Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

C S A S / **S C C S**

Canadian Science Advisory Secretariat / **Secrétariat canadien de consultation scientifique**

Research Document 2011/111 / **Document de recherche 2011/111**

Stock assessment for Pacific ocean perch (*Sebastes alutus*) in Queen Charlotte Sound, British Columbia

Évaluation du stock de sébaste à longue mâchoire (*Sebastes alutus*) dans le détroit de la Reine Charlotte, Colombie-Britannique

Andrew M. Edwards[1], Paul J. Starr[2] and Rowan Haigh[1]

[1]Pacific Biological Station, Science Branch,
Fisheries and Oceans Canada, 3190 Hammond Bay Road,
Nanaimo, British Columbia, V9T 6N7, Canada.

[2]Canadian Groundfish Research and Conservation Society,
1406 Rose Ann Drive, Nanaimo, British Columbia, V9T 4K8, Canada.

ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)

Canada

TABLE OF CONTENTS

LIST OF MAIN TABLES

LIST OF MAIN FIGURES

Correct citation for this publication:

Edwards, A.M., Starr, P.J. and Haigh, R. 2012. Stock assessment for Pacific ocean perch (*Sebastes alutus*) in Queen Charlotte Sound, British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/111. viii +172 p.

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 in Queen Charlotte Sound, British Columbia, is assessed here under the assumption that it is a single stock harvested entirely in Pacific Marine Fisheries Commission (PMFC) major areas 5A, 5B and 5C. This stock has supported a domestic trawl fishery for decades and was heavily fished by foreign fleets from the mid-1960s to mid-1970s.

We used an annual catch-at-age model tuned to three fishery-independent trawl survey series, annual estimates of commercial catch since 1940, and age composition data from two of the survey series (8 years of data) and the commercial fishery (29 years of data). The model starts from an assumed equilibrium state in 1940, and the survey data cover the period 1967 to 2010 (although not all years are represented). The two-sex model was implemented in a Bayesian framework (using the Markov Chain Monte Carlo procedure) under four scenarios, in which natural mortality, M, and steepness of the stock-recruit function, h, were fixed or estimated.

All four model runs suggest that strong recruitment in the early 1950s sustained the foreign fishery, and that a few strong year classes spawned in the late 1970s and 1980s sustained the domestic fishery into the 1990s. At the Pacific Region Centre for Science Advice review meeting, participants endorsed the two runs that estimated h as being equally plausible (one is termed “Estimate *M & h*” and the other “Estimate *h*”). Participants rejected the other two runs for provision of advice to management.

The spawning biomass (mature females only) at the beginning of 2011 is estimated to be 26% (12%, 43%) of unfished biomass (median and 5th and 95th quantiles of the Bayesian posterior distribution) for run “Estimate *M & h*”, and 14% (8%, 24%) for run “Estimate *h*”. The estimated spawning biomass at maximum sustainable yield, B_{MSY}, is estimated to be 25% (17%, 35%) of unfished biomass for run “Estimate *M & h*”, and 24% (16%, 32%) for run “Estimate *h*”.

Advice to managers is presented as decision tables that provide probabilities of exceeding limit and upper stock reference points for five-year projections across a range of constant catch scenarios for both model runs. The DFO provisional ‘Precautionary Approach compliant’ reference points were used, which specify a ‘limit reference point’ of $0.4B_{MSY}$ and an ‘upper stock reference point’ of $0.8B_{MSY}$. The estimated spawning biomass at the beginning of 2011 has a 0.96 or 0.82 probability (runs “Estimate *M* & *h*” and “Estimate *h*”, respectively) of being above the limit reference point, and a 0.68 or 0.24 probability of being above the upper stock reference point. Five-year projections to 2016 indicate that the spawning biomass has probabilities of 0.91 or 0.57 of remaining above the limit reference point, and of 0.63 or 0.15 of remaining above the upper stock reference point, if catches average 3,500 t/y, which is the average level of removals from 2006–2010.

We note that the definitions of the PMFC areas differ from the Groundfish Management Areas (GMAs) used by the GMU. Based on the most recent five years, the combined POP landings in GMAs 5AB and 5CD were about 5% greater than the landings in the combined PMFC areas 5ABC. Current POP Total Allowable Catches are 2,070 t for GMAs 5AB and 2,118 t for GMAs 5CD.

RÉSUMÉ

Le sébaste à longue mâchoire (*Sebastes alutus*) est une espèce de sébaste d'importance commerciale qui habite les canyons marins le long de la côte de la Colombie-Britannique. L'état du sébaste à longue mâchoire dans le détroit de la Reine-Charlotte, en Colombie-Britannique, est évaluée ici en fonction de l'hypothèse selon laquelle il s'agirait d'un seul stock faisant l'objet de prélèvements uniquement dans les principales zones 5A, 5B et 5C de la Commission des pêches maritimes du Pacifique (CPMP). Ce stock soutient une pêche nationale au chalut depuis les années 1960 et a été exploité de façon intensive par des flottilles étrangères du milieu des années 1960 au milieu des années 1970.

Nous avons utilisé un modèle annuel de prises selon l'âge ajusté à trois séries de relevés au chalut indépendants de la pêche, les estimations annuelles des prises dans le cadre de la pêche commerciale depuis 1940 et les données sur la composition selon l'âge de deux des séries de relevés (huit ans de données) et de la pêche commerciale (29 ans de données). Le modèle débute avec une présumée valeur au point d'équilibre en 1940 et les données du relevé couvrent la période s'échelonnant de 1967 à 2010 (les années ne sont cependant pas toutes représentées). Le modèle structuré selon le sexe a été mis en œuvre dans un cadre bayésien (à l'aide de la méthode de Monte Carlo par chaînes de Markov) pour quatre scénarios dans lesquels la mortalité naturelle (*M)* et la pente de la fonction stock-recrues (*h)* ont été fixées ou estimées.

Les quatre modélisations donnent à penser que le fort recrutement au début des années 1950 a soutenu la pêche des pays étrangers et que quelques classes d'âge abondantes produites vers la fin des années 1970 et le début des années 1980 ont soutenu la pêche nationale dans les années 1990. Lors de la réunion d'examen du Centre des avis scientifiques, Région du Pacifique, les participants ont accepté les deux modélisations qui ont permis d'estimer *h* comme étant aussi plausibles l'une que l'autre (une est appelée « estimation de *M et de h* » et l'autre « estimation de *h* »). Les participants ont rejeté les deux autres modélisations pour donner des avis à la direction.

On estime que la biomasse reproductrice (femelles adultes seulement) au début de 2011 se situe à 26 % (12 %, 43 %) de la biomasse non exploitée (la médiane et les 5^{e} et 95^{e} quantiles de la distribution a posteriori bayésienne) pour la modélisation « estimation de *M et de h* » et de 14 % (8 %, 24 %) pour la modélisation « estimation de *h* ». La biomasse reproductrice estimée au rendement maximal soutenu, B_{RMS}, est estimée à 25 % (17 %, 35 %) de la biomasse non exploitée pour la modélisation « estimation de *M et de h* » et de 24 % (16 %, 32 %) pour la modélisation « estimation de *h* ».

L'avis aux gestionnaires est présenté sous forme de tables de décision présentant les probabilités d'excéder les points de référence limites et supérieurs du stock pour des projections sur cinq ans en fonction d'un éventail de scénarios de prises constantes pour les deux modélisations. Les points de référence provisoires du MPO conformes à « l'approche de précaution » ont été utilisés et précisent un « point de référence limite du stock » de $0,4B_{RMS}$ et un « point de référence supérieur du stock » de $0,8B_{RMS}$. La biomasse reproductrice estimée au début de 2011 a une probabilité de 0,96 ou de 0,82 (modélisations « estimation de *M et de h* » et « estimation de *h* », respectivement) d'être au-dessus du point de référence limite et une probabilité de 0,68 ou de 0,24 d'être au-dessus du point de référence supérieur du stock. Les projections sur cinq ans jusqu'en 2016 indiquent que la biomasse reproductrice a des probabilités de 0,91 ou de 0,57 de demeurer au-dessus du point de référence limite et de 0,63 ou de 0,15 de demeurer au-dessus du point de référence supérieur du stock, si la moyenne des prises est de 3 500 t/a, qui représente le niveau moyen de prélèvement de 2006 à 2010.

Nous constatons que les définitions des zones de la CPMP diffèrent de celles des zones de gestion des poissons de fond utilisées par l'Unité de gestion des poissons de fond. Selon les cinq années les plus récentes, les quantités débarquées de sébaste à longue mâchoire dans les zones de gestion des poissons de fond 5AB et 5CD combinées étaient d'environ 5 % supérieures aux quantités débarquées dans les zones de la CPMP 5ABC combinées. Le total autorisé des captures (TAC) annuelles pour le sébaste à longue mâchoire est de 2 070 t pour les zones de gestion des poissons de fond 5AB et de 2 118 t pour les zones de gestion des poissons de fond 5CD.

INTRODUCTION

Pacific ocean perch (*Sebastes alutus*, POP) is a long-lived, commercially important species of rockfish found along the rim of the North Pacific. Its commercial attractiveness stems from the bright red colour and long shelf life when properly processed. It is also 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 likely ranging from three to twelve months as free-swimming pelagic larvae before settling to the bottom as juveniles. POP reproduction appears to follow onshore-offshore migration patterns where females move onshore for insemination and then migrate deeper to the entrances of submarine gullies where they release larvae from February to May (Love et al. 2002). The larvae depend on vertical upwelling to bring them into the upper pelagic zone to facilitate growth and dispersal. The larvae can spend up to a year in the water column before settling into benthic habitat (Kendall and Lenarz 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 reported age in the literature for POP is 98 years for a specimen from the Aleutian Islands (Munk 2001); however, our database (GFBio) reports two specimens older than 98 y (age 100 y: female specimen from Langara at 329 m in 1983; age 103 y: female specimen from Moresby Gully at 364 m in 2002). Values used for the natural mortality rate of POP in other published stock assessments are usually close to 0.06 (e.g., Schnute *et al*. 2001, Hanselman *et al*. 2007, 2009). In comparison, the longest-living *Sebastes* species is rougheye rockfish (*S. aleutianus*), with a maximum reported age of 205 years (Munk et al. 2001) and a fixed natural mortality rate set to 0.035 (McDermott 1994).

Pacific ocean perch supports the largest rockfish fishery in British Columbia (BC) with an annual coastwide TAC (total allowable catch) of 6,148 t and an average annual catch of about 5,000 t from 2006-2010. The trawl fishery accounts for 99.98% of the coastwide TAC, with the rest allocated to the hook and line fishery. Since 2006, 700 t of the TAC for groundfish management area 5CD has been deducted for use in possible research programs.

Past assessments of POP have used a set of "slope rockfish areas" (SRFA: 3C, 3D, 5AB, 5CD, 5ES, 5EN) based on locality codes (fishing grounds) recorded in the DFO catch databases. This has been especially true for the three main gullies in Queen Charlotte Sound (QCS) that constitute the primary fishing grounds for this species. Earlier population modelling for POP focused on Goose Island Gully (GIG) because the most complete set of otolith data originated from this area. 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). The catch-age model used to assess the stock status for GIG POP (Schnute and Richards 1995) related process error in recruitments with measurement error in the abundance index. This concept was carried forward in subsequent POP stock assessments (e.g., Richards and Schnute 1998) up to the 2001 assessment (Schnute et al. 2001).

In this assessment, we depart from previous catch-age model formulations for POP and follow recent west coast Canadian groundfish assessments using a modified version of the Coleraine statistical catch-at-age software (Hilborn et al. 2003) called Awatea (Appendix F). Other significant departures from earlier assessments include: (i) a sex-specific model, (ii) three sets of proportion-at-age data (commercial catch, GIG historic surveys, QCS synoptic surveys), (iii) three survey abundance index series (GIG historic, QCS synoptic, QCS shrimp), (iv) an expanded area of assessment from GIG to include the entire QCS bounded by Pacific Marine Fisheries Commission (PMFC) areas 5A, 5B, and 5C, and (v) a maximum modelled age of 60 instead of 30. This assessment also uses independent selectivities for the commercial fishery and for each of the survey indices, whereas the earlier assessments assumed that all selectivities were the same.

RANGE AND DISTRIBUTION

Pacific ocean perch occur 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). They appear to be most abundant north of 50°N (Allen and Smith 1988). In BC, hotspots, (≥ the 0.95 quantile) of catch per unit effort (CPUE) from trawl tows over fifteen years (1996-2010) occur SE off Moresby Is. (Moresby Gully), SW off Moresby Is. (Anthony Is., Ninstints), NW off Graham Is. (Langara Spit), and in Dixon Entrance north of Graham Island (Figure 1). The mean CPUE in Mitchell's and Goose Island Gullies appear to be lower, although both support substantial fisheries. The bulk of the commercial captures of the QCS population lies between depths 79 m and 443 m (Appendix H).

ASSESSMENT BOUNDARIES

For this assessment, we use Pacific Marine Fisheries Commission (PMFC) major areas 5A, 5B, and 5C (herein referred to as 5ABC), as shown in Figure 2. These standard areas account for the main QCS population of POP that occurs in QCS proper (the area between the southern tip of Moresby Island, northwest tip of Vancouver Island, and the mainland) and southern Hecate Strait. The PMFC areas are similar but not identical to the groundfish management areas (GMAs) used by the Groundfish Management Unit (GMU), which uses combinations of DFO Pacific Fishery Management areas. We have not used the GMAs because reporting from these areas has only been available since 1996. A further complication for Pacific ocean perch is that the GMAs have been modified so that GMA 5C is expanded around Cape St. James, incorporating parts of GMA 5B and 5E. However, when these two blocks of areas are compared in terms of their total POP catches, they only differ by about 5%, based on the most recent five years (that is, for 2006-2010 the combined GMAs of 5ABCD have averaged 5% greater catch than the combined PMFC 5ABC). Appendix B documents this result and proposes an algorithm for managers to prorate the PMFC 5ABC yield options from this assessment into yield advice scaled appropriately for GMA 5AB and 5CD, for which the current TACs are 2,070 t and 2,118 t, respectively.

CATCH DATA

The preparation methods and a full catch history for this POP 5ABC assessment are presented in detail in Appendix B. Information about finfish and shark species caught concurrently with POP commercial catches are presented in Appendix H.

FISHERIES MANAGEMENT

Appendix B summarises all management actions taken for POP in QCS since 1979.

SURVEY DESCRIPTIONS

Three sets of fishery independent survey indices, all located in QCS, have been used to track changes in the biomass of this population (Appendix C):

1. an early series of 8 indices extending from 1967 to 1994. Most of these surveys were performed by the research vessel GB Reed, but two commercial vessels (Eastward Ho and Ocean Selector) were used in 1984 and 1994 respectively. Only tows located in Goose Island Gully (GIG) have been used to ensure continuity across all surveys;
2. a random-stratified "synoptic" trawl survey covering all of QCS and targeting a wide range of finfish species. This survey has been repeated for 5 years between 2003 to 2009 using the same vessel (Viking Storm) and a consistent design;
3. a survey targeting shrimp, operating at the head of GIG on the west and south sides of Calvert Island. This survey has been performed in each of 12 years from 1999 to 2010 using the research vessel WE Ricker (except in 2005 when the Frosti was used).

The relative biomass survey indices are used as data in the model along with the associated relative error for each index value.

BIOLOGICAL INFORMATION

BIOLOGICAL SAMPLES

In QCS, commercial catches of POP by trawl gear have been sampled for age proportions since the 1960s. However, only otoliths aged using the "break and burn" method have been included in the age samples used in this assessment because the earlier surface ageing method was known to be biased, especially with increasing age. Practically, this means that no age data were available prior to 1978. Commercial fishery age samples were summarised for each quarter, weighted by the POP catch weight for the sampled trip. The total quarterly samples were scaled up to the entire year using the quarterly landed commercial catch weights. See Appendix E for details.

Age samples were available from two survey series: the historical GIG series (1984 and 1994 only), and from all five QCS "synoptic" surveys as well as a sixth survey operated in 1995 which used a similar net configuration but was not included in the biomass index series (see Appendix C). These samples were scaled up to represent the total survey in a manner similar to that used for the commercial samples: within a depth/area stratum, samples were weighted by the POP catch weight in the sampled tow; stratum samples were then weighted by the total POP catch weight for the stratum (described in Appendix E).

GROWTH PARAMETERS

Growth parameters were estimated from POP length and age data from biological samples collected from 1978 to 2009 (Appendix D). Parameters for the allometric weight-length relationship were estimated for POP of both sexes. Biological samples were obtained from all sampling sources in 5ABC, with the majority being obtained from port sampling of the commercial fishery. Combining the available data sources was considered acceptable because growth models fitted to each of the data sources separately did not generate substantially different parameter estimates (Appendix D). Growth by sex was specified as a von Bertalanffy model with parameters specified in Appendix D.

MATURITY AND FECUNDITY

The proportion of females that mature at ages 1 through 23 was computed from biological samples. Stage of maturity was determined macroscopically, partitioning the samples into one of seven maturity stages (Stanley and Kronlund 2000). Fish assigned to stages 1 or 2 were considered immature while those assigned to stages 3-7 were considered mature. 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. A monotonic increasing maturity-at-age vector was constructed by fitting a double normal function (equivalent to that in Equation F.7) to the observed maturity values (Appendix D). This function was adjusted slightly by using the observed maturity values for ages less than 9. This was done because the fitted model appeared to overestimate the proportion mature at these ages (Figure D5). Females older than age 23 were assumed to be 100% mature and maturity was assumed to be constant over time. Fecundity was assumed to be proportional to the female body weight.

NATURAL MORTALITY

Male and female natural mortalities were estimated as parameters of the model (see Appendix F), using a strong informed prior based on a posterior taken from an assessment of POP from the Gulf of Alaska (Hanselman et al. 2009). The mean value of the estimate for M from the Alaska assessment was 0.06 with a standard deviation of 0.006 (CV=10%). These values specified a normal prior which was used for the estimation of M. Runs that fixed this parameter used the mean of the prior.

STEEPNESS

A Beverton-Holt (BH) stock-recruitment function was used to generate average recruitment estimates in each year, based on the biomass of female spawners (Equation F.10). Recruitments were allowed to deviate from this average (Equations F.17 and F.24) in order to improve the fit of the model to the data. The BH function was parameterised using a "steepness" parameter, h, which specified the proportion of the maximum recruitment that was available at 0.2 B_0, where B_0 is the virgin spawning biomass (mature females). The parameter h was estimated, 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. Runs that fixed this parameter used the mean of the prior.

AGE-STRUCTURED MODEL

A two-sex age-structured stochastic model was used to reconstruct the population trajectory of QCS POP from 1940 to the beginning of 2011. Ages were tracked from 1 to 60, with 60 being an accumulator age category. The population was assumed to be in equilibrium with average recruitment and with no fishing at the beginning of the reconstruction. Selectivities by sex for two of the surveys and the commercial fishery were estimated using four parameters describing double half-Gaussian functions, although the right-hand limb was assumed to be fixed at the maximum selectivity. The model and its equations are described in Appendix F.

The model was fit to the available data (3 sets of survey indices, 29 annual proportions-at-age samples from the commercial fishery and 8 proportions-at-age samples from two surveys) by minimising a function which summed the likelihoods arising from each data set, the deviations from mean recruitment and the penalties stemming from the Bayesian priors.

Initial model fits to the data gave sensible and reasonably consistent results. Sensitivity runs that explored the effect of different components of the data on model results did not seem justified, given the small amount of available data when spread over the long period of stock reconstruction (particularly in the early years) and the relative consistency seen in the interpretation of the available data under a range of model assumptions. As well, the selectivity functions for the commercial fishery and the QCS synoptic survey seemed well estimated and did not introduce much uncertainty. It was decided that much of the uncertainty in this assessment lay not in the fits to the data, but in the underlying assumptions for several key model parameters, notably natural mortality M and stock-recruitment steepness h. This uncertainty was explored by alternately fixing or estimating these parameters in a pairwise pattern:

a) estimate both M and h using informed priors described in Appendix F [Estimate M & h];

b) estimate M and fix h = 0.674, which is the mean value for its prior [Estimate M];

c) estimate h and fix M = 0.06, which is the mean value for its prior [Estimate h];

d) fix M = 0.06 and h = 0.674 [Fix M & h];

The minimised MPD (mode of the posterior distribution) "best fit" was used as the starting point for a Bayesian search across the joint posterior distributions of the parameters using the Monte Carlo Markov Chain (MCMC) procedure. All model runs were judged to have converged after 10,000,000 iterations, sampling every 10,000th, to give 1,000 samples.

MODEL RESULTS

Model fits to the data were satisfactory, with some divergence from the distributional assumptions used in the likelihood, most likely arising from inconsistencies between the various sources of data. However, the four model runs investigated all had similar fits to the data, without any one of the four hypotheses investigated showing a noticeably better fit (details in Appendix G). The differences observed between the fits were small and did not provide reliable guidance to select among hypotheses. Visual examination of the fits to the data and the patterns of residuals showed nearly identical results for all four models described above.

The results from the MPD "best fit" and the subsequent MCMC searches show the same pattern: the fits to the data are similar for all four model runs, resulting in similar patterns of biomass trajectories (Figure 3 and Figure 4), recruitments (Figure 5), and exploitation rates (Figure 6). However, the two runs that estimated M tended to estimate a higher overall level of biomass and consequently less depletion than did the two runs that fixed M (Figure 3 and Figure 4). As well, the two models which estimated M incorporated a much greater level of uncertainty than did either of the models which fixed these parameters (Figure 3). The MCMC convergence properties were best for the 'Estimate M & h' run, slightly poorer for the 'Estimate M' run and deteriorated further for the two runs which did not estimate M (see Appendix G).

Comparative plots of the posterior distributions for the QCS synoptic survey catchability coefficient, q_2, (Figure 7) illustrate the difference in scale between the two pairs of model runs (those that estimated or fixed *M*) and how this is resolved in the distribution of parameter estimates. The two runs that estimate *M* have survey q_2 posterior distributions with a mode near 0.35 (that is, they estimate that the QCS synoptic survey is monitoring about one-third of the available biomass and there is a low probability for a long right-hand tail) while the two runs that fix *M* are bimodal with considerable weight for parameter estimates from 0.5 to nearly 1.0 (well to the right of the MPD estimate). This latter result implies that the lower biomass levels estimated by the two runs that fix *M* result in a relatively large probability of high levels of efficiency for this survey. However, such high levels of efficiency seem implausible (even for doorspread estimates), lending further credibility to the model runs that estimate *M*.

ADVICE FOR MANAGERS

PROJECTIONS

Projections were made for five years under a range of constant catch scenarios, starting with the beginning-year biomass in 2011 (which is the final year of the stock reconstruction) using the parameters from each sample of the MCMC-generated posterior distributions from the four model runs. Random recruitments scaled to the mean average recruitment from each MCMC sample were generated from a normal distribution in log space with mean zero and standard deviation of 0.9. Note that the short-term nature of these projections, given the longevity and consequent low natural mortality rate, will make use of year classes which have been estimated during the stock reconstruction and that none of the new randomly generated recruitments will affect the projections.

MANAGEMENT TARGETS

Advice to management is reported using the DFO Science reference values from the provisional harvest rule described in DFO (2009). These reference points are the “limit reference point” (below which the stock should never go) of $0.4B_{MSY}$ and an “upper stock reference point” of $0.8B_{MSY}$, where B_{MSY} is the spawning biomass associated with the maximum sustainable yield (MSY). The zone below the limit reference point is termed the “critical zone” while the zone lying between the limit and upper stock reference points is termed the “cautious zone”. The region above the upper stock reference point is termed the “healthy zone”. B_{MSY} is also reported as an additional reference point. All reference points were derived from the posterior distributions.

The PA-compliant yields for 2011 are calculated based on U_{MSY} (the exploitation rate associated with the MSY), as outlined in equation (F.28). If the stock is above the upper stock reference level, then U_{MSY} is applied to the vulnerable biomass to calculate the potential yield. If the stock is in the “cautious zone”, then U_{MSY} is discounted proportionally, relative to how far the stock is below the upper reference level, until the limit reference point is reached, before multiplying by the stock size to estimate the yield. If the stock size is below the limit reference point, yield is set equal to 0. The expected value for the PA-compliant yield for the ‘Estimate *M* & *h*’ run is above MSY because it applies the posterior distribution of U_{MSY} to a posterior distribution of the 2011 biomass that is, on average, greater than B_{MSY} (Table 1, and see equation F.28). Similarly, the PA-compliant yields are lower than MSY for the remaining three runs because U_{MSY} will be discounted.

PROJECTION RESULTS

The differences described above between the two 'Estimate *M*' models and two 'Fixed *M*' models apply here as well. The higher *M* values estimated in the first two model runs (see Appendix G) result in higher biomass levels, less depletion, and higher yields. Consequently, the picture of the current stock status varies between these two pairs of model runs.

The horizontal black line in Figure 8 shows that the distribution of the ratio B_{2011}/B_{MSY} for the base run 'Estimate *M* & *h*' lies above 0.4 (so B_{2011} is above the limit reference point of $0.4B_{MSY}$), and is mostly above 0.8 (corresponding to the upper stock reference point). However, Figure 8 also shows that these conclusions differ for the other three model runs. Although the median of B_{2011}/B_{MSY} for the 'Estimate *M*' run lies above 0.8, it is closer to this reference point than for the base run and the upper tail does not extend as far to the right. The tails of the distribution of B_{2011}/B_{MSY} for both the 'Estimate *h*' and 'Fixed *M* & *h*' runs extend into the "critical zone" (< 0.4) while the median values for these runs lie within the "cautious zone" (Figure 8).

The vertical dimension of Figure 8 shows that only for the 'Estimate *M* & *h*' run does the bulk of the posterior distribution of U_{2010} / U_{MSY}, the ratio of the current exploitation rate to the exploitation rate associated with MSY, lie below one. For the 'Estimate *M*' run the median is about one, and for the other two models the medians and 10-90% credibility intervals are mainly or wholly above one, such that the current exploitation rate is estimated to be above the value that would give the maximum sustainable yield.

Advice to management is presented in the form of decision tables, based on the posterior distributions of projected spawning biomass (projected for 5 years from the estimated biomass in 2011), under a range of constant annual catch scenarios extending from 0 to 6000 t. The probability of exceeding the limit reference point in 2016 over the range of catch projections for all runs is provided in Figure 9 and for all years from 2012 to 2016 in Table 2. Similarly, the probability of exceeding the upper stock reference point in 2016 over the range of catch projections is provided in Figure 10 and for all years from 2012 to 2016 in Table 3. Finally, the probability of exceeding B_{MSY} in 2016 over the range of catch projections is provided in Figure 11 and for all years from 2012 to 2016 in Table 4.

Figure 9 and Table 2 show that there is high probability of staying above $0.4B_{MSY}$ for the two runs which estimate *M* over all catch levels investigated, while the two runs which fix *M* have lower probabilities of staying above the limit reference point. This is particularly true for the run which fixes both *M* and *h*. Only the runs which estimate *M* have a reasonable probability of staying above the upper stock reference point of $0.8B_{MSY}$ at the current level of catch (approximately 3500 t/year, the average for the most recent five years) (Figure 10 and Table 3), with the two fixed *M* runs predicting that the stock would decline under this catch. Finally only the 'Estimate *M* & *h*' run predicts that stock size will stay near B_{MSY} under this catch (Figure 11 and Table 4).

GENERAL COMMENTS

All four models were considered by the Pacific Region Centre for Science Advice review committee. The committee selected the "Estimate *M* & *h*" and "Estimate *h"* models as being equally plausible, and these should be used to formulate the advice for management because they both estimated *h*. The "Estimate *M* " and "Fix *M* & *h*" models were rejected because *h* was fixed.

The picture presented from this assessment is of a slow-growing, low productivity stock which was severely depleted in the mid-1970s from commercial fishing by foreign fleets (Figure 4). It appears that this early fishery was sustained from a strong recruitment event that occurred in the early 1950s (Figure 5). The depletion of this stock halted briefly in the early 1980s before resuming due to the development of a domestic bottom trawl fleet. Again the fishery was sustained by a few strong year classes spawned in the late 1970s and early 1980s. The declining trend appears to have halted since 2006, which coincides with a 700 t reduction in the TAC (Table B1).

Annual exploitation rates have increased since the 1980s, and are approaching or have reached the historic high levels associated with the high catches by the foreign fleets in the late 1960s (Figure 6). For the two recommend runs (‘Estimate *M* & *h*’ and ‘Estimate *h*’), the median current spawning biomass is estimated to be 0.26 and 0.14, respectively, of virgin levels (with respective 90% credible intervals of (0.12, 0.43) and (0.08, 0.24); Table G4). These are historic low levels (Figure 4). Recent (2005-2009) catch levels must be near the level of surplus production because there is little evidence of a stock recovery in the data.

Since 1990 the model estimates that there have been no recruitment events as large as the earlier ones mentioned above. The 2001 recruitment appears to be the largest since 1990, though there is uncertainty from 2001 onwards because young fish have not yet been fully selected by the commercial fishery and the surveys.

Where this stock lies at present relative to the management target levels depends on which model run is selected to evaluate the stock. The two model runs which estimate *M* indicate that the stock is mainly above the “upper stock reference” level, lying primarily in the “healthy” zone (Figure 8). On the other hand, the two model runs which fix *M* indicate a less optimistic result, with the stock lying mainly in the “cautious zone” and may extend into the “critical zone”.

These four model runs span a range of plausible hypotheses, all of which fit the existing data reasonably well. Formal selection methods, based on information criteria, cannot be used because the reweighting procedure (see Appendix F) results in different model inputs. The differences (as determined from the residual patterns) among the four model runs are relatively small when placed in the context of model and data uncertainty. Figure 3 and Figure 5 also show clearly that the level of uncertainty contained in the two ‘Fixed *M*’ runs is small relative to the two ‘Estimate *M*’ runs, indicating that the ‘Estimate *M*’ runs capture more of the overall uncertainty.

It is uncertain whether a fixed value of $M = 0.06$ is preferable to an *M* characterised by a posterior distribution centred near $M = 0.07$ with a low CV of about 5% (see Figure G22). The model and data appear to favour a higher value for *M* when this parameter is estimated (compared to the fixed value of $M = 0.06$), whether or not the steepness parameter is also estimated. Hanselman *et al.* (2007, 2009) reported a similar tendency for the Gulf of Alaska POP assessment, with their estimate of *M* increasing from the prior mean $M = 0.05$ (CV = 10%) to $M = 0.06$, a result which was reported for both the 2007 and 2009 assessments.

The three runs that estimate *M* and/or *h* have resulting posterior distributions for those parameters that are credible, being within their prior distributions (see Figures G22 and G23). We also note that the posterior distributions of *M* and *h*, when estimated independently of each other, are nearly the same as when they are estimated concurrently (particularly the *M* posteriors). This result indicates that the estimates of these parameters appear to be independent. This conclusion is supported by a pairs plot of the posteriors for *M* and *h* when they are estimated concurrently (Figure 12), showing that they are uncorrelated (correlation coefficient ρ = -0.07 for females and ρ = -0.06 for males). Thus the ‘Estimate *M* & *h*’ model appears to be capable of estimating *M* and *h* in the Bayesian context.

We note that the results of this assessment are uncertain. Although QCS POP is the most data-rich rockfish stock in western Canadian waters, the amount of historical data available to support the interpretation of the long early catch history is relatively small, particularly for the early stock reconstruction. There are no biomass indices prior to the mid-1960s and the available age composition data are all relatively recent. It is fortunate that the earliest available age data are able to provide information on year class strengths in the 1950s and 1960s, due to the long-lived nature of the species and the apparent high precision of the ageing methodology. Furthermore, the observation that the declining trend has halted is largely based on the two active surveys that each show a levelling off in the estimated indices. But this is only a recent observation and may not be maintained. However, in support of these observations, there are anecdotal reports of good catches and catch rates of POP in QCS in 2010.

The decision tables provide guidance to 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. Uncertainty in the parameters is explicitly addressed using a Bayesian approach but reflects only the specified model and weights assigned to the various data components. Projection accuracy also depends on highly uncertain future recruitment values.

We expect that the results from the several surveys initiated in the previous decade will continue to provide monitoring capability for POP. Catches in the commercial groundfish fisheries are also well-monitored. These ongoing research initiatives give confidence that this stock is currently well-monitored and that corrective action can be taken if required.

FUTURE RESEARCH AND DATA REQUIREMENTS

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

1. Continue the suite of fishery-independent trawl surveys that have been established across the BC coast. This includes obtaining age and length composition samples, which will allow the estimation of survey-specific selectivity ogives. We note that there are no usable age composition data from the QCS shrimp survey. We suggest collecting these data for a few years so that the selectivity from this survey can be estimated rather than fixed as it is in this assessment.
2. Review and potentially improve the commercial sampling programme for POP age composition with the goal of continuing the representative sampling of all fisheries that take significant amounts of POP.
3. It may be possible to construct informed priors for survey catchability parameters that can be used in Bayesian models like the catch-age model presented in this report. Such priors could be developed by placing meaningful bounds on survey catchability, which in turn would help scale the biomass levels in the assessment.
4. More thought should be given on how to advance the management of species assemblages that are taken in the BC trawl fleet, and what information needs to be collected to accomplish this management.

5. Effort could be directed to studying how single populations, such as POP, are part of a complex system consisting of biological and economic components (Walker and Salt, 2006). Such systems can have multiple stable states, which may have implications in our understanding of POP population dynamics and resilience.

ACKNOWLEDGEMENTS

Allan Hicks (NOAA) has kindly supported the Awatea version of Coleraine stock assessment model used in this assessment. The staff in the Ageing Lab at PBS were particularly accommodating in expediting additional otolith requests. We thank the members of the POP Working Group (Greg Workman, Rob Kronlund and Rick Stanley) for their advice as this assessment progressed, and thank the reviewers (Steven Martell, Jon Schnute, and Nathan Taylor) plus other members of the review committee for their thoughtful insights.

REFERENCES

Allen, M .J., and G. B. Smith. 1988. Atlas and zoogeography of common fishes in the Bering Sea and northeastern Pacific. U.S. Department of Commerce, *NOAA Technical Report* **NMFS 66**, 151 p.

Beamish, R.J. 1979. New information on the longevity of Pacific ocean perch (*Sebastes alutus*). *Journal of the Fisheries Research Board of Canada.* **36**: 1395-1400.

Bull, B., Francis, R.I.C.C, Dunn, A., McKenzie, A., Gilbert, D.J., and Smith, M.H. 2005. CASAL (C++ algorithmic stock assessment laboratory), user manual v2.07-2005/08/21. *NIWA Technical Report* **127**, 272 p.

Carlson, H.R. and Straty, R.R. 1981. Habitat and nursery grounds of Pacific rockfish, Sebastes spp., in rocky coastal areas of southeastern Alaska. *Marine Fisheries Review* **43(7)**: 13-19.

Caswell, H. 2001. Matrix population models, 2nd edition. Sinauer Associates, Massachusetts, 722 p.

DFO. 2006. A harvest strategy compliant with the precautionary approach. *Fisheries and Oceans Canada. Canadian Science Advisory Secretariat, Science Advisory Report.* **2006/023**. 7 p.

DFO. 2009. A fishery decision-making framework incorporating the Precautionary Approach, (last modified 23 May 2009). http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/precaution-eng.htm

Forrest, R.E, McAllister, M.K., Dorn, M.W., Martell, S.J.D., and Stanley, R.D. 2010. Hierarchical Bayesian estimation of recruitment parameters and reference points for Pacific rockfishes (*Sebastes* spp.) under alternative assumptions about the stock-recruit function. *Canadian Journal of Fisheries and Aquatic Sciences* **67**: 1611-1634.

Fournier, D.A, Hampton, J. and Sibert, J.R. 1998. MULTIFAN-CL: a length-based, age-structured model for fisheries stock assessment, with application to South Pacific albacore, *Thunnus alalunga. Canadian Journal of Fisheries and Aquatic Sciences* **55**: 2105-2116.

Fournier, D.A, Sibert, J.R., Majkowski, J., and Hampton, J. 1990. MULTIFAN a likelihood-based method for estimating growth parameters and age composition from multiple length frequency data sets illustrated using data for southern bluefin tuna (*Thunnus maccoyii*) *Canadian Journal of Fisheries and Aquatic Sciences* **47**: 301-317.

Gelman, A., Carlin, J.B., Stern, H.S, and Rubin, D.B. 2004. Bayesian data analysis, 2nd edition. Chapman and Hall/CRC, New York, 668 p.

Haigh, R. and Yamanaka, K.L. 2011. Catch history reconstruction for rockfish (*Sebastes* spp.) caught in British Columbia coastal waters. *Canadian Technical Report of Fisheries and Aquatic Science* **2943**: viii + 124 p.

Hanselman, D., Heifetz, J., Fujioka, J.T., Shotwell, S.A., and Ianelli, J.N. 2007. Gulf of Alaska Pacific ocean perch. Chapter 9 (p. 563-622) In: Stock Assessment and Fishery Evaluation (SAFE) Report for the Groundfish Resources of the Gulf of Alaska, North Pacific Fishery Management Council (NPFMC), November 2007.

Hanselman, D. , Shotwell, S.A., Heifetz, J., Fujioka, J.T., and Ianelli, J.N. 2009. Assessment of Pacific ocean perch in the Gulf of Alaska. Chapter 9 (p. 743-816) In: Stock Assessment and Fishery Evaluation (SAFE) Report for the Groundfish Resources of the Gulf of Alaska, North Pacific Fishery Management Council (NPFMC), December 2009.

Hilborn, R., Maunder, M., Parma, A., Ernst, B. Payne, J. and Starr, P. 2003. Coleraine: a generalized age-structured stock assessment model. *School of Aquatic and Fishery Sciences, University of Washington,* 54 p.

Kendall Jr., A.W., Lenarz, W.H., 1986. Status of early life history studies of northeast Pacific rockfishes. In: Proceedings of the International Rockfish Symposium. University of Alaska, Alaska Sea Grant College Program Report **AK-SG-87-2**, Anchorage, Alaska, p. 99-128.

Ketchen, K.S. 1976. Catch and effort statistics of the Canadian and United States trawl fisheries in waters adjacent to the British Columbia coast 1950-1975. Fisheries and Marine service, Data Record No. 6. Nanaimo, BC, May 1976.

Ketchen , K.S. 1980. Reconstruction of Pacific ocean perch (Sebastes alutus) stock history in Queen Charlotte Sound. Part I. Estimation of foreign catches, 1965-1976. *Canadian Manuscript Report of Fisheries and Aquatic Sciences* **1570**: iv + 46 p.

Love, M.S., Yoklavich, M., and Thorsteinson, L. 2002. The Rockfishes of the Northeast Pacific. University of California Press, Berkeley and Los Angeles, California, 404 p.

Mace, P.M., and Doonan, I.J. 1988. A generalized bioeconomic simulation for fish population dynamics. *New Zealand Fisheries Assessment Research Document.* **88/4**. (Held in library at NIWA, Wellington, New Zealand).

MacLellan, S.E. 1997. How to age rockfish (*Sebastes*) using *S. alutus* as an example – the otolith burnt section technique. *Canadian Technical Report of Fisheries and Aquatic Sciences* **2146**, 39 p.

McDermott, S.F. 1994. Reproductive biology of rougheye and shortraker rockfish, *Sebastes aleutianus* and *Sebastes borealis*. M.S. thesis, University of Washington, Seattle, WA. 81 p.

Michielsens, C.G.J. and McAllister, M.K. 2004. A Bayesian hierarchical analysis of stock-recruit data: quantifying structural and parameter uncertainties. *Canadian Journal of Fisheries and Aquatic Sciences* **61**: 1032-1047.

Munk, K.M. 2001. Maximum ages of groundfishes in waters off Alaska and British Columbia and considerations of age determination. *Alaska Fisheries Research Bulletin* **8(1)**:12-21.

Otter Research Ltd. 1999. An introduction to AD Model Builder for use nonlinear modeling and statistics. *Otter Research Ltd., British Columbia.* 194 p.

PFMAR. 2007. Pacific Fishery Management Area Regulations, 2007. Registration SOR/2007-77, April 19, 2007. *Canada Gazette Part II*: **141(9)**: 449-637.

Richards, L.J., and Olsen, N. 1996. Slope rockfish assessment for the west coast of Canada in 1996 and recommended yield options for 1997. *Canadian Technical Report of Fisheries and Aquatic Sciences* **2134**, 91 p.

Richards, L.J. and Schnute, J.T. 1998. Model complexity and catch-age analysis. *Canadian Journal of Fisheries and Aquatic Sciences* **55**: 949-957.

Rooper, C.N., Boldt, J.L., Zimmermann, M. 2007. An assessment of juvenile Pacific Ocean perch (*Sebastes alutus*) habitat use in a deepwater nursery. *Estuarine, Coastal and Shelf Science* **75**: 371-380.

Schnute, J.T., Haigh, R., Krishka, B., and Starr, P. 2001. Pacific ocean perch assessment for the west coast of Canda in 2001. *Fisheries and Oceans Canada. Canadian Science Advisory Secretariat, Research Document* **2001/138**, 90 p.

Schnute, J.T. and Richards, L.J. 1995. The influence of error on population estimates from catch-age models. Canadian *Journal of Fisheries and Aquatic Sciences* **52**: 2063-2077.

Stanley, R.D., and Kronlund, A.R. 2000. Silvergray rockfish (*Sebastes brevispinis*) assessment for 2000 and recommended yield options for 2001/2002. *Fisheries and Oceans Canada. Canadian Stock Assessment Secretariat,* **2000/173**, 116 p.

Stanley, R.D., Starr, P., and Olsen, N. 2009. Stock assessment for Canary rockfish (*Sebastes pinniger*) in British Columbia waters. *Fisheries and Oceans Canada. Canadian Science Advisory Secretariat, Research Document* **2009/013**, 198 p.

Walker, B., and Salt, D. 2006. Resilience Thinking. Island Press. Washington DC. 174 p.

Yamanaka, K.L., Richards, L.J., and Workman, G.D. 1996. Bottom trawl survey for rockfish in Queen Charlotte Sound, September 11 to 22, 1995. *Canadian Manuscript Report of Fisheries and Aquatic Sciences* **2362**: iv + 116 p.

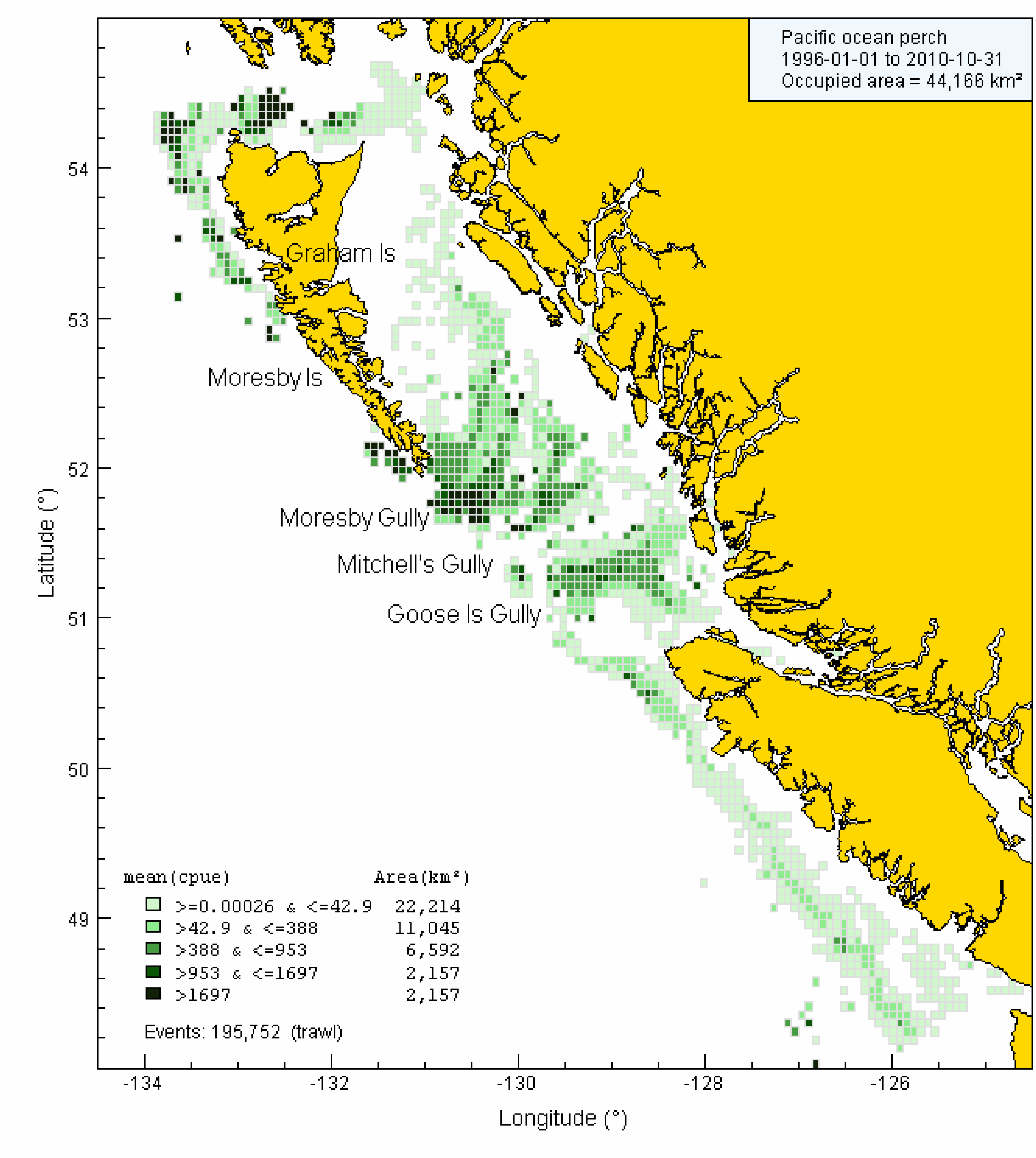


Figure 1. Mean catch per unit effort (CPUE, kg/h) of POP in grid cells 0.075° longitude by 0.055° latitude (roughly 32 km²). The shaded cells (delimited by the quantiles 0.5, 0.75, 0.9, 0.95) give an approximation of the area of occupancy using fishing events from the groundfish trawl fishery from Feb 1996 to Oct 2010.

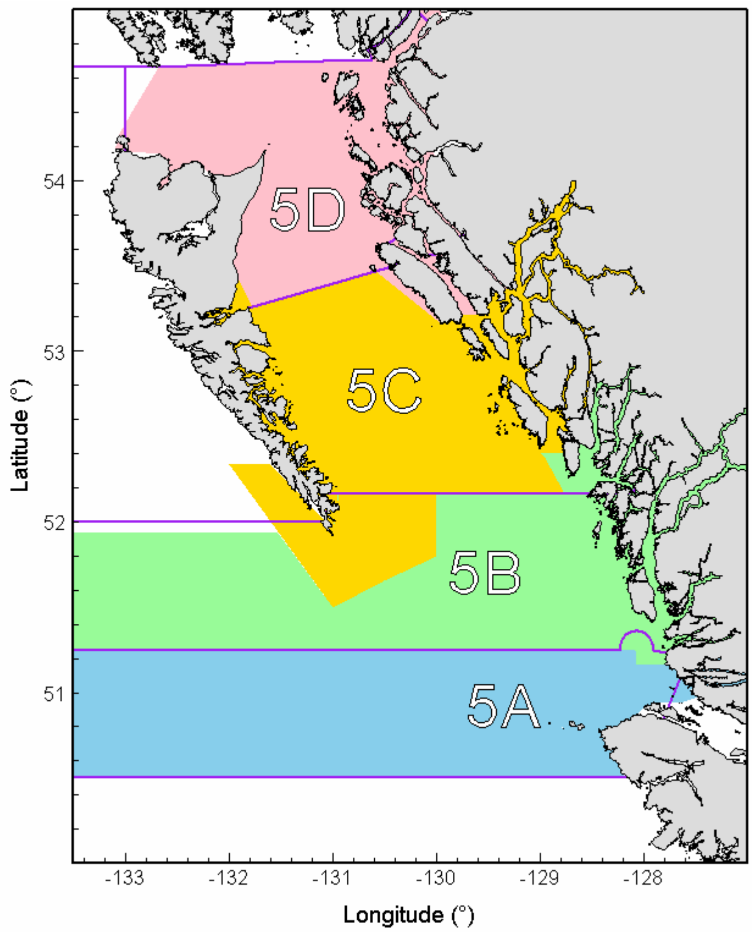


Figure 2. Pacific Marine Fisheries Commission major areas (outlined in purple). This assessment covers Areas 5A, 5B and 5C. Groundfish Management Unit areas for Pacific ocean perch are shaded in four colours.

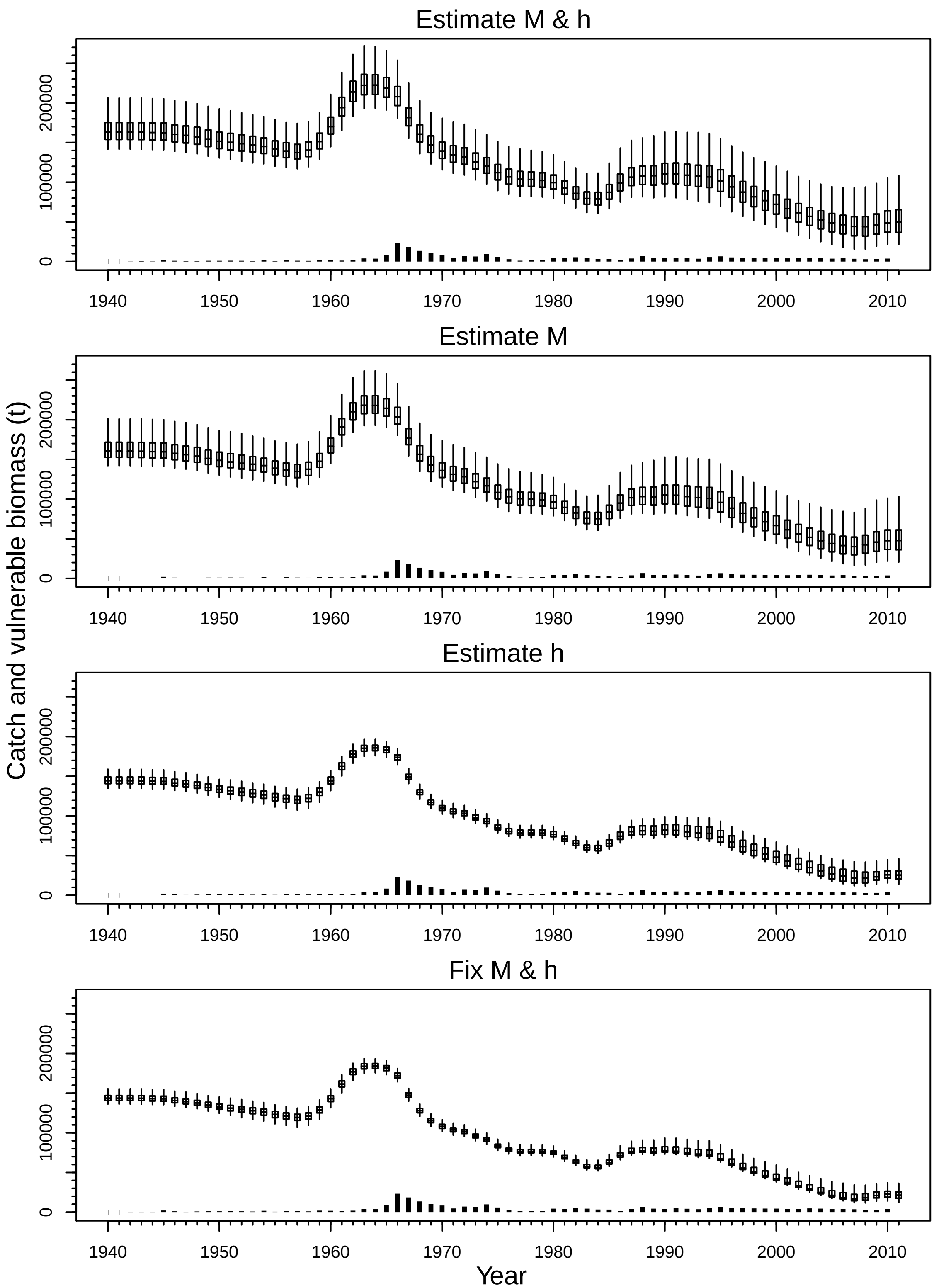


Figure 3. Commercial catch (vertical bars) and vulnerable biomass (boxplots showing 2.5, 25, 50, 75 and 97.5 percentiles of the posteriors from the MCMC results) for the four model runs.

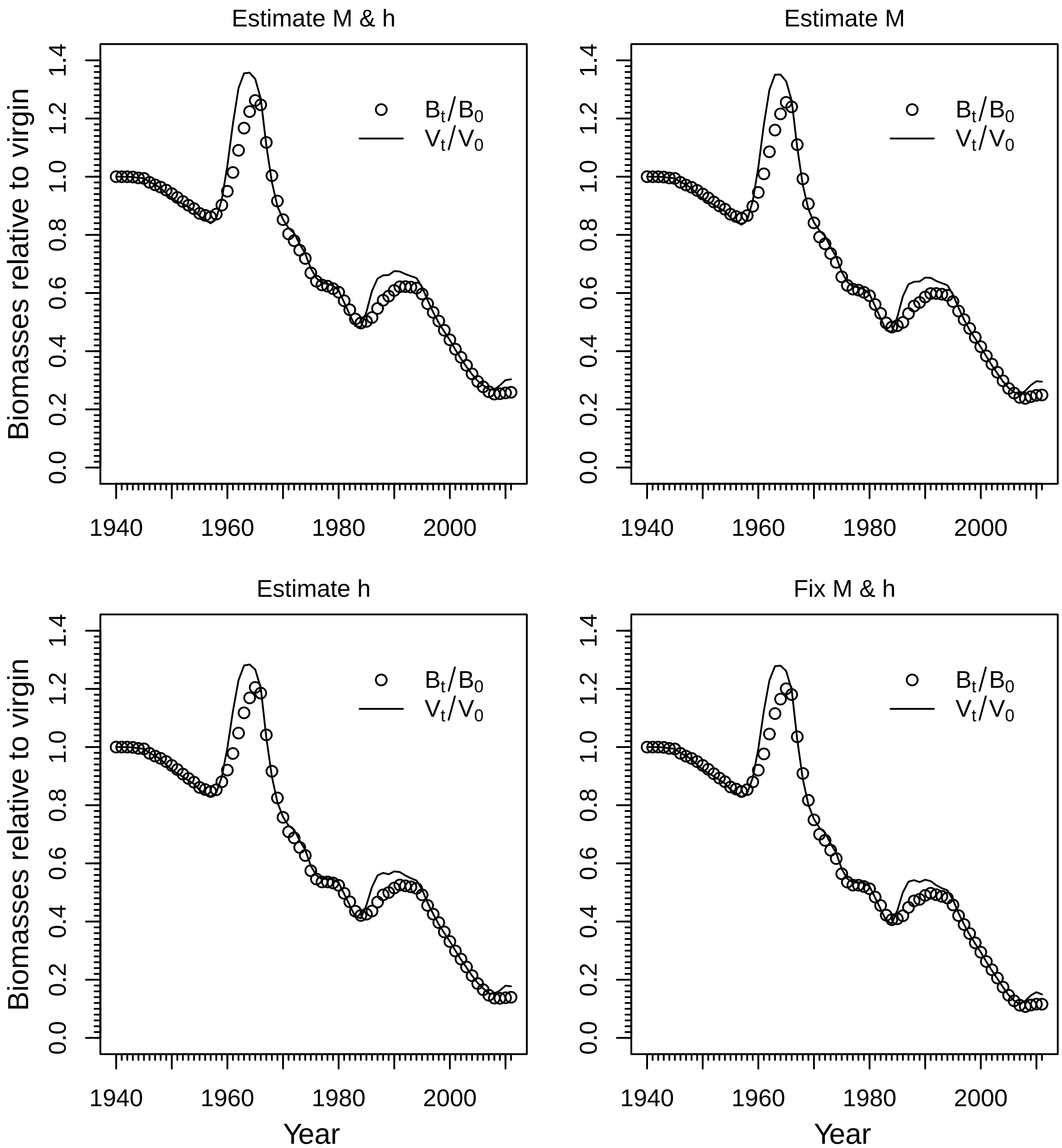


Figure 4. Trajectories of spawning and vulnerable biomass relative to virgin levels, B_t / B_0 and V_t / V_0 respectively, over time, shown as the medians of the MCMC posteriors for the four model runs.

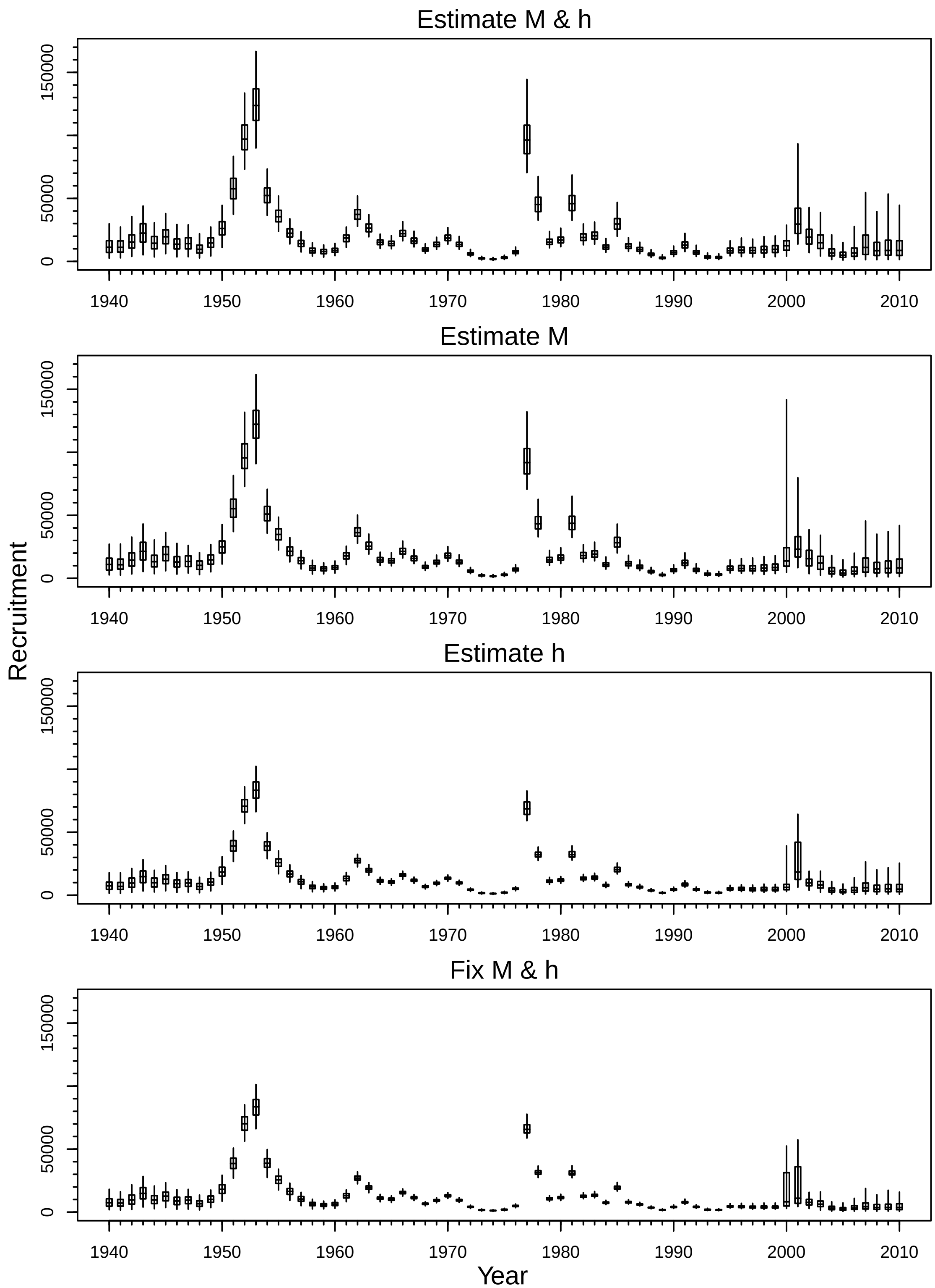


Figure 5. Marginal posterior distribution of recruitment in 1000's of age 1 fish plotted over time for each model run. The boxes give the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results.

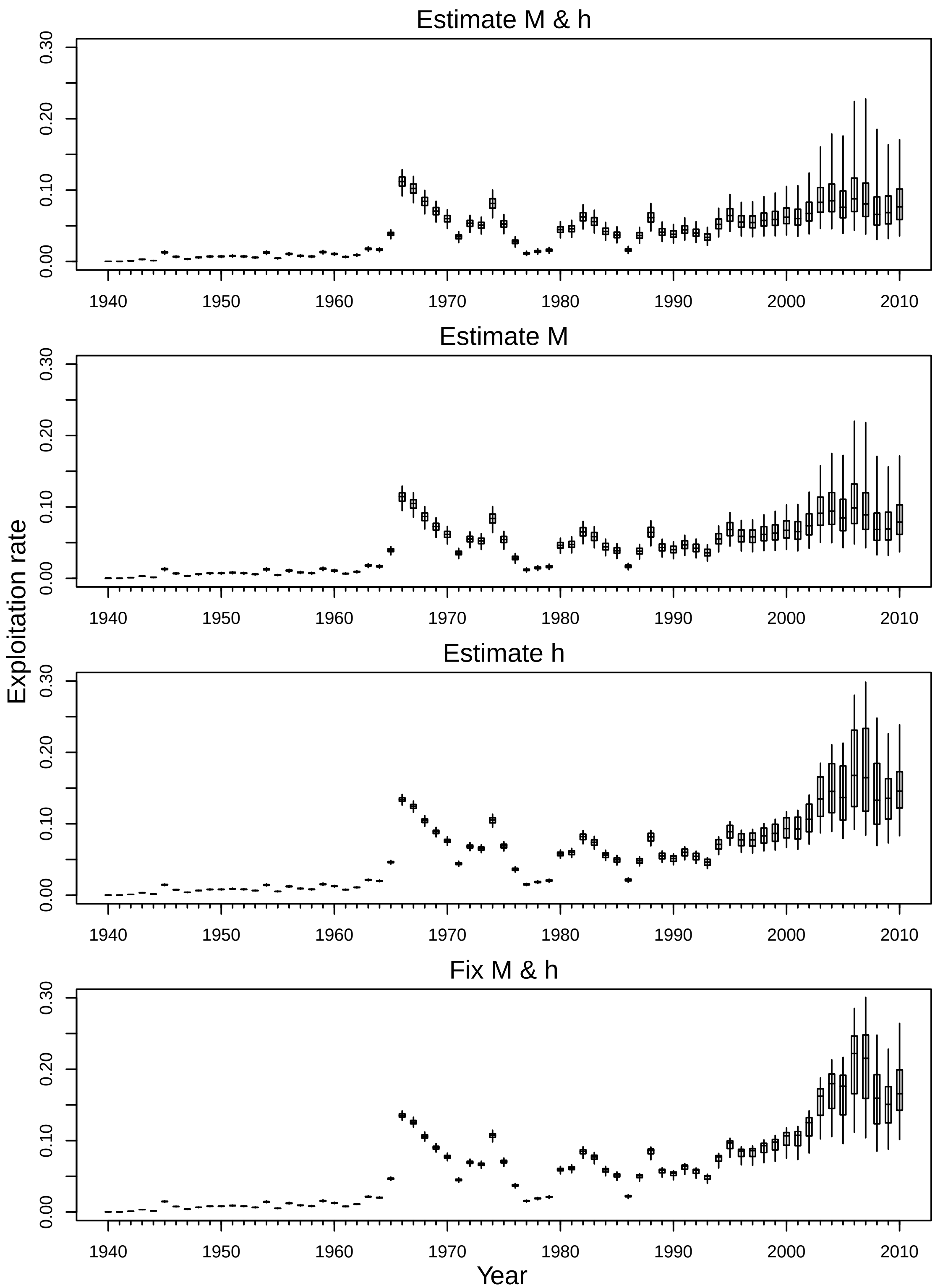


Figure 6. Marginal posterior densities of annual exploitation rate (see equation F.12) by year for each model run. The boxes give the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results.

