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Stock assessment and recovery potential assessment for Yellowmouth Rockfish (*Sebastes reedi*) along the Pacific coast of Canada

Évaluation du stock et évaluation du potentiel de rétablissement du sébaste à bouche jaune (*Sebastes reedi*) le long de la côte du Pacifique au Canada

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ABSTRACT

Yellowmouth Rockfish along the Pacific coast of Canada has been designated as *Threatened* by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), with commercial fishing being the primary threat. The purpose of this document is to be the Recovery Potential Assessment that formulates the scientific information concerning the current status of the species, threats to its survival and recovery, and the feasibility of its recovery. This document also serves as a stock assessment for the provision of advice to fisheries managers.

We used an annual catch-at-age model tuned to five fishery-independent survey series, annual estimates of commercial catch since 1940, six years of age composition data from two survey series, and 18 years of age composition data from the commercial fishery. The model started from an 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 two main scenarios which were considered equally plausible, in which natural mortality was either estimated or fixed (termed run 'Estimate M' and run 'Fix M', respectively).

Both model scenarios imply a slow-growing, low productivity stock that has undergone periods of high recruitment in the early 1960s and the early 1980s. For run 'Estimate M', the estimate of B_{2011}/B_0, where B_{2011} is the spawning biomass (mature females only) at the beginning of 2011 and B_0 is the unfished equilibrium spawning biomass, is 0.614 (0.431-0.829), denoting median and 5th and 95th quantiles of the Bayesian posterior distribution. For run 'Fix M', the estimate of B_{2011}/B_0 is 0.409 (0.289-0.547). Denoting the estimated spawning biomass at maximum sustainable yield as B_{MSY}, the estimate of B_{MSY}/B_0 is 0.233 (0.149-0.314) for run 'Estimate M', and 0.216 (0.147-0.298) for run 'Fix M'.

The exploitation rate (ratio of total commercial catch to vulnerable biomass) for 2010 is estimated to be 0.020 (0.010-0.036) for run 'Estimate M' and 0.038 (0.026-0.059) for run 'Fix M', compared to respective historic highs of 0.090 (0.059-0.123) and 0.130 (0.110-0.154) estimated for 1966 during intense fishing by foreign fleets.

Current and projected probabilities of the status of the population are given with respect to (i) the DFO Sustainable Fisheries Framework provisional reference points of $0.4B_{MSY}$ and $0.8B_{MSY}$, (ii) reference points of $0.2B_0$ and $0.4B_0$, and (iii) reference criteria given by COSEWIC assessment indicators A1 and A2.

Projections are presented for up to three generations (90 years) for both model runs. For each level of constant catch, these give probabilities of future population status with respect to the above reference points and reference criteria, as well as estimates of the time taken to attain them (with different levels of confidence) assuming random recruitment.

RÉSUMÉ

Le sébaste à bouche jaune le long de la côte du Pacifique du Canada a été désigné comme étant *menacé* par le Comité sur la situation des espèces en péril au Canada (COSEPAC); la pêche commerciale figure au premier rang des menaces. Ce document a pour objectif de constituer l'évaluation du potentiel de rétablissement qui énonce les renseignements scientifiques à propos de la situation de l'espèce, les menaces à sa survie et à son rétablissement et la faisabilité de son rétablissement. À titre d'évaluation du stock, ce document sert également à conseiller les gestionnaires des pêches.

Nous avons eu recours à un modèle de prises selon l'âge annuelles tenant compte de cinq séries de relevés indépendants de la pêche, des estimations de prises commerciales annuelles depuis 1940, des données concernant la composition selon l'âge de deux séries de relevés pour une période de six ans et des données sur la composition selon l'âge de la pêche commerciale pour une période de 18 ans. Le modèle débute sur un état d'équilibre en 1940; les données des relevés couvrent les années 1967 à 2010 (tous les ans ne sont cependant pas représentés). Le modèle des deux sexes a été utilisé dans un cadre d'évaluation bayésienne (à l'aide de la méthode de Monte-Carlo par chaîne de Markov) pour deux scénarios considérés comme aussi plausibles l'un que l'autre, dans lesquels la mortalité naturelle était estimée ou fixe (deux passages de modèle avec respectivement « M estimée » et « M fixe »).

Les deux scénarios modèles suggèrent un stock dont la croissance est lente et le taux de productivité est faible, et qui a traversé des périodes de recrutement élevé au début des années 1960 et 1980. Pour le passage de modèle « M estimée », l'estimation de B_{2011}/B_0 – B_{2011} étant la biomasse du stock reproducteur (femelles adultes uniquement) au début de 2011 et B_0 étant la biomasse d'équilibre non exploitée du stock reproducteur, s'élève à 0,614 (0,431-0,829), indiquant la valeur médiane (quantiles d'ordre 5 et 95) de la distribution bayésienne a posteriori. Pour le passage de modèle « M fixe », l'estimation de B_{2011}/B_0 est de 0,409 (0,289-0,547). La biomasse du stock reproducteur à production maximale étant désigné comme B_{MSY}, l'estimation de B_{MSY}/B_0 est de 0,233 (0,149-0,314) pour le passage de modèle « M estimée », et de 0,216 (0,147-0,298) pour le passage de modèle « M fixe ».

Pour 2010, on estime un taux d'exploitation (rapport du total des prises commerciales et de la biomasse vulnérable) de 0,020 (0,010-0,036) pour le passage de modèle « M estimée » et de 0,038 (0,026-0,059) pour le passage de modèle « M fixe », par rapport aux niveaux historiques records de 0,090 (0,059-0,123) et de 0,130 (0,110-0,154) estimés pour 1966, lorsque les flottes étrangères pratiquaient une pêche intensive.

On donne les probabilités actuelles et projetées concernant la situation des populations par rapport i) aux points de référence provisoires du Cadre pour la pêche durable du MPO de $0{,}4B_{MSY}$ et $0{,}8B_{MSY}$, ii) aux points de référence de $0{,}2B_0$ et de $0{,}4B_0$ iii) aux critères de référence fournis par les indicateurs A1 et A2 de l'évaluation du COSEPAC.

On présente les projections jusqu'à un maximum de trois générations (90 années) pour les deux passages de modèle. Pour chaque niveau de prises constantes, ces projections donnent les probabilités concernant la situation future des populations par rapport aux points et aux critères de référence susmentionnés ainsi que des estimations du temps nécessaire pour les atteindre (avec divers niveaux de confiance) en supposant un niveau de recrutement aléatoire.

INTRODUCTION

Yellowmouth Rockfish (*Sebastes reedi*, Westrheim and Tsuyuki 1967) is an important commercial species in British Columbia, often caught along with Pacific Ocean Perch (*S. alutus*). Yellowmouth Rockfish (YMR) gets its scientific name from the Fisheries and Oceans Canada research vessel G.B. Reed (Westrheim and Tsuyuki 1967), which in turn was named after the late Professor G.B. Reed (Queen's University) who acted as chairman of the Fisheries Research Board of Canada during 1947-55 (Johnstone 1977). Its common name stems from yellow-black blotches in the mouth (Westrheim and Tsuyuki 1967). The body sports a mixture of colours – red, orange, yellow – and features a thin pink-red strip along the lateral line and dusky saddles along the back (Figure 1). Genetically, this species has close ties to Darkblotched Rockfish (*S. crameri*, Love *et al.* 2002).

The life history of YMR remains largely unknown but probably follows similar patterns to other *Sebastes* species, with release of larvae that spend months as free-swimming pelagic larvae before settling to the bottom as juveniles. In British Columbia (BC) waters, larval release occurs from February to June. Males achieve 50% maturity at 37 cm, females at 38 cm. Lengths reach a maximum at approximately 54 cm (Hart 1973).

Yellowmouth Rockfish ranges from the Gulf of Alaska southward to northern California near San Francisco, typically at depths between 180 and 275 m (Love *et al.* 2002). In BC, the population centre occurs in Queen Charlotte Sound with isolated hotspots around Haida Gwaii (Figure 2, see Figure 3 for location names). This species occurs along the west coast of Vancouver Island (WCVI) but its density appears to be low there. Westrheim and Tsuyuki (1967) noted a decrease in modal size from south to north along the BC coast, although this observation might have been confounded with increasing depth. Adults occur frequently in midwater above high-relief rocks. The maximum estimate of age from ageing work for this species is 99 years (Munk 2001).

Yellowmouth Rockfish has the third highest total allowable catch (TAC) for rockfish in BC (after Pacific Ocean Perch and Yellowtail Rockfish), with an annual coastwide TAC of 2,444 t. The total Canadian catch of YMR had a landed value of approximately $1.5 million for the 2007-2008 fishing season (COSEWIC 2010). The trawl fishery accounts for 97% of the coastwide TAC of YMR, with the rest allocated to the hook and line fishery. Appendix 8 of the 2011-2013 Department of Fisheries and Oceans (DFO) Integrated Fisheries Management Plan (IFMP) reports the coastwide *trawl* TAC for YMR at 2,365 t. This has not changed since 2001.

PURPOSE OF DOCUMENT

Yellowmouth Rockfish along the Pacific coast of Canada has been designated as *Threatened* by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), with commercial fishing being the primary threat (COSEWIC 2010). This designation means that Fisheries and Oceans Canada (DFO), as the responsible jurisdiction under the Species at Risk Act (SARA), is required to undertake a number of actions. Many of these actions require scientific information on the current status of the species, threats to its survival and recovery, and the feasibility of its recovery. The purpose of this document is to be the Recovery Potential Assessment (RPA) that formulates the scientific information. An RPA provides scientific background, identification of threats and probability of recovery of a population that is deemed to be at risk. Specifically, an RPA addresses the 17 tasks identified in DFO (2007). These are explicitly listed and addressed below in the Section 'The 17 RPA Framework Tasks from DFO

(2007)'. Previously, Haigh and Starr (2008) summarised the available data for Yellowmouth Rockfish along the Pacific coast of Canada. The data were subsequently used by COSEWIC (2010) to designate this stock.

This document also serves as a stock assessment for the provision of advice to fisheries managers. This is the first stock assessment for Yellowmouth Rockfish along the Pacific coast of Canada that uses a population model. Advice was requested (see Appendix A) to be guided by the DFO Sustainable Fisheries Framework, particularly the *Fishery Decision-making Framework Incorporating the Precautionary Approach* (DFO 2009). Consequently, advice to managers is presented as decision tables that provide probabilities of exceeding reference points for various years of projections across a range of constant catch scenarios. Reference points and reference criteria are defined below in 'Reference points and criteria'.

We follow recent west coast Canadian groundfish assessments, such as Stanley *et al.* (2009) and Edwards *et al.* (2012), in using a modified version of the Coleraine statistical catch-at-age software (Hilborn *et al.* 2003), called Awatea, to implement the model (Appendix F). The model is an annual two-sex catch-at-age model tuned to: five fishery-independent trawl survey series, annual estimates of commercial catch since 1940, age composition data from the commercial fishery (18 years of data) and age composition data from two of the survey series (six years of data). Growth parameters were estimated from Yellowmouth length and age data using research biological samples collected from 1978 to 2009. The model estimates parameters from the stock-recruitment function, natural mortality (independently for females and males), catchability coefficients for the survey series, and selectivity parameters for the commercial fishery and the two survey series for which age data are available.

The model is used to estimate the past and present vulnerable biomass, spawning stock biomass and age structure. Estimated parameters are then used to calculate maximum sustainable yield (MSY) and the reference points. Projections are then performed to estimate future probabilities of the spawning biomass being greater than the reference points under a range of constant catch scenarios.

RANGE AND DISTRIBUTION

The BC population of Yellowmouth Rockfish appears to be centered in Queen Charlotte Sound (central BC coast), specifically in association with the three main gullies – Goose Island, Mitchell's, and Moresby (Figure 2). There are also density 'hotspots' off the southwest coast of Haida Gwaii (near Cape St. James), off Rennell Sound, off the northwest coast of Haida Gwaii, and off the northwest coast of Vancouver Island. Densities of YMR appear to be low off the west coast of Vancouver Island south of Brooks Peninsula. This species has been encountered by the BC trawl fleet over an estimated 29,488km^2, and the bulk of the population lies between depths 110 m and 437 m (Appendix H). Adults are known to occur frequently in midwater above high-relief rocks. In areas where there is surficial geology information, catches of YMR are concentrated over glacial outwash along the canyon walls of Goose Island Gully (Appendix H).

ASSESSMENT BOUNDARIES

Given the absence of population genetic studies of Yellowmouth Rockfish, COSEWIC (2010) considered all individuals within Canadian Pacific waters as a single population. Thus the area of assessment covers the Pacific Marine Fisheries Commission (PMFC) major areas (except for 4B) shown in Figure 3, namely: 3C and 3D (west coast Vancouver Island (WCVI)), 5A, 5B, and 5C (Queen Charlotte Sound (QCS) and lower Hecate Strait), 5D (upper Hecate Strait and Dixon

Entrance), and 5E (west coast Haida Gwaii (WCHG)). These standard areas account for the entire YMR population along the BC coast, except for seamounts.

The PMFC areas are similar but not identical to the groundfish management areas (GMA) used by the DFO Groundfish Management Unit, which are based on combinations of DFO Pacific Fishery Management areas (PFMA). A further complication for YMR, and Pacific Ocean Perch, is that the GMAs have been modified for these two species so that GMA 5C is expanded around Cape St. James (pink area in Figure 3), incorporating parts of 5B and 5E. However, as the assessed population comprises the complete BC coast, no adjustments are required to the assessment results to account for this shift in management areas. There is an issue of how a coastwide yield would be allocated to the TAC boundaries for YMR (3C, 3D+5AB, 5CD, and 5E). One solution would be to allocate yield based on the existing TAC proportions (see Appendix B); however, such allocation decisions are outside the scope of the document.

CATCH DATA

The preparation methods and the full catch history for this assessment are given in Appendix B. The resulting time series of catch data that is used as model input is shown in Figure 4, reaching a peak of 6,843 t in 1966 (during a period of intense fishing by foreign fleets) and a recent (2006-2010) average catch of 1,442 t. Information about other species caught concurrently with Yellowmouth Rockfish commercial catches is presented in Appendix H.

FISHERIES MANAGEMENT

Appendix B summarises all management actions taken for Yellowmouth Rockfish in Canadian waters since 1979.

SURVEY DESCRIPTIONS

Ten fishery-independent surveys have the potential to provide information for this assessment. Five of them were found to contain sufficient information to be used as indices for the assessment model (details in Appendix C, including justification for inclusion or exclusion of surveys). Only one of the five surveys is available for the period prior to 1999. The remaining four surveys cover the period 1999 to 2010. The five surveys are:

1. an early series of eight indices extending from 1967 to 1994. These surveys were performed by the research vessel *GB Reed* up to 1984, with two commercial vessels (fishing vessel (FV) *Eastward Ho* and FV *Ocean Selector*) used in 1984 and 1994 respectively. A comparison of the observed 1984 catch rates from the *GB Reed* and *Eastward Ho* showed that there was no significant difference in these catch rates, allowing for the combining of the 1984 tows from the two vessels and the inclusion of the 1994 *Ocean Selector* survey (which used the same design as the pre-1994 surveys). Only tows located in Goose Island Gully (GIG) were used to ensure continuity across all surveys. This survey series is referred to as the “GIG historical series”.
2. a random-stratified “synoptic” trawl survey covering all of Queen Charlotte Sound and targeting a wide range of finfish species. This survey was repeated for five years between 2003 to 2009 using the same vessel (FV *Viking Storm*) and a consistent design, and the series is referred to here as the “QCS synoptic series”.
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 FV *Frosti* was used), and the series is referred to here as the "QCS shrimp series".

4. a random-stratified "synoptic" trawl survey covering the west coast of Graham Island in Haida Gwaii and western part of Dixon Entrance. As in the QCS synoptic survey, these surveys target a wide range of finfish species. This survey has been repeated for four years between 2006 to 2010 using three vessels (FV *Viking Storm* in 2006 and 2010, FV *Nemesis* in 2007 and FV *Frosti* in 2008) and a consistent design, and the series is referred to here as the "WCHG synoptic series".
5. a random-stratified "synoptic" trawl survey covering the west coast of Vancouver Island, targeting a wide range of finfish species. This survey has been repeated for four years between 2006 to 2010 using the same vessel (*WE Ricker*) and a consistent design, and the series is referred to here as the WCVI synoptic series.

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

Commercial catches of rockfish by trawl gear have been sampled for age proportions since the 1960s. However, only YMR 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 is 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 YMR catch weight for the sampled trip. The quarterly samples were scaled by the quarterly landed commercial catch weights to give annual proportions-at-age data (details are in Appendix E).

Age samples were available from two survey series: the historical GIG series (1994 and 1995 only), and from four of the QCS synoptic surveys (see Appendix C). These samples were scaled 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 Yellowmouth catch weight in the sampled tow; strata samples were then weighted by the total Yellowmouth catch weight for the stratum (described in Appendix E).

GROWTH PARAMETERS

Growth parameters for both sexes were estimated from YMR length and age data from biological samples collected from 1978 to 2009 by research surveys (Appendix D). Sex-specific growth was specified as a three-parameter von Bertalanffy model. Parameters for allometric weight-length relationships by sex were estimated for YMR also using research survey data. These two models allow determination of weights-at-age, which are used to convert population numbers to biomass.

MATURITY AND FECUNDITY

The proportions of females that are mature at ages 1-25 were computed from all biological samples (research survey and commercial) that identified YMR maturity. 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 through 7 were considered mature. Data from January to July, representing staged and aged females (using the "break and burn" method), were pooled 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 vector was adjusted by using the observed maturity values for ages less than 9 because the fitted model appeared to overestimate the proportion mature at ages 1 through 8. Females older than age 17 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, M_s, where s=1 for females and s=2 for males, were estimated as parameters of the model (see Appendix F). This was done using a strong informed prior based on the Hoenig (1983) estimator that assumes natural mortality is inversely proportional to fish longevity. Hamel (NOAA, pers. comm.) calculated a log-normal prior using Hoenig's calculation of (sex-independent) natural mortality M at longevity 100 y, together with the variance in Hoenig's data, to yield a mean M of 0.051 (standard deviation = 0.029) in real space. After experimentation, we rejected such a wide prior and settled on a normal distribution with mean 0.047 and standard deviation 0.005 (CV ~10%) for both sexes, and fixed natural mortality for both sexes at 0.047 when it was not being estimated. See Appendix I for a sensitivity run that used Hamel's 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 to the model 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 Pacific Ocean Perch (R. Forrest, DFO, pers. comm., as we had done for our recent Pacific Ocean Perch assessment, Edwards *et al.* 2012, though this removal barely changes the prior). This prior took the form of a beta distribution with mean 0.674 and standard deviation 0.168.

AGE-STRUCTURED MODEL

A two-sex, age-structured stochastic model was used to reconstruct the population trajectory of coastwide Yellowmouth Rockfish 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 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 equations and implementation are described in Appendix F.

The model was fit to the available data (five sets of survey indices, 18 annual proportions-at-age samples from the commercial fishery and six proportions-at-age samples from two surveys) by minimising a function which summed the negative log-likelihoods arising from each data set, the deviations from mean recruitment and the penalties stemming from the Bayesian priors.

The minimised MPD (mode of the posterior distribution) “best fit” was used as the starting point for the Bayesian search across the joint posterior distributions of the parameters using the Monte Carlo Markov Chain (MCMC) procedure. The MCMC procedure was run for 5,000,000 iterations, sampling every 5,000th, to give 1,000 samples. These samples were used to estimate parameters and quantities of interest, including stock sizes and the probabilities of being above reference points.

Results from two model runs that either estimate or fix sex-specific natural mortalities are presented here and used to formulate the advice to management (at the review meeting, participants felt that both models were equally plausible). The two model runs are termed ‘Estimate *M*’ and ‘Fix *M*’ respectively, with natural mortality, *M*, being estimated in the first run (separately for males and females) and held fixed in the second run. Further discussion of this choice of model runs is given in Appendix G.

Initial model fits to the data gave sensible and consistent results for both runs. Sensitivity runs that systematically explored the effect of different components of the data on model results initially 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). However, in response to reviewers, seven sensitivity runs were developed and are presented in Appendix I. These runs investigate, for example, the effects of ageing error, inclusion of the omitted US Triennial Survey and inclusion of a commercial catch-per-unit-effort time series. While we acknowledge that there will be error in the ageing of this species, we felt that a full investigation of ageing error would require more resources than were available.

MODEL RESULTS

Both main model runs had equally credible fits to the data, with neither showing a noticeably better fit (full results are presented in Appendix G). The statistical differences observed between the models were small and did not provide reliable guidance to select among hypotheses, with visual examination of the fits to the data and the patterns of residuals showing nearly identical results for both models. Participants of the review meeting proposed that both model runs be used to formulate advice.

The MCMC results show the same biomass trajectory patterns for both runs, though differing in absolute magnitude and the amount of variability expressed in the posterior distributions. The vulnerable biomass (Figure 5) is estimated to be higher for run ‘Estimate *M*’ than for run ‘Fix *M*’. The large catches in the mid-1960s consequently have a greater relative impact on the population for run ‘Fix *M*’ than for run ‘Estimate *M*’ (Figure 6). Both runs show a steady decline from the onset of fishing in the mid-1940s, followed by a further sharp drop during the heavy fishing period by foreign fleets in the mid-1960s. After the cessation of foreign fishing, there were a few years of recovery, due to reduced fishing mortality and good recruitment, but the recovery reversed with increasing domestic catches in the late 1970s and early 1980s. Both runs indicate that there was a large recovery (back to unfished equilibrium levels for run ‘Estimate *M*’) in the 1980s caused by a major recruitment event, followed by a slowly declining trend to the present day. The estimated ratio of female spawning biomass relative to its unfished level, B_t/B_0, for this latter recovery and decline, are (Figure 6): for run ‘Estimate *M*’ a low of 0.52 (median of the MCMC posterior distribution) in 1989 increasing to 1.06 in 1999 and then declining down to 0.61 at the start of 2011; and, for run ‘Fix *M*’, a low of 0.40 in 1990, increasing to 0.75 in 1999, and then declining down to 0.41 at the start of 2011. The similarity of the qualitative patterns of trajectories between the model runs arises because they are based on the same data and differ only in their handling of natural mortality. The greater decline for run 'Fix *M*' is because of the lower natural mortality and the estimated stock productivity (discussed below).

Estimates of various quantities of interest are given in Table1 (run 'Estimate *M*') and Table 2 (run 'Fix *M*'). In particular, the median (and 5-95% credible interval) for depletion, the ratio of current spawning biomass to the unfished equilibrium level (B_{2011} / B_0), is 0.614 (0.431-0.829) for run 'Estimate *M*' and 0.409 (0.289-0.547) for run 'Fix *M*'.

The main model runs attribute the two periods of biomass recovery to strong recruitment (Figure 7). There were evidently relatively long periods of low recruitment punctuated by an occasional few years of good recruitment, showing relatively large recruitment in the early 1960s and a period of very strong recruitment in the early 1980s. Evidence for these two large recruitment events can be seen in the commercial proportions-at-age data (Figures G7-G11). Such episodic large recruitment events are characteristic of many rockfish *Sebastes* populations (Love *et al*. 2002). The estimated exploitation rates (Figure 8) peak in the mid-1960s due to the large catches, and peak again (though not as high) in the late 1980s to early 1990s.

The differences in the magnitudes of estimated biomasses and recruitment between the two model runs arise because run 'Estimate *M*' estimates median natural mortalities of 0.0595 (0.0544-0.0648) for females and 0.0559 (0.0507-0.0613) for males (Table G3), which are 27% and 19% greater than the 'Fix *M*' value of 0.047 (which was the mean for the 'Estimate *M*' prior). The estimated increased level of natural mortality results in a larger estimated stock size (Figure 5), higher levels of productivity and larger estimated recruitments (Figure 7) for run 'Estimate *M*' than for run 'Fix *M*', to sustain the same absolute level of catches. The estimated survey catchability parameters are consequently lower for run 'Estimate *M*' than for run 'Fix *M*' (compare estimates of q_1, q_2, q_3, q_4 and q_5 between Tables G3 and G4).

The other major difference in results between the two model runs is the greater uncertainty seen for estimated vulnerable biomass (Figure 5) and recruitment (Figure 7) for run 'Estimate *M*' compared to run 'Fix *M*'. This arises because estimating natural mortality introduces additional uncertainty to the model compared to holding it fixed and known. We note that the value for natural mortality used in run 'Fix *M*' was developed through the application of a generic formula, for which the only YMR data used is the maximum observed age. However, run 'Estimate *M*' uses all available data to find the most plausible estimates for natural mortality.

ADVICE FOR MANAGERS

CURRENT STOCK LEVEL

The estimated median MSY (with 5-95% credible interval, tonnes) is 2,567 (1,717-4,297) for run 'Estimate *M*' (Table 1), and 1,693 (1,236-2,108) for run 'Fix *M*' (Table 2). For reference, the average catch from 2006-2010 is 1,442 t.

The estimated ratio of spawning biomass at the start of 2011 to the equilibrium spawning biomass associated with MSY, $B_{2011}/B_{\mathrm{MSY}}$, is 2.685 (1.606-4.573) for run 'Estimate *M*' (Table 1), and 1.922 (1.085-3.204) for run 'Fix *M*' (Table 2).

As noted above, the estimated depletion, the ratio of current spawning biomass to the virgin level (B_{2011} / B_0), is 0.614 (0.431-0.829) for run 'Estimate *M*' and 0.409 (0.289-0.547) for run 'Fix *M*'.

REFERENCE POINTS AND CRITERIA

Decision tables are presented with respect to three sets of reference points or reference criteria. Each set is based on either B_{MSY} (the estimated equilibrium spawning biomass (mature females only) that will support the maximum sustainable yield, MSY), B_0 (the estimated unfished equilibrium spawning biomass) or $B_{t\text{-3Gen}}$ (the spawning biomass three generations before B_t, which is itself the spawning biomass at the beginning of year t). *Reference criteria* are defined here in terms of a changing reference biomass ($B_{t\text{-3Gen}}$), whereas *reference points* are based on fixed biomass values (fractions of B_{MSY} or B_0). All reference points and criteria and the associated probabilities were derived from the posterior distributions of Bayesian output from the model.

As part of the Sustainable Fisheries Framework, DFO (2009) suggested provisional reference points to guide management and assess harvest in relation to sustainability. Because reference points for Canadian west coast groundfish species have not yet been specified by policy, the suggested provisional DFO limit and upper stock reference points of $0.4B_{MSY}$ and $0.8B_{MSY}$ have been adopted . Further reference points and criteria, defined below, have been added as a result of discussions held at the review meeting for this assessment.

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

Figure 9 shows that the stock is estimated to be (in 2010) in the 'healthy zone', above the upper stock reference point of $0.8B_{MSY}$, for both model runs.

A second component of the provisional harvest rule of DFO (2009) is that, when in the healthy zone, the fishing mortality should be at or below that associated with MSY under equilibrium conditions (u_{MSY}), be ramped down when in the cautious zone, and be zero when in the critical zone. Thus, Figure 9 also shows the exploitation rate in year t, u_t, relative to u_{MSY}. The estimated exploitation rate in 2010 is below that associated with MSY for both runs (i.e. $u_{2010} < u_{MSY}$). Furthermore, the blue and grey circles in Figure 9 show that the biomass is estimated to have been in the healthy zone since the start of fishing, and only once (1966 for run 'Fix *M*') has the median exploitation rate been $>u_{MSY}$.

Other agencies and jurisdictions often use 'proxy' reference points that are expressed in terms of B_0 rather than B_{MSY} (e.g. New Zealand Ministry of Fisheries 2007, 2011), because B_{MSY} is often poorly estimated as it is dependent on estimated parameters and a consistent fishery. Therefore, the reference points of $0.2B_0$ and $0.4B_0$ are also presented here; these are the respective default values used in New Zealand as a 'soft' limit (below which management action needs to be taken) and a 'target' biomass for low productivity stocks (a mean around which the biomass is expected to vary).

The reference criteria used here to assess COSEWIC recovery are defined by the COSEWIC indicators A1 and A2 for species that have been assessed as *Threatened* (http://www.cosewic.gc.ca/eng/sct0/assessment_process_e.cfm, updated August 2010). The indicators are based on a decline in the total number of mature individuals over the most recent 10 years or 3 generations, whichever is longer. Given our modelling framework, we calculate decline in terms of spawning biomass rather than mature individuals (similarly, DFO 2005 used 'biomass' and 'abundance' interchangeable to reflect population size). Because the generation time for Yellowmouth Rockfish is estimated to be 30 years, three generations (90 years) was used as the period over which to calculate the decline. Indicator A1 is reserved for those species where the causes of the reduction are clearly reversible, understood, and ceased. Indicator A2 is used when the population reduction may not be reversible, may not be understood, or may not have ceased. COSEWIC (2010) designated Yellowmouth Rockfish in Canada as *Threatened* under criterion A2b (where the '*b'* indicates that the designation was based on "an index of abundance appropriate to the taxon").

Under A1, a species is considered *Threatened* if the decline has been between 50% and 70% over three generations; under A2, the decline thresholds for the *Threatened* designation are between 30% and 50%. Therefore, since COSEWIC designated Yellowmouth Rockfish under A2, the recovery reference criteria become $0.5B_{t\text{-3Gen}}$ (a 50% decline) and $0.7B_{t\text{-3Gen}}$ (a 30% decline), where $B_{t\text{-3Gen}}$ is the biomass three generations previous to the biomass in year *t*. For the initial 19 years of the projection, $B_{t\text{-3Gen}}$ is set to B_0 because the reconstructed population from 1940 to 2011 is less than 3 generations; therefore, the COSEWIC criteria are expressed in terms of B_0 for the first 19 years of the projections. From year 20 of the projections, $B_{t\text{-3Gen}}$ moves forward in time as a 90-year long moving window; for example, the projected spawning biomass in 2048, B_{2048}, is compared with that 90 years earlier, $B_{t\text{-3Gen}} = B_{2048\text{-}90} = B_{1958}$.

Figure 10 summarizes the relationship between the reference points and criteria, relative to B_0, for the estimated biomass at the start of 2011 (for both model runs). The estimated current spawning biomass, B_{2011} (green boxplots), lies mostly in the COSEWIC A2 *Threatened* region for run 'Estimate *M*', and mostly in the COSEWIC A2 *Endangered* region for run 'Fix *M*', yet is $>0.8B_{\text{MSY}}$ for both model runs and thus lies in the provisional healthy zone of the DFO Sustainable Fisheries Framework.

Figure 10 also shows that, for both model runs, the distribution of $0.8B_{\text{MSY}}$ lies $<0.5B_0$ (and thus a population at $0.8B_{\text{MSY}}$ would be considered *Endangered* in 2011 under COSEWIC indicator A2).

Figure 10 also includes the locations of $0.4B_{\text{MSY}}$ and $0.8B_{\text{MSY}}$ for the Schaefer surplus production model, which assumes that B_{MSY} is $0.5B_0$ (Quinn and Deriso 1999, p53). Even for these precautionary reference points, the provisional healthy zone definition ($>0.8B_{\text{MSY}}$) overlaps with the definition of COSEWIC *Threatened* and/or *Endangered* status.

Using the provisional boundaries of $0.4B_{\text{MSY}}$ and $0.8B_{\text{MSY}}$, Figure 10 shows that for Yellowmouth Rockfish both boundaries lie in the *Endangered* zone of COSEWIC indicator A2 (and that the same is also true for a Schaefer surplus production model). DFO (2005) discusses whether a species should be considered "recovered" at either the critical-cautious boundary or the cautious-healthy boundary of the Sustainable Fisheries Framework.

PROJECTION RESULTS AND DECISION TABLES

Projections were made to evaluate the future behaviour of the population under different levels of constant catch, given the model assumptions. The projections, starting with the biomass at the beginning of 2011, were made over a range of constant catch strategies (0-3,000 t) for each of the 1,000 MCMC samples in the posterior, generating future biomass trends by assuming random recruitment deviations. Future recruitments were generated through the stock-recruitment function using recruitment deviations drawn randomly from a lognormal distribution with zero mean and constant standard deviation (see Appendix F for full details).

Resulting projections of spawning biomass are shown for selected catch strategies for run 'Estimate *M*' (Figure 11) and run 'Fix *M*' (Figure 12). Projections for run 'Estimate *M*' (Figure 11) suggest that the recent decline of spawning biomass would eventually cease for catch strategies up to 2,000 t, and for run 'Fix M' (Figure 12) this occurs for catch strategies up to 1,500 t.

Decision tables give the probabilities of exceeding the reference points or reference criteria in specified years, calculated by counting the proportion of MCMC samples that satisfied the reference points or reference criteria.

Results for the three B_{MSY}-based reference points are presented for years 1-5 for each model run (Tables 3-8). In particular, the probability of being above the upper stock reference point at the start of 2011, $P(B_{2011} > 0.8B_{MSY})$, is 1.000 and 0.990, respectively, for each run (see the 2011 column in Table 4 and in Table 7). A probability of 1.000 means that all 1,000 MCMC samples conclude that $B_{2011} > 0.8B_{MSY}$.

To address the potential for recovery of a *Threatened* species, DFO (2007) requested that projections be made over 'three generations (or other biologically reasonable time)'. Although a 20-year time frame was presented at the review meeting (based on advice from DFO SARA experts), the review meeting participants requested that projections were run to a maximum of 90 years, given a 30-year generation time (which is the average age of parents) for Yellowmouth Rockfish.

We caution that, although uncertainty is built into the projections (and the overall assessment) by taking a Bayesian approach for parameter estimation, these results depend heavily on model and data assumptions, particularly the average recruitment assumptions used for the projections. Ninety-year projections assume (as in the stock assessment model) that life-history parameters and other conditions remain stationary. Recruitment is drawn from the estimated stock-recruitment curve with lognormal error that has a standard deviation of 0.9 and a mean of zero. However, this approach does not accurately simulate the apparent recruitment dynamics for this stock, which appear to depend on the occasional rare, but very large, recruitment event. Figures 13 and 14 demonstrate that only two such events have been observed during the model reconstruction period. The rarity of these events make it impossible to estimate their frequency and their potential impact on abundance. Consequently, it is not possible to simulate these observed recruitment dynamics in the projections and the advice must be based on an underlying assumption of average recruitment. Finally, the assumption that a constant catch scenario will operate continuously without feedback intervention is a strong assumption that is unlikely to persist as stock sizes change.

Decision tables for selected years of the 90-year projections are given for the reference points in Table 9 ('Estimate *M*') and Table 10 ('Fix *M*'), and then for the reference criteria in Table 11 ('Estimate *M*') and Table 12 ('Fix *M*').

The interpretation of the COSEWIC reference criteria is more difficult than for reference points, because the reference biomass is not constant over time. For instance, Tables 11 and 12 show that, for a catch of 1,000 t and for both model runs, the probabilities of satisfying the reference criteria increase from projection years 15 to 30 to 45 to 60, but then decrease (or stay constant) for year 75, even though the projected biomass is still increasing (Figures 11 and 12). This is because the biomass in 1996 (90 years before) underwent a large increase (Figures 6, 11 and 12), and so the reference criteria of $0.5B_{t\text{-3Gen}}$ and $0.7B_{t\text{-3Gen}}$ become larger (and therefore harder to satisfy). However, in Tables 9 and 10 for the reference points, the reference biomass levels remain fixed through time.

The estimated number of years to initially exceed the four reference points and to satisfy the COSEWIC reference criteria are given in Table 13 ('Estimate *M*') and Table 14 ('Fix *M*'). The number of years is given for three different levels of confidence: 50%, 80% and 95%. New Zealand Ministry of Fisheries (2011) guidelines aim to achieve a *target* with a 50% probability, given that a 50% confidence represents an equal probability of being above or below the target. A probability of 95% is often used in statistics to conclude statistical significance and is likely most appropriate for *limit* reference points, where a high degree of certainty is required to be above the reference point. The 80% confidence level is intermediate between 50 and 95%.

THE 17 RPA FRAMEWORK TASKS FROM DFO (2007)

DFO (2007) specified that Recovery Potential Assessments should routinely address the following 17 tasks, given below (in italics), together with the associated advice arising from this assessment and the review meeting (DFO 2012). In every case, the best possible science advice should be provided, given the information that can be assembled, and uncertainties taken into account (DFO 2007). Where appropriate in the responses below, estimated quantities are given for run 'Estimate *M*' followed by run 'Fix *M*' as medians (with 5-95% credible intervals) from the MCMC posterior distributions.

Phase I: Assess current/recent species status

1. Evaluate ***present species status*** *for abundance, range and number of populations.*

A single coastwide population of Yellowmouth Rockfish was considered by COSEWIC (2010).

The estimated ratio of current spawning biomass (mature females) to the unfished equilibrium level (B_{2011} / B_0) is 0.61 (0.43-0.83) for run 'Estimate *M*' and 0.41 (0.29-0.55) for run 'Fix *M*'. The present stock status for the two model runs with respect to the reference points and reference criteria is shown in Figure 10, with the probabilities of achieving them given in the '0 Projection Year' column of Tables 9-12.

Figure 2 shows the occupancy range of Yellowmouth Rockfish (as measured by catches from the groundfish trawl fishery over the last 15 years). This species has been encountered by the British Columbia trawl fleet over an estimated 29,500 km^2.

2. Evaluate ***recent species trajectory*** *for abundance, range, and number of populations.*

The estimated ratio of spawning biomass (mature females) to the unfished equilibrium level (B_t / B_0) over the most recent period of increase and decrease (Figure 6) are: for run 'Estimate *M*', from a low of 0.52 (median of the MCMC posterior distribution) in 1989 increasing to 1.06 in 1999 and then declining down to 0.64 at the start of 2011; and for run 'Fix *M*,' from a low of 0.40 in 1990 increasing to 0.75 in 1999 and then declining down to 0.41 at the start of 2011. The increase through the 1990s is the result of a period of very strong recruitment in the early 1980s. Evidence for this high recruitment can be seen in the proportions-at-age data from the commercial fishery and research surveys (Figures G7-G11).

There is no evidence for a change in the occupied range of the population.

*3. Estimate, to the extent that information allows, the current or recent **life history parameters** for the species (total mortality [Z], natural mortality [m], fecundity, maturity, recruitment, etc.) or reasonable surrogates, and associated uncertainties for all parameters.*

For run 'Estimate *M*', the natural mortality rate was estimated to be 0.0595 (0.0544-0.0648) for females and 0.0559 (0.0507-0.0613) for males, and the current exploitation rate (ratio of total catch to vulnerable biomass in the middle of the year) was estimated to be 0.020 (0.010-0.036). The current total mortality rate (Z), calculated from $Z = M+F = M - \log(1-u)$ for mortality rate M and exploitation u, is 0.080 (0.072-0.094) for females and 0.076 (0.068-0.091) for males.

For run 'Fix *M*', natural mortality was fixed at 0.047 for females and males, which was taken from Hoenig's estimator (Appendix D). Current exploitation was estimated to be 0.038 (0.026-0.059), giving an estimated total mortality rate Z of 0.086 (0.073-0.108) for both females and males.

For each model run, the estimated parameter values for the assumed Beverton-Holt stock-recruitment relationship were R_0 (unfished equilibrium recruitment of age-1 fish, in 1000s of fish): 7,342 (5,185-12,290) and 4,034 (3,624-4,589), and h (steepness): 0.807 (0.605-0.951) and 0.841 (0.640-0.957), given in Tables G3 and G4.

At age 11, 48% of females were estimated from data to be mature.

*4. Address the separate terms of reference for describing and quantifying (to the extent possible) the **habitat requirements and habitat use patterns** of the species.*

Habitat is not thought to be a limiting factor for Yellowmouth Rockfish. Maps of the catch distribution of Yellowmouth Rockfish (from 1996-2011), overlaid with the spatial distribution of surficial geology, are shown in Figure H8 for Queen Charlotte Sound (equivalent data are not available elsewhere). These maps show that catches of YMR are concentrated over glacial outwash along the canyon walls of Goose Island Gully.

*5. Estimate expected **population and distribution targets** for recovery, according to DFO guidelines.*

The values for the population targets (whether based on reference points or COSEWIC reference criteria) can be calculated from the B_0 and B_{MSY} estimates in Tables 1 and 2 (although for the reference criteria that are based on the biomass three generations prior, the target will change continuously after 2030).

*6. Project **expected population trajectories** over three generations (or other biologically reasonable time), and trajectories over **time to the recovery target** (if possible to achieve), given current population dynamics parameters and associated uncertainties using DFO guidelines on long-term projections.*

Projections over three generations (reliant on the assumptions regarding the data, the model and future management responses) under different constant catch strategies are presented in

Figures 11 and 12. Probabilities of reaching reference points and reference criteria are given in Tables 9-12, and projected number of years to reach them are given in Tables 13 and 14.

7. Evaluate ***residence requirements*** *for the species, if any.*

Yellowmouth Rockfish does not have any known dwelling place similar to a den or nest during any part of its life-cycle. Therefore, the concept of residence does not apply.

Phase II: Scope for management to facilitate recovery

8. Assess the ***probability that the recovery targets can be achieved*** *under current rates of population dynamics parameters, and* ***how that probability would vary with different mortality (****especially lower****) and productivity (****especially higher****) parameters.***

See Task 6 (and Figures 11 and 12 and Tables 9-14). A range of constant catch strategies were considered in the projections, with productivity parameters estimated by the model under two accepted model runs. The effect of higher productivity was not considered, but the two accepted runs show some contrast in productivity. Under current levels of catch, the median spawning biomass is projected to be increasing within one generation (Figures 11 and 12). The infrequent, episodic nature of recruitment in this species should be taken into account in recovery planning (although this aspect of the life history is unquantifiable).

9. Quantify to the extent possible the ***magnitude of each major potential source of mortality*** *identified in the pre-COSEWIC RAP and considering information in the COSEWIC Status Report, from DFO sectors, and other sources.*

Commercial fishing was identified as the primary threat to Yellowmouth Rockfish (COSEWIC 2010). For run 'Estimate *M*', the current exploitation rate (ratio of total catch in 2010 to the vulnerable biomass in the middle of 2010) was estimated to be 0.020 (0.010-0.036), compared to total mortality rates of 0.080 (0.072-0.094) for females and 0.076 (0.068-0.091) for males. For run 'Fix *M*', the estimated current exploitation rate is 0.038 (0.026-0.059), compared to a total mortality rate of 0.086 (0.073-0.108) for both females and males. Exploitation rate is estimated to be below natural mortality for both model runs.

10. Quantify to the extent possible the ***likelihood that the current quantity and quality of habitat is sufficient*** *to allow population increase, and would be sufficient to support a population that has reached its recovery targets (using the same methods as in step 4).*

Habitat is not believed to be a limiting factor for Yellowmouth Rockfish, and under current levels of catch the median spawning biomass is projected to be increasing within one generation.

11. Assess to the extent possible the magnitude by which current ***threats to habitats have reduced habitat quantity and quality.***

Habitat is not believed to be a limiting factor for Yellowmouth Rockfish.

Phase III: Scenarios for mitigation and alternative to activities

12. Using input from all DFO sectors and other sources as appropriate, develop an ***inventory of all feasible measures to minimize/mitigate*** *the impacts of activities that are threats to the* *species and its habitat (steps 9 and 11).*

The primary threat is commercial fishing, thus changing the catch level would be a feasible measure if it is required to reduce fishing mortality.

*13. Using input from all DFO sectors and other sources as appropriate, develop an inventory of all reasonable **alternatives to the activities** that are threats to the species and its habitat (steps 9 and 11), but with potential for less impact. (e.g. changing gear in fisheries causing bycatch mortality, relocation of activities harming habitat).*

The primary threat is commercial fishing, thus, if necessary, the catch level could be reduced. Habitat is not believed to be a limiting factor.

*14. Using input from all DFO sectors and other sources as appropriate, develop an inventory of all **reasonable and feasible activities that could increase the productivity or survivorship parameters** (steps 3 and 8).*

There do not appear to be any practical means for increasing the productivity of Yellowmouth Rockfish.

*15. Estimate, to the extent possible, the **reduction in mortality rate expected** by each of the mitigation measures in step 12 or alternatives in step 13 and **the increase in productivity or survivorship** associated with each measure in step14.*

See Figures 11 and 12 and Tables 9-14 for the projected effects on the population of different levels of constant catch.

*16. Project **expected population trajectory** (and uncertainties) over three generations (or other biologically reasonable time), and to the time of reaching recovery targets when recovery is feasible; given mortality rates and productivities from 15 that are **associated with specific scenarios** identified for exploration. Include scenarios which provide as high a probability of survivorship and recovery as possible for biologically realistic parameter values.*

See Figures 11 and 12 and Tables 9-14 for the projected effects on the population of different levels of constant catch, including times to reach reference points and criteria.

*17. Recommend **parameter values for population productivity and starting mortality rates,** and where necessary, specialized features of population models that would be required to allow exploration of additional scenarios as part of the assessment of economic, social, and cultural impacts of listing the species.*

Parameter estimates for natural mortality and recruitment for the two model runs are summarised under Task 3 above.

GENERAL COMMENTS

This assessment depicts a slow-growing, low productivity stock that has undergone periods of high recruitment in the early 1960s and the early 1980s. We note that for the recent Pacific Ocean Perch assessment for Queen Charlotte Sound (DFO 2011, Edwards *et al.* 2012), there were also two important recruitment periods, in the late 1950s and late 1970s. However, the magnitude of the first period had the greater impact on the Pacific Ocean Perch stock while the magnitude of the latter period had a greater impact on Yellowmouth.

Quantities of interest are summarized in Tables 1 and 2. The resulting advice for management is given in the form of decision tables (Tables 3-14) and associated Figures 9-12. Decisions regarding harvest and SARA listing depend upon the choice of reference points or criteria.

Although Yellowmouth Rockfish is characterised as a long-lived, slow growing species, this population has shown the capacity to make a rapid recovery from biomass levels $<0.5B_0$. For both model runs, the spawning biomass roughly doubled through the 1990s (Figure 6), with run 'Estimate *M*' peaking above B_0, and run 'Fix *M*' reaching $0.75B_0$. These observed recoveries demonstrate that large episodic recruitments, although infrequent, have the capacity to rebuild the stock to high levels.

The results from the assessment suggest that, whether or not natural mortality is estimated, the coastwide stock of Yellowmouth Rockfish is in the provisional 'healthy zone', given the provisional DFO (2009) upper stock reference point of $0.8B_{MSY}$. The median estimated current depletion (B_{2011} / B_0) is 0.61 (0.43-0.83) for run 'Estimate *M*' and 0.41 (0.29-0.55) for run 'Fix *M*'. The present stock status for the two model runs with respect to the reference points and reference criteria is shown in Figure 10, with the probabilities of achieving them given in the '0 Projection Year' column of Tables 9-12.

The estimates of depletion (B_{2011} / B_0) from this assessment differ from the equivalent estimate previously made by COSEWIC (2010). There are a number of reasons for this difference, including that this assessment uses a full population model, fitted to data, while COSEWIC (2010) combined available surveys into a single analysis without employing an underlying population model. One of the surveys included by COSEWIC (2010) was the US National Marine Fisheries Service Triennial Survey, which was omitted from this assessment because it did not monitor an area of representative abundance for this species (Figure 2 shows a much lower catch per unit effort below 50°N, which was the northernmost extent of the survey and which was not reached in every survey year). Also, the decline observed by the Triennial Survey was not consistent with the increased abundance that was estimated by the assessment model from the strong recruitment evident in the age composition data. This signal of increased abundance was very strong and persisted even when the Triennial Survey was included in the assessment as a sensitivity run (see Appendix I).

Furthermore, COSEWIC (2010) designated the population as *Threatened*, "based on a suspected continuous long-term decline from an unfished condition to a level inferred to between 30 and 50% of the optimal level for an exploited population" (COSEWIC 2010, p41). The population model used here provides a more comprehensive analysis that explicitly includes age composition data (Figures G5 and G6) that were not considered in the COSEWIC (2010) analysis. The COSEWIC determination was based on an analysis of amalgamated survey data, not on an integrated stock assessment model, combining observations between surveys using a methodology which necessarily made assumptions that were not required in the age-structured model presented here.

The two assessment model runs span a limited range of plausible hypotheses, both of which fit the existing data reasonably well. Formal selection methods, based on information criteria, would be difficult to use because the reweighting procedure (Appendix F) results in different model inputs. The differences (as determined from the residual patterns) between the two model runs are relatively small when placed in the context of model and data uncertainty.
We re-iterate that these results are dependent on the assumptions of the model and the data.

Unlike for Pacific Ocean Perch (DFO 2011, Edwards *et al.* 2012), there is no independent estimate for natural mortality of Yellowmouth Rockfish, and so its value was developed from a generic formula that only uses maximum observed age. Consequently, results from run 'Estimate *M*' are based on a broader range of data and incorporate more uncertainty. We also note that estimates of natural mortality and steepness are uncorrelated (Figure G22) for run 'Estimate *M*'. Thus, run 'Estimate *M*' appears to be capable of concurrently estimating natural mortality and steepness in the Bayesian context. We anticipate submitting the assessment results to the RAM Legacy Stock Assessment Database (Ricard *et al.* 2011). If the results are to be used in future meta-analyses (such as in Ricard *et al.* 2011), and it is preferable to use results from just a single model run (rather than two), then we recommend the use of the results from run 'Estimate *M*'.

We note that the results of this assessment are uncertain. Although this stock is relatively data-rich compared to other shelf and slope rockfish populations 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 years of stock reconstruction. There are no biomass indices prior to the 1967 and the available age composition data are all relatively recent. It is fortunate that the earliest available age data are able to provide some information on year class strengths in the 1950s and 1960s, due to the long-lived nature of the species and the apparent precision of the ageing methodology. Prior to 1991, species identification in the commercial catch was not rigorous, and Pacific Ocean Perch was the only rockfish identified routinely. Even fish identified as Pacific Ocean Perch may have actually been other rockfish such as Yellowmouth.

It is acknowledged that there will be error in the ageing of Yellowmouth Rockfish, and preliminary runs investigating the effects of ageing error were explored. These runs added uncertainty to the model output without materially affecting the results (Appendix I), although this sensitivity run does not represent a comprehensive investigation of this issue.

Tables 3-14 provide guidance to the selection of short-term management actions using a range of catch strategies, and describe possible future outcomes over the projection period at fixed levels of annual catch. The accuracy of the projections is predicated on the model, including all underlying assumptions, 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 and the assumed lack of management intervention in the constant catch scenarios.

FUTURE RESEARCH AND DATA REQUIREMENTS

The following issues should be considered when planning future stock assessments and management evaluations for Yellowmouth Rockfish:

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 in this assessment.

2. 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 here. Such priors could be developed by placing meaningful bounds on survey catchability, which in turn would help scale the biomass levels in the assessment. Also, an informed prior on natural mortality would greatly facilitate future assessments by allowing presentation of only one model.
3. The Sclerochronology Laboratory at the Pacific Biological Station currently records uncertainty for each aged otolith. Research into the quantification of such uncertainty would allow ageing error to be better incorporated into models as used in this assessment.
4. Effort could be directed to studying how single populations, such as Yellowmouth Rockfish, are part of a complex system consisting of biological and economic components. Such systems can have multiple stable states, which may have implications in our understanding of Yellowmouth Rockfish population dynamics and resilience.
5. The large amount of age data might be used to investigate time-varying growth.
6. Given the regulatory changes noted in Table B1, the issue of time-varying selectivity could also be investigated.
7. As demonstrated by Figure 10, a species can simultaneously be considered *Threatened* or *Endangered* under COSEWIC criteria, yet lie within the provisional healthy zone of the DFO Sustainable Fisheries Framework. Effort should be directed to resolve this situation of conflicting advice.

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REFERENCES

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.

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

COSEWIC. 2010. COSEWIC assessment and status report on the yellowmouth rockfish *Sebastes reedi* in Canada. 64 p. http://www.sararegistry.gc.ca/document/default_e.cfm?documentID=2099

DFO. 2005. A framework for developing science advice on recovery targets for aquatic species in the context of the Species at Risk Act*. Fisheries and Oceans Canada. Canadian Science Advisory Secretariat, Science Advisory Report.* **2005/054**. 16 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. 2007. Revised Protocol for Conducting Recovery Potential Assessments. *Fisheries and Oceans Canada. Canadian Science Advisory Secretariat, Science Advisory Report.* **2007/039**. 11 p. (Revised in April 2009). http://www.dfo-mpo.gc.ca/csas/Csas/status/2007/SAR-AS2007_039_e.pdf

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

DFO. 2011. Stock assessment for Pacific ocean perch (*Sebastes alutus*) in Queen Charlotte Sound, British Columbia in 2010. *Fisheries and Oceans Canada. Canadian Science Advisory Secretariat Science Advisory Report.* **2011/017**. 11 p. http://www.dfo-mpo.gc.ca/Csas-sccs/publications/sar-as/2011/2011_017-eng.pdf

DFO. 2012. Recovery Potential Assessment for Yellowmouth Rockfish (*Sebastes reedi*) along the Pacific Coast of Canada. *Fisheries and Oceans Canada. Canadian Science Advisory Secretariat Science Advisory Report.* **2011/060**. 20 p. http://www.dfo-mpo.gc.ca/Csas-sccs/publications/sar-as/2011/2011_060-eng.pdf

Edwards, A.M., Starr, P.J. and Haigh, R. 2012. Stock assessment for Pacific ocean perch (*Sebastes alutus*) in Queen Charlotte Sound, British Columbia. *Fisheries and Oceans Canada. Canadian Science Advisory Secretariat Research Document.* **2011/111**. viii+172 p. http://www.dfo-mpo.gc.ca/Csas-sccs/publications/resdocs-docrech/2011/2011_111-eng.pdf

Efron, B. 1982. The jackknife, the bootstrap and other resampling plans. Society for Industrial & Applied Mathematics CBMS-NSF Monographs, **38**: 92 p.

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.

Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences* **68**: 1124-1138.

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 Starr, P. 2008. A review of yellowmouth rockfish *Sebastes reedi* along the Pacific coast of Canada: biology, distribution, and abundance trends. *Canadian Science Advisory Secretariat Research Document.* **2008/055**. 97 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 Sciences* **2943**: viii + 124 p.

Hamel, O.S. 2008. Status and Future Prospects for the Darkblotched Rockfish Resource in Waters off Washington, Oregon, and California as Assessed in 2007. Northwest Fisheries Science Center, Seattle WA, January 24, 2008. 179 p. http://www.pcouncil.org/wp-content/uploads/Darkblotched_2007_Final.pdf

Hart, J.L. 1973. Pacific fishes of Canada. *Bulletins of the Fisheries Research Board of Canada* **180**. Reprinted 1988. 740 pp.

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.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. *U.S. Fisheries Bulletin* **82**: 898-903.

Johnstone, K. 1977. The Aquatic Explorers: A History of the Fisheries Research Board of Canada. University of Toronto Press, Toronto, Ontario. 342 p.

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.

Leisch, F. 2002. Sweave: dynamic generation of statistical reports using literate data analysis. In Wolfgang Härdle and Bernd Rönz, editors, *Compstat 2002 - Proceedings in Computational Statistics*, pages 575-580. Physica Verlag, Heidelberg, 2002.

http://www.statistik.lmu.de/~leisch/Sweave/

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.

Magnusson, A. 2009. Scape - statistical catch-at-age plotting environment, R package. http://cran.r-project.org/web/packages/scape/

Magnusson, A. and Stewart, I. 2007. MCMCscape - MCMC diagnostic plots. R package. http://cran.r-project.org/web/packages/scapeMCMC/

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.

New Zealand Ministry of Fisheries. 2007. Operational guidelines for New Zealand's harvest strategy standard. 67 p. http://www.fish.govt.nz/NR/rdonlyres/8419AC9A-8DDA-48A6-833C-AF6E70052244/0/OperationalGuidelinesHSS.pdf

New Zealand Ministry of Fisheries. 2011. Operational guidelines for New Zealand's harvest strategy standard. June 2011, 78 p. http://fs.fish.govt.nz/Doc/22847/Operational_Guidelines_for_HSS_rev_1_Jun_2011.pdf.ashx

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.

Quinn, T.R. and R.B. Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press. 542 p.

R Development Core Team (2009). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Ricard, D., Minto, C., Jensen, O.P., and Baum, J.K. 2011. Examining the knowledge base and status of commercially exploited marine species with the RAM Legacy Stock Assessment Database. *Fish and Fisheries*. 1-19. doi: 10.1111/j.1467-2979.2011.00435.x

Rutherford, K.L. 1999. A brief history of GFCatch (1954-1995), the groundfish catch and effort database at the Pacific Biological Station. *Canadian Technical Report of Fisheries and Aquatic Sciences* **2299**. v + 66 p.

Schnute, J.T., Olsen, N., and Haigh, R. 1999. Slope rockfish assessment for the west coast of Canada in 1998. *Canadian Stock Assessment Secretariat Research Document.* **99/184**. 104 p.

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

Sinclair, A.F., Conway, K.W., and Crawford, W.R. 2005. Associations between bathymetric, geologic and oceanographic features and the distribution of the British Columbia bottom trawl fishery. *In* Theme Session L: The Spatial Dimension of Ecosystem Structure and Dynamics. ICES Annual Science Conference, Aberdeen, Scotland, Sep. 20-24, 2005. CM 2005/L:25. 31 p.

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 Research Document.* **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. http://www.dfo-mpo.gc.ca/CSAS/Csas/Publications/ResDocs-DocRech/2009/2009_013_e.pdf

Westrheim, S.J., and Tsuyuki, H. 1967. *Sebastodes reedi*, a new Scorpaenid fish in the Northeast Pacific Ocean. J*ournal of Fisheries Research Board of Canada* **24**: 1945-1954.

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. Yellowmouth Rockfish (Sebastes reedi). Photograph by Terri Bonnet. Source: http://pacpbsgfiis/gfimages/photos/020811_04W.jpg.

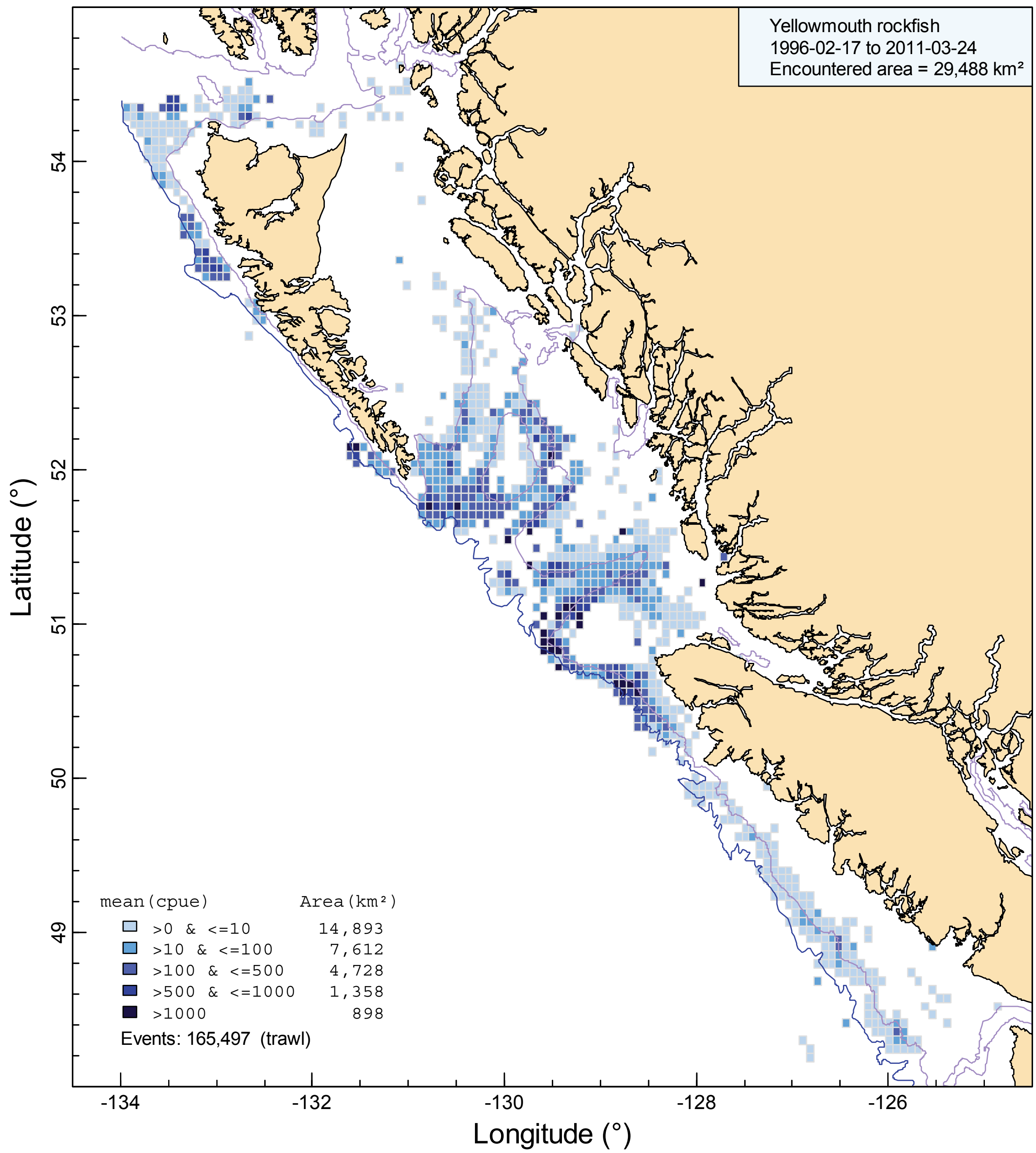


Figure 2. Mean CPUE (kg/h) of Yellowmouth Rockfish in grid cells 0.075° longitude by 0.055° latitude (roughly 32 km²). The shaded cells give an approximation of the area where Yellowmouth Rockfish was encountered by fishing events from the groundfish trawl fishery from Feb 1996 to Mar 2011. Contours are 200 m and 1000 m isobaths.

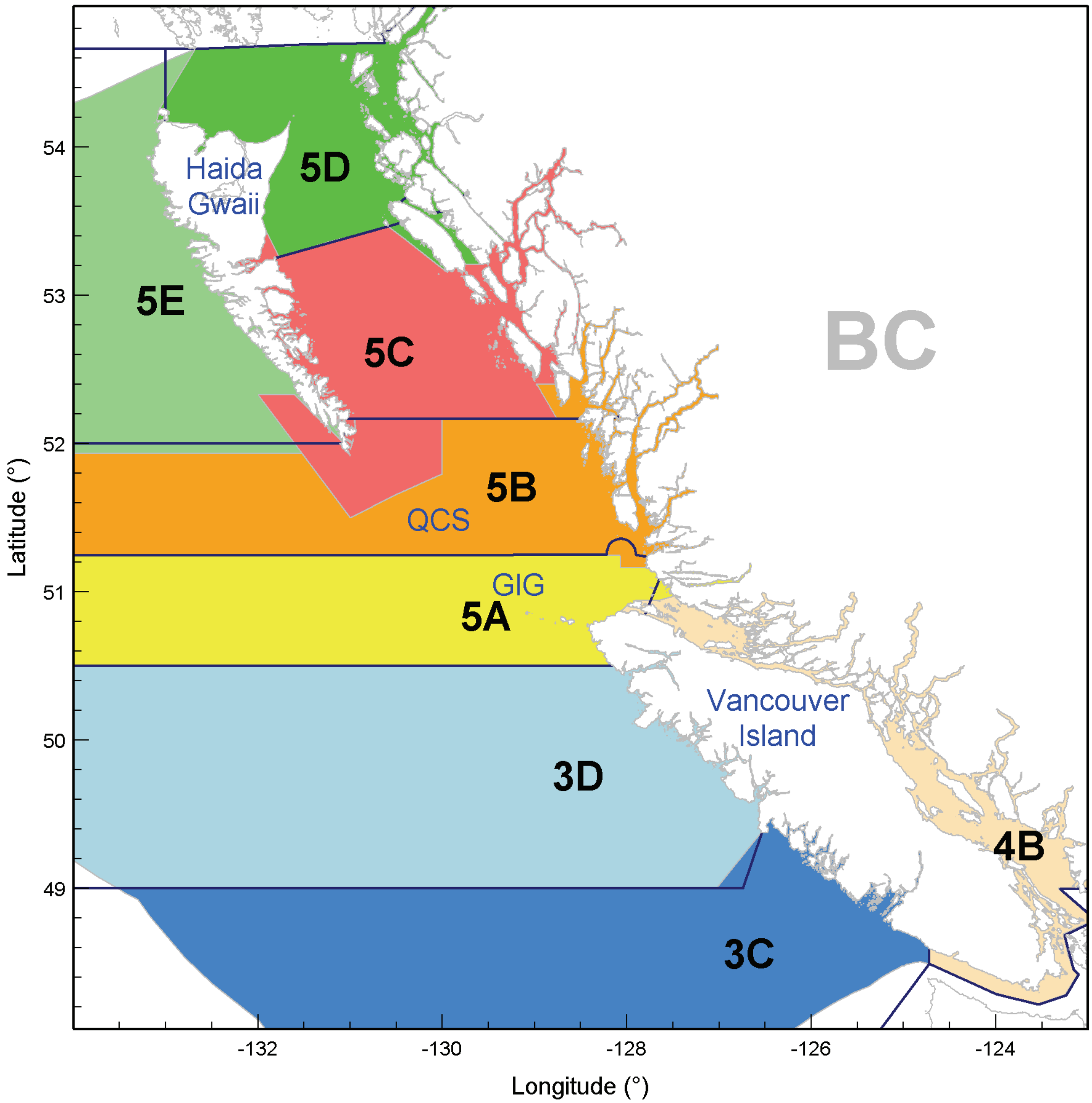


Figure 3. Pacific Marine Fisheries Commission major areas (outlined in purple) compared with Groundfish Management Unit areas for YMR (shaded). For reference, map indicates Queen Charlotte Sound (QCS) and Goose Island Gully (GIG).

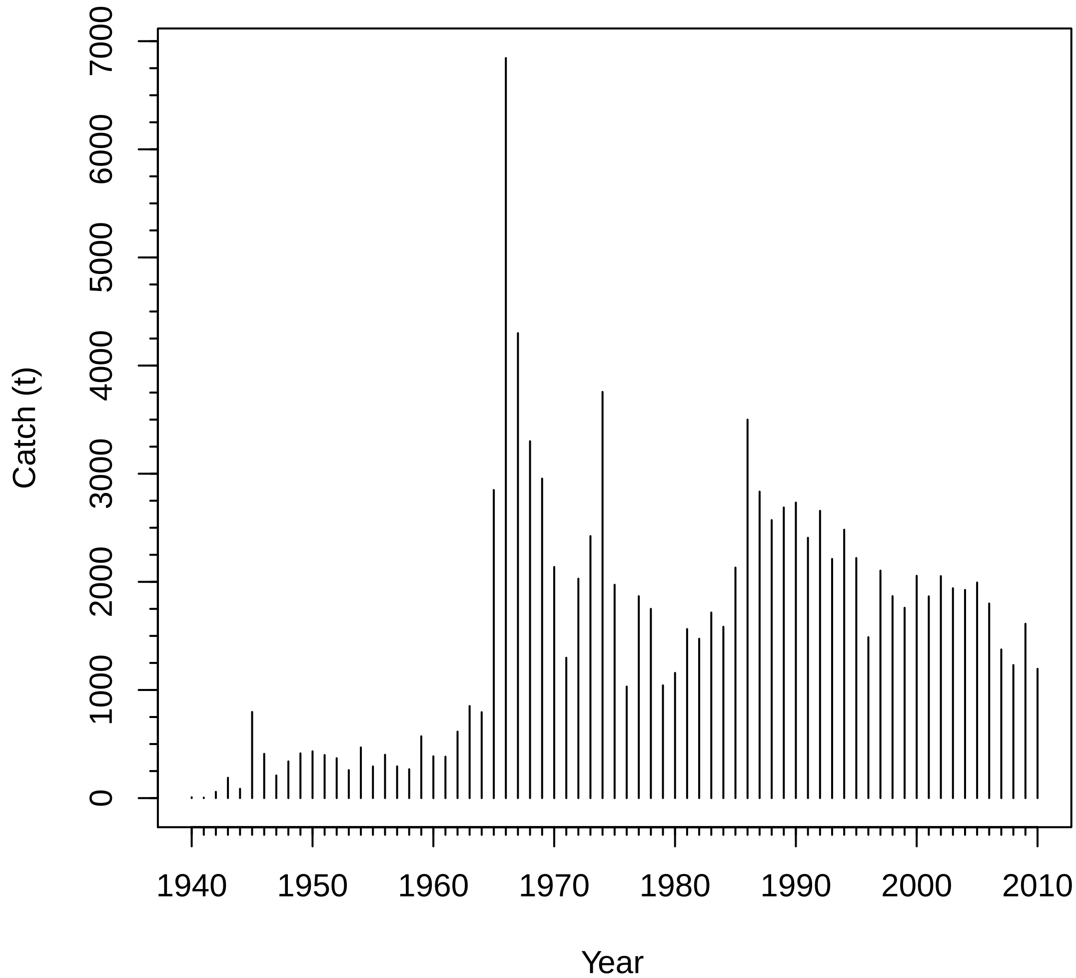


Figure 4. Commercial catch data (tonnes) of Yellowmouth Rockfish along the west coast of Canada, constituting input to the model – see Appendix B for full details of the catch reconstruction.

