_{MSY}$	6,677	8,851	10,719	12,986	17,063
	$0.8B_{MSY}$	13,353	17,702	21,438	25,973	34,126
	B_{2024} / B_{MSY}	1.409	1.894	2.326	2.859	3.872
	B_{MSY} / B_0	0.1605	0.2143	0.2544	0.2975	0.3636
	u_{MSY}	0.04189	0.06605	0.09016	0.1167	0.1672
	u_{2023} / u_{MSY}	0.1442	0.2218	0.3074	0.4304	0.7210
5ABC	B_0	47,759	57,364	65,469	74,842	90,531
	B_{2024}	21,853	27,195	32,243	38,669	52,341
	B_{2024} / B_0	0.328	0.420	0.495	0.594	0.770
	u_{2023}	0.015	0.021	0.025	0.029	0.037
	u_{max}	0.089	0.100	0.108	0.115	0.125
	MSY	1,803	2,418	2,993	3,618	4,744
	B_{MSY}	9,681	13,364	16,311	20,390	27,164
	$0.4B_{MSY}$	3,872	5,346	6,524	8,156	10,866
	$0.8B_{MSY}$	7,745	10,691	13,049	16,312	21,731
	B_{2024} / B_{MSY}	1.101	1.574	1.994	2.522	3.537
	B_{MSY} / B_0	0.161	0.214	0.254	0.298	0.364
	u_{MSY}	0.029	0.046	0.064	0.083	0.118
	u_{2023} / u_{MSY}	0.176	0.281	0.394	0.563	0.925
3CD	B_0	13,298	17,039	20,370	23,856	29,456
	B_{2024}	7,700	11,088	14,105	17,904	24,562
	B_{2024} / B_0	0.356	0.540	0.710	0.922	1.316
	u_{2023}	0.018	0.024	0.031	0.039	0.055
	u_{max}	0.168	0.190	0.202	0.214	0.234
	MSY	514	740	918	1,131	1,482
	B_{MSY}	2,829	4,028	5,048	6,290	8,652
	$0.4B_{MSY}$	1,132	1,611	2,019	2,516	3,461
	$0.8B_{MSY}$	2,264	3,222	4,039	5,032	6,922
	B_{2024} / B_{MSY}	1.291	2.078	2.806	3.817	5.843
	B_{MSY} / B_0	0.161	0.214	0.254	0.298	0.364
	u_{MSY}	0.051	0.080	0.112	0.152	0.228
	u_{2023} / u_{MSY}	0.106	0.185	0.274	0.407	0.777
5DE	B_0	13,238	17,157	20,513	23,831	30,002
	B_{2024}	9,819	12,305	14,491	17,157	22,138
	B_{2024} / B_0	0.426	0.583	0.715	0.899	1.263
	u_{2023}	0.028	0.036	0.042	0.049	0.061
	u_{max}	0.238	0.267	0.289	0.311	0.350
	MSY	518	749	921	1,138	1,483
	B_{MSY}	2,860	4,056	5,123	6,334	8,676
	$0.4B_{MSY}$	1,144	1,623	2,049	2,534	3,470
	$0.8B_{MSY}$	2,288	3,245	4,098	5,067	6,941
	B_{2024} / B_{MSY}	1.482	2.198	2.876	3.819	5.661
	B_{MSY} / B_0	0.161	0.214	0.254	0.298	0.364
	u_{MSY}	0.072	0.113	0.156	0.214	0.325
	u_{2023} / u_{MSY}	0.110	0.187	0.268	0.389	0.666

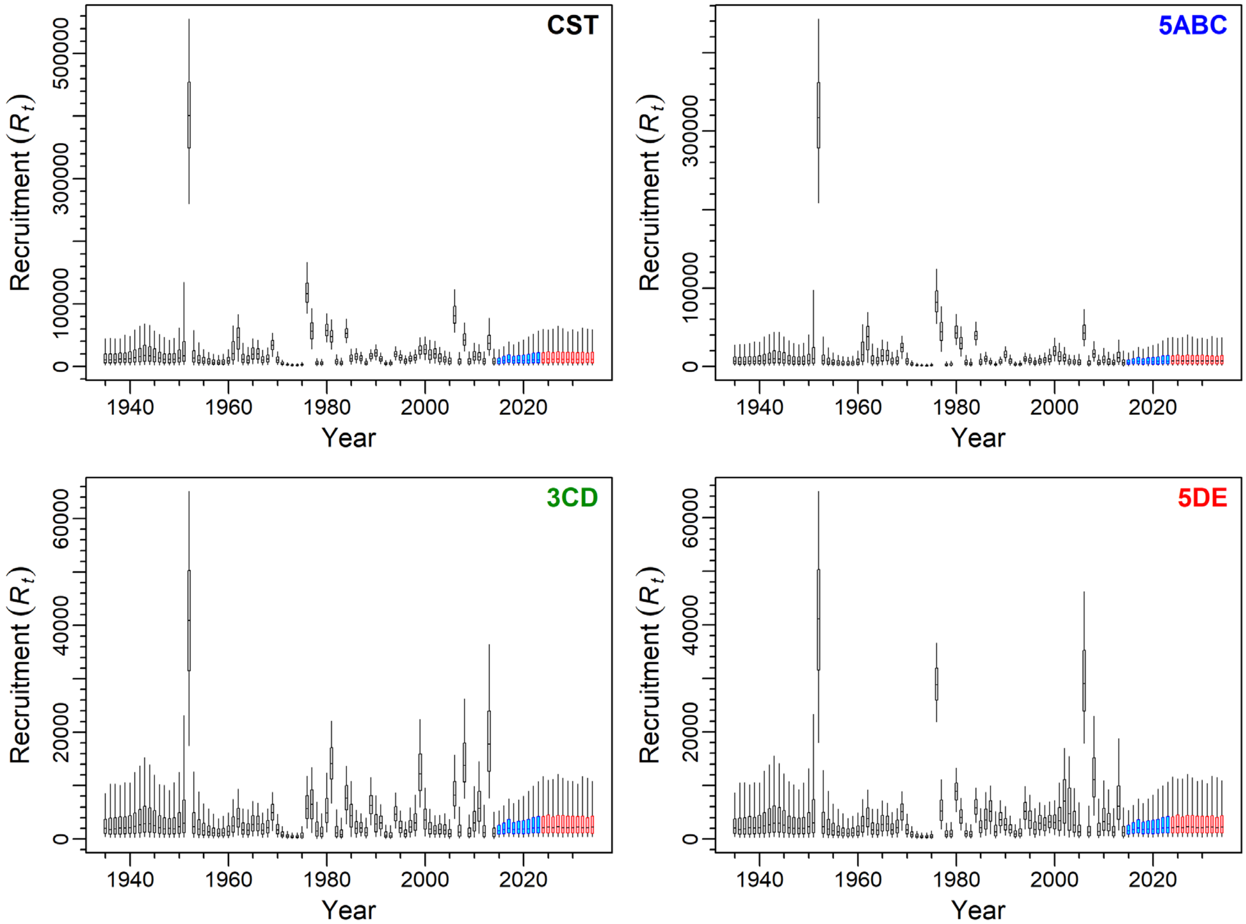

Figure 5. Recruitment trajectory and projection (1,000s age-0 fish) for the coastwide multi-area model (top left), and the three subareas: 5ABC (top right), 3CD (bottom left), and 5DE (bottom right). Black boxes indicate main recruitment period (1935–2014), blue boxes indicate late recruitment period (2015–2023), and red boxes indicate forecast period (2024–2034), assuming catches of 3,306, 1,618, 800, and 848 t/y, respectively. Boxplots delimit the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles.

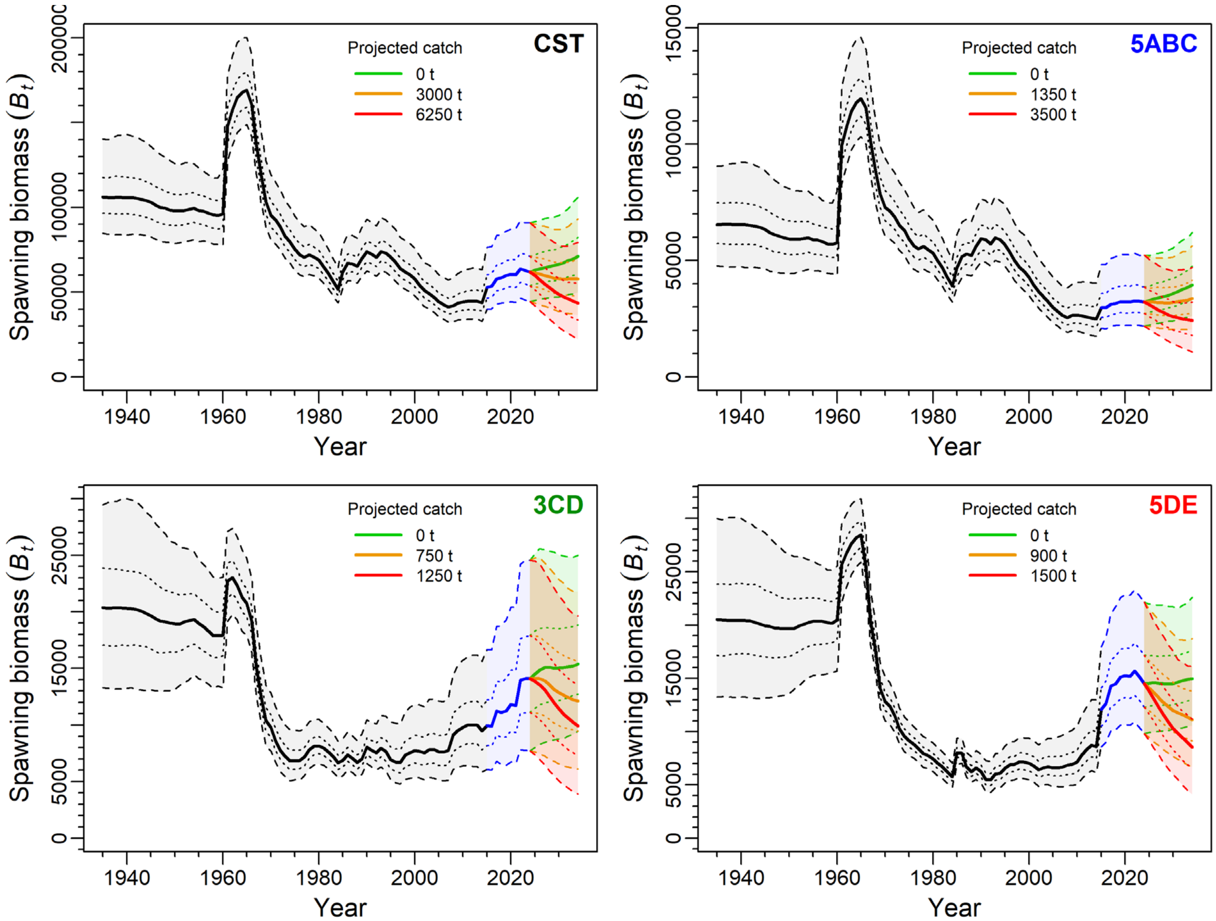

Figure 6. Estimates of spawning biomass B_t (tonnes) from the coastwide multi-area model (top left), and the three subareas: 5ABC (top right), 3CD (bottom left), and 5DE (bottom right). The median biomass trajectory appears as a solid curve surrounded by a 90% credibility envelope (quantiles: 0.05–0.95) in black (main recruitment period) and blue (late recruitment period), and delimited by dashed lines for years t=1935–2024; projected biomass (2025–2034) appears for three catch policies: no catch (green), average catch (orange), and high catch (red). Also delimited (by dotted lines) is the 50% credibility interval (quantiles: 0.25-0.75).

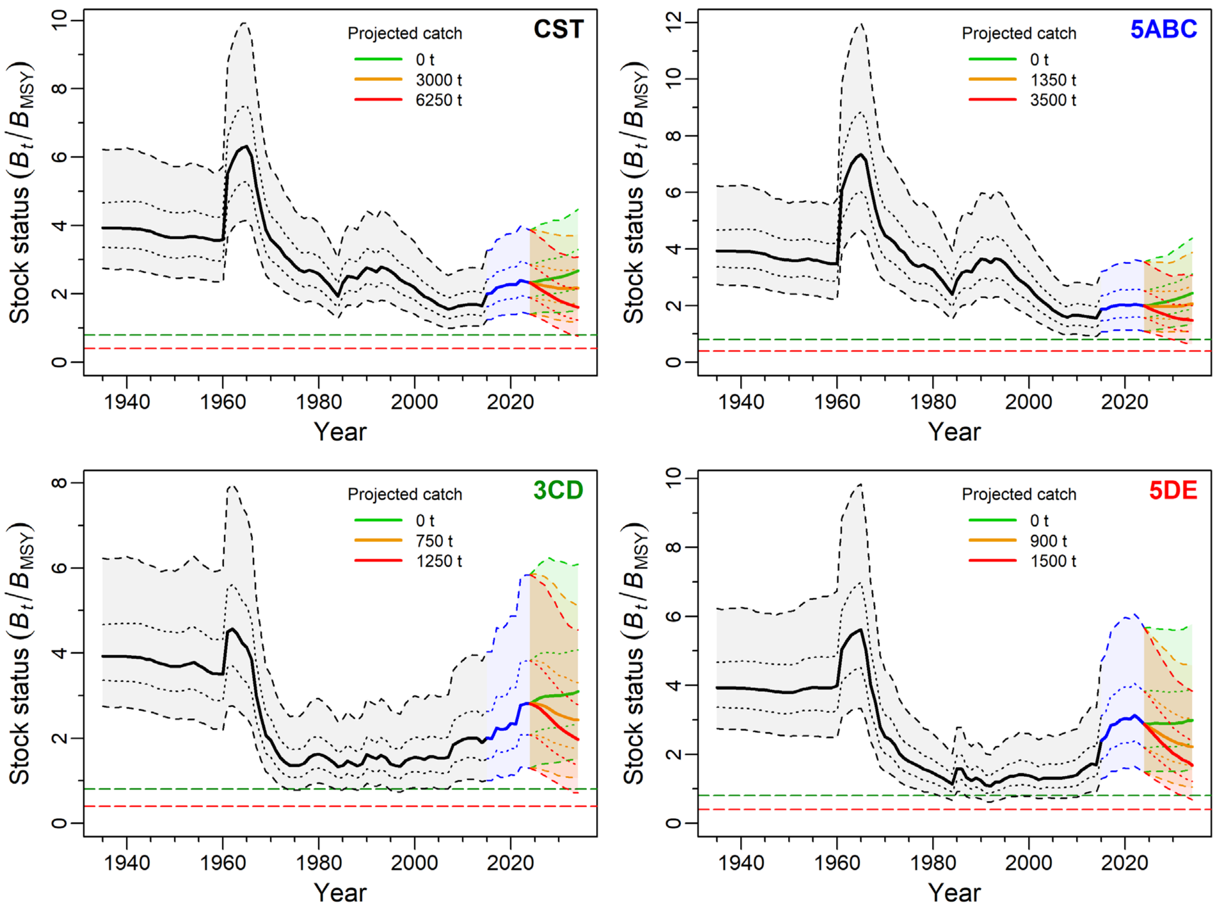

Figure 7. Estimates of spawning biomass B_t relative to B_{MSY} from the coastwide multi-area model (top left), and the three subareas: 5ABC (top right), 3CD (bottom left), and 5DE (bottom right). See Figure 6 caption for details. The horizontal dashed lines show the LRP = $0.4B_{MSY}$ and USR = $0.8B_{MSY}$.

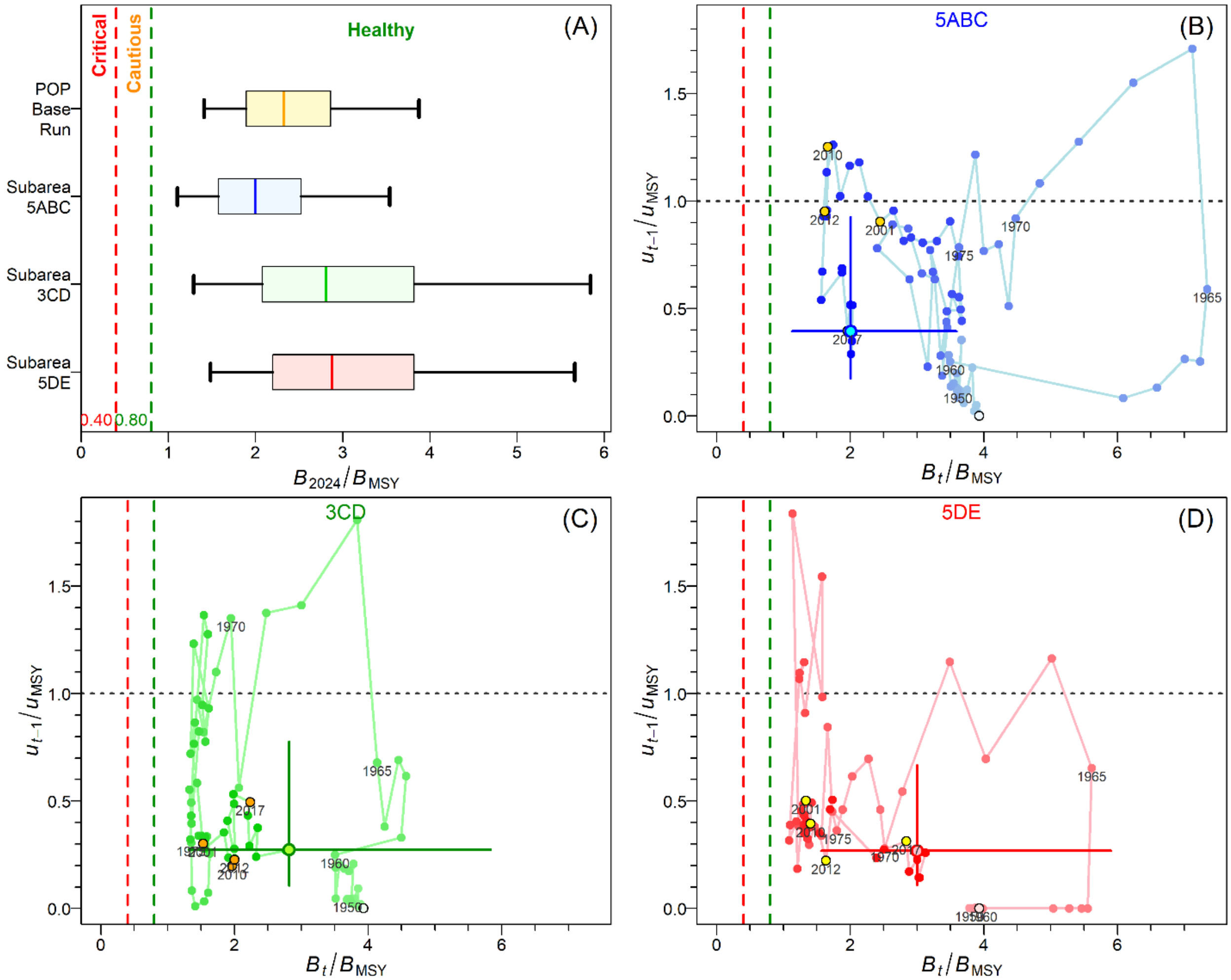

Figure 8. (A) Stock status at beginning of 2024 of the coastwide multi-area POP stock and its three subareas relative to the DFO PA provisional reference points of 0.4B_{MSY} and 0.8B_{MSY}. Boxplots show the 0.05, 0.25, 0.5, 0.75 and 0.95 quantiles from the MCMC posterior. (B) Phase plot through time for subarea 5ABC showing the medians of the ratios B_t/B_{MSY} (the spawning biomass at the start of year t relative to B_{MSY}) and fishing pressure relative to u_{MSY} (u_{t-1}/u_{MSY}, where the exploitation rate occurs in the middle of year t-1) from the multi-area model[7]. The filled white circle is the equilibrium starting year (1935) for the coastwide multi-area model. Years then proceed from lighter shades through to darker with the final year (t=2024) as a shaded circle, with cross lines represent the 0.05 and 0.95 quantiles of the posterior distributions for the final year. Previous assessment years for POP (2001, 2010, 2012, and 2017) are indicated by yellow/gold circles. Red and green vertical dashed lines indicate the PA provisional LRP = 0.4B_{MSY} and USR = 0.8B_{MSY}, and the horizontal grey dotted line indicates u_{MSY}. (C) Same as panel B but for subarea 3CD. (D) Same as panel B but for subarea 5DE.

8.2. SINGLE-AREA MODELS

Single-area models were fit to the area-specific data from 5ABC (Queen Charlotte Sound, QCS), 3CD (west coast Vancouver Island, WCVI), and 5DE (west coast Haida Gwaii, WCHG, and Dixon Entrance), using the same assumptions as those for the multi-area model (e.g., Multinomial fit of age frequencies and one Francis mean-age reweight). This was done to provide a direct link to the single-area models that were used to assess these stock areas in the

[7] 35 MCMC samples yielded anomalous (not a number) MSY-based quantities.

previous iterations of the BC POP stock assessment (5ABC: Haigh et al. 2018; 3CD: Edwards et al. 2014a; 5DE: Edwards et al. 2014b) and to validate and compare with the subarea results from the multi-area model described in Section 8.1.

The fits to the survey data for the single-area models were predictably better than the fits to the same survey data by the multi-area model (Table 3). This was expected because the multi-area model is fitting to all the surveys simultaneously while there would be fewer data conflicts with the less complex models. However it is reassuring that the multi-area model was able to obtain very similar fits to the survey data as did the single-area models. It is not possible to compare the fits to the AF data across these models because of the differential Francis weights.

Table 3. Negative log likelihoods for the fits to the six primary surveys (described in Appendix B) for the coastwide base run and for each of the single-area base runs.

Survey	Coastwide multi-area	5ABC single-area	3CD single-area	5DE single-area
QCS synoptic	-13.690	-13.839	–	–
WCVI synoptic	1.345	–	-0.709	–
WCHG synoptic	-2.832	–	–	-3.228
GIG historical	-4.312	-3.929	–	–
NMFS Triennial	6.772	–	6.636	–
WCVI historical	5.475	–	5.421	–

The single-area model estimates for the leading parameters were similar to those made by the equivalent multi-area models in most cases, but reflected differences in the amount of data that were available to each of the three single-area models. Unsurprisingly, the single-area model parameter estimates for 5ABC most closely resembled the estimates from the 5ABC multi-area model because the majority of the AF data came from the 5ABC stock area and consequently dominated the model fitting process. Natural mortality (M) was generally near 0.05 for females and near 0.06 for males for all models, although the 3CD single-area model estimated a slightly higher M and the 5DE single-area M estimates were slightly lower than the multi-area model estimates (Table 4).

The steepness parameter (h) differed the most among the parameters across the four models, reflecting differences in the recruitments relative to spawners in the single-area models. The multi-area model used a single selectivity function for all three commercial trawl fisheries, so it is not surprising that the 3CD and 5DE single-area models differed from the multi-area selectivity parameter estimates while the 5ABC single-area selectivity parameters were quite close to the multi-area estimates. There were larger AF residuals for the 3CD commercial AF data fit by the multi-area model compared to the 3CD single-area model fit (compare Figure F.7 with Figure F.43), indicating that the shared selectivity used by the multi-area model was not optimised for the 3CD AF data. The 5DE multi-area fit to the commercial trawl AF data did not show as many large residuals when compared to the single-area model fit (compare Figure F.9 with Figure F.48).

Table 4. Median leading parameter estimates from the base run multi-area model compared with the equivalent parameter estimates from each of the single-area models.

Parameter	Base run multi-area	5ABC single-area	3CD single-area	5DE single-area
LN(R_0)	9.845	9.372	8.464	8.327
Rdist_area(1)	1.173	–	–	–
Rdist_area(2)	-0.00856	–	–	–
M_1 (female)	0.0523	0.0532	0.0591	0.0509
M_2 (male	0.0594	0.0594	0.0648	0.0633
h	0.754	0.714	0.601	0.837
μ (trawl)	11.330	11.140	11.770	10.170
v_L (trawl)	2.193	2.121	2.717	0.887
Δ (trawl)	-0.0595	-0.059	-0.0250	-0.0259
μ (QCS)	17.740	16.560	–	–
v_L (QCS)	4.315	4.159	–	–
Δ (QCS)	-0.00365	0.053	–	–
μ (WCVI)	20.490	–	19.140	–
v_L (WCVI)	4.741	–	4.620	–
Δ (WCVI)	0.274	–	0.2638	–
μ (WCHG)	12.290	–	–	12.410
v_L (WCHG)	2.235	–	–	2.255
Δ (WCHG)	-0.0161	–	–	-0.106
μ (GIG)	8.473	8.530	–	–
v_L (GIG)	3.034	3.076	–	–
Δ (GIG)	-0.325	-0.295	–	–
μ (NMFS)	5.222	–	5.241	–
v_L (NMFS)	2.955	–	2.981	–
Δ (NMFS)	-0.231	–	-0.210	–

A comparison of the recruitment trajectories from the four models illustrates the difference between the multi-area subareas with each of the corresponding single-area models (Figure 9). Unsurprisingly, the 5ABC single-area recruitment series was nearly identical to the equivalent multi-area series (top left panel, Figure 9). The 3CD series had almost no AF information before 1975, so the relative recruitments vary only a little around the mean in the early part of the series for the single-area 3CD model, while the multi-area model essentially "borrowed" recruitment information from the other areas (top right panel, Figure 9). There is more AF information in the 5DE AF data set which appeared to be reasonably consistent with the 5ABC AF information, even to showing a strong recruitment spike in 1952 and another in 1976, which were also seen in the 5ABC AF data (bottom panel, Figure 9), This consistency in the recruitment information derived from the AF data gives credence to the multi-area approach adopted for this stock assessment.

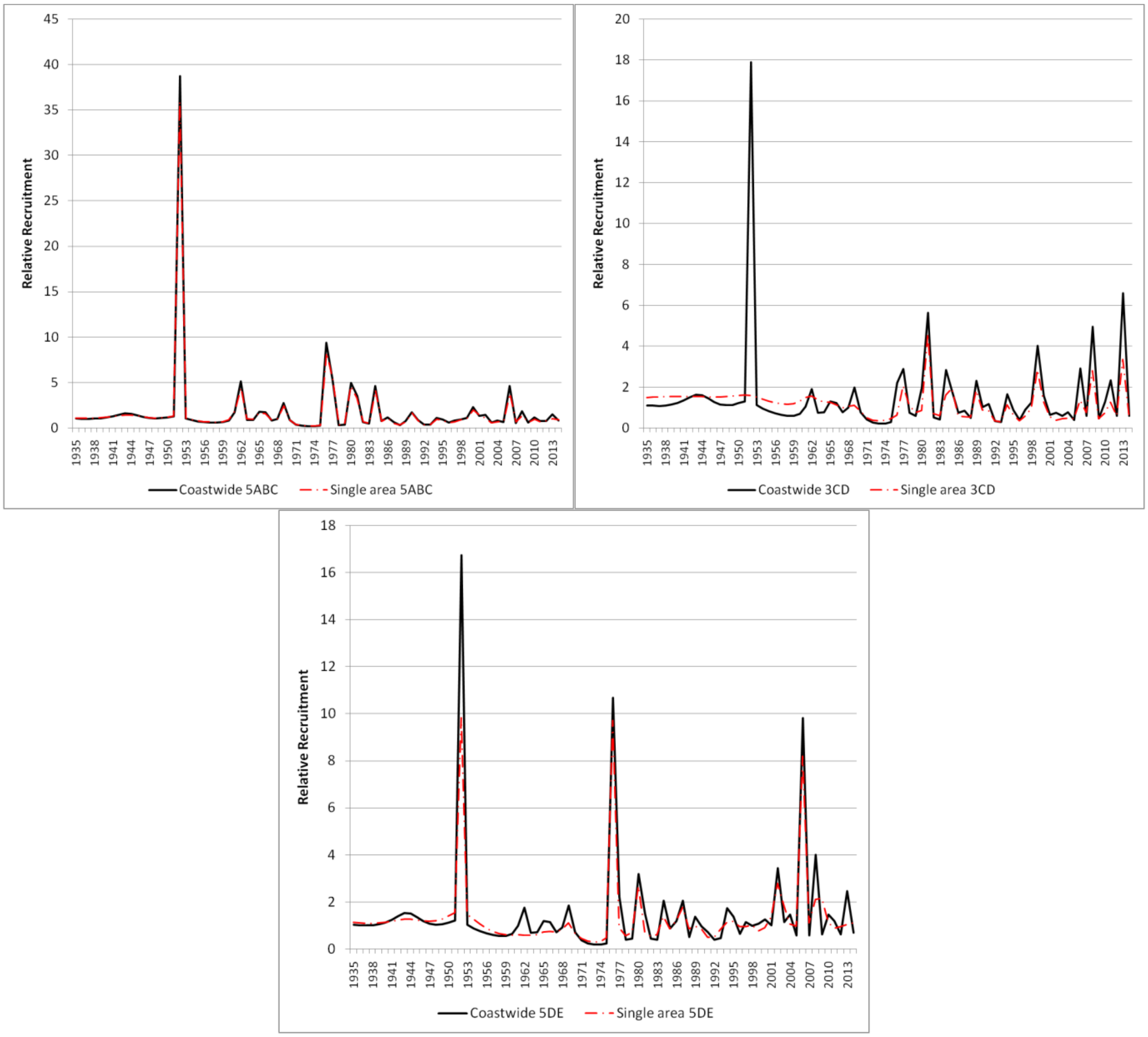

Figure 9. Comparison of the main recruitment MPD trajectory for each subarea of the coastwide multi-area model with the MPD recruitment trajectory from the corresponding single-area model (5ABC: top left; 3CD: top right; 5DE: bottom). Each recruitment trajectory has been standardised by dividing the annual recruitment by the geometric mean recruitment for the 1935–2014 period.

The differences in the available data for each area led to differences in the outcome of the stock assessments between the multi-area model and the matching single-area model, with the biggest difference arising for area 3CD (Table 5). The estimates by the multi-area model of stock size (B_0) and stock depletion (B_{2024}/B_0) for 5ABC and 5DE are similar to the equivalent estimates from the single-area models. The median 5ABC B_0 estimates by both models are near 65,000 t and the estimates for current stock size relative to B_0 are just under 0.5 for both models (Table 5). The equivalence for 5DE is less compelling, with both models estimating the current stock size relative to B_0 to be just over 0.7, but the single-stock 5DE model estimated a larger B_0 and B_{2024} than did the multi-area model. This is likely because the single area 5DE model (also true for the 3CD single-area model) needed to estimate a larger B_0 in order to accommodate the considerable removals that occurred in the late 1960s and early 1970s, but only using deterministic recruitment while the 5ABC model estimated a very large year class in the early 1950s to additionally account for the large removals. These higher biomass estimates resulted in slightly higher yields. For instance, the 5DE MSY estimate was larger by almost 300 t (a 30% increase) over the 5DE multi-area subarea estimate. The stock size and stock status estimates by the 3CD single-area model are likely less reliable than the 3CD subarea estimates because they are affected by the lack of 3CD data and the contradictory nature of some of these data. The fits to the WCVI and NMFS triennial surveys were not very good given the large interannual variation observed in these surveys (see Figures F.2 and F.41). The fits to the 3CD AF data also tended to have larger residuals than the other two models, even for the single-area model. For these reasons, the multi-area subarea 3CD model should be preferred over the single-area model.

Table 5. Median derived parameter estimates from the coastwide multi-area model (base run) compared with the equivalent derived parameter estimates from each of the subareas in the multi-area model and the main areas in the single-area models.

Derived Quantity	Coastwide multi-area	5ABC subarea	3CD subarea	5DE subarea	5ABC single-area	3CD single-area	5DE single-area
B_0	106,054	65,469	20,370	20,513	64,999	22,310	24,619
B_{2024}	61,965	32,243	14,105	14,491	30,556	9,743	17,146
B_{2024}/B_0	0.582	0.495	0.710	0.715	0.473	0.441	0.707
F_{2023}	0.0279	0.0252	0.0313	0.0430	0.0272	0.0429	0.0271
u_{2023}	0.0275	0.0249	0.0308	0.0421	0.0269	0.0420	0.0267
MSY	4,865	2,993	918	921	2,912	931	1,198
B_{MSY}	26,798	16,311	5,048	5,123	17,239	6,621	5,223
B_{2024}/B_{MSY}	2.326	1.994	2.806	2.876	1.813	1.547	3.370
B_{MSY}/B_0	0.254	0.254	0.254	0.254	0.267	0.305	0.213
F_{MSY}	0.0945	0.0657	0.1185	0.1700	0.0873	0.0699	0.1205
u_{MSY}	0.0902	0.0636	0.1117	0.1563	0.0836	0.0675	0.1135
u_{2023}/u_{MSY}	0.307	0.394	0.274	0.268	0.326	0.614	0.232

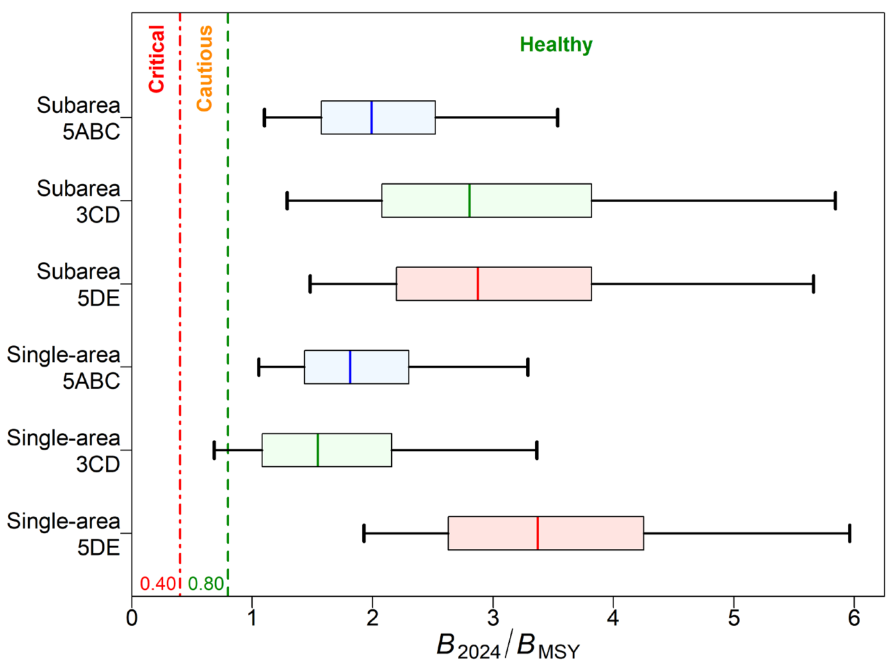

Figure 10. Stock status at beginning of 2024 comparing the three subareas from the multi-area model and the three single-area models relative to the DFO PA provisional reference points of 0.4B_{MSY} and 0.8B_{MSY}. Boxplots show the 0.05, 0.25, 0.5, 0.75 and 0.95 quantiles from the MCMC posterior.

8.2.1. 5ABC Queen Charlotte Sound

MCMC diagnostics (Figures F.52 and F.53) were good for this model (A1: R24v1a), with similar characteristics as those seen for the multi-area model presented in Section F.2.1.2. Traces for all the leading parameters were stable and only a small amount of fraying was present among the eight MCMC chains in a few of the leading parameters There was no evidence of autocorrelation in any of the leading parameters.

The fits to the two surveys assigned to this stock area were good, closely resembling the fits observed for the 5ABC subarea in the multi-area model (Figure F.37, Table 3). The fits to the AF data (Figure F.38) were very similar to the fits observed for the 5ABC subarea model. The plot of depletion (B_t/B_0) showed the stock dipping below $0.4B_0$ from about 2,000 to around 2015 (Figure F.39, left panel); however, the single-area 5ABC base run stock assessment indicated that this stock has never gone into the Cautious zone at the 5% level (Figure 11, right panel).

A retrospective analysis showed that the 5ABC spawning biomass reconstruction did not change greatly after the sequential removal of 13 years of data back to 2010 (Figure F.41). Similarly, the removal of data did not materially change the fit to the QCS synoptic survey index series. This retrospective analysis did not reveal any underlying problems in the 5ABC model, with all between-year shifts explained through the introduction of new information into the model.

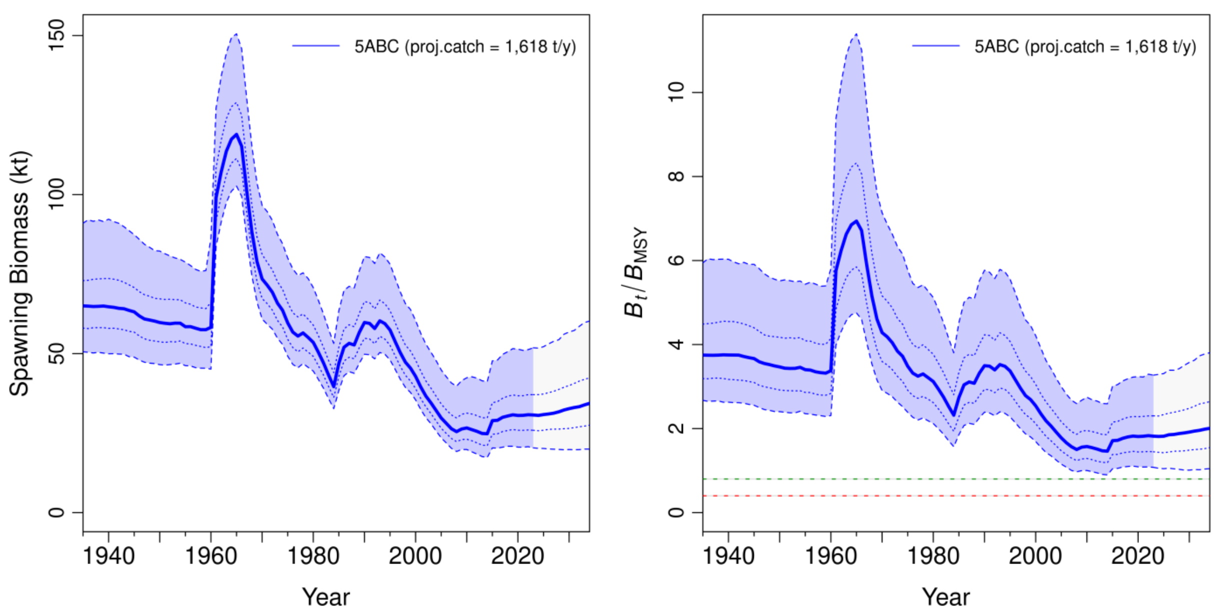

Figure 11. Spawning biomass trajectory for the 5ABC single-area model (left) and 5ABC stock status ratio B_t/B_{MSY} (right). Forecast period (2024–2034) assumes a catch of 1,618 t/y (5-y mean, 2018–2022). Credibility envelopes delimit the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles.

8.2.2. 3CD West Coast Vancouver Island

MCMC diagnostics (Figures F.52 and F.53) are good for this model (A2: R25v1a), but not as good as those seen for the multi-area model presented in Section F.2.1.2. Traces for all the leading parameters are stable but there is more fraying present among the eight MCMC chains in several of the leading parameters There was no evidence of autocorrelation in any of the leading parameters.

The fits to the two surveys assigned to this area were reasonable (although three of the indices are missed), with the fit to the WCVI survey improved over the equivalent fit by the 3CD subarea in the multi-area model (Figure F.42, Table 3). The fits to the AF data (Figure F.43) are much better than that observed for the 3CD subarea model, with the outlier standardised residuals considerably reduced compared to the equivalent fits by the 3CD subarea. The plot of depletion (B_t/B_0) shows the stock in the zone between 0.2 and 0.4B_0 from the late 1960s to near 2015 (Figure F.44, left panel); the single-area 3CD base run stock assessment indicated that there was some probability (probably less than 10%) that this stock was in the Cautious zone from the early 1970s to the present (Figure 12, right panel).

A retrospective analysis showed that the 3CD spawning biomass reconstruction did not change greatly after the sequential removal of 13 years of data back to 2010 (Figure F.46). There was a strong increase in biomass for 2014 and 2015, resulting from a large index value observed in 2014 (Figure F.46). This retrospective analysis did not reveal any underlying problems in the 3CD model, with all between-year shifts explained through the introduction of new information into the model.

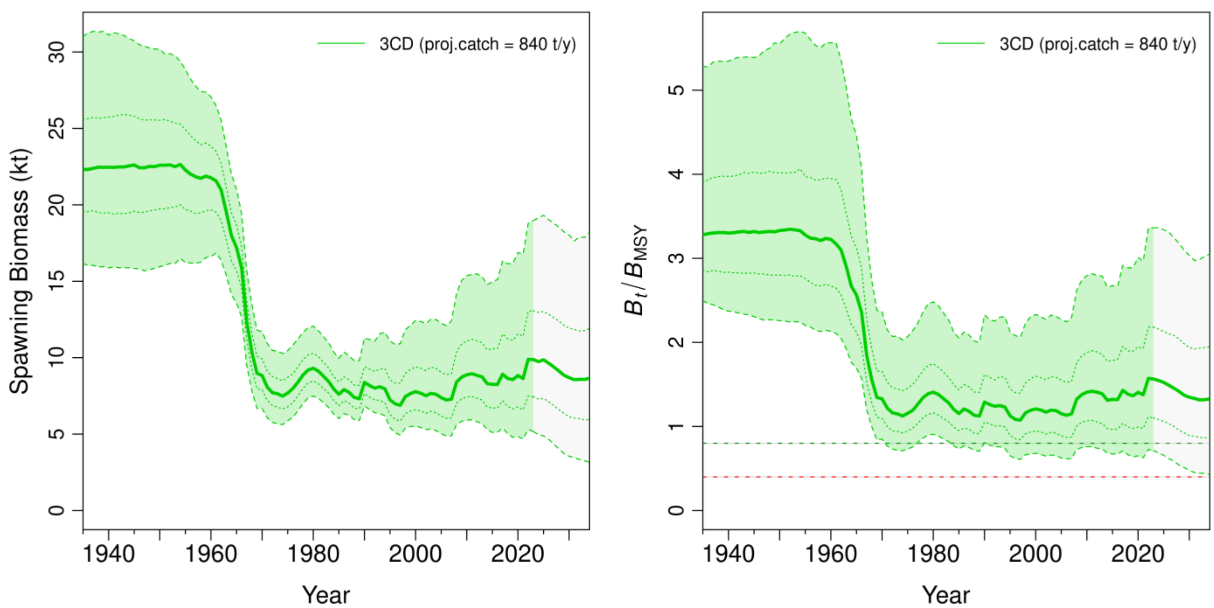

Figure 12. Spawning biomass trajectory for the 3CD single-area model (left) and 3CD stock status ratio B_t/B_{MSY} (right).Forecast period (2024–2034) assumes a catch of 840 t/y (5-y mean, 2018–2022). Credibility envelopes delimit the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles.

8.2.3. 5DE West Coast Haida Gwaii

MCMC diagnostics (Figures F.52 and F.53) were good for this model (A3: R26v1a), but not as good as those seen for the multi-area model presented in Section F.2.1.2. Traces for all the leading parameters were stable but there was more fraying present among the eight MCMC chains in many of the leading parameters. There was no evidence of autocorrelation in any of the leading parameters.

The fits to the WCHG survey were good, with the fit improved over the equivalent fit by the 5DE subarea in the multi-area model (Figure F.47, Table 3). The fits to the AF data (Figure F.48) are about the same as observed for the 5DE subarea model, with few outlier standardised residuals. The plot of depletion (B_t/B_0) showed the stock going even lower into the zone between 0.2 and 0.4B_0 than did the 3CD single-area model (over the period from the late 1960s to near 2015) (Figure F.49, left panel); the single-area 5DE stock assessment indicated that there was a small probability (probably less than 5%) that this stock was in the Cautious zone from the mid-1980s to the mid-1990s (Figure 13, right panel).

A retrospective analysis shows that the 5DE spawning biomass reconstruction progressed from pessimistic in the early years (2010–2015) to an increasingly optimistic outlook as successive years of higher index values from the WCHG survey were added to the model (Figure F.51). This retrospective analysis did not reveal any underlying problems in the 5DE model, with between-year shifts explained through the introduction of new information into the model.

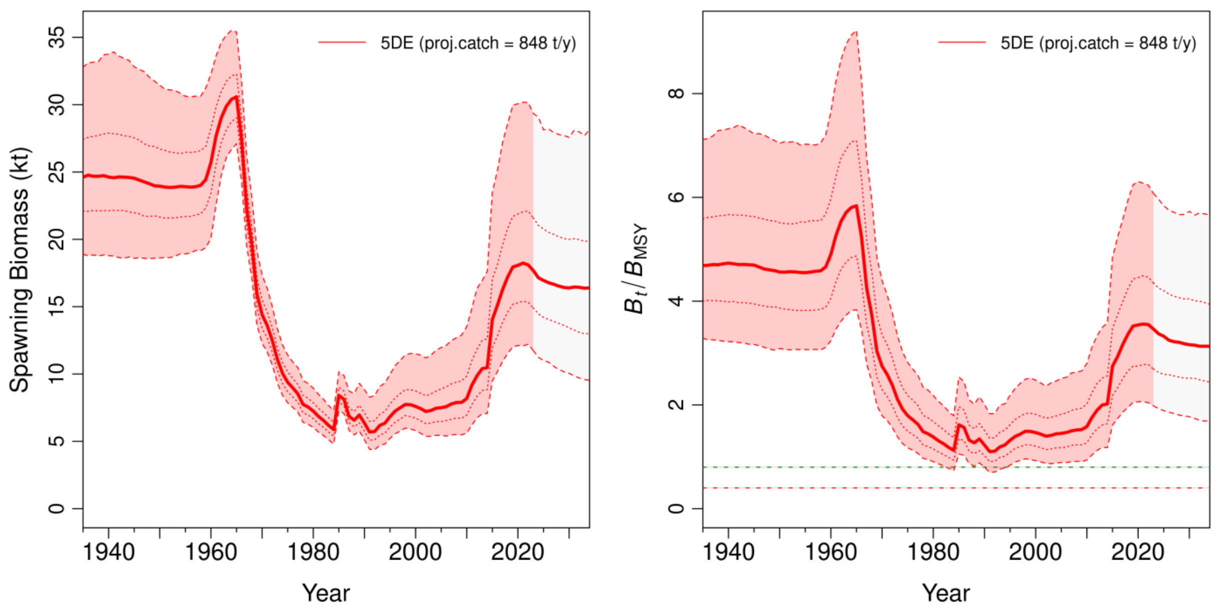

Figure 13. Spawning biomass trajectory for the 5DE single-area model (left) and 5DE stock status ratio B_t/B_{MSY} (right). Forecast period (2024–2034) assumes a catch of 848 t/y (5-y mean, 2018–2022). Credibility envelopes delimit the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles.

8.3. SENSITIVITY ANALYSES

Table 6. Sensitivity runs used to test a range of base run assumptions. Ten primary sensitivity runs were taken to MCMC to generate 2,000 samples that were used to generate posterior distributions for all estimated parameters. Three additional sensitivity runs were taken to MPD only.

Sens	Run	Eval	Description
S01	17v18a	MCMC	used the Dirichlet-Multinomial parameterisation in SS3 for AF data
S02	27v1a	MCMC	fixed recruitment distribution area 1 (5ABC) when allocating recruitment to areas
S03	28v1a	MCMC	fixed recruitment distribution area 2 (3CD) when allocating recruitment to areas
S04	29v1a	MCMC	applied no ageing error
S05	30v1a	MCMC	applied ageing error derived from age-reader CVs
S06	31v1a	MCMC	applied ageing error using constant CV of 10%
S07	32v1a	MCMC	reduced commercial catch (1965-1995; foreign + unobserved domestic) by 30%
S08	33v1a	MCMC	increased commercial catch (1965-1995; foreign + unobserved domestic) by 50%
S09	34v1a	MCMC	reduced sigmaR (σ_R) to 0.6 from 0.9
S10	35v1a	MCMC	increased sigmaR (σ_R) to 1.2 from 0.9
S11	22v2	MPD	separated midwater and bottom trawl catches in 3CD and 5ABC with a shared selectivity based on combined AF data (3CD+5ABC)
S12	36v2	MPD	added Hecate St synoptic survey to the 5DE data set
S13	37v1	MPD	used empirical proportions mature rather than model fit

8.3.1. Sensitivity analyses taken to MCMC level

Ten primary sensitivity analyses were run (with full MCMC simulations, see Table 6) relative to the base run (Run21v3a) to test the sensitivity of the outputs to alternative model assumptions. The differences among the sensitivity runs (including the base run) are summarised in tables of median parameter estimates (Table F.28) and median derived parameter quantities (Table F.29).

MCMC diagnostics were evaluated using the following subjective criteria:

- Good – no trend in traces and no spikes in log (R_0), split-chains align, no autocorrelation;
- Fair – trace trend temporarily interrupted, occasional spikes in log (R_0), split-chains somewhat frayed, some autocorrelation;
- Poor – trace trend fluctuates substantially or shows a persistent increase/decrease, split-chains differ from each other, substantial autocorrelation; and
- Unacceptable – trace trend shows a persistent increase/decrease that has not levelled, split-chains differ markedly from each other, persistent autocorrelation.

The diagnostic plots (Figures F.58, F.59 and F.60) suggested that nine sensitivity runs exhibited good MCMC behaviour and only one was fair. None were in the poor or unacceptable categories. A measure of how many samples exceeded an estimated LN(R0)=11 is provided as a metric of a run's propensity to explore high R_0 excursions.

- Good – no trend in traces, no sudden spikes in log (R_0), split-chains align, no autocorrelation
    - S01 (DM parameterisation), excursions =28
    - S03 (Rdist for 3CD fixed), excursions =1
    - S04 (AE1 no ageing error), excursions =290
    - S05 (AE5age-reader CVs), excursions =0
    - S06 (AE6 CASAL CV=0.1), excursions =0
    - S07 (reduce catch 30%), excursions =0
    - S08 (increase catch 50%), excursions =31
    - S09 (sigmaR=0.6), excursions =0
    - S10 (sigmaR=1.2), excursions =3
- Fair – trace trend temporarily interrupted, split-chains somewhat frayed, some autocorrelation
    - S02 (Rdist for 5ABC fixed), excursions =2

Comparing female spawning biomass medians (Figure 14), three sensitivities consistently estimated a larger standing stock in all years than did the base run: S08 (increase catch), S04 (no age error), and S01 (D-M parameterisation). A less productive stock was estimated when catches were reduced (S07). The remainder of the sensitivities varied little from the base run.

The trajectories of the B_t/B_0 medians (stock depletion, Figure 15) indicate that all sensitivities followed a similar trajectory to the base run trajectory with some variation. The median final-year depletion (Table F.29) ranged from a low of 0.543 by S04 (no age error) to a high of 0.644 by S01 (D-M parameterisation). Compared to S01, which was intended originally to be the base run, the Francis method yielded higher depletion (lower B_{2024}/B_0) and a lower B_0/B_{MSY}, implying lower overall productivity.

The implementation of the multi-area model by the SS3 platform required fixing the relative distribution of recruitment for one of the areas and then allowing the model to estimate a recruitment distributional parameter for the remaining two areas relative to the reference area.

For the base run, the 5DE area was arbitrarily chosen as the reference area; consequently the `Rdist area` parameters for the base run applied to 5ABC and 3CD. Sensitivity runs S02 and S03 explored setting the reference area to 5ABC (S02) and to 3CD (S03), respectively. In terms of the overall model performance, both S02 and S03 returned leading parameter estimates (Table F.28) and derived quantities (Table F.29) that were consistent with the base run. As well, the fits to the survey data were similar for all three runs except for the WCVI synoptic survey, which obtained a better fit when 5ABC (S02) was the reference area (Table F.30). Although the overall model performance seemed to be relatively insensitive to the choice of the reference area, the relative distribution of the three subareas was sensitive to this choice. Table 7 shows how the distributions among the three POP areas differed with the choice of the base area, with the base run and S03 returning similar proportions among the B_0 estimates while S02 estimated a lower proportion assigned to 3CD than for the other models. Note that summing the independent single-area models should be interpreted cautiously, because these models, unlike the three multi-area models estimate different natural mortality and steepness parameters. Consequently, productivity in these three models is not limited to just stock size, unlike the multi-area models which share the underlying estimated productivity parameters.

Table 7. Proportional MPD distribution by POP subarea for the base run, with the addition of the three single-area models and sensitivity runs S02 and S03.

	B_0			B_{2024}		
Run	5ABC	3CD	5DE	5ABC	3CD	5DE
base	0.598	0.200	0.202	0.533	0.225	0.241
single-area	0.560	0.221	0.220	0.543	0.168	0.289
S02	0.639	0.142	0.219	0.602	0.128	0.269
S03	0.593	0.193	0.214	0.521	0.185	0.294

Three of the sensitivity runs addressed ageing error issues: S04 dropped ageing error entirely; S05 used an alternative ageing error vector based on the error between paired reads of the same otolith; and S06 implemented a constant 10% error term for every age. These alternative ageing error vectors are shown concurrently in Figure D.20. The sensitivity runs employing the alternative ageing error vectors (S05 and S06) resulted in model runs that were nearly identical to the base run when plotted as a percentage of B_0 (Figure 15). When plotted as an absolute biomass (Figure 14), sensitivity S06 lay slightly below the base run while sensitivity S05 lay just above the base run. The estimates for *M* and *h* from these runs were also close to those made by the base run, implying that these runs would return similar levels of overall productivity. Sensitivity S04, which dropped ageing error entirely, was slightly less optimistic in terms of percentage B_0 (median B_{2024}/B_0 =0.54 instead of 0.58 for the base run, Table F.29) but the overall biomass was estimated to be considerably larger in terms of absolute B_t (Figure 14) than the base run (the median *S04* $B_0 \sim 1.6B_0$, see Table F.29). This result, plus the higher estimates for *M* from this run (Table F.28), make this sensitivity an unlikely scenario for providing advice. In terms of model fits to the survey data, S04 (no ageing error) generally returned poorer fits to the survey data than the base run, while S05 (age reader CV) returned fits similar to the base run, and S06 (constant CV=0.1) returned somewhat better fits to the survey series than did the base run (Table F.30).

The two sensitivity runs which adjusted early (1965–1995) catches downward (S07) and upward (S08) provided predictable results, with S07 returning a lower B_0 compared to the base run while S08 proved to be a much larger stock. This result is consistent with raising and lowering the input catches. In terms of percent B_0, S07 returned more optimistic results compared to the base run (especially after about 1990) while S08 was consistently about the same as the base run. In terms of model fits to the survey data, both models showed variable results, with S07 (reduce catches by 30%) generally returning similar fits to the survey data compared to the base run, while S08 (increase catch by 50%) returned poorer fits to the survey data compared to the base run (Table F.30). It is of interest that the S07 fit to the GIG historical survey is better than any of the runs in Table F.30, possibly implying that the early historical catches are being overestimated.

The two sensitivity runs which varied the σ_R parameter (standard deviation of recruitment process error) showed similar results to the base run. Both S09 (sigmaR=0.6) and S10 (sigmaR=1.2) returned estimates of M, h, B_0 and B_{2024}/B_0 that were close to those made by the base run. This implies that this stock assessment is not very sensitive to this assumed parameter. In terms of model fits to the survey data, both models fit the survey data about as well as the base run, apart from a better fit to the WCHG survey by S10 (Table F.30).

The SS3 platform calculates[8] an alternative sigmaR based on the estimated variance of the recruitment deviations. This value was 1.05 for the base run main recruitment period, which aligned well with the assumption made by the base run (σ_R=0.9).

The sensitivity run that used the Dirichlet-Multinomial procedure to weight the AF data (S01) had good MCMC diagnostics, but was generally more optimistic than the base run, estimating higher stock size relative to B_0 (median B_{2024}/B_0 =0.64 instead of 0.58 for the base run, Table F.29). The median estimates for natural mortality were higher for S01 compared to the base run: M_1 (female) =0.058 vs. 0.052 and M_2 (male) =0.065 vs. 0.059 (Table F.28). The derived parameters showed more variation with S01 estimating a 22% higher B_0 than that for the base run and a current spawning stock size (B_{2024}) 35% higher than by the base run. In terms of model fits to the survey data, S01 (D-M model) fit the survey data similarly to the base run, apart from a much better fit to the WCHG survey (Table F.30).

The stock status (B_{2024}/B_{MSY}) for the 10 sensitivities taken to MCMC were all in the DFO Healthy zone, being well above the USR even at the 5% level (Figure 16).

[8] R code: `require(r4ss); replist=SS_output(dir="."); replist$sigma_R_info` (also see Chantel Wetzel, pers. comm. 2015).

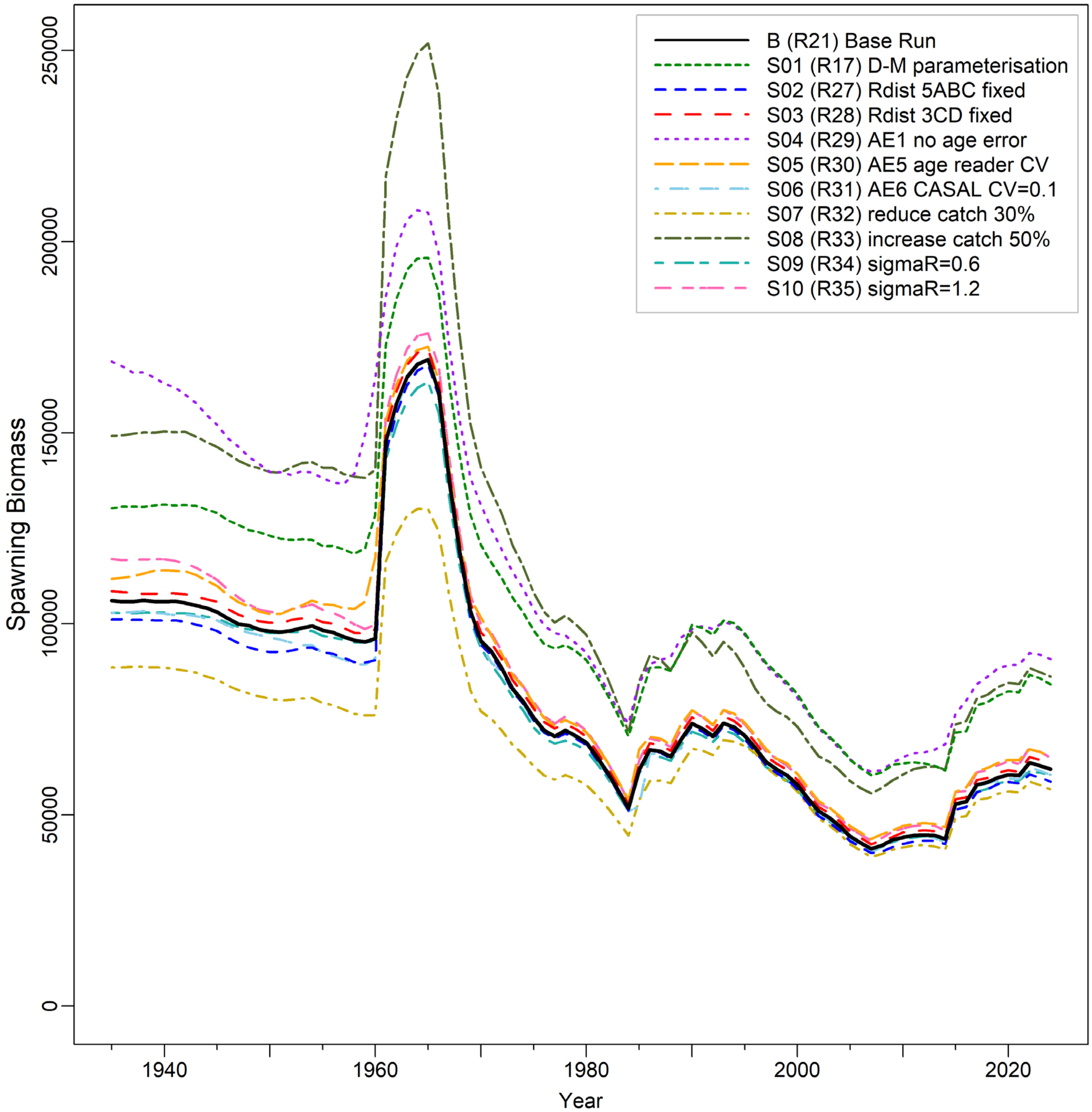

Figure 14. Model median trajectories of female spawning biomass (B_t) for the base run and ten sensitivity runs (see legend upper right).

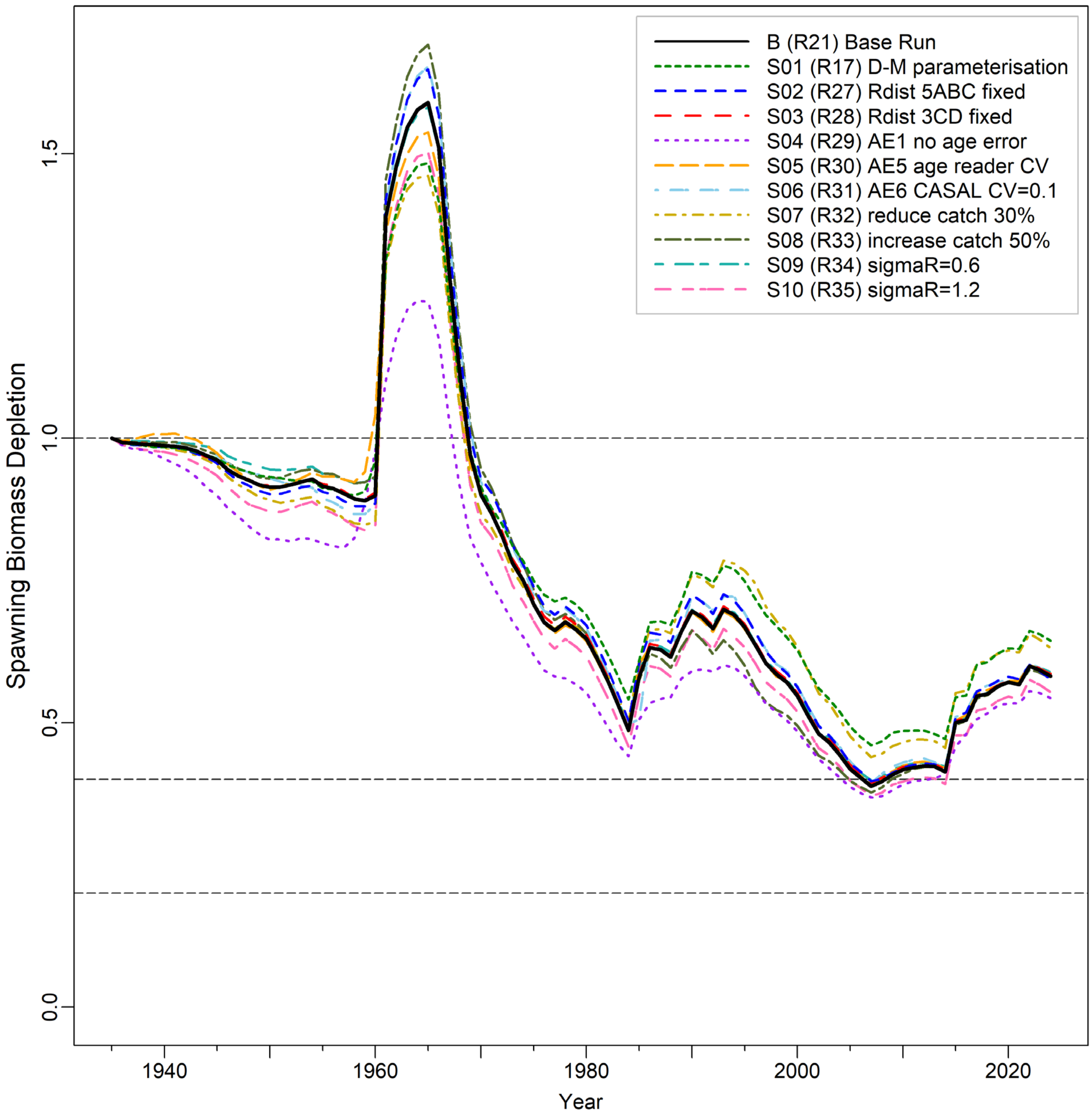

Figure 15. Model median trajectories of female spawning biomass as a proportion of unfished equilibrium biomass (B_t/B_0) for the base run and ten sensitivity runs (see legend upper right). Horizontal dashed lines show alternative reference points used by other jurisdictions: $0.2B_0$ (~DFO's USR), $0.4B_0$ (often a target level above B_{MSY}), and B_0 (equilibrium initial spawning biomass).

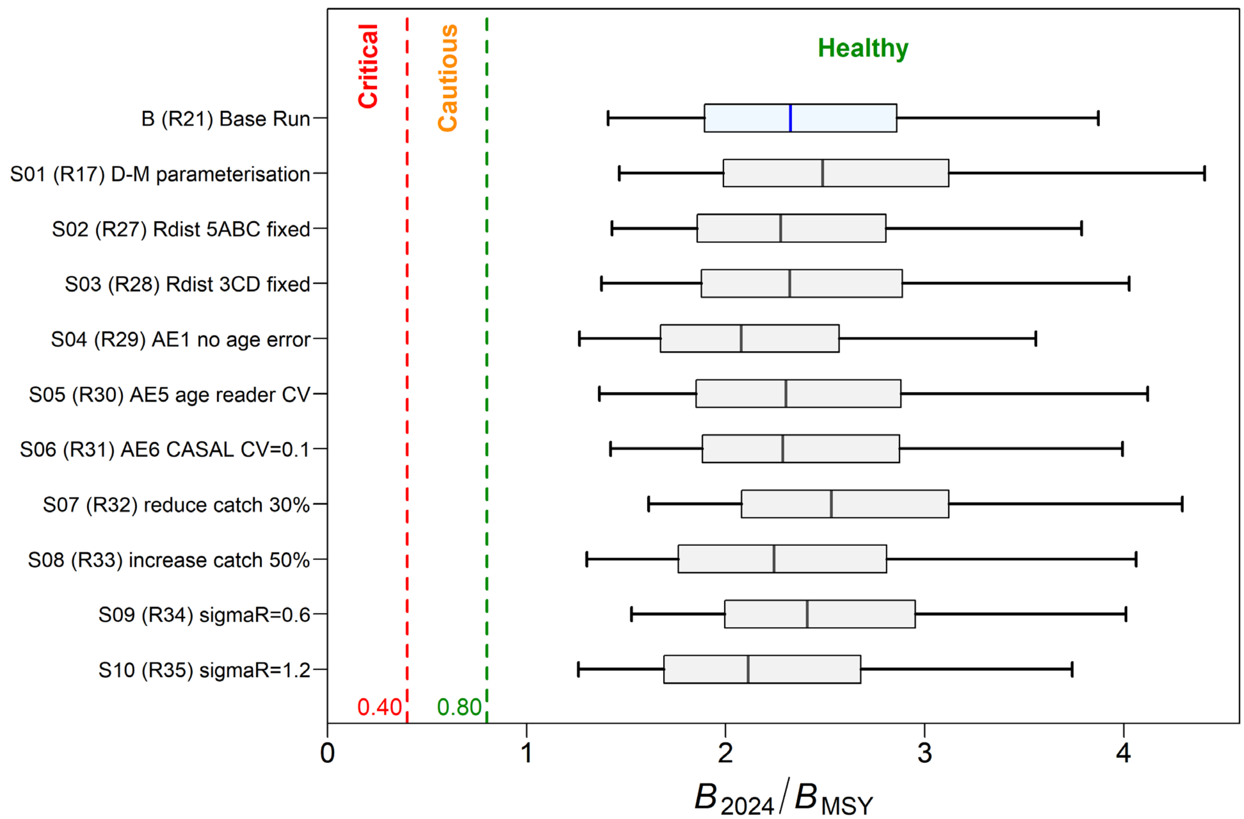

Figure 16. Stock status at beginning of 2024 of the POP stock relative to the DFO PA provisional reference points of 0.4B_{MSY} and 0.8B_{MSY} for the base run and ten sensitivity runs (see y-axis notation and sensitivity descriptions in the main text). Boxplots show the 0.05, 0.25, 0.5, 0.75 and 0.95 quantiles from the MCMC posterior.

8.3.2. Sensitivity analyses taken to MPD level

Three additional sensitivity analyses were done, which were not included in the MCMC set of sensitivity runs (Table 6, Section 8.3) because they were either close variants of the base run (B1, Run21) that would be expected to return similar MCMC diagnostics or else an MCMC extension seemed unnecessary. These runs are described in Section 7 and consist of:

- S11 (R22v2) add midwater trawl fisheries for 3CD and 5ABC and estimate a shared selectivity based on combined AF data (label: “add 3CD 5ABC midwater”);
- S12 (R36v2) add Hecate Strait synoptic survey to 5DE data (label: “add HS synoptic”); and
- S13 (R37v1) use empirical proportions mature (label: “empirical proportions mature”).

Run S11 implemented a separate fishery for midwater trawl (MW) in subareas 3CD and 5ABC. Subarea 5DE was omitted because the MW fishery was known to be small in that area. This implementation required strong assumptions because the MW catch and age data were sparse and were not reliable before 1996. Therefore, MW catches before 1996 were assumed to be zero, with the MW fishery only starting in 1996 when the catch data became reliable. There were insufficient MW trawl AF data to have separate data sets for 3CD and 5ABC, so the available data were combined into a single AF data set covering six years from 2007 to 2018. The fits to these data were poor with strong negative residual patterns from age 10 to the mid-20s (not shown).

Run S12 added the HS synoptic survey series to the data set and assumed this survey monitored the 5DE subarea population. This was because the large majority of the POP catches by this survey occurred in the western part of Dixon Entrance, directly above the north coast of Graham Island (see Figures B.51 to B.59 in Appendix B). Unfortunately, there were insufficient POP AF data from this survey to reliably estimate a selectivity function, so the model fitted the survey indices by using the selectivity function estimated for the neighbouring WCHG synoptic survey.

Neither of these sensitivity run models had much improved fits to the survey data relative to the fits obtained by the base run (Table 8). The fits to the WCHG and the WCVI surveys deteriorated for S12 relative to that obtained by the base run. The remaining fits were the same for S11 and S12.

Table 9 demonstrates that neither of these sensitivity runs moved very far from the estimates in the base run. Both S11 and S12 had leading parameter estimates for M, h, LN(R_0), and the main selectivity parameters that were nearly the same as for the base run (Table 9). There were some minor changes in the estimates for B_0 and B_{2024}, with a 5% drop in the 3CD B_0 and a 13% drop in 3CD B_{2024} for S11, which is the subarea with the most active MW fishery. But the differences were small and it is difficult to conclude that combining the BT and MW fisheries had generated a bias in this stock assessment, given the data that are presently available. Similarly, S12 demonstrated that the effect of adding the HS survey to the data set was small because it did not change any of the parameter estimates and may have been responsible for slightly reducing the relative size of the 5DE current biomass, with the ratio with B_0 dropping from 0.635 in the base run to 0.600 in run S12 (Table 9).

Run S13 was added at the regional peer review meeting after one of the participants noted the poor fit to empirical proportions mature. There was concern that this poor fit might skew the overall model fit to the data. It was suggested to simply use the empirical maturity in place of the fitted maturity ogive. The resultant fits to the primary parameters were identical to those of the base run, and derived quantities showed small reductions in spawning biomass (Table 9).

Table 8. Negative log likelihood values for the two sensitivity runs that were only taken to MPD level. see text for run descriptions.

Run	QCS	WCVI	WCHG	GIG	NMFS	WCVI historic	HS
Base run	-13.690	1.345	-2.832	-4.312	6.772	5.475	–
S11	-13.717	1.539	-2.895	-4.305	6.996	5.478	–
S12	-13.713	1.207	-1.521	-4.307	6.777	5.479	-1.225
S13	-13.690	1.345	-2.832	-4.311	6.772	5.475	–

Table 9. Selected MPD leading and derived parameter estimates for the three sensitivity runs that were only taken to MPD level. See text for run descriptions.

				Run
	Base run	S11	S12	S13
Leading parameters				
M_{female}	0.046	0.046	0.046	0.046
M_{male}	0.053	0.053	0.053	0.053
h	0.821	0.818	0.817	0.821
LN(R_0)	1.099	1.121	1.107	1.099
μ_{BT}	11.334	11.398	11.329	11.344
vL_{BT}	2.199	2.291	2.197	2.199
Δ_{BT}	-0.057	-0.055	-0.056	-0.057
μ_{MW}	–	14.541	–	–
vL_{MW}	–	2.45	–	–
Δ_{MW}	–	0.896	–	–
Derived parameters (*B* rounded to nearest hundred)				
Coast B_0	93,600	92,200	93,400	91,400
Coast B_{2024}	49,700	47,500	48,500	47,800
Coast B_{2024}/B_0	0.531	0.515	0.519	0.523
5ABC B_0	56,000	55,900	55,800	54,700
5ABC B_{2024}	26,500	26,300	26,300	25,600
5ABC B_{2024}/B_0	0.474	0.470	0.472	0.467
3CD B_0	18,700	17,800	18,700	18,300
3CD B_{2024}	11,200	9,700	10,800	10,800
3CD B_{2024}/B_0	0.597	0.545	0.581	0.593
5DE B_0	18,900	18,400	18,900	18,500
5DE B_{2024}	12,000	11,500	11,400	11,500
5DE B_{2024}/B_0	0.635	0.626	0.600	0.620

9. ADVICE FOR MANAGERS

9.1. REFERENCE POINTS

The Sustainable Fisheries Framework (SFF, DFO 2009) established provisional reference points, which incorporated the 'precautionary approach' (PA), to guide management and assess harvest in relation to sustainability. These reference points are the limit reference point (LRP) of $0.4B_{\text{MSY}}$ and the upper stock reference point (USR) of $0.8B_{\text{MSY}}$, which have been adopted by previous rockfish stock assessments (Edwards et al. 2012 a,b, 2014 a,b; DFO 2015, 2022c; Haigh et al. 2018; Starr et al. 2016; Starr and Haigh 2017, 2021a,b, 2022 a,b,c, 2023) and were used here. To determine the suitability of these reference points for this stock (or any *Sebastes* stock) would require a separate investigation involving simulation testing using a range of operating models.

The zone below $0.4B_{\text{MSY}}$ is termed the 'Critical zone' by the SFF, the zone lying between $0.4B_{\text{MSY}}$ and $0.8B_{\text{MSY}}$ is termed the 'Cautious zone', and the region above the upper stock reference point ($0.8B_{\text{MSY}}$) is termed the 'Healthy zone'. Generally, stock status is evaluated as the probability of the spawning female biomass in year *t* being above the reference points, i.e., P(B_t>$0.4B_{\text{MSY}}$) and P(B_t>$0.8B_{\text{MSY}}$). The SFF also stipulates that, when in the Healthy zone, a Removal Reference (RR, either instantaneous fishing mortality, F_t, or annual exploitation rate, u_t) must be at or below that associated with MSY under equilibrium conditions (e.g., u_{MSY}), i.e., P(u_t<u_{MSY}). Furthermore, the removal rate is to be proportionately ramped down when the stock is deemed to be in the Cautious zone, and set equal to zero when in the Critical zone.

The term 'stock status' should be interpreted as 'perceived stock status at the time of the assessment for the year ending in 2023 (i.e., beginning of year 2024)' because the value is calculated as the ratio of two estimated biomass values (B_{2024}/B_{MSY}) by a specific model using the data available up to 2023. Further, the estimate of B_{MSY} depends on the model assessment of stock productivity as well as the catch split among fisheries (if there are more than one). Therefore, comparisons of stock status among various model scenarios can be misleading because the B_{MSY} space is not the same from one model to the next.

MSY-based reference points estimated within a stock assessment model can be sensitive to model assumptions about natural mortality and stock recruitment dynamics (Forrest et al. 2018). As a result, other jurisdictions use reference points that are expressed in terms of B_0 rather than B_{MSY} (Edwards et al. 2012a, N.Z. Ministry of Fisheries 2011). These reference points, for example, are default values used in New Zealand, with $0.2B_0$ as the 'soft limit', below which management action needs to be taken, and $0.4B_0$ considered a 'target' biomass for low productivity stocks, a mean around which the biomass is expected to vary. The 'soft limit' is most equivalent to the upper stock reference (USR, $0.8B_{MSY}$) in the DFO SFF, while a 'target' biomass is not specified by the DFO SFF. New Zealand also defines another limit at $0.1B_0$, known as the 'hard limit', below which the fishery should be closed (N.Z. Ministry of Fisheries 2011). This limit is most like the SFF LRP ($0.4B_{MSY}$). Results are also provided comparing projected spawning biomass to B_{MSY} and to current spawning biomass B_{2024}, and comparing projected harvest rate to current harvest rate u_{2023} (Appendix F).

9.2. STOCK STATUS AND DECISION TABLES

In this stock assessment, projections have been made that were extended to the end of 2033 (beginning of 2034). Projections out to three generations (75 years), where one generation was determined to be 25 years (Appendix D, Section D.1.6), were not computed because the stock status of POP (in the Healthy zone) did not warrant such projections.

The base run model estimated the probability of being in the Healthy zone, $P(B_{2024} > 0.8B_{MSY})$ at 0.996 for subarea 5ABC, 0.993 for subarea 3CD, and 0.999 for subarea 5DE. The probability of being in the Cautious zone was 0.004 for 5ABC, 0.007 for 3CD, and 0.001 for 5DE. The probability of being in the Critical zone was <0.001 for all subareas. The probability of the exploitation rate being less than that at MSY, $P(u_{2023} < u_{MSY})$, was 0.954 for 5ABC, 0.976 for 3CD, and 0.998 for 5DE.

Decision tables for the POP base run provide advice to managers as probabilities that projected biomass B_t (t = 2025, ..., 2034) will exceed biomass-based reference points (or that projected exploitation rate u_t (t = 2024, ..., 2033) will fall below harvest-based reference points) under constant-catch policies (Table 10). That is, the table presents probabilities that projected B_t using the base run will exceed the LRP and the USR or will be less than the exploitation rate at MSY. All decision tables (including those for alternate reference points) for the base run can be found in Appendix F (Tables F8 to F17).

Assuming that a catch of 1,750 t (close to the recent 5-y mean) will be taken in 5ABC for each year over the next 10 years, Table 10 indicates that a manager would be >99% certain that both B_{2029} and B_{2034} lie above the LRP of $0.4B_{MSY}$, >99% certain that both B_{2029} and B_{2034} lie above the USR of $0.8B_{MSY}$, and >99% certain that both u_{2028} and u_{2033} lie below u_{MSY} for the base run. Generally, it is up to managers to choose the preferred catch levels or harvest levels (if available) using their preferred risk levels. For example, it may be desirable to be 95% certain that B_{2034} exceeds an LRP whereas exceeding a USR might only require a 50% probability. Assuming this risk profile, all catch policies satisfy the LRP constraint in Table 10. Assuming that u_{MSY} is a target exploitation rate in 5ABC, all catch policies ≤ 2,150 t/y have a probability greater than 95% of the harvest rate remaining below u_{MSY} in 10 years, whereas catch policies ≤2,500 t/y would have a probability greater than 50%.

Although uncertainty was built into the assessment and its projections by taking a Bayesian approach for parameter estimation, these results depend heavily on the assumed model structure, the informative priors, and data assumptions (particularly the average recruitment assumptions) used for the projections.

9.2.1. Decision Tables

Table 10. Base run subareas: decision table for the limit reference point (LRP=0.4B_{MSY}) for 1–10 year projections for a range of constant catch policies (in tonnes) using the base run (B1) applied to each subarea of the base coastwide stock assessment. Values are the probability (proportion of 1,965 MCMC samples[9]) of the female spawning biomass at the start of year t being greater than the LRP. For reference, the average catch over the last 5 years (2018–2022) was CST=3,306 t, 5ABC=1,618 t, 3CD=840 t, and 5DE=848 t.

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,000	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,350	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,750	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	2,150	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	2,550	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	3,500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99
3CD	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	750	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	875	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,000	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,125	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99
	1,250	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99
5DE	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	700	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	900	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,050	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,200	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,350	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99

[9] 35 MCMC samples yielded anomalous (not a number) MSY-based quantities.

Table 11. Base run subareas: decision table for the upper stock reference (USR=0.8B_{MSY}) for 1–10 year projections for a range of constant catch policies (in tonnes) using the base run (B1) applied to each subarea of the base coastwide stock assessment. Values are the probability (proportion of 1,965 MCMC samples) of the female spawning biomass at the start of year t being greater than the USR. For reference, the average catch over the last 5 years (2018–2022) was CST=3,306 t, 5ABC=1,618 t, 3CD=840 t, and 5DE=848 t.

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,000	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.99	>0.99	>0.99
	1,350	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	1,750	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	2,150	>0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98
	2,550	>0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.97	0.97	0.97	0.96
	3,500	>0.99	0.99	0.99	0.98	0.97	0.96	0.95	0.93	0.92	0.90	0.89
3CD	0	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	500	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	750	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98
	875	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.98	0.98
	1,000	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.97	0.97	0.96
	1,125	0.99	0.99	0.99	0.98	0.98	0.98	0.97	0.97	0.96	0.95	0.95
	1,250	0.99	0.99	0.99	0.98	0.98	0.97	0.96	0.96	0.95	0.94	0.93
5DE	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	700	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99
	900	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.99
	1,050	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.97
	1,200	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.98	0.97	0.96
	1,350	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.97	0.96	0.96	0.95
	1,500	>0.99	>0.99	>0.99	0.99	0.99	0.98	0.98	0.96	0.95	0.94	0.92

Table 12. Base run subareas: decision table for the removal reference (RR=u_{MSY}) for 1–10 year projections for a range of constant catch policies (in tonnes) using the base run (B1) applied to each subarea of the base coastwide stock assessment. Values are the probability (proportion of 1,965 MCMC samples) of the exploitation rate at the middle of year t being less than the RR. For reference, the average catch over the last 5 years (2018–2022) was CST=3,306 t, 5ABC=1,618 t, 3CD=840 t, and 5DE=848 t.

area	CC(t/y)	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
5ABC	0	1	1	1	1	1	1	1	1	1	1	1
	1,000	>0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	>0.99	>0.99	>0.99
	1,350	0.98	0.98	0.98	0.98	0.98	0.97	0.97	0.97	0.97	0.97	0.97
	1,750	0.93	0.93	0.92	0.92	0.92	0.91	0.91	0.91	0.91	0.91	0.91
	2,150	0.86	0.85	0.85	0.84	0.83	0.83	0.82	0.82	0.82	0.81	0.81
	2,550	0.78	0.77	0.75	0.74	0.73	0.72	0.70	0.70	0.70	0.69	0.69
	3,500	0.59	0.55	0.53	0.50	0.47	0.44	0.43	0.41	0.41	0.40	0.40
3CD	0	1	1	1	1	1	1	1	1	1	1	1
	500	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.99
	750	0.98	0.98	0.98	0.98	0.98	0.98	0.97	0.97	0.97	0.97	0.97
	875	0.97	0.97	0.97	0.96	0.96	0.96	0.95	0.95	0.95	0.94	0.94
	1,000	0.96	0.96	0.95	0.94	0.94	0.93	0.92	0.91	0.91	0.90	0.90
	1,125	0.94	0.93	0.92	0.91	0.91	0.90	0.88	0.88	0.87	0.86	0.84
	1,250	0.92	0.91	0.89	0.88	0.87	0.86	0.83	0.82	0.80	0.79	0.78
5DE	0	1	1	1	1	1	1	1	1	1	1	1
	700	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	900	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.98	0.98
	1,050	>0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.97	0.97	0.96	0.96
	1,200	0.99	0.99	0.98	0.98	0.97	0.96	0.95	0.95	0.94	0.93	0.93
	1,350	0.98	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91	0.89	0.87
	1,500	0.97	0.96	0.95	0.94	0.93	0.91	0.89	0.87	0.85	0.83	0.80

Table 13. Base run subareas: decision table for an alternative reference point (>0.2B_0) based on equilibrium, unfished spawning biomass (B_0) for 1–10 year projections for a range of constant catch policies (in tonnes) using the base run (B1) applied to each subarea of the base coastwide stock assessment. Values are the probability (proportion of 1,965 MCMC samples) of the female spawning biomass at the start of year t being greater than 0.2B_0. For reference, the average catch over the last 5 years (2018–2022) was CST=3,306 t, 5ABC=1,618 t, 3CD=840 t, and 5DE=848 t.

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,000	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,350	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,750	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	2,150	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99
	2,550	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.98
	3,500	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.98	0.96	0.95	0.94	0.93
3CD	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	750	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99
	875	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	1,000	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98
	1,125	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.98	0.97	0.97	0.96
	1,250	>0.99	>0.99	>0.99	0.99	0.99	0.98	0.98	0.97	0.96	0.95	0.94
5DE	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	700	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	900	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99
	1,050	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99
	1,200	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.98
	1,350	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.98	0.97
	1,500	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.98	0.96	0.94

Table 14. Base run subareas: decision table for an alternative reference point (>0.4B_0) based on equilibrium, unfished spawning biomass (B_0) for 1–10 year projections for a range of constant catch policies (in tonnes) using the base run (B1) applied to each subarea of the base coastwide stock assessment. Values are the probability (proportion of 1,965 MCMC samples) of the female spawning biomass at the start of year t being greater than 0.4B_0. For reference, the average catch over the last 5 years (2018–2022) was CST=3,306 t, 5ABC=1,618 t, 3CD=840 t, and 5DE=848 t.

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	0.81	0.82	0.85	0.86	0.88	0.89	0.9	0.92	0.94	0.95	0.96
	1,000	0.81	0.8	0.81	0.81	0.81	0.81	0.81	0.82	0.84	0.85	0.86
	1,350	0.81	0.79	0.79	0.79	0.79	0.77	0.77	0.78	0.79	0.79	0.81
	1,750	0.81	0.79	0.77	0.76	0.74	0.73	0.72	0.72	0.73	0.73	0.73
	2,150	0.81	0.78	0.76	0.73	0.71	0.68	0.66	0.66	0.65	0.66	0.66
	2,550	0.81	0.77	0.74	0.70	0.67	0.63	0.61	0.60	0.59	0.59	0.59
	3,500	0.81	0.75	0.69	0.63	0.57	0.51	0.48	0.46	0.43	0.42	0.42
3CD	0	0.92	0.93	0.94	0.94	0.95	0.95	0.95	0.95	0.96	0.96	0.97
	500	0.92	0.92	0.92	0.92	0.91	0.90	0.90	0.90	0.90	0.90	0.90
	750	0.92	0.92	0.91	0.90	0.89	0.88	0.87	0.85	0.85	0.84	0.84
	875	0.92	0.91	0.90	0.89	0.88	0.86	0.84	0.83	0.82	0.81	0.80
	1,000	0.92	0.91	0.90	0.88	0.87	0.84	0.82	0.81	0.79	0.77	0.76
	1,125	0.92	0.91	0.89	0.88	0.85	0.82	0.80	0.78	0.75	0.74	0.72
	1,250	0.92	0.90	0.88	0.87	0.84	0.80	0.78	0.75	0.72	0.70	0.67
5DE	0	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.98	0.98	0.98
	700	0.97	0.96	0.95	0.94	0.93	0.92	0.91	0.90	0.89	0.88	0.87
	900	0.97	0.96	0.95	0.93	0.92	0.89	0.87	0.86	0.84	0.83	0.82
	1,050	0.97	0.96	0.94	0.92	0.90	0.87	0.85	0.82	0.8	0.77	0.75
	1,200	0.97	0.95	0.93	0.91	0.88	0.85	0.82	0.79	0.75	0.72	0.69
	1,350	0.97	0.95	0.92	0.90	0.86	0.82	0.78	0.73	0.69	0.66	0.62
	1,500	0.97	0.95	0.92	0.89	0.84	0.79	0.74	0.68	0.64	0.59	0.56

9.2.2. Decision Tables (0.5R)

In the 2022 Canary Rockfish stock assessment (Starr and Haigh 2023), an attempt was made to incorporate an environmental index series (winter Pacific Decadal Oscillation) to predict the impact of this series on predicted recruitment. However, it was found that the influence of this series on recruitment was dependent on how much relative weight was assigned to the series (through added process error). This analysis was not repeated for POP because it was inconclusive and objectivity was lost. Instead, to simulate the effects of poor environmental conditions, recruitment strength was reduced arbitrarily by half from the base-run forecast. This was done for two reasons. The first was that the SS3 platform did not provide a simple procedure by which recruitment could be reduced to a specified level (e.g., the mean of 2005–2014 recruitment), requiring a more pragmatic approach. The second was that it was felt that a strong recruitment reduction represented a short-term “worst-case” scenario that did not require additional intermediate analysis that was difficult to justify.

The decision tables presented below (Table 15 to Table 17, see Appendix F for a complete set) were generated from the base case (B1) stock assessment and then projected forward, beginning in 2015, with mean recruitment reduced by 50% relative to the projections in Section 9.2.1. SS3 replaces the ‘late recruitment deviations’ and the projected recruitment deviations estimated during the model reconstruction phase with deviations randomly drawn from a lognormal distribution with mean $0.5R_0$ and standard deviation = 0.9 (see Figure 17).

These decision tables show some effect from the reduced recruitment. While there is virtually no impact on the response to the $0.4B_{\text{MSY}}$ reference level (Table 15), there is some reduction in the predicted probabilities in Table 16 ($0.8B_{\text{MSY}}$) at the highest catch levels in all three subareas. Table 17 indicates that exploitation rate (u_t) will remain below u_{MSY} with relativity high probability, except for 5ABC in the mid-1990s. The full set of tables in Appendix F show probabilities that are consistent with the above observations: higher reference levels are more difficult to achieve under reduced recruitment.

While lowering forecast recruitment is not a definitive test, it does indicate that, under severe and continuous recruitment failure, POP stock status will drop at high catch levels. However, such an outcome seems extreme; therefore, the scenarios demonstrated in these tables are unlikely to occur.

Table 15. Low-recruitment forecast: decision table for the limit reference point (LRP=0.4B_{MSY}) for 1–10 year projections for a range of constant catch policies (in tonnes) using the base run applied to each subarea of the base coastwide stock assessment. Values are the probability (proportion of 1,972 MCMC samples[10]) of the female spawning biomass at the start of year t being greater than the LRP. For reference, the average catch over the last 5 years (2018–2022) was CST=3,306 t, 5ABC=1,618 t, 3CD=840 t, and 5DE=848 t.

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,350	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	3,500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.98	0.96	0.93
3CD	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	750	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,250	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.98	0.97	0.95	0.93
5DE	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	900	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.98	0.95

Table 16. Low-recruitment forecast: decision table for the upper stock reference (USR=0.8B_{MSY}) for 1–10 year projections for a range of constant catch policies (in tonnes) using the base run applied to each subarea of the base coastwide stock assessment. Values are the probability (proportion of 1,972 MCMC samples) of the female spawning biomass at the start of year t being greater than the USR. For reference, the average catch over the last 5 years (2018–2022) was CST=3,306 t, 5ABC=1,618 t, 3CD=840 t, and 5DE=848 t.

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	>0.99	0.99	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,350	>0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.97	0.97	0.96
	3,500	>0.99	0.99	0.98	0.97	0.95	0.92	0.87	0.81	0.75	0.69	0.63
3CD	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	>0.99	>0.99
	750	>0.99	0.99	0.99	0.99	0.98	0.97	0.97	0.96	0.95	0.94	0.92
	1,250	>0.99	0.99	0.99	0.98	0.96	0.94	0.92	0.89	0.86	0.81	0.77
5DE	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	900	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.98	0.97	0.96	0.95
	1,500	>0.99	>0.99	0.99	0.99	0.98	0.97	0.96	0.91	0.86	0.80	0.74

Table 17. Low-recruitment forecast: decision table for the removal reference (RR=u_{MSY}) for 1–10 year projections for a range of constant catch policies (in tonnes) using the base run applied to each subarea of the base coastwide stock assessment. Values are the probability (proportion of 1,972 MCMC samples) of the exploitation rate at the middle of year t being less than the RR. For reference, the average catch over the last 5 years (2018–2022) was CST=3,306 t, 5ABC=1,618 t, 3CD=840 t, and 5DE=848 t.

area	CC(t/y)	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
5ABC	0	1	1	1	1	1	1	1	1	1	1	1
	1,350	1	0.98	0.98	0.97	0.97	0.97	0.96	0.95	0.95	0.94	0.93
	3,500	1	0.52	0.47	0.42	0.38	0.34	0.30	0.27	0.24	0.21	0.18
3CD	0	1	1	1	1	1	1	1	1	1	1	1
	750	0.98	0.98	0.98	0.97	0.97	0.96	0.95	0.95	0.94	0.93	0.92
	1,250	1	0.89	0.87	0.84	0.81	0.77	0.74	0.70	0.66	0.62	0.58
5DE	0	1	1	1	1	1	1	1	1	1	1	1
	900	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.97	0.97	0.96
	1,500	1	0.95	0.94	0.92	0.90	0.87	0.83	0.78	0.73	0.67	0.61

[10] 28 MCMC samples yielded anomalous (not finite) MSY-based quantities.

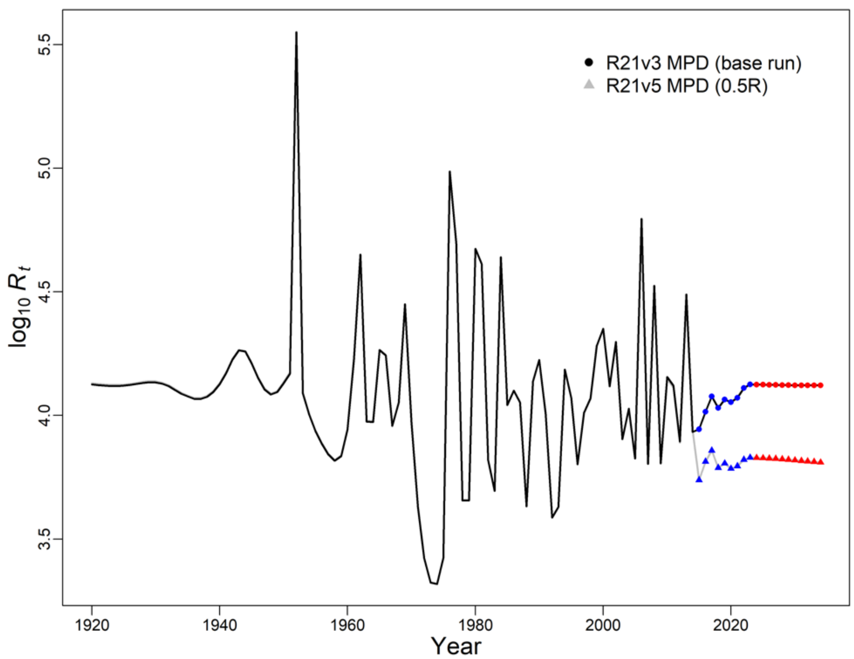

Figure 17. Low recruitment: MPD trajectories of predicted recruitment (in $\log_{10}$ space) comparing the base run (R21v3) to the 50% forecast recruitment run (R21v5). Blue symbols used for late recruitment (2015–2023), red symbols used for predicted recruitment (2024–2034)

9.3. STOCK REBUILDING

A rebuilding plan was not required because the POP stocks were assessed to be in the Healthy zone at the beginning of 2024, and were projected to remain in the Healthy zone up to the beginning of 2034 at catch levels up to 3,500 t/y in 5ABC (P>0.89), 1,250 t/y in 3CD (P>0.93), and 1,500 t/y (P>0.92) (Table 11) under the assumption of average recruitment calculated over the period 1935 to 2014.

9.4. ASSESSMENT SCHEDULE

Advice was also requested concerning the appropriate time interval between future stock assessments and, for the interim years between stock updates, potential values of indicators that could trigger a full assessment earlier than usual (as per DFO 2016). Three of the existing synoptic trawl surveys, the QCS, WCVI, and WCHG surveys, should be capable of signalling a major reduction in stock abundance. The next full stock assessment should be scheduled no earlier than 2032, given the currently assessed Healthy state and exploitation rates which are below u_{MSY}. Recent recruitment appeared to be good and the 2013 year class may have been quite good, if the signal in the 5ABC recruitment series were credible. Regardless of when a new stock assessment is to be initiated, at least 6–12 months lead time is required to allow for the reading of new ageing structures that will be needed for the interpretation of the population trajectory. Advice for interim years is explicitly included in the decision tables and managers can select another line on the table if stock abundance appears to have changed or if greater certainty of staying above the reference point is desired. During intervening years the trend in abundance can be tracked by the fishery independent surveys used in this stock assessment. The groundfish synopsis reports (Anderson et al. 2019; DFO 2022b) summarise these trends and can be used as a tracking tool.

10. GENERAL COMMENTS

In common with stock assessments for other BC rockfish, this stock assessment depicted a slow-growing, low productivity stock. Fortunately, this assessment was able to obtain credible estimates for *M*, for both males and females, which meant that it was not necessary to construct a complex synthetic composite stock to cover an appropriate range of values for this parameter. Although the female estimates for *M* are always less than those for males (see Table F.4), the differences were relatively minor compared to those observed for Canary (see Starr and Haigh 2023) and there was considerable overlap in the male and female *M* posterior distributions (see Table F.4, Figure F.28). The sex differences in *M* appeared to be adequately explained in this model by estimating a small negative shift in the *Δ* selectivity parameters (see Table F.4, Table F.28).

The greatest uncertainty in this stock assessment is the relative size of the three subarea stocks in the multi-area model. Table 7 demonstrates that this uncertainty largely centres around the size of the 3CD stock, with the estimates varying depending on the choice of arbitrary underlying assumptions. As explained in Section 8.3.1, the base run set the reference subarea to 5DE (the most northerly), calculating the proportion of average coastwide recruitment in the remaining two areas relative to the average proportion in 5DE .Two sensitivity runs (S02: fix recruitment distribution in 5ABC and S03: fix recruitment distribution in 3CD) were conducted to evaluate the sensitivity of this stock assessment to the choice of the reference subarea assumption. While the three runs (base, S02, S03) agree on the total size of the three underlying stocks, the distribution of recruitment varies among the three runs, an outcome which may be linked to the amount of available data in each subarea (Table 7). The base run and S03, which use 5DE and 3CD as the reference areas respectively, each allocated approximately 20% of the recruitment to these smaller stocks, leaving the remaining ~60% to 5ABC. On the other hand, Run S02, which used 5ABC as the reference area, allocated less than 15% of the recruitment to 3CD, 22% to 5DE and the balance to 5ABC. This is the only run that downsized 3CD, because even the single-area models, if summed, allocated over 20% of the total stock size to 3CD. This latter comparison is not the same as that from the three multi-area models, because the three single-area models differ in terms of the estimated *M* and steepness, while the multi-area models share these parameters and thus allow for direct comparison. The 3CD single-area estimate of B_0 may also be biased high in order to accommodate the large pre-1978 catches under the assumption of deterministic recruitment. It is not possible to resolve this issue, given the present state of the data. The choice of the reference area in the base run was arbitrary and the authors did not want to change that choice, once this issue became apparent over the course of the stock assessment. It is likely best to continue with the chosen base run, but to treat the evaluation and predictions for 3CD with caution.

Foreign fleet effort in 1965–76 along the BC coast targeted offshore rockfish (mainly POP), but the magnitude of the foreign fleet removals of POP remains uncertain because reporting back then, even for total rockfish catch, was not as rigorous as now and the uncertainty in the catch by species was also great. Another source of uncertainty in the historical catch series comes from domestic landings from the mid-1980s to 1995 (pre-observer coverage) which may have misreported lesser rockfish species to bypass quota restrictions on more desirable species like POP (Starr and Haigh 2022a), leading to uncertainty in the allocation of catch by rockfish species. The sensitivity runs on catch (S07: -30%; S08: +50%) showed that catch uncertainty did not have a major effect on the model’s biomass trajectory or on the estimates of the relative stock size at the beginning of 2024 (Table F.29). However, S08 (+50%) resulted in an increase in absolute stock size (Figure 14), which would imply greater productivity than was estimated by the base run while S07 (-30%) showed a drop in stock size which implies a lowering of potential productivity.

Following the lead of the recent Canary stock assessment (Starr and Haigh 2023), three sensitivity runs in addition to the base run were made to address the issue of potential bias entering the model predictions depending on the ageing error assumptions. In these analyses, ageing error was introduced into the model using a smoothed function rather than the highly variable information based on the individual observations at each age. Figure D.20 plots the smoothed functions along with the underlying age-specific observations.

- The base run (B1) used the AE3 series that resulted from a smoothing function (Figure D.20) of standard deviations (SD) derived from CVs of length-at-age. This function overlapped with the AE5 series (see next bullet) up to age 20, and then continued to increase right up to age 60 (Figure D.20).
- Sensitivity run S05 implemented the AE5 series (smoothed SD derived from reader error CVs) which dropped away from the AE3 series after age 20, but continued to increase more slowly than the AE3 series, reaching a lower relative adjustment than the AE3 series at age 60. This run generated a similar biomass trajectory to the base run, lying slightly above the base run for B_0, and B_{2024} (Figure 14), but reaching the same median estimate for B_{2024}/B_0 as did B1 (Table F.29).
- Sensitivity run S06 implemented a constant 10% error at all ages (series AE6), resulting in a series that rose more quickly than AE3 (Figure D.20). This run again resulted in a biomass trajectory that was similar to, but lying slightly below, the base run for B_0, and B_{2024} (Figure 14), but again reaching the same median estimate for B_{2024}/B_0 compared to B1 (Table F.29).
- Sensitivity run S04 dropped ageing error entirely. This run diverged from the base run, with B_0 estimated to be about 60% greater than for the base run and B_{2024} was about 45% greater than for the base run although the median B_{2024}/B_0 only dropped to 0.54 compared to 0.58 for B1 (Table F.29).

While S04 (no ageing error) diverged from the base run in that it estimated a much larger stock size, the runs which applied ageing error all returned similar estimates for B_{2024}/B_0. Therefore we concluded that, while ageing error needed to be included in the assessment, model results were not sensitive to the applied procedure. We also note that even the 'no ageing error' run did not materially change the stock status advice. This result was quite similar to the conclusions of the Canary Rockfish stock assessment (Starr and Haigh 2023).

Raising (S10) or lowering (S09) the standard deviation of recruitment residuals (σ_R) marginally affected the estimate of B_0, where the median estimate rose 10% for S10 and dropped 4% for S09. However, the estimates of B_{2024}/B_0 were similar to the base run, with the median estimate for S09 at 0.58 and at 0.55 for S10 compared to 0.58 for the base run (Table F.29). These results indicate that this stock assessment was not sensitive to this model assumption. Also, as reported in Section 8.3.1, the empirical calculation of the standard deviation of the recruitment deviations was 1.05, which is close to the assumed 0.9 value used in the base run.

The implementation of the Dirichlet-Multinomial procedure for weighting the AF data was the initial choice for this stock assessment, after having successfully used this procedure for assessing Canary Rockfish in 2022 (Starr and Haigh 2023). However, exploratory analyses which used larger alternative sample weights resulted in a considerable downward shift in the estimated POP stock size (-38%) when using the D-M procedure but almost no change in the stock size when using the Francis (2011) procedure (see discussion in E.6.2.3). Consequently the D-M procedure was relegated to a sensitivity run (S01) and should not be used for management advice.

Two runs (S11 and S12) were only taken to the MPD level to test the sensitivity of the stock assessment to two assumptions made when choosing the data inputs used in the base run (B1): the amalgamation of the BT and MW fisheries into a single fishery (S11) and the exclusion of the Hecate Strait synoptic survey (S12). As presented in Section 8.3.2, these choices appeared to have had little impact on the advice stemming from the base run, thus corroborating the data choices made for the base run.

The 2022 Canary Rockfish stock assessment suggested, based on the recruitment deviation time series, that there had been a period (1935–1995) of below-average recruitment followed by a period of above-average recruitment, which possibly could be interpreted as a “regime shift” (Starr and Haigh 2023). There is little suggestion of this in the POP recruitment deviation time series from this stock assessment (see top panel in Figure F.24), leading to little incentive to explore possible environmental scenarios for this stock. Consequently, a single projection run after arbitrarily reducing the mean recruitment by 50% has been presented as a possible “worst case” scenario in terms of recruitment over the next 10 years to 2034 (see Section 9.2.2).

The decision tables provide guidance to the selection of short-term catch recommendations and describe the range of possible future outcomes over the projection period at fixed levels of annual catch. The accuracy of the projections was predicated on the model being correct. Uncertainty in the parameters was explicitly addressed using a Bayesian approach but reflected only the specified model and weights assigned to the various data components.

11. FUTURE RESEARCH AND DATA REQUIREMENTS

The following issues should be considered when planning future stock assessments and management evaluations for Pacific Ocean Perch:

1. Continue the suite of fishery-independent trawl surveys that have been established across the BC coast. This includes obtaining age and length composition samples, which will allow the estimation of survey-specific selectivity ogives.
2. Support/improve the collection of additional ageing structures, particularly from the commercial bottom and midwater trawl fisheries. The lack of biological sampling in the commercial fisheries after 2019 was a serious deficiency in this stock assessment.
3. If sufficient midwater trawl fishery biological data become available, consider adding midwater trawl as a separate fishery.
4. Consider using constant harvest rates if it is required to project farther than 10 years.
5. Explore changes in selectivity over time and how this might be affecting recruitment deviations.
6. If using SS3’s multi-area model, consider fixing 5ABC as the reference area when allocating coastwide recruitment. In this assessment, 5DE was fixed (arbitrarily).
7. Explore options for including environmental information into a *Sebastes* rockfish stock assessment. First, a wider range of environmental covariates needs to be identified and the potential effect by each series on fish recruitment evaluated. Then the candidate covariates should be evaluated across a range of species, not just within a single-species stock assessment. It is fairly clear that this approach could create a source document that could be referenced by future stock assessments. If an index series relevant to a species is identified, then the stock assessment will have a more defensible basis on which to include the series.

8. Consider using a single-sex (combined-sex) model in the next POP assessment. This would be a sensitivity to check if possible biases have been introduced through the use of sex-specific data.
9. Explore alternative analyses of age composition data (e.g., standardisation techniques) that could produce model estimates of sampling uncertainty rather than *ad hoc* weighting assumptions.
10. Estimate growth by cohort to explore potential density-dependent responses in growth (i.e., large cohorts exhibit slower growth possibly due to resource competition).
11. Conduct research on the spatial distribution of life-cycle stages. We note that this recommendation is outside of the scope of a stock assessment.
12. Continue collaboration of POP genetics along the BC coast in conjunction with the research by Wes Larson in Alaska.
13. Explore using a more flexible maturity function in future assessments such that the function more closely fits the observed maturities. For POP, assess if the parasite (*Sarcotaces*) affects maturity. This would require an understanding of the prevalence of this parasite in the POP population.
14. Estimate q (survey catchability) in the next stock assessment (even if it's only a sensitivity) rather than treat it as a nuisance parameter.
15. It is not possible, given the existing data set, to directly test whether age samples have been randomly selected from a tow or a trip. The best that can be done would be to test for randomness between the length frequencies associated with the age frequency samples and the overall length frequency samples obtained from the commercial fishery. This should be done by fishing year and stock area (3CD, 5ABC, 5DE). We note that the total length frequencies by year and stock area are not well known because a comprehensive sampling programme of the BC rockfish trawl fishery was not implemented until 2023.
16. Explore standardisation methods that could be used to fill in missing AF data (by year and age).
17. Explore the bycatch of COSEWIC species by targeted POP fisheries.

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APPENDIX A. CATCH DATA

A.1. BRIEF HISTORY OF THE FISHERY

Forrester (1969) provides a brief history of the Pacific Marine Fisheries Commission (PMFC), which is reproduced (with some modification) below. Currently, the PMFC is called the Pacific States Marine Fisheries Commission; however, this document retains the acronym 'PMFC' for historical context.

> *The Pacific Marine Fisheries Commission (PMFC) was created in 1947 when the states of Washington, Oregon, and California jointly formed an interstate agreement (called a 'compact') with the consent of the 80th Congress of the USA. In 1956, informal agreement was reached among various research agencies along the Pacific coast to establish a uniform description of fishing areas as a means of coordinating the collection and compilation of otter trawl catch statistics. This work was undertaken by the PMFC with the informal cooperation of the Fisheries Research Board of Canada. Areas 1A, 1B, and 1C encompass waters off the California coast, while Areas 2A-2D involve waters adjacent to Oregon and a small part of southern Washington. The remainder of the Washington coast and the waters off the west coast of Vancouver Island comprise Areas 3A-3D, while United States and Canadian inshore waters (Juan de Fuca Strait, Strait of Georgia, and Puget Sound) are represented by Areas 4A and 4B, respectively. Fishing grounds between the northern end of Vancouver Island and the British Columbia-Alaska boundary are represented by Areas 5A-5E. The entire Alaskan coast is designated as Area 6, but except for a small amount of fishing in inshore channels, this area has not been trawled intensively by North American nationals.*

The early history of the British Columbia (BC) trawl fleet is discussed by Forrester and Smith (1972). A trawl fishery for slope rockfish has existed in BC since the 1940s. Aside from Canadian trawlers, foreign fleets targeted Pacific Ocean Perch (POP, *Sebastes alutus*) in BC waters for approximately two decades. These fleets came from the USA (1950–1975), the USSR (1965–1972), and Japan (1966–1977). The foreign vessels removed large amounts of rockfish biomass (POP included), particularly in Queen Charlotte Sound (5ABC). Canadian effort escalated in 1965 but the catch never reached the levels of those by the combined foreign vessels.

Prior to 1977, no quotas were in effect for slope rockfish species. Since then, the groundfish management unit (GMU) at the Department of Fisheries and Oceans (DFO) imposed a combination of species/area quotas, area/time closures, and trip limits on the major species. Quotas were first introduced for POP (and Yellowmouth Rockfish *Sebastes reedi*) in 1979 for GMU area 5AB (Table A.1 and Table A.2). On April 18, 1997 (one month into the IVQ program) the boundaries of GMU areas 5AB, 5CD, and 5E were adjusted to extend 5CD southwest around Cape St. James (see Section A.2.3.8) for these two species only (Barry Ackerman, GMU, pers. comm.).

In the 1980s, experimental over-harvesting of POP stocks was attempted in two regions along the BC coast (Leaman and Stanley 1993; Leaman 1998). The objectives of the experiments included (i) ground-truthing trawl survey biomass estimates, (ii) estimating fishing mortality, (iii) validating ageing techniques by introducing a large negative anomaly in the age composition, (iv) exploring stock-recruitment relationships, and (v) involving industry in research and management.

The first experiment occurred off the WCVI where a specified overharvest was set (TAC = 500 t) from 1980 to 1984 before returning to a level deemed sustainable at 300 t (Stocker 1981). The experiment experienced no implementation problems and reporting by industry was deemed acceptable. The 3C TAC was subsequently reduced to 100 t in 1986 and remained low until 1993.

The second overharvesting experiment occurred in the Langara Spit area of PMFC 5E off the northwest coast of Haida Gwaii. This experiment differed from the WCVI one in that quotas were removed entirely in 1983 to allow five years of unrestricted fishing followed by five years of severely limited fishing. However, a scheduled closure set for 1988 did not occur because the harvesters and the region had become dependent on the higher harvest levels (Leaman 1998). Some of the fishers maintained that there was little or no evidence of over-exploitation, and misreporting of catch could not be controlled. Discussions involving harvesters, politicians, and DFO managers negotiated extensions of the fishery, but eventually the Langara Spit area was closed in 1993 to all trawl fishing.

In 1996, an onboard observer program was initiated, placing observers aboard all offshore trawl vessels (Option B). In 1997, an Individual Vessel Quota (IVQ) system was put in place to allocate tradable rights to each registered vessel for a share of the total allowable catch (TAC) by species. In 2001, DFO reduced the 5CD POP TAC by 300 t for research use as payment for the Hecate Strait Pacific Cod charter (over three seasons), and in 2006 DFO again reduced the 5CD POP TAC by 700 t for use in possible research programs (Table A.2). After the 2010 assessment (Edwards et al 2012), management implemented a conservation-measure TAC reduction in 5AB+5CD of 258 t per year over a three year period (for a 774 t total reduction).

In 2012, measures were introduced to reduce and manage the bycatch of corals and sponges by the BC groundfish bottom trawl fishery. These measures were developed jointly by industry and environmental non-governmental organisations (Wallace et al. 2015), and included: limiting the footprint of groundfish bottom trawl activities, establishing a combined bycatch conservation limit for corals and sponges, and establishing an encounter protocol for individual trawl tows when the combined coral and sponge catch exceeded 20 kg. These measures have been incorporated into DFO's Pacific Region Groundfish Integrated Fisheries Management Plan (Feb 21, 2023, version 3.0) and apply to all vessels using trawl gear in BC.

Table A.1. Annual Total Allowable Catch (TAC tonnes/year) for POP caught in BC waters: year can either be calendar year (1993–1996) or fishing year (1997 on). See Table A.2 for details on sector and research allocations, as well management actions.

Year	Start	End	3C	3D	3CD	5AB	5C	5CD	5DE	5E	Coast	Notes*
1979	1/1/1979	12/31/1979	50	—	—	2,000	—	—	—	600	2,650	—
1980	1/1/1980	12/31/1980	600	—	—	2,200	—	—	—	800	3,600	a
1981	1/1/1981	12/31/1981	500	—	—	1,500	—	1,800	—	800	4,600	—
1982	1/1/1982	12/31/1982	500	250	—	1,000	—	2,000	—	800	4,550	—
1983	1/1/1983	12/31/1983	500	250	—	1,000	—	2,000	—	—	3,750	b
1984	1/1/1984	12/31/1984	500	250	—	800	—	2,000	—	—	3,550	c
1985	1/1/1985	12/31/1985	300	350	—	850	—	2,000	—	—	3,500	—
1986	1/1/1986	12/31/1986	100	350	—	500	—	2,000	—	—	2,950	d
1987	1/1/1987	12/31/1987	100	350	—	500	—	2,000	—	—	2,950	—
1988	1/1/1988	12/31/1988	100	350	—	700	—	3,000	—	—	4,150	—
1989	1/1/1989	12/31/1989	150	400	—	850	—	3,000	—	400	4,800	e
1990	1/1/1990	12/31/1990	150	400	—	850	—	2,450	—	400	4,250	—
1991	1/1/1991	12/31/1991	0	400	—	850	—	2,150	—	400	3,800	—
1992	1/1/1992	12/31/1992	0	400	—	850	—	2,400	—	400	4,050	—

Year	Start	End	3C	3D	3CD	5AB	5C	5CD	5DE	5E	Coast	Notes*
1993	1/1/1993	12/31/1993	150	400	—	850	—	2,400	—	400	4,200	f,g
1994	1/15/1994	12/31/1994	1,173	207	—	2,177	—	1,107	—	253	4,917	h,i
1995	1/1/1995	12/31/1995	548	72	—	1,892	—	1,178	—	544	4,234	j
1996	2/6/1996	3/31/1997	491	164	—	1,500	—	4,003	—	726	6,884	k,l
1997	4/1/1997	3/31/1998	431	230	—	2,358	—	2,818	—	644	6,481	m,n,o
1998	4/1/1998	3/31/1999	300	230	—	2,070	—	2,817	—	730	6,147	—
1999	4/1/1999	3/31/2000	300	230	—	2,070	—	2,817	—	730	6,147	—
2000	4/1/2000	3/31/2001	300	230	—	2,070	—	2,818	—	730	6,148	p
2001	4/1/2001	3/31/2002	300	230	—	2,070	—	2,818	—	730	6,148	q,r
2002	4/1/2002	3/31/2003	300	230	—	2,070	—	2,518	—	730	5,848	s
2003	4/1/2003	3/31/2004	300	230	—	2,070	—	2,818	—	730	6,148	—
2004	4/1/2004	3/31/2005	300	230	—	2,070	—	2,818	—	730	6,148	—
2005	4/1/2005	3/31/2006	300	230	—	2,070	—	2,818	—	730	6,148	—
2006	4/1/2006	3/31/2007	300	230	—	2,070	—	2,118	—	730	5,448	t,u,v
2007	3/10/2007	3/31/2008	300	230	—	2,070	—	2,118	—	730	5,448	—
2008	3/8/2008	2/20/2009	300	230	—	2,070	—	2,118	—	730	5,448	—
2009	2/21/2009	2/20/2010	300	230	—	2,070	—	2,118	—	730	5,448	—
2010	2/21/2010	2/20/2011	300	230	—	2,070	—	2,118	—	730	5,448	—
2011	2/21/2011	2/20/2013	300	230	—	1,942	—	1,987	—	730	5,189	w
2012	2/21/2011	2/20/2013	300	230	—	1,814	—	1,856	—	730	4,930	x
2013	2/21/2013	2/20/2014	—	—	750	1,664	1,555	—	1,200	—	5,169	y,z,A,B,C
2014	2/21/2014	2/20/2015	—	—	750	1,687	1,544	—	1,200	—	5,192	D
2015	2/21/2015	2/20/2016	—	—	750	1,687	1,544	—	1,200	—	5,192	E,F
2016	2/21/2016	2/20/2017	—	—	750	1,687	1,544	—	1,200	—	5,192	G
2017	2/21/2017	2/20/2018	—	—	750	1,687	1,544	—	1,200	—	5,192	H
2018	2/21/2018	2/20/2019	—	—	750	1,687	1,544	—	1,200	—	5,192	I
2019	2/21/2019	2/20/2020	—	—	750	1,687	1,544	—	1,200	—	5,192	J
2020	2/21/2020	2/20/2021	—	—	750	1,687	1,555	—	1,200	—	5,192	K
2021	2/21/2021	2/20/2022	—	—	750	1,687	1,555	—	1,200	—	5,192	L
2022	2/21/2022	2/20/2023	—	—	750	1,687	1,555	—	1,200	—	5,192	M
2023	2/21/2023	2/20/2024	—	—	750	1,687	1,555	—	1,200	—	5,192	N

Table A.2. Codes to notes on management actions and quota adjustments that appear in Table A.1. Abbreviations that appear under 'comments': Agg = Aggregate, DFO = Department of Fisheries & Oceans, DMP = dockside monitoring program, GTAC =Groundfish Trawl Advisory Committee, H&L = hook and line, IFMP = Integrated Fisheries Management Plan, IVQ = individual vessel quota, MC =Mortality Cap, PMFC=Pacific Marine Fisheries Commission, TAC =Total Allowable Catch, TWL = Trawl. For further details, search for archived Pacific Region Integrated Fisheries Management Plans on DFO's Federal Science Libraries Network. Rockfish species codes: POP=Pacific Ocean Perch, SRF=slope rockfish (offshore), BKR=Black, CAR=Canary, CHR=China, CPR=Copper, LST=Longspine Thornyhead, ORF=Other rockfish, QBR=Quillback, RER=Rougheye/Blackspotted, RSR=Redstripe, SCR=Sharpchin, SGR=Silvergray, SKR=Shortraker, SST=Shortspine Thornyhead, TIR=Tiger, WWR=Widow, YMR=Yellowmouth, YTR=Yellowtail.

*	year	comment
a	1980	POP: Started experimental over-harvesting of SW Vancouver Island POP stock.
b	1983	POP: Started experimental unlimited harvesting of Langara Spit POP stock (5EN).
c	1984	POP: Ended experimental over-harvesting of SW Vancouver Island POP stock.
d	1986	SRF: Slope rockfish (POP, YMR, RER) coastwide quota = 5,000 t.
e	1989	POP: In 1989, quota rockfish comprising Pacific Ocean Perch, Yellowmouth Rockfish, Canary Rockfish and Silvergray Rockfish, will be managed on a coastwide basis.
f	1993	POP: Stopped experimental fishing of Langara Spit POP stock.
g	1993	POP: Closed POP fishery in PMFC area 5EN (Langara Spit).
h	1994	TWL: Started a dockside monitoring program (DMP) for the Trawl fleet.
i	1994	POP: As a means of both reducing at-sea discarding and simplifying the harvesting regime, rockfish aggregation was implemented. Through consultation with GTAC, the following aggregates were identified: Agg 1= POP, YMR, RER, CAR, SGR, YTR; Agg 2= RSR, WWR; Agg 3= SKR, SST, LST; Agg 4= ORF.
j	1995	POP: Trawl aggregates established in 1994 changed: Agg 1= CAR, SGR, YTR, WWR, RER; Agg 2= POP, YMR, RSR; Agg 3= SKR, SST, LST; Agg 4= ORF.
k	1996	TWL: Started 100% onboard observer program for offshore Trawl fleet.
l	1996	POP: Rockfish aggregation will continue on a limited basis in 1996: Agg 1= YTR, WWR; Agg 2= CAR, SGR; Agg 3= POP, YMR; Agg 4= RER, SKR; Agg 5= RSR, SCR; Agg 6= ORF incl. SST, LST
m	1997	TWL: Started IVQ system for Trawl Total Allowable Catch (TAC) species (April 1, 1997)
n	1997	POP: Permanent boundary adjustment – Pacific Ocean Perch and Yellowmouth Rockfish caught within Subarea 102-3 and those portions of Subareas 142-1, 130-3 and 130-2 found southerly and easterly of a straight line commencing at 52°20'00"N 131°36'00"W thence to 52°20'00"N 132°00'00"W thence to 51°30'00"N 131°00'00"W and easterly and northerly of a straight line commencing at 51°30'00"N 131°00'00"W thence to 51°39'20"N 130°30'30"W will be deducted from the vessel's 5CD IVQ for those two species.
o	1997	H&L: All H&L rockfish, with the exception of YYR, shall be managed under the following rockfish aggregates: Agg 1= QBR, CPR; Agg 2= CHR, TIR; Agg 3= CAR, SGR; Agg 4= RER, SKR, SST, LST; Agg 5= POP, YMR, RSR; Agg 6= YTR, BKR, WWR; Agg 7= ORF excluding YYR.
p	2000	ALL: Formal discussions between the hook and line rockfish (ZN), halibut and trawl sectors were initiated in 2000 to establish individual rockfish species allocations between the sectors to replace the 92/8 split. Allocation arrangements were agreed to for rockfish species that are not currently under TAC. Splits agreed upon for these rockfish will be implemented in the future when or if TACs are set for those species.

*	year	comment
q	2001	ALL: An agreement reached amongst the commercial groundfish industry has established the allocation of the rockfish species between the commercial Groundfish Trawl and Groundfish Hook and Line sectors.
r	2001	POP: TAC reduction (3y) for POP – DFO reduced the 5CD POP TAC by 300 tonnes for research use as payment for the Hecate Strait Pacific Cod charter for each of the next three fishing seasons.
s	2002	TWL: Closed areas to preserve four hexactinellid (glassy) sponge reefs.
t	2006	ALL: Introduced an Integrated Fisheries Management Plan (IFMP) for all directed groundfish fisheries.
u	2006	H&L: Implemented 100% at-sea electronic monitoring and 100% dockside monitoring for all groundfish H&L fisheries.
v	2006	POP: TAC reduction for POP – DFO reduced the 5CD POP TAC by 700 tonnes for use in possible research programs.
w	2011	POP: TAC adjustment (3y) for POP – combined 5ABCD POP TAC reduction to 3,413 t will be achieved over a three year period through an annual reduction of 258 t. The expected catch level will be 68% of TAC.
x	2012	TWL: Froze the footprint of where groundfish bottom trawl activities can occur (all vessels under the authority of a valid Category T commercial groundfish trawl license selecting Option A as identified in the IFMP).
y	2013	TWL: To support groundfish research, the groundfish trawl industry agreed to the trawl TAC offsets to account for unavoidable mortality incurred during the joint DFO-Industry groundfish multi-species surveys in 2013.
z	2013	POP: New species-area groups have been created for Pacific Ocean Perch for 3CD, 5AB, 5C and 5DE.
A	2013	POP: Combine 5ABCD TACs reduction to 3413 mt is to be achieved over a three year period through an annual reduction of 258 mt. 2013/14 is the third year of this three year period. The expected catch level is to be 68% of TAC. TAC is subject to annual review.
B	2013	POP: Pacific Ocean Perch within Subarea 127-1 and that portion of Subareas 127-2 found northerly and westerly of 50°06'00"N will be deducted from the vessel's Pacific Ocean Perch rockfish 5A/B IVQ.
C	2013	POP: Research allocations (trawl): 5AB=22.6 t
D	2014	POP: Research allocations (trawl): 5DE=49.4 t
E	2015	ALL: Research allocations were specified starting in 2015 to account for the mortalities associated with survey catches to be covered by TACs.
F	2015	POP: Research allocations (trawl): 5AB=16.4 t, 5C=0.6 t, Total=17 t
G	2016	POP: Research allocations (trawl): 3CD=15.3 t, 5DE=41.8 t, Total=57.1 t
H	2017	POP: Research allocations (trawl): 5AB=17.1 t, 5C=0.8 t, Total=17.9 t
I	2018	POP: Research allocations (trawl): 3CD=32 t, 5DE=41.8 t, Total=73.8 t
J	2019	POP: Research allocations (trawl): 5AB=20.8 t, 5C=1.0 t, Total=21.8 t
K	2020	POP: Research allocations (trawl): 3CD=12.8 t, 5E=87.1 t, Total=99.9 t
L	2021	POP: Research allocations (trawl): 5AB=19.4 t, 5CD=1.5 t, Total=20.8 t
M	2022	POP: Research allocations (trawl): 3CD=9.8 t, 5E=106.5 t, Total=116.3 t
N	2023	POP: Research allocations (trawl): 5AB=21.8 t, 5CD=1.5 t, Total=23.3 t

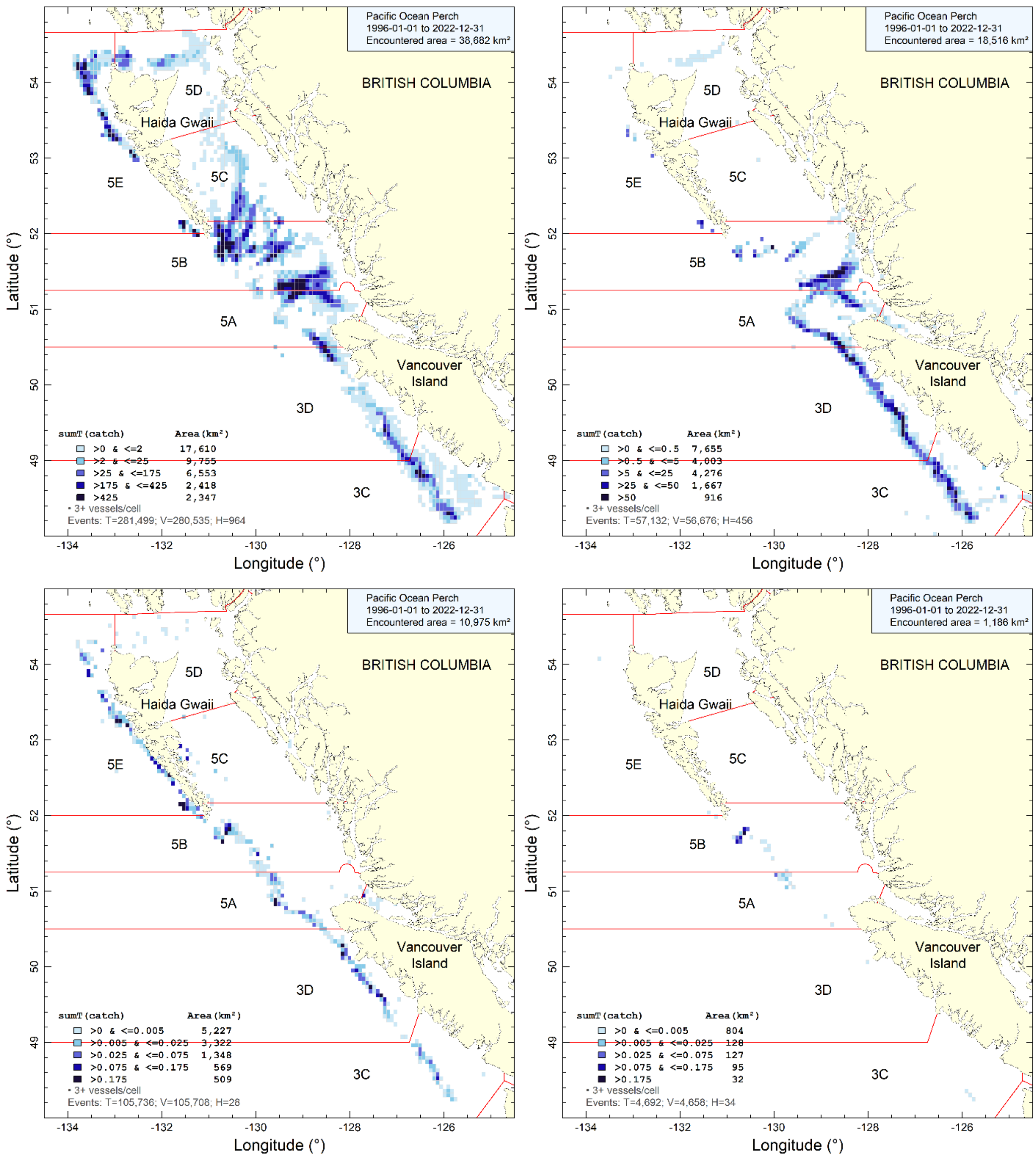

Figure A.1. Areal distribution of accumulated POP catch (tonnes) by bottom trawl (upper left), midwater trawl (upper right), hook and line fisheries (lower left), and trap fisheries (lower right) from 1996 to 2022 in grid cells 0.075° longitude by 0.055° latitude (roughly 32 km²). Isobaths show the 100, 200, 500, and 1,200 m depth contours. Cells with <3 fishing vessels are not displayed (T=total events, V=viewed events, H=hidden events). Catch scales differ among panels to highlight hotspots.

