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Stock assessment for bocaccio (*Sebastes paucispinis*) in British Columbia waters

Évaluation du stock de bocaccio (*Sebastes paucispinis*) dans les eaux de la Colombie-Britannique

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Abstract

This document provides a stock assessment for bocaccio in B.C. waters. Results of the work are intended to serve as advice over the short term to managers and stakeholders on stock status, and likely impacts of different harvest options. As such, it also provides the scientific advice required to develop a Recovery Strategy should this be deemed necessary. A Bayesian Schaefer surplus production model was used owing to an insufficient time series of age-structured data and lack of information on fishery vulnerability at size or age in the fisheries. It was fitted to one fishery dependent and six fishery independent stock biomass trend indices, and a reconstructed catch history back to 1935 when the population was assumed to be near to an unfished equilibrium. Some of the catch histories data were imputed from limited data. Informative Bayesian priors were used when estimating the survey proportionality constants, based in part on interviews with experienced fishermen. The reference run indicates a current stock size of about 3,000-5,000 t, with the stock estimated to lie between 10-15% of unfished stock size[1]. The impacts on current stock status of alternative model assumptions to those made in the reference case were explored in 31 runs. Long term biomass projections were made for the reference case and a selection of the sensitivity runs over 5, 20, and 40 year scenarios under varying fixed harvest assumptions. Results of the forecasts were presented relative to the DFO draft policy target references points of $0.4*B_{MSY}$ and $0.8*B_{MSY}$. These projections are shown as harvest tables for the reference set of assumptions as well as two additional scenarios which assume either a lower or higher estimate of productivity (r). While the Bayesian approach used in this assessment provides a formal mechanism to include uncertainty in model output (including predictions), managers and stakeholders are advised that not all sources of uncertainty have been addressed and that it is likely that the true uncertainty is even greater than that presented here.

[1] Readers are advised that the assessment results have since been updated and published in a CSAS Science Advisory Report (DFO 2009).

Resumé

Ce document présente une évaluation du stock de bocaccio dans les eaux de la Colombie-Britannique. Le but des résultats de ces travaux vise à prodiguer des conseils à court terme aux gestionnaires et aux intervenants relativement à l'état du stock et aux effets probables sur les diverses options de capture. Par conséquent, le document procure également l'avis scientifique requis pour élaborer une stratégie de rétablissement, le cas échéant. Un modèle de production excédentaire de Bayes et de Schaefer a été utilisé en raison du manque de séries chronologiques de données structurées en fonction de l'âge et du manque d'information sur la vulnérabilité selon la taille ou l'âge au cours des pêches. On y a intégré un indice de tendance de la biomasse du stock dépendant de la pêche et six indices indépendants, ainsi qu'un historique des captures reconstitué et reculant jusqu'en 1935, à une époque où la population était présumée atteindre un équilibre non exploité. Certaines données de l'historique des captures ont été imputées à partir de données limitées. Des distributions bayésiennes a priori ont été utilisées pour les paramètres du modèle au moment de l'estimation des constantes de proportionnalité du sondage, fondées en partie sur des entrevues réalisées auprès de pêcheurs d'expérience. Le scénario de référence indique une taille actuelle du stock évaluée entre 3 000 et 5 000 tonnes, le stock étant estimé se situer entre 10 et 15 % de la taille du stock non exploité2. Les effets sur l'état du stock actuel associés aux hypothèses d'autres modèles que celui utilisé pour le scénario de référence ont été étudiés dans le cadre de 31 passages. Des projections à long terme de la biomasse ont été faites pour le scénario de référence en plus d'une sélection de passages de sensibilité sur 5, 20 et 40 ans, en vertu de diverses hypothèses de captures fixes. Les résultats des prévisions ont été présentés conformément aux points de référence associés à l'ébauche de politique du MPO, soit au rendement maximal soutenable de 0,4*BMSY et de 0,8*BMSY. Ces projections sont indiquées dans des tableaux de captures pour l'ensemble des hypothèses de référence ainsi que deux scénarios supplémentaires présumant soit une estimation plus faible ou plus élevée de productivité (r). Bien que l'approche bayésienne utilisée dans le cadre de cette évaluation tienne lieu d'outil formel pour ajouter le niveau d'incertitude à la sortie du modèle (y compris les prévisions), les gestionnaires et les intervenants sont avertis que toutes les sources d'incertitude n'ont pas été abordées et qu'il est probable que le degré d'incertitude réel soit bien plus important que celui indiqué dans les présentes.

[2] Le lecteur est avisé que les résultats de l'évaluation ont été mis à jour et publiés depuis dans un avis scientifique du Secrétariat canadien de consultation scientifique (SCCS) (MPO, 2009).

Introduction

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) recommended a "Threatened" designation for the bocaccio (*Sebastes paucispinis*) population in British Columbia (B.C.)[3]. A "Regional Listing Recommendation" is required from DFO staff by the fall of 2009 to assist the Federal Minister of the Environment in reviewing this designation. The review will be followed by a "Proposed" Listing Decision in February 2010 and a Final Listing Decision by December 2010. The objective of this working paper is to provide a stock assessment for bocaccio in B.C. waters. The results of this work will be used to assist development of the Regional Listing Recommendation as well as a Recovery Potential Assessment and Recovery Strategy, should these be deemed necessary. Over the shorter term, it is also intended to provide harvest advice to fishery managers.

This document follows from previous summaries on the status of bocaccio (Stanley *et al*. 2001, Stanley *et al*. 2004, Stanley and Starr 2004) but differs significantly in three key respects. First, we have attempted to reconstruct historical catches back to at least 1935 in both trawl, and hook and line fisheries. Second, we have provided for the first time a full stock assessment using population modelling, and third, we provide a series of harvest decision tables framed within the current DFO harvests policy guidelines (DFO 2006, DFO 2008)[4].

Distribution, Habitat, and Stock Structure

As reported in previous documents, adult bocaccio continue to exhibit a widespread distribution on the outer coast of B.C. (Figure 1). There are also scatted observations from within enclosed waters or inlets. Most catches are taken close to bottom over depths of 60-200 m near the break-in-slope of the continental shelf as well of the edges of troughs in Queen Charlotte Sound (QCSd) and Hecate Strait (HS). As commented in Stanley *et al*. (2001), there are no obvious signs of contraction in the distribution; however, we did not conduct a rigorous review of this issue. Bocaccio range overall from the Alaska Peninsula to Baja California (Love *et al*. 2002).

Research in California has indicated that larval bocaccio have been caught up to 480 km from the coast. Late larvae and pelagic juvenile bocaccio are found close to the surface (Love *et al*. 2002). Young of the year reside near the surface for a few months then settle in nearshore areas where they form schools and are found over bottom depths of 30-120 m (Eschmeyer *et al.* 1983). Juvenile bocaccio (19-25 cm) have been caught in gillnets in sub-tidal depths off the west coast of Vancouver Island (Gillespie *et al.* 1993). Adult bocaccio can be semi-pelagic and are found over a variety of bottom types although harvesters suggest they favour proximity to high-relief and rocky bottom. Juvenile bocaccio feed on larvae, euphausiids, young rockfish, surfperch, mackerel, and various small inshore fishes. Adult bocaccio prey on other rockfishes, sablefish, anchovies, lanternfishes, and squids (Love *et al*. 2002). In B.C., they are caught with several

[3] http://www.sararegistry.gc.ca/species/speciesDetails_e.cfm?sid=740

[4] Note that subsequent to the review of this document at PSARC, results were further updated and modified, and presented in a Recovery Potential Assessment (DFO 2009). Readers wishing to seethe the latest advisory document on the status of bocaccio should refer to the more recent document.

other groundfish species including Pacific ocean perch (*S. alutus*), yellowtail rockfish (*S. flavidus*), and canary rockfish (*S. pinniger*).

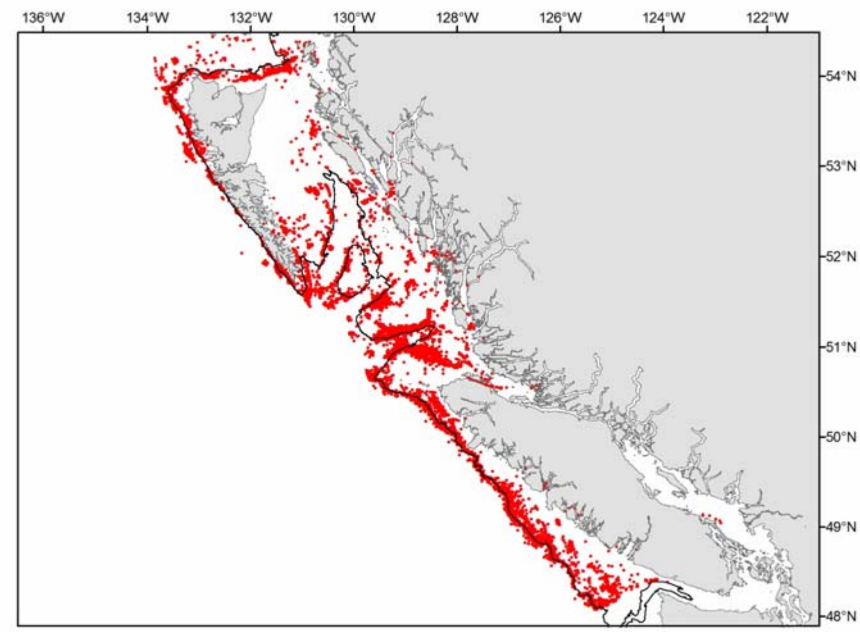


Figure 1. Catch locations of bocaccio in commercial groundfish fishing and groundfish research catches 2004-2008. The 200 m depth contour is shown by a black line.

Given that bocaccio appear to be a semi-pelagic and aggregating species, there appears to be no basis to assume they occupy specific residences as adults. Given their presumed mobility, their widespread distribution, the extent of rocky habitat in the preferred depths, and indications that they are currently at a relatively low level of abundance (see below), we can find no reason for assuming that habitat quality or quantity is currently limiting abundance. While all life stages are presumed to exhibit habitat preference with respect to bottom depth, depth in the water column, and bottom relief or rugosity, we have not identified any specific sites that could be considered critical to the sustainability of the population in B.C.

Matala *et al*. (2004) noted evidence of genetics structure in bocaccio in a comparison of samples from the Hecate Strait to Baja California. The analyses were consistent in suggesting no difference between a West Coast Vancouver Island sample and the Central California samples, but equivocal with respect whether to whether the Hecate Strait sample could be considered significantly different from samples to the south. We continue to assume one population of bocaccio in B.C. waters but have confined this analysis to using the catch and abundance data from the coastal waters and Hecate Strait. We have excluded the limited catch and biological observations from the Strait of Georgia and other semi-enclosed marine waters. Readers are referred to the earlier documents and Love *et al.* (2002) for additional background information on the biology of bocaccio.

Estimates of Life History Parameters

The estimates of size-at-age and maturity-at-age were derived from 940 aged specimens that were collected in B.C. waters from 2001-2006 (DFO Groundfish GFBio database, Figure 2, Figure 3). These were the only ageing data available at the time of report preparation. These samples came from both research survey and commercial fishery catches. The commercial samples in turn, came from both the at-sea observer program and port sampling, which in turn came from both midwater and bottom trawl catches. There were 24 samples that contained more than four fish. We concluded that there were too few data to explore the influence of catch source, gear, location, depth, and season on the estimates of size-at-age, maturity-at-age, or length/weight. Furthermore, the time series was too short, too variable, and too scattered with respect to source, to consider catch-at-age analysis.

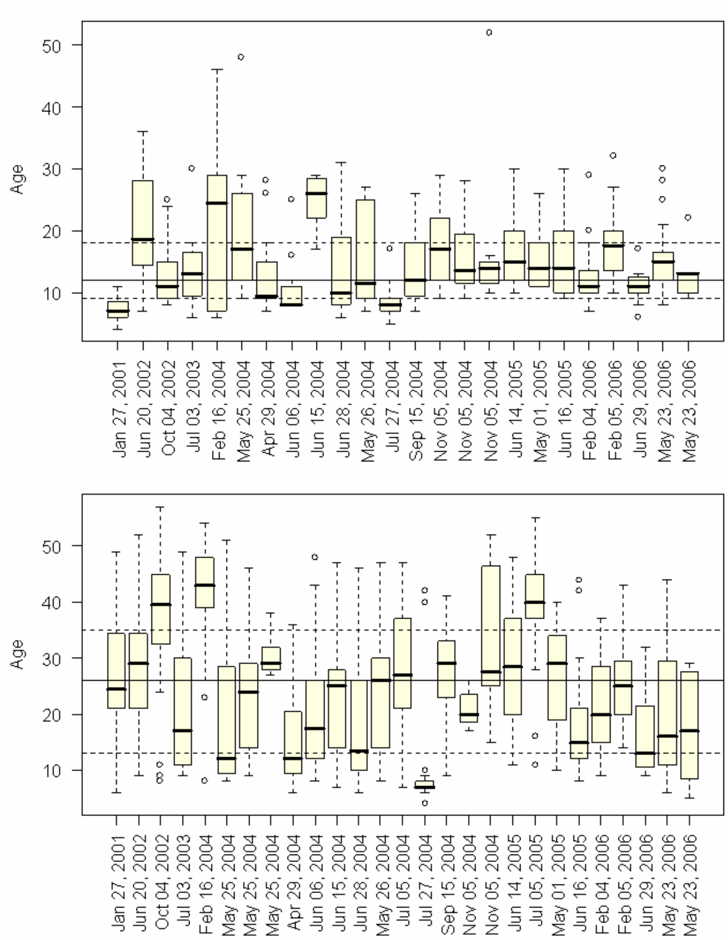


Figure 2. Boxplots of aged bocaccio samples (2001-206), females and males in upper and lower plots, respectively.

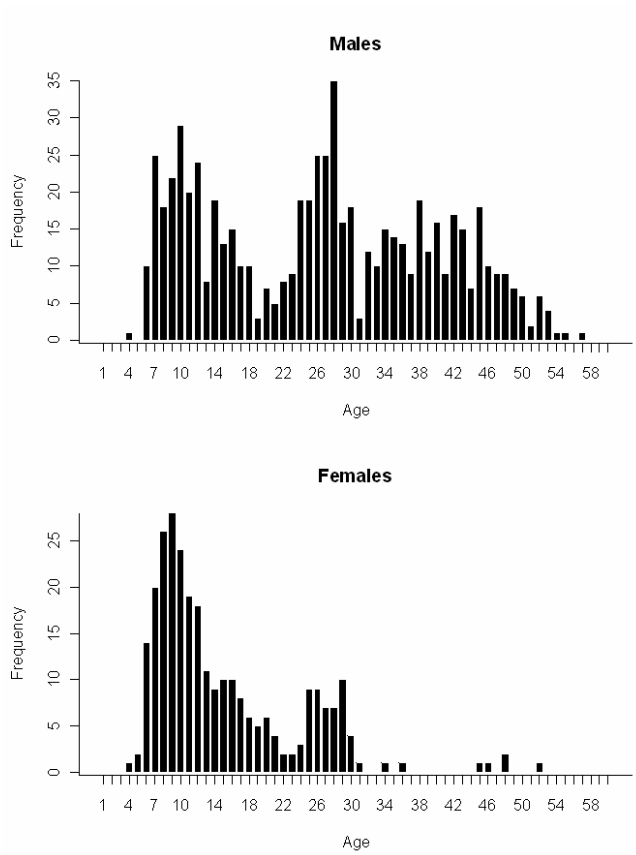


Figure 3. Age frequency histograms for male and female bocaccio, all samples combined.

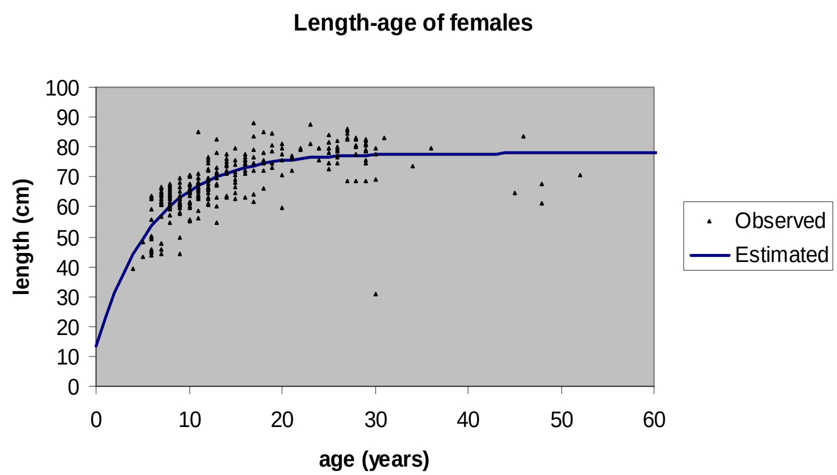
Growth, Maturity, and Fecundity

The von Bertalanffy growth model was fitted to 282 and 658 length-age observations for male and female bocaccio, respectively, using least squares (Figure 4, Table 1). The estimates for *k* and t_0 are highly uncertain due to having only one observation below the age of seven years for males and only three observations below the age of six for females. The length-weight conversion factors applied were *a* = 3.58E-05 and *b*=2.754 based on the same data. The von Bertalanffy growth model was fitted to the fraction mature-at-age observations using least squares. The asymptotic parameter was estimated at 0.999, the growth parameter was estimated at 0.421, and the intercept (i.e., the t_0 analogue) was estimated at 5.07 yr (
Figure 5). We assumed that fecundity was directly proportional to the estimated female mass at age.

Table 1. Growth parameters for female and male bocaccio.

Parameter	Females	Males
L_{inf} (cm)	78.32	69.98
k (yr^{-1})	0.163	0.108
t_0 (yr)	-1.20	-8.46

(a)



(b)

Figure 4. Observed and estimated length at age of (a) female and (b) male bocaccio.

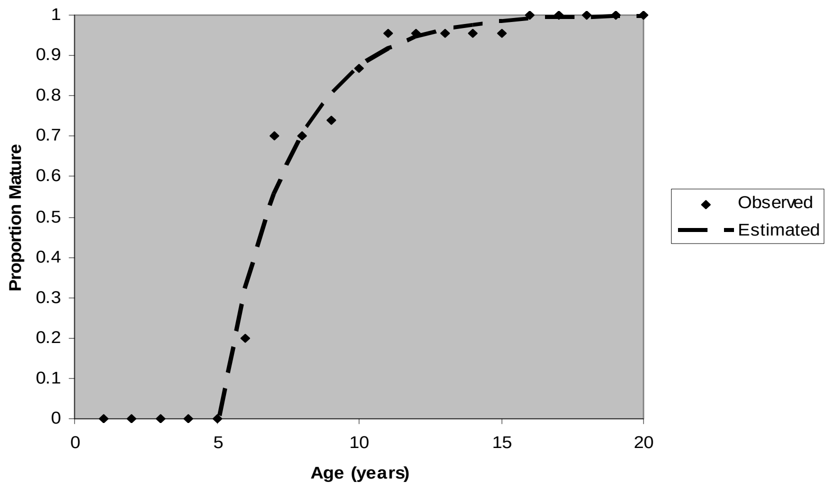


Figure 5. Observed and estimated proportion mature by age of female bocaccio

A graphical comparison of the proportion mature-at-age with the age frequency samples from the commercial fishery implies that recruitment to the fishery and the maturity ogives are similar, which may indicate that there is limited exploitation on juveniles (Figure 6). However, this issue should be re-examined in the future as additional age samples become available.

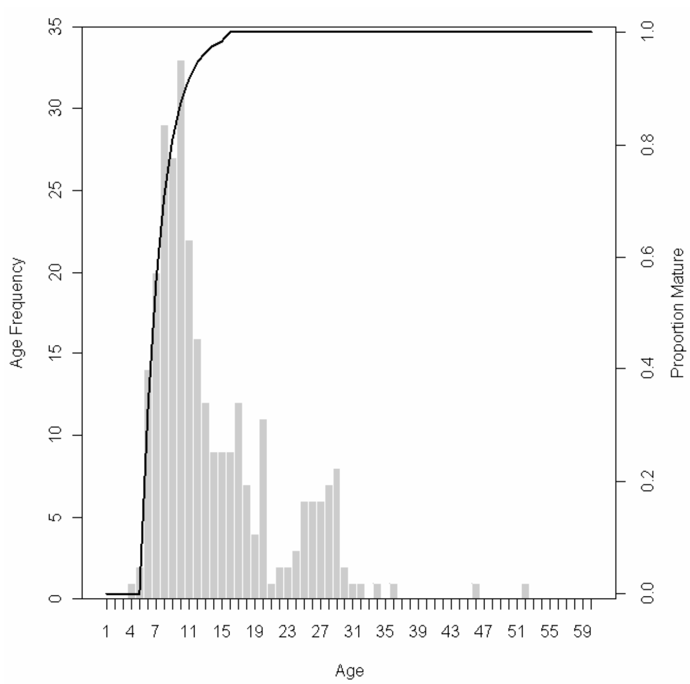


Figure 6. Female bocaccio proportion mature-at-age (line) compared with histogram of age frequency of females for all commercial samples combined.

Natural Mortality

The instantaneous rate of natural mortality for females, *M*, was treated as a lognormal random variable with a median of 0.075 yr^{-1}. This analysis was based partly on an analysis of proportion at age data which indicated a total mortality rate, *Z*, (including fishing mortality) of about 0.11 yr^{-1} for females. The proportion at age data was analysed using the method of Schnute and Haigh (2007) (Figure 7). The value for the standard deviation in the natural logarithm of *M* set was at 0.2. Note that when we used commercial samples only the Schnute and Haigh model indicated an estimate that *Z*=0.147.

This density function was truncated at a minimum of 0.025 and a maximum of 0.10 yr^{-1}. The estimate of *M* was used subsequently to estimate a prior for *r*, the maximum intrinsic rate of increase (see Appendix G).

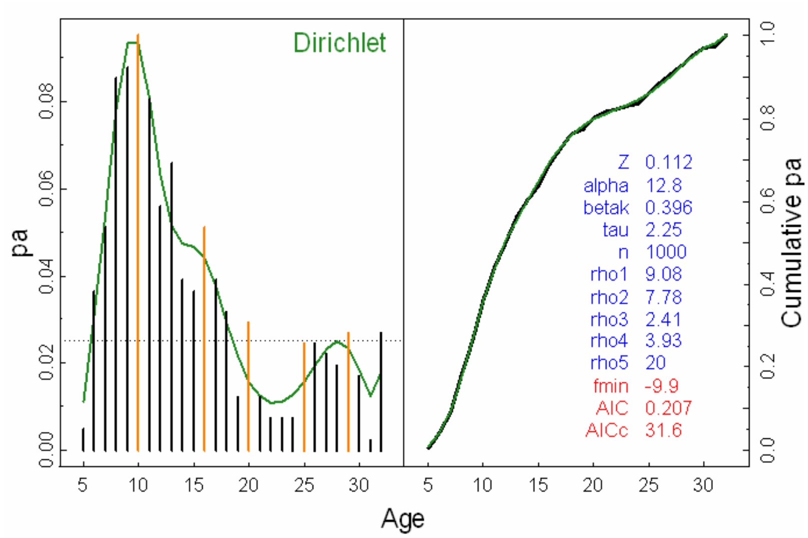


Figure 7. Catch curve analysis of all female bocaccio age observations (from method of Schnute and Haigh 2007).

If generation time is defined as the mean age of mature females in an unfished population, given the estimates of maturity-at-age and an *M* of 0.075 yr^{-1}, generation time is 20.4 years[5].

Alternative Estimates of *M* and Generation Time

The base runs of recent US assessments (MacCall 2003, 2005, 2007) have used an *M* of 0.15, although sensitivity tests examined a range from 0.10-0.20 in 2003 and 2005. MacCall (2003) notes that using a maximum observed age of 45 and a mean bias corrected version of Hoenig's method (Hoenig 1983) indicates a total instantaneous mortality rate (*Z*) of 0.10. The issue continues to be disputed in US assessments with the Pacific Marine Fisheries Council's Stock Assessment Review team (STAR panel) overruling the stock assessment team's recommendation of 0.10 and selecting 0.15.

[5] We have assumed a working estimate of generation time of 20 y for forecasting populations in the decision tables (Section 12).

Maximum and 99% percentile ages in B.C. samples were 57 and 52 for males, and 52 and 46 for females. Using the 99 percentile values and the Hoenig (1983) method for Z wherein:

Eq. 1 $Z=e^{(a+b(Ln(max\ age)))}$

and the bias correction recommended by MacCall (2003)[6], the estimates of Z are 0.097 and 0.086 for females and males, respectively (Table 2). The most recent U.S. assessment (MacCall 2007) estimated mean generation time from the net maternity function as 14 years under the assumption of M=0.15.

Table 2. Estimates of Z from maximum and 99th percentile observed B.C. bocaccio ages from all B.C. samples combined.

Sex	Age	a	b	$e^{(a+b(Ln(age)))}$	bias correction (MacCall 2003)	Z
females (99%)	46	1.46	-1.01	0.0901	1.08	**0.097**
females (100%)	52	1.46	-1.01	0.0796	1.08	0.086
males (99%)	52	1.46	-1.01	0.0796	1.08	**0.086**
males (100%)	57	1.46	-1.01	0.0725	1.08	0.078

Commercial Catch Data

This assessment differs from previous bocaccio reviews by attempting to reconstruct catch of bocaccio further back in time for a larger number of fisheries (Table 3) (Appendices A-C).

Table 3. Fisheries examined in reconstruction of overall catch history.

Gear	Commercial Sector	Years	Fixed or Estimated	Appendix
Trawl	US domestic	1935-2006	Fixed	A
Trawl	CDN domestic	1950-2006	Fixed	A
Trawl	Soviet and Japanese	1965-1977	Fixed	A
Handline and Setline (HL)	CDN Rockfish ZN	1940-2006	Fixed	B
Setline	CDN and US Halibut	1935-2006	Estimated	B
Troll	CDN Salmon troll	1935-2006	Estimated	C

We did not consider catches from the commercial fisheries for National and Supplemental hake, salmon seine and gillnet or shellfish, nor recreational and First Nations' fisheries. We assumed that historical catches in these fisheries were negligible with respect to this analysis.

"Catch" refers to total removals by fishing gear, both retained (landed) or discarded. We have assumed that all bocaccio die after capture so we treat total catch as equivalent to total fishery-generated mortality. With the exception of the occasional targeting in the domestic trawl and

[6] According to MacCall (2003), the Hoenig estimator is based on a geometric mean, and therefore requires a "geometric mean bias correction factor" of $exp(s^2/2)$ which approximates to 1.08.

hook-and-line, bocaccio has been predominantly a non-directed or bycatch species in all of the B.C. fisheries. Consequently, for the remainder of the document we do not distinguish between directed and non-directed catches.

Where we have inferred total catch from piece count estimates (the salmon troll and halibut fisheries), we have assumed a mean weight of 4.3 kg per fish. This value was derived from Dockside Monitoring Program (DMP) observations from the hook-and-line fishery in 2006-2007. There are no observations from earlier decades. However, the estimate of 4.3 kg per fish is consistent with interviews with many salmon troll, halibut, and rockfish fishermen who suggested that the size of the bocaccio they caught was generally in the range of "5-10 lbs" (2.3-4.5 kg) per fish. They reported very few "small" individuals observed but the occasional larger specimen up to 11 kg.

Catches for the trawl and Rockfish (ZN license), but not halibut or salmon troll fisheries were fixed at the same values in all model runs and assumed to be known without error (Figure 8). Bocaccio catch in the halibut and salmon troll fisheries were estimated within each assessment run as they are assumed to be proportional to abundance (see Appendices B and C). Three model runs examined low, medium and high versions of the troll catch of bocaccio, while one model run assumed no salmon troll or halibut catch (see below and Appendix G: Reference run and runs C.1-C.3).

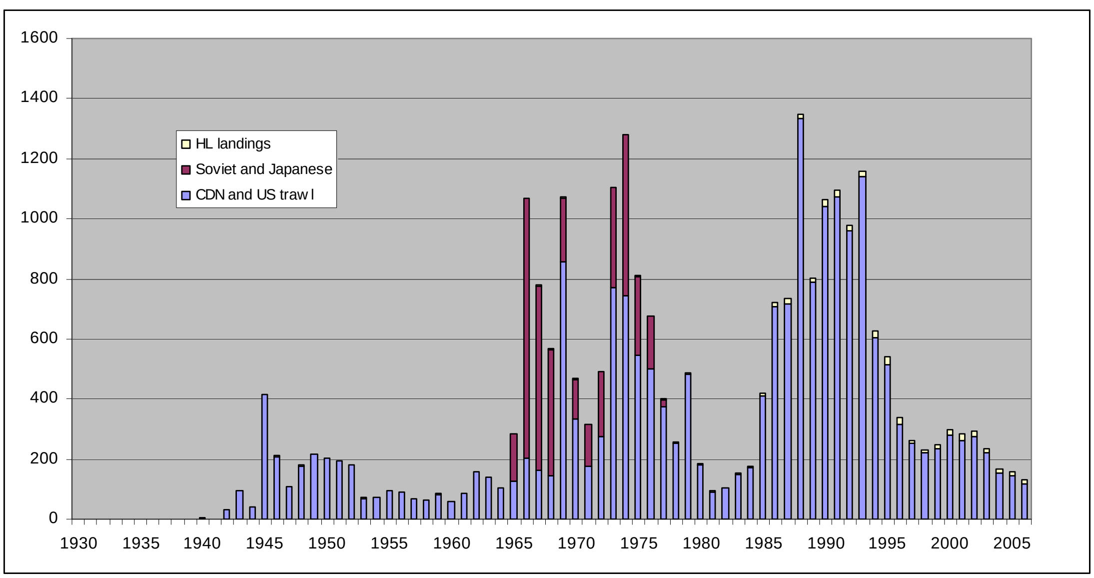


Figure 8. Total trawl catch and Canadian (CDN) hook and line (HL) landings for 1930-2006

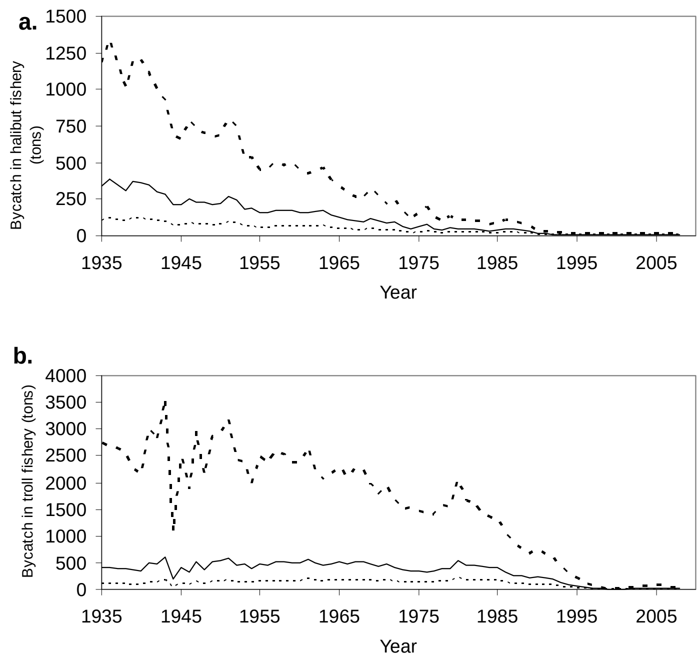


Figure 9. Posterior median and 80% probability intervals for the reference case model run for a. halibut and b. salmon troll fishery catches of bocaccio in B.C. waters. Solid lines are the medians and dashed/dotted lines are the 80% probability intervals

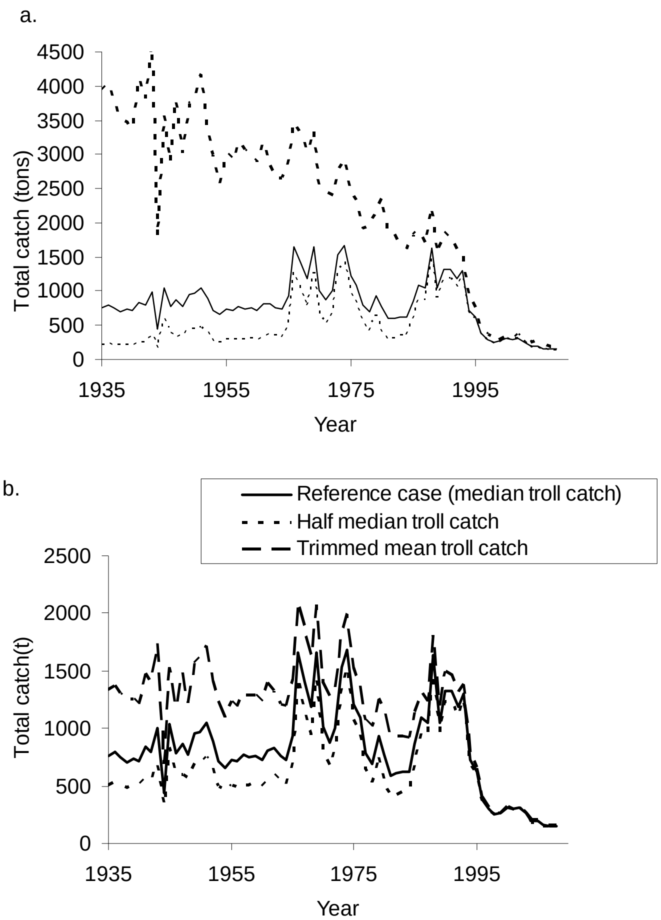


Figure 10. Total bocaccio catch from B.C. waters. a. Reference case median total catch (landings and estimated catches from halibut and salmon troll fisheries combined) with 80% probability intervals; b. Median total catch from the reference case, half median salmon troll catch and trimmed mean troll catch cases.

Other Sources of Mortality

As noted above, bocaccio are occasionally caught in other commercial salmon fisheries (seine and gillnet), as well as recreational, and First Nations fisheries. We also have had reports of small bocaccio being caught in prawn traps; however we assume the total mortality caused by these fisheries have been negligible in the past and will continue so in the near future. We know of no other human activities in B.C. waters that are causing, or will cause, significant mortality to the B.C. population of bocaccio.

Since we assume that the bocaccio population in B.C. must overlap to some extent with the U.S. populations, particularly to the south, it is possible that fishing activity in U.S. waters has had, and will continue to have, an impact on the abundance in B.C. waters (see Section 16 below for a summary of the most recent US assessment)[7]. Reported landings are now low (Table 4), averaging less than 10 t/y from 2005-2007 as compared with many thousands of t/y in earlier decades (Figure 11)[8].

Table 4. Summary of reported landings (t) of bocaccio from US waters (2005-2007).

INPFC Area	Region	2005	2006	2007
Vancouver-US	N. Washington	1.6	0.6	0.7
Columbia	S. Washington	0.2	0.1	0.2
OR-Coast	Oregon	0.0	0.0	0.0
Eureka	N. California	0.0	0.0	0.0
Monterey	C. California	2.8	2.8	4.2
Conception	S. California	2.2	2.0	2.5

[7] Note that US groundfish fishing is not monitored with 100% observer coverage so the landings figures will underestimate catch (mortality). However, owing to the low abundance of bocaccio, canary rockfish and other species in US waters (Washington-California), bottom trawl effort has been substantially restricted and in some areas eliminated in typical bocaccio depths since the mid 1990s (see the Pacific Fisheries Management Council website for details on management decisions: http://www.pcouncil.org).

[8] Catch estimates were obtained from http://www.psmfc.org/pacfin/pfmc.html. We used report #001 from the PFMC Groundfish Management Team Reports, 2005-2007. We note, however, that MacCall (2007) indicated a total catch of 67 t for 2006.

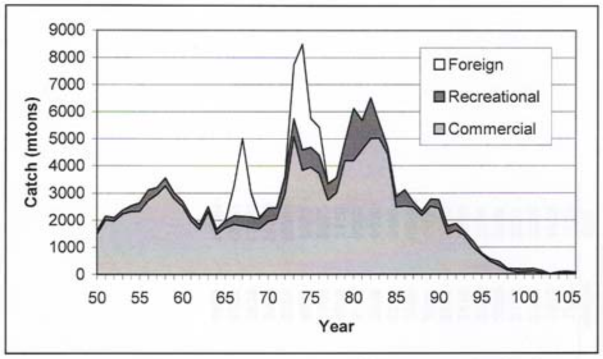


Figure ES1. History of bocaccio catches, showing foreign, recreational and commercial components. A catch of 2000 mtons is assumed prior to 1950.

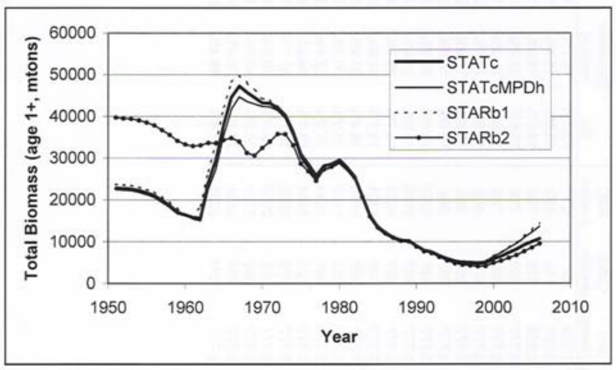


Figure ES2. History of total biomass (age 1+) of bocaccio estimated by four alternative models.

Figure 11. Summary of the 2007 assessment of bocaccio in California waters (from MacCall 2007).

Commercial CPUE

We provide model runs tuned with, and without, a commercial CPUE index for 1996/1997 to 2003/2004 (Appendix D). This index was based on commercial catch and effort data collected from bottom trawl fishing by independent observers over the period 1996–2004. As explained in previous documents (Stanley *et al.* 2001, Stanley and Starr 2004), we did not attempt to use catch and effort data prior to 1996 because these data are neither trustworthy nor were they collected and archived in a comparable fashion.

We only used data through to 31 March 2004, which is the end of the fishing year. After this date, in response to concerns expressed about the status of bocaccio, most participants in the trawl fishery voluntarily agreed to relinquish[9] the value of all bocaccio landings. This initiative not only removed the incentive to target bocaccio but, encouraged harvesters to avoid bocaccio.

[9] The individual harvester did not receive any payment for bocaccio landings. Revenue was "relinquished" to the Canadian Groundfish Research and Conservation Society.

Trawl catches in this sector declined from around 200-250 t annually to nearly 100 t by the 2006/2007 fishing year. Consequently, we believe that bocaccio catch rates after the 2003/2004 fishing year are not comparable to the earlier period because we assumed that targeting ceased and avoidance may have increased. We therefore did not include values for years after relinquishment was adopted by the fishing fleet. The standardized and nominal trends indicate little change from 1996/1997 to 2003/2004 (Figure 12).

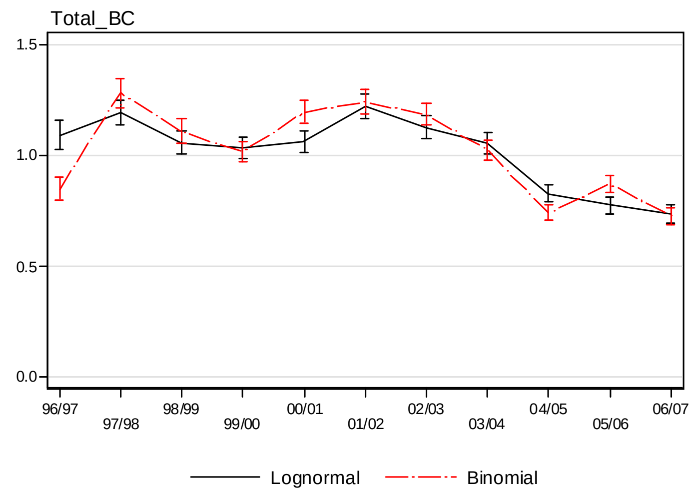


Figure 12. Comparison of the lognormal and binomial standardised CPUE indices for bocaccio. The error bars show ± 95% confidence bounds.

Nominal catch data were standardized using Generalized Linear modelling (GLM) as in many recent stock assessment documents (Appendix D). The nominal and standardized indices, as well as other treatments of the data, provided similar flat trends over the selected time period. This does not validate the methodology but does indicate that alternative methods are unlikely to provide a significantly different signal.

Survey Indices

We used the results from seven surveys in the stock assessment (Table 5 and Table 6, Appendix E). We excluded from consideration the Hecate Strait Assemblage survey (1984-2003), International Pacific Halibut Commission survey (IPHC), the G.B. Reed Queen Charlotte Sound survey, and DFO longline surveys because they did not capture enough bocaccio to be informative. Although they consist of only 2-4 recent data points, we used the four recent large-scale synoptic groundfish trawl surveys to estimate survey catchabilities and to provide information on recent trends. None of these surveys catch large amounts of bocaccio (Table 7).

Table 5. Fishery independent surveys used in this assessment, and additional surveys that have been used in recent rockfish assessments but were not included in this assessment.

Survey	**Start year**	**End year**	**Number survey years**	**Depth range (m)**	**Gear used**	**Used as index in assessment model**
WCVI Shrimp [1]	1975	2007	31	80–160 [2]	Shrimp BT	Yes
QCSd Shrimp	1999	2006 [3]	8	100–235	Shrimp BT	Yes
US NMFS Triennial [4]	1980	2001	7	55–366 [2]	Gfish BT	Yes
QCSd Synoptic Gfish	2003	2007	4	37–543	Gfish BT	Yes
WCVI Synoptic Gfish	2004	2006	2	46–750	Gfish BT	Yes
Hecate St. Synoptic Gfish	2005	2007	2	11–230	Gfish BT	Yes
WCQCI Synoptic Gfish	2006	2007	2	180–1800	Gfish BT	No

[1] Survey began in 1972 but rockfish catch not recorded until 1975
[2] indicates depth range analyzed for indices used in assessment
[3] 2007 index for QCSd shrimp not used as no bocaccio were captured
[4] index from Canadian waters only

Table 6. Summary of observations by year for the abundance indices used in the assessment.

Survey/Index	**Year**																																
	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07
WCVI Shrimp	x	x	x	x	x	x	x	x	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
QCSd Shrimp																									x	x	x	x	x	x	x	x	x
US NMFS						x			x						x			x			x			x			x						
QCSd Synoptic Gfish																													x	x	x		x
WCVI Synoptic Gfish																														x		x	
Hecate Str. Gfish																															x		x
WCQCI Gfish																																x	x
Trawl CPUE																						x	x	x	x	x	x	x	x	x			

Table 7**.** Survey catch rates (pieces/survey), frequency of occurrence, and mean lengths.

Survey/Index	**Number of survey years**	**Mean number of bocaccio per year**	**Total number of Tows**	**Tows with bocaccio**	**Mean length (cm)**		
					Mean	**5th percentile**	**95th percentile**
WCVI Shrimp	32	15	2,593	158	65.1	58.3	72.7
QCSd Shrimp	9	4	629	22	64.5	54.4	70.1
US NFMS Triennial	7	391	878	91	-	-	-
QCSd Synoptic Gfish	4	63	947	61	66.7	55.5	76.6
WCVI Synoptic Gfish	3	104	422	84	64.0	47.0	77.2
Hecate St. Synoptic Gfish	2	13	364	18	65.8	28.4	79.1
WCQCI Synoptic Gfish	3	16	340	30	71.1	63.2	82.0

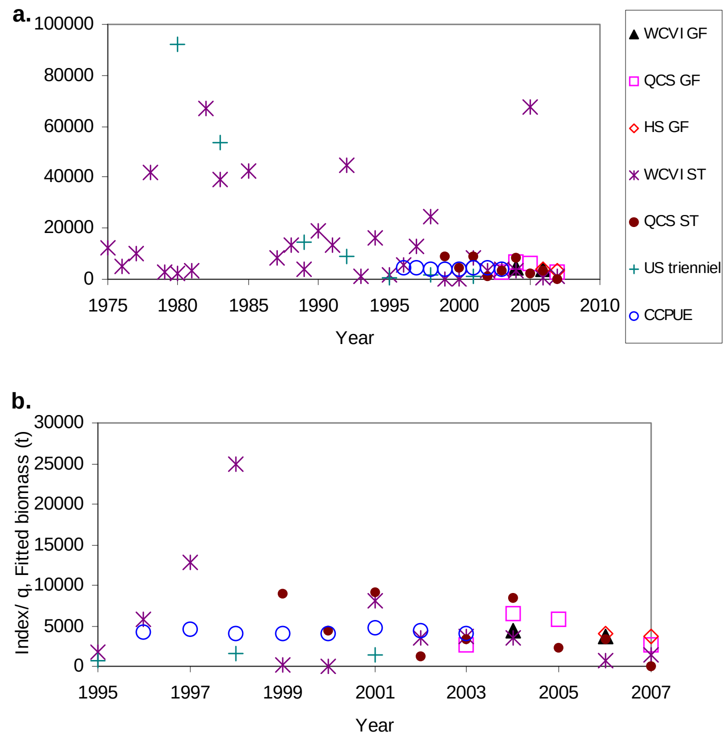


Figure 13. Survey index values for a. 1975-2007, b. for the last 12 years on a finer scale with the 2005 WCVI shrimp trawl point excluded. Survey values scaled as fitted in the model.

Trawl Catchability

The Bayesian Surplus Production (BSP) model was initially run using only relative abundance in the various surveys and the fixed trawl and ZN catch data together with non-informative priors for the survey index constants of proportionality (q). This preliminary analysis indicated very large uncertainty in the current status of the stock with a probability tail for initial stock sizes extending well over 200,000 t. While appropriately characterizing the low information content of the indices and catch data, the wide range was disappointing.

This result prompted us to seek additional information to constrain stock biomass on the absolute scale. We chose to explore the potential of constraining the estimate of the catchability (q) by developing an informed prior for q for each survey based on expert judgement and a separate analysis of the survey information (Appendix F). Without constraints and with the use of a non-informative prior for q, q was estimated with only a moderate amount of precision by the BSP model following the inclusion of salmon troll and halibut fishery catch and we had no independent means with which to judge the reliability of the estimates obtained. The development of an informative prior for q, derived from first principles, including survey data not directly used in the BSP model and expert judgement, offered an approach to further bound q estimates. To formulate an informative prior for the survey q, we broke q into three components: the percentage of fish captured from those initially in the path of the trawl net, the proportion of the coastwide biomass that the survey area covers, and the relative density of biomass in trawlable and untrawlable bottom in each survey. We attempted to bound the prior for *q* from these three perspectives.

The probabilistic model formulated and applied to produce prior density functions for the survey *q* parameters incorporated expert judgement of the survey net catchability factors from 12 B.C. groundfish trawler skippers. It also used groundfish trawl survey data on the fraction of stock biomass in each survey area (i.e., components of the data not contained in the stock trend indices to which the BSP model was fitted). Finally, it incorporated subjective judgement on the extent to which density is higher in untrawlable areas, and observations of ratios of catch rates in some areas where both shrimp and groundfish trawl survey nets were applied (Appendix F). The output distributions for the "survey *q-gross*" parameters for the seven surveys that were estimated by the model and incorporated both the survey net catchability and the fraction of fish in the survey area had large correlations among them (up to about 0.97), high variance and a large positive skew (Figure 14, Table 8, Appendix F). The west coast Queen Charlotte Island groundfish survey *q* was dropped since this index was not used in the assessment. The joint prior for survey catchability was approximated by a six dimensional lognormal density function (one dimension for each of the six survey datasets) incorporating the median and covariance of log *q* which were used as the *q* prior distribution in the assessment model.

Table 8. Posterior means, medians, standard deviations (SD), CVs and 95% probability intervals for *q-gross* (*qgfin*). *lqgfin* is the natural logarithm of the random variable *qgfin*. The last three columns show the 2.5th, 50th and 97.5th percentiles of the random variable *qgfin*. The mean and SD of *lgfin* were used as inputs to the multivariate log normal prior density function for the survey *q* parameter in the stock assessment.