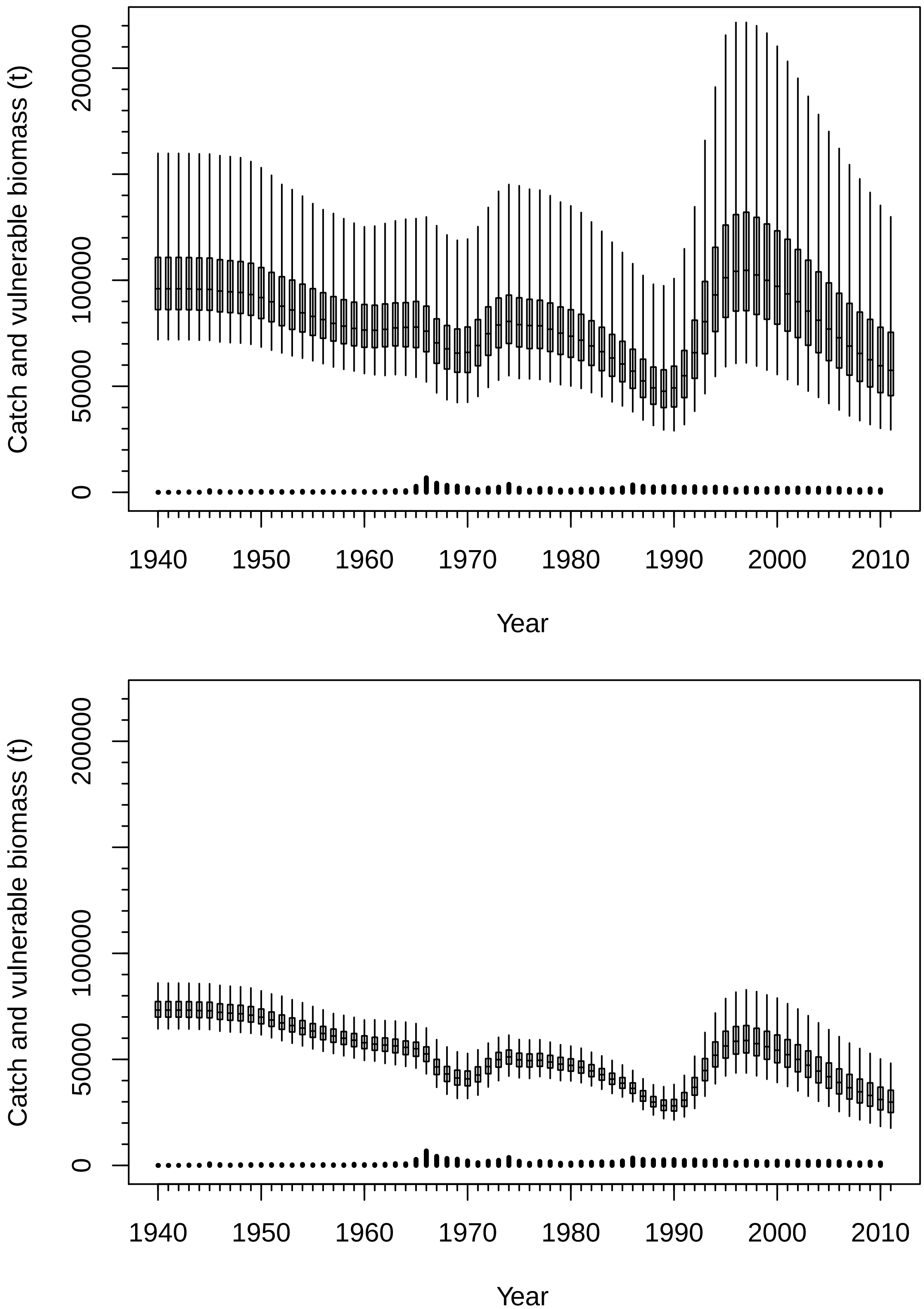


Figure 5. Estimated vulnerable biomass (boxplots) and commercial catch (vertical bars) over time for run 'Estimate M*' (top) and 'Fix* M*' (bottom). Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results. Catch is shown to compare its magnitude to the estimated vulnerable biomass.*

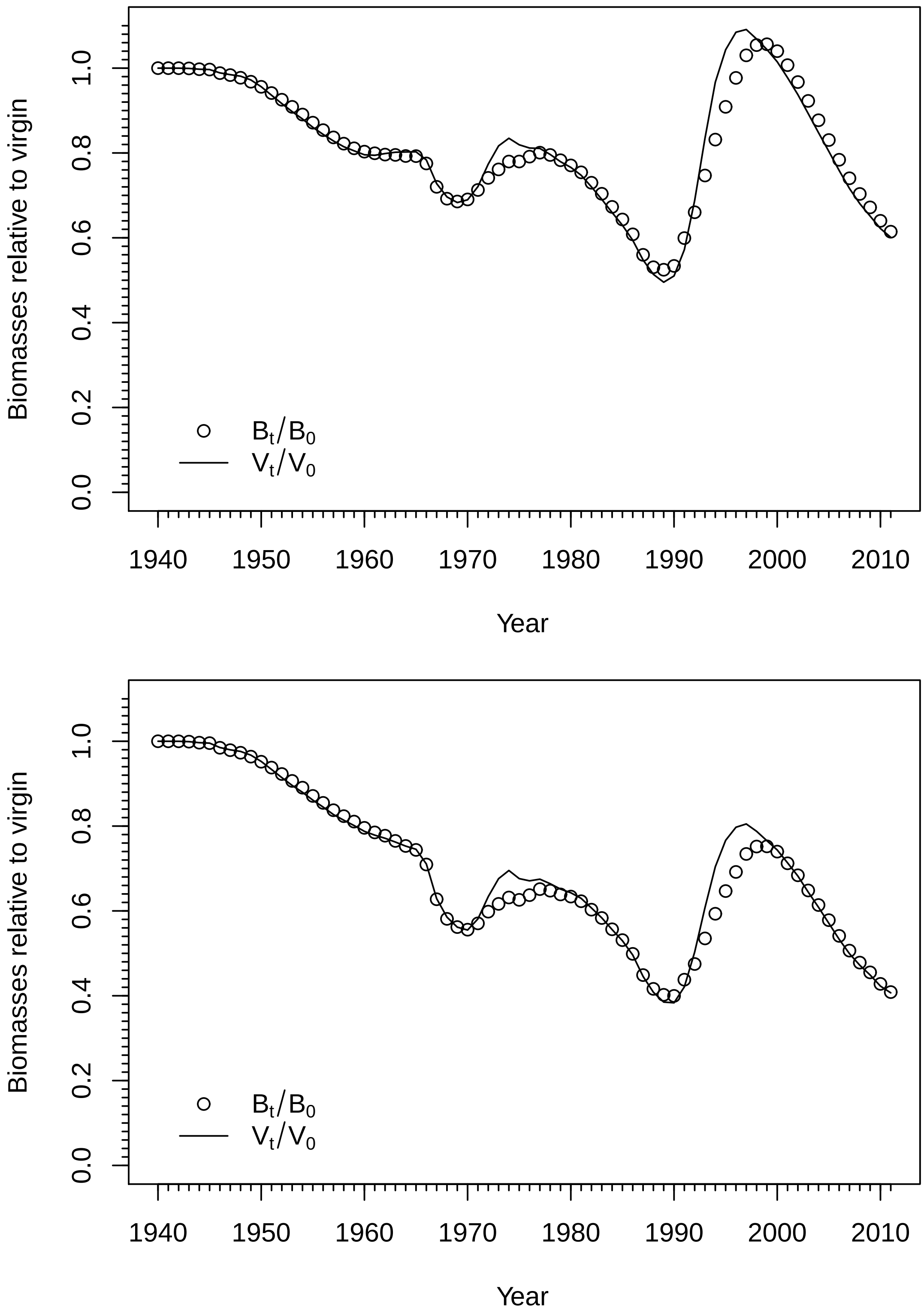


Figure 6. Changes in B_t/B_0 and V_t/V_0 (spawning and vulnerable biomass relative to virgin levels) over time for run 'Estimate M*' (top) and 'Fix* M*' (bottom), shown as the medians of the MCMC posteriors.*

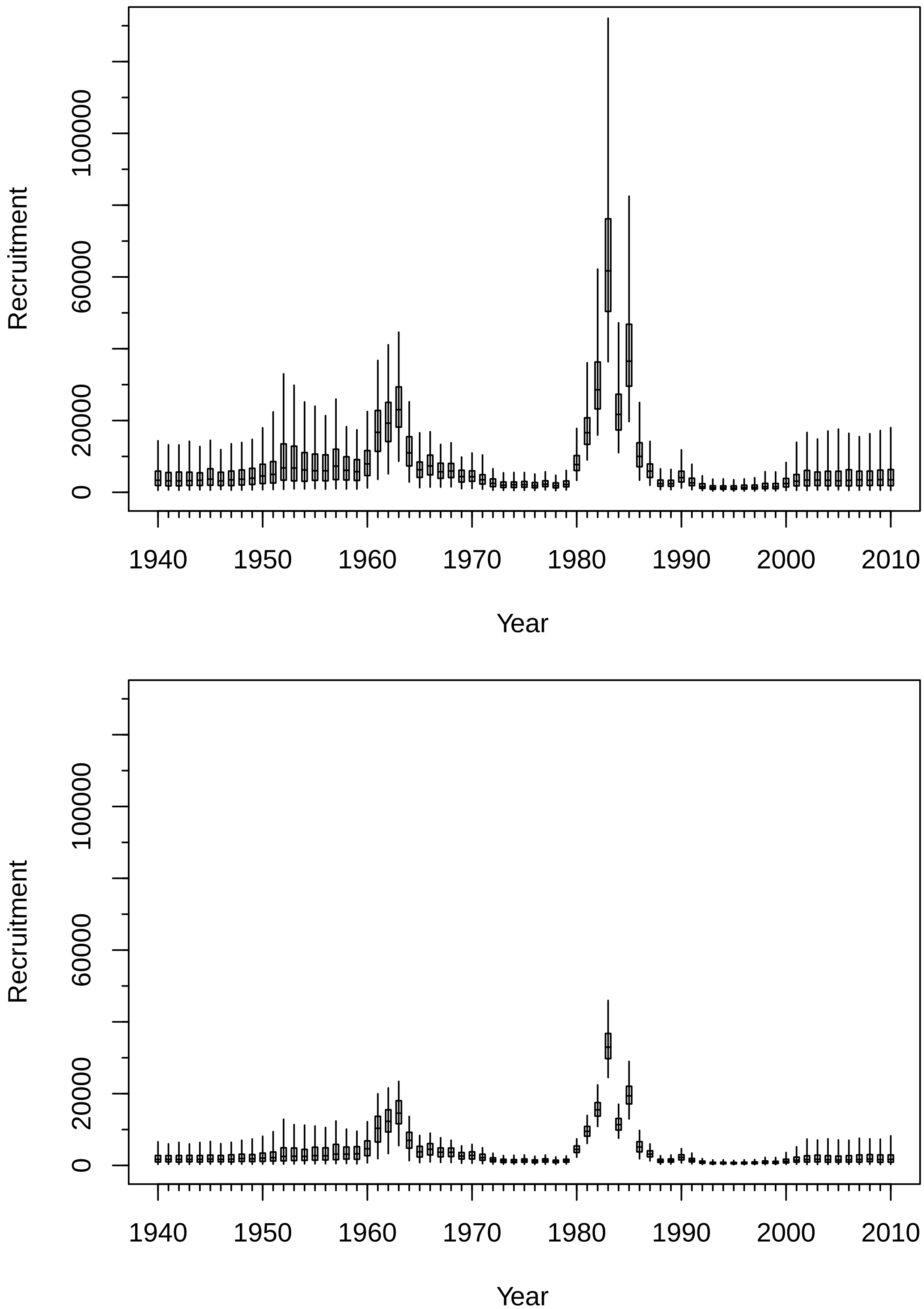
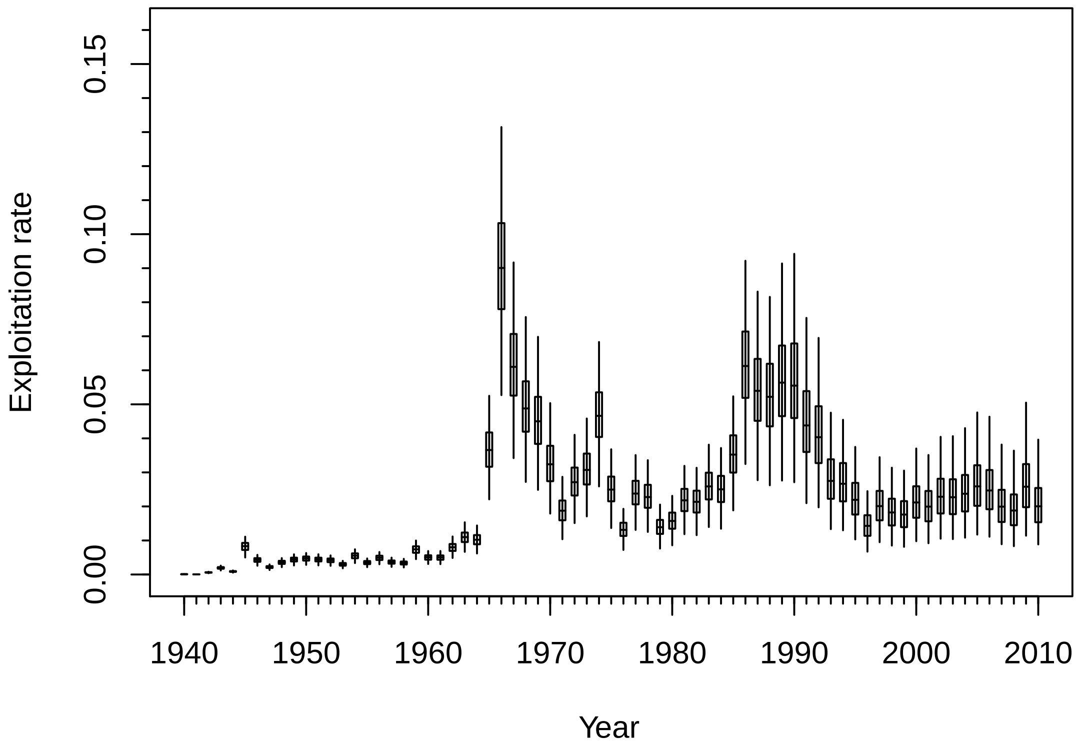


Figure 7. Marginal posterior distribution of recruitment in 1000's of age 1 fish plotted over time for run 'Estimate M*' (top) and run 'Fix* M*' (bottom). Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results.*



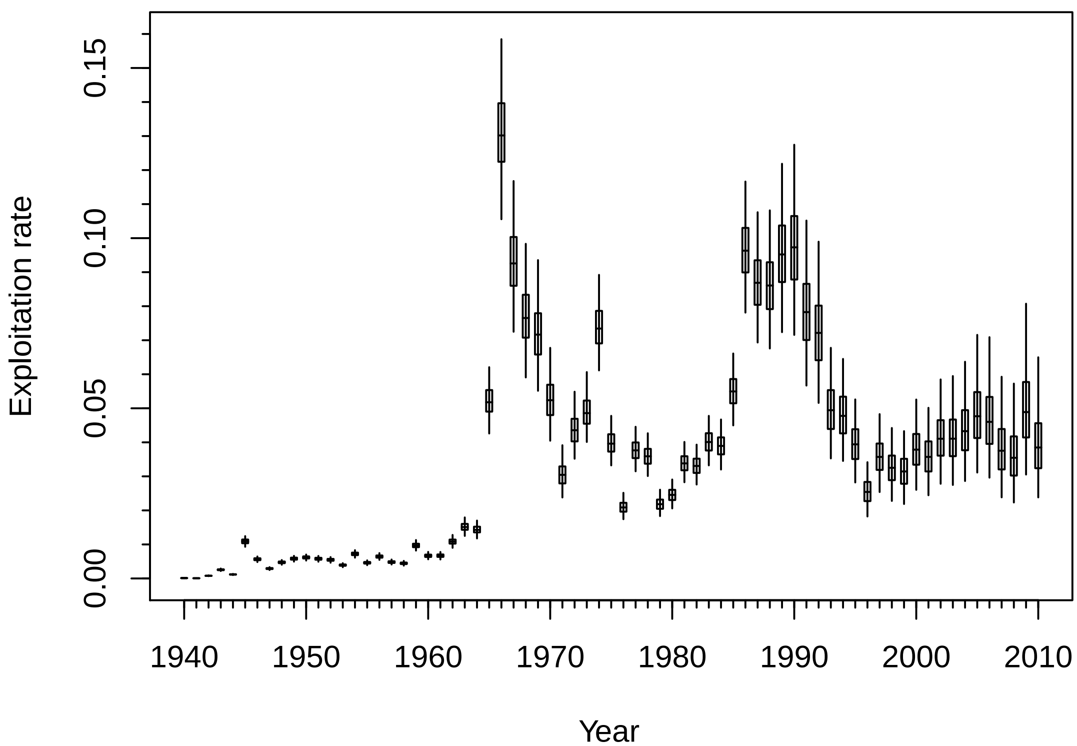
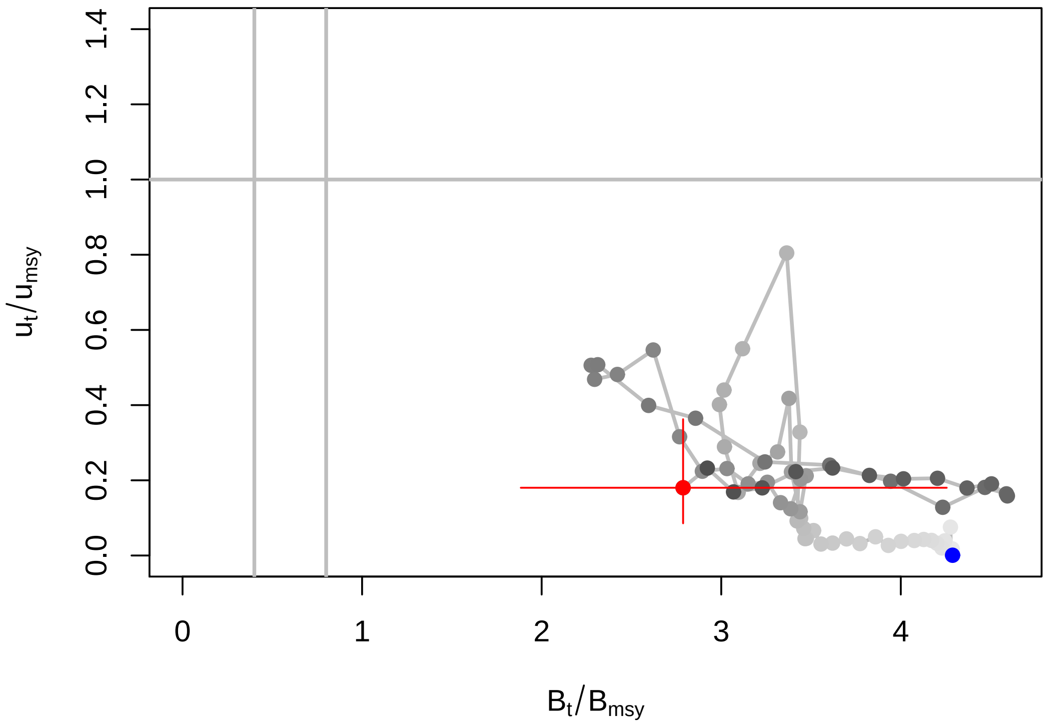


Figure 8. Marginal posterior distribution of exploitation rate (commercial catch divided by vulnerable biomass) plotted over time for run 'Estimate M*' (top) and 'Fix* M*' (bottom). Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results.*



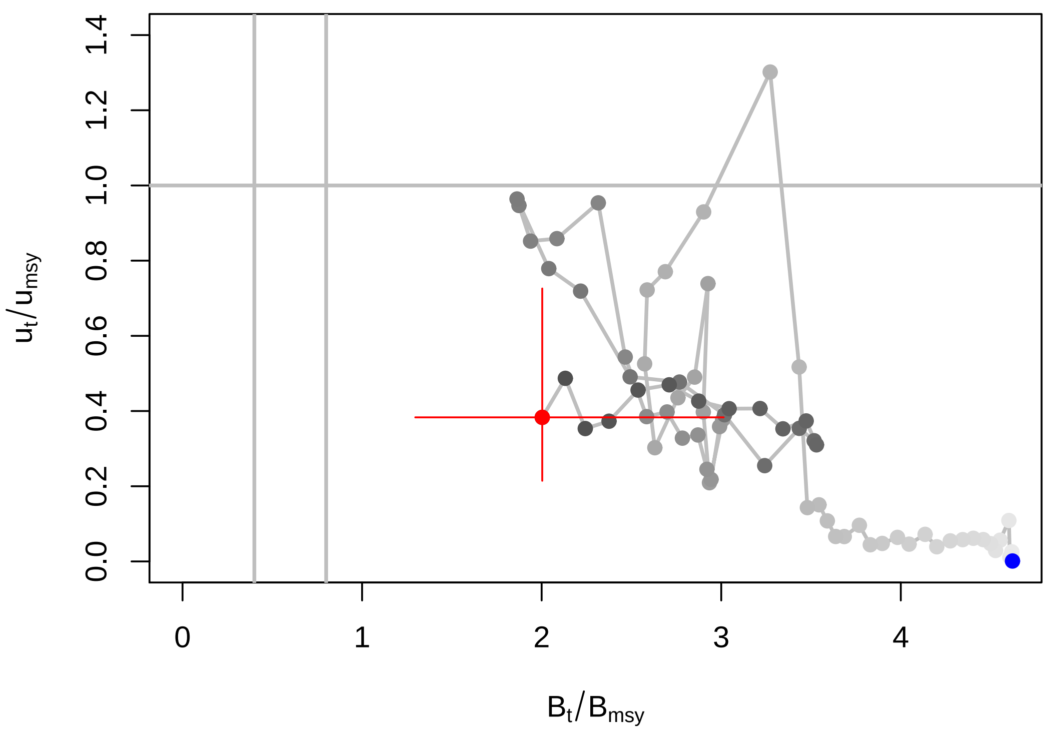


Figure 9. Trace through time of the medians of the ratios B_t/B_{MSY} (the spawning biomass in year t relative to B_{MSY}) and u_t/u_{MSY} (the exploitation rate in year t relative to u_{MSY}) for runs 'Estimate M*' (top) and 'Fix* M*' (bottom). Blue filled circle is the starting year (1940). Years then proceed from light grey through to dark grey with the final year (2010) as a filled red circle, and the red lines represent the 10% and 90% percentiles of the posterior distributions for the final year. Vertical grey lines indicate the provisional limit and upper stock reference points of 0.4B_{MSY} and 0.8B_{MSY}, and horizontal grey line indicates u_{MSY}.*

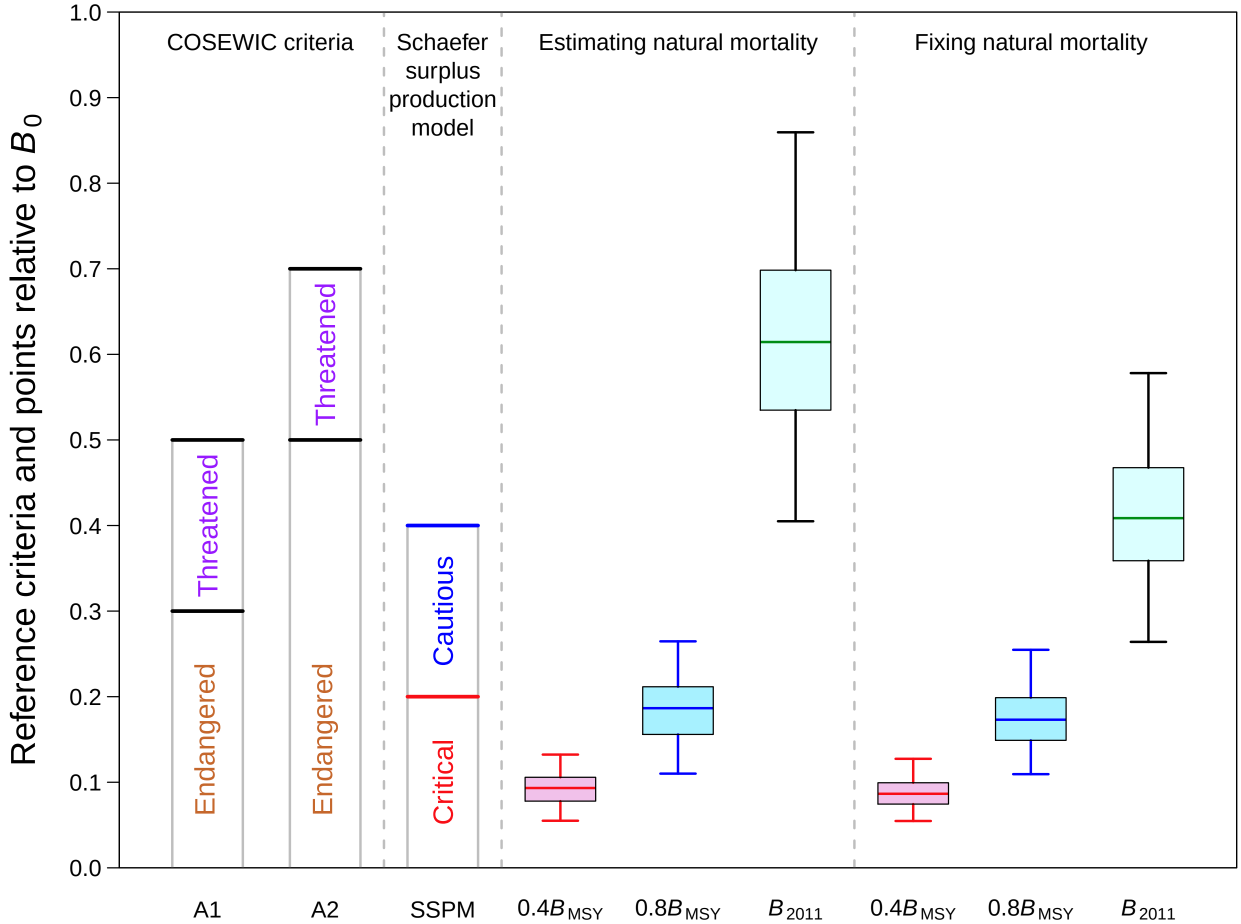


Figure 10. Reference criteria (for 2011), reference points and stock sizes as proportions of the unfished equilibrium spawning biomass (mature females), B_0. COSEWIC criteria A1 and A2 are defined in terms of percentage declines over three generations (90 years). Therefore the indicators A1 and A2 become fixed proportions of B_0 in 2011 because the model starts less than three generations ago. For a Schaefer surplus production model (SSPM), by definition $B_{\mathrm{MSY}} = 0.5B_0$; hence the provisional DFO Sustainable Fisheries Framework reference points of $0.4B_{\mathrm{MSY}}$ and $0.8B_{\mathrm{MSY}}$ lie at $0.2B_0$ (red bar) and $0.4B_0$ (blue bar), respectively. Thus, for such a model the population could be simultaneously in the healthy zone ($> 0.8B_{\mathrm{MSY}} = 0.4B_0$) with respect to the DFO Sustainable Fisheries Framework, but be considered Endangered ($< 0.5B_0$) with respect to COSEWIC indicator A2. For the Yellowmouth Rockfish age-structured model used here, the relationship between B_{MSY} and B_0 is determined by the biological parameters of the model rather than external fixed assumptions. The resulting estimates of $0.4B_{\mathrm{MSY}}$ (red boxplots) and $0.8B_{\mathrm{MSY}}$ (blue boxplots) are shown for the two model runs (horizontal bars are medians, boxes are the 25-75 percentiles and whiskers extend to the 2.5 and 97.5 percentiles). Green boxplots show the present estimated spawning biomass, B_{2011}.

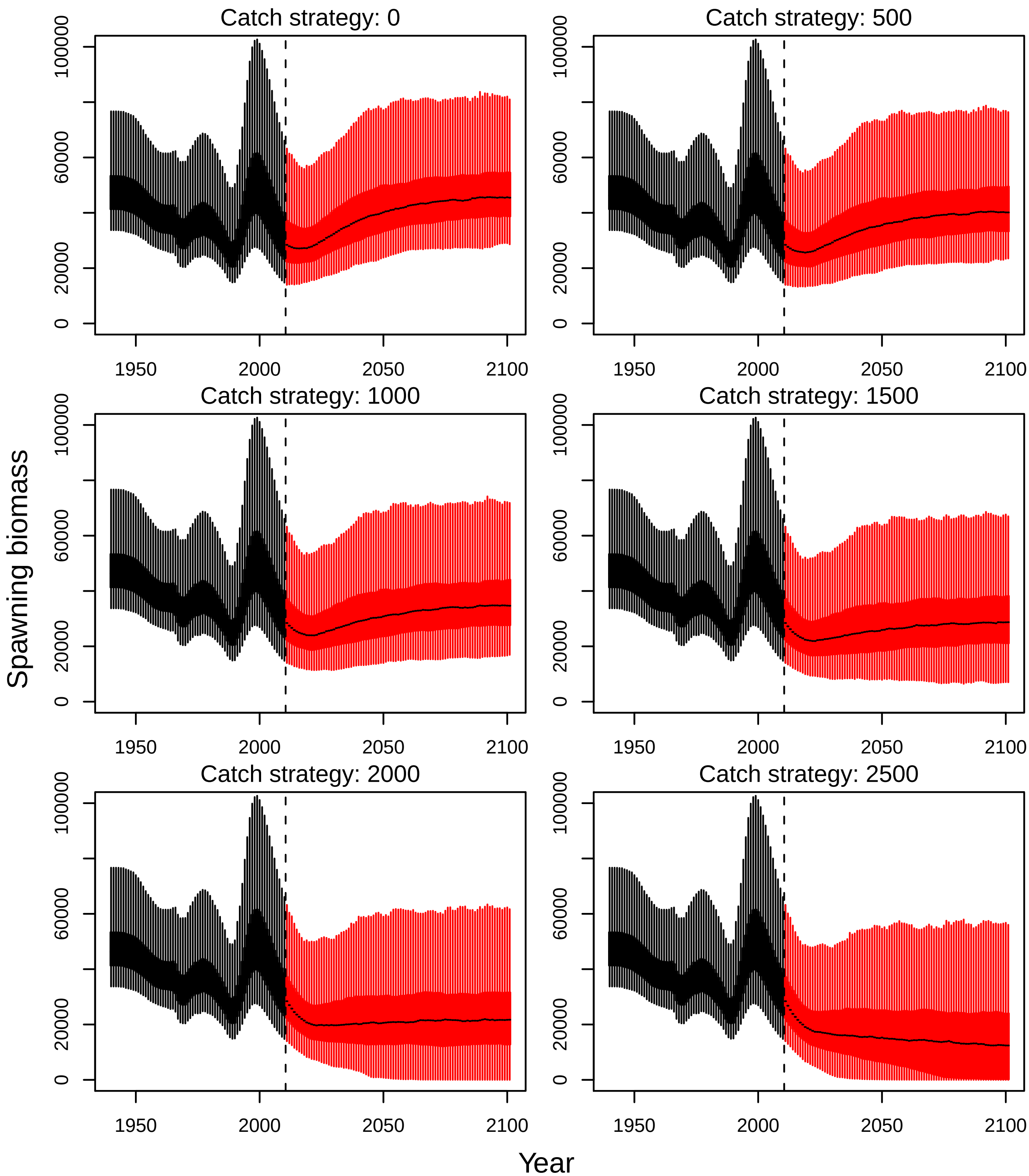


Figure 11. Projected spawning biomass (t) under different constant catch strategies (t) for run 'Estimate M' (boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results; given the large number of years the boxes appear as bolder regions). Black boxplots are estimates for 1940-2011. For each of the 1,000 samples from the MCMC posterior, the model was run forward in time (red, with medians in black) with a constant catch, and recruitment was simulated from the stock-recruitment function with lognormal error (see equation F.24). For reference, the average catch over the last five years (2006-2010) is 1442 t.

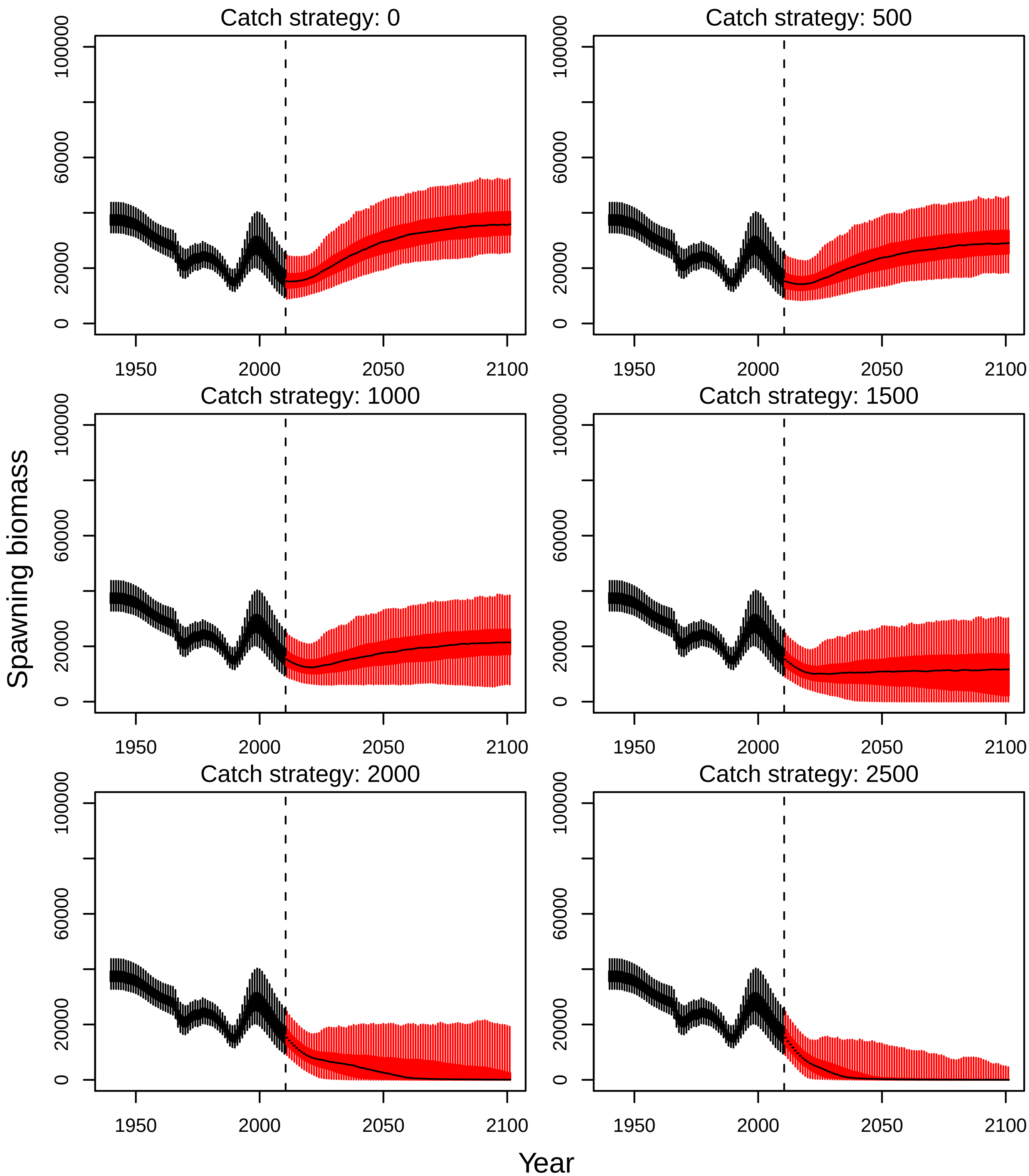


Figure 12. As for Figure 11 (on the same axes) but for run 'Fix M*'.*

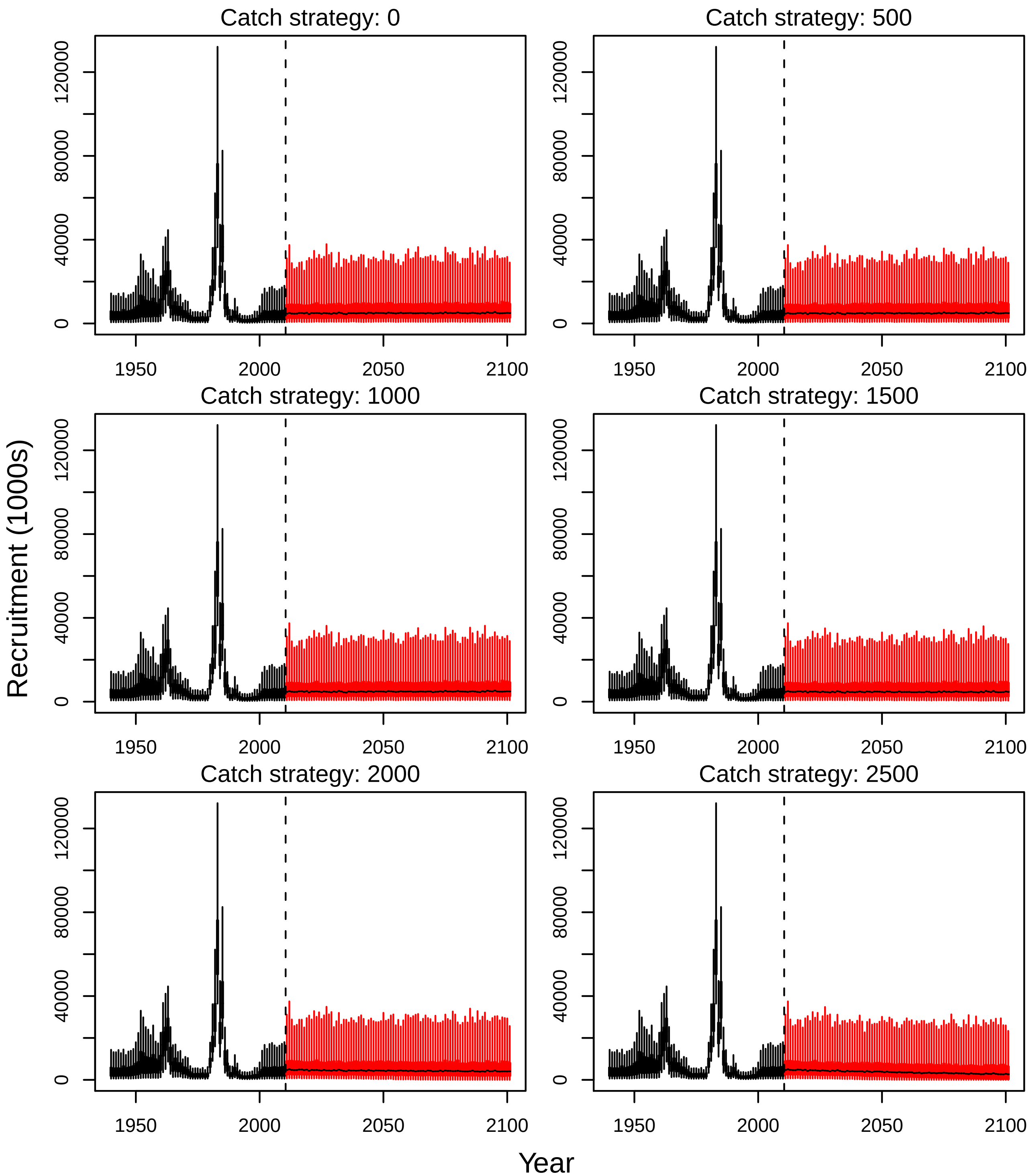


Figure 13. Projected recruitments (red) under different constant catch strategies for run 'Estimate M' (boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results; historical recruitments in black). This shows that the random projected recruitments are fairly similar from year-to-year, without the large recruitment events that are seen in the past. While individual MCMC simulations may have occasional large recruitments, this will not happen in a particular year for all MCMC simulations concurrently, as occurred in the early 1980s when the estimated 2.5 percentiles of recruitment were high (driven by the data). For the projections, the 2.5 percentiles will always be low.

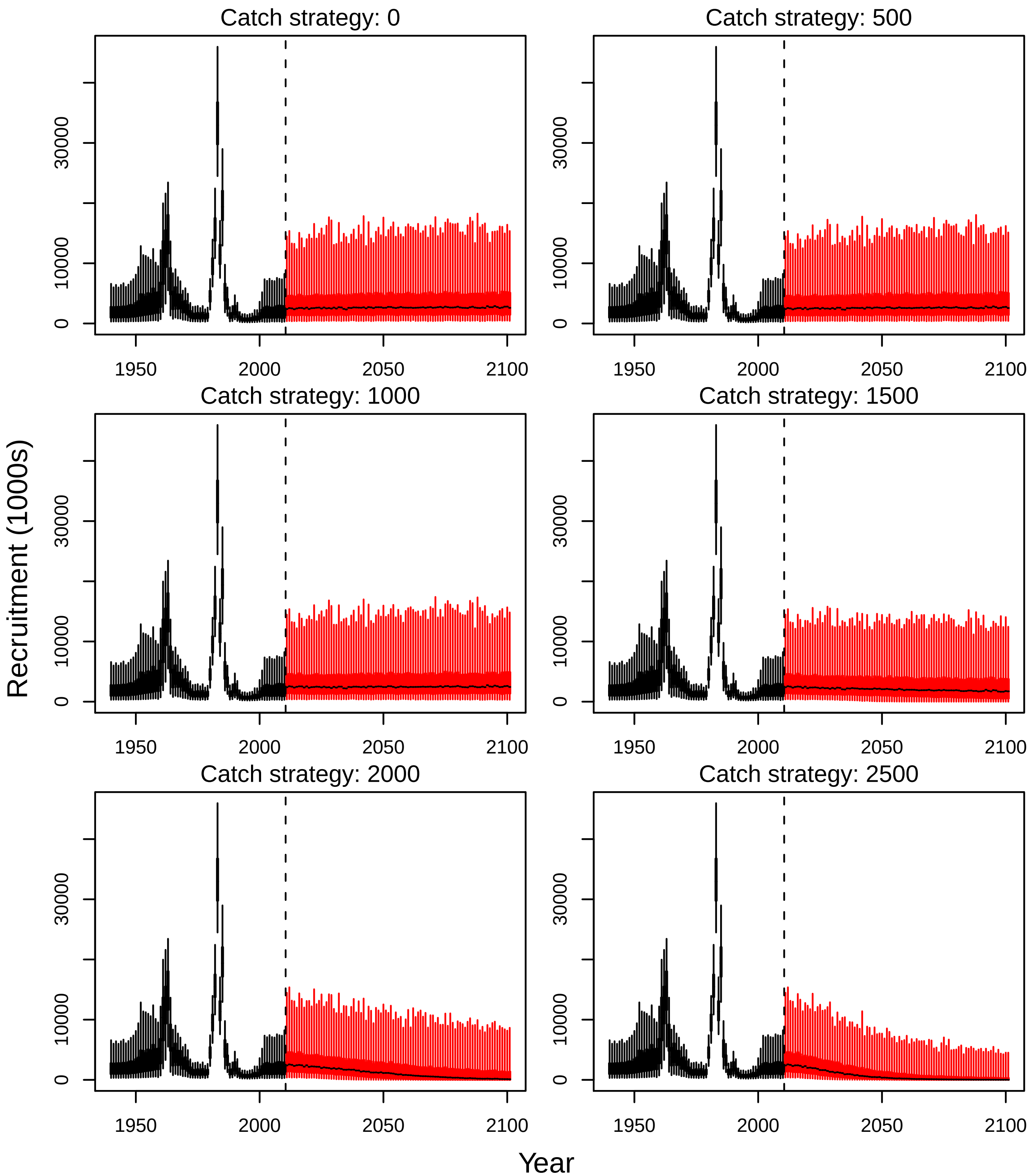


Figure 14. As for Figure 13 (with different vertical axes) but for run 'Fix M*'.*

Table 1. The 5th, 50th and 95th percentiles of MCMC-derived quantities from the 1,000 samples of the MCMC posterior for run 'Estimate M'. Definitions are: B_0 – unfished equilibrium spawning biomass (mature females), V_0 – unfished equilibrium vulnerable biomass (males and females), B_{2011} – spawning female biomass at the start of 2011, V_{2011} – vulnerable biomass in the middle of 2011, u_{2010} – exploitation rate (ratio of total catch to vulnerable biomass) in the middle of 2010, $u_{\max}$ – maximum exploitation rate (calculated for each sample as the maximum exploitation rate from 1940-2010), B_{MSY} – equilibrium spawning biomass at MSY (maximum sustainable yield), u_{MSY} – equilibrium exploitation rate at MSY, V_{MSY} – equilibrium vulnerable biomass at MSY. All biomass values (and MSY) are in tonnes. For reference, the average catch over the last five years (2006-2010) is 1,442 t.

Quantity	Percentile		
	5%	50%	95%
	From model output		
B_0	35,684	46,295	70,317
V_0	74,412	95,978	145,837
B_{2011}	15,866	28,425	57,052
V_{2011}	32,043	57,528	115,834
B_{2011}/B_0	0.431	0.614	0.829
V_{2011}/V_0	0.425	0.601	0.806
u_{2010}	0.010	0.020	0.036
$u_{\max}$	0.059	0.090	0.123
	MSY-based quantities		
$0.4B_{\mathrm{MSY}}$	2,590	4,304	6,863
$0.8B_{\mathrm{MSY}}$	5,180	8,608	13,725
B_{MSY}	6,475	10,760	17,156
B_{MSY}/B_0	0.149	0.233	0.314
$B_{2011}/B_{\mathrm{MSY}}$	1.606	2.685	4.573
MSY	1,717	2,567	4,297
u_{MSY}	0.061	0.109	0.201
$u_{2010}/u_{\mathrm{MSY}}$	0.070	0.180	0.433
V_{MSY}	14,841	23,693	37,241
V_{MSY}/V_0	0.163	0.245	0.323

Table 2. Percentiles of MCMC-derived quantities as for Table 1, but for run 'Fix M'. Definitions are: B_0 – unfished equilibrium spawning biomass (mature females), V_0 – unfished equilibrium vulnerable biomass (males and females), B_{2011} – spawning female biomass at the start of 2011, V_{2011} – vulnerable biomass in the middle of 2011, u_{2010} – exploitation rate (ratio of total catch to vulnerable biomass) in the middle of 2010, $u_{\max}$ – maximum exploitation rate (calculated for each sample as the maximum exploitation rate from 1940-2010), B_{MSY} – equilibrium spawning biomass at MSY (maximum sustainable yield), u_{MSY} – equilibrium exploitation rate at MSY, V_{MSY} – equilibrium vulnerable biomass at MSY. All biomass values (and MSY) are in tonnes. For reference, the average catch over the last five years (2006-2010) is 1,442 t.

Quantity	Percentile		
	5%	50%	95%
	From model output		
B_0	33,497	37,290	42,418
V_0	65,591	73,252	83,543
B_{2011}	9,727	15,239	22,718
V_{2011}	19,073	29,849	44,596
B_{2011}/B_0	0.289	0.409	0.547
V_{2011}/V_0	0.288	0.407	0.542
u_{2010}	0.026	0.038	0.059
$u_{\max}$	0.110	0.130	0.154
	MSY-based quantities		
$0.4B_{\mathrm{MSY}}$	2,170	3,254	4,532
$0.8B_{\mathrm{MSY}}$	4,340	6,507	9,065
B_{MSY}	5,425	8,134	11,331
B_{MSY}/B_0	0.147	0.216	0.298
$B_{2011}/B_{\mathrm{MSY}}$	1.085	1.922	3.204
MSY	1,236	1,693	2,108
u_{MSY}	0.056	0.100	0.167
$u_{2010}/u_{\mathrm{MSY}}$	0.191	0.383	0.872
V_{MSY}	11,831	17,044	23,400
V_{MSY}/V_0	0.163	0.232	0.309

Table 3. Decision table detailing the limit reference point $0.4B_{\mathrm{MSY}}$ for 1-5 year projections for run 'Estimate M*' at a range of constant catch strategies (in tonnes). Values are P$(B_t > 0.4B_{\mathrm{MSY}})$, i.e. the probability of the spawning biomass at the start of year t being greater than the limit reference point. The probabilities are the proportion of the 1,000 MCMC samples for which $B_t > 0.4B_{\mathrm{MSY}}$.*

'Estimate *M*': P$(B_t > 0.4B_{\mathrm{MSY}})$

Annual catch	Projection year					
strategy	2011	2012	2013	2014	2015	2016
0	1.000	1.000	1.000	1.000	1.000	1.000
250	1.000	1.000	1.000	1.000	1.000	1.000
500	1.000	1.000	1.000	1.000	1.000	1.000
750	1.000	1.000	1.000	1.000	1.000	1.000
1000	1.000	1.000	1.000	1.000	1.000	1.000
1250	1.000	1.000	1.000	1.000	1.000	1.000
1500	1.000	1.000	1.000	1.000	1.000	1.000
1750	1.000	1.000	1.000	1.000	1.000	1.000
2000	1.000	1.000	1.000	1.000	1.000	1.000
2250	1.000	1.000	1.000	1.000	1.000	0.999
2500	1.000	1.000	1.000	1.000	1.000	0.999
2750	1.000	1.000	1.000	1.000	0.999	0.998
3000	1.000	1.000	1.000	1.000	0.999	0.998

Table 4. Decision table for the upper reference point $0.8B_{\mathrm{MSY}}$ for 1-5 year projections for run 'Estimate M*', such that values are P$(B_t > 0.8B_{\mathrm{MSY}})$.*

'Estimate *M*': P$(B_t > 0.8B_{\mathrm{MSY}})$

Annual catch	Projection year					
strategy	2011	2012	2013	2014	2015	2016
0	1.000	1.000	1.000	1.000	1.000	1.000
250	1.000	1.000	1.000	1.000	1.000	1.000
500	1.000	1.000	1.000	1.000	1.000	1.000
750	1.000	1.000	1.000	1.000	1.000	1.000
1000	1.000	1.000	1.000	1.000	0.999	0.998
1250	1.000	1.000	1.000	1.000	0.997	0.997
1500	1.000	1.000	1.000	0.998	0.997	0.997
1750	1.000	1.000	1.000	0.997	0.997	0.997
2000	1.000	1.000	0.998	0.997	0.997	0.997
2250	1.000	1.000	0.998	0.997	0.997	0.994
2500	1.000	1.000	0.997	0.997	0.996	0.991
2750	1.000	1.000	0.997	0.996	0.994	0.982
3000	1.000	1.000	0.997	0.996	0.989	0.977

Table 5. Decision table for B_{MSY} for 1-5 year projections for run 'Estimate M*', such that values are P$(B_t > B_{\mathrm{MSY}})$.*

'Estimate *M*': P$(B_t > B_{\mathrm{MSY}})$

Annual catch strategy	Projection year					
	2011	2012	2013	2014	2015	2016
0	0.998	0.998	0.998	0.998	0.998	0.998
250	0.998	0.997	0.997	0.998	0.998	0.998
500	0.998	0.997	0.997	0.996	0.997	0.997
750	0.998	0.997	0.996	0.996	0.996	0.997
1000	0.998	0.996	0.996	0.996	0.996	0.995
1250	0.998	0.996	0.996	0.996	0.995	0.993
1500	0.998	0.996	0.996	0.996	0.993	0.990
1750	0.998	0.996	0.996	0.995	0.992	0.982
2000	0.998	0.996	0.996	0.994	0.984	0.980
2250	0.998	0.996	0.996	0.990	0.981	0.971
2500	0.998	0.996	0.996	0.990	0.978	0.966
2750	0.998	0.996	0.995	0.984	0.971	0.957
3000	0.998	0.996	0.993	0.980	0.966	0.953

Table 6. Decision table for the limit reference point $0.4B_{\mathrm{MSY}}$ for 1-5 year projections for run 'Fix M*', such that values are P$(B_t > 0.4B_{\mathrm{MSY}})$.*

'Fix *M*': P$(B_t > 0.4B_{\mathrm{MSY}})$

Annual catch strategy	Projection year					
	2011	2012	2013	2014	2015	2016
0	1.000	1.000	1.000	1.000	1.000	1.000
250	1.000	1.000	1.000	1.000	1.000	1.000
500	1.000	1.000	1.000	1.000	1.000	1.000
750	1.000	1.000	1.000	1.000	1.000	1.000
1000	1.000	1.000	1.000	1.000	1.000	1.000
1250	1.000	1.000	1.000	1.000	1.000	0.999
1500	1.000	1.000	1.000	1.000	0.999	0.997
1750	1.000	1.000	1.000	0.999	0.997	0.994
2000	1.000	1.000	0.999	0.999	0.995	0.991
2250	1.000	1.000	0.999	0.997	0.993	0.989
2500	1.000	1.000	0.999	0.996	0.991	0.979
2750	1.000	1.000	0.999	0.994	0.986	0.968
3000	1.000	1.000	0.998	0.991	0.980	0.951

Table 7. Decision table for the upper reference point $0.8B_{\mathrm{MSY}}$ for 1-5 year projections for run 'Fix M*', such that values are P$(B_t > 0.8B_{\mathrm{MSY}})$.*

'Fix *M*': P$(B_t > 0.8B_{\mathrm{MSY}})$

Annual catch	Projection year					
strategy	2011	2012	2013	2014	2015	2016
0	0.990	0.992	0.993	0.994	0.994	0.995
250	0.990	0.991	0.991	0.992	0.992	0.992
500	0.990	0.991	0.989	0.987	0.987	0.986
750	0.990	0.991	0.987	0.986	0.985	0.985
1000	0.990	0.989	0.986	0.984	0.976	0.968
1250	0.990	0.986	0.984	0.973	0.961	0.958
1500	0.990	0.985	0.977	0.968	0.956	0.940
1750	0.990	0.984	0.971	0.958	0.940	0.923
2000	0.990	0.983	0.969	0.951	0.926	0.891
2250	0.990	0.982	0.965	0.939	0.908	0.865
2500	0.990	0.981	0.959	0.925	0.879	0.820
2750	0.990	0.977	0.952	0.914	0.855	0.780
3000	0.990	0.975	0.946	0.898	0.820	0.721

Table 8. Decision table for B_{MSY} for 1-5 year projections for run 'Fix M*', such that values are P$(B_t > B_{\mathrm{MSY}})$.*

'Fix *M*': P$(B_t > B_{\mathrm{MSY}})$

Annual catch	Projection year					
strategy	2011	2012	2013	2014	2015	2016
0	0.967	0.967	0.968	0.967	0.973	0.977
250	0.967	0.965	0.964	0.962	0.961	0.962
500	0.967	0.960	0.958	0.953	0.952	0.952
750	0.967	0.958	0.951	0.946	0.942	0.938
1000	0.967	0.956	0.947	0.937	0.925	0.916
1250	0.967	0.954	0.940	0.924	0.904	0.887
1500	0.967	0.951	0.931	0.909	0.885	0.854
1750	0.967	0.946	0.920	0.895	0.852	0.827
2000	0.967	0.943	0.914	0.875	0.833	0.778
2250	0.967	0.939	0.903	0.852	0.799	0.721
2500	0.967	0.936	0.894	0.831	0.758	0.670
2750	0.967	0.934	0.883	0.809	0.717	0.609
3000	0.967	0.931	0.868	0.780	0.670	0.552

Table 9. Decision tables for four reference points (RP) $0.4B_{MSY}$, $0.8B_{MSY}$, $0.2B_0$ and $0.4B_0$, projected from 2011 for 90 years over a range of constant catch strategies (in tonnes), for run 'Estimate M'. Value $P(B_t > RP)$ is the probability of the spawning biomass at the beginning of year t being greater than the reference point. The probabilities are based on the MCMC posterior distributions of B_t and B_{MSY} or B_0.

Annual catch strategy	Projection Year 0	5	10	15	30	45	60	75	90
$P(B_t > 0.4B_{MSY})$									
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1500	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.98	0.98
2000	1.00	1.00	1.00	0.99	0.97	0.94	0.90	0.88	0.86
2500	1.00	1.00	0.99	0.97	0.87	0.78	0.71	0.67	0.63
$P(B_t > 0.8B_{MSY})$									
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1500	1.00	1.00	1.00	0.98	0.98	0.97	0.97	0.97	0.97
2000	1.00	1.00	0.98	0.95	0.90	0.87	0.85	0.83	0.82
2500	1.00	0.99	0.95	0.88	0.74	0.67	0.62	0.60	0.58
$P(B_t > 0.2B_0)$									
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1500	1.00	1.00	0.99	0.99	0.98	0.98	0.97	0.97	0.97
2000	1.00	1.00	0.98	0.96	0.90	0.87	0.86	0.84	0.83
2500	1.00	0.99	0.95	0.87	0.74	0.65	0.61	0.59	0.56
$P(B_t > 0.4B_0)$									
0	0.98	0.99	0.99	0.99	1.00	1.00	1.00	1.00	1.00
500	0.98	0.96	0.96	0.97	1.00	1.00	1.00	1.00	1.00
1000	0.98	0.92	0.88	0.88	0.94	0.97	0.98	0.99	0.99
1500	0.98	0.87	0.76	0.72	0.77	0.83	0.84	0.86	0.88
2000	0.98	0.81	0.61	0.57	0.58	0.59	0.59	0.61	0.62
2500	0.98	0.76	0.47	0.41	0.39	0.36	0.37	0.35	0.34

Table 10. As for Table 9 but for run 'Fix M'.

Annual catch strategy	Projection Year 0	5	10	15	30	45	60	75	90
$P(B_t > 0.4B_{MSY})$									
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1000	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.98	0.98
1500	1.00	1.00	0.99	0.96	0.89	0.83	0.78	0.76	0.74
2000	1.00	0.99	0.93	0.82	0.57	0.42	0.34	0.29	0.24
2500	1.00	0.98	0.79	0.56	0.23	0.12	0.08	0.05	0.04
$P(B_t > 0.8B_{MSY})$									
0	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	0.99	0.99	0.99	0.98	1.00	1.00	1.00	1.00	1.00
1000	0.99	0.97	0.95	0.95	0.95	0.96	0.96	0.96	0.96
1500	0.99	0.94	0.85	0.80	0.75	0.72	0.69	0.68	0.67
2000	0.99	0.89	0.67	0.55	0.39	0.31	0.27	0.23	0.20
2500	0.99	0.82	0.45	0.29	0.13	0.08	0.06	0.03	0.02
$P(B_t > 0.2B_0)$									
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1000	1.00	0.99	0.97	0.96	0.96	0.97	0.97	0.97	0.97
1500	1.00	0.96	0.84	0.76	0.71	0.68	0.66	0.66	0.65
2000	1.00	0.89	0.59	0.44	0.31	0.25	0.21	0.19	0.16
2500	1.00	0.79	0.34	0.19	0.09	0.05	0.03	0.03	0.01
$P(B_t > 0.4B_0)$									
0	0.55	0.58	0.77	0.92	1.00	1.00	1.00	1.00	1.00
500	0.55	0.42	0.44	0.62	0.92	0.98	0.99	0.99	0.99
1000	0.55	0.27	0.19	0.29	0.58	0.70	0.78	0.82	0.87
1500	0.55	0.15	0.07	0.10	0.22	0.28	0.30	0.32	0.34
2000	0.55	0.09	0.01	0.04	0.06	0.06	0.06	0.05	0.05
2500	0.55	0.05	0.00	0.01	0.02	0.01	0.00	0.00	0.00

Table 11. Decision tables for run 'Estimate M' for two COSEWIC reference criteria ($RC=0.5B_{t-3Gen}$ and $RC=0.7B_{t-3Gen}$), where B_{t-3Gen} is the spawning biomass 3 generations (90 years) before year t. Value $P(B_t > RC)$ is the probability of the spawning biomass at the beginning of year t satisfying (being greater than) the reference criterion RC, based on the MCMC posterior samples. $B_{t-3Gen}=B_0$ if t<2030 because the model start year is <90 years beforehand. The criterion $RC=0.5B_{t-3Gen}$ corresponds to a 50% decline over 3 generations, and $RC=0.7B_{t-3Gen}$ corresponds to a 30% decline over three generations, which are the respective COSEWIC A2 criteria for Endangered and Threatened. Values are shown over a range of constant catch strategies (in tonnes).

Annual catch strategy	Projection Year 0	15	30	45	60	75	90
$P(B_t > 0.5B_{t-3Gen})$							
0	0.84	0.94	1.00	1.00	1.00	1.00	1.00
500	0.84	0.79	0.98	1.00	1.00	0.99	1.00
1000	0.84	0.61	0.84	0.97	0.99	0.95	1.00
1500	0.84	0.44	0.63	0.84	0.87	0.75	0.96
2000	0.84	0.29	0.44	0.60	0.63	0.42	0.75
2500	0.84	0.19	0.28	0.40	0.39	0.17	0.43
$P(B_t > 0.7B_{t-3Gen})$							
0	0.25	0.31	0.86	1.00	1.00	0.95	1.00
500	0.25	0.19	0.64	0.95	0.98	0.84	1.00
1000	0.25	0.11	0.42	0.79	0.87	0.61	0.99
1500	0.25	0.06	0.25	0.55	0.63	0.29	0.86
2000	0.25	0.04	0.14	0.34	0.37	0.10	0.54
2500	0.25	0.02	0.08	0.18	0.18	0.04	0.23

Table 12. As for Table 11 but for run 'Fix M'.

Annual catch strategy	Projection Year 0	15	30	45	60	75	90
$P(B_t > 0.5B_{t-3Gen})$							
0	0.14	0.54	0.99	1.00	1.00	1.00	1.00
500	0.14	0.23	0.79	0.99	1.00	1.00	1.00
1000	0.14	0.07	0.38	0.80	0.90	0.90	0.98
1500	0.14	0.03	0.12	0.37	0.48	0.40	0.64
2000	0.14	0.01	0.03	0.09	0.12	0.07	0.14
2500	0.14	0	0.01	0.02	0.01	0.01	0.01
$P(B_t > 0.7B_{t-3Gen})$							
0	0	0.03	0.63	1.00	1.00	1.00	1.00
500	0	0.01	0.25	0.87	0.98	0.97	1.00
1000	0	0	0.07	0.46	0.71	0.67	0.96
1500	0	0	0.02	0.15	0.26	0.16	0.52
2000	0	0	0	0.03	0.05	0.02	0.08
2500	0	0	0	0	0	0	0

Table 13. Decision table showing the number of years to exceed the four reference points (RP): $0.4B_{MSY}$, $0.8B_{MSY}$, $0.2B_0$ and $0.4B_0$, and the two COSEWIC reference criteria (RC) of $0.5B_{t\text{-}3Gen}$ and $0.7B_{t\text{-}3Gen}$ over a range of constant catch strategies (in tonnes) for three levels of confidence for run 'Estimate M'. Values are the first year that the RP or RC is reached with the given confidence level (and the population is increasing), where 0 means that the projected population always exceeds the RP or RC and 90 means that the RP or RC is not reached within 90 years.

Annual catch strategy	Reference Point or Reference Criterion					
	$0.4B_{\text{MSY}}$	$0.8B_{\text{MSY}}$	$0.2B_0$	$0.4B_0$	$0.5B_{t\text{-}3Gen}$	$0.7B_{t\text{-}3Gen}$
50% confidence						
0	0	0	0	0	0	20
500	0	0	0	0	0	26
1000	0	0	0	0	0	32
1500	0	0	0	0	21	41
2000	0	0	0	0	34	64
2500	0	0	0	90	66	90
80% confidence						
0	0	0	0	0	0	29
500	0	0	0	0	16	34
1000	0	0	0	0	28	46
1500	0	0	0	38	39	65
2000	0	0	0	90	90	90
2500	90	90	90	90	90	90
95% confidence						
0	0	0	0	0	17	35
500	0	0	0	0	28	45
1000	0	0	0	38	40	64
1500	0	0	0	90	67	90
2000	90	90	90	90	90	90
2500	90	90	90	90	90	90

Table 14. As for Table 13, but for run 'Fix M'.

Annual catch strategy	Reference Point or Reference Criterion					
	$0.4B_{\mathrm{MSY}}$	$0.8B_{\mathrm{MSY}}$	$0.2B_0$	$0.4B_0$	$0.5B_{t\text{-}3Gen}$	$0.7B_{t\text{-}3Gen}$
50% confidence						
0	0	0	0	0	15	29
500	0	0	0	12	23	35
1000	0	0	0	25	34	46
1500	0	0	0	90	62	67
2000	90	90	90	90	90	90
2500	90	90	90	90	90	90
80% confidence						
0	0	0	0	12	21	33
500	0	0	0	22	31	43
1000	0	0	0	65	46	63
1500	90	90	90	90	90	90
2000	90	90	90	90	90	90
2500	90	90	90	90	90	90
95% confidence						
0	0	0	0	17	27	38
500	0	0	0	36	38	46
1000	0	27	0	90	65	89
1500	90	90	90	90	90	90
2000	90	90	90	90	90	90
2500	90	90	90	90	90	90

APPENDIX A. 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)***:** 24/11/2010

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

Initiating Branch Contact:	
Name: Tamee Mawani/Karen Calla	Telephone Number: 604-666-9033 **/** 604-666-0395
Email:Tameezan.mawani@dfo-mpo.gc.ca Karen.calla@dfo-mpo.gc.ca	Fax Number:

Issue Requiring Science Advice (i.e., "the question"): *Issue posed as a question for Science response.*
Compilation of a research document (which will be the RPA) concerning the stock of yellowmouth rockfish along the coast of British Columbia. It will include the required information as stated in the revised protocol for conducting recovery potential assessments (revised in 2009). The RPA provides scientific background, identification of threats and probability of recovery of a species, or population, that is deemed to be at risk. In July 2004, the ADM Fisheries and Aquaculture Management agreed to work towards integrating the Precautionary Approach (PA) into Fisheries Management Renewal on groundfish fisheries. To this end staff were instructed to ensure all future Science assessments begin to include candidate Limit Reference Points for groundfish and pelagic fisheries. In this context is it appropriate to recommend candidate Limit Reference Points (LRP), an Upper Stock Reference Point (USR) and target reference point (TRP) for the yellowmouth rockfish (coastwide)? If so what would the candidate points be (include biological considerations and rationale used to form these recommended candidate points.) What is the current status of the yellowmouth rockfish stock (coastwide) relative to the DFO Precautionary Approach harvest default reference points? Provide rationale for if the LRP, USR and TRP candidates differ from the PA default reference points and include decision tables which forecast the impact of varying harvest levels on future population trends. Any assessment should give consideration to recreational and food, social, ceremonial harvest of yellowmouth.

Rationale for Advice Request: *What is the issue, what will it address, importance, scope and breadth of interest, etc.?*
This species has been designated as threatened by COSEWIC and the completion of a RPA is a

mandated requirement in the listing decision process for species at risk.

Possibility of integrating this request with other requests in your sector or other sector's needs?
n/a

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?*
This advice will be used in the Species at Risk Act legal listing decision for yellowmouth and possibly included in the 2012/2013 groundfish IFMP.

Date Advice Required:

Latest possible date to receive Science advice: May 2011.

