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Pacific Ocean Perch (*Sebastes alutus*) stock assessment for the north and west coasts of Haida Gwaii, British Columbia

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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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TABLE OF CONTENTS

ABSTRACT

Pacific Ocean Perch (*Sebastes alutus*, POP) is a commercially important species of rockfish that inhabits the marine canyons along the coast of British Columbia. The status of POP off the north and west coasts of Haida Gwaii, British Columbia, is assessed here under the assumption of a single stock harvested entirely in Pacific Marine Fisheries Commission (PMFC) major areas 5D and 5E. This is the first time that a population model has been used to assess this stock.

We used an annual two-sex catch-at-age model tuned to: one fishery-independent trawl survey series, annual estimates of commercial catch since 1940, and age composition data from the commercial fishery (29 years of data) and from the survey series (five years of data). The model starts from an assumed unfished equilibrium state in 1940, and the survey data cover five of the years from 1997 to 2010. The model was implemented in a Bayesian framework (using the Markov Chain Monte Carlo procedure) to quantify uncertainty of estimated quantities.

Estimated exploitation rates were calculated as the ratio of total catch to the vulnerable biomass in the middle of each year. Rates peaked in the late-1960s due to large catches by foreign fleets, and peaked again at higher values in the mid-1980s, coincident with an overfishing experiment operating in the Langara Spit region of area 5E. The exploitation rate for 2012 is estimated to be 0.053 (0.023-0.119), denoting median and 5th and 95th quantiles of the Bayesian posterior distribution.

The spawning biomass (mature females only) at the beginning of 2013 is estimated to be 0.37 (0.16-0.67) of unfished spawning biomass. It is estimated to be 1.61 (0.57-3.57) of B_{MSY}, where B_{MSY} is the equilibrium spawning biomass that would support the maximum sustainable yield (MSY). There was estimated to have been an exceptionally strong recruitment of age-1 fish in 1977.

Advice to managers is presented as a set of decision tables that provide probabilities of exceeding limit and upper stock reference points for ten-year projections across a range of constant catch scenarios. The primary reference points used are a limit reference point of $0.4B_{\mathrm{MSY}}$ and an upper stock reference point of $0.8B_{\mathrm{MSY}}$, which are the Fisheries and Oceans Canada Precautionary Approach provisional reference points. Decision tables are also presented with respect to alternative reference points based on proportions of unfished equilibrium biomass, on current biomass and on the exploitation rate at MSY.

The estimated spawning biomass at the beginning of 2013 has a 0.98 probability of being above the limit reference point of $0.4B_{\mathrm{MSY}}$, and a 0.88 probability of being above the upper stock reference point of $0.8B_{\mathrm{MSY}}$.

The estimated median MSY (tonnes) is 1,488 (998-2,258), compared to the recent mean catch (from 2007-2011) of 937 t. The probability that the exploitation rate in 2012 is below that associated with MSY is 0.84.

Ten-year projections, for constant catches of 1,000 t (slightly above the recent mean catch), indicate essentially no change in the aforementioned probabilities of the spawning biomass being above the reference points.

Évaluation des stocks de sébaste à longue mâchoire (*Sebastes alutus*) sur les côtes nord et ouest de l'archipel Haida Gwaii, en Colombie-Britannique

RÉSUMÉ

Le sébaste à longue mâchoire (*Sebastes alutus*) est une espèce commerciale de sébaste importante qui fréquente les canyons marins le long de la côte de la Colombie-Britannique. On a évalué l'état des stocks de sébaste à longue mâchoire au large des côtes nord et ouest de l'archipel Haida Gwaii, en Colombie-Britannique, en présupposant l'existence d'un seul stock exploité entièrement dans les zones principales 5D et 5E de la Commission des pêches maritimes du Pacifique (CPMP). C'est la première fois qu'un modèle de population est utilisé pour évaluer ce stock.

Nous avons utilisé un modèle des deux sexes fondé sur les prises selon l'âge syntonisé avec : les données d'une série de relevés au chalut indépendants de la pêche; des estimations annuelles des prises commerciales depuis 1940; des données sur la composition selon l'âge de la pêche commerciale (données obtenues sur une période de 29 ans) et de la série de relevés (données obtenues sur une période de 5 ans). Le modèle part de l'hypothèse d'un état d'équilibre non exploité en 1940 et les données dérivées de relevés couvrent 5 années de la période de 1997 à 2010. Ce modèle a été utilisé dans un cadre d'évaluation bayesienne (à l'aide de la méthode de Monte-Carlo par chaîne de Markov) pour quantifier les incertitudes entourant les quantités estimées.

Les taux d'exploitation estimés ont été calculés en divisant les prises totales par la biomasse vulnérable au milieu de l'année. Les taux ont atteint un pic à la fin des années 1960 en raison du nombre considérable de prises effectuées par les flottes étrangères; il y a eu de nouveaux pics au milieu des années 1980 au même moment qu'une expérience de surpêche qui s'est déroulée dans la région de l'île Langara de la zone 5E. Le taux d'exploitation de 2012 a été estimé à 0,053 (0,023-0,119); ces chiffres indiquent respectivement la valeur médiane ainsi que les quantiles d'ordre 5 et 95 de la distribution bayésienne a posteriori.

On estime la biomasse reproductrice (femelles adultes uniquement) au début de 2013 à 0,37 (0,16-0,67) de la biomasse reproductrice non exploitée. Sa valeur estimée est de 1,61 (0,57-3,57) de B_{PMS}, où B_{PMS} représente la biomasse reproductrice à l'équilibre qui soutiendrait la production maximale soutenable (PMS). Selon les estimations, le recrutement de poissons d'âge 1 a été exceptionnellement élevé en 1977.

Les avis à l'intention des gestionnaires sont présentés sous la forme de tables de décision qui indiquent les probabilités de dépasser le niveau de référence limite et le niveau de référence supérieur du stock pour des projections décennales réalisées à partir d'un éventail de scénarios de prises constantes. Les principaux niveaux de référence utilisés sont un niveau de référence limite de $0{,}4B_{\text{PMS}}$ et un niveau de référence supérieur de $0{,}8B_{\text{PMS}}$, qui constituent les niveaux de référence provisoires de l'approche de précaution de Pêches et Océans Canada. On présente aussi des tables de décision avec d'autres niveaux de référence biomasse fondés sur des proportions de la biomasse d'équilibre non exploitée, la biomasse actuelle et le taux d'exploitation en fonction de la PMS.

La probabilité pour que la biomasse reproductrice estimée au début de 2013 a une probabilité de 0,98 de dépasser le niveau de référence limite de 0,4B_{PMS} et une probabilité de 0,88 de dépasser le niveau de référence supérieur de 0,8B_{PMS}.

La médiane de la PMS estimée est de 1 488 tonnes (998 t-2258 t) tandis que les prises moyennes récentes (de 2007 à 2011) s'élevaient à 937 t. La probabilité pour que le taux d'exploitation en 2012 soit inférieur à celui qui est associé à la PMS s'établit à 0,84.

Les projections décennales pour des prises constantes de 1 000 t (chiffre légèrement au-dessus des prises moyennes récentes) indiquent que les probabilités pour que la biomasse reproductrice se situe au-dessus des niveaux de référence sont fondamentalement les mêmes que nous venons de mentionner ci-dessus.

1 INTRODUCTION

This stock assessment is for Pacific Ocean Perch in combined Pacific Marine Fisheries Commission (PMFC) major areas 5D and 5E, off the north and west coasts of Haida Gwaii, British Columbia (Figure 1). A concurrent stock assessment for Pacific Ocean Perch in PMFC major areas 3C and 3D, off the coast of Vancouver Island, is documented in Edwards et al. (2013). The same modelling approach is used for both stocks. Given that almost all the input data and all the results are different for the two stocks, it was deemed preferable to produce two independent stand-alone documents rather than one larger one, although there will inevitably be some overlap between the two documents. Some background information is taken from Edwards et al. (2012*b*).

This main section presents background information, an overview of the assessment model and input data, the main model results and the advice to managers. Further technical details are given in the relevant Appendices.

1.1 BIOLOGICAL BACKGROUND

Pacific Ocean Perch (*Sebastes alutus*, POP) is a long-lived, commercially important species of rockfish found along the rim of the North Pacific Ocean. Its commercial attractiveness stems from its bright red colour and long shelf life when properly processed. It is also 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 release of larvae that spend periods ranging from about three to twelve months as free-swimming pelagic larvae before settling to the bottom as juveniles. 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 on benthic habitat (Kendall Jr. and Lenarz, 1986). 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 known age appears to be 103 y for a female specimen from Moresby Gully at 364 m in 2002, from the Department of Fisheries and Oceans Canada (DFO) Groundfish database GFBio (Edwards et al., 2012*b*).

1.2 RANGE AND DISTRIBUTION

Pacific Ocean Perch occurs along the North Pacific rim, ranging from Honshu (Japan), through the Bering Sea, along the Aleutian Islands (Alaska), then southward through BC down to central Baja California (Love et al., 2002). The species appears to be most abundant north of 50° N (Allen and Smith, 1988). In BC (Figure 2), hotspots ($\geq$ the 0.95 quantile of catch per unit effort

(CPUE) from trawl tows from 1996-2012) occur southeast of Moresby Island (Moresby Gully), southwest of Moresby Island (Anthony Island), northwest of Graham Island (Langara Spit), and in Dixon Entrance north of Graham Island. Pacific Ocean Perch has been encountered by the BC trawl fleet over an estimated 46,240 km^2 (Figure 2). For PMFC areas 5D and 5E, 98% of the commercial trawl captures of POP lie between depths 104 m and 530 m (based on starting depths of tows; Appendix H).

1.3 OVERVIEW OF FISHERY

Pacific Ocean Perch supports the largest rockfish fishery in British Columbia (BC) with an annual coastwide TAC (total allowable catch) of 5,448 t in 2010, which is being progressively reduced to 5,189 t over three years (see Appendix B). The mean annual coastwide catch from 2006-2010 was about 5,000 t and the mean coastwide landed value of the POP catch from 2007-2010 was $4.4 million (landed value data from D. Lau, DFO Economics Sector). The trawl fishery accounts for 99.98% of the coastwide TAC, with the rest allocated to the hook and line fishery. A detailed history of the POP fishery prior to the inception of the observer trawl program in 1996 can be found in Richards and Olsen (1996).

2 ASSESSMENT BOUNDARIES AND BACKGROUND

For this assessment, we use PMFC major areas 5D and 5E (herein referred to as area 5DE), covering the north and west coasts of Haida Gwaii (and the northern part of the east coast; Figure 1). This choice of areas was requested by the DFO Groundfish Management Unit (Appendix A), and assumes that there is a single stock harvested entirely in area 5DE. The PMFC areas are similar but not identical to the groundfish management areas (GMAs) used by the DFO Groundfish Management Unit; those areas (Figure 1) are more attuned to the pattern of fishing for a range of demersal species. We have not used the GMAs because reporting from these areas has only been available since 1996 and there is no procedure to alter historical landings to conform to current boundaries.

The GMA area 5E differs from PMFC area 5E, with GMA 5C incorporating fishing locations on the west side of Moresby Island that are included in PMFC area 5E (Figure 1). The earlier POP assessment for Queen Charlotte Sound (Edwards et al., 2012*b*) was based on PMFC area 5ABC, and so did not include catches from such locations; these catches are included here.

The TAC for GMA 5CD in 2012 is 1,856 t, and the TAC for GMA 5E has been 730 t since 1998 (Table B.1). The mean catch from 2007-2011 in PMFC area 5DE was 937 t.

This is the first quantitative stock assessment for the stock of POP in area 5DE. The most recent POP assessment for BC waters considered only Queen Charlotte Sound (QCS, combined PMFC area 5ABC, Edwards et al. 2012*b*), the primary fishing grounds for POP. Earlier population modelling for POP (Schnute and Richards, 1995; Richards and Schnute, 1998; Schnute et al., 2001) focused on Goose Island Gully, one of the three main gullies in QCS. Schnute et al. (2001) extended their results to the rest of the BC coast.

We follow several recent west coast Canadian rockfish assessments (Stanley et al., 2009;

Edwards et al., 2012*a*,*b*) in using a modified version of the Coleraine statistical catch-at-age software (Hilborn et al., 2003), called Awatea, to implement the model (Appendix F). The model is an annual two-sex catch-at-age model tuned to: one fishery-independent trawl survey series, annual estimates of commercial catch since 1940, and age composition data from the commercial fishery (29 years of data) and from the survey series (five years of data).

The model estimates parameters from the stock-recruitment function, natural mortality (independently for females and males), the catchability coefficient for the survey series, and selectivity parameters for the commercial fishery and the survey series.

The model is used to estimate the past and present vulnerable biomass (the biomass that is vulnerable to capture by the fishery, taking into account selectivity), spawning stock biomass (mature females only) and population age structure. Estimated parameters are then used to calculate maximum sustainable yield (MSY) and reference points. Projections are performed to estimate future probabilities of the spawning biomass being greater than the reference points under a range of constant catch scenarios. All of these calculations are made in a Bayesian context to capture the uncertainty associated with parameter estimation. Uncertainty relative to some data sets is explored through two sensitivity runs (Appendix I).

Advice for managers was requested (see Appendix A) to be guided by the DFO Sustainable Fisheries Framework, particularly the Fishery Decision-making Framework Incorporating the Precautionary Approach (DFO, 2009). Consequently, advice to managers is presented as a set of decision tables that provide probabilities of exceeding reference points for various years of projections across a range of constant catch scenarios.

A DFO Technical Working Group provided valuable guidance with respect to many of the decisions that were made in the course of this work.

3 CATCH DATA

The preparation methods and the full catch history for this assessment are given in Appendix B. Catches were estimated back to 1940. Poorly reported historical catches by foreign fleets were reconstructed based on sparse historical sampling data, and minor catches from other capture methods have been added to the totals. All available discard estimates were added to the catches, with estimates of historical discards based on current observed levels. The resulting time series of catch data that is used as model input is shown in Figure B.2, and reaches a peak of 8,683 t in 1966 (during a period of intense fishing by Russian and Japanese fleets); the recent (2007-2011) average catch is 937 t. Catch data were only available for part of 2012, and so, for input to the model, the 2012 catch total was assumed to be the same as for 2011. Information about other species caught concurrently with POP commercial catches is presented in Appendix H.

4 FISHERIES MANAGEMENT

Appendix B summarises all management actions taken for POP (coastwide) since 1979. In particular, there has been a 100% onboard observer program for the offshore trawl fleet since 1996, and Individual Vessel Quota management for TAC trawl species has been in place since 1997. There was a recent reduction in the combined GMA 5ABCD total allowable catch (from 4,188 t to 3,413 t, implemented progressively over three years), that was put in place in response to the QCS POP stock assessment (Edwards et al., 2012*b*) conducted in 2010.

5 OVERFISHING EXPERIMENTS

In the 1980s, experimental overfishing 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 west coast of Vancouver Island. The second occurred in the Langara Spit area (north of 54° and west of 133°) of PMFC area 5E off the west coast of Haida Gwaii (WCHG). This experiment removed quota limits 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). Discussions involving harvesters, politicians, and DFO managers (excluding the original researchers) negotiated extensions of the fishery, but eventually the Langara Spit area was closed in 1993. Examination of the data from the DFO GFCatch database shows that catches were reported from the Langara Spit area only from 1984-1990.

6 SURVEY DESCRIPTIONS

Only one set of fishery independent survey indices was available to track changes in the biomass of the 5DE stock (Appendix C). This was a “synoptic” survey, targetting a wide range of demersal species and covering the west coast of Graham Island in Haida Gwaii and western part of Dixon Entrance, and was conducted in 2006, 2007, 2008 and 2010. A fifth survey, conducted in August-September 2012, was not completed in time for inclusion in this assessment. A sixth survey, conducted in September 1997 over a similar depth range and primarily off the north and west coasts of Graham Island, was included as an additional observation in the same series. This latter survey used a design similar to the one used for the “synoptic” surveys and was restratified to match the three depth strata used for the “synoptic” series. The resulting series is referred to here as the ‘WCHG synoptic survey series’.

The relative biomass survey indices are used as data in the model along with the associated relative error for each index value. See Appendix C for justification of inclusion or exclusion of survey data.

Pre-1996 commercial catch and effort data were also investigated with the intent of creating CPUE-based abundance indices for use in the stock assessment model. This approach was abandoned because it was felt that there were problems with the reliability of the data as well as questions as to the representative nature of the resulting indices, given the schooling behaviour of the species and the capacity of fishers to target these schools. Given the concern that the resulting indices would be hyperstable, they were not used in this assessment.

7 BIOLOGICAL INFORMATION

7.1 BIOLOGICAL SAMPLES

Commercial catches of rockfish by trawl gear have been sampled for age proportions since the 1960s. However, only POP otoliths aged using the 'break and burn' method have been included in the age samples for this assessment because the earlier surface ageing method is known to be biased (Beamish, 1979), especially with increasing age. Practically, this means that no usable age data were available for this assessment prior to 1978. Commercial fishery age samples were summarised for each quarter, with samples combined within a trip and weighted by the POP catch weight for the sampled trip. The quarterly samples were then scaled by the quarterly landed commercial catch weights to give annual proportions-at-age data (details are in Appendix E; Table F.1 gives the years of data).

Survey age samples were only available from the WCHG synoptic survey series for 1997, 2006, 2007, 2008 and 2010. These samples were scaled by catch density of sampled tows within a stratum and by stratum areas between strata (see Appendix E).

7.2 GROWTH PARAMETERS

Growth parameters for both sexes were taken from the POP QCS assessment (Edwards et al., 2012*b*), which estimated parameters from biological samples collected from 1978 to 2009 by research surveys and from the commercial fishery (Appendix D). Estimates of growth parameters were compared across the major assessment areas (3CD, 5ABC and 5DE) and across sample origins (research and commercial), and found to be consistent in all comparisons (Edwards et al., 2012*b*). Consequently, the same sex-specific growth parameters have been used for all three assessment areas, with sex-specific growth specified as a three-parameter von Bertalanffy model that estimates length-at-age. Weights-at-age, used to convert population numbers to biomass, were given by an allometric length-weight relationship. See Appendix D for details.

7.3 MATURITY AND FECUNDITY

The maturity ogive was also taken from Edwards et al. (2012*b*). Stage of maturity was determined macroscopically, partitioning the samples into one of seven maturity stages (Stanley and Kronlund, 2000) during the months of January to June. The analysis was restricted to this period because it is the period of maximum expected maturity. Fish assigned to stages 1 or 2 were considered immature while those assigned to stages 3-7 were considered mature. Data representing staged and aged females (using the break and burn method) were pooled from all sampling sources and the observed proportion mature at each age was calculated, and a model fitted (see Appendix D). Fecundity was assumed to be proportional to the female body weight.

7.4 NATURAL MORTALITY

Male and female natural mortalities were estimated as parameters of the model (see Appendix F), using an informed prior based on the marginal posterior distributions from the QCS POP assessment (Edwards et al., 2012*b*), specifically a normal prior with mean 0.07 and standard deviation 0.007 for both sexes (see Appendix F). The QCS assessment used a prior based on a POP assessment for the Gulf of Alaska (Hanselman et al., 2009), with mean 0.06 and standard deviation 0.006.

In recent assessments (Edwards et al., 2012*a*,*b*), model runs that fixed natural mortality were also used to provide the final advice to managers. However, because we were able to develop a prior based on Canadian POP data, and since the resulting Bayesian estimates of natural mortality and steepness (defined below) are uncorrelated (Appendix G), only runs that estimate natural mortality are used in this assessment (as agreed upon by the Technical Working Group). Prior distributions for all estimated parameters are given in Table F.4.

7.5 STEEPNESS

A Beverton-Holt stock-recruitment function was used to generate average recruitment estimates in each year, based on the biomass of female spawners (Appendix F). Recruitments, defined as numbers of age-1 fish, were allowed to deviate from this average in order to improve the fit of the model to the data, constrained by an assumed recruitment standard deviation. The Beverton-Holt function was parameterised using a steepness parameter, h, which specified the proportion of the maximum recruitment that was available at $0.2B_0$, where B_0 is the unexploited equilibrium spawning biomass (mature females). The parameter h was estimated in all model runs, constrained by a prior developed for west coast rockfish by Forrest et al. (2010), after removing all information for QCS POP (R. Forrest, DFO, pers. comm.). This prior took the form of a beta distribution with mean 0.674 and standard deviation 0.168. This approach is the same as that in our previous rockfish assessments (Edwards et al., 2012*a*,*b*).

8 AGE-STRUCTURED MODEL

A two-sex, age-structured stochastic model was used to reconstruct the population trajectory of POP in area 5DE from 1940 to the beginning of 2013. Although no ageing or survey data were available for 2012 (and the 2012 catch was set to the 2011 value), the model was run to the beginning of 2013 for consistency with the companion assessment for area 3CD (Edwards et al., 2013). Ages were tracked from 1 to 30, with 30 being an accumulator age class, as for the companion assessment (Edwards et al., 2013) and the earlier Goose Island Gully POP assessment by Schnute et al. (2001).

The population at the beginning of the reconstruction was assumed to be in equilibrium with average recruitment and no fishing. Selectivities by sex for the commercial fishery and the survey were estimated using three parameters describing a half-Gaussian function (that is set to 1 above a certain age). The model equations and implementation are described in Appendix F.

The model was fit to the available data by minimising a function that summed the negative log-likelihoods arising from each data set, the deviations from mean recruitment and the penalties stemming from the Bayesian priors. The resulting MPD (mode of the posterior distribution) ‘best fit’ was used as the starting point for the Bayesian search across the joint posterior distributions of the parameters using the Monte Carlo Markov Chain (MCMC) procedure.

The MCMC procedure was run for 10,000,000 iterations, sampling every 10,000th, to give 1,000 samples. These samples were used to estimate parameters and quantities of interest, including stock sizes and the probabilities of being above reference points.

Initial model fits to the data gave sensible and consistent results. Numerous sensitivity runs that systematically explored the effect of different components of the data on model results did not seem justified, given the small amount of available abundance data when spread over the long period of stock reconstruction (particularly for the early years).

Two sensitivity runs are presented in Appendix I, with one dropping the 1997 Ocean Selector survey index along with its associated age composition data from the WCHG synoptic survey series, and the other exploring possible systematic catch over-reporting in the Langara Spit experimental fishery from 1984 to 1989.

We did not explore ageing error. Such a sensitivity run was conducted for the Yellowmouth Rockfish assessment (Edwards et al., 2012*a*), with the conclusion that a full investigation of ageing error would require an independent dedicated analysis, which was beyond the capacity of the current assessment.

9 RESULTS

The base case model run had credible fits to the data, as demonstrated by visual examination of the MPD fits and the patterns of residuals (results in Appendix G). The MCMC diagnostics showed satisfactory convergence of the MCMC search procedure (Appendix G). Priors and marginal posteriors of the estimated parameters are also given in Appendix G, along with the values of the estimated parameters (Table G.2). For example, natural mortality is estimated as having median (and 5-95% credible interval) of 0.063 (0.055-0.073) for females and 0.076 (0.067-0.085) for males. Such a difference between sexes did not occur for either the POP QCS assessment (Edwards et al., 2012*b*) or the companion POP assessment for area 3CD (Edwards et al., 2013). Steepness is estimated to be 0.79 (0.55-0.94). The remaining MCMC results, of more general interest, are given here.

Figure 3 shows the MCMC results for the vulnerable biomass, together with the reconstructed historical catches, and Figure 4 shows the estimated medians of vulnerable and spawning (mature females) biomass relative to their unfished values. (The full MCMC results for spawning biomass are included later in Figure 9 regarding projections).

Figures 3 and 4 show an increasing trend in the estimated spawning and vulnerable biomass from about 1948 to 1965; the median of B_t/B_0 (spawning biomass at the start of year t, B_t, relative to the unfished equilibrium spawning biomass, B_0) peaks at 1.25 in 1965. This increase in biomass is the result of good recruitment (age-1 fish) in the early 1950s (Figure 5, and see the positive recruitment deviations in Figure G.14). The QCS assessment (Edwards et al., 2012*b*) identified even stronger year classes in the early 1950s; for area 5DE this cannot occur because of the lower accumulator age class of age 30, compared to age 60 used for QCS. The estimated increase in biomass is also likely to be a model response to the high levels of catch associated with foreign fishing observed in the 1960s.

Recruitment is estimated to have been below average through the 1960s and early 1970s (Figure 5), with a consequent drop in the estimated biomass over these two decades. The median of B_t/B_0 reached an overall minimum of 0.28 in 1987 (Figure 4), then increased to 0.41 in 2000, and has since declined to 0.37 in 2013.

The increase in estimated biomass from 1988 was caused by the exceptional recruitment of age-1 fish in 1977 (Figure 5). The estimated recruitment in 1977 has a median of 27,846 (1,000s of age-1 fish), more than five times larger than the long-term mean (of all the median recruitments) of 4,851. The minimum median recruitment of 1,383 was reached in 1974; thus, the median in 1977 was over 20 times the value three years before.

A similar exceptional 1977 recruitment event was estimated for the QCS area 5ABC stock (Figure 5 of Edwards et al. 2012*b*), which also estimated good recruitment in 1978 and 1981 (similar to Figure 5). In the companion assessment for the more southerly area 3CD (Edwards et al., 2013), the recruitment in 1977 was high but it was by no means as exceptional as for the other two areas (and higher values were attained in four subsequent years).

Estimates (with credible intervals) of various quantities of interest are given in Table 1. In particular, the median (and 5-95% credible interval) for B_{2013}/B_0, the ratio of current spawning biomass (B_{2013}) to B_0 is 0.37 (0.16-0.67).

The estimated exploitation rates (ratio of total catch to the vulnerable biomass in the middle of the year; Figure 6) reached a median near 0.15 in 1966, associated with high catches by the foreign fleets. The exploitation rate peaked in the mid-1980s (maximum median of 0.19, reached in 1984), caused by the high catches associated with the experimental Langara Spit fishery. These catches were not as large as the foreign fleet catches observed in the 1960s, but the biomass was lower by then. Exploitation rates declined from the early 1990s with the end of the Langara Spit fishery and the introduction of controlled fishing in 1996. Median exploitation rates rose to near 0.05 in 2000, and then decreased and increased, with the exploitation rate for 2012, u_{2012}, estimated to be 0.053 (0.023-0.119).

Estimates of further quantities of interest, such as absolute values of biomass (rather than relative values), are also given in Table 1, as well as quantities based on MSY, discussed below.

10 ADVICE FOR MANAGERS

10.1 CURRENT STOCK LEVEL

The estimated median MSY (with 5-95% credible interval, tonnes) is 1,488 (998-2,258), compared to the mean catch over the last five years (2007-2011) of 937 t. The MSY is calculated as an equilibrium yield under constant average recruitment.

The estimated ratio $B_{2013}/B_{\mathrm{MSY}}$ of spawning biomass (mature females only) at the start of 2013 (B_{2013}) to the equilibrium spawning biomass that will support the maximum sustainable yield (B_{MSY}), is 1.61 (0.57-3.57).

As noted above, B_{2013}/B_0, the ratio of current spawning biomass to the unfished equilibrium level, is 0.37 (0.16-0.67). The estimate of the ratio B_{MSY}/B_0 is 0.23 (0.15-0.33).

10.2 REFERENCE POINTS

Decision tables are presented with respect to two sets of reference points as determined from consultation with N. Davis (DFO Groundfish Management Unit, pers. comm.); see below for rationale for the reference points. Each set is based on either B_{MSY} or B_0. Decision tables are also given with respect to additional reference points based on current biomass and u_{MSY}. All reference points and the associated probabilities were derived from the posterior distributions of Bayesian output from the model.

As part of the Sustainable Fisheries Framework, DFO (2009) suggested provisional reference points to guide management and to assess harvest in relation to sustainability. Because alternative reference points for Canadian west coast groundfish species have not been specified by policy, the suggested provisional DFO limit and upper stock reference points of $0.4B_{\mathrm{MSY}}$ and $0.8B_{\mathrm{MSY}}$ have been adopted here. These were the reference points used for the POP stock in QCS (Edwards et al., 2012*b*). Note that no modelling has been carried out to determine the suitability of these reference points for these stocks, nor have acceptable levels of risk been specified.

The zone below the limit reference point ($0.4B_{\mathrm{MSY}}$) is termed the "critical zone" while the zone lying between the two reference points is termed the "cautious zone". The region above the upper stock reference point ($0.8B_{\mathrm{MSY}}$) is termed the "healthy zone". B_{MSY} is also reported here as an additional reference point because it "provides a useful basis for comparing stocks" (Ricard et al., 2011) when conducting meta-analyses of assessment results.

Figure 7 shows the distribution of $B_{2013}/B_{\mathrm{MSY}}$ relative to the reference points of $0.4B_{\mathrm{MSY}}$ and $0.8B_{\mathrm{MSY}}$. The stock is estimated to be currently above the critical zone with probability P$(B_{2013} > 0.4B_{\mathrm{MSY}}) = 0.98$, and in the healthy zone with probability P$(B_{2013} > 0.8B_{\mathrm{MSY}}) = 0.88$. For comparison, Figure 7 also shows the status of the other two POP stocks, where the status for the 5ABC stock is based on a different year.

A second component of the provisional harvest rule of DFO (2009) concerns the relationship of the exploitation rate relative to that associated with MSY under equilibrium conditions (u_{MSY}).

The rule specifies that the exploitation rate should be at or below u_{MSY} when the stock is in the healthy zone, it should be ramped down when in the cautious zone, and it should be kept to an absolute minimum when in the critical zone. Figure 8 shows the exploitation rate in 2012 relative to that at u_{MSY} (red dot and vertical red line). The estimated ratio of $u_{2012}/u_{\mathrm{MSY}}$ is $0.48\ (0.17 - 1.70)$. The probability that the exploitation rate is below that associated with MSY is P$(u_{2012} < u_{\mathrm{MSY}}) = 0.84$.

The blue and grey circles in Figure 8 shows that, based on medians, the stock is estimated to have been in the healthy zone since the start of fishing (and the spawning biomass has always been $> B_{\mathrm{MSY}}$). The median exploitation rate has been $> u_{\mathrm{MSY}}$ for a total of seven years, with the most recent being 1989.

Other agencies and jurisdictions often use 'proxy' reference points that are expressed in terms of B_0 rather than B_{MSY} (e.g. New Zealand Ministry of Fisheries 2007, 2011), because B_{MSY} is dependent on a consistent fishery. Therefore, the reference points of $0.2B_0$ and $0.4B_0$ are also presented here (see decision tables described below), as for the Yellowmouth Rockfish assessment (Edwards et al., 2012*a*). These reference points are the respective default values used in New Zealand 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).

10.3 PROJECTION RESULTS AND DECISION TABLES

Projections were made to evaluate the future behaviour of the population under different levels of constant catch, given the model assumptions. The projections, starting with the biomass at the beginning of 2013, were made over a range of constant catch strategies (0-2,000 t in 250 t steps) for each of the 1,000 MCMC samples in the posterior. Future recruitments were generated through the stock-recruitment function using recruitment deviations drawn randomly from a lognormal distribution with zero mean and constant standard deviation (see Appendix F for full details). Projections were made for 10 years, as agreed upon with N. Davis (DFO Groundfish Management Unit, pers. comm.). This time frame was considered as long enough to satisfy the 'long-term' requirement of the Request for Science Information and Advice (Appendix A), yet short enough for the projected recruitments to be mainly based on individuals spawned before 2013 (and hence already estimated by the model, due to the approximate 10-year lag between spawning and recruitment to the fishery).

Resulting projections of spawning biomass are shown for selected catch strategies (Figure 9). For a constant catch of 1,000 t, above the recent (2007-2011) mean of 937 t, the median biomass is projected to increase over the 10-year time period.

Decision tables give the probabilities of the spawning biomass exceeding the reference points in specified years, for various constant catch strategies, calculated as the proportion of MCMC samples for which the biomass exceeded the given reference point. Note that catches are held constant, without feedback control simulation. Consequently, there is no ramping down of fishing mortality if the stock reaches the cautious or critical zones.

Results for the three B_{MSY}-based reference points are presented in Tables 2-4. As an example of how to read the tables, the estimated probability that the stock is in the provisional healthy zone in 2017 under a constant catch strategy of 1,000 t is P$(B_{2017} > 0.8B_{\mathrm{MSY}}) = 0.86$ (‘1000’ row and ‘2017’ column of Table 3). Results for the two B_0-based reference points are given in Tables 5 and 6.

For a constant catch of 1,000 t, above the average recent catch of 937 t, the probability of the stock remaining above the critical zone, P$(B_t > 0.4B_{\mathrm{MSY}})$, essentially remains constant and above 0.95 over the ten-year projections (‘1000’ row in Table 2). Similarly, the probability of remaining in the healthy zone, P$(B_t > 0.8B_{\mathrm{MSY}})$, remains constant and above 0.85 over the ten-year projections (Table 3).

The probabilities over time also essentially remain constant (for a catch of 1,000 t) for the reference point $0.2B_0$, as shown by P$(B_t > 0.2B_0)$ in Table 5. However, the probabilities of exceeding the reference point $0.4B_0$ increase over the 10 years from P$(B_{2013} > 0.4B_0) = 0.40$ to P$(B_{2023} > 0.4B_0) = 0.50$, Table 6.

Also given are two further tables of potential interest to management. Table 7 gives probabilities P$(B_t > B_{2013})$ for the projected spawning biomass to exceed the current spawning biomass. Table 8 gives probabilities P$(u_t > u_{\mathrm{MSY}})$ for the projected exploitation rate to exceed that at MSY.

The choice of which decision table to use depends on the current status of the stock, since the status will determine the objectives, which may be based on conservation, stock growth or fisheries catch.

11 GENERAL COMMENTS

This assessment depicts a slow-growing, low-productivity stock that, despite apparent heavy commercial fishing by foreign and domestic fleets, has remained above B_{MSY} (based on median values of spawning biomass) for the entire assessed period (Figure 8).

The stock produced an exceptionally strong recruitment (of age-1 fish) in 1977 (Figure 5), followed by good recruitment in 1978 and 1981. A similar pattern was seen in the POP assessment for area 5ABC (Edwards et al., 2012*b*).

Annual exploitation rates were highest in the mid-1960s and mid-1980s, coincident with high catches by the foreign fleet in the 1960s and the Langara Spit overfishing experiment in the 1980s. The current median exploitation rate is 0.053. This is less than the estimated median natural mortality rates of 0.063 (females) and 0.076 (males).

The spawning biomass (mature females only) at the beginning of 2013 is estimated to be 0.37 (0.16-0.67) of B_0 and 1.61 (0.57-3.57) of B_{MSY}. Using the DFO Precautionary Approach provisional reference points of $0.4B_{\mathrm{MSY}}$ and $0.8B_{\mathrm{MSY}}$ to delimit zones, the stock is estimated to be currently above the critical zone with probability P$(B_{2013} > 0.4B_{\mathrm{MSY}}) = 0.98$, and in the healthy zone with probability P$(B_{2013} > 0.8B_{\mathrm{MSY}}) = 0.88$.

The decision tables provide guidance on the selection of short-term TAC recommendations and describe the range of possible future outcomes over the projection period at fixed levels of annual catch. The accuracy of the projections is predicated on the model being correct and assumes no management intervention in the time period covered by the tables.

Uncertainty in the estimated parameters and quantities is explicitly addressed using a Bayesian approach, but reflects only the specified model and weights assigned to the various data components. Sensitivity runs provide some insight into model uncertainty. However, the sensitivity runs presented here do not differ greatly from the base run, indicating that model results are not substantially changed when catches during the 1980s are reduced, or the additional 1997 survey point is removed.

We expect that the results from the WCHG synoptic survey will continue to provide monitoring capability for this stock. Catches in the commercial groundfish fisheries are very well recorded. These ongoing initiatives give confidence that this stock is currently well monitored and that corrective action can be taken if required.

12 FUTURE RESEARCH AND DATA REQUIREMENTS

The following issues could 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 along the BC coast. This includes obtaining age and length composition samples, which will allow the estimation of survey-specific selectivity ogives.

2. Review and potentially improve the commercial sampling program for POP age composition with the goal of continuing the representative sampling of all fisheries that take significant amounts of POP.

3. Research how best to incorporate the uncertainty of ageing error into Canadian rockfish assessment models – the Sclerochronology Laboratory at the Pacific Biological Station currently records uncertainty for each aged otolith.

4. Investigate the effects of environmental variation on Pacific Ocean Perch recruitment, as a necessary first step to providing a framework that accounts for potential impacts of climate change when formulating advice to fisheries management.

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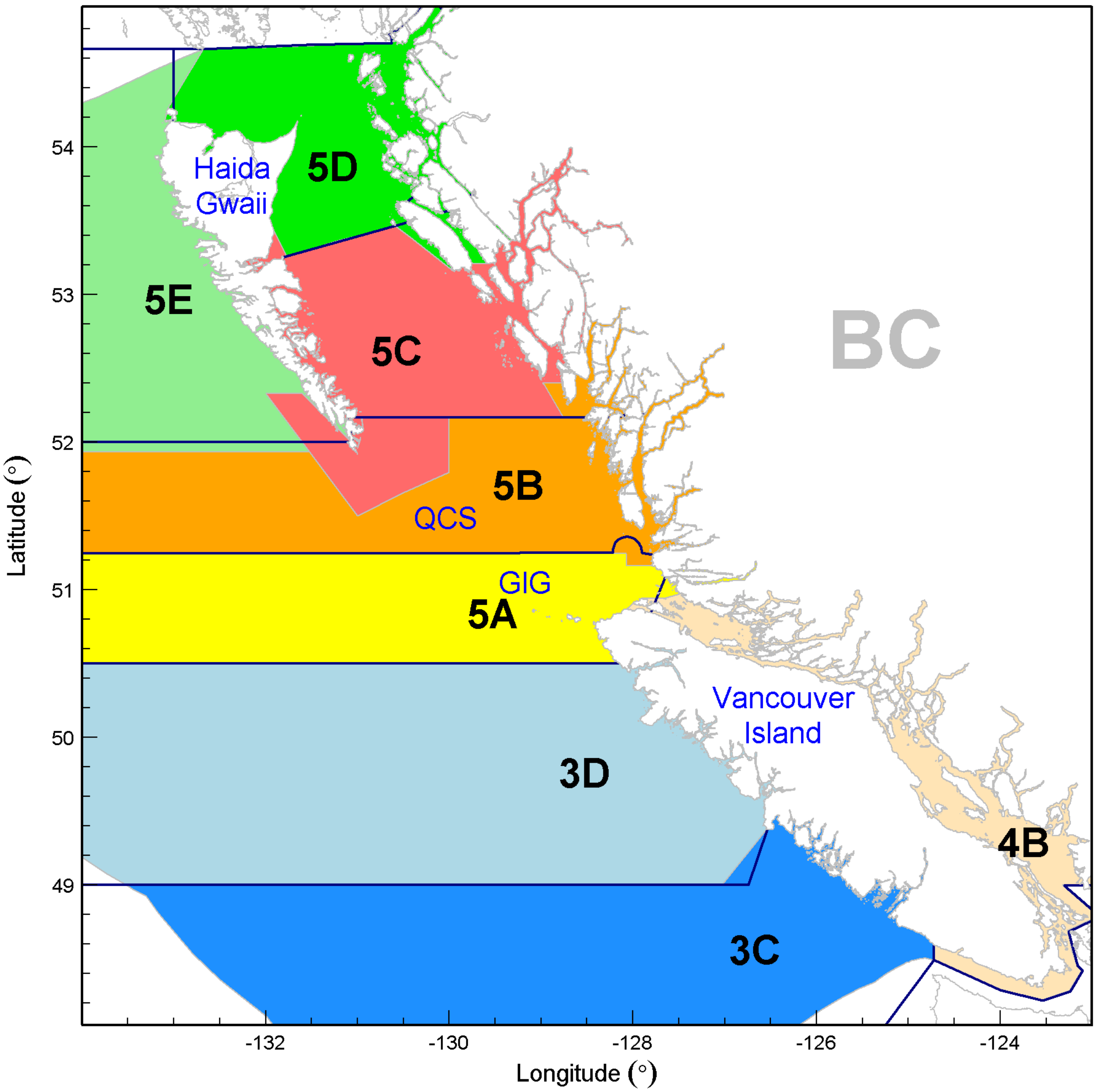

Figure 1. Pacific Marine Fisheries Commission (PMFC) major areas (outlined in dark blue) compared with Groundfish Management Unit areas for POP (shaded). For reference, map indicates Queen Charlotte Sound (QCS) and Goose Island Gully (GIG). This assessment is for the stock in PMFC areas 5D and 5E (termed area 5DE).

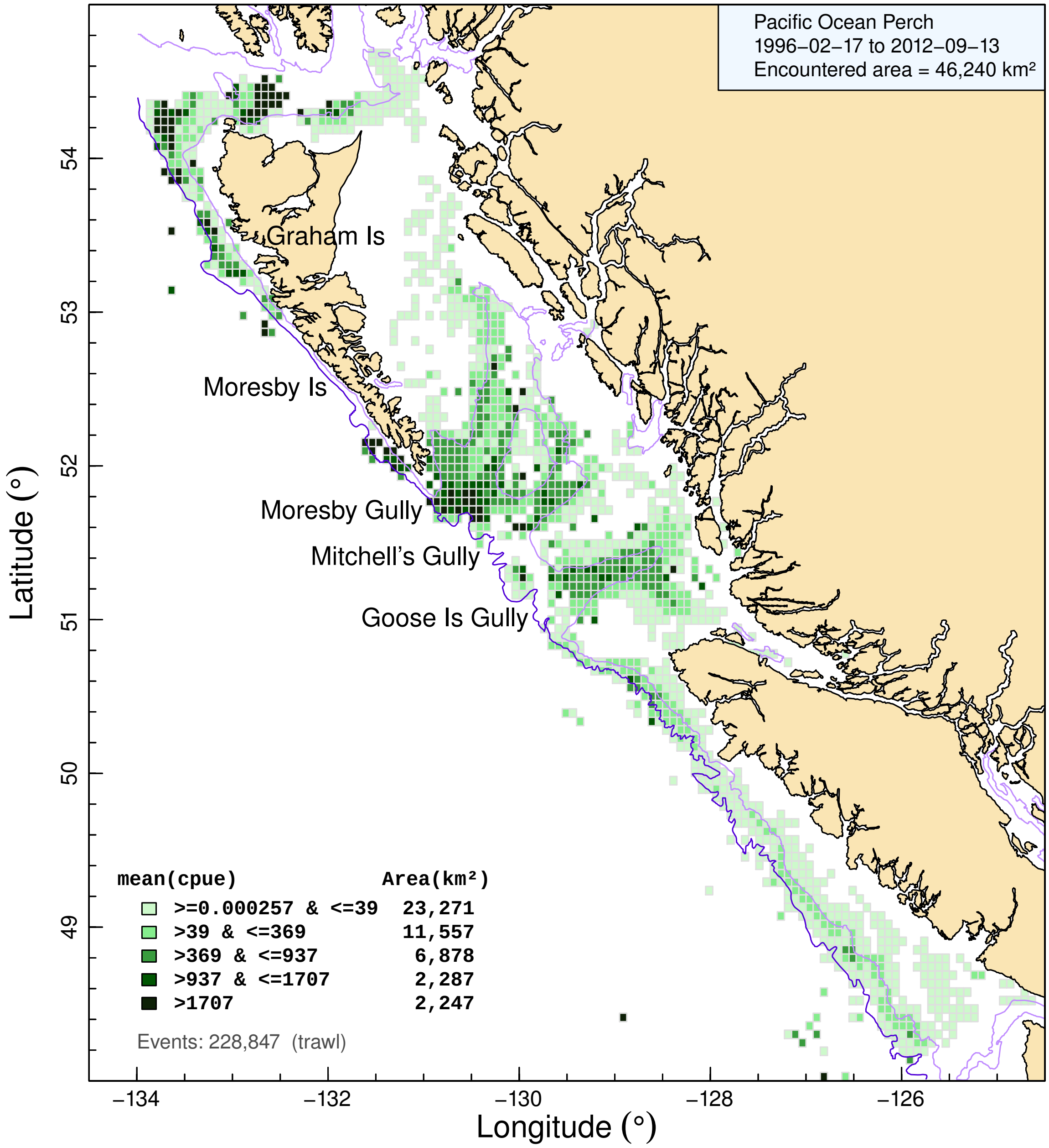

Figure 2. Mean catch-per-unit-effort (CPUE, kg/h) of POP in grid cells 0.075° longitude by 0.055° latitude (roughly 32 km^2). The shaded cells give an approximation of the area where POP was encountered by fishing events from the groundfish trawl fishery from February 1996 to September 2012. Named gullies are to the northeast of their labels. Contours are 200 m and 1000 m isobaths.

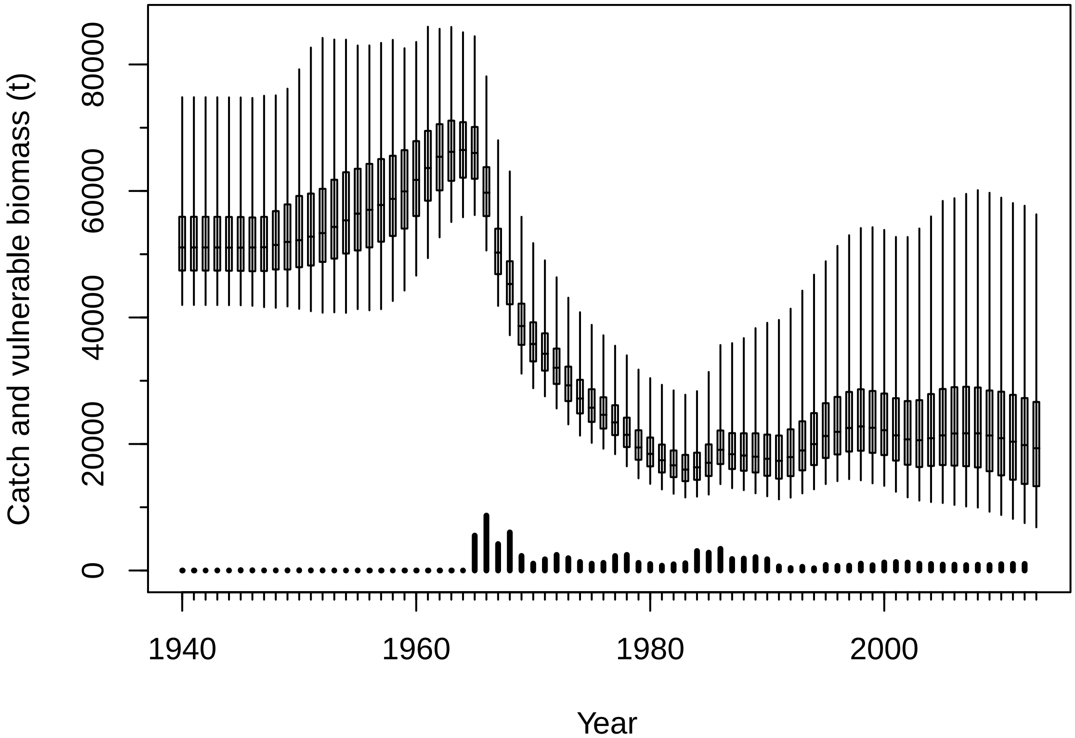

Figure 3. Estimated vulnerable biomass (boxplots) and commercial catch (vertical bars), in tonnes, over time. Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results. Catch is shown to compare its magnitude to the estimated vulnerable biomass.