Survey	mean	SD	CV	mean(*lqgfin*)	SD(*lqgfin*)	exp(mean(*lqgfin*))	2.5	50	97.5
#1 - WCVI Gfish	6.26E-02	4.86E-02	7.77E-01	-3.06E+00	8.08E-01	4.68E-02	7.80E-03	4.92E-02	1.92E-01
#2 - QCSd-Gfish	4.09E-02	3.34E-02	8.17E-01	-3.51E+00	8.33E-01	3.00E-02	4.83E-03	3.14E-02	1.30E-01
#3 - HS - Gfish	5.93E-03	4.98E-03	8.40E-01	-5.45E+00	8.46E-01	4.30E-03	6.79E-04	4.50E-03	1.93E-02
#4 - WCQCI - Gfish	1.90E-03	1.52E-03	7.99E-01	-6.57E+00	8.20E-01	1.40E-03	2.31E-04	1.47E-03	5.95E-03
#5 - WCVI Shrimp	2.67E-03	4.02E-03	1.50E+00	-6.57E+00	1.16E+00	1.40E-03	1.39E-04	1.42E-03	1.28E-02
#6 - QCSd Shrimp	1.17E-03	7.22E-03	6.15E+00	-9.33E+00	2.38E+00	8.90E-05	8.10E-07	8.98E-05	8.76E-03
#7 - US Triennial Gfish	7.30E-02	1.52E-01	2.09E+00	-4.02E+00	1.87E+00	1.79E-02	3.74E-04	1.95E-02	5.01E-01

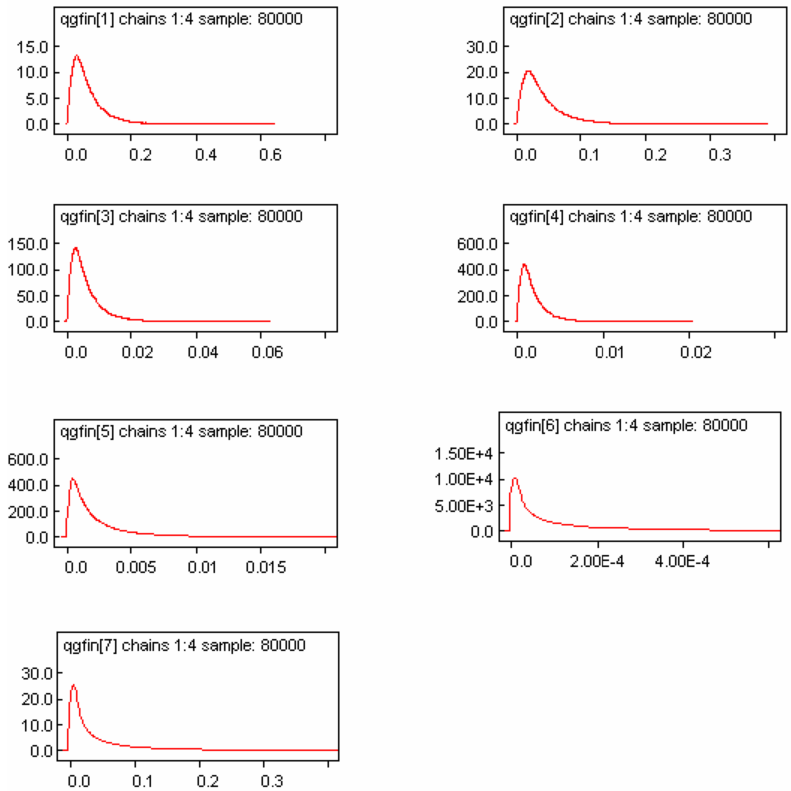


Figure 14. Marginal density functions for *q-gross* (*qgfin*) for the seven different surveys when Bayesian updating and uncertainty factors are applied to the *q-net* factors**.**

Bayesian Surplus Production Model

Owing to the paucity of age-structured data, a non-equilibrium age-aggregated surplus production model was used to assess this stock (McAllister *et al*. 2001a). A state-space version incorporating stochastic process error in the fish stock dynamics (Meyer and Millar 1999) permitted more thorough accounting for uncertainty in estimates of stock biomass, stock projections, and deviations from deterministic surplus production. A Bayesian statistical approach was adopted to fit the model to data, allowing for the use in the model of informed priors which incorporate information and expert judgements. The BSP model was fitted to six stock trend indices to evaluate historical trends in abundance of B.C. bocaccio and to evaluate the potential future trends in abundance from alternative total allowable catch (TAC) policies. TAC refers to total combined catch from all fisheries.

General Structure of the Model

We use a version of the Schaefer surplus production function (Hilborn and Walters 1992) that applies continuous fishing mortality rate equations (Prager 1994):

Eq. 2 $$B_t = B_{t-1} + B_{t-1} r \left(1 - \frac{B_{t-1}}{K}\right) - F_{t-1} B_{t-1}$$

where B_t is stock biomass in year t, r is the maximum intrinsic rate of increase, K is the average unfished stock size or carrying capacity, and C_t is the catch in year t. The estimation performance of a Bayesian version of this model was evaluated and found to perform acceptably under a range of conditions. These included misspecification of priors provided that the priors for key parameters (e.g., r and constants of proportionality for stock trend indices, q), were not overly precise and strongly biased (McAllister and Kirkwood 1998). This version will tend to provide more accurate representations of fish stock dynamics than a discrete harvest rate version, especially when fishing mortality occurs throughout the year and when exploitation rates are high. It is slightly more cumbersome because the annual fishing mortality rate (F_t) must be solved numerically (in the discrete version, harvest rates are obtained analytically) (see McAllister and Babcock 2002 and McAllister *et al.* 1999; 2001a for details on the model).
We applied a state-space version of the BSP that incorporates lognormal deviates from total annual biomass predictions:

Eq. 3 $$B_t = \left(B_{t-1} + B_{t-1} r \left(1 - \frac{B_{t-1}}{K} \right) - F_{t-1} B_{t-1} \right) \exp\left(\varepsilon_t - \frac{\sigma_p^2}{2} \right)$$

where the prior probability distribution for the process error term is given by $\varepsilon_t \sim \text{Normal}\left(0, \sigma_p^2\right)$. ε_t from 1935 to 2008 were treated as estimated parameters and σ_p was set at 0.1, and 0.05 and 0.15 in two additional runs for a sensitivity test. This bounds the mean of the value for σ_p applied in Meyer and Millar (1999). No attempt was made to estimate the process error variance or observation error variance, owing to the paucity of time series data that could inform estimates of variance in ε_t and low precision in most of the indices.

Details on specific inputs to the BSP Model

The reference case prior distributions for K, r, the ratio of stock size in 1935 to K (B_{1935}/K) and the constants of proportionality (q) for the stock trend indices are provided in Table 9 (see Appendix G). A commonly applied demographic approach to formulating a prior for the maximum intrinsic rate of increase (McAllister *et al.* 2001c) was applied to compute a prior for r for bocaccio. This utilized available life history data on growth, natural mortality rate, maturity-at-age and the stock-recruit steepness parameter from a hierarchical meta analysis of rockfish stock-recruit data (Dorn 2002) (see Figure 15 and Figure 16 and Appendix G for plots of the reference case steepness prior and two alternative steepness priors applied to compute the prior for r). The mean and standard deviation (SD) for r were 0.117 and 0.037 (Table 9). The histogram for r can be closely approximated by a lognormal pdf with a mean of 0.117 and standard deviation of the natural log of r of 0.297 (Figure 16).

Table 9. Prior pdfs of parameters K, q for the commercial catch rate data, P_0, and r

Parameter	Prior density function	Comments
K	Uniform (500, 200,000)	Units in tons
q for commercial cpue	Proportional to $1/q$	This prior is non-informative with respect to K and stock biomass. See Table 4, Appendix F11, F13 for key details on the informative prior for the survey qs
P_0	Lognormal($\ln(0.9)$, 0.2^2)	This indicates that the stock was near to carrying capacity in 1935.
r	LogNormal($\ln(0.112)$, 0.294^2) Prior mean $r = 0.117$ Prior SD $r = 0.037$	The relatively low prior mean comes largely from the late median age at maturity of 7 years. It also comes from the relatively low estimates of recruits per ton of spawner biomass at the origin of the stock-recruit function which in turn derives partly from the low prior mean for steepness obtained from the meta-analysis of stock recruit data (Dorn 2002).

The Schaefer surplus production model presumes that B_{msy}/K occurs at 50% of K. A recent hierarchical meta-analysis of more recent stock-recruit data for rockfish indicated that under a Beverton-Holt function, the range for the median B_{msy}/K by species was from about 0.3 to 0.5 and for the Ricker stock recruit function this range was from about 0.45 to 0.65. As some cannibalism has been observed in bocaccio (Love *et al*. 2002), this could imply that a Ricker model might be a more appropriate representation of the stock-recruitment function for this species. Given the plausibility of a wide range of values for B_{msy}/K, it appears that a Schaefer model can be used as a reasonable reference case model as it lies within the middle of the range of possibilities and is plausible under either stock-recruit function.

To test the sensitivity of stock assessment results to the form of the surplus production function, two alternative forms were implemented in sensitivity tests. A variant of the Fletcher generalized surplus production function, which allows the value of B_{msy}/K to take on any value between 0 and 1, was applied. This is because the classical forms of the Pella-Tomlinson and Fletcher generalized surplus production functions have the anomalous property in which the value for r tends to increase markedly as the value for B_{msy}/K decreases and becomes infinity when B_{msy}/K decreases below the value of 1/e (about 0.37) (Quinn and Deriso 1999). This variant uses the parabolic Schaefer production form for the portion of the production function below B_{msy}/K such that the Schaefer production is continuous with the Fletcher form at MSY (McAllister *et al.* 1999). This also permits the prior for r to be incorporated directly in the generalized model; the classical generalized forms do not permit this. The variant Fletcher-Schaefer model was parameterized in two additional sensitivity tests that fixed B_{msy}/K at 0.4 and 0.6.

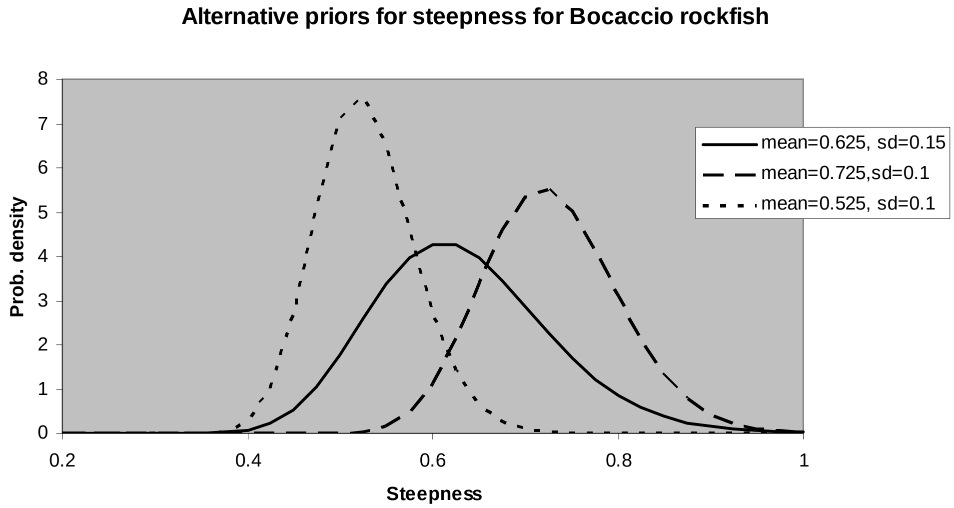


Figure 15. Lognormal approximations of probability density functions of steepness for bocaccio from Dorn (2002). The base case, high and low scenarios that were applied in forming priors for *r* are shown.

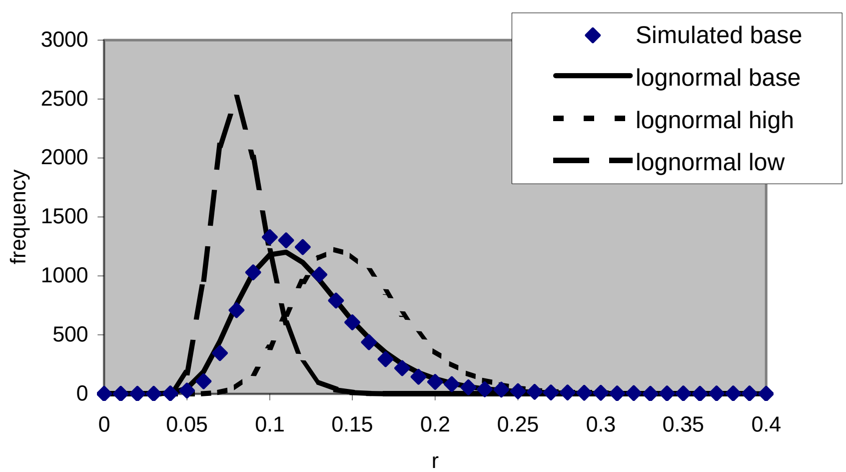


Figure 16. A histogram and fitted lognormal prior density function of the maximum intrinsic rate of increase (*r*) for B.C. bocaccio. The reference or base case, and low and high prior *r* cases are shown here.

The "Reference Case" of the BSP Analysis

For the reference case runs, all inputs, assumptions, and settings were formulated based on the base available information and scientific judgment. The key settings are as follows:

- prior mean $r = 0.117$, sd($\ln(r)$)$= 0.294$;

- all stock trend indices;
- likelihood function for catch: truncated normal, CV=0.6 for troll, CV=0.5 for halibut
- observed mean annual troll catch for 1976-1985 calculated from median recalled daily value;
- limit on average daily troll catch set at 40 bocaccio per day;
- Schaefer surplus production function (B_{msy}/K=0.5);
- process error SD = 0.1;
- prior mean B_{35}/K = 0.9;
- informative priors for survey *q* with Bayesian update;
- density in trawlable area < untrawlable area (triangular distribution);
- lag 1 autocorrelation starts in 2007;
- CVs for stock trend indices obtained by iterative reweighting.

In all instances, the model fitted the stock trend data quite poorly with large deviations between observed and predicted indices and some apparent autocorrelation in deviates for some of the indices (Figure 17). For the most recent three years, the annual deviates from the predicted surplus production were strongly negative, indicating that the surplus production function predicted higher production than was realized in the stock trend indices (Figure 13). For the reference case and other model runs, autocorrelation at lag 1 in the surplus production deviates from 1935 to 2006 was estimated at about 0.66 and was significant at the alpha = 0.05 level. In the reference case, the posterior mean for the intrinsic rate of increase *r,* 0.095 (26%), was less than the prior mean of 0.117 (31%). The decrease in mean value and decrease in CV suggest that the stock trend data provided some information on *r* (Figure 18, Table 10).

Under the reference case, the posterior mean and median for stock biomass in 2008 are 4,765t and 3,565t, respectively (Table 10). Under the reference case, stock size is low relative to its unfished stock size (*K*) and its B_{MSY} reference point (i.e., the posterior mean for B_{2008}/K *is* 12% (95%) and B_{2008}/B_{msy} is 25% (95%) (Figure 18, Figure 19, Table 10). The posterior medians are somewhat less, at 8.6% and 17%, respectively, due to the high positive skew in the marginal posteriors. Stock biomass has shown a progressive decline since the 1930s with the steepest decline from 1985 to 1995 and stock size changing relatively little since then (Figure 17). The posterior mean of F_{2008}/F_{MSY} is 1.1 (57%), with the median at 1.0. The posterior median for the replacement yield in 2008 (the amount that can be harvested so that the stock will not increase or decrease in the next year) is 288 tons (67%) (Table 10). The posterior mean ratio of the total harvest in 2008 to replacement yield is 62% (266%) with the median at 57%. The CV is large for the latter due to large uncertainty in the catch estimates and the occurrence of some instances in which replacement yield is very small.

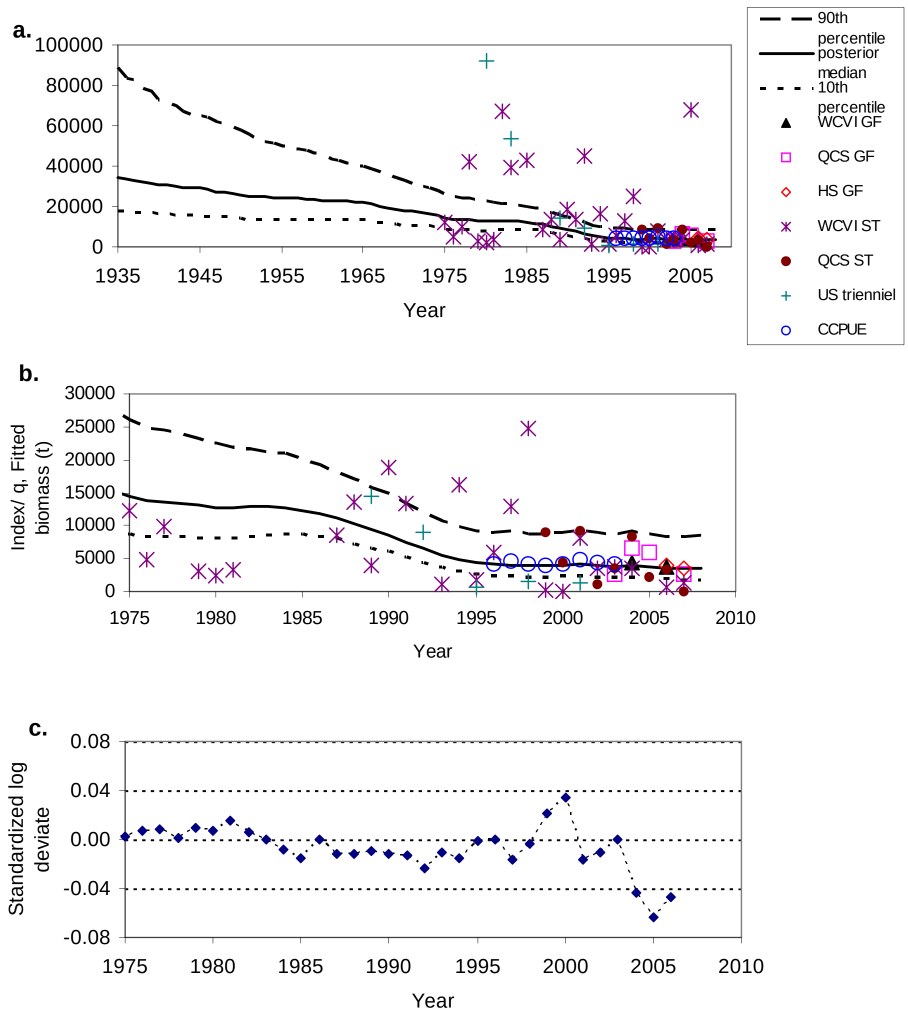


Figure 17. For the reference case, a. posterior median and 80% probability intervals for stock biomass, and the stock trend indices divided by their posterior modal value for of constants of proportionality for years 1935-2008, b. the same as a. but with high values cut off and for years from 1975 to 2008; and c. log standardized annual deviates in surplus production for years from 1975 to 2006.

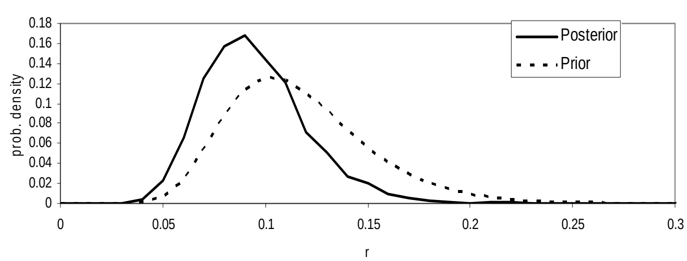


Figure 18. The reference case result for the marginal prior and posterior densities for *r*.

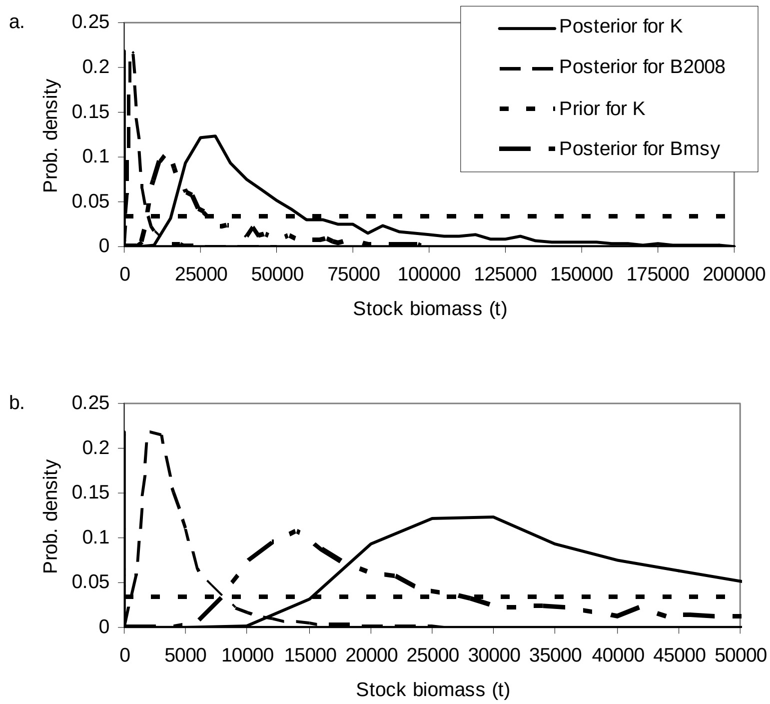


Figure 19. Reference case posterior density functions for *K*, stock biomass in 2008, and B_{msy} a. with range to 200,000 t and b. truncated to 50,000 t on the x-axis.

Table 10. For the reference run, the posterior mean, SD, coefficient of variation (standard deviation/mean), 10th, 50th, and 90th percentiles and posterior mode for key parameters and stock status indicators under the reference case run. B_{08} and C_{08} are recruited stock biomass and catch biomass in 2008, *RepY* is the replacement yield in 2008. Biomass values in tons. *k(halibut)* and *k(troll)* are the catchability coefficients for catch in the halibut and salmon troll fisheries.

	Mean	SD	CV	10%	Median	90%	Mode
K	52659	35646	0.68	21107	39977	106665	28865
r	0.095	0.026	0.27	0.066	0.092	0.129	0.088
MSY	1181	761	0.64	523	914	2267	680
B08	4765	4421	0.93	1691	3565	8790	1830
B08/K	0.123	0.118	0.950	0.027	0.086	0.265	0.045
F08/FMSY	1.122	0.638	0.570	0.434	1.002	1.916	0.881
B08/ BMSY	0.247	0.236	0.950	0.056	0.171	0.529	0.071
C08/ RepY	0.623	1.660	2.660	0.294	0.566	1.015	0.479
BMSY	26329	17823	0.68	10651	19973	53434	13577
RepY	346	232	0.67	145	288	607	190

Sensitivity Tests

Thirty-one additional model runs were carried out to evaluate the sensitivity of the results to alternative model settings (Table 11).

Table 11. Summary of sensitivity test runs, including their categorisation

Category Code	Category Description	Code	Run Description
Ref	Reference run	Ref	Reference run
A	B_{msy}/K	A.1	$B_{msy}/K = 0.4$
		A.2	$B_{msy}/K = 0.6$
B	r prior mean	B.1	low r (mean = 0.0836)
		B.2	high r (mean = 0.1520)
C	catch assumptions	C.1	low mean troll catch
		C.2	high mean troll catch
		C.3	exclude troll and halibut catch
		C.4	pre-1996 catch x 0.5
		C.5	pre 1996 catch x 1.5
		C.6	relax troll catch per day cap at 40
		C.7	likelihood function for catch: lognormal, CV=0.6 for troll, CV=0.5 for halibut
		C.8	Catch fixed at best estimates as opposed to being imputed with uncertainty
D	Process error assumptions	D.1	low process error (SD = 0.05)
		D.2	high process error (SD = 0.15)
		D.3	deterministic with no process error
E	B_{init}/K	E.1	$B_{init}/K = 0.7$
		E.2	$B_{init}/K = 1.0$
F	survey q priors	F.1	Non-informative priors for survey q
		F.2	Density in trawlable area set to be equal to untrawlable area
		F.3	survey q prior with no Bayesian update
		F.4	Survey q prior covariance = 0
G	effect of data	G.1	Leave out CCPUE data (commercial trawl CPUE)
		G.2	Leave out US NMFS triennial survey
		G.3	Leave out WCVI shrimp survey
		G.4	Leave out QCSd shrimp survey
		G.5	Leave out QCSd synoptic survey
		G.6	Leave out WCVI synoptic survey
		G.7	Leave out HS synoptic survey
		G.8	exclude all survey data from 2003+
H	autocorrelation assumptions	H.1	no autocorrelation in lag 1 process error
		H.2	autocorrelation in process error starts in 2009

Table 12. Medians and 80% credibility intervals drawn from the posterior distributions for seven parameters taken from the bocaccio assessment for the reference run and all 31 sensitivity runs. Codes used for each run along with a run description can be found in Table 7. Biomass values are in tons.

	B_{msy}			**$B_{current}$**			***Replacement_yield***			**$B_{current}/K$**			**$F_{current}/F_{msy}$**			**$B_{current}/B_{msy}$**			***$Catch_{curr}$/Replce_yield***		
Code	**10%**	**Median**	**90%**	**10%**	**Median**	**90%**	**10%**	**Median**	**90%**	**10%**	**Median**	**90%**	**10%**	**Median**	**90%**	**10%**	**Median**	**90%**	**10%**	**Median**	**90%**
Ref.	10000	20000	54000	2000	4000	9000	150	300	600	0.025	0.075	0.275	0.400	1.000	1.900	0.050	0.175	0.525	0.300	0.600	1.000
	B_{msy}/K																				
A.1	10000	18000	46000	2000	4000	9000	150	300	600	0.025	0.075	0.250	0.400	1.000	1.900	0.050	0.200	0.600	0.300	0.600	1.000
A.2	10000	20000	60000	2000	3000	8000	150	250	600	0.025	0.100	0.275	0.400	0.800	1.600	0.050	0.150	0.475	0.300	0.600	1.100
	***r* prior median**																				
B.1	12000	24000	62000	2000	4000	9000	150	250	550	0.025	0.075	0.225	0.500	1.100	2.300	0.050	0.150	0.450	0.300	0.600	1.200
B.2	8000	14000	40000	1000	3000	9000	200	350	700	0.025	0.100	0.375	0.300	0.800	1.600	0.050	0.200	0.725	0.300	0.500	0.800
	Catch assumptions																				
C.1	10000	16000	48000	2000	4000	9000	150	300	600	0.025	0.100	0.325	0.400	1.000	1.900	0.075	0.200	0.625	0.300	0.500	1.000
C.2	14000	26000	60000	2000	4000	9000	150	300	600	0.025	0.075	0.225	0.500	1.000	1.900	0.050	0.125	0.425	0.300	0.600	1.000
C.3	8000	14000	30000	3000	11000	34000	200	500	1300	0.150	0.400	0.725	0.100	0.300	0.900	0.300	0.775	1.450	0.100	0.300	0.600
C.4	8000	16000	52000	2000	3000	9000	150	250	550	0.025	0.100	0.375	0.400	1.100	2.200	0.050	0.200	0.750	0.300	0.600	1.200
C.5	14000	24000	56000	2000	4000	9000	150	300	650	0.025	0.075	0.225	0.400	0.900	1.800	0.050	0.150	0.450	0.300	0.500	0.900
C.6	10000	20000	62000	2000	4000	9000	150	300	600	0.025	0.075	0.250	0.400	1.000	1.900	0.050	0.150	0.525	0.300	0.600	1.000
C.7	10000	18000	36000	2000	3000	9000	150	250	600	0.025	0.100	0.300	0.400	1.000	2.000	0.075	0.200	0.575	0.300	0.600	1.100
C.8	10000	18000	34000	3000	11000	38000	250	600	1500	0.125	0.325	0.700	0.100	0.300	1.000	0.225	0.675	1.375	0.100	0.200	0.600
	Process error assumptions																				
D.1	10000	18000	54000	2000	4000	8000	150	300	500	0.025	0.100	0.250	0.500	1.100	1.800	0.050	0.175	0.500	0.400	0.600	1.000
D.2	12000	24000	60000	2000	4000	10000	150	300	750	0.025	0.075	0.250	0.400	0.900	1.800	0.050	0.150	0.475	0.200	0.500	1.000
D.3	10000	16000	52000	2000	4000	7000	150	300	450	0.025	0.100	0.250	0.600	1.000	1.700	0.075	0.200	0.475	0.400	0.600	0.900
	B_{init}/K																				
E.1	12000	22000	60000	2000	3000	9000	150	300	600	0.025	0.075	0.250	0.400	1.000	2.000	0.050	0.150	0.500	0.300	0.600	1.000
E.2	10000	20000	52000	2000	3000	9000	150	300	600	0.025	0.075	0.275	0.400	1.000	1.900	0.050	0.175	0.525	0.300	0.600	1.000
	Survey *q* priors																				
F.1	10000	18000	48000	1000	3000	7000	100	250	500	0.025	0.075	0.225	0.500	1.200	2.400	0.050	0.125	0.475	0.300	0.700	1.200
F.2	10000	20000	52000	1000	3000	5000	100	200	400	0.025	0.075	0.175	0.700	1.300	2.300	0.050	0.125	0.350	0.400	0.700	1.200
F.3	10000	20000	52000	2000	3000	8000	150	300	600	0.025	0.075	0.250	0.500	1.000	1.900	0.050	0.175	0.500	0.300	0.600	1.000
F.4	10000	20000	56000	3000	5000	9000	200	350	650	0.050	0.125	0.300	0.400	0.800	1.400	0.075	0.225	0.600	0.300	0.500	0.800
	Effect of data																				
G.1	10000	20000	52000	1000	3000	7000	100	250	500	0.025	0.075	0.225	0.500	1.300	2.800	0.050	0.125	0.425	0.300	0.700	1.400
G.2	10000	18000	44000	2000	5000	15000	150	350	800	0.050	0.150	0.450	0.200	0.700	1.600	0.075	0.275	0.925	0.200	0.400	0.900
G.3	10000	22000	58000	1000	3000	7000	150	250	500	0.025	0.050	0.200	0.500	1.200	2.300	0.050	0.125	0.425	0.300	0.600	1.200
G.4	10000	20000	50000	2000	3000	6000	150	250	500	0.025	0.075	0.200	0.600	1.100	2.100	0.050	0.150	0.400	0.400	0.600	1.100
G.5	10000	20000	50000	2000	3000	6000	150	250	500	0.025	0.075	0.200	0.600	1.100	2.100	0.050	0.150	0.425	0.400	0.600	1.100
G.6	10000	18000	48000	2000	3000	6000	150	250	500	0.025	0.075	0.225	0.500	1.100	2.000	0.050	0.150	0.425	0.300	0.600	1.100
G.7	10000	18000	48000	2000	4000	9000	150	300	600	0.025	0.100	0.275	0.400	0.900	1.700	0.075	0.225	0.575	0.300	0.500	0.900
G.8	10000	18000	50000	2000	4000	10000	150	300	650	0.025	0.100	0.300	0.400	0.900	1.900	0.050	0.200	0.625	0.300	0.500	1.000
	Autocorrelation assumptions																				
H.1	10000	20000	54000	2000	4000	9000	150	300	600	0.025	0.100	0.275	0.400	1.000	1.900	0.050	0.175	0.550	0.300	0.600	1.000
H.2	10000	20000	54000	2000	4000	9000	150	300	600	0.025	0.075	0.275	0.400	1.000	1.900	0.050	0.175	0.550	0.300	0.600	1.000

Note that the medians obtained for Table 12 were obtained from the grids used to produce histograms due to the numerous runs involved, whereas the medians for the reference case in Table 10 were obtained based on a more accurate interpolation method. Thus the medians for the reference case values differ slightly in these two tables. Many of the alternative runs had relatively little impact on the results (Table 12). However, the high and low prior means for *r* gave more contrasting results on stock status. Leaving out the salmon troll and halibut catches entirely (C.3) or fixing them at their posterior modal estimates (C.8) had similarly large impact on the assessment results. These two runs gave far less depletion and much higher uncertainty in the posterior outputs and current stock status. In the reference case, higher initial stock sizes lead to comparatively higher catch and higher depletion. This is because annual catch under the reference case was made to be a function of the historic effort and the stock biomass and higher biomass would lead to higher predicted catch and stronger depletion than instances without catch or with low fixed catch. Without the scaling of catch with stock size in runs C.3 and C.8, larger stock sizes were associated with much lower exploitation rates and the stock could be much less depleted than in the reference case, resulting in much higher uncertainty in the current status of the stock.

During final report preparation it was noted that the catches used during all model runs should have been 13 t less for 2006 and 2007. We conducted one additional run to test the impact of this error and found the impact on the assessment and decision tables to be negligible (see Appendix G for details of the additional run and see DFO 2009 for updated results).

Projections and Decision Tables

Based on the analyses presented above, we have provided three forecasting scenarios over 5, 20 (1 generation) and 40 year (2 generations) time horizons (Table 13-Table 15). The forecasts are summarized in the form of decision tables relative to the limit reference point (LRP) and upper target reference point (URP) of $0.4*B_{MSY}$ and $0.8*B_{MSY}$ respectively (DFO 2006, 2008), as well as additional relative metrics of stock status.

The three scenarios represent different assumptions of productivity (*r*). While uncertainty in *r* is already taken into account by applying an informative prior density function for *r* that incorporates key life history information and productivity results from analyses of other rockfish populations, we examined additional uncertainty in productivity by applying alternative priors for *r* which had lower and higher prior mean values (cases B.1 and B.2). These choices bracket the range of plausible productivity for this stock and represent the greatest contrast among the sensitivity runs in response to the constant harvest strategy. All other sensitivities used the same *r* prior as in the reference case and thus behaved similarly, barring differences in the expected value of B_{2008}/K at the start of the projection period. Projections based on other sensitivity runs are presented in Appendix G.

Constant quota policies ranging from 0 to 300 t/y were considered in the decision tables. This should not be construed as an endorsement of a constant harvest policy; rather they are presented to show the predictions of the expected trends of the population size under these catches, given the model assumptions. The probability of *r* across the three hypotheses was also computed, starting with equal prior probabilities for each alternative scenario for *r*. However, as there is relatively little information in the catch and stock trend data about *r*, the posteriors for the three alternative runs were very similar to the priors, with the run with the smallest prior mean for *r* having slightly more weight than the other runs (Table 16).

The decision tables provided for the reference case, bracketed by two runs with higher and lower productivity, are presented to help initiate and focus discussion of short-term harvest strategies for B.C. bocaccio.

Table 13. Stock status indicators bocaccio after 5, 20 and 40 years. Policies are constant TAC policies in t. Biomass values are in thousands of t (kt). **Reference case (**see DFO 2009 for the results of the updated analyses).

Horizon	**Policy**	**$E(B_{fin}/B_{msy})$**	**$P(B_{fin}>0.4\ B_{msy})$**	**$P(B_{fin}>0.8\ B_{msy})$**	**$P(B_{fin}>B_{cur})$**	**$P(F_{fin}<F_{cur})$**
5 -year	0	0.33	0.26	0.08	0.73	1.00
	50	0.33	0.26	0.08	0.71	1.00
	100	0.31	0.24	0.08	0.63	0.91
	150	0.30	0.23	0.07	0.57	0.62
	200	0.28	0.22	0.07	0.51	0.36
	250	0.27	0.21	0.07	0.45	0.19
	300	0.26	0.20	0.06	0.40	0.09
20 -year	0	0.83	0.65	0.39	0.92	1.00
	50	0.76	0.6	0.36	0.86	0.98
	100	0.68	0.52	0.32	0.76	0.84
	150	0.59	0.45	0.27	0.65	0.67
	200	0.51	0.4	0.24	0.55	0.50
	250	0.44	0.34	0.20	0.46	0.38
	300	0.38	0.29	0.18	0.38	0.26
40 -year	0	1.38	0.87	0.69	0.97	1.00
	50	1.25	0.80	0.63	0.92	0.97
	100	1.09	0.71	0.56	0.80	0.84
	150	0.92	0.61	0.46	0.68	0.69
	200	0.75	0.50	0.39	0.55	0.53
	250	0.62	0.42	0.32	0.46	0.41
	300	0.50	0.33	0.25	0.36	0.30

Table 14. Stock status indicators for bocaccio after 5, 20 and 40 years. Policies are constant TAC policies in tons. Biomass values are in thousands of tons (kt). **Case B.1 low prior *r* mean (**see DFO 2009 for the results the updated analyses).

Horizon	Policy	$E(B_{fin}/B_{msy})$	$P(B_{fin}>0.4\ B_{msy})$	$P(B_{fin}>0.8\ B_{msy})$	$P(B_{fin}>B_{cur})$	$P(F_{fin}<F_{cur})$
5 -year	0	0.27	0.20	0.05	0.68	1.00
	50	0.26	0.20	0.05	0.64	1.00
	100	0.25	0.19	0.05	0.58	0.88
	150	0.24	0.18	0.05	0.51	0.57
	200	0.23	0.17	0.05	0.45	0.31
	250	0.22	0.16	0.04	0.40	0.15
	300	0.21	0.15	0.04	0.36	0.08
20 -year	0	0.66	0.51	0.29	0.88	1.00
	50	0.60	0.46	0.26	0.81	0.96
	100	0.53	0.41	0.23	0.68	0.79
	150	0.46	0.36	0.20	0.56	0.58
	200	0.40	0.31	0.17	0.47	0.42
	250	0.34	0.27	0.15	0.39	0.32
	300	0.30	0.24	0.13	0.32	0.23
40 -year	0	1.20	0.79	0.59	0.95	1.00
	50	1.06	0.71	0.51	0.87	0.94
	100	0.88	0.59	0.43	0.73	0.78
	150	0.73	0.48	0.35	0.59	0.60
	200	0.60	0.40	0.29	0.48	0.45
	250	0.49	0.33	0.24	0.38	0.34
	300	0.40	0.27	0.19	0.31	0.26

While the posterior probabilities give slightly higher weight to the run with the lowest prior mean for *r*, the posterior probabilities from these three alternative runs are not very different from the priors and can be explained entirely by chance variation in the data rather than a genuinely better fit of the low prior mean *r* model to the data. The two alternative runs shown in the decision tables, based on higher and lower prior means for *r*, can be viewed as plausible bounds for the potential consequences of alternative assumptions on stock productivity. We continue to assume, however, that the prior used for *r* in the reference run is the most plausible of the three. However, readers are cautioned that the projections are based on strong assumptions, including stationarity in model parameters and that total stock biomass and not age nor size structure determines annual surplus production. Therefore, as with most assessments, these long-term projections are provided as guidelines to distinguish between model hypotheses, rather than as actual predictions of stock size.

Table 15. Stock status indicators for bocaccio after 5, 20 and 40 years. Policies are constant TAC policies in tons. Biomass values are in thousands of tons (kt). **Case B.2, high prior *r* mean (**see DFO 2009 for the results of the updated analyses).

Horizon	Policy	$E(B_{fin}/B_{msy})$	$P(B_{fin}>0.4\ B_{msy})$	$P(B_{fin}>0.8\ B_{msy})$	$P(B_{fin}>B_{cur})$	$P(F_{fin}<F_{cur})$
5 -year	0	0.43	0.37	0.15	0.81	1.00
	50	0.43	0.37	0.15	0.78	1.00
	100	0.41	0.35	0.15	0.73	0.93
	150	0.39	0.31	0.14	0.65	0.70
	200	0.37	0.30	0.13	0.58	0.41
	250	0.35	0.29	0.13	0.50	0.21
	300	0.34	0.27	0.12	0.45	0.12
20 -year	0	1.10	0.81	0.58	0.96	1.00
	50	1.02	0.76	0.54	0.93	0.99
	100	0.92	0.68	0.48	0.86	0.91
	150	0.81	0.61	0.42	0.76	0.77
	200	0.71	0.55	0.37	0.64	0.61
	250	0.62	0.47	0.31	0.55	0.45
	300	0.54	0.40	0.28	0.46	0.35
40 -year	0	1.69	0.96	0.86	0.98	1.00
	50	1.58	0.93	0.82	0.96	0.99
	100	1.43	0.86	0.73	0.90	0.92
	150	1.24	0.76	0.64	0.78	0.78
	200	1.05	0.64	0.55	0.66	0.64
	250	0.89	0.55	0.46	0.56	0.51
	300	0.73	0.46	0.38	0.45	0.38

Under the reference case, a constant total[10] catch of 200 t appears is predicted to result in a 50% probability that the abundance of bocaccio will reach the LRF (0.4*B_{msy}) within 40 years (2 generations) (Table 13). Catches less than 200 t can be expected to either increase the likelihood or reduce the time required to reach the 50% threshold. For example, a 100 t constant catch could be expected to reach the LRF with a 50% likelihood within 20 years or one generation. Under an assumption of lower productivity (lower *r*), a constant total catch of less than 150 t/y is required to provide a 50% chance of reaching the LRF in 40 years (Table 14). Under higher productivity, (higher *r*), the same target, timing and probability could be achieved with total catches of between 250 and 300 t/y (Table 15).

[10] Note that total catch refers to all mortalities by all fisheries used in this catch reconstruction.

Table 16. Summary decision table for the probability that stock biomass exceeds 40% of B_{MSY} within 40 years under each alternative constant TAC policy (in tons) and under each alternative hypothesized prior mean value for the parameter for the maximum intrinsic rate of increase, *r*.

	Hypothesized prior mean *r*		
	Low *r*	**Reference *r***	**High *r***
	0.0836	0.117	0.152
Probability	0.55	0.30	0.15
TAC			
0	0.79	0.87	0.96
50	0.71	0.8	0.93
100	0.59	0.71	0.86
150	0.48	0.61	0.76
200	0.40	0.50	0.64
250	0.33	0.42	0.55
300	0.27	0.33	0.46

Several different sources of information and data have been compiled and analysed to support these projections and the results show great uncertainty in the form of wide posterior distributions for model outputs. The large depletion for bocaccio suggested by this assessment, with stock size estimated in the reference case at 12% of the unfished level, is conditioned largely on the imputation of large unrecorded and unobserved historic catches of bocaccio in the salmon troll and halibut longline fisheries. This imputation presumes that the catchability of bocaccio in the B.C. halibut and salmon troll fisheries has been stationary since the 1930s and that the annual bocaccio mortality rates for these fisheries have been directly proportional to the annual fishing effort in these early decades. However, if changes in fishing practices and gear have altered the catchability of bocaccio over the seven to eight decades covered by this assessment, then the assumption of stationarity in this coefficient is not correct. The effect of this misspecification will depend on the magnitude and direction of the change in catchability. We note that there are no available observations of bocaccio catch in the halibut and troll fisheries in these earlier decades, and therefore we have no other information with which to improve or refine our imputation of historic catches in these fisheries. However, we have shown that catches in these fisheries are likely to have been an important factor in determining the current stock status of this species, particularly if the historical catchability was near the currently observed levels.

Additional Comments for Preparation of a Recovery Potential Assessment

As noted in the introduction, should bocaccio be identified as threatened or endangered by the Minister of the Environment, then DFO-Science is required to prepare a Recovery Potential Assessment (RPA) following the template provided in DFO (2007). The template requires that the RPA address 17 tasks. One of the intentions of this document is to address each of these tasks so that, if required, the entire RPA can be developed from this source document. The stock assessment and decision tables provided above and in the appendix cover most of the core material identified in the RPA template. To further aid development of the RPA, we have provided below some additional clarification on a selected group of the tasks. We have used the numbering provided in DFO (2007) to aid in cross-referencing. Readers should refer to DFO 2009 for an updated discussion of the issue below.

(7) Evaluate residence requirement

Love *et al.* (2002) suggest that the largest bocaccio are deep-bodied, sedentary, and live in caves and crevices. The significant harvests of mature and relatively old individuals by trawl and troll harvesters indicates they are not exclusively cave or crevice-dwelling. Furthermore, there is clearly no shortage of high rugosity bottom habitat on the outer and inner coasts of B.C.

(9) Magnitude of each major source of mortality

As noted above, the only known major source of mortality caused by human activities is fishing. With the reduction in troll effort, most of the catch currently comes from the commercial groundfish trawl and HL fisheries[11]. Total catch in the 2007/2008 fishing year was 135 t in trawl and 17 t in HL[12]. These catches are incidental while targeting on other fisheries. We have noted above that additional small amounts (<2t) are likely caught in First Nations' fisheries, recreational, shellfish and non-troll salmon fisheries. While we have suggested the amounts are negligible with respect to the above analysis of stock status, these catches should not be ignored in development of a Recovery Strategy, especially if total catches of less than 100 t need to be considered. Recreational catches may grow rapidly as targeting shifts from salmon to groundfish. It is important to note that verifiable catch estimates of bocaccio are not currently available from this fishery.

(10) Likelihood that the current quantity and quality of habitat is sufficient

Given that bocaccio appear to be a semi-pelagic and aggregating species, comments by Love *et al*. 2002 notwithstanding, we know of no basis for assuming that the availability of specific residences serves to limit bocaccio abundance. Given their presumed mobility, their widespread distribution, and the extent of rocky habitat in the preferred depths, we can find no reason for assuming that habitat quality or quantity is currently limiting abundance.

While all life stages are presumed to exhibit habitat preference with respect to bottom depth, depth in the water column, and bottom relief or rugosity, we have not identified any specific sites that could be considered critical to the sustainability of the population in B.C. We do not know of any human activities which have been shown to threaten bocaccio habitat, however, the biology of bocaccio, particularly, for the early life history

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[11] Note that the distinction between the Rockfish ZN and halibut fisheries has virtually disappeared with the introduction of the Groundfish Integration Pilot Project in 2005.
[12] Total catches include 88 t retained and 48 t discarded in the trawl fleet and 4,100 pieces (@4.3 kg) in the HL fleets.

stages is not well enough understood to categorically declare that no current human activities are having adverse effects on bocaccio habitat.

Fishing gear (trawl and setline) may have, or have had, an impact on bocaccio habitat but no work has been directed specifically at this issue.

(12) Develop an inventory of all feasible measures to minimize or mitigate the impacts of activities that are threats to the species and its habitat

We suggest that a discussion on mitigation measures can focus on harvest controls in the various fisheries. These discussions could be informed, through analyses and graphical rendering of time/space windows of high bocaccio catches. However, these catches are widespread in time and space, as well as being somewhat unpredictable, thus the authors of this document know of no obvious and practical spatial or temporal restrictions/regulations that might enhance implementation of catch controls. Nor is it obvious how gear modification might support mitigation. These issues, however, are best addressed with experts from the harvesting sectors.

Possibly, the best measure for avoiding a mobile and aggregating species is ensuring that harvesters continue to communicate with each other as bocaccio shows up in the catches.

(13) Develop an inventory of all reasonable alternatives to the activities that are threats to the species and its habitat

Apart from more restrictive harvest controls on existing fisheries, there do not appear to be any reasonable alternative to current activities that would reduce threats to bocaccio abundance or bocaccio habitat.

While Marine Protected Areas (MPAs) are an integral part of managing populations of nearshore rockfish species in B.C., this management tool would seem to have limited benefit for bocaccio. Unlike nearshore species such as yelloweye, tiger, quillback and copper rockfish which tend to stay closer to bottom and we think exhibit more restricted movement as adults, bocaccio are a semi-pelagic aggregating species that are presumed to exhibit much greater mobility. Therefore, even if the existing set of relatively small MPAs were expanded, all bocaccio could be assumed to spend significant parts of their lives occupying exploitable fishery grounds.

(14). Develop an inventory of all reasonable and feasible activities that could increase the productivity or survivorship parameters

Altering harvest patterns to reduce to the harvest of mature females might augment the benefits of harvest controls; however, analyses of the limited sample data did not indicate particular time/space windows in which fishing mortality was disproportionately directed at mature females or juveniles.

(15) Estimate, to the extent possible, the reduction in mortality rate expected by each of the mitigation measures and the increase in productivity or survivorship associated with each measure above.

As stated above, we view controlling total catch in the commercial groundfish fisheries as the best means to control abundance. The predicted impacts of varying catch are shown in Table 13 to Table 15.

Status of Bocaccio in U.S. Waters

Only the California portion of the U.S. population has been assessed in recent years (MacCall 2003, 2005, 2007) (Figure 11). Depending on the model run, current relative depletion is estimated at 10.9-16.3% for the spawning population (MacCall 2007). The 1+ biomass in 2006 was estimated to be 9,582-14,559 t. The assessment indicates some rebuilding since the late 1990s concurrent with a major reduction in catch. The senior assessment author noted that the 2007 assessment "confirmed" a "strong" 2003 year class (A. MacCall, pers. comm.). The model uses catches from five different fishery sectors and six relative indices of abundance (trawl logbook CPUE, three recreational CPUEs, US triennial survey, CALCOFI[13] larval index). There have been no assessments of bocaccio stock status for Alaskan waters.

Summary

This document provides a stock assessment for bocaccio in B.C. waters. Results of the work are intended to serve as advice over the short term to managers and stakeholders on stock status, and likely impacts of different fixed harvest options. As such, it also provides the scientific advice and related information needed to produce a Recovery Potential Assessment (RPA) following the template provided in DFO 2007. The RPA, in turn, can be used as the scientific input for developing a Recovery Strategy, should this be deemed necessary.

The reference run estimates of current stock size are in the order of 3000-5000 tons, with the stock estimated to lie between 10-15% of unfished stock size[14]. The impacts on current stock status of alternative model assumptions to those made in the reference case were explored over an additional 31 runs. Long term biomass projections were made for the reference case and a selection of the sensitivity runs over 5, 20, and 40 year scenarios under varying fixed harvest assumptions to predict stock abundance relative to the DFO draft policy target references points of $0.4*B_{MSY}$ and $0.8*B_{MSY}$. These projections are shown as harvest tables for the reference set of assumptions as well as two additional scenarios which assume either a lower or higher estimate of productivity (r). While the Bayesian approach used in this assessment provides a formal mechanism to include

[13] California Cooperative Oceanic Fishery Investigations
[14] Readers are referred to DFO 2009 an updated version of the stock status and forecasts.

uncertainty in model output (including predictions), managers and stakeholders are advised that not all sources of uncertainty have been addressed and that it is likely that the true uncertainty is even greater than that presented here.

Recommendations for Future Work

Subject to the availability of research resources and the many other competing priorities related to the more than 100 other exploited populations of groundfish on the Pacific coast of Canada, we suggest that consideration be given to the following research directions:

1. Continue work on improving estimates of historical catch, however, this process would be more efficient and more consistent if done for many or all of the key species at the same time.
2. Consider using the number of troll licenses as a surrogate for relative troll effort in the reconstruction of bycatch in the early salmon troll fishery.
3. Explore the potential to work with U.S. biologists for a coastwide assessment of bocaccio, especially as the time series of abundance indices and ageing data expands.
4. Develop software and an empirical basis to carry out management strategy evaluation (MSE) of alternative feedback control fisheries management regimes for bocaccio alone or combinations of rockfish species.
5. Examine the feasibility of a trolling or gillnet experiment to estimate the ratio of the densities of bocaccio or other species in trawlable and untrawlable areas.
6. Update the model to address the reviewer's suggestion that the model account for the fact that a significant portion of the area **within** each trawlable block may, in fact, be untrawlable. Conversely, a significant portion of the area **within** each untrawlable block may, in fact, be trawlable.
7. Evaluate the possibility of obtaining additional prior information of the survey net catchability coefficient by studying the relationship between stock size estimates and groundfish survey area swept estimates in the U.S. bocaccio assessments.
8. Evaluate the feasibility of a stock structure study of bocaccio in B.C. and U.S. waters using samples of chemical microconstituents in bocaccio body parts. The presence of much older fish in recent samples from B.C. and Washington State in comparison with California samples, in spite of significant fishing morality for many decades implies the possibility of gradual migration to B.C. waters as US fish become older. Microconstituent analysis might reveal the source of larvae and juveniles that recruit to B.C. fisheries.
9. Evaluate the feasibility of acoustic studies of bocaccio or other rockfish behaviour in response to trawl gear.