Funding: Specific funds may already have been identified to cover a given issue (e.g. SARCEP, Ocean Action Plan, etc.)
Source of funding: SARCEP Expected amount: $48K

Initiating Branch's Approval:

Approved by Initiating Director: Date:

Name of initiating Director:

<u>**Send form via email attachment following instructions below**</u>:

<u>Regional request</u>: 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.

<u>National request</u>: At HQ, the Director of the Canadian Science Advisory Secretariat (Ghislain.Chouinard@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.

PART 2: **<u>RESPONSE FROM SCIENCE</u>**

<u>In the regions</u>: to be filled by the Regional Centre for Science Advice.
<u>At HQ</u>: to be filled by the Canadian Science Advisory Secretariat in collaboration with the Directors of the Science program(s) of concern.

Criteria characterising the request:	*Constraints regarding the planning of a standard peer review/Workshop:*	*Other criteria that could affect the choice of the process, the timelines, or the scale of the meeting:*

☐ ***Science advice is requested (rather than just information)***
☐ ***A sound basis of peer-reviewed information and advisory precedent already exists.***
☐ ***Inclusiveness is an issue***
☐ ***Advice on this specific issue has been provided in the past.***
☐ ***Urgent request.***
☐ ***DFO is not the final advisory body.***
    ☐ ***CEAA process***
    ☐ ***COSEWIC process***
    ☐ ***Other:***
	☐ ***External expertise required***
	☐ ***This is a scientifically controversial issue, i.e., consensus does* not *currently exist within DFO science.***
	☐ ***Extensive preparatory work is required.***
	☐ ***Determination of information availability is required (prior to provision of advice).***
	☐ ***Resources supporting this process are not available.***
	☐ ***Expected time needed for the preparatory work:***
	☐ ***Other (please specify):***
		☐ ***The response provided could be considered as a precedent that will affect other regions.***
		☐ ***The response corresponds to a new framework or will affect the framework currently in place.***
		☐ ***Expertise from other DFO regions is necessary.***
		☐ ***Other (please specify):***

Recommendation regarding the advisory process and the timelines:		
☐ ***Science Special Response Process (SSRP)***	☐ ***Workshop***	☐ ***Peer Review Meeting***

Rationale justifying the choice of process:

Types of publications expected and if already known, number of report for each series:

☐ ***Science Advisory Report ( )*** ☐ ***Research Document ( )***
☐ ***Proceeding ( )*** ☐ ***Science Response Report ( )***
☐ ***Other:***

Date Advice to be Provided:

☐ Date specified can be met.
☐ Date specified can NOT be met.

Alternate date, as agreed to by client Branch lead and Science lead:

OR

☐ ***No Formal Response to be Provided by Science*** *Rationale:* ☐ ***DFO Science Region does not have the expertise required.*** ☐ ***DFO Science Region does not have resources available at this time.*** ☐ ***The deadline can not be met.*** ☐ ***Not a natural science issue (e.g. socio-economic)*** ☐ ***Response to a similar question has been provided elsewhere:*** ***Reference:*** ***Additional explanation:***

Science Branch Lead:	
Name:	Telephone Number:
Email:	
* Please contact Science Branch lead for additional details on this request.	

Science Branch Approval:
Approved by Regional Director, Science (or their delegate authority): ☐ Date: Name of the person who approved the request: Once part 2 completed, the form is sent via email attachment to the initiating Branch contact person.

PART 3: **PLANNING OF THE ADVISORY PROCESS**

Science Branch Approval:
Coordinator of the event: Potential chair(s): Suggested date / period for the meeting: Need a preparatory meeting: Leader of the Steering Committee:

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, *Sebastes alutus*) in BC waters for approximately two decades. It seems likely that this heavy fishing activity also caught significant numbers of Yellowmouth Rockfish (YMR) along with POP. The foreign fleets were primarily from the US (1959-1980), the USSR (1965-1968) and Japan (1966-1976). The foreign vessels removed large amounts of POP biomass, particularly in Queen Charlotte Sound. Canadian effort escalated in 1965 but the catch never reached the levels of those by the combined foreign vessels.

Prior to 1977, no quotas were in effect for any slope rockfish species. Since then, the groundfish management unit (GMU) at the Department of Fisheries and Oceans (DFO) imposed a combination of species/area quotas, area/time closures, and trip limits on the major species. Quotas were first introduced for YMR in 1979 for GMU area 3D+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 YMR and POP only.

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

Year	3C	3D+5AB	5CD	[5ES | 5EN]	Coast	Notes
1979	---	50	---	[750 | ---]	800	a
1980	---	250	---	[800 | ---]	1050	b
1981	---	---	---	[800 | ---]	800	c
1982	---	250	---	[100 | 600]	950	
1983	---	250	---	[agg | open]	UnLtd	d
1984	---	250	300	[agg | open]	UnLtd	e
1985	---	350	250	[agg | open]	UnLtd	
1986	---	---	250	[agg | open]	UnLtd	
1987	---	350	250	[agg | open]	UnLtd	
1988	---	375	250	[agg | open]	UnLtd	
1989	---	500	350	[600 | open]	UnLtd	
1990	---	500	330	[550 | open]	UnLtd	f
1991	---	500	330	[550 | 0]	1380	g,h
1992	---	500	330	[550 | 0]	1380	i
1993	---	500	330	[550 | 0]	1380	j,k
1994	---	---	---	[--- | 0]	---	l
1995	---	---	---	---	---	m
1996	---	---	---	---	---	n,o
1997	100	1866	360	104	2430	+,p,q
1998	221	1145	691	328	2385	+
1999	223	1156	697	331	2407	+
2000	223	1156	697	331	2408	+,r,s
2001	219	1135	685	325	2365	+
2002	219	1135	685	325	2365	+,t,u,v
2003	219	1135	685	325	2365	+
2004	219	1135	685	325	2365	+
2005	219	1135	685	325	2365	+
2006	219	1135	685	325	2365	+,w,x,y,z
2007	219	1135	685	325	2365	+
2008	219	1135	685	325	2365	+
2009	219	1135	685	325	2365	+
2010	219	1135	685	325	2365	+
2011	219	1135	685	325	2365	+

[1] one month into the IVQ (Individual Vessel Quota) program, Barry Ackerman, GMU, pers. comm.

Table B1a. Note codes 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 H&L fleet inside.
i	Start limited vessel entry for H&L fleet outside.
j	End experimental fishing of Langara Spit POP stock.
k	Close POP fishery in PMFC area 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 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 has reduced the 5C/D Pacific Ocean Perch 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 has reduced the 5C/D Pacific ocean perch TAC by 700 tonnes for use in possible research programs.
x	Introduce IFMP (integrated fisheries management plan) 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.

YMR CATCH RECONSTRUCTION

A detailed account of how we reconstruct rockfish 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 YMR/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, e.g., to allocate the annual catch U_t from unknown areas to each

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

PMFC areas i using the proportions $C_{ti} \Big/ \sum_{i \in \mathrm{PMFC}} C_{ti}$ of known catch C_{ti} in PMFC area i. But decisions made include all identified removals whenever possible. There may exist data sources not incorporated here, but this procedure includes currently available sources of potential removals.

Annual catches of most rockfish species, including YMR, are known with 'certainty' from 1996 on, as opposed to POP catches which 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). We expect that given YMR's close association with POP, catches of YMR were also high during this period. 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 tradable 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 Yellowmouth Rockfish in all PMFC major areas along the BC coast. Values marked ‘0’ indicate catches less than 0.05 t; those marked ‘–’ indicate no catch.

	Trawl					H&L+ Trap					All Fisheries				
Year	**3C**	**3D+5A**	**5CD**	**5E**	**Total**	**3C**	**3D+5A**	**5CD**	**5E**	**Total**	**3C**	**3D+5A**	**5CD**	**5E**	**Total**
1940	0.4	7.5	0	---	7.9	0	0.1	0	0	0.1	0.4	7.6	0	0	8.0
1941	0.3	3.7	0.2	---	4.2	0	0.3	0	0	0.3	0.3	4.0	0.2	0	4.5
1942	2.8	54	0.2	---	57	0	0.6	0	0	0.6	2.8	55	0.3	0	58
1943	8.6	175	0.7	---	184	0	1.5	0	0	1.5	8.7	176	0.7	0	186
1944	4.7	75	0.6	---	80	0	1.9	0	0.1	2.0	4.7	77	0.7	0.1	82
1945	34	755	2.2	---	791	0	1.9	0.1	0.1	2.1	34	757	2.3	0.1	793
1946	17	385	1.9	---	404	0	2.1	0.1	0.1	2.3	17	387	1.9	0.1	406
1947	8.9	199	0.6	---	208	0	0.5	0	0	0.5	8.9	199	0.6	0	209
1948	14	322	0.9	---	338	0	0.8	0	0	0.8	14	323	0.9	0	339
1949	18	392	1.1	---	411	0	1.0	0	0	1.1	18	393	1.2	0	412
1950	17	413	1.3	---	432	0	0.4	0	0	0.5	17	414	1.3	0	432
1951	17	378	1.1	---	396	0	1.7	0.1	0.1	1.9	17	380	1.2	0.1	398
1952	19	347	0.8	---	367	0	1.5	0	0.1	1.6	19	349	0.9	0.1	369
1953	12	246	0.3	---	258	0	0.7	0	0	0.8	12	247	0.3	0	259
1954	20	447	0.5	---	467	0	0.7	0	0	0.7	20	448	0.5	0	468
1955	14	277	0.4	---	291	0	0.5	0	0	0.5	14	277	0.4	0	292
1956	17	379	3.8	---	400	0	0.5	0	0	0.6	17	380	3.8	0	401
1957	16	276	0.8	---	293	0	0.8	0	0	0.9	16	277	0.8	0	293
1958	7.6	257	1.1	---	266	0	0.7	0	0	0.7	7.6	258	1.1	0	267
1959	29	541	0.6	---	570	0	0.7	0	0	0.8	29	541	0.6	0	571
1960	32	351	1.7	---	384	0	1.0	0	0	1.1	32	352	1.7	0	385
1961	33	348	0.6	---	381	0	1.3	0	0	1.3	33	349	0.6	0	382
1962	62	550	0.9	---	613	0	1.5	0	0	1.6	62	551	0.9	0	615
1963	55	793	1.8	---	849	0	1.6	0	0	1.7	55	795	1.8	0	851
1964	32	760	1.3	---	793	0	0.8	0	0	0.8	32	761	1.3	0	794
1965	58	2,265	19	505	2,848	0	0.5	0	0	0.6	58	2,266	19	505	2,849
1966	150	5,890	24	779	6,842	0	0.8	0	0	0.8	150	5,890	24	779	6,843
1967	34	4,139	5.5	120	4,299	0	0.9	0	0	0.9	34	4,140	5.6	120	4,300
1968	39	3,109	5.1	146	3,299	0	0.7	0	0	0.7	39	3,110	5.1	146	3,300
1969	18	2,933	1.2	1.1	2,953	0	1.2	0	0	1.3	18	2,934	1.3	1.1	2,954
1970	41	2,091	1.4	1.7	2,135	0.1	1.6	0.1	0	1.7	41	2,093	1.5	1.7	2,137
1971	34	1,253	1.5	8.4	1,297	0	0.9	0.1	0	1.1	34	1,254	1.6	8.4	1,298
1972	18	2,007	2.6	---	2,027	0.1	1.9	0.1	0	2.1	18	2,009	2.6	0	2,029
1973	9.3	2,410	2.7	---	2,422	0.0	1.0	0.1	0	1.1	9.3	2,411	2.7	0	2,423
1974	7.1	3,745	2.8	---	3,755	0.1	1.0	0.2	0	1.2	7.3	3,746	2.9	0	3,756
1975	10	1,953	8.6	---	1,971	0.1	1.2	0.2	0	1.5	10	1,954	8.8	0	1,973

Table B2 cont'd. Catch reconstruction (landings + discards, tonnes) for Yellowmouth Rockfish in all PMFC major areas along the BC coast. Values marked '0' indicate catches less than 0.05 t; those marked '–' indicate no catch.

	Trawl					H&L+ Trap					All Fisheries				
Year	3C	3D5AB	5CD	5E	Total	3C	3D5AB	5CD	5E	Total	3C	3D5AB	5CD	5E	Total
1976	3.6	1,011	7.2	8.0	1,030	0.1	1.4	0.1	0	1.5	3.7	1,012	7.3	8.0	1,031
1977	9.4	581	14	1,260	1,864	0.1	2.4	0.1	0	2.6	10	583	14	1,260	1,867
1978	3.2	624	19	1,102	1,748	0.1	1.7	0.2	0.1	2.0	3.2	625	19	1,102	1,750
1979	8.4	581	43	406	1,039	0.2	2.9	0.2	0.1	3.4	8.6	584	43	407	1,042
1980	7.9	516	130	501	1,155	0.1	2.4	0.1	0.1	2.8	8.1	518	130	501	1,158
1981	9.0	501	123	927	1,561	0.1	1.8	0.1	0.1	2.1	9.2	503	124	927	1,563
1982	13	742	225	483	1,464	0.1	8.6	0.1	0.1	8.8	13	751	225	484	1,473
1983	33	920	86	642	1,682	8.5	26	0.1	0	34	41	946	86	642	1,716
1984	22	932	109	515	1,578	0.4	5.4	0.1	0.3	6.2	22	938	109	516	1,584
1985	19	1,151	215	677	2,061	3.0	66	0.4	0.2	70	22	1,217	215	678	2,131
1986	28	1,706	565	1,182	3,482	0.5	16	0.6	0.4	18	28	1,723	566	1,183	3,500
1987	23	2,067	167	561	2,818	0.6	15	0.8	0.2	16	24	2,081	167	561	2,834
1988	38	1,733	318	452	2,540	1.4	18	0.6	0.4	20	39	1,751	318	452	2,561
1989	44	1,799	319	425	2,587	3.6	96	0.5	0.4	100	47	1,895	319	426	2,687
1990	40	1,734	315	478	2,567	10	142	2.4	11	165	50	1,876	317	489	2,732
1991	37	1,940	144	195	2,315	28	46	11	6.9	91	65	1,985	154	202	2,406
1992	59	2,054	251	242	2,606	8.8	34	1.1	6.4	50	68	2,088	252	248	2,657
1993	54	1,674	112	313	2,153	20	30	0.9	7.3	58	74	1,703	113	320	2,211
1994	103	1,746	229	263	2,343	10	127	0.5	2.2	139	113	1,873	230	266	2,482
1995	65	1,727	131	235	2,158	15	35	6.6	5.8	62	81	1,761	138	240	2,220
1996	117	1,204	28	122	1,471	0.1	13	1.1	2.6	16	117	1,216	29	125	1,488
1997	22	1,998	28	47	2,095	---	6.6	0.1	2.6	9.2	22	2,005	28	49	2,104
1998	43	1,595	72	145	1,855	0	7.9	0.3	4.7	13	43	1,603	72	150	1,868
1999	76	1,446	62	164	1,748	0.3	8.9	0.4	2.0	12	76	1,455	62	166	1,760
2000	29	1,505	79	427	2,040	0.1	11	0.3	4.4	16	29	1,516	80	431	2,056
2001	25	1,366	57	401	1,849	0.1	13	0.6	2.8	16	25	1,379	57	404	1,865
2002	58	1,571	20	370	2,018	0.2	26	1.0	8.2	35	58	1,596	21	378	2,053
2003	30	1,495	33	358	1,916	0	22	0.6	1.8	25	30	1,518	33	359	1,941
2004	51	1,571	28	255	1,905	---	18	0	2.9	21	51	1,589	28	258	1,926
2005	26	1,749	43	150	1,968	---	24	0	1.6	25	26	1,773	43	152	1,994
2006	30	1,540	15	201	1,785	0.1	14	0	0.1	14	30	1,554	15	201	1,800
2007	12	1,172	5.7	174	1,364	0	11	0	0	11	12	1,183	5.7	174	1,375
2008	18	1,072	8.4	121	1,219	0.0	11	0	0.4	11	19	1,083	8.4	121	1,231
2009	14	1,436	3.0	151	1,604	---	7.6	---	0.5	8.1	14	1,444	3.0	152	1,612
2010	2.9	1,085	2.2	97	1,187	0	8.5	0	0.1	8.6	2.9	1,093	2.2	97	1,196

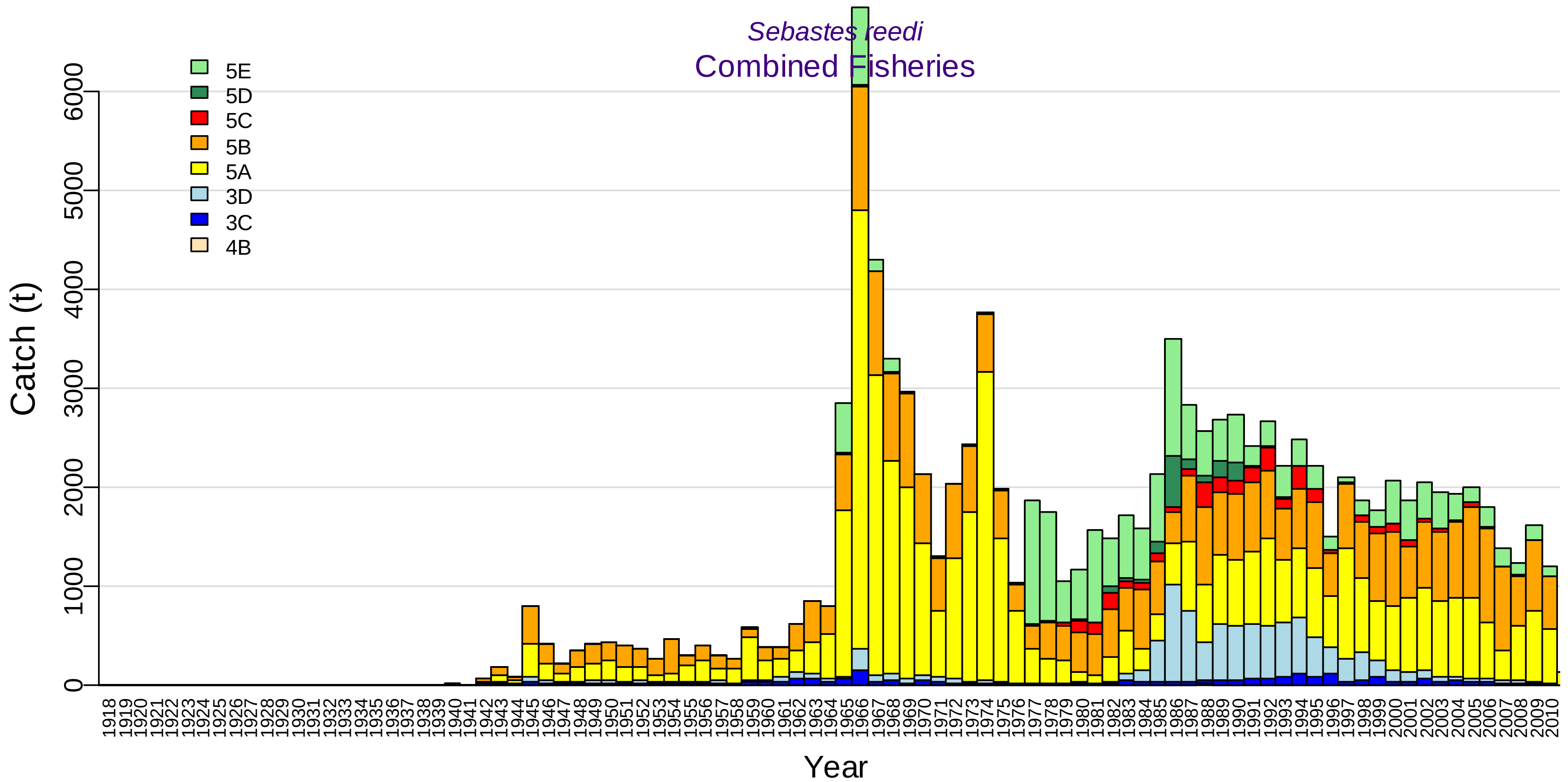


Figure B1. Reconstructed total (landed + discarded) catch (t) for Yellowmouth Rockfish from all fisheries combined in all PMFC major areas along the BC coast.

SCALING PMFC AREA YIELD TO GROUNDFISH MANAGEMENT AREA TOTAL ALLOWABLE CATCHES

The area definitions used by the DFO Groundfish Science Unit 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 slope rockfish (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 YMR stock assessment were based on PMFC major areas 3CD and 5ABCDE, that is, BC's offshore waters. The centre of this coastwide stock occurs in QCS, which comprises 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) as defined in the Pacific Fishery Management Area Regulations (PFMAR, 2007). The PMFC and GMU areas are similar but not identical (Figure 3).

As this assessment covers the YMR stock as a coastwide unit, there is no need to re-scale the yield option. Management can either divide the chosen yield by the existing TAC proportions or by some recent catch proportion (e.g., 5-y average). It is interesting to note that unlike POP, catches of YMR do not vary much between GMU and PMFC areas (Table B4), despite the sizable adjustment to the 5CD boundary.

Table B3. Potential proportions to allocate yield options. TACs (t) are specified per Groundfish Management Area in 2010, catches (t) averaged over 2006-2010 are reported by GMU areas only for records where a PMFC area can also be identified.

GMA	TAC	pTAC	Avg. Catch	pCatch
3C	219	9.3%	15	1.1%
3D+5AB	1,135	48.0%	1,230	88.0%
5CD	685	29.0%	7	0.5%
5E	325	13.7%	146	10.4%
Coast	2,365	100%	1,397	100.0%

Table B4. Ratio of catch in GMU areas to catch in PMFC areas (POP on left, YMR on right).

POP : GMA / PMFC								**YMR: GMA / PMFC**							
year	**3C**	**3D**	**5A**	**5B**	**5C**	**5D**	**5E**	**year**	**3C**	**3D**	**5A**	**5B**	**5C**	**5D**	**5E**
1996	1.02	0.99	1.01	0.27	6.52	0.90	0.93	1996	1.03	0.99	1.00	1.00	1.01	1	1.00
1997	1.00	0.99	1.02	0.49	5.54	0.86	0.89	1997	1.02	1.00	1.00	1.00	1	0.96	1.01
1998	1.00	1.00	1.00	0.35	5.21	1	0.98	1998	1.02	1.00	1.00	1.00	1	1	1.01
1999	0.99	1.01	1.02	0.37	4.35	1	1	1999	1.01	1.00	1.00	1.00	1.01	1	1
2000	1.00	1.00	1.01	0.41	7.12	1	0.53	2000	1.20	0.95	1.00	0.99	1.02	1	1.01
2001	1.01	0.99	1.01	0.47	7.21	1	0.71	2001	1	1	1.00	1.00	1.02	1	1.00
2002	1.00	1.00	1.02	0.41	7.84	1	0.64	2002	1.07	0.95	1.00	1.00	1.09	1	1.00
2003	1.02	0.97	1.00	0.37	10.77	1	0.70	2003	1.05	0.97	1.00	1.00	1	1	1.00
2004	0.99	0.99	1	0.36	20.00	1	0.84	2004	1.00	0.99	1	1.00	1	1	1.00
2005	1.02	0.98	1	0.65	8.83	1.01	0.93	2005	1.19	0.85	1.00	1.00	1.03	1.06	0.99
2006	0.99	1.01	1	0.65	14.47	1	0.84	2006	1.01	0.99	1	1.00	1.04	1	1.01
2007	1.04	0.96	1.00	0.46	31.41	1.00	0.84	2007	1.00	1.00	0.98	1.01	1.01	1	1.00
2008	1.02	0.97	1.00	0.56	36.93	1.00	0.96	2008	1.00	1.00	1.00	1.00	1	1	1.00
2009	1.01	0.98	1.01	0.48	30.45	1	0.93	2009	1.03	0.98	1.00	1.00	1	1	1.00
2010	1.00	1.00	1.01	0.49	80.94	1	0.85	2010	1.00	1.00	1	1.00	1	1	1.00

CATCH PER UNIT EFFORT (CPUE) DATA

Catch-per-unit-effort (CPUE) data from the commercial fishery are used in models as a dataset of last resort. Typically commercial effort is driven by behaviour that reacts to fisheries regulations and quota restrictions. Additional confounding factors include restrictions on other species that co-occur with the target, species misidentification, and economic drivers such as fuel costs and market prices for fish. We tried various CPUE indices in our initial analyses; however, the trend in CPUE during the 1980s conflicted with that for the Goose Island Gully survey, which correctly portrayed the effects of the biggest recruitment event during the time period of the model (Figure B2). This conflict caused the re-weighting scheme to yield oscillating scenarios. For this reason we chose not to include the CPUE trend in the main model runs for this assessment, but do so as a sensitivity test in Appendix I.

Catch and effort data prior to 1991 were not reported on a tow-by-tow basis, but rolled up by area, gear, and depth (Rutherford 1999). Therefore, any single series that includes years earlier than 1991 must also roll up data to be somewhat comparable, even if the latter-year data contain tow-by-tow details. For YMR, catch records specifying the species code '440' exist as early as 1973; however, the scarcity of these records precludes using any data prior to 1977. Initially we tried using three separate series – 1977-1991: rolled-up records, 1992-1995: tow-by-tow records before observer coverage, and 1996-2010: tow-by-tow records with observer coverage and individual vessel quotas (1997 on). The model results were neither stable nor credible. Additionally, the series from 1996-2010 yielded a flat trend that offered no useful contrast.

After trying various combinations of years, we settled on using rolled-up data from 1977 to 1995 (Figure B3), but the trend was negative following a very good recruitment in the year 1982. For the CPUE analysis, catch and effort were summed by year, month, area, gear, and depth. A general linear model was applied using the methods outlined in Haigh and Starr (2008) using the explanatory factors 'year', 'month', 'depth', 'gear', and 'fishing locality' (Figure B4). Table B5 provides an interesting summary that reports fishing grounds with higher than average CPUE density for this species (i.e., hotspots).

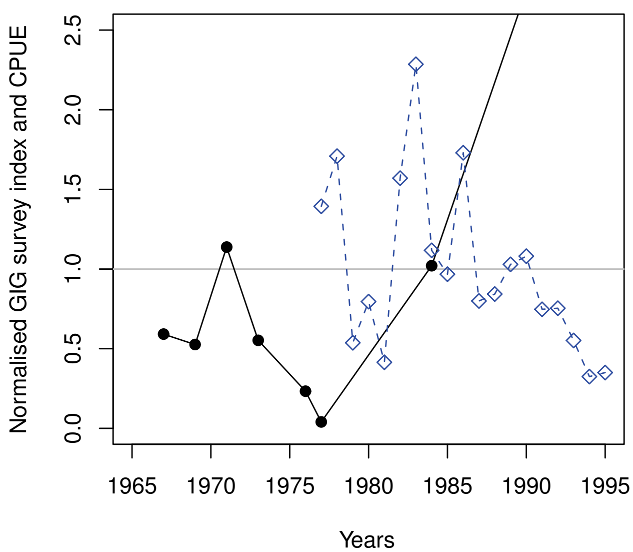


Figure B2. Time series of the GIG historical survey index (black solid circles connected by solid line) and the commercial CPUE from 'rolled-up' commercial data (blue open circles connected by dashed line), each normalised to their means. The CPUE series gives a conflicting signal to the survey index.

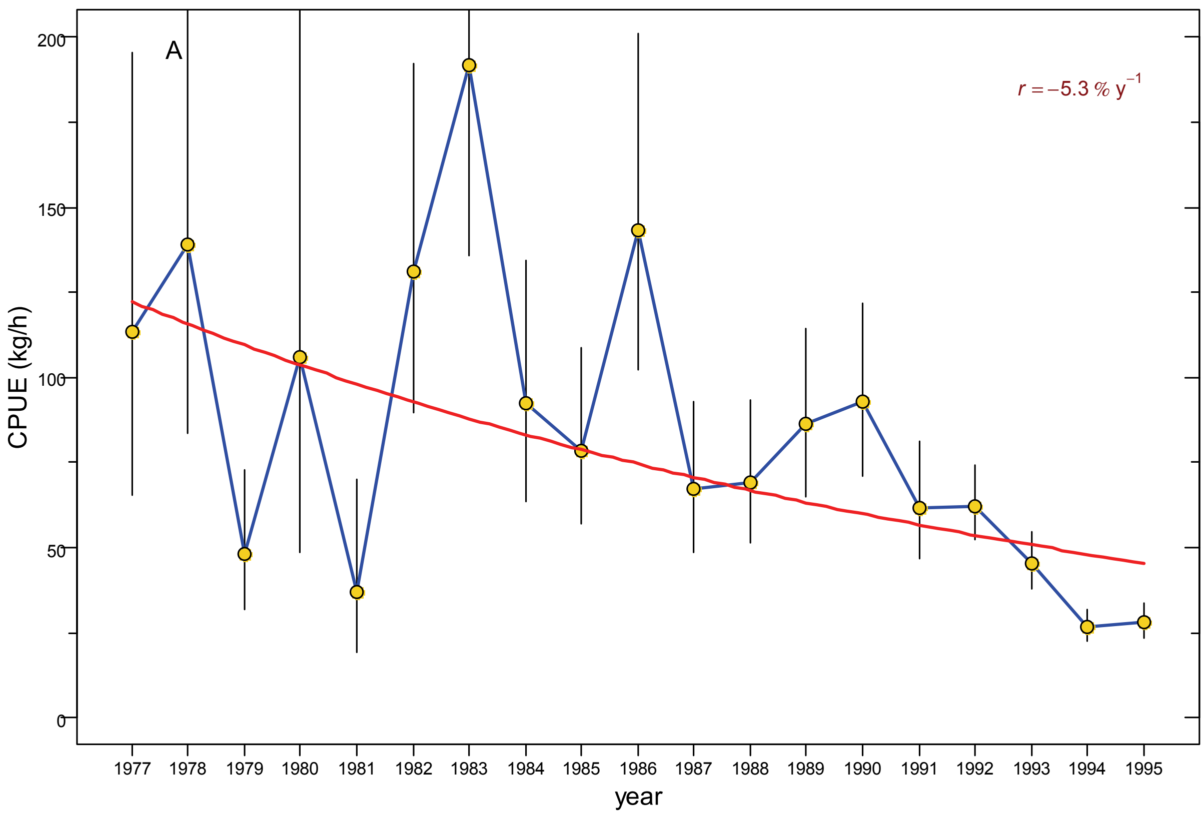


Figure B3. Annual CPUE indices for Yellowmouth Rockfish from 'rolled-up' commercial data (1977-1995). Error bars show 95% confidence intervals. Trend line through the index points is simply a linear fit in $\log_2$ space.

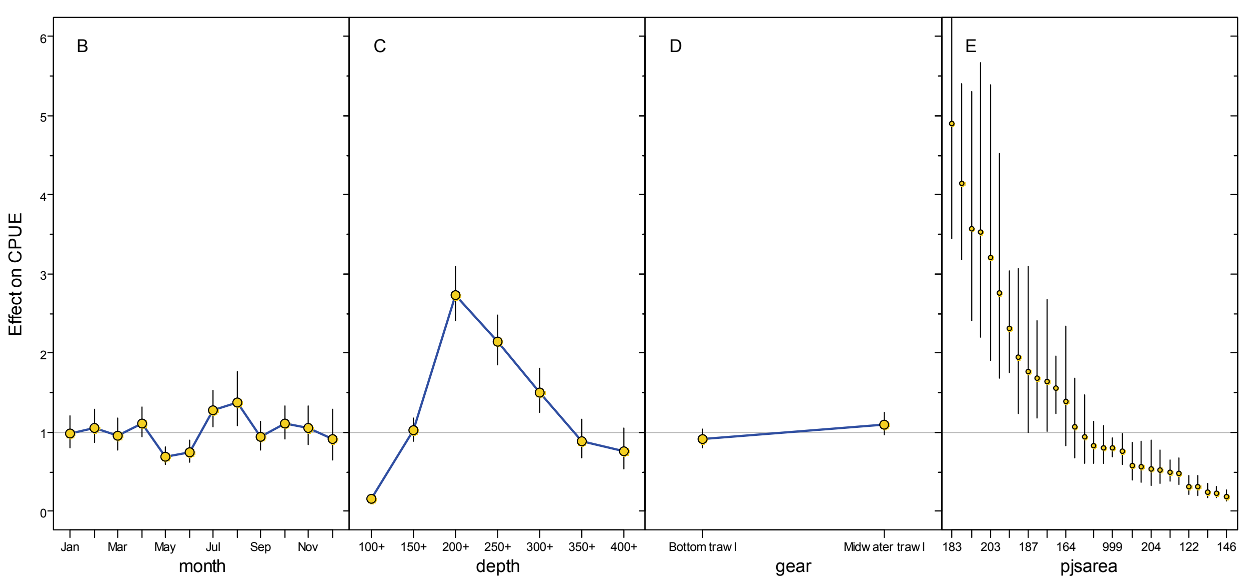


Figure B4. Effects included in CPUE analysis to derive the annual CPUE indices for Yellowmouth Rockfish in Figure B3. Depth bins are 50 m; 'pjsareas' comprise DFO localities (Table B5). Error bars show 95% confidence intervals.

Table B5. Fishing localities and their influence on commercial Yellowmouth Rockfish CPUE. Ratios above 1 have greater than average CPUE, those below have less than average CPUE.

Code & Fishing Locality	WT	Code & Fishing Locality	WT
183 SOUTH SCOTT ISLANDS	4.90	195 SW GOOSE	0.83
271 RENNELL SOUND	4.15	179 CAPE SCOTT SPIT	0.81
188 PISCES CANYON	3.57	999 LESSER CATCH AREAS COMBINED	0.80
284 SOUTH HOGBACK	3.53	197 SE CAPE ST. JAMES	0.76
203 OUTSIDE CAPE ST. JAMES	3.21	294 N FRED-LANGARA (DEEP)	0.58
177 UNKNOWN	2.76	192 NE GOOSE	0.57
178 TRIANGLE	2.31	204 WEST VIRGIN ROCKS	0.54
287 ANTHONY ISLAND	1.95	272 FREDERICK ISLAND	0.52
187 SOUTH TRIANGLE	1.76	193 SE GOOSE	0.50
181 TOPKNOT	1.69	139 CLAYOQUOT CANYON	0.48
201 OUTSIDE GOOSE & MITCHELL'S	1.65	122 DEEP BIG BANK / BARKLEY CANYON	0.31
166 QUATSINO SOUND	1.56	145 NORTH ESTEVAN	0.31
164 KAINS ISLAND	1.39	138 FATHER CHARLES CANYON	0.25
273 BUCK POINT	1.07	212 SOUTH MORSEBY	0.23
196 MITCHELL'S GULLY	0.94	146 NOOTKA	0.19

APPENDIX C. TRAWL SURVEYS

INTRODUCTION

There exist ten surveys which have potential for providing information about Yellowmouth Rockfish (YMR) relative abundance which have operated in British Columbia waters since 1967 (Table C1). Four of these surveys (West Coast Vancouver Island Shrimp, Hecate Strait Pacific cod monitoring, Hecate Strait assemblage and Hecate Strait synoptic) have caught so few YMR that their utility as a biomass index series for this species cannot be considered, mainly due to the large number of years with zero catches. The US National Marine Fisheries Service triennial survey has some observations in every year, but, in several of the years, the number of observations is very small. For instance, four of seven survey years for the Triennial survey have fewer than five observations. This number of observations will be insufficient to populate the design stratification, leading to unreliable indices with large relative errors. Furthermore, the US NMFS Triennial survey did not monitor an area of representative abundance for this species (Figure 2 shows a much lower catch per unit effort below 50°N, which was the northernmost extent of the survey and which was not reached in every survey year). Also, the decline observed by the Triennial Survey was not consistent with the increased abundance that was estimated by the assessment model from the strong recruitment evident in the age composition data. This signal of increased abundance was very strong and persisted even when the Triennial Survey was included in the assessment as a sensitivity run (see Appendix I).

For these reasons, only five surveys will be reported:

1. historical Goose Island Gully (GIG) surveys within Queen Charlotte Sound (QCS);
2. QCS groundfish synoptic survey;
3. QCS shrimp survey;
4. west coast Haida Gwaii (WCHG) synoptic survey;
5. west coast Vancouver Island (WCVI) synoptic 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 $\{C_{yij}, E_{yij}\}$ for tows $j = 1, \ldots, n_{yi}$,

(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:

(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

$$\text{(C3)} \quad \delta_{yi} = \frac{1}{n_{yi}} \sum_{j=1}^{n_{yi}} \frac{C_{yij}}{D_{yij} w_{yij}} ,$$

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 (B_y) is then the sum of the product of CPUE densities and bottom areas across m strata:

$$\text{(C4)} \quad B_y = \sum_{i=1}^{m} \delta_{yi} A_i = \sum_{i=1}^{m} B_{yi} ,$$

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:

$$\text{(C5)} \quad V_y = \sum_{i=1}^{m} \frac{\sigma_{yi}^2 A_i^2}{n_{yi}} = \sum_{i=1}^{m} V_{yi} ,$$

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

The coefficient of variation (CV_y) of the annual biomass estimates (B_y) is

$$\text{(C6)} \quad CV_y = \frac{\sqrt{V_y}}{B_y} .$$

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 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 C2).

The 1967 ([left panel] Figure C2) and 1969 ([right panel] Figure C2) surveys performed tows on the west coast of Vancouver Island, the west coast of Haida Gwaii and SE Alaska, but both of these surveys had a reasonable number of tows in the GIG grounds (Table C2). 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 C2), 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 C3). 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: RV *GB Reed* and FV *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 – Greg 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 (FV *Ocean Selector*, Table C3) ([left panel] Figure C6), was used in the series without modification except for the removal of 19 tows which were done as part of an acoustic experiment and therefore were not considered appropriate for biomass estimation (they were tows used to estimate species composition for ensonified schools). The remaining tows from the 1994 survey could be used without modification because this survey used a design that emulated as closely as possible the previous *GB Reed* surveys (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: FV *Ocean Selector* and FV *Frosti* (Table C3), 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 YMR population (Table C2).

The original depth stratification of these surveys was in 20 fathom (36.1 m) intervals, with the important strata for YMR ranging from 100 fathoms (183 m) to 180 fathoms (329 m). This depth range accounted for about 95% of the tows which captured YMR (Table C4). For the GIG survey series, the shallowest tow capturing YMR was 121 m. Similarly, the deepest tow capturing YMR 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 333 tows from the eight accepted survey years (Table C5).

A doorspread density (C4) was calculated for each tow based on the catch of YMR, 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 YMR were caught in the GIG indicate that this species is mainly found along the 200 m depth contour in all years (Figure C7). The densities for this species were relatively low in all years with the exception of some very large tows during the 1994 survey. Estimated biomass levels in the GIG for Yellowmouth Rockfish from the historical GIG trawl surveys were low for all of the historical surveys, with the exception of the 1994 survey, consistent with the density observations (Figure C8; Table C6). The proportion of tows which caught YMR is variable, ranging from a low of 17% in 1977 to a high of 66% in 1994 (Figure C9). Overall, 123 from a total 333 tows contained YMR. Survey relative errors are very high for this species in this survey, ranging from 0.50 to 0.82 (Table C6). These high relative errors mean that the expected value of this survey for monitoring this species will be low.

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 using the same vessel (FV *Viking Storm*). 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 C1; Figure C10). However, the original design bisected the centre of Mitchell's Gully, an area of high YMR concentration. Therefore, a more appropriate stratification has been adopted for YMR 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 C1).

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 (for the Pacific Ocean Perch assessment, Edwards et al. 2012) 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 Pacific Ocean Perch (POP) while the QCS synoptic survey targets a broad range of species, including YMR and POP. The meeting concluded that this difference in survey target species would affect the way that the survey skippers fished, leading to YMR catch rates that would not be comparable between the 1995 survey and the surveys that have been undertaken since 2003.

A doorspread density value (C4) was generated for each tow based on the catch of YMR, 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

Yellowmouth Rockfish were mainly taken at depths from 120 to 300 m (5 to 95% quantiles), but there were sporadic observations at depths down to about 380 m (Figure C11). Catch densities of YMR from this survey were generally higher in the combined Mitchell/Moresby stratum than in the GIG stratum (Figure C12).

Estimated YMR doorspread biomass from this trawl survey show no real trend, with the highest biomass estimate observed in 2004 and the second highest in 2009 (Figure C13; Table C8). The estimated relative errors are high (but not as high as for the GIG historical surveys), lying between 31 and 48% (Table C8). The proportion of tows that captured YMR was moderate, ranging from 12 to 31%, with the north stratum showing an upturn in the two most recent surveys while the south stratum has been very consistent in its proportion (Figure C14). Overall, 264 of the 1177 valid survey tows contained YMR.

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 C9). 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 RV *W.E. Ricker* (except in 2005 when FV *Frosti* was used) in April, May or June. 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 YMR 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 C10). 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 C10).

These data were analysed using (C1) to (C6), which assume that tow locations were selected randomly within a stratum relative to the biomass of YMR, 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 (C4) was generated for each tow based on the catch of YMR, 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 (James 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 YMR tend to be distributed along the 200 m contour of the Goose Island Gully (Figure C17). One very large tow observed in 2002 obscures the remaining much smaller tows and adds greatly to the high relative errors for this species in this survey. Yellowmouth Rockfish were only taken from 160-240 m and have been taken entirely in stratum 109, with the maximum catch weight in stratum 109 being 91 kg/tow (Figure C18).

Estimated biomass levels for YMR from the QCS shrimp trawl survey are low but consistent across years, showing no strong trend with CVs ranging between 37% and 94% (Figure C19; Table C11). The proportion of tows with Yellowmouth Rockfish is variable and low in stratum 109, with values from 0.04 to 0.20 (Figure C20). There are no observations of YMR in stratum 110.

WEST COAST HAIDA GWAII SYNOPTIC TRAWL SURVEY

Data selection

This survey has been conducted four times over the period 2006 to 2010 off the west and north coasts of Haida Gwaii by three vessels (FV *Viking Storm* in 2006 and 2010, FV *Nemesis* in 2007 and FV *Frosti* in 2008), using a consistent design. It comprises a single areal stratum and four depth strata: 180–330 m; 330–500 m; 500–800 m; and 800–1300 m (Figure C21; Table C12). Note that the depth stratum boundaries for this survey differ from those used for the Queen Charlotte Sound and west coast Vancouver Island synoptic surveys due to the considerable difference in the seabed topography of the area being surveyed (Table C1 and Table C14). The deepest stratum (800–1300 m) has not been consistently monitored over the four survey years and consequently has been omitted from the analysis.

A doorspread density value (C4) was generated for each tow based on the catch of Yellowmouth Rockfish, the mean doorspread for the tow and the distance travelled. The distance travelled 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 (26 of the 459 valid tows) for the doorspread field were populated using the mean doorspread for the stratum in the survey year. Missing values in the vessel speed field were populated using the mean value for the entire survey in that year (11 values over all years). Missing values in the bottom contact time field used the winch time instead (time from winch lockup to winch retrieval; 35 values missing over the three survey years, including 17 in 2008).

Results

Yellowmouth Rockfish were mainly taken at depths from 205 to 300 m (5 to 95% quantiles), but there were sporadic observations at depths down to 360 m (Figure C22). Catch densities of Yellowmouth Rockfish from this survey were highest off the northwest corner of Graham Island, with some tows containing YMR on a long shallow ridge west of Rennell Sound observed in 2007 (Figure C23).

Estimated YMR doorspread biomass from this trawl survey show no obvious trend, with the highest biomass estimate observed in 2007, the second highest in 2008, and the lowest index in 2010 (Figure C24; Table C13). The estimated relative errors are high, lying between 37 and 56% (Table C13). The proportion of tows that captured YMR was moderate, ranging from 18 to 24% over the four survey years (Figure C25). Overall, 92 of the 442 valid survey tows contained YMR.

WEST COAST VANCOUVER ISLAND SYNOPTIC TRAWL SURVEY

<u>Data selection</u>

This survey has been conducted four times during the period 2004 to 2010 off Vancouver Island by RV *WE Ricker*. It consists of a single areal stratum and four depth strata: 50–125 m; 125–200 m; 200–330 m; and 330–500 m (Table C14; Figure C26). Note that the depth stratum boundaries differ from those used for the Queen Charlotte Sound synoptic survey (Table C1).

A doorspread density value (C4) was generated for each tow based on the catch of Yellowmouth Rockfish, the mean doorspread for the tow and the distance travelled. The distance travelled 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 were filled in either using the mean doorspread for the stratum in the survey year or a default value of 73 m (159 of the 421 valid tows had missing doorspread values replaced with mean value for the year/stratum cell; a further 90 tows were replaced with the default value as there were no observations in the year/stratum cell). Missing values in the vessel speed field were filled in using the mean value for the entire survey in that year (77 values over all years, including 67 in 2008). Missing values in the bottom contact time field substituted the winch time (time from winch lockup to winch retrieval; 70 values were missing over the three survey years, including 38 in 2004 and 30 in 2008).

Results

The largest catches of YMR in this survey tended to be in the more northwesterly sections of Vancouver Island (Figure C27). Yellowmouth Rockfish catches were very low in the 2004 survey and were mainly taken at depths from 160 to 280 m, but with sporadic observations at depths up to about 340 m (Figure C28). Estimated biomass levels for YMR from this trawl survey have been variable, with the largest estimate occurring in 2010 and with the 2004 estimate very poorly determined because only 2 of the 90 valid tows captured this species (Figure C29; Table C14 and Table C15). The estimated relative errors (CV) were very high for all four years of the survey (38–73%) (Table C15). The proportion of tows which took YMR was low, ranging between 2 and 9% for the four survey years (Figure C30). Overall, 31 of the 556 valid survey tows contained YMR.

Table C1. Number of tows with recorded catch of YMR in 10 candidate surveys operating in British Columbia waters from 1967 to 2010. An entry marked '0' means the survey was executed but no YMR were captured.

Year	Triennial (N of Columbia River)	WCVI Shrimp	WCVI Synoptic	GIG Historical	QCS Synoptic	QCS Shrimp	Hecate St Assem-blage	Hecate St Pacific Cod	Hecate St Synoptic	WCHG Synoptic
1967				8						
1969				13						
1971				19						
1973				13						
1975		0								
1976		0		11						
1977		0		8						
1978		0								
1979		0								
1980	2	0								
1981		0								
1982		0								
1983	7	0								
1984				18			0			
1985		0								
1987		0					0			
1988		1								
1989	6	0					2			
1990		0								
1991		0					0			
1992	5	0								
1993		0					0			
1994		0		47						
1995	3	1		60			0			
1996		0					0			
1997		0								
1998	2	0					0			
1999		0				6				
2000		0				3	0			
2001	1	0				8				
2002		0				9	0	0		
2003		0			46	8	0	0		
2004		0	2		53	7		0		
2005		0			55	2			0	
2006		0	9			7				29
2007		0			83	12			0	22
2008		0	8			10				26
2009		0			63	6			6	
2010		0	12			5				22
Total	26	2	31	197	300	83	2	0	6	99

Table C2. 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 C3. Total 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. Some of the tows in the GIG portion of the table have usability codes other than 0,1,2, or 6.

Survey	20 fathom depth interval (m)									Total
year	66-146	147-183	184-219	220-256	257-292	293-329	330-366	367-402	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	1	2	1	1	4		16
1969		1		1		1				3
1971										
1973			4	3	2	2	2			13
1976			4	4	4	4	4			20
1977			3	2	2	3	2			12
1979	11	2	1	5	1					20
1984			4	10	7	7	6			34
1994										
1995										
GIG										
1965		2	4	1	1					8
1966	3	2	3	5	2					15
1967	1	6	11	6	10					34
1969		9	11	6	6					32
1971		5	15	9	10					39
1973		7	11	7	8					33
1976		7	15	8	6					36
1977	1	12	14	14	9					50
1979	23	12	18	6						59
1984		13	25	17	13	1				69
1994		15	18	20	18					71
1995	2	23	47	22	15	6				115

Table C4. Catch weight (t) of Yellowmouth Rockfish 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	66-146	147-183	184-219	220-256	257-292	293-329	330-366	367-402	440-549	Weight
Areas other than GIG										
1965	0.00	0.07	3.94	0.02	0.00	0.00	0.00	0.00	0.00	4.03
1966	0.00	2.73	12.16	1.07	0.00	0.00	0.00	0.00	0.00	15.95
1967	0.00		0.01	0.00	0.00	0.00	0.00	0.00		0.01
1969		0.00		0.19		0.00				0.19
1971										
1973			0.01	0.00	0.00	0.00	0.00			0.01
1976			0.01	0.00	0.00	0.00	0.00			0.01
1977			0.00	0.00	0.00	0.00	0.00			0.00
1979	0.00	0.00	0.00	0.03	0.00					0.03
1984			0.23	0.03	0.00	0.00	0.00			0.26
1994										
1995										
GIG										
1965		0.00	0.00	0.00	0.00					0.00
1966	0.00	0.00	0.00	0.00	0.00					0.00
1967	0.00	0.04	0.53	0.00	0.01					0.58
1969		0.04	0.48	0.00	0.00					0.53
1971		0.00	1.73	0.02	0.02					1.77
1973		0.00	0.29	0.00	0.29					0.58
1976		0.00	0.24	0.01	0.08					0.34
1977	0.00	0.00	0.05	0.00	0.00					0.05
1979	0.00	0.00	0.12	7.01						7.13
1984		0.00	0.81	1.60	0.06	0.04				2.50
1994		5.45	1.20	0.32	0.25					7.22
1995	0.00	13.24	2.27	0.47	3.42	0.00				19.40

Table C5. 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	10	16	24	50
Total	70	114	149	333

Table C6. Biomass estimates for Yellowmouth Rockfish from the historical Goose Island Gully trawl surveys for the years 1967 to 1994. Biomass estimates are based on three depth strata (Table C5), 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 (C6)
1967	398	408	65	880	0.499	0.504
1969	354	356	46	863	0.564	0.553
1971	766	767	85	2,681	0.820	0.839
1973	372	361	89	840	0.507	0.507
1976	157	160	29	374	0.534	0.520
1977	27	27	5	70	0.621	0.625
1984	687	684	143	1,811	0.609	0.606
1994	2,624	2,614	430	6,697	0.587	0.574

Table C7. Stratum designations and number of useable tows for each year of the QCS synoptic survey using the re-stratified YMR 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 C8. Biomass estimates for YMR 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 (C6)
2003	1,639	1,623	707	2,849	0.332	0.341
2004	4,130	4,119	1,109	9,093	0.484	0.473
2005	1,512	1,493	657	2,893	0.381	0.380
2007	1,403	1,379	743	2,494	0.312	0.306
2009	2,801	2,896	1,165	5,114	0.357	0.370

Table C9. 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 C10. 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 C11. Biomass estimates for Yellowmouth Rockfish 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 (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	18	18	3	45	0.589	0.609
2000	27	26	0	98	0.937	0.938
2001	45	45	9	102	0.525	0.538
2002	97	98	9	329	0.821	0.836
2003	34	34	9	71	0.449	0.455
2004	36	36	7	88	0.567	0.584
2005	11	11	0	43	0.888	0.887
2006	56	56	6	127	0.541	0.539
2007	63	63	26	116	0.372	0.371
2008	52	51	10	133	0.632	0.649
2009	8	8	2	18	0.491	0.482
2010	16	16	2	50	0.760	0.759

Table C12. Stratum designations, number of usable and unusable tows for each year of the west coast Haida Gwaii synoptic survey. Also shown is the area of each stratum.

	Depth stratum				
	180-330m	330-500m	500-800m	Total	Unusable
Stratum no.:	1	2	3	Tows[1]	tows
2006	56	26	16	98	26
2007	68	34	9	111	5
2008	71	31	8	110	17
2010	82	29	12	123	8
Area (km^2)	1,326	1,090	927	3,343[2]	–

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

Table C13. Biomass estimates for Yellowmouth Rockfish from the WCHG synoptic trawl survey for the survey years 2006 to 2010. 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 (C6)
2006	145	147	52	287	0.418	0.423
2007	410	408	107	928	0.490	0.458
2008	276	270	69	716	0.563	0.544
2010	57	57	23	104	0.372	0.384

Table C14. Stratum designations and number of usable and unusable tows for each year of the West Coast Vancouver Island synoptic survey. Also shown is the area of each stratum.

	Depth zone					
Survey year	**50-125 m 1**	**125-200 m 2**	**200-330 m 3**	**330-500 m 4**	**Total Tows[1]**	**Unusable tows**
2004	35	34	13	8	90	16
2006	62	63	28	13	166	10
2008	54	51	34	24	163	15
2010	58	47	22	10	137	7
Area (km^2)	7,012	4,313	804	789	12,918[2]	–

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

Table C15. Biomass estimates for Yellowmouth Rockfish from the WCVI synoptic trawl survey for the survey years from 2004 to 2010. 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 (C6)
2004	33	33	0	90	0.726	0.739
2006	115	114	42	212	0.381	0.371
2008	39	40	5	109	0.662	0.690
2010	196	194	72	398	0.431	0.433

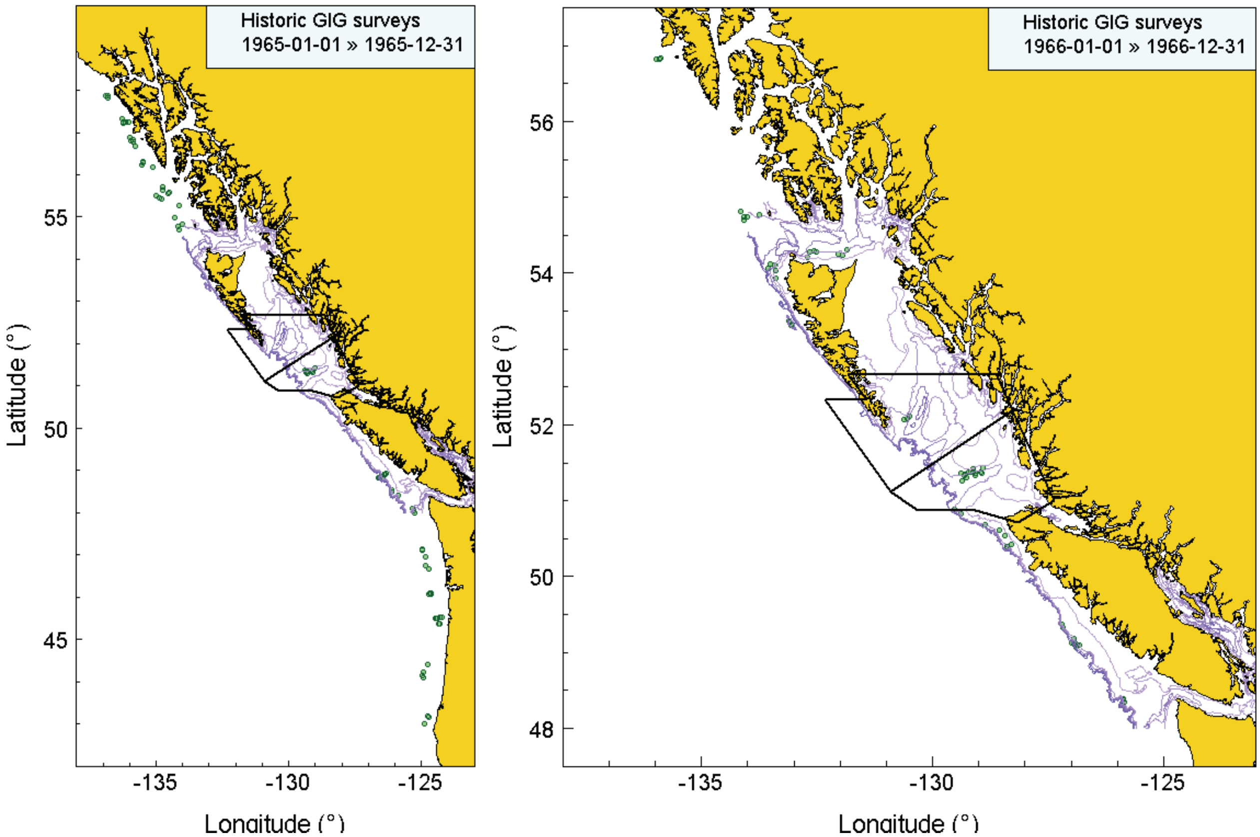


Figure C1. Extent of the first two GB Reed surveys: [left panel] tow locations for the 1965 survey; [right panel] tow locations for the 1966 survey. Black lines on all figures show the re-stratified YMR stratum definitions for the QCS synoptic survey (see Figure C10).

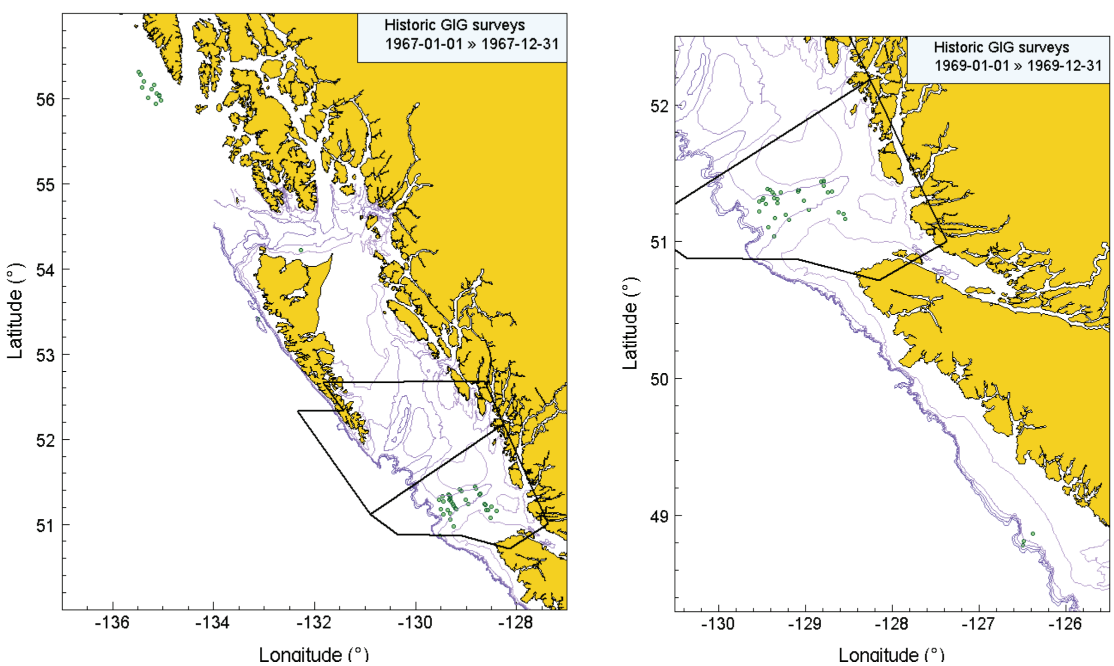


Figure C2. Extent of the next two historical GB Reed surveys. [left panel] location of tows from the 1967 survey; [right panel] location of tows from the 1969 survey.

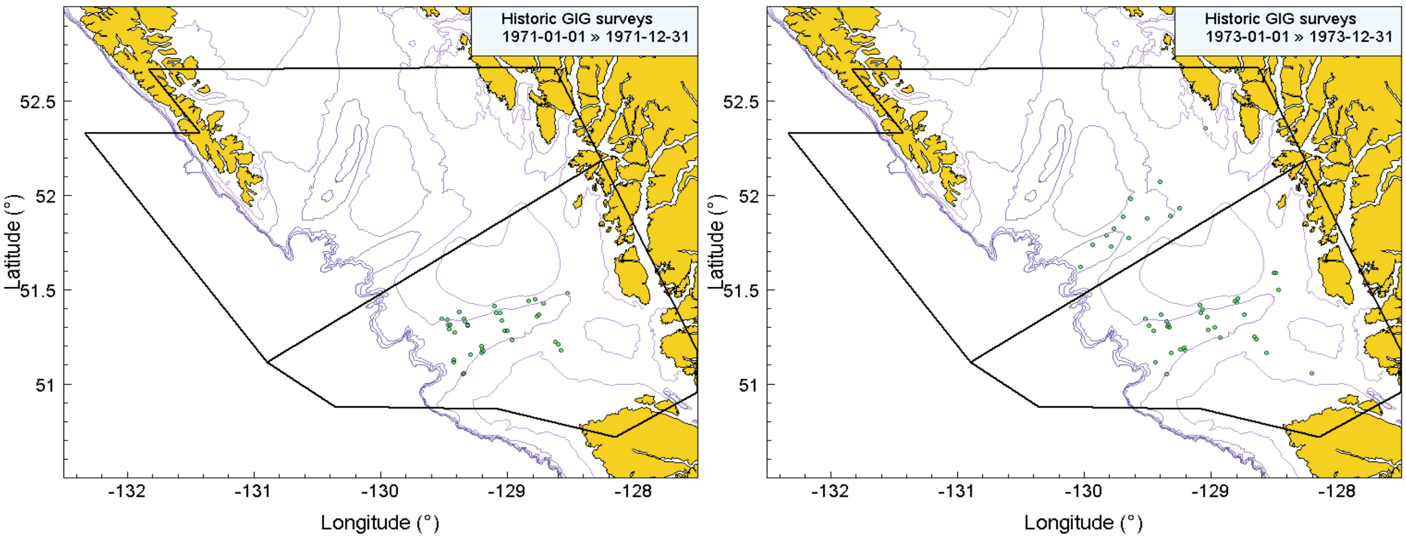


Figure C3. Extent of the following two historical GB Reed surveys. [left panel] location of tows from the 1971 survey; [right panel] location of tows from the 1973 survey.

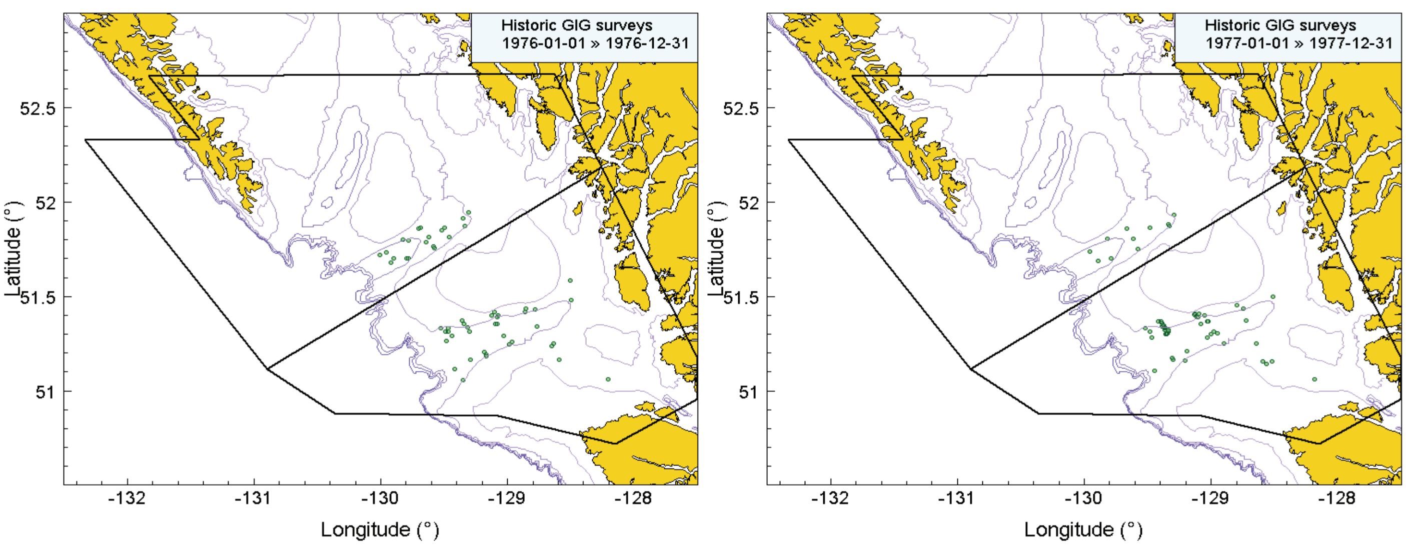


Figure C4. Extent of the following two historical GB Reed surveys. [left panel] location of tows from the 1976 survey; [right panel] location of tows from the 1977 survey.

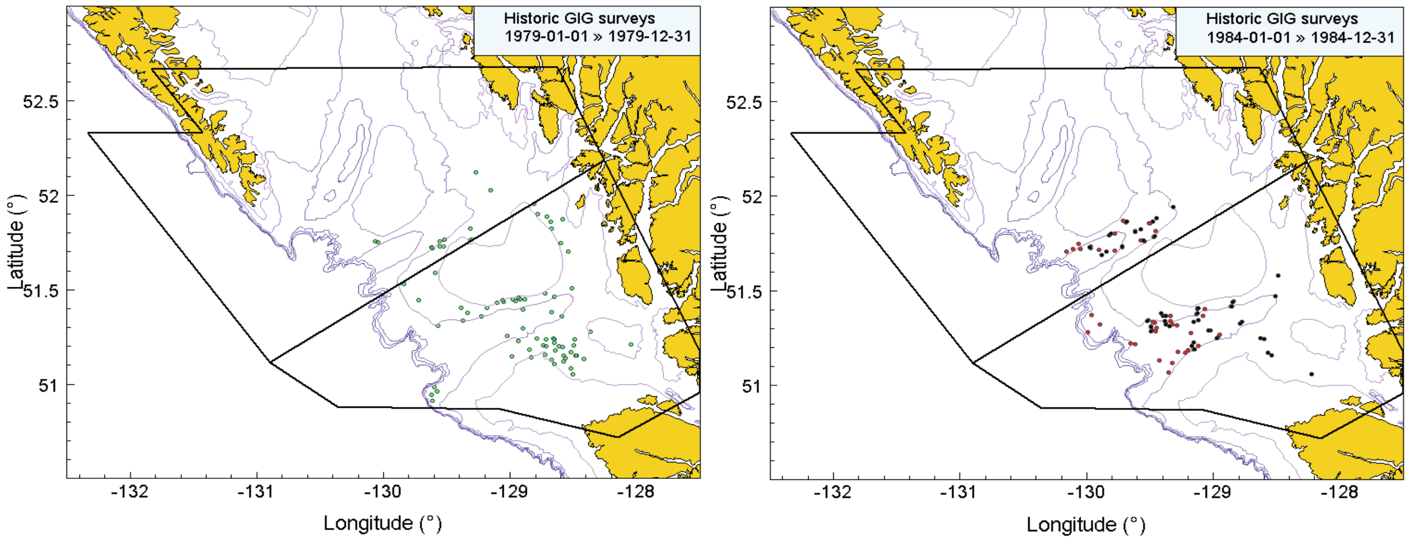


Figure C5. Extent of the following two historical GB Reed surveys. [left panel] location of tows from the 1979 survey; [right panel] location of tows from the 1984 survey (note: GB Reed tows are black and Eastward Ho tows are red).

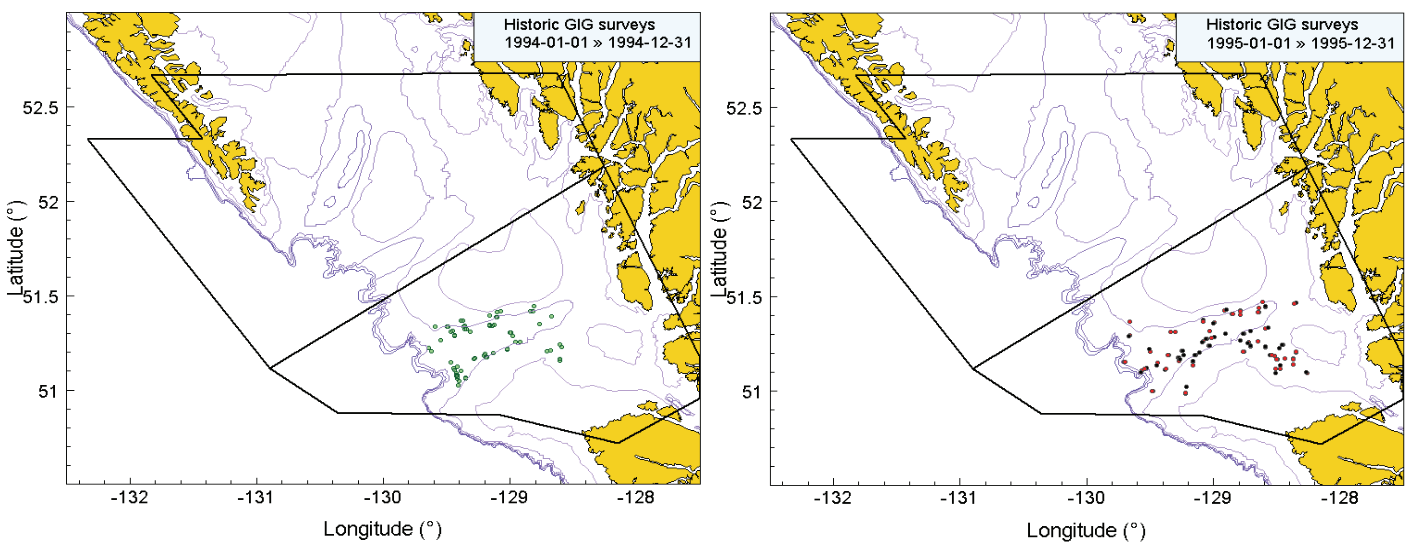


Figure C6. Extent of the final two historical GB Reed surveys. [left panel] location of tows from the 1994 survey; [right panel] location of tows from the 1995 survey (note: Ocean Selector tows are black and Frosti tows are red).