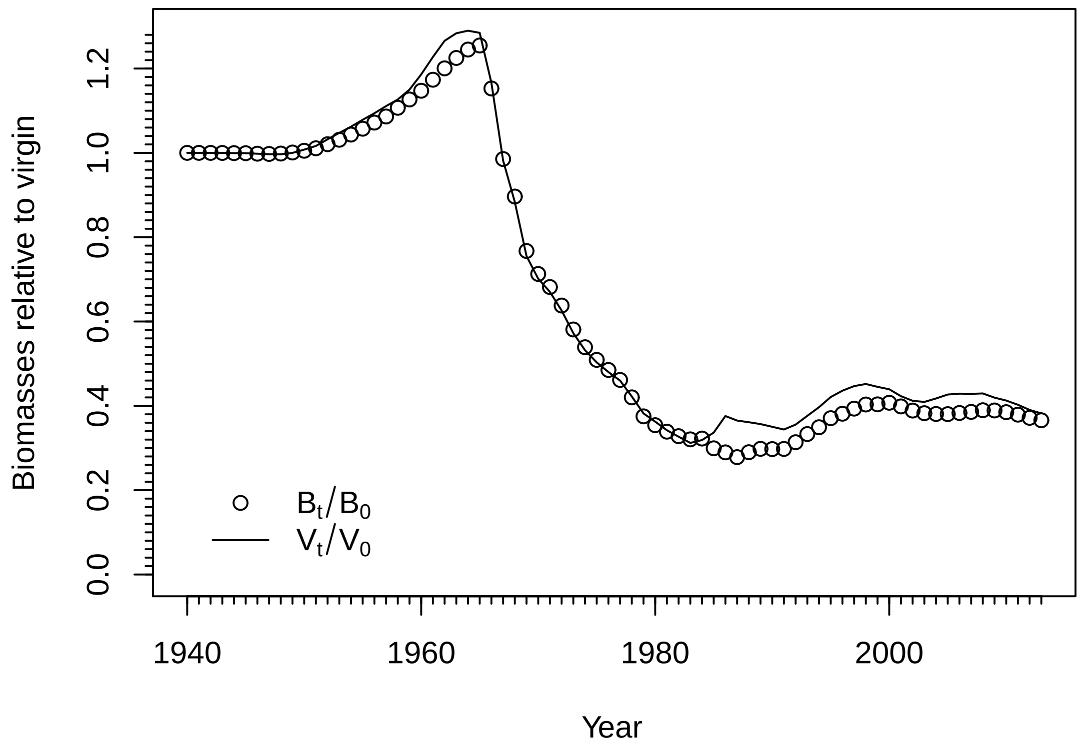

Figure 4. Changes in B_t/B_0 and V_t/V_0 (spawning and vulnerable biomass relative to unfished equilibrium levels) over time, shown as the medians of the MCMC posteriors.

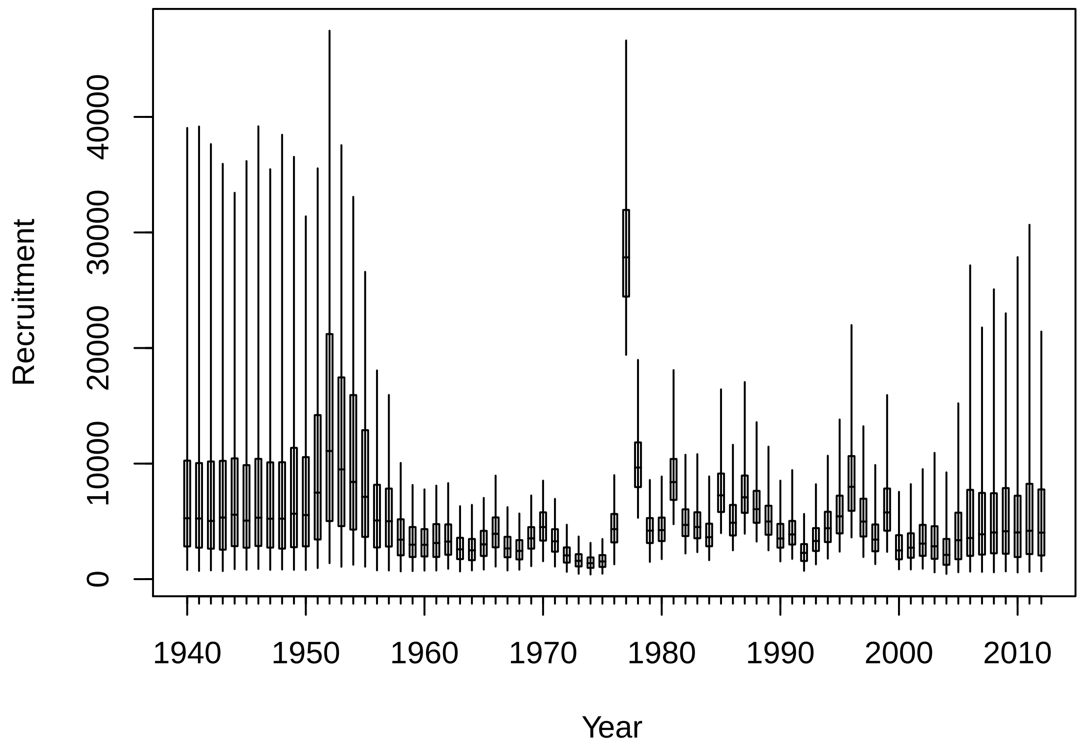

Figure 5. Marginal posterior distribution of recruitment in 1,000's of age-1 fish plotted over time. Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results. Note that the first year for which there are age data is 1978, and the plus-age class is 30, such that there are no direct data concerning age-1 fish before 1949. Also, the final few years have no direct age-data from which to estimate recruitment, because fish are not fully selected until almost age 11 by the commercial vessels or the WCHG survey (using the MCMC median ages of full selectivity for commercial catch, μ_2, and for the WCHG survey, μ_1, from Table G.2).

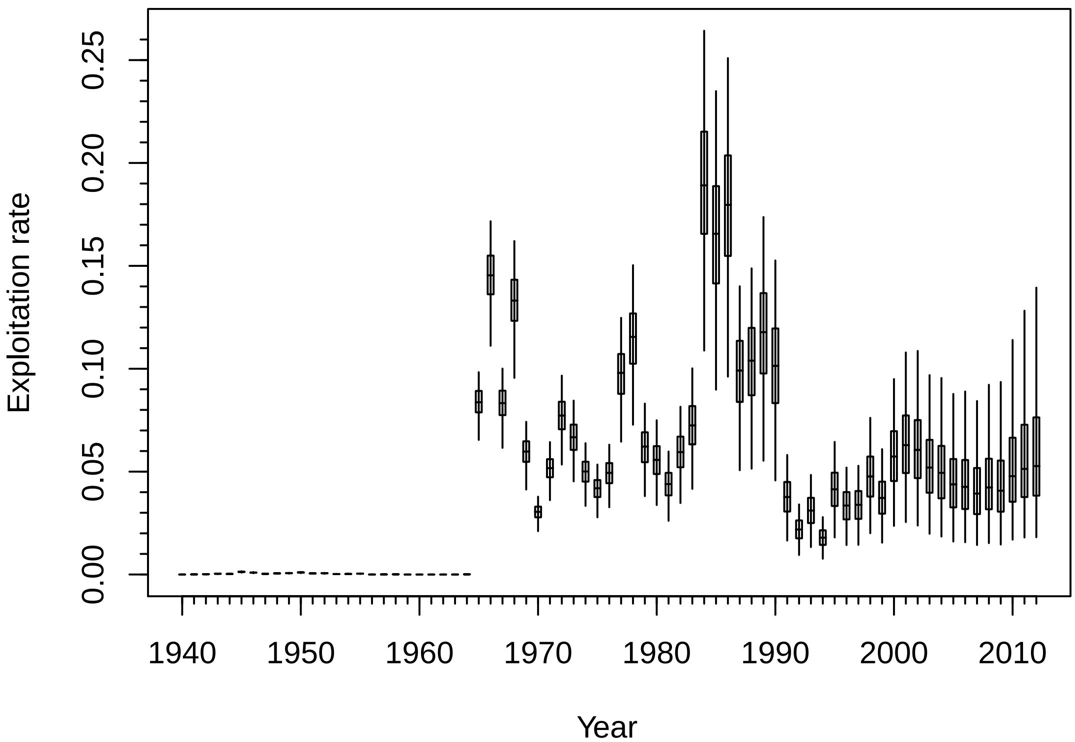

Figure 6. Marginal posterior distribution of exploitation rate plotted over time. Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results.

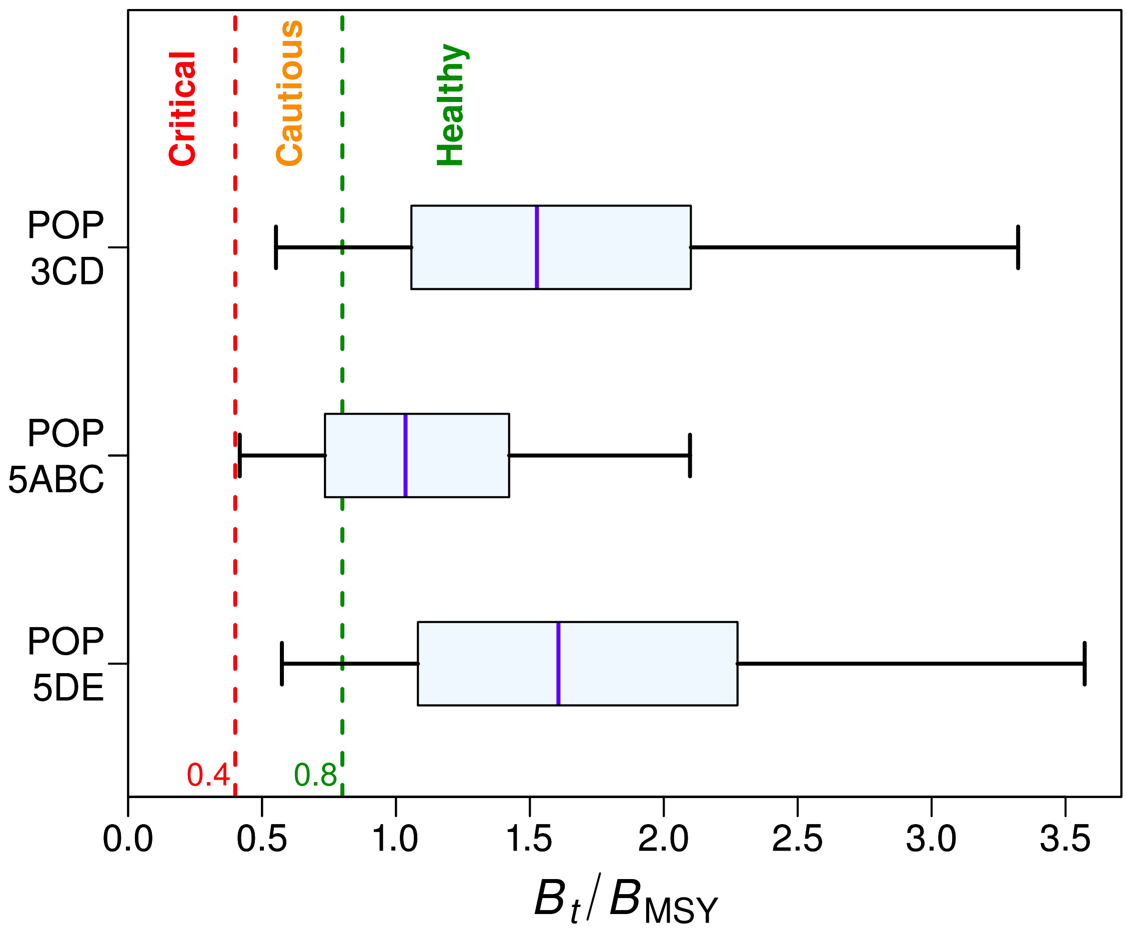

Figure 7. Current status of the three Canadian POP stocks relative to the DFO Precautionary Approach provisional reference points of $0.4B_{\mathrm{MSY}}$ and $0.8B_{\mathrm{MSY}}$. The value of B_t/B_{MSY} is for $t = 2013$ for 3CD (Edwards et al., 2013) and 5DE (this assessment), and for $t = 2011$ for area 5ABC (run 'Estimate $M\&h$' from Edwards et al. 2012b). Boxplots show the 5, 25, 50, 75 and 95 percentiles from the MCMC results.

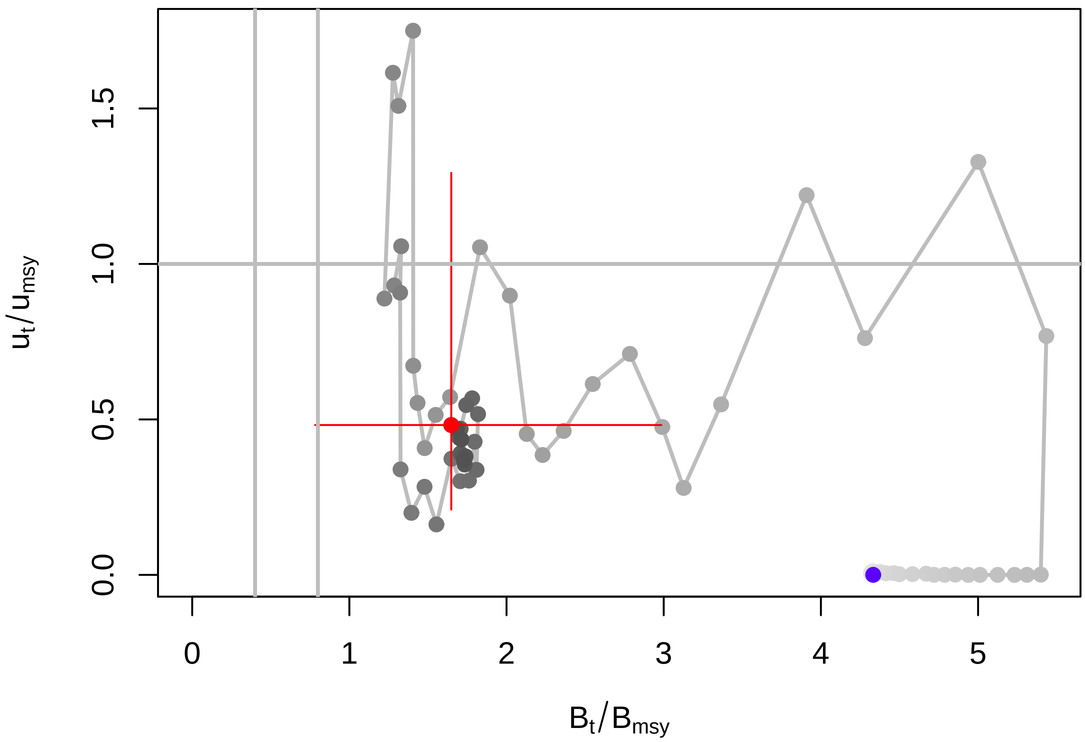

Figure 8. Phase plot through time of the medians of the ratios B_t/B_{MSY} (the spawning biomass in year t relative to B_{MSY}) and u_t/u_{MSY} (the exploitation rate in year t relative to u_{MSY}). Blue filled circle is the starting year (1940). Years then proceed from light grey through to dark grey with the final year (2012) as a filled red circle, and the red lines represent the 10% and 90% percentiles of the posterior distributions for the final year. Vertical grey lines indicate the Precautionary Approach provisional limit and upper stock reference points of 0.4B_{MSY} and 0.8B_{MSY}, and horizontal grey line indicates u_{MSY}.

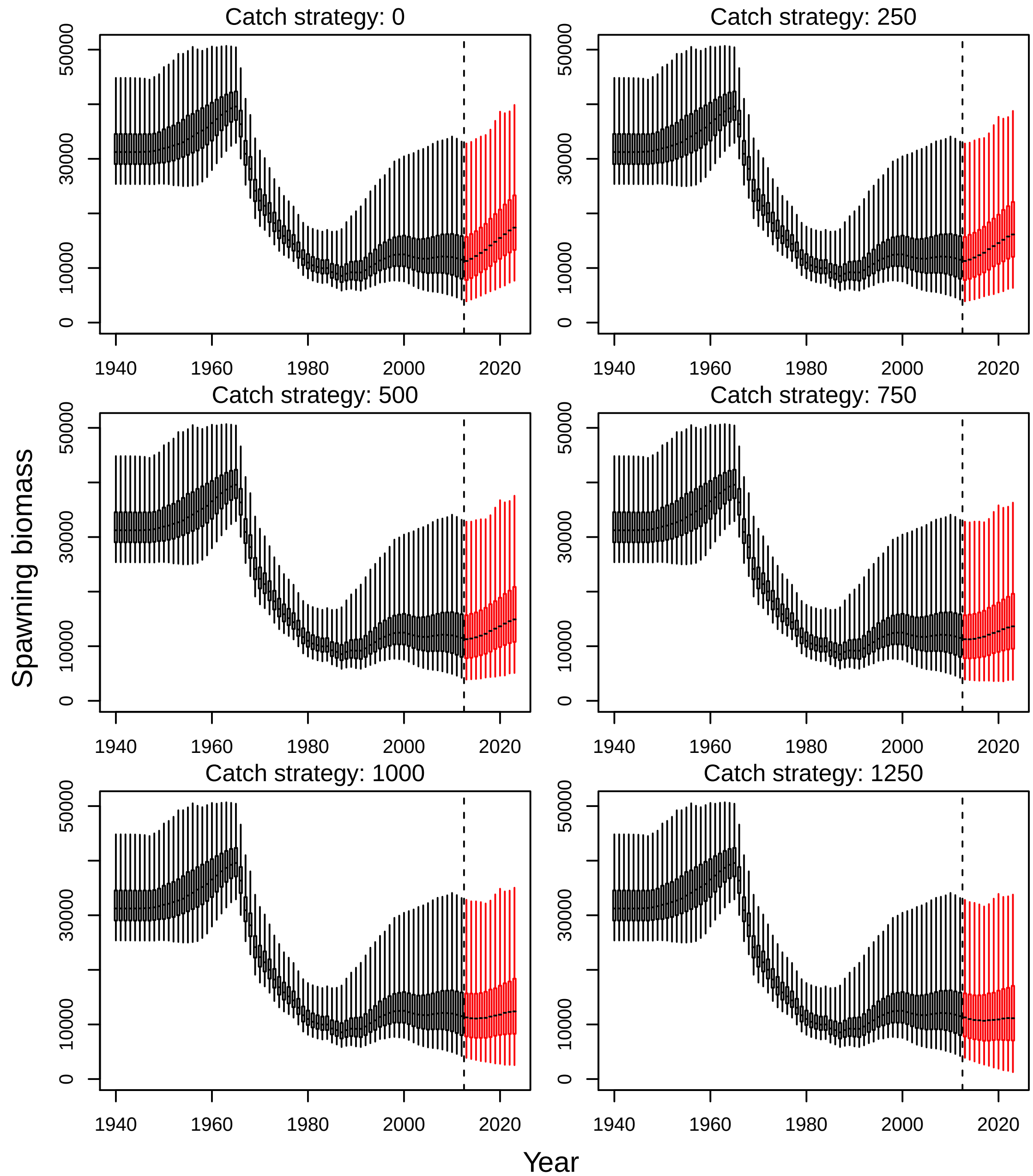

Figure 9. Projected biomass (t) under different constant catch strategies (t); boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results. For each of the 1,000 samples from the MCMC posterior, the model was run forward in time (red, with medians in black) with a constant catch, and recruitment was simulated from the stock-recruitment function with lognormal error (see equation F.24). For reference, the average catch over the last 5 years (2007-2011) is 937 t.

Table 1. The 5th, 50th and 95th percentiles of MCMC-derived quantities from the 1,000 samples of the MCMC posterior. Definitions are: B_0 – unfished equilibrium spawning biomass (mature females), V_0 – unfished equilibrium vulnerable biomass (males and females), B_{2013} – spawning biomass at the start of 2013, V_{2013} – vulnerable biomass in the middle of 2013, u_{2012} – exploitation rate (ratio of total catch to vulnerable biomass) in the middle of 2012, $u_{\max}$ – maximum exploitation rate (calculated for each sample as the maximum exploitation rate from 1940-2012), $B_{\rm MSY}$ – equilibrium spawning biomass at MSY (maximum sustainable yield), $u_{\rm MSY}$ – equilibrium exploitation rate at MSY, $V_{\rm MSY}$ – equilibrium vulnerable biomass at MSY. All biomass values (and MSY) are in tonnes. For reference, the average catch over the last 5 years (2007-2011) is 937 t.

Value	Percentile		
	5%	50%	95%
	From model output		
B_0	26,148	31,242	40,568
V_0	43,100	51,073	66,999
B_{2013}	4,703	11,286	25,672
V_{2013}	8,140	19,334	43,835
B_{2013}/B_0	0.162	0.366	0.666
V_{2013}/V_0	0.175	0.382	0.675
u_{2012}	0.023	0.053	0.119
$u_{\max}$	0.127	0.192	0.254
	MSY-based quantities		
$0.4B_{\rm MSY}$	1,832	2,921	4,520
$0.8B_{\rm MSY}$	3,664	5,843	9,041
$B_{\rm MSY}$	4,580	7,304	11,301
$B_{\rm MSY}/B_0$	0.150	0.231	0.325
$B_{2013}/B_{\rm MSY}$	0.574	1.607	3.572
MSY	998	1,488	2,258
$u_{\rm MSY}$	0.053	0.109	0.194
$u_{2012}/u_{\rm MSY}$	0.168	0.482	1.697
$V_{\rm MSY}$	9,496	14,056	20,861
$V_{\rm MSY}/V_0$	0.192	0.272	0.359

Table 2. Decision table concerning the limit reference point $0.4B_{\mathrm{MSY}}$ for 1-10 year projections for a range of constant catch strategies (in tonnes). Values are P$(B_t > 0.4B_{\mathrm{MSY}})$, 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 1000 MCMC samples for which $B_t > 0.4B_{\mathrm{MSY}}$. For reference, the average catch over the last 5 years (2007-2011) is 937 t.

P$(B_t > 0.4B_{\mathrm{MSY}})$

Annual catch	Projection year										
strategy	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
0	0.98	0.99	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00	1.00
250	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.00	1.00	1.00
500	0.98	0.98	0.98	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	0.98	0.98	0.98	0.98	0.98
1000	0.98	0.98	0.97	0.97	0.97	0.97	0.97	0.96	0.96	0.96	0.96
1250	0.98	0.98	0.97	0.97	0.96	0.96	0.95	0.95	0.95	0.94	0.94
1500	0.98	0.97	0.96	0.95	0.94	0.94	0.93	0.92	0.92	0.91	0.90
1750	0.98	0.97	0.96	0.94	0.92	0.91	0.90	0.88	0.87	0.86	0.84
2000	0.98	0.97	0.95	0.92	0.91	0.88	0.86	0.85	0.83	0.80	0.78

Table 3. Decision table for the upper reference point $0.8B_{\mathrm{MSY}}$ for 1-10 year projections, such that values are P$(B_t > 0.8B_{\mathrm{MSY}})$. For reference, the average catch over the last 5 years (2007-2011) is 937 t.

P$(B_t > 0.8B_{\mathrm{MSY}})$

Annual catch	Projection year										
strategy	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
0	0.88	0.90	0.91	0.92	0.94	0.96	0.96	0.97	0.97	0.97	0.98
250	0.88	0.89	0.90	0.91	0.92	0.94	0.95	0.96	0.96	0.96	0.97
500	0.88	0.88	0.89	0.89	0.90	0.91	0.92	0.93	0.94	0.94	0.95
750	0.88	0.87	0.88	0.88	0.88	0.89	0.90	0.90	0.91	0.91	0.91
1000	0.88	0.86	0.86	0.87	0.86	0.87	0.87	0.87	0.87	0.87	0.87
1250	0.88	0.86	0.85	0.84	0.83	0.83	0.84	0.83	0.83	0.83	0.82
1500	0.88	0.86	0.84	0.82	0.81	0.80	0.79	0.79	0.78	0.77	0.76
1750	0.88	0.85	0.82	0.79	0.77	0.76	0.74	0.72	0.71	0.70	0.69
2000	0.88	0.84	0.80	0.77	0.74	0.71	0.69	0.68	0.66	0.65	0.61

Table 4. Decision table for the reference point B_{MSY} for 1-10 year projections, such that values are P($B_t > B_{\mathrm{MSY}}$). For reference, the average catch over the last 5 years (2007-2011) is 937 t.

P($B_t > B_{\mathrm{MSY}}$)

Annual catch	Projection year										
strategy	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
0	0.79	0.82	0.84	0.87	0.89	0.90	0.92	0.93	0.95	0.96	0.96
250	0.79	0.80	0.83	0.84	0.86	0.88	0.90	0.91	0.92	0.93	0.94
500	0.79	0.80	0.81	0.82	0.84	0.85	0.87	0.88	0.89	0.90	0.91
750	0.79	0.79	0.79	0.80	0.81	0.82	0.84	0.84	0.84	0.85	0.86
1000	0.79	0.78	0.77	0.78	0.78	0.79	0.80	0.81	0.81	0.81	0.81
1250	0.79	0.77	0.76	0.76	0.75	0.74	0.74	0.74	0.74	0.75	0.75
1500	0.79	0.77	0.75	0.73	0.71	0.70	0.69	0.70	0.69	0.69	0.69
1750	0.79	0.76	0.73	0.70	0.67	0.66	0.65	0.64	0.63	0.62	0.61
2000	0.79	0.75	0.71	0.67	0.64	0.62	0.60	0.59	0.56	0.54	0.52

Table 5. Decision table for the alternative reference point $0.2B_0$ for 1-10 year projections, such that values are P($B_t > 0.2B_0$). For reference, the average catch over the last 5 years (2007-2011) is 937 t.

P($B_t > 0.2B_0$)

Annual catch	Projection year										
strategy	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
0	0.90	0.92	0.94	0.95	0.97	0.98	0.98	0.99	0.99	0.99	1.00
250	0.90	0.91	0.93	0.94	0.95	0.96	0.97	0.97	0.98	0.98	0.98
500	0.90	0.91	0.91	0.92	0.93	0.94	0.95	0.95	0.96	0.96	0.96
750	0.90	0.89	0.90	0.90	0.91	0.91	0.92	0.93	0.93	0.93	0.94
1000	0.90	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.89	0.89	0.90
1250	0.90	0.88	0.86	0.85	0.84	0.84	0.84	0.84	0.84	0.83	0.82
1500	0.90	0.87	0.84	0.82	0.80	0.80	0.79	0.78	0.77	0.76	0.75
1750	0.90	0.86	0.82	0.79	0.77	0.75	0.73	0.72	0.71	0.69	0.68
2000	0.90	0.85	0.80	0.76	0.73	0.69	0.67	0.65	0.64	0.60	0.58

Table 6. Decision table for the alternative reference point $0.4B_0$ for 1-10 year projections, such that values are P($B_t > 0.4B_0$). For reference, the average catch over the last 5 years (2007-2011) is 937 t.

P($B_t > 0.4B_0$)

Annual catch	Projection year										
strategy	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
0	0.40	0.44	0.48	0.54	0.59	0.65	0.70	0.77	0.80	0.83	0.86
250	0.40	0.42	0.45	0.50	0.55	0.59	0.64	0.68	0.73	0.76	0.79
500	0.40	0.41	0.43	0.45	0.49	0.54	0.57	0.61	0.65	0.67	0.70
750	0.40	0.40	0.40	0.42	0.44	0.47	0.50	0.53	0.56	0.58	0.59
1000	0.40	0.39	0.39	0.39	0.40	0.41	0.43	0.45	0.47	0.49	0.50
1250	0.40	0.38	0.37	0.36	0.36	0.37	0.38	0.39	0.40	0.40	0.41
1500	0.40	0.37	0.35	0.34	0.33	0.32	0.33	0.33	0.33	0.33	0.34
1750	0.40	0.36	0.34	0.31	0.29	0.29	0.29	0.29	0.29	0.28	0.28
2000	0.40	0.35	0.32	0.28	0.27	0.25	0.25	0.25	0.24	0.24	0.23

Table 7. Decision table for comparing the projected biomass to the current biomass, given by probabilities P$(B_t > B_{2013})$. For reference, the average catch over the last 5 years (2007-2011) is 937 t.

P$(B_t > B_{2013})$

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
0	-	0.96	0.96	0.96	0.97	0.97	0.97	0.98	0.98	0.98	0.98
250	-	0.86	0.89	0.91	0.92	0.93	0.94	0.95	0.95	0.96	0.96
500	-	0.64	0.69	0.74	0.78	0.80	0.83	0.84	0.86	0.88	0.88
750	-	0.40	0.46	0.54	0.60	0.64	0.68	0.69	0.71	0.73	0.74
1000	-	0.23	0.27	0.34	0.40	0.46	0.50	0.54	0.56	0.58	0.59
1250	-	0.13	0.17	0.21	0.26	0.31	0.36	0.39	0.42	0.43	0.43
1500	-	0.08	0.10	0.13	0.17	0.20	0.24	0.28	0.28	0.30	0.30
1750	-	0.04	0.06	0.08	0.11	0.14	0.16	0.17	0.19	0.19	0.20
2000	-	0.03	0.04	0.06	0.07	0.09	0.10	0.12	0.13	0.13	0.13

Table 8. Decision table for comparing the projected exploitation rate to that at MSY, such that values are P$(u_t > u_{\mathrm{MSY}})$, i.e. the probability of the exploitation rate in the middle of year t being greater than that at MSY. For reference, the average catch over the last 5 years (2007-2011) is 937 t.

P$(u_t > u_{\mathrm{MSY}})$

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
250	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
500	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02
750	0.09	0.10	0.09	0.09	0.08	0.08	0.07	0.07	0.07	0.07	0.07
1000	0.16	0.17	0.17	0.17	0.16	0.16	0.15	0.15	0.15	0.15	0.15
1250	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.24	0.24	0.25	0.25
1500	0.32	0.34	0.34	0.34	0.35	0.35	0.36	0.37	0.36	0.36	0.37
1750	0.41	0.43	0.45	0.46	0.45	0.46	0.46	0.47	0.48	0.49	0.49
2000	0.47	0.50	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.60	0.60

A REQUEST FOR SCIENCE INFORMATION AND ADVICE

Data / Données

Fisheries and Oceans Canada | Pêches et Océans Canada

REQUEST FOR PEER REVIEWED SCIENCE INFORMATION AND/OR ADVICE

Title of Request	ID# (for internal use only)
Request for CSAP review: Pacific Ocean Perch (3CD, 5DE) (PMFC areas)	

Branch Contact

Name Tamee Karim	Title Regional Manager, Groundfish
Telephone Number (604) 666-9033	Email tameezan.karim@dfo-mpo.gc.ca
Region Pacific	Sector Groundfish Management Unit
Directorate	Branch Fisheries Management

Request Details

Issue requiring science information and/or advice (i.e., "the question" or "the need"). Posed as a question to be answered by Science.

What is the current status of the POP (3CD, 5DE) stocks relative to the DFO Precautionary Approach reference points for areas 3CD and 5DE? Please include a pictorial of the status of POP relative to the PA policy graph.

Is it appropriate to recommend alternative Limit Reference Points (LRP), Upper Stock Reference Points (USR) and Target Reference Points (TRP) for POP (3CD/5DE)? If so what would the alternative points be (include biological considerations and rationale used to form them)?

Include decision tables which forecast the impact/risk of varying total fishing mortality levels on future population trends. Please also include long-term trajectory graphs.

This request is consistent with the work on the groundfish strategic assessment plan with respect to prioritizing of species assessments.

Rationale or context for the request: What will the information/advice be used for? Who will be the end user(s)? Will it impact other DFO programs or regions?

This species accounts for the largest single species proportion of quotas making up the annual rockfish TAC for west coast of Canada. POP accounts for 25% of the total weight of rockfish landed by bottom trawl gear. A detailed stock assessment has never been done for these stocks. Updated harvest advice is required to determine if current harvest levels are sustainable and compliant with the PA.

Once an accepted assessment is completed, the fishery checklist for this species can be created (if it falls within the decision tree that indicates it is a species that requires a checklist). The management portion for this species has been completed and requires the science portion to be updated.

Additional Information (please be as concise as possible)

What is the expected course of action if science advice is not provided? Could this negatively affect species, habitat(s) or ecosystem(s) of concern?

In the absence of updated science information, the GMU has been making management decisions based on dated information and will continue to do so until new information is provided.

Canada

Page 1 of 3 FP-5097-E (2011-09)

Data / Données

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Will this request help DFO move towards an ecosystem approach to management? For example, does this request relate to overarching national objectives of conserving biodiversity, productivity or habitat, or more specific bioregional ecosystem objectives (if they exist)? Are there specific ecosystem considerations that should be taken into account?

(•) Yes ( ) No

If yes, please elaborate.
While this not an ecosystem (based) assessment it is critical to know the relative abundance of various ecosystem components before one can move towards ecosystem based fisheries management. This assessment will provide a time series of biomass estimates for the target species that can be used in the future to inform an ecosystem based approach.

Is the provision of this information/advice required to meet a legal or regulatory requirement?

( ) Yes (•) No

If yes, please elaborate.

Does this issue have public, media and/or government (outside DFO) interest or involvement at the local, regional, national or international level?

(•) Yes ( ) No

If yes, please elaborate.
Fishing industry and environmental organizations will be interested. These stocks border the United States waters, and so there may be international interest.

Is the provision of this information/advice required to support a departmental priority?

(•) Yes ( ) No

If yes, describe which priority and provide a short rationale.
This work contributes to the implementation of the policies within the Sustainable Fisheries Framework.

Is the provision of this information/advice required to respond to or meet an international commitment?

( ) Yes (•) No

If yes, which commitment?

Administrative Details

Deadline

Latest Possible Date to Receive Science Advice
November 2012

Rationale
Updated advice from this assessment is requested for inclusion in the 2013 Groundfish Integrated Fisheries Management Plan.

Funding

Do you have funds to cover any extra costs associated with this request (i.e.: special analysis, meeting costs, translation)?

( ) Yes (•) No

If yes, please elaborate.

Branch Approval

Canada

Page 2 of 3 FP-5097-E (2011-09)

Data / Données

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Approval Date	Name of Director (or Delegated Authority)	Submission Date

Approved request forms are to be submitted to the CSA/CSAS Coordinator in your region.

Canada

B CATCH DATA

B.1 BRIEF HISTORY OF THE FISHERY

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 were primarily from the US (1959–1980), the USSR (1965–1968), and Japan (1966–1976). The foreign vessels removed large amounts of POP biomass, particularly in Queen Charlotte Sound. 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 any slope rockfish species. Since then, the groundfish management unit (GMU) at the Department of Fisheries and Oceans (DFO) has 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 *S. reedi*) in 1979 for GMU area 5E (Tables B.1 and B.2); areas are defined in Figure 1. The west coast of Haida Gwaii (WCHG, 5E) has historically shown isolated pockets of high POP density; however, the smaller habitat area translates into significantly lower fishery removals than those in 5ABC.

Table B.1. Annual trawl Total Allowable Catches (TACs) in tonnes for Pacific Ocean Perch in Groundfish Management Unit areas. Year can either be calendar year (1979-1996) or fishing year (1997 on). See Table B.2 for explanation of Notes column.

Year	3C	3D	5AB	5CD	5E	Coast	Notes
1979	50		2000		600	2650	a
1980	600		2200		800	3600	b
1981	500		1500	1800	800	4600	c
1982	500	250	1000	2000	800	4550	
1983	500	250	1000	2000		3750	d
1984	500	250	800	2000		3550	e
1985	300	350	850	2000		3500	
1986	100	350	500	2000		2950	
1987	100	350	500	2000		2950	
1988	100	350	700	3000		4150	
1989	150	400	850	3000	400	4800	
1990	150	400	850	2450	400	4250	f
1991	0	400	850	2150	400	3800	g,h
1992	0	400	850	2400	400	4050	i
1993	150	400	850	2400	400	4200	j,k
1994	1173	207	2177	1107	253	4917	l
1995	548	72	1892	1178	544	4234	m
1996	491	164	1500	4003	726	6884	n,o
1997	431	230	2358	2818	644	6481	+,p,q
1998	300	230	2070	2817	730	6147	+
1999	300	230	2070	2817	730	6147	+
2000	300	230	2070	2818	730	6148	+,r,s
2001	300	230	2070	2818	730	6148	+
2002	300	230	2070	2518	730	5848	+,t,u,v
2003	300	230	2070	2818	730	6148	+
2004	300	230	2070	2818	730	6148	+
2005	300	230	2070	2818	730	6148	+
2006	300	230	2070	2118	730	5448	+,w,x,y,z
2007	300	230	2070	2118	730	5448	+
2008	300	230	2070	2118	730	5448	+
2009	300	230	2070	2118	730	5448	+
2010	300	230	2070	2118	730	5448	+
2011	300	230	1942	1987	730	5189	+,A
2012	300	230	1814	1856	730	5189	+,A

Table B.2. Codes to notes on management actions and quota adjustments that appear in Table B.1.

Code	Management Actions
a	Started limited vessel entry for Halibut fleet.
b	Started experimental over-harvesting of SW Vancouver Island POP stock.
c	Started limited vessel entry for Sablefish fleet.
d	Started experimental unlimited harvesting of Langara Spit POP stock (5EN).
e	Ended experimental over-harvesting of SW Vancouver Island POP stock.
f	Started *Individual Vessel Quotas* (IVQ) systems for Halibut and Sablefish.
g	Started *Dockside Monitoring Program* (DMP) for the Halibut fleet.
h	Started limited vessel entry for *Hook and Line* (H&L) fleet inside.
i	Started limited vessel entry for H&L fleet outside.
j	Stopped experimental fishing of Langara Spit POP stock.
k	Closed POP fishery in PMFC area 5EN (Langara Spit).
l	Started DMP for Trawl fleet.
m	Implemented catch limits (monthly) on rockfish aggregates for H&L.
n	Started 100% onboard observer program for offshore Trawl fleet.
o	Started DMP for H&L fleet.
p	Started IVQ system for Trawl *Total Allowable Catch* (TAC) species (April 1, 2007)
q	Implemented catch limits (15,000 lbs per trip) on combined non-TAC rockfish for the Trawl fleet.
r	Implemented catch limits (20,000 lbs per trip) on rockfish aggregates for the Halibut option D fleet.
s	Implemented formal allocation of rockfish species between Halibut and H&L sectors.
t	*Department of Fisheries and Oceans* (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.
u	Established the inshore rockfish conservation strategy.
v	Closed areas to preserve four hexactinellid (glassy) sponge reefs.
w	DFO reduced the 5CD POP TAC by 700 tonnes for use in possible research programs.
x	Introduced an *Integrated Fisheries Management Plan* (IFMP) for most groundfish fisheries.
y	Started 100% at-sea electronic monitoring for H&L.
z	Implemented mandatory retention of rockfish for H&L.
+	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.
A	POP combined 5ABCD TAC reduction to 3413 t will be achieved over a three year period (from 2010) through an annual reduction of 258 t. The expected catch level will be 68% of TAC. TAC is subject to annual review.

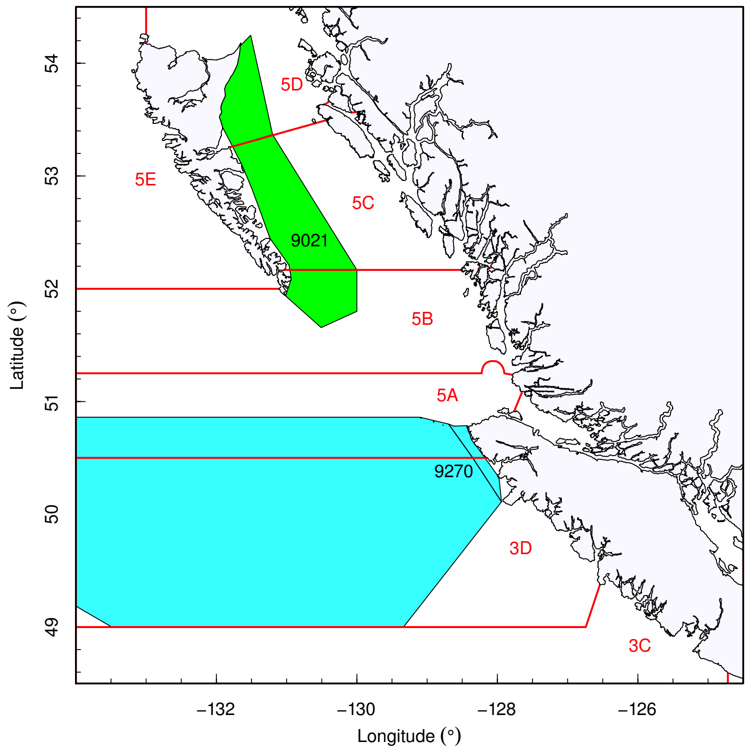

Figure B.1. Problematic statistical areas in the PacHarv3 database that span multiple PMFC areas – 9021 (shaded) in the figure shows DFO statistical area 102 and 9270 (shaded) shows statistical area 127, where the inshore areas 2E and 27, respectively, are excluded.

B.2 POP CATCH RECONSTRUCTION

A detailed account of how we reconstruct Pacific Ocean Perch catch on the BC coast can be found in Haigh and Yamanaka (2011). The algorithm uses eight historical data sources (the earliest extending back to 1918) and five modern catch databases housed at various DFO facilities. The historical data comprise landings statistics for two broad categories of rockfish – Pacific Ocean Perch (POP) and rockfish other than POP (ORF). The sum of these two combine to form total rockfish (TRF) landings.

As reported in Edwards et al. (2013), we document a significant departure from previous reconstructions in that for the trawl and trap fisheries from 1954 to 1995 we use only the database GFCatch (Rutherford, 1999). In previous reconstructions, we used both GFCatch (logbook records) and PacHarv3 (sales slips) because they should be recording the same landings. Assuming this, landings from the two sources can be compared by year and area, and the maximum values used. Unfortunately, sales slips used large statistical areas while logbooks used PMFC areas and subareas. Conversion from the former to the latter can be performed reasonably well, but two large statistical areas in particular straddle PMFC boundaries with no easy way to assign the catch (Figure B.1). The first area, coded 9021, comprises statistical areas 2E and 102, which cover large portions of PMFC 5B, 5C, and 5D. For POP in particular, area 9021 includes Moresby Gully in PMFC areas 5B and 5C. The second area, coded 9270, comprises statistical areas 27 and 127 which include a POP agglomeration in PMFC areas 3D and 5A off the NW tip of Vancouver Island. The problem occurs, for example, when GFCatch reports POP landings from 3D and 5A in the 9270 region while the POP landings reported by PacHarv3 are assigned to 3D or 5A only, neither of which matches the GFCatch landings. At this time, we have no method for splitting the PacHarv3 catch from these two statistical areas.

Another departure from Haigh and Yamanaka (2011) is the addition of a previously unused source of foreign catch numbers (Ketchen, 1980*a*). In the earlier POP assessment for 5ABC (Edwards et al., 2012*b*), Russian and Japanese catch were estimated by Ketchen (1980*b*) for the Queen Charlotte Sound (QCS) area; however, he only supplied a one-page Appendix for estimates of Russian rockfish catch for the west coast of Vancouver Island (WCVI) and the west coast of Haida Gwaii (WCHG). Japanese catch numbers were not supplied for WCVI and WCHG in his QCS reconstruction. Fortunately, Ketchen (1980*a*) reported landings estimates of "Pacific Ocean Perch", a term most likely including all rockfish, by the Japanese fleet. Therefore, in this document we use the Russian catch in Ketchen (1980*b*) and the Japanese catch in Ketchen (1980*a*).

Composition ratios of specific rockfish species (herein POP/TRF), derived from modern landings data, are used to disaggregate the two broad rockfish categories in the historical series. Historical discard rates are also estimated based on recent discard rates. The reconstruction yields catches (landings + discards) by calendar year, fishery (Trawl, Halibut, Sablefish, Dogfish-Lingcod, Hook & Line Rockfish), and Pacific Marine Fisheries Commission (PMFC) major areas in BC (4B, 3C, 3D, 5A, 5B, 5C, 5D, 5E). There are numerous decisions made during the reconstruction procedure that affect the final outcome, e.g. to allocate the annual catch U_t (for year t) from unknown areas to each PMFC area i using the proportions $C_{ti}/\sum_{i\in\mathtt{PMFC}} C_{ti}$ of known catch C_{ti} in PMFC area i. But decisions made include all identified removals whenever possible. Some data sources are not incorporated here (e.g. research survey catch), but this procedure includes currently available sources of commercial removals.

Catch of rockfish species is known with 'certainty' from 1996 on; however, because POP supports a major fishery, catches of this species are fairly well-known back to 1956 (Ketchen, 1976). During the period 1950–1975, US vessels were not active in 5E like they were in the more southerly regions (5ABC and 3CD). Heavy exploitation by foreign fleets in 5E north of 54°N was led by the Russians in 1965 followed by the Japanese in 1966 (Ketchen, 1980*a*). Russian fishing ended by 1970 whereas the Japanese remained until 1977. These large catches were reported by Ketchen (1980*a*) in the stock assessments of the day, and subsequently used by researchers such as Leaman and Stanley (1993). Ketchen (1980*b*) re-examined the foreign fleet catch in Queen Charlotte Sound, which accounts for 75% of POP removals along the BC coast, primarily because statistics from the USSR called all rockfish 'perches' while the Japanese used the term 'Pacific ocean perch' indiscriminately. Ketchen's reconstruction provided estimates (minimum, intermediate, and maximum) of POP catch in QCS by these two nationalities, but only reported estimated 'rockfish' catch by Russian vessels along WCVI and WCHG, as noted above.

This assessment reconstructs catch back to 1940 (Figure B.2, Table B.3) when fisheries to the south increased during World War II. In 5DE, removals from 1918 to 1964, were negligible compared to those that came after 1964 when foreign fleets began intensive fishing. Canadian vessels began fishing in this area in 1977, and an experimental fishery conducted from 1983–1993 in Langara Spit (Leaman and Stanley, 1993) saw catches rise, but not to anywhere near the estimated foreign removals (Figure B.2).