A.2. CATCH RECONSTRUCTION

This assessment reconstructs POP catch back to 1918 but considers the start of the fishery to be 1935 (Figure A.2) before the fishery started to increase during World War II. Prior to this, trawl catches of POP were negligible (~1 tonne/year) and non-trawl fleet catches occurred in trace amounts. During the period 1950–1975, US vessels routinely caught more rockfish than did Canadian vessels. Additionally, from the mid-1960s to the mid-1970s, foreign fleets (Russian and Japanese) removed large amounts of rockfish, primarily POP. These large catches were first reported by various authors (Westrheim et al. 1972; Gunderson et al. 1977; Leaman and Stanley 1993); however, Ketchen (1980a,b) re-examined the foreign fleet catch, primarily because statistics from the USSR called all rockfish 'perches' while the Japanese used the term 'Pacific ocean perch' indiscriminately. In the catch reconstruction, all historical foreign catches (annual rockfish landings) were tracked separately from Canadian landings, converted to foreign-caught POP (Section A.2.2), and added to total POP landings during the reconstruction process.

A.2.1. Data sources

Starting in 2015, all official Canadian catch tables from the databases below (except `PacHarv3`) have been merged into one table called '`GF_MERGED_CATCH`', which is available in DFO's `GFFOS` database. All groundfish DFO databases are now housed on the `DFBCV9TWVASP001` server. POP catch by fishery sector ultimately comes from the following seven DFO databases:

- `PacHarv3` sales slips (1982–1995) – hook and line only;
- `GFCatch` (1954–1995) – trawl and trap;
- `PacHarvHL` merged data table (1986–2006) – halibut, Schedule II troll, ZN rockfish;
- `PacHarvSable` fisherlogs (1995–2005) – Sablefish trap and longline;
- `PacHarvest` observer trawl (1996–2007) – primarily bottom trawl;
- `GFFOS` groundfish subset from Fishery Operation System (2006–present) – all fisheries and modern surveys; and
- `GFBioSQL` joint-venture hake and research survey catches (1947–present) – multiple gear types. `GFBioSQL` is an SQL Server database that mirrors the `GFBio` Oracle database.

All data sources other than `PacHarv3` were superseded by `GFFOS` from 2007 on because this latter repository was designed to record all Canadian west coast landings and discards from commercial fisheries and research activities. Reporting changed in GFFOS to reflect fishing 'sectors' that were different for some of the fisheries; primarily, Schedule II became 'Spiny Dogfish' and 'Lingcod' while ZN hook and line became "Rockfish Inside' (waters between Vancouver Island and the BC mainland) and 'Rockfish Outside' (waters offshore and excluding Inside waters).

Prior to the modern catch databases, historical landings of aggregate rockfish – either total rockfish (TRF) or rockfish other than POP (ORF) – are reported by eight different sources (see Haigh and Yamanaka 2011). The earliest historical source of rockfish landings comes from Canada Dominion Bureau of Statistics (1918–1950). Ketchen (1976) provides the bulk of trawl landings in the middle period (1950–1975).

The purpose of this procedure was to estimate the reconstructed catch of any rockfish species (generically designated as RRF) from ratios of RRF/ORF or RRF/TRF to determine landings, and then adding estimated discards from the ratio RRF/TAR (where TAR is the target species landed by fishery) to reconstruct the total catch removal (or total mortality, using GMU's language) of species RRF.

A.2.2. Reconstruction details

A.2.2.1. Definition of terms

A brief synopsis of the catch reconstruction (CR) follows, with a reminder of the definition of terms:

Fisheries: there are five fisheries in the reconstruction (even though trawl dominates the POP fishery):

- T = groundfish trawl (bottom + midwater),
- H = Halibut longline,
- S = Sablefish trap/longline,
- DL = Dogfish and Lingcod troll/longline (originally called 'Schedule II'),
- ZN = hook and line rockfish (sector called 'ZN' from 1986 to 2006 and 'Rockfish Outside' and 'Rockfish Inside' from 2007 on).

TRF: acronym for 'total rockfish' (all species of *Sebastes* + *Sebastolobus*)

ORF: acronym for 'other rockfish' (= TRF minus POP), landed catch aggregated by year, fishery, and PMFC (Pacific Marine Fisheries Commission) major area

POP: Pacific Ocean Perch

RRF: Reconstructed rockfish species – in this case, POP

TAR: Target species landed catch, used for discard calculations

L & D: L =landed catch, D =releases (formerly called 'discards')

gamma: mean of annual ratios of landed catch, $\sum_i \mathrm{RRF}_i^L / \mathrm{ORF}_i^L$, grouped by major PMFC area and fishery. For POP the reference years were set to 1998–2020 for the trawl fishery and for the four non-trawl fisheries.

delta: mean of annual ratios of discarded catch to landed catch, $\sum_i \mathrm{RRF}_i^D / \mathrm{TAR}_i^L$, grouped by major PMFC area and fishery using reference years i = 1997–2006 for the trawl fishery and 2000–2004 for all other fisheries. Observer records were used to gather data on releases.

A.2.2.2. Reconstruction results

The stock assessment population model uses calendar year, requiring calendar year catch estimates.

Pacific Ocean Perch remains one of the few species that have reported Canadian and American trawl landings extending back to 1954 (Ketchen 1976). The catch of POP by foreign (primarily Russian and Japanese) fleets was extensively reviewed and estimated by Ketchen (1980a,b). These reported landings (domestic and foreign) were used in the 2010 and 2017 stock assessments (Edwards et al. 2013a,b; Haigh et al. 2018), and the practise was continued in this stock assessment. Various technical working groups have noted the reporting of POP as other, less desirable rockfish species, from 1985 (start of restrictive trip limits) to 1994 (start of the

DMP) to avoid quota restrictions during this period, an issue that affects all rockfish stock assessments.

Landings were reconstructed before 1954 for the trawl fishery, before 1987 for the hook and line fishery, and before 2001 for the remaining non-trawl fisheries using gamma ratios (Table A.3). These ratios were used to convert historical landings of TRF to POP. The ratios were calculated from a relatively modern period (see Section A.2.4); therefore, an obvious caveat to this procedure is that ratios derived from a modern fishery likely do not reflect catch ratios during times of heavy exploitation (e.g., historical foreign fleet activity) or regulatory regimes not using IVQs (individual vessel quotas). Consequently, sets of years where gamma does not fluctuate wildly were used in an attempt to minimise additional process error.

After POP landings were estimated, non-retained catch (releases or discards) were estimated and added during years identified by fishery: T = 1954-1995, H = 1918–2005, and S/DL = 1950–2005, and ZN = 1986–2005. Non-retained catch was estimated using the `delta` ratios of POP discarded by a fishery to fishery-specific landed targets (TAR): T = POP, H = Pacific Halibut, S = Sablefish, DL = Spiny Dogfish + Lingcod, ZN = POP (Table A.3).

The current annual catches of POP by trawl fishery and those from the non-trawl fisheries appear in Table A.4 and Figure A.2. The combined fleet catches were used in the population models as plotted in Figure A.4. The catch reconstruction used for POP was built on May 12, 2023. The 2023 catch was set equal to the catch in 2022.

Table A.3. Calculated ‘gamma’ (POP/TRF) and 'delta' (discard) ratios for each fishery and PMFC area used in the catch reconstruction of POP.

PMFC	Trawl	Halibut	Sablefish	Dogfish/ Lingcod	H&L Rockfish
gamma (proportion POP/TRF)					
3C	0.13043	0.00138	0.00029	0.00033	0.00022
3D	0.07213	0.00109	0.00015	0.00011	0.00045
5A	0.15150	0.00049	0.00008	0	0.00009
5B	0.43886	0.00078	0.00008	0	0.00005
5C	0.53440	0.00044	0.00018	0.00086	0.00063
5D	0.07824	0.00004	0	0	0.00004
5E	0.38337	0.00023	0.00000	0.00024	0.00047
delta (discard rate)					
3C	0.03484	0	0.00008	0	0
3D	0.03032	0	0.00054	0	0
5A	0.01240	0.00003	0.00010	0	0
5B	0.01778	0.00005	0.00067	0	0
5C	0.01284	0.00003	0.00002	0	0
5D	0.00711	0	0	0	0
5E	0.00200	0.00000	0.00002	0	0

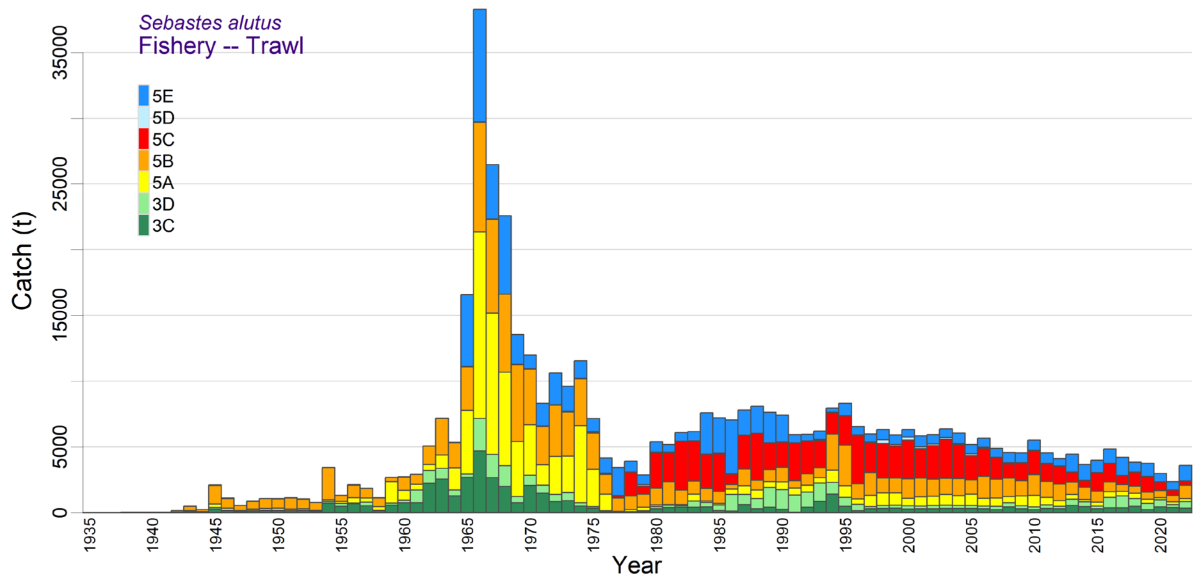

*Figure A.2. Reconstructed total (landed + released) catch (t) for POP from the **trawl** fishery in PMFC major areas 3C to 5E.*

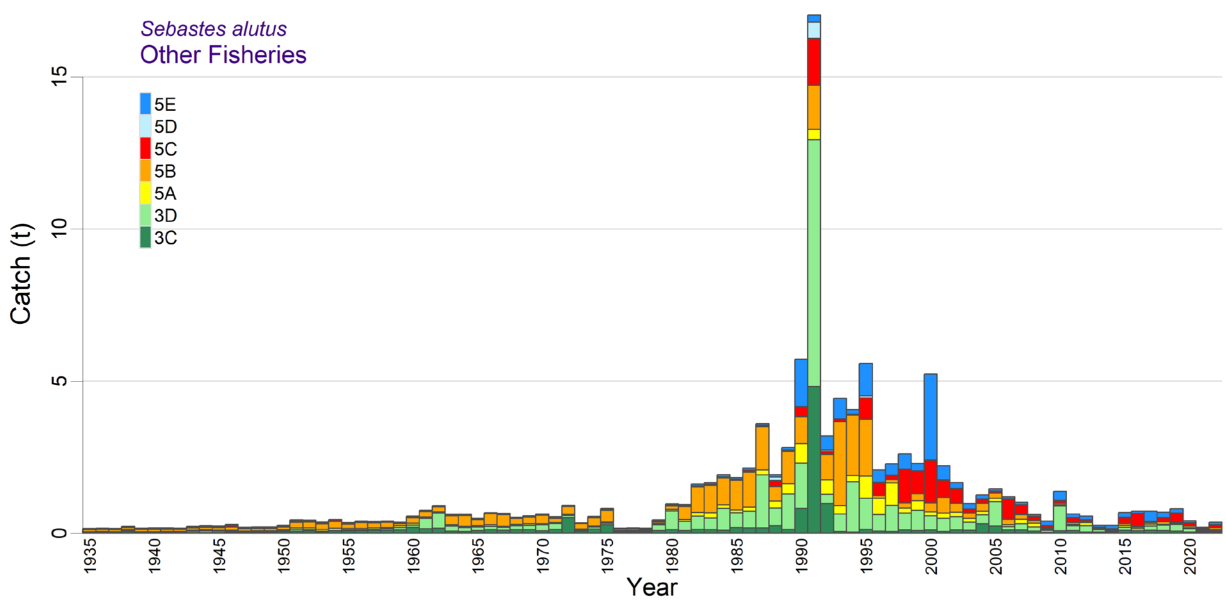

*Figure A.3. Reconstructed total (landed + released) catch (t) for POP from the **other** fisheries in PMFC major areas 3C to 5E.*

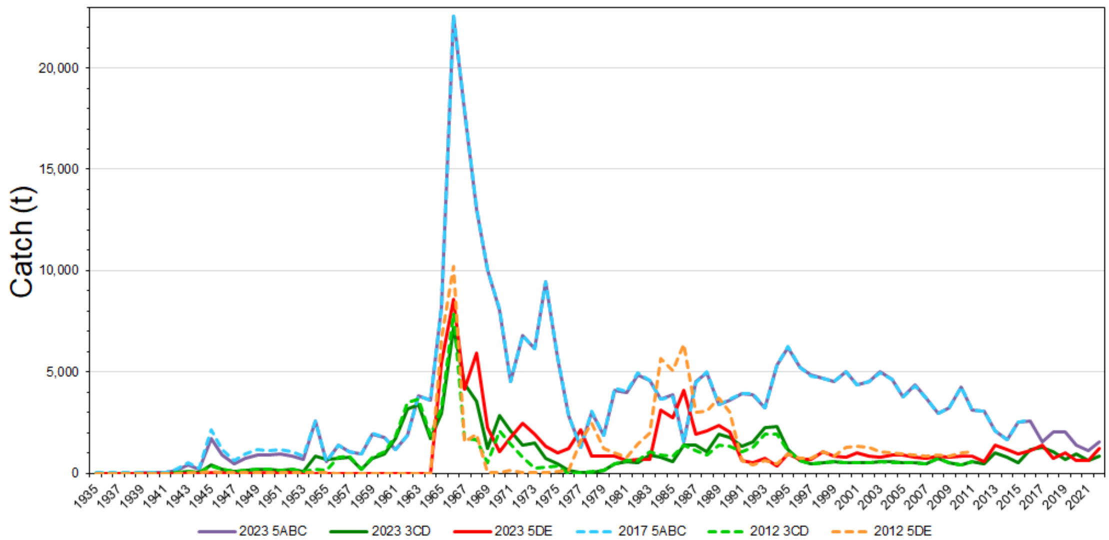

Figure A.4. Plot of reconstructed catch by fishery for POP from 1935 to 2022 used in the 2023 population model (solid lines) and in previous assessments (dashed lines, 5ABC in 2017, 3CD and 5DE in 2012). Data values are provided in Table A.4. Catch in 2023 was set to values in 2022.

Table A.4. Reconstructed catches (in tonnes, landings + releases) of POP in three PMFC regions (5ABC, 3CD, 5DE) from trawl (bottom + midwater) and non-trawl fisheries (Halibut, Sablefish, Dogfish/Lingcod, and H&L Rockfish). The final three columns show catches used in the population model. Area catches for 2023 were set to values in 2022.

	TRAWL			OTHER			TOTAL		
Year	**5ABC**	**3CD**	**5DE**	**5ABC**	**3CD**	**5DE**	**5ABC**	**3CD**	**5DE**
1918	4.12	0.398	1.13	0.188	0.038	0.017	4.31	0.436	1.15
1919	0.593	0.748	0.151	0.147	0.071	0.010	0.740	0.818	0.161
1920	0.804	0.435	0.214	0.180	0.041	0.012	0.984	0.476	0.226
1921	0.054	0.262	0.010	0.202	0.025	0.012	0.255	0.286	0.023
1922	0.047	0.552	0.004	0.164	0.052	0.010	0.211	0.604	0.014
1923	0.101	0.260	0.023	0.145	0.025	0.009	0.246	0.285	0.032
1924	0.226	0.252	0.058	0.133	0.024	0.008	0.359	0.276	0.067
1925	0.325	0.166	0.087	0.121	0.016	0.008	0.446	0.182	0.095
1926	0.697	0.297	0.187	0.147	0.028	0.010	0.844	0.325	0.197
1927	1.06	0.416	0.285	0.134	0.039	0.010	1.19	0.455	0.295
1928	0.778	0.385	0.208	0.153	0.036	0.010	0.930	0.422	0.218
1929	1.13	0.328	0.307	0.132	0.031	0.010	1.27	0.359	0.316
1930	0.615	0.239	0.165	0.112	0.023	0.008	0.726	0.261	0.173
1931	0.115	0.244	0.028	0.118	0.023	0.007	0.233	0.267	0.035
1932	0.137	0.142	0.018	0.115	0.012	0.007	0.252	0.154	0.025
1933	0.017	0.087	0.003	0.115	0.008	0.007	0.132	0.095	0.010
1934	0.625	0.196	0.024	0.122	0.008	0.008	0.747	0.204	0.031
1935	4.84	0.934	0.212	0.130	0.010	0.009	4.97	0.944	0.221
1936	6.38	1.28	0.315	0.130	0.020	0.009	6.51	1.30	0.325
1937	4.98	1.01	0.086	0.134	0.005	0.008	5.11	1.01	0.095
1938	7.19	2.19	0.073	0.140	0.074	0.009	7.33	2.27	0.082
1939	8.03	2.08	0.152	0.153	0.004	0.009	8.18	2.08	0.162
1940	17.2	3.65	0.243	0.154	0.002	0.010	17.3	3.65	0.253
1941	11.1	2.64	0.865	0.149	0.008	0.011	11.3	2.65	0.875
1942	124	27.3	1.55	0.130	0.021	0.009	124	27.3	1.56
1943	397	86.0	4.58	0.153	0.055	0.013	397	86.1	4.59
1944	176	44.1	3.69	0.151	0.073	0.014	176	44.2	3.70
1945	1,707	389	16.2	0.159	0.057	0.017	1,708	389	16.2
1946	900	188	12.2	0.206	0.050	0.023	901	188	12.3
1947	448	91.4	4.23	0.160	0.016	0.011	448	91.5	4.24
1948	728	148	6.94	0.164	0.024	0.013	728	148	6.95
1949	888	180	10.3	0.157	0.033	0.013	888	180	10.3
1950	878	181	11.7	0.174	0.067	0.011	878	181	11.7

Year	TRAWL 5ABC	3CD	5DE	OTHER 5ABC	3CD	5DE	TOTAL 5ABC	3CD	5DE
1951	958	165	7.72	0.292	0.116	0.024	958	165	7.75
1952	842	182	8.60	0.290	0.113	0.019	843	182	8.62
1953	661	112	2.63	0.282	0.063	0.014	662	112	2.65
1954	2,585	855	---	0.346	0.084	0.015	2,586	855	0.015
1955	602	707	0.914	0.223	0.105	0.012	602	707	0.926
1956	1,411	732	0.076	0.284	0.100	0.011	1,411	733	0.087
1957	1,066	782	1.84	0.249	0.121	0.012	1,067	782	1.86
1958	957	173	5.48	0.248	0.138	0.010	957	173	5.49
1959	1,954	727	---	0.167	0.182	0.009	1,954	727	0.009
1960	1,776	952	---	0.285	0.263	0.011	1,776	952	0.011
1961	1,167	1,732	0.457	0.247	0.487	0.009	1,167	1,733	0.466
1962	1,882	3,195	---	0.238	0.654	0.009	1,882	3,196	0.009
1963	3,807	3,371	1.57	0.372	0.231	0.012	3,807	3,371	1.59
1964	3,602	1,727	5.63	0.421	0.184	0.007	3,602	1,727	5.64
1965	8,186	2,934	5,452	0.273	0.202	0.009	8,186	2,934	5,452
1966	22,550	7,153	8,570	0.442	0.219	0.007	22,551	7,153	8,570
1967	17,904	4,428	4,131	0.441	0.193	0.007	17,904	4,428	4,131
1968	13,049	3,571	5,950	0.263	0.245	0.006	13,049	3,571	5,950
1969	10,038	1,226	2,279	0.314	0.248	0.007	10,038	1,227	2,279
1970	8,067	2,835	1,076	0.355	0.270	0.006	8,067	2,836	1,076
1971	4,501	2,080	1,748	0.217	0.310	0.006	4,501	2,081	1,748
1972	6,791	1,385	2,443	0.335	0.571	0.007	6,791	1,386	2,443
1973	6,163	1,522	1,926	0.230	0.102	0.005	6,163	1,523	1,926
1974	9,459	739	1,343	0.340	0.204	0.004	9,459	739	1,343
1975	5,689	457	1,016	0.479	0.322	0.007	5,690	457	1,016
1976	2,829	124	1,199	0.097	0.059	0.006	2,830	124	1,199
1977	1,256	16.7	2,158	0.099	0.071	0.005	1,256	16.8	2,158
1978	3,027	57.9	824	0.092	0.062	0.010	3,027	57.9	824
1979	1,881	129	843	0.136	0.273	0.025	1,882	129	843
1980	4,097	444	857	0.209	0.726	0.028	4,097	445	857
1981	3,987	566	619	0.527	0.385	0.027	3,988	566	620
1982	4,876	528	688	1.00	0.551	0.059	4,877	529	688
1983	4,565	884	706	1.11	0.492	0.054	4,566	884	706
1984	3,670	775	3,145	1.03	0.811	0.082	3,671	776	3,146
1985	3,890	597	2,721	1.10	0.668	0.054	3,891	598	2,721
1986	1,554	1,381	4,113	1.34	0.718	0.076	1,555	1,382	4,113
1987	4,500	1,381	1,921	1.62	1.92	0.060	4,502	1,383	1,921
1988	4,951	1,068	2,074	0.910	0.815	0.192	4,952	1,069	2,074
1989	3,377	1,910	2,348	1.45	1.29	0.078	3,378	1,911	2,348
1990	3,624	1,746	2,036	1.85	2.29	1.58	3,626	1,749	2,038
1991	3,937	1,349	642	3.33	12.9	0.775	3,940	1,362	643
1992	3,891	1,560	509	1.40	1.28	0.517	3,892	1,561	509
1993	3,222	2,248	739	3.12	0.630	0.675	3,226	2,249	740
1994	5,315	2,293	338	2.21	1.69	0.159	5,318	2,295	338
1995	6,202	1,152	960	3.29	1.15	1.13	6,205	1,153	961
1996	5,249	625	682	1.06	0.603	0.411	5,250	626	683
1997	4,851	459	678	0.979	0.912	0.380	4,852	460	679
1998	4,706	541	1,071	1.43	0.658	0.515	4,708	542	1,072
1999	4,516	555	838	1.28	0.750	0.253	4,517	556	838
2000	5,016	511	784	1.83	0.564	2.84	5,018	512	787
2001	4,352	501	998	1.26	0.486	0.476	4,353	502	999
2002	4,545	543	855	0.922	0.531	0.201	4,546	543	855
2003	5,004	569	783	0.434	0.351	0.182	5,004	569	783
2004	4,626	549	880	0.498	0.600	0.153	4,626	550	880
2005	3,765	546	881	0.351	1.03	0.079	3,766	547	881
2006	4,377	509	771	0.902	0.216	0.078	4,378	509	771
2007	3,714	467	713	0.621	0.300	0.092	3,714	468	713
2008	2,969	742	853	0.343	0.198	0.062	2,970	742	853
2009	3,214	513	813	0.153	0.085	0.156	3,215	513	813
2010	4,248	426	858	0.187	0.887	0.295	4,248	427	858
2011	3,095	598	852	0.260	0.240	0.131	3,096	598	853
2012	3,045	483	581	0.188	0.244	0.121	3,045	484	581
2013	2,073	1,020	1,362	0.085	0.110	0.060	2,073	1,020	1,362
2014	1,642	814	1,194	0.096	0.042	0.119	1,642	814	1,194
2015	2,544	504	936	0.318	0.191	0.164	2,545	505	936
2016	2,593	1,155	1,101	0.502	0.144	0.066	2,593	1,156	1,101
2017	1,552	1,264	1,391	0.143	0.235	0.340	1,552	1,264	1,391
2018	2,024	1,066	755	0.243	0.258	0.184	2,024	1,066	755

	TRAWL			OTHER			TOTAL		
Year	5ABC	3CD	5DE	5ABC	3CD	5DE	5ABC	3CD	5DE
2019	2,033	711	1,009	0.368	0.283	0.145	2,034	711	1,010
2020	1,364	970	639	0.193	0.142	0.065	1,364	970	639
2021	1,118	606	636	0.098	0.067	0.026	1,118	606	636
2022	1,551	849	1,200	0.188	0.076	0.091	1,551	849	1,200
2023	1,551	849	1,200	0.188	0.076	0.091	1,551	849	1,200

A.2.3. Changes to the reconstruction algorithm since 2011

Stock assessments since Haigh and Yamanaka (2011) have made either permanent changes to the catch reconstruction algorithm or choices specific to the stock being assessed. A history of the changes appears in Table A.5, with the final; column showing which changes were adopted for the POP assessment in 2023.

Table A.5. Summary of changes made to the catch reconstruction algorithm since its inception in 2011. Final column indicates which changes have been adopted for the current stock assessment using a check mark. Acronyms: ASO=at-sea observers, BOR=Bocaccio (rockfish), EM=electronic monitoring, GFBio=Groundfish Biology database, GFFOS=Groundfish Fishery Operation System database, GFM=groundfish merged data table, FID=fishery ID, H&L=hook and line, LIN=Lingcod, PH3=PacHarv3 database, POP=Pacific Ocean Perch, RSR=Redstripe Rockfish, RRF=reference rockfish, SBF=Sablefish, SST=Shortspine Thornyhead, TWL=trawl, WWR=Widow Rockfish, YTR=Yellowtail Rockfish, YYR=Yelloweye Rockfish.

Year	Stock	Change since Haigh and Yamanaka (2011)	POP23
2012	POP	drop use of trawl and trap data from the sales slip database PacHarv3	✓
2012	POP	use PacHarv3 data for H&L fisheries	✓
2012	POP	add Japanese removals of rockfish reported in Ketchen (1980a)	✓
2014	YTR	select specific areas of coast to calculate gamma and delta	–
2015	SST	use the merged catch table ‘GF_MERGED_CATCH’ in GFFOS	✓
2015	YYR	use depth-stratified gamma and delta	–
2015	YYR	remove seamount data	✓
2015	YYR	exclude catch from offshore foreign fleets	–
2015	YYR	exclude catch from Langara Spit experimental fishery	–
2018	RSR	use geometric means instead of arithmetic to calculate gamma/delta	✓
2018	RSR	calculate RRF landings in years with verifiable catch through: ASO (TWL=1996+) or EM (H&L=2006+, TWL=2020+)	–
2018	RSR	calculate RRF landings in years with reported but unverified catch (before ASO/EM)	✓
2018	RSR	specify years by fishery for adding discards	✓
2019	WWR	allocate GFBio-specified foreign catch to fisheries using gear type	✓
2019	BOR	use fishery-specific reference years to calculate gamma	✓
2019	BOR	reconcile GFM and PH3 data by fishery ID: FID 1 = GFM, FIDs 2-4 = GFM+PH3, FID 5 = max(GFM,PH3)	✓
2019	BOR	scale SBF and LIN landings to calculate FID 3&4 landings to improve delta	✓
2019	BOR	reallocate PH3 landings from 1952-95 to reconstruction fisheries (FIDs 1-5)	✓
2023	POP	reallocate 5B Moresby Gully and 5E Flamingo Inlet/Anthony Island catches to 5C	✓

A.2.3.1. Pacific Ocean Perch (2012)

In two previous stock assessments for POP in areas 3CD and 5DE (Edwards et al. 2013a,b), the authors documented two departures from the catch reconstruction algorithm introduced by Haigh and Yamanaka (2011). The first dropped the use of trawl and trap data from the sales slip database `PacHarv3` because catches were sometimes reported by large statistical areas that could not be clearly mapped to PMFC areas. In theory, `PacHarv3` should report the same catch as that in the `GFCatch` database (Rutherford 1999), but area inconsistencies cause catch inflation when certain large statistical areas cover multiple PMFC areas. Therefore, only the

GFCatch database for the trawl and trap records from 1954 to 1995 were used, rather than trying to mesh GFCatch and PacHarv3. The point is somewhat moot as assessments since 2015 by the Offshore Rockfish Program use the merged-catch data table (Section A.2.1). Data for the H&L fisheries from PacHarv3 are still used as these do not appear in other databases.

The second departure was the inclusion of an additional data source for BC rockfish catch by the Japanese fleet reported in Ketchen (1980a).

A.2.3.2. Yellowtail Rockfish (2014)

The Yellowtail Rockfish assessment (DFO 2015) selected offshore areas that reflected the activity of the foreign fleets' impact on this species to calculate gamma (RRF/ORF) and delta ratios (RRF/TAR). This option was not used in the POP reconstruction.

A.2.3.3. Shortspine Thornyhead (2015)

The Shortspine Thornyhead assessment (Starr and Haigh 2017) was the first to use the merged catch table (GF_MERGED_CATCH in GFFOS). Previous assessments required the meshing together of caches from six separate databases: GFBioSQL (research, midwater joint-venture Hake, midwater foreign), GFCatch (trawl and trap), GFFOS (all fisheries), PacHarvest (trawl), PacHarvHL (hook and line), and PacHarvSable (trap and longline). See Section A.2.1 for further details.

A.2.3.4. Yelloweye Rockfish Outside (2015)

The Yelloweye Rockfish (YYR) assessment (Yamanaka et al. 2018) introduced the concept of depth-stratified gamma and delta ratios for an inshore rockfish (shallow water, reef-based species); however, this functionality has not been used for offshore rockfish to date.

Also in the YYR assessment, rockfish catch from seamounts was removed (implemented in all subsequent reconstructions), as well as an option to exclude rockfish catch from the foreign fleet and the experimental Langara Spit POP fishery. The latter option is more likely appropriate for inshore rockfish species because they did not experience historical offshore foreign fleet activity or offshore experiments.

A.2.3.5. Redstripe Rockfish (2018)

The Redstripe Rockfish assessment (Starr and Haigh 2021a), introduced the use of summarising annual gamma and delta ratios from reference years (Section A.2.2) by calculating the geometric mean across years instead of using the arithmetic mean. This choice reduces the influence of single anomalously large annual ratios.

Also new in 2018 was the ability to estimate RRF (using gamma) for landings later than 1996, should the user have reason to replace observed landings with estimated ones. For POP, observed landings by fishery were used starting in 1996 for the trawl fishery and 2006 for the non-trawl fisheries; prior to these years, landings were estimated using gamma.

Another feature introduced in 2018 was the ability to specify years by fishery for discard regimes, that is, when discard ratios were to be applied. Previously, these had been fixed to 1954–1995 for the trawl fishery and 1986–2005 for the non-trawl fisheries. For POP, discard regimes by fishery were set to T = 1954–1995, H = 1918–2005, S/DL = 1950–2005, and ZN = 1986–2005. As previously, years before the discard period assume no discarding, and years after the discard period assume that discards have been reported in the databases.

A.2.3.6. Widow Rockfish (2019)

The Widow Rockfish (WWR) assessment (Starr and Haigh 2021b) found a substantial amount of WWR reported as foreign catch in the database `GFBioSQL` that came from midwater gear off WCVI. Subsequently, the catch reconstruction algorithm was changed to assign GFBio foreign catch to four of the five fisheries based on gear type:

- bottom and midwater trawl gear assigned to the T fishery,
- longline gear assigned to the H fishery,
- trap and line-trap mix gear assigned to the S fishery, and
- h&l gear assigned to the ZN fishery.

The assignment only happens if the user chooses to use foreign catch in the reconstruction (see Section A.2.3.3). These foreign catches occurred well after the foreign fleet activity between 1965 and the implementation of an exclusive economic zone in 1977. POP foreign catches in GFBio occurred primarily in 1987–1990 (603 t).

A.2.3.7. Bocaccio (2019)

The Bocaccio rockfish (BOR) assessment (Starr and Haigh 2022a) used advice from the technical working group, which identified specific reference years for the calculation of `gamma`: 1990–2000 for trawl (to capture the years before decreasing mortality caps for BOR were placed on the trawl fleet) and 2007–2011 for non-trawl (to capture years after some form of observer program like electronic monitoring was applied to the hook and line fleets). The catch reconstruction algorithm was previously coded to only allow one set of reference years to be applied across all fisheries. The algorithm was changed so that a user can now specify separate reference years for each fishery.

Once the merged catch table (`GF_MERGED_CATCH` in `GFFOS`) was introduced (Section A.2.3.3), catch from all databases other than `PacHarv3` have been reconciled so that caches are not double counted. In the BOR assessment, the remaining two catch data sources (GFM and PH3, for brevity) were re-assessed by comparing ORF data, and the CR algorithm was changed in how the data sources were merged for the categories RRF landed, RRF discarded, ORF landed, POP landed, and TRF landed:

- GFM catch is the only source needed for FID 1 (Trawl fishery), as was previously assumed;
- GFM and PH3 catches appear to supplement each other for FIDs 2 (Halibut fishery), 3 (Sablefish fishery), and 4 (Dogfish/Lingcod fishery), and the catches were added in any given year up to 2005 (electronic monitoring started in 2006 and so the GFFOS database was reporting all catch for these fisheries by then);
- GFM and PH3 catches appear to be redundant for FID 5 (H&L Rockfish fishery), and so the maximum catch was used in any given year.

Also new in the BOR assessment was the introduction of historical Sablefish (SBF) and Lingcod (LIN) trawl landings from 1950 to 1975 (Ketchen 1976) for use in calculating historical discards for FIDs 3 and 4 during this period. These landings could not be used directly because they were taken by the trawl fleet; therefore, an estimation of SBF and LIN landed catch by FIDs 3 and 4, respectively, relative to SBF and LIN landed catch by FID 1 (trawl) was calculated from GFM. Annual ratios of SBF_3/SBF_1 and LIN_4/LIN_1 from 1996–2011 were chosen to calculate a geometric mean; the ratios from 2012 on started to diverge from those in the chosen period. The procedure yielded average ratios: SBF_3/SBF_1 = 10.235 and LIN_4/LIN_1 = 0.351, which were used to scale the 1950–75 trawl landings of SBF and LIN, respectively. From these estimated landings, discards of the RRF were calculated by applying `delta` (see Section A.2.2.1).

Another departure was the re-allocation of PH3 records to the various catch reconstruction fisheries based on data from 1952–95 (see the 2019 Bocaccio stock assessment by Starr and Haigh 2022a, Section A.2.3.7).

A.2.3.8. Pacific Ocean Perch (2023)

In the 2023 stock assessment of POP, the catch reconstruction (and other biological functions) were updated to more fully transfer catches from Moresby Gully in PMFC 5B and from Flamingo Inlet and Anthony Island in southern 5E to area 5C, the boundaries of which were extended around Cape St. James in 1996 for Pacific Ocean Perch and Yellowmouth Rockfish. This reallocation was previously achieved (but not implemented in catch reconstructions) by determining if tows' geographical coordinates fell within a 5C polygon extension (Figure A.5). However, catch data prior to 1996 typically did not contain specific coordinate information, and an update to the historical data extract included minor PMFC areas and fishing localities to better characterise the major PMFC area identifier. Combinations of these three areas were used to reallocate fishing events to 5C when no geographical coordinates were provided:

- 5B – SE Cape St. James major 6, minor 8, locality 6
- 5B – Outside Cape St. James major 6, minor 8, locality 12
- 5E – Anthony Island major 9, minor 34, locality 1
- 5E – Flamingo Inlet major 9, minor 34, locality 5

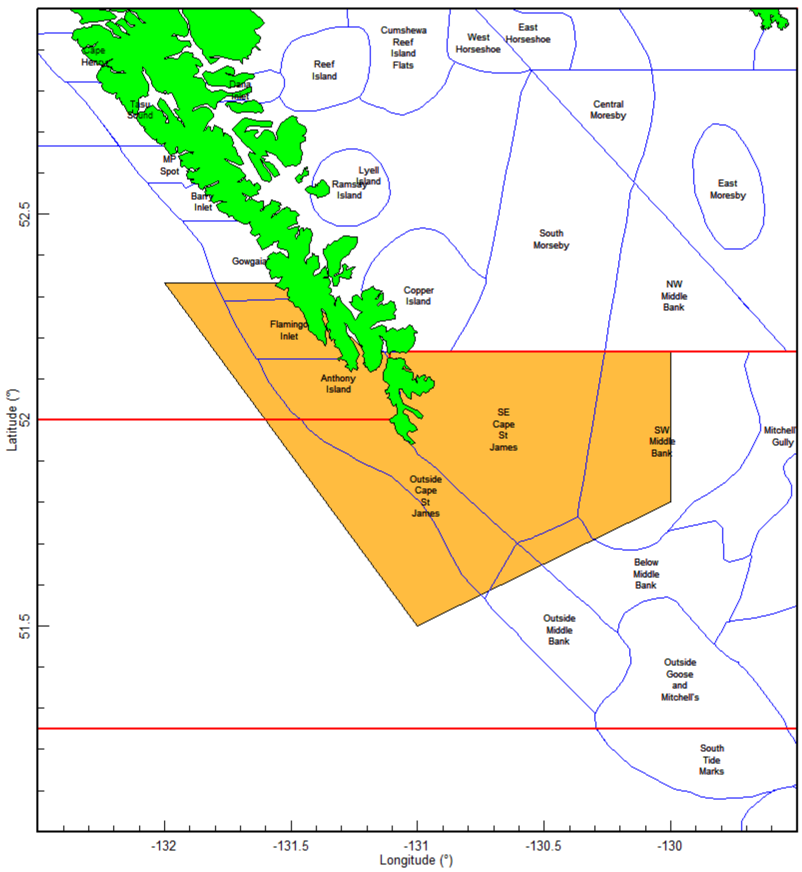

Figure A.5. PMFC area extension of PMFC area 5C around Cape St. James used to manage Pacific Ocean Perch and Yellowmouth Rockfish since 1996.

A.2.4. Specific decisions made in 2023

During the POP catch reconstruction, the annual gammas for the trawl fishery experienced moderate fluctuations from 1996 to 2022 (Figure A.6). Annual gammas for the other fisheries were predictably low and showed occasional spikes (Figure A.7) but the running geometric means were fairly stable. Based on these figures, the reference years chosen to calculate a geometric mean gamma by fishery were 1998 to 2020 for all fisheries. The decision to remove two years off each end was partially arbitrary: fishers were getting familiar with a new at-sea observer program (1996) and IVQ system (1997) in the beginning, and then they were dealing with the aftermath of the COVID pandemic in the end (2021–2022).

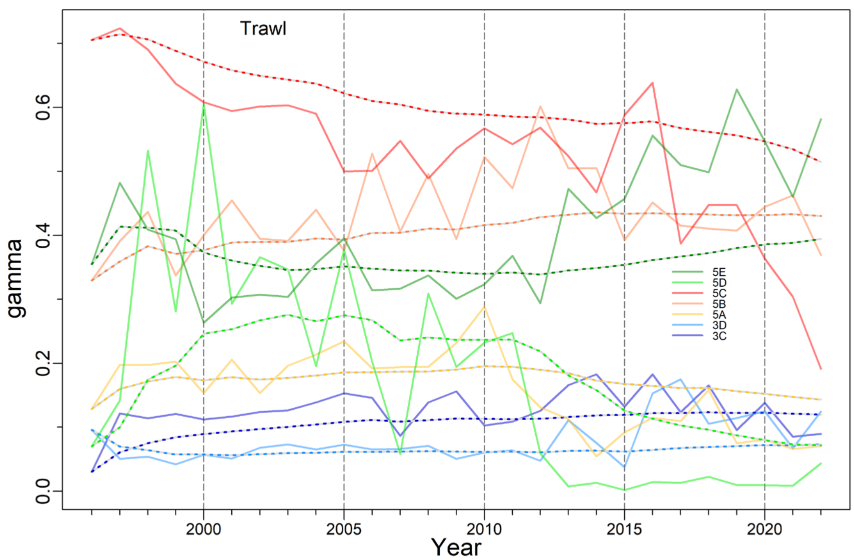

Figure A.6. Annual gamma ratios (POP/TRF) for the trawl commercial groundfish fishery (solid lines). Dotted lines trace the running geometric mean. Vertical dashed lines delimit 5-yr intervals.

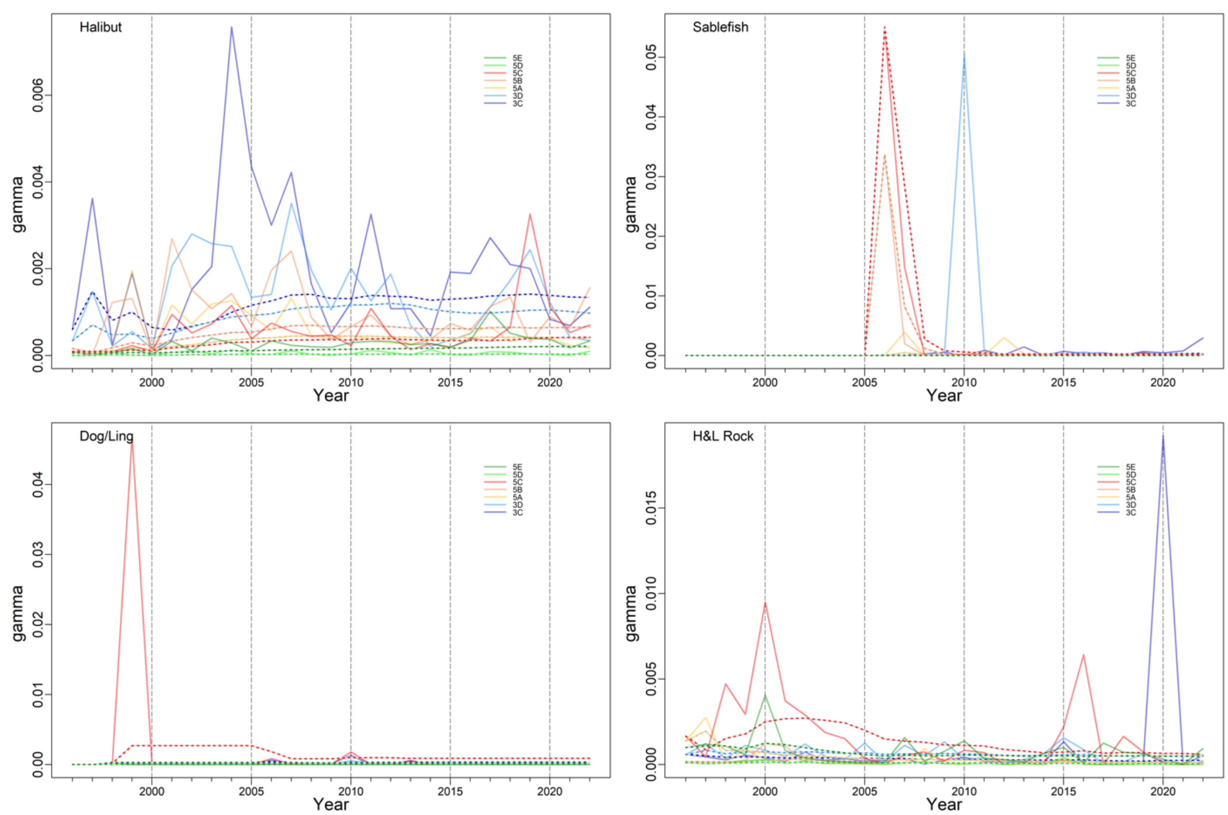

Figure A.7. Annual gamma ratios (POP/TRF) for the four non-trawl commercial groundfish fisheries.

A.2.5. Caveats

The available catch data before 1996 (first year of onboard observer program) present difficulties for use in a stock assessment model without some form of interpretation, both in terms of misreporting (i.e., reporting catches of one species as another) or misidentifying species. There is also the possible existence of at-sea discarding due to catches exceeding what was permitted for retention. Although there were reports that fishermen misreported the location of catches, this issue is not a large problem for an assessment of a coastwide stock. Additionally, there was a significant foreign fishery for rockfish in BC waters, primarily by the United States, the Soviet Union and Japan from 1965 to 1976. These countries tended to report their catches in aggregate form, usually lumping rockfish into a single category. These fisheries ceased after the declaration of the 200 nm exclusive economic zone by Canada in 1977.

The accuracy and precision of reconstructed catch series inherently reflect the problems associated with the development of a commercial fishery:

- trips offloading catch with no area information,
- unreported discarding,
- recording catch of one species as another to avoid quota violations,
- developing expertise in monitoring systems,
- shifting regulations,
- changing data storage technologies, etc.

Many of these problems have been eliminated through the introduction of:

- observer programs – at-sea observers (ASO) starting in 1996 for the offshore trawl fleet, electronic monitoring (EM) starting in 2006 for the H&L fleets, and EM replacing ASO in the trawl fleet starting in 2020 during the COVID pandemic;
- dockside [observer] monitoring, and
- tradeable individual vessel quotas (IVQs starting in 1997) that confer ownership of the resource to the fishing sector.

The catch reconstruction procedure does not rebuild catch by gear type (e.g., bottom trawl vs. midwater trawl, trap vs. longline). While adding this dimension is possible, it would mean splitting catches back in time using ratios observed in the modern fishery, which likely would not accurately represent historical activity by gear type (see Section A.2.2 for similar caveats regarding the use of modern catch ratios to reconstruct the catch of one species from a total rockfish catch). In this assessment, catches of POP by bottom and midwater trawl were combined, even though the biological data (Appendix D) by gear showed differences in selectivity. For the two areas (3CD, 5ABC) with notable midwater catches (Figure A.9), age frequency data for midwater trawls were too sparse to estimate midwater fleet selectivity for each fleet (Figure D.18). Filtering data for at least 2 samples and at least 75 specimens (combined sex), 3CD selectivity would depend on observations from three years and 5ABC would depend on observations from one year. To use AF data in a minor sensitivity (to MPD level only), they were combined to yield six years of data, and a joint selectivity was estimated for the two MW fisheries.

Table A.6 and Figure A.9 show the reported coastwide catch (landings plus non-retained) by gear type. Note that the catch reconstruction allocates catch of an RRF from unknown areas to PMFC areas proportionally by known catch in PMFC areas to reflect all potential removals of biomass from BC waters. Consequently, reported catches by area are often less than the reconstructed catches by area.

The catch for 2023 was incomplete and the 2022 catch was used on the advice of industry and which was accepted by the Technical Working Group.

Table A.6. Reported catch (tonnes) by gear type, sector, and fishery for BC POP coastwide starting when trawl fleet activity was monitored by onboard observers. BT=bottom trawl, MW=midwater trawl, HL=hook and line, GFT=groundfish trawl, ZN=license for hook and line, RO=HL rockfish outside, H=halibut longline, S=sablefish trap, HS=halibut + sablefish, DL=dogfish/lingcod.

	Gear				Sector						Fishery				
Year	BT	MW	HL	Trap	GFT	ZN	RO	H	HS	S	T	H	S	DL	HL
1996	6,318	174	0.900	—	6,492	0.898	—	0.002	—	—	6,492	0.002	—	—	0.898
1997	5,892	41.0	1.15	—	5,933	1.13	—	0.021	—	—	5,933	0.021	—	—	1.13
1998	6,284	32.2	1.35	—	6,317	1.28	—	0.075	—	—	6,317	0.075	—	0.001	1.28
1999	5,740	168	1.56	—	5,908	0.882	—	0.098	—	—	5,908	0.098	—	0.583	0.882
2000	6,103	204	3.99	—	6,305	3.99	—	---	—	—	6,305	—	—	—	3.99
2001	5,604	161	1.37	0.001	5,765	0.894	—	0.478	—	0.001	5,765	0.478	0.001	—	0.894
2002	5,578	361	0.766	0.001	5,939	0.322	—	0.405	—	0.038	5,939	0.405	0.038	0.003	0.322
2003	6,182	146	0.319	—	6,328	0.082	—	0.211	—	0.026	6,328	0.211	0.026	—	0.082
2004	5,976	58.7	0.748	0.009	6,034	0.000	—	0.696	—	0.059	6,034	0.696	0.059	0.002	0.000
2005	5,145	30.5	0.446	—	5,176	0.068	—	0.377	—	—	5,176	0.377	—	—	0.068
2006	5,155	424	0.519	0.557	5,578	0.005	—	0.328	0.175	0.568	5,578	0.503	0.568	—	0.005
2007	4,395	411	0.609	0.246	4,805	—	0.022	0.362	0.222	0.248	4,805	0.584	0.248	0.001	0.022
2008	3,635	867	0.507	—	4,502	—	0.145	0.208	0.150	—	4,502	0.358	—	0.004	0.145
2009	4,342	163	0.288	0.001	4,505	—	0.100	0.094	0.085	0.006	4,505	0.179	0.006	0.004	0.100
2010	5,250	237	1.25	—	5,487	—	0.277	0.106	0.155	0.694	5,487	0.261	0.694	0.020	0.277
2011	4,218	298	0.500	—	4,516	—	0.072	0.223	0.163	0.041	4,516	0.386	0.041	0.001	0.072
2012	3,739	290	0.415	0.053	4,029	—	0.043	0.113	0.255	0.056	4,029	0.368	0.056	0.001	0.043
2013	3,816	497	0.171	—	4,312	—	0.014	0.051	0.095	0.012	4,312	0.145	0.012	—	0.014
2014	3,290	330	0.210	—	3,620	—	0.062	0.100	0.048	—	3,620	0.148	—	—	0.062
2015	3,800	163	0.342	—	3,963	—	0.160	0.088	0.081	0.009	3,963	0.170	0.009	0.003	0.160
2016	4,404	363	0.646	—	4,767	—	0.390	0.100	0.148	0.008	4,767	0.248	0.008	—	0.390
2017	3,695	486	0.628	0.000	4,181	—	0.127	0.216	0.285	0.000	4,181	0.501	0.000	—	0.127
2018	3,202	523	0.519	0.001	3,725	—	0.142	0.129	0.245	0.003	3,725	0.374	0.003	—	0.142
2019	3,210	520	0.673	0.007	3,730	—	0.087	0.325	0.251	0.017	3,730	0.576	0.017	—	0.087
2020	2,085	765	0.321	—	2,850	—	0.003	0.083	0.233	0.002	2,850	0.317	0.002	—	0.003
2021	2,012	328	0.127	0.003	2,340	—	0.002	0.080	0.041	0.007	2,340	0.121	0.007	—	0.002
2022	3,025	423	0.253	0.005	3,449	—	0.021	0.126	0.101	0.010	3,449	0.224	0.013	—	0.021

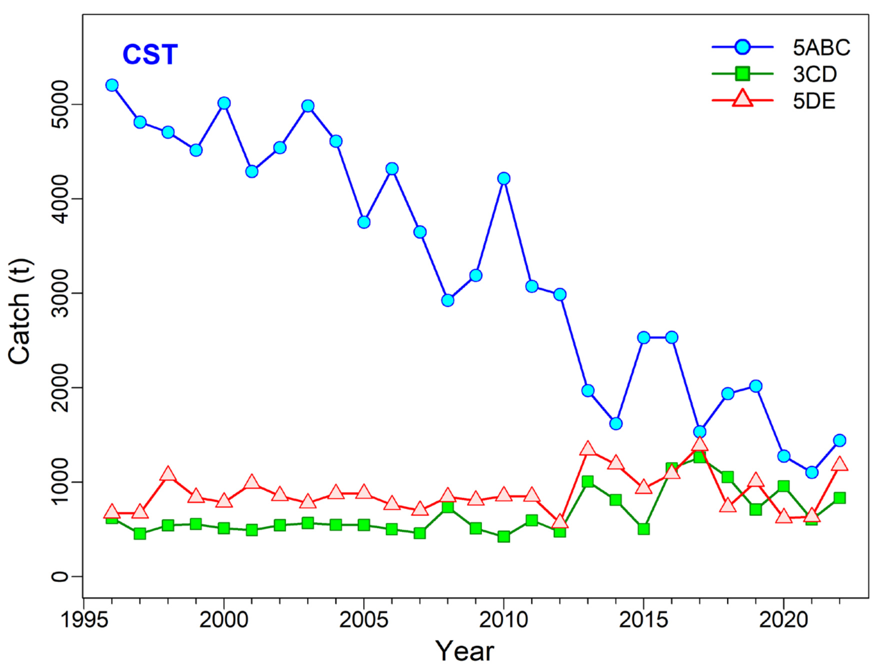

Figure A.8. Reported POP catch (landings + released) by groundfish management area since the implementation of the trawl fishery onboard-observer program in 1996.

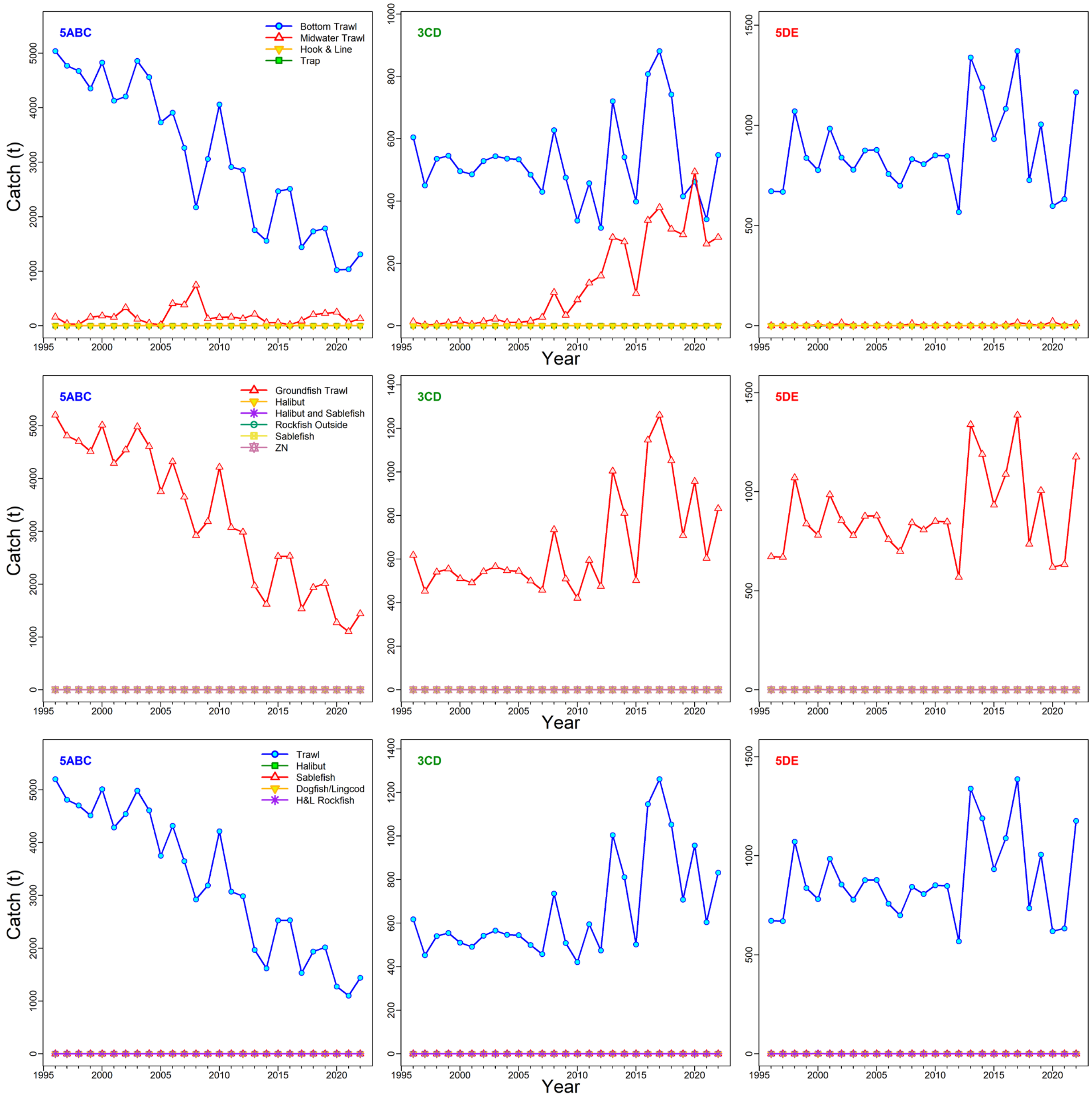

Figure A.9. Reported POP catch (landings + released) by gear (top row), by sector (middle row), and by fishery (bottom row) since the implementation of the trawl fishery onboard-observer program in 1996.

A.3. SCALING CATCH POLICY TO GMU AREA TACS

The area definitions used by DFO Groundfish Science (PMFC areas) differ somewhat from those used by the DFO Groundfish Management, which uses Pacific Fishery Management Areas (PFMA). The reasons for these discrepancies vary depending on the species, but they occur to address different requirements by Science and Management. For Science, there is a need to reference historical catch using areas that are consistently reported across all years in the databases and catch records. The PMFC and GMU areas, while similar but not identical (Figure 1), address current management requirements.

As this assessment covers three stocks coastwide, and GMU issues four area-specific TACs, a catch policy for the coastwide stock could be allocated to PMFC areas using the average 5-year proportional catch ratios in Table A.7. For example, a catch policy of 5,000 tonnes/year of POP would be allocated as follows:

- 3CD = 1,293 t/y = (0.1161 + 0.1424) * 5,000 t/y
- 5AB = 1,368 t/y = (0.0800 + 0.1936) * 5,000 t/y
- 5C = 1,027 t/y = 0.2053 * 5,000 t/y
- 5DE = 1,313 t/y = (0.0008 + 0.2617) * 5,000 t/y

Table A.7. Catch of POP from the combined fishery in PMFC areas from the last 5 years of complete catch statistics. Annual proportions of catch by area are shown in rows marked by year. Area-specific 5-year geometric means of annual proportions (normalised) are shown in the final row.

Year	3C	3D	5A	5B	5C	5D	5E	BC
Catch(t)								
2018	484	582	400	558	1,067	1.27	753	4,850
2019	232	478	311	549	1,174	3.13	1,006	4,207
2020	438	532	168	534	662	1.98	637	3,845
2021	375	232	211	489	418	3.23	633	3,754
2022	341	508	223	1,014	314	3.33	1,197	2,973
Proportion								
2018	0.0998	0.1199	0.0824	0.1150	0.2199	0.0003	0.1553	1
2019	0.0552	0.1137	0.0739	0.1305	0.2791	0.0007	0.2393	1
2020	0.1140	0.1383	0.0437	0.1389	0.1722	0.0005	0.1657	1
2021	0.0998	0.0617	0.0561	0.1302	0.1114	0.0009	0.1686	1
2022	0.1146	0.1709	0.0750	0.3412	0.1055	0.0011	0.4025	1
GeoMean	0.0936	0.1148	0.0645	0.1561	0.1655	0.0006	0.2110	0.8060
Normalise	0.1161	0.1424	0.0800	0.1936	0.2053	0.0008	0.2617	1

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APPENDIX B. TRAWL SURVEYS

B.1. INTRODUCTION

This appendix summarises the derivation of relative abundance indices for Pacific Ocean Perch (POP) from the following bottom trawl surveys:

- a set of historical surveys operated in the Goose Island Gully of Queen Charlotte Sound (Section B.3);
- a set of historical surveys operated off the west coast of Vancouver Island (Section B.4);
- National Marine Fisheries Service (NMFS) Triennial survey operated off the lower half of Vancouver Island (Section B.5);
- Queen Charlotte Sound (QCS) synoptic survey (Section B.6);
- West coast Vancouver Island (WCVI) synoptic survey (Section B.7);
- West coast Haida Gwaii (WCHG) synoptic survey (Section B.8); and
- Hecate Strait (HS) synoptic survey (Section B.9).

Only surveys used in the POP stock assessment are presented in this appendix. The Hecate Strait multi-species survey and the WCVI shrimp/Queen Charlotte Sound shrimp surveys have been omitted because the presence of POP in these surveys has been either sporadic or the coverage, either spatial or by depth, has been incomplete, rendering these surveys poor candidates to provide abundance series for this species. Rockfish stock assessments, beginning with Yellowtail Rockfish (DFO 2015), have explicitly omitted using the two shrimp surveys because of the truncated depth coverage, which ends at 160 m for the WCVI shrimp survey, and the constrained spatial coverage of the QC Sound shrimp survey as well as its truncated depth coverage, which ends at 231 m. The International Pacific Halibut Commission (IPHC) and the DFO hard bottom hook and line surveys were not considered because this species is not vulnerable to this type of gear (Anderson et al. 2019; Doherty et al. 2019), indicating an expectation that these surveys will not provide reliable POP abundance indices. While the occurrence of POP in the Hecate Strait synoptic survey was considered too sporadic for use in the base model, this survey has been documented in this Appendix because it was used in a sensitivity run (Run36v2) as an index series for the 5DE stock.

B.2. ANALYTICAL METHODS

Catch and effort data for strata i in year y yield catch per unit effort (CPUE) values U_{yi}. Given a set of data $\left\{C_{yij}, E_{yij}\right\}$ for tows $j = 1,\ldots,n_{yi}$,

Eq. B.1 $$U_{yi} = \frac{1}{n_{yi}} \sum_{j=1}^{n_{yi}} \frac{C_{yij}}{E_{yij}},$$

where C_{yij} = catch (kg) in tow j, stratum i, year y;

E_{yij} = effort (h) in tow j, stratum i, year y;

n_{yi} = number of tows in stratum i, year y.

CPUE values U_{yi} convert to CPUE densities δ_{yi} (kg/km^2) using:

Eq. B.2 $$\delta_{yi} = \frac{1}{vw} U_{yi} ,$$

where v = average vessel speed (km/h);
w = average net width (km).

Alternatively, if vessel information exists for every tow, CPUE density can be expressed

Eq. B.3 $$\delta_{yi} = \frac{1}{n_{yi}} \sum_{j=1}^{n_{yi}} \frac{C_{yij}}{D_{yij} w_{yij}} ,$$

where C_{yij} = catch weight (kg) for tow j, stratum i, year y;
D_{yij} = distance travelled (km) for tow j, stratum i, year y;
w_{yij} = net opening (km) for tow j, stratum i, year y;
n_{yi} = number of tows in stratum i, year y.

The annual biomass estimate is then the sum of the product of CPUE densities and bottom areas across m strata:

Eq. B.4 $$B_y = \sum_{i=1}^{m} \delta_{yi} A_i = \sum_{i=1}^{m} B_{yi} ,$$

where δ_{yi} = mean CPUE density (kg/km^2) for stratum i, year y;
A_i = area (km^2) of stratum i;
B_{yi} = biomass (kg) for stratum i, year y;
m = number of strata.

The variance of the survey biomass estimate V_y (kg^2) follows:

Eq. B.5 $$V_y = \sum_{i=1}^{m} \frac{\sigma_{yi}^2 A_i^2}{n_{yi}} = \sum_{i=1}^{m} V_{yi} ,$$

where σ_{yi}^2 = variance of CPUE density (kg^2/km^4) for stratum i, year y;
V_{yi} = variance of the biomass estimate (kg^2) for stratum i, year y.

The coefficient of variation (CV) of the annual biomass estimate for year y is

Eq. B.6 $$CV_y = \frac{\sqrt{V_y}}{B_y} .$$

B.3. EARLY SURVEYS IN QUEEN CHARLOTTE SOUND GOOSE ISLAND GULLY

This set of surveys, used in this stock assessment to represent the 5ABC POP population, is described in Appendix C of Edwards et al. (2012). Only the tows conducted in the Goose Island section of Queen Charlotte Sound were used to generate a biomass index series because this was the only area consistently surveyed by these surveys. Two early surveys, conducted in 1965 and 1966 by the Canadian Coast Guard Ship (CCGS) *G.B. Reed*, were not included because of the exploratory design. Six subsequent *G.B. Reed* surveys were conducted in 1967, 1969, 1971, 1973, 1976 and 1977, each consistently covering the Goose Island Gully (GIG) with a fixed station design and were considered suitable for inclusion in the series. A 1984 survey was conducted by two vessels: the *G.B. Reed* and the fishing vessel (FV) *Eastward Ho*, with these surveys covering both the Goose Island and Mitchell Gullies (the latter being immediately to the north of the GIG) and with both vessels using a fixed station design. The tows from both vessels were pooled for inclusion in the survey (see discussion in Edwards et al. 2012). Two further surveys were conducted in the Goose Island Gully in 1994 and 1995. The 1994 survey was conducted by a commercial vessel (FV *Ocean Selector*) using a fixed station design that emulated the previous *G.B. Reed* surveys. The 1995 survey, which targeted POP and was conducted by two vessels (*Ocean Selector* and FV *Frosti*), was not used because of its random design rather than the fixed station design. A 1979 survey conducted by the FV *Southward Ho*, was also not used because it employed a considerably different design compared to the *G.B. Reed* surveys (Edwards et al. 2012).

B.4. HISTORIC WEST COAST VANCOUVER ISLAND GB REED TRAWL SURVEYS

This set of surveys, used in this stock assessment to represent the 3CD POP population, is described in Section C.5 in Appendix C of Edwards et al. (2014b). Of the surveys described in that paper, the 1965 and 1966 *G.B. Reed* surveys were not considered to be comparable to the remaining *G.B. Reed* series because of the exploratory nature of these two surveys (and the lack of WCVI tows by the 1966 survey). Of the remaining five surveys investigated, four surveys spanning the period 1967–1970 were considered to be comparable, given that they were conducted in the same area by the same vessel over reasonably comparable time periods. The fifth survey, conducted in September 1972, was not considered comparable because the timing of that survey coincided with a period when it is thought that POP are moving away from the area and which differed from the other four surveys.

B.5. NMFS TRIENNIAL TRAWL SURVEY

While this survey was described in Section C.3 of Appendix C in Edwards et al. (2014b), there have been changes in the analysis of the data from this survey in the intervening years. Specifically, ‘water hauls’ (tows that caught no fish or invertebrates) have been dropped from the estimation procedure on the advice of a NOAA scientist who was close to the survey and its data (DFO 2015).

B.5.1. Data selection

Tow-by-tow data from the US National Marine Fisheries Service (NMFS) triennial survey covering the Vancouver INPFC (International North Pacific Fisheries Commission) region were provided by Mark Wilkins (NMFS, pers. comm., 2008) for the seven years that the survey operated in BC waters (Table B.1; 1980: Figure B.1; 1983: Figure B.2; 1989: Figure B.3; 1992: Figure B.4; 1995: Figure B.5; 1998: Figure B.6; 2001: Figure B.7). These tows were assigned to strata by the NMFS, but the size and definition of these strata have changed over the life of the survey (Table B.2). The NMFS survey database also identified in which country the tow was located. This information was plotted and checked against the accepted Canada/USA marine boundary: all tows appeared to be appropriately located with respect to country, based on the tow start position (Figure B.1 to Figure B.7). The NMFS designations were accepted for tows located near the marine border.

Table B.1. Number of tows by stratum and by survey year for the NFMS triennial survey. Strata coloured grey and marked with an astertisk have been excluded from the analysis due to incomplete coverage across the seven survey years or were from locations outside the Vancouver INPFC area (Table B.2).

Stratum	1980		1983		1989		1992		1995		1998		2001	
No.	CDN	US	CDN	US	CDN	US	CDN	US	CDN	US	CDN	US	CDN	US
10	–	17	–	7	–	–	–	–	–	–	–	–	–	–
11	48	–	–	39	–	–	–	–	–	–	–	–	–	–
12	–	–	38	–	–	–	–	–	–	–	–	–	–	–
17N	–	–	–	–	–	8	–	9	–	8	–	8	–	8
17S*	–	–	–	–	–	27	–	27	–	25	–	26	–	25
18N*	–	–	–	–	1	–	1	–	–	–	–	–	–	–
18S	–	–	–	–	–	32	–	23	–	12	–	20	–	14
19N	–	–	–	–	58	–	53	–	55	–	48	–	33	–
19S	–	–	–	–	–	4	–	6	–	3	–	3	–	3
27N	–	–	–	–	–	2	–	1	–	2	–	2	–	2
27S*	–	–	–	–	–	5	–	2	–	3	–	4	–	5
28N*	–	–	–	–	1	–	1	–	2	–	1	–	–	–
28S	–	–	–	–	–	6	–	9	–	7	–	6	–	7
29N	–	–	–	–	7	–	6	–	7	–	6	–	3	–
29S	–	–	–	–	–	3	–	2	–	3	–	3	–	3
30	–	4	–	2	–	–	–	–	–	–	–	–	–	–
31	7	–	–	11	–	–	–	–	–	–	–	–	–	–
32	–	–	5	–	–	–	–	–	–	–	–	–	–	–
37N*	–	–	–	–	–	–	–	–	–	1	–	1	–	1
37S*	–	–	–	–	–	–	–	–	–	2	–	1	–	1
38N*	–	–	–	–	–	–	–	–	1	–	–	–	–	–
38S*	–	–	–	–	–	–	–	–	–	2	–	–	–	3
39*	–	–	–	–	–	–	–	–	6	–	4	–	2	–
50	–	5	–	1	–	–	–	–	–	–	–	–	–	–
51	4	–	–	10	–	–	–	–	–	–	–	–	–	–
52	–	–	4	–	–	–	–	–	–	–	–	–	–	–
Total	59	26	47	70	67	87	61	79	71	68	59	74	38	72

All usable tows had an associated median net width (with 1–99% quantiles) of 13.4 (11.3–15.7) m and median distance travelled of 2.8 (1.4–3.5) km, allowing for the calculation of the area swept by each tow. Biomass indices and the associated analytical CVs for Pacific Ocean Perch were calculated for each of the Canadian and US Vancouver sub-regions, using appropriate area estimates for each stratum and year (Table B.2). Strata that were not surveyed consistently in all seven years of the survey were dropped from the analysis (Table B.1; Table B.2), allowing the remaining data to provide comparable coverage in each year (Table B.3).

The stratum definitions used in the 1980 and 1983 surveys were different than those used in subsequent surveys, particularly in Canadian waters (Table B.3). Therefore, the 1980 and 1983 Canadian indices were scaled by the ratio (9,166 km^2 / 7,399 km^2 = 1.24) of the total stratum areas relative to the 1989 and later surveys so that the coverage from the first two surveys would be comparable to the surveys conducted from 1989 onwards. Correspondingly, the 1980 and 1983 US indices were scaled down slightly (4,699 km^2 / 4,738 km^2 = 0.99) in the same manner. The tow density was much higher in the US-Vancouver waters although the overall number of tows was approximately the same for each country (Table B.3). This occurred because the size of the total area fished in the INPFC Vancouver area was about twice as large in Canadian waters than in US waters (Table B.3). Note that the northern extension of the survey varied from year to year (see Figure B.1 to Figure B.7), but this difference has been compensated for by using a constant survey area for all years and assuming that catch rates in the unsampled areas were the same as in the sampled area.

Table B.2. Stratum definitions by year used in the NMFS triennial survey to separate the survey results by country and by INPFC area. Stratum definitions in grey and marked with an asterisk are those strata which have been excluded from the final analysis due to incomplete coverage across the seven survey years or because the locations were outside the Vancouver INPFC area.

Year	Stratum No.	Area (km^2)	Start	End	Country	INPFC area	Depth range
1980	10	3,537	47°30	US-Can Border	US	Vancouver	55–183 m
1980	11	6,572	US-Can Border	49°15	CDN	Vancouver	55–183 m
1980	30	443	47°30	US-Can Border	US	Vancouver	184–219 m
1980	31	325	US-Can Border	49°15	CDN	Vancouver	184–219 m
1980	50	758	47°30	US-Can Border	US	Vancouver	220–366 m
1980	51	503	US-Can Border	49°15	CDN	Vancouver	220–366 m
1983	10	1,307	47°30	47°55	US	Vancouver	55–183 m
1983	11	2,230	47°55	US-Can Border	US	Vancouver	55–183 m
1983	12	6,572	US-Can Border	49°15	CDN	Vancouver	55–183 m
1983	30	66	47°30	47°55	US	Vancouver	184–219 m
1983	31	377	47°55	US-Can Border	US	Vancouver	184–219 m
1983	32	325	US-Can Border	49°15	CDN	Vancouver	184–219 m
1983	50	127	47°30	47°55	US	Vancouver	220–366 m
1983	51	631	47°55	US-Can Border	US	Vancouver	220–366 m
1983	52	503	US-Can Border	49 °15	CDN	Vancouver	220–366 m
1989&after	17N	1,033	47°30	47°50	US	Vancouver	55–183 m
1989&after	17S*	3,378	46°30	47°30	US	Columbia	55–183 m
1989&after	18N*	159	47°50	48°20	CDN	Vancouver	55–183 m
1989&after	18S	2,123	47°50	48°20	US	Vancouver	55–183 m
1989&after	19N	8,224	48°20	49°40	CDN	Vancouver	55–183 m
1989&after	19S	363	48°20	49°40	US	Vancouver	55–183 m
1989&after	27N	125	47°30	47°50	US	Vancouver	184–366 m
1989&after	27S*	412	46°30	47°30	US	Columbia	184–366 m
1989&after	28N*	88	47°50	48°20	CDN	Vancouver	184–366 m
1989&after	28S	787	47°50	48°20	US	Vancouver	184–366 m
1989&after	29N	942	48°20	49°40	CDN	Vancouver	184–366 m
1989&after	29S	270	48°20	49°40	US	Vancouver	184–366 m
1995&after	37N*	102	47°30	47°50	US	Vancouver	367–500 m
1995&after	37S*	218	46°30	47°30	US	Columbia	367–500 m
1995&after	38N*	66	47°50	48°20	CDN	Vancouver	367–500 m
1995&after	38S*	175	47°50	48°20	US	Vancouver	367–500 m

Table B.3. Number of usable tows performed and area surveyed in the INPFC Vancouver region separated by the international border between Canada and the United States. Strata 18N, 28N, 37, 38 and 39 (Table B.2) were dropped from this analysis as they were not consistently surveyed. All strata occurring in the Columbia INPFC region (17S and 27S; Table B.2) were dropped. Thirty-three "water hauls" are separately listed in this table.

	Tows: Canada waters			Tows: US waters			All Tows			Coverage (km^2)		
Year	Usable tows	Water hauls	Total	Usable tows	Water hauls	Total	Usable tows	Water hauls	Total	Canada waters	US waters	Total
1980	48	11	59	23	3	26	71	14	85	7,399	4,738	12,137
1983	39	8	47	65	5	70	104	13	117	7,399	4,738	12,137
1989	63	2	65	54	1	55	117	3	120	9,166	4,699	13,865
1992	59	–	59	47	3	50	106	3	109	9,166	4,699	13,865
1995	62	–	62	35	–	35	97	–	97	9,166	4,699	13,865
1998	54	–	54	42	–	42	96	–	96	9,166	4,699	13,865
2001	36	–	36	37	–	37	73	–	73	9,166	4,699	13,865
Total	361	21	382	303	12	315	664	33	697	–	–	–

Six hundred and ninety-seven tows across seven survey years remained in the data set after the inconsistently surveyed strata identified in Table B.2 were removed (Table B.3). A further 33 tows were identified as "water hauls" (Table B.3) after a reviewer from NOAA for the 2014 Yellowtail Rockfish stock assessment (DFO 2015) pointed out that a number of the early Triennial survey tows had been so designated because they caught no fish or invertebrates and recommended that they should be discarded from the estimation procedure.

B.5.2. Methods

The data were analysed using the equations in Section B.1. When calculating the variance for this survey, it was assumed that the variance and CPUE within any stratum were equal, even for strata that were split by the Canada/USA border. The total biomass $\left(B_{y_i}\right)$ within a stratum that straddled the border was split between the two countries $\left(B_{y_{i_c}}\right)$ by the ratio of the relative area within each country:

Eq. B.7 $$B_{y_{i_c}} = B_{y_i} \frac{A_{y_{i_c}}}{A_{y_i}},$$

where $A_{y_{i_c}}$ = area (km^2) within country *c* in year *y* and stratum *i*.

The variance $V_{y_{i_c}}$ for that part of stratum *i* within country *c* was calculated as being in proportion to the ratio of the square of the area within each country *c* relative to the total area of stratum *i*. This assumption resulted in the CVs within each country stratum being the same as the CV in the entire stratum:

Eq. B.8 $$V_{y_{i_c}} = V_{y_i} \frac{A^2_{y_{i_c}}}{A^2_{y_i}}.$$

The partial variance $V_{y_{i_c}}$ for country *c* was used in Eq. B.5 instead of the total variance in the stratum V_{y_i} when calculating the variance for the total biomass in Canadian or American waters. CVs were calculated as in Eq. B.6.

The biomass estimates Eq. B.4 and the associated standard errors were adjusted to a constant area covered using the ratios of area surveyed provided in Table B.3. This was required to adjust the Canadian biomass estimates for 1980 and 1983 to account for the smaller area surveyed in those years compared to the succeeding surveys. The 1980 and 1983 biomass estimates from Canadian waters were consequently multiplied by the ratio 1.24 (= 9,166 km^2 / 7,399 km^2) to make them equivalent to the coverage of the surveys from 1989 onwards.

Biomass estimates were bootstrapped using 1,000 random draws with replacement to obtain bias-corrected (Efron 1982) 95% confidence intervals for each year and for the two regions (Canadian-Vancouver and US-Vancouver) based on the distribution of biomass estimates and using the above equations.

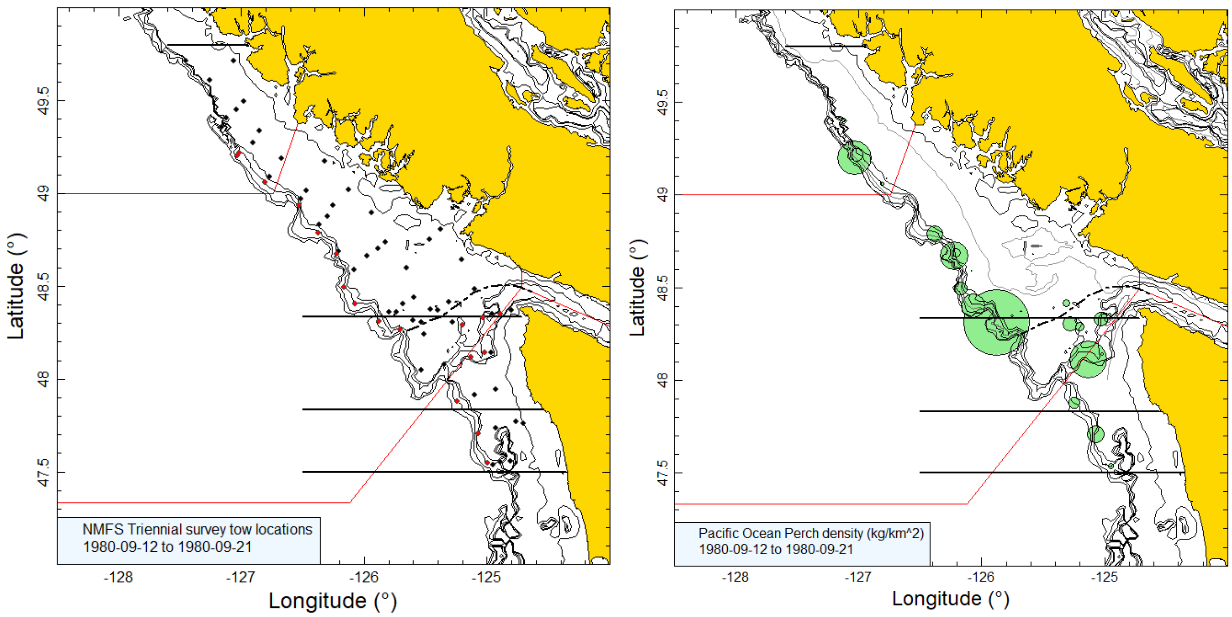

Figure B.1. [left panel]: plot of tow locations in the Vancouver INPFC region for the 1980 NMFS triennial survey in US and Canadian waters. Tow locations are colour-coded by depth range: black=55–183 m; red=184-366 m. Dashed line shows approximate position of the Canada/USA marine boundary. Horizontal lines are the stratum boundaries: 47°30', 47°50', 48°20' and 49°50'. Tows south of the 47°30' line were not included in the analysis. [left panel]:water hauls (Table B.3) have been excluded; [right panel]: circle sizes in the density plot are scaled across all years (1980, 1983, 1989, 1992, 1995, 1998, and 2001), with the largest circle = 39,918 kg/km^2 in 1980 (Canadian waters). The red solid lines indicate the boundaries between PMFC areas 3B, 3C and 3D. Depth contours denote 50 m, 200 m, 300 m, 400 m, 500 m. The survey dates denote the period over which the survey tows used for estimation were conducted.

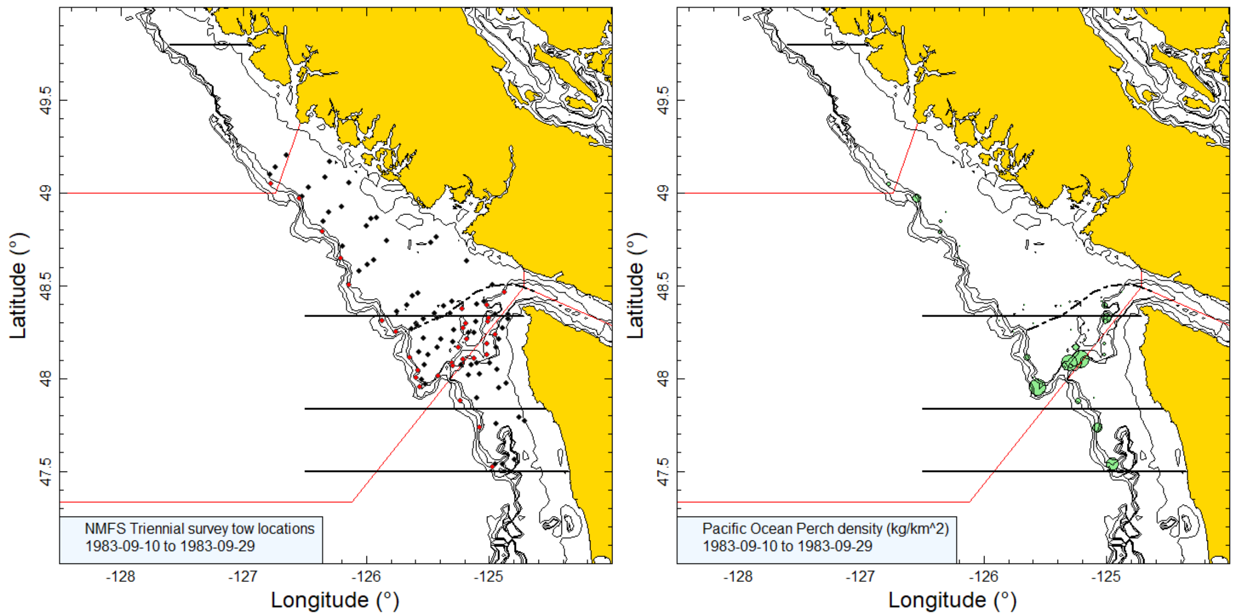

Figure B.2. Tow locations and density plots for the 1983 NMFS triennial survey in US and Canadian waters (see Figure B.1 caption).

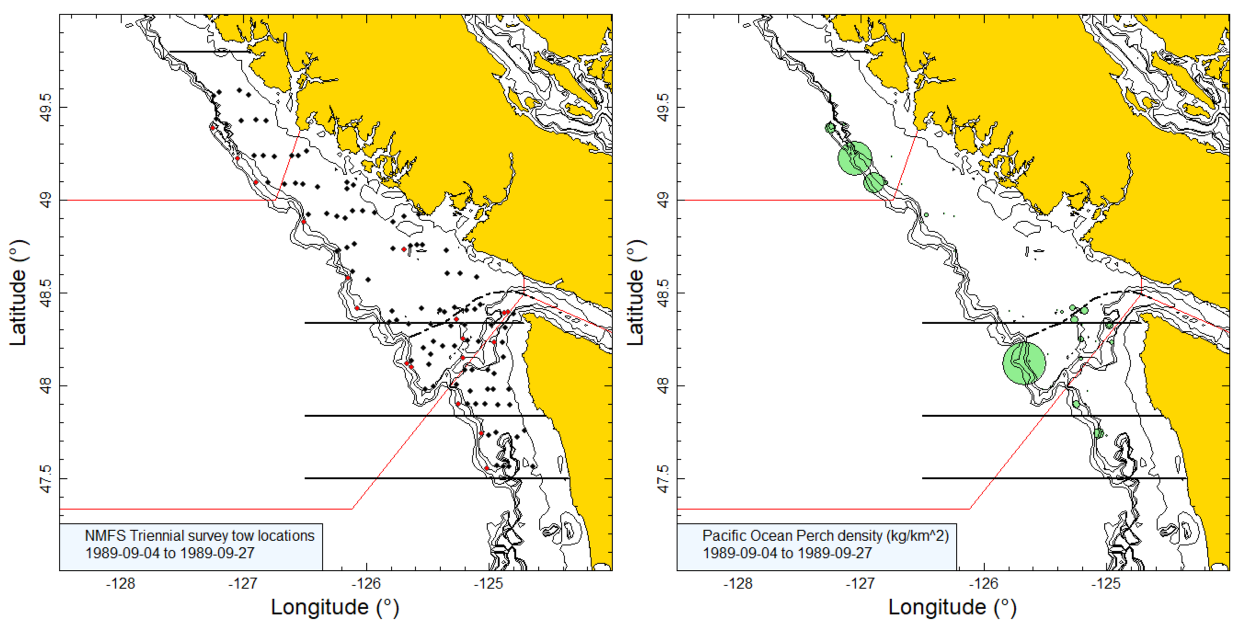

Figure B.3. Tow locations and density plots for the 1989 NMFS triennial survey in US and Canadian waters (see Figure B.1 caption).

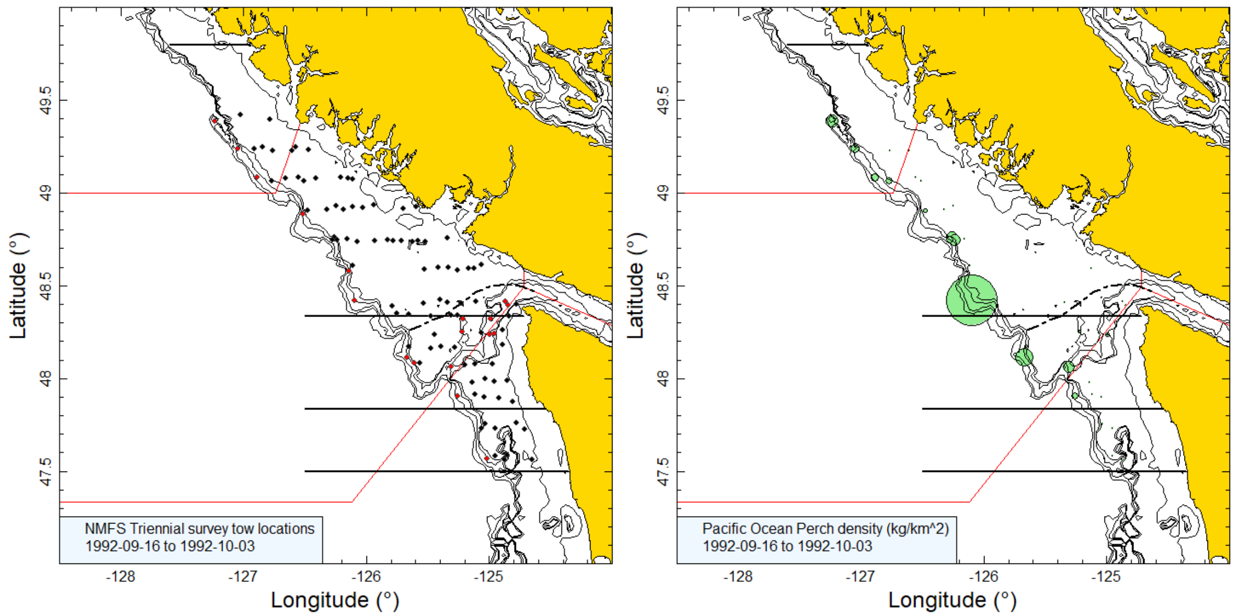

Figure B.4. Tow locations and density plots for the 1992 NMFS triennial survey in US and Canadian waters (see Figure B.1 caption).

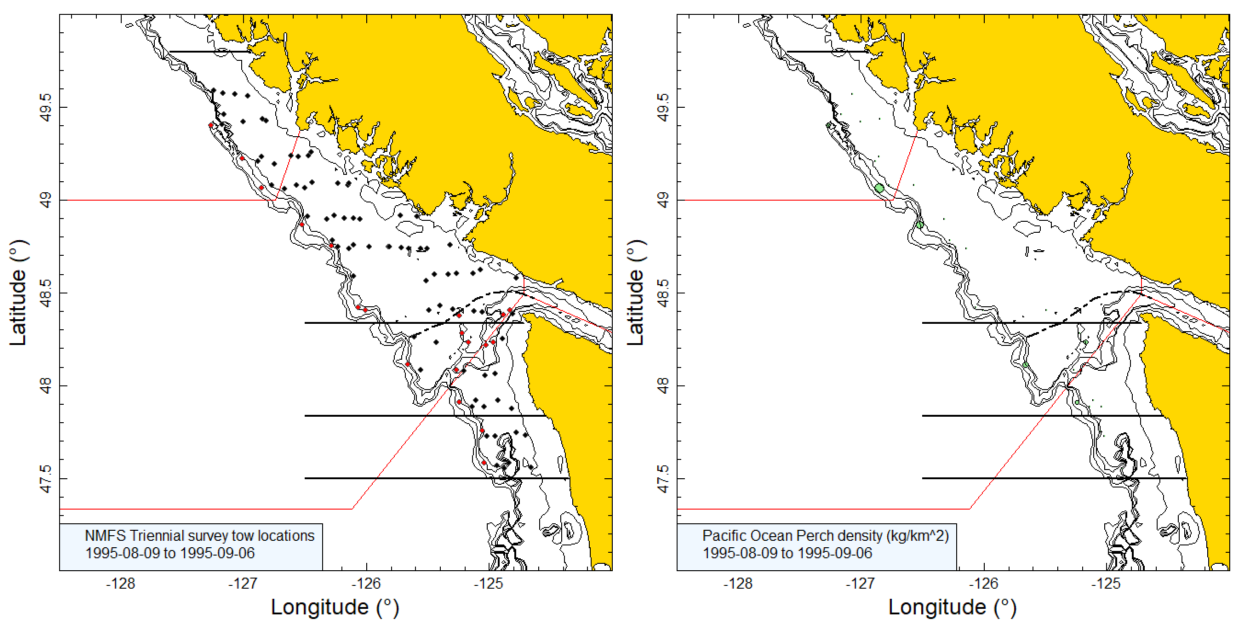

Figure B.5. Tow locations and density plots for the 1995 NMFS triennial survey in US and Canadian waters (see Figure B.1 caption).

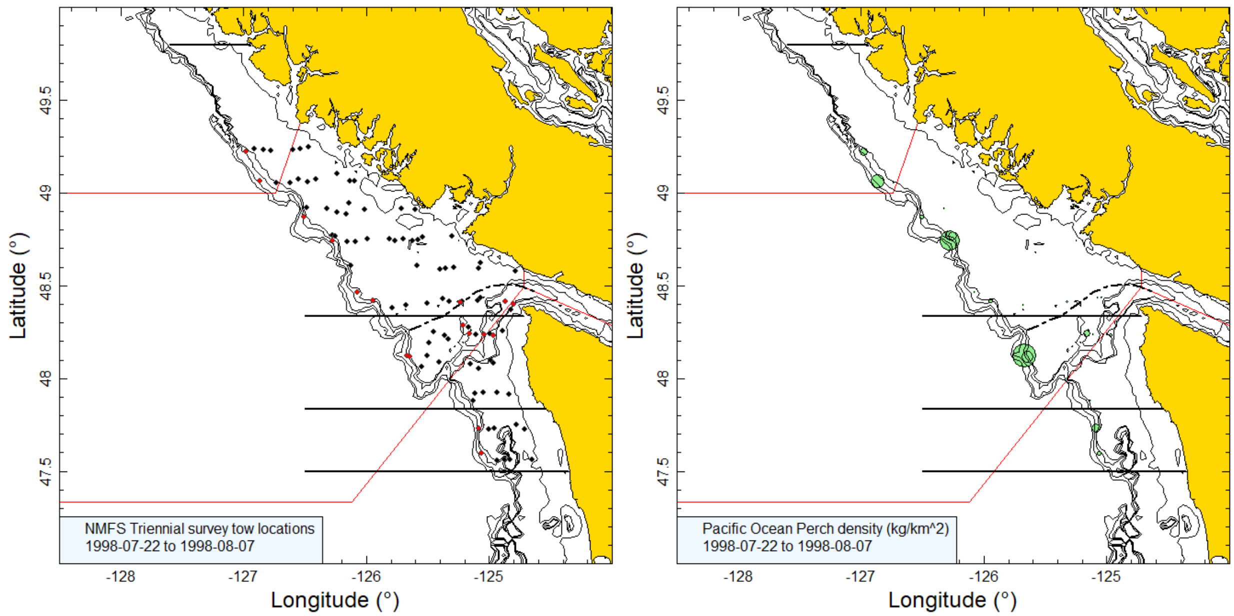

Figure B.6. Tow locations and density plots for the 1998 NMFS triennial survey in US and Canadian waters (see Figure B.1 caption).

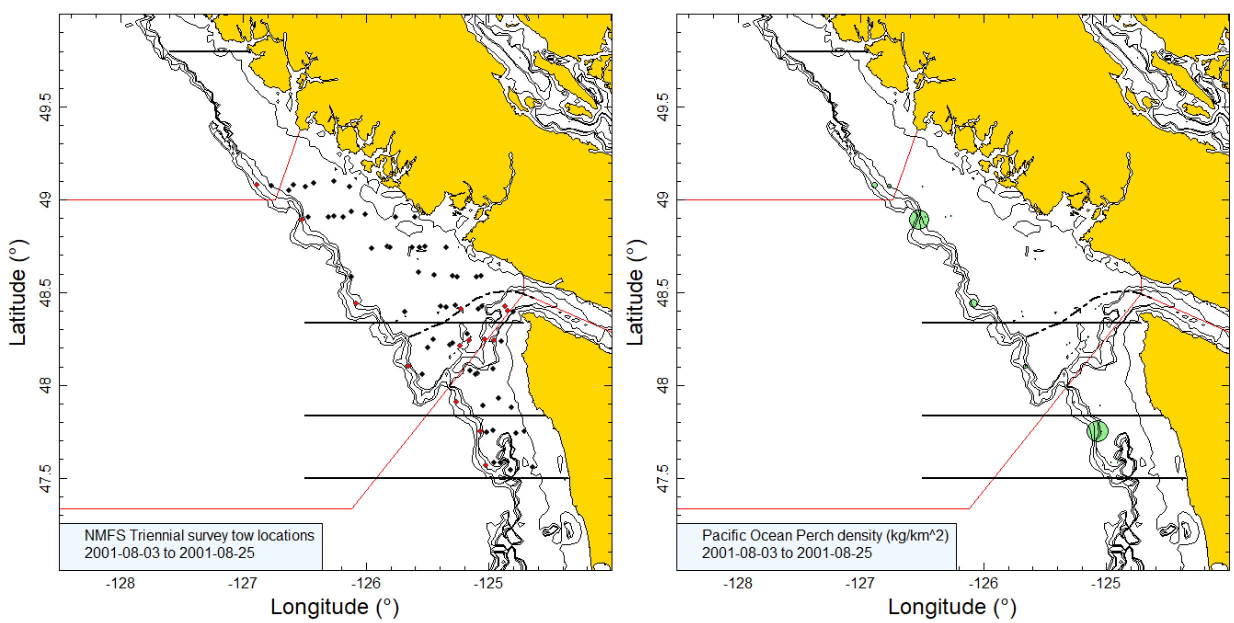

Figure B.7. Tow locations and density plots for the 2001 NMFS triennial survey in US and Canadian waters (see Figure B.1 caption).

B.5.3. Results

The occurrence of Pacific Ocean Perch (POP) in this survey was generally consistent across the seven surveys, with the median catch weight for the tows catching POP at 4.54 kg while there were 27 tows (from the 230 estimation tows which captured POP within the total area) which caught more than 100 kg of POP. Two tows among the 230 tows captured more than 1,000 kg of POP. The total POP catch weight among the estimation tows exceeded 1,000 kg of POP in six of the seven surveys, with the 1995 survey catching a total of only 700 kg. The first three survey years (1980, 1983, 1989) totaled more than 2,000 kg of POP among the estimation tows. Figure B.8 shows that this species was mainly captured between 150 and 300 m (the 10 and 90% quantiles of [bottom_depth] were 129 m and 271 m respectively), with the deepest observation at 357 m, indicating that this survey covered the full depth range for this species.

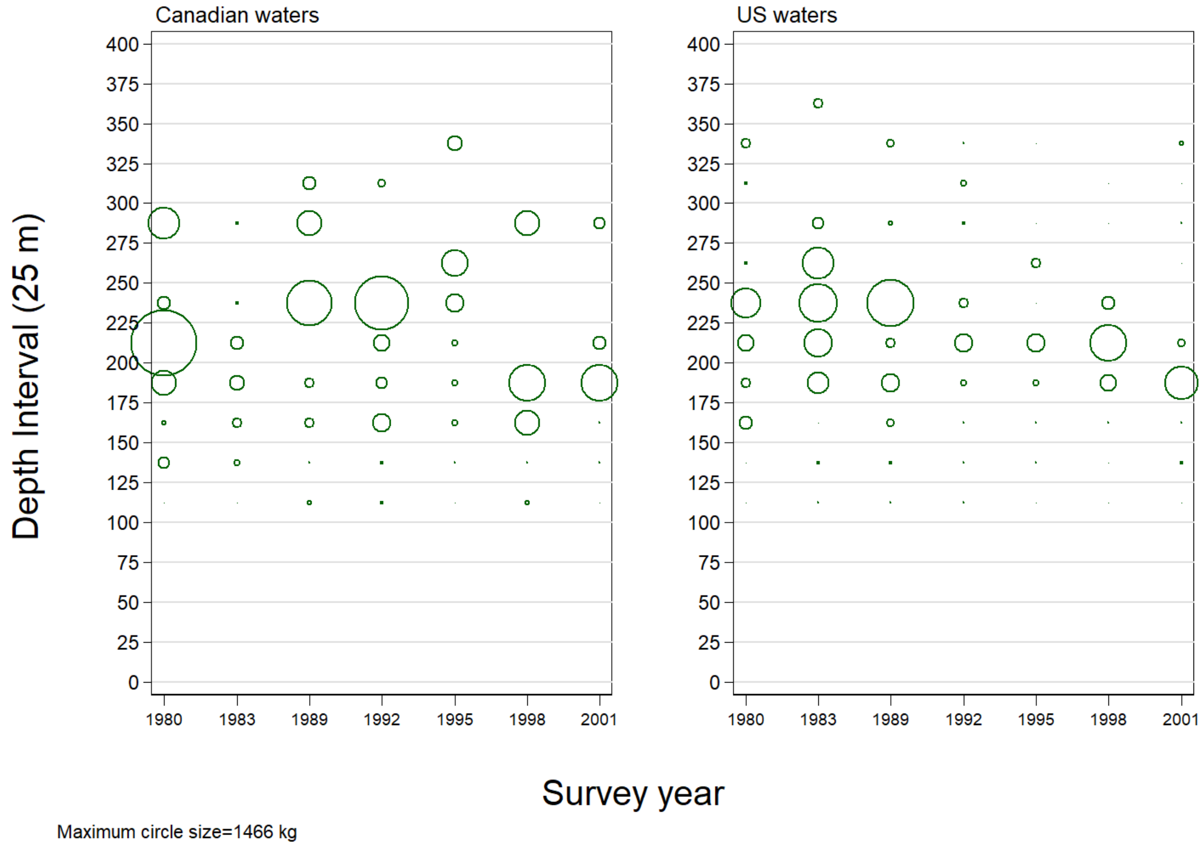

Figure B.8. Distribution of Pacific Ocean Perch catch weights for each survey year summarised into 25 m depth intervals for all valid tows (Table B.3) in Canadian and US waters of the Vancouver INPFC area. Catches are plotted at the mid-point of the interval.

The biomass estimates were variable across the seven surveys, with the 1980 and 1989 having the largest swept-area biomass estimates in the Canadian waters. All the survey estimates were associated with large relative errors, ranging from 0.34 (in 1983) to 0.74 (in 1992) in Canadian waters and from 0.37 (in 1983) to 0.76 (in 1989) in US waters (Figure B.9; Table B.4). This results in a series with little apparent trend over the 22 year period covered by these surveys, especially given the wide error bars associated with this survey. Note that the bootstrap estimates of relative error do not include any uncertainty with respect to the ratio expansion required to make the 1980 and 1983 survey estimates comparable to the 1989 and later surveys. Therefore, it is likely that the true uncertainty for this series is even greater than presented here.

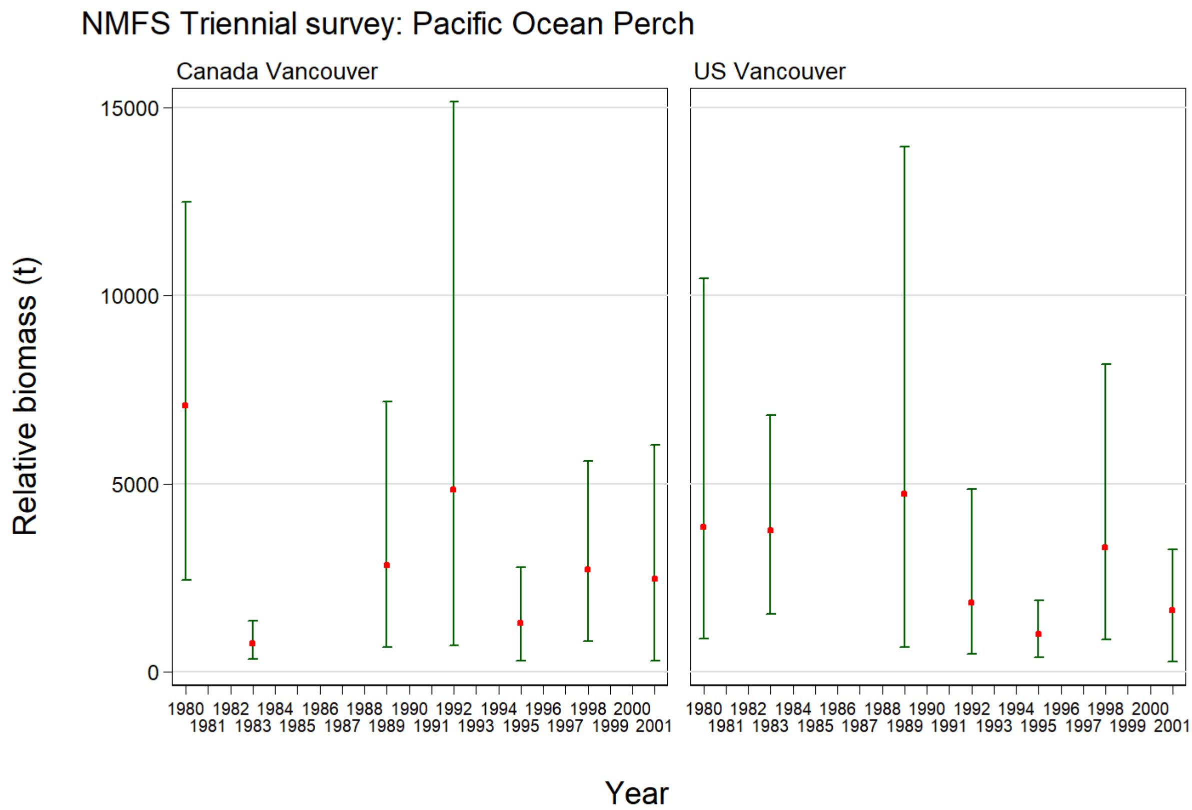

Figure B.9. Biomass estimates for Pacific Ocean Perch in the INPFC Vancouver region (Canadian waters only, US waters only) with 95% error bars estimated from 1,000 bootstrap random draws with replacement.

Table B.4. Two sets of biomass estimates for Pacific Ocean Perch in the Vancouver INPFC region (Canadian waters; US waters) with 95% confidence bounds based on the bootstrap distribution of biomass. Bootstrap estimates were based on 1,000 random draws with replacement.

Estimate series	Year	Biomass (Eq. B.4)	Mean bootstrap biomass	Lower bound biomass	Upper bound biomass	CV bootstrap	CV Analytic (Eq. B.6)
Canada Vancouver	1980	7,072	7,175	2,436	12,495	0.359	0.391
	1983	758	749	348	1,361	0.340	0.345
	1989	2,829	2,844	653	7,186	0.549	0.567
	1992	4,834	4,888	707	15,150	0.740	0.747
	1995	1,303	1,289	293	2,787	0.487	0.497
	1998	2,724	2,676	816	5,607	0.440	0.445
	2001	2,481	2,458	300	6,036	0.660	0.684
US Vancouver	1980	3,843	3,874	892	10,471	0.585	0.618
	1983	3,758	3,702	1,535	6,818	0.370	0.376
	1989	4,726	4,773	658	13,966	0.757	0.735
	1992	1,832	1,665	469	4,858	0.612	0.594
	1995	1,015	1,003	395	1,889	0.371	0.360
	1998	3,304	3,280	859	8,168	0.558	0.550
	2001	1,635	1,485	278	3,261	0.527	0.583

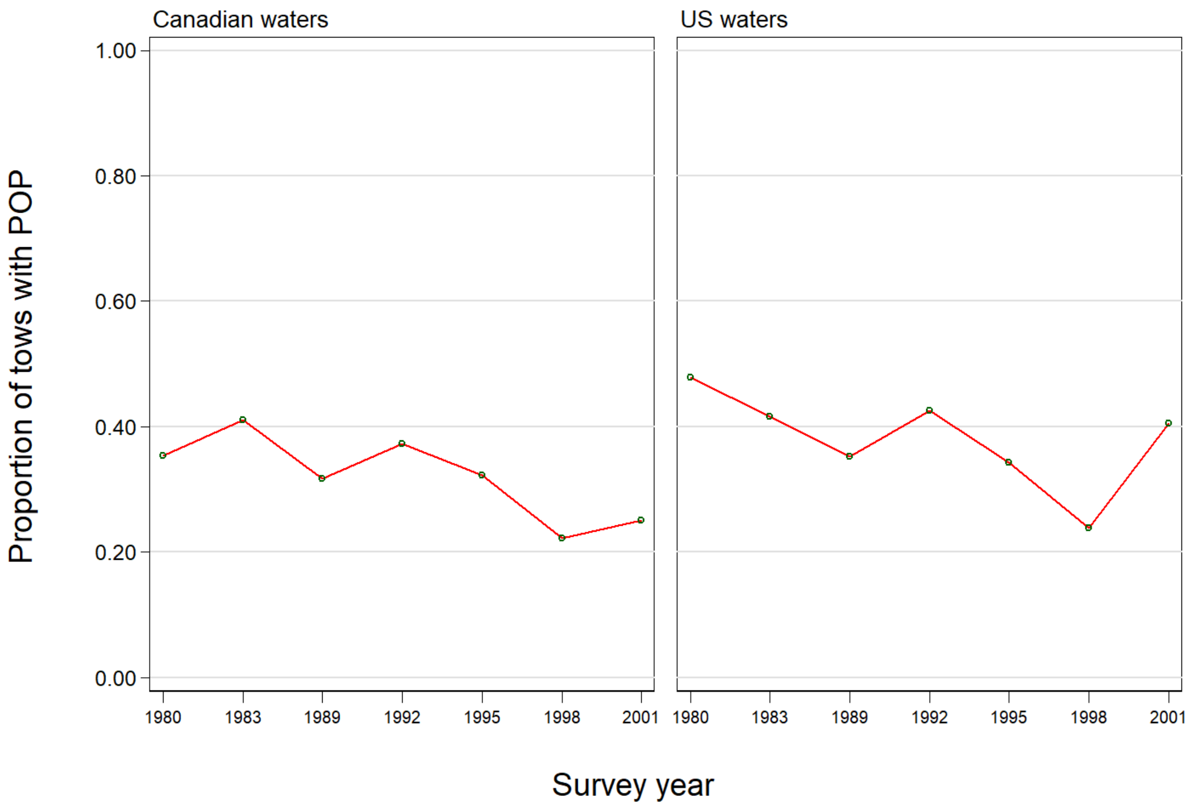

Figure B.10. Proportion of tows with Pacific Ocean Perch by year for the Vancouver INPFC region (Canadian and US waters).

The proportion of tows which contained Pacific Ocean Perch ranged between 22% and 41% in Canadian waters while the range was wider in US waters (24% to 48%)(Figure B.10). The overall mean was 32% in Canadian waters and 38% in US waters. The incidence of POP in Canadian waters for this survey is somewhat lower than the synoptic survey operating after 2004 off the west coast of Vancouver Island, with the latter survey having a mean incidence of 37% (range: 32–43%) of the tows containing POP.

The seven Triennial survey indices from the Canada Vancouver region, spanning the period 1980 to 2001, were used as abundance indices in the stock assessment model to represent the 3CD POP population (described in Appendix F).

B.6. QUEEN CHARLOTTE SOUND SYNOPTIC TRAWL SURVEY

B.6.1. Data selection

This survey has been conducted eleven times over the period 2003 to 2021 in the Queen Charlotte Sound (QCS), which lies between the top of Vancouver Island and the southern portion of Moresby Island and extends into the lower part of Hecate Strait between Moresby Island and the mainland. The design divided the survey into two large areal strata which roughly correspond to the PMFC regions 5A and 5B while also incorporating part of 5C (all valid tow starting positions are shown by survey year in Figure B.11 to Figure B.21). Each of these two areal strata was divided into four depth strata: 50–125 m; 125–200 m; 200–330 m; and 330–500 m (Table B.5).

Table B.5. Number of usable tows for biomass estimation by year and depth stratum for the Queen Charlotte Sound synoptic survey over the period 2003 to 2021. Also shown is the area of each stratum for the 2021 survey and the charter vessel conducting the survey by survey year.

		South depth strata				North depth strata				Total
Year	**Vessel**	**50–125**	**125–200**	**200–330**	**330–500**	**50–125**	**125–200**	**200–330**	**330–500**	**tows**[1]
2003	*Viking Storm*	29	56	29	6	5	38	46	19	228
2004	*Viking Storm*	42	48	30	8	20	38	37	6	229
2005	*Viking Storm*	29	60	28	8	8	43	37	8	221
2007	*Viking Storm*	33	61	24	7	19	56	48	7	255
2009	*Viking Storm*	34	60	27	8	10	43	42	6	230
2011	*Nordic Pearl*	38	67	23	8	10	51	43	8	248
2013	*Nordic Pearl*	32	65	29	10	9	45	41	5	236
2015	*Frosti*	30	65	26	4	12	49	44	8	238
2017	*Nordic Pearl*	36	57	28	8	12	51	40	7	239
2019	*Nordic Pearl*	35	62	26	9	15	52	35	8	242
2021	*Nordic Pearl*	24	53	28	3	5	40	37	3	193
Area (km^2)[2]		5,012	5,300	2,640	528	1,740	3,928	3,664	1,236	24,048[2]

[1] GFBio usability codes=0,1,2,6 [2] Total area (km^2) for 2021 synoptic survey

Table B.6. Number of missing doorspread values by year for the Queen Charlotte Sound synoptic survey over the period 2003 to 2021 as well as showing the number of available doorspread observations and the mean doorspread value for each survey year.

Year	Number tows with missing doorspread [1]	Number tows with doorspread observations [2]	Mean doorspread (m) used for tows with missing values [2]
2003	13	236	72.1
2004	8	267	72.8
2005	1	258	74.5
2007	5	262	71.8
2009	2	248	71.3
2011	30	242	67.0
2013	42	226	69.5
2015	0	249	70.5
2017	1	264	64.7
2019	8	264	62.9
2021	8	202	65.5
Total	118	2,718	69.4

[1] valid biomass estimation tows only [2] includes tows not used for biomass estimation

A doorspread density value (Eq. B.3) was generated for each tow based on the catch of POP from the mean doorspread for the tow and the distance travelled. [`distance travelled`] is a database field which is calculated directly from the tow track. This field is used preferentially for the variable D_{yij} in Eq. B.3. A calculated value ([`vessel speed`] X [`tow duration`]) was used for this variable if [`distance travelled`] was missing, but there were only two instances of this occurring in the eleven trawl surveys. Missing values for the [`doorspread`] field were filled in with the mean doorspread for the survey year (118 values over all years, Table B.6).

B.6.2. Results

An examination of the spatial plots provided from Figure B.11 to Figure B.21 shows that POP were caught in each of the three gullies: Goose Island, Mitchell and Moresby (e.g., Figure B.11, Figure B.15). POP were found in most tows ranging from 150 m to 350 m (Figure B.22). The POP relative biomass estimates ranged from 10,400 to 22,100 t, with the relative error ranging from 11% to 27% (Table B.7, Figure B.23) and without an overall trend in biomass. The relative error is generally low for this species, with six of the eleven survey years at less than 0.2. This result means that this survey is informative for this species. An examination of the density plots shows that this species is widely dispersed across the shelf, with catches in more than half the tows and consistently extending up each of the three gullies.

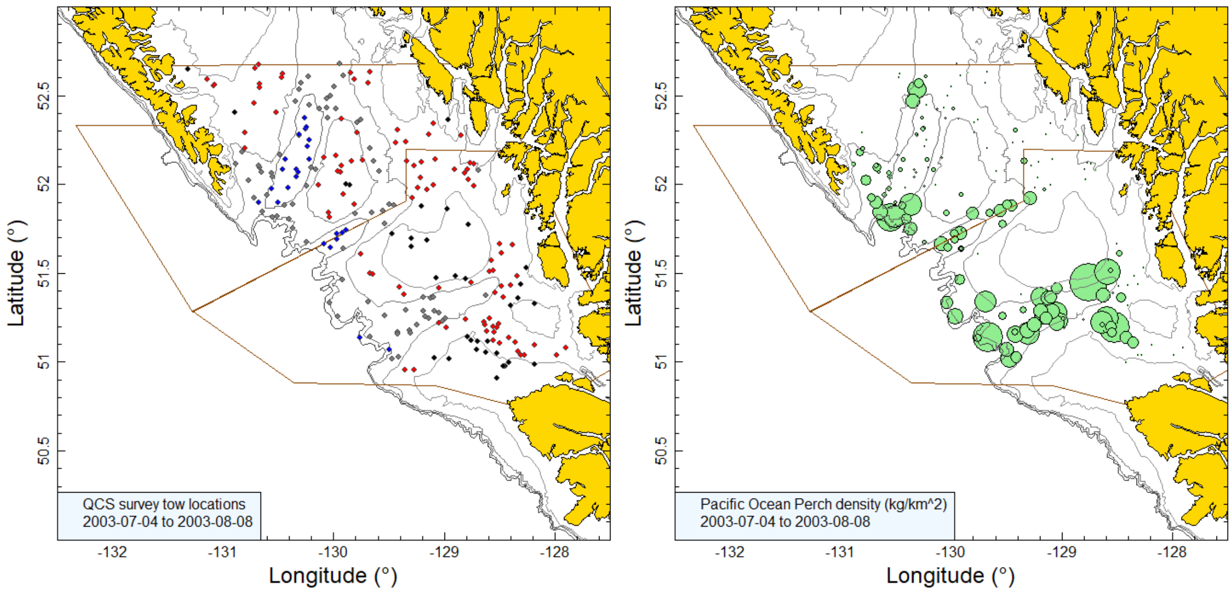

Figure B.11. Valid tow locations (50–125 m stratum: black; 126–200 m stratum: red; 201–330 m stratum: grey; 331–500 m stratum: blue) and density plots for the 2003 QC Sound synoptic survey. Circle sizes in the right-hand density plot scaled across all years (2003–2005, 2007, 2009, 2011, 2013, 2015, 2017, 2019, 2021), with the largest circle = 34,852 kg/km^2 in 2004. Boundaries delineate the North and South areal strata.

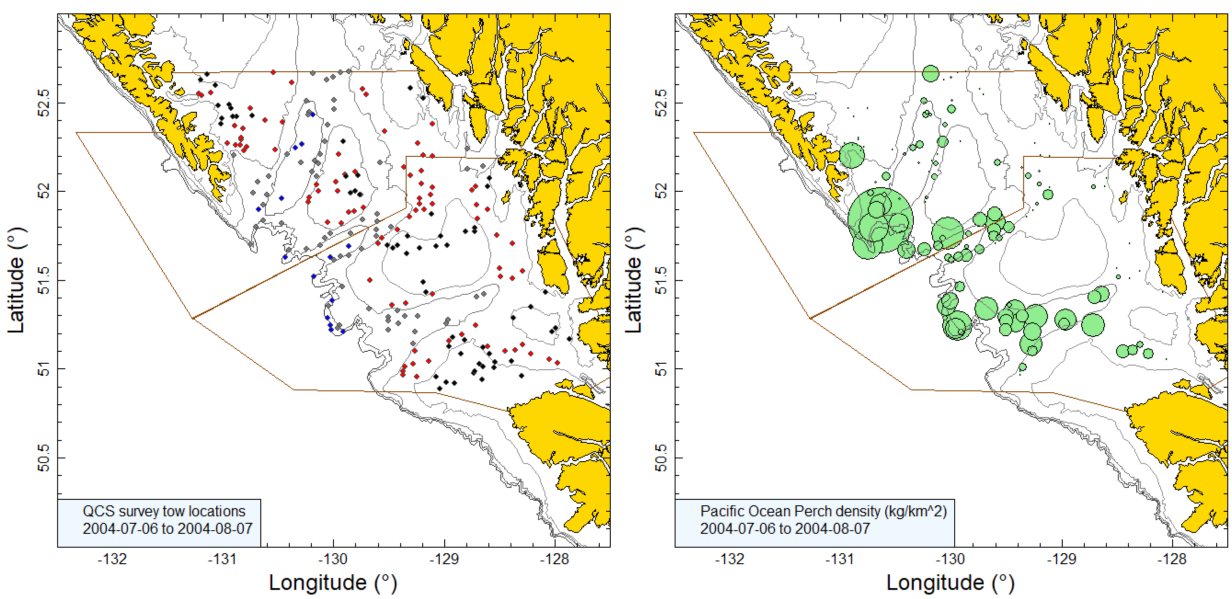

Figure B.12. Tow locations and density plots for the 2004 Queen Charlotte Sound synoptic survey (see Figure B.11 caption).

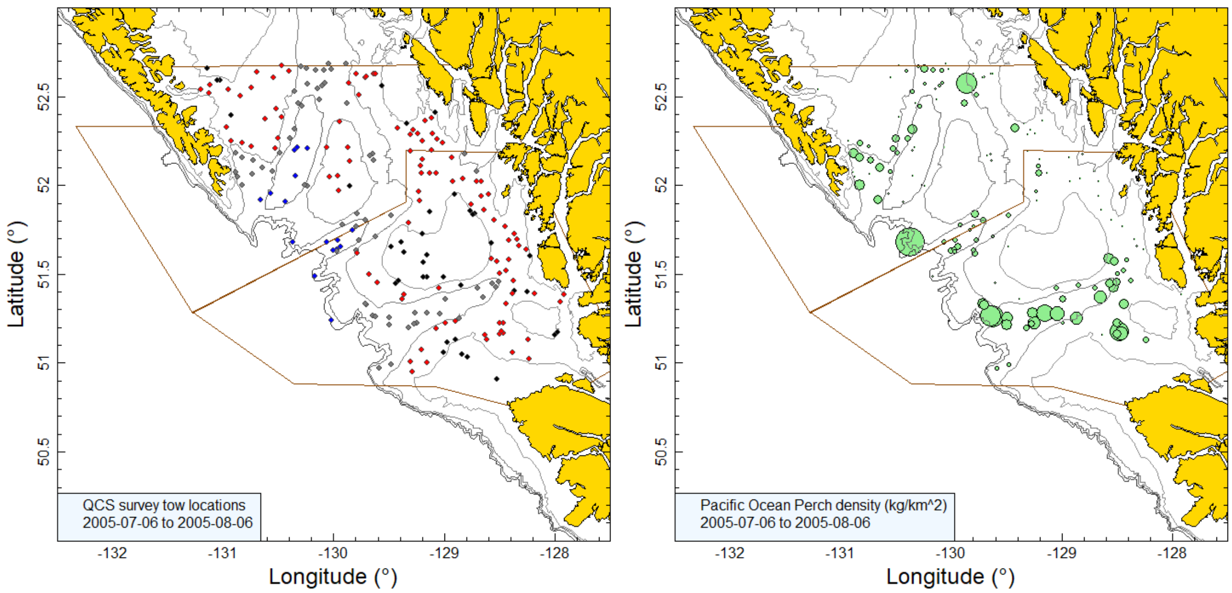

Figure B.13. Tow locations and density plots for the 2005 Queen Charlotte Sound synoptic survey (see Figure B.11 caption).

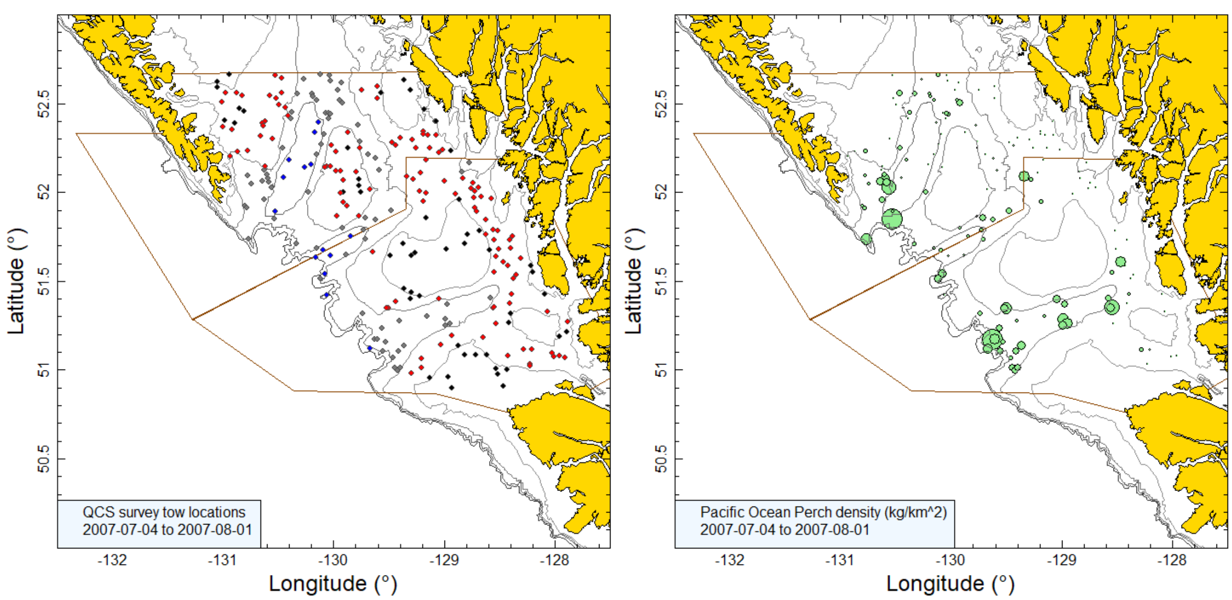

Figure B.14. Tow locations and density plots for the 2007 Queen Charlotte Sound synoptic survey (see Figure B.11 caption).

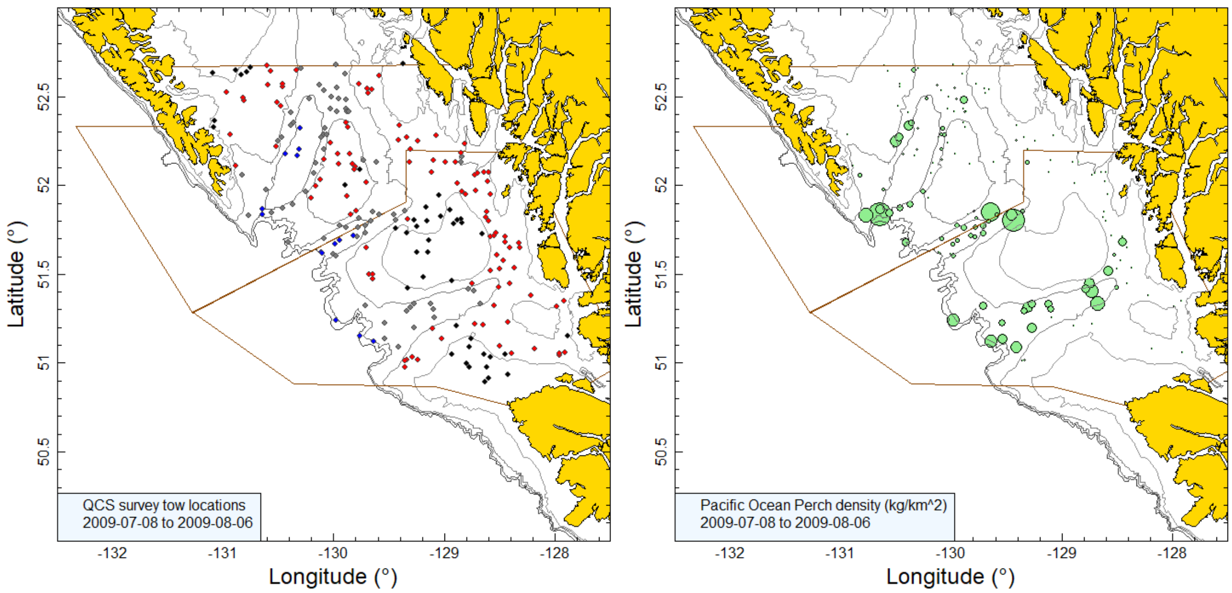

Figure B.15. Tow locations and density plots for the 2009 Queen Charlotte Sound synoptic survey (see Figure B.11 caption).