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Literature Cited

Akaike, A. 1974. A new look at the statistical model identification. IEEE Transactions on Automatic Control AC-19: 716-723.

Davenport, D. 1985. Biological observations of the foreign hake fishery for 1983. Can. Man. Rep. Fish. Aquat. Sci. 1811.

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

DFO, 2007. Revised Protocol for Conducting Recovery Potential Assessments. DFO Can. Sci. Advis. Sec. Advis. Rep. 2007/039.

DFO, 2008. Draft. Fisheries Stewardship and Sustainability Checklist.

DFO. 2009. Recovery potential assessment of bocaccio in British Columbia waters. DFO Can. Sci. Adv. Sec. Sc. Advis. Rep. 2009/040.

Dorn, M.W. 2002. Advice on west coast rockfish harvest rates from Bayesian meta-analysis of stock recruitment relationships. N. Am. J. Fish. Manage. 22(1): 280-300.

Efron, B. 1982. The jackknife, the bootstrap and other resampling plans. Society for Industrial and Applied Mathematics, Philadelphia.

Eschemeyer, W.N., E.S. Herald, and H. Hammann. 1983. A Field Guide to Pacific Coast Fishes of North America. Houghton Mifflin, Boston.

Forester, J.E. and A.D. Forester. 1975. Fishing: British Columbia's commercial fishing history. Hancock House, Saanichton, B.C.

Forrest, R.E., M.K. McAllister, M.W. Dorn, S.J.D. Martell and R.D. Stanley. (in prep). Hierarchical Bayesian estimation of recruitment parameters and reference points for Pacific rockfishes (*Sebastes* spp.) under alternative assumptions about the stock-recruit function (submitted to Can. J. Fish. Aquat. Sci.).

Fraidenburg, M., J.E. Smith, W.H. Barss, and T. Jow. 1977. Minimum estimates of all nation removals, North American trawl species composition and CPUE for "other rockfish" in the Northeastern Pacific Ocean. Wash. Dept. Fish. Tech. Rep. 34.

Francis, R.I.C.C. 1999. The impact of correlations on standardised CPUE indices. New Zealand Fishery Assessment Research Document 1999/42. 30 p. (Unpublished report held in NIWA library, Wellington, New Zealand).

Francis, R.I.C.C. 2001. Orange roughy CPUE on the South and East Chatham Rise. New Zealand Fishery Assessment Report 2001/26.

Gelman, A. and D.R. Rubin. 1992. A single series from the Gibbs sampler provides a false sense of security. pp. 625-631. *In* Bayesian Statistics 4 (eds. J. M. Bernardo *et al*.), Oxford University Press, Oxford.

Gillespie, G.E., R.D. Stanley, and B.M. Leaman. 1993. Cruise details and biological information form the juvenile rockfish surveys aboard the R/V *W.E. Ricker*, May 13-25, 1991, and the F/V *Island Sun*, June 3-11, 1991. Can. Data Rep. Fish. Aquat. Sci. 920.

Hilborn, R. and C.J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics. Routledge, Chapman and Hall. New York.

Hoenig, J. 1983. Empirical use of longevity data to estimate morality rates. Fish. Bull. 82: 898-903.

Kass, R.E. and A. E. Raftery. 1995. Bayes factors. J. Am. Stat. Assoc. 90: 773–795.

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. Fish. Mar. Serv. Data Record 6.

Ketchen, K.S. 1980a. Reconstruction of Pacific ocean perch (*Sebastes alutus*) stock history in Queen Charlotte Sound Part I. Estimation of foreign catches 1965-1976. Can. Man. Rep. Fish. Aquat. Sci. No. 1570.

Ketchen, K.S. 1980b. Assessment of groundfish stocks off the West Coast of Canada (1979). Can. Data Rep. Fish. Aquat. Sci. No. 185.

Ketchen, K.S., B.M. Leaman, S.J. Westrheim, and C.C. Wood. 1978. Total allowable catches for 1978 from stocks of rockfish, blackcod, and dogfish in waters off the west coast of Canada. Sci. Adv. Comm. Rep., Dept. Fish. Environ.

Kirkwood, G.P. 1997. The revised management procedure of the International Whaling Commission. pp. 91-99. *In* Global trends: fishery management. (eds. E.K. Pikitch, D.D. Huppert, and M.P. Sissenwine). Amer. Fish. Soc. Symp. 20, Bethesda, Maryland.

Korotkov, V.K. 1984. Fish behaviour in a catching zone and influence of bottom trawl rig elements on selectivity. Int. Council Explor. Sea, Council Meeting 1984. B: 15.

Krieger, K.J., and M.F. Sigler. Catchability coefficient for rockfish estimated from trawl and submersible surveys. Fish. Bull. 9: 282-288.

Lotka, A.J. 1907. Studies on the model of growth of material aggregates. Am. J. Sci. 24: 199-216.

Love, M.S., M. Yoklavich, and L. Thorsteinsson. 2002. University of California Press. London.

Ludwig, D., and C.J. Walters. 1985. Are age structured models appropriate for catch-effort data? Can. J. Fish. Aquat. Sci 42: 1066-1072.

MacCall, A.D. 2003. Status of bocaccio off California in 2003. http://www.pcouncil.org/groundfish/gfsafe0803/bocaccio.pdf

MacCall, A.D. 2005. Status of bocaccio off California in 2005. http://www.pcouncil.org/groundfish/gfsafe0406/bocaccio2005final.pdf

MacCall, A.D. 2007. Bocaccio rebuilding analysis for 2007. http://www.pcouncil.org/groundfish/gfsafe1008/bocaccio2007final.pdf

Matala, A.P., A.K. Gray, and A.J. Gharrett. 2004. Microsatellite variation indicates population structure of bocaccio. N. Amer. Jour. Fish. Manage. 24: 1189-1202.

Matthews, K.R., J.R. Candy, L.J. Richards, and C.M. Hand. Experimental gillnet fishing on trawlable and untrawlable areas off Northwestern Vancouver island, from the MV Caledonian August 15-28, 1989. Can. Man. Rep. Fish. Aquat. Sci. No. 2046.

Martin, T.G., P.M. Kuhnert, K. Mengersen, and H.P. Possingham. 2005. The power of expert opinion in ecological models using Bayesian methods: impact of grazing on birds. Ecol. Appl. 15: 266-80.

McAllister, M. K., E.K. Pikitch, A.E. Punt, and R. Hilborn, R. 1994. A Bayesian approach to stock assessment and harvest decisions using the sampling/importance resampling algorithm. Can. J. Fish. Aquat. Sci. 51: 2673–2687.

McAllister, M.K. and J.N. Ianelli. 1997. Bayesian stock assessment using catch-age data and the Sampling/Importance Resampling Algorithm. Can. J. Fish. Aquat. Sci. 54: 284–300.

McAllister, M.K. and G.P. Kirkwood. 1998. Using Bayesian decision analysis to help achieve a precautionary approach to managing newly developing fisheries. Can. J. Fish. Aquat. Sci. 55: 2642-2661.

McAllister, M.K., E.A. Babcock, E.K. Pikitch, and M.H. Prager. 1999. Application of a non-equilibrium generalized production model to South and North Atlantic Swordfish: combining Bayesian and demographic methods for parameter estimation. ICCAT Col. Vol. Sci. Papers. SCRS/99/85.

McAllister, M.K., E.A. Babcock, and E.K. Pikitch. 2001a. Using Bayesian methods to provide an empirical basis to weight conflicting stock assessment results on stock rebuilding when there is uncertainty over processes affecting future recruitment. ICCAT Col. Vol. Sci. Papers. SCRS/00/103.

McAllister, M.K., E.A. Babcock, and E.K. Pikitch. 2001b. Evaluating the relative merits of alternative methods to weight different time series of abundance indices in stock assessment. ICCAT Col. Vol. Sci. Papers. SCRS/00/104.

McAllister, M.K., E.K. Pikitch, and E.A. Babcock. 2001c. Using demographic methods to construct Bayesian priors for the intrinsic rate of increase in the Schaefer model and implications for stock rebuilding. Can. J. Fish. Aquat. Sci. 58(9): 1871-1890.

McAllister, M.K., and E.A. Babcock. 2002. Bayesian surplus production model with the Sampling Importance Resampling algorithm (BSP): a user's guide. National Marine Fisheries Service 2002 Shark Evaluation Workshop, Panama City, Florida. SB-02-26. Also see: BSP at http://www.iccat.int/downloads.htm

McAllister, M.K. and C.H. Kirchner. 2002. Accounting for structural uncertainty to facilitate precautionary fishery management: illustration with Namibian orange roughy. Bull. of Mar. Sci. 70(2): 499-540.

Meyer, R. and R.B. Millar. 1999. BUGS in Bayesian stock assessments. Can. J. Fish. Aquat. Sci. 56: 1078-1086.

Millar, R.B. and R.D. Methot. 2002. Age-structured meta-analysis of U.S. West Coast rockfish (Scorpaenidae) populations and hierarchical modelling of trawl survey catchabilities. Can. J. Fish. Aquat. Sci. 59: 383-392.

Milne, D.J. and H. Godfrey. 1964. The Chinook and Coho salmon fisheries of British Columbia. Fish. Res. Board Can. Bull. 142. Tables III and XI.

Myhre, R.J., G.J.Peltonen, G. St.-Pierre, B.E. Skud, and R.E.Walden. 1977. The Pacific halibut fishery: catch, effort and CPUE, 1929-1975. Tech. Rep. No. 14.

Olsen, N., G.D. Workman, and R.D. Stanley. 2007. Queen Charlotte Sound bottom trawl survey, July 5th to August 9th, 2005. Can. Man. Rep. Fish. Aquat. Sci. 2784.

Prager, M.H. 1994. A suite of extensions to a nonequilibrium surplus production model. Fish. Bull. 92: 374-389.

Punt, A.E. 1993. The comparative performance of production-model and ad hoc tuned VPA based feedback-control management procedures for the stock of Cape hake off the west coast of South Africa. pp. 283-299. *In*: Risk Evaluation and Biological Reference Points for Fisheries Management (eds. S.J. Smith, J.J. Hunt, and D. Rivard). Can. Spec. Publ. Fish. Aquat. Sci. 120.

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

Rubin, D.B. 1987. Comment on "The calculation of posterior distributions by data augmentation". J. Am. Stat. Assoc. 82: 543–546.

Rutherford, K.L. 1999. A brief history of GFCATCH (1954-1995), the groundfish catch and effort database at the Pacific Biological Station. Can. Tech. Rep. Fish. Aquat. Sci. 2299.

Schnute, J.T. and R. Haigh. 2007. Compositional analysis of catch curve data with an application to *Sebastes maliger*. ICES J. Mar. Sci. 64: 218-233.

Somerton, D.A., P.T. Munro, and K.L. Weinberg. 2007. Whole-gear efficiency of a benthic survey trawl for flatfish. Fish. Bull. 105: 278-291.

Spiegelhalter, D., A. Thomas, N. Best, and D. Lunn. 2003. WinBUGS user Manual. Version 1.4, January 2003.

Stanley, R.D., N. Olsen, G.D. Workman, J. Cleary, and W. de la Mare. 2007. A review of the Queen Charlotte bottom trawl survey. Can. Tech. Rep. Fish. Aquat. Sci. 2709.

Stanley, R.D., K.L. Rutherford, and N. Olsen. 2001. Preliminary status report on bocaccio (*Sebastes paucispinis*). DFO. Can. Sci. Advis. Sec. Res. Doc. 2001/148.

Stanley, R.D. and P. Starr. 2004. Scientific advice for input to the allowable harm assessment for bocaccio. DFO. Can. Sci. Advis. Sec. Res. Doc. 2004/098.

Stanley, R.D., P. Starr, and N. Olsen. 2004. Bocaccio update. DFO. Can. Sci. Advis. Sec. Res. Doc. 2004/027.

Starr, P.J., A.S. Sinclair, J. Boutillier. 2002. West Coast Vancouver Island Pacific cod assessment. DFO. Can. Sci. Advis. Sec. Res. Doc. 2002/113.

Stewart, I. 2007. Status of the canary rockfish resource in 2007. Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/gfsafe1008/2007_canary_SAFE.pdf

Sullivan, P.J., A.M. Parma, and W.G. Clark. 1999. The Pacific halibut stock assessment of 1997. Int. Pac. Hal. Comm. Sci. Rep. 79.

Tagart, J.V. and D. Kimura. 1982. Review of Washington's coastal trawl fishery/. Wash. Dep. Fish. Tech. Rep. No. 68.

Uusitalo, L., S. Kuikka, and A. Romakkaniemi. 2005. Estimation of Atlantic salmon smolt carrying capacity of rivers using expert knowledge. ICES Jour. Mar. Sci. 62: 708-722.

Walters, C.J. and D. Ludwig. 1994. Calculation of Bayes posterior distributions for key population parameters. Can. J. Fish. Aquat. Sci. 51(3): 713-722.

Weinberg, K.L., M.E. Wilkins, F.R. Shaw, and M. Zimmerman, M. 2002. The 2001 Pacific west coast bottom trawl survey of groundfish resources: estimates of distribution, abundance and length and age composition. NOAA Tech. Mem. NMFS-AFSC-128.

Workman, G.D., N. Olsen, J.J. Fargo, and R.D. Stanley. 2008. West Coast Vancouver Island groundfish bottom trawl survey, R/V W.E.Ricker, May 25 to June 12, 2004. Can. Man. Rep. Fish. Aquat. Sci. 2826.

Workman, G.D., N. Olsen, and K.L. Rutherford. 2007. West Coast Charlotte Islands groundfish bottom trawl survey, August 28th to September 25th, 2006. Can. Man. Rep. Fish. Aquat. Sci. 2840.

Workman, G.D., K.L. Rutherford, and N. Olsen. 2008. Hecate Strait groundfish bottom trawl survey, May 25 to June 29, 2005. Can. Man. Rep. Fish. Aquat. Sci. 2805.

Wrohan, I.A., B.W. Beaith, and L. Hop Wo. 2002. Summary of observer bycatch data for non-salmonid fish, seabirds and marine mammals in the commercial salmon fishery 1997-2001. Fish. Oceans, Canada. Pac Region. Science Branch. Stock Assessment Division. Catch Monitoring Report No.1.

Vignaux, M. 1993. Catch per unit effort (CPUE) analysis of the hoki fishery, 1987–92. N.Z. Fisheries Assessment Research Document 93/14. 23 p. (Unpublished report held in NIWA library, Wellington, New Zealand).

Vignaux, M. 1994. Catch per unit effort (CPUE) analysis of west coast South Island and Cook Strait spawning hoki fisheries, 1987–93. N.Z. Fisheries Assessment Research Document 94/11. 29 p. (Unpublished report held in NIWA library, Wellington, New Zealand)

Yamanaka, K.L. and A.R. Kronlund. 1997. Inshore rockfish stock assessment for the west coast of Canada in 1997 and recommended yield options for 1998. DFO. Can. Stock. Assess. Sec. Res. Doc. 97/133.

Appendix A. Trawl Catch

Introduction

This appendix summarises the reconstruction of trawl catches by the "domestic" fleets of Canada (CDN) and the United States (U.S.) and the "foreign" catches by the Soviet Union, Japan, and Poland. The reconstructed time series is input as fixed catches in the surplus production model (Appendix G).

Domestic (U.S. and Canadian) Trawl Catch (1930-2007)

The reconstruction of Canadian (CDN) and U.S. trawl catches from B.C. waters were developed separately for three periods, 1930-1949 (U.S. only), 1950-1966 (U.S. and CDN), 1967-2007 (U.S. and CDN) (Table 17). We did not attempt to reconstruct CDN trawl catches for the earlier years of 1930-1949. We assume these to have been negligible with respect to this stock assessment.

Domestic Trawl Catch (U.S. 1930-1949)

U.S. catches for 1930-1949 were reconstructed in seven steps:

Step 1:
Catches from CDN waters by U.S. trawlers from 1930-1949 were estimated from the "Other" rockfish (ORF) category of landings to Washington State (Stewart, pers. comm.)[15], (Table 17: Col, 1 and 2). The ORF category was distinguished in the source documents from the "Pacific ocean perch" market category, which tended to include the deeper red rockfish species.

Step 2:
Since the ORF landings to Washington State could have originated anywhere in Oregon-B.C. waters, we reduced the total ORF landed by 29% to remove fish caught south of Area 3C (CDN and U.S.) (Figure 20, Table 17: Col. 3). This proportion was estimated by comparing total landings of ORF caught only in Areas 3C-5E in 1950-1953 from (Ketchen 1976: Tables 1-4) with all ORF landings to Washington in 1950-1953 from the Stewart working tables (Table 18: 12,301/17,209=71%).

Step 3:
Total 3C-5E ORF landings for 1930-1949 were then allocated into each PMFC area: Table 17: Col. 4-15: 1930-1949) by using the proportion by area of capture observed in 1950-1953 ORF landings to Washington State (Table 19 from Ketchen 1976: Tables 1-4). Thus, if 22% of the 3C-5E catches originated from 3C in the pooled landings from 1950-1953, then we assumed the same percent came from 3C in 1930-1949.

[15] The ORF landings were collated from Pacific Fisherman Yearbooks and Pacific States Fish Commission Annual Reports by Dr. Ian Stewart (U.S. National Marine Fisheries Service) in preparation for a U.S. canary rockfish assessment Stewart (2007). ORF landings were taken from working tables provided by Dr. Stewart to the senior author (1942:1949 Column R and 1930-1941: Column AE).

Step 4:
We then separated total 3C landings from 1930-1949 into catches originating from either the U.S. or CDN portions of 3C (Figure 20: Table 17: Col. 16 converted to Col. 17). We used the proportions observed in Washington trawl landings pooled over 1966-1970 (Tagart and Kimura 1982: Table 4) to estimate that 29% of the landings from 3C originated from the CDN portion of 3C (3C/CDN) (Table 20. Note that Table 17: Col. 17 of is the sum of 3C/CDN (i.e. 29% of all 3C) and 3D landings.

Step 5:
Total ORF landings by area of catch (Areas 3C/CDN to 5E) were then converted to bocaccio by using a proportion of 0.03 for Areas 3C/CDN and 3D and a proportion of 0.07 for Areas 5A-5E (Table 17: Col. 21 and 22). These proportions were observed in landings to Washington State from 1967-1970 (Fraidenburg *et al*. 1977: p.12 and 14) (Table 21)

Step 6:
Landings from the two regions were then added: Col. 23 and converted to t (Col. 24). As mentioned above, note that we assumed no trawl catches by CDN vessels prior to 1950. Inferring from Table 1, CDN vessel catches would have produced about 10 t of bocaccio in 1950.

Step 7:
Total landings were then increased by 1.29% for discards of damaged, undersized, or unmarketable product (see below "Discards").

Domestic Trawl Catch (U.S. and CDN 1950-1966)
The process for reconstructing 1950-1966 trawl landings was similar to that used for 1930-1949 except that we took advantage of published ORF landings from U.S. and CDN vessels by Major Area (Ketchen 1976: Tables 1-17: 1950-1966). This reconstruction involved four steps similar to those above except that we obtained ORF landings from Ketchen (1976) for Major Areas 3C to 5E: Table 17: Cols. 4-15 for 1950-1966). Steps 2-7 were completed as above.

Domestic Trawl Catch (U.S. and CDN 1967-2007)
Landings
Catches of bocaccio by U.S. vessels in B.C. waters continued from 1967 until they were terminated in 1979 with the phasing in of the "200-mile Extended Jurisdiction" (EJP) for CDN waters (Table 22). U.S. vessel landings by Major Area were taken from Tagart and Kimura (1982: Table 16). Landings by CDN vessels for 1967-2006 were obtained from the DFO-PacHarvTrawl databases as in Stanley *et al.* (2001), except that for this analysis we excluded a small amount of landings from the 3C/U.S. area by CDN vessels for the years of 1967-1980 (Table 22)[16].

[16] These 3C/CDN catches could be identified because the CDN logbooks noted the locality of capture. For example, catches by CDN vessels from "Ollie Spot" and "Cape Flattery Spit" were assigned to U.S. waters (see Rutherford 1999, p. 61).

Discards

Monitoring of discards began in 1996 with introduction of 100% observer coverage of bottom trawl fishing (Table 22 and Table 23: Col. 2). Discards averaged an additional 1.29% over reported landings from 1996-2003, prior to the trawl fleet voluntarily relinquishing their landings in order to remove the incentive to target on bocaccio. We assume that the discarding from 1996 to 2003 were fish that were rendered unmarketable owing to capture or storage damage, damage from sampling, or were too small, although small fish (<30 cm) are rarely are seen in commercial or research catches. We have assumed that these reasons for discarding were present over the term of the fishery, so we have assumed a "chronic" level of discarding of 1.29% over the entire period of the fishery: Table 17:Col. 25; Table 23: Col. 2).

We also included an additional pulse of discarding for the CDN domestic trawl fishery for 1967-1975. The senior author observed during observer trips from 1969-1971 that CDN vessels discarded all bocaccio while U.S. vessels retained their catches even though captured in Canadian waters. The explanation provided at the time was that Canadian food inspection authorities would not allow the export of bocaccio fillets owing to the high parasite load in the fillets. This effect is indicated in Table 24 where it appears that the markets of rockfish changed in about 1975-1977 such that the reported landings of bocaccio increased by at least 50 times, while shelf rockfish landings increased by about 10 times. It appears that as CDN vessels begin to target shelf rockfish[17], markets improved and bocaccio were then retained.

To account for "inspection-driven" discarding by CDN vessels prior to 1976 (1967-1975), we assumed that the bocaccio represented the same proportion of ORF rockfish from 1967-1975 as they did from 1976-1980 (Table 24: 0.055). We therefore multiplied reported catch of bocaccio by 0.055/0.010 to estimate this additional discarding by CDN vessel (Table 23: Col. 4). Note that we have not incorporated this inspection-driven discarding for CDN catches prior to 1967. First, we do not know when this regulation was implemented. Second as noted above, for these earlier years, our estimates of CDN catches were derived from the proportions of bocaccio observed in U.S. vessel landings. Therefore, although the estimates of CDN catches expressed as landings in the above tables for pre-1967 may actually have been discarded, the catches are still included in this summary.

Finally, with respect to U.S. and CDN trawl catches, anecdotal comments have indicated that from the early-mid 1980s until 1995, significant catches of rockfish were discarded at sea, misidentified or even secretly sold on a black market as harvesters attempted to circumvent quota and trip limit constraints. Unfortunately, we have no means of estimating these amounts. Since bocaccio were not under quota or trip limits for much of this period, landings may have been over-estimated as other rockfish species under quota were misreported as bocaccio. Our model runs assume no additional unreported catch of marketable fish in this period. If this assumption requires further investigation, this could

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[17] Canary, silvergray, yellowtail, widow, yellowmouth and redbanded rockfish, and bocaccio as categorized by Fraidenburg *et al.* (1977).

be explored as a modelling or sensitivity analysis using alternative/hypothetical catch histories for 1985-1995, however these tests were not conducted for this assessment.

Foreign (Soviet, Japanese, and Polish) Trawl Catches (1965-1977)

In addition to the domestic bottom trawl fisheries for rockfish, there was a brief but intensive bottom trawl harvest of rockfish by Soviet and Japanese vessels and midwater harvest of rockfish by Polish vessels from 1965 to1977 (Figure 21, Table 25). Total reported landings from these fisheries reached almost 50,000 t for all rockfish in 1966 and peaked again at over 30,000 t in 1974.

The Polish fishery was conducted with midwater trawl in 1974 and 1975 and was reputed to have caught over 12,000 t. However, Ketchen (1980b) reported that yellowtail, widow, and canary rockfish represented all but 65 t over the two years; therefore we have assumed negligible catches of bocaccio from this fishery.

The estimates of total catch of "All rockfish" in the Soviet and Japanese fisheries are thought to be representative, but little information is available to directly allocate the catch to species. Previous attempts to reconstruct species composition have been focused on Pacific ocean perch, the dominant species in these catches (Ketchen 1980a). For bocaccio the problem is exacerbated, since "production" logs of the foreign processor boats can be assumed to have ignored some of the bocaccio. One salmon troll fisher reported to the senior author that bocaccio were discarded by the Soviet vessels.

The Soviet data is effectively limited to "All rockfish" while Japanese catches were divided into "Pacific ocean perch" and "Other rockfish" with a noticeable shift in proportions towards the latter category in the later years[18]. Since we could not differentiate the Soviet and Japanese catches by species directly, we chose to estimate bocaccio catches from the "All Rockfish" totals (Table 25). These were partitioned into bocaccio catches by using the proportion of bocaccio observed in rockfish catches during DFO rockfish research trips on the *FRV G.B.Reed* over a similar period of years (Figure 22, Table 26). To parallel the reconstruction of U.S. domestic catches we developed separate catch ratios of bocaccio to all rockfish for 3C-D and 5A-E. We made no other attempt to weight the catches over space or time. We did eliminate the catch observations from a few *G.B.Reed* tows that were obviously made well outside the area where foreign fishing was thought to have occurred (i.e. Smith Sound in the central coast).

While Soviet vessels fished well within QCSd (Ketchen 1980a), the Japanese were excluded beyond the closing line at the mouth of QCSd as of 1970 (Ketchen *et al.* 1978) (Figure 22). The deeper Japanese tows may have tended to be deeper than the research

[18] Note that the "Other rockfish" category in Japanese catches does not appear comparable to the U.S. catch category of the same name. The Japanese designation appeared to include all non-Pacific ocean perch, including deep and red-coloured species (sharpchin rockfish etc.) while the U.S. "Other rockfish" category tended to be more the shelf species of non-red rockfish (but including yellowmouth rockfish).

tows and therefore have produced a lower catch rate than inferred from *G.B.Reed* results. Countering this possible bias, Mr. Jergen Westrheim, the chief scientist on the research cruises, suggested that the *G.B.Reed* index was a reasonable surrogate for bocaccio catch proportions (given little else to use), but suggested it might underestimate the bocaccio incidence since Soviet and Japanese vessels fished over harder bottom[19]. Soviet and Japanese catches of bocaccio were estimated to have peaked at 865 t in 1966 and 537 t in 1974 (Table 26).

Bocaccio catches also occurred in the "National" and "Supplemental" directed midwater fishing for hake that took place in some years since the mid 1970s. These foreign vessels were allowed to fish for hake prior to development of the Joint-Venture fishery wherein CDN catcher vessels supplied catches to foreign processors. In some years they were allowed to fish at the same time if CDN vessels could not catch the entire quota.

While we included records of bocaccio catch from the CDN joint-venture vessels (Table 22), we did not include bocaccio catches from directed foreign hake fishing. There is probably sufficient information from published observer reports to generate bocaccio catch estimates for this sector. However, a quick scan of some of these reports indicated that while there were significant catches of other rockfish species, especially yellowtail rockfish, bocaccio catches were probably too small to have an impact on this assessment. For example, Davenport (1985) estimated a total catch of 4-6 t of bocaccio in this fishery for 1983, while the hake catch was about 40,000 t. This additional source of bocaccio catch could be examined more closely for the next review of bocaccio.

[19] For comparison only, the current catch ratio of bocaccio to POP (by weight) in the CDN trawl fishery (1996-2007) is about 1% depending on how the ratio is calculated (i.e. all catches or targeted POP fishing).

Appendix B. Rockfish ZN and Halibut Fisheries Catch

Introduction

Consistent with our reconstruction of the trawl history, we attempted a reconstruction of the catch in the commercial hook-and-line (HL) fisheries. With respect to historical catch in this bocaccio assessment, we treat the HL fisheries as having three significant sectors:

1) Rockfish ZN (set-line, and handline and lingcod troll) (this Appendix)
2) Halibut (set-line) (this Appendix)
3) Salmon troll (Appendix C).

We have assumed 100% mortality of all catches.

Rockfish ZN Catches (1940 to 2006)

Unlike the procedures used to estimate catch in the halibut and salmon troll (catch rate expanded by effort), we estimated bocaccio catch in the Rockfish ZN based on landed estimates of total rockfish. Records of total rockfish landings from sales slips and dockside monitoring for commercial HL vessels landing rockfish from Areas 3C-5E are available back to 1956 (Yamanaka and Kronlund 1997; p. 25: excluding catches from the Strait of Georgia) (Table 27). We converted these total rockfish estimates to bocaccio by assuming a constant proportion of 0.012. This proportion was derived from the combined 1995 and 1996 species composition from ZN logbooks records of <u>catch</u> (Yamanaka and Kronlund 1997, p. 23-24). We lacked sales slips for earlier years (1930-1955), so we assumed landings for this period were 0.6 t/y, the mean of 1956-1960.

Note first that we have estimated bocaccio catch (retained or discarded) by multiplying the observed proportion by weight of bocaccio to total catch in logbooks by total landings of all rockfish. This implicitly assumes all bocaccio were landed. If all were discarded the estimates would be approximately 1.2% larger than the values show in Table 27 or about 0.2 t/y more for the early years.

Note secondly that the total rockfish landings of Table 27 represent the combined landings from Rockfish ZN, halibut, and the salmon troll sectors. Since we subsequently, and independently, estimated bocaccio total catch (as opposed to just landings) in the halibut and salmon troll those two fisheries we implicitly entered an estimate of landed bocaccio in these two fisheries twice. This mistake was noted to late to re-do the assessment, however the impact would be negligible. From Yamanaka and Kronlund (1997: p.6), 84% of the rockfish landings came from Rockfish ZN landings. From Table 27 this implies that the amount that was "double-counted" would be about 16% of the catches shown or <0.5 t/y (1940-1984) and <1.0 t/y in more recent years. The exception is 2006, wherein 13.9 t was added to the total catch for both ZN rockfish and the halibut fishery. Therefore, the catch vector input to all model runs includes an extra and incorrect 13.9 t for 2006 and < 1t for 1940-1984 (note these corrections were made for the updated tables provided in the DFO 2009).

Future catch reconstructions should harmonize the reconstruction approaches for the various HL sectors. The most reasonable approach would be to estimate bocaccio catch in the

Rockfish ZN sector based on the product of estimates of catch rate and total effort procedure as was used in the halibut and salmon troll procedures.

Catches in the Halibut Fishery

Bocaccio catch in the directed halibut fishery was reconstructed for 1929-2007 by multiplying total effort in numbers of skates by catch rate (kg/skate).

Total Effort in the Halibut Fishery

We used the effort time series for 1929-2007 for B.C. waters (Area 2B) as recommended by staff at the International Pacific Halibut Commission (IPHC) (Figure 23, Table 28)[20,21]. Results were not available for 1983, so we used the mean of the adjacent years, 1980-1982, and1984-1986.

Circle-Hooks versus J-Hooks.

The IPHC standardizes the effort to account for the fleet-wide conversion in 1983 from J-hooks to circle-hooks. The catchability of circle-hooks for halibut is treated as being 2.2 times that of J-hooks based on directed research on the two hook types (Sullivan *et al.* 1999). The IPHC has not calculated a hook conversion factor for other species but collected data on other species during its investigation on the effect on for halibut. At our request, data from these experiments were summarized for non- halibut species (Table 29).

With equal (paired) fishing effort, J-hooks and Circle-hooks captured 96 and 120 rockfish, respectively, however results varied widely among trips. The results do not indicate a strong hook effect. This is consistent with comments from various HL fishermen. They reported they did not notice a strong influence on rockfish bycatch by hook type, although emphasized they did not focus on the issue. We therefore did not make a catchability adjustment for hook type in the catch reconstruction.

Catch Rate per Skate

Catch rate per skate was resolved as a 2-step procedure. The first step used catch figures from the halibut fishery in B.C. in 2006 and 2007 to estimate a current catch rate of bocaccio in the halibut fishery. These results are from the first years of the Groundfish Integrated Fishery Pilot Project, which saw the implementation of 100% monitoring and 100% retention of rockfish. While this monitoring process is still in a process of maturation, we assume that the reported catch rate of bocaccio in the halibut fleet was accurate (Table 30)[22]. The catch rate was 0.115 kg/skate averaged over 2006-2007.

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[20] 1930-1973 B.C. effort from Table 2 in Myhre *et al.* 1977. Effort was calculated as the sum of effort for INPFC Vancouver and Charlotte Areas. Note: we summed effort by PMFC Stat Area (Myhre *et al*. 1977: Table 1) to exclude any US-Vancouver effort but obtained virtually the same values.

[21] 1974-2007 W. Clark, IPHC (pers. comm.).

[22] Note the disagreement in total skate number between IPHC records and DFO-FOS results (Table 30). IPHC data are standardized for hook spacing and we have assumed that the two data systems are not using exactly the same protocol for classifying trips by sector although they are much closer for 2007. Since the bocaccio catch is taken from the FOS system, we used the FOS estimate of skates deployed to calculate bocaccio catch per skate. Were we have used the IPHC skate values, the catch rate would be about 17% higher.

Within the stock assessment model, we have applied a simple model for annual catch that uses fishing effort as a covariate for catch fishing mortality rate and assumes that the catchability coefficient is constant over the time series:

Eq. 4 $$\hat{G}_{f,y} = B_y\left(1-\exp\left(-k_f E_{f,y}\right)\right)$$

where $\hat{G}_{f,y}$ is the model-predicted catch in fishery *f* (here *f* is the halibut fishery), in year *y*, B_y is the stock biomass of bocaccio in year y, k_f is the bocaccio catchability coefficient for fishery *f*, and $E_{f,y}$ is the effort for fishery *f* in year y. This bocaccio catch model requires a prior for the parameter k_f. We presumed a non-informative prior on the halibut fishery bocaccio harvest rate for the year 2007, assuming that it could range between zero and 1. We have thus presumed a uniform (0, 1) density function for harvest rate, the ratio of bocaccio catch to stock biomass in 2007 over this range. Making the transformation of variable from harvest rate to the catchability coefficient for bocaccio and treating halibut fishery effort value in 2007 as a constant, this gives a prior for k_h with an exponential density function:

Eq. 5 $$p(k_h) = E_{2007}\exp\left(-k_h E_{2007}\right)$$

We updated the prior for the bocaccio catchability coefficient in the halibut fishery with the observed values of $G_{f,y}$ in the years 2006 and 2007:

Eq. 6 $$G_{f,y} \sim \log\text{normal}\left(\log\left(\hat{G}_{f,y}\right), \sigma_f^2\right)$$

Thus, the model calculates a random variable for historical bocaccio catch in each historic year based on the random variable for annual bocaccio stock biomass, the random variable for the bocaccio catchability coefficient, and the record for the annual B.C. halibut fishery effort. We have assumed all other influences on bocaccio catch rates in the halibut fishery did not vary significantly over time. For example, we aggregated results for B.C. as one area. We could have derived the history of bocaccio catches for each statistical-area strata separately (using stat-area catch rates in 2006 and 2007) then summed the results.

While there are a number of assumptions and possible biases in this reconstruction the most notable comment from fishermen was that actual bocaccio catch rates probably dropped in 2006-2007, owing to increased avoidance of all rockfish catch under the Groundfish Integration Pilot Project. This bias would lead the reconstruction to underestimate historical catches. Some fishers commented that there was very little bocaccio catch in the halibut fishery and therefore perhaps not an issue. However, when we pointed out that the observed rates in 2006 and 2007 equated only to one fish for very 35-40 skates, or 2-3 fish a trip, they agreed that these catch rates were reasonable.

Appendix C. Salmon Troll Catch

Introduction

Preliminary discussions with troll fishers revealed that bocaccio catches in the salmon troll fishery might have been significant in earlier decades and that virtually all of the catch was discarded. The DFO sales slip database revealed that the salmon troll effort peaked at about 160,000 days per year in 1980 (excluding Area 4B) and declined to relatively negligible levels by 1998 (Figure 24, Figure 25, Table 31.). Since even a modest assumption of 1 fish/day at 4 kg/piece implied peak catches of over 600 t/y, we chose to include an estimate of catch from this sector in the model.

Salmon Troll Effort (1952-2007)

We first confirmed that recorded effort data are considered to be reasonably accurate. DFO staff acquainted with these records suggested that they were representative of effort in the fishery[23]. The only comment was that the data might modestly underestimate actual effort owing to some unreported fishing in those years. They noted that effort conformed to aerial surveys at the time. There were 2,702 salmon troll licenses in 1983 which provided 160,913 troll days coastwide (including the Strait of Georgia). This translates to an average of about 60 days per license. Since the main season in outside waters was April 1-Mid-September, or about 160-170 days, total coastwide effort of almost 200,000 days (1980) are plausible for that size of fleet and length of season.

Salmon Troll Effort (1915-1951)

We were not able to locate troll effort for years prior to 1952. However, Milne and Godfrey (1964) provide a summary of troll chinook and coho salmon catch from 1920 to 1962 (Figure 26). These data imply that the troll catches increased almost linearly from negligible levels around 1915 to the early 1950s. Therefore, we assumed for this assessment that salmon troll effort of bocaccio followed a similar pattern of increasing linearly from 0 days fishing in 1915 to the levels reported above in 1952[24,25].

Mean Weight of Individual Bocaccio

We are not aware of any documented information on mean size of bocaccio in this fishery. The interviews with many trollers who fished in earlier years were consistent in suggesting that the bocaccio were virtually all "big fish" in the 5-10 lb range. Very few smaller but a significant number bigger, up to 40 lbs (18 kg). Given the lack of

[23] Brenda Ridgway. Science Branch, Department of Fisheries and Oceans. February 2008.
[24] Forester and Forester (1975) suggest an "official" start year of salmon trolling in 1899. However, it was limited to handlining and day fishing. Owing to increased activity in this sector, the Federal Government introduced personal troll licensing ($1) in 1916-1917. Automated hauling "gurdies" and fishing with up to six lines became widespread in the following years.
[25] Discussions during the PSARC review (S. Argue, pers. comm.) suggested troll licenses might provide a better surrogate for troll effort than landings.

information we used the same value of 4.3 kg observed in the 2006 and 2007 HL groundfish fishery (Table 30).

Estimation of Bocaccio Catch Rate (Pieces/Day) in the Salmon Troll Fishery

To obtain a catch rate (pieces/day), we first examined the available published records of catch in the troll fleet. Wrohan (2002) summarized troll observer data for 1998-2001 for the west coast of Vancouver Island. Of 781 rockfish recorded to species, none was bocaccio. This program involved 485 observer days, but was not designed to monitor rockfish bycatch. Most of the rockfish were not identified to species.

More recently, observer data for 2006 for the west coast of Vancouver Island extracted from the DFO Fishery Operating System (FOS) identified 39 bocaccio in 53 days of trolling. Twenty-nine of these were identified in two days of trolling. As with the earlier work, these studies were not designed to monitor catch of rockfish.

Salmon researchers at PBS and with the Pacific Salmon Commission commented that little of the historical observer data exists in electronic format and observers were not instructed to record catch of non-salmon. We made no attempt to examine this archived material but instead interviewed 12 harvesters who salmon trolled during the peak effort years of the salmon troll fishery.

Troll Harvester Interviews

The interviews were informal. The individuals were selected in an *ad hoc* manner. Most were referrals from the first few interviews. All are still active harvesters although not necessarily salmon trolling. Each was first asked for background information such as when they fished, which species of salmon they targeted, and whether they were a fresh, ice, or freezer boat. They were then presented with a chart of the coast showing PMFC statistical area boundaries (Figure 25) and asked to estimate a catch rate of bocaccio for the overall period of 1970-1990 in each statistical area they had fished. They were free to express the catch rate in any manner such as pieces/day, pieces/trip, or as a range. We did not question them for trends over time.

All those interviewed said they caught bocaccio and that they were confident they could distinguish them from other rockfish. All said that the fish were relatively large in the 5-10 lb range or bigger. All but one said that they assumed that all of the bocaccio died after capture. They all commented that the bocaccio showed signs of barotrauma (everted stomachs and distended eyes) and that many floated belly-up after release.

With respect to catch rate, virtually all of the respondents were initially reluctant to answer the question. They all commented that “it was a long time ago” and that catch rates of bocaccio were highly variable depending on many different factors such as:

- local spatial and habitat effects (nearness to rocky bottom);
- larger scale spatial effects (i.e. “off Kyuquot Sound”);
- time of day (many said catches were highest <u>before</u> dawn);

- gear (whether they using sockeye, coho or chinook tackle);
- depth.

They reported that catches might be 0/day in most areas under most conditions, but catch rates of 40 or more per day on multiple days were not uncommon within one season of fishing. The respondents were consistent in commenting that the question was problematic and were concerned that their "best guess" about bocaccio catch rates from up to 30 years ago might have inappropriate influence on the assessment. Nevertheless, we explained that the estimates would be used to infer general magnitude, and various alternatives would be explored. Furthermore, their concerns would be communicated in the final document.

Their nominal responses (Table 32) were converted to units of catch/day (Table 33). None of the interviewees fished in Statistical Areas 104/4 or 109/9 so we assumed a 0.0 catch rate in these two areas. Summary statistics for the interviews are provided in Table 34.

Bayesian Reconstruction of Bocaccio Catch in the B.C. Salmon Troll Fishery

We applied the same general catch model for bocaccio in the B.C. salmon troll fleet as we did for the halibut fishery (Equation 4). This requires as input reconstructions of annual B.C. troll effort since 1935 and an estimate of annual troll bocaccio catch for one or more years. As noted above, we obtained approximations of average annual catch (note we are assuming that virtually all of the bocaccio catch was discarded) for the most recent years with relatively high catch (1976-1985) through interviews with twelve troll fishers. We surmised that fishers might tend to remember the higher catch rate days. Based on these recollected values, we thus obtained trimmed mean estimates, median and half median values for each statistical area to provide high, middle, and low values of average daily catch for each statistical area for use in the sensitivity tests.

The bocaccio stock assessment model is not spatially stratified and thus troll catch can only be computed based on aggregate stock biomass and aggregate troll fishing effort. To account for the difference in bocaccio density between areas in the formulation of an annual effort value, we weighted the effort in each statistical area in proportion to the average daily catch rate in each statistical area.

Eq. 7 $$E_{f,y} = \frac{\eta}{\sum_{i=1}^{\eta} \gamma_{f,a,y}} \sum_{a=1}^{n} \gamma_{a,f,1976-85} \times E_{f,a,y}$$

where $\gamma_{f,a,1976-85}$ is an approximation of the average daily catch in area *a* for years 1976-1985, η is the total number of areas in which bocaccio catch was recollected to have occurred, and $E_{f,a,y}$ is the number of days fished in area *a* in year y by the troll fleet. Thus, if catch was zero in a given area, this area was not included in the total annual effort computation. If catch was very low in a given area, the effort in this area was given proportionally lower weight in the total annual effort computation, and interannual variation in effort in the areas with lowest bocaccio catch was given the least weight in the computation of annual troll effort.

Effort by statistical area was available for 1952-2007. The troll effort time series goes back only to 1952. It is unlikely that salmon effort was zero prior to then, so effort values from 1935 to 1951 were imputed using the total salmon troll catch values going back to 1938, assuming that effort is directly proportional to the total annual salmon catch. A no-constant linear regression of effort on catch was applied for the years 1952-1962 to estimate the slope coefficient for effort as a function of catch. Catch was missing for the years 1949-1950 and a linear regression was applied for the years 1945-51 of available catch on time to impute the troll salmon catch values for 1949 and 1950. Annual troll effort for 1938-1951 was set by multiplying the estimated slope coefficient by the total annual troll catch value. The effort values for 1935-1937 were set equal to the value for 1938, since the total annual troll catch values were deemed to be unreliable for years before 1938. The resulting effort time series for years 1935-2007 is shown in Figure 27.

The trimmed mean values for recalled bocaccio troll catch by area were applied for $\gamma_{f,a,1976-85}$ in this weighted calculation (Equation 7) because these approximations included all areas in which at least some bycatch was reported. In contrast, the median estimates excluded some of the areas in which bycatch was reported by at least some of the trollers.

The annual average bycatch by statistical area for the years 1976-1985 were computed by taking the product of the average daily catch rate and the total number of days fished per year in that area:

Eq. 8 $\quad G_{f,a,y} = E_{f,a,y} \times \gamma_{a,f,76-85}$

An approximation of the total annual troll bycatch was obtained by summing the bycatch across areas where bycatch was recollected to have occurred:

Eq. 9 $\quad G_{f,y} = \sum_{a=1}^{\eta} G_{f,a,y}$

Because trollers have provided an estimate of average daily catch rate for the years 1976-1985, we took an average of the annual values computed for this period:

Eq. 10 $\quad G_{f,76-85} = \frac{1}{10} \sum_{a=1}^{\eta} G_{f,y}$

The median, half median and trimmed mean estimates of $G_{f,76-85}$ are 238, 119, and 497 tons.

A catchability coefficient for total annual troll catch of bocaccio was estimated by fitting the catch model within the Bayesian surplus production model to the stratified estimate for the average annual 1976-1985 troll catch. The annual troll catch was thus estimated for each year from 1935-2008, as a function of the random variables for annual stock biomass, the troll bocaccio catchability coefficient, and the stratified weighted estimates of the total annual troll fishing effort in areas that were reported to contain bocaccio troll catch. This approach assumes that total annual fishing effort in these areas serves as an unbiased covariate for troll bocaccio fishing mortality rate for years from 1935-2008.

A non-informative prior pdf for the troll bocaccio catchability coefficient was formulated. As with the halibut catch model this is an exponential density function with the average effort for 1976-1985 set as the parameter value for this density function, since the only "data point" for troll catch comes from 1980.

Eq. 11 $p(k_t) = E_{t,2007} \exp(-k_t E_{t,2007})$

The stratified estimate for average annual bocaccio catch in 1976-1986 in the troll fishery was treated as a "pseudo" data-point and the prior for k_t was updated using Bayes theorem within the stock assessment model. A lognormal likelihood function of $G_{f,76-85}$ was applied with a standard deviation term of 0.7 (i.e., relatively low precision in the data point):

Eq. 12 $G_{t,1976-85} \sim \text{log normal}\left(\log\left(\hat{G}_{t,1976-85}\right), \sigma_t^2\right)$

Using the estimates for troll catchability and troll fishery effort, annual troll fishery catch for the full time series was thus estimated, modeled as a function of the modeled bocaccio stock biomass, and reconstructed bycatch-weighted trolling effort, and treated as a random variable within the stock assessment model.

Appendix D. Trawl CPUE

Introduction

We derived one fishery dependent abundance index as the CPUE from the commercial bottom trawl fishery as described below.

Methods

A stepwise general linear model (GLM) regression procedure was used to estimate an annual series of the relative changes in canary rockfish abundance over time. The regression was based on the relationship between CPUE for canary rockfish and available predictive factors. The data were derived from the DFO *PacHarvestTrawl* and *GFCatch* commercial catch and effort databases. This approach is commonly used to analyse fisheries catch and effort data and has been described by various authors (e.g., Hilborn and Walters 1992, Quinn and Deriso 1999). Quinn and Deriso (1999; page 19) described a general linear model based on the lognormal distribution:

Eq. 13 $$U_{ijk} = U_0 \prod_i \prod_j P_{ij}^{X_{ij}} e^{\varepsilon_{ijk}}$$

where U_{ijk} is an observed CPUE, U_0 is the reference CPUE, P_{ij} is a factor i at level j, and X_{ij} takes a value of 1 when the jth level of the factor P_{ij} is present and 0 when it is not. The random deviate ε_{ijk} for observation k is a normal random variable with 0 mean and standard deviation σ.

Taking the logarithm of Eq. 13 yields an additive linear regression model:

$$\ln U_{ijk} = \ln U_0 + \sum_{i=1}^{p} \sum_{j=1}^{n_i - 1} X_{ij} \ln P_{ij} + \varepsilon_{ijk}$$

Eq. 14 or

$$Y_{ijk} = \beta_0 + \sum_{i=1}^{p} \sum_{j=1}^{n_i - 1} \beta_{ij} X_{ij} + \varepsilon_{ijk}$$

In the second form of the model, β_0 is the intercept of the model and β_{ij} is the logged coefficient of the factor j at level i under consideration.

The model described by Eq. 13 and Eq. 14 is over-parameterised and constraints must be imposed to allow estimation of model parameters. A common solution is to create a reference level by setting a factor coefficient to zero, usually the first. The remaining n_i-1 coefficients of each factor i represent incremental effects relative to the reference level.

The estimated factor coefficients are not unique: coefficients obtained by fixing a factor level will differ with the choice of reference level. However, the relative differences among the estimated coefficients will not be affected by the choice of constraint. Following the suggestion of Francis

(1999), coefficients for factor *i* were transformed to "canonical" coefficients over all levels *j* calculated relative to their geometric mean $\bar{\beta} = \sqrt[n]{\prod_{1}^{n} \beta_j}$ (including the level where β_j=0), so that

Eq. 15 $$\beta_j^{'} = \beta_j / \bar{\beta} \ .$$

As the analysis is done in log space, this is equivalent to:

Eq. 16 $$b_j^{'} = \mathrm{e}^{(\beta_j - \bar{\beta})} \ .$$

The use of the canonical form allows the computation of standard errors for every coefficient, including the fixed coefficient (Francis 1999). Ordinarily, the use of a fixed reference coefficient sets the standard error for that coefficient to zero and spreads the error associated with that coefficient to the other coefficients in the variable.

A range of factors (P_{ij}) are available in the data which may be used to account for variability in the observed CPUE. These include factors such as date of capture (usually year and month), vessel, depth, and location of capture. The year of capture is usually given special significance in these analyses as variations in the estimated year coefficients are interpreted as relative changes in the annual abundance. The resulting series of 'year' or 'fishing year' canonical coefficients is termed the "Standardised" annual CPUE index $\left[Y_j^{'}\right]$ in this report.