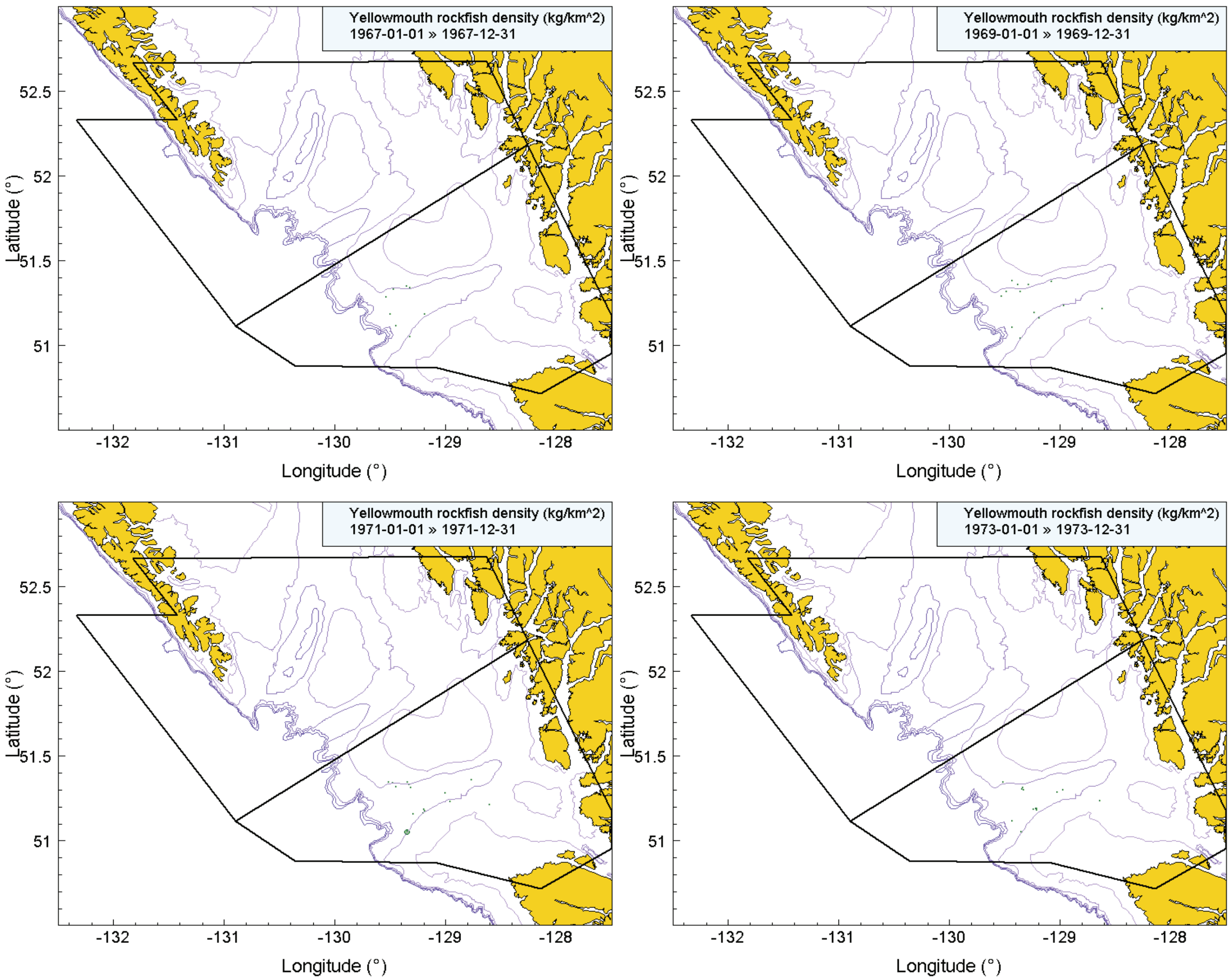


Figure C7. Map of the locations of all trawls which caught Yellowmouth Rockfish from the historical Goose Island Gully trawl surveys by survey year (1967–1994). Circles are proportional to YMR catch density (largest circle=30,731 kg/km^2 in 1976). Also shown are the 100, 200, 300 and 400 m isobaths.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

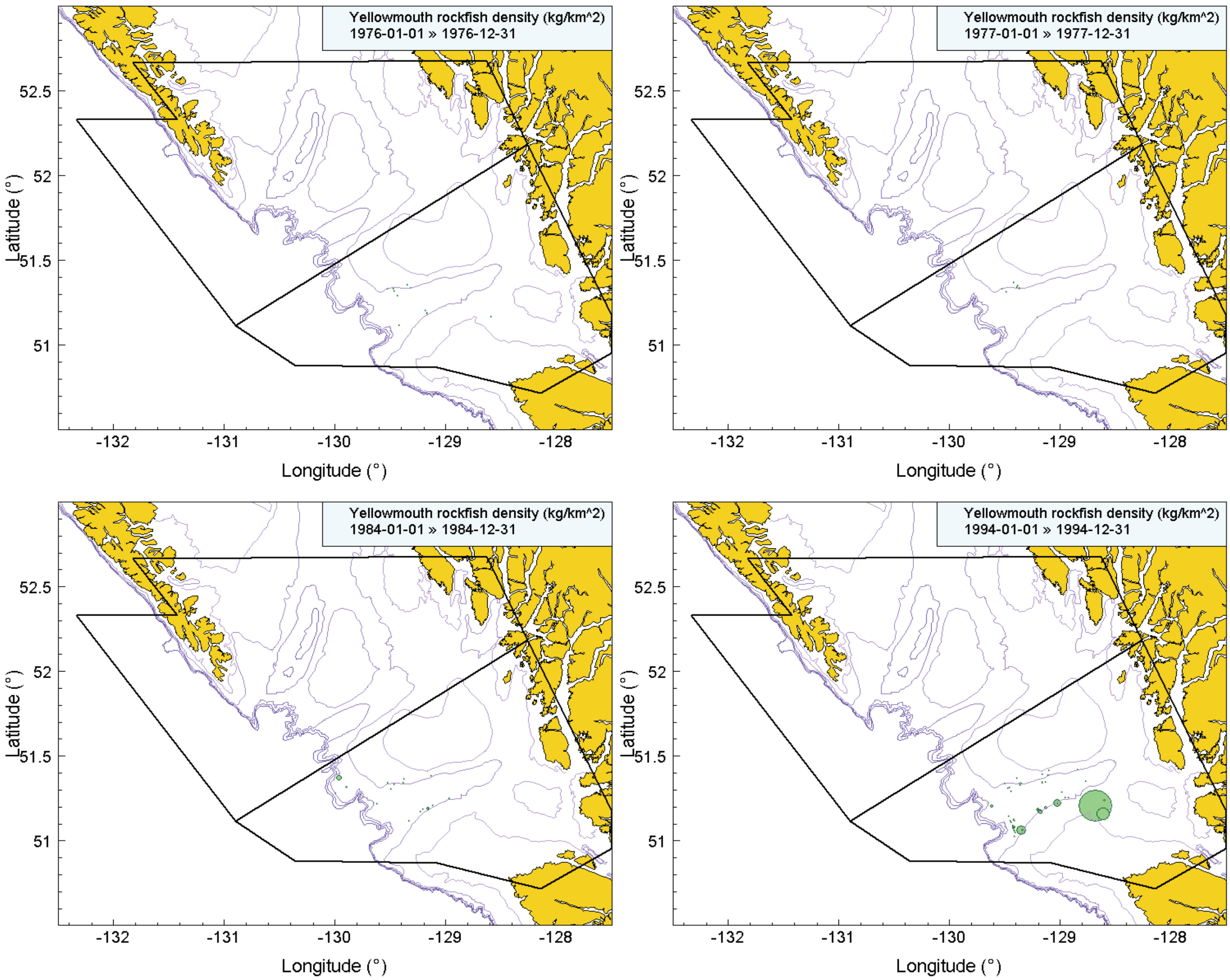


Figure C7. (cont.)

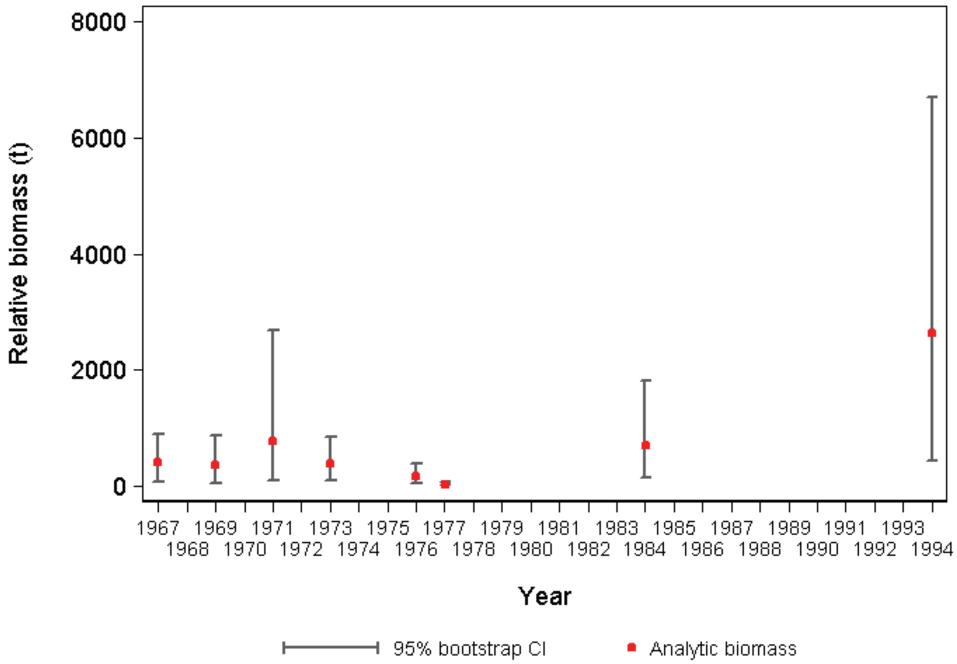


Figure C8. Plot of biomass estimates for Yellowmouth Rockfish from the historical Goose Island Gully GB Reed trawl surveys for the period 1967 to 1994. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

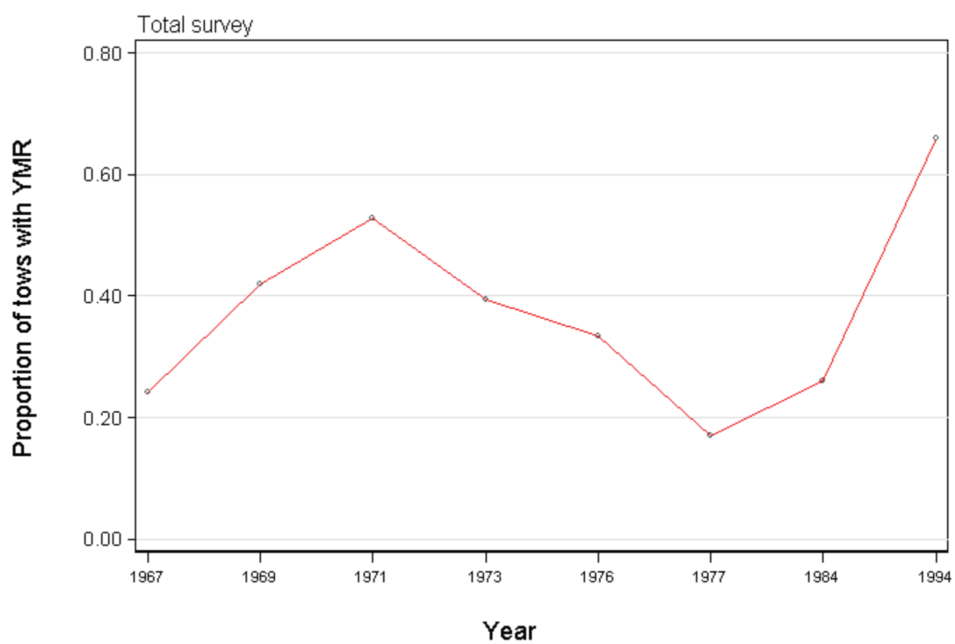


Figure C9. Proportion of tows by year which contain YMR from the usable Goose Island Gully surveys.

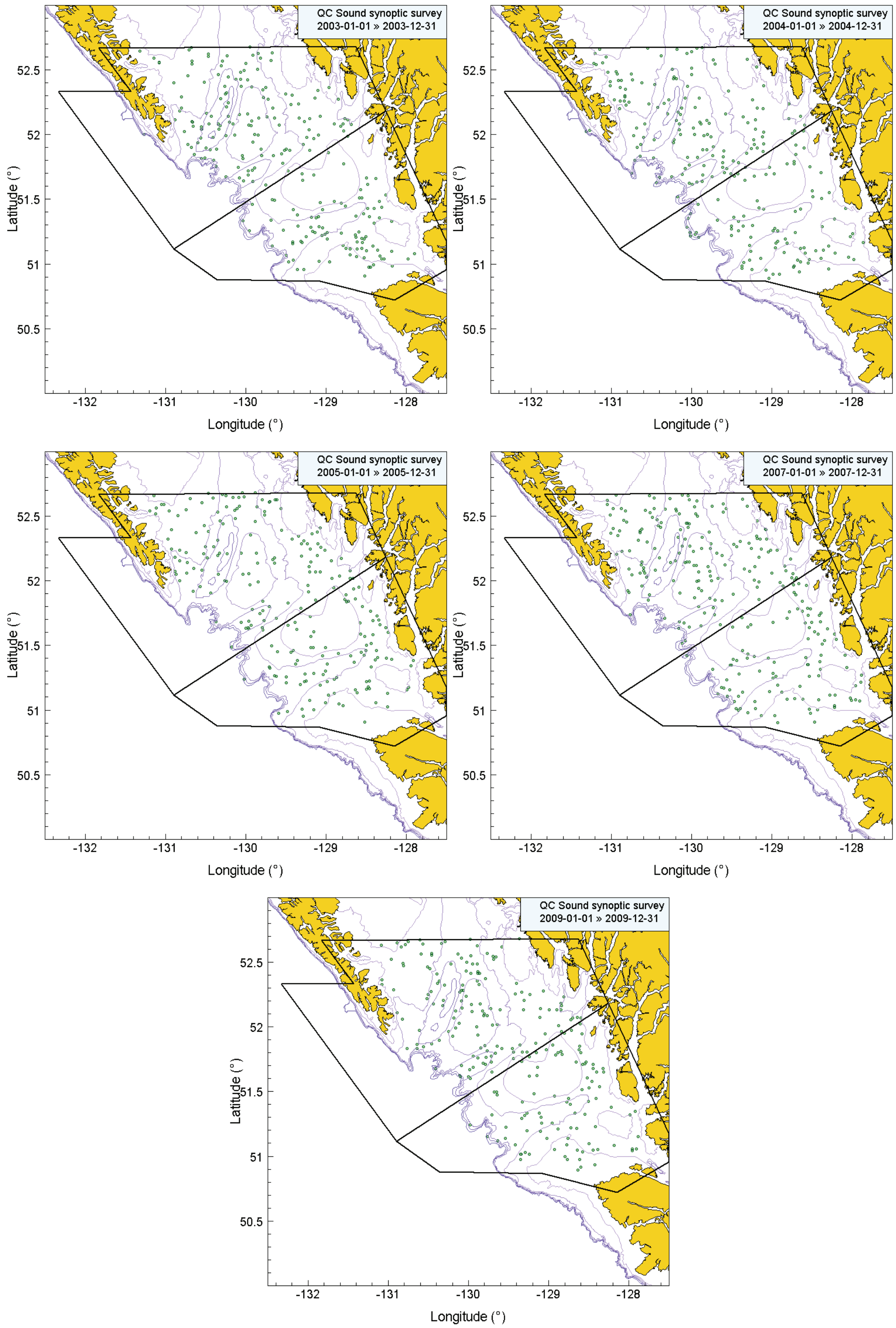


Figure C10. Map showing the locations of valid tows conducted by the QCS synoptic trawl survey over the period 2003 to 2009. The boundaries for the re-stratified YMR stratum definitions (southern: Goose Island Gully and northern: combined Mitchell and Moresby Gullies) are shown.

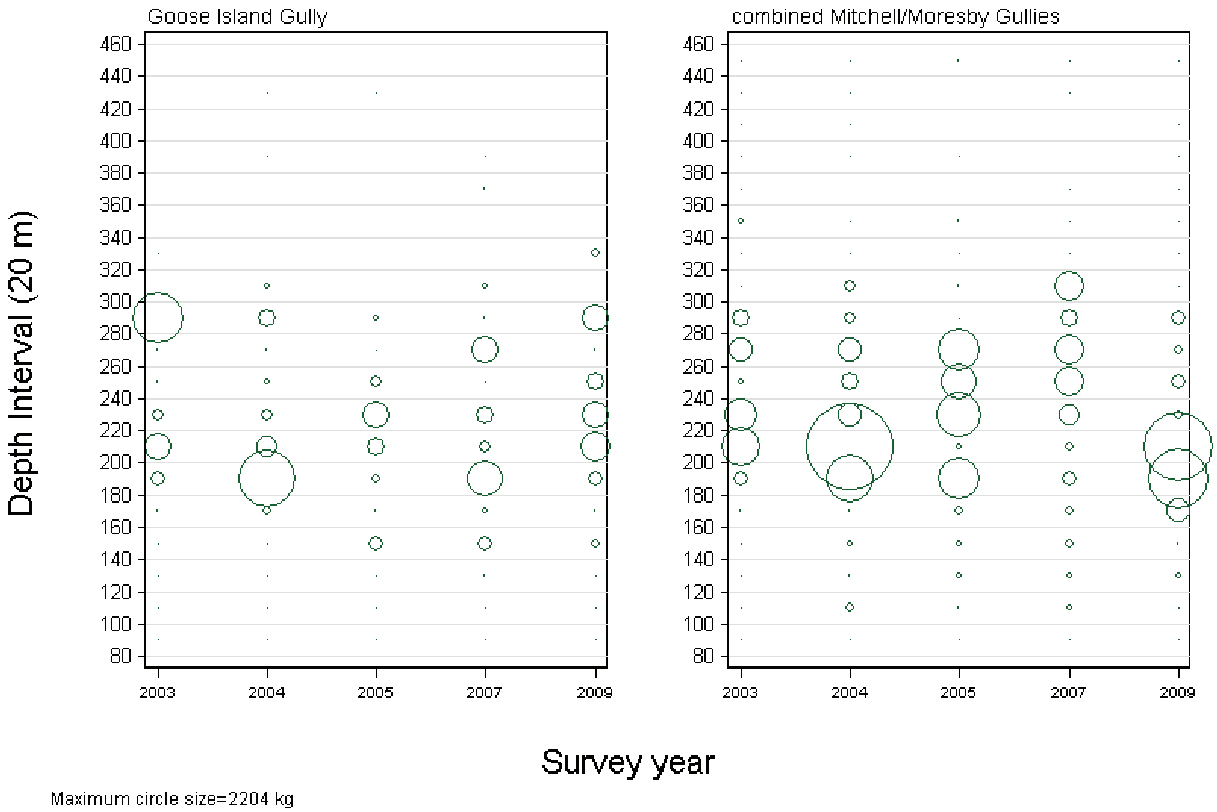


Figure C11. Distribution of observed catch weights of Yellowmouth Rockfish by the two larger aerial strata (Table C1), survey year and 20 m depth zone for the QCS synoptic survey. Depth zones are indicated by the mid point of the depth interval and circles in the panel are scaled to the maximum value in the Mitchell-Moresby stratum (2204 kg: 200–220 m interval in 2004). Minimum depth observed for YMR: 82 m; maximum depth observed for YMR: 445 m. Depth is taken at the start position for each tow.

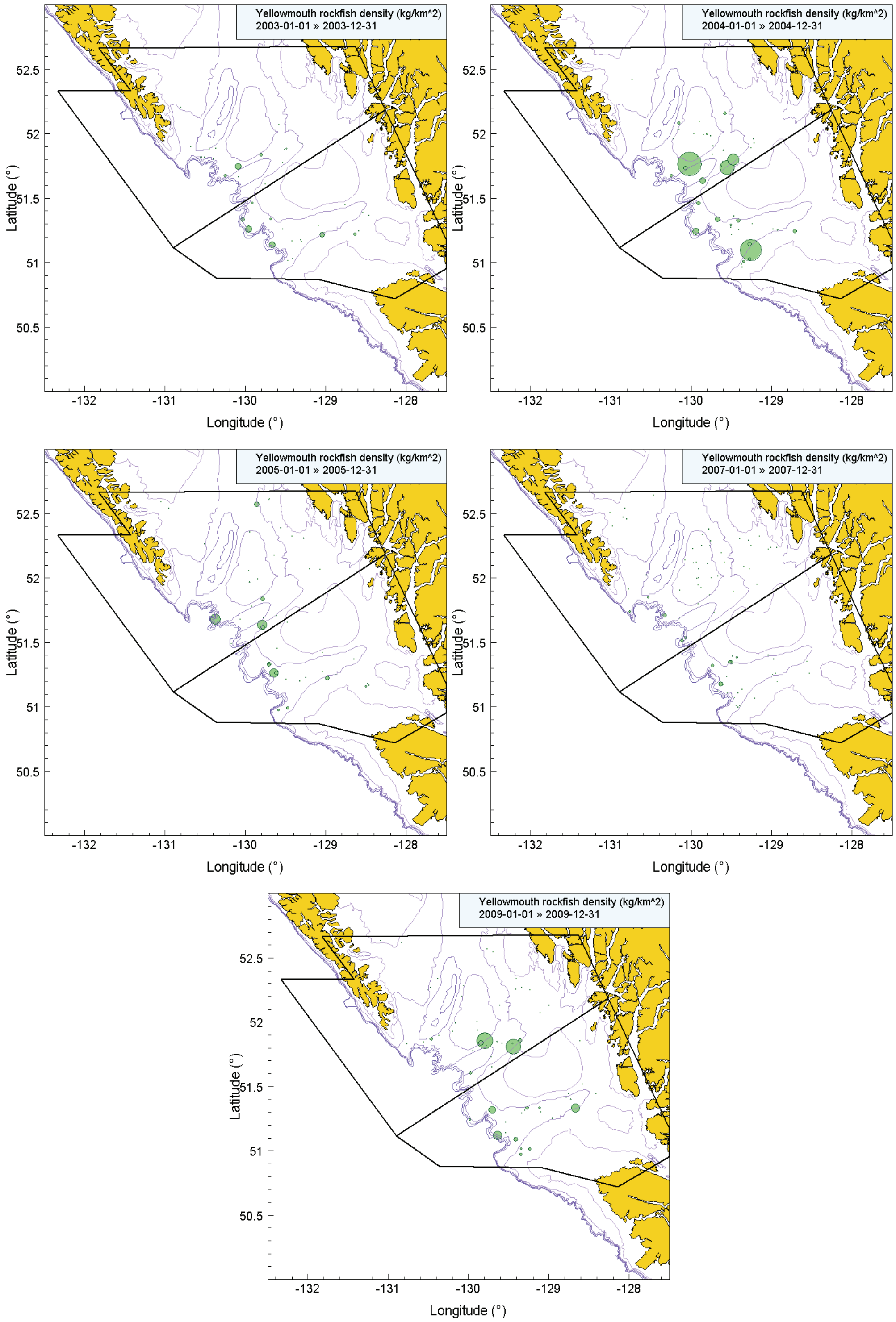


Figure C12. Map of the locations of tows by survey year from the QCS synoptic trawl survey (2003–2009) which caught Yellowmouth Rockfish. Circles are proportional to catch density (largest circle = 12,659 kg/km^2 in 2004). Also shown are the 100, 200, 300, 400 and 500 m isobaths and the YMR re-stratified area stratum boundaries.

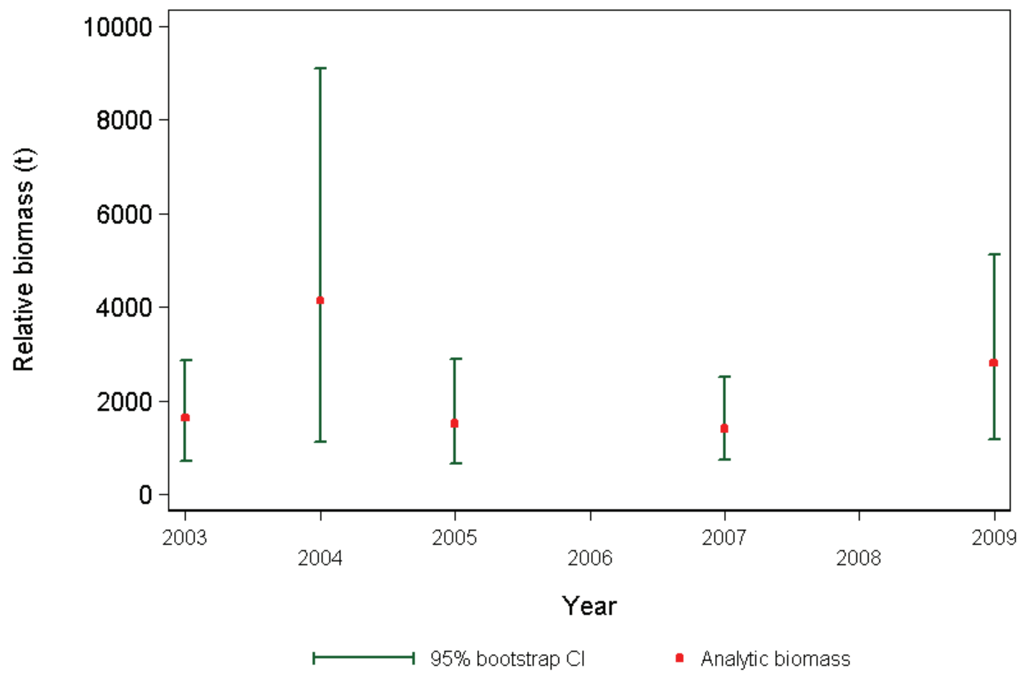


Figure C13. Plot of biomass estimates for YMR from the QCS synoptic trawl survey from 2003 to 2009. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

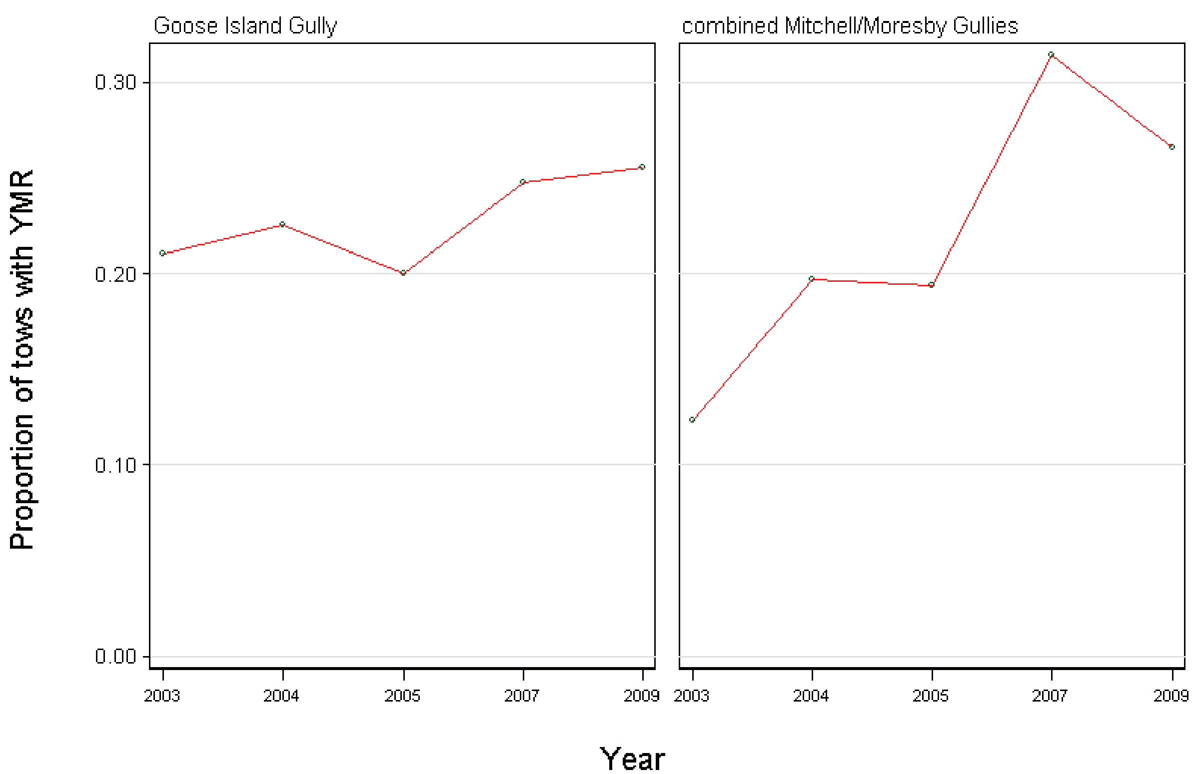


Figure C14. Proportion of tows by stratum and year which contain YMR for the QCS synoptic trawl survey.

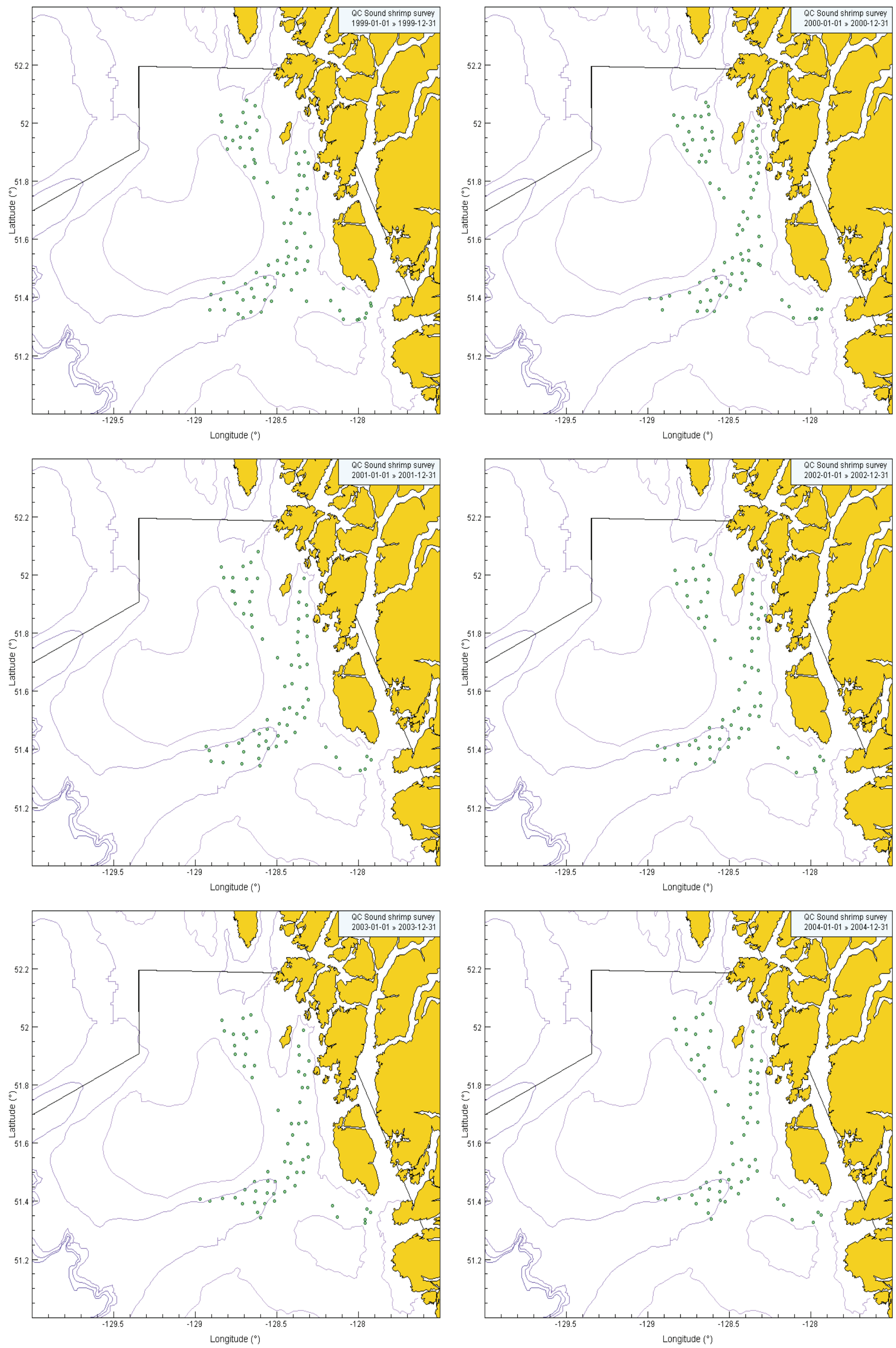


Figure C15. Maps showing the locations by survey year of valid tows (stratum numbers 109 and 110) conducted by the QCS shrimp survey over the period 1999 to 2010. Tows on the inside of Calvert Island (stratum 111) which were not used in the analysis of this survey for Yellowmouth Rockfish have been omitted.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

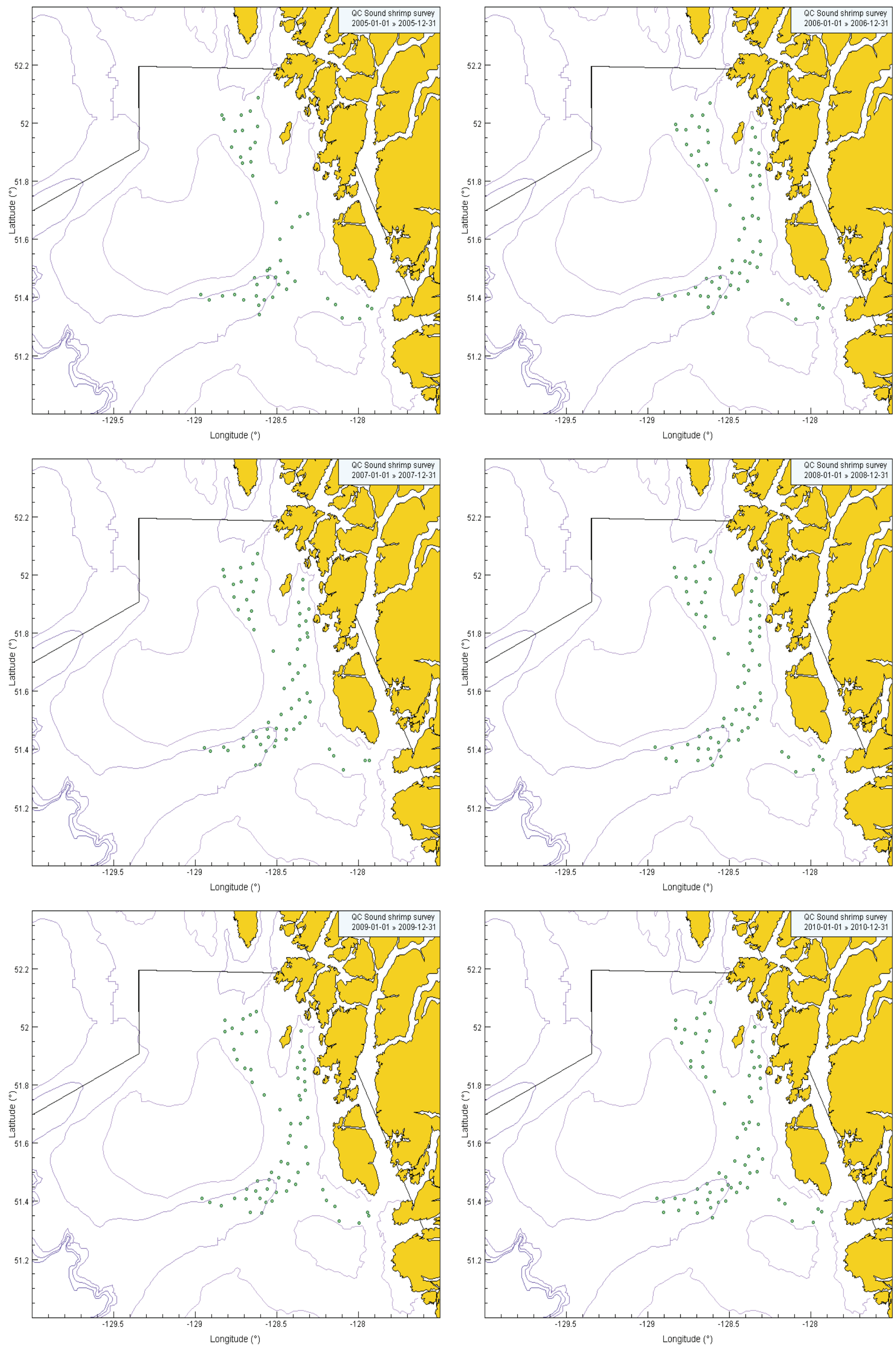


Figure C15. (cont.)

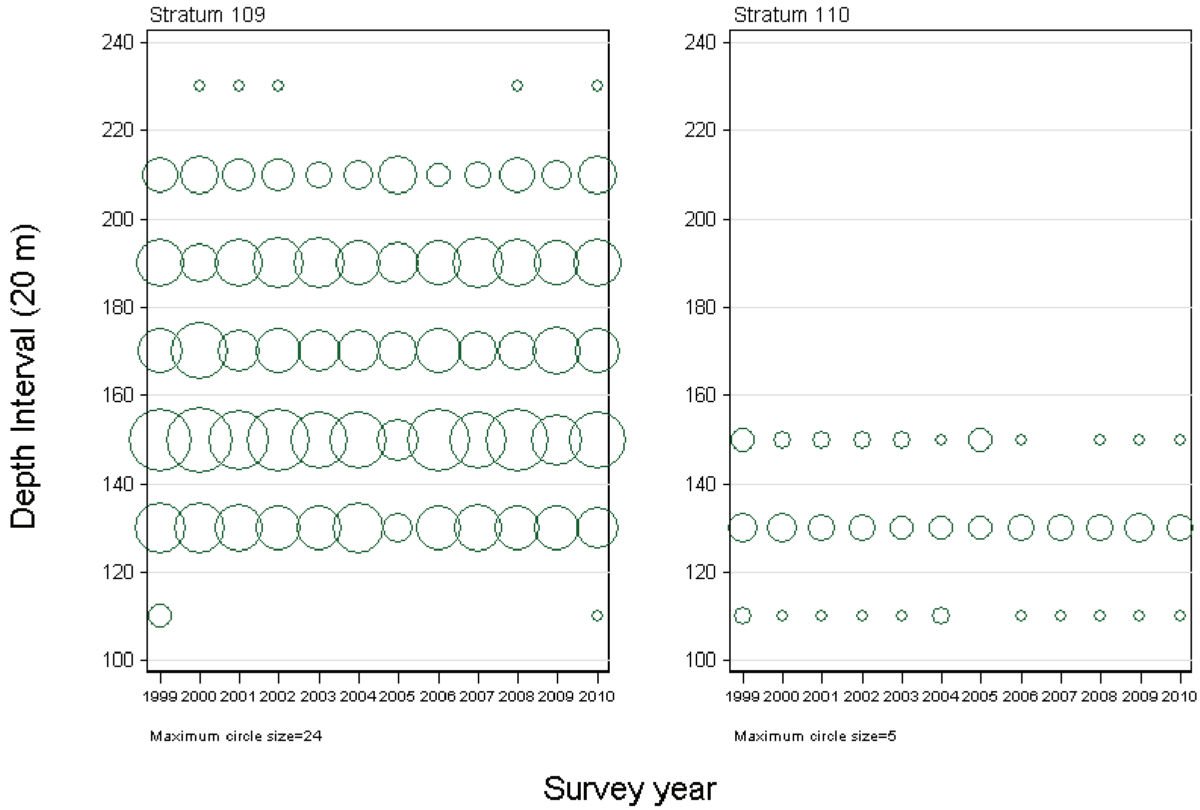


Figure C16. Distribution of tows by stratum, survey year and 20 m depth zone. Depth zones are indicated by the midpoint value of the depth interval, weighted by the number of tows. Depth is the start depth for the tow.

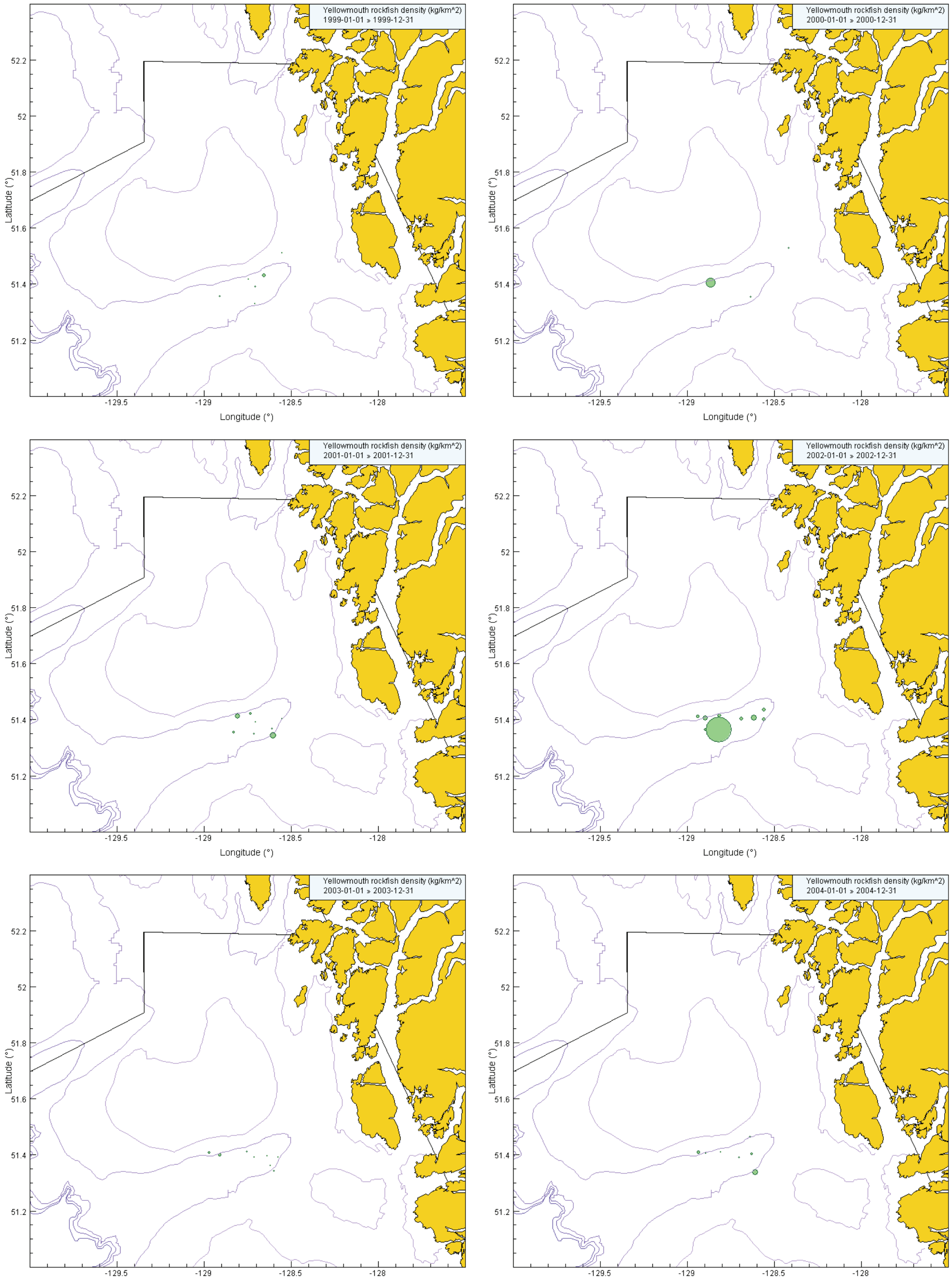


Figure C17. Map of the locations of all trawls from the QCS shrimp trawl survey (1999–2010) by survey year which caught Yellowmouth Rockfish. Circles are proportional to catch density (largest circle = 13 846 kg/km^2 in 2002). Also shown are the 100, 200 and 300 m isobaths and the area stratum boundary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

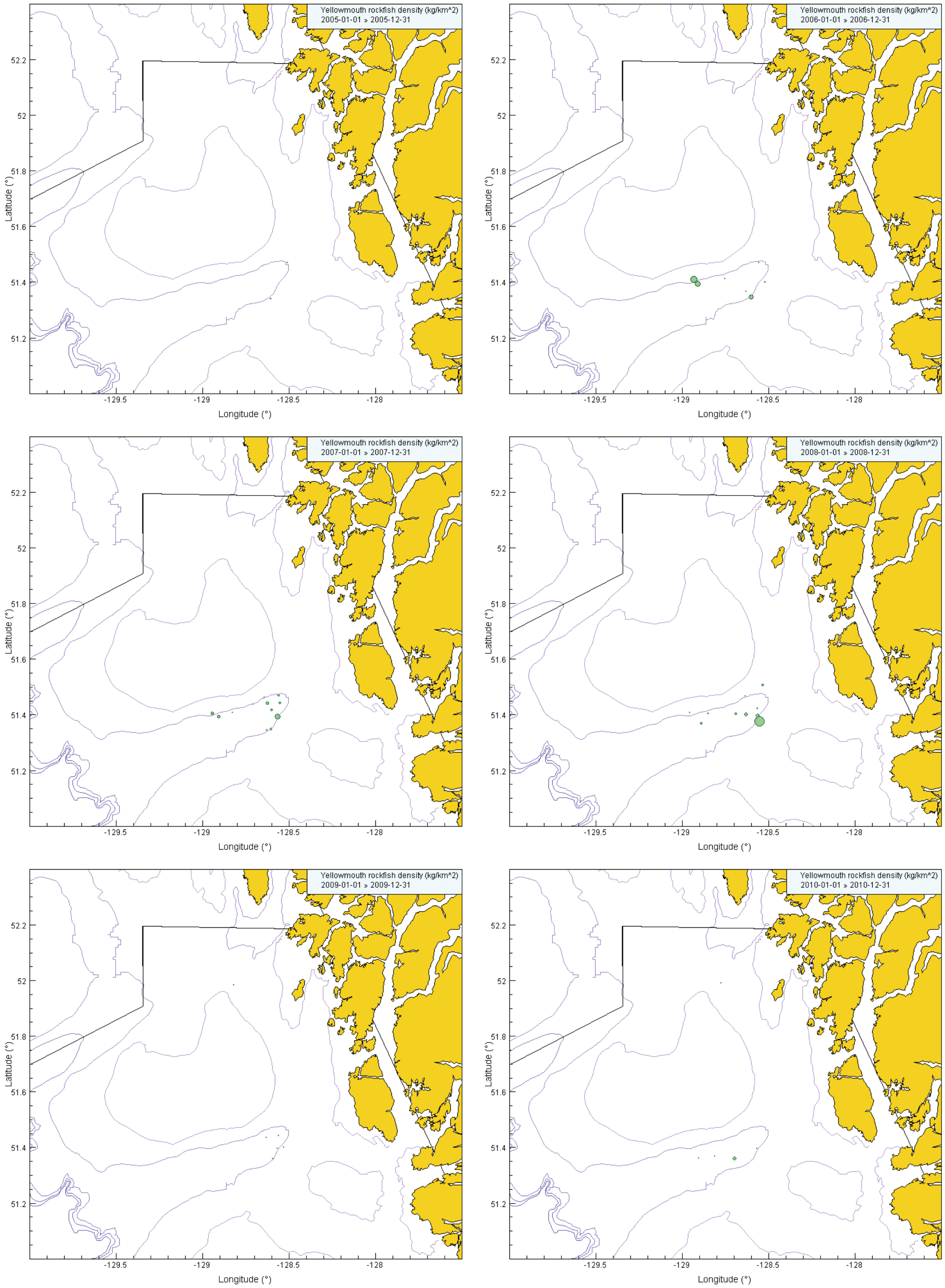


Figure C17. (cont.)

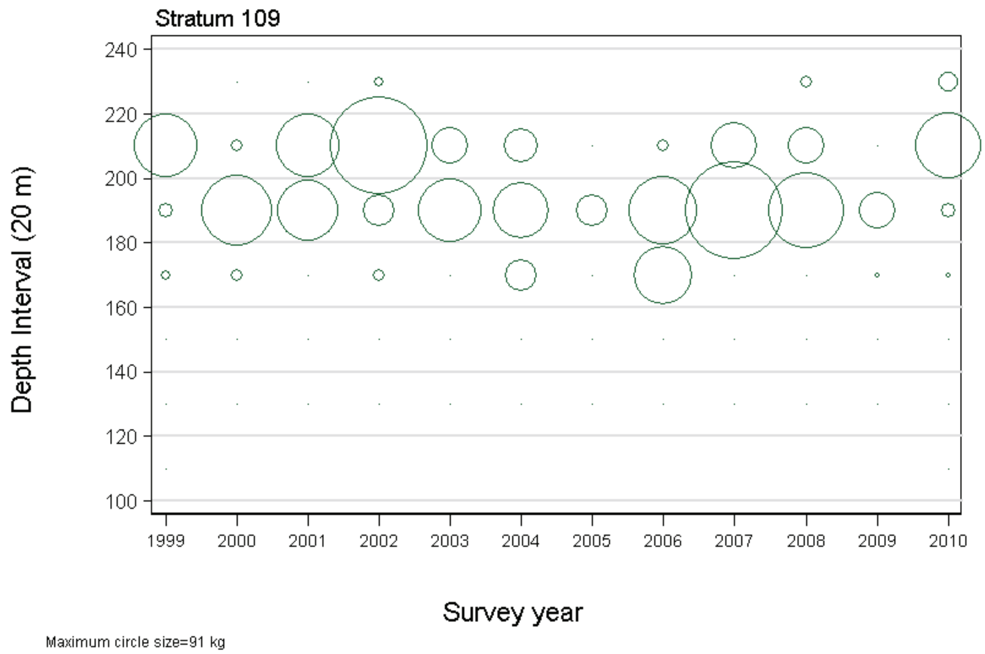


Figure C18. Distribution of catch weight of YMR for stratum 109 (there no records of YMR in stratum 110) (Table C10), survey year and 20 m depth zone. Depth zones are indicated by the mid-point of the depth interval. Maximum circle size: 91 kg (200–220 m bin in 2002). Minimum depth observed for YMR: 163 m; maximum depth observed for YMR: 225 m. Depth is defined as the start depth for the tow.

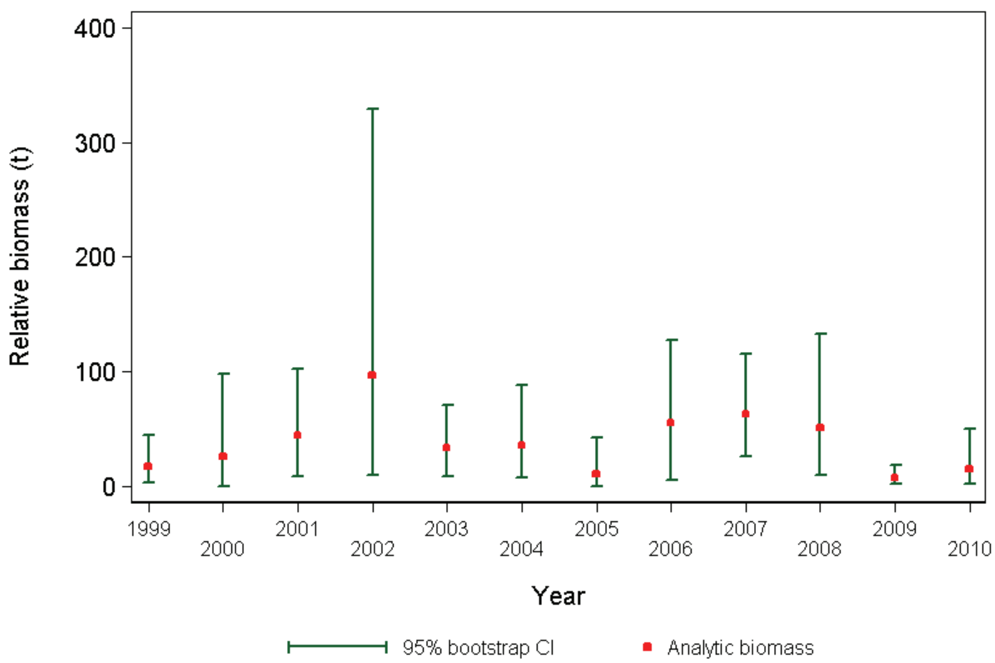


Figure C19. Plot of biomass estimates for Yellowmouth Rockfish from the QCS shrimp trawl survey for 1999 to 2010. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

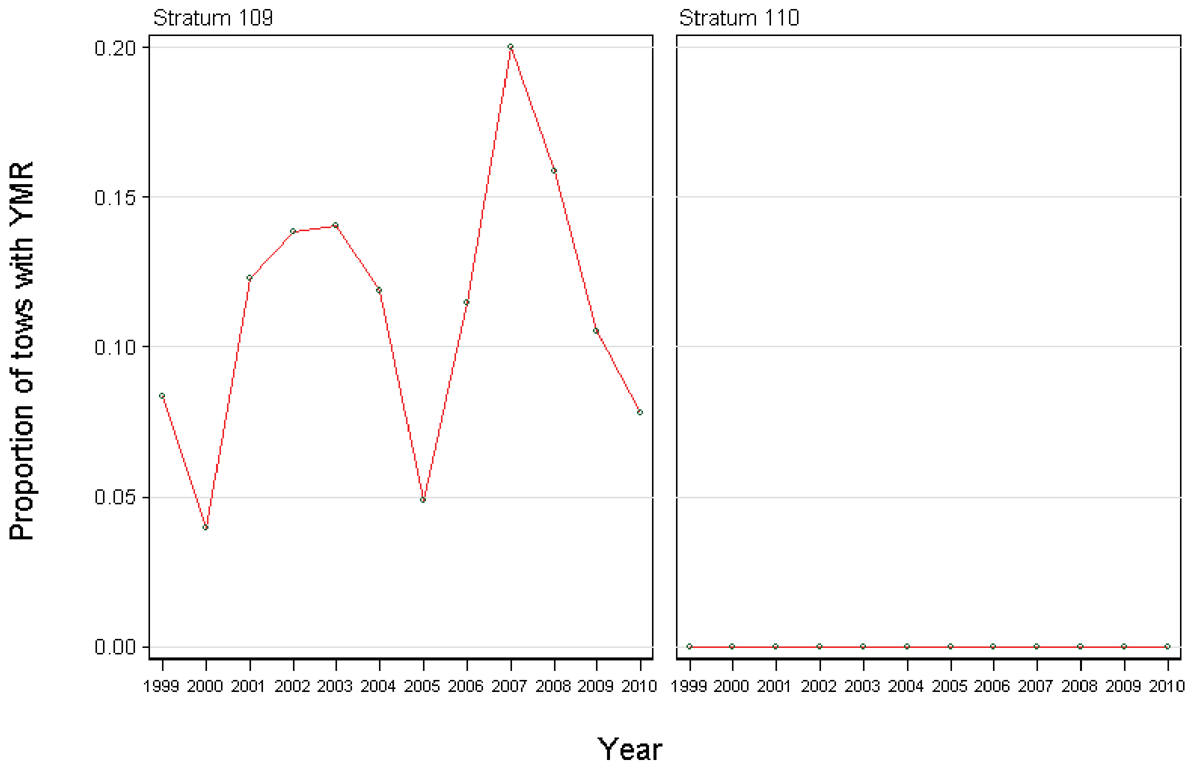


Figure C20. Proportion of tows by stratum and year which contain YMR for the Queen Charlotte Sound shrimp trawl survey.

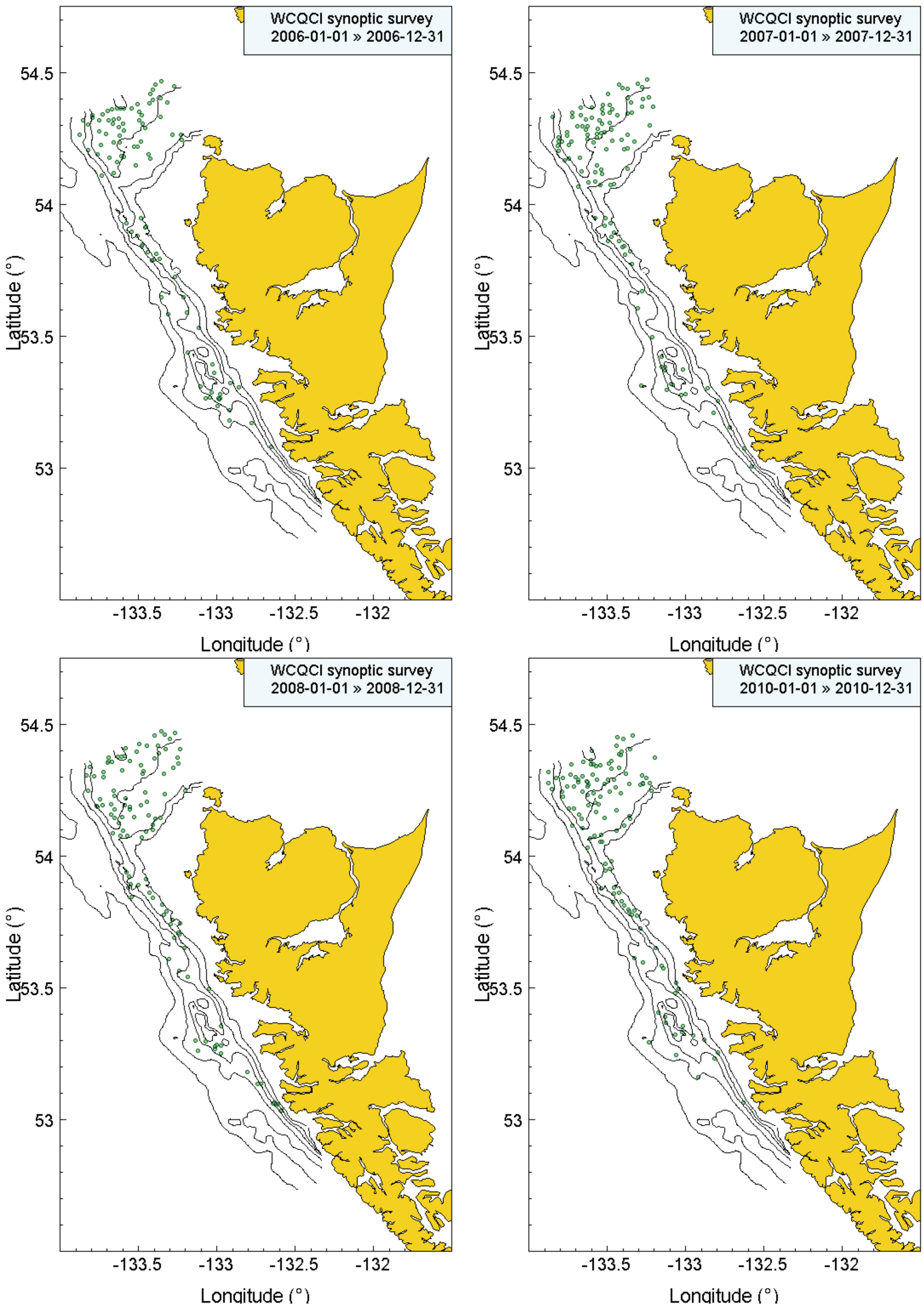


Figure C21. Map showing the locations of valid tows conducted by the west coast Haida Gwaii synoptic trawl survey over the period 2006 to 2010. Dark lines indicate depth stratum boundaries as defined in Table C12.

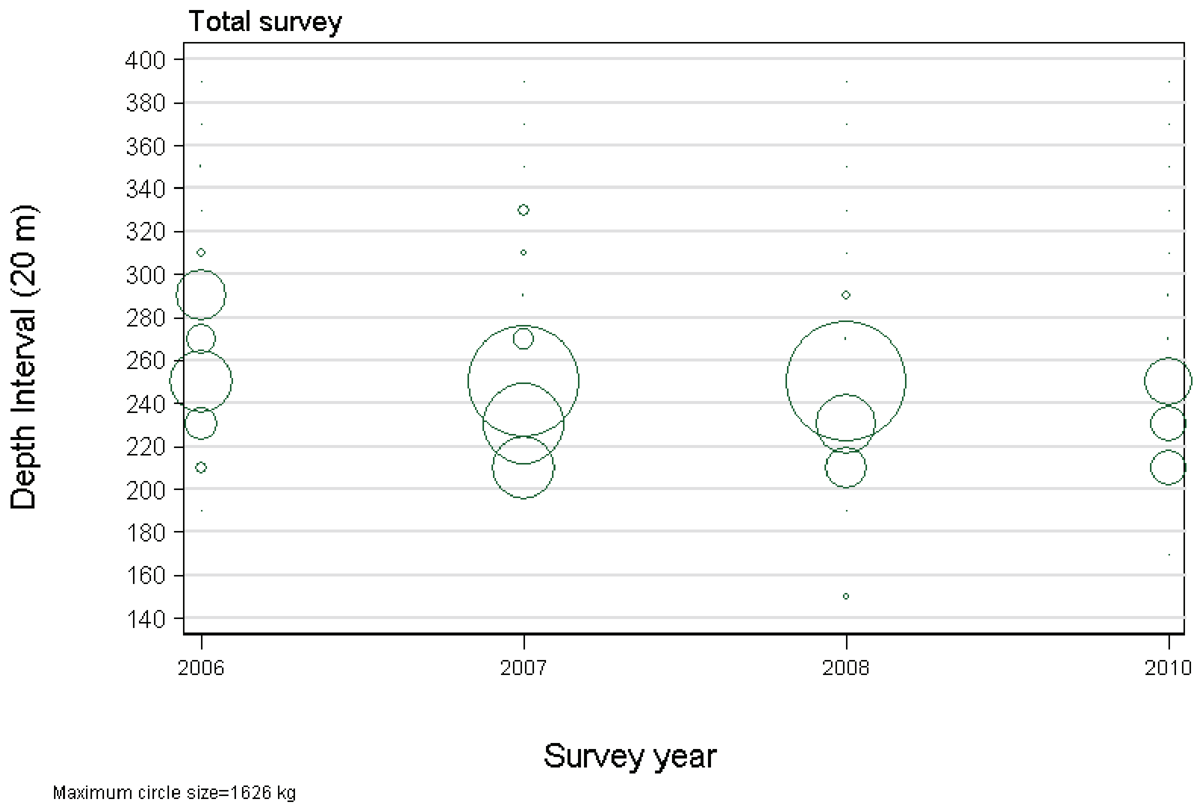


Figure C22. Distribution of observed weights of Yellowmouth Rockfish in the west coast Haida Gwaii synoptic trawl survey by survey year and 20 m depth zone. Depth zones are indicated by the mid-point of the depth interval and circles in the each panel are scaled to the maximum value (1,626 kg [240–260 m bin in 2008]). Minimum depth observed for YMR: 157 m; maximum depth observed for YMR: 360 m. Depth is taken at the start position for each tow.

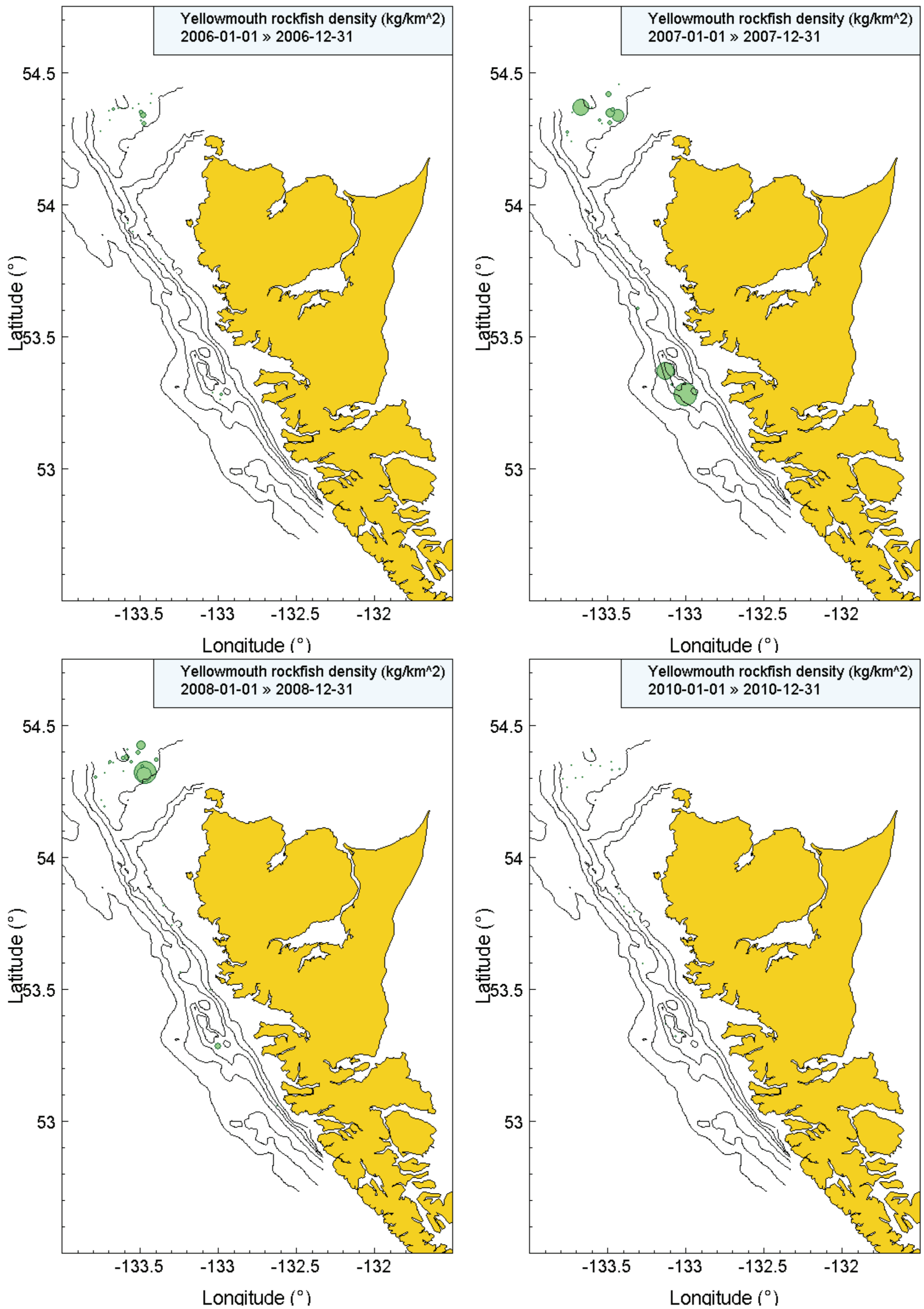


Figure C23. Map of the locations of all trawls from the west coast Haida Gwaii synoptic trawl survey by year (2006, 2007, 2008 and 2010) which caught Yellowmouth Rockfish. Circles are proportional to catch density (largest circle=7,631 kg/km^2 in 2007). Dark lines indicate depth stratum boundaries as defined in Table C12.