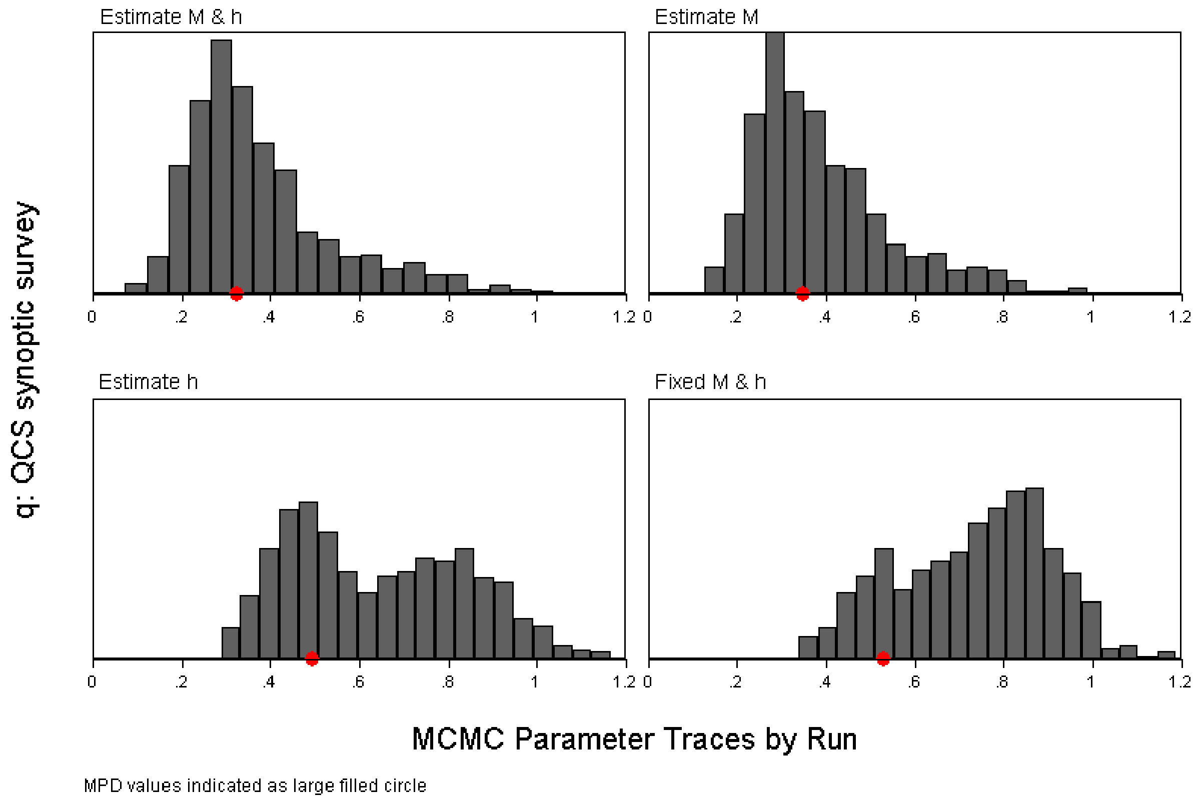


Figure 7. Marginal posterior densities for the parameter q_2 for four POP assessment runs. Horizontal and vertical axes are all to same scale. Filled red circle indicates MPD value.

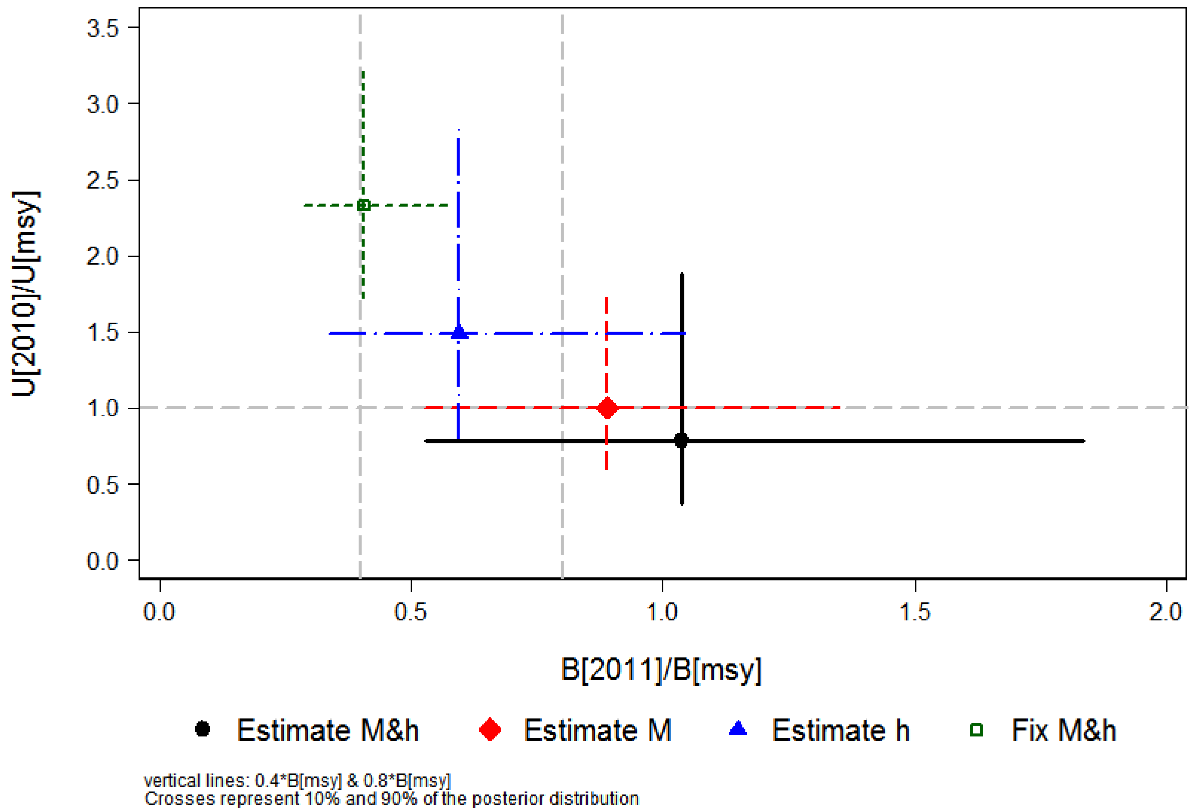


Figure 8. Cross plots showing the medians and the 10-90% credibility intervals for the ratio U_{2010} / U_{MSY} against the ratio B_{2011} / B_{MSY} for all four model runs. Vertical lines at 0.4 and 0.8 correspond to the default limit and upper stock "PA-compliant" reference points of $0.4B_{MSY}$ and $0.8B_{MSY}$.

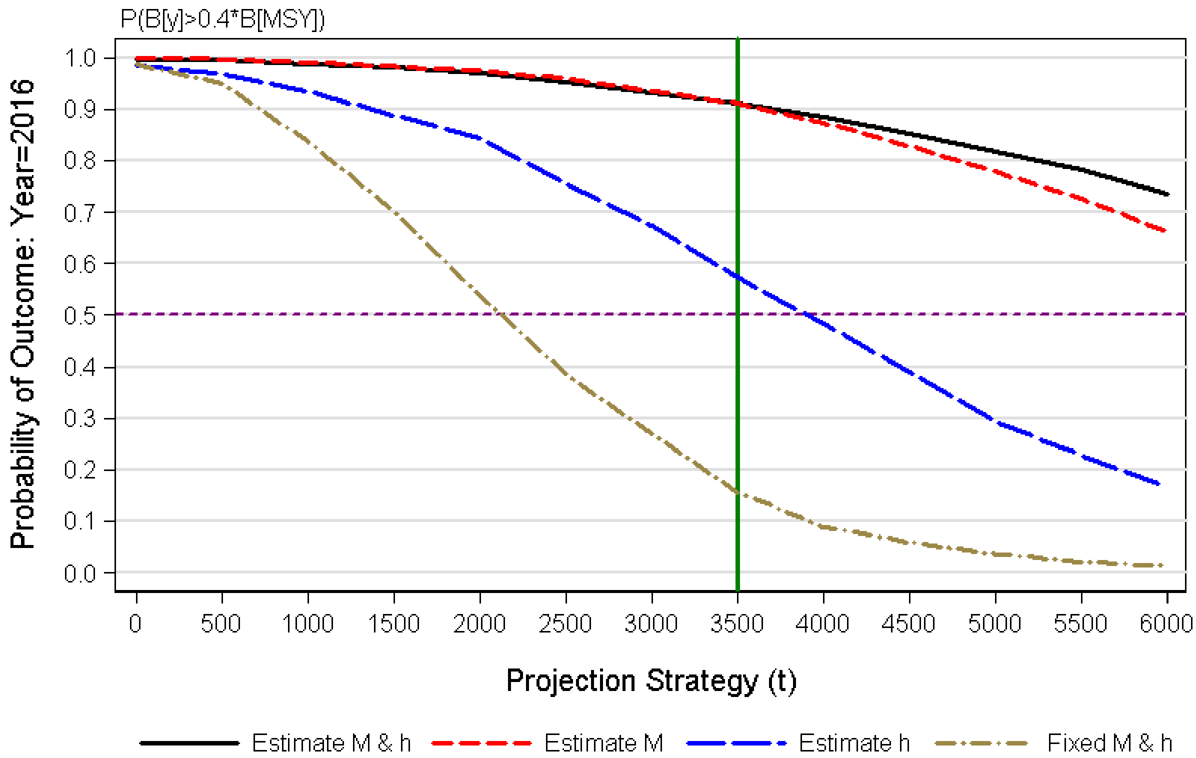


Figure 9. Probability of B_t exceeding $0.4B_{MSY}$ by the end of the projection period (2016) for four model runs. The green vertical line indicates the approximate position of the average catch over the most recent 5 years.

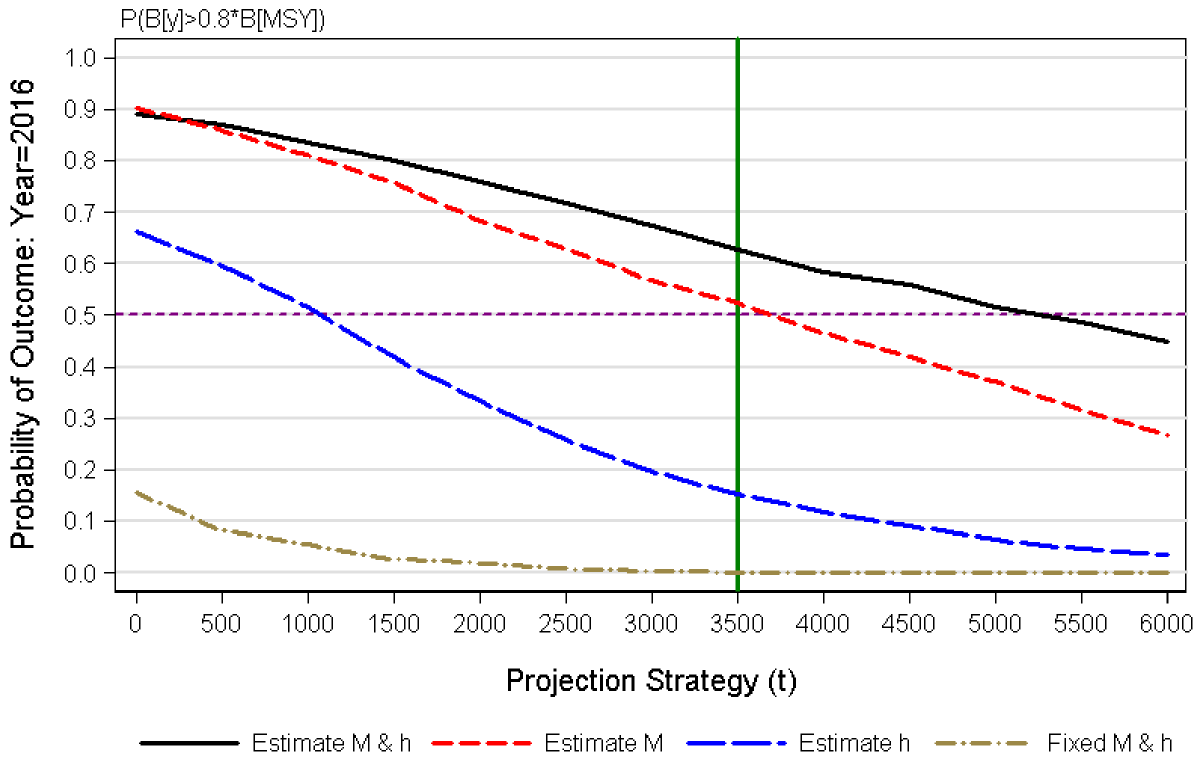


Figure 10. Probability of B_t exceeding $0.8B_{MSY}$ by the end of the projection period (2016) for four model runs. The green vertical line indicates the approximate position of the average catch over the most recent 5 years.

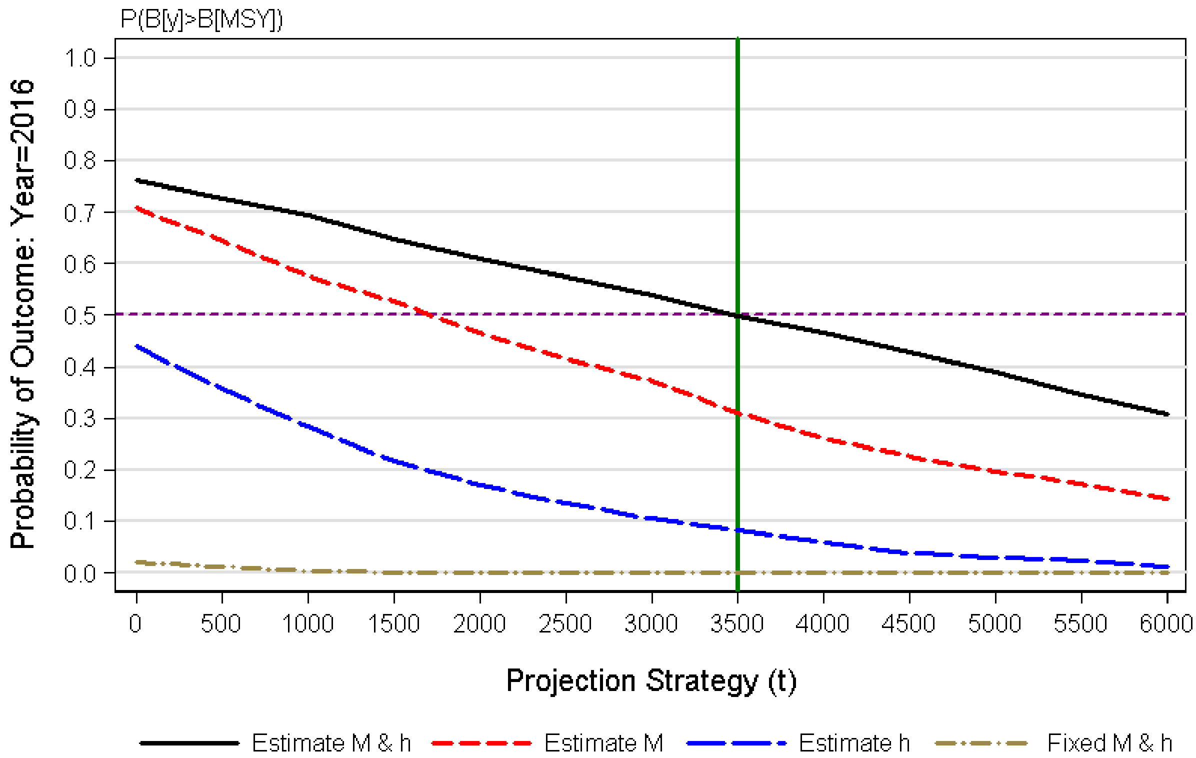


Figure 11. Probability of B_t exceeding B_{MSY} by the end of the projection period (2016) for four model runs. The green vertical line indicates the approximate position of the average catch over the most recent 5 years.

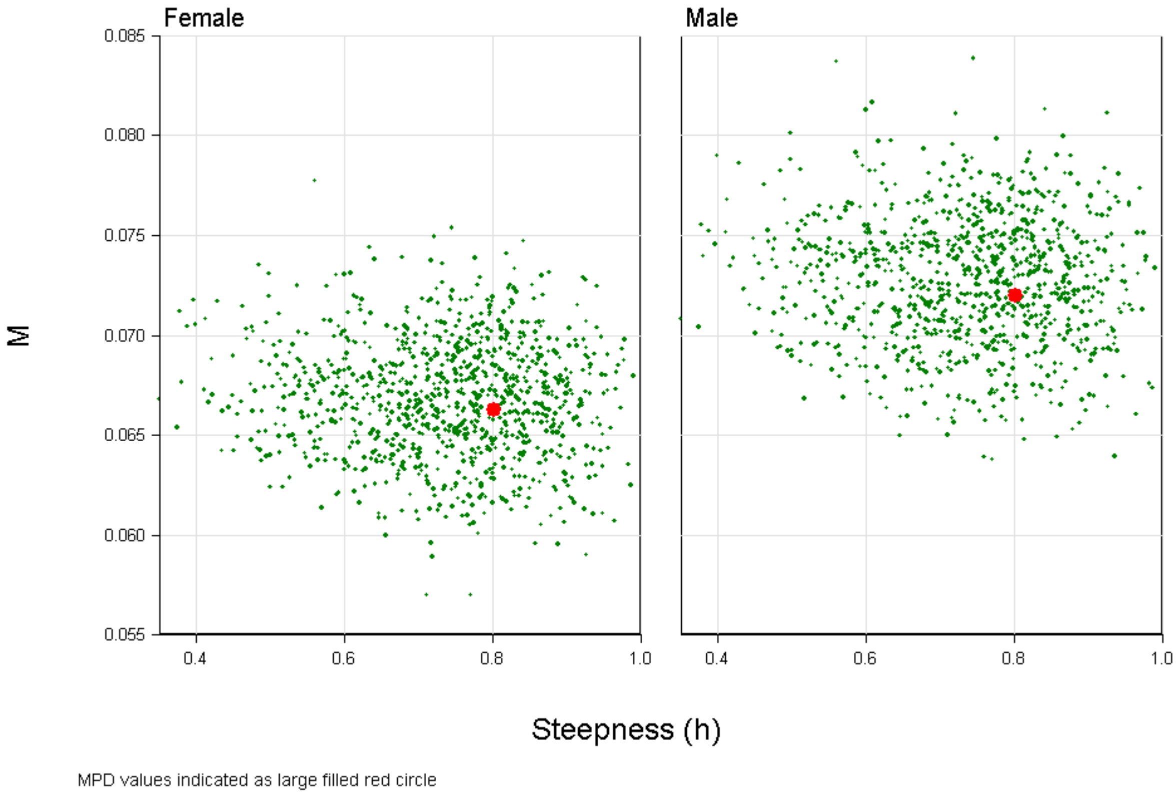


Figure 12. Pairs plot by sex of M with steepness (h) for base run 'Estimate M & h', matching the estimates of M and h for each sample from the posterior.

Table 1. Calculation of the PA (Precautionary Approach) compliant harvest strategy for 2011, where B_{MSY}, V_{MSY} and U_{MSY} are, respectively, the spawning biomass, vulnerable biomass and exploitation rate at the maximum sustainable yield (MSY), B_{2011} is the estimated spawning biomass in 2011, U_{2010} is the estimated exploitation rate in 2010, and U_{2011} and Y_{2011} are the calculated PA-compliant exploitation rate and yield for 2011. Biomasses and yields are in tonnes. All derived quantities were calculated for each sample of the MCMC posterior. Continued overleaf.

Run	Quantile		
	5th	**50th**	**95th**
		$0.4B_{MSY}$	
Estimate *M* & *h*	6,071	9,202	13,384
Estimate *M*	9,014	10,081	11,984
Estimate *h*	4,872	7,385	9,955
Fix *M* & *h*	8,241	8,657	9,257
		$0.8B_{MSY}$	
Estimate *M* & *h*	12,141	18,403	26,769
Estimate *M*	18,027	20,162	23,969
Estimate *h*	9,744	14,771	19,910
Fix *M* & *h*	16,482	17,314	18,515
		B_{MSY}	
Estimate *M* & *h*	15,177	23,004	33,461
Estimate *M*	22,534	25,203	29,961
Estimate *h*	12,180	18,463	24,888
Fix *M* & *h*	20,603	21,642	23,144
		V_{MSY}	
Estimate *M* & *h*	33,022	47,272	65,263
Estimate *M*	45,203	50,616	60,589
Estimate *h*	27,461	39,273	50,586
Fix *M* & *h*	42,352	44,639	47,802
		MSY	
Estimate *M* & *h*	2,916	4,535	6,339
Estimate *M*	3,401	3,953	4,934
Estimate *h*	2,760	3,722	4,698
Fix *M* & *h*	3,031	3,177	3,381
		B_{2011}	
Estimate *M* & *h*	10,076	23,690	46,452
Estimate *M*	10,702	22,662	44,729
Estimate *h*	6,091	10,580	19,592
Fix *M* & *h*	5,505	8,772	14,822
		U_{MSY}	
Estimate *M* & *h*	0.048	0.098	0.170
Estimate *M*	0.073	0.078	0.085
Estimate *h*	0.055	0.095	0.165
Fix *M* & *h*	0.070	0.070	0.073
		U_{2010}	
Estimate *M* & *h*	0.041	0.077	0.152
Estimate *M*	0.041	0.079	0.153
Estimate *h*	0.089	0.146	0.224
Fix *M* & *h*	0.110	0.166	0.248

Run	Quantile 5th	50th	95th
	U_{2011} (PA compliant)		
Estimate *M* & *h*	0.003	0.093	0.170
Estimate *M*	0.012	0.078	0.085
Estimate *h*	0.000	0.045	0.163
Fix *M* & *h*	0.000	0.001	0.045
	Y_{2011} (PA compliant)		
Estimate *M* & *h*	68	4,780	12,137
Estimate *M*	287	3,721	7,704
Estimate *h*	0	1,220	5,618
Fix *M* & *h*	0	23	1,466

Table 2. Decision tables detailing the limit reference point $0.4B_{MSY}$ for 1-5 year projections for all four model runs. Values are $P(B_t > 0.4\,B_{MSY})$, i.e. the probability of the spawning biomass at the start of year t being greater than the limit reference point. The probabilities are based on the MCMC posterior distributions of B_t and B_{MSY}. Catch strategies (in tonnes) are in increments of 500, and 3500 is the approximate average catch over the last 5 years. The final column values trace out the lines in Figure 9. Continued overleaf.

Annual catch strategy	**Projection Year**					
	2011	**2012**	**2013**	**2014**	**2015**	**2016**
	Run: Estimate *M* & *h*					
0	0.957	0.976	0.989	0.993	0.997	0.997
500	0.957	0.972	0.985	0.991	0.992	0.995
1000	0.957	0.971	0.981	0.985	0.988	0.986
1500	0.957	0.969	0.975	0.981	0.982	0.980
2000	0.957	0.968	0.969	0.969	0.969	0.968
2500	0.957	0.966	0.964	0.964	0.963	0.953
3000	0.957	0.964	0.961	0.956	0.937	0.931
3500	0.957	0.956	0.956	0.939	0.926	0.911
4000	0.957	0.953	0.943	0.924	0.909	0.884
4500	0.957	0.949	0.933	0.910	0.886	0.853
5000	0.957	0.946	0.923	0.900	0.863	0.816
5500	0.957	0.943	0.915	0.882	0.832	0.781
6000	0.957	0.937	0.904	0.868	0.804	0.736
	Run: Estimate *M*					
0	0.972	0.983	0.991	0.997	0.999	1.000
500	0.972	0.982	0.989	0.993	0.996	0.997
1000	0.972	0.981	0.984	0.988	0.990	0.990
1500	0.972	0.980	0.982	0.982	0.983	0.983
2000	0.972	0.979	0.979	0.979	0.975	0.974
2500	0.972	0.977	0.974	0.971	0.966	0.959
3000	0.972	0.974	0.969	0.960	0.947	0.935
3500	0.972	0.970	0.962	0.946	0.929	0.911
4000	0.972	0.966	0.949	0.929	0.908	0.873
4500	0.972	0.963	0.944	0.915	0.873	0.829
5000	0.972	0.958	0.931	0.897	0.840	0.778
5500	0.972	0.955	0.919	0.865	0.800	0.727
6000	0.972	0.946	0.904	0.841	0.766	0.662
	Run: Estimate *h*					
0	0.816	0.895	0.942	0.966	0.981	0.985
500	0.816	0.883	0.923	0.948	0.959	0.968
1000	0.816	0.873	0.905	0.922	0.932	0.935
1500	0.816	0.860	0.882	0.893	0.893	0.888
2000	0.816	0.846	0.857	0.859	0.855	0.844
2500	0.816	0.829	0.831	0.816	0.784	0.755
3000	0.816	0.818	0.801	0.766	0.723	0.674
3500	0.816	0.800	0.762	0.712	0.652	0.574
4000	0.816	0.783	0.728	0.659	0.564	0.484
4500	0.816	0.760	0.695	0.593	0.483	0.390
5000	0.816	0.741	0.655	0.529	0.407	0.294
5500	0.816	0.728	0.619	0.468	0.320	0.228
6000	0.816	0.713	0.571	0.397	0.254	0.167

Annual catch strategy	2011	2012	2013	2014	2015	2016
						Projection Year
	Run: Fix *M* & *h*					
0	0.518	0.726	0.863	0.947	0.973	0.987
500	0.518	0.697	0.811	0.880	0.926	0.950
1000	0.518	0.664	0.747	0.799	0.824	0.838
1500	0.518	0.625	0.681	0.712	0.708	0.703
2000	0.518	0.592	0.621	0.613	0.582	0.539
2500	0.518	0.560	0.557	0.518	0.454	0.386
3000	0.518	0.530	0.488	0.418	0.330	0.270
3500	0.518	0.496	0.422	0.324	0.240	0.157
4000	0.518	0.460	0.356	0.251	0.157	0.089
4500	0.518	0.433	0.302	0.186	0.095	0.059
5000	0.518	0.389	0.257	0.132	0.067	0.037
5500	0.518	0.362	0.203	0.094	0.05	0.022
6000	0.518	0.332	0.172	0.071	0.029	0.013

Table 3. As for Table 2, but for the upper reference point 0.8 B_{MSY}, such that values shown are P(B_t > 0.8 B_{MSY}) and the final column values trace out the lines in Figure 10.

Annual catch strategy						**Projection Year**
	2011	**2012**	**2013**	**2014**	**2015**	**2016**
	Run: Estimate *M* & *h*					
0	0.680	0.754	0.810	0.847	0.875	0.890
500	0.680	0.747	0.790	0.829	0.850	0.869
1000	0.680	0.741	0.777	0.800	0.823	0.835
1500	0.680	0.729	0.759	0.782	0.793	0.800
2000	0.680	0.720	0.738	0.762	0.764	0.759
2500	0.680	0.708	0.726	0.731	0.723	0.717
3000	0.680	0.693	0.705	0.699	0.689	0.674
3500	0.680	0.685	0.679	0.671	0.650	0.626
4000	0.680	0.676	0.663	0.644	0.615	0.584
4500	0.680	0.666	0.644	0.615	0.583	0.559
5000	0.680	0.660	0.628	0.590	0.558	0.516
5500	0.680	0.646	0.612	0.569	0.523	0.485
6000	0.680	0.640	0.595	0.547	0.497	0.447
	Run: Estimate *M*					
0	0.624	0.704	0.774	0.827	0.871	0.903
500	0.624	0.692	0.753	0.800	0.835	0.859
1000	0.624	0.672	0.737	0.766	0.793	0.810
1500	0.624	0.662	0.712	0.743	0.750	0.757
2000	0.624	0.654	0.677	0.695	0.697	0.684
2500	0.624	0.642	0.658	0.656	0.646	0.629
3000	0.624	0.628	0.627	0.620	0.595	0.567
3500	0.624	0.616	0.605	0.584	0.551	0.524
4000	0.624	0.609	0.581	0.545	0.508	0.465
4500	0.624	0.596	0.559	0.513	0.463	0.419
5000	0.624	0.583	0.538	0.481	0.436	0.371
5500	0.624	0.573	0.513	0.458	0.386	0.316
6000	0.624	0.561	0.485	0.437	0.352	0.268
	Run: Estimate *h*					
0	0.239	0.317	0.437	0.546	0.613	0.661
500	0.239	0.303	0.407	0.489	0.559	0.596
1000	0.239	0.288	0.365	0.426	0.477	0.515
1500	0.239	0.268	0.327	0.381	0.398	0.418
2000	0.239	0.260	0.292	0.324	0.334	0.333
2500	0.239	0.256	0.266	0.274	0.264	0.258
3000	0.239	0.239	0.236	0.226	0.213	0.197
3500	0.239	0.225	0.209	0.189	0.168	0.152
4000	0.239	0.215	0.189	0.163	0.143	0.119
4500	0.239	0.203	0.178	0.137	0.113	0.091
5000	0.239	0.188	0.154	0.116	0.088	0.064
5500	0.239	0.181	0.133	0.098	0.074	0.046
6000	0.239	0.174	0.121	0.082	0.057	0.035

Annual catch strategy	Projection Year					
	2011	2012	2013	2014	2015	2016
	Run: Fix *M* & *h*					
0	0.009	0.017	0.036	0.070	0.103	0.156
500	0.009	0.015	0.028	0.049	0.071	0.082
1000	0.009	0.012	0.023	0.034	0.047	0.055
1500	0.009	0.011	0.020	0.024	0.025	0.027
2000	0.009	0.010	0.013	0.018	0.019	0.019
2500	0.009	0.010	0.011	0.012	0.011	0.008
3000	0.009	0.009	0.009	0.009	0.005	0.004
3500	0.009	0.009	0.009	0.004	0.001	0.001
4000	0.009	0.009	0.007	0.002	0.001	0.000
4500	0.009	0.008	0.003	0.001	0.000	0.000
5000	0.009	0.007	0.002	0.001	0.000	0.000
5500	0.009	0.006	0.001	0.000	0.000	0.000
6000	0.009	0.004	0.001	0.000	0.000	0.000

Table 4. As for Table 2, but for B_{MSY}, such that values shown are $P(B_t > B_{MSY})$ and the final column values trace out the lines in Figure 11.

Annual catch strategy	Projection Year					
	2011	2012	2013	2014	2015	2016
	Run: Estimate *M* & *h*					
0	0.523	0.586	0.647	0.704	0.739	0.762
500	0.523	0.575	0.624	0.674	0.708	0.727
1000	0.523	0.567	0.609	0.649	0.675	0.695
1500	0.523	0.560	0.594	0.614	0.637	0.647
2000	0.523	0.556	0.575	0.593	0.599	0.609
2500	0.523	0.550	0.566	0.572	0.578	0.575
3000	0.523	0.535	0.545	0.548	0.542	0.540
3500	0.523	0.528	0.532	0.525	0.513	0.497
4000	0.523	0.522	0.518	0.503	0.483	0.465
4500	0.523	0.515	0.499	0.483	0.453	0.429
5000	0.523	0.510	0.483	0.452	0.418	0.390
5500	0.523	0.503	0.464	0.428	0.392	0.345
6000	0.523	0.495	0.445	0.408	0.359	0.307
	Run: Estimate *M*					
0	0.388	0.458	0.538	0.610	0.658	0.708
500	0.388	0.450	0.510	0.567	0.615	0.645
1000	0.388	0.438	0.486	0.530	0.557	0.576
1500	0.388	0.431	0.473	0.498	0.513	0.527
2000	0.388	0.422	0.451	0.465	0.467	0.465
2500	0.388	0.414	0.437	0.444	0.436	0.415
3000	0.388	0.408	0.411	0.409	0.387	0.373
3500	0.388	0.400	0.396	0.375	0.350	0.311
4000	0.388	0.394	0.372	0.342	0.298	0.260
4500	0.388	0.383	0.348	0.308	0.260	0.227
5000	0.388	0.367	0.326	0.279	0.233	0.197
5500	0.388	0.350	0.303	0.252	0.206	0.173
6000	0.388	0.339	0.281	0.228	0.186	0.145
	Run: Estimate *h*					
0	0.113	0.159	0.218	0.291	0.379	0.439
500	0.113	0.149	0.199	0.255	0.310	0.357
1000	0.113	0.142	0.182	0.218	0.247	0.283
1500	0.113	0.135	0.166	0.185	0.206	0.217
2000	0.113	0.125	0.140	0.159	0.166	0.171
2500	0.113	0.120	0.124	0.132	0.133	0.135
3000	0.113	0.117	0.118	0.113	0.111	0.105
3500	0.113	0.110	0.104	0.097	0.088	0.082
4000	0.113	0.102	0.092	0.080	0.069	0.059
4500	0.113	0.097	0.086	0.071	0.057	0.038
5000	0.113	0.090	0.077	0.063	0.040	0.031
5500	0.113	0.088	0.069	0.048	0.032	0.024
6000	0.113	0.085	0.066	0.039	0.029	0.013

Annual catch strategy	2011	2012	2013	2014	2015	Projection Year 2016
	Run: Fix *M* & *h*					
0	0.000	0.001	0.003	0.008	0.016	0.021
500	0.000	0.001	0.002	0.006	0.008	0.012
1000	0.000	0.000	0.001	0.002	0.003	0.004
1500	0.000	0.000	0.001	0.001	0.001	0.001
2000	0.000	0.000	0.000	0.001	0.001	0.000
2500	0.000	0.000	0.000	0.000	0.000	0.000
3000	0.000	0.000	0.000	0.000	0.000	0.000
3500	0.000	0.000	0.000	0.000	0.000	0.000
4000	0.000	0.000	0.000	0.000	0.000	0.000
4500	0.000	0.000	0.000	0.000	0.000	0.000
5000	0.000	0.000	0.000	0.000	0.000	0.000
5500	0.000	0.000	0.000	0.000	0.000	0.000
6000	0.000	0.000	0.000	0.000	0.000	0.000

Table 5. Median values of B_t / B_{MSY} (ratio of spawning biomass in year t to the spawning biomass at the maximum sustainable yield) for 1-5 year projections for all four model runs.

Annual catch strategy	2011	2012	2013	2014	2015	2016
						Projection Year
	Run: Estimate *M* & *h*					
0	1.036	1.113	1.202	1.278	1.342	1.398
500	1.036	1.102	1.183	1.239	1.294	1.342
1000	1.036	1.092	1.157	1.202	1.248	1.291
1500	1.036	1.083	1.135	1.173	1.205	1.221
2000	1.036	1.073	1.114	1.142	1.161	1.168
2500	1.036	1.064	1.090	1.107	1.111	1.112
3000	1.036	1.056	1.068	1.073	1.065	1.050
3500	1.036	1.048	1.044	1.037	1.022	0.994
4000	1.036	1.037	1.021	1.002	0.971	0.942
4500	1.036	1.026	0.997	0.968	0.928	0.885
5000	1.036	1.015	0.976	0.934	0.881	0.830
5500	1.036	1.005	0.952	0.900	0.839	0.778
6000	1.036	0.993	0.930	0.866	0.792	0.726
	Run: Estimate *M*					
0	0.890	0.966	1.029	1.085	1.136	1.178
500	0.890	0.956	1.010	1.054	1.096	1.129
1000	0.890	0.946	0.989	1.024	1.054	1.077
1500	0.890	0.936	0.970	0.995	1.015	1.026
2000	0.890	0.926	0.951	0.966	0.975	0.976
2500	0.890	0.916	0.930	0.935	0.933	0.926
3000	0.890	0.906	0.908	0.904	0.892	0.875
3500	0.890	0.896	0.888	0.872	0.849	0.823
4000	0.890	0.885	0.866	0.841	0.808	0.772
4500	0.890	0.875	0.847	0.810	0.766	0.721
5000	0.890	0.865	0.827	0.780	0.727	0.671
5500	0.890	0.855	0.808	0.751	0.686	0.621
6000	0.890	0.845	0.789	0.720	0.645	0.570
	Run: Estimate *h*					
0	0.594	0.676	0.761	0.834	0.895	0.945
500	0.594	0.663	0.734	0.795	0.842	0.876
1000	0.594	0.652	0.709	0.754	0.786	0.811
1500	0.594	0.640	0.683	0.713	0.732	0.743
2000	0.594	0.627	0.656	0.672	0.675	0.669
2500	0.594	0.616	0.630	0.632	0.618	0.602
3000	0.594	0.603	0.605	0.591	0.563	0.528
3500	0.594	0.590	0.579	0.552	0.506	0.455
4000	0.594	0.577	0.551	0.510	0.448	0.387
4500	0.594	0.565	0.525	0.468	0.391	0.317
5000	0.594	0.553	0.498	0.422	0.331	0.251
5500	0.594	0.541	0.472	0.378	0.277	0.183
6000	0.594	0.531	0.446	0.336	0.224	0.120

Annual catch strategy	Projection Year 2011	2012	2013	2014	2015	2016
	Run: Fix *M* & *h*					
0	0.406	0.469	0.529	0.579	0.619	0.649
500	0.406	0.460	0.507	0.545	0.571	0.590
1000	0.406	0.450	0.485	0.510	0.525	0.532
1500	0.406	0.440	0.463	0.476	0.478	0.473
2000	0.406	0.430	0.440	0.441	0.431	0.415
2500	0.406	0.420	0.418	0.407	0.385	0.355
3000	0.406	0.409	0.396	0.373	0.337	0.297
3500	0.406	0.398	0.374	0.338	0.291	0.240
4000	0.406	0.388	0.352	0.303	0.244	0.185
4500	0.406	0.378	0.330	0.268	0.198	0.130
5000	0.406	0.367	0.308	0.234	0.153	0.077
5500	0.406	0.357	0.287	0.200	0.110	0.043
6000	0.406	0.347	0.265	0.167	0.067	0.034

APPENDIX A. REQUEST FOR SCIENCE ADVICE

REQUEST FOR SCIENCE INFORMATION AND/OR ADVICE

PART 1: DESCRIPTION OF THE REQUEST – TO BE FILLED BY THE CLIENT REQUESTING THE INFORMATION/ADVICE

Date *(when initial client's submission is sent to Science) (dd/mm/yyyy)***:** 04/10/2010

Directorate, Branch or group initiating the request and category of request	
Directorate/Branch/Group ☒ Fisheries and Aquaculture Management ☐ Oceans & Habitat Management and SARA ☐ Policy ☒ Science ☐ Other (please specify):	Category of Request ☒ Stock Assessment ☐ Species at Risk ☐ Human impacts on Fish Habitat/ Ecosystem components ☐ Aquaculture ☐ Ocean issues ☐ Invasive Species ☐ Other (please specify):

Initiating Branch Contact:	
Name: Greg Workman, MEAD/Barry Ackerman, GMU	Telephone Number: 250-756-7113
Email: Greg.Workman@dfo-mpo.gc.ca	Fax Number: 250-756-7053

Issue Requiring Science Advice (i.e., "the question"): *Issue posed as a question for Science response.*
What is the current biomass and status of Pacific ocean perch (POP, Sebastes alutus) in Queen Charlotte Sound (current groundfish management areas 5AB and 5CD)? In the context of developing Precautionary Approach (PA) compliant stock assessments is it appropriate to recommend a candidate Limit Reference Point, an Upper Stock Reference Point and a Target Reference Point for each of the Pacific ocean perch stocks? If so, what candidate points would be recommended (include biological considerations and rationale used to form these recommended candidate points). Rationale should be provided if the candidate points differ from the PA default reference points. The assessment document must also provide (i) decision tables forecasting the impacts of varying harvest levels in comparision to historic (unfished), current and future population trends; (ii) identification of additional information needed to enhance appropriate stock assessment advice consistent with goal of implementing ecosystem-based fisheries management, as articulated in the Sustainable Fisheries Framework.

Rationale for Advice Request: *What is the issue, what will it address, importance, scope and breadth of interest, etc.?*
Of the annual Total Allowable Catch for rockfish on the west coast of Canada, POP is the species that has the largest single-species quota. Pacific ocean perch accounts for 25% of the total weight of rockfish landed by bottom trawl gear. The last assessment of this species was in 2001. Recent trends in survey abundance indices, plus reports from industry, indicate the stock may be declining, at least in some areas. Updated harvest advice is required to determine if current harvest levels are sustainable and are compliant with the PA. The request was initially submitted to science by staff in the GMU in 2007. Due to personel changes and limited resources it has not been possible to address this question prior to now.

Possibility of integrating this request with other requests in your sector or other sector's needs?
It may be possible to apply the analytical methods that will be developed for POP to other slope rockfish species, and to POP in other areas.

Intended Uses of the Advice, Potential Impacts of Advice within DFO, and on the Public: *Who will be the end user of the advice (e.g. DFO, another government agency or Industry?). What impact could the advice have on other sectors? Who from the Public will be impacted by the advice and to what extent?*
Intended user is the Groundfish Management Unit (DFO) for setting quotas. The assessment could form the basis for a Management Strategy Evaluation approach at a later date. The groundfish fishery could be impacted by the advice.

Date Advice Required:

Latest possible date to receive Science advice (dd/mm/yyyy): 15/12/2010

Rationale justifying this date: November 2010 PSARC meeting

Funding: Specific funds may already have been identified to cover a given issue (e.g. SARCEP, Ocean Action Plan, etc.)
Source of funding: N/A Expected amount:

Initiating Branch's Approval:

Approved by Initiating Director: ☐ Date (dd/mm/yyyy):

Name of initiating Director:

Send form via email attachment following instructions below:

Regional request: Depending on the region, the coordinator of the Regional Centre for Science Advice or the Regional Director of Science will be the first contact person. Please contact the coordinator in your region to confirm the approach.

National request: At HQ, the Director of the Canadian Science Advisory Secretariat (Denis.Rivard@dfo-mpo.gc.ca) AND the Director General of the Ecosystem Science Directorate (Sylvain.Paradis@dfo-mpo.gc.ca) will be the first contact persons.

APPENDIX B. CATCH DATA

BRIEF HISTORY OF THE FISHERY

A trawl fishery for slope rockfish has existed in British Columbia (BC) since the 1940s. Aside from Canadian trawlers, foreign fleets targeted Pacific ocean perch (POP) in BC waters for approximately two decades. These fleets were primarily from the US (from 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) imposed a combination of species/area quotas, area/time closures, and trip limits on the major species. Quotas were first introduced for POP (and yellowmouth rockfish *Sebastes reedi*) in 1979 for GMU area 5AB (Table B1). On April 18, 1997[1] the boundaries of GMU areas 5AB, 5CD, and 5E were adjusted to extend 5CD southwest around Cape St. James (see Figure 2) for these two species only.

Table B1. Annual trawl Total Allowable Catches (TACs) in tonnes for Pacific ocean perch in groundfish management areas. Note: year can either be calendar year (1979-1996) or fishing year (1997 on).

Year	3C	3D	5AB	5CD	5E	Notes
1979	50		2000		600	a
1980	600		2200		800	b
1981	500		1500	1800	800	c
1982	500	250	1000	2000	800	
1983	500	250	1000	2000		d
1984	500	250	800	2000		e
1985	300	350	850	2000		
1986	100	350	500	2000		
1987	100	350	500	2000		
1988	100	350	700	3000		
1989	150	400	850	3000	400	
1990	150	400	850	2450	400	f
1991	0	400	850	2150	400	g,h
1992	0	400	850	2400	400	i
1993	150	400	850	2400	400	j,k
1994	1173	207	2177	1107	253	l
1995	548	72	1892	1178	544	m
1996	491	164	1500	4003	726	n,o
1997	431	230	2358	2818	644	+,p,q
1998	300	230	2070	2817	730	+
1999	300	230	2070	2817	730	+
2000	300	230	2070	2818	730	+,r,s
2001	300	230	2070	2818	730	+
2002	300	230	2070	2518	730	+,t,u,v
2003	300	230	2070	2818	730	+
2004	300	230	2070	2818	730	+
2005	300	230	2070	2818	730	+
2006	300	230	2070	2118	730	+,w,x,y,z
2007	300	230	2070	2118	730	+
2008	300	230	2070	2118	730	+
2009	300	230	2070	2118	730	+
2010	300	230	2070	2118	730	+

[1] one month into the IVQ program, Barry Ackerman, GMU, pers. comm.

Table B1a. Codes to notes on management actions and quota adjustments that appear in Table B1.

	Management Actions
a	Start limited vessel entry for halibut fleet.
b	Start experimental overharvesting of SW Vancouver Island POP stock.
c	Start limited vessel entry for sablefish fleet.
d	Start experimental unlimited harvesting of Langara Spit POP stock (5EN).
e	End experimental overharvesting of SW Vancouver Is. POP stock.
f	Start Individual Vessel Quotas (IVQ) systems for halibut and sablefish
g	Start Dockside Monitoring Program (DMP) for halibut fleet.
h	Start limited vessel entry for hook and line (H&L) fleet inside.
i	Start limited vessel entry for H&L fleet outside.
j	Stop experimental fishing of Langara Spit POP stock.
k	Close POP fishery in Groundfish Management Area (GMA) 5EN (Langara Spit).
l	Start DMP for trawl fleet.
m	Implement catch limit (monthly) on rockfish aggregate for H&L.
n	Start 100% onboard observer program for offshore trawl fleet.
o	Start DMP for H&L fleet.
p	Start IVQ system for trawl TAC (Total Allowable Catch) species (April 1, 2007)
q	Implement catch limit (15,000 lbs per trip) on combined non-TAC rockfish for trawl fleet
r	Implement catch limit (20,000 lbs per trip) on rockfish aggregate for halibut option D fleet.
s	Implement formal allocation of rockfish species between halibut and H&L sectors.
t	The Department reduces the 5C/D Pacific ocean perch quota by 300 tonnes for research use as payment for the Hecate Strait Pacific Cod charter for each of the next three fishing seasons.
u	Establish inshore rockfish conservation strategy.
v	Close areas to preserve four unique sponge reefs.
w	DFO reduces the 5C/D Pacific ocean perch TAC by 700 tonnes for use in possible research programs.
x	Introduce Integrated Fisheries Management Plan (IFMP) for most groundfish fisheries.
y	Start 100% at-sea electronic monitoring for H&L.
z	Implement 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 5C/D IVQ for those two species.

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[2] 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.

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. 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; for example, allocate the annual catch from unknown areas, U_t , to

[2] PacHarv3 (Oracle), GFCatch (SQL), PacHarvest (SQL), PacHarvHL (SQL), GFFOS (Oracle)

each PMFC area i as $U_t\left(C_{ti}\big/\sum_{i\in\text{PMFC}}C_{ti}\right)$, where C_{ti} is the annual catch known to come from PMFC area i. But decisions made include all identified removals whenever possible. There may exist data sources not incorporated here, but this procedure includes all currently known sources of potential removals.

The catch of most 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 routinely caught more POP than did Canadian vessels. Additionally, from the mid-1960s to the mid-1970s, foreign fleets (Russian, Japanese) removed large amounts of POP (Ketchen 1980). This assessment uses catch reconstructed back to 1940 (Table B2) as the fishery increased during World War II. From 1918 to 1939, removals were negligible compared to those which came after 1939 (Figure B1).

The accuracy and precision of reconstructed catch series inherently reflect the problems associated with the development of a commercial fishery: trips offloading catch with no area information, unreported discarding, recording catch of one species as another to avoid quota violations, developing expertise in monitoring systems, shifting regulations, changing data storage technologies, etc. Many of these problems have been solved through the introduction of onboard observer programs (started in 1996 for the offshore trawl fleet), dockside monitoring, and tradeable individual vessel quotas (IVQs, 1997) that confer ownership of the resource to the fishing sector. Improvements in data storage and retrieval technologies are still ongoing.

Table B2. Catch reconstruction (landings + discards, tonnes) for Pacific ocean perch in PMFC major areas 5ABC.Values marked '0' indicate catches less than 0.05 t; those marked '–' indicate no catch.

	Trawl				**H&L + Trap**				**All Fisheries**			
Year	**5A**	**5B**	**5C**	**Total**	**5A**	**5B**	**5C**	**Total**	**5A**	**5B**	**5C**	**Total**
1940	3.3	18	0.2	21	0	0	0	0	3.3	18	0.2	21
1941	1.3	11	1.0	13	0	0	0	0	1.3	11	1.0	13
1942	24	127	1.3	152	0	0	0	0	24	127	1.3	152
1943	77	408	3.8	489	0	0	0	0	77	408	3.8	489
1944	32	179	3.7	215	0	0	0	0	32	179	3.7	215
1945	335	1,755	12	2,102	0	0.0	0	0.1	335	1,755	12	2,102
1946	169	904	10	1,084	0	0.1	0	0.1	169	904	10	1,084
1947	88	462	3.0	553	0	0	0	0	88	462	3.0	553
1948	143	749	4.8	897	0	0	0	0	143	749	4.8	897
1949	174	912	6.0	1,092	0	0	0	0	174	912	6.0	1,092
1950	202	871	6.1	1,079	0	0	0	0	202	871	6.1	1,079
1951	140	1,029	6.0	1,175	0	0.1	0	0.1	140	1,029	6.1	1,175
1952	137	895	3.8	1,036	0	0.0	0	0.1	137	895	3.8	1,036
1953	77	737	1.5	816	0	0	0	0	77	737	1.5	816
1954	87	1,703	3.4	1,794	0	0	0	0	87	1,703	3.4	1,794
1955	165	469	2.1	636	0	0	0	0	165	469	2.1	636
1956	425	974	88	1,487	0	0	0	0	425	974	88	1,487
1957	350	761	5.5	1,116	–	0	0	0	350	761	5.5	1,116
1958	285	693	19	996	–	0	0	0	285	693	19	996
1959	1,669	322	2.8	1,995	0	0	0	0	1,669	322	2.8	1,995
1960	769	1,000	36	1,805	0	0	0	0	769	1,000	36	1,805
1961	451	814	---	1,265	0	0	0	0	451	814	0	1,265
1962	482	1,460	---	1,942	0	0	0	0	482	1,460	0	1,942
1963	1,060	2,861	30	3,951	0	0	0	0.1	1,060	2,861	31	3,951
1964	1,717	1,979	16	3,712	0	0	0	0	1,717	1,979	16	3,712
1965	5,009	3,395	62	8,466	0	0	0	0	5,009	3,395	62	8,466
1966	14,821	8,464	0.6	23,285	0	0	0	0	14,821	8,464	0.6	23,285
1967	11,204	7,315	42	18,561	0	0	0	0	11,204	7,315	42	18,561

Year	Trawl				H&L + Trap				All Fisheries			
	5A	5B	5C	Total	5A	5B	5C	Total	5A	5B	5C	Total
1968	7,373	6,163	---	13,535	0	0	0	0	7,373	6,163	0	13,535
1969	4,328	6,055	---	10,382	0	0	0	0	4,328	6,055	0	10,382
1970	3,975	4,393	0.6	8,368	0	0.1	0	0.1	3,975	4,393	0.6	8,368
1971	1,579	3,077	1.8	4,658	0	0	0	0.1	1,579	3,077	1.9	4,658
1972	2,904	4,149	---	7,052	0	0	0	0.1	2,904	4,149	0	7,052
1973	2,880	3,495	29	6,404	0	0	0	0	2,880	3,495	29	6,404
1974	6,074	3,695	26	9,795	0	0	0	0.1	6,074	3,695	26	9,796
1975	2,931	2,786	167	5,885	0	0	0.1	0.1	2,931	2,786	168	5,885
1976	1,319	1,553	60	2,932	0	0	0	0.1	1,319	1,553	60	2,932
1977	73	1,064	53	1,190	0	0	0	0.1	73	1,064	53	1,190
1978	172	1,202	84	1,458	0	0	0	0.1	172	1,202	84	1,458
1979	293	1,143	177	1,613	0	0	0	0.1	293	1,143	178	1,613
1980	139	1,823	2,482	4,443	0	0	0	0.1	139	1,823	2,482	4,443
1981	39	2,507	1,697	4,243	0	0	0	0.1	39	2,507	1,697	4,243
1982	314	2,908	2,085	5,307	7.9	54	0	62	321	2,962	2,085	5,368
1983	552	2,498	1,318	4,368	39	31	0	69	590	2,528	1,318	4,437
1984	118	2,589	579	3,286	13	19	0	32	131	2,608	579	3,318
1985	112	2,291	698	3,100	0	134	1.3	136	112	2,425	699	3,236
1986	400	841	130	1,372	56	162	0.1	219	457	1,003	130	1,591
1987	609	2,749	502	3,860	1.4	11	0.2	12	610	2,760	502	3,872
1988	591	3,197	2,843	6,631	11	0.4	0.1	11	602	3,198	2,843	6,642
1989	380	2,073	1,743	4,196	224	27	0.1	251	604	2,100	1,743	4,447
1990	494	1,914	1,605	4,013	207	1.2	0.2	208	701	1,915	1,605	4,222
1991	425	2,251	2,195	4,872	12	30	0.3	42	437	2,281	2,196	4,914
1992	398	2,158	1,746	4,303	0.8	44	0.2	45	399	2,202	1,747	4,348
1993	344	1,655	1,613	3,611	0.3	13	19	32	344	1,668	1,631	3,643
1994	671	3,091	1,635	5,397	154	0.4	1.2	156	825	3,092	1,636	5,553
1995	657	3,383	2,461	6,500	32	2.2	0.6	35	689	3,385	2,462	6,535
1996	411	4,223	566	5,200	0.6	0.2	0	0.8	412	4,223	566	5,201
1997	867	3,493	408	4,768	0.7	0.3	0	1.0	868	3,493	408	4,769
1998	950	3,243	500	4,694	0.1	0.3	0.1	0.5	951	3,243	501	4,694
1999	953	3,002	563	4,517	0.3	0.5	0.2	1.0	953	3,002	563	4,518
2000	572	3,488	417	4,477	0.2	1.5	0.1	1.8	572	3,490	417	4,479
2001	704	2,998	311	4,012	0.2	1.6	0.4	2.1	704	2,999	311	4,015
2002	709	3,112	325	4,145	0.1	0.4	0.1	0.6	709	3,112	325	4,146
2003	814	3,640	263	4,718	0.1	0.2	0	0.2	814	3,640	263	4,718
2004	735	3,610	129	4,474	0.1	0.2	–	0.3	735	3,610	129	4,474
2005	859	2,724	130	3,713	0.1	0.3	–	0.3	859	2,724	130	3,713
2006	537	3,447	98	4,082	0.1	0.8	0	0.8	537	3,447	98	4,082
2007	657	2,856	56	3,569	0.1	0.4	0	0.5	657	2,856	56	3,569
2008	500	2,368	30	2,898	0.1	0.1	–	0.2	500	2,368	30	2,898
2009	753	2,363	43	3,159	0	0.1	–	0.1	753	2,363	43	3,159
2010	479	2,360	19	2,858	0	0.1	0	0.1	479	2,360	19	2,858

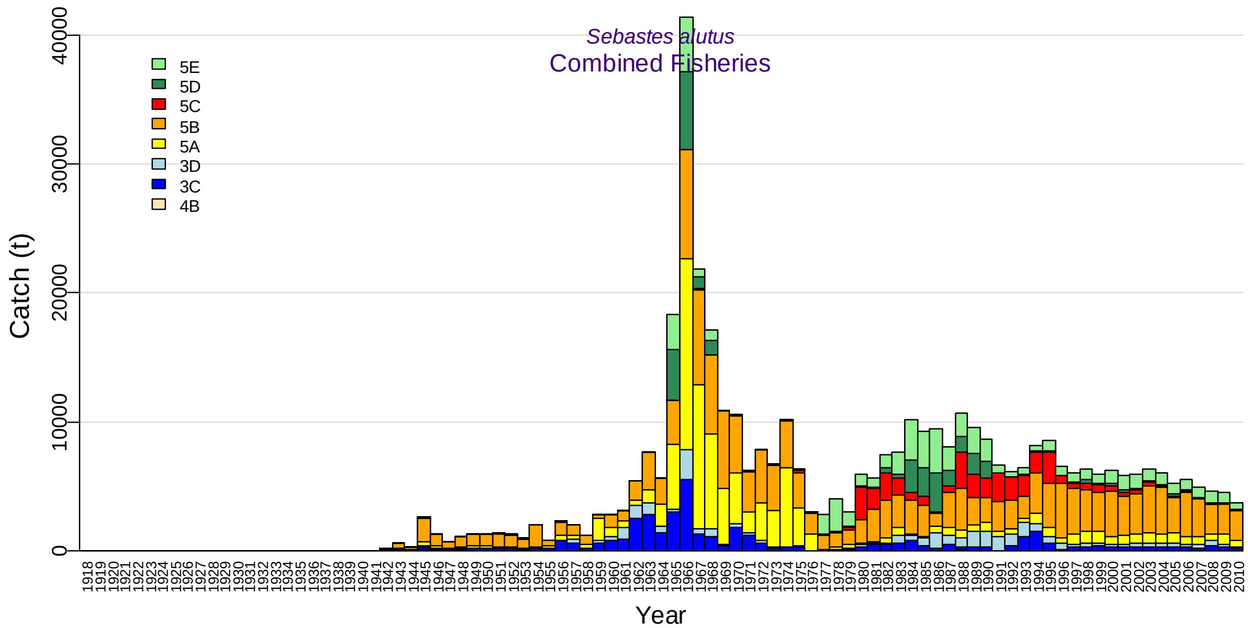


Figure B1. Reconstructed total (landed + discarded) catch (t) for Pacific ocean perch from all fisheries combined in PMFC major areas.

SCALING PMFC AREA YIELD TO GROUNDFISH MANAGEMENT AREA TOTAL ALLOWABLE CATCHES

The area definitions used by the DFO Groundfish Science Unit appear to differ somewhat from those used by the DFO Groundfish Management Unit (GMU). The reasons for the existence of these discrepancies will vary depending on the species, but it appears that these occur because of the need to address different requirements. Past assessments of POP (e.g., Schnute *et al*. 2001) have used "slope rockfish areas" (SRFA) based primarily on existing PMFC areas with additional boundary adjustments that separate Moresby and Mitchell's Gullies in Queen Charlotte Sound (QCS) and delimit the Langara Spit stock off NW Haida Gwaii.

The catch and age composition data used in this POP stock assessment were based entirely on PMFC major areas 5A, 5B, and 5C combined (5ABC). This area logically delimits the stock in QCS, which comprises POP populations in the three main gullies: Goose Island, Mitchell's, and Moresby. The GMU manages the groundfish stocks using Groundfish Management Areas (GMA), which are based on DFO Pacific Fishery Management Areas (PFMA) and which are defined in the Pacific Fishery Management Area Regulations (PFMAR 2007). The PMFC and GMU areas are similar but not identical (Figure 2).

To facilitate the scaling of yield estimates presented in this assessment (based on the combined PMFC area 5ABC) to GMAs 5AB and 5CD, we summarise annual catches for all tows which have valid identifiers for both PMFC and GMU areas and calculate a scaling ratio (Table B3). The sum of these annual ratios will be greater than 1.0 because we are scaling catch from a smaller area (PMFC 5ABC) to a larger one (GMA 5ABCD). These ratios will be only slightly larger than unity because the non-assessed area 5D does not constitute much catch compared to the sum of catch from the three assessed areas.

Table B3. Annual catches (t) of POP from tows that have valid identifiers for both PMFC and GMU areas.

Year	PMFC				GMA				PMFC	GMA		GMA/PMFC	
	5A	5B	5C	5D	5A	5B	5C	5D	5ABC	5AB	5CD	5AB	5CD
1996	407	4,180	561	32	412	1,137	3,655	29	5,147	1,549	3,684	0.3010	0.7158
1997	859	3,461	404	59	874	1,696	2,240	51	4,724	2,570	2,291	0.5440	0.4850
1998	950	3,242	500	292	954	1,145	2,605	292	4,692	2,099	2,898	0.4474	0.6176
1999	952	3,000	562	110	969	1,102	2,445	110	4,515	2,071	2,555	0.4587	0.5659
2000	569	3,476	416	227	577	1,409	2,963	227	4,461	1,985	3,190	0.4450	0.7151
2001	694	2,952	306	152	703	1,379	2,207	152	3,952	2,082	2,359	0.5268	0.5969
2002	707	3,106	324	144	719	1,282	2,541	144	4,138	2,001	2,685	0.4836	0.6489
2003	811	3,617	262	122	814	1,340	2,823	122	4,690	2,154	2,945	0.4593	0.6279
2004	732	3,598	129	76	732	1,309	2,573	76	4,458	2,041	2,649	0.4578	0.5942
2005	855	2,713	129	162	855	1,755	1,141	164	3,697	2,609	1,305	0.7057	0.3530
2006	518	3,326	95	90	518	2,177	1,375	90	3,939	2,695	1,465	0.6842	0.3719
2007	626	2,730	53	23	628	1,244	1,670	23	3,409	1,872	1,694	0.5491	0.4969
2008	478	2,274	29	72	478	1,270	1,069	72	2,781	1,749	1,141	0.6289	0.4103
2009	747	2,343	43	74	755	1,122	1,310	74	3,133	1,877	1,384	0.5991	0.4417
2010	606	2,971	21	48	614	1,404	1,714	48	3,597	2,018	1,762	0.5610	0.4899

We suggest the following algorithm to parse out a PMFC 5ABC yield option to the current POP GMA 5AB and 5CD areas:

1. Start with the yield option from the 5ABC stock assessment.
2. Increase this yield by the incremental difference in catches between the PMFC and GMA area definitions (column headed “Difference”, Table B4).
3. Split the resulting yield proportionate to the existing TAC split.

Step 3 is important because it maintains existing ratios in terms of the quota holdings by individual operators. That way, if the quota is changed, then the changes will be made proportionate to the existing situation.

The worked example in Table B4 assumes that the most recent five complete catch years (2005-2009) are used to calculate the incremental difference between the two sets of area definitions. The mean difference is +4.8%. If the assessment yield option is 1,000 t, then the revised yield will be 1,048 t and the yields assigned to 5AB and 5CD would be 518 t and 530 t, respectively.

Table B4. Algorithm to convert the yield recommendation (t) from PMFC 5ABC to GMA TACs (t) in 5AB and 5CD, for an example yield of 1000t.

Year	PMFC 5ABC	GMA 5ABCD	Difference
1996	5,147	5,233	1.7%
1997	4,724	4,861	2.9%
1998	4,692	4,997	6.5%
1999	4,515	4,626	2.5%
2000	4,461	5,175	16.0%
2001	3,952	4,441	12.4%
2002	4,138	4,686	13.2%
2003	4,690	5,099	8.7%
2004	4,458	4,690	5.2%
2005	3,697	3,914	5.9%
2006	3,939	4,160	5.6%
2007	3,409	3,565	4.6%
2008	2,781	2,889	3.9%
2009	3,133	3,261	4.1%
Average			4.8%

Example	Result
1st year in average	2005
Assessment yield (t)	1,000
Revised yield (t)	1,048
Existing TACC: 5AB	2,070
Existing TACC: 5CD	2,118
Yield allocation: 5AB	518
Yield allocation: 5CD	530

APPENDIX C. TRAWL SURVEYS

TABLE OF CONTENTS / TABLE DES MATIÈRES

LIST OF TABLES / LISTE DES TABLEAUX

LIST OF FIGURES / LISTE DES FIGURES

INTRODUCTION

This appendix summarises the derivation of the relative Pacific ocean perch (POP) abundance indices from the:

1. historical Goose Island Gully (GIG) surveys within Queen Charlotte Sound (QCS)
2. QCS groundfish synoptic survey
3. QCS shrimp survey

ANALYTICAL METHODS

Catch and effort data for stratum i in year y yield catch per unit effort (CPUE) values U_{yi}.

Given a set of data $\left\{C_{yij}, E_{yij}\right\}$ for tows $j = 1, \ldots, n_{yi}$,

Eq. C1 $U_{yi} = \frac{1}{n_{yi}} \sum_{j=1}^{n_{yi}} \frac{C_{yij}}{E_{yij}}$,

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

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

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

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

Eq. C2 $\delta_{yi} = \frac{1}{vw} U_{yi}$,

where v = average vessel speed (km/h);

w = average net width (m).

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

Eq. C3 $\delta_{yi} = \frac{1}{n_{yi}} \sum_{j=1}^{n_{yi}} \frac{C_{yij}}{D_{yij} w_{yij}}$,

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

D_{yij} = distance travelled (km) for tow j, stratum i, year y;

w_{yij} = net opening (km) for tow j, stratum i, year y;

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

The annual biomass estimate $\left(B_y\right)$ is then the sum of the product of CPUE densities and bottom areas across m strata:

Eq. C4 $B_y = \sum_{i=1}^{m} \delta_{yi} A_i = \sum_{i=1}^{m} B_{yi}$, where δ_{yi} = mean CPUE density (kg/km^2) for stratum i, year y;

A_i = area (km^2) of stratum i;

B_{yi} = biomass (kg) for stratum i, year y;

m = number of strata.

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

Eq. C5 $$V_y = \sum_{i=1}^{m} \frac{\sigma_{yi}^2 A_i^2}{n_{yi}} = \sum_{i=1}^{m} V_{yi} ,$$

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

V_{yi} = variance of the biomass estimate (kg^2) for stratum i, year y.

The coefficient of variation $\left(CV_y\right)$ of the annual biomass estimates $\left(B_y\right)$ is

Eq. C6 $$CV_y = \frac{\sqrt{V_y}}{B_y} .$$

EARLY GIG SURVEYS IN QCS

Data selection

Tow-by-tow data from a series of historical trawl surveys were available for 12 years spanning the period from 1965 to 1995. The first two surveys, in 1965 and 1966, were quite wide ranging, with the 1965 survey extending from near San Francisco to halfway up the Alaskan panhandle ([left panel] Figure C1). The 1966 survey was only slightly less ambitious, ranging from the southern US-Canada border in Juan de Fuca Strait into the Alaskan panhandle ([right panel] Figure C1). It was apparent that the design of these two early surveys was exploratory and that these surveys would not be comparable to the subsequent QCS surveys which were much narrower in terms of area covered and which had a much higher density of tows in GIG. This can be seen in the small number of tows used by the first two surveys in GIG (Table C1).

The 1967 ([left panel] Figure C2) and 1969 ([right panel] Figure C2) surveys performed tows on the west coast of Vancouver Island, the Queen Charlotte Islands and SE Alaska, but both of these surveys had a reasonable number of tows in the GIG grounds (Table C1). The 1971 survey ([left panel] Figure C3) was entirely confined to GIG while the 1973, 1976 and 1977 surveys covered both Goose Island and Mitchell Gullies in QCS ([right panel] Figure C3 and Figure C4).

The 1979 survey was conducted by a commercial fishing vessel (Southward Ho, Table C1), with the distribution of tows being very different from the preceding and succeeding surveys ([left panel] Figure C5). As well, the distribution of tows by depth was also different from the other surveys (Table C2). These observations imply a substantially different survey design and consequently this survey was not included in the time series used in the assessment.