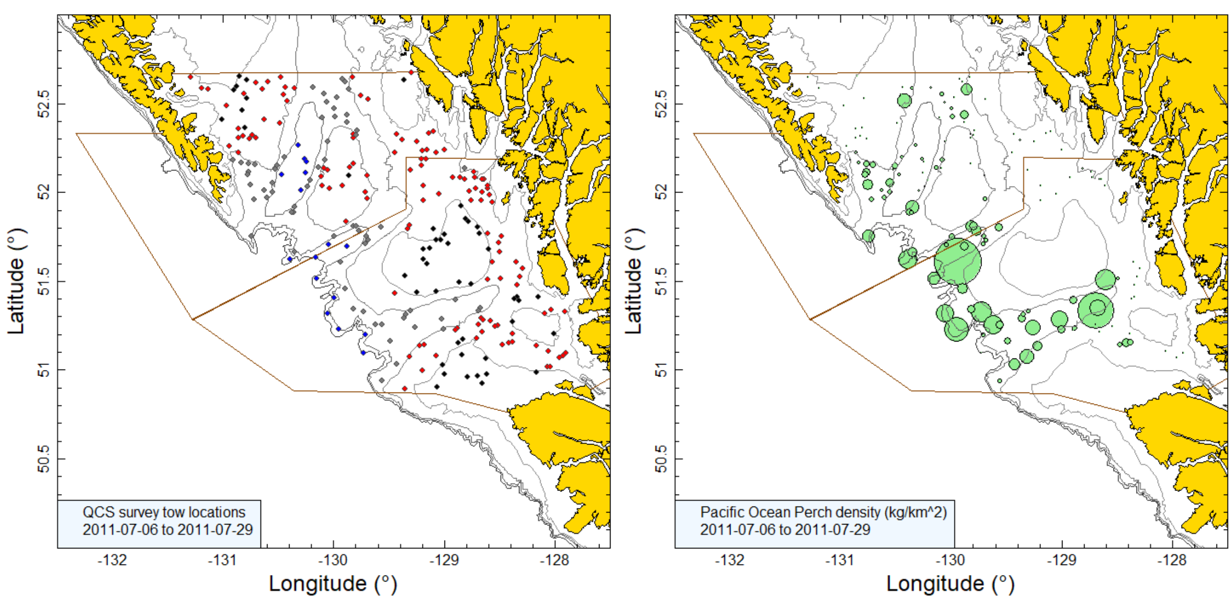

Figure B.16. Tow locations and density plots for the 2011 Queen Charlotte Sound synoptic survey (see Figure B.11 caption).

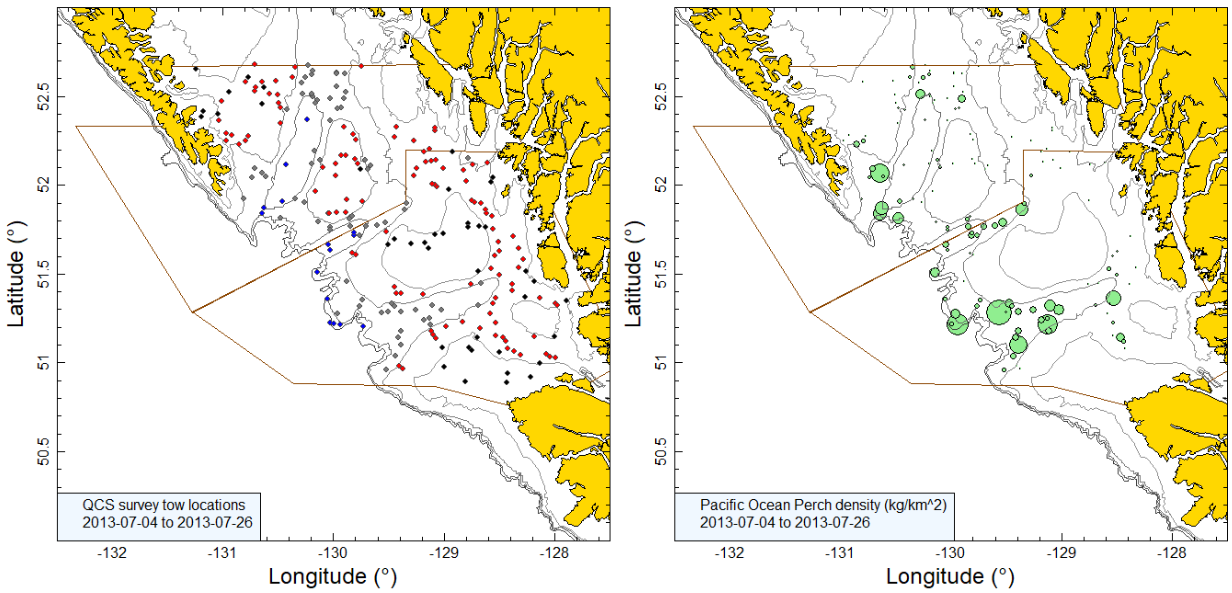

Figure B.17. Tow locations and density plots for the 2013 Queen Charlotte Sound synoptic survey (see Figure B.11 caption).

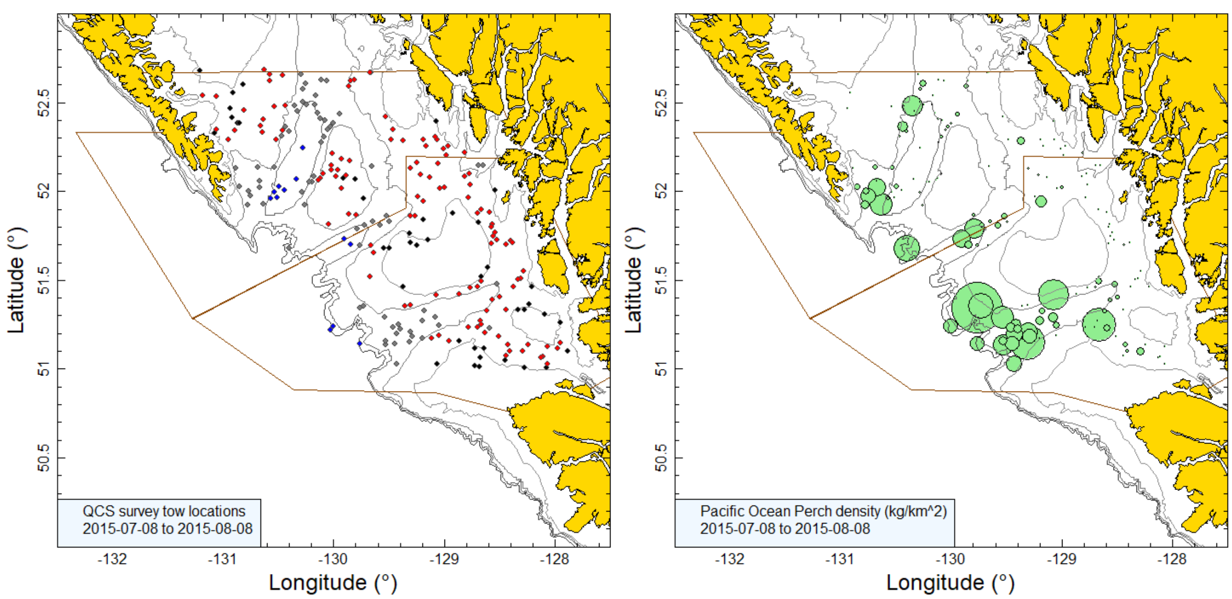

Figure B.18. Tow locations and density plots for the 2015 Queen Charlotte Sound synoptic survey (see Figure B.11 caption).

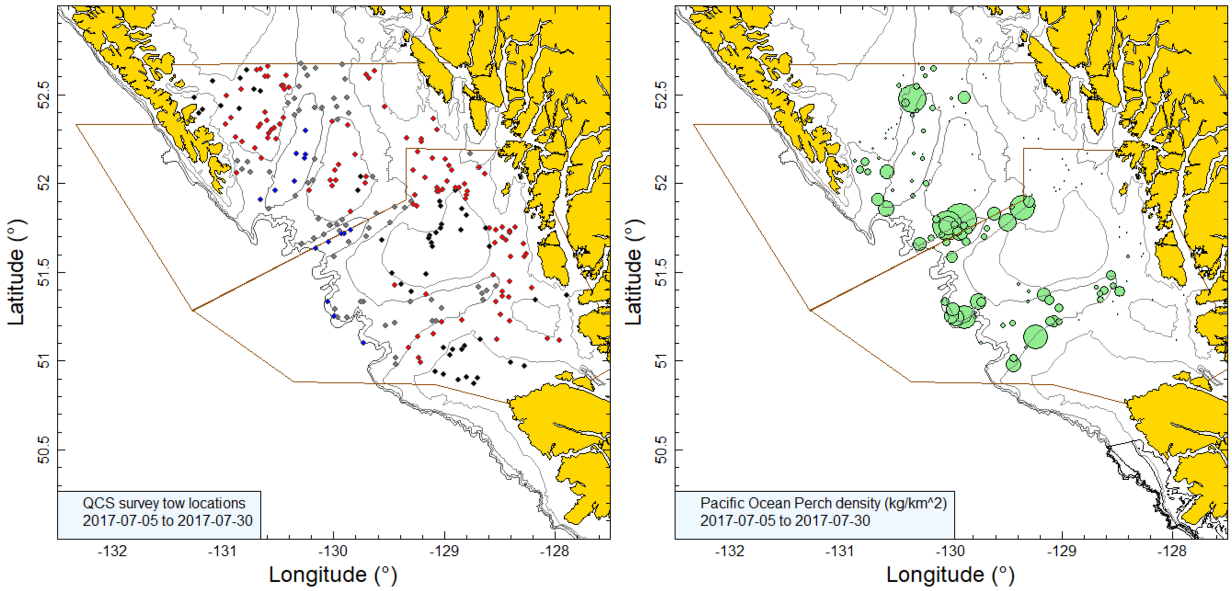

Figure B.19. Tow locations and density plots for the 2017 Queen Charlotte Sound synoptic survey (see Figure B.11 caption).

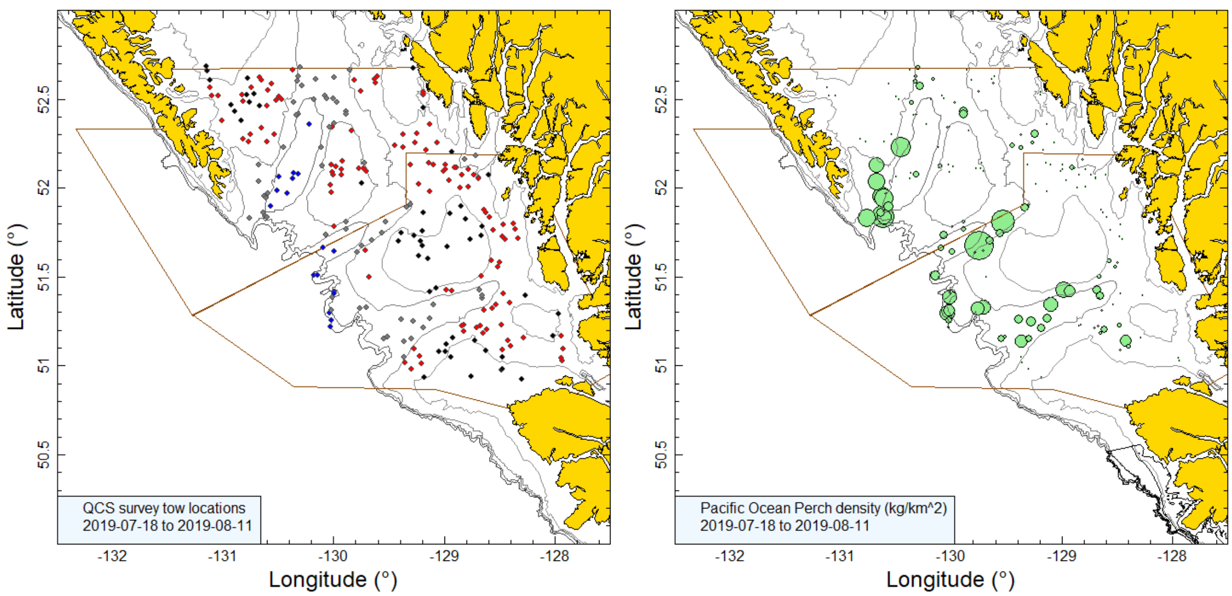

Figure B.20. Tow locations and density plots for the 2019 Queen Charlotte Sound synoptic survey (see Figure B.11 caption).

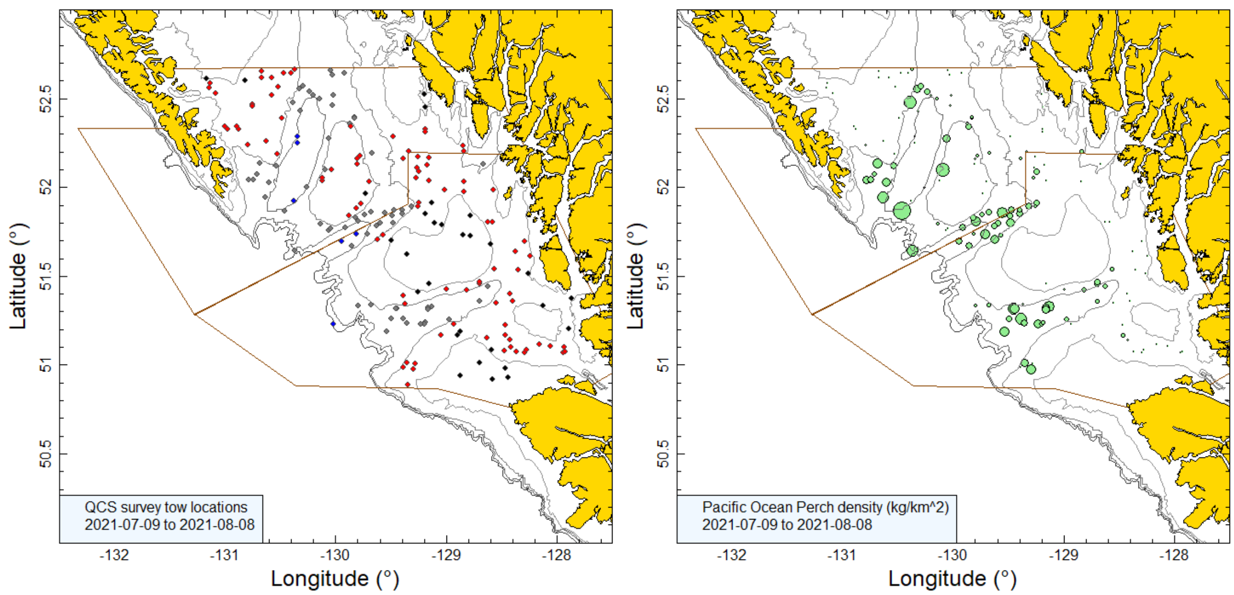

Figure B.21. Tow locations and density plots for the 2021 Queen Charlotte Sound synoptic survey (see Figure B.11 caption).

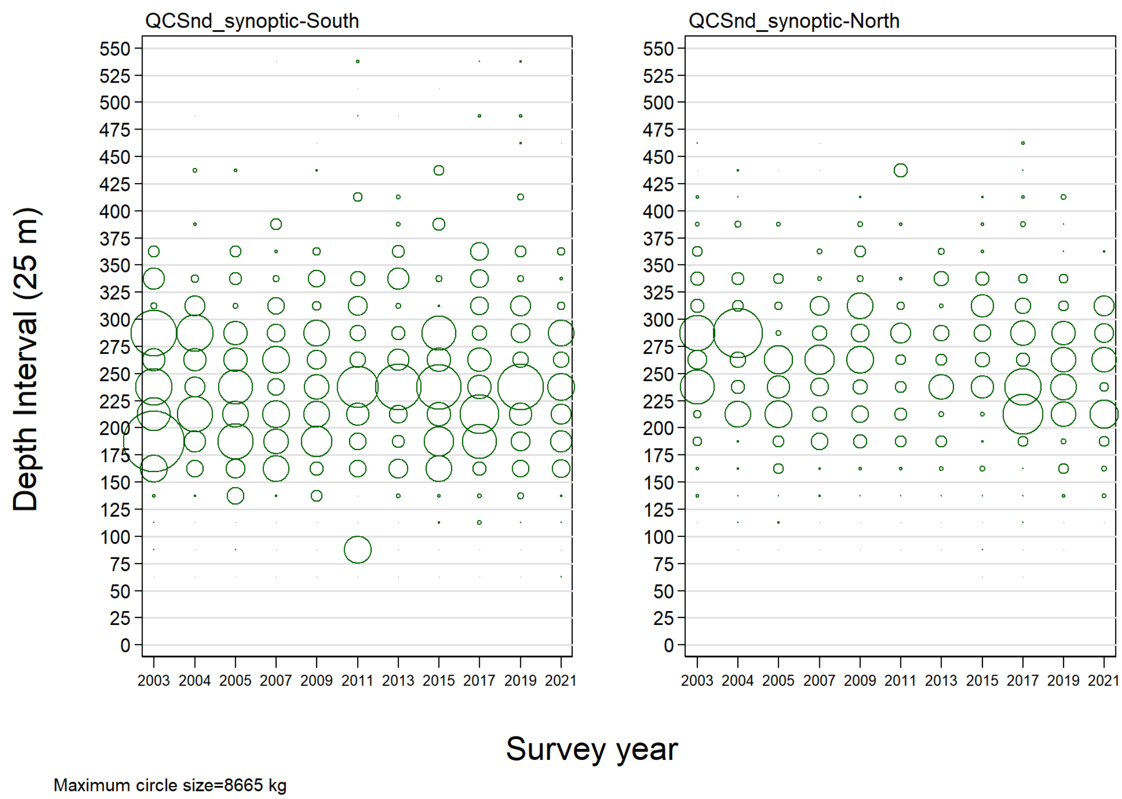

Figure B.22. Distribution of observed catch weights for tows used in biomass estimation for POP in the two main Queen Charlotte Sound synoptic survey areal strata (Table B.5) by survey year and 25 m depth zone. Catches are plotted at the mid-point of the interval and circles in the panel are scaled to the maximum value (8,665 kg) in the 175–200 m interval in the 2003 southern stratum. The 1% and 99% quantiles for the POP start of tow depth distribution= 113 m and 437 m respectively.

Table B.7. Biomass estimates for POP from the Queen Charlotte Sound synoptic trawl survey for the survey years 2003 to 2021. Bootstrap bias corrected confidence intervals and CVs are based on 1,000 random draws with replacement.

Survey Year	Biomass (t) (Eq. B.4)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV (Eq. B.6)
2003	22,061	22,010	17,161	30,081	0.140	0.142
2004	16,572	16,609	10,663	26,189	0.237	0.226
2005	14,000	14,029	9,567	20,681	0.206	0.200
2007	10,359	10,334	7,593	14,130	0.159	0.163
2009	12,405	12,411	7,900	20,513	0.245	0.236
2011	12,312	12,413	7,067	20,195	0.275	0.267
2013	11,021	11,043	7,503	15,645	0.186	0.189
2015	14,350	14,324	9,116	22,196	0.235	0.234
2017	16,595	16,614	12,185	22,938	0.167	0.169
2019	15,111	15,032	10,886	21,346	0.170	0.166
2021	12,811	12,770	10,511	16,141	0.110	0.109

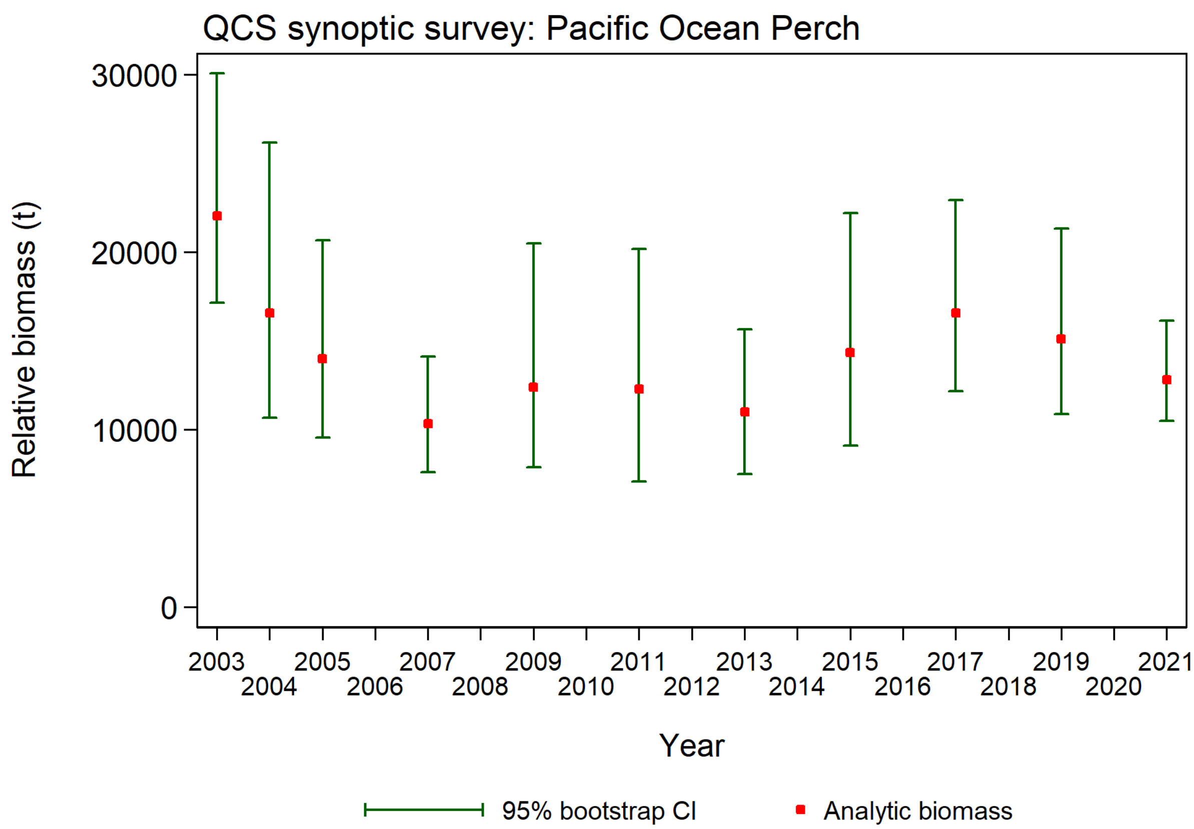

Figure B.23. Plot of biomass estimates for POP (values provided in Table B.7) from the Queen Charlotte Sound synoptic survey over the period 2003 to 2021. Bias corrected 95% confidence intervals from 1,000 bootstrap replicates are plotted.

On average, POP were captured in 64% of tows across both areal strata, ranging from 45% to 69% of the tows in the South strata and 63% to 86% of the tows in the North strata (Figure B.24). Overall, 1,625 of the 2,559 valid survey tows (63.5%) contained POP. The median catch weight for positive tows used in biomass estimation was 22.6 kg/tow across the eleven surveys, and the maximum catch weight in a tow was 3,961 kg in the 2004 survey.

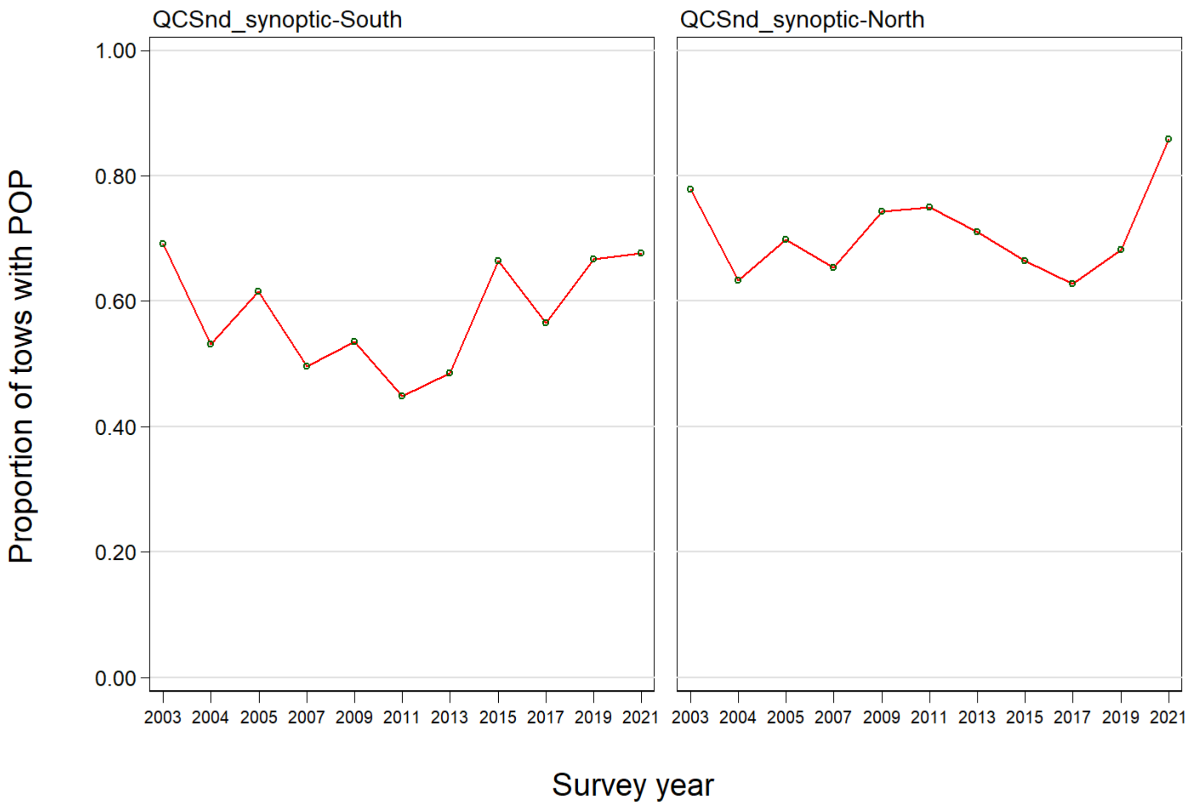

Figure B.24. Proportion of tows by stratum and year which contain POP from the Queen Charlotte Sound synoptic survey over the period 2003 to 2021.

B.7. WEST COAST VANCOUVER ISLAND SYNOPTIC TRAWL SURVEY

B.7.1. Data selection

This survey was conducted seven times over the period 2004 to 2016 off the west coast of Vancouver Island by the CCGS *W.E. Ricker*. However, due to the decommissioning of the *W.E. Ricker* in 2017, two subsequent surveys in 2018 and 2021 were conducted by the FV *Nordic Pearl*. The 2020 survey was rescheduled to 2021 due to restrictions on the deployment of government vessels imposed by Canadian policy pertaining to the ongoing COVID-19 epidemic. A tenth survey was conducted by the newly commissioned CCGS *Sir John Franklin* in 2022, putting this survey on track with the pre-COVID-19 schedule. This survey comprises a single areal stratum, separated into four depth strata: 50–125 m; 125–200 m; 200–330 m; and 330–500 m (Table B.8). Approximately 150 to 2-km^2 blocks are selected randomly among the four depth strata when conducting each survey (Olsen et. al. 2008).

A further survey, conducted off the west coast of Vancouver Island by the FV *Caledonian* in 1996, was considered for inclusion in this series by the 2012 3CD POP stock assessment (Edwards et al. 2014b). However, this survey index was not accepted into this series because of the substantial difference in timing for this survey (September) compared to the timing of the synoptic surveys (late spring). It was felt that this difference would lead to varying availability for this species between surveys and consequently there would be a difference in comparability between this survey and remaining synoptic surveys.

A “doorspread density” value was generated for each tow based on the catch of POP, the mean doorspread for the tow and the distance travelled (Eq. B.3). The distance travelled was provided as a data field, determined directly from vessel track information collected during the tow. There were only two missing values in this field (in 2004 and 2010) which were filled in by multiplying the vessel speed by the time that the net was towed. There were a large number of missing values for the doorspread field in the first five surveys, which were filled in using the mean doorspread for the survey year or a default value of 64.0 m for the three years with no doorspread data (Table B.9). The default value is based on the mean of the observed doorspread from the net mensuration equipment, averaged across the years with doorspread estimates.

Table B.8. Stratum designations, number of usable and unusable tows, for each year of the west coast Vancouver Island synoptic survey. Also shown is the area of each depth stratum in 2018 and the start and end dates for each survey.

Survey year	Stratum depth zone 50–125 m	125–200 m	200–330 m	330–500 m	Total Tows[1]	Unusable tows	Start date	End date
2004	34	34	13	7	88	18	26-May-04	09-Jun-04
2006	61	62	28	13	164	12	24-May-06	18-Jun-06
2008	54	50	32	23	159	19	27-May-08	21-Jun-08
2010	58	47	22	9	136	8	08-Jun-10	28-Jun-10
2012	60	46	25	20	151	6	23-May-12	15-Jun-12
2014	55	49	29	13	146	7	29-May-14	20-Jun-14
2016	54	41	26	19	140	7	25-May-16	15-Jun-16
2018	69	64	36	21	190	12	19-May-18	12-Jun-18
2021	60	57	31	21	169	6	16-May-21	08-Jun-21
2022	50	45	23	8	126	11	19-May-22	11-Jun-22
Area (km^2)	5,716	3,768	708	572	10,764[2]	–	–	–

[1] GFBio usability codes=0,1,2,6 [2] Total area (km^2) for 2021 synoptic survey

Table B.9. Number of valid survey tows with and without doorspread measurements by survey year for the WCVI synoptic survey. Mean doorspread values for those tows with measurements are provided.

Survey year	Number tows: Without doorspread	With doorspread	Mean doorspread (m)
2004	88	0	–
2006	96	69	64.3
2008	58	107	64.5
2010	136	0	–
2012	151	0	–
2014	14	139	64.3
2016	0	147	65.5
2018	0	202	64.3
2021	2	174	61.7
2022	0	136	59.3
All surveys	545	974	63.3

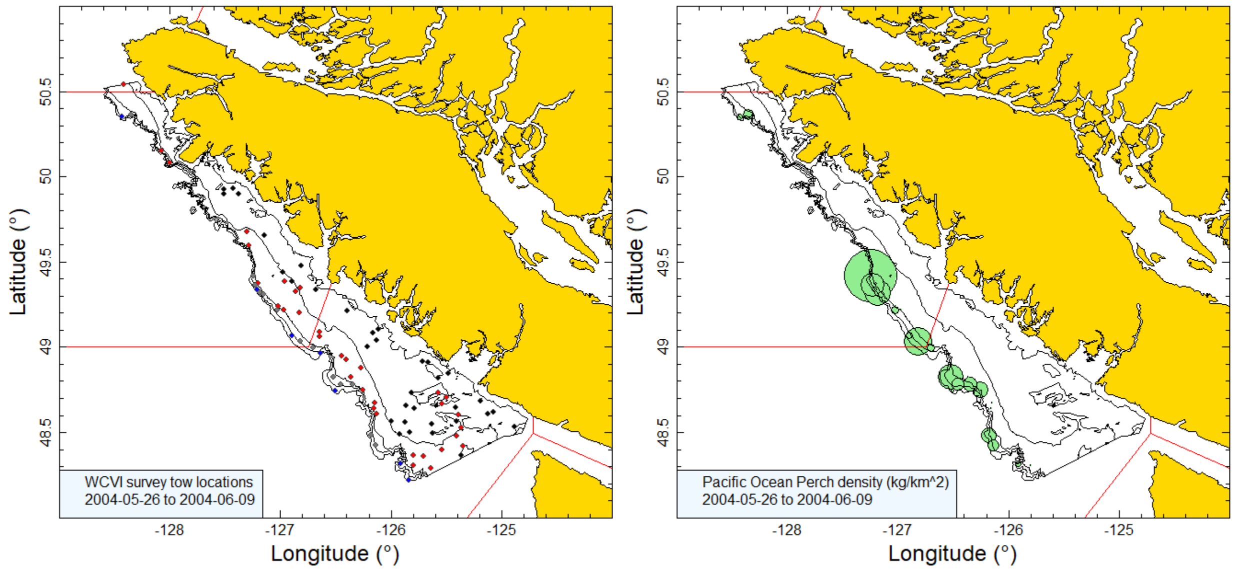

Figure B.25. Valid tow locations (50–125 m stratum: black; 126–200 m stratum: red; 201–330 m stratum: grey; 331–500 m stratum: blue) and density plots for the 2004 west coast Vancouver Island synoptic survey. Circle sizes in the right-hand density plot scaled across all years (2004, 2006, 2008, 2010, 2012, 2014, 2016, 2018, 2021, 2022), with the largest circle = 43,434 kg/km² in 2010. The red solid lines indicate the boundaries for PMFC areas 3C, 3D and 5A.

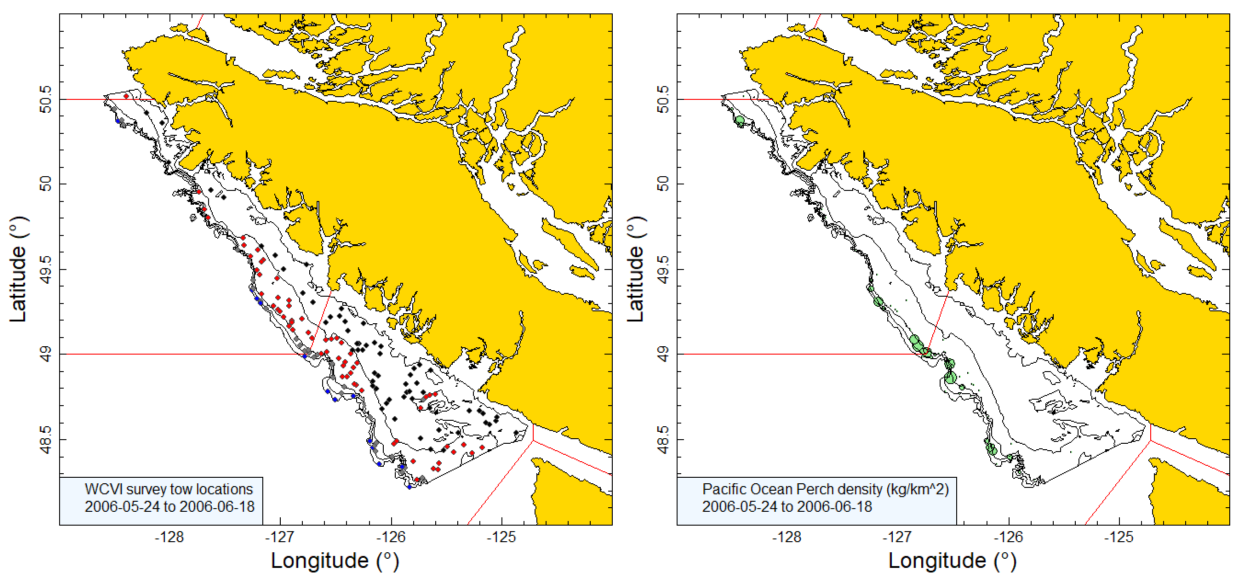

Figure B.26. Tow locations and density plots for the 2006 west coast Vancouver Island synoptic survey (see Figure B.25 caption).

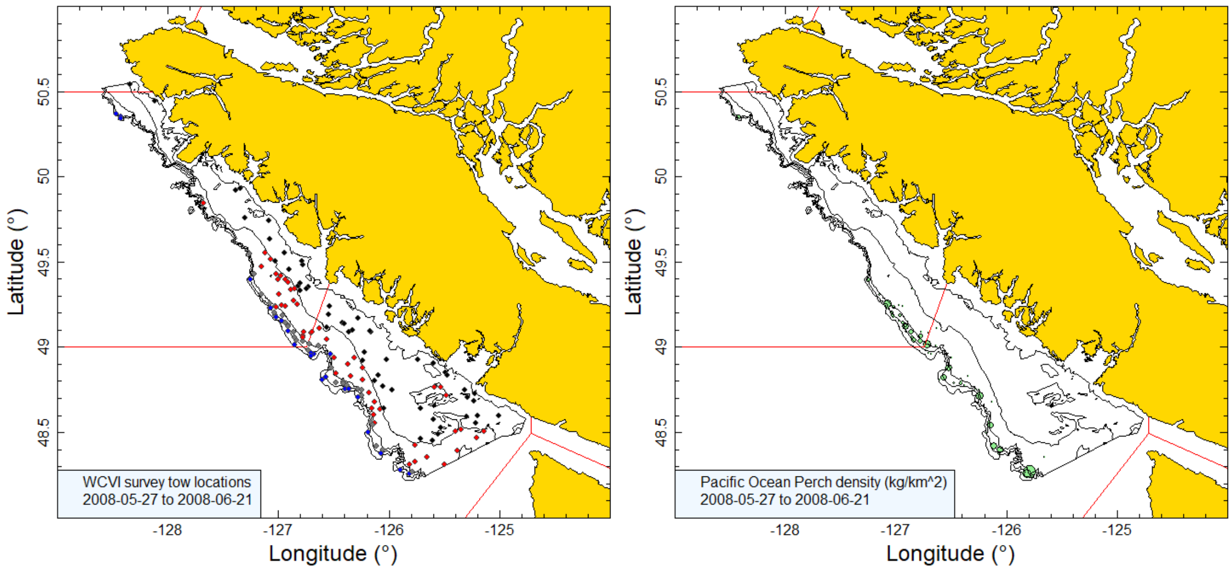

Figure B.27. Tow locations and density plots for the 2008 west coast Vancouver Island synoptic survey (see Figure B.25 caption).

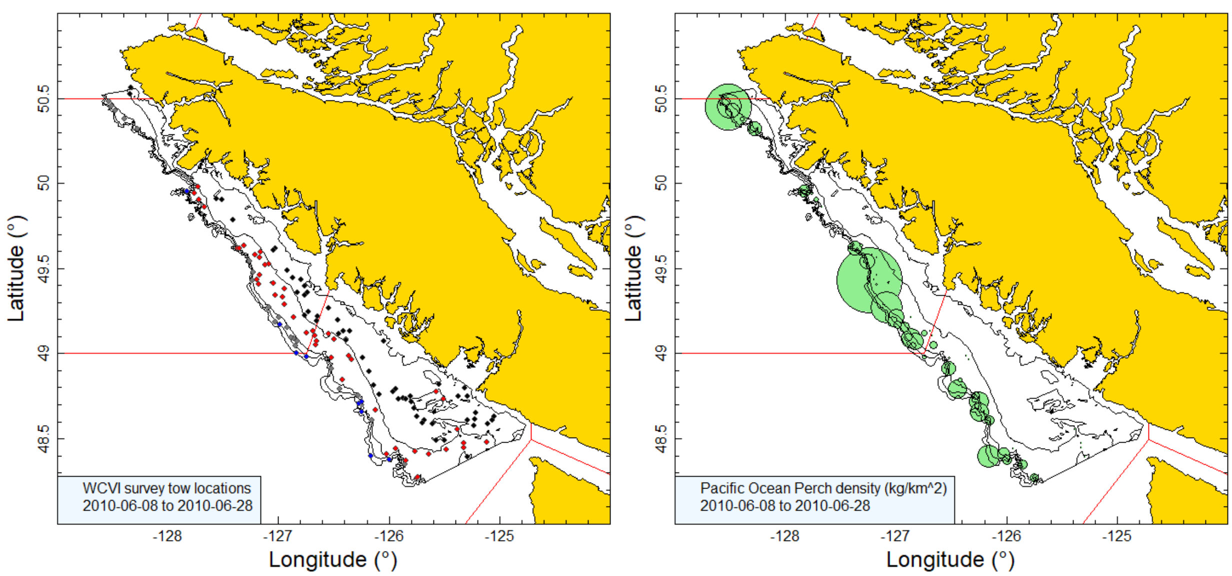

Figure B.28. Tow locations and density plots for the 2010 west coast Vancouver Island synoptic survey (see Figure B.25 caption).

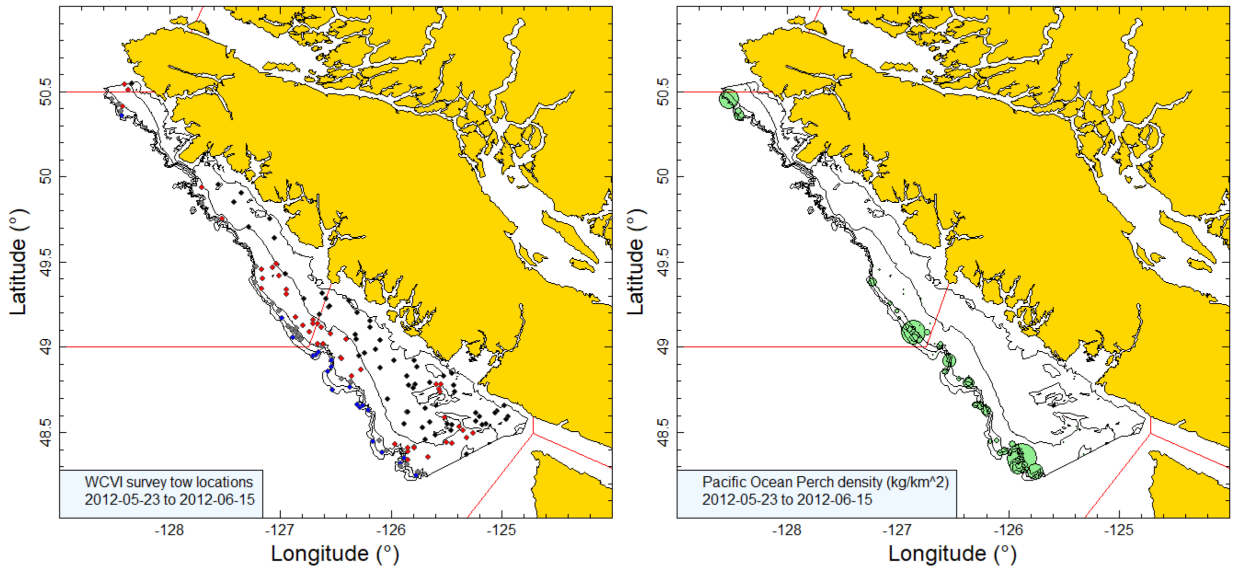

Figure B.29. Tow locations and density plots for the 2012 west coast Vancouver Island synoptic survey (see Figure B.25 caption).

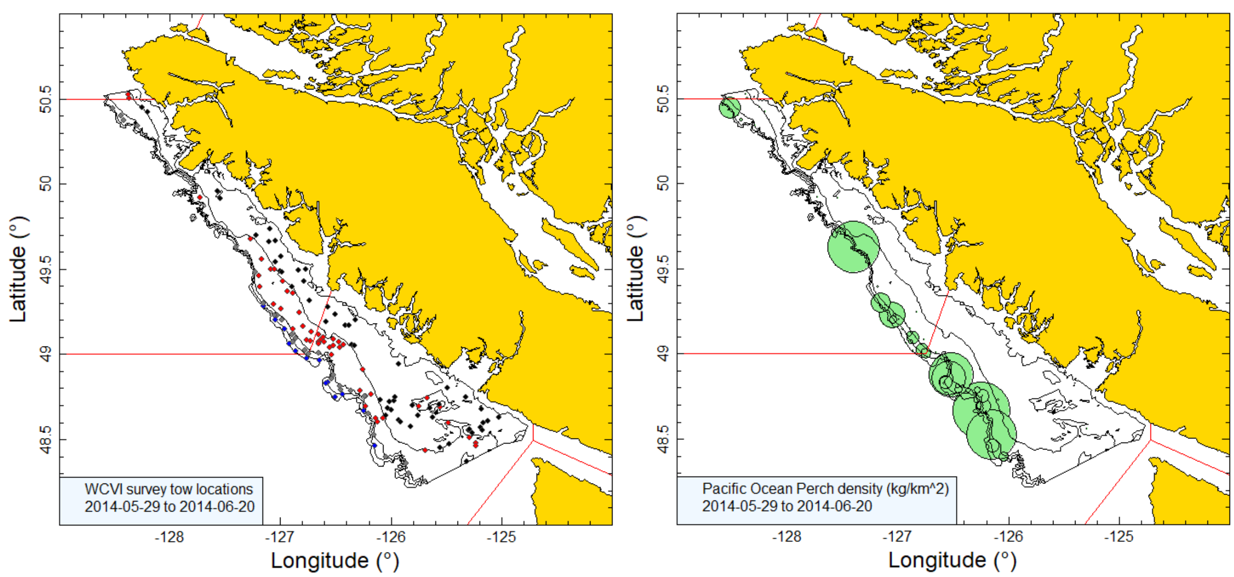

Figure B.30. Tow locations and density plots for the 2014 west coast Vancouver Island synoptic survey (see Figure B.25 caption).

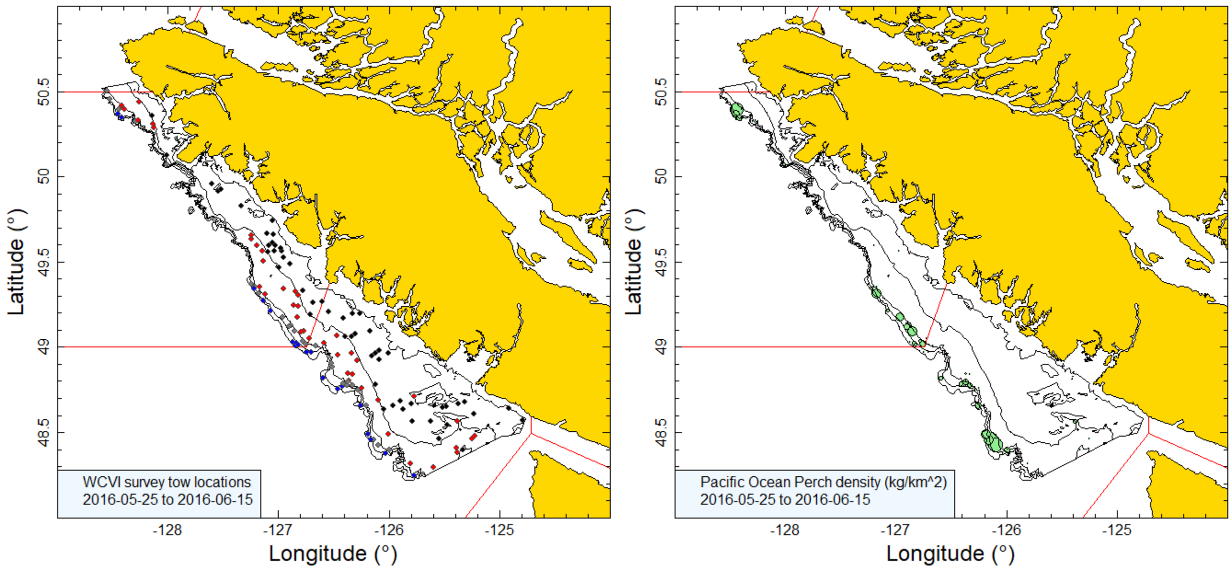

Figure B.31. Tow locations and density plots for the 2016 west coast Vancouver Island synoptic survey (see Figure B.25 caption).

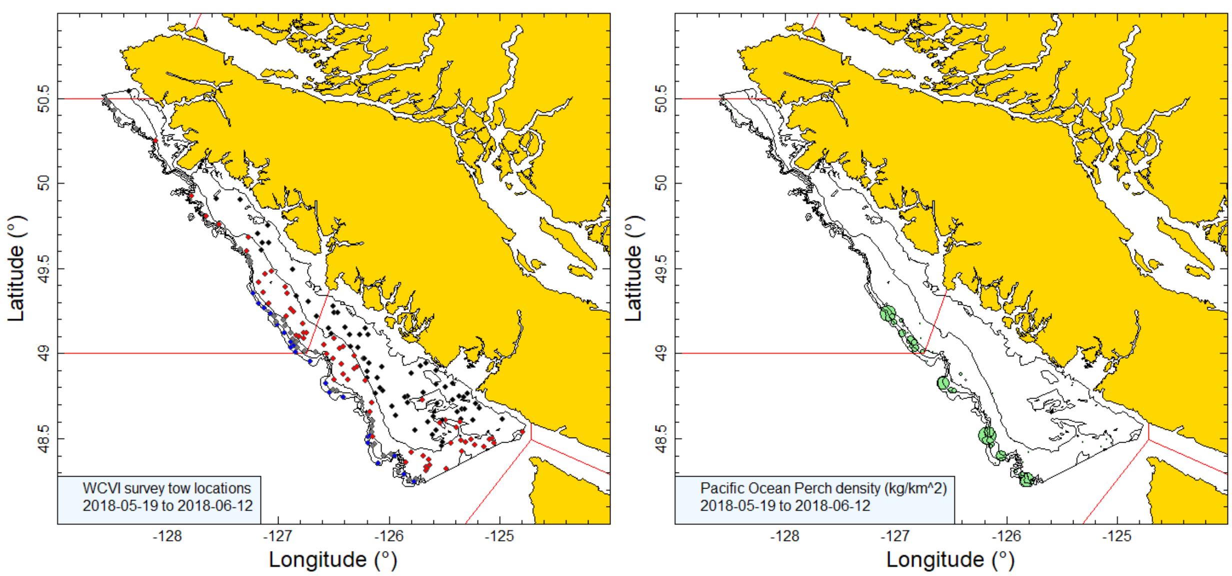

Figure B.32. Tow locations and density plots for the 2018 west coast Vancouver Island synoptic survey (see Figure B.25 caption).

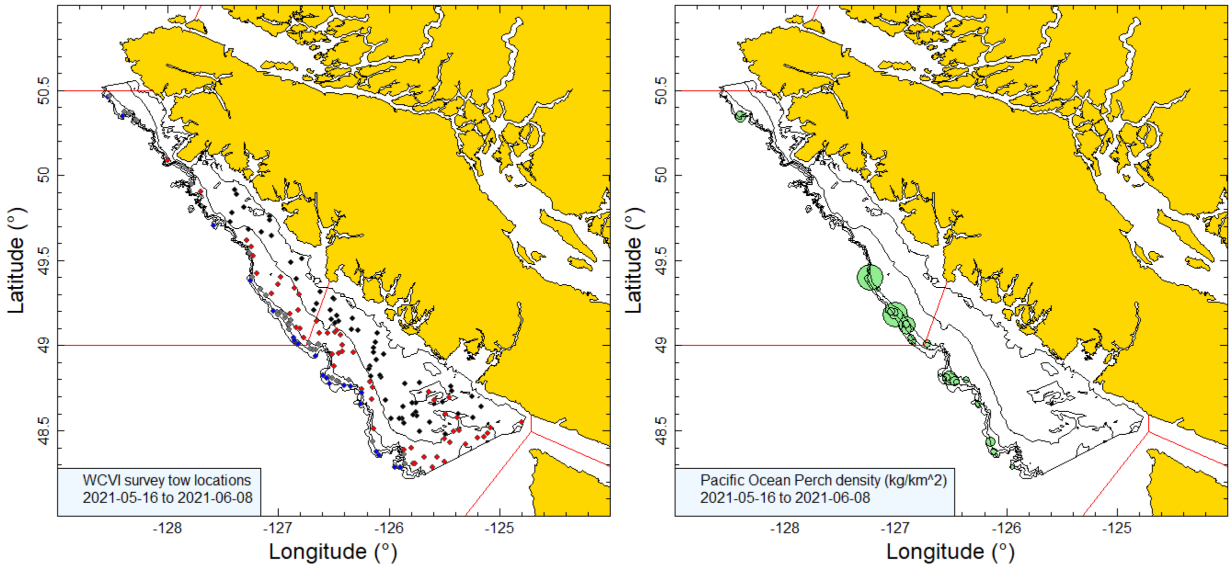

Figure B.33. Tow locations and density plots for the 2021 west coast Vancouver Island synoptic survey (see Figure B.25 caption).

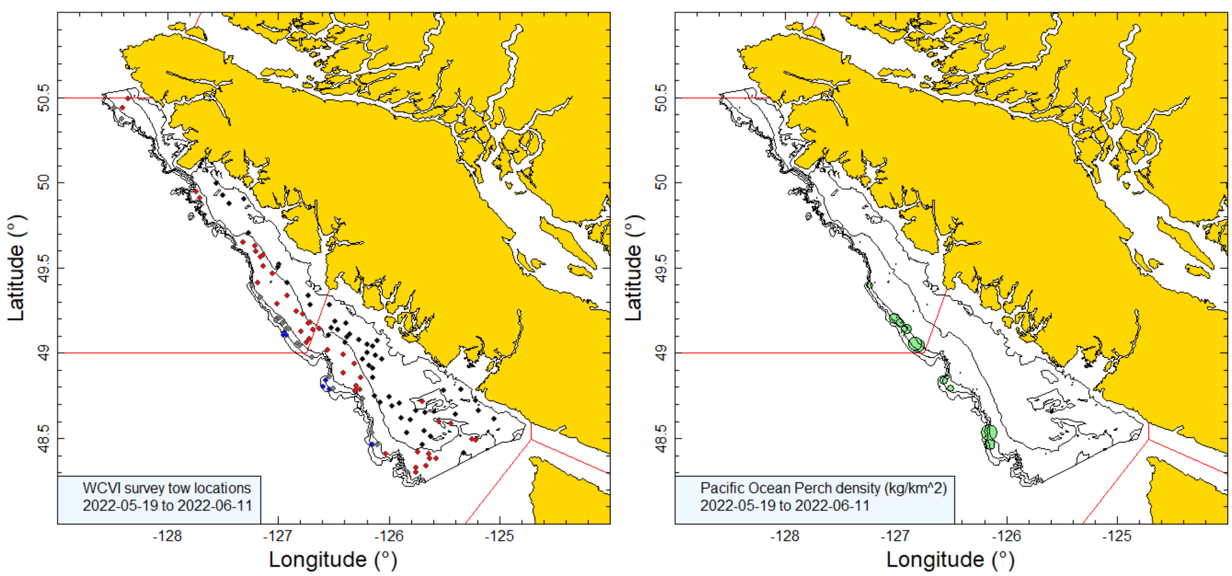

Figure B.34. Tow locations and density plots for the 2022 west coast Vancouver Island synoptic survey (see Figure B.25 caption).

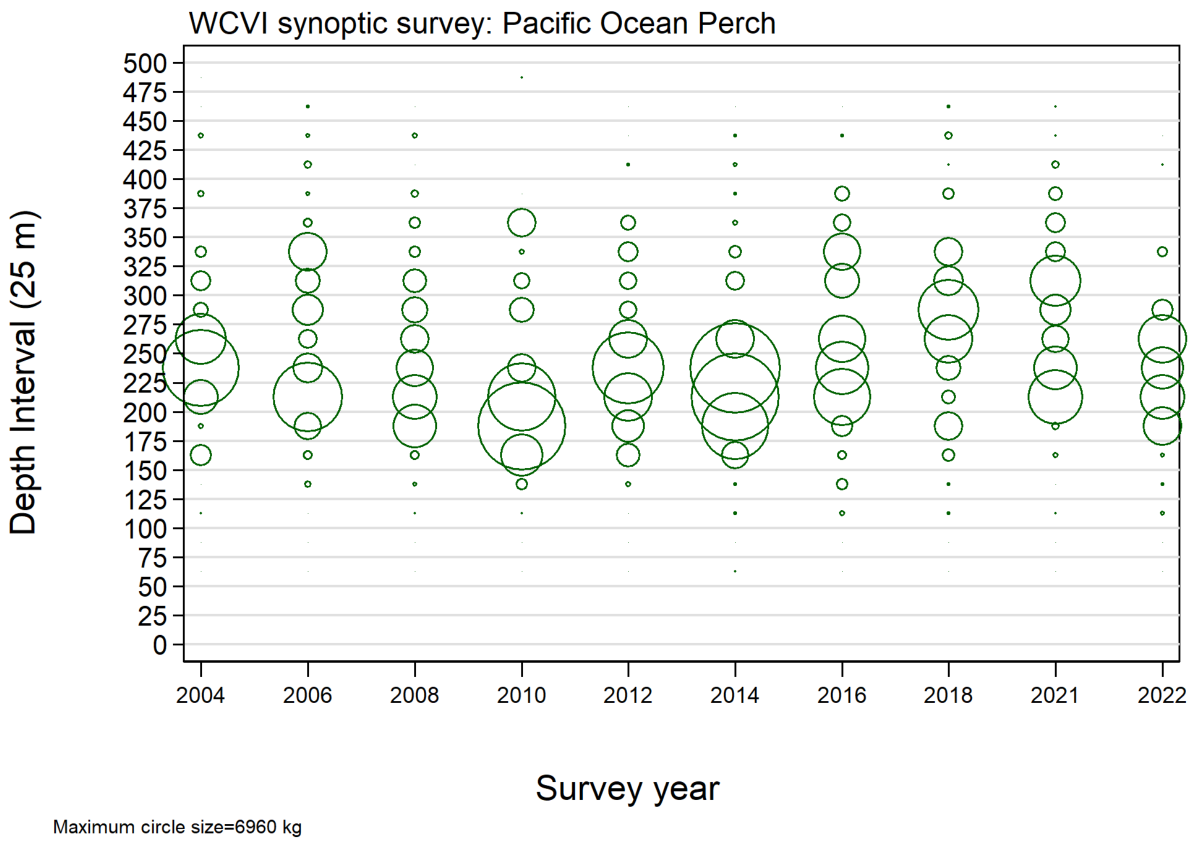

Figure B.35. Distribution of observed weights of POP by survey year and 25 m depth zone. Catches are plotted at the mid-point of the interval and circles in the panel are scaled to the maximum value (6,960 kg) in the 225–250 m depth interval in 2014. The 1st and 99th percentiles for the POP start of tow depth distribution = 108 m and 453 m, respectively.

B.7.2. Results

POP were taken primarily along the shelf edge from near the US border to the most northern section of the survey, well above Brooks Peninsula near the top of Vancouver Island (Figure B.25 to Figure B.33). The distribution appeared to predominate in the lower two-thirds of Vancouver Island, with the highest density tows taken in the central section of the coast. POP were mainly taken in a wide depth range, from about 150 to 400 m (5–95 percentiles=131 to 400 m) (Figure B.35). Relative biomass indices for POP from this trawl survey were reasonable but variable, ranging from 1,400 to 5,200 t, with variable relative errors, which ranged from 0.18 to 0.39 (Figure B.36; Table B.10). There is little evidence of a trend in the biomass indices, given the high relative errors in the years with high biomass estimates.

The proportion of tows capturing POP ranged between 32 and 43% over the ten surveys and with a mean value of 37% (Figure B.37). Five hundred forty-three of the 1,469 usable tows (37%) from this survey contained POP, with a median catch weight for positive tows of 27 kg/tow. One tow caught more than 4,000 kg of POP, in 2010.

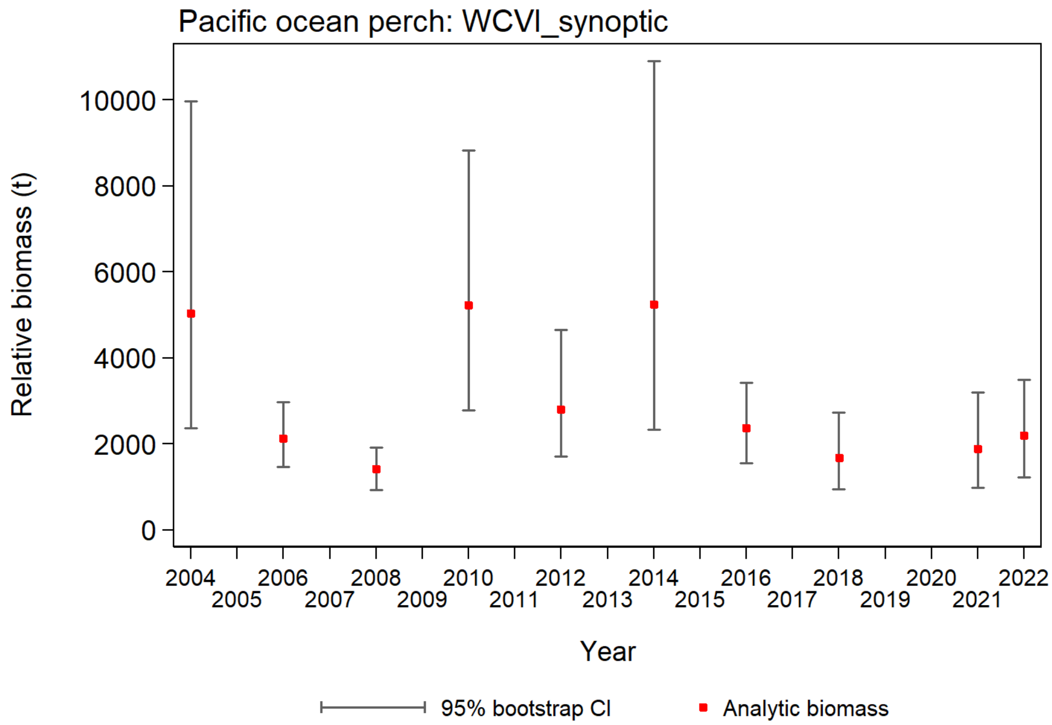

Figure B.36. Plot of biomass estimates for POP from the 2004 to 2022 west coast Vancouver Island synoptic trawl surveys (Table B.10). Bias-corrected 95% confidence intervals from 1,000 bootstrap replicates are plotted.

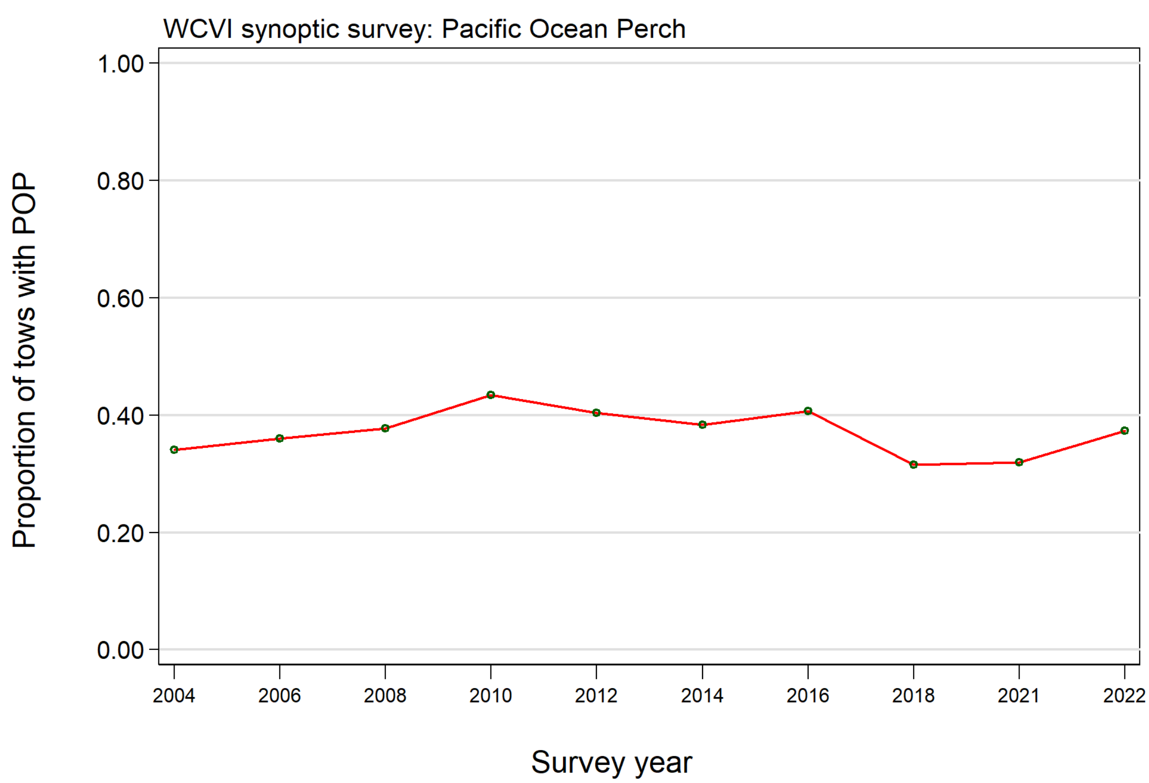

Figure B.37. Proportion of tows by stratum and year capturing POP in the WCVI synoptic trawl surveys, 2004–2022.

Table B.10. Biomass estimates for POP from the WCVI synoptic trawl survey for the survey years 2004 to 2022. Bootstrap bias-corrected confidence intervals and CVs are based on 1,000 random draws with replacement.

Survey Year	Biomass (t) (Eq. B.4)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV (Eq. B.6)
2004	5,031	5,072	2,362	9,964	0.379	0.369
2006	2,132	2,133	1,463	2,975	0.178	0.181
2008	1,407	1,409	931	1,922	0.185	0.187
2010	5,223	5,228	2,785	8,832	0.298	0.296
2012	2,804	2,821	1,712	4,656	0.260	0.263
2014	5,248	5,240	2,339	10,898	0.390	0.385
2016	2,366	2,354	1,548	3,419	0.197	0.199
2018	1,681	1,675	950	2,727	0.273	0.276
2021	1,887	1,855	986	3,190	0.291	0.299
2022	2,199	2,169	1,219	3,495	0.265	0.268

B.8. WEST COAST HAIDA GWAII SYNOPTIC TRAWL SURVEY

B.8.1. Data selection

The west coast Haida Gwaii (WCHG) survey has been conducted ten times over the period 2006 to 2022 off the west coast of Haida Gwaii. This includes a survey conducted in 2014 which did not complete a sufficient number of tows for it to be considered comparable to the remaining surveys and which is consequently omitted from Table B.11. An earlier survey, conducted in 1997, also using a random stratified design similar to the current synoptic survey design along with an Atlantic Western II box trawl net (Workman et al. 1998), has been included in this time series because of its similarity of design and a comparable incidence of POP (this survey was also used in the 2012 5DE POP stock assessment; see Edwards et al. 2014a). The design of the synoptic survey comprises a single areal stratum extending from 53°N to the BC-Alaska border and east to 133°W (Olsen et al. 2008), stratified into four depth strata: 180–330 m; 330–500 m; 500–800 m; and 800–1,300 m (Table B.11). Tows are assigned to a stratum based on the mean of the beginning and end depths of each tow. The 2006 synoptic survey used a different depth stratification (150–200 m, 200–330 m, 330–500 m, 500–800 m, and 800–1,300 m) and has been re-stratified to conform to the stratification adopted beginning in 2007. Tows conducted S of 53°N have been dropped. Plots of the locations of all valid tows by year and stratum are presented in Figure B.39 (2006), Figure B.40 (2007), Figure B.41 (2008), Figure B.42 (2010), Figure B.43 (2012), Figure B.44 (2016), Figure B.45 (2018), Figure B.46 (2020) and Figure B.47 (2022). Note that the range of the depth stratum boundaries for this survey differ from those used for the Queen Charlotte Sound (Edwards et al. 2012) and west coast Vancouver Island (Edwards et al. 2014b) synoptic surveys due to the considerable difference in the seabed topography of the area being surveyed. The deepest stratum (800–1,300 m) has been omitted from this analysis because of lack of coverage in 2007.

A doorspread density (Eq. B.3) was generated for each tow based on the catch of POP from the mean doorspread for the tow and the distance travelled. [`distance travelled`] is a database field which is calculated directly from the tow track. This field was used preferentially for the variable D_{yij} in Eq. B.3. A calculated value ([`vessel speed`] X [`tow duration`]) was used for this variable if [`distance travelled`] was missing, but there were no instances of this occurring in the eight trawl surveys. Missing values for the [`doorspread`] field were filled in with the mean doorspread for the survey year (108 values over all years, Table B.12).

Table B.11. Stratum designations, charter vessel name, number of usable and unusable tows, for each completed year of the west coast Haida Gwaii synoptic survey. Also shown are the dates of the first and last survey tow in each year.

		Depth stratum							
Survey year	Vessel	180-330m	330-500m	500-800m	800-1300m	Total tows[1]	Unusable tows	Minimum date	Maximum date
1997	*Ocean Selector*	39	57	6	3	102[2]	2	07-Sep-97	21-Sep-97
2006	*Viking Storm*	53	27	16	11	96	16	30-Aug-06	22-Sep-06
2007	*Nemesis*	66	32	8	–	106	10	14-Sep-07	12-Oct-07
2008	*Frosti*	70	31	8	8	109	10	28-Aug-08	18-Sep-08
2010	*Viking Storm*	78	28	11	6	117	8	28-Aug-10	16-Sep-10
2012	*Nordic Pearl*	73	28	9	16	110	15	27-Aug-12	16-Sep-12
2016	*Frosti*	66	27	5	10	98	12	28-Aug-16	24-Sep-16
2018	*Nordic Pearl*	66	30	10	11	106	13	05-Sep-18	20-Sep-18
2020	*Nordic Pearl*	65	26	3	2	94	16	29-Aug-20	18-Sep-20
2022	*Nordic Pearl*	66	27	8	6	101	17	21-Aug-20	14-Sep-20
Area (km^2)	–	1,036	980	900	2,232	5,148[3]	–	–	–

[1] GFBio usability codes=0,1,2,6 and omitting the 800–1,300 m stratum; [2] excludes 2 tows S of 53°N; [3] Total area for 2022 (km^2)

Table B.12. Number of valid tows with doorspread measurements, the mean doorspread values (in m) from these tows for each survey year and the number of valid tows without doorspread measurements. The 2006 doorspread measurements were not used because of unknown reliability and no net mensuration instruments were used by the 1997 survey.

Year	Tows with doorspread	Tows missing doorspread	Mean doorspread (m)
1997	n/a	n/a	n/a
2006	93	30	77.7
2007	113	3	68.5
2008	123	4	80.7
2010	129	2	79.1
2012	92	49	73.8
2016	105	15	74.1
2018	131	0	67.0
2020	107	5	67.5
2022	124	0	64.2
Total/Average	1,017	108	71.9[1]

[1] average 2007–2022: all observations

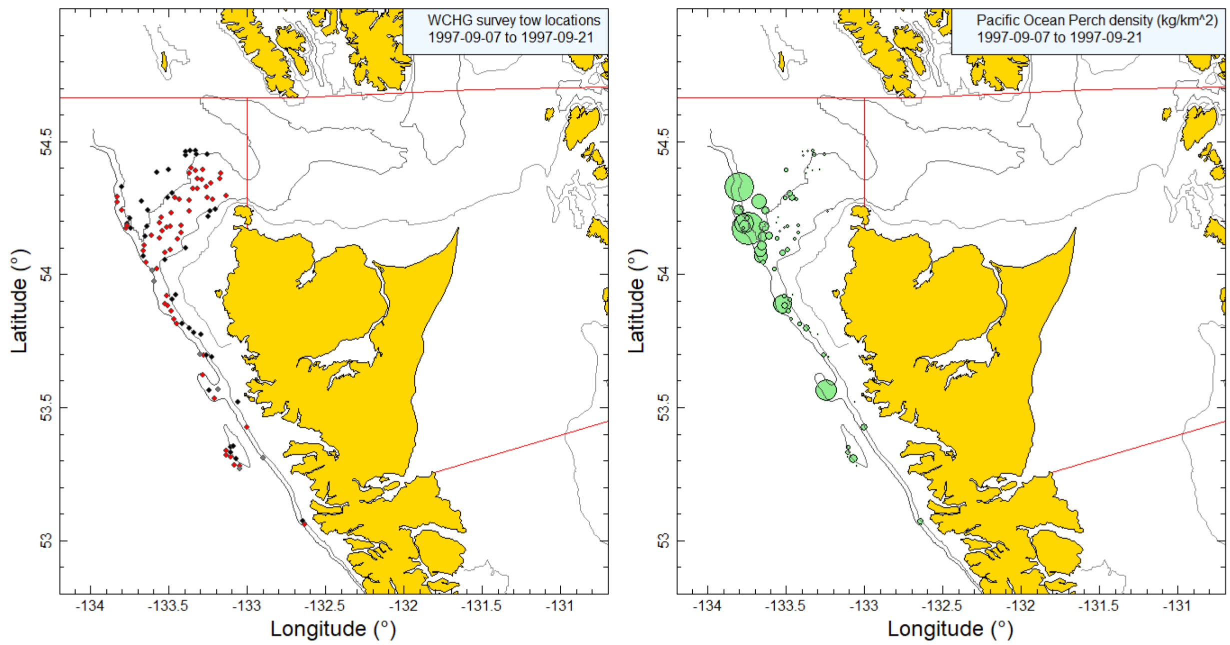

Figure B.38. Valid tow locations by stratum (180–330 m: black; 330–500 m: red; 500–800 m: grey; 800–1,300 m: blue) and density plots for the 1997 Ocean Selector survey. Circle sizes in the right-hand density plot scaled across all years (1977–2022), with the largest circle =108,603 kg/km^2 in 2018. The red lines show the Pacific Marine Fisheries Commission 5E and 5D major area boundaries. Depth contour lines denote 100, 300 and 500 m.

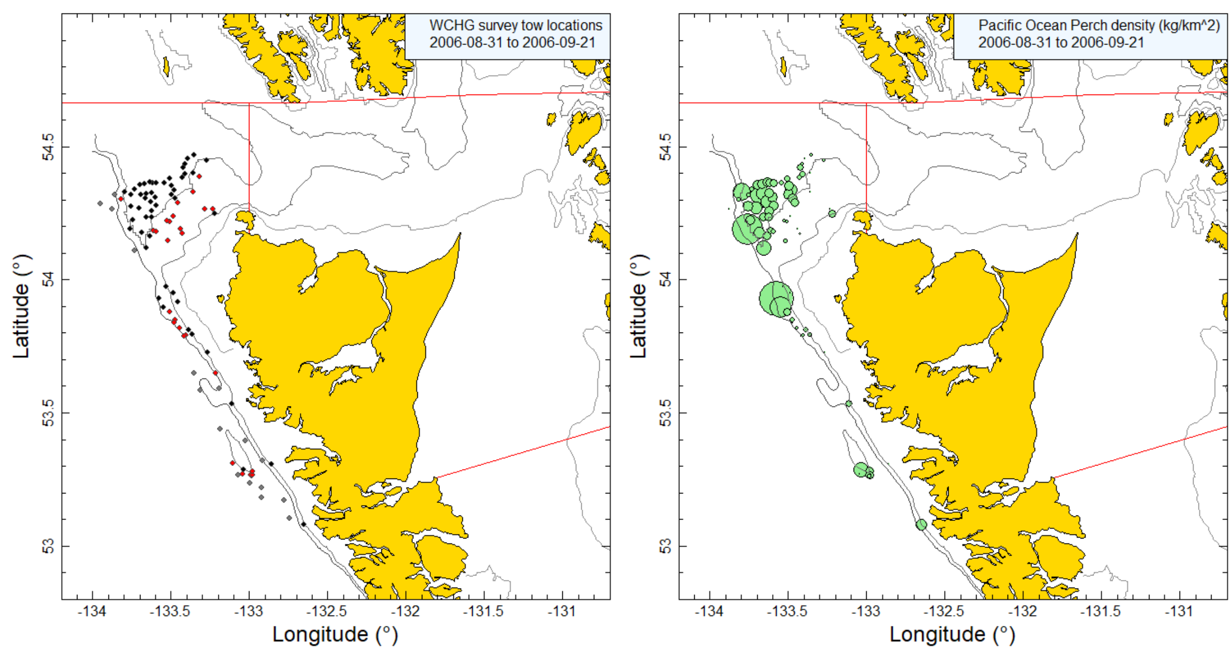

Figure B.39. Tow locations and density plots for the 2006 Viking Storm synoptic survey (see Figure B.38 caption).

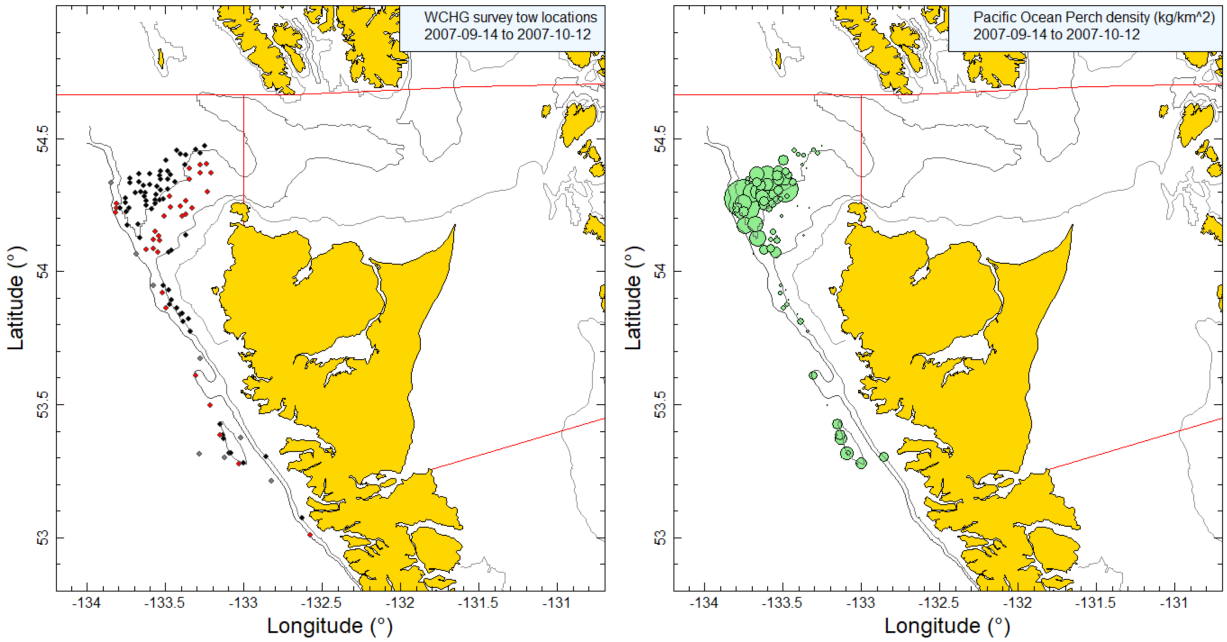

Figure B.40. Tow locations and density plots for the 2007 Nemesis synoptic survey (see Figure B.38 caption).

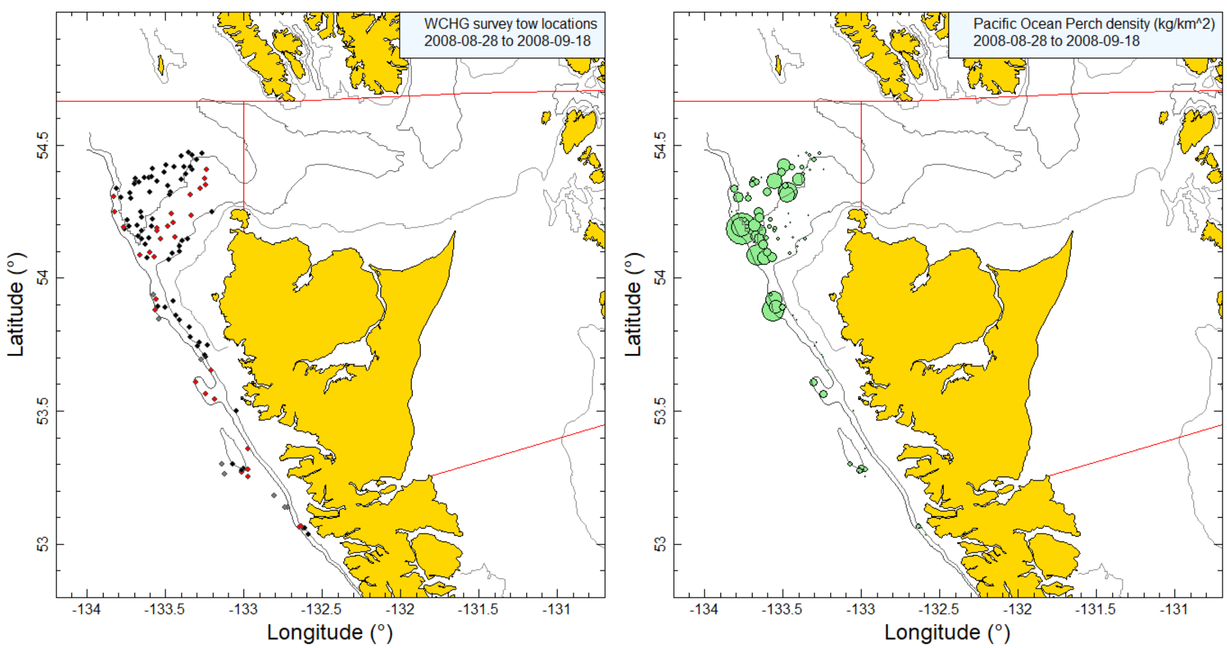

Figure B.41. Tow locations and density plots for the 2008 Frosti synoptic survey (see Figure B.38 caption).

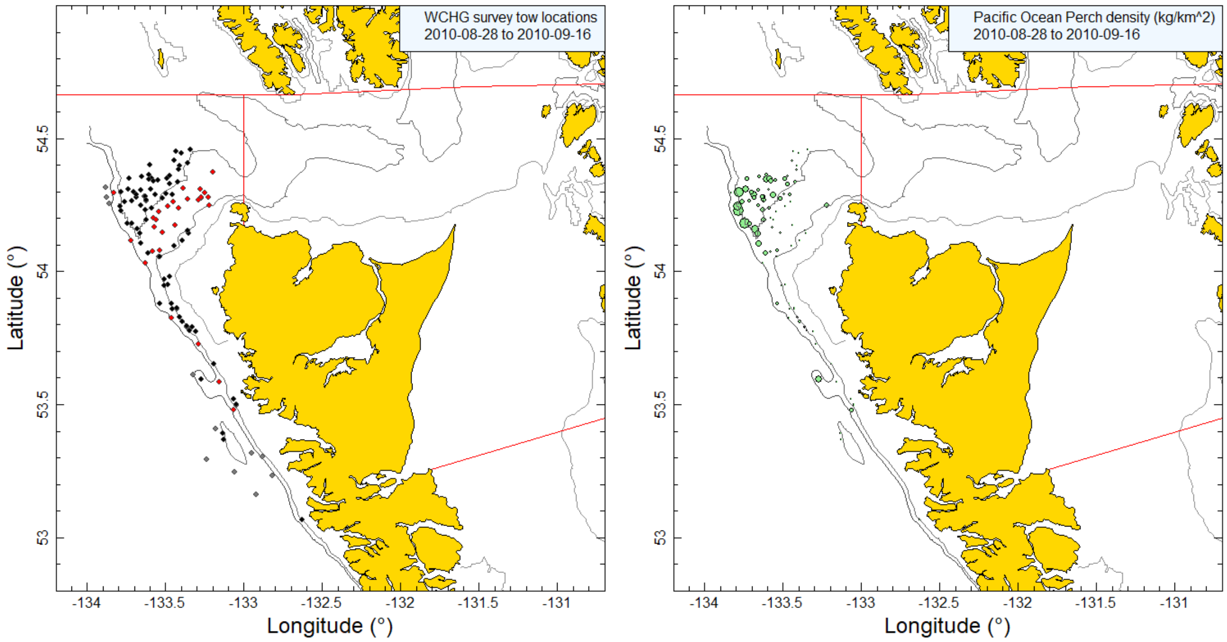

Figure B.42. Tow locations and density plots for the 2010 Viking Storm synoptic survey (see Figure B.38 caption).

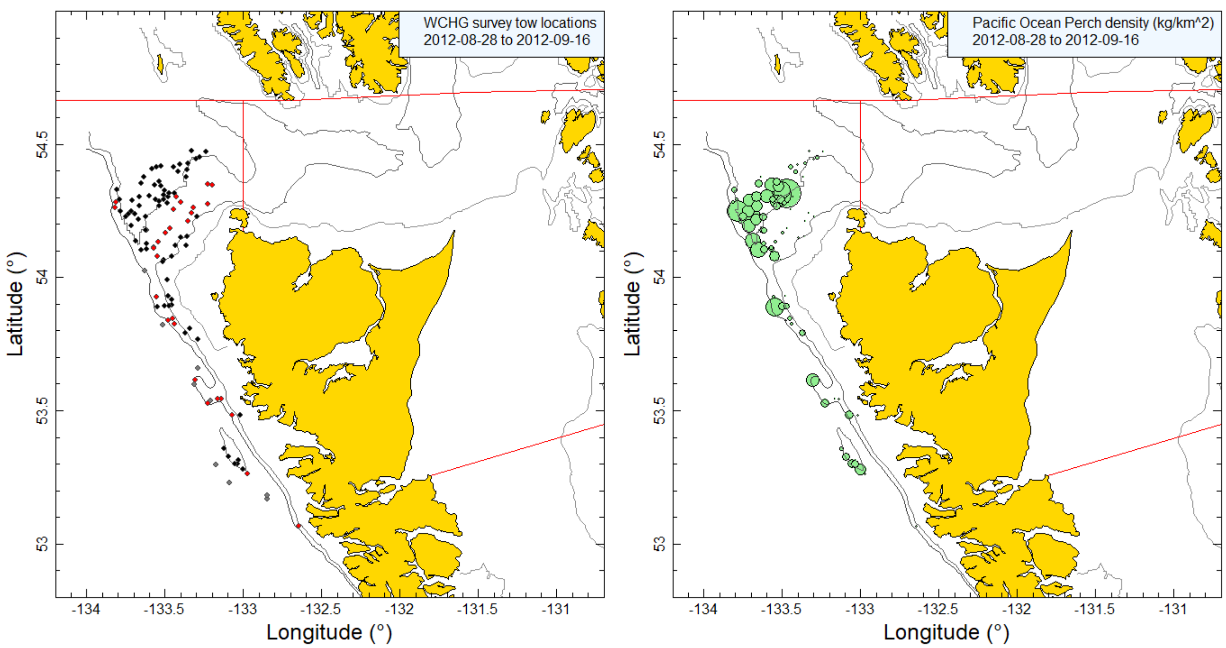

Figure B.43. Tow locations and density plots for the 2012 Nordic Pearl synoptic survey (see Figure B.38 caption).

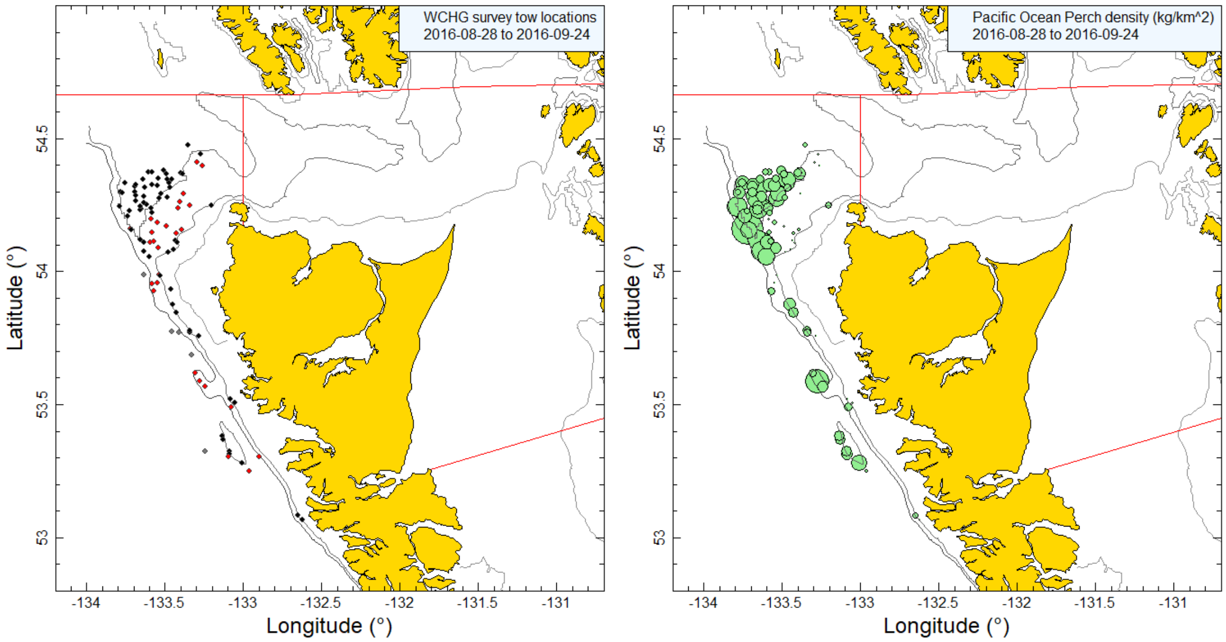

Figure B.44. Tow locations and density plots for the 2016 Frosti synoptic survey (see Figure B.38 caption).

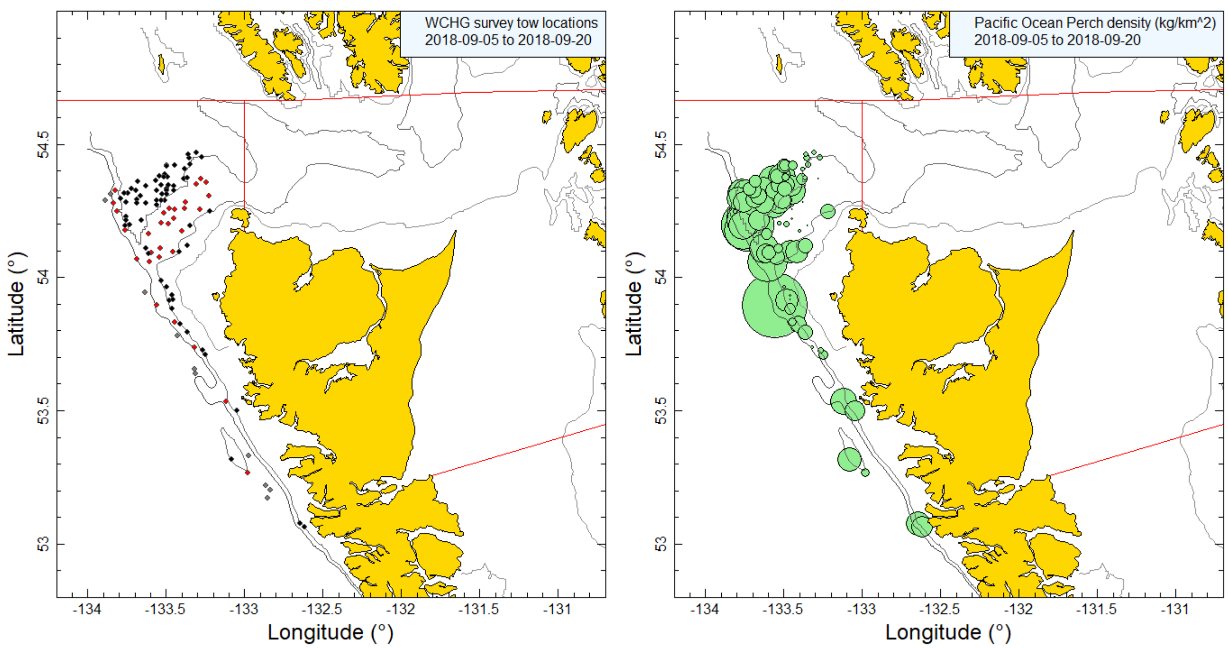

Figure B.45. Tow locations and density plots for the 2018 Nordic Pearl synoptic survey (see Figure B.38 caption).

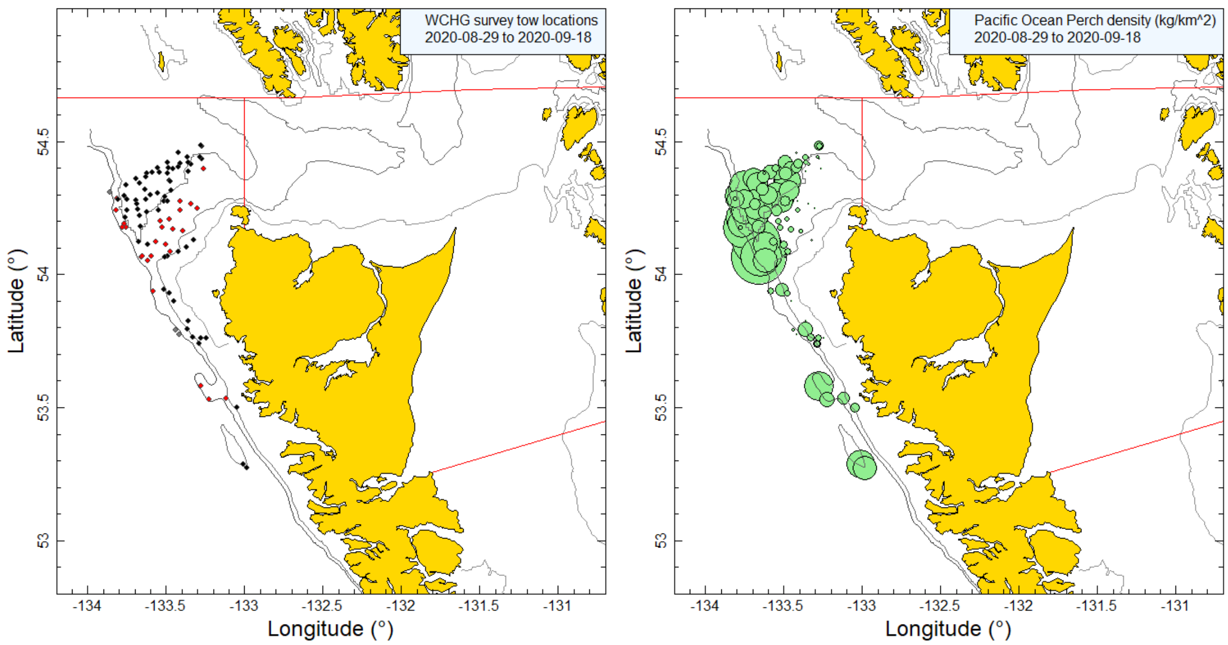

Figure B.46. Tow locations and density plots for the 2020 Nordic Pearl synoptic survey (see Figure B.38 caption).

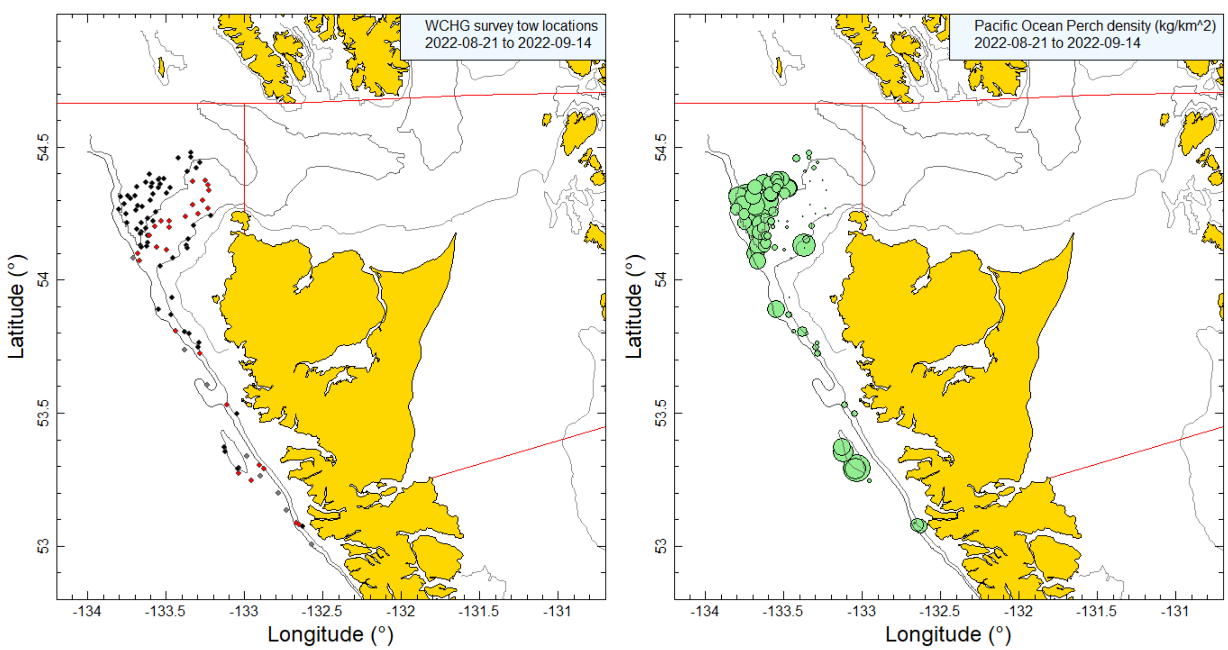

Figure B.47. Tow locations and density plots for the 2022 Nordic Pearl synoptic survey (see Figure B.38 caption).

B.8.2. Results

These ten surveys have taken POP consistently in an area northwest of Langara between the 200 to 400 m contours and also along the west coast of Graham Island within the same depth range (Figure B.38 to Figure B.47). This species is well represented in this survey, given the high densities observed in nearly every survey which are greater than those observed in both the QCS and WCVI synoptic surveys (compare with the listed densities in the captions for

Figure B.12 and Figure B.26). In this survey, POP were mainly taken over a reasonably wide depth range between 200 m and 400 m (5 to 95% quantiles of the starting tow depth=215–421 m) (Figure B.48).

Estimated biomass levels for POP from these trawl surveys are increasing, going from around 7,000 t at the beginning of the survey to between 15,000 to 20,000 t by the end of the survey series in 2018–2022 (Figure B.49; Table B.13). The estimated relative errors (RE) for these surveys are also relatively precise, ranging from 0.11 in 2022 to 0.30 in 1997 and with all the synoptic surveys beginning in 2006 having REs near to or below 0.2 (Table B.13).

The incidence of this species in this survey is high, with the proportion of tows that captured POP averaging 81% (844 of 1039 valid tows) and ranging from 67% to 97% of the valid tows over the ten survey years (Figure B.50). The median POP catch weight for positive tows used in the biomass estimation was 339 kg/tow while the mean catch weight was 810 kg/tow. The maximum catch weight for the estimation tows across the ten surveys was a single tow of 13,280 kg in 2018 and there have been 15 tows over the history of the survey where the catch weight of POP exceeded 5,000 kg. Three more tows exceeded 11,000 kg in 2022; but these tows were deemed not usable for biomass estimation.

Table B.13. Biomass estimates for POP from the ten west coast Haida Gwaii synoptic surveys used in the stock assessment. Bootstrap bias-corrected confidence intervals and coefficients of variation (CVs) are based on 1,000 random draws with replacement.

Survey Year	Biomass (t) (Eq. B.4)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV (Eq. B.6)
1997	6,615	6,636	3,384	11,280	0.303	0.300
2006	7,634	7,608	5,188	11,113	0.198	0.196
2007	7,067	7,040	5,262	10,158	0.175	0.174
2008	7,046	7,025	4,428	10,382	0.218	0.219
2010	3,512	3,545	2,598	4,566	0.144	0.141
2012	6,634	6,660	4,584	9,032	0.166	0.164
2016	11,812	11,689	8,364	17,392	0.189	0.196
2018	18,914	19,078	12,495	28,439	0.213	0.217
2020	21,190	21,322	13,924	32,622	0.215	0.212
2022	15,446	15,461	12,455	19,481	0.112	0.110

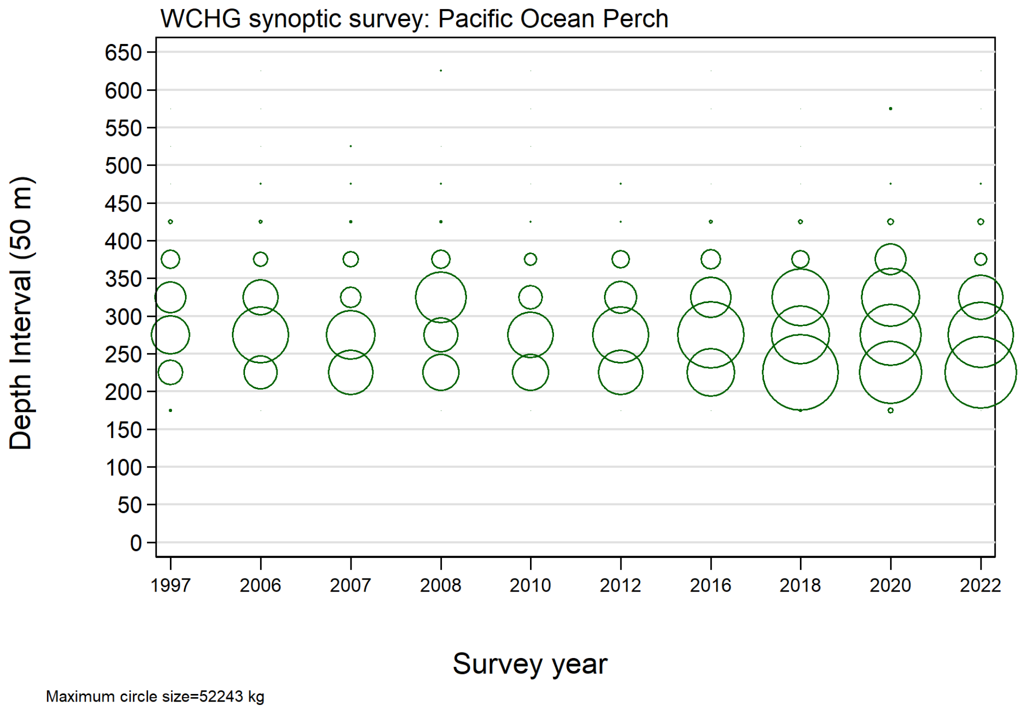

Figure B.48. Distribution of observed weights of POP by survey year and 25 m depth zone intervals. Catches are plotted at the mid-point of the interval and circles in the each panel are scaled to the maximum value (52,243 kg – 200–250 m interval in 2050). Minimum and maximum depths observed for POP: 157 m and 558 m, respectively.

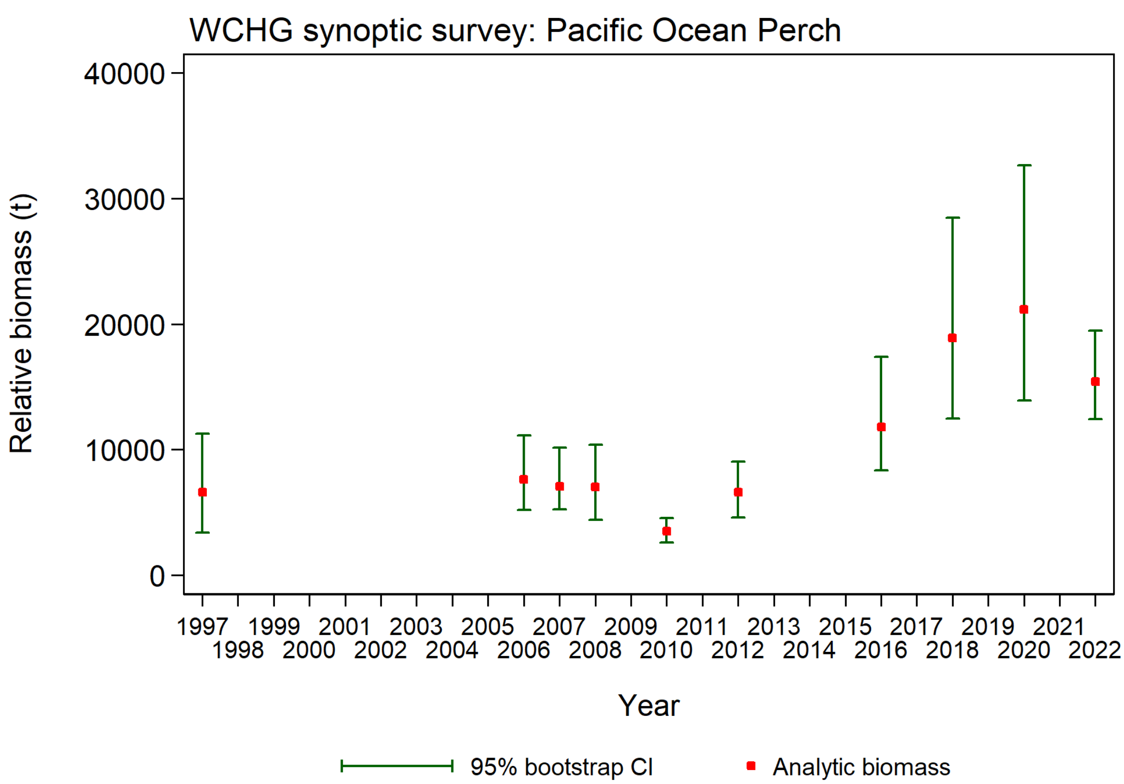

Figure B.49. Biomass estimates for POP from the 1997 to 2022 west coast Haida Gwaii synoptic surveys (Table B.13). Bias-corrected 95% confidence intervals from 1,000 bootstrap replicates are plotted.

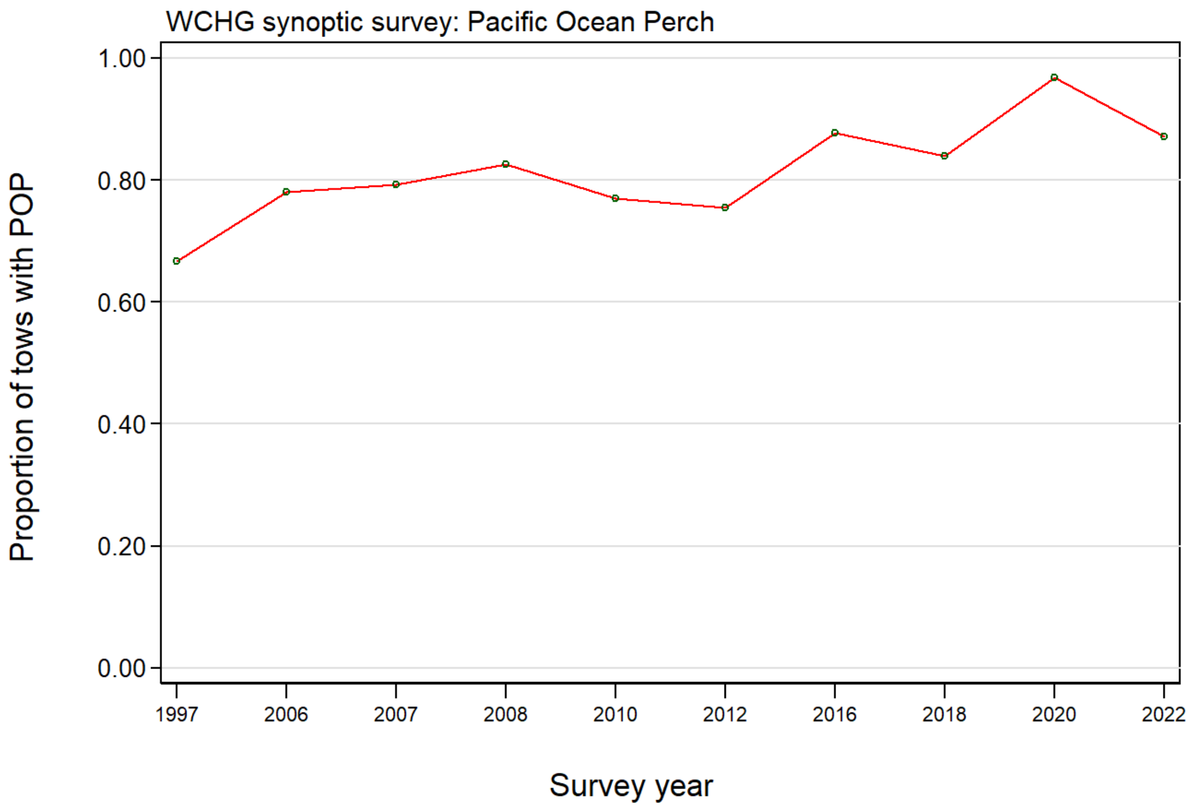

Figure B.50. Proportion of tows by year that contain POP for the ten west coast Haida Gwaii synoptic surveys.

B.9. HECATE STRAIT SYNOPTIC SURVEY

B.9.1. Data selection

This survey has been conducted in nine alternating years over the period 2005 to 2021 in Hecate Strait (HS) between Moresby and Graham Islands and the mainland and in Dixon Entrance at the top of Graham Island (all valid tow starting positions by survey year are shown in Figure B.51 to Figure B.58). This survey treats the full spatial coverage as a single areal stratum divided into four depth strata: 10–70 m; 70–130 m; 130–220 m; and 220–500 m (Table B.14).

A doorspread density value (Eq. B.3) was generated for each tow based on the catch of POP from the mean doorspread for the tow and the distance travelled. [distance travelled] is a database field which is calculated directly from the tow track. This field was used preferentially for the variable D_{yij} in Eq. B.3. A calculated value ([vessel speed] X [tow duration]) would have been used for this variable if [distance travelled] were missing, but there were no instances of this occurring among the valid tows in the nine trawl surveys. Missing values for the [doorspread] field were filled in with the mean doorspread for the survey year (223 values over all years: Table B.15).

Table B.14. Number of usable tows for biomass estimation by year and depth stratum for the Hecate Strait synoptic survey over the period 2005 to 2021. Also shown is the area of each depth stratum, the charter vessel conducting the survey by survey year, the number of unusable tows and the beginning and end dates for each survey year. The final dates are the minimum and maximum start and end dates among all the survey years.

Year	Vessel	Depth stratum (m) 10–70	70–130	130–220	220–500	Total tows[1]	Unusable tows	Minimum date	Maximum date
2005	Frosti	77	86	26	9	198	38	27-May-05	27-Jun-05
2007	W.E. Ricker	47	42	36	7	132	24	24-May-07	16-Jun-07
2009	W.E. Ricker	53	43	47	12	155	8	28-May-09	18-Jun-09
2011	W.E. Ricker	70	51	49	14	184	18	26-May-11	18-Jun-11
2013	W.E. Ricker	74	42	43	16	175	0	30-May-13	21-Jun-13
2015	W.E. Ricker	47	46	40	15	148	4	28-May-15	20-Jun-15
2017	Nordic Pearl	47	44	38	9	138	14	21-May-17	12-Jun-17
2019	Nordic Pearl	40	44	37	14	135	11	19-May-19	07-Jun-19
2021	Sir John Franklin	44	34	30	8	116	12	20-May-21	10-Jun-21
Area (km^2)		5,958	3,011	2,432	1,858	13,259[2]	–	19-May	27-Jun

[1] GFBio usability codes=0,1,2,6 [2] Total area (km^2) for 2021 synoptic survey

Table B.15. Number of missing doorspread values by year for the Hecate Strait synoptic survey over the period 2005 to 2021 as well as showing the number of available doorspread observations and the mean doorspread value for the survey year.

Year	Number tows with missing doorspread [1]	Number tows with doorspread observations [2]	Mean doorspread (m) used for tows with missing values [2]
2005	7	217	64.4
2007	97	37	59.0
2009	93	70	54.0
2011	13	186	54.8
2013	6	169	51.7
2015	0	151	59.4
2017	2	150	64.2
2019	5	141	59.2
2021	0	128	54.4
Total	223	1,249	58.3

[1] valid biomass estimation tows only [2] includes tows not used for biomass estimation

B.9.2. Results

Pacific Ocean Perch have been present in this survey for all survey years, with most of the tows capturing this species located in Dixon Entrance west of Rose Point at the easternmost part of Graham Island (Figure B.51 to Figure B.58). There is only an occasional presence of POP east of Rose Point or further south in Hecate Strait. Occasionally POP was captured at the lower end of the survey coverage which corresponds to the upper part of Moresby Gully (e.g., see Figure B.52 and Figure B.57). In some years, there is a tow with a large catch of POP, which contributes to a large relative error (RE) for that year (e.g. see Figure B.57 where there is a large catch of POP just north of Rose Point with an overall RE of 0.63 – see Table B.16). POP were captured consistently between 125 m and 250 m in this survey, which is shallower than this species is found in either the WCVI or the QCS synoptic surveys (compare Figure B.60 with Figure B.22 and Figure B.35), reflecting the shallow territory covered by the Hecate Strait survey. Other *Sebastes* species taken in this survey tend to be young (e.g., Canary Rockfish – see Starr and Haigh 2023) but the POP age composition data were too sparse to arrive at a conclusion for this species (see Section D.2.2 Appendix D).

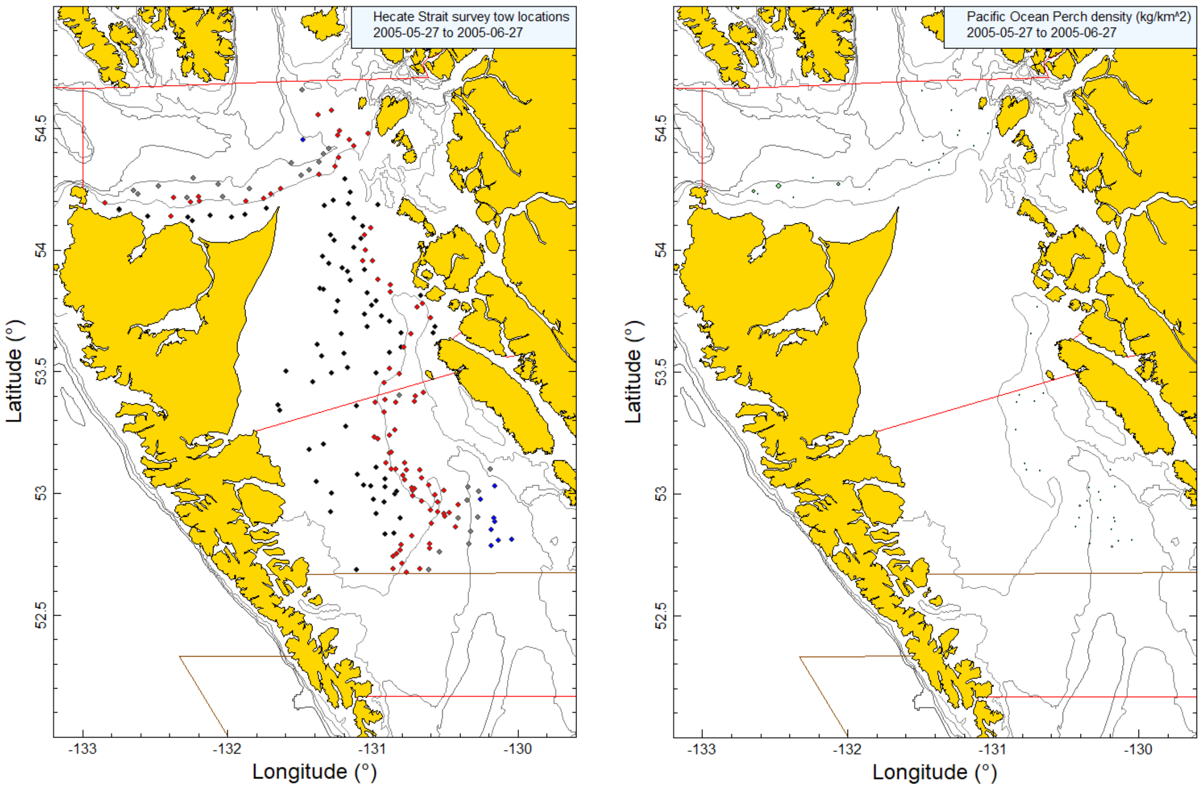

Figure B.51. Valid tow locations (10–70 m stratum: black; 70–130 m stratum: red; 130–220 m stratum: grey; 220–500 m stratum: blue) and density plots for the 2005 Hecate Strait synoptic survey. Circle sizes in the right-hand density plot scaled across all years (2005, 2007, 2009, 2011, 2013, 2015, 2017, 2019, 2021), with the largest circle = 9001 kg/km^2 in 2019. Red lines indicate boundaries for PMFC major statistical areas 5C, 5D and 5E. Brown lines indicate the upper boundary of the QC Sound survey. Depth contour lines denote 100, 200, 300 and 500 m.

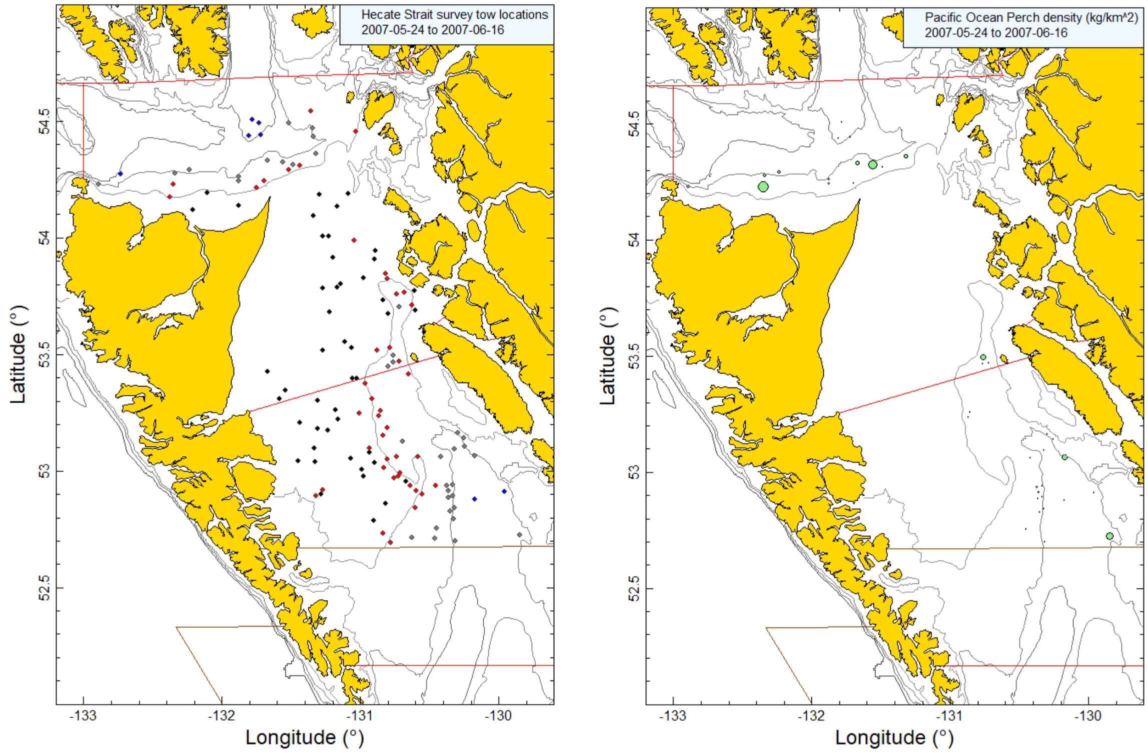

Figure B.52. Tow locations and density plots for the 2007 Hecate Strait synoptic survey (see Figure B.51 caption).

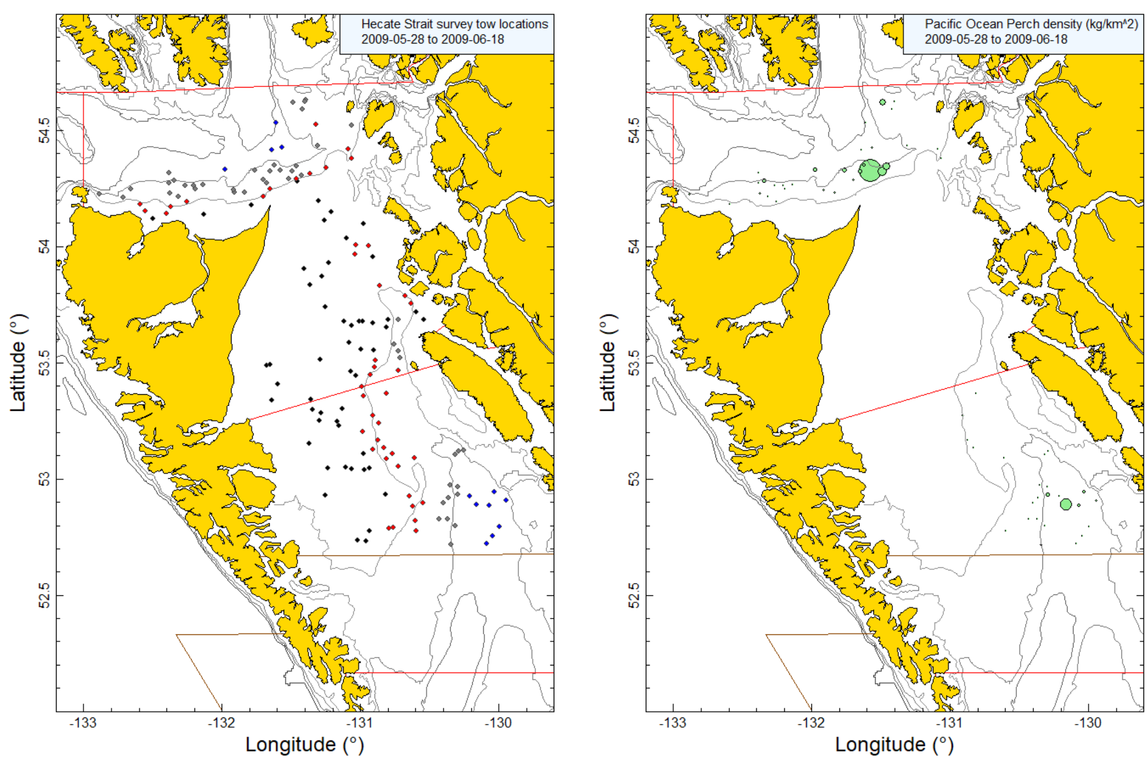

Figure B.53. Tow locations and density plots for the 2009 Hecate Strait synoptic survey (see Figure B.51 caption).

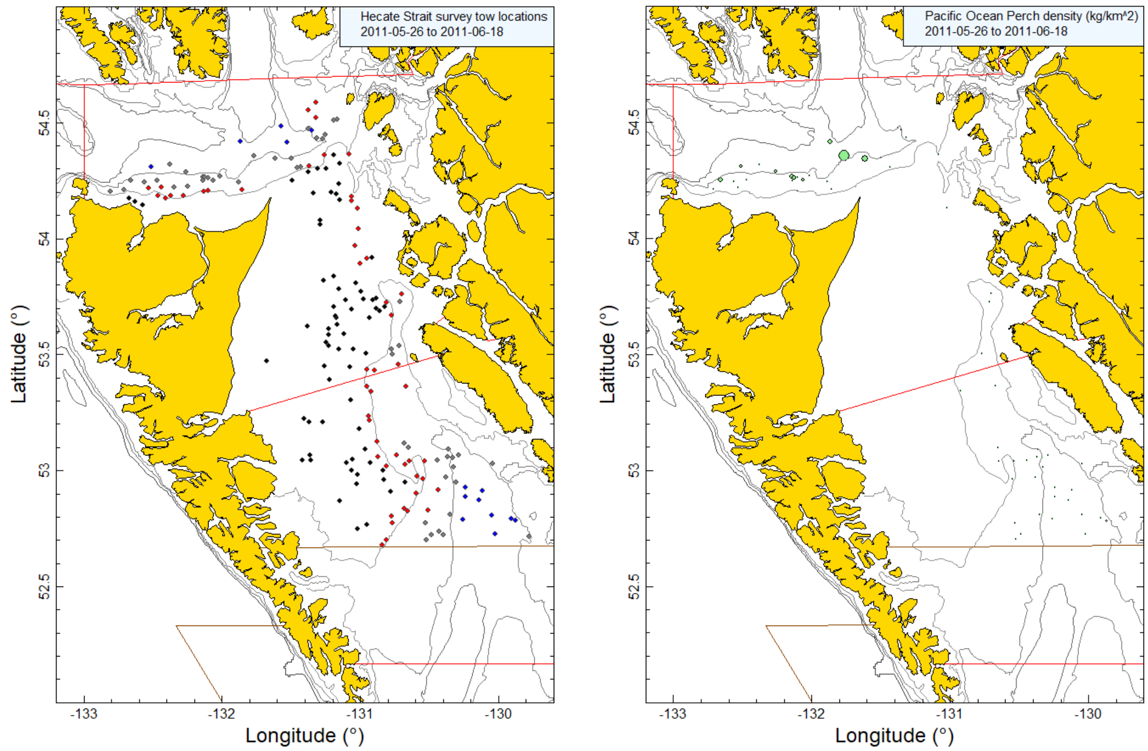

Figure B.54. Tow locations and density plots for the 2011 Hecate Strait synoptic survey (see Figure B.51 caption).

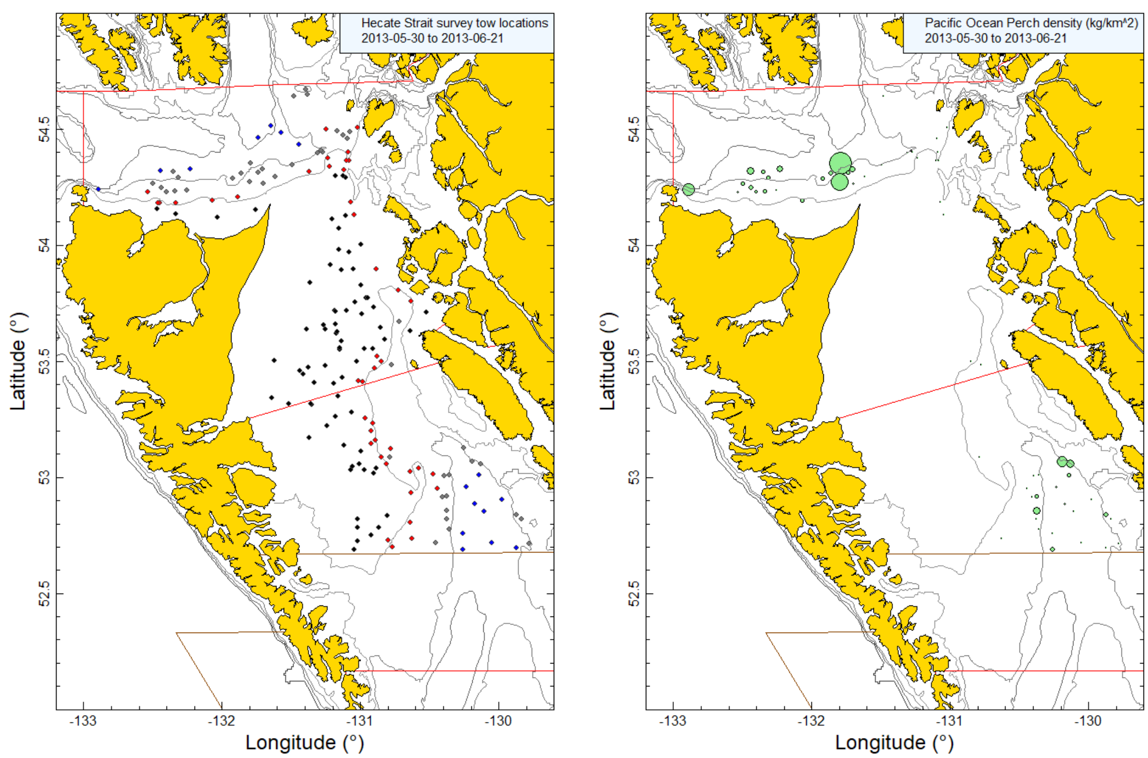

Figure B.55. Tow locations and density plots for the 2013 Hecate Strait synoptic survey (see Figure B.51 caption).

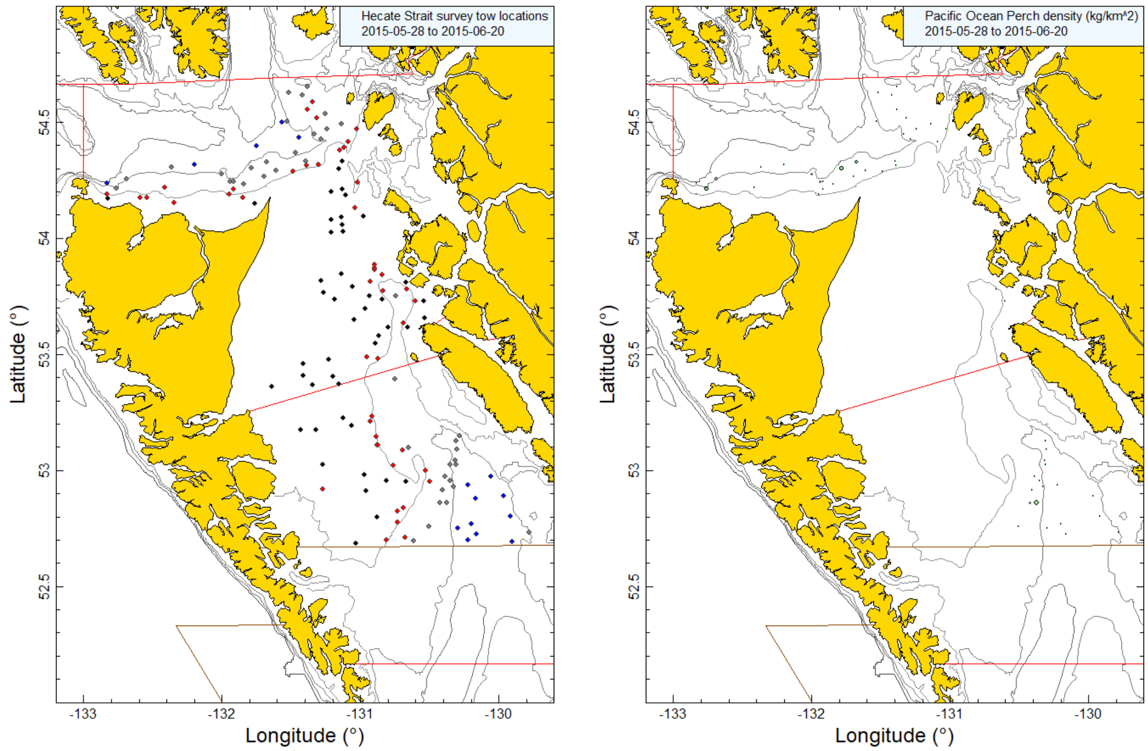

Figure B.56. Tow locations and density plots for the 2015 Hecate Strait synoptic survey (see Figure B.51 caption).

