STOCK ASSESSMENT UPDATE FOR BRITISH COLUMBIA CANARY ROCKFISH

Context

In November 2007, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed canary rockfish as "Threatened". The Minister of the Environment will forward the assessment to the Governor in Council in early 2010, triggering a nine-month legal deadline. By Fall 2010, the Governor in Council's proposed listing decision, based on a recommendation from the Minister of the Environment in consultation with the Minister of Fisheries and Oceans, will be published in Canada Gazette I. Public comments will be accepted for 30 days. The Governor in Council will then make a final listing decision, which will be published in Canada Gazette II, at the end of the nine-month timeline. The decision can be to 1) accept the COSEWIC assessment and list the species, 2) decide not to list the species, or 3) send the assessment back to COSEWIC for further information or consideration. If the COSEWIC assessment of this species is accepted, a Recovery Strategy will be required within two years.

The intent of this document is to update a previous stock assessment that was provided in November 2007. This document updates the previous work by including more recent catch, survey, and biological data. It also incorporates the results of a meta-analysis of the stock-recruitment relationship for canary and other rockfish. The meta-analysis provides an objective basis for selecting plausible estimates for the steepness parameter, which affects stock productivity, an option that was not available when the 2007 assessment was prepared and reviewed. This document summarizes the current status relative to the DFO Precautionary Approach harvest reference points and provides decision tables which forecast the impact of varying fixed harvests on short and long term population trends.

Background

This document updates the previous canary rockfish stock assessment provided in November 2007 (DFO 2009, Stanley et al. 2009a) with new data and information that have since become available. The additional data include two years of additional catch and survey data, and three years of ageing data. The update also incorporates the results of a meta-analysis of the stock-recruitment relationship for canary and other rockfish. Readers are referred to the two previous documents for details on the inputs and the stock assessment model.

Analysis and Responses

Methods

Data

Catch data for the British Columbia (BC) commercial groundfish fisheries for the fishing years FY 07/08-09/10[1] were added to the previous catch time series (Figure 1, Table 1). Catch for FY 09/10 was projected to 800 t based on a proration of catches from April-August/2009.

The catch-at-age information incorporates two additional years of aged samples from specimens collected in 2005 and 2006 (Figure 2, Table 2). It also includes ageing data from four samples collected in 1979 that were previously omitted because it was mistakenly concluded that 1979 was represented by only three samples, below the minimum criterion of four samples required for inclusion in the assessment. Fixed estimates of life history parameters, such as growth, natural mortality, and maturity-at-age, were not changed.

This assessment used relative abundance indices from the same surveys used by the previous assessment (Table 3). Two additional index values (for 2008 and 2009) were added from the two shrimp surveys (Figure 3, Figure 4, Figure 5, Table 4, Table 5) and one index value)for 2009) was added from the Queen Charlotte Sound (QCSd) groundfish bottom trawl survey (Figure 6, Figure 7, Table 6). The results of discontinued surveys that were used in the previous and present assessments include the US Triennial survey (west coast of Vancouver Island) (Figure 6, Table 7) and the G.B. Reed Goose Island Gully (QCSd) survey (Figure 3 and Table 8). As done in the previous assessment, this analysis did not include the West Coast Vancouver Island (WCVI) or the Hecate Strait (HS) Groundfish surveys, although updated results are provided in Figure 8 and Figure 9. This was done for consistency with the previous assessment as well as noting that there are only three observations available for each of these surveys.

Analysis

All methods and equations employed in the 2007 assessment have been repeated in this assessment, except as noted below. Both used the Awatea version of the Coleraine statistical catch-at-age model software (Hilborn et al. 2003; Allen Hicks, pers. comm.) to update Runs 11 and 17 from the previous assessment. However, the new runs (Runs 11-u and 17-u) used an updated version of Awatea (Vers. 0.9.4) which included a modification to constrain estimated recruitment deviations from average to zero in log space over all model years. This feature was added to limit the capacity of the model to trade-off between increasing or decreasing the mean of the recruitment deviations relative to the size of the long-term spawning biomass. This is a common constraint used in this type of model (e.g., the CASAL stock assessment package; see Bull et al. 2005). This change in the model had a negligible impact on the output in the current assessment, especially in comparison to the impact of adding the new catch, survey, and age composition data. We did not examine the effect of the change on the previous assessment (omitting the new data), but we expect that it would also have a minimal effect on the previous results, given the small observed effect when using the full data set.

[1] Fishing year (FY) corresponds to April 1-March 31 (i.e., FY 07/08 is April 1/07-March 31/08).

We also present one new run, Run 18-u. This required a further modification to Awatea, for this run alone, so that an appropriate Bayesian prior for steepness (*h*) could be used when estimating steepness within a Bayesian framework (see below).

The previous assessment investigated the following factors which contribute to the overall uncertainty:

1. The effect of including the proportion-at-age data from the commercial fishery;
2. The effect of assuming a deterministic or stochastic recruitment;
3. The effect of estimating or fixing the commercial selectivity;
4. The effect of varying the steepness assumption: two values were tested (0.55 and 0.70).

Six model runs, which attempted to cover the above uncertainties, were presented to the Pacific Science Advice Review Committee (PSARC) in November 2007. PSARC considered that the model runs which used deterministic recruitment were not credible, but accepted Runs 05, 11, and 17, which assumed stochastic recruitment (Table 9).

Run 05, in addition to assuming stochastic recruitment, fixed the commercial selectivity at values used as a prior for Runs 11 and 17 (which estimated selectivity). This prior was based on a length-based selectivity ogive published as part of the 2007 US canary assessment and its derivation is documented in Stanley et al. (2009a).

Plots of the posterior for selectivity for all three update runs (Runs 11-u, 17-u, and 18-u), which estimated the selectivity parameters, are characterised by very tight distributions and show a considerable shift away from the US-based prior, particularly for females (Figure 10). This was also observed during the previous assessment, but not presented. This strong shift away from the prior and the resulting tight posterior distributions imply that the available Canadian age data were informative for these parameters which differ substantially from those used to estimate selectivity in the US assessment. This, in turn, indicates that the Run 05 configuration is not appropriate for the Canadian context and was therefore not updated for this analysis.

Run 18-u estimates the steepness parameter (*h*) as a free parameter of the model, constrained by a prior. The prior was derived from a Bayesian hierarchical meta-analysis of this parameter for the genus *Sebastes* (Forrest et al., in review) (Figure 11). Run 18-u has been added to address concerns expressed during the review of the 2007 assessment about the lack of an objective basis for selecting a fixed value for steepness. Two levels of fixed steepness were explored in that assessment (h=0.70 in Run 11 and h=0.55 in Run 17), but no guidance was provided to managers as to which of these runs should be accepted as the more plausible. The two values were thought to bracket the plausible range of steepness for canary rockfish. As steepness plays a major role in defining the productivity of a stock, it requires due consideration, especially when considering stocks that may be in need of rebuilding.

Forrest et al. (in review) estimated a mean value for *h* of 0.714 (st.dev.=0.16) for "generic" rockfish when using a Beverton-Holt stock recruit function (as used in this assessment). The posterior distribution from this meta-analysis is well approximated by the beta probability function presented in Figure 11, which was used as an informed prior for input into Run 18-u. The Forrest et al. meta-analysis, when confined to canary data only (primarily data from the California-Washington stock), estimated an even higher mean value (h=0.750) with much lower variance, probably due to the scarcity of available data. Forrest et al. noted that most of the variation in the estimates of steepness for the generic rockfish analysis was derived from one species (Pacific ocean perch, *S. alutus*) and recommended that, for stocks not specifically examined in the analysis, it would be more prudent to use the generic rockfish analysis as this approach was based on a wider range of assessments and thus included a greater range of possible values for this parameter.

The latest US assessment (Stewart 2009) assumed a mid-level value of h=0.5, the value used in the previous 2007 assessment (Stewart 2008). However, in recent discussions (December 2009), Dr. Stewart commented that unpublished but more recent US analyses for many rockfish species, and for canary rockfish in particular, indicate that it would be more appropriate to use median values of h closer to 0.7. In his view, these higher values for steepness are likely to be used in the next US canary rockfish assessment.

Results

Current status (B_{2010}) relative to B_0 and B_{MSY}

The updated runs produced similar long term trends and estimates for B_0 (unfished equilibrium spawning biomass) as the previous assessment. The population went through a long term decline from at least 1940 (the first model year), reaching a minimum of about 20% of B_0[2] (Note: B_0 and ${}^{v}B_0$ refer to female spawning biomass, and total male and female vulnerable biomass, respectively) in approximately 2004 and followed by an increase in abundance through to 2010, the final year of the model reconstruction (Figure 12, Figure 13, Figure 14, Figure 15, Table 10, Table 11). Note that Figure 13 from the previous assessment is provided for comparison.

The updated runs estimate higher median ratios for current biomass relative to B_0 (B_{2010}/B_0) as compared with the previous assessment, increasing from 0.236 to 0.313 and from 0.177 to 0.248 for Runs 11-u and 17-u respectively (Figure 16, Table 10, Table 11). Note that the higher estimates for B_{2010}/B_0 in the current assessment are caused by both an upward adjustment of biomass in recent years (i.e., 2005-2008) due to the addition of new data and a continuation of the upward trend estimated by the previous assessment. These results confirm that the added recent data are consistent with the trends estimated by the previous assessment. Run 18-u estimates similar values for B_0 as did the other runs, but estimates a higher median value with greater uncertainty for B_{2010}/B_0 than for the other runs (i.e., the posterior bounds are wider).

Estimates of the median ratios of B_{MSY}/B_0 did not change from the previous assessment (0.29 for Runs 11 and 11-u, and 0.35 for Runs 17 and 17-u) (Table 11) because the life history parameters were not changed. However, since both Run 11-u and 17-u estimate that current biomass is greater than in the previous assessment, both runs estimated a higher abundance relative to B_{MSY} (B_{2010}/B_{MSY}) (Table 12). For example, the median estimate of B_{2010}/B_{MSY} increased from 0.797 (0.483-1.154)[3] to 1.065 (0.741-1.439) from Run 11 to Run 11-u.

Unlike Runs 11-u and 17-u, which use fixed values for steepness, each draw in the MCMC posterior for Run 18-u provides a separate estimate for B_{MSY} and consequently the ratio of B_{MSY}/B_0 will differ for each draw. This results in a wider distribution for this ratio compared to the runs with fixed steepness, giving greater uncertainty. The posterior for steepness from Run 18-u also showed a shift to the right of the prior (Figure 17) and some attenuation of the variance through dropping runs with low steepness (i.e., there is almost no posterior density at steepness values less than 0.5). The effect is to estimate a stock with higher overall productivity than the other runs but with greater uncertainty.

[2] The analysis assumes that the model starts in 1940 from the unfished equilibrium B_0, a common initialisation assumption.
[3] Note all bracketed intervals indicate 90% credibility intervals

Run 18-u estimates a lower median ratio for B_{MSY}/B_0 than for the other runs (Table 11), possibly due to the shift towards higher values for the steepness parameter. It also estimates higher median values for B_{2010}/B_0 and B_{2010}/B_{MSY} than those estimated by the two updated runs (Table 12).

The median estimates and 90% credibility intervals for *MSY* (i.e., vulnerable biomass) are 981 t (909-1,073), 806 t (743-884 t) and 1,120 t (859-1,734 t) for Runs 11-u, 17-u, and 18-u, respectively (Table 13). All three estimates are close to the long term mean harvest level of 900 t/y. An average extraction of 900 t/y is likely to be a minimum estimate of the average removals, given that there were removals that are not documented, especially in the early years of the fishery when catch reporting was poor. The model assumes that undocumented catches are proportionately constant throughout the reconstruction. If this were not the case and that there was a change in the relative underreporting of catch, then the model estimates of yield and stock status will be biased. In the case of a reduction in the proportionate level of unreported catch, this bias will tend to underestimate the true yield while overestimating the status of the stock relative to target and limit reference points.

Harvest advice

Run 11-u estimates that current spawning biomass is in the healthy zone, given that the median estimate of spawning biomass is above the *upper stock reference point* (USR) of $0.8B_{MSY}$, as outlined in the PA policy document and is well above the limit reference point (LRP) of $0.4B_{MSY}$ (DFO 2006, 2008) (Figure 18 and Table 12). Under the PA-compliant harvest control rule, the median estimate for harvest for Run 11-u in FY 2010/11 is 1,168 t (683-1,706 t). The PA-compliant harvest control rule is applied to the posterior distribution of the beginning year vulnerable biomass for 2010 (Table 13). Note that the PA-based harvest for Run 11-u is greater than *MSY* because it is an exploitation-based rule and a considerable proportion of the posterior for the 2010 biomass for this run is above B_{MSY}.

Decision tables which forecast stock status relative to the USR and LRP under a range of constant catch scenarios projected over five years are provided in Figure 19, Figure 20, Figure 21, Table 14, Table 15, Table 16. Longer term projections to 2050 (two generations) are also provided relative to B_0 ($\mathrm{P}\left(\tilde{B}_y > B_{2010}\right)$, $\mathrm{E}\left(\tilde{B}_y / B_0\right)$ and $\mathrm{E}\left(\tilde{B}_y / B_{2010}\right)$ (Figure 22, Table 17, Table 18, Table 19)[4]. The intent of these latter tables is to provide information for forecasting the future status of the canary rockfish population relative to the decline criteria used by the International Union for the Conservation of Nature (IUCN) and COSEWIC. These forecasts indicate that, for Run 11-u, spawning biomass will continue to increase if annual harvests are below 900 t (Table 19).

Run 17-u estimates that median spawning biomass lies within the cautious zone as outlined in the PA policy document (i.e., between the limit LRP of $0.4B_{MSY}$ and USR point of $0.8B_{MSY}$) (Table 12). The PA-compliant harvest for FY 2010/2011 is 481 t (81-932 t), less than the median estimate of *MSY* from Run 17-u of 806 t (743-884 t). Run 17-u indicates that catches of less than or equal 700 t/y are required to achieve a greater than 50% probability of rebuilding beyond the USR in 5 years.