The 1984 survey was conducted by two vessels: the GB Reed and the Eastward Ho. Part of the design of this survey was to compare the catch rates of the two vessels (one was a commercial fishing vessel and the other a government research vessel – G. Workman, DFO, pers. comm.), thus they both followed similar design specifications, including the configuration of the net. Unfortunately, the tows were not distributed similarly in all areas, with the GB Reed fishing mainly in the shallower portions of the GIG, while the Eastward Ho fished more in the deeper and seaward parts of the GIG ([right panel] Figure C5). However, the two vessels fished more contiguously in Mitchell Gully ([right panel] Figure C5). When the depth-stratified catch rates of the two vessels were compared within the GIG only (using a simple ANOVA), the Eastward Ho catch rates were significantly higher (p=0.049) than those observed for the GB Reed. However, the difference in catch rates was no longer significant when tows from Mitchell's Gully were added to the analysis (p=0.12). Given the lack of significance when the full suite of available tows were compared, along with the uneven spatial distribution of tows among vessels within the GIG (although the ANOVA was depth-stratified, it is possible that the depth categories were too coarse), the most parsimonious conclusion was that there was no detectable difference between the two vessels. Consequently, all the GIG tows from both vessels were pooled for this survey year.

The 1994 survey, conducted by another commercial vessel (the Ocean Selector, Table C2) ([left panel] Figure C6), was used in the series without modification. This was done because the 1994 survey was executed using a design that emulated the previous GB Reed surveys as closely as possible (G. Workman, DFO, pers. comm.), as well as being supported by the conclusion that, in 1984, the research and commercial vessels did not have significantly different catch rates.

The 1995 survey, conducted by two commercial fishing vessels: the Ocean Selector and the Frosti (Table C2), used a random stratified design with each vessel duplicating every tow ([right panel] Figure C6) (G. Workman, DFO, pers. comm.). This design was entirely different from that used in the previous surveys and thus this survey could not be used in the GIG series.

Given that the only area that was consistently monitored by these surveys was the GIG grounds, tows lying between 50.9°N and 51.6°N latitude from the eight acceptable survey years, covering the period from 1967 to 1994, were used to index the QCS POP population (Table C1).

The original depth stratification of these surveys was in 20 fathom (36.1 m) intervals, with the important strata for POP ranging from 100 fathoms (183 m) to 180 fathoms (329 m). This depth range accounted for about 95% of the tows which captured POP (Table C3). For the GIG survey series, the shallowest tow capturing POP was 121 m. Similarly, the deepest tow capturing POP was 428 m (and was also the deepest recorded tow). These depth strata were combined for analysis into three ranges: 70–100 fm, 100–120 fm and 120–160 fm, for a total of 352 tows from the eight accepted survey years (Table C4).

A doorspread density value (Eq. C4) was calculated for each tow based on the catch of POP, using a fixed doorspread value of 61.6 m (Yamanaka et al. 1996) for every tow and the recorded distance travelled. Unfortunately, the speed, effort and distance travelled fields were not well populated for these surveys. Therefore, missing values for these fields were filled in with the mean values for the survey year. This resulted in the majority of the tows having distances towed near 3 km, which was the expected result given the design specification of ½ hour tows at an approximate speed of 6 km/h (about 3.2 knots).

Results

Maps showing the locations where POP were caught in the GIG indicate that this species is found throughout the entire gully in all years (Figure C7). Estimated biomass levels in the GIG for Pacific ocean perch from the historical GIG trawl surveys declined from the late 1960s to the end of the 1970s, with a possible recovery into the 1980s and early 1990s (Figure C8; Table C5). However, the long interval between surveys during this period reduces our confidence in this interpretation. The proportion of tows which caught POP is high, exceeding 95% in all survey years except for 1994 where 90% of the tows captured POP (Figure C9). Survey relative errors are low for this species, consistent with the high frequency of this species in the tows, ranging from 0.09 to 0.21 and with seven of the eight accepted surveys below 0.20 (Table C5).

QCS SYNOPTIC TRAWL SURVEY

Data selection

This survey has been conducted in five years over the period 2003 to 2009 in QCS between Vancouver Island and Moresby Island and extending into the lower part of Hecate Strait between Moresby Island and the mainland. The original design divided the survey into two large aerial strata which roughly corresponded to the PMFC regions 5A and 5B while also incorporating part of 5C (Figure C10). Each of these two areas was divided into four depth strata: 50–120 m; 120–250 m; 250–370 m; and 370–500 m (Table C6; Figure C10). However, the original design bisected the centre of Mitchell's Gully, an area of high POP concentration. Therefore, a more appropriate stratification has been adopted for POP which combines the two more northerly QCS gullies (Mitchell's and Moresby) into a single northern stratum and assigns GIG to the southern stratum (Figure C10). The original depth stratification has been retained (Table C6).

The 1995 random stratified survey, described in the previous section ([right panel] Figure C6), was considered for inclusion in this series. However, this suggestion was reviewed by a Centre for Science Advice Pacific (CSAP) meeting held in December 2009 and was not accepted. The reason for this rejection was that, while both surveys were based on a random stratified design, the 1995 survey was exclusively targeting POP while the QCS synoptic survey targets a broad range of species, including POP. The meeting concluded that this difference in survey target species would affect the way that the survey skippers fished, leading to POP catch rates that would not be comparable between the 1995 survey and the surveys that have been undertaken since 2003.

A doorspread density value (Eq. C4) was generated for each tow based on the catch of POP, the mean doorspread for the tow and the distance travelled. The latter was calculated by multiplying the mean vessel speed for the tow by the total time on the bottom as determined from the bottom contact sensor. Missing values for the doorspread field used the mean doorspread for the stratum in the survey year (53 values over all years). Missing values in the vessel speed field used the mean value for the entire survey in that year (24 values over all years). Missing values in the bottom contact time field substituted the winch time (time from winch lockup to winch retrieval; 42 values over the four survey years).

Results

Pacific ocean perch were mainly taken at depths from 160 to 320 m, but there were sporadic observations at depths up to about 400 m (Figure C11). Catch densities of POP from this survey were generally higher in the combined Mitchell/Moresby stratum than in the GIG stratum (Figure C12).

Estimated POP doorspread biomass from this trawl survey decreased from 2003 to 2007, with the 2009 estimate showing a small increase or staying at the 2007 level (Figure C13; Table C7). The estimated relative errors were low, lying between 14 and 20% (Table C7). The proportion of tows that captured POP was relatively high (between 43 and 80%), with both strata showing an upturn in 2009 after dropping from 2003 to 2007 (Figure C14). The proportion of positive tows may be slightly higher in the combined Mitchell/Moresby stratum. Overall, 749 of the 1180 valid survey tows contained POP.

QCS SHRIMP SURVEY

Data selection

This survey covers the SE corner of QCS extending westward from Calvert Island and Rivers Inlet into the Goose Island Gully (Figure C15). There is also a stratum providing coverage between Calvert Island and the mainland. Five vessels took part in the first year that the survey was conducted (1998) and the timing in that year was later than in subsequent years (July instead of April/May; Table C8). It was decided to discard this initial survey year, given the apparent exploratory nature of the design and the potential for non-comparability among vessels in the same year and with subsequent surveys. After the initial year, the survey has been conducted routinely by the *W.E. Ricker* (except in 2005 when the *Frosti* was used) in April or May. This assessment uses all years from1999 on.

The survey is divided into three aerial strata: stratum 109 lying to the west of the outside islands and extending into Goose Island Gully; stratum 110 lying to the south of Calvert Island and stratum 111 lying between Calvert Island and the mainland (Figure C16). Stratum 111 has been discarded as its location does not provide good habitat for rockfish species and no POP have ever been captured here. The majority of tows occur in stratum 109 (the larger of the two remaining strata) while only a few are placed in Stratum 110 (Table C9). Only tows with usability codes of 1 (usable), 2 (fail, but all data usable), and 6 (gear torn, but all data usable) were included in the biomass estimate. Over 800 usable tows have been conducted by this survey over the 12 available survey years (Table C9).

These data were analysed using Eq. C1 to Eq. C6, which assume that tow locations were selected randomly within a stratum relative to the biomass of POP, using the area stratification definition in Figure C15. One thousand bootstrap replicates with replacement were made on the survey data to estimate bias corrected 95% confidence regions for each survey year (Efron 1982).

A doorspread density value (Eq. C3) was generated for each tow based on the catch of POP, an arbitrary doorspread (25 m) for the tow, and the distance travelled. The distance travelled was determined at the time of the tow, based on the bottom contact time (J. Boutillier, DFO, *pers. comm.*). The few missing values for this field were filled in by multiplying the vessel speed and the tow time. All tows were used regardless of depth because this survey, unlike the west coast Vancouver Island shrimp survey, has consistently sampled depths up to about 240 m

(Figure C16), so there was no need to truncate the tows at depth to ensure comparability across survey years.

Results

Catches of POP tend to be distributed along the trench of Goose Island Gully and along the shelf edge of the outside islands (Figure C17). Pacific ocean perch were mainly taken at depths from 140-240 m and have been taken almost entirely in Stratum 109, with the maximum catch weight in Stratum 110 being 1.0 kg/tow (Figure C18).

Estimated biomass levels for POP from the QCS shrimp trawl survey are reasonably consistent across years, showing no strong trend with CVs ranging between 22% and 47% (Figure C19; Table C10). The proportion of tows with Pacific ocean perch is high in Stratum 109, with values from 0.31 to 0.93 (Figure C20). There are usually fewer than 10 tows per year in Stratum 110 (Table C9) and this stratum tended to sample the shallowest depths where POP rarely occur (although 2009 had a high proportion of POP in the tows from both strata: 93% in Stratum 109 and 86% in Stratum 110; Figure C20). Note that the biomass estimate for 2009 is the lowest in the series, in spite of the high proportion of tows which contained POP.

Table C1. Number of tows in GIG and in all other areas (Other) by survey year and vessel conducting the survey for the 12 historical (1965 to 1995) surveys. Survey years in grey were not used in the assessment.

Survey	GB Reed		Southward Ho		Eastward Ho		Ocean Selector		Frosti	
Year	Other	GIG	Other	GIG	Other	GIG	Other	GIG	Other	GIG
1965	76	8								
1966	49	15								
1967	17	33								
1969	3	32								
1971	3	36								
1973	13	33								
1976	23	33								
1977	15	47								
1979			20	59						
1984	19	42			15	27				
1994							2	69		
1995							2	55	1	57

Table C2. Number of tows by 20 fathom depth interval (in metres) in GIG and in all other areas (Other) by survey year for the 12 historical (1965 to 1995) surveys. Survey years in grey were not used in the assessment.

Survey	20 fathom depth interval (m)									Total
year	146–183	184–219	220–256	257–292	293–329	330–366	367–402	403–439	440–549	Tows
Areas other than GIG										
1965	3	15	26	17	6	6	1	1	1	76
1966	3	11	18	8	2	1	3	2	1	49
1967	1		6	2	2	1	1	4		17
1969		1		1		1				3
1971		1		1	1					3
1973			4	3	2	2	2			13
1976			6	4	5	4	4			23
1977			3	2	5	3	2			15
1979	11	2	1	5	1					20
1984			4	10	7	7	6			34
1994					2					2
1995		2		1						3
GIG										
1965		2	4	1	1					8
1966	3	2	3	5	2					15
1967	1	6	11	5	10					33
1969		9	11	6	6					32
1971		4	15	8	9					36
1973		7	11	7	8					33
1976		7	13	8	5					33
1977	1	12	14	14	6					47
1979	23	12	18	6						59
1984		13	25	17	13	1				69
1994		15	18	20	16					69
1995	2	21	47	21	15	6				112

Table C3. Catch weight (t) of Pacific ocean perch by 20 fathom depth interval (in metres) GIG and in all other areas (Other) by survey year for the 12 historical (1965 to 1995) surveys. Survey years in grey were not used in the assessment.

Survey									20 fathom depth interval (m)	Total
year	146–183	184–219	220–256	257–292	293–329	330–366	367–402	403–439	440–549	Weight
Areas other than GIG										
1965	0.00	8.09	13.90	29.40	2.64	4.99	0.27	0.81	0.02	60.12
1966	0.09	1.76	9.55	6.00	1.35	0.35	7.28	0.92	0.10	27.40
1967	0.00		0.38	1.83	1.08	0.02	0.84	5.84		9.99
1969		0.04		1.86		1.30				3.20
1971		0.01		0.47	0.56					1.04
1973			1.99	0.68	0.37	0.31	0.29			3.64
1976			4.04	4.66	5.76	4.72	2.62			21.80
1977			0.25	0.47	2.66	0.73	0.86			4.97
1979	0.95	0.03	0.00	0.72	0.00					1.70
1984			3.13	3.38	2.29	2.37	0.96			12.13
1994					0.00					0.00
1995		0.00		0.00						0.00
GIG										
1965		1.78	1.91	1.60	2.06					7.35
1966	0.66	0.31	2.18	4.17	2.43					9.75
1967	0.00	1.93	10.79	5.29	9.56					27.57
1969		7.84	4.88	4.27	5.45					22.44
1971		0.05	7.70	10.17	9.26					27.18
1973		1.19	3.24	2.60	3.73					10.76
1976		1.38	20.21	9.81	8.86					40.26
1977	0.00	0.43	5.36	4.36	1.73					11.88
1979	0.03	0.48	6.38	1.92						8.81
1984		1.39	22.87	8.52	9.29	0.24				42.31
1994		3.02	14.50	9.02	12.11					38.65
1995	0.01	12.99	22.77	18.92	13.9	4.00				72.59

Table C4. Number of tows available by survey year and depth stratum for the analysis of the historical GIG trawl survey series.

	Depth stratum			
Survey Year	120-183 m (70–100 fm)	184-218 m (100–120 fm)	219-300 m (100–160 fm)	Total
1967	7	11	15	33
1969	9	11	12	32
1971	4	15	17	36
1973	7	11	15	33
1976	7	13	13	33
1977	13	14	20	47
1984	13	23	33	69
1994	14	18	37	69
Total	74	116	162	352

Table C5. Biomass estimates for Pacific ocean perch from the historical Goose Island Gully trawl surveys for the years 1967 to 1994. Biomass estimates are based on three depth strata (Table C4), assuming that the survey tows were randomly selected within these areas. Bootstrap bias corrected confidence intervals and 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 (Eq. C6)
1967	19,539	19,609	15,321	24,432	0.116	0.121
1969	20,289	20,224	14,039	28,920	0.183	0.180
1971	13,799	13,795	11,579	16,462	0.092	0.093
1973	8,380	8,291	5,479	12,427	0.212	0.219
1976	11,902	11,890	9,064	15,187	0.131	0.133
1977	6,132	6,141	4,279	8,699	0.178	0.177
1984	10,409	10,454	8,625	12,321	0.096	0.098
1994	14,722	14,682	11,531	18,427	0.119	0.122

Table C6. Stratum designations and number of usable tows for each year of the QCS synoptic survey using the restratified POP stratum definitions. Also shown is the area of each stratum.

Area:	Goose Island Gully				Mitchell & Moresby Gullies				Total
Depth (m):	50-125	125-200	200-330	330-500	50-125	125-200	200-330	330-500	tows
2003	27	39	27	2	7	54	54	24	234
2004	38	31	19	5	22	57	49	11	232
2005	27	45	22	1	10	60	46	13	224
2007	31	49	20	1	17	73	55	11	257
2009	29	47	16	2	16	54	58	11	233
Area (km^2)	4,717	4,148	2,200	240	2,314	5,666	4,657	1,462	25,404

Table C7. Biomass estimates for POP from the QCS synoptic trawl survey for the survey years 2003 to 2009. Bootstrap bias corrected confidence intervals and 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 (Eq. C6)
2003	22,554	22,476	17,690	30,675	0.139	0.139
2004	18,438	18,515	12,913	26,981	0.197	0.199
2005	14,322	14,297	10,904	18,976	0.147	0.151
2007	11,042	10,759	8,419	15,999	0.164	0.156
2009	12,508	12,491	8,958	17,358	0.174	0.178

Table C8. Number of sets made by each vessel involved in the QCS shrimp trawl by month and survey year. All QCS sets are included, not just sets used in the analysis.

	Month				
Vessel and Year	**Apr**	**May**	**Jun**	**Jul**	**Total**
Frosti					
2005		54			54
Ocean Dancer					
1998				18	18
Pacific Rancher					
1998				18	18
Parr Four					
1998				17	17
W. E. Ricker					
1999			88		88
2000		86			86
2001		75			75
2002	75				75
2003	63				63
2004	69				69
2006	71				71
2007	68				68
2008	72				72
2009	69				69
2010		73			73
Westerly Gail					
1998				21	21
Western Clipper					
1998				18	18

Table C9. Stratum designations and number of useable tows, for the QCS shrimp survey from 1999 to 2010.

	Stratum		
Survey year	**109**	**110**	**Total**
1999	72	10	82
2000	76	8	84
2001	65	7	72
2002	65	7	72
2003	57	6	63
2004	59	6	65
2005	41	6	47
2006	61	6	67
2007	60	5	65
2008	63	6	69
2009	57	7	64
2010	64	6	70
Total	740	80	820
Area (km^2)	2,142	159	2,301

Table C10. Biomass estimates for Pacific ocean perch from the QCS shrimp trawl survey for the survey years 1999 to 2010. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement. The analytic CV (Eq. C6) is based on the assumption of random tow selection within a stratum.

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
1999	2,215	2,203	1,399	3,323	0.219	0.216
2000	1,561	1,536	870	2,600	0.293	0.303
2001	1,865	1,857	807	3,304	0.336	0.351
2002	1,420	1,443	438	3,003	0.449	0.468
2003	661	655	239	1,306	0.421	0.426
2004	1,664	1,670	832	2,604	0.271	0.269
2005	1,439	1,427	679	2,668	0.349	0.349
2006	2,245	2,266	1,294	3,437	0.243	0.245
2007	1,726	1,720	987	2,657	0.254	0.251
2008	1,371	1,362	745	2,120	0.264	0.274
2009	451	450	233	809	0.316	0.319
2010	926	931	408	1,698	0.338	0.347

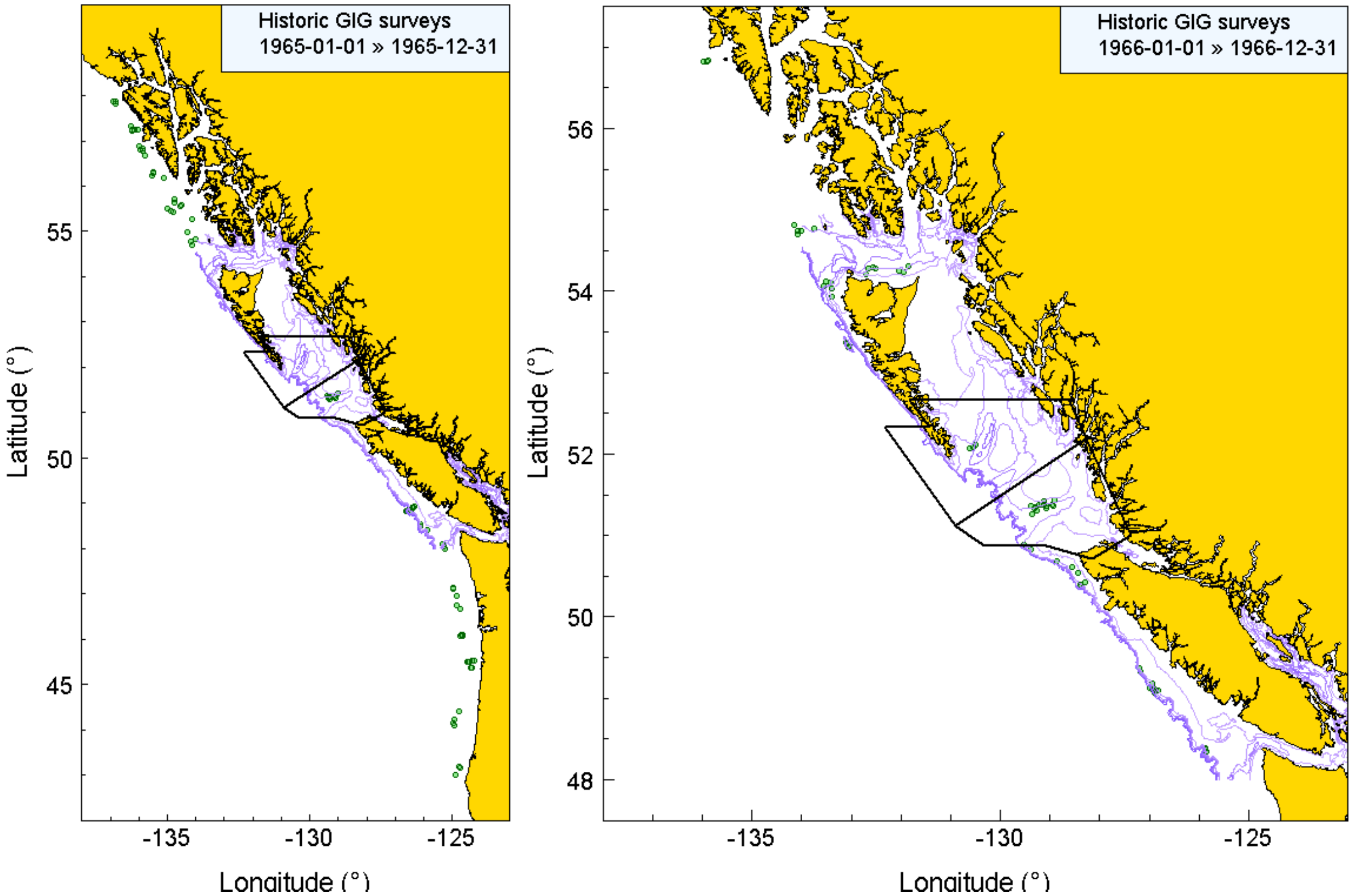


Figure C1. Extent of the first two GB Reed surveys: [left panel] tow locations for the 1965 survey; [right panel] tow locations for the 1966 survey.

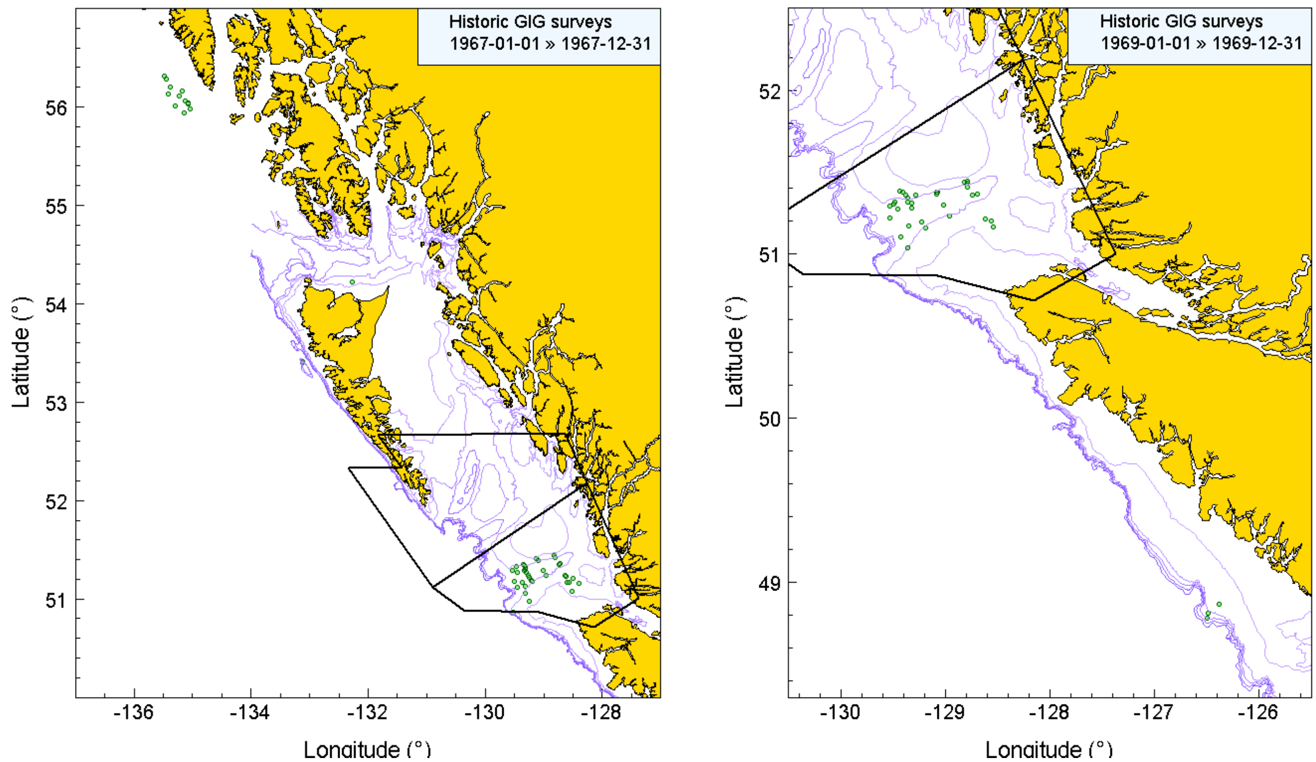


Figure C2. Extent of the next two historical GB Reed surveys. [left panel] location of tows from the 1967 survey; [right panel] location of tows from the 1969 survey.

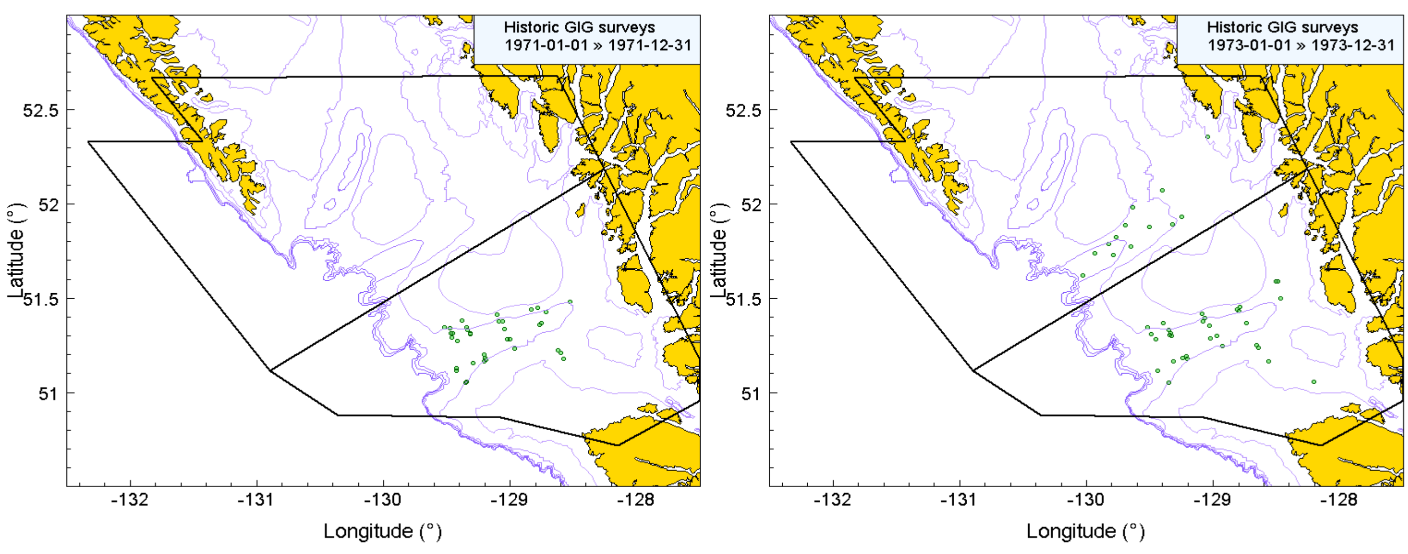


Figure C3. Extent of the following two historical GB Reed surveys. [left panel] location of tows from the 1971 survey; [right panel] location of tows from the 1973 survey.

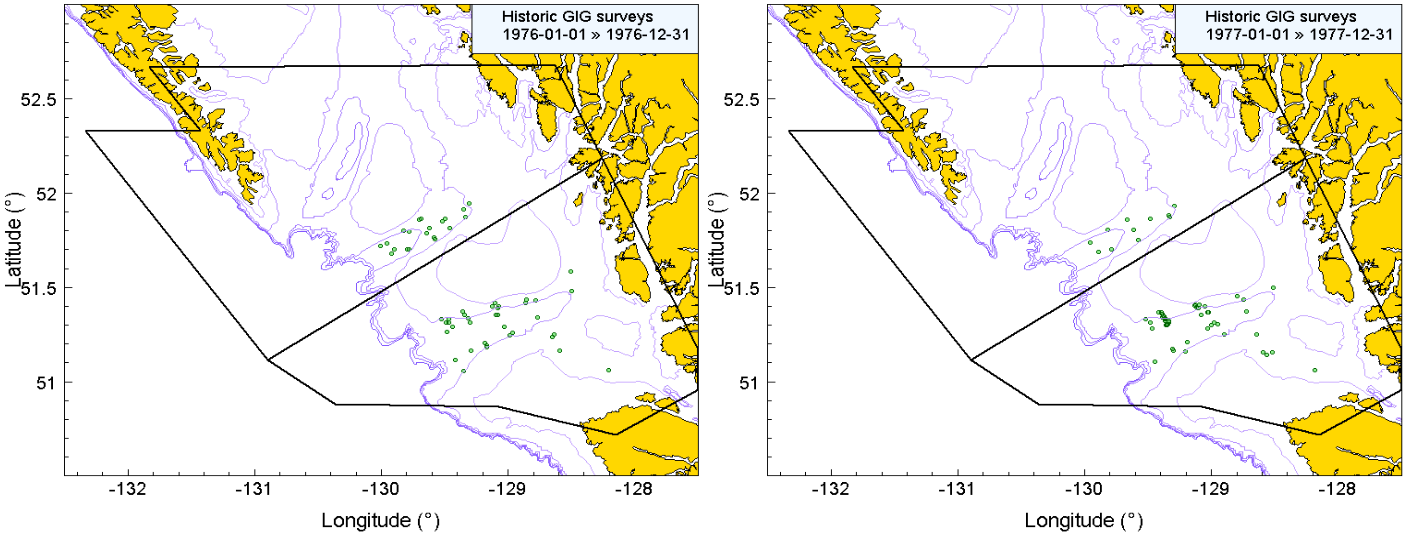


Figure C4. Extent of the following two historical GB Reed surveys. [left panel] location of tows from the 1976 survey; [right panel] location of tows from the 1977 survey.

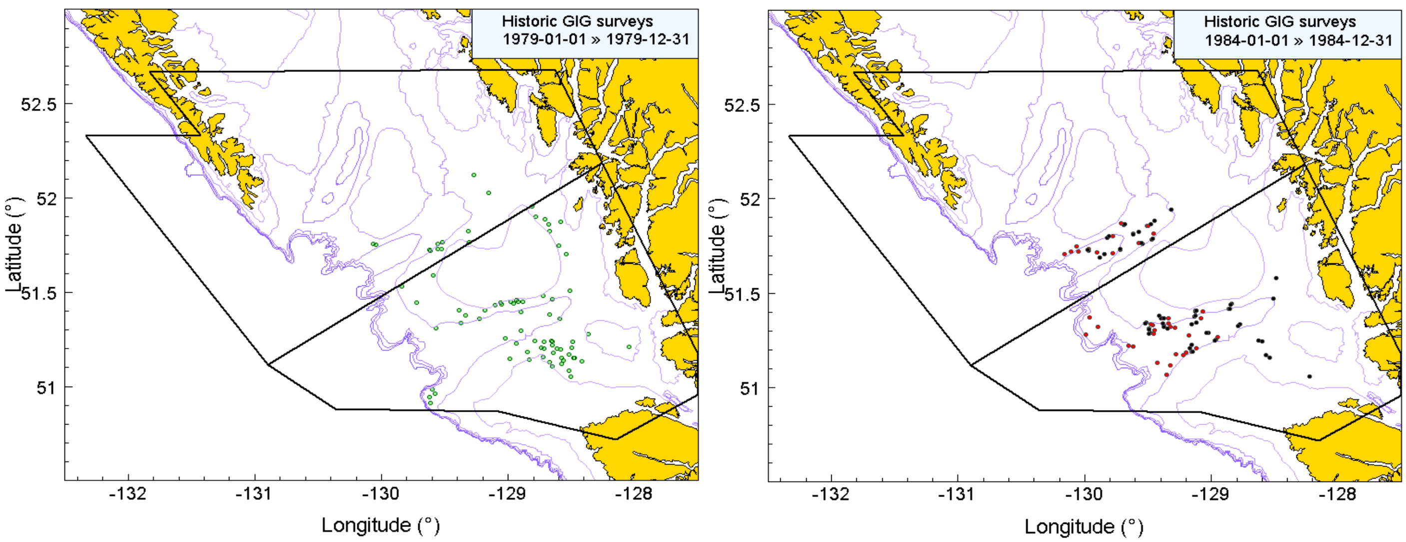


Figure C5. Extent of the following two historical GB Reed surveys. [left panel] location of tows from the 1979 survey; [right panel] location of tows from the 1984 survey (note: GB Reed tows are black and Eastward Ho tows are red).

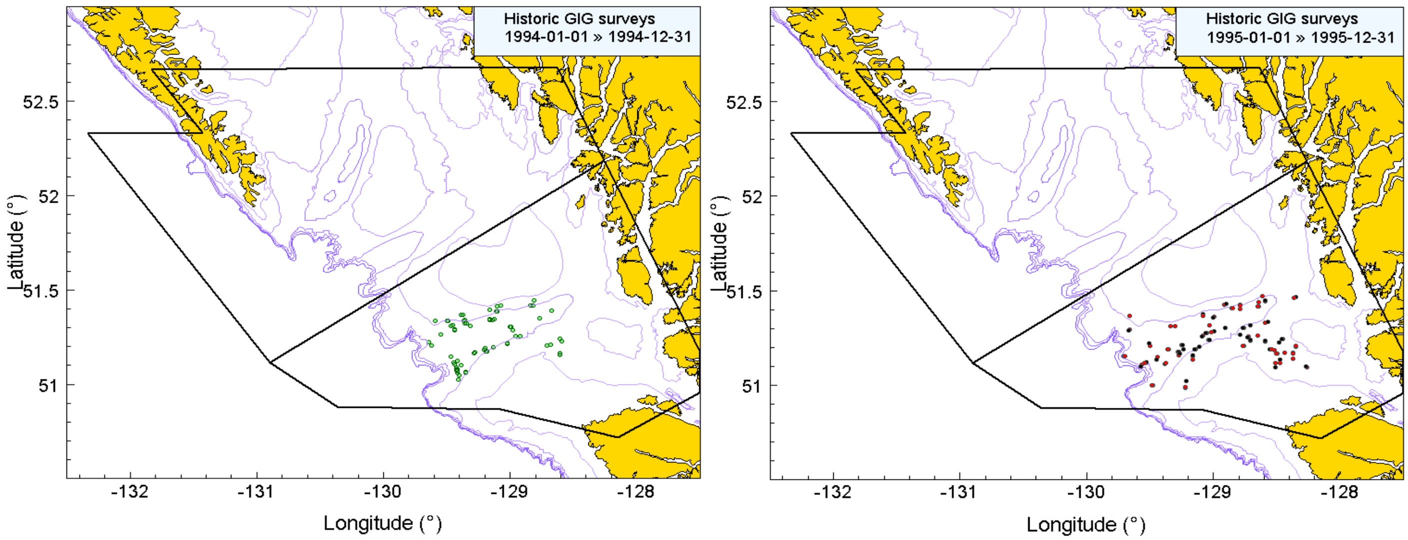


Figure C6. Extent of the final two historical GB Reed surveys. [left panel] location of tows from the 1994 survey; [right panel] location of tows from the 1995 survey (note: Ocean Selector tows are black and Frosti tows are red).

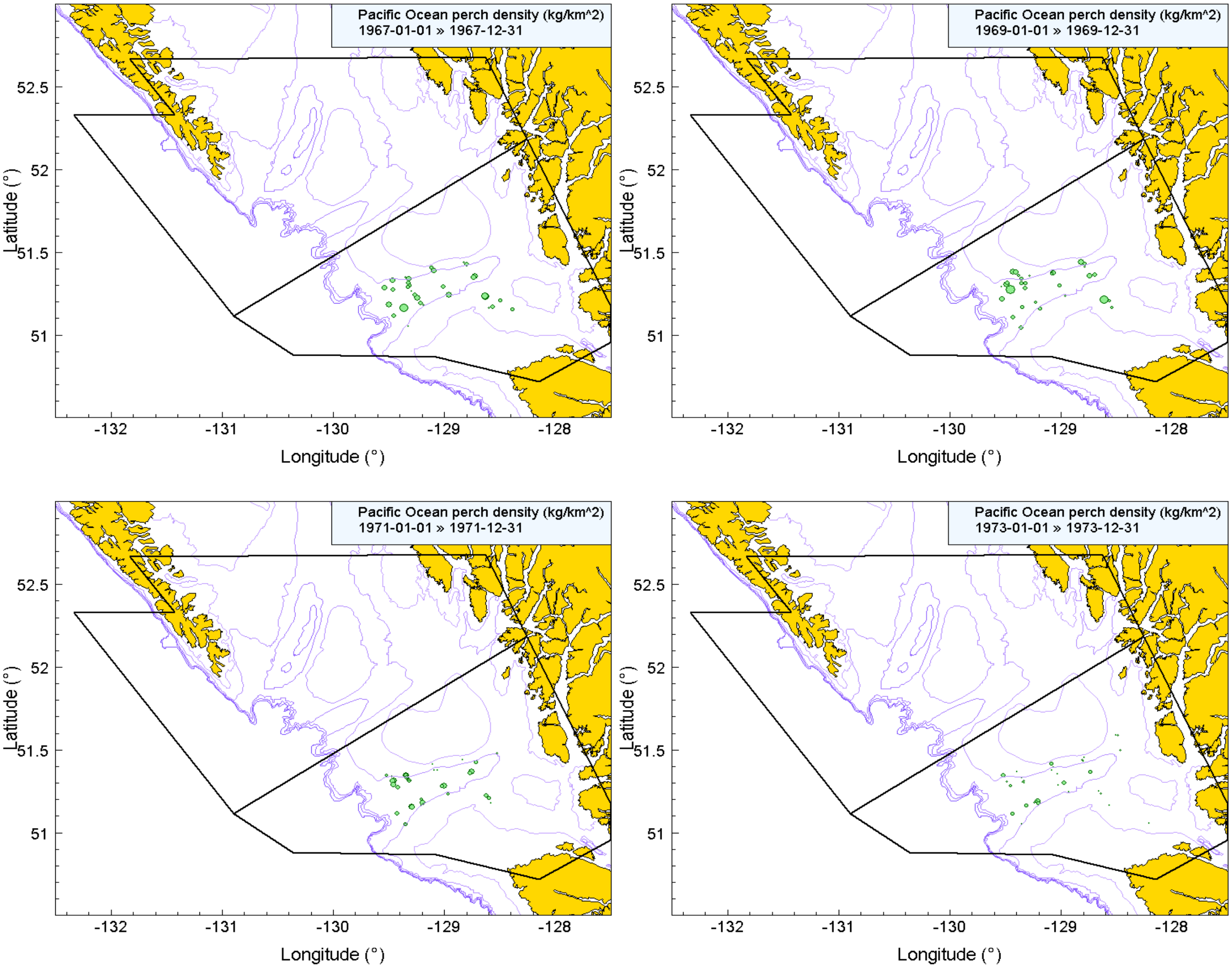


Figure C7. Map of the locations of all trawls which caught Pacific ocean perch from the historical Goose Island Gully trawl surveys by survey year (1967–1994). Circles are proportional to POP catch density (largest circle=30,731 kg/km^2 in 1976). Also shown are the 100, 200, 300 and 400 m isobaths. Lines indicate the stratum boundaries for the restratified QCS synoptic survey.

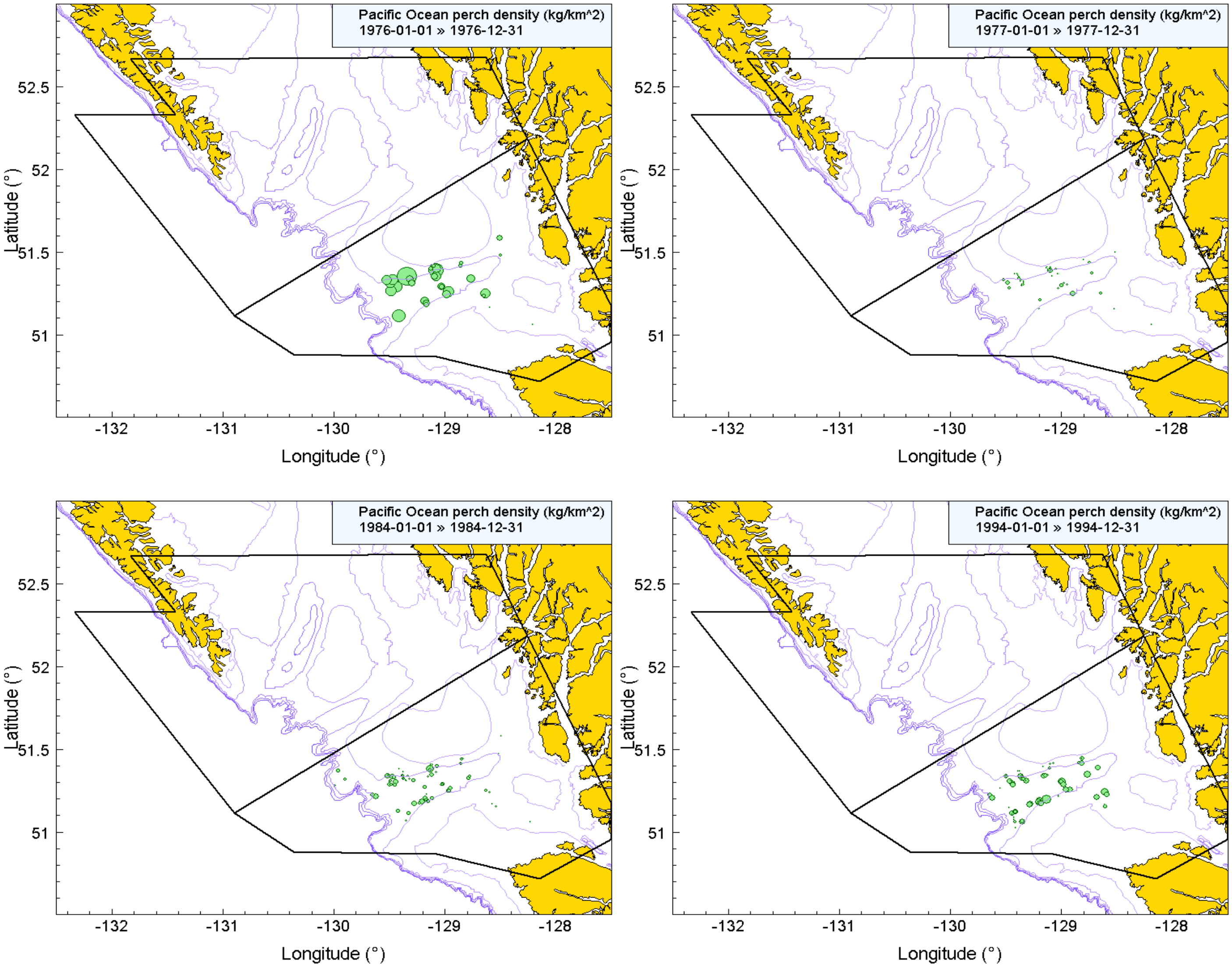


Figure C.7 (cont.).

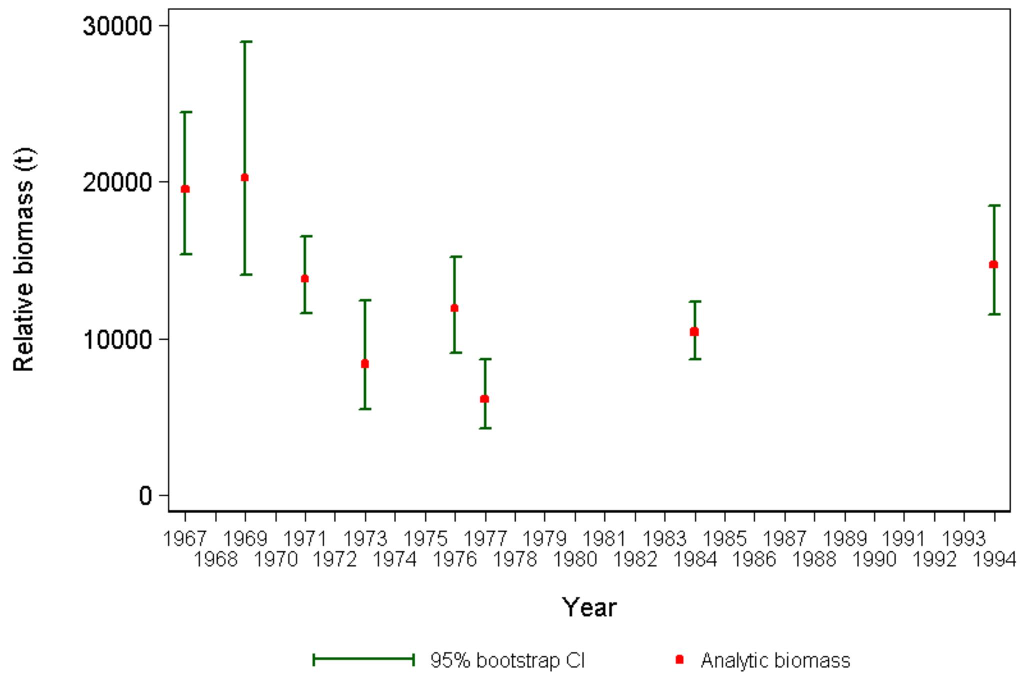


Figure C8. Plot of biomass estimates for Pacific ocean perch from the historical Goose Island Gully GB Reed trawl surveys for the period 1967 to 1994. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

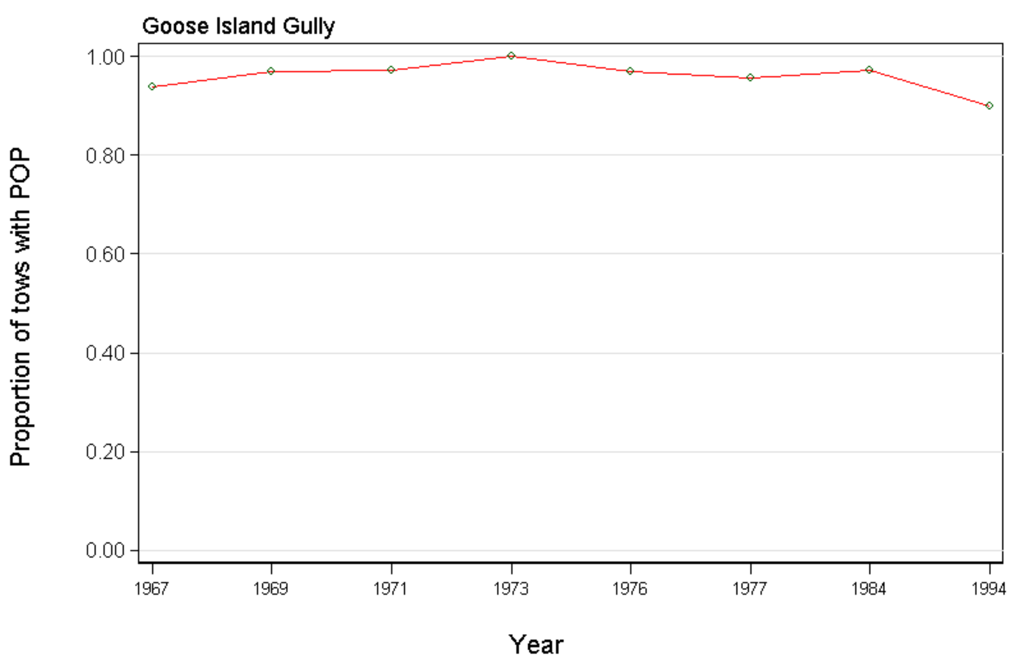


Figure C9. Proportion of tows by year which contain POP from the usable Goose Island Gully surveys.

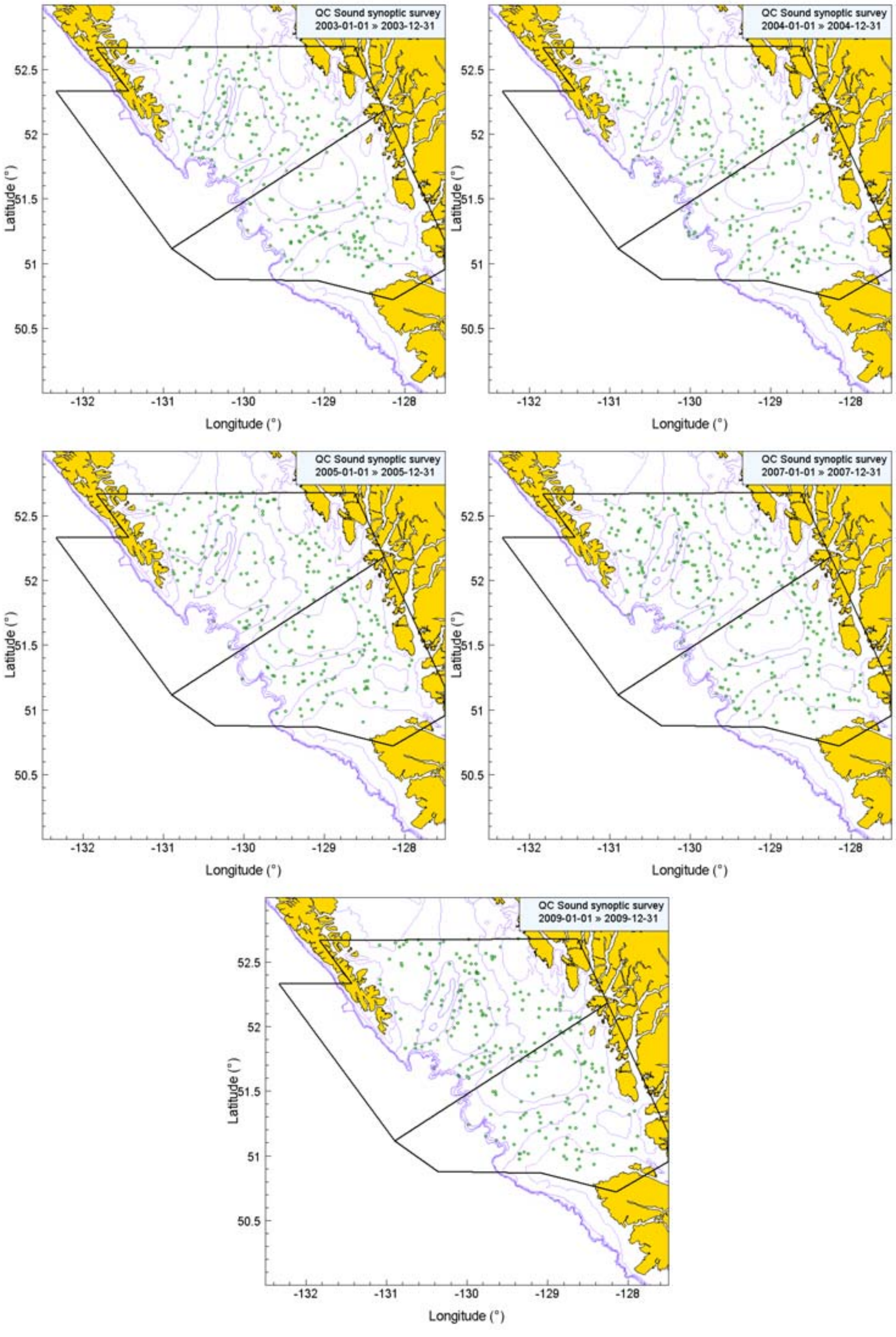


Figure C10. Map showing the locations of valid tows conducted by the QCS synoptic trawl survey over the period 2003 to 2009. The boundaries for the restratified POP stratum definitions (southern: Goose Island Gully and northern: combined Mitchell and Moresby Gullies) are shown.

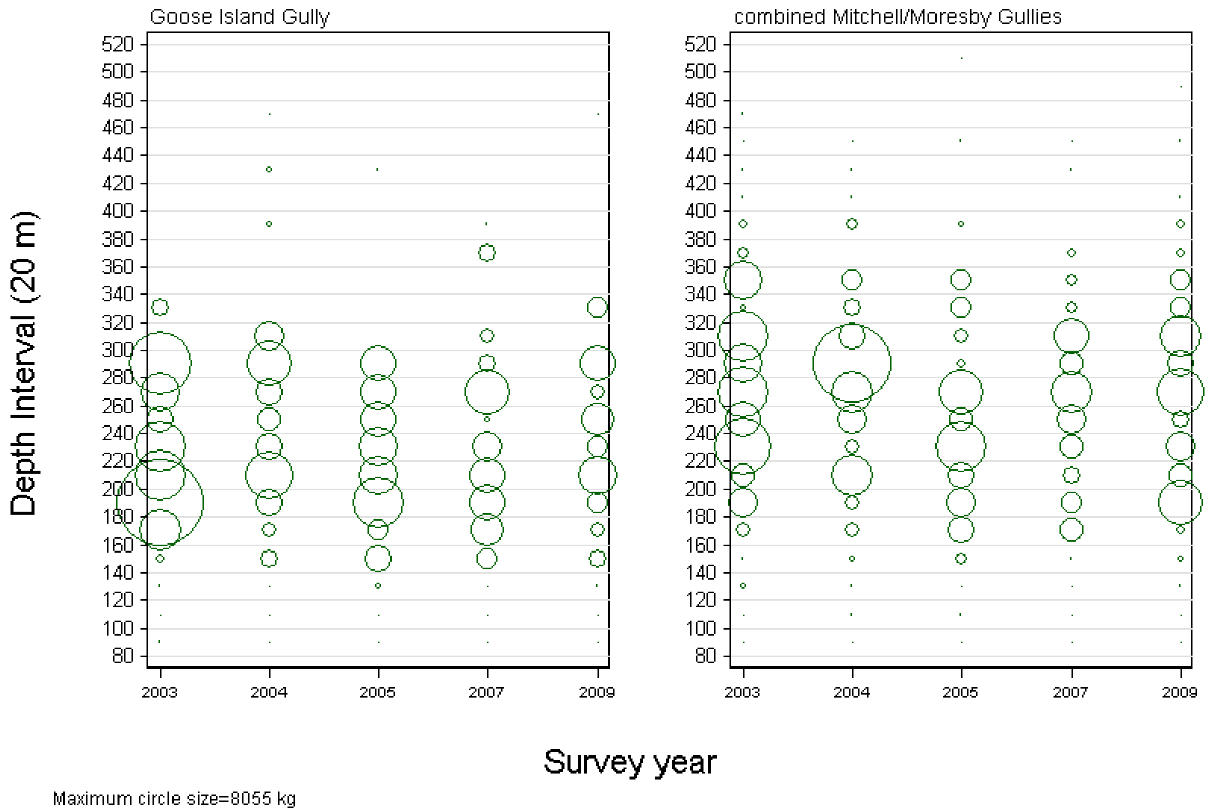


Figure C11. Distribution of observed catch weights of Pacific ocean perch by the two larger aerial strata (Table C6), survey year and 20 m depth zone. Depth zones are indicated by the mid point of the depth interval and circles in the panel are scaled to the maximum value in the GIG stratum (8055 kg: 180–200 m interval in 2003). Minimum depth observed for POP: 82 m; maximum depth observed for POP: 514 m. Depth is taken at the start position for each tow.

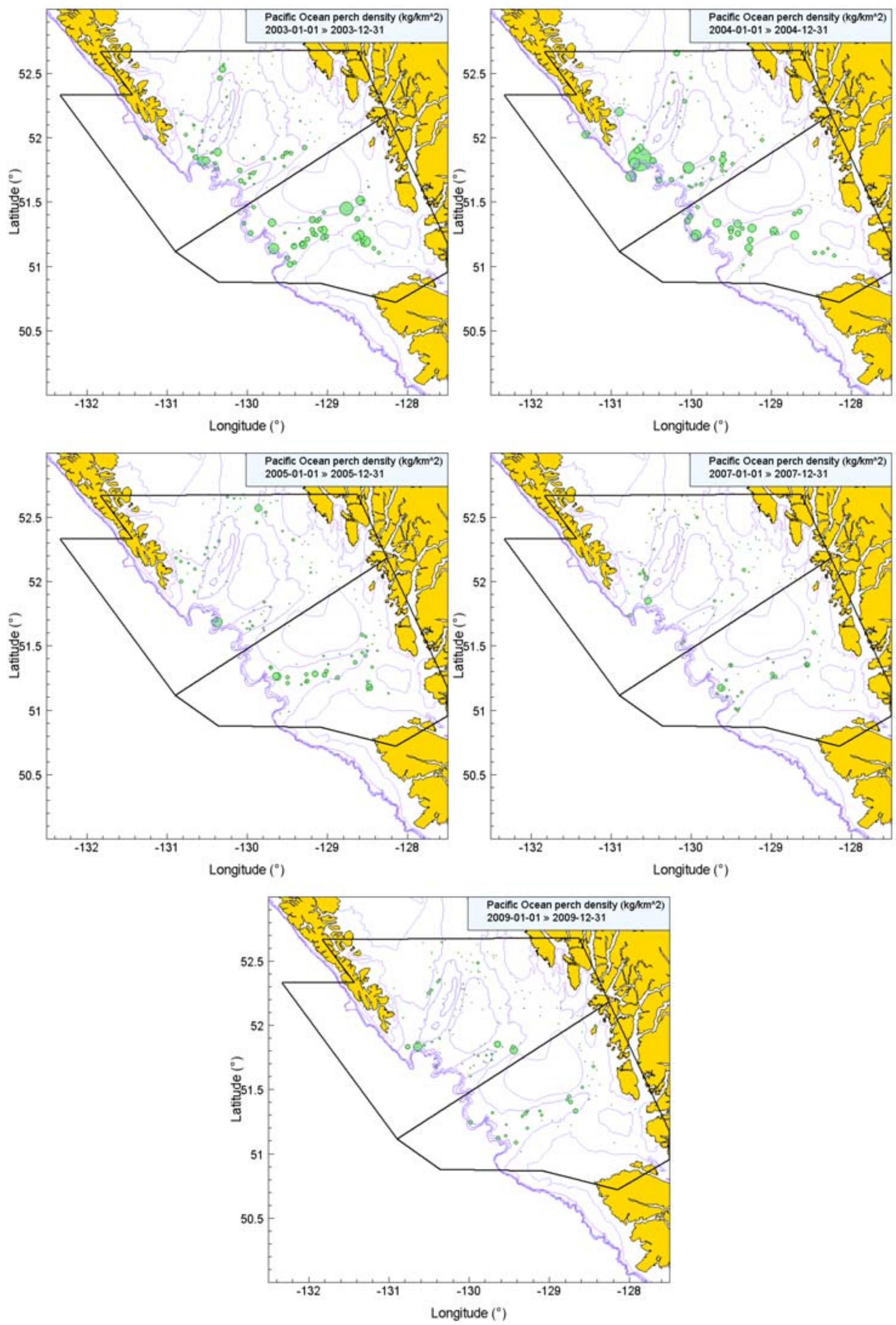


Figure C12. Map of the locations of tows by survey year from the QCS synoptic trawl survey (2003–2009) which caught Pacific ocean perch. Circles are proportional to catch density (largest circle=29 931 kg/km^2 in 2004). Also shown are the 100, 200, 300, 400 and 500 m isobaths and the POP restratified area stratum boundaries.

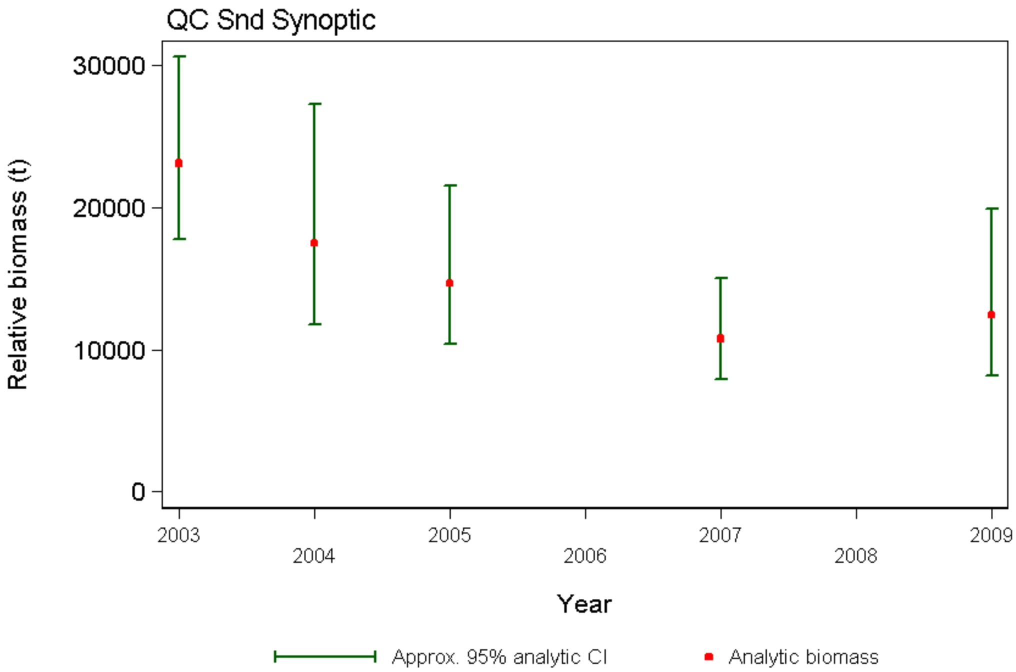


Figure C13. Plot of biomass estimates for POP from the QCS synoptic trawl survey from 2003 to 2009. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

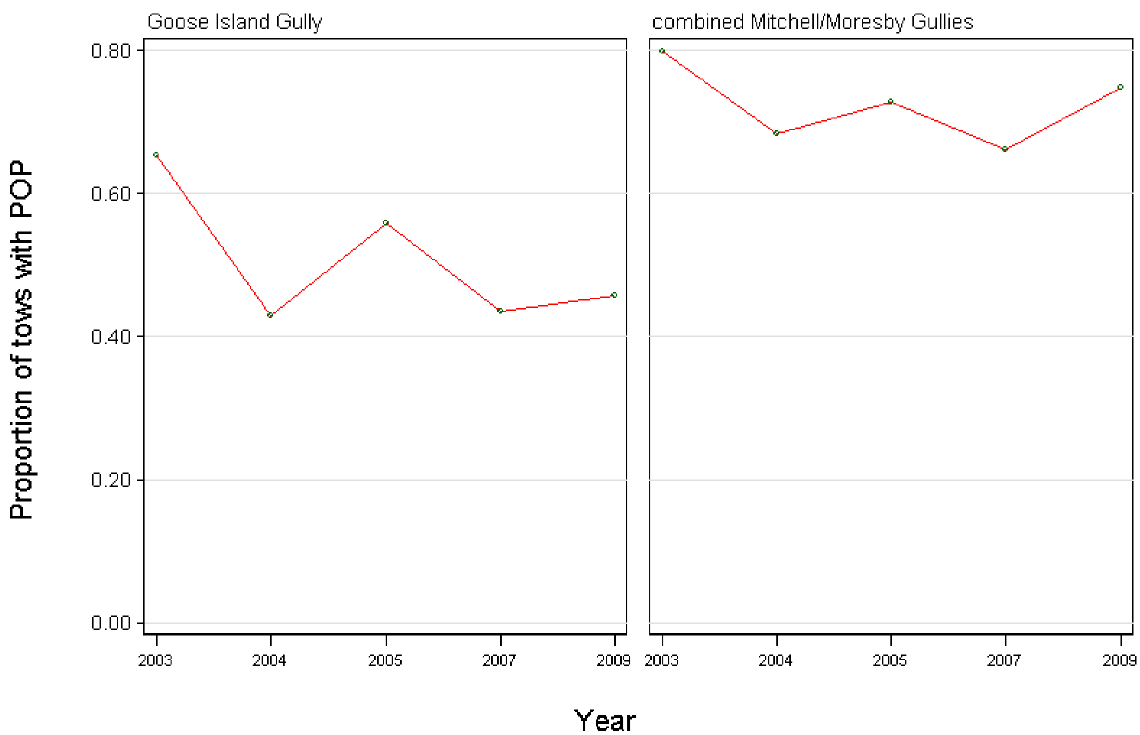


Figure C14. Proportion of tows by stratum and year which contain POP for the QCS synoptic trawl survey.