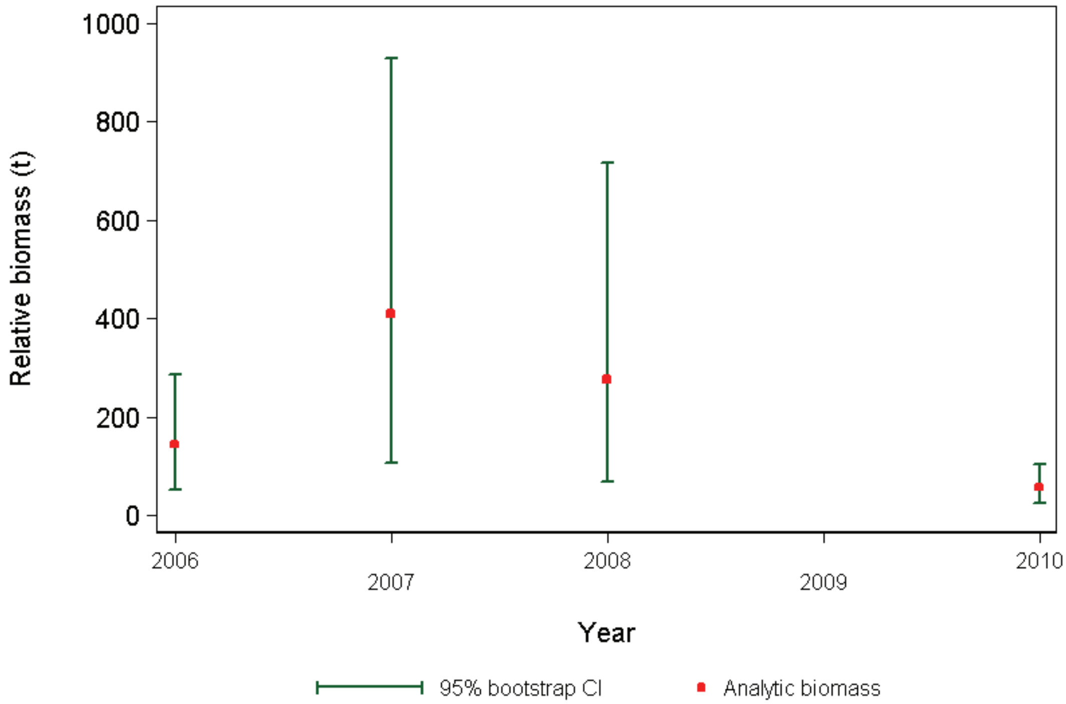


Figure C24. Plot of biomass estimates for Yellowmouth Rockfish from the west coast Haida Gwaii synoptic trawl survey for 2006 to 2010. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

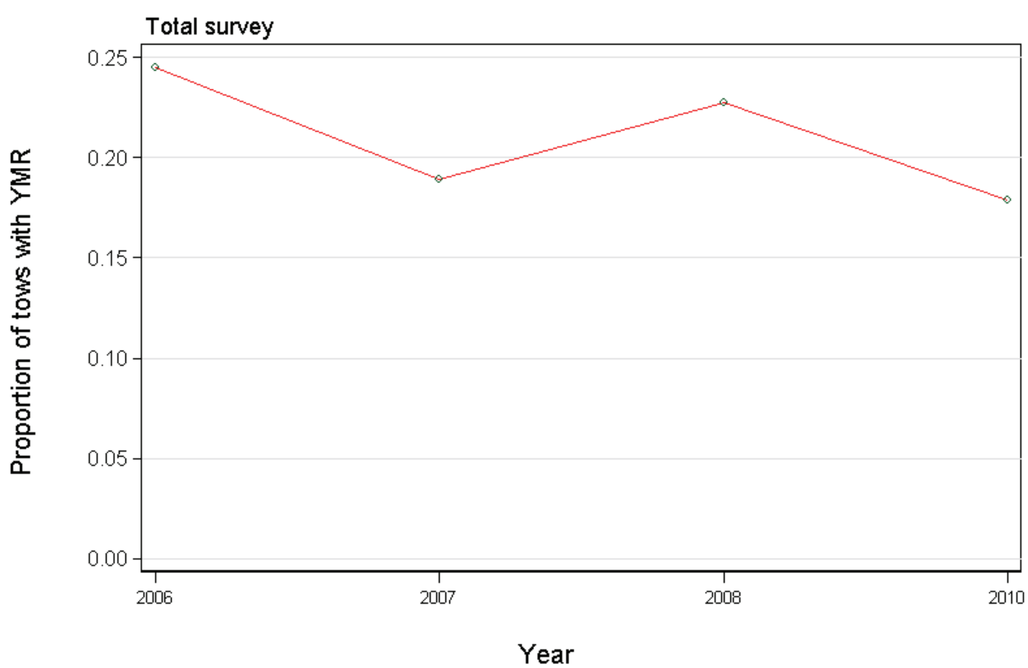


Figure C25. Proportion of tows by year which contain Yellowmouth Rockfish for the west coast Haida Gwaii synoptic trawl survey.

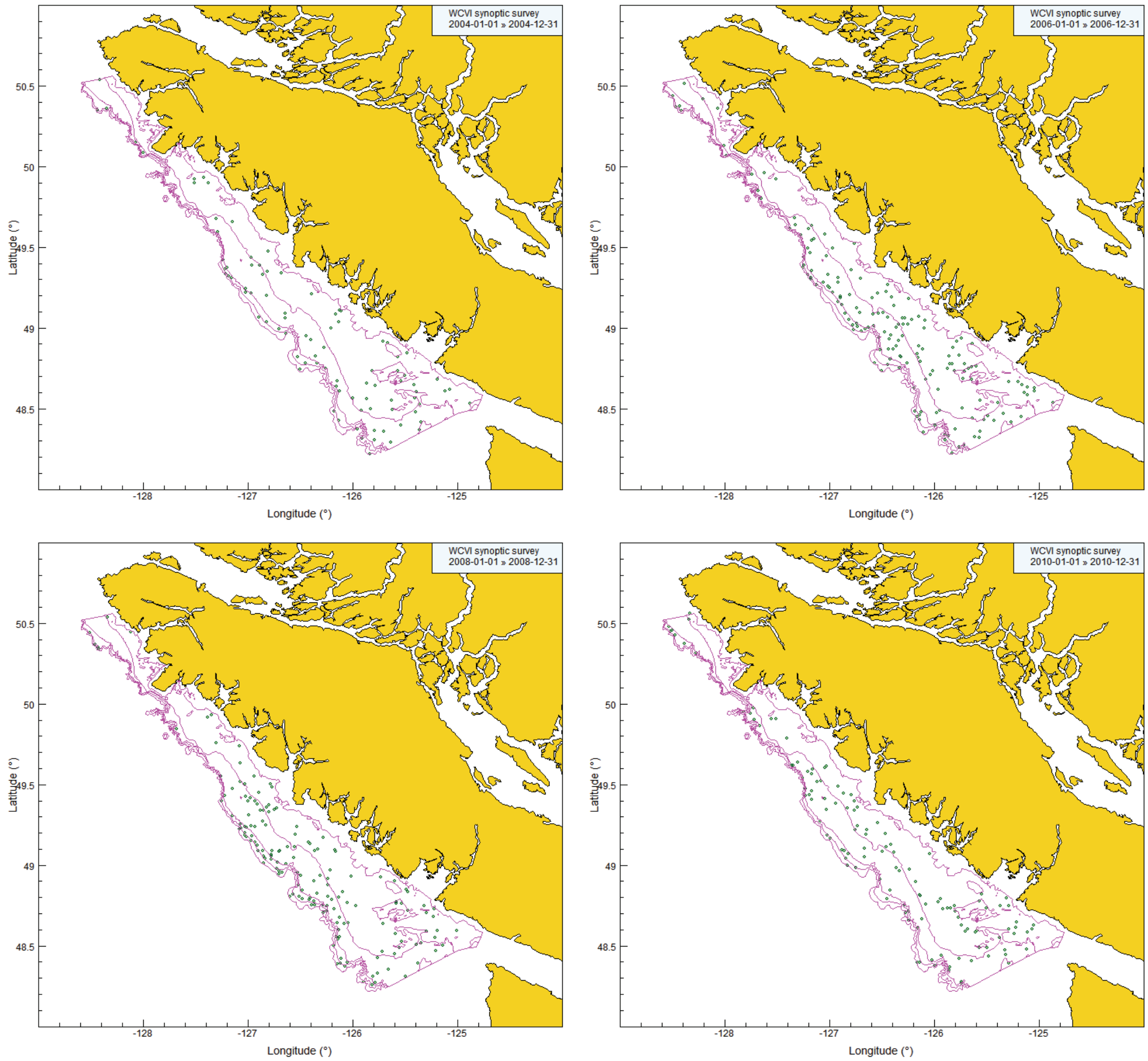


Figure C26. Map showing the locations by survey year of valid tows conducted by the west coast Vancouver Island synoptic trawl survey over the period 2004 to 2010. Bathymetric lines represent the WCVI synoptic survey strata as defined in Table C14.

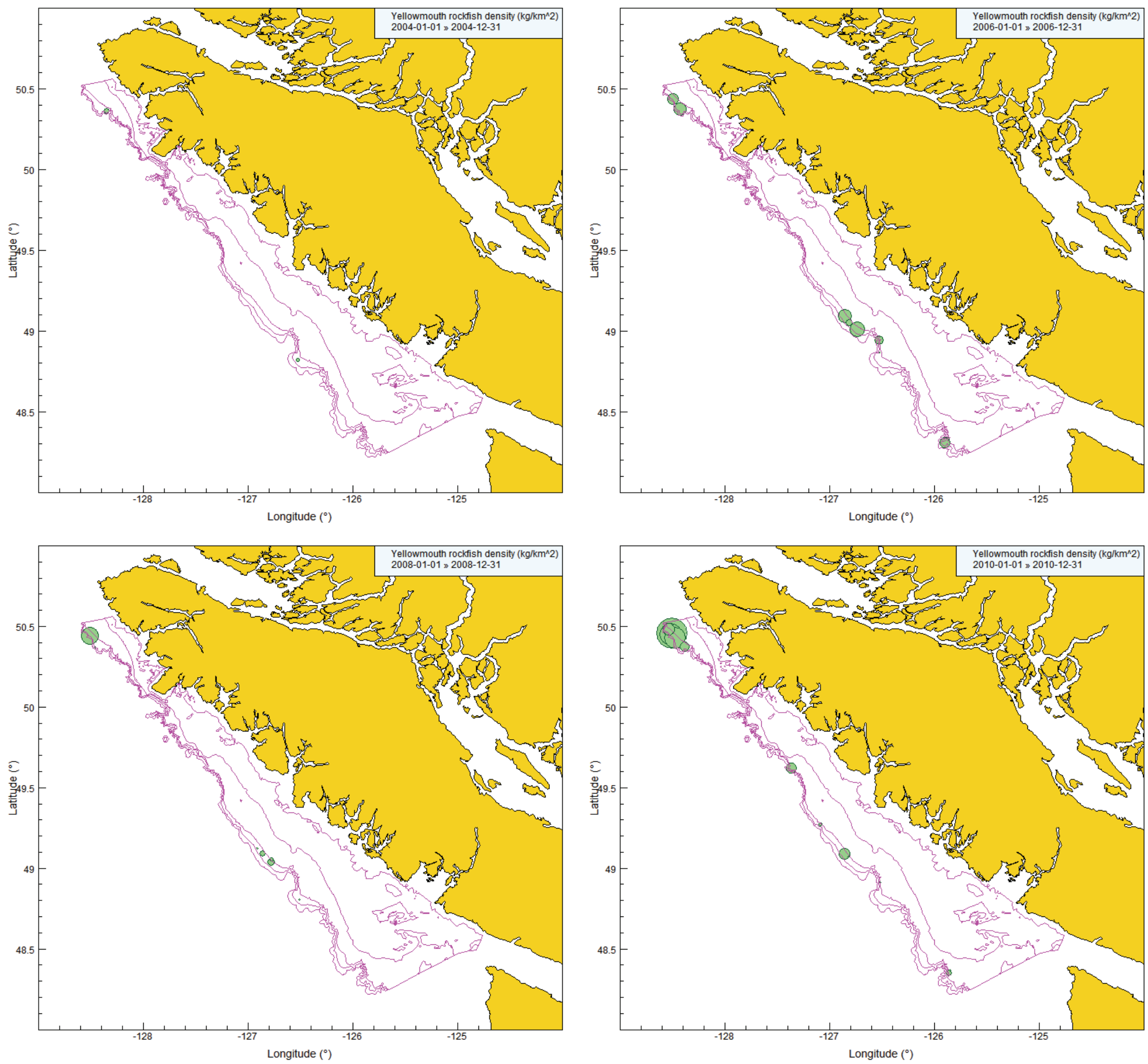


Figure C27. Map of the locations by year of all trawls from the west coast Vancouver Island synoptic trawl survey (2004, 2006, 2008, and 2010) which caught Yellowmouth Rockfish. Circles are proportional to catch density (largest circle=2,094 kg/km^2 in 2010). Bathymetric lines represent the WCVI synoptic survey strata as defined in Table C14.

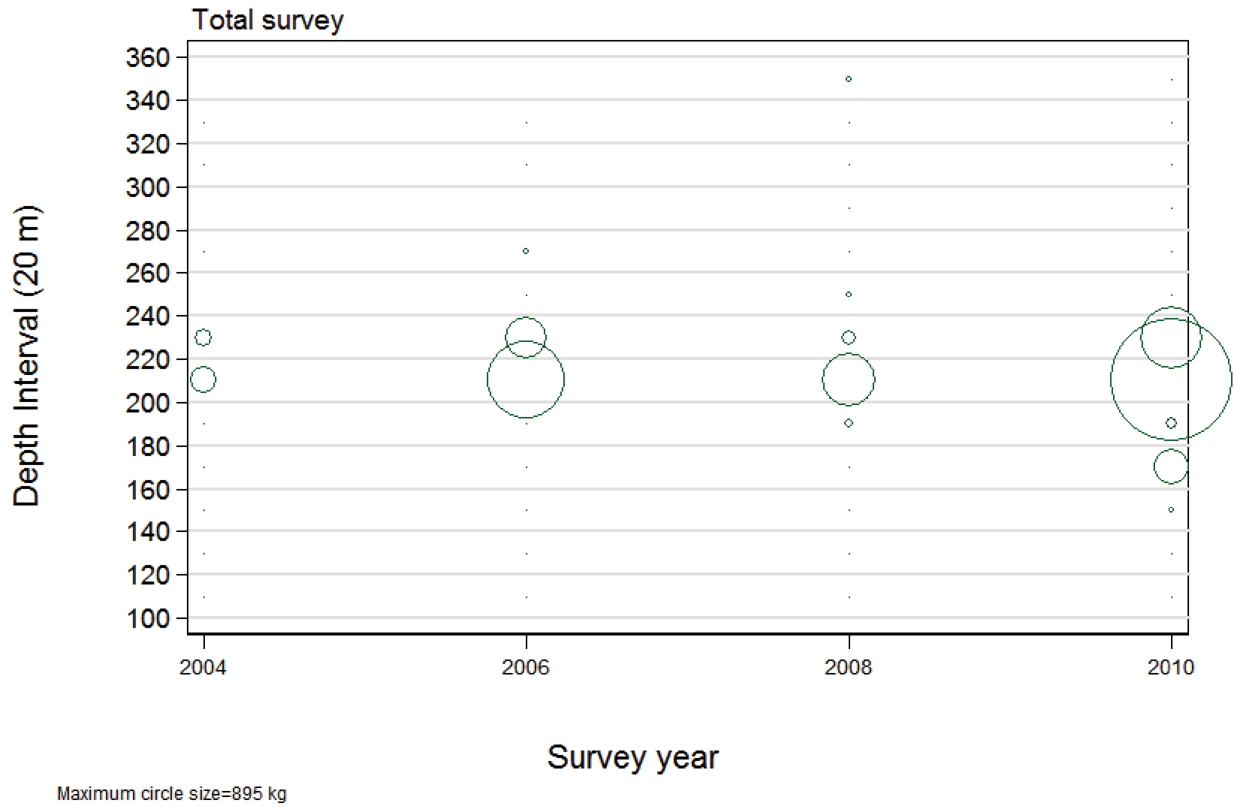


Figure C28. Distribution of observed weights of Yellowmouth Rockfish for the west coast Vancouver Island synoptic trawl survey by survey year and 20 m depth zone. Depth zones are indicated by the mid-point of the depth interval. Minimum depth observed for YMR: 148 m; maximum depth observed for YMR: 348 m. Depth is taken at the start position for each tow.

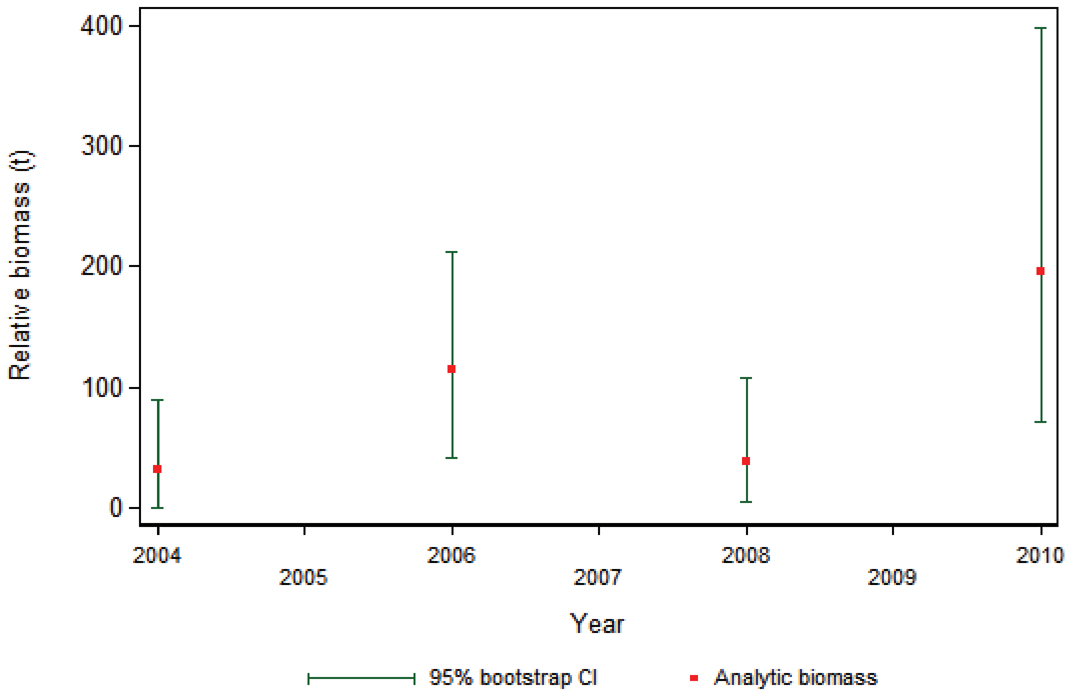


Figure C29. Plot of biomass estimates for Yellowmouth Rockfish from the west coast Vancouver Island synoptic trawl survey from 2004 to 2010. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

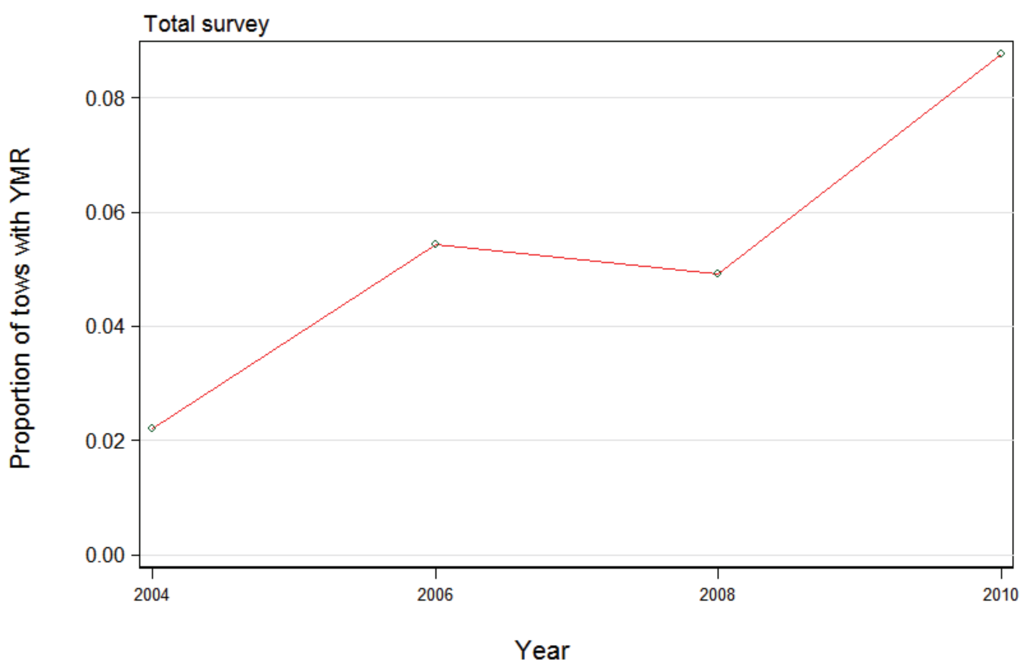


Figure C30. Proportion of tows by stratum and year which contain Yellowmouth Rockfish for the west coast Vancouver Island synoptic trawl survey.

APPENDIX D. BIOLOGICAL ANALYSES FOR YELLOWMOUTH ROCKFISH

All data come from PMFC areas 3CD and 5ABCDE combined (herein BC coast), unless otherwise specified.

LENGTH-WEIGHT PARAMETERS

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

(D1) $$W_{s,i} = a_s \left(L_{s,i} \right)^{b_s}$$

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 $\log(a_s)$ was then exponentiated to provide the a_s parameter for use in the stock assessment.

Models were fit by sex to length-weight pairs from research survey samples (Figure D1). The number of available observations n_s are approximately 2,500. The fixed parameter estimates used to describe allometric growth in the YMR stock assessment model appear in Table D1.

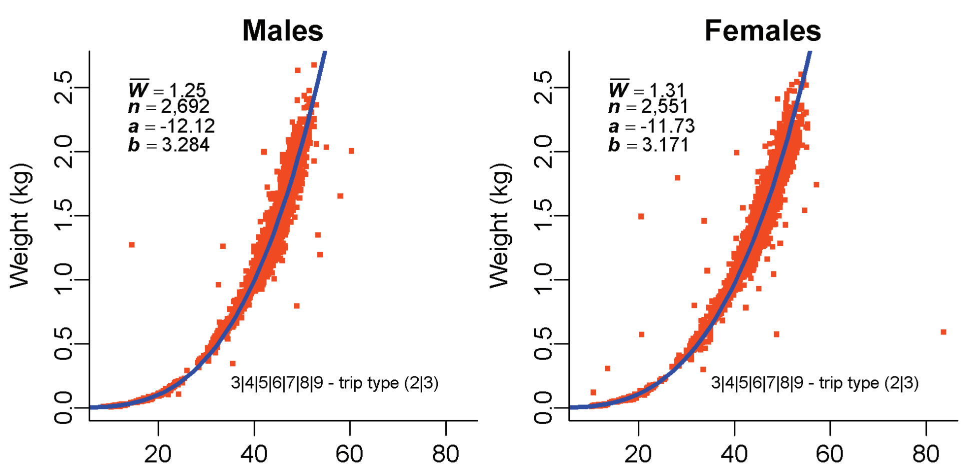


Figure D1. Regression analyses showing the fitted model (D1) and research survey length-weight pairs used to estimate a_s and b_s in the assessment.

Table D1. Regression statistics for model (D1) fitted as a linear regression on the logged length and weight pairs. Parameters values in bold are used in the population model.

Source	n_s	$\log(a_s)$	SE $\log(a_s)$	a_s	b_s	SE b_s
Females						
Research Survey	2551	-11.72594	0.03788	**8.08148E-06**	**3.17064**	0.01015
Males						
Research Survey	2692	-12.12311	0.02651	**5.43248E-06**	**3.28442**	0.00718

VON-BERTALANFFY GROWTH PARAMETERS

The parameterisation of the von-Bertalanffy growth model is:

$$\text{(D2)} \qquad L_{a,s} = L_{\infty,s}\left(1 - e^{-k_s\left(a - t_{0,s}\right)}\right)$$

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.

A non-linear von-Bertalanffy model was fit to age-length pairs categorised by sex for research survey samples with data available up to Feb 14, 2011. No effort was made to filter out obvious errors. Growth model fits (Figure D2) indicate a lack of data at younger ages to anchor the von Bertalanffy. This deficiency is even more extreme in the commercial samples (not used). The growth parameters used in the stock assessment model appear in Table D2.

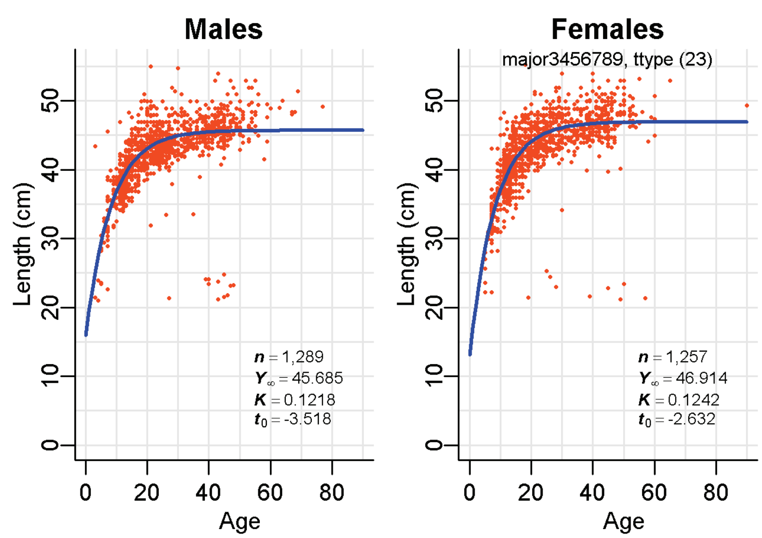


Figure D2. Length-at-age relationships for YMR specimens collected on research survey trips using the von Bertalanffy growth model (D2). n = number of specimens; Y_∞ = $L_{\infty,s}$.

Table D2. Growth parameters for Yellowmouth Rockfish using the von Bertalanffy model (D2). Additionally, Awatea uses normal priors for lengths at age 1 and at the last age.

Source	$L_{\infty,s}$	k_s	$t_{0,s}$	$L_{1,s}$	$\sigma_{1,s}$	$L_{60,s}$	$\sigma_{60,s}$
Females							
Research Survey	46.91404	0.12419	-2.63197	17.032	1.543	46.894	2.015
Males							
Research Survey	45.68536	0.12177	-3.51836	19.333	1.549	45.665	1.652

PROPORTION OF MATURE FEMALES BY AGE

The maturity analysis was based on all “staged” (examined for maturity status) females in the DFO GFBio database for the BC coast that had also been aged using the break and burn method, regardless of sample origin. This selection resulted in 2,650 observations (Table D3). Only females sampled from January to July were used in creating the maturity curve because these months contained the majority of spawning and spent females (Table D4). 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. A double-normal function (similar to Equation F.7) was fitted to the observed proportions mature at age to smooth the observations and obtain an increasing monotonic function for use in the stock assessment model (Figure D3). 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. The maturity ogive used in the stock assessment model was based on the observed proportions of mature females from ages 1 to 8 and then switched to the fitted monotonic function for ages 9 to 17, after which it was assumed that all females were mature (Table D5). This approach is reasonable as it is not necessary for the maturity function to be highly accurate in the stock assessment model – its only function is to calculate the spawning biomass used in the Beverton-Holt stock recruitment function and is treated as a constant known without error.

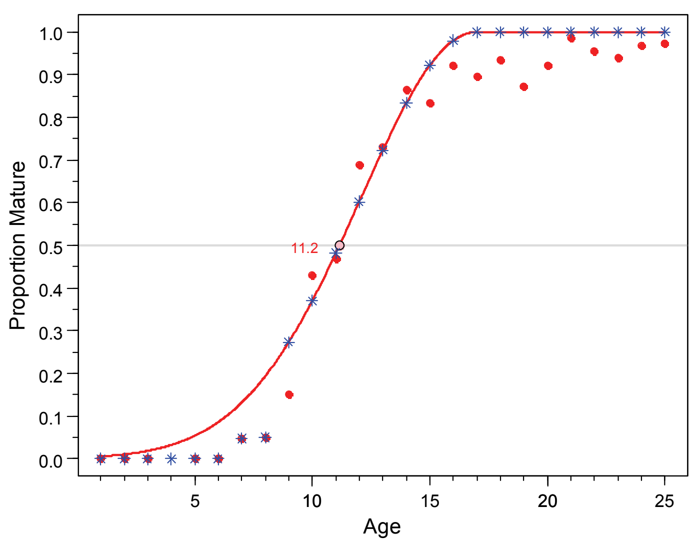


Figure D3. Maturity ogives for BC YMR females: double normal curve(red line) fits the observed proportions (red circles) from the available commercial and research data; proportions used in the assessment model (blue asterisks) use observed proportions for ages 1-8 and fitted proportions for ages 9 and older. Age at 50% maturity is indicated along the median line.

Table D3. Number of YMR females with maturity codes by month and PMFC major area.

month ▶ PMFC ▼	1	2	3	4	5	6	7	8	9	10	11	12
3C	0	0	0	0	0	0	0	0	38	0	0	0
3D	20	14	36	14	0	0	0	0	26	0	0	15
5A	114	162	108	66	35	52	117	17	256	52	29	11
5B	0	75	21	13	51	51	176	158	84	15	0	0
5C	0	0	0	6	0	11	8	0	0	0	0	0
5E	0	42	27	4	231	158	83	0	147	95	12	0

Table D4. Number of YMR females at various maturity stages by month.

month ▶ maturity ▼	1	2	3	4	5	6	7	8	9	10	11	12
immature	5	39	22	12	18	15	50	8	47	0	1	0
maturing	17	58	17	15	48	38	59	30	157	82	6	1
mature	112	186	45	3	6	3	5	28	193	64	32	25
fertilized	0	3	64	10	1	0	1	0	1	0	2	0
embryos	0	0	23	55	33	1	7	1	0	0	0	0
spent	0	0	15	6	90	19	53	5	7	1	0	0
resting	0	7	6	2	121	196	209	103	146	15	0	0

Table D5. Proportion of YMR females mature by age used in the catch-age model. Maturity stages 1 and 2 were assumed to be immature fish and all other staged fish (stages 3 to 7) were assumed to be mature. Only fish sampled from January to July were used in the calculation of observed proportion mature.

Age	# Fish	Observed Proportion Mature	Fitted Proportion Mature	Model Proportion Mature
1	1	0	0.006	0
2	1	0	0.010	0
3	4	0	0.019	0
4	0	0	0.032	0
5	3	0	0.054	0
6	1	0	0.086	0
7	21	0.048	0.132	0.048
8	20	0.050	0.193	0.050
9	73	0.151	0.273	0.273
10	102	0.431	0.370	0.370
11	143	0.469	0.482	0.482
12	145	0.690	0.602	0.602
13	134	0.731	0.723	0.723
14	133	0.865	0.833	0.833
15	91	0.835	0.922	0.922
16	90	0.922	0.980	0.980
17	86	0.895	1	1
18	108	0.935	1	1
19	79	0.873	1	1
20	117	0.923	1	1

NATURAL MORTALITY PRIOR

Natural mortality remains unknown, but past authors (e.g., Schnute et al. 1999) assumed M = 0.05 for Pacific Ocean Perch. Haigh and Starr (2008) used the simple formula presented by Quinn and Deriso (1999), based on Hoenig's (1983) finding that natural mortality is inversely proportional to longevity. The calculation assumes that the proportion of a population reaching the maximum observed age t_m is 0.01. Their rearrangement of the exponential law of population decline

(D3) $$M = \frac{-\log(0.01)}{t_m} = \frac{4.605}{99} = 0.047$$

yields M = 0.047 for YMR, using the maximum observed age of 99 (Munk 2001).

Owen Hamel (Northwest Fisheries Science Center, 2725 Montlake Blvd. East, Seattle, WA 98112-2097, pers. comm.) has been looking at a variety of datasets to develop natural mortality priors. The work has not been completed but using Hoenig's estimator alone, and assuming (i) a maximum age of 100 and (ii) the variance in Hoenig's data is due to true variability in the relationship, rather than observation error, he calculates a log-normal prior for M with μ = -3.1295 and σ = 0.5361. In real space,

median	=	e^{μ}	=	0.04374
mean	=	$e^{\mu+\sigma^2/2}$	=	0.0505
SD	=	$e^{\mu+\sigma^2/2}\sqrt{e^{\sigma^2}-1}$	=	0.02914
CV	=	$\sqrt{e^{\sigma^2}-1}$	=	0.5770

Hamel's estimation of mean/median M is close to that of the Hoenig estimate, but the large standard deviation would make our prior far too broad. In preliminary runs with loose priors, estimated M increases to values that don't seem credible. Therefore, the 'Estimate M' model for YMR uses the Hoenig estimate of 0.047 as the mean of a normal prior on M_s with standard deviation 0.005 (roughly 10%). The 'Fix M' model fixes M_s to 0.047. A sensitivity run that uses the Hamel prior is given in Appendix I.

PRIORS ON THE COMMERCIAL AND SURVEY SELECTIVITIES

No prior information from population model output exists for YMR; however, Hamel (2008) provides selectivity parameter estimates for Darkblotched Rockfish (DBR, *Sebastes crameri*), a species that is reportedly most closely related to YMR genetically (Love *et al*. 2002). We use Hamel's estimates to derive selectivity priors for YMR as outlined below.

Hamel's (2008) assessment of DBR, which uses a length-based model, derives parameter estimates for selectivity based on a double-normal distribution that allows broad peaks. The DBR estimates therefore comprise the fish length at which the dome-shaped curve first reaches the peak, the width of the peak, the variance of the left normal, and the variance of the right normal (Table D6). The YMR assessment also uses a double-normal selectivity distribution but the shape is restricted to be asymptotic $(\mu_g,\, v_{gL})$.

Using Hamel's (2008) estimates for DBR's von Bertalanffy growth parameters – $L_{1.7\,\mathrm{years}}$ = 14.8923 cm, $L_{29\,\mathrm{years}}$ = 42.174 cm (females), K = 0.214137 (females) – we iteratively determine L_∞ = 42.2531 cm by changing t_0, which settles on the value -0.329384. Selectivity-at-length s_{lg} is calculated using the double normal distribution (F.7), where υ_{gR} is fixed to 100. Ages are calculated using

$$a = t_0 - \frac{\log\left(1 - \frac{L_a}{L_\infty}\right)}{K}$$, where L_a = the length-at-age.

From calculated ages and selectivity values s_{lg}, we fit double-normal curves to estimate μ_g and υ_{gL} for YMR priors. Initially, we used separate survey priors based on US survey estimates for modelling, but switched to the fishery estimate based on US fishery data for all selectivity priors (Table D7). The only exception is that for the QCS Shrimp survey where we use the estimate from the NWFSC shelf survey (Table D6). The standard deviations on all priors were calculated as 30% of the mean prior estimate, except for the SD on log υ_{3L} which was calculated at 20%. However, only those parameters estimated (for g = 1, 2, and 6) used the normal prior. The selectivity offset parameter Δ_g for males uses the normal prior $N(0,1)$.

Table D6. Selectivity parameter estimates for Darkblotched Rockfish from proportion-at-length (cm) data for various fishing agencies g (Hamel 2008).

Parameter	Fishery	Triennial	AFSC slope	NWFSC slope	NWFSC shelf
μ_g	34.9749	21.5886	23.1085	24.3454	16.4491
width of peak	0.414884	-5.99999	-1.02227	1.26326	-1.24981
υ_{gL}	3.90223	3.54535	2.36933	3.1702	0.184223
υ_{gR}	5.5315	4.05594	2.30353	4.02345	2.85191

Table D7. Selectivity priors for Yellowmouth Rockfish derived from US Darkblotched Rockfish selectivity estimates (Table D6). Parameters μ_g and υ_{gL} are estimated using the normal prior for $g \in (1,2,6)$ (shaded), otherwise the parameters are fixed at the mean of the prior.

g	Series	μ_g	SD	log υ_{gL}	SD	Model	US data
1	GIG POP	7.212906	2.163872	1.764103	0.529231	Est	Fishery
2	QCS Synoptic	7.212906	2.163872	1.764103	0.529231	Est	Fishery
3	QCS Shrimp	4.202634	1.260790	1.098612	0.219722	Fix	NWFSC Shelf
4	WCHG Synoptic	7.212906	2.163872	1.764103	0.529231	Fix	Fishery
5	WCVI Synoptic	7.212906	2.163872	1.764103	0.529231	Fix	Fishery
6	Commercial	7.212906	2.163872	1.764103	0.529231	Est	Fishery

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 YMR in tows that were sampled. A second weighting is then applied using the catch weight of YMR 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 YMR 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 (1978 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 1982 year class is still evident in the proportions-at-age data, although its presence is declining. Figure E1 also shows that the 2002 year class may have contributed a large set of recruits to the population. The QCS Synoptic survey proportions-at-age data do not appear to be particularly informative or consistent (Figure E2). In part, this may be due to the inconsistent level of sampling within each stratum (Table E3). The GIG Rockfish survey (Figure E3, Table E4) clearly shows a predominance of young fish aged around 10 y, which remains consistent with the large 1982 recruitment 10 years earlier.

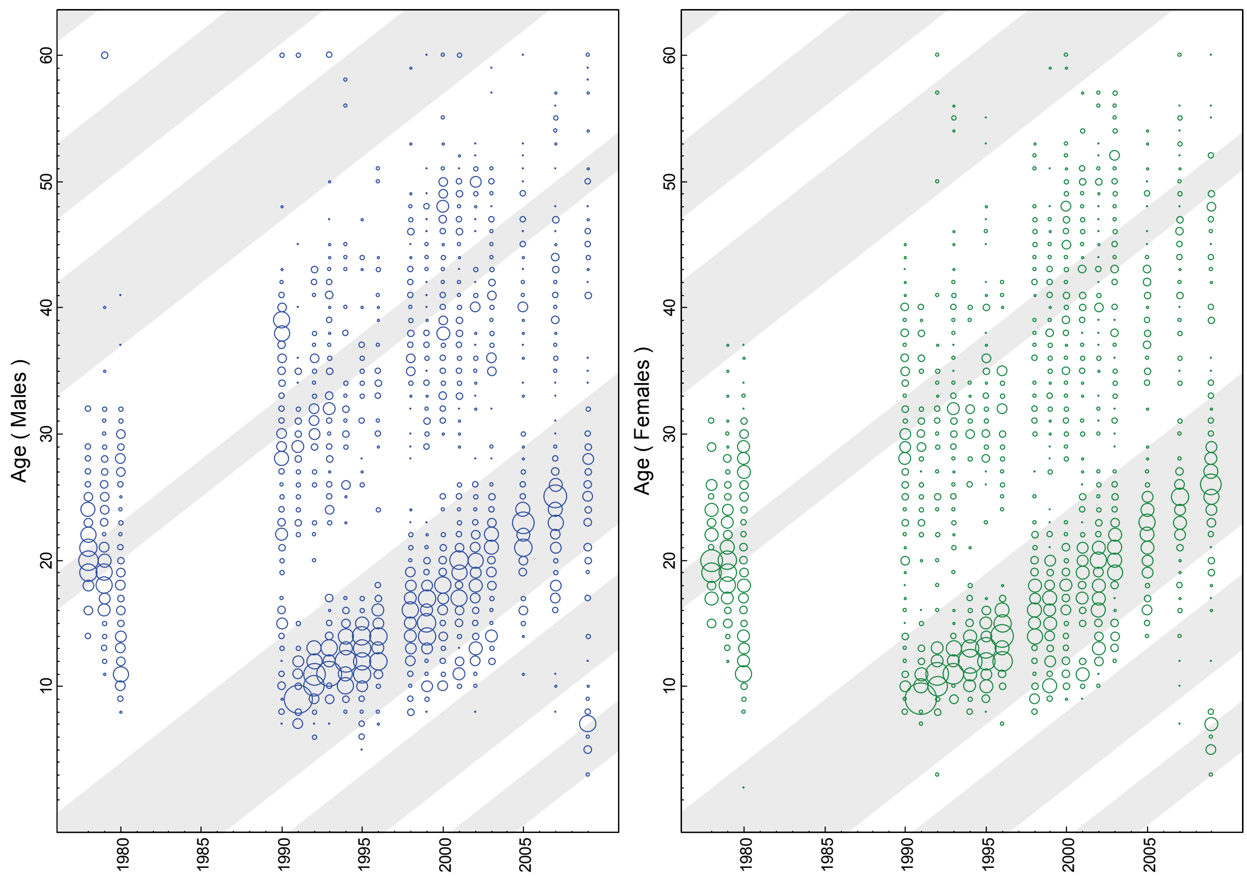


Figure E1. Commercial YMR proportions-at-age based on age frequencies weighted by trip catch within quarters and commercial catch within years. Diagonal shaded bands indicate cohorts that were born when the Pacific Decadal Oscillation was positive, potentially creating conditions in pelagic waters that foster productivity.

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

Year	# Trips				Trip catch (t)				Commercial catch (t)			
Quarter	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1978	0	1	0	0	0	2.9	0	0	86	266	552	311
1979	3	2	0	0	42.8	2.5	0	0	142	240	56	0
1980	0	2	3	2	0	56.4	57.3	54.8	0	230	224	97
1990	7	3	0	0	78.6	58.3	0	0	355	816	434	61
1991	4	0	1	0	50.9	0	4.5	0	411	479	236	103
1992	6	1	2	0	52.1	1.4	7.9	0	345	589	408	135
1993	2	5	0	1	12.4	16.1	0	5.9	389	369	139	264
1994	0	1	1	2	0	6.8	15.0	14.3	382	252	164	436
1995	4	0	3	1	42.7	0	16.0	3.4	540	461	419	31
1996	4	1	0	0	68.2	15.0	0	0	536	639	117	171
1998	4	3	2	1	70.4	36.1	23.5	6.0	466	657	530	202
1999	3	6	2	0	18.0	27.9	2.2	0	410	638	478	223
2000	1	3	3	0	1.8	27.9	11.1	0	672	647	594	126
2001	2	3	4	0	9.9	8.3	6.7	0	448	571	561	268
2002	0	4	4	1	0	24.4	21.3	4.5	534	575	724	185
2003	0	3	3	2	0	15.0	20.7	16.0	462	579	557	316
2005	0	2	5	2	0	4.5	22.7	33.1	441	533	761	231
2007	0	5	3	0	0	20.6	5.3	0	181	484	583	79
2009	3	1	3	0	8.8	0.0	22.5	0	257	483	721	132

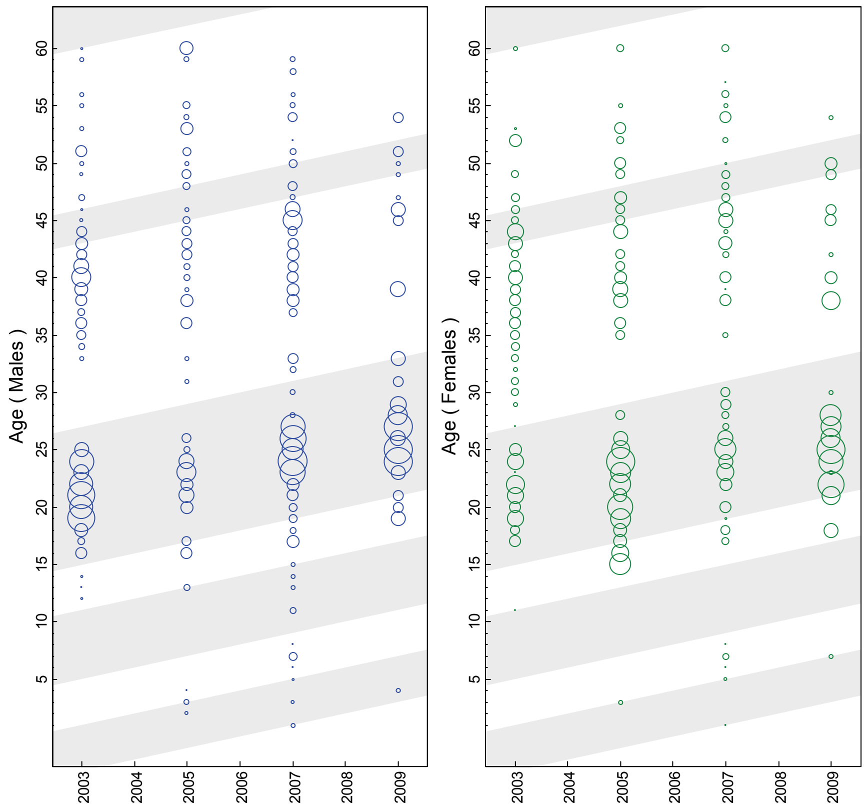


Figure E2. QCS Synoptic survey YMR proportions-at-age based on age frequencies weighted by sampled catch within strata and total catch within survey. See Figure E1 for details on diagonal shaded bands.

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

Strata▶ Year▼	**166**	**167**	**168**	**170**	**171**	**172**
#Samples						
2003	2	6	0	0	10	1
2005	0	1	1	2	3	0
2007	1	2	0	3	2	0
2009	0	3	0	0	2	0
Sample catch (t)						
2003	0.367	1.241	0	0	0.886	0.041
2005	0	0.062	0.002	0.026	0.679	0
2007	0.063	0.286	0	0.020	0.335	0
2009	0	0.542	0	0	1.104	0
Survey catch (t)						
2003	0.448	1.266	0	0.005	0.915	0.058
2005	0.142	1.025	0.002	0.130	1.375	0.005
2007	0.716	0.735	0.001	0.067	0.809	0
2009	0.143	1.153	0.008	0.170	2.536	0

*165 = S.50-125m 166 = S.125-200m 167 = S.200-330m 168 = S.330-500m
*169 = N.50-125m 170 = N.125-200m 171 = N.200-330m 172 = N.330-500 m

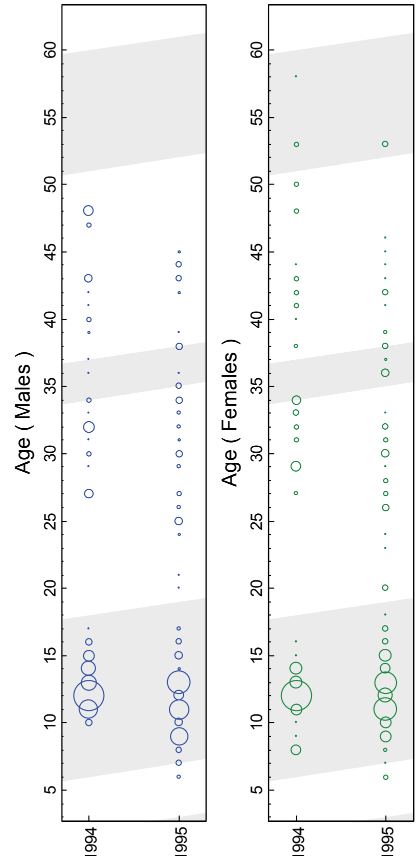


Figure E3. GIG Rockfish survey YMR proportions-at-age based on age frequencies weighted by sampled catch within strata and total catch within survey. See Figure E1 for details on diagonal shaded bands.

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

Year▼	**# Samples**			**Sample catch (t)**			**Survey catch (t)**		
Strata▶	**185**	**186**	**187**	**185**	**186**	**187**	**185**	**186**	**187**
1994	3	2	2	5.282	0.165	0.137	5.450	1.204	0.567
1995	4	2	2	9.558	1.150	1.077	11.063	4.399	3.935

*185 = 120-183m 186 = 183-218m 187 = 218-300m

APPENDIX F. DESCRIPTION OF CATCH-AT-AGE MODEL

INTRODUCTION

We used a sex-specific, age-structured model in a Bayesian framework. In particular, the model can simultaneously estimate the steepness of the stock-recruitment function and separate mortalities for males and females. This approach follows that used in our recent stock assessment of Pacific Ocean Perch (*Sebastes alutus*) in Queen Charlotte Sound (DFO 2011; further details in Edwards *et. al* 2012). For that assessment we presented results from four model runs, for which natural mortality and steepness were each either fixed or estimated. The two model runs that estimated steepness were endorsed as being equally plausible (DFO 2011) and the results were used to provide advice to management. The two runs that fixed steepness were rejected by the review committee. Thus, here we use model runs that estimate steepness, and either estimate natural mortality (run 'Estimate *M*') or fix it (run 'Fix *M*').

The model structure is the same as that used for the Pacific Ocean Perch assessment, although instead of the iterative reweighting procedure that was based on the standard deviation of normalised residuals (and did not perform well for the current assessment), we used the new weighting scheme of Francis (2011) desribed below.

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).

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

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

MODEL ASSUMPTIONS

The assumptions of the model are:

1. The stock in British Columbia waters was treated as a single coastwide stock. No population genetic studies of Yellowmouth Rockfish have been conducted, which led COSEWIC (2010) to consider all individuals as being part of a single population.

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 estimated when ageing data were available.

5. Natural mortality was held invariant over time, and either estimated independently for females and males (run ‘Estimate *M*’) or held fixed (run ‘Fix *M*’).

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. However, ageing error was incorporated into sensitivity runs (Appendix I).

10. Commercial samples of catch-at-age in a given year were assumed to be representative of the fishery if there were $\geq$5 samples (except for the 1994 sample – see Appendix E).

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

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 - West Coast Haida Gwaii synoptic survey 5 - West Coast Vancouver Island synoptic survey 6 - 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, $g = 1, 2, 3, 4, 5$, 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 = \{$1999, 2000, 2001, ..., 2010$\}$ $\mathbf{T}_4 = \{$2006, 2007, 2008, 2010$\}$ $\mathbf{T}_5 = \{$2004, 2006, 2008, 2010$\}$
$\mathbf{U}_g$	sets of model years with proportion-at-age data, $g = 1, 2, 6$ (listed here as actual years): $\mathbf{U}_1 = \{$1994, 1995$\}$ $\mathbf{U}_2 = \{$2003, 2005, 2007, 2009$\}$ $\mathbf{U}_6 = \{$1979, 1980, 1990, 1991, ..., 1996, 1998, ..., 2003, 2005, 2007, 2009$\}$
	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 $t \in \mathbf{U}_g$, $g = 1, 2, 6$
n_{tg}	assumed sample size that yields corresponding p_{atgs}
C_t	observed catch biomass in year $t = 1, 2, ..., T-1$, tonnes
w_{as}	average weight of individual of age-class a of sex s from fixed parameters, kg
m_a	proportion of age-class a females that are mature, fixed from data
I_{tg}	biomass estimates from surveys $g = 1, 2, 3, 4, 5$ 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, $v_R = e^{100}$

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 of age-1 fish (numbers of fish, 1000s)
M_s	natural mortality rate for sex s, $s = 1, 2$
h	steepness parameter for Beverton-Holt recruitment
q_g	catchability for survey series g, $g = 1, 2, 3, 4, 5$
μ_g	age of full selectivity for females for series $g = 1, 2, ..., 6$
Δ_g	shift in vulnerability for males for series g
v_{gL}	variance parameter for left limb of selectivity curve for series $g = 1, 2, ..., 6$
s_{ags}	selectivity for age-class a, series $g = 1, 2, ..., 6$, 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)
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 ($2 \leq t \leq T,\ s=1,2$)

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

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

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

Initial conditions ($t=1$)

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

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

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

Selectivities ($g = 1, 2, ..., 6$)

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

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

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

$$\widehat{I}_{tg} = q_g \sum_{s=1}^{2} \sum_{a=1}^{A} e^{-M_s/2}(1 - u_{ats}/2) w_{as} s_{ags} N_{ats}\,; \quad t \in \mathbf{T}_g,\ g = 1,2,3,4,5 \tag{F.14}$$

$$\widehat{p}_{atgs} = \frac{e^{-M_s/2}(1 - u_{ats}/2) s_{ags} N_{ats}}{\sum_{s=1}^{2} \sum_{a=1}^{A} e^{-M_s/2}(1 - u_{ats}/2) s_{ags} N_{ats}}; \quad 1 \leq a \leq A,\ t \in \mathbf{U}_g,\ g = 1,2,6,\ s = 1,2 \tag{F.15}$$

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

$$\boldsymbol{\Theta} = \{R_0, M_1, M_2, h, q_1, q_2, q_3, q_4, q_5, \mu_1, \mu_2, \mu_6, \Delta_1, \Delta_2, \Delta_6, v_{1L}, v_{2L}, v_{6L}\} \tag{F.16}$$

Recruitment deviations

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

Log-likelihood functions

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

$$\begin{aligned}\log L_2(\boldsymbol{\Theta}|\{\widehat{p}_{atgs}\}) = &-\frac{1}{2}\sum_{g=1,2,6}\sum_{a=1}^{A}\sum_{t\in\mathbf{U}_g}\sum_{s=1}^{2}\log\left[p_{atgs}(1-p_{atgs}) + \frac{1}{10A}\right] \\ &+ \sum_{g=1,2,6}\sum_{a=1}^{A}\sum_{t\in\mathbf{U}_g}\sum_{s=1}^{2}\log\left[\exp\left\{\frac{-(p_{atgs}-\widehat{p}_{atgs})^2\;n_{tg}}{2\left(p_{atgs}(1-p_{atgs})+\frac{1}{10A}\right)}\right\} + \frac{1}{100}\right]\end{aligned} \tag{F.19}$$

$$\log L_3(\boldsymbol{\Theta}|\{\widehat{I}_{tg}\}) = \sum_{g=1}^{5}\sum_{t\in\mathbf{T}_g}\left[-\frac{1}{2}\log 2\pi - \log\kappa_{tg} - \frac{(\log I_{tg} - \log\widehat{I}_{tg})^2}{2\kappa_{tg}^2}\right] \tag{F.20}$$

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

Joint prior distribution and objective function

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

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

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
R_0	uniform	–	[1,10^7]	10^5
M_1, M_2	normal	0.047, 0.005	[0.01,0.12]	0.047
h	beta	0.674, 0.168	[0.2,0.999]	0.674
$\log q_g, g = 1,2,3,4,5$	uniform	–	[-12,5]	-5
$\mu_g, g = 1,2,6$	normal	7.21291, 2.16387	[1,40]	7.21291
$\log v_{gL}, g = 1,2,6$	normal	1.7641, 0.529231	[-15,15]	1.7641
$\Delta_g, g = 1,2,6$	normal	0,1	[-8,10]	0

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 virgin (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 five 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, $g = 3$ is the Queen Charlotte Sound shrimp survey, $g = 4$ is the West Coast Haida Gwaii synoptic survey (note that Haida Gwaii was formerly known as the Queen Charlotte Islands) and $g = 5$ is the West Coast Vancouver Island synoptic 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 assumed sample sizes n_{tg}). Note that there are no

$\mathbf{U_3}, \mathbf{U_4}$ or $\mathbf{U_5}$ because there are no age data for those surveys.

Commercial data

As described in Appendix B, the commercial catch has been reconstructed back to 1918. Given the negligible catches in the early years, the model was started in 1940, and catches prior to 1940 were not considered. The time series for catches is denoted C_t. The set $\mathbf{U}_6$ (Table F1) gives the years of available ageing data from the commercial fishery. The proportions-at-age values are given by p_{atgs} with assumed sample size n_{tg}, where $g = 6$ (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 is assumed fix 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 (Appendix B). The initial conditions (F.4) and (F.5) are obtained by setting $R_t = R_0$ (virgin recruitment), $N_{ats} = N_{a1s}$ (equilibrium condition) and $u_{ats} = 0$ (no fishing) into (F.1)-(F.3). The virgin spawning biomass B_0 is then obtained from (F.9).

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 $s_{\dots}$ 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 natural mortality term $e^{-M_s/2}$ (that accounts for half of the annual natural mortality), the term $1 - u_{ats}/2$ (that accounts for half of the commercial catch), weights-at-age w_{as} (to convert to biomass) and selectivity s_{ags}. The sum (over ages and sexes) is then multiplied by the catchability parameter q_g to give the model biomass estimate $\widehat{I}_{tg}$. 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 $\mathbf{\Theta}$ 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, which was the value used in the Pacific Ocean Perch assessment (determined empirically from model fits).

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
   - a reweighting procedure is performed
2. generate samples from the joint posterior distributions of the parameters using Monte Carlo Markov Chain (MCMC) procedure, starting the chains from the MPD estimates.

The details for these steps are now given.

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, q_4, q_5

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_6

phase 4: selectivity parameters Δ_g, v_{gL} for $g = 1, 2, 6$, and mortalities M_1, M_2 if they were estimated

phase 5: steepness h.

Reweighting

Given that sample sizes are not comparable between different types of data, a procedure that adjusts the relative weights between data sources is required. For the

Pacific Ocean Perch assessment we used an iterative reweighting scheme based on adjusting the standard deviation of normal residuals of data sets until these standard deviations were approximately 1. This procedure did not perform well for the Yellowmouth Rockfish assessment, leading to spurious cohorts. Instead we used the reweighting scheme proposed by Francis (2011).

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

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

For each survey index, I_{tg} ($g = 1, 2, 3, 4, 5; t \in \mathbf{T}_g$), the associated standard deviation is κ_{tg}. The associated coefficient of variation is therefore κ_{tg}/I_{tg}, which is used in (F.25) to determine the reweighted coefficient of variation associated with κ_{tg}. This reweighted coefficient of variation is then converted back to a standard deviation, which is used as the reweighted standard deviation κ_{tg} in the likelihood function (F.20).

Francis (2011) maintains that correlation effects are usually strong in age-composition data. Each age-composition data set has a sample size n_{tg} ($g = 1, 2, 6$, $t \in \mathbf{U}_g$), which is typically in the range 5-20. Francis' (2011) equation (T3.4) is used to iteratively reweight the sample size as

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

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

The Francis (2011) weight $W_g^{(r)}$ given to each data set takes into account deviations from the mean weight for each year, rather than the scheme used for the Pacific Ocean Perch assessment that considered deviations from each proportion-at-age value. It is given by Francis' (2011) equation (TA1.8):

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

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

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

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

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

and Var$_t$ is the usual finite-sample variance function applied over the index t. We used this approach iteratively with $r = 1, 2, ..., 6$, but found that reweightings after the first ($r = 1$) had little effect, and so reported model runs are based on the first reweighting.

Prior distributions

Descriptions of the prior distributions for the 18 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.

A uniform prior over a large range was used for R_0. The parameters for the normal priors for M_1 and M_2 were based on Haigh and Starr (2008) and ongoing work by O. Hamel (NOAA, pers. comm.), as described in Appendix D. For steepness, h, the same prior was used as for the Pacific ocean perch assessment – a beta distribution with values fitted to the posterior distribution for rockfish calculated by Forrest *et al.* (2010), with the Pacific ocean perch data removed (R. Forrest, DFO, pers. comm., though removing those data made little difference to the distribution). Uniform priors on a logarithmic scale were used for the catchability parameters q_g The priors for the selectivity parameters μ_g are discussed in Appendix D.

MCMC properties

The MCMC searches for both presented model runs were the same: starting from the MPD values, 5,000,000 iterations were performed, sampling every 5,000th for 1,000 samples, which were used with no burn-in period (because the MCMC searches started from the MPD values).

REFERENCE POINTS, PROJECTIONS AND ADVICE TO MANAGERS

Advice to managers is given with respect to three sets of reference points or reference criteria. The first set consists of the provisional reference points of the DFO

Precautionary Approach (DFO 2006), namely $0.4B_{MSY}$ and $0.8B_{MSY}$ (and we also provide B_{MSY} – see main text); B_{MSY} is the estimated equilibrium spawning biomass at the maximum sustainable yield (MSY). The second set of reference points is based on B_0, the estimated unfished equilibrium spawning biomass. The reference criteria are defined in terms of a changing reference biomass, B_{t-3Gen} (the spawning biomass three generations before B_t, which is itself the spawning biomass at the beginning of year t). See main text for further discussion.

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

For run 'Estimate *M*', an equilibrium was not reached for only 3 out of the 1,000 MCMC samples (the maximum value of $u_t = 0.3$ was attained). For the other 997 samples (and for all 1,000 samples for run 'Fix *M*'), equilibrium was reached (the model was run for a maximum of 15,000 years with a 0.01 tolerance for defining that equilibrium yield had been reached).

The probability P$(B_{2011} > 0.8B_{MSY})$ is then calculated as the proportion of the 1,000 MCMC samples for which $B_{2011} > 0.8B_{MSY}$ (and similarly for the other reference points).

Projections were made for 90 years (as requested at the review meeting), starting with the biomass and age structure calculated for the start of 2011. A range of constant catch strategies were used, from 0-3000 t (the average catch from 2006-2010 is 1442 t). For each strategy, projections were performed for each of the 1,000 MCMC samples (resulting in posterior distributions of future spawning biomass). Recruitments were randomly calculated using (F.24) (i.e. based on lognormal recruitment deviations from the estimated stock-recruitment curve), using randomly generated values of $\epsilon_t \sim$ Normal$(0, \sigma_R^2)$. For each of the 1,000 MCMC samples a time series of $\{\epsilon_t\}$ was generated. For each MCMC sample, the same time series of $\{\epsilon_t\}$ was used for each catch strategy (so that, for a given MCMC sample, all catch strategies experience the same recruitment stochasticity).

APPENDIX G. STOCK ASSESSMENT MODEL RESULTS

INTRODUCTION

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

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, indices from five fishery-independent surveys, and proportions-at-age data from three sources:

a) the commercial trawl fishery (weighted to reflect sample catch and the quarterly commercial catch of Yellowmouth Rockfish);

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

c) four years of the QCS synoptic survey.

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. All available discard estimates were added to the catches.

Biomass indices

The annual biomass indices from the five fishery-independent surveys and the associated relative error from each survey year were used as model inputs, and are calculated in Appendix C.

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 age, 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 mean-age adjustment procedure of Francis (2011) described in Appendix F.

Weight-at-age and growth

Growth parameters were estimated from Yellowmouth Rockfish length and age data from biological samples from research surveys (Appendix D). Parameters for the allometric length-weight relationship were estimated for Yellowmouth of both sexes. 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 mature at ages 1 through age 20 was computed from biological samples (Appendix D). Maturity for females older than 20 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

The model was implemented using a modified version of the Coleraine statistical catch-at-age software (Hilborn *et al.* 2003) called Awatea (A. Hicks, NOAA, pers. comm.), which implements the ADMB (Automatic Differentiation Model Builder) software (Otter Research 1999). Appendix F provides details of the model, including all major assumptions, equations, and brief discussion of the approach used to streamline the implementation and handling of output.

For the recent Pacific Ocean Perch assessment for Queen Charlotte Sound waters (DFO 2011, Edwards *et al.* 2012), the same Awatea model as used for this Yellowmouth assessment (except for the new reweighting scheme of Francis 2011, discussed in Appendix F).

Results are presented here from two model runs, differing in their handling of sex-specific natural mortality. The two model runs are termed 'Estimate *M*' and 'Fix *M*':

a) `Estimate *M*' – estimate mortalities of males and females separately, using informed priors described in Appendix F;

b) `Fix *M*' – fix mortality for both sexes at the mean value of the prior.

Model fits to the data gave sensible and reasonably consistent results for both model runs. 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.

Sensitivity tests are discussed in Appendix I, including one concerning ageing error. Using the simple assumption that 10% of observed ages were actually one year below the true age, and that 10% were one year above, had little influence on the results. Increasing the error percentages to 20% resulted in poorly performing MCMC simulations. Ranges of possible ages for each otolith are recorded by the ageing specialists who analyse the otoliths, and inspection of these ages showed that to properly incorporate ageing error would require exploratory research.

MPD (MODE OF THE POSTERIOR DISTRIBUTION) STOCK ASSESSMENT RESULTS

Awatea first determines the mode of the posterior distribution (MPD) for each estimated parameter. These are then used as the starting points for the MCMC simulations. Likelihood components for the MPD fits to the data were similar for both runs (Table G2).

The differences observed between the two runs were small and were not considered to be a reliable way to select between them. Visual examination of the MPD fits to the data and the patterns of residuals showed nearly identical results for both runs. Accordingly, plots of the MPD model fits and residual patterns are only provided for one run (‘Estimate *M*’), which is the run that incorporates the greatest amount of uncertainty (because it estimates, rather than fixes, natural mortality).

The MPD fits for run ‘Estimate *M*’ are shown for the survey indices (Figures G1-G4), the commercial catch-at-age data (as bubble plots in Figures G5-G8 and as overlaid age structures in Figures G9 and G10), the GIG historical survey series age data (Figure G11) and the QCS synoptic survey age data (Figure G12). Mean ages for the three age data sets are shown in Figure G13. Residuals to the MPD model fits are provided for the survey indices (Figure G14 and G15), the three age data sets (Figures G16-G18). The model is able to capture the main features of the age data fairly well. For example, the strong cohort seen entering the fishery in the early 1990s (Figures G5 and G6) is fitted by the model (Figures G9 and G10). However, older age classes seem slightly under-represented. The residuals show no strong trends over time. All these features were the same for the ‘Fix *M*’ run.

A comparison of the stock-recruitment functions resulting from the two model runs shows a similar pattern (Figure G19), but the magnitudes of estimated spawning biomass and recruitment differ due to the ‘Estimate *M*’ run estimating larger-sized populations than the ‘Fix *M*’ run, as described below with respect to the MCMC results.

BAYESIAN (MCMC) STOCK ASSESSMENT RESULTS

MCMC search

The MCMC searches for both model runs were the same: 5,000,000 iterations were performed, sampling every 5,000th for 1,000 samples. The 1,000 samples were used with no burn-in period (because the MCMC searches started from the MPD values). MCMC traces for run ‘Estimate *M*’ show good convergence properties (no trend with increasing sample number) for the estimated parameters (Figure G20), as does a diagnostic analysis that splits the samples into three segments (Figure G21). Pairs plots of the estimated parameters (Figures G22-G24) show no undesirable correlations between parameters. In particular, steepness, h, and the two natural mortality parameters, M_1 and M_2, show little correlation, suggesting there are sufficient data to estimate them simultaneously. Trace plots of the derived quantities ‘female spawning biomass’ (Figure G25) and recruitment (Figure G26) also show good convergence properties. Similar results hold for run ‘Fix *M*’. Thus, the MCMC computations seem satisfactory.

Marginal posterior distributions and corresponding priors for the estimated parameters are shown for run ‘Estimate *M*’ (Figure G27) and run ‘Fix *M*’ (Figure G28). For most parameters, it appears that there is enough information in the data to move the posterior distribution away from the prior. Corresponding summary statistics for the estimated parameters are given for run ‘Estimate *M*’ in Table G3 and for run ‘Fix *M*’ in Table G4.

Tables G3 and G4 demonstrate the main difference between the two runs. Run ‘Estimate *M*’ estimates median natural mortalities of 0.0595 and 0.0559 (for females and males, respectively), larger than the fixed value of 0.047 for run ‘Fix *M*’ (this fixed value is the mean of the prior used for run ‘Estimate *M*’). The increased mortality requires run ‘Estimate *M*’ to estimate larger spawning biomasses and recruitments (see Figure G19) than for run ‘Fix *M*’, to sustain the same absolute level of catches This results in a median estimate of virgin recruitment (R_0) of 7,342 (1000s of fish) for run 'Estimate *M*', 82% larger than the median of 4,034 for run 'Fix *M*'. The medians of the catchability parameters (q_g) are consequently smaller for run 'Estimate *M*' (Table G3) compared to those for run 'Fix *M*' (Table G4), because of the larger estimated biomasses for run 'Estimate *M*'.

The MPD selectivity curves for run 'Estimate *M*' (Figure G29) show that, when estimated, the estimated age at full selectivity for females (mu_1, mu_2 and mu_6 in Figure G28) is over 11 years, whereas the prior for these parameters had a mean of 7.2 years (Table F4). Initial model exploration used informed priors but in the end we used a prior derived from the US commercial fishery on Darkblotched Rockfish for all surveys (or fixed it at such values if selectivity was not estimated) except the QCS shrimp survey (see Appendix D) The latter used selectivity estimates from a US shelf survey as the fixed parameter values.