[4] Note: these longer term tables were added after the PSARC review.

Run 18-u indicates that that stock status lies almost entirely within the healthy zone (Table 12). For this run, the median total PA-compliant harvest for FY2010/11 is 1,784 t (859 t–1,734 t), well above the median estimate for *MSY* from Run 18-u of 1,120 t (859-1,734 t) (Table 13). Table 16 and Table 19 indicate that spawning biomass will continue to increase if catches are 1,100 t/y or less.

Current management

As noted in previous documents, the only documented threat to canary rockfish appears to be catches in the various BC fisheries and possibly catches in U.S. fisheries operating in Washington and perhaps as far south as Oregon. The commercial BC groundfish trawl fishery has been monitored since 1997 with 100% observer coverage. The hook-and-line sectors have been monitored by 100% video monitoring, requiring 100% retention of rockfish since 2006[5]. Catches of canary rockfish are less well monitored in the First Nations, salmon troll, and recreational sectors, although efforts are being made to improve catch estimates of groundfish in these fisheries. Catches of canary rockfish in these fisheries are presumed to be small relative to harvests in the groundfish commercial fisheries, but this is not possible to verify at this time.

The current (FY 09/10) Canadian Groundfish trawl and HL overall canary rockfish TAC is 679 t with 88% allocated to trawl and 12% to outer coast HL harvesters[6]. Catches are constrained by annual and vessel-specific quotas. In consultation with the commercial industry, the TAC of 679 t was chosen under the expectation that the trawl fishery would undercatch the TAC for canary rockfish as it tends to do for most quota species (B. Ackerman, pers. comm., and see Figure 1). As of September 30 2009, six months through the fishing year, the total trawl and HL catch was 324 t.

The status of the US population (California-Washington) has been recently re-assessed (Stewart 2009) (Figure 23) and continues to indicate rebuilding but to lesser degree than in the previous 2007 assessment (Stewart 2008). Catches and fishing effort on canary rockfish grounds in these waters have been severely curtailed since 1999.

Discussion

We recommend that Run 11-u be used as the reference case run. It is an update of one of the accepted runs from the previous assessment with additional catch, survey, and ageing data. The fixed value used for steepness in this assessment run (h=0.7) is close to the mean of the posterior (h=0.71) for this parameter from the Forrest et al. (in review) meta-analysis for *Sebastes*, based on a Beverton-Holt stock-recruitment function. While fixing steepness causes the assessment model to underestimate the variability of the results, it acknowledges that there is little information in any single assessment with which to reliably estimate this parameter.

The results of Run 11-u, like the other runs, indicate that BC canary rockfish have undergone a significant decline since at least 1940. The decline appeared to end in about 2004 after the spawning population had declined to approximately 20% of B_0. Since 2004, the spawning

[5] See Stanley et al. 2009b for an examination of the accuracy of the catch data provided by the Groundfish Hook-and-line Catch Monitoring Program.
[6] For the groundfish management plan see: http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/MPLANS/MPlans.htm

biomass has increased to a median estimate of 31% of B_0, higher than the estimate for the same year of 24% from the previous assessment. Run 11-u indicates that the population is now most likely to be in the healthy zone, as defined by DFO PA, unlike the conclusion from the previous assessment, where Run 11 indicated the population was most likely in the upper portion of the cautious zone.

We view Run 17-u, which uses a fixed steepness value of 0.55, a value near the lower end of the probability density prior function for steepness (Figure 11), as a sensitivity run testing the consequences for a lower level of productivity. However, we suggest it is less plausible than either Run 11-u or Run 18-u. Run 18-u is presented as an alternative reference case where steepness is not fixed but is constrained by an informed prior. Results for Run 18-u indicate that the population has higher ratios for B_{2010}/B_{MSY} than for Run 11-u, but with a much wider range of uncertainty. This result is due to the lower estimates for B_{MSY}/B_0 made by this run which in turn are caused by the higher estimated steepness values and the wide range of uncertainty allowed for this parameter.

This stock assessment estimates an improved stock status for canary compared to the 2007 assessment and uses a Bayesian approach to provide a mechanism to include uncertainty in the assessment. However, managers and stakeholders are advised that not all sources of uncertainty have been addressed. For instance, we note that this assessment did not attempt to reconstruct additional sources of historical catches, such as those that must have occurred in the salmon troll and halibut fisheries. Such a reconstruction was done in a recent analysis of bocaccio and this led to lower estimates of biomass relative to the unfished spawning biomass (Stanley et al. 2009c). The effect of not including these early catches will probably be to overestimate the current status of the stock relative to the target reference points and to also underestimate the stock productivity.

Recent trawl survey results have played an influential role in this assessment, resulting in higher estimates of biomass relative to reference levels for both of the repeated runs. In the case of Run 11-u, the effect has been to move the population into the healthy zone. While the three active surveys all show a recent upturn, managers are cautioned that the length of the upturn remains short and may not be sustained.

Conclusions

This document provides an assessment of the status of canary rockfish in BC waters, current to the end of FY 09/10. This update is consistent with the previous assessment in indicating a rebuilding trend from low levels observed in about 2004. This assessment now estimates that the population is most likely in the healthy zone as defined by DFO PA, unlike the previous assessment where it was estimated to within the cautious zone.

The reference run estimates a mean total PA-compliant harvest (combined groundfish trawl and HL) for FY 10/11 of approximately 1,200 t. This level of harvest is greater than the current canary rockfish TAC of 679 t and the long term maximum estimate of sustainable catch levels of 900 t/y. However, the intent of the PA-compliant harvest estimate is that it be applied for a single year and then updated, as this level of harvest will cause the stock decline towards the estimate of B_{MSY}. Over the longer term, the reference run indicates that spawning biomass will continue to increase if annual harvests are kept below 900 t/y.

We note that the results of this assessment are highly uncertain. This assessment also did not attempt to reconstruct bycatch estimates from other historical fisheries. Inclusion of additional historical catches will lead to lower estimates of current biomass relative to target and limit reference points and to higher estimates of long-term yield. While the three active surveys have all shown a recent upturn, the length of the upturn is short and may not be sustained.

We expect that over the next 5-10 years, the results from the several surveys initiated in the previous decade will continue to improve the monitoring capability for canary rockfish. Catches in the commercial groundfish fisheries are well monitored. However, catches are less well monitored in the First Nations, recreational and salmon troll fisheries, although these catch are presumed to be much smaller than those from the commercial groundfish fisheries.

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Approved by

The Pacific Scientific Advice Review Committee (PSARC) Groundfish Subcommittee met December 17, 2009 at the Vancouver Island Conference Center in Nanaimo, B.C. The Subcommittee reviewed an update of Canary rockfish (*Sebastes pinniger*) status presented as a CSAS Science Special Response Processes document. The Groundfish Subcommittee accepted the Science Special Response Process document subject to revisions. The subcommittee report is on file at the Center for Science Advice (CSA), Pacific Region (see final page of document). The final revisions were approved by the same office.

Sources of information

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

DFO. 2006. A harvest strategy compliant with a precautionary approach. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2006/023.

DFO. 2008. Draft. Fisheries Stewardship and Sustainability Checklist 2008/09.

DFO. 2009. Recovery potential assessment for canary rockfish (*Sebastes pinniger*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/041.

Forrest, R.E., M.K. McAllister, M.W. Dorn, S.J.D. Martell, and R.D. Stanley. (in review). Hierarchical Bayesian meta-analysis of rockfish stock-recruit data: two approaches to estimation of productivity parameters. Submitted to Can. J. Fish. Aquat. Sci.

Hilborn, R., M. Maunder, A. Parma, B. Ernst, J. Payne, and P. Starr. 2003. Coleraine: A generalised age-structured stock assessment model. User's manual version 2.0. SAFS-UW-0116, Uni. Wash. ii+54p.

Stanley, R.D., P. Starr, and N. Olsen. 2009a. Stock assessment for canary rockfish (*Sebastes pinniger*) in British Columbia waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/013.

Stanley, R.D., N. Olsen, and A. Fedoruk. 2009b. The accuracy of yelloweye rockfish catch estimates from the British Columbia Groundfish Integration Project. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 1:354–362.

Stanley, R.D., M. McAllister, P. Starr, and N. Olsen. 2009c. Stock assessment for bocaccio (*Sebastes paucispinis*) in British Columbia waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/055.

Stewart, I. 2008. Status of the U.S. canary rockfish resource in 2007. Status of the Pacific Coast Groundfish Fishery through 2008, Stock Assessment and Fishery Evaluation: Stock Assessments, STAR Panel Reports, and Rebuilding Analyses. Pacific Fishery Management Council, Portland, OR. 362 p.

Stewart, I. 2009. Status of the U.S. canary rockfish resource in 2009 (update of the 2007 assessment model). http://www.pcouncil.org/groundfish/background/.

Appendices

Figures

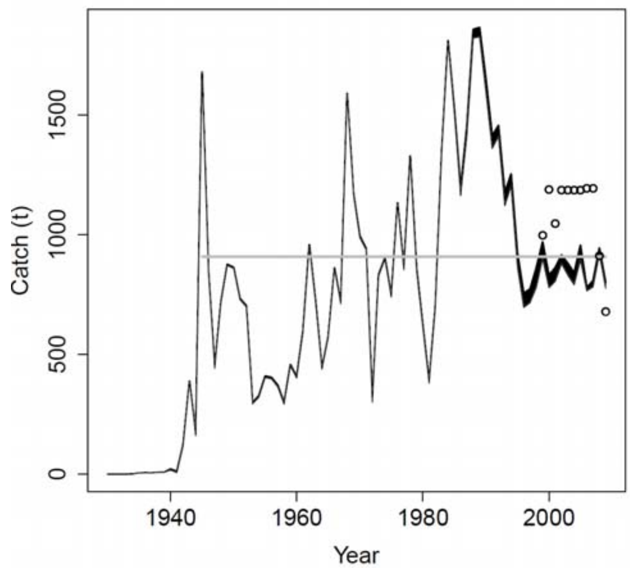

Figure 1. Total estimated canary rockfish catch from BC waters, 1945-2009. Average annual catch is approximately 900 t (solid line), black-shaded area is additional commercial groundfish hook-and-line catch, and the horizontal grey line is average annual catch. The recent TACs are shown in a dotted line. Note that FY 09/10 catch (last data point) is a projected value.

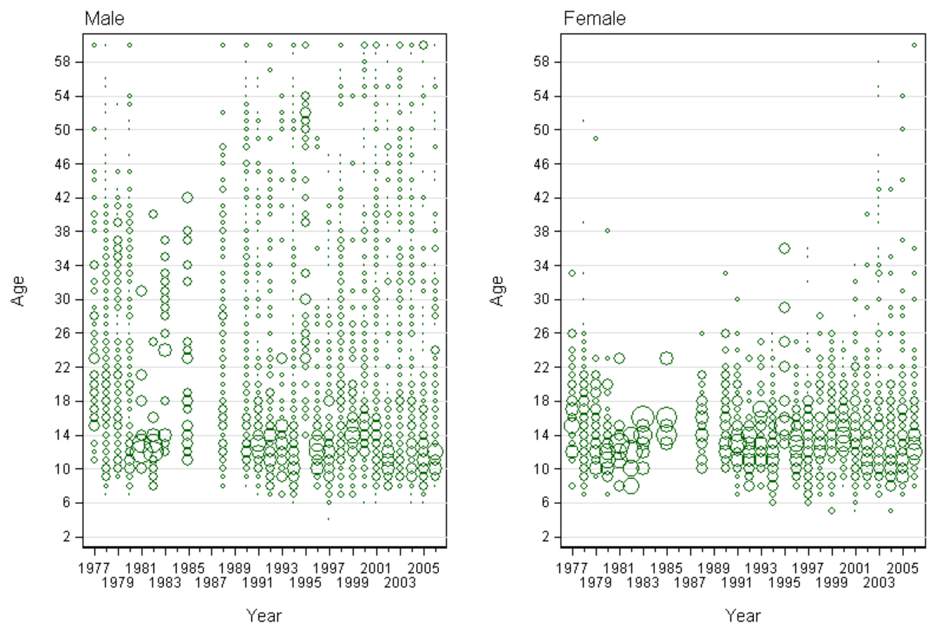

Figure 2. Relative age class size of canary rockfish by sex and fishing year over all samples for all areas (bottom trawl only). Vertical columns sum to one from age 2 to age 60 for each sex, with age 60 treated

as a plus-group. Circles are scaled by the proportion at age and sex. This plot combines port sampling with At-sea Observer Program sampling, without weighting.

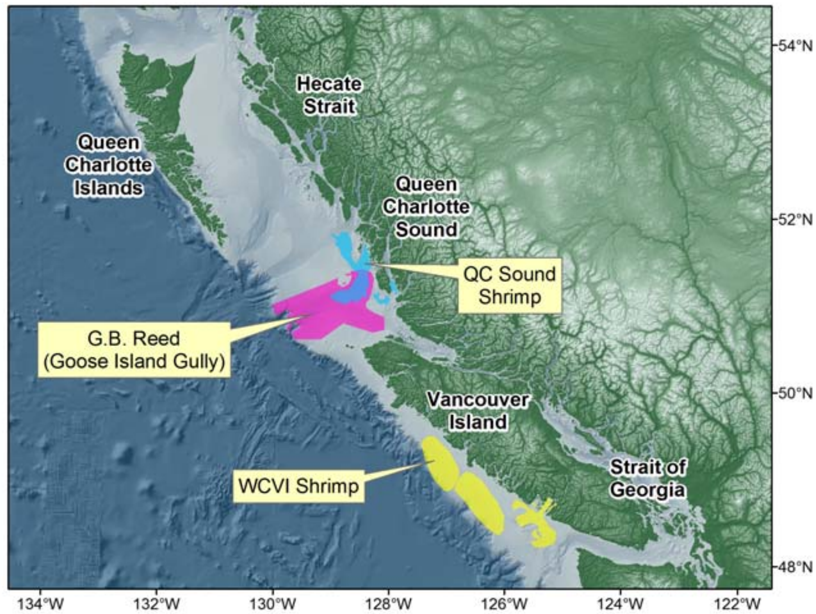

Figure 3. Locations of the QCSd and WCVI shrimp surveys, and the G.B. Reed QCSd survey.