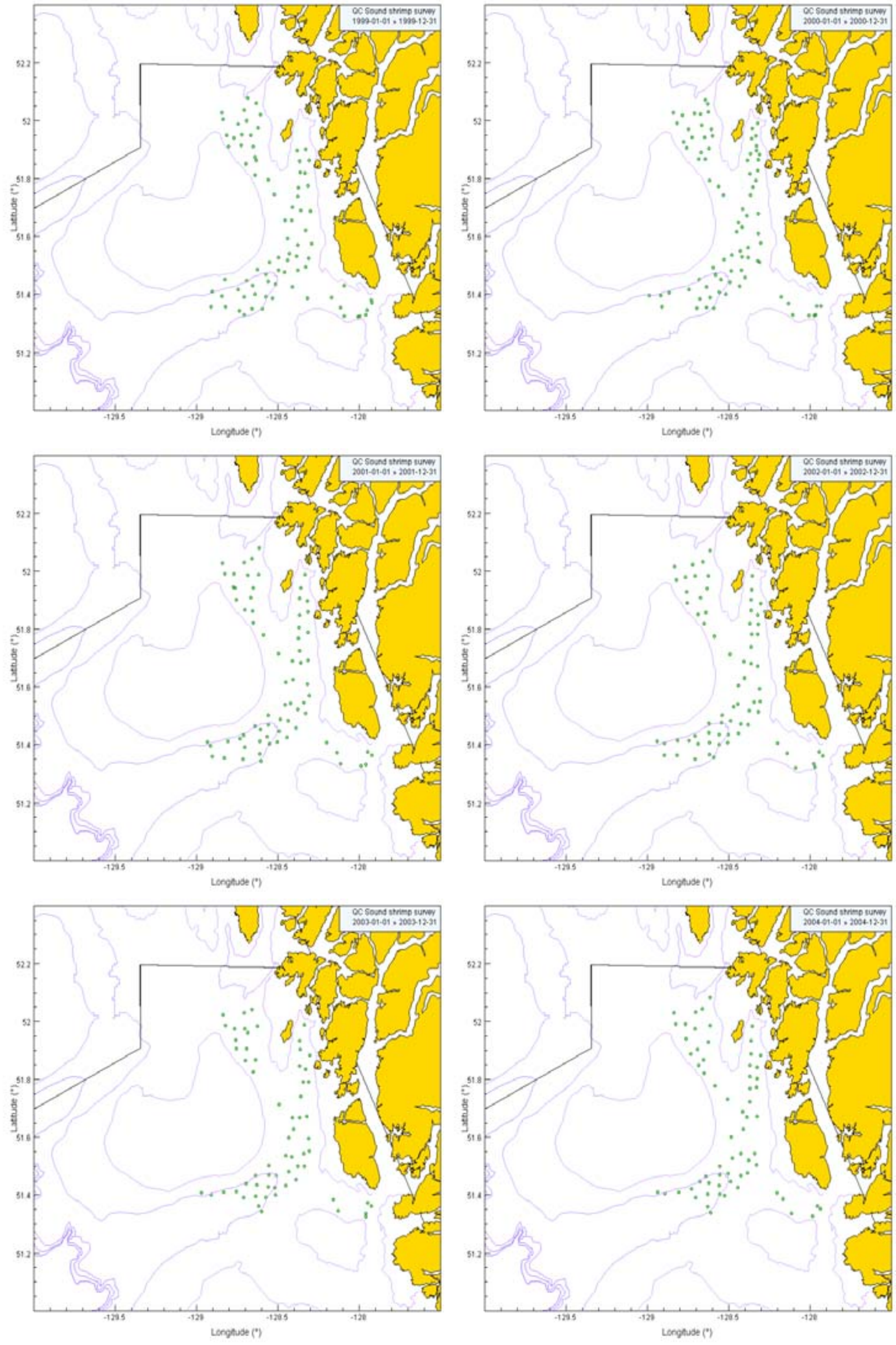


Figure C15. Maps showing the locations by survey year of valid tows (stratum numbers 109 and 110) conducted by the QCS shrimp survey over the period 1999 to 2010. Tows on the inside of Calvert Island (stratum 111) which were not used in the analysis of this survey for Pacific ocean perch have been omitted. Calvert Island is located at approximately 51.6° latitude by -128° longitude.

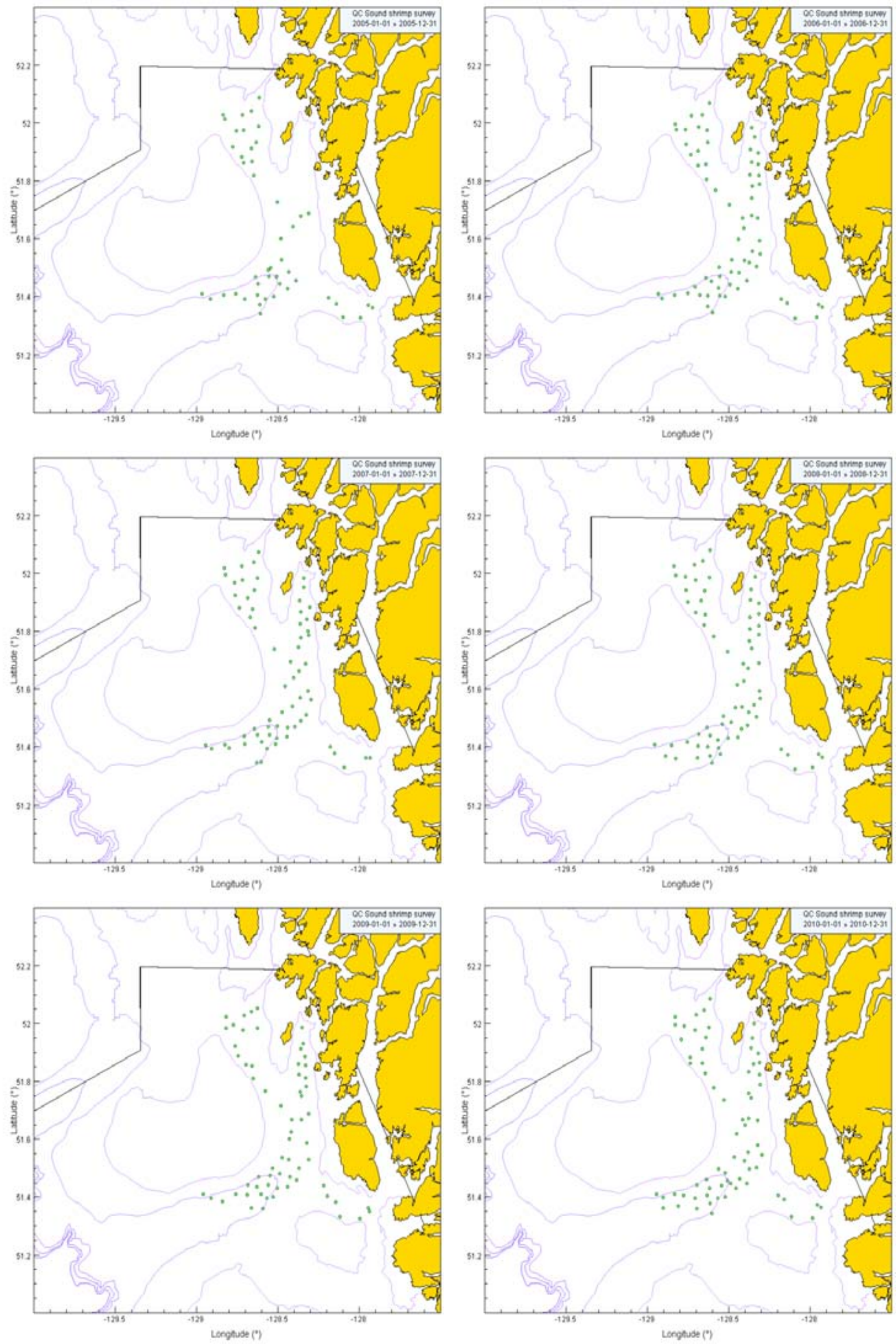


Figure C15. (cont.)

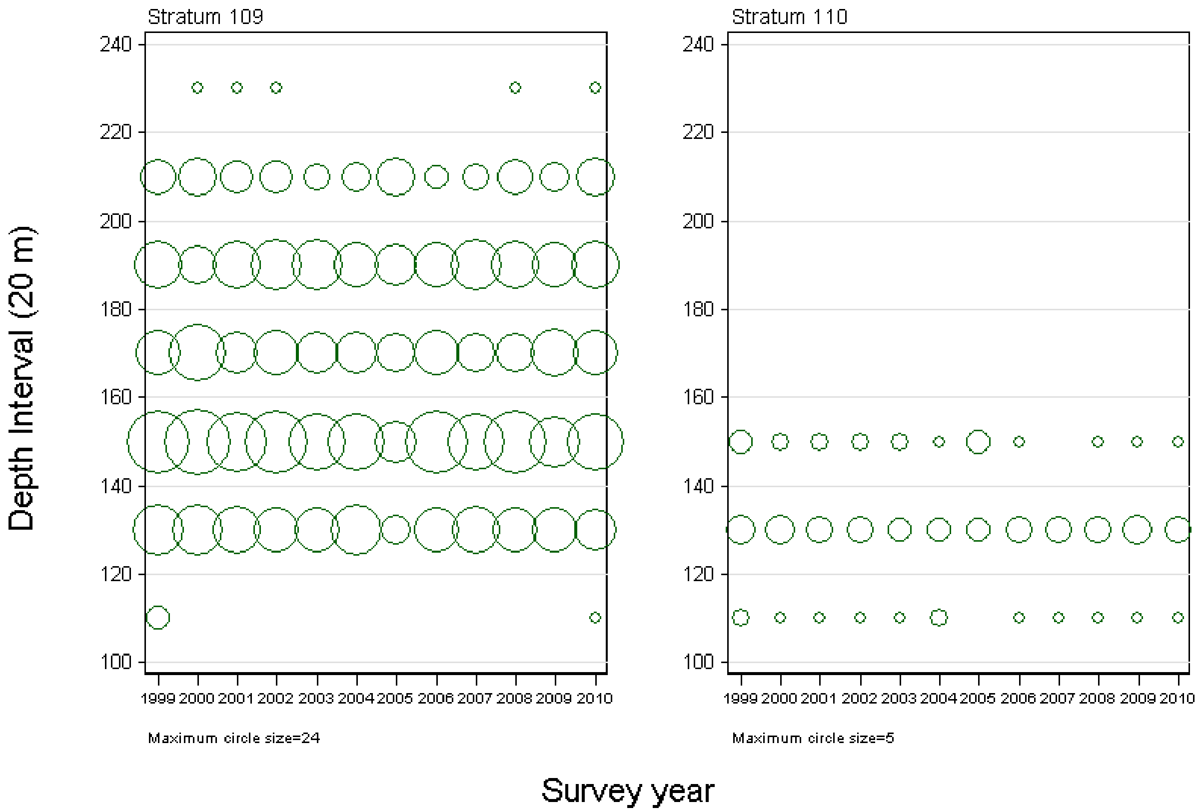


Figure C16. Distribution of tows by stratum, survey year and 20 m depth zone. Depth zones are indicated by the midpoint value of the depth interval, weighted by the number of tows. Depth is the start depth for the tow.

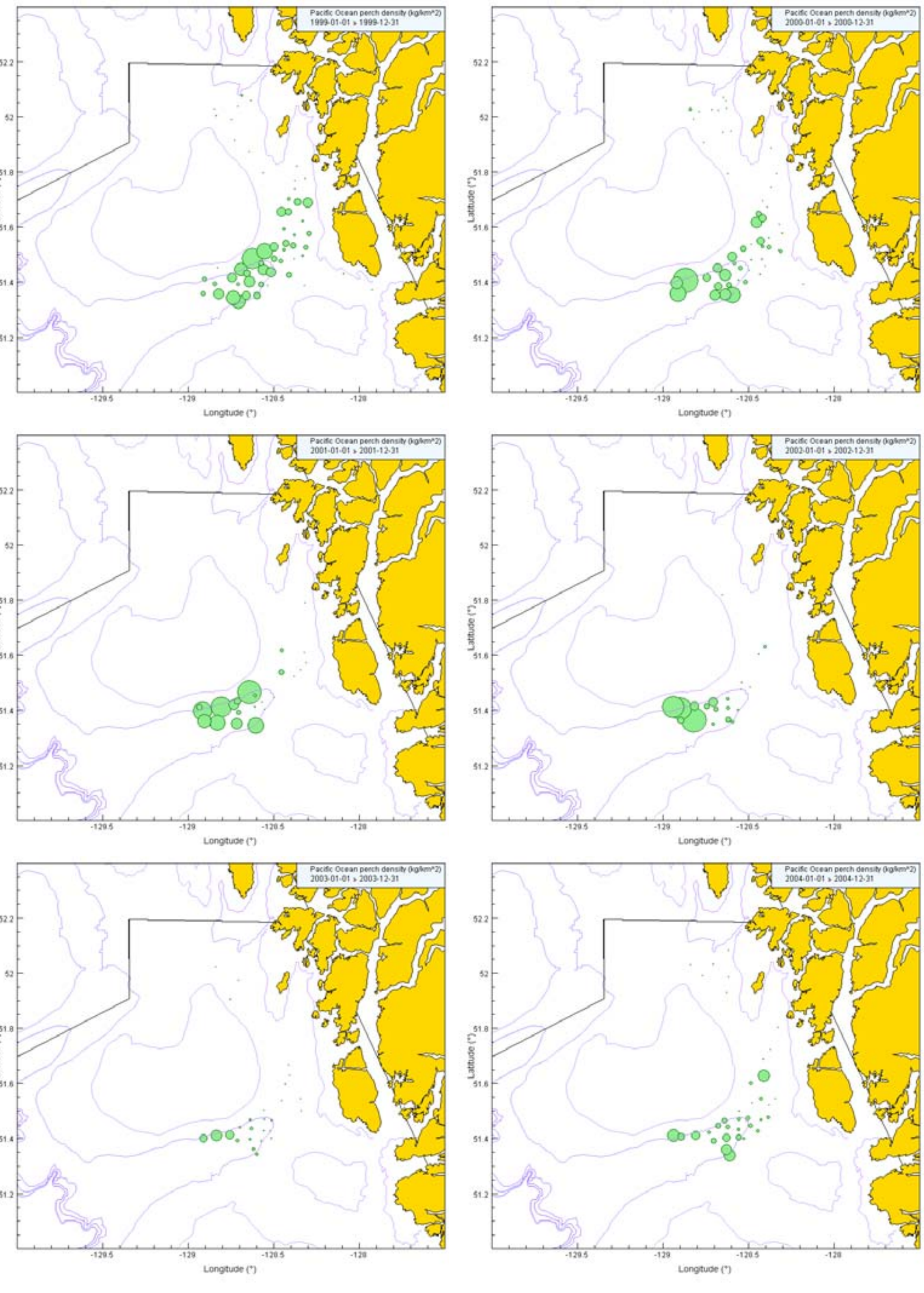


Figure C17. Map of the locations of all trawls from the QCS shrimp trawl survey (1999–2010) by survey year which caught Pacific ocean perch. Circles are proportional to catch density (largest circle=13 846 kg/km^2 in 2002). Also shown are the 100, 200 and 300 m isobaths and the area stratum boundary for the QCS synoptic survey.

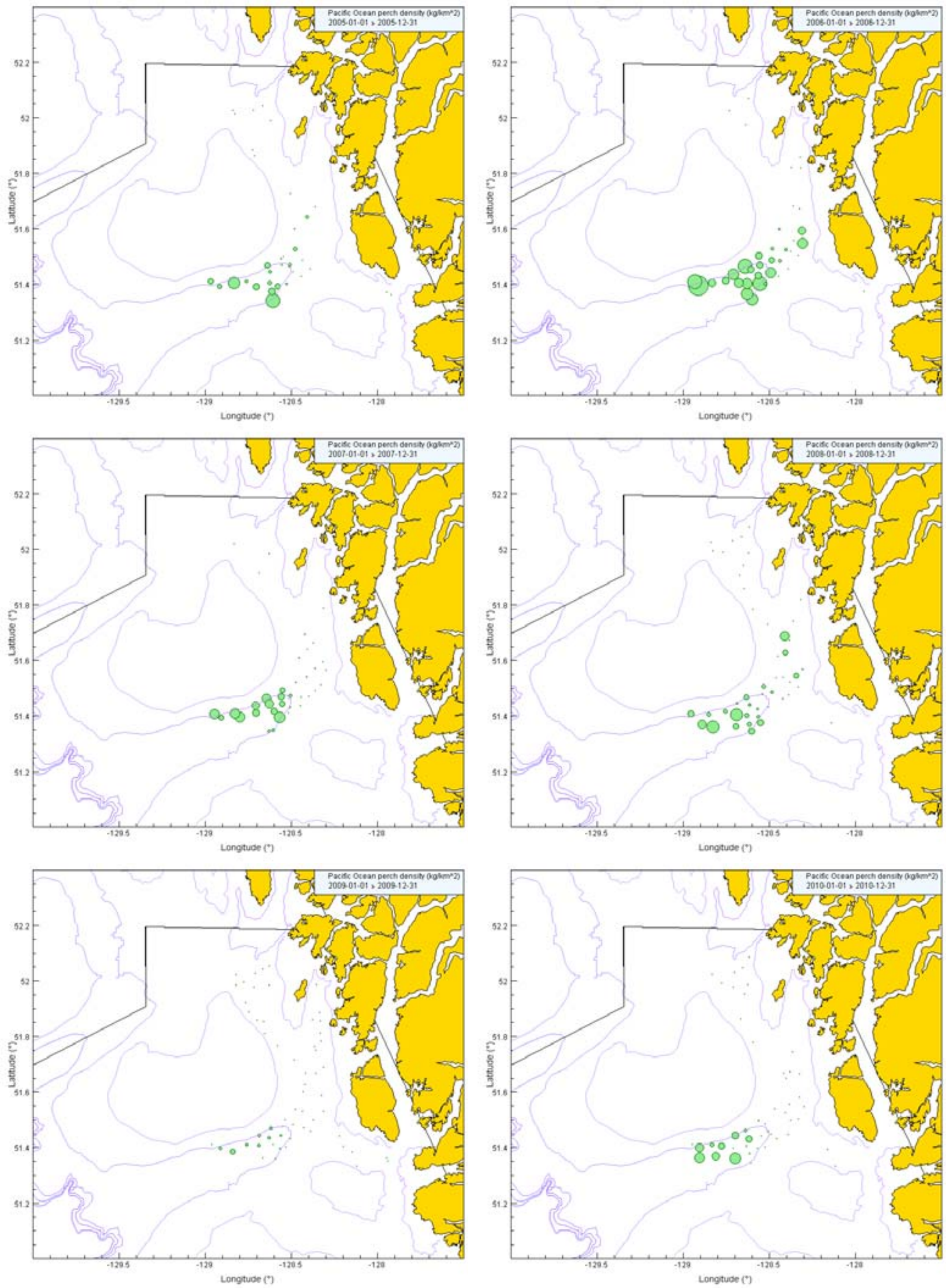


Figure C17. (cont.)

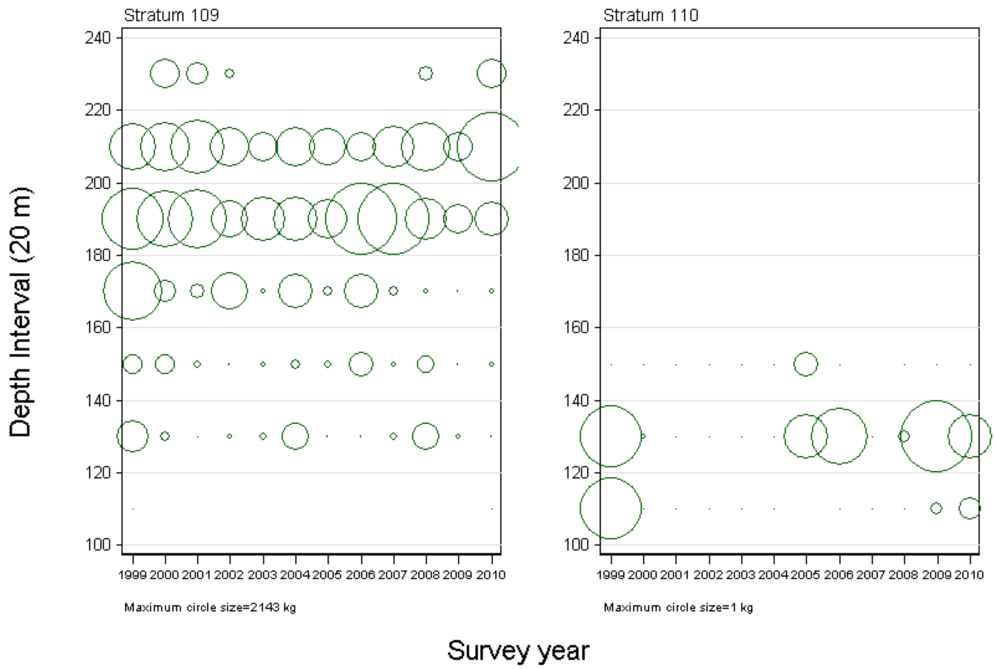


Figure C18. Distribution of catch weight of Pacific ocean perch by stratum (Table C9), survey year and 20 m depth zone. Depth zones are indicated by the centre of the depth interval. Maximum circle size: 2143 kg (180–200 m bin in 2007 in Stratum 109). Minimum depth observed for POP: 106 m; maximum depth observed for POP: 231 m. Depth is defined as the start depth for the tow.

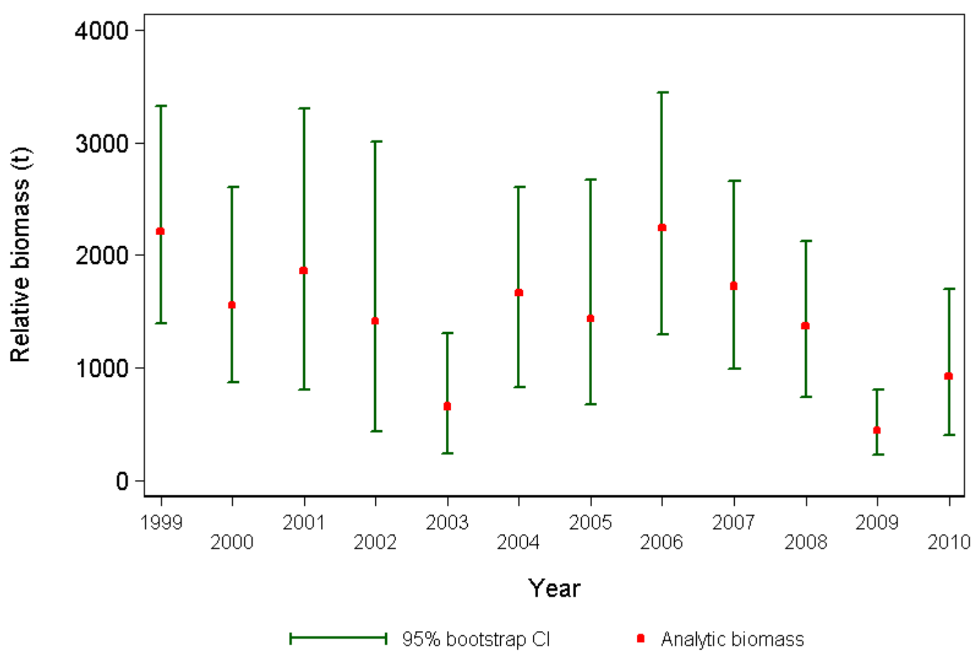


Figure C19. Plot of biomass estimates for Pacific ocean perch from the QCS shrimp trawl survey for 1999 to 2010. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

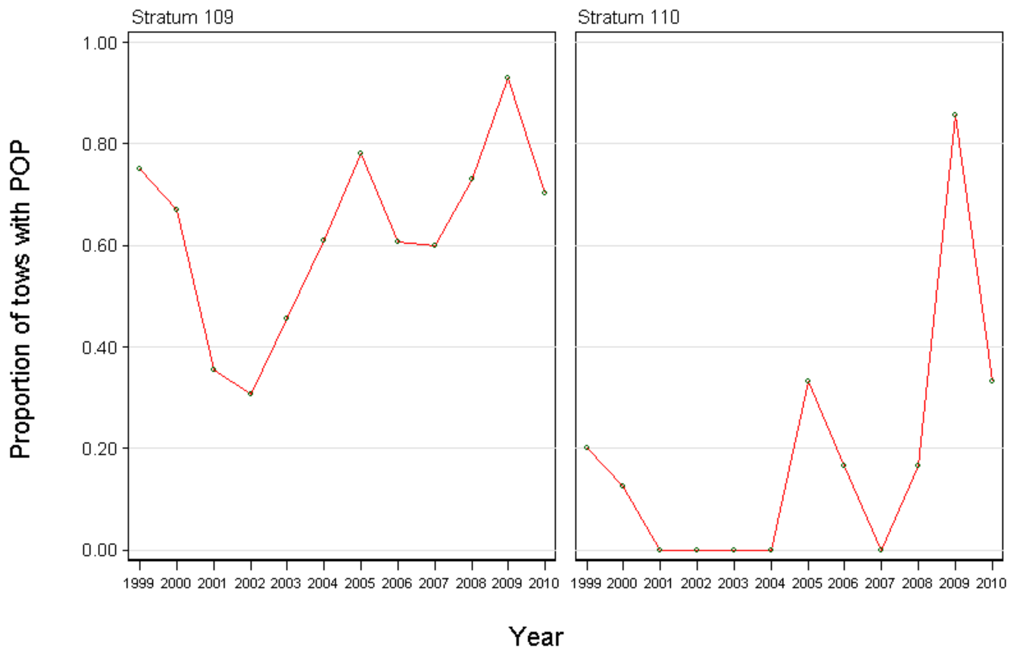


Figure C20. Proportion of tows by stratum and year which contain Pacific ocean perch for the QCS shrimp trawl survey.

APPENDIX D. BIOLOGICAL ANALYSES FOR PACIFIC OCEAN PERCH

ESTIMATION OF VON-BERTALANFFY GROWTH PARAMETERS

Methods

A non-linear von-Bertalanffy model was fit to age-length pairs categorised by sex and data origin (either research sampling, commercial sampling or both data sets combined) across five major Pacific ocean perch (POP) regions defined by Schnute et al. (2001). The regions selected included all data that could be reliably separated into the three known Queen Charlotte Sound POP populations (Goose Island Gully, Mitchell's Gully and Moresby Gully) (Table D1). Data from the west coasts of Vancouver Island and the Queen Charlotte Islands were also analysed. The purpose of the analysis was to investigate whether there are major differences in the estimated growth parameters between the areas for each sex. One outlier (length = 723 mm and age = 23) was removed and approximately 1,000 length/age pairs were corrected where the data were clearly in centimetres rather than the default millimetres. Only age records which were coded as having been determined by the break and burn method were included in the analysis.

The von-Bertalanffy model is:

Eq. D1 $L_{a,s} = L_{\infty,s}\left(1 - e^{-k_s\left(a - t_{0,s}\right)}\right)$

where $L_{a,s}$ = the average length (mm) of a sex s individual at age a,

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

k_s = the growth rate coefficient for sex s, and

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

Two sets of analyses were performed: the first used the appropriate age-length pairs as available in the database, under the assumption that the implicit weighting of these data is appropriate for estimating these models. The second approach was to calculate a mean length at each age and then fit the model in Eq. D1, effectively assigning equal weight to each age. Each of these approaches were then compared across the available area, data origin and sex combinations.

The above analysis was performed on the age-length data available in 2008 and was directed at detecting whether there were regional differences in POP growth rates. Additional age-length observations became available in 2009 and the growth rates were re-estimated for the assessment. Based on the 2008 analysis, research and commercial age-length pairs from PMFC areas 5A, 5B, 5C, and 5E were combined across all available years to estimate growth parameters for the assessment (Table D3).

Results

The number of age-length data pairs available by year, sex, data origin and area are presented in Table D1. The parameter estimates for each area, sex and data type combination are summarised in Table D2. The results in this table indicate that the differences between areas are relatively small and those that exist are probably due to data issues rather than reflecting actual differences in growth rates among the five areas. The largest difference is between the sexes, with females consistently having a larger $L_{\infty,s}$ than observed for males by approximately 30-40 mm, across all areas and data types. Parameter estimates for research data from Mitchell's Gully appear to be different than those from Goose Island or Moresby gullies, but this difference disappears when only the fishery data are used or when the two data types are combined (Table D2).

Plots have been prepared which compare the growth models across data origin and sex for each analysis type (unweighted or one observation per age). Model differences between the two data origin types appear to occur at either the lower or upper ends of the growth curve, indicating the observed model differences are likely to be caused by the relative amount of data available (Figure D1). There appears to be little qualitative difference between the two model weighting assumptions, particularly when the research and fishery data are combined to give a broader range of available data to fit the model (Figure D2). Finally there appears to be little difference among the models fitted to the five areas, including model fits to data originating north and south of Queen Charlotte Sound (Figure D3).

The 2008 analysis determined that there was little sensitivity to combining age-length pairs from research and commercial sources. It also determined that there was little difference whether an unweighted analysis was performed or whether each age class was given equal weight. All age-length pairs available in 2009 from combined PMFC areas 5A, 5B, 5C and southern 5E (Anthony Island) (herein called 5ABCE) from research and commercial age samples (Table D3) were used to estimate the assessment growth parameters. The analyses were repeated by sex across a range of maximum ages, showing very little sensitivity to this variation (Table D4). The parameters obtained for a maximum age of 50 were used in the stock assessment.

ESTIMATION OF LENGTH-WEIGHT PARAMETERS

Methods

A model was fit to length-weight pairs from 5ABCE categorised by sex without regard for year or data origin. The model was fit twice, first using all data and the second dropping length-weight pairs with standardised (Pearson) residuals that were greater than 4. This was done to eliminate large outliers, most likely the result of data errors.

The parameterisation of the length-weight model used in the stock assessment is:

Eq. D2 $W_{s,i} = a_s \left(L_{s,i}\right)^{b_s}$

where $W_{s,i}$ = the observation of weight (kg) of individual i of sex s,

$L_{s,i}$ = the observation of length (cm) of individual i of sex s,

a_s = the growth rate scalar for sex s, and

b_s = the growth rate exponent for sex s.

The above model was fitted as a linear regression to the logged length and weight pairs. The resulting estimate for $\log\left(a_s\right)$ was then exponentiated to provide the a_s parameter for use in the stock assessment.

Results

The model fit the available length-weight pairs very well, without any apparent trend to the standardised residuals with predicted weight (Figure D4). The number of available observations are close to or above 3,000 for each sex, resulting in highly significant parameter estimates (Table D5). The fixed parameter estimates used to describe allometric growth in the stock assessment model are provided in Table D6.

ESTIMATION OF PROPORTION OF MATURE FEMALES BY AGE FOR 5ABCE POP

This analysis was based on all "staged" (examined for maturity status) females in the DFO GFBio database from PMFC areas 5ABCE that had also been aged using the break and burn method, regardless of sample origin. This selection resulted in just over 21,000 observations (Table D7). Only females sampled from January to June were used in creating the maturity curve because these months contained the majority of spawning and spent females (Table D8). As well, the proportion of immature fish started to rise in July concurrently with a drop in the proportion of spent fish, likely signalling the completion of spawning. The proportion of mature females at each age with at least 10 observations was calculated (thereby dropping ages 1 and 2, which were assumed to be 100% immature) by assuming that stage 1 and 2 females were immature and that the remaining staged females would spawn or had spawned in that year (Table D9). A double-normal function (similar to Equation F.7) was fitted to the observed proportions mature at age to smooth the observations to obtain an increasing monotonic function for use in the stock assessment model (Figure D5). Following the procedure adopted by Stanley et al. (2009) for canary rockfish, the observed proportions were used for ages less than nine because the fitted line appeared to overestimate the proportion of mature females(Figure D5). The maturity ogive used in the stock assessment model was based on the observed proportions of mature females from ages 3 to 8 and then switched to the fitted monotonic function for ages 9 to 23, after which it was assumed that all females were mature (Table D9). The only function of this ogive is to calculate the spawning biomass used in the Beverton-Holt stock recruitment function and is treated as a constant known without error.

PREPARATION OF AN INFORMED PRIOR FOR THE SURVEY SELECTIVITIES

Preliminary model runs determined that it was not necessary to use an informed prior for the commercial selectivity parameters estimated in the assessment. This was because the parameter estimates were insensitive to an informed prior and found the same estimates when a uniform prior was used. This was not the case for the survey selectivity parameters, particularly the QCS shrimp survey which had no available usable age data.

A published assessment is available for the Gulf of Alaska POP (Hanselman et al. 2007, 2009). This assessment provides values for the proportion selected by age for the survey that is used to monitor this stock. A double normal curve (Figure D6) was fitted to these estimates (similar to Equation F.7) to obtain prior values for the parameterisation used by the Coleraine/Awatea software (Table D10). These values became the mean of the informed Gaussian priors used in the model fitting procedure along with an arbitrary 30% CV. The GOA assessment combined males and females so the prior for the $\Delta_g \left(g = 1 \text{ to } 3\right)$ parameter was arbitrarily set equal to 0 with a CV=1.0. Note that the QCS shrimp survey selectivities used these prior values as fixed parameters because the selectivities for this survey could not be reliably estimated.

Table D1. Distribution of available age-length pairs for Pacific ocean perch (POP) by calendar year, sex and data origin for 5 regions: west coast Vancouver Island (WCVI), Goose Island Gully (GIG), Mitchell's Gully (MI), Moresby Gully (MR) and west coast Queen Charlotte Islands (QCI)

	Males					Females				
	WCVI	**GIG**	**MI**	**MR**	**QCI**	**WCVI**	**GIG**	**MI**	**MR**	**QCI**
Research observations (includes both DFO and research charters)										
1979	902				145	994				195
1981	49			130		148			70	
1982	107	214	1	264	215	230	230	6	239	252
1983					246					328
1984		950	271				1,023	233		
1985	406	244		121	212	456	349		230	424
1989	137	135	134	358	175	205	164	166	386	267
1993					571					480
1994		315					534			
1995	111	150				54	250			
1996	278				1,009	399				858
1997				39	250				36	294
1999		194	79				179	88		
2003		136	60	138			92	63	138	
2004		148	33	169			129	47	104	
2005		223	116				167	120		
Total	1,990	2,709	694	1,219	2,823	2,486	3,117	723	1,203	3,098
Commercial observations (all from at-sea observers)										
1996			11					9		
1997		47			49		68			39
1998	64	125		72		83	160		97	
1999	93	103		45	22	107	167		78	21
2000	89	167	52	131	21	53	124	54	143	28
2001	188	205	117	211	49	211	149	171	273	112
2002	189	95	15	194	72	89	109	17	273	88
2003	36	161	71	133	28	75	181	51	248	36
2004	106	101	27	201	45	92	107	13	222	84
2005		192	58	110			225	94	166	
2006	7	97	20	149		26	130	40	63	
Total	772	1,293	371	1,246	286	736	1,420	449	1,563	408
Combined research and commercial samples										
Total	2,762	4,002	1,065	2,465	3,109	3,222	4,537	1,172	2,766	3,506

Table D2. Summary of parameter estimates by sex for all areas (see Table D1 caption for area codes), data types and weighting assumptions for valid age-length pairs from 1977–2006. '–': sex/area/data type estimate not made

		Male			Female		
Area	**Parameter**	**Research**	**Fishery**	**Combined**	**Research**	**Fishery**	**Combined**
One observation for each age class							
GIG	$L_{\infty,s}$	409.9	421.8	412.6	446.6	454.9	447.3
	k_s	0.174	0.114	0.170	0.149	0.122	0.147
	$t_{0,s}$	-0.937	-5.308	-1.014	-1.062	-2.369	-1.119
MI	$L_{\infty,s}$	396.4	419.5	400.6	428.1	451.6	435.2
	k_s	0.187	0.132	0.188	0.178	0.130	0.166
	$t_{0,s}$	-0.835	-4.024	-0.808	-0.276	-1.876	-0.467
MR	$L_{\infty,s}$	416.8	421.9	417.9	440.6	446.9	443.5
	k_s	0.164	0.122	0.182	0.154	0.147	0.158
	$t_{0,s}$	-0.876	-6.834	-0.498	-0.759	-1.592	-0.668
Unweighted data set							
WCVI	$L_{\infty,s}$	–	–	402.9	–	–	441.2
	k_s	–	–	0.171	–	–	0.148
	$t_{0,s}$	–	–	-2.453	–	–	-2.023
GIG	$L_{\infty,s}$	405.9	415.3	407.5	447.1	452.2	448.3
	k_s	0.186	0.135	0.182	0.147	0.128	0.142
	$t_{0,s}$	-0.739	-3.742	-0.818	-1.182	-1.968	-1.330
MI	$L_{\infty,s}$	396.5	414.9	401.3	429.2	450.1	435.0
	k_s	0.204	0.145	0.202	0.174	0.119	0.164
	$t_{0,s}$	-0.249	-3.280	-0.299	-0.381	-3.269	-0.616
MR	$L_{\infty,s}$	414.3	423.1	414.6	443.3	452.4	445.0
	k_s	0.186	0.113	0.202	0.165	0.116	0.160
	$t_{0,s}$	-0.081	-7.888	0.030	-0.150	-4.438	-0.573
QCI	$L_{\infty,s}$			412.9			440.5
	k_s			0.177			0.174
	$t_{0,s}$			-1.439			-0.520

Table D3. Distribution of available age-length pairs for POP by calendar year, sex and four PMFC regions for the analysis used to estimate the von-Bertalanffy parameters used in the assessment:

	Males					**Females**				
Year	**5A**	**5B**	**5C**	**5E**	**Total**	**5A**	**5B**	**5C**	**5E**	**Total**
1977		157			157		149			149
1978		253	127		380		258	71		329
1979		433	224		657		460	72		532
1980		820	442		1,262		664	317		981
1981	109	130	208		447	40	270	142		452
1982		899	383		1,282		602	493		1,095
1983	27	141	18		186	73	159	32		264
1984	322	1,344	17		1,683	366	1,342	33		1,741
1985	168	572	75		815	182	701	146		1,029
1986		56	138		194		37	162		199
1987		716	131		847		534	121		655
1988		390	32		422		258	16		274
1989		607	129	81	817		638	67	115	820
1990	31	214	67		312	25	250	56		331
1991	49	167	41		257	101	151	39		291
1992	46	214	50		310	79	231	55		365
1993	63	206	80		349	90	115	45		250
1994	118	626	44		788	197	685	43		925
1995	90	261	41		392	162	409	47		618
1996	7	223	58		288	12	268	43		323
1997	87	260		29	376	91	307		21	419
1998	121	281	102		504	166	279	102		547
1999	80	488	100		668	128	552	117		797
2000	79	483	100		662	30	473	16		519
2001	42	474	127	19	662	68	513	137	73	791
2002	14	425	78	61	578	33	337	110	111	591
2003	77	482	84	83	726	118	449	93	132	792
2004	115	516	54	24	709	100	489	33	37	659
2005	208	552	175		935	274	601	178		1,053
2006	36	237			273	88	171			259
2007	98	527	165		790	146	647	154		947
2008	12	188			200	19	163			182
2009		90	15		105		49	9		58
Total	1,999	13,432	3,305	297	19,033	2,588	13,211	2,949	489	19,237

Table D4. Von-Bertalanffy model (Eq. D1) parameter estimates from the age-length pairs summarised in Table D3. Growth estimates were made based on the mean length at each age, extending from age 3 to the maximum age indicated in each row of the table. Parameters shaded grey were used in the 2010 POP stock assessment for combined areas 5ABC.

Max Age	Parameter estimate			Standard error (SE)		
	$L_{\infty,s}$	k_s	$t_{0,s}$	$\mathrm{SE}(L_{\infty,s})$	$\mathrm{SE}(k_s)$	$\mathrm{SE}(t_{0,s})$
Males						
age30	411	0.184	-0.643	0.139	0.006	0.158
age40	414	0.174	-0.854	0.098	0.005	0.154
age50	416	0.168	-1.021	0.084	0.004	0.164
age60	417	0.165	-1.098	0.074	0.004	0.168
age70	417	0.165	-1.078	0.066	0.004	0.168
age80	416	0.170	-0.966	0.078	0.005	0.214
Females						
age30	446	0.150	-0.997	0.151	0.004	0.138
age40	449	0.145	-1.160	0.098	0.003	0.126
age50	451	0.140	-1.303	0.082	0.003	0.135
age60	450	0.143	-1.221	0.074	0.003	0.142
age70	448	0.146	-1.101	0.089	0.004	0.193
age80	445	0.155	-0.849	0.124	0.007	0.289

Table D5. Regression statistics for model (Eq. D2) fitted as a linear regression on the logged length and weight pairs.

Sex	Parameter	Estimated value	Standard error	Lower bound	Upper bound	t-value	P(t)
Males	b_s	3.1551	0.00919	3.1370	3.1731	343.14	0
	$\log(a_s)$	-11.7204	0.03315	-11.7855	-11.6554	-353.51	0
Females	b_s	3.1157	0.00841	3.0992	3.1322	370.29	0
	$\log(a_s)$	-11.5900	0.03083	-11.6505	-11.5296	-375.92	0

Table D6. Fixed allometric growth parameter values used in the 5ABC POP stock assessment model.

Parameter	males	females
$L_{\infty,s}$ (cm)	41.62	45.11
k_s	0.1675	0.1404
$t_{0,s}$	-1.0210	-1.3035
a_s	8.13E-06	9.26E-06
b_s	3.155	3.116

Table D7. Number of aged females using the break and burn method available by maturity stage and age for the period 1978 to 2009 for PMFC areas 5ABCE. Maturity stages 1 and 2 are considered immature or "resting". Stages greater than 2 apply to mature fish that either will spawn or have spawned in the year of sampling.

	Maturity stage							
	1	2	3	4	5	6	7	
Age	**Immature**	**Immature**	**Developing**	**Gravid**	**Spawning**	**Spent**	**Resting**	**Total**
3	383	16	3					402
4	342	27	2				1	372
5	370	102	7			1	1	481
6	278	178	30			2	8	496
7	398	425	95	1		3	27	949
8	432	401	160	4	3	24	165	1,189
9	245	625	352	21	3	59	326	1,631
10	179	637	224	39	19	60	426	1,584
11	81	726	228	70	36	108	616	1,865
12	50	508	285	92	29	64	648	1,676
13	34	512	271	72	37	77	472	1,475
14	16	300	262	78	39	86	485	1,266
15	15	277	265	85	27	102	405	1,176
16	8	240	221	91	32	71	384	1,047
17	4	178	214	46	16	47	378	883
18	10	241	233	77	22	56	439	1,078
19	4	156	198	51	12	60	336	817
20	2	148	202	78	12	57	298	797
21		135	192	51	16	61	288	743
22	2	111	155	47	20	48	267	650
23	1	92	158	44	12	40	195	542
Total	2,854	6,035	3,757	947	335	1,026	6,165	21,119

Table D8. Proportion of staged females by month and maturity category for all staged POP without reference to age, area or year.

Month	Stages 1 +2 **Immature**	**Stages 3+4** **Mature**	**Stage 5** **Spawning**	**Stages 6+7** **Spent**
Jan	0.128	0.822	0.009	0.042
Feb	0.226	0.521	0.213	0.041
Mar	0.331	0.315	0.265	0.089
Apr	0.229	0.023	0.226	0.522
May	0.335	0.016	0.051	0.598
Jun	0.302	0.043	0.001	0.654
Jul	0.465	0.160	0.001	0.374
Aug	0.435	0.394	0.000	0.171
Sep	0.331	0.613	0.000	0.056
Oct	0.235	0.747	0.000	0.017
Nov	0.147	0.846	0.000	0.006
Dec	0.087	0.910	0.000	0.003

Table D9. Summary of data used to estimate the female proportion mature used in the catch-age model. Stages 1 and 2 were assumed to be immature fish and all other staged fish (stages 3 to 7) were assumed to be mature (Table D7). Only ages with at least 10 staged observed fish sampled from January to June were used. The observed proportions and the fitted model are plotted in Figure D5.

Age	Number ages	Mean length (cm) immature	Mean length (cm) mature	Observed prop. immature	Observed prop. mature	Fitted prop. mature	Model prop. mature
3	16	20.3		1.000		0.018	0.000
4	24	22.8		1.000		0.033	0.000
5	44	25.6	24.5	0.977	0.023	0.058	0.023
6	29	27.5	27.5	0.966	0.034	0.098	0.034
7	52	30.3	33.2	0.904	0.096	0.157	0.096
8	161	31.9	34.7	0.789	0.211	0.237	0.211
9	198	33.3	35.6	0.646	0.354	0.341	0.341
10	283	35.0	36.4	0.417	0.583	0.465	0.465
11	367	36.7	38.1	0.371	0.629	0.601	0.601
12	422	37.4	38.5	0.227	0.773	0.738	0.738
13	336	37.4	39.3	0.199	0.801	0.860	0.860
14	302	38.4	39.8	0.109	0.891	0.950	0.950
15	236	39.0	40.0	0.165	0.835	0.996	0.996
16	246	40.6	41.1	0.134	0.866	1.000	1.000
17	214	39.0	41.3	0.075	0.925	1.000	1.000
18	231	40.2	41.5	0.056	0.944	1.000	1.000
19	146	41.6	42.0	0.055	0.945	1.000	1.000
20	156	40.1	42.6	0.051	0.949	1.000	1.000
21	139	41.0	42.7	0.036	0.964	1.000	1.000
22	111	41.5	43.3	0.036	0.964	1.000	1.000
23	84	42.6	43.0	0.060	0.940	1.000	1.000

Table D10. Values used for survey selectivity priors in the 5ABC POP stock assessment. See Table F1 for parameter definitions.

Parameter	Distribution	Mean	Standard Deviation	CV
μ_g	Normal	8.069	2.421	0.300
Δ_g	Normal	0	1	
υ_{gL}	Normal	2.277	0.683	0.300

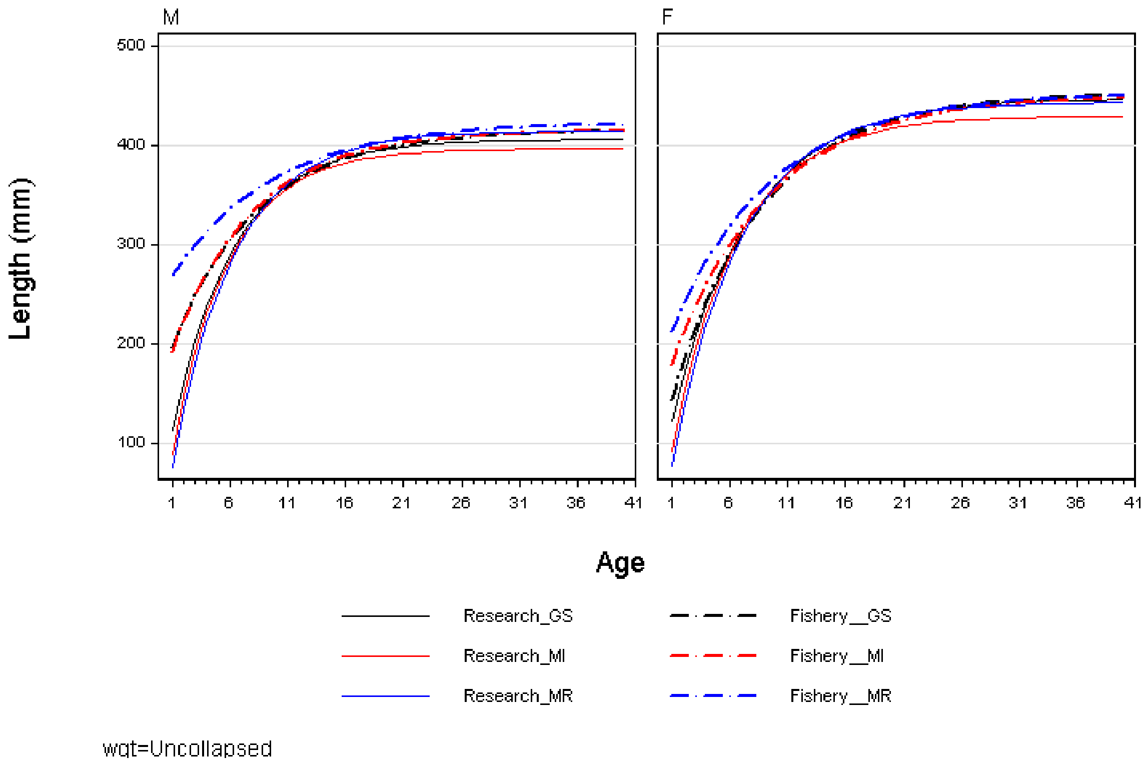


Figure D1. Comparison of results across the three Queen Charlotte Sound areas for unweighted age data showing the effect by sex and data type origin.

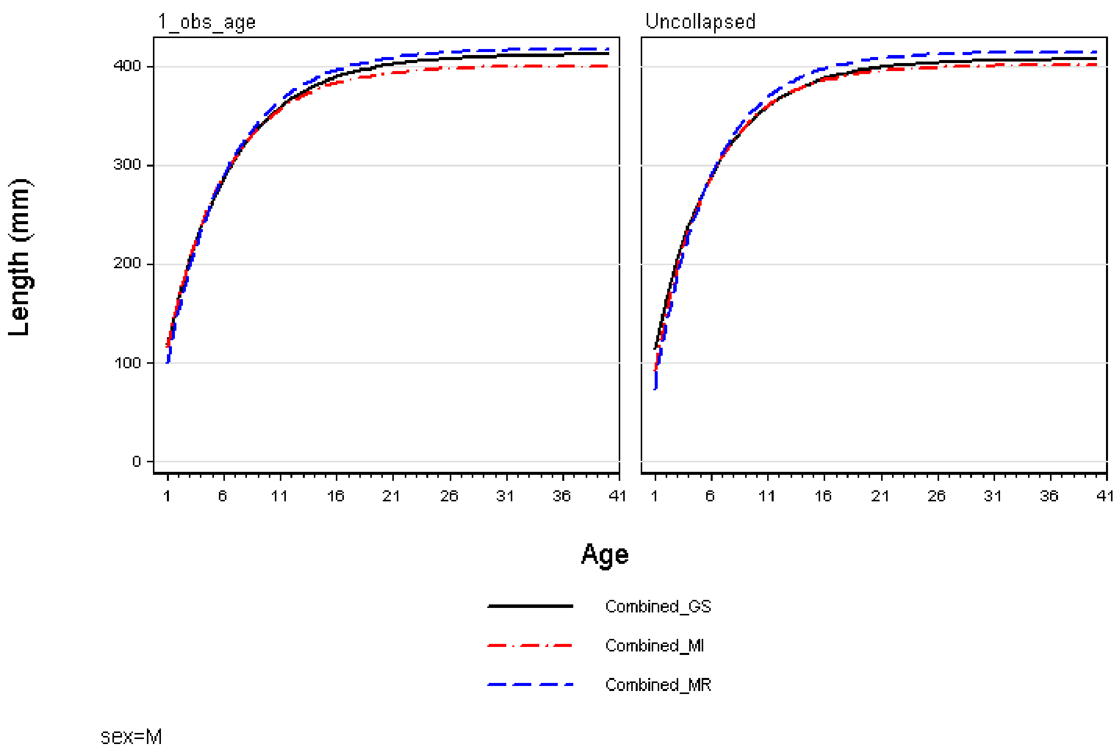


Figure D2. Comparison of results across the three Queen Charlotte Sound areas for males showing the effect of different weighting assumptions for the combined research and fishery data.

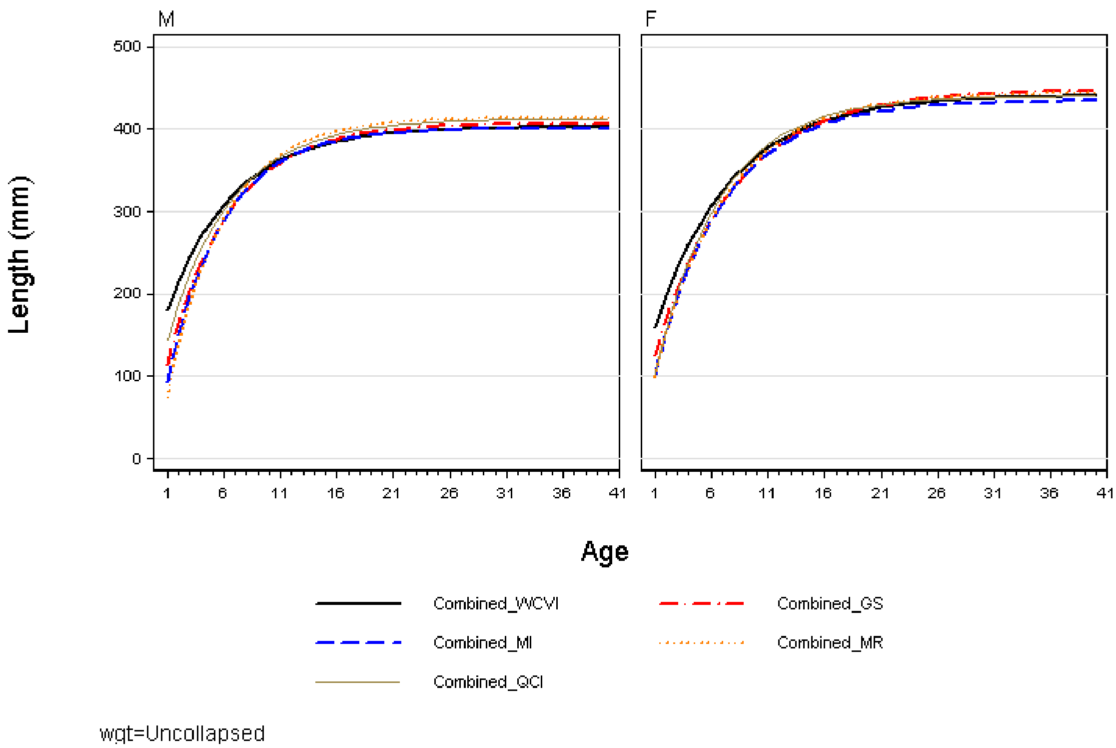


Figure D3. Comparison of results across the three Queen Charlotte Sound areas, the west coast Vancouver Island and the Queen Charlotte Islands for the unweighted combined data sets for each sex.

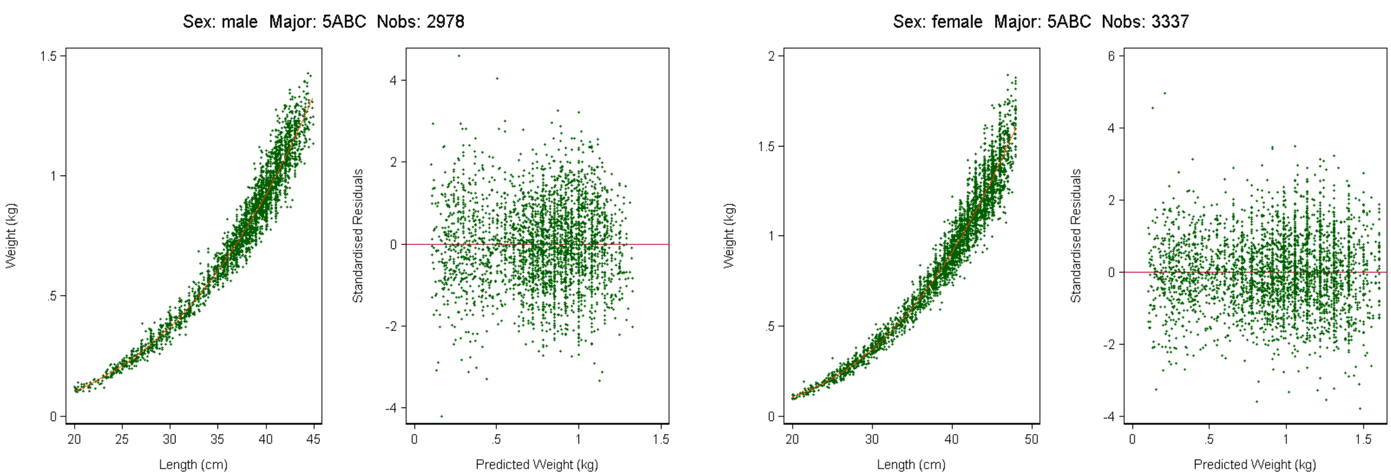


Figure D4. Regression analyses showing the fitted model (Eq. D2) and observed length-weight pairs used to estimate a_s and b_s in the assessment. Also shown are the standardised residuals plotted against the predicted weight. [left panel]: males; [right panel]: females.

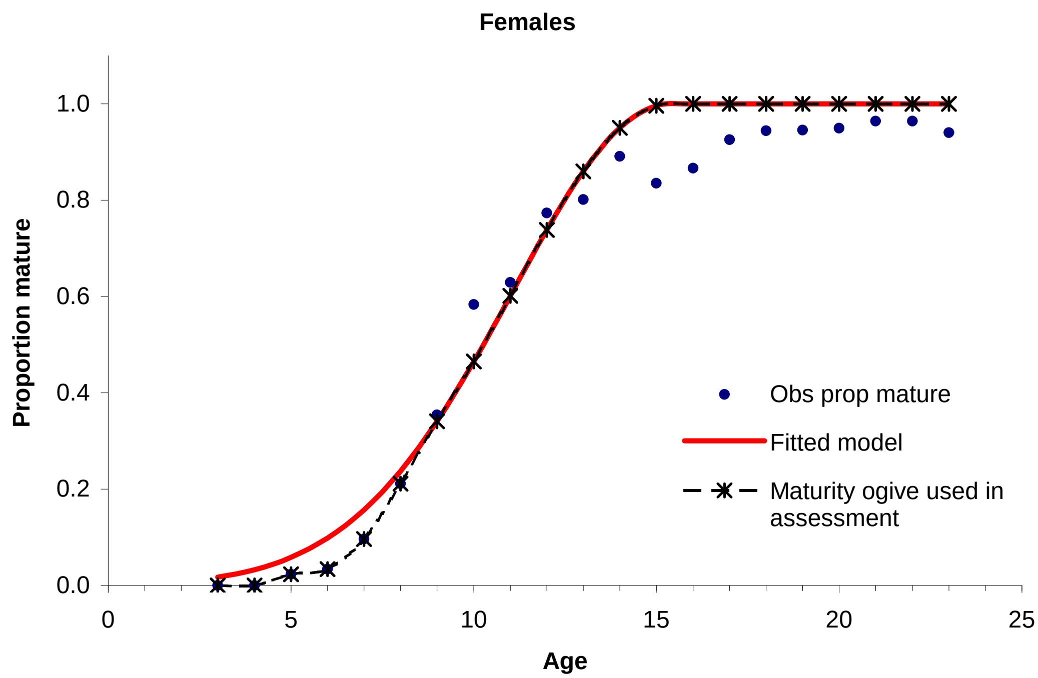


Figure D5. Maturity ogives for 5ABCE POP females: 1) observed from the available commercial and research data (Table D9); 2) double normal curve fitted to the observed proportions in Table D9; 3) Compound ogive used in the 5ABC POP stock assessment.

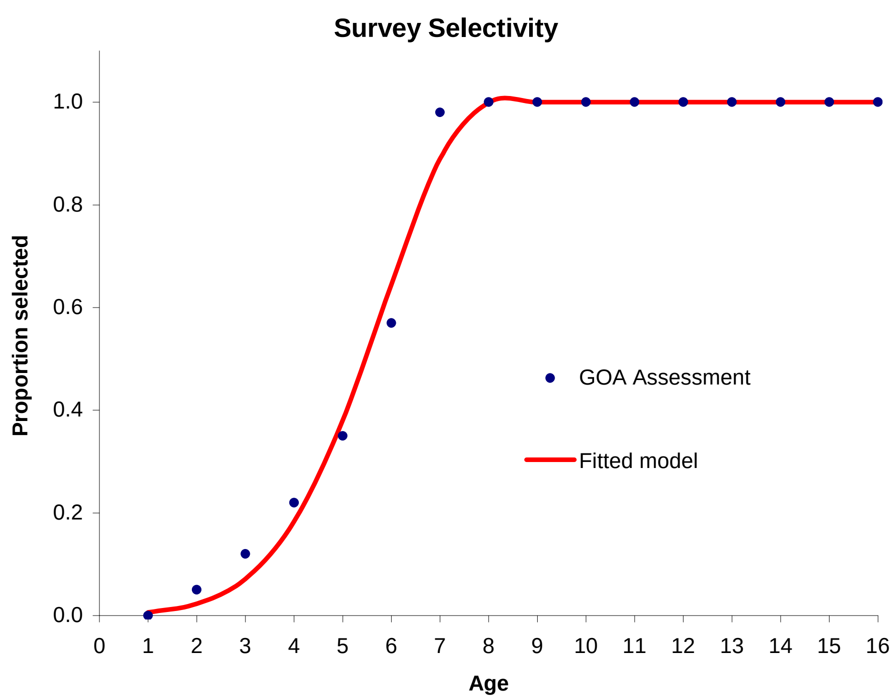


Figure D6. Data points from the Gulf of Alaska POP survey selectivity (Hanselman et al. 2007) and the fitted double normal curve used to set an informed prior in the 5ABC POP stock assessment

APPENDIX E. WEIGHTED AGE FREQUENCIES / PROPORTIONS

This appendix summarizes 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 in defined strata. 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, sample age frequencies are weighted proportionally by the catch weight of POP in tows that were sampled. A second weighting is then applied using the catch weight of POP from all tows within each stratum as a proportion of total catch weight in the year or survey, depending on the source. 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, we illustrate the weighting of age frequencies n_a, unless otherwise specified. The weighting occurs at two levels: h (quarters for commercial, strata for survey) and i (years for commercial, surveys in series for survey). Notation is summarised in Table E1.

Table E1. Notation for weighted commercial age equations for a given species.

Symbol	Description
Indices	
a	age class (1 to 60, where 60 is an accumulator age-class)
u	commercial ...... trip IDs as sample units survey .... sample IDs as sample units
h	commercial ...... quarters (1 to 4), 91.5 days each survey .... strata (area-depth)
i	commercial ...... years (1977 to 2009) survey .... survey IDs in series (e.g., QCS Synoptic)
Data	
n_{auhi}	frequency at age a for sample unit u in quarter/stratum h of year/survey i
S_{uhi}	catch of a given species for sample unit u in quarter/stratum h of year/survey i
S'_{uhi}	S_{uhi} as a proportion of total catch $S_{hi} = \sum_u S_{uhi}$
m_{ahi}	weighted age frequencies at age a in quarter/stratum h of year/survey i
C_{hi}	total catch of species in quarter/stratum h of year/survey i
C'_{hi}	C_{hi} as a proportion of total catch $C_i = \sum_h C_{hi}$
w_{ai}	weighted age frequencies at age a in year/survey i
p_{ai}	weighted proportions at age a in year/survey i

For each quarter/stratum h we weight sample unit frequencies n_{au} by sample unit catch of a given species. (For commercial ages, we use trip as the sample unit, though at times one trip may contain multiple samples. In these instances, multiple samples from a single trip will be merged into a single sample unit.) Within any quarter/stratum h and year/survey i there is a set of sample catches S_{uhi} that can be transformed into a set of catch proportions:

$$S'_{uhi} = \frac{S_{uhi}}{\sum_u S_{uhi}} .$$

The age frequencies are weighted using S'_{uhi} to derive weighted age frequencies by quarter/stratum:

$$m_{ahi} = \sum_u n_{auhi} \, S'_{uhi} .$$

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

$$\frac{\sum_a n_{ahi}}{\sum_a m_{ahi}}$$

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

At the second level of stratification by year/survey i, we calculate the annual/survey proportion of quarterly/stratum catch

$$C'_{hi} = \frac{C_{hi}}{\sum_h C_{hi}}$$

to weight m_{ahi} and derive weighted age frequencies by year/survey:

$$w_{ai} = \sum_h m_{ahi} \, C'_{hi} .$$

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

$$\frac{\sum_a m_{ai}}{\sum_a w_{ai}}$$

to retain the original number of observations.

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

$$p_{ai} = \frac{w_{ai}}{\sum_a w_{ai}}.$$

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

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 frequencies emphasises our belief in individual observations at specific ages while weighting proportions emphasises our belief in sampled age distributions. Neither method yields inherently better results; however, if the original sampling methodology favoured sampling few fish from many tows rather than sampling many fish from few tows, then weighting frequencies probably makes more sense than weighting proportions. In this assessment, we weight age frequencies n.

The clearest cohort patterns appear in the commercial age data (Figure E1). The strong 1976 year class (34 year-old fish in 2010) is still evident in the proportions-at-age data, although its presence is declining. Figure E1 also shows that the 2000 year class may have contributed a large set of recruits to the population. The survey proportions-at-age data do not appear to be particularly informative or consistent (Figure E2, Figure E3, Figure E4). In part, this may be due to the inconsistent level of sampling within each stratum (Table E3).