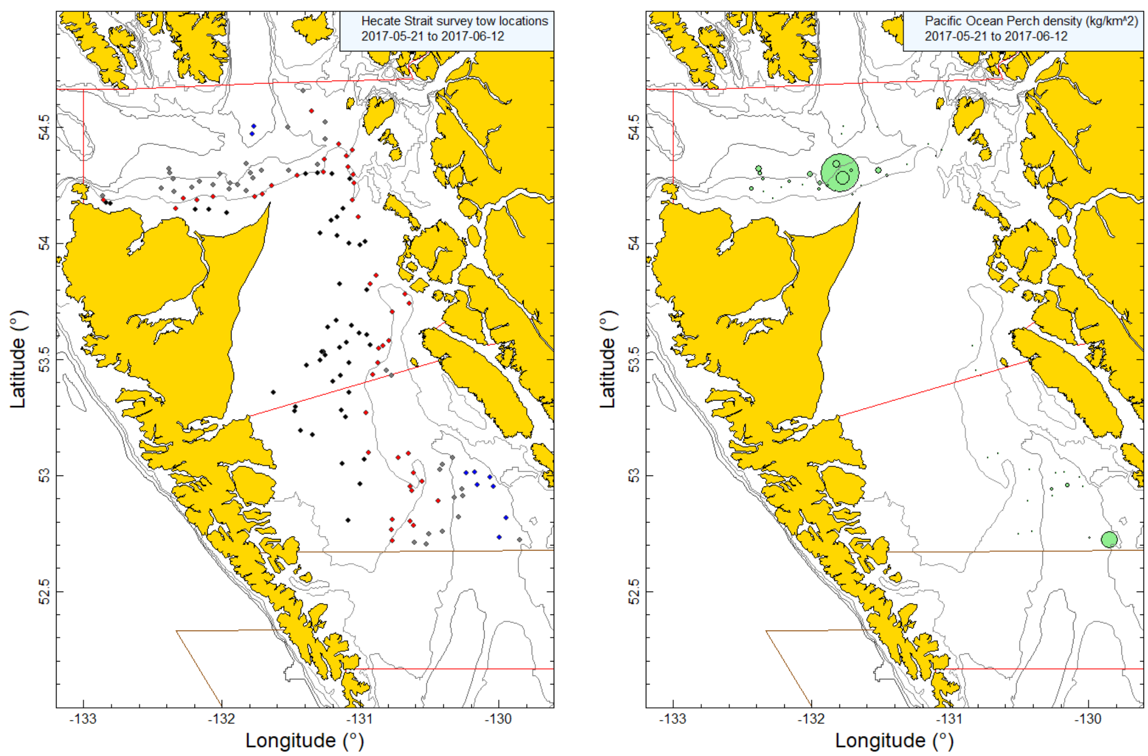

Figure B.57. Tow locations and density plots for the 2017 Hecate Strait synoptic survey (see Figure B.51 caption).

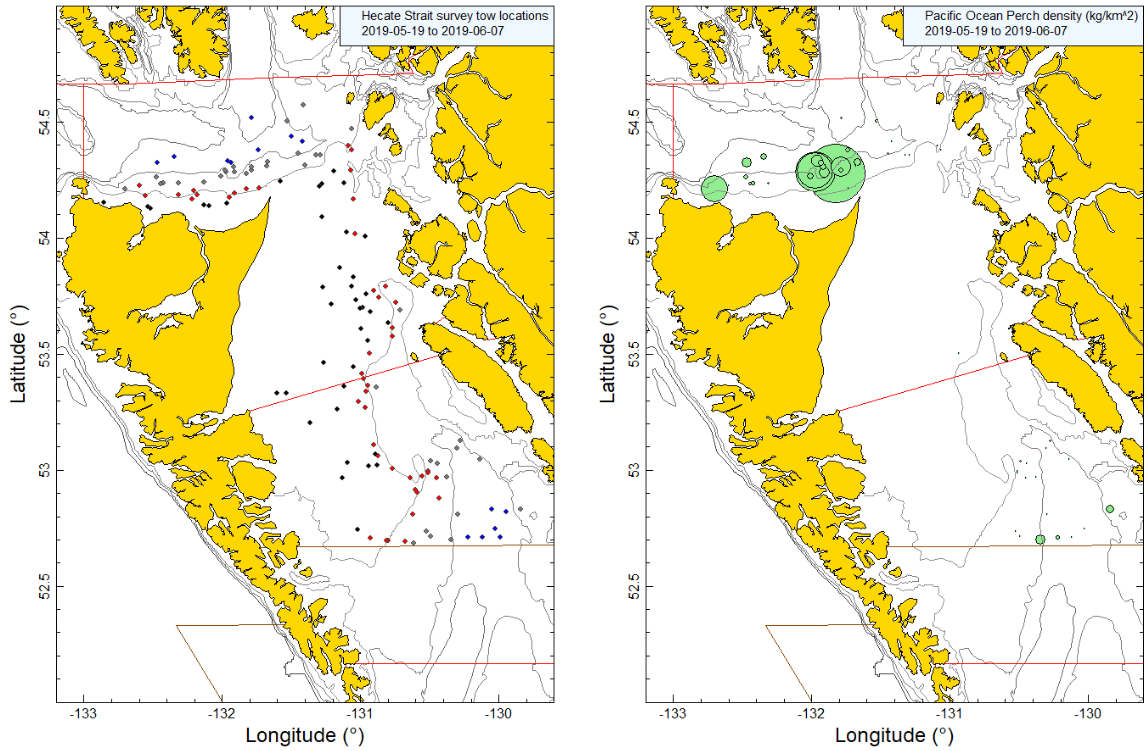

Figure B.58. Tow locations and density plots for the 2019 Hecate Strait synoptic survey (see Figure B.51 caption).

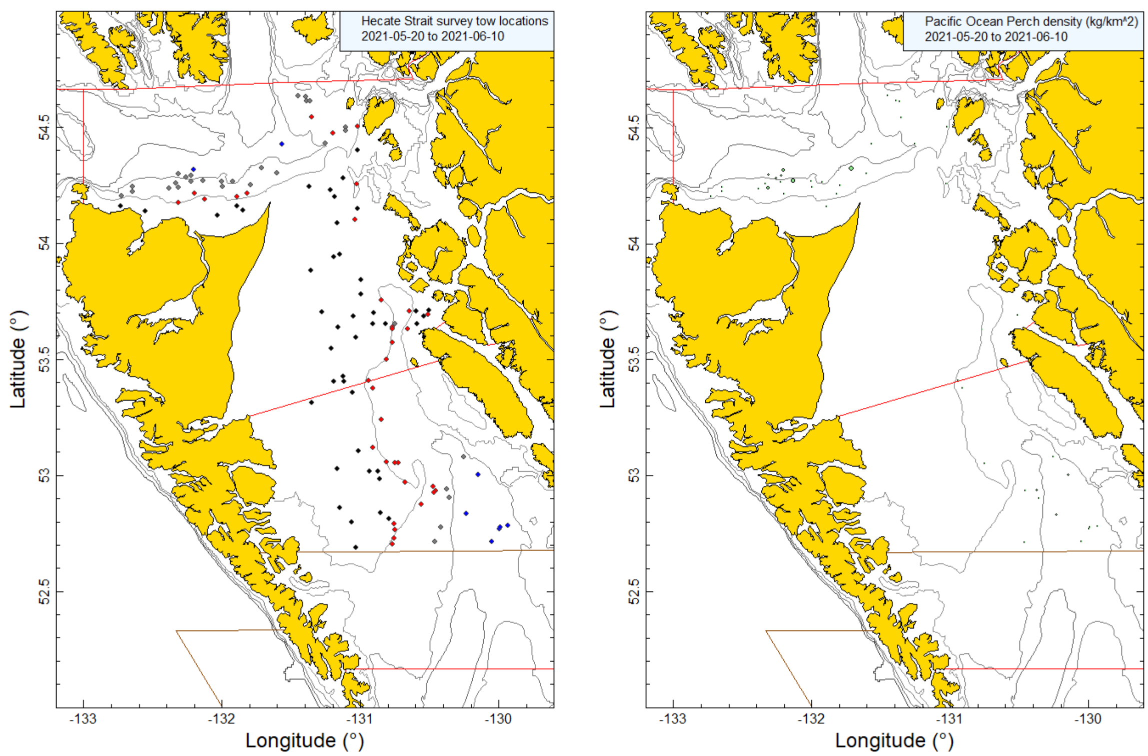

Figure B.59. Tow locations and density plots for the 2021 Hecate Strait synoptic survey (see Figure B.51 caption).

Estimated POP doorspread biomass indices from this trawl survey showed no overall trend over the period 2005 to 2021 (Table B.16; Figure B.61), with the 2019 index, the highest in the series, followed by a low index in 2021. The estimated relative errors associated with these surveys were generally high, ranging from 0.23 to 0.63 (Table B.16). The incidence of POP in this survey was low compared to the other synoptic surveys, with an average occurrence of 33% of tows capturing this species, ranging from 23% (2005) to 39% (2021) (Figure B.62). Overall, 453 (33%) of the 1,381 usable survey tows contained POP.

The nine Hecate Strait survey indices, spanning the period 2005 to 2021, were used as abundance indices in a stock assessment sensitivity run to represent the 5DE POP population (described in Appendix F).

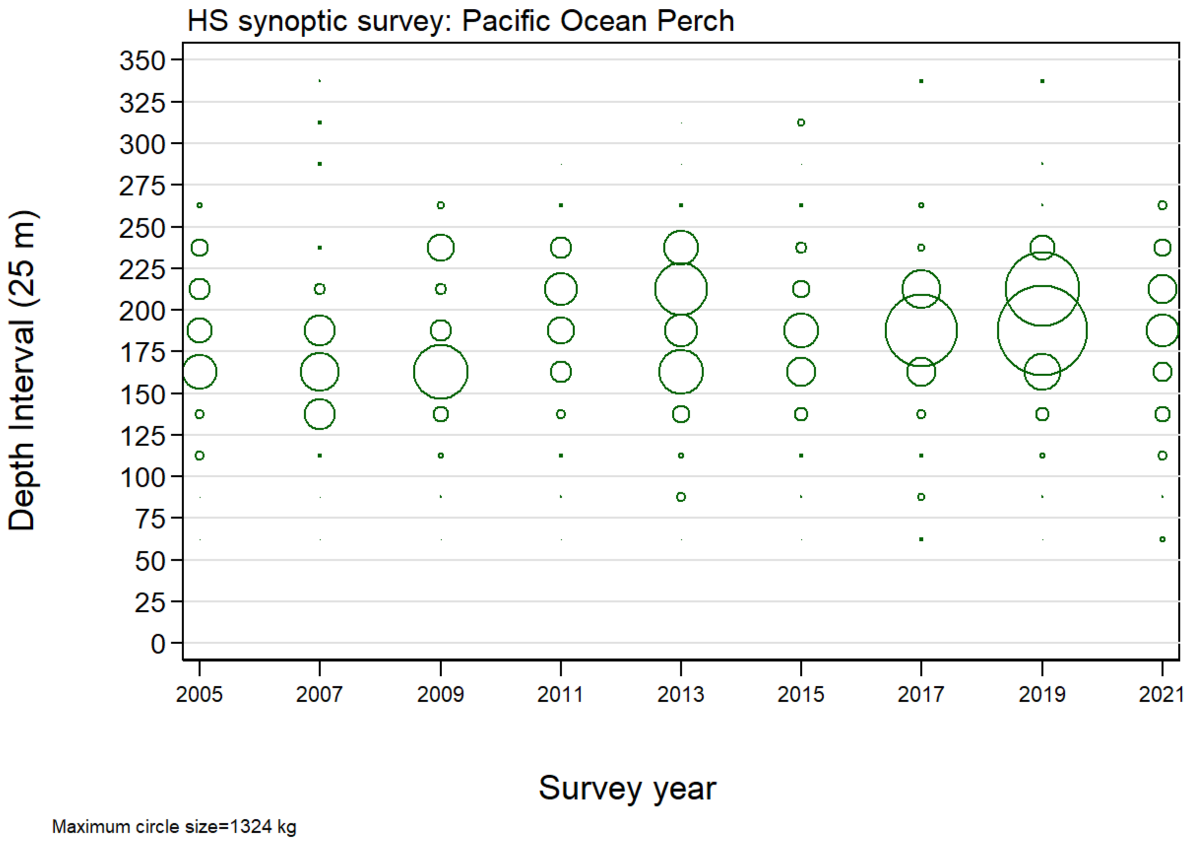

Figure B.60. Distribution of observed catch weights of Pacific Ocean Perch for the Hecate Strait synoptic survey (Table B.16) by survey year and 25 m depth zone. Catches are plotted at the mid-point of the interval and circles in the panel are scaled to the maximum value (1,324 kg) in the 175–200 m interval in 2019. The 5% and 95% quantiles for the POP empirical start of tow depth distribution= 98 m and 257 m respectively.

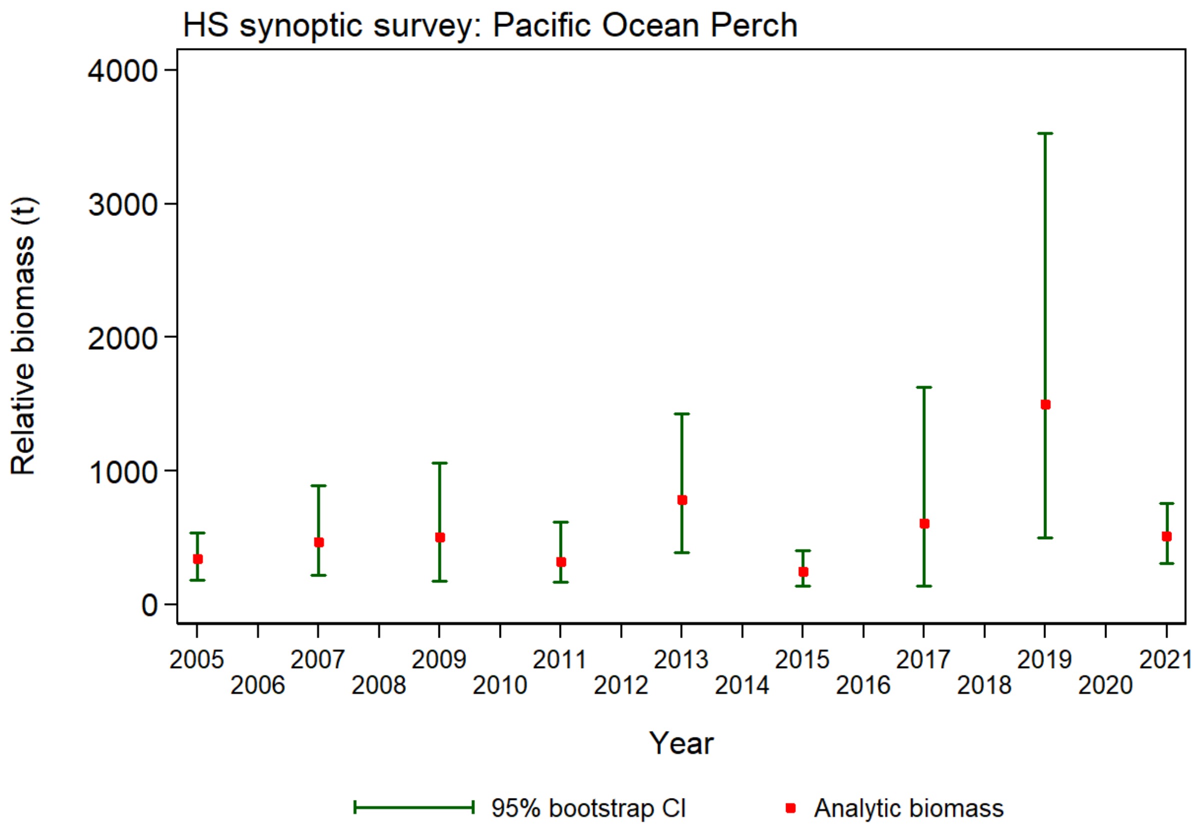

Figure B.61. Plot of biomass estimates for Pacific Ocean Perch values provided in Table B.16 from the Hecate Strait synoptic survey over the period 2005 to 2021. Bias corrected 95% confidence intervals from 1,000 bootstrap replicates are plotted.

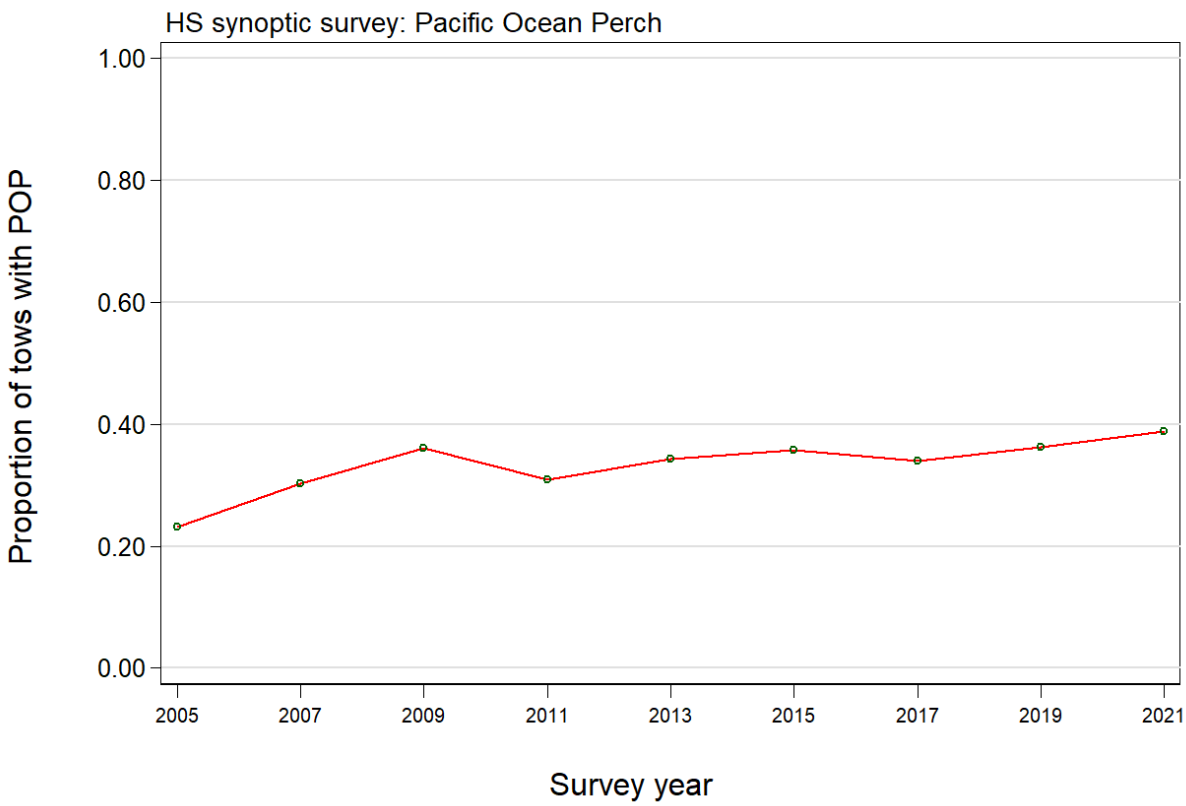

Figure B.62. Proportion of tows by year which contain Pacific Ocean Perch from the Hecate Strait synoptic survey over the period 2005 to 2021.

Table B.16. Biomass estimates for Pacific Ocean Perch from the Hecate Strait synoptic trawl survey for the survey years 2005 to 2021. Bootstrap bias corrected confidence intervals and CVs are based on 1,000 random draws with replacement.

Survey Year	Biomass (t) (Eq. B.4)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV (Eq. B.6)
2005	344	343	183	537	0.259	0.263
2007	465	469	217	888	0.341	0.339
2009	507	510	172	1,061	0.437	0.441
2011	323	322	168	616	0.343	0.336
2013	786	790	388	1,426	0.336	0.332
2015	249	247	140	406	0.265	0.273
2017	607	602	142	1,628	0.632	0.628
2019	1,498	1,522	501	3,524	0.465	0.452
2021	514	518	308	756	0.230	0.232

B.10. REFERENCES – SURVEYS

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APPENDIX C. COMMERCIAL TRAWL CPUE

C.1. INTRODUCTION

Commercial catch and effort data have been used to generate CPUE biomass index series for a number of recent *Sebastes* stock assessments from the west coast of Canada (e.g., Canary Rockfish – Starr and Haigh 2023; Bocaccio Rockfish – Starr and Haigh 2022). These index series were developed under the assumption that the commercial fishery was not preferentially targeting the species in question, either because its abundance was relatively low or that it was associated with a complex of preferred species that meant they weren't singled out. These circumstances tend not to be the case for Pacific Ocean Perch, which are ubiquitous and abundant over most of the BC coast, rendering this species one of the most desirable in the *Sebastes* complex. Because of these reasons, previous BC POP stock assessments (Edwards et al. 2012, 2014a, 2014b; Starr and Haigh 2018) have chosen not to include commercial CPUE for tracking POP biomass, relying on the availability of survey biomass indices, which tend to be associated with relatively low relative errors. Consequently, no CPUE index series have been developed for this stock assessment.

C.2. REFERENCES – CPUE

Edwards, A.M., Haigh, R. and Starr, P.J. 2014a. Pacific Ocean Perch (*Sebastes alutus*) stock assessment for the north and west coasts of Haida Gwaii, British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/092. vi + 126 p.

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APPENDIX D. BIOLOGICAL DATA

This appendix describes analyses of biological data for Pacific Ocean Perch (POP) along the British Columbia (BC) coast. These analyses follow the methods adopted in previous rockfish stock assessments (e.g., Starr and Haigh 2022), including length-weight relationships, von Bertalanffy growth models, maturity schedules, natural mortality, and age proportions for use in the POP catch-at-age stock assessment model (Sections D.1 and D.2). The stock assessment covers three POP stocks by region: 5ABC or Queen Charlotte Sound (QCS), 3CD or west coast of Vancouver Island (WCVI), and 5DE or west coast Haida Gwaii (WCHG, including Dixon Entrance). All biological analyses are based on POP data extracted from the Fisheries and Oceans Canada (DFO) Groundfish database GFBioSQL on 2023-01-17 (791,259 records). Results from some analyses were used for input to the model platform Stock Synthesis 3 (SS3, see Appendix E). General data selection criteria for most analyses are summarised in Table D.1, although data selection sometimes varied depending on the analysis.

Pacific Ocean Perch and Yellowmouth Rockfish (YMR) are managed using a modified set of PMFC (Pacific Marine Fisheries Commission, see Appendix A for details) areas. Specifically, the 5C boundary was expanded in 1996 to include lower Moresby Gully in 5B and Flamingo Inlet/Anthony Island localities in 5E. The biological data were reallocated accordingly.

Table D.1. Data selection criteria for analyses of biological data for allometric and growth analyses.

Field	Criterion	Notes
Trip type	`[trip_type] == c(2,3)`	Definition of research observations
	`[trip_type] == c(1,4,5)`	Definition of commercial observations
Sample type	`[sample_type] == c(1,2,6,7,8)`	Only random or total samples

Ageing method	`[agemeth] == c(2:4, 17) or`
	`== (0 & [year]>=1980) or`
	`== 1 for ages 1:3`
		Break & burn|bake or thin-sectioned
		unknown from 1980 on (assumed B&B)
		surface readings for young fish

Species category code	`[SPECIES_CATEGORY_CODE]==1 (or 3)`	1 = Unsorted samples 3 = Sorted (keeper) samples
Sex code	`[sex] == c(1,2)*`	Clearly identified sex (1=male or 2=female)
Area code	`[stock]` select stock area (coastwide)	PMFC major area codes 3:9

*GFBioSQL codes for `sex` (1=male, 2=female) are reversed in SS3 (1=female, 2=male).

D.1. LIFE HISTORY

D.1.1. Allometry – Weight vs. Length

A log-linear relationship with additive errors was fit to females (*s*=2), males (*s*=1), and combined to all valid weight and length data pairs i , $\{W_{is}, L_{is}\}$:

$$\ln\left(W_{is}\right) = \alpha_s + \beta_s \ln\left(L_{is}\right) + \varepsilon_{is}, \quad \varepsilon \sim N(0,\sigma^2) \tag{D.1}$$

where α_s and β_s are the intercept and slope parameters for each sex s .

Survey and commercial samples, regardless of gear type, were used independently to derive length-weight parameters for consideration in the model (Table D.2); however, only survey data coastwide were adopted for model use (Figure D.2). Commercial fishery weight data were not as abundant as those from research surveys and tended to represent a restricted range of weights compared to those from surveys (compare minimum, maximum and mean weights in Table D.2). It is also possible that the commercial weights were less precise than the survey weight data.

Table D.2. Length-weight parameter estimates, standard errors (SE) and number of observations (n) for POP (females, males, and combined) from survey and commercial samples, regardless of gear type from 1953 to 2022. W_i = weight (kg) of specimen i, W_{pred} = predicted weight from fitted data set. Shaded values for the coastwide population (grey and marked with an asterisk) were used in all SS3 models.

Source	Stock	Sex	n	ln(*a*)	SE ln(*a*)	*b*	SE *b*	mean W_i	SD W_i	min W_i	max W_i	mean W_{pred}
Survey	CST	F	32,257	-11.535*	0.007	3.102*	0.002	0.840	0.423	0.006	2.448	0.773
		M	33,972	-11.549*	0.007	3.107*	0.002	0.702	0.319	0.008	1.984	0.647
		F+M	66,228	-11.540	0.005	3.104	0.001	0.769	0.379	0.006	2.448	0.707
Comm.	CST	F	2,956	-11.192	0.061	3.013	0.016	1.015	0.284	0.203	2.240	0.967
		M	2,114	-11.165	0.070	3.000	0.019	0.814	0.200	0.162	1.551	0.796
		F+M	5,073	-11.293	0.043	3.038	0.012	0.930	0.272	0.170	2.240	0.885
Survey	5ABC	F	15,892	-11.555	0.008	3.106	0.002	0.770	0.452	0.007	2.136	0.751
		M	16,866	-11.661	0.008	3.141	0.002	0.659	0.359	0.008	1.984	0.639
		F+M	32,755	-11.600	0.006	3.121	0.002	0.713	0.410	0.007	2.136	0.694
Comm.	5ABC	F	1,696	-11.268	0.071	3.031	0.019	1.054	0.300	0.135	2.138	0.964
		M	1,249	-11.244	0.084	3.024	0.023	0.852	0.228	0.162	1.551	0.811
		F+M	2,950	-11.268	0.052	3.031	0.014	0.969	0.290	0.135	2.138	0.888
Survey	3CD	F	5,579	-11.397	0.016	3.077	0.004	0.884	0.423	0.006	2.082	0.782
		M	4,995	-11.475	0.015	3.099	0.004	0.670	0.308	0.008	1.676	0.642
		F+M	10,574	-11.438	0.011	3.088	0.003	0.783	0.388	0.006	2.082	0.709
Comm.	3CD	F	364	-11.532	0.160	3.123	0.044	0.997	0.273	0.460	1.812	1.024
		M	393	-10.511	0.210	2.826	0.058	0.758	0.127	0.476	1.299	0.772
		F+M	755	-11.823	0.123	3.195	0.034	0.873	0.242	0.460	1.812	0.913
Survey	5DE	F	10,759	-11.733	0.019	3.151	0.005	0.922	0.354	0.016	2.448	0.889
		M	12,064	-11.571	0.020	3.105	0.005	0.778	0.239	0.031	1.690	0.751
		F+M	22,833	-11.680	0.014	3.136	0.004	0.846	0.308	0.023	2.448	0.817
Comm.	5DE	F	889	-11.395	0.118	3.065	0.032	0.936	0.237	0.451	1.929	0.936
		M	471	-10.926	0.178	2.926	0.049	0.757	0.140	0.424	1.308	0.744
		F+M	1,361	-11.596	0.096	3.116	0.026	0.874	0.225	0.424	1.929	0.854

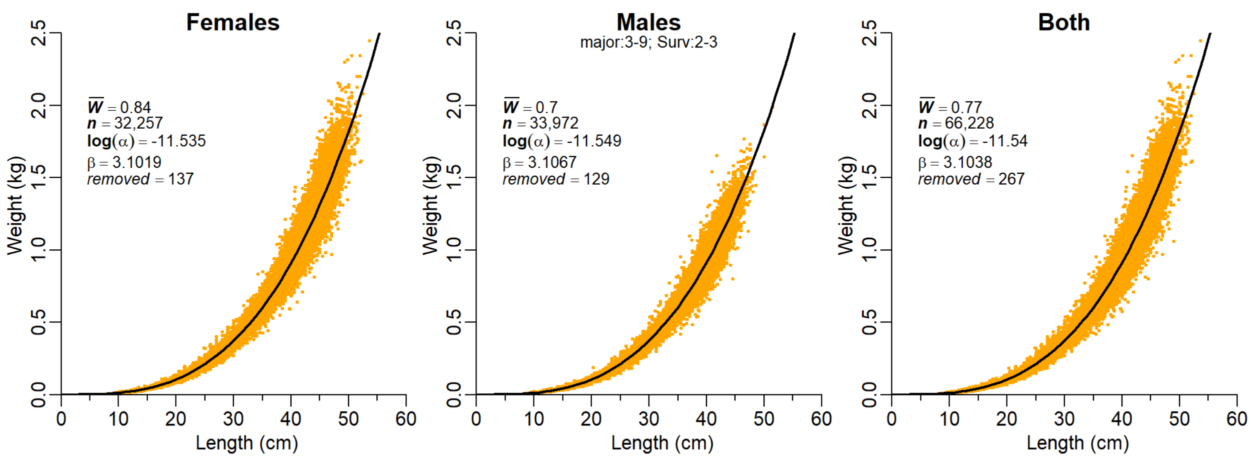

Figure D.1. Length-weight relationship for POP derived from all research and survey data for BC coastwide. Records with absolute value of standardised residuals >3 (based on a preliminary fit) were dropped.

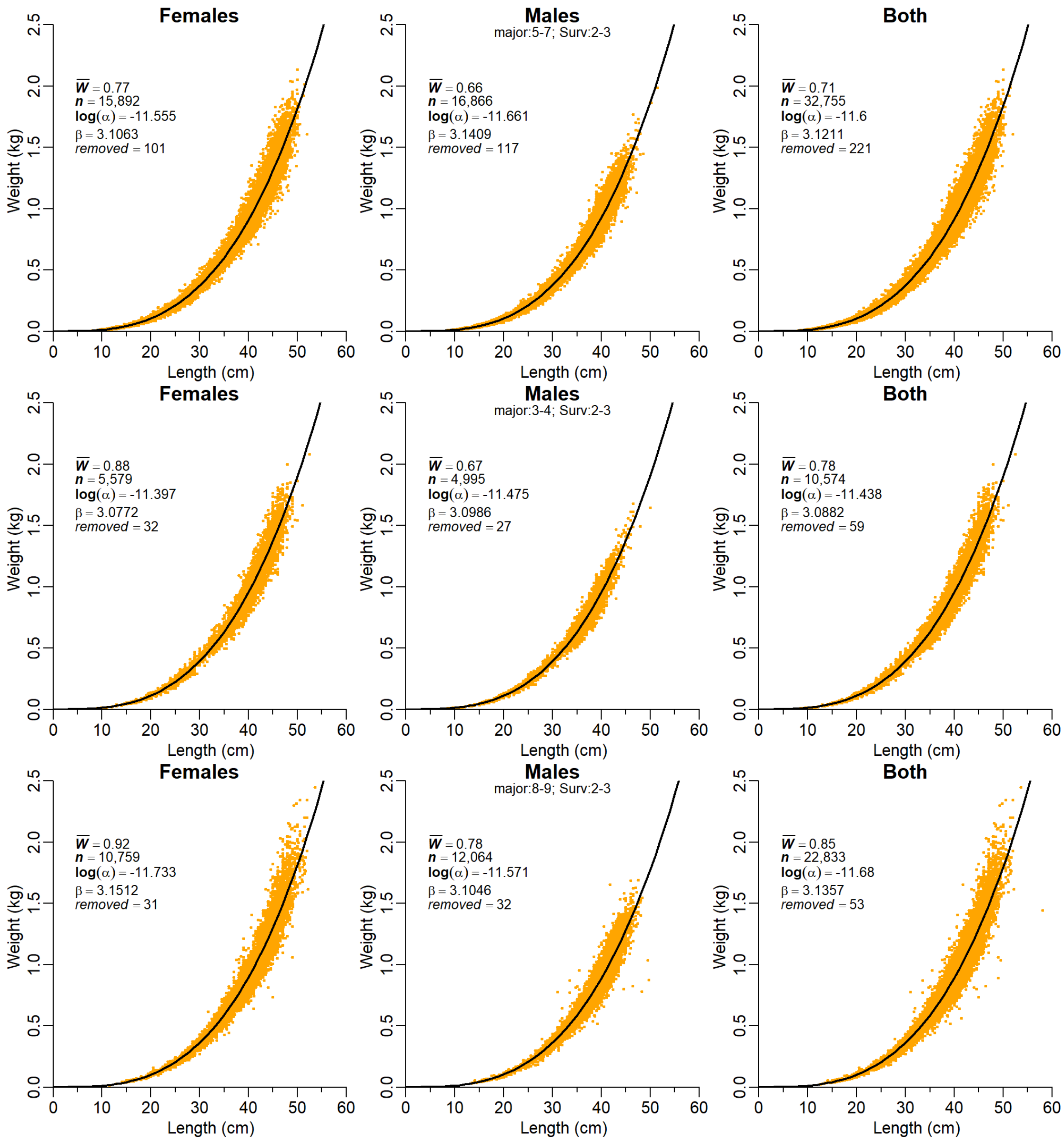

Figure D.2. Length-weight relationship for POP by area derived from all research and survey data – (top) 5ABC or QCS, (middle) 3CD or WCVI, and (bottom) 5DE or WCHG. Records with absolute value of standardised residuals >3 (based on a preliminary fit) were dropped.

D.1.2. Growth – Length vs. Age

Otolith age data were available from both surveys and commercial fishing trips; however, data from the surveys were used in determining the growth function used in the model. Of the 20,426 records with age data, 20,309 records had concurrent lengths, and 5,322 records were suitable for growth analysis after qualifying by sex (female|male), trip type (research|surveys), sample type (random), and ageing methodology. The majority of these ages were determined using the break-and-burn (B&B) method (MacLellan 1997). Table D.3 summarises the availability of all POP otoliths.

Growth was formulated as a von Bertalanffy model where lengths by sex, L_{is}, for fish $i = 1,\ldots,n_s$ are given by:

$$L_{is} = L_{\infty s}\left[1 - e^{-\kappa_s\left(a_{is} - t_{0s}\right)}\right] + \varepsilon_{is}, \quad \varepsilon \sim N\left(0,\sigma^2\right) \tag{D.2}$$

where for each sex s,

$L_{\infty s}$ = the average length at maximum age of an individual,

κ_s = growth rate coefficient, and

t_{0s} = age at which the average size is zero.

The negative log likelihood for each sex s, used for minimisation is:

$$\ell\left(L_\infty, \kappa, t_0, \sigma\right) = n\ln\left(\sigma\right) + \frac{\sum_i^n\left(L_i - \hat{L}_i\right)^2}{2\sigma^2}, \quad i = 1,\ldots,n$$

.

D.1.2.1. Maximum Likelihood Estimation

Various maximum likelihood estimation (MLE) fits were made for the length vs. age data. One growth model (von Bertalanffy) was used on the full set of research|survey data (Figure D.3), three regions (Figure D.4), and the four primary synoptic surveys (Figure D.5). See Table D.4 for all parameter fits. Figure D.6 shows cumulative length frequencies the synoptic surveys using 4-year periods. The HS survey tended to capture smaller fish than the other surveys.

Table D.3. Number of POP specimen structures (usually otoliths) for ageing by various methods. Number of samples appear in parentheses and are not additive between the sexes (i.e., otoliths in a sample usually come from both sexes). The 'Charter' samples come from research surveys conducted on commercial vessels. These structures were collected over the period 1963 to 2022.

Trip Type	Activity	Age method	Female	Male	Unknown
Non-obs domestic	commercial	thin section	26 (8)	37 (10)	—
Non-obs domestic	commercial	break & burn	14,135 (342)	13,775 (344)	78 (16)
Research	survey	unknown method	5,577 (114)	5,425 (114)	—
Research	survey	surface read	5,112 (105)	5,612 (105)	243 (11)
Research	survey	break & burn	6,585 (268)	6,069 (263)	9 (5)
Charter	survey	unknown method	1,146 (66)	1,283 (66)	29 (3)
Charter	survey	surface read	—	1 (1)	2 (1)
Charter	survey	break & burn	10,426 (751)	9,794 (750)	22 (12)
Charter	survey	unknown otolith	22 (3)	17 (3)	23 (4)
Obs domestic	commercial	unknown method	31 (1)	12 (1)	—
Obs domestic	commercial	break & burn	13,649 (726)	12,424 (726)	652 (59)
Obs domestic	commercial	unknown fin	1 (1)	—	—

Table D.4. Age-length parameter estimates for POP (females, males, and both combined) from fits using the von Bertalanffy growth model (Quinn and Deriso 1999) using specimens from research and surveys combined for the BC coast and PMFC areas (5ABC=QCS, 3CD=WCVI, 5DE=WCHG), as well as for three synoptic surveys and one triennial survey (QCS = Queen Charlotte Sound, WCVI = west coast Vancouver Island, WCHG = west coast Haida Gwaii, NMFS = US National Marine Fisheries Service). Shaded values for the coastwide population (grey and marked with an asterisk) were used in all SS3 models.

Stock/Survey	Data Source	Sex	n	Linf (cm)	K	t_0 (cm)
BC Coast	all surveys	F	13,464	43.9*	0.1663*	-0.56*
		M	12,995	40.7*	0.1895*	-0.61*
		F+M	26,506	42.4	0.1738	-0.68
5ABC	all surveys	F	5,598	44.1	0.1563	-0.65
		M	5,557	40.8	0.1826	-0.48
		F+M	11,171	42.4	0.1688	-0.57
3CD	all surveys	F	3,789	43.8	0.1633	-1.08
		M	3,328	39.6	0.2094	-0.77
		F+M	7,128	42.2	0.1680	-1.34
5DE	all surveys	F	4,082	43.9	0.1687	-0.76
		M	4,102	41.5	0.1561	-2.60
		F+M	8,202	42.7	0.1642	-1.54
QCS	synoptic survey	F	3,741	43.9	0.1577	-0.67
		M	4,034	40.8	0.1821	-0.50
		F+M	7,777	42.2	0.1708	-0.56
WCVI	synoptic survey	F	2,134	44.2	0.1576	-1.19
		M	1,860	39.7	0.2094	-0.79
		F+M	3,999	42.3	0.1685	-1.28
WCHG	synoptic survey	F	1,815	45.4	0.1120	-5.00
		M	1,804	42.1	0.1284	-4.85
		F+M	3,622	43.4	0.1320	-3.79
NMFS	triennial survey	F	1,140	44.6	0.1590	-1.37
		M	1,275	40.4	0.2086	-0.90
		F+M	2,415	42.6	0.1760	-1.23

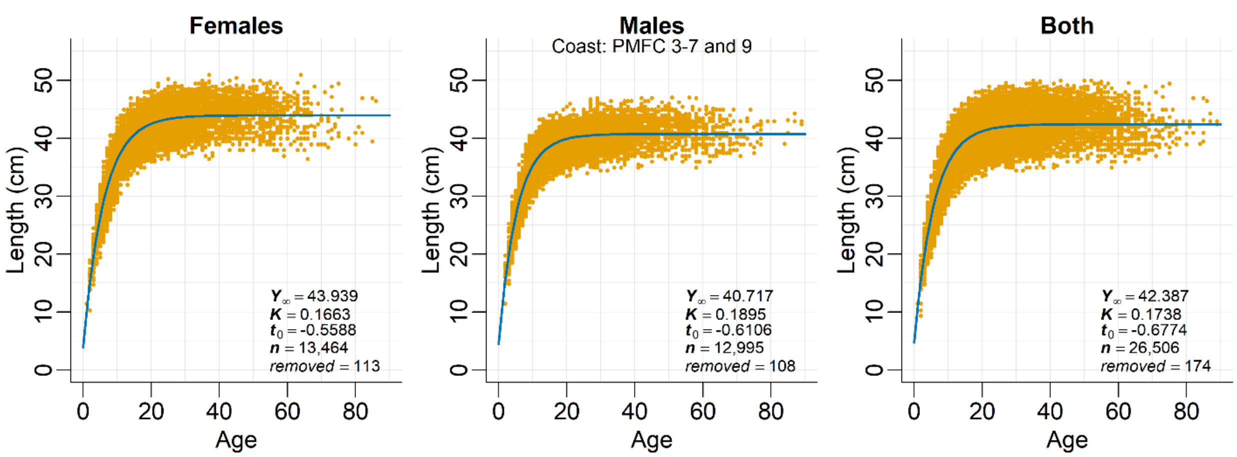

Figure D.3. Growth specified by age-length relationship: von Bertalanffy fits to POP coastwide using data from research and surveys. Ages were determined by break-and-burn otoliths and surface-read otoliths from ages 1 to 3. Records with absolute value of standardised residuals >3 (based on a preliminary fit) were dropped.

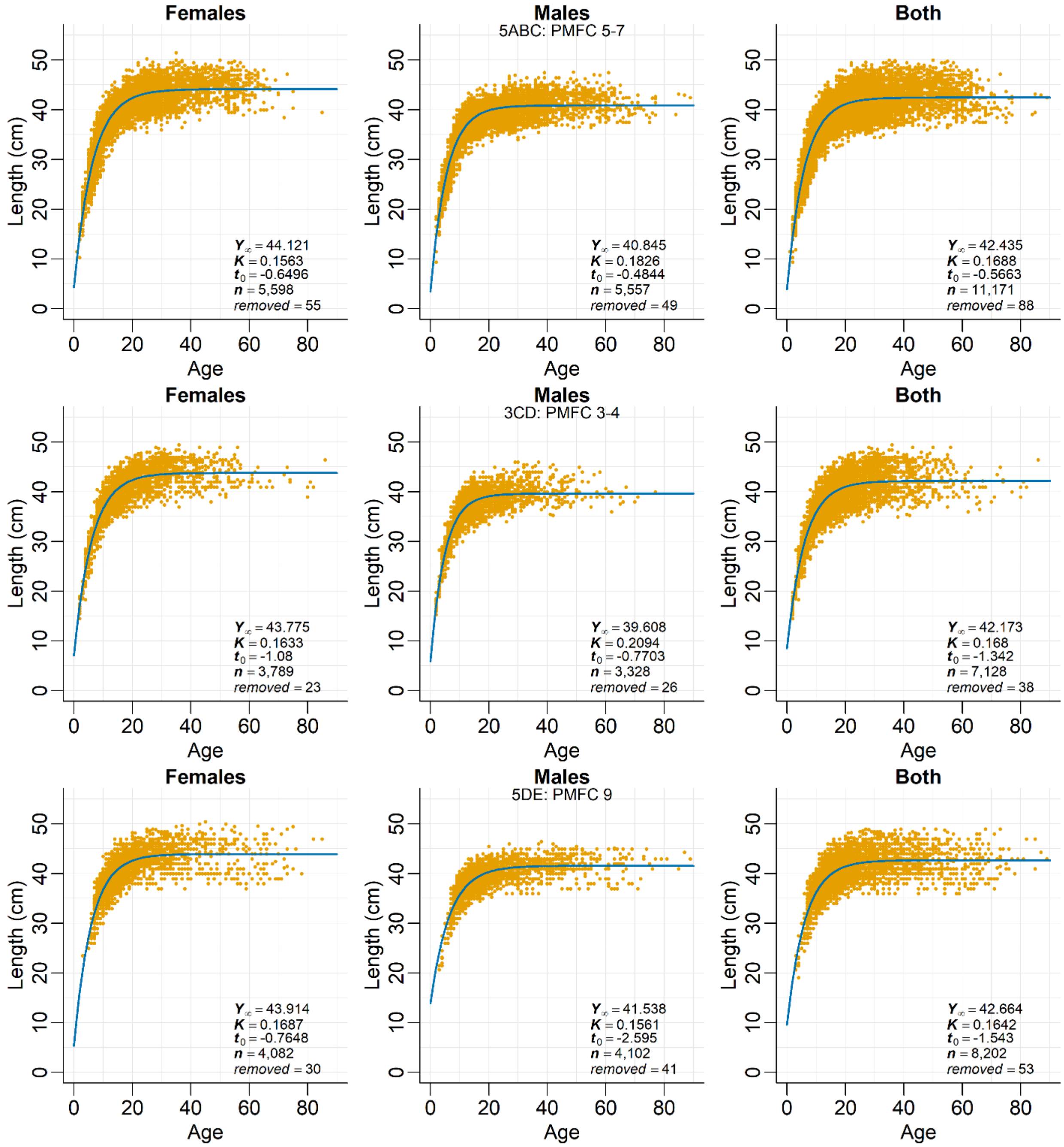

Figure D.4. Growth specified by age-length relationship: von Bertalanffy fits to POP using data from research and surveys – (top) 5ABC=QCS, (middle) 3CD=WCVI, and (bottom) 5DE=WCHG. See caption in Figure D.3 for additional details.

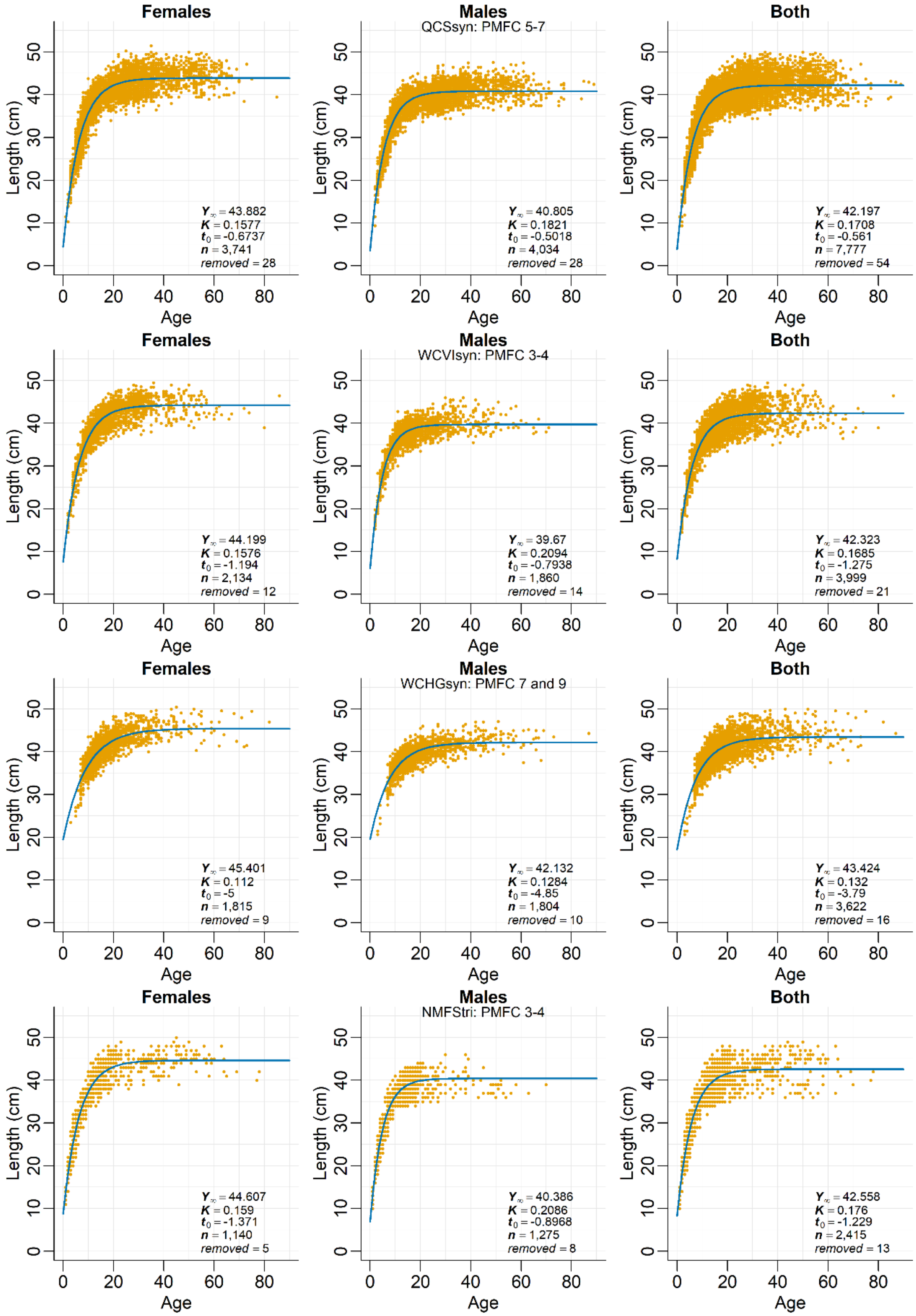

Figure D.5. Growth specified by age-length relationship: von Bertalanffy fits to POP from four surveys: QCS synoptic, WCVI synoptic, WCHG synoptic, and NMFS triennial. See caption in Figure D.3 for additional details.

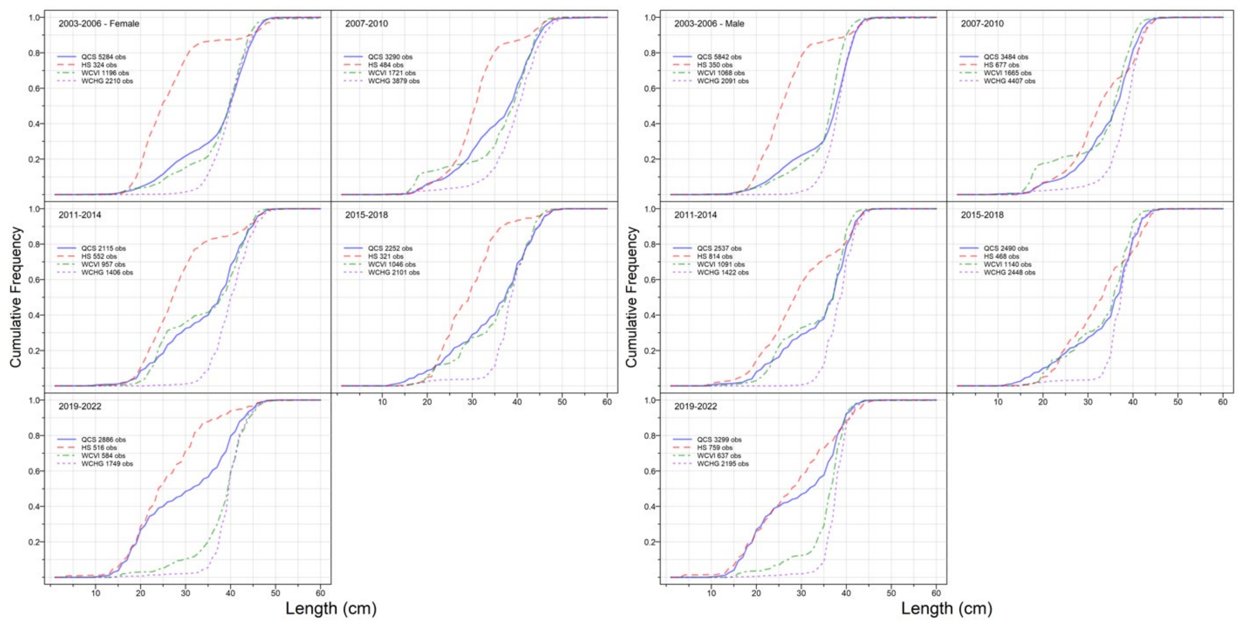

Figure D.6. Cumulative length frequencies for POP females (left) and males (right) comparing synoptic surveys over 4-year blocks. QCS = Queen Charlotte Sound, HS = Hecate Strait, WCVI = west coast Vancouver Island, WCHG = west coast Haida Gwaii.

D.1.3. Maturity

This analysis was based on all (research, survey, and commercial combined) "staged" (examined for maturity status) females and males in the DFO GFBioSQL database. Maturity codes for POP in the database (Table D.5) come from `MATURITY_CONVENTION_CODE = 1`, which describes seven maturity conditions for Rockfish (1977+).

Table D.5. GFBio maturity codes for rockfish, including BC rockfish.

Code	Female	Male
1	Immature - translucent, small	Immature - translucent, string-like
2	Maturing - small yellow eggs, translucent or opaque	Maturing - swelling, brown-white
3	Mature - large yellow eggs, opaque	–
4	Fertilised - large, orange-yellow eggs, translucent	Mature - large white, easily broken
5	Embryos or larvae - includes eyed eggs	Ripe - running sperm
6	Spent - large flaccid red ovaries; maybe a few larvae	Spent - flaccid, red
7	Resting - moderate size, firm, red-grey ovaries	Resting - ribbon-like, small brown

Mature (stage 3) POP females start appearing in July and are most abundant during the months of November and December, with fertilised females appearing in January through March followed by embryo-bearing fish in February through April (Figure D.7, upper left). All months were used in creating the maturity curve because these data provided cleaner fits than using a subset of months. This required combining commercial and research data because most of the research/survey data do not extend into the late autumn, winter and early spring months.

For the maturity analysis, all stages 3 and higher were assumed to be mature, and a maturity ogive was fit to the filtered data using a double-normal model:

$$m_{as} = \begin{cases} e^{-(a-v_s)^2 / \rho_{sL}}, & a \le v_s \\ 1, & a > v_s \end{cases} \quad \text{(D.3)}$$

where, m_{as} = maturity at age a for sex s (combined),

v_s = age of full maturity for sex s,

ρ_{sL} = variance for the left limb of the maturity curve for sex s.

Generally, rockfish biological analyses use ages from otoliths processed and read using the 'break and burn' (B&B) procedure (`ameth=3`) or coded as 'unknown' (`ameth=0`) but processed in 1980 or later. There is also a method termed 'break and bake' (`ameth=17`); however, no POP were processed using this technique (Table D.3). Additionally, rockfish otoliths aged 1–3 y are sometimes processed using surface readings (`ameth=1`) because the ageing lab finds this technique more reliable than B&B for very young fish; however, the protocol is usually applied to flatfish and hake only (S. Wischniowski, DFO, pers. comm., June 21, 2018).

Using various qualifiers (e.g., valid ageing methods), the above qualification yielded 11,258 mature POP females coastwide from research surveys and the commercial fishery with maturity readings and valid ages. Mature specimens comprised those coded 3 to 7 for rockfish (Table D.5). The empirical proportion of mature females|males at each age was calculated (Figure D.8). A double-normal function (Eq. D.3) was fitted to the observed proportions mature at ages 1 to 30[1] to smooth the observations and determine an increasing monotonic function for use in the stock assessment model (Figure D.8). Additionally, a logistic function used by Vivian Haist (VH) for length models in New Zealand rock lobster assessments (Haist et al. 2009) was used to compare with the double normal model.

Following a procedure adopted by Stanley et al. (2009) for Canary Rockfish (*S. pinniger*), the proportions mature for young ages fitted by Eq. D.3 were not used because the fitted line may overestimate the proportion of mature females (Figure D.8). Therefore, the maturity ogive used in the stock assessment model (column marked 'Model CST m_a' in Table D.6), set proportion mature to zero for ages 1 to 4, then switched to the fitted monotonic function for ages 5 to 15. All ages from 16 were forced to 1 (fully mature). This strategy follows previous BC rockfish stock assessments where it was recognised that younger ages are not well sampled and those that are, tend to be larger and more likely to be mature. The function of this ogive in the stock assessment model is to calculate the spawning biomass used in the Beverton-Holt stock recruitment function, and is treated as a constant known without error. The ages at 50% and full maturity are estimated from the double-normal fit at 9.5 y and 15.5 y, respectively for females, and 8.9 and 19.7 y for males, respectively. Only the coastwide female maturity ogive was used in the coastwide and regional SS3 population models.

[1] The ages used for fitting exclude ages greater than 30 to avoid potentially influential proportions caused by spurious values (due to sparse data).

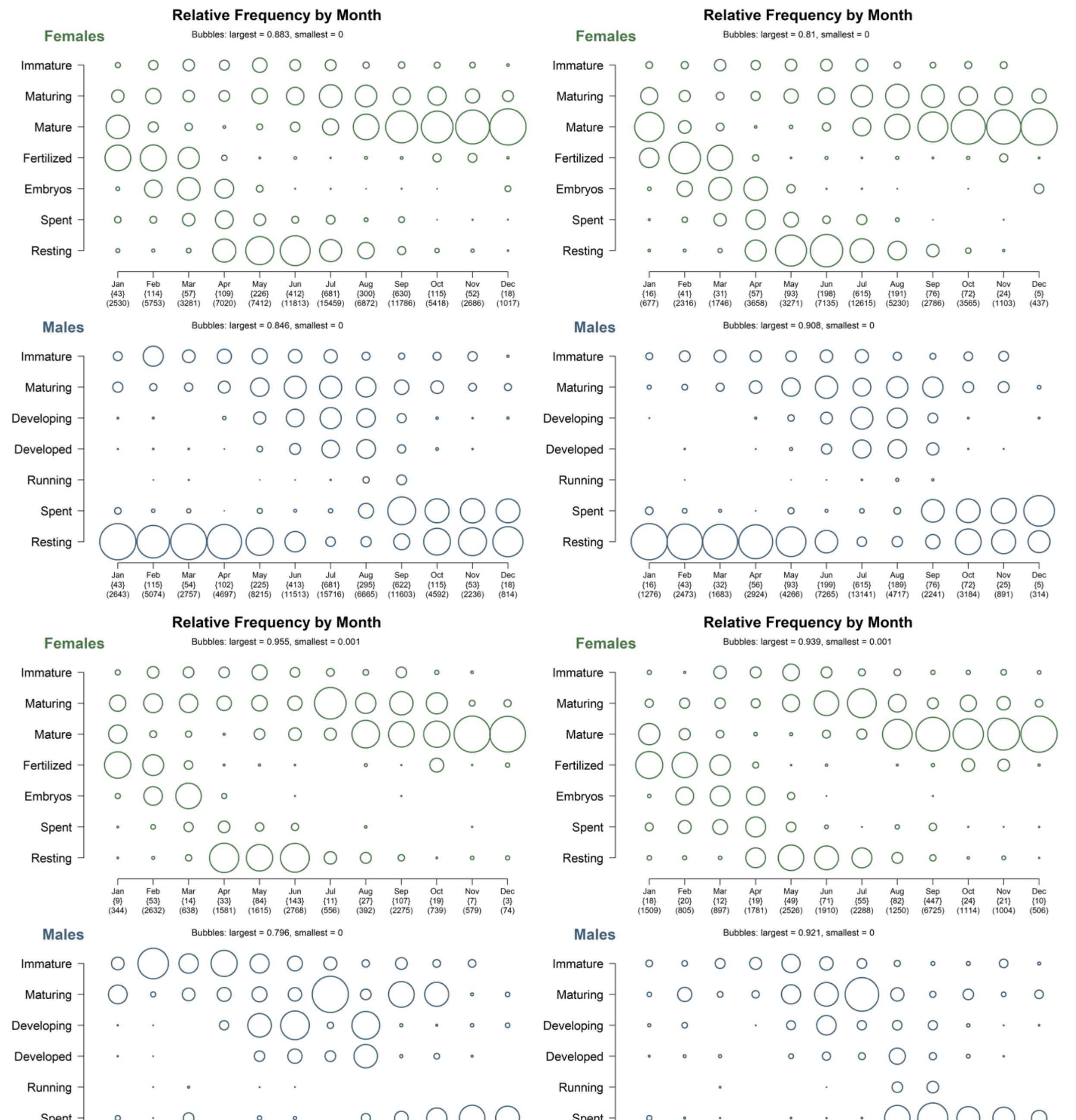

Figure D.7. Relative frequency of maturity codes by month (top left: coastwide, top right: 5ABC, bottom left: 3CD, bottom right: 5DE) for POP females and males. Data include maturities from commercial and research specimens. Frequencies are calculated among each maturity category for every month.

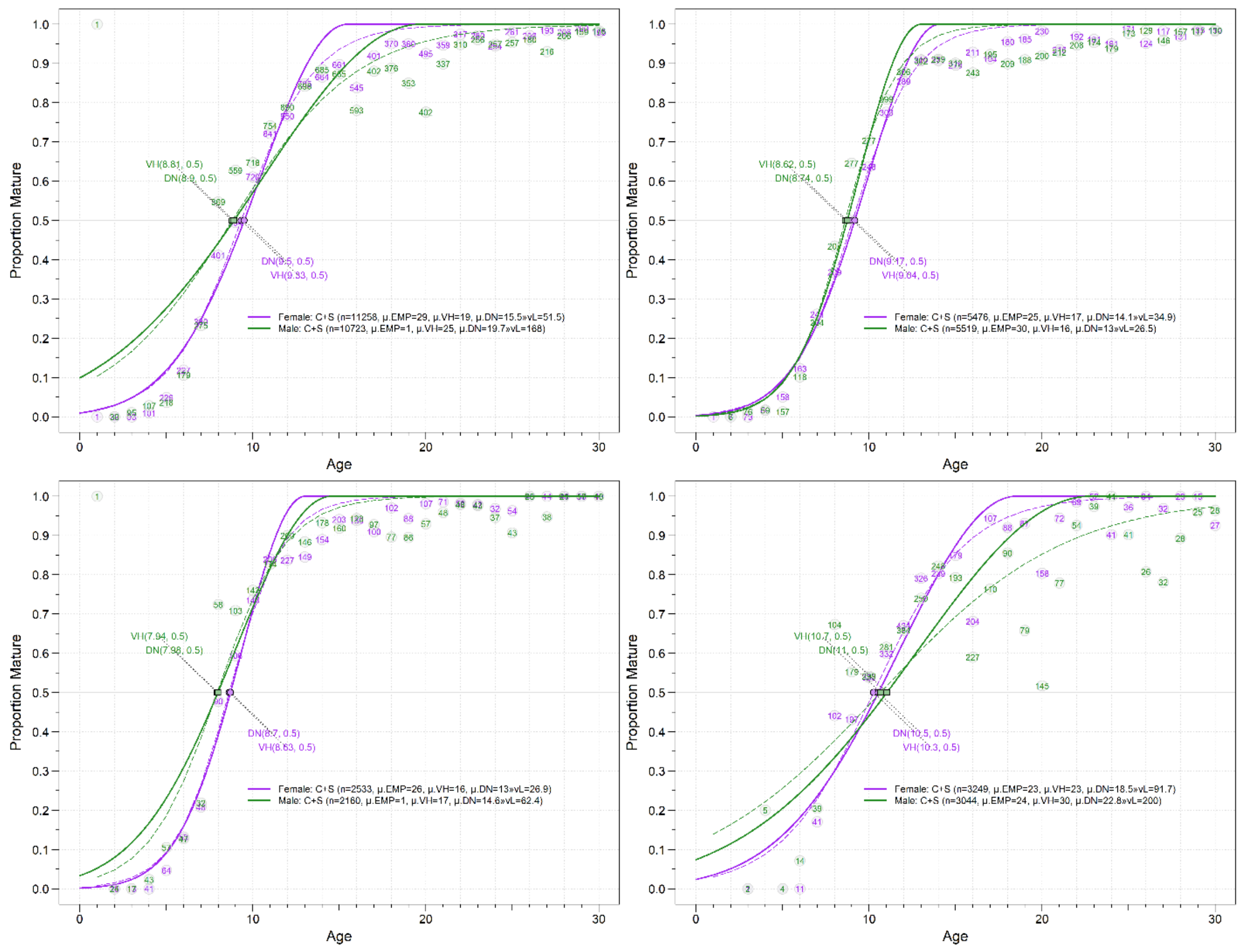

Figure D.8. Maturity ogives for POP females (purple) and males (green) coastwide (top left), in 5ABC (top right), in 3CD (bottom left), and in 5DE (bottom right). Solid line shows double-normal (DN) curve fit; dashed line shows logistic model fit (VH = Vivian Haist); numbers in circles denote number of specimens used to calculate the input proportions-mature (EMP =empirical). Estimated ages at 50% maturity are indicated near the median line; ages at full maturity (μ.VH, μ.DN) are displayed in the legend. Maturity data were limited to years from 1996 to 2022.

Table D.6. Proportion POP females mature by age (m_a) used in the catch-age model (first 'Model' column). Maturity stages 1 and 2 were assumed to be immature fish and all other staged fish (stages 3 to 7) were assumed to be mature. EMP = empirical, BL = binomial logit, VH =logistic used by Vivian Haist, DN = double normal (Eq.D.3), Model = for use in population models but only coastwide was used in all model runs.

Age	# Fish	EMP m_a	BL m_a	VH m_a	DN m_a	Model CST m_a	Model 5ABC m_a	Model 3CD m_a	Model 5DE m_a
1	0	–	0.0715	0.0187	0.0171	0	0	0	0
2	22	0	0.0957	0.0297	0.0294	0	0	0	0
3	93	0	0.1268	0.0470	0.0487	0	0	0	0
4	101	0.0099	0.1663	0.0734	0.0775	0	0	0	0
5	226	0.0487	0.2150	0.1131	0.1187	0.1187	0.0939	0.0914	0.1367
6	227	0.1189	0.2732	0.1702	0.1749	0.1749	0.1536	0.1599	0.1815
7	330	0.2424	0.3405	0.2480	0.2478	0.2478	0.2372	0.2596	0.2358
8	401	0.4115	0.4148	0.3467	0.3378	0.3378	0.3459	0.3915	0.2998
9	594	0.4949	0.4932	0.4605	0.4430	0.4430	0.4764	0.5479	0.3730
10	720	0.6111	0.5720	0.5786	0.5587	0.5587	0.6195	0.7120	0.4539
11	841	0.7218	0.6472	0.6883	0.6779	0.6779	0.7609	0.8589	0.5406
12	950	0.7663	0.7158	0.7803	0.7910	0.7910	0.8825	0.9619	0.6299
13	785	0.8484	0.7757	0.8510	0.8879	0.8879	0.9666	1.0000	0.7181
14	664	0.8660	0.8261	0.9019	0.9587	0.9587	0.9998	1	0.8010
15	661	0.8971	0.8670	0.9366	0.9957	0.9957	1	1	0.8742
16	545	0.8385	0.8995	0.9596	1	1	1	1	0.9335
17	401	0.9202	0.9248	0.9745	1	1	1	1	0.9754
18	370	0.9514	0.9441	0.9840	1	1	1	1	0.9972
19	360	0.9500	0.9586	0.9900	1	1	1	1	1
20	495	0.9253	0.9695	0.9938	1	1	1	1	1
25	261	0.9808	0.9936	0.9994	1	1	1	1	1
30	195	0.9795	0.9987	0.9999	1	1	1	1	1

D.1.4. Natural Mortality

The maximum reported age in the literature for POP is 98 years for a specimen from the Aleutian Islands (Munk 2001). The DFO database GFBio reports one older specimen (age 103 y: female specimen from locality 'South Moresby' at 362 m in 2002). Archibald et al. (1981) estimated POP natural mortality to be 0.04–0.05; however, values used for the natural mortality rate of POP in other published stock assessments are usually close to 0.06 (e.g., Schnute et al. 2001; Hanselman et al. 2007, 2009). Estimates of *M* from previous BC POP stock assessments (Haigh et al. 2018; Edwards et al. 2013 a,b) are:

- 5ABC – 0.060 (0.055, 0.066) for females and 0.065 (0.060, 0.071) for males;
- 3CD – 0.069 (0.060, 0.079) for females and 0.072 (0.063, 0.082) for males; and
- 5DE – 0.063 (0.055, 0.073) for females and 0.076 (0.067, 0.085) for males.

In this stock assessment, *M* prior means were based on the 2017 5ABC medians with a 20% CV applied: N (0.06, 0.012) for females and N (0.065, 0.013) for males.

The Hoenig (1983) estimator describes an exponential decay LN(k) = $-Z\,t_L$, where Z = natural mortality, t_L = longevity of a stock, and k = proportion of animals that are still alive at t_L. Quinn and Deriso (1999) popularised this estimator by re-arranging Hoenig's equation and setting k=0.01 (as originally suggested by Hoenig):

$$M = -\ln(0.01) / t_{\max} \qquad \text{(D.4)}$$

Then et al. (2015) revisited various natural mortality estimators and recommended the use of an updated Hoenig estimator based on nonlinear least squares:

$$M = 4.899\, t_{\max}^{-0.916} \quad \text{(D.5)}$$

where t_{max} = maximum age.

During the review process for Redstripe Rockfish (DFO 2022a), one of the principal reviewers, Vladlena Gertseva (Northwest Fisheries Science Center, NOAA, pers. comm., 2018), noted that Then et al. (2015) did not consistently apply a log transformation. In real space, one might expect substantial heteroscedasticity in both the observation and process errors associated with the relationship of *M* to t_{max}. Re-evaluating the data used in Then et al. (2015) by fitting the one-parameter t_{max} model using a log-log transformation (such that the slope is forced to be -1 in the transformed space, as in Hamel 2015), Gertseva recalculated the point estimate for *M* as:

$$M = 5.4 \,/\, t_{\max} \quad \text{(D.6)}$$

In past CSAS Regional Peer Review meetings, participants have been averse to adopting a maximum age that comes from a single, usually isolated individual, preferring instead to observe the tail distribution of ages (Figure D.9). For POP, setting t_{max} = 99% quantile of the age data by sex: female t_{max}=62 y, male t_{max}=60 y yields Hoenig (1983) and Gertseva/Hamel estimators, female *M*=0.074 and 0.087, respectively, while male *M*=0.077 and 0.090, respectively. These values exceed what we deemed plausible for a fish that lives to 100 y, which would yield a low *M* of 0.046 and 0.054 using Hoenig and Gertseva/Hamel estimators, respectively. Table D.7 calculates possible *M* values based on the two estimators.

Table D.7. Estimates of POP natural mortality M using equations based on fish longevity (males and females combined). Various ages > 0.95 quantile up to the observed t_{max} = 103y (females) are used to illustrate the variability in M based on alternative 'maximum' ages. Empirical cumulative distribution function in R [function(x,pc) ecdf(x)(pc)] was used to estimate quantiles for various ages.

Age	Quantile from `ecdf`	Hoenig (1983) `M=-LN(0.01)/tmax`	Gertseva/Hamel `M=5.4/tmax`
50	0.96930	0.092	0.108
60	0.98931	0.077	0.090
70	0.99716	0.066	0.077
80	0.99968	0.058	0.068
90	0.99995	0.051	0.060
103	1	0.045	0.052

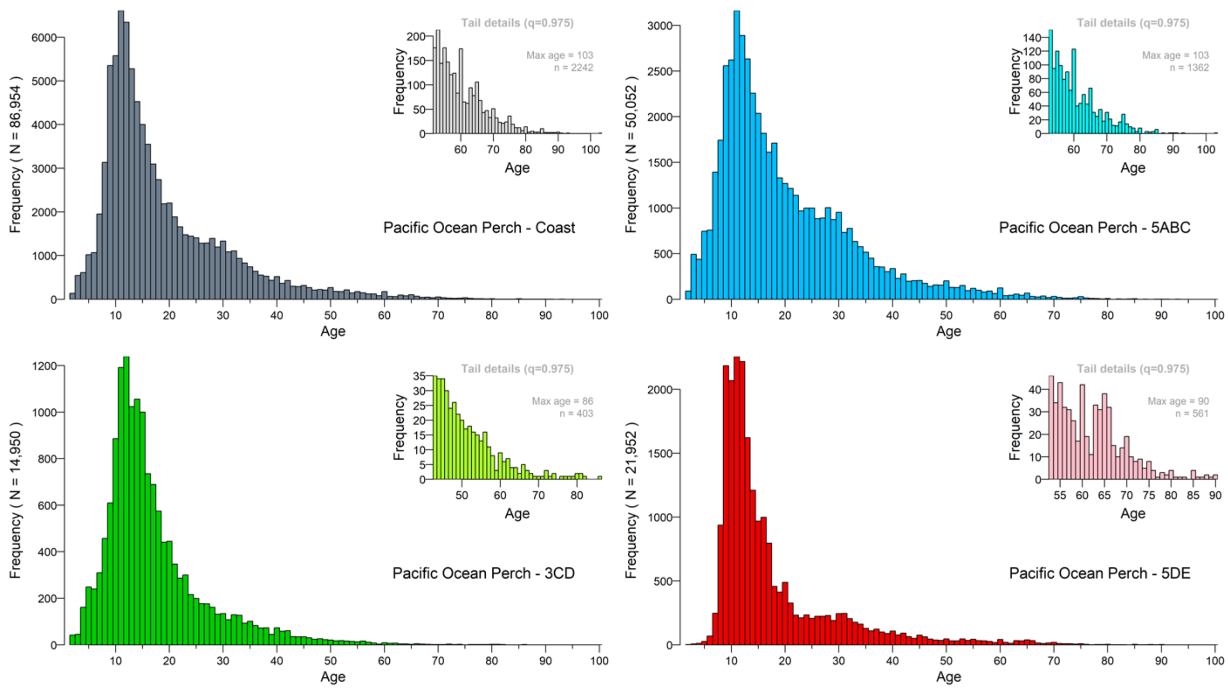

Figure D.9. Distribution of POP ages (combined females and males) for all gear types along the BC coast (top left), in 5ABC (top right), in 3CD (bottom left), and in 5DE (bottom right); insets shows details for ages >= 0.975 quantiles of the age data set by area.

D.1.5. Generation Time

Generation time t_G is assumed to be the average age of adults (males and females) in the population, approximated by the age of first reproduction plus the inverse of adult natural mortality[2], and takes the form:

$$t_G = k + \frac{1}{e^M - 1} \qquad \text{(D.7)}$$

where k = age at 50% maturity,
M = instantaneous rate of natural mortality.

Using a Taylor expansion, $e^M = 1 + M + M^2/2$, COSEWIC adopts a rough approximation to generation time for small values of M:

$$t_G = k + \frac{1}{M} \qquad \text{(D.8)}$$

From Section D.1.3, k = 9.5 y for POP females. If we assume that M = 0.052 (using age=103 in Table D.7), then the COSEWIC estimate of generation time (D.8) t_G = 28.7 y for the coastwide

[2] This equation assumes that natural mortality after the age of first reproduction is well known, and mortality and fecundity do not change with age after the age of first reproduction (i.e., there is no senescence). For species that exhibit senescence (mortality increasing and fecundity decreasing) with age, this formula will overestimate generation time (Section 4.4, option 2 of IUCN Standards and Petitions Committee 2022).

stock. For simplicity, we adopt t_G = 25 years, which was close to the generation time of 27 years (M~0.062) for a 2012 US assessment (Hanselman et al. 2012).

D.2. WEIGHTED AGE PROPORTIONS

This section summarises a method for representing commercial and survey age structures in the stock assessment model for a given species (herein called 'target') through weighting observed age frequencies x_a or proportions x'_a by catch‖density in defined strata (h). (Throughout this section, the symbol '‖' is used to delimit parallel values for commercial and survey analyses, respectively, as the mechanics of the weighting procedure are similar for both. The symbol can be read 'or', e.g., catch or density.) For commercial samples, these strata comprise quarterly periods within a year, while for survey samples, the strata are defined by longitude, latitude, and depth boundaries unique to each survey series. A two-tiered weighting system is used as follows:

Within each stratum *h*, commercial age samples were identified by trip (usually one sample per trip[3]) and the age frequencies per trip were weighted by the target catch weight (tonnes) of the tows that were sampled to yield one weighted age frequency per stratum (quarter). For each year, the quarterly age frequencies were then weighted by the quarterly fishery catch of the target. If a quarter had not been sampled, it was not used in the weighting for the year. For example, if samples of the target were missing in Oct–Dec of a particular year, only the first three quarters of target catch would be used to prorate three quarterly age frequencies in that year, resulting in a single age frequency for the year.

Annual survey ages were weighted similarly. Each sampled tow in a survey stratum was weighted by the tow's target catch density (t/km^2) to yield a single weighted age frequency per stratum. As above, not all survey strata had age samples and so weighted age frequencies by sampled stratum were weighted by the appropriate stratum area (km^2). For example, if only shallow strata were sampled for age, the deep strata areas were not used to prorate the shallow-strata age frequencies. As for commercial ages, the two-tiered weighting scheme yielded one age frequency per survey year.

Ideally, sampling effort would be proportional to the amount of the target caught, but this is not usually the case. Personnel can control the sampling effort on surveys more than on board commercial vessels, but the relative catch among strata over the course of a year or survey cannot be known with certainty until the events have occurred. Therefore, the stratified weighting scheme outlined above and detailed below attempts to adjust for unequal sampling effort among strata.

For simplicity, the weighting of age frequencies x_a is used for illustration, unless otherwise specified. The weighting occurs at two levels: h (quarters for commercial ages, strata for survey ages) and i (years if commercial, total stratum area if survey). Notation is summarised in Table D.8.

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[3] Samples were combined, weighted by the tow weight, for trips with more than one sample to give a single age frequency for each trip.

Table D.8. Equations for weighting age frequencies or proportions; (c) = commercial, (s) = survey.

Symbol	Description
	Indices
a	age class (1 to A, where A is an accumulator age-class)
d	(c) trip ID as sample unit (usually one sample per trip) (s) sample ID as sample unit (usually one sample per survey tow)
h	(c) calendar year quarter (1 to 4), 91.5 days each (s) survey stratum (area-depth combination)
i	(c) calendar year (1977 to present) (s) single survey ID in survey series (e.g., 2003 QCS Synoptic)
	Data
x_{adhi}	observations-at-age a for sample unit d in quarter‖stratum h of year‖survey i
x'_{adhi}	proportion-at-age a for sample unit d in quarter‖stratum h of year‖survey i
C_{dhi}	(c) commercial catch (tonnes) of the target for sample unit d in quarter h of year i (s) density (t/km^2) of the target for sample unit d in stratum h of survey i
C'_{dhi}	C_{dhi} as a proportion of total catch‖density $C_{hi} = \sum_d C_{dhi}$
y_{ahi}	weighted age frequencies at age a in quarter‖stratum h of year‖survey i
K_{hi}	(c) total commercial catch (t) of the target in quarter h of year i (s) stratum area (km^2) of stratum h in survey i
K'_{hi}	K_{hi} as a proportion of total catch‖area $K_i = \sum_h K_{hi}$
p_{ai}	weighted frequencies at age a in year‖survey i
p'_{ai}	weighted proportions at age a in year‖survey i

For each quarter‖stratum h, sample unit frequencies x_{ad} are weighted by sample unit catch‖density of the target species. (For commercial ages, trip is used as the sample unit, though at times one trip may contain multiple samples. In these instances, multiple samples from a single trip will be merged into a single sample unit.) Within any quarter‖stratum h and year‖survey i there is a set of sample catches‖densities C_{dhi} that can be transformed into a set of proportions:

$$C'_{dhi} = C_{dhi} \Big/ \sum_d C_{dhi} \ . \qquad \text{(D.9)}$$

The proportion C'_{dhi} is used to weight the age frequencies x_{adhi} summed over d, which yields weighted age frequencies by quarter‖stratum for each year‖survey:

$$y_{ahi} = \sum_d \left(C'_{dhi} x_{adhi} \right). \qquad \text{(D.10)}$$

This transformation reduces the frequencies x from the originals, and so y_{ahi} is rescaled (multiplied) by the factor

$$\sum_a x_{ahi} \Big/ \sum_a y_{ahi} \qquad \text{(D.11)}$$

to retain the original number of observations. (For proportions x' this is not needed.) Although this step is performed, it is strictly not necessary because at the end of the two-step weighting, the weighted frequencies are transformed to represent proportions-at-age.

At the second level of stratification by year‖survey i, the annual proportion of quarterly catch (t) for commercial ages or the survey proportion of stratum areas (km²) for survey ages is calculated

$$K'_{hi} = K_{hi} \Big/ \sum_h K_{hi} \qquad \text{(D.12)}$$

to weight y_{ahi} and derive weighted age frequencies by year‖survey:

$$p_{ai} = \sum_h \left(K'_{hi} y_{ahi} \right). \qquad \text{(D.13)}$$

Again, if this transformation is applied to frequencies (as opposed to proportions), it reduces them from the original, and so p_{ai} is rescaled (multiplied) by the factor

$$\sum_a y_{ai} \Big/ \sum_a p_{ai} \qquad \text{(D.14)}$$

to retain the original number of observations.

Finally, the weighted frequencies are transformed to represent proportions-at-age:

$$p'_{ai} = p_{ai} \Big/ \sum_a p_{ai} . \qquad \text{(D.15)}$$

If initially we had used proportions x'_{adhi} instead of frequencies x_{adhi}, the final transformation would not be necessary; however, its application does not affect the outcome.

The choice of data input (frequencies x vs. proportions x') can sometimes matter: the numeric outcome can be very different, especially if the input samples comprise few observations. Theoretically, weighting frequencies emphasises our belief in individual observations at specific ages while weighting proportions emphasises our belief in sampled age distributions. Neither method yields inherently better results; however, if the original sampling methodology favoured sampling few fish from many tows rather than sampling many fish from few tows, then weighting frequencies probably makes more sense than weighting proportions. In this assessment, age frequencies x are weighted.

D.2.1. Commercial Ages

For the POP stocks, sampled age frequencies (AF) from the trawl fisheries (bottom, midwater, unknown) were combined; shrimp trawl data were discarded. No age data were available from the hook and line fisheries. Effectively, the model was run assuming a joint selectivity for all trawl gear types (e.g., bottom and midwater). The commercial trawl AF dataset spanned years 1977 to 2019, but dropped years 1993 and 1996 for 3CD and 1981, 1983, 2010–2012, and 2019 for 5DE because these years were only represented by one sample each or had fewer than 75 aged specimens (Table D.9, Figure D.10). The remaining trawl AF dataset included 43 years in 5ABC, 27 years in 3CD, and 33 years in 5DE. Note that samples originally in 5DE were reallocated to 5ABC if they occurred in Flamingo Inlet or Anthony Island localities immediately NW of Cape St. James.

The POP AF data included both sorted and unsorted samples for reasons provided in Starr and Haigh (2021a). Sorted samples generally occur earlier in the time series than do unsorted samples. Consequently, dropping sorted samples loses information about early recruitment strength.

Table D.9. Commercial trip quarterly data from the BC Trawl fishery used to weight POP proportions-at-age: number of sampled trips, POP catch (t) by all trips, ratio (%) sampled catch to fishery catch.

Year	# Trips, # Samples, # Specimens				Fishery catch (t)				Sampled/fishery catch (%)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Coastwide Trawl Fishery*												
1977	---	1, 1, 101	2, 2, 205	---	219	1,180	867	463	---	1.2	8.4	---
1978	---	6, 6, 597	4, 4, 408	2, 2, 208	305	668	1,513	1,396	---	39.8	11.5	4.9
1979	4, 4, 392	12, 12, 1282	8, 9, 875	4, 4, 380	320	930	1,225	356	43.7	36.1	19.3	20.6
1980	3, 3, 297	12, 12, 1197	9, 9, 896	4, 4, 395	303	1,911	2,139	973	32.4	27.7	19.0	11.4
1981	---	5, 5, 650	3, 3, 249	---	458	3,107	1,378	167	---	8.1	10.4	---
1982	6, 6, 1197	10, 10, 1769	---	4, 4, 650	778	3,080	1,329	847	21.5	21.5	---	24.3
1983	1, 1, 50	8, 8, 375	4, 6, 697	---	1,212	3,225	977	291	4.1	13.7	16.6	---
1984	2, 2, 250	13, 13, 1548	---	5, 5, 997	1,223	3,432	870	1,249	8.4	20.6	---	18.0
1985	1, 1, 30	2, 2, 56	2, 2, 400	5, 5, 1499	1,721	2,649	645	1,104	3.6	2.4	15.5	39.4
1986	---	4, 4, 447	2, 2, 55	2, 2, 600	1,151	2,910	1,040	847	---	8.3	7.7	2.9
1987	5, 5, 964	3, 3, 593	3, 3, 852	---	1,216	2,803	1,421	1,164	13.4	7.6	3.9	---
1988	5, 6, 998	3, 3, 622	1, 1, 48	---	1,182	3,021	1,272	1,668	14.8	6.5	1.5	---
1989	5, 5, 250	8, 9, 344	---	---	1,302	2,458	1,236	1,409	15.8	10.9	---	---
1990	8, 8, 320	9, 13, 492	2, 2, 74	2, 2, 73	1,061	2,476	1,335	945	9.1	8.7	6.7	5.8
1991	6, 6, 258	7, 7, 169	5, 5, 223	15, 15, 372	1,038	1,608	753	1,030	11.8	5.0	6.1	39.3
1992	4, 4, 60	12, 12, 405	14, 14, 334	6, 6, 173	720	1,575	1,326	522	9.6	9.5	12.9	4.8
1993	4, 4, 166	17, 17, 647	1, 1, 45	4, 4, 167	623	2,170	656	1,180	3.2	8.1	0.3	2.4
1994	2, 2, 124	21, 26, 419	18, 24, 383	12, 17, 330	559	1,328	1,552	2,354	1.1	13.1	13.9	7.3
1995	13, 14, 464	27, 43, 314	16, 25, 269	1, 1, 34	2,037	2,559	1,651	65	5.4	17.9	8.2	5.9
1996	4, 4, 40	23, 27, 381	12, 14, 333	4, 4, 40	358	2,851	1,006	2,278	10.1	14.8	10.8	3.9
1997	3, 3, 114	4, 4, 176	8, 8, 326	5, 5, 192	1,093	2,333	1,362	1,146	2.1	2.2	6.1	3.5
1998	12, 12, 450	13, 13, 477	12, 12, 511	7, 7, 233	1,176	2,493	1,728	921	10.6	4.1	5.3	7.1
1999	1, 1, 53	10, 10, 437	10, 10, 456	7, 7, 308	808	2,541	1,514	1,046	0.3	4.1	6.3	6.4
2000	6, 6, 319	15, 15, 821	4, 4, 201	6, 6, 286	1,123	2,365	1,726	1,096	2.1	5.5	2.1	5.3
2001	7, 8, 405	18, 20, 1157	8, 8, 446	3, 3, 169	860	2,183	1,754	969	6.4	6.1	2.2	2.2
2002	4, 4, 176	13, 13, 685	9, 9, 468	8, 8, 422	975	1,775	2,129	1,062	1.7	4.4	2.9	3.6
2003	6, 6, 312	7, 7, 316	9, 9, 495	2, 2, 114	1,151	2,037	2,419	721	1.9	2.5	1.9	0.1
2004	4, 4, 120	22, 22, 598	10, 11, 227	3, 3, 131	933	1,937	2,249	917	1.0	2.5	1.7	1.2
2005	5, 5, 191	15, 15, 715	7, 7, 375	5, 5, 235	1,015	1,648	1,645	868	0.9	4.2	3.5	2.6
2006	9, 9, 357	7, 7, 229	5, 5, 272	4, 4, 145	1,181	1,695	2,109	594	1.7	0.6	0.6	5.8
2007	4, 5, 131	15, 15, 433	9, 9, 294	3, 3, 84	921	1,636	1,698	552	3.6	5.5	1.6	8.6
2008	1, 1, 68	5, 5, 232	8, 8, 220	2, 2, 78	950	1,351	1,541	661	0.3	2.8	4.8	3.0
2009	4, 4, 118	7, 7, 165	8, 8, 137	3, 3, 89	1,026	1,464	1,271	744	2.8	1.8	2.1	5.1
2010	4, 4, 123	10, 10, 398	4, 4, 84	2, 3, 175	913	1,819	1,812	944	7.0	1.6	1.0	2.7
2011	7, 7, 200	10, 10, 307	6, 6, 268	1, 1, 40	958	1,495	1,251	813	12.5	1.6	0.9	0.6
2012	4, 4, 197	4, 7, 313	3, 5, 134	5, 5, 247	602	1,410	1,348	669	2.4	1.1	1.2	2.6
2013	8, 9, 333	5, 7, 301	3, 3, 157	3, 4, 194	982	1,123	1,347	861	8.0	1.8	0.7	0.9
2014	4, 4, 204	4, 5, 214	3, 3, 133	2, 2, 110	906	1,111	1,042	562	0.9	0.4	2.0	1.2
2015	2, 2, 65	7, 7, 347	5, 5, 224	---	736	1,156	1,581	491	0.4	2.0	0.8	---
2016	1, 1, 39	8, 10, 417	6, 6, 197	2, 2, 74	764	1,210	1,888	906	0.7	3.0	1.4	0.7
2017	8, 8, 331	5, 5, 197	6, 6, 227	2, 2, 76	1,074	1,017	1,253	838	1.7	0.8	1.3	0.3
2018	4, 4, 184	5, 5, 195	2, 3, 73	4, 4, 153	1,011	1,073	943	699	0.7	0.8	0.6	0.3
2019	2, 2, 97	6, 6, 286	1, 1, 46	1, 1, 28	1,131	1,104	778	717	1.4	3.4	0.1	0.4
5ABC Trawl Fishery												
1977	---	1, 1, 101	2, 2, 205	---	102	368	617	161	---	3.7	11.9	---
1978	---	4, 4, 398	4, 4, 408	1, 1, 103	0	421	1,390	1,175	---	40.8	12.5	4.2
1979	3, 3, 292	9, 9, 895	6, 7, 694	1, 1, 97	188	430	976	259	57.2	34.2	23.3	25.2
1980	1, 1, 97	10, 10, 997	9, 9, 896	3, 3, 297	27	1,481	1,746	786	76.2	31.9	23.2	13.2
1981	---	4, 4, 450	3, 3, 249	---	196	2,465	1,233	45	---	7.8	11.7	---
1982	1, 1, 200	8, 8, 1373	---	1, 1, 50	501	2,662	1,296	358	15.6	21.6	---	24.2
1983	1, 1, 50	7, 7, 350	4, 6, 697	---	1,004	2,546	555	26	4.9	15.8	29.1	---
1984	1, 1, 50	7, 7, 698	---	2, 2, 398	955	1,403	363	618	5.0	21.7	---	12.1
1985	---	---	---	3, 3, 900	1,013	1,385	162	536	---	---	---	54.6
1986	---	1, 1, 93	---	1, 1, 300	384	537	202	254	---	7.4	---	6.9
1987	2, 2, 350	1, 1, 300	3, 3, 852	---	557	1,537	990	673	10.9	4.6	5.7	---
1988	2, 2, 349	1, 1, 299	1, 1, 48	---	505	1,826	908	1,153	7.9	1.7	2.1	---

Year	# Trips, # Samples, # Specimens				Fishery catch (t)				Sampled/fishery catch (%)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1989	1, 1, 50	4, 5, 244	---	---	414	1,183	664	545	7.4	5.5	---	---
1990	6, 6, 204	6, 6, 317	1, 1, 49	2, 2, 73	398	1,163	751	646	18.5	6.3	2.9	8.4
1991	1, 1, 50	4, 4, 80	3, 3, 148	12, 12, 270	425	974	620	959	7.3	6.4	3.3	41.6
1992	4, 4, 60	9, 9, 217	13, 13, 273	5, 5, 125	228	1,247	1,029	173	30.3	10.8	16.4	12.2
1993	3, 3, 108	12, 12, 396	1, 1, 45	2, 2, 50	180	1,493	296	411	9.9	10.3	0.6	3.6
1994	---	20, 25, 371	17, 23, 328	9, 14, 165	163	891	1,170	1,632	---	19.3	17.9	9.0
1995	6, 7, 58	26, 42, 249	16, 25, 269	1, 1, 34	1,260	1,932	1,294	59	3.1	23.7	10.4	6.6
1996	4, 4, 40	23, 27, 381	11, 11, 150	4, 4, 40	150	2,554	747	1,752	24.1	16.5	13.6	5.0
1997	3, 3, 114	4, 4, 176	7, 7, 278	4, 4, 152	697	1,961	1,266	887	3.2	2.6	6.5	4.3
1998	4, 4, 164	9, 9, 383	8, 8, 342	4, 4, 163	468	2,165	1,541	532	11.7	3.5	4.3	5.6
1999	---	9, 9, 387	9, 9, 407	3, 3, 132	265	2,351	1,377	523	---	4.3	6.9	3.3
2000	3, 3, 166	13, 13, 722	4, 4, 201	4, 4, 192	626	2,135	1,566	688	1.4	5.3	2.3	7.0
2001	3, 4, 207	12, 14, 782	8, 8, 446	3, 3, 169	263	1,890	1,576	560	17.3	5.9	2.5	3.8
2002	1, 1, 53	12, 12, 636	6, 6, 311	3, 3, 169	476	1,536	1,890	640	0.9	5.0	2.8	2.7
2003	5, 5, 264	5, 5, 246	6, 6, 331	1, 1, 50	612	1,837	2,184	350	3.5	2.1	1.0	0.1
2004	1, 1, 31	15, 15, 349	10, 11, 227	3, 3, 131	353	1,646	2,063	550	0.2	2.2	1.9	2.1
2005	2, 2, 84	11, 11, 556	6, 6, 318	3, 3, 139	464	1,335	1,451	503	0.2	4.8	1.5	4.1
2006	6, 6, 270	3, 3, 125	4, 4, 212	1, 1, 26	672	1,386	1,907	357	1.0	0.4	0.5	1.2
2007	2, 2, 53	14, 14, 389	9, 9, 294	---	451	1,359	1,572	267	1.6	5.4	1.8	---
2008	1, 1, 68	3, 3, 176	6, 6, 159	2, 2, 78	374	1,085	1,212	253	0.8	2.7	4.9	8.0
2009	2, 2, 58	5, 5, 122	8, 8, 137	---	474	1,120	1,118	476	2.7	1.1	2.3	---
2010	3, 3, 69	10, 10, 398	4, 4, 84	1, 1, 58	380	1,619	1,680	537	15.4	1.8	1.1	0.6
2011	---	10, 10, 307	6, 6, 268	1, 1, 40	212	1,196	1,168	498	---	2.1	1.0	1.0
2012	---	3, 6, 263	3, 5, 134	3, 3, 161	95	1,205	1,174	513	---	1.3	1.3	1.9
2013	3, 3, 93	3, 5, 251	2, 2, 95	1, 2, 111	139	667	874	289	26.5	1.3	0.8	1.7
2014	2, 2, 101	2, 3, 167	2, 2, 89	---	223	425	831	141	0.2	0.4	2.5	---
2015	1, 1, 16	4, 4, 177	4, 4, 172	---	128	713	1,422	266	0.4	1.8	0.9	---
2016	1, 1, 39	4, 6, 217	3, 3, 89	1, 1, 24	127	698	1,373	335	4.4	3.1	0.9	0.5
2017	5, 5, 175	---	5, 5, 167	1, 1, 25	263	285	754	232	3.9	---	1.8	1.0
2018	3, 3, 160	2, 2, 75	2, 3, 73	---	502	577	668	191	1.3	1.3	0.9	---
2019	---	4, 4, 241	1, 1, 46	---	496	777	438	306	---	4.6	0.3	---
3CD Trawl Fishery												
1980	2, 2, 200	---	---	---	240	77	4	109	32.2	---	---	---
1982	4, 4, 799	---	---	2, 2, 400	141	89	13	269	55.2	---	---	35.0
1984	---	1, 1, 200	---	2, 2, 400	29	322	172	221	---	4.3	---	47.5
1990	2, 2, 116	---	---	---	395	518	206	90	5.9	---	---	---
1991	2, 2, 96	2, 2, 51	---	1, 1, 27	374	402	60	33	3.5	3.4	---	5.8
1993*	---	1, 1, 38	---	---	307	523	266	555	---	0.9	---	---
1994	2, 2, 124	---	---	2, 2, 102	288	349	364	619	2.2	---	---	3.3
1995	1, 1, 66	1, 1, 65	---	---	186	392	334	7	2.8	0.4	---	---
1996*	---	---	1, 3, 183	---	80	205	204	129	---	---	3.3	---
1998	3, 3, 74	3, 3, 38	3, 3, 111	2, 2, 26	266	144	37	93	0.7	3.1	24.2	10.7
1999	1, 1, 53	1, 1, 50	1, 1, 49	1, 1, 48	189	132	96	138	1.3	1.4	0.6	2.0
2000	2, 2, 95	1, 1, 47	---	1, 1, 45	189	153	55	114	2.4	2.0	---	4.4
2001	2, 2, 97	5, 5, 315	---	---	204	111	74	102	1.8	17.9	---	---
2002	2, 2, 74	1, 1, 49	1, 1, 61	3, 3, 129	213	117	77	135	0.6	0.6	0.9	7.8
2003	1, 1, 48	2, 2, 70	1, 1, 63	---	235	123	51	157	0.3	10.6	0.6	---
2004	1, 1, 21	4, 4, 157	---	---	192	113	84	159	0.1	3.3	---	---
2005	1, 1, 48	3, 3, 92	---	1, 1, 60	183	180	78	104	0.0	1.4	---	0.1
2006	2, 2, 56	2, 2, 48	1, 1, 60	1, 1, 61	144	140	96	120	3.0	1.2	2.3	1.9
2008	---	2, 2, 56	2, 2, 61	---	188	144	191	213	---	5.8	7.1	---
2010	1, 1, 54	---	---	1, 1, 58	178	97	52	95	2.9	---	---	15.1
2011	5, 5, 191	---	---	---	252	146	34	163	12.2	---	---	---
2012	3, 3, 152	1, 1, 50	---	2, 2, 86	182	111	129	53	5.4	0.3	---	14.8
2013	4, 5, 179	2, 2, 50	---	1, 1, 25	255	299	217	233	15.3	3.9	---	1.1
2014	---	2, 2, 47	1, 1, 44	1, 1, 58	197	248	167	198	---	1.3	0.0	3.3
2015	1, 1, 49	2, 2, 123	---	---	166	193	35	109	1.4	0.4	---	---
2016	---	2, 2, 90	1, 1, 48	---	237	258	341	310	---	2.8	0.3	---
2017	2, 2, 96	2, 2, 100	---	1, 1, 51	296	310	295	360	0.9	0.8	---	0.1
2018	1, 1, 24	3, 3, 120	---	4, 4, 153	242	268	208	334	0.1	0.4	---	0.7
2019	1, 1, 55	1, 1, 25	---	1, 1, 28	159	124	171	254	5.4	0.9	---	1.1
5DE Trawl Fishery												
1978	---	2, 2, 199	---	1, 1, 105	302	246	120	173	---	38.1	---	10.9
1979	1, 1, 100	3, 3, 387	2, 2, 181	3, 3, 283	130	499	126	85	24.8	37.8	7.1	9.2
1980	---	2, 2, 200	---	1, 1, 98	35	352	388	79	---	16.1	---	8.5
1981*	---	1, 1, 200	---	---	135	218	144	121	---	27.2	---	---
1982	1, 1, 198	2, 2, 396	---	1, 1, 200	136	330	20	221	8.3	26.5	---	11.4

Year	# Trips, # Samples, # Specimens				Fishery catch (t)				Sampled/fishery catch (%)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1983*	---	1, 1, 25	---	---	184	308	218	26	---	12.4	---	---
1984	1, 1, 200	5, 5, 650	---	1, 1, 199	239	1,707	334	410	22.9	22.7	---	10.8
1985	1, 1, 30	2, 2, 56	2, 2, 400	2, 2, 599	512	1,130	369	441	12.1	5.5	27.2	32.2
1986	---	3, 3, 354	2, 2, 55	1, 1, 300	466	2,061	478	278	---	9.7	16.8	2.6
1987	3, 3, 614	2, 2, 293	---	---	509	906	146	49	20.2	15.8	---	---
1988	3, 4, 649	2, 2, 323	---	---	501	723	143	426	26.9	22.7	---	---
1989	4, 4, 200	4, 4, 100	---	---	555	887	184	392	31.4	22.8	---	---
1990	---	3, 7, 175	1, 1, 25	---	269	795	379	210	---	18.1	18.0	---
1991	3, 3, 112	1, 1, 38	2, 2, 75	2, 2, 75	239	232	73	38	32.6	1.9	35.0	10.0
1992	---	3, 3, 188	1, 1, 61	1, 1, 48	205	72	45	59	---	19.3	5.7	6.8
1993	1, 1, 58	4, 4, 213	---	2, 2, 117	135	154	94	214	1.5	10.5	---	6.1
1994	---	1, 1, 48	1, 1, 55	1, 1, 63	108	88	18	102	---	2.6	32.3	5.2
1995	6, 6, 340	---	---	---	592	235	23	0	11.1	---	---	---
1997	---	---	1, 1, 48	1, 1, 40	295	202	36	137	---	---	1.3	1.2
1998	5, 5, 212	1, 1, 56	1, 1, 58	1, 1, 44	442	184	150	296	15.5	12.4	10.6	8.7
1999	---	---	---	3, 3, 128	354	58	41	385	---	---	---	12.3
2000	1, 1, 58	1, 1, 52	---	1, 1, 49	308	77	106	295	3.2	18.1	---	1.7
2001	2, 2, 101	1, 1, 60	---	---	393	181	104	306	1.4	0.9	---	---
2002	1, 1, 49	---	2, 2, 96	2, 2, 124	285	121	161	287	3.7	---	5.2	3.8
2003	---	---	2, 2, 101	1, 1, 64	304	76	185	214	---	---	12.0	0.1
2004	2, 2, 68	3, 3, 92	---	---	387	178	102	209	2.3	5.2	---	---
2005	2, 2, 59	1, 1, 67	1, 1, 57	1, 1, 36	369	133	115	261	2.2	1.5	31.1	0.6
2006	1, 1, 31	2, 2, 56	---	2, 2, 58	365	170	107	117	2.4	1.8	---	23.7
2007	2, 3, 78	1, 1, 44	---	3, 3, 84	342	114	62	182	7.5	14.0	---	26.1
2009	2, 2, 60	2, 2, 43	---	3, 3, 89	359	223	70	156	4.6	5.8	---	24.1
2010*	---	---	---	1, 1, 59	355	102	80	313	---	---	---	2.5
2011*	2, 2, 9	---	---	---	494	152	48	153	18.0	---	---	---
2012*	1, 1, 45	---	---	---	325	94	45	104	1.5	---	---	---
2013	1, 1, 61	---	1, 1, 62	1, 1, 58	587	156	256	339	0.5	---	0.7	0.1
2014	2, 2, 103	---	---	1, 1, 52	485	438	44	222	1.6	---	---	0.0
2015	---	1, 1, 47	1, 1, 52	---	443	250	123	116	---	4.0	0.2	---
2016	---	2, 2, 110	2, 2, 60	1, 1, 50	401	253	174	260	---	3.3	7.3	1.6
2017	1, 1, 60	3, 3, 97	1, 1, 60	---	515	422	204	246	1.0	1.3	1.1	---
2019*	1, 1, 42	1, 1, 20	---	---	476	202	170	157	1.5	0.0	---	---

*Years not used in the SS3 model.

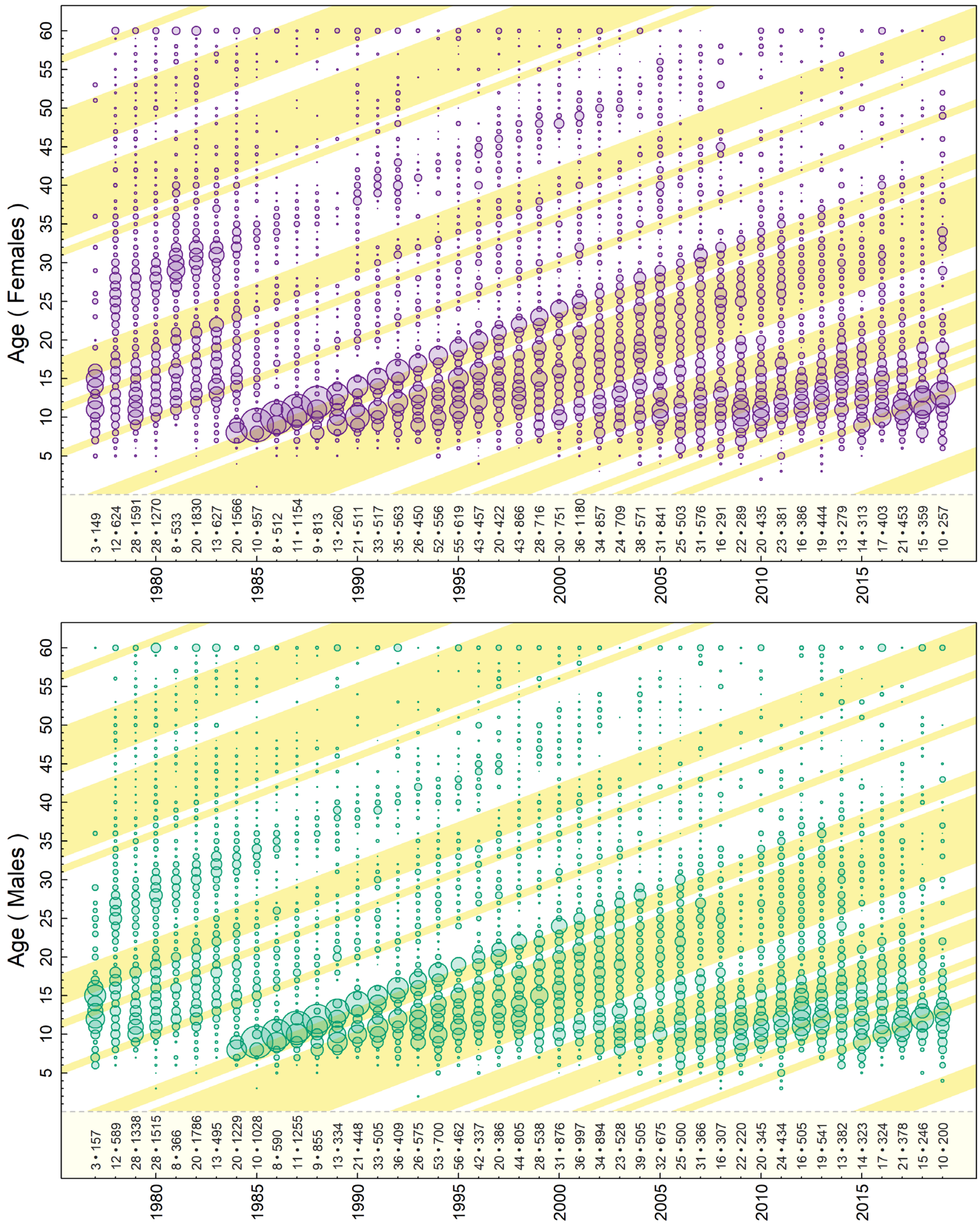

Figure D.10. Proportions-at-age for POP caught along the coast of BC by commercial trawl gear calculated as age frequencies weighted by trip catch within quarters and commercial catch within years. Diagonal shaded bands indicate year when the mean winter (Dec–Mar) Pacific Decadal Oscillation was positive. Numbers displayed along the bottom axis indicate number of samples and number of fish aged (bullet delimited) by year. All annual data are displayed but not necessarily used in the SS3 model.

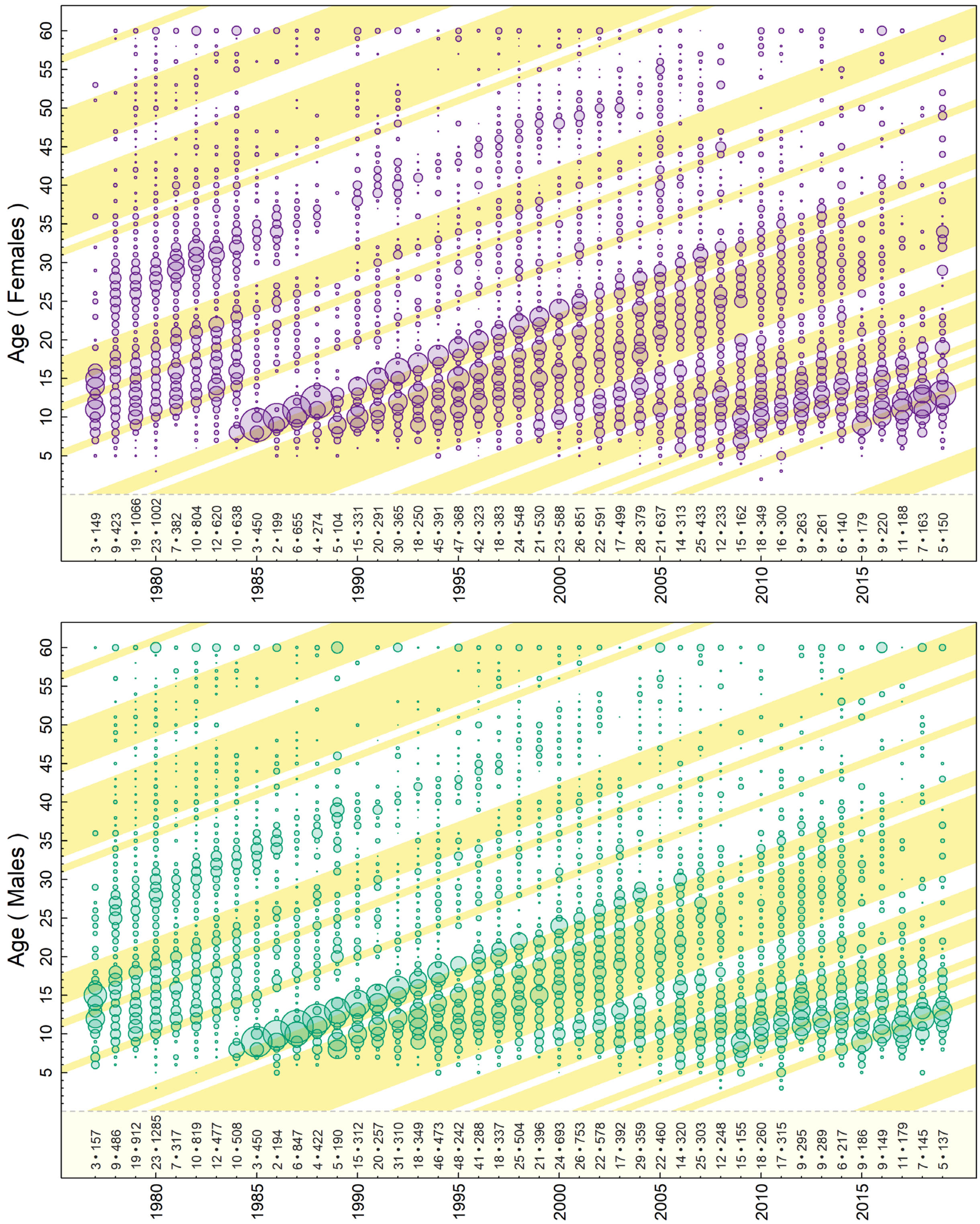

Figure D.11. Proportions-at-age for POP caught in PMFC 5ABC by commercial trawl gear calculated as age frequencies weighted by trip catch within quarters and commercial catch within years. See Figure D.10 caption for details on diagonal shaded bands and displayed numbers.

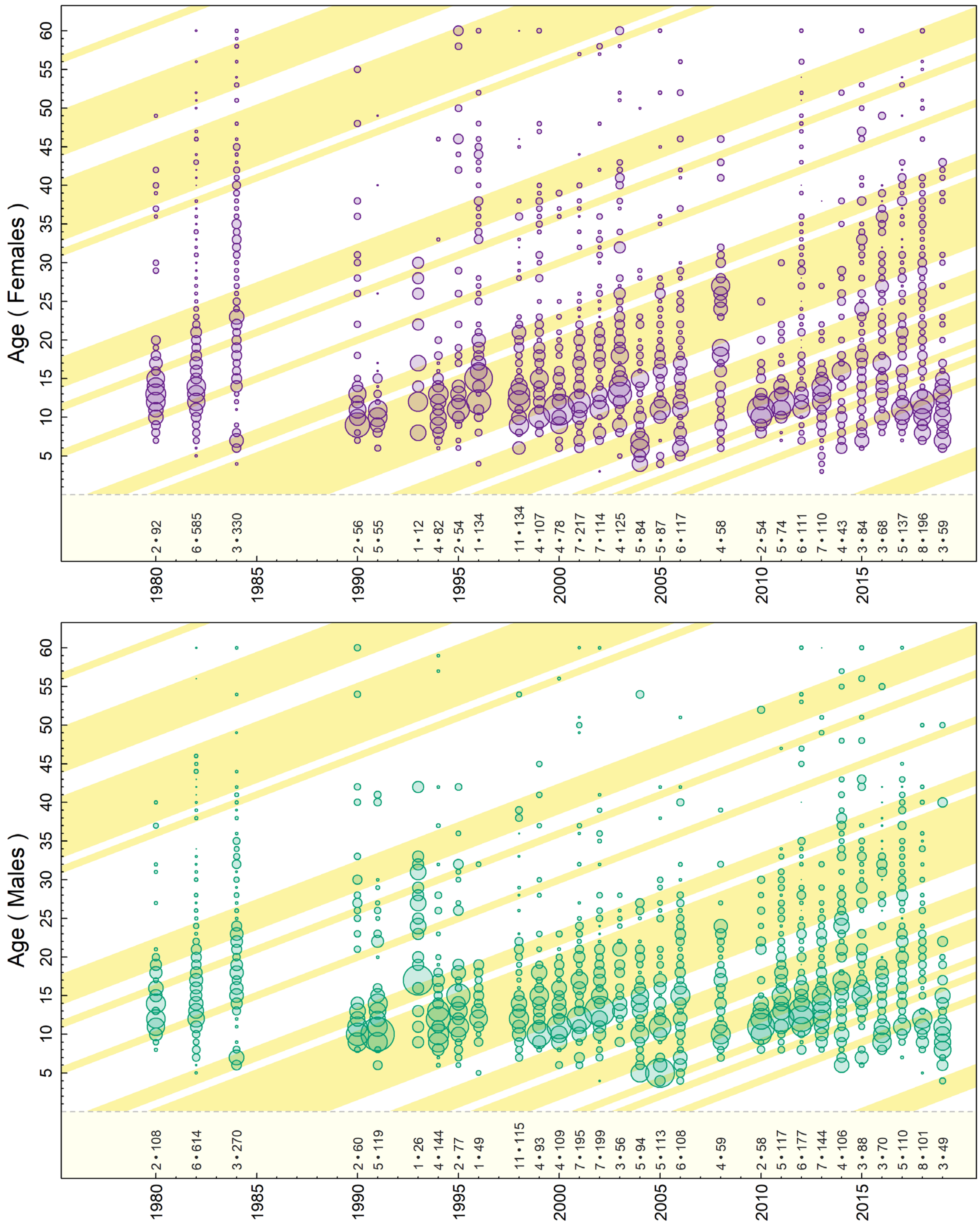

Figure D.12. Proportions-at-age for POP caught in PMFC 3CD by commercial trawl gear calculated as age frequencies weighted by trip catch within quarters and commercial catch within years. See Figure D.10 caption for details on diagonal shaded bands and displayed numbers.

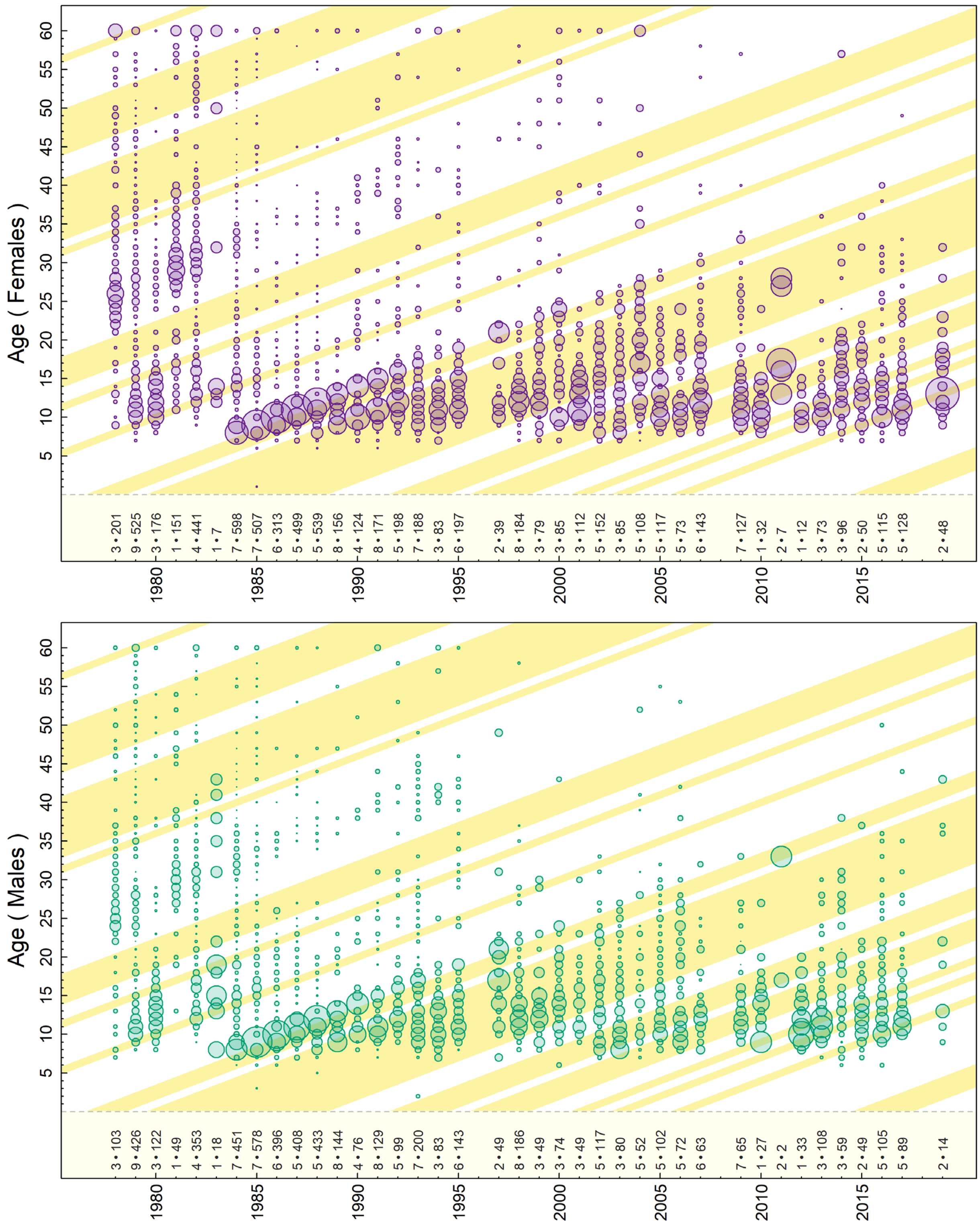

Figure D.13. Proportions-at-age for POP caught in PMFC 5DE by commercial trawl gear calculated as age frequencies weighted by trip catch within quarters and commercial catch within years. See Figure D.10 caption for details on diagonal shaded bands and displayed numbers.

D.2.2. Research/Survey Ages

Age data for POP from the surveys cover years from 1984 to 2022 (Table D.10). Age cohort patterns are typically less evident in survey data compared to commercial data.

The coastwide POP stock is covered by several surveys with AF data (Figure D.14 to Figure D.17), but only the following five AF series were used in the base model run:

- QCS Synoptic (11 y AF) from 2003 to 2021;
- WCVI Synoptic (11 y AF) from 1996 to 2022;
- WCHG Synoptic (10 y AF) from 1997 to 2022;
- GIG Historical (3 y AF) from 1984 to 1995; and
- NMFS Triennial (5 y AF) from 1989-2001.

Two sensitivity analyses explored the inclusion of additional fleet data:

- 3CD and 5ABC midwater trawls (8 y and 5 y AF, respectively, Figure D.18); however, these were combined to yield 10 y AF data, 6 years of which (spanning 2007 to 2018) were used in the sensitivity analysis; and
- HS Synoptic (1 y AF) in 2007; however, two samples only had 33 aged fish and so these data were excluded from the sensitivity run (R36v2).

Table D.10. Number of POP age samples (s) collected from trawl surveys used in base run and POP density (d=kg/km²) by survey stratum identifier (h); stratum area is shown in parentheses.

Year	Survey Strata						
QCS	h=19 (5,300 km²)	h=20 (2,640 km²)	h=21 (528 km²)	h=23 (3,928 km²)	h=24 (3,664 km²)	h=25 (1,236 km²)	—
2003	s=4, d=4.949	s=4, d=4.504	—	s=1, d=0.238	s=6, d=1.328	s=2, d=0.338	—
2004	s=3, d=0.725	s=5, d=2.491	s=1, d=2.480	—	s=6, d=2.509	s=1, d=2.357	—
2005	s=8, d=1.847	s=4, d=0.898	—	s=4, d=0.737	s=6, d=1.512	s=1, d=15.263	—
2007	s=3, d=2.178	s=5, d=2.132	—	s=5, d=0.951	s=7, d=2.102	s=3, d=0.258	—
2009	s=5, d=1.175	s=6, d=4.609	s=2, d=0.583	s=2, d=0.486	s=9, d=1.894	s=3, d=5.000	—
2011	s=4, d=2.324	s=17, d=3.981	s=4, d=3.415	s=1, d=2.277	s=15, d=1.375	s=2, d=2.184	—
2013	s=4, d=1.884	s=20, d=1.548	s=5, d=2.723	s=3, d=1.423	s=11, d=1.662	s=3, d=3.098	—
2015	s=5, d=4.866	s=18, d=2.699	s=3, d=1.688	s=2, d=0.499	s=12, d=2.539	s=2, d=1.803	—
2017	s=2, d=6.269	s=7, d=6.063	s=1, d=3.417	—	s=4, d=9.208	—	—
2019	s=1, d=4.999	s=6, d=6.783	s=1, d=4.142	—	s=8, d=6.278	—	—
2021	s=3, d=2.403	s=11, d=2.735	—	—	s=15, d=3.205	—	—
WCVI	h=66 (3,768 km²)	h=67 (708 km²)	h=68 (572 km²)	h=118 (1,207 km²)	h=119 (497 km²)	h=120 (600 km²)	—
1996	—	—	—	s=6, d=0.537	s=53, d=3.293	s=8, d=0.380	—
2004	s=1, d=3.266	s=8, d=7.593	s=1, d=0.540	—	—	—	—
2006	s=1, d=0.083	s=7, d=4.824	s=1, d=4.111	—	—	—	—
2008	—	s=5, d=2.140	s=3, d=1.362	—	—	—	—
2010	s=4, d=1.261	s=18, d=5.966	s=7, d=2.803	—	—	—	—
2012	s=1, d=0.942	s=11, d=3.682	s=5, d=5.349	—	—	—	—
2014	—	s=14, d=8.773	s=4, d=10.839	—	—	—	—
2016	s=2, d=0.655	s=14, d=3.583	s=7, d=2.675	—	—	—	—
2018	—	s=11, d=2.587	s=7, d=4.697	—	—	—	—
2021	—	s=13, d=4.933	s=9, d=3.307	—	—	—	—
2022	—	s=10, d=4.834	s=2, d=3.918	—	—	—	—
WCHG	h=114 (1,244 km²)	h=115 (892 km²)	h=116 (744 km²)	h=126 (1,266 km²)	h=127 (1,090 km²)	h=151 (1,036 km²)	h=152 (980 km²)
1997	s=10, d=9.636	s=36, d=6.547	s=12, d=1.610	—	—	—	—
2006	—	—	—	s=6, d=24.470	s=1, d=1.625	—	—
2007	—	—	—	—	—	s=9, d=13.572	s=2, d=2.605
2008	—	—	—	—	—	s=9, d=9.937	s=4, d=3.280
2010	—	—	—	—	—	s=14, d=9.860	s=6, d=2.065
2012	—	—	—	—	—	s=15, d=15.207	s=1, d=10.054
2014*	—	—	—	—	—	s=19, d=16.503	—
2016	—	—	—	—	—	s=16, d=15.451	s=3, d=31.832
2018	—	—	—	—	—	s=15, d=23.917	s=3, d=62.359
2020	—	—	—	—	—	s=9, d=29.991	s=8, d=35.962
2022	—	—	—	—	—	s=15, d=28.050	—
GIG	h=121 (1,166 km²)	h=122 (1,677 km²)	h=123 (731 km²)	h=124 (686 km²)	h=138 (1,190 km²)	h=139 (1,023 km²)	h=160 (3,034 km²)
1984	—	—	—	—	s=3, d=0.858	s=6, d=2.640	s=1, d=1.553
1994	—	—	—	—	s=4, d=0.903	s=15, d=3.531	—
1995	s=1, d=2.072	s=5.5, d=5.686	s=3, d=16.969	s=2.5, d=6.460	—	—	—
cont'd	h=161 (1,826 km²)	h=162 (953 km²)	h=163 (339 km²)	h=185 (2,122 km²)	h=186 (1,199 km²)	h=187 (1,746 km²)	—
1984	s=6, d=4.787	s=4, d=2.773	s=1, d=2.032	—	s=1, d=8.509	s=1, d=11.668	—
1994	—	—	—	s=1, d=0.875	s=1, d=6.542	s=15, d=4.514	—
1995	—	—	—	—	—	—	—
NMFS	h=476 (2,991 km²)	h=479 (2,991 km²)	h=480 (2,991 km²)	h=482 (2,991 km²)	h=483 (2,991 km²)	h=485 (2,991 km²)	h=488 (2,991 km²)
1977*	—	—	—	—	—	—	—

Year	Survey Strata						
1980*	s=1, d=0.157	—	—	—	—	s=1, d=8.306	—
1989	—	s=2, d=0.098	s=1, d=0.011	s=2, d=6.117	s=4, d=1.403	—	—
1992	—	—	s=4, d=0.158	s=2, d=4.974	s=2, d=0.275	—	—
1995	—	—	s=7, d=0.011	s=4, d=1.626	s=4, d=0.652	—	s=1, d=0.112
1998	—	—	s=2, d=0.004	s=4, d=1.687	s=3, d=0.162	—	—
2001	—	s=2, d=0.008	s=5, d=0.030	s=3, d=0.060	s=4, d=0.795	—	s=1, d=0.049
cont'd	h=489 (2,991 km^2)	h=498 (2,991 km^2)	h=499 (2,991 km^2)	—	—	—	—
1977*	—	s=4, d=0.781	s=1, d=1.122	—	—	—	—
1980*	—	—	—	—	—	—	—
1989	—	—	—	—	—	—	—
1992	—	—	—	—	—	—	—
1995	s=5, d=0.259	—	—	—	—	—	—
1998	s=1, d=1.069	—	—	—	—	—	—
2001	s=1, d=0.553	—	—	—	—	—	—

*Years not used in the SS3 model.

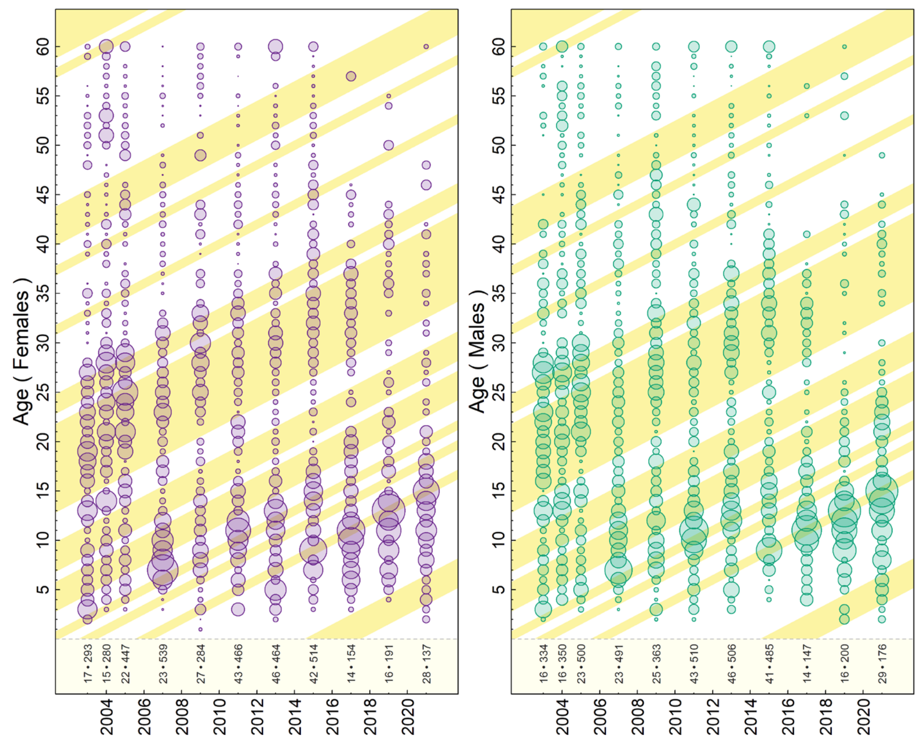

Figure D.14. QCS synoptic survey – proportions-at-age based on age frequencies weighted by mean fish density within strata and by total stratum area within survey (Table D.10). See Figure D.10 caption for details on diagonal shaded bands and displayed numbers.