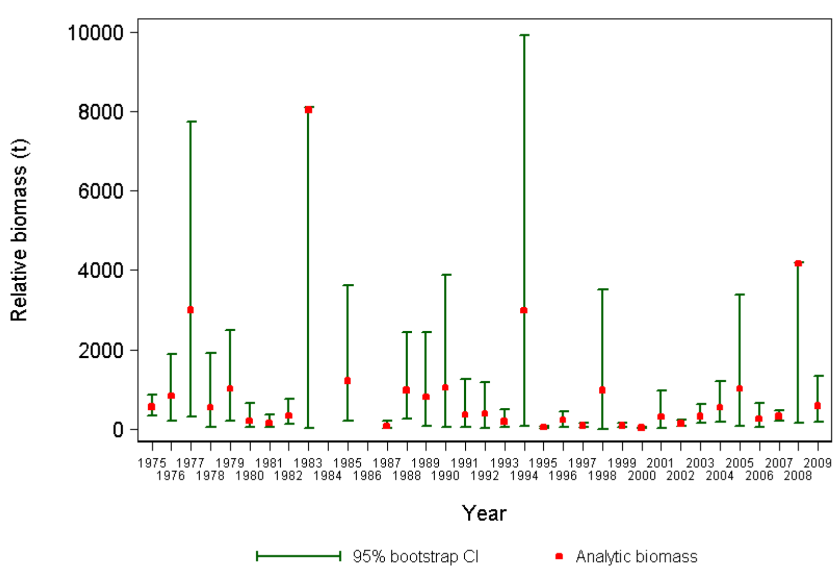

Figure 4. Plot of biomass estimates for canary rockfish from the WCVI shrimp trawl survey for 1975-2009. Bias corrected 95% confidence intervals from 1,000 bootstrap replicates are plotted. Note that the upper error bars for 1983 and 2008, which exceed the y-axis scaling have been omitted for clarity in the presentation.

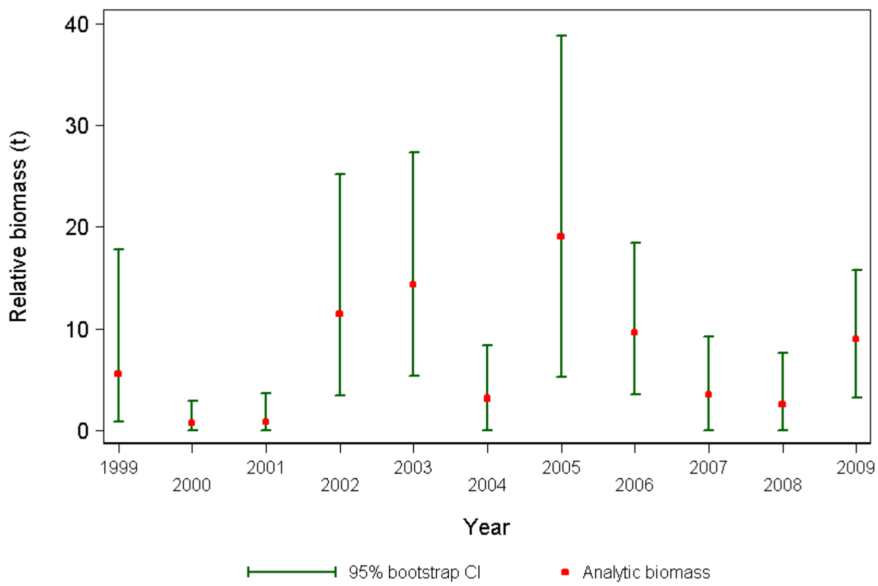

Figure 5. Plot of biomass estimates for canary rockfish from the QCSd shrimp trawl survey for 1999-2009. Bias corrected 95% confidence intervals from 1,000 bootstrap replicates are plotted.

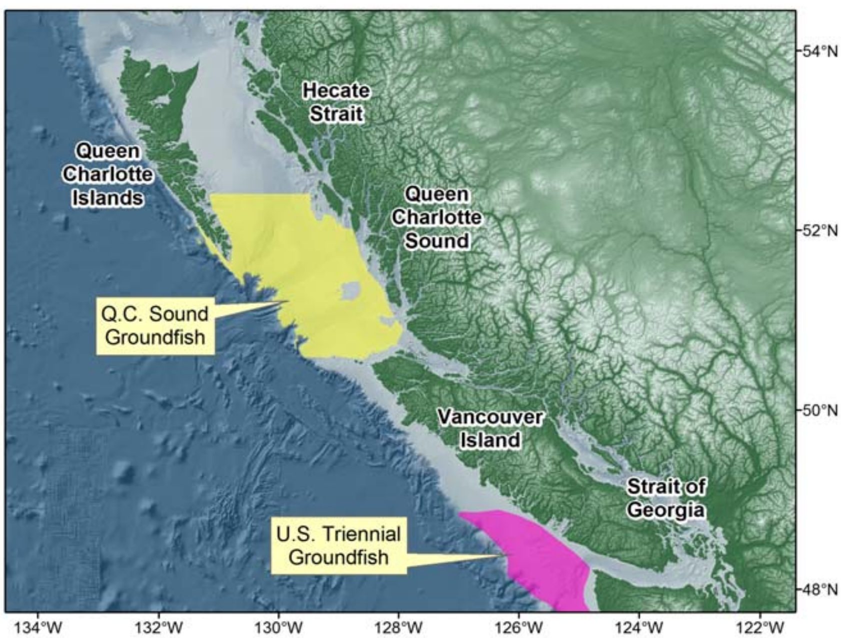

Figure 6. Locations of the QCSd and US Triennial groundfish surveys.

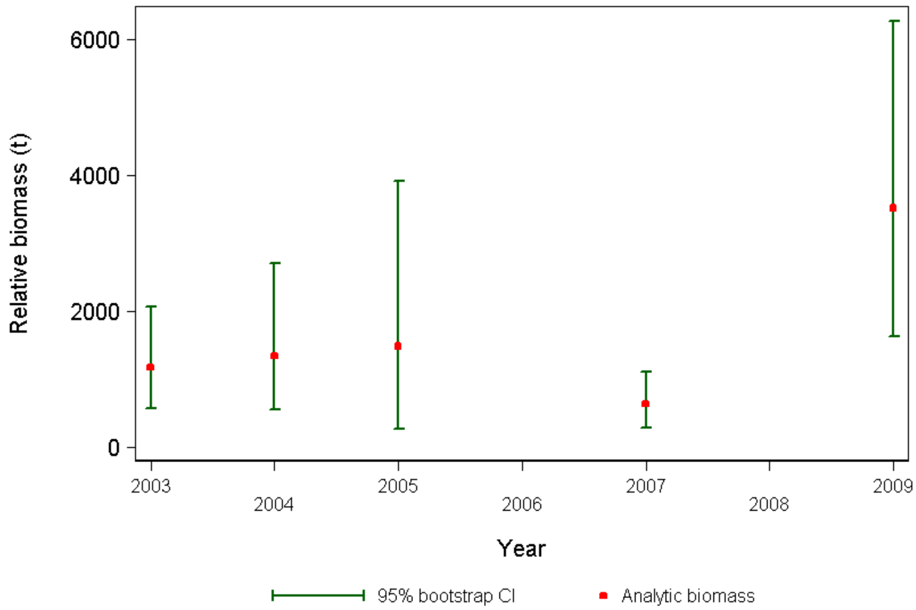

Figure 7. Plot of biomass estimates for canary rockfish from the QCSd groundfish bottom trawl survey for 2003-2009. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

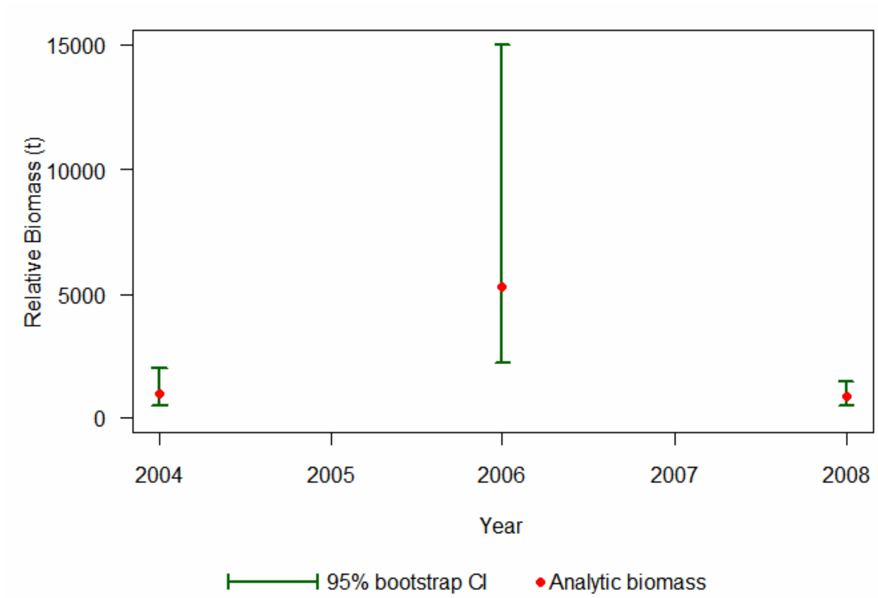

Figure 8. Plot of biomass estimates for canary rockfish from the West Coast Vancouver Island groundfish survey for the period 2004-2008 with bias corrected 95% confidence intervals from 1000 bootstrap replicates.

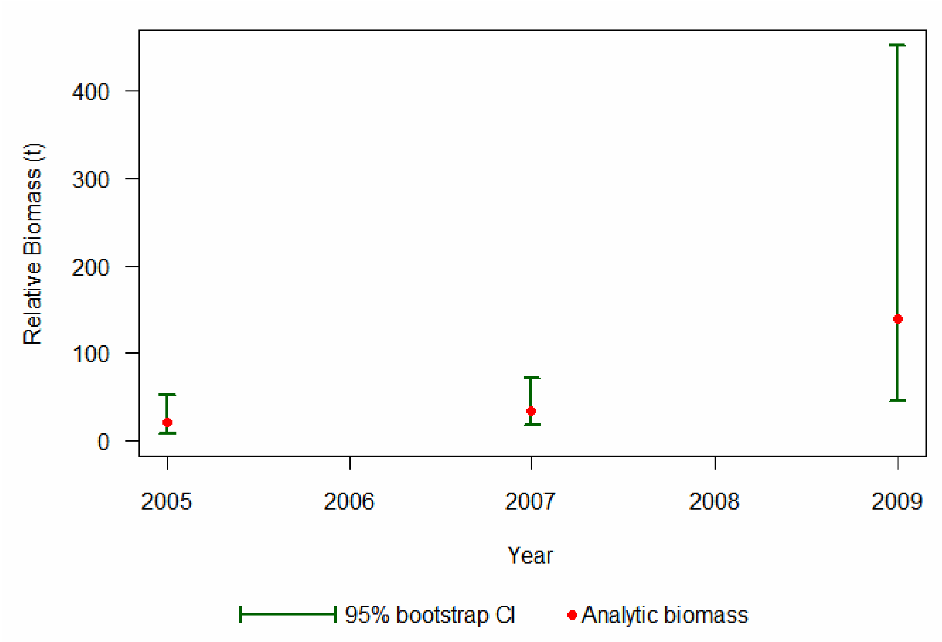

Figure 9. Plot of biomass estimates for canary rockfish from the Hecate Strait groundfish survey for the period 2005-2009 with bias corrected 95% confidence intervals from 1000 bootstrap replicates.

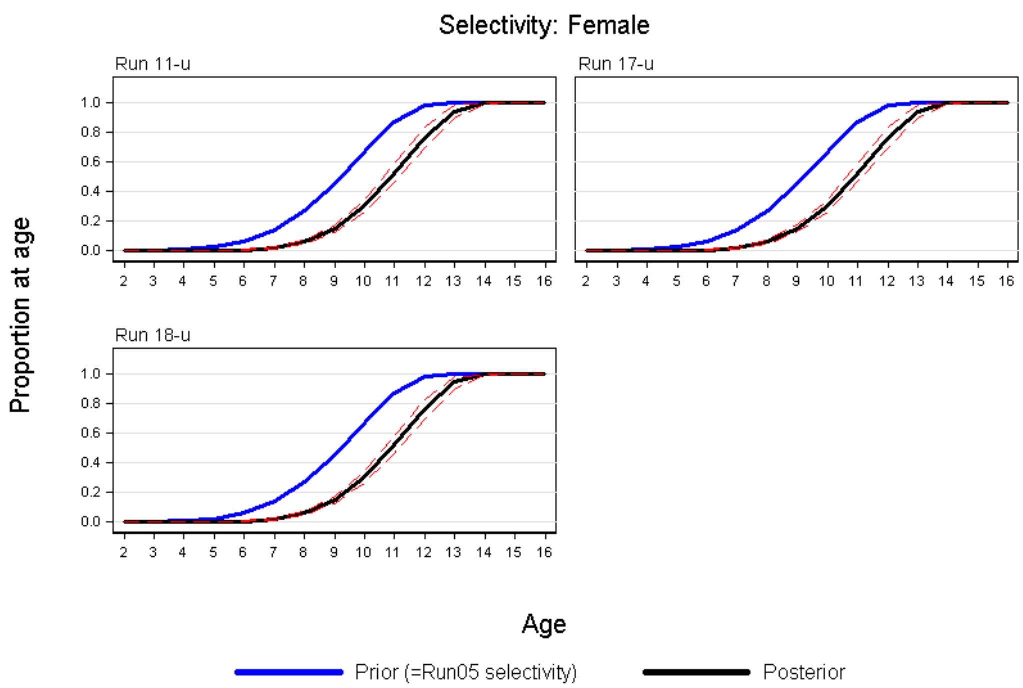

Figure 10. Comparison of the female commercial selectivity prior and posterior distributions by assessment run. 5th and 95th percentiles of the credibility intervals are shown for the posterior distribution.