Marginal posterior densities are also shown for run 'Estimate *M*' for the annual spawning biomass (Figures G30-G32) and the annual age-1 recruitments (Figures G33-G35). Some of these show appropriately wide distributions, resulting from the wide distributions shown for some of the estimated parameters (Figure G27). However, in most instances, the mode of the posterior distribution is very close to the MPD estimates, indicating that the posterior distributions do not appear to be skewed by data outliers.

Plots of marginal posterior distributions of annual recruitment, exploitation rate, vulnerable biomass, and biomass relative to virgin levels are presented in the main text (for both model runs), because of their interest to management. Time-evolution of spawning biomass and exploitation rate relative to reference points and criteria are also shown in the main text, together with projections and resulting decision tables.

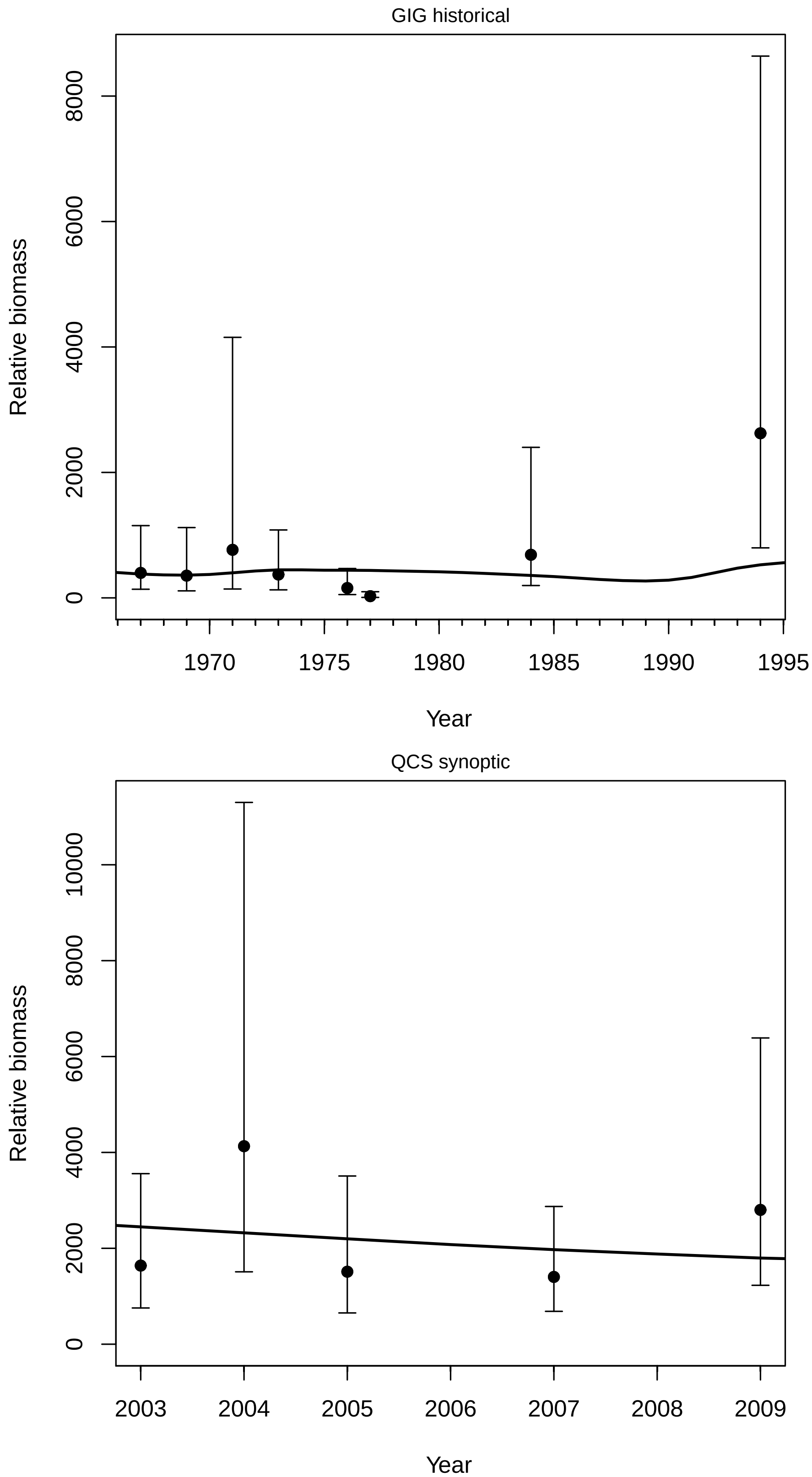


Figure G1. Survey index (points) values with 95% confidence intervals (bars) and MPD model fits (curves) for run 'Estimate M', for GIG historical and QCS synoptic survey series.

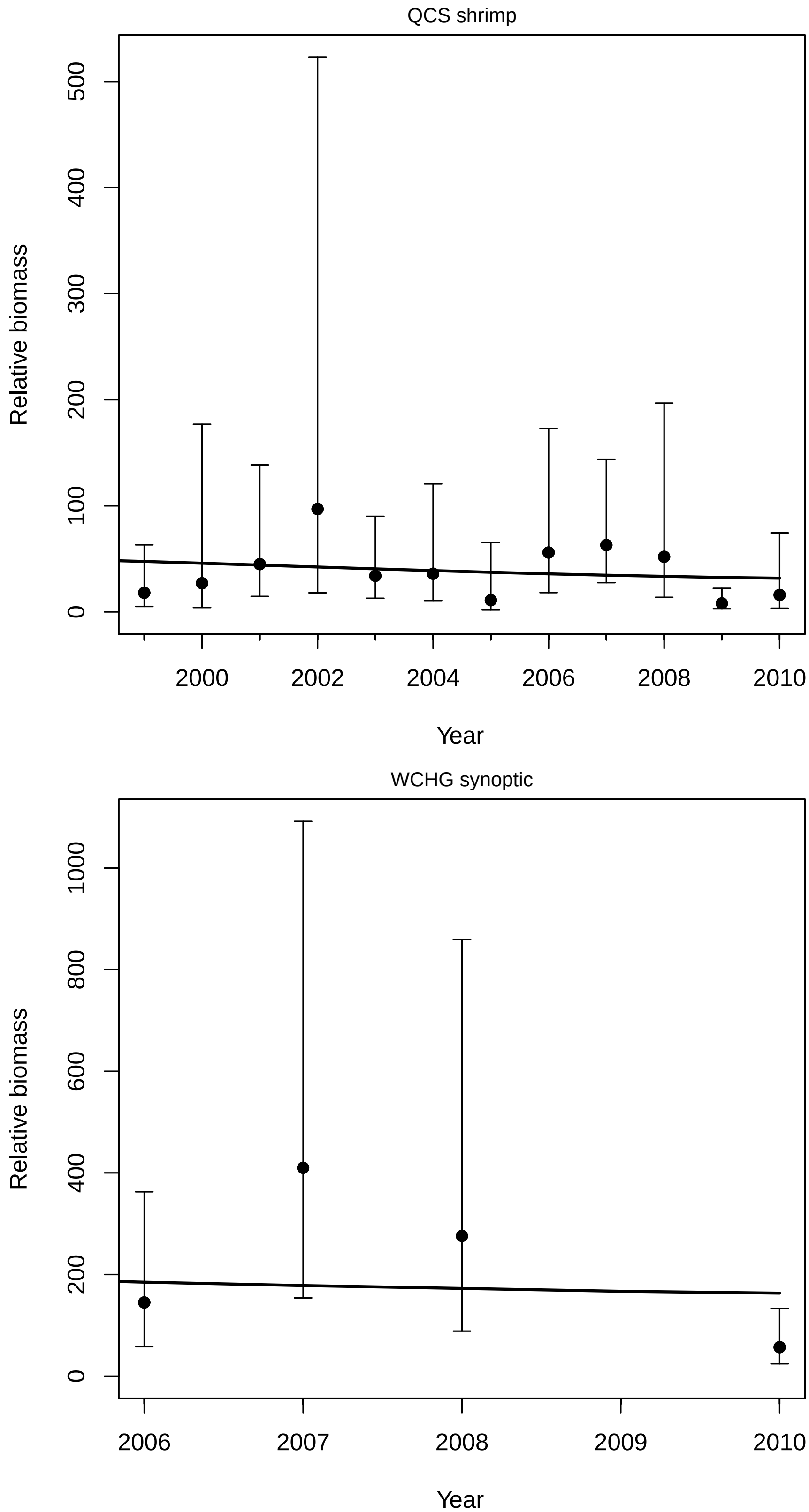


Figure G2. Survey index (points) values with 95% confidence intervals (bars) and MPD model fits (curves) for run 'Estimate M', for QCS shrimp and WCHQ synoptic survey series.

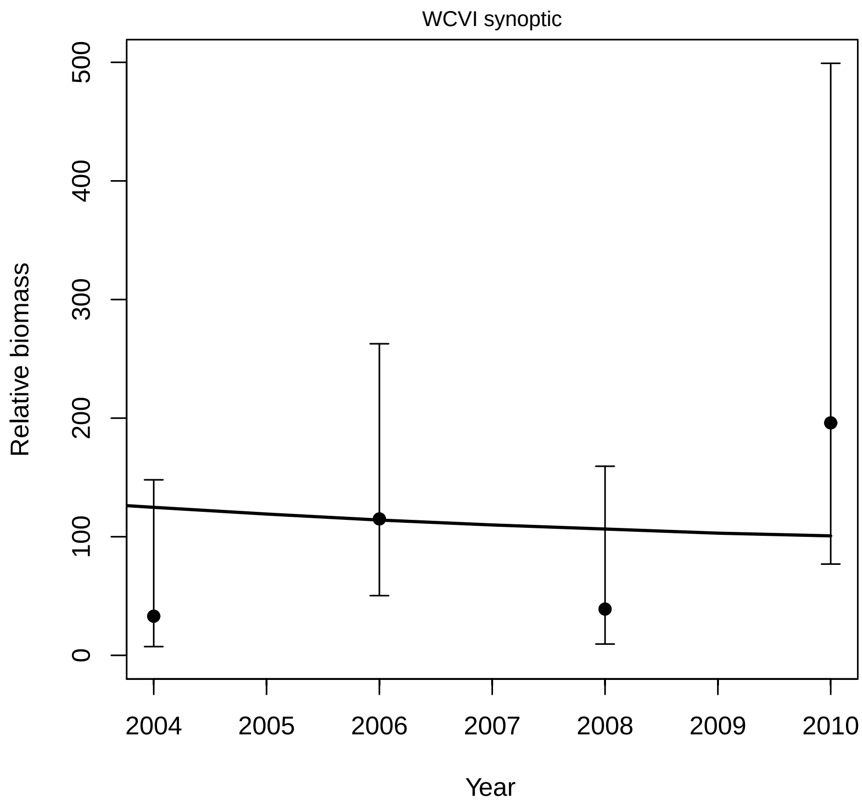


Figure G3. Survey index (points) values with 95% confidence intervals (bars) and MPD model fits (curves) for run 'Estimate M', for WCVI synoptic survey series.

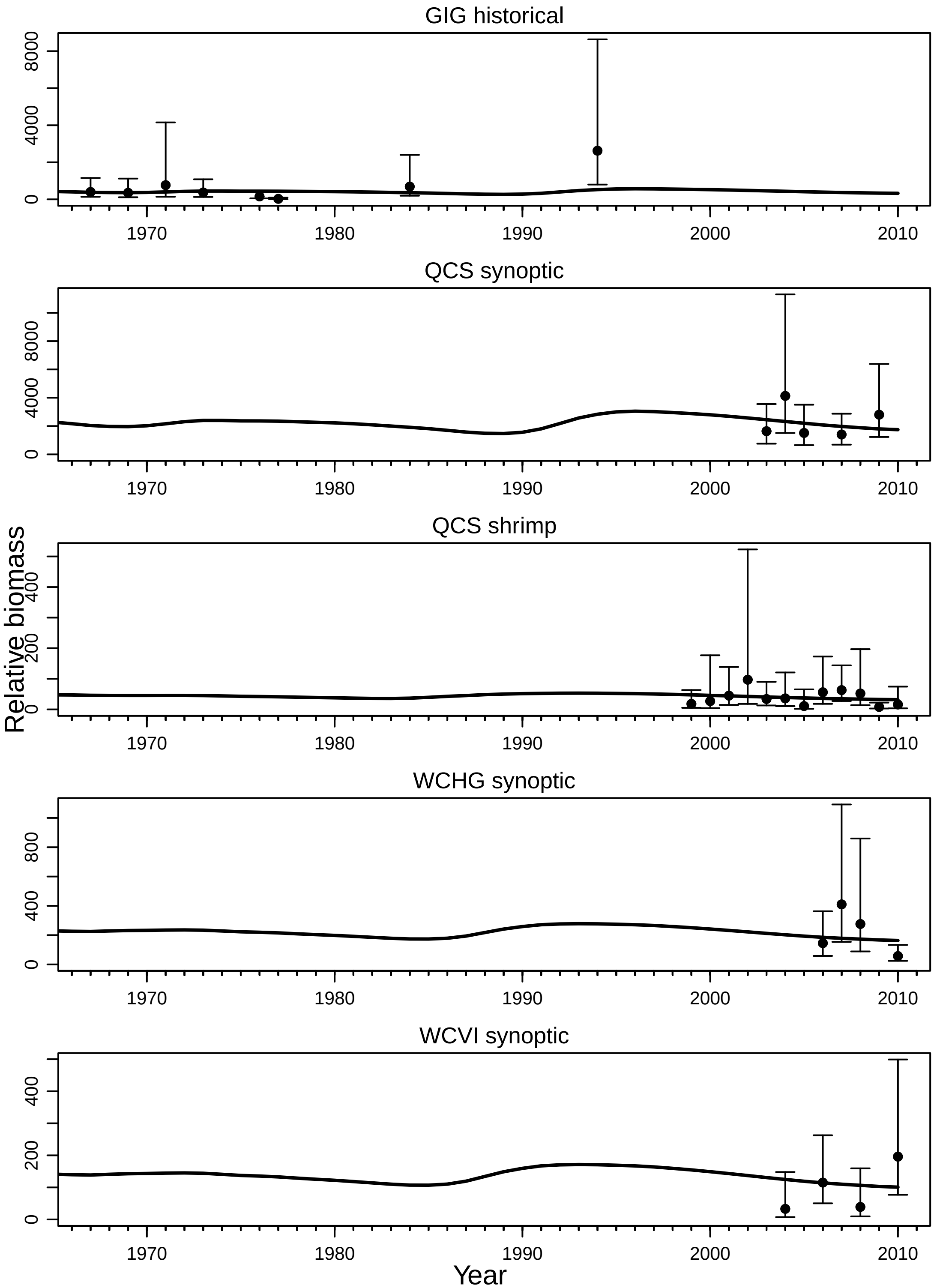


Figure G4. Fits to the five fishery-independent surveys for run 'Estimate M', with the same year axis for all time series.

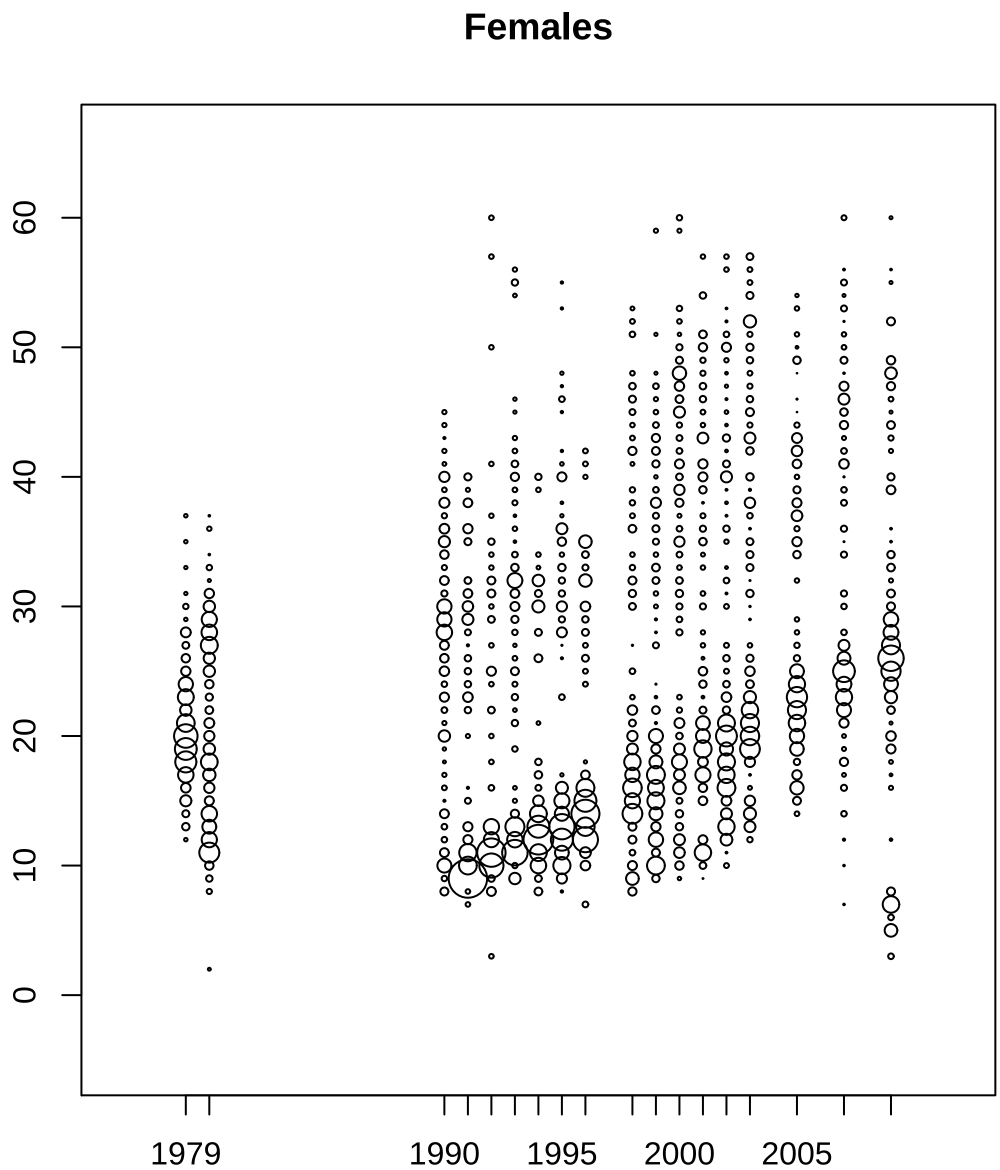


Figure G5. Commercial catch-at-age data for females. Bubbles are, for each year, the proportions assigned to each age class, based on the weighted age calculations described in Appendix E. Bubble areas are proportional to the respective proportions, such that areas sum to 1 for each year.

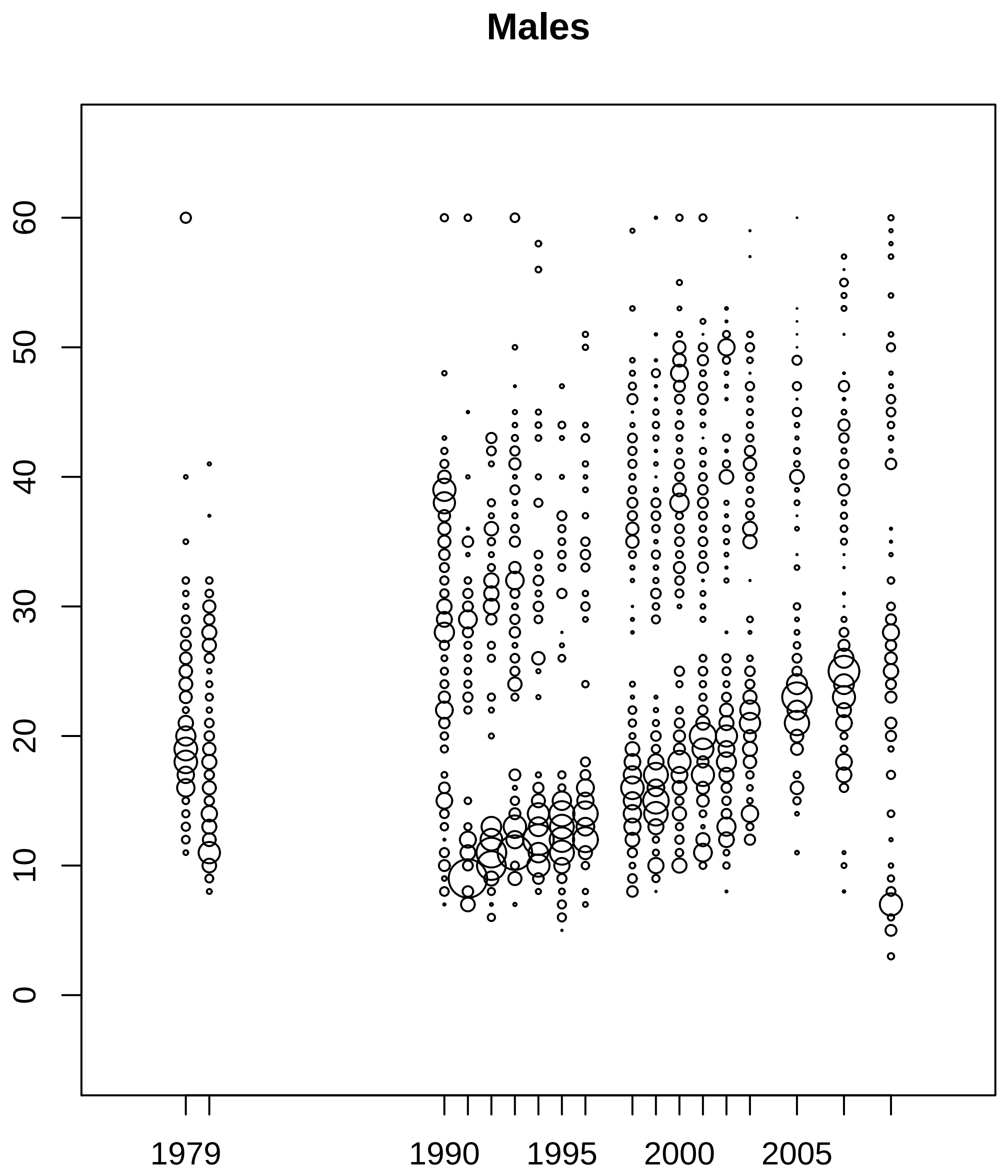


Figure G6. Commercial catch-at-age data for males, details as for Figure G5.

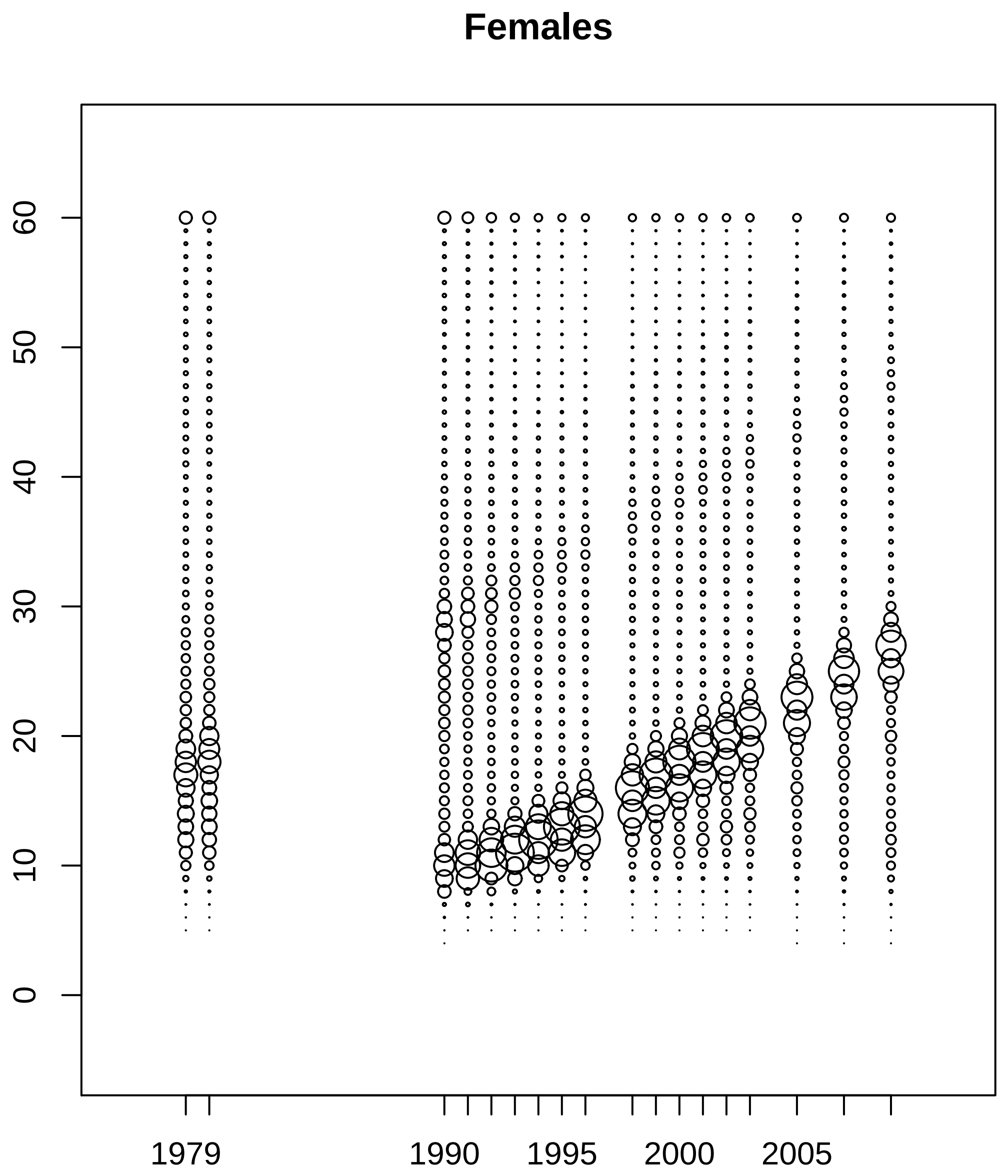


Figure G7. Estimated proportions-at-age for females from run 'Estimate M'. Only years for which commercial data are available are shown.

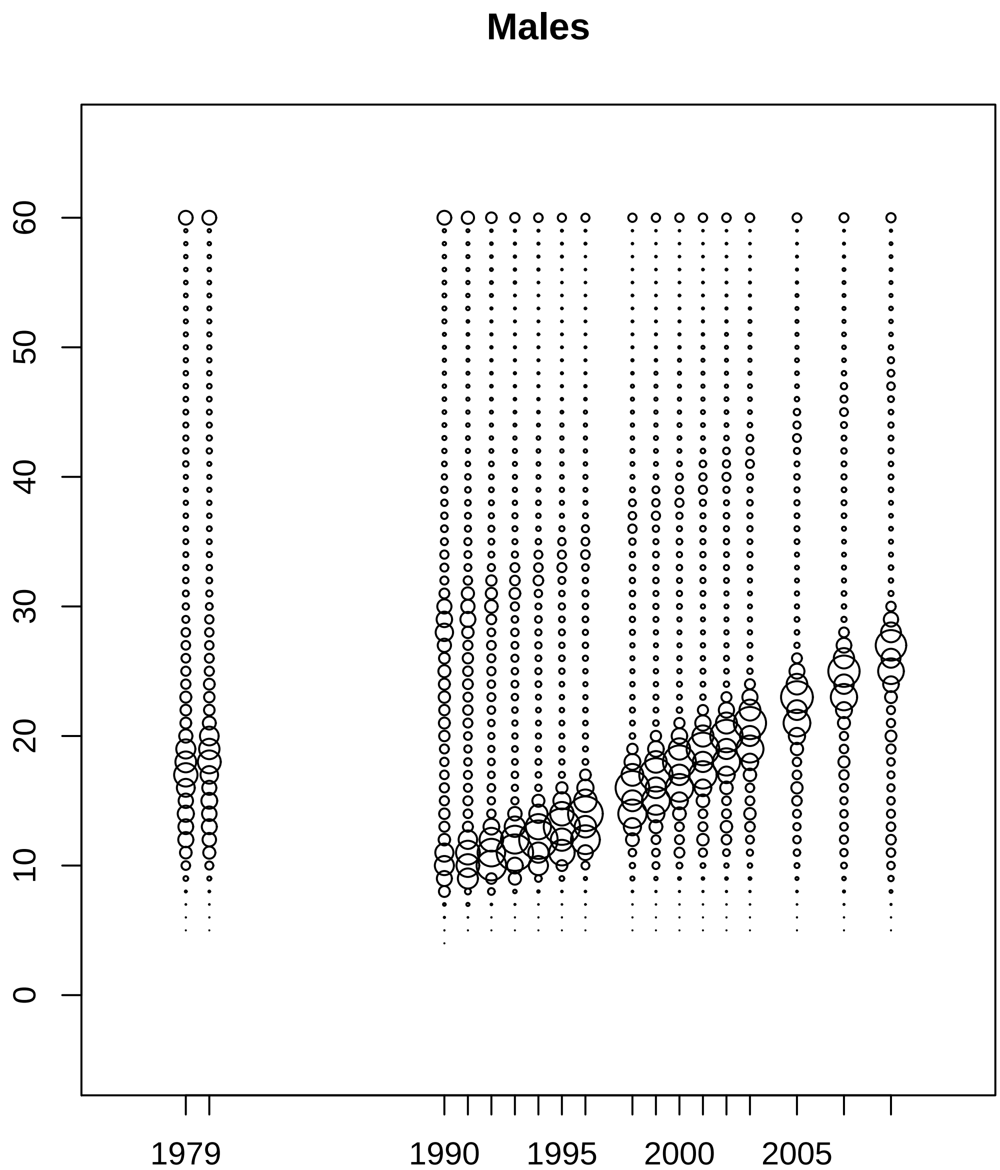


Figure G8. Estimated proportions-at-age for males from run 'Estimate M'. Only years for which commercial data are available are shown.

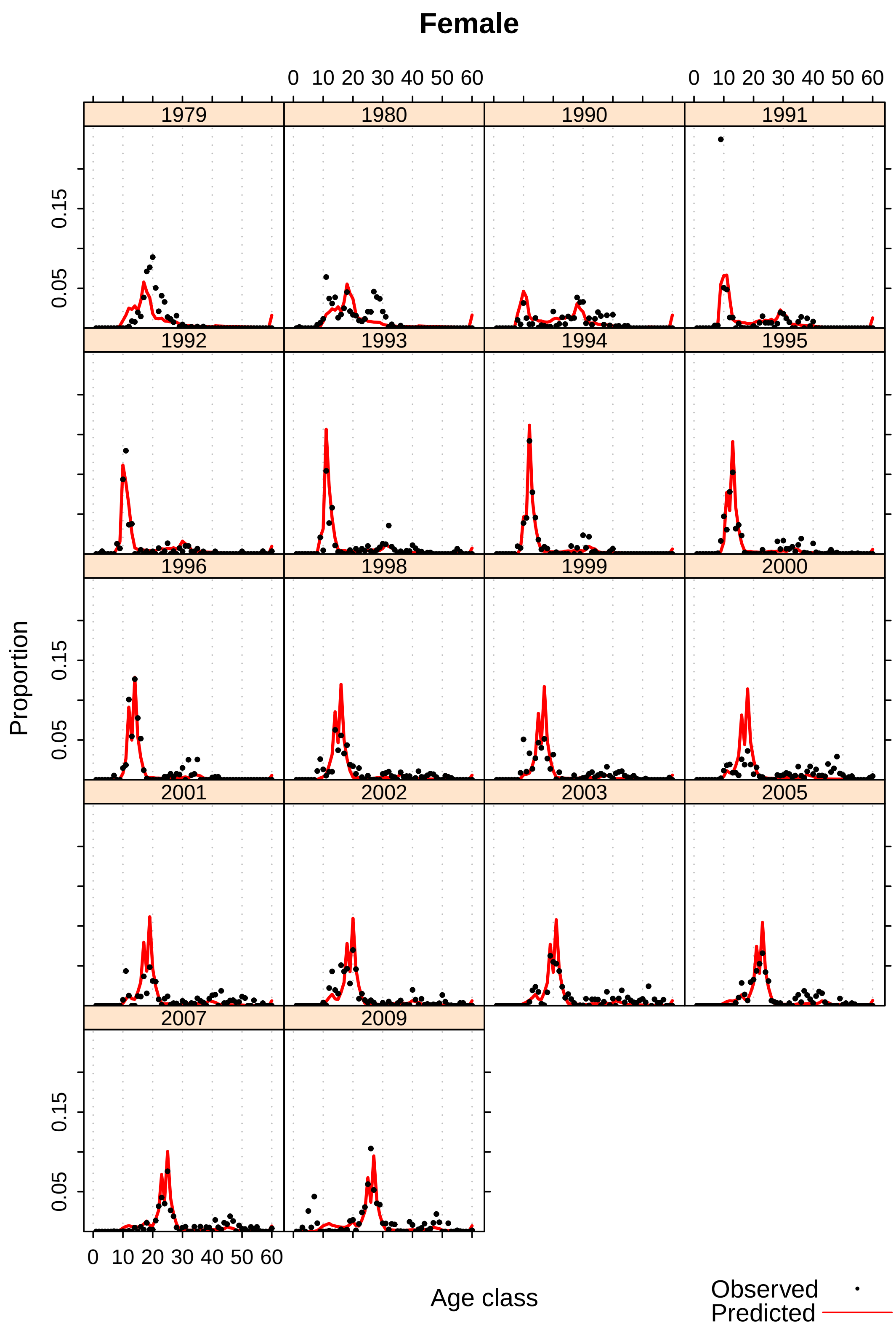


Figure G9. Observed and predicted commercial proportions-at-age for females for run 'Estimate M'. Note that years are not consecutive.

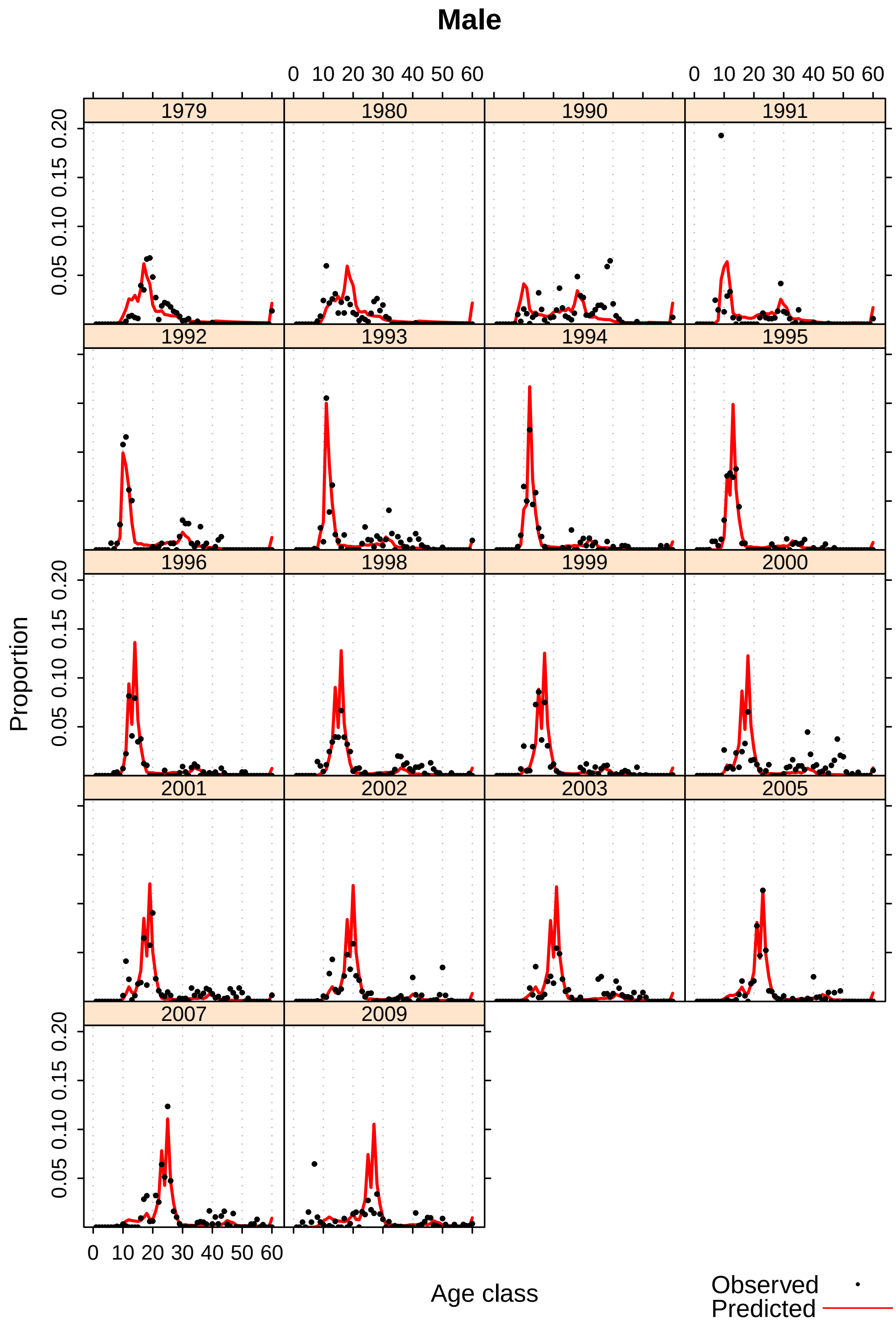


Figure G10. Observed and predicted commercial proportions-at-age for males for run 'Estimate M'. Note that years are not consecutive.

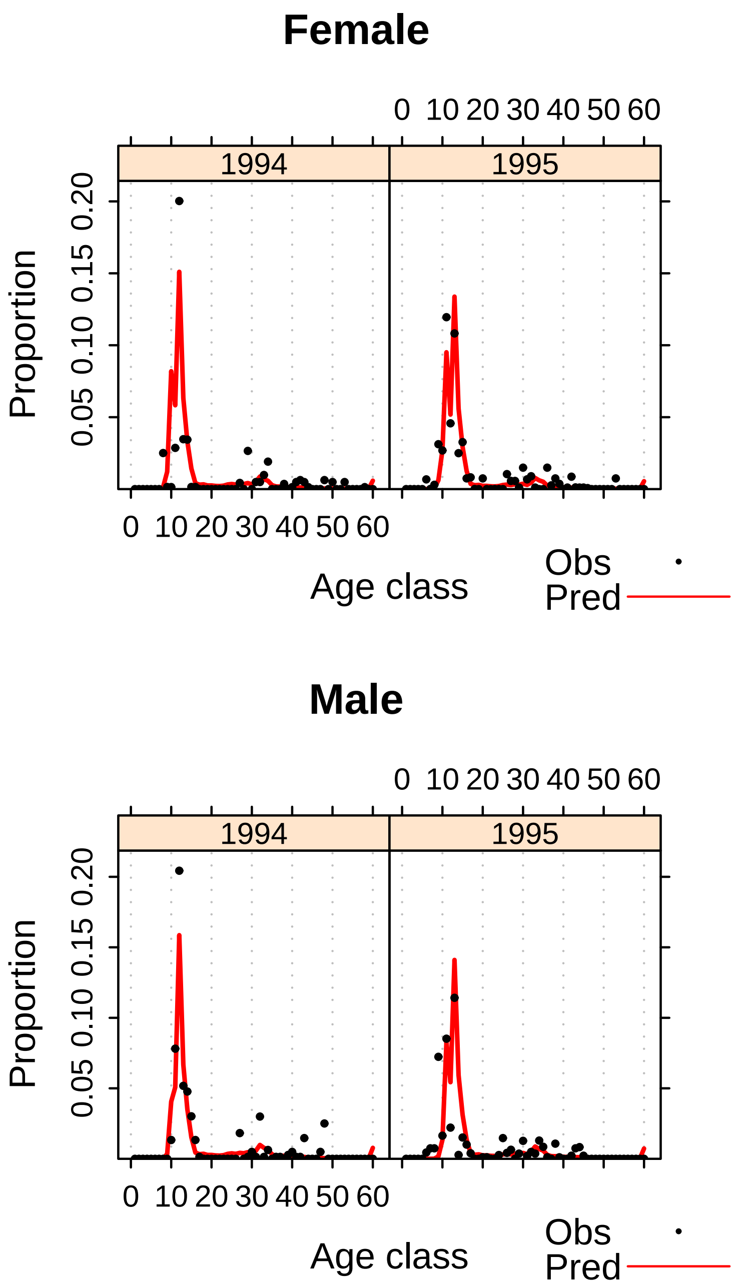
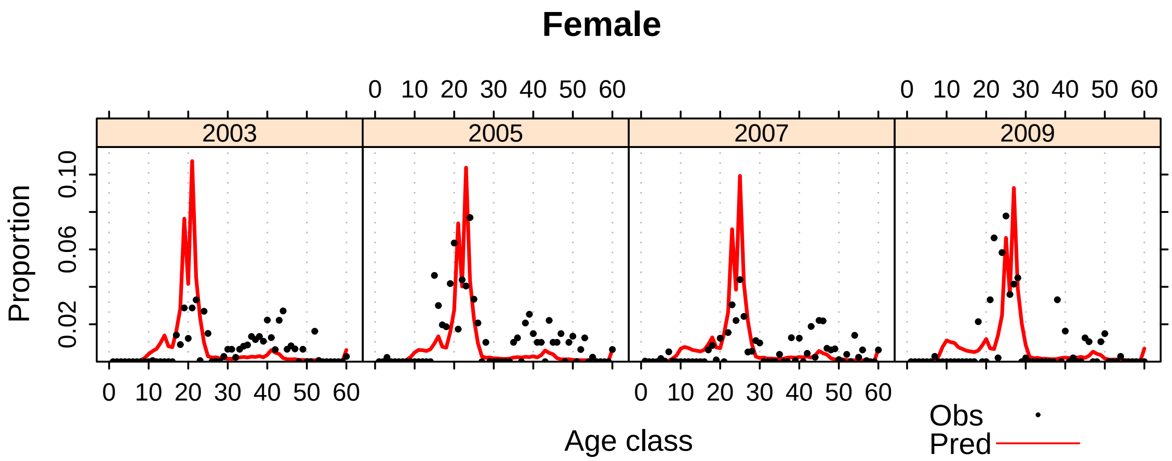


Figure G11. Observed and predicted proportions-at-age for data from Goose Island Gully survey data for run 'Estimate M'.



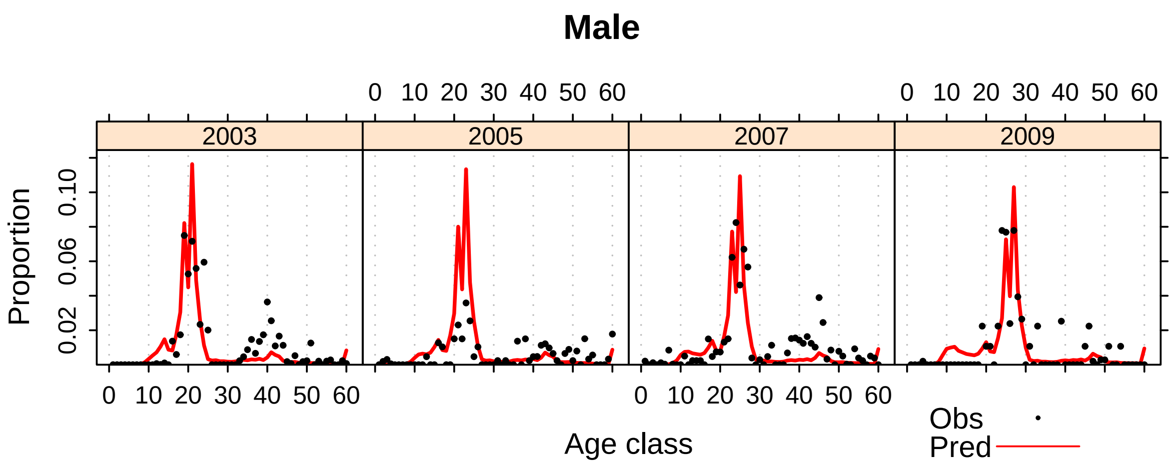


Figure G12. Observed and predicted proportions-at-age for data from Queen Charlotte Sound synoptic survey series for run 'Estimate M'.

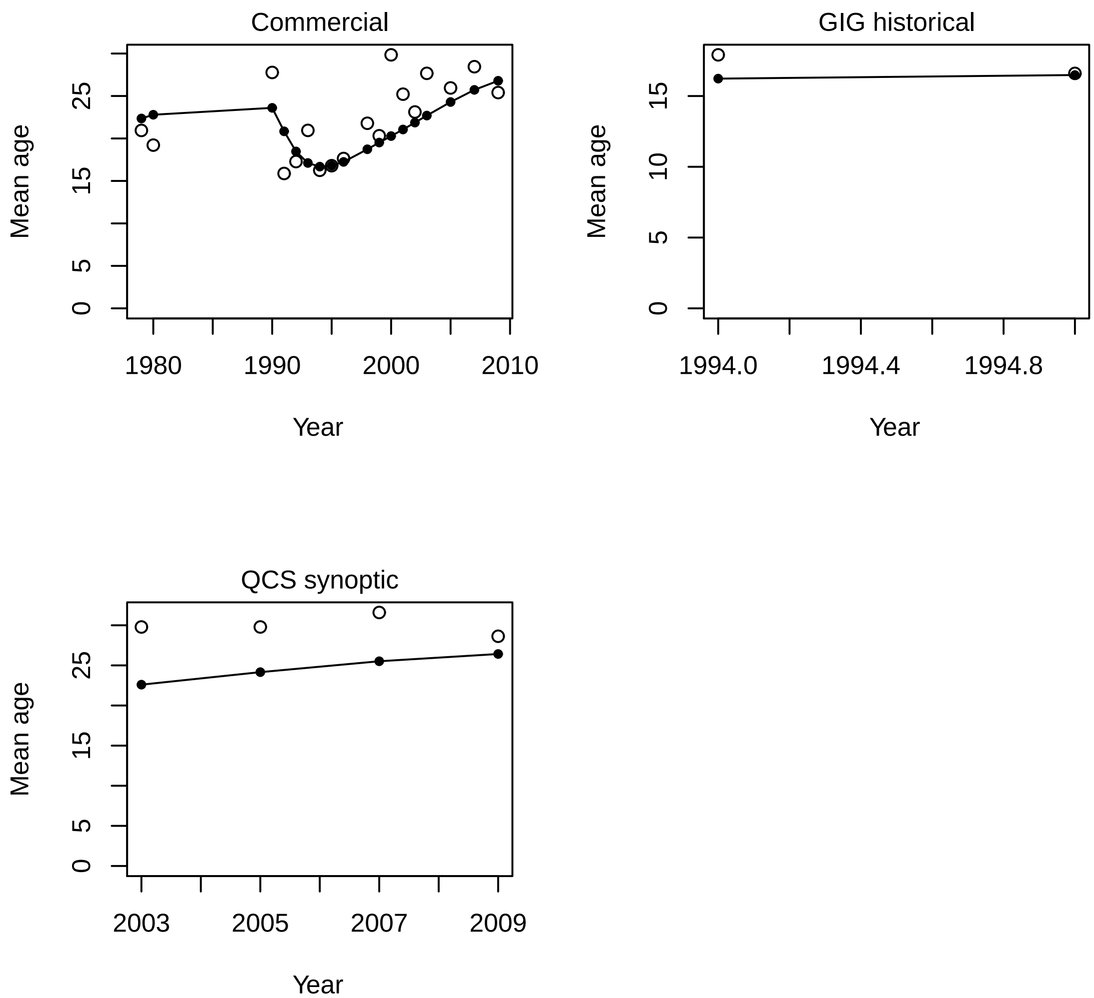


Figure G13. Mean ages each year for the data (open circles) and model estimates for run 'Estimate M', for the commercial data and the GIG historical and QCS synoptic survey series.

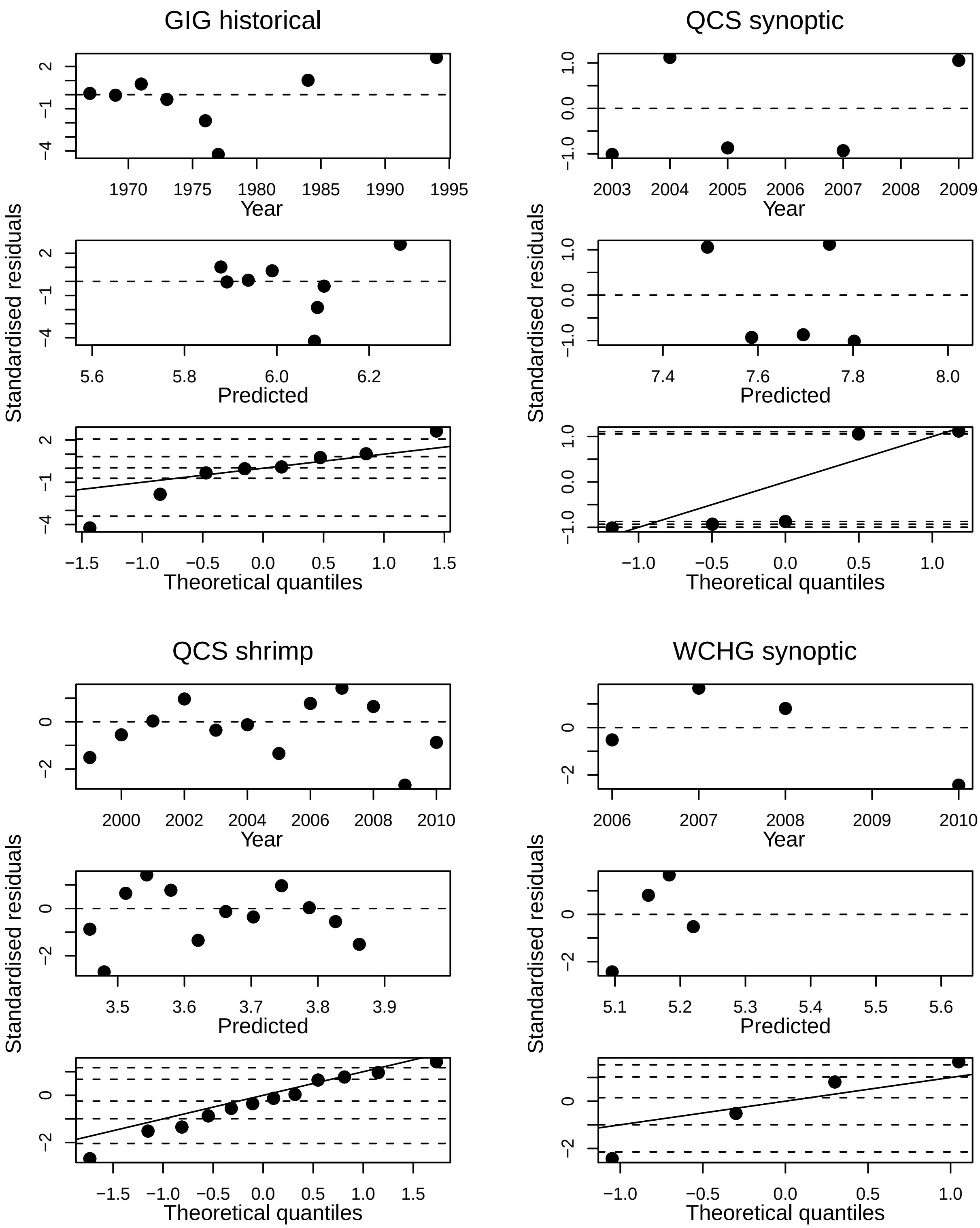


Figure G14. Residuals of fits of model to four of the fishery-independent surveys (MPD values) for run 'Estimate M'. Vertical axes are standardised residuals. The three plots for each survey show, respectively, residuals by year of index, residuals relative to predicted index, and normal qqplot for residuals (horizontal lines give 5, 25, 50, 75 and 95 percentiles.

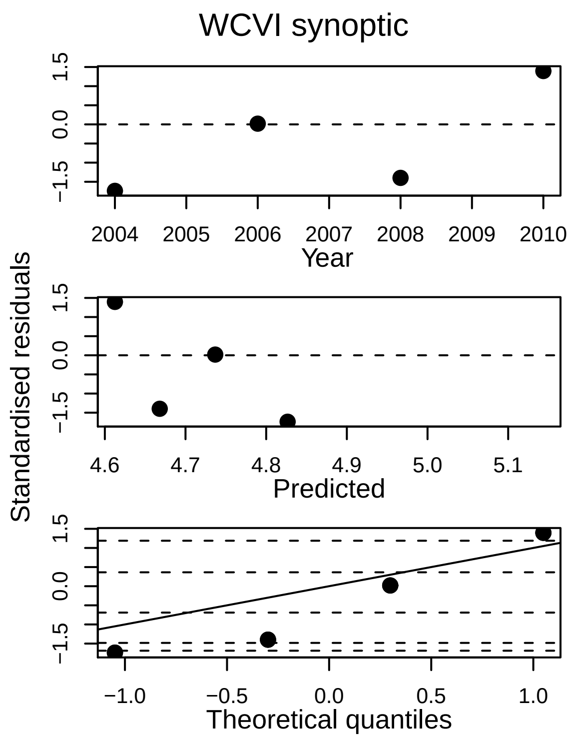


Figure G15. As for Figure G14, but for the WCVI synoptic survey series.

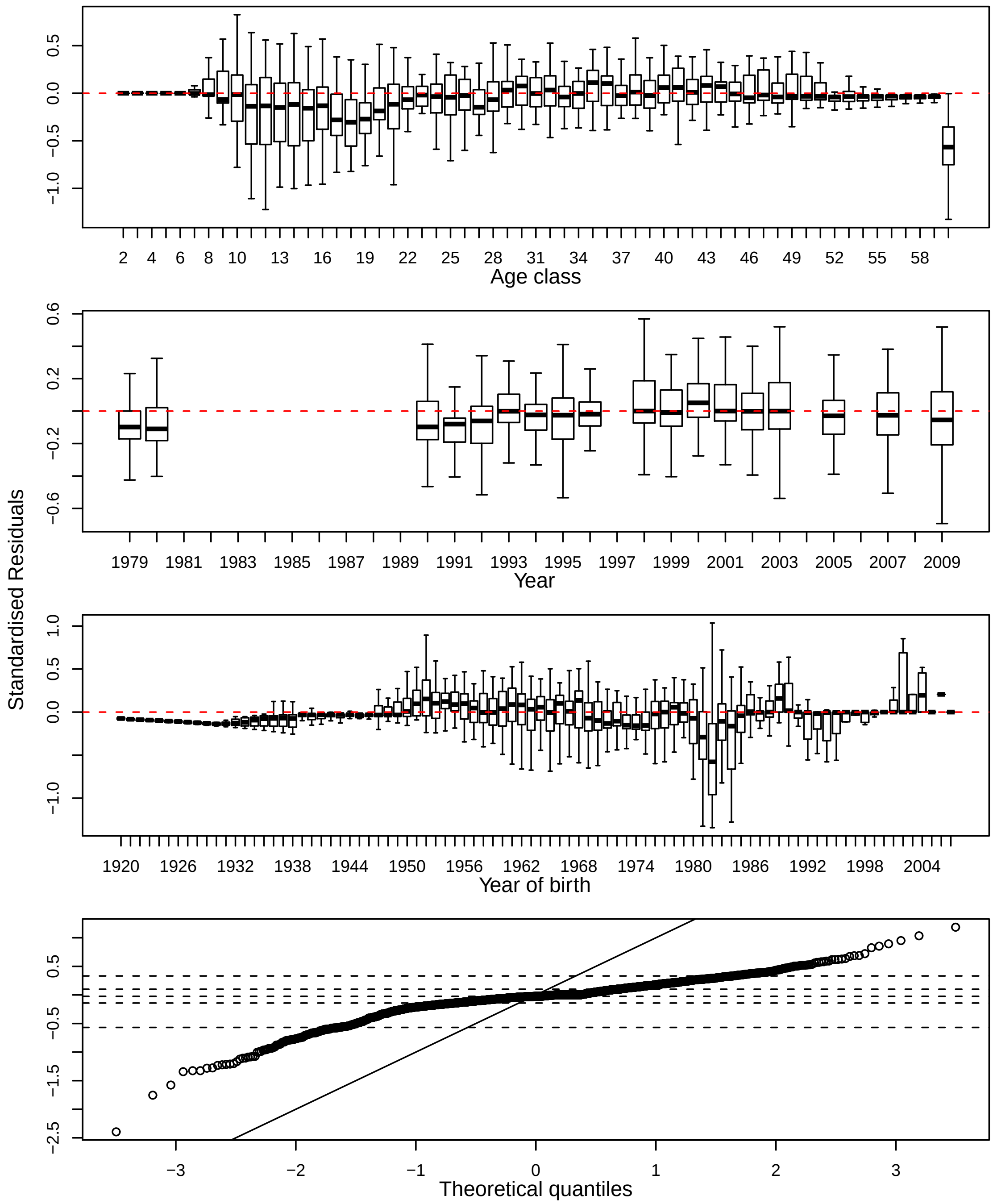


Figure G16. Residual of fits of model to commercial proportions-at-age data (MPD values) for run 'Estimate M'. Vertical axes are standardised residuals. Boxplots show, respectively, residuals by age class, by year of data, and by year of birth (following a cohort through time). Boxes give interquartile 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 2,160 residuals).

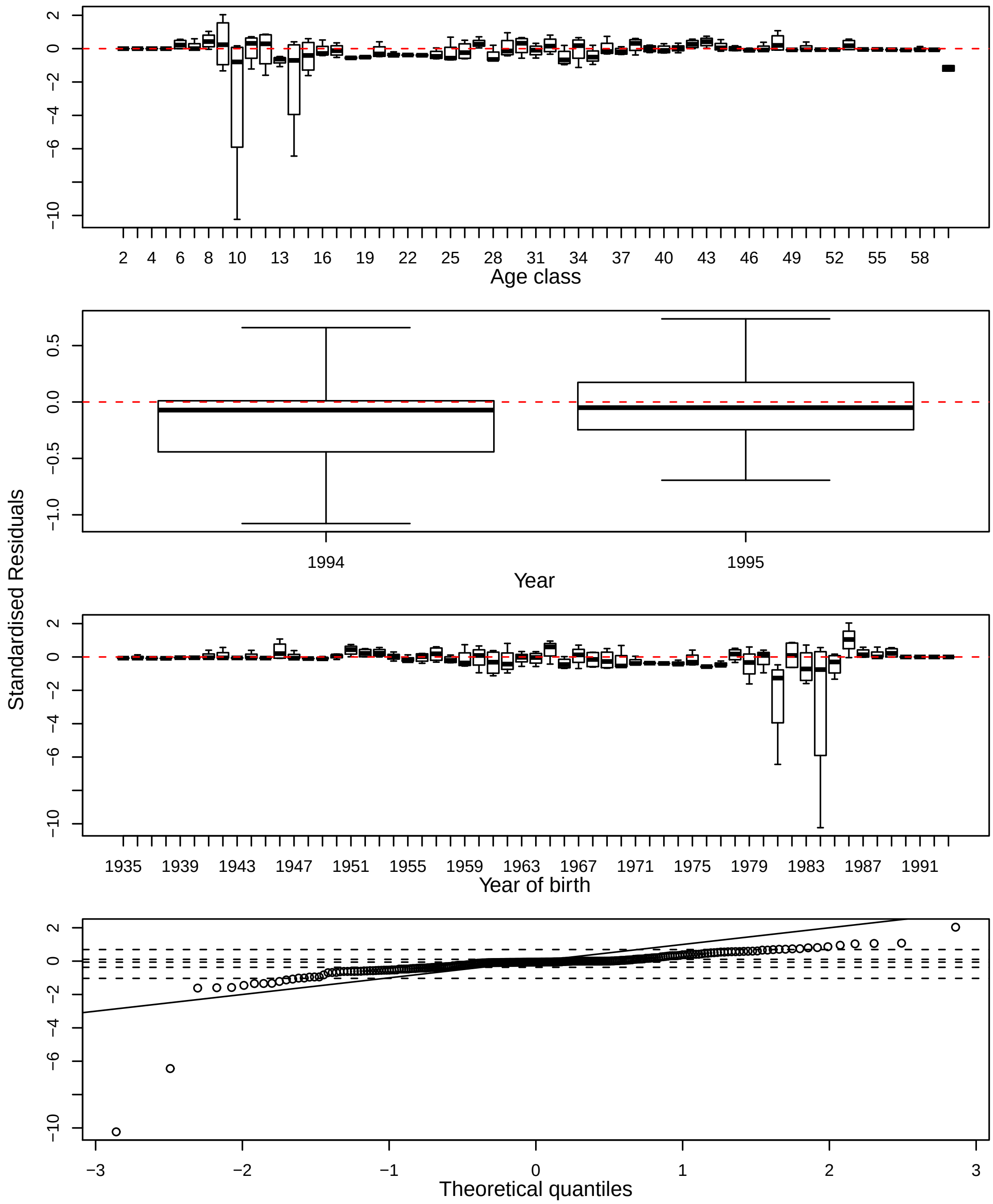


Figure G17. Residuals of fits of model to proportions-at-age data (MPD values) from historical GIG survey series for run 'Estimate M'. Details as for Figure G16, for a total of 240 residuals.

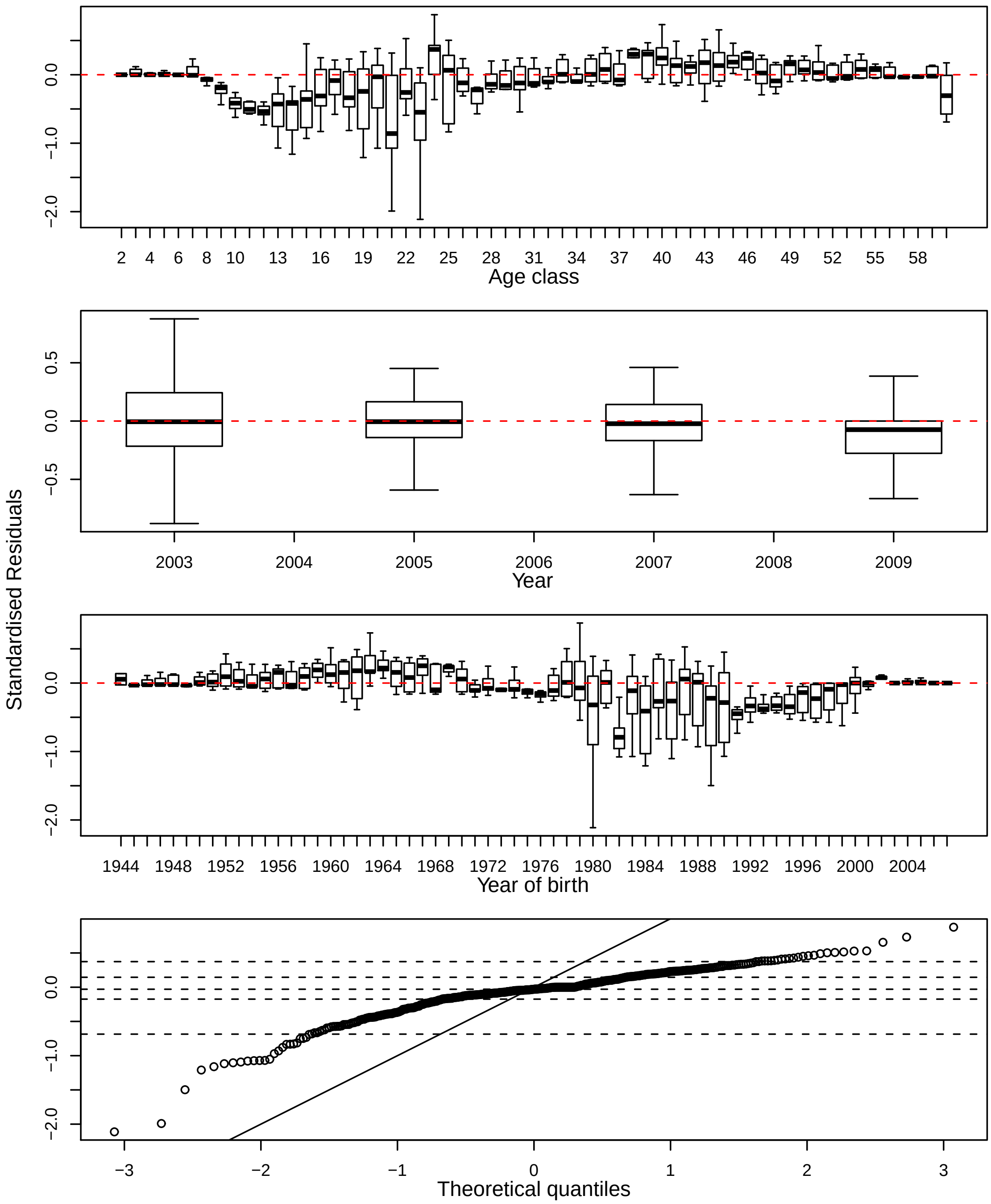


Figure G18. Residuals of fits of model to proportions-at-age data (MPD values) from QCS synoptic survey series for run 'Estimate M'. Details as for Figure G16, for a total of 480 residuals.

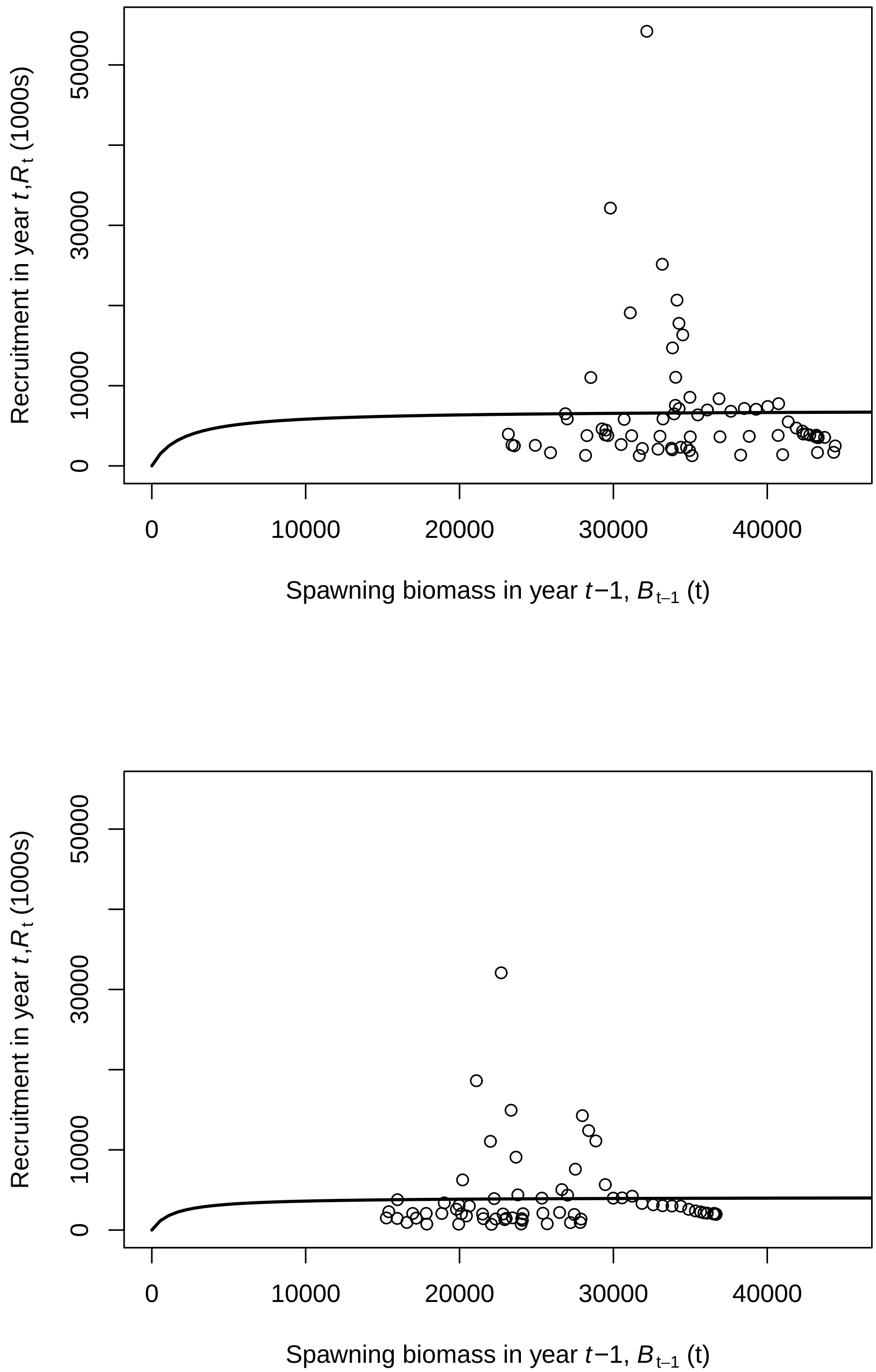


Figure G19. Deterministic stock-recruit relationship (black curve) and estimated model values (circles) using MPD parameter estimates, for run 'Estimate M' (top panel) and run 'Fix M' (bottom panel).