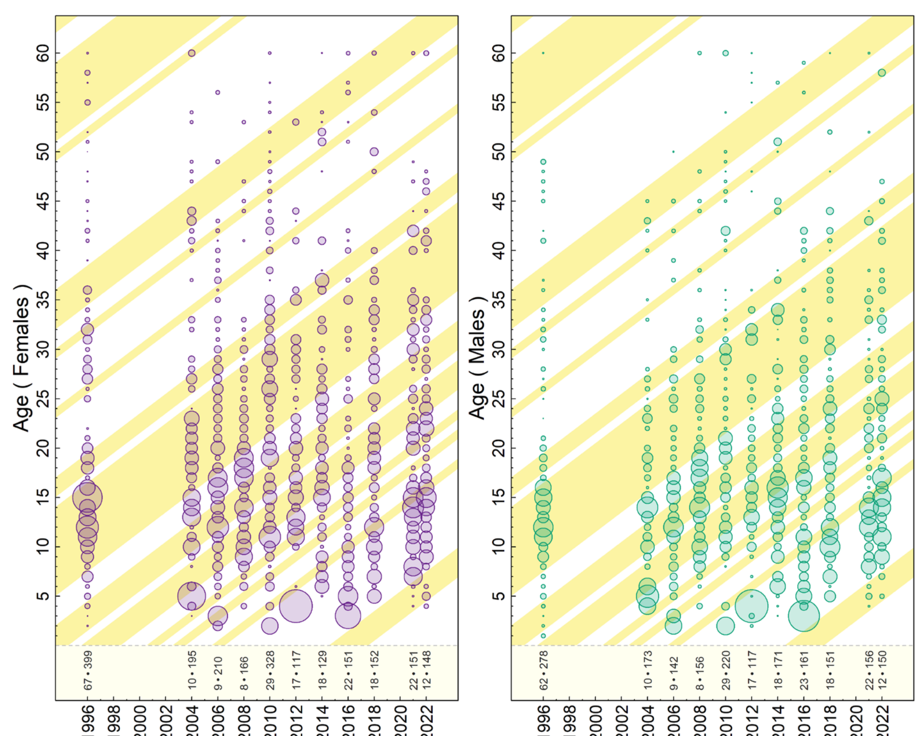

Figure D.15. WCVI synoptic survey – proportions-at-age based on age frequencies weighted by mean fish density within strata and by total stratum area within survey (Table D.10). See Figure D.10 caption for details on diagonal shaded bands and displayed numbers.

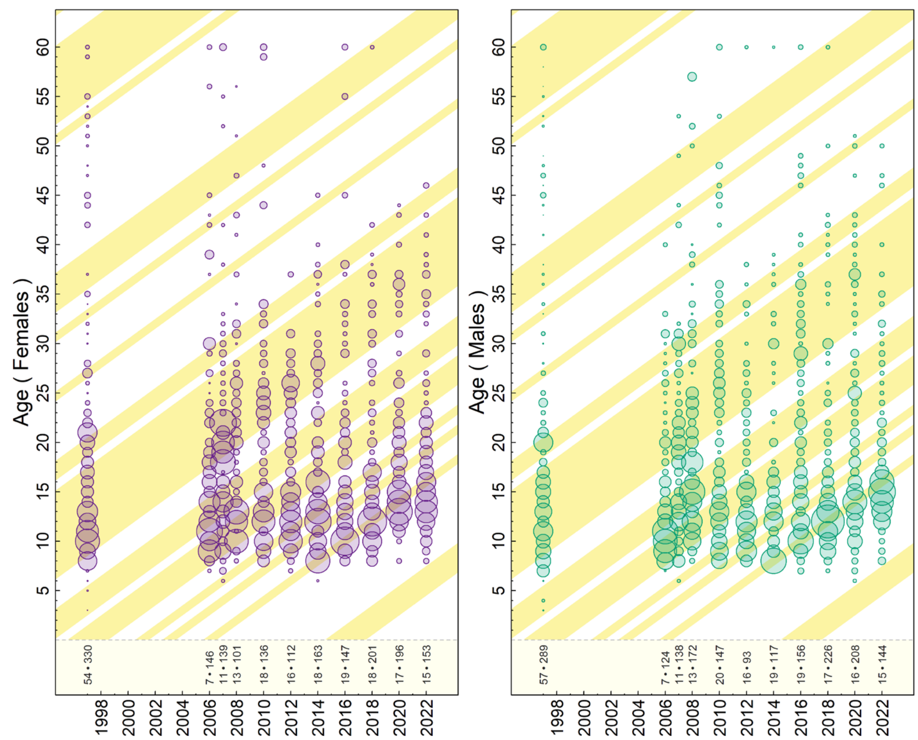

Figure D.16. WCHG synoptic survey – proportions-at-age based on age frequencies weighted by mean fish density within strata and by total stratum area within survey (Table D.10). See Figure D.10 caption for details on diagonal shaded bands and displayed numbers.

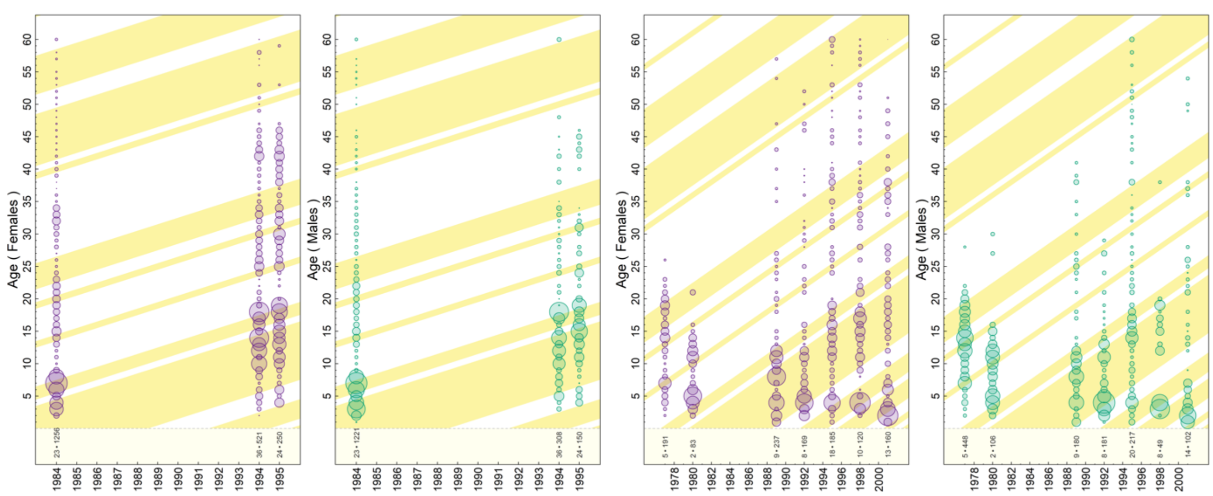

Figure D.17. GIG historical (left) and US NMFS triennial (right) – proportions-at-age based on age frequencies weighted by mean fish density within strata and by total stratum area within survey (Table D.10). See Figure D.10 caption for details on diagonal shaded bands and displayed numbers.

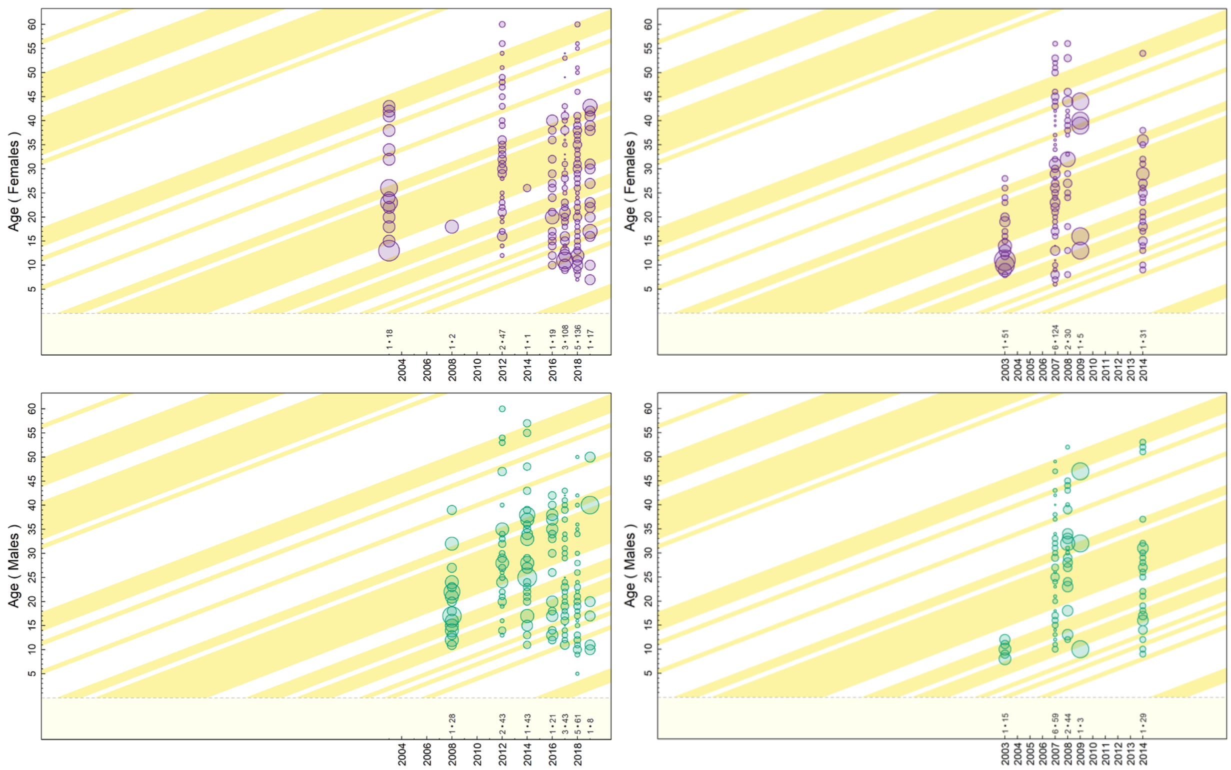

Figure D.18. Midwater trawl age frequency data availability for 3CD (left) and 5ABC (right). See Figure D.10 caption for details on diagonal shaded bands and displayed numbers.

D.2.3. Ageing Error

Accounting for ageing error in stock assessments helps to identify episodic recruitment events. Figure D.19 suggests that POP ages determined by primary readers are produced fairly consistently by secondary readers when performing spot-check analyses; however, there are some large deviations which become more extreme at older ages. Therefore, the population model for POP uses an ageing error (AE) vector based on standard deviations that are calculated from the CV of observed lengths-at-age (AE2, Figure D.20, Table D.11). Explicitly, the ageing error vector used was the standard deviation for each age determined as the CV of lengths-at-age multiplied by the corresponding age a :

$$\mathrm{AE}_2 = \sigma_a = a\ \mathrm{CV}_{L_a}\text{, where }\mathrm{CV}_{L_a} = \sigma_{L_a} / \mu_{L_a}\,.$$

Based on feedback during the Yellowmouth Rockfish assessment of 2021 (DFO 2022b), AE2 was loess-smoothed to produce AE3, which was used in the current POP assessment's base run.

Additionally, ageing error can be determined from the CVs of otolith ages spot-checked by secondary readers for otoliths previously read by a primary reader (counting of otolith rings):

$$\mathrm{AE}_4 = \sigma_a = a\ \mathrm{CV}_{A_a}\text{, where }\mathrm{CV}_{A_a} = \sigma_{A_a} / \mu_{A_a}\,.$$

Similarly, AE5 is the loess-smoothed vector of AE4.

Lastly, AE6 describes a CASAL-style (constant CV, Bull et al. 2012) ageing error where the standard deviation used in SS3 was directly proportional to age (Figure D.20). Essentially,

$$\mathrm{AE}_6 = \sigma_a = a\ \mathrm{CV}_{A_a}\text{, where } \mathrm{CV}_{A_a} = 0.1$$

Alternative AE vectors (AE1: no ageing error, AE5, and AE6), were explored in sensitivity analyses (R29v1a, R30v1a, and R31v1a, respectively).

In the SS3 data file, ages start at 0 and end at *A* (60 for POP), which means A+1 entries are needed. In the ageing error section of the data file, we specified ages 0.5 to 60.5 with the entries of σ_a from Table D.11 for ages 1 to 61.

Ageing error can also be estimated using statistical models that use multiple age readings from individual fish to derive a classification matrix that defines the probability of assigning an observed age to a fish based on its true age (Richards et al. 1992). True ages are not known but can be considered the most probable value for the observed ages with a degree of imprecision depicted using normal, exponential, or age reader error (Richards et al. 1992).

Table D.11. Calculating ageing error (AE) vector for use in SS3 from CVs of observed lengths-at age L_a or CVs of primary age readers' ages spot-checked by secondary readers A_a, where n_{La} /n_{Aa} = number of lengths observed at each age a, μ_{La} /μA_a = mean length at age, σ_{La} /σ_{Aa} = standard deviation of mean length at age, and CV=σ/μ.

a	n_{La}	μ_{La}	σ_{La}	CV_{La}	n_{Aa}	μ_{Aa}	σ_{Aa}	CV_{Aa}	AE2	AE3	AE4	AE5	AE6
1	0	0.0	0.000	0.200	0	0.0	0	0.2	0.200	0.201	0.200	0.456	0.1
2	38	16.5	1.355	0.082	9	2.0	0.000	0.000	0.164	0.254	0.000	0.494	0.2
3	81	20.4	1.768	0.087	20	3.2	0.768	0.240	0.261	0.306	0.720	0.532	0.3
4	83	23.9	2.774	0.116	15	4.4	1.183	0.269	0.464	0.359	1.076	0.569	0.4
5	301	26.8	2.303	0.086	50	5.2	0.681	0.132	0.429	0.412	0.660	0.607	0.5
6	221	29.1	3.156	0.108	39	6.1	0.695	0.113	0.651	0.466	0.681	0.646	0.6
7	295	31.4	2.998	0.095	66	7.2	0.789	0.110	0.667	0.519	0.772	0.684	0.7
8	489	34.2	2.794	0.082	83	8.2	0.872	0.107	0.653	0.573	0.852	0.721	0.8
9	812	35.6	2.414	0.068	165	9.1	0.707	0.078	0.610	0.628	0.701	0.759	0.9
10	1171	36.6	2.117	0.058	243	10.0	0.784	0.079	0.578	0.683	0.786	0.798	1
11	1442	37.5	2.197	0.059	275	11.0	0.801	0.073	0.645	0.738	0.803	0.837	1.1
12	1530	38.1	2.044	0.054	315	11.9	0.783	0.066	0.644	0.793	0.789	0.874	1.2
13	1240	38.8	2.168	0.056	221	12.9	0.736	0.057	0.727	0.847	0.739	0.909	1.3
14	1041	39.0	2.365	0.061	197	13.8	1.029	0.074	0.848	0.901	1.042	0.943	1.4
15	876	39.7	2.398	0.060	154	14.8	1.004	0.068	0.906	0.956	1.015	0.977	1.5
16	670	40.1	2.650	0.066	139	15.9	1.114	0.070	1.057	1.015	1.124	1.011	1.6
17	560	40.3	2.511	0.062	93	16.8	0.914	0.055	1.060	1.078	0.927	1.044	1.7
18	451	40.6	2.486	0.061	72	17.8	1.021	0.057	1.103	1.144	1.030	1.075	1.8
19	385	41.0	2.507	0.061	86	18.9	0.983	0.052	1.161	1.213	0.988	1.105	1.9
20	413	41.3	2.565	0.062	75	19.8	2.268	0.115	1.241	1.286	2.292	1.137	2
21	312	41.4	2.541	0.061	46	20.6	1.326	0.064	1.289	1.361	1.353	1.170	2.1
22	306	41.5	2.717	0.065	51	21.9	1.194	0.055	1.439	1.436	1.201	1.200	2.2
23	257	41.8	2.667	0.064	47	22.6	1.441	0.064	1.469	1.511	1.468	1.229	2.3
24	236	41.3	2.641	0.064	47	23.7	1.491	0.063	1.533	1.589	1.511	1.256	2.4
25	245	42.1	2.788	0.066	41	24.8	1.135	0.046	1.657	1.666	1.147	1.281	2.5
26	231	42.4	3.598	0.085	53	25.7	1.119	0.044	2.205	1.742	1.133	1.304	2.6
27	247	42.0	2.855	0.068	40	26.9	1.343	0.050	1.836	1.817	1.350	1.324	2.7
28	250	42.0	3.133	0.075	46	27.7	1.449	0.052	2.088	1.894	1.467	1.341	2.8
29	236	42.4	3.063	0.072	53	28.7	1.295	0.045	2.097	1.970	1.308	1.357	2.9
30	285	42.3	2.809	0.066	55	29.6	1.512	0.051	1.991	2.044	1.533	1.373	3
31	216	42.1	2.845	0.068	50	30.9	1.340	0.043	2.094	2.117	1.346	1.386	3.1
32	206	42.7	2.958	0.069	27	32.2	1.476	0.046	2.218	2.189	1.466	1.398	3.2
33	208	42.4	2.962	0.070	46	32.7	1.492	0.046	2.303	2.260	1.506	1.413	3.3
34	181	43.0	2.934	0.068	39	33.7	1.221	0.036	2.319	2.328	1.233	1.429	3.4
35	203	42.7	3.032	0.071	34	34.9	2.171	0.062	2.483	2.393	2.178	1.444	3.5
36	147	43.3	3.062	0.071	25	36.3	1.429	0.039	2.547	2.460	1.418	1.456	3.6
37	140	43.3	2.711	0.063	28	36.8	1.0758	0.029	2.316	2.528	1.083	1.466	3.7
38	100	43.0	3.100	0.072	24	37.9	1.316	0.035	2.742	2.597	1.319	1.475	3.8
39	78	43.8	2.738	0.063	18	37.3	3.325	0.089	2.440	2.663	3.474	1.485	3.9
40	107	43.2	3.341	0.077	19	39.6	1.427	0.036	3.091	2.730	1.442	1.493	4
41	66	43.4	2.757	0.063	15	41.7	2.374	0.057	2.603	2.797	2.333	1.497	4.1
42	69	43.3	2.628	0.061	15	41.7	1.710	0.041	2.547	2.865	1.721	1.499	4.2

a	n_{La}	μ_{La}	σ_{La}	CV_{La}	n_{Aa}	μ_{Aa}	σ_{Aa}	CV_{Aa}	AE2	AE3	AE4	AE5	AE6
43	58	43.3	3.481	0.080	10	43.3	1.8288	0.042	3.455	2.934	1.816	1.504	4.3
44	48	43.8	2.894	0.066	8	43.1	1.3562	0.031	2.906	3.000	1.384	1.510	4.4
45	41	43.2	2.888	0.067	7	43.1	3.5322	0.082	3.012	3.067	3.684	1.515	4.5
46	39	43.8	3.164	0.072	6	44.8	1.6021	0.036	3.326	3.135	1.644	1.518	4.6
47	35	43.7	3.349	0.077	6	46.0	1.2649	0.027	3.604	3.207	1.292	1.525	4.7
48	32	43.6	3.004	0.069	5	46.8	2.387	0.051	3.305	3.282	2.449	1.542	4.8
49	38	43.4	3.448	0.079	8	49.1	1.3562	0.028	3.892	3.358	1.353	1.560	4.9
50	44	43.6	2.766	0.063	9	49.4	1.5899	0.032	3.171	3.433	1.608	1.573	5
51	23	43.8	2.975	0.068	6	48.8	2.6394	0.054	3.467	3.509	2.757	1.587	5.1
52	25	43.0	2.968	0.069	4	52.5	1.291	0.025	3.587	3.587	1.279	1.607	5.2
53	33	43.2	3.029	0.070	7	52.1	4.3753	0.084	3.717	3.665	4.447	1.629	5.3
54	25	44.9	2.938	0.065	2	52.0	2.8284	0.054	3.531	3.742	2.937	1.647	5.4
55	25	43.3	3.536	0.082	3	55.0	0	0.000	4.493	3.819	0.000	1.663	5.5
56	23	42.9	4.375	0.102	3	57.3	1.1547	0.020	5.707	3.897	1.128	1.682	5.6
57	25	43.9	3.025	0.069	3	58.0	1.732	0.030	3.930	3.974	1.702	1.701	5.7
58	22	42.8	3.590	0.084	4	58.3	1.7078	0.029	4.870	4.051	1.700	1.719	5.8
59	22	43.1	2.723	0.063	2	59.5	0.7071	0.012	3.723	4.129	0.701	1.738	5.9
60	41	43.3	3.205	0.074	8	59.3	4.0267	0.068	4.442	4.207	4.078	1.759	6
61	145	42.9	2.995	0.070	30	63.2	2.592	0.041	4.261	4.285	2.502	1.779	6.1

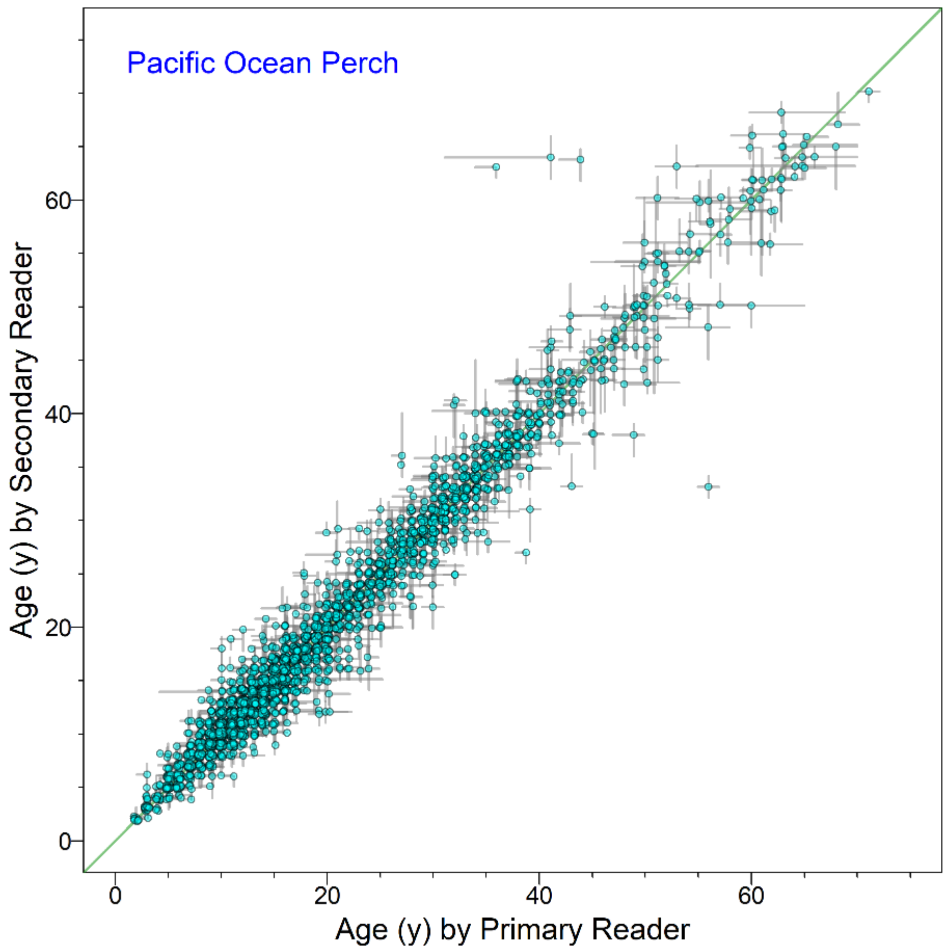

Figure D.19. Ageing error of POP specified as the range between minimum and maximum age (grey bars) determined by primary and secondary readers for each accepted age (points). The data are jittered using a random uniform distribution between -0.25 and 0.25 y for display purposes only.

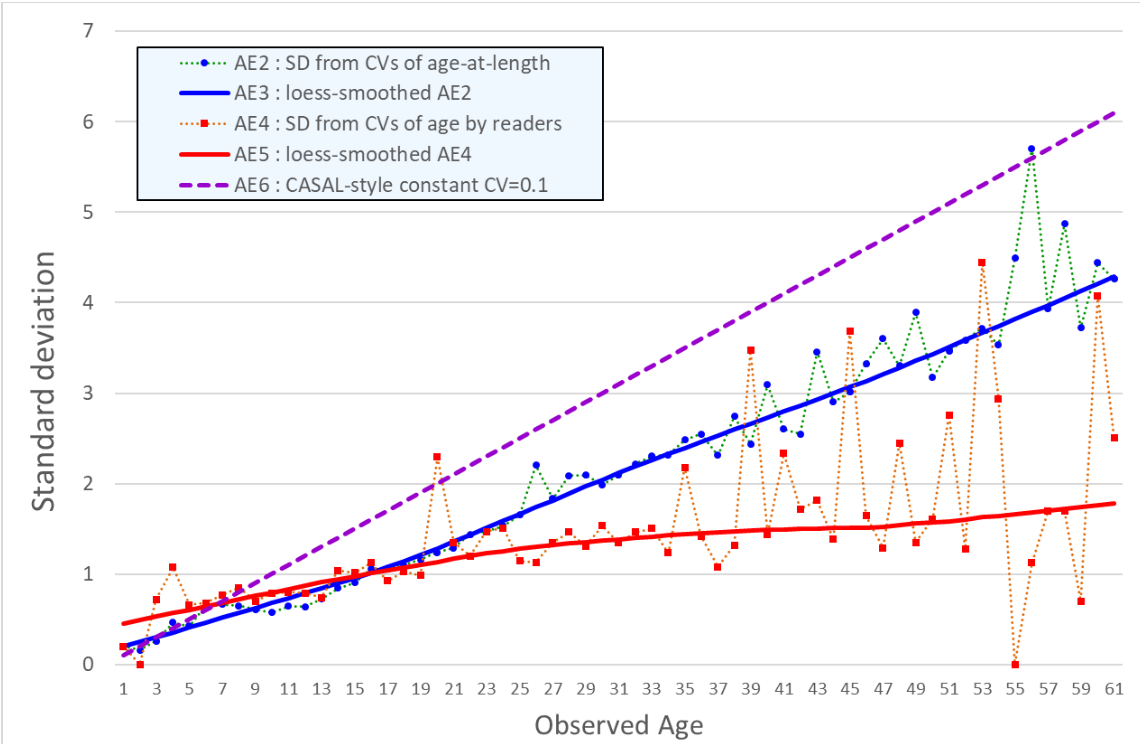

Figure D.20. Standard deviation of POP ages used for model's ageing error – SDs calculated by age from SDs of length (AE2) and age-reader precision (AE4), and loess-smoothed series (AE3, AE5), respectively. CASAL-style (AE6) standard deviation simply uses CV=10%.

D.3. STOCK STRUCTURE

D.3.1. Stock Definition

POP stocks are already defined by modified PMFC areas: 5ABC, 3CD, and 5DE, where 5C include portions of 5B and 5E (as discussed in the Introduction).

Genetic information exists for POP; however, this stock assessment did not use the information, primarily because previous assessments found no utility in refining POP stock boundaries (Schnute et al. 2001). The coastwide distribution of catch over 27 years suggests one continuous coastwide stock (Figure D.21), but Canadian legislation requires sustainability advice on the three stocks described above.

Previous stock assessments of other rockfish (Starr and Haigh 2021, 2022) have noted a physical separation of stocks between 5DE and more southerly PMFC areas. This separation may be caused by the North Pacific Current bifurcation (Pickard and Emery 1982; Freeland 2006; Cummins and Freeland 2006; Batten and Freeland 2007) whereby free-swimming larvae from the two regions are kept separated.

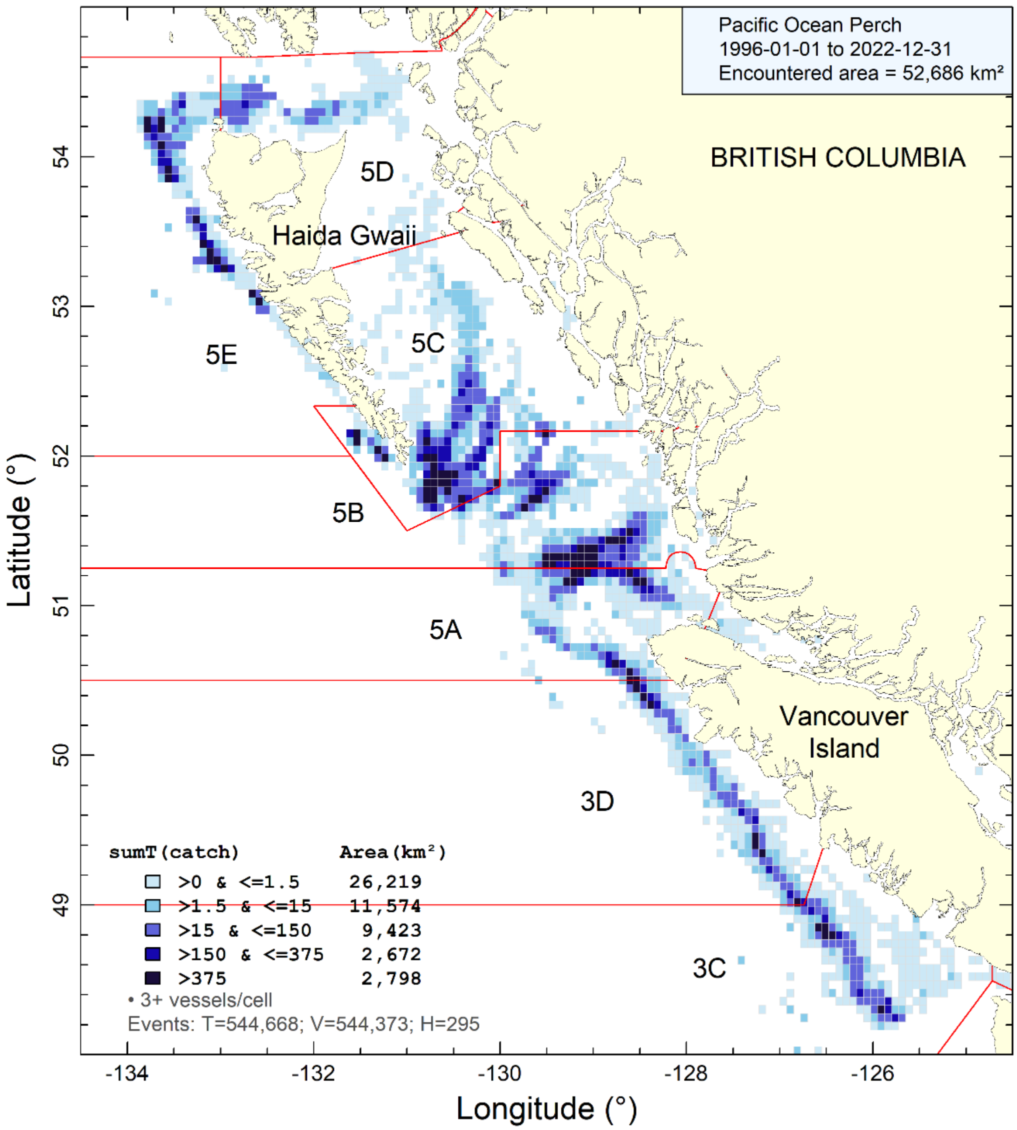

Figure D.21. Coastwide distribution of POP catch by all fleets from 1996 to 2022.

D.3.2. Fish Length Distributions

Simple comparisons of commercial length distributions by stock from the trawl fisheries show some evidence that length frequency distributions differ by capture method (Figure D.22). Specifically, POP captured by midwater trawl, and sometimes unknown trawl, tend to be slightly larger. These differences are accentuated in the age distributions, with POP caught by midwater trawls often being much older than those caught by bottom trawl (Figure D.23). While these differences may be sufficient to treat midwater trawl as a separate fishery, there are inadequate data to characterise the midwater fishery as well as the observation that this fishery overall accounts for 6.5% of the annual catch of POP from 1996 to 2022 coastwide. Consequently, we chose to combine the AF data from midwater trawl gear with the bottom trawl data.

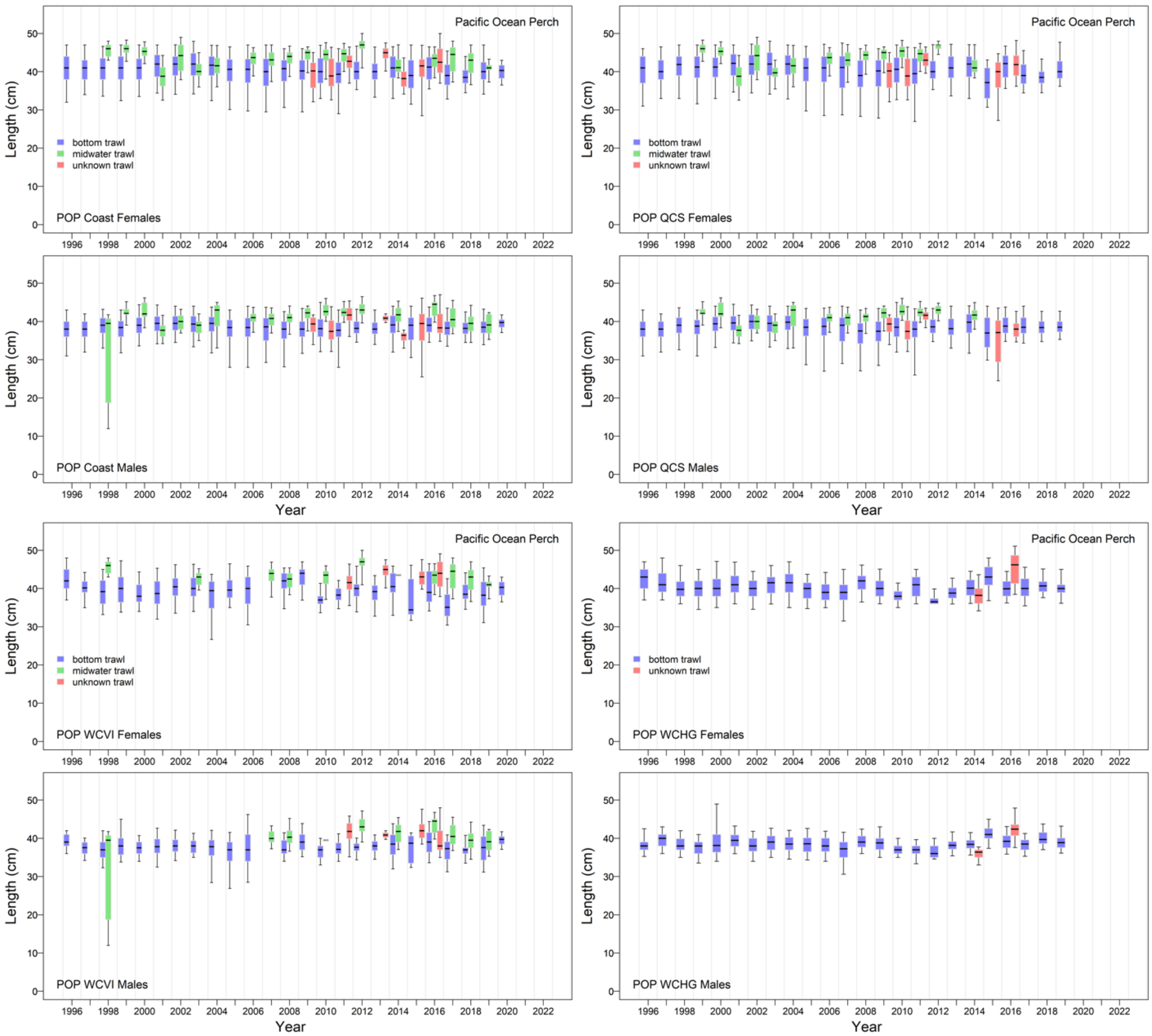

Figure D.22. Comparison of annual distributions of POP length by sex among gear types in the commercial fisheries: coastwide (top left), QCS/5ABC (top right), WCVI/3CD (bottom left), and WCHG/5DE (bottom right). Boxplot quantiles: 0.05, 0.25, 0.5, 0.75, 0.95.

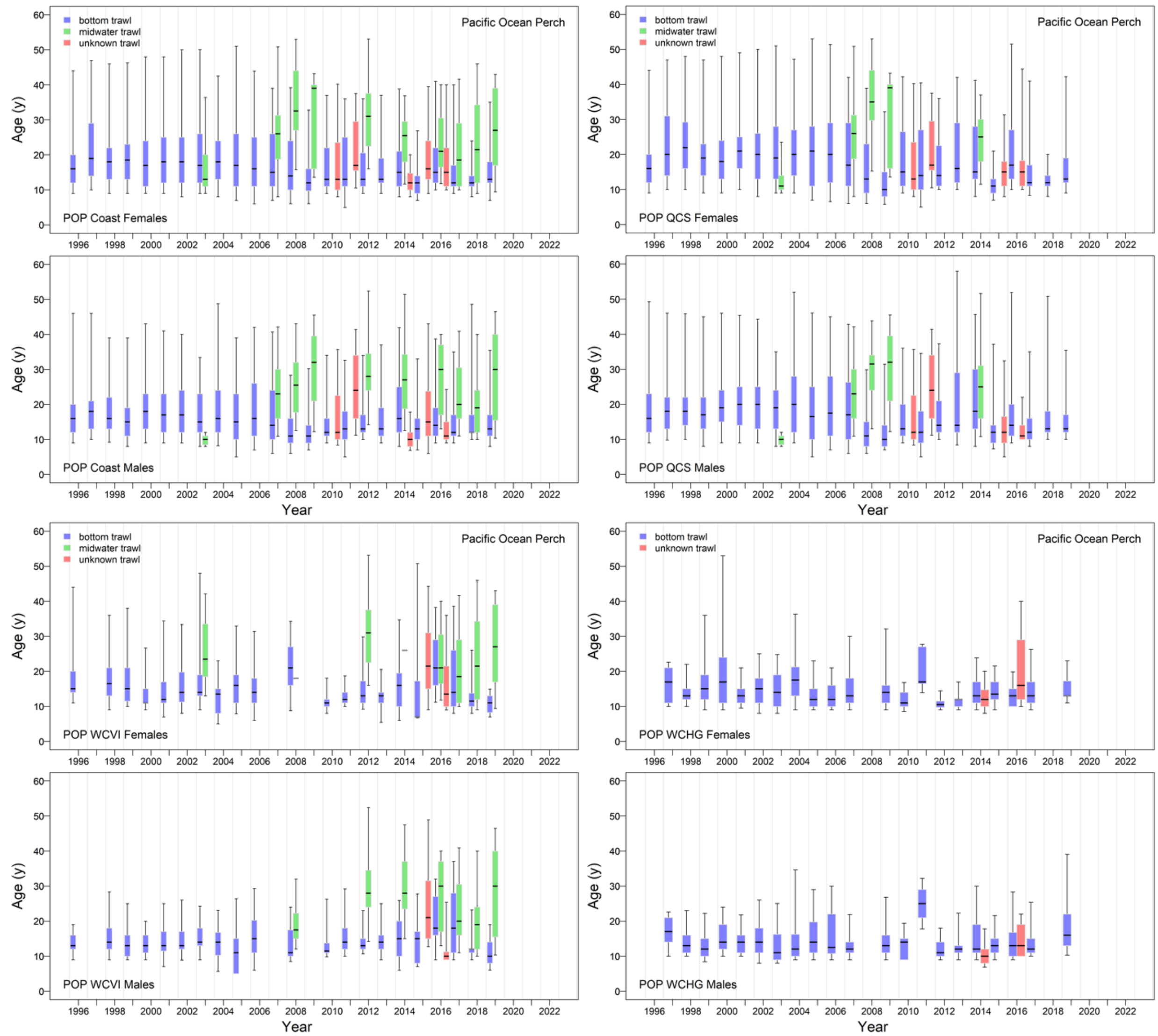

Figure D.23. Comparison of annual distributions of POP age by sex among gear types in the commercial fisheries: coastwide (top left), QCS/5ABC (top right), WCVI/3CD (bottom left), and WCHG/5DE (bottom right). Boxplot quantiles: 0.05, 0.25, 0.5, 0.75, 0.95.

The distributions of commercial lengths and ages (Figure D.24) by POP stock area show no differences in length and fluctuating differences in age. There was perhaps a large recruitment in 2008 that shows up as younger fish thereafter. Regardless, the three stocks were assessed by a single multi-area model that allocates coastwide recruitment into the three areas, and by three separate area models for comparison.

The distribution of lengths from a variety of surveys (Figure D.25) show inter-survey differences in mean length that likely stem from survey selectivity differences, perhaps influenced by depth:

- the HS synoptic survey and the shrimp trawl surveys catch smaller fish consistently compared to the other surveys;
- the acoustic survey is not used for abundance index calculations and appears to catch only large fish; and
- the three primary synoptic surveys all show similar ages.

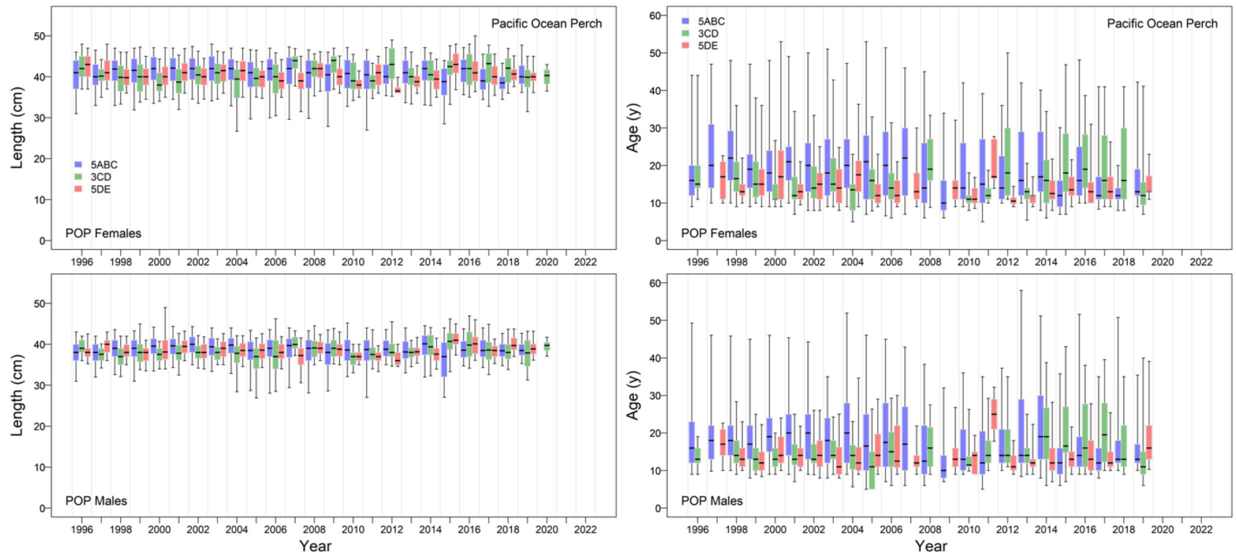

Figure D.24. Comparison of annual distributions of POP length (left) and age (right) along the BC coast by stock (5ABC/QCS, 3CD/WCVI, and 5DE/WCHG) in the commercial fisheries. Boxplot quantiles: 0.05, 0.25, 0.5, 0.75, 0.95.

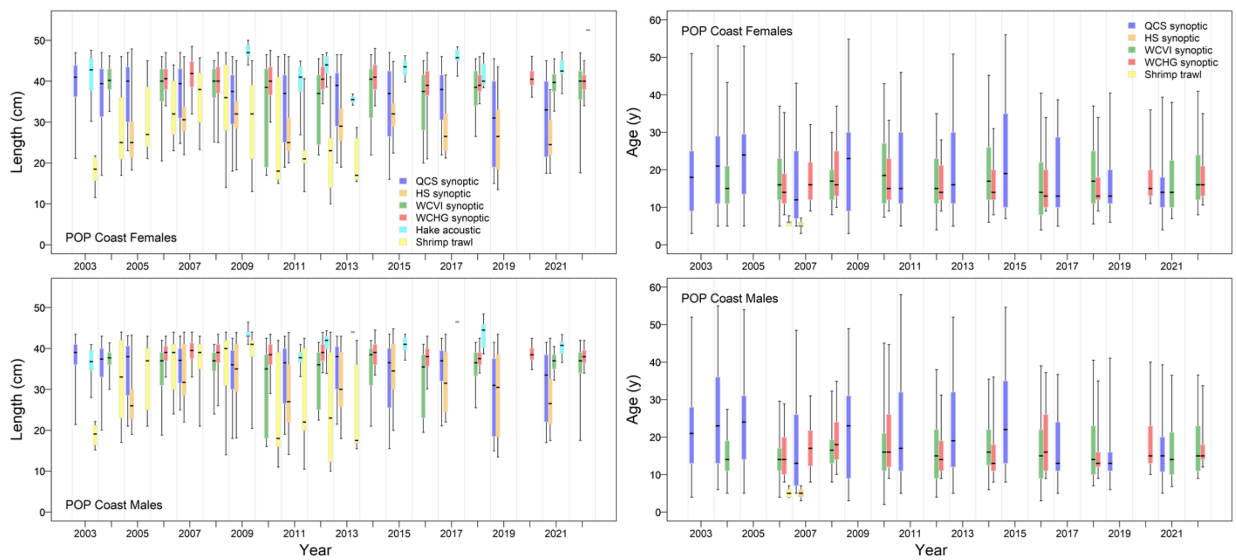

Figure D.25. Comparison of annual distributions of POP length (left) and age (right) among six surveys (four synoptic trawl, one shrimp trawl, and one acoustic). Boxplot quantiles: 0.05, 0.25, 0.5, 0.75, 0.95.

D.3.3. Comparison of Growth Models

A comparison of growth models among three stocks using survey length-age data (Figure D.26) shows the following trends for L-infinity:

- female estimates are larger than those for males;
- female estimates are very similar among the three stocks;
- male estimates show a small but steady decrease from north (5DE) to south (3CD); and
- coastwide estimates are very similar to those for 5ABC.

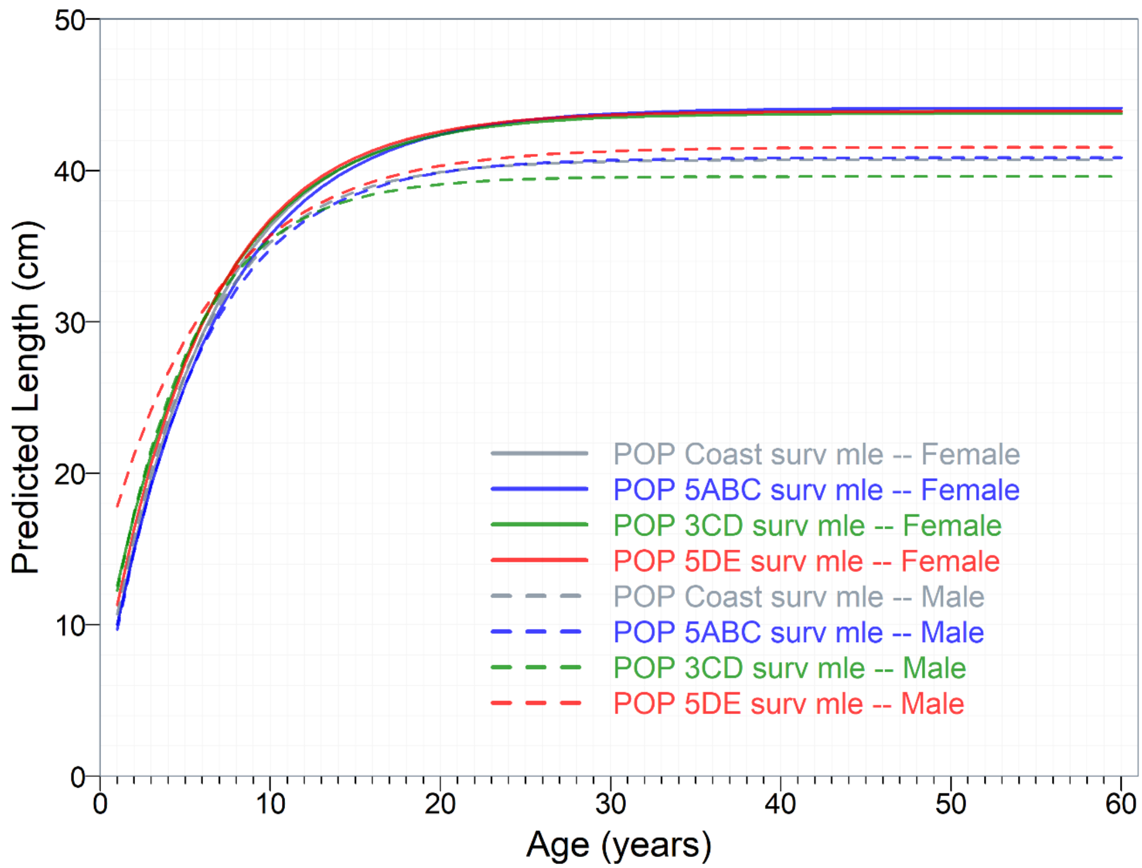

Figure D.26. von Bertalanffy MLE fits comparing growth among three BC POP stocks: 5ABC (QCS), 3CD (WCVI), and 5DE (WCHG) by sex from survey length-age data. Line type indicates sex (solid=female, dashed=male). Line colour indicates region (blue=5ABC, green=3CD, red=5DE).

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APPENDIX E. MODEL EQUATIONS

E.1. INTRODUCTION

The 2023 stock assessment of Pacific Ocean Perch (POP) adopted Stock Synthesis 3 (SS3), version 3.30.20 (Methot et al. 2022, downloaded Jan 30, 2023), which is a statistical age-structured population modelling framework (Methot and Wetzel 2013) that uses ADMB's power for Bayesian estimation of population trajectories and their uncertainties. The Stock Synthesis Development Team at NOAA (National Oceanic and Atmospheric Administration, U.S. Dept. Commerce) provides executables and documentation on how to run SS3, and the SS3 source code is available on GitHub.

Previously, POP was assessed using a simpler age-structured model called 'Awatea', which is a version of Coleraine (Hilborn et al. 2003) that was modified and maintained by Allan Hicks (then at Univ. Washington, now at IPHC). Both Awatea and SS3 are platforms for implementing Automatic Differentiation Model Builder software (ADMB Project 2009), which provides (a) maximum posterior density estimates using a function minimiser and automatic differentiation, and (b) an approximation of the posterior distribution of the parameters using the Markov Chain Monte Carlo (MCMC) method, specifically using the Metropolis algorithm (Gelman et al. 2004).

SS3 has been used previously in age-structured assessments for ⟨ BC stocks ⟩ since 2021:

- 2022 – Canary Rockfish ⟨ CAR, BC coast ⟩ (Starr and Haigh 2023)
- 2021 – Yellowmouth Rockfish ⟨ YMR, BC coast ⟩ (Starr and Haigh 2022*c*)

Awatea has been used in age-structured assessments for ⟨ BC stocks ⟩ since 2007:

- 2021 – Bocaccio ⟨ BOR, BC coast ⟩ update of 2019 assessment (DFO 2022);
- 2020 – Rougheye/Blackspotted Rockfish complex ⟨ REBS, 5DE and 3CD5AB ⟩ (Starr and Haigh 2022*b*);
- 2019 – Bocaccio ⟨ BOR, BC coast ⟩ (Starr and Haigh 2022*a*);
- 2019 – Widow Rockfish ⟨ WWR, BC coast ⟩ (Starr and Haigh 2021*a*);
- 2018 – Redstripe Rockfish ⟨ RSR, 5DE and 3CD5ABC ⟩ (Starr and Haigh 2021*b*);
- 2017 – Pacific Ocean Perch ⟨ POP, 5ABC ⟩ (Haigh et al. 2018);
- 2014 – Yellowtail Rockfish ⟨ YTR, BC coast ⟩ (DFO 2015);
- 2013 – Silvergray Rockfish ⟨ SGR, BC coast ⟩ (Starr et al. 2016);
- 2013 – Rock Sole ⟨ ROL, BC coast ⟩ (Holt et al. 2016);
- 2012 – Pacific Ocean Perch ⟨ POP, 3CD ⟩ (Edwards et al. 2014*b*);
- 2012 – Pacific Ocean Perch ⟨ POP, 5DE ⟩ (Edwards et al. 2014*a*);
- 2011 – Yellowmouth Rockfish ⟨ YMR, BC coast ⟩ (Edwards et al. 2012*a*),
- 2010 – Pacific Ocean Perch ⟨ POP, 5ABC ⟩ (Edwards et al. 2012*b*);
- 2009 – Canary Rockfish ⟨ CAR, BC coast ⟩ update of 2007 assessment (DFO 2009);
- 2007 – Canary Rockfish ⟨ CAR, BC coast ⟩ (Stanley et al. 2009).

The chief strength of Coleraine|Awatea is the use of a robust likelihood formulation proposed by Fournier et al. (1998) for the composition data by sex and age (or length). The robust normal model was used over the more traditional Multinomial error model because it reduced the influence of observations with standardised residuals > 3 standard deviations (Fournier et al. 1990). Fournier et al. (1990) identified two types of deviations:

- type I – occasional occurrence of an event of very low probability; and

- type II – probability of observing an event with higher frequency than normal in the population (e.g., school of young fish).

Their robustified likelihood function reduces both types of deviations.

SS3 offers two error models: the Multinomial and a compound Dirichlet-Multinomial. The latter can estimate effective sample sizes that are similar to iterative reweighting methods, but without requiring multiple iterations of running the assessment model (Thorson et al. 2017).

The data inputs to SS3 comprise four files – 'starter.ss', 'data.ss', 'control.ss', and 'forecast.ss' – instead of a single file used by Awatea. Parameter control and priors appear in the control.ss file, and data appear in the data.ss file; these two files can be named anything the user wishes because the starter.ss file specifies their names. The names for the starter.ss and forecast.ss files must remain invariant. Unlike Awatea, which requires specifying an input file from the command line (e.g. 'awatea -ind fielname.txt'), calling SS3 is done by typing only 'ss' on the command line (assuming 'ss.exe' occurs on the Windows system's PATH) because the software assumes the presence of the four files listed above. Additionally, this stock assessment used the safe version of SS3 ('ss_win.v3.30.20.exe', compile date: Sep 30 2022), which performs bound checks, rather than the 'optimized' version ('ss_opt_win.v3.30.20.exe'), which is reportedly 'fast and optimized for speedy execution'. (The safe version was renamed to 'ss.exe' for convenience.) The options in SS3 for fitting the data are more complex than those for Awatea and offer a greater degree of flexibility; however, this flexibility requires a steep learning curve and increases opportunties for inadvertent errors.

The Dirichlet-Multinomial distribution, implemented in SS3 as a model-based method for estimating effective sample size (Thorson et al. 2017) was not used in this assessment for the base run because it was found that model fits were sensitive to the magnitude of sample sizes placed on the AF data (see Appendix E.6.2.3 for details). In contrast, using the Francis (2011) mean-age method of reweighting showed no such sensitivity, and estimated credible model fits for the two contrasting sample size options presented. In past stock assessments for offshore rockfish, the Francis (2011) mean-age reweighting method was used. Alternatively, an explicit reweighting using a harmonic mean ratio method based on McAllister and Ianelli (1997) can be used (e.g., Yellowmouth Rockfish in 2021, Starr and Haigh 2022*c*).

The running of SS3 was streamlined using custom R code (archived on the GitHub site 'PBS Software' in the repository 'PBSsynth'), which relied heavily on code provided by the R packages 'PBSawatea', 'r4ss' (Taylor et al. 2021), and 'adnuts' (Monnahan 2018). Figures and tables of output were automatically produced in R, an environment for statistical computing and graphics (R Core Team 2021). The R function Sweave (Leisch 2002) automatically collated, via LaTeX, the large amount of figures and tables into 'pdf' files for model runs and Appendix F.

Methot and Wetzel (2013) provide mathematical notation of equations used in the SS3 model in their Appendix A. Below we present mathematical notation of selected equations used in the SS3 age-structured model (merged with notation used in previous DFO Awatea models), the Bayesian procedure, the reweighting scheme, the prior distributions, and the methods used for calculating reference points and performing projections.

E.2. MODEL ASSUMPTIONS

The key model assumptions are:

1. The assessed BC population of Pacific Ocean Perch (POP) comprised three stocks in PMFC areas 5ABC, 3CD, 5DE. Independent regional (area-specific) models were also run for comparison.
2. The POP fishery was dominated by trawl gear (~99.9% by catch in the last five years). Annual catches used in the model were taken by 'Trawl' fisheries (bottom + midwater gear) in three areas. Negligible catch by other gears (halibut longline, sablefish trap, lingcod & salmon troll, and rockfish hook & line) was added to account for total removals. The annual catch was known without error and occurred in the middle of each year.
3. The Beverton-Holt stock-recruitment relationship was time-invariant, with a log-normal error structure.
4. Selectivity was different among fleets (fishery and surveys), and remained invariant over time. Trawl selectivity for the 5ABC fishery (fleet 1) was estimated and trawl selectivities for 3CD (fleet 2) and 5DE (fleet 3) were linked to those from 5ABC. Selectivity parameters for surveys were estimated when ageing data were available (all but WCVI Historical, which was linked to GIG Historical).
5. Mortality (estimated), maturity (fixed), and growth parameters (fixed) were specific to a coastwide population in the multi-area model while these parameters were specific to the populations in the independent regional models.
6. Natural mortality M was estimated using a normal prior, and held invariant over time. This parameter differed between the two sexes.
7. Growth parameters were fixed and invariant over time. These parameters differed between the two sexes.
8. Maturity-at-age for females was fixed and invariant over time.
9. Female fecundity-at-age was directly proportional to female weight-at-age.
10. Recruitment at age 0 was 50% females and 50% males.
11. Recruitment standard deviation (σ_R) was fixed at 0.9.
12. Recruitment settlement distribution among areas was estimated, as were annual deviations (with standard error of annual deviations fixed at 1.0).
13. Only fish ages determined using the preferred otolith break-and-burn methodology (MacLellan 1997) were used because ages determined by surface ageing methods (chiefly before 1978) were biased (Beamish 1979). Surface ageing was deemed suitable for very young rockfish (ages 1-3).
14. An ageing error (AE) vector based on CVs of observed lengths-at-age was used.
15. Commercial samples of catch-at-age were representative of the fishery in a given year if there were ≥2 samples and ≥75 aged otoliths in that year.
16. Relative abundance indices were proportional to the vulnerable biomass at the mid point of the year, after half the catch and half the natural mortality had been removed.
17. The age composition samples came from the middle of the year after half the catch and half the natural mortality had been removed.

E.3. MODEL NOTATION AND EQUATIONS

Model notation is given in Table E.1, the model equations in Tables E.2 and E.3, and description of prior distributions for estimated parameters in Table E.4. The model description is divided into the deterministic components, stochastic components and Bayesian priors. Full details of notation and equations are given after the tables. Links to model inputs appear in Section E.8.

The deterministic components in Table E.2 iteratively calculate numbers of fish in each age class (and of each sex) through time, while allowing for the commercial catch data, weight-at-age and maturity data, and known fixed values for all parameters.

Parameters not assumed to be fixed were estimated in the context of recruitment stochasticity. This is accomplished by the stochastic components given in Table E.3.

Incorporation of the prior distributions for estimated parameters is necessary for a full Bayesian implementation, the goal of which is to minimise the objective function $\mathcal{F}(\boldsymbol{\Theta})$ given by (E.52). This function is derived from sum of the negative log likelihoods from the the deterministic, stochastic and prior components of the model.

E.3.1. Model notation

Table E.1. Notation for the SS3 catch-at-age model (continued overleaf). The assessment model uses only 'cohorts' (age-classes by year) even though SS3 recognises finer subdivisions of time called 'morphs' (seasons), which can be further characterised by 'platoons' (rates of growth).

Symbol	Description and units
	Indices (all subscripts)
a	▸ age class, where a = $1, 2, 3, ...A$, and ▹ a' = reference age near youngest age well-represented in data; ▹ a'' = reference age near oldest age well-represented in data
l	▸ length bin, where l = $1, 2, 3, ...\Lambda$, and Λ is the bin index of the largest length; ▹ L' = reference length for a'; ▹ L'' = reference length for a''; ▹ $\breve{L}_l$, $\mathring{L}_l$ = minimum and middle length of length bin l, respectively
t	▸ model year, where t = $1, 2, 3, ...T$, corresponds to actual years: 1935, ..., 2024, and $t = 0$ represents unfished equilibrium conditions
g	▸ index for series (abundance|composition) data: 1 – 5ABC Trawl Fishery (commercial data) 2 – 3CD Trawl Fishery (commercial data) 3 – 5DE Trawl Fishery (commercial data) 4 – QCS Synoptic trawl survey series 5 – WCVI Synoptic trawl survey series 6 – WCHG Synoptic trawl survey series 7 – GIG Historical trawl survey series 8 – NMFS Triennial trawl survey series 9 – WCVI Historical trawl survey series
s	▸ sex, 1=females, 2=males

Symbol	Description and units
	Index ranges
A	▸ accumulator age-class, $A \in \{60\}$
G	▸ number of fleets (fisheries and surveys)
Λ	▸ number of length bins
T	▸ number of model years, $T = 90$
$\mathbf{T}_g$	▸ sets of model years for survey abundance indices from series g, listed here for clarity as actual years (subtract 1934 to give model year t): $\mathbf{T}_4$ = {2003:2005, 2007, 2009, 2011, 2013, 2015, 2017, 2019, 2021} $\mathbf{T}_5$ = {2004, 2006, 2008, 2010, 2012, 2014, 2016, 2018, 2021} $\mathbf{T}_6$ = {1997, 2006:2008, 2010, 2012, 2016, 2018, 2020, 2022} $\mathbf{T}_7$ = {1967, 1969, 1971, 1973, 1976:1977, 1984, 1994} $\mathbf{T}_8$ = {1980, 1983, 1989, 1992, 1995, 1998, 2001} $\mathbf{T}_9$ = {1967, ..., 1970}
$\mathbf{U}_g$	▸ sets of model years with proportion-at-age data for series g: $\mathbf{U}_1$ = {1977, ..., 2019} $\mathbf{U}_2$ = {1980, 1982, 1984, 1990:1991, 1994:1995, 1998:2006, 2008, 2010:2019} $\mathbf{U}_3$ = {1978:1980, 1982, 1984:1995, 1997:2007, 2009, 2013:2017} $\mathbf{U}_4$ = {2003:2005, 2007, 2009, 2011, 2013, 2015, 2017, 2019, 2021} $\mathbf{U}_5$ = {1996, 2004, 2006, 2008, 2010, 2012, 2014, 2016, 2018, 2021:2022} $\mathbf{U}_6$ = {1997, 2006:2008, 2010, 2012, 2016, 2018, 2020, 2022} $\mathbf{U}_7$ = {1984, 1994:1995} $\mathbf{U}_8$ = {1989, 1992, 1995, 1998, 2001}
	Data and fixed parameters
$\widetilde{a}_a$	▸ age after bias adjustment for age a (used in ageing error)
ξ_a	▸ standard deviation for age a (used in ageing error)
p_{atgs}	▸ observed weighted proportion of fish from series g in each year $t \in \mathbf{U}_g$ that are age-class a and sex s; so $\sum_{a=1}^{A}\sum_{s=1}^{2} p_{atgs} = 1$ for each $t \in \mathbf{U}_g$
n_{tg}	▸ specified sample size that yields corresponding p_{atgs}
$\widetilde{n}_{tg}$	▹ effective sample size based on $\widehat{p}_{atgs}$
m_a	▸ proportion of age-class a females that are mature, fixed from data
w_{as}	▸ average weight (kg) of individual of age-class a of sex s from fixed parameters
$(\overline{w}_{tg}, \psi_{tg}, \psi'_{tg})$	▸ mean body weight (kg) by year (t) and fleet (g); SD $\overline{w}_{tg}$; SD offset to ψ_{tg}
(C_{tg}, τ_{tg})	▸ observed catch biomass (tonnes) in year t=1 to T-1 for fleet g; SD C_{tgs}
$(d_{tg}, \delta_{tg}, \delta'_{tg})$	▸ discarded catch biomass (tonnes) in year t for fleet g; SD d_{tg}; SD offset to δ_{tg}
$(I_{tg}, \kappa_{tg}, \kappa'_{tg})$	▸ biomass indices from surveys $g = 4, ..., 9$, for year $t \in \mathbf{T}_g$; SD I_{tg}; SD offset to κ_{tg}
σ_R	▸ standard deviation parameter for recruitment process error, $\sigma_R = 0.9$
ϵ_t	▸ recruitment deviations arising from process error, where $\epsilon_t \sim \mathcal{N}(0, \sigma_R^2)$
b_t	▸ recruitment bias adjustment, modulates recruitment variance over time: $b_t \sigma_R^2$ ▹ ranges from 1 (data-rich years) to 0 (data-poor years)
$\widehat{x}$	▸ estimated values of observed data x (generalised)
	Estimated parameters
$\mathbf{\Theta}$	▸ set of estimated parameters:
R_0	▸ virgin recruitment of age-0 fish (numbers of fish, 1000s)
$(\mathring{p}_\alpha, \nu_{t,\alpha}, \zeta_\alpha)$	▸ log proportion recruitment allocated to subarea α; SD added to $\mathring{p}_\alpha$; SE of $\nu_{t,\alpha}$

Symbol	Description and units
M_s	▸ natural mortality rate for sex $s = 1, 2$
h	▸ steepness parameter for Beverton-Holt recruitment
q_g	▸ catchability for fleets ($g = 4, ..., 9$)
β_{itg}	▸ double-normal parameters for females (s = 1), where i=$1, ..., 6$ for the six β parameters that determine selectivity S_{atgs} for year t and series g=$1, ..., 8$, using joiner functions j_{1atgs} and j_{2atgs} for ascending- and descending-limb functions π_{1atgs} and π_{2atgs}, respectively, where γ_{1tgs} and γ_{2tgs} describe exponential terms
Δ_{itg}	▸ shift in vulnerability for males (s = 2), where i=$1, ..., 5$ for the five Δ parameters and subscripts tg are the same as those for β
	Derived states
N_{ats}	▸ number of age-class a fish (1000s) of sex s at the start of year t
B_t	▸ spawning biomass (tonnes mature females) at the start of year t
B_0	▸ virgin spawning biomass (tonnes mature females) at the start of year 0
R_t	▸ recruitment of age-0 fish (numbers of fish, 1000s) in year t
ρ_t	▹ recruitment deviations (log thousands age-0 fish) in year t
V_{tg}	▸ vulnerable biomass (tonnes, females + males) in the middle of year t
$\mathcal{B}_{tg}$	▸ mid-season retained dead biomass (tonnes, females + males)
F_{tg}	▸ instantaneous fishing mortality rate for time period t by fishery g ▹ hybrid method uses Pope's approximation and Baranov's equation ▹ calculations facilitated by temporary variables $\mathcal{T}_{tg}$ and joiners $\mathcal{J}_{tg}$
Z_{ats}	▸ total mortality rate (natural & fishing) for time period t and sex s
	Log-likelihood components
$\mathcal{L}_{1g}(\mathbf{\Theta}\|\{\widehat{I}_{tg}\})$	▸ CPUE or abundance index
$\mathcal{L}_{2g}(\mathbf{\Theta}\|\{d_{tg}\})$	▸ discard biomass
$\mathcal{L}_{3g}(\mathbf{\Theta}\|\{\overline{w}_{tg}\})$	▸ mean body weight
$\mathcal{L}_{4g}(\mathbf{\Theta}\|\{l_{tg}\})$	▸ length composition
$\mathcal{L}_{5g}(\mathbf{\Theta}\|\{a_{tg}\})$	▸ age composition
$\mathcal{L}_{6g}(\mathbf{\Theta}\|\{z_{tg}\})$	▸ generalised size composition
$\mathcal{L}_{7g}(\mathbf{\Theta}\|\{C_{tg}\})$	▸ initial equilibrium catch
$\mathcal{L}_{R}(\mathbf{\Theta}\|\{R_{tg}\})$	▸ recruitment deviations
$\mathcal{L}_{\phi_j}(\mathbf{\Theta}\|\{\phi_j\})$	▸ parameter priors
$\mathcal{L}_{P_t}(\mathbf{\Theta}\|\{P_t\})$	▸ random parameter deviations (if time-varying)
$\mathcal{L}(\mathbf{\Theta})$	▸ total log-likelihood
	Prior distributions and objective function
$\phi_j(\mathbf{\Theta})$	▸ prior distribution for parameter j
$\phi(\mathbf{\Theta})$	▸ joint prior distribution for all estimated parameters
$\mathcal{F}(\mathbf{\Theta})$	▸ objective function to be minimised

E.3.2. Deterministic components

Table E.2. Deterministic components. Using the catch, weight-at-age and maturity data, with fixed values for all parameters, the initial conditions are calculated from (E.1)-(E.6), and then state dynamics are iteratively calculated through time using the main equations (E.7), selectivity functions (E.8)-(E.14), and the derived states (E.15)-(E.33). Estimated observations for survey biomass indices and proportions-at-age can then be calculated using (E.36) and (E.37). In Table E.3, the estimated observations of these are compared to data.

Initial conditions ($t=0$; $s=1,2$)

$$N_{a0s} = 0.5 R_0 e^{-aM_s} \;;\quad 0 \le a \le 3A\text{-}1 \tag{E.1}$$

$$N_{A0s} = \sum_{a=A}^{3A-1} N_{a0s} + \left(N_{3A-1,0s}\, e^{-M_{as}}\right) / \left(1 - e^{-M_{as}}\right) \tag{E.2}$$

$$B_0 = B_1 = \sum_{a=0}^{A} f_{as} N_{a0s} \;;\quad \text{where} \quad f_{as} = w_{as} m_{as} o_{as};\quad s{=}1 \text{ (female)} \tag{E.3}$$

$$L_{a0s} = \begin{cases} \breve{L}_1 + (\,a/a'\,)\,(\,L'_s - \breve{L}_1\,) & ;\; a \le a' \\ L_{\infty s} + (\,L'_s - L_{\infty s}\,)\, e^{-k_s(a-a')} & ;\; a' < a \le A\text{-}1 \end{cases} \tag{E.4}$$

$$\text{where} \;\; L_{\infty s} = L'_s + (L''_s - L'_s)\left[1 - e^{-k_s(a''-a')}\right] \tag{E.5}$$

$$L_{A0s} = \frac{\sum_{a=A}^{2A} \left[e^{-0.2(a-A-1)}\right]\left[L_{As} + (a/A - 1)(L_{\infty s} - L_{A0s})\right]}{\sum_{a=A}^{2A} e^{-0.2(a-A-1)}} \tag{E.6}$$

State dynamics ($2 \le t \le T$; $s=1,2$)

$$N_{ats} = \begin{cases} cR_{0t} & ;\; a = 0, c = \text{proportion female} \\ N_{a-1,t-1,s}\, e^{-Z_{a,t-1,s}} & ;\; 1 \le a \le A\text{-}1 \\ N_{A-1,t-1,s}\, e^{-Z_{A-1,t-1,s}} + N_{A,t-1,s}\, e^{-Z_{A,t-1,s}} & ;\; a = A \end{cases} \tag{E.7}$$

Selectivity pattern 20 ($g = 1, \ldots, 8$)

$$S_{atgs} = \pi_{1atgs}(1 - j_{1atgs}) + j_{1atgs}\left[(1 - j_{2atgs}) + j_{2atgs}\pi_{2atgs}\right] \tag{E.8}$$

$$j_{1atgs} = 1 \,/\, \left[1 + e^{-20(a-\beta_{1tgs})/(1+|a-\beta_{1tgs}|)}\right] \;;\quad \beta_{1tgs} = \text{first age when } S_{tgs}{=}1 \tag{E.9}$$

$$j_{2atgs} = 1 \,/\, \left[1 + e^{-20(a-a^\star_{tgs})/(1+|a-a^\star_{tgs}|)}\right] \;;\quad a^\star_{tgs} = \text{last age when } S_{tgs}{=}1 \tag{E.10}$$

$$a^\star_{tgs} = \beta_{1tgs} + \left(0.99A - \beta_{1tgs}\right)/\left(1 + \beta_{2tgs}\right) \;;\quad \text{assuming age bin = 1y} \tag{E.11}$$

$$\pi_{1atgs} = \left(\frac{1}{1 + e^{-\beta_{5tgs}}}\right)\left(\frac{1}{1 - (1 + e^{-\beta_{5tgs}})}\right)\left(\frac{e^{-(a-\beta_{1tgs})^2/e^{\beta_{3tgs}}} - \gamma_{1tgs}}{1 - \gamma_{1tgs}}\right) \tag{E.12}$$

$$\pi_{2atgs} = 1 + \left[\left(\frac{1}{1 + e^{-\beta_{6tgs}}}\right) - 1\right]\left(\frac{e^{-(a-a^\star_{tgs})/e^{\beta_{4tgs}}} - 1}{\gamma_{2tgs} - 1}\right) \tag{E.13}$$

$$\gamma_{1tgs} = e^{-(1-\beta_{1tgs})^2/e^{\beta_{3tgs}}} \;;\quad \gamma_{2tgs} = e^{-(A-a^\star_{tgs})^2/e^{\beta_{4tgs}}} \tag{E.14}$$

Derived states ($1 \le t \le T-1$)

$$L_{ats} = L_{a\text{-}1,t\text{-}1,s} + \left(L_{a\text{-}1\text{-}k,t\text{-}1,s} - L_{\infty s} \right) \left(e^{-k_s} - 1 \right); \quad a < A \tag{E.15}$$

$$L_{Ats} = \frac{N_{A\text{-}1,ts}\overline{L}_{Ats} + N_{Ats}\left[L_{Ats} - \left(L_{Ats} + L_{\infty s} \right) \left(e^{-k_s} - 1 \right) \right]}{N_{A\text{-}1,ts} + N_{Ats}} \tag{E.16}$$

$$\overline{L}_{ats} = L_{ats} + \left(L_{ats} - L_{\infty s} \right) \left(e^{-0.5k_s} - 1 \right) \tag{E.17}$$

$$\alpha_{ats} = \begin{cases} \overline{L}_{ats}\nu'_s \,|\, a_{ts}\nu'_s & ; \; a \le a' \\ \overline{L}_{ats}\left[\nu'_s + (\overline{L}_{ats}\text{-}L'_s)/(L''_s\text{-}L'_s)(\nu''_s\text{-}\nu'_s)\right] \,| & \\ \quad a_{ts}\nu'_s\left[\nu'_s + (a_{ts}\text{-}a'_s)/(a''_s\text{-}a'_s)(\nu''_s\text{-}\nu'_s)\right] & ; \; a' < a < a'' \\ \overline{L}_{ats}\nu''_s \,|\, a_{ts}\nu''_s & ; \; a'' \le a \end{cases} \tag{E.18}$$

$$\varphi_{lats} = \begin{cases} \Phi\left[(\breve{L}_l - \overline{L}_{ats})/\alpha_{ats}\right] & ; \; l = 1 \\ \Phi\left[(\breve{L}_{l+1} - \overline{L}_{ats})/\alpha_{ats}\right] - \Phi\left[(\breve{L}_l - \overline{L}_{ats})/\alpha_{ats}\right] & ; \; 1 < l < L \\ 1 - \Phi\left[(\breve{L}_l - \overline{L}_{ats})/\alpha_{ats}\right] & ; \; l = L \end{cases} \tag{E.19}$$

$$w_{ls} = a_s \mathring{L}_l^{b_s} \; ; \quad \mathring{L}_l = \text{mid-size of length bin } l \tag{E.20}$$

$$f_a = \textstyle\sum_{l=1}^{\Lambda} \varphi_{las} m_l o_l w_{ls} \; ; \quad s{=}1, m{=}\text{maturity}, o{=}\text{eggs/kg} \tag{E.21}$$

$$Z_{ats} = M_{as} \textstyle\sum_{g\in 1,\ldots,3} \left(S_{atgs} F_{tg} \right) ; \quad F_{tg} = \text{apical fishing mortality rate} \tag{E.22}$$

$$\mathcal{T}_{1tg} = C_{tg}/(\widehat{\mathcal{B}}_{tg} + 0.1C_{tg}) \; ; \; \mathcal{J}_{1tg} = 1/\left[1 + e^{30(\mathcal{T}_{1tg} - 0.95)}\right] \; ; \; \mathcal{T}_{2tg} = \mathcal{J}_{1tg}\mathcal{T}_{1tg} + 0.95(1 - \mathcal{J}_{1tg}) \tag{E.23}$$

$$F_{1tg} = -\log\left(1 - \mathcal{T}_{2tg} \right) \tag{E.24}$$

$$\widehat{C}_t = \textstyle\sum_{g\in 1,\ldots,3} \sum_{s=1}^{2} \sum_{a=0}^{A} \dfrac{F_{1tg}}{Z_{ats}} w_{as}N_{ats}S_{atgs}\lambda_{ats} \; ; \quad \lambda_{ats} = \left(1 - e^{-Z_{ats}} \right)/\left(Z_{ats} \right) \tag{E.25}$$

$$\overrightarrow{Z}_t = C_t/(\widehat{C}_t + 0.0001) \; ; \; Z'_{ats} = M_{as} + \overrightarrow{Z}_t(Z_{ats} - M_{as}) \; ; \; \lambda'_{ats} = (1 - e^{-Z'_{ats}})/(Z'_{ats}) \tag{E.26}$$

$$\mathcal{T}_{3tg} = \textstyle\sum_{s=1}^{2} \sum_{a=0}^{A} w_{as}N_{ats}S_{atgs}\lambda'_{ats} \tag{E.27}$$

$$F_{2tg} = C_{tg}/(\mathcal{T}_{3tg} + 0.0001) \; ; \quad \mathcal{J}_{2tg} = 1/\left[1 + e^{30(F_{2tg} - 0.95F_{\max})}\right] \tag{E.28}$$

$$F_{tg} = \mathcal{J}_{2tg}F_{2tg} + (1 - \mathcal{J}_{2tg})F_{\max} \; ; \quad \text{updated estimate of } F \text{ using hybrid method above} \tag{E.29}$$

$$C_{ats} = \textstyle\sum_{g\in 1,\ldots,3} \dfrac{F_{tg}}{Z'_{ats}} w_{as}N_{ats}S_{atgs}\lambda'_{ats} \tag{E.30}$$

$$B_t = \textstyle\sum_{a=0}^{A} N_{ats}f_a \; ; \quad s{=}1, f{=}\text{fecundity} \tag{E.31}$$

$$V_{tg} = \sum_{s=1}^{2}\sum_{a=1}^{A} e^{-M_s/2} w_{as} N_{ats} S_{atgs} \; ; \quad g \in \{1, \ldots, 3\}, \; u_{tg} = C_{tg}/V_{tg}, \; u_{atgs} = u_{tg}S_{atgs} \tag{E.32}$$

$$R_t = \frac{4hR_0B_{t-1}}{(1-h)B_0 + (5h-1)B_{t-1}} \quad \left(\equiv \frac{B_{t-1}}{\alpha + \beta B_{t-1}} \right) \tag{E.33}$$

Ageing error

$$\Phi(x|\mu,\sigma) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{(x-\mu)/\sigma} e^{-(t^2/2)}\, dt \quad \text{cumulative normal distribution} \tag{E.34}$$

$$\Psi_a = \begin{cases} \Phi\left(\frac{a-\widetilde{a}_a}{\xi_a}\right) & ; \; a = 1 \\ \Phi\left(\frac{a+1-\widetilde{a}_a}{\xi_a}\right) - \Phi\left(\frac{a-\widetilde{a}_a}{\xi_a}\right) & ; \; 1 < a < A \\ 1 - \Phi\left(\frac{A-\widetilde{a}_a}{\xi_a}\right) & ; \; a = A \end{cases} \tag{E.35}$$

Estimated observations

$$\widehat{I}_{tg} = q_g \sum_{s=1}^{2} \sum_{a=1}^{A} e^{-M_s/2}(1 - u_{ats}/2) w_{as} S_{ags} N_{ats}\,; \quad t \in \mathbf{T}_g,\; g = 4, ..., 9 \tag{E.36}$$

$$\widehat{p}_{atgs} = \frac{e^{-M_s/2}(1 - u_{ats}/2) S_{ags} N_{ats}}{\sum_{s=1}^{2} \sum_{a=1}^{A} e^{-M_s/2}(1 - u_{ats}/2) S_{ags} N_{ats}}; \; {\scriptstyle 1 \le a \le A,\; t \in \mathbf{U}_g,\; g=1,...,8,\; s=1,2} \tag{E.37}$$

E.3.3. Stochastic components

Table E.3. Stochastic components. Calculation of likelihood function $\mathcal{L}(\mathbf{\Theta})$ for stochastic components of the model in Table E.2, and resulting objective function $f(\mathbf{\Theta})$ to be minimised.

Estimated parameters

$$\mathbf{\Theta} = \{R_0; M_{1,2}; h; q_{4,\dots,9}; \mu_{1,\dots,8}, \pi_{\mathsf{T}1,\dots,8}, \upsilon_{\mathsf{L}1,\dots,8L}, \upsilon_{\mathsf{R}1,\dots,8}, \pi_{\mathsf{F}1,\dots,8}, \theta_{1,\dots,8}\} \tag{E.38}$$

Recruitment deviations

$$\rho_{t+1} = \log R_{t+1} - \log B_t + \log(\alpha + \beta B_t) + 0.5 b_t \sigma_R^2 + \epsilon_t \; ; \quad \epsilon_t \sim \mathcal{N}(0, \sigma_R^2)\,, \; 1 \le t \le T\text{-}1 \tag{E.39}$$

$$\text{where } b_t = \begin{cases} 0 & ; \; t \le t_1^b \\ b_{\mathsf{max}}\left[1 - (t - t_1^b)/(t_2^b - t_1^b)\right] & ; \; t_1^b < t < t_2^b \\ b_{\mathsf{max}} & ; \; t_2^b \le t \le t_3^b \\ b_{\mathsf{max}}\left[1 - (t_3^b - t)/(t_4^b - t_3^b)\right] & ; \; t_3^b < t < t_4^b \\ 0 & ; \; t_4^b \le t \end{cases} \tag{E.40}$$

Log-likelihood components (⊛ active, ◃ inactive)

$$\circledast \; \mathcal{L}_{1g}(\mathbf{\Theta}|\{\widehat{I}_{tg}\}) = \sum_{t \in \mathbf{T}_g} \left[\frac{(\log I_{tg} - \log(q_g B_{tg}))^2}{2\kappa_{tg}^2} + \kappa'_{tg} \log \kappa_{tg} \right] \tag{E.41}$$

$$\triangleleft \; \mathcal{L}_{2g}(\mathbf{\Theta}|\{d_{tg}\}) = \sum_{t=1}^{T} 0.5(\mathsf{df}_g + 1) \log \left[\frac{1 + (d_{tg} - \widehat{d}_{tg})^2}{\mathsf{df}_g \delta_{tg}^2} \right] + \delta'_{tg} \log \delta_{tg} \tag{E.42}$$

$$\triangleleft \; \mathcal{L}_{3g}(\mathbf{\Theta}|\{\overline{w}_{tg}\}) = \sum_{t=1}^{T} 0.5(\mathsf{df}_{\overline{w}} + 1) \log \left[\frac{1 + (\overline{w}_{tg} - \widehat{\overline{w}}_{tg})^2}{\mathsf{df}_{\overline{w}} \psi_{tg}^2} \right] + \psi'_{tg} \log \psi_{tg} \tag{E.43}$$

$$\triangleleft \; \mathcal{L}_{4g}(\mathbf{\Theta}|\{l_{tg}\}) = \textstyle\sum_{t \in \mathbf{U}_g} \sum_{s=1}^{2} \sum_{l=1}^{L} n_{tgs} p_{ltgs} \log\left(p_{ltgs} / \widehat{p}_{ltgs}\right) \text{; composition option 1} \tag{E.44}$$

$$\circledast \; \mathcal{L}_{5g}(\mathbf{\Theta}|\{a_{tg}\}) = \textstyle\sum_{t \in \mathbf{U}_g} \sum_{s=1}^{2} \sum_{a=1}^{A} n_{tgs} p_{atgs} \log\left(p_{atgs} / \widehat{p}_{atgs}\right) \text{; composition option 2} \tag{E.45}$$

$$\triangleleft \; \mathcal{L}_{6g}(\mathbf{\Theta}|\{z_{tg}\}) = \textstyle\sum_{t \in \mathbf{U}_g} \sum_{s=1}^{2} \sum_{z=1}^{\Lambda} n_{tgs} p_{ztgs} \log\left(p_{ztgs} / \widehat{p}_{ztgs}\right) \text{; composition option 3} \tag{E.46}$$

$$\circledast \; \mathcal{L}_{7g}(\mathbf{\Theta}|\{C_{tg}\}) = \textstyle\sum_{t=1}^{T} \left[\log C_{tg} - \log(\widehat{C}_{tg} + 1\mathsf{e}\text{-}6)\right]^2 / \, 2\tau_{tg}^2 \tag{E.47}$$

$$\circledast \; \mathcal{L}_R(\mathbf{\Theta}|\{R_t\}) = 0.5 \textstyle\sum_{t=1}^{T} (\widetilde{R}_t^2 / \sigma_R^2) + b_t \log \sigma_R^2 \tag{E.48}$$

$$\circledast \; \mathcal{L}_{\phi_j}(\mathbf{\Theta}|\{\phi_j\}) = 0.5 \left[(\phi_j - \mu_{\phi_j})/\sigma_{\phi_j}\right]^2 \quad \text{; normal prior distributions for parameter } j \tag{E.49}$$

$$\circledast \; \mathcal{L}_{\phi_j}(\mathbf{\Theta}|\{\phi_j\}) = 0.5 \left[(\log \phi_j - \mu_{\phi_j})/\sigma_{\phi_j}\right]^2 \quad \text{; lognormal prior distributions for parameter } j \tag{E.50}$$

$$\triangleleft \; \mathcal{L}_{P_j}(\mathbf{\Theta}|\{P_{jt}\}) = (1/2\sigma_P^2) \textstyle\sum_{t=1}^{T} \widetilde{P}_{jt}^2 \quad \text{; for time-varing parameters, if any} \tag{E.51}$$

Objective function

$$\mathcal{F}(\mathbf{\Theta}) = \sum_{i=1}^{7} \sum_{g=1}^{G} \omega_{ig} \mathcal{L}_{ig} + \omega_R \mathcal{L}_R + \sum_{\phi} \omega_\phi \mathcal{L}_\phi + \sum_{P} \omega_P \mathcal{L}_P \quad \text{; } \omega = \text{weighting factors for each } \mathcal{L} \tag{E.52}$$

E.3.4. Base run prior expectation

Table E.4. Details for estimation of parameters, including prior distributions with corresponding means and standard deviations, bounds between which parameters are constrained, and initial values to start the minimisation procedure for the MPD (mode of the posterior density) calculations. In SS3, an analytical solution for q is calculated when the parameter is allowed to 'float'.

Parameter	Phase	Prior distribution	Mean, SD	Bounds	Initial value
Multi-area model					
M_1 (female)	4	normal	0.06, 0.018	[0.02, 0.2]	0.06
M_2 (male)	4	normal	0.06, 0.018	[0.02, 0.2]	0.06
h	5	beta	0.67, 0.17	[0.2, 1]	0.67
$\log R_0$	1	normal	10, 10	[1, 16]	10
$\mathring{p}_{\alpha=1}$	3	normal	0, 1	[-5, 5]	0
$\mathring{p}_{\alpha=2}$	3	normal	0, 1	[-5, 5]	0
$\log q_{1,\ldots,8}$	-1	analytic	-3, 6	[-15, 15]	-3
μ_1	3	normal	10, 10	[5, 40]	10
$\mu_{2,3}$ ~ μ_1	-	linked	—	—	—
$\mu_{4,5}$	3	normal	12, 12	[5, 40]	12
μ_6	3	normal	12, 3.6	[5, 40]	12
$\mu_{7,8}$	3	normal	12, 3.6	[0, 40]	12
μ_9 ~ μ_7	-	linked	—	—	—
$\log v_{\text{L1}}$	4	normal	2, 2	[-15, 15]	2
$\log v_{\text{L2,3}}$ ~ $\log v_{\text{L1}}$	4	linked	—	—	—
$\log v_{\text{L4,5}}$	4	normal	2.5, 2.5	[-15, 15]	2.5
$\log v_{\text{L6,7,8}}$	4	normal	2.5, 0.75	[-15, 15]	2.5
$\log v_{\text{L9}}$ ~ $\log v_{\text{L7}}$	4	linked	—	—	—
$\Delta_{1,\ldots,8}$	4	normal	0, 1	[-8, 10]	0
Δ_9 ~ Δ_7	4	linked	—	—	—

E.4. DESCRIPTION OF DETERMINISTIC COMPONENTS

Notation (Table E.1) and deterministic components (Table E.2) are described below. Acronyms: SS3 = Stock Synthesis 3, AW = Awatea, AF = age frequencies|proportions, POP = Pacific Ocean Perch.

E.4.1. Age classes

Index (subscript) a represents age classes, going from 1 to the accumulator age class A of 60. Age class $a = 5$, for example, represents fish aged 4-5 years (which is the usual, though not universal, convention, Caswell 2001), and so an age-class 1 fish was born the previous year. Unlike Awatea, SS3 uses an age class 0 that presumably represents fish at birth (new recruits). The variable N_{ats} is the number of age-class a fish of sex s at the *start* of year t, so the model is run to year T which corresponds to the beginning of year 2024.

E.4.2. Years

Index t represents model years, going from 1 to $T = 90$, and $t = 0$ represents unfished equilibrium conditions. The actual year corresponding to $t = 1$ is 1935, and so model year $T = 90$

corresponds to 2024. The interpretation of year depends on the model's derived state or data input:

- beginning of year: N_{ats}, B_t, R_t
- middle of year: C_{tg}, V_{tg}, F_{tg}, u_{tg}, $\widehat{I}_{tg}$, $\widehat{p}_{atgs}$

E.4.3. Commercial Data

As described in Appendix A, the commercial catch was reconstructed back to 1918 for five fisheries – (1) trawl, (2) halibut longline, (3) sablefish trap|longline, (4) dogfish|lingcod|salmon troll, and (5) hook & line rockfish in outside (offshore) waters – all excluding PMFC area 4B (Strait of Georgia). In this assessment, three commercial fleets were used – 'Trawl + Other' in three regions or areas (5ABC, 3CD, 5DE), where 'Other' refers to negligible non-trawl fisheries. Given the small catches in the early years, the model was started in 1935, with catches prior to 1935 not considered. The time series for catches by fleet are denoted C_{tg} and include retained and discarded catches (either observed or reconstructed). The set $\mathbf{U}_{1,2,3}$ (Table E.1) gives the years of available ageing data from the commercial fishing fleets. The proportions-at-age values are given by p_{atgs} with observed sample size n_{tg}, where $g = 1, 2, 3$ corresponds to the commercial fleets. The proportions are calculated using the stratified weighting scheme, described in Appendix D, that adjusts for unequal sampling effort across temporal and spatial strata.

E.4.4. Survey Data

Survey data from six fleets (g=$4, ..., 9$) were used in the model, as described in detail in Appendix B. These surveys are indexed using g, with each subscript corresponding to a survey: g=4: Queen Charlotte Sound (QCS) Synoptic; g=5: West Coast Vancouver Island (WCVI) Synoptic; g=6: West Coast Haida Gwaii (WCHG) Synoptic; g=7: Goose Island Gully (GIG) Historical; g=8: NMFS Triennial; g=9: West Coast Vancouver Island (WCVI) Historical. The years for which data were available for each survey are given in Table E.1; $\mathbf{T}_g$ corresponds to years for the survey biomass estimates I_{tg} (and corresponding standard deviations κ_{tg}), and $\mathbf{U}_g$ corresponds to years for proportion-at-age data p_{atgs} (with observed sample sizes n_{tg}). Note that for surveys, sample size refers to the number of tows sampled, where each sample comprises specimens, typically ~10-50 fish/sample.

E.4.5. Sex

A two-sex model was used, with subscript s=1 for females and s=2 for males (note that these subscripts are the reverse of the codes used in the GFBioSQL database). Ageing data were partitioned by sex, as were the weights-at-age inputs. Selectivities and natural mortality were specified by sex.

E.4.6. Weights-at-age

The weights-at-age w_{as} were assumed fixed over time and were based on sex-specific allometric (length-weight) and growth (age-length) model parameters derived from the biological data; see Appendix D for details.

E.4.7. Maturity of females

The proportion of age-class a females that are mature is m_a, and was assumed to be invariant over time; see Appendix D for details. Fecundity-at-age for females was assumed to be proportional to their weights-at-age.

E.4.8. Initial conditions

An unfished equilibrium at the beginning of the reconstruction was assumed because there was no evidence of significant removals prior to 1935. The initial conditions (E.1) and (E.2) were obtained by setting $R_t = R_0$ (virgin recruitment), $N_{ats} = N_{a1s}$ (equilibrium condition) and $u_{ats} = 0$ (no fishing). The virgin spawning biomass B_0 was obtained from (E.3). The initial lengths were set using the growth equations of Schnute (1981) (E.4)-(E.6).

E.4.9. State dynamics

The core of the model is the set of dynamic equations (E.7) for the estimated number N_{ats} of age-class a fish of sex s at the start of year t. The proportion of female new recruits c in Equation (E.7) was set to 0.5. Equation (E.7) calculates the numbers of fish in each age class (and of each sex) that survive to the following year, where Z_{ats} represents the total mortality rate, which in this case comprises the sum of natural mortality M and fishing mortality F. The accumulator age class A retains survivors from this class in following years.

Natural mortality M_s was estimated separately for males and females. This parameter enters the equations in the form e^{-M_s} as the proportion of unfished individuals that survive the year.

E.4.10. Selectivities

Separate selectivities were estimated for each of the fleets with AF data using SS3's selectivity pattern 20 for females (Equations E.8-E.14) and selectivity option 3 for males. Note that 'log' herein refers to natural logarithms. Pattern 20 describes double normal selectivity for females where the parameters β_i ($i = 1, ..., 6$) for fleet g are:

1. β_{1g} – age at which selectivity first reaches maximum selectivity:
   - SS3: beginning age (year) for the plateau;
   - AW: age of full selectivity (μ_g) for females;
2. β_{2g} – (SS3 only) used to generate a logistic between peak (β_{1g}) and maximum age (A) that determines width of top plateau ($a_g^\star - \beta_{1g}$), where $a_g^\star$ is the final age of the top plateau;
3. β_{3g} – used to determine width of the ascending limb of double normal curve:
   - SS3: determines slope of ascending limb by tweaking its variance;
   - AW: log of variance for left limb ($\upsilon_{\mathrm{L}g}$) of selectivity curve;
4. β_{4g} – used to determine width of the descending limb of double normal curve:
   - SS3: determines slope of descending limb by tweaking its variance;
   - AW: log of variance for right limb ($\upsilon_{\mathrm{R}g}$) of selectivity curve;
5. β_{5g} – (SS3 only) determines initial selectivity by generating a logistic between 0 and 1 at first age;
   - where selectivity $S_{a=1,g} = 1/(1 + e^{-\beta_{5g}})$; however,
   - use -999 to ignore initial selectivity algorithm and decay small-fish selectivity using β_{3g};
6. β_{6g} – (SS3 ony) determines final selectivity by generating a logistic between 0 and 1 at final age bin;
   - where selectivity $S_{Ag} = 1/(1 + e^{-\beta_{6g}})$.

Option 3 for pattern 20 describes male selectivity as offsets to female selectivity, where parameters Δ_i ($i = 1, ..., 5$) for fleet g are:

1. Δ_{1g} = male peak offset (Δ_g in AW) added to the first female selectivity parameter, β_{1g} (μ_g in AW);
2. Δ_{2g} = male width offset (log width) added to the third selectivity parameter, β_{3g} (same as female $v_{\mathrm{L}g}$ in AW);
3. Δ_{3g} = male width offset (log width) added to the fourth selectivity parameter, β_{4g} (same as female $v_{\mathrm{R}g}$ in AW);
4. Δ_{4g} = male plateau offset added to the sixth selectivity parameter, β_{6g} (not present in AW);
5. Δ_{5g} = apical selectivity for males (usually 1 but could be different than that for females; not present in AW).

Dome selectivity only occurs under three conditions:

- the width of the top plateau (between β_{1g} and $a_g^\star$) must be less than $A - \beta_{1g}$;
- the steepnees of the descending limb (controlled by β_{4g}) must not be too shallow; and
- the final selectivity (controlled by β_{6g}) must be less than peak selectivity (usually 1).

Generally for males, the same selectivity function is used except that some of the selectivity parameters (β_{ig} for $i \in \{1, 3, 4, 6\}$) may be shifted if male AF data are sufficiently different from female AF data.

E.4.11. Derived states

The spawning biomass (biomass of mature females, in tonnes) B_t at the start of year t is calculated in (E.31) by multiplying the numbers of females N_{at1} by fecundity f_a (E.21), which is a function of a length-age matrix φ_{lats} (E.19), the maturity ogive (m_l), egg production (o_l), and weights-at-length w_{l1} (E.20).

The fishing mortality rate F_{tg} (E.29) is derived through an iterative process to fit observed catches closely rather than removing the catches by subtraction. A mid-season harvest rate is calculated using Pope's approximation (Pope 1972), which is then converted to an instantaneous F using the Baranov equation (Baranov 1918). Each fleet's approximate F is repeated iteratively several times (usually three to four) using the Newton-Rhapson procedure until its value yields a close match to the observed catches by the fleet. Details can be found in Methot and Wetzel (2013).

Although SS3 does not report vulnerable biomass *per se*, equation (E.32) provides an equation from Awatea for V_{tg} mid-year. Assuming that C_{tg} is taken mid-year, the harvest rate is simply C_{tg}/V_{tg}. Further, for year t, the proportion u_{tg} of age-class a and sex s fish that are caught in fishery g can be calculated by multiplying the commercial selectivities S_{atgs} and the ratio u_t (E.32).

E.4.12. Stock-recruitment function

A Beverton-Holt recruitment function is used, parameterised in terms of steepness, h, which is the proportion of the long-term unfished recruitment obtained when the stock abundance is reduced to 20% of the virgin level (Mace and Doonan 1988; Michielsens and McAllister 2004). Awatea uses a prior on h taken from Forrest et al. (2010), where shape parameters for a beta distribution are $\alpha = (1-h)B_0/(4hR_0)$ and $\beta = (5h-1)/4hR_0$ (Hilborn et al. 2003; Michielsens and McAllister 2004). Substituting these into the Beverton-Holt equation, $R_t = B_{t-1}/(\alpha + \beta B_{t-1})$, where R_0 is the virgin recruitment, R_t is the recruitment in year t, B_t is the spawning biomass at the start of year t, and B_0 is the virgin spawning biomass. SS3 offers several recruitment options including Ricker, Beverton-Holt, and a three-parameter survivorship-based function suitable for low-fecundity species (Taylor et al. 2013).

The multi-area model in SS3 estimates one recruitment for the coastwide population, which is then allocated amongst the three areas: 5ABC, 3CD, and 5DE. Two allocation parameters (number areas - 1) are estimated in natural log space, while the third parameter is fixed at zero. The equation to calculate the proportion allocations by area α in linear space is:

$$p_\alpha^R = e^{\mathring{p}_\alpha} / (e^{\mathring{p}_{\alpha=1}} + e^{\mathring{p}_{\alpha=2}} + e^{\mathring{p}_{\alpha=3}}), \text{ where } \alpha \in 1, 2, 3 \tag{E.53}$$

In order to have varying recruitment by year in each area, a time-varying component was added to p_α^R by estimating annual deviance parameters $\nu_{t,\alpha}$. The period over which this was applied varied among areas and runs: 1935 to 2014 for 5ABC (Base and Sensitivity S03), 1975 to 2014 for 3CD (Base and S02), and 1935 to 2014 for 5DE (S02 and S03). These years were selected based on the availability of age frequency data and the number of observations obtained for a cohort. Additionally, a standard error (ζ_α) for the deviance values can be estimated; however, this stock assessment fixed ζ_α to 1. Annual time-varying recruitment proportions are then calculated by adjusting the estimated proportions in log space:

$$\mathring{p}_{t,\alpha} = \mathring{p}_\alpha + \nu_{t,\alpha}\zeta_\alpha \tag{E.54}$$

and then applying (E.53) to transform these annually adjusted values into linear space, $p_{t,\alpha}^R$.

E.4.13. Fitting to data

Model estimates of the survey biomass indices I_{tg} are denoted $\widehat{I}_{tg}$ and are calculated in (E.36). The estimated numbers N_{ats} are multiplied by the natural mortality term $e^{-M_s/2}$ (that accounts for half of the annual natural mortality), the term $1 - u_{ats}/2$ (that accounts for half of the commercial catch), weights-at-age w_{as} (to convert to biomass), and selectivity S_{ags}. The sum (over ages and sexes) is then multiplied by the catchability parameter q_g to give the model biomass estimate $\widehat{I}_{tg}$.

The estimated proportions-at-age $\widehat{p}_{atgs}$ are calculated in (E.37). For a particular year and gear type, the product $e^{-M_s/2}(1 - u_{ats}/2)S_{ags}N_{ats}$ gives the relative expected numbers of fish caught for each combination of age and sex. Division by $\sum_{s=1}^{2}\sum_{a=1}^{A} e^{-M_s/2}(1 - u_{ats}/2)S_{ags}N_{ats}$ converts these to estimated proportions for each age-sex combination, such that $\sum_{s=1}^{2}\sum_{a=1}^{A} \widehat{p}_{atgs} = 1$.

Ageing error (AE) in this stock assessment was applied using SS3's vector-style inputs of bias and precision. The bias vector used was 0.5 to 60.5 at increments of 1 year for ages 0 through 60, which in SS3 signifies no age bias. The precision vector for ages 0 through 60 was estimated as the standard deviation of ages 1 through 61 calculated from the CVs of lengths-at-age: $\sigma_a = a(\sigma_{L_a}/\mu_{L_a})$, where $a = 1, ..., 61$. Using these vectors, SS3 applies a cumulative normal distribution for each age to calculate the frequency of expected age given a mean assigned age and standard deviation (see E.35).

> "SS3 never adjusts input data. Rather, it adjusts expected values for data to take into account known factors that influenced the creation of the observations. So, ageing error is applied to a modeled distribution of true ages (after selectivity has taken a subset from the population) to create a new distribution of ages that includes the influence of ageing error."
>
> – Richard Methot, 2021, *pers. comm.*

E.5. DESCRIPTION OF STOCHASTIC COMPONENTS

E.5.1. Parameters

The set Θ gives the parameters that are estimated. The estimation procedure is described in the Bayesian Computations section below.

E.5.2. Recruitment deviations

For recruitment, a log-normal process error is assumed, such that the stochastic version of the deterministic stock-recruitment function (E.33) is

$$R_t = \frac{B_{t-1}}{\alpha + \beta B_{t-1}} e^{-0.5 b_t \sigma_R^2 + \epsilon_t} \qquad \text{(E.55)}$$

where $\epsilon_t \sim \mathcal{N}(0, \sigma_R^2)$, and the bias-correction term $-b_t \sigma_R^2/2$ term in (E.55) ensures that the mean of the recruitment deviations equals 0. This then gives the recruitment deviation equation (E.39) and log-likelihood function (E.48). In this assessment, the value of σ_R was fixed at 0.9 based on values used in recent BC rockfish stock assessments. Other assessments have used σ_R = 0.6 following an assessment of Silvergray Rockfish (Starr et al. 2016) in which the authors stated that the value was typical for marine 'redfish' (Mertz and Myers 1996). An Awatea model of Rock Sole used σ_R = 0.6 (Holt et al. 2016), citing that it was a commonly used default for finfish assessments (Beddington and Cooke 1983). In recent BC rockfish assessments, we have adopted σ_R = 0.9 based on an empirical model fit consistent with the age composition data for 5ABC POP (Edwards et al. 2012*b*). A study by Thorson et al. (2014) examined 154 fish populations and estimated σ_R = 0.74 (SD=0.35) across seven taxonomic orders; the marginal value for Scorpaeniformes was σ_R=0.78 (SD=0.32) but was only based on 7 stocks.

Most BC offshore rockfish models in past (using Awatea 2009–2020 and SS3 2021-2022) have used a recruitment deviation vector (during the main recruitment period) that sums to 0; however, a bug in ADMB became apparent to Ian Taylor when running MCMC simulations. Using the command line option `-mcmc`, the value of `sum(effort_devs)` was never close to 0, but using the option `-mceval` (i.e., evaluate the contents of `[model].psv`), `sum(effort_devs)` was very close to 0. One of the consequences was that ~10% of the posterior samples lead to a crashed population. During the current POP model runs, evaluated MCMC posterior samples led to 35 out of 2000 samples (1.75%) with undefined MSY values (specified as `'NaN'`, or not a number). The population had not crashed but the forecast fishing mortality had been evaluated as `'NaN'` for no apparent reason.

E.5.3. Log-likelihood functions

The objective funtion function $\mathcal{F}(\Theta)$ (E.52) comprises a weighted sum of individual likelihood components that include:

- $\mathcal{L}_{I_g}$ (E.41) – CPUE or abundance index by fleet
- $\mathcal{L}_{a_g}$ (E.45) – age composition by fleet
- $\mathcal{L}_{C_g}$ (E.47) – catch by fleet
- $\mathcal{L}_{R}$ (E.48) – recruitment deviations
- $\mathcal{L}_{\phi_j}$ (E.49) to (E.50) – parameter priors
- $\mathcal{L}_{P_j}$ (E.51) – random parameter deviations

See Methot and Wetzel (2013) and Methot et al. (2021) for more likelihood options and details.

E.6. BAYESIAN COMPUTATIONS

Estimation of parameters compares the estimated (model-based) observations of survey biomass indices and proportions-at-age with the data, and minimises the recruitment deviations. This is done by minimising the objective function $f(\Theta)$, which equation (E.52) shows is the negative of the sum of the total log-likelihood function comprising the logarithmic components (E.41)-(E.51).

The procedure for the Bayesian computations is as follows:

1. minimise the objective function $f(\Theta)$ to give estimates of the mode of the posterior density (MPD) for each parameter: (a) done in phases, and (b) perform a reweighting;
2. generate samples from the joint posterior distributions of the parameters using Monte Carlo Markov Chain (MCMC) procedure, starting the chains from the MPD estimates.

E.6.1. Phases

The MPD estimates were obtained by minimising the objective function $f(\Theta)$, from the stochastic (non-Bayesian version) of the model. The resulting estimates were then used to initiate the chains for the MCMC procedure for the full Bayesian model.

Simultaneously estimating all the estimable parameters for complex nonlinear models is ill advised, and so ADMB allows some of the estimable parameters to be kept fixed during the initial part of the optimisation process ADMB Project (2009). Some parameters are estimated in phase 1, then some further ones in phase 2, and so on. The order (if estimated) typically used by the BC Offshore Rockfish assessment team is:

phase 1: virgin recruitment R_0 and survey catchabilities $q_{4,...,9}$
(although the q fit herein adopts a 'float' option, which calculates an analytical solution);
phase 2: recruitment deviations ϵ_t (held at 0 in phase 1);
phase 3: natural mortality M_s and age of full selectivity for females β_{1g} for g=$1, ..., 8$;
phase 4: additional selectivity parameters β_{ng} for n=$2, ..., 6$ and g=$1, ..., 8$;
phase 5: steepness h.

E.6.2. Reweighting

> "Sample sizes are used to calculate the variance for a data source and are useful to indicate the relative differences in uncertainty across years within each data source. However, sample size may not represent the relative difference in the variance between different data sources (usually abundance vs. composition). Therefore, the relative weights for each data source in an integrated stock assessment should be adjusted to reflect the information content of each, while retaining the relative differences across years. This can be accomplished by applying adjustment factors to abundance and composition data to weight either data source up or down relative to the other. "
>
> – Allan Hicks, IPHC, Aug 17, 2021, *pers. comm.*

Previous rockfish stock assessments using the Awatea platform (from 2011) adopted the Francis (2011) reweighting approach – adding series-specific process error to abundance index CVs on the first reweight, and iteratively reweighting age frequency (composition data) sample size by mean age on the first and subsequent reweights.

E.6.2.1. Abundance

For abundance data (survey indices, commercial CPUE indices), Francis (2011) recommends reweighting observed coefficients of variation, c_0, by first adding process error c_p ~ 0.2 to give a reweighted coefficient of variation

$$c_1 = \sqrt{c_0^2 + c_\mathsf{p}^2}\ . \tag{E.56}$$

Survey abundance indices for POP exhibited moderate relative error, and so no additional error c_p was added to these indices.

This stock assessment did not use commercial CPUE because POP is targeted by the trawl fleet, and because the survey indices provided sufficient signals on abundance.

For stock assessments using commercial CPUE, a procedure was developed for estimating process error c_p to add to CPUE indices based on a spline-smoother analysis (Starr and Haigh 2021*a*). The idea for this analysis came from Francis (2011), citing Clark and Hare (2006), who recommended using a smoothing function to determine the appropriate level of process error to add to CPUE data, with the goal of finding a balance between rigorously fitting the indices while not removing the majority of the signal in the data. The equation for process error c_p used in BC offshore rockfish stock assessments is:

$$c_\mathsf{p} = \sqrt{\frac{\rho_k}{N-2}}\ \left[\frac{1}{N}\sum_{t=1996}^{2023} I_t\right]^{-1}, \tag{E.57}$$

where ρ_k = residual sum of squares at inflection point k after fitting a spline smoother with a range of degrees of freedom v_i = 2 to N, N = number of CPUE values from t=1996 to 2023, and I_t = CPUE index at time t.

E.6.2.2. Composition

In a previous stock assessment (Starr and Haigh 2023), composition data were reweighted using the Dirichlet-Multinomial distribution available in SS3 (Thorson et al. 2017). This approach adds an estimable parameter (θ) which automatically scales the input sample size as part of the likelihood.

> “In consultation with Jim Thorson, Ian Taylor proposed a normal $\mathcal{N}$(0,1.813) prior for the `ln(DM_parm)` parameters to counteract the effect of the logistic transformation between this parameter and the data weighting. The 1.813 value was calculated as the standard deviation of the distribution of $\log(\theta)$ values derived from starting with a uniform distribution on the weights, weight = $\theta/(1+\theta) \sim \mathcal{U}(0,1)$, and solving for $\log(\theta)$.”
>
> – Methot et al. (2021), *Data Weighting*

If the calculated weight $\theta/(1+\theta)$ ratio is close to 1.0, the model is trying to tune the sample size as high as possible. In this case, Methot et al. (2021) suggest fixing the $\log$ DM θ parameter to a high value, like the upper bound of 20, which will result in 100% weight being applied to the input sample sizes. One caveat of using the $\log$ DM θ parameter is that it does not allow weights above 100% (by design).

E.6.2.3. Selection of the Francis procedure for the base run

The SS3 platform provides three options for weighting compositional data: the Francis (2011) mean-age procedure, the McAllister and Ianelli (1997) harmonic-mean procedure, and the self-weighting Dirichlet-Multinomial (D-M) option (Thorson et al. 2017), which estimates a weighting parameter for each compositional dataset. Two of these procedures have been used in recent BC stock assessments: the D-M parameterisation for Canary Rockfish (Starr and Haigh 2023) and the McAllister and Ianelli (1997) harmonic-mean procedure for Yellowmouth Rockfish (Starr and Haigh 2022*c*). Due to its ease of use, the D-M parameterisation was favoured initially for the 2023 POP multi-area stock assessment; however, the MCMC posterior for the $\mathring{p}_{\alpha=2}$ (`Rdist_area(2)`, 3CD) parameter (see Table E.1 and Section E.4.12.) showed occasional excursions into implausibly high values, given the underlying data for the associated area. Despite this, the bulk of the $\mathring{p}_{\alpha=2}$ posterior distribution was in a credible region, which allowed provisional acceptance of this model. On the other hand, the MCMC posterior for the same parameter in a model weighted using the Francis (2011) procedure, but otherwise using the same data and parameterisation as the D-M model (and using the Multinomial to fit AFs), was stable and showed no equivalent excursions to excessively large values.

Examination of the MCMC posterior estimates for the D-M θ parameter (Section E.6.2.2.) showed that, while none approached the nominal upper bound of 10, the bulk of the distribution was between 5 and 6 (in natural log space), resulting in the model giving nearly full weight to the age frequency data. It was suggested that this behaviour was due to the practice of using the number of sampled tows as the initial value for the compositional sample weight, resulting in relatively low sample weights for the AF data. Unlike the Francis (2011) procedure, the D-M procedure cannot upweight compositional data. Consequently, if the AF data are highly informative, the D-M procedure will estimate large values for θ, thus giving full weight to the compositional data (Section E.6.2.2.). In order to test the proposition that the initial sample weights were affecting the θ parameter estimates, sample sizes using the number of age structures (otoliths) were tested. Both models were repeated, one using the D-M procedure and the other using the Francis (2011) procedure (Table E.5).

Column 3 (Francis) and column 5 (Dirichlet) in Table E.5 demonstrate that the switch to the larger sample sizes determined from the number of otoliths was effective, with a strong drop in the Francis weights compared to the original values and a considerable drop in the estimated θ parameters for each AF data set. However, there was a loss of fit to the WCHG synoptic survey (likelihood rose from -4.4 to +6.2) by the second D-M model (although the likelihoods for the other two synoptic surveys did not change) while the two Francis models had similar fits to all three synoptic surveys.

More problematic was the shift in the distribution of biomass among the three areas estimated by the two D-M models. Table E.6 shows that the total B_0 estimate for the sum of the three stocks dropped by nearly 40% between the two D-M runs, with similar proportional drops for B_0 in each area. B_{2024} also dropped between the two D-M runs, but by different levels in each of the three areas, leading to widely differing estimates of status relative to B_0. These stock depletion estimates differed greatly from the D-M model estimates based on the low sample weights and from either of the Francis (2011) reweight estimates. On the other hand, the Francis (2011) reweight method appeared to be stable, returning similar estimates of B_0, B_{2024}, and B_{2024}/B_0 for all three areas under either of the two weighting options (Table E.6). This result gave confidence in the results generated by the Francis (2011) procedure and caused a switch to the

Francis (2011) model as the base run, with the D-M model being relegated to a sensitivity run S01 (R17v18).

Table E.5. Francis (2011) reweight multiplier values for each AF data set for tow-based and otolith-based sample weights. Dirichlet-Multinomial MPD theta (θ) parameter estimates for the same AF data sets and using the tow-based and otolith-based sample weights are shown in the final two columns.

	Francis multiplier		**D-M θ estimates**	
SS3 fleet	samples as # tows	samples as # otoliths	samples as # tows	samples as # otoliths
Trawl 5ABC	2.7923	0.0486	6.945	-0.9737
Trawl 3CD	3.1274	0.0479	6.638	-0.0746
Trawl 5DE	2.8821	0.0462	6.792	-0.6878
QCS synoptic	0.5744	0.0197	5.877	-0.6305
WCVI synoptic	1.0766	0.0521	5.727	-0.4936
WCHG synoptic	1.2071	0.0951	6.018	0.7567
GIG historical	0.7348	0.0330	4.642	-1.1028
NMFS triennial	0.4874	0.0173	5.447	-0.3869

Table E.6. MPD estimates of stock size at equilibrium and at the beginning of 2024, and stock depletion for the same runs as reported in Table E.5. Note that biomass estimates have been rounded to nearest 100 t.

	Francis multiplier		**D-M θ estimates**	
Area	samples as # tows	samples as # otoliths	samples as # tows	samples as # otoliths
B_0 – female spawning biomass at unfished equilibrium				
5ABC	56,000	54,500	66,400	41,300
3CD	18,700	18,100	22,600	13,400
5DE	18,900	18,300	21,400	13,300
Coastwide	93,600	90,900	110,400	68,000
B_{2024} – female spawning biomass in current year of model				
5ABC	26,500	26,500	33,200	23,500
3CD	11,200	10,200	15,700	13,500
5DE	12,000	12,100	13,400	16,100
Coastwide	49,700	48,700	62,300	53,100
B_{2024}/B_0 – female spawning biomass depletion				
5ABC	0.474	0.485	0.501	0.568
3CD	0.597	0.563	0.692	1.010
5DE	0.635	0.662	0.626	1.220
Coastwide	0.531	0.536	0.564	0.781

E.6.3. Prior distributions

Descriptions of the prior distributions for the estimated parameters (without including recruitment deviations) are given in Table E.4. A wide normal prior $\mathcal{N}$(10,10) was used for $\log R_0$; this often provides more stability in the model than using a uniform prior without affecting the estimation process. Steepness was estimated using a beta distribution, with priors generated by Forrest et al. (2010): β(0.67,0.17). Catchability parameters q_g were determined analytically by SS3 (using `float=1`).

Natural mortality priors, which were based loosely on MCMC medians from Table 1 of the 5ABC POP assessment in 2017 (Haigh et al. 2018), used a normal prior of $\mathcal{N}$(0.06,0,018) for both sexes in the base run of the current stock assessment. For two of the area-based models, priors on M were tightened to achieve acceptable MCMC diagnostics (5ABC model used a 20% CV, 3CD model used a 10% CV).

Selectivity prior means were initially based on MCMC medians estimated from three previous POP stock assessments: Table 1 in Haigh et al. (2018) for 5ABC, Table G.2 in Edwards et al. (2014*b*) for 3CD, and Table G.2 in Edwards et al. (2014*a*) for 5DE, and applying a 30% CV. During the evolution of model runs, these normal priors were generalised and broadened to emulate the pseudo-uniform prior on $\log R_0$. The priors used for μ_g were set to $\mathcal{N}$(10,10) for the fisheries and $\mathcal{N}$(12,12) for the surveys. Similarly, the priors for $\log v_{\mathsf{L}g}$ were set to $\mathcal{N}$(2,2) for the fisheries and $\mathcal{N}$(2.5,2.5) for the surveys. These did not work well for three of the surveys due to noisy AF data, and so the priors for WCHG synoptic, GIG historical, and NMFS triennial were tightened to $\mathcal{N}$(12,3.6) for μ and $\mathcal{N}$(2.5,0.75) for $\log v_{\mathsf{L}}$.

E.6.4. MCMC properties

The MCMC procedure used the 'no U-turn sampling' (NUTS) algorithm (Monnahan and Kristensen 2018; Monnahan et al. 2019) to produce {40,000 (for base-model) | 40,000 (for area-model) | 20,000 (for sensitivity)} iterations, parsing the workload into 8 parallel chains (using the R package `snowfall`, Knaus 2015). For each chain, {5,000 (base) | 5,000 (area) | 2,500 (sens)} iterations were performed, discarding the first {2,500 (base) | 2,500 (area) | 1,250 (sens)} samples as a 'burn-in', leaving the final {2,500 (base) | 2,500 (area) | 1,250 (sens)} samples for use in the MCMC analysis. The parallel chains were then merged for a total of {20,000 (base) | 20,000 (area) | 10,000 (sens)} samples to approximate the posterior distribution. For the base and area runs, an excess of samples were thinned every {10 (base) | 10 (area) | 5 (sens)} samples; sensitivity runs were not thinned because sampling was not prolonged. Code (bash and R) was supplied by Chris Grandin (DFO, pers. comm. 2023) to perform the MCMC simulations on a remote Linux server.

E.7. REFERENCE POINTS, PROJECTIONS, AND ADVICE TO MANAGERS

Advice to managers is given with respect to a suite of reference points. The first set is based on MSY (maximum sustainable yield) and includes the provisional reference points of the DFO Precautionary Approach (DFO 2006), namely 0.4B_{MSY} and 0.8B_{MSY} (and also provided are B_{MSY} and u_{MSY}, which denote the estimated equilibrium spawning biomass and harvest rate at MSY, respectively). A second set of reference points, based on the current spawning biomass B_{2024} and harvest rate u_{2023}, is used to show the probability of the stock size increasing from the current female spawning biomass or decreasing from the current harvest rate. A third set of reference points, based on B_0 (the estimated unfished equilibrium spawning biomass) is provided as an alternative to the B_{MSY} reference points. See main text for further discussion.

The probability P($B_{2024} > 0.4B_{\mathsf{MSY}}$) is calculated as the proportion of the {20,000 (base) | 20,000 (area) | 10,000 (sens)} MCMC samples (after thinning) for which $B_{2024} > 0.4B_{\mathsf{MSY}}$ (and similarly for the other biomass-based reference points). For harvest rates, the probability P($u_{2023} < u_{\mathsf{MSY}}$) is calculated so that both B- and u-based stock status indicators (and projections when $t = 2025, ..., 2034$) state the probability of being in a 'good' place.

Projections were made for 11 years starting with the biomass for the start of 2024. All derived values in SS3 are for a start-of-year time period. Therefore, if the end year in the data file is specified as 2023, derived quantities like spawning biomass B_t are estimated to start of year 2023. By default, SS3 will project forward at least one year so that catch in 2023 can be applied and derived quantities will be generated for 2024 (one-year forecast). Therefore, in the file `forecast.ss`, a user needs to specify the current year plus any additional forecast years (e.g., a 10-yr forecast would need 11 specified catches from 2024 to 2034). Additionally, if a user needs generational forecasts (e.g, three POP generations = 75 years), then 76 forecast years need to be specified before any MCMC runs are attempted.

For decision tables, a range of constant catch strategies were used, from 0 to {3,500 t (5ABC) | 1,250 t (3CD) | 1,500 t (5DE)} at various increments. Recruitments were randomly calculated using (E.33) (i.e. based on lognormal recruitment deviations from the estimated stock-recruitment curve), using randomly generated values of ϵ_t ~ Normal$(0, \sigma_R^2)$. Unfortunately, SS3 calculates projected recruitment deviations at the time of the MCMC runs and so the user should be aware that changing the catch policy after the MCMCs had been performed is not possible. In Awatea, the `-mceval` switch can generate a user-specified time series of $\{\epsilon_t\}$ for each of the MCMC samples, which means that different catch policies can be generated after the MCMC analysis.

E.8. SS3 INPUTS

Input files for each model run are hosted on Github in the code repository PBSsynth. The file names comprise '`starter.ss`', '`forecast.ss`', '`data.xx.yy.ss`', and '`control.xx.yy.ss`', where xx = run number and yy = reweight number.

Synopsis of runs:
  00ReadMe.txt – Information on the runs used in 2023 POP

Base run:
  Run21v3 – BC coastwide multi-area model

Area runs:
  Run24v1 – 5ABC single-area model
  Run25v1 – 3CD single-area model
  Run26v1 – 5DE single-area model

Sensitivity runs (MCMC):
  S01.R17v18 – use Dirichlet-multinomial parameterisation
  S02.R27v1 – fix parameter Rdist for 5ABC to 0
  S03.R28v1 – fix parameter Rdist for 3CD to 0
  S04.R29v1 – apply no ageing error
  S05.R30v1 – use smoothed ageing error from age-reader CVs
  S06.R31v1 – use constant-CV ageing error
  S07.R32v1 – reduce commercial catch (1965-95) by 30%
  S08.R33v1 – increase commercial catch (1965-95) by 50%
  S09.R34v1 – reduce sigmaR to 0.6 (from 0.9)
  S10.R35v1 – increase sigmaR to 1.2 (from 0.9)
Sensitivity runs (MPD):
  S11.R22v2 – use separate midwater and bottom trawl fleets for 3CD and 5ABC
  S12.R36v2 – add HS synoptic survey to 5DE
  S13.R37v1 – use empirical proportions mature instead of MLE fit

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APPENDIX F. MODEL RESULTS

F.1. INTRODUCTION

This appendix describes model results for a coastwide stock of Pacific Ocean Perch (POP, *Sebastes alutus*) that spans the outer BC coast, covering PMFC areas 5ABC (central), 3CD (south), and 5DE (north). The central coast subarea (5ABC) hosts the largest POP population, which has been the focus of historical stock assessments (last one in 2017, Haigh et al. 2018). The smaller-population subareas (3CD and 5DE) have been assessed only once (in 2012, Edwards et al. 2014*a*,*b*).

A multi-area model for three subareas was run using the Stock Synthesis 3 (SS3) platform, v.3.30.20 (Methot et al. 2022, see also Appendix E for model details). Model results include:

- mode of the posterior distribution (MPD, also called maximum posterior density, and synonymous with maximum likelihood estimate [MLE]) calculations, when prior contributions to the likelihood are included, to compare model estimates to observations;
- Markov chain Monte Carlo (MCMC) simulations to derive posterior distributions for the estimated parameters for a base run;
- MCMC diagnostics for the base run; and
- a range of sensitivity model runs, including their MCMC diagnostics.

MCMC diagnostics are evaluated using the following subjective criteria:

- Good – no trend in traces and no spikes in $\log R_0$, split-chains align, no autocorrelation;
- Fair – trace trend temporarily interrupted, occasional spikes in $\log R_0$, split-chains somewhat frayed, some autocorrelation;
- Poor – trace trend fluctuates substantially or shows a persistent increase/decrease, split-chains differ from each other, substantial autocorrelation;
- Unacceptable – trace trend shows a persistent increase/decrease that has not levelled, split-chains differ markedly from each other, persistent autocorrelation.

The final advice consists of a single base run that estimates natural mortality (M) and steepness (h). A range of sensitivity runs are presented to show the effect of the important modelling assumptions. Additionally, single-area model runs, which treat each subarea as independent stocks, for 5ABC (area 1), 3CD (area 2), and 5DE (area 3) are presented to confirm subarea results found by the base run's multi-area model. Estimates of major quantities and advice to management (subarea decision tables) are presented here and in the main text.

Throughout this appendix, model runs are identified by combinations of run, reweight, and version (e.g., 21.01.v3). MCMCs are distinguished from MPDs by a letter suffix after the version. For example, the base run MPD is called 'R21.01.v3' and the subsequent MCMC is called 'R21.01.v3a', where 'a' designates the first MCMC simulation. Often, run labels drop the decimals and the reweight component for a cleaner look (e.g., R21v3a).

F.2. PACIFIC OCEAN PERCH

The base run (21.01.v3a) for POP 2023 was selected after running a range of preliminary models. The start year of the model was 1935 and the end year was 2023 (with catch in 2023 set to the value in 2022).

The key model assumptions/inputs for the base run of the stock assessment model:

- delineated three stocks by subarea, corresponding to PMFC boundaries 5ABC, 3CD, and 5DE (Figure 1), with shared coastwide recruitment;
- used sex-specific (female, male) parameters;
- adopted nine SS3 fleets (three fisheries, six surveys):
  (1) 5ABC = commercial fishery in PMFC area 5ABC,
  (2) 3CD = commercial fishery in PMFC area 3CD,
  (3) 5DE = commercial fishery in PMFC area 5DE,
  (4) QCS = Queen Charlotte Sound synoptic survey,
  (5) WCVI = west coast Vancouver Island synoptic survey,
  (6) WCHG = west coast Haida Gwaii synoptic survey,
  (7) GIG = Goose Island Gully historical survey,
  (8) NMFS = US National Marine Fisheries Service triennial survey, and
  (9) WCVI′ = west coast Vancouver Island historical survey;
- used survey series abundance indices (six fleets) by year (y):
  - three synoptic bottom trawl surveys
    QCS (11y, spanning 2003 to 2021),
    WCVI (10y, spanning 2004 to 2022),
    WCHG (10y, spanning 1997 to 2022);
  - three historical bottom trawl surveys
    GIG (8y, spanning 1967 to 1994),
    NMFS (7y, spanning 1980 to 2001),
    WCVI′ (4y, spanning 1967 to 1970);
  - no commercial bottom trawl CPUE used for POP;
- used proportions-at-age data (eight fleets) by year (y):
  - 5ABC (43y, spanning 1977 to 2019),
  - 3CD (27y, spanning 1980 to 2019),
  - 5DE (33y, spanning 1978 to 2017),
  - QCS (11y, spanning 2003 to 2021),
  - WCVI (11y, spanning 1996 to 2022),
  - WCHG (10y, spanning 1997 to 2022),
  - GIG (3y, spanning 1984 to 1995),
  - NMFS (5y, spanning 1989 to 2001);
- set accumulator age A = 60 (pooled age for ages $a \geq$ 60);
- used an ageing error vector of smoothed standard deviations derived from CVs of observed lengths-at-age;
- added no process error to the abundance indices;
- used the Francis (2011) mean-age reweighting method for adjusting sample sizes in the composition data;
- fit age frequncy (AF) data using the Multinomial error distribution;
- used a model-derived analytical solution for the abundance series scaling parameters (q_g), where q values are not estimated as active parameters (Methot et al. 2022);
- assumed a wide (weak) normal prior $\mathcal{N}(10, 10)$ on $\log R_0$ to help stabilise the model;
- used wide normal priors for the three primary selectivity parameters (μ_g, $v_{g\mathsf{L}}$, Δ_g) for most fleets (see Table E.4);
- fixed the standard deviation of recruitment residuals (σ_R) to 0.9.