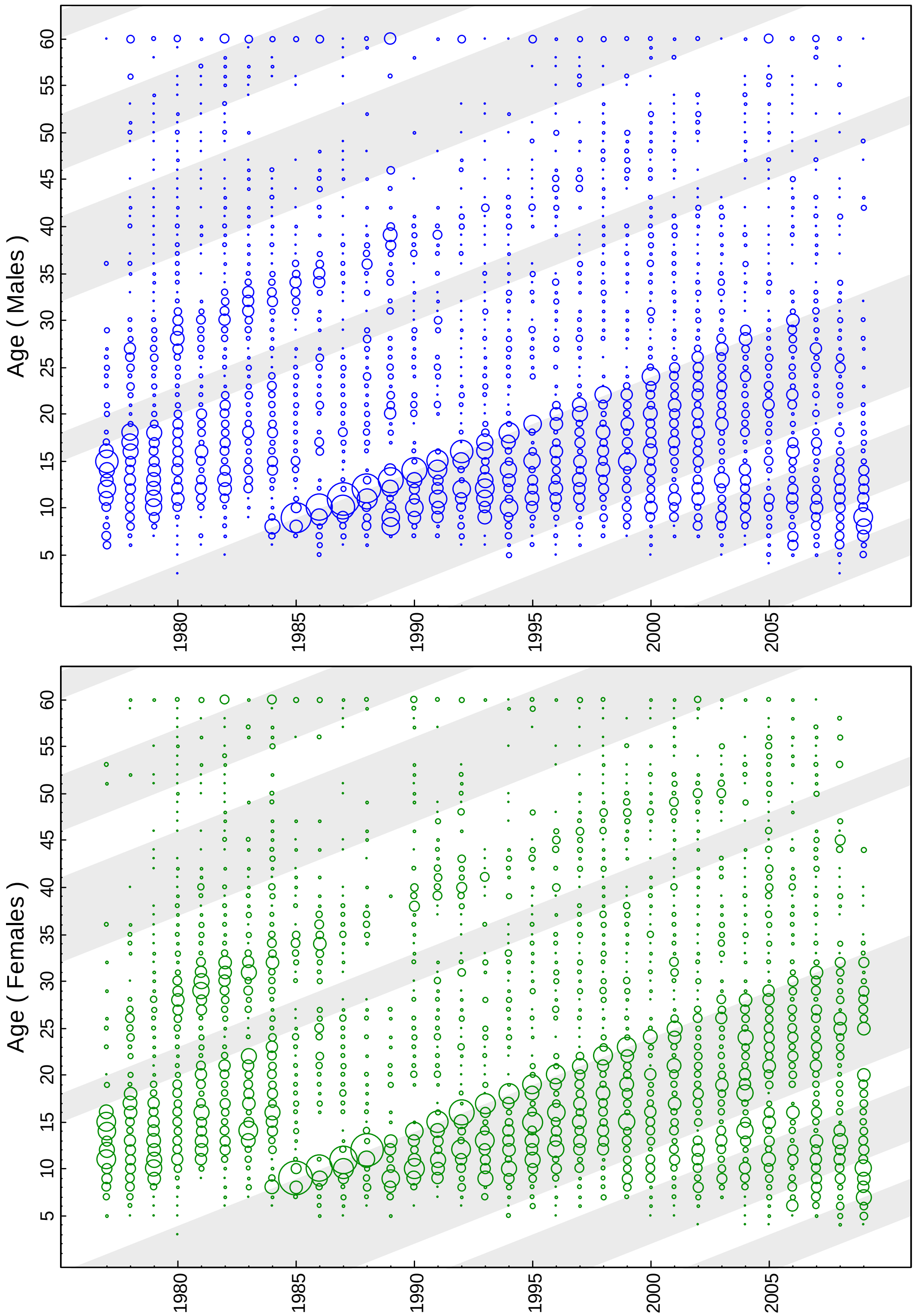


Figure E1. Commercial POP proportions-at-age based on age frequencies weighted by trip catch within quarters and commercial catch within years. Bubbles are, for each year, the proportion assigned to each age class. Bubble areas are proportional to the respective proportions, such that areas sum to 1 for each year. Diagonal shaded bands indicate cohorts that were born when the Pacific Decadal Oscillation was positive, potentially creating conditions in pelagic waters that foster productivity.

Table E2. Commercial trips: number of sampled trips, trip POP catch (t), and total POP catch (t) per quarter.

Year	# Trips				Trip catch (t)				Commercial catch (t)			
Quarter	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1977		1	2			13.6	73.2		0.1	353	617	161
1978		3	3	1		73.5	94.2	49.3	0.5	267	746	356
1979		4	6	1		53.6	227.6	65.4	46	223	976	259
1980	1	10	9	3	20.8	472.2	405.4	104.0	27	1,561	1,675	711
1981		4	3			191.5	143.9		196	2,387	1,219	2
1982	1	7		1	78.1	474.2		86.4	482	2,407	1,394	358
1983	1	6	2		49.3	355.7	148.7		892	2,249	553	3
1984	1	7		1	47.9	304.8		44.0	893	1,327	185	587
1985				3				293.0	845	1,269	120	536
1986		1		1		39.6		17.6	335	493	202	254
1987	2	1	3		60.7	70.9	56.1		499	1,408	990	673
1988	2	1	1		40.1	31.7	19.3		497	1,826	901	1,099
1989	1	4			30.7	65.2			396	1,156	639	507
1990	6	6	1	2	73.6	72.9	21.7	54.5	368	1,063	751	646
1991	1	4	3	12	31.1	62.6	20.3	398.7	422	908	620	957
1992	4	9	13	5	69.1	135.0	169.1	21.0	221	1,244	1,029	173
1993	3	12	1	2	17.8	154.0	1.9	14.8	173	1,493	296	411
1994		20	18	10		171.5	209.5	147.4	163	891	1,167	1,593
1995	6	30	17	1	38.8	457.2	135.0	3.9	1,244	1,931	1,294	59
1996	4	23	11	4	36.1	420.9	101.4	88.1	150	2,555	725	1,723
1997	3	4	7	4	22.4	51.9	82.8	38.1	620	1,958	1,265	882
1998	4	9	8	4	54.6	75.0	66.8	29.8	465	2,157	1,542	529
1999		9	9	3		101.4	95.0	17.5	265	2,349	1,377	523
2000	3	11	4	4	8.5	70.1	35.5	47.9	615	1,809	1,485	572
2001		11	8	3		109.1	38.9	21.6	183	1,712	1,548	533
2002		12	5	2		77.1	53.0	15.5	305	1,375	1,869	589
2003	2	4	6	1	17.2	36.4	22.8	0.2	416	1,776	2,176	330
2004		14	10	3		34.2	38.5	11.4	278	1,576	2,056	549
2005	1	10	6	3	0.5	40.2	21.2	20.9	423	1,326	1,447	503
2006	5	3	3		6.6	6.0	7.2		614	1,366	1,780	310
2007	2	14	8		7.3	73.8	24.5		360	1,328	1,458	265
2008	1	3	6	2	2.9	29.4	59.7	20.1	361	1,063	1,106	253
2009	1	5	8		8.2	12.8	26.3		441	1,099	1,116	476

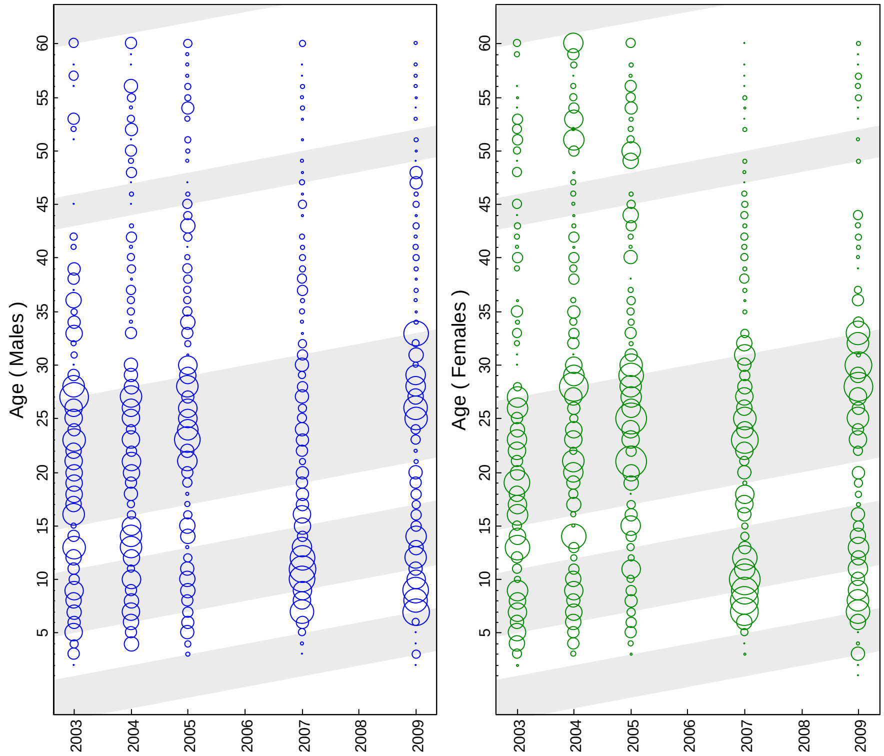


Figure E2. QCS Synoptic survey POP proportions-at-age based on age frequencies weighted by sampled catch within strata and total catch within survey. See Figure E1 for details on bubbles and diagonal shaded bands.

Table E3. QCS Synoptic survey: number of sampled tows, sampled POP catch (t), and total POP catch (t) per strata.

Year	166	167	168	170	171	172
# Samples						
2003	4	3	0	1	6	3
2004	1	4	1	2	7	1
2005	6	2	0	7	8	0
2007	2	5	0	6	7	3
2009	4	4	0	4	10	5
Sample catch (t)						
2003	2.460	2.251	0	0.021	0.769	0.561
2004	0.166	1.629	0.348	0.160	2.316	0.374
2005	1.377	0.406	0	1.241	3.537	0
2007	0.898	1.467	0	0.690	1.956	0.117
2009	0.769	1.971	0	0.697	4.360	2.466
Survey catch (t)						
2003	7.723	15.250	0.467	0.740	11.673	2.996
2004	1.651	7.452	0.433	0.339	13.291	0.813
2005	3.436	7.975	0.020	2.220	7.312	0.859
2007	2.809	5.105	0.287	1.095	6.577	0.345
2009	1.104	4.696	0.468	0.806	7.813	2.663
Proportion of survey catch sampled						
2003	0.318	0.148	0	0.029	0.066	0.187
2004	0.101	0.219	0.803	0.470	0.174	0.460
2005	0.401	0.051	0	0.559	0.484	0
2007	0.320	0.287	0	0.630	0.297	0.338
2009	0.696	0.420	0	0.865	0.558	0.926

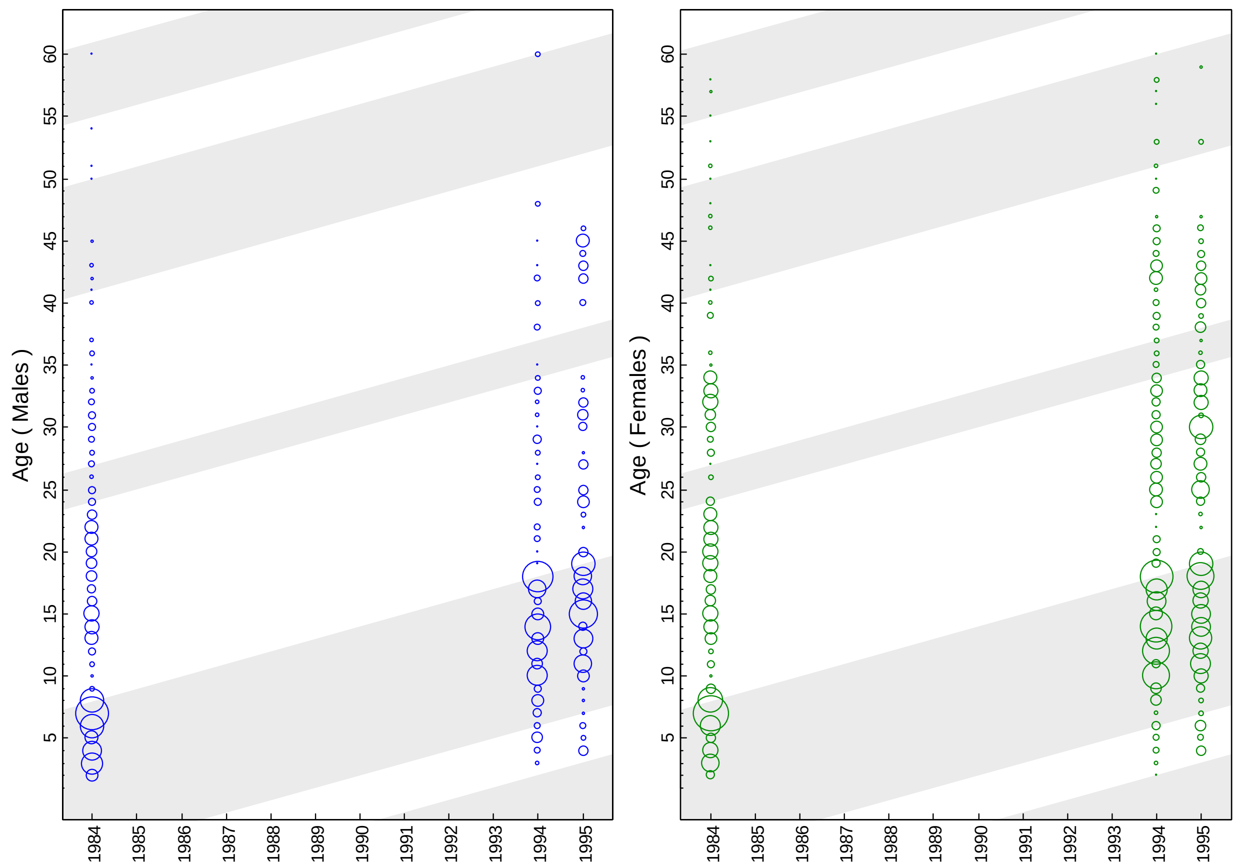


Figure E3. GIG Rockfish survey POP proportions-at-age based on age frequencies weighted by sampled catch within strata and total catch within survey. See Figure E1 for details on bubbles and diagonal shaded bands.

Table E4. GIG Rockfish survey: number of sampled tows, sampled POP catch (t), and total POP catch (t) per strata.

Year	**# Samples**			**Sample catch (t)**			**Survey catch (t)**		
Strata	**185**	**186**	**187**	**185**	**186**	**187**	**185**	**186**	**187**
1984	4	6	8	0.465	2.482	4.086	1.390	18.761	22.161
1994	6	12	19	1.117	9.033	14.626	3.022	14.081	21.549
1995	3	9	12	1.684	8.556	8.256	12.360	21.721	38.505

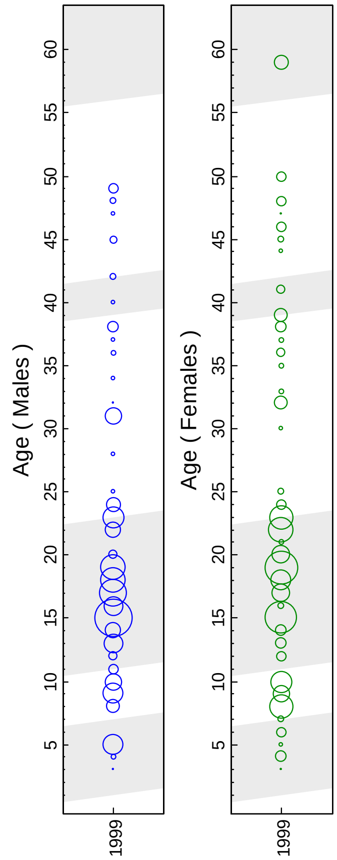


Figure E4. QCS Shrimp survey POP proportions-at-age based on age frequencies weighted by sampled catch within strata and total catch within survey. See Figure E1 for details on bubbles and diagonal shaded bands.

Table E5. QCS Shrimp survey: number of sampled tows, sampled POP catch (t), and total POP catch (t) per strata.

Year	**# Samples**	**Sample catch (t)**	**Survey catch (t)**
Strata	**109**	**109**	**109**
1999	15	2.624	4.484

APPENDIX F. DESCRIPTION OF CATCH-AT-AGE MODEL

MODEL OUTLINE AND ASSUMPTIONS

We used a sex-specific, age-structured model in a Bayesian framework. In particular, we simultaneously estimated the steepness of the stock-recruitment function and separate mortalities for males and females.

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 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). Equations are given below.

The assumptions of the model are:

1. The stock in Queen Charlotte Sound was treated as a single stock.

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

3. A time-invariant Beverton-Holt stock-recruitment relationship was assumed, with log-normal error structure.

4. Selectivity was different between sexes and surveys and invariant over time. Selectivity parameters were mostly estimated.

5. Natural mortality was held invariant over time, and either estimated independently for females and males, or held fixed.

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

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

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

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

10. Commercial samples of catch-at-age in a given year were assumed to be representative of the fishery if there were $>$6 samples.

11. Relative abundance indices were assumed to be proportional to the vulnerable biomass at the mid point of the year, after half of catch had been removed.

12. The age composition samples were assumed to come from the middle of the year after half of the catch and half of the natural mortality had been accounted for.

MODEL NOTATION AND EQUATIONS

The notation for the model is given in Table F1, the model equations in Tables F2 and F3, and description of prior distributions for estimated parameters in Table F4. 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 F2 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.

Given we do not in practice have known fixed values 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 F3.

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

Table F1 (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 $A = 60$ is the accumulator age class
t	model year, where $t = 1, 2, 3, ...T$, corresponds to actual years 1940, 1941, 1942, ..., 2011, and $t = 0$ represents virgin conditions
g	index for certain data: 1 - Goose Island Gully historical survey 2 - Queen Charlotte Sound synoptic survey 3 - Queen Charlotte Sound shrimp survey 4 - commercial trawl data
s	sex, $1 =$ females, $2 =$ males
	Index ranges
A	accumulator age-class, $A = 60$
T	number of model years, $T = 72$
$\mathbf{T}_g$	sets of model years for survey index series g, $g = 1, 2, 3$, listed here for clarity as actual years (subtract 1939 to give model year t): $\mathbf{T}_1 = \{$1967, 1969, 1971, 1973, 1976, 1977, 1984, 1994$\}$ $\mathbf{T}_2 = \{$2003, 2004, 2005, 2007, 2009$\}$ $\mathbf{T}_3 = \{$1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010$\}$
$\mathbf{U}_g$	sets of model years with proportion-at-age data, $g = 1, 2, 4$ (listed here as actual years): $\mathbf{U}_1 = \{$1984, 1994$\}$ $\mathbf{U}_2 = \{$1995, 2003, 2004, 2005, 2007, 2009$\}$ $\mathbf{U}_4 = \{$1978, 1979, ..., 1984, 1987, 1989, 1990, ..., 2009$\}$
	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 $t \in \mathbf{U}_g$, $g = 1, 2, 4$
τ_{tg}	inverse of 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 surveys $g = 1, 2, 3$ for year $t \in \mathbf{T}_g$, tonnes
κ_{tg}	standard deviation of I_{tg}
σ_R	standard deviation parameter for recruitment process error, $\sigma_R = 0.9$
v_R	variance parameter for right limb of selectivity curves, $v_R = 100$

Table F1 (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 (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, $g = 1, 2, 3$
μ_g	age of full selectivity for females for series $g = 1, 2, 3, 4$
Δ_g	shift in vulnerability for males for series g
v_{gL}	variance parameter for left limb of selectivity curve for series $g = 1, 2, 3, 4$
s_{ags}	selectivity for age-class a, series $g = 1, 2, 3, 4$, and sex s, calculated from the parameters μ_g, Δ_g, v_{gL} and v_{gR}
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); often referred to as U_t outside of this Appendix
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
$\log L_1(\boldsymbol{\Theta}\|\{\epsilon_t\})$	log-likelihood component related to recruitment residuals
$\log L_2(\boldsymbol{\Theta}\|\{\widehat{p}_{atgs}\})$	log-likelihood component related to estimated proportions-at-age
$\log L_3(\boldsymbol{\Theta}\|\{\widehat{I}_{tg}\})$	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 F2. 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 F3, 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 ($g = 1, 2, 3, 4$)

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

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

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

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

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

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

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

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

Estimated observations

$$\widehat{I}_{tg} = q_g \sum_{s=1}^{2} \sum_{a=1}^{A} e^{-M_s/2}(1 - u_{ats}/2) w_{as} s_{ags} N_{ats}\,; \quad t \in \mathbf{T}_g,\ g = 1,2,3 \tag{F.14}$$

$$\widehat{p}_{atgs} = \frac{e^{-M_s/2}(1 - u_{ats}/2) s_{ags} N_{ats}}{\sum_{s=1}^{2} \sum_{a=1}^{A} e^{-M_s/2}(1 - u_{ats}/2) s_{ags} N_{ats}}; \quad 1 \leq a \leq A,\ t \in \mathbf{U}_g,\ g = 1,2,4,\ s = 1,2 \tag{F.15}$$

Table F3. Calculation of likelihood function $L(\boldsymbol{\Theta})$ for stochastic components of the model in Table F2, and resulting objective function $f(\boldsymbol{\Theta})$ to be minimised.

Estimated parameters

$$\boldsymbol{\Theta} = \{R_0, M_1, M_2, h, q_1, q_2, q_3, \mu_1, \mu_2, \mu_4, \Delta_1, \Delta_2, \Delta_4, \upsilon_{1L}, \upsilon_{2L}, \upsilon_{4L}\} \tag{F.16}$$

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

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

$$\begin{aligned}\log L_2(\boldsymbol{\Theta}|\{\widehat{p}_{atgs}\}) = &-\frac{1}{2}\sum_{g=1,2,4}\sum_{a=1}^{A}\sum_{t\in\mathbf{U}_g}\sum_{s=1}^{2}\log\left[p_{atgs}(1-p_{atgs}) + \frac{1}{10A}\right] \\ &+ \sum_{g=1,2,4}\sum_{a=1}^{A}\sum_{t\in\mathbf{U}_g}\sum_{s=1}^{2}\log\left[\exp\left\{\frac{-(p_{atgs}-\widehat{p}_{atgs})^2}{2\left(p_{atgs}(1-p_{atgs}) + \frac{1}{10A}\right)\tau_{tg}}\right\} + \frac{1}{100}\right]\end{aligned} \tag{F.19}$$

$$\log L_3(\boldsymbol{\Theta}|\{\widehat{I}_{tg}\}) = \sum_{g=1}^{3}\sum_{t\in\mathbf{T}_g}\left[-\frac{1}{2}\log 2\pi - \log\kappa_{tg} - \frac{(\log I_{tg} - \log\widehat{I}_{tg})^2}{2\kappa_{tg}^2}\right] \tag{F.20}$$

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

Joint prior distribution and objective function

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

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

DESCRIPTION OF DETERMINISTIC COMPONENTS

Notation (Table F1) and set up of the deterministic components (Table F2) are now described.

Age classes

Index (subscript) a represents age classes, going from 1 to the accumulator age class, A, of 60. Age class $a = 5$, for example, represents fish aged 4-5 years (which is the usual, though not universal, convention, Caswell 2001), and so an age-class 1 fish was born the previous year. 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 2011.

Years

Index t represents model years, going from 1 to $T = 72$, and $t = 0$ represents unfished equilibrium conditions. The actual year corresponding to $t = 1$ is 1940, and so model year $T = 72$ corresponds to 2011.

Survey data

Data from three survey series were used, as described in detail in Appendix C. Here, subscript $g = 1$ corresponds to the Goose Island Gully historical survey, $g = 2$ is the Queen Charlotte Sound synoptic survey, and $g = 3$ is the Queen Charlotte Sound shrimp survey. The years for which data are available for each survey are given in Table F1; $\mathbf{T}_g$ corresponds to years for the survey biomass estimates I_{tg} (and corresponding standard deviations κ_{tg}), and $\mathbf{U}_g$ corresponds to years for proportion-at-age data p_{atgs} (with inverses of assumed sample sizes τ_{tg}, which were adjusted during the iterative reweighting, as described below). Note that there is no $\mathbf{U_3}$ because there are no age data for the Queen Charlotte Sound shrimp survey.

Commercial data

As described in Appendix B, the commercial catch has been reconstructed back to 1918. Given the very low catches (< 10 tonnes) 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 $\mathbf{U}_4$ (Table F1) gives the years of available ageing data from the commercial fishery. All years are represented from 1978 to 2009, except for 1985, 1986 and 1988, and the proportions-at-age values are given by p_{atgs} with inverses of assumed sample size τ_{tg}, where $g = 4$ (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.

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.

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.

Maturity of females

The proportion of age-class a females that are mature is m_a, and does not change over time; see Appendix D for details.

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.

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 over two decades. 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).

Selectivities

Separate selectivities were modelled for the commercial catch data and for each survey series. A double 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 $s_{...}$ always represents selectivity). This permits an increase in selectivity up to the age of full selection (μ_g for females), and then a descending right limb. However, there was no evidence to suggest a dome-shaped function, so the variance parameter v_R was fixed at the high value of e^{100}, such 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).

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.

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.

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 mortality term $e^{-M_s/2}$ (that accounts for half of the annual natural mortality), the term $1 - u_{ats}/2$ (that accounts for half of the commercial catch), weights-at-age w_{as} (to convert to biomass) and selectivity s_{ags}. The sum (over ages and sexes) is then multiplied by the catchability parameter q_g to give the model biomass estimate $\widehat{I}_{tg}$. 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 $\sum_{s=1}^{2}\sum_{a=1}^{A} \widehat{p}_{atgs} = 1$.

DESCRIPTION OF STOCHASTIC COMPONENTS

Parameters

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

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

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

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. This value was determined empirically from model fits, and is consistent with the age composition data.

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).

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
    - an iterative 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.

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 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 catchabilities q_1, q_2, q_3

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

phase 3: age of full selectivity for females, μ_1, μ_2, μ_4

phase 4: selectivity parameters Δ_g, v_{gL} for $g = 1, 2, 4$, and mortalities M_1, M_2 if they were estimated (see below).

phase 5: steepness h if it was estimated (see below).

Iterative 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. The standard deviation of normal residuals (SDNR), or standard deviation of Pearson residuals, was calculated for each data source (three series of biomass estimates from surveys and the commercial and survey proportions-at-age data). Successive fits of a given model involved adjusting the relative weights until SDNR values close to 1 were obtained for each data source (the 1 comes from a standard normal distribution having a mean zero and a standard deviation of 1).

In general, the normal residual for an observation i is

$$r_i = \frac{O_i - P_i}{d(O_i)}, \qquad \text{(F.25)}$$

where O_i is the observed value, P_i is the predicted value, and $d(O_i)$ is the standard deviation associated with the observed value.

Each survey biomass estimate I_{tg} has an associated standard deviation κ_{tg}, so the resulting normal residual r_{tg} is

$$r_{tg} = \frac{I_{tg} - \widehat{I}_{tg}}{\kappa_{tg}}. \qquad \text{(F.26)}$$

For each survey series $g = 1, 2, 3$, the standard deviation of the normal residuals r_{tg} was then calculated. This thus results in three SDNR values.

For the proportions-at-age data, the robust normal likelihood function is used. For a given year t and data series g, the standard deviation (used to calculate the normal residuals) of the observed proportion-at-age, p_{atgs}, can be written

$$d(p_{atgs}) = \sqrt{\left(p_{atgs}(1 - p_{atgs}) + \frac{1}{10A}\right) \Big/ N'_{tg}} \tag{F.27}$$

where $N'_{tg} = \min(N_{tg}, 200)$, as in Stanley *et al.* (2009), for which N_{tg} is the effective sample size. Initially, $N_{tg} = 1/\tau_{tg}$. The definition of N'_{tg} gives a maximum effective sample size of 200, which avoids putting excessive weight on any one set of age composition data. Also, any standardised residual > 3 was set to 3.

For the ageing data from the commercial catch, a single SDNR was calculated as the standard deviation of all the normal residuals for all the data. For the ageing data from surveys, a single SDNR was calculated as the standard deviation of all the normal residuals for all the survey ageing data combined. Thus, there were five SDNR values in total (one for each survey index series, one for the commercial age data and one for the survey age data).

The standard deviations κ_{tg} and effective sample sizes N_{tg} are essentially weights associated with each data set. The weights were iteratively adjusted manually until each SDNR was was approximately 1.0, consistent with the error assumptions. If the SDNR for a data set was $<$1.0, the data set was judged to have too little weight (hence the weight for that data set was increased), while the opposite was true if SDNR was $>$1.0. The SDNRs for the age composition data could not reach 1.0 because of the truncation to 3, and the maximum effective sample size of 200. Each model run described in Appendix G was independently reweighted, yet all model runs resulted in similar weighting terms and SDNRs. Note that the recruitment deviations are not part of the reweighting process, because there are no associated sample sizes from data.

Prior distributions

Descriptions of the prior distributions for the 16 estimated parameters are given in Table F4. The resulting probability density functions give the $\pi_j(\mathbf{\Theta})$, whose logarithms are then summed in (F.22) to give the joint prior distribution $\pi(\mathbf{\Theta})$. 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 $\pi(\mathbf{\Theta})$, only those priors that are not uniform need to be considered in the summation.

The values for the priors for M_1 and M_2 come from the posterior distributions of the Gulf of Alaska assessments of Pacific ocean perch (Hanselman *et al.* 2007, 2009). A uniform prior over a large range was used for R_0. For estimating steepness h, a beta distribution was used 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.), because some of that data were used in this assessment. The priors for the selectivity

Table F4. 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 $\pi_j(\mathbf{\Theta})$ functions that contribute to the joint prior distribution in (F.22).

Parameter	Prior distribution	Mean, standard deviation	Bounds	Initial value
$\mu_g, g = 1, 2$	normal	8.069, 2.421	[5,40]	8.069
μ_4	uniform	–	[5,40]	12.289
$\Delta_g, g = 1, 2$	normal	0,1	[-8,10]	0
Δ_4	uniform	–	[-8,10]	0
$\log v_{gL}, g = 1, 2$	normal	2.277, 0.683	[-15,15]	2.277
$\log v_{4L}$	uniform	–	[-15,15]	2.757
$\log q_g, g = 1, 2, 3$	uniform	–	[-12,5]	-5
$M_s, s = 1, 2$	normal	0.06, 0.006	[0.01,0.12]	0.06
R_0	uniform	–	[1,10^7]	10^5
h	beta	0.674, 0.168	[0.2,0.999]	0.674

parameters μ_g were also based on Hanselman *et al.* (2009) – see Appendix D.

MCMC properties

Properties of the MCMC runs (such as number of iterations) are given in Appendix G when the results are discussed.

Performance indicators and advice to managers

Advice to managers is given with respect to performance indicators based on the DFO Precautionary Approach (DFO 2006). The indicators and consequent decision tables are based on the posterior samples from the MCMC output and various future harvest policies, and are described in Appendix G.

The equation used to calculate the Precautionary-Approach compliant yield, P_t, for year t is

$$P_t = \begin{cases} 0, & B_t \leq 0.4B_{\text{MSY}} \\ \frac{(B_t - 0.4B_{\text{MSY}})}{0.4B_{\text{MSY}}} u_{\text{MSY}}, & 0.4B_{\text{MSY}} < B_t \leq 0.8B_{\text{MSY}} \\ u_{\text{MSY}} B_t, & 0.8B_{\text{MSY}} < B_t \end{cases} \tag{F.28}$$

where B_{MSY} and u_{MSY} are the respective biomass and exploitation rate at the maximum sustainable yield, and we have assumed the reference points of $0.4B_{\text{MSY}}$ and $0.8B_{\text{MSY}}$ and a harvest policy that declines linearly between these points. This is the provisional harvest rule described in DFO's *A fishery decision-making framework incorporating the Precautionary Approach* (23rd March 2009), available at:

http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/precaution-eng.htm. The calculations for B_{MSY} and u_{MSY} are described in Appendix G, and are done for each of the 1000 MCMC samples. If a significant amount of the weight of the posterior distribution of B_t lies above B_{MSY} then the median value for P_t can be greater than the median value of the maximum sustainable yield. The Precautionary-Approach compliant yield is calculated only for the year 2011. Future projections are made assuming constant catches.

APPENDIX G. STOCK ASSESSMENT MODEL RESULTS

TABLE OF CONTENTS / TABLE DES MATIÈRES

LIST OF FIGURES / LISTE DES FIGURES

LIST OF TABLES / LISTE DES TABLEAUX

INTRODUCTION

This Appendix describes the assessment model inputs, the selection of model runs to examine, the preliminary MPD results for each model run, the Bayesian procedures followed to obtain the posterior probability distributions, and the projection procedures used to formulate the advice for management. The procedures used to estimate the limit and upper stock reference points and the evaluation of the projections relative to these reference points are also described.

ASSESSMENT MODEL INPUTS

Data used to fit the model are listed in Table G1 and include the time series of catches from a bottom trawl fishery encompassing all of Queen Charlotte Sound (QCS), indices from three fishery independent surveys, and proportions-at-age from three sources:

a) the commercial QCS trawl fishery (weighted to reflect sample size and the quarterly commercial catch);

b) two years of the historical Goose Island Gully (GIG) trawl survey; and

c) each year of the QCS synoptic survey, plus an age sample taken from the 1995 GIG survey which was not used as a biomass index (see Appendix C) but did use the same net configuration.

The single age composition sample from the QCS shrimp survey was not used because preliminary model fits indicated that the year class information contained in this sample was not consistent with the information contained in other similar data sources, leading to unstable model behaviour and questionable model results.

Catch

Catches were estimated back to 1940 as described in Appendix B. Poorly reported historical catches by foreign fleets have been reconstructed and minor catches from other capture methods have been added. Unlike the situation for other rockfish species, discards are not an important consideration because this is a valuable commercial species that is only infrequently discarded. All available discard estimates were added to the catches. The final model year, 2010, was incomplete. The total annual catch for 2010 was estimated from the catches up to June 2010, based on the equivalent average ratios from 2005-2009.

Biomass indices

Biomass indices from three fishery independent surveys, each spanning a different range of years, were assembled for this assessment (Table G1). The annual biomass indices and the associated relative error from each survey year were used as model inputs.

Proportions at age

The model was fitted to sex-specific age data summarised by year (Table G1). Only otoliths aged using the "break and burn" method were included in the age samples. Practically, this meant that no age data were available prior to 1978. Plots of the age distributions by sex and sample origin are presented in Appendix E. The accumulator or plus group was set to age A=60. Annual age samples were given an initial weight in the model that represented the number of samples for that year. These weights were subsequently adjusted using the iterative procedure described in Appendix F.

Weight-at-age and growth

Growth parameters were estimated from POP length and age data from biological samples collected from 1978 to 2009 (Appendix D). Parameters for the allometric weight-length relationship were estimated for POP of both sexes. Biological samples were obtained from all sampling sources in 5ABC, with the majority being obtained from port sampling. Combining the available data sources was considered acceptable as fits to each of the data sources separately did not generate substantially different parameter estimates (Appendix D). Growth by sex was specified as a von Bertalanffy model with parameters specified in Appendix D.

Maturity-at-age and fecundity

The proportion of females that mature at ages 1 through 23 was computed from biological samples. Stage of maturity was determined macroscopically, partitioning the samples into one of seven maturity stages (Stanley and Kronlund 2000). Fish assigned to stages 1 or 2 were considered immature while those assigned to stages 3-7 were considered mature. Data representing staged and aged females (using the "break and burn" method) were pooled from all sampling sources and the observed proportion mature-at-age was calculated. A monotonic increasing maturity-at-age vector was constructed by fitting a double normal function (similar to Equation F.7) to the observed maturity values (Appendix D). This function was adjusted slightly by using the observed maturity values for ages less than 9. This was done because the fitted model appeared to overestimate the proportion mature at these ages (Figure D5). Maturity for females older than 23 years was assumed to be 100% and the maturity ogive was used as a constant over time. Fecundity was assumed to be proportional to the female body weight.

MODEL DEFINITION

Documentation for the model implemented using the Coleraine/Awatea software is provided in detail in Appendix F, including all major assumptions.

Model fits to the data gave sensible and reasonably consistent results, with the exception of the single age composition data set for the QCS shrimp survey which was discarded. Sensitivity runs that explored the effect of different components of the data on model results did not seem justified, given the small amount of available data when spread over the long period of stock reconstruction and the relative consistency seen between the available data sources. As well, the selectivity functions for the commercial fishery and the QCS synoptic survey seemed well estimated and did not introduce much uncertainty. It was decided that much of the uncertainty in this assessment lay not in the fits to the data, but in the underlying assumptions for several key model parameters, notably natural mortality M_s and stock-recruitment steepness h. This uncertainty was explored by alternately fixing or estimating these parameters in a pairwise pattern:

a) estimate both *M* and *h* using informed priors described in Appendix F [Estimate *M* & *h*];

b) estimate *M* and fix *h* = 0.674, which is the mean value for its prior [Estimate *M*];

c) estimate *h* and fix *M* = 0.06, which is the mean value for its prior [Estimate *h*];

d) fix *M* = 0.06 and *h* = 0.674 [Fix *M* & *h*];

MPD (MODE OF THE POSTERIOR DISTRIBUTION) STOCK ASSESSMENT RESULTS

Model fits to the data were similar for all four sensitivity runs, with slightly better fits to the QCS synoptic survey for the two models with fixed *M* values and slightly better fits to some of the age composition data for the models which estimated *M* (see likelihood results in Table G2). The differences observed between these four hypotheses were small and were not considered to be a reliable way to select between the range of hypotheses investigated. Visual examination of the fits to the data and the patterns of residuals showed nearly identical results for all four models described above. Accordingly, plots of the MPD model fits and residual patterns are only provided for the "Estimate *M* & *h*" run (called the 'base run'), which incorporates the most uncertainty of the four models.

Base run MPD fits are provided for the survey indices (Figure G1), the commercial catches-at-age (Figure G2 and Figure G3), the historic GIG survey series age data (Figure G4) and the QCS synoptic survey age data (Figure G5). Residuals to these model fits are provided for the survey indices (Figure G6), the commercial catches-at-age (Figure G7), the historic GIG survey series (Figure G8) and the QCS synoptic survey (Figure G9). The model is able to capture the main features of the age data fairly well, and the residuals show no strong trends over time.

Two sets of figures are presented that illustrate the fact that the overall pattern of model fits are not affected by the four sets of model assumptions investigated. Figure G10 shows that each set of model assumptions estimates a period of high exploitation rates in the mid-1960s to mid-1970s, corresponding to heavy fishing from foreign fleets just prior to the implementation of the 200-mile EEZ (Exclusive Economic Zone). This was followed by a substantial drop in exploitation once the foreign fleet was eliminated, followed by a gradual increasing trend as the domestic fleet turned its attention to POP in Queen Charlotte Sound (specifically with the discovery of the Moresby Gully sub-population), culminating in high exploitation rates by the 2000s. The main difference between the model assumptions investigated is that the two runs which estimate *M* also estimate a larger overall population size, leading to lower exploitation rates and less depletion in recent years. This can also be seen in the model parameter estimates, with the 'Estimate *M* & *h*' and 'Estimate *M*' runs having q_2 (QCS synoptic survey) parameter estimates of 0.32 and 0.35 while the remaining two models ('Estimate *h*' and 'Fixed *M* & *h*') estimate values for this parameter at 0.50 and 0.53, respectively. These values seem high for a trawl survey, with these two sets of model runs estimating that this survey sampled, on average, between 30 to 50% of the total population of POP in QCS vulnerable to the survey between 2003 and 2009.

A comparison of the stock-recruitment functions resulting from the four sets of assumptions shows a similar result (Figure G11). The pattern of the stock-recruitment pairs are similar for each model, arising from the fits to the proportions-at-age data, but again the overall scale is different. The two models which estimate *M* have larger-sized populations than the two populations estimated by the models which fix these parameters.

BAYESIAN (MCMC) STOCK ASSESSMENT RESULTS

MCMC search

The MCMC searches for the four model runs were the same: 10,000,000 iterations were performed, sampling every 10,000th for 1000 samples, which were used with no burn-in period (because the searches started from the MPD values). MCMC traces for the base run (Estimate *M* & *h*) show good convergence properties for the primary parameters (Figure G12), the spawning biomass derived parameters (Figure G13) and the age 1 recruitments (Figure G14). The convergence properties were best for the base run (Estimate *M* & *h*), slightly poorer for the 'Estimate *M*' run and deteriorate further for the two runs which did not estimate *M*. To illustrate this, Figure G15 compares the traces for the QCS survey *q* parameter for all four model runs, showing an increasing trend in this parameter with an increasing sample number for the 'Estimate *h*' and 'Fixed *M* & *h*' model runs. Fortunately, there is no increasing trend for the derived parameter B_{2011}/B_0 (a quantity of management interest: Figure G16), indicating that reasonable reliance can be placed on the management advice from all four model runs.

Marginal posterior distributions are presented for the 'Estimate *M* & *h*' base run for the primary parameters (Figure G17), the annual spawning biomass (Figure G18) and the annual age 1 recruitments (Figure G19). We note that these posteriors show appropriately wide distributions in many instances (particularly for some of the selectivity parameters; Figure G17). However, in most instances, the mode of the posterior distribution is very close to the MPD estimates for the base run, indicating that the base run posterior distributions do not appear to be skewed by data outliers. Summary statistics (5^{th}, 50^{th} and 95^{th} quantiles) of the posterior distributions are presented in Table G3 for all the primary parameters from each of the four model runs investigated.

Boxplots of the posterior distributions of age 1 recruitment by year for each of the assessment runs show the consistency in the interpretation of the age composition data by each of these assessment runs, in spite of the difference in the underlying assumptions regarding *M* and *h* (Figure G20). However, while the recruitment patterns are similar for all four model runs, the scale of the recruitments is much lower for the two runs which fixed M.

The difference in scale between the two pairs of model runs (estimated and fixed *M*) can be clearly seen in comparative plots of the posterior distributions for the QCS synoptic survey catchability coefficient (Figure G21). The two 'Estimate *M*' runs have survey q_2 posterior distributions with a mode near 0.35 (that is, these runs estimate that this survey is monitoring about one-third of the available biomass with a low probability of a long right-hand tail) while the two 'Fixed *M*' runs are bimodal with considerable weight for parameter estimates from 0.5 to nearly 1.0 (well to the right of the MPD estimate). This latter result implies that the lower biomass levels estimated by the two 'Fixed *M*' runs result in a relatively large probability of high levels of efficiency for this survey. However, such high levels of efficiency seem implausible, lending credibility to the model runs which estimate *M*.

Plots of the prior and posteriors for the estimates of *M* for the two runs which estimated these parameters show almost no difference in the posterior distribution for either sex, regardless of whether *h* was estimated concurrently or held fixed (Figure G22). The estimate of *M* is shifted well to the right-hand tail of the prior distribution, but does not extend very much beyond it. This shift, in the face of the tight prior placed on this parameter, indicates that there is a strong tendency in the data to favour a higher value for *M*, given the model assumptions.

This is in contrast to the behaviour of the *h* (steepness) parameter, which shows relatively little divergence from the prior when *M* is estimated concurrently (although it shifts to the right), while showing a greater shift to the right when *M* is held fixed (Figure G23). This difference in behaviour may indicate that the *h* parameter, when *M* is held fixed, may be compensating for some of the adjustments that the model makes when it can change *M*. In either case, the tendency is to favour a somewhat higher value for steepness relative to the mean of the prior. Note that there appears to be almost no correlation between *M* and *h* for either sex (correlation

coefficient ρ = -0.07 for females and ρ = -0.06 for males; Figure G24) when these parameters are estimated concurrently.
The model run that estimates both *M* and *h* has been selected as the base run on the basis that the resulting posterior distributions for these parameters are credible, being within the prior distributions (Figure G22 and Figure G23). Also, the posterior distributions of *M* and *h*, when estimated independently of each other, are nearly the same as when they are estimated concurrently (particularly the *M* posteriors). This result indicates that the estimates of these parameters are not highly interdependent. This conclusion is supported by a pairs plot of the posteriors for *M* and *h* (Figure G24), showing that when these parameters are estimated concurrently, they are not strongly correlated. Given that the model is capable of estimating *M* and *h*, it seems preferable for these parameters to be estimated in a Bayesian context, using strong priors to ensure that the posterior distributions remain credible. Pairs plots for all the parameters listed in Θ in equation (F.16) are shown in Figure G39, demonstrating that the MCMC process had apparently converged on a solution.

Plots of the posterior distributions for the estimated selectivity functions show relatively wide credibility bounds for the GIG historical series for females (Figure G25) and males (Figure G26). However, the posterior distributions for both sexes have shifted well away from the informed prior in all model runs because the lower 5th quantile is greater than or similar to the mean of the prior. This observation is also very true for the QCS synoptic survey, where the lower 5th quantile is well to the right of the prior for females (Figure G27) and males (Figure G28). Clearly this shift is caused by the availability of age samples from each of these trawl surveys series and indicates that the Alaskan survey from which the prior was formulated appears to have sampled younger POP than do the Canadian surveys. In contrast, the selectivity functions for the commercial fishery are tight for both females (Figure G29) and males (Figure G30) in all four model runs, in spite of the lack of informed priors to control these parameters. Initial model exploration used informed priors for these parameters, but these were changed to uniform when it was discovered that the model ignored the prior entirely when estimating these parameters. This behaviour reflects the large amount of available data and the consistency in ageing protocol over the 32 years spanning the ageing data, as well as the assumption that selectivity has been invariant over the model reconstruction period. Note that mature females are fully vulnerable to fishing, given the estimated selectivity ogive in Figure G29.

Plots of the trajectory of vulnerable biomass (Figure G31) reflect the strong year classes estimated from 1951 to 1954 (see Figure G19 and Figure G20 – note that the spread of strong year classes across four years may reflect some ageing error relative to a single very strong year class in the early 1950s). The presence of these strong year classes drove up the stock size and supported the very large foreign fleet fisheries in the mid- to late-1970s. Subsequently the vulnerable stock size declined until the mid-1980s, when it increased again due to strong year classes which were spawned in the late 1970s (see Figure G19 and Figure G20). The large fisheries which preceded the imposition of Individual Vessel Quotas (IVQs) to the bottom trawl fishery in the mid-1990s again drove down the stock size into the years following 2000, after which the model estimates that there has been a mild recovery to the most recent year. This story is similar for all four runs whether the plots show vulnerable or spawning biomass (Figure G32), although the final upturn is more apparent for the vulnerable rather than the spawning biomass. This difference in recovery trajectories may be due to above average recruitment for several year classes spawned around the year 2000 which have entered the vulnerable population but which have not yet recruited to the spawning population. These fish will tend to recruit at an earlier age to the fishery than to the spawning population because the maturity ogive is shifted to the right of the commercial selectivity ogive (see Figure G29).

Estimation of B_{MSY}

The biomass at the maximum sustainable yield, B_{MSY}, was estimated for all four runs by projecting the stock forward from each posterior sample across a range (0 to 0.3) of constant harvest rates until equilibrium was reached, with the exploitation rate giving the greatest equilibrium yield becoming U_{MSY}, the equilibrium biomass associated with that exploitation rate becoming B_{MSY}, and the yield associated with that biomass becoming MSY. Plots of the marginal posterior densities of the ratio B_{MSY}/B_0 for each model run show that B_{MSY}/B_0 varies considerably when *h* is estimated but is effectively constant when *h* is fixed (Figure G33). This observation is also true for U_{MSY} (Table G4), but not true for MSY, which shows a great deal of variation when either *M* or *h* is estimated (Figure G34).

All four runs estimated the median ratio for B_{MSY}/B_0 to be between 0.24 and 0.29 (Table G4). However, the two runs which estimated the steepness parameter *h* tended to have lower values for this ratio and a much broader distribution of values for B_{MSY} and B_{MSY}/B_0. The expected value for the spawning biomass at the start of 2011, B_{2011}, is near to or above B_{MSY} for the two runs which estimated *M* while the upper 95^{th} quantile only just reaches this level for the 'Estimate *h*' run and is not even near B_{MSY} for the 'Fixed *M* & *h*' run (compare B_{MSY} and B_{2011} in Table G5).

Performance indicators and management advice

Projections were made for five years starting with the beginning year biomass in 2011 and ending with the 2015 catch year under a range of constant catch scenarios based on the parameters from the MCMC-generated posterior distributions for the four model runs. Random recruitments scaled to the mean average recruitment from each MCMC sample were generated from a normal distribution in log space with mean zero and standard deviation of 0.9. Note that these projections, given the longevity and consequent low natural mortality rate, will make use of year classes which were estimated during the stock reconstruction and that none of the new randomly generated recruitments will affect the projections because they will be too young to become part of the mature or vulnerable biomasses by the end of the five-year projection period.

Advice for management is reported using the DFO Science provisional reference points (termed "PA-compliant" – DFO 2006); a PA-compliant approach was requested by the DFO Pacific Region Groundfish Management Unit (GMU) (Appendix A). These reference points are the "limit reference point" (below which the stock should never go) of $0.4B_{MSY}$ and an "upper stock reference point" of $0.8B_{MSY}$. The zone below the limit reference point is termed the "critical zone" while the zone lying in between the limit and upper stock reference points is termed the "cautious zone". The region above the upper stock reference point is termed the "healthy zone". B_{MSY} is also reported here as an additional reference point.

Advice for management stemming from this assessment will vary depending on which model run is used. Figure G35 shows that the distribution of the ratio B_{2011}/B_{MSY} for the base run 'Estimate *M* & *h*' lies above 0.4 (so B_{2011} is above the limit reference point of $0.4B_{MSY}$), and is mostly above 0.8 (corresponding to the upper stock reference point). However, Figure G35 also shows that these conclusions differ for the other three model runs. Although the median of B_{2011}/B_{MSY} for the 'Estimate *M*' run lies above 0.8, it is closer to this reference point than for the base run and the upper tail does not extend as far to the right. The tails of the distribution of B_{2011}/B_{MSY} for both the 'Estimate *h*' and 'Fixed *M* & *h*' runs extend into the "critical zone" (< 0.4) while the median values for these runs lie within the "cautious zone" (Figure G35).

The vertical dimension of Figure G35 shows that only for the 'Estimate *M* & *h*' run does the bulk of the posterior distribution of U_{2010} / U_{MSY}, the ratio of the current exploitation rate to the exploitation rate associated with MSY, lie below one. For the 'Estimate *M*' model the median is at one, and for the other two models the medians and 10-90% credibility intervals are mainly or wholly above one, such that the current exploitation rate is estimated to be above the value that would give the maximum sustainable yield.
Figure G40 shows the trajectory since 1940 of the ratios shown in Figure G35.

The expected value for the PA-compliant yield for 2011 for the 'Estimate *M* & *h*' run is above MSY because it applies the posterior distribution of U_{MSY} to a posterior distribution of the 2011 biomass that is, on average, greater than B_{MSY} (Table G5 and see equation F.28). Similarly, the PA-compliant yields are lower than MSY for the remaining three runs because U_{MSY} will be discounted as described above.

Management advice is presented in the form of decision tables, based on the posterior distributions of projected spawning biomass under a range of constant catch scenarios from 0 to 6000 t/year. The probability of exceeding the limit reference point in 2016 over the range of catch projections is provided in Figure G36 and for all years from 2012 to 2016 in Table G6. Similarly, the probability of exceeding the upper stock reference point in 2016 over the range of catch projections is provided in Figure G37 and for all years from 2012 to 2016 in Table G7. Finally, the probability of exceeding B_{MSY} in 2016 over the range of catch projections is provided in Figure G38 and for all years from 2012 to 2016 in Table G8.

Figure G36 and Table G6 show that there is high probability of staying above $0.4B_{MSY}$ for the two runs which estimate *M* over all catch levels investigated while the two runs which fix *M* have lower probabilities of staying above the limit reference point, particularly the run which fixes both *M* and *h*. Only the runs which estimate *M* have a reasonable probability of staying above the upper stock reference point of $0.8B_{MSY}$ at the current level of catch (approximately 3500 t / year, the average for the most recent five years) (Figure G37; Table G7), with the two fixed *M* runs predicting that the stock would decline under this catch. Finally only the 'Estimate *M* & *h*' run predicts that stock size will stay near B_{MSY} under this catch (Figure G38; Table G8).

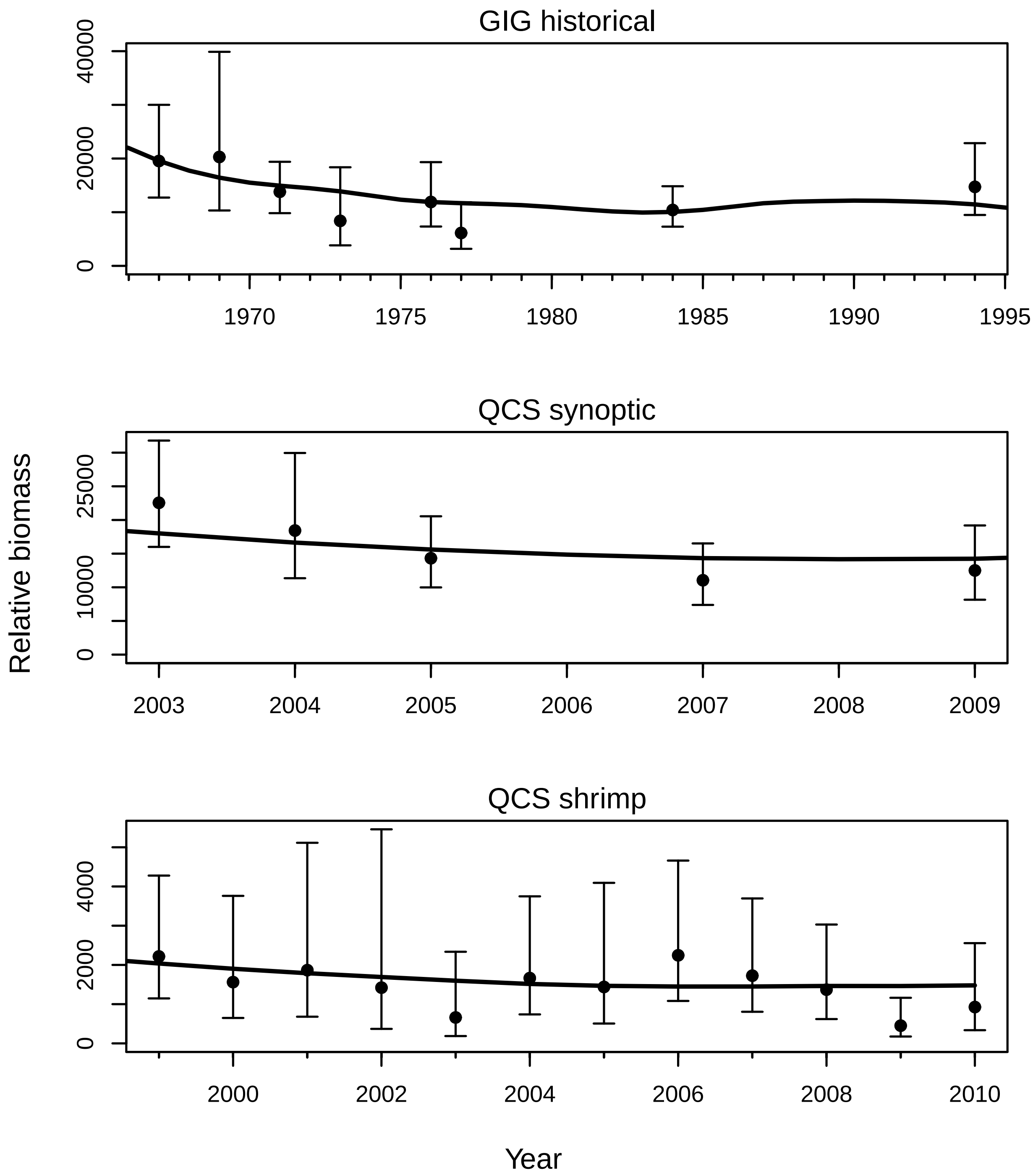
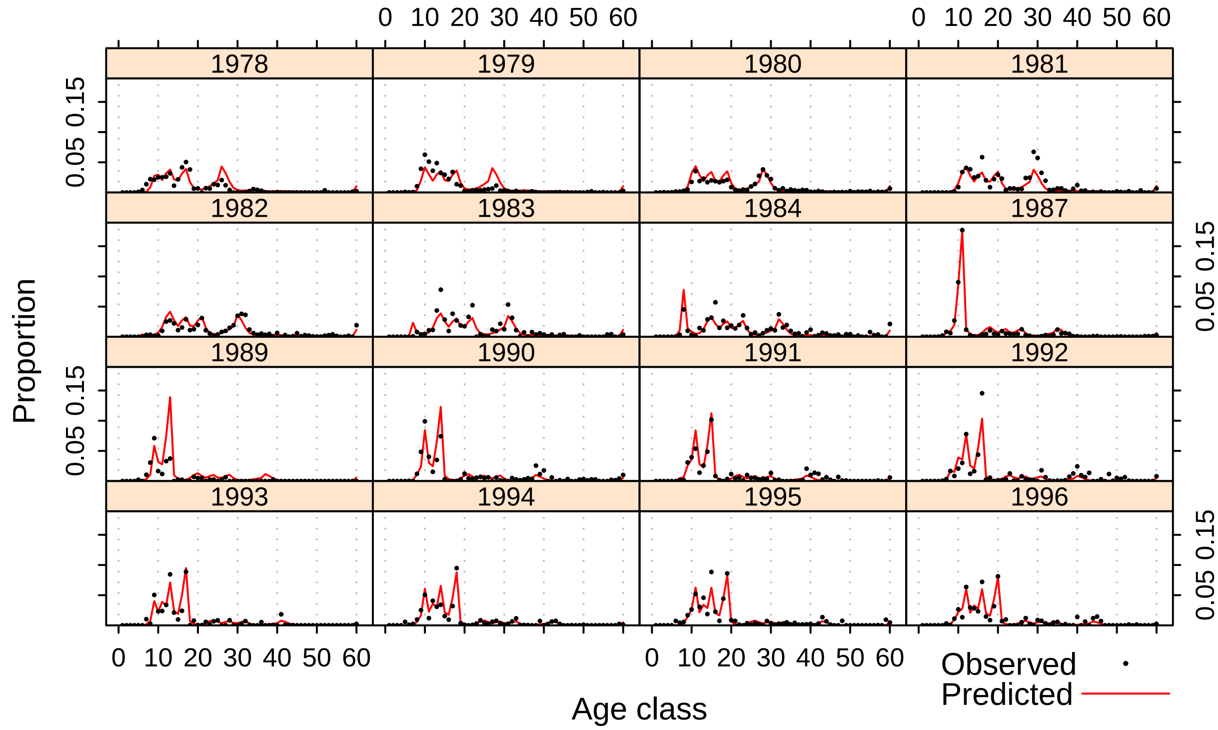


Figure G1. Survey index values (points) with 95% confidence intervals (bars) and MPD model fits (curves) for the three fishery independent surveys for the base run: Estimate M & h.

Female



Male

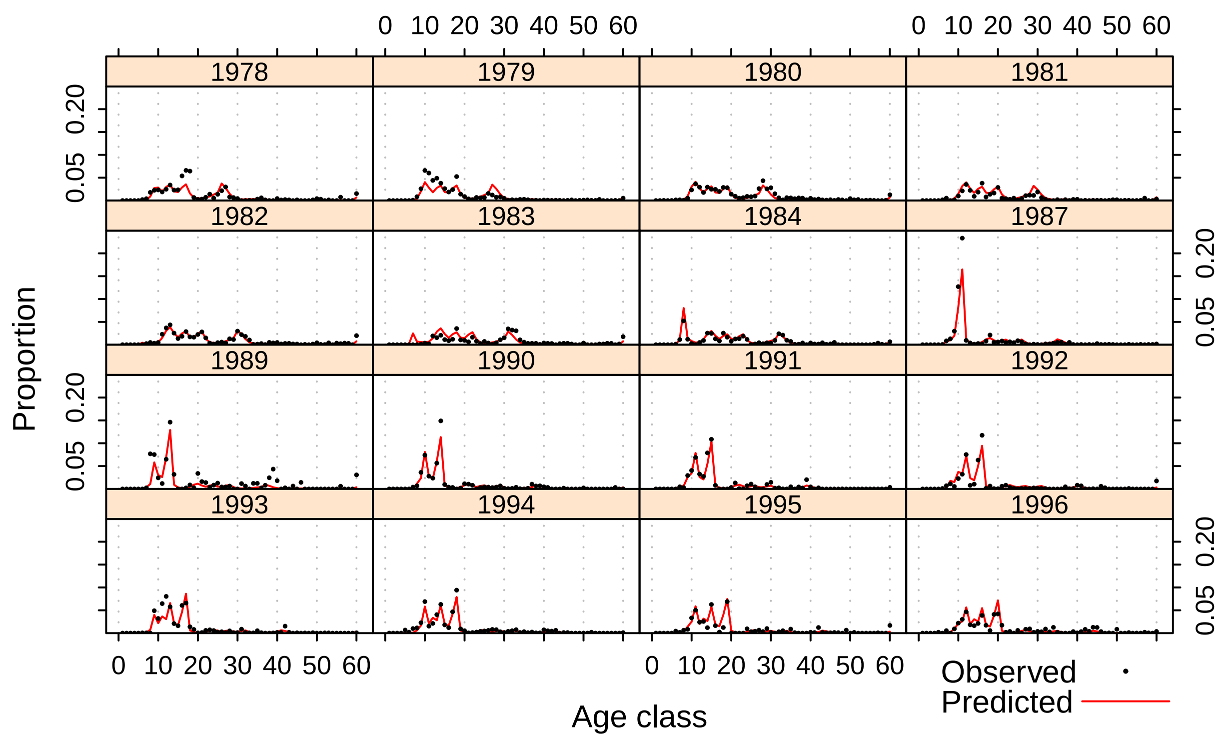


Figure G2. Observed and predicted proportions-at-age for the commercial data for base run: Estimate M & h, 1978-1996.

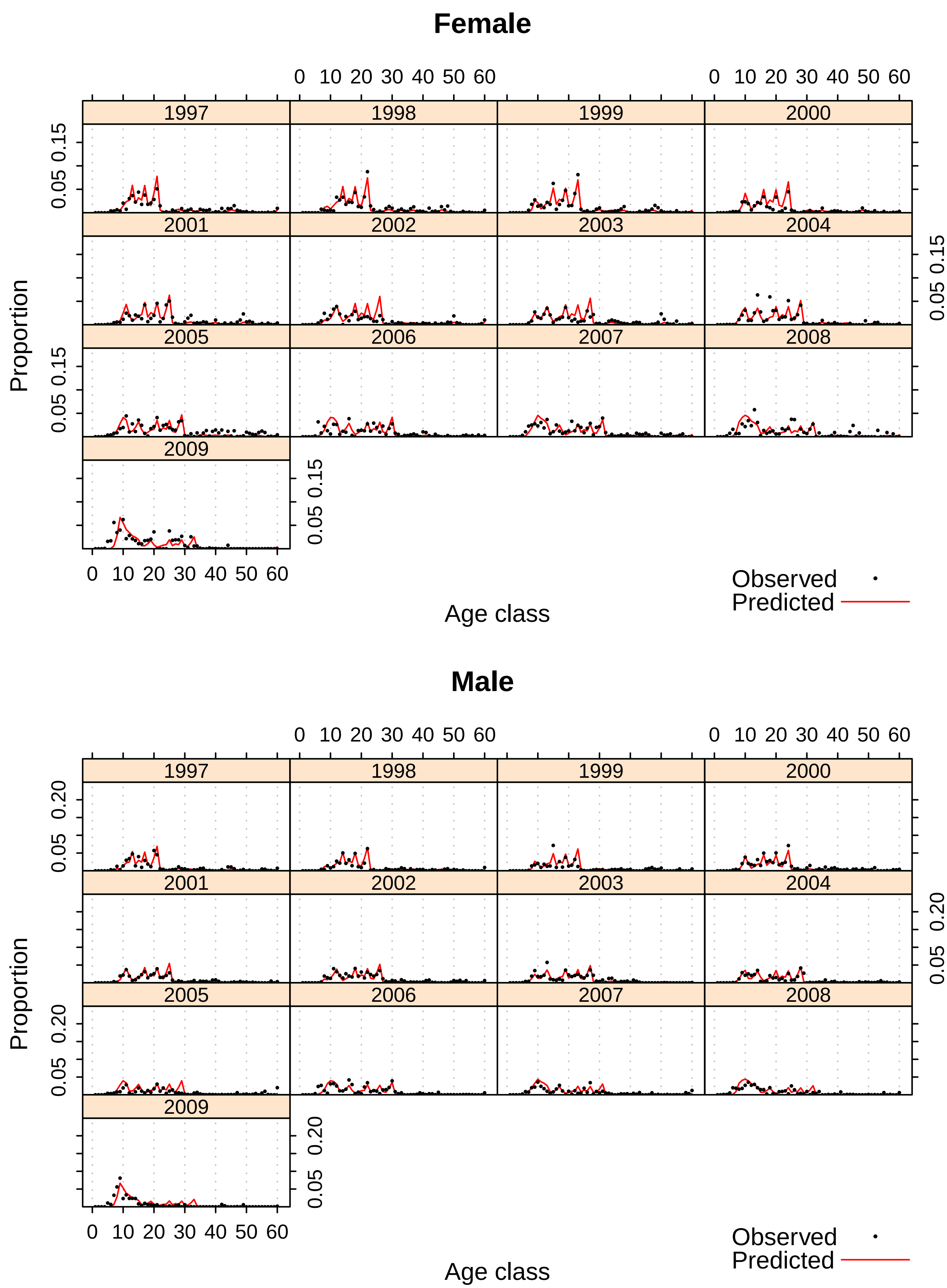


Figure G3. Observed and predicted proportions-at-age for the commercial data, 1997-2009 for base run: Estimate M & h.

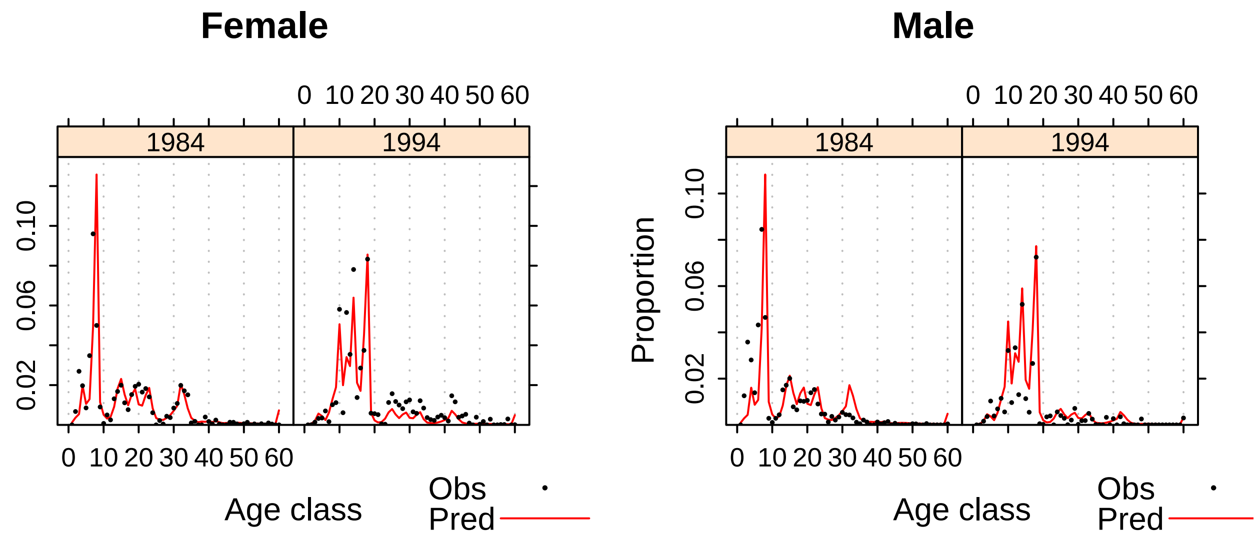


Figure G4. Observed and predicted proportions-at-age for the Goose Island Gully survey series for base run Estimate M & h.