The accuracy and precision of reconstructed catch series inherently reflect the problems

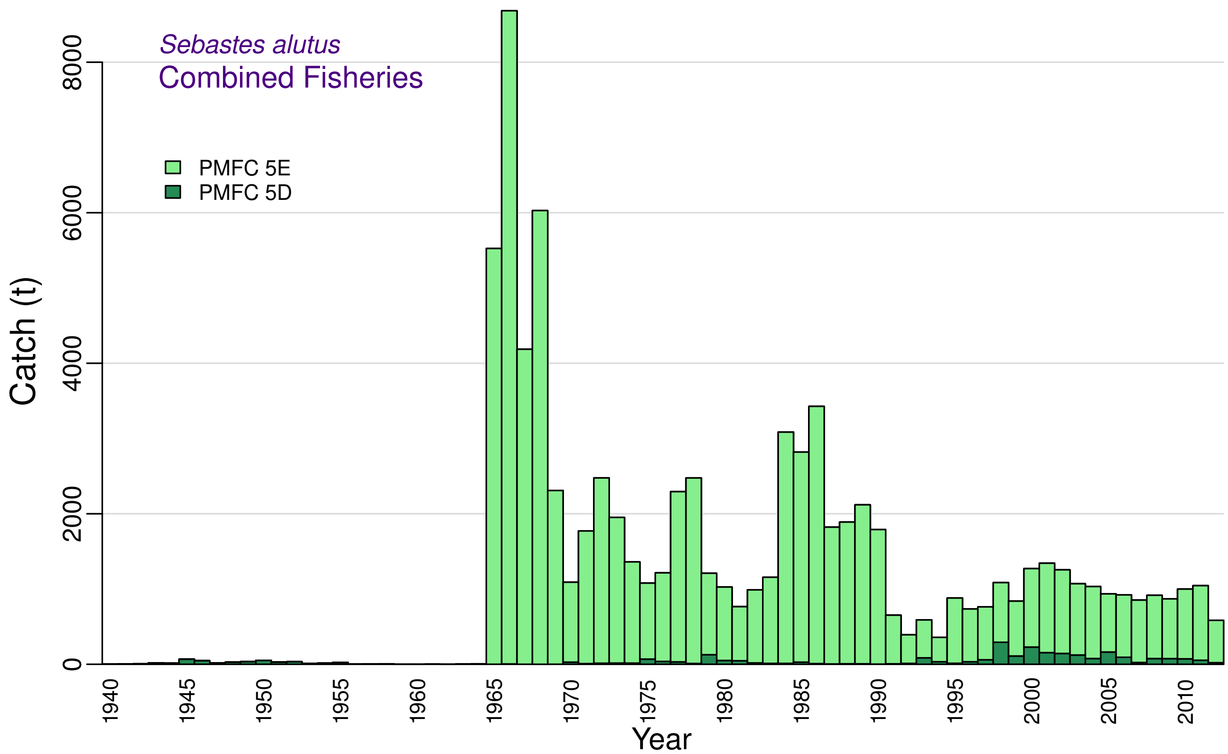

Figure B.2. Reconstructed total (landed + discarded) catch (t) for Pacific Ocean Perch from all fisheries combined in PMFC major areas 5D and 5E.

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 solved through the introduction of onboard observer programs (started in 1996 for the offshore trawl fleet), dockside monitoring, and tradable individual vessel quotas (IVQs, 1997). Improvements in data storage and retrieval technologies are still ongoing.

Table B.3. Catch reconstruction (landings + discards, tonnes) for Pacific Ocean Perch in PMFC major areas 5D & 5E, where k denotes fishery ID: 1=Trawl, 2=Halibut, 3=Sablefish, 4=Dogfish–Lingcod, and 5=H&L Rockfish. The final three columns give the totals across all fisheries. Values $<$ 1000 are reported to three significant figures. 2012 data remain incomplete (up to September 2012).

Year	5D$_{k=1}$	5E$_{k=1}$	5DE$_{k=1}$	5D$_{k\in(2:5)}$	5E$_{k\in(2:5)}$	5DE$_{k\in(2:5)}$	5D	5E	5DE
1940	0.970	0	0.970	9.87	0.000989	0.00109	0.970	0.000989	0.972
1941	3.08	0	3.08	0.000627	0.00628	0.00691	3.08	0.00628	3.08
1942	6.28	0	6.28	0.000549	0.00550	0.00604	6.28	0.00550	6.28
1943	18.8	0	18.8	0.00144	0.0145	0.0159	18.8	0.0145	18.8
1944	14.1	0	14.1	0.00196	0.0197	0.0216	14.1	0.0197	14.1
1945	67.2	0	67.2	0.00312	0.0313	0.0344	67.2	0.0313	67.3
1946	47.4	0	47.4	0.00451	0.0452	0.0497	47.4	0.0452	47.4
1947	17.3	0	17.3	0.000742	0.00744	0.00818	17.3	0.00744	17.3
1948	27.8	0	27.8	0.00113	0.0113	0.0124	27.8	0.0113	27.8
1949	34.4	0	34.4	0.00150	0.0151	0.0166	34.4	0.0151	34.4
1950	52.0	0	52.0	0.000640	0.00642	0.00706	52.0	0.00642	52.0
1951	28.6	0	28.6	0.00432	0.0391	0.0435	28.6	0.0391	28.6

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Table B.3 – continued from previous page

Year	5D$_{k=1}$	5E$_{k=1}$	5DE$_{k=1}$	5D$_{k\in(2:5)}$	5E$_{k\in(2:5)}$	5DE$_{k\in(2:5)}$	5D	5E	5DE
1952	33.6	0	33.6	0.00218	0.0262	0.0283	33.6	0.0262	33.6
1953	11.7	0	11.7	0.000663	0.00318	0.00384	11.7	0.00318	11.7
1954	14.4	0	14.4	0.000943	0.00579	0.00674	14.4	0.00579	14.4
1955	23.0	0	23.0	0.000405	0.00710	0.00750	23.0	0.00710	23.0
1956	0.933	0	0.933	6.45	0.00193	0.00200	0.933	0.00193	0.935
1957	1.88	0	1.88	0.000237	0.00990	0.0101	1.88	0.00990	1.89
1958	5.60	0	5.60	3.23	0.000654	0.000686	5.60	0.000654	5.60
1959	0	0	0	2.15	0.000934	0.000956	2.15	0.000934	0.000956
1960	0	0	0	0.000592	0.00280	0.00339	0.000592	0.00280	0.00339
1961	0.466	0	0.466	0.000247	0.00318	0.00342	0.467	0.00318	0.470
1962	0	0	0	3.94	0.00262	0.00266	3.94	0.00262	0.00266
1963	1.40	0	1.40	0.000473	0.0130	0.0135	1.40	0.0130	1.41
1964	5.75	0	5.75	5.02	0.00106	0.00111	5.75	0.00106	5.76
1965	0.718	5,524	5,525	0.000183	0.00835	0.00853	0.719	5,524	5,525
1966	4.12	8,680	8,684	0.000513	0.00417	0.00468	4.12	8,680	8,684
1967	0.466	4,186	4,186	0.00132	0.00483	0.00615	0.468	4,186	4,186
1968	0	6,029	6,029	0.000244	0.000654	0.000898	0.000244	6,029	6,029
1969	0.803	2,309	2,309	0.000108	0.000280	0.000388	0.803	2,309	2,309
1970	28.1	1,062	1,090	0.00182	0.000249	0.00207	28.1	1,062	1,090
1971	8.52	1,763	1,772	0.00196	0.00152	0.00349	8.52	1,763	1,772
1972	14.0	2,462	2,476	0.00268	0.00286	0.00555	14.0	2,462	2,476
1973	15.6	1,936	1,952	0.00247	0.00405	0.00652	15.6	1,936	1,952
1974	15.4	1,345	1,361	0.00369	0.000623	0.00432	15.4	1,345	1,361
1975	68.6	1,010	1,079	0.00366	0.00623	0.00988	68.6	1,010	1,079
1976	37.7	1,178	1,215	0.00269	0.00623	0.00892	37.7	1,178	1,215
1977	31.5	2,262	2,294	0.00262	0.00498	0.00760	31.5	2,262	2,294
1978	10.3	2,466	2,476	0.00616	0.0192	0.0254	10.3	2,466	2,476
1979	127	1,083	1,210	0.00498	0.0357	0.0407	127	1,083	1,210
1980	50.5	976	1,027	0.00711	0.0439	0.0510	50.5	976	1,027
1981	46.6	719	766	0.00517	0.0292	0.0344	46.6	719	766
1982	18.0	971	989	0.00101	0.00140	0.00241	18.0	971	989
1983	11.8	1,144	1,156	0.0136	0.00149	0.0151	11.8	1,144	1,156
1984	11.8	3,074	3,085	0.00313	0.00451	0.00764	11.8	3,074	3,085
1985	28.1	2,792	2,820	0.00539	0.00432	0.00971	28.1	2,792	2,820
1986	8.54	3,419	3,427	0.00548	0.0152	0.0206	8.54	3,419	3,427
1987	4.11	1,818	1,822	0.0107	0.00849	0.0192	4.12	1,818	1,822
1988	6.20	1,883	1,889	0.366	0.0502	0.416	6.56	1,883	1,890
1989	6.10	2,113	2,119	0.0126	0.0133	0.0260	6.12	2,113	2,119
1990	2.22	1,786	1,788	0.0183	1.91	1.93	2.24	1,788	1,790
1991	6.05	646	652	0.0370	1.18	1.22	6.08	647	653
1992	11.4	380	391	0.110	0.642	0.752	11.5	381	392
1993	85.4	504	589	0.0241	0.563	0.587	85.4	504	590
1994	33.3	325	358	0.0249	0.0733	0.0983	33.3	325	358
1995	13.0	866	879	0.0821	0.994	1.08	13.1	867	880
1996	32.8	701	734	0.0307	0.504	0.535	32.9	702	735
1997	59.5	703	763	0.00329	0.382	0.385	59.5	704	763
1998	292	792	1,084	0.00634	1.38	1.38	292	793	1,086
1999	110	728	838	0.00730	1.18	1.18	110	729	839
2000	228	1,040	1,269	0.0241	2.60	2.62	228	1,043	1,271
2001	154	1,187	1,341	0.0758	2.27	2.35	155	1,189	1,343
2002	144	1,111	1,255	0.00489	0.724	0.729	144	1,112	1,255

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Table B.3 – continued from previous page

Year	5D$_{k=1}$	5E$_{k=1}$	5DE$_{k=1}$	5D$_{k\in(2:5)}$	5E$_{k\in(2:5)}$	5DE$_{k\in(2:5)}$	5D	5E	5DE
2003	123	947	1,070	0.0133	0.318	0.331	123	948	1,071
2004	76.2	956	1,033	0	0.310	0.310	76.2	957	1,033
2005	163	773	936	0.00135	0.133	0.134	163	773	936
2006	93.2	829	922	0.00294	0.0147	0.0176	93.2	829	922
2007	23.2	830	853	0.0166	0.0827	0.0993	23.2	830	853
2008	75.8	841	917	0.00773	0.100	0.108	75.8	841	917
2009	74.9	794	869	0	0.198	0.198	74.9	794	869
2010	72.1	927	999	0.000861	0.308	0.308	72.1	927	999
2011	53.5	991	1,045	0.00395	0.278	0.282	53.5	991	1,045
2012	21.2	563	584	0	0.0673	0.0673	21.2	563	584

B.3 SCALING ASSESSMENT CATCH OPTION FOR PMFC AREAS TO TOTAL ALLOWABLE CATCH FOR GROUNDFISH MANAGEMENT AREAS

The catch and age composition data used in this POP stock assessment were based entirely on PMFC major areas 5D and 5E combined (5DE). This area logically delimits the stock in Dixon Entrance (5D) and off the west coast of Haida Gwaii (5E). The Groundfish Management Unit (GMU) manages groundfish using Groundfish Management Areas (GMA), which are based on DFO Pacific Fishery Management Areas (PFMA), defined in the Pacific Fishery Management Area Regulations (PFMAR, 2007). The PMFC and GMA areas 5E are similar but not identical (Figure 1).

The GMU manages a single TAC for GMA 5CD. Edwards et al. (2012*b*), who assessed PMFC area 5ABC, suggested an algorithm to prorate the 5CD TAC (note that catches in PMFC 5D are relatively low, Table B.4). We use the same algorithm here to facilitate the scaling of catch options presented in this assessment (based on the combined PMFC area 5DE) to GMA 5E. In Table B.4 we summarise annual catches for all tows that have valid identifiers for both PMFC and GMA areas, and calculate scaling ratios of catches:

$$\frac{\text{GMA 5E}}{\text{PMFC 5E}} \tag{B.1}$$

and

$$\frac{\text{GMA 5E}}{\text{PMFC 5D} + \text{PMFC 5E}}. \tag{B.2}$$

The ratio (B.1) does not get used in the calculations, but is presented to demonstrate the difference between the area definitions; it is ≤ 1 because GMA 5E excludes the waters near Anthony Island (SW Haida Gwaii), a hotspot for POP that is assigned to GMA 5C (Figures 1 and 2).

The ratio (B.1) is shown in Table B.4, and Table B.5 shows the proportional difference

$$\frac{\text{GMA 5E} - (\text{PMFC 5D} + \text{PMFC 5E})}{\text{PMFC 5D} + \text{PMFC 5E}} = \frac{\text{GMA 5E}}{\text{PMFC 5D} + \text{PMFC 5E}} - 1. \tag{B.3}$$

Table B.4. Annual catches (t) of POP from tows that have valid identifiers for both PMFC and GMA areas, with ratios calculated from (B.1) and (B.2).

	PMFC		GMA		GMA/PMFC ratios	
Year	5D	5E	5DE	5E	(B.1): 5E/5E	(B.2): 5E/(5D+5E)
1996	32	694	726	643	0.926	0.884
1997	59	681	739	605	0.888	0.818
1998	291	745	1,036	732	0.983	0.706
1999	106	676	782	676	1.000	0.865
2000	226	979	1,205	531	0.542	0.441
2001	151	1,139	1,290	813	0.713	0.630
2002	137	1,030	1,167	670	0.650	0.574
2003	122	906	1,028	642	0.708	0.624
2004	76	929	1,005	783	0.843	0.779
2005	162	765	927	711	0.929	0.767
2006	89	786	875	663	0.843	0.757
2007	23	775	798	656	0.847	0.823
2008	72	807	879	770	0.955	0.877
2009	74	787	861	733	0.931	0.851
2010	71	917	988	778	0.849	0.788
2011	53	979	1,032	795	0.812	0.771

We suggest the following algorithm to allocate the PMFC 5DE catch option to the current POP GMA 5E area:

1. Start with the catch option from the 5DE stock assessment.

2. Adjust this catch option by the proportional difference in catches between the PMFC and GMA area definitions, given by (B.3) and calculated in Table B.5.

The worked example in Table B.5 uses the most recent five complete catch years (2007-2011) to calculate the proportional difference between the two sets of area definitions (-17.8%). If the assessment catch option is, say, 1,000 t, then the revised catch for GMA 5E would be 822 t.

Table B.5. Algorithm to convert the catch option (t) from PMFC 5DE to a TAC (t) for GMA 5E, using an example catch option of 1,000 t and the average difference over the past five years.

Year	PMFC 5DE	GMA 5E	Difference (B.3)
1996	726	643	-11.6%
1997	739	605	-18.2%
1998	1,036	732	-29.4%
1999	782	676	-13.5%
2000	1,205	531	-55.9%
2001	1,290	813	-37.0%
2002	1,167	670	-42.6%
2003	1,028	642	-37.6%
2004	1,005	783	-22.1%
2005	927	711	-23.3%
2006	875	663	-24.3%
2007	798	656	-17.7%
2008	879	770	-12.3%
2009	861	733	-14.9%
2010	988	778	-21.2%
2011	1,032	795	-22.9%
Average from 2007-2011:			-17.8%

Example	Result
1st year in 5-year average	2007
Difference based on 5-year average	-17.8%
Assessment catch (t) for 5DE	1,000
Adjustment (t) between 5DE and 5E calculated as -17.8% of 1,000	-178
Revised catch (t) for 5E (1,000 - 178)	822

APPENDIX C. TRAWL SURVEYS

C.1. INTRODUCTION

This appendix summarises the derivation of the relative Pacific Ocean Perch (POP) abundance indices from the:

- west coast Haida Gwaii synoptic survey plus 1997 Ocean Selector west coast Haida Gwaii survey (Section C.3);
- historic surveys N of 54°N latitude and west of 133°W longitude (Section C.4).

Only the first set of indices was used as an index of abundance in the 5DE stock assessment model (Appendix F). The second set of indices was not accepted as being representative of the 5DE stock, for reasons given in that section. Note that Haida Gwaii was formerly known as the Queen Charlotte Islands.

C.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 $j = 1, \ldots, n_{yi}$,

$$U_{yi} = \frac{1}{n_{yi}} \sum_{j=1}^{n_{yi}} \frac{C_{yij}}{E_{yij}}, \qquad \text{(C.1)}$$

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:

$$\delta_{yi} = \frac{1}{vw} U_{yi}, \qquad \text{(C.2)}$$

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

$$\delta_{yi} = \frac{1}{n_{yi}} \sum_{j=1}^{n_{yi}} \frac{C_{yij}}{D_{yij} w_{yij}}, \qquad \text{(C.3)}$$

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:

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

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:

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

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

$$CV_y = \frac{\sqrt{V_y}}{B_y} \ . \tag{C.6}$$

C.3. THE WEST COAST HAIDA GWAII SYNOPTIC TRAWL SURVEY AND THE 1997 WEST COAST HAIDA GWAII OCEAN SELECTOR SURVEY

C.3.1. DATA SELECTION

The west coast Haida Gwaii (WCHG) survey has been conducted four times in the period 2006 to 2010 off the west coast of Haida Gwaii. It comprises a single areal stratum extending from 53°N to the BC-Alaska border and east to 133°W (e.g., Olsen et al. 2008). The 2006 survey used a different depth stratification scheme compared to the later synoptic surveys: 150-200 m, 200-330 m, 330-500 m, 500-800 m, and 800-1300 m (Workman et al. 2007). All tows from this survey were re-stratified into the four depth strata used from 2007 onwards: 180-330 m; 330-500 m; 500-800 m; and 800-1300 m, based on the mean of the beginning and end depths of each tow (Table C.1). Plots of the locations of all valid tows by year and stratum are presented in Figure C.2 (2006), Figure C.3 (2007), Figure C.4 (2008), and Figure C.5 (2010). Note that the depth stratum boundaries for this survey differ from those used for the Queen Charlotte Sound (Edwards et al., 2012*b*) and west coast Vancouver Island (Edwards et al., 2013) synoptic surveys due to the considerable difference in the seabed topography of the area being surveyed. The deepest stratum (800-1300 m) was omitted from this analysis because of inconsistent coverage.

A survey using the *Ocean Selector* was conducted in September 1997 (Workman et al. 1998), using a design that closely resembled that subsequently used for the WCHG synoptic survey, including the random selection of survey blocks and the use of Atlantic Western II box trawl net (Figure C.1, Table C.1). Tow times were set at 15 minutes, which was similar to the 20 minute target tow period used in the synoptic survey. Given the similarity in design, the familiarity of the skipper with this section of the coast and the use of three different vessels in the synoptic surveys (Table C.1), it seemed reasonable to link this survey with the four WCHG synoptic surveys conducted from 2006. Two tows conducted by this survey off the southern end of Moresby Island were dropped because the WCHG synoptic survey did not go south of 53°N latitude in 2007 and 2010, and none of the four synoptic surveys went as far south as the 1997 survey. The 1997 survey used a different depth stratification scheme compared to the later synoptic surveys: 180-275 m, 275-365 m, 365-460 m, 460-625 m, with the depth of all tows ranging from 166 m to 573 m (based on the mean of beginning and end depths). These tows were re-stratified to the WCHG stratum scheme used from 2007 onwards, taking the depth of the tow as the mean of the beginning and end depths of the tow (Table C.1).

A "doorspread density" value (C.4) was generated for each tow based on the catch of Pacific Ocean Perch, the mean doorspread for the tow and the distance travelled for both the WCHG and the 1997 Selector survey. The distance travelled was determined directly by measuring the tow path for all five surveys. There were no missing values in the distance travelled field for these five surveys, but there were some missing doorspread values in valid tows from the four synoptic surveys, which had mean doorspread values that ranged from 69 m to 81 m (Table C.2). Missing doorspread values were populated with the mean doorspread for the survey year. The 1997 Ocean Selector survey had no associated doorspread values for any of its tows because net mensuration instruments were not present at the time of the survey.

There were inconsistencies in the reported net dimensions for the 1997 survey in Workman et al. (1998), with Figure 3 of that document reporting 46 m as the combined length of the bridle plus sweeps, while the same dimension was reported as 55 m in the text of the document. Interviews with skippers who were active at the time, including Dave Clattenberg, the skipper of the 1997 Selector survey, indicated that the 55 m dimension was correct. Fifty-five metres was also the length of the bridle and sweeps used for the synoptic surveys. Consequently, the mean doorspread observed over all four synoptic surveys (76.6 m) (Table C.2) was used to populate the missing doorspread field for the 1997 Ocean Selector survey. Stratum areas were held constant for all five surveys (Table C.1).

Table C.1. Stratum designations, vessel name, number of usable and unusable tows, for each year of the west coast Haida Gwaii synoptic survey as well as the 1997 Ocean Selector survey. Also shown are the area of each stratum and 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**	**Start date**	**End date**
1997	Ocean Selector	39[2]	57	6	–	102[2]	7	07-Sep-97	21-Sep-97
2006	Viking Storm	54	27	16	13	110	20	30-Aug-06	22-Sep-06
2007	Nemesis	68	34	9	–	111	5	14-Sep-07	12-Oct-07
2008	Frosti	71	31	8	8	118	9	28-Aug-08	18-Sep-08
2010	Viking Storm	82	29	12	6	129	2	28-Aug-10	16-Sep-10
Area (km^2)		1128	1044	960	2248	5380[3]	–	–	–

[1] GFBio usability codes=0,1,2,6
[2] excludes 2 tows S of 53°N
[3] Total area (km^2)

Table C.2. Number of valid tows with doorspreads, the mean doorspread values (in m) from these tows for each survey year and the number of valid tows without doorspreads.

Year	Tows with doorspreads	Tows missing doorspreads	Mean doorspread (m)
2006	96	21	77.6
2007	113	2	68.5
2008	123	1	80.7
2010	129	2	79.1
Total/Average	461	26	76.6

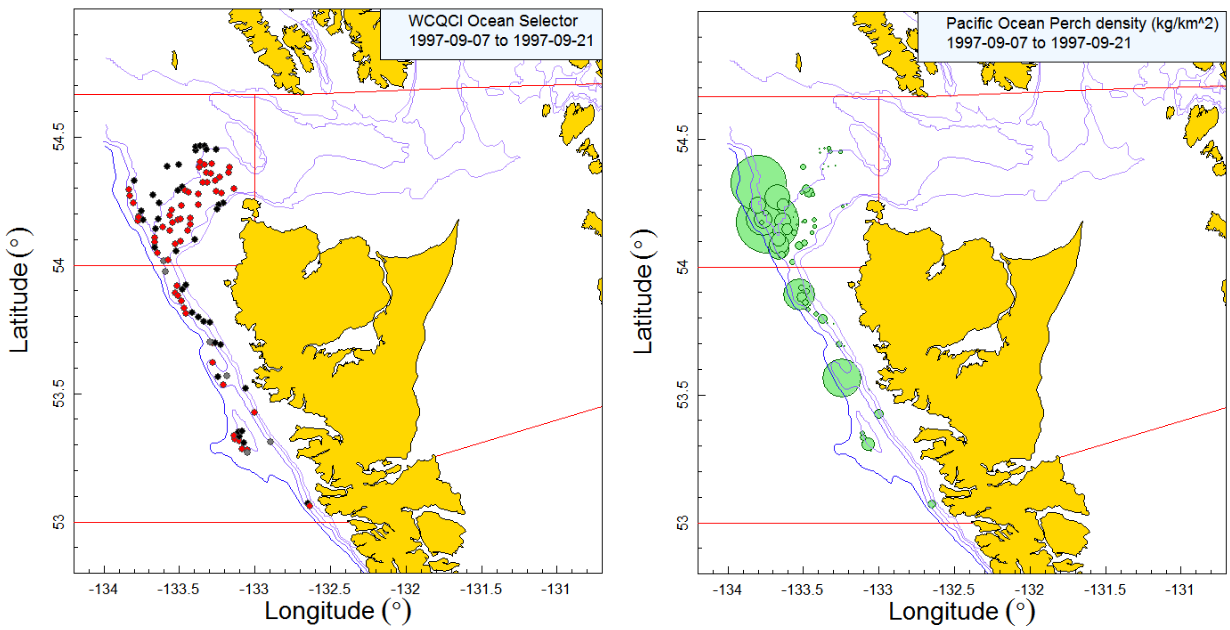


Figure C.1. Valid tow locations (180-330m stratum: black; 330-500m stratum: red; 500-800m stratum: grey) and density plots for the 1997 Ocean Selector random survey. Circle sizes in the right-hand density plot scaled across all years (1997, 2006-2010), with the largest circle = 67,694 kg/km^2 in 1997. The line at 53°N represents the effective southern boundary of these surveys, with the other red lines showing 54°N and the Pacific Marine Fisheries Commission major area boundaries.

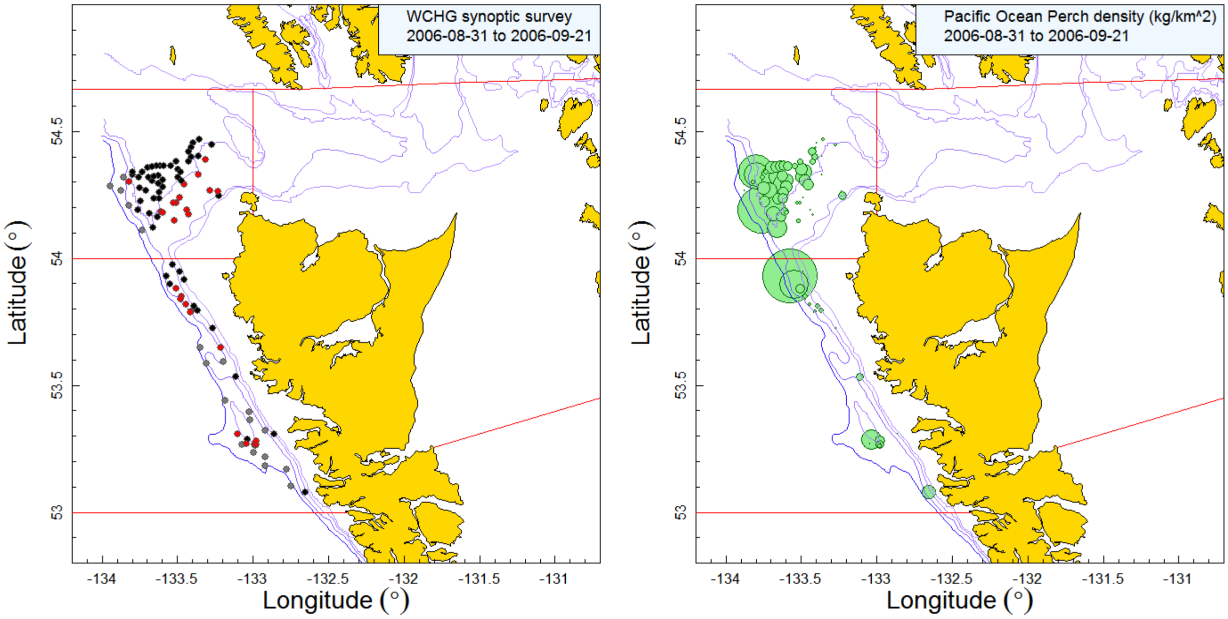


Figure C.2. Tow locations and density plots for the 2006 Viking Storm synoptic survey (see Figure C.1 caption).

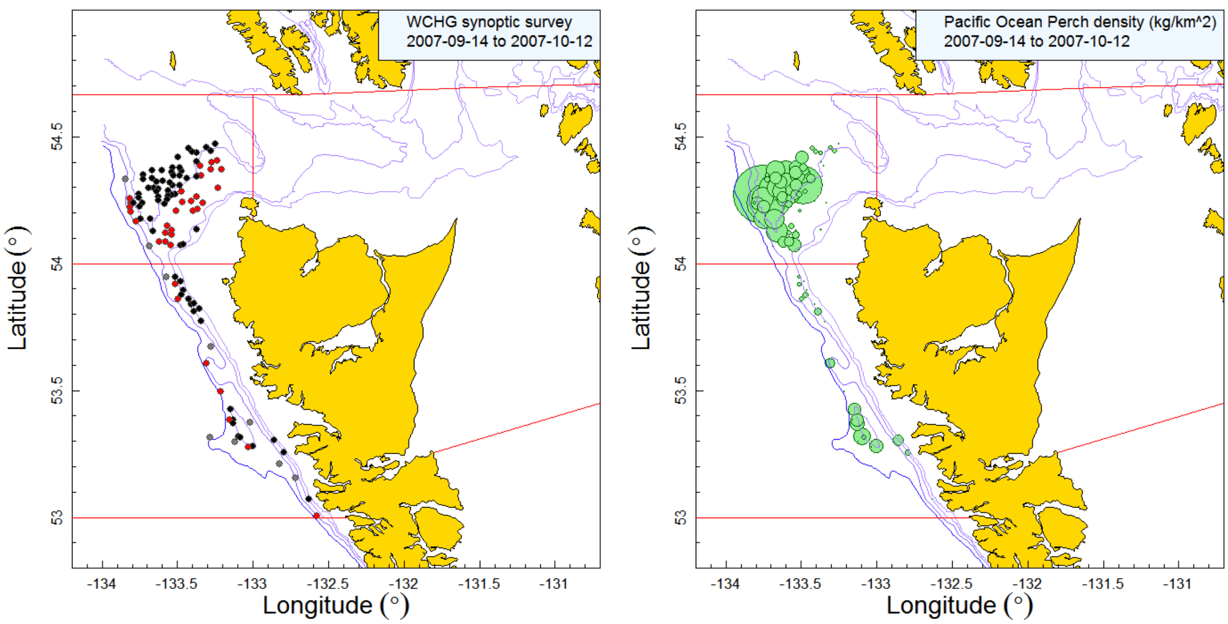


Figure C.3. Tow locations and density plots for the 2007 Nemesis synoptic survey (see Figure C.1 caption).

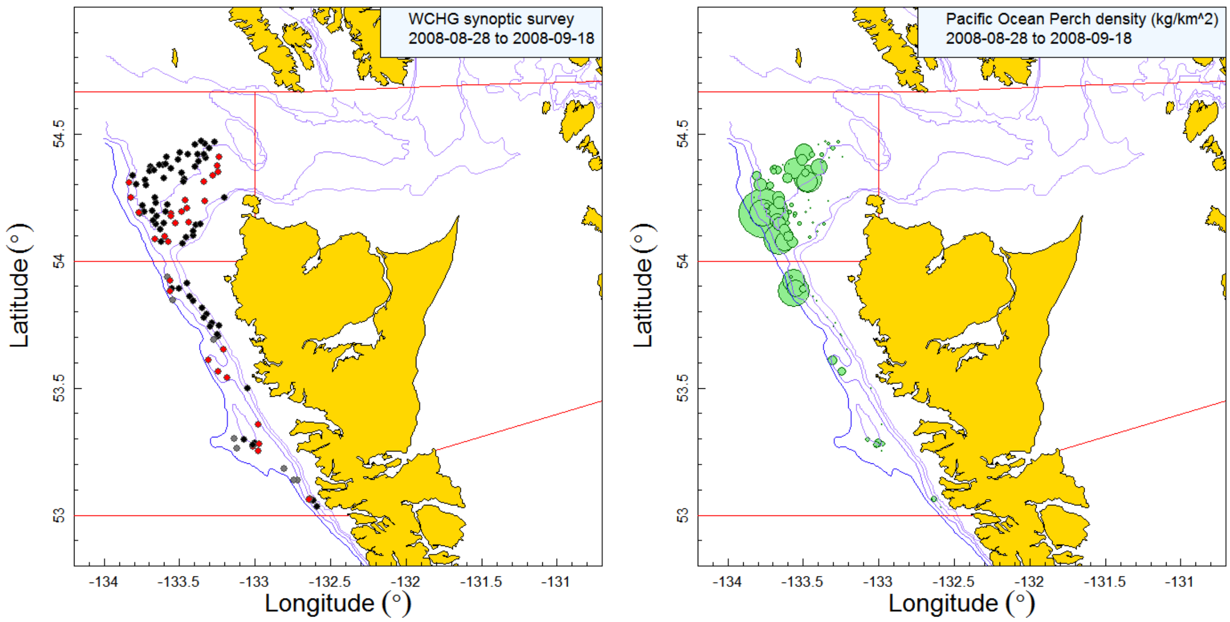


Figure C.4. Tow locations and density plots for the 2008 Frosti synoptic survey (see Figure C.1 caption).

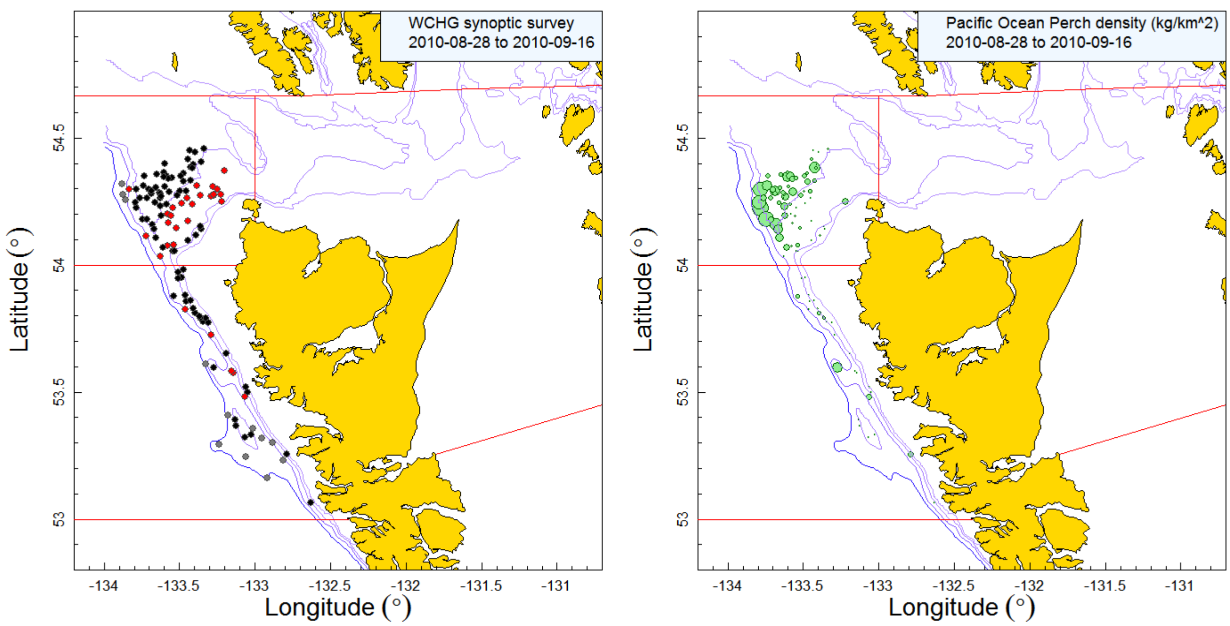


Figure C.5. Tow locations and density plots for the 2010 Viking Storm synoptic survey (see Figure C.1 caption).

C.3.2. RESULTS

Catch densities of Pacific Ocean Perch from this survey series were highest off the northwest corner of Graham Island, along with frequent tows containing POP on a long shallow ridge west of Rennell Sound [Figure C.1 (1997), Figure C.2 (2006), Figure C.3 (2007), Figure C.4 (2008), and Figure C.5 (2010)]. Pacific Ocean Perch were mainly taken at depths from 200 to 400 m, with very few observations in the deeper strata (Figure C.6).

Table C.3. Biomass estimates for Pacific Ocean Perch from the four west coast Haida Gwaii synoptic surveys and the 1997 Ocean Selector random survey. Bootstrap bias-corrected confidence intervals and coefficients of variation (CVs) are based on 1000 random draws with replacement.

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV (C.6)
1997	7,173	7,122	3,645	12,048	0.297	0.301
2006	8,763	8,750	5,976	12,542	0.192	0.191
2007	7,455	7,422	5,431	10,380	0.167	0.175
2008	7,536	7,566	4,759	11,239	0.212	0.219
2010	3,824	3,817	2,894	4,938	0.137	0.137

Estimated biomass levels for Pacific Ocean Perch from these trawl surveys were variable with no trend over the first four surveys, including the 1997 Ocean Selector survey (Figure C.7; Table C.3). However, the most recent 2010 survey biomass estimate was about one-half the 2008 biomass estimates. The estimated CVs for the 2006-2010 surveys were acceptable, lying between 14 and 22%, with the CV for the 1997 Ocean Selector survey being higher at 30% (Table C.3). The proportion of tows that captured Pacific Ocean Perch in the synoptic surveys was consistently near 80% of the valid tows over the four synoptic survey years, while being closer to 70% for the 1997 Ocean Selector survey (Figure C.8).

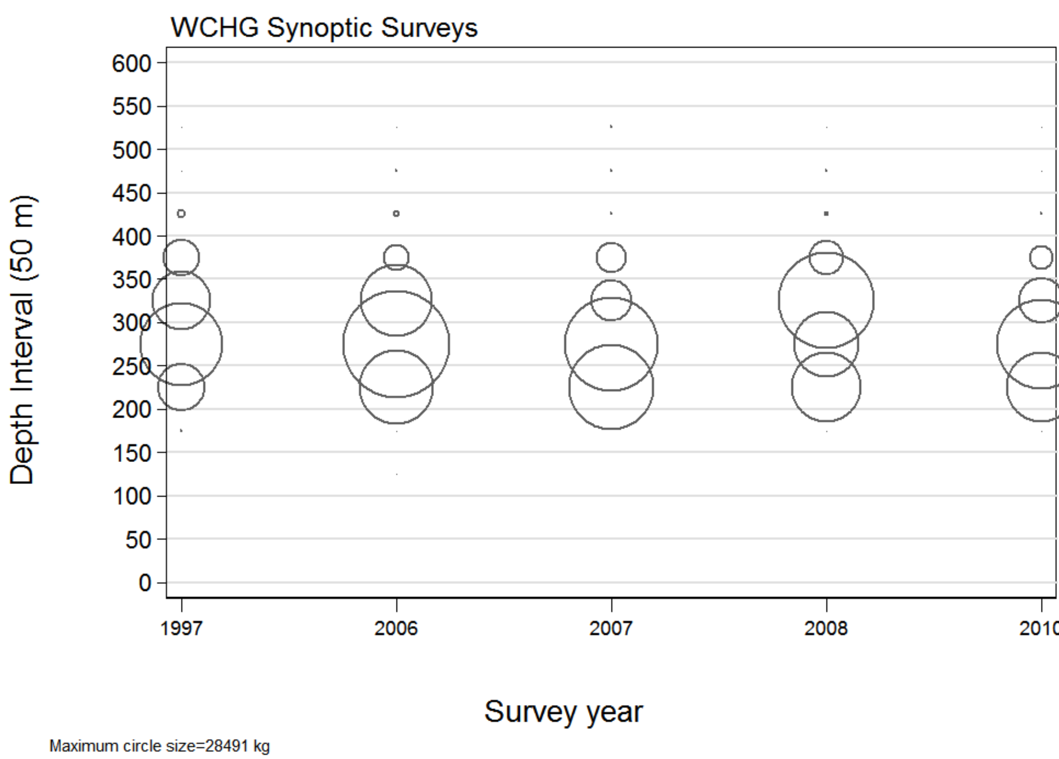


Figure C.6. Distribution of observed weights of Pacific Ocean Perch by survey year and 50-m depth zone. Depth zones are indicated by the mid point of the depth interval and circles in the each panel are scaled to the maximum value of 28,491 kg for the 250-300 m interval in 2006. Minimum and maximum depths observed for POP: 146 m and 628 m, respectively. Depth is taken at the start position for each tow.

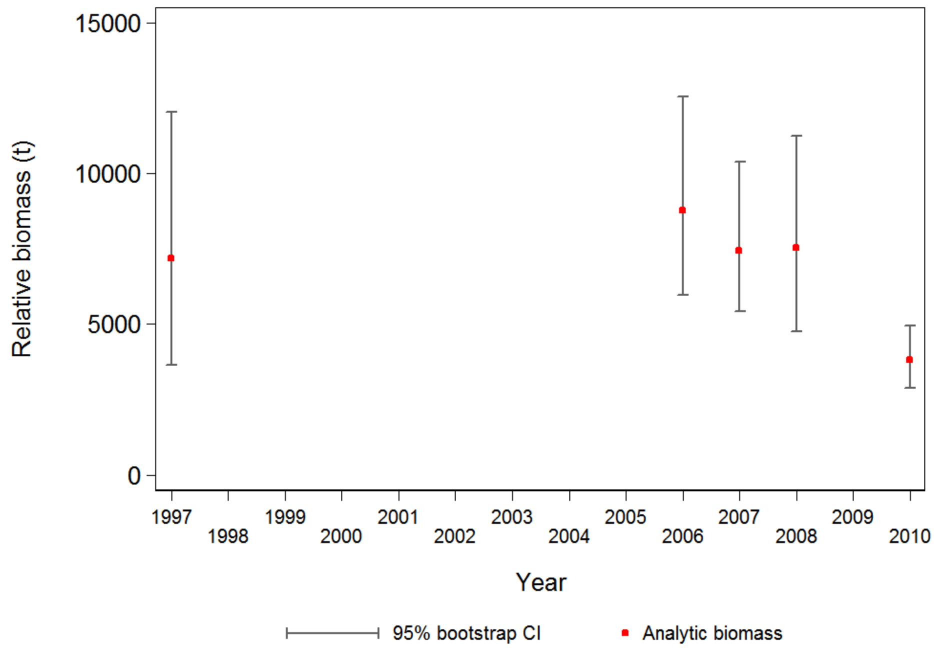


Figure C.7. Biomass estimates for Pacific Ocean Perch from the four west coast Haida Gwaii synoptic surveys and the 1997 Ocean Selector random survey (Table C.3). Bias-corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

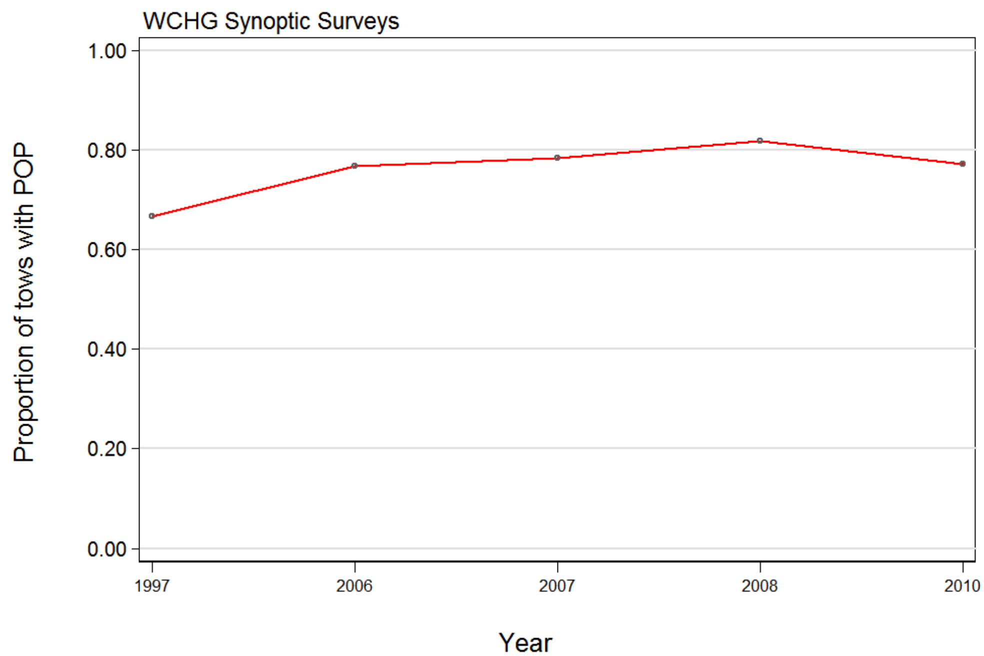


Figure C.8. Proportion of tows by year that contain Pacific Ocean Perch for the four west coast Haida Gwaii synoptic surveys and the 1997 Ocean Selector random survey.

The 1997 Ocean Selector survey and the 2006-2010 synoptic surveys were accepted as a linked series of abundance indices for use in the stock assessment model (described in Appendix F).

C.4. HISTORICAL TRAWL SURVEYS CONDUCTED OFF THE WEST COAST HAIDA GWAII

C.4.1. DATA SELECTION

A subset of the DFO database GFBio, called GFBioCatEff, was queried for all bottom trawl research trips that operated on the west coast of Haida Gwaii over the period 1965 to 1996. This query was further restricted to trips with at least four valid tows in the Pacific Marine Fisheries Commission major statistical area 5E. Twenty-four trips were identified (Table C.4) as potential candidates. This list was further reduced to 11 trips, all of which had at least twenty tows and spanned 8 years over the period 1977 to 1996. Three trips conducted by the G.B. Reed and the Free Enterprise in the mid-1980s were included in this list, even though there were fewer than twenty tows, because they were known to have been conducted as biomass surveys. These 11 trips have been plotted by year (1977 and 1978: Figure C.9; 1979 and 1982: Figure C.10; 1983 and 1985: Figure C.11; 1993 and 1996: Figure C.12) as a first step in identifying suitable trips.

Table C.4. List of all research trips in GFBioCatEff which operated in WCHG (5E) from 1965 to 1997. Filters applied to get table results include: trawl gear, tows with a valid start position and starting depth, and ≥ 4 valid tows in 5E for the trip. Trips highlighted in blue/grey have been extracted for plotting.