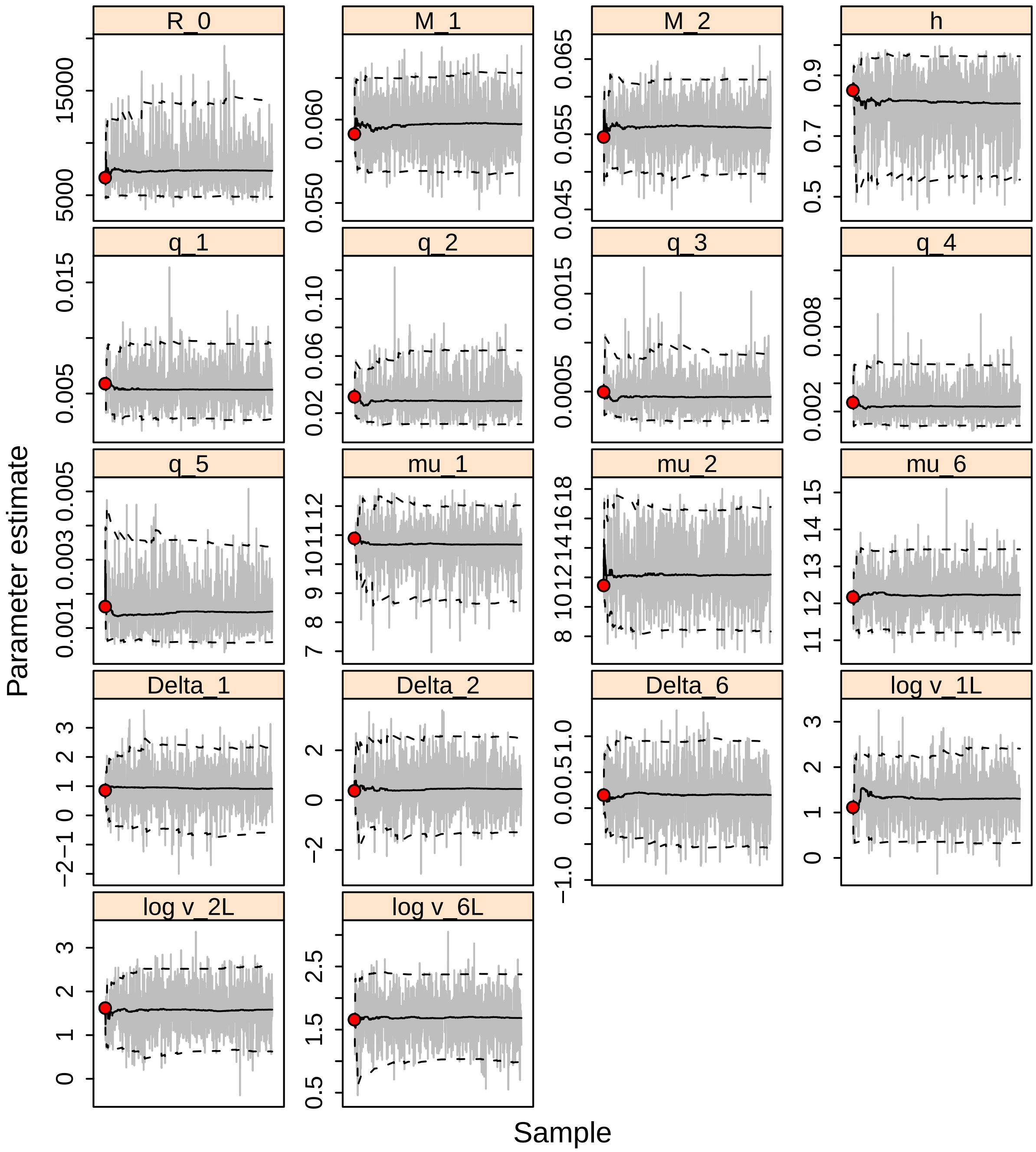


Figure G20. MCMC traces for the primary estimated parameters for run 'Estimate M'. Grey lines show the 1,000 samples for each parameter, solid lines show the cumulative median (up to that sample), and dashed lines show the cumulative 2.5 and 97.5 quantiles. Red circles are the MPD estimates. Subscripts 1 to 5 (except for M_1, M_2) are for surveys: GIG historical, QCS synoptic, QCS shrimp, WCHQ synoptic and WCVI synoptic. Subscript 6 is the commercial fishery.

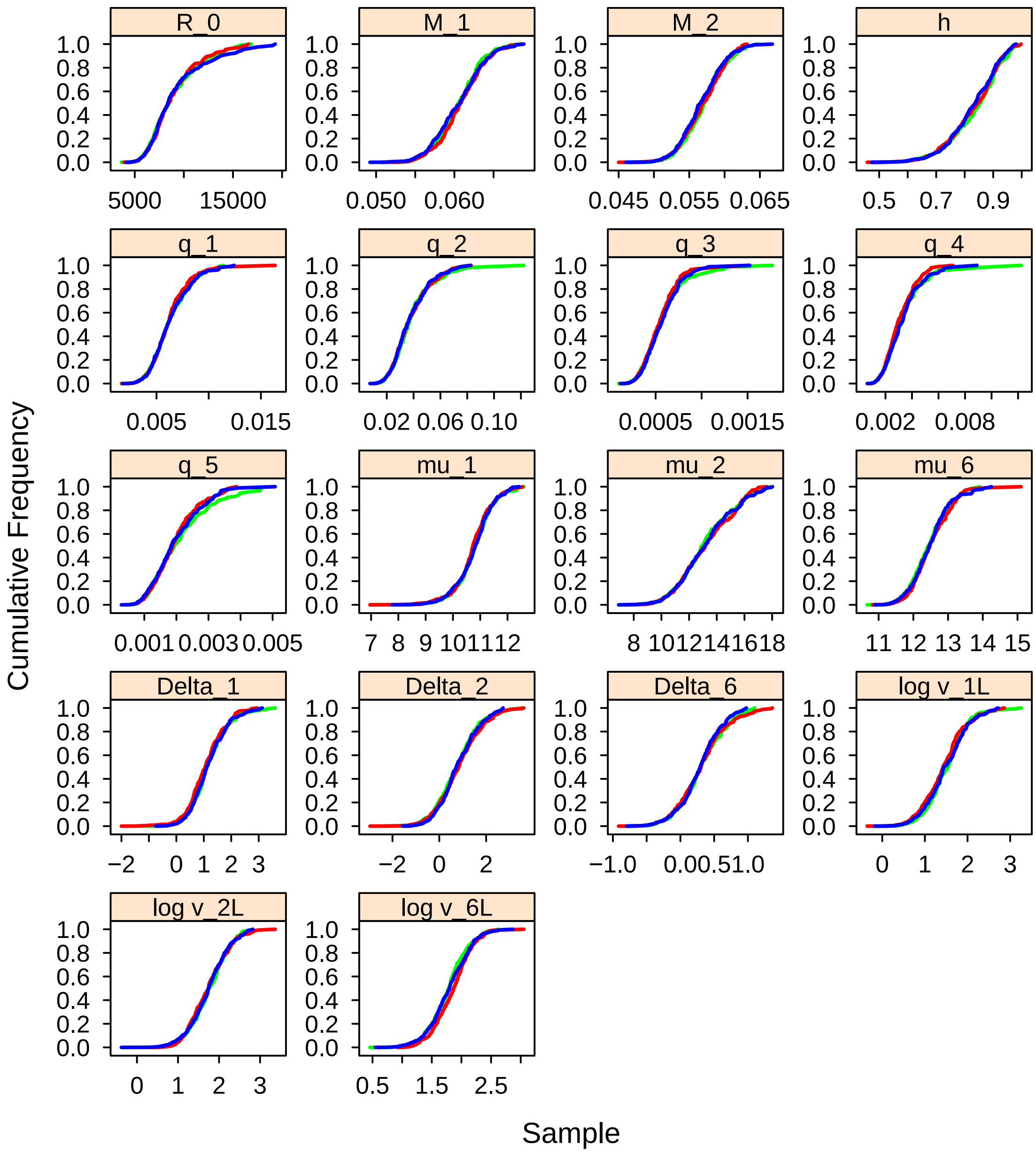


Figure G21. Diagnostic plot for run 'Estimate M', obtained by dividing the MCMC chain of 1,000 MCMC samples into three segments, and overplotting the cumulative distributions of the first segment (green), second segment (red) and final segment (blue).

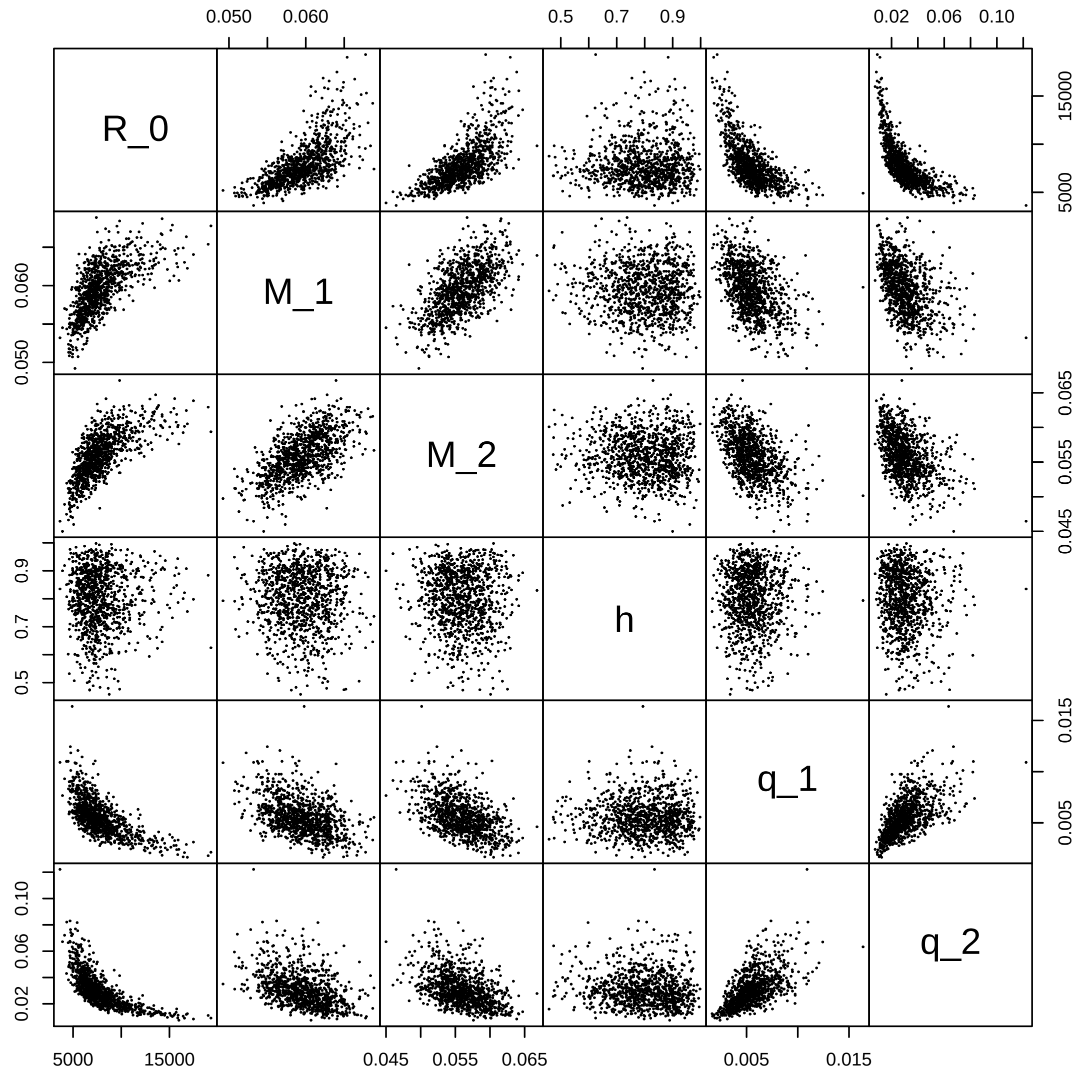


Figure G22. Pairs plot of 1,000 MCMC samples for first six parameters for run 'Estimate M'.

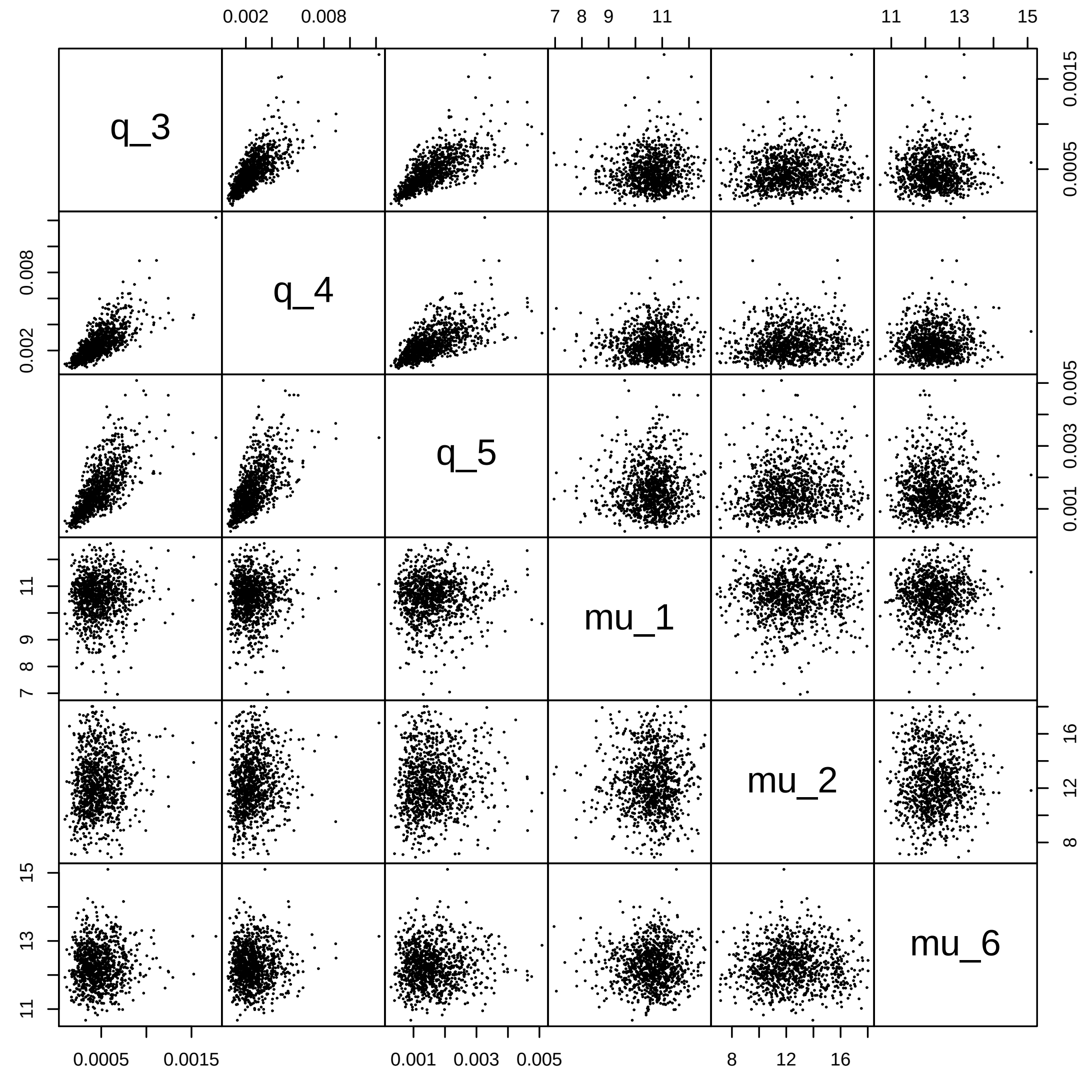


Figure G23. Pairs plot of 1,000 MCMC samples for second six parameters for run 'Estimate M'.

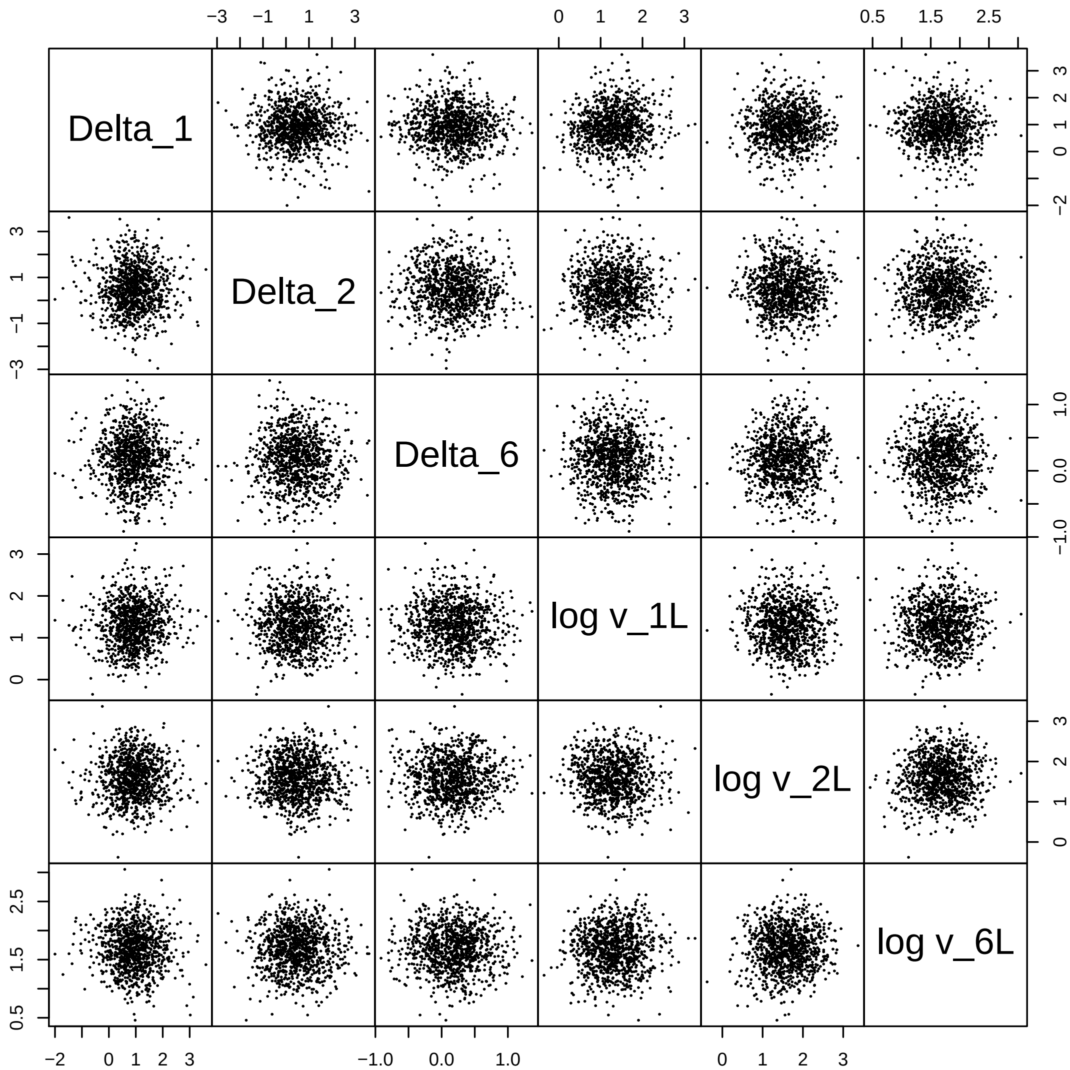


Figure G24. Pairs plot of 1,000 MCMC samples for final parameters for run 'Estimate M'.

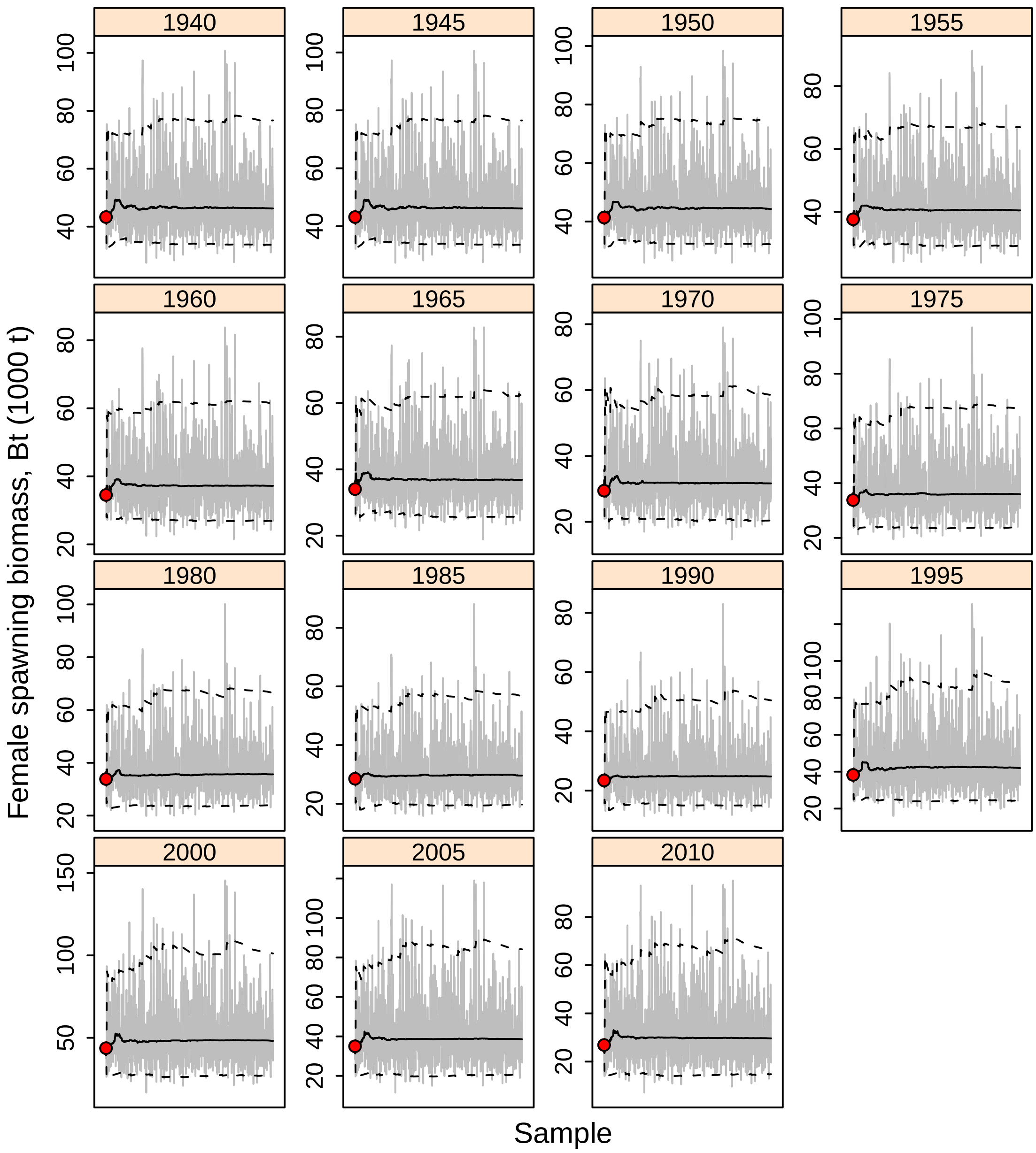


Figure G25. MCMC traces for female spawning biomass estimates at five-year intervals for run 'Estimate M'. Note that vertical scales are different for each plot (to show convergence of the MCMC chain, rather than absolute differences in annual values). Grey lines show the 1,000 samples for each parameter, solid lines show the cumulative median (up to that sample), and dashed lines show the cumulative 2.5 and 97.5 quantiles. Red circles are the MPD estimates.

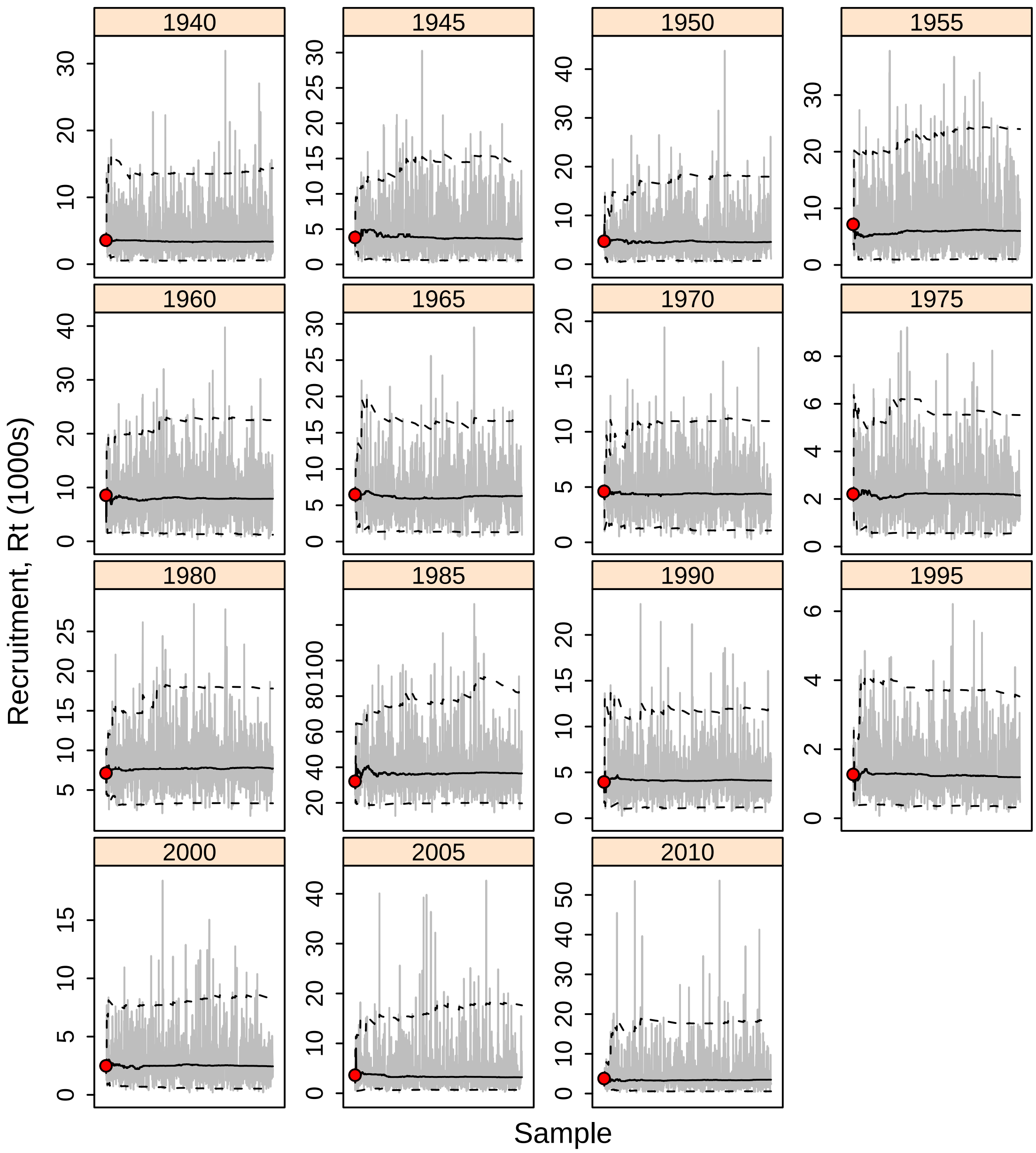


Figure G26. MCMC traces for recruitment estimates at five-year intervals for run 'Estimate M'. Note that vertical scales are different for each plot (to show convergence of the MCMC chain, rather than absolute differences in annual recruitment). Grey lines show the 1,000 samples for each parameter, solid lines show the cumulative median (up to that sample), and dashed lines show the cumulative 2.5 and 97.5 quantiles. Red circles are the MPD estimates.

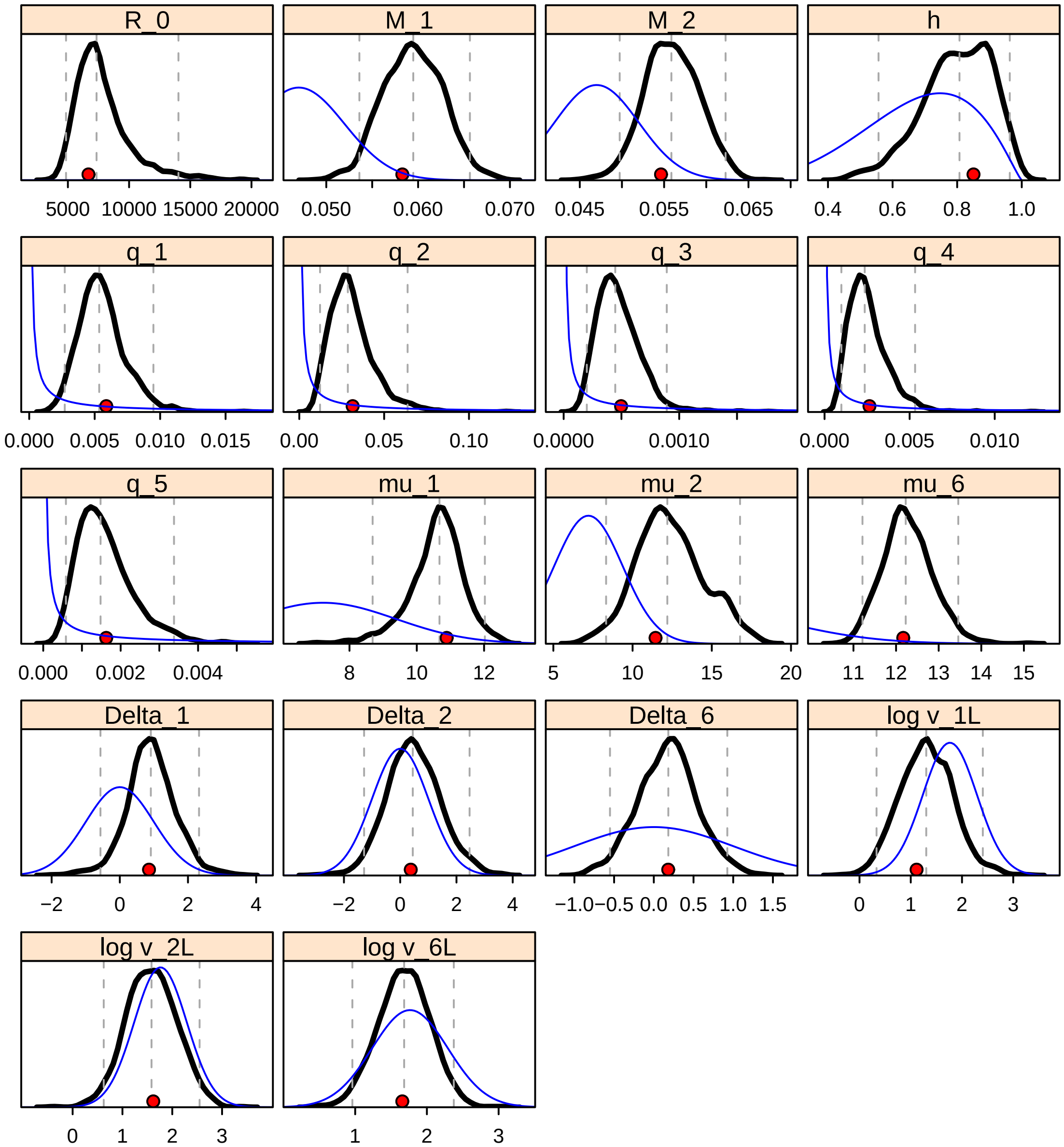


Figure G27. Marginal posterior densities (thick black curves) and prior density functions (thin blue curves) for the estimated parameters for run 'Estimate M'. Vertical lines represent the 2.5, 50 and 97.5 percentiles, and red filled circles are the MPD estimates. The prior for R_0 (uniform in the range $[1, 10^7]$) is too low too show up. The priors for q_g are uniform on a log-scale, and so the probability density function is $1/(x(b-a))$ on a linear scale (where $a = -5$ and $b = 12$ represent the bounds on the log scale), such that the median of the prior is at 0.03, which is not obvious from the graphs.

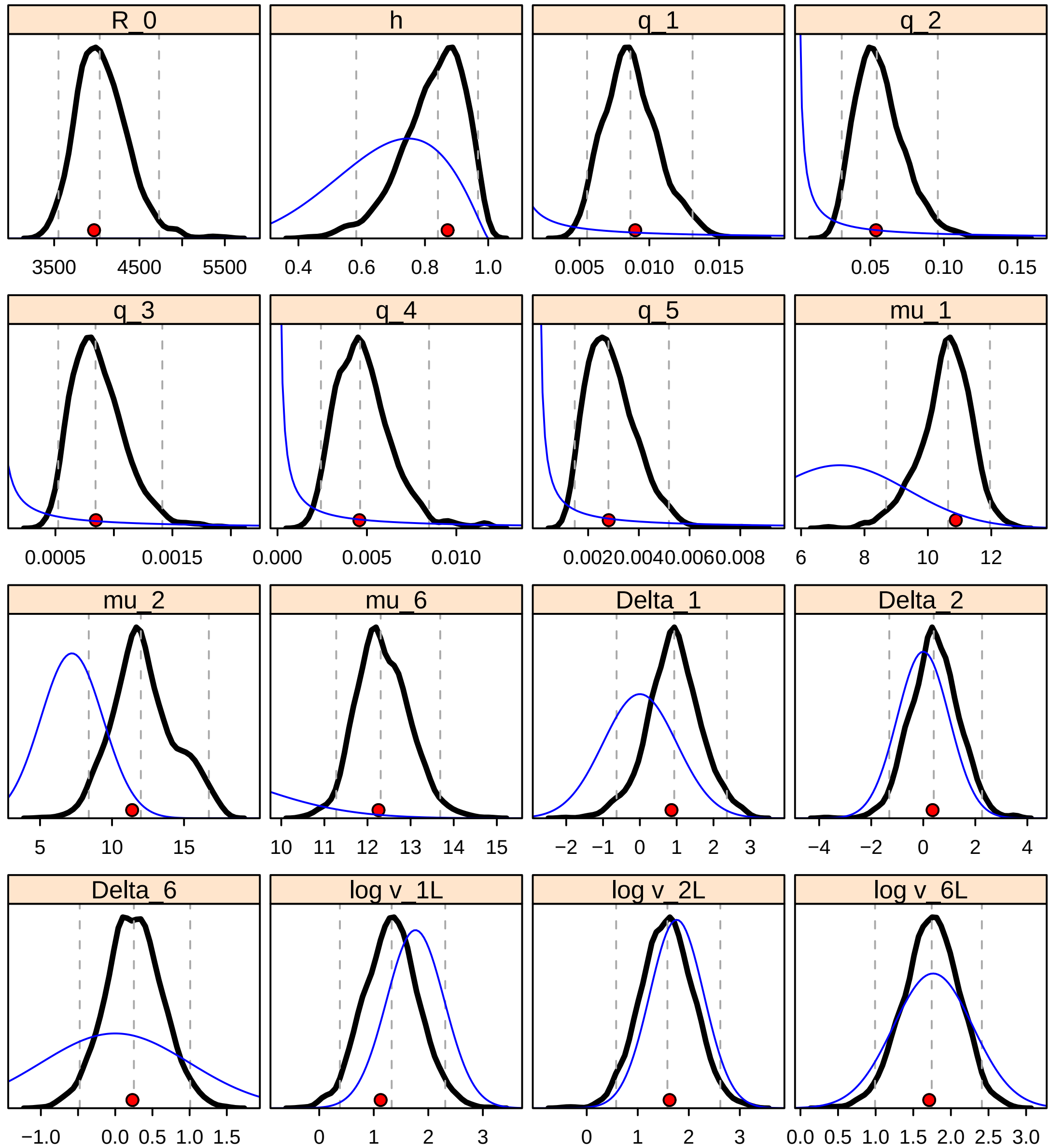


Figure G28. Marginal posterior densities (thick black curves) and prior density functions (thin blue curves) for the estimated parameters for run 'Fix M'. Vertical lines represent the 2.5, 50 and 97.5 percentiles, and red filled circles are the MPD estimates.

Yellowmouth rockfish Selectivity

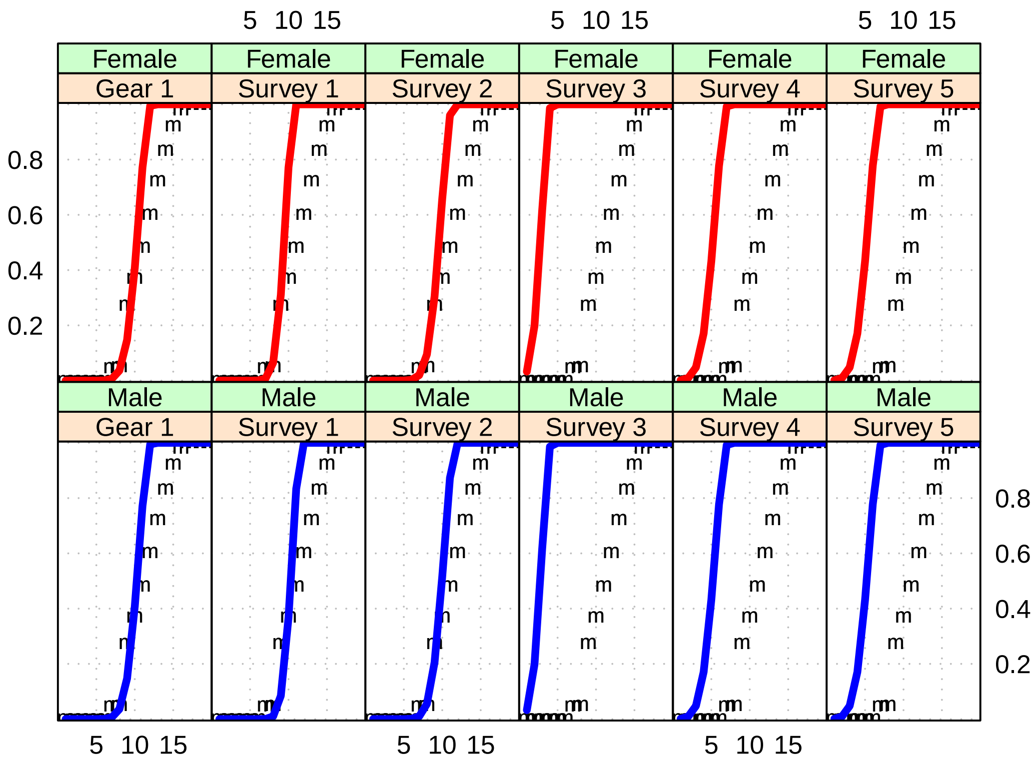


Figure G29. Selectivity curves for the commercial fishery (labelled 'Gear 1') and surveys, as estimated by the MPD results for run 'Estimate M'(except that selectivities for surveys 3, 4 and 5 were fixed), together with the maturity ogive (m) obtained from data.

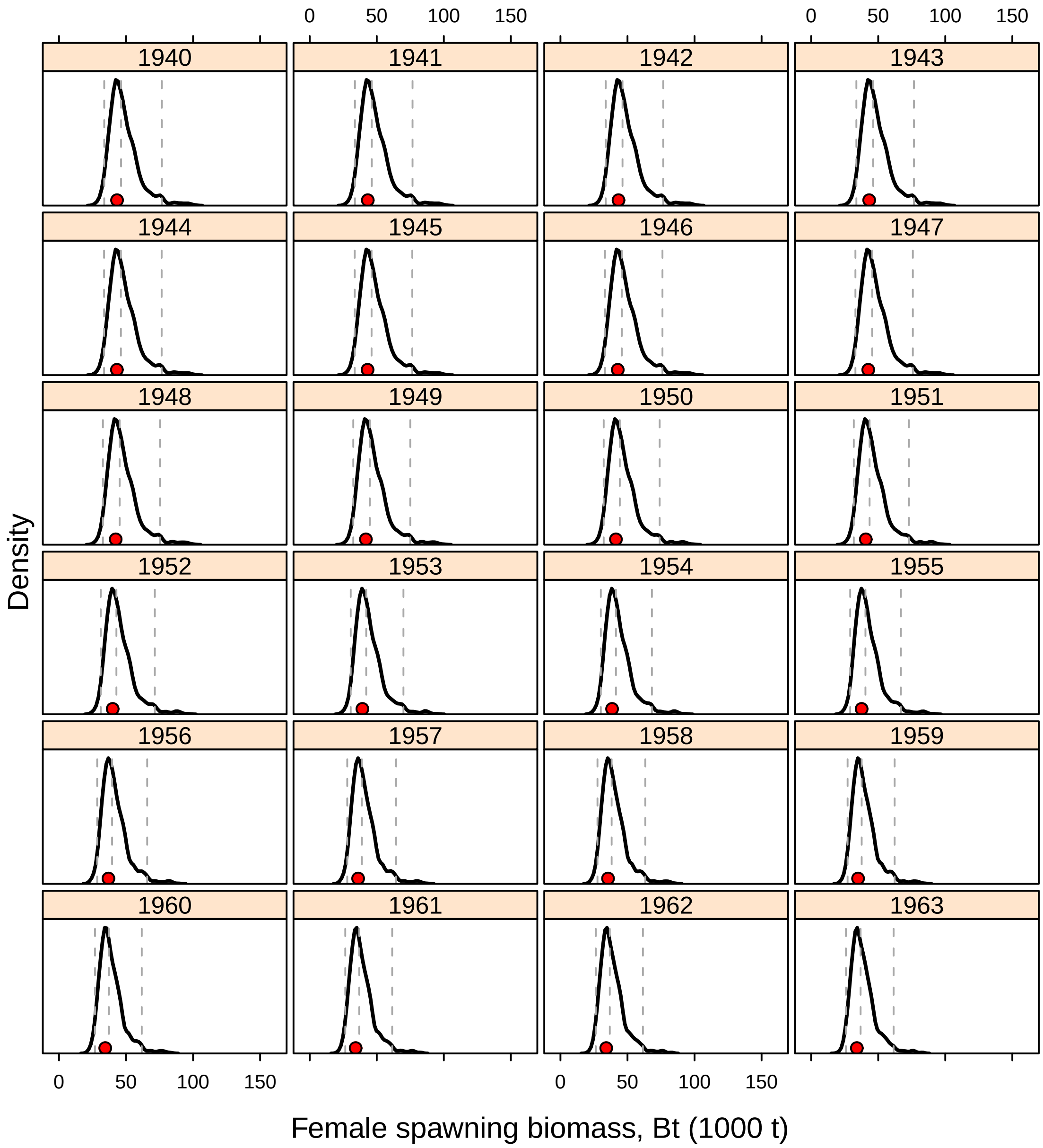


Figure G30. Marginal posterior densities for beginning year female spawning biomass (1,000 tonnes) for years 1940-1963 for run 'Estimate M'. Horizontal axes are all to same scale. Note that vertical axes are not to the same scale, but each is scaled to the peak of the density; with the area under each curve integrating to 1.0. Vertical lines are 2.5, 50 and 97.5 percentiles, and filled red circle indicates MPD value.

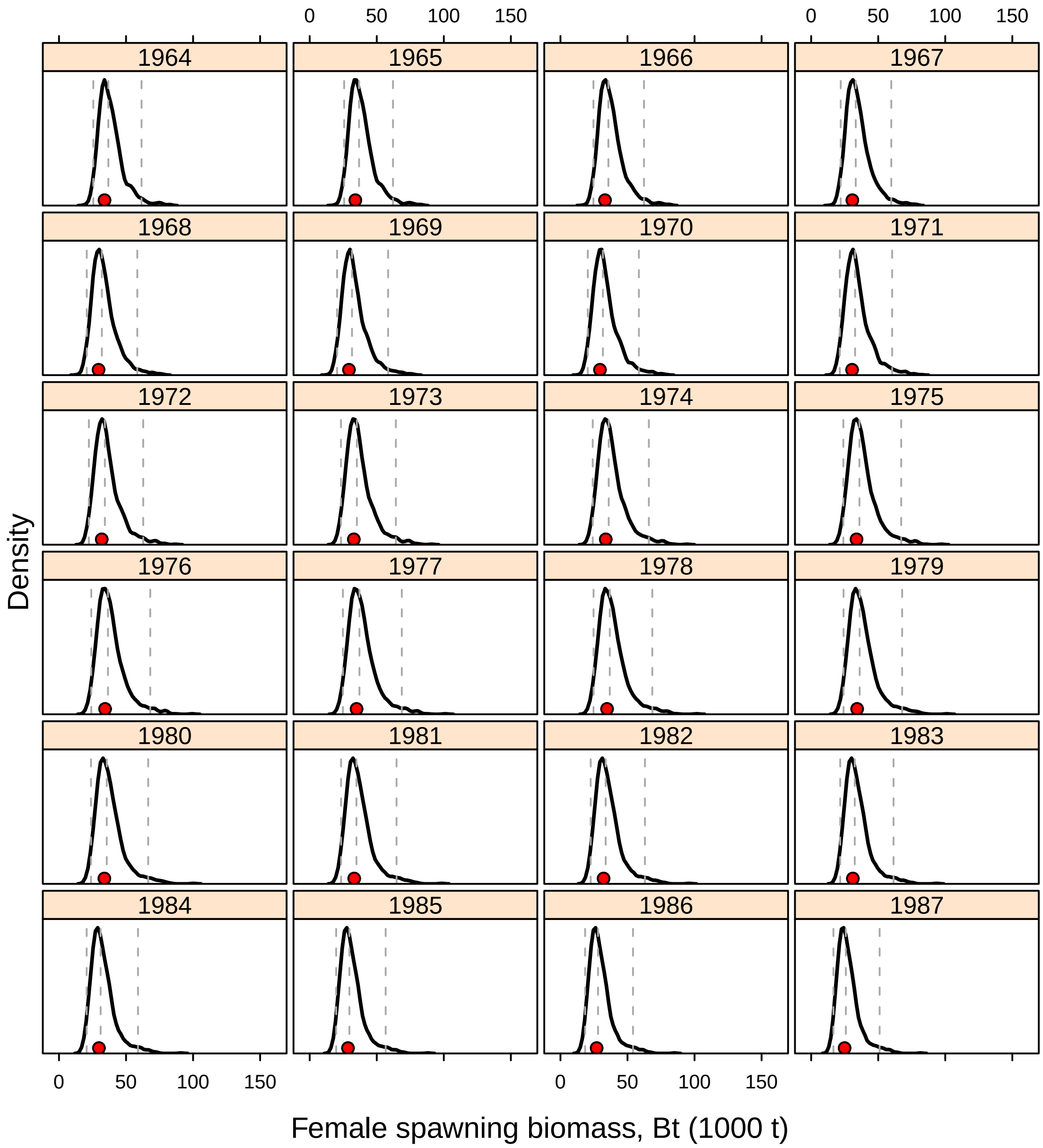


Figure G31. As for Figure G30 for years 1964-1987.

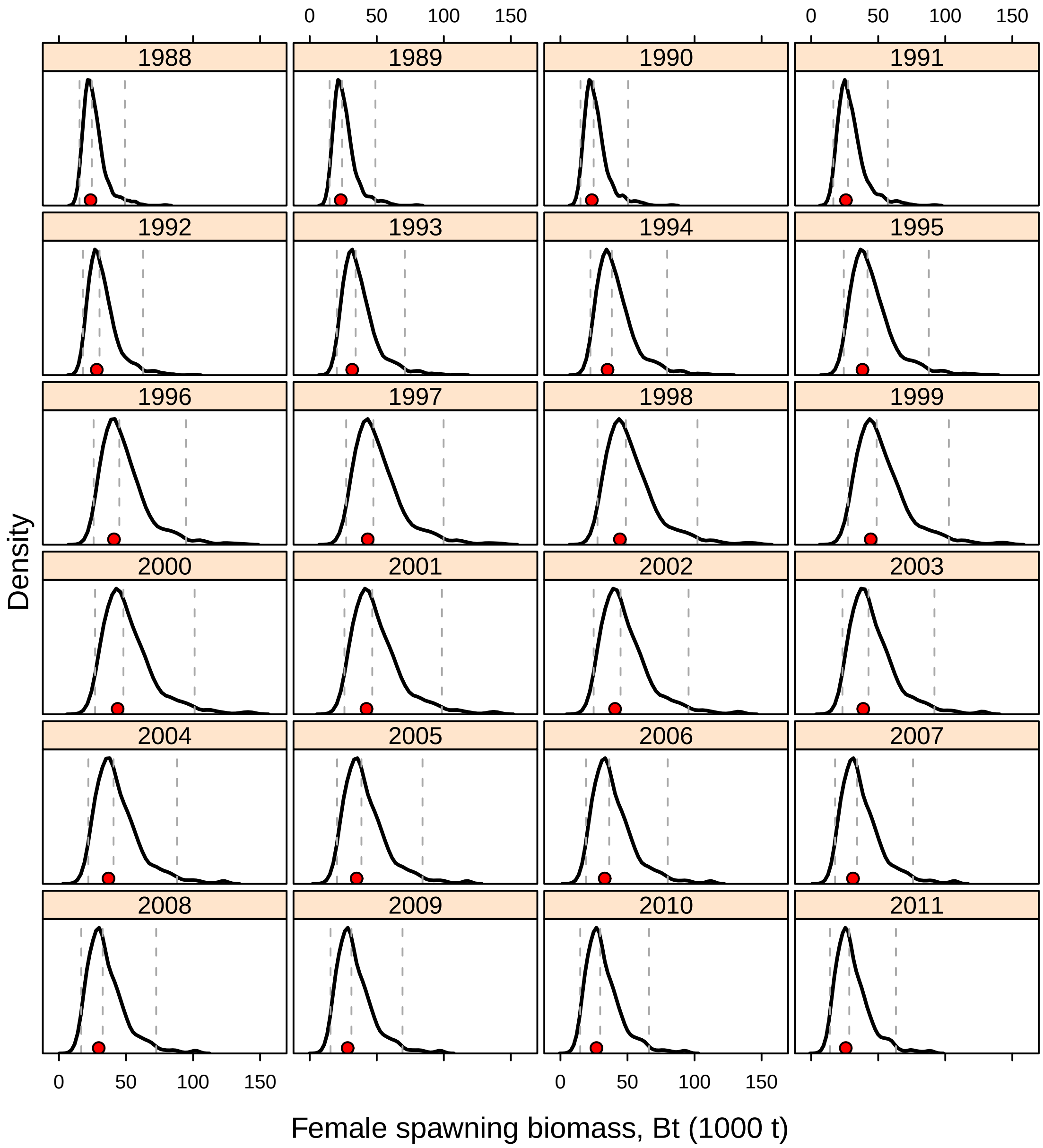


Figure G32. As for Figure G30 for years 1988-2011.

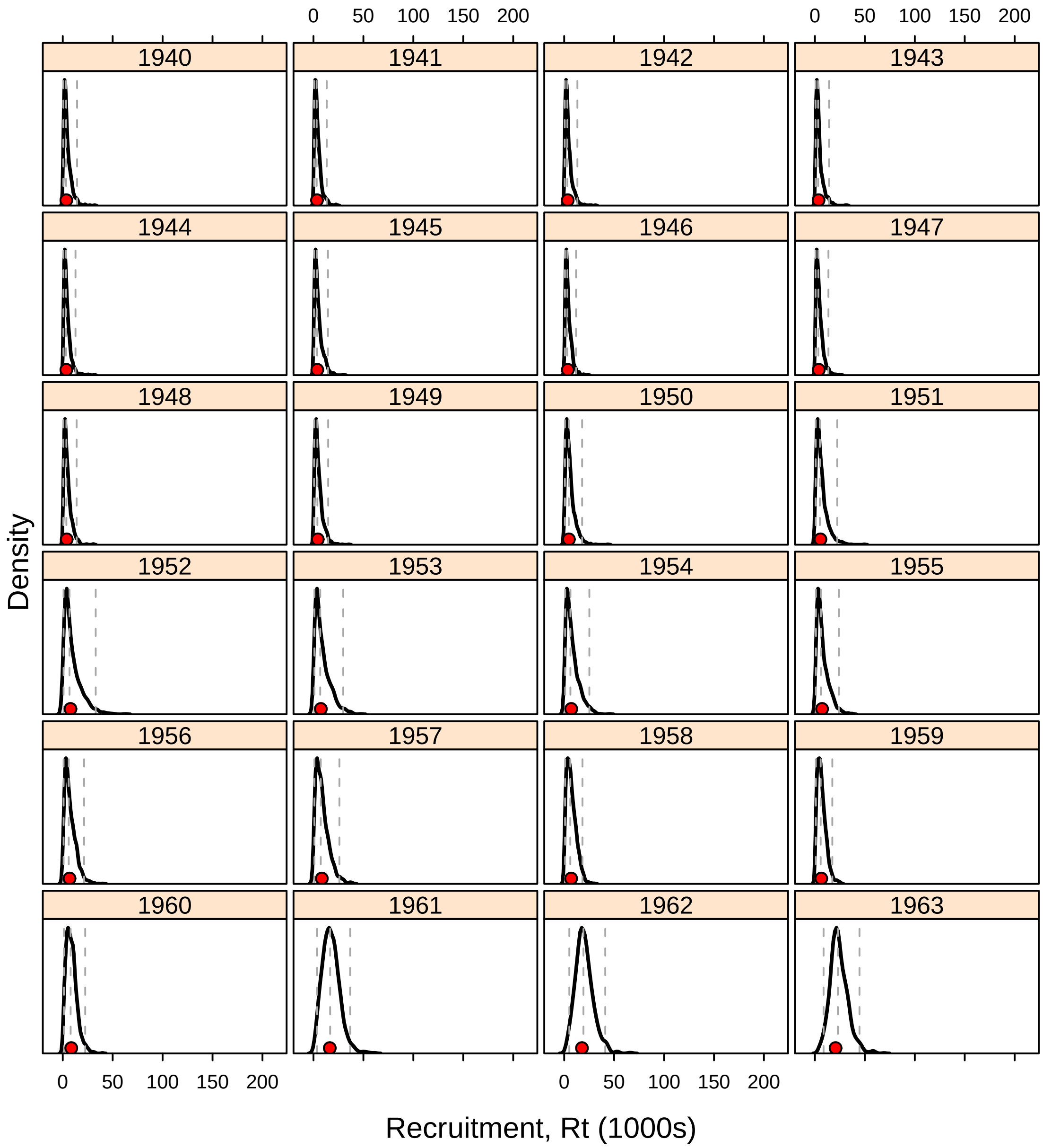


Figure G33. Marginal posterior densities for recruitment for years 1940-1963 for run 'Estimate M'. Horizontal axes are all to same scale, such that large recruitments in certain large years can be seen. Note that vertical axes are not to the same scale, but each is scaled to the peak of the density; 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.

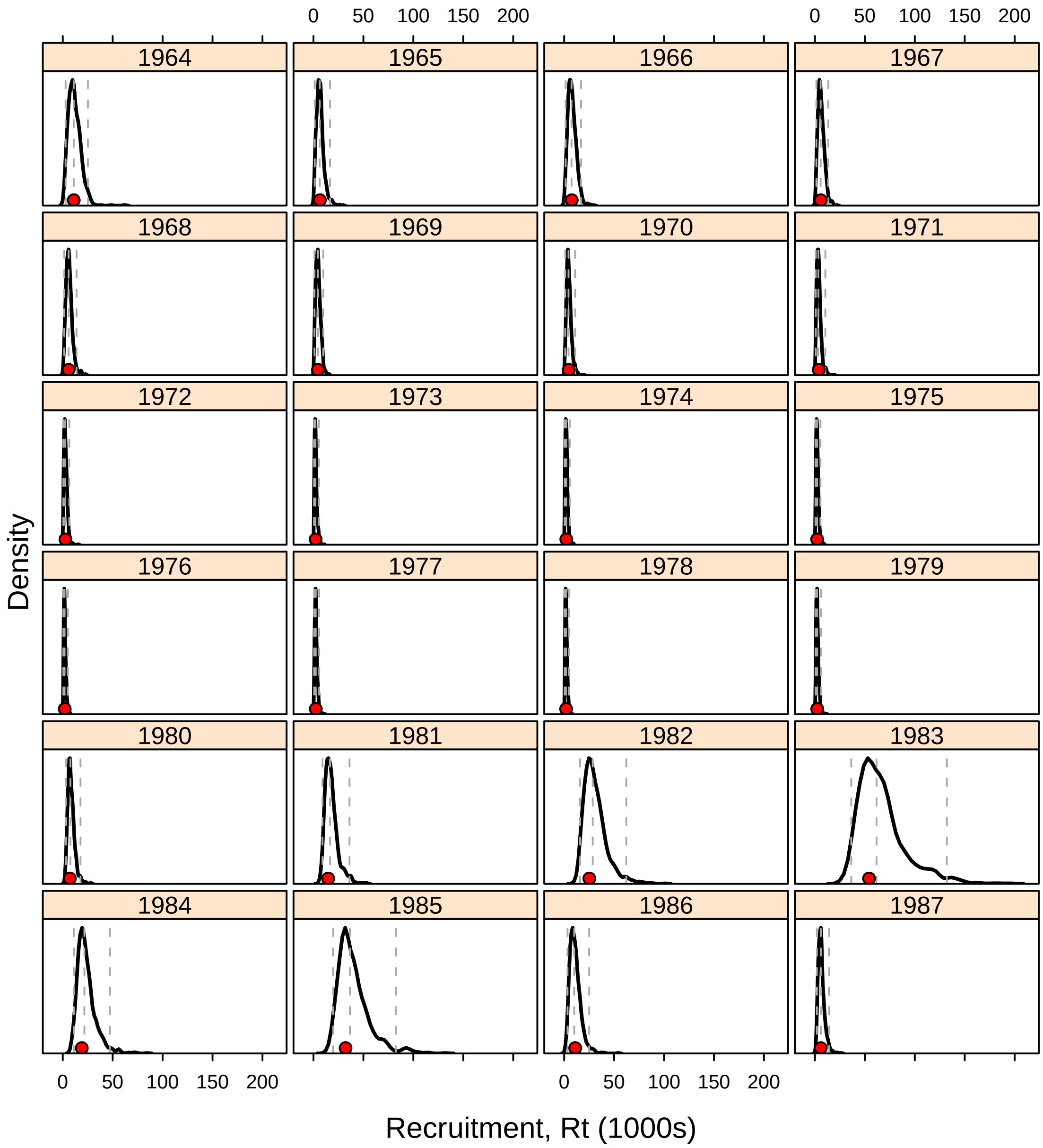


Figure G34. As for Figure G33 for years 1964-1987.

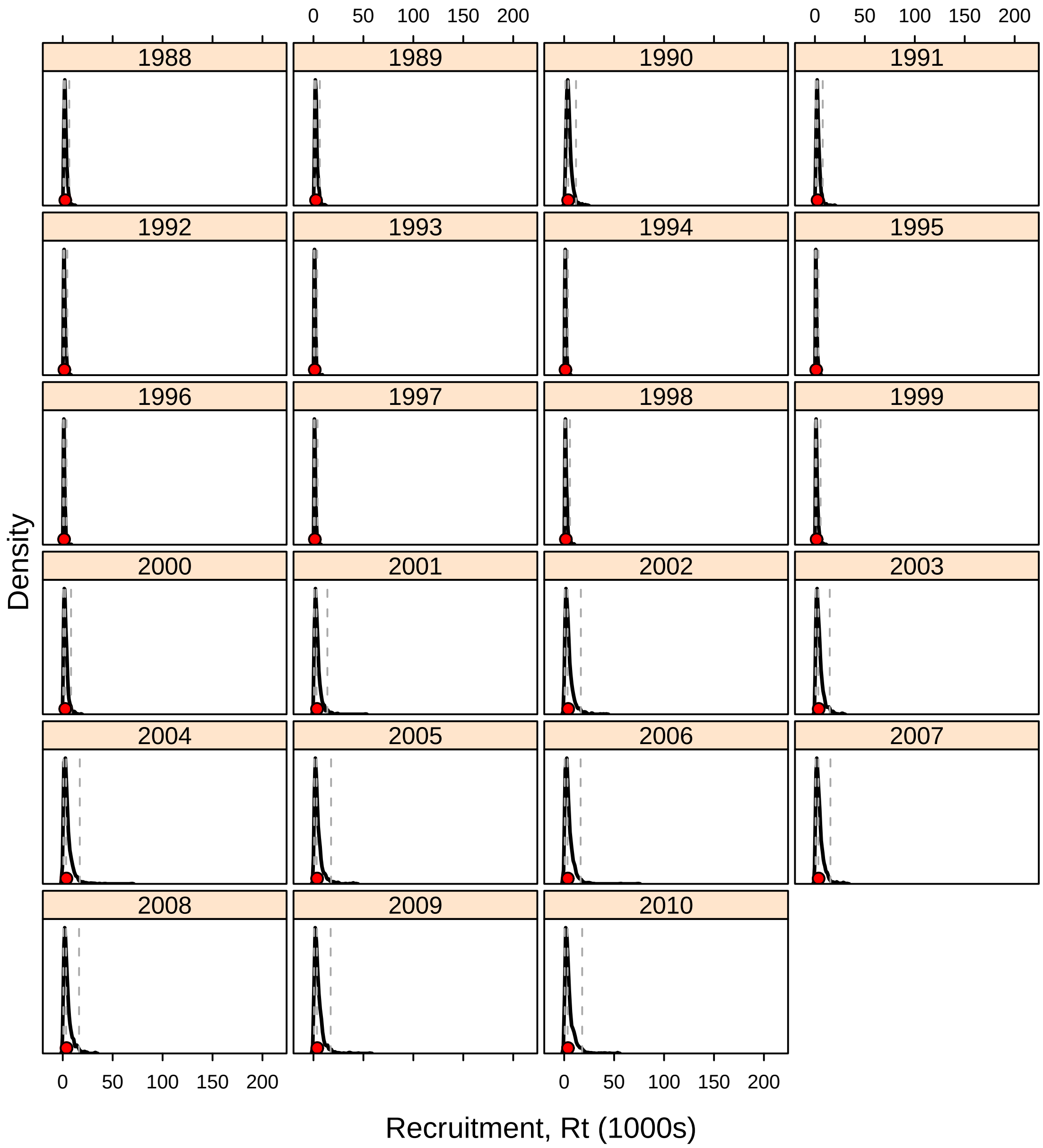


Figure G35. As for Figure G33 for years 1988-2011.

Table G1. Summary of data sources used in this assessment. See respective appendices for more details. Years quoted are the range of years for which data were used, but not every intermediate year will be represented (exact years are summarised in Table F1 in Appendix F). Subscript g is used in the model notation to identify each survey series and the commercial catch.

Data type	Years	Reference	Subscript g
Survey indices:			
Goose Island Gully (GIG) historical trawl survey series	1967-1994	Appendix C	1
Queen Charlotte Sound (QCS) synoptic trawl survey	2003-2009	Appendix C	2
Queen Charlotte Sound (QCS) shrimp trawl survey	1999-2010	Appendix C	3
West Coast Haida Gwaii (WCHG) synoptic trawl survey	2006-2010	Appendix C	4
West Coast Vancouver Island (WCVI) synoptic trawl survey	2004-2010	Appendix C	5
Commercial catch	1940-2010	Appendix B	6
Age composition data:			
Commercial trawl fishery	1979-2009	Appendices D, E	6
GIG historical trawl survey series	1994-1995	Appendices D, E	1
QCS synoptic trawl survey	2003-2009	Appendices D, E	2

Table G2. Negative log likelihoods and objective function from the MPD results for the two models. Parameters and likelihood symbols are defined in Appendix F. For indices ($\hat{I}_{tg}$) and proportions-at-age ($\hat{p}_{atgs}$), subscripts $g = 1 - 5$ refer to the trawl surveys and subscript $g = 6$ refers to the commercial fishery.

Negative log likelihood component	'Estimate M'	'Fix M'
$\log \mathsf{L}_3 \left(\boldsymbol{\Theta} \middle\| \left\{\hat{I}_{t1}\right\}\right)$	13.24	13.72
$\log \mathsf{L}_3 \left(\boldsymbol{\Theta} \middle\| \left\{\hat{I}_{t2}\right\}\right)$	-1.73	-1.66
$\log \mathsf{L}_3 \left(\boldsymbol{\Theta} \middle\| \left\{\hat{I}_{t3}\right\}\right)$	2.65	2.65
$\log \mathsf{L}_3 \left(\boldsymbol{\Theta} \middle\| \left\{\hat{I}_{t4}\right\}\right)$	2.36	2.32
$\log \mathsf{L}_3 \left(\boldsymbol{\Theta} \middle\| \left\{\hat{I}_{t5}\right\}\right)$	1.01	1.10
$\log \mathsf{L}_2 \left(\boldsymbol{\Theta} \| \left\{\hat{p}_{at1s}\right\}\right)$	-634.72	-635.44
$\log \mathsf{L}_2 \left(\boldsymbol{\Theta} \| \left\{\hat{p}_{at2s}\right\}\right)$	-1267.26	-1269.14
$\log \mathsf{L}_2 \left(\boldsymbol{\Theta} \| \left\{\hat{p}_{at6s}\right\}\right)$	-5755.22	-5754.61
$\log \mathsf{L}_1 \left(\boldsymbol{\Theta} \| \left\{\epsilon_t\right\}\right) - \log\left(\pi(\boldsymbol{\Theta})\right)$	41.88	39.08
Objective function $f(\boldsymbol{\Theta})$	-7597.78	-7601.98

Table G3. Summary statistics of MCMC results for estimated parameters for run 'Estimate M'. Parameters are defined in Appendix F. Except for M_1 and M_2, subscripts 1 to 5 correspond to the fishery-independent surveys, and subscript 6 corresponds to the commercial fishery.

Parameter	Percentile		
	5%	50%	95%
R_0	5,185	7,342	12,290
M_1	0.0544	0.0595	0.0648
M_2	0.0507	0.0559	0.0613
h	0.605	0.807	0.951
q_1	0.00306	0.00535	0.00869
q_2	0.01372	0.02860	0.05610
q_3	0.00023	0.00045	0.00078
q_4	0.00113	0.00236	0.00474
q_5	0.00069	0.00148	0.00302
μ_1	9.1	10.7	11.8
μ_2	9.1	12.2	16.1
μ_6	11.4	12.2	13.3
Δ_1	-0.22	0.91	2.11
Δ_2	-1.06	0.45	2.14
Δ_6	-0.43	0.18	0.79
$\log v_{1L}$	0.47	1.30	2.16
$\log v_{2L}$	0.76	1.58	2.41
$\log v_{6L}$	1.08	1.68	2.27

Table G4. Summary statistics of MCMC results for estimated parameters for run 'Fix M'. Parameters are defined in Appendix F. Except for M_1 and M_2, subscripts 1 to 5 correspond to the fishery-independent surveys, and subscript 6 to the commercial fishery. For natural mortalities M_1 and M_2, the fixed values are shown.