A selection procedure (Vignaux 1993, Vignaux 1994, Francis 2001) was applied to determine the relative importance of these factors in the model to the prediction of CPUE. The procedure involves a forward stepwise fitting algorithm which generates regression models iteratively, starting with the simplest model (one dependent and one independent variable) then progressively adds terms to the model subject to a stopping rule designed to include only the most important factors.

The following general procedure was used to fit the models, given a data set with candidate predictor variables:

1. Calculate a regression for each predictive factor (variable) against the natural log of CPUE (kg/h).
2. Generate the Akaike Information Criterion (AIC) (Akaike 1974) and select the predictor variable that has the lowest AIC. The AIC is used for model selection to account for variables which may have equivalent explanatory power in terms of residual deviance but require fewer degrees of freedom for the model (Francis 2001).
3. Repeat Steps 1 and 2, accumulating the number of selected predictor variables and increasing the model degrees of freedom, until the increase in residual deviance (as measured by R^2) for the final iteration is less than 0.01. The selection of 0.01 as the threshold is arbitrary but adding factors which explain small amounts of the total variance has little effect on the year coefficients and other coefficients of interest.

Other annual indices can be generated from the catch and effort data used for the linear modelling described above. The simplest estimate of mean annual CPUE is given by:

Eq. 17 $$R_j = \frac{\sum_{k=1}^{M_j} C_{jk}}{\sum_{k=1}^{M_j} E_{jk}}$$

where C_{jk} denotes that catch and E_{jk} denotes the effort for each record k in year j. The series of annual estimates is termed the "Arithmetic" CPUE index in this report.

Another annual index is specified by

Eq. 18 $$U_j = \exp\left[\frac{\sum_{k=1}^{M_j} \ln\left(\frac{C_{jk}}{E_{jk}}\right)}{M_j}\right]$$

where U_j is the annual geometric mean of the CPUE observations. The resulting annual index is termed the "Unstandardised" CPUE index in this report. Annual estimates obtained using Eq. 18 are equivalent to the results obtained from a linear model where year is the only predictive factor.

Like the scaling described for the standardised index, the series specified by Eq. 17, and Eq. 18 can be scaled relative to their geometric means. This is done to provide comparability with the standardised index. Given n years in each series, the geometric means of the arithmetic and unstandardised series are given by $\bar{R} = \sqrt[n]{\prod_1^n R_j}$ and $\bar{U} = \sqrt[n]{\prod_1^n U_j}$, respectively. Thus, each series can be scaled to the corresponding geometric mean as:

Eq. 19 $$R_j' = R_j / \bar{R}$$

and

Eq. 20 $$U_j' = U_j / \bar{U}$$

The procedures described by Eq. 13, Eq. 14, and Eq. 18 are necessarily confined to the positive catch observations in the data set as $\ln(0)$ is undefined. Observations with zero catch can be handled in a number of ways:

1. Zero catch records are frequently dropped from further consideration, usually because they are not accurately recorded. This is particularly true for catch records which are maintained by fishermen who frequently discount small amounts of catch as being inconsequential.
2. A small increment can be added to the zero catch records so that ln(0) can be calculated. This is not a satisfactory solution because model parameter estimates have been shown to be sensitive to the value selected for the increment.
3. A linear regression model based on a binomial distribution and using the presence/absence of the fish species as the dependent variable can be estimated using the same data set. Explanatory factors are estimated in this model in the manner described in Eq. 13 and Eq.

14. Such a model will provide another series of standardised coefficients of relative annual changes that may be analogous to the series estimated from the lognormal regression, depending on whether the probability of presence/absence can be considered an index of abundance. Such an approach should only be used for data sets where zero catch records are known to have good reliability, which is not the case for the long term series presented here.

4. A combined model which integrates the two series of relative annual changes estimated by the lognormal and binomial models can be estimated using the delta distribution which allows zero and positive observations (Vignaux 1994):

Eq. 21 $$C_i = \frac{L_i}{\left(1 - P_0\left[1 - \frac{1}{B_i}\right]\right)}$$

where C_i = combined index for year i
L_i = lognormal index for year i
B_i = binomial index for year i
P_0 = proportion zero for base year 0

It is relatively straightforward to calculate standard errors for the indices L_i and B_i. However, this is not the case for the combined index C_i because the standard errors of the two sets of indices are likely be correlated since they come from the same dataset. Francis (2001) suggests that a bootstrap procedure is the appropriate way to estimate the variability of the combined index.

Data Selection and Model Specification

Data were selected from the DFO PacHarvestTrawl database using the following criteria:

Tow start date between 1 April 1996 and 31 March 2007
Bottom trawl type
Fished in a valid outside DFO Major region (3C, 3D, 5A, 5B, 5C, 5D, or 5E)
Fishing success code <=1 (code 0= unknown; code 1= useable)
Catch of at least one fish or invertebrate species (no water hauls)
Valid depth field
Vessel had been in the fishery for at least 8 years with a minimum of 8 trips in each of those years
Valid latitude and longitude co-ordinates
Valid estimate of time towed that was greater than 0 hours and less than 24 hours

The following explanatory variables were offered to the model, based on the tow-by-tow information in each record for the data remaining after the selection procedure:

Fishing year (1 April–31 March)
Month
DFO locality (Rutherford 1995)
Latitude separated in 0.1° bands beginning with 48°N
Vessel
Depth aggregated into 25 m depth bands
DFO Major region (3C, 3D, 5A, 5B, 5C, 5D, or 5E)

Locality and latitude categories with relatively few observations were pooled into a single ("Plus") category to reduce the number of parameters estimated. Vessels were never pooled. Instead, the vessel selection criteria were tightened to reduce the number of categories.

Catches

Total annual landings and discards for bocaccio are presented by major DFO region from 1979–80 to 2006–07 (Table 35). Landings from the PacHarvestTrawl database (1996/1997 and later) are considered more reliable than earlier landings from the GFCatch database as they are verified by the presence of an observer. Discard estimates are not available prior to 1996 and the establishment of the independent observer program.

The majority of bocaccio landings have been from the northern half of Vancouver Island (Area 3D) (Figure 20) and Queen Charlotte Sound (Areas 5A and 5B), although there were significant bocaccio landings in the 1980s from the lower half of Vancouver Island (Area 3C). Bocaccio landings in Hecate Strait (Areas 5C and 5D) and the west coast Queen Charlotte Islands (Area 5E) have generally been minor (less than 50 t per year), with greater landings in some years from northern Hecate Strait (Area 5D) where landings approached 100 t per year. Discards for this species were minor up to the 2003/04 fishing, totalling less than 5 t per year for all of B.C. (Table 35). However, beginning in 2004/05, discards increased to levels ranging from 26 t to 48 t per fishing year (for total B.C.), in conjunction with the trawl industry agreement to relinquish all bocaccio landings as a measure to reduce the fishery mortalities of this species[26].

Combined Areas 3C-5E (Total B.C. Outside West Coast)

The depth distribution of the majority of successful catch records data ranged from about 60 m to about 350 m, with sporadic observations at deeper depths (Figure 28). The GLM model used all valid tows occurring between 50 and 350 m.

Results from Standardised GLM

The GLM analysis for the total outside areas of B.C. (Areas 3C-5E) selected DFO locality (45 categories), vessel (37 categories), 0.1° degree of latitude (44 categories), depth band (12 categories), and month (12 categories) as explanatory variables in addition to fishing year, in the final model and accounted for 14% of the total model variation (Table 36). Only DFO Major Area did not enter the model. Fishing year explained about 1% of the total variance. The analysis was performed on total landed catch (verified landings plus discards) to account for the higher levels of discards occurring since the 2004/05 fishing year (Table 35). The selected lognormal model shows little trend from the beginning of the series to 2001/02, after which it declines steadily to 2006/07 (Figure 29, Table 37).

There is an acceleration of the decline associated with voluntary relinquishment by the trawl industry described in the previous section. It is likely that the decline in relative CPUE presented in Figure 29 is due to behavioural adjustments by the trawl fishing fleet rather than to a change in the abundance of bocaccio, particularly since 2004/05. The standardised model does not vary much from the simple arithmetic mean CPUE or the geometric mean of the non-zero catches,

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[26] Relinquish means the trawl fishers forego any payment for landed rockfish thereby removing incentive to target n bocaccio.

possibly indicating that the fishery has remained reasonably consistent with respect to the model explanatory variables across the eleven years of available data (Figure 29). The estimated coefficients for the selected explanatory variables appear to be reasonable, with high catch rates in a few localities in upper part of Vancouver Island and Queen Charlotte Sound (top left panel; Figure 30). One vessel stands out with a high catch rate, while the remaining vessels are near the overall mean. The depth categorical variable shows a peak between 175 m with good catch rates from 125 m to 225 m (Figure 30). The latitude bands show peaks scattered throughout the coast, which is consistent with the ubiquity of this species. Finally, the month variable shows a peak in the late autumn/early winter.

Model residuals fit the model assumption of log-normal error well through most of the distribution, with some deviation at the tails, particularly the upper tail (Figure 31). A binomial model fit to the presence/absence of bocaccio using the same dataset which provided the lognormal model shows a generally flat trend in the series up to 2003/04, with a strong drop to a lower level from 2004/05 coincident with the start of the relinquishment agreement for bocaccio (Figure 32). At the same time, there has been little variation in the proportion of tows reported with zero catch over all years, which is high (nearly ¾ of the tows; Figure 32). There is little difference in the two series when the lognormal and binomial series are superimposed (Figure 33) indicating that the two models are tracking the fleet with respect to bocaccio in a similar manner.

Appendix E. Trawl Surveys

Introduction

This appendix summarizes the derivation of the relative bocaccio abundance indices from the:
1. West Coast Vancouver Island Shrimp survey
2. Queen Charlotte Sound Shrimp survey
3. US Triennial survey
4. Groundfish Synoptic Surveys (4)
   - West Coast Queen Charlotte Islands (WCQCI)
   - Hecate Strait (HS)
   - Queen Charlotte Sound (QCSd)
   - West Coast Vancouver Island (WCVI)

Analytical Methods

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

Eq. 22 $$U_{yi} = \frac{1}{n_{yi}} \sum_{j=1}^{n_{yi}} \frac{C_{yij}}{E_{yij}},$$

where C_{yij} = catch (kg) in tow j, stratum i, year y;
E_{yij} = effort (h) in tow j, stratum i, year y;
n_{yi} = number of tows in stratum i, year y.

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

Eq. 23 $$\delta_{yi} = \frac{1}{vw} U_{yi},$$

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

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

Eq. 24 $$\delta_{yi} = \frac{1}{n_{yi}} \sum_{j=1}^{n_{yi}} \frac{C_{yij}}{D_{yij} w_{yij}},$$

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

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

Eq. 25 $$B_y = \sum_{i=1}^{m} \delta_{yi} A_i = \sum_{i=1}^{m} B_{yi} ,$$

where δ_{yi} = mean CPUE density (kg/km^2) for stratum i, year y;

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

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

m = number of strata.

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

Eq. 26 $$V_y = \sum_{i=1}^{m} \frac{\sigma_{yi}^2 A_i^2}{n_{yi}} = \sum_{i=1}^{m} V_{yi} ,$$

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 CV of the annual biomass estimates is

Eq. 27 $$CV_y = \frac{\sqrt{V_y}}{B_y} .$$

West Coast Vancouver Island Shrimp Survey

Data Selection

Tow-by-tow data from a west coast Vancouver Island shrimp trawl survey are available for 33 years spanning the period from 1972 to 2007. However, rockfish were not identified to the species level for the 1972 and 1973 surveys and 1974 is a missing year. Therefore, for rockfish species, this survey begins in 1975 and is the longest series available to monitor this species in Canadian waters.

These survey data were analysed following the recommendations made by Starr *et al.* (2002) in their re-analysis of the data from the same survey for west coast Vancouver Island pacific cod, with some modifications. These recommendations and modifications include:

- post-stratifying the data into two areas, Areas 124 and 125 (Figure 34) because these are the areas that have been monitored the most consistently over the history of the survey. The main modifications applied included dropping some tows which occurred in the most northerly part of Area 125 in 1975 and 1976 because these tows were not repeated in later surveys.
- moving tows east of the longitude 125° 54’ from Area 124 to 123 as these tows were made in inshore waters and were spatially more closely associated with Area 123.
- only using tows made by the following vessels: *G.B. Reed*, *W.E. Ricker*, *Sharlene K.* and the *Frosti* (Table 38.). The latter two vessels are included because they are the only vessels which operated in 1989 and 2005 respectively. This vessel selection also rules out tows made in September 1977 and September 1978 which appear to be outside the scope of this survey.

The number of tows available for use in the analysis and the area weights in square kilometres for the defined strata are presented in Table 39. There are almost no tows at depths shallow o f 100 m in Area 125 (Figure 35) although there is reasonable coverage in the 80-100 m depth zone in Area 124. Coverage is continuous in all survey years up to the 140-160 m depth zone in both of the area strata, but the coverage in the 160-180 m depth zone is sporadic in many of the survey years. This analysis used 80 m to 160 m as the depth range for all survey years. This should not affect the comparability of Area 125 because there is a consistent lack of tows in depths less than 100 m across all surveys (Figure 35). Stratum area weights were used which reflect the reduced area associated with the truncated depth range (Table 39).

No tows were recorded in Area 125 for the 1989 and 1991 survey years (Table 39.). The catch rates estimated for Area 124 were also applied to the Area 125 stratum to ensure that the indices for these survey years were comparable to the indices in the years when Area 125 was surveyed.

Methods

These data were analysed using Equations 22-27 which assume that tow locations were selected randomly within a stratum relative to the biomass of bocaccio. This was not an assumption made by the original survey design and the area stratification definition in Figure 34 was not used when conducting the survey. The original survey design used latitudinal transects and selected the stations randomly along the transect. 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).

Results

Catches of bocaccio have been recorded along the shelf for the full range of the usable tows, with greater apparent abundance in Area 125 relative to Area 124 (Figure 36). The distribution of bocaccio catches by depth is concentrated between 100 and 160 m (Figure 37). Estimated biomass levels for bocaccio from the WCVI shrimp trawl survey appear to have been relatively consistent throughout the history of this survey, with the exception of some years with high biomass estimates associated with high levels of relative error (e.g. 1978, 1982, 1983, and 2005; Figure 38; Table 40). The proportion of tows which contain bocaccio has been consistently below 20% in Stratum 124, with a possibly decreasing trend since the early 1980s (Figure 39). The proportion of tows with bocaccio in Stratum 125 is high in the 1980s and early 1990s, culminating in over 60% in 1992 (Figure 39). These higher values may be an artefact of the smaller number of tows in this stratum (averaging about 20 per year compared to nearly 60 per year in Stratum 124), with only six tows recorded in 1992. That said, the incidence of tows with bocaccio in Stratum 125 (12%) is about three times higher than in Stratum 124 (4%) over the 31 survey years.

Queen Charlotte Sound Shrimp Survey

Data Selection

This survey covers the lower half of QCSd extending westward from Calvert Island and Rivers Inlet into the Goose Island Gully (Figure 40). 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 slightly later than in subsequent years (Table 41). It was decided to discard this survey year, given the exploratory nature of the first survey year and that five different vessels collected the data. Subsequent to that year, the survey has been conducted routinely by the *W.E.Ricker* (except in 2005 when the *Frosti* was used) in April or May and all years are reported. The survey is divided into three spatial 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 41). Stratum 111 has been discarded as its location is not considered good habitat for rockfish species and no bocaccio has ever been taken in that stratum. The majority of tows occur in the larger of the two remaining strata (109) while only a few are placed in Stratum 110 (Table 42.). 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 600 usable tows have been conducted by this survey over the nine available survey years (Table 42).

A doorspread density value (Eq. 23) was generated for each tow based on the catch of bocaccio, an arbitrary doorspread (25 m) for the tow, and the distance travelled. The distance travelled was determined at the time of the tow, based on the bottom contact time (J. Boutillier, DFO, *pers. comm.*). The two 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 WCVI shrimp survey, has consistently sampled depths up to about 220 m (Figure 41), so there was no need to truncate the tows at depth to ensure comparability across survey years.

Methods

These data were analysed using the Equations 22-27 which assume that tow locations were selected randomly within a stratum relative to the biomass of bocaccio. This was an assumption made by the original survey design using the area stratification definition in Figure 40. 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).

Results

Catches of bocaccio tend to be distributed along the trench of Goose Island Gully and along the shelf edge of the outside islands (Figure 42). Bocaccio were mainly taken at depths from 110-210 m and have been taken in both of the selected strata (Figure 43).
Estimated biomass levels for bocaccio from the QC Sound shrimp trawl survey are small and highly variable, with CVs ranging between 43% and over 100% (Figure 44; Table 43). No bocaccio captured in the 2007 survey (Table 43). The proportion of tows with bocaccio is consistently low in Stratum 109, with values from 2-10% (Figure 45). There are usually fewer than 10 tows in Stratum 110 (Table 42) and this stratum tends to sample more shallow depths (Figure 43). However, bocaccio appear to occur relatively more frequently in the tows from this stratum, although this proportion is highly variable (Figure 45).

NMFS Triennial Trawl Survey

Data Selection

Tow-by-tow data from the US National Marine Fisheries Service (NMFS) triennial survey covering the Vancouver INPFC region were provided by (Mark Wilkins, NMFS, pers. comm.) for the seven years that the survey worked in BC waters (Figure 46, Table 44) (see also Weinberg *et al.* 2002). These tows are assigned to strata by the NMFS, but the size and definition of these strata have changed over the life of the survey (Table 45). The NMFS survey database also identified in which country the tow was located (Table 46). This information was plotted and checked against the accepted US/Canada marine boundary: all tows appeared to be appropriately located with respect to country, based on the tow start position (Figure 46). The NMFS designations were accepted for tows located near the marine border.

All usable tows have an associated net width and distance travelled, allowing for the calculation of the area swept by the tow. Biomass indices and the associated analytical CVs for bocaccio were calculated for the total Vancouver INPFC region and for each of the Canadian- and US-Vancouver sub-regions, using appropriate area estimates for each stratum and year (Table 46 and Table 47). Strata that were not surveyed consistently in all seven years of the survey were dropped from the analysis (Table 44 and Table 45), allowing the remaining data to provide a comparable set of data for each year from 1989 onwards (Table 46).

The strata definitions used in the 1980 and 1983 surveys were considerably different than those used in subsequent surveys, particularly in Canadian waters (Table 46). Therefore, the 1980 and 1983 indices were scaled up by the ratio (1.24=9169 km^2/7399 km^2) of the total stratum areas relative to the 1989 and later surveys so that the coverage from the first two surveys would be comparable to the surveys conducted from 1989 onwards. The tow density was much higher in the US waters although the overall number of tows was approximately the same for each country (Table 46). This is because the size of the total area fished was about twice as large in Canadian waters than in US waters (Table 46).

Methods

The data were analysed using the equations in analytical methods described earlier in this section (Eq. 22-27). When calculating the variance for this survey, it was assumed that the variance and CPUE within any stratum was equal, even for strata that were split by the presence of the US/Canada border. The total biomass $\left(B_{y_i}\right)$ within a stratum which straddled the border was split between the two countries $\left(B_{y_{i_c}}\right)$ by the ratio of the relative area within each country:

Eq. 28 $$B_{y_{i_c}} = B_{y_i} \frac{A_{y_{i_c}}}{A_{y_i}}$$

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

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

Eq. 29 $$V_{y_{i_c}} = V_{y_i} \frac{A^2_{y_{i_c}}}{A^2_{y_i}}$$

The partial variance $V_{y_{i_c}}$ for country c was used in Eq. 29 instead of the total variance in the stratum V_{y_i} when calculating the variance for the total biomass in US or Canadian waters. CVs were calculated as in Eq. 26.

The biomass estimates (Eq. 25) and the associated standard errors were adjusted to a constant area covered using the ratios of area surveyed provided in Table 46. This was required to adjust the Canadian biomass estimates for 1980 and 1983 to account for the smaller area surveyed in those years compared to the succeeding surveys. The biomass estimates from Canadian waters were consequently multiplied by the ratio 1.24 (i.e. 9,166/7,399) to make them equivalent to the coverage of the surveys from 1989 onwards.

Biomass estimates were bootstrapped for 1000 random draws with replacement to obtain bias corrected (Efron 1982) 95% confidence regions for each year and for three area categories (total Vancouver region, Canadian-Vancouver only, and US-Vancouver only) based on the distribution of biomass estimates and using the above equations.

Results

One very large tow in US waters during the 1989 survey characterises this series (Figure 47). The northern extension of the survey has varied between years (Figure 47). This difference has been compensated for by using a constant survey area for all years. Coverage by depth has been consistent for all seven years of the survey (Figure 48). This plot shows the relative size of the single large tow in 1989 relative to all other tows which took this species over the range of seven surveys.

The biomass estimates and the associated annual CVs obtained from the above methods show a decreasing trend for the Canada-Vancouver sub-region (Figure 49). The single large tow in US waters in 1989 completely dominates the trends for the US Vancouver and the total Vancouver INPFC regions. All surveys have very imprecise CVs, ranging from a minimum 30% in the Canada Vancouver region in 1998 to over 100% for the 1989 US Vancouver region (Table 47). Six of the surveys have CVs greater than 80%, indicating that the confidence in this series must be low. Note that the bootstrap estimates of CV do not include any uncertainty with respect to the ratio expansion required to make the 1980 and 1983 survey estimates comparable to the 1989 and later surveys. Therefore, it is likely that the true uncertainty for this series is even greater than estimated.

Eighty-seven of the 697 tows in this data set caught bocaccio over the entire history of the survey. The proportion of tows which contain bocaccio has been highly variable, declining from 20% to 5% in Canadian waters while showing no trend in U.S. waters (Figure 50).

During the PSARC review, an external reviewer, Dr. Ian Stewart of the U.S. Marine Fisheries Service noted that:

The 2007 U.S. canary rockfish stock assessment (Stewart, 2007) identified a previously unexplored shift in the dates over which the U.S. Triennial survey had been conducted, with the years including and subsequent to 1995 being conducted roughly a month earlier in the summer than earlier years.

Indirect information from other data sources in that assessment indicated that catchability might have been reduced by as much as 50% in these later years, and the time-series was therefore separated into two portions with separate catchability parameters. Since the sensitivity of this bocaccio assessment is relatively large (Alternate G-2 roughly doubles the estimate of current relative stock status), it may be worth evaluating whether this survey has the same effect when separated into two time-periods. Further, evaluation of the timing of all surveys included for trends in dates of operation may be warranted.

The authors were not aware of the timing issue during the analysis, nevertheless, we have no reason, *a priori*, to think that surveys centered on mid-July should have different catch rate than surveys centered on August 15. If we were to split the results into two time series and treat as different surveys, it may remove the "depletion" signal that the Triennial survey currently inputs to the model. The results of this run could be presented as an optimistic scenario, but we see little that would be gained by this exercise beyond what has been presented in Sensitivity Run G.2. Unless we were aware of a strong July vs. August impact on the relative catchability of bocaccio, we have no reason to alter the "Reference" case run.

With respect to early years being biased, the U.S. work on reconstructing the Triennial survey indicated that the trawl net was not always on the bottom in the early years. Thus, catch rates in early years were potentially biased downwards. If we could correct for this effect, the series would likely indicate a greater depletion over the period. However, the model already has difficulty matching the size of the decline in the original values of the survey (see Figure 17).

We did not attempt to accommodate this issue in the analysis for three reasons. First, we have no correction factor to use that is specific to bocaccio or semi-pelagic rockfish. Secondly the U.S. analysis was confined to the impact of this bias on benthic species, so it has not been demonstrated that the impact was significant for adult rockfish. Thirdly, there are only 7 available data points and we doubt this is sufficient information to separate this effect from other processes operating in this survey. We note that the two issues raised about the Triennial survey tend to counteract each other.

Groundfish Synoptic Surveys

Methods

The Canadian Groundfish Research and Conservation Society (CGRCS) and DFO initiated four large scale synoptic bottom trawl surveys starting in 2003 (Figure 51,Table 49). These surveys use the Atlantic Western IIA (AWII) bottom trawls nets and a random stratified design (Stanley et. al. 2007). Bocaccio biomass in any year y was obtained using the methods provided in Equations 22-27. One thousand bootstrap replicates with replacement were made on the survey data to estimate bias corrected 95% confidence regions and relative error for each survey year (Efron 1982).

Data Selection

Unlike the Shrimp and US surveys, these recently initiated surveys have used a consistent methodology so no additional filtering of the tows was required.

Results

Catch Rates

A summary of the catch rates by depth for all four surveys is provided in Figure 52 and the distribution of catches by locations for all four surveys is provided in Figure 53 to Figure 56. Biomass indices with 95% confidence limits are provided for all years for all surveys in Figure 57.

Method for Estimating Untrawlable Bottom in the Groundfish surveys

Estimates of the per cent untrawlable bottom of each survey were used in the estimation of trawl catchability (Appendix F). The survey area is divided into 4km^2 blocks within each depth stratum. Blocks are chosen at random for each survey and then evaluated during the survey by the Captain (see Stanley *et al.* 2007). If the bottom topography of the block is thought to present to great a risk of losing the gear, then the block is classified as untrawlable. Since each block in the first year was chosen randomly we can determine an unbiased estimate of the proportion of blocks that is untrawlable. The estimate can then be updated with additional observations in subsequent surveys. While blocks that are deemed untrawlable are permanently removed from the sampling frame and thus the sampling with respect to estimating untrawlable ground is now biased, an updated and unbiased estimate can be derived using Maximum Likelihood theory.

Take a hypothetical example in which there are N_1=6000 potential survey locations. In the first instance, m_1=300 sites may be chosen at random. If, for example, u_1 = 30 turned out to be untrawlable, then a binomial likelihood function can be applied to estimate p_1, the fraction of untrawlable sites:

Eq. 30 $u_1 \approx Binomial(p_1, m_1)$

In the second year, the total number of sample locations is adjusted to $N_2 = N_1 - m_1$ = 5970. In this year another n_2 = 300 sites were chose at random from the 5970 possible sites. If, for example, u_2 = 27 turned out to be untrawlable. In this instance, the probability of there being a nontrawlable location is adjusted as follows:

Eq. 31 $p_2 = {(p_1 \times N_1 - u_1)}\big/{(N_1 - u_1)}$

The likelihood function for this second sample could also be approximated by a binomial likelihood function:

Eq. 32 $u_2 \approx Binomial(p_2, m_2)$

In the third year, the total number of sample locations is again adjusted to $N_3 = N_2 - m_2 = 5970-27 = 5947$. In this year another $n_3 = 300$ sites were chose at random from the 5947 possible sites. In this instance, the probability of there being a nontrawlable location is adjusted as follows:

Eq. 33 $$p_3 = {(p_1 \times N_1 - u_1 - u_2)}\Big/{(N_1 - u_1 - u_2)}$$

The likelihood function for this second sample could also be approximated by a binomial likelihood function:

Eq. 34 $$u_3 \approx Binomial(p_3, m_3)$$

We can thus estimate p_1 by maximizing the joint likelihood function from the three binomial likelihood functions (Table 51).

In this assessment, we incorrectly estimated the percent untrawlable by simply pooling the data from the years. This mistake was found to late to be corrected for this assessment but a comparison of the two methods indicates that impact is negligible with respect to the analysis and advice provided in this document (Table 52).

Appendix F. Survey Catchability

Introduction

To help bound Bayesian posteriors for carrying capacity, stock biomass, and related quantities, we developed and applied a methodology to formulate a prior probability density function (pdf) for the constant of proportionality that scales total B.C. stock biomass to the survey biomass index for each area. We called this constant of proportionality, q_{gross}. q_{gross} includes three inter-related factors that affect the constant of proportionality for each survey index:

*q-gross = q-availability * q-trawlable* q-net*

where:
- *q-availability* is the fraction of coast-wide exploitable biomass indexed by a given survey (the proportion of the coastwide biomass in the survey area);
- *q-net* reflects the fraction of exploitable biomass within the horizontal path (i.e., between the trawl doors) of a given type of survey net that is on average captured by the net.
- *q-trawlable* accounts for the relative difference in bocaccio density between trawlable and untrawlable areas and the fraction of the surveyed area that is trawlable. For two of the surveys, an additional factor was applied to adjust *q-gross* to account for the use of the distance between the trawl wingtips instead of the distance between the doors in the swept area biomass estimate.

These different factors are detailed below.

q-availability - The fraction of Total Exploitable Bocaccio in Each Surveyed Region

We applied the following protocol to approximate the percentage of the coastwide exploitable biomass that is available to each of the surveys. This protocol included the following assumptions:

1. The relative distribution of stock biomass among areas has been relatively constant over time.
2. The total stock biomass within each surveyed region has been relatively constant between 2003 and 2007.
3. The proportion of untrawlable area to trawlable area within a surveyed region varies among regions and can be approximated from the observed frequencies of trawlable and untrawlable sites in the large number of randomly allocated survey locations in each survey area.
4. The ratio of bocaccio density in trawlable and untrawlable areas is equal across areas.
5. The habitat for bocaccio rockfish is assumed to be the surface area between 100-300 m in depth.

Building on the above assumptions, we assumed that the proportion of the coastwide stock biomass available to each survey is the ratio of the swept area biomass (adjusted for trawlable area) estimated during the recent Groundfish surveys divided by a coastwide estimate of bocaccio exploitable biomass. This was the sum of the biomasses observed in each survey area plus an estimate from the unsurveyed area using a global estimate of density from the surveys.

For the non-DFO groundfish surveys, we estimated biomass present in the areas covered by these surveys based on densities observed in 2003-2007 Groundfish surveys. Note that the regions covered by both shrimp surveys and the triennial surveys lay within the Groundfish surveys (Appendix E). For example, the biomass available in the WCVI Shrimp trawl survey is based on the density observed in the tows conducted during the Groundfish WCVI survey, within the area covered by the shrimp survey.

The standard error in the average of the natural logarithm of the available annual swept area biomass estimates for each region (Table 53) was computed and applied in the simulation model to generate samples of potential stock biomass in each region and the potential fraction of total stock biomass in each region. Some of these SEs were very large and this created large uncertainty in fraction of stock biomass in each of the regions.

As the average catch per tow is based on tows over trawlable bottom, the swept area estimate was adjusted to account for the estimate of the fraction of trawlable area in the survey area and the average relative difference in bocaccio density between trawlable and untrawlable bocaccio habitat (see below for the derivation and equations applied).

The swept area estimate for unsurveyed regions was obtained from stratified estimates of density from trawled areas and the estimated habitat area outside of surveyed areas. “SE ln(bio)” is the standard error in the mean of the natural logarithm of swept area estimates of stock biomass in each region with the mean taken from swept area estimates in different years. “% trawlable” is the estimate of the percentage of the region that was found to be trawlable based on random sampling of locations in each region for trawling and large sample sizes (>500 sites in each region).

q-trawlable – Differences in Density Between Untrawlable/Trawlable Areas

Trawl captains and groundfish researchers believe that the density of bocaccio is higher over untrawlable bottom than trawlable bottom. These opinions are based on the tendency for catch rates for virtually all rockfish species to be higher on, or nearer, rougher bottom as well as the tendency for untrawlable bottom to be associated with a much stronger acoustic sign.

Currently, the swept area biomass estimates are computed by presuming that the average catch rate of survey hauls in a given area is a random sample of the entire survey area and multiplied by the total survey area to provide the biomass index for the survey area. In this section, we derive a bias correction factor to account for the relative difference in bocaccio density between bottom trawlable and untrawlable areas in a surveyed area and the fraction of the surveyed area that is untrawlable. We begin with an expression for the true bocaccio biomass ($B_{true,\,a}$) in a given area a. In this and the following equations we drop the subscript a for area.

Eq. 35 $B_{true} = d_T \; A_T + d_{UT} A_{UT}$

where d_T and A_T are the true density and area in the trawlable zones of the survey region and d_{UT} and A_{UT} are the density and area of untrawlable zones. This can be expanded to:

Eq. 36 $B_{true} = d_T f_T A + d_{UT}(1 - f_T)A$

where f_T is the fraction of the total survey area A that is trawlable. Rearranging, this becomes:

Eq. 37 $B_{true} = (d_T f_T + d_{UT}(1 - f_T))A$.

The expected value for the survey index, if it were sampling in both trawlable and untrawlable habitats can be expressed as:

Eq. 38 $E(I_{TUT}) = q_n s\ B_{BC}$

where s is the fraction of the total B.C. bocaccio stock biomass (B_{BC}) present in the surveyed area. This can also be expressed as:

Eq. 39 $E(I_{TUT}) = q_n(d_T f_T + d_{UT}(1 - f_T))A$

This can be restated as:

Eq. 40 $E(I_{TUT}) = q_n(d_T f_T + \alpha\ d_T(1 - f_T))A$

where α is the ratio of bocaccio density in untrawlable to trawlable habitat.
The last equation can be rearranged to:

Eq. 41 $E(I_{TUT}) = q_n d_T A(f_T + \alpha\ (1 - f_T))$.

In contrast, the expected value for the survey biomass index when computed from tows only in trawlable habitat is:

Eq. 42 $E(I_T) = q_n d_T A$.

It can be deduced then that:

Eq. 43 $E(I_{TUT}) = E(I_T)(f_T + \alpha\ (1 - f_T))$

and

Eq. 44 $E(I_T) = \dfrac{E(I_{TUT})}{(f_T + \alpha\ (1 - f_T))}$.

This can also be expressed as:

Eq. 45 $E(I_T) = \dfrac{q_n s\, B_{BC}}{(f_T + \alpha\,(1 - f_T))}$.

We can let:
Eq. 46 $g = f_T + \alpha\ (1\text{-}f_T)$,
where f_T is the fraction of area in a stratum that is trawlable and α is the ratio of bocaccio density (t/km^2) in untrawlable area to trawlable habitat. If we set $f_T = 0.75$ and α at 3, we then obtain $g = 0.75+3*0.25 = 1.5$. This means that without accounting for the difference in fish density between trawled and untrawled areas, the true biomass would, on average, be 1.5 times the computed survey biomass value.

While it is plausible that the factor α varies with survey area, we do not have any information that would allow us to estimate this factor by survey area. We thus presume a single prior for α for all survey areas. However, we have data on the fraction of trawlable area for each survey area and can thus compute factor g for each survey area. Factor g, thus becomes:

Eq. 47 $g_a = f_{T,a} + \alpha\ (1\text{-}f_{T,a})$.

In the q prior model we treated the factor α as a random variable, with a triangular distribution of minimum 1, maximum 10, and mode at 3[27]. f_T is provided by survey area (Table 53) and treated as known since the number of sites sampled per survey area is high in all areas (300-1,000 depending on the survey area). f_T in areas where there are no surveys is presumed to be 0%.

Note that the factor s, the fraction of the total B.C. bocaccio stock biomass (B_{BC}) in the surveyed area, also needs to account for $f_{T,a}$ and α for each area. The fraction of total stock biomass in a given area a, can be obtained by:

Eq. 48 $s_a = \dfrac{I_{T,a}(f_{T,a} + \alpha\,(1 - f_{T,a}))}{\sum_{j=1}^{n_{areas}} I_{T,j}(f_{T,j} + \alpha\,(1 - f_{T,j}))}$.

In the q simulation model, $I_{T,\mathrm{a}}$ and α are treated as random variables as described above using the values in Table 53. f_{T} is treated as fixed and known and values for it are specified in Table 53.

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[27] The authors noted subsequent to the review, that Mathews *et al.* (1989) compared gillnet catch rates between "untrawlable and trawlable bottom" and reported that the catch rate of bocaccio over untrawlable bottom was 1.4 times higher than that over trawlable bottom. Therefore, this comparison would suggest a prior triangular distribution intermediate between the Reference Case and the F2 runs presented in the current document. Future analyses might consider a prior triangular distribution such as 1, 1.4, and 5 for the reference case.

q-net – The Fraction of Bocaccio in the Net's Path That Can be Captured

The long history of attempts to estimate trawl catchability (*q-net*) directly has met with limited success especially for rockfish. The principal difficulty lies in assessing the actual abundance that initially lies in front of the doors, let alone the net. Krieger and Sigler (1996) attempted to estimate catchability of Pacific ocean perch (*S. alutu*s) for a bottom trawl relative to observations from a submersible. They reported estimates of 0.97-1.27 for trawl catchability based on wingtip spread. Given the reported ratio of doorspread to wingspread of 15.8m/45.0m, this converts to a doorspread catchability of 0.34-0.45 for Pacific ocean perch. Korotkov (1984) used an underwater camera-mounted sled towed in front of the trawl to ground truth actual abundance. This work indicated a doorspread catchability of 0.1-0.4 for unspecified species of groundfish.

The Northwest Fisheries Center (NMFS) in Seattle spent many years attempting to estimate catchability of the trawl used in the west coast groundfish surveys. Their most successful work was with flatfish for which they observed maximum door-spread catchability for large arrowtooth flounder (*Atheresthes stomias*) of 0.47 (Somerton *et al.* 2007, K. Weinberg, NMFS, pers. comm.).

Millar and Methot (2002) attempted hierarchical modelling of trawl survey catchabilities for rockfish based on the U.S. triennial survey. The log transformed mode in the posterior PDF of "bulk" catchability equated to about 1.27 between the wingtips. The ratio of doorspread to wingspread ratio for this survey is not available, but is probably similar to the approximately 5:1 ratio of the Atlantic Western IIA configuration used in the DFO Groundfish surveys. This translates to a catchability estimate of about 0.25. It is worth noting, however, that U.S. Assessment teams do not use these estimates in their assessment models.

Due to lack of experimental data on bocaccio catchability, expert judgment from B.C. groundfish trawl captains was sought to characterize knowledge and uncertainty about the potential factors affecting *q-net* for bocaccio rockfish for the three types of survey nets. All captains had experience (11-22 years) with the types of trawls used in the DFO Groundfish and U.S. triennial surveys (Table 54.). One captain fished with the shrimp trawl used in the DFO shrimp survey.

Captains 1 and 2, and 3 and 4, were interviewed in pairs, the remaining captains were interviewed separately. The selection of candidates was *ad hoc*. An attempt was made in each interview to provide the same explanation although the interview was conducted in a conversational format. Interviews undoubtedly varied in subtle ways over the course of the 12 interviews (Tables 55, 56, and 57).

All captains expressed concern about their answers. They commented that there had been few opportunities in their careers to compare actual catches with acoustic sign for bocaccio. Three captains said that they could not provide an estimate for at least one question. All captains expressed that they would have been more comfortable estimating these values for other schooling rockfish, particular yellowtail rockfish (*S. flavidus*) and widow rockfish (*S. entomelas*). Furthermore, they commented that for bocaccio as well as other species, catchability would be influenced by factors such as location and bottom type, time of day, and whether the fish were in large schools or stragglers.

We assume that a trawl net captures less than 100% of the fish that lie in its path defined over the horizontal as the path between the trawl doors over the vertical from surface to bottom. Fish can escape for a variety of reasons including, but not limited to (Figure 58):

1. fish that are initially up in the water column which do not "dive" to lie below the headrope of the trawl.
2. fish that are near bottom but driven away horizontally by the influence of the warps.
3. fish that are initially in front of the paths of the sweeps and bridles but are not herded into the path of the net.
4. fish that escape over the headrope or under the footrope.
5. fish that have been captured in the last few minutes of the tows and escape during retrieval (note that Groundfish survey tows are usually 19 minutes).

The probabilistic modeling approach that was applied to synthesize the captains' inputs was similar to that taken by Uusitalo *et al.* (2005) and Martin *et al.* (2005) to formulate priors based on interviews with several different experts. For each net, the resulting *q-net* was modelled as a mixture of the distributions resulting from the specifications from each of the interviewed captains. The 12 captains were asked to specify most likely, minimum plausible, and maximum plausible average values for a set of key factors conjectured to determine *q-net*. The minimum, most likely and maximum points supplied for each factor for each survey net by each captain were used to formulate a triangular distribution for each factor for each survey net as specified by each captain.

The *q-net* refers to that component of catchability that is determined by the interaction between trawl fishing gear and fish in the horizontal path between the trawl doors. It is assumed that:

1. *q-net* is constant among areas for the same type of trawl net.
2. *q-net* represents fishing during a bottom trawl survey, as opposed to commercial fishing. We characterize "typical survey fishing" to occur on average:
    a. at 150 m depth;
    b. from June to July;
    c. from 1 hr after sunrise to 1 hr before sunset.
3. the component factors of *q-net* specified below refer to "average" effects. The minimum and maximum values do not reflect a predicted response for 1 case (the population of all tows), but the minimum and maximum likely estimates for all tows combined (central tendency). We have attempted to define the distribution of the mean, not the population to help shape the PDF.
4. *q-net* does not vary with abundance.

Steps involved in partitioning the process of catching a bocaccio.

1. Resolve the Relative Distribution in the Water Column

Question 1): What is your best estimate (and minimum and maximum) of the percent of bocaccio that would to be near-bottom (within 3-4 fm) as the vessel passed overhead?

Bocaccio are thought to occupy the water column from surface to bottom, with density increasing with depth. The factor, a_1, for the relative distribution of bocaccio in the water column (Figure 58: Area A, Table 55):

1. defines the proportion of fish below the headrope, prior to the vessel passing over the fish.
2. assumes that fish below the headrope at the beginning, stay below headrope until they arrive at mouth of net.
3. assumes fish outside doors (horizontally), stay outside the doors.
4. assumes that a_1 is the same for all nets; although headrope opening varies from 2.7-7.1m, the variation is small compared with overall depth.

2. Resolve the Proportion of Off-Bottom Bocaccio That "Dive" Into the Kill Zone

Question 2): What percentage of those initially "up in the water" would dive into the kill zone?

The factor, a_2, is the proportion of fish in Area B that would dive into the kill-zone from those initially above the head rope (Figure 58: Area B, Table 56). Factor a_2 assumes that:

1. all fish that start below the headrope, stay below the headrope until at the mouth of the net.
2. fish dive in response to vessel noise and warps.
3. dive rate is equal for all net/warp/vessel combinations

3: Resolve the Proportion of Fish Which Lie in the "Dead" Zone Between the Doors but are "Trapped" Between the Warps and the Doors

The answers to Questions 1 and 2 provided the percentage of fish that were initially in the path of the trawl doors that would lie in the capture zone as the doors approach (between the doors and within 3-4 fm of the bottom) (Figure 58: Area C-D). The disposition of the fish would then be partially determined by whether they lay directly in the path of the net between or outside the wingtips but still within the door path. Fish in area C were assumed to stay in the capture zone as the net approach (Area E). Fish in D would have to be herded inwards to Area C by the sweeps and bridles..

However, discussions with some captains indicated that for fish which lie within 6 m of doors and within the doorspread path have zero catchability (Figure 59). As the trawl warps approach the doors near the bottom; they angle out towards the doors, possibly scaring fish away from the kill-zone. Therefore, as the doors approach the fish, the fish are assumed to be distributed across the path of the doors in one of three sectors, in proportion to the linear dimensions.

1. in the path of net (i.e. between wingtips, Figure 59: Area C)
2. in the path of the sweep/bridles but more than 6 m inside of the door path (herding zone (Figure 59: D1) (factor $a_{3,1}$).
3. in the path of sweep/bridles but within 6 m the doors (Figure 59: D2).

[1] Captain #1 commented that his estimate of herding referred to those fish which were in "live zone". He had already considered that fish in the "dead zone" had escaped.

4. **Resolve Arithmetic Correction for the Relative Proportions Remaining in Front of the Net (Between Wingtips) or in Front of Sweeps/Bridles (Inside of Dead Zone)**

After allowing fish in dead-zone to escape, we estimated the proportions of remaining fish that either lie in front of the net (Figure 59:C) or the "herdable" section of the sweep/bridles (Figure 59:D1).

5. Proportion of fish that will be herded from path of the sweep/bridles (Area D1) to lie in front of the path of net (Area C)

Question 3): What percentage of the fish in front of the bridles and sweeps would be herded into the path of the net?

This factor, a_6, concerns the remaining fish in sweep/bridle path (Table 57, Table 58, Table 59). Only one of the captains presumed that a_6 proportion reflected the proportion of fish between the dead zone and the path of the net that are herded into the path of the net. The rest of the captains presumed that this proportion reflected the fraction of fish between the doors and the path of the net that are herded into the path of the net. The doorspread of the Triennial Survey Nor-Eastern net was not measured. We have assumed this to be the same ratio of wingtip to doorspread as for the AW II net. Factor a_6:

1. assumes fish initially in front of net, stay in front of net.
2. is assumed to be the same for all nets.

6. Proportions of Fish that are Captured of Those that End up in Front of the Net

Question 4): What percentage of the fish that make it to Area E will be captured and retained by the:

1. *DFO Atlantic Western Trawl (3 knots and ~2 fm opening)?*
2. *U.S. Nor-Eastern trawl (3 knots and 3 fm opening)?*
3. *DFO shrimp trawl (2 knots and 1.5 fm opening)?*

Finally, of the fish that have ended up in front of the net (Figure 59: Area E in front of footrope), what percent will be captured and retained in the net (Table 60). For this question, each captain was asked for estimates for each of the three nets. The nets are towed at different speeds, have different vertical openings and, most perhaps most importantly, the mouth opening of the shrimp trawl does not have a "cape". Most groundfish trawls have a shorter headrope than footrope so that the headrope precedes the footrope through the water providing a "cape" or "hood". As a fish encounters the footrope, it cannot escape by swimming directly up. On the shrimp trawl, however, the headrope and footrope are virtually in line. Presumably, as bocaccio sense the proximity of the shrimp trawl mouth opening, the net front is effectively a 4 m vertical "wall" of footrope, disturbed sediment, and headrope. It is reasonable some bocaccio would escape vertically. By the time a bocaccio encounters the groundfish foot rope, however, it is surrounded on four sides (wings, cape, and the bottom). We assume that none of the relatively large bocaccio escape through the net. The value for this factor, $a_{7,j}$ depends on the net.

- $a_{7,1}$ - AW II (vertical = 3.7 m, wingspread 14.4)
- $a_{7,2}$ – Triennial/Nor'Eastern (vertical = 7.1 m, 13.4)

- $a_{7,3}$ – Shrimp trawl (vertical = 2.7 m, 10.6)

Conversion of U.S. Triennial and WCVI Shrimp Indices to Door-Spread Estimates

A further adjustment factor was applied for the U.S. Triennial and shrimp trawl nets because the swept area estimates obtained for these nets applied to the wingspread and not the doorspread (Table 61. The ratio of wingspread to doorspread the U.S. Triennial and the shrimp trawl nets was ($a_{8,n}$).

Steps in the Algorithm to Compute a Prior PDF for Survey Catchability

WinBUGS 1.4 (Spiegelhalter *et al.* 2003) was applied to synthesize the inputs from the trawl captains and other technical settings and to produce output density functions for the *q-gross* values for each of the surveys. The steps of the algorithm applied are provided below.

1. Draw a value for the ratio of fish density in untrawlable to trawlable areas, α. This is a triangular distribution with the mode at 3, and a minimum and maximum value of 1 and 10.

2. Draw a value for swept area biomass in each of the eight coastal areas, using the lognormal density function and the swept area value as the mean and the standard error value in (Table 53) for the variance in the natural logarithm of the estimate.

Eq. 49 $$I_{T,a} \sim \log normal\left(\ln\left(I_{T,a}^{med}\right), SE_a^2\right)$$

3. The median for the lognormal density function, $I_{T,a}^{med}$, was computed from the swept area biomass estimate ($I_{T,a}^{Sw.A.}$) and SE values in Table 53 before inputting it into the WinBUGS data input file:

Eq. 50 $$I_{T,a}^{med} = \text{mean}(I_{T,a}^{Sw.A.}) * \exp(-SE^2/2).$$

Note that in the few instances in which the SE was less than 0.15 in Table 53, this value was set to 0.15, since it was believed that the uncertainty in a relative stock size in a given area could have a CV of no less than about 0.15. Using equation 48, compute the fraction of total stock biomass in each area. First multiply the lognormal random variable for swept area biomass values from equation 49 by the correction factor (equation 47) for trawlable to untrawlable area for each survey area, using the random variable for α that was generated in step 1, and the inputted values for the fraction of trawlable area in each of the survey regions $f_{T,a}$. Then compute the fraction by dividing the result by the sum of the adjusted swept area biomass values.

4. For each captain draw a value for the proportion of fish below the headrope (a_1) using the parameters of the triangular distribution provided by each captain.

5. For each captain draw a value for the proportion of fish above the headrope that stay above the headrope as the net approaches (a_2), using the parameters of the triangular distribution provided by each captain.

6. For each captain, compute the proportion of fish going into path of the net and doors from those in the water column that are in the path of the net and the doors. The following equation is applied for this:

Eq. 51 $a_{1.2,s} = 1 - (1 - a_{1,s})*a_{2,s}$

7. For each captain, draw a value for the proportion of fish that will successfully be herded from the path of sweep/bridles to path of net (one captain) or herded from the path of the doors to the path of the net (the other captains) ($a_{6,s}$). To do this, use the parameters of the triangular distribution provided by each captain.

8. For each captain, compute the fraction of fish between the doors that end up in front of the net given the proportion of doorspread that is between the wingtips ($a_{3,1}$) (step 3 above), in the dead zone ($a_{3,2}$), between the dead zone and the wingtips (of the area not in the dead zone) (a_4), between the wingtips (of the area not in the dead zone), (a_5) and the fraction of fish herded into the path of the net ($a_{6,s}$).

For the captains that conditioned herding on the zone between the doors and the wingtips, the equation utilized is:

Eq. 52a $a_{3\text{-}6,1,s} = (1\text{-}a_{3,1}) \times a_{6,s} + a_{3,1}$.

For the captain that conditioned herding on the area not including the dead zone, the equation utilized is:

Eq. 52b $a_{3\text{-}6,2,s} = (1\text{-}a_{3,2}) \times (a_4 \times a_{6,s} + a_5)$.