The leading estimated parameters for the base run of the stock assessment model included:

- unfished, equilibrium recruitment of age-0 fish, LN(R_0);

- natural mortality rate (M) per sex to represent all ages over time;
- steepness parameter (h) for Beverton-Holt recruitment;
- selectivity parameters (β_1 = μ, β_3 = $\log v_L$, $\Delta 1$ = Δ) for the 5ABC commercial fishery (3CD and 5DE fisheries adopted 5ABC selectivity) and for each of the survey series (WCVI historical adopted GIG historical selectivity);
- main recruitment deviations from 1935 to 2014 (using simple deviations without the sum-to-zero constraint) and late recruitment deviations (2015-2023);
- `Rdist_area(1)` and `Rdist_area(2)`: proportion recruitment (in natural log space) allocated to areas 1 (5ABC) and 2 (3CD) relative to fixed area 3 (5DE).

F.2.1. Multi-area Model

F.2.1.1. MPD fits

The modelling procedure first determined the best fit (MPD = mode of posterior distribution, also called the maximum likelihood estimate, or MLE, in SS3) to the data by minimising the negative log likelihood. The MPD was used as the starting point for the MCMC simulations.

The following plot references apply to the base run.

- Figure F.1 – parameter fits showing the MLE and the prior distributions;
- Figure F.2-F.3 – model fits and residuals to the survey indices across observed years;
- Figures F.4-F.19 – model fits to the female and male age frequency data for three fishery and five survey data sets along with respective standardised residuals of model fits;
- Figure F.20 – model estimates of mean age compared to the observed mean ages;
- Figure F.21 – estimated gear selectivity by fleet, together with the ogive for female maturity;
- Figure F.22 – time series of female spawning biomass depletion and exploitation rate;
- Figure F.23 – time series of recruitment and areal distribution of recruitment;
- Figure F.24 – recruitment deviations and stock-recruitment curve.

Both natural mortality (M) and steepness (h) were estimated without difficulty, there being only weak correlation between these two parameters (see Section F.2.1.2.). This eliminated the requirement used in some previous stock assessments where multiple runs using fixed M values were needed to build a composite base case that covered a plausible range of values for this parameter. The MPD value (in Table F.1) for female natural mortality (M=0.046) shifted lower than the prior mean value (M=0.06), as did the male MPD (M=0.053). Steepness was estimated to be much higher at 0.82 than the prior mean (h=0.67). The MPD values for the selectivity parameter age-at-full selectivity (μ_g) for the 5ABC trawl fishery and for the synoptic surveys all shifted higher than their prior values, whereas the MPD values for the historical surveys all shifted lower than their prior values (Table F.1). However, this stock assessment only used the Bayesian estimates for parameters and derived quantities for advice (Section F.2.1.2.).

Model fits to the survey abundance indices were generally satisfactory (Figure F.2), although some annual indices were missed entirely (e.g., 2004 and 2010 in WCVI synoptic; 2010 in WCHG synoptic; 1973, 1977, and 1994 in GIG historical; 1980 and 1983 in NMFS triennial; 1968 and 1969 WCVI historical). These coincide with the years when standardised residuals for survey fits exceeded 2 standard deviations (Figure F.3). The synoptic survey abundance series showed increasing trends, especially since 2010, whereas the earlier historical abundance series were either declining or flat. The WCHG series exhibited a dramatic surge in relative abundance over the past decade.

Fits to the 5ABC trawl fishery AF data were reasonable, with the model tracking year classes consistently across the 42-year time span represented by the commercial AF data (Figure F.4). Standardised residuals ranged from -1 to 3 for most age classes (Figure F.5). Age fits for the other two fisheries (3CD and 5DE) tended to be poorer, with some standardised residuals ranging from 4 to 12 (Figures F.6–F.9). Some of this poor fit would have been due to using the 5ABC selectivity to fit the 3CD and 5DE AF data. Better fits to these AF data were obtained by the 3CD and 5DE single-area models, which estimated selectivity functions that were specific to these data (see discussion below). Fits to the survey AFs were acceptable, with a lesser number of extreme standardised residuals than seen in the 3CD and 5DE fishery AF data (Figures F.10–F.19). The survey AF fits tended to have runs of negative residuals for certain age classes (e.g., 10-30 for the QCS females), indicating that the model tended to overestimate these age proportions.

Mean ages appeared to be well tracked (Figure F.20), suggesting that the Francis (2011) reweighting and fitting to the Multinomial were effective. The maturity ogive, generated from an externally fitted model (see Appendix D), was largely situated to the right of the fishery selectivity ogive for ages 9 and older, indicating that immature fish were being harvested by the commercial fishery. The selectivity ogives for the QCS and WCVI synoptic surveys were estimated to the right of the maturity ogive, indicating that these surveys were mainly capturing mature POP. These estimates were probably due to the preponderance of older POP in the AF distributions. In contrast, the selectivity ogives for the WCHG synoptic and the three historical surveys were estimated to the left of the maturity ogive, indicating that these surveys caught sub-mature fish and may have been affected by the high exploitation rates from the 1960s and 1970s.

Female spawning biomass depletion (Figure F.22) showed different trends between the main central population (5ABC) and the outlying areas (3CD to the south and 5DE to the north). In 5ABC, a large recruitment event in 1952 resulted in a spike in biomass in 1965, followed by a sharp decline during the years when foreign fleets targeted POP. The decline was reversed in 1984 when a second strong recruitment occurred in 1976. Biomass increased until 1993, after which it declined until 2014. Thereafter, it increased slowly until the present (2024). In 3CD, peak biomass occurred in 1962, followed by a rapid decline until 1974. The population stayed below 0.4B_0 from 1972 until 2008 (37 years) until it slowly increased to the present. The biomass trend in 5DE showed a similar pattern to that in 3CD, remaining below 0.4B_0 from 1978 to 2014 (37 years) before rising quickly to a peak in 2022, resulting from good recruitment in 2006 and driven by the increasing trend in the abundance index series.

Exploitation rates (u_t) tended to be much higher in the outlying areas than along the central BC coast (Figure F.22). While u_t peaked during the foreign fleet years (1965-1976) in 5ABC, these rates were doubled by those in 3CD and 5DE during the 1980s when the Canadian fleets were fishing at a time when the 3CD and 5DE stock sizes were low.

As mentioned above, recruitment spikes occurred in 1952, 1962, 1976, 1980, 1984, and 2006 in 5ABC. The 1952 spike was by far the largest, and supported the strong foreign fishery along the central BC coast from 1965 on. In the outlying areas, the 1952 peak was allocated to the other areas based primarily on data from 5ABC and, to a lesser extent, from 5DE. The 3CD AF data did not show evidence of this recruitment event because the 3CD AF data from the 1980s do not show any strong year classes, even though they likely occurred. On the other hand, 3CD did show some evidence for a small recruitment spike in 2013, which did not show up in the 5ABC AF data. The benefit of the multi-area model is that regions can take advantage of data sharing, as long as coastwide recruitment represents recruitment at subarea scales. The other single-area models showed some commonality of coastwide recruitment patterns (Section F.2.2.).

F.2.1.1.1. MPD Tables

Table F.1. Base run: Priors and MPD estimates for estimated parameters. Prior information – distributions: 2 = beta, 6 = normal

Parameter	Phase	Range	Type	(Mean,SD)	Initial	MPD
LN(R0)	1	(1, 16)	6	(10, 10)	10	9.546
Rdist area(1)	3	(-5, 5)	6	(0, 1)	0	1.099
Rdist area(2)	3	(-5, 5)	6	(0, 1)	0	-0.011
M Female	4	(0.02, 0.2)	6	(0.06, 0.018)	0.06	0.046
M Male	4	(0.02, 0.2)	6	(0.06, 0.018)	0.06	0.053
BH h	5	(0.2, 1)	2	(0.67, 0.17)	0.67	0.821
mu(1) TRAWL 5ABC	3	(5, 40)	6	(10, 10)	10	11.334
varL(1) TRAWL 5ABC	4	(-15, 15)	6	(2, 2)	2	2.199
delta(1) TRAWL 5ABC	4	(-8, 10)	6	(0, 1)	0	-0.057
mu(4) QCS	3	(5, 40)	6	(12, 12)	12	17.006
varL(4) QCS	4	(-15, 15)	6	(2.5, 2.5)	2.5	4.194
delta(4) QCS	4	(-8, 10)	6	(0, 1)	0	0.027
mu(5) WCVI	3	(5, 40)	6	(12, 12)	12	20.367
varL(5) WCVI	4	(-15, 15)	6	(2.5, 2.5)	2.5	4.707
delta(5) WCVI	4	(-8, 10)	6	(0, 1)	0	0.273
mu(6) WCHG	3	(5, 40)	6	(12, 3.6)	12	12.407
varL(6) WCHG	4	(-15, 15)	6	(2.5, 0.75)	2.5	2.262
delta(6) WCHG	4	(-8, 10)	6	(0, 1)	0	-0.011
mu(7) GIG	3	(0, 40)	6	(12, 3.6)	12	7.707
varL(7) GIG	4	(-15, 15)	6	(2.5, 0.75)	2.5	2.746
delta(7) GIG	4	(-8, 10)	6	(0, 1)	0	-0.329
mu(8) NMFS	3	(0, 40)	6	(12, 3.6)	12	4.815
varL(8) NMFS	4	(-15, 15)	6	(2.5, 0.75)	2.5	2.583
delta(8) NMFS	4	(-8, 10)	6	(0, 1)	0	-0.219

Table F.2. Base run: Likelihood components reported in `likelihoods_used`*.*

Likelihood Component	values	lambdas
TOTAL	1,090	—
Equilibrium catch	0	—
Survey	-7.242	—
Age composition	1,048	—
Recruitment	29.77	1
Initial equilibrium regime	0	1
Forecast recruitment	0.2018	1
Parameter priors	4.916	1
Parameter softbounds	0.002760	—
Parameter deviations	14.90	1
Crash penalty	0	1

Table F.3. Base run: Likelihood components reported in `likelihoods_by_fleet`*. Notation: λ = emphasis factors in the likelihood; $\mathcal{L}$ = negative log likelihood*

Label	ALL	TRWL 5ABC	TRWL 3CD	TRWL 5DE	QCS SYN	WCVI SYN	WCHG SYN	GIG HIS	NMFS TRI	WCVI HIS
Catch λ	—	1	1	1	1	1	1	1	1	1
Catch $\mathcal{L}$	0	0	0	0	0	0	0	0	0	0
Initial EQ λ	—	1	1	1	1	1	1	1	1	1
Initial EQ $\mathcal{L}$	0	0	0	0	0	0	0	0	0	0
Survey λ	—	0	0	0	1	1	1	1	1	1
Survey $\mathcal{L}$	-7.242	0	0	0	-13.69	1.345	-2.832	-4.312	6.772	5.475
Survey N use	—	0	0	0	11	10	10	8	7	4
Survey N skip	—	0	0	0	0	0	0	0	0	0
Age λ	—	1	1	1	1	1	1	1	1	0
Age $\mathcal{L}$	1,048	472.7	170.4	167.8	44.87	95.49	59.20	18.67	18.71	0
Age N use	—	43	27	33	11	11	10	3	5	0
Age N skip	—	0	0	0	0	0	0	0	0	0

F.2.1.1.2. MPD Figures

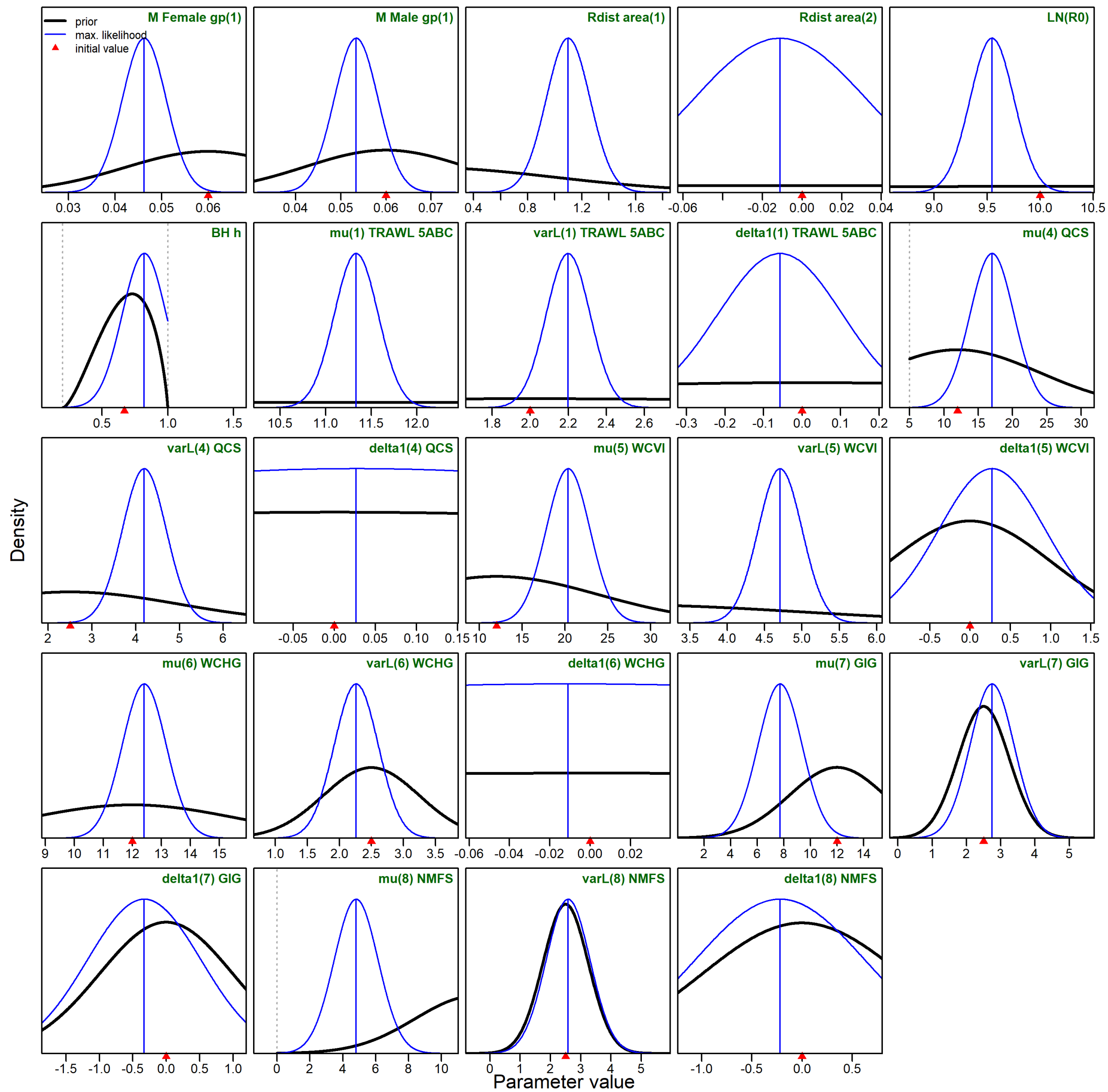


Figure F.1. Base run: likelihood profiles (thin blue curves) and prior density functions (thick black curves) for the estimated parameters. Vertical lines represent the maximum likelihood estimates; red triangles indicate initial values used in the minimization process.

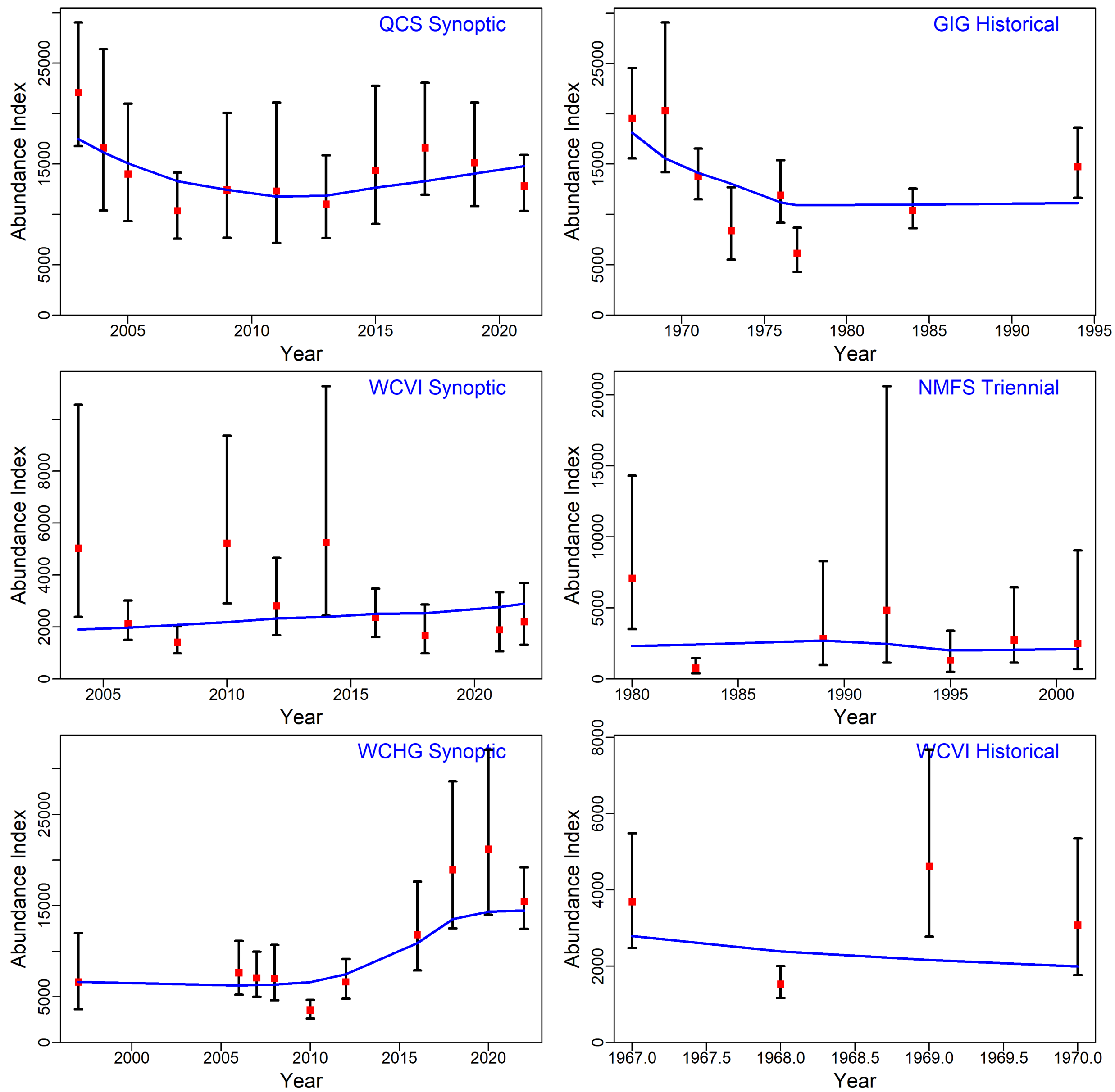


Figure F.2. Base run: survey index values (points) with 95% confidence intervals (bars) and MPD model fits (curves) for the fishery-independent survey series.

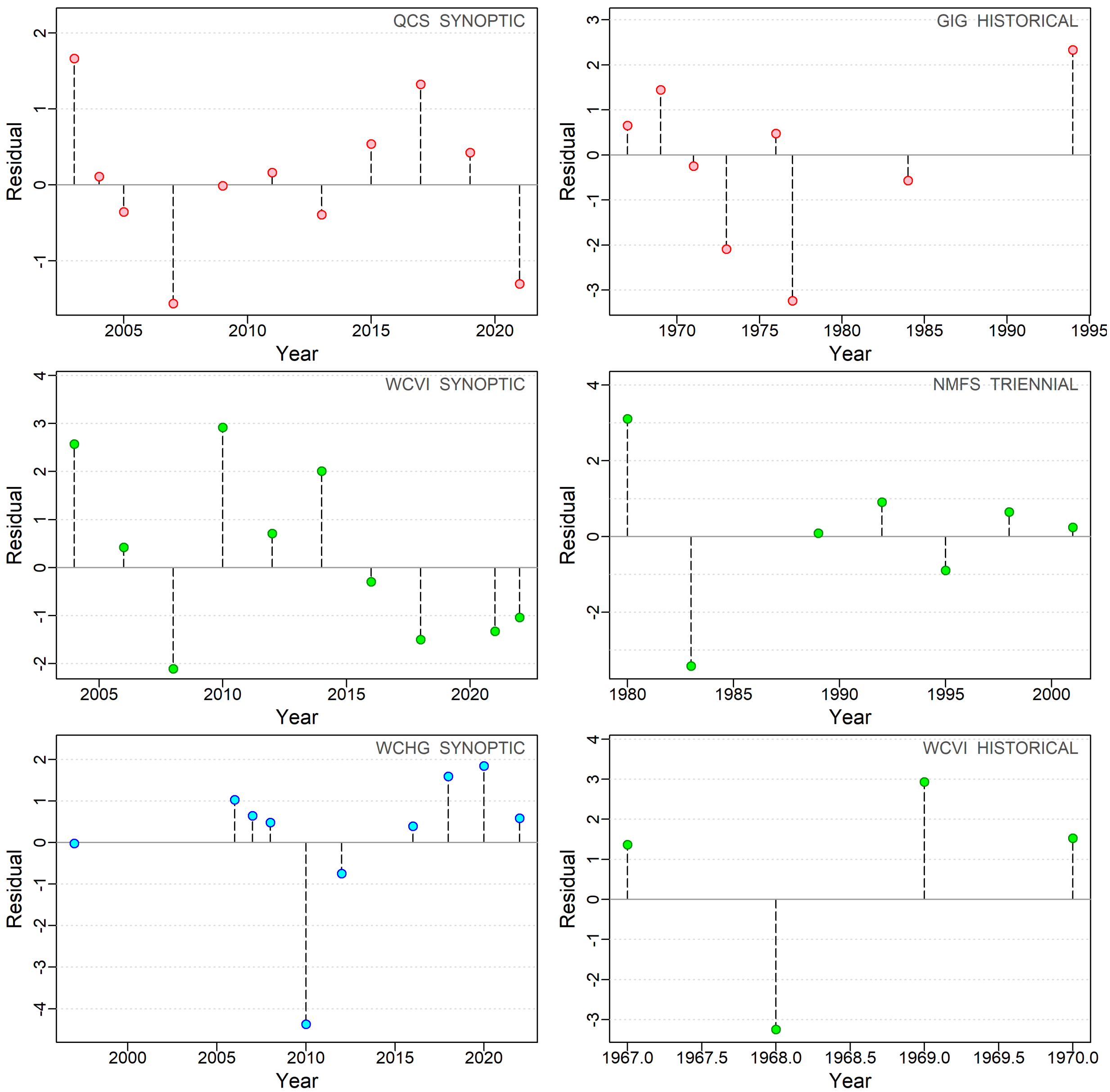


Figure F.3. Base run: survey index residuals calculated as (log(Obs) - log(Exp))/SE, where SE is the total standard error including any estimated additional uncertainty.

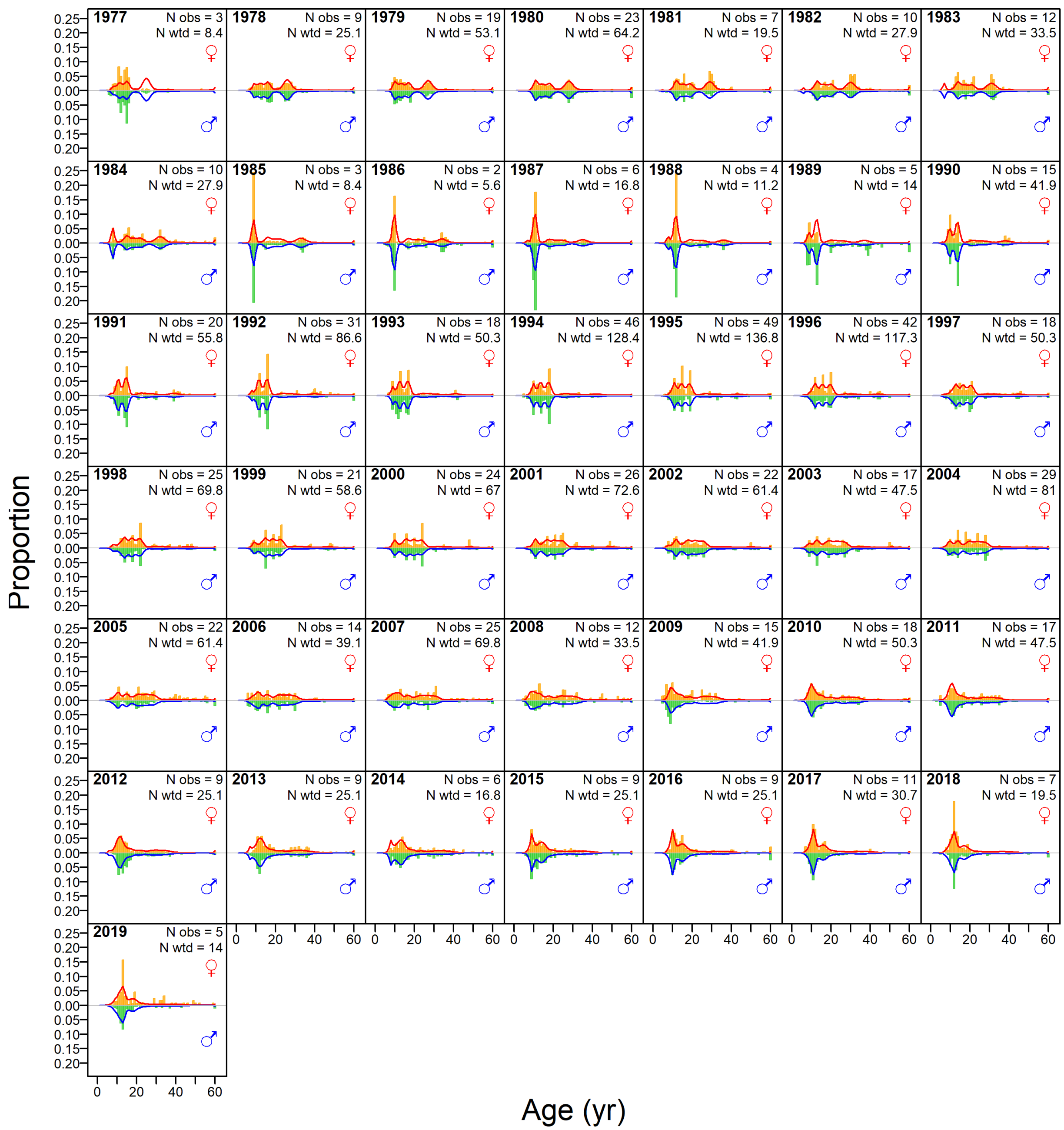


Figure F.4. Base run: 5ABC Trawl Fishery proportions-at-age (bars=observed, lines=predicted) for females and males.

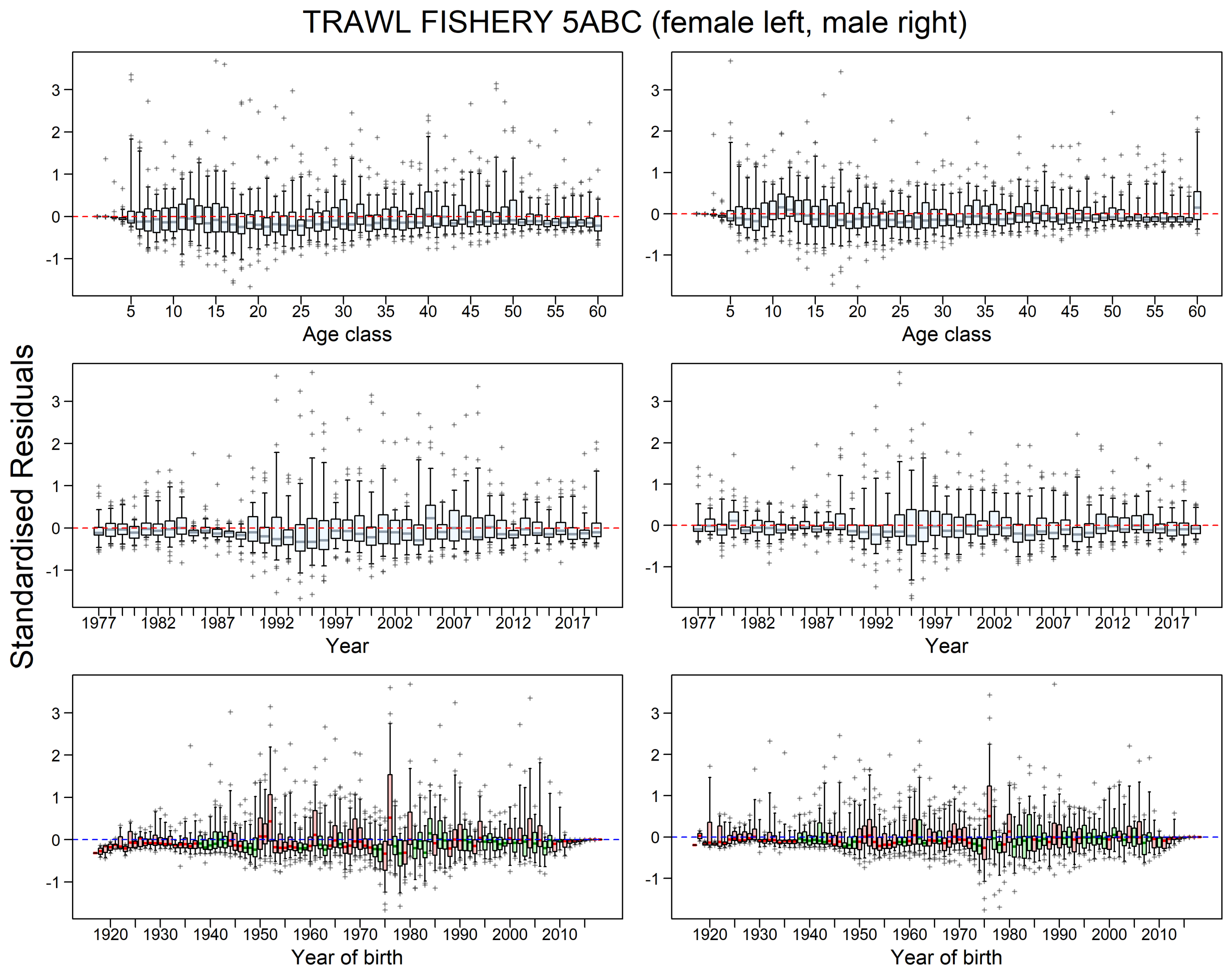


Figure F.5. Base run: 5ABC Trawl Fishery residuals of model fits to proportion-at-age data. Vertical axes are standardised residuals. Boxplots in three panels show residuals by age class, by year of data, and by year of birth (following a cohort through time). Cohort boxes are coloured green if recruitment deviations in birth year are positive, red if negative. Boxes give quantile ranges (0.25-0.75) with horizontal lines at medians, vertical whiskers extend to the the 0.05 and 0.95 quantiles, and outliers appear as plus signs.

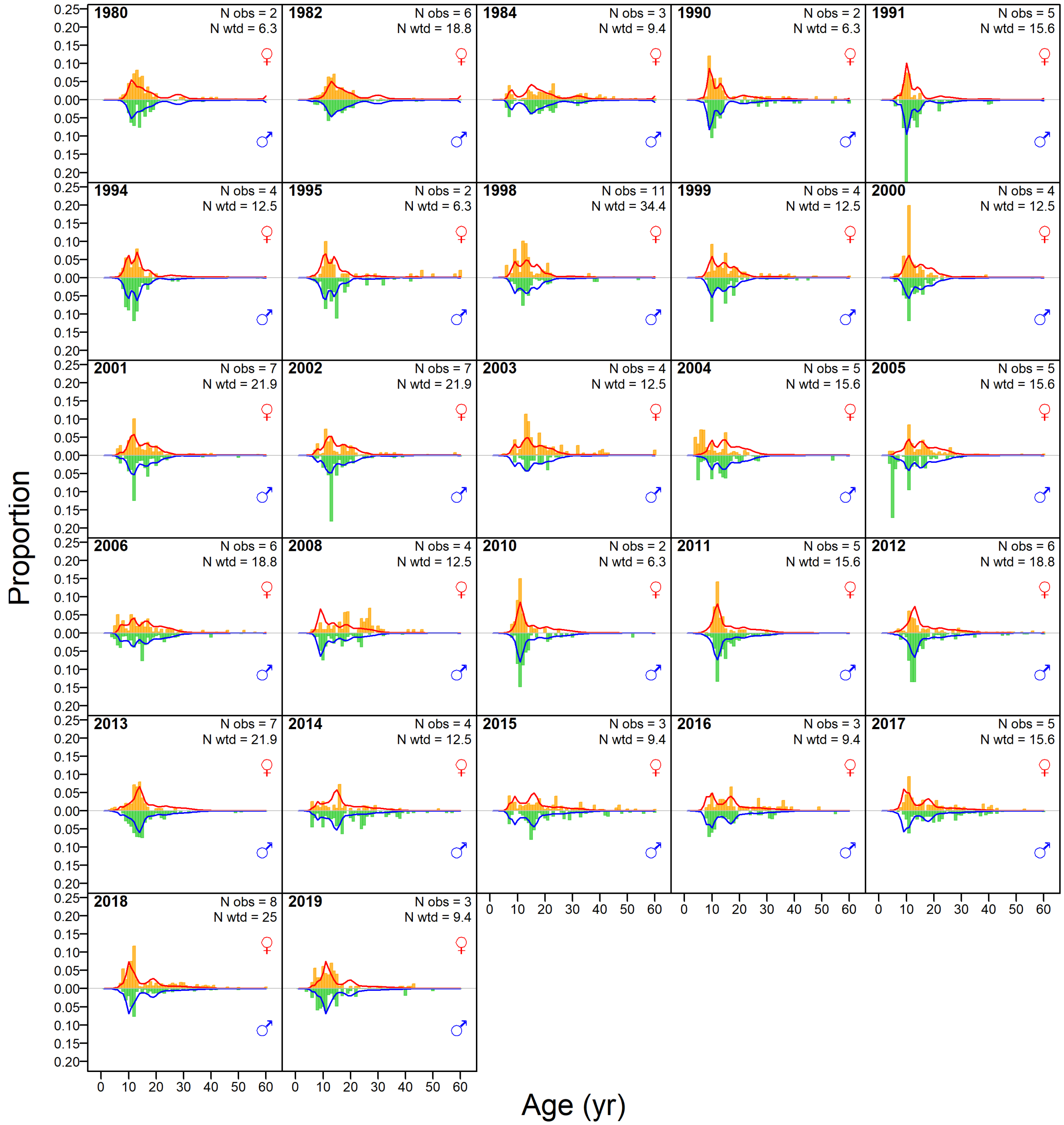


Figure F.6. Base run: 3CD Trawl Fishery proportions-at-age (bars=observed, lines=predicted) for females and males.

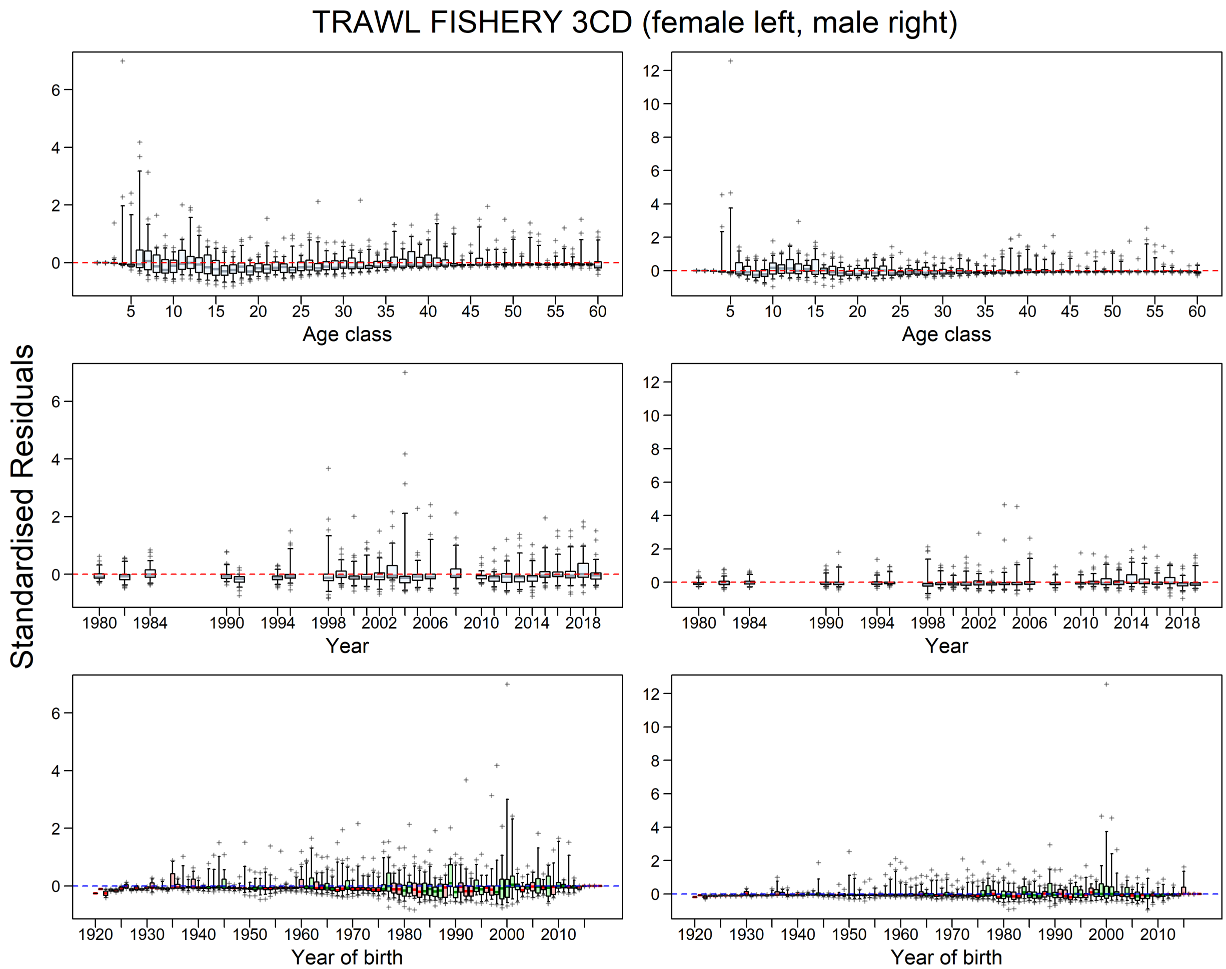


Figure F.7. Base run: 3CD Trawl Fishery residuals of model fits to proportion-at-age data. See Figure F.5 caption for details.

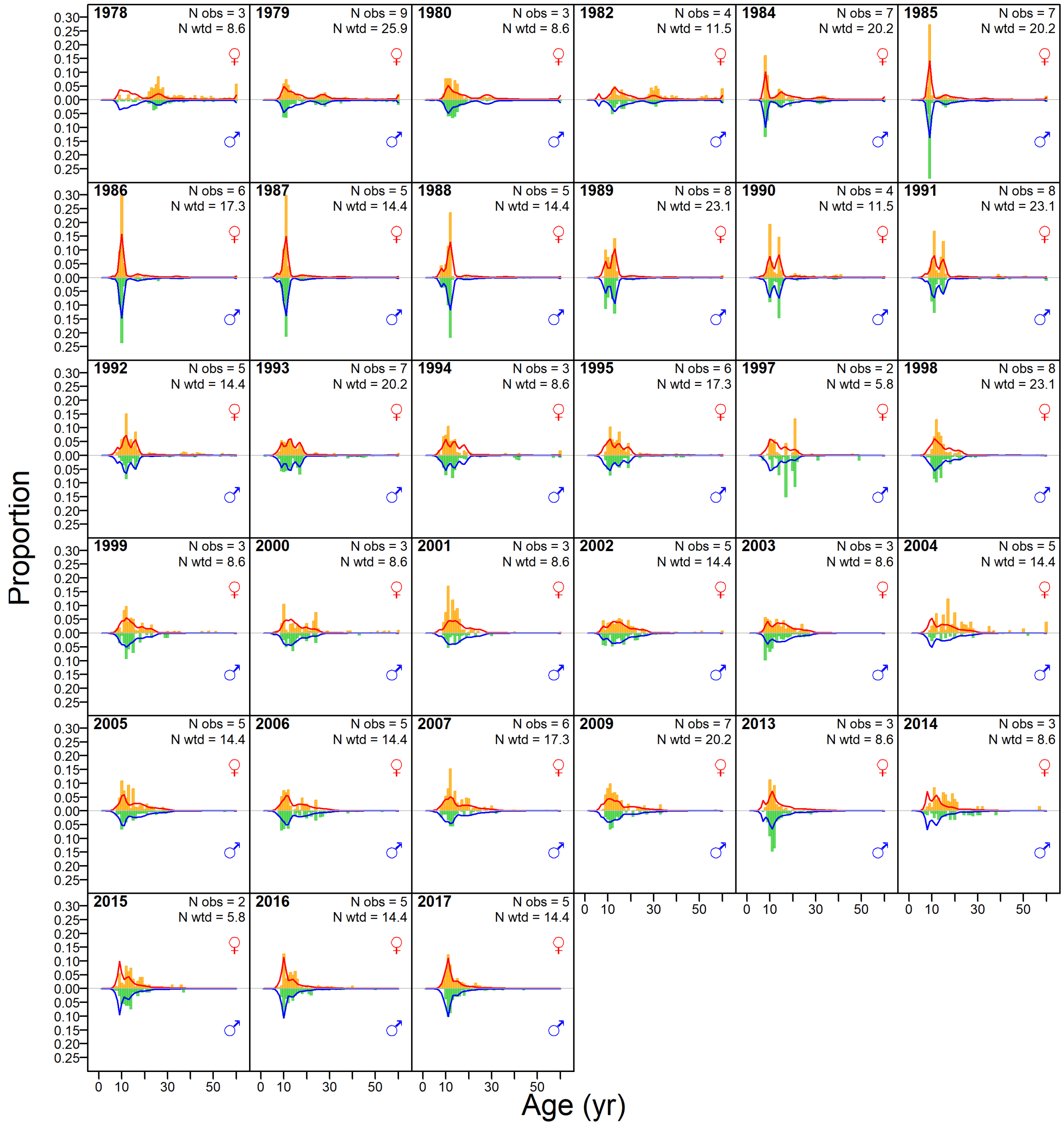


Figure F.8. Base run: 5DE Trawl Fishery proportions-at-age (bars=observed, lines=predicted) for females and males.

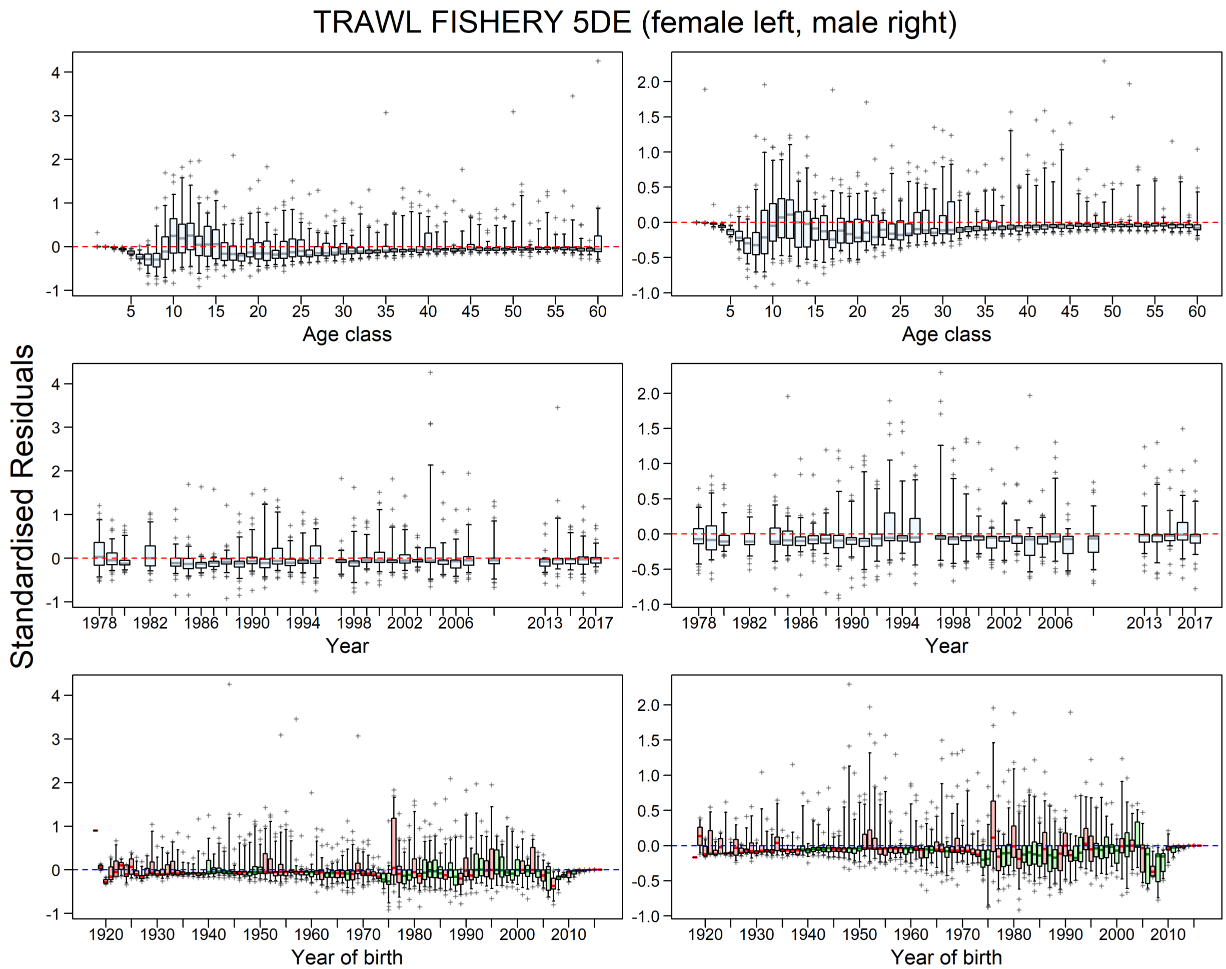


Figure F.9. Base run: 5DE Trawl Fishery residuals of model fits to proportion-at-age data. See Figure F.5 caption for details.

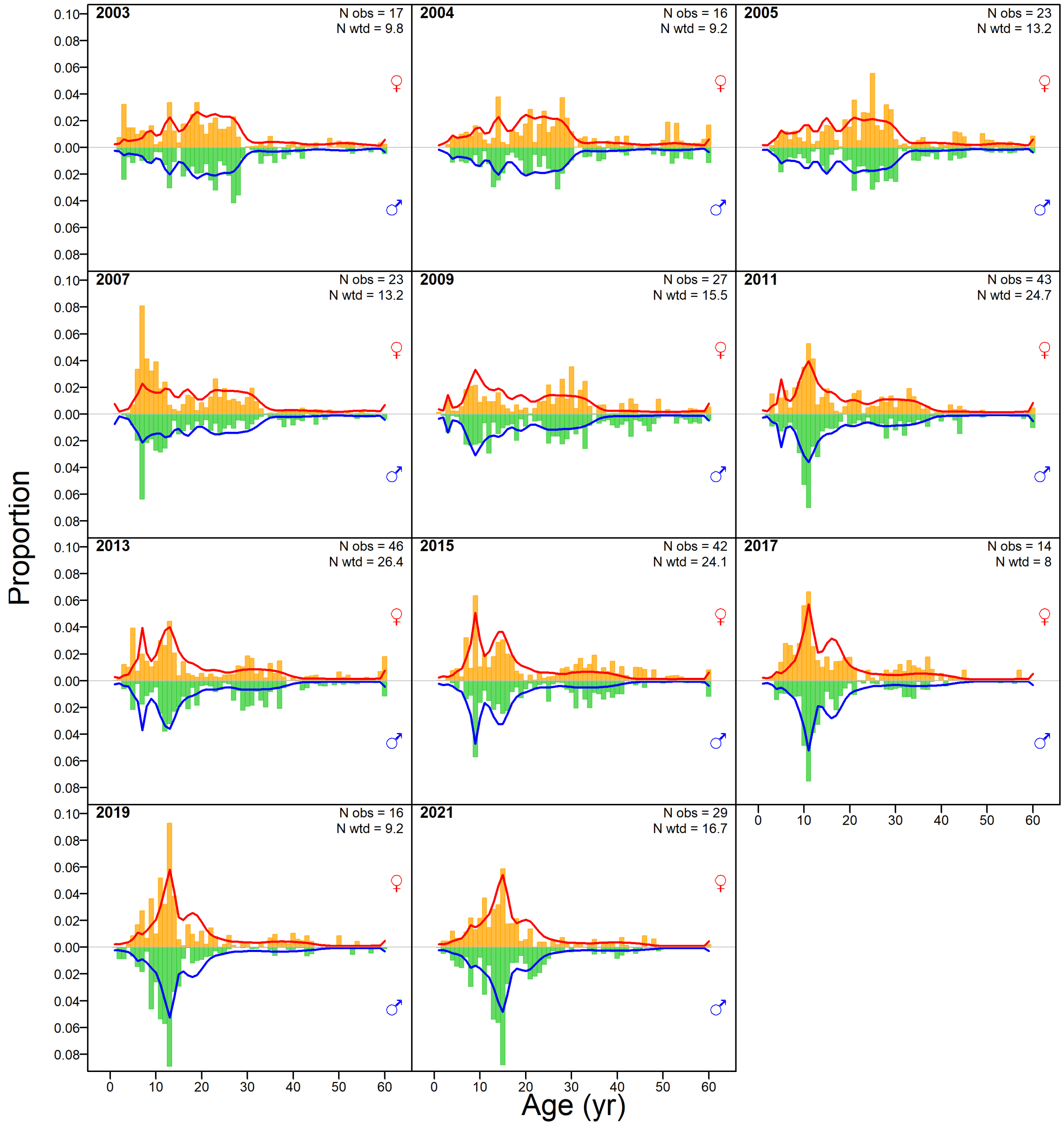


Figure F.10. Base run: QCS Synoptic proportions-at-age (bars=observed, lines=predicted) for females and males.

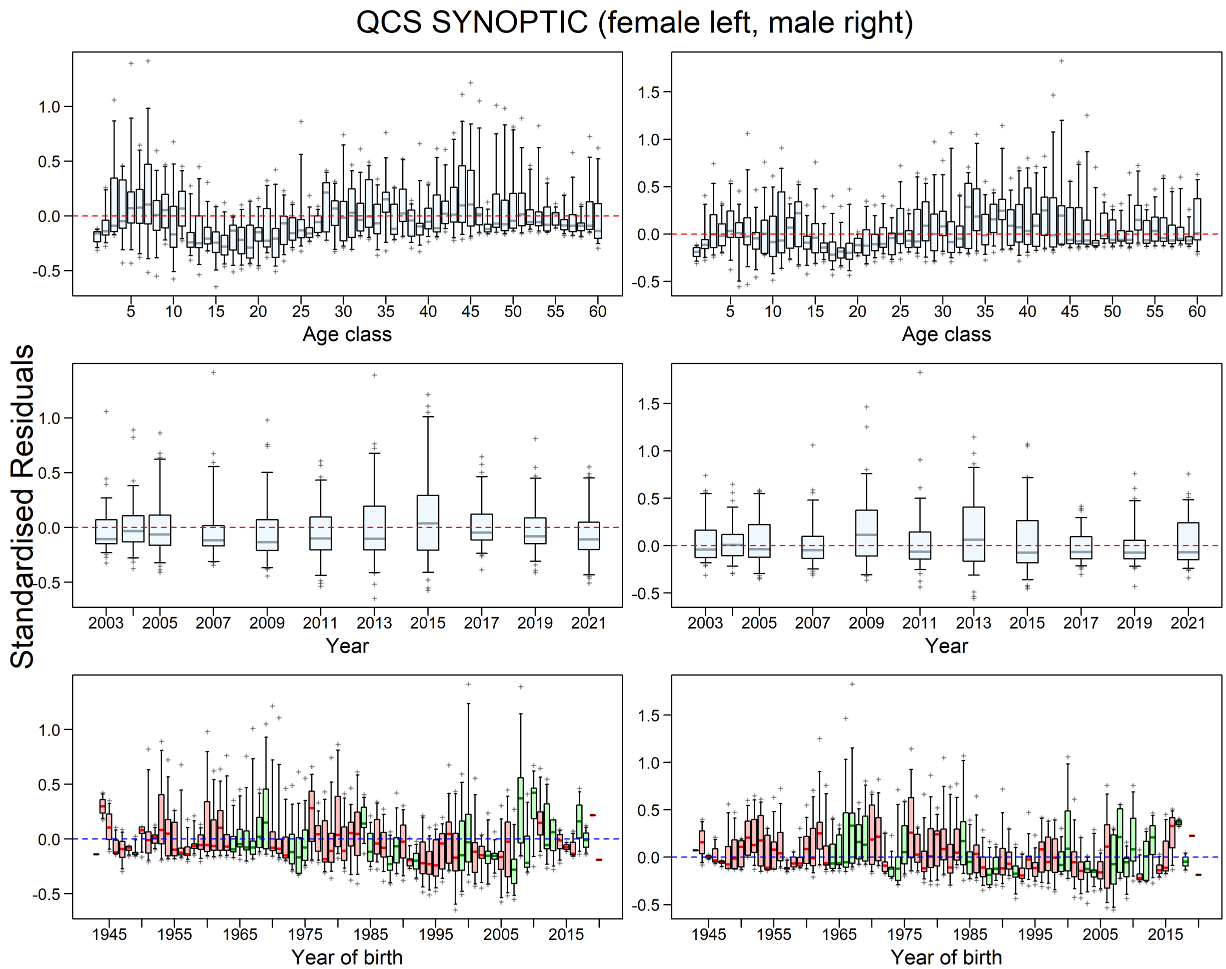


Figure F.11. Base run: QCS Synoptic residuals of model fits to proportion-at-age data. See Figure F.5 caption for details.

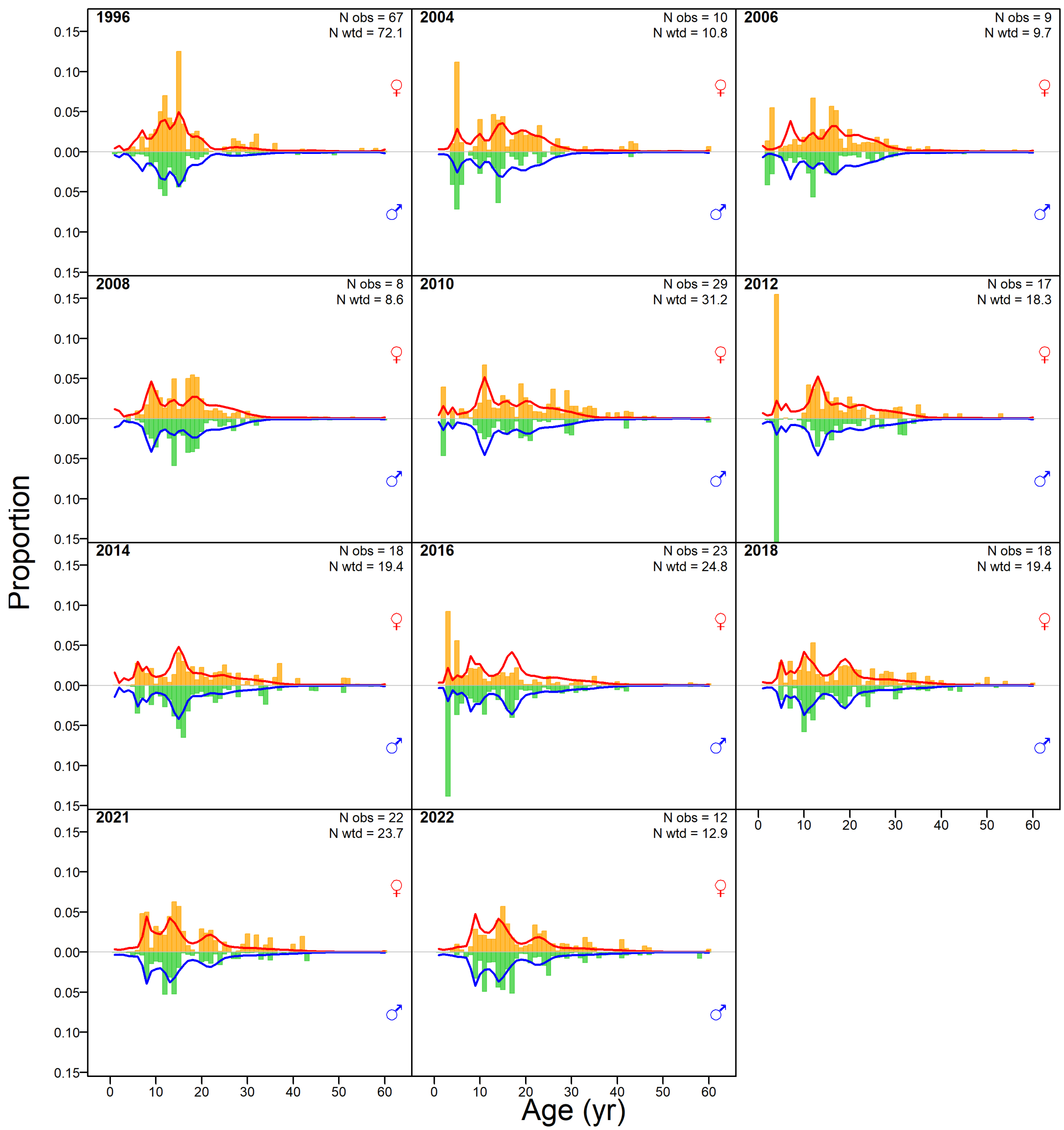


Figure F.12. Base run: WCVI Synoptic proportions-at-age (bars=observed, lines=predicted) for females and males.

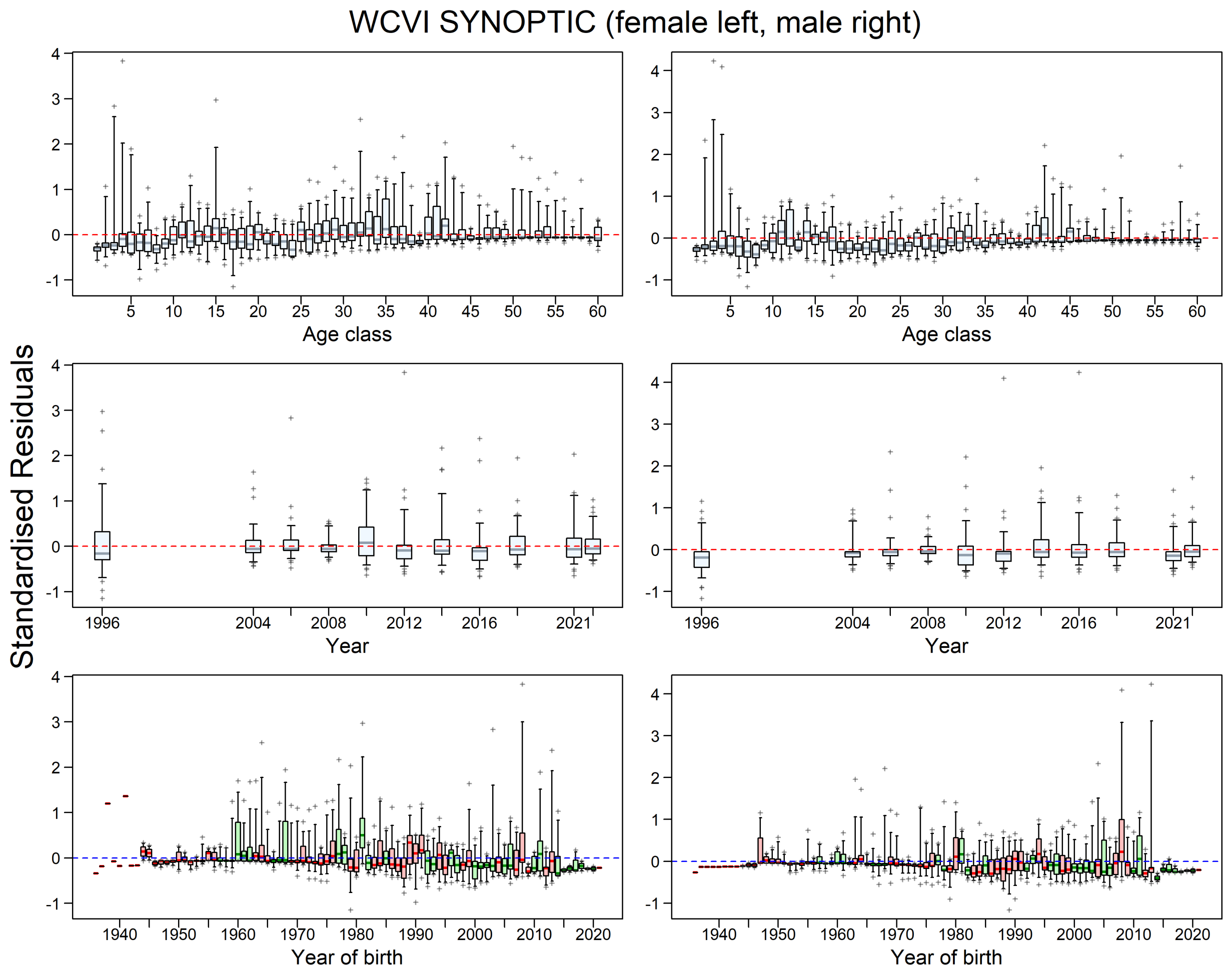


Figure F.13. Base run: WCVI Synoptic residuals of model fits to proportion-at-age data. See Figure F.5 caption for details.

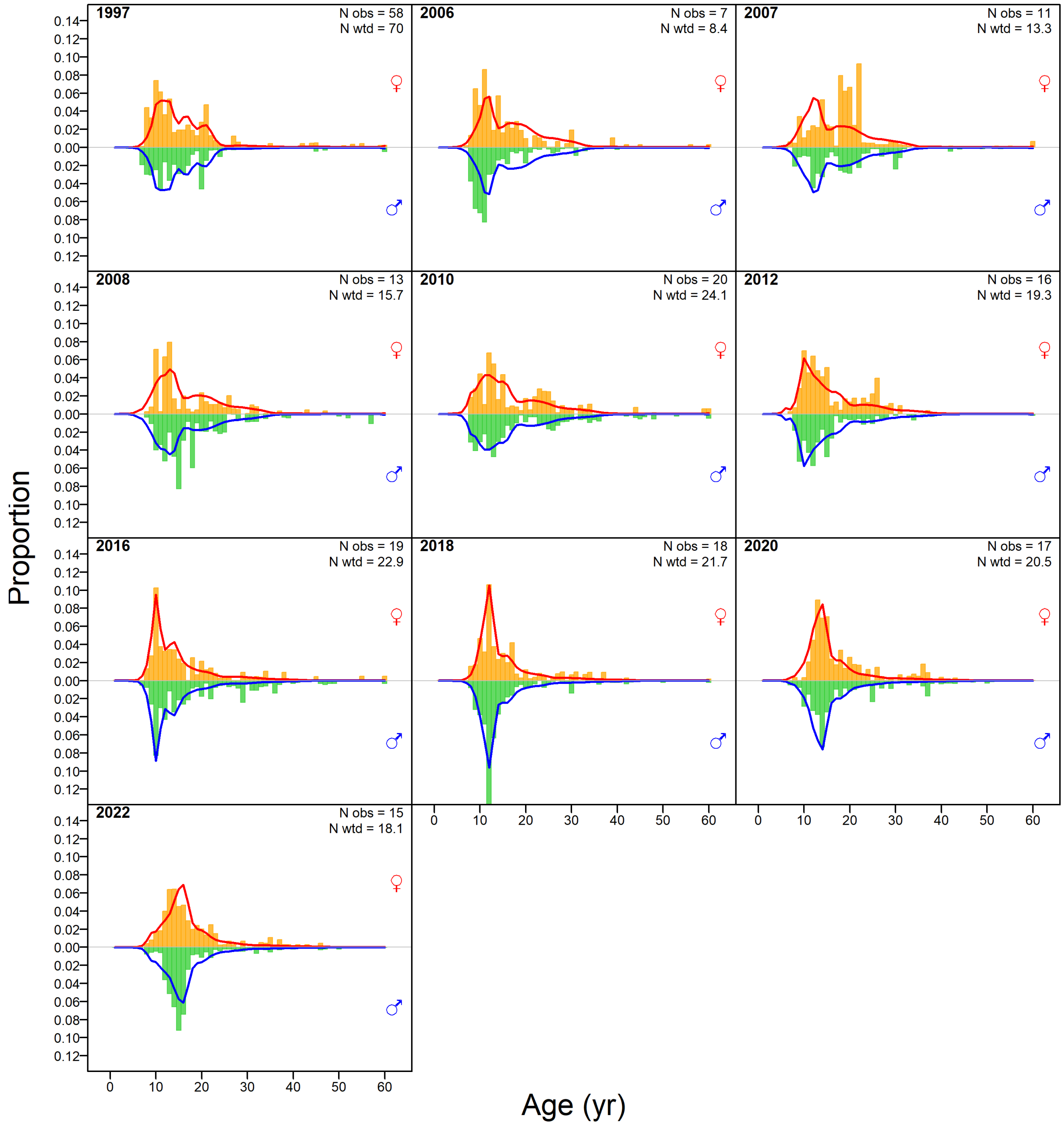


Figure F.14. Base run: WCHG Synoptic proportions-at-age (bars=observed, lines=predicted) for females and males.

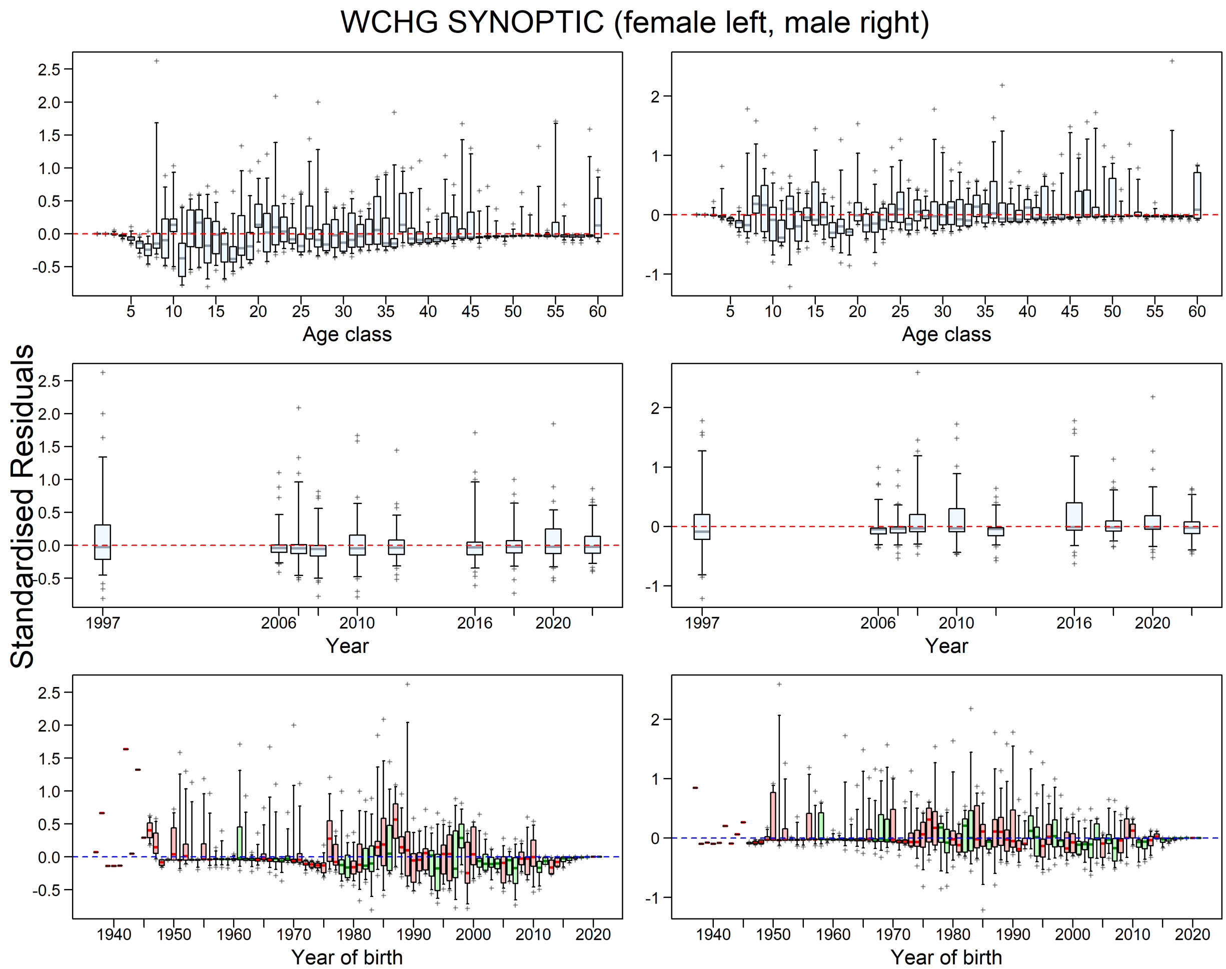


Figure F.15. Base run: WCHG Synoptic residuals of model fits to proportion-at-age data. See Figure F.5 caption for details.

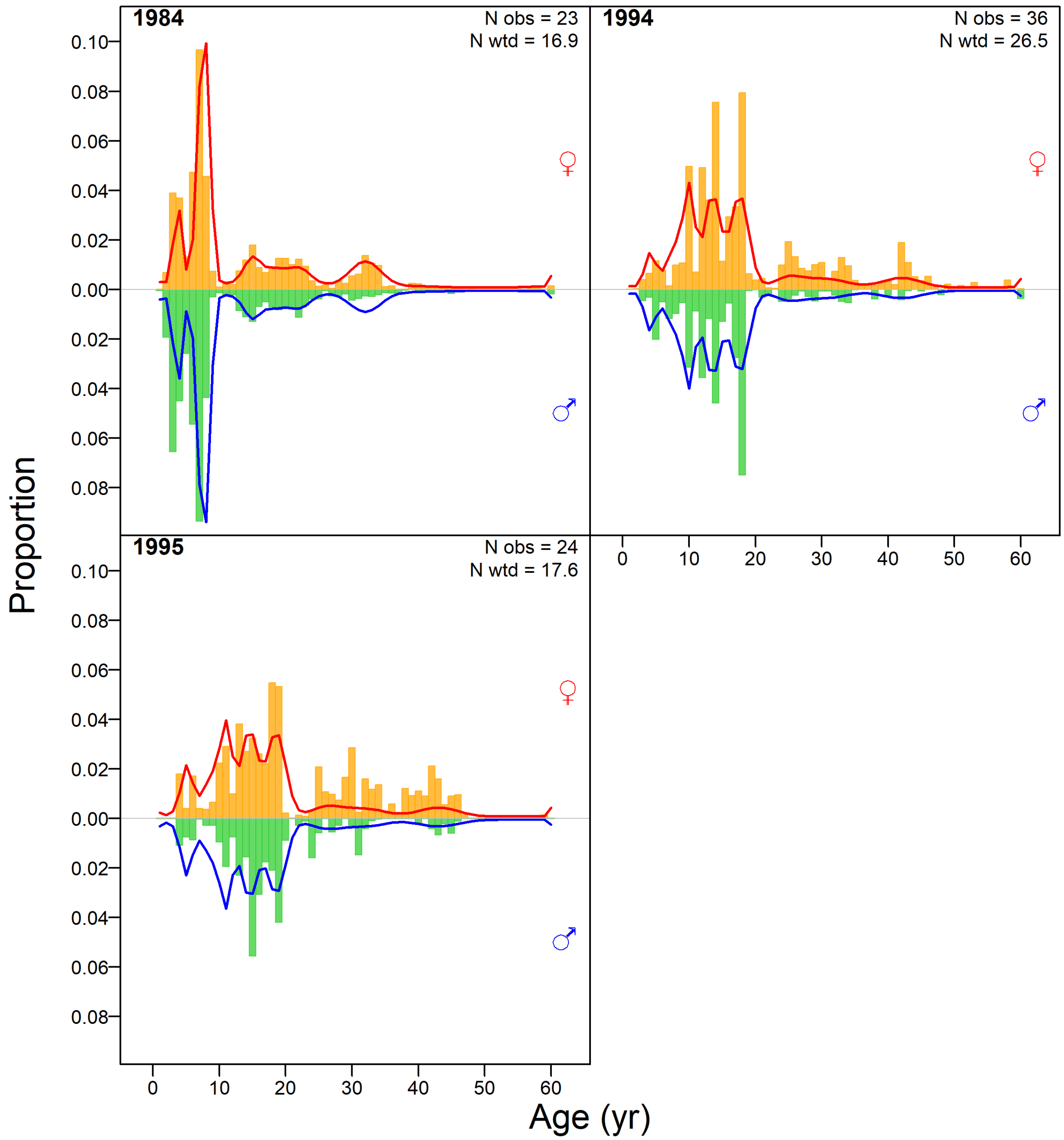


Figure F.16. Base run: GIG Historical proportions-at-age (bars=observed, lines=predicted) for females and males.

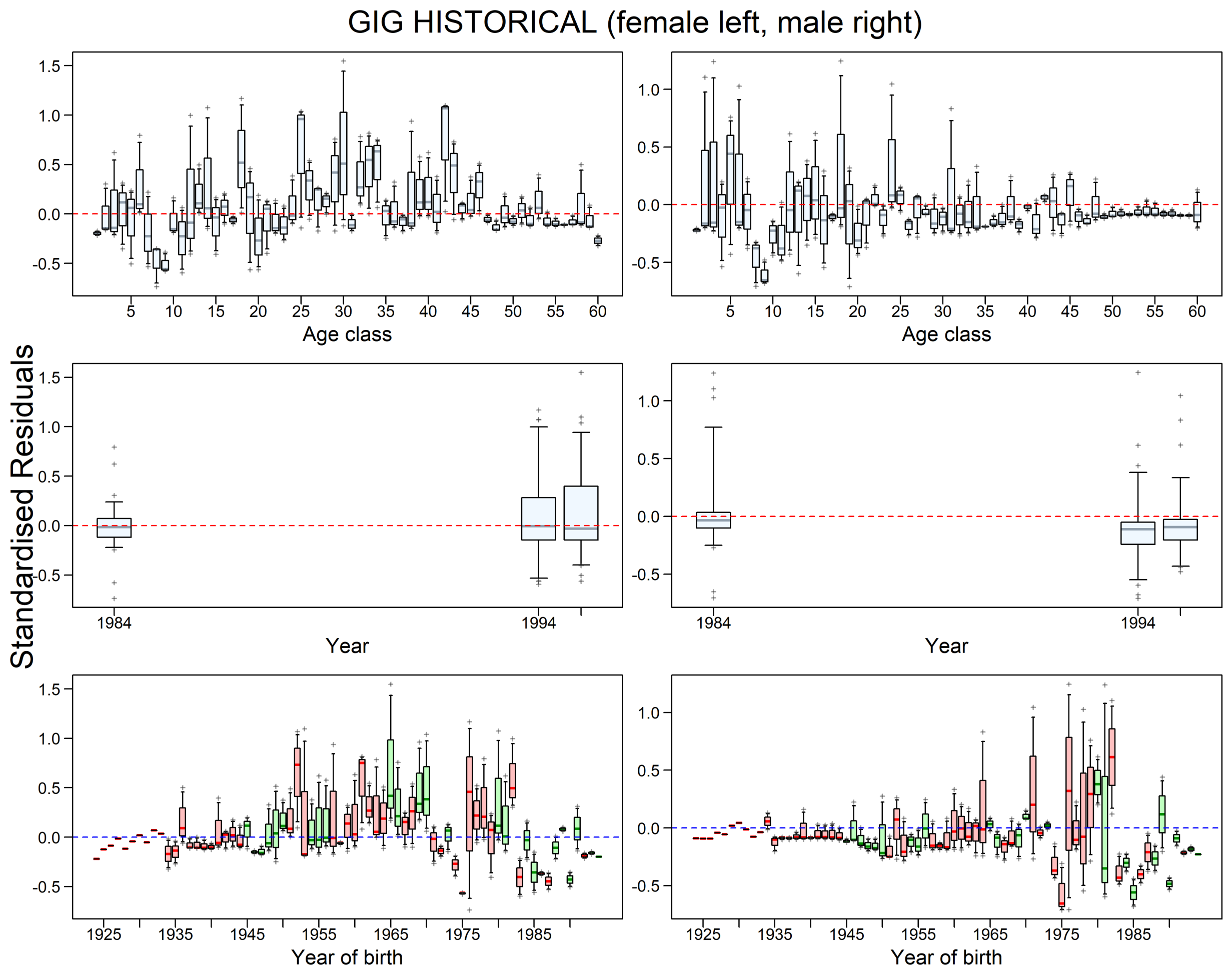


Figure F.17. Base run: GIG Historical residuals of model fits to proportion-at-age data. See Figure F.5 caption for details.

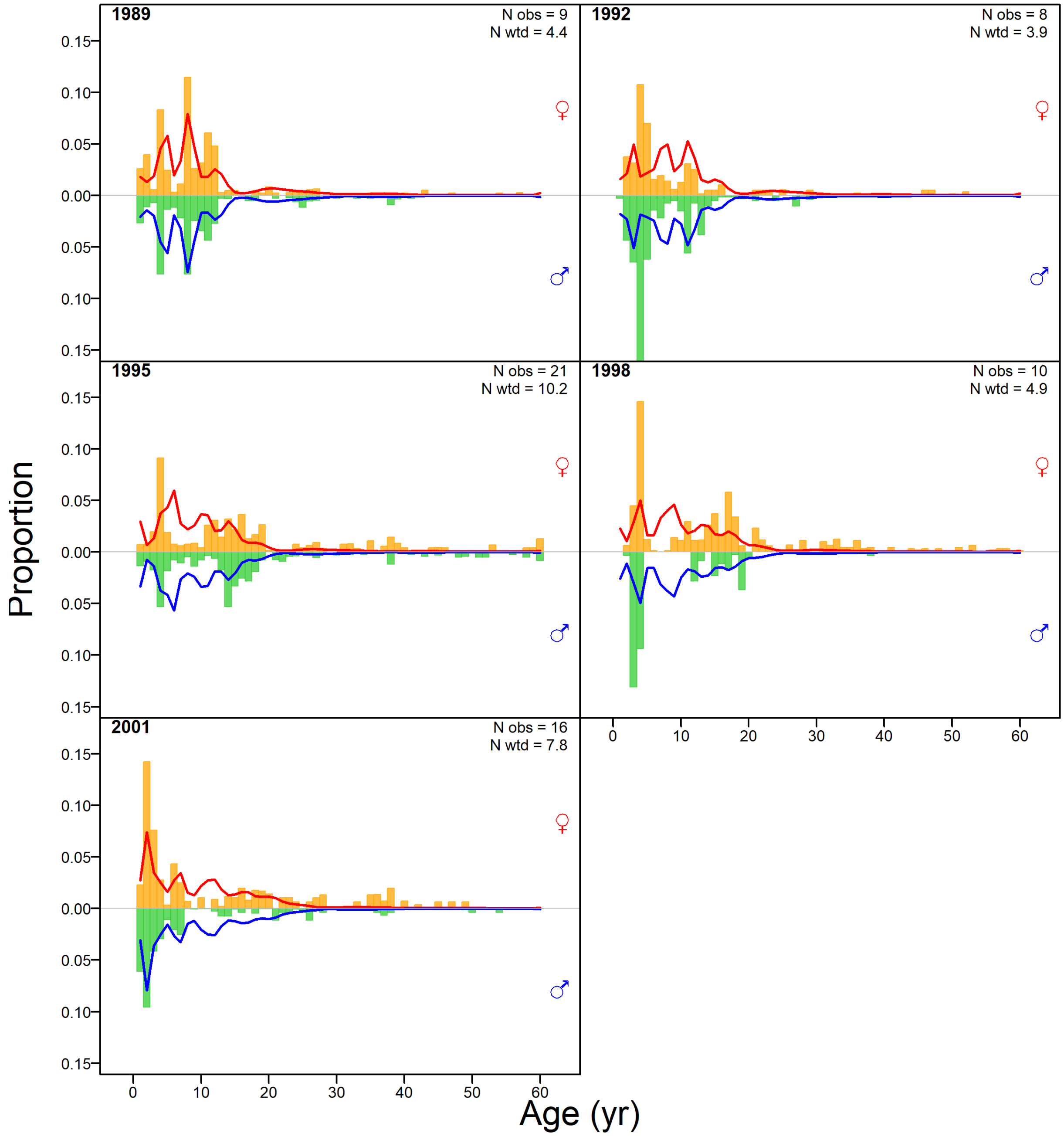


Figure F.18. Base run: NMFS Triennial proportions-at-age (bars=observed, lines=predicted) for females and males.

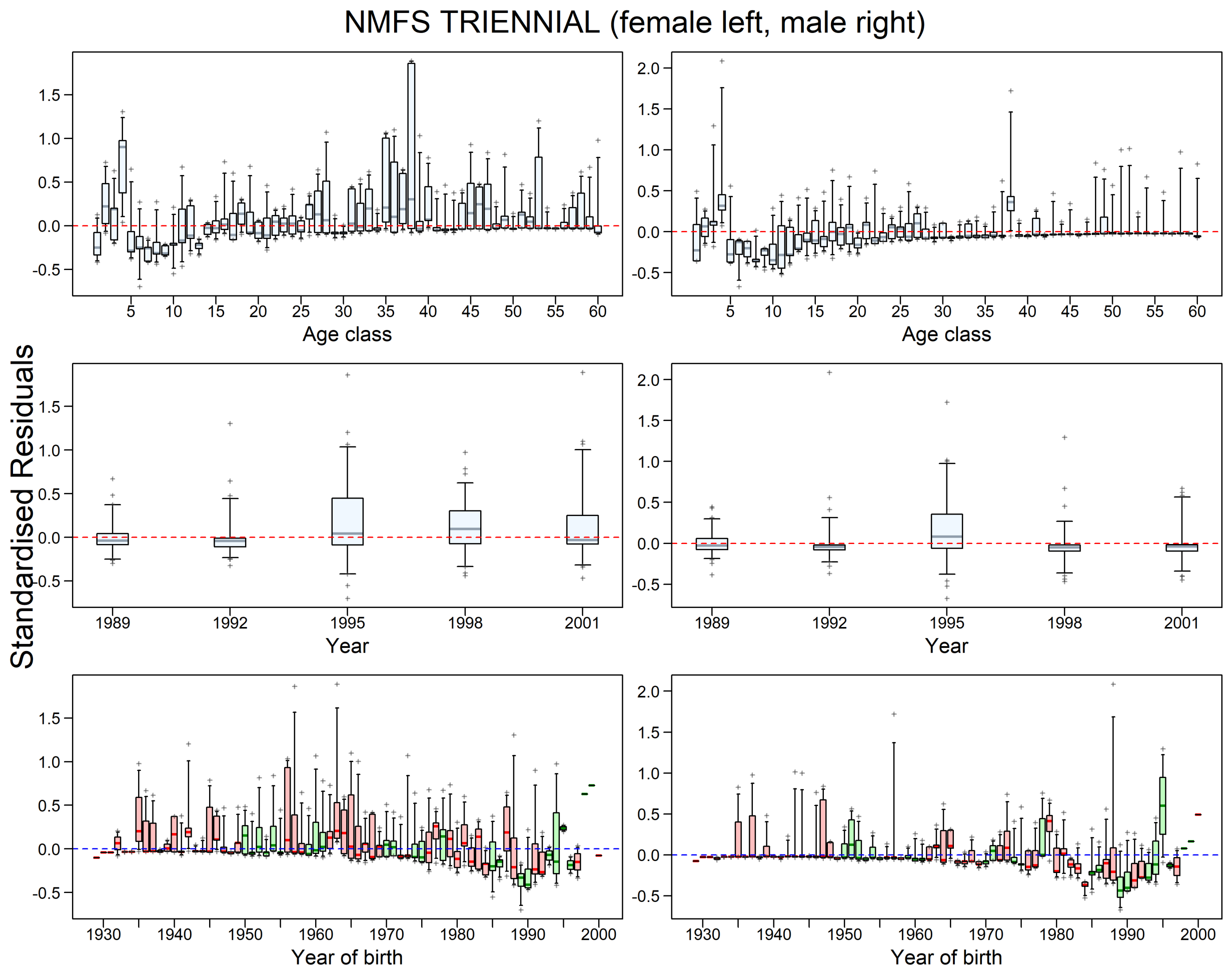


Figure F.19. Base run: NMFS Triennial residuals of model fits to proportion-at-age data. See Figure F.5 caption for details.

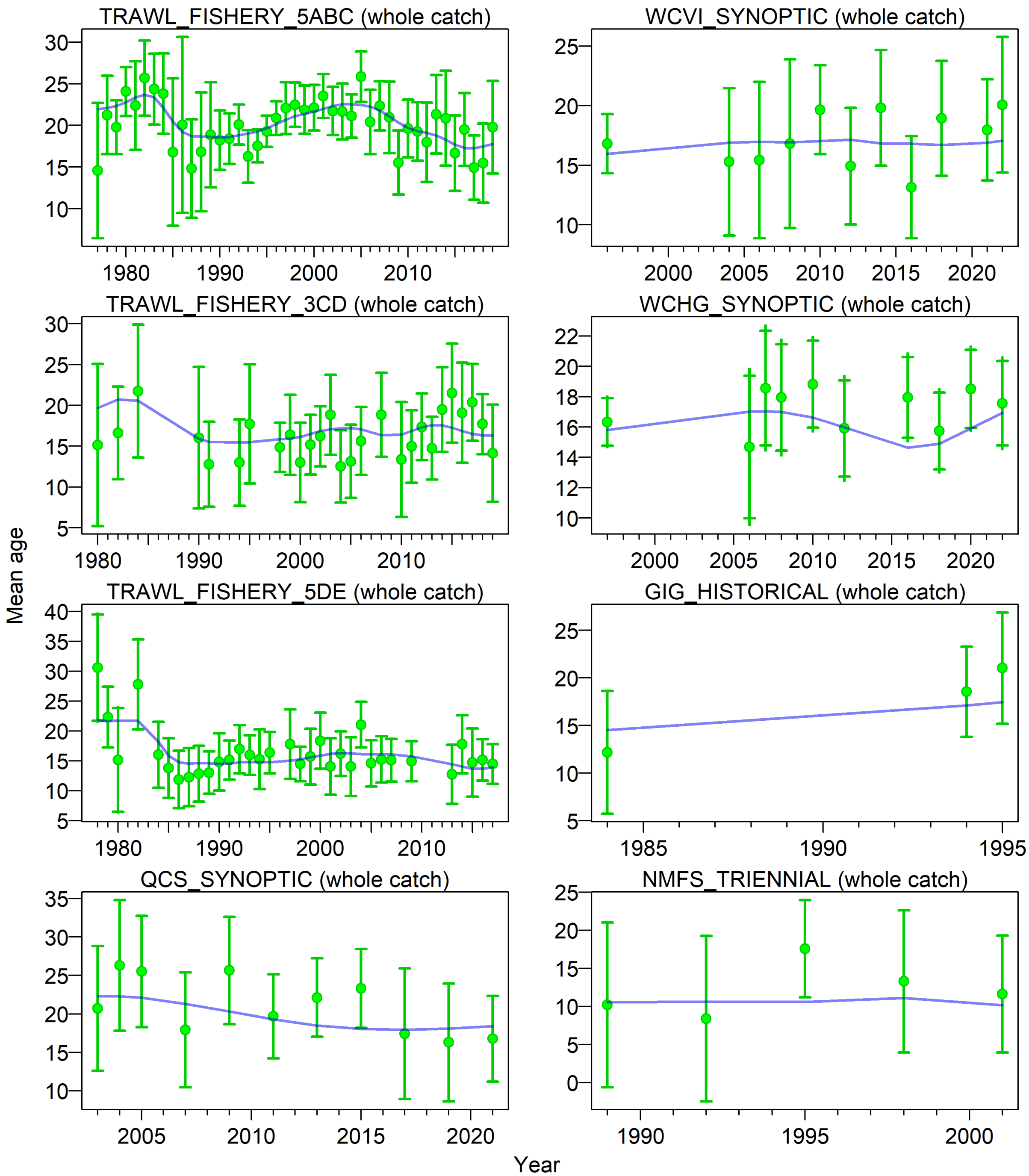


Figure F.20. Base run: mean ages each year for the weighted data (solid circles) with 95% confidence intervals and model estimates (blue lines) for the commercial and survey age data.

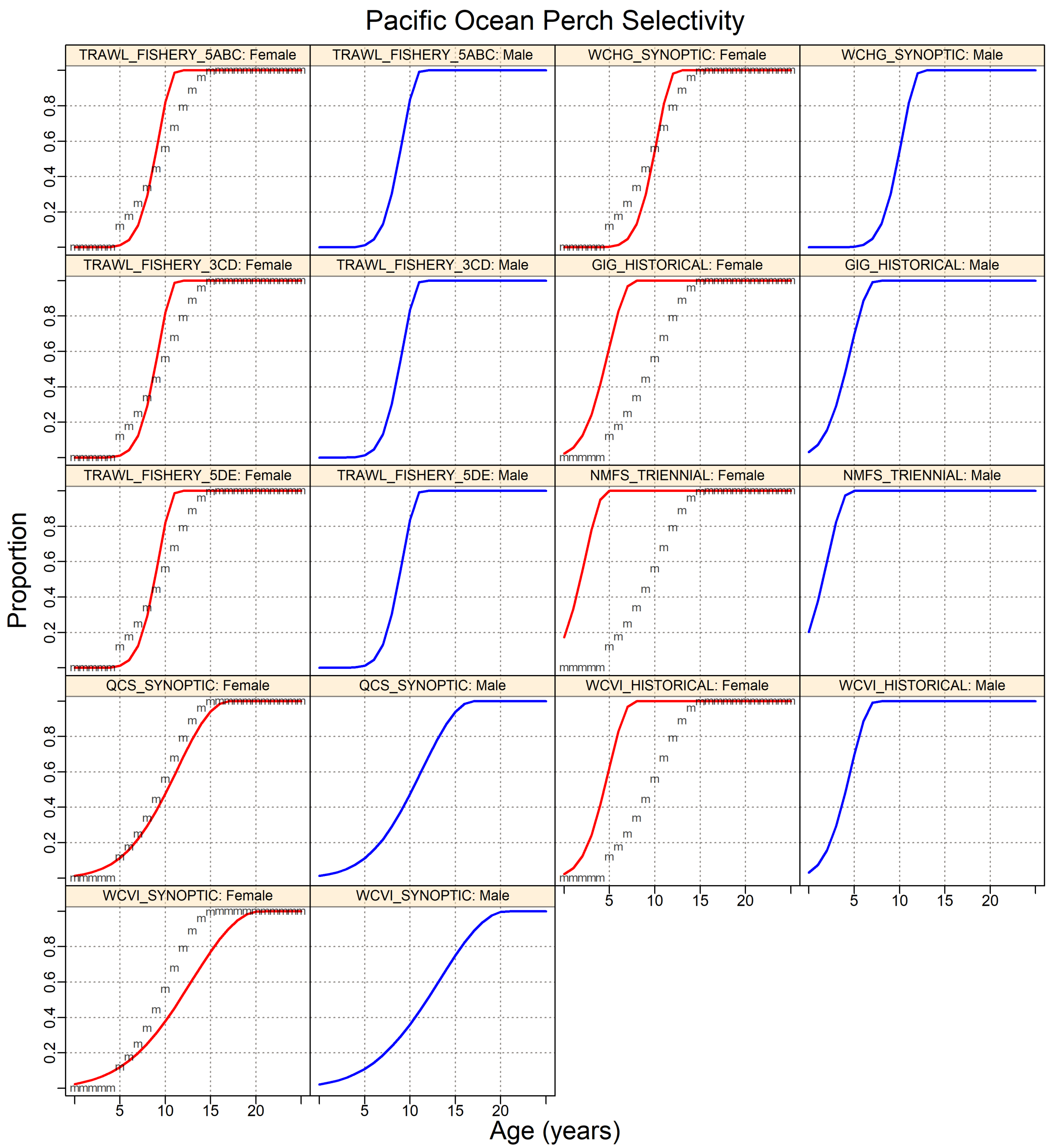


Figure F.21. Base run: selectivities for commercial fleet catch and surveys (all MPD values), with maturity ogive for females indicated by ‘m’.

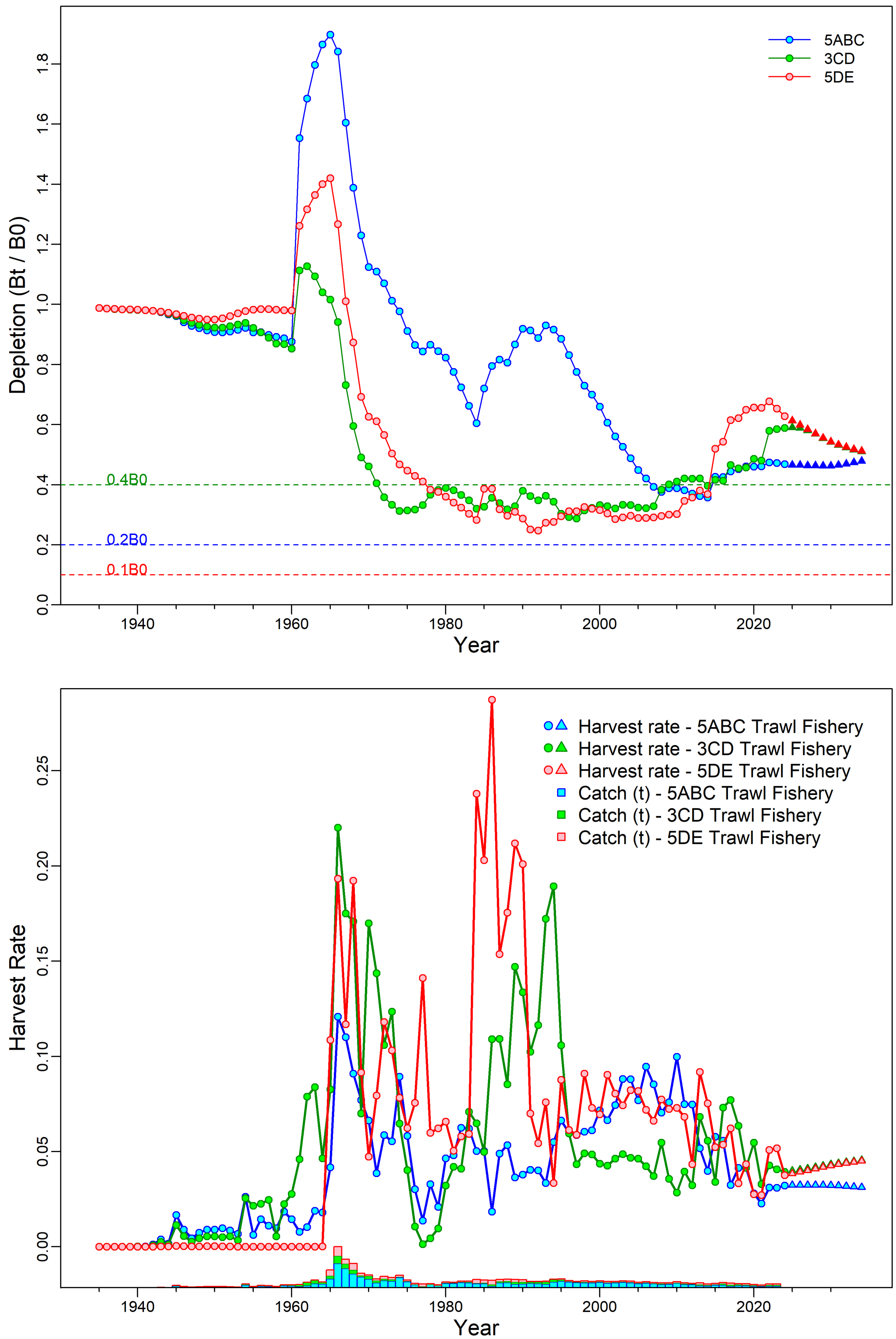


Figure F.22. Base run: female spawning biomass B_t relative to unfished equilbrium spawning biomass B_0 (top) and exploitation (harvest) rate (bottom). Triangles indicate projections at 5-year (2018-22) mean catches.

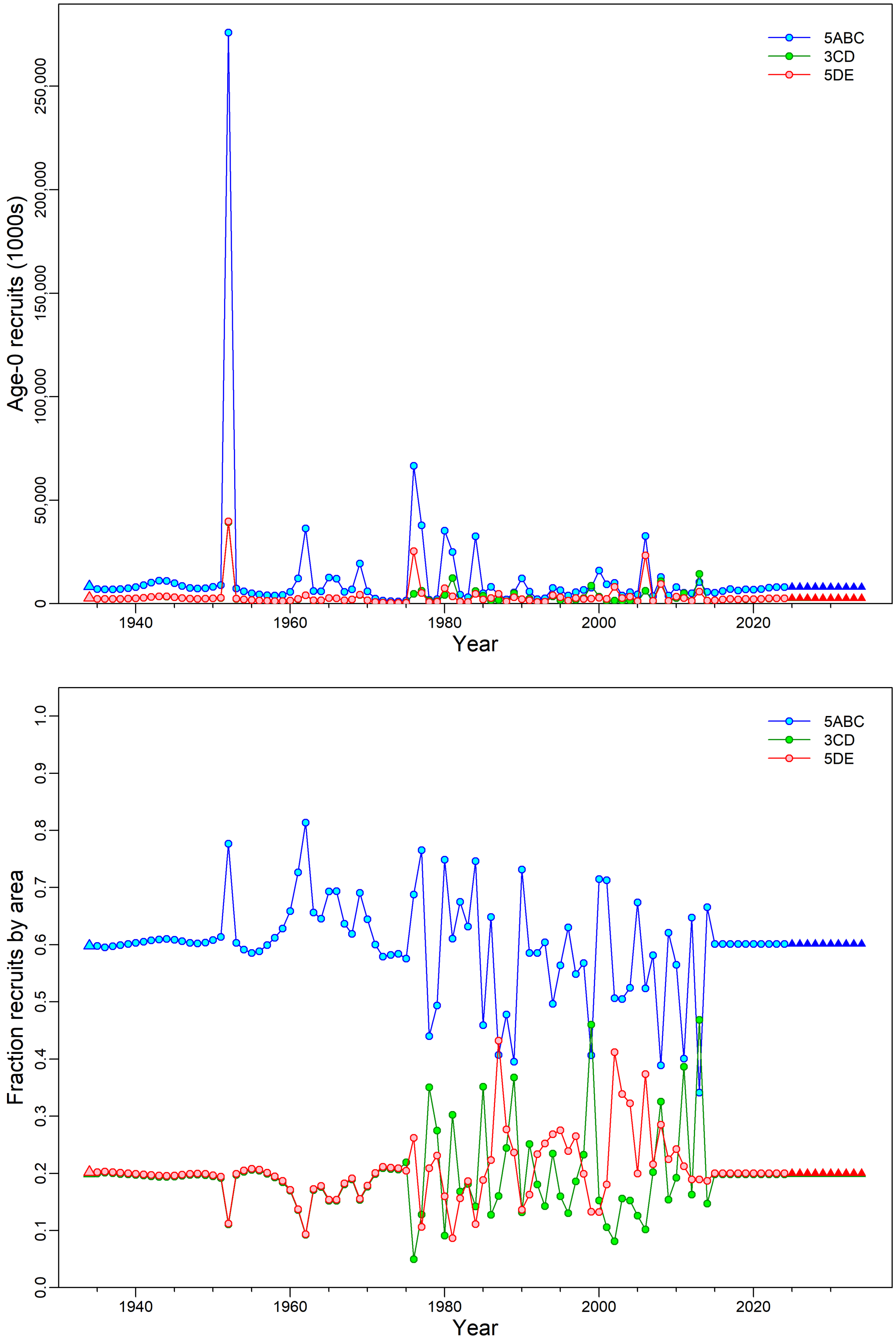


Figure F.23. Base run: recruitment (thousands of fish) over time (top) and proportion recruitment settlement by area (bottom). Triangles indicate projections at 5-year (2018-22) mean catches.

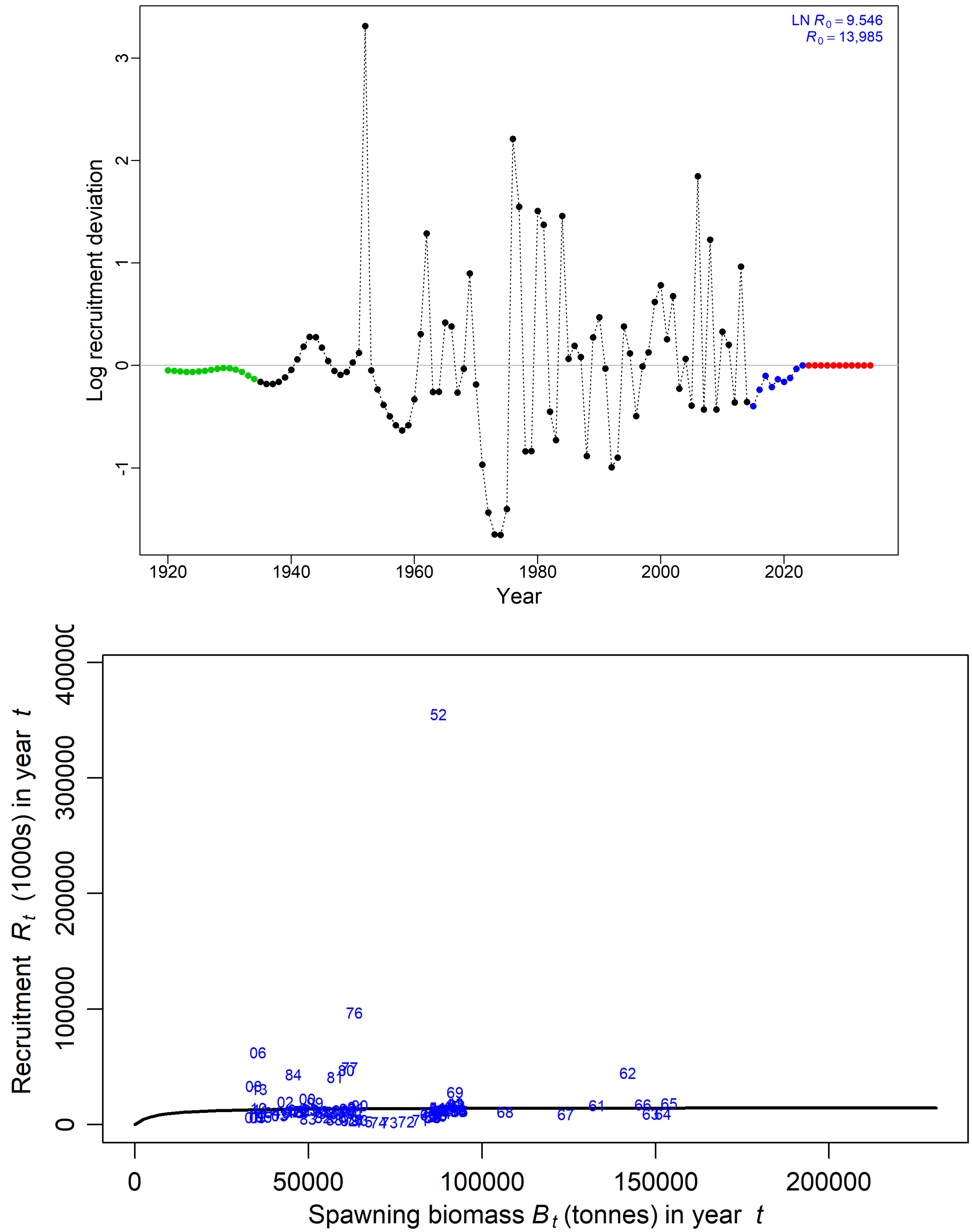


Figure F.24. Base run: log of annual recruitment deviations (top) and deterministic stock-recruit relationship (black curve) and observed values, labelled by year of spawning (bottom).

F.2.1.2. MCMC results

The MCMC procedure used the 'no U-turn sampling' (NUTS) algorithm (Monnahan and Kristensen 2018; Monnahan et al. 2019) to produce 40,000 iterations, parsing the workload into 8 parallel chains (Knaus 2015) of 5,000 iterations each, discarding the first 2,500 iterations and saving the last 2,500 samples per chain. The parallel chains were then merged for a total of 2,000 samples, after thinning every 10th sample, for use in the MCMC analysis.

For the primary estimated parameters, MCMC plots show:

- Figure F.25 – traces for 2,000 samples;
- Figure F.26 – split-chain diagnostics;
- Figure F.27 – auto-correlation diagnostics;
- Figure F.28 – marginal posterior densities compared to their respective prior density functions.
- Figure F.29 – pairs plot comparing estimated parameters using kernel density and correlation.

MCMC traces for the base run (R21v3) showed good diagnostics (no trend with increasing sample number) for the estimated parameters (Figure F.25). In particular, a desired feature for good fit is the lack of high-excursion events for the parameter LN(R0). When this excursion occurs, it indicates samples with poor convergence. The split-chain diagnostic plot (Figure F.26), which splits posterior samples into eight equal consecutive segments (paralleling the eight chains used by `adnuts`), were largely consistent (overlaying each other), with some minor fraying in the QCS and WCVI μ_g parameters. Autocorrelation out to 60 lags showed no large spikes or predictable patterns (Figure F.27). Most of the parameter medians did not move far from their maximum likelihood estimates from the MPD fits, with the possible exception of natural mortality, $\log R_0$, and the primary selectivity parameters for GIG (Figure F.28).

Estimated values from the posterior are expressed as 'median (0.05 and 0.95 quantiles)', where values in parentheses represent 90% credibility intervals. The median values for natural mortality (Table F.4) shifted higher than their MPD estimates: M_1 = 0.053 (0.044, 0.061) vs. 0.046 and M_2 = 0.059 (0.051, 0.069) vs. 0.053, whereas median steepness was estimated to be lower: 0.75 (0.47, 0.94) vs. 0.82. The selectivity parameter age-at-full selectivity (μ_g) for the trawl fisheries, all represented by the 5ABC trawl fishery: 11.3 (10.9, 11.7), was lower than that for the synoptic surveys (Table F.4), which was unexpected given that the latter employs smaller mesh codends, but was probably driven by the high proportion of POP greater than age 30 in some survey years that were not observed in the commercial samples. The estimated μ_g values for the historical surveys were estimated to be low: GIG at 8.5 (5.4, 12.9) and NMFS at 5.2 (2.8, 9.8), reflecting much younger age distributions in these surveys.

In this stock assessment, projections extended 10 years to 2034. Projections out to three generations (75 years), where one generation was determined to be 25 years (see Appendix D), were not computed because the stock status of POP, both coastwide and by subarea, fell unambiguously into the Healthy zone and thus did not require any rebuilding. Various model trajectories and final stock status for the base run appear in the figures:

- Figure F.30 – estimated female spawning biomass B_t (top) and exploitation rate u_t (bottom) from model posteriors;
- Figure F.31 – estimated recruitment R_t (1000s age-0 fish, top) and recruitment deviations (bottom) from model posteriors;

- Figure F.32 – estimated spawning biomass B_t relative to spawning biomass at maximum sustainable yield, B_{MSY} (top); estimated exploitation rate u_t relative to exploitation rate at MSY, u_{MSY} (bottom);
- Figure F.33 – trajectories of recruitment (1000s of age-0 fish, top) and exploitation rate (bottom), coastwide and by subarea;
- Figure F.34 – trajectories of estimates of spawning biomass B_t relative to B_0 (top) and B_{MSY} (bottom), coastwide and by subarea;
- Figure F.35 – phase plot through time of median B_t/B_{MSY} and u_{t-1}/u_{MSY} relative to DFO's Precautionary Approach (PA) default reference points;
- Figure F.36 – POP 2023 stock status at beginning of 2024.

The area allocation parameter ($\mathring{p}_\alpha$) appeared to be the most important component of uncertainty in this stock assessment because results varied by which subarea to hold constant when estimating the other two (see sensitivity run discussion below). Additionally, this parameter was sensitive to the reweighting technique. For example, when using the D-M parameterisation, sample size of the AF data seemed to unduly affect subarea allocation and biomass scaling. Fortunately, the Francis (2011) mean-age method offered stability with respect to both factors (see Section E.6.2.3). This stock assessment also explored a range of other model uncertainties in sensitivity runs relative to the base run (B1: R21.01.v3).

The base run was used to calculate a set of parameter estimates (Table F.4) and derived quantities at equilibrium and those associated with MSY (Table F.5). Estimated median spawning biomass B_t coastwide in t=1935, 2024, and 2034 (assuming a constant catch of 3,000 t/y) was 106,053, 61,965, and 57,910 tonnes, respectively (Figure F.30). Figure F.34 indicated that the median stock biomass would remain above the USR coastwide for the next 10 years at annual catches equal to all catches (up to 6,250 t/y) used in catch projections. By subarea, median stock biomass would also remain above the USR at annual catches as high as 3,500 t in 5ABC, 1,250 t in 3CD, and 1,500 t in 5DE; however, the 90% credibility envelope would begin to breach the USR before 10 years at the highest catch levels simulated (Figure F.34). Median exploitation rates largely stayed below u_{MSY} for most of the fishery's history (Figure F.32), only exceeding u_{MSY} in 1966-68 (Figure F.35. POP showed fairly modest recruitment of age-0 fish (mean of annual medians from 1935 to 2014 = 22 million fish), with one big recruitment event in 1952 of 401 million fish (18x the mean).

A phase plot of the time-evolution of spawning biomass and exploitation rate by the modelled fisheries in MSY space (Figure F.35) suggested that the stock was in the Healthy zone at the beginning of 2024, with a current position at B_{2024}/B_{MSY} = 2.326 (1.409, 3.873) and u_{2023}/u_{MSY} = 0.307 (0.144, 0.721). The current-year stock status figure (Figure F.36) showed that the base run lay in the DFO Healthy zone coastwide and by subarea.

F.2.1.2.1. MCMC Tables

Table F.4. Base run: the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles for model parameters (defined in Appendix E) from MCMC estimation of one base run of 2,000 samples.

	5%	25%	50%	75%	95%
$\log R_0$	9.448	9.680	9.845	10.01	10.26
$\mathring{p}_{\alpha=1}$ (subarea 1)	0.8684	1.049	1.173	1.299	1.486
$\mathring{p}_{\alpha=2}$ (subarea 2)	-0.09547	-0.04481	-0.008557	0.02760	0.08419
M (Female)	0.04365	0.04847	0.05229	0.05575	0.06146
M (Male)	0.05050	0.05572	0.05939	0.06306	0.06902
BH (h)	0.4736	0.6379	0.7544	0.8482	0.9431
μ_1 (TRAWL 5ABC)	10.93	11.17	11.33	11.49	11.72
$\log v_{\mathrm{L1}}$ (TRAWL 5ABC)	1.996	2.112	2.193	2.265	2.374
Δ_1 (TRAWL 5ABC)	-0.3206	-0.1700	-0.05945	0.05119	0.2221
μ_4 (QCS)	13.50	15.69	17.74	20.32	24.91
$\log v_{\mathrm{L4}}$ (QCS)	3.561	3.987	4.315	4.671	5.172
Δ_4 (QCS)	-1.188	-0.4484	-0.003651	0.4669	1.138
μ_5 (WCVI)	17.00	18.84	20.49	22.35	25.74
$\log v_{\mathrm{L5}}$ (WCVI)	4.290	4.544	4.741	4.935	5.259
Δ_5 (WCVI)	-0.8162	-0.2012	0.2744	0.7112	1.403
μ_6 (WCHG)	11.08	11.80	12.29	12.89	13.81
$\log v_{\mathrm{L6}}$ (WCHG)	1.597	1.988	2.235	2.484	2.816
Δ_6 (WCHG)	-0.7172	-0.2951	-0.01605	0.2739	0.6846
μ_7 (GIG)	5.398	7.072	8.473	10.16	12.91
$\log v_{\mathrm{L7}}$ (GIG)	1.801	2.544	3.034	3.523	4.135
Δ_7 (GIG)	-1.682	-0.9182	-0.3249	0.3004	1.150
μ_8 (NMFS)	2.820	4.180	5.222	6.774	9.789
$\log v_{\mathrm{L8}}$ (NMFS)	1.748	2.408	2.955	3.535	4.348
Δ_8 (NMFS)	-1.666	-0.8098	-0.2313	0.3689	1.240

Table F.5. Base run: the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles of MCMC-derived quantities from 2,000 samples from a single base run. Definitions are: B_0 – unfished equilibrium spawning biomass (mature females), B_{2024} – spawning biomass at the beginning of 2024, u_{2023} – exploitation rate (ratio of total catch to vulnerable biomass) in the middle of 2023, u_{max} – maximum exploitation rate (calculated for each sample as the maximum exploitation rate from 1935-2023), B_{MSY} – equilibrium spawning biomass at MSY (maximum sustainable yield), u_{MSY} – equilibrium exploitation rate at MSY, All biomass values (and MSY) are in tonnes. For reference, the average catch over the last 5 years (2018-2022) was 1,618 t in 5ABC, 840 t in 3CD, 848 t in 5DE, and 3,306 t along the BC coast.

	5%	25%	50%	75%	95%
B_0	84,811	96,679	106,054	117,619	140,309
B_{2024}	44,390	53,822	61,965	71,222	90,825
B_{2024}/B_0	0.4239	0.5114	0.5816	0.6621	0.8116
u_{2023}	0.01892	0.02389	0.02749	0.03166	0.03813
u_{max}	0.1051	0.1162	0.1231	0.1300	0.1380
MSY	3,090	4,073	4,865	5,795	7,262
B_{MSY}	16,692	22,127	26,798	32,466	42,658
$0.4B_{\text{MSY}}$	6,677	8,851	10,719	12,986	17,063
$0.8B_{\text{MSY}}$	13,353	17,702	21,438	25,973	34,126
B_{2024}/B_{MSY}	1.409	1.894	2.326	2.859	3.872
B_{MSY}/B_0	0.1605	0.2143	0.2544	0.2975	0.3636
u_{MSY}	0.04189	0.06605	0.09016	0.1167	0.1672
u_{2023}/u_{MSY}	0.1442	0.2218	0.3074	0.4304	0.7210

Table F.6. Log likelihood (LL) values reported by the single base run for survey indices, age composition (AF), recruitment, and total (not all LL components reported here)

LL value	21.01
Run	21
CPUE Bottom Trawl	0
QCS Synoptic	-13.7
WCVI Synoptic	1.34
WCHG Synoptic	-2.83
GIG Historical	-4.31
NMFS Triennial	6.77
WCVI Historical	5.47
Abundance Index	-7.24
Age Frequency	1,048
Recruitment	29.8
Total	1,090

F.2.1.2.2. MCMC Diagnostics

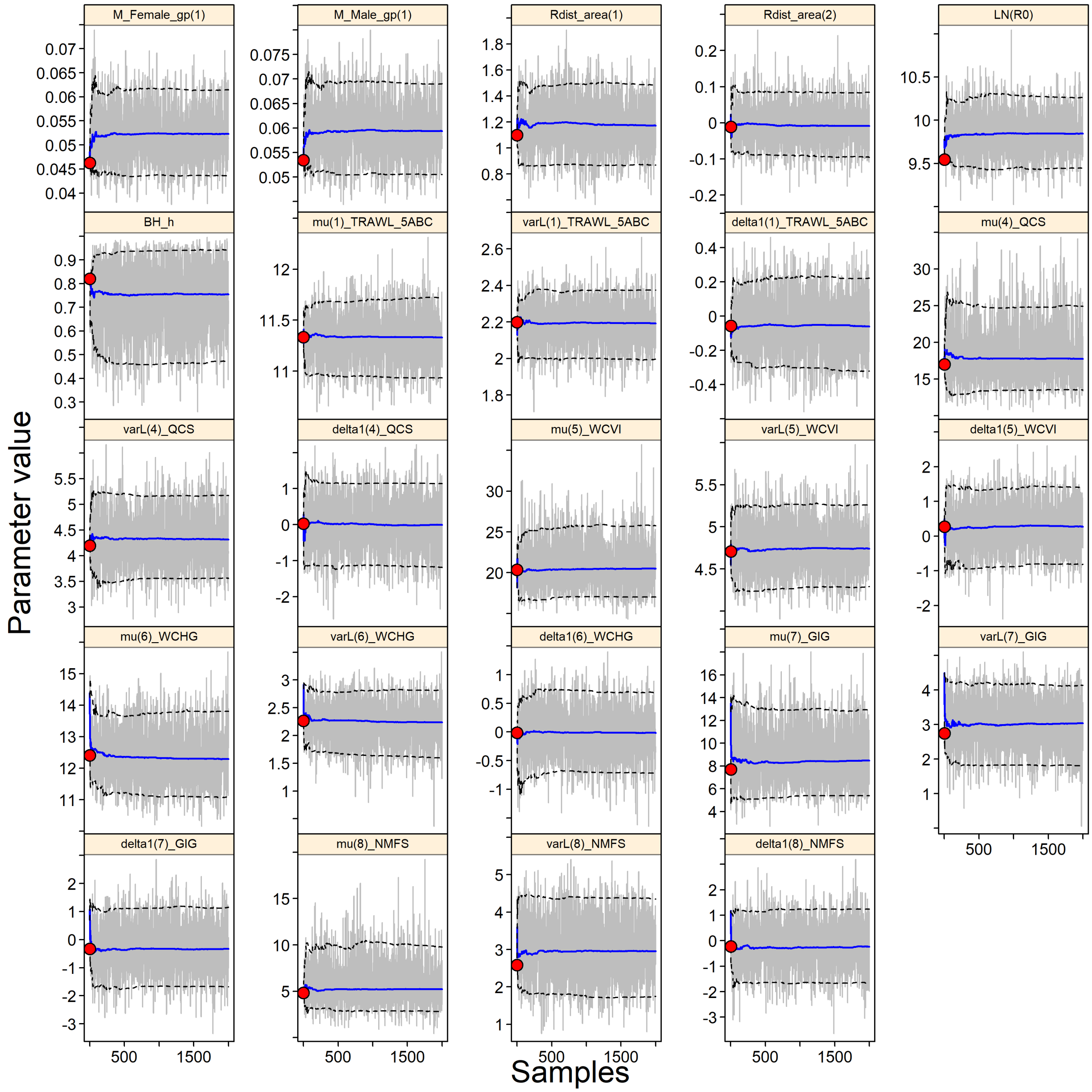


Figure F.25. Base run: MCMC traces for the estimated parameters. Grey lines show the 2,000 samples for each parameter, solid lines show the cumulative median (up to that sample), and dashed lines show the cumulative 0.05 and 0.95 quantiles. Red circles are the MPD estimates. For parameters other than M (if estimated), subscripts 1-9 correspond to fleets (fisheries and surveys).

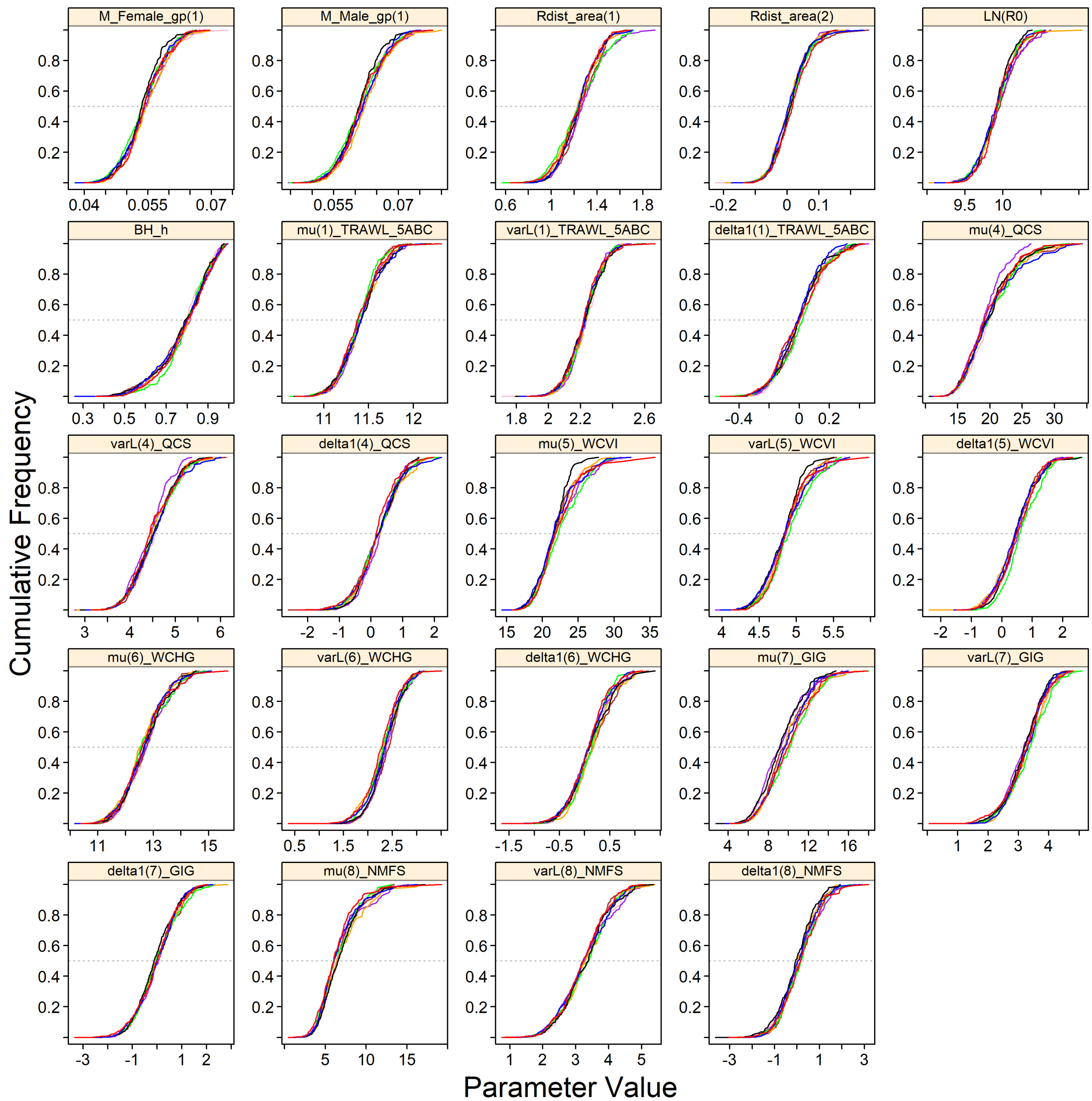


Figure F.26. Base run: diagnostic plot obtained by dividing the MCMC chain of 2,000 MCMC samples into eight segments (original number of chains), and overplotting the cumulative distributions of the segments from first to eighth using colours pink, brown, purple, orange, green, black, blue, and red.

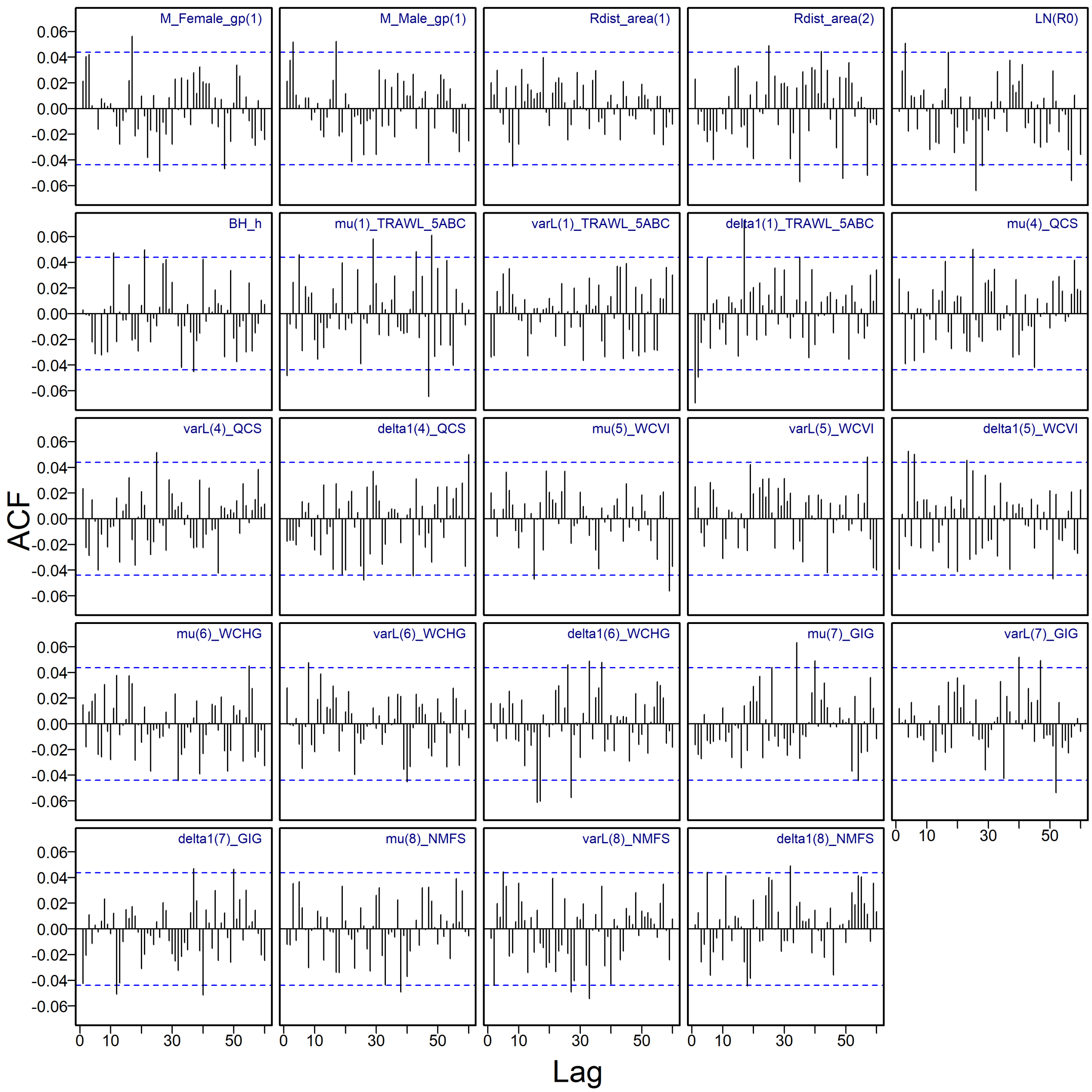


Figure F.27. Base run: autocorrelation plots for the estimated parameters from the MCMC output. Horizontal dashed blue lines delimit the 95% confidence interval for each parameter's set of lagged correlations.