Year	TRIP_ID	vessel_ID	VESSEL_NAME	Number tows
1966	41333	2001	G. B. REED	10
1970	65086	2001	G. B. REED	4
1971	70988	2001	G. B. REED	4
1977	25394	362	BLUE WATERS	19
1977	25400	380	NEMESIS	34
1977	25436	392	SCOTIA BAY	17
1978	65806	362	BLUE WATERS	81
1978	66107	424	FREEPORT	8
1978	70848	2001	G. B. REED	19
1978	70867	398	ARCTIC HARVESTER	18
1978	71008	2506	NORE-DICK (USA)	5
1979	60606	362	BLUE WATERS	65
1979	60607	392	SCOTIA BAY	42
1979	65646	362	BLUE WATERS	75
1979	70967	380	NEMESIS	14
1979	70968	392	SCOTIA BAY	4
1980	58280	432	CALLISTRATUS	5
1982	65366	2001	G. B. REED	10
1983	65826	437	FREE ENTERPRISE NO 1	13
1983	69347	2001	G. B. REED	4
1985	58580	2001	G. B. REED	5
1989	10378	412	OCEAN SELECTOR	11
1993	53020	2000	W. E. RICKER	44
1996	30864	2000	W. E. RICKER	39

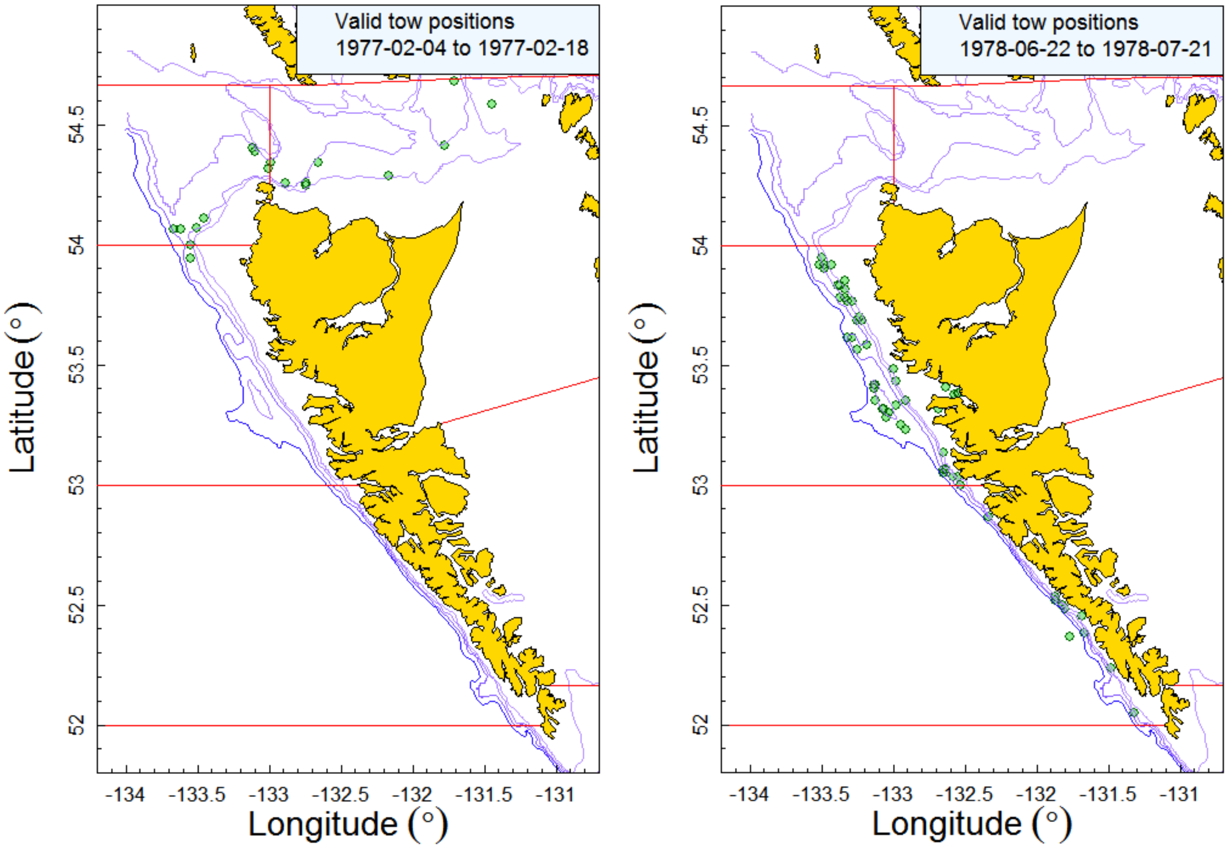


Figure C.9. Tow locations for trip ID 25394 (Blue Waters) in 1977 and for trip ID 65806 (Blue Waters) in 1978. Latitudes 53°N and 54°N are shown with horizontal red lines.

The dates spanned in each year and the number of valid tows by year are shown in Table C.5. Based on the information in this table and on the distribution of available tows, three years were selected as potential candidates for a survey reconstruction: 1979, 1993 and 1996. These years were selected because there appeared to be adequate and consistent coverage in a 'box' defined on the south by the 54°N latitude line, on the north by the U.S.A.-Canada border and on the east by 133°W longitude (e.g., see Figure C.10) in approximately equivalent time periods (Table C.6). Tows from two 1983 trips, which operated in the correct time period and area (see [left panel] Figure C.11), were not used because the design of this survey was not compatible with the assumption that the locations of the observed tows had been selected randomly (R. Stanley, pers. comm.).

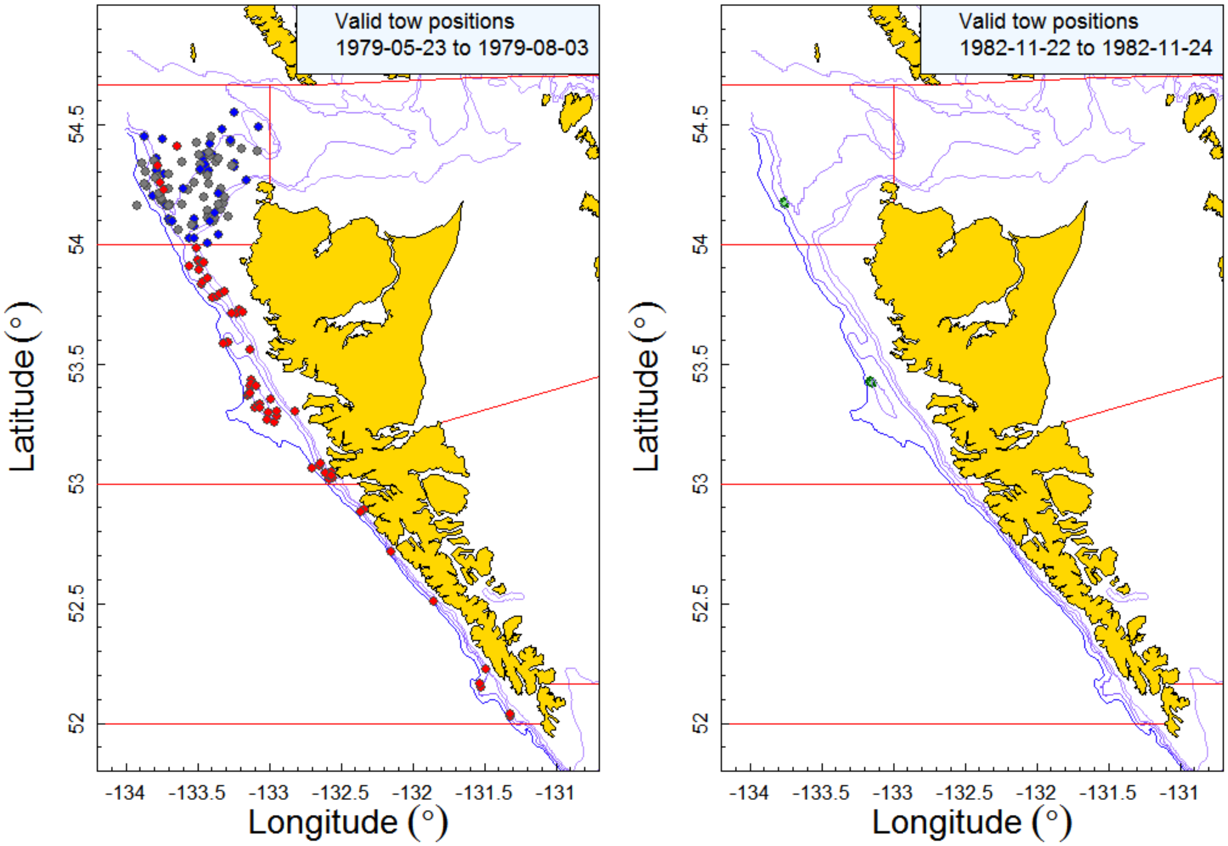


Figure C.10. Tow locations for trip ID 60606 (Blue Waters - black), 60607 (Scotia Bay - red), 65646 (Blue Waters - grey) in 1979 and for trip ID 65366 (GB Reed) in 1982. Latitudes 53°N and 54°N are shown with horizontal red lines.

Table C.5. Number of usable tows by survey year for the trips identified in Table C.4. Also shown are the dates of the first and last survey tow in each year. Tows were usable if they either had a valid beginning or ending depth observation, a complete latitude/longitude pair, and a valid usability code. Years highlighted in grey were selected for further consideration.

Year	Tows[1]	Start Date	End Date
1977	19	1977-02-04	1977-02-18
1978	61	1978-06-22	1978-07-21
1979	154	1979-05-23	1979-08-03
1982	10	1982-11-22	1982-11-24
1983	18	1983-07-09	1983-07-19
1985	5	1985-11-03	1985-11-05
1993	42	1993-06-19	1993-06-27
1996	39	1996-07-05	1996-07-13
Total	348	–	–

[1] GFBio usability codes=0,1,2,6

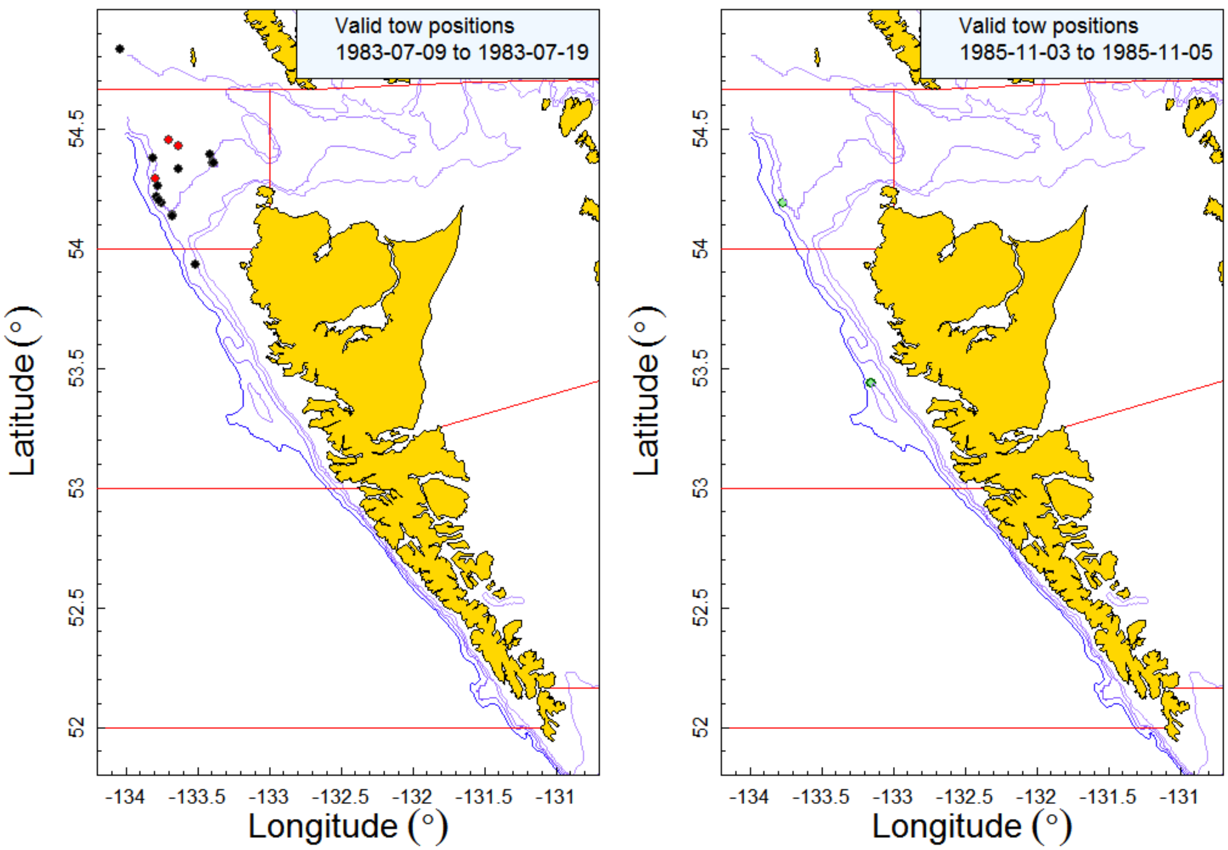


Figure C.11. Tow locations for trip ID 65826 (Free Enterprise – black) and trip ID 69347 (GB Reed - red) in 1983 and for trip ID 58580 (GB Reed) in 1985. Latitudes 53°N and 54°N are shown with horizontal red lines.

It is not known whether the 1979 trips can be treated as random stations. The available published report (Lapi and Richards 1981) does not contain a description of how the tow locations were selected, nor is there a description of the procedure followed when towing. The two W.E. Ricker survey documents for 1993 (Leaman et al. 1996) and 1996 (Leaman et al. 1997) state that the surveys followed a "stratified-random design", but the documents do not describe in detail how stations were selected nor do they describe the procedure followed when towing.

The available data for gauging the comparability of the nets used in these candidate surveys are problematic. The two vessels which conducted the 1979 tows are reported to have widely different net configurations (in spite of using the same basic net), with the FV Scotia Bay having very short bridle plus sweeps dimensions (41 m) compared to 91 m for the FV Blue Waters (Table C.7). Neither of these dimensions were commonly used industry standards for this component of the net, with 55 m (180 feet) being a more usual value when fishing in this area for Pacific Ocean Perch (skippers: Don Vaccher, pers. comm., Brian Mose pers. comm.). This large difference in bridle + sweep length will translate into a substantial difference in the realised doorspread, compromising the comparability between these vessels, especially given that there are no direct observations of doorspread available.

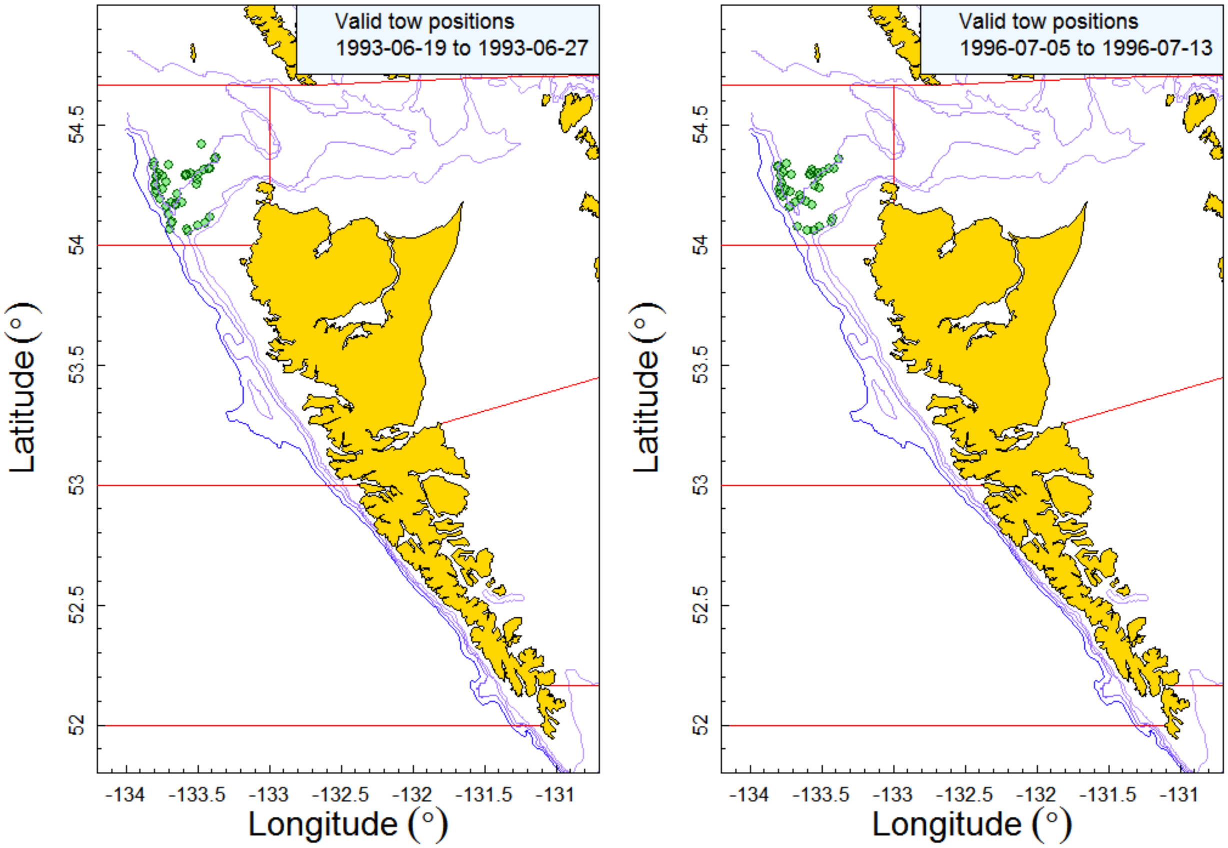


Figure C.12. Tow locations for trip ID 53020 (W.E. Ricker) in 1993 and for trip ID 30864 (W.E. Ricker) in 1996. Latitudes 53°N and 54°N are shown with horizontal red lines.

Table C.6. Stratum designations, GFBioCatEff trip ID number, vessel name, number of usable tows, for each year of the trips which operated north of 54°N and west of 133°W. Also shown are the area of each stratum and the dates of the first and last survey tow in each year and trip.

Survey year	**Trip #**	**Vessel**	**Stratum depth zone 180-330m**	**330-500m**	**Total Tows[1]**	**Start Date**	**End Date**
1979	60606	BLUE WATERS	28	19	47	12-Jul-79	01-Aug-79
1979	60607	SCOTIA BAY	26	8	34	21-Jul-79	03-Aug-79
1993	53020	W. E. RICKER	31	10	41	19-Jun-93	27-Jun-93
1996	30864	W. E. RICKER	35	4	39	05-Jul-96	13-Jul-96
Area (km^2)			808	648	1,456[2]	–	–

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

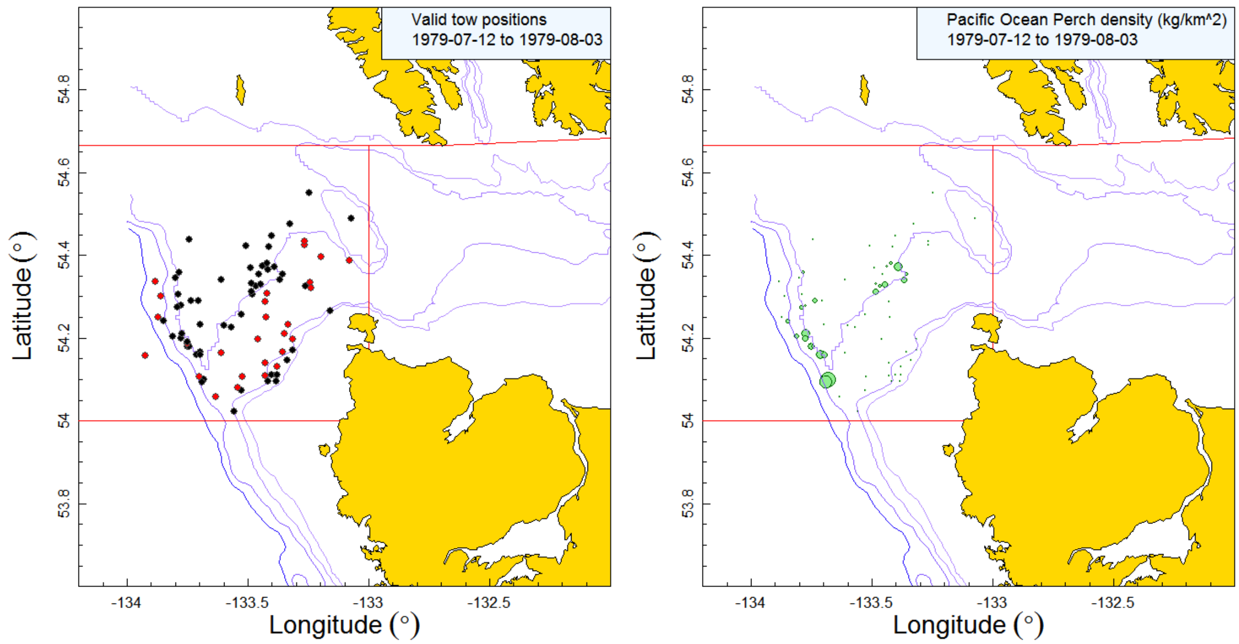


Figure C.13. Tow locations (180-330m stratum: black; 330-500m stratum: red) and density plots for 1979: combined trip IDs 60606 (Blue Waters) and 60607 (Scotia Bay). Circle size in the right-hand density plot scaled across all years (1979, 1993 and 1996, with the largest circle = 115,211 kg/km^2 in 1996).

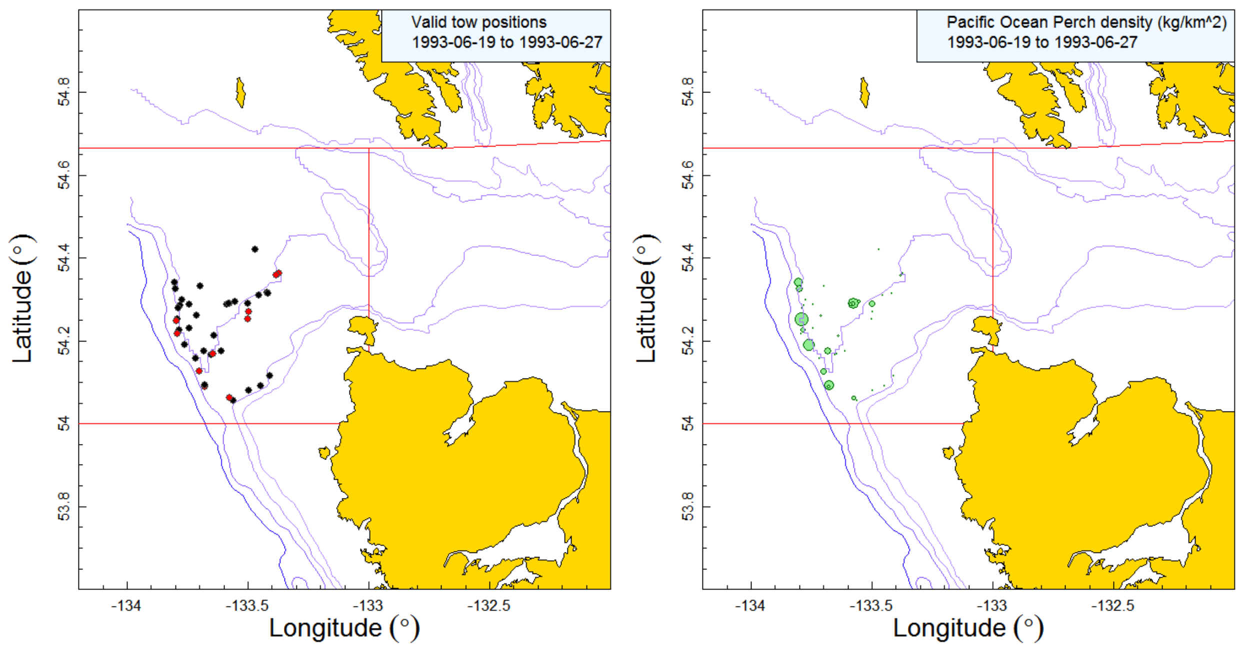


Figure C.14. Tow locations (180-330m stratum: black; 330-500m stratum: red) and density plots for 1993 survey: trip ID 53020 (W.E. Ricker). Circle size in the right-hand density plot scaled across all years (1979, 1993 and 1996, with the largest circle = 115,211 kg/km^2 in 1996).

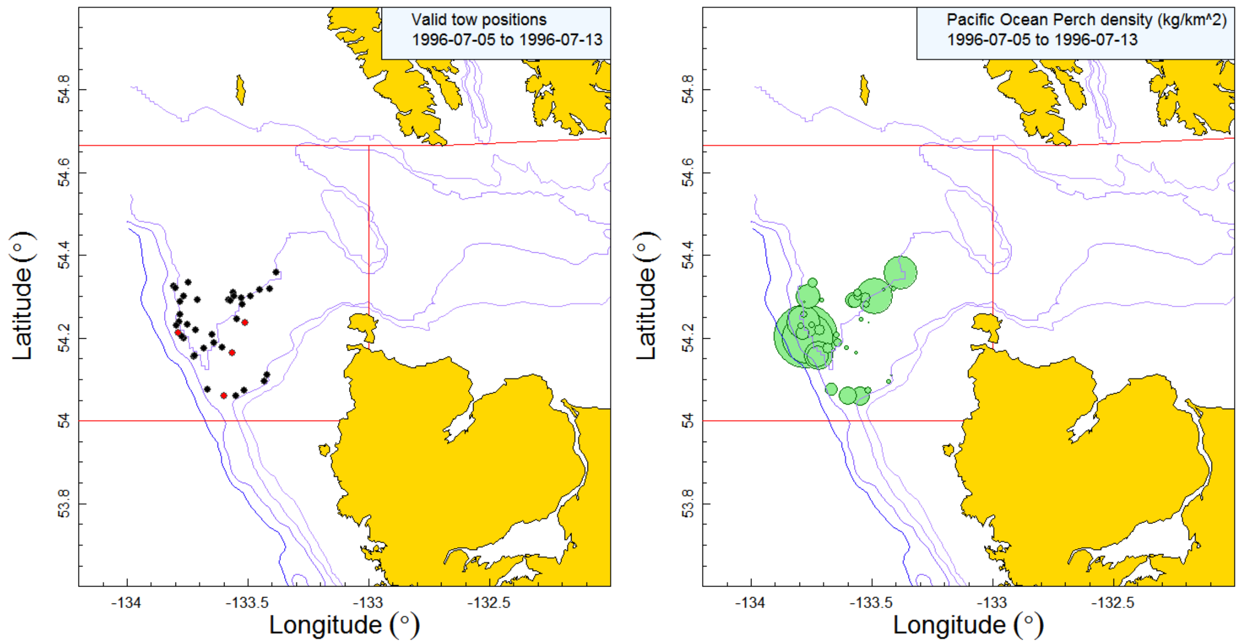


Figure C.15. Tow locations (180-330m stratum: black; 330-500m stratum: red) and density plots for 1996 survey: trip ID 30824 (W.E. Ricker). Circle size in the right-hand density plot scaled across all years (1979, 1993 and 1996, with the largest circle = 115,211 kg/km^2 in 1996).

Table C.7. Net used, combined length of sweeps and bridles, and calculated doorspread for the four trips identified for possible use as a survey series from Table C.6.

Year	Vessel	Skipper	Net	Bridle + sweeps (m)	Calculated doorspread (m)
1979	BLUE WATERS	Don Vaccher	Western III	91	unknown
1979	SCOTIA BAY	Vagn Marks	Western III	41	unknown
1993	W. E. RICKER	unknown	Western IIIA	46	51
1996	W. E. RICKER	unknown	Western IIIA	46	51
1996[1]			damaged	37[1]	44[1]

[1] damaged net; sweeps removed

There were significant problems with analysing the 1996 W.E. Ricker survey data due to incomplete information available in the database and damage sustained by the trawl net while undertaking the survey (Leaman et al. 1997). Specifically, this survey did not have associated usability codes, a field which is used in the database to indicate which tows are available for biomass estimation or might have been affected by net damage or other problems. As can be seen from the information in Table C.7, the documented net damage resulted in a significantly reduced doorspread because of the removal of the sweeps, which would, as described in Leaman et al. (1997), affect the catchability of the survey net. Again, without the availability of *in situ* net mensuration data to monitor the actual doorspreads, the comparability of the survey tow data, even within the same survey, was compromised.

C.4.2. RESULTS

Catch densities of Pacific Ocean Perch from these three candidate surveys tended to be distributed along the 200 m contour off the NW tip of Graham Island (1979: Figure C.13; 1993: Figure C.14; 1996: Figure C.15). Pacific Ocean Perch were mainly taken at depths from 200 to 400 m, with very few observations in the deeper strata (Figure C.16). This plot also shows that the 1993 W.E. Ricker survey may have had a slightly deeper distribution for POP compared to the 1979 and 1996 data. Nearly every tow from the 1993 and 1996 survey data contained POP, while about 18% of the tows from the 1979 data did not contain POP (Figure C.17).

Estimated biomass levels for Pacific Ocean Perch are not presented for these three survey years because of the potential for poor or no comparability within and between years. The 1979 data were compromised within the survey year because of the extreme difference in the net configuration used between vessels (Table C.7). Similarly, the 1996 W.E. Ricker survey sustained net damage without the database capacity to identify the affected tows. Finally, the comparability of the 1979 data with the two W.E. Ricker surveys is unknown, particularly without having confidence in the doorspread information needed to calculate comparable swept area estimates for each of these three survey years.

For the reasons given above, these three (1979, 1993 and 1996) survey indices were not accepted as a linked series of abundance indices for use in the stock assessment model (Appendix F).

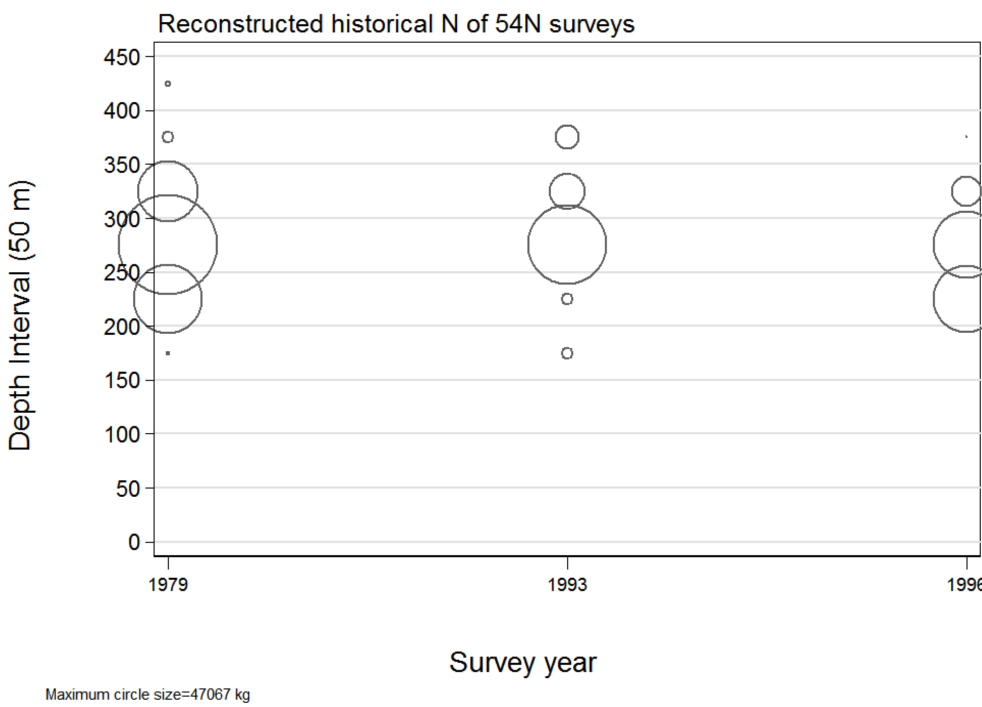


Figure C.16. Distribution of observed weights of Pacific Ocean Perch by survey year and 50-m depth zone. Depth zones are indicated by the mid point of the depth interval and circles in the each panel are scaled to the maximum value 47,067 kg (250-300 m interval in 1979). Minimum and maximum depths observed for POP: 190 m and 424 m, respectively. Depth is taken at the start position for each tow.

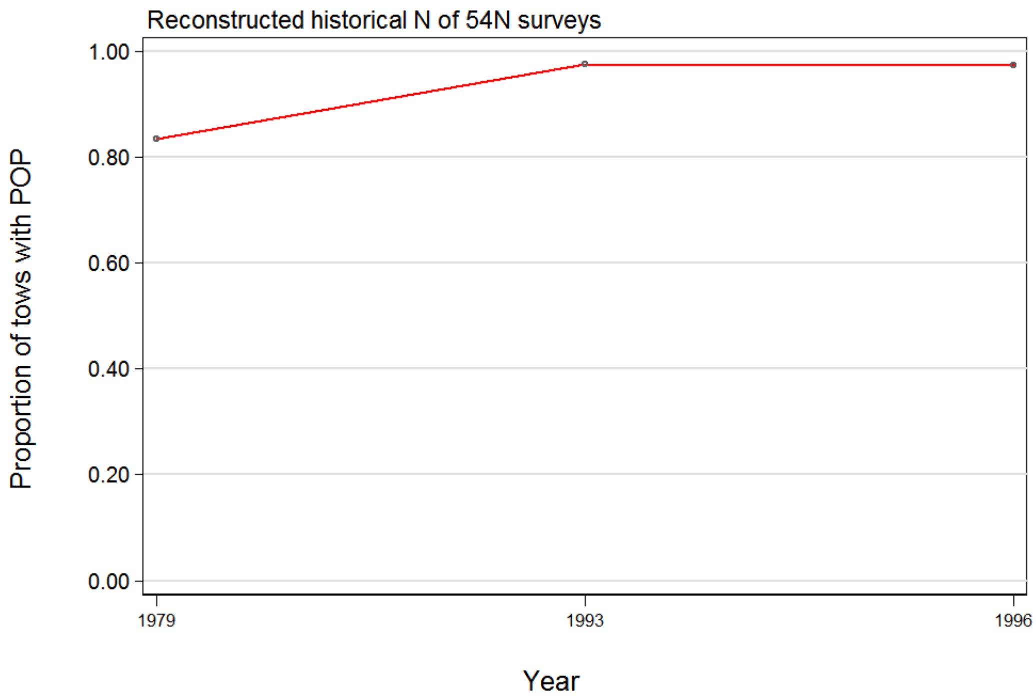


Figure C.17. Proportion of tows by year which contain Pacific Ocean Perch for the three reconstructed surveys north of 54°N for 1979, 1993 and 1996.

D BIOLOGICAL DATA

Here we present the parameterisation of the weights-at-age and female maturity. These are taken from our Pacific Ocean Perch assessment for Queen Charlotte Sound (Edwards et al., 2012*b*); the same values are used for the companion assessment (Edwards et al., 2013) for area 3CD.

D.1 PARAMETERISATION OF WEIGHTS-AT-AGE

The estimates of weights-at-age are the same as those used in Edwards et al. (2012*b*). The average weight of an individual of age-class a of sex s is denoted w_{as} (kg), and is given by

$$w_{as} = \alpha_s L_{as}^{\beta_s}, \tag{D.1}$$

where (for each sex, s) α_s is the growth rate scalar, L_{as} is the length (cm) of an individual of age a, and β_s is the growth rate exponent. Sex $s = 1, 2$ for females and males, respectively.

The lengths L_{as} are given by the von-Bertalanffy model

$$L_{as} = L_{\infty,s}\left(1 - e^{-k_s(a - t_{0,s})}\right), \tag{D.2}$$

where (for each sex, s) $L_{\infty,s}$ is the average length at maximum age of an individual, k_s is the growth rate coefficient, and $t_{0,s}$ is the age at which the average size is zero.

In Edwards et al. (2012*b*) data came from Queen Charlotte Sound and the west coasts of Vancouver Island and Haida Gwaii. The differences between areas were found to be relatively small and probably a result of data issues rather than reflecting actual differences in growth rates among the five areas. There was also little sensitivity to combining length-age pairs from research and commercial sources or using each source separately. The parameters were calculated from combining data from areas 5A, 5B, 5C and 5E. Given the similarities between areas, here we use the same estimated parameters as in Edwards et al. (2012*b*). The values are given in Table D.1, and were used as fixed inputs to the stock assessment model (to calculate w_{as} for each a and s). Figure D.1 shows the resulting mean lengths-at-age and mean weights-at-age.

Table D.1. Fixed allometric growth parameters for females and males, used as inputs for the stock assessment model. See text for parameter definitions.

Parameter	Females	Males
$L_{\infty,s}$	45.11	41.62
k_s	0.1404	0.1675
$t_{0,s}$	-1.303	-1.021
α_s	9.258×10^{-6}	8.126×10^{-6}
β_s	3.116	3.155

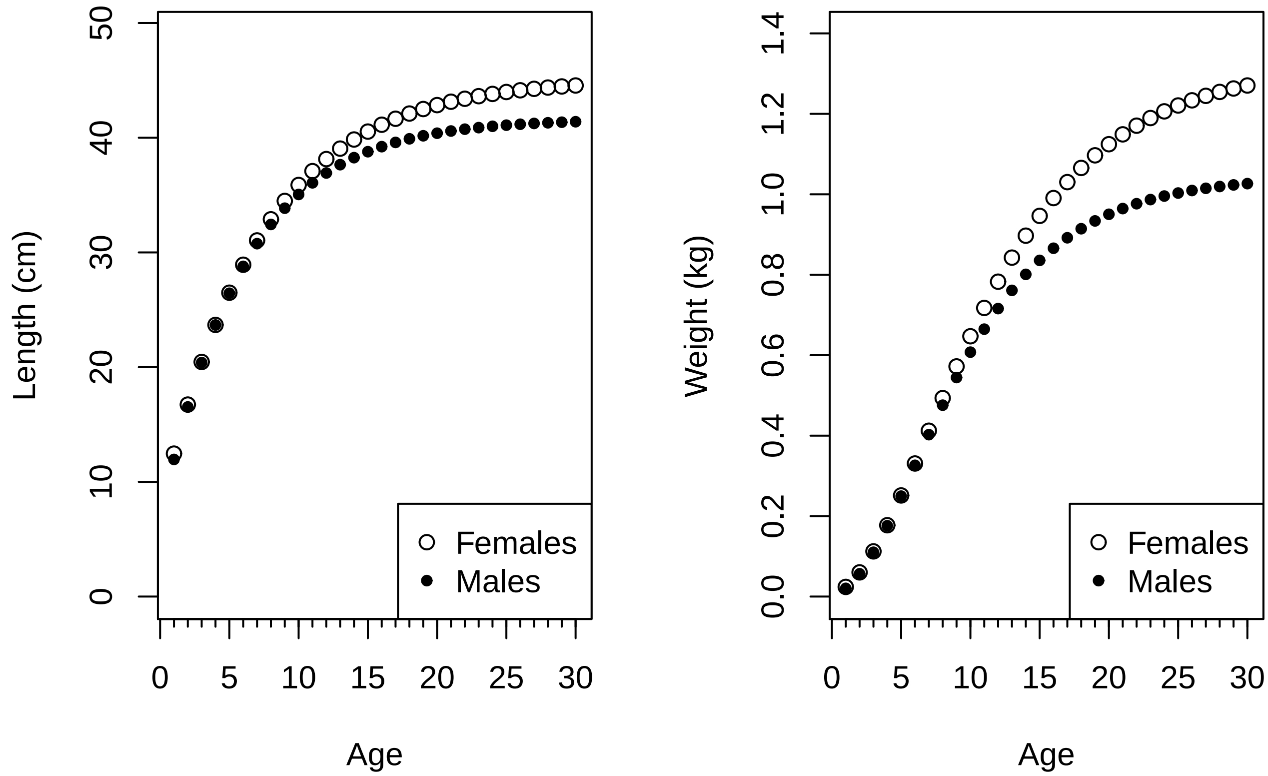


Figure D.1. Mean lengths-at-age and mean weights-at-age for each sex, as given by (D.2) and (D.1) with parameter values from Table D.1.

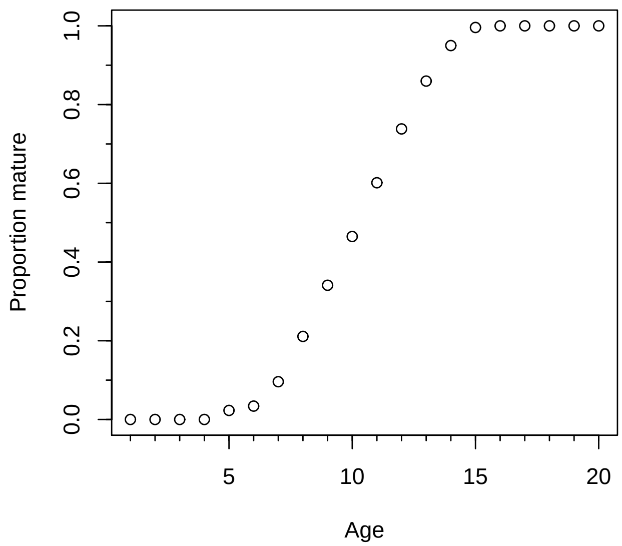


Figure D.2. Maturity ogive for females used in the stock assessment model. Values are given in Table D.2.

D.2 PARAMETERISATION OF FEMALE MATURITY

The proportion of age-class a females that are mature, m_a, was also taken from Edwards et al. (2012*b*). The resulting ogive is given in Figure D.2 and Table D.2, and was based on 21,000 observations from PMFC areas 5ABCE. It was calculated by fitting a double-normal function to the observed proportions that were mature at each age, and then, as for Stanley et al. (2009) for Canary Rockfish, using the observed proportions for ages < 9 because the fitted function appeared to overestimate the proportion of mature females.

Table D.2. Maturity ogive for females used in the stock assessment model, as plotted in Figure D.2.

Age	Proportion mature	Age	Proportion mature
1	0.000	11	0.601
2	0.000	12	0.738
3	0.000	13	0.860
4	0.000	14	0.950
5	0.023	15	0.996
6	0.034	16	1.000
7	0.096	17	1.000
8	0.211	18	1.000
9	0.341	19	1.000
10	0.465	20	1.000

E WEIGHTED AGE FREQUENCIES/PROPORTIONS

We summarize a method for representing commercial and survey age structures for a given species through weighting age frequencies n_a or proportions n'_a by catch$\|$density in defined strata. (We use the symbol '$\|$' to delimit parallel values for commercial and survey analyses, respectively, as the mechanics of the weighting procedure are similar for both.) For commercial samples, these strata comprise quarterly periods within a year, while for survey samples, the strata are defined by longitude, latitude, and depth. Within each stratum, commercial ages are weighted by the catch weight (kg) of Pacific Ocean Perch (POP) in tows that were sampled, and survey ages are weighted by the catch density (kg/km^2) of POP in sampled tows. A second weighting is then applied: quarterly commercial ages are weighted by the commercial catch weight of POP from all tows within each quarter; stratum survey ages are weighted by stratum areas (km^2) in the survey. For the commercial data, the overall method is the same as that used in (Edwards et al., 2012*a*,*b*); for survey data we now weight by density then stratum area, as opposed to sample catch and then stratum catch.

Ideally, sampling effort would be proportional to the amount of POP caught, but this is not usually the case. Personnel can control the sampling effort on surveys more than that aboard 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 presented below attempts to adjust for unequal sampling effort among strata.

For simplicity herein, we illustrate the weighting of age frequencies n_a, unless otherwise specified. The weighting occurs at two levels: h (quarters for commercial ages, strata for survey ages) and i (years if commercial, surveys in series if survey). Notation is summarised in Table E.1.

For each quarter$\|$stratum h we weight sample unit frequencies n_{ad} by sample unit catch$\|$density of a given species. (For commercial ages, we use trip as the sample unit, though if one trip contains multiple samples these 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:

$$C'_{dhi} = \frac{C_{dhi}}{\sum_d C_{dhi}} \ . \tag{E.1}$$

The proportions C'_{dhi} are used to weight the age frequencies n_{adhi} to yield weighted age frequencies by quarter$\|$stratum for each year$\|$survey:

$$m_{ahi} = \sum_d \left(C'_{dhi} n_{adhi} \right) \ . \tag{E.2}$$

This transformation reduces the frequencies n from the originals, and so we rescale (multiply) m_{ahi} by the factor

$$\frac{\sum_a n_{ahi}}{\sum_a m_{ahi}} \tag{E.3}$$

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

Table E.1. Equations for weighting age frequencies or proportions for a given species.
*(**c**) = commercial, (**s**) = survey*

Symbol	Description
	Indices
a	age class (1 to 30, where 30 is an accumulator age-class)
d	(**c**) trip IDs as sample units
	(**s**) sample IDs as sample units
h	(**c**) quarters (1 to 4), 91.5 days each
	(**s**) strata (area-depth combinations)
i	(**c**) calendar years (1977 to 2012)
	(**s**) survey IDs in survey series (e.g., WCHG Synoptic)
	Data
n_{adhi}	frequency-at-age a for sample unit d in quarter$\|$stratum h of year$\|$survey i
n'_{adhi}	proportion-at-age a for sample unit d in quarter$\|$stratum h of year$\|$survey i
C_{dhi}	(**c**) commercial catch (kg) of a given species for sample unit d in quarter h of year i
	(**s**) density (kg/km^2) of a given species for sample unit d in stratum h of survey i
C'_{dhi}	C_{dhi} as a proportion of total catch$\|$density $C_{hi} = \sum_d C_{dhi}$
m_{ahi}	weighted age frequencies at age a in quarter$\|$stratum h of year$\|$survey i
K_{hi}	(**c**) total commercial catch (kg) of species 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

At the second level of stratification by year$\|$survey i, we calculate the annual proportion of quarterly catch (t) for commercial ages or the survey proportion of stratum areas (km^2) for survey ages

$$K'_{hi} = \frac{K_{hi}}{\sum_h K_{hi}} \tag{E.4}$$

to weight m_{ahi} and derive weighted age frequencies by year$\|$survey:

$$p_{ai} = \sum_h \left(K'_{hi} m_{ahi}\right) \ . \tag{E.5}$$

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

$$\frac{\sum_a m_{ai}}{\sum_a p_{ai}} \ . \tag{E.6}$$

to retain the original number of observations.