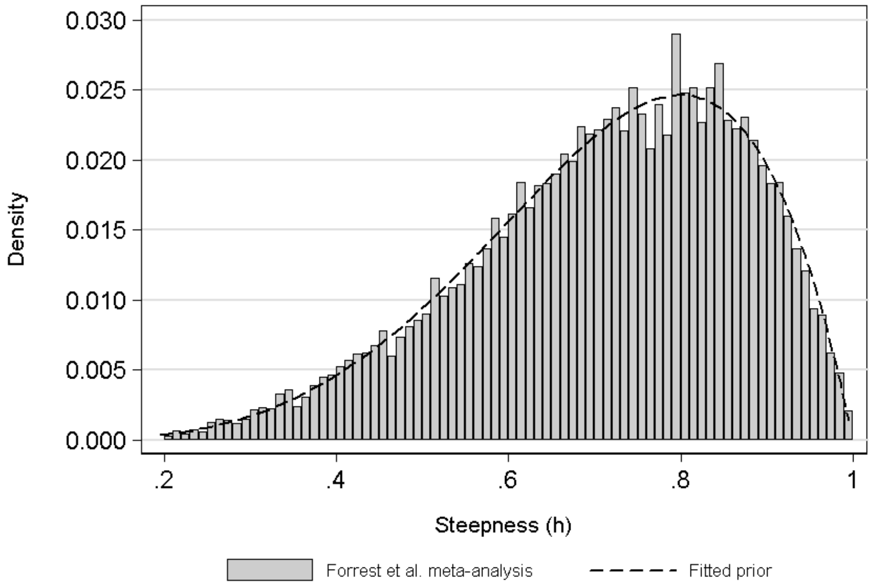

Figure 11. Distribution of plausible estimates for the Beverton-Holt steepness parameter (h) over a range of northeastern Pacific Ocean Sebastes species based on a meta-analysis from Forrest et al. (in review). The dashed line shows the prior used in Run 18-u of the current assessment, approximated from a beta density distribution with parameters α=5.0 and β=2.0 (mean=0.714; st.dev.=0.160).

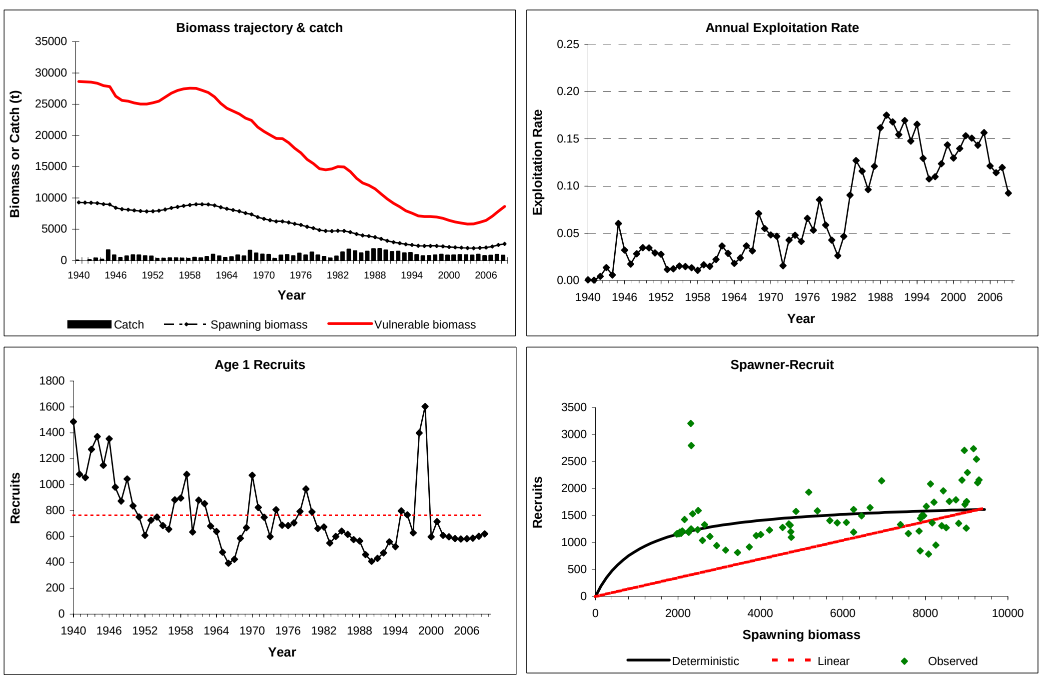

Figure 12. Marginal posterior distribution plots of ***Run 11-u****. [Top left]: vulnerable and female spawning biomass and annual catch; [Top right]: exploitation rate; [Bottom left]: female recruitment in numbers at age 1 (male recruitment is the same); [Bottom right]: stock recruitment function. The red line in panel [bottom right] is the stock-recruitment replacement line.*

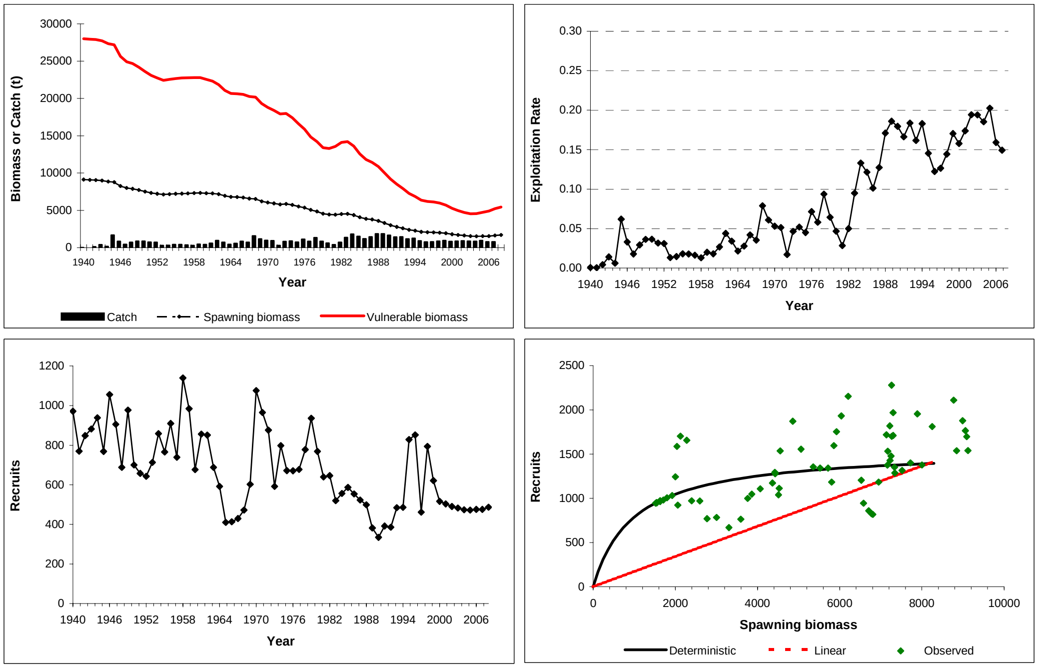

*Figure 13. Marginal posterior distribution plots of **Run 11**. [Top left]: vulnerable and female spawning biomass and annual catch; [Top right]: exploitation rate; [Bottom left]: female recruitment in numbers at age 1 (male recruitment is the same); [Bottom right]: stock recruitment function. The red line in panel [bottom right] is the stock-recruitment replacement line.*

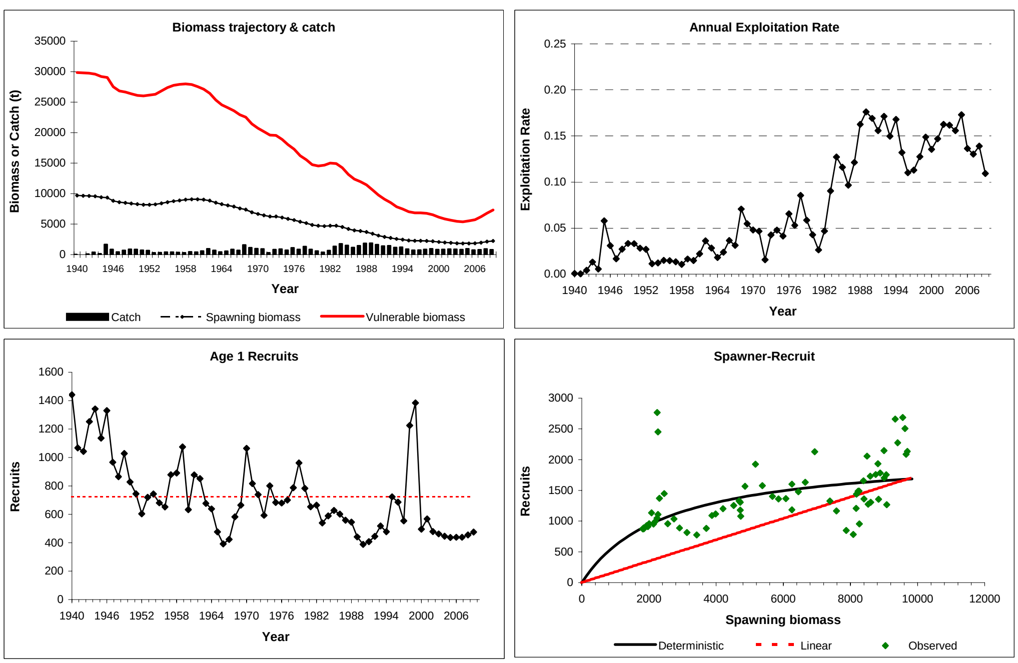

*Figure 14. Marginal posterior distribution plots of **Run 17-u.** [Top left]: vulnerable and female spawning biomass and annual catch; [Top right]: exploitation rate; [Bottom left]: female recruitment in numbers at age 1 (male recruitment is the same); [Bottom right]: stock recruitment function. The red line in panel [bottom right] is the stock-recruitment replacement line.*

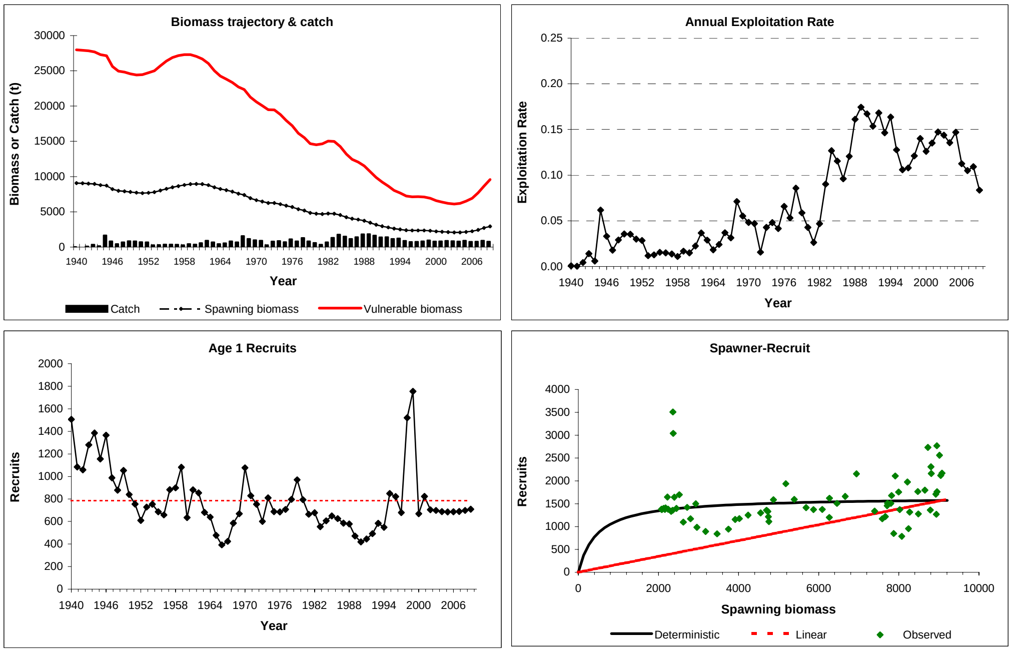

*Figure 15. Marginal posterior distribution plots of **Run 18-u**. [Top left]: vulnerable and female spawning biomass and annual catch; [Top right]: exploitation rate; [Bottom left]: female recruitment in numbers at age 1 (male recruitment is the same); [Bottom right]: stock recruitment function. The red line in panel [bottom right] is the stock-recruitment replacement line.*

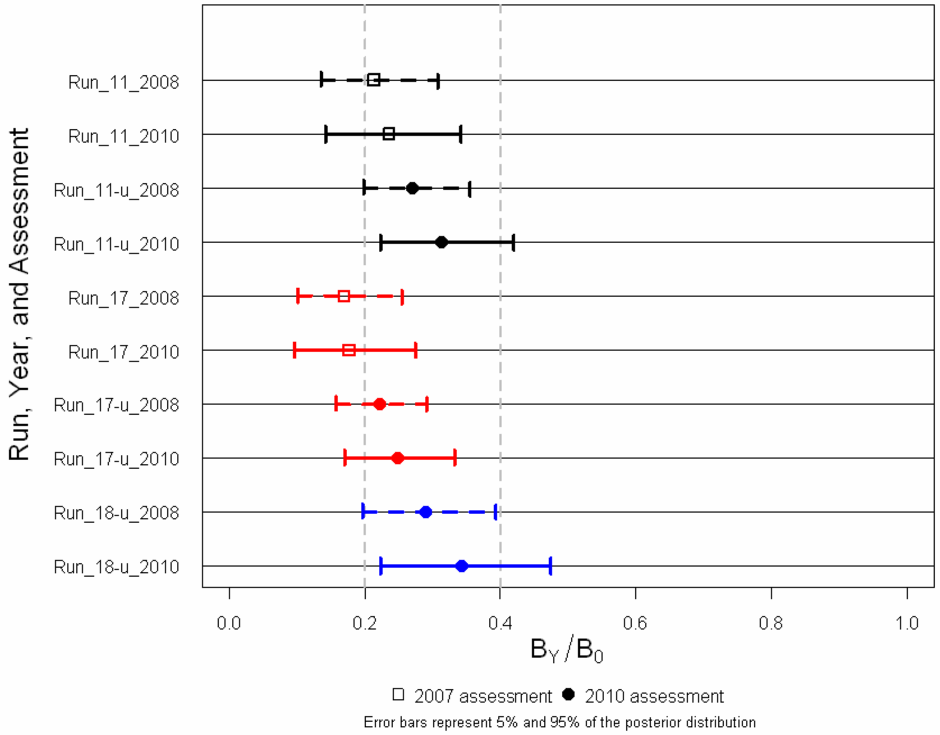

Figure 16. Mean and the 5th and 95th credibility intervals for B_{year}/B_0, where year=2008 or 2010 for runs performed in the 2007 and 2009 assessments. Vertical lines at 0.2 B_0 and 0.4* B_0 are presented to aid the eye and do not represent reference points.*