F.2.1.2.3. Coastwide multi-area model

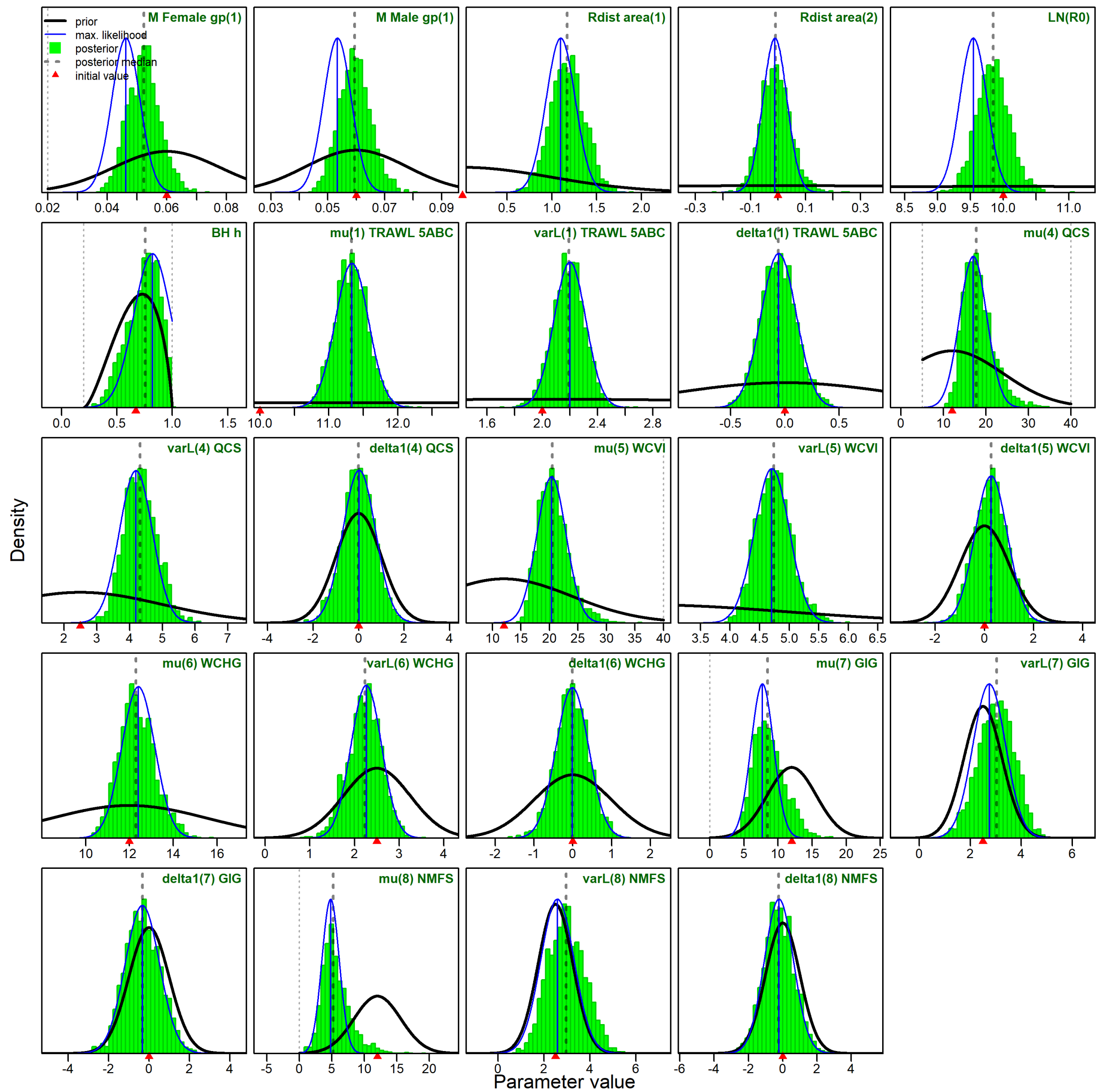


Figure F.28. Base run: posterior distribution (vertical green bars), likelihood profile (thin blue curve), and prior density function (thick black curve) for estimated parameters. Vertical dashed line indicates the MCMC posterior median; vertical blue line represents the MPD; red triangle indicates initial value for each parameter.

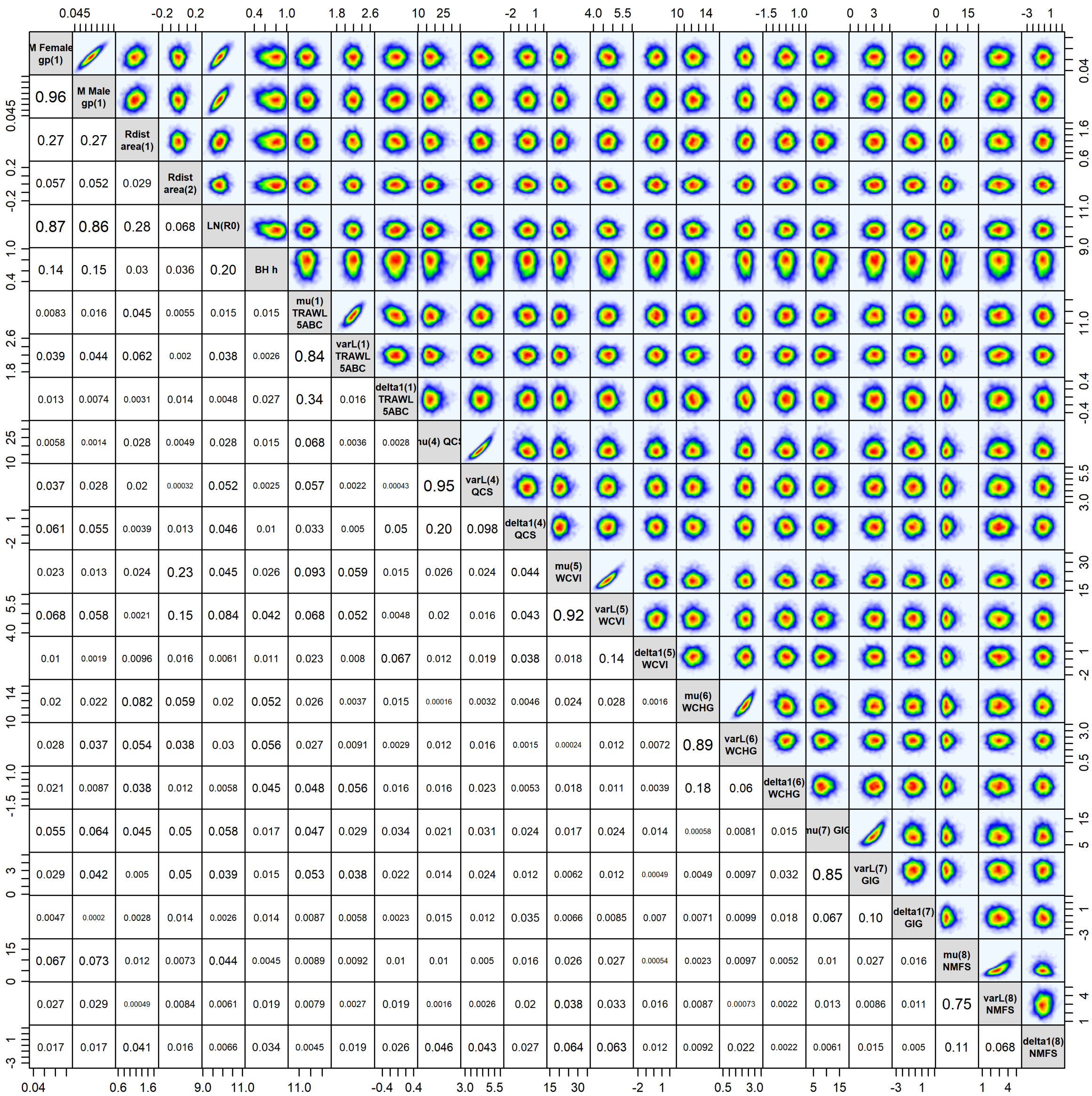
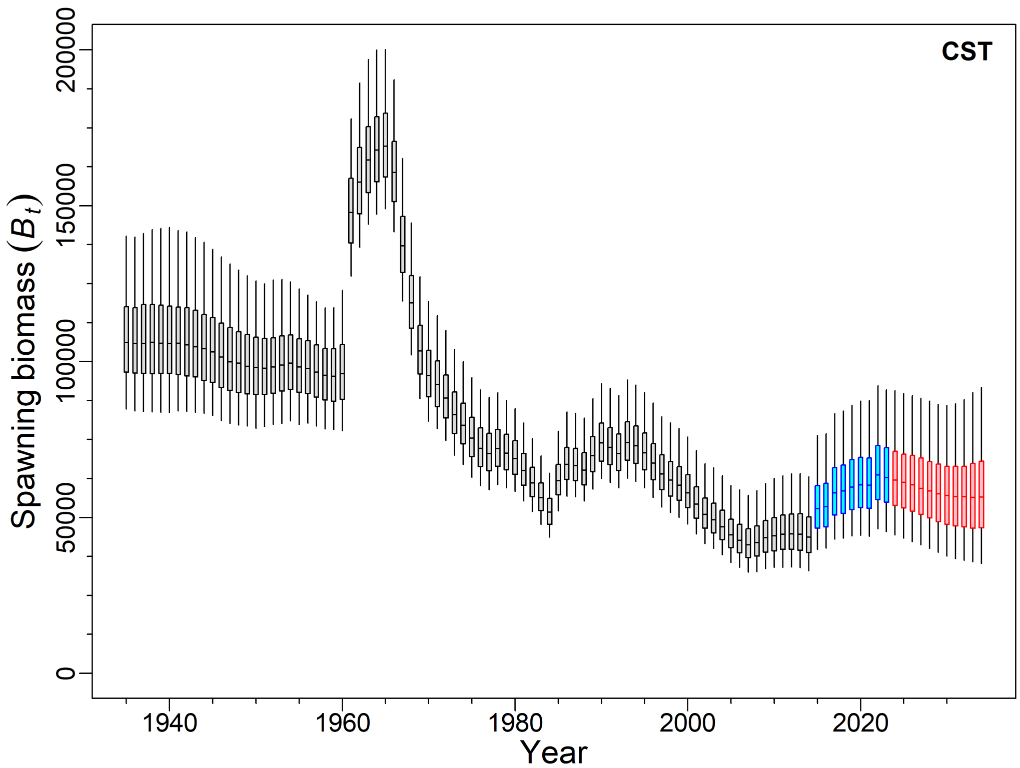


Figure F.29. Base run: kernel density plot of 2,000 MCMC samples for 24 parameters. Numbers in the lower panels are the absolute values of the correlation coefficients.



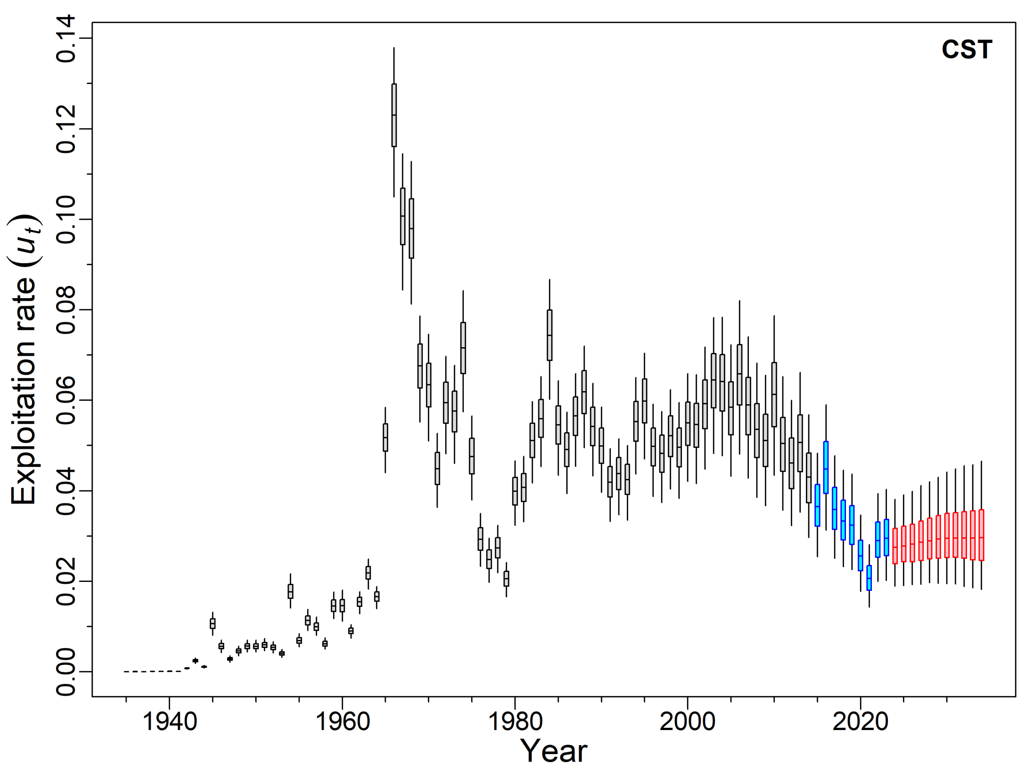


Figure F.30. Base run: marginal posterior distribution of female spawning biomass B_t (top) and exploitation rate u_t (bottom) over time. Boxplots show the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles from the MCMC results.

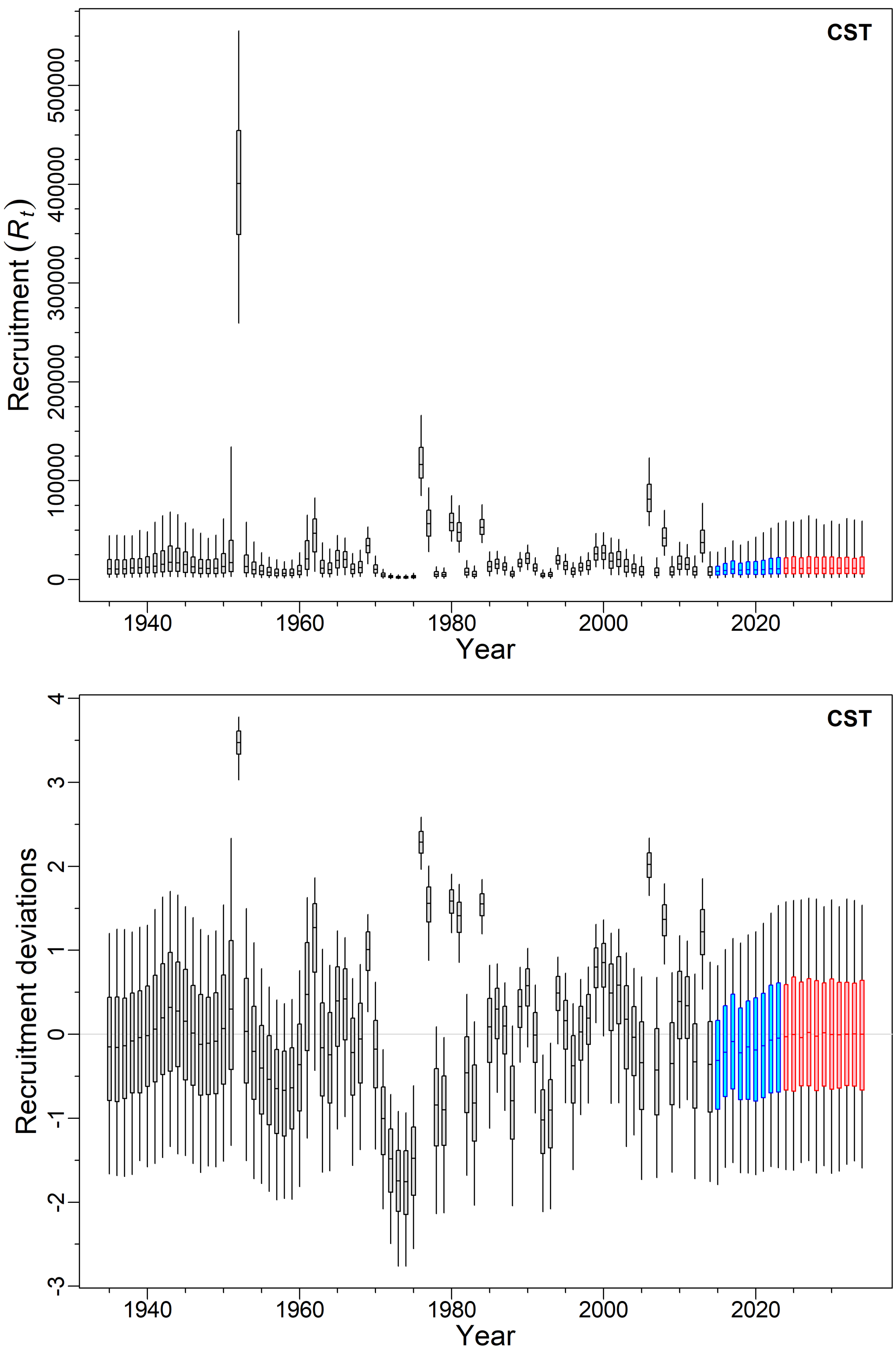


Figure F.31. Base run: marginal posterior distribution of recruitment in 1,000s of age-0 fish (top) and recruitment deviations (bottom) over time. Boxplots show the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles from the MCMC results.

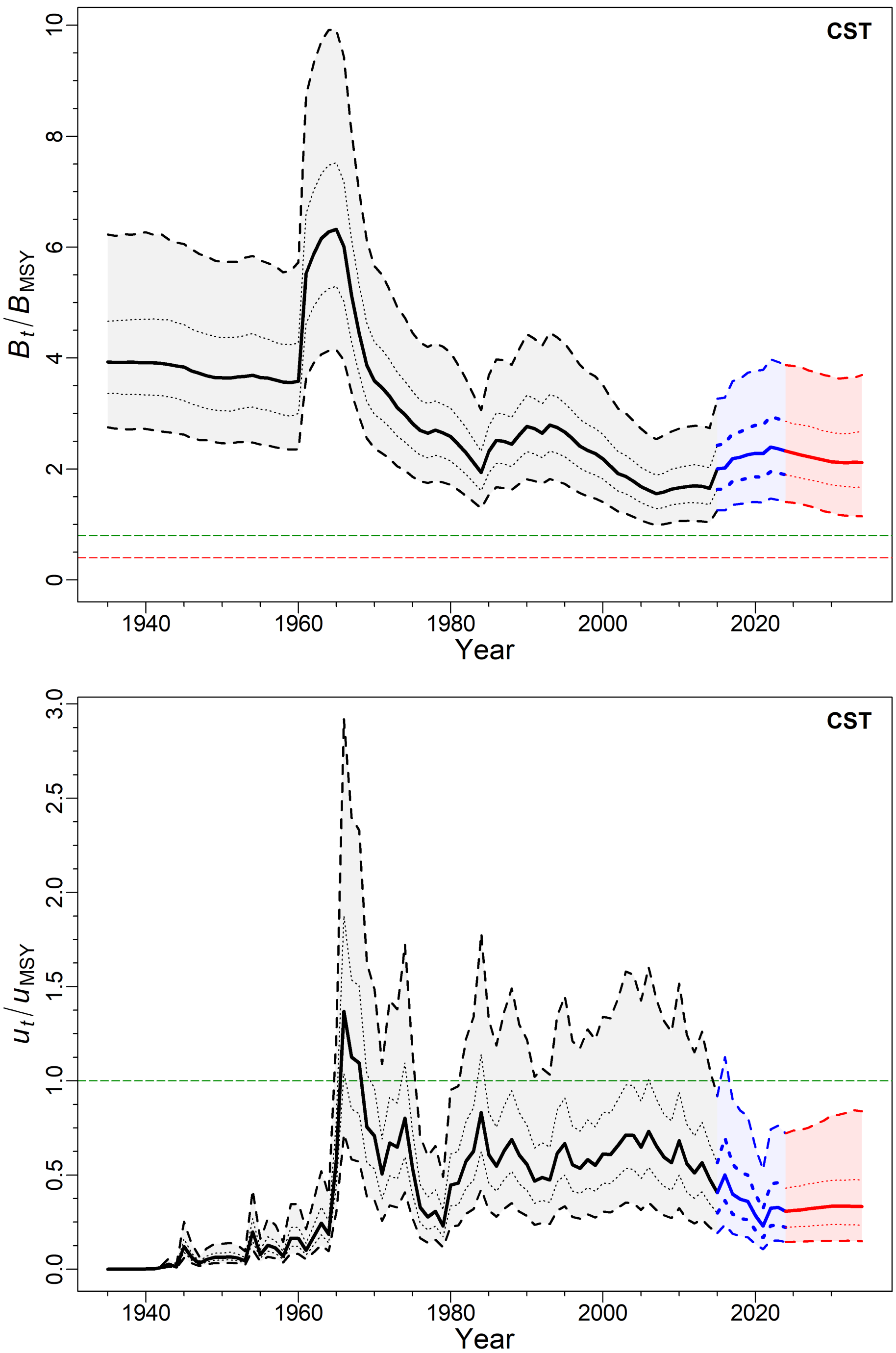


Figure F.32. Base run: estimated spawning biomass B_t relative to spawning biomass at maximum sustainable yield (B_{MSY})(top); estimated exploitation rate u_t relative to exploitation rate at MSY (u_{MSY})(bottom). The median trajectories appear as a solid curves surrounded by 90% credibility envelopes (quantiles: 0.05-0.95) in grey and delimited by dashed lines for years t=1935-2024; quantities appear in light blue for the late recruitment deviation period and light red for the projection years t=2025-2034. Also delimited is the 50% credibility interval (quantiles: 0.25-0.75) delimited by dotted lines. The horizontal dashed lines show the median LRP and USR (top) and u_{MSY} (bottom).

F.2.1.2.4. Coastwide subarea components

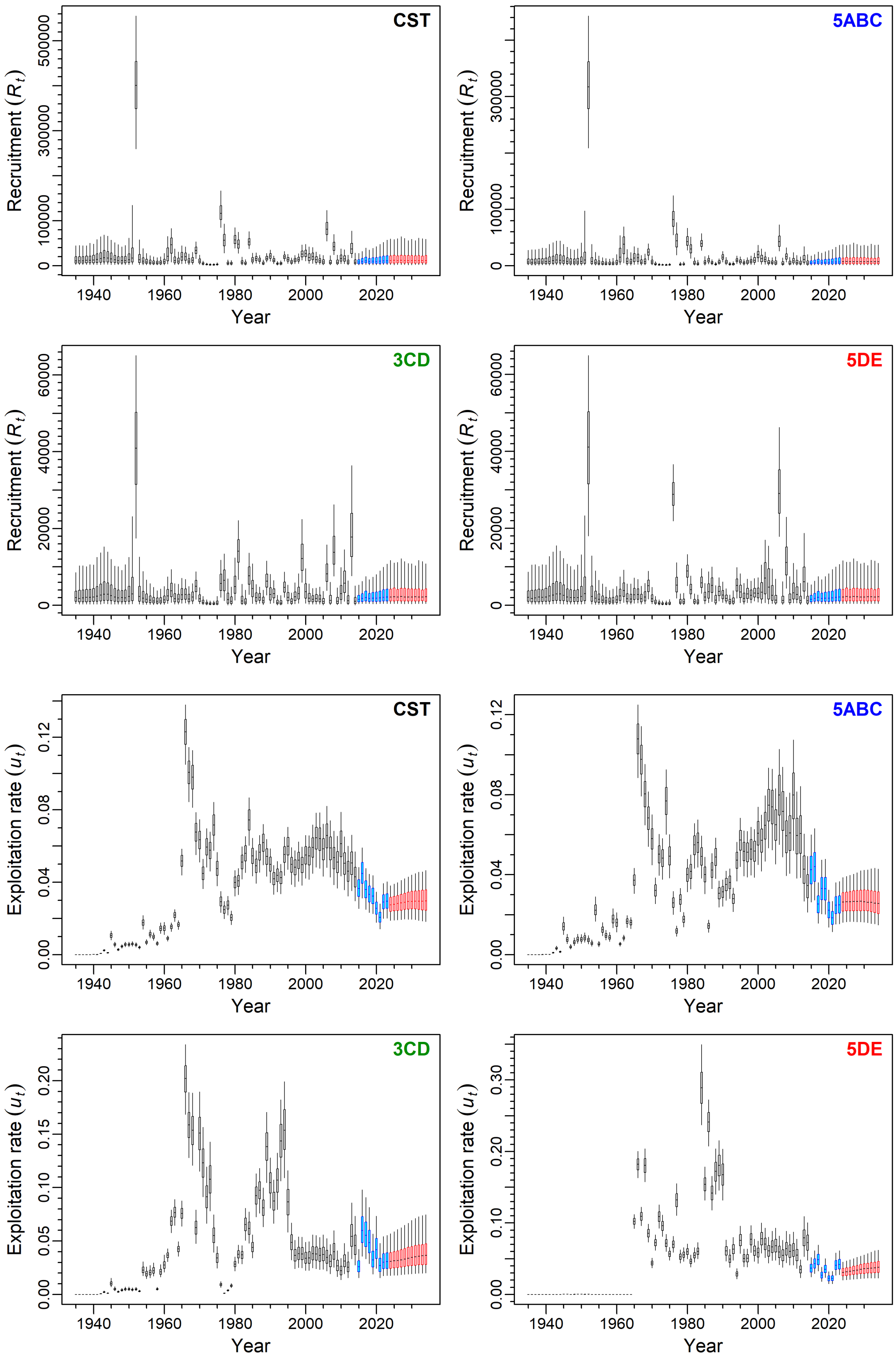


Figure F.33. Base run subareas: posterior distribution of recruitment (1000s of age-0 fish, top) and exploitation rate (bottom).

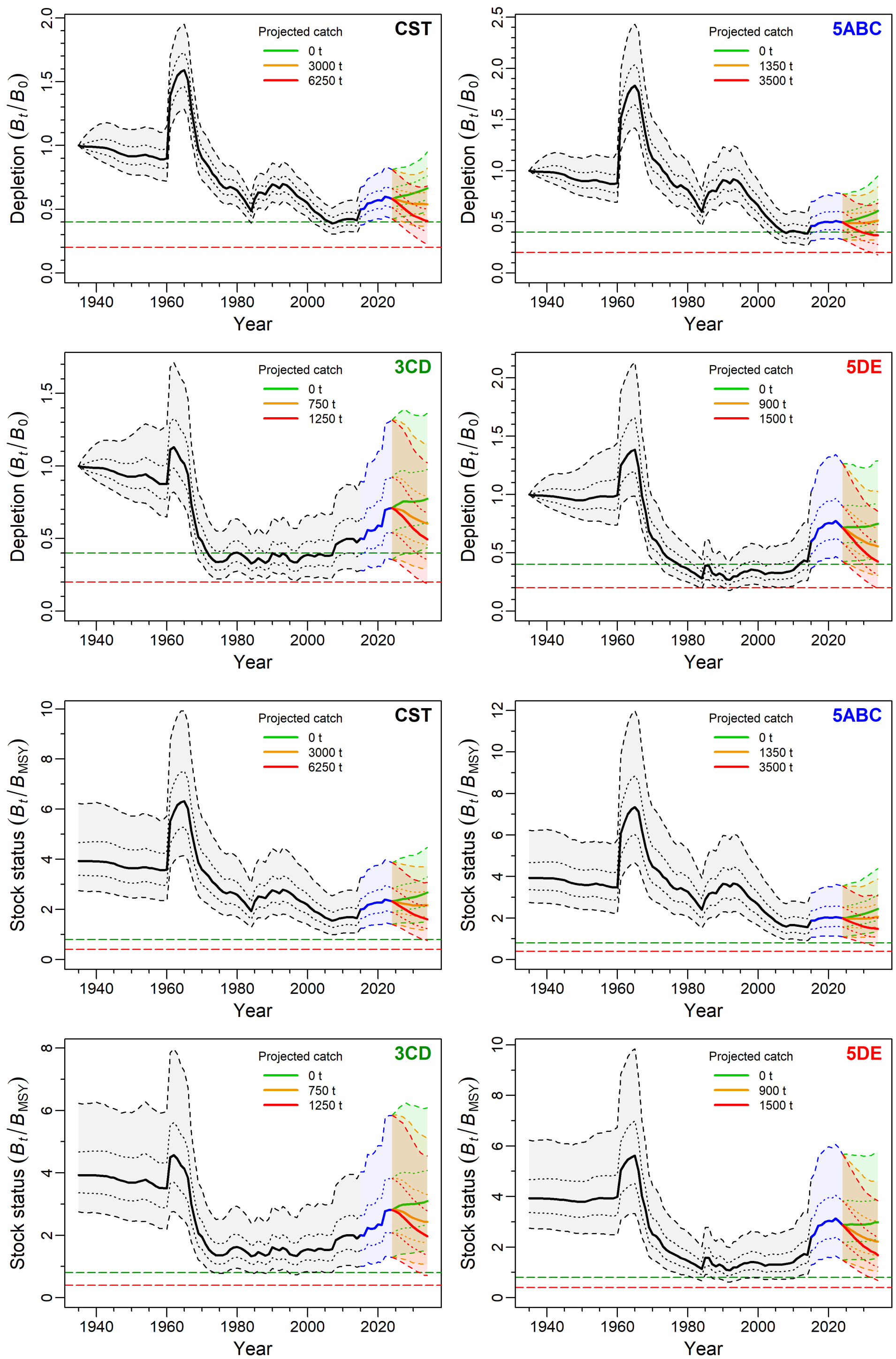


Figure F.34. Base run subareas: estimates of spawning biomass B_t relative to (top) B_0 and (bottom) B_{MSY} from model posteriors. The median biomass trajectory appears as a solid curve surrounded by a 90% credibility envelope (quantiles: 0.05-0.95) in grey (main) and blue (late) and delimited by dashed lines for years t=1935:2024; projected biomass for years t=2025:2034 appear in green for no catch, orange for average catch, and red for high catch. Also delimited is the 50% credibility interval (quantiles: 0.25-0.75) delimited by dotted lines.The horizontal dashed lines show 0.2B_0 & 0.4B_0 (top) and 0.4B_{MSY} & 0.8B_{MSY} (bottom).

F.2.1.2.5. Coastwide stock status

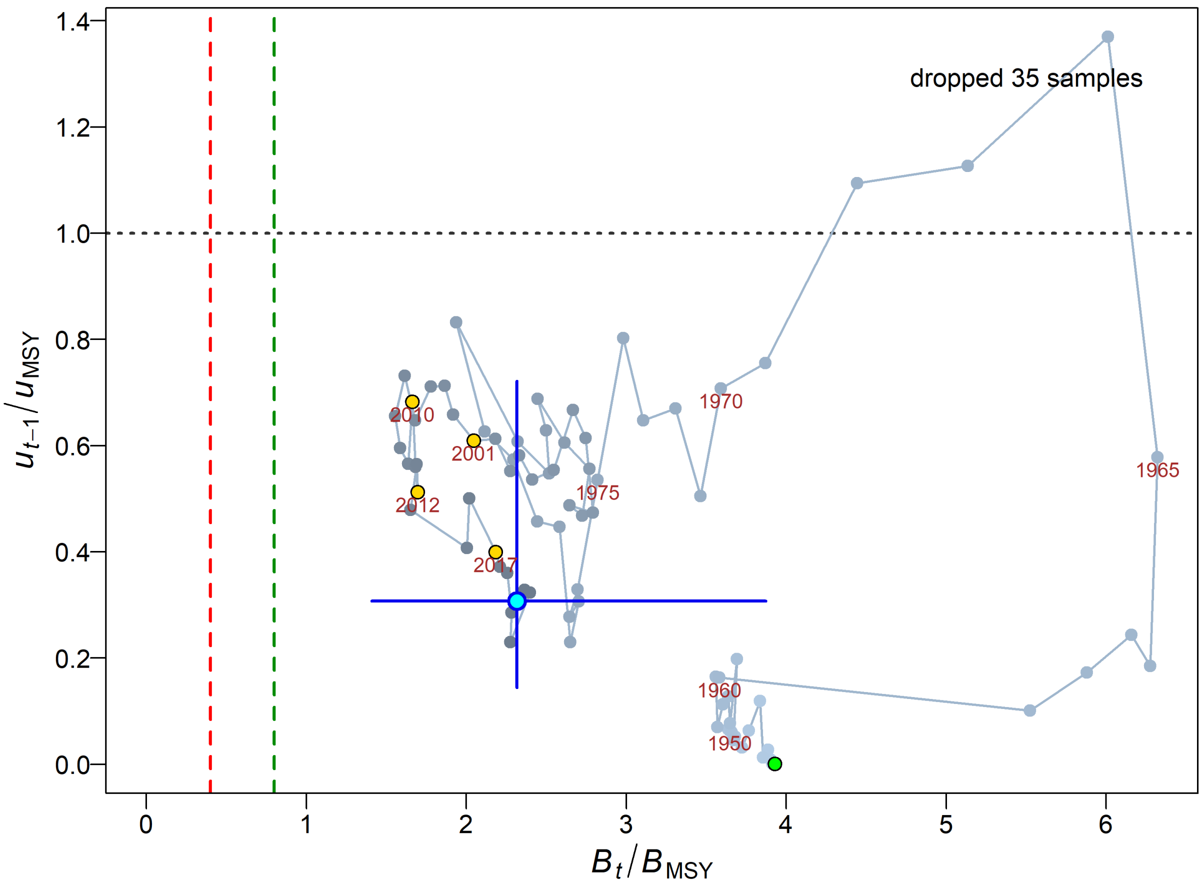


Figure F.35. Base run: phase plot through time of the medians of the ratios B_t/B_{MSY} (the spawning biomass in year t relative to B_{MSY}) and u_{t-1}/u_{MSY} (the exploitation rate in year $t-1$ relative to u_{MSY}) for the combined fishery (5ABC Trawl + 3CD Trawl + 5DE Trawl). The filled green circle is the equilibrium starting year (1935). Years then proceed along lines gradually darkening from light grey, with the final year (2024) as a filled cyan circle, and the blue cross lines represent the 0.05 and 0.95 quantiles of the posterior distributions for the final year. Red and green vertical dashed lines indicate the PA limit and upper stock reference points (0.4, 0.8 B_{MSY}), and the horizontal grey dotted line indicates u at MSY.

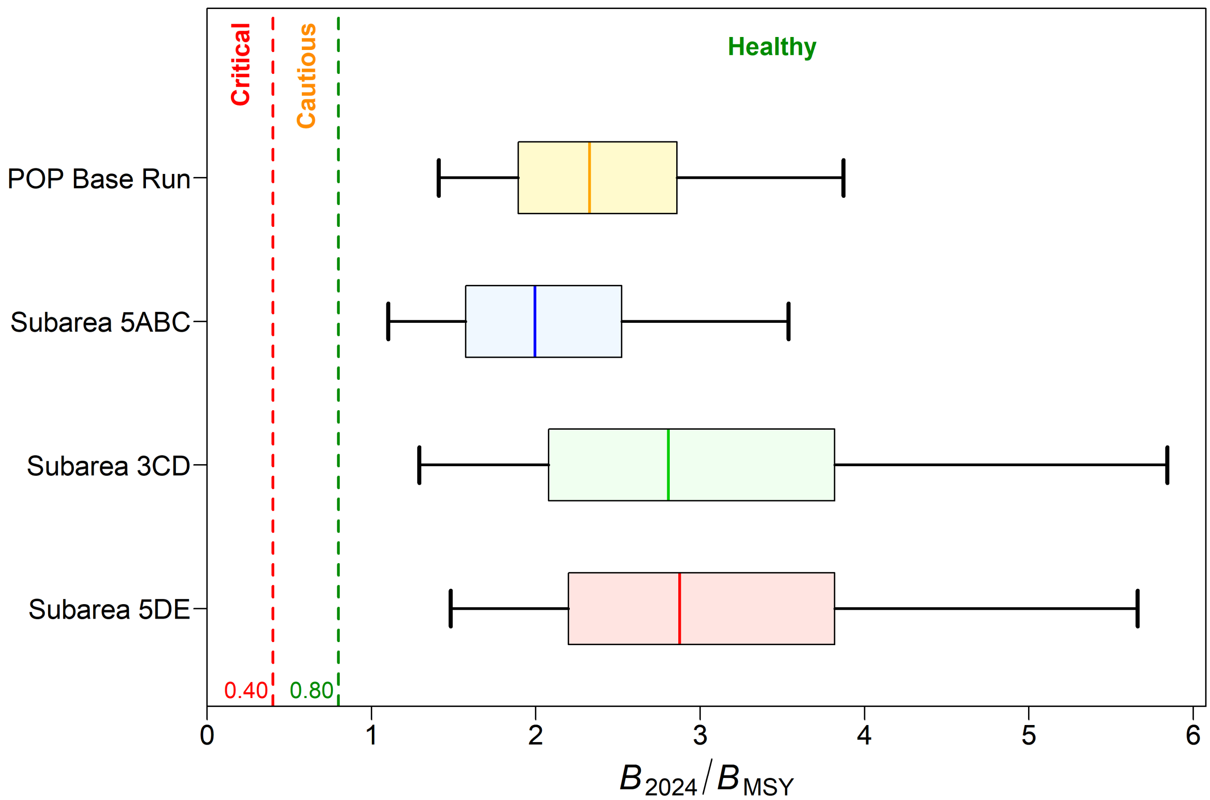


Figure F.36. Base run: stock status at beginning of 2024 relative to the PA reference points of 0.4B_{MSY} and 0.8B_{MSY} for the base run. Quantile plots show the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles from the MCMC posteriors.

F.2.2. Single-area Models

Single-area models were fit to the area-specific data from 5ABC (Queen Charlotte Sound, QCS), 3CD (west coast Vancouver Island, WCVI), and 5DE (west coast Haida Gwaii, WCHG plus Dixon Entrance), using the same assumptions as those for the multi-area model (e.g., Multinomial fit of age frequencies and one Francis mean-age reweight) and treating each area as an independent stock. These individual models provide a direct link to the single-area models that were used to assess these stock areas in the previous iterations of the BC POP stock assessment (5ABC: Haigh et al. 2018; 3CD: Edwards et al. 2014*b*; 5DE: Edwards et al. 2014*a*). Additionally, they were used to validate the subarea results from the multi-area model described in Section F.2..

F.2.2.1. 5ABC – Area 1

Fits to the two survey series in 5ABC were good, with biomass decreasing from 1967 to 1977 (GIG historical), and continuing to decrease from 2003 to 2013 before increasing until 2021 (QCS synoptic; Figure F.37). Selectivity showed that the fishery captured sub-mature fish older than nine years (Figure F.37). The QCS synoptic survey captured no sub-mature fish while the GIG historical survey captured sub-mature fish up to age 15. The fits to the commercial AF data were similar to those obtained by the multi-area model, with few large residuals and no strong patterns in the residuals (Figure F.38). Spawning biomass depletion remained at, or just above, $0.4B_0$ from 2005 on (Figure F.39), which was also seen by the multi-area model (Figure F.34). Notable recruitment events in 5ABC occurred in 1952, 1976-77, 1980-81, 1984, and 2006 (Figure F.40), which were the same events identified in the multi-area model (Figure F.33).

A retrospective analysis showed that the 5ABC spawning biomass reconstruction did not change greatly after the sequential removal of 13 years of data back to 2010 (Figure F.41). Similarly, the removal of data revealed no great surprises in the fits to the QCS synoptic index series. This retrospective analysis did not did not materially change the fit to the QCS synoptic survey index series nor did it reveal any underlying problems in the 5ABC model, with all between-year shifts explained through the introduction of new information into the model.

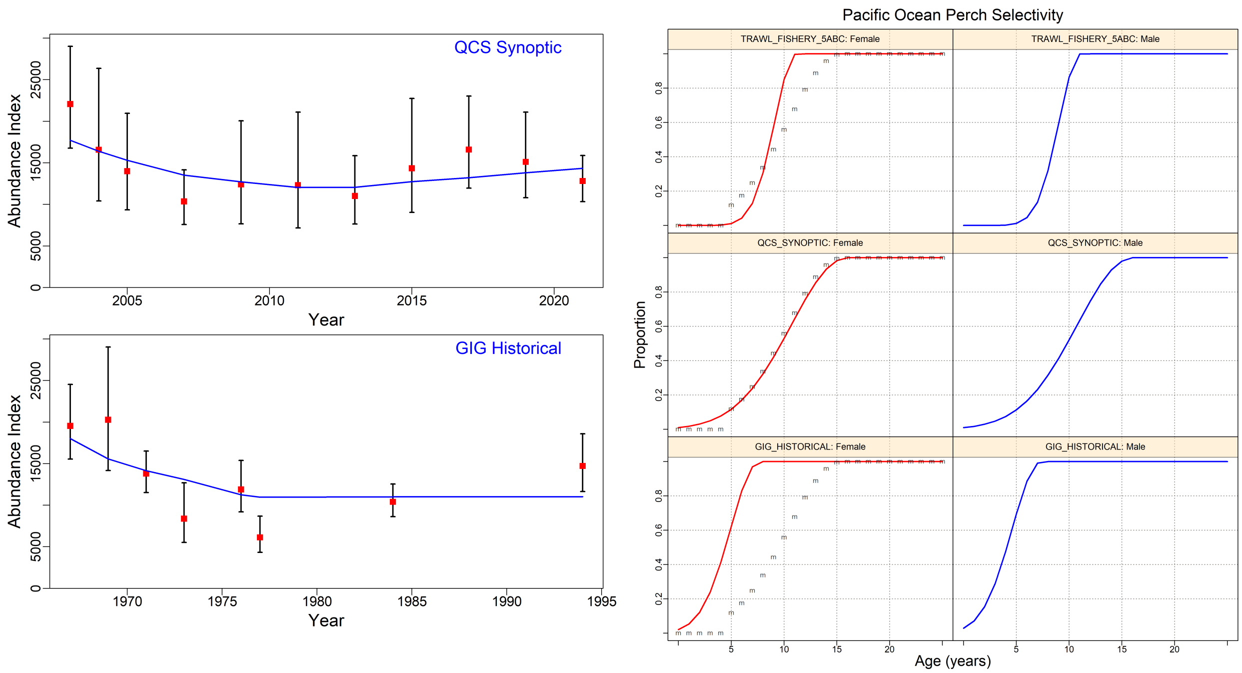
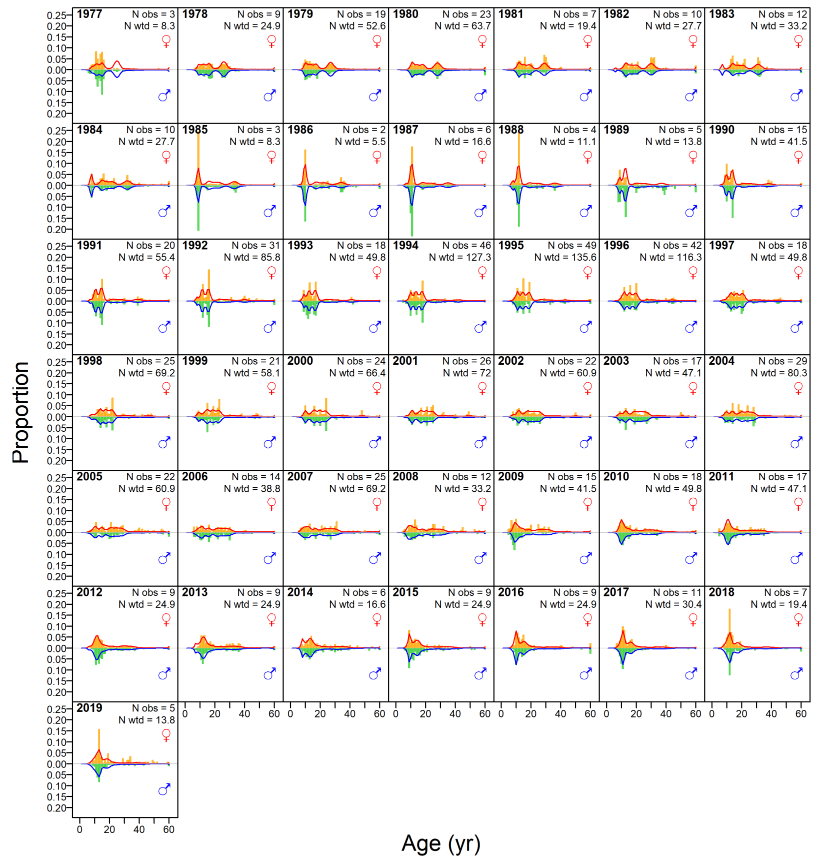


Figure F.37. 5ABC single-area model: survey index values (points) with 95% confidence intervals (bars) and MPD model fits (curves) for the fishery-independent survey series (left); selectivities for commercial fleet catch and surveys, with maturity ogive for females indicated by 'm' (right).



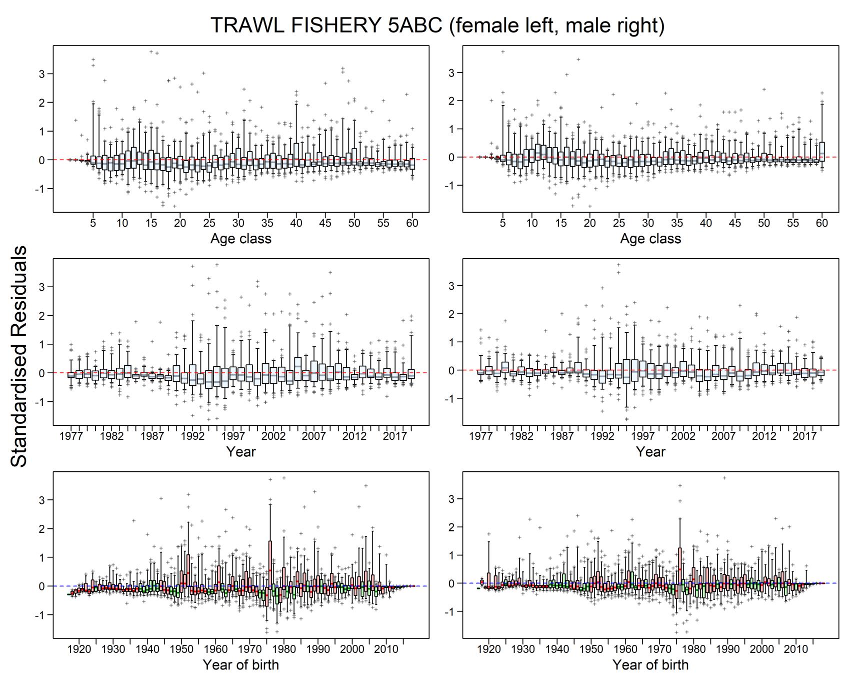


Figure F.38. 5ABC single-area model: model fits (top) and model fit residuals (bottom) for commercial fishery proportion-at-age data. See captions in Figs. F.4 and F.5 for details.

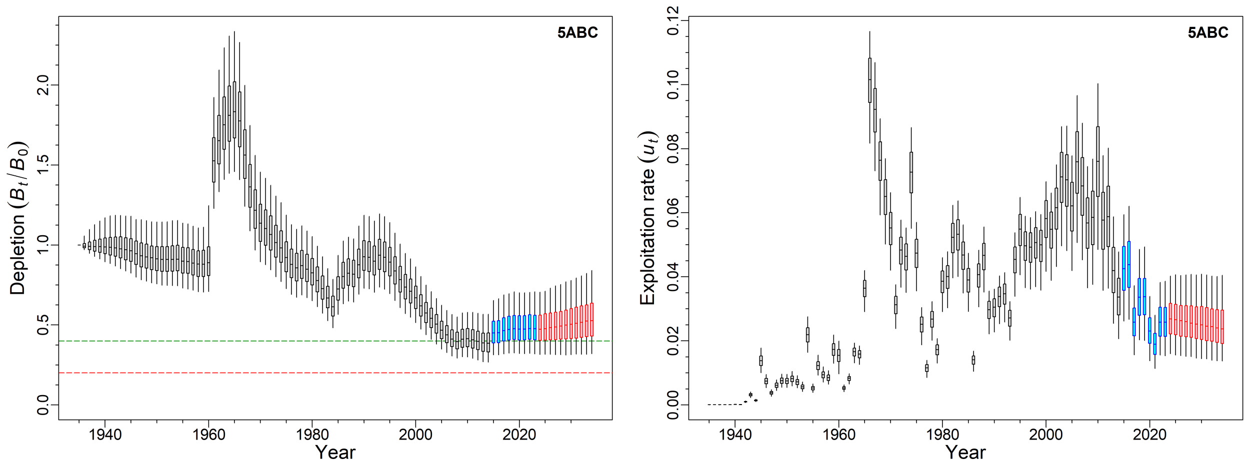


Figure F.39. 5ABC single-area model: marginal posterior distribution of spawning biomass depletion (B_t/B_0, left) and exploitation rate (right) over time. Boxplots show the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles from the MCMC results.

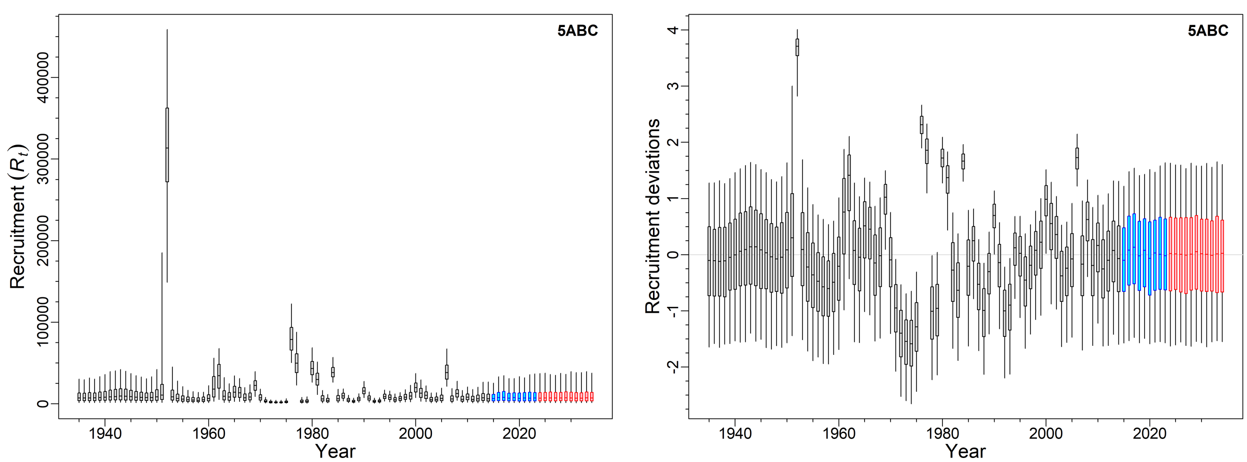


Figure F.40. 5ABC single-area model: marginal posterior distribution of recruitment (1000s age-0 fish, left) and recruitment deviations (right) over time. Boxplots show the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles from the MCMC results.

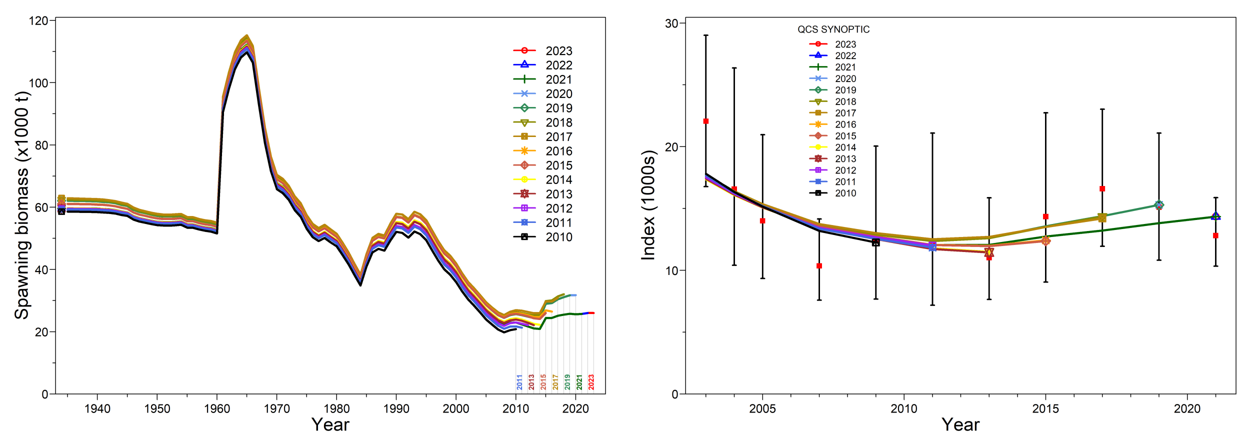


Figure F.41. 5ABC single-area model: retrospective analysis showing results for fits to spawning stock biomass (left) and QCS synoptic survey index (right).

F.2.2.2. 3CD – Area 2

Fits to the three survey series in 3CD were fair, with biomass either flat (WCVI synoptic, NMFS triennial) or decreasing (WCVI historical; Figure F.42, left panel). Commercial selectivity showed that the fishery captured sub-mature fish older than eight years (Figure F.42, right panel). The WCVI synoptic survey captured no sub-mature fish while the NMFS triennial survey showed full selectivity for POP at age 5. Selectivity for the WCVI historical survey was linked to that for the WCVI synoptic survey. The fits to the 3CD commercial AF data appeared to be better than those obtained by the multi-area model, with fewer large residuals and no strong patterns in the residuals, indicating that the 5ABC selectivity used for these data in the base run was not optimal (Figure F.43). Spawning biomass depletion remained between 0.2B_0 and 0.4B_0 from approximately 1970 to 2005, after which it increased to around 0.4B_0 (Figure F.44). This pattern for the 3CD biomass trajectory was also seen by the multi-area model (Figure F.34). However, spawning biomass in 3CD made a greater improvement beginning with 2010 in the multi-area model compared to the single-area model (median B_{2024}/B_0 = 0.44 for the single-area model compared to 0.71 for the 3CD subarea of the multi-area model). Strong recruitment events in 3CD occurred in 1981, 1999, 2008, and 2013 (Figure F.45), which were the same events identified in the multi-area model for 3CD (Figure F.33); however, the latter analysis also showed good recruitment in 1952, which was borrowed from the data in 5ABC and 5DE.

A retrospective analysis showed that the 3CD spawning biomass reconstruction did not change greatly after the sequential removal of 13 years of data back to 2010 (Figure F.46). There was a strong increase in biomass for 2014 and 2015, resulting from a large WCVI survey index value observed in 2014. This retrospective analysis did not reveal any underlying problems in the 3CD model, with between-year shifts explained through the introduction of new information into the model.

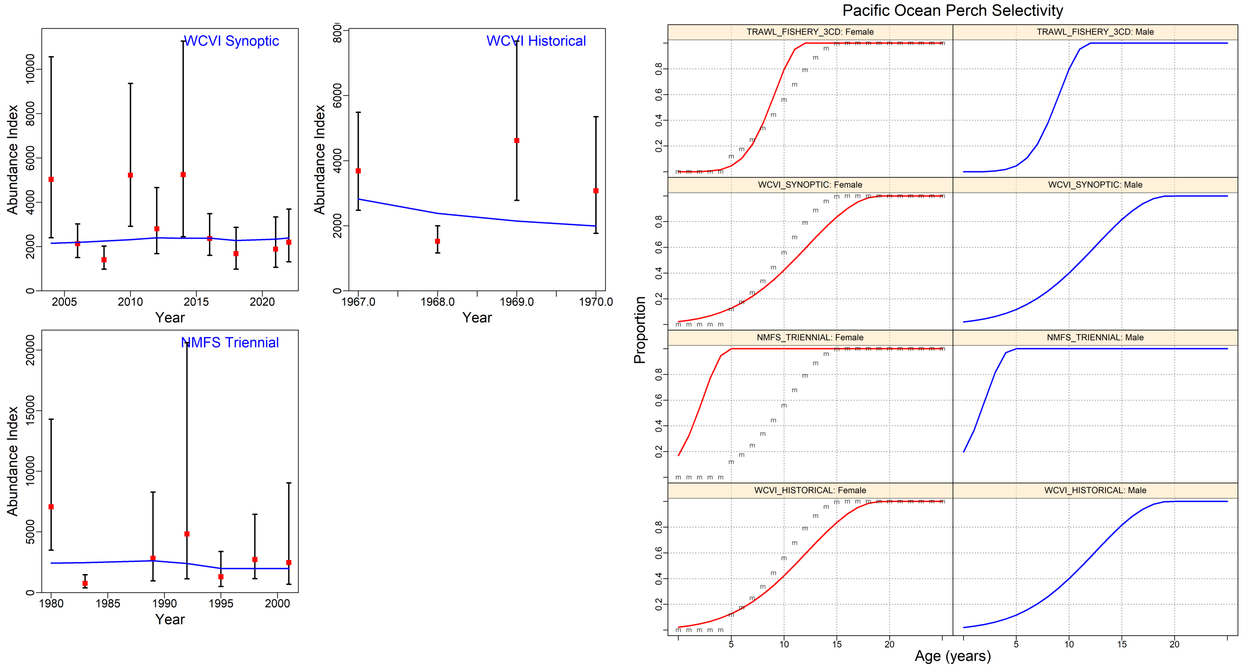


Figure F.42. 3CD single-area model: survey index values (points) with 95% confidence intervals (bars) and MPD model fits (curves) for the fishery-independent survey series (left); selectivities for commercial fleet catch and surveys, with maturity ogive for females indicated by 'm' (right).

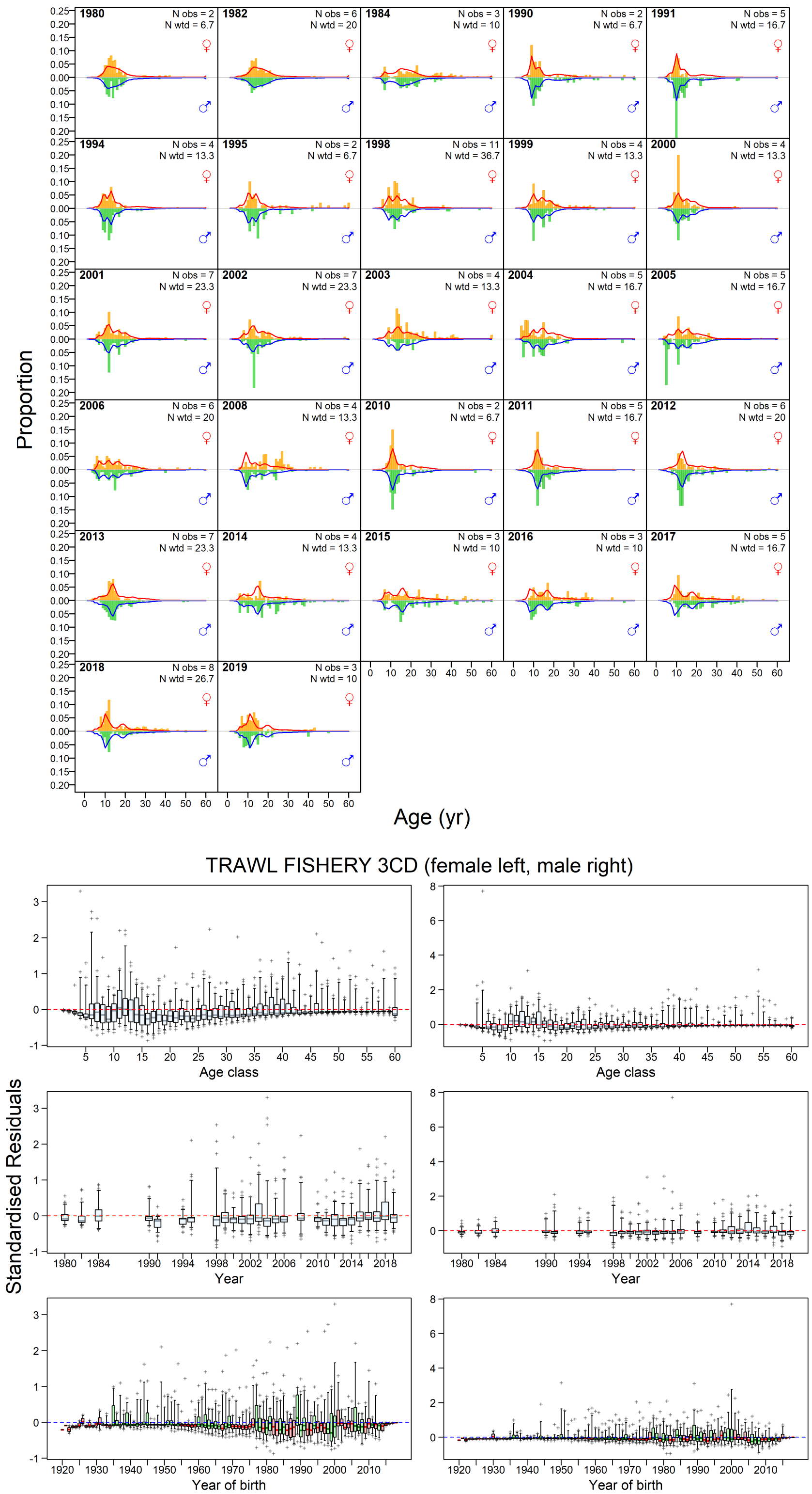


Figure F.43. 3CD single-area model: model fits (top) and model fit residuals (bottom) for commercial fishery proportion-at-age data. See captions in Figs. F.4 and F.5 for details.

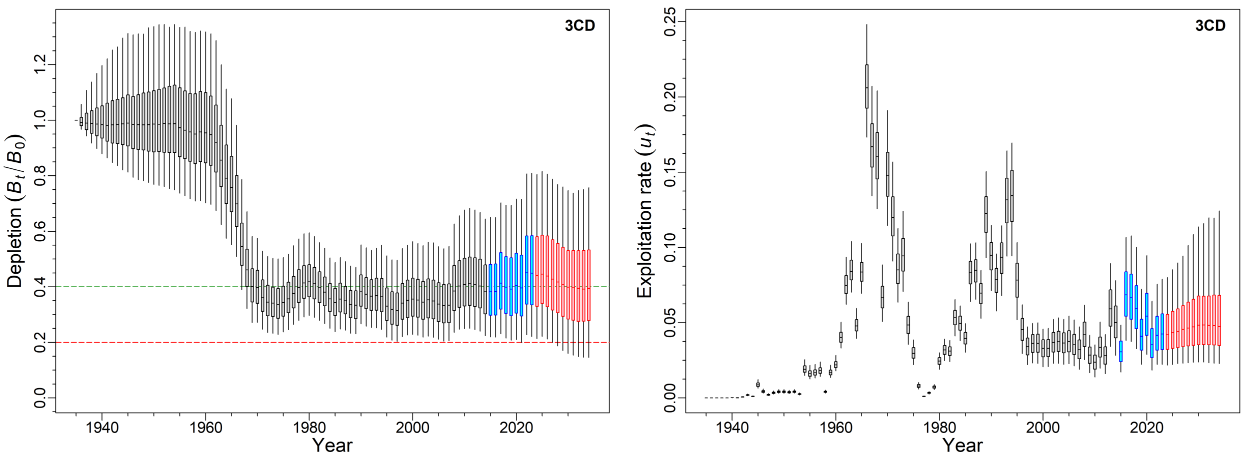


Figure F.44. 3CD single-area model: marginal posterior distribution of spawning biomass depletion (B_t/B_0, left) and exploitation rate (right) over time. Boxplots show the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles from the MCMC results.

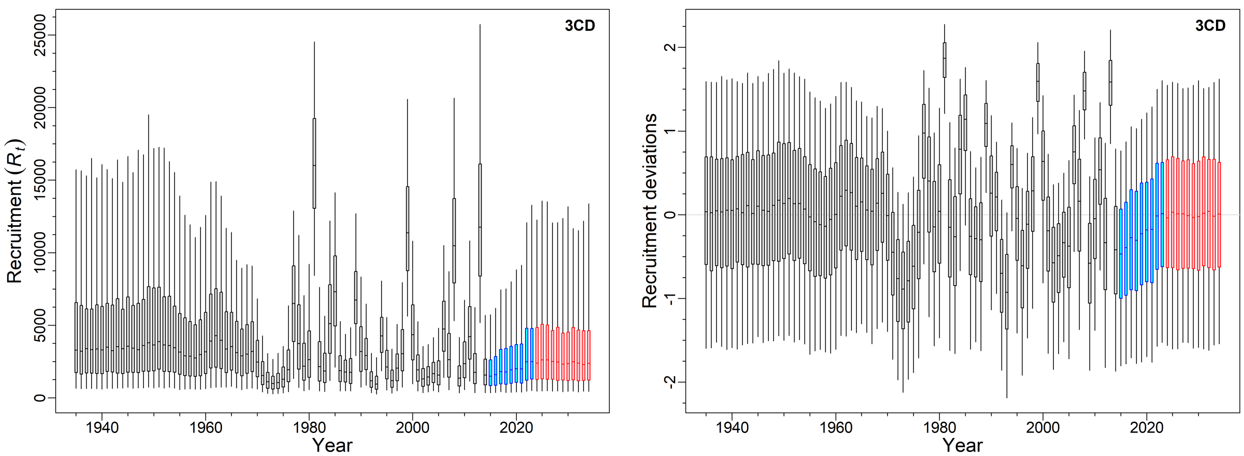


Figure F.45. 3CD single-area model: marginal posterior distribution of recruitment (1000s age-0 fish, left) and recruitment deviations (right) over time. Boxplots show the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles from the MCMC results.

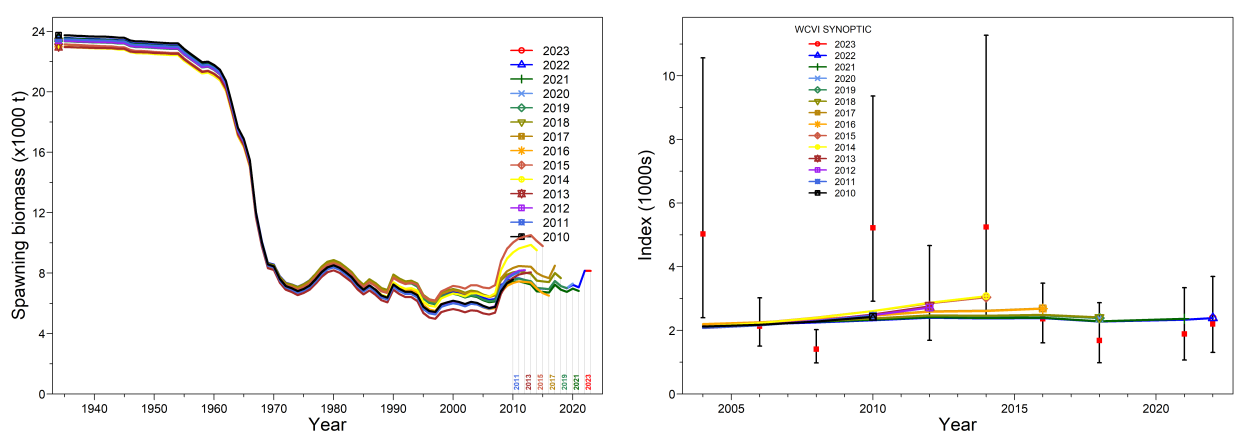


Figure F.46. 3CD single-area model: retrospective analysis showing results for fits to spawning stock biomass (left) and WCVI synoptic survey index (right).

F.2.2.3. 5DE – Area 3

The fits to the WCHG synoptic survey indices were good, with the fit improved over the equivalent fit by the 5DE subarea in the multi-area model (Figure F.47). Selectivity showed that the fishery captured sub-mature fish older than nine years (Figure F.42). The WCHG synoptic survey captured sub-mature fish older than 11 years. The fits to the AF data (Figure F.48) were similar to those observed for the 5DE subarea model, with few outlier standardised residuals. The plot of depletion (B_t/B_0) showed the stock going even lower into the zone between 0.2 and 0.4B_0 than did the 3CD single-area model (over the period from the late 1960s to near 2015) (Figure F.34, left panel). The single-area 5DE base stock assessment indicated that there was a small probability (probably less than 5%) that this stock was in the Cautious zone from the mid-1980s to the mid-1990s (Figure 13, right panel).

A retrospective analysis showed that the 5DE spawning biomass reconstruction progressed from pessimistic in the early years (2010-2015) to an increasingly optimistic outlook as successive years of higher index values from the WCHG survey were added to the model (Figure F.51). This retrospective analysis did not reveal any underlying problems in the 5DE model, with between-year shifts explained through the introduction of new information into the model.

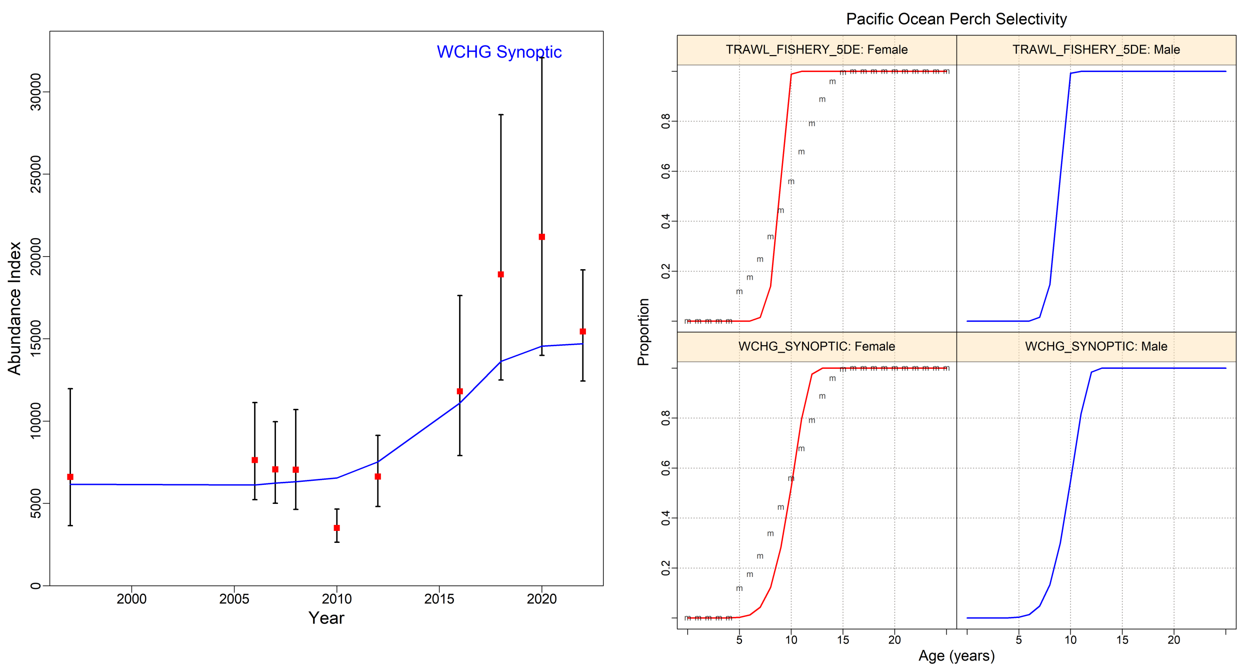


Figure F.47. 5DE single-area model: survey index values (points) with 95% confidence intervals (bars) and MPD model fits (curves) for the fishery-independent survey series (left); selectivities for commercial fleet catch and surveys, with maturity ogive for females indicated by 'm' (right).

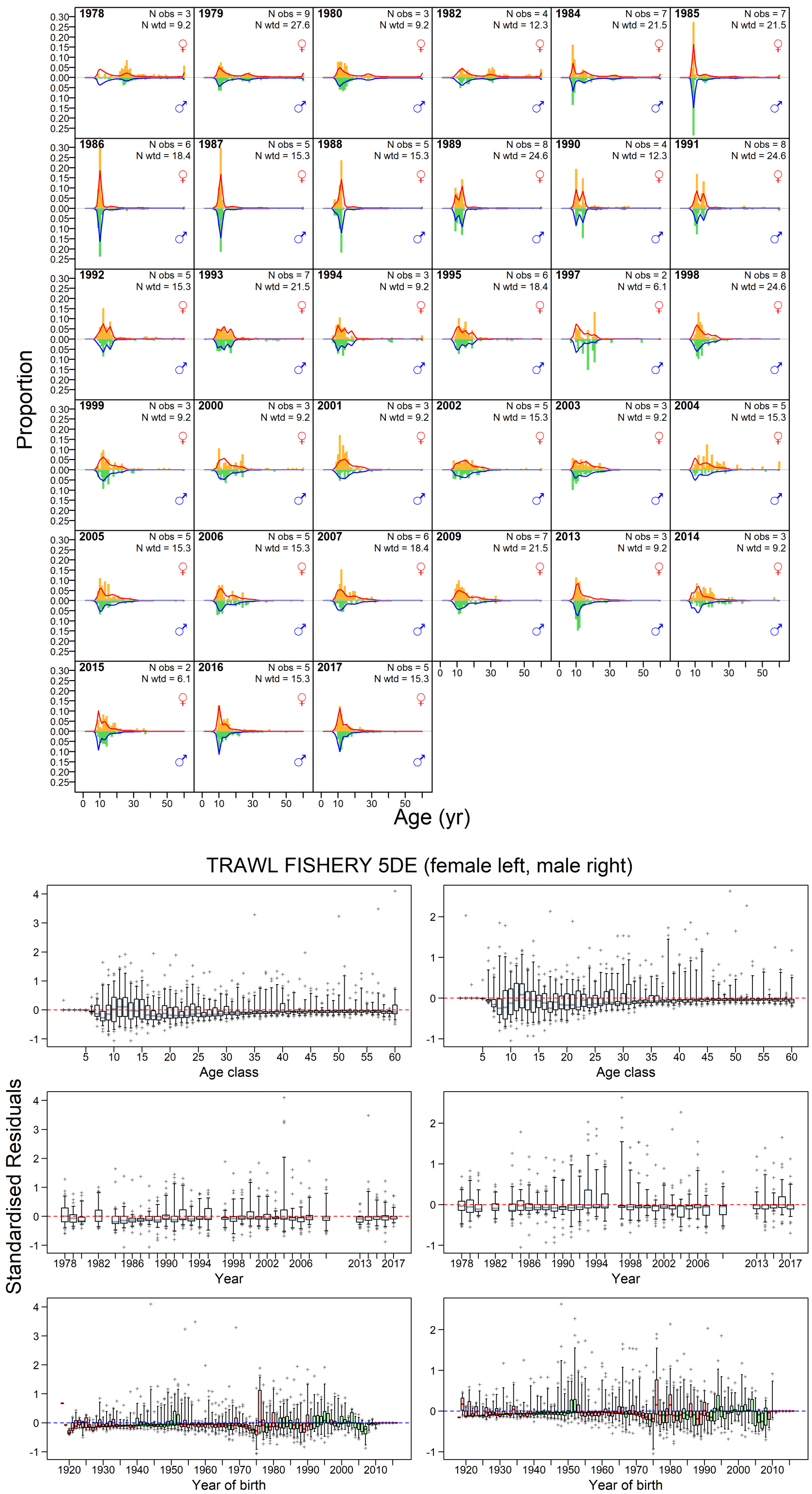


Figure F.48. 5DE single-area model: model fits (top) and model fit residuals (bottom) for commercial fishery proportion-at-age data. See captions in Figs. F.4 and F.5 for details.

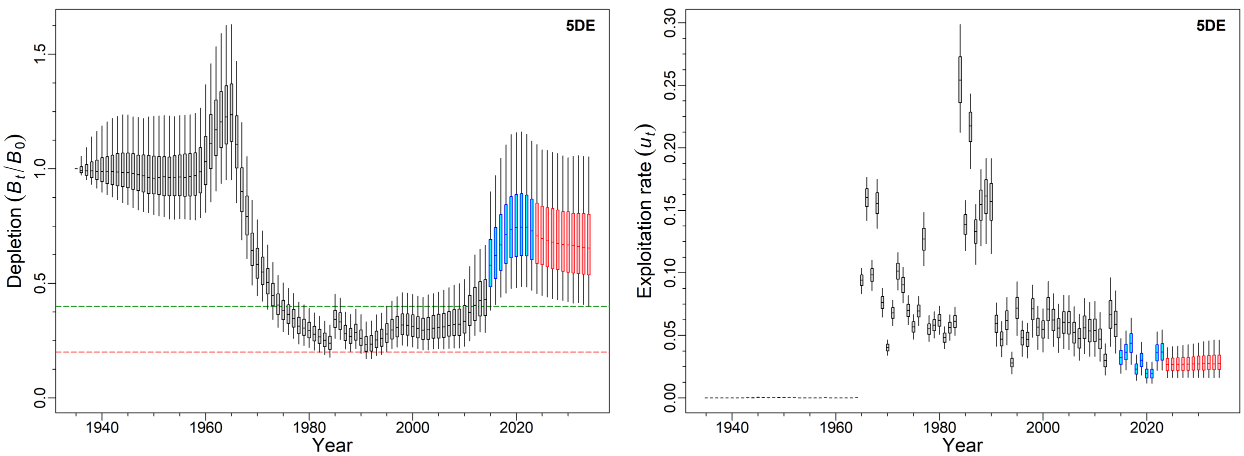


Figure F.49. 5DE single-area model: marginal posterior distribution of spawning biomass depletion (B_t/B_0, left) and exploitation rate (right) over time. Boxplots show the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles from the MCMC results.

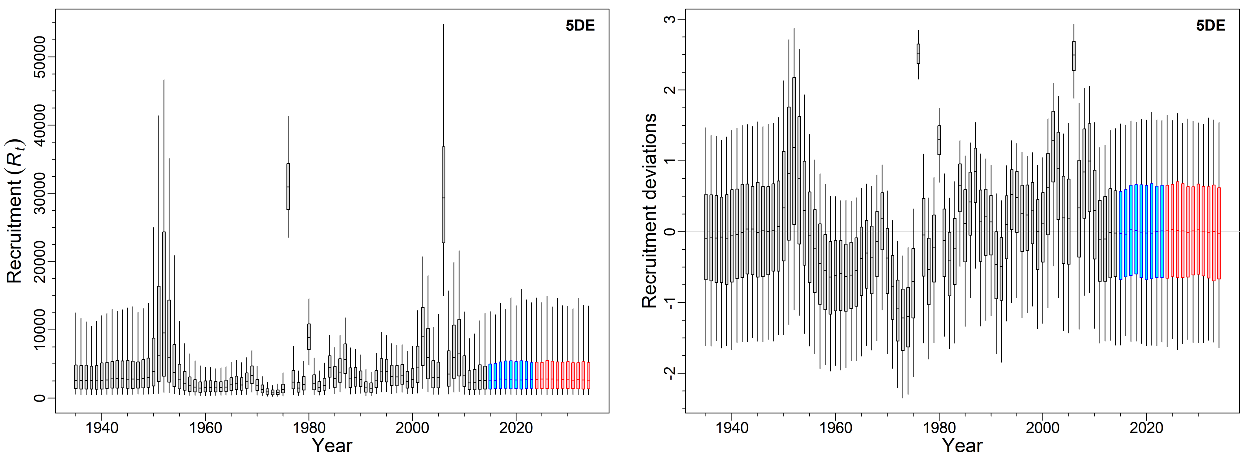


Figure F.50. 5DE single-area model: marginal posterior distribution of recruitment (1000s age-0 fish, left) and recruitment deviations (right) over time. Boxplots show the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles from the MCMC results.

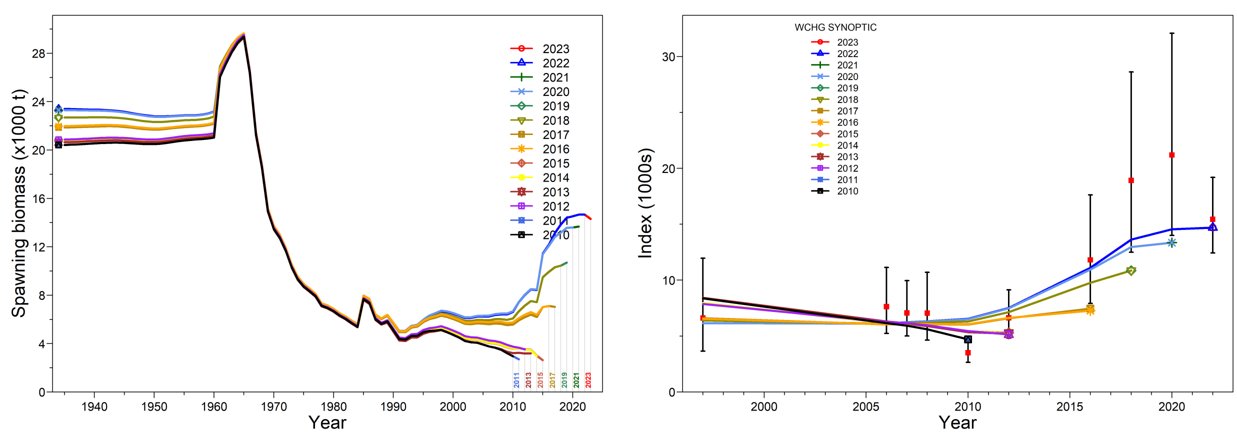


Figure F.51. 5DE single-area model: retrospective analysis showing results for fits to spawning stock biomass (left) and WCHG synoptic survey index (right).

F.2.2.4. Model comparisons

MCMC diagnostics (Figure F.52) were good for all three single-area models, at least for the $\log R_0$ parameter. Area 5ABC displayed similar characteristics as those seen for the multi-area model presented in Section F.2.1.2. Diagnostics for areas 3CD and 5DE, however, were not as good as those seen for the multi-area model presented in Section F.2.1.2. All area models displayed a small amount of fraying in the eight MCMC chains. There was no evidence of autocorrelation in any of the leading parameters.

Trajectories comparing the coastwide base model run with the single-area models are displayed in Figures F.54 to F.55. Female spawning biomass (Figure F.54, left panel) was clearly higher in 5ABC than the two outlying areas (3CD and 5DE). The base run multi-area model (Figure F.23, bottom panel), with 5DE as the reference area, indicated that the proportional split was roughly 60:20:20 among the subareas, and this seemed to be reflected by the single-area models. Depletion (B_t/B_0) trajectories (Figure F.54, right panel) showed that the median ratio for 5ABC did not fall below 0.4B_0, whereas the other two stocks remained between 0.2 and 0.4B_0 for decades. All three single-area models indicated that each stock recovered to a depletion ratio above 0.4B_0 in 2024.

Recruitment deviations (Figure F.55, left panel) for the single-area models were largely consistent with each other. Notable exceptions appeared for area 3CD in 1952 and 5DE during the 1960s. There was also a set of opposing deviations among the areas centred around the year 2000. The coastwide median deviations show how the multi-area model reconciled the deviations from the three subareas.

Exploitation rates (Figure F.55, right panel) during the foreign-fleet years reach $\sim$0.10 in the 5ABC single-area model (and $\sim$0.12 coastwide in the multi-area model); however, rates in 3CD peaked at $\sim$0.20 in 3CD and $\sim$0.15 in 5DE. Thereafter, exploitation rates in 5ABC remained at $\sim$0.05 for decades while rates reached $\sim$0.17 and $\sim$0.25 in 3CD and 5DE, respectively, during the pre-observer years in the Canadian fisheries.

Stock status of the three single-area models (Figure F.56) showed some differences compared to the stock status of the multi-area subareas (Figure F.68). The most notable was the lower status of 3CD from the single-area model, which did not have the benefit of recruitment signals from the other two areas. The 3CD single-area stock status remained in the Healthy zone, but there was at least a 5% probability of lying in the Cautious zone, which did not occur in the multi-area analysis. At the other extreme was the higher status of the 5DE stock from the single-area model compared to the multi-area model, reflecting a variable interpretation of the relative stock sizes for these three areas (Figure F.47).

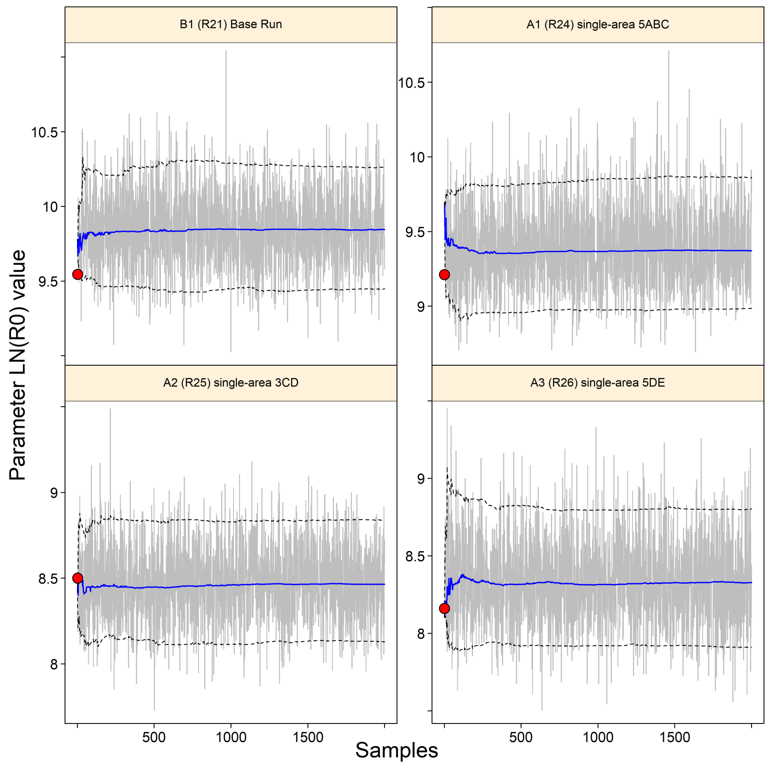


Figure F.52. Model comparisons: trace plots for the coastwide base run and three single-area models (5ABC, 3CD, and 5DE). See caption in Fig. F.25 for details.

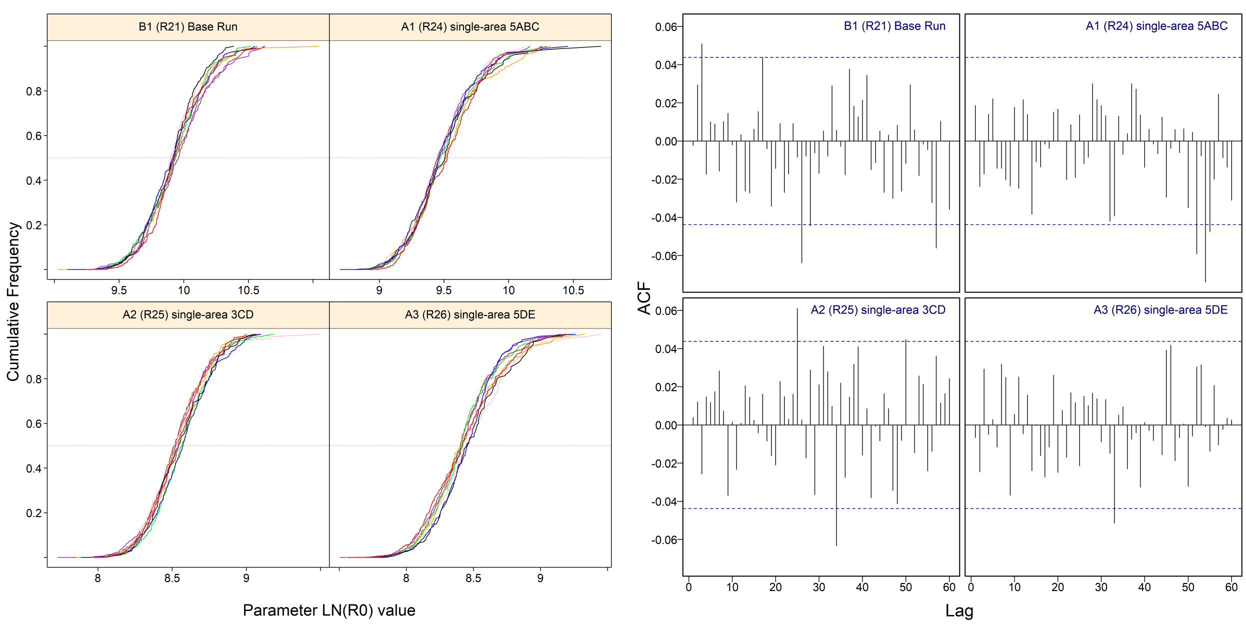


Figure F.53. Model comparisons: split chains (left) and autocorrelation plots (right) for the coastwide base run and three single-area models (5ABC, 3CD, and 5DE). See captions in Figs. F.26–F.27 for details.

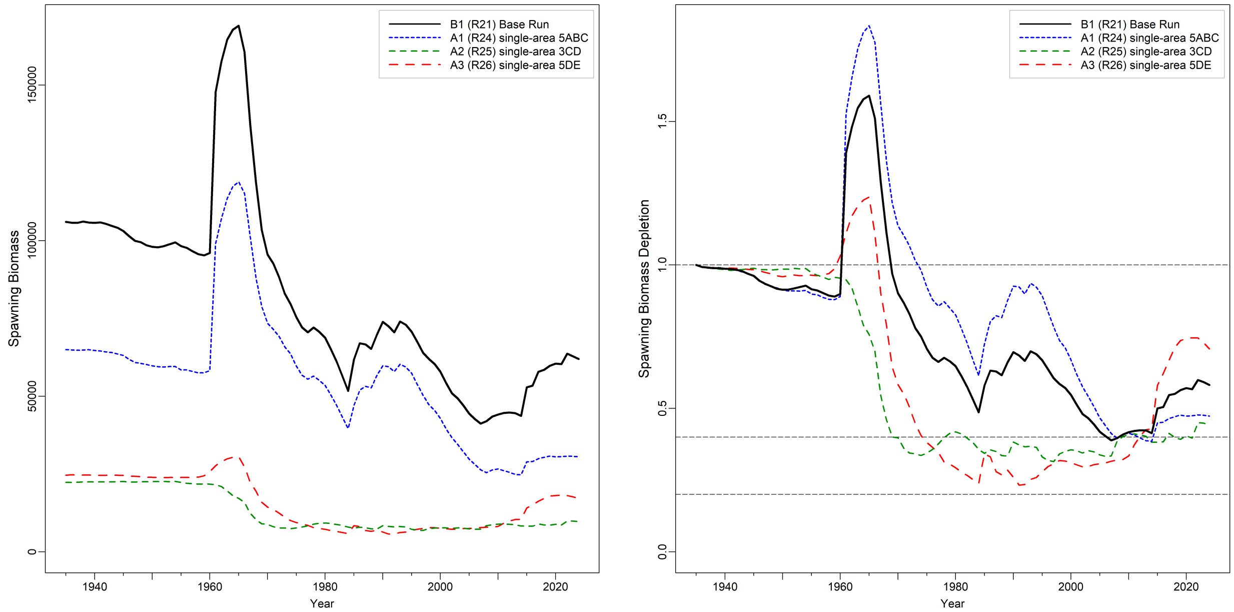


Figure F.54. Model comparisons: trajectories of median female spawning biomass (tonnes, left) and median spawning biomass depletion (B_t/B_0, right) for the coastwide base run and three single-area models (5ABC, 3CD, and 5DE). Horizontal dashed lines show alternative reference points used by other jurisdictions: 0.2B_0 (~DFO's USR), 0.4B_0 (often a target level above B_{MSY}), and B_0 (equilibrium spawning biomass).

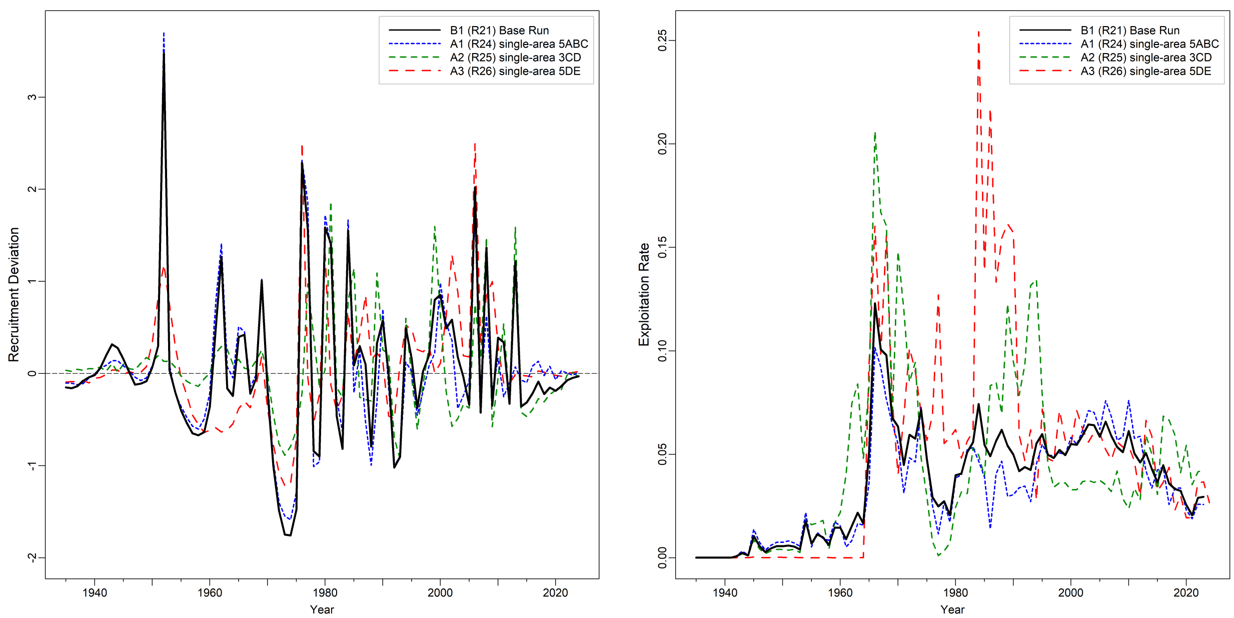


Figure F.55. Model comparisons: trajectories of median recruitment deviations (left) and median exploitation rate (u_t, right) for the coastwide base run and three single-area models (5ABC, 3CD, and 5DE).

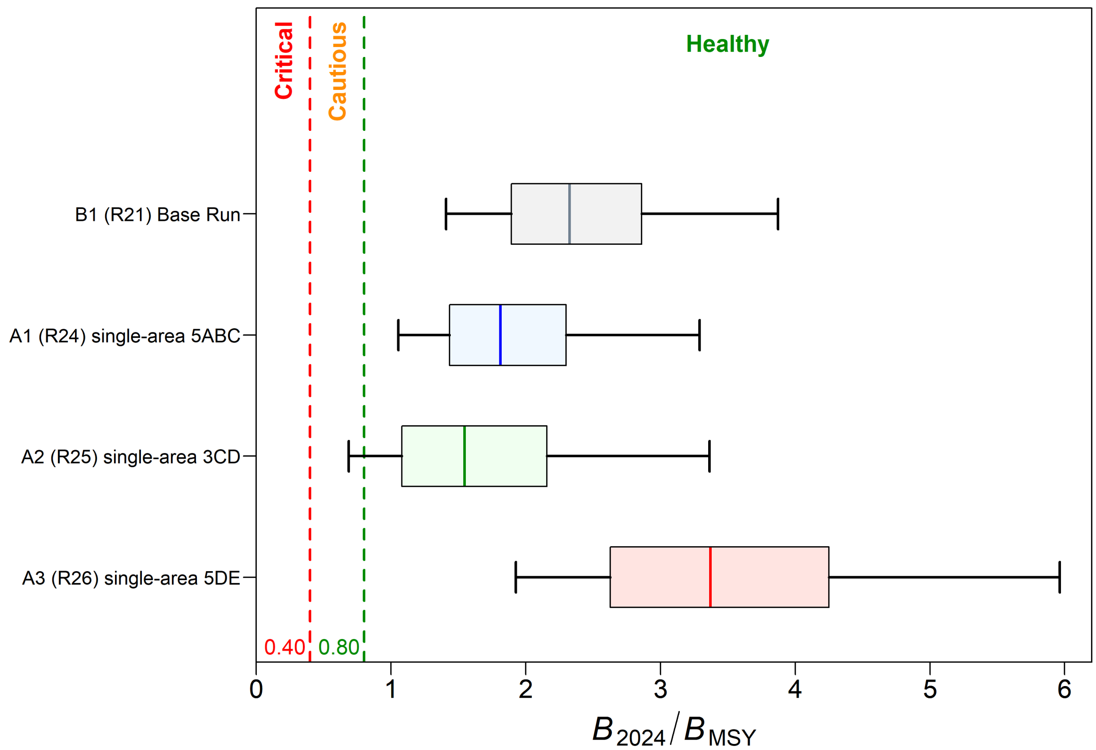


Figure F.56. Model comparisons: spawning stock biomass status (B_{2024}/B_{MSY}) for the coastwide base run and three single-area models (5ABC, 3CD, and 5DE). Boxplots show the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles from the MCMC posterior.

F.2.3. GMU – Guidance for setting TACs

Decision tables for the base run provide advice to managers as probabilities that current and projected biomass B_t $(t = 2024, ..., 2034)$ will exceed biomass-based reference points (or that projected exploitation rate u_t will fall below harvest-based reference points) under constant catch (CC) policies. Note that years for biomass-based reference points refer to the start of years, whereas years for harvest-based reference points refer to years prior to the start ($\sim$mid-year). A small number of samples were dropped before constructing the decision tables because the estimated MSY values were undefined (NaN values).

Decision tables in the document (all under a constant catch policy):

- Table F.7 – probability of B_t exceeding the LRP, P$(B_t > 0.4B_{\text{MSY}})$;
- Table F.8 – probability of B_t exceeding the USR, P$(B_t > 0.8B_{\text{MSY}})$;
- Table F.9 – probability of B_t exceeding biomass at MSY, P$(B_t > B_{\text{MSY}})$;
- Table F.11 – probability of u_t falling below harvest rate at MSY, P$(u_t < u_{\text{MSY}})$;
- Table F.10 – probability of B_t exceeding current-year biomass, P$(B_t > B_{2024})$;
- Table F.12 – probability of u_t falling below current-year harvest rate, P$(u_t < u_{2023})$;
- Table F.13 – probability of B_t exceeding a non-DFO ‘soft limit’, P$(B_t > 0.2B_0)$;
- Table F.14 – probability of B_t exceeding a non-DFO ‘target’ biomass, P$(B_t > 0.4B_0)$;

MSY-based reference points estimated within a stock assessment model can be highly sensitive to model assumptions about natural mortality and stock recruitment dynamics (Forrest et al. 2018). As a result, other jurisdictions use reference points that are expressed in terms of B_0

rather than B_{MSY} (e.g., N.Z. Min. Fish. 2011) because B_{MSY} is often poorly estimated as it depends on estimated parameters and a consistent fishery (although B_0 shares several of these same problems). Therefore, the reference points of 0.2B_0 and 0.4B_0 are also presented here. These are default values used in New Zealand respectively as a 'soft limit', below which management action needs to be taken, and a 'target' biomass for low productivity stocks, a mean around which the biomass is expected to vary. The 'soft limit' is equivalent to the upper stock reference (USR, 0.8B_{MSY}) in the DFO Sustainable Fisheries Framework while a 'target' biomass is not specified by the DFO SFF. Additionally, results are provided comparing projected biomass to B_{MSY} and to current spawning biomass B_{2024}, and comparing projected harvest rate to current harvest rate u_{2023}.

COSEWIC indicator A1 is reserved for those species where the causes of the reduction are clearly reversible, understood, and ceased. Indicator A2 is used when the population reduction may not be reversible, may not be understood, or may not have ceased. Under A2, a species is considered Endangered or Threatened if the decline has been >50% or >30% below B_0, respectively.

Additional short-term tables for COSEWIC's A2 criterion:

- Table F.15 – probability of B_t exceeding 'Endangered' status (P($B_t > 0.5B_0$);
- Table F.16 – probability of B_t exceeding 'Threatened' status (P($B_t > 0.7B_0$).

F.2.3.1. Decision Tables

*Table F.7. Base run subareas: decision table for the limit reference point 0.4B_{MSY} featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes). Values are P($B_t > 0.4B_{\text{MSY}}$), i.e. the probability of the spawning biomass (mature females) at the start of year t being greater than the limit reference point. The probabilities are the proportion (to two decimal places) of the 1,965 MCMC samples for which $B_t > 0.4B_{\text{MSY}}$. For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.*

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,000	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,350	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,750	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	2,150	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	2,550	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	3,500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99
3CD	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	750	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	875	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,000	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,125	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99
	1,250	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99
5DE	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	700	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	900	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,050	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
	1,200	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,350	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99

*Table F.8. Base run subareas: decision table for the upper stock reference point 0.8B_{MSY} featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes), such that values are P($B_t > 0.8 B_{MSY}$). For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.*

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,000	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.99	>0.99	>0.99
	1,350	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	1,750	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	2,150	>0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98
	2,550	>0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.97	0.97	0.97	0.96
	3,500	>0.99	0.99	0.99	0.98	0.97	0.96	0.95	0.93	0.92	0.90	0.89
3CD	0	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	500	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	750	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98
	875	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.98	0.98
	1,000	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.97	0.97	0.96
	1,125	0.99	0.99	0.99	0.98	0.98	0.98	0.97	0.97	0.96	0.95	0.95
	1,250	0.99	0.99	0.99	0.98	0.98	0.97	0.96	0.96	0.95	0.94	0.93
5DE	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	700	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99
	900	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.99
	1,050	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.97
	1,200	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.98	0.97	0.96
	1,350	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.97	0.96	0.96	0.95
	1,500	>0.99	>0.99	>0.99	0.99	0.99	0.98	0.98	0.96	0.95	0.94	0.92

*Table F.9. Base run subareas: decision table for the reference point B_{MSY} featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes), such that values are P($B_t > B_{MSY}$). For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.*

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	0.98	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99	>0.99
	1,000	0.98	0.98	0.98	0.98	0.97	0.97	0.98	0.98	0.98	0.98	0.98
	1,350	0.98	0.98	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
	1,750	0.98	0.97	0.97	0.96	0.96	0.96	0.96	0.95	0.96	0.95	0.95
	2,150	0.98	0.97	0.96	0.96	0.95	0.95	0.94	0.93	0.93	0.93	0.93
	2,550	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91	0.90	0.90	0.89
	3,500	0.98	0.96	0.95	0.93	0.91	0.89	0.87	0.84	0.82	0.80	0.78
3CD	0	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
	500	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
	750	0.98	0.98	0.98	0.98	0.97	0.97	0.97	0.96	0.96	0.96	0.96
	875	0.98	0.98	0.98	0.97	0.97	0.97	0.96	0.96	0.95	0.95	0.95
	1,000	0.98	0.98	0.98	0.97	0.97	0.96	0.95	0.94	0.94	0.93	0.93
	1,125	0.98	0.98	0.97	0.97	0.96	0.95	0.94	0.93	0.92	0.91	0.90
	1,250	0.98	0.98	0.97	0.97	0.96	0.95	0.93	0.92	0.90	0.89	0.88
5DE	0	0.99	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	700	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98
	900	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.97	0.97	0.96	0.96
	1,050	0.99	0.99	0.99	0.99	0.98	0.98	0.97	0.96	0.95	0.95	0.94
	1,200	0.99	0.99	0.99	0.99	0.98	0.97	0.96	0.94	0.94	0.93	0.92
	1,350	0.99	0.99	0.99	0.99	0.98	0.96	0.95	0.93	0.92	0.91	0.88
	1,500	0.99	0.99	0.99	0.98	0.97	0.95	0.93	0.92	0.90	0.87	0.84

*Table F.10. Base run subareas: decision table for the reference point B_{2024} featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes), such that values are P$(B_t > B_{2024})$. For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.*

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	0	0.67	0.75	0.76	0.78	0.79	0.81	0.83	0.85	0.87	0.89
	1,000	0	0.37	0.45	0.46	0.47	0.47	0.50	0.53	0.58	0.61	0.64
	1,350	0	0.31	0.36	0.36	0.37	0.37	0.39	0.43	0.47	0.50	0.54
	1,750	0	0.25	0.27	0.26	0.27	0.27	0.29	0.33	0.36	0.39	0.42
	2,150	0	0.19	0.20	0.19	0.19	0.20	0.21	0.23	0.26	0.29	0.31
	2,550	0	0.15	0.15	0.13	0.14	0.15	0.15	0.16	0.18	0.20	0.23
	3,500	0	0.08	0.07	0.06	0.06	0.06	0.07	0.07	0.08	0.10	0.12
3CD	0	0	0.95	0.94	0.91	0.84	0.79	0.74	0.71	0.70	0.71	0.70
	500	0	0.62	0.59	0.48	0.38	0.30	0.27	0.26	0.26	0.28	0.30
	750	0	0.41	0.37	0.26	0.19	0.15	0.13	0.12	0.13	0.14	0.15
	875	0	0.33	0.28	0.18	0.13	0.10	0.09	0.09	0.09	0.10	0.11
	1,000	0	0.26	0.21	0.12	0.09	0.06	0.06	0.06	0.07	0.07	0.08
	1,125	0	0.19	0.15	0.09	0.06	0.04	0.05	0.05	0.05	0.05	0.05
	1,250	0	0.16	0.11	0.07	0.04	0.04	0.03	0.03	0.03	0.03	0.04
5DE	0	0	0.46	0.50	0.49	0.47	0.46	0.47	0.49	0.52	0.55	0.57
	700	0	0.12	0.11	0.09	0.07	0.08	0.08	0.09	0.10	0.11	0.13
	900	0	0.08	0.07	0.05	0.04	0.05	0.05	0.06	0.06	0.07	0.07
	1,050	0	0.06	0.05	0.03	0.03	0.03	0.03	0.03	0.04	0.05	0.05
	1,200	0	0.05	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03
	1,350	0	0.03	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02
	1,500	0	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02

*Table F.11. Base run subareas: decision table for the reference point u_{MSY} featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes), such that values are P$(u_t < u_{MSY})$. For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.*

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	1	1	1	1	1	1	1	1	1	1	1
	1,000	>0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	>0.99	>0.99	>0.99
	1,350	0.98	0.98	0.98	0.98	0.98	0.97	0.97	0.97	0.97	0.97	0.97
	1,750	0.93	0.93	0.92	0.92	0.92	0.91	0.91	0.91	0.91	0.91	0.91
	2,150	0.86	0.85	0.85	0.84	0.83	0.83	0.82	0.82	0.82	0.81	0.81
	2,550	0.78	0.77	0.75	0.74	0.73	0.72	0.70	0.70	0.70	0.69	0.69
	3,500	0.59	0.55	0.53	0.50	0.47	0.44	0.43	0.41	0.41	0.40	0.40
3CD	0	1	1	1	1	1	1	1	1	1	1	1
	500	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.99
	750	0.98	0.98	0.98	0.98	0.98	0.98	0.97	0.97	0.97	0.97	0.97
	875	0.97	0.97	0.97	0.96	0.96	0.96	0.95	0.95	0.95	0.94	0.94
	1,000	0.96	0.96	0.95	0.94	0.94	0.93	0.92	0.91	0.91	0.90	0.90
	1,125	0.94	0.93	0.92	0.91	0.91	0.90	0.88	0.88	0.87	0.86	0.84
	1,250	0.92	0.91	0.89	0.88	0.87	0.86	0.83	0.82	0.80	0.79	0.78
5DE	0	1	1	1	1	1	1	1	1	1	1	1
	700	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	900	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.98	0.98
	1,050	>0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.97	0.97	0.96	0.96
	1,200	0.99	0.99	0.98	0.98	0.97	0.96	0.95	0.95	0.94	0.93	0.93
	1,350	0.98	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91	0.89	0.87
	1,500	0.97	0.96	0.95	0.94	0.93	0.91	0.89	0.87	0.85	0.83	0.80

*Table F.12. Base run subareas: decision table for the reference point u_{2023} featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes), such that values are P$(u_t < u_{2023})$. For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.*

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	1	1	1	1	1	1	1	1	1	1	1
	1,000	>0.99	1	>0.99	>0.99	>0.99	1	1	>0.99	1	>0.99	>0.99
	1,350	>0.99	1	>0.99	>0.99	>0.99	0.98	0.97	0.94	0.93	0.91	0.91
	1,750	0	0.02	0.06	0.09	0.11	0.14	0.16	0.19	0.23	0.27	0.30
	2,150	0	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.02	0.04	0.05	0.06
	2,550	0	<0.01	0	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.01
	3,500	0	<0.01	0	0	0	<0.01	<0.01	0	<0.01	0	0
3CD	0	1	1	1	1	1	1	1	1	1	1	1
	500	>0.99	1	>0.99	>0.99	>0.99	1	1	>0.99	1	>0.99	>0.99
	750	>0.99	1	0.99	0.92	0.75	0.59	0.50	0.44	0.42	0.40	0.39
	875	0	0.03	0.05	0.05	0.04	0.05	0.06	0.06	0.08	0.09	0.09
	1,000	0	<0.01	0	<0.01	<0.01	0.01	0.01	0.01	0.01	0.02	0.02
	1,125	0	<0.01	0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	1,250	0	<0.01	0	0	0	<0.01	<0.01	0	<0.01	<0.01	<0.01

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5DE	0	1	1	1	1	1	1	1	1	1	1	1
	700	>0.99	1	>0.99	>0.99	0.98	0.89	0.75	0.67	0.62	0.58	0.56
	900	0	0.01	0.02	0.02	0.02	0.03	0.04	0.04	0.05	0.06	0.06
	1,050	0	<0.01	0	<0.01	<0.01	<0.01	0.01	0.01	0.01	0.01	0.01
	1,200	0	<0.01	0	0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	1,350	0	<0.01	0	0	0	<0.01	<0.01	0	<0.01	0	0
	1,500	0	<0.01	0	0	0	<0.01	<0.01	0	<0.01	0	0

*Table F.13. Base run subareas: decision table for the reference point 0.2B_0 featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes), such that values are P($B_t > 0.2B_0$). For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.*

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,000	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,350	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,750	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	2,150	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99
	2,550	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.98
	3,500	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.98	0.96	0.95	0.94	0.93
3CD	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	750	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99
	875	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	1,000	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98
	1,125	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.98	0.97	0.97	0.96
	1,250	>0.99	>0.99	>0.99	0.99	0.99	0.98	0.98	0.97	0.96	0.95	0.94
5DE	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	700	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	900	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99
	1,050	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99
	1,200	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.98
	1,350	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.98	0.97
	1,500	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.98	0.96	0.94

*Table F.14. Base run subareas: decision table for the reference point 0.4B_0 featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes), such that values are P($B_t > 0.4B_0$). For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.*

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	0.81	0.82	0.85	0.86	0.88	0.89	0.90	0.92	0.94	0.95	0.96
	1,000	0.81	0.80	0.81	0.81	0.81	0.81	0.81	0.82	0.84	0.85	0.86
	1,350	0.81	0.79	0.79	0.79	0.79	0.77	0.77	0.78	0.79	0.79	0.81
	1,750	0.81	0.79	0.77	0.76	0.74	0.73	0.72	0.72	0.73	0.73	0.73

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
	2,150	0.81	0.78	0.76	0.73	0.71	0.68	0.66	0.66	0.65	0.66	0.66
	2,550	0.81	0.77	0.74	0.70	0.67	0.63	0.61	0.60	0.59	0.59	0.59
	3,500	0.81	0.75	0.69	0.63	0.57	0.51	0.48	0.46	0.43	0.42	0.42
3CD	0	0.92	0.93	0.94	0.94	0.95	0.95	0.95	0.95	0.96	0.96	0.97
	500	0.92	0.92	0.92	0.92	0.91	0.90	0.90	0.90	0.90	0.90	0.90
	750	0.92	0.92	0.91	0.90	0.89	0.88	0.87	0.85	0.85	0.84	0.84
	875	0.92	0.91	0.90	0.89	0.88	0.86	0.84	0.83	0.82	0.81	0.80
	1,000	0.92	0.91	0.90	0.88	0.87	0.84	0.82	0.81	0.79	0.77	0.76
	1,125	0.92	0.91	0.89	0.88	0.85	0.82	0.80	0.78	0.75	0.74	0.72
	1,250	0.92	0.90	0.88	0.87	0.84	0.80	0.78	0.75	0.72	0.70	0.67
5DE	0	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.98	0.98	0.98
	700	0.97	0.96	0.95	0.94	0.93	0.92	0.91	0.90	0.89	0.88	0.87
	900	0.97	0.96	0.95	0.93	0.92	0.89	0.87	0.86	0.84	0.83	0.82
	1,050	0.97	0.96	0.94	0.92	0.90	0.87	0.85	0.82	0.80	0.77	0.75
	1,200	0.97	0.95	0.93	0.91	0.88	0.85	0.82	0.79	0.75	0.72	0.69
	1,350	0.97	0.95	0.92	0.90	0.86	0.82	0.78	0.73	0.69	0.66	0.62
	1,500	0.97	0.95	0.92	0.89	0.84	0.79	0.74	0.68	0.64	0.59	0.56

Table F.15. Base run subareas: decision table for COSEWIC reference criterion A2 'Endangered' featuring current- and 10-year projections for a range of ***constant catch*** *strategies (in tonnes), such that values are P*$(B_t > 0.5B_0)$*. For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.*

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	0.49	0.50	0.53	0.56	0.59	0.61	0.64	0.67	0.70	0.74	0.78
	1,000	0.49	0.47	0.48	0.48	0.50	0.50	0.52	0.53	0.56	0.57	0.60
	1,350	0.49	0.47	0.47	0.47	0.46	0.46	0.47	0.48	0.50	0.52	0.53
	1,750	0.49	0.46	0.45	0.43	0.42	0.42	0.42	0.43	0.43	0.45	0.47
	2,150	0.49	0.45	0.43	0.41	0.39	0.38	0.37	0.37	0.38	0.39	0.40
	2,550	0.49	0.44	0.41	0.38	0.36	0.34	0.33	0.32	0.32	0.33	0.33
	3,500	0.49	0.42	0.38	0.33	0.29	0.25	0.23	0.21	0.20	0.20	0.21
3CD	0	0.81	0.83	0.84	0.85	0.86	0.86	0.87	0.87	0.88	0.89	0.90
	500	0.81	0.82	0.81	0.81	0.79	0.78	0.77	0.77	0.77	0.77	0.77
	750	0.81	0.81	0.79	0.78	0.76	0.75	0.73	0.71	0.70	0.69	0.68
	875	0.81	0.80	0.79	0.77	0.75	0.72	0.70	0.68	0.67	0.65	0.64
	1,000	0.81	0.80	0.78	0.76	0.73	0.69	0.67	0.65	0.62	0.60	0.59
	1,125	0.81	0.79	0.77	0.75	0.71	0.67	0.65	0.61	0.58	0.56	0.54
	1,250	0.81	0.79	0.76	0.73	0.69	0.65	0.62	0.57	0.54	0.52	0.49
5DE	0	0.87	0.88	0.88	0.88	0.88	0.88	0.88	0.89	0.90	0.90	0.91
	700	0.87	0.85	0.83	0.81	0.80	0.76	0.75	0.73	0.72	0.71	0.69
	900	0.87	0.85	0.82	0.79	0.76	0.73	0.69	0.66	0.64	0.63	0.61
	1,050	0.87	0.84	0.81	0.78	0.73	0.69	0.65	0.61	0.59	0.57	0.55
	1,200	0.87	0.83	0.80	0.76	0.71	0.65	0.61	0.57	0.53	0.51	0.48
	1,350	0.87	0.83	0.79	0.74	0.68	0.62	0.56	0.52	0.48	0.45	0.42
	1,500	0.87	0.82	0.78	0.72	0.65	0.58	0.52	0.47	0.43	0.39	0.36

*Table F.16. Base run subareas: decision table for COSEWIC reference criterion A2 'Threatened' featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes), such that values are P$(B_t > 0.7B_0)$. For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.*

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	0.10	0.10	0.11	0.12	0.13	0.15	0.17	0.19	0.22	0.25	0.29
	1,000	0.10	0.10	0.09	0.09	0.10	0.10	0.11	0.12	0.13	0.15	0.17
	1,350	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.11	0.12	0.15
	1,750	0.10	0.09	0.09	0.08	0.08	0.08	0.08	0.09	0.09	0.10	0.11
	2,150	0.10	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.08	0.08	0.09
	2,550	0.10	0.08	0.08	0.07	0.06	0.06	0.06	0.06	0.06	0.07	0.07
	3,500	0.10	0.08	0.07	0.05	0.04	0.04	0.03	0.03	0.03	0.04	0.04
3CD	0	0.52	0.54	0.56	0.57	0.57	0.57	0.57	0.58	0.59	0.60	0.61
	500	0.52	0.52	0.52	0.52	0.50	0.49	0.47	0.46	0.45	0.45	0.44
	750	0.52	0.51	0.50	0.49	0.47	0.44	0.41	0.40	0.39	0.37	0.36
	875	0.52	0.51	0.49	0.48	0.45	0.42	0.39	0.37	0.35	0.34	0.32
	1,000	0.52	0.50	0.48	0.46	0.43	0.39	0.37	0.35	0.33	0.31	0.29
	1,125	0.52	0.50	0.47	0.45	0.41	0.38	0.33	0.31	0.29	0.27	0.25
	1,250	0.52	0.49	0.47	0.43	0.39	0.35	0.32	0.28	0.26	0.23	0.22
5DE	0	0.53	0.53	0.54	0.54	0.54	0.54	0.54	0.55	0.56	0.57	0.59
	700	0.53	0.50	0.47	0.45	0.42	0.38	0.37	0.36	0.34	0.34	0.34
	900	0.53	0.49	0.46	0.42	0.39	0.35	0.33	0.31	0.29	0.27	0.27
	1,050	0.53	0.48	0.45	0.40	0.36	0.33	0.30	0.28	0.25	0.24	0.22
	1,200	0.53	0.47	0.43	0.38	0.34	0.30	0.26	0.24	0.21	0.20	0.18
	1,350	0.53	0.47	0.42	0.37	0.32	0.27	0.24	0.20	0.19	0.16	0.15
	1,500	0.53	0.46	0.40	0.35	0.30	0.24	0.21	0.18	0.15	0.13	0.12

F.2.3.2. Decision Tables Assuming Low Recruitment

In the 2022 Canary Rockfish stock assessment (Starr and Haigh 2023), an attempt was made to incorporate an environmental index (winter Pacific Decadal Oscillation) to predict the impact of this series on predicted recruitment. However, it was found that the influence of this series on recruitment was dependent on how much relative weight was assigned to the series (through added process error). This analysis was not repeated for POP because it was inconclusive and objectivity was lost. Instead, to simulate environmental impacts, recruitment strength was reduced arbitrarily by half from the base-run forecast. This was done for two reasons. The first was that the SS3 platform did not provide a simple procedure by which recruitment could be reduced to a specified level (e.g., the mean of 2005-2014 recruitment), requiring a more pragmatic approach. The second was that it was felt that a strong recruitment reduction represented a short-term "worst case" scenario that did not require additional intermediate analysis that was difficult to comprehend or justify.

The decision tables presented below (Tables F.17–F.26) were generated from the base case (B1) stock assessment and then projected forward, beginning in 2015, with mean recruitment reduced by 50% relative to the projections made in Tables F.7–F.16. SS3 replaces the 'late recruitment deviations' and the projected recruitment deviations estimated during the model reconstruction phase with deviations randomly drawn from a lognormal distribution with mean 0.5R_0 and standard deviation = 0.9 (see Figure F.57).

These decision tables show some effect from the reduced recruitment. While there is virtually no impact on the response to the 0.4B_{MSY} reference level (Table F.17) or the 0.2B_0 reference level (Table F.23, – with the exception of the highest catch levels in all three subareas beginning in 2029), there is some reduction in the predicted probabilities in Table F.18 (0.8B_{MSY}) at the highest catch levels in all three subareas. Table F.20 indicates that, under reduced recruitment, there is little to no expectation that any of the three subareas will increase in size over the next 10 years. Table F.21 indicates that u_t will remain below u_{MSY} with relativity high probability except for 5ABC in the mid-1990s. Table F.24 indicates that this stock, under 50% reduced recruitment, will drop below 0.4B_0 in 5ABC even at the intermediate level of catch while the two smaller stocks (3CD and 5DE) continue to increase with the intermediate catch assumption. The remaining tables show probabilities that are consistent with the above observations: higher reference levels are more difficult to achieve under reduced recruitment.

While lowering forecast recruitment is not a definitive test, it does indicate that, under severe and continuous recruitment failure, POP stock status will drop at high catch levels. However, such an outcome seems extreme; therefore, the scenarios demonstrated in these tables are unlikely to occur.

Table F.17. Base run subareas (0.5R): decision table for the limit reference point 0.4B_{MSY} featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes). Values are P$(B_t > 0.4B_{MSY})$, i.e. the probability of the spawning biomass (mature females) at the start of year t being greater than the limit reference point. The probabilities are the proportion (to two decimal places) of the 1,972 MCMC samples for which $B_t > 0.4B_{MSY}$. For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,350	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	3,500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.98	0.96	0.93
3CD	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	750	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,250	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.98	0.97	0.95	0.93
5DE	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	900	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.98	0.95

Table F.18. Base run subareas (0.5R): decision table for the upper stock reference point 0.8B_{MSY} featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes), such that values are P$(B_t > 0.8B_{MSY})$. For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	>0.99	0.99	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,350	>0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.97	0.97	0.96
	3,500	>0.99	0.99	0.98	0.97	0.95	0.92	0.87	0.81	0.75	0.69	0.63
3CD	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	>0.99	>0.99
	750	>0.99	0.99	0.99	0.99	0.98	0.97	0.97	0.96	0.95	0.94	0.92
	1,250	>0.99	0.99	0.99	0.98	0.96	0.94	0.92	0.89	0.86	0.81	0.77
5DE	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	900	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.98	0.97	0.96	0.95
	1,500	>0.99	>0.99	0.99	0.99	0.98	0.97	0.96	0.91	0.86	0.80	0.74

Table F.19. Base run subareas (0.5R): decision table for the reference point B_{MSY} featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes), such that values are P$(B_t > B_{MSY})$. For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	0.98	0.98	0.98	0.98	0.98	0.98	0.97	0.97	0.97	0.97	0.97
	1,350	0.98	0.97	0.97	0.96	0.95	0.94	0.93	0.91	0.89	0.88	0.87
	3,500	0.98	0.96	0.93	0.90	0.85	0.78	0.71	0.65	0.58	0.52	0.47
3CD	0	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
	750	0.98	0.98	0.97	0.96	0.96	0.95	0.93	0.91	0.90	0.88	0.85
	1,250	0.98	0.97	0.96	0.94	0.92	0.89	0.86	0.81	0.76	0.72	0.67
5DE	0	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	900	0.99	0.99	0.99	0.99	0.98	0.97	0.96	0.94	0.92	0.89	0.86
	1,500	0.99	0.99	0.98	0.97	0.96	0.93	0.88	0.82	0.76	0.69	0.60

*Table F.20. Base run subareas (0.5R): decision table for the reference point B_{2024} featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes), such that values are P($B_t > B_{2024}$). For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.*

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	0	0.48	0.49	0.45	0.41	0.38	0.37	0.35	0.35	0.36	0.37
	1,350	0	0.12	0.12	0.09	0.07	0.06	0.05	0.05	0.04	0.05	0.05
	3,500	0	0.02	0.01	0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
3CD	0	0	0.90	0.87	0.77	0.63	0.48	0.37	0.32	0.29	0.27	0.26
	750	0	0.22	0.14	0.07	0.03	0.02	0.01	0.01	0.01	0.01	0.01
	1,250	0	0.06	0.03	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
5DE	0	0	0.27	0.26	0.20	0.16	0.13	0.11	0.10	0.09	0.09	0.09
	900	0	0.02	0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	1,500	0	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

*Table F.21. Base run subareas (0.5R): decision table for the reference point u_{MSY} featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes), such that values are P($u_t < u_{MSY}$). For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.*

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	1	1	1	1	1	1	1	1	1	1	1
	1,350	0.98	0.98	0.98	0.97	0.97	0.97	0.96	0.95	0.95	0.94	0.93
	3,500	0.56	0.52	0.47	0.42	0.38	0.34	0.30	0.27	0.24	0.21	0.18
3CD	0	1	1	1	1	1	1	1	1	1	1	1
	750	0.98	0.98	0.98	0.97	0.97	0.96	0.95	0.95	0.94	0.93	0.92
	1,250	0.91	0.89	0.87	0.84	0.81	0.77	0.74	0.70	0.66	0.62	0.58
5DE	0	1	1	1	1	1	1	1	1	1	1	1
	900	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.97	0.97	0.96
	1,500	0.97	0.95	0.94	0.92	0.90	0.87	0.83	0.78	0.73	0.67	0.61

*Table F.22. Base run subareas (0.5R): decision table for the reference point u_{2023} featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes), such that values are P($u_t < u_{2023}$). For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.*

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	1	1	1	1	1	1	1	1	1	1	1
	1,350	>0.99	1	>0.99	>0.99	0.97	0.84	0.66	0.53	0.46	0.38	0.35
	3,500	0	<0.01	0	0	<0.01	0	<0.01	<0.01	0	<0.01	0
3CD	0	1	1	1	1	1	1	1	1	1	1	1
	750	>0.99	1	0.96	0.69	0.38	0.17	0.09	0.06	0.04	0.03	0.03
	1,250	0	<0.01	0	0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0
5DE	0	1	1	1	1	1	1	1	1	1	1	1
	900	0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	1,500	0	<0.01	0	0	<0.01	<0.01	<0.01	<0.01	0	<0.01	0

*Table F.23. Base run subareas (0.5R): decision table for the reference point 0.2B_0 featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes), such that values are P($B_t > 0.2B_0$). For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.*

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,350	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99
	3,500	>0.99	>0.99	>0.99	0.99	0.98	0.95	0.91	0.85	0.79	0.73	0.66
3CD	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	750	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.98	0.97	0.96	0.94
	1,250	>0.99	>0.99	0.99	0.99	0.98	0.96	0.93	0.90	0.87	0.84	0.79
5DE	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	900	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.98	0.97
	1,500	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.97	0.94	0.90	0.84	0.77

*Table F.24. Base run subareas (0.5R): decision table for the reference point 0.4B_0 featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes), such that values are P($B_t > 0.4B_0$). For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.*

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	0.77	0.77	0.77	0.77	0.77	0.77	0.75	0.75	0.75	0.74	0.74
	1,350	0.77	0.74	0.71	0.68	0.65	0.62	0.58	0.54	0.51	0.47	0.45
	3,500	0.77	0.69	0.62	0.53	0.44	0.36	0.28	0.22	0.18	0.13	0.11
3CD	0	0.88	0.89	0.90	0.90	0.90	0.90	0.89	0.88	0.88	0.88	0.88
	750	0.88	0.87	0.86	0.84	0.81	0.77	0.74	0.70	0.65	0.62	0.58
	1,250	0.88	0.86	0.83	0.79	0.73	0.67	0.61	0.54	0.47	0.41	0.36
5DE	0	0.97	0.96	0.96	0.95	0.95	0.94	0.93	0.93	0.93	0.92	0.91
	900	0.97	0.94	0.92	0.89	0.86	0.81	0.77	0.71	0.66	0.60	0.55
	1,500	0.97	0.93	0.88	0.83	0.76	0.68	0.58	0.49	0.41	0.33	0.26

*Table F.25. Base run subareas (0.5R): decision table for COSEWIC reference criterion A2 'Endangered' featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes), such that values are P($B_t > 0.5B_0$). For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.*

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	0.48	0.48	0.48	0.47	0.47	0.46	0.44	0.43	0.43	0.43	0.42
	1,350	0.48	0.45	0.41	0.37	0.34	0.31	0.28	0.25	0.23	0.21	0.20
	3,500	0.48	0.40	0.32	0.25	0.20	0.14	0.11	0.08	0.07	0.05	0.04
3CD	0	0.74	0.76	0.77	0.77	0.76	0.75	0.74	0.72	0.71	0.69	0.69
	750	0.74	0.73	0.71	0.68	0.64	0.60	0.55	0.50	0.45	0.41	0.38
	1,250	0.74	0.71	0.66	0.61	0.56	0.48	0.41	0.36	0.31	0.26	0.23
5DE	0	0.84	0.84	0.83	0.83	0.82	0.80	0.79	0.77	0.76	0.75	0.74
	900	0.84	0.81	0.77	0.73	0.67	0.60	0.54	0.48	0.42	0.37	0.32
	1,500	0.84	0.79	0.72	0.64	0.54	0.46	0.37	0.29	0.23	0.17	0.12

*Table F.26. Base run subareas (0.5R): decision table for COSEWIC reference criterion A2 'Threatened' featuring current- and 10-year projections for a range of **constant catch** strategies (in tonnes), such that values are P$(B_t > 0.7B_0)$. For reference, the average catch over the last 5 years (2018-2022) was CST=3306, 5ABC=1618, 3CD=840, 5DE=848 t.*

area	CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	0	0.10	0.10	0.10	0.09	0.09	0.08	0.08	0.07	0.07	0.07	0.07
	1,350	0.10	0.08	0.08	0.07	0.06	0.05	0.04	0.03	0.03	0.02	0.02
	3,500	0.10	0.07	0.06	0.04	0.03	0.02	0.01	0.01	0.01	<0.01	<0.01
3CD	0	0.41	0.43	0.44	0.44	0.43	0.40	0.38	0.37	0.36	0.35	0.33
	750	0.41	0.40	0.38	0.35	0.33	0.30	0.26	0.23	0.20	0.17	0.15
	1,250	0.41	0.38	0.35	0.31	0.27	0.23	0.18	0.15	0.12	0.10	0.07
5DE	0	0.50	0.49	0.48	0.45	0.43	0.41	0.39	0.38	0.37	0.35	0.33
	900	0.50	0.44	0.40	0.36	0.30	0.26	0.20	0.16	0.14	0.11	0.09
	1,500	0.50	0.42	0.36	0.28	0.22	0.16	0.11	0.08	0.05	0.04	0.03

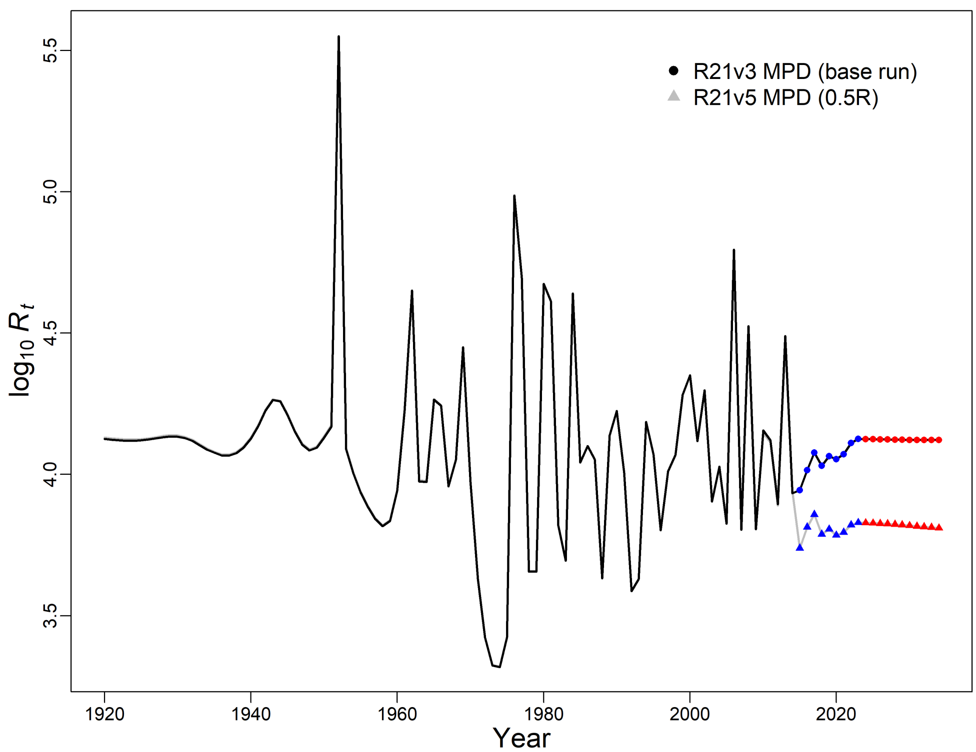


Figure F.57. Low recruitment: MPD trajectories of predicted recruitment (in $\log_{10}$ space) comparing the base run (R21v3) to the 50% forecast recruitment run (R21v5). Blue symbols used for late recruitment (2015-2023), red symbols used for predicted recruitment (2024-2034).