Finally, we standardise the weighted frequencies to represent proportions-at-age:

$$p'_{ai} = \frac{p_{ai}}{\sum_a p_{ai}} \ . \tag{E.7}$$

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

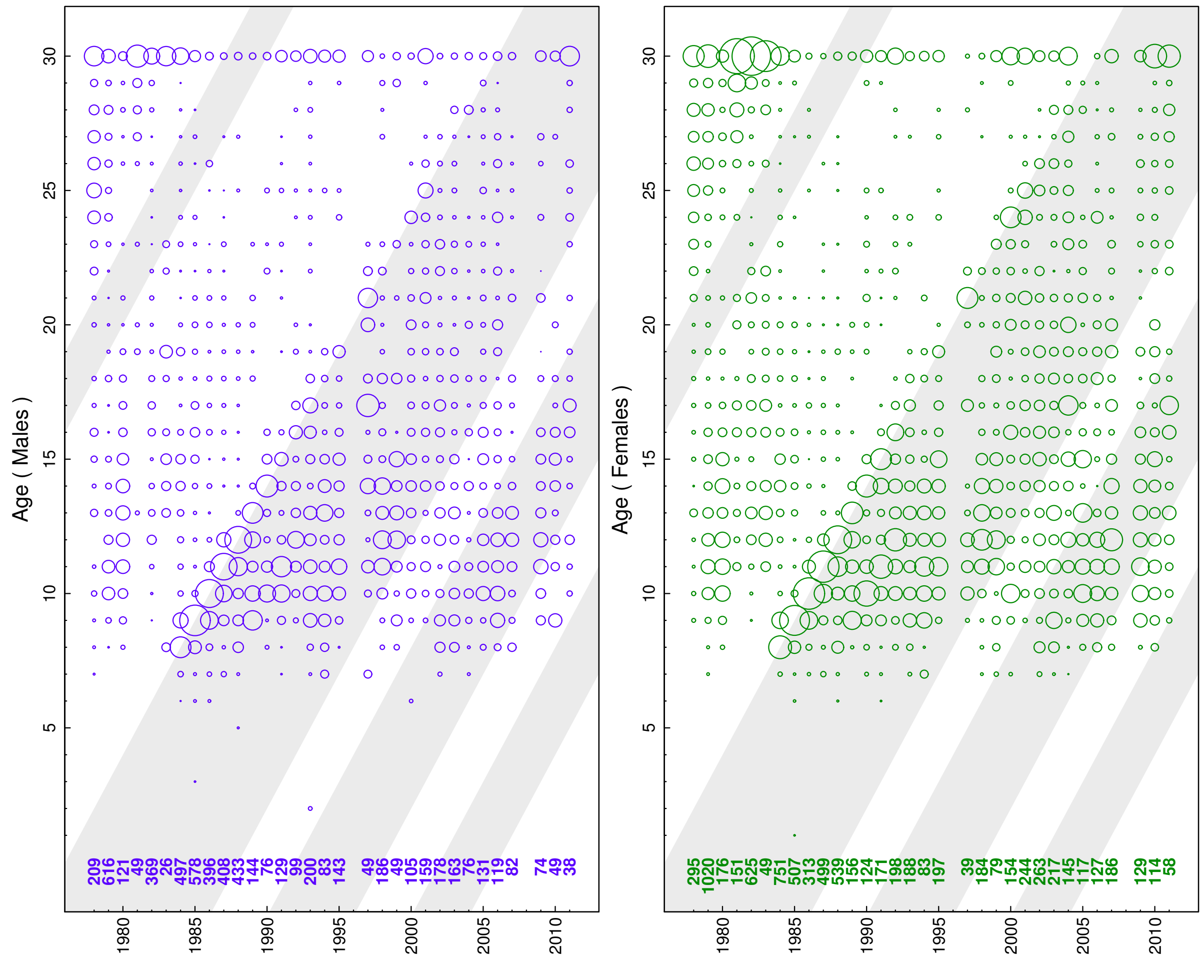


Figure E.1. Commercial POP proportions-at-age in PMFC 5DE based on age frequencies weighted by trip catch within quarters and commercial catch within years. Diagonal shaded bands indicate cohorts that were born when the Pacific Decadal Oscillation was positive, potentially creating conditions in pelagic waters that foster productivity. Number of specimens aged are displayed along the bottom axis.

The choice of data input (frequencies n *vs.* proportions n') does matter: the numeric outcome can be very different, especially if the input samples comprise few observations. Theoretically, weighting by frequencies emphasises our belief in individual observations at specific ages while weighting by 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, we weight age frequencies n.

The commercial age data (Figure E.1) show a very strong cohort originating in 1976, which remains prominently in the data 20 or more years after these fish were born. This pattern was also seen for POP in Queen Charlotte Sound (Edwards et al., 2012*b*) but not off the west coast of Vancouver Island (Edwards et al., 2013). Young ages are under-represented due to the usual gear selectivity issues, and the annual 30-y plus classes exhibit an episodic pattern. The 1982 plus class for females is especially strong and likely reflects a strong 1952 year class, as observed in QCS POP (Edwards et al., 2012*b*). There is no evidence for an incoming pulse of

Table E.2. Quarterly data for commercial trips: number of sampled trips N_h, where h is quarter, POP catch(t) by sampled trip C_h, and POP catch (t) for all trips in quarter h, K_h.

Year	$N_{h=1}$	$N_{h=2}$	$N_{h=3}$	$N_{h=4}$	$C_{h=1}$	$C_{h=2}$	$C_{h=3}$	$C_{h=4}$	$K_{h=1}$	$K_{h=2}$	$K_{h=3}$	$K_{h=4}$
1978	0	3	1	1	0.0	191.9	79.2	18.8	302	400	763	991
1979	4	8	2	2	139.9	282.1	8.9	7.8	272	707	126	85
1980	0	2	0	1	0.0	56.7	0.0	6.7	35	362	460	154
1981	0	1	0	0	0.0	59.3	0.0	0.0	135	297	159	164
1982	1	3	0	1	11.2	187.2	0.0	25.2	155	683	30	221
1983	0	2	0	0	0.0	85.0	0.0	0.0	295	605	221	49
1984	1	5	0	2	54.7	388.2	0.0	75.4	302	1783	513	441
1985	1	2	2	2	61.9	62.3	100.3	142.2	681	1245	411	441
1986	0	3	2	1	0.0	200.5	80.3	7.2	515	2105	478	278
1987	3	2	0	0	102.6	142.8	0.0	0.0	566	1034	146	49
1988	3	2	0	0	134.9	164.3	0.0	0.0	509	723	149	480
1989	4	4	0	0	174.4	202.2	0.0	0.0	573	915	209	429
1990	0	3	1	0	0.0	143.7	68.2	0.0	298	895	377	210
1991	3	1	2	2	78.1	4.4	25.4	3.8	242	298	73	38
1992	0	3	1	1	0.0	13.9	2.6	4.1	212	75	45	59
1993	1	4	0	2	2.1	16.1	0.0	13.0	143	153	94	216
1994	0	1	1	1	0.0	2.3	5.9	5.3	108	88	21	141
1995	6	0	0	0	65.8	0.0	0.0	0.0	616	235	23	0
1997	0	0	1	1	0.0	0.0	0.5	1.7	373	204	37	142
1998	5	1	1	1	68.6	22.7	15.9	25.9	445	190	149	299
1999	0	0	0	3	0.0	0.0	0.0	47.2	354	58	41	385
2000	1	3	0	1	10.0	57.0	0.0	4.9	318	403	151	391
2001	5	2	0	0	51.1	4.2	0.0	0.0	472	359	147	353
2002	2	0	3	3	14.9	0.0	8.8	12.4	457	283	183	331
2003	3	1	2	1	3.9	1.5	22.2	0.1	501	139	193	233
2004	3	4	0	0	9.6	11.1	0.0	0.0	463	248	109	209
2005	3	1	1	1	8.5	2.1	35.8	1.6	410	142	120	261
2006	2	2	1	3	8.9	3.1	2.7	31.9	424	189	118	158
2007	2	1	1	3	25.8	15.9	3.3	47.4	432	145	72	182
2009	3	2	0	3	20.9	12.9	0.0	37.6	392	244	70	156
2010	1	1	0	1	7.4	5.1	0.0	7.7	394	178	101	317
2011	2	1	1	0	40.4	3.9	4.4	0.0	511	184	173	164

recruits to the fishery in recent years. For the model analysis, years with fewer than three sampled trips were excluded: 1981, 1983, and 1997 (Table E.2).

The WCHG survey age data (Figure E.2), which are weighted by POP density and stratum area, suggest a better-than average recruitment for the year 1995, but cohort patterns are not strong. There is perhaps a pulse of recruitment from the 2000 year class, which appears as 10-year old fish in 2010. The survey collected 20 samples in 2010 up from 13 samples in 2008, 11 samples in 2007, and 7 samples in 2006 (Table E.3). For the assessment model, the age data from the 1997 Ocean Selector survey (see Appendix C) were added to this data set – see Appendix G for the data (and model fits).

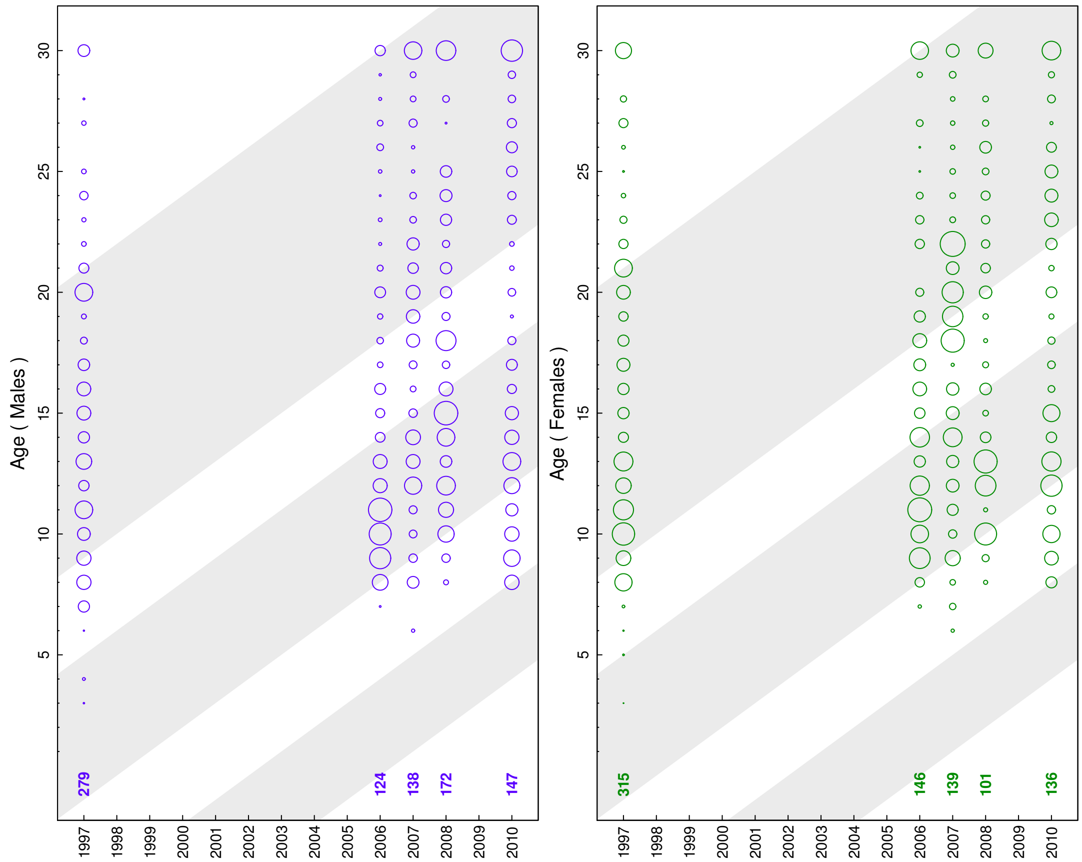


Figure E.2. WCHG Synoptic survey POP proportions-at-age based on age frequencies weighted by POP density (kg/km^2) within strata and stratum area (km^2) within survey. See Figure E.1 for details on diagonal shaded bands. Number of specimens aged are displayed along the bottom axis. The 1997 Ocean Selector survey is also included here.

Table E.3. WCHG Synoptic survey (plus 1997 Ocean Selector survey): number of sampled tows N_h, where h identifies the stratum, POP density (kg/km^2) C_h from stratum samples, and stratum area (km^2) K_h.

	year	h=114	h=115	h=116	h=151	h=152
N_h	1997	10	35	12	0	0
	2006	0	0	0	6	1
	2007	0	0	0	9	2
	2008	0	0	0	9	4
	2010	0	0	0	14	6
C_h	1997	9636	6643	1610	0	0
	2006	0	0	0	24470	1625
	2007	0	0	0	13572	2605
	2008	0	0	0	9937	3280
	2010	0	0	0	9860	2065
K_h	1997	1244	892	744	1128	1044
	2006	1244	892	744	1128	1044
	2007	1244	892	744	1128	1044
	2008	1244	892	744	1128	1044
	2010	1244	892	744	1128	1044

F DESCRIPTION OF CATCH-AT-AGE MODEL

F.1 INTRODUCTION

We used a sex-specific, age-structured model in a Bayesian framework. In particular, the model can simultaneously estimate the steepness of the stock-recruitment function and separate mortalities for males and females. This approach follows that used in our recent stock assessments of Pacific Ocean Perch (POP) in Queen Charlotte Sound (Edwards et al., 2012*b*) and Yellowmouth Rockfish along the Pacific coast of Canada (Edwards et al., 2012*a*).

The model structure is the same as that used previously, and, as for the Yellowmouth Rockfish assessment, we used the weighting scheme of Francis (2011) described below. The same methodology is used in the companion POP assessment for area 3CD (Edwards et al., 2013), but with different input data for commercial catch, survey indices and age compositions; the only changes here are in notation and years of available data.

Implementation was done using a modified version of the Coleraine statistical catch-at-age software (Hilborn et al., 2003) called Awatea (A. Hicks, NOAA, pers. comm.). Awatea is a platform for implementing the AD (Automatic Differentiation) Model Builder software (Otter Research Limited, 1999), 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 Hastings-Metropolis algorithm (Gelman et al., 2004).

Running of Awatea was streamlined using code written in R (R Development Core Team, 2012), rather than the original Excel implementation. Figures and tables of output were automatically produced through R using code adapted from the R packages `scape` (Magnusson, 2009) and `scapeMCMC` (Magnusson and Stewart, 2007). We used the R software `Sweave` (Leisch, 2002) to automatically collate, via LaTeX, the large amount of figures and tables into a single pdf file for each model run. We have incorporated our code for this into our new R package `PBSawatea`.

Below we describe details of the age-structured model, the Bayesian procedure, the reweighting scheme, the prior distributions, and the methods for calculating reference points and performing projections.

F.2 MODEL ASSUMPTIONS

The assumptions of the model are:

1. The stock in area 5DE is treated as a single stock.

2. Catches are taken by a single fishery, known without error, and occur in the middle of the year.

3. Recruitment is modelled using a time-invariant Beverton-Holt stock-recruitment relationship with log-normal error structure.

4. Selectivity differs between sexes and surveys and remains invariant over time. Selectivity

parameters are estimated when ageing data are available.

5. Natural mortality is held invariant over time, and estimated independently for females and males.

6. Growth parameters are fixed and assumed to be invariant over time.

7. Maturity-at-age parameters for females are fixed and assumed to be invariant over time. Male maturity is not considered because it is assumed that there are always sufficient mature males.

8. Recruitment at age 1 comprises 50% females and 50% males.

9. Fish ages determined using the surface ageing methods (prior to 1977) are too biased to use (Beamish, 1979). Ages determined using the otolith break-and-burn methodology (MacLellan, 1997) are aged without error.

10. Commercial samples of catch-at-age in a given year are representative of the fishery when $\geq$3 samples are available.

11. Relative abundance indices are proportional to the vulnerable biomass in the middle of the year, after half the catch and half the natural mortality are accounted for.

12. The age composition samples come from the middle of the year after half the catch and half the natural mortality are accounted for.

F.3 MODEL NOTATION AND EQUATIONS

The notation for the model is given in Table F.1, the model equations in Tables F.2 and F.3, and description of prior distributions for estimated parameters in Table F.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.

The main structure is that the deterministic components in Table F.2 can iteratively calculate numbers of fish in each age class (and of each sex) through time. The only requirements are the commercial catch data, weight-at-age and maturity data, and known fixed values for all parameters.

As known fixed values are not available for all parameters, we need to estimate many of them, and add stochasticity to recruitment. This is accomplished by the stochastic components given in Table F.3.

Incorporation of the prior distributions for estimated parameters gives the full Bayesian implementation, the goal of which is to minimise the objective function $f(\boldsymbol{\Theta})$ given by (F.23). This function is derived from the deterministic, stochastic and prior components of the model.

Table F.1 (continued overleaf). Notation for the catch-at-age model.

Symbol	Description and units
	Indices (all subscripts)
a	age class, where $a = 1, 2, 3, ...A$, and $A = 30$ is the accumulator age class
t	model year, where $t = 1, 2, 3, ...T$, corresponds to actual years 1940, 1941, 1942, ..., 2013, and $t = 0$ represents unfished equilibrium conditions
g	index for certain data: 1 - west coast Haida Gwaii synoptic survey series 2 - commercial trawl data
s	sex, $1 =$ females, $2 =$ males
	Index ranges
A	accumulator age-class, $A = 30$
T	number of model years, $T = 74$
$\mathbf{T}_g$	sets of model years for survey abundance indices from series $g = 1$, listed here for clarity as actual years (subtract 1939 to give model year t): $\mathbf{T}_1 = \{$1997, 2006, 2007, 2008, 2010$\}$
$\mathbf{U}_g$	sets of model years with proportion-at-age data, $g = 1, 2$ (listed here as actual years): $\mathbf{U}_1 = \{$1997, 2006, 2007, 2008, 2010$\}$ $\mathbf{U}_2 = \{$1978, 1979, 1980, 1982, 1984, 1985, ..., 1995, 1998, 1999, ..., 2006, 2007, 2009, 2010, 2011$\}$
	Data and fixed parameters
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 $\Sigma_{a=1}^{A} \Sigma_{s=1}^{2} p_{atgs} = 1$ for each $t \in \mathbf{U}_g$, $g = 1, 2$
n_{tg}	assumed sample size that yields corresponding p_{atgs}
C_t	observed catch biomass in year $t = 1, 2, ..., T-1$, tonnes
w_{as}	average weight of individual of age-class a of sex s from fixed parameters, kg
m_a	proportion of age-class a females that are mature, fixed from data
I_{tg}	biomass estimates from survey $g = 1$ for year $t \in \mathbf{T}_g$, tonnes
κ_{tg}	standard deviation of I_{tg}
σ_R	standard deviation parameter for recruitment process error, $\sigma_R = 0.9$

Table F.1 (cont.). Notation for the catch-at-age model.

Symbol	Description, with fixed values and/or units where appropriate
	Estimated parameters
$\boldsymbol{\Theta}$	set of estimated parameters
R_0	virgin recruitment of age-1 fish (numbers of fish, 1000s)
M_s	natural mortality rate for sex s, $s = 1, 2$
h	steepness parameter for Beverton-Holt recruitment
q_g	catchability for survey series $g = 1$
μ_g	age of full selectivity for females for series $g = 1, 2$
Δ_g	shift in vulnerability for males for series $g = 1, 2$
v_{gL}	variance parameter for left limb of selectivity curve for series $g = 1, 2$
s_{ags}	selectivity for age-class a, series $g = 1, 2$, and sex s, calculated from the parameters μ_g, Δ_g and v_{gL}
α, β	alternative formulation of recruitment: $\alpha = (1-h)B_0/(4hR_0)$ and $\beta = (5h-1)/(4hR_0)$
$\widehat{x}$	estimated value of observed data x
	Derived states
N_{ats}	number of age-class a fish of sex s at the start of year t, 1000s
u_{ats}	proportion of age-class a and sex s fish in year t that are caught
u_t	ratio of total catch to vulnerable biomass in the middle of the year (exploitation rate)
B_t	spawning biomass (mature females) at the start of year t, $t = 1, 2, 3, ..., T$; tonnes
B_0	virgin spawning biomass (mature females) at the start of year 0, tonnes
R_t	recruitment of age-1 fish in year t, $t = 1, 2, ..., T-1$, numbers of fish, 1000s
V_t	vulnerable biomass (males and females) in the middle of year t, $t = 1, 2, 3, ..., T$; tonnes
	Deviations and likelihood components
ϵ_t	Recruitment deviations arising from process error
$\log L_1(\boldsymbol{\Theta} \mid \{\epsilon_t\})$	log-likelihood component related to recruitment residuals
$\log L_2(\boldsymbol{\Theta} \mid \{\widehat{p}_{atgs}\})$	log-likelihood component related to estimated proportions-at-age
$\log L_3(\boldsymbol{\Theta} \mid \{\widehat{I}_{tg}\})$	log-likelihood component related to estimated survey biomass indices
$\log L(\boldsymbol{\Theta})$	total log-likelihood
	Prior distributions and objective function
$\pi_j(\boldsymbol{\Theta})$	Prior distribution for parameter j
$\pi(\boldsymbol{\Theta})$	Joint prior distribution for all estimated parameters
$f(\boldsymbol{\Theta})$	Objective function to be minimised

Table F.2. Deterministic components (continued overleaf). Using the catch, weight-at-age and maturity data, with fixed values for all parameters, the initial conditions are calculated from (F.4)-(F.6), and then state dynamics are iteratively calculated through time using the main equations (F.1)-(F.3), selectivity functions (F.7) and (F.8), and the derived states (F.9)-(F.13). Estimated observations for survey biomass indices and proportions-at-age can then be calculated using (F.14) and (F.15). In Table F.3, the estimated observations of these are compared to data.

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

$$N_{1ts} = 0.5 R_t \tag{F.1}$$

$$N_{ats} = e^{-M_s}(1 - u_{a-1,t-1,s}) N_{a-1,t-1,s}\,; \quad 2 \leq a \leq A-1 \tag{F.2}$$

$$N_{Ats} = e^{-M_s}(1 - u_{A-1,t-1,s}) N_{A-1,t-1,s} + e^{-M_s}(1 - u_{A,t-1,s}) N_{A,t-1,s} \tag{F.3}$$

Initial conditions ($t = 1$)

$$N_{a1s} = 0.5 R_0 e^{-M_s(a-1)}\,; \quad 1 \leq a \leq A-1,\ s = 1, 2 \tag{F.4}$$

$$N_{A1s} = 0.5 R_0 \frac{e^{-M_s(A-1)}}{1 - e^{-M_s}}\,; \quad s = 1, 2 \tag{F.5}$$

$$B_0 = B_1 = \sum_{a=1}^{A} w_{a1} m_a N_{a11} \tag{F.6}$$

Selectivities ($g = 1, 2$)

$$s_{ag1} = \begin{cases} e^{-(a-\mu_g)^2/v_{gL}}, & a \leq \mu_g \\ 1, & a > \mu_g \end{cases} \tag{F.7}$$

$$s_{ag2} = \begin{cases} e^{-(a-\mu_g-\Delta_g)^2/v_{gL}}, & a \leq \mu_g + \Delta_g \\ 1, & a > \mu_g + \Delta_g \end{cases} \tag{F.8}$$

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

$$B_t = \sum_{a=1}^{A} w_{a1} m_a N_{at1} \tag{F.9}$$

$$R_t = \frac{4hR_0 B_{t-1}}{(1-h)B_0 + (5h-1)B_{t-1}} \quad \left(\equiv \frac{B_{t-1}}{\alpha + \beta B_{t-1}} \right) \tag{F.10}$$

$$V_t = \sum_{s=1}^{2} \sum_{a=1}^{A} e^{-M_s/2}\, w_{as}\, s_{a4s}\, N_{ats} \tag{F.11}$$

$$u_t = \frac{C_t}{V_t} \tag{F.12}$$

$$u_{ats} = s_{a4s}\, u_t\, ; \quad 1 \le a \le A,\ s = 1,2 \tag{F.13}$$

Estimated observations

$$\widehat{I}_{tg} = q_g \sum_{s=1}^{2} \sum_{a=1}^{A} e^{-M_s/2}(1 - u_{ats}/2) w_{as} s_{ags} N_{ats}\, ; \quad t \in \mathbf{T}_g,\ g = 1 \tag{F.14}$$

$$\widehat{p}_{atgs} = \frac{e^{-M_s/2}(1 - u_{ats}/2) s_{ags} N_{ats}}{\sum_{s=1}^{2} \sum_{a=1}^{A} e^{-M_s/2}(1 - u_{ats}/2) s_{ags} N_{ats}}; \quad 1 \le a \le A,\ t \in \mathbf{U}_g,\ g = 1,2,\ s = 1,2 \tag{F.15}$$

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

Estimated parameters

$$\boldsymbol{\Theta} = \{R_0, M_1, M_2, h, q_1, \mu_1, \mu_2, \Delta_1, \Delta_2, v_{1L}, v_{2L}\} \tag{F.16}$$

Recruitment deviations

$$\epsilon_t = \log R_t - \log B_{t-1} + \log(\alpha + \beta B_{t-1}) + \sigma_R^2/2\,; \quad 1 \le t \le T-1 \tag{F.17}$$

Log-likelihood functions

$$\log L_1(\boldsymbol{\Theta}|\{\epsilon_t\}) = -\frac{T}{2}\log 2\pi - T\log\sigma_R - \frac{1}{2\sigma_R^2}\sum_{t=1}^{T-1}\epsilon_t^2 \tag{F.18}$$

$$\begin{aligned}\log L_2(\boldsymbol{\Theta}|\{\widehat{p}_{atgs}\}) = &-\frac{1}{2}\sum_{g=1,2}\sum_{a=1}^{A}\sum_{t\in\mathbf{U}_g}\sum_{s=1}^{2}\log\left[p_{atgs}(1-p_{atgs}) + \frac{1}{10A}\right] \\ &+ \sum_{g=1,2}\sum_{a=1}^{A}\sum_{t\in\mathbf{U}_g}\sum_{s=1}^{2}\log\left[\exp\left\{\frac{-(p_{atgs}-\widehat{p}_{atgs})^2\; n_{tg}}{2\left(p_{atgs}(1-p_{atgs}) + \frac{1}{10A}\right)}\right\} + \frac{1}{100}\right]\end{aligned} \tag{F.19}$$

$$\log L_3(\boldsymbol{\Theta}|\{\widehat{I}_{tg}\}) = \sum_{t\in\mathbf{T}_g}\left[-\frac{1}{2}\log 2\pi - \log\kappa_{tg} - \frac{(\log I_{tg} - \log\widehat{I}_{tg})^2}{2\kappa_{tg}^2}\right]; \quad g=1 \tag{F.20}$$

$$\log L(\boldsymbol{\Theta}) = \sum_{i=1}^{3}\log L_i(\boldsymbol{\Theta}|\cdot) \tag{F.21}$$

Joint prior distribution and objective function

$$\log(\pi(\boldsymbol{\Theta})) = \sum_j \log(\pi_j(\boldsymbol{\Theta})) \tag{F.22}$$

$$f(\boldsymbol{\Theta}) = -\log L(\boldsymbol{\Theta}) - \log(\pi(\boldsymbol{\Theta})) \tag{F.23}$$

Table F.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. For uniform prior distributions, the bounds completely parameterise the prior. The resulting non-uniform prior probability density functions are the $\pi_j(\boldsymbol{\Theta})$ functions that contribute to the joint prior distribution in (F.22).

Parameter	Prior distribution	Mean, standard deviation	Bounds	Initial value
R_0	uniform	–	[1, 100,000]	4,000
M_1, M_2	normal	0.07, 0.007	[0.01, 0.12]	0.07
h	beta	0.674, 0.168	[0.2, 0.999]	0.674
$\log q_g, g = 1$	uniform	–	[-12, 5]	0
μ_1	normal	13.3, 4	[5, 40]	13.3
μ_2	normal	10.5, 3.15	[5, 40]	10.5
$\log v_{1L}$	normal	3.3, 1	[-15, 15]	3.3
$\log v_{2L}$	normal	1.52, 0.456	[-15, 15]	1.52
Δ_1	normal	0.22, 0.066	[-8, 10]	0.22
Δ_2	normal	0, 0.3	[-8, 10]	0

F.4 DESCRIPTION OF DETERMINISTIC COMPONENTS

Notation (Table F.1) and set up of the deterministic components (Table F.2) are now described.

F.4.1 AGE CLASSES

Index (subscript) a represents age classes, going from 1 to the accumulator age class, A, of 30. 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. 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 2013.

In Edwards et al. (2012*a*,*b*) an accumulator age class of 60 was used, but this did not perform well in preliminary model runs for area 3CD, and so, in consultation with the Technical Working Group, the accumulator age class was set to 30 for this assessment also.

F.4.2 YEARS

Index t represents model years, going from 1 to $T = 74$, and $t = 0$ represents unfished equilibrium conditions. The actual year corresponding to $t = 1$ is 1940, and so model year $T = 74$ corresponds to 2013. The model was run to the start of 2013 for consistency with the companion assessment for area 3CD, although there are no data for area 5DE for 2012. Catch data for the whole of 2012 are not available (since the assessment model is being run in September 2012), and so the catch for 2012 was set to that for 2011.

F.4.3 SURVEY DATA

Data from one survey series was used, the west coast Haida Gwaii survey (plus data from a 1997 cruise by the Ocean Selector) as described in detail in Appendix C. Here, subscript $g = 1$ corresponds to this series, and subscript $g = 2$ corresponds to the commercial fishery (note that in Edwards et al. 2013 $g = 4$ corresponds to the commercial fishery because that assessment uses more surveys). The years for which data are available for the survey are given in Table F.1; for $g = 1$, $\mathbf{T}_g$ corresponds to the 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 assumed sample sizes n_{tg}).

F.4.4 COMMERCIAL DATA

As described in Appendix B, the commercial catch has been reconstructed back to 1918. Given the negligible catches in the early years, the model was started in 1940, and catches prior to 1940 were not considered. The time series for catches is denoted C_t. The set $\mathbf{U}_2$ (Table F.1) gives the years of available ageing data from the commercial fishery. The proportions-at-age values are given by p_{atgs} with assumed sample size n_{tg}, where $g = 2$ (to correspond to the commercial data). These proportions are the weighted proportions calculated using the stratified weighting scheme described in Appendix E, that adjusts for unequal sampling effort across temporal and spatial strata.

F.4.5 SEX

A two-sex model was used, with subscript $s = 1$ for females and $s = 2$ for males. Ageing data were partitioned by sex, as were the weights-at-age inputs. Selectivities and natural mortality were estimated by sex.

F.4.6 WEIGHTS-AT-AGE

The weights-at-age w_{as} are assumed fixed over time and based on the biological data; see Appendix D for details.

F.4.7 MATURITY OF FEMALES

The proportion of age-class a females that are mature is m_a, and is assumed fix over time; see Appendix D for details.

F.4.8 STATE DYNAMICS

The crux of the model is the set of dynamical equations (F.1)-(F.3) for the estimated number N_{ats} of age-class a fish of sex s at the start of year t. Equation (F.1) states that half of new recruits are males and half are females. Equation (F.2) calculates the numbers of fish in each age class (and of each sex) that survive to the following year, where u_{ats} represents the proportion caught by the commercial fishery, and e^{-M_s} accounts for natural mortality. Equation (F.3) is for the accumulator age class A, whereby survivors from this class remain in this class the following year.

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

F.4.9 INITIAL CONDITIONS

An unfished equilibrium situation at the beginning of the reconstruction is assumed, because there is no evidence of significant removals prior to 1940, and 1940 predates significant removals by 25 years (Appendix B). The initial conditions (F.4) and (F.5) are obtained by setting $R_t = R_0$ (virgin recruitment), $N_{ats} = N_{a1s}$ (equilibrium condition) and $u_{ats} = 0$ (no fishing) into (F.1)-(F.3). The virgin spawning biomass B_0 is then obtained from (F.9).

F.4.10 SELECTIVITIES

Separate selectivities were modelled for the survey data and the commercial catch data. A half-Gaussian formulation was used, as given in (F.7) and (F.8), to give selectivities s_{ags} (note that the subscript $\cdot_s$ always represents the index for sex, whereas the variable $s_{\dots}$ always represents selectivity). This permits an increase in selectivity up to the age of full selection (μ_g for females). Given there was no evidence to suggest a dome-shaped function, it was assumed that fish older than μ_g remain fully selected. The rate of ascent of the left limb is controlled by the parameter v_{gL} for females. For males, the same function is used except that the age of full selection is shifted by an amount Δ_g, see (F.8).

F.4.11 DERIVED STATES

The spawning biomass (biomass of mature females, in tonnes) B_t at the start of year t is calculated in (F.9) by multiplying the numbers of females N_{at1} by the proportion that are mature (m_a), and converting to biomass by multiplying by the weights-at-age w_{a1}.

Equation (F.13) calculates, for year t, the proportion u_{ats} of age-class a and sex s fish that are caught. This requires the commercial selectivities s_{a4s} and the ratio u_t, which equation (F.12) shows is the ratio of total catch to vulnerable biomass in the middle of the year, V_t, given by equation (F.11). So (F.12) calculates the proportion of the vulnerable biomass that is caught, and (F.13) partitions this out by sex and age.

F.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). This was done so that a prior for h could be taken from Forrest et al. (2010). The formulation shown in (F.10) comes from substituting $\alpha = (1-h)B_0/(4hR_0)$ and $\beta = (5h-1)/(4hR_0)$ into the Beverton-Holt equation $R_t = B_{t-1}/(\alpha + \beta B_{t-1})$, where α and β are from the standard formulation given in the Coleraine manual (Hilborn et al. 2003; see also Michielsens and McAllister 2004), 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.

F.4.13 ESTIMATES OF OBSERVED DATA

The model estimates of the survey biomass indices I_{tg} are denoted $\widehat{I}_{tg}$ and are calculated in (F.14). The estimated numbers N_{ats} are multiplied by the natural mortality term $e^{-M_s/2}$ (that accounts for half the annual natural mortality), the term $1-u_{ats}/2$ (that accounts for half 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 $\widehat{I}_{tg}$. A 0.001 coefficient in (F.14) is not needed to convert kg into tonnes, because N_{ats} is in 1000s of fish (true also for (F.6) and (F.9)).

The estimated proportions-at-age $\widehat{p}_{atgs}$ are calculated in (F.15). 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 $\sum_{s=1}^{2}\sum_{a=1}^{A}\widehat{p}_{atgs} = 1$.

F.5 DESCRIPTION OF STOCHASTIC COMPONENTS

F.5.1 PARAMETERS

The set $\boldsymbol{\Theta}$ gives the parameters that are estimated. The estimation procedure is described in the Bayesian Computations section below.

F.5.2 RECRUITMENT DEVIATIONS

For recruitment, a log-normal process error is assumed, such that the stochastic version of the deterministic stock-recruitment function (F.10) is

$$R_t = \frac{B_{t-1}}{\alpha + \beta B_{t-1}} e^{\epsilon_t - \sigma_R^2/2} \qquad \text{(F.24)}$$

where $\epsilon_t \sim$ Normal$(0, \sigma_R^2)$, and the bias-correction term $-\sigma_R^2/2$ term in (F.24) ensures that the mean of the recruitment deviations equals 0. This then gives the recruitment deviation equation

(F.17) and log-likelihood function (F.18). The value of σ_R was fixed at 0.9, which was the value used in the Queen Charlotte Sound (QCS) POP assessment (Edwards et al., 2012*b*), where the value was determined empirically from model fits.

F.5.3 LOG-LIKELIHOOD FUNCTIONS

The log-likelihood function (F.19) arises from comparing the estimated proportions-at-age with the data. It is the Coleraine (Hilborn et al., 2003) modification of the Fournier et al. (1990, 1998) robust likelihood equation. The Coleraine formulation replaces the expected proportions $\widehat{p}_{atgs}$ from the Fournier et al. (1990, 1998) formulation with the observed proportions p_{atgs}, except in the $(p_{atgs} - \widehat{p}_{atgs})^2$ term (Bull et al., 2005).

The $1/(10A)$ term in (F.19) reduces the weight of proportions that are close to or equal zero. The $1/100$ term reduces the weight of large residuals $(p_{atgs} - \widehat{p}_{atgs})$. The net effect (Stanley et al., 2009) is that residuals larger than three standard deviations from the fitted proportion are treated roughly as $3(p_{atgs}(1 - p_{atgs}))^{1/2}$.

Lognormal error is assumed for the survey indices, resulting in the log-likelihood equation (F.20). The total log-likelihood $\log L(\mathbf{\Theta})$ is then the sum of the likelihood components – see (F.21).

F.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 $f(\mathbf{\Theta})$, which equation (F.23) shows is the negative of the sum of the total log-likelihood function and the logarithm of the joint prior distribution, given by (F.22).

The procedure for the Bayesian computations is as follows:

1. minimise the objective function $f(\mathbf{\Theta})$ to give estimates of the mode of the posterior density (MPD) for each parameter
   - this is done in phases
   - a reweighting procedure is performed
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.

The details for these steps are now given.

F.6.1 PHASES

Simultaneously estimating all the estimable parameters straight away 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 (Otter Research Limited, 1999). Some parameters are estimated in phase 1, then some further ones in phase 2, and so on. The order used here was:

phase 1: virgin recruitment R_0 and survey catchability q_1

phase 2: recruitment deviations ϵ_t (held at 0 in phase 1)

phase 3: age of full selectivity for females, μ_1, μ_2

phase 4: selectivity parameters Δ_g, v_{gL} for $g = 1, 2$, and mortalities M_1, M_2

phase 5: steepness h.

F.6.2 REWEIGHTING

Given that sample sizes are not comparable between different types of data, a procedure that adjusts the relative weights between data sources is required. For the QCS POP assessment (Edwards et al., 2012*b*) we used an iterative reweighting scheme based on adjusting the standard deviation of normal residuals of data sets until these standard deviations were approximately 1. This procedure did not perform well for the Yellowmouth Rockfish assessment (Edwards et al., 2012*a*), leading to spurious cohorts, and so for that assessment we used the reweighting scheme proposed by Francis (2011).

For abundance data such as survey indices, Francis (2011) recommends reweighting observed coefficients of variation, c_0, by adding process error $c_p = 0.2$ to give a reweighted coefficient of variation

$$c_1 = \sqrt{c_0^2 + c_p^2}\,. \tag{F.25}$$

For the survey index, I_{tg} ($g = 1; t \in \mathbf{T}_g$), the associated standard deviation is κ_{tg}. The associated coefficient of variation is therefore κ_{tg}/I_{tg}, which is used in (F.25) to determine the reweighted coefficient of variation associated with κ_{tg}. This reweighted coefficient of variation is then converted back to a standard deviation, which is used as the reweighted standard deviation κ_{tg} in the likelihood function (F.20).

Francis (2011) maintains that correlation effects are usually strong in age-composition data. Each age-composition data set has a sample size n_{tg} ($g = 1, 2$, $t \in \mathbf{U}_g$), which is typically in the range 3-20. Equation (T3.4) of Francis (2011) is used to iteratively reweight the sample size as

$$n_{tg}^{(r)} = W_g^{(r)} n_{tg}^{(r-1)} \tag{F.26}$$

where $r = 1, 2, 3, ..., 6$ represents the reweighting iteration, $n_{tg}^{(r)}$ is the effective sample size for reweighting r, $W_g^{(r)}$ is the weight applied to obtain reweighting r, and $n_{tg}^{(0)} = n_{tg}$. So a single weight $W_g^{(r)}$ is calculated for each series $g = 1, 2$ for reweighting r.

The Francis (2011) weight $W_g^{(r)}$ given to each data set takes into account deviations from the mean age for each year, rather than the scheme used for the QCS POP assessment (Edwards et al., 2012*b*) that considered deviations from each proportion-at-age value. It is given by equation (TA1.8) of Francis (2011):

$$W_g^{(r)} = \left\{ \text{Var}_t \left[\frac{\bar{O}_{gt} - \bar{E}_{gt}}{\sqrt{\theta_{gt} / n_{tg}^{(r-1)}}} \right] \right\}^{-1} \tag{F.27}$$

where the observed mean age, the expected mean age and the variance of the expected age distribution are, respectively,

$$\bar{O}_{gt} = \sum_{a=1}^{A} \sum_{s=1}^{2} a p_{atgs} \tag{F.28}$$

$$\bar{E}_{gt} = \sum_{a=1}^{A} \sum_{s=1}^{2} a \widehat{p}_{atgs} \tag{F.29}$$

$$\theta_{gt} = \sum_{a=1}^{A} \sum_{s=1}^{2} a^2 \widehat{p}_{atgs} - \bar{E}_{gt}^2 \tag{F.30}$$

and Var$_t$ is the usual finite-sample variance function applied over the index t. For the Yellowmouth Rockfish assessment (Edwards et al., 2012*a*) we used this approach iteratively with $r = 1, 2, ..., 6$, but found that reweightings after the first ($r = 1$) had little effect, and so the reported results were based on the first reweighting. Therefore, for the current assessment we used just one reweighting.

F.6.3 PRIOR DISTRIBUTIONS

Descriptions of the prior distributions for the 11 estimated parameters are given in Table F.4. The resulting probability density functions give the $\pi_j(\boldsymbol{\Theta})$, whose logarithms are then summed in (F.22) to give the joint prior distribution $\pi(\boldsymbol{\Theta})$. Since uniform priors are, by definition, constant across their bounded range (and zero outside), their contributions to the objective function can be ignored. Thus, in the calculation (F.22) of the joint prior distribution $\pi(\boldsymbol{\Theta})$, only those priors that are not uniform need to be considered in the summation.

A uniform prior over a large range was used for R_0. The priors for female and male natural mortality, M_1 and M_2 respectively, were based on the results of the QCS POP assessment (Edwards et al., 2012*b*). We first fit normal distributions, using maximum likelihood, to the posteriors from the 'Estimate M and h' model run of Edwards et al. (2012*b*), yielding N(0.0668, 0.00293) [indicating a normal distribution with mean 0.0668 and standard deviation 0.00293] for females, and N(0.0727, 0.00314) for males. For the QCS POP assessment we had taken priors from the posterior distributions of the Gulf of Alaska assessment of POP (Hanselman et al., 2007, 2009), namely N(0.06, 0.006) [rounding the mean to one decimal place] for both females and males. To avoid the overly tight priors based on our likelihood analysis, we set the coefficient of variation here to 0.1 (the same as the Gulf of Alaska value). Given the closeness of the resulting female and male distributions, with an overall mean of 0.0697, for the current assessment we used a single prior for females and males of N(0.07, 0.007).

For steepness, h, the same prior was used as for the QCS POP assessment (Edwards et al., 2012*b*) – a beta distribution with values fitted to the posterior distribution for rockfish calculated by

Forrest et al. (2010), with the Pacific Ocean Perch data removed (R. Forrest, DFO, pers. comm., though removing those data made little difference to the distribution). Uniform priors on a logarithmic scale were used for the catchability parameters q_g.

Selectivity was estimated for the west coast Haida Gwaii synoptic survey series ($g = 1$), because age data were available. Priors for the three selectivity parameters, μ_1, Δ_1, and v_{1L} were based on the results from the QCS POP assessment (Edwards et al., 2012*b*). Normal distributions were used for the priors, with means taken from the median values of the posteriors for the QCS synoptic survey series for the 'Estimate M and h' model run, given as $\mu_2 = 13.3, \log v_{2L} = 3.30$ and $\Delta_2 = 0.22$ in Table G3 (p156) of Edwards et al. (2012*b*). To give broad priors here, the standard deviations of the priors were set to give coefficients of variation of 0.3.

For the other two survey series, the National Marine Fisheries Service triennial survey series and the GB Reed historical survey series, no age data were available, and so the selectivity parameters were held fixed rather than estimated. The aforementioned median values were used for the fixed values.

For the commercial selectivity ($g = 2$), age data were available and so selectivity was estimated. Again, the priors for the three parameters were normal distributions with means based on the median values of the posteriors for the 'Estimate M and h' model run of the QCS assessment, given in Table G3 (p156) of Edwards et al. (2012*b*) as $\mu_4 = 10.5, \log v_{4L} = 1.52$ and $\Delta_4 = 0.00$ (corresponding to μ_2 etc. here). To give broad priors, the standard deviations of the priors were set to give coefficients of variation of 0.3 (except for Δ_2 for which the standard deviation was set to 0.3, because its mean was 0).

F.6.4 MCMC PROPERTIES

The MCMC searches started from the MPD values. 10,000,000 iterations were performed, sampling every 10,000th for 1,000 samples, which were used with no burn-in period (because the MCMC searches started from the MPD values).

F.7 REFERENCE POINTS, PROJECTIONS AND ADVICE TO MANAGERS

Advice to managers is given with respect to two sets of reference points or reference criteria. The first set consists of the provisional reference points of the DFO Precautionary Approach (DFO, 2006), namely $0.4B_{\mathrm{MSY}}$ and $0.8B_{\mathrm{MSY}}$ (and we also provide B_{MSY}); B_{MSY} is the estimated equilibrium spawning biomass at the maximum sustainable yield (MSY). The second set of reference points comprises $0.2B_0$ and $0.4B_0$, where B_0 is the estimated unfished equilibrium spawning biomass. See main text for further discussion.

To estimate B_{MSY}, the model was projected forward across a range (0 to 0.3 in increments of 0.001) of constant harvest rates (u_t), for a maximum of 15,000 years until equilibrium was reached (with a tolerance of 0.01 t). The MSY is the largest of the equilibrium yields, and the associated exploitation rate is then u_{MSY} and the associated spawning biomass is B_{MSY}. This calculation was done for each of the 1,000 MCMC samples, resulting in marginal posterior distributions for MSY, u_{MSY} and B_{MSY}.

The probability P$(B_{2013} > 0.8B_{\mathrm{MSY}})$ is then calculated as the proportion of the 1,000 MCMC samples for which $B_{2013} > 0.8B_{\mathrm{MSY}}$ (and similarly for the other reference points).

Projections were made for 10 years (as agreed upon with N. Davis, DFO Groundfish Management Unit, pers. comm.), starting with the biomass and age structure calculated for the start of 2013. A range of constant catch strategies were used, from 0-2,000 t (the average catch from 2007-2011 was 937 t). For each strategy, projections were performed for each of the 1,000 MCMC samples (resulting in posterior distributions of future spawning biomass). Recruitments were randomly calculated using (F.24) (i.e. based on lognormal recruitment deviations from the estimated stock-recruitment curve), using randomly generated values of $\epsilon_t \sim$ Normal$(0, \sigma_R^2)$. For each of the 1,000 MCMC samples a time series of $\{\epsilon_t\}$ was generated. For each MCMC sample, the same time series of $\{\epsilon_t\}$ was used for each catch strategy (so that, for a given MCMC sample, all catch strategies experience the same recruitment stochasticity).

G RESULTS

G.1 INTRODUCTION

This Appendix describes the results from the mode of the posterior distribution (MPD) (to compare model estimates to observations), diagnostics of the Markov chain Monte Carlo (MCMC) results, and the MCMC results for the estimated parameters. The final advice and major outputs are obtained from the MCMC results. Estimates of major quantities and advice to management (such as decision tables) are presented in the main text.

G.2 MODE OF THE POSTERIOR DISTRIBUTION (MPD) RESULTS

Awatea first determines the mode of the posterior distribution (MPD) for each estimated parameter. These are then used as the starting points for the MCMC simulations. The MPD fits are shown for the survey indices (Figure G.1), the commercial catch-at-age data (as bubble plots in Figures G.2-G.5 and as overlaid age structures in Figures G.6 and G.7), and the west coast Haida Gwaii (WCHG) synoptic survey series age data (Figure G.8). The results are sensible and are able to capture the main features of the data sets fairly well. There appears to be relative consistency between the available data sources.

Residuals to the MPD model fits are provided for the WCHG survey indices (Figure G.9), and the two sets of age data (Figures G.10 and G.11). These results suggest that the model fits are reasonably consistent with the data. The predicted mean ages for the two sets of age data track the observed mean ages (Figure G.12), indicating that the model is capturing the primary trend in the age composition data (Francis, 2011).

Figure G.13 shows the resulting stock-recruitment function and the MPD values of recruitment over time (though see Figure 5 for the MCMC values of recruitment). Figure G.14 shows that the recruitment deviations display some long-term oscillations over time, with a significant but relatively low first-order correlation. Figure G.15 gives the MPD fits for the selectivities, together with ogive for female maturity. The values of the log-likelihood and objective functions for the MPD fits are given in Table G.1.