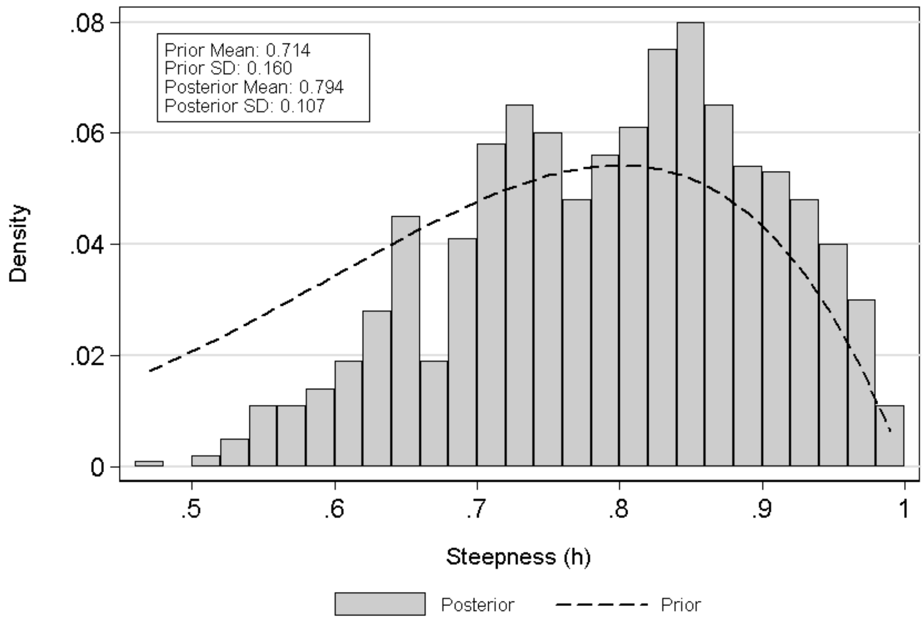

Figure 17. Comparison of prior and posterior for steepness (h) for Run18-u.

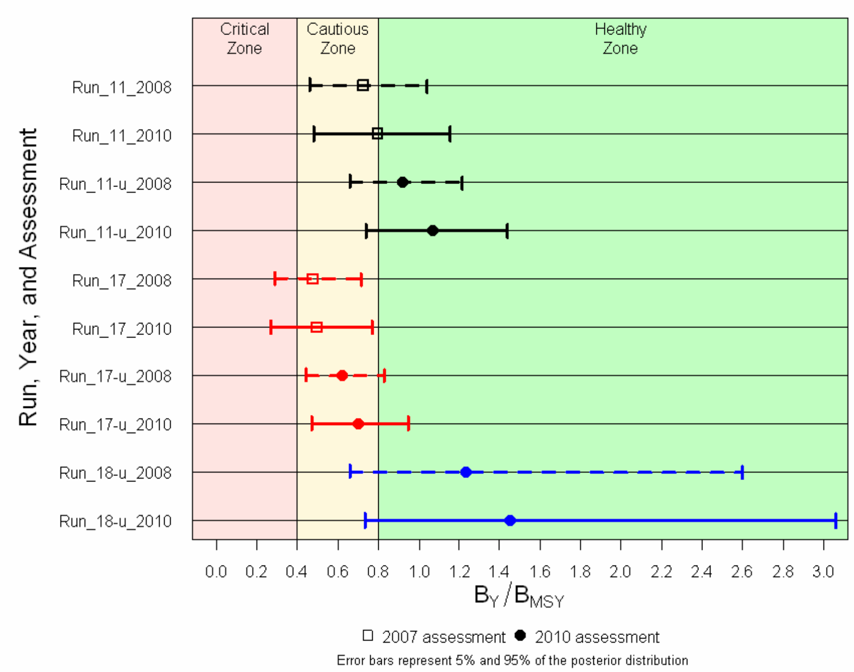

Figure 18. Mean and the 5th and 95th credibility intervals for B_{year}/B_0, where year=2008 or 2010 for three runs performed in the 2007 and 2009 assessments. Vertical lines at 0.4 B_{MSY} and 0.8* B_{MSY} are the lower and upper "PA-compliant points.*

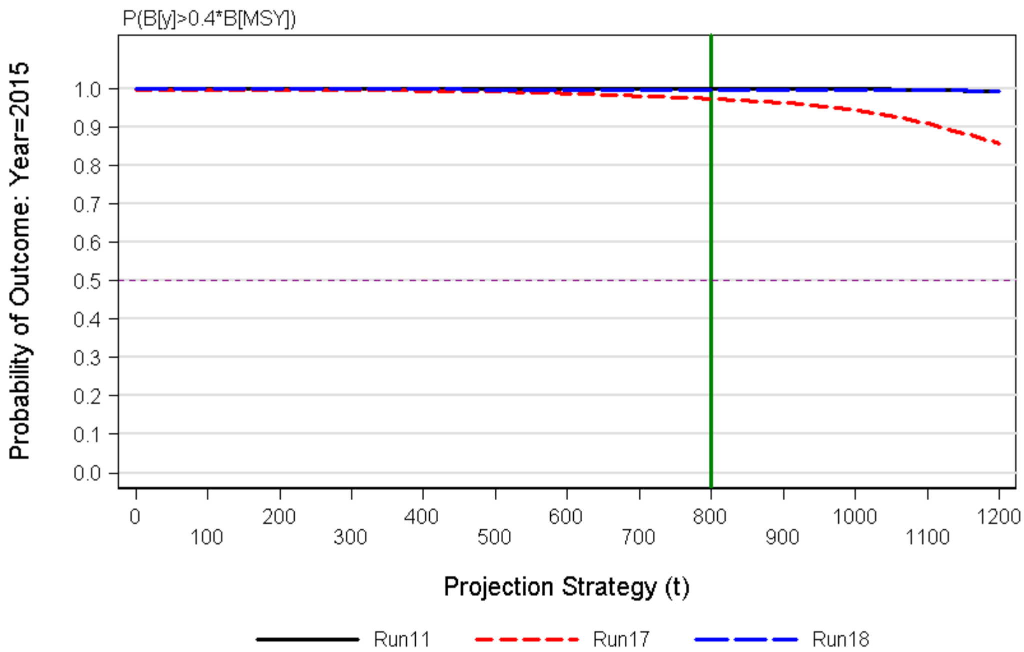

Figure 19 Comparison of the probability of $\tilde{B}_y$ exceeding 0.4B_{MSY} by the end of the projection period (2015) for model runs 11-u, 17-u, and 18-u. The green vertical line indicates the approximate position of the level of catch under the current management regime.

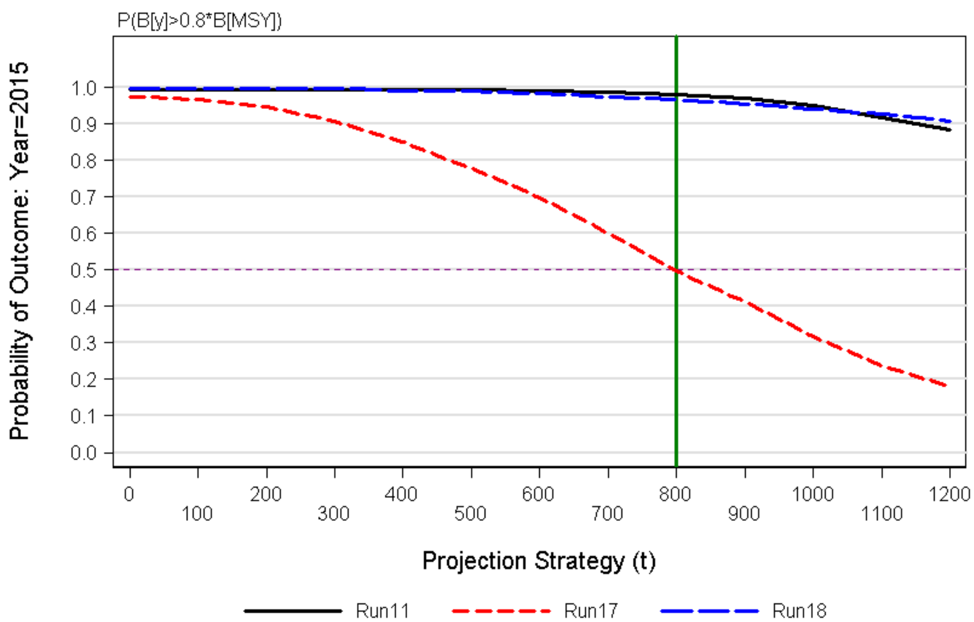

Figure 20. Comparison of the probability of $\tilde{B}_y$ exceeding 0.8B_{MSY} by the end of the projection period (2015) for model runs 11-u, 17-u, and 18-u. The green vertical line indicates the approximate position of the level of catch under the current management regime.

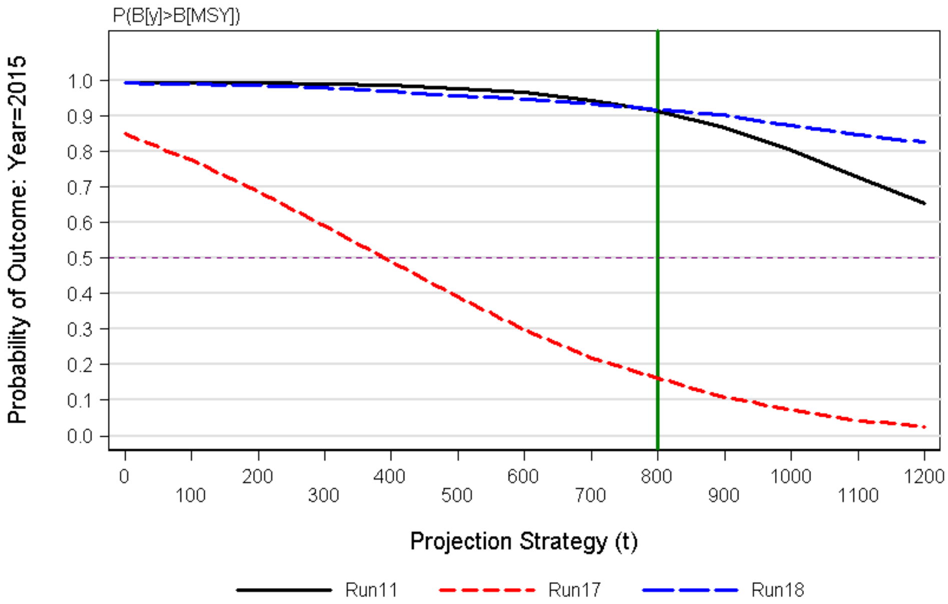

Figure 21. Comparison of the probability of $\tilde{B}_y$ exceeding B_{MSY} by the end of the projection period (2015) for model runs 11-u, 17-u, and 18-u. The green vertical line indicates the approximate position of the level of catch under the current management regime.

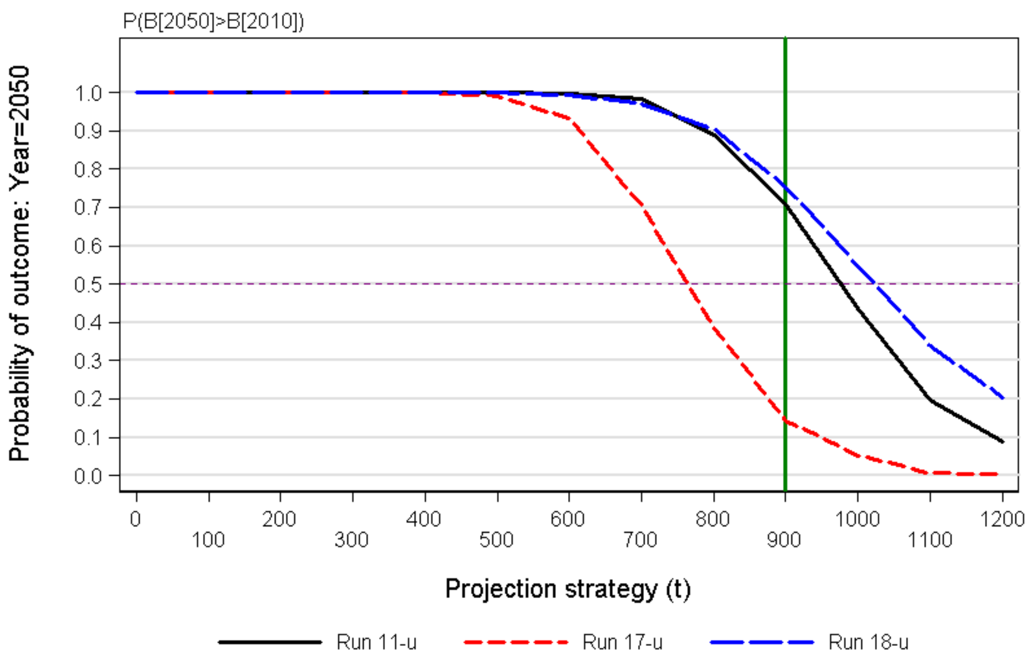

Figure 22. Comparison of the probability of $\tilde{B}_{2050}$ exceeding B_{2010} for model runs 11-u, 17-u, and 18-u. The green vertical line indicates the approximate position of the 2010 catch level.