9. For each captain and net type (Nor'Eastern, AWII and shrimp trawl), draw a value for the proportion of fish that are captured of those end up in front of the net ($a_{7,n,s}$). To do this, use the parameters of the triangular distribution provided by each captain for each net type.

10. Compute q_{net} for each captain and net type:

Eq. 53 $q_{net,n,s} = a_{1.2} \times a_{3\text{-}6,s} \times a_{7,n,s}.$

11. To ensure that the density functions are not overly precise, apply a multiplicative uncertainty factor, $U_{n,s}$, to each $q_{net,n,s}$. An uncertainty factor was drawn from a lognormal density function with a CV of 0.5 and a median of 1 for each captain and net type.

12. Compute the *q-gross* for each survey for each captain:

Eq. 54 $q_{gross,n,s} = q_{net,n,s}\ x\ U_{n,s}\ x\ S_s\,/\,(g_s \text{ x } a_{8,n})$

where $U_{n,s}$ is the uncertainty random variable for each net type and captain, $q_{avail,a}$ is the random variable for the fraction of exploitable stock biomass in region a, g_a is the random variable accounting for trawlable area in survey area s, and $a_{8,n}$ is the fixed correction factor applied where the wingtip distance had been applied to compute the swept area biomass.

13. Give each captain's q_{gross} equal prior weight in the final q_{gross} distribution such that the chance of including a given captain's input has equal prior probability. A twelve dimensional Dirichlet density function with the all 12 input parameters for this density function set to 0.5 was applied as the multivariate prior pdf for the relative weight give to each captain's *q-gross* distribution for a given survey. In each Monte Carlo iteration, one of the twelve captain's *q-gross* values was randomly chosen for the *q-gross* random variable for each of the seven research surveys. Thus, without any Bayesian updating with new data, each captain's inputs are given equal weight in the output probability distribution *q-gross* for each regional survey.

14. Use observations of catch rates from the DFO shrimp trawl and groundfish surveys in areas where these tows co-occur to update the $q_{net,s}$ density functions for the AW II and shrimp trawl nets (Table 62., Figure 60 and Figure 61). Both survey gears were applied in the same years in the survey area of the WCVI shrimp survey and the QCSd shrimp survey. The observed mean ratio of bocaccio density between the trawl and shrimp survey nets for QCSd for the years 2003-2007 is 8.76 with a SE in the natural logarithms of the estimates of 0.59. The observed mean ratio for density estimates for the WCVI shrimp survey region between the groundfish and shrimp nets for the years 2004 and 2006 was 3.95 with a SE of 0.116. This latter CV was increased to 0.3 for the statistical estimation, since it was judged unlikely that the precision could be so high and there were only two years of survey data to provide this estimate. In each Monte Carlo iteration, the natural logarithms of the computed *q-net* values chosen for the shrimp and groundfish surveys were taken and differenced. This was used as the expected log ratio for these survey catch rates for these two types of trawl nets. A lognormal density function was then applied to compute the probability of the observed ratio given the model predicted ratio of q_{net} for these two types of survey net:

Eq. 55 $lrGF\_SH = log(q_{net,1}) - log(q_{net,2})$

Eq. 56a $rWCVI\_ob \sim lognormal(lrGF\_SH\ ,0.30^2)$

Eq. 56b $rQCS\_ob \sim lognormal(lrGF\_SH\ ,0.59^2)$

where subscripts 1, and 2 denote the DFO groundfish survey, shrimp survey nets, respectively, rWCVI_ob and rQCS_ob are the observed ratio of density values from groundfish and shrimp nets for WCVI and QCSd respectively. The observed ratios of densities for the DFO groundfish to shrimp groundfish trawl nets thus gave more weight to captain inputs that were more consistent with the observed ratios for these two survey net types.

15. Repeat the above 14 steps or MCMC iterations multiple times, apply diagnostics to remove the burn-in and summarize the posterior results.

16. Since the *q-gross* distributions for the different survey regions utilized identical input values for *q-net* across survey regions, the *q-gross* variables tended to be highly correlated across survey regions. Although there was the potential for multi-modality in the marginal density functions for *q-gross* for the different survey areas, all were uni-modal and in all instances positively skewed. Thus, a multivariate lognormal density function was formulated to summarize the joint prior density function for *q-gross* for the six survey time series used in the stock assessment.

The Gelman-Rubin (Gelman and Rubin 1992) statistic was applied to assess the burn-in period which was judged to be about 500 iterations. A total of 40,000 iterations with two chains were judged to be sufficient to provide precise approximations of the target density function. Using the results after the burn-in, the ratio of MC error to the posterior SDs for all outputted variables was far less than the minimum standard of 5%.

Results

The posterior mean and median estimates, standard deviations, and 95% probability intervals (PIs) for *q-gross* for the seven different surveys that capture bocaccio rockfish are shown in Table 63. The same statistical metrics from the log transformed *q-gross* value outputs are also shown in Table 64. These are the values utilized for the lognormal parametric approximation of the *q* prior model outputs. Surveys with the largest swept area biomass values tend to have the largest values for *q*, as expected. The posterior sds range from about 80% to up to about six times larger than the posterior means, indicating large uncertainty in the values for *q-gross*. The values for exp(mean(ln(*q-gross*))) were very similar to the median values for *q-gross* for each survey suggesting that a log normal density function is a reasonable parametric approximation of the empirical output distributions for *q-gross* from the *q* prior model. The SD in the natural logarithm of the *q-gross* values ranged from about 80% to about 240% of the mean.

All of the marginal density functions for *q-gross* were unimodal and highly positively skewed (Figure 62 and Figure 63). The *q-net* output distributions were also unimodal and highly skewed (Figure 64). The posterior correlation and covariance matrices for *q-gross* are shown in Table 65. Due to the common random variable inputs to the *q-net* variable making up *q-gross* for surveys and the use the same net in different survey areas, the posterior correlation was in several instances very high and positive. The observed ratios of catch rate observations for the AWII and shrimp trawl nets markedly updated the relative weighting of the captain inputs, with some captains' inputs being heavily downweighted, leaving only about four captains' inputs carrying the bulk of the weight (Figure 65).

When no uncertainty factor was applied but Bayesian updating was still applied, the marginal density functions for *q-gross* were slightly more precise and show very similar central tendencies to the reference case (Figure 66; Table 66).

The output distributions for *q-net* show distinct multimodality when no uncertainty factor is applied (
Figure 67). The marginal posterior for each captain's inputs is very similar to the reference case (Figure 65 and Figure 68).

When the uncertainty factor was applied and Bayesian updating was removed, the marginal density functions for *q-gross* were less precise and the central tendencies for the shrimp *q-gross* values were about 75% higher than the reference case while the DFO AWII nets were about 94% of the reference case (
Figure 69, Table 66). The output distributions for *q-net* are less precise and show unimodality (
Figure 70). The marginal posterior for each captain's inputs shows equal weighting by captain (Figure 71). When no uncertainty factor is applied and Bayesian updating was removed, the marginal density functions for *q-gross* had precision similar to the reference case but the central tendencies for the shrimp trawl survey *q*s were about 75% larger than the reference case (Figure 72, Table 66). The output distributions for *q-net* are less precise and show highly pronounced multi-modality (
Figure 73).

Appendix G. 2008 Stock Assessment and Projections

Introduction

This appendix summarizes the assessment methodologies developed to estimate population dynamics parameters, historic trends in population biomass, and population projections under current and alternative stock recovery policy options. Due to the paucity of age-structured data, a non-equilibrium age-aggregated surplus production model was used to assess this stock (McAllister *et al.* 2001a). A state-space version incorporating stochastic process error in the fish stock dynamics (Meyer and Millar 1999) permitted more thorough accounting for uncertainty in estimates of stock biomass, stock projections, and deviations from deterministic recruitment.

A Bayesian statistical approach was adopted to fit the model to data, allowing for the use in the model of informed priors which incorporate information and expert judgements. The Bayesian surplus production (BSP) model was fitted to available stock trend indices to evaluate historical trends in abundance of B.C. bocaccio and the potential future trends in abundance from alternative total allowable catch (TAC) policies. A prior probability density function (pdf) for a key parameter, the maximum intrinsic rate of increase, *r*, was formulated with a methodology that uses demographic data for the stock of interest (McAllister *et al*. 2001c) and estimates of the maximum potential recruitment per unit spawner biomass for U.S. bocaccio from a recent meta-analysis of stock-recruit data for Pacific rockfish (Dorn 2002). The BSP model uses records of domestic and foreign trawl, and hook-and-line (HL) catch (landings and discards) from 1935, and is fitted in separate runs to six fishery independent stock trend indices and one commercial catch rate stock trend index. Catch in the salmon troll and halibut (setline) fisheries back to 1935 is imputed using fishing effort data and independent estimates of catch for some historic years. Informative prior probability distributions for constant of proportionality for the research survey stock trend indices were formulated to reduce uncertainty in stock biomass estimates. Stock projections from 2008-2048 are carried out to evaluate the potential consequences for stock rebuilding under alternative fixed TAC policies.

Methods

Surplus production models (SPMs), which model surplus production and stock biomass and ignore age structure, are commonly applied in stock assessments. The most common implementation has been in the form of stock reduction analyses (SRAs) whereby the model projects from the fishery's beginning to the present using the entire catch time series and is fitted to stock trend indices. While this approach is potentially prone to bias from ignoring age-structured processes, evaluation studies based on age structured models to simulate data have shown that this relatively simple model can often reliably estimate stock abundance trends and provide reliable predictions of future stock trends (Ludwig and Walters 1985, Punt 1993, Kirkwood 1997). These results, combined with the simplicity of the model and the small number of parameters compared to age-structured models, have made it attractive to stock assessment scientists, especially when age-structured data and other information are sparse or unavailable while catch biomass and stock trend indices are available.

We use a version of the Schaefer surplus production function (Hilborn and Walters 1992) that applies continuous fishing mortality rate equations (Prager 1994):

Eq. 57 $$B_t = B_{t-1} + B_{t-1} r \left(1 - \frac{B_{t-1}}{K}\right) - C_t$$

where B_t is stock biomass in year t, r is the maximum intrinsic rate of increase, K is the average unfished stock size or carrying capacity, and C_t is the catch in year t. The estimation performance of a Bayesian version of this model was evaluated and found to perform acceptably under a range of conditions including misspecification of priors, providing that priors for key parameters, e.g., r and constants of proportionality for stock trend indices (q), were not overly precise and strongly biased (McAllister and Kirkwood 1998). This version will tend to provide more accurate representations of fish stock dynamics than a discrete harvest rate version, especially when fishing mortality occurs throughout the year and when exploitation rates are high. It is slightly more cumbersome because the annual fishing mortality rate (F_t) must be solved for numerically (in the discrete version, harvest rates are obtained analytically). For details on the BSP stock assessment methodology and software, we refer readers to McAllister and Babcock (2002) and McAllister *et al.* (1999, 2001a).
The state space version of the BSP is given by:

Eq. 58 $$B_t = \left(B_{t-1} + B_{t-1} r \left(1 - \frac{B_{t-1}}{K}\right) - F_{t-1} B_{t-1}\right) \exp\left(\varepsilon_t - \frac{\sigma_p^2}{2}\right)$$

where
the prior probability distribution for the process error term is given by
$\varepsilon_t \sim \text{Normal}\left(0, \sigma_p^2\right)$. ε_t from 1935 to 2008 were treated as estimated parameters and σ_p was set at 0.1, as well as 0.05 and 0.15 in two additional runs for a sensitivity test. This bounds the mean of the value for σ_p applied in Meyer and Millar (1999). No attempt was made to estimate the process error variance or observation error variance, due to the paucity of time series data that could inform estimates of variance in ε_y and low precision in most of the stock trend indices.

Prior PDFs for the Estimated Parameters

In all model runs, the parameters estimated included average unfished stock size or "carrying capacity" (K), the maximum intrinsic rate of increase (r), the stock size in 1935 relative to carrying capacity ($P_0 = B_{35}/K$), and the constant of proportionality for each stock trend index (q). The prior for K is uniform over a large range of values (i.e., between 500 t and 200,000 t). The upper bound was set at about three times the pre-fishery stock biomass estimates of assessed U.S. bocaccio (MacCall 2007). As there are no data to help estimate the initial stock size in 1935, relative to carrying capacity, an informative prior is assumed for P_0:

Eq. 59 $P_0 \sim \text{lognormal}\left(\ln(0.9), \sigma^2_{P_0}\right)$

It is reasonable to assume that the stock was not quite at unfished conditions in 1935, since while reported landings were very small (1-2 tons) in the 1930s, the effort in the salmon troll and halibut fleets was moderate to high during this period (Appendices A-C).

Both informative and non-informative priors for the constants of proportionality for stock trend indices (q) were applied. The prior density function for q that is proportional to $1/q$ is non-informative with respect to carrying capacity and stock biomass, i.e., if the data are uninformative, then the marginal posteriors or priors obtained for K and stock biomass are uniform density functions (Walters and Ludwig 1994). Informative priors for q were formulated for each swept area survey index based on auxiliary data and expert judgment of the various factors that contribute to scaling each swept area estimate of abundance to the coast-wide stock biomass (Appendix F). A multi-variate lognormal prior density function for q was applied to account for the positive skew and correlation in q between surveys in the Monte Carlo simulation results to compute a prior for q. See Table 66 and Table 67 for the summary statistics and prior correlation used for the joint prior on the survey q values.

We reformulated the demographic approach of McAllister *et al*. (2001a) for computing an informative prior pdf for r so that the inputs conform to those more commonly available for exploited fish stocks. The Euler-Lotka equation (Lotka 1907) is numerically solved for r with the integration over ages starting at age 0:

Eq. 60 $1 = \int_{a=0}^{\infty} l_a m_a \exp(-a \times r)\, da$

where l_a is the fraction of animals surviving from age 0 to age *a,* the fraction is set at 1 for l_0, and m_a is the number of age 0 offspring expected to be produced by an individual of age *a*

Eq. 61 $l_a = l_0 \exp\left(-\sum_{i=0}^{a-1} M_i\right)$

It can be shown that, providing that there is no reproduction in the first year, a computation in which the integration starts at age 1 and l_1 is set to 1 and m_a is specified in terms of age 1 recruits is analytically equivalent to equations Eq. 60. A discretized version of this is:

Eq. 62 $1 = \sum_{a=1}^{a_{\max}} l_a m_a \exp(-a \times r)$

Eq. 63 $l_a = l_1 \exp\left(-\sum_{i=1}^{a-1} M_i\right)$

where $l_1 = 1$ and a_{max} = the maximum age considered.
The formulation in equations 62 and 63 are more convenient for fisheries modelling. This is because most exploited fish species do not reproduce in their first year. Also, estimates of the number of age 1 recruits produced per unit of spawning potential (e.g.,

per ton of spawners) at spawner abundance approaching zero ($\tilde{R}_S$) and the expected mass-at-age of spawners, W_a, are more commonly available. In contrast, the corresponding conventional life table parameters, e.g., the annual survival rate of larval fish to 1-year-old and the expected production of larval fish per spawner, are much more difficult to estimate and estimates of these quantities are typically unavailable for fish populations.

The expected number of recruits produced per adult female of age *a*, m_a, is thus obtained by:

Eq. 64 $m_a = \tilde{R}_S W_a G_a$

where $\tilde{R}_S$ is the number of age 1 recruits produced per ton of spawners when spawner abundance approaches zero, W_a is the mass per fish of age *a* in tons, and G_a is the fraction of animals of age *a* that are mature.

The computation thus requires a value for the rate of natural mortality (*M*) for ages 1 and older (*M*), the fraction mature at age, the number of age 1 recruits produced per ton of spawners, and the mass per fish in tons for each age. A plus group was presumed at age 60 years. The *M* for females was treated as a lognormal random variable with a median of 0.075 yr^{-1} based on an analysis of proportion at age data aggregated from commercial catch and survey data. It indicates a total mortality rate of about 0.11 yr^{-1} for females and the value for the standard deviation in the natural logarithm of *M* set at 0.2. This prior density function for *M* was truncated at a minimum of 0.025 and a maximum of 0.10 yr^{-1}. $\tilde{R}_S$ was computed using the posterior predictive distribution for the Beverton-Holt steepness parameter, and *h*, for U.S. bocaccio was computed by Dorn (2002). This was approximated by a lognormal density function with a median of 0.625 and a SD in the natural log of h of 0.15. $\tilde{R}_S$ is a function of steepness and the spawner biomass produced per single age 1 recruit ($\tilde{S}$):

Eq. 65 $$\tilde{R}_S = \frac{4h}{\tilde{S}\,(1-h)}$$

The von Bertalanffy growth curve was fitted to the length at age data for B.C. female bocaccio to obtain estimates of the parameters *k*, $L_{inf,}$ and t_0 of 0.1628 yr^{-1}, 78.316 cm and -1.20 yr. The length to mass parameters *a* and *b* for this population ($a = 3.58 \times 10^{-5}$ and $b = 2.754$) was applied to compute female mass at age (Table 68.). The mass at age of females, fraction mature, G_a (Table 68) and the random variable natural mortality rate, *M*, and were applied to compute $\tilde{S}$:

Eq. 66 $$\tilde{S} = \left(\sum_{a=1}^{a_p - 1} \left(W_a G_a \exp(-a\,M) \right) \right) + W_{a_p} G_{a_p} \frac{\exp(-a_p M)}{1-\exp(-M)}$$

The mean and standard deviation (SD) for *r* were 0.117 and 0.037. The histogram for *r* can be closely approximated by a lognormal pdf (
Figure 74). See Table 69 for a summary of the prior pdfs for parameters other than for survey *q*.

Given bocaccio's high median age at maturity of about 7 years, and the relatively low estimate of steepness for U.S. bocaccio (about 0.625 from Dorn 2002), the prior mean for r is quite low at about 0.117. Given the relatively high degree of certainty in the recent updated estimate of the median age at maturity, the prior distribution for r is quite precise with a prior SD of 0.04. This is despite the considerable uncertainty in the rate of natural mortality (prior CV of about 0.2) and in the recruits per unit of spawner biomass at the lowest stock size.

Catch Data, Catch Estimates, and Stock Trend Indices

Annual domestic (U.S. and Canadian) catch biomass data for B.C. bocaccio were compiled for 1935 to 2006 based on historic trawl and hook-and-line records (Appendices A-C) (Table 70). As records extended only to 2006, the values in 2007 and 2008 were presumed to be the same as the record for 2006.

As described in Appendices B and C, catches in the halibut and salmon troll fisheries were imputed using time series of effort data for these fisheries and fisherman recollections of catch rates for some of the historic years. In the halibut fishery, 100% monitoring records have provided estimates of catch in 2006 and 2007. For the salmon troll fishery, 12 troll captains were interviewed to obtain recollections of daily catch rates in each of the fishery statistical areas from 1976-1985, the period with the highest troll effort. A stratified estimate of salmon troll catch was obtained using this interview information (Appendix C). The observed and recollected catch estimates were treated as data in the estimation of catch catchability coefficients. Effort was used as a covariate for catch mortality rate and the catch was predicted by the product of the annual modelled bocaccio stock biomass and the harvest rate from the fleet. A non-informative prior for the catchability coefficients was formulated and applied. The historic effort data for the troll and halibut fisheries are shown in Figure 75.

The stock trend indices to which the BSP model was fitted (Appendices D and E) included the west coast Vancouver Island shrimp trawl survey which has provided indices in all years since 1975 except for 1984 and 1986 (Figure 76, Table 71). This series is highly variable but with slightly higher frequency of large estimates in the earlier part of the time series. The U.S. triennial survey index extends from 1980 to 2001 at a frequency of every 3 years with 1986 missing. This shows a severe decline with the 2001 value only 1.5% of the 1980 value when the data are confined to Canadian waters only. The QCSd synoptic survey from 2003-2007 (missing 2006) shows no apparent trend. The QCSd shrimp trawl survey from 1999-2007 shows no significant trend. The commercial catch per unit effort data from 1996-2003 also show no significant trend (Appendix D). Values after 2003 were not used since there was apparent active avoidance of bocaccio after 2003. The WCVI ground fish survey points in 2004 and 2006 and the QCSd groundfish survey points in 2006 and 2007 show very little change (Appendix E).

The most striking characteristic of the longer survey time series (U.S. Triennial and WCVI shrimp) is extreme high interannual variability, much more so than would be expected in the interannual variability of a population with a low natural mortality rate.

There is also no consistency in the annual deviations across the time series. These characteristics indicate large variability in the longer survey series and that each one can serve only as an imprecise index of relative abundance. Furthermore, there is no single coast-wide survey targeted at shelf rockfish and thus each of the surveys provides only a regional index of bocaccio abundance. Together they provide information on relative changes in total stock abundance only if it is assumed that there have been no major systematic shifts in spatial distribution over time (e.g., from surveyed to unsurveyed areas and vice versa).

Fitting a stock assessment model to all of the available stock trend indices that cover different spatial zones even if some show inconsistent trends is common (e.g., McAllister *et al.* 2001b). Since no single index covers the entire range of the stock, there is no other choice for this stock assessment. No single index could be expected to provide a stand-alone reliable index of coast wide bocaccio abundance due to all surveys having only limited regional coverage, some of the indices covering only very short time series and the very low precision in the longer time series.

Probability Models for the Stock Trend Indices

A lognormal probability density function was presumed to represent the probability of the observation given the model prediction of it.

Eq. 67 $I_{j,t} \sim \text{Lognormal}\left(\ln\left(q_j B_t\right), \sigma_j^2\right)$

where $I_{j,t}$ is the observed index of abundance for series j in year t, q_j is the constant of proportionality for series j and σ_j is the standard deviation in the error deviation between the log predicted index and the log observed index. Note that where a survey time series gave a zero value, this could not be applied in the lognormal density function and was thus omitted from the likelihood function. This could bias estimates of stock trends if zeros indicate low stock size. There are two observations in the index series which are zero: one in the WCVI shrimp survey in 2000 and in the QCSd shrimp survey in 2007. σ_j were fixed at constant values and obtained by rounding up the posterior modal estimates obtained by iterative re-weighting of the state space surplus production models to each stock trend index (Table 71).

Method to Obtain Posterior Probability Distributions

The software applies the sampling importance resampling (SIR) algorithm to integrate the joint posterior pdf of model parameters and sample from the posterior for stock projections (Rubin 1987, McAllister *et al.* 1994, McAllister and Ianelli 1997). The function used in importance sampling was a multivariate log t distribution with 25 degrees of freedom and with the median set to the posterior modal estimate for each estimated parameter and the marginal variance set at a value the same as or slightly larger than the prior variance, and covariance set to 0. The parameters r and P_0 were log transformed in this density function. The standard deviation in K for the importance function was set at relatively large values, e.g., 90,000 t to 190,000 t, to ensure that the largest posterior weights (importance ratios) did not fall in the tails of the posterior.

The estimation model had moderate dimensionality with three key population dynamics parameters (r, K, P_{35}), and nine nuisance parameters, i.e., the catchability coefficients, k, the constants of proportionality, q, and 74 process error terms. Sampling from an importance function with all of these terms was highly inefficient using a multivariate t distribution, as described above. Efficient importance sampling was enabled by applying Walters and Ludwig (1994) shortcut calculations to speed integration of joint posterior pdfs with more than a few dimensions. The nuisance parameters q are removed from the importance function to reduce its dimensionality, and for each candidate set of values of population dynamics parameters, the closed-form maximum likelihood estimate of nuisance parameters, q, is computed. This gives marginal posteriors for the key population parameters and variables identical to those that would have been obtained if a non-informative prior had been applied to q (i.e., a uniform on log q prior). For the survey qs for which an informative prior is applied, the MLE values for q are computed for each draw of the other parameter values from the importance function and the joint prior pdf of the MLE for survey q is applied in the computation of importance ratios (or posterior weights). The extension of the Walters and Ludwig (1994) shortcut to instances with an informative prior for q, providing that the prior for q is either normal or lognormal in form, can be expected to provide unbiased estimates of marginal posteriors for all model quantities.

Efficient importance sampling was achieved for all model runs with the maximum weight for a single draw as a percentage of the total cumulative posterior weight, dropping progressively to well below 1% within nine million draws from the importance function. This required a few hours on a 2-3 gigahertz Pentium with two gigabytes of RAM using a compiled executable version of the model. The coefficient of variation (CV) in the importance ratios computed (used to weight each draw from the importance function) was also much less than the CV for the product of likelihood and prior, and always less than about 40, indicating that the posterior surface was being sampled efficiently (McAllister and Kirchner 2002).

The main stopping basis for importance sampling approximations to the target posterior probability distributions included the following rules. The maximum relative probability weight assigned to a single draw was set to 0.5% and the number of draws of parameters that resulted in non-zero stock size to the present had to exceed 50,000. Importance functions with different marginal variance values were used in different runs for the same estimation to ensure that the posterior results obtained were insensitive to the importance function used in importance sampling. A total of 5,000 re-sampled importance draws were used in the stock projections.

Output Statistics

Key stock assessment output statistics include the:

- marginal posterior distributions of current stock biomass (B_{2008}),
- current stock biomass to carrying capacity (B_{2008}/K),
- current stock biomass to stock biomass at MSY (B_{2008}/B_{msy}),
- replacement yield (the value for the current catch biomass that could be expected to cause no net change in stock biomass between the current and next year) ($repy_{2008}$)
- ratio of $repy_{2008}$ to the catch biomass in 2008, ($repy_{2008}/c_{2008}$),
- ratio of fishing mortality rate in 2008 (F_{2008}) to F_{msy} (F_{2008}/F_{msy}).

The marginal prior and posterior pdfs of the intrinsic rate of increase and *K* are also plotted to show the extent to which priors have been updated.

Reference Case

Due to the large number of alternative possible model forms and inputs, it is not straightforward to arrive at a credible set of assumptions and inputs for the stock assessment model based on objective empirical grounds that can be selected as the "most preferred" case. The analysts can formulate a "reference case" that they believe is defensible based on the available information. There will be some arbitrariness to some of the choices, and some may be determined by common practice. Nonetheless, we propose that the reference case is the most credible set of model inputs and structures, given the available options. For the reference case run we have chosen the following:

- the standard deviation in log process error deviates is set at 0.1, to account for large uncertainty in stock dynamics processes,
- informative priors for *q* are applied to incorporate the best available expert judgement on the plausibility of alternative values for factors that scale swept area biomass estimates to total population biomass,
- a uniform prior for *K* is used to enable equal credibility for small and large possible values for *K*,
- positive lag 1 autocorrelation in process error deviates is set to 0.6, with the simulation beginning in 2007, the first year for which there is no informative in the data about historic process error.

In summary, the reference case has the following specifications:

- prior mean $r = 0.117$, sd(ln(r))= 0.294,
- all stock trend indices,
- likelihood function for catches: truncated normal, CV=0.6 for troll, CV=0.5 for halibut,
- observed mean annual troll catches for 1976-1985 calculated from median recalled daily value,
- limit on average daily troll catches set at 40 bocaccio per day,
- Schaefer surplus production function (B_{msy}/K=0.5),
- process error prior SD = 0.1,
- prior mean $B_{35}/K = 0.9$,
- informative priors for survey *q* with Bayesian update,
- density in trawlable area < untrawlable area (triangular distribution),
- lag 1 autocorrelation starts in 2007
- CVs for stock trend indices obtained by iterative reweighting
-

Sensitivity Tests

We evaluated the sensitivity of stock assessment and projection results to a range of model assumptions. Some of the key sensitivity tests are as follows (summarized in Table 72):

1. Assumed value for B_{msy}/K – The Schaefer surplus production model assumes that B_{msy}/K falls at 50% of *K*, without reference to the species being modelled. Recent hierarchical meta-analyses of rockfish stock-recruit data (Forrest *et al.* in prep.) suggest that B_{msy}/K for bocaccio may fall in the range of 30-50% if the presumed stock-recruit function is Beverton-Holt and 45–65% if the presumed stock-recruit function is Ricker. There is no strong evidence supporting one or the other of these stock-recruit functions for bocaccio. However, there have been observations of cannibalism in bocaccio (Love *et al.* 2002), lending suggesting that a Ricker stock-recruitment function may be more appropriate for this species. Given these observations, the choice of 50% as the reference case value for B_{msy}/K appears reasonable as it lies within the middle of the range of possibilities and is not implausible under either stock-recruit function. For sensitivity analysis, two alternative surplus production functions were applied, both using the Fletcher parameterization of the three-parameter generalized surplus production function (Prager 1994). We applied a Schaefer-Fletcher spline surplus production function (McAllister *et al.* 1999). This avoids the anomalously high values for r when B_{msy}/K approaches and drops below $1/e$ and, unlike for the Pella-Tomlinson form of the generalized function, retains the same interpretation of parameter r as in the surplus production function. It therefore can use the informative prior for r. One sensitivity run set B_{msy}/K to 0.4 and the other set it to 0.6.

2. Prior mean value for r - The sensitivity of model results to the informative prior for r was evaluated with the application that used steepness priors with means 0.1 above and below the reference case steepness prior and prior SDs reduced from 0.15 to 0.1. This accounted for shifting the mean of the prior closer to the lower and upper limits for steepness. The low r sensitivity run had a prior median value for r of 0.0836 and SD in the natural logarithm of r of 0.197. The high r run had a prior median value of r of 0.152 and SD in the natural logarithm of r of 0.226.

3. Uncertainty in catch and catch estimates - Uncertainty in the salmon troll catch estimates during the early 1980s was evaluated by presuming a higher and lower value for the mean daily troll catch. The stratified estimate of troll catch from the low daily catch value (1/2 the value of the median daily catch rate by area recalled by expert fishermen) was 119 tons. The high value from the truncated mean daily catch rate by area was 497 tons. In another sensitivity run, the salmon troll and halibut catches were excluded from the assessment. In yet another sensitivity run, the troll and halibut catch values were fixed at their posterior modal estimates to evaluate the effect on the assessment results of treating these catches as uncertain random variables compared to fixing them at it's most credible value, as is commonly done for uncertain catch time series. The relative impacts of uncertainty in historic trawl and line catches were evaluated by carrying out sensitivity runs where these catches before 1996 were set to 0.5 times and 1.5 times the estimated time series of catch before 1996. Another sensitivity run was made where the upper cap of 40 bocaccio per day in the salmon troll fishery was removed. A further run was carried out where the likelihood function for the imputed catch estimates was changed from a truncated normal distribution to a log-normal distribution with the same CVs as in the truncated normal case.

4. Uncertainty in process error - The sensitivity of state-space model results to the value chosen for the process error variance was evaluated by setting a smaller and larger value for the process error ($\sigma_p = 0.05$, and $\sigma_p = 0.15$). Another sensitivity run was done with the process error set to zero.

5. Uncertainty in initial stock size relative to K - Additional runs were carried out in which the prior mean for the ratio of initial stock size to carrying capacity (B_{1935}/K) was set to 0.7 and to 1.0.

6. Formulation of the prior for the survey *q* values - The effect on stock biomass estimates of presuming informative priors for survey *q*s was evaluated by conducting model sensitivity runs which used non-informative priors for *q*. Another sensitivity run used an alternative survey *q* prior which assumed that the density of fish in untrawlable areas was the same as that in trawlable areas. A further sensitivity run was carried out using survey *q* priors which had been calculated with the covariance between the surveys set to zero (i.e., this run assumes that each survey prior was derived using independent information). This effectively presumes that the survey *q*s are more precise than is actually the case. Another sensitivity run was carried out using a prior for survey *q* which was not updated by the catch rate ratios between the DFO groundfish survey to shrimp survey nets.

7. Impact of the stock trend data on the assessment results - The relative impact of each stock trend index on the assessment was evaluated by conducting sensitivity runs wherein each stock trend index was left out, one at a time. The indices from the DFO groundfish surveys were also used to estimate random variables for the fraction of total stock biomass in each survey area and also to update the ratio of net catchability coefficients for the B.C. groundfish and shrimp trawl nets (when formulating the informed priors for survey *q*s). It may be argued that some of the key information in the B.C. groundfish survey data is used more than once in the assessment and therefore should only be used for the formulation of priors for the groundfish survey *q* values and not included in parameter estimation. The effect on the assessment model results of leaving the DFO groundfish survey data out of the assessment was evaluated by removing these data in one sensitivity run.

8. Impact of alternative assumptions about autocorrelation in process error - This effect was evaluated with a sensitivity run where the autocorrelation was set to zero. Another sensitivity run was carried out with the autocorrelation starting in the first projection year, 2009, rather than in 2007. This sensitivity run represents what is often done in some applications, especially when the autocorrelation terms for the last few years are estimated to be zero, owing to lack of information in the data about the most recent process error deviates.

Marginal posteriors for alternative model settings (e.g., for the alternative B_{msy}/K inflection point cases) were computed using the average of the importance function for each model run as an approximation of the probability of the data for each model given the model and equal prior probabilities for each hypothesized alternative model (Kass and Raftery 1995, McAllister and Kirchner 2002).

Projections Considered

Projections were done for 5, 20 (~1 generation) and 40 (~ 2 generations) years to evaluate the potential future stock trends resulting from alternative fixed TAC policies under the assumptions of stationarity in recruitment and all model parameters. The median stock biomass of recruited fish and stock biomass to stock biomass at *MSY* trajectories with 90% PIs were computed for each TAC policy.

Results

In all instances, the model fitted the stock trend data quite poorly with large deviations between observed and predicted indices and some apparent autocorrelation in deviates for some of the indices (Figure 76a, b). For the last few years, the annual deviates from the predicted surplus production were strongly negative, indicating that the surplus production function predicted higher production than was realized in the stock trend indices (Figure 76c). Autocorrelation at lag 1 in the surplus production deviates from 1935 to 2006 was estimated at 0.66 and was significant at the alpha = 0.05 level. In the reference case, the posterior mean for the intrinsic rate of increase r, 0.095 (26%), was less than the prior mean of 0.117 (31%). The decrease in mean value and decrease in CV suggest that the stock trend data provided some information on r (Figure 77a and Table 73). The posterior mean for the average unfished stock size, K, 52,700 t (68%) was updated considerably from the uniform prior for K (Figure 77b and Table 73). However, the median is considerably less at about 40,000 t indicating that the skew of the posterior for K (and other biomass values) is high with the posterior tail stretching up to values of nearly 200,000 t. The posterior mean for B_{msy} mirrors that for K with values half of those of K, due to the structure of the surplus production model. The posterior mean for MSY is 1180 t (64%) (Figure 77c and Table 73). The priors for the constants of proportionality for the stock trend indices were updated considerably with prior CVs dropping from values of over 80% to between 37% and 56% for the posterior CVs (Figure 78). The posterior means, in most instances, were updated mostly to larger values compared to the prior means (Table 73). The sparse data on troll and halibut catch provided minor updates of priors for the catchability coefficients with posterior CVs of 91% and 70% for the halibut and troll catch coefficients, respectively (Table 73, Figure 79).

Under the reference case, the posterior mean and median for stock biomass in 2008 are 4765t and 3565t, respectively (Table 73). Under the reference case, stock size is low relative to its unfished stock size (K) and its B_{MSY} reference point, i.e., the posterior mean for B_{2008}/K is 12% (95%) and B_{2008}/B_{msy} is 25% (95%) (Figure 80, Table 73). The posterior medians are somewhat less, at 8.6% and 17%, respectively, due to the high positive skew in the marginal posteriors. Stock biomass has shown a progressive decline since the 1930s with the steepest decline from 1985 to 1995 and stock size changing relatively little since then (Figure 76). The posterior mean of F_{2008}/F_{MSY} is 1.1 (57%), with the median at 1.0. The posterior median and mean for the replacement yield in 2008 (the amount that can be harvested so that the stock will not increase or decrease in the next year) are 288 t and 346 t (67%) (Figure 80, Table 73). The posterior mean ratio of the total harvest in 2008 to replacement yield is 62% (266%) with the median at 57%

(Figure 80, Table 73). The CV is large for the latter due to large uncertainty in the catch estimates and the occurrence of some instances in which replacement yield is very small. Posterior mean catch in 2008 in the halibut and troll fisheries is 10 t (78%) and 25 t (109%) with medians at 8 t and 17 t (Table 73). The posterior median catch in the halibut fishery early in the time series was as high as 385 t in 1936 (80% PI of 121t, 1,341t) and declining steadily as stock size was depleted and halibut effort has decreased substantially since then (Figure 81a). The posterior median catch in the troll fishery has fluctuated at about 500t for several decades up to the mid 1980s and was as high as 587 tons (90% PI of 172t, 3174t) in 1951 when troll effort was highest and stock size was still relatively high. Troll catch has since the mid 1980s declined considerably with declining stock size and declining troll effort in the 1990s (Figure 75, Figure 81b).

Most of the sensitivity runs had relatively little impact on the overall perception of stock status relative to carrying capacity and B_{MSY} and estimates of replacement yield were relatively insensitive to variation in model assumptions and inputs (Figure 82-Figure 89, Table 74.). Note that the medians obtained for Table 74 were obtained from the grids used to produce histograms due to the numerous runs involved, whereas the medians for the reference case in Table 73 were obtained based on a more refined interpolation method. Thus the medians for the reference case values differ slightly in these two tables. Altering the position of B_{MSY}/K from 0.5 to 0.4 and then to 0.6 (cases A.1 and A.2) had relatively little impact on perceptions of stock status with only negligible changes in the estimates of the ratio of current harvest to replacement yield for both of these alternative settings (Table 74.). The estimates of B_{2008} and replacement yield changed very little and decreased slightly for the two alternative settings, A.1 and A.2, respectively. The estimates of B_{2008}/K were almost the same and slightly higher for cases A.1 and A.2, respectively. The estimates of B_{2008}/B_{MSY} were slightly higher and slightly lower than the reference case for cases A.1 and A.2.

Altering the prior mean for r to lower and higher values had among the most pronounced impacts on perception of stock status (Figure 82a- Figure 89a, Table 74). The estimates of B_{MSY} increased and decreased considerably when the prior mean for r was decreased and then increased (cases B.1 and B.2) (e.g., from about 20,000 t to 24,000 t and 14,000 t, respectively). The replacement yield decreased from about 300 t to 250t and increased to 350 t, under cases B.1 and B.2, respectively. For cases B.1 and B.2, the estimates of B_{2008}/B_{msy} decreased to about 15% and increased to about 20%, respectively, from 17.5% under the reference case.

Variations in assumptions about historic catches also had the most pronounced impacts on stock status. The low and high mean catch scenarios (C.1 and C.2) for troll catch, gave approximately 25% lower and 30% higher estimates of B_{MSY} relative to the reference case (Table 74.). All of the other status statistics for cases C.1 and C.2 differed relatively little from the reference case (Table 74.). Excluding halibut and troll catch entirely from the model (case C.3) had the most marked impacts on the posterior results. Several of the posterior results were considerably wider (Figure 82-Figure 89, Table 74). For example, for B_{2008}, the 10th, 50th and 90th percentiles increased to approximately 3000t, 11000t, and 34000t, compared to 2000t, 4000t, and 9000t under the reference case.

These percentiles for the replacement yield in 2008 increased to 200t, 500t, and 1300t compared to 150t, 300t, and 600t under the reference case. B_{2008}/B_{MSY} increased to 30%, 77.5% and 145% compared to 5%, 17.5%, and 52.5% under the reference case. In contrast, the estimate of B_{MSY} was much smaller with the posterior median decreasing to 14,000t compared to 20,000t under the reference case. Decreasing and increasing the historic catches by 50% (cases C.4 and C.5, respectively) decreased and increased B_{2008}/B_{MSY} by about 0.025 from the reference case value of 0.175, and had similarly relatively small impacts on other stock status indicators (). Relaxing the upper cap of troll catch per day of 40 bocaccio (case C.6), increased the upper bounds for B_{MSY}, and B_{2008}/B_{msy} slightly ((Table 74.) but other indicators remained unchanged. Changing the likelihood function for observed catch values from a truncated normal density function to a lognormal likelihood function (case C.7) had relatively little impact on stock status indicators (Table 74). Fixing the annual catch values at their posterior modal estimates (case C.8) had large impacts on stock status results, similar to the case where catches were left out (case C.3) (Figure 82-Figure 89, Table 74).

Altering the process error assumptions, that is decreasing and then increasing the SD in log process error to 0.05 and 0.15, and then setting it to zero (cases, D.1., D.2, and D.3), had relatively little impact on stock status indicators. The main effect was to slightly decrease or widen posterior probability intervals for stock status indicators, when the process error was either decreased or increased, respectively (Table 74). Altering the initial stock size relative to *K* also had relatively little impact on stock status results (Table 74, cases E.1 and E.2).

Altering assumptions about the survey *q* priors had intermediate impacts on stock status results. Replacing the informative survey *q* priors with non-informative priors (case F.1), gave slightly more pessimistic and slightly less certain results overall (Table 74). Modifying the survey *q* priors so that bocaccio density in untrawlable areas was set to be equal to that in trawlable areas (case F.2) made results slightly more pessimistic (Table 74). Modifying the survey *q* priors so that there was no Bayesian update of the captain inputs with the observed ratio of catch rates in areas with both DFO groundfish survey and shrimp trawl survey net tows (case F.3) gave slightly more pessimistic results. Modifying the survey *q* prior so that the prior covariance among the *q*s for the different surveys was set to 0, as opposed to applying the positive covariance due to common inputs (case F.4), gave slightly more optimistic and slightly more certain results.

Leaving out one stock trend index at a time permitted evaluation of its impact on the reference case results. Leaving out the commercial catch rate index (case G.1) gave slightly more pessimistic results overall. Leaving out the U.S. triennial index (case G.2) gave markedly more optimistic results, e.g., with B_{2008}/B_{MSY} increasing to 0.275 from 0.175 (Table 74). In comparison, leaving out the other stock trend indices one at a time or leaving out all survey indices after 2002, had relatively little effect on the posterior results (cases G.3-G.8).

Modifying the process error autocorrelation assumptions, i.e., setting the autocorrelation coefficient to zero and then having autocorrelation start in 2009, as opposed to 2007, both had virtually no impact on assessment results (cases H.1 and H.2, Table 74).

Projections

Five, 20-, and 40-year projections (2009-2048) were made on the basis of differing levels of constant total allowable catch ranging from 0 tons up to 300 tons[28]. The results for the reference case run are summarized for B_y/B_{MSY} and F_y/F_{MSY} in Figure 90, Figure 91, and Table 75. Upward median trajectories of B_y/B_{MSY} occur only in cases where the TAC is ≤ 200 t. Similarly, sustainable rates of F_y/F_{MSY} (approximately <2) are achievable in the future where TAC is ≤ 200 t. At levels of TAC of ≥ 250t or more, the median B_y falls steadily in future years and F_y/F_{MSY} gradually increases and eventually exceeds 2. Projections with a TACs ≤ 100 t exceed $0.8*B_y/B_{MSY}$ by 2048 with 50% probability or higher. Projections with a TACs of up to 200 t exceed $0.4*B_y/B_{MSY}$ by 2048 with 50% probability or higher. When the prior mean for r was decreased to 0.0836 (case B.1), TACs of ≤ 100 t had 50% or higher probability of exceeding $0.4*B_{msy}$ within 40 years.

Projections are presented for the reference case and for six sensitivity runs which we felt would provide some contrast in the projected results. Two of runs selected (B.1 and B.2) bracket the range of plausible productivity for this stock and represent the greatest contrast in response to a constant harvest strategy. Two other runs (H.1 and H.2) investigate the effect of autocorrelation on the projections, with H.1 dropping the autocorrelation effect and H.2 delaying its implementation. Finally, sensitivity runs A.1 and A.2 were projected to investigate the effect of the B_{MSY}/K assumption on the projections, with run A.1 fixing this value to 0.4 and A.2 to 0.6. All other sensitivities used the same r prior as used for the reference case and thus would be expected to behave similarly to the reference case scenario, barring differences in the expected value of B_{2008}/K at the start of the projection period.

When the prior mean for r was increased to 0.152 (case B.2), TACs of 250 t and smaller had 50% or higher probability of exceeding $0.4*B_{msy}$ within 40 years (Table 75, Table 76, Table 77). Setting the autocorrelation coefficient in process error deviates to zero (case H.1, Table 78) gave results similar to case B.2. Starting the autocorrelation function in 2009 as opposed to 2007 (case H.2) gave results slightly more optimistic than the reference case (Table 79). The projection results under alternative inflection points for B_{MSY}/K (cases A.1 and A.2) gave very similar rebuilding results to the reference case, e.g., in both instances the highest constant TAC that would lead to rebuilding to $0.4*B_{MSY}$ with at least 50% was the 200 t TAC (Table 80 and Table 81). The marginal posteriors for each of these alternative hypotheses were very similar at 0.46, 0.34 and 0.19 for the B_{MSY} = 0.4, 0.5 and 0.6 hypotheses, respectively. A summary decision table of the key results accounting for uncertainty in the prior mean value for the maximum intrinsic rate of increase is shown in Table 82. This also shows the marginal posterior probabilities for each alternative model run under each of the three alternative priors for r.

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[28] The projections based on constant catch do not represent an endorsement of a constant catch policy. They are solely intended to provide managers with some insight about the predicted stock trajectory over the short term under various short-term harvest levels.

Discussion

The stock assessment model was fitted to stock trend indices obtained from six different research surveys of varying durations and one commercial catch rate time series from 1996-2003. While the commercial catch rate time series shows very little interannual error variability, all of the survey indices, particularly the longer time series such as the U.S. triennial and WCVI shrimp trawl surveys, show large interannual fluctuations indicating considerable error variability in the stock trend indices. However, the indices on average show a substantial decline up to the mid-1990s and then for the last decade no apparent trend. When fitted to these data, the reference case BSP model indicates that B.C. bocaccio is at a historic low in abundance remaining at about 12% of unfished stock size over the last decade. Stock biomass estimates are still highly uncertain with coefficients of variation at about 60-70%. Although catches have decreased substantially over the last 15-20 years, the stock as yet shows no signs of recovery from the available fishery independent biomass indices.

Under the reference case, the stock projections indicate that stock recovery to 40% of B_{MSY} can be achievable with at least 50% probability with constant quota policies of 200 tons or less. This TAC decreases to 100 tons under the low prior mean r scenario and increases to 250 t under the high prior mean r scenario. The marginal posterior probability for each of these alternative runs (i.e., ranking the overall goodness of fit of each alternative prior for r) differed relatively little, but favoured only slightly the smallest prior mean r with a posterior of 55%; as opposed to 30% and 15% for the reference case and high prior mean r runs. It is not surprising that the data do not enable any of the hypotheses about prior mean for r to be rejected (which would be appropriate if the posterior to prior odds for a hypothesis dropped to a very low value, e.g., to less than 1/100). The lowest prior mean r may be favoured due to the apparent lack of increase in stock size over the last decade given the substantial decline in landings and fishing effort over this period. This is reflected in the assessment also by the update of the marginal posterior for r, e.g., in the reference case, which supports lower values for r than in the prior.

The BSP model tracks abundance from 1935 to the year 2008 under the assumption that the stock started near to unfished conditions in 1935. This appears to be reasonable since in the 1930s, reported catches (landings) were relatively low at about 1 t, much less than those in the 1960s and 1970s; however, halibut and troll effort had already been at relatively high values in the 1920s indicating that the stock had already departed from a pristine state in the 1930s. Nonetheless, stock status and projection results were very similar when the prior mean for B_{1935}/K was changed from 0.9 to 0.7 and 1.

The BSP model also assumes that the catch estimates are accurate and that there is autocorrelated process error in the surplus production function. Decreasing and increasing the historic catch records by 50% prior to 1996, when catch records improved considerably, had comparatively little impact on the stock status results. The positive autocorrelation at lag 1 was found to be significant and quite substantial at about 0.66 for the reference case and several other cases. Including autocorrelation produced somewhat more pessimistic results than when it was left out, as the last few estimable process error deviates from 2004-2006 were strongly negative. It was also more accurate to model the autocorrelation starting in the final year in which stock trend data are available (2007), since this is the first year in which there can be no empirical information about process error deviations from the surplus production function. The current application also presumes approximate stationarity in key population dynamics parameters since 1935. There is no strong evidence to suggest that carrying capacity or the stock's capacity for increase have changed or for that matter, remained constant, over this period. The estimated process error terms in surplus production show strong significant positive autocorrelation and, if anything, suggest a systematic decline in surplus production potential since the mid-1990s. The positive autocorrelation and recent negative deviates in surplus production are directly accounted for in the projections.

Stock status and projection results were also relatively insensitive to alternative formulations of the surplus production function. For this we applied an *ad hoc* Fletcher-Schaefer formulation that permits the inflection point for B_{MSY}/K to be fixed at values other than 0.5 (with settings in this study at 0.4 and 0.6). It disallows the anomalous infinite values for r as the inflection point drops below 0.5 in the Fletcher model, and permits uptake of the informative prior for r (McAllister *et al.* 1999). These alternatives gave very similar estimates of stock status and projection results to the reference case. And not surprisingly, the posterior probabilities for these alternative hypotheses for the B_{MSY}/K inflection point were very similar, though slightly favouring the lower inflection point of 0.4.

The informative prior for the survey qs was updated quite markedly in the reference model run, indicating that there is information in the catch removal and stock trend data for the estimation of model parameters. The effect of the informative priors for survey q was generally to favour slightly larger stock size estimates in recent years. The assumption that bocaccio density is substantially higher in untrawlable areas also resulted in higher stock biomass estimates.