Parameter	Percentile		
	5%	50%	95%
R_0	3,624	4,034	4,589
M_1	-	0.047	-
M_2	-	0.047	-
h	0.640	0.841	0.957
q_1	0.00586	0.00865	0.01236
q_2	0.03339	0.05435	0.08757
q_3	0.00057	0.00084	0.00131
q_4	0.00271	0.00462	0.00772
q_5	0.00163	0.00280	0.00480
μ_1	9.0	10.6	11.7
μ_2	8.8	12.0	16.1
μ_6	11.4	12.3	13.4
Δ_1	-0.31	0.93	2.17
Δ_2	-1.05	0.40	1.93
Δ_6	-0.38	0.25	0.90
$\log v_{1L}$	0.52	1.33	2.16
$\log v_{2L}$	0.69	1.58	2.43
$\log v_{6L}$	1.12	1.75	2.31

APPENDIX H. CRITICAL HABITAT AND CONCURRENT SPECIES

The depth distribution of bottom trawl tows that captured Yellowmouth Rockfish (YMR, *Sebastes reedi*) along the BC coast – Pacific Marine Fisheries Commission (PMFC) areas 3CD and 5ABCDE – shows that 99% of the encounters lie between 110 and 437 m, with a depth-of-median-catch at 219 m (Figure H1, data extracted from the PacHarvest and GFFOS databases). Hereafter, we refer to the BC coast bottom tows between 110 and 437 m as "YMR bottom tows" even though YMR is not necessarily the predominant species in all tows. The distribution of YMR bottom tows differs from the effort of the trawl fishery (shaded background histogram) due to a large flatfish fishery in Hecate Strait and deepwater thornyhead/sablefish fisheries along the west coast of Vancouver Island.

Similarly, we refer to BC coast (PMFC 3CD & 5ABCDE) midwater tows that encounter YMR between 49 and 300 m as "YMR midwater tows" (Figure H2). Asymmetric 92% 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 that seem to be more frequent in the most recent four years. Another possible reason for YMR 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 YMR bottom tows comprise predominantly a mixture of rockfish and flatfish (Figure H3). Pacific Ocean Perch remains the most abundant species by weight in these tows (38% by catch weight), followed by YMR (19%), Arrowtooth Flounder *Atheresthes stomias* (9%), and Silvergray Rockfish *Sebastes brevispinis* (5%). Two other species of rockfish of interest to COSEWIC (Committee on the Status of Endangered Wildlife in Canada) also occur in the top 20 caught – Rougheye Rockfish *S. aleutianus* (1.2%) and Canary Rockfish *S. pinniger* (0.9%) (Table H1).

Yellowmouth Rockfish midwater tows are dominated by Pacific Hake *Merluccius productus* (55% by catch weight; Figure H4, Table H2). Other species in these tows are Widow Rockfish *Sebsates entomelas* (14%), Yellowtail Rockfish *S. flavidus* (10%), and Redstripe Rockfish *S. proriger* (7%). Three rockfish species of interest to COSEWIC occur in YMR midwater tows – YMR (6.7%), Canary Rockfish *S. pinniger* (0.2%), and Bocaccio *S. paucispinis* (0.2%) (Table H2).

The distribution of YMR in BC coastal waters is best viewed as CPUE density from commercial bottom trawl records that span 1996 to 2011 (Figure H5). The BC population appears to be centered in Queen Charlotte Sound (central BC coast), specifically in association with the three main gullies – Goose Island, Mitchell's, and Moresby (from S to N). There are also density 'hotspots' off the NW coast of Vancouver Island, off the SW coast of Haida Gwaii (near Cape St. James), off Rennell Sound, and off the NW coast of Haida Gwaii. Densities of YMR appear to be low off the west coast of Vancouver Island south of Brooks Peninsula.

The distribution of YMR displayed in Figure H5 stems from tow encounters by the commercial trawl fleet. A more objective proxy uses bathymetry limits to delineate potential habitat. For instance, isobaths (110 m, 437 m) identified in Figure H1 by YMR bottom tows outline bottom regions along the BC coast that could potentially host YMR (Figure H6). This highlighted region covers 59,789 km^2; however, not all areas are amenable to YMR habitation (e.g., Strait of Georgia, mainland inlets). Also, some of this highlighted region occurs off the coasts of Washington and Alaska. Figure H7 shows the bottom area that is encompassed by bathymetry limits (49 m, 300 m) identified by midwater tows (Figure H2). This area covers 77,157 km^2, but the concept of bottom terrain defined by midwater limits is not easily interpreted. We include it here solely for comparison with terrain defined by the more plausible bottom-defined limits.

There is little information on bottom type for deepwater regions along the BC coast. Sinclair et al. (2005) present a map of surficial geology in the Queen Charlotte Basin that Haigh and Starr (2008) used to calculate YMR's presence on bottom type. The latter's finding was that YMR appears to prefer sand, gravel and bedrock over mud. Figure H8 illustrates how the catch distribution (from 1996 to 2011) of YMR coincides with four surficial geology types – (i) glacial outwash, (ii) sand and gravel, (iii) bedrock, and (iv) mud. Catch is noticeably concentrated over glacial outwash along the canyon walls of Goose Island Gully. There is no surficial geology information for the mouth of Moresby Gully.

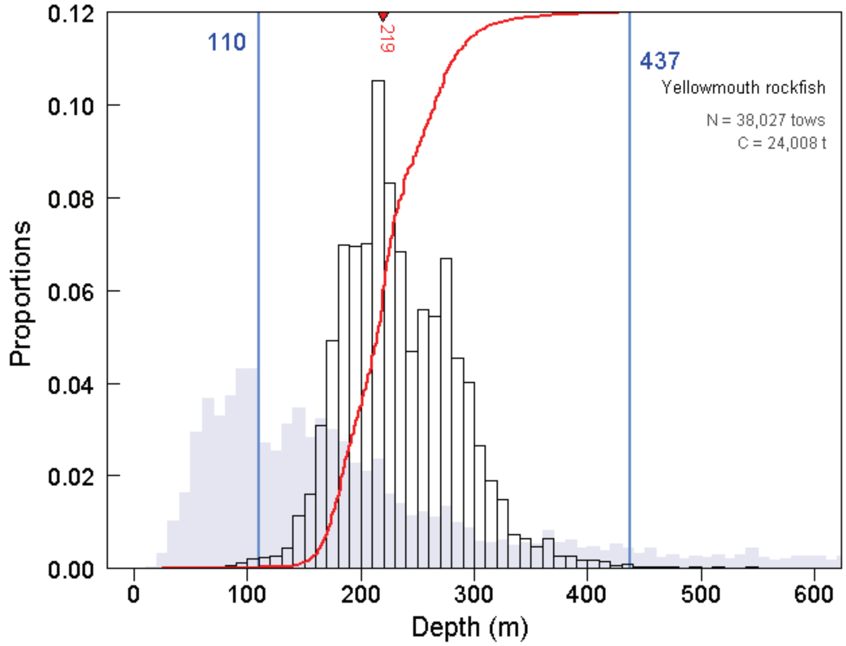


Figure H1. Depth frequency of bottom tows that capture YMR from commercial trawl logs (1996-2007 in PacHarvest, 2007-2011 in GFFOS, where 2011 records are incomplete) in PMFC major areas 3CD and 5ABCDE. The vertical solid lines denote the 0.5% and 99.5% quantiles. The red curve shows the cumulative catch of YMR at depth (scaled from 0 to 1). The median depth of cumulative catch (inverted red triangle) is indicated along the upper axis. 'N' reports the total number of tows; 'C' reports the total catch (t). The shaded histogram in the background reports the relative trawl effort on all species at all depths.

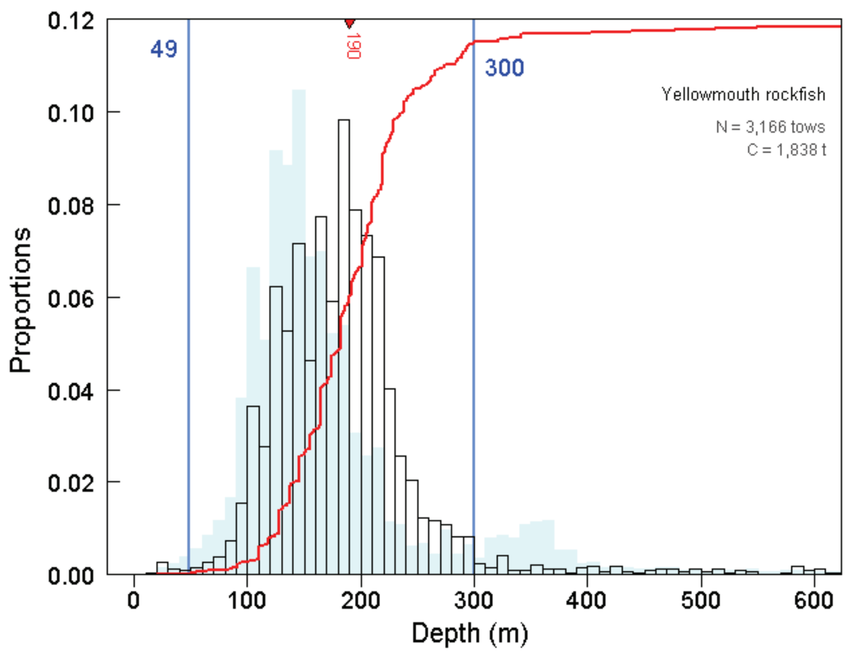


Figure H2. Depth frequency of midwater tows that capture YMR from commercial trawl logs (1996-2011) in BC offshore waters. The vertical solid lines denote the 0.5% and 92.5% quantiles. See Figure H1 for plot details.

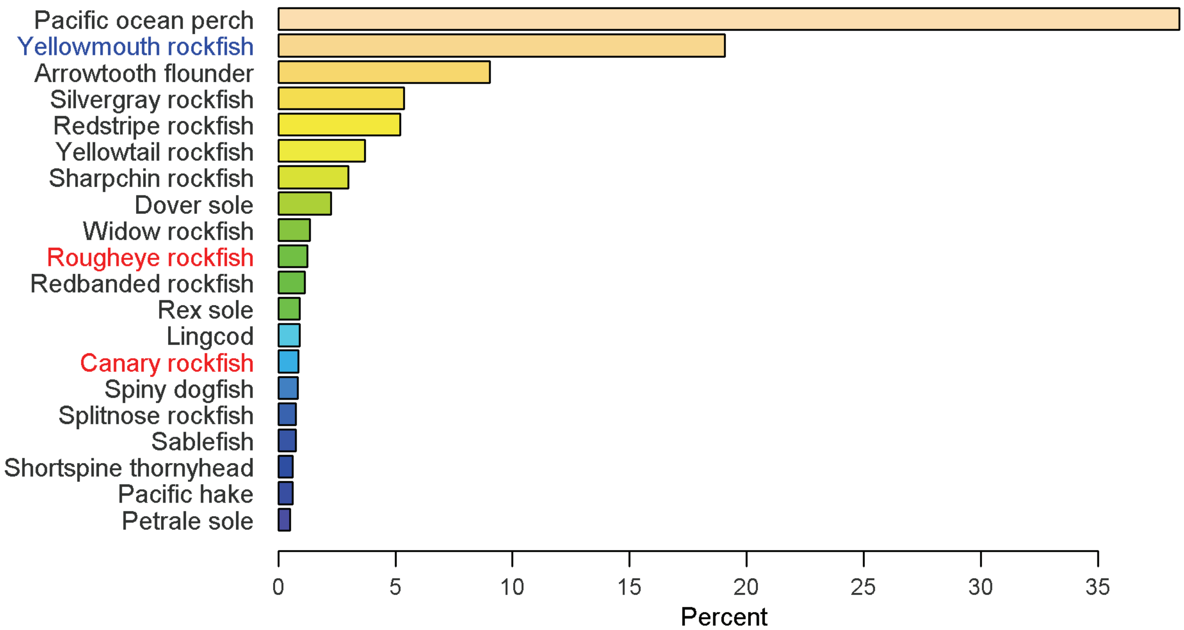


Figure H3. Concurrence of species in YMR bottom trawl tows (1996-2011 observer logs). Abundance is expressed as a percent of total catch weight. YMR is indicated in blue on the y-axis; other species of interest to COSEWIC are indicated in red.

Table H1. Top 20 species by catch weight (landed + discarded) that co-occur in YMR bottom tows (total from 1996-2011 observer logs). Species of interest to COSEWIC have been shaded grey.

Code	Species	Latin name	Catch (t)	Catch (%)
396	Pacific ocean perch	*Sebastes alutus*	48,318	38.479
440	Yellowmouth rockfish	*Sebastes reedi*	23,935	19.061
602	Arrowtooth flounder	*Atheresthes stomias*	11,346	9.035
405	Silvergray rockfish	*Sebastes brevispinis*	6,755	5.380
439	Redstripe rockfish	*Sebastes proriger*	6,522	5.194
418	Yellowtail rockfish	*Sebastes flavidus*	4,632	3.689
450	Sharpchin rockfish	*Sebastes zacentrus*	3,738	2.977
626	Dover sole	*Microstomus pacificus*	2,833	2.256
417	Widow rockfish	*Sebastes entomelas*	1,693	1.349
394	Rougheye rockfish	*Sebastes aleutianus*	1,551	1.235
401	Redbanded rockfish	*Sebastes babcocki*	1,406	1.119
610	Rex sole	*Errex zachirus*	1,137	0.905
467	Lingcod	*Ophiodon elongatus*	1,135	0.904
437	Canary rockfish	*Sebastes pinniger*	1,090	0.868
044	Spiny dogfish	*Squalus acanthias*	1,058	0.842
412	Splitnose rockfish	*Sebastes diploproa*	948	0.755
455	Sablefish	*Anoplopoma fimbria*	925	0.736
451	Shortspine thornyhead	*Sebastolobus alascanus*	767	0.610
225	Pacific hake	*Merluccius productus*	754	0.600
607	Petrale sole	*Eopsetta jordani*	646	0.515

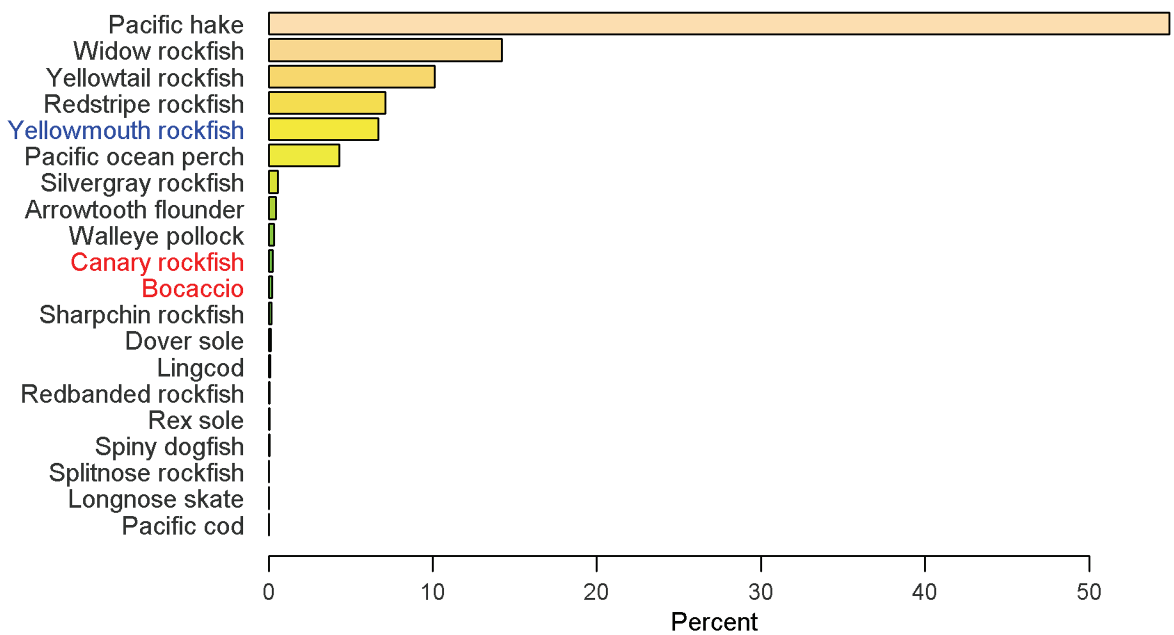


Figure H4. Concurrence of species in YMR midwater trawl tows (1996-2011 observer logs). Abundance is expressed as a percent of total catch weight. YMR is indicated in blue on the y-axis; other species of interest to COSEWIC are indicated in red.

Table H2. Top 20 species by catch weight (landed + discarded) that co-occur in YMR midwater tows (total from 1996-2011 observer logs). Rockfish species of interest to COSEWIC have been shaded grey.

Code	Species	Latin name	Catch (t)	Catch (%)
225	Pacific hake	*Merluccius productus*	13,455	54.913
417	Widow rockfish	*Sebastes entomelas*	3,487	14.231
418	Yellowtail rockfish	*Sebastes flavidus*	2,478	10.113
439	Redstripe rockfish	*Sebastes proriger*	1,747	7.128
440	Yellowmouth rockfish	*Sebastes reedi*	1,635	6.671
396	Pacific ocean perch	*Sebastes alutus*	1,055	4.305
405	Silvergray rockfish	*Sebastes brevispinis*	136	0.555
602	Arrowtooth flounder	*Atheresthes stomias*	111	0.454
228	Walleye pollock	*Theragra chalcogramma*	79	0.322
437	Canary rockfish	*Sebastes pinniger*	60	0.243
435	Bocaccio	*Sebastes paucispinis*	56	0.229
450	Sharpchin rockfish	*Sebastes zacentrus*	43	0.177
626	Dover sole	*Microstomus pacificus*	35	0.142
467	Lingcod	*Ophiodon elongatus*	22	0.091
401	Redbanded rockfish	*Sebastes babcocki*	15	0.060
610	Rex sole	*Errex zachirus*	13	0.052
044	Spiny dogfish	*Squalus acanthias*	10	0.042
412	Splitnose rockfish	*Sebastes diploproa*	7	0.030
059	Longnose skate	*Raja rhina*	4	0.018
222	Pacific cod	*Gadus macrocephalus*	4	0.018

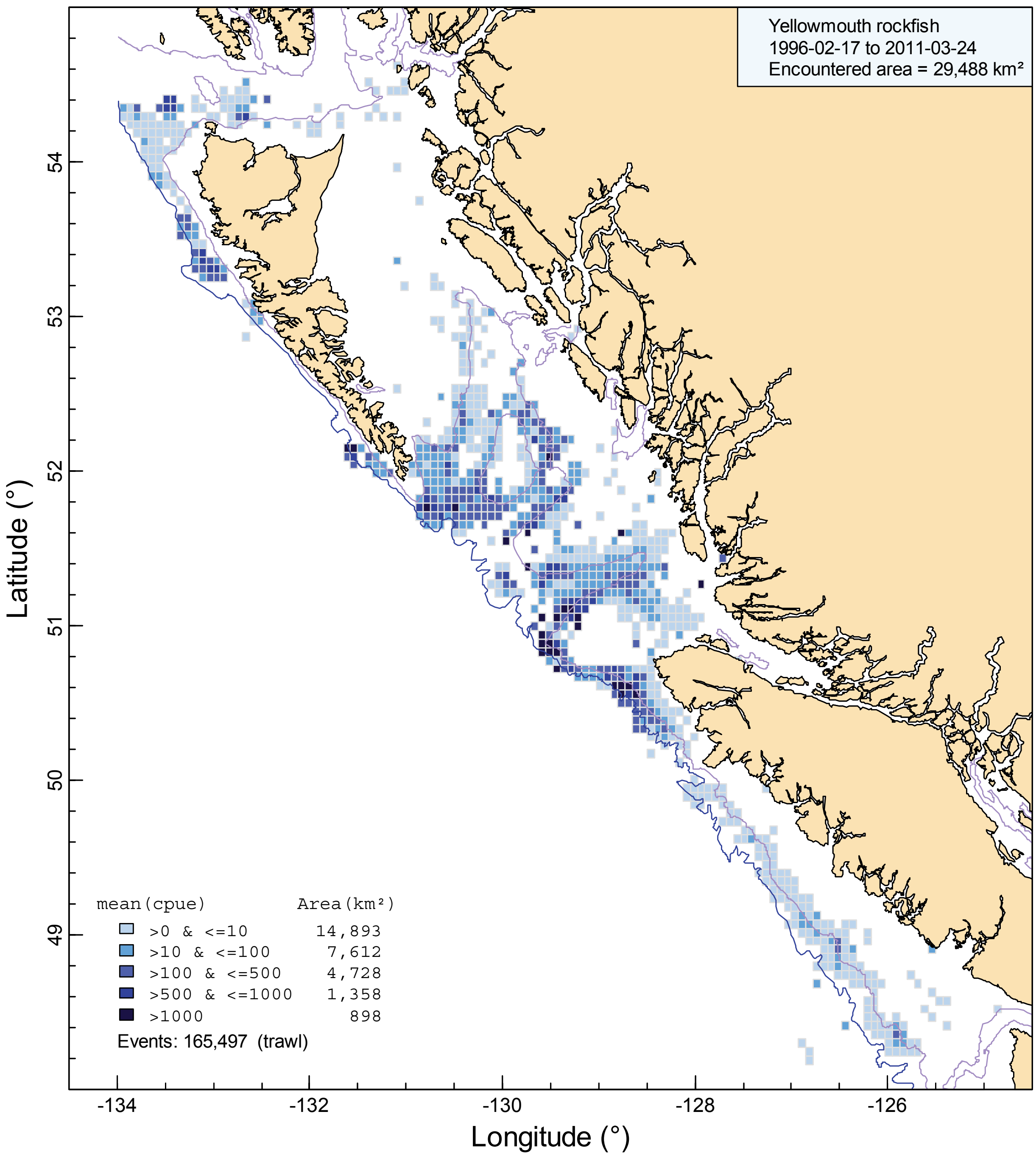


Figure H5. Mean CPUE (kg/h) of YMR in grid cells 0.075° longitude by 0.055° latitude (roughly 32 km²). The shaded cells give an approximation of the area where YMR was encountered by fishing events from the groundfish trawl fishery from Feb 1996 to Mar 2011.

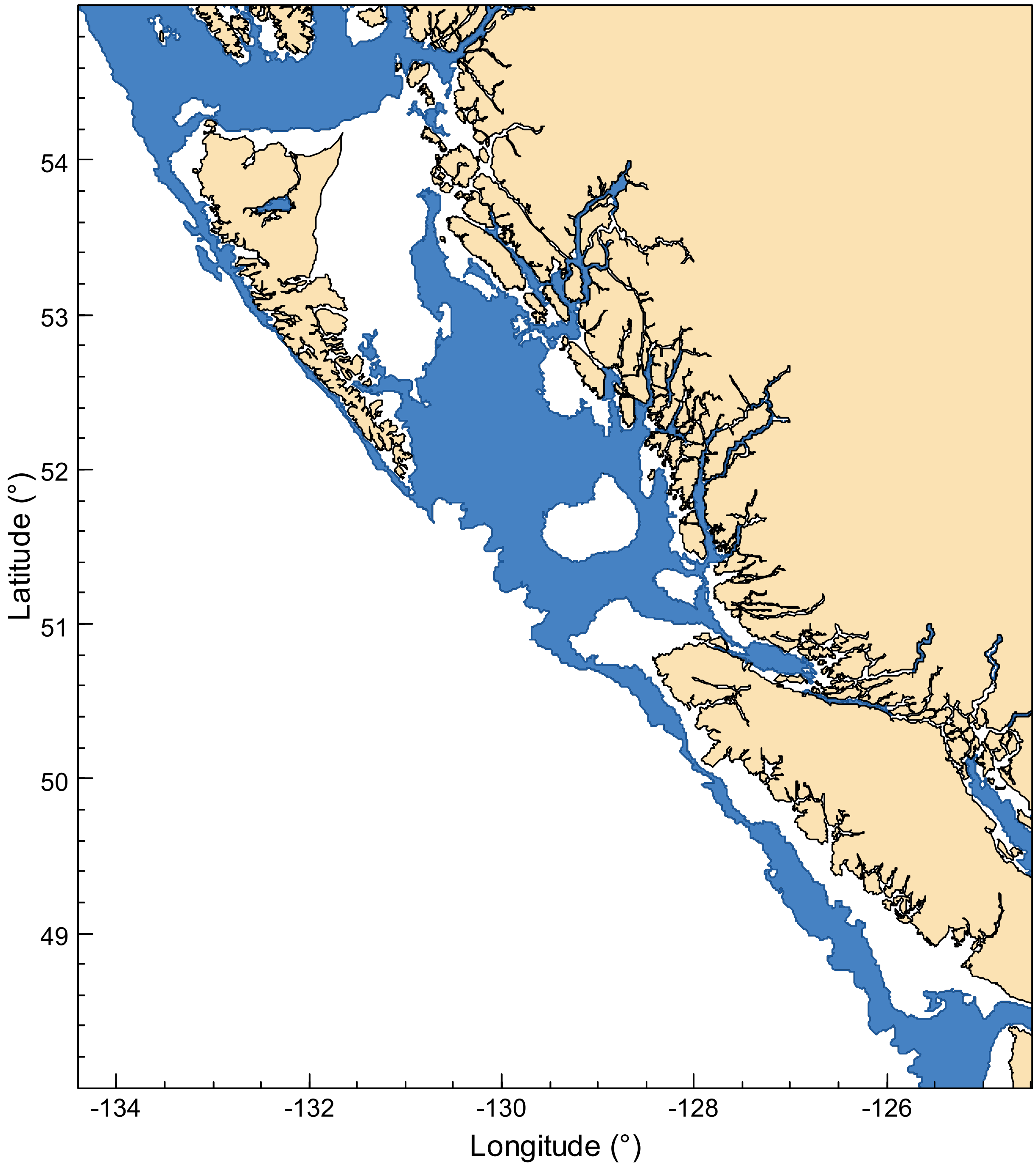


Figure H6. Highlighted bathymetry (blue) between 110 and 437 m serves as a proxy for benthic Yellowmouth Rockfish habitat along the BC coast. Highlighted region covers 59,789 km^2.

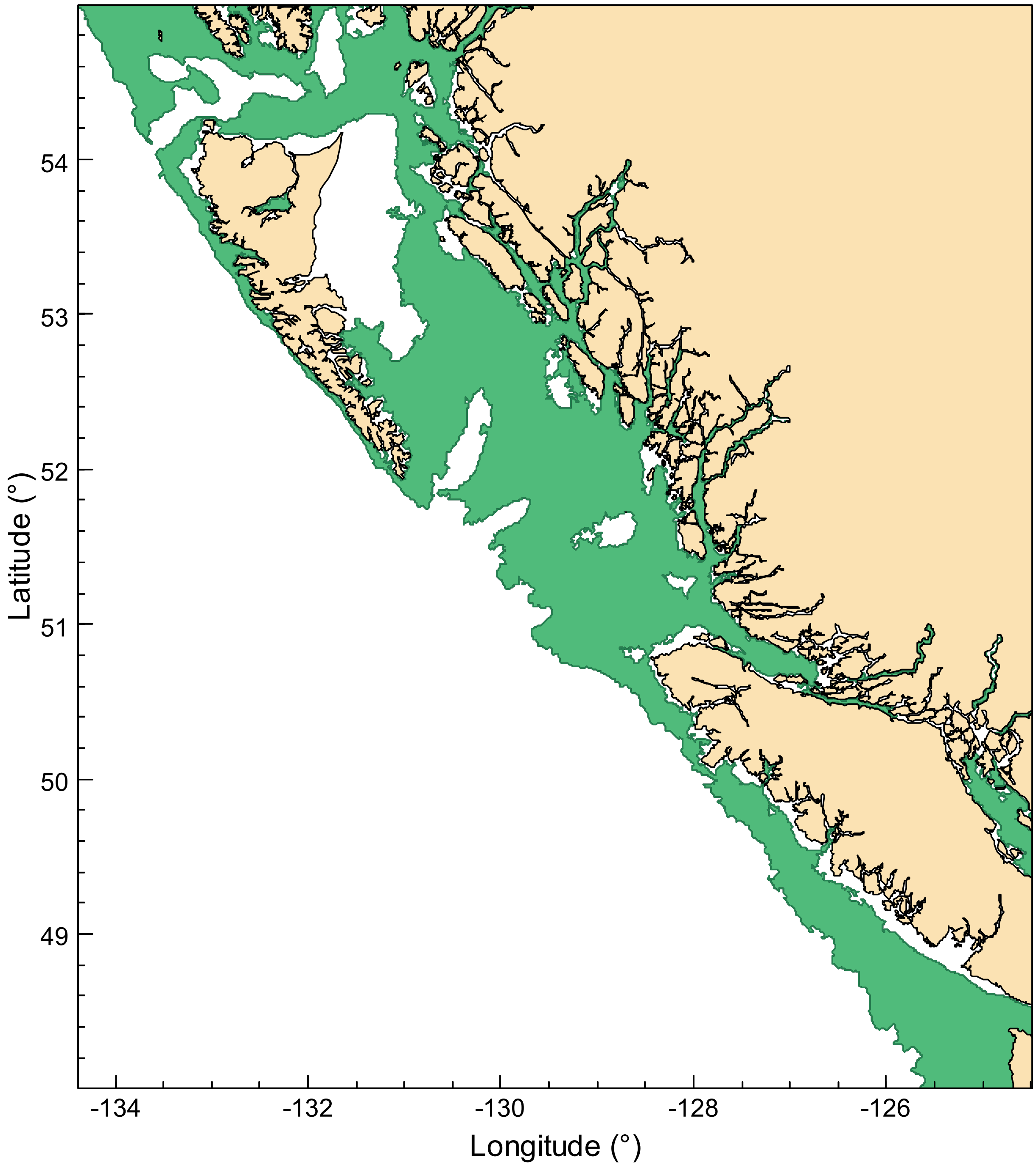


Figure H7. Highlighted bathymetry (blue) between 49 and 300 m serves as a proxy for midwater Yellowmouth Rockfish habitat along the BC coast. Highlighted region covers 77,157 km^2.

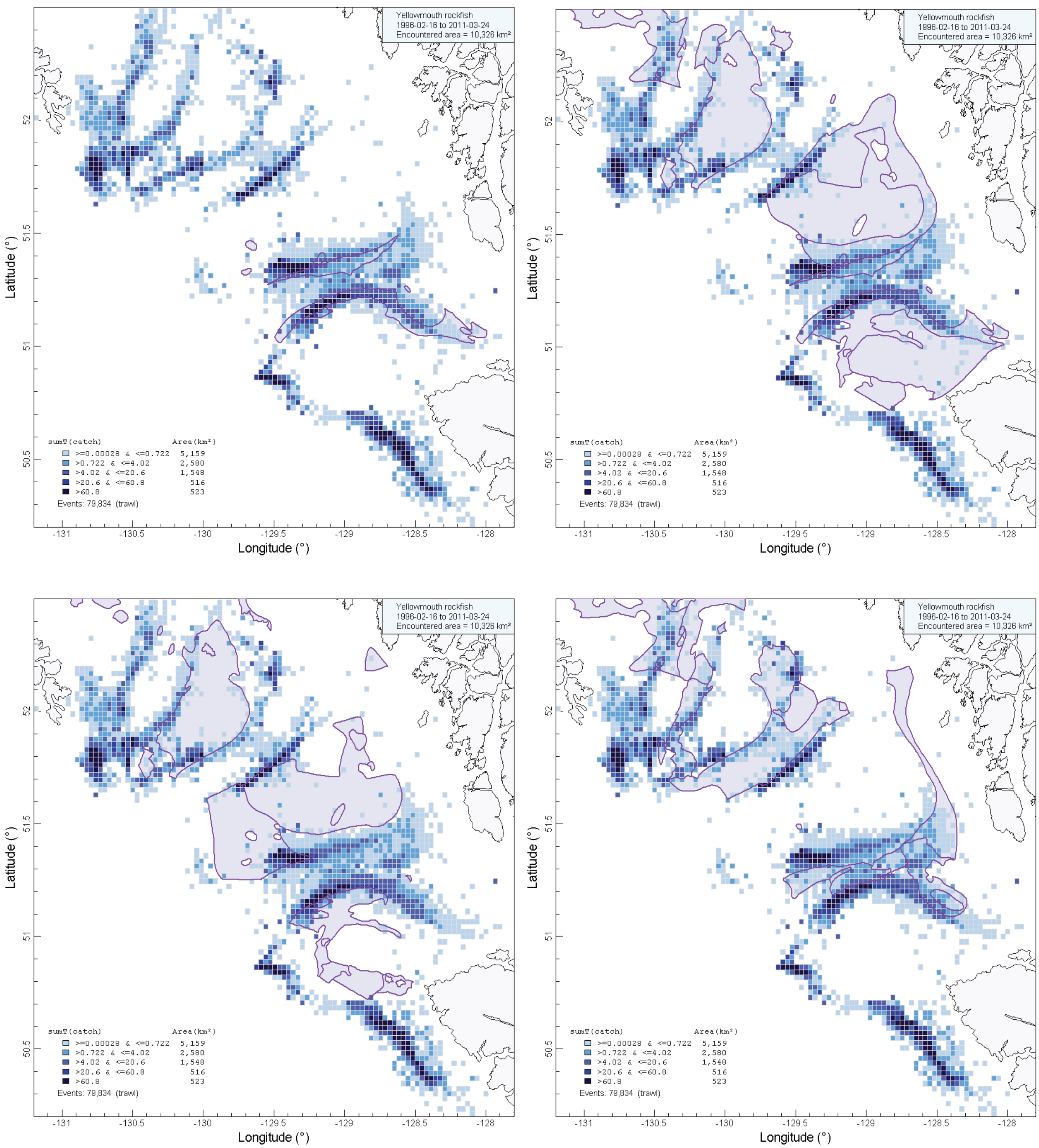


*Figure H8. Catch distribution of YMR (1996-2011) in Queen Charlotte Sound and its spatial relationship with the basin's surficial geology (shaded lavender, outlined in purple; **top left**: glacial outwash, **top right**: sand and gravel, **bottom left**: bedrock, **bottom right**: mud).*

APPENDIX I – MODEL SENSITIVITY ANALYSES

A number of sensitivity tests were run after receiving the reviews of the Yellowmouth Rockfish working paper and before the CSAP review meeting (held on 30th May 2011). Here we describe results for a number of variations based on the run 'Estimate *M*'. All results are presented for the maximum posterior density (MPD) estimates.

BASE RUNS (B):

Run 29 – B1 (Estimate *M*)

- five surveys, indexed by the value g :
  1 = GIG Historical, 2 = QCS Synoptic, 3 = QCS Shrimp,
  4 = WCHG Synoptic, 5 = WCVI Synoptic;
- no commercial CPUE (catch per unit effort) series ($g = 6$);
- composition re-weighted using mean ages (Francis 2011);
- abundance CVs with added process error c_p = 0.2: $c_t = \sqrt{c_o^2 + c_p^2}$;
- M_s as a normal prior distribution: $\mathbf{N}$(0.047, 0.005);
- survey selectivity priors for g = {1,2,4,5} set to those for commercial ($g = 6$):
  $\mu_{\{1,2\}}$ = $\mathbf{N}$(7.21291, 2.16387), $\log \upsilon_{\{1,2\}L}$ = $\mathbf{N}$(1.7641, 0.529231), $\Delta_{\{1,2\}}$ = $\mathbf{N}$(0,1)
  (standard deviation SD of $\mu_{\{1,2\}}$ = $0.3\mu_{\{1,2\}}$; SD of $\log \upsilon_{\{1,2\}L}$ = $0.3 \log \upsilon_{\{1,2\}L}$);
  μ_3 = 4.20263, $\log \upsilon_{3L}$ = 1.09861, Δ_3 = 0;
  $\mu_{\{4,5\}}$ = 7.21291, $\log \upsilon_{\{4,5\}L}$ = 1.7641, $\Delta_{\{4,5\}}$ = 0;
- no ageing error;
- GIG survey indices corrected after exclusion of tows used for acoustic verification.

Run 30 – B2 (Fix *M*)

- As for Run 29 but M_s fixed at 0.047
  (Hoenig estimate using maximum age t_m = 99:
  $M = -\log(0.01)/t_m = 4.605/99 = 0.047$).

SENSITIVITY RUNS (S):

Run 24 – S1 (Age Error)

- As for Run 29 (Est. *M*) except:
- symmetric ageing error matrix (0.1, 0.8, 0.1) was used;
- GIG survey indices were not recalculated to exclude acoustic calibration tows (this sensitivity run was performed before the indices were recalculated as for the base case).

Run 31 – S2 (CPUE)

- As for Run 29 (Est. *M*) except:
- commercial CPUE index (1977-95, coastwide, trawl) was used with uniform priors:
  $\log q_6$ = $\mathbf{U}$(-15, 15), log beta-CPUE = $\mathbf{U}$(-2, 2).
  Allan Hicks (NOAA, unpublished manuscript, 'Estimation of a non-linear parameter when relating CPUE to abundance in an orange roughy fishery') describes the hyperdepletion parameter β using the relationship:
  $U = \alpha N^{\beta}$, where U = CPUE and N = abundance.

Run 32 – S3 (1994 GIG)

- As for Run 29 (Est. *M*) except:
- the 1994 Historical GIG survey index was removed.

Run 33 – S4 (Hamel)

- As for Run 29 (Est. *M*) except:
- Hamel's *M* prior $\mathbf{N}$(0.0505, 0.02914) was used.

Run 34 – S5 (POP)

- As for Run 29 (Est. *M*) except:
- POP selectivity posterior medians (Edwards et al. 2012) were used as priors:
  μ_1 = $\mathbf{N}$(12.4, 3.72), $\log v_{1L}$ = $\mathbf{N}$(3.52, 1.056), Δ_1 = $\mathbf{N}$(0,1);
  μ_2 = $\mathbf{N}$(13.3, 3.99), $\log v_{2L}$ = $\mathbf{N}$(3.30, 0.99), Δ_2 = $\mathbf{N}$(0,1);
  μ_3 = 4.20263, $\log v_{3L}$ = 1.09861, Δ_3 = 0;
  $\mu_{\{4,5\}}$ = 10.5, $\log v_{\{4,5\}L}$ = 1.52, $\Delta_{\{4,5\}}$ = 0;
  μ_6 = $\mathbf{N}$(10.5, 3.15), $\log v_{6L}$ = $\mathbf{N}$(1.52, 0.456), Δ_6 = $\mathbf{N}$(0,1).

Run 35 – S6 (sigma R)

- As for Run 29 (Est. *M*) except:
- standard deviation parameter σ_R for recruitment process error was changed from 0.9 to 0.6.

Run 36 – S7 (NMFS)

- As for Run 29 (Est. *M*) except:
- US NMFS Triennial survey indices were added as a new abundance series.

DISCUSSION

These sensitivity runs did not alter the general shape of the biomass trajectory (Figure I1) or the recruitment reconstruction (Figure I2). However, two sensitivity runs in particular – S2 (CPUE) and S4 (Hamel) – did alter the magnitude of biomass profoundly (Table I1). The estimated recruitment data in some of the runs also suggested the presence of a recruitment anomaly in the early 1950s, although the same age data was used by the two base runs . Some of the sensitivity runs – S2 (CPUE), S3 (1994 GIG), and S4 (Hamel) – interpreted good recruitment in this early period, but the level of recruitment was minor compared to the strong recruitment observed in the early 1960s and early 1980s. The following discussions are observations for each sensitivity run relative to base run B1, unless otherwise specified.

Sensitivity 1 – Ageing error

For this sensitivity run, a simple ageing error matrix was assumed, where each age was read with constant precision, with the observed age accurately determined 80% of the time. The remaining error is assumed to be plus one year 10% of the time and minus one year 10% of the time (0.1, 0.8, 0.1). Age 1 and Age 60, the youngest and oldest ages present in the model, were assumed to be aged accurately 90% of the time. This sensitivity run did not greatly alter the parameter estimates (Table I1). Virgin recruitment R_0 increased slightly from 6,682 to 6,902 thousand fish, and B_0 increased from 43,308 t to 44,883 t, but the estimate of depletion remained nearly the same (0.60 vs. 0.61).

Very young ages are infrequently encountered in the fishery and thus the Sclerochronology Laboratory at the Pacific Biological Station has little experience with these fish. As well, there appears to be a general decline in ageing precision with age (Table I2) which was not investigated in the sensitivity. One recommendation from this assessment will be to explore the ageing error data more thoroughly by developing ageing error matrices that reflect decreasing precision with older ages and more realistically reflect the inherent precision in the ageing procedure. As well, there will be a need to investigate the potential for bias (rather than just changing precision) in the ageing methodology.

Sensitivity 2 – Commercial CPUE

This sensitivity run added a commercial CPUE series covering the period from 1977 to 1995 (fourth panel, Figure I1), which was excluded from the base model runs due to an obvious conflict with the GIG survey index – the CPUE series showed a decline during a period when the GIG index was rising dramatically (Figure I3). The very high 1994 GIG index value is supported by a strong recruitment event in 1982 (seen clearly in the age composition data, Figure E1). Additionally, there are confounding factors present in commercial CPUE data which can affect the indices for reasons other than abundance changes, as well as known changes in the catch reporting system during this period that reduce the reliability of this series. The inclusion of this CPUE index series caused a strong decline in the model biomass estimates, reducing the estimate of depletion (B_{2011}/B_0)from 0.60 to 0.31.

Sensitivity 3 – Removal of the 1994 GIG index

The 1994 GIG index point occurred 10 years after the previous GIG index, and the survey vessel (Ocean Selector) employed was the first time that this vessel contributed to this series. However, apart from the change in vessel, the survey design (including net configuration) was carefully replicated. The 1994 index point for Yellowmouth is 2624 t, which is 3.8 times higher than the 1984 index and 97 times higher than the 1977 index. Although the 1994 index is supported by the age composition data, which indicates a strong 1982 year class, we removed the 1994 index from the GIG series for exploratory purposes. The change does not affect the parameter estimates greatly (Table I1). However, the virgin recruitment R_0 decreases from 6,682 to 6,262 thousand fish, virgin spawning biomass B_0 decreases from 43,308 t to 40,622 t and the depletion ratio B_{2011}/B_0 decreases from 0.60 to 0.53.

Sensitivity 4 – Owen Hamel's *M* prior

Using Hoenig's estimator and observed variance from Hoenig's data, Owen Hamel (Northwest Fisheries Science Center, Seattle) derived a normal prior on M for Yellowmouth Rockfish: $\mathbf{N}(0.0505, 0.02914)$. We used this prior for both males and females as an alternative to the one used by the 'Estimate *M*' run (B1). The effect of this change on the model estimates was the greatest of all sensitivity runs explored (Table I1), with the model estimates of M rising to 0.082 (females) and 0.077 (males) due to the wide bounds on the M prior (CV=58%). This near doubling of M resulted in a strong increase in the apparent productivity of the stock, increasing the estimate of recruits (R_0 = 637,293 thousand fish), spawning biomass (B_0 = 219,532 t), current biomass (B_{2011} = 204,862 t), and depletion (B_{2011}/B_0 = 0.93). B_{1998} was estimated at 356,597 t, which is 1.6 times higher than the virgin biomass B_0. This run highlighted the sensitivity of the model results to small changes in the estimated value of *M* and the failure of the model data to constrain the estimate of this parameter. Such constraint can be achieved by employing a tight prior or even by fixing this parameter (as was done with the 'Fix *M*' run). However, fixing *M* reduces the underlying uncertainty expressed by the model and there is little in the way of objective information to use when setting these limits.

Sensitivity 5 – Use POP selectivity posterior means as priors

One reviewer suggested that the use of selectivity priors (from Hamel 2008) based on US Darkblotched Rockfish fisheries may not have been appropriate. As an alternative, the reviewer suggested that we base our priors on the selectivity posteriors estimated by a recently completed Queen Charlotte Sound POP assessment (Edwards et al. 2012). That assessment is for a related species taken in the same fishery that is responsible for the majority of the Yellowmouth exploitation. Using priors from the POP assessment resulted in minor changes to the estimates of natural mortality *M* or steepness *h*, with shifts of the survey selectivity functions to the right of those estimated with the Hamel priors (Table I1). The estimate of virgin recruitment (R_0) declined from 6,682 to 5,881 thousand fish, while that for virgin spawning biomass (B_0) declined from 43,308 t to 38,555 t and for depletion (B_{2011}/B_0) declined from 0.60 to 0.55.

Sensitivity 6 – Set recruitment process error standard deviation σ_R to 0.6

Recruitment variability σ_R , which was fixed at 0.9 for the base runs, was dropped to 0.6 for this sensitivity. This change reduced the recruitment process error, resulting in a predictable decline in the variation in the size of year class strengths (Figure I2), including the disappearance of a weak recruitment anomaly in the early 1950s. As with the previous sensitivity run, most of the parameter estimates were not greatly affected (Table I1), although the estimate of virgin recruitment R_0 increased from 6,682 to 6,850 thousand fish, virgin spawning biomass B_0 also increased from 43,308 t to 43,919 t and the estimate of depletion (B_{2011}/B_0) increased slightly from 0.60 to 0.62.

Sensitivity 7 – Include US NMFS Triennial survey

The US NMFS Triennial survey (covering the period 1980 to 2001) was excluded from the base runs because its area of coverage ended at mid-Vancouver Island and did not extend into the northern part of WCVI, which is where Yellowmouth Rockfish become much more abundant. Given that YMR was assumed to be a single coastwide stock, each survey used in the assessment had to serve as an index of the entire stock, a strong assumption for a survey which operated at the apparent fringe of the range for this species and for which the northern extension varied from survey year to survey year. This sensitivity run included the NMFS survey (Table I3), which affected the reconstruction by increasing the relative importance of the early recruitment events (1950s, 1960s) relative to the major event in the 1980s (Figure I2). This sensitivity run mimicked sensitivity S3 (which removed the 1994 GIG survey index) by decreasing the estimate of virgin spawning biomass (B_0) from 43,308 t to 40,200 t and decreasing the estimate of depletion (B_{2011}/B_0)from 0.60 to 0.52.

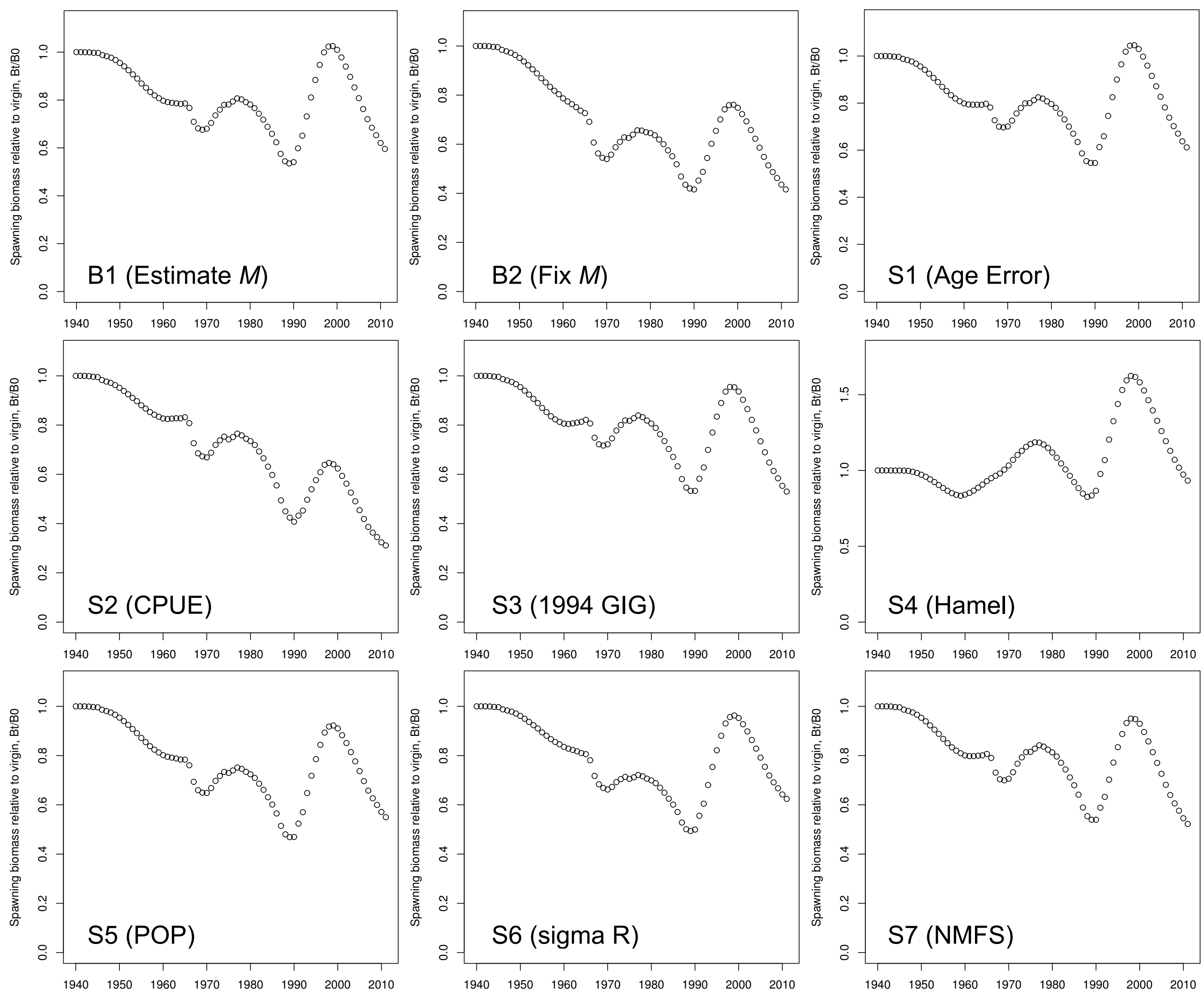


Figure I1. Spawning biomass (mature females) relative to virgin level, B_t/B_0. Panels show base runs B1 and B2, and sensitivity runs S1 to S7.

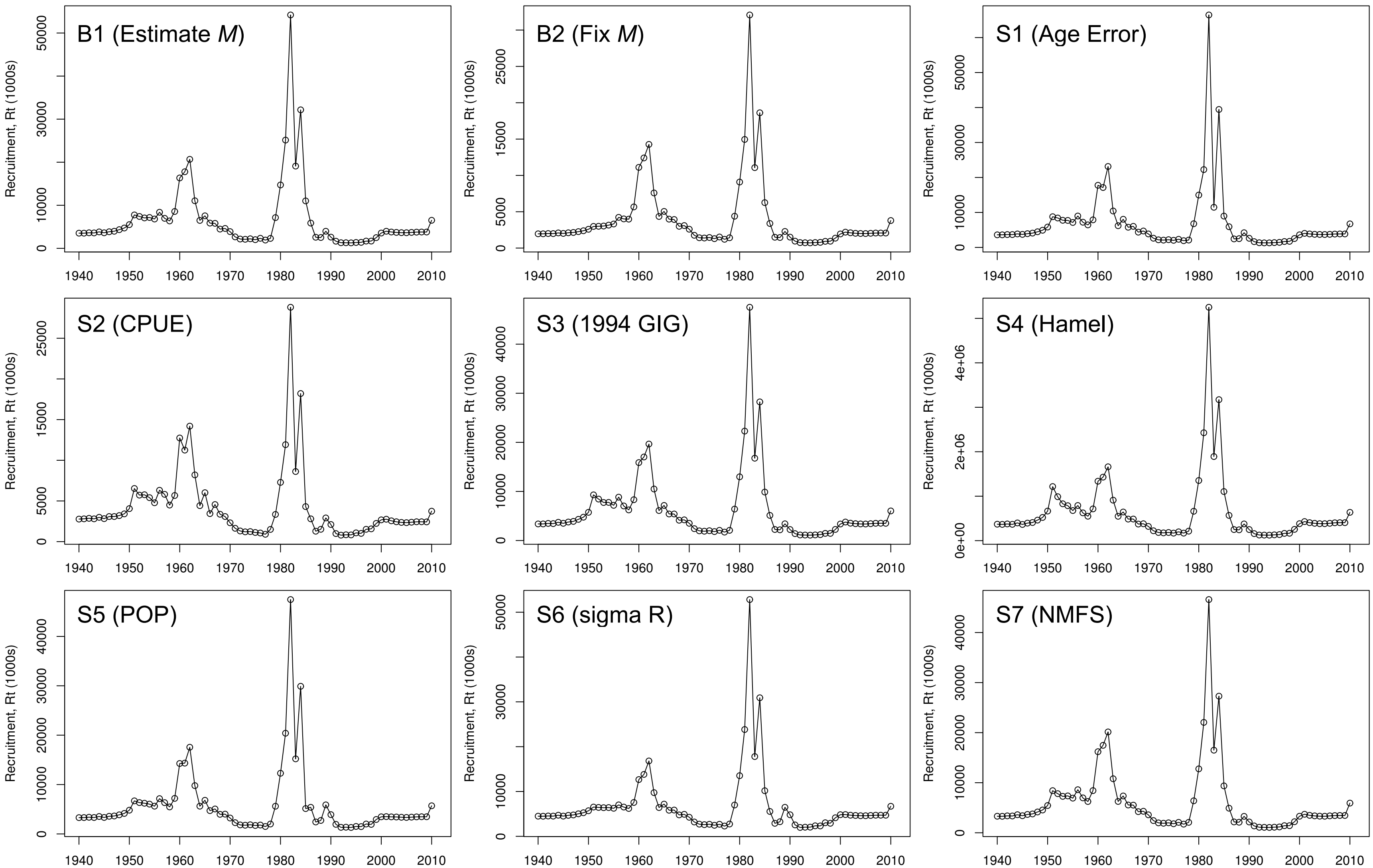


Figure I2. Reconstructed recruitment (1000s fish). Panels show base runs B1 and B2, and sensitivity runs S1 to S7.

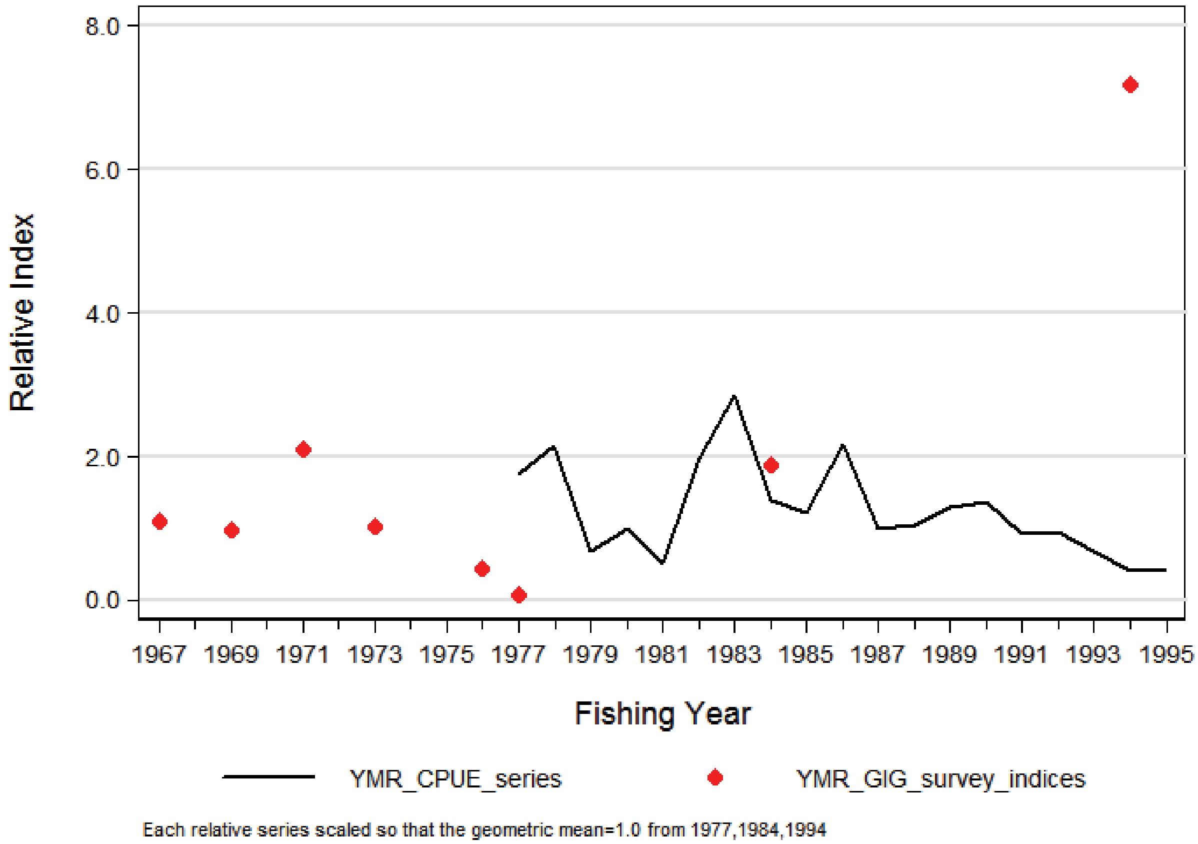


Figure I3. Comparison of the YMR CPUE series with the GIG survey indices, scaled such that the geometric mean of each series equals 1.0 for the three overlapping years.

Table I1. Mode of the posterior distribution (MPD) estimates for the two base cases: B1 (Estimate M) and B2 (Fix M); and the seven sensitivity runs based on B1: S1 (Age Error), S2 (CPUE), S3 (1994 GIG), S4 (Hamel), S5 (POP), S6 (sigma R), and S7 (NMFS). The subscript $_T$ refers to the NMFS Triennial survey that was purposely excluded from the base runs.

Parameter	B1	B2	S1	S2	S3	S4	S5	S6	S7
R_0	6,682	3,968	6,902	4,348	6,262	637,293	5,881	6,850	6,169
M_1	0.058	0.047	0.058	0.055	0.058	0.082	0.058	0.059	0.058
M_2	0.055	0.047	0.054	0.050	0.055	0.077	0.054	0.055	0.054
h	0.851	0.872	0.848	0.766	0.837	0.838	0.851	0.858	0.837
q_1	-5.13	-4.71	-6.02	-4.77	-5.37	-9.46	-5.01	-5.09	-5.09
q_2	-3.46	-2.92	-3.52	-2.45	-3.29	-7.84	-3.16	-3.38	-3.27
q_3	-7.61	-7.07	-7.66	-6.80	-7.45	-12.00	-7.43	-7.65	-7.43
q_4	-5.94	-5.39	-6.00	-5.09	-5.77	-10.33	-5.68	-6.00	-5.75
q_5	-6.42	-5.87	-6.48	-5.58	-6.26	-10.81	-6.17	-6.48	-6.24
q_T	---	---	---	---	---	---	---	---	-6.74
q_6	---	---	-4.43	---	---	---	---	---	---
$\log \beta$	---	---	-0.19	---	---	---	---	---	---
μ_1	10.89	10.88	11.15	10.67	10.92	10.92	11.04	10.83	10.87
μ_2	11.45	11.40	11.42	16.26	11.67	11.63	18.63	16.11	11.69
μ_3	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20
μ_4	7.21	7.21	7.21	7.21	7.21	7.21	10.50	7.21	7.21
μ_5	7.21	7.21	7.21	7.21	7.21	7.21	10.50	7.21	7.21
μ_T	---	---	---	---	---	---	---	---	7.21
μ_6	12.17	12.26	12.08	14.00	12.16	12.09	12.52	12.43	12.15
$\log \upsilon_{L1}$	1.11	1.13	1.14	0.97	1.11	1.12	1.93	1.08	1.11
$\log \upsilon_{L2}$	1.62	1.62	1.62	1.36	1.60	1.60	2.70	1.37	1.60
$\log \upsilon_{L3}$	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
$\log \upsilon_{L4}$	1.76	1.76	1.76	1.76	1.76	1.76	1.52	1.76	1.76
$\log \upsilon_{L5}$	1.76	1.76	1.76	1.76	1.76	1.76	1.52	1.76	1.76
$\log \upsilon_{LT}$	---	---	---	---	---	---	---	---	1.76
$\log \upsilon_{L6}$	1.66	1.71	1.61	2.45	1.66	1.60	1.78	1.83	1.66
Δ_1	0.86	0.86	0.78	0.46	0.84	0.83	0.52	0.89	0.85
Δ_2	0.38	0.36	0.38	0.58	0.37	0.38	0.14	0.59	0.38
Δ_3	0	0	0	0	0	0	0	0	0
Δ_4	0	0	0	0	0	0	0	0	0
Δ_5	0	0	0	0	0	0	0	0	0
Δ_T	0	0	0	0	0	0	0	0	0
Δ_6	0.18	0.23	0.14	0.67	0.18	0.13	0.14	0.18	0.18
B_0	43,308	36,673	44,883	31,137	40,622	219,532	38,555	43,919	40,201
B_{2011}	25,799	15,255	27,464	9,690	21,538	204,862	21,208	27,411	21,010
B_{2011}/B_0	0.596	0.416	0.612	0.311	0.530	0.933	0.550	0.624	0.523

Table I2. Ageing imprecision for Yellowmouth Rockfish expressed as the proportion of true age determined by age ranges for each 'Final' age reported in the GFBio database. Ages coinciding with Final ages fall into the bin marked '0' (no age difference). All other ages are expressed as years different than the Final age. Age anomalies ≤5 y or ≥5 y are grouped into age bins '-5+' or '+5+', respectively. Ages never observed are assumed to have no error. The column marked 'Noto' reports the number of otoliths contributing to the empirical distribution at each age.*

Age	Anom▶ Noto▼	- 5+	- 4	- 3	- 2	- 1	**0**	+ 1	+ 2	+ 3	+ 4	+ 5+
1	0						**1.00**					
2	0						**1.00**					
3	0						**1.00**					
4	1						**1.00**					
5	3					0.14	**0.43**	0.29	0.14			
6	84					0.04	**0.71**	0.24	0.01			
7	16					0.34	**0.50**	0.16				
8	8					0.08	**0.62**	0.31				
9	20					0.04	**0.74**	0.22				
10	19					0.13	**0.63**	0.23				
11	8					0.29	**0.57**	0.14				
12	10					0.20	**0.50**	0.30				
13	17				0.12	0.21	**0.50**	0.15	0.03			
14	9					0.30	**0.45**	0.25				
15	13					0.18	**0.59**	0.23				
16	18					0.18	**0.47**	0.26	0.08			
17	51				0.01	0.11	**0.64**	0.21	0.03			
18	23				0.03	0.28	**0.40**	0.22	0.07			
19	8				0.05	0.20	**0.40**	0.30	0.05			
20	20	0.06	0.04	0.04	0.04	0.22	**0.39**	0.16	0.04	0.02		
21	27				0.07	0.22	**0.46**	0.20	0.03	0.02		
22	16				0.11	0.17	**0.46**	0.23	0.03			
23	16				0.03	0.13	**0.53**	0.23	0.07			
24	32				0.04	0.17	**0.42**	0.23	0.08	0.05	0.01	
25	25			0.01	0.03	0.13	**0.32**	0.29	0.08	0.04	0.03	0.08
26	26				0.02	0.26	**0.45**	0.21	0.03	0.02	0.02	
27	29				0.02	0.24	**0.46**	0.25	0.03			
28	29			0.01	0.07	0.23	**0.40**	0.23	0.05			
29	23		0.02	0.02	0.08	0.27	**0.36**	0.22	0.03	0.02		
30	19				0.04	0.21	**0.40**	0.25	0.06	0.04		
31	22				0.02	0.33	**0.40**	0.18	0.07			
32	25	0.01	0.01	0.03	0.05	0.27	**0.34**	0.25	0.03			
33	14		0.03	0.03	0.03	0.29	**0.37**	0.24	0.03			
34	13		0.05	0.05	0.08	0.23	**0.33**	0.10	0.10	0.05		
35	13				0.10	0.24	**0.31**	0.19	0.10	0.05	0.02	
36	15				0.08	0.25	**0.31**	0.23	0.10	0.02		
37	8	0.03	0.03	0.03	0.10	0.20	**0.27**	0.20	0.07	0.03	0.03	
38	18			0.02	0.06	0.24	**0.36**	0.24	0.08			
39	22			0.06	0.13	0.20	**0.32**	0.20	0.07	0.01		
40	28			0.04	0.08	0.24	**0.28**	0.22	0.10	0.03	0.01	0.01
41	23		0.01	0.02	0.15	0.26	**0.28**	0.21	0.05	0.01		
42	15		0.01	0.03	0.12	0.19	**0.22**	0.22	0.15	0.06		
43	34		0.01	0.06	0.08	0.17	**0.24**	0.20	0.11	0.06	0.04	0.03
44	18		0.01	0.04	0.10	0.15	**0.25**	0.21	0.10	0.06	0.06	0.03

Age	Anom▶ Noto▼	- 5+	- 4	- 3	- 2	- 1	**0**	+ 1	+ 2	+ 3	+ 4	+ 5+
45	27	0.03	0.03	0.06	0.10	0.17	**0.22**	0.20	0.10	0.06	0.02	0.02
46	26	0.03	0.04	0.06	0.12	0.21	**0.24**	0.20	0.09	0.02		
47	10			0.07	0.14	0.20	**0.23**	0.20	0.11	0.05		
48	17	0.04	0.04	0.07	0.07	0.18	**0.23**	0.12	0.10	0.07	0.04	0.04
49	13	0.11	0.06	0.06	0.09	0.22	**0.24**	0.20	0.02			
50	14		0.05	0.07	0.12	0.17	**0.24**	0.19	0.10	0.02	0.02	0.02
51	16	0.02	0.02	0.03	0.06	0.20	**0.24**	0.23	0.14	0.03	0.02	0.03
52	19		0.02	0.04	0.11	0.20	**0.23**	0.22	0.12	0.04	0.01	0.01
53	10		0.03	0.08	0.13	0.20	**0.25**	0.20	0.08	0.03	0.03	
54	19		0.01	0.04	0.13	0.26	**0.27**	0.21	0.06	0.01		
55	22				0.05	0.32	**0.35**	0.22	0.06			
56	17	0.04	0.03	0.03	0.12	0.19	**0.25**	0.19	0.10	0.01	0.03	
57	12	0.09	0.04	0.04	0.10	0.18	**0.18**	0.16	0.10	0.09		
58	17	0.03	0.03	0.03	0.10	0.18	**0.28**	0.15	0.18			
59	10		0.02	0.05	0.17	0.24	**0.24**	0.29				
60	13		0.03	0.06	0.16	0.19	**0.56**					

*The Sclerochronology laboratory at the Pacific Biological Station provides information on ageing imprecision through its ageing procedure. A first reader ages each fish, supplying a minimum and maximum age which is used as an estimate of relative precision for that reader. For approximately 15% of the aged otoliths, a second reader also ages the fish and supplies another precision estimate without reference to the first reader estimates. Then the second reader compares the two sets of results, attempting to reconcile them into a “best estimate” and precision range. If the second reader cannot complete this stage (perhaps discrepancy is too high), the otolith goes back to the first reader who re-evaluates the reading and makes a final determination. The outcome of this procedure is that every otolith eventually receives a final age determination with an accompanying precision estimate which serve as input data into the stock assessment model.

Table I3. Relative biomass estimates for Yellowmouth Rockfish in the Vancouver INPFC region (total region, Canadian waters only and US waters only) with 95% confidence regions based on the bootstrap distribution of biomass. The bootstrap estimates are based on 5000 random draws with replacement. Highlighted indices and CVs are used in S7 (NFMS). Source: Haigh and Starr (2008, Table 32).*

Estimate type	Survey Year	Relative biomass (t)	Mean bootstrap biomass	Lower bound biomass	Upper bound biomass	Bootstrap CV	Analytic CV
Total Vancouver	1980	139	141	0	361	0.609	0.661
	1983	613	627	138	1,608	0.575	0.585
	1989	202	203	16	622	0.735	0.753
	1992	15	14	2	43	0.713	0.726
	1995	72	69	1	222	0.778	0.791
	1998	6	6	0	20	0.925	1.000
	2001	0	0	NA	NA	NA	NA
Canada Vancouver	1980	151	153	0	391	0.609	0.661
	1983	442	461	0	1,478	0.746	0.739
	1989	187	189	18	594	0.752	0.771
	1992	11	10	0	41	0.898	0.917
	1995	56	55	1	172	0.780	0.791
	1998	4	5	0	17	0.931	1.000
	2001	0	0	NA	NA	NA	NA
US Vancouver	1980	0	0	NA	NA	NA	NA
	1983	180	177	3	650	0.943	0.946
	1989	14	14	1	36	0.624	0.616
	1992	4	4	0	10	0.606	0.631
	1995	16	15	0	51	0.825	0.791
	1998	1	1	0	5	0.972	1.000
	2001	0	0	NA	NA	NA	NA

* International North Pacific Fisheries Commission