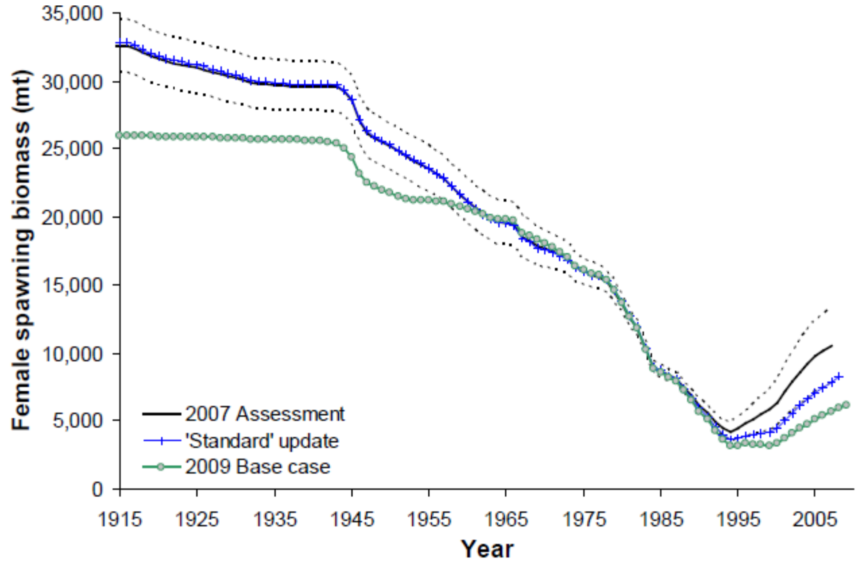

Figure 23. Estimated spawning biomass times-series for the US (California-Washington) population of canary rockfish (1916-2009) for the 2007 assessment base case model (solid line) with approximate asymptotic 95% confidence interval (dashed lines), results of 'standard' update of recent data and catches (crosses), and 2009 base case model (round symbols) (from Stewart 2009, p.5, figure b).

Tables

*Table 1. Reconstruction of canary rockfish catches from BC waters (1930/31-2009/10). This assessment updated catch for years FY 07/08-09/10. *: catches for 09/10 were prorated based on catches from April-August 09.*

	Catch (t)				Catch (t)			Quotas		
Year	Trawl	HL	Total	Year	Trawl	HL	Total	Trawl	HL	Total
1930	0	0	0	1970	988	8	996			
1931	0	0	0	1971	938	6	943			
1932	0	0	0	1972	299	7	307			
1933	0	0	0	1973	828	6	834			
1934	1	0	1	1974	897	7	904			
1935	4	0	4	1975	739	7	745			
1936	5	0	5	1976	1,128	6	1,134			
1937	5	0	5	1977	853	7	860			
1938	7	0	7	1978	1,322	8	1,329			
1939	7	0	7	1979	852	10	862			
1940	16	5	21	1980	612	9	621			
1941	6	5	11	1981	379	8	387			
1942	119	4	124	1982	697	6	704			
1943	385	4	389	1983	1,344	7	1,351			
1944	160	4	164	1984	1,800	10	1,811			
1945	1,676	4	1,680	1985	1,508	16	1,524			
1946	845	4	849	1986	1,163	32	1,195			
1947	441	5	446	1987	1,415	39	1,454			
1948	717	5	721	1988	1,822	36	1,858			
1949	872	5	876	1989	1,826	40	1,866			
1950	859	4	864	1990	1,596	55	1,652			
1951	729	5	734	1991	1,360	54	1,414			
1952	699	5	704	1992	1,409	47	1,457			
1953	293	6	299	1993	1,121	55	1,176			
1954	321	6	327	1994	1,201	53	1,254			
1955	403	7	410	1995	866	59	925			
1956	398	6	404	1996	696	60	756			
1957	364	7	371	1997	716	57	773			
1958	292	6	298	1998	780	83	862			
1959	451	6	458	1999	898	72	971	921	76	997
1960	401	7	408	2000	778	52	831	1,097	92	1,189
1961	591	7	598	2001	805	58	863	1,046	N/A	1,046
1962	951	8	959	2002	879	37	915	1,046	140	1,186
1963	714	7	721	2003	830	50	880	1,046	140	1,186
1964	437	5	443	2004	791	51	841	1,046	140	1,186
1965	569	5	574	2005	893	63	956	1,046	140	1,186
1966	857	5	862	2006	765	13	779	1,046	147	1,193
1967	710	5	716	2007	782	27	809	1,046	147	1,193
1968	1,587	4	1,591	2008	917	28	945	800	112	912
1969	1,168	6	1,174	2009			* 800	595	84	679

Table 2. Number of age samples by year. The 1979, 2005, and 2006 samples were added in this update. Samples sizes range from approximately from 30 to 300, with more recent samples (1990-2006) ranging from 30 to 80.

Year	Number of samples	Year	Number of samples
1978	8	1999	13
1979	4	2000	10
1990	8	2001	10
1991	7	2002	8
1993	4	2003	11
1994	11	2004	14
1995	5	2005	17
1996	7	2006	12
1997	8		
1998	20		

Table 3. Survey indices included and excluded from the current assessment. Start and end years refer to the survey years used in this document, not necessarily the complete survey series.

Survey	Start	End	Ongoing	Surveys	Depth (m)	Gear Used	Included
WCVI Shrimp[1]	1975	2009	Y	30	15-258	Shrimp trawl	Yes
QCSd Shrimp	1999	2009	Y	11	15-309	Shrimp trawl	Yes
GBReed QCSd	1967	1984	N	7	147-256	Groundfish bottom trawl	Yes
U.S. Triennial[2]	1980	2001	N	8	55-477	Groundfish bottom trawl	Yes
QCSd Gfish	2003	2009	Y	5	37-543	Groundfish bottom trawl	Yes
WCVI Gfish	2004	2008	Y	3	46-750	Groundfish bottom trawl	No, three data points
Hecate Strait Gfish	2005	2009	Y	3	11-230	Groundfish bottom trawl	No, three data points
WCQCI Gfish	2006	2008	Y	3	180-1800	Groundfish bottom trawl	No, too few fish
Hecate Strait Assemblage[3]	1984	2003	N	11	18-232	Groundfish bottom trawl	No, too few fish
DFO longline (N and S)	2006	2009	Y	2	20-260	Set line	No, two data points

Notes:

[1] Survey started in 1972 but rockfish catch not recorded until 1975.

[2] Information only for those surveys conducted in Canadian waters.

[3] Survey was substantially redesigned in 2005, thus this series effectively ends in 2003.

Table 4. Biomass estimates for canary rockfish from the WCVI shrimp trawl survey for survey years 1975-2009. Biomass estimates are based on a post-stratification of this survey into two strata and by assuming that the survey tows were randomly selected within these areas. Bootstrap bias corrected confidence intervals and CVs are based on 1,000 random draws with replacement. The analytic CV 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
1975	557	553	327	862	0.236	0.238
1976	830	829	202	1,889	0.516	0.524
1977	3,003	3,031	299	7,736	0.626	0.665
1978	550	549	42	1,897	0.835	0.821
1979	1,020	1,025	204	2,498	0.537	0.543
1980	208	204	33	640	0.754	0.747
1981	158	160	35	366	0.519	0.542
1982	340	341	110	753	0.471	0.447
1983	8,045	7,687	17	27,886	0.989	0.996
1985	1,213	1,227	204	3,617	0.658	0.667
1987	69	70	8	214	0.716	0.696
1988	981	975	255	2,423	0.532	0.530
1989	798	781	62	2,437	0.727	0.692
1990	1,050	1,013	56	3,882	0.936	0.912
1991	366	349	43	1,265	0.818	0.865
1992	395	385	17	1,175	0.808	0.794
1993	192	195	43	481	0.575	0.583
1994	2,979	3,073	84	9,917	0.884	0.895
1995	39	39	10	84	0.479	0.489
1996	220	223	55	438	0.436	0.436
1997	83	83	35	159	0.379	0.388
1998	981	961	4	3,518	1.017	0.985
1999	82	82	44	139	0.298	0.300
2000	29	30	11	54	0.372	0.376
2001	307	314	25	976	0.833	0.865
2002	138	138	69	240	0.316	0.315
2003	321	329	148	635	0.379	0.381
2004	548	551	173	1,209	0.444	0.444
2005	1,010	1,039	66	3,372	0.849	0.881
2006	259	264	37	639	0.580	0.575
2007	320	322	202	475	0.219	0.220
2008	4,166	4,090	144	14,882	0.947	0.953
2009	581	572	177	1,330	0.501	0.516

Table 5. Biomass estimates for canary rockfish from the QCSd shrimp trawl survey for the survey years 1999-2009. Bootstrap bias corrected confidence intervals and CVs are based on 1,000 random draws with replacement. The analytic CV is based on the assumption of random tow selection within a stratum.

Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
1999	5.5	5.7	0.8	17.8	0.717	0.691
2000	0.7	0.7	0.0	2.9	0.989	1.000
2001	0.8	0.8	0.0	3.6	1.017	1.000
2002	11.5	11.6	3.4	25.2	0.470	0.484
2003	14.4	14.3	5.3	27.3	0.387	0.398
2004	3.1	3.1	0.0	8.3	0.683	0.701
2005	19.0	19.4	5.2	38.8	0.434	0.446
2006	9.6	9.8	3.5	18.5	0.386	0.384
2007	3.5	3.5	0.0	9.2	0.601	0.601
2008	2.5	2.5	0.0	7.5	0.711	0.707
2009	8.9	9.1	3.2	15.8	0.351	0.349

Table 6. Biomass estimates for canary rockfish from the QC Sound synoptic trawl survey for the survey years 2003-2009. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement. The analytic CV is based on the assumption of random tow selection within a stratum (see equations in Stanley et al. 2009a).

Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
2003	1,169	1,161	568	2,068	0.331	0.334
2004	1,335	1,329	555	2,704	0.395	0.383
2005	1,481	1,498	265	3,922	0.602	0.589
2007	629	637	273	1,105	0.335	0.342
2009	3,519	3,479	1,621	6,267	0.329	0.345

Table 7. Biomass estimates for canary rockfish in the Vancouver INPFC region for the US Triennial survey (total region, Canadian waters only, and U.S. waters only) with 95% confidence regions based on the bootstrap distribution of biomass. The bootstrap estimates are based on 5,000 random draws with replacement.

Area	**Year**	**Mean bootstrap biomass**	**Lower bound biomass**	**Upper bound biomass**
Total Vancouver	1980	7,633	427	28,611
	1983	11,063	4,976	19,812
	1989	7,918	3,389	16,711
	1992	1,654	801	2,884
	1995	293	109	594
	1998	2,233	1,275	3,472
	2001	622	271	1,151
Canada Vancouver	1980	8,082	306	30,811
	1983	6,241	1,078	14,815
	1989	4,814	1,303	13,362
	1992	1,310	555	2,469
	1995	253	88	504
	1998	1,805	957	2,888
	2001	351	75	850
US Vancouver	1980	158	0	390
	1983	4,647	1,726	8,963
	1989	3,104	1,106	6,165
	1992	344	138	801
	1995	40	12	103
	1998	427	242	707
	2001	271	102	508

Table 8. Biomass estimates for canary rockfish from the Goose Island Gully G.B. Reed trawl surveys for the 1967-1984. Biomass estimates are based on three depth strata and by assuming that the survey tows were randomly selected within these areas. Bootstrap bias corrected confidence intervals and CVs are based on 5,000 random draws with replacement. The analytic CV 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**
1967	79	79	32	137	0.342	0.354
1969	120	116	35	309	0.556	0.541
1971	973	964	25	3,768	0.954	0.956
1973	122	124	20	366	0.703	0.703
1976	110	111	34	223	0.410	0.415
1977	470	471	70	1,202	0.588	0.612
1984	120	122	49	216	0.348	0.351

Table 9. Configuration of assessment runs in the previous and current assessments.

Run number	Catch-at-age data	Recruitment	Commercial selectivity	Steepness
Model runs accepted by PSARC in November 2007 (Stanley et al. 2009a)				
Run 05	Used	Stochastic	Fixed (US)	0.70
Run 11	Used	Stochastic	Estimated	0.70
Run 17	Used	Stochastic	Estimated	0.55
Model runs presented in this update				
Run 11-u	Used	Stochastic	Estimated	0.70
Run 17-u	Used	Stochastic	Estimated	0.55
Run 18-u	Used	Stochastic	Estimated	Estimated

Table 10. Median, 5th and 95th percentiles (credibility intervals) of the posterior distribution of B_{year}/B_0, where year=2008 or 2010 for runs conducted in the previous and current assessments.

		2007 Assessment			2010 Assessment		
Assessment Run	Year	5th Percentile	Median	95th Percentile	5th Percentile	Median	95th Percentile
Run 11 or 11-u	2008	0.136	0.214	0.308	0.198	0.270	0.356
	2010	0.143	0.236	0.342	0.224	0.313	0.420
Run 17 or 17-u	2008	0.102	0.170	0.255	0.158	0.221	0.291
	2010	0.096	0.177	0.274	0.170	0.248	0.333
Run 18-u	2008	–	–	–	0.197	0.290	0.394
	2010	–	–	–	0.223	0.342	0.475

Table 11. Bayesian MCMC derived parameter estimates for model runs 11-u, 17-u, and 18-u. Summary statistics (5th, median and 95th percentiles) are shown for posteriors corresponding to the selected derived parameters of management interest. B_{MSY} was calculated for each draw of the MCMC posterior. B and B^v represent spawning and vulnerable biomass, respectively.