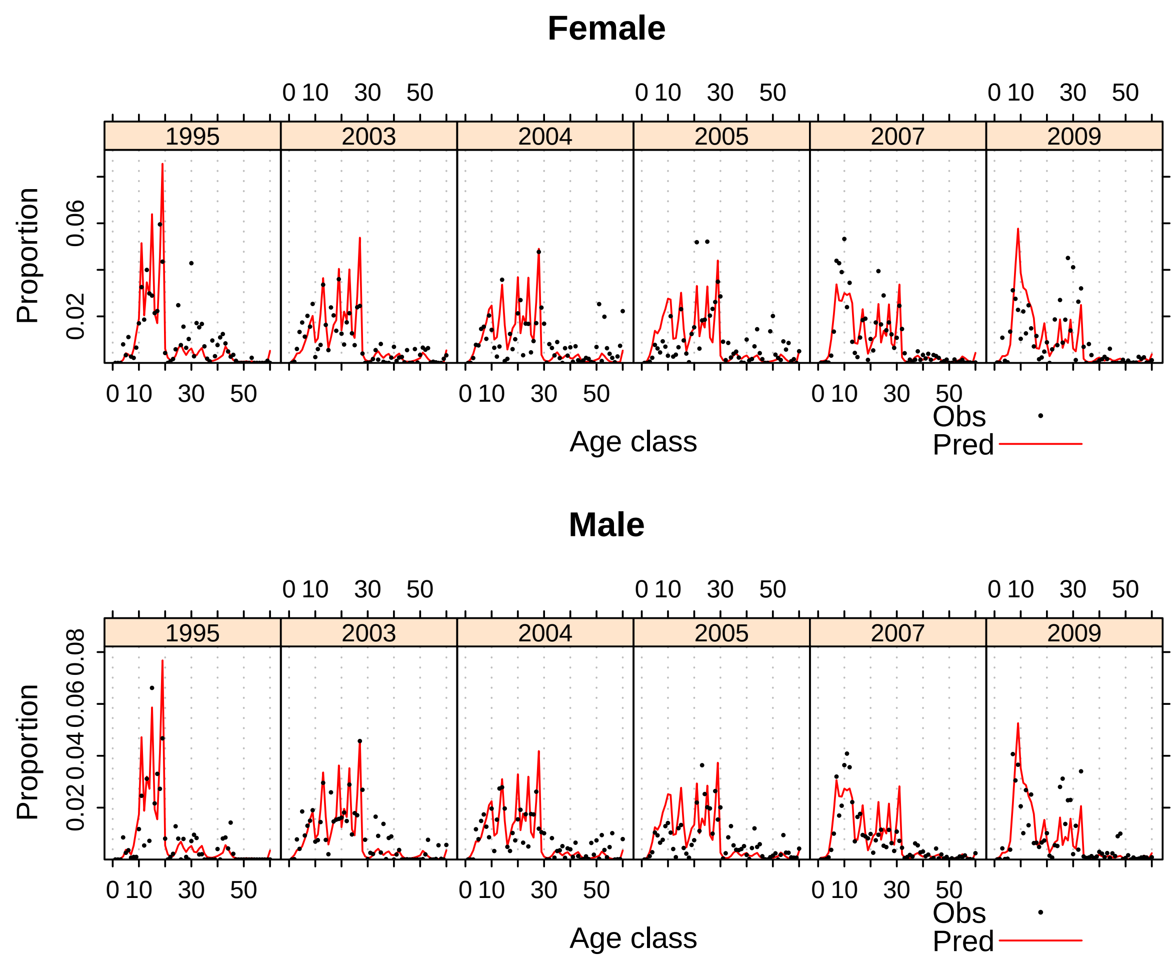


Figure G5. Observed and predicted proportions-at-age for Queen Charlotte Sound synoptic survey series for base run: Estimate M & h.

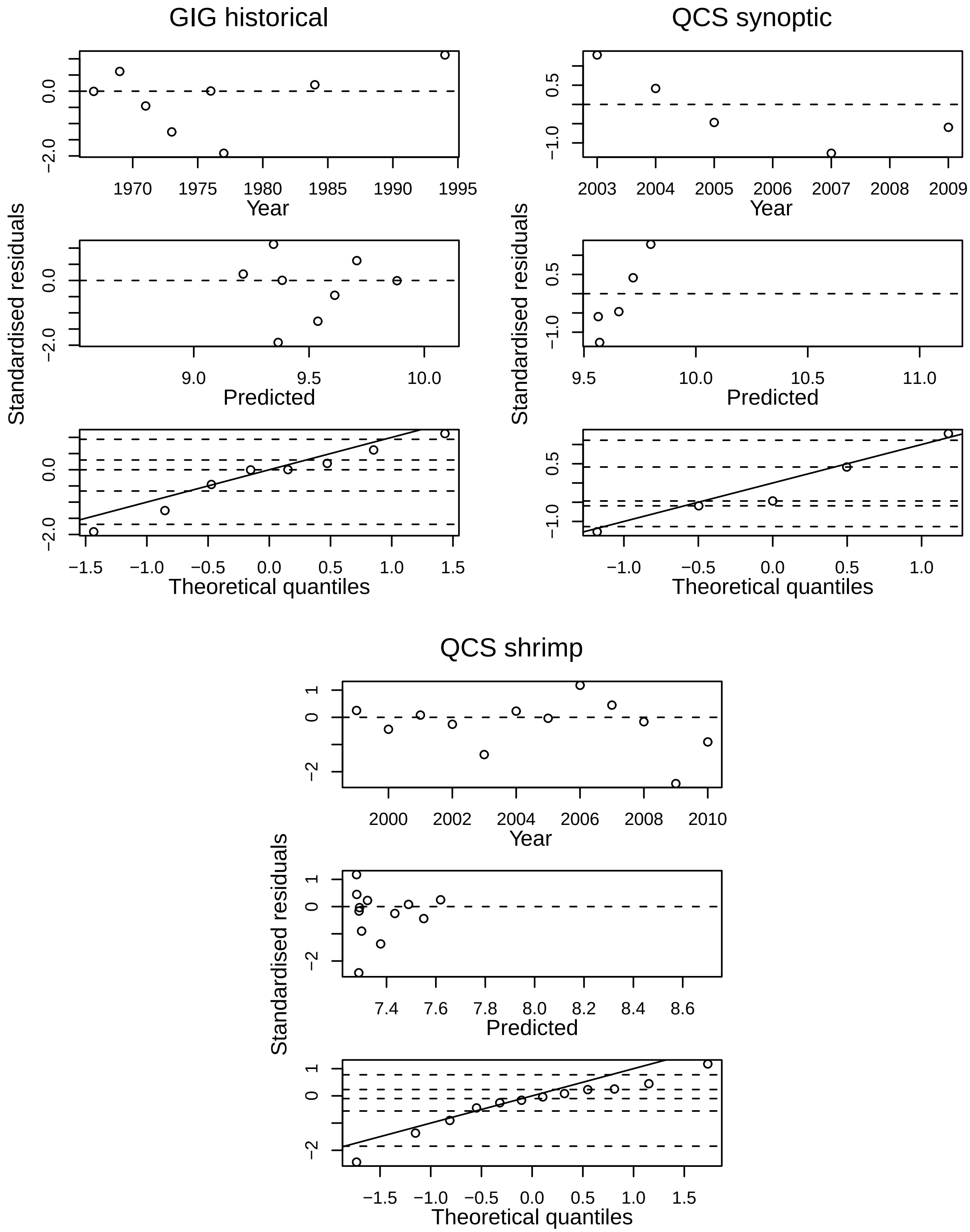


Figure G6. Residual of fits of model to each of three fishery independent surveys (MPD values) for base run: Estimate M & h. Vertical axes are standardised residuals. The two top plots show, respectively, residuals by year of index, and relative to the predicted index. Bottom panel is the normal qqplot for residuals, with the 1:1 line; horizontal lines give the 5, 25, 50, 75, and 95 percentiles.

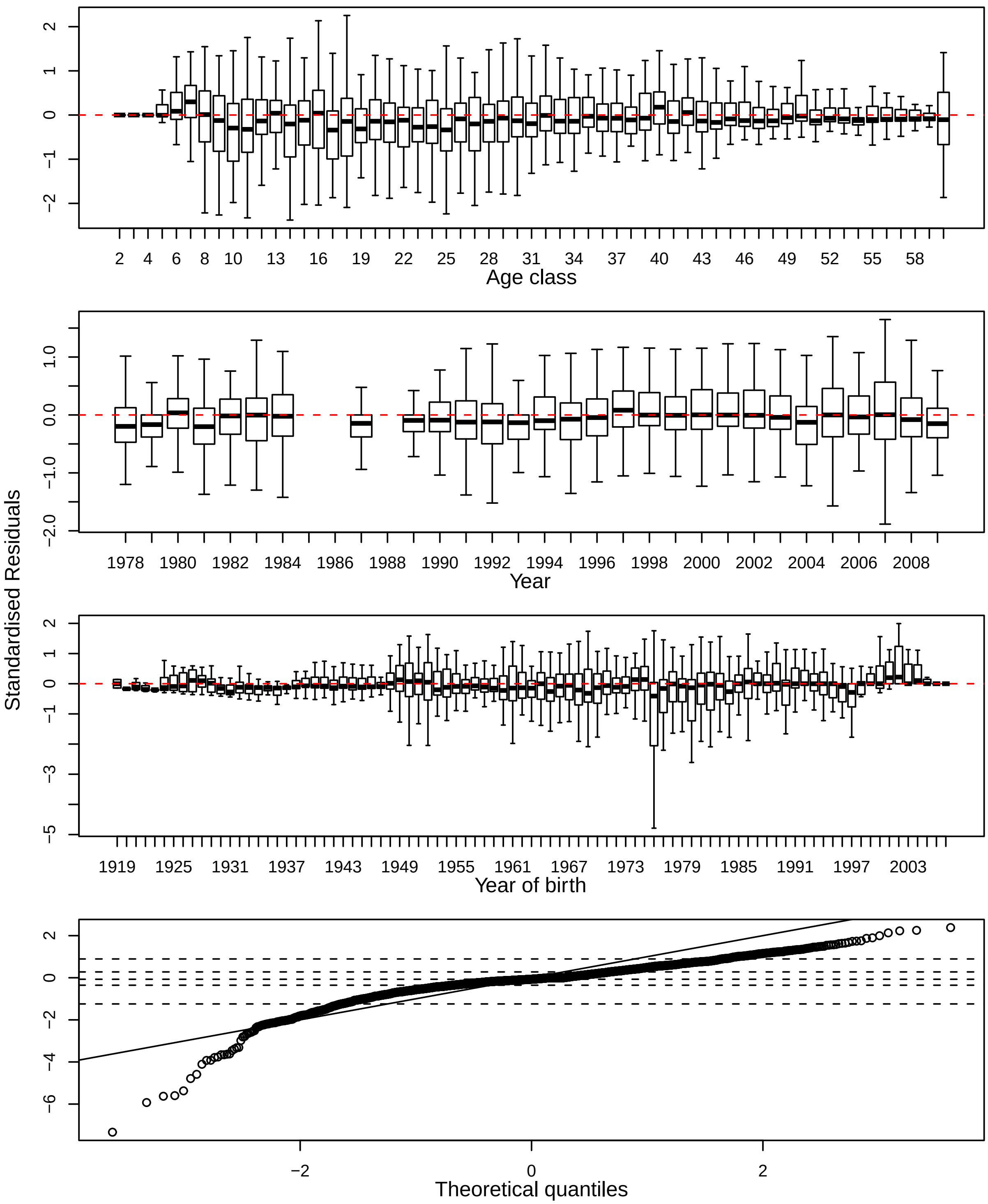


Figure G7. Residual of fits of model to commercial proportions-at-age data (MPD values) for base run: Estimate M & h. Vertical axes are standardised residuals. Boxplots show, respectively, residuals by age class, by year of data, and by year of birth (following a cohort through time). Boxes give interquartile 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 qqplot for residuals, with the 1:1 line; horizontal lines give the 5, 25, 50, 75, and 95 percentiles (for the total of 3,480 residuals).

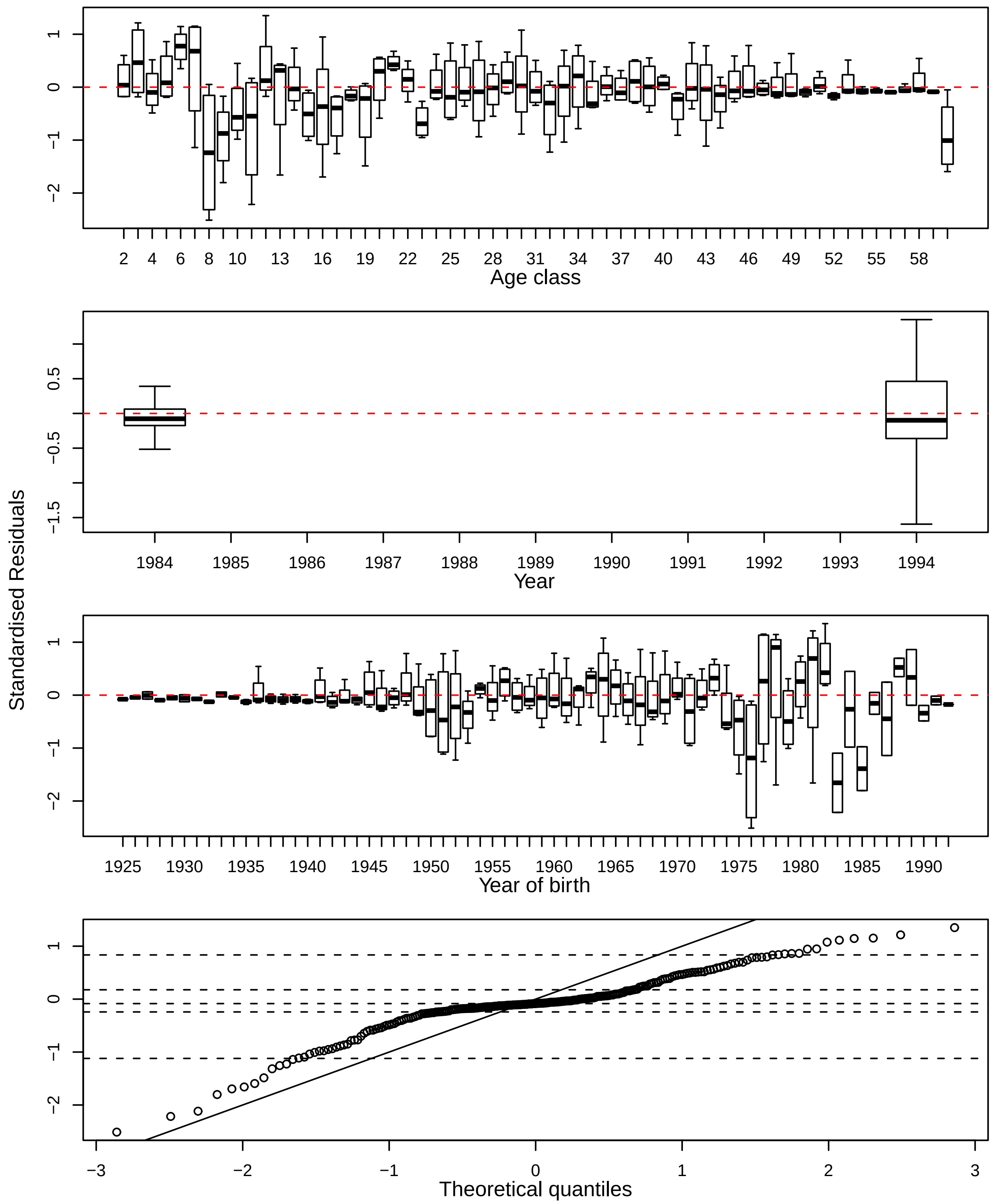


Figure G8. Residuals of fits of model to proportions-at-age data (MPD values) from historical Goose Island Gully survey series for base run "Estimate M & h". Details as for Figure G7, for a total of 240 residuals.

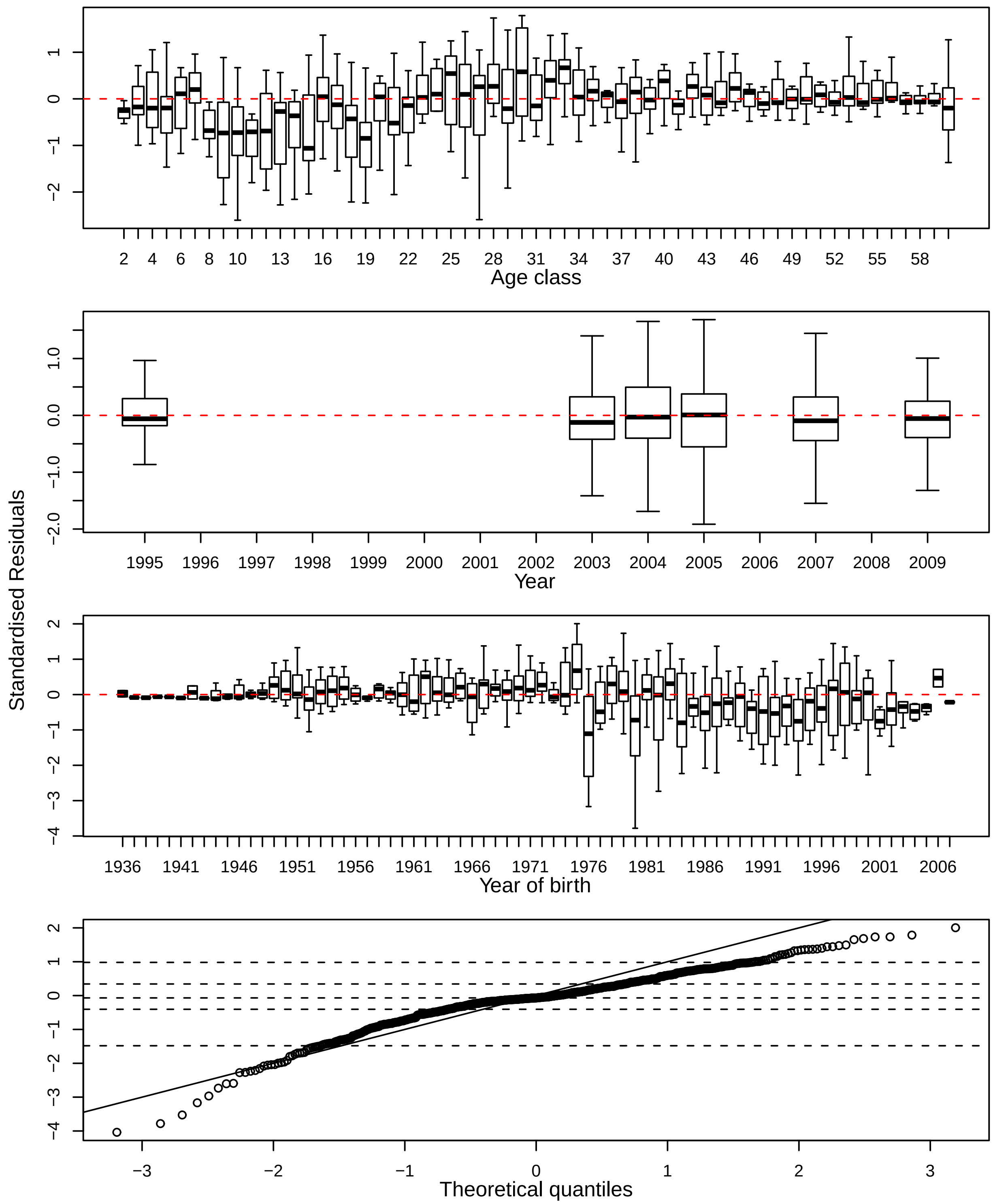


Figure G9. Residuals of fits of model to proportions-at-age data (MPD values) from Queen Charlotte Sound synoptic survey series for base run "Estimate M & h". Details as for Figure G7, for a total of 720 residuals.

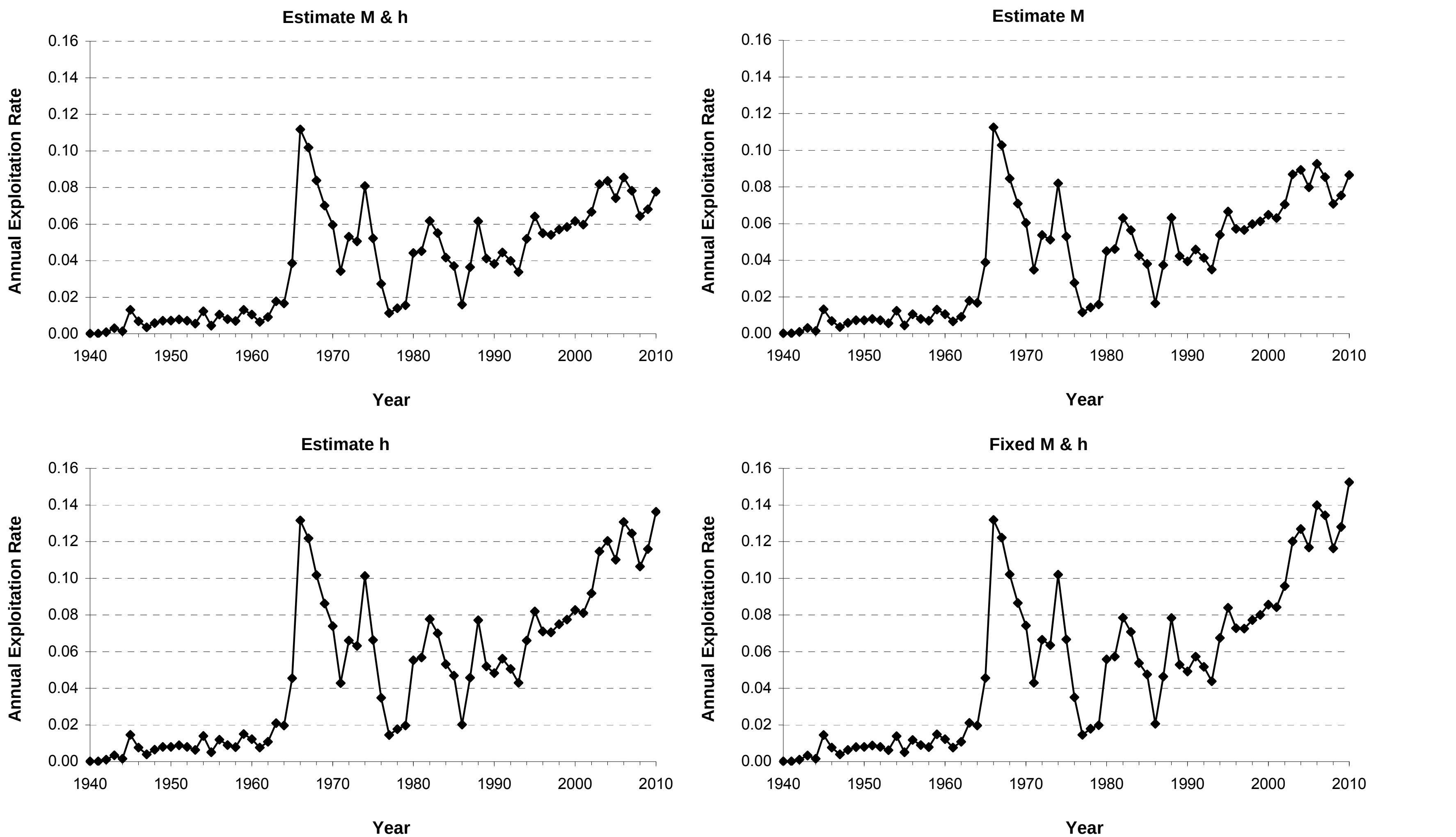


Figure G10. Annual exploitation rate (MPD values), calculated as the ratio of total catch to mid-year vulnerable biomass (see equation D.11)) for each of the four assessment runs .

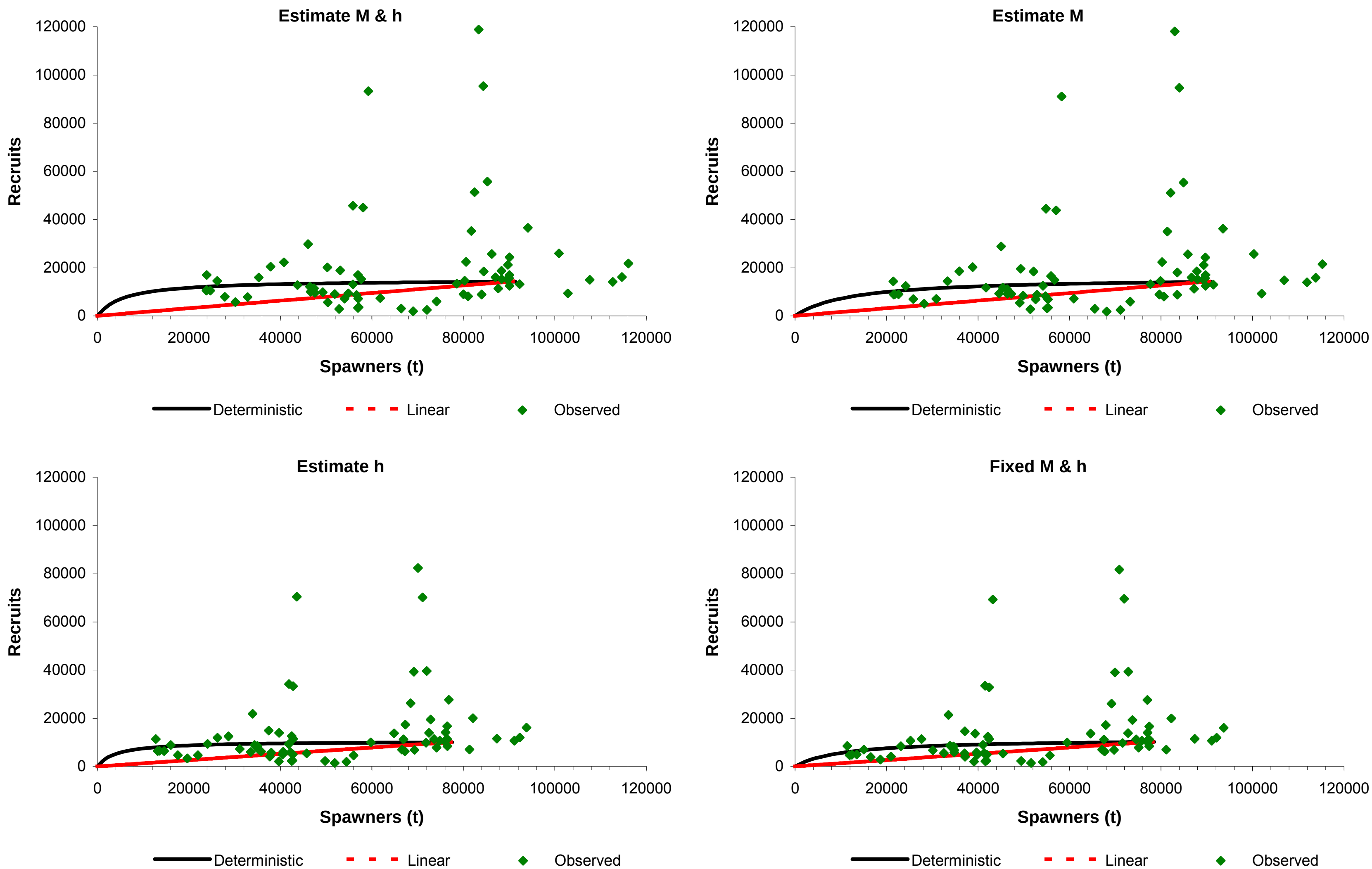


Figure G11. Stock-recruitment relationship (MPD values) for each of the four assessment runs.

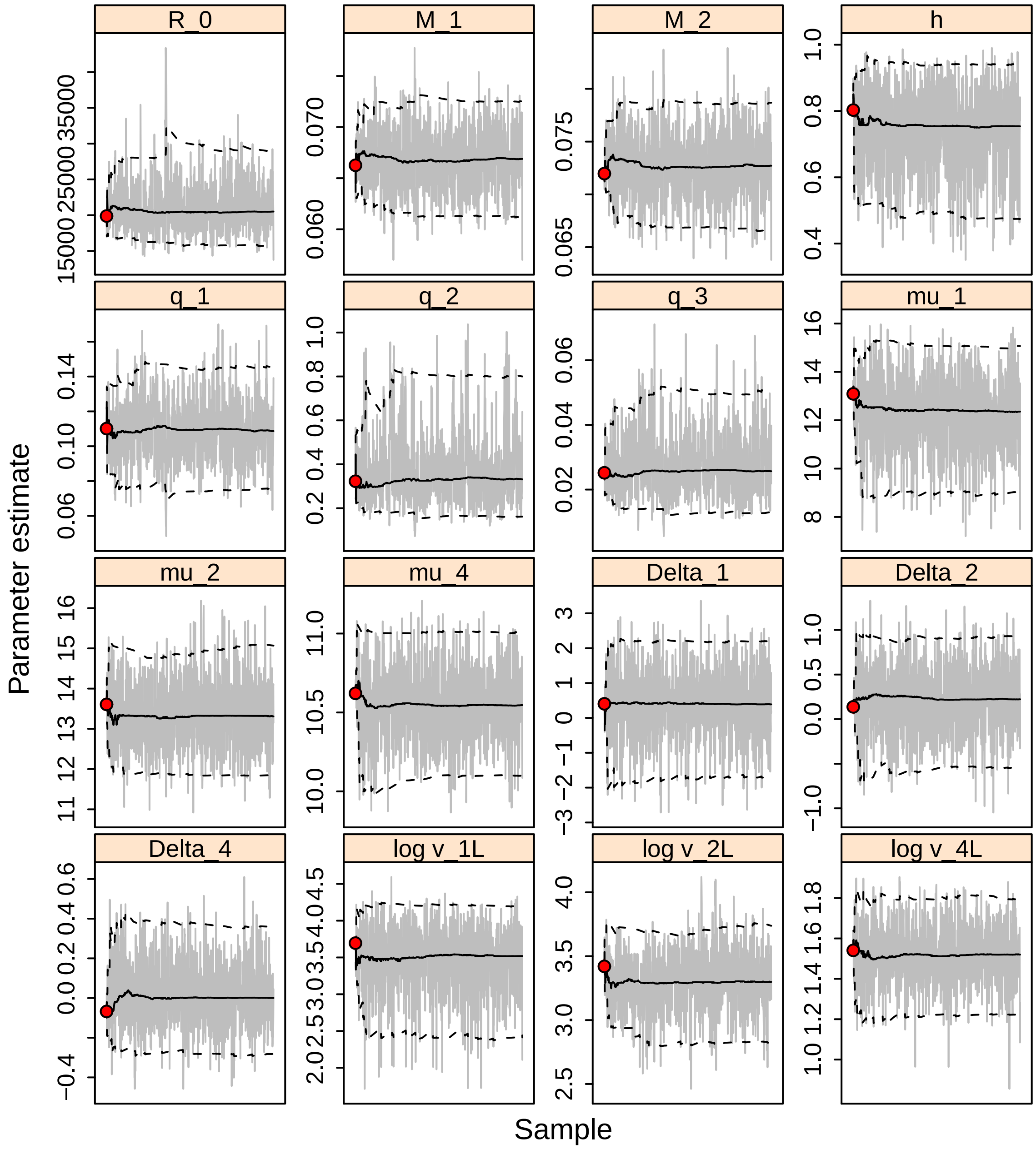


Figure G12. MCMC traces for the 19 primary estimated parameters for the base run "Estimate M & h". Grey lines show the 1000 samples for each parameter, solid lines show the cumulative median (up to that sample), and dashed lines show the cumulative 2.5 and 97.5 quantiles. Red circles are the MPD estimates. Subscripts 1 to 3 are the GIG historical survey, the QCS synoptic survey and QCS shrimp survey. Subscript 4 is the commercial fishery.

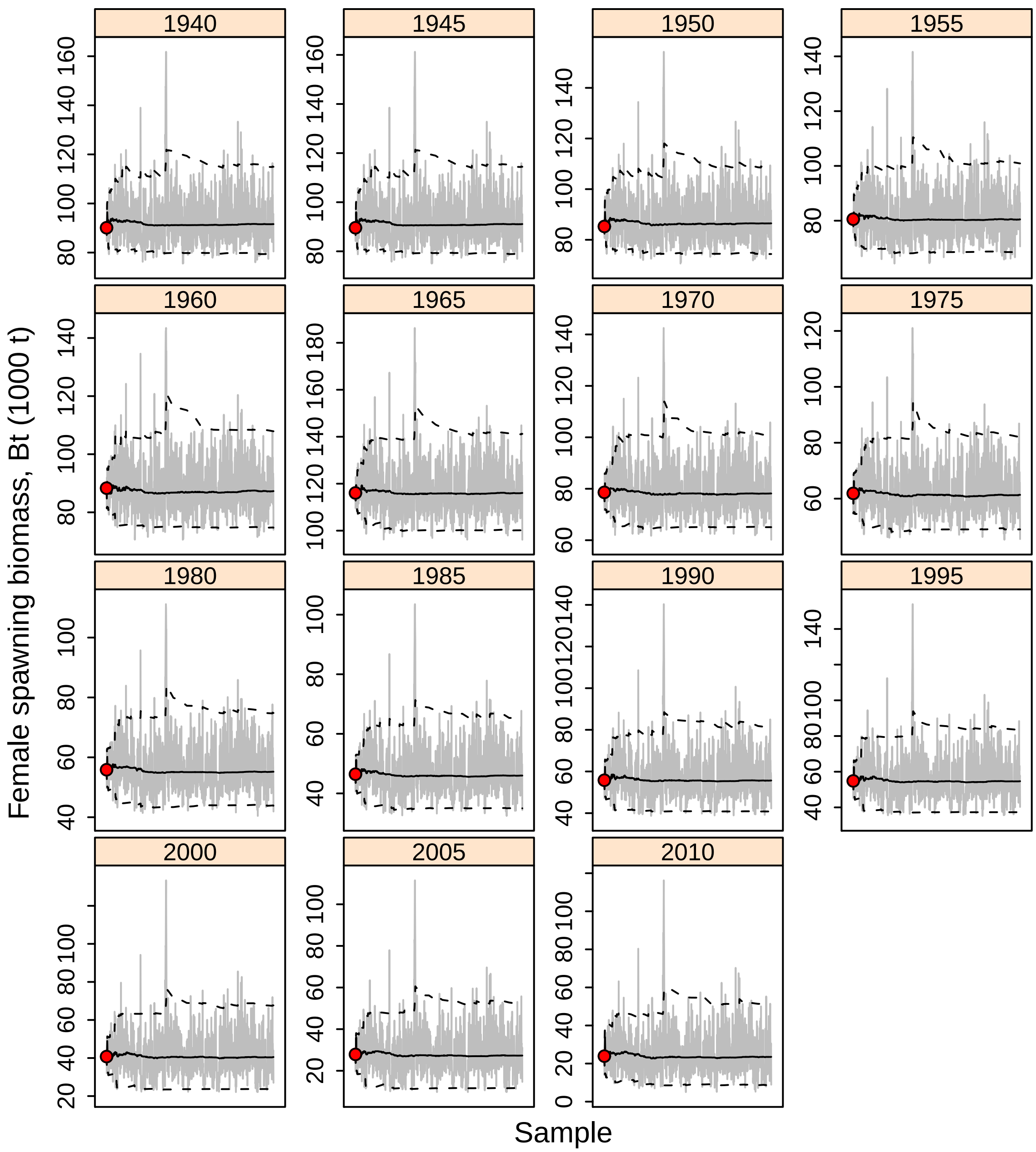


Figure G13. MCMC traces for female spawning biomass estimates at five-year intervals for the base run "Estimate M & h". Note that vertical scales are different for each plot (to show convergence of the MCMC chain, rather than absolute differences in annual recruitment). Grey lines show the 1000 samples 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.

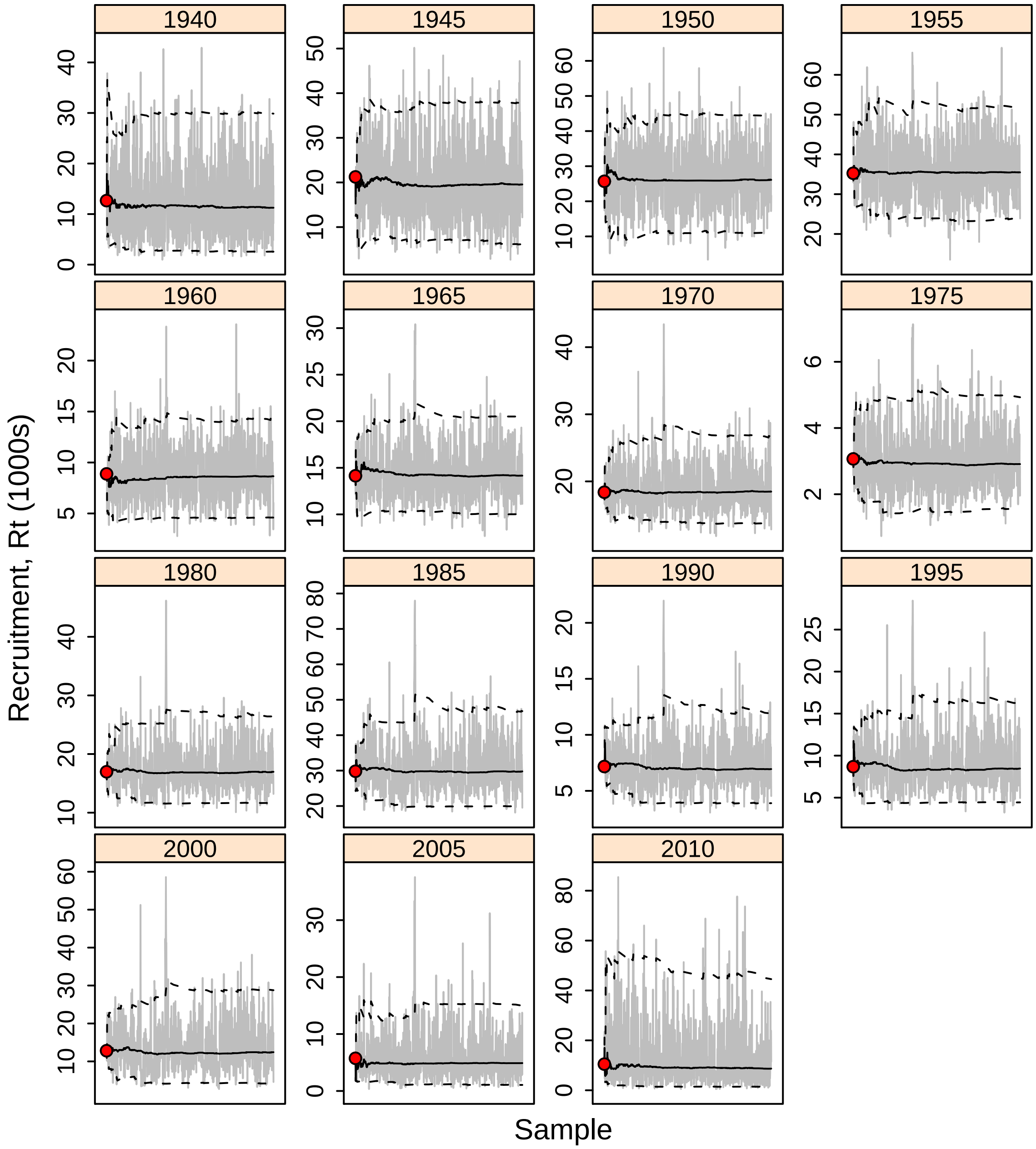


Figure G14. MCMC traces for recruitment estimates at five-year intervals for the base run "Estimate M & h". Note that vertical scales are different for each plot (to show convergence of the MCMC chain, rather than absolute differences in annual recruitment). Grey lines show the 1000 samples for each 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

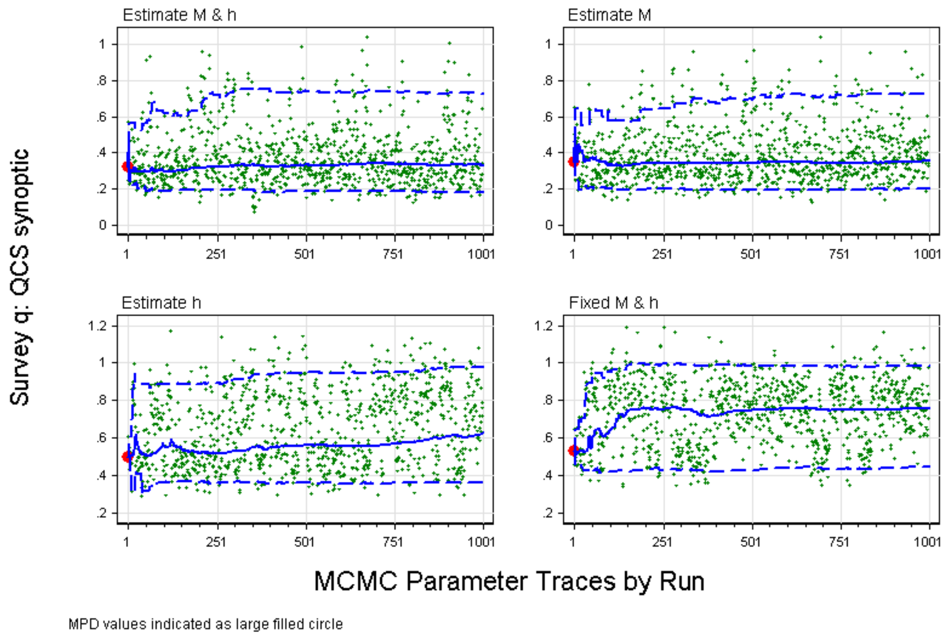


Figure G15. MCMC traces for the parameter q_2 for four POP assessment runs. Note that vertical scales are different for each plot (to show convergence of the MCMC chain). Red circles are the MPD estimates. Horizontal lines are the cumulative 5^{th}, 50^{th} and 95^{th} quantiles up to the sample number

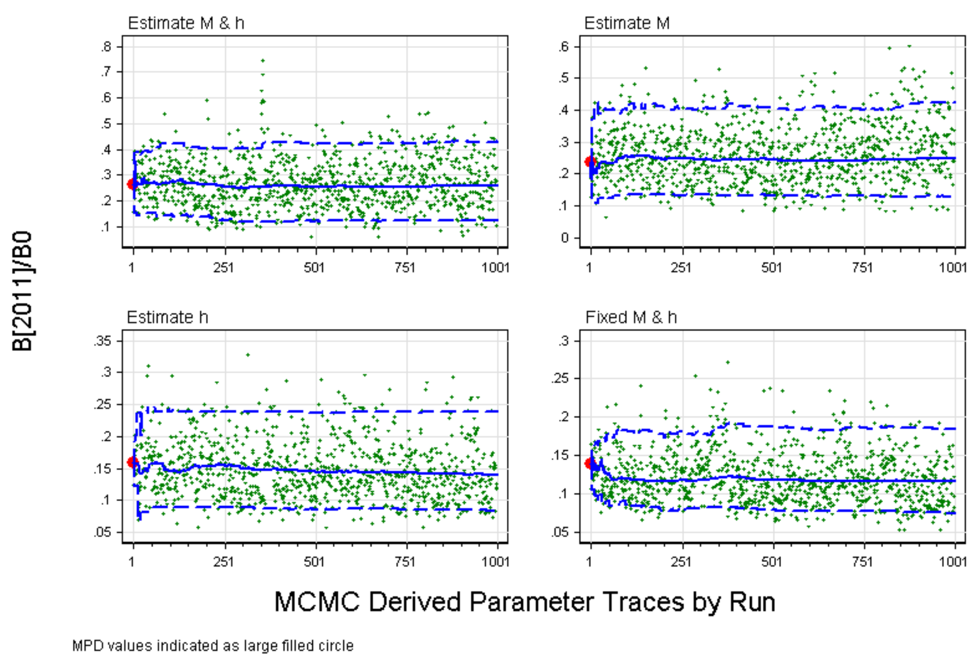


Figure G16. MCMC traces for the derived parameter B_{2011}/B_0 for four POP assessment runs. Note that vertical scales are different for each plot (to show convergence of the MCMC chain). Red circles are the MPD estimates. Horizontal lines are the cumulative 5^{th}, 50^{th} and 95^{th} quantiles up to the sample number

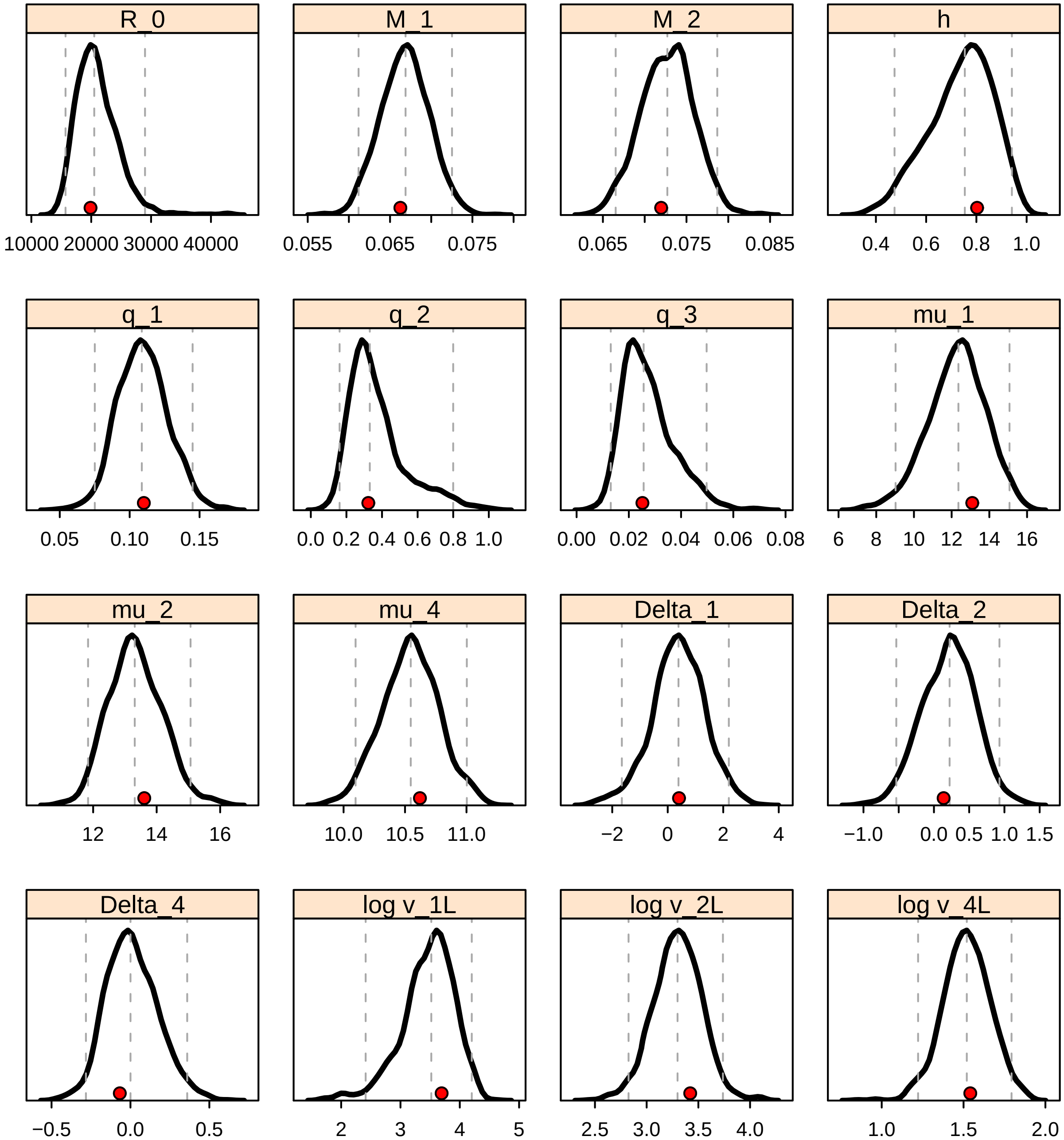


Figure G17. Marginal posterior densities for the 16 primary estimated parameters for the base run "Estimate M & h". Vertical lines represent the 2.5, 50 and 97.5 percentiles, and red filled circles are the MPD estimates. Subscripts 1 to 3 are the GIG historical survey, the QCS synoptic survey and QCS shrimp survey. Subscript 4 is the commercial fishery.

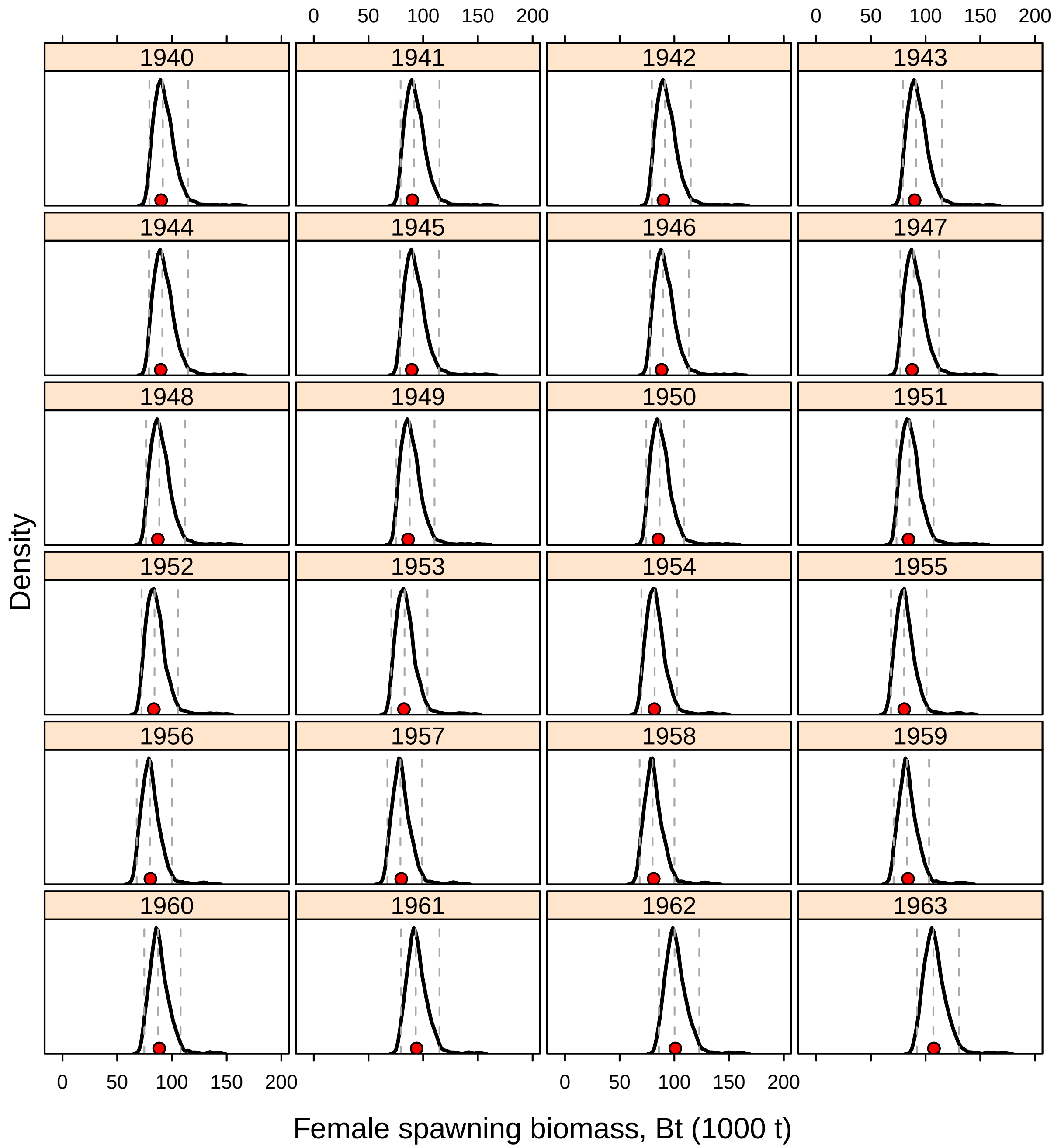


Figure G18. Marginal posterior densities for beginning year female spawning biomass (1000 tonnes) for years 1940-1963 for base run "Estimate M & h". Horizontal axes are all to same scale. Note that vertical axes are not to the same scale, but each is scaled to the peak of the density; with the area under each curve integrating to 1.0. Vertical lines are 2.5, 50 and 97.5 percentiles, and filled red circle indicates MPD value.

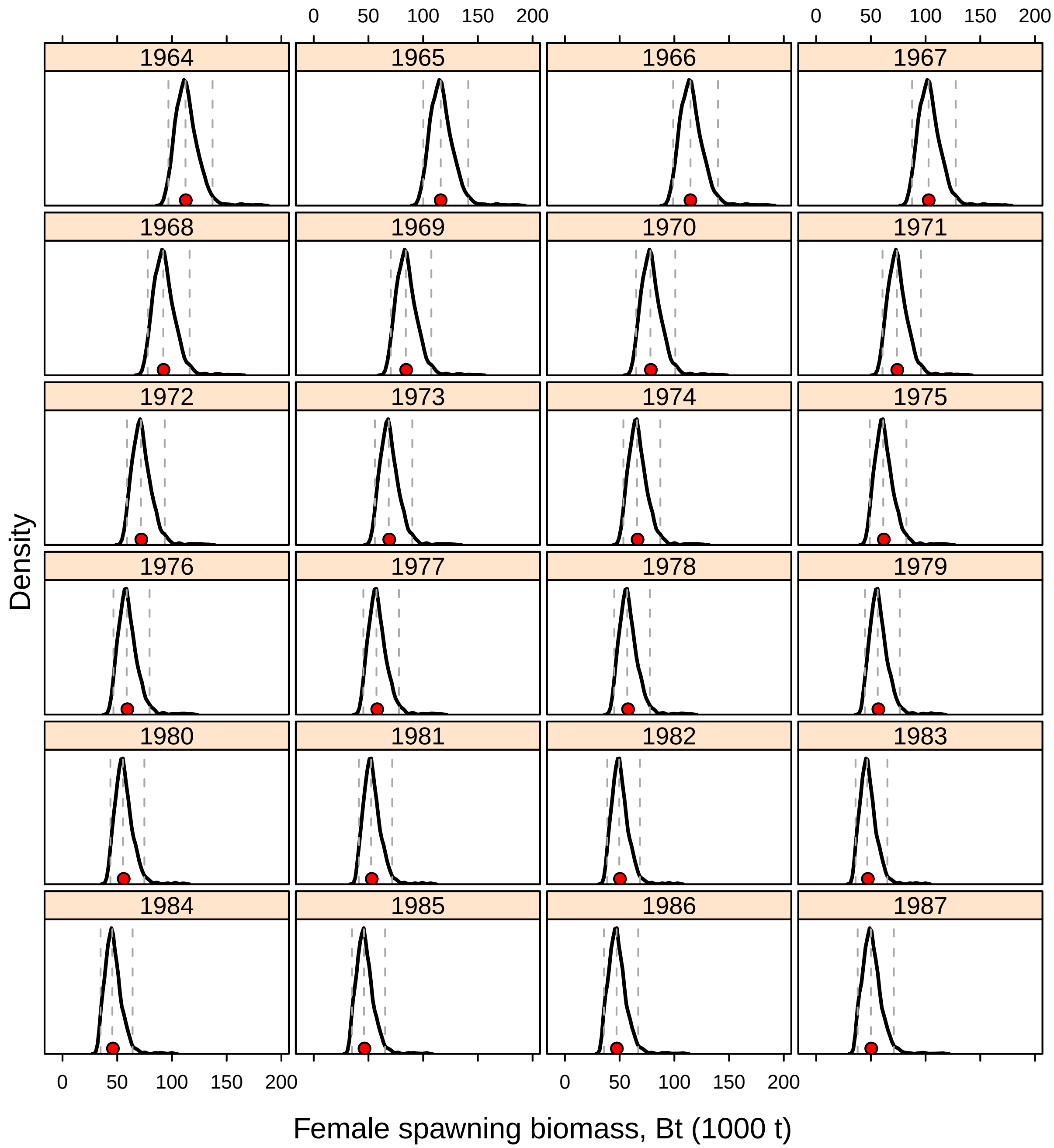


Figure G18 (cont.: for years 1964-1987).

.

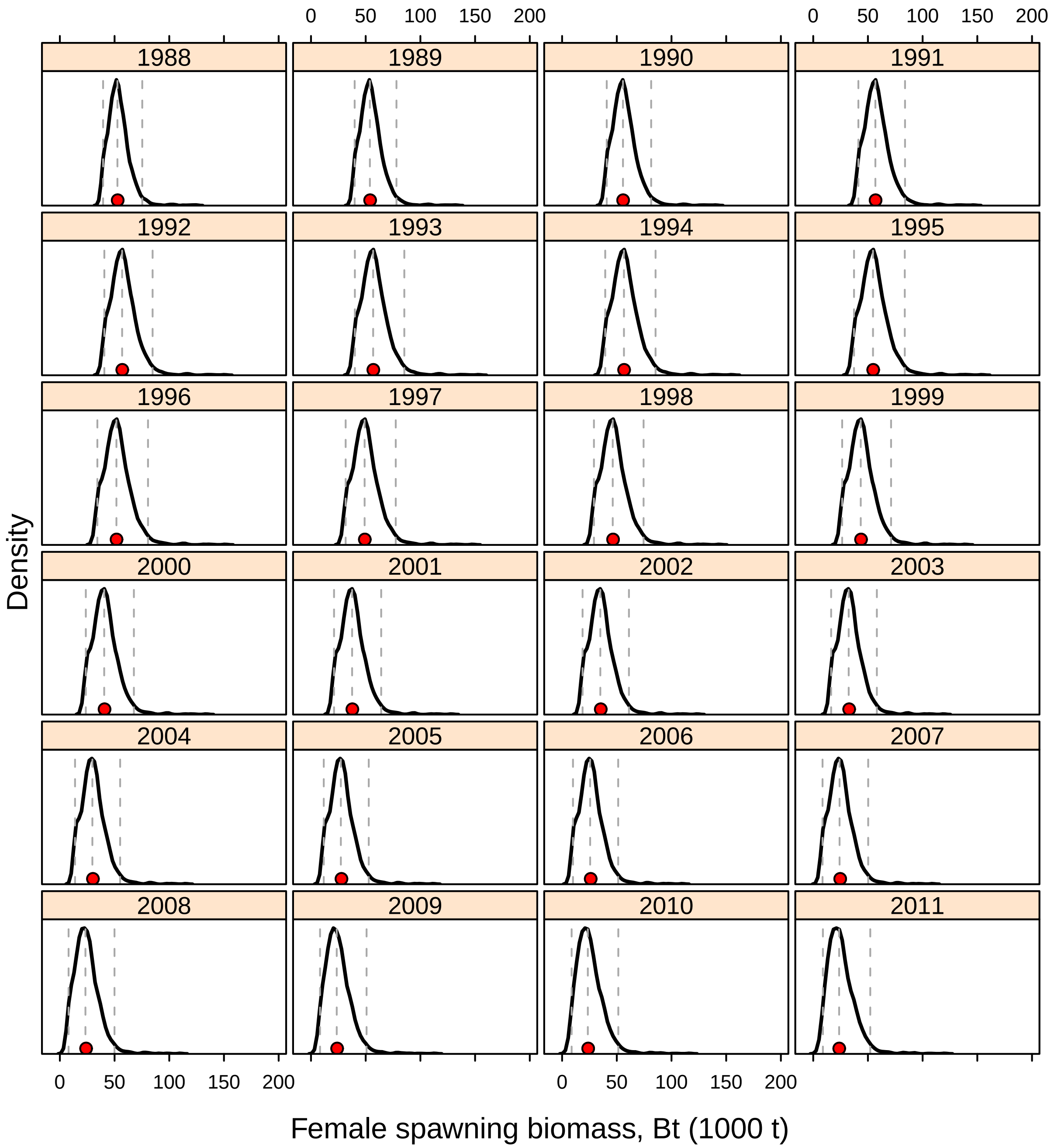


Figure G18 (cont.: for years 1988-2011).

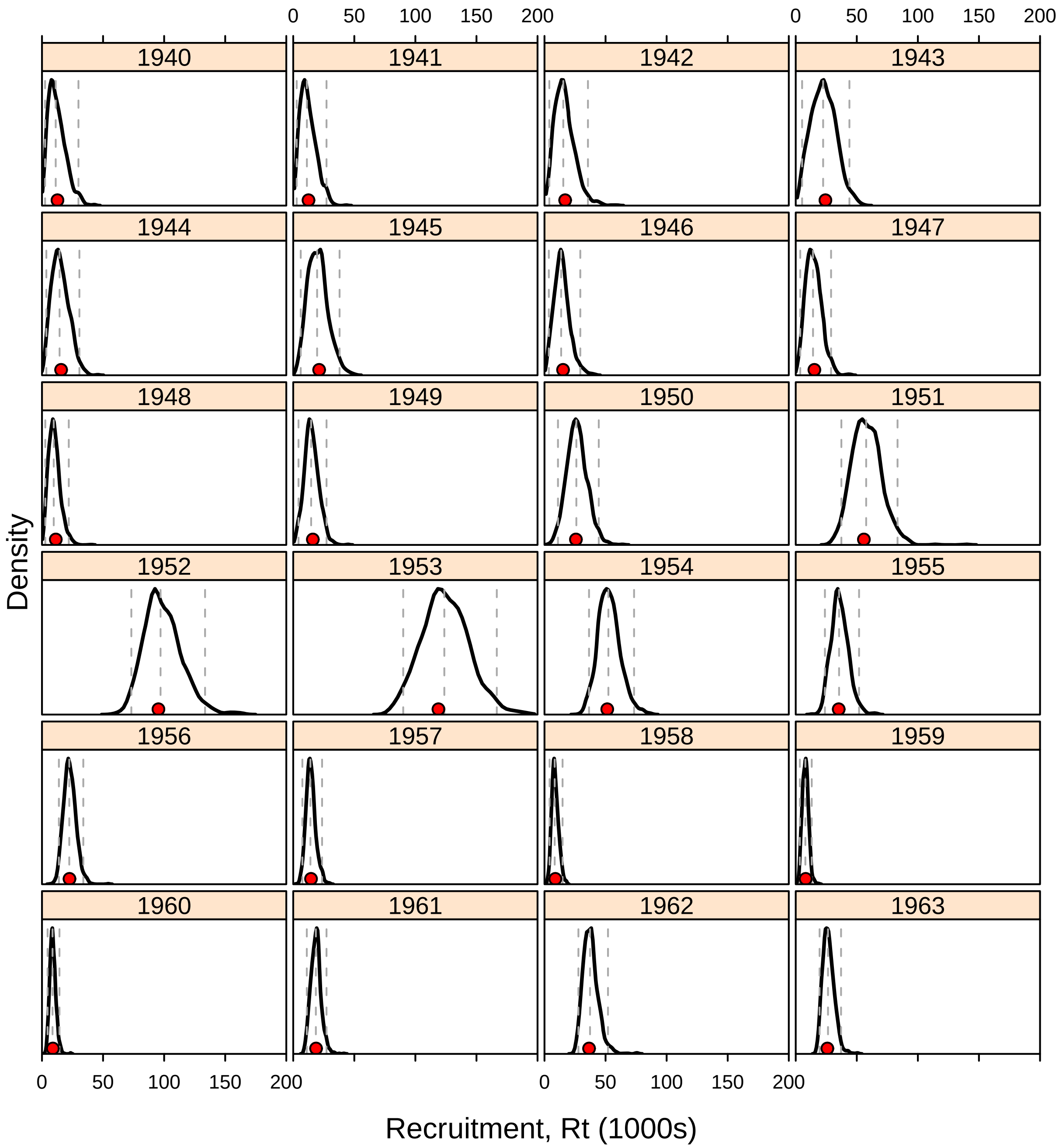


Figure G19. Marginal posterior densities for recruitment for years 1940-1963 for base run "Estimate M & h". Horizontal axes are all to same scale, such that large recruitments in certain years (e.g. 1953) can be seen. Note that vertical axes are not to the same scale, but each is scaled to the peak of the density; areas under each curve will integrate to 1.0. Vertical lines are 2.5, 50 and 97.5 percentiles, and filled red circle indicates MPD value.