G.3 BAYESIAN MCMC RESULTS

The MCMC procedure performed 10,000,000 iterations, sampling every 10,000th to give 1,000 MCMC samples. The 1,000 samples were used with no burn-in period (because the MCMC searches started from the MPD values). MCMC traces show good convergence properties (no trend in the median with increasing sample number) for the estimated parameters (Figure G.16), as does a diagnostic analysis that compares successive thirds of the MCMC sample (Figure G.17). There are some occasional large values of R_0 in the second half of the MCMC sample (Figure G.16), which increases the cumulative 97.5 quantile (ragged line) for that parameter, but the cumulative median remains constant.

Pairs plots of the estimated parameters (Figures G.18-G.19) show no undesirable correlations between parameters. In particular, steepness, h, and the two natural mortality parameters, M_1 and M_2, show little correlation, suggesting there are sufficient data to estimate them simultaneously. Trace plots of the derived quantities 'female spawning biomass' (Figure G.20) and recruitment (Figure G.21) also show good convergence properties, with the aforementioned MCMC samples with high R_0 values resulting in high estimates of spawning biomass and recruitment for those samples. Overall, the MCMC computations seem satisfactory.

Marginal posterior distributions and corresponding priors for the estimated parameters are shown in Figure G.22. For most parameters, it appears that there is enough information in the data to move the posterior distribution away from the prior. Corresponding summary statistics for the estimated parameters are given in Table G.2.

For natural mortality, identical priors were used for males and females based on our previous Queen Charlotte Sound POP assessment (Edwards et al., 2012*b*); see Appendix F. For females (parameter M_1), the posterior distribution moved to the left of the prior (Figure G.22), whereas for males (parameter M_2) the posterior moved to the right. The estimated female natural mortality is 0.063 (0.055-0.073), denoting median (5 and 95% percentiles), whereas male natural mortality is somewhat higher at 0.076 (0.067-0.085). This relative directional shift in the sexes did not occur in the companion POP assessment for area 3CD (Edwards et al., 2013).

Plots of marginal posterior distributions of vulnerable biomass, spawning biomass, annual recruitment and exploitation rate are presented in the main text, because of their interest to management. Phase plots showing the time-evolution of spawning biomass and exploitation rate relative to reference points are also shown in the main text, together with projections and resulting decision tables.

For the maximum sustainable yield (MSY) calculations, projections were run for 301 values of constant exploitation rate u_t between 0 and 0.3, until an equilibrium yield was reached within a tolerance of 0.01 t (or until 15,000 years had been reached). The exploitation rate that gives the maximum equilibrium yield is reached is then u_{MSY}. This was done for each of the 1,000 samples.

For all MCMC samples, u_{MSY} lay between the bounds of 0 and 0.3. Of the total of 301,000 projection calculations, all had converged by 15,000 years.

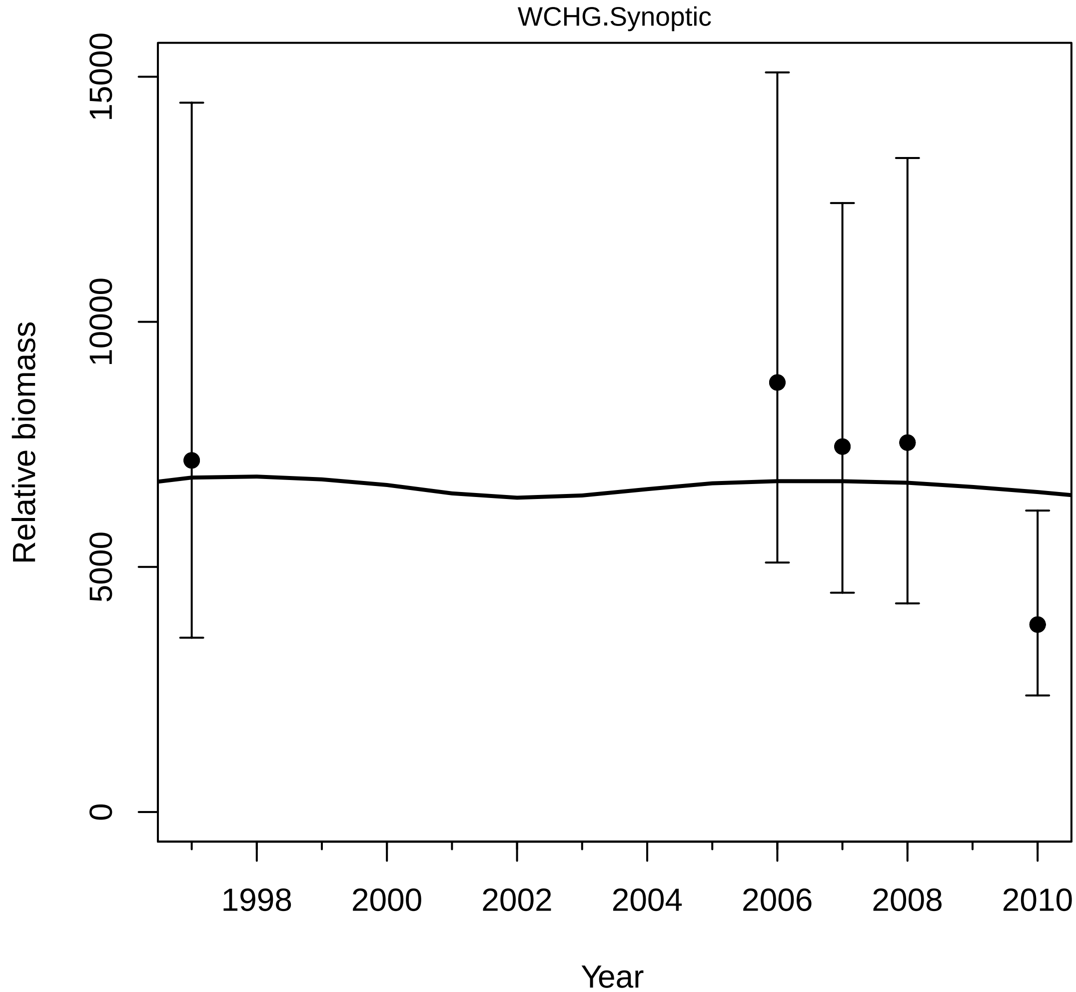


Figure G.1. Survey index values (points) with 95% confidence intervals (bars) and MPD model fits (curves) for the WCHG survey series.

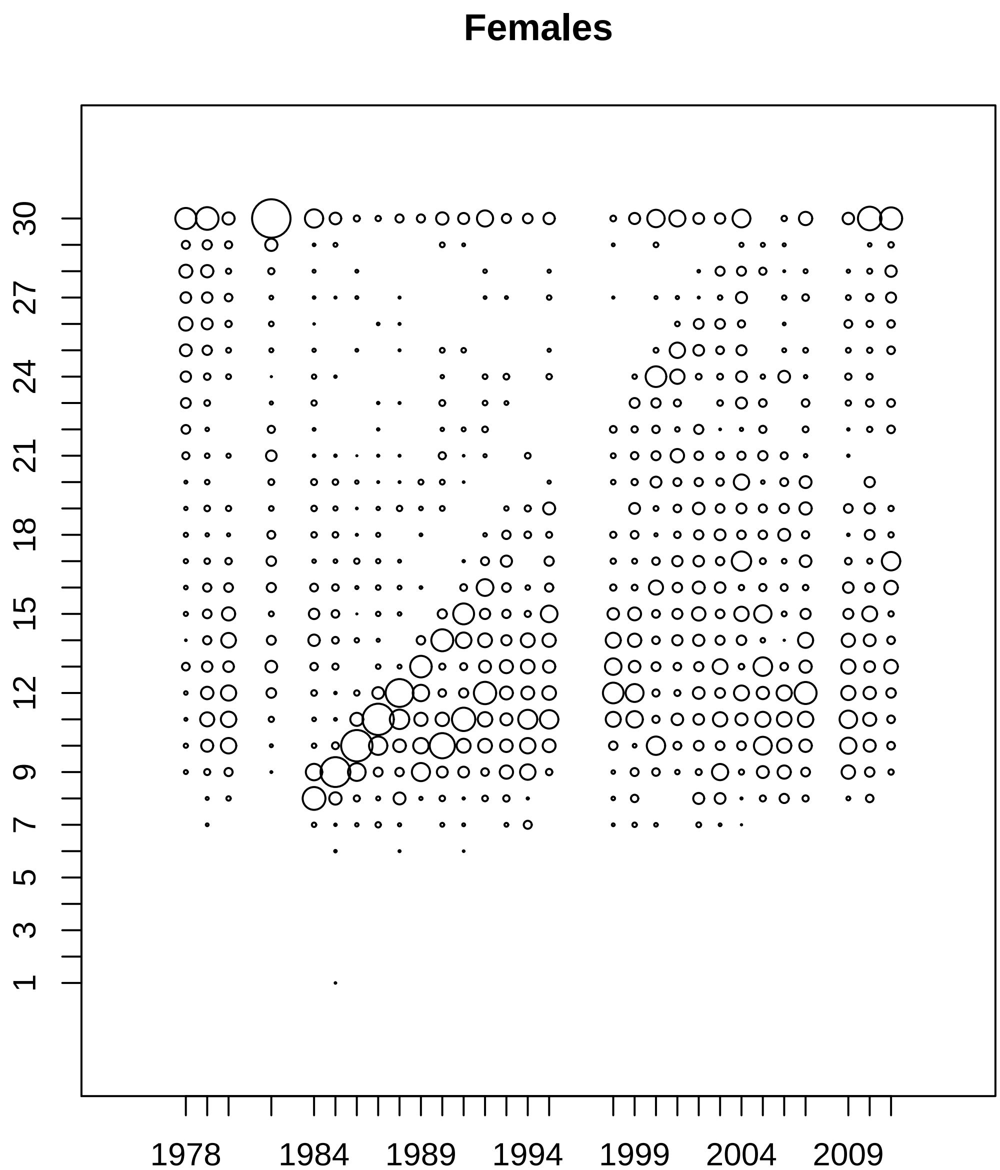


Figure G.2. Commercial catch-at-age data for females. Bubbles are, for each year, the proportions assigned to each age class, based on the weighted age calculations described in Appendix E. Bubble areas are proportional to the respective proportions.

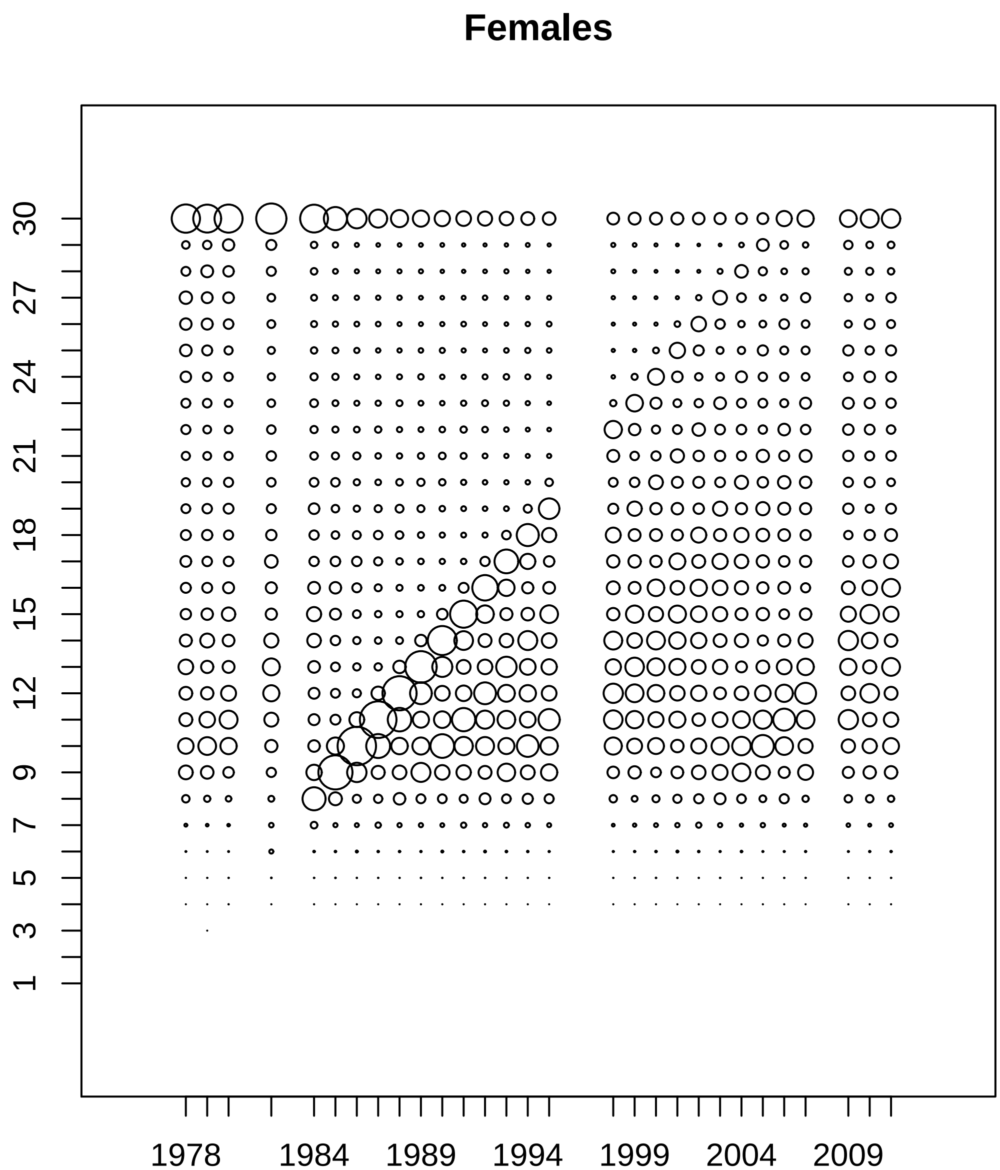


Figure G.3. Estimated proportions-at-age of females that are vulnerable to the fishery. Only years for which commercial data are used in the model are shown. Details as for Figure G.2.

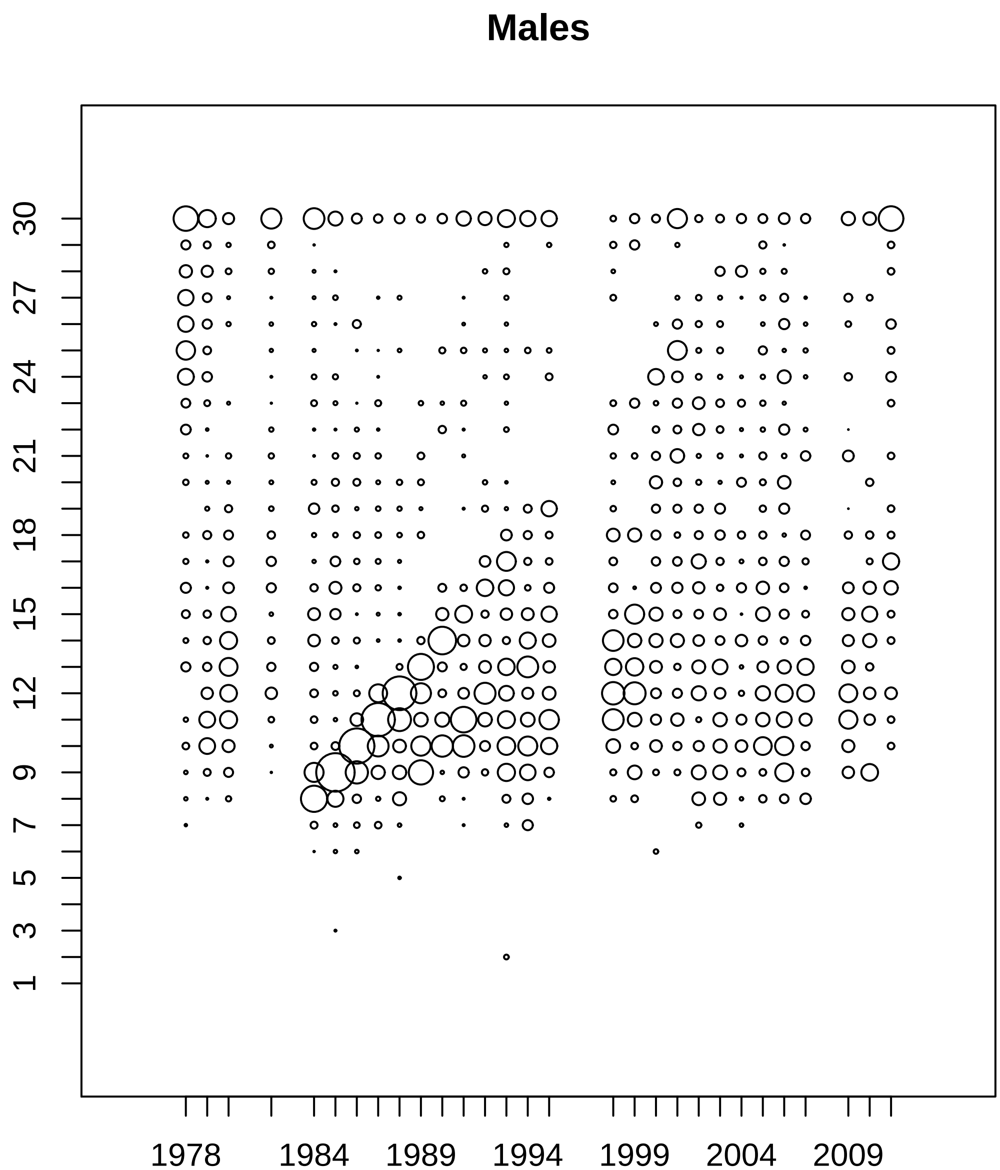


Figure G.4. Commercial catch-at-age data for males, details as for Figure G.2.

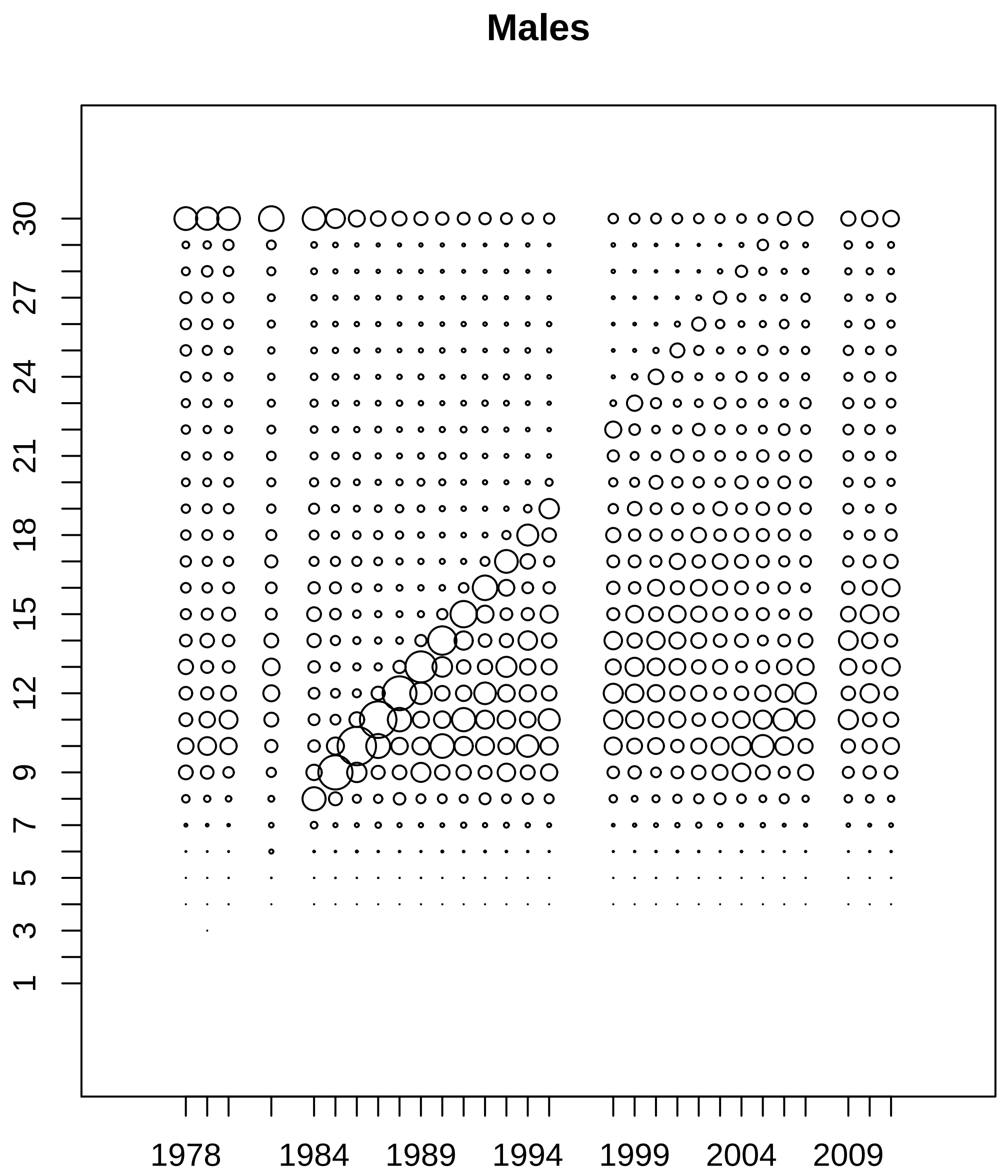


Figure G.5. Estimated proportions-at-age of males that are vulnerable to the fishery. Only years for which commercial data are used in the model are shown. Details as for Figure G.2.

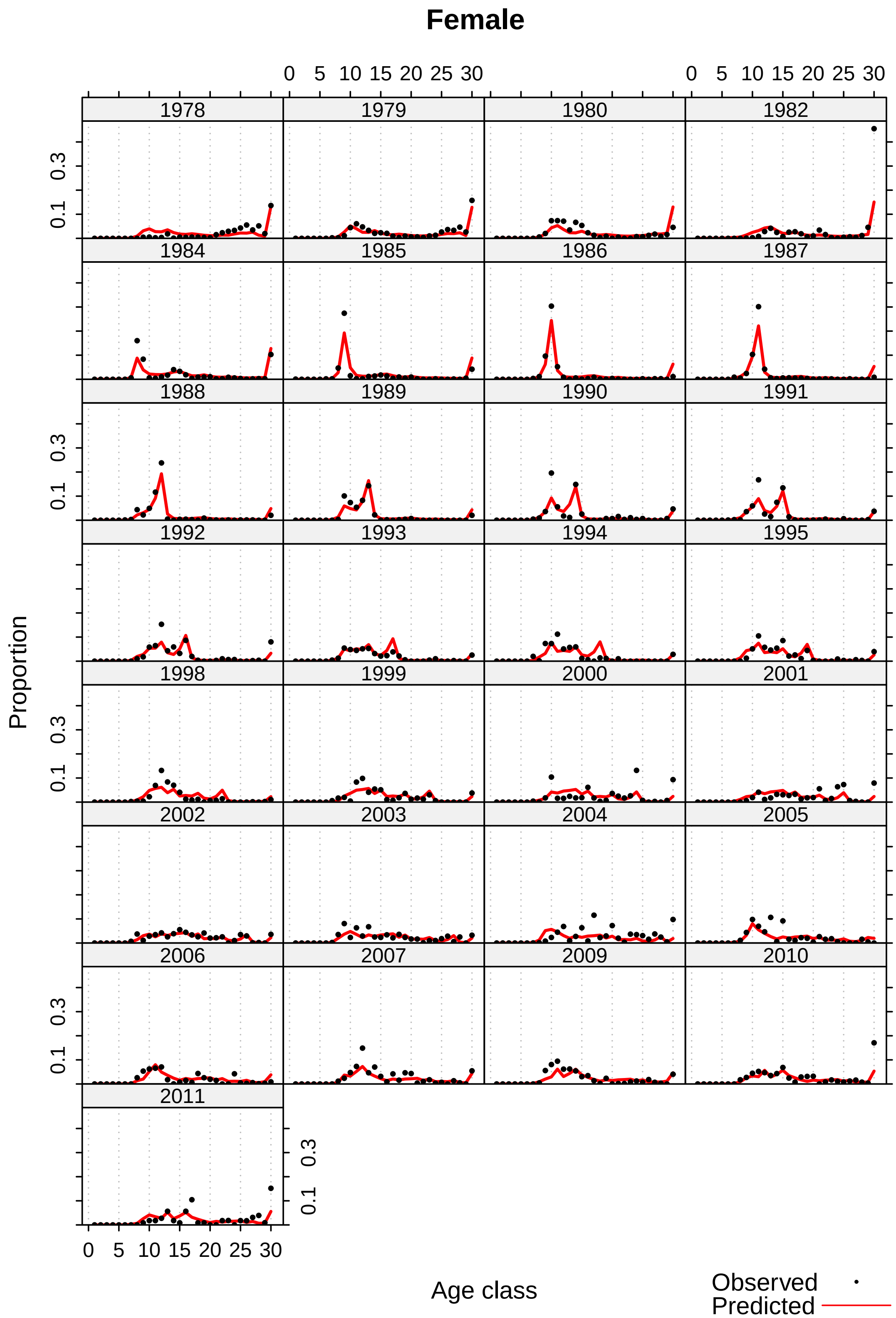


Figure G.6. Observed and predicted commercial proportions-at-age for females. Note that years are not consecutive.

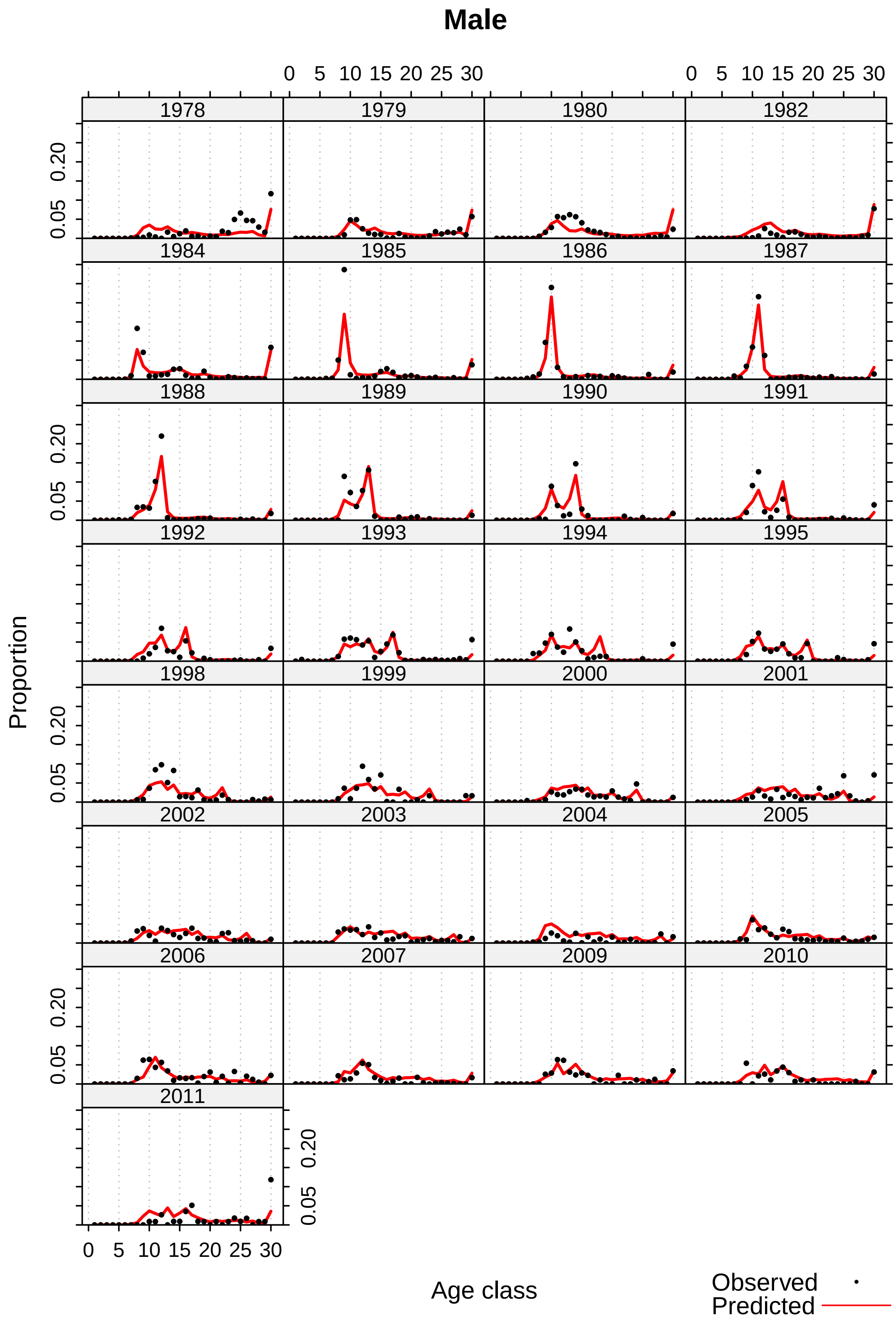


Figure G.7. Observed and predicted commercial proportions-at-age for males. Note that years are not consecutive.

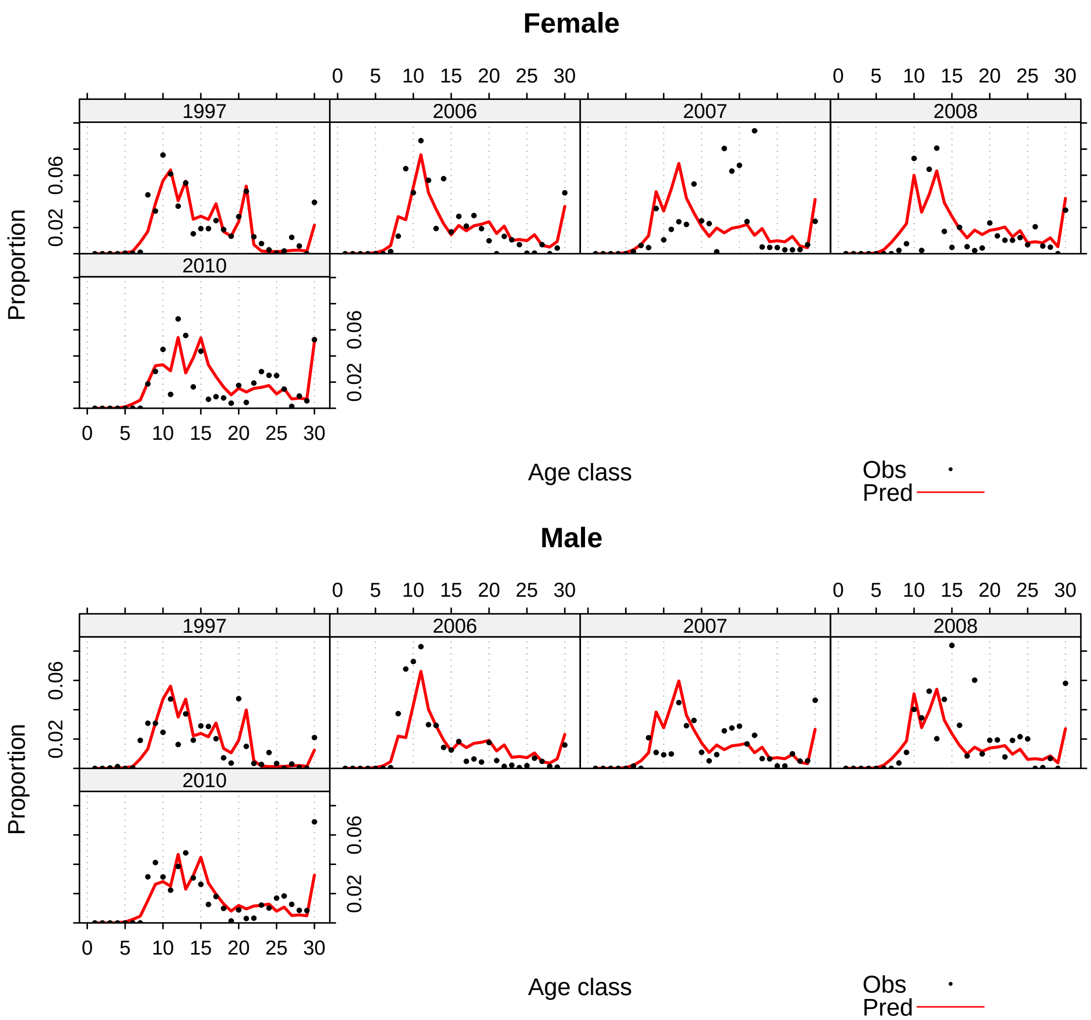


Figure G.8. Observed and predicted proportions-at-age for the WCHG synoptic survey series.

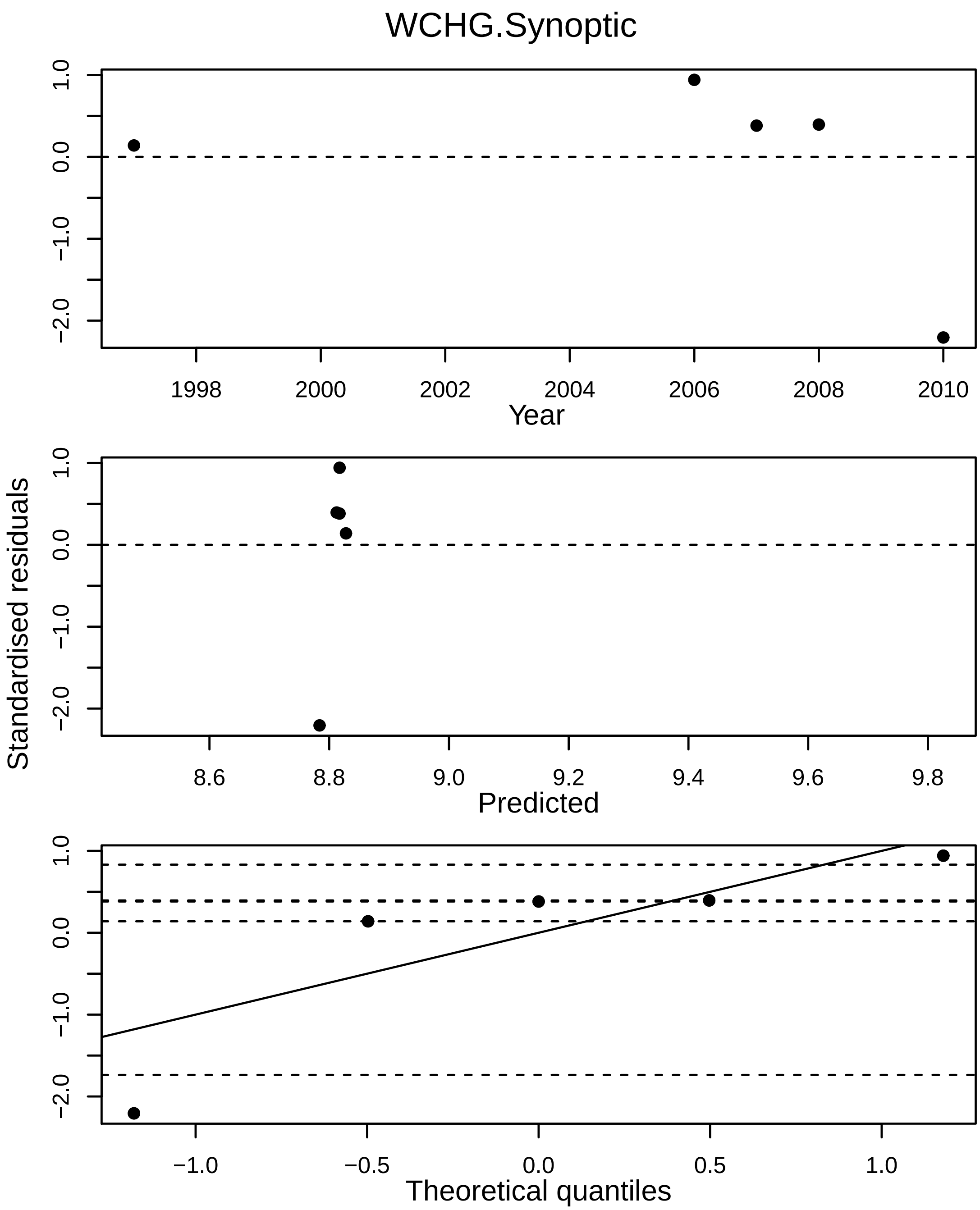


Figure G.9. Residuals of fits of model to the WCHG synoptic survey series (MPD values). Vertical axes are standardised residuals. The three plots show, respectively, residuals by year of index, residuals relative to predicted index, and normal quantile-quantile plot for residuals (horizontal lines give 5, 25, 50, 75 and 95 percentiles).

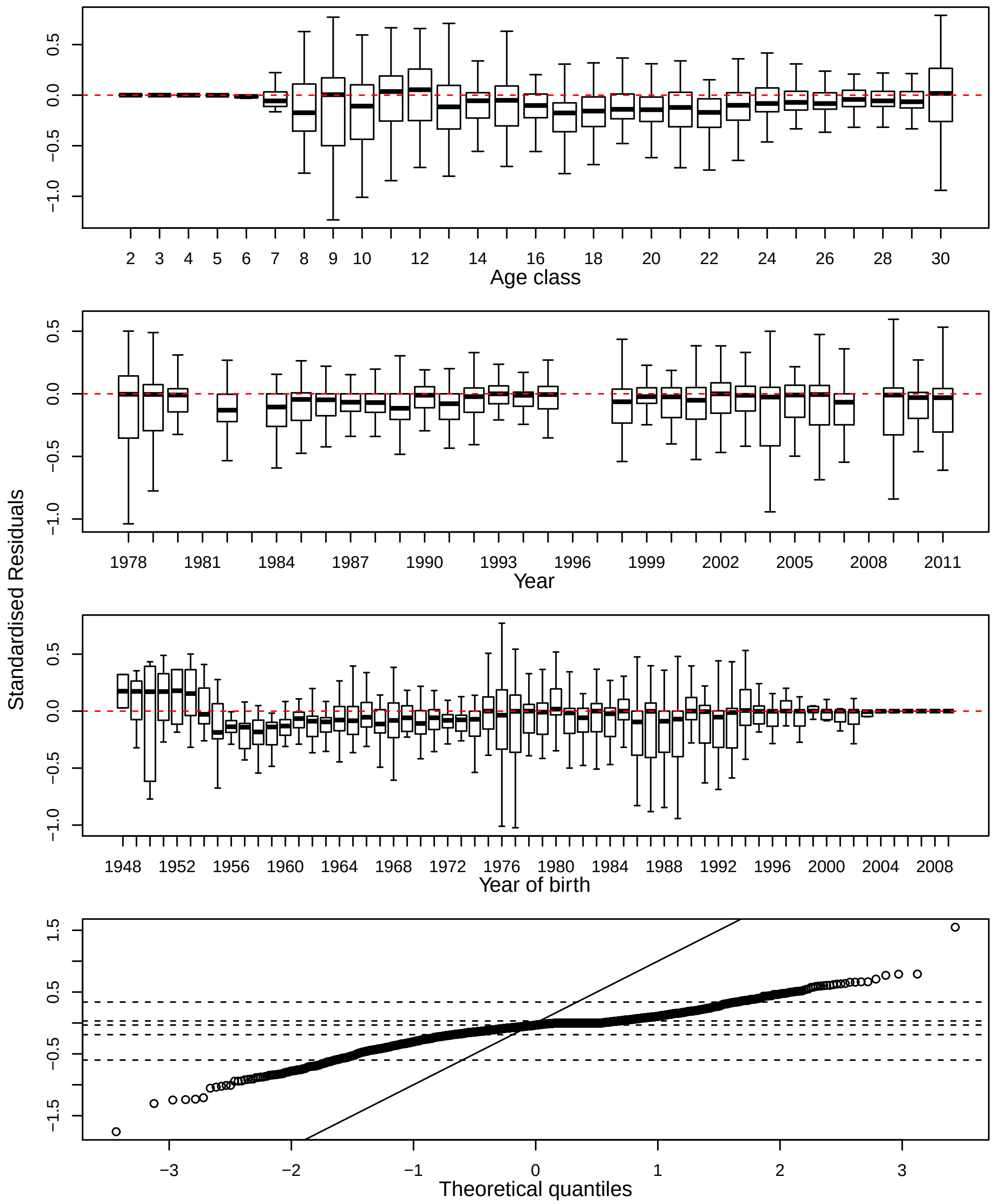


Figure G.10. Residual of fits of model to commercial proportions-at-age data (MPD values). Vertical axes are standardised residuals. Boxplots show, respectively, residuals by age class, by year of data, and by year of birth (following a cohort through time). Boxes give interquartile ranges, with bold lines representing medians and whiskers extending to the most extreme data point that is <1.5 times the interquartile range from the box. Bottom panel is the normal quantile-quantile plot for residuals, with the 1:1 line, though residuals are not expected to be normally distributed because of the likelihood function used; horizontal lines give the 5, 25, 50, 75, and 95 percentiles (for the total of 1682 residuals).

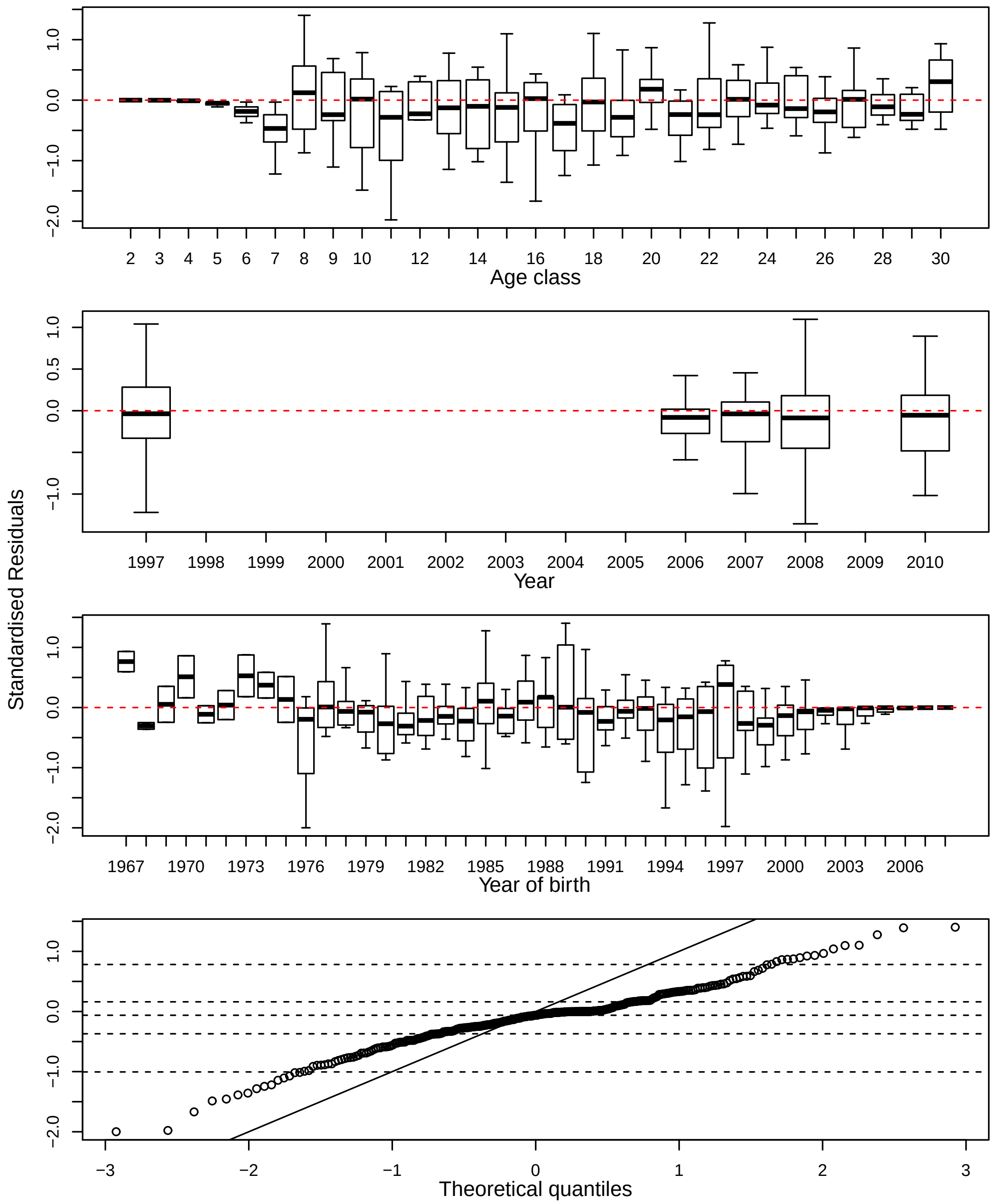


Figure G.11. Residuals of fits of model to proportions-at-age data (MPD values) from the WCHG synoptic survey series. Details as for Figure G.10, for a total of 290 residuals.