	5%	**Median**	**95%**	**5%**	**Median**	**95%**
		B_0			B_0^v	
Run 11-u	8,773	9,456	10,252	27,054	29,171	31,678
Run 17-u	9,098	9,872	10,710	28,126	30,493	33,062
Run 18-u	8,574	9,283	10,136	26,451	28,635	31,340
		B_{MSY}/B_0			B^v_{MSY}/B_0	
Run 11-u	0.292	0.294	0.295	0.273	0.278	0.284
Run 17-u	0.352	0.354	0.357	0.325	0.330	0.335
Run 18-u	0.124	0.239	0.332	0.131	0.234	0.312
		B_{2010}/B_0			B^v_{2010}/B_0	
Run 11-u	0.224	0.313	0.420	0.237	0.332	0.446
Run 17-u	0.170	0.248	0.333	0.180	0.263	0.352
Run 18-u	0.223	0.342	0.475	0.237	0.360	0.507
		u_{2009}			$u^v{}_{2009}$	
Run 11-u	0.063	0.090	0.130	0.164	0.177	0.202
Run 17-u	0.076	0.107	0.161	0.166	0.180	0.226
Run 18-u	0.058	0.084	0.129	0.164	0.177	0.197

Table 12. 5th, Median and 95th percentiles of the posterior distribution of B_{year}/B_{MSY}, where year=2008 or 2010 for three assessment runs performed in the 2007 and 2009 canary rockfish assessments.

		2007 Assessment			**2010 Assessment**		
Assessment Run	**Year**	**5th Percentile**	**Median**	**95th Percentile**	**5th Percentile**	**Median**	**95th Percentile**
Run 11 or 11-u	2008	0.461	0.724	1.041	0.659	0.916	1.214
	2010	0.483	0.797	1.154	0.741	1.065	1.439
Run 17 or 17-u	2008	0.287	0.478	0.715	0.444	0.623	0.828
	2010	0.269	0.496	0.770	0.474	0.700	0.948
Run 18-u	2008	–	–	–	0.662	1.235	2.599
	2010	–	–	–	0.736	1.453	3.058

Table 13. Application of the PA compliant harvest strategy to canary rockfish assessment results (units for spawning biomass (B) are in t). B_{MSY} and $B^{v}{}_{MSY}$ (spawning and vulnerable biomass levels associated with MSY) were calculated for each draw of the MCMC posterior

	5th percentile	Median	95th percentile
		$0.4 * B_{MSY}$	
Run 11-u	1,030	1,113	1,213
Run 17-u	1,288	1,401	1,525
Run 18-u	450	879	1,304
		$0.8 * B_{MSY}$	
Run 11-u	2,061	2,225	2,426
Run 17-u	2,575	2,803	3,050
Run 18-u	900	1,758	2,608
		B_{MSY}	
Run 11-u	2,576	2,781	3,032
Run 17-u	3219	3,504	3,812
Run 18-u	1125	2,198	3,260
		$B^{v}{}_{MSY}$	
Run 11-u	7,472	8,120	8,892
Run 17-u	9,233	10,054	10,962
Run 18-u	3,719	6,650	9,511
		MSY^{v}	
Run 11-u	909	981	1,073
Run 17-u	743	806	884
Run 18-u	859	1,120	1,734
		$B^{v}{}_{2010}$	
Run 11-u	6,637	9,646	14,034
Run 17-u	5,281	7,960	11,389
Run 18-u	6,699	10,345	15,141
		U_{MSY}	
Run 11-u	0.117	0.121	0.125
Run 17-u	0.078	0.080	0.083
Run 18-u	0.094	0.17	0.423
		U_{2009}	
Run 11-u	0.063	0.090	0.130
Run 17-u	0.076	0.107	0.161
Run 18-u	0.058	0.084	0.129
		U_{2010} _ PA compliant	
Run 11-u	0.103	0.121	0.125
Run 17-u	0.015	0.061	0.082
Run 18-u	0.084	0.170	0.423
		Y_{2010} _ PA compliant	
Run 11-u	683	1,168	1,706
Run 17-u	81	481	932
Run 18-u	639	1,784	4,604

Table 14. Decision tables of B_{MSY} performance indicators for 1-5 year projections for ***Reference*** *Run 11-u. Statistics relate to the beginning of year female spawning biomass (B_y) relative to the MSY female spawning biomass (B_{MSY}). The probabilities of biomass in the projection year exceeding one of the reference values (upper three tables) are based on the MCMC posterior distribution of B_y and B_{MSY}, wherein B_y and B_{MSY} are calculated for each draw. These results can then be compared to the observed median value of the ratio of to B_y/B_{MSY} (lowest table) where, as noted before, B_y and B_{MSY} are calculated for each draw. The analysis conducted 2,000,000 MCMC iterations, drawing every 2,000, for a posterior sample of 1,000.*

Annual catch strategy					**Projection Year**	
	2010	**2011**	**2012**	**2013**	**2014**	**2015**
	$\mathrm{P}\left(\tilde{B}_y > 0.4B_{MSY}\right)$					
0	1.000	1.000	1.000	1.000	1.000	1.000
100	1.000	1.000	1.000	1.000	1.000	1.000
200	1.000	1.000	1.000	1.000	1.000	1.000
300	1.000	1.000	1.000	1.000	1.000	1.000
400	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
600	1.000	1.000	1.000	1.000	1.000	1.000
700	1.000	1.000	1.000	1.000	1.000	1.000
800	1.000	1.000	1.000	1.000	1.000	1.000
900	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
1100	1.000	1.000	1.000	1.000	1.000	0.999
1200	1.000	1.000	1.000	1.000	0.999	0.996
	$\mathrm{P}\left(\tilde{B}_y > 0.8B_{MSY}\right)$					
0	0.904	0.981	0.992	0.994	0.996	0.996
100	0.904	0.979	0.992	0.994	0.996	0.996
200	0.904	0.977	0.990	0.994	0.994	0.996
300	0.904	0.975	0.988	0.993	0.994	0.994
400	0.904	0.969	0.986	0.992	0.994	0.994
500	0.904	0.966	0.985	0.990	0.994	0.994
600	0.904	0.959	0.978	0.988	0.990	0.992
700	0.904	0.954	0.975	0.982	0.986	0.989
800	0.904	0.951	0.971	0.975	0.978	0.981
900	0.904	0.946	0.960	0.967	0.969	0.971
1000	0.904	0.942	0.955	0.959	0.959	0.951
1100	0.904	0.937	0.947	0.949	0.938	0.918
1200	0.904	0.929	0.930	0.922	0.904	0.885
	$\mathrm{P}\left(\tilde{B}_y > B_{MSY}\right)$					
0	0.621	0.864	0.966	0.988	0.993	0.994
100	0.621	0.856	0.956	0.985	0.993	0.993
200	0.621	0.839	0.946	0.977	0.989	0.993
300	0.621	0.822	0.933	0.973	0.985	0.991
400	0.621	0.814	0.913	0.962	0.977	0.987
500	0.621	0.794	0.888	0.954	0.968	0.978
600	0.621	0.777	0.872	0.931	0.958	0.967
700	0.621	0.767	0.852	0.903	0.934	0.946
800	0.621	0.755	0.831	0.867	0.900	0.913
900	0.621	0.738	0.800	0.836	0.857	0.869
1000	0.621	0.722	0.776	0.794	0.806	0.806
1100	0.621	0.709	0.745	0.750	0.740	0.728
1200	0.621	0.697	0.708	0.706	0.684	0.655

Table 14. (cont.)

Annual catch strategy	2010	2011	2012	2013	2014	2015
	Projection Year					
	$\mathrm{E}\left(\tilde{B}_y / B_{MSY}\right)$					
0	1.065	1.241	1.404	1.562	1.711	1.838
100	1.065	1.231	1.381	1.527	1.661	1.776
200	1.065	1.220	1.359	1.491	1.613	1.716
300	1.065	1.210	1.337	1.456	1.566	1.656
400	1.065	1.199	1.314	1.421	1.516	1.597
500	1.065	1.188	1.292	1.386	1.467	1.536
600	1.065	1.177	1.269	1.351	1.419	1.477
700	1.065	1.166	1.246	1.317	1.372	1.418
800	1.065	1.156	1.224	1.283	1.326	1.359
900	1.065	1.145	1.202	1.247	1.278	1.299
1000	1.065	1.134	1.179	1.213	1.229	1.240
1100	1.065	1.123	1.157	1.177	1.181	1.180
1200	1.065	1.112	1.135	1.142	1.133	1.121

*Table 15. Decision tables of B_{MSY} performance indicators for 1-5 year projections for **low productivity** Run 17-u. Statistics relate to the beginning of year female spawning biomass (B_y) relative to the MSY female spawning biomass (B_{MSY}). The probabilities of biomass in the projection year exceeding one of the reference values (upper three tables) are based on the MCMC posterior distribution of B_y and B_{MSY}, wherein B_y and B_{MSY} are calculated for each draw. These results can then be compared to the observed median value of the ratio of to B_y/B_{MSY} (lowest table) where, as noted before B_y and B_{MSY} are calculated for each draw. The analysis conducted 2,000,000 MCMC iterations, drawing every 2,000, for a posterior sample of 1,000.*

Annual catch strategy	**Projection Year**					
	2010	**2011**	**2012**	**2013**	**2014**	**2015**
	$P\left(\tilde{B}_y > 0.4B_{MSY}\right)$					
0	0.979	0.989	0.996	0.997	0.997	0.999
100	0.979	0.989	0.995	0.997	0.997	0.998
200	0.979	0.989	0.994	0.997	0.997	0.997
300	0.979	0.988	0.994	0.997	0.997	0.997
400	0.979	0.987	0.990	0.995	0.996	0.996
500	0.979	0.985	0.988	0.991	0.994	0.995
600	0.979	0.985	0.986	0.986	0.988	0.989
700	0.979	0.982	0.983	0.983	0.982	0.982
800	0.979	0.982	0.982	0.979	0.977	0.975
900	0.979	0.980	0.979	0.977	0.972	0.965
1000	0.979	0.980	0.975	0.971	0.960	0.947
1100	0.979	0.975	0.972	0.960	0.940	0.911
1200	0.979	0.972	0.966	0.945	0.912	0.859
	$P\left(\tilde{B}_y > 0.8B_{MSY}\right)$					
0	0.248	0.523	0.768	0.900	0.959	0.976
100	0.248	0.502	0.733	0.858	0.936	0.967
200	0.248	0.485	0.689	0.823	0.903	0.947
300	0.248	0.481	0.647	0.775	0.854	0.908
400	0.248	0.460	0.603	0.729	0.802	0.851
500	0.248	0.434	0.555	0.672	0.735	0.778
600	0.248	0.408	0.520	0.602	0.664	0.699
700	0.248	0.389	0.489	0.542	0.580	0.601
800	0.248	0.364	0.449	0.493	0.505	0.498
900	0.248	0.334	0.415	0.436	0.431	0.413
1000	0.248	0.316	0.372	0.376	0.361	0.318
1100	0.248	0.303	0.321	0.311	0.285	0.237
1200	0.248	0.286	0.288	0.258	0.221	0.181
	$P\left(\tilde{B}_y > B_{MSY}\right)$					
0	0.025	0.129	0.306	0.534	0.722	0.850
100	0.025	0.118	0.282	0.477	0.653	0.777
200	0.025	0.108	0.251	0.429	0.568	0.689
300	0.025	0.099	0.225	0.358	0.487	0.591
400	0.025	0.089	0.197	0.307	0.411	0.490
500	0.025	0.080	0.167	0.249	0.332	0.391
600	0.025	0.072	0.138	0.217	0.257	0.298
700	0.025	0.069	0.120	0.168	0.204	0.219
800	0.025	0.062	0.104	0.131	0.162	0.163
900	0.025	0.057	0.086	0.105	0.112	0.108
1000	0.025	0.049	0.076	0.082	0.085	0.073
1100	0.025	0.044	0.064	0.066	0.057	0.043
1200	0.025	0.041	0.053	0.050	0.037	0.026

Table 15. (cont.)

Annual catch strategy	Projection Year 2010	2011	2012	2013	2014	2015
	$\mathrm{E}\left(\tilde{B}_y / B_{MSY}\right)$					
0	0.700	0.810	0.918	1.018	1.107	1.189
100	0.700	0.801	0.900	0.991	1.069	1.139
200	0.700	0.792	0.882	0.963	1.031	1.091
300	0.700	0.783	0.864	0.934	0.993	1.042
400	0.700	0.775	0.846	0.907	0.953	0.995
500	0.700	0.766	0.829	0.878	0.915	0.945
600	0.700	0.758	0.810	0.850	0.876	0.897
700	0.700	0.749	0.792	0.822	0.839	0.847
800	0.700	0.741	0.776	0.795	0.801	0.799
900	0.700	0.733	0.757	0.767	0.764	0.754
1000	0.700	0.724	0.739	0.738	0.724	0.705
1100	0.700	0.716	0.721	0.709	0.686	0.658
1200	0.700	0.707	0.703	0.681	0.648	0.610

Table 16. Decision tables of B_{MSY} performance indicators for 1-5 year projections for ***Alternative*** *reference Run 18-u. Statistics relate to the beginning of year female spawning biomass (B_y) relative to the MSY female spawning biomass (B_{MSY}). The probabilities of biomass in the projection year exceeding one of the reference values (upper three tables) are based on the MCMC posterior distribution of B_y and B_{MSY}, wherein B_y and B_{MSY} are calculated for each draw. These results can then be compared to the observed median value of the ratio of to B_y/B_{MSY} (lowest table) where, as noted before B_y and B_{MSY} are calculated for each draw. The analysis conducted 2,000,000 MCMC iterations, drawing every 2,000, for a posterior sample of 1,000.*