This assessment demonstrates that the results are highly sensitive to manner in which historic catch is imputed. A conventional approach is to formulate the most credible historic values of catch and then to treat these as fixed values in the stock assessment and then possibly try high and low sets of values to evaluate the sensitivity of results to the imputed catch. The approach taken in this paper recognizes that the information available to impute catches in the troll and halibut fisheries is a historic time series of effort data and relatively recent catch observations. With the formulation of a simple catch prediction function that uses fishing effort (E), stock biomass (B), and a catch coefficient (k), the catch coefficient becomes estimable. If k and B are modelled as estimated random variables, then given a fixed value of historic effort, the catch must also be a random variable and fixing catch at some particular best estimate value will fail to account for the uncertainty in historic catches and the effect of this uncertainty on the estimation of model parameters. The sensitivity tests showed that stock biomass estimates produced by the posterior modal estimates of catch varied markedly from those obtained by treating catch as a random variable and that potentially highly biased results can be obtained by fixing catch estimates at their best estimates, as opposed to imputing them probabilistically within the stock assessment model. However, the approach adopted in this assessment assumes that the catch coefficient (*k*) is constant over the approximately 50 years of stock reconstruction. This is a strong assumption, given the large changes that these fisheries have experienced as well as the substantial improvements in fishing power which have taken place during this period.

We have assumed that B.C. bocaccio is a single breeding stock with negligible immigration and emigration to and from B.C. waters. Too little is known about stock structure of bocaccio along the western coast of North America to justify the application of more sophisticated stock structure models. But should there be substantial immigration or emigration, the assessment of status and projection results could be substantially biased and evaluations of stock status and rebuilding recommendations from a model that accounted for such could be substantially different.

It was discovered in a very late stage of the computations that the halibut catch for 2006 and 2007 was already incorporated in the catch records entered into the stock assessment whereas the model presumed that these were not already accounted for. This will tend to make the results slightly too pessimistic. However, halibut catches were very small in these years, about 10 tons, so the bias introduced in the present results should be very small. A rerun of the BSP reference case with corrected halibut catches confirmed this. The stock status estimates are virtually the same, with current stock biomass less than 1% greater than this report's reference case. All other results were virtually the same. The current catch/replacement yield was modified slightly more with the posterior mean ratio in the corrected run being 0.594 compared to this report's value of 0.623. This smaller value is expected since the total catch in the corrected run is slightly lower without double counting the halibut discards. While the posterior CVs for nearly all quantities remained practically the same, the CV in the catch/ replacement decreased from 2.66 to 2.18. This CV for this ratio remains high due to the occasional incidence of very low replacement yield values in the denominator. The projection results also change hardly at all. The 200 t total catch quota still gives a 50% chance of bring the stock to 40% B_{MSY} or larger and the 300t quota has a 35% chance (corrected) rather than a 33% chance (uncorrected) of reaching 40% B_{MSY}

Appendix Tables

Table 17. Reconstruction of domestic bocaccio trawl landings (1930-1966).

Year	Total ORF landings to Washington State	Total ORF landings to Washington State	Total ORF landings from 3C-5E	3C		3D		5A		5B		5C		5D		3C+3D	3C/CDN+ 3D	5A:5D	Prop. Bocaccio		Bocaccio landings for 3C-CDN+3D	Bocaccio landings for 5A-5D	Total bocaccio rockfish landings from 3C-CDN- 5D		Total Plus 1.298% discards
	(mt)	('000 lbs)	('000 lbs)	('000 lbs)	('000 lbs)	('000 lbs)	('000 lbs)	('000 lbs)	('000 lbs)	('000 lbs)	('000 lbs)	('000 lbs)	('000 lbs)	('000 lbs)	('000 lbs)	('000 lbs)	('000 lbs)	('000 lbs)	3C-3D	5A-5D	('000 lbs)	('000 lbs)	('000 lbs)	(mt)	(mt)
				CDN	US	CDN	US	CDN	US	CDN	US	CDN	US	CDN	US	CDN and US	CDN and US	CDN and US							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1930	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.07	0	0	0	0	**0**
1931	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.07	0	0	0	0	**0**
1932	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.07	0	0	0	0	**0**
1933	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.07	0	0	0	0	**0**
1934	4	8	6	0	1	0	1	0	1	0	2	0	0	0	0	2	1	4	0.03	0.07	0	0	0	0	**0**
1935	29	63	45	0	10	0	7	0	9	0	17	0	0	0	1	17	10	28	0.03	0.07	0	2	2	1	**1**
1936	37	81	58	0	13	0	9	0	12	0	22	0	0	0	1	22	13	36	0.03	0.07	0	2	3	1	**1**
1937	33	73	52	0	11	0	8	0	11	0	20	0	0	0	1	20	12	32	0.03	0.07	0	2	3	1	**1**
1938	49	107	76	0	17	0	12	0	16	0	29	0	0	0	1	29	17	47	0.03	0.07	1	3	4	2	**2**
1939	51	112	80	0	18	0	13	0	17	0	31	0	0	0	1	31	18	49	0.03	0.07	1	3	4	2	**2**
1940	113	249	177	0	39	0	29	0	37	0	68	0	0	0	3	68	40	109	0.03	0.07	1	8	9	4	**4**
1941	42	93	66	0	15	0	11	0	14	0	26	0	0	0	1	25	15	41	0.03	0.07	0	3	3	2	**2**
1942	821	1809	1284	0	282	0	209	0	268	0	498	0	3	0	23	492	291	793	0.03	0.07	9	55	64	29	**30**
1943	2652	5848	4152	0	913	0	677	0	867	0	1609	0	11	0	75	1590	941	2562	0.03	0.07	28	179	208	94	**95**
1944	1102	2430	1725	0	379	0	281	0	360	0	669	0	5	0	31	661	391	1065	0.03	0.07	12	75	86	39	**40**
1945	11552	25468	18082	0	3977	0	2947	0	3777	0	7006	0	49	0	327	6924	4100	11159	0.03	0.07	123	781	904	410	**415**
1946	5824	12839	9115	0	2005	0	1486	0	1904	0	3532	0	25	0	165	3490	2067	5625	0.03	0.07	62	394	456	207	**209**
1947	3042	6707	4762	0	1047	0	776	0	995	0	1845	0	13	0	86	1823	1080	2939	0.03	0.07	32	206	238	108	**109**
1948	4940	10891	7733	0	1701	0	1260	0	1615	0	2996	0	21	0	140	2961	1753	4772	0.03	0.07	53	334	387	175	**178**
1949	6008	13246	9405	0	2068	0	1533	0	1964	0	3644	0	25	0	170	3601	2133	5804	0.03	0.07	64	406	470	213	**216**
1950				31	1919	7	1654	15	2246	26	2736	0	35	91	214	3611	2227	5363	0.03	0.07	67	375	442	201	**203**
1951				48	1867	10	1056	10	1266	76	3774	2	13	80	98	2981	1621	5319	0.03	0.07	49	372	421	191	**193**
1952				124	1439	4	1174	28	1439	200	2987	1	15	97	112	2741	1631	4879	0.03	0.07	49	342	390	177	**179**
1953				35	739	0	536	2	713	20	1011	0	10	7	66	1310	760	1829	0.03	0.07	23	128	151	68	**69**
1954				118	769	10	614	6	568	116	1065	0	19	13	74	1511	881	1861	0.03	0.07	26	130	157	71	**72**
1955				65	695	13	821	8	1417	135	788	0	7	17	115	1594	1054	2487	0.03	0.07	32	174	206	93	**95**
1956				27	630	2	892	0	1485	84	696	6	18	9	31	1551	1085	2329	0.03	0.07	33	163	196	89	**90**
1957				22	843	0	956	40	626	91	708	1	8	9	33	1821	1207	1516	0.03	0.07	36	106	142	65	**65**
1958				13	635	2	652	50	918	94	429	12	0	9	63	1302	842	1575	0.03	0.07	25	110	136	61	**62**
1959				29	2331	0	782	169	1037	326	300	5	0	39	85	3142	1466	1961	0.03	0.07	44	137	181	82	**83**
1960				16	2350	4	821	28	459	48	535	1	3	21	55	3191	1511	1150	0.03	0.07	45	81	126	57	**58**
1961				36	2392	6	1530	29	902	86	573	0	1	44	21	3964	2240	1656	0.03	0.07	67	116	183	83	**84**
1962				36	2943	31	2428	56	1394	401	1459	0	0	106	52	5438	3323	3468	0.03	0.07	100	243	342	155	**157**
1963				25	1308	1	1862	58	1237	168	1785	0	27	27	10	3196	2250	3312	0.03	0.07	67	232	299	136	**138**
1964				26	1237	13	755	358	975	207	1077	3	17	53	34	2031	1134	2724	0.03	0.07	34	191	225	102	**103**
1965				20	1453	72	1065	225	1291	210	1437	10	56	25	40	2610	1564	3294	0.03	0.07	47	231	278	126	**128**
1966				46	1405	24	1772	119	3174	168	1846	8	3	45	0	3247	2217	5363	0.03	0.07	67	375	442	200	**203**

Table 18. Proportion of Washington State trawl landings ('000 lbs.) from 3C-5D in 1950-1953 (79%).

Year	3C		3D		5A		5B		5C		5D		Total ORF(3C-5D)		Total ORF to Washington from Stewart
	CDN	US	CDN	US	CDN	US	CDN	US	CDN	US	CDN	US	Sum (lbs)	Sum (t)	(t)
1950	31	1919	7	1654	15	2246	26	2736	0	35	91	214	8804	3993	5774
1951	48	1867	10	1056	10	1266	76	3774	2	13	80	98	8074	3662	4831
1952	124	1439	4	1174	28	1439	200	2987	1	15	97	112	7166	3250	4607
1953	35	739	0	536	2	713	20	1011	0	10	7	66	3075	1395	1998
Total													27119	12301	17209

Table 19. PMFC Originating area of ORF catch (t) for U.S. vessels landing to Washington State.

Year	3C	3D	5A	5B	5C	5D	3C-5D
	US	US	US	US	US	US	US
1950	1919	1654	2246	2736	35	214	8804
1951	1867	1056	1266	3774	13	98	8074
1952	1439	1174	1439	2987	15	112	7166
1953	739	536	713	1011	10	66	3075
Total	5964	4420	5664	10508	73	490	27119
Proportion	0.220	0.163	0.209	0.387	0.003	0.018	1.000

Table 20. Proportion of ORF caught in the Canadian portion of 3C (CD/CDN) from U.S. vessel landings to Washington State (29%).

	3C/US lbs.	3C/CDN lbs.	3C Total lbs.
1966	724501	562352	1286853
1967	356402	286304	642706
1968	944492	159066	1103558
1969	1057437	373953	1431390
1970	818097	214954	1033051
Total	3900929	1596629	5497558

Table 21. Proportion of bocaccio in U.S. trawl vessel ORF landings to Washington from 3C-3D and 5A-5D in 1967-1970.

Year	Area 3C-3D			Areas 5A-5E		
	Bocaccio	ORF	$p_{Bocaccio}$	Bocaccio	ORF	$p_{Bocaccio}$
1967	58	1210	0.05	248	2068	0.12
1968	59	2599	0.02	74	2754	0.03
1969	119	3500	0.03	544	4949	0.11
1970	93	2614	0.04	103	3636	0.03
Total	329	9923	0.03	969	13407	0.07

Notes:

1 from Fraidenburg *et al*. 1977: p12 and p14.

Table 22. Summary of reported catches of U.S. and CDN trawl catches of bocaccio 1967-2006 (L=landings; D=discards).

Year	4B					3C/CDN							3D							5A						
Nation	CDN		CDN			CDN		CDN		USA	Hake		CDN		CDN		USA	Hake		CDN		CDN		USA	Hake	
Gear	Midwater trawl		Bottom trawl			Midwater trawl		Bottom trawl		Trawl	Trawl		Midwater trawl		Bottom trawl		Trawl	Trawl		Midwater trawl		Bottom trawl		Trawl	Trawl	
	L	D	L	D	Total	L	D	L	D	L	L&D	Total	L	D	L	D	L	L&D	Total	L	D	L	D	USA	L&D	Total
1967					0.00							0.00					51.96		51.96			0.22		88.91		89.13
1968					0.00					0.08		0.08			1.43		32.73		34.16			5.66		13.37		19.03
1969					0.00					2.27		2.27			1.03		86.22		87.25			1.11		246.68		247.79
1970					0.00					78.69		78.69			3.04		126.39		129.43			0.39		54.88		55.27
1971					0.00					12.11		12.11					19.89		19.89					36.45		36.45
1972					0.00					9.26		9.26					63.00		63.00					11.21		11.21
1973					0.00					24.18		24.18					74.07		74.07					170.47		170.47
1974					0.00			0.37		8.16		8.53			3.01		27.01		30.02			1.48		203.58		205.06
1975					0.00			0.54		16.66		17.20					20.07		20.07			3.41		249.98		253.39
1976					0.00			2.59		45.58		48.17			6.24		155.74		161.98	0.82		7.42		178.74		186.98
1977					0.00			22.99		0.46		23.45			10.14		10.74		20.88	0.65		16.76		30.28		47.69
1978			0.06		0.06			6.87		1.49		8.36	0.03		19.11		0.52		19.66			76.04		13.26		89.30
1979			0.29		0.29			14.76		2.02		16.78			31.79		35.27		67.06			44.33		42.16		86.49
1980			0.06		0.06			3.03				3.03			11.63				11.63			27.03				27.03
1981			0.08		0.08			3.56				3.56			7.47				7.47			13.94				13.94
1982					0.00			1.56				1.56			9.78				9.78			26.80				26.80
1983			1.52		1.52			9.30				9.30			36.73				36.73			28.76				28.76
1984					0.00			14.90				14.90			50.08				50.08			42.52				42.52
1985					0.00			35.46				35.46			128.18				128.18			85.25				85.25
1986			0.43		0.43	0.18		81.30				81.48	25.10		197.80				222.90			157.00				157.00
1987					0.00	1.49		31.70				33.19	23.16		149.57				172.73	1.39		169.81				171.20
1988					0.00			288.95			4.34	293.29	44.24		256.34			0.60	301.18	2.25		231.57				233.82
1989			0.01		0.01			101.23			2.38	103.61	5.64		223.79			2.70	232.13	0.39		162.10				162.49
1990					0.00			81.08			2.31	83.39	18.54		167.25			0.40	186.19	5.10		251.85				256.95
1991			0.11		0.11	0.30		76.40			1.92	78.62	5.92		236.46			0.48	242.86			304.24				304.24
1992	0.04		0.21		0.25	1.04		148.78			2.46	152.28	4.02		204.88			0.02	208.92	15.19		243.26				258.45
1993	0.21		0.54		0.75	0.27		130.68			3.04	133.99	32.51		290.06			1.28	323.85	3.87		246.20				250.07
1994	0.24		0.05		0.29	0.67		96.40			6.57	103.64	17.26		155.64			4.09	176.99	5.40		113.38				118.78
1995	0.20				0.20	2.67		53.16			1.60	57.43	9.78		103.05				112.83	7.99		139.18				147.17
1996	0.10		0.03		0.13	1.07	0.01	41.39	0.11		2.93	45.51	29.56	0.09	41.22	0.15			71.02	4.64	0.00	63.41	0.39			68.44
1997					0.00	0.29		28.32	1.42		1.26	31.29	17.88	0.17	38.81	0.52			57.38	4.31	0.04	59.42	0.03			63.80
1998					0.00	1.04		19.13	0.44		1.41	22.02	10.97	0.01	33.43	0.19			44.60	8.09		63.34	0.07			71.50
1999			0.01		0.01	3.80		24.67	0.24		1.62	30.33	28.17		38.78	0.08			67.03	12.27	0.18	43.13	0.09			55.67
2000					0.00	1.73		25.71	0.39		0.22	28.05	14.50	0.06	52.01	1.43			68.00	7.74		39.27			2.63	49.64
2001					0.00	0.79		29.65			0.66	31.10	8.96		51.67	0.06			60.69	12.70	0.04	44.51	0.21			57.46
2002	0.06	0.03			0.09	0.26		16.66	0.08			17.00	11.84	0.01	38.70	0.17			50.72	21.68	0.09	46.50	0.11			68.38
2003	0.04	0.02			0.06	1.29		20.70	0.03			22.02	9.03		31.15	0.08			40.26	13.89		39.35	0.05			53.29
2004					0.00	0.30	0.09	9.53	2.41		0.62	12.95	4.87	2.78	13.88	7.21			28.74	4.30	1.58	31.79	13.55			51.22
2005	0.02	0.29			0.31	0.17	0.27	13.22	7.13		0.64	21.43	9.63	5.02	15.82	4.06			34.53	3.68	2.60	34.02	6.59			46.89
2006		0.01			0.01	1.12	0.07	5.72	4.77		0.22	11.90	9.33	1.00	14.98	5.28			30.59	7.44	0.90	18.64	6.08		0.14	33.20

Table 22 cont'd

5B							5C					5D						5E						Unkn.
CDN Midwater trawl		CDN Bottom trawl		USA Trawl	Hake Trawl		CDN Midwater trawl		CDN Bottom trawl			CDN Midwater trawl		CDN Bottom trawl		Hake Trawl		CDN Midwater trawl		CDN Bottom trawl		Hake Trawl		CDN
L	D	L	D	USA	L&D	Total	L	D	L	D	Total	L	D	L	D	L&D	Total	L	D	L	D	L&D	Total	Trawl
				19.84		19.84					0.00						0.00						0.00	
				48.61		48.61					0.00						0.00						0.00	
		3.22		474.06		477.28					0.00						0.00						0.00	
				41.98		41.98					0.00			0.63			0.63						0.00	
				103.63		103.63					0.00						0.00						0.00	
				130.31		130.31					0.00			9.02			9.02						0.00	
				475.20		475.20					0.00			2.37			2.37						0.00	
				464.09		464.09					0.00						0.00						0.00	
				211.51		211.51					0.00			2.03			2.03						0.00	
		18.96		63.82		82.78			0.05		0.05			14.84			14.84						0.00	
1.85		22.64		192.48		216.97			0.23		0.23			59.46			59.46			1.37			1.37	
		61.83				61.83			7.89		7.89	4.28		43.54			47.82	0.08		14.30			14.38	
0.05		117.79		61.74		179.58			67.65		67.65	2.17		54.48			56.65	0.05		3.69			3.74	
		93.37				93.37			23.57		23.57	0.34		17.97			18.31			0.46			0.46	
		44.92				44.92			3.43		3.43			15.72			15.72			0.59			0.59	
		52.33				52.33			1.86		1.86			7.79			7.79			0.52			0.52	
		65.00				65.00			4.61		4.61	0.04		3.06			3.10	0.09					0.09	
		35.87				35.87			16.32		16.32	0.40		9.16			9.56						0.00	
		74.54				74.54			75.40		75.40	2.49		4.95			7.44			0.33			0.33	
		194.78				194.78			25.99		25.99			10.84			10.84			7.25			7.25	
		246.38				246.38			57.77		57.77			22.95			22.95			5.39			5.39	
3.80		388.46				392.26			35.92		35.92			18.29			18.29			48.15			48.15	
23.87		152.62				176.49			43.29		43.29			22.57			22.57			44.03			44.03	
11.37		367.13				378.50			95.61		95.61	0.23		30.11			30.34			1.48			1.48	
0.43		367.41				367.84			45.75		45.75	0.01		15.86			15.87			8.17			8.17	
0.27		193.69				193.96			50.96		50.96	9.05		63.93			72.98			11.81			11.81	
0.45		239.04				239.49			49.27		49.27	13.91		75.80			89.71	0.22		42.13			42.35	
0.42		110.89				111.31			46.74		46.74	2.92		38.27			41.19	0.04		8.73			8.77	
4.19		88.89				93.08	0.09		63.85		63.94	5.48		22.49			27.97			7.71			7.71	
1.60	0.02	64.89	1.42			67.93	0.03		19.41	0.22	19.66	2.70	0.04	16.44	0.18		19.36	0.20	0.02	9.52	0.02		9.76	14.77
1.48		54.99	0.13			56.60	0.03		11.41		11.44	3.03	0.09	17.05	0.05		20.22			7.39	0.03		7.42	3.14
0.49		51.74	0.15			52.38			11.73	0.01	11.74	1.53		10.16	0.03		11.72			3.13	0.13		3.26	3.94
0.61		50.26	0.11			50.98			12.14	0.02	12.16	3.03		4.11	0.01		7.15	0.71		3.36	0.45		4.52	4.44
0.56		101.64	0.08		3.71	105.99			8.64	0.01	8.65	1.29		5.45	0.02	0.18	6.94	1.91		4.81	0.04	0.49	7.25	5.72
7.32		64.22	0.25			71.79	0.01		9.90		9.91	0.71		14.24	0.01		14.96	3.64		7.67			11.31	4.76
6.90		85.18	0.38			92.46	0.10		19.32	0.01	19.43	0.92		14.61	0.01		15.54	2.95		5.17			8.12	3.62
1.34	0.01	74.38	0.05			75.78	0.02		8.37	0.02	8.41	4.44		4.91			9.35	2.94		4.73	0.02		7.69	3.62
	0.12	24.73	13.43			38.28			3.88	3.60	7.48	0.58	0.73	1.68	1.02		4.01	0.47		1.83	1.01		3.31	5.59
0.06	0.13	20.82	6.66			27.67			2.89	0.32	3.21	0.42	0.16	2.36	0.73		3.67	0.61	0.7	0.90	0.24		2.45	4.70
0.20	0.12	16.44	4.95		0.26	21.97			2.18	0.88	3.06	0.88	0.76	2.64	0.65		4.93	2.03	0.55	1.49	0.07		4.14	7.55

Table 23. Summary of U.S. and CDN trawl catches of bocaccio (1967-2006).

Year	Total landings from BC excl. 4B	Total reported discards from BC excl. 4B	Market-driven discards" by US and CDN vessels (total landings *0.01298)	Inspection-driven discards by CDN vessels (Table A-8))	Total US and CDN trawl catch
	1	**2**	**3**	**4**	**5**
1967	161		2	1	164
1968	102		1	39	142
1969	815		11	29	855
1970	306		4	22	332
1971	172		2	0	174
1972	223		3	50	275
1973	746		10	13	769
1974	708		9	27	744
1975	504		7	33	544
1976	495		6		501
1977	370		5		375
1978	249		3		252
1979	478		6		484
1980	177		2		180
1981	90		1		91
1982	101		1		102
1983	148		2		149
1984	169		2		171
1985	407		5		412
1986	700		9		709
1987	710		9		719
1988	1318		17		1335
1989	780		10		790
1990	1030		13		1043
1991	1061		14		1075
1992	947		12		959
1993	1124		15		1139
1994	597		8		604
1995	509		7		515
1996	311	6			316
1997	248	4			251
1998	219	2			221
1999	229	3			232
2000	271	9			280
2001	261	1			262
2002	274	1			275
2003	220	0			220
2004	103	48			152
2005	109	36			145
2006	91	27			117

Table 24. Landings of shelf rockfish and bocaccio by CDN vessels 1967-1980.

Year	CDN vessel landings of shelf rockfish	CDN vessel landings of bocaccio	Ratio of bocaccio to all shelf rockfish	Estimate of discards owing to regulations
Column	1	2	3	4
1967	149	0.2	0.001	1
1968	169	7.1	0.042	39
1969	314	5.4	0.017	29
1970	331	4.1	0.012	22
1971	488	0.0	0.000	0
1972	867	9.0	0.010	50
1973	682	2.4	0.003	13
1974	311	4.9	0.016	27
1975	497	6.0	0.012	33
1976	1486	50.1	0.034	
1977	3354	133.6	0.040	
1978	4661	229.6	0.049	
1979	4130	334.5	0.081	
1980	3061	177.1	0.058	
1976-1980	16691	924.8	0.055	
1967-1975	3809	39.0	0.010	

Notes:

1 Canary, redbanded, silvergray, widow, yellowmouth, yellowtail rockfish and bocaccio

2 CDN landings from DFO-GFSel.

Table 25. Summary of Soviet, Japanese and Polish catches (t) of rockfish[29].

Year	By Area									By Nation			Grand total
	WCQCI		QCSd		WCQCI +QCSd	WCVI							
	1	2	3	4	5	6	7	8	9	10	11	12	13
	Soviet	Jap.	Soviet	Jap.	Total	Soviet	Jap.	Polish	Total	Soviet	Jap.	Polish	
1965	10026		6870		6870					16896			16896
1966	15453		20910	1425	22335	11589			11589	47952	1425		49377
1967	2381		13560	3221	16781	1883			1883	17824	3221		21045
1968	2900		5650	4515	10165	2953			2953	11503	4515		16018
1969	21		70	7247	7317	41			41	132	7247		7379
1970	34		0	3330	3330	344			344	378	3330		3708
1971	167	3113	120	410	530	743	1944		2687	1030	5467		6497
1972		4559		2676	2676	499	1834		2333	499	9069		9568
1973		4208		5678	5678		4042		4042		13928		13928
1974		2883		14266	14266		5465	12200	17665		22614	12200	34814
1975		2954		6693	6693		1638	3500	5138		11285	3500	14785
1976		3538		3408	3408		622		622		7568		7568
1977				980	980						980		980

[29] Cols. 1 and 6 from Ketchen 1980a (Table 1, p.46); Col. 2 from Ketchen *et al*. 1978 (Table 1a, p.4); Col. 3 from Ketchen 1980a (p. 7, p. 21, “Intermediate Estimate); Col. 4: from Ketchen 1980a (Table 3, p.17, “Total rockfish”); Col. 7 from Ketchen *et al*. 1978 (Table 18, p.60); Col. 8 from Ketchen 1980b (p. 23).

Table 26. Estimated catch (t) of bocaccio in the Soviet and Japanese fisheries (1965-1977).

	3C-3D			5A-5E			Total
	All Rockfish (Soviet and Japanese)	Based on GB Reed index (1965-1977)		All Rockfish (Soviet and Japanese)	Based on GB Reed index (1965-1977)		
Year		**$p_{bocaccio}$**	**Bocaccio catch**		**$p_{bocaccio}$**	**Bocaccio catch**	**Bocaccio catch**
1965				6870	0.0229	157	157
1966				37788	0.0229	865	865
1967	6678	0.0261	174	19162	0.0229	439	613
1968	4751	0.0261	124	13065	0.0229	299	423
1969	1787	0.0261	47	7338	0.0229	168	215
1970	2186	0.0261	57	3364	0.0229	77	134
1971	2049	0.0261	53	3810	0.0229	87	141
1972	1911	0.0261	50	7235	0.0229	166	216
1973	4123	0.0261	108	9886	0.0229	226	334
1974	5518	0.0261	144	17149	0.0229	393	537
1975	1639	0.0261	43	9647	0.0229	221	264
1976	622	0.0261	16	6946	0.0229	159	175
1977				980	0.0229	22	22

Table 27. Estimates of catches (t) from the Rockfish ZN fishery (1940-2006).

Year	All rockfish landings	Estimated bocaccio landings	Year	All rockfish landings	Estimated bocaccio landings	Year	All rockfish landings	Estimated bocaccio landings
1940		0.6	1963	94.2	1.1	1986	966.3	11.6
1941		0.6	1964	41.0	0.5	1987	1182.0	14.2
1942		0.6	1965	42.9	0.5	1988	1101.6	13.2
1943		0.6	1966	47.1	0.6	1989	1216.4	14.6
1944		0.6	1967	71.4	0.9	1990	1746.0	21.0
1945		0.6	1968	56.8	0.7	1991	1714.5	20.6
1946		0.6	1969	103.4	1.2	1992	1519.8	18.2
1947		0.6	1970	148.2	1.8	1993	1757.3	21.1
1948		0.6	1971	94.4	1.1	1994	1668.0	20.0
1949		0.6	1972	155.2	1.9	1995		28.0
1950		0.6	1973	97.7	1.2	1996		23.0
1951		0.6	1974	159.8	1.9	1997		12.0
1952		0.6	1975	181.3	2.2	1998		10.0
1953		0.6	1976	133.5	1.6	1999		13.5
1954		0.6	1977	175.2	2.1	2000		18.1
1955		0.6	1978	202.0	2.4	2001		22.5
1956	33.7	0.4	1979	290.5	3.5	2002		15.4
1957	59.9	0.7	1980	263.0	3.2	2003		12.4
1958	45.6	0.5	1981	201.3	2.4	2004		14.4
1959	46.1	0.6	1982	161.3	1.9	2005		13.1
1960	67.3	0.8	1983	177.4	2.1	2006		13.9
1961	74.9	0.9	1984	291.9	3.5			
1962	105.1	1.3	1985	451.6	5.4			

Notes:

- 1940-1955 bocaccio landings estimated as mean of 1956-1960;
- 1956-1994 estimated as 0.012 of all rockfish;
- 1995-2005 from DMP;
- 2006 from DMP with 100% retention of all rockfish.

Table 28. Number of skates set in B.C. in the halibut fishery for 1929-2007.

Year	# of Skates	Year	# of Skates	Year	# of Skates
1929	382900	1956	153800	1983	80105
1930	381400	1957	175200	1984	61149
1931	376200	1958	170500	1985	71361
1932	307600	1959	180500	1986	95250
1933	286100	1960	165700	1987	94809
1934	283000	1961	159900	1988	94234
1935	234900	1962	170300	1989	78209
1936	269600	1963	184100	1990	49657
1937	251400	1964	149600	1991	49054
1938	226000	1965	139900	1992	44912
1939	282500	1966	131400	1993	51538
1940	278800	1967	123800	1994	46419
1941	264800	1968	116600	1995	44110
1942	239200	1969	157800	1996	42345
1943	231600	1970	136700	1997	51701
1944	177100	1971	116700	1998	57026
1945	174600	1972	137600	1999	59812
1946	212200	1973	98700	2000	47336
1947	195700	1974	72188	2001	45708
1948	195900	1975	104853	2002	54550
1949	191900	1976	137358	2003	51169
1950	199400	1977	89016	2004	57547
1951	247600	1978	73175	2005	62792
1952	233700	1979	101250	2006	59604
1953	174900	1980	86923	2007	58837
1954	177900	1981	84478		
1955	151000	1982	81471		

Table 29. Catch by hook type in the 1984 IPHC hook experiment (Bruce Leaman. pers. comm.).

Region	Vessel	Species	J-Hook	C-Hook	Total
Kodiak	Chelsea	Unid. rockfish	9	7	16
Kodiak	Seymour	Unid. rockfish	2	12	14
BC	Star Wars II	Canary rockfish	2	2	4
		Pacific ocean perch	1	2	3
		Quillback rockfish	1	0	1
		Redbanded rockfish	9	10	19
		Unid. rockfish	16	10	26
BC	Windward Isle	Canary rockfish	0	4	4
		Quillback rockfish	4	6	10
		Redbanded rockfish	18	21	39
		Unid. rockfish	17	17	34
Total			79	91	170

Table 30. Catch rate (pieces) of bocaccio during halibut fishing 2006 and 2007.

Year	Number of skates (FOS)	Number of skates (IPHC)	Weight (kg)	Count	Kg/ FOS skate	Piece/FOS skate	Kg/piece
2006	78045	59604	8245	1922	0.106	0.025	4.29
2007	60885	58837	7717	1778	0.127	0.029	4.34
Mean					0.115	0.027	4.31

Table 31. Salmon troll effort in days fished by Major Area.

Year	Statistical Area																			
	Areas 1 & 101	Areas 2E, 2 & 102	Areas 2W & 142	Area 3	Area 4	Area 5	Areas 6 & 106	Areas 7 & 107	Areas 8 & 108	Areas 9 & 109	Areas 10 & 110	Areas 11 & 111	Areas 30 & 130	Areas 21 & 121	Area 22	Areas 23 & 123	Areas 24 & 124	Areas 25 & 125	Areas 26 & 126	Areas 27 & 127
Total	**568846**	**121707**	**122716**	**178980**	**102977**	**58567**	**97138**	**161486**	**58575**	**22485**	**26829**	**139895**	**8765**	**111583**	**56**	**1200970**	**512556**	**213323**	**261922**	**344011**
1952	7954	1902	721	5887	4900	3112	652	3152	1710	224	8	555	14	1779	0	21023	11207	7884	4886	3914
1953	10314	1423	324	4072	3766	1792	943	1965	1536	162	19	23	342	2201	1	21148	9299	6467	5048	3276
1954	8780	1029	221	2881	5092	1423	189	1432	1505	40	39	37	75	997	0	23195	6374	7218	4130	3055
1955	10532	1557	262	4978	2614	1230	363	1728	1564	20	31	27	36	692	0	20127	7981	8119	5582	2802
1956	8131	1864	386	4288	2177	1145	222	1643	1460	27	14	16	0	682	0	22907	7729	8454	5683	2858
1957	9379	1746	542	4520	1893	1350	300	2154	1494	43	51	64	39	941	0	24428	8763	10136	6662	2697
1958	8675	1701	220	6142	2527	1218	815	2836	1592	140	126	125	130	735	0	24744	8667	6561	6454	4683
1959	8237	1405	289	6263	2707	1565	1037	2272	1301	228	221	160	195	718	0	27479	7189	4308	7000	3337
1960	8181	2436	308	7317	3063	2120	1716	4277	1625	100	285	214	119	431	0	21065	9962	3015	7304	3341
1961	9927	2047	383	5323	3360	2251	2658	4955	1241	117	196	106	55	1536	0	27527	11549	4681	7597	5831
1962	8379	2019	853	5589	3111	2758	2011	4797	1422	67	252	81	56	1858	0	28416	7245	3765	6730	4576
1963	7985	1672	747	3788	3103	3376	2497	5555	539	45	196	626	85	3120		26100	9587	4599	5797	4833
1964	9969	2693	698	4863	4892	4114	6160	6113	1500	340	193	158	31	1481		32669	13446	1749	6634	3235
1965	9337	2539	1082	3826	4519	5544	6781	4892	984	117	256	167	80	1700		33586	16738	2406	7162	5111
1966	8544	2545	1064	4559	3784	5156	4942	4923	1552	172	641	370	76	1706		38243	15921	2971	6994	3692
1967	9477	2218	1406	3238	3007	4859	3773	5284	1194	234	2059	407	120	2404	12	37069	14719	4037	8282	5018
1968	10835	2607	703	5828	5427	6258	5184	5418	2251	2090	1956	396	86	1335		37610	14823	4857	7340	6665
1969	11552	3639	1501	4726	4141	3972	2928	4961	1236	352	1120	482	193	3249		36945	12397	4036	6178	7017
1970	13848	3924	1157	4511	2894	3289	5696	6320	2370	393	841	3851	237	5099		31910	13361	3733	6210	4443
1971	11101	3749	1767	3840	2813		1994	5655	1402	244	240	1895	582	6501		40304	14887	5178	6442	8354
1972	9783	4376	1495	4237	3277		4962	6382	2218	607	830	5228	590	4292		35218	10288	3848	6503	5472
1973	8781	3750	736	3100	2044		2988	5037	1557	805	567	5632	438	4180		38319	12329	2140	6291	5712
1974	9292	3572	1338	2644	1338		3159	3605	2259	1014	502	3789	593	2685	1	32597	12912	4658	6322	6934
1975	11531	3727	1574	2405	2305		2250	3453	1363	705	563	4189	388	2434		31330	12273	2363	6171	6952
1976	8857	5481	1773	1903	2131		1461	4825	2790	2328	1481	6151	329	2794		29915	14988	2501	7024	5899
1977	8769	3931	2015	2278	1255		2159	5570	2317	2576	707	8130	468	4303		37172	15891	1994	6359	8748
1978	11190	4118	2766	3036	982		2497	5096	2484	1490	581	7193	171	3158		31246	16839	5892	7590	9290
1979	13897	3991	2583	2029	1155		1805	6178	1938	1315	686	7324	308	2757		40583	18636	6866	6674	9926
1980	25361	6320	7122	3600	1100		2864	6147	2362	1544	808	8645	331	5513	20	46190	16784	6251	6772	12398
1981	19343	5305	7398	3495	1192		2465	5121	2187	990	971	10750	353	4897		36480	14257	6986	4542	13344
1982	18151	4461	6139	3208	1520		2224	5033	906	748	836	4355	169	4238		38278	18082	8151	4530	15731
1983	20803	4691	3289	7116	2639		2844	3799	1325	420	2284	11165	650	6054		30945	18622	6372	4430	12353
1984	21128	1339	3482	5292	1991		2420	4352	1221	304	910	6615	250	4233		31128	11841	3607	4825	13411
1985	18328	1785	7321	2445	1193		1049	2415	817	284	512	5192		5841		23839	11041	3755	4868	13727
1986	13745	3022	2433	4567	1640		1461	2451	1029	613	1489	6654	17	1997		14601	11728	6550	4199	14232
1987	15824	2995	7519	2813	888		1169	2193	830	174	594	4271	57	1138	8	10471	10430	2925	3063	7161
1988	15450	1518	3100	2092	594		1312	1116	223	318	341	3735	58	1964		15731	11267	3513	3935	10545
1989	11484	846	6409	1972	401		500	619	105	68	275	3306	131	710		12012	8804	3464	3183	10896
1990	13821	1860	5106	3431	774		1214	1454	314	184	1080	3386	31	986		15580	7289	4704	5146	12841
1991	17464	2033	4489	4073	1140		1013	2037	117	39	527	1803	42	1814		14665	7391	6650	4428	10816
1992	12181	1754	2160	3147	1285		1238	1514	113	436	357	3104	47	726		12336	7478	3902	5908	17828
1993	11761	1051	4409	2045	371		437	842	58	107	90	2548		1216	14	8140	6190	3738	4104	12870
1994	11945	1125	6880	4010	197		428	735	179	136	716	5379	17	2850		8490	4418	1955	2232	5304
1995	13029	906	1691	2348	168		621	435	56	73	198	1237		547		9594	3009	1696	1889	4765
1996	5738	502	70	4193	546	943	262	37	60	0	63	8		885		5524	2195	1068	1679	2429
1997	8093	901	1201	93	280	352	334	238	42	15	37	76		8		930	428	259	485	815
1998	80	78	5787	7	35	19	182	80	42	0	4	108	26	2		276	272	110	90	455
1999	106	192	1835	24	34	100	68	66	54	8	10	13	4	81		1169	513	154	345	381
2000	263	44	787	0	0	35	32	37	7	4	5	38		5		649	555	545	472	229
2001	554	107	747	221	335	20	11	10	28	18	13	11		16		2397	811	270	195	89
2002	2090	204	1430	72	17	96	156	49	14	0	12	0		39		2076	1107	317	1143	332
2003	2802	254	1064	201	10	242	90	100	42	0	21	0	3	0		1550	310	584	1251	251
2004	3115	331	726	326	84	127	205	67	11	0	0	18	7	18		1010	515	385	1621	560
2005	4389	247	494	84	86	0	157	33	29	7	5	41	300	23		905	419	271	2427	1026
2006	5312	42	174	27	7	101	112	6	0	0	10	41	37	10		1151	371	415	2083	932
2007	3249	133	540	7	173	0	128	22	0	0	0	0	399	4		1978	429	290	1028	619

Table 32. Summary of responses about bocaccio pieces/day while salmon troll fishing. NF indicates little or no experience in that area.

Statistical Area	**Troll-fisher**												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**10**	**11**	**12**	**13**	**14**
Statistical Areas 1 & 101	NF	NF	0	2/day	1/2 days		0	3-4/15 days	5-20	2/day	6	NF	NF
Statistical Areas 2E & 102	NF	NF		2-3/day or none	1/2 days		NF	NF		NF	2-3	NF	NF
Statistical Areas 2W & 142	2/day	1-2	0	1/day	10-20/day		5/day	3-4/15 days		NF	10-15	3-4/day	0
Statistical Areas 3 & 103	NF	NF	NF	NF	1/2 days		NF	NF		NF	NF	NF	NF
Statistical Areas 4 &104	NF	NF	NF	NF	NF		NF	NF		NF	NF	NF	NF
Statistical Areas 5 & 105	0	NF	NF	0	1/2 days		NF	NF		NF	0	NF	NF
Statistical Areas 6 & 106	0	NF	NF	0	NF		NF	NF		NF	0	NF	NF
Statistical Areas 7 & 107	0	NF	NF	0	NF		NF	NF		NF	0	NF	NF
Statistical Areas 8 & 108	2/day	NF	NF	NF	NF		0	NF		1/day	0	NF	NF
Statistical Areas 9 & 109	NF	NF	NF	NF	NF		NF	NF		NF	NF	NF	NF
Statistical Areas 10 & 110	NF	NF	NF	NF	NF		0	NF		NF	0	NF	NF
Statistical Areas 11 & 111	NF	0	0	3-4/day	1/2 days		0	1-2/30 days		5/day	0	0	NF
Statistical Area 130	NF	NF	NF	NF	1/2 days		NF	NF		NF	NF	NF	NF
Statistical Areas 21 & 121	NF	0	0	5/day	NF		1/60 days	1-2/30 days		NEVER	0	0	NF
Statsitical Area 122	NF	0	0	NF	1/2 days		NF	NF		NEVER	NF	NF	NF
Statistical Areas 23 & 123	NF	0	0	3/day	1/2 days		1/2 days	1-2/30 days		NEVER	0	1-2/week	NF
Statistical Areas 24 & 124	NF	1/month	0	0	1/2 days		0	1/day		NEVER	0	1-2/week	NF
Statistical Areas 25 & 125	NF	1/week	0	1/day	1/2 days		NF	1/10 days		NEVER	3-4	1-2/day	NF
Statistical Areas 26 & 126	NF	0-1	4-40	1/day	NF		10/day	3-4/trip		NEVER	15-20	1-2/day	NF
Statistical Areas 27 & 127	NF	0-1	1-10	3/day	1/2 days	1-2/day	2/day	3-4/trip		10/day	30-40	1-2/day	NF

Table 33. Interview responses Table 32 converted to pieces/day.

Statistical Area	**Troll-Fisher**												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Statistical Areas 1 & 101			0.00	2.00	0.50		0.00	0.23	10.00		6.00		
Statistical Areas 2E & 102				1.25	0.50						2.50		
Statistical Areas 2W & 142	2.00	1.50	0.00	1.00	15.00		5.00	0.23			2.50	3.50	0.00
Statistical Areas 3 & 103					0.50								
Statistical Areas 4 &104													
Statistical Areas 5 & 105	0.00			0.00	0.50						0.00		
Statistical Areas 6 & 106	0.00			0.00							0.00		
Statistical Areas 7 & 107	0.00			0.00							0.00		
Statistical Areas 8 & 108	2.00						0.00				0.00		
Statistical Areas 9 & 109													
Statistical Areas 10 & 110							0.00				0.00		
Statistical Areas 11 & 111		0.00	0.00	3.50	0.50		0.00	0.05			0.00	0.00	
Statistical Area 130					0.50								
Statistical Areas 21 & 121		0.00	0.00	5.00			0.02	0.05			0.00	0.00	
Statsitical Area 122		0.00	0.00										
Statistical Areas 23 & 123		0.00	0.00	3.00	0.50		0.50	0.00			0.00	0.21	
Statistical Areas 24 & 124		0.03	0.00	0.00	0.50		0.00	0.05			0.00	0.21	
Statistical Areas 25 & 125		0.14	0.00	1.00	0.50			0.20			3.50	1.50	
Statistical Areas 26 & 126		0.50	22.00	1.00			10.00	0.23			17.50	1.50	
Statistical Areas 27 & 127		0.50	5.50	3.00	0.50	1.50	2.00	0.23			35.00	1.50	

Table 34. Summary estimates of bocaccio discard rate in the salmon troll fishery. The trimmed mean was the mean of all observations after removing the minimum and maximum values.

Statsitical Area	**Interview Statistics**						
	Sum	**Average**	**Median**	**Min**	**Max**	**Count**	**Trimmed mean**
Statistical Areas 1 & 101	18.73	2.68	0.50	0.00	10.00	7	1.75
Statistical Areas 2E & 102	4.25	1.42	1.25	0.50	2.50	3	1.25
Statistical Areas 2W & 142	30.73	3.07	1.75	0.00	15.00	10	1.97
Statistical Areas 3 & 103	0.50	0.50	0.50	0.50	0.50	1	0.50
Statistical Areas 4 &104						0	
Statistical Areas 5 & 105	0.50	0.13	0.00	0.00	0.50	4	0.00
Statistical Areas 6 & 106	0.00	0.00	0.00	0.00	0.00	3	0.00
Statistical Areas 7 & 107	0.00	0.00	0.00	0.00	0.00	3	0.00
Statistical Areas 8 & 108	2.00	0.67	0.00	0.00	2.00	3	0.00
Statistical Areas 9 & 109						0	
Statistical Areas 10 & 110	0.00	0.00	0.00	0.00	0.00	2	0.00
Statistical Areas 11 & 111	4.05	0.51	0.00	0.00	3.50	8	0.09
Statistical Area 130	0.50	0.50	0.50	0.50	0.50	1	0.50
Statistical Areas 21 & 121	5.07	0.72	0.00	0.00	5.00	7	0.01
Statsitical Area 122	0.00	0.00	0.00	0.00	0.00	2	0.00
Statistical Areas 23 & 123	4.21	0.53	0.11	0.00	3.00	8	0.20
Statistical Areas 24 & 124	0.79	0.10	0.02	0.00	0.50	8	0.05
Statistical Areas 25 & 125	6.84	0.98	0.50	0.00	3.50	7	0.67
Statistical Areas 26 & 126	52.73	7.53	1.50	0.23	22.00	7	6.10
Statistical Areas 27 & 127	49.73	5.53	1.50	0.23	35.00	9	2.07

Table 35. Total landed and discarded catches for bocaccio in the combined GFCatch/PacHarvestTrawl databases, summarised by standard 1 April–31 March fishing years for each of the major DFO reporting areas. Data from 1 April 1979 to 27 December 1995 are from the GFCatch database (Rutherford 1995). Data from 16 February 1996 to 31 March 2007 are from the PacHarvestTrawl database. The groundfish fishery was closed from 28 December 1995 to 15 February 1996. These catches have been processed without data selection criteria.

Fishing year	DFO Major Area							
	3C	3D	5A	5B	5C	5D	5E	Total
Landed catch								
79/80	1.4	31.8	39.9	120.2	68.5	37.6	2.4	301.9
80/81	3.0	12.5	28.9	56.5	18.5	18.4	0.4	138.3
81/82	3.6	7.9	10.0	26.8	2.7	3.6	0.3	54.8
82/83	1.5	9.4	23.4	38.5	1.4	7.8	0.5	82.4
83/84	13.1	35.6	28.1	60.2	4.6	1.7	0.1	143.3
84/85	26.8	82.5	47.2	35.1	14.1	9.8	0.0	215.4
85/86	18.4	164.5	115.6	76.4	71.0	7.4	3.8	457.2
86/87	84.3	165.5	129.9	196.3	29.9	11.8	5.7	623.3
87/88	30.8	173.1	194.2	246.3	57.8	22.8	20.4	745.4
88/89	293.3	300.9	253.8	394.1	40.6	20.6	31.7	1,335.0
89/90	107.9	233.0	146.1	179.2	48.6	22.6	43.5	780.9
90/91	70.5	183.8	286.7	373.8	87.8	20.8	2.9	1,026.3
91/92	101.2	234.5	289.1	386.9	43.1	31.8	13.4	1,100.1
92/93	142.3	235.7	254.1	197.9	50.5	53.8	10.1	944.4
93/94	113.4	294.7	214.3	226.4	52.6	89.9	38.4	1,029.7
94/95	101.1	177.3	123.0	113.5	42.2	45.9	11.5	614.4
95/96	50.6	102.4	134.1	75.4	62.1	19.9	6.2	450.7
96/97	41.0	65.4	60.6	63.6	19.2	18.1	7.6	275.4
97/98	28.6	56.7	63.7	56.5	11.4	20.1	7.4	244.4
98/99	20.2	44.4	71.4	52.2	11.7	11.7	3.1	214.7
99/00	28.5	66.9	55.4	50.9	12.1	7.1	4.1	225.0
00/01	27.4	66.5	47.0	102.2	8.6	6.7	6.7	265.3
01/02	30.4	60.6	57.2	71.5	9.9	15.0	11.3	256.0
02/03	16.9	50.5	68.2	92.1	19.4	15.5	8.1	270.8
03/04	22.0	40.2	53.2	75.7	8.4	9.4	7.7	216.6
04/05	9.8	18.7	36.1	24.7	3.9	2.3	2.3	97.8
05/06	13.4	25.5	37.7	20.9	2.9	2.8	1.5	104.6
06/07	6.8	24.3	26.1	16.6	2.2	3.5	3.5	83.1
Total	1,408.4	2,964.9	2,895.0	3,430.5	805.7	538.2	254.7	12,297.4
Discarded catch								
96/97	0.1	0.2	0.3	1.4	0.2	0.2	0.1	2.5
97/98	1.4	0.7	0.1	0.1	0.0	0.1	0.0	2.5
98/99	0.4	0.2	0.1	0.1	0.0	0.0	0.1	1.0
99/00	0.2	0.1	0.3	0.1	0.0	0.0	0.4	1.2
00/01	0.4	1.5	0.0	0.1	0.0	0.0	0.0	2.0
01/02	0.0	0.1	0.2	0.3	0.0	0.0	0.0	0.6
02/03	0.1	0.2	0.2	0.4	0.0	0.0	0.0	0.9
03/04	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.3
04/05	2.5	10.0	15.1	13.5	3.6	1.8	1.0	47.5
05/06	7.4	9.1	9.2	6.8	0.3	0.9	0.9	34.6
06/07	4.8	6.3	7.0	5.1	0.9	1.4	0.6	26.1
Total	17.5	28.3	32.5	28.0	5.1	4.5	3.3	119.2

Table 36. Order of acceptance of variables into the 3C-5E model of successful total mortalities (verified landings plus discards) of bocaccio by core vessels (based on the vessel selection criteria of at least 5 trips in three or more fishing years) with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Fishing year was forced as the first variable.

Variable	1	2	3	4	5	6	7
Fishing year*	**0.011**						
DFO locality*	0.051	**0.065**					
Vessel*	0.038	0.048	**0.090**				
0.1° Latitude bands*	0.049	0.063	0.088	**0.111**			
Depth bands*	0.023	0.037	0.082	0.107	**0.127**		
Month*	0.015	0.025	0.076	0.100	0.122	**0.138**	
DFO Major region	0.019	0.032	0.072	0.097	0.114	0.130	0.142
Improvement in deviance	0.000	0.054	0.025	0.021	0.016	0.011	0.004

Table 37. Arithmetic and standardised CPUE indices with upper and lower bounds of the standardised indices and the associated standard error for the 3C-5E model of non-zero catches of bocaccio. The geometric mean of the standardised series has been scaled so that it equals the geometric mean of the arithmetic series.