F.2.4. Sensitivity Analyses

Ten sensitivity analyses were run (with full MCMC simulations) relative to the base run (Run21). The MCMC used for sensitivity runs followed the same procedure (NUTS algorithm) as that for the base run but differed in the number of simulations (20,000 iterations, parsing the workload into 8 parallel chains of 2,500 iterations each, discarding the first 1,250 iterations and saving the last 1,250 samples per chain for a total of 2,000 samples, after thinning every 5th sample). These analyses were run to test the sensitivity of the outputs to alternative model assumptions:

- **S01** (R17.00.v18a) – use Dirichlet-Mutinomial parameterisation (label: "D-M parameterisation");
- **S02** (R27.01.v1a) – fix parameter Rdist for 5ABC to 0 (label: "Rdist 5ABC fixed");
- **S03** (R28.01.v1a) – fix parameter Rdist for 3CD to 0 (label: "Rdist 3CD fixed");
- **S04** (R29.01.v1a) – apply no ageing error (label: "AE1 no age error");
- **S05** (R30.01.v1a) – use smoothed ageing error from age-reader CVs (label: "AE5 age reader CV");
- **S06** (R31.01.v1a) – use constant-CV ageing error (label: "AE6 CASAL CV=0.1");
- **S07** (R32.01.v1a) – reduce commercial catch (1965-95) by 30% (label: "reduce catch 30%");
- **S08** (R33.01.v1a) – increase commercial catch (1965-95) by 50% (label: "increase catch 50%");
- **S09** (R34.01.v1a) – reduce σ_R to 0.6 (label: "sigmaR=0.6");
- **S10** (R35.01.v1a) – increase σ_R to 1.2 (label: "sigmaR=1.2").

All sensitivity runs (except (S01) were reweighted once for composition using the Francis (2011) mean-age method. No process error was added to survey indices because the observed error was already sufficiently large.

The differences among the sensitivity runs (including the base run) are summarised in tables of median parameter estimates (Table F.28) and median MSY-based quantities (Table F.29). Sensitivity plots appear in:

- Figure F.58 – trace plots for chains of $\log R_0$ MCMC samples;
- Figure F.59 – diagnostic split-chain plots for $\log R_0$ MCMC samples;
- Figure F.60 – diagnostic autocorrelation plots for $\log R_0$ MCMC samples;
- Figure F.61 – trajectories of median B_t (tonnes);
- Figure F.62 – trajectories of median B_t/B_0;
- Figure F.63 – trajectories of median recruitment deviations;
- Figure F.64 – trajectories of median recruitment R_t (1000s age-0 fish);
- Figure F.65 – trajectories of median exploitation rate u_t;
- Figure F.66 – quantile plots of selected parameters for the sensitivity runs;
- Figure F.67 – quantile plots of selected derived quantities for the sensitivity runs;
- Figure F.68 – stock status plots of B_{2024}/B_{MSY}.

Three additional sensitivity runs were explored only to the MPD level:

- **S11** (R22.01.v2) – add midwater trawl fleets in 3CD and 5ABC;
- **S12** (R36.01.v2) – add HS Synoptic survey data to subarea 5DE;
- **S13** (R37.01.v1) – use empirical proportions mature.

Sensitivity S11 required the separation of fleets 1 (5ABC) and 2 (3CD) into midwater and bottom trawl (both with catch and AF data). The AF data for the two midwater components were insufficient on their own, so these data were merged into one set of AF data to represent both midwater fleets. Midwater 3CD selectivity was estimated by the model, and midwater 5ABC selectivity was linked to the 3CD estimate.

Sensitivity 12 added the Hecate Strait (HS) synoptic survey index data to the third subarea, 5DE. AF data from HS were minimal, with two samples comprising 33 aged fish in 2007. Therefore, HS AF data were not used in the sensitivity run, and selectivity for the HS synoptic survey was linked to the estimate for the WCHG survey.

Sensitivity 13 was requested by a participant of the Regional Peer Review (RPR) meeting because there was concern over the poor fit to maturity data. Specifically, the fitted female maturity ogive reached full maturity at age 15.5 despite the empirical data showing a smooth asymptotic rise from age 12 (EMP m_a = 0.77, see Table D.6) to age 30 (EMP ma = 0.98). The fitted maturity ogive was determined using a simple two-parameter model (D.3) that approximated a double-normal distribution. The sensitivity of the base case to using fitted maturity was tested by substituting the empirical proportions-mature at age.

F.2.4.1. Sensitivity diagnostics

The diagnostic plots (Figures F.58 to F.60) show that nine sensitivity runs exhibited good MCMC behaviour and one was fair. None were in the poor or unacceptable categories.

- Good – no trend in traces and no spikes in $\log R_0$, split-chains align, no autocorrelation:
  - S01 (D-M parameterisation)
  - S03 (Rdist 3CD fixed)
  - S04 (AE1 no age error)
  - S05 (AE5 age reader CV)
  - S06 (AE6 CASAL CV=0.1)
  - S07 (reduce catch 30%)
  - S08 (increase catch 50%)
  - S09 (sigmaR=0.6)
  - S10 (sigmaR=1.2)
- Fair – trace trend temporarily interrupted, occasional spikes in $\log R_0$, split-chains somewhat frayed, some autocorrelation:
  - S02 (Rdist 5ABC fixed)

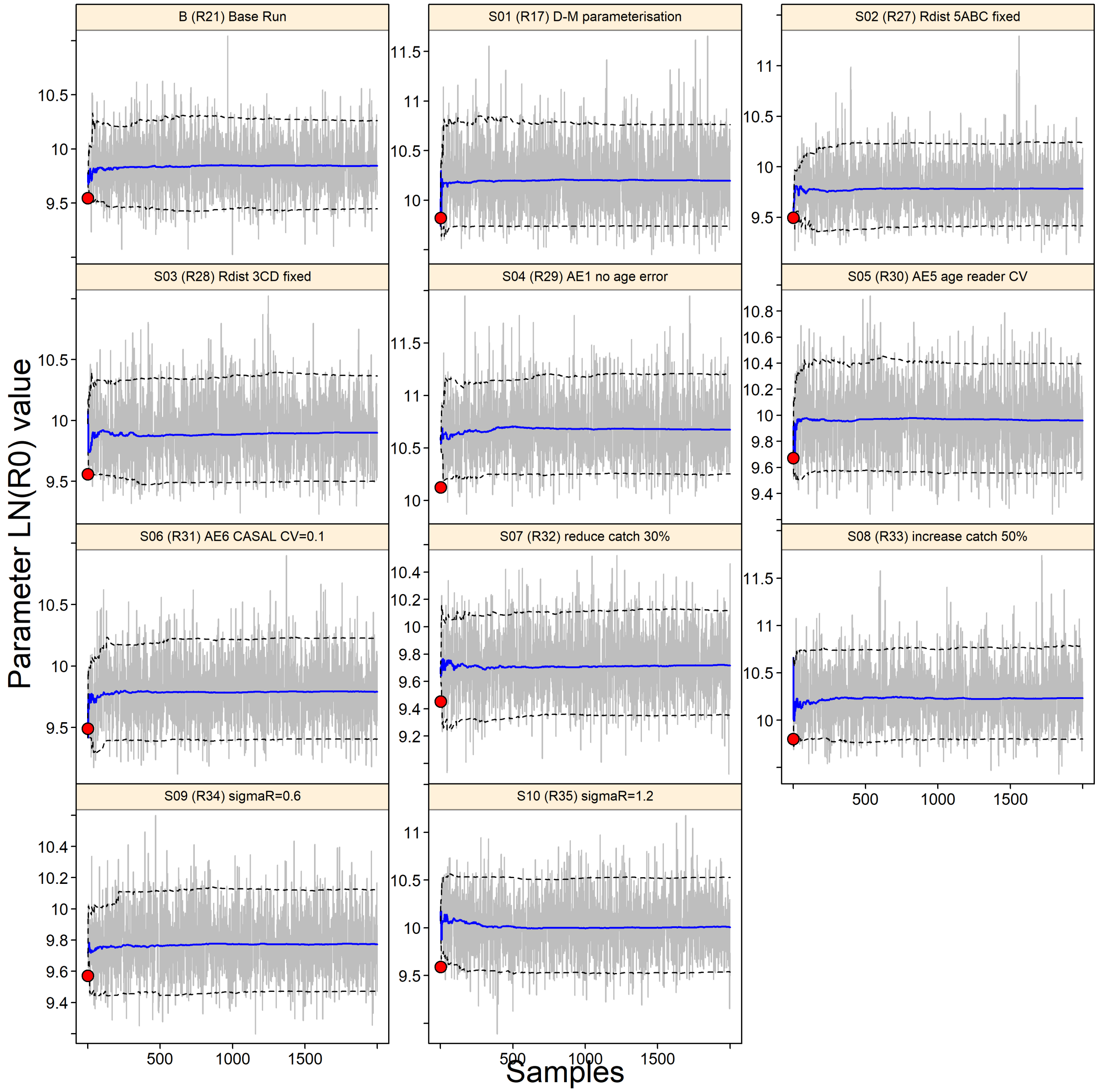


Figure F.58. POP sensitivity R_0: MCMC traces for the estimated parameters. Grey lines show the 2,000 samples for each parameter, solid blue lines show the cumulative median (up to that sample), and dashed lines show the cumulative 0.05 and 0.95 quantiles. Red circles are the MPD estimates.

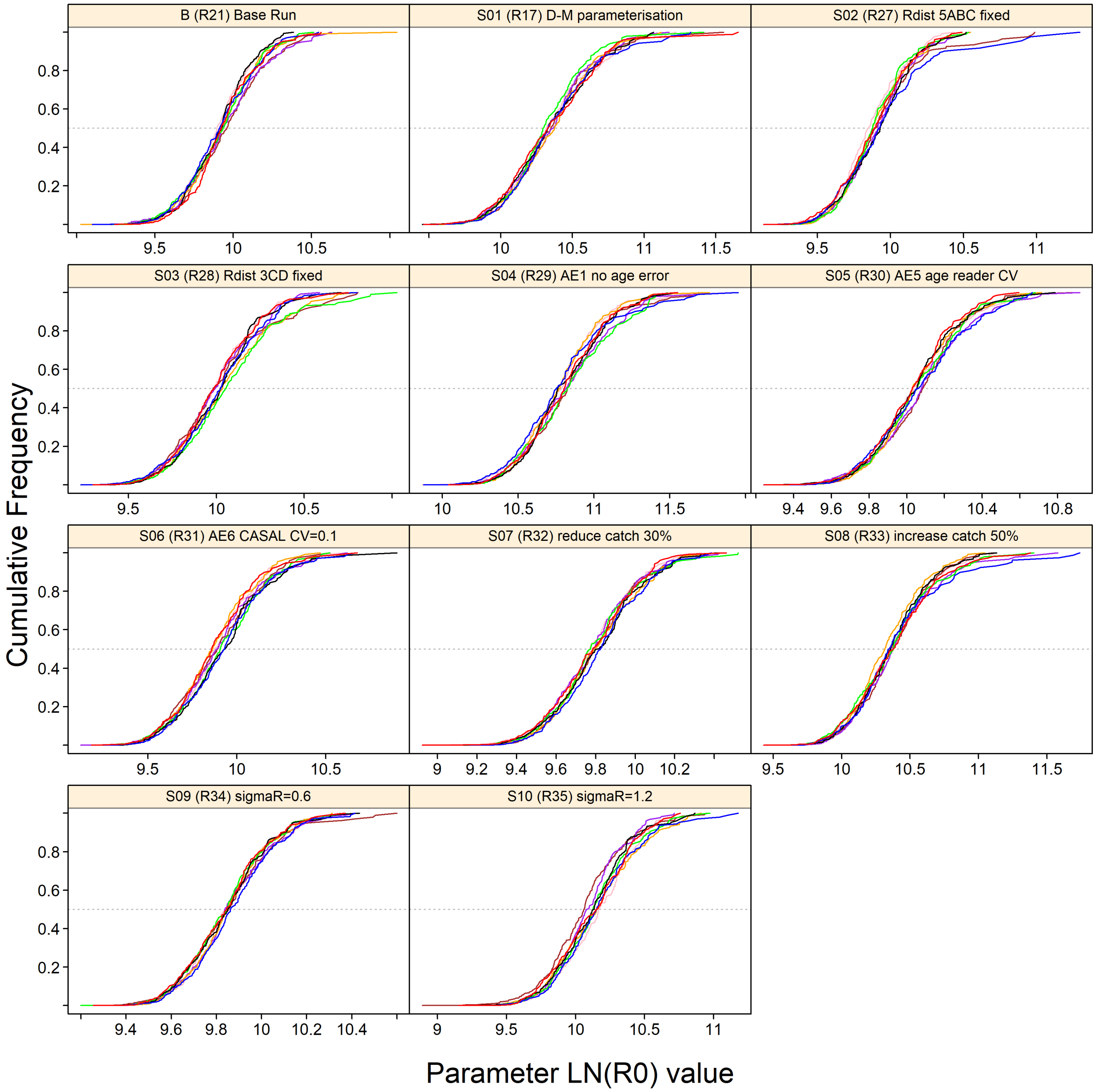


Figure F.59. POP sensitivity R_0: diagnostic plots obtained by dividing the MCMC chain of 2,000 MCMC samples into three segments, and overplotting the cumulative distributions of the first segment (red), second segment (blue) and final segment (black).

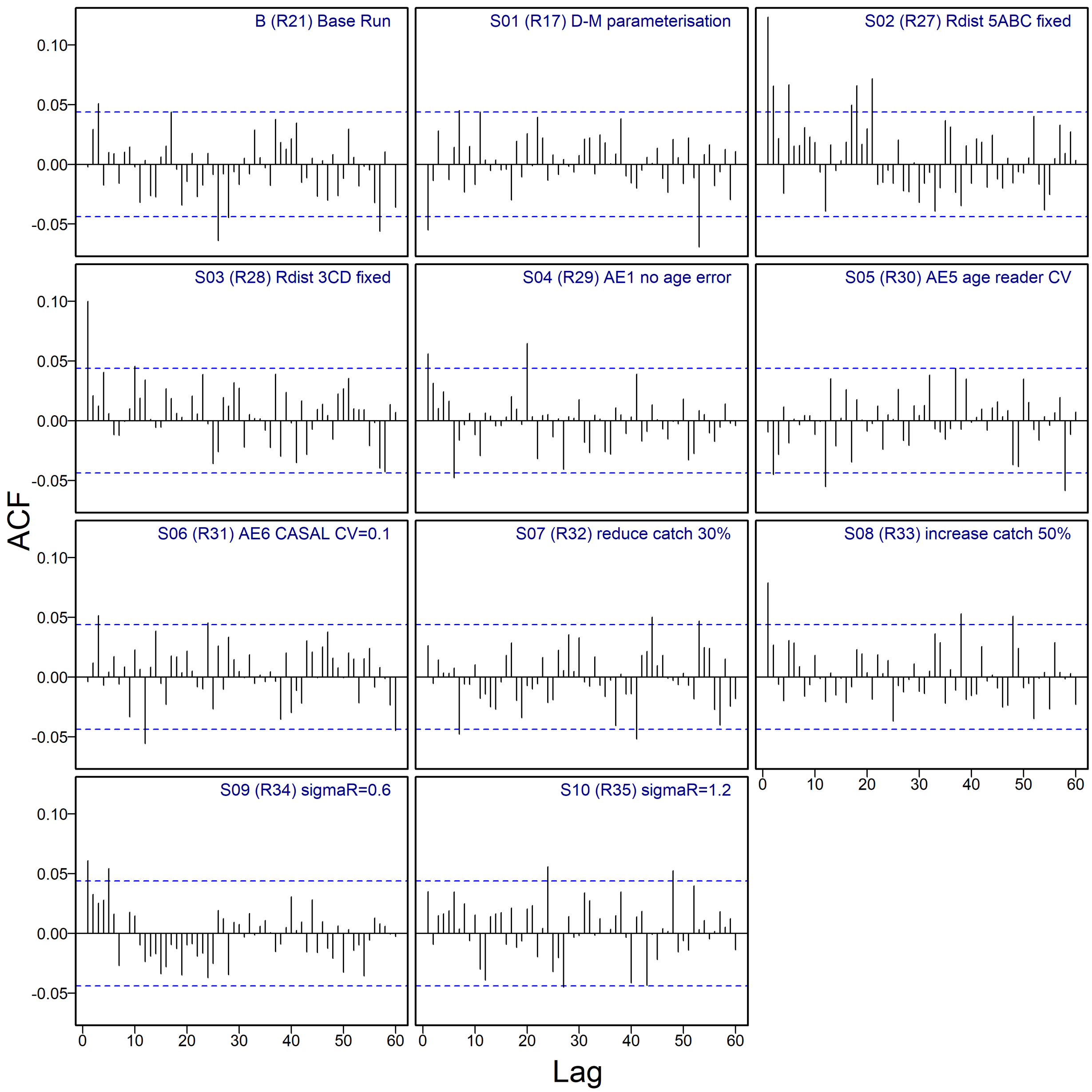


Figure F.60. POP sensitivity R_0: autocorrelation plots for the estimated parameters from the MCMC output. Horizontal dashed blue lines delimit the 95% confidence interval for each parameter's set of lagged correlations.

F.2.4.2. Sensitivity comparisons

The trajectories of the B_t medians relative to B_0 (Figure F.62) indicate that all sensitivities followed a similar trajectory to the base run trajectory with some attributable variation. The median final-year depletion ranged from a low of 0.543 by S04 (no age error) to a high of 0.644 by S01 (D-M parameterisation). Compared to S01, which was initially the base run, the Francis method yielded greater depletion (lower B_{2024}/B_0) and a lower B_0/B_{MSY}, implying lower overall productivity.

Comparing spawning biomass medians (Figure F.61), three sensitivities consistently estimated a larger standing stock in all years than did the base run: S08 (increase catch), S04 (no age error), and S01 (D-M parameterisation). A less productive stock was estimated when catches were reduced (S07). The remainder of the sensitivities varied little from the base run.

The implementation of the multi-area model by the SS3 platform required fixing the relative distribution of recruitment for one of the subareas and then allowing the model to estimate the recruitment distributional parameter for the remaining two subareas relative to the reference subarea. For the base run, the 5DE subarea was arbitrarily chosen as the reference area; consequently the `Rdist_area(1)` parameter for the base run applied to 5ABC and the `Rdist_area(2)` parameter applied to 3CD. Sensitivity runs S02 and S03 explored setting the reference subarea to 5ABC (S02) and to 3CD (S03), respectively. In terms of the overall model performance, both S02 and S03 returned leading parameter estimates (Table F.28) and derived quantities (Table F.29) that were consistent with the base run. As well, the fits to the survey data were similar for all three runs except for the WCVI synoptic survey, which obtained a better fit when 5ABC (S02) was the reference subarea (Table F.30). Although the overall model performance seemed to be relatively insensitive to the choice of the reference subarea, the relative distribution of biomass among the three subareas was sensitive to this choice.

Table F.27 shows how the distributions among the three POP subareas differed with the choice of the base subarea, with the base run and S03 returning similar proportions among the B_0 estimates while S02 estimated a lower proportion assigned to 3CD than for the other models. Note that summing the independent single-area models should be interpreted cautiously, because these models, unlike the three multi-area models, estimate different natural mortality and steepness parameters. Consequently, productivity in these three models is not limited to just stock size, unlike the multi-area models which share the underlying estimated productivity parameters.

Table F.27. Proportional MPD distribution by POP subarea for the base run, with the addition of the three single-area models and sensitivity runs S02 (fix `Rdist_area_5ABC`*) and S03 (fix* `Rdist_area_3CD`*).*

	B_0			B_{2024}		
Run	5ABC	3CD	5DE	5ABC	3CD	5DE
base	0.598	0.200	0.202	0.533	0.225	0.241
single-area	0.560	0.221	0.220	0.543	0.168	0.289
S02	0.639	0.142	0.219	0.602	0.128	0.269
S03	0.593	0.193	0.214	0.521	0.185	0.294

Three of the sensitivity runs addressed ageing error issues: S04 dropped ageing error entirely; S05 used an alternative ageing error vector based on the error between paired reads of the same otolith; and S06 implemented a constant 10% error term for every age. These alternative ageing error vectors are shown concurrently in Figure D.19. The sensitivity runs employing the alternative ageing error vectors (S05 and S06) resulted in model runs that were nearly identical to the base run when plotted as a percentage of B_0 (Figure F.62). When plotted as an absolute biomass (Figure F.61), sensitivity S06 lay slightly below the base run while sensitivity S05 lay just above the base run. The estimates for M and h from these runs were also close to those made by the base run, implying that these runs would return similar levels of overall productivity. Sensitivity S04, which dropped ageing error entirely, was slightly less optimistic in terms of percentage B_0 (median B_{2024}/B_0 = 0.54 instead of 0.58 for the base run, Table F.29), but the overall biomass was estimated to be considerably larger in terms of absolute B_t (Figure F.61) than the base run (the median S04 $B_0 \sim$ 1.6 * base B_0, see Table F.29). This result, plus the higher estimates for M from this run (Table F.28), make this sensitivity run an unlikely scenario for providing advice. In terms of model fits to the survey data, S04 (no ageing error) generally returned poorer fits to the survey data than the base run, while S05 (age reader CV) returned fits similar to the base run, and S06 (constant CV=0.1) returned somewhat better fits to the survey series than did the base run (Table F.30).

The two sensitivity runs which adjusted early (1965-1995) catches downward (S07) and upward (S08) provided predictable results, with S07 returning a lower B_0 compared to the base run, while S08 yielded a much larger stock. This result is consistent with raising and lowering the input catches. In terms of percent B_0, S07 returned more optimistic results compared to the base run (especially after about 1990), while S08 was consistently about the same as the base run. In terms of model fits to the survey data, both models showed variable results, with S07 (reduce catches by 30%) generally returning similar fits to the survey data compared to the base run, while S08 (increase catch by 50%) returned poorer fits to the survey data compared to the base run (Table F.30). It is of interest that the S07 fit to the GIG historical survey was better than any of the runs in Table F.30, possibly implying that the early historical catches were being overestimated.

The two sensitivity runs which varied the σ_R parameter (standard deviation of recruitment process error) showed similar results to the base run. Both S09 (σ_R=0.6) and S10 (σ_R=1.2) returned estimates of M, h, B_0, and B_{2024}/B_0 that were close to those of the base run. This implies that the stock assessment was not very sensitive to this fixed parameter. In terms of model fits to the survey data, both models fit the survey data about as well as the base run, apart from a better fit to the WCHG survey by S10 (Table F.30). The SS3 platform calculates an alternative sigmaR value based on the estimated variance of the recruitment deviations. This value was 1.05 for the base run main recruitment period, which aligned well with the assumption made by the base run (σ_R=0.9).

The sensitivity run that used the Dirichlet-multinomial procedure to weight the AF data (S01) had good MCMC diagnostics, but was generally more optimistic than the base run, estimating higher stock size relative to B_0 (median coastwide B_{2024}/B_0=0.64 instead of 0.58 for the base run (Table F.29). The median estimates for natural mortality M were higher for S01 compared to the base run: M_1(female)=0.058 vs. 0.052 and M_2(male)=0.065 vs. 0.059 (Table F.28). The derived parameters showed more variation with S01 estimating a 22% higher B_0 than that for the base run and a current spawning stock size (B_{2024}) 35% higher than by the base run. In terms of model fits to the survey data, S01 (D-M model) fit the survey data similarly to the base run, apart from a much better fit to the WCHG survey (Table F.30).

The stock status (B_{2024}/B_{MSY}) for the MCMC sensitivities (Figure F.68) were all in the DFO

Healthy zone. The observed variation in estimated stock status among these ten sensitivities was not great.

Three additional sensitivity analyses were done which were not included in the MCMC set of sensitivity runs (Section 8.3.1) because they were either close variants of the base run (B1, Run21), which would be expected to return similar MCMC diagnostics, or because an MCMC extension seemed unnecessary. These runs are described above – S11 (R22v2): add midwater trawl fisheries for 3CD and 5ABC, and estimate separate selectivity functions for each fishery; S12 (R36v2): add Hecate Strait synoptic survey to the 5DE data set; and S13 (R37v1): use empirical proportions mature instead of a fitted maturity ogive.

Run S11 implemented a separate fishery for midwater trawl (MW) in subareas 3CD and 5ABC. Subarea 5DE was omitted because the MW fishery was known to be small in that area. This implementation required strong assumptions because the MW data were sparse and were not reliable before 1996. Therefore, MW catches before 1996 were assumed to be zero, with the MW fishery only starting in 1996 when the catch data became reliable. There were insufficient MW trawl AF data to have separate data sets for 3CD and 5ABC, so the available data were combined into a single AF data set covering six years from 2007 to 2018. The fits to these data were poor with strong negative residual patterns from age 10 to the mid-20s (not shown).

Run S12 added the HS synoptic survey series to the data set and assumed this survey monitored the 5DE subarea population. This was because the large majority of the POP catches by this survey occurred in the western part of Dixon Entrance, directly above the north coast of Graham Island (see Figures B.51 to B.59 in Appendix B). Unfortunately, there were insufficient POP AF data from this survey to reliably estimate a selectivity function, so the model fitted the survey indices by using the selectivity function estimated for the neighbouring WCHG synoptic survey.

Neither of these sensitivity run models had much improved fits to the survey data relative to the fits obtained by the base run (Table 8). The fits to the WCHG and the WCVI surveys deteriorated for S12 relative to that obtained by the base run. The remaining fits were the same for S11 and S12.

Table 9 demonstrates that neither of these sensitivity runs moved very far from the estimates in the base run. Both S11 and S12 had leading parameter estimates for M, h, LN(R_0), and the main selectivity parameters that were nearly the same as for the base run (Table 9). There were some minor changes in the estimates for B_0 and B_{2024}, with a 5% drop in the 3CD B_0 and a 13% drop in 3CD B_{2024} for S11, which is the subarea with the most active MW fishery. But the differences were small and it is difficult to conclude that combining the BT and MW fisheries had generated a bias in this stock assessment, given the data that are presently available. Similarly, S12 demonstrated that the effect of adding the HS survey to the data set was small because it did not change any of the parameter estimates and may have been responsible for slightly reducing the relative size of the 5DE current biomass, with the ratio with B_0 dropping from 0.635 in the base run to 0.600 in run S12 (Table 9).

Run S13 was added at the RPR meeting after one of the participants noted the poor fit to empirical proportions mature. There was concern that this poor fit might skew the overall model fit to the data. It was suggested to simply use the empirical maturity in place of the fitted maturity ogive. The resultant fits to the primary parameters were identical to those of the base run, and derived quantities showed small reductions in female spawning biomass (Table 9)

Table F.28. POP 2023: median values of MCMC samples for the primary estimated parameters, comparing the base run to 10 sensitivity runs (2,000 samples each). R = Run, S = Sensitivity. Numeric subscripts other than those for R_0 and M indicate the following gear types g: 1 = QCS Synoptic, 5 = WCVI Synoptic, 6 = WCHG Synoptic, 7 = GIG Historical, 8 = NMFS Triennial, and 9 = WCVI Historical. Sensitivity runs: S01 = D-M parameterisation, S02 = Rdist 5ABC fixed, S03 = Rdist 3CD fixed, S04 = AE1 no age error, S05 = AE5 age reader CV, S06 = AE6 CASAL CV=0.1, S07 = reduce catch 30%, S08 = increase catch 50%, S09 = sigmaR=0.6, S10 = sigmaR=1.2

	B(R21)	S01(R17)	S02(R27)	S03(R28)	S04(R29)	S05(R30)	S06(R31)	S07(R32)	S08(R33)	S09(R34)	S10(R35)
$\log R_0$	9.845	10.20	9.784	9.899	10.67	9.960	9.790	9.717	10.23	9.773	10.00
Rdist area(1)	1.173	1.307	—	1.281	1.502	1.259	1.159	1.265	1.212	1.188	1.179
Rdist area(2)	-0.008557	0.1174	-1.556	—	-0.007375	-0.005827	-0.01037	0.08255	-0.06920	-0.008081	-0.007046
Rdist area(3)	—	—	-1.305	0.03811	—	—	—	—	—	—	—
M_1	0.05229	0.05754	0.05177	0.05360	0.06421	0.05435	0.05182	0.05388	0.05467	0.05093	0.05438
M_2	0.05939	0.06467	0.05904	0.06104	0.07139	0.06152	0.05909	0.06117	0.06188	0.05812	0.06161
BH h	0.7544	0.7223	0.7486	0.7415	0.7608	0.7513	0.7348	0.7611	0.7036	0.7852	0.7254
μ_1 (TRAWL 5ABC)	11.33	11.02	11.29	11.29	11.52	11.25	11.17	11.35	11.26	11.31	11.32
$\log\ v_{\mathrm{L}1}$ (TRAWL 5ABC)	2.193	2.125	2.164	2.167	2.321	2.130	2.077	2.188	2.178	2.185	2.186
$\Delta 1_1$ (TRAWL 5ABC)	-0.05945	-0.05560	-0.04657	-0.04737	-0.04971	-0.05397	-0.06955	-0.05163	-0.05753	-0.05528	-0.04901
μ_4 (QCS)	17.74	14.58	17.72	17.29	17.80	17.48	17.44	18.08	16.80	17.54	17.79
$\log\ v_{\mathrm{L}4}$ (QCS)	4.315	3.849	4.313	4.249	4.308	4.275	4.266	4.343	4.204	4.289	4.327
$\Delta 1_4$ (QCS)	-0.003651	0.1253	-0.001029	0.005860	-0.003704	0.03996	0.03433	0.003645	0.01808	0.01199	0.04443
μ_5 (WCVI)	20.49	17.54	21.04	20.12	20.09	20.21	20.92	20.70	20.07	20.13	20.55
$\log\ v_{\mathrm{L}5}$ (WCVI)	4.741	4.489	4.791	4.708	4.661	4.706	4.786	4.758	4.700	4.715	4.753
$\Delta 1_5$ (WCVI)	0.2744	0.1587	0.2857	0.2844	0.2504	0.2787	0.2960	0.2436	0.2937	0.2686	0.3041
μ_6 (WCHG)	12.29	12.16	12.24	12.23	12.49	12.29	12.24	12.43	12.21	12.24	12.35
$\log\ v_{\mathrm{L}6}$ (WCHG)	2.235	2.174	2.217	2.208	2.374	2.200	2.087	2.266	2.208	2.218	2.258
$\Delta 1_6$ (WCHG)	-0.01605	-0.03035	-0.03345	-0.03428	-0.03102	-0.02545	-0.02130	-0.03458	-0.03766	-0.03272	0.002341
μ_7 (GIG)	8.473	8.647	8.754	8.528	8.696	8.706	8.686	8.947	8.361	8.420	8.622
$\log\ v_{\mathrm{L}7}$ (GIG)	3.034	3.107	3.094	3.059	3.104	3.025	3.097	3.149	3.016	3.036	3.065
$\Delta 1_7$ (GIG)	-0.3249	-0.3364	-0.3082	-0.3223	-0.2666	-0.2657	-0.2443	-0.3178	-0.2947	-0.3354	-0.2394
μ_8 (NMFS)	5.222	4.441	5.325	5.276	5.263	5.270	5.363	5.412	5.307	5.185	5.266
$\log\ v_{\mathrm{L}8}$ (NMFS)	2.955	2.634	3.002	3.007	2.984	2.964	2.984	2.984	2.976	2.932	2.955
$\Delta 1_8$ (NMFS)	-0.2313	-0.2121	-0.2357	-0.2608	-0.2170	-0.1974	-0.2522	-0.2172	-0.1996	-0.1772	-0.1651
$\log$ (DM θ_1)	—	7.084	—	—	—	—	—	—	—	—	—
$\log$ (DM θ_2)	—	6.794	—	—	—	—	—	—	—	—	—
$\log$ (DM θ_3)	—	6.951	—	—	—	—	—	—	—	—	—
$\log$ (DM θ_4)	—	6.057	—	—	—	—	—	—	—	—	—
$\log$ (DM θ_5)	—	5.895	—	—	—	—	—	—	—	—	—
$\log$ (DM θ_6)	—	6.119	—	—	—	—	—	—	—	—	—
$\log$ (DM θ_7)	—	4.821	—	—	—	—	—	—	—	—	—
$\log$ (DM θ_8)	—	5.631	—	—	—	—	—	—	—	—	—

Table F.29. POP 2023: medians of MCMC-derived quantities from the base run and 10 sensitivity runs (2,000 samples each) from their respective MCMC posteriors. Definitions are: B_0 – unfished equilibrium spawning biomass (mature females), B_{2024} – spawning biomass at the end of 2024, u_{2024} – exploitation rate (ratio of total catch to vulnerable biomass) in the middle of 2024, u_{max} – maximum exploitation rate (calculated for each sample as the maximum exploitation rate from 1935 - 2024), MSY – maximum sustainable yield at equilibrium, B_{MSY} – equilibrium spawning biomass at MSY, u_{MSY} – equilibrium exploitation rate at MSY. All biomass values (and MSY) are in tonnes. Sensitivity runs: S01 = D-M parameterisation, S02 = Rdist 5ABC fixed, S03 = Rdist 3CD fixed, S04 = AE1 no age error, S05 = AE5 age reader CV, S06 = AE6 CASAL CV=0.1, S07 = reduce catch 30%, S08 = increase catch 50%, S09 = sigmaR=0.6, S10 = sigmaR=1.2

	B(R21)	S01(R17)	S02(R27)	S03(R28)	S04(R29)	S05(R30)	S06(R31)	S07(R32)	S08(R33)	S09(R34)	S10(R35)
B_0	106,054	130,221	101,087	108,553	168,639	111,740	102,805	88,586	149,119	102,912	116,939
B_{2024}	61,965	84,154	58,649	63,287	90,769	65,305	60,460	56,603	86,227	60,386	65,008
B_{2024}/B_0	0.582	0.644	0.576	0.586	0.543	0.586	0.584	0.631	0.578	0.589	0.554
u_{2023}	0.0275	0.0203	0.0291	0.0269	0.0189	0.0262	0.0282	0.0300	0.0197	0.0282	0.0263
u_{max}	0.123	0.106	0.124	0.121	0.0993	0.120	0.122	0.112	0.124	0.126	0.119
MSY	4,865	6,278	4,707	5,000	9,770	5,350	4,576	4,296	6,603	4,819	5,465
B_{MSY}	26,798	34,669	26,082	27,772	44,279	28,851	26,491	22,445	39,418	25,357	30,893
$0.4B_{MSY}$	10,719	13,867	10,433	11,109	17,712	11,540	10,597	8,978	15,767	10,143	12,357
$0.8B_{MSY}$	21,438	27,735	20,865	22,218	35,423	23,081	21,193	17,956	31,534	20,286	24,714
B_{2024}/B_{MSY}	2.33	2.49	2.28	2.32	2.08	2.30	2.29	2.53	2.24	2.41	2.11
B_{MSY}/B_0	0.254	0.265	0.259	0.255	0.264	0.260	0.260	0.251	0.265	0.246	0.266
u_{MSY}	0.0902	0.0888	0.0873	0.0892	0.107	0.0906	0.0850	0.0939	0.0817	0.0939	0.0861
u_{2023}/u_{MSY}	0.307	0.221	0.326	0.300	0.177	0.282	0.328	0.321	0.236	0.302	0.303

Table F.30. Log likelihood (LL) values reported by base and sensitivity runs for survey indices, age composition (AF), recruitment, and total (not all LL components reported here)

Sen.Run	Label	QCS_SYN	WCVI_SYN	WCHG_SYN	GIG_HIS	NMFS_TRI	WCVI_HIS	Index	AF	Recruit	Total
B (R21)	base run	-13.69	1.345	-2.832	-4.312	6.772	5.475	-7.242	1,048	29.77	1,090
S01 (R17)	D-M parameterisation	-13.40	1.079	-4.352	-4.422	6.621	5.170	-9.308	3,447	21.92	3,522
S02 (R27)	Rdist 5ABC fixed	-13.38	-0.8845	-3.289	-4.426	6.942	5.209	-9.831	1,031	30.31	1,071
S03 (R28)	Rdist 3CD fixed	-13.72	0.4439	-2.961	-4.133	6.837	5.137	-8.398	1,051	30.01	1,093
S04 (R29)	AE1 no age error	-12.78	1.284	-1.387	-3.686	6.796	5.410	-4.361	883.7	13.81	911.7
S05 (R30)	AE5 age reader CV	-13.56	1.227	-3.123	-4.182	6.791	5.472	-7.371	1,013	30.12	1,055
S06 (R31)	AE6 CASAL CV=0.1	-13.79	1.015	-4.216	-4.533	6.692	5.481	-9.353	1,187	30.43	1,230
S07 (R32)	reduce catch 30%	-13.87	0.9810	-3.151	-5.005	6.891	5.357	-8.797	1,050	30.75	1,092
S08 (R33)	increase catch 50%	-12.97	2.017	-2.522	-0.8218	7.045	5.542	-1.705	1,014	28.72	1,060
S09 (R34)	sigmaR=0.6	-13.62	1.356	-2.370	-4.374	6.791	5.473	-6.743	1,060	36.52	1,111
S10 (R35)	sigmaR=1.2	-13.71	1.254	-3.013	-4.226	6.760	5.481	-7.458	1,042	29.89	1,084

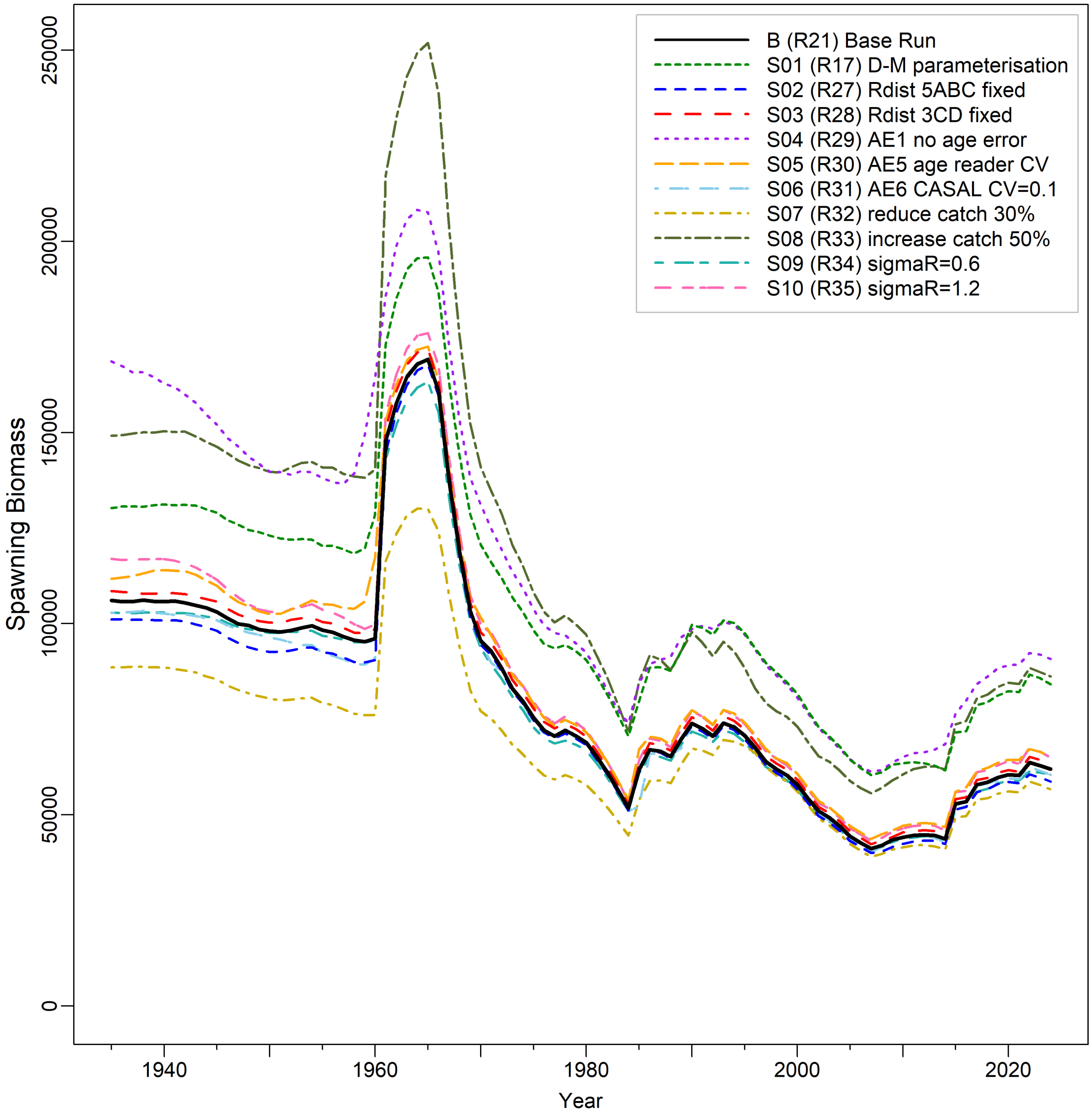


Figure F.61. POP sensitivity: model trajectories of median spawning biomass (tonnes) for the base run and 10 sensitivity runs.

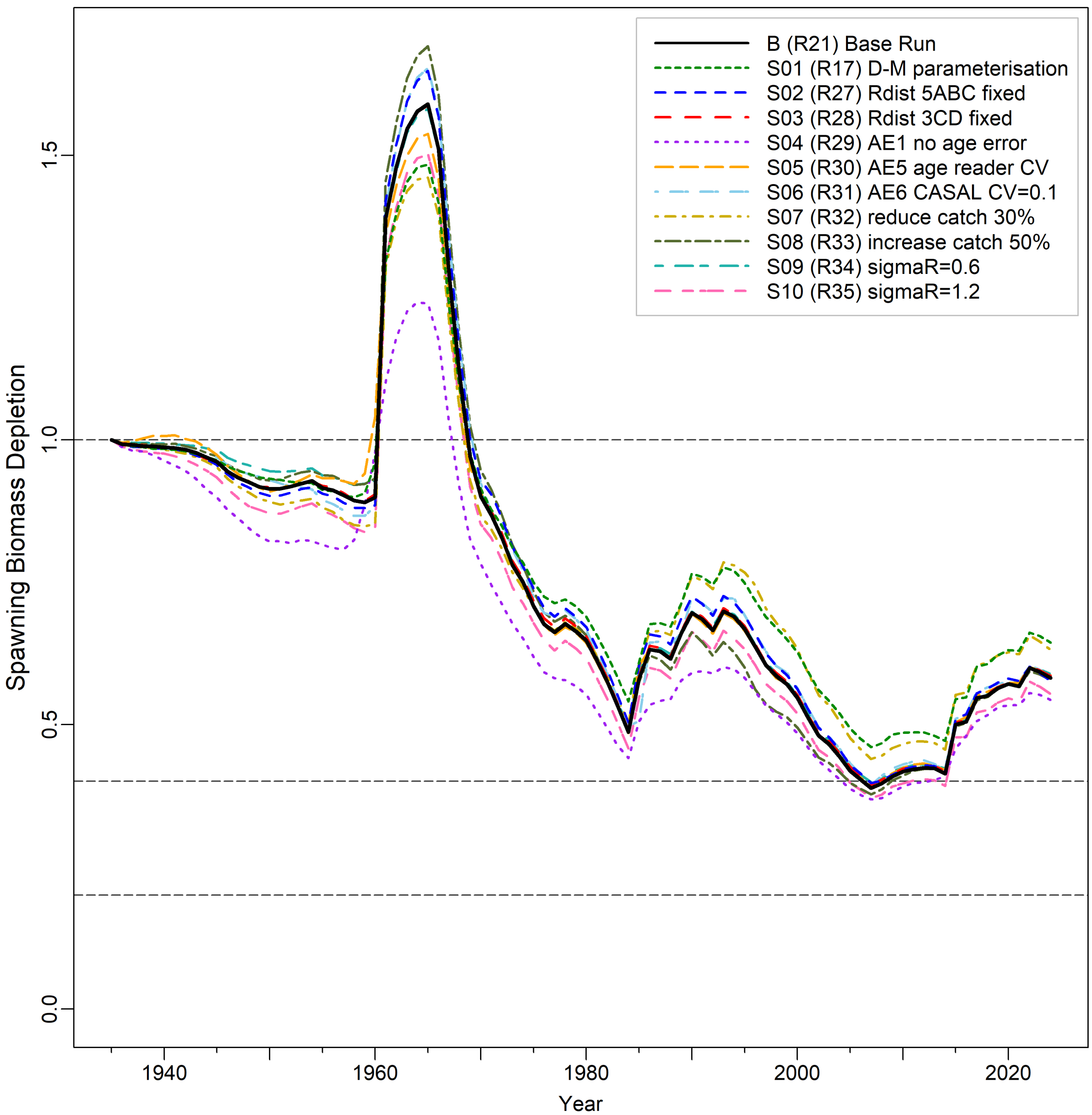


Figure F.62. POP sensitivity: model trajectories of median spawning biomass as a proportion of unfished equilibrium biomass (B_t/B_0) for the base run and 10 sensitivity runs. Horizontal dashed lines show alternative reference points used by other jurisdictions: 0.2B_0 (∼DFO's USR), 0.4B_0 (often a target level above B_{MSY}), and B_0 (equilibrium spawning biomass).

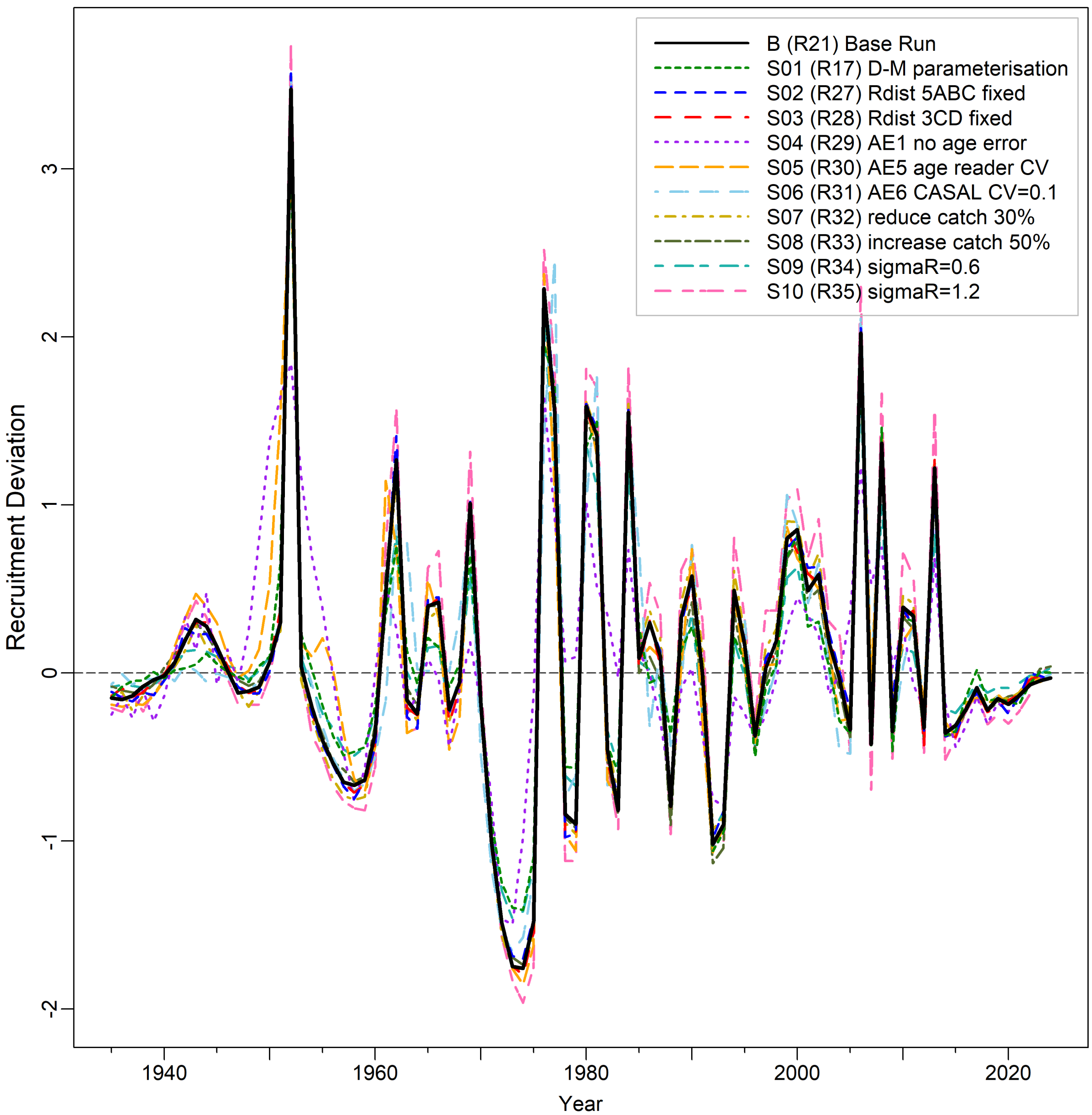


Figure F.63. POP sensitivity: model trajectories of median recruitment deviations for the base run and 10 sensitivity runs.

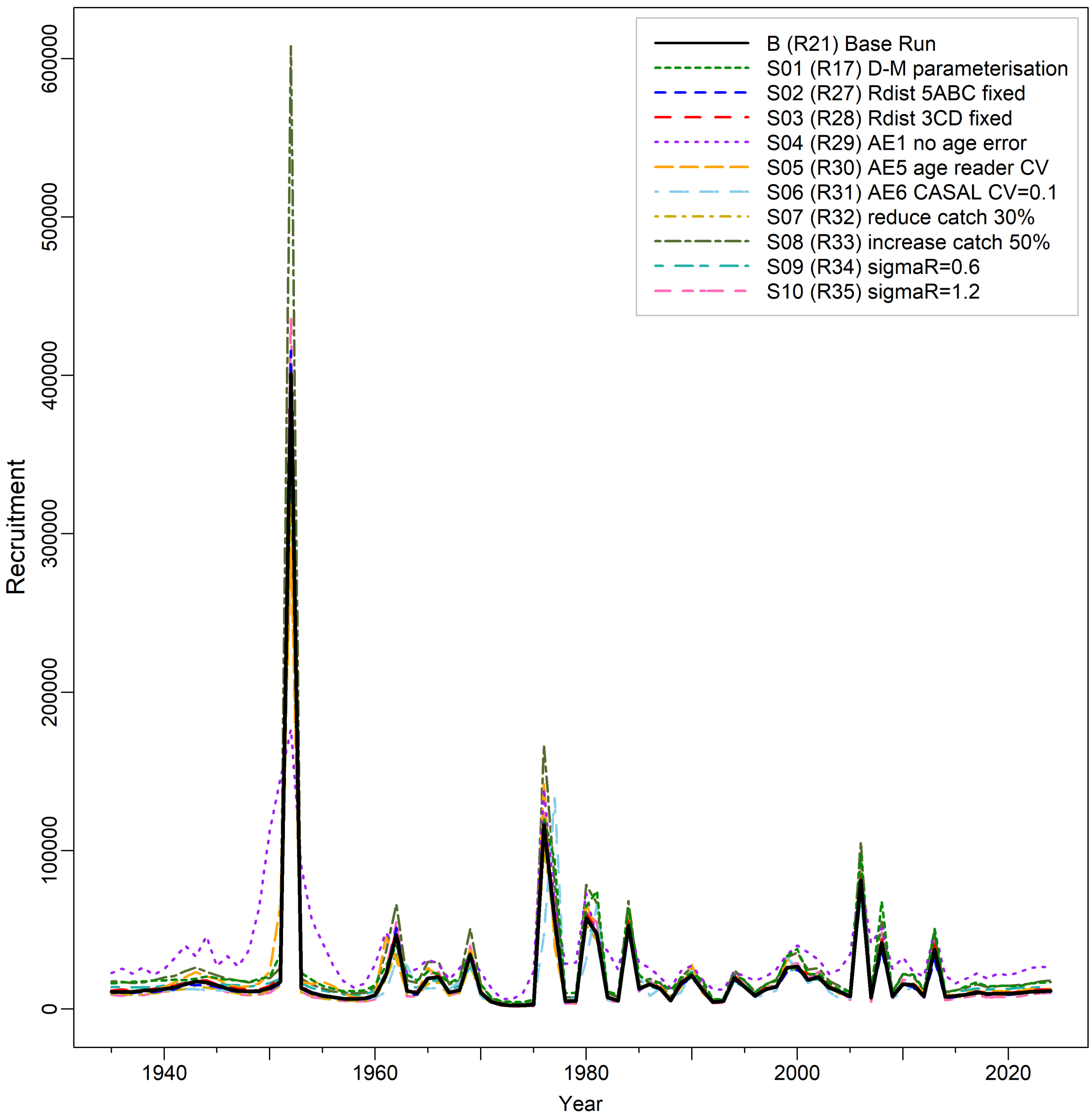


Figure F.64. POP sensitivity: model trajectories of median recruitment of one-year old fish (R_t, 1000s) for the base run and 10 sensitivity runs.

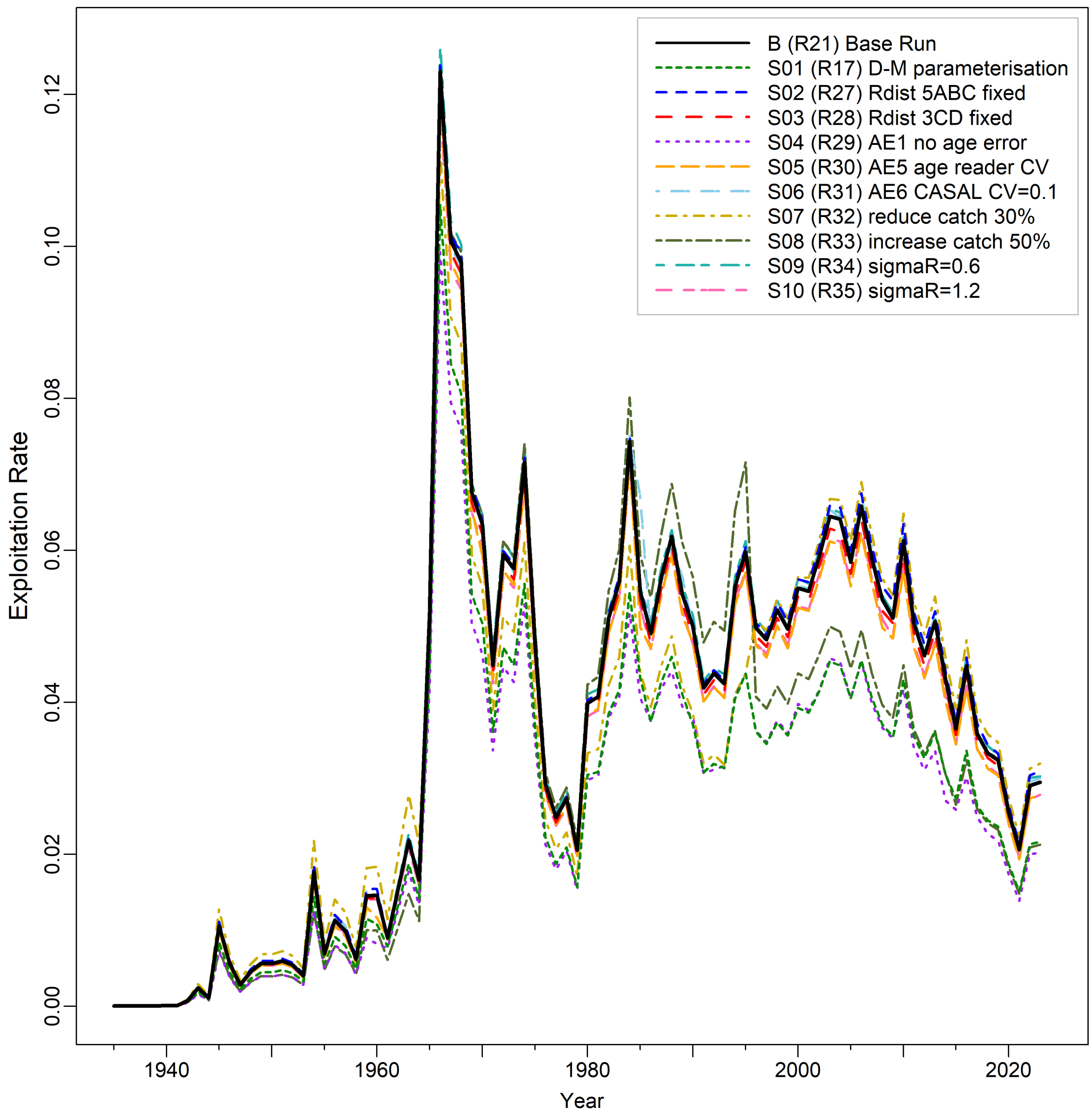


Figure F.65. POP sensitivity: model trajectories of median exploitation rate of vulnerable biomass (u_t) for the base run and 10 sensitivity runs.

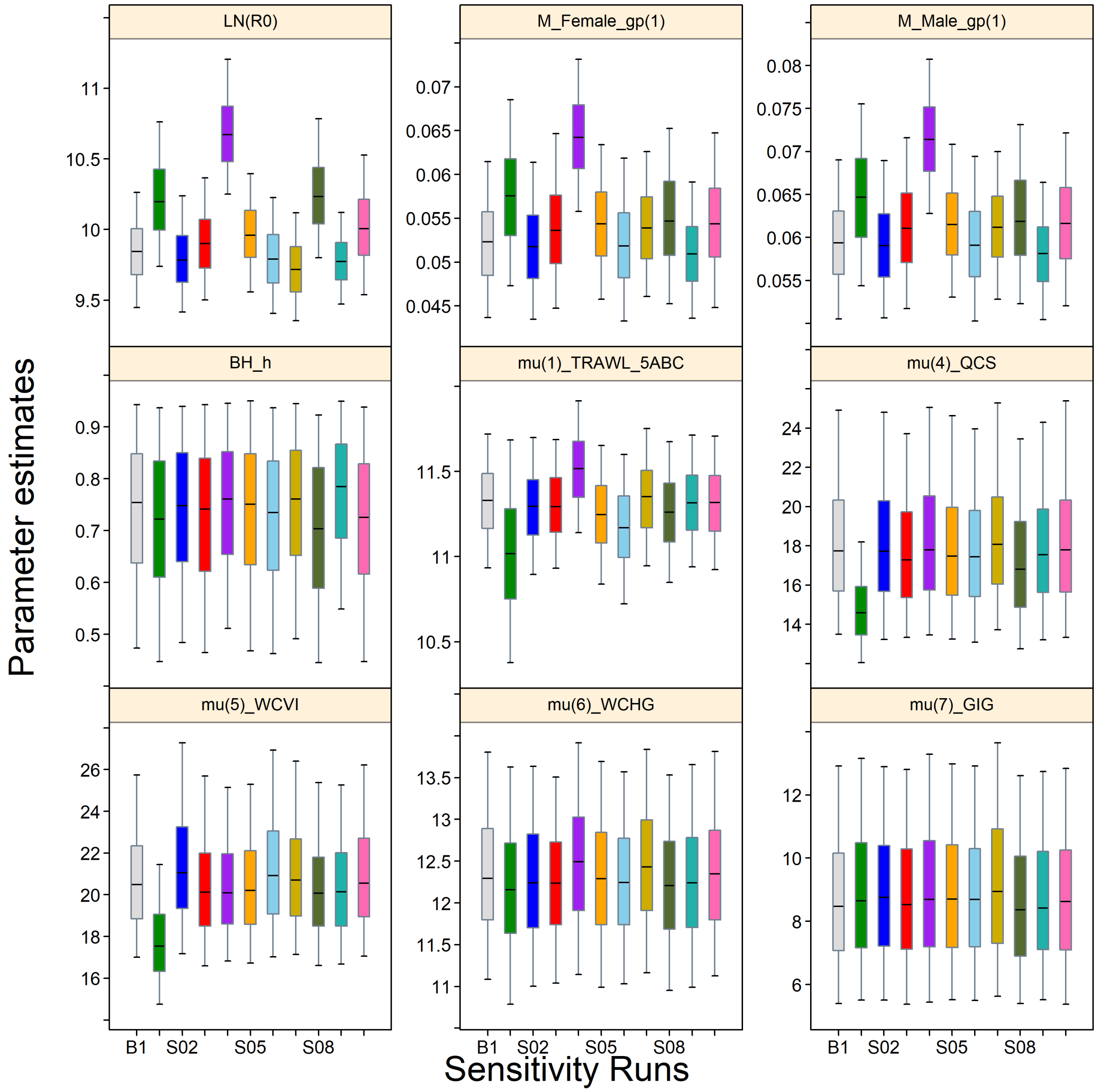


Figure F.66. POP sensitivity: quantile plots of selected parameter estimates ($\log R_0$, $M_{s=1,2}$, h, $\mu_{g=1}$, $\log v_{Lg=1}$) comparing the base run with 10 sensitivity runs. See text on sensitivity numbers. The boxplots delimit the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles; outliers are excluded.

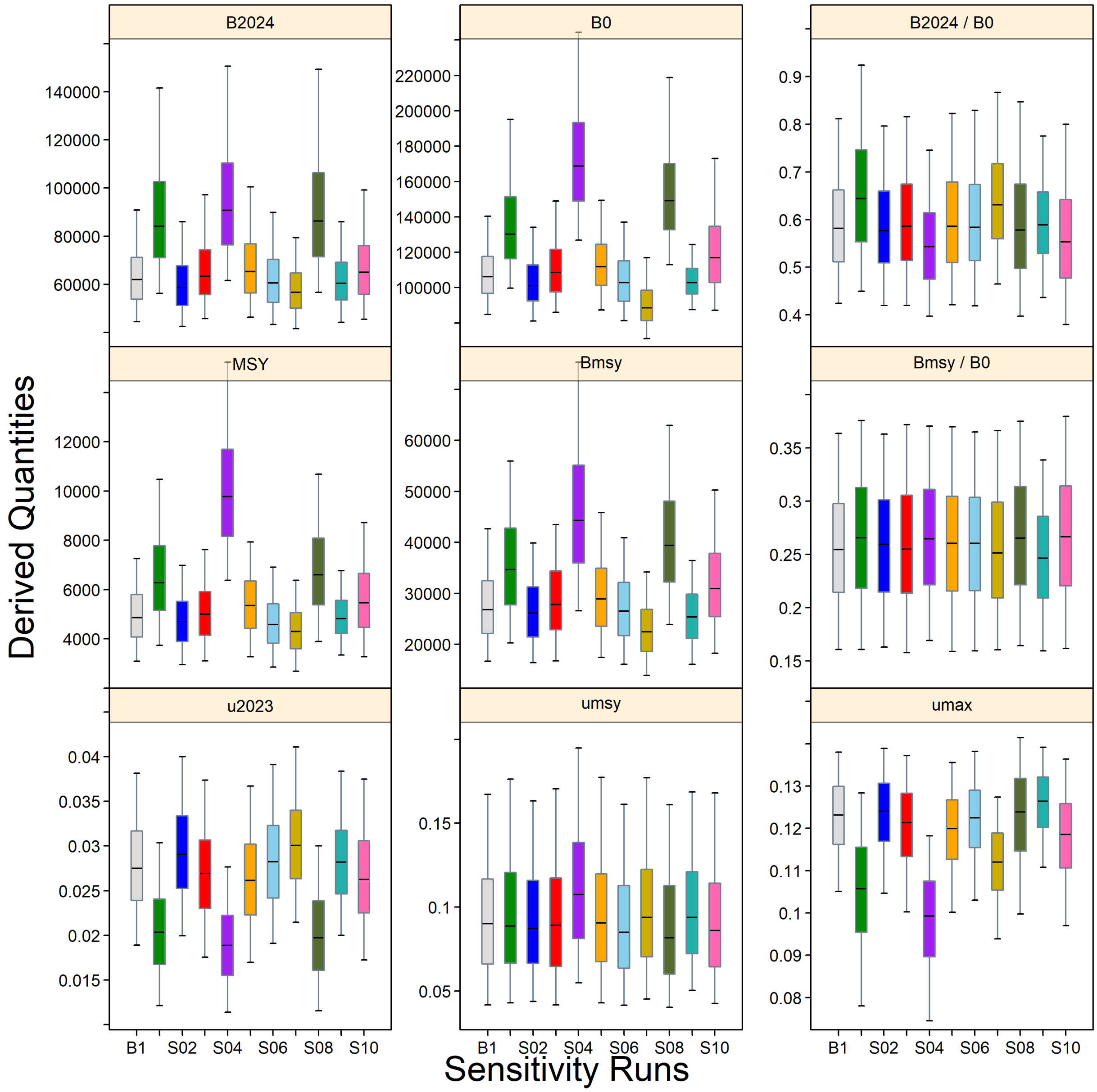


Figure F.67. POP sensitivity: quantile plots of selected derived quantities (B_{2024}, B_0, B_{2024}/B_0, MSY, B_{MSY}, B_{MSY}/B_0, u_{2023}, u_{MSY}, u_{max}) comparing the base run with 10 sensitivity runs. See text on sensitivity numbers. The boxplots delimit the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles; outliers are excluded.

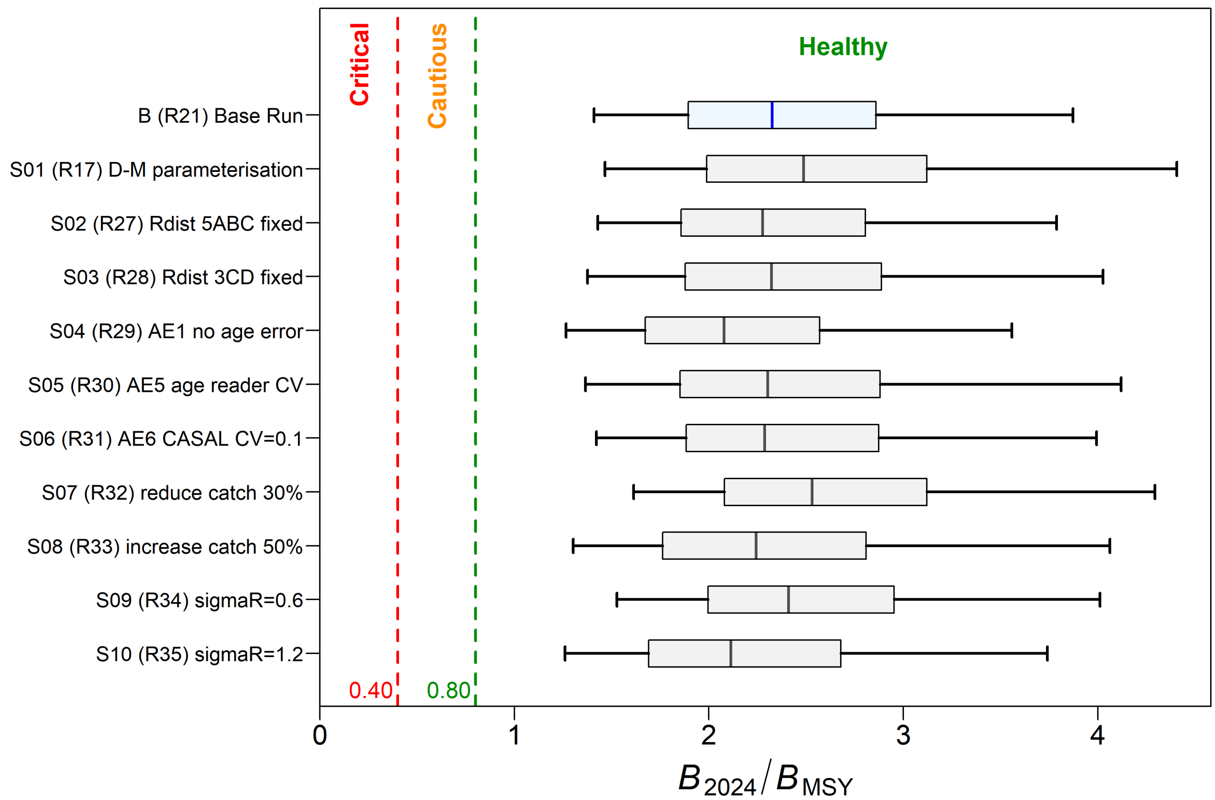


Figure F.68. POP sensitivity: stock status at beginning of 2024 relative to the DFO PA reference points of $0.4B_{MSY}$ and $0.8B_{MSY}$ for the base run (Run21) and 10 sensitivity runs. Vertical dotted line uses median of the base run to faciliate comparisons with sensitivity runs. Boxplots show the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles from the MCMC posterior.

F.3. REFERENCES – MODEL RESULTS

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ANNEXE G. ECOSYSTEM INFORMATION

This appendix describes ecosystem information relevant to Pacific Ocean Perch (POP, GFBioSQL code ‘396’) along the British Columbia (BC) coast (PMFC areas 3CD + 5ABCDE). The analyses herein compare three regions that delineate stocks. The central BC stock in Queen Charlotte Sound (QCS, PMFC areas 5ABC) is the largest and most important to the fishery. Two smaller stocks flank the larger one: a southern BC stock off the west coast of Vancouver Island (WCVI, PMFC areas 3CD) and a northern BC stock off the north and west coasts of Haida Gwaii (WCHG, PMFC areas 5DE). The 2023 stock assessment models the BC coastwide population of POP as three stocks with a shared coastwide recruitment that is apportioned to each area. The information in this appendix provides information that might be useful to other agencies, and supplements the POP spatial and biological information in other appendices in the 2023 stock assessment document.

G.1. SPATIAL DISTRIBUTION

Data for spatial analyses of POP were extracted from the SQL DFO database ‘GFFOS[1]’ on Apr 25, 2023, specifically using the GF_MERGED_CATCH table which reconciles observer and fisher logs. Some of the analyses below are designed to facilitate the reporting of findings to COSEWIC (Committee on the Status of Endangered Wildlife in Canada), regardless of its assessed status by that agency.

Table G.1. Values of potential interest to COSEWIC.

Metric↓ Area→	BC	5ABC	3CD	5DE
Extent of Occurrence (km^2)	104,982	49,529	19,876	26,486
Bathymetry habitat (km^2)	52,386	32,983	6,178	11,601
Area of Occupancy (km^2)	23,020	12,076	6,768	4,328
Depth at POP tow frequency (1%)	100	96	128	97
Depth at POP tow frequency (99%)	528	442	590	549
Sum POP catch (27y) in POP tows (kt)	122.8	83.6	14.3	24.7
Prop. POP (27y) in POP tows (%)	18.1	27.3	5.7	18.4

Pacific Ocean Perch is ubiquitous along the BC coast, with CPUE hotspots in Moresby Gully, around Anthony Island, off Rennell Sound, off the NW coast of Haida Gwaii, and in Dixon Entrance near Langara Island (Figure G.1). The ‘extent of occurrence’ (EO), calculated as a convex hull surrounding fishing events, provides the most coarse measure of spatial habitat. For marine species, it can include areas that provide poor habitat depending on the fishing events’ spatial convolutions (Figure G.2). Table G.1 reports the area on water covered by various convex hulls (BC coastwide, 5ABC, 3CD, and 5DE). The next level of spatial coverage is provided by bathymetry envelopes delimited by depths at which POP has been observed, specifically the 0.01 and 0.99 depth quantiles (Table G.1, Figure G.3 to Figure G.6). The bathymetry envelopes (Figure G.7) provide areas where 98% of POP might be found, without knowing habitat suitability for the species. Finally, the ‘area of occupancy’ narrows the suitable habitat to those areas where POP has been observed. A point estimate of one location has no meaningful physical dimension; therefore, a 2 km by 2 km grid is superimposed on coastal

[1] GFFOS is the Groundfish interface to DFO’s current database platform for catch statistics called ‘Fishery Operation System’. Groundfish catch records from the H&L fisheries were switched to GFFOS in 2006 while those from the trawl fisheries were switched to GFFOS in 2007.

waters, and any one grid cell is assumed to be occupied if three unique fishing vessels have caught at least one POP in that grid cell. The occupied grid cells are summed (each cell being equal to 4 km^2) to represent the minimum area of POP habitat (Table G.1, Figure G.8).

Representations of spatial extent can also include a ranking of the catch in fishing localities by each fishery. For the trawl fishery, the top three localities that catch POP are SE Cape St. James, SE Goose, and Frederick Island (Figure G.9), based on catches since 1996. Similarly, the top localities for the minor fisheries are SE Cape St. James (halibut fishery, Figure G.10), Quatsino Canyon (Sablefish fishery, Figure G.11), Flamingo Inlet (dogfish/lingcod fishery, Figure G.12), and Barry Inlet (outside hook and line fishery, Figure G.13).

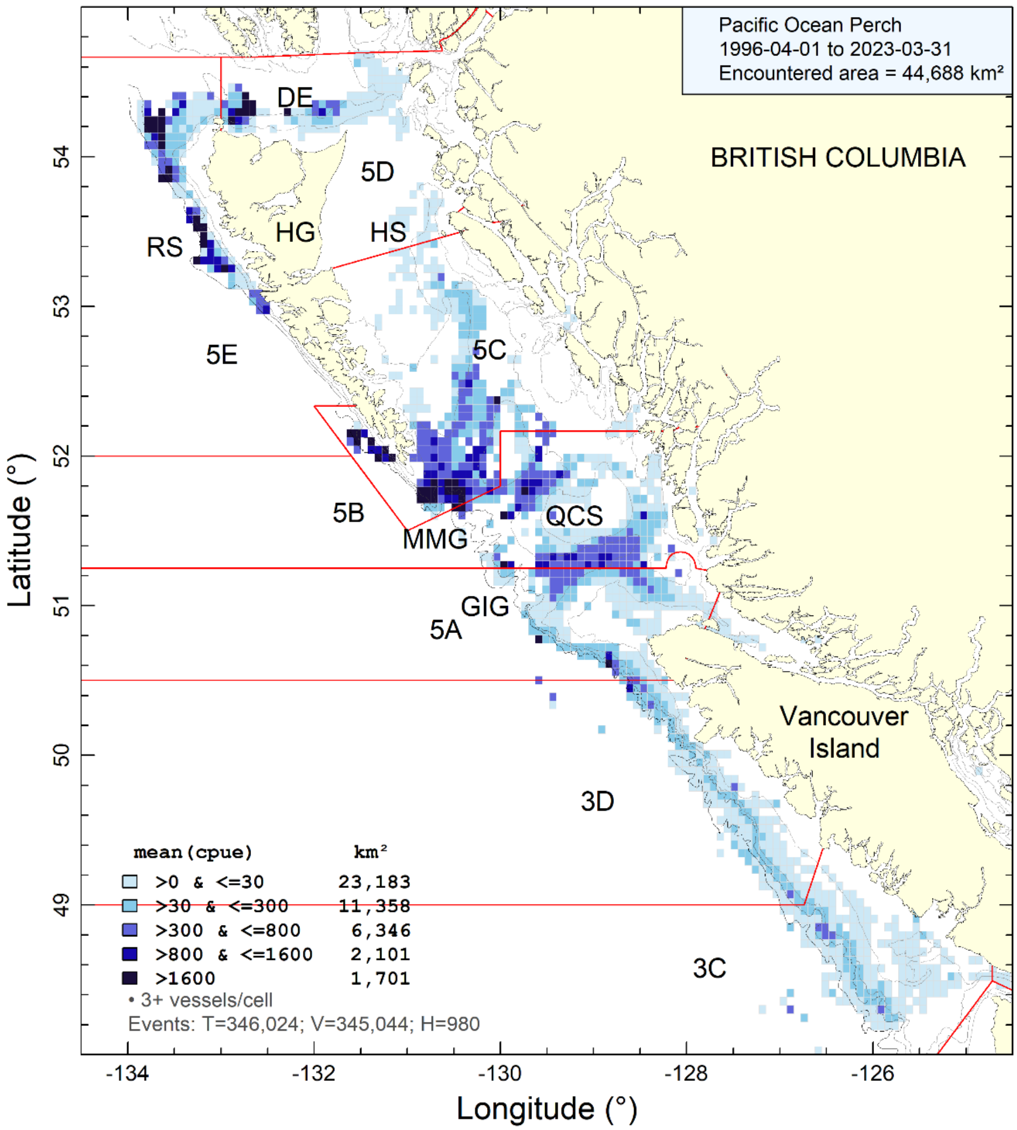

Figure G.1. CPUE density of POP from trawl tows (bottom and midwater) occurring from Apr 1996 to Mar 2023. DE = Dixon Entrance, GIG = Goose Island Gully, HG = Haida Gwaii, HS = Hecate Strait, MMG = Moresby and Mitchell's Gullies, QCS = Queen Charlotte Sound, RS = Rennell Sound.

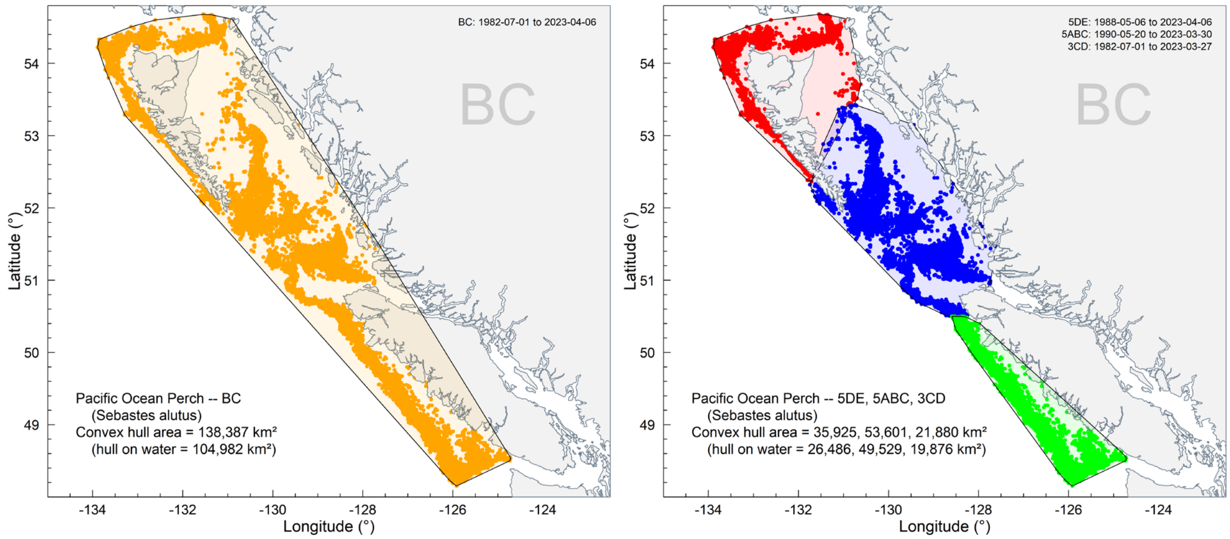

Figure G.2. Extent of Occurrence as convex hulls surrounding fishing events that caught POP coastwide (left panel) and in three regions (right panel, north: 5DE, central: 5ABC, south: 3CD) along the BC coast.

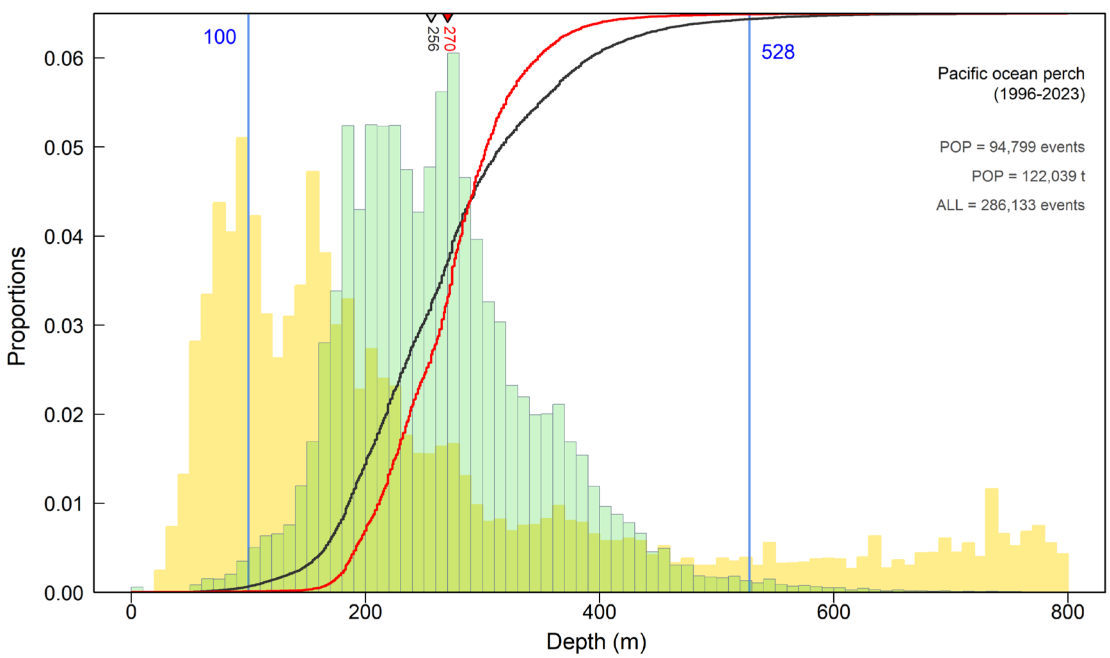

Figure G.3. POP coastwide – Depth frequency of bottom trawl tows (green histogram) that captured POP from commercial catch data in PMFC areas 3CD and 5ABCDE. The vertical solid lines denote the 0.01 and 0.99 quantiles. The black curve shows the cumulative frequency of tows that encounter POP while the red curve shows the cumulative catch of POP at depth (scaled from 0 to 1). The median depths of POP encounters (inverted grey triangle) and of cumulative catch (inverted red triangle) are indicated along the upper axis. The yellow histogram in the background reports the relative trawl effort on all species offshore down to 800 m.

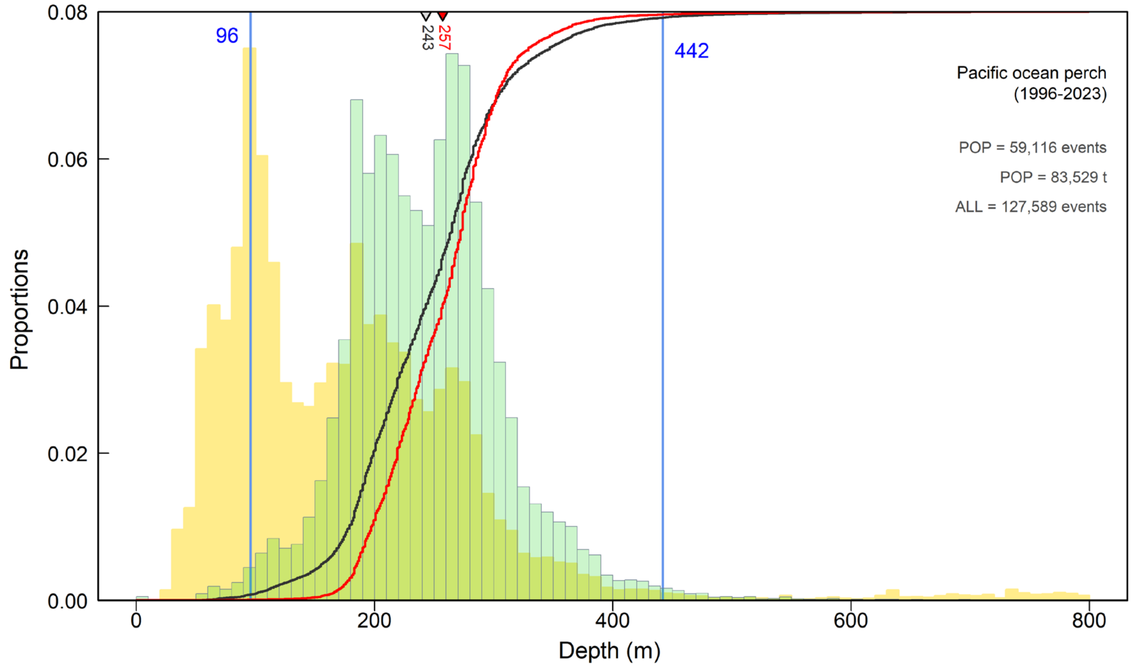

Figure G.4. POP 5ABC – Depth frequency of bottom trawl tows (green histogram) that captured POP from commercial catch data in PMFC areas 5ABC. See Figure G.2 caption for additional details.

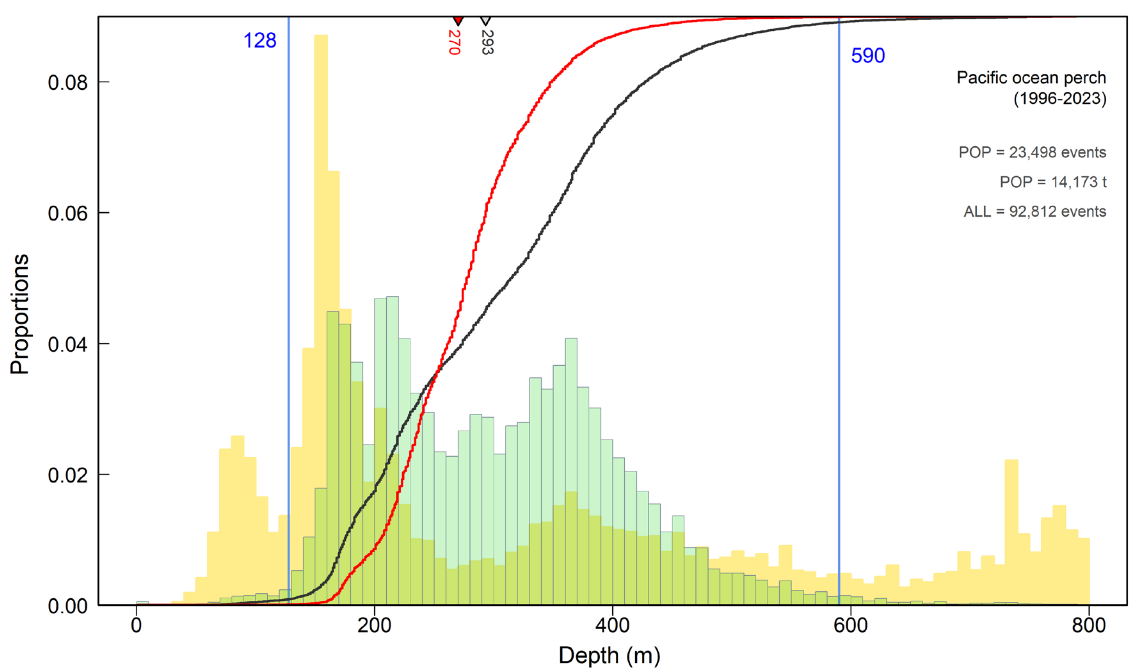

Figure G.5. POP 3CD – Depth frequency of bottom trawl tows (green histogram) that captured POP from commercial catch data in PMFC areas 3CD. See Figure G.2 caption for additional details.

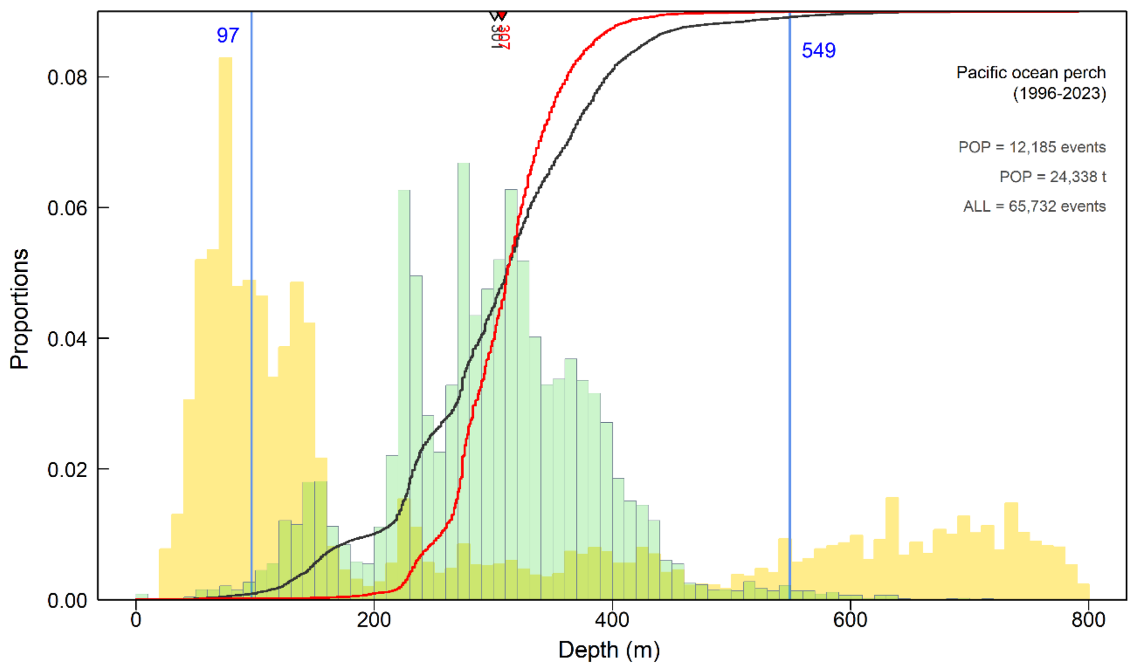

Figure G.6. POP 5DE – Depth frequency of bottom trawl tows (green histogram) that captured POP from commercial catch data in PMFC areas 5DE. See Figure G.2 caption for additional details.

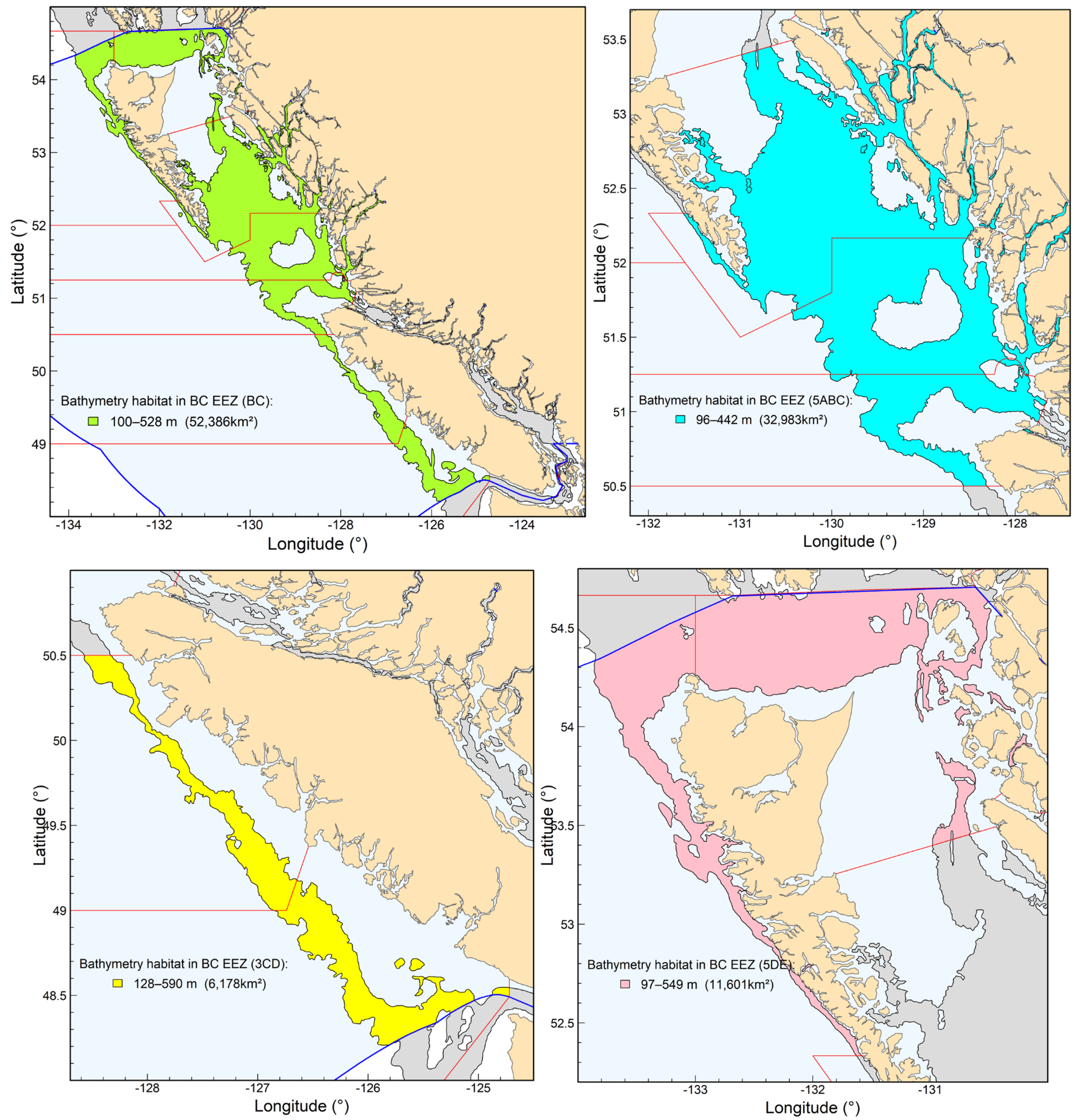

Figure G.7. Highlighted bathymetry serves as a proxy for benthic habitat along the BC coast for POP: 3CD+5ABCDE (top left, green), 5ABC (top right, cyan), 3CD (bottom left, yellow), and 5DE (bottom right, pink). The highlighted regions (green, cyan, yellow, pink) within Canada's exclusive economic zone (EEZ, light blue highlighted area) are determined by depth limits presented in Figure G.3 to Figure G.6. The boundary lines in red delimit PMFC areas.

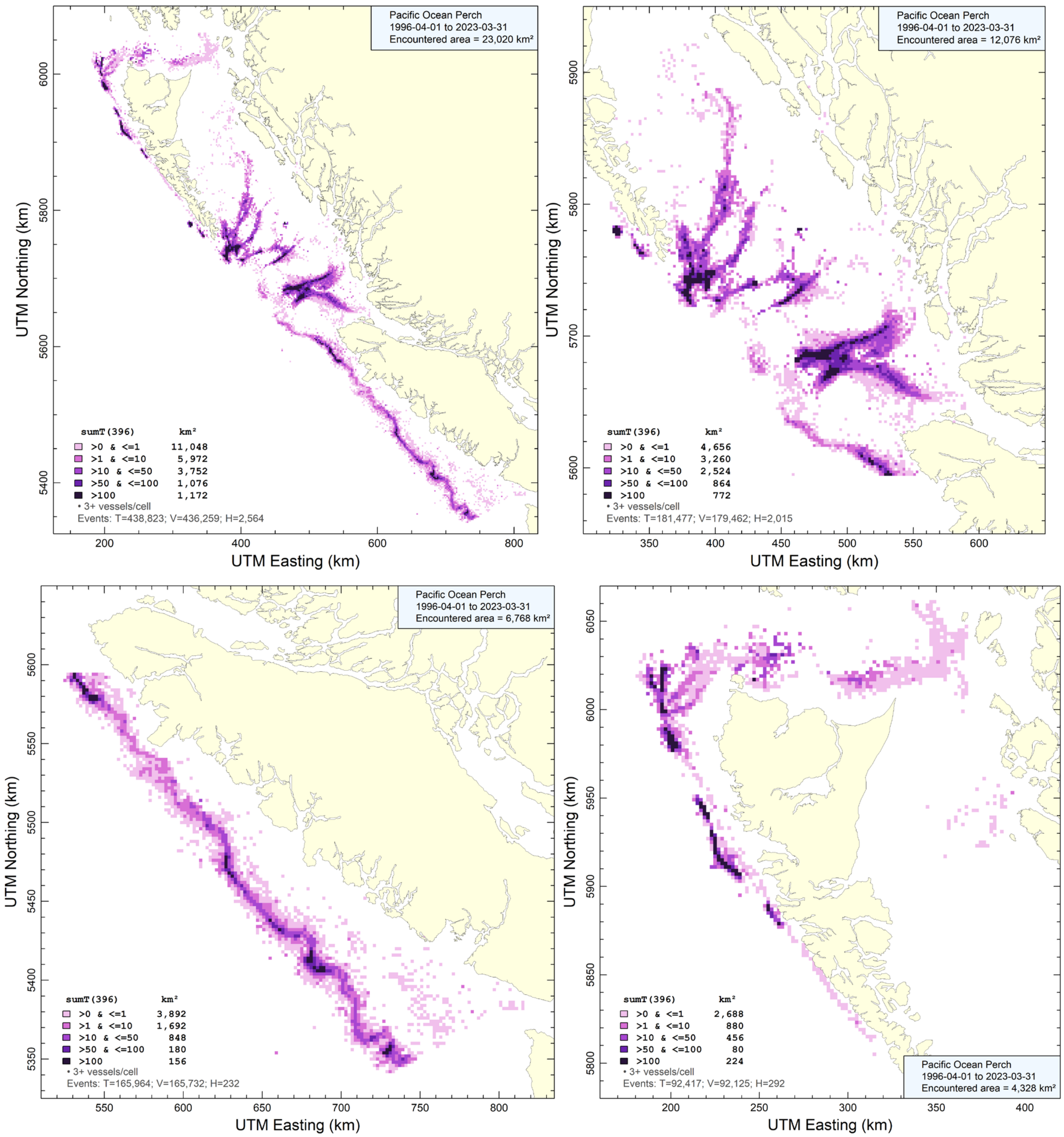

Figure G.8. Area of Occupancy (AO) determined by all-gear capture of POP in grid cells 2 km × 2 km. Cells with fewer than three fishing vessels are excluded. The estimated AO is 23,020 km² in 3CD+5ABCDE (top left), 12,076 km² in 5ABC (top right), 6,768 km² in 3CD (bottom left), and 4,328 km² in 5DE (bottom right).

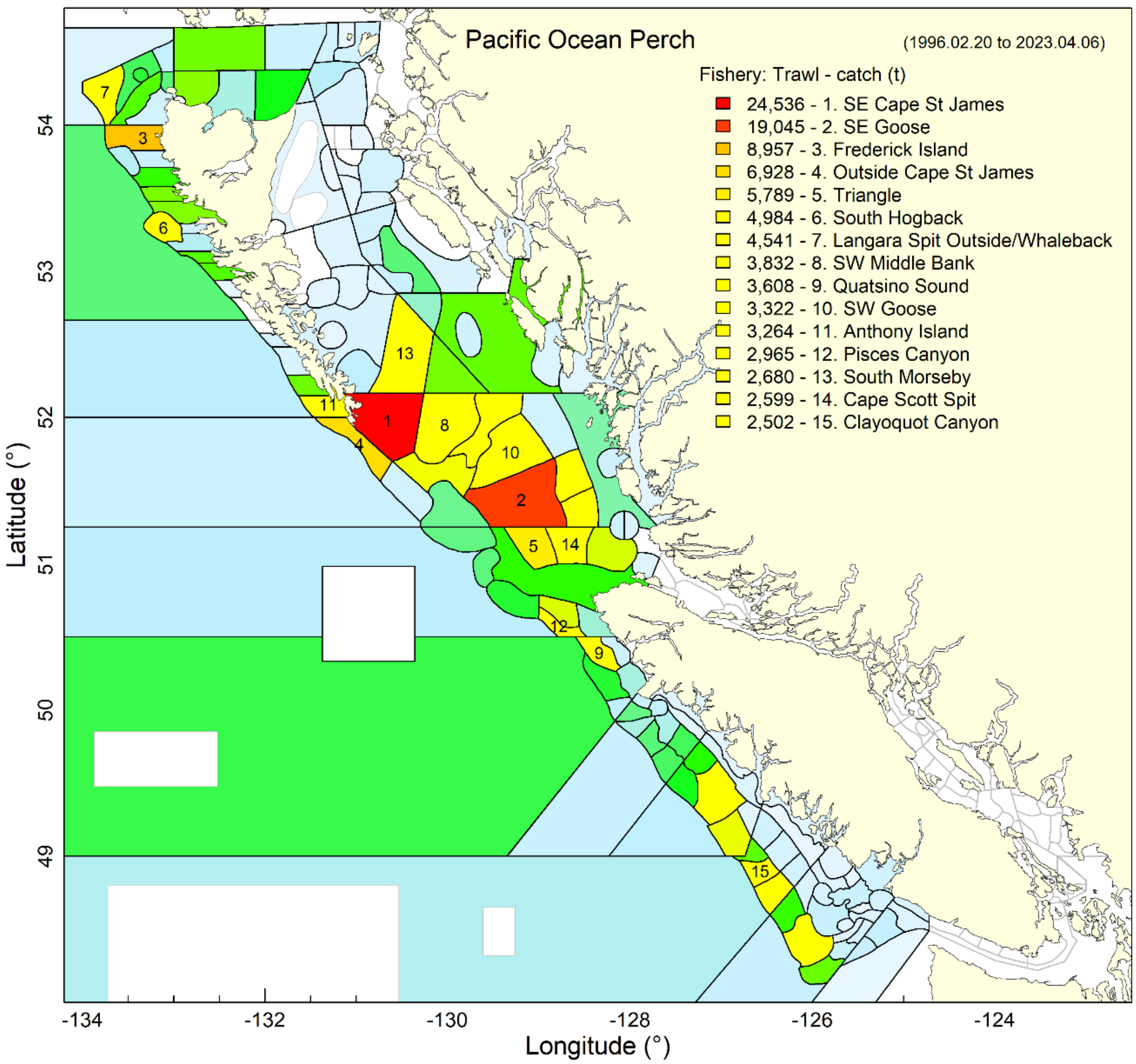

Figure G.9. POP Trawl – Top 15 fishing localities by total catch (tonnes) where POP was caught by the trawl fishery. All shaded localities indicate areas where POP was encountered from 1996 to 2023, ranging from relatively low numbers in cool blue, through the spectrum, to relatively high catches in red. Seamount catches are excluded.

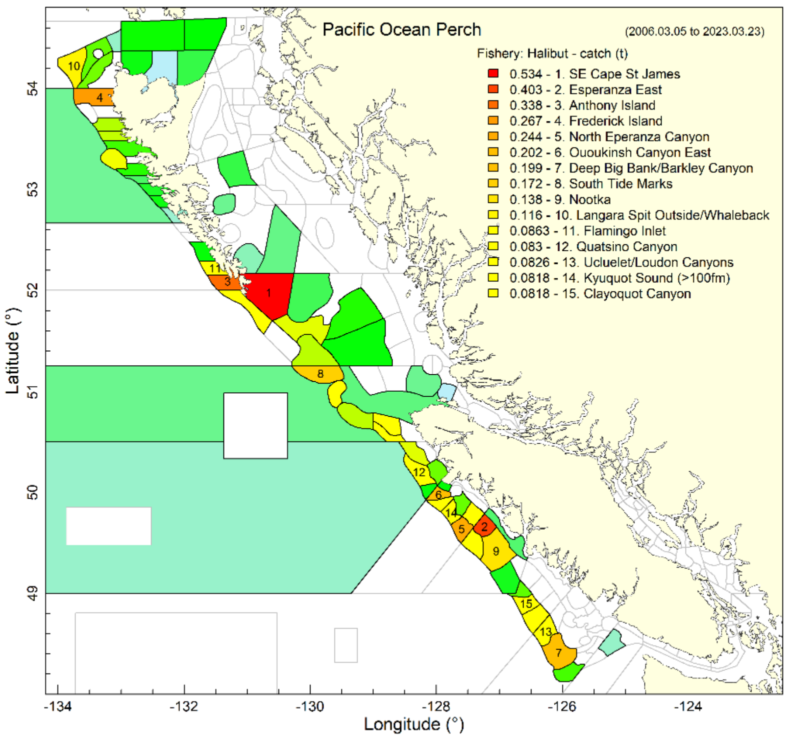

Figure G.10. POP Halibut – Top 15 fishing localities by total catch (tonnes) where POP was caught by the halibut fishery. See Figure G.9 caption for further details.

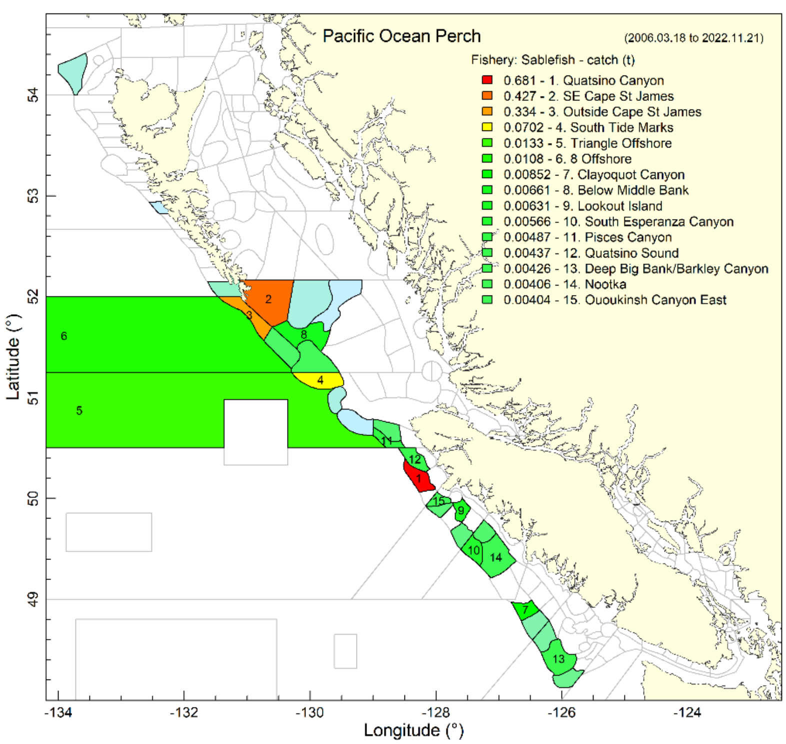

Figure G.11. POP Sablefish – Top 15 fishing localities by total catch (tonnes) where POP was caught by the sablefish fishery. See Figure G.9 caption for further details.

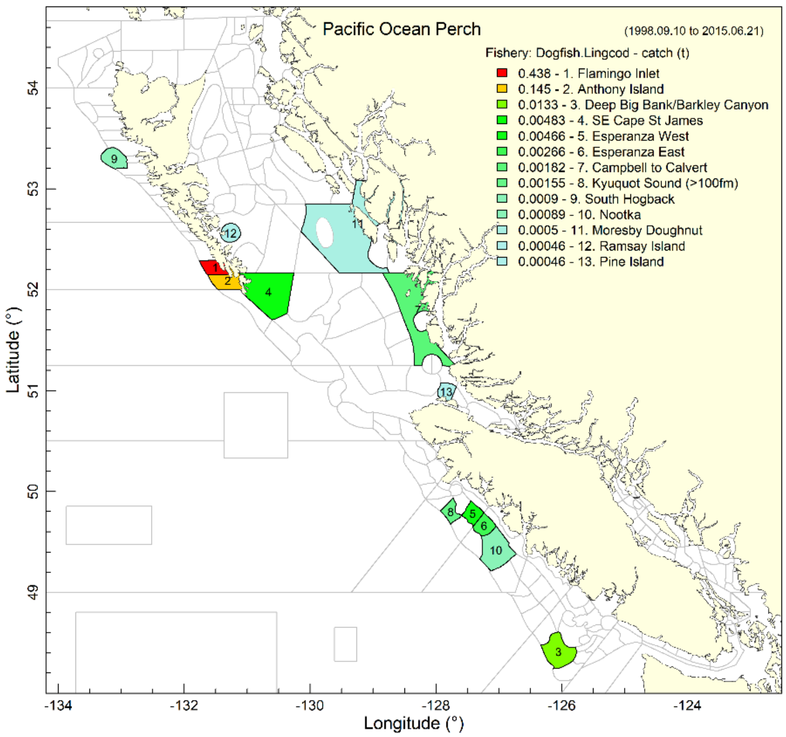

Figure G.12. POP Dogfish/Lingcod – Top 15 fishing localities by total catch (tonnes) where POP was caught by the dogfish/lingcod (formerly Schedule II) fishery. See Figure G.9 caption for further details.

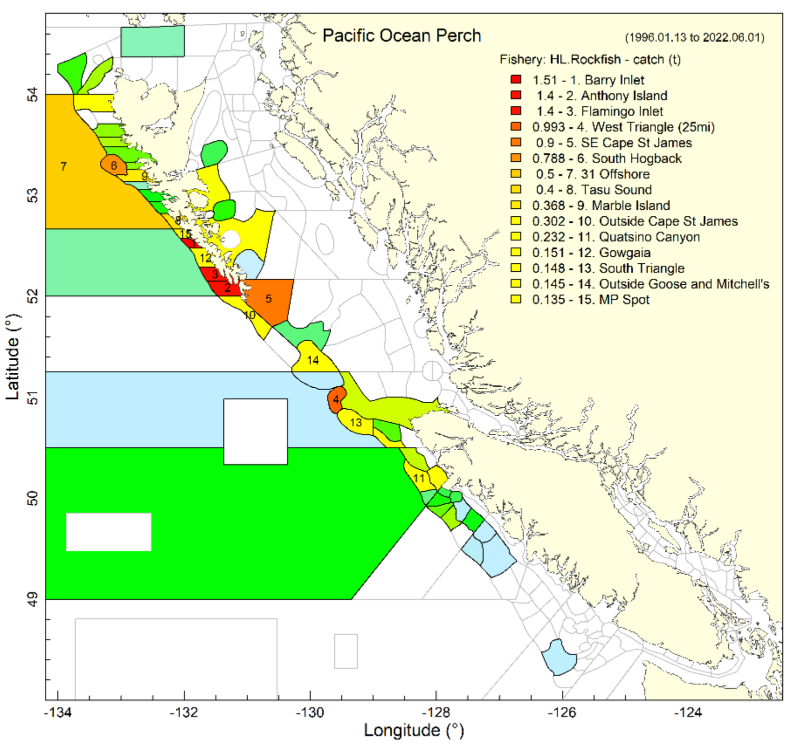

Figure G.13. POP H&L Rockfish – Top 15 fishing localities by total catch (tonnes) where POP was caught by the hook and line rockfish (Outside H&L, formerly ZN) fishery. See Figure G.9 caption for further details.

G.2. CONCURRENT SPECIES

Species caught concurrently in coastwide bottom trawl tows that captured **at least one** POP specimen (Table G.2, Figure G.14) comprised, by region:

- BC (3CD+5ABCDE):
  24% Arrowtooth Flounder[2], 18% Pacific Ocean Perch, 8% Yellowtail Rockfish, 8% Dover Sole, and 5% Silvergray Rockfish by weight;
- 5ABC:
  27% POP, 20% Arrowtooth Flounder, 9% Yellowmouth Rockfish, 7% Silvergray Rockfish, and 7% Yellowtail Rockfish by weight;
- 3CD:
  33% Arrowtooth Flounder, 12% Yellowtail Rockfish, 10% Dover Sole, 6% Pacific Ocean Perch, and 5% Canary Rockfish by weight;
- 5DE:
  21% Arrowtooth Flounder, 18% POP, 15% Dover Sole, 8% Rougheye/Blackspotted Rockfish, and 5% Silvergray Rockfish by weight;

Note that these results include all components (target fishing and bycatch) of the POP fishery.

The other gear types that intercept POP (midwater trawl, hook and line, trap) do so in very small amounts (if at all), and are not presented.

[2] Note that the percentages in this table apply to the entire reported catch (all species) from tows which contained at least one POP. Therefore, 24% for ARF indicates that 24% of the total catch comprised ARF.

Table G.2. POP bottom trawl – Top 10 species by catch weight (sum of landed + discarded 1996–2023) that co-occur in POP bottom trawl fishing events (tows with at least one POP specimen) by PMFC area, where BC = 3CD+5ABCDE. Rockfish species of interest to COSEWIC appear in red font, target species appears in blue font.

Code*	Species	Latin Name	Catch (tonnes)	Catch (%)	∑Catch (%)
Area:	**BC**				
602	Arrowtooth Flounder	*Atheresthes stomias*	164,230	24.2	24.2
396	Pacific Ocean Perch	*Sebastes alutus*	122,780	18.1	42.3
418	Yellowtail Rockfish	*Sebastes flavidus*	54,415	8.02	50.3
626	Dover Sole	*Microstomus pacificus*	51,467	7.59	57.9
405	Silvergray Rockfish	*Sebastes brevispinis*	34,620	5.10	63.0
440	Yellowmouth Rockfish	*Sebastes reedi*	34,232	5.05	68.1
467	Lingcod	*Ophiodon elongatus*	21,411	3.16	71.2
437	Canary Rockfish	*Sebastes pinniger*	17,634	2.60	73.8
439	Redstripe Rockfish	*Sebastes proriger*	17,362	2.56	76.4
394	Rougheye Rockfish	*Sebastes aleutianus*	14,108	2.08	78.4
Area:	**5ABC**				
396	Pacific Ocean Perch	*Sebastes alutus*	83,570	27.3	27.3
602	Arrowtooth Flounder	*Atheresthes stomias*	62,403	20.4	47.7
440	Yellowmouth Rockfish	*Sebastes reedi*	28,647	9.36	57.1
405	Silvergray Rockfish	*Sebastes brevispinis*	21,715	7.09	64.1
418	Yellowtail Rockfish	*Sebastes flavidus*	20,822	6.80	70.9
626	Dover Sole	*Microstomus pacificus*	9,831	3.21	74.2
467	Lingcod	*Ophiodon elongatus*	9,713	3.17	77.3
439	Redstripe Rockfish	*Sebastes proriger*	7,659	2.50	79.8
222	Pacific Cod	*Gadus macrocephalus*	5,868	1.92	81.8
437	Canary Rockfish	*Sebastes pinniger*	5,467	1.79	83.5
Area:	**3CD**				
602	Arrowtooth Flounder	*Atheresthes stomias*	83,451	33.4	33.4
418	Yellowtail Rockfish	*Sebastes flavidus*	30,558	12.2	45.7
626	Dover Sole	*Microstomus pacificus*	25,630	10.3	55.9
396	Pacific Ocean Perch	*Sebastes alutus*	14,300	5.73	61.6
437	Canary Rockfish	*Sebastes pinniger*	11,525	4.61	66.3
467	Lingcod	*Ophiodon elongatus*	10,984	4.40	70.7
044	Spiny Dogfish	*Squalus acanthias*	7,931	3.18	73.8
607	Petrale Sole	*Eopsetta jordani*	7,800	3.12	77.0
225	Pacific Hake	*Merluccius productus*	6,397	2.56	79.5
439	Redstripe Rockfish	*Sebastes proriger*	6,165	2.47	82.0
Area:	**5DE**				
602	Arrowtooth Flounder	*Atheresthes stomias*	27,711	20.7	20.7
396	Pacific Ocean Perch	*Sebastes alutus*	24,678	18.4	39.1
626	Dover Sole	*Microstomus pacificus*	19,552	14.6	53.6
394	Rougheye Rockfish	*Sebastes aleutianus*	10,231	7.63	61.3
405	Silvergray Rockfish	*Sebastes brevispinis*	6,925	5.16	66.4
066	Spotted Ratfish	*Hydrolagus colliei*	4,704	3.51	69.9
610	Rex Sole	*Errex zachirus*	4,521	3.37	73.3
628	English Sole	*Parophrys vetulus*	3,603	2.69	76.0
439	Redstripe Rockfish	*Sebastes proriger*	3,524	2.63	78.6
440	Yellowmouth Rockfish	*Sebastes reedi*	3,472	2.59	81.2

*COSEWIC species in {‘027’, ‘034’, ‘394’, ‘410’, ‘424’, ‘435’, ‘437’, ‘440’, ‘442’, ‘453’}

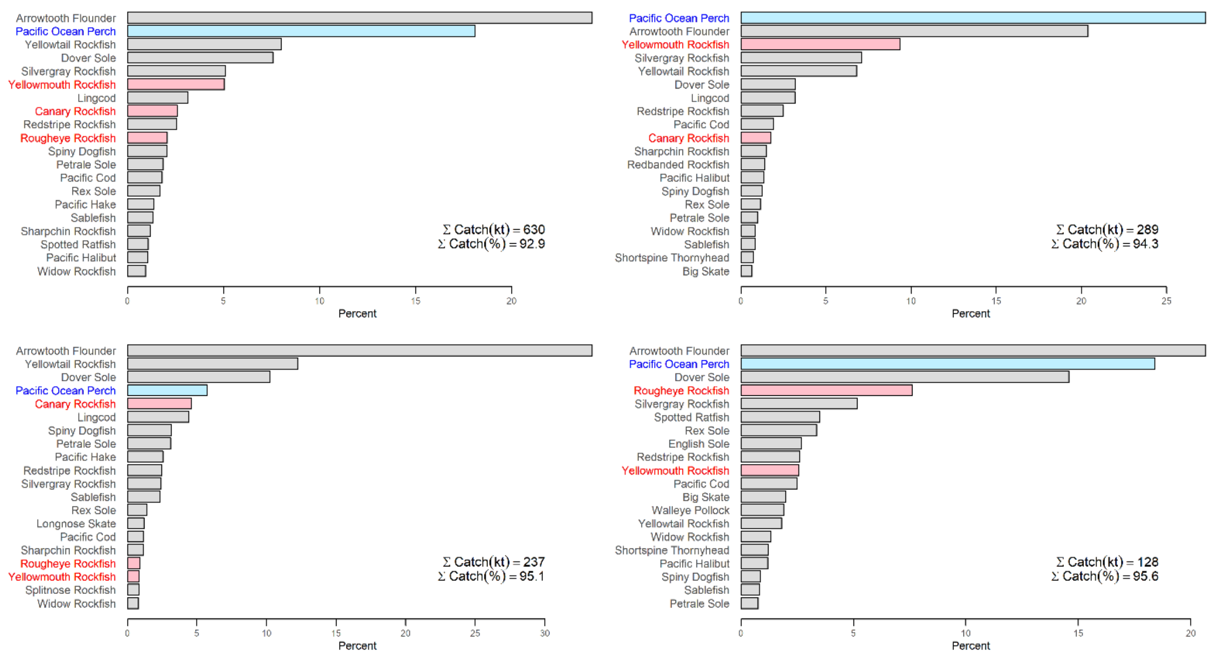

Figure G.14. POP bottom trawl – Distribution of catch weights summed over the period Feb 1996 to Mar 2023 for important finfish species from bottom trawl fishing events in GFFOS that caught at least one POP in PMFC areas 3CD5ABCDE (top left), 5ABC (top right), 3CD (bottom left), and 5DE (bottom right). Fishing events were selected over various depth ranges: 100–528 m coastwide, 96–442 m in 5ABC, 128–590 m in 3CD and 97–549 m in 5DE (the 0.01 and 0.99 quantile ranges, see Figure G.3 to Figure G.6). Relative concurrence is expressed as a percentage by species relative to the total catch weight summed over all finfish species in the specified period. Assessment species appears in blue; COSEWIC species appear in red.

G.3. TROPHIC INTERACTIONS

Fu et al (2017) used an ecosystem model (OSMOSE: Object-oriented Simulator of Marine Ecosystems Exploitation) to explore predator-prey interactions in a previously-defined ecosystem called PNCIMA[3]. The study used 10 key populations and 19 background taxa; POP was treated as a separate background taxon. The OSMOSE model focused on a pelagic group of species that included Pacific Herring, Walleye Pollock, and Pacific Cod; however, the model could be applied to other functional groups.

GFBioSQL reports the stomach contents of POP as 72% euphausiids, 13% amphipods, 9% squids, 1% jellyfish, 1% invertebrates, and trace amounts of shrimp, herring, and other fish. Love et al. (2002) reported that POP pelagic juveniles eat primarily copepods, while the adults consume krill, mysids, amphipods, and midwater fish (smelts, lanternfish). Conversely, POP are preyed upon by Northern Fur Seals while the pelagic juveniles are eaten by albacore (Love et all. 2002).

Based on three observations out of 182 female specimens, Stanley and Kronlund (2005) observed that gonads of Silvergray Rockfish (*S. brevispinis*) infected with the copepod parasite, *Sarcotaces arcticus*, were smaller than those of similarly aged fish, and surmised that infected females were less fecund. Current research is exploring the relationship between coelomic

[3] Pacific North Coast Integrated Management Area – encompasses Queen Charlotte Sound, Hecate Strait, Dixon Entrance , and the west coast of Haida Gwaii.

infection by parasites and fecundity/maturity for POP (Matthew Siegle, PBS, DFO, pers. comm. 2024).

G.4. ENVIRONMENTAL EFFECTS

Various environmental indices were explored by Edwards et al. in Appendix F of Haigh et al. (2018) for Pacific Ocean Perch (POP). The working hypothesis was that the release of POP larvae in February-March would be influenced by winter environmental conditions (e.g., eddy movement, upwelling, wind circulation, water transport). They adopted the period December to March to represent winter in the various environmental indices explored.

One of the most commonly used indices is the Pacific Decadal Oscillation (PDO), which was defined in Haigh et al. (2018) as:

> *"the first mode of an Empirical Orthogonal Function (EOF) analysis of gridded sea surface temperature in the North Pacific (Zhang et al. 1997 and reported in Mantua et al. 1997). The PDO represents sea surface temperature and sea surface height anomalies in the North Pacific and is connected to the El Niño Southern Oscillation (ENSO, Alexander et al., 2002; Newman et al., 2003)."*

A negative phase of the PDO is associated with cold temperatures in the eastern North Pacific (Mantua et al. 1997) and a weak Aleutian Low (Di Lorenzo et al. 2010, 2013). NOAA Fisheries often refer to cooler waters with higher dissolved oxygen as 'minty', and associate these conditions with strong recruitment events (Schroeder et al. 2019).

While the PDO index series has shown congruity with marine populations on the scale of the NE Pacific basin (e.g., Alaskan salmon, Mantua et al. 1997), other indices are perhaps more relevant to populations that occupy smaller scales. For instance, the Aleutian Low Pressure Index was used to identify a regime shift in 1977 that increased the recruitment success of BC Sablefish (King et al. 2000). At lower trophic levels, an upwelling index at 54°N was better correlated than PDO with primary production along the BC shelf (Preikshot 2005).

Thompson et al. (2022) used a spatiotemporal multispecies model that evaluated species density and total biomass with a suite of environmental predictor variables; however, for POP, depth was the most important explanatory covariate. Thompson et al. (2022) also noted that overall species density and biomass had increased along the BC coast from 2003 to 2018, and attributed it to a reduction in fishing pressure. The trend for POP was flat with little contrast.

G.5. GENETIC DISTRIBUTION

Withler et al. (2001) identified three populations of POP in BC waters based on five genetic markers (microsatellite loci) : Vancouver Island (western side), eastern Queen Charlotte Islands (QCI, now Haida Gwaii), and western QCI. Eastern QCI samples were taken from Goose Island Gully and northern Moresby Gully while western QCI samples were taken from southern Moresby Gully, Flamingo Inlet, and Rennell Sound. The latter two populations appeared to coexist in the Langara region off the NW corner of Haida Gwaii and in Moresby Gully.

A more recent study by Wes Larson (Alaska Fisheries Science Center, NOAA, pers. comm. 2023), using single nucleotide polymorphisms (SNPs), shows four clusters in the NE Pacific Ocean off North America, with clusters A, C, and D predominating in the Bering Sea and Aleutian Islands while cluster B is the predominant cluster off Washington and Oregon. The central Gulf of Alaska acts as a mixing area for all four clusters. The expectation is that BC will be a mixture of B subgroups (B1–B4) or ecotypes (adapted to local environmental conditions) rather than taxonomic subspecies.

G.6. ADVICE FOR MANAGERS

There is potential for environmental indicators to be incorporated into stock assessment models. Andrew Edwards (DFO, pers. comm. 2021) secured three years funding for a project entitled '*Incorporating environmental information into management advice by understanding historical declines of Pacific Herring and recent increases of Bocaccio*'. It will build on work in Edwards et al. (2017) and Haigh et al. (2018) while using the framework of the Gulf of St. Lawrence Ecosystem Approach project.

The modelling platform Stock Synthesis 3 (SS3) has a few methods for including environmental effects into the recruitment estimation process function (Methot et al. 2021). However, the SS3 authors provide the following advice:

> *"The preferred approach to including environmental effects on recruitment is not to use the environmental effect in the direct calculation of the expected level of recruitment. Instead, the environmental data would be used as if it were a survey observation of the recruitment deviation."*

(Methot, pers. comm. 2021)

Starr and Haigh (2023) tried both methods in a Canary Rockfish model, focusing on the latter, and found that the influence of the environmental index depended on how much weight was applied to the series (through adding various levels of process error to the index).

In future stock assessments, adding environmental data can be explored, but will be necessarily constrained by the modelling platform implementation. Alternatively, geospatial indices for the synoptic surveys are being developed to include more environmental factors (specifically, temperature and perhaps oxygen, Sean Anderson, DFO, pers. comm. 2022). The factors are largely limited by data that are collected by instruments deployed alongside trawl tows, but might also include measurements derived from satellites or oceanic/atmospheric models. This work could be used to inform analysts of the covariates that affect the distribution or apparent catchability of the species. This highlights the other major limitation to this type of analysis which is the lack of supporting work to identify environmental covariates that would be expected to affect recruitment or catchability, rather than selecting series without real understanding of their potential impact.

G.7. REFERENCES – ECOSYSTEM

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