Annual catch strategy	**Projection Year**					
	2010	**2011**	**2012**	**2013**	**2014**	**2015**
	$\mathrm{P}\left(\tilde{B}_y > 0.4B_{MSY}\right)$					
0	0.999	0.999	1.000	1.000	1.000	1.000
100	0.999	0.999	0.999	1.000	1.000	1.000
200	0.999	0.999	0.999	1.000	1.000	1.000
300	0.999	0.999	0.999	0.999	1.000	1.000
400	0.999	0.999	0.999	0.999	0.999	1.000
500	0.999	0.999	0.999	0.999	0.999	0.999
600	0.999	0.999	0.999	0.999	0.999	0.999
700	0.999	0.999	0.999	0.999	0.999	0.999
800	0.999	0.999	0.999	0.999	0.999	0.999
900	0.999	0.999	0.999	0.999	0.999	0.999
1000	0.999	0.999	0.999	0.999	0.999	0.999
1100	0.999	0.999	0.999	0.999	0.999	0.999
1200	0.999	0.999	0.999	0.999	0.998	0.995
	$\mathrm{P}\left(\tilde{B}_y > 0.8B_{MSY}\right)$					
0	0.923	0.966	0.990	0.995	0.999	0.999
100	0.923	0.964	0.989	0.993	0.999	0.999
200	0.923	0.962	0.981	0.991	0.996	0.999
300	0.923	0.959	0.978	0.991	0.991	0.998
400	0.923	0.956	0.976	0.989	0.991	0.991
500	0.923	0.954	0.971	0.980	0.988	0.991
600	0.923	0.952	0.966	0.975	0.983	0.985
700	0.923	0.951	0.962	0.968	0.970	0.975
800	0.923	0.946	0.956	0.961	0.964	0.967
900	0.923	0.943	0.951	0.958	0.956	0.956
1000	0.923	0.940	0.945	0.946	0.947	0.942
1100	0.923	0.935	0.938	0.939	0.934	0.928
1200	0.923	0.933	0.934	0.928	0.922	0.908
	$\mathrm{P}\left(\tilde{B}_y > B_{MSY}\right)$					
0	0.826	0.899	0.949	0.973	0.991	0.994
100	0.826	0.898	0.942	0.967	0.983	0.991
200	0.826	0.896	0.936	0.961	0.977	0.987
300	0.826	0.893	0.929	0.956	0.969	0.980
400	0.826	0.889	0.918	0.947	0.960	0.970
500	0.826	0.884	0.913	0.937	0.951	0.957
600	0.826	0.880	0.905	0.926	0.939	0.948
700	0.826	0.875	0.901	0.915	0.928	0.936
800	0.826	0.864	0.896	0.910	0.917	0.918
900	0.826	0.860	0.882	0.894	0.901	0.903
1000	0.826	0.858	0.873	0.879	0.879	0.873
1100	0.826	0.851	0.864	0.864	0.856	0.848
1200	0.826	0.846	0.853	0.846	0.838	0.827

Table 16. (cont.)

Annual catch strategy	Projection Year					
	2010	2011	2012	2013	2014	2015
	$\mathrm{E}\left(\tilde{B}_y / B_{MSY}\right)$					
0	1.453	1.690	1.938	2.158	2.368	2.558
100	1.453	1.676	1.907	2.115	2.301	2.481
200	1.453	1.663	1.869	2.063	2.234	2.402
300	1.453	1.651	1.836	2.014	2.178	2.321
400	1.453	1.636	1.808	1.969	2.120	2.238
500	1.453	1.622	1.780	1.926	2.061	2.164
600	1.453	1.611	1.747	1.880	2.000	2.084
700	1.453	1.599	1.718	1.841	1.934	2.012
800	1.453	1.587	1.694	1.798	1.876	1.933
900	1.453	1.572	1.668	1.751	1.822	1.851
1000	1.453	1.557	1.644	1.713	1.760	1.777
1100	1.453	1.541	1.618	1.666	1.693	1.708
1200	1.453	1.525	1.592	1.620	1.626	1.637

Table 17. Decision tables of 5 to 40 year projections for $\mathrm{P}\left(\tilde{B}_y > B_{2010}\right)$ *by run in 5-year intervals. Statistics relate to the probability that the beginning of year female spawning biomass will be greater than the female spawning biomass in 2010.*

Annual catch strategy	Year of Projection							
	2015	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
	Run 11-u							
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
100	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
200	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
300	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
400	1.000	1.000	1.000	0.999	0.999	1.000	1.000	1.000
500	1.000	0.999	0.998	0.998	0.998	1.000	1.000	0.999
600	1.000	0.995	0.989	0.993	0.991	0.993	0.997	0.996
700	0.999	0.974	0.962	0.962	0.963	0.966	0.969	0.982
800	0.991	0.924	0.873	0.869	0.877	0.882	0.891	0.889
900	0.962	0.817	0.743	0.723	0.707	0.707	0.695	0.709
1000	0.881	0.673	0.553	0.531	0.507	0.478	0.459	0.435
1100	0.780	0.501	0.383	0.341	0.299	0.264	0.242	0.198
1200	0.636	0.336	0.235	0.190	0.145	0.127	0.109	0.090
	Run 17-u							
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
100	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
200	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
300	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
400	1.000	0.999	0.997	0.998	1.000	1.000	1.000	1.000
500	1.000	0.990	0.972	0.981	0.987	0.988	0.987	0.991
600	0.996	0.939	0.897	0.897	0.908	0.914	0.929	0.933
700	0.967	0.801	0.711	0.718	0.718	0.720	0.705	0.703
800	0.870	0.546	0.435	0.442	0.424	0.416	0.398	0.386
900	0.698	0.321	0.246	0.236	0.202	0.178	0.166	0.144
1000	0.513	0.152	0.116	0.095	0.079	0.066	0.056	0.053
1100	0.331	0.064	0.046	0.039	0.030	0.022	0.014	0.007
1200	0.174	0.022	0.017	0.015	0.011	0.006	0.005	0.003
	Run 18-u							
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
100	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
200	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
300	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
400	1.000	1.000	0.999	1.000	1.000	1.000	1.000	1.000
500	1.000	1.000	0.998	0.998	0.999	0.999	0.999	1.000
600	1.000	0.998	0.991	0.985	0.986	0.991	0.990	0.993
700	0.999	0.984	0.966	0.964	0.961	0.965	0.967	0.972
800	0.992	0.942	0.899	0.891	0.892	0.901	0.907	0.904
900	0.963	0.861	0.792	0.771	0.769	0.765	0.760	0.755
1000	0.911	0.760	0.672	0.622	0.606	0.589	0.573	0.548
1100	0.836	0.644	0.518	0.467	0.412	0.394	0.365	0.340
1200	0.742	0.491	0.383	0.306	0.249	0.228	0.219	0.205

Table 18. Expected median values for 0 to 40 year projections for $\mathrm{E}\left(\tilde{B}_y/B_0\right)$ *by run in 5-year intervals. Statistics relate to beginning of year female spawning biomass relative to the female spawning* B_0 *biomass.*

Annual catch strategy	Year of Projection								
	2010	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
	Run 11-u								
0	0.313	0.540	0.670	0.738	0.797	0.851	0.895	0.927	0.940
100	0.313	0.522	0.638	0.698	0.755	0.804	0.846	0.877	0.892
200	0.313	0.504	0.606	0.658	0.711	0.756	0.796	0.826	0.841
300	0.313	0.486	0.575	0.618	0.667	0.708	0.744	0.773	0.790
400	0.313	0.469	0.543	0.579	0.621	0.657	0.692	0.717	0.736
500	0.313	0.452	0.511	0.538	0.575	0.607	0.638	0.657	0.675
600	0.313	0.434	0.478	0.496	0.528	0.554	0.577	0.598	0.611
700	0.313	0.416	0.447	0.456	0.477	0.497	0.517	0.533	0.543
800	0.313	0.399	0.414	0.415	0.428	0.441	0.456	0.464	0.469
900	0.313	0.381	0.382	0.372	0.379	0.380	0.387	0.389	0.388
1000	0.313	0.364	0.349	0.329	0.325	0.319	0.311	0.306	0.297
1100	0.313	0.347	0.318	0.287	0.272	0.252	0.232	0.212	0.187
1200	0.313	0.330	0.286	0.244	0.218	0.186	0.149	0.107	0.058
	Run 17-u								
0	0.248	0.421	0.506	0.557	0.632	0.703	0.768	0.817	0.851
100	0.248	0.403	0.475	0.519	0.585	0.652	0.713	0.758	0.792
200	0.248	0.387	0.444	0.481	0.539	0.599	0.653	0.698	0.729
300	0.248	0.369	0.413	0.442	0.493	0.545	0.593	0.632	0.665
400	0.248	0.351	0.383	0.403	0.445	0.487	0.529	0.565	0.594
500	0.248	0.334	0.351	0.364	0.397	0.429	0.464	0.490	0.513
600	0.248	0.317	0.320	0.325	0.348	0.369	0.393	0.407	0.426
700	0.248	0.300	0.290	0.285	0.295	0.304	0.315	0.321	0.327
800	0.248	0.283	0.259	0.245	0.241	0.237	0.230	0.221	0.213
900	0.248	0.266	0.228	0.203	0.186	0.164	0.137	0.109	0.070
1000	0.248	0.250	0.198	0.162	0.129	0.088	0.041	0.015	0.008
1100	0.248	0.233	0.168	0.122	0.072	0.023	0.013	0.006	0.003
1200	0.248	0.216	0.138	0.081	0.026	0.014	0.006	0.003	0.002
	Run 18-u								
0	0.342	0.597	0.743	0.813	0.863	0.895	0.927	0.944	0.958
100	0.342	0.579	0.710	0.772	0.820	0.850	0.879	0.898	0.910
200	0.342	0.561	0.677	0.732	0.775	0.804	0.832	0.851	0.862
300	0.342	0.543	0.644	0.692	0.729	0.757	0.783	0.802	0.813
400	0.342	0.526	0.611	0.650	0.682	0.708	0.733	0.751	0.761
500	0.342	0.508	0.578	0.608	0.636	0.658	0.679	0.697	0.708
600	0.342	0.490	0.545	0.568	0.590	0.608	0.623	0.643	0.649
700	0.342	0.471	0.513	0.526	0.542	0.555	0.571	0.583	0.588
800	0.342	0.453	0.480	0.484	0.493	0.501	0.511	0.519	0.520
900	0.342	0.435	0.447	0.441	0.444	0.447	0.449	0.452	0.451
1000	0.342	0.417	0.415	0.399	0.394	0.391	0.385	0.380	0.376
1100	0.342	0.399	0.382	0.357	0.344	0.330	0.317	0.306	0.290
1200	0.342	0.381	0.350	0.312	0.291	0.265	0.242	0.225	0.202

Table 19. Expected median values for 5 to 40 year projections for $\mathrm{E}\left(\tilde{B}_y / B_{2010}\right)$ *by run in 5-year intervals. Statistics relate to beginning of year female spawning biomass relative to the female spawning biomass in 2010.*

Annual catch strategy	Year of Projection							
	2015	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Run 11-u								
0	1.729	2.128	2.354	2.556	2.744	2.871	2.991	3.022
100	1.670	2.028	2.223	2.428	2.594	2.713	2.826	2.865
200	1.615	1.923	2.099	2.287	2.438	2.545	2.655	2.689
300	1.558	1.816	1.979	2.138	2.270	2.378	2.488	2.510
400	1.501	1.713	1.849	1.988	2.109	2.216	2.304	2.331
500	1.444	1.610	1.724	1.847	1.931	2.034	2.114	2.144
600	1.387	1.507	1.591	1.691	1.764	1.850	1.917	1.938
700	1.327	1.404	1.454	1.527	1.580	1.639	1.698	1.719
800	1.268	1.303	1.318	1.357	1.391	1.428	1.469	1.478
900	1.211	1.204	1.182	1.193	1.200	1.212	1.224	1.231
1000	1.153	1.103	1.049	1.030	1.004	0.981	0.952	0.916
1100	1.099	1.001	0.908	0.856	0.800	0.736	0.665	0.598
1200	1.045	0.900	0.770	0.690	0.582	0.464	0.337	0.189
Run 17-u								
0	1.702	2.036	2.272	2.574	2.890	3.120	3.320	3.454
100	1.630	1.905	2.118	2.387	2.677	2.889	3.079	3.225
200	1.557	1.783	1.955	2.195	2.454	2.665	2.842	2.981
300	1.484	1.655	1.794	1.997	2.232	2.411	2.576	2.698
400	1.411	1.530	1.630	1.806	1.976	2.145	2.290	2.401
500	1.342	1.400	1.458	1.599	1.730	1.850	1.972	2.073
600	1.273	1.276	1.282	1.403	1.472	1.554	1.621	1.706
700	1.208	1.148	1.115	1.178	1.207	1.230	1.266	1.292
800	1.142	1.023	0.956	0.959	0.920	0.893	0.858	0.820
900	1.073	0.897	0.790	0.727	0.641	0.535	0.419	0.282
1000	1.004	0.781	0.631	0.508	0.344	0.163	0.062	0.033
1100	0.937	0.670	0.474	0.291	0.094	0.050	0.022	0.011
1200	0.871	0.558	0.321	0.106	0.055	0.026	0.012	0.006
Run 18-u								
0	1.739	2.149	2.357	2.506	2.625	2.734	2.797	2.812
100	1.684	2.045	2.242	2.374	2.483	2.599	2.655	2.680
200	1.629	1.953	2.128	2.240	2.344	2.456	2.506	2.534
300	1.577	1.853	2.002	2.106	2.203	2.305	2.361	2.388
400	1.525	1.756	1.883	1.968	2.057	2.144	2.206	2.239
500	1.472	1.660	1.754	1.830	1.908	1.985	2.054	2.059
600	1.415	1.567	1.627	1.699	1.751	1.817	1.865	1.880
700	1.359	1.476	1.508	1.559	1.588	1.627	1.673	1.694
800	1.305	1.378	1.390	1.419	1.428	1.453	1.474	1.495
900	1.252	1.281	1.269	1.276	1.259	1.274	1.274	1.277
1000	1.202	1.189	1.141	1.119	1.091	1.084	1.071	1.048
1100	1.151	1.093	1.017	0.979	0.922	0.890	0.854	0.807
1200	1.100	0.994	0.887	0.821	0.748	0.683	0.624	0.554

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ISSN 1919-3750 (Print)
ISSN 1919-3769 (Online)

La version française est disponible à l'adresse ci-dessus.

Correct Citation for this Publication

DFO. 2010. Stock assessment update for British Columbia canary rockfish. DFO Can. Sci. Advis. Sec. Sci. Resp. 2009/019.