Fishing year	Arithmetic	Standardised	Lower bound	Upper bound	Standard error
96/97	29.8	28.9	27.1	30.8	0.032
97/98	29.4	31.5	30.0	33.1	0.025
98/99	27.4	27.9	26.6	29.3	0.025
99/00	25.2	27.4	26.2	28.7	0.024
00/01	32.1	28.1	26.9	29.3	0.022
01/02	33.5	32.3	30.9	33.8	0.022
02/03	29.4	29.9	28.6	31.2	0.022
03/04	27.1	27.9	26.7	29.2	0.023
04/05	26.0	21.9	20.9	23.0	0.025
05/06	18.9	20.5	19.5	21.5	0.024
06/07	18.2	19.5	18.4	20.6	0.028

Table 38. Number of sets made by each vessel involved in the west coast Vancouver Island shrimp trawl by month and survey year. All sets south of 50°N are included, not just sets used in the analysis.

Vessel & Year	Month					
	April	May	June	July	August	September
Challenger						
1977						13
Deliverance						
1977						15
Frosti						
2005		108				
G. B. Reed						
1975		92				
1976		90				
1977		76				
1978		101				
1979		77				
1980		85				
1981		88				
1982		82				
1983		77				
1985		51	32			
Pacific Trident						
1977						21
Ocean King						
1978						95
Ricker						
1987					68	
1988	19	62				
1990	61	21				
1991	2	85				
1992		83				
1993	29	74				
1994	31	73				
1995		88				
1996	6	105				
1997		130				
1998		114				
1999		129				
2000		117				
2001		116				
2002	56	65				
2003	62	45				
2004	20	97				
2006	31	81				
2007	41	66				
Sharlene K.						
1989		67				
Sunnfjord						
1977						19

Table 39. List of tows used from the WCVI shrimp trawl survey by survey year and stratum, including the number and weight of bocaccio for tows dropped from the analysis and tows shifted from 124 to 123. All tows with starting depths >160 m have been excluded.

	Stratum				**Stratum**		
Year	**124**	**125**	**Tows**	**Year**	**124**	**125**	**Tows**
1975	61	18	79	1993	69	31	100
1976	70	18	88	1994	66	29	95
1977	52	20	72	1995	60	23	83
1978	83	16	99	1996	55	17	72
1979	51	24	75	1997	60	21	81
1980	59	22	81	1998	42	20	62
1981	53	25	78	1999	48	30	78
1982	54	23	77	2000	41	29	70
1983	49	22	71	2001	45	22	67
1985	57	21	78	2002	48	25	73
1987	52	12	64	2003	46	19	65
1988	66	10	76	2004	46	25	71
1989	67	0	67	2005	45	25	70
1990	68	10	78	2006	48	21	69
1991	87	0	87	2007	47	22	69
1992	75	6	81				
Total					1770	606	2376
Area (km^2)[1]					1844	1396	3240

[1] Area out to 160 m maximum depth

Table 40. Biomass estimates for bocaccio from the WCVI shrimp trawl survey for the survey years 1975 to 2007. Biomass estimates are based on a post-stratification of this survey into two strata (Figure 34) 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 (Eq. 27) 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	106.1	107.0	48.7	190.9	0.340	0.350
1976	42.3	42.3	11.5	99.4	0.508	0.521
1977	84.7	84.6	28.4	177.1	0.449	0.467
1978	362.1	357.3	8.5	1000.2	0.715	0.713
1979	25.6	25.6	5.1	52.9	0.456	0.494
1980	21.2	20.8	0.0	58.2	0.735	0.768
1981	28.6	28.6	0.7	89.5	0.752	0.781
1982	577.0	581.6	54.0	1741.1	0.821	0.823
1983	339.6	352.4	7.3	1293.4	0.920	0.926
1985	366.9	368.2	168.6	606.0	0.301	0.302
1987	73.7	73.5	26.6	138.9	0.379	0.380
1988	117.9	115.0	25.7	275.7	0.537	0.525
1989	33.6	33.3	7.0	89.8	0.558	0.531
1990	162.6	163.5	30.0	421.3	0.612	0.591
1991	115.3	115.3	5.4	395.0	0.826	0.903
1992	387.0	379.6	111.6	854.0	0.449	0.426
1993	10.0	10.1	0.0	40.9	1.001	1.000
1994	139.6	138.5	0.0	535.3	0.958	0.945
1995	15.4	15.1	0.0	59.2	0.991	1.000
1996	50.5	50.2	0.0	174.2	0.870	0.902
1997	110.9	111.0	21.4	267.0	0.575	0.576
1998	214.3	212.2	0.0	729.4	0.909	0.940
1999	2.0	2.0	0.0	7.0	0.951	1.000
2000	0.0	0.0	–	–	–	0.000
2001	70.2	69.5	19.4	156.3	0.468	0.460
2002	30.6	30.7	1.0	93.5	0.758	0.765
2003	32.1	32.3	0.0	72.5	0.530	0.552
2004	30.2	29.7	0.0	88.9	0.731	0.726
2005	583.2	570.8	0.0	2050.1	0.976	0.971
2006	6.4	6.5	0.0	26.8	0.977	1.000
2007	11.6	11.3	0.3	37.5	0.732	0.693

Table 41. Number of sets made by each vessel involved in the QCSd shrimp trawl by month and survey year. All QCSd sets are included, not just sets used in the analysis.

	Month				
Vessel and Year	**Apr**	**May**	**Jun**	**Jul**	**Total**
Frosti					
2005		55			55
Ocean Dancer					
1998				18	18
Pacific Rancher					
1998				18	18
Parr Four					
1998				17	17
W. E. Ricker					
1999			133		133
2000		87			87
2001		75			75
2002	76				76
2003	65				65
2004	71				71
2006	72				72
2007	70				70
Westerly Gail					
1998				21	21
Western Clipper					
1998				18	18

Table 42. Stratum designations, area covered, and number of useable tows, for the QCSd shrimp survey from 1999 to 2007.

	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
Total	556	61	617
Area (km^2)	2,142	159	2,301

Table 43. Biomass estimates for bocaccio from the QCSd shrimp trawl survey for the survey years 1999 to 2007. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement (see Eq. 22-27). The analytic CV (Eq. 27) is based on the assumption of random tow selection within a stratum. – indicates not applicable

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
1999	18.8	19.0	5.3	38.4	0.432	0.445
2000	9.2	9.3	0.0	29.1	0.796	0.761
2001	19.4	19.5	5.7	39.7	0.432	0.420
2002	2.5	2.6	0.0	10.3	0.980	1.000
2003	7.2	7.5	0.0	17.0	0.557	0.571
2004	17.7	17.5	0.0	51.8	0.840	0.865
2005	4.7	4.4	0.0	19.1	1.014	1.000
2006	7.1	7.0	1.6	16.2	0.522	0.532
2007	0	0	–	–	–	0

Table 44. Number of tows by stratum and by survey year for the NMFS triennial survey. Strata which are coloured grey have been excluded from the analysis due to incomplete coverage across the seven survey years or were from locations outside of the Vancouver INPFC area (Table 45.).

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

Table 45. Stratum definitions by year used in the NMFS triennial survey to separate the survey results by country and by INPFC area. Stratum definitions in grey are those strata which have been excluded from the final analysis due to incomplete coverage across the seven survey years or because the locations were outside of the Vancouver INPFC area.

Year	Stratum No.	Area (km^2)	Start	End	Country	INPFC area	Depth range
1980	10	3537	47°30	US-Can Border	US	Vancouver	55-183 m
1980	11	6572	US-Can Border	49°15	CDN	Vancouver	55-183 m
1980	30	443	47°30	US-Can Border	US	Vancouver	184-219 m
1980	31	325	US-Can Border	49°15	CDN	Vancouver	184-219 m
1980	50	758	47°30	US-Can Border	US	Vancouver	220-366 m
1980	51	503	US-Can Border	49°15	CDN	Vancouver	220-366 m
1983	10	1307	47°30	47°55	US	Vancouver	55-183 m
1983	11	2230	47°55	US-Can Border	US	Vancouver	55-183 m
1983	12	6572	US-Can Border	49°15	CDN	Vancouver	55-183 m
1983	30	66	47°30	47°55	US	Vancouver	184-219 m
1983	31	377	47°55	US-Can Border	US	Vancouver	184-219 m
1983	32	325	US-Can Border	49°15	CDN	Vancouver	184-219 m
1983	50	127	47°30	47°55	US	Vancouver	220-366 m
1983	51	631	47°55	US-Can Border	US	Vancouver	220-366 m
1983	52	503	US-Can Border	49 °15	CDN	Vancouver	220-366 m
1989&after	17N	1033	47°30	47°50	US	Vancouver	55-183 m
1989&after	17S	3378	46°30	47°30	US	Columbia	55-183 m
1989&after	18N	159	47°50	48°20	CDN	Vancouver	55-183 m
1989&after	18S	2123	47°50	48°20	US	Vancouver	55-183 m
1989&after	19N	8224	48°20	49°40	CDN	Vancouver	55-183 m
1989&after	19S	363	48°20	49°40	US	Vancouver	55-183 m
1989&after	27N	125	47°30	47°50	US	Vancouver	184-366 m
1989&after	27S	412	46°30	47°30	US	Columbia	184-366 m
1989&after	28N	88	47°50	48°20	CDN	Vancouver	184-366 m
1989&after	28S	787	47°50	48°20	US	Vancouver	184-366 m
1989&after	29N	942	48°20	49°40	CDN	Vancouver	184-366 m
1989&after	29S	270	48°20	49°40	US	Vancouver	184-366 m
1995&after	37N	102	47°30	47°50	US	Vancouver	367-500 m
1995&after	37S	218	46°30	47°30	US	Columbia	367-500 m
1995&after	38N	66	47°50	48°20	CDN	Vancouver	367-500 m
1995&after	38S	175	47°50	48°20	US	Vancouver	367-500 m

Table 46. Number of usable tows performed and area surveyed in the INPFC Vancouver region separated by the international border between Canada and the United States. Strata 18N, 28N, 37, 38 and 39 (Table 45.) were dropped from this analysis as they were not consistently conducted over the survey period. All strata occurring in the Columbia INPFC region (17S and 27S; Table 45.) were also dropped.

Survey year	Number of tows CDN waters	US waters	Total	Area surveyed (km^2) CDN waters	US waters	Total
1980	59	26	85	7,399	4,738	12,137
1983	47	70	117	7,399	4,738	12,137
1989	65	55	120	9,166	4,699	13,865
1992	59	50	109	9,166	4,699	13,865
1995	62	35	97	9,166	4,699	13,865
1998	54	42	96	9,166	4,699	13,865
2001	36	37	73	9,166	4,699	13,865
Total	382	315	697	–	–	–

Table 47. Biomass estimates for bocaccio 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. Biomass estimates are calculated as described earlier (see Eq. 22-27). The bootstrap estimates are based on 5000 random draws with replacement.

Estimate type	Year	Biomass	Mean bootstrap biomass	Lower bound biomass	Upper bound biomass	CV bootstrap	CV Analytic
Total Vancouver	1980	7,653	7,797	423	28,630	0.904	0.915
	1983	4,741	4,629	1,020	14,053	0.642	0.634
	1989	16,040	15,317	799	59,992	0.951	0.914
	1992	969	953	170	2,666	0.643	0.680
	1995	76	75	22	164	0.461	0.482
	1998	269	267	129	439	0.301	0.301
	2001	147	149	0	423	0.777	0.823
Canada Vancouver	1980	8,103	8,261	296	30,812	0.923	0.937
	1983	4,731	4,611	681	14,566	0.697	0.688
	1989	1,279	1,302	338	2,657	0.454	0.456
	1992	792	797	135	2,149	0.633	0.654
	1995	65	64	16	135	0.448	0.467
	1998	141	140	49	279	0.409	0.408
	2001	120	123	0	365	0.768	0.798
US Vancouver	1980	159	157	16	415	0.597	0.605
	1983	332	330	104	724	0.447	0.456
	1989	14,761	14,015	85	58,697	1.038	0.992
	1992	177	156	16	597	0.856	0.815
	1995	11	11	1	31	0.650	0.629
	1998	128	127	49	236	0.385	0.388
	2001	27	26	0	90	0.936	0.955

Table 48. Groundfish synoptic bottom trawl surveys

Survey	Abbr.	Years	Citation
West Coast Queen Charlotte Islands	WCQCI	2006, 2007	Workman *et al*. (2007)
Hecate Strait	HS	2005, 2007	Workman *et al.* (2008
Queen Charlotte Sound	QCSd	2003, 2004, 2005, 2007	Olsen *et al*. (2007)
West Coast Vancouver Island	WCVI	2004, 2006, 2008	Workman *et al.* (2008)

Table 49. Number of total trawl tows by stratum and year for each of the groundfish trawl surveys.

Survey	Stratum (m)	2003	2004	2005	2006	2007
West Coast Vancouver Island	50 - 125		34		62	
	125 - 200		34		63	
	200 - 330		13		28	
	330 - 500		8		13	
Queen Charlotte Sound	50 - 125	34	62	37		52
	125 - 200	95	86	105		119
	200 - 330	81	70	66		72
	330 - 500	25	15	16		14
Hecate Strait	10 - 70			83		48
	70 - 130			91		45
	130 - 220			32		37
	220 - 500			20		13
West Coast Queen Charlotte Islands	180 - 330				55	68
	330 - 500				25	35
	500 - 800				16	9

Table 50. Biomass estimates for bocaccio from groundfish synoptic surveys

Survey	Year	Biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV
HS	2005	20.7	9.6	44.2	0.37
HS	2007	53.0	22.9	106.0	0.37
QCS	2003	117.3	38.2	400.5	0.61
QCS	2004	331.0	69.1	1,596.8	0.76
QCS	2005	308.3	77.4	1,370.8	0.70
QCS	2007	127.4	40.4	531.0	0.62
WCQCI	2006	10.9	5.1	20.2	0.34
WCQCI	2007	9.8	4.6	17.4	0.32
WCVI	2004	416.7	69.4	1,732.3	0.78
WCVI	2006	354.0	103.6	1,345.2	0.66

Table 51. An Excel spreadsheet illustration of the conditional maximum likelihood method applied to estimate the fraction of sites in a survey area that are untrawlable

First sample population	Na	6000	
random sample	ma	300	
untrawlable spots	ua	30	
Second sample population	Nb	5970	
random sample	mb	300	
untrawlable spots	ub	27	
Third sample population	Nc	5943	
random sample	mc	300	
untrawlable spots	uc	24	
unbiased estimated proportion untrawlable	pa	0.094231	
derived proportion untrawl for 2nd	pb	0.0897	
derived proportion untrawl for 3rd	pc	0.085543	
			loglike
	likehd(ua)	0.072286	-2.627123
	likehd(ub)	0.080218	-2.523004
	likehd(uc)	0.079668	-2.529888
		sum	-7.680016

find the value of pa that maximizes the objective function (cell 18D) using solver

use solver to maximimze this objective function

Table 52. Pooled and MLE of the percent untrawlable bottom by survey and stratum.

Survey	**Depth Range (m)**	**Area (km2)**	**Total Number of Blocks**	**Percent Untrawlable (Pooled data)**	**Percent untrawlable (MLE)**
WCQCI	50 - 125	687	-	-	-
	125 - 180	495	-	-	-
	180 - 330	1,451	308	17.0	17.4
HS	50 - 125	4,148	1,629	28.0	28.8
	125 - 200	2,759	822	14.7	15.4
	200 - 330	3,029	800	27.7	28.4
QCS	50 - 125	7,810	1,984	33.2	34.8
	125 - 200	10,652	2,763	19.7	21.1
	200 - 330	7,936	1,950	17.0	18.1
WCVI	50 - 125	6,821	1,742	43.0	44.7
	125 - 200	4,402	1,094	27.8	29.5
	200 - 330	776	194	20.7	23.9
Combined	50 - 125	19,467	5,355	34.7	36.1
Survey	125 - 200	18,308	4,679	20.8	22.0
Regions	200 - 330	13,193	3,252	20.6	21.9

Table 53. Swept area estimates of bocaccio rockfish biomass based on DFO groundfish survey tows in each region in the years 2003-2007

Region	Biomass (kg)	Years of data	SE ln(bio)	% trawlable
#1 - WCVI Gfish	375,207	2004,6	0.0540	71.6
#2 - QCSd-Gfish	247,966	2003,4,5,7	0.2950	76.5
#3 - HS - Gfish	35,340	2005,7	0.2670	78.3
#4 - WCQCI - Gfish	11,255	2006,7	0.0507	87.2
#5 - WCVI Shrimp	20,787	2004,6	0.0262	100.0
#6 - QCSd Shrimp	27,767	2003,4,5	2.1010	100.0
#7 - US Triennial Gfish	180,599	2004,6	1.8590	82.0
#8 - Unsurveyed	76,664	2003,4,5,6,7	0.2020	0.0

Table 54. Summary of experience of interviewed captains

Captain	Years of experience	Total landings (t)	Total Bocaccio catch (t)
1	22	27,325	229
2	19	18,367	247
3	21	29,029	380
4	22	47,519	550
5	16	16,486	43
6	11	6,779	21
7	14	16,570	53
8	19	17,845	77
9	12	21,986	23
10	22	21,587	225
11	20	27,013	151
12	22	25,015	133
Total	220	275,520	2,131

Table 55. Estimates of *a1* from 12 trawl captains of the proportion of fish within 3-4 fm off bottom as the vessel passes overhead for the 12 trawl captains.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**[1]	**12**
Minimum	0.02	0.05	0.30	0.50	0.25	0.05	0.15	0.30	0.30	0.15	0.026	0.5
Best	0.05	0.20	0.50	0.60	0.50	0.125 (0.10-0.15)	0.20	0.50	0.50	0.375 (0.35-0.40)	0.055	0.8
Maximum	0.50	0.35	0.70	0.70	0.50	0.35	0.30	0.70	0.70	0.55	0.092	1.00

[1] Captain provided different estimates depending on the time of day which were converted to a mean time-average value.

Table 56. Estimates of *a2* from 12 captains of the proportion of fish that are initially above headrope height that dive to near bottom (* indicates Captain could not provide an estimate)

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Minimum	0.02	0.02	*	*	0.05	0.5	0.20	0.00	0.25	0.30	*	*
Best	0.04	0.05	0.50	0.30	0.15	0.65 (0.6-0.7)	0.30	0.075 (0.05-0.10)	0.50	0.50	*	*
Maximum	0.10	0.10	*	*	0.75	0.85	0.40	0.1	0.75	0.70	0.60	*

Table 57. Estimate of *a3,2* from 12 captains on the proportion of fish in front of sweep/bridles that will be “herded” to lie in front of the net

	1[1]	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Minimum	0.10	0.40	0.15	0.50	0.05	0.75	0.70	0.0	0.25	0.30	0.60	0.0
Best	0.25	0.75	0.3	0.75	0.15	0.85	0.75	0.1	0.50	0.45	0.70 (0.60-0.80	0.10
Maximum	0.80	0.95	0.65	0.75	0.25	1.0	0.80	0.175 (0.15-0.2)	0.75	0.60	0.80	0.20

[1] Captain #1 commented that his estimate of herding referred to those fish which were in “live zone”. He had already considered that fish in the “dead zone” had escape

Table 58. Relative distribution of fish in different sectors parts of the kill zone as the gear approaches a stationary fish. The factors in the last two columns, proportion within wingtips (*a3,1*: D1) and proportion in the dead zone (*a3,2* :D2) are utilized in the *q* prior model

	Nominal D-spread	Nominal W-spread	Nominal distance between doors, outside of wings	Deadzone in herding area	Effective herding zone	Proportion remaining in herding zone ($a_{3,2}$)	Proportion within wingtips ($a_{3,1}$)	Proportion removed by dead zone
	1	2	3	4	5	6	7	8
AWII (Gfish)	63.3	14.4	48.9	6.0	36.9	0.583	0.227	0.190
Nor'Eastern (U.S.Tri.)	58.9	13.4	45.5	6.0	33.5	0.569	0.228	0.204
Shrimp trawl	26.5	10.6	15.9	6.0	3.9	0.147	0.400	0.453

Table 59. Relative proportions (*P*) of remaining fish in areas C and D1 (from columns 6 and 7 in Table 58.). Both of these factors (*a4* and *a5*, respectively) are utilized in the *q* prior model.

Net	*P* between wingtips	*P* in herding zone
AWII (Gfish)	0.281	0.719
Nor-Eastern (USTri.)	0.286	0.714
Shrimp trawl	0.731	0.269

Table 60. Final capture rate for those fish which encounter the net (* indicates Captain did not provide a range).

		1	2	3	4	5	6	7	8	9	10	11	12
AWII	Minimum	0.50	0.60	*	*	0.05	0.60	0.70	0.45 (0.40-0.50)	0.50	0.50	0.70	0.65
	Best	0.75	0.80	0.95	0.9	0.50	0.80	0.85	0.775 (0.75-0.80)	0.60	0.60	0.9 (0.85-0.95)	0.85
	Maximum	0.85	0.95	*	*	0.75	0.85	0.90	0.98	0.75	0.70	0.95	1.00
Shrimp trawl	Minimum	0.10	0.01	*	*	0.05	0.125 (0.1-0.15)	0.70	0.25	0.10	0.25	0.02	0.015 (0.01-0.02
	Best	0.40	0.03	0.8	0.65	0.50	0.20	0.85	0.725 (0.70-0.75)	0.25	0.35	0.025 (0.02-0.03)	0.10
	Maximum	0.45	0.20	*	*	0.75	0.40	0.90	0.90	0.50	0.45	0.03	0.20
U.S. net	Minimum	0.5	0.60	*	*	0.10	0.60	0.70	0.45 (0.40-0.50)	0.55	0.60	0.75	0.70
	Best	0.75	0.80	0.95	0.95	0.70	0.80	0.85	0.775 (0.75-0.80)	0.65	0.70	0.925 (0.90-0.95)	0.90
	Maximum	0.85	0.95	*	*	0.80	0.85	0.90	0.98	0.80	0.80	0.95	1.00

Table 61. Initial conversion of survey biomass estimates based on doorspread rather than wingspread.

	Opening used to generate biomass estimates	Average doorspread	Average Wingspread	Ratio (W/D)	Correction required?
AWII (Gfish)	Doorspread	63.3	14.4	0.23	N
Nor'Eastern (USTri.)	Wingspread	58.9	13.4	0.23	**Y**
Shrimp trawl (WCVI)	Wingspread	25.0	10.6	0.42	**Y**
Shrimp trawl (QCSd)	Doorspread	25.0	10.6	0.42	N

Table 62. Biomass estimates of bocaccio based on tows within surveys masks shown in Figure 60 and Figure 61

Area	Year	Depth Range (m)	Shrimp Surveys			Groundfish Surveys		
			Number of Tows	Density (kg/km^2)	Biomass (kg)	Number of Tows	Density (kg/km^2)	Biomass (kg)
QCS	2003	50 - 125	1	0.00	0	0	-	-
		125 - 180	41	5.79	4,843	5	0.00	0
		180 - 330	13	0.00	0	1	0.00	0
	2004	50 - 125	1	0.00	0	0	0.00	0
		125 - 180	43	14.93	12,442	9	226.86	189,462
		180 - 330	11	0.00	0	2	0.00	0
	2005	50 - 125	1	0.00	0	0	0.00	0
		125 - 180	36	2.47	2,088	15	3.52	2,923
		180 - 330	10	0.00	0	4	0.00	0
	2007	50 - 125	0	-	-	0	-	-
		125 - 180	42	0.00	0	15	0.00	0
		180 - 330	13	0.00	0	1	0.00	0
	Combined	50 - 125	3	0.00	0	0	-	-
		125 - 180	162	5.98	4,993	44	47.60	39,746
		180 - 330	47	0.00	0	8	0.00	0
	Combined Total		212		4,993	52		39,746
WCVI	2004	50 - 125	23	0.00	0	3	0.00	0
		125 - 180	48	4.77	7,007	11	17.81	26,153
		180 - 330	-	-	-	1	61.81	1,614
	2006	50 - 125	24	2.95	3,289	19	6.96	7,765
		125 - 180	46	0.00	0	31	5.93	8,703
		180 - 330	-	-	-	1	0.00	-
	Combined	50 - 125	47	1.51	1,679	22	6.01	6,706
		125 - 180	94	2.44	3,578	42	9.04	13,273
		180 - 330	-	-	-	2	30.90	807
	Combined Total		141		5,258	66		20,787

Table 63. Posterior means, medians, standard deviations (SD), CVs and 95% probability intervals for *q-gross* (*qgfin*). *lqgfin* is the natural logarithm of the random variable *qgfin*. The last three columns show the 2.5th, 50th, and 97.5th percentiles of the random variable *qgfin*. The mean and SD of lgfin were used as inputs to the multivariate log normal prior density function for the survey *q* parameter in the stock assessment.

	mean	**SD**	**CV**	**mean(lqgfin)**	**SD(lqgfin)**	**exp(mean(lqgfin))**	**2.5**	**50**	**97.5**
#1 - WCVI Gfish	6.26E-02	4.86E-02	7.77E-01	-3.06E+00	8.08E-01	4.68E-02	7.80E-03	4.92E-02	1.92E-01
#2 - QCSd-Gfish	4.09E-02	3.34E-02	8.17E-01	-3.51E+00	8.33E-01	3.00E-02	4.83E-03	3.14E-02	1.30E-01
#3 - HS - Gfish	5.93E-03	4.98E-03	8.40E-01	-5.45E+00	8.46E-01	4.30E-03	6.79E-04	4.50E-03	1.93E-02
#4 - WCQCI - Gfish	1.90E-03	1.52E-03	7.99E-01	-6.57E+00	8.20E-01	1.40E-03	2.31E-04	1.47E-03	5.95E-03
#5 - WCVI Shrimp	2.67E-03	4.02E-03	1.50E+00	-6.57E+00	1.16E+00	1.40E-03	1.39E-04	1.42E-03	1.28E-02
#6 - QCSd Shrimp	1.17E-03	7.22E-03	6.15E+00	-9.33E+00	2.38E+00	8.90E-05	8.10E-07	8.98E-05	8.76E-03
#7 - U.S. Triennial Gfish	7.30E-02	1.52E-01	2.09E+00	-4.02E+00	1.87E+00	1.79E-02	3.74E-04	1.95E-02	5.01E-01

Table 64. Posterior means and standard deviations (SD) in the natural logarithm for *q-gross* (*qgfin*).

	Bayes update Uncertainty factor		**Bayes update No uncertainty factor**		**No Bayes update Uncertainty factor**		**No Bayes update No uncertainty factor**	
	exp(mean(ln*q*))	**sd(ln*q*)**	**exp(mean(lnq))**	**sd(ln*q*)**	**exp(mean(lnq))**	**sd(ln*q*)**	**exp(mean(lnq))**	**sd(ln*q*)**
#1 - WCVI Gfish	4.68E-02	8.08E-01	4.61E-02	7.58E-01	4.39E-02	8.46E-01	4.39E-02	7.91E-01
#2 - QCSd-Gfish	3.00E-02	8.33E-01	2.95E-02	7.84E-01	2.81E-02	8.70E-01	2.81E-02	8.16E-01
#3 - HS - Gfish	4.30E-03	8.46E-01	4.22E-03	7.98E-01	4.03E-03	8.83E-01	4.04E-03	8.30E-01
#4 - WCQCI - Gfish	1.40E-03	8.20E-01	1.38E-03	7.69E-01	1.31E-03	8.56E-01	1.32E-03	8.02E-01
#5 - WCVI Shrimp	1.40E-03	1.16E+00	1.39E-03	8.41E-01	2.45E-03	1.53E+00	2.45E-03	1.31E+00
#6 - QCSd Shrimp	8.90E-05	2.38E+00	8.73E-05	2.24E+00	1.54E-04	2.57E+00	1.54E-04	2.45E+00
#7 - US Triennial Gfish	1.79E-02	1.87E+00	1.77E-02	1.85E+00	1.75E-02	1.88E+00	1.75E-02	1.85E+00

Table 65. Posterior correlation and covariance matrices for the natural logarithm of the *q-gross* values for the seven B.C. surveys that capture bocaccio rockfish. The index number in the first column and first row indicate the survey for which the correlations apply - see Table 53 above for a key to the survey indices.

a. Posterior correlation matrix for the natural logarithm of the *q-gross* values for the seven B.C. surveys that capture bocaccio rockfish

	1	**2**	**3**	**4**	**5**	**6**	**7**
1	1.000	0.919	0.932	0.966	0.614	0.272	0.152
2	0.919	1.000	0.888	0.920	0.584	0.258	0.142
3	0.932	0.888	1.000	0.933	0.596	0.263	0.151
4	0.966	0.920	0.933	1.000	0.616	0.273	0.157
5	0.614	0.584	0.596	0.616	1.000	0.461	0.118
6	0.272	0.258	0.263	0.273	0.461	1.000	0.048
7	0.152	0.142	0.151	0.157	0.118	0.048	1.000

b. Posterior covariance matrix for the natural logarithm of *q-gross* values for the seven B.C. surveys that capture bocaccio rockfish

	1	**2**	**3**	**4**	**5**	**6**	**7**
1	0.653	0.618	0.637	0.640	0.575	0.524	0.230
2	0.618	0.693	0.625	0.628	0.562	0.511	0.220
3	0.637	0.625	0.715	0.647	0.583	0.530	0.239
4	0.640	0.628	0.647	0.673	0.585	0.533	0.241
5	0.575	0.562	0.583	0.585	1.339	1.271	0.256
6	0.524	0.511	0.530	0.533	1.271	5.674	0.214
7	0.230	0.220	0.239	0.241	0.256	0.214	3.489

Table 66. Reference case posterior means, medians, standard deviations (SD), and 95% probability intervals for the survey constants of proportionality that scale total population biomass to the swept area biomass index value (*q*). *ln*(*q*) is the natural logarithm of the random variable *q*. The last three columns show the 2.5th, 50th and 97.5th posterior percentiles of the random variable *q*. The mean and SD of *ln*(*q*) and cross correlation matrix shown in Table 67. below were used as inputs to the multivariate log normal prior density function for the survey *q* parameter in the stock assessment. Note that the WCQCI Gfish survey is not used due to high imprecision in this survey.

	mean(ln(q))	**SD(ln(q))**	**exp(mean(ln(q))**	**2.5**	**50**	**97.5**
WCVI Gfish	-3.06E+00	8.08E-01	4.68E-02	7.80E-03	4.92E-02	1.92E-01
QCSd Gfish	-3.51E+00	8.33E-01	3.00E-02	4.83E-03	3.14E-02	1.30E-01
HS Gfish	-5.45E+00	8.46E-01	4.30E-03	6.79E-04	4.50E-03	1.93E-02
WCQCI Gfish	-6.57E+00	8.20E-01	1.40E-03	2.31E-04	1.47E-03	5.95E-03
WCVI Shrimp	-6.57E+00	1.16E+00	1.40E-03	1.39E-04	1.42E-03	1.28E-02
QCSd Shrimp	-9.33E+00	2.38E+00	8.90E-05	8.10E-07	8.98E-05	8.76E-03
U.S. Triennial Gfish	-4.02E+00	1.87E+00	1.79E-02	3.74E-04	1.95E-02	5.01E-01

Table 67. Prior correlation matrix for the natural logarithm of the survey *q* values for the seven swept area estimates of bocaccio. The index number in the first column and first row indicate the survey for which the correlations apply.

	WCVI Gfish	**QCSd Gfish**	**HS Gfish**	**WCQCI Gfish**	**WCVI Shrimp**	**QCSd Shrimp**	**U.S. Triennial Gfish**
WCVI Gfish	1.000	0.919	0.932	0.966	0.614	0.272	0.152
QCSd Gfish	0.919	1.000	0.888	0.920	0.584	0.258	0.142
HS Gfish	0.932	0.888	1.000	0.933	0.596	0.263	0.151
WCQCI Gfish	0.966	0.920	0.933	1.000	0.616	0.273	0.157
WCVI Shrimp	0.614	0.584	0.596	0.616	1.000	0.461	0.118
QCSd Shrimp	0.272	0.258	0.263	0.273	0.461	1.000	0.048
U.S. Triennial Gfish	0.152	0.142	0.151	0.157	0.118	0.048	1.000

Table 68. Demographic parameters used to compute a prior pdf for the intrinsic rate of increase, *r*.

age	female mass at age (in kg)	fraction mature at age
1	0.216	0.000
2	0.492	0.000
3	0.850	0.000
4	1.258	0.000
5	1.688	0.000
6	2.120	0.323
7	2.537	0.555
8	2.930	0.708
9	3.292	0.808
10	3.622	0.874
11	3.917	0.917
12	4.181	0.945
13	4.413	0.964
14	4.617	0.976
15	4.795	0.984
16	4.949	1.000
17	5.083	1.000
18	5.198	1.000
19	5.297	1.000
20	5.383	1.000
21	5.456	1.000
22	5.519	1.000
23	5.573	1.000
24	5.618	1.000
25	5.658	1.000
26	5.691	1.000
27	5.719	1.000
28	5.744	1.000
29	5.764	1.000
30	5.782	1.000

Table 69. Prior pdfs of parameters K, q for the cpue data, P_0, and r.

Parameter	Prior density function	Comments
K	Uniform(500, 200,000)	Units in tons
q for commercial cpue	Proportional to 1/q	This prior is non-informative with respect to K and stock biomass. See Table 67 for details on the informative prior for the survey qs.
P_0	Lognormal(ln(0.9), 0.2^2)	This indicates that the stock was near to carrying capacity in 1935.
r	LogNormal(ln(0.117), 0.294^2) Prior mean r = 0.117 Prior SD r = 0.037	The relatively low prior mean comes largely from the late median age at maturity of 7 years and relatively low estimates of recruits per ton of spawner biomass at the origin of the stock-recruit function which derives partly from the low prior mean for steepness obtained from the meta-analysis of stock recruit data in Dorn (2002).

Table 70. Estimates of total catch biomass (t) of B.C. bocaccio for the trawl and Rockfish ZN fishery (Appendices A and B). This is the component of total catch that was fixed in the model.

Year	Catch biomass	Year	Catch biomass	Year	Catch biomass	Year	Catch biomass
1935	1	1953	70	1971	316	1989	804
1936	1	1954	73	1972	493	1990	1064
1937	1	1955	95	1973	1104	1991	1095
1938	2	1956	90	1974	1282	1992	977
1939	2	1957	66	1975	809	1993	1160
1940	5	1958	63	1976	678	1994	624
1941	2	1959	84	1977	399	1995	543
1942	30	1960	59	1978	255	1996	339
1943	96	1961	85	1979	488	1997	263
1944	40	1962	159	1980	183	1998	231
1945	416	1963	139	1981	93	1999	246
1946	210	1964	104	1982	104	2000	298
1947	110	1965	285	1983	152	2001	284
1948	178	1966	1069	1984	175	2002	291
1949	217	1967	778	1985	417	2003	233
1950	204	1968	566	1986	721	2004	166
1951	194	1969	1071	1987	733	2005	158
1952	180	1970	468	1988	1348	2006	131

Table 71. Relative stock trend indices for B.C. bocaccio. "-1" entries indicate no index available for that year. The values in parentheses are the standard deviations in the natural logarithms of the ratio of observed to expected values in the lognormal likelihood function for these indices.

	WCVI shrimp trawl survey (1.35)	U.S. triennial (1.35)	QCSd SS (0.55)	QCSd ST (0.75)	C CPUE (0.15)	WCVI GF (0.15)	HS GF (0.15)
1975	106.1	-1	-1	-1	-1	-1	-1
1976	42.3	-1	-1	-1	-1	-1	-1
1977	84.7	-1	-1	-1	-1	-1	-1
1978	362.1	-1	-1	-1	-1	-1	-1
1979	25.6	-1	-1	-1	-1	-1	-1
1980	21.2	8,103	-1	-1	-1	-1	-1
1981	28.6	-1	-1	-1	-1	-1	-1
1982	577	-1	-1	-1	-1	-1	-1
1983	339.6	4,731	-1	-1	-1	-1	-1
1984	-1	-1	-1	-1	-1	-1	-1
1985	366.9	-1	-1	-1	-1	-1	-1
1986	-1	-1	-1	-1	-1	-1	-1
1987	73.7	-1	-1	-1	-1	-1	-1
1988	117.9	-1	-1	-1	-1	-1	-1
1989	33.6	1,279	-1	-1	-1	-1	-1
1990	162.6	-1	-1	-1	-1	-1	-1
1991	115.3	-1	-1	-1	-1	-1	-1
1992	387	792	-1	-1	-1	-1	-1
1993	10	-1	-1	-1	-1	-1	-1
1994	139.6	-1	-1	-1	-1	-1	-1
1995	15.4	65	-1	-1	-1	-1	-1
1996	50.5	-1	-1	-1	28.9	-1	-1
1997	110.9	-1	-1	-1	31.5	-1	-1
1998	214.3	141	-1	-1	27.9	-1	-1
1999	2	-1	-1	18.8	27.4	-1	-1
2000	0	-1	-1	9.2	28.1	-1	-1
2001	70.2	120	-1	19.4	32.3	-1	-1
2002	30.6	-1	-1	2.5	29.9	-1	-1
2003	32.1	-1	134.1	7.2	27.9	-1	-1
2004	30.2	-1	338.5	17.7	-1	416.7	-1
2005	583.2	-1	305.7	4.7	-1	-1	-1
2006	6.4	-1	-1	7.1	-1	354.0	10.9
2007	11.6	-1	138.9	0	-1	-1	9.8

Table 72. Summary of sensitivity runs, including their categorization.

Category code	Category Description	Code	Run Description
Ref	Reference run	Ref	Reference run
A	B_{MSY}/K	A.1	$B_{MSY}/K = 0.4$
		A.2	$B_{MSY}/K = 0.6$
B	r prior mean	B.1	low r (mean = 0.0836)
		B.2	high r (mean = 0.152)
C	Catch assumptions	C.1	low mean troll catch
		C.2	high mean troll catch
		C.3	exclude troll and halibut catch
		C.4	pre-1996 catch x 0.5
		C.5	pre 1996 catch x 1.5
		C.6	relax troll catch per day cap at 40
		C.7	likelihood function for catch: lognormal, CV=0.6 for troll, CV=0.5 for halibut
		C.8	Catch fixed at best estimates as opposed to being imputed with uncertainty
D	Process error assumptions	D.1	low process error (SD = 0.05)
		D.2	high process error (SD = 0.15)
		D.3	deterministic with no process error
E	B_{init}/K	E.1	$B_{init}/K = 0.7$
		E.2	$B_{init}/K = 1.0$
F	survey q priors	F.1	Non-informative priors for survey q
		F.2	Density in trawlable area set to be equal to untrawlable area
		F.3	survey q prior with no Bayesian update
		F.4	Survey q prior covariance = 0
G	effect of data	G.1	Leave out Comm. CPUE data
		G.2	Leave out U.S. NMFS triennial
		G.3	Leave out WCVI shrimp
		G.4	Leave out QCSd shrimp
		G.5	Leave out QCSd synoptic
		G.6	Leave out WCVI synoptic
		G.7	Leave out HS synoptic
		G.8	exclude all survey data from 2003+
H	autocorrelation assumptions	H.1	no autocorrelation in lag 1 process error
		H.2	autocorrelation in process error starts in 2009

Table 73. For reference run, the posterior mean, SD, CV (standard deviation/ mean), 10th, 50th, and 90th percentiles and posterior mode for key parameters and stock status indicators for bocaccio. B_{08} and C_{08} are the recruited stock biomass and catch biomass in 2008, *RepY* is the replacement yield in 2008. Biomass values are in tons. *k*(halibut) and *k*(troll) are the catchability coefficients for catch in halibut and troll fisheries. Medians are were obtained using a more refined interpolation algorithm than the medians obtained in Table G-8 where 31 additional model runs were carried out.

	Mean	**SD**	**CV**	**10%**	**Median**	**90%**	**Mode**
K	52659	35646	0.68	21107	39977	106665	28865
r	0.095	0.026	0.27	0.066	0.092	0.129	0.088
MSY	1181	761	0.64	523	914	2267	680
B_{08}	4765	4421	0.93	1691	3565	8790	1830
B_{08}/K	0.123	0.118	0.95	0.027	0.086	0.265	0.045
B_{1935}	47072	32002	0.68	21107	39977	106665	28865
B_{08}/B_{1935}	0.141	0.139	0.99	0.030	0.097	0.305	0.044
C_{08}/MSY	0.182	0.081	0.44	0.097	0.166	0.286	0.139
F_{08}/F_{MSY}	1.122	0.638	0.57	0.434	1.002	1.916	0.881
B_{08}/ B_{MSY}	0.247	0.236	0.95	0.056	0.171	0.529	0.071
$C_{08}/ RepY$	0.623	1.660	2.66	0.294	0.566	1.015	0.479
B_{MSY}	26329	17823	0.68	10651	19973	53434	13577
$RepY$	346	232	0.67	145	288	607	190
$q1$ - WCVI Gfish	1.11E-01	5.96E-02	0.54	5.14E-02	9.79E-02	1.87E-01	7.61E-02
$q2$ - QCSd-Gfish	6.04E-02	3.20E-02	0.53	2.82E-02	5.34E-02	1.01E-01	4.17E-02
$q3$ - HS – Gfish	3.20E-03	1.81E-03	0.56	1.42E-03	2.79E-03	5.47E-03	2.11E-03
$q4$ - WCVI Shrimp	9.30E-03	3.49E-03	0.37	5.47E-03	8.71E-03	1.39E-02	7.64E-03
$q5$ - QCSd Shrimp	2.41E-03	1.19E-03	0.49	1.19E-03	2.16E-03	3.94E-03	1.74E-03
$q6$ - U.S. Triennial Gfish	9.46E-02	3.47E-02	0.37	5.63E-02	8.88E-02	1.40E-01	7.82E-02
$q7$ - CCPUE	7.70E-03	3.63E-03	0.47	3.93E-03	6.97E-03	1.24E-02	5.71E-03
k(halibut)	5.29E-03	4.83E-03	0.91	1.44E-03	3.91E-03	1.06E-02	2.13E-03
k(troll)	4.70E-03	3.28E-03	0.70	1.72E-03	3.85E-03	8.64E-03	2.59E-03
Halibut catch 2008	10	8	0.78	3	8	19	5
Troll catch 2008	25	27	1.09	5	17	52	8

Table 74. Medians and 80% credibility intervals drawn from the posterior distributions for 7 parameters taken from the bocaccio assessment for the reference run and all 31 sensitivity runs. Codes used for each run along with a run description can be found in Table 72. Biomass values are in tons.

	B_{MSY}			***$B_{current}$***			***Replacement_yield***			***$B_{current}/K$***			***$F_{current}/F_{MSY}$***			***$B_{current}/B_{MSY}$***			***$Catch_{curr}$/Replce_yield***		
Code	**10%**	**Median**	**90%**	**10%**	**Median**	**90%**	**10%**	**Median**	**90%**	**10%**	**Median**	**90%**	**10%**	**Median**	**90%**	**10%**	**Median**	**90%**	**10%**	**Median**	**90%**
	Reference run																					
Ref.	10000	20000	54000	2000	4000	9000	150	300	600	0.025	0.075	0.275	0.400	1.000	1.900	0.050	0.175	0.525	0.300	0.600	1.000
	B_{MSY}/K																					
A.1	10000	18000	46000	2000	4000	9000	150	300	600	0.025	0.075	0.250	0.400	1.000	1.900	0.050	0.200	0.600	0.300	0.600	1.000
A.2	10000	20000	60000	2000	3000	8000	150	250	600	0.025	0.100	0.275	0.400	0.800	1.600	0.050	0.150	0.475	0.300	0.600	1.100
	***r* prior median**																					
B.1	12000	24000	62000	2000	4000	9000	150	250	550	0.025	0.075	0.225	0.500	1.100	2.300	0.050	0.150	0.450	0.300	0.600	1.200
B.2	8000	14000	40000	1000	3000	9000	200	350	700	0.025	0.100	0.375	0.300	0.800	1.600	0.050	0.200	0.725	0.300	0.500	0.800
C.1	10000	16000	48000	2000	4000	9000	150	300	600	0.025	0.100	0.325	0.400	1.000	1.900	0.075	0.200	0.625	0.300	0.500	1.000
C.2	14000	26000	60000	2000	4000	9000	150	300	600	0.025	0.075	0.225	0.500	1.000	1.900	0.050	0.125	0.425	0.300	0.600	1.000
C.3	8000	14000	30000	3000	11000	34000	200	500	1300	0.150	0.400	0.725	0.100	0.300	0.900	0.300	0.775	1.450	0.100	0.300	0.600
C.4	8000	16000	52000	2000	3000	9000	150	250	550	0.025	0.100	0.375	0.400	1.100	2.200	0.050	0.200	0.750	0.300	0.600	1.200
C.5	14000	24000	56000	2000	4000	9000	150	300	650	0.025	0.075	0.225	0.400	0.900	1.800	0.050	0.150	0.450	0.300	0.500	0.900
C.6	10000	20000	62000	2000	4000	9000	150	300	600	0.025	0.075	0.250	0.400	1.000	1.900	0.050	0.150	0.525	0.300	0.600	1.000
C.7	10000	18000	36000	2000	3000	9000	150	250	600	0.025	0.100	0.300	0.400	1.000	2.000	0.075	0.200	0.575	0.300	0.600	1.100
C.8	10000	18000	34000	3000	11000	38000	250	600	1500	0.125	0.325	0.700	0.100	0.300	1.000	0.225	0.675	1.375	0.100	0.200	0.600
D.1	10000	18000	54000	2000	4000	8000	150	300	500	0.025	0.100	0.250	0.500	1.100	1.800	0.050	0.175	0.500	0.400	0.600	1.000
D.2	12000	24000	60000	2000	4000	10000	150	300	750	0.025	0.075	0.250	0.400	0.900	1.800	0.050	0.150	0.475	0.200	0.500	1.000
D.3	10000	16000	52000	2000	4000	7000	150	300	450	0.025	0.100	0.250	0.600	1.000	1.700	0.075	0.200	0.475	0.400	0.600	0.900
	B_{init}/K																					
E.1	12000	22000	60000	2000	3000	9000	150	300	600	0.025	0.075	0.250	0.400	1.000	2.000	0.050	0.150	0.500	0.300	0.600	1.000
E.2	10000	20000	52000	2000	3000	9000	150	300	600	0.025	0.075	0.275	0.400	1.000	1.900	0.050	0.175	0.525	0.300	0.600	1.000
	Survey *q* priors																					
F.1	10000	18000	48000	1000	3000	7000	100	250	500	0.025	0.075	0.225	0.500	1.200	2.400	0.050	0.125	0.475	0.300	0.700	1.200
F.2	10000	20000	52000	1000	3000	5000	100	200	400	0.025	0.075	0.175	0.700	1.300	2.300	0.050	0.125	0.350	0.400	0.700	1.200
F.3	10000	20000	52000	2000	3000	8000	150	300	600	0.025	0.075	0.250	0.500	1.000	1.900	0.050	0.175	0.500	0.300	0.600	1.000
F.4	10000	20000	56000	3000	5000	9000	200	350	650	0.050	0.125	0.300	0.400	0.800	1.400	0.075	0.225	0.600	0.300	0.500	0.800
	Effect of data																					
G.1	10000	20000	52000	1000	3000	7000	100	250	500	0.025	0.075	0.225	0.500	1.300	2.800	0.050	0.125	0.425	0.300	0.700	1.400
G.2	10000	18000	44000	2000	5000	15000	150	350	800	0.050	0.150	0.450	0.200	0.700	1.600	0.075	0.275	0.925	0.200	0.400	0.900
G.3	10000	22000	58000	1000	3000	7000	150	250	500	0.025	0.050	0.200	0.500	1.200	2.300	0.050	0.125	0.425	0.300	0.600	1.200
G.4	10000	20000	50000	2000	3000	6000	150	250	500	0.025	0.075	0.200	0.600	1.100	2.100	0.050	0.150	0.400	0.400	0.600	1.100
G.5	10000	20000	50000	2000	3000	6000	150	250	500	0.025	0.075	0.200	0.600	1.100	2.100	0.050	0.150	0.425	0.400	0.600	1.100
G.6	10000	18000	48000	2000	3000	6000	150	250	500	0.025	0.075	0.225	0.500	1.100	2.000	0.050	0.150	0.425	0.300	0.600	1.100
G.7	10000	18000	48000	2000	4000	9000	150	300	600	0.025	0.100	0.275	0.400	0.900	1.700	0.075	0.225	0.575	0.300	0.500	0.900
G.8	10000	18000	50000	2000	4000	10000	150	300	650	0.025	0.100	0.300	0.400	0.900	1.900	0.050	0.200	0.625	0.300	0.500	1.000

Code	B_{MSY}			$B_{current}$			*Replacement_yield*			$B_{current}/K$			$F_{current}/F_{MSY}$			$B_{current}/B_{MSY}$			$Catch_{curr}/Replce\_yield$		
	10%	**Median**	**90%**	**10%**	**Median**	**90%**	**10%**	**Median**	**90%**	**10%**	**Median**	**90%**	**10%**	**Median**	**90%**	**10%**	**Median**	**90%**	**10%**	**Median**	**90%**
	Autocorrelation assumptions																				
H.1	10000	20000	54000	2000	4000	9000	150	300	600	0.025	0.100	0.275	0.400	1.000	1.900	0.050	0.175	0.550	0.300	0.600	1.000
H.2	10000	20000	54000	2000	4000	9000	150	300	600	0.025	0.075	0.275	0.400	1.000	1.900	0.050	0.175	0.550	0.300	0.600	1.000

Table 75. Reference case: Stock status indicators for B.C. bocaccio after 5, 20, and 40 years. Descriptions of the settings for each run are provided in Table 72. Policies are constant TAC policies in tons. Biomass values are in thousands of tons (kt).