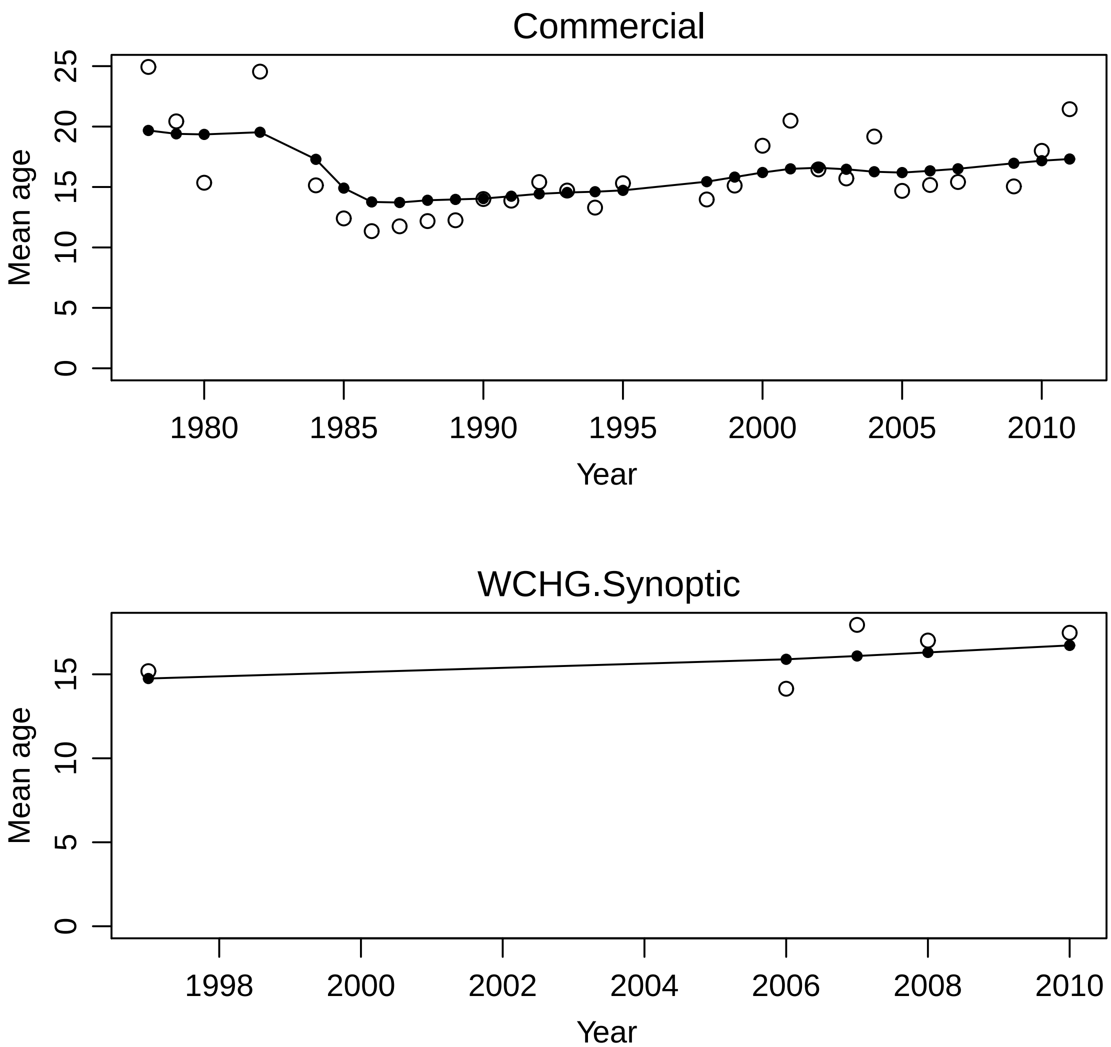


Figure G.12. Mean ages each year for the data (open circles) and model estimates (joined filled circles) for the commercial and survey age data.

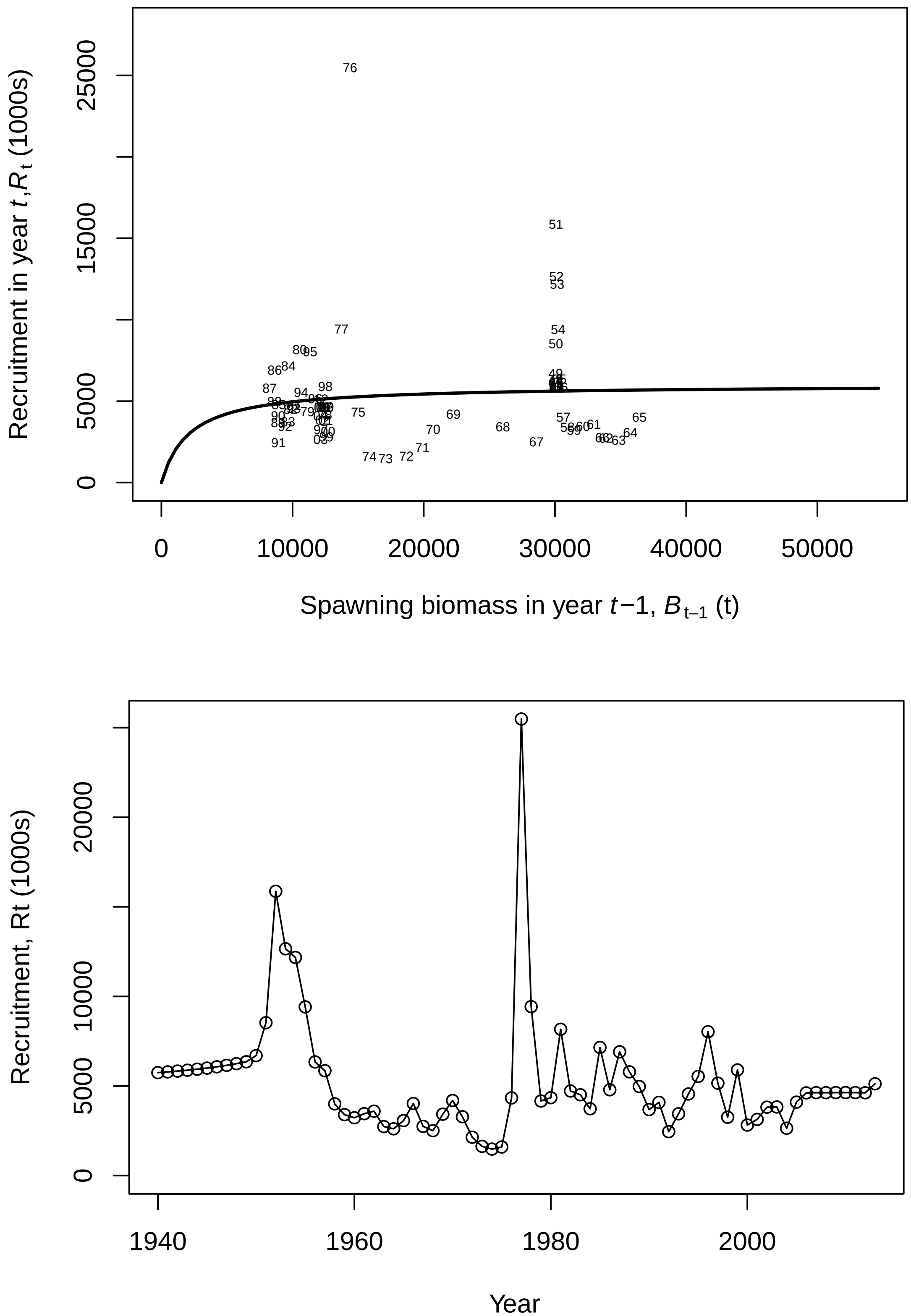
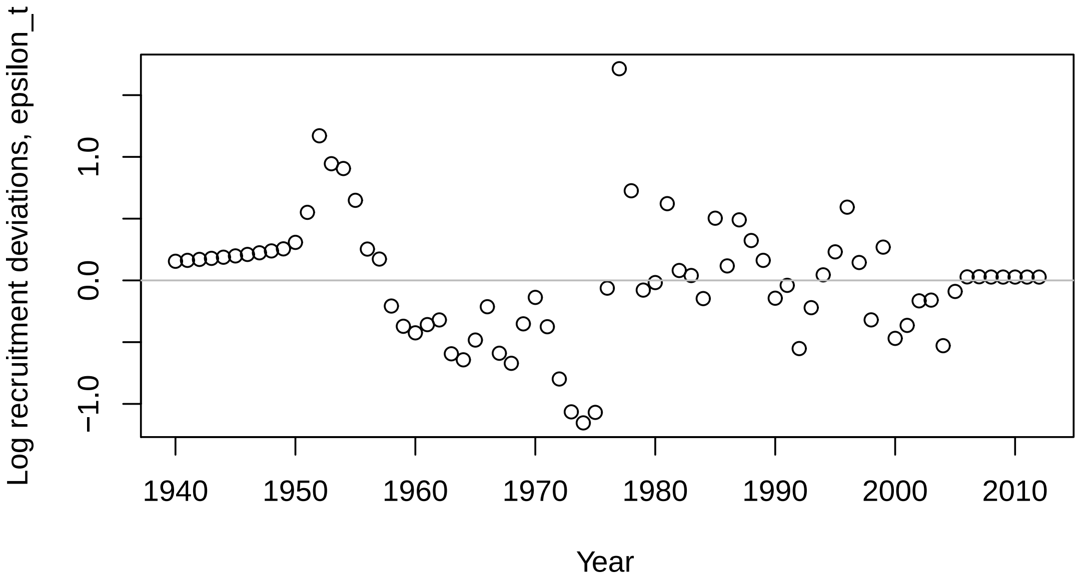


Figure G.13. Top: Deterministic stock-recruit relationship (black curve) and observed values (labelled by year of spawning) using MPD values. Bottom: Recruitment (MPD values of age-1 individuals in year t) over time, in 1,000s of age-1 individuals, with a mean of 5,313.



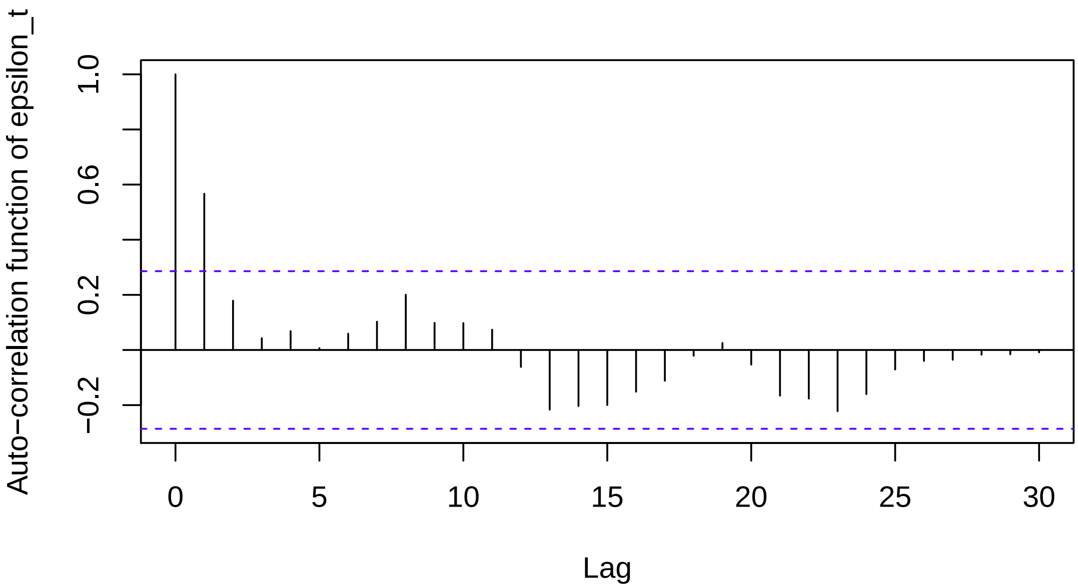


Figure G.14. Top: log of the annual recruitment deviations, ϵ_t, where bias-corrected multiplicative deviation is $e^{\epsilon_t - \sigma_R^2/2}$ where $\epsilon_t \sim$ Normal$(0, \sigma_R^2)$. Bottom: Auto-correlation function of the logged recruitment deviations (ϵ_t), for years 1957-2003 (determined as the first year of commercial age data minus the accumulator age class plus the age for which commercial selectivity for females is 0.5, to the final year that recruitments are calculated minus the age for which commercial selectivity for females is 0.5).

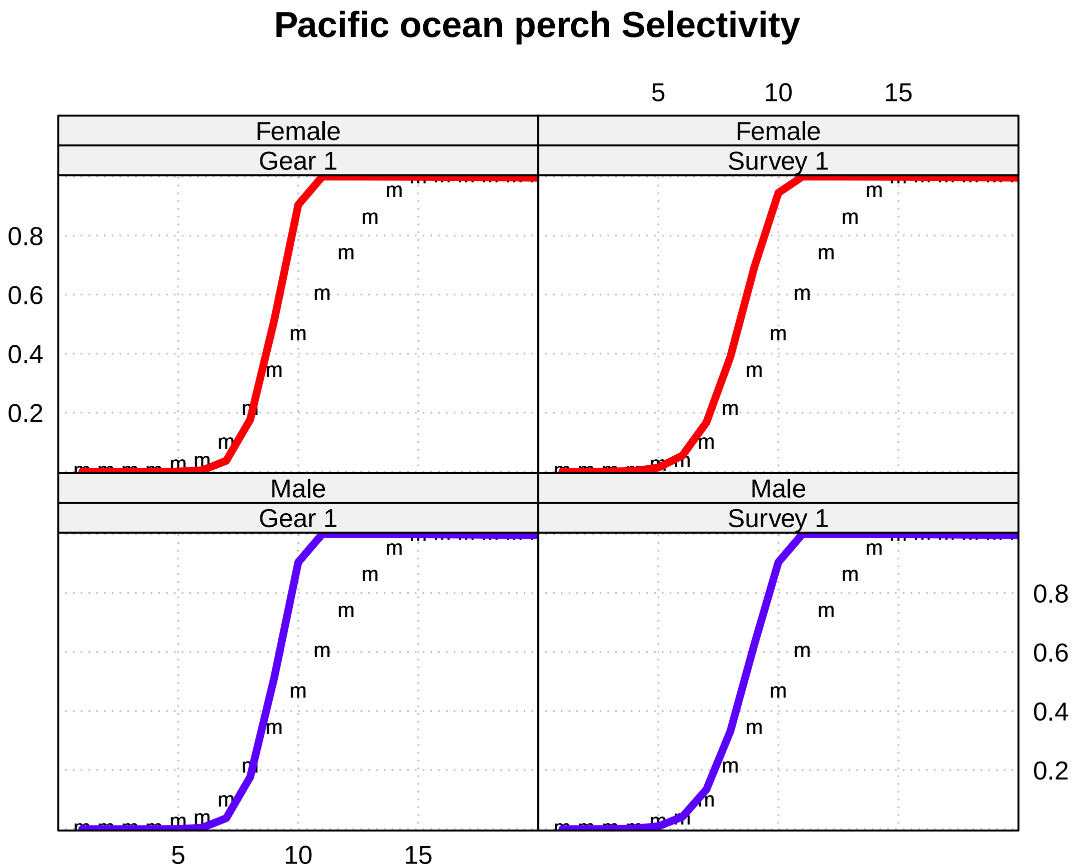


Figure G.15. Selectivities for commercial catch (labelled 'Gear 1' here) and the WCHG synoptic survey (all MPD values), with maturity ogive for females indicated by 'm'.

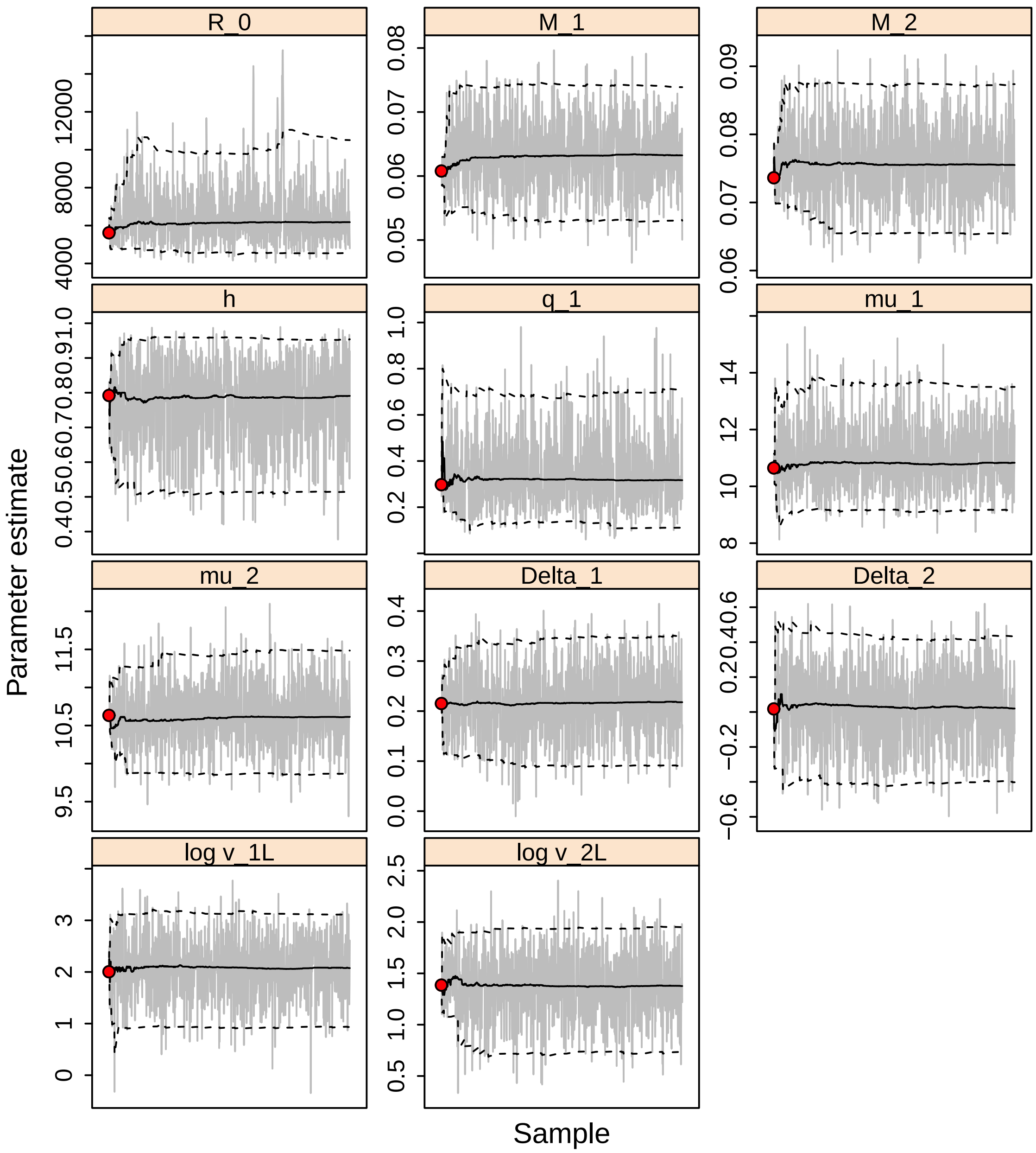


Figure G.16. MCMC traces for the estimated parameters. Grey lines show the 1,000 samples for each parameter, solid lines show the cumulative median (up to that sample), and dashed lines show the cumulative 2.5 and 97.5 quantiles. Red circles are the MPD estimates. Except for M_1 and M_2, subscript 1 corresponds to the WCHG survey series and subscript 2 to the commercial fishery.

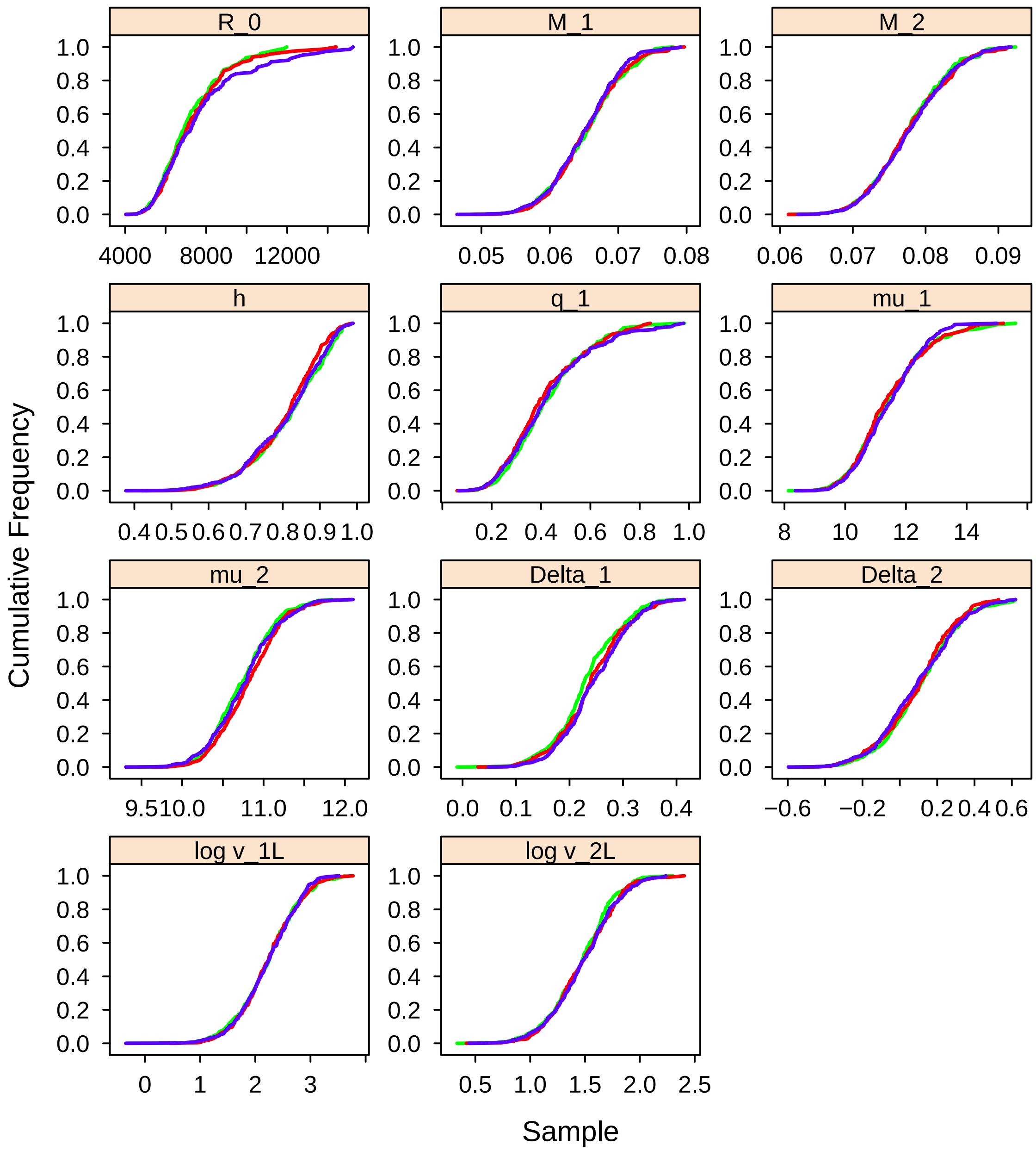


Figure G.17. Diagnostic plot obtained by dividing the MCMC chain of 1,000 MCMC samples into three segments, and overplotting the cumulative distributions of the first segment (green), second segment (red) and final segment (blue).

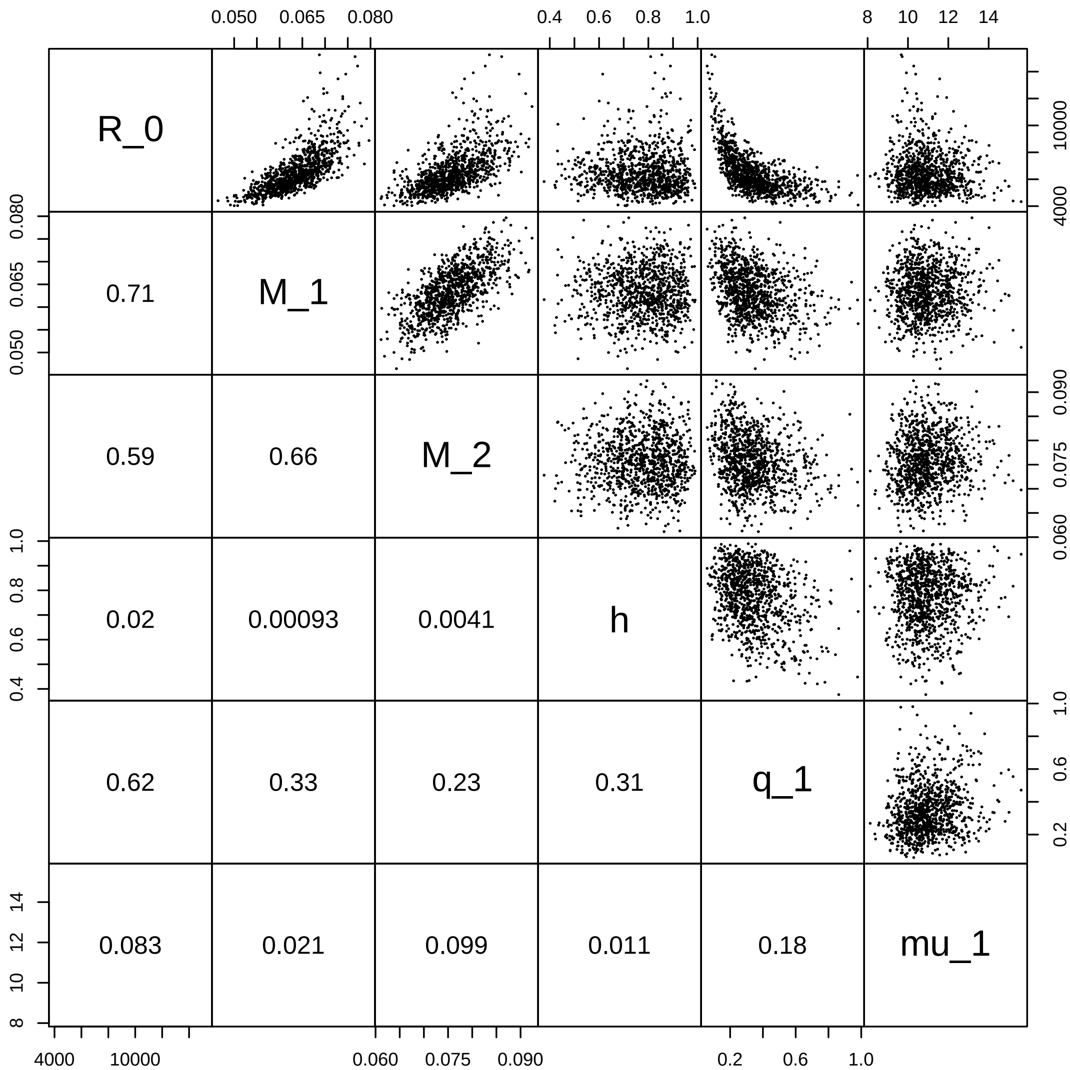


Figure G.18. Pairs plot of 1,000 MCMC samples for 1st six parameters. Numbers are the absolute values of the correlation coefficients.

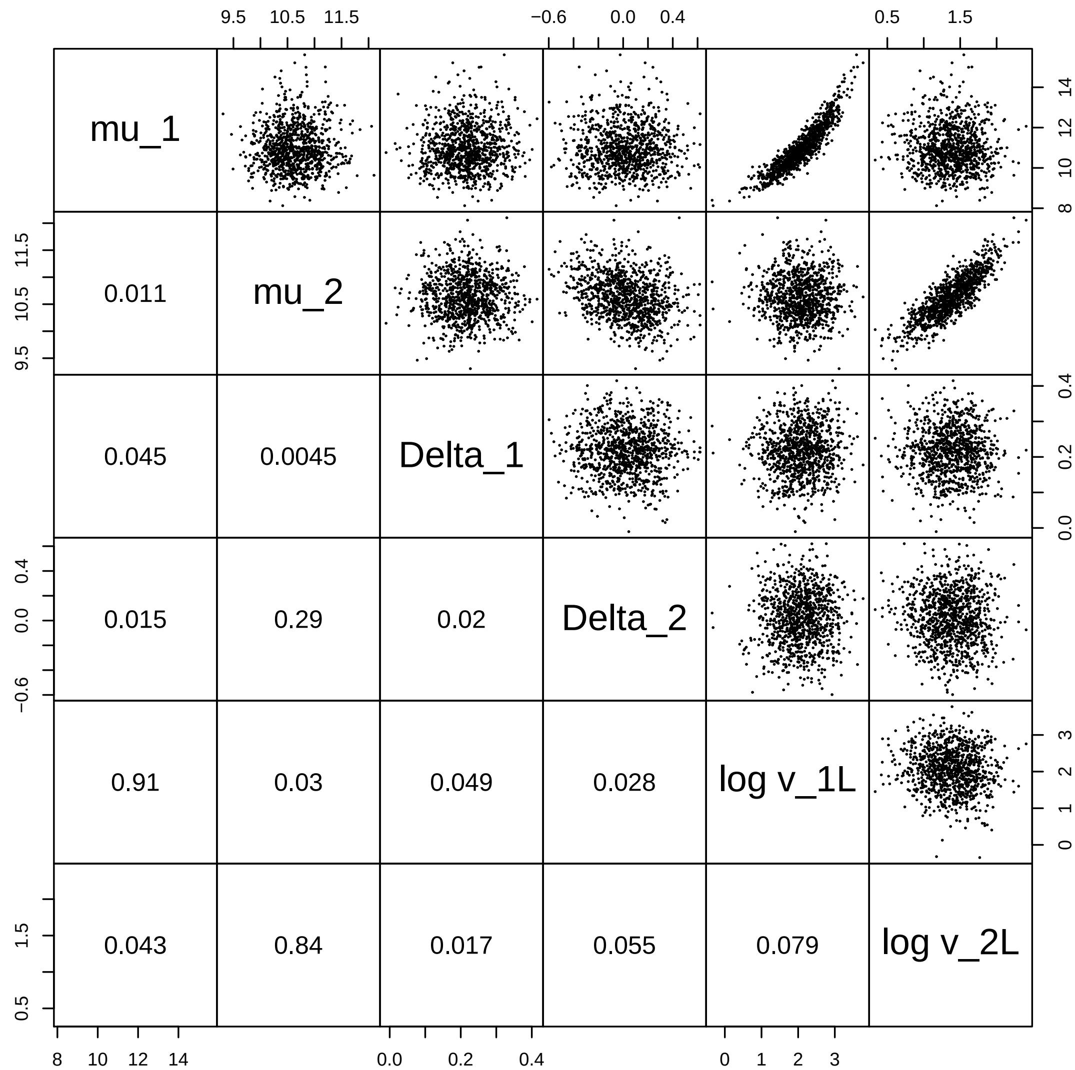


Figure G.19. Pairs plot of 1,000 MCMC samples for 2nd six parameters. Numbers are the absolute values of the correlation coefficients.

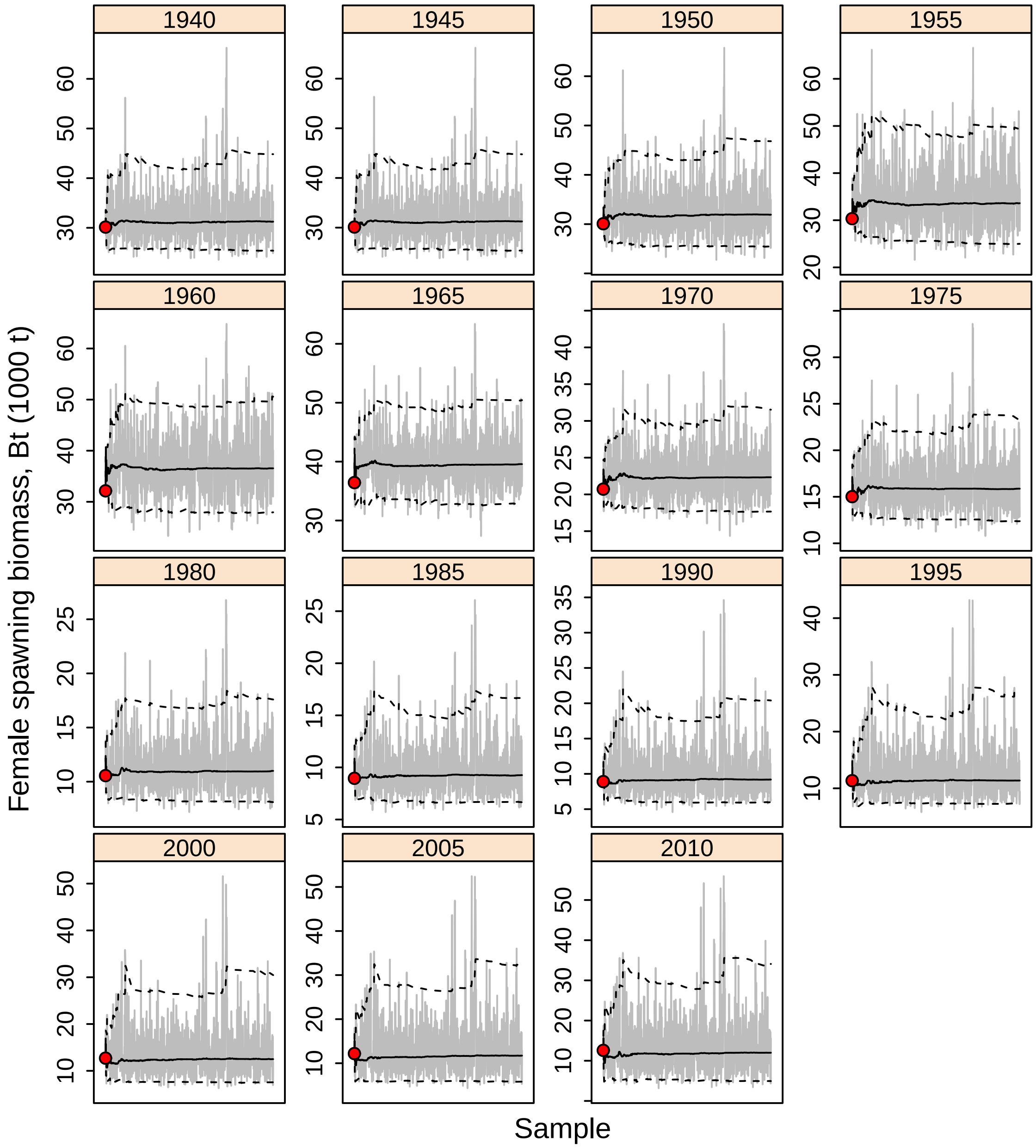


Figure G.20. MCMC traces for female spawning biomass estimates at five-year intervals. Note that vertical scales are different for each plot (to show convergence of the MCMC chain, rather than absolute differences in annual values). Grey lines show the 1,000 samples for each parameter, solid lines show the cumulative median (up to that sample), and dashed lines show the cumulative 2.5 and 97.5 quantiles. Red circles are the MPD estimates.

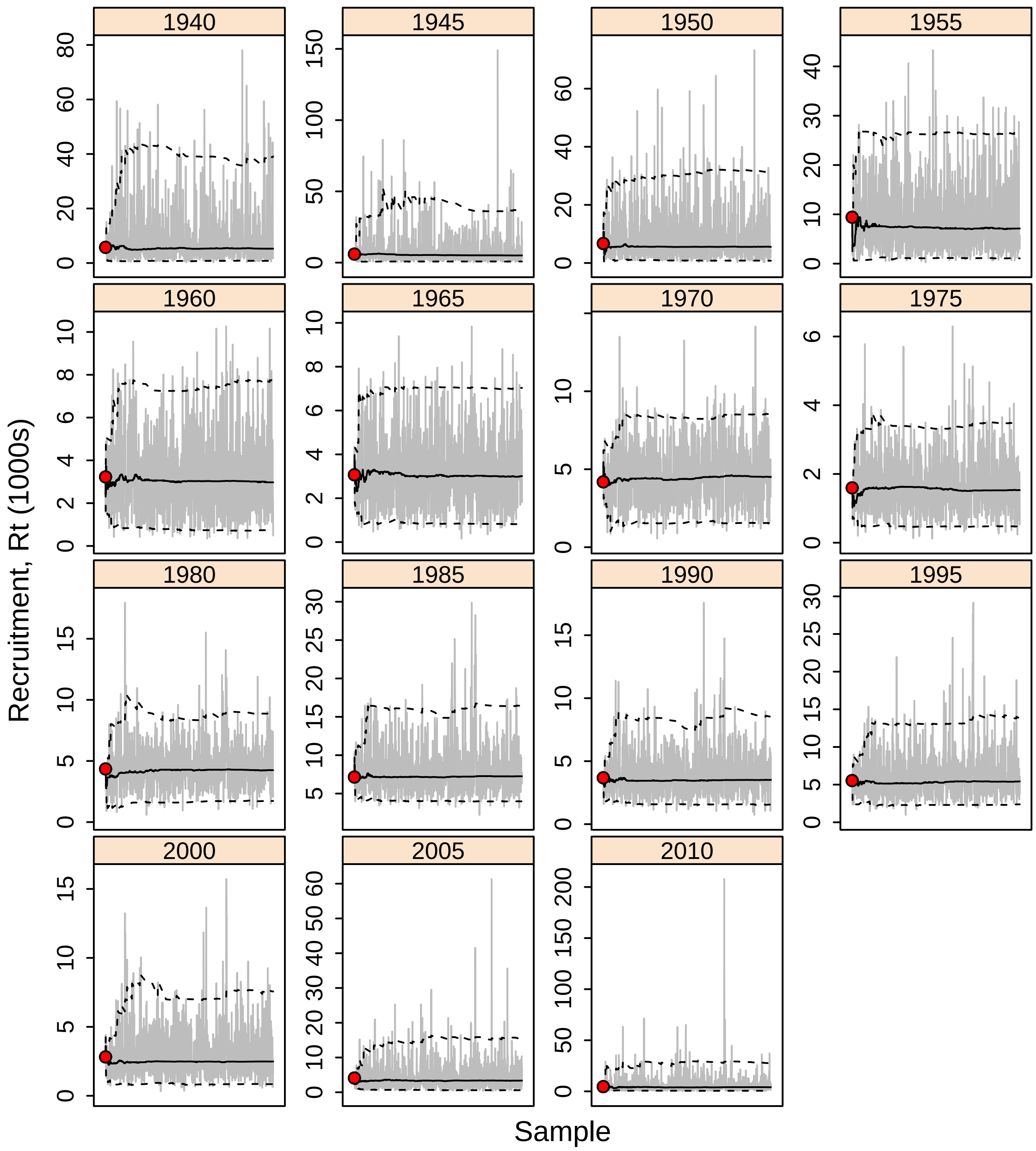


Figure G.21. MCMC traces for recruitment estimates at five-year intervals. Note that vertical scales are different for each plot (to show convergence of the MCMC chain, rather than absolute differences in annual recruitment). Grey lines show the 1,000 samples for each parameter, solid lines show the cumulative median (up to that sample), and dashed lines show the cumulative 2.5 and 97.5 quantiles. Red circles are the MPD estimates.

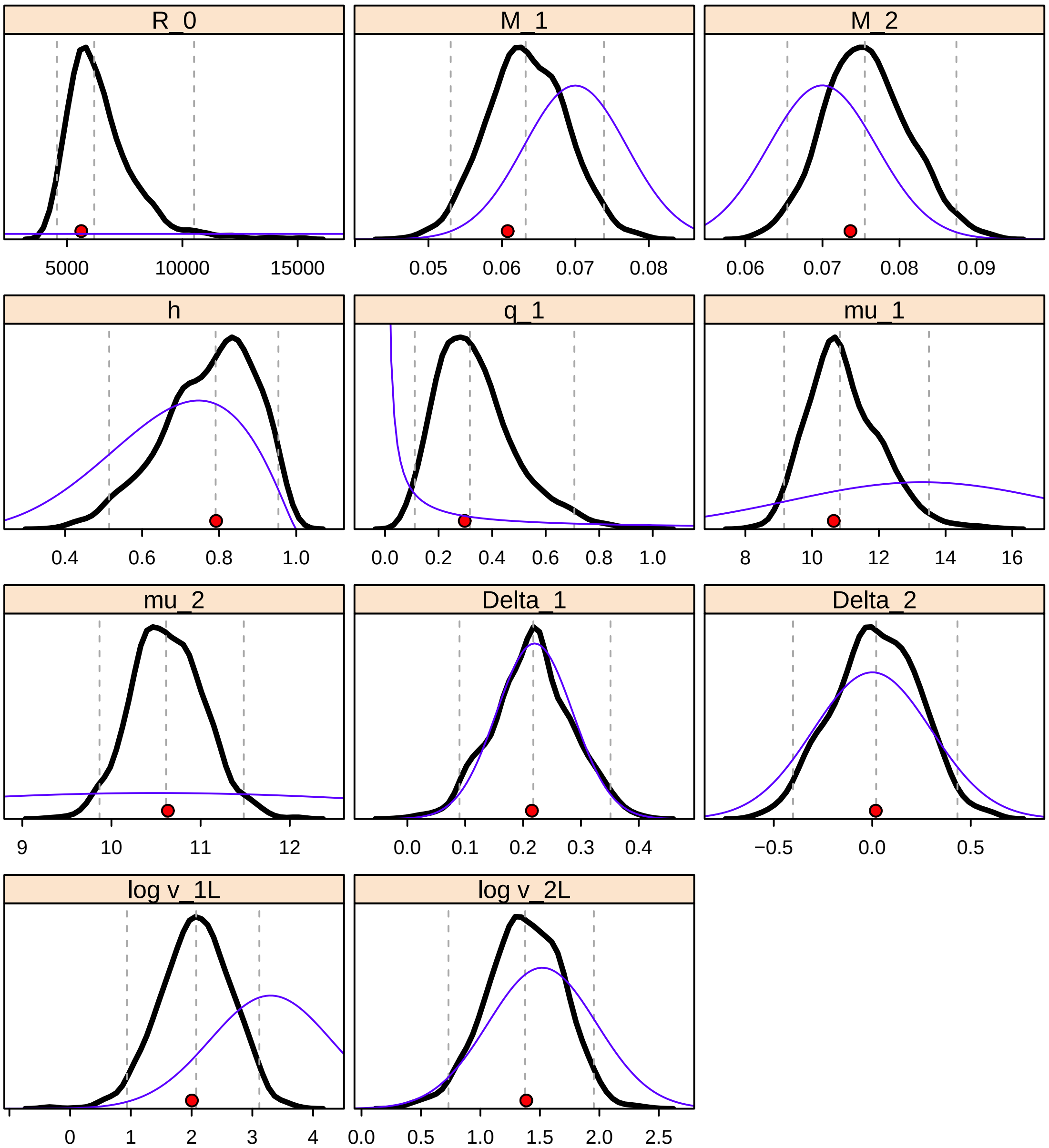


Figure G.22. Marginal posterior densities (thick black curves) and prior density functions (thin blue curves) for the estimated parameters. Vertical lines represent the 2.5, 50 and 97.5 percentiles, and red filled circles are the MPD estimates. For R_0 the prior is a uniform distribution on the range [1, 100000], and is at too low a value to show up on the graph. The prior for q_1 is uniform on a log-scale, and so the probability density function is $1/(x(b-a))$ on a linear scale (where a and b are the bounds on the log scale).

Table G.1. Negative log-likelihoods and objective function from the MPD results. Parameters and likelihood symbols are defined in Appendix F. For indices ($\hat{I}_{tg}$) and proportions-at-age ($\hat{p}_{atgs}$), subscript $g = 1$ refers to the survey series and subscript $g = 2$ refers to the commercial fishery.

Negative log likelihood component	Value
$\log \mathsf{L}_3 \left(\boldsymbol{\Theta} \middle| \left\{ \hat{I}_{t1} \right\} \right)$	-3.23
$\log \mathsf{L}_2 \left(\boldsymbol{\Theta} \middle| \left\{ \hat{p}_{at1s} \right\} \right)$	-626.63
$\log \mathsf{L}_2 \left(\boldsymbol{\Theta} \middle| \left\{ \hat{p}_{at2s} \right\} \right)$	-3975.01
$\log \mathsf{L}_1 \left(\boldsymbol{\Theta} \middle| \left\{ \epsilon_t \right\} \right) - \log \left(\pi(\boldsymbol{\Theta}) \right)$	16.73
Objective function $f(\boldsymbol{\Theta})$	-4588.14

Table G.2. Summary statistics of MCMC results for estimated parameters (defined in Appendix F). Except for M_1 and M_2, subscript 1 corresponds to the WCHG survey series and subscript 2 to the commercial fishery.

Parameter	Percentile		
	5%	50%	95%
R_0	4,711	6,178	9,256
M_1	0.0545	0.0632	0.0727
M_2	0.0670	0.0755	0.0850
h	0.552	0.791	0.942
q_1	0.1448	0.3169	0.6301
μ_1	9.5	10.8	13.0
μ_2	10.0	10.6	11.3
Δ_1	0.10	0.22	0.33
Δ_2	-0.34	0.02	0.36
$\log v_{1L}$	1.10	2.08	2.97
$\log v_{2L}$	0.83	1.38	1.88

H HABITAT AND CONCURRENT SPECIES

The distribution of the starting depths of bottom trawl tows that captured Pacific Ocean Perch (POP, *Sebastes alutus*) along the west coast of Haida Gwaii (WCHG) – Pacific Marine Fisheries Commission (PMFC) areas 5D and 5E – shows that 98% of the encounters lie between 104 and 530 m, with a depth-of-median-catch at 300 m (Figure H.1); data extracted from the PacHarvest and GFFOS databases. Hereafter, we refer to the WCHG bottom tows between 104 and 530 m as "POP bottom tows" even though POP is not necessarily the predominant species in all tows. The distribution of POP bottom tows differs from the effort of the trawl fishery (shaded background histogram) due to flatfish fisheries off WCHG and deepwater Thornyhead/Sablefish fisheries (shaded bars occur deeper than the depths shown).

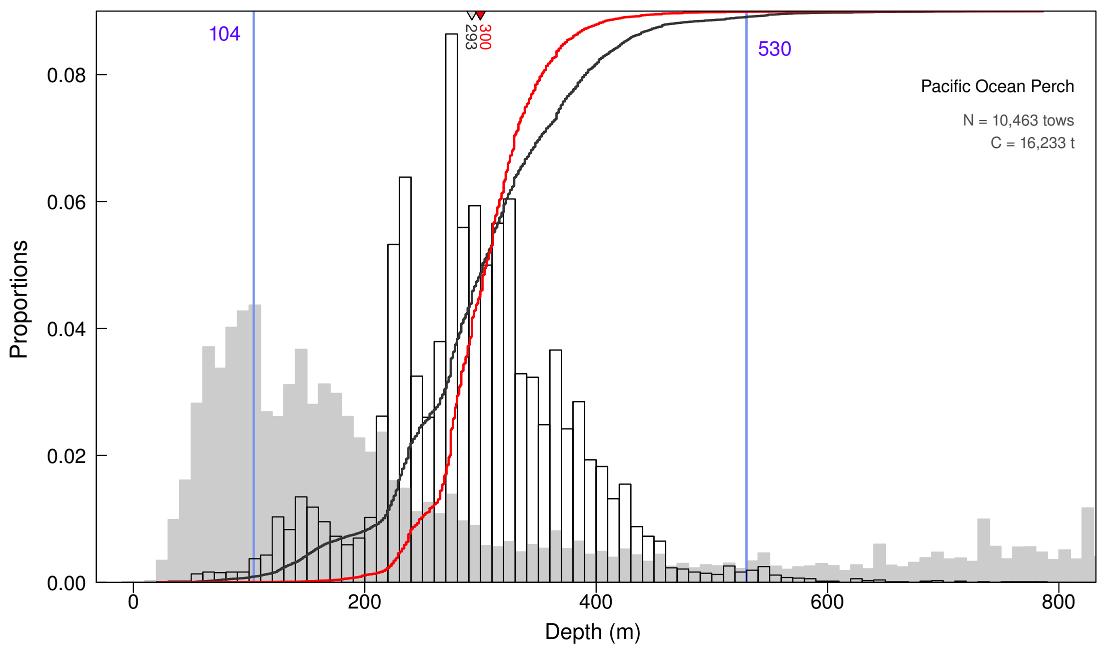


Figure H.1. Depth frequency of bottom tows that capture POP from commercial trawl logs (1996–2007 in PacHarvest, 2007–2012 in GFFOS, where 2012 records are incomplete) in PMFC major area 5DE. The vertical solid lines denote the 1% and 99% quantiles. The black curve shows the cumulative frequency of tows that encounter POP while the red curve shows the cumulative catch of POP at depth (scaled from 0 to 1). The median depth of cumulative catch (inverted red triangle) is indicated along the upper axis. 'N' reports the total number of tows; 'C' reports the total catch (t). The shaded histogram in the background reports the relative trawl effort on all species at all depths (deeper effort not shown).