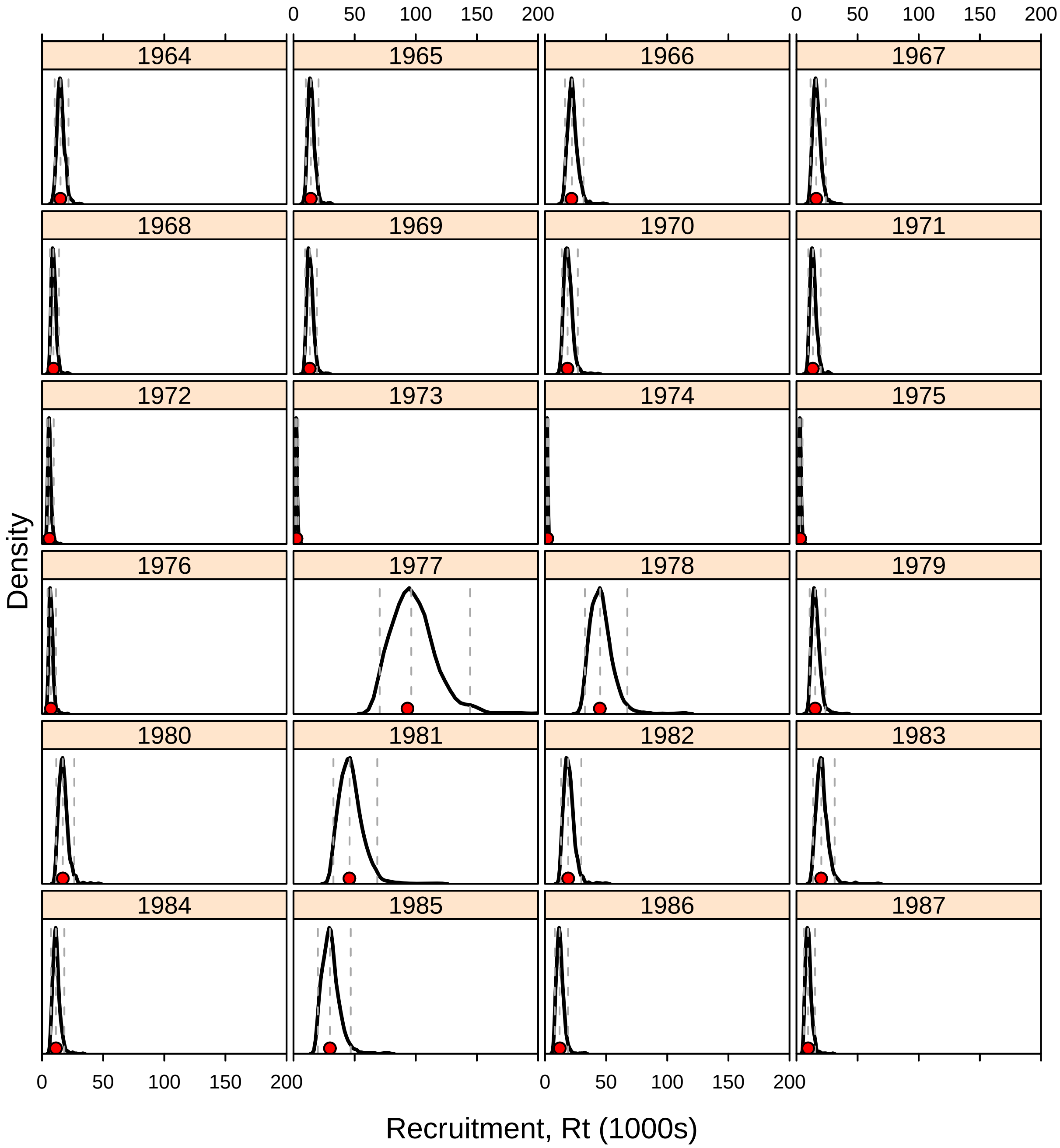


Figure G19 (cont.: for years 1964–1987).

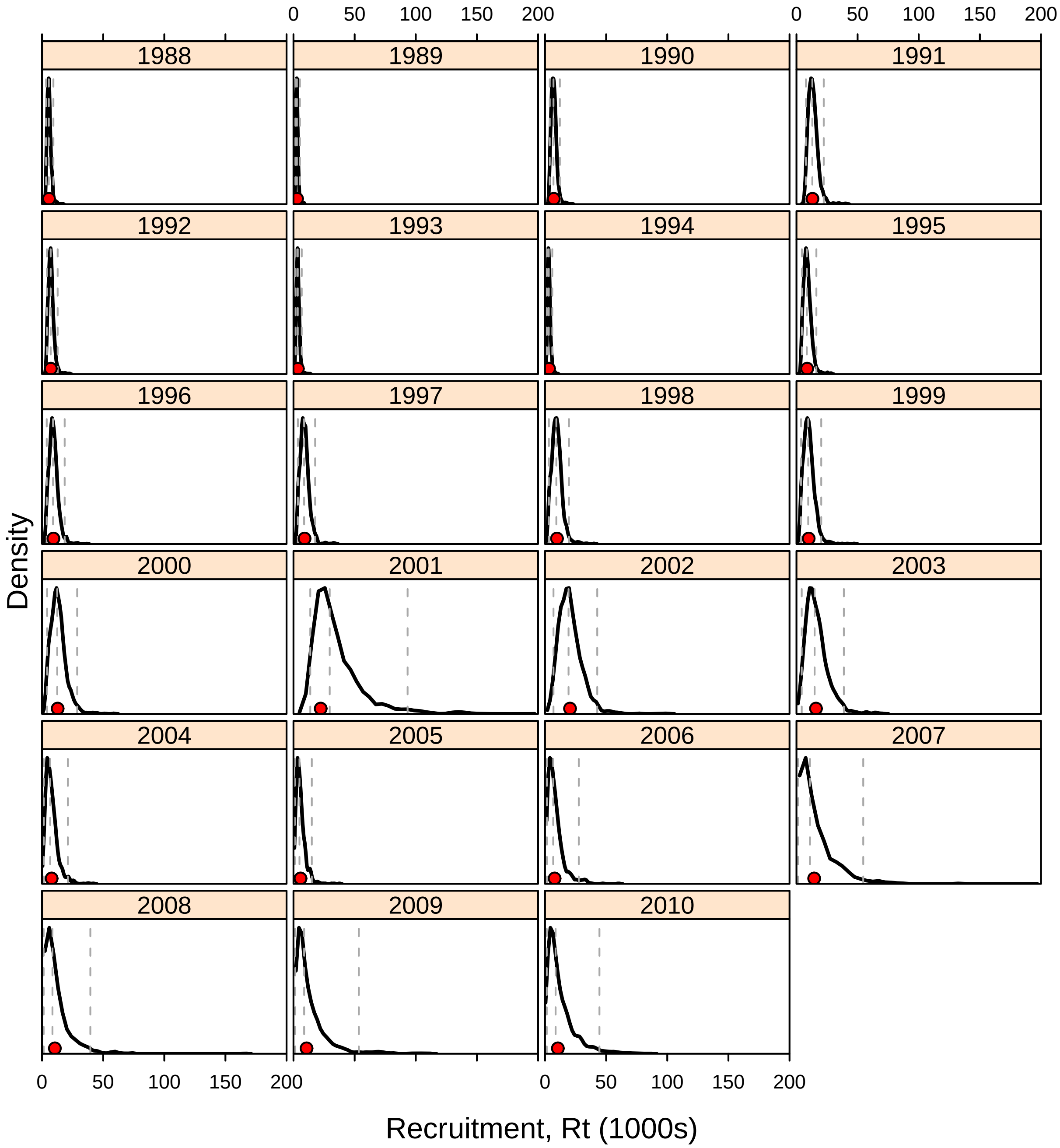


Figure G19 (cont.: for years 1988–2010).

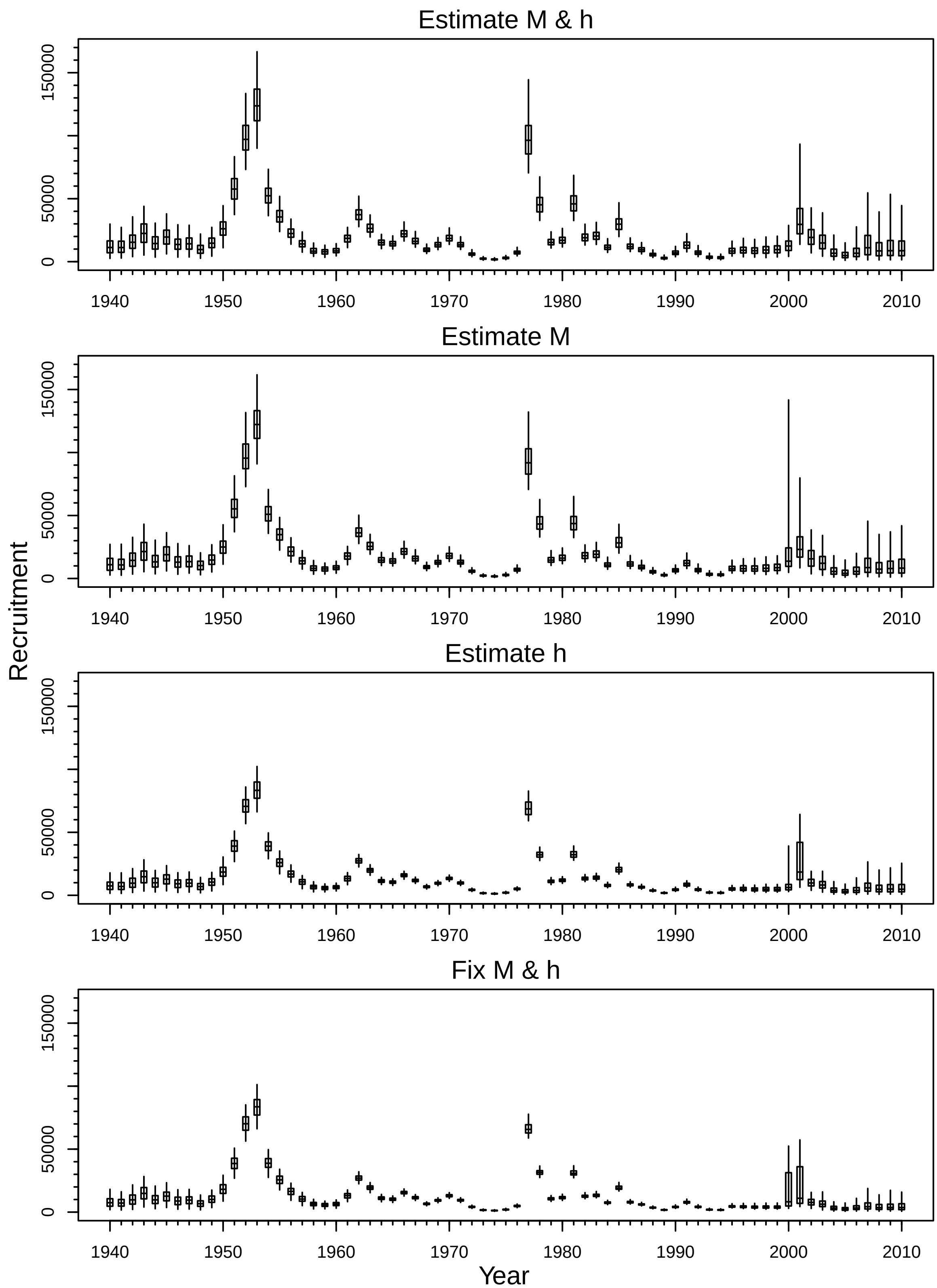


Figure G20. Marginal posterior distribution of recruitment in 1000's of age 1 fish plotted over time for each model run. The boxes give the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results.

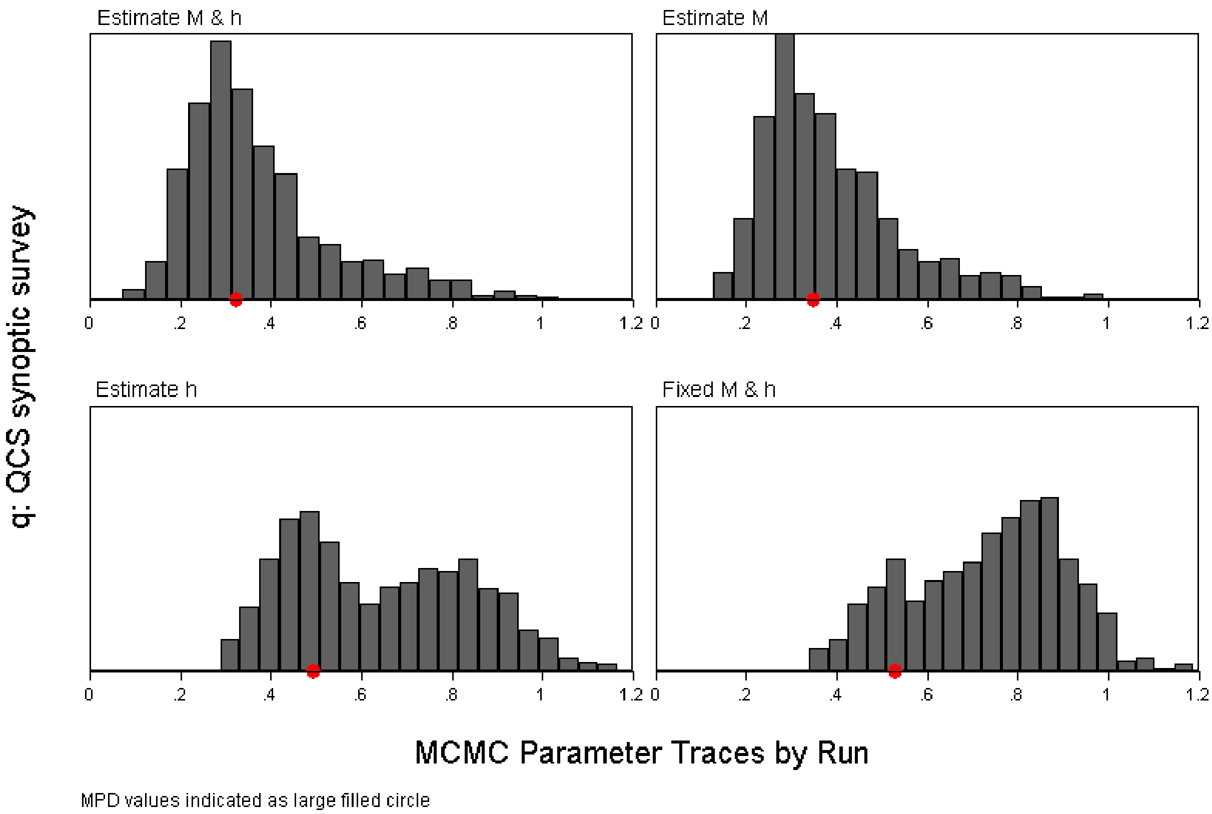


Figure G21. Marginal posterior densities for the parameter q_2 for four POP assessment runs. Horizontal and vertical axes are all to same scale. Filled red circle indicates MPD value.

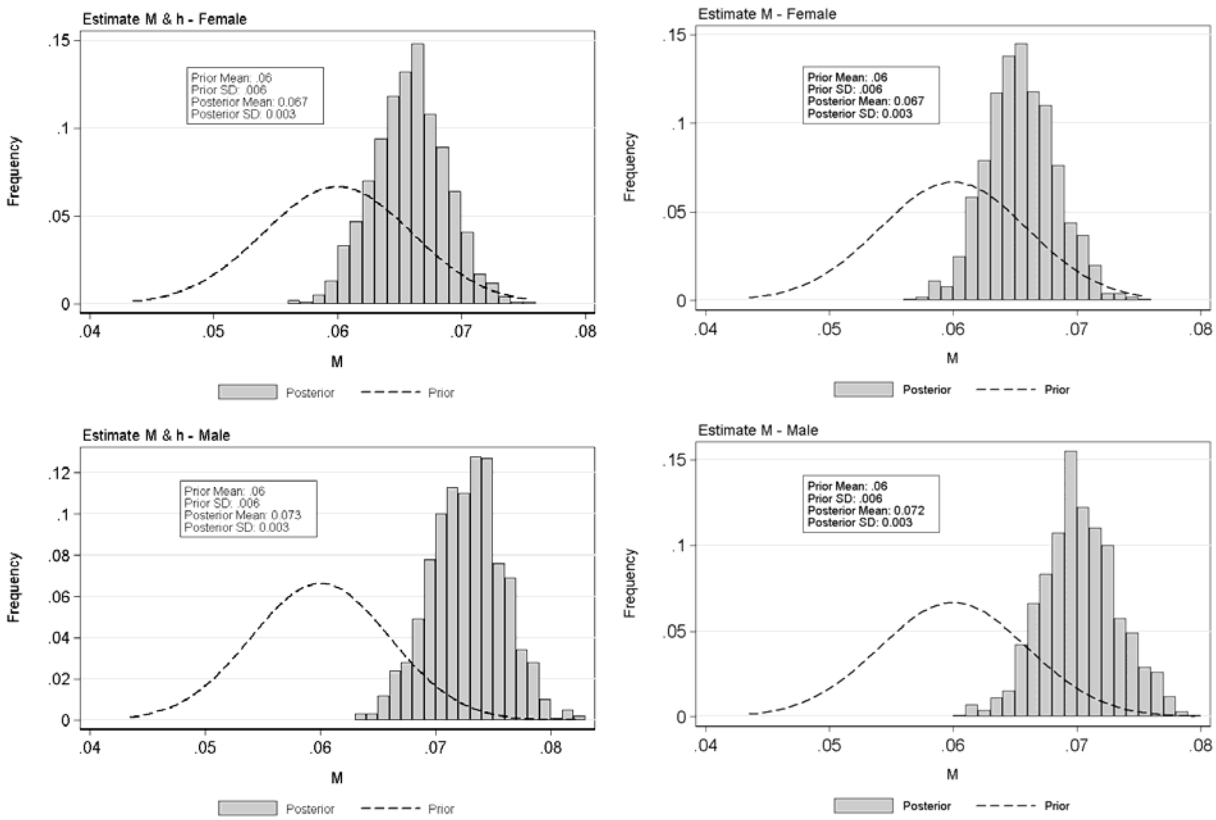


Figure G22. Comparison of prior and posterior for M_s for base run "Estimate M & h" [left column] and run "Estimate M" [right column].

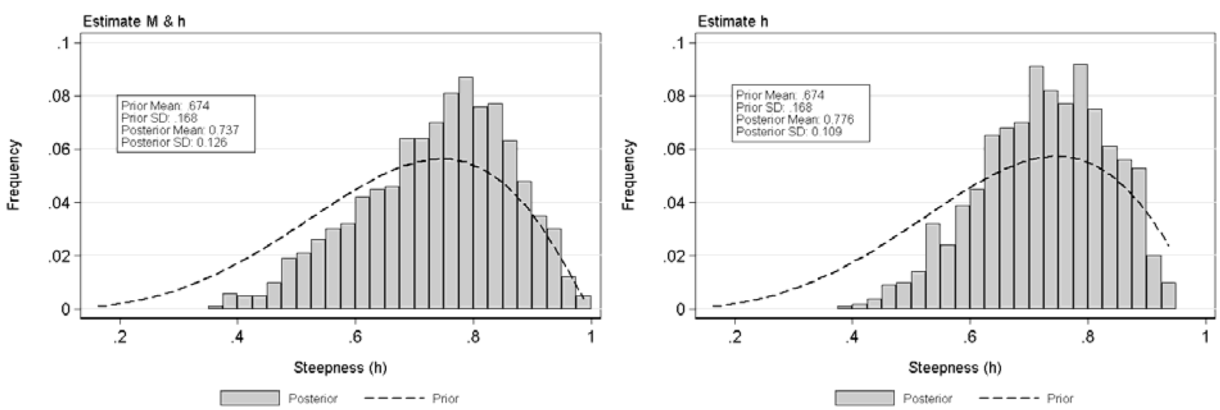


Figure G23. Comparison of prior and posterior for h (steepness) for base run "Estimate M & h" [left panel] and run "Estimate h" [right panel].

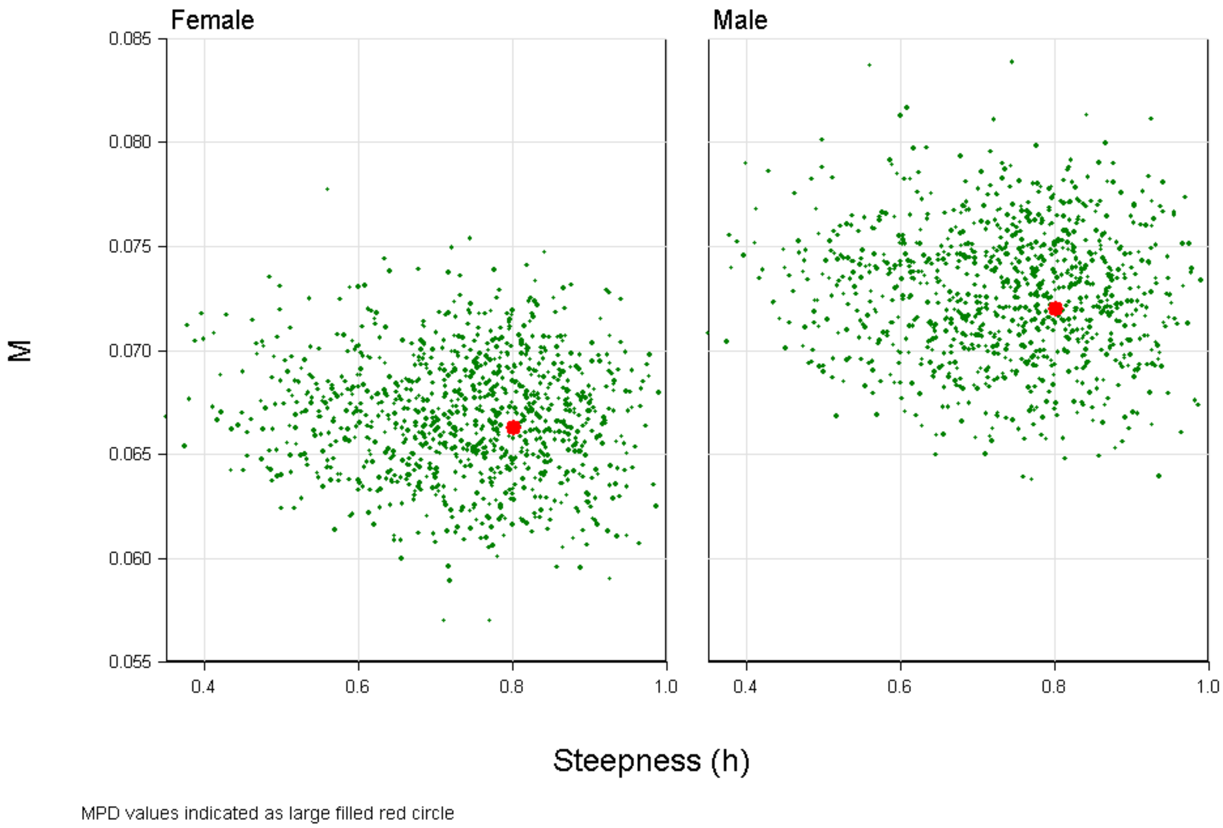


Figure G24. Pairs plot by sex of M with steepness (h) for base run 'Estimate M & h', matching the estimates of M and h for each sample from the posterior.

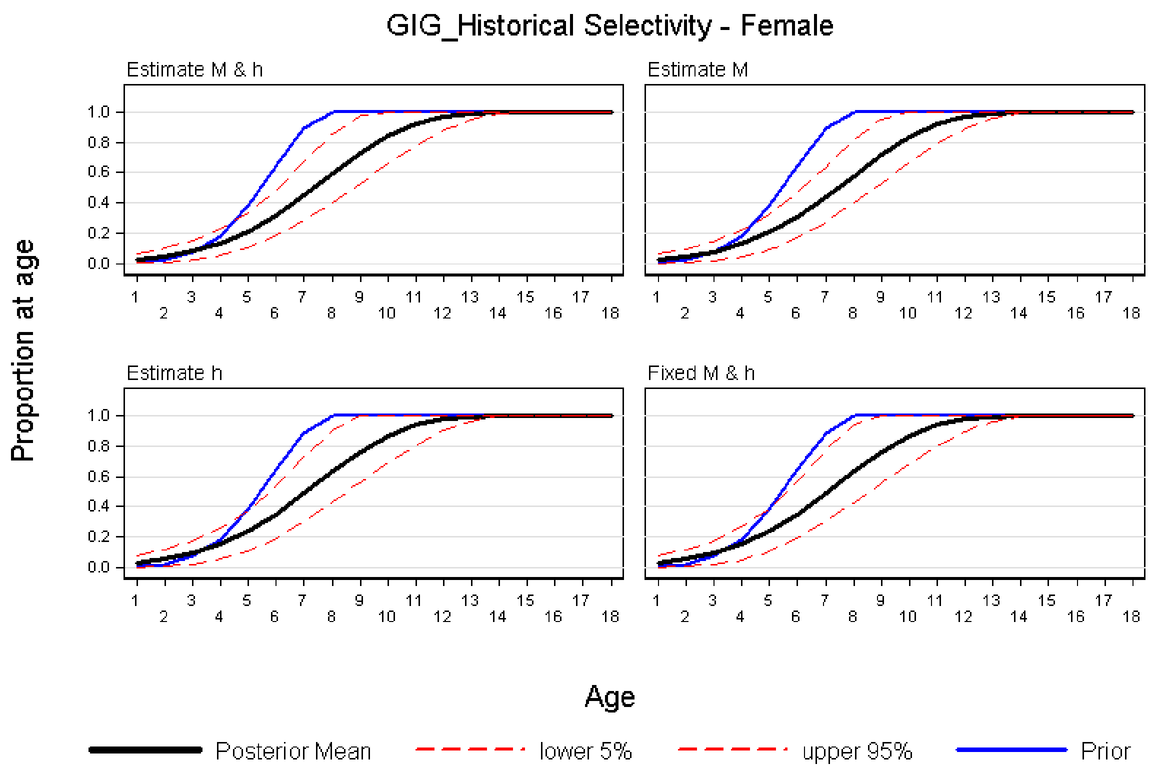


Figure G25. Comparison of priors and posteriors (5th, 50th and 95th quantiles) for female selectivities in the historical GIG survey series for all four assessment runs.

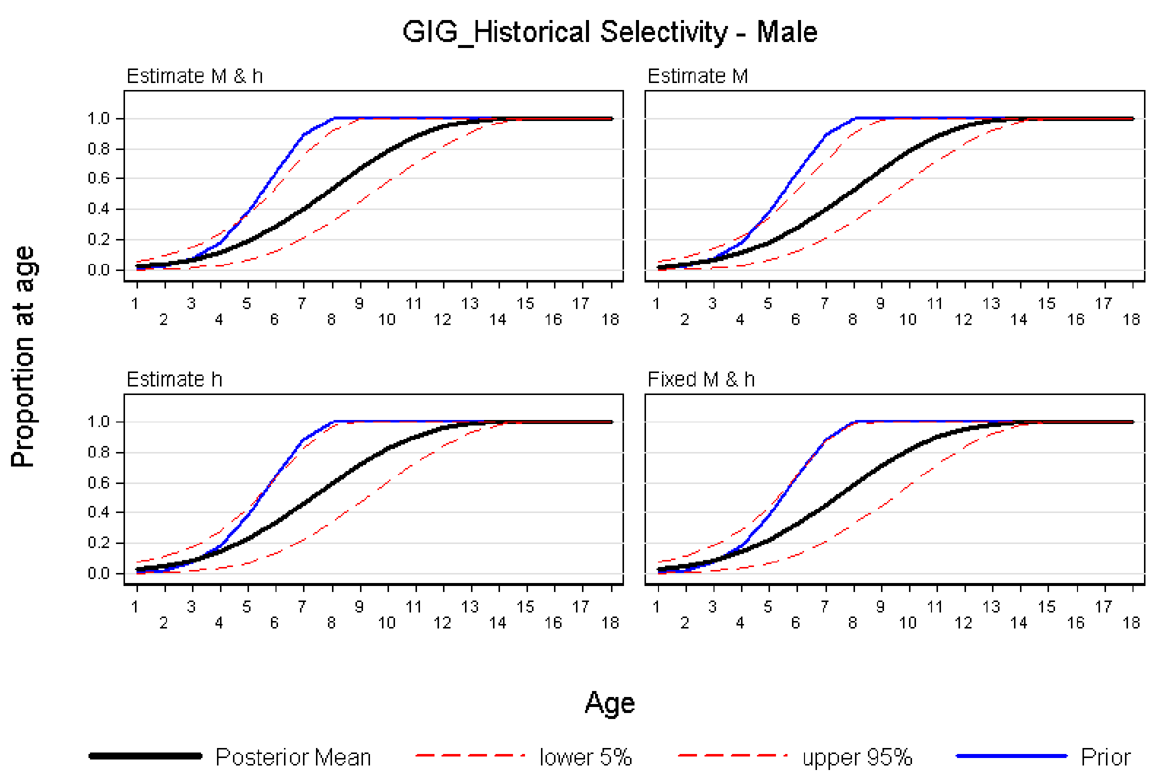


Figure G26. Comparison of priors and posteriors (5th, 50th and 95th quantiles) for male selectivities in the historical GIG survey series for all four assessment runs.

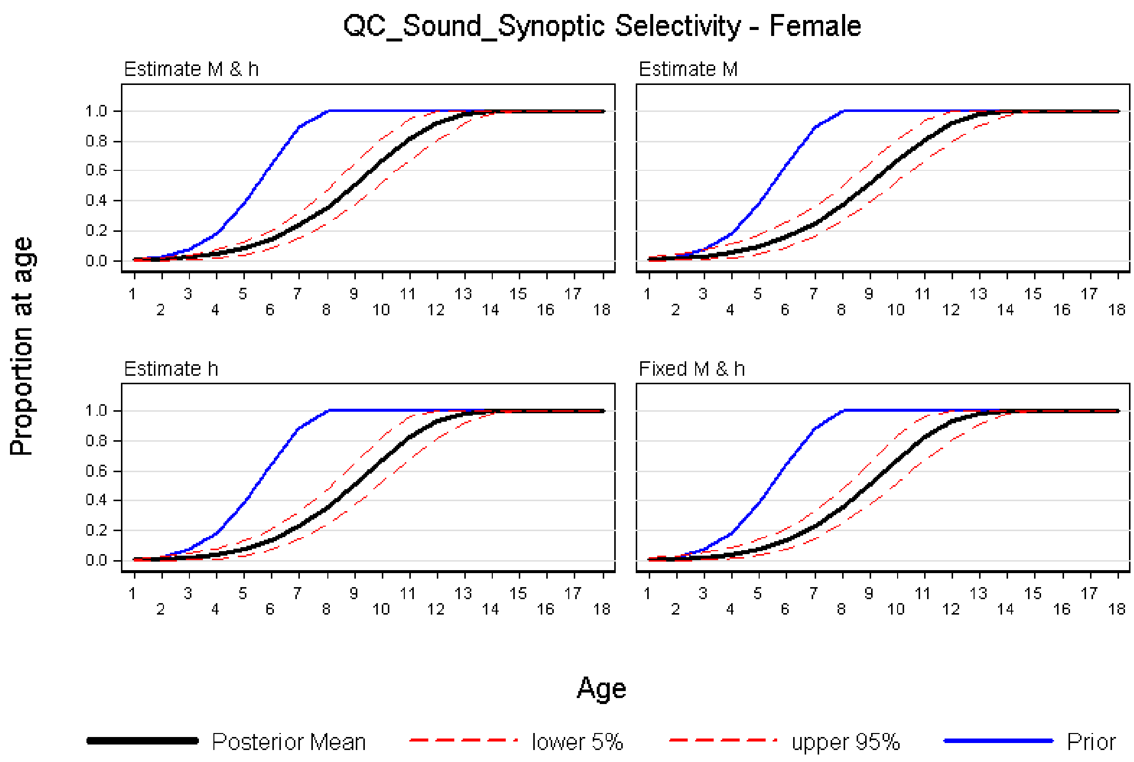


Figure G27. Comparison of priors and posteriors (5th, 50th and 95th quantiles) for female selectivities in the QCS synoptic survey series for all four assessment runs.

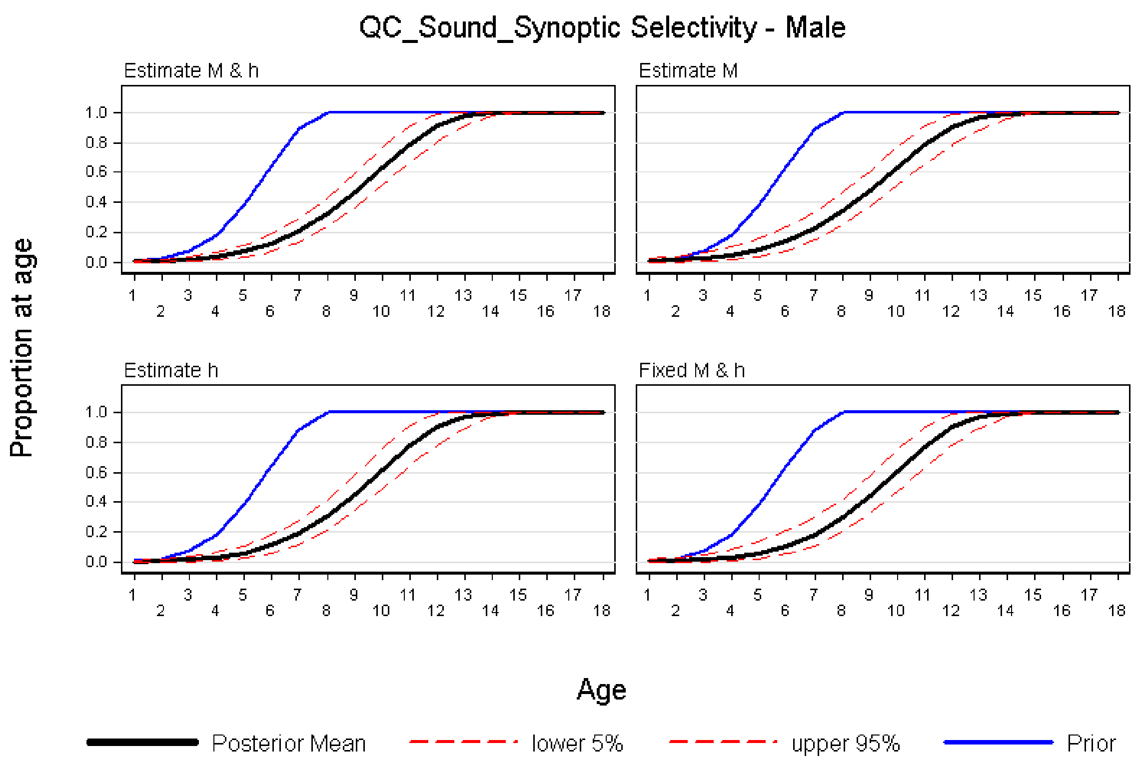


Figure G28. Comparison of priors and posteriors (5th, 50th and 95th quantiles) for male selectivities in the QCS synoptic survey series for all four assessment runs.

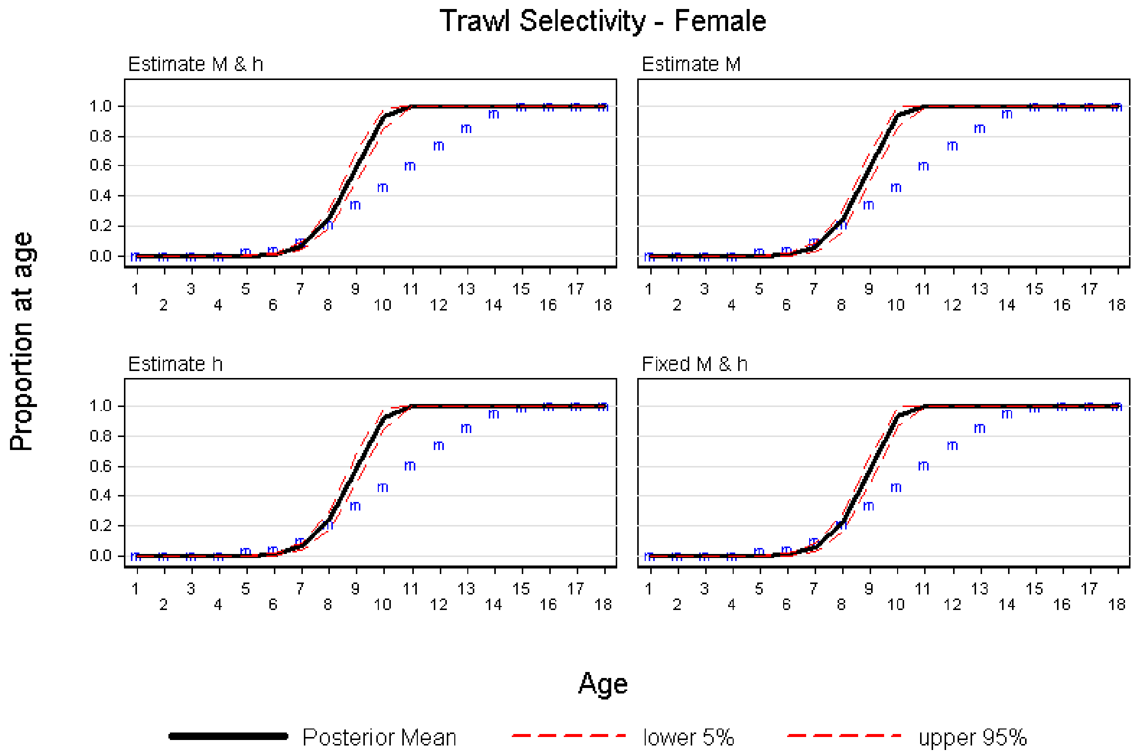


Figure G29. Posteriors (5th, 50th and 95th quantiles) for female selectivities (based on a uniform prior) in the commercial trawl fishery series for all four assessment runs. The symbols "m" track the fixed female maturity ogive used in the assessment.

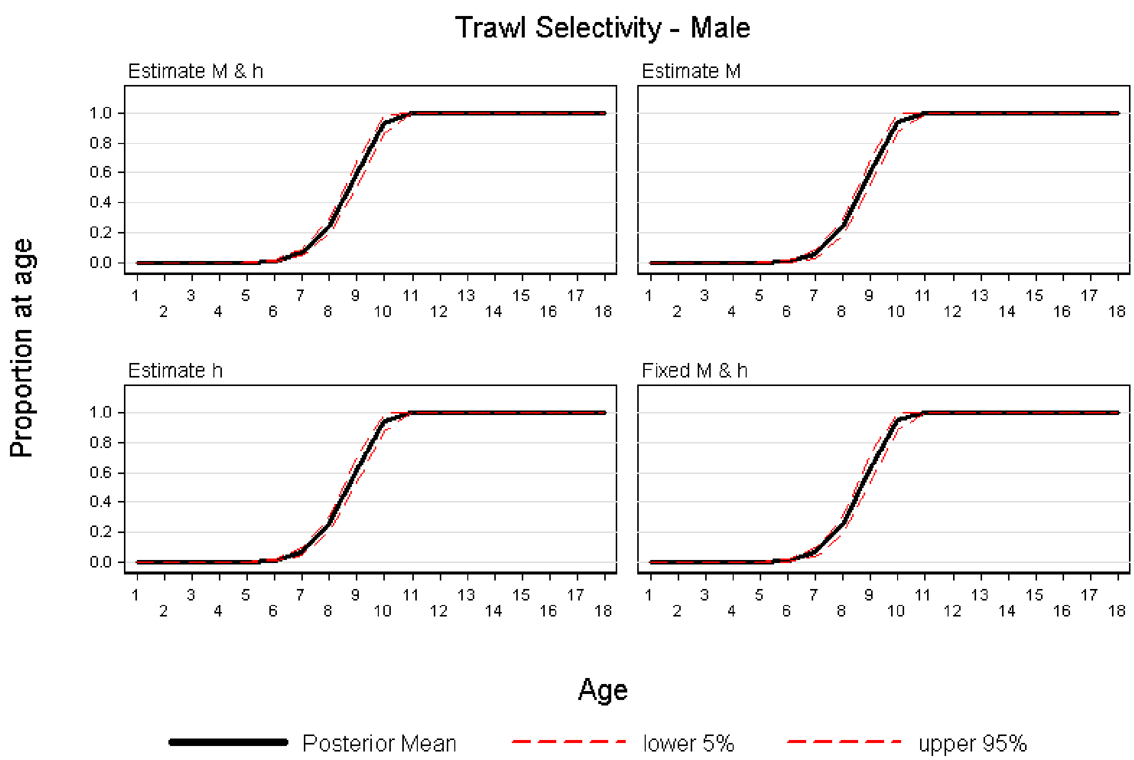


Figure G30. Posteriors (5th, 50th and 95th quantiles) for male selectivities (based on a uniform prior) in the commercial trawl fishery series for all four assessment runs.

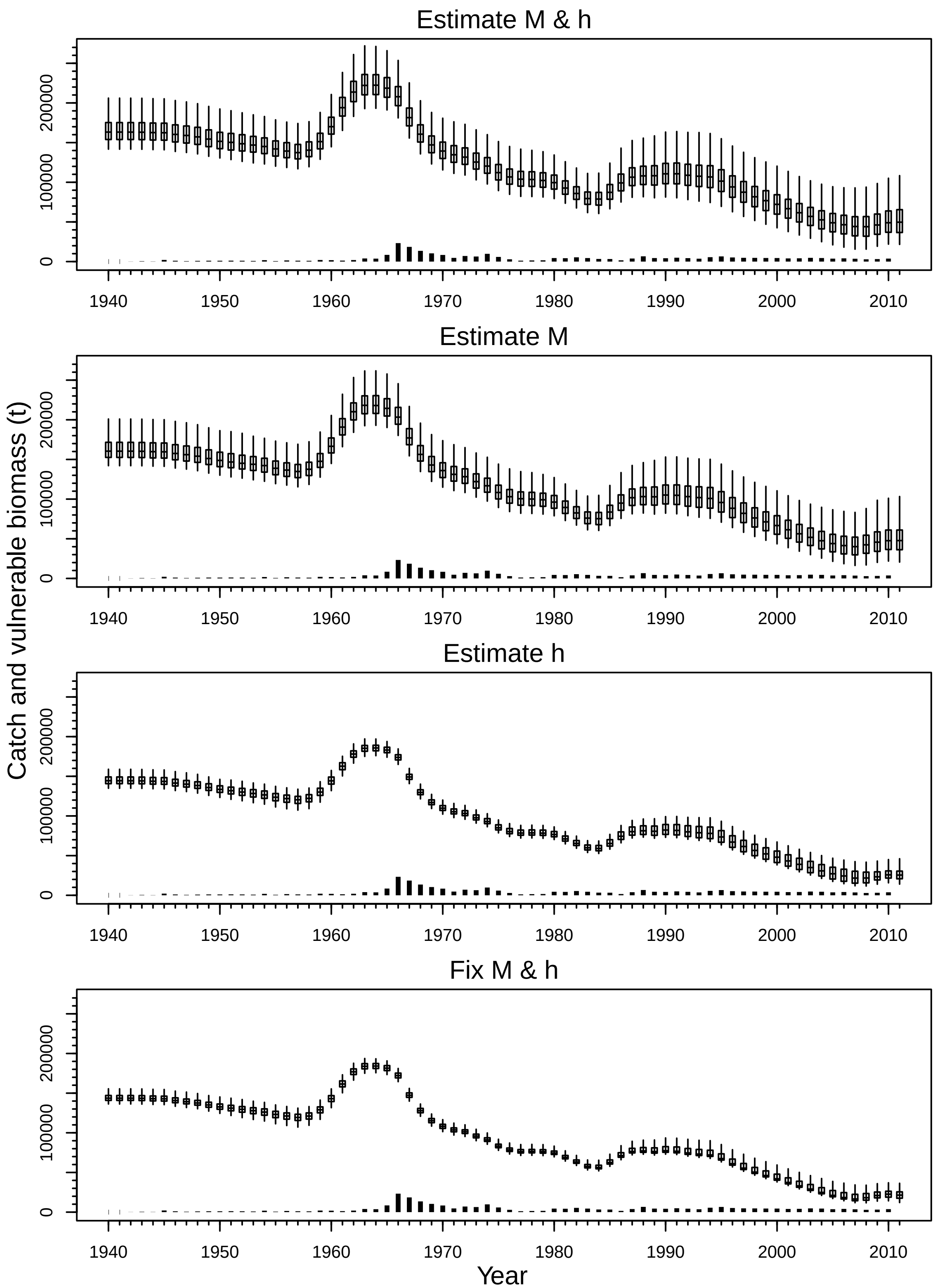


Figure G31. Vulnerable biomass and commercial catch over time for each model run. Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles of the posteriors from the MCMC results.

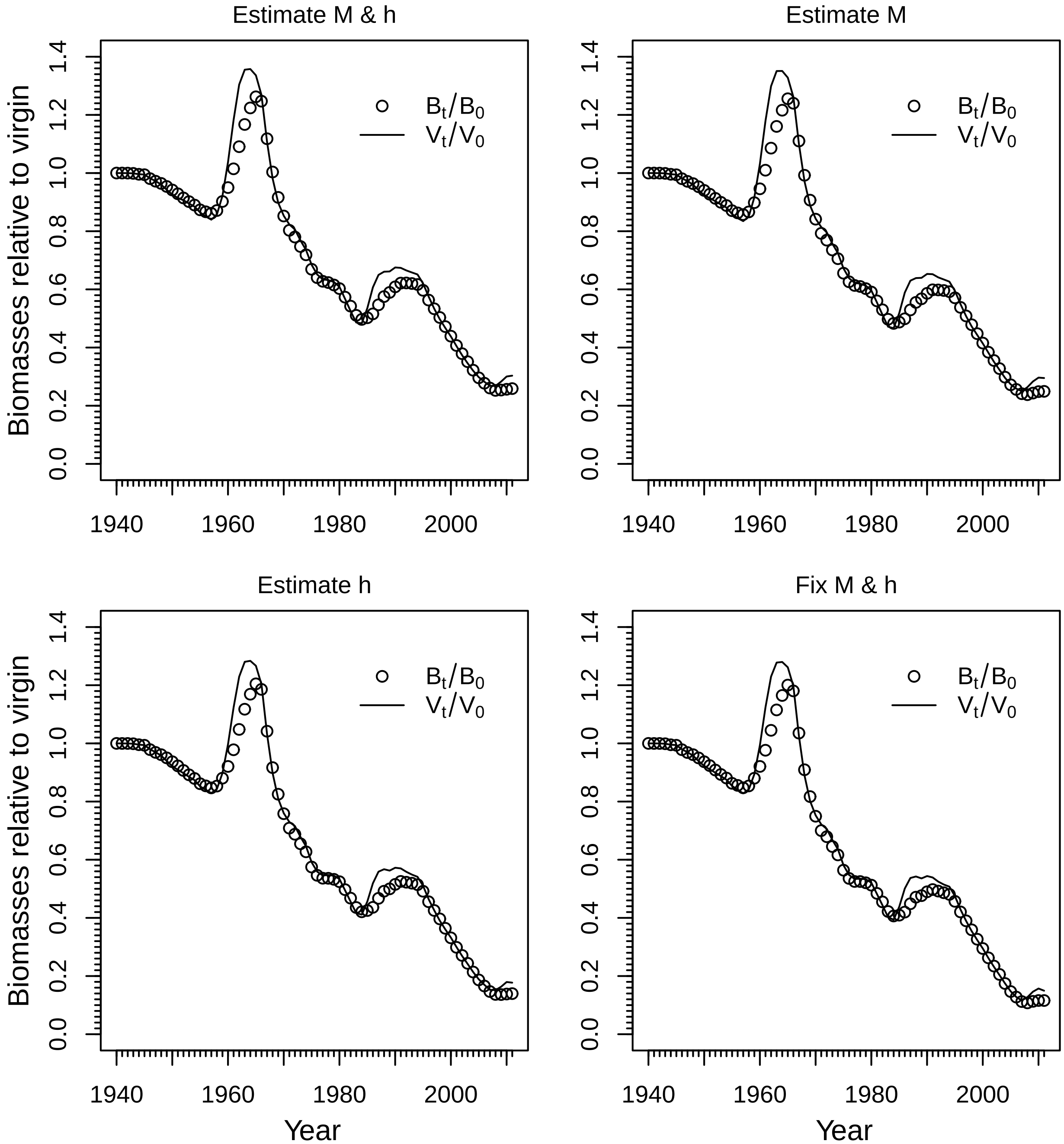


Figure G32. Changes in B_t / B_0 and V_t / V_0 over time, shown as the medians of the MCMC posteriors for all four model runs.

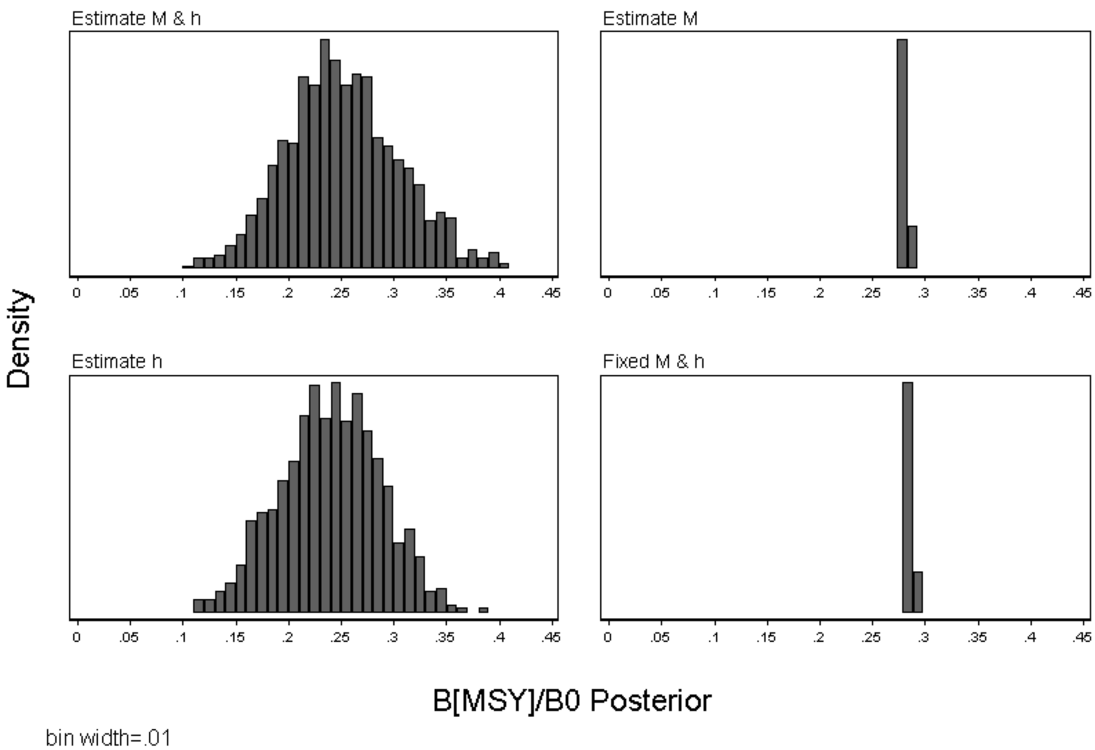


Figure G33. Marginal posterior densities for the ratio B_{MSY}/B_0 for four POP assessment runs. Horizontal axes are all to same scale, but vertical axes differ.

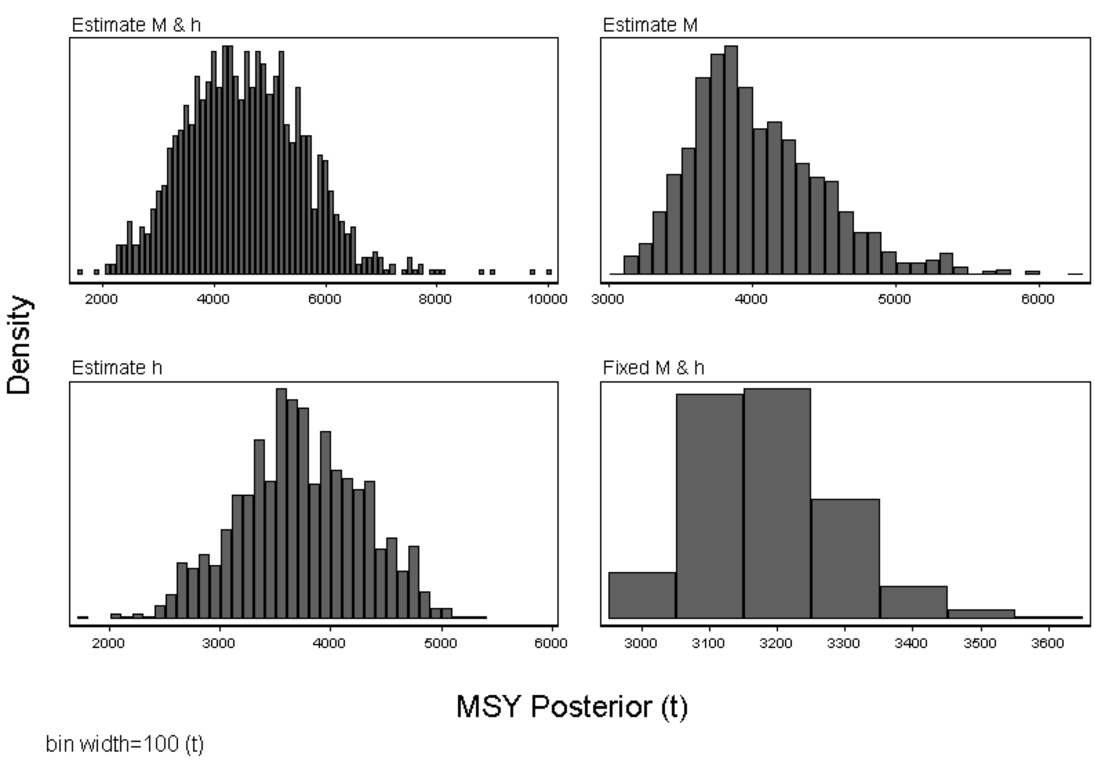


Figure G34. Marginal posterior densities for MSY for four POP assessment runs. Horizontal and vertical axes are all to different scales.

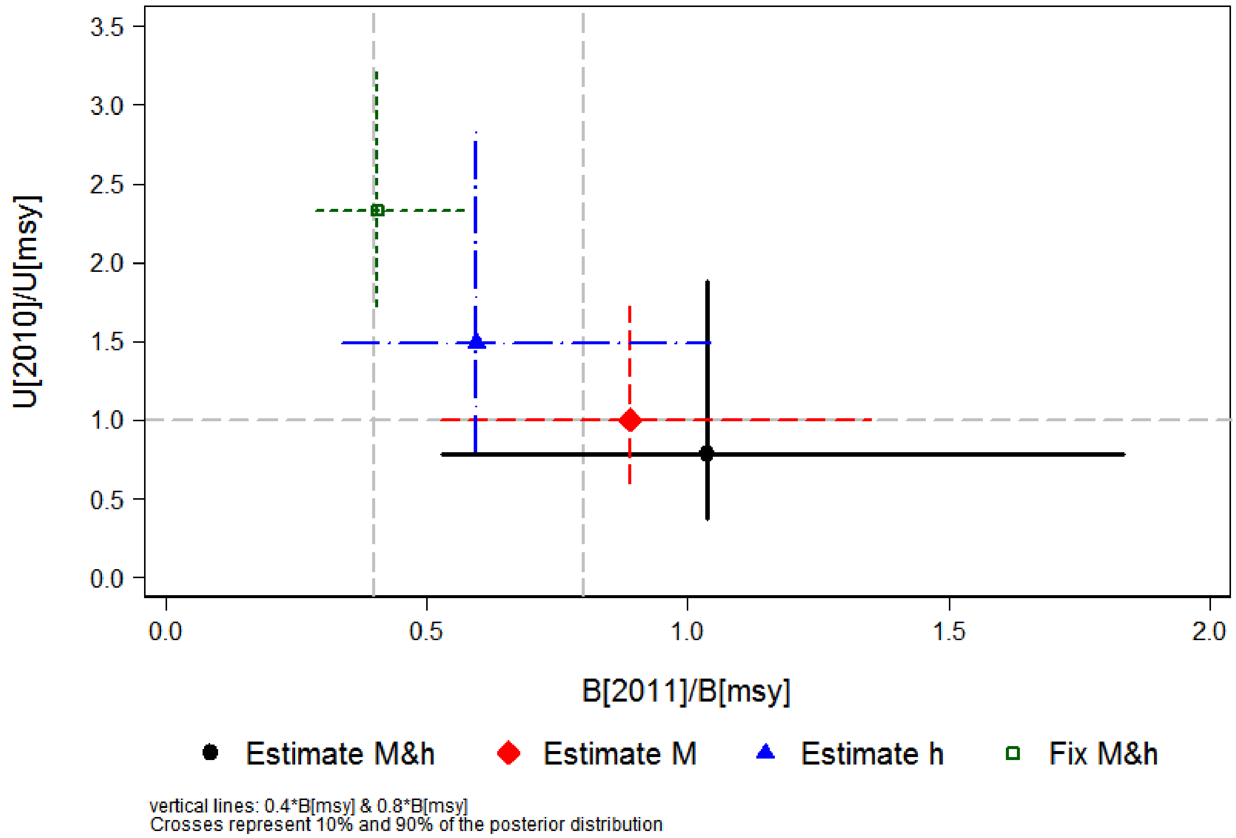


Figure G35. Cross plots showing the medians and the 10-90% credibility intervals for the ratio U_{2010} / U_{MSY} against the ratio B_{2011} / B_{MSY} for all four model runs. Vertical lines at 0.4 and 0.8 correspond to the default limit and upper stock "PA-compliant" reference points of $0.4B_{MSY}$ and $0.8B_{MSY}$.

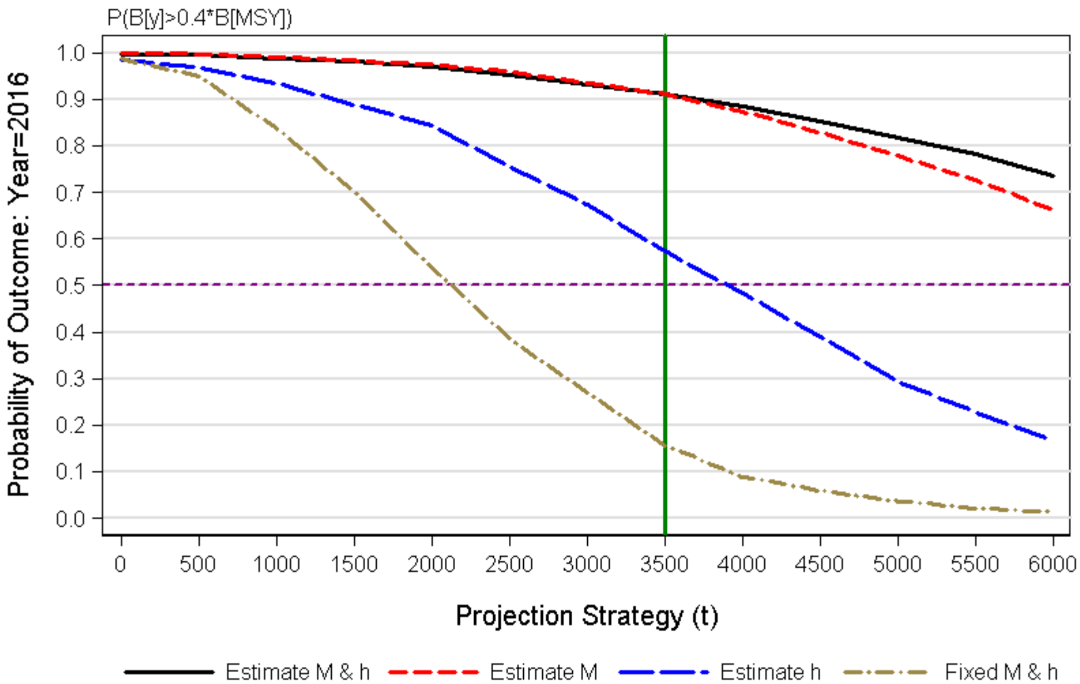


Figure G36. Probability of B_t exceeding 0.4B_{MSY} by the end of the projection period (2016) for the four runs performed for the assessment. The green vertical line indicates the approximate position of the average catch over the most recent 5 years.

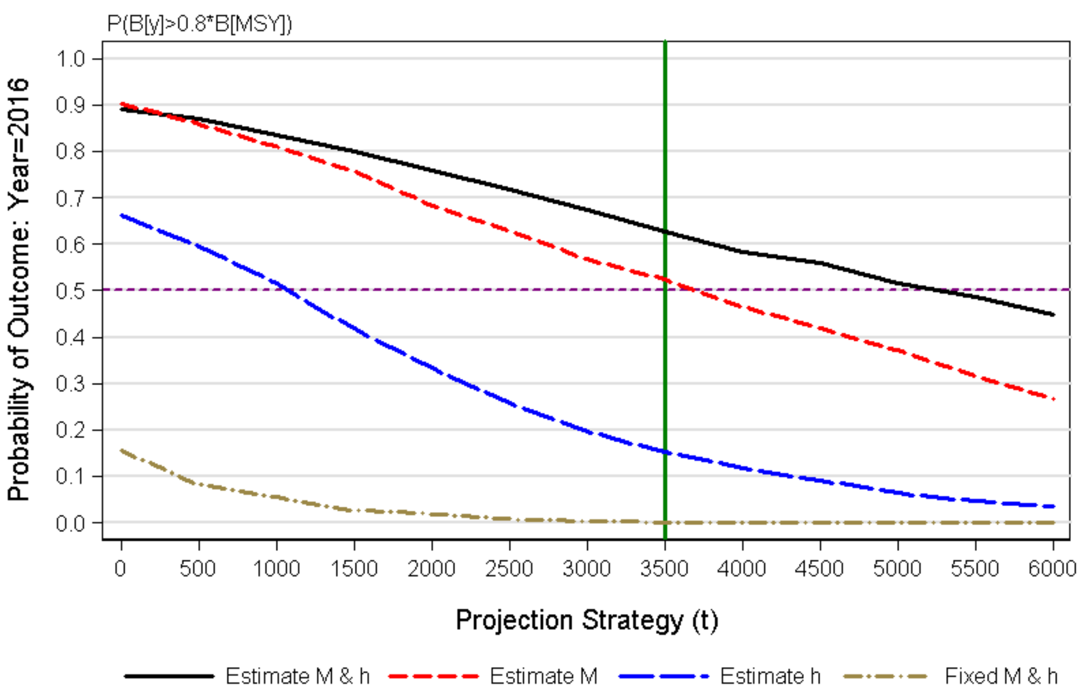


Figure G37. Probability of B_t exceeding 0.8B_{MSY} by the end of the projection period (2016) for the four runs performed for the assessment. The green vertical line indicates the approximate position of the average catch over the most recent 5 years.

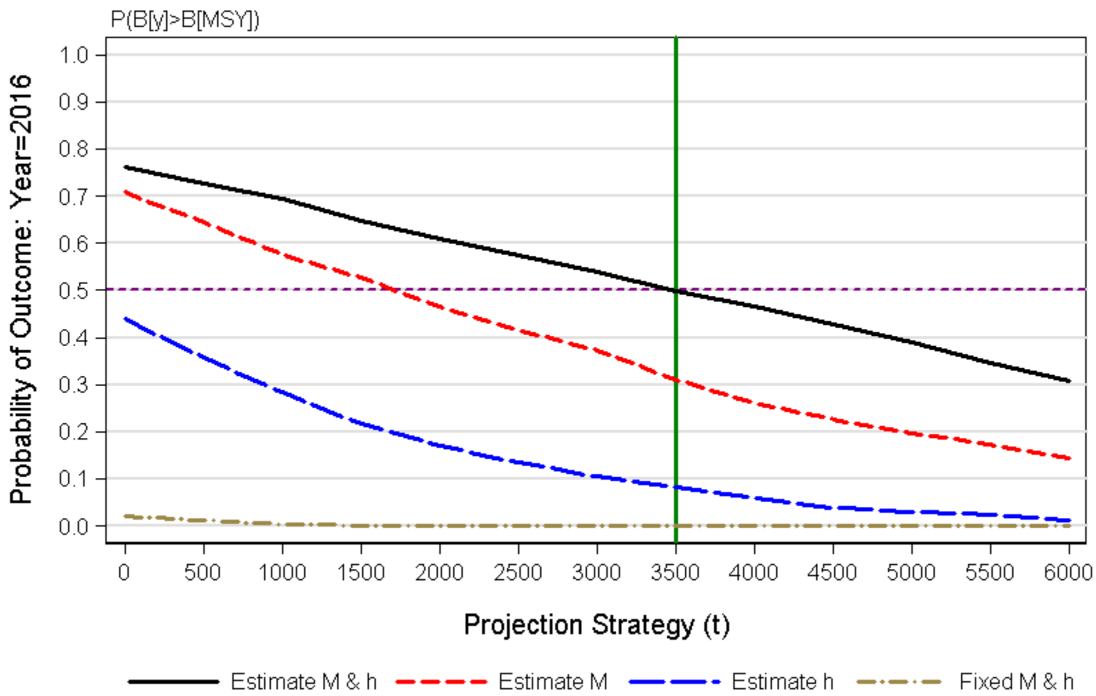


Figure G38. Probability of B_t exceeding B_{MSY} by the end of the projection period (2016) for the four runs performed for the assessment. The green vertical line indicates the approximate position of the average catch over the most recent 5 years.