The reported species caught in POP bottom tows comprise predominantly a mixture of rockfish and flatfish (Figure H.2, Table H.1). Pacific Ocean Perch *Sebastes alutus* remains the most abundant species by catch weight in these tows (44%), followed by the Rougheye Rockfish complex *S. aleutianus/melanostictus* (15%), Arrowtooth Flounder *Atheresthes stomias* (7.7%), Yellowmouth Rockfish *S. reedi* (7.1%), Silvergray Rockfish *S. brevispinis* (5.8%), and Dover Sole *Microstomus pacificus* (4.9%). Two rockfish species of interest to COSEWIC (Committee on the Status of Endangered Wildlife in Canada) occur in the top six mentioned above – the Rougheye Rockfish complex and Yellowmouth Rockfish. Additionally, Darkblotched Rockfish *S. crameri* occupies the 25th position, accounting for only 0.21% of the catch.

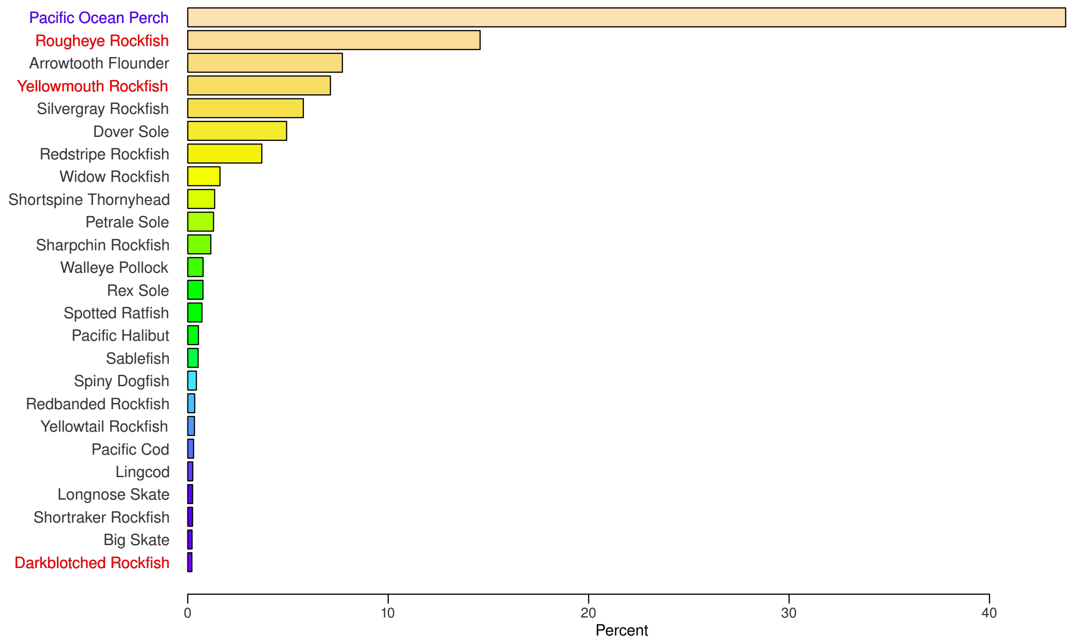


Figure H.2. Concurrence of species in POP bottom trawl tows (1996–2012). Abundance is expressed as a percent of total catch weight. POP is indicated in blue on the y-axis; other species of interest to COSEWIC are indicated in red.

Table H.1. Top 25 species by catch weight (landed + discarded) that co-occur in POP bottom tows (total from 1996–2012). Rockfish species of interest to COSEWIC appear in shaded rows.

Code	Species	Latin name	Catch (t)	Catch (%)
396	Pacific Ocean Perch	*Sebastes alutus*	16,201	43.799
394	Rougheye Rockfish	*Sebastes aleutianus*	5,395	14.585
602	Arrowtooth Flounder	*Atheresthes stomias*	2,853	7.712
440	Yellowmouth Rockfish	*Sebastes reedi*	2,633	7.117
405	Silvergray Rockfish	*Sebastes brevispinis*	2,133	5.766
626	Dover Sole	*Microstomus pacificus*	1,824	4.930
439	Redstripe Rockfish	*Sebastes proriger*	1,367	3.695
417	Widow Rockfish	*Sebastes entomelas*	595	1.609
451	Shortspine Thornyhead	*Sebastolobus alascanus*	496	1.341
607	Petrale Sole	*Eopsetta jordani*	475	1.285
450	Sharpchin Rockfish	*Sebastes zacentrus*	425	1.150
228	Walleye Pollock	*Theragra chalcogramma*	283	0.765
610	Rex Sole	*Errex zachirus*	281	0.760
066	Spotted Ratfish	*Hydrolagus colliei*	262	0.708
614	Pacific Halibut	*Hippoglossus stenolepis*	197	0.532
455	Sablefish	*Anoplopoma fimbria*	191	0.515
044	Spiny Dogfish	*Squalus acanthias*	159	0.431
401	Redbanded Rockfish	*Sebastes babcocki*	128	0.346
418	Yellowtail Rockfish	*Sebastes flavidus*	123	0.334
222	Pacific Cod	*Gadus macrocephalus*	107	0.289
467	Lingcod	*Ophiodon elongatus*	92	0.248
059	Longnose Skate	*Raja rhina*	89	0.240
403	Shortraker Rockfish	*Sebastes borealis*	88	0.238
056	Big Skate	*Raja binoculata*	79	0.214
410	Darkblotched Rockfish	*Sebastes crameri*	76	0.205

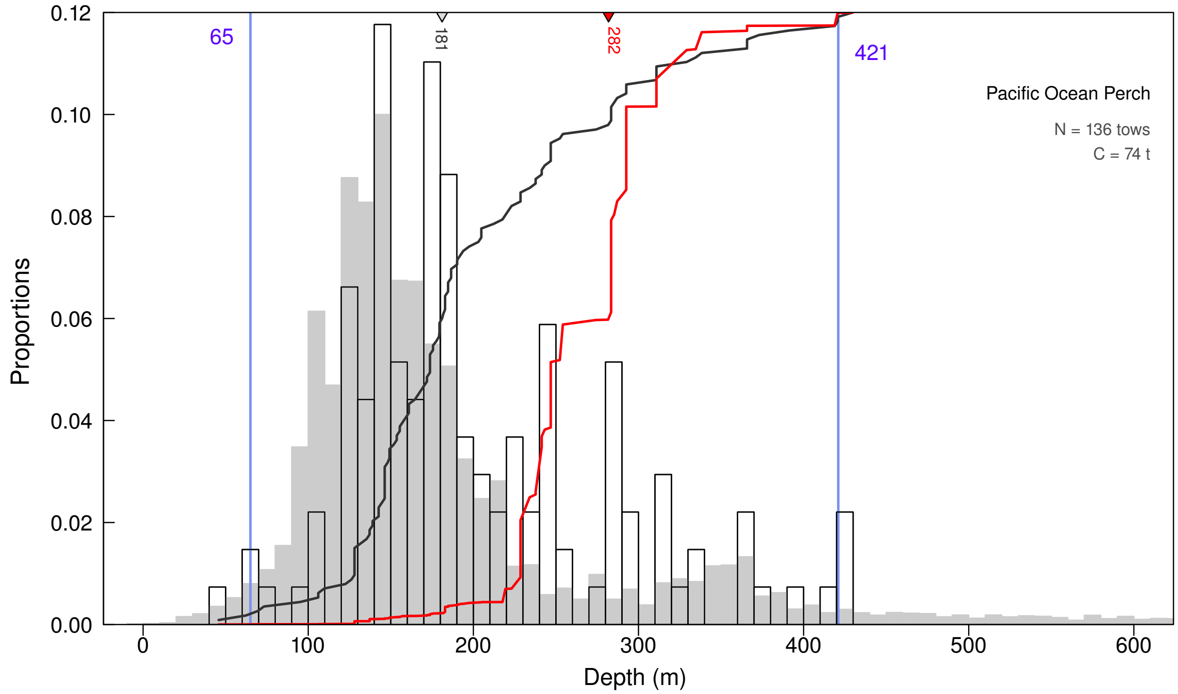


Figure H.3. Depth frequency of midwater tows that capture POP from commercial trawl logs (1996–2011) in PMFC major area 5DE. The vertical solid lines denote the 1% and 99% quantiles. See Figure H.1 for plot details.

We refer to WCHG (PMFC 5DE) midwater tows that encounter POP between 65 and 421 m as "POP midwater tows" (Figure H.3). The midwater data in 5DE are sparse (N = 136 tows), which accounts for the jagged distribution of POP midwater tows. Still, the 98% limits suggest a long right-hand tail in the tow frequency distribution, probably because POP are caught at shallower depths as the net descends or ascends from deep midwater tows. Pacific Ocean Perch midwater tows (Figure H.4, Table H.2) are dominated by Walleye Pollock *Theragra chalcogramma* (41% by catch weight) and Pacific Hake *Merluccius productus* (38%). Pacific Ocean Perch accounts for 6.1% of the POP midwater tows, with Yellowtail Rockfish *S. flavidus* (6.1%) and Widow Rockfish *S. entomelas* (4.9%) close behind. Five rockfish species of interest to COSEWIC occur in POP midwater tows - Yellowmouth Rockfish *S. reedi* (1.1%), the Rougheye Rockfish complex *S. aleutianus/melanostictus* (0.19%), Bocaccio *S. paucispinis* (0.11%), Canary Rockfish *S. pinniger* (0.027%), and Darkblotched Rockfish *S. crameri* (0.026%) (Table H.2).

The distribution of POP along the WCHG is best viewed as CPUE density from commercial bottom trawl records that span 1996 to 2012 (Figure H.5). The 5DE population lies chiefly between 200 and 600 m with highest densities NE of Langara Island and smaller pockets off the NW and SW corners of Haida Gwaii. These densities can rival or exceed those in Queen Charlotte Sound (Figure 2); however, the areas of high density are much smaller. The grid cells in Figure H.5, roughly 6.5 km^2 each, identify regions of positive CPUE. Specifically, these cells cover 3,525 km^2 in 5D and 2,617 km^2 in 5E for an encountered area of 5,142 km^2 in PMFC 5DE.

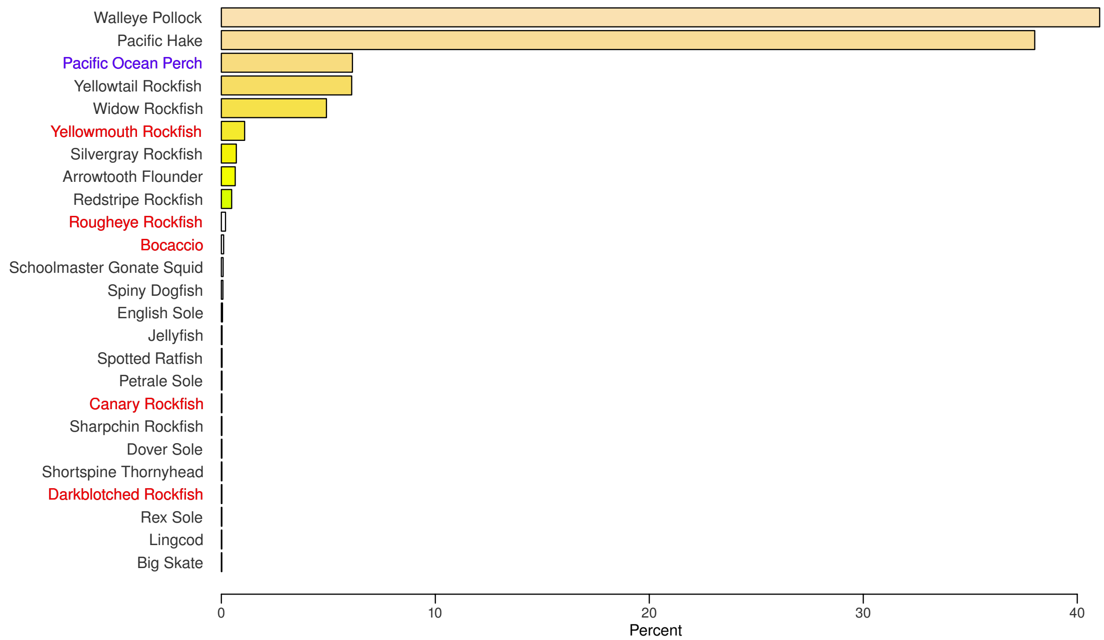


Figure H.4. Concurrence of species in POP midwater trawl tows (1996–2012). Abundance is expressed as a percent of total catch weight. POP is indicated in blue on the y-axis; other species of interest to COSEWIC are indicated in red.

Table H.2. Top 25 species by catch weight (landed + discarded) that co-occur in POP midwater tows (total from 1996–2012). Rockfish species of interest to COSEWIC appear in shaded rows.

Code	Species	Latin name	Catch (t)	Catch (%)
228	Walleye Pollock	*Theragra chalcogramma*	493	41.047
225	Pacific Hake	*Merluccius productus*	457	38.012
396	Pacific Ocean Perch	*Sebastes alutus*	74	6.127
418	Yellowtail Rockfish	*Sebastes flavidus*	73	6.091
417	Widow Rockfish	*Sebastes entomelas*	59	4.912
440	Yellowmouth Rockfish	*Sebastes reedi*	13	1.088
405	Silvergray Rockfish	*Sebastes brevispinis*	8	0.700
602	Arrowtooth Flounder	*Atheresthes stomias*	8	0.649
439	Redstripe Rockfish	*Sebastes proriger*	6	0.482
394	Rougheye Rockfish	*Sebastes aleutianus*	2	0.194
435	Bocaccio	*Sebastes paucispinis*	1	0.107
095	Schoolmaster Gonate Squid	*Alosa sapidissima*	1	0.082
044	Spiny Dogfish	*Squalus acanthias*	1	0.073
628	English Sole	*Parophrys vetulus*	1	0.053
3G0	Jellyfish	*Scyphozoa*	0	0.034
066	Spotted Ratfish	*Hydrolagus colliei*	0	0.034
607	Petrale Sole	*Eopsetta jordani*	0	0.032
437	Canary Rockfish	*Sebastes pinniger*	0	0.027
450	Sharpchin Rockfish	*Sebastes zacentrus*	0	0.027
626	Dover Sole	*Microstomus pacificus*	0	0.027
451	Shortspine Thornyhead	*Sebastolobus alascanus*	0	0.027
410	Darkblotched Rockfish	*Sebastes crameri*	0	0.026
610	Rex Sole	*Errex zachirus*	0	0.024
467	Lingcod	*Ophiodon elongatus*	0	0.022
056	Big Skate	*Raja binoculata*	0	0.022

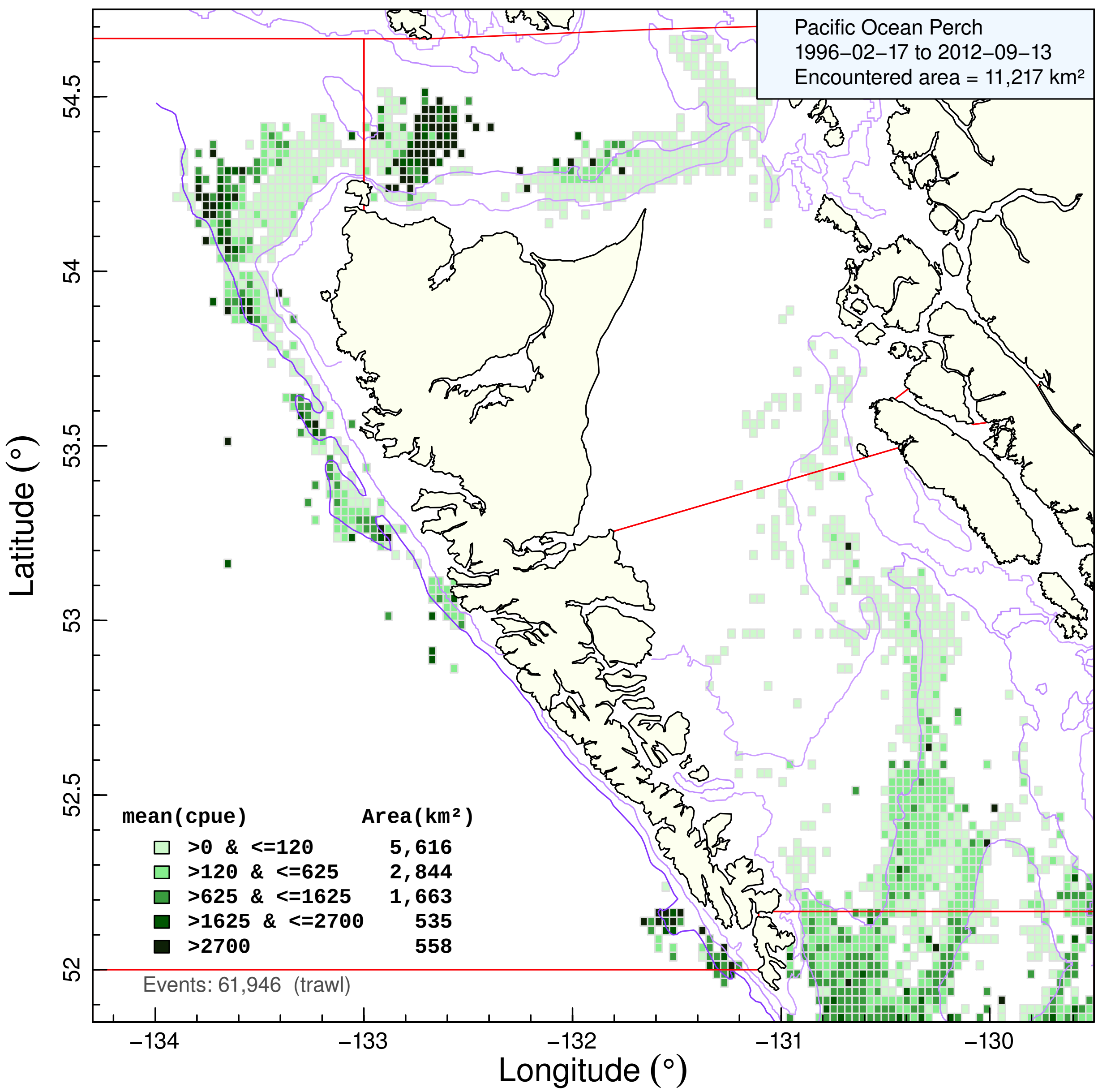


Figure H.5. Mean CPUE (kg/h) of POP in grid cells 0.035° longitude by 0.025° latitude (roughly 6.5 km^2). The shaded cells give an approximation of the area where POP was encountered by fishing events from the groundfish trawl fishery from Feb 1996 to Sep 2012. Encountered grid cells in 5D cover 2,525 km^2 and in 5E cover 2,617 km^2 for a total area of 5,142 km^2 in PMFC 5DE. Contour lines trace the 100, 200, and 600 m isobaths.

The distribution of POP displayed in Figure H.5 stems from tow encounters by the commercial trawl fleet. An alternative proxy for potential habitat uses bathymetry limits. For instance, isobaths (104 m, 530 m), identified in Figure H.1 as POP bottom tows, outline bottom regions along the WCHG that might host POP (Figure H.6). This highlighted region covers 29,771 km^2; however, not all areas are amenable to POP habitation (e.g., Masset Inlet, mainland inlets, US waters). The bathymetry limits within PMFC 5D cover an estimated 7,502 km^2 and within 5E cover 5,829 km^2 for a total 5DE estimate of 13,331 km^2.

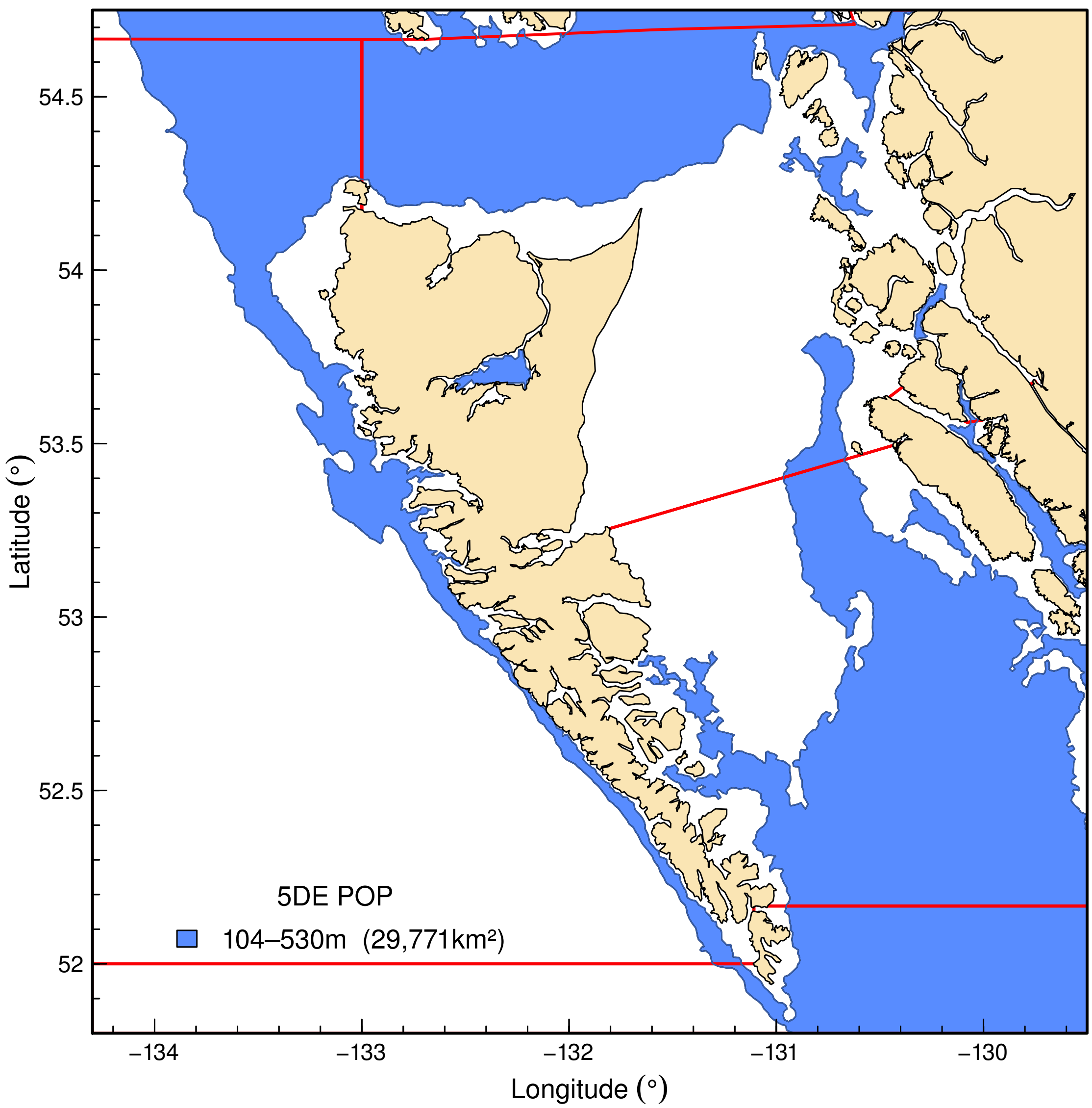


Figure H.6. Highlighted bathymetry (blue) between 104 and 530 m serves as a proxy for benthic Pacific Ocean Perch habitat along the WCHG. Highlighted region covers 29,771 km^2; however, the shaded region in 5D covers 7,502 km^2 and in 5E covers 5,829 km^2 for a total area of 13,331 km^2 in PMFC 5DE.

I SENSITIVITY RUNS

Two sensitivity runs were conducted on the base model run, namely:

Run S1: remove the 1997 Ocean Selector index and age data from the survey series.

Run S2: decreasing catches in 1984 (by 19%), 1985 (by 18%), 1986 (by 27%), 1987 (by 10%), 1988 (by 11%) and 1989 (by 15%).

Run S1 tests the sensitivity of the stock assessment to the insertion of the 1997 Ocean Selector survey index into the linked synoptic survey series conducted off the west coast of Haida Gwaii from 2006 to 2010 (Appendix C). The 1997 survey used a similar, but not identical, design compared to the subsequent synoptic surveys, occupying a different depth range and conducted from a vessel that was not used in the subsequent surveys. In addition, electronic net mensuration instruments were not available for this survey and there was uncertainty about the values used to represent the width of the net at the trawl doors. This run tested the sensitivity of the stock assessment to the assumption that the 1997 index, as reconstructed through depth and area post-stratification and assuming a fixed value to represent the unknown doorspread, could be modelled with the same catchability parameter as the four later synoptic surveys.

Run S2 was performed because of possible misreporting of POP landings. An experimental fishery in Langara Spit (north of 54^{o}N and west of 133^{o}W), originally designed to allow fishers to take as much rockfish as they wanted for five years followed by five years of closure (Leaman and Stanley, 1993; Leaman, 1998), was initiated in 1983 (Table B.1). There were reports that POP landings had been falsified in this fishery, with an unknown amount of catch attributed to the Langara Spit area which may have originated from another part of the BC coast. Following consultation with industry participants, some of the catch and effort data from five vessels for the years 1984 to 1989 were removed due to possible errors associated with the confounding of catch reports from multiple areas. The Langara Spit landings for these five vessels were reduced by 50% from 1984 to 1989 and all remaining vessels had landings from the Langara Spit fishery reduced by 10% over the same years. These percentage reductions were based on discussions with industry participants close to the fishery during that period. Relative proportional reductions by year (see Run S2 catch reductions above) were then calculated from this data set and applied to the total catch used in the stock assessment for this sensitivity run. Although the experimental fishery ended in 1990, catch reductions ended in 1989 because on-board observers were employed in 1990, curtailing misreporting in this final year. The Langara Spit fishery was closed in 1993 (Leaman, 1998).

As occurred for the base run, the MPD fits capture the main features of the data sets fairly well, and the MCMC diagnostics show good convergence (results not shown). Tables I.1-I.3 give the estimated parameter values for the three runs (with Table I.1 identical to Table G.2 but repeated here for ease of comparison). Both sensitivity runs estimate a less productive stock, with lower values of R_0 (initial unfished recruitment). Natural mortality M and h (steepness of the Beverton-Holt recruitment function) did not change greatly from the base run. Oddly, μ_1 (age of maximum selectivity for females) increases from 10.8 to 12.7 in Run S1, which implies that the 1997 age data had some leverage on this parameter. Tables I.4-I.6 give the resulting derived quantities for the three model runs. The lower productivity for the sensitivity runs results in, for example, lower unfished equilibrium spawning biomass (B_0), lower maximum sustainable yield

(MSY), and lower biomass at maximum sustainable yield (B_{MSY}).

Figure I.1 shows the medians of the changes in relative biomass over time (as in Figure 4) for the base run and the two sensitivity runs. The trajectories are similar for all three runs; however, Run S2 (reduced catches from 1984 to 1989) results in a more optimistic median value of B_{2013}/B_0 (spawning biomass at the start of 2013 relative to unfished equilibrium level) of 0.37 compared to 0.33 for the base run and 0.30 for Run S1.

Figure I.2 shows the phase plots through time of the status of the stock. These appear almost identical except that in Run S1 (removal of Ocean Selector data) the exploitation rate u_t exceeds that for maximum sustainable yield u_{MSY} more often than it does for the base run and Run S2. The final status of the stock relative to B_{MSY} for the three model runs is summarised in Figure I.3. Sensitivity Run S2 appears very similar to the base run while Run S1 offers a more pessimistic status, though all runs have a median $B_{2013}/B_{\mathrm{MSY}}$ greater than 1. The probabilities of being in the healthy zone at the start of 2013, P$(B_{2013} > 0.8B_{\mathrm{MSY}})$, for each model run are, respectively, 0.88, 0.73 and 0.87. Thus, the status of the stock has worsened for Run S1 and essentially remained unchanged for sensitivity Run S2.

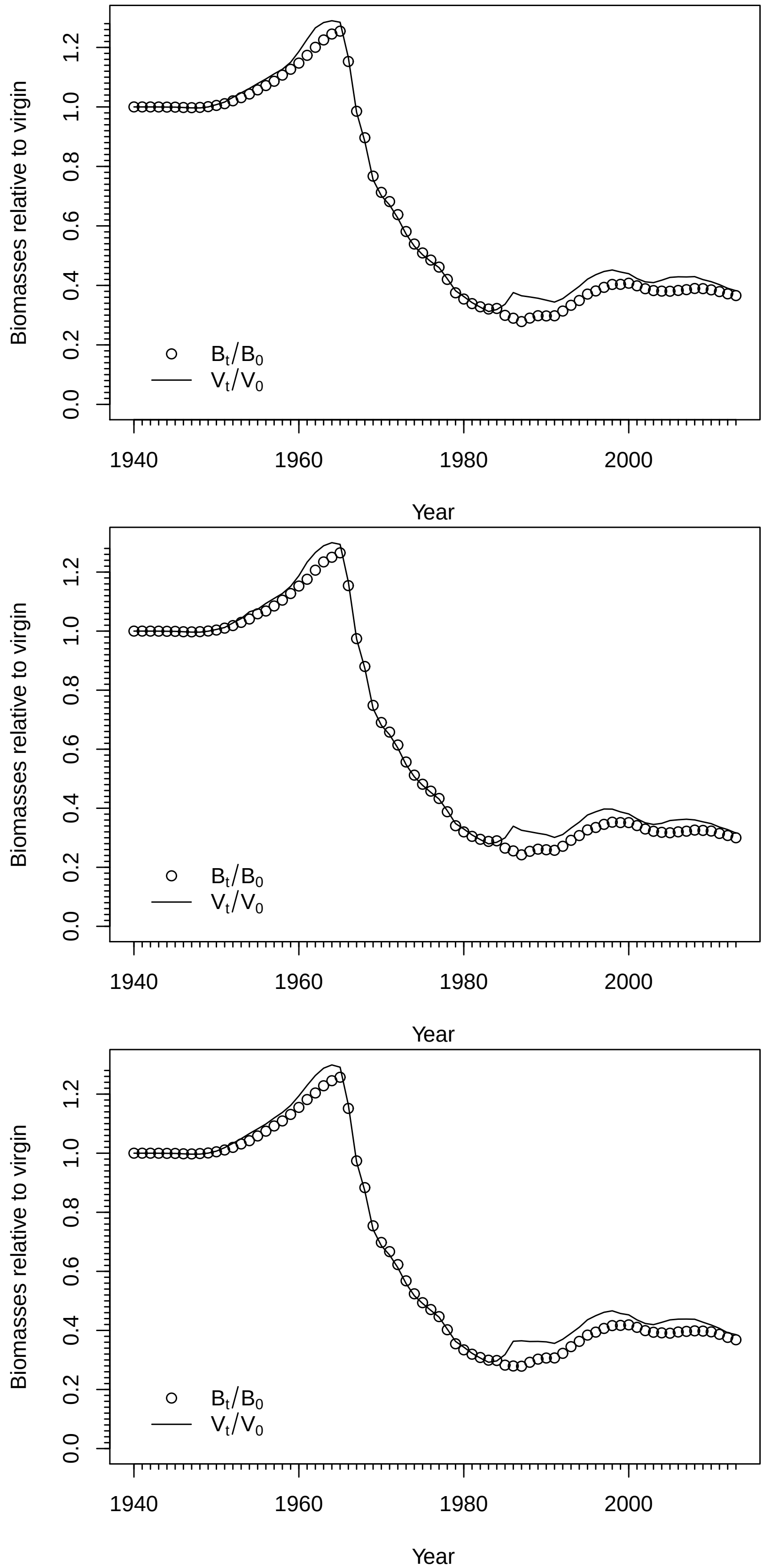


Figure I.1. Changes in B_t/B_0 and V_t/V_0 (spawning and vulnerable biomass relative to unfished equilibrium levels) over time, shown as the medians of the MCMC posteriors. Top: base run, middle: run S1, bottom: run S2.

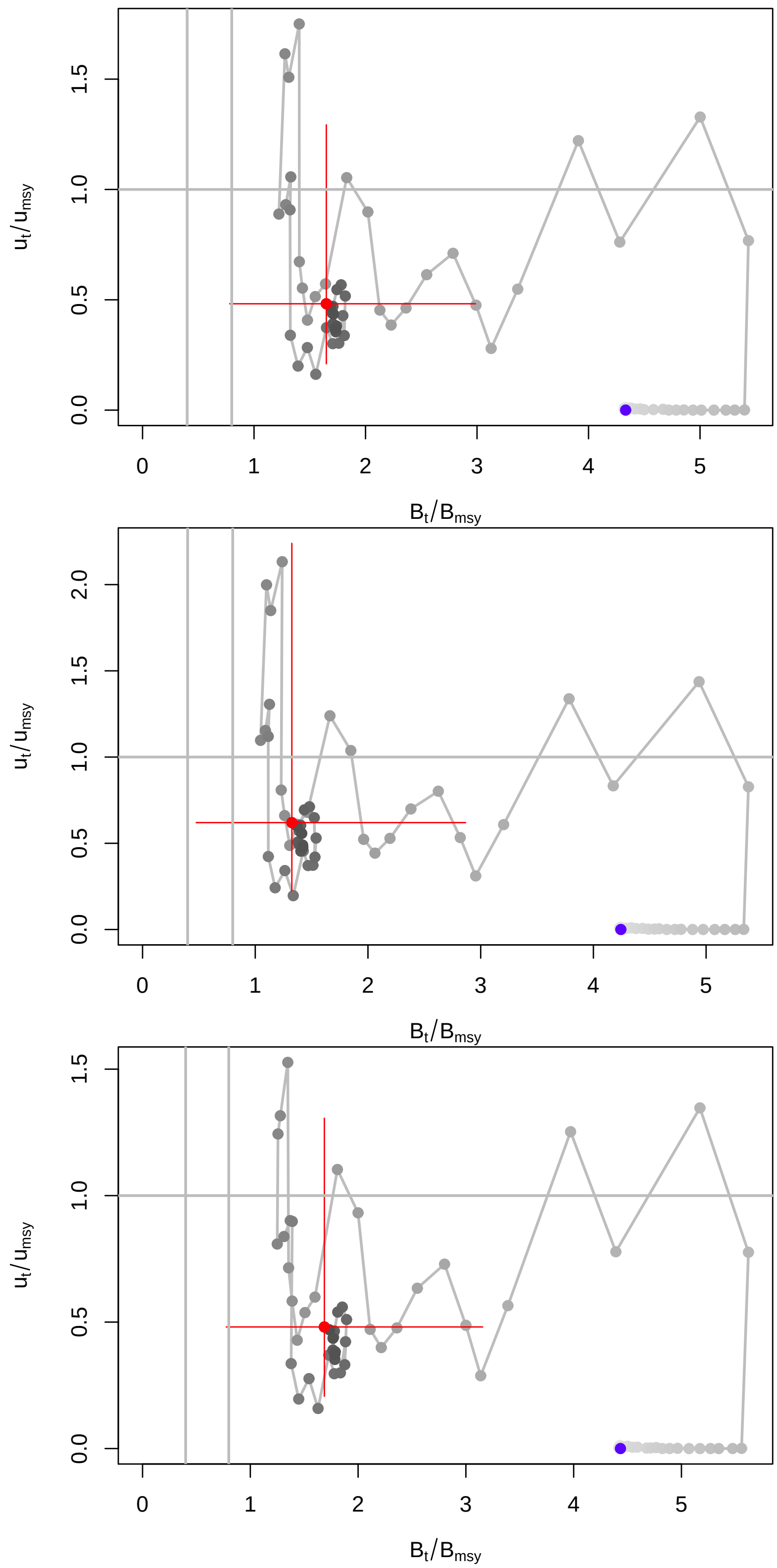


Figure I.2. Phase plot through time of the medians of the ratios B_t/B_{MSY} (the spawning biomass in year t relative to B_{MSY}) and u_t/u_{MSY} (the exploitation rate in year t relative to u_{MSY}). Blue filled circle is the starting year (1940). Years then proceed from light grey through to dark grey with the final year (2012) as a filled red circle, and the red lines represent the 10% and 90% percentiles of the posterior distributions for 2012. Vertical grey lines indicate reference points 0.4B_{MSY} and 0.8B_{MSY}, and horizontal grey line indicates u_{MSY}. Top: base run, middle: run S1, bottom: run S2. Axes not identical.

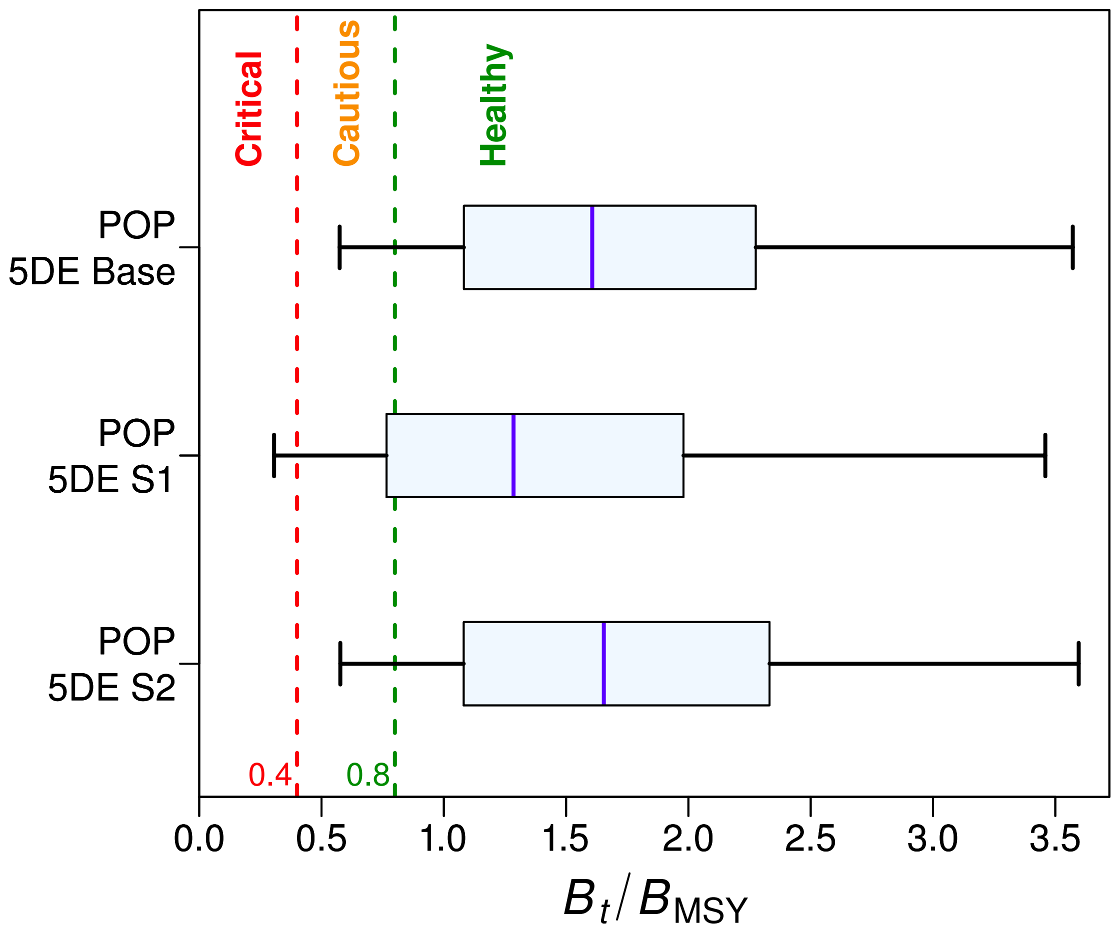


Figure I.3. Current status of the 3CD stock for the three model runs (Base run, sensitivity run S1 and sensitivity run S2), relative to the DFO Precautionary Approach provisional reference points of $0.4B_{\mathrm{MSY}}$ and $0.8B_{\mathrm{MSY}}$. B_t/B_{MSY} is for $t = 2013$. Boxplots show the 5, 25, 50, 75 and 95 percentiles from the MCMC results.

Table I.1. Summary statistics of MCMC results for estimated parameters (defined in Appendix F). Except for M_1 and M_2, subscript 1 corresponds to the WCHG survey series and subscript 2 to the commercial fishery.

Parameter	Percentile		
	5%	50%	95%
R_0	4,711	6,178	9,256
M_1	0.0545	0.0632	0.0727
M_2	0.0670	0.0755	0.0850
h	0.552	0.791	0.942
q_1	0.1448	0.3169	0.6301
μ_1	9.5	10.8	13.0
μ_2	10.0	10.6	11.3
Δ_1	0.10	0.22	0.33
Δ_2	-0.34	0.02	0.36
$\log v_{1L}$	1.10	2.08	2.97
$\log v_{2L}$	0.83	1.38	1.88

Table I.2. For run S1, summary statistics of MCMC results for estimated parameters (defined in Appendix F). Except for M_1 and M_2, subscript 1 corresponds to the WCHG survey series and subscript 2 to the commercial fishery.

Parameter	Percentile		
	5%	50%	95%
R_0	4,384	5,802	8,278
M_1	0.0545	0.0634	0.0722
M_2	0.0656	0.0747	0.0834
h	0.536	0.781	0.937
q_1	0.1677	0.4167	1.0986
μ_1	10.2	12.7	15.9
μ_2	10.1	10.7	11.4
Δ_1	0.11	0.21	0.33
Δ_2	-0.31	0.05	0.41
$\log v_{1L}$	1.49	2.7	3.69
$\log v_{2L}$	0.90	1.42	1.88

Table I.3. For run S2, summary statistics of MCMC results for estimated parameters (defined in Appendix F). Except for M_1 and M_2, subscript 1 corresponds to the WCHG survey series and subscript 2 to the commercial fishery.

Parameter	Percentile		
	5%	50%	95%
R_0	4,497	5,942	8,645
M_1	0.0541	0.0632	0.0724
M_2	0.0662	0.0755	0.0843
h	0.560	0.801	0.945
q_1	0.1510	0.3172	0.6766
μ_1	9.4	10.8	12.9
μ_2	10.0	10.6	11.3
Δ_1	0.11	0.21	0.32
Δ_2	-0.35	0.01	0.37
$\log v_{1L}$	1.04	2.04	2.95
$\log v_{2L}$	0.87	1.36	1.89

Table I.4. The 5th, 50th and 95th percentiles of MCMC-derived quantities from the 1,000 samples of the MCMC posterior. Definitions are: B_0 – unfished equilibrium spawning biomass (mature females), V_0 – unfished equilibrium vulnerable biomass (males and females), B_{2013} – spawning biomass at the start of 2013, V_{2013} – vulnerable biomass in the middle of 2013, u_{2012} – exploitation rate (ratio of total catch to vulnerable biomass) in the middle of 2012, $u_{\max}$ – maximum exploitation rate (calculated for each sample as the maximum exploitation rate from 1940-2012), B_{MSY} – equilibrium spawning biomass at MSY (maximum sustainable yield), u_{MSY} – equilibrium exploitation rate at MSY, V_{MSY} – equilibrium vulnerable biomass at MSY. All biomass values (and MSY) are in tonnes. For reference, the average catch over the last 5 years (2007-2011) is 937 t.

Value	Percentile		
	5%	50%	95%
	From model output		
B_0	26,148	31,242	40,568
V_0	43,100	51,073	66,999
B_{2013}	4,703	11,286	25,672
V_{2013}	8,140	19,334	43,835
B_{2013}/B_0	0.162	0.366	0.666
V_{2013}/V_0	0.175	0.382	0.675
u_{2012}	0.023	0.053	0.119
$u_{\max}$	0.127	0.192	0.254
	MSY-based quantities		
$0.4B_{\mathrm{MSY}}$	1,832	2,921	4,520
$0.8B_{\mathrm{MSY}}$	3,664	5,843	9,041
B_{MSY}	4,580	7,304	11,301
B_{MSY}/B_0	0.150	0.231	0.325
$B_{2013}/B_{\mathrm{MSY}}$	0.574	1.607	3.572
MSY	998	1,488	2,258
u_{MSY}	0.053	0.109	0.194
$u_{2012}/u_{\mathrm{MSY}}$	0.168	0.482	1.697
V_{MSY}	9,496	14,056	20,861
V_{MSY}/V_0	0.192	0.272	0.359

Table I.5. For run S1, the derived quantities. See Table I.4 for definitions.

Value	Percentile		
	5%	50%	95%
		From model output	
B_0	24,285	29,214	37,899
V_0	40,740	47,756	61,586
B_{2013}	2,355	8,542	22,632
V_{2013}	4,270	14,974	38,983
B_{2013}/B_0	0.091	0.300	0.627
V_{2013}/V_0	0.100	0.316	0.652
u_{2012}	0.027	0.068	0.220
$u_{\max}$	0.152	0.229	0.326
		MSY-based quantities	
$0.4B_{\mathrm{MSY}}$	1,729	2,768	4,241
$0.8B_{\mathrm{MSY}}$	3,458	5,536	8,483
B_{MSY}	4,323	6,920	10,603
B_{MSY}/B_0	0.154	0.236	0.330
$B_{2013}/B_{\mathrm{MSY}}$	0.306	1.285	3.459
MSY	891	1,381	2,103
u_{MSY}	0.052	0.106	0.193
$u_{2012}/u_{\mathrm{MSY}}$	0.178	0.620	3.265
V_{MSY}	8,924	13,296	19,023
V_{MSY}/V_0	0.194	0.275	0.363

Table I.6. For run S2, the derived quantities. See Table I.4 for definitions.

Value	Percentile		
	5%	50%	95%
	From model output		
B_0	25,042	30,279	38,717
V_0	41,470	49,348	64,201
B_{2013}	4,149	10,903	23,887
V_{2013}	7,476	18,969	40,516
B_{2013}/B_0	0.160	0.368	0.643
V_{2013}/V_0	0.172	0.386	0.659
u_{2012}	0.025	0.054	0.132
$u_{\max}$	0.127	0.173	0.234
	MSY-based quantities		
$0.4B_{\mathrm{MSY}}$	1,718	2,709	4,169
$0.8B_{\mathrm{MSY}}$	3,437	5,417	8,338
B_{MSY}	4,296	6,772	10,422
B_{MSY}/B_0	0.147	0.226	0.322
$B_{2013}/B_{\mathrm{MSY}}$	0.577	1.654	3.596
MSY	951	1,441	2,175
u_{MSY}	0.055	0.111	0.202
$u_{2012}/u_{\mathrm{MSY}}$	0.165	0.481	1.882
V_{MSY}	8,848	13,210	19,104
V_{MSY}/V_0	0.188	0.267	0.354