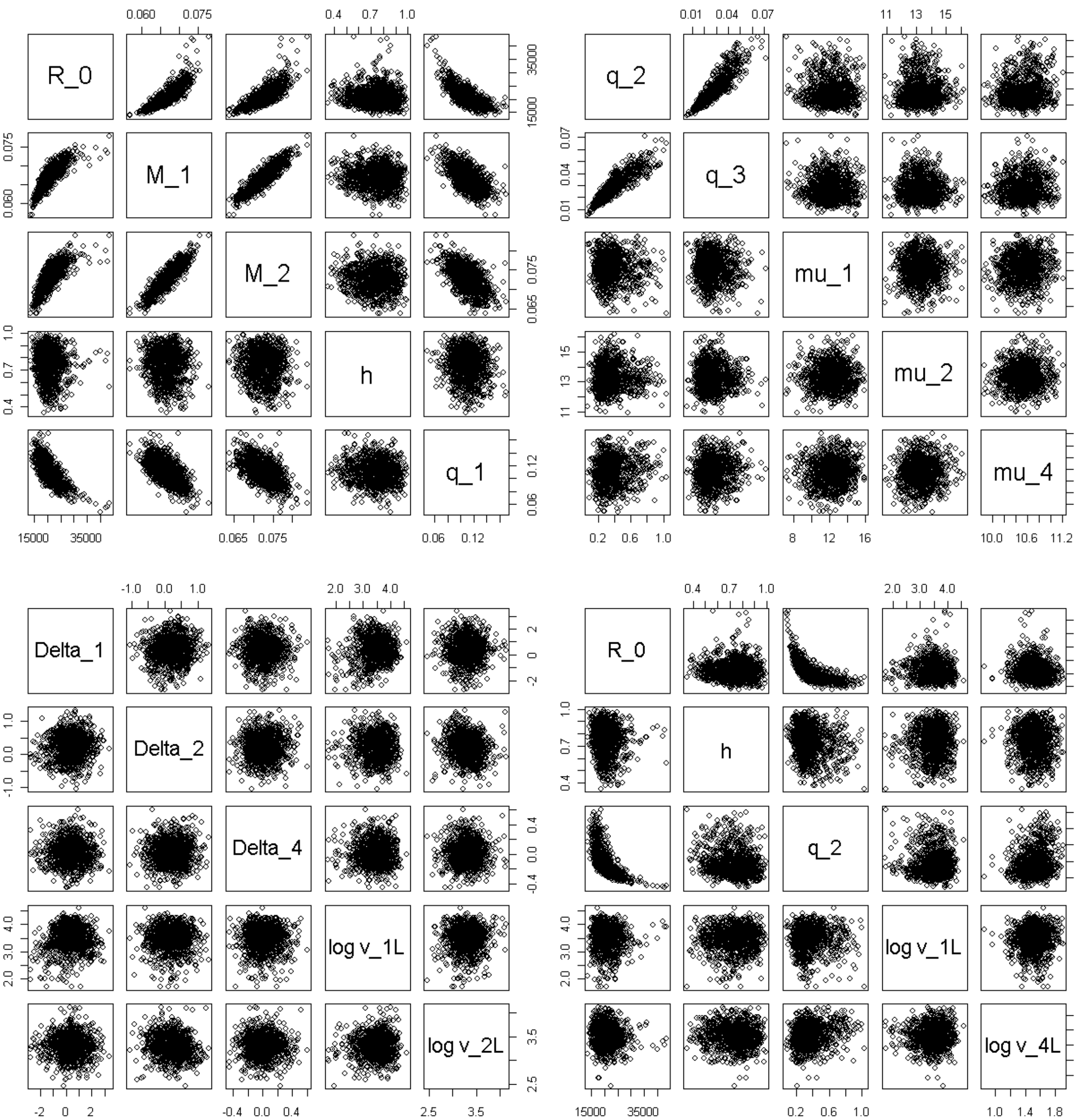
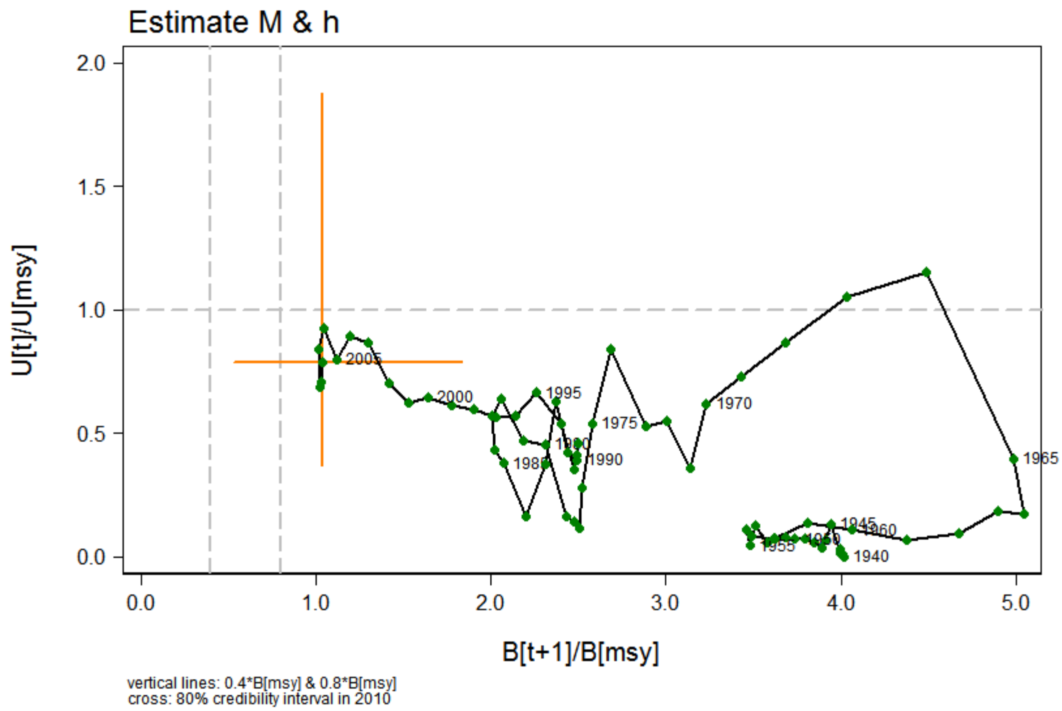


Figure G39. Pairs plots of MCMC posteriors for the estimated parameters.



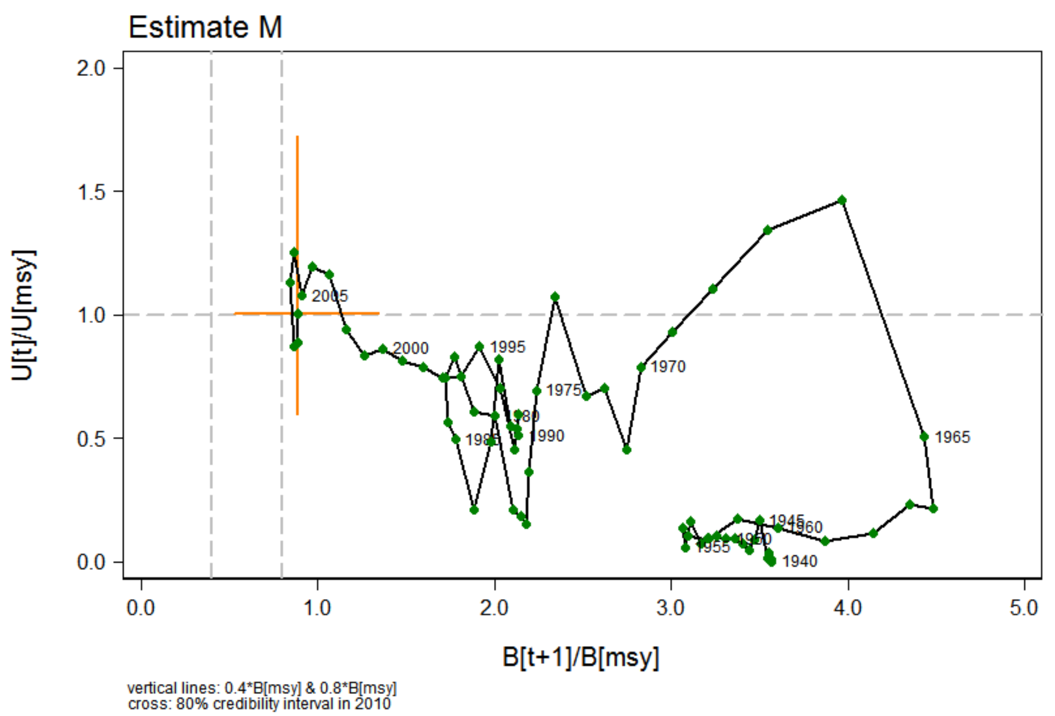
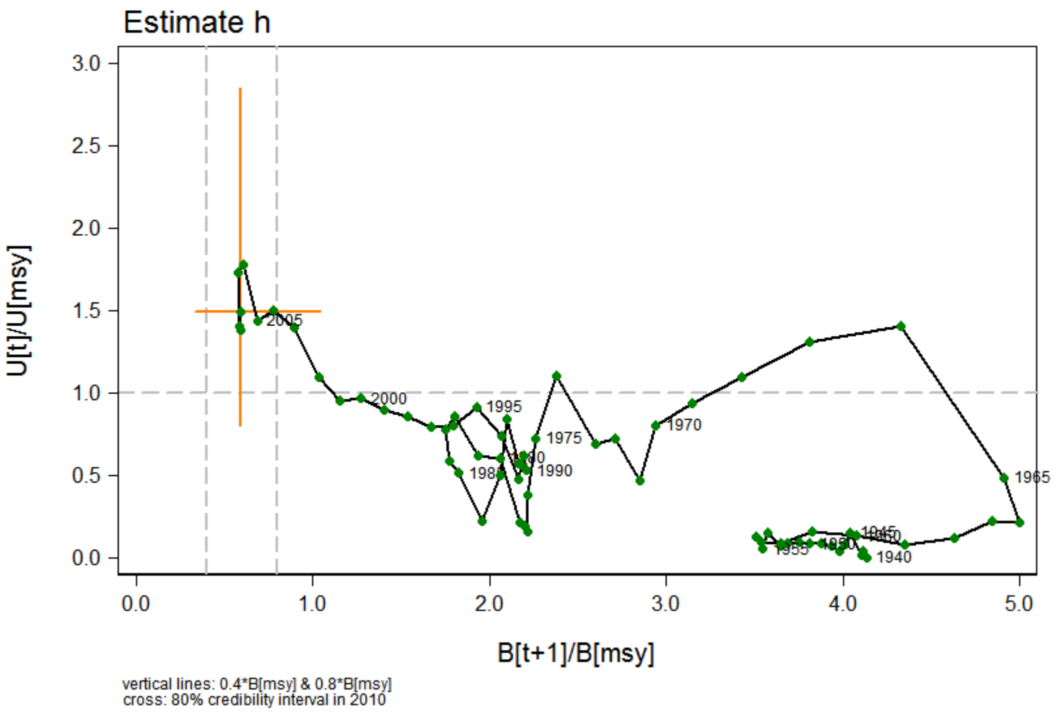


Figure G40. 'Snail-trail' plots showing the trajectory of U_t / U_{MSY} against the ratio B_{t+1} / B_{MSY} through time, from 1940 to 2010, for each model run. Green dots are medians for each year, connected by the black lines; numbers are years. For 2010 the orange lines give the 10-90% credible intervals, as for Figure G35. Thus, the trajectories start in the lower-right area and finish in the top left. Vertical dashed lines at 0.4 and 0.8 correspond to the default limit and upper stock "PA-compliant" reference points of $0.4B_{MSY}$ and $0.8B_{MSY}$. Continued overleaf.



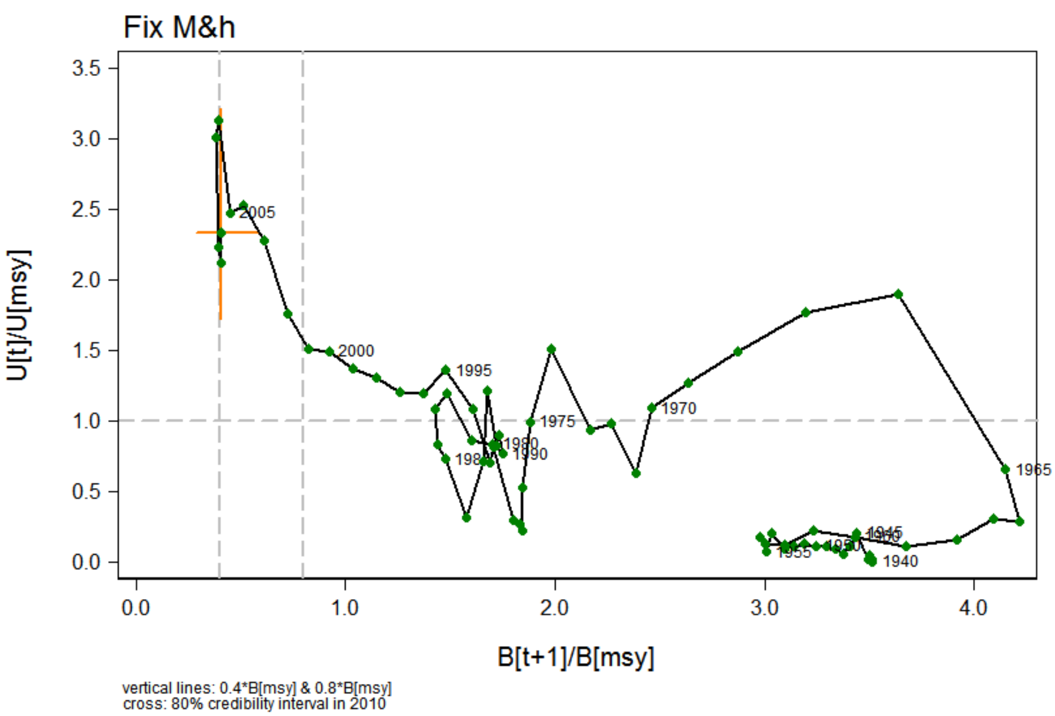


Figure G40 (continued).

Table G1. Data used in the Queen Charlotte Sound Pacific ocean perch catch-age stock assessment model.

Data type	Years	Reference
Catch	1940–2010	Appendix B
Goose Island Gully historical trawl survey series	1967–1994	Appendix C
QCS synoptic trawl survey	2003–2009	Appendix C
QCS shrimp trawl survey	1999–2010	Appendix C
Age composition from commercial trawl fishery	1978–2009	Appendices D, E
GIG historical trawl survey series age composition	1984 & 1994	Appendices D, E
QCS synoptic trawl survey age composition (plus one sample from an earlier survey using the same net configuration)	1995, 2003–2009	Appendices D, E

Table G2. MPD results for four model runs considered in the Queen Charlotte Sound POP stock assessment. Fixed parameters are shaded in grey. Parameter and likelihood symbols are defined in Appendix F. Subscripts 1 to 3, in the context of indices $\left(\hat{I}\right)$ and proportions-at-age $(\hat{p})$, are used to index the three trawl surveys and subscript 4 is the commercial fishery.

Run	Estimate *M* & *h*	Estimate *M*	Estimate *h*	Fix *M* & *h*
Negative Log Likelihoods				
$\log L_3\left(\Theta \mid \left\{\hat{I}_{t1}\right\}\right)$	-7.6	-7.5	-7.6	-7.5
$\log L_3\left(\Theta \mid \left\{\hat{I}_{t2}\right\}\right)$	-6.0	-6.3	-7.6	-8.0
$\log L_3\left(\Theta \mid \left\{\hat{I}_{t3}\right\}\right)$	-4.6	-4.7	-4.9	-5.0
$\log L_2\left(\Theta \mid \left\{\hat{p}_{at1s}\right\}\right)$	-593.5	-593.5	-590.4	-590.4
$\log L_2\left(\Theta \mid \left\{\hat{p}_{at2s}\right\}\right)$	-1,647.7	-1,647.7	-1,649.3	-1,649.5
$\log L_2\left(\Theta \mid \left\{\hat{p}_{at4s}\right\}\right)$	-8,448.4	-8,448.5	-8,451.4	-8,450.9
$\log L_1\left(\Theta \mid \left\{\varepsilon_t\right\}\right) + \log\left(\pi\left(\Theta\right)\right)$	42.2	38.6	40.6	36.6
$f\,(\Theta)$	-10,665.6	-10,669.6	-10,670.7	-10,674.5
Standard Deviation of Normalised Residuals (SDNR)				
$\mathrm{SDNR}\left\{\hat{I}_{t1}\right\}$	1.00	1.01	1.00	1.00
$\mathrm{SDNR}\left\{\hat{I}_{t2}\right\}$	1.00	0.99	0.98	0.99
$\mathrm{SDNR}\left\{\hat{I}_{t3}\right\}$	1.00	1.00	1.00	1.00
$\mathrm{SDNR}\left\{\hat{p}_{at4s}\right\}$	0.71	0.71	0.71	0.71
$\mathrm{SDNR}\left\{\hat{p}_{atgs}\right\} \quad g = 1, 2$	0.76	0.76	0.76	0.76
Parameters				
R_0	19,882	19,830	14,243	14,419
h	0.803	0.674	0.831	0.674
M_1	0.066	0.066	0.06	0.06
M_2	0.072	0.072	0.06	0.06

Run	Estimate *M* & *h*	Estimate *M*	Estimate *h*	Fix *M* & *h*
μ_4	10.6	10.6	10.6	10.6
Δ_4	-0.067	-0.067	-0.093	-0.095
$\log(\upsilon_{4L})$	1.54	1.54	1.53	1.54
q_1	0.110	0.112	0.138	0.139
q_2	0.323	0.349	0.495	0.530
q_3	0.025	0.027	0.038	0.041
μ_1	13.1	13.1	12.9	12.9
μ_2	13.6	13.6	13.7	13.7
μ_3	8.1	8.1	8.1	8.1
Δ_1	0.406	0.407	0.517	0.515
Δ_2	0.138	0.139	0.243	0.247
Δ_3	0.000	0.000	0.000	0.000
$\log(\upsilon_{1L})$	3.69	3.70	3.71	3.71
$\log(\upsilon_{2L})$	3.42	3.43	3.46	3.48
$\log(\upsilon_{3L})$	2.28	2.28	2.28	2.28
Derived parameters				
B_0	90,108	89,729	76,492	77,435
V_0	160,848	160,203	144,568	146,356
B_{2010}/B_0	0.26	0.24	0.16	0.14
V_{2010}/V_0	0.30	0.27	0.19	0.16
$U_{\max}$	0.11	0.11	0.13	0.14
Year of $U_{\max}$	1966	1966	1966	2006

Table G3. MCMC results for four model runs considered in the Queen Charlotte Sound POP assessment. Summary statistics (5th, 50th and 95th quantiles) are shown for posteriors corresponding to selected parameters. Parameter and likelihood symbols are defined in Appendix F. Subscripts 1 to 3, in the context of indices $(\hat{\imath})$ and the selectivity parameters are used to index the three trawl surveys and subscript 4 is the commercial fishery. –: not estimated

	Quantile			Quantile			Quantile			Quantile		
Run	**5th**	**50th**	**95th**	**5th**	**50th**	**95th**	**5th**	**50th**	**95th**	**5th**	**50th**	**95th**
		R_0			M_1			M_2			h	
Estimate *M* & *h*	16,309	20,507	27,150	0.062	0.067	0.072	0.067	0.073	0.078	0.507	0.754	0.922
Estimate *M*	16,330	19,811	25,779	0.062	0.066	0.072	0.067	0.072	0.078	–	–	–
Estimate *h*	13,376	14,221	15,372	–	–	–	–	–	–	0.581	0.783	0.940
Fixed *M* & *h*	13,507	14,149	15,061	–	–	–	–	–	–	–	–	–
		q_1			q_2			q_3				
Estimate *M* & *h*	0.082	0.109	0.141	0.182	0.331	0.727	0.015	0.026	0.046			
Estimate *M*	0.087	0.114	0.142	0.198	0.353	0.723	0.016	0.027	0.047			
Estimate *h*	0.117	0.141	0.167	0.363	0.625	0.977	0.028	0.044	0.062			
Fixed *M* & *h*	0.123	0.146	0.173	0.445	0.758	0.984	0.033	0.049	0.067			
		μ_1			μ_2			μ_3			μ_4	
Estimate *M* & *h*	9.6	12.4	14.7	12.0	13.3	14.7	–	–	–	10.2	10.5	10.9
Estimate *M*	9.8	12.5	14.5	12.1	13.5	15.1	–	–	–	10.0	10.5	10.9
Estimate *h*	9.2	12.2	14.4	11.9	13.2	14.8	–	–	–	10.1	10.6	11.0
Fixed *M* & *h*	8.8	12.2	14.4	11.7	13.1	14.9	–	–	–	10.1	10.5	10.9
		Δ_1			Δ_2			Δ_3			Δ_4	
Estimate *M* & *h*	-1.24	0.39	1.94	-0.42	0.22	0.80	–	–	–	-0.23	0.00	0.30
Estimate *M*	-1.26	0.35	1.86	-0.47	0.21	0.85	–	–	–	-0.27	-0.02	0.28
Estimate *h*	-1.55	0.33	1.91	-0.33	0.33	1.01	–	–	–	-0.33	-0.08	0.19
Fixed *M* & *h*	-1.38	0.39	2.01	-0.44	0.39	1.17	–	–	–	-0.34	-0.11	0.15
		$\log(\upsilon_{1L})$			$\log(\upsilon_{2L})$			$\log(\upsilon_{3L})$			$\log(\upsilon_{4L})$	
Estimate *M* & *h*	2.65	3.52	4.10	2.92	3.30	3.67	–	–	–	1.28	1.52	1.75
Estimate *M*	2.61	3.53	4.06	2.95	3.39	3.90	–	–	–	0.95	1.48	1.72
Estimate *h*	2.49	3.53	4.13	2.76	3.25	3.69	–	–	–	1.17	1.53	1.77
Fixed *M* & *h*	2.41	3.52	4.10	2.76	3.19	3.79	–	–	–	0.96	1.45	1.74

Table G4. MCMC derived parameters for four model runs considered in the Queen Charlotte Sound POP assessment. Summary statistics (5th, 50th and 95th quantiles) are shown for posteriors corresponding to the selected derived parameters of management interest. B and V represent spawning and vulnerable biomass, respectively, and U is exploitation rate. B_{MSY} and V_{MSY} (spawning and vulnerable biomass levels associated with MSY) were calculated for each sample of the MCMC posterior.

Run	Quantile 5th	50th	95th	Quantile 5th	50th	95th
		B_0			V_0	
Estimate *M* & *h*	80,666	91,595	110,045	143,629	163,273	196,742
Estimate *M*	80,596	89,836	106,782	143,913	160,448	191,843
Estimate *h*	71,835	76,374	82,554	135,961	144,409	156,293
Fixed *M* & *h*	72,539	75,985	80,887	137,224	143,685	153,064
		B_{MSY}/B_0			V_{MSY}/V_0	
Estimate *M* & *h*	0.165	0.249	0.346	0.208	0.287	0.373
Estimate *M*	0.275	0.280	0.285	0.309	0.315	0.321
Estimate *h*	0.161	0.242	0.318	0.195	0.272	0.341
Fixed *M* & *h*	0.280	0.285	0.290	0.305	0.312	0.316
		B_{2011}/B_0			V_{2011}/V_0	
Estimate *M* & *h*	0.124	0.259	0.428	0.165	0.303	0.490
Estimate *M*	0.130	0.249	0.423	0.163	0.295	0.490
Estimate *h*	0.083	0.140	0.238	0.110	0.177	0.277
Fixed *M* & *h*	0.075	0.116	0.184	0.096	0.150	0.222
		U_{2010}			U_{max} [1]	
Estimate *M* & *h*	0.041	0.077	0.152	0.096	0.112	0.213
Estimate *M*	0.041	0.079	0.153	0.099	0.115	0.204
Estimate *h*	0.089	0.146	0.224	0.128	0.183	0.285
Fixed *M* & *h*	0.110	0.166	0.248	0.132	0.223	0.285

[1] Maximum observed annual exploitation rate from 1940 to 2010

Table G5. Calculation of the PA (Precautionary Approach) compliant harvest strategy for 2011, where B_{MSY}, V_{MSY} and U_{MSY} are, respectively, the spawning biomass, vulnerable biomass and exploitation rate at the maximum sustainable yield (MSY). Also, B_{2011} is the estimated spawning biomass in 2011, U_{2010} is the estimated exploitation rate in 2010, and U_{2011} and Y_{2011} are the calculated PA-compliant exploitation rate and yield for 2011. Biomasses and yields are in tonnes. All derived quantities were calculated for each sample of the MCMC posterior. Continued overleaf.

Run	Quantile 5th	50th	95th
		$0.4B_{MSY}$	
Estimate *M* & *h*	6,071	9,202	13,384
Estimate *M*	9,014	10,081	11,984
Estimate *h*	4,872	7,385	9,955
Fixed *M* & *h*	8,241	8,657	9,257
		$0.8B_{MSY}$	
Estimate *M* & *h*	12,141	18,403	26,769
Estimate *M*	18,027	20,162	23,969
Estimate *h*	9,744	14,771	19,910
Fixed *M* & *h*	16,482	17,314	18,515

Run	Quantile 5th	50th	95th
		B_{MSY}	
Estimate *M* & *h*	15,177	23,004	33,461
Estimate *M*	22,534	25,203	29,961
Estimate *h*	12,180	18,463	24,888
Fixed *M* & *h*	20,603	21,642	23,144
		V_{MSY}	
Estimate *M* & *h*	33,022	47,272	65,263
Estimate *M*	45,203	50,616	60,589
Estimate *h*	27,461	39,273	50,586
Fixed *M* & *h*	42,352	44,639	47,802
		MSY	
Estimate *M* & *h*	2,916	4,535	6,339
Estimate *M*	3,401	3,953	4,934
Estimate *h*	2,760	3,722	4,698
Fixed *M* & *h*	3,031	3,177	3,381
		B_{2011}	
Estimate *M* & *h*	10,076	23,690	46,452
Estimate *M*	10,702	22,662	44,729
Estimate *h*	6,091	10,580	19,592
Fixed *M* & *h*	5,505	8,772	14,822
		U_{MSY}	
Estimate *M* & *h*	0.048	0.098	0.170
Estimate *M*	0.073	0.078	0.085
Estimate *h*	0.055	0.095	0.165
Fixed *M* & *h*	0.070	0.070	0.073
		U_{2010}	
Estimate *M* & *h*	0.041	0.077	0.152
Estimate *M*	0.041	0.079	0.153
Estimate *h*	0.089	0.146	0.224
Fixed *M* & *h*	0.110	0.166	0.248
		U_{2011} (PA compliant)	
Estimate *M* & *h*	0.003	0.093	0.170
Estimate *M*	0.012	0.078	0.085
Estimate *h*	0.000	0.045	0.163
Fixed *M* & *h*	0.000	0.001	0.045
		Y_{2011} (PA compliant)	
Estimate *M* & *h*	68	4,780	12,137
Estimate *M*	287	3,721	7,704
Estimate *h*	0	1,220	5,618
Fixed *M* & *h*	0	23	1,466

Table G6. Decision tables detailing the limit reference point $0.4B_{MSY}$ for 1-5 year projections for all four model runs. Values are P(B_t > 0.4 B_{MSY}), i.e. the probability of the spawning biomass at the start of year t being greater than the limit reference point. The probabilities are based on the MCMC posterior distributions of B_t and B_{MSY}. Catch strategies (in tonnes) are in increments of 500, and 3500 is the approximate average catch over the last 5 years. Continued overleaf.

Annual catch strategy	Projection Year 2011	2012	2013	2014	2015	2016
	Run: Estimate *M* & *h*					
0	0.957	0.976	0.989	0.993	0.997	0.997
500	0.957	0.972	0.985	0.991	0.992	0.995
1000	0.957	0.971	0.981	0.985	0.988	0.986
1500	0.957	0.969	0.975	0.981	0.982	0.980
2000	0.957	0.968	0.969	0.969	0.969	0.968
2500	0.957	0.966	0.964	0.964	0.963	0.953
3000	0.957	0.964	0.961	0.956	0.937	0.931
3500	0.957	0.956	0.956	0.939	0.926	0.911
4000	0.957	0.953	0.943	0.924	0.909	0.884
4500	0.957	0.949	0.933	0.910	0.886	0.853
5000	0.957	0.946	0.923	0.900	0.863	0.816
5500	0.957	0.943	0.915	0.882	0.832	0.781
6000	0.957	0.937	0.904	0.868	0.804	0.736
	Run: Estimate *M*					
0	0.972	0.983	0.991	0.997	0.999	1.000
500	0.972	0.982	0.989	0.993	0.996	0.997
1000	0.972	0.981	0.984	0.988	0.990	0.990
1500	0.972	0.980	0.982	0.982	0.983	0.983
2000	0.972	0.979	0.979	0.979	0.975	0.974
2500	0.972	0.977	0.974	0.971	0.966	0.959
3000	0.972	0.974	0.969	0.960	0.947	0.935
3500	0.972	0.970	0.962	0.946	0.929	0.911
4000	0.972	0.966	0.949	0.929	0.908	0.873
4500	0.972	0.963	0.944	0.915	0.873	0.829
5000	0.972	0.958	0.931	0.897	0.840	0.778
5500	0.972	0.955	0.919	0.865	0.800	0.727
6000	0.972	0.946	0.904	0.841	0.766	0.662
	Run: Estimate *h*					
0	0.816	0.895	0.942	0.966	0.981	0.985
500	0.816	0.883	0.923	0.948	0.959	0.968
1000	0.816	0.873	0.905	0.922	0.932	0.935
1500	0.816	0.860	0.882	0.893	0.893	0.888
2000	0.816	0.846	0.857	0.859	0.855	0.844
2500	0.816	0.829	0.831	0.816	0.784	0.755
3000	0.816	0.818	0.801	0.766	0.723	0.674
3500	0.816	0.800	0.762	0.712	0.652	0.574
4000	0.816	0.783	0.728	0.659	0.564	0.484
4500	0.816	0.760	0.695	0.593	0.483	0.390
5000	0.816	0.741	0.655	0.529	0.407	0.294
5500	0.816	0.728	0.619	0.468	0.320	0.228
6000	0.816	0.713	0.571	0.397	0.254	0.167

Annual catch strategy	Projection Year					
	2011	2012	2013	2014	2015	2016
	Run: Fixed *M* & *h*					
0	0.518	0.726	0.863	0.947	0.973	0.987
500	0.518	0.697	0.811	0.880	0.926	0.950
1000	0.518	0.664	0.747	0.799	0.824	0.838
1500	0.518	0.625	0.681	0.712	0.708	0.703
2000	0.518	0.592	0.621	0.613	0.582	0.539
2500	0.518	0.560	0.557	0.518	0.454	0.386
3000	0.518	0.530	0.488	0.418	0.330	0.270
3500	0.518	0.496	0.422	0.324	0.240	0.157
4000	0.518	0.460	0.356	0.251	0.157	0.089
4500	0.518	0.433	0.302	0.186	0.095	0.059
5000	0.518	0.389	0.257	0.132	0.067	0.037
5500	0.518	0.362	0.203	0.094	0.05	0.022
6000	0.518	0.332	0.172	0.071	0.029	0.013

Table G7. As for Table G6, but for the upper reference point 0.8 B_{MSY}, such that values shown are P(B_t > 0.8 B_{MSY}).

Annual catch strategy						Projection Year
	2011	2012	2013	2014	2015	2016
	Run: Estimate *M* & *h*					
0	0.680	0.754	0.810	0.847	0.875	0.890
500	0.680	0.747	0.790	0.829	0.850	0.869
1000	0.680	0.741	0.777	0.800	0.823	0.835
1500	0.680	0.729	0.759	0.782	0.793	0.800
2000	0.680	0.720	0.738	0.762	0.764	0.759
2500	0.680	0.708	0.726	0.731	0.723	0.717
3000	0.680	0.693	0.705	0.699	0.689	0.674
3500	0.680	0.685	0.679	0.671	0.650	0.626
4000	0.680	0.676	0.663	0.644	0.615	0.584
4500	0.680	0.666	0.644	0.615	0.583	0.559
5000	0.680	0.660	0.628	0.590	0.558	0.516
5500	0.680	0.646	0.612	0.569	0.523	0.485
6000	0.680	0.640	0.595	0.547	0.497	0.447
	Run: Estimate *M*					
0	0.624	0.704	0.774	0.827	0.871	0.903
500	0.624	0.692	0.753	0.800	0.835	0.859
1000	0.624	0.672	0.737	0.766	0.793	0.810
1500	0.624	0.662	0.712	0.743	0.750	0.757
2000	0.624	0.654	0.677	0.695	0.697	0.684
2500	0.624	0.642	0.658	0.656	0.646	0.629
3000	0.624	0.628	0.627	0.620	0.595	0.567
3500	0.624	0.616	0.605	0.584	0.551	0.524
4000	0.624	0.609	0.581	0.545	0.508	0.465
4500	0.624	0.596	0.559	0.513	0.463	0.419
5000	0.624	0.583	0.538	0.481	0.436	0.371
5500	0.624	0.573	0.513	0.458	0.386	0.316
6000	0.624	0.561	0.485	0.437	0.352	0.268
	Run: Estimate *h*					
0	0.239	0.317	0.437	0.546	0.613	0.661
500	0.239	0.303	0.407	0.489	0.559	0.596
1000	0.239	0.288	0.365	0.426	0.477	0.515
1500	0.239	0.268	0.327	0.381	0.398	0.418
2000	0.239	0.260	0.292	0.324	0.334	0.333
2500	0.239	0.256	0.266	0.274	0.264	0.258
3000	0.239	0.239	0.236	0.226	0.213	0.197
3500	0.239	0.225	0.209	0.189	0.168	0.152
4000	0.239	0.215	0.189	0.163	0.143	0.119
4500	0.239	0.203	0.178	0.137	0.113	0.091
5000	0.239	0.188	0.154	0.116	0.088	0.064
5500	0.239	0.181	0.133	0.098	0.074	0.046
6000	0.239	0.174	0.121	0.082	0.057	0.035

Annual catch strategy	Projection Year 2011	2012	2013	2014	2015	2016
	Run: Fixed *M* & *h*					
0	0.009	0.017	0.036	0.070	0.103	0.156
500	0.009	0.015	0.028	0.049	0.071	0.082
1000	0.009	0.012	0.023	0.034	0.047	0.055
1500	0.009	0.011	0.020	0.024	0.025	0.027
2000	0.009	0.010	0.013	0.018	0.019	0.019
2500	0.009	0.010	0.011	0.012	0.011	0.008
3000	0.009	0.009	0.009	0.009	0.005	0.004
3500	0.009	0.009	0.009	0.004	0.001	0.001
4000	0.009	0.009	0.007	0.002	0.001	0.000
4500	0.009	0.008	0.003	0.001	0.000	0.000
5000	0.009	0.007	0.002	0.001	0.000	0.000
5500	0.009	0.006	0.001	0.000	0.000	0.000
6000	0.009	0.004	0.001	0.000	0.000	0.000

Table G8. As for Table G6, but for B_{MSY}, such that values shown are $P(B_t > B_{MSY})$.

Annual catch strategy	**Projection Year**					
	2011	**2012**	**2013**	**2014**	**2015**	**2016**
	Run: Estimate *M* & *h*					
0	0.523	0.586	0.647	0.704	0.739	0.762
500	0.523	0.575	0.624	0.674	0.708	0.727
1000	0.523	0.567	0.609	0.649	0.675	0.695
1500	0.523	0.560	0.594	0.614	0.637	0.647
2000	0.523	0.556	0.575	0.593	0.599	0.609
2500	0.523	0.550	0.566	0.572	0.578	0.575
3000	0.523	0.535	0.545	0.548	0.542	0.540
3500	0.523	0.528	0.532	0.525	0.513	0.497
4000	0.523	0.522	0.518	0.503	0.483	0.465
4500	0.523	0.515	0.499	0.483	0.453	0.429
5000	0.523	0.510	0.483	0.452	0.418	0.390
5500	0.523	0.503	0.464	0.428	0.392	0.345
6000	0.523	0.495	0.445	0.408	0.359	0.307
	Run: Estimate *M*					
0	0.388	0.458	0.538	0.610	0.658	0.708
500	0.388	0.450	0.510	0.567	0.615	0.645
1000	0.388	0.438	0.486	0.530	0.557	0.576
1500	0.388	0.431	0.473	0.498	0.513	0.527
2000	0.388	0.422	0.451	0.465	0.467	0.465
2500	0.388	0.414	0.437	0.444	0.436	0.415
3000	0.388	0.408	0.411	0.409	0.387	0.373
3500	0.388	0.400	0.396	0.375	0.350	0.311
4000	0.388	0.394	0.372	0.342	0.298	0.260
4500	0.388	0.383	0.348	0.308	0.260	0.227
5000	0.388	0.367	0.326	0.279	0.233	0.197
5500	0.388	0.350	0.303	0.252	0.206	0.173
6000	0.388	0.339	0.281	0.228	0.186	0.145
	Run: Estimate *h*					
0	0.113	0.159	0.218	0.291	0.379	0.439
500	0.113	0.149	0.199	0.255	0.310	0.357
1000	0.113	0.142	0.182	0.218	0.247	0.283
1500	0.113	0.135	0.166	0.185	0.206	0.217
2000	0.113	0.125	0.140	0.159	0.166	0.171
2500	0.113	0.120	0.124	0.132	0.133	0.135
3000	0.113	0.117	0.118	0.113	0.111	0.105
3500	0.113	0.110	0.104	0.097	0.088	0.082
4000	0.113	0.102	0.092	0.080	0.069	0.059
4500	0.113	0.097	0.086	0.071	0.057	0.038
5000	0.113	0.090	0.077	0.063	0.040	0.031
5500	0.113	0.088	0.069	0.048	0.032	0.024
6000	0.113	0.085	0.066	0.039	0.029	0.013

Annual catch strategy	Projection Year					
	2011	2012	2013	2014	2015	2016
	Run: Fixed *M* & *h*					
0	0.000	0.001	0.003	0.008	0.016	0.021
500	0.000	0.001	0.002	0.006	0.008	0.012
1000	0.000	0.000	0.001	0.002	0.003	0.004
1500	0.000	0.000	0.001	0.001	0.001	0.001
2000	0.000	0.000	0.000	0.001	0.001	0.000
2500	0.000	0.000	0.000	0.000	0.000	0.000
3000	0.000	0.000	0.000	0.000	0.000	0.000
3500	0.000	0.000	0.000	0.000	0.000	0.000
4000	0.000	0.000	0.000	0.000	0.000	0.000
4500	0.000	0.000	0.000	0.000	0.000	0.000
5000	0.000	0.000	0.000	0.000	0.000	0.000
5500	0.000	0.000	0.000	0.000	0.000	0.000
6000	0.000	0.000	0.000	0.000	0.000	0.000

Table G9. Median values of B_t / B_{MSY} (ratio of spawning biomass in year t to the spawning biomass at the maximum sustainable yield) for 1-5 year projections for all four model runs.

Annual catch strategy	Projection Year					
	2011	2012	2013	2014	2015	2016
	Run: Estimate *M* & *h*					
0	1.036	1.113	1.202	1.278	1.342	1.398
500	1.036	1.102	1.183	1.239	1.294	1.342
1000	1.036	1.092	1.157	1.202	1.248	1.291
1500	1.036	1.083	1.135	1.173	1.205	1.221
2000	1.036	1.073	1.114	1.142	1.161	1.168
2500	1.036	1.064	1.090	1.107	1.111	1.112
3000	1.036	1.056	1.068	1.073	1.065	1.050
3500	1.036	1.048	1.044	1.037	1.022	0.994
4000	1.036	1.037	1.021	1.002	0.971	0.942
4500	1.036	1.026	0.997	0.968	0.928	0.885
5000	1.036	1.015	0.976	0.934	0.881	0.830
5500	1.036	1.005	0.952	0.900	0.839	0.778
6000	1.036	0.993	0.930	0.866	0.792	0.726
	Run: Estimate *M*					
0	0.890	0.966	1.029	1.085	1.136	1.178
500	0.890	0.956	1.010	1.054	1.096	1.129
1000	0.890	0.946	0.989	1.024	1.054	1.077
1500	0.890	0.936	0.970	0.995	1.015	1.026
2000	0.890	0.926	0.951	0.966	0.975	0.976
2500	0.890	0.916	0.930	0.935	0.933	0.926
3000	0.890	0.906	0.908	0.904	0.892	0.875
3500	0.890	0.896	0.888	0.872	0.849	0.823
4000	0.890	0.885	0.866	0.841	0.808	0.772
4500	0.890	0.875	0.847	0.810	0.766	0.721
5000	0.890	0.865	0.827	0.780	0.727	0.671
5500	0.890	0.855	0.808	0.751	0.686	0.621
6000	0.890	0.845	0.789	0.720	0.645	0.570
	Run: Estimate *h*					
0	0.594	0.676	0.761	0.834	0.895	0.945
500	0.594	0.663	0.734	0.795	0.842	0.876
1000	0.594	0.652	0.709	0.754	0.786	0.811
1500	0.594	0.640	0.683	0.713	0.732	0.743
2000	0.594	0.627	0.656	0.672	0.675	0.669
2500	0.594	0.616	0.630	0.632	0.618	0.602
3000	0.594	0.603	0.605	0.591	0.563	0.528
3500	0.594	0.590	0.579	0.552	0.506	0.455
4000	0.594	0.577	0.551	0.510	0.448	0.387
4500	0.594	0.565	0.525	0.468	0.391	0.317
5000	0.594	0.553	0.498	0.422	0.331	0.251
5500	0.594	0.541	0.472	0.378	0.277	0.183
6000	0.594	0.531	0.446	0.336	0.224	0.120

Annual catch strategy	Projection Year					
	2011	2012	2013	2014	2015	2016
	Run: Fixed *M* & *h*					
0	0.406	0.469	0.529	0.579	0.619	0.649
500	0.406	0.460	0.507	0.545	0.571	0.590
1000	0.406	0.450	0.485	0.510	0.525	0.532
1500	0.406	0.440	0.463	0.476	0.478	0.473
2000	0.406	0.430	0.440	0.441	0.431	0.415
2500	0.406	0.420	0.418	0.407	0.385	0.355
3000	0.406	0.409	0.396	0.373	0.337	0.297
3500	0.406	0.398	0.374	0.338	0.291	0.240
4000	0.406	0.388	0.352	0.303	0.244	0.185
4500	0.406	0.378	0.330	0.268	0.198	0.130
5000	0.406	0.367	0.308	0.234	0.153	0.077
5500	0.406	0.357	0.287	0.200	0.110	0.043
6000	0.406	0.347	0.265	0.167	0.067	0.034

APPENDIX H. SPECIES CAUGHT CONCURRENTLY WITH PACIFIC OCEAN PERCH

Tows that capture Pacific ocean perch (POP) remove other species of fish as well. This appendix evaluates the available data for species caught concurrently with POP in bottom and midwater tows.

The depth distribution of bottom trawl tows that captured POP in Pacific Marine Fisheries Commission (PMFC) areas 5ABC shows that 99% of the encounters lie between 79 and 443 m, with a median tow depth of 236 m and a depth-of-median-catch at 252 m (Figure H1, data extracted from the PacHarvest and GFFOS databases). Hereafter, we refer to 5ABC bottom tows between 79 and 443 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 in 5ABC (shaded background histogram) due to a large flatfish fishery in 5C.

Similarly, we refer to 5ABC midwater tows that encounter POP between 54 and 321 m as “POP midwater tows” (Figure H2). Asymmetric 95% limits are required to truncate a long right-hand tail in the tow frequency distribution, which is likely present as a result of data errors which seem to be more frequent in the most recent four years. Another possible reason for POP to appear in deep tows is that they may be caught at shallower depths as the net descends or ascends from midwater tows.

The reported species caught in POP bottom tows comprise predominantly of a mixture of rockfish and flatfish (Figure H3). Pacific ocean perch remains the most abundant species by weight in these tows (45% by catch weight), followed by arrowtooth flounder *Atheresthes stomias* (17%), yellowmouth rockfish *Sebastes reedi* (10%), and Dover sole *Microstomus pacificus* (5%). Three of the four rockfish species of interest to COSEWIC (Committee on the Status of Endangered Wildlife in Canada) each account for less than 1% of the total mortalities by weight (Table H1). The fourth species, yellowmouth rockfish, is the third most frequent species by weight reported from these tows (Figure H3; Table H1).

Pacific ocean perch midwater tows are dominated by Pacific hake *Merluccius productus* (81% by catch weight; Figure H4, Table H2). Other species in these tows are POP (6%), yellowtail rockfish *Sebastes flavidus* (5%), and widow rockfish *S. entomelas* (3%). The four rockfish species of interest to COSEWIC identified in POP bottom tows also occur in POP midwater tows (Table H2).

The total annual reported catch in POP bottom tows appears to decline after the change in data management from DFO Science (PacHarvest) to DFO Management (GFFOS) in 2007 (Figure H5, Table H3). This may reflect changes in reporting accuracy or may be an artefact of the change from one data recording system to another. The relative composition of the catch has remained stable, with a mean annual composition of 45% POP, 25% other rockfish, 17% turbot (arrowtooth flounder), 8% flatfish, 1% hake, 1% sharks (incl. skates), and 3% other fish.

The relative composition of the catch in POP midwater tows has shifted away from rockfish, which predominated from 1996-2005, to hake since 2006 (Figure H6, Table H4). Up to 2005, catch composition primarily comprised rockfish other than POP, with a proportional mean annual contribution of 53% and a relatively low catch tonnage. A shift occurred after 2006, with hake contributing a large tonnage to POP midwater tows as well as dominating the proportional catch, with a mean annual contribution by weight of 93%. This shift was probably due to the northern limit of the hake fishery moving north from the WCVI (west coast Vancouver Island, PMFC 3CD) to Queen Charlotte Sound (PMFC 5AB).

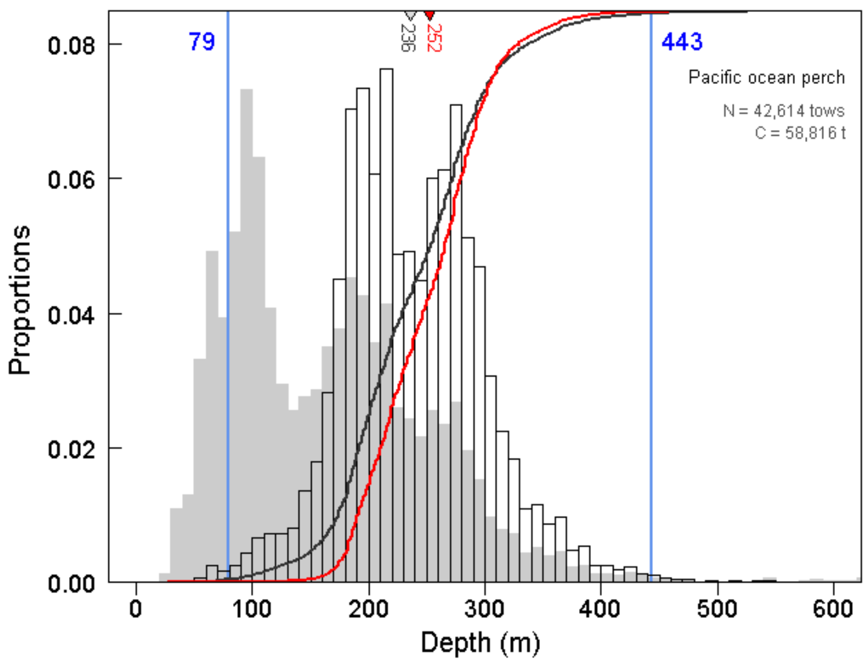


Figure H1. Depth frequency of bottom tows that capture POP from commercial trawl logs (1996-2007 in PacHarvest, 2007-2010 in GFFOS, where 2010 records are incomplete) in PMFC major areas 5ABC. The vertical solid lines denote the 0.5% and 99.5% quantiles. The black curve shows the cumulative tow depth distribution; the red curve shows the cumulative catch of POP at depth (both curves scaled from 0 to 1). The median depth of tows (inverted grey triangle) and median depth of cumulative catch (inverted red triangle) are 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.

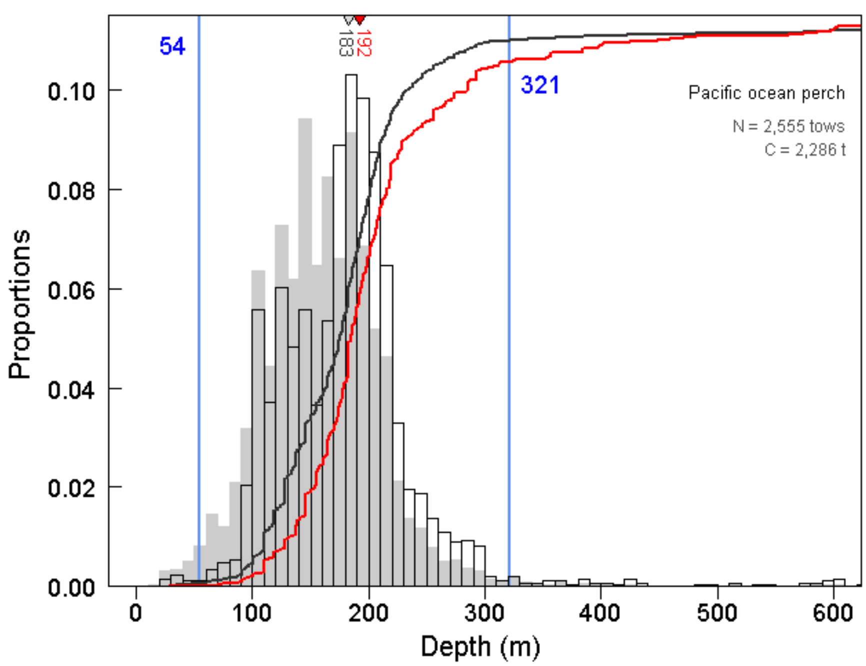


Figure H2. Depth frequency of midwater tows that capture POP from commercial trawl logs (1996-2010) in PMFC major areas 5ABC. See Figure H1 for plot details.

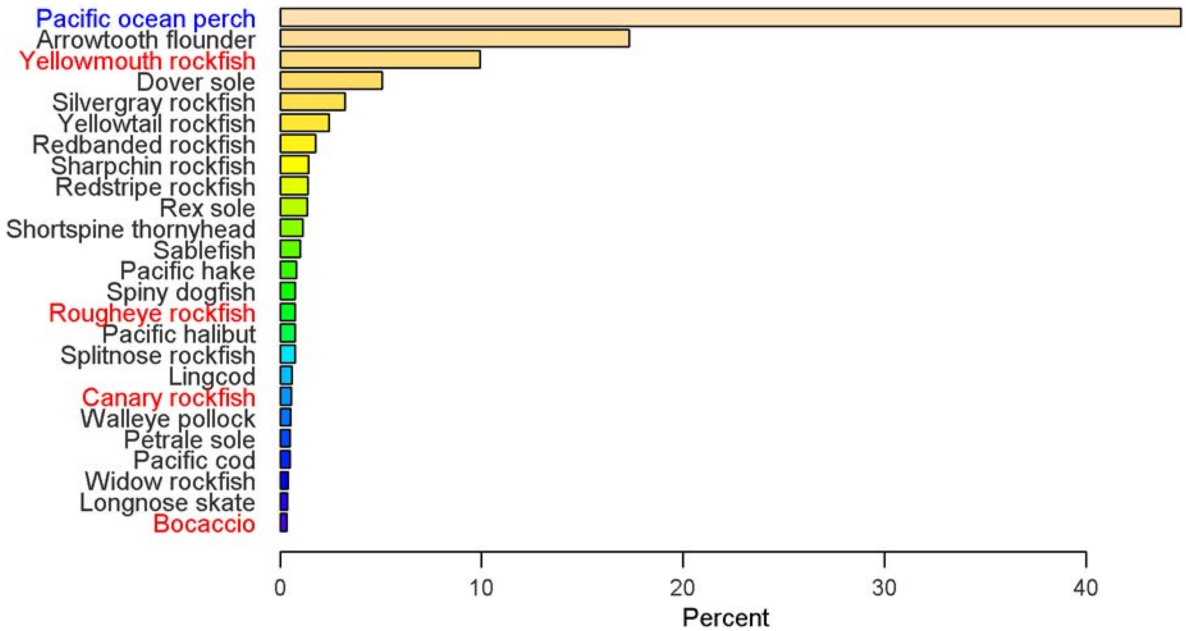


Figure H3. Concurrence of species in POP bottom trawl tows (1996-2010 observer logs). Abundance is expressed as a percent of total catch weight. POP is indicated in blue on the y-axis; COSEWIC-concern species are indicated in red.

Table H1. Top 25 species by catch weight (landed + discarded) that co-occur in POP bottom tows (total from 1996-2010 observer logs). Species of interest to COSEWIC have been shaded grey.

Code	Species	Latin name	Catch (t)	Catch (%)
396	Pacific ocean perch	*Sebastes alutus*	58,599	44.720
602	Arrowtooth flounder	*Atheresthes stomias*	22,699	17.323
440	Yellowmouth rockfish	*Sebastes reedi*	12,993	9.915
626	Dover sole	*Microstomus pacificus*	6,656	5.079
405	Silvergray rockfish	*Sebastes brevispinis*	4,240	3.236
418	Yellowtail rockfish	*Sebastes flavidus*	3,192	2.436
401	Redbanded rockfish	*Sebastes babcocki*	2,312	1.765
450	Sharpchin rockfish	*Sebastes zacentrus*	1,862	1.421
439	Redstripe rockfish	*Sebastes proriger*	1,817	1.387
610	Rex sole	*Errex zachirus*	1,754	1.338
451	Shortspine thornyhead	*Sebastolobus alascanus*	1,486	1.134
455	Sablefish	*Anoplopoma fimbria*	1,293	0.987
225	Pacific hake	*Merluccius productus*	1,055	0.805
044	Spiny dogfish	*Squalus acanthias*	995	0.759
394	Rougheye rockfish	*Sebastes aleutianus*	992	0.757
614	Pacific halibut	*Hippoglossus stenolepis*	987	0.753
412	Splitnose rockfish	*Sebastes diploproa*	963	0.735
467	Lingcod	*Ophiodon elongatus*	787	0.600
437	Canary rockfish	*Sebastes pinniger*	726	0.554
228	Walleye pollock	*Theragra chalcogramma*	686	0.523
607	Petrale sole	*Eopsetta jordani*	656	0.501
222	Pacific cod	*Gadus macrocephalus*	655	0.500
417	Widow rockfish	*Sebastes entomelas*	519	0.396
059	Longnose skate	*Raja rhina*	482	0.368
435	Bocaccio	*Sebastes paucispinis*	437	0.334

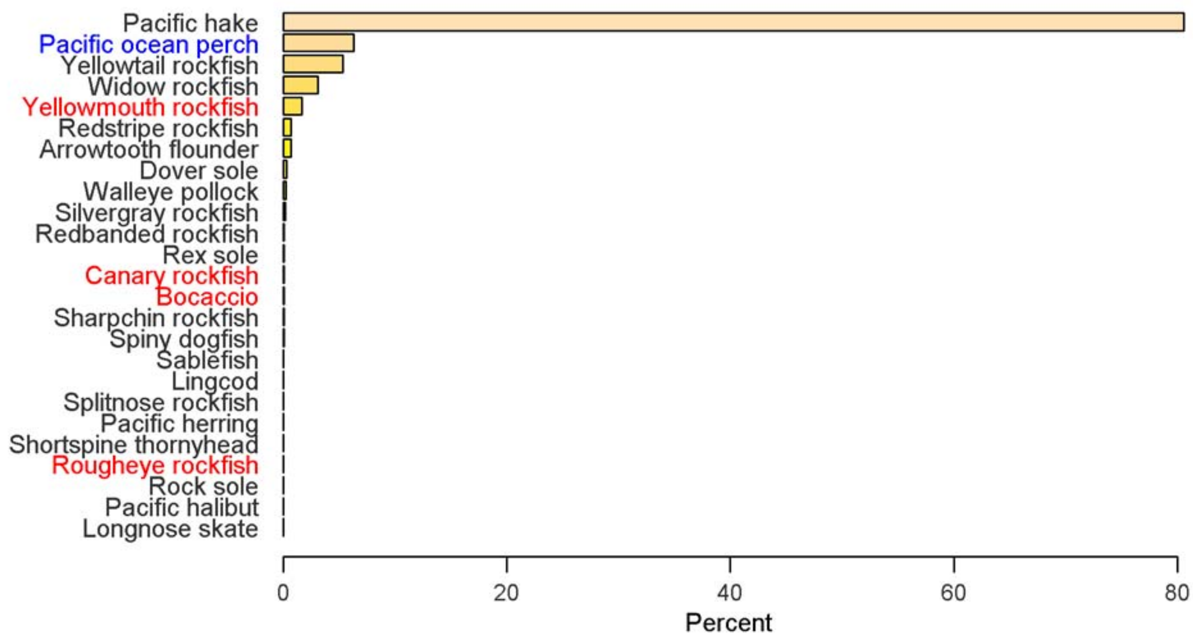


Figure H4. Concurrence of species in POP midwater trawl tows (1996-2010 observer logs). Abundance is expressed as a percent of total catch weight. POP is indicated in blue on the y-axis; Species of interest to COSEWIC are indicated in red.

Table H2. Top 25 species by catch weight (landed + discarded) that co-occur in POP midwater tows (total from 1996-2010 observer logs). Rockfish species of interest to COSEWIC have been shaded grey.

Code	Species	Latin name	Catch (t)	Catch (%)
225	Pacific hake	*Merluccius productus*	21,031	80.609
396	Pacific ocean perch	*Sebastes alutus*	1,647	6.312
418	Yellowtail rockfish	*Sebastes flavidus*	1,390	5.326
417	Widow rockfish	*Sebastes entomelas*	820	3.143
440	Yellowmouth rockfish	*Sebastes reedi*	444	1.702
439	Redstripe rockfish	*Sebastes proriger*	185	0.709
602	Arrowtooth flounder	*Atheresthes stomias*	181	0.693
626	Dover sole	*Microstomus pacificus*	80	0.308
228	Walleye pollock	*Theragra chalcogramma*	60	0.231
405	Silvergray rockfish	*Sebastes brevispinis*	55	0.211
401	Redbanded rockfish	*Sebastes babcocki*	19	0.073
610	Rex sole	*Errex zachirus*	18	0.071
437	Canary rockfish	*Sebastes pinniger*	17	0.066
435	Bocaccio	*Sebastes paucispinis*	17	0.064
450	Sharpchin rockfish	*Sebastes zacentrus*	15	0.056
044	Spiny dogfish	*Squalus acanthias*	14	0.055
455	Sablefish	*Anoplopoma fimbria*	12	0.046
467	Lingcod	*Ophiodon elongatus*	8	0.032
412	Splitnose rockfish	*Sebastes diploproa*	8	0.030
096	Pacific herring	*Clupea pallasi*	8	0.030
451	Shortspine thornyhead	*Sebastolobus alascanus*	5	0.021
394	Rougheye rockfish	*Sebastes aleutianus*	5	0.019
621	Rock sole	*Lepidopsetta bilineatus*	5	0.018
614	Pacific halibut	*Hippoglossus stenolepis*	4	0.017
059	Longnose skate	*Raja rhina*	4	0.017

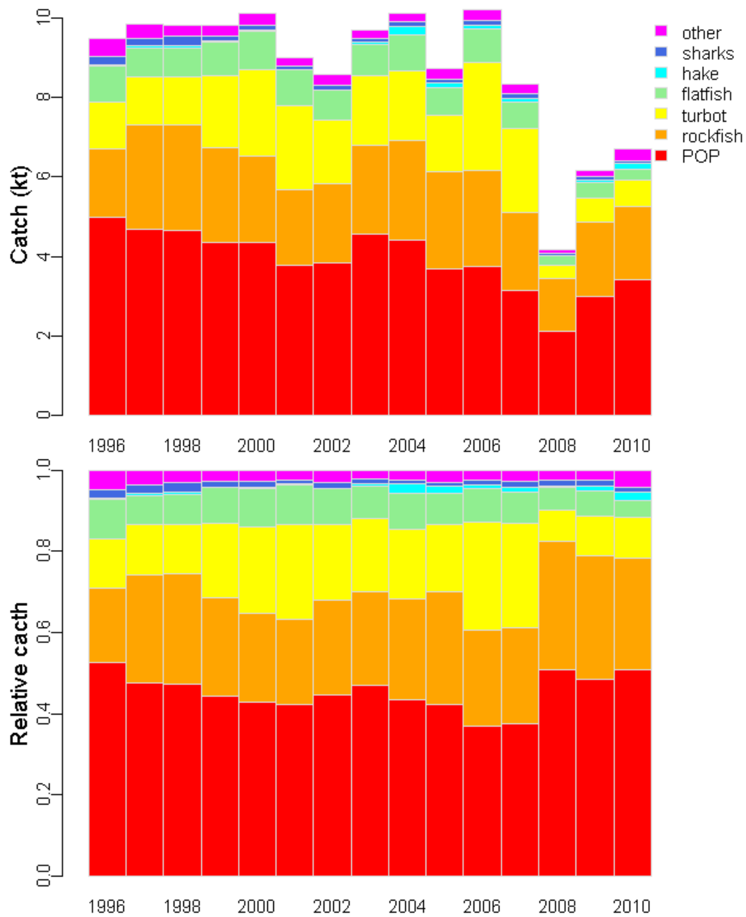


Figure H5. Temporal distribution of catch (landed + discarded) for exclusive fish groups caught in POP bottom tows. Upper: Annual reported catch (kt) from PacHarvest (1996-2007) and GFFOS (2007-2010, where 2010 records are incomplete). Lower: Relative composition where each groups' catch is expressed as a proportion of the total annual catch. Note: 'turbot' = arrowtooth flounder (Atheresthes stomias); 'sharks' include sharks and skates.

Table H3. Reported catch (t), including discards, of exclusive fish groups from POP bottom tows. Data sources: PacHarvest (1996-2007) and GFFOS (2007-2010, where 2010 records are incomplete).

year	POP	other rockfish	turbot	flatfish	hake	sharks	other fish
1996	4,979	1,732	1,176	909	26	204	450
1997	4,675	2,626	1,225	718	55	192	357
1998	4,660	2,656	1,209	733	41	236	296
1999	4,351	2,389	1,800	855	19	124	280
2000	4,338	2,198	2,157	978	22	134	288
2001	3,792	1,892	2,114	889	11	92	213
2002	3,833	1,988	1,600	768	10	116	260
2003	4,559	2,241	1,763	762	68	97	217
2004	4,409	2,513	1,746	897	217	115	231
2005	3,678	2,446	1,441	671	143	90	257
2006	3,760	2,404	2,725	841	93	121	254
2007	3,134	1,960	2,135	648	107	116	225
2008	2,123	1,328	325	232	21	53	104
2009	2,991	1,870	613	376	82	79	154
2010	3,411	1,832	671	279	140	71	289

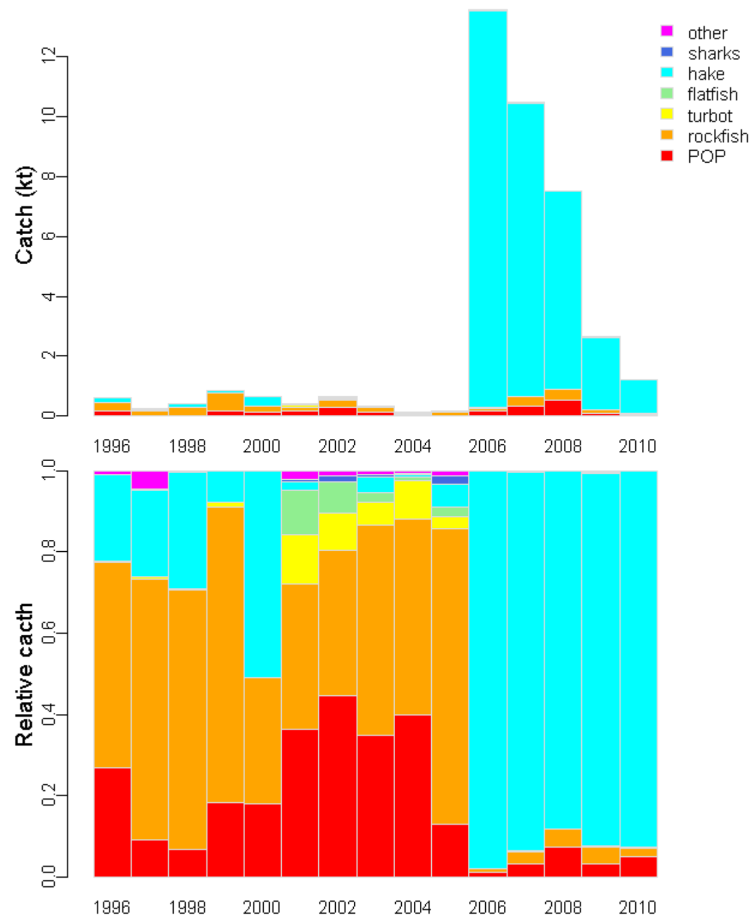


Figure H6. Temporal distribution of catch (landed + discarded) for exclusive fish groups caught in POP midwater tows. See Figure H5 for details. (Note: 2010 records incomplete).

Table H4. Reported catch (t), including discards, of exclusive fish groups from POP midwater tows. Data sources: PacHarvest (1996-2007) and GFFOS (2007-2010, where 2010 records are incomplete).

year	POP	other rockfish	turbot	flatfish	hake	sharks	other fish
1996	161	303	1	0	128	0	5
1997	21	152	1	0	50	0	11
1998	27	257	1	0	115	0	2
1999	155	610	10	0	64	0	1
2000	118	201	1	0	331	0	0
2001	152	149	50	46	9	2	9
2002	288	231	59	50	0	9	9
2003	119	178	19	8	13	2	3
2004	46	56	11	1	1	0	1
2005	20	111	4	4	9	3	2
2006	159	106	3	2	13,281	1	11
2007	319	331	17	0	9,773	1	43
2008	541	346	6	1	6,605	0	3
2009	84	111	4	1	2,428	4	10
2010	59	27	2	0	1,130	1	2