Horizon	Policy	$E(B_{fin}/B_{MSY})$	$P(B_{fin}>0.4\ B_{MSY})$	$P(B_{fin}>0.8\ B_{MSY})$	$P(B_{fin}>B_{cur})$	$P(F_{fin}<F_{cur})$
5 -year	0	0.33	0.26	0.08	0.73	1.00
	50	0.33	0.26	0.08	0.71	1.00
	100	0.31	0.24	0.08	0.63	0.91
	150	0.30	0.23	0.07	0.57	0.62
	200	0.28	0.22	0.07	0.51	0.36
	250	0.27	0.21	0.07	0.45	0.19
	300	0.26	0.20	0.06	0.40	0.09
20-year	0	0.83	0.65	0.39	0.92	1.00
	50	0.76	0.60	0.36	0.86	0.98
	100	0.68	0.52	0.32	0.76	0.84
	150	0.59	0.45	0.27	0.65	0.67
	200	0.51	0.40	0.24	0.55	0.50
	250	0.44	0.34	0.20	0.46	0.38
	300	0.38	0.29	0.18	0.38	0.26
40-year	0	1.38	0.87	0.69	0.97	1.00
	50	1.25	0.80	0.63	0.92	0.97
	100	1.09	0.71	0.56	0.80	0.84
	150	0.92	0.61	0.46	0.68	0.69
	200	0.75	0.50	0.39	0.55	0.53
	250	0.62	0.42	0.32	0.46	0.41
	300	0.50	0.33	0.25	0.36	0.30

Table 76. Case B.1, low prior *r* mean: Stock status indicators for B.C. bocaccio after 5, 20, and 40 years. Descriptions of the settings for each run are provided in Table 72. Policies are constant TAC policies in tons. Biomass values are in thousands of tons (kt).

Horizon	Policy	$E(B_{fin}/B_{MSY})$	$P(B_{fin}>0.4\ B_{MSY})$	$P(B_{fin}>0.8\ B_{MSY})$	$P(B_{fin}>B_{cur})$	$P(F_{fin}<F_{cur})$
5-year	0	0.27	0.20	0.05	0.68	1.00
	50	0.26	0.20	0.05	0.64	1.00
	100	0.25	0.19	0.05	0.58	0.88
	150	0.24	0.18	0.05	0.51	0.57
	200	0.23	0.17	0.05	0.45	0.31
	250	0.22	0.16	0.04	0.40	0.15
	300	0.21	0.15	0.04	0.36	0.08
20-year	0	0.66	0.51	0.29	0.88	1.00
	50	0.60	0.46	0.26	0.81	0.96
	100	0.53	0.41	0.23	0.68	0.79
	150	0.46	0.36	0.20	0.56	0.58
	200	0.40	0.31	0.17	0.47	0.42
	250	0.34	0.27	0.15	0.39	0.32
	300	0.30	0.24	0.13	0.32	0.23
40-year	0	1.20	0.79	0.59	0.95	1.00
	50	1.06	0.71	0.51	0.87	0.94
	100	0.88	0.59	0.43	0.73	0.78
	150	0.73	0.48	0.35	0.59	0.60
	200	0.60	0.40	0.29	0.48	0.45
	250	0.49	0.33	0.24	0.38	0.34
	300	0.40	0.27	0.19	0.31	0.26

Table 77. Case B.2, high prior *r* mean: Stock status indicators for B.C. bocaccio after 5, 20, and 40 years. Descriptions of the settings for each run are provided in Table 72 . Policies are constant TAC policies in tons. Biomass values are in thousands of tons (kt).

Horizon	Policy	$E(B_{fin}/B_{MSY})$	$P(B_{fin}>0.4\ B_{MSY})$	$P(B_{fin}>0.8\ B_{MSY})$	$P(B_{fin}>B_{cur})$	$P(F_{fin}<F_{cur})$
5-year	0	0.43	0.37	0.15	0.81	1.00
	50	0.43	0.37	0.15	0.78	1.00
	100	0.41	0.35	0.15	0.73	0.93
	150	0.39	0.31	0.14	0.65	0.70
	200	0.37	0.30	0.13	0.58	0.41
	250	0.35	0.29	0.13	0.50	0.21
	300	0.34	0.27	0.12	0.45	0.12
20-year	0	1.10	0.81	0.58	0.96	1.00
	50	1.02	0.76	0.54	0.93	0.99
	100	0.92	0.68	0.48	0.86	0.91
	150	0.81	0.61	0.42	0.76	0.77
	200	0.71	0.55	0.37	0.64	0.61
	250	0.62	0.47	0.31	0.55	0.45
	300	0.54	0.40	0.28	0.46	0.35
40-year	0	1.69	0.96	0.86	0.98	1.00
	50	1.58	0.93	0.82	0.96	0.99
	100	1.43	0.86	0.73	0.90	0.92
	150	1.24	0.76	0.64	0.78	0.78
	200	1.05	0.64	0.55	0.66	0.64
	250	0.89	0.55	0.46	0.56	0.51
	300	0.73	0.46	0.38	0.45	0.38

Table 78. Case H.1, no auto-correlation in process error deviates: Stock status indicators for B.C. bocaccio after 5, 20, and 40 years. Descriptions of the settings for each run are provided in Table 72. Policies are constant TAC policies in tons. Biomass values are in thousands of tons (kt).

Horizon	Policy	$E(B_{fin}/B_{MSY})$	$P(B_{fin}>0.4\ B_{MSY})$	$P(B_{fin}>0.8\ B_{MSY})$	$P(B_{fin}>B_{cur})$	$P(F_{fin}<F_{cur})$
5 -year	0	0.34	0.29	0.08	0.91	1.00
	50	0.34	0.29	0.08	0.89	1.00
	100	0.33	0.27	0.08	0.82	0.99
	150	0.31	0.26	0.08	0.74	0.78
	200	0.30	0.24	0.07	0.63	0.39
	250	0.29	0.22	0.07	0.55	0.16
	300	0.27	0.21	0.07	0.47	0.06
20 -year	0	0.80	0.74	0.42	0.99	1.00
	50	0.74	0.68	0.38	0.98	1.00
	100	0.66	0.60	0.33	0.93	0.96
	150	0.57	0.52	0.28	0.82	0.83
	200	0.49	0.44	0.24	0.70	0.63
	250	0.42	0.38	0.20	0.57	0.42
	300	0.36	0.33	0.17	0.46	0.26
40 -year	0	1.38	0.96	0.81	1.00	1.00
	50	1.28	0.92	0.76	0.99	1.00
	100	1.13	0.84	0.68	0.94	0.96
	150	0.96	0.74	0.58	0.84	0.84
	200	0.80	0.62	0.48	0.70	0.69
	250	0.64	0.50	0.38	0.58	0.52
	300	0.51	0.41	0.30	0.46	0.37

Table 79. Case H.2, Autocorrelation in process error deviates starts in 2009, rather than 2007: Stock status indicators for B.C. bocaccio after 5, 20, and 40 years. Descriptions of the settings for each run are provided in Table 72. Policies are constant TAC policies in tons. Biomass values are in thousands of tons (kt).

Horizon	Policy	$E(B_{fin}/B_{MSY})$	$P(B_{fin}>0.4\ B_{MSY})$	$P(B_{fin}>0.8\ B_{MSY})$	$P(B_{fin}>B_{cur})$	$P(F_{fin}<F_{cur})$
5-year	0	0.36	0.31	0.09	0.79	1.00
	50	0.36	0.30	0.10	0.77	1.00
	100	0.34	0.28	0.09	0.70	0.94
	150	0.33	0.27	0.09	0.64	0.70
	200	0.32	0.25	0.08	0.58	0.42
	250	0.30	0.24	0.08	0.52	0.24
	300	0.29	0.22	0.08	0.46	0.12
20-year	0	0.86	0.69	0.43	0.94	1.00
	50	0.80	0.65	0.40	0.90	0.99
	100	0.72	0.58	0.35	0.81	0.89
	150	0.64	0.51	0.31	0.72	0.74
	200	0.56	0.45	0.27	0.61	0.57
	250	0.49	0.39	0.23	0.52	0.42
	300	0.42	0.34	0.20	0.43	0.31
40-year	0	1.44	0.90	0.74	0.97	1.00
	50	1.32	0.85	0.68	0.94	0.98
	100	1.17	0.76	0.60	0.85	0.89
	150	1.01	0.66	0.52	0.74	0.75
	200	0.85	0.57	0.45	0.62	0.60
	250	0.71	0.48	0.37	0.52	0.48
	300	0.59	0.39	0.31	0.42	0.36

Table 80. Case A.1, B_{MSY}/K inflection point set at 0.4: Stock status indicators for B.C. bocaccio after 5, 20, and 40 years. Descriptions of the settings for each run are provided in Table 72. Policies are constant TAC policies in tons. Biomass values are in thousands of tons (kt).

Horizon	Policy	$E(B_{fin}/B_{MSY})$	$P(B_{fin}>0.4\ B_{MSY})$	$P(B_{fin}>0.8\ B_{MSY})$	$P(B_{fin}>B_{cur})$	$P(F_{fin}<F_{cur})$
5-year	0	0.42	0.35	0.14	0.79	1.00
	50	0.40	0.33	0.13	0.72	1.00
	100	0.38	0.31	0.12	0.65	0.93
	150	0.37	0.30	0.11	0.58	0.67
	200	0.35	0.28	0.11	0.52	0.41
	250	0.33	0.27	0.10	0.45	0.26
	300	0.32	0.25	0.09	0.39	0.21
20-year	0	0.98	0.69	0.45	0.92	1.00
	50	0.89	0.63	0.40	0.86	0.99
	100	0.79	0.56	0.35	0.77	0.92
	150	0.70	0.49	0.32	0.67	0.82
	200	0.62	0.44	0.27	0.55	0.76
	250	0.54	0.38	0.24	0.47	0.72
	300	0.47	0.34	0.21	0.39	0.71
40-year	0	1.69	0.88	0.72	0.96	1.00
	50	1.52	0.82	0.65	0.92	0.99
	100	1.32	0.72	0.57	0.82	0.95
	150	1.12	0.62	0.48	0.69	0.90
	200	0.94	0.52	0.41	0.57	0.88
	250	0.79	0.43	0.35	0.46	0.87
	300	0.66	0.36	0.29	0.38	0.86

Table 81. Case A.2, B_{MSY}/K inflection point set at 0.6: Stock status indicators for B.C. bocaccio after 5, 20, and 40 years. Descriptions of the settings for each run are provided in Table 72. Policies are constant TAC policies in tons. Biomass values are in thousands of tons (kt).

Horizon	Policy	$E(B_{fin}/B_{MSY})$	$P(B_{fin}>0.4\ B_{MSY})$	$P(B_{fin}>0.8\ B_{MSY})$	$P(B_{fin}>B_{cur})$	$P(F_{fin}<F_{cur})$
5-year	0	0.36	0.29	0.11	0.81	1.00
	50	0.34	0.28	0.11	0.74	1.00
	100	0.33	0.26	0.10	0.66	0.93
	150	0.31	0.24	0.10	0.58	0.68
	200	0.30	0.22	0.10	0.50	0.42
	250	0.28	0.21	0.09	0.43	0.30
	300	0.27	0.19	0.08	0.37	0.24
20-year	0	0.84	0.67	0.46	0.93	1.00
	50	0.76	0.60	0.41	0.87	0.99
	100	0.67	0.53	0.36	0.76	0.93
	150	0.58	0.47	0.31	0.65	0.86
	200	0.50	0.40	0.27	0.55	0.81
	250	0.43	0.34	0.22	0.45	0.78
	300	0.38	0.29	0.20	0.37	0.77
40-year	0	1.25	0.87	0.74	0.97	1.00
	50	1.15	0.80	0.68	0.91	0.99
	100	1.00	0.72	0.59	0.81	0.97
	150	0.84	0.60	0.50	0.67	0.94
	200	0.70	0.51	0.42	0.56	0.92
	250	0.58	0.41	0.34	0.45	0.90
	300	0.47	0.34	0.28	0.36	0.89

Table 82. Summary decision table for the probability that stock biomass exceeds 40% of B_{MSY} within 40 years under each alternative constant TAC policy (t) and under each alternative hypothesized prior mean value for the parameter for the maximum intrinsic rate of increase, *r*.

	Hypothesized prior mean r		
Productivity	Low r	Reference case	High r
	0.0836	0.117	0.152
Probability	0.55	0.30	0.15
TAC policy			
0	0.79	0.87	0.96
50	0.71	0.80	0.93
100	0.59	0.71	0.86
150	0.48	0.61	0.76
200	0.40	0.50	0.64
250	0.33	0.42	0.55
300	0.27	0.33	0.46

Appendix Figures

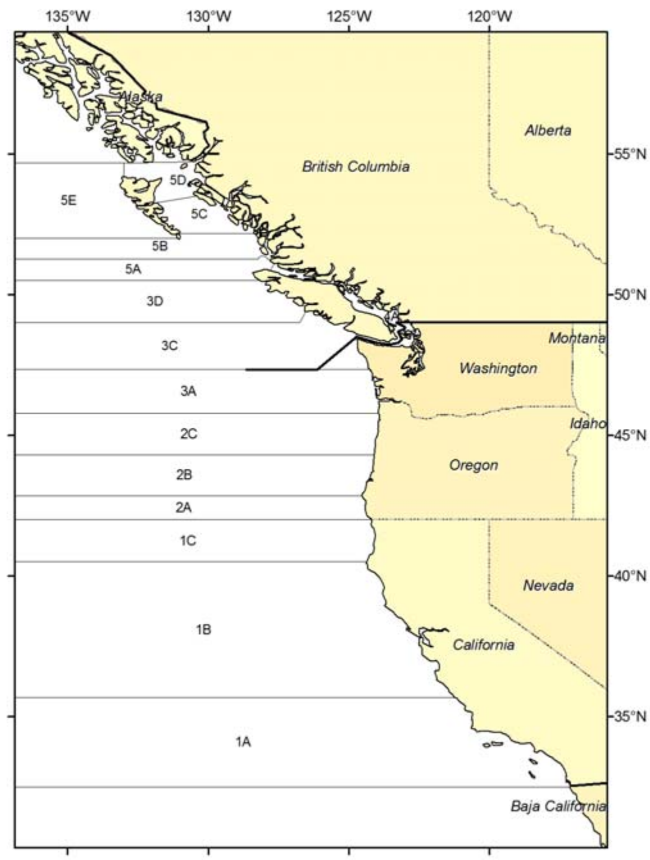

Figure 20. Pacific Marine Fisheries Commission Major Areas off the B.C. and U.S. coast.

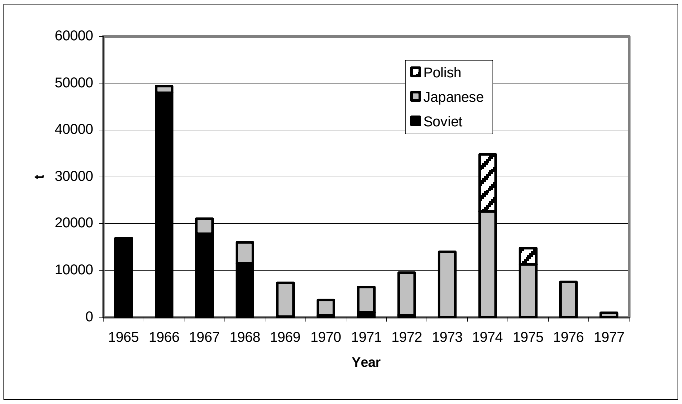

Figure 21. Total rockfish catch from Soviet, Japanese and Polish vessels 1965-1977.

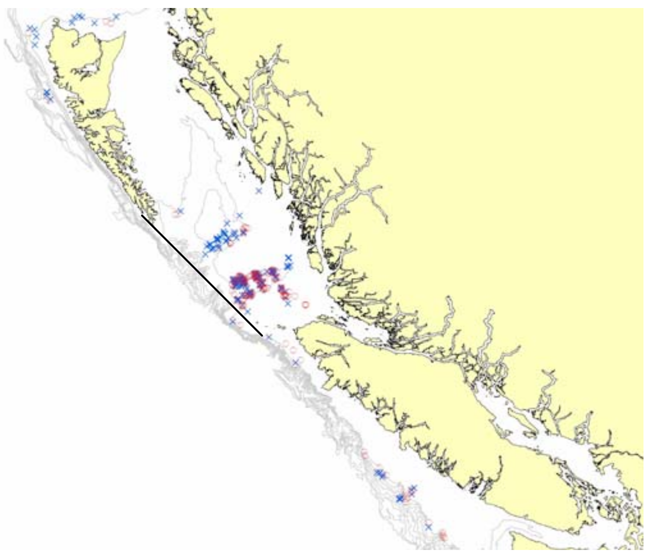

Figure 22. Spatial distribution of *FRV G.B.Reed* tows. Black line indicates boundary for foreign fishing in 1970 (Ketchen *et al.* 1978).

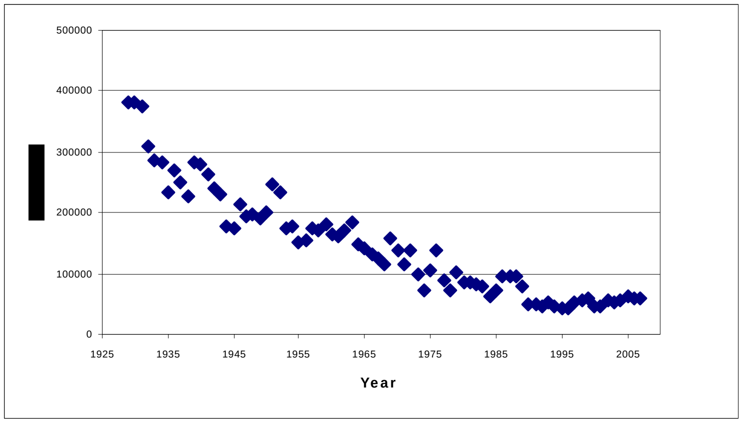

Figure 23. Total effort (skates) in the halibut fishery (1929-2007).

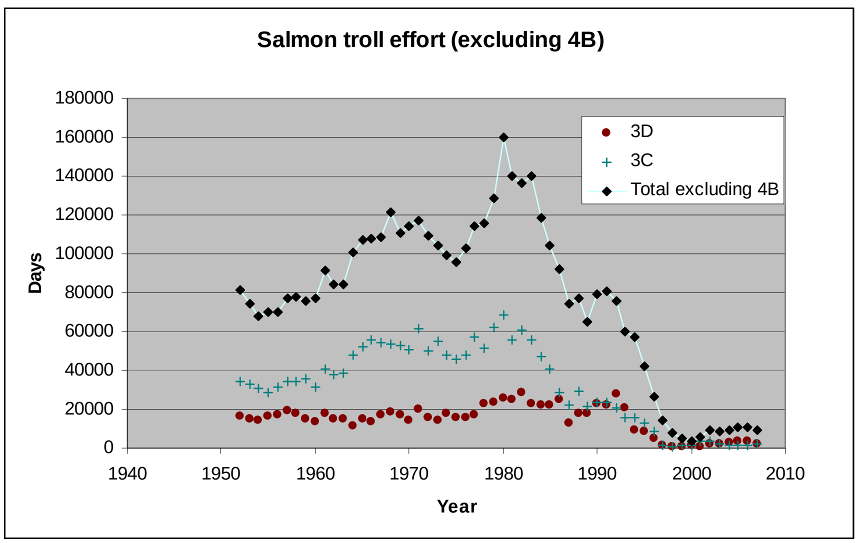

Figure 24. Summary of nominal salmon troll fishery effort in days fished (1952-2007).

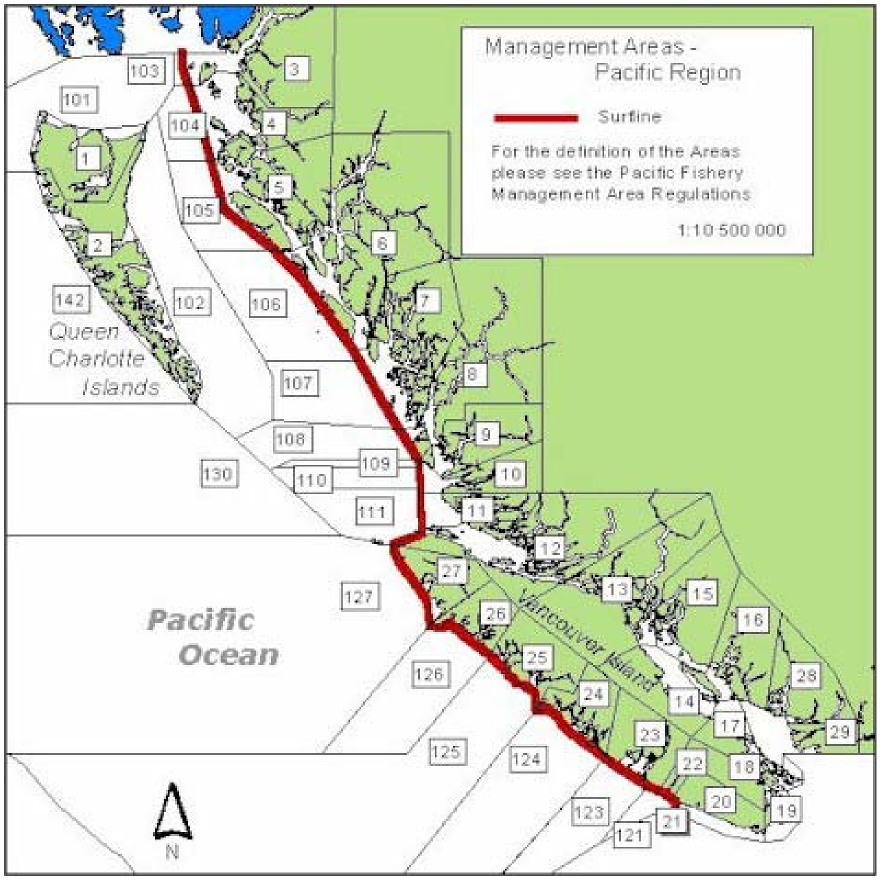

Figure 25. Salmon management areas.

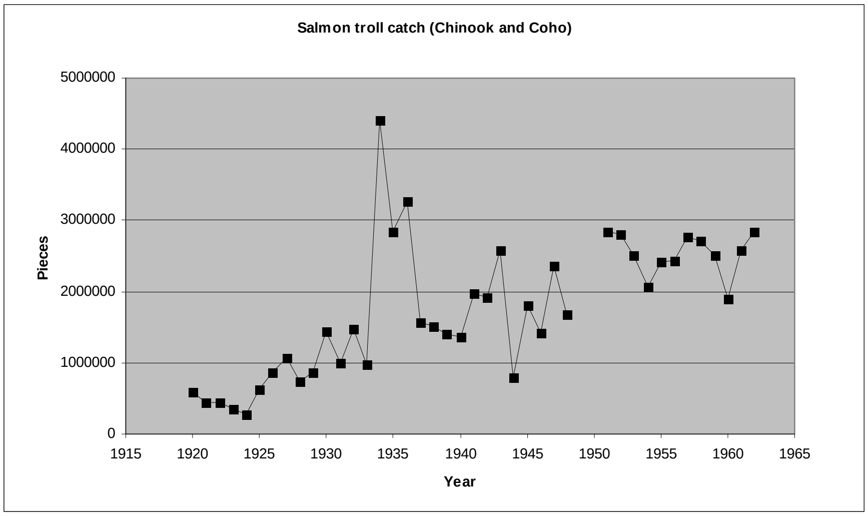

Figure 26. Total reported troll catch of chinook and coho salmon in B.C. waters (1920-1962) (from Milne and Godfrey 1962: note data for 1949-1950 not provided in the source document with no explanation provided). The authors also commented that results for 1934-1937 were considered unreliable.

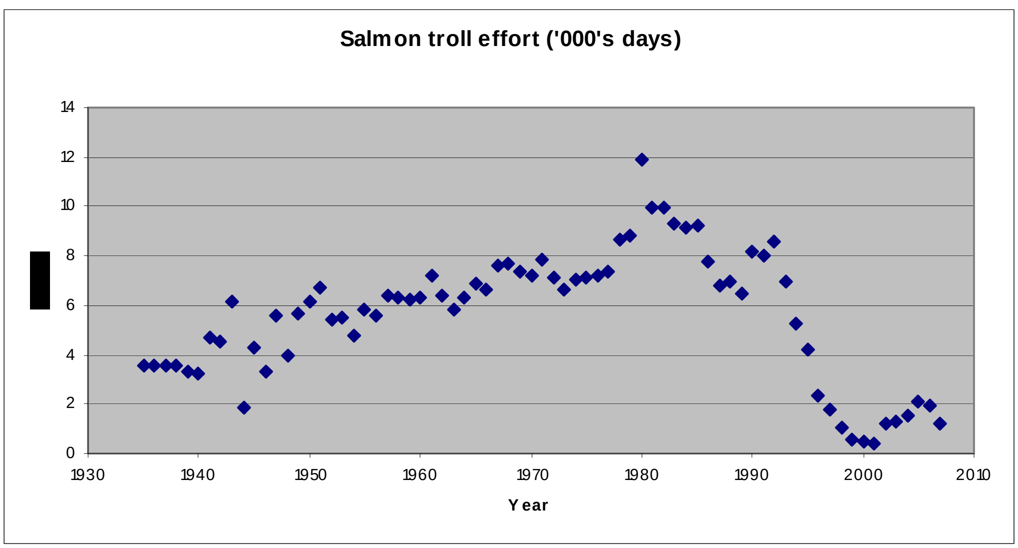

Figure 27. Approximation of weighted total annual salmon troll effort relevant to the bycatch of bocaccio rockfish.

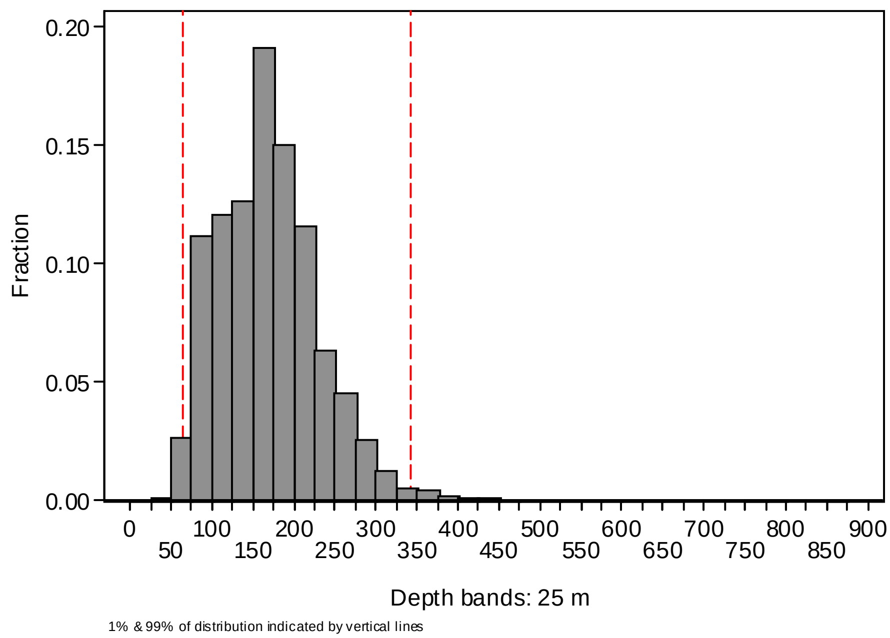

Figure 28. Depth distribution of bocaccio for tows with landed catch in the combined Areas 3C-5E from 1996/97 to 2006/07 in 25 m depth intervals. Each bin interval is labelled with the upper bound of the interval. Vertical lines: 1%=64 m; 99%=342 m.

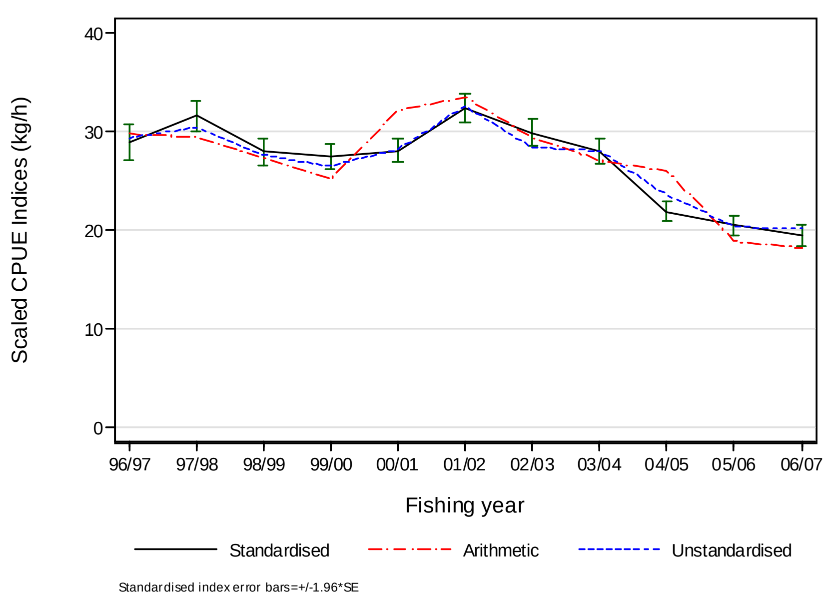

Figure 29. Three CPUE series for 3C-5E landed bocaccio catches for the 1996/97 to 2006/07 fishing years. The solid line is a standardised analysis correcting for 0.1° latitude band, 25 m depth band, DFO locality, and vessel effects. The arithmetic series is the sum of the non-zero catch divided by the sum of the associated effort (Eq. 5) and the unstandardised series is the geometric mean of all positive CPUE observations (Eq. 7).

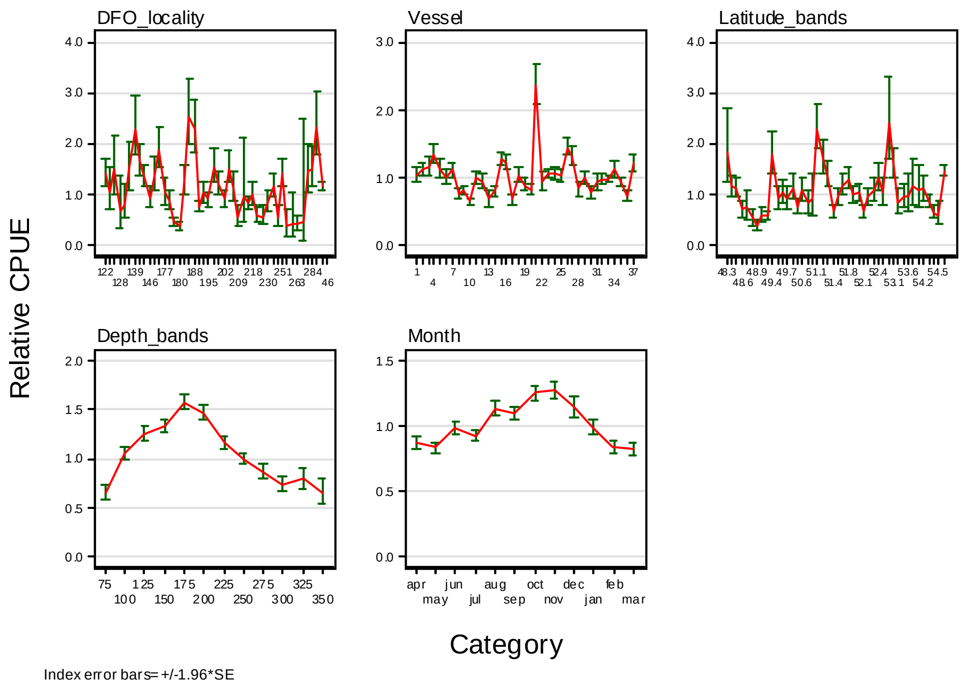

Figure 30. Plots of the coefficients for the categorical explanatory variables included in the standardised GLM analysis presented in Figure 29 (DFO localities with indices greater than 2.0: 139: Clayoquot Canyon; 183: South Scott Islands; 188: Pisces Canyon; 287: Anthony Island)

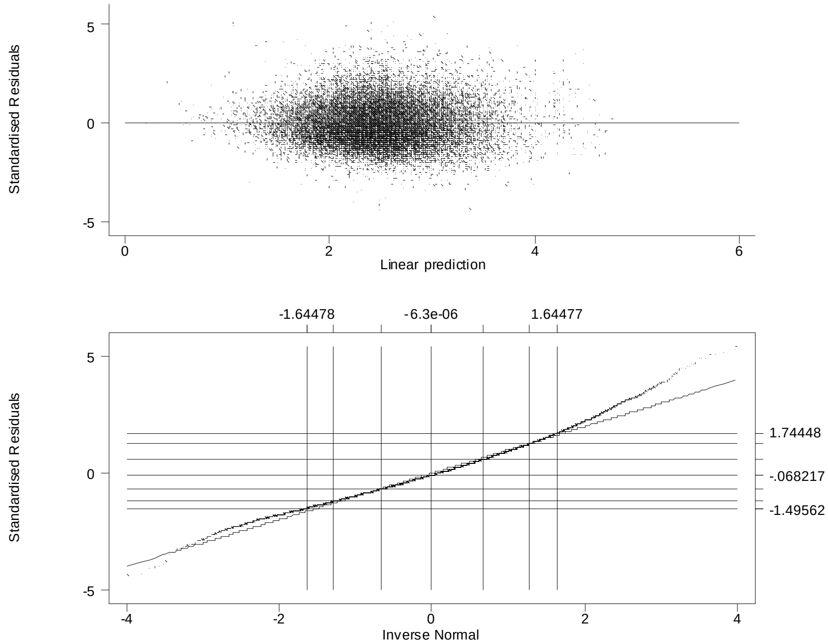

Figure 31. Standardised (Pearson) residuals for the 3C-5E GLM analysis presented in Figure 29. The outside horizontal and vertical lines represent the 5th and 95th percentiles of the theoretical and observed distributions.

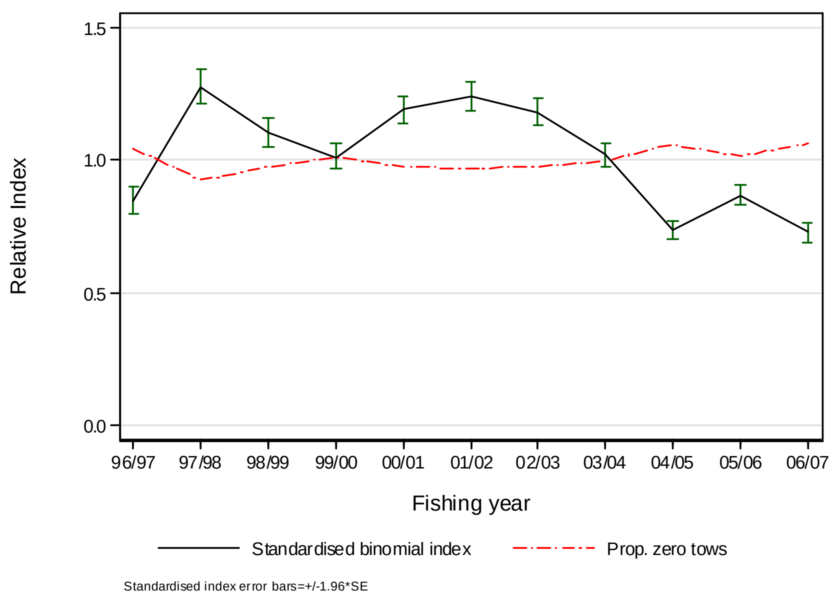

Figure 32. Year effects from a standardised binomial logit model for 3C-5E model fit to the presence/absence of bocaccio using the same dataset that provided the lognormal regression model (Figure 29). Also shown is the relative proportion of tows with zero bocaccio by fishing year (mean=0.73). Each series has been normalised to its geometric mean.

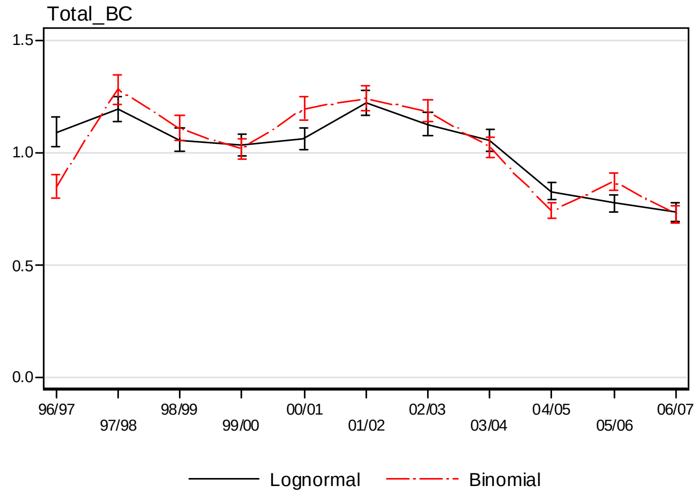

Figure 33. Comparison of the lognormal and binomial standardised CPUE indices for bocaccio for the 3C-5E model. The error bars show ± 95% confidence bounds.

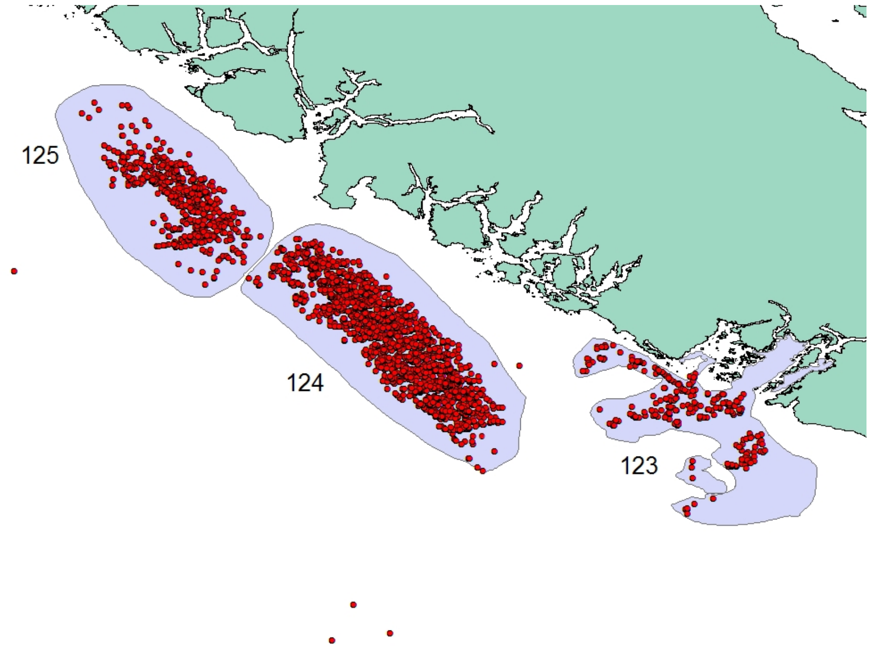

Figure 34. Map of the locations of all trawls in areas 123, 124 and 125 that were associated with the west coast Vancouver Island shrimp trawl survey. Areas 124 and 125 are the strata that have been surveyed consistently over the history of the survey and which are in locations most likely to catch bocaccio.

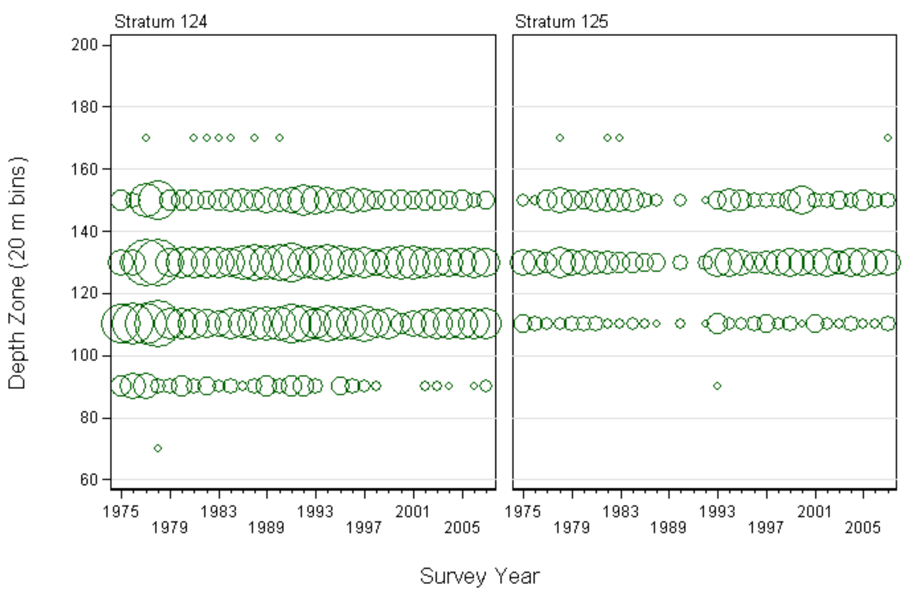

Figure 35. Distribution of tows in 20 m depth zones by survey year and area stratum for all tows. Each 20 m depth bin is indicated by the mid-point of the bin (i.e.: 110 m= 100-120 m). Tow depth determined by the start depth. Circles are weighted by the number of sets observed in each depth bin. Maximum circle size: stratum 124=48 tows and stratum 125=20 tows, both in the 130 m depth bin.

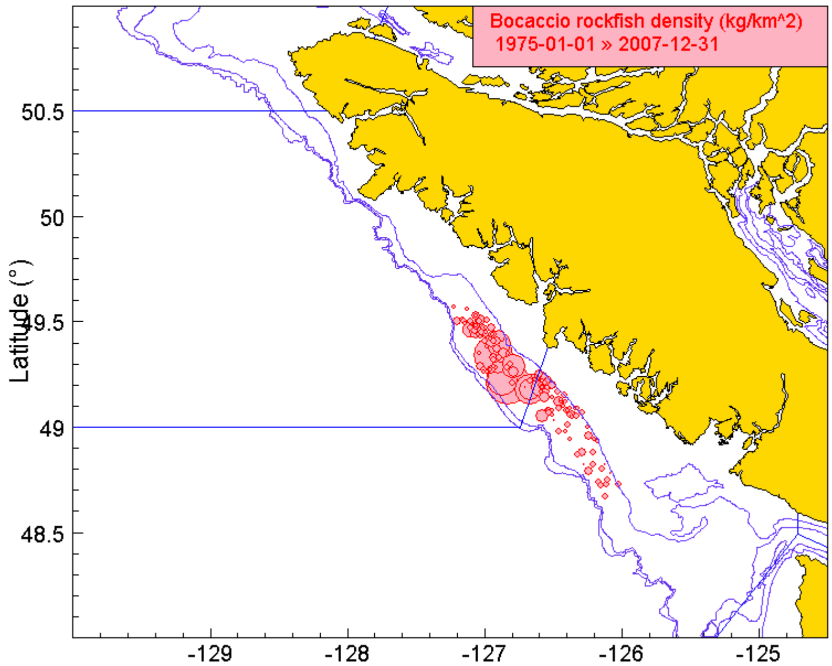

Figure 36. Chart of the locations of all trawls from the west coast Vancouver Island shrimp trawl survey (1975–2007) which caught bocaccio. Circles are proportional to catch density (largest circle=10.1 kg/km^2). Also shown are the 100, 200 and 300 m isobaths and the PMFC major area boundaries for Areas 123 and 124.

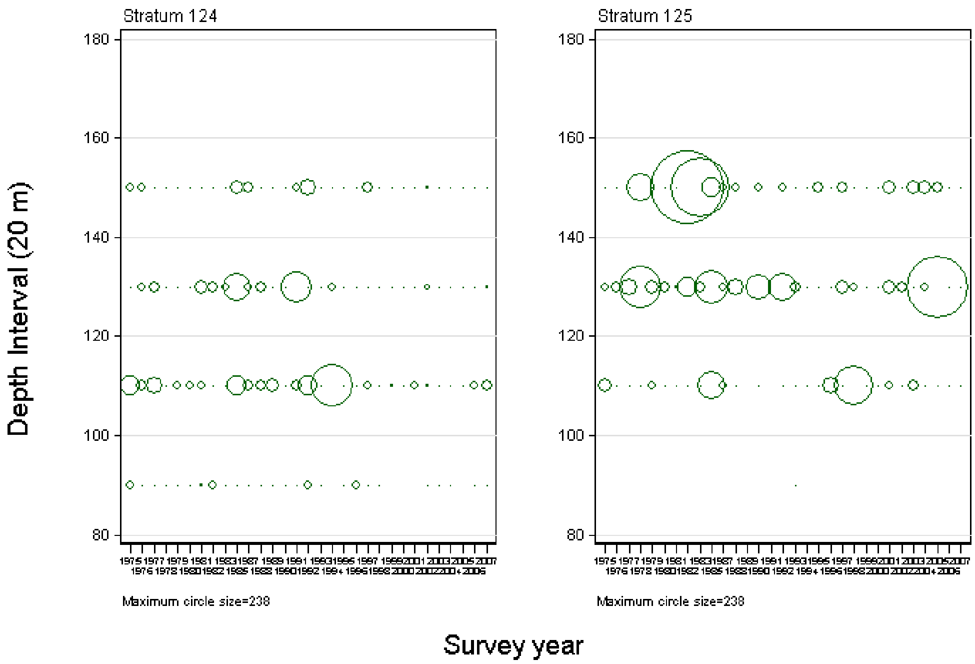

Figure 37. Distribution of catch weight of bocaccio by stratum (Table 39), survey year, and 20 m depth zone in the WCVI shrimp survey. Depth zones are indicated by the centre of the depth interval. Minimum depth observed for bocaccio: 90 m; maximum depth observed for bocaccio: 163 m. Depth is the start depth for the tow.

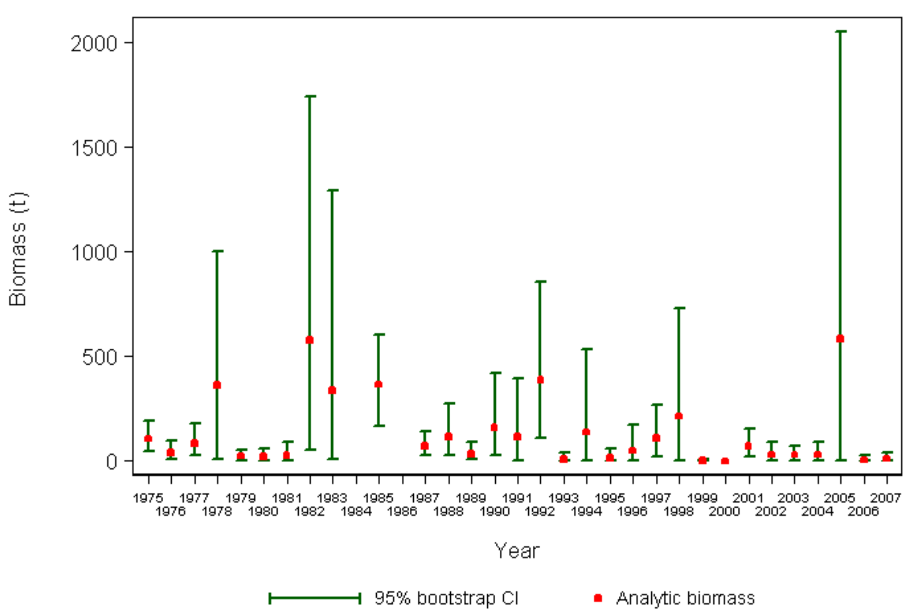

Figure 38. Plot of biomass estimates for bocaccio from the WCVI shrimp trawl survey for the period 1975 to 2007. Bias corrected 95% confidence intervals from 1,000 bootstrap replicates are plotted.

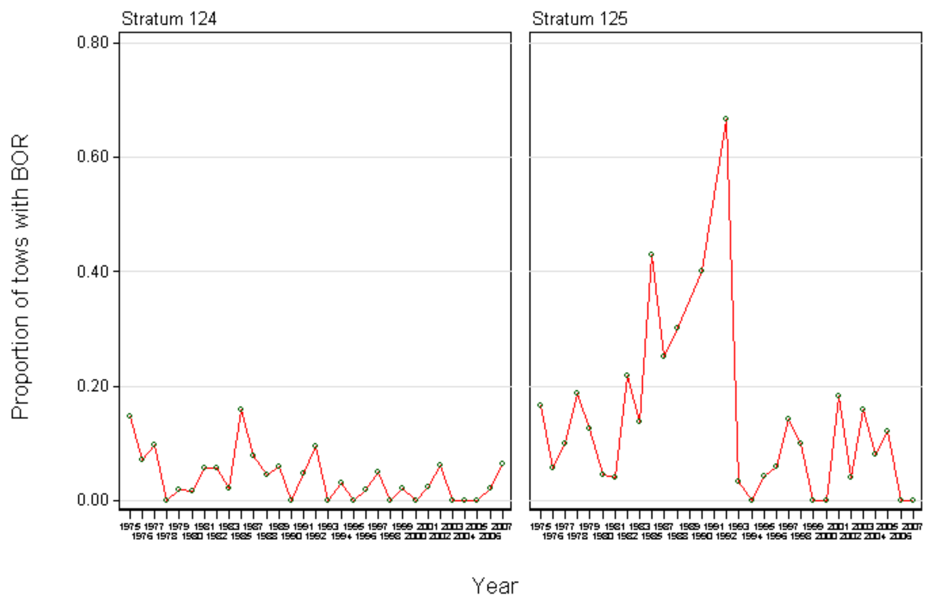

Figure 39. Proportion of tows by stratum and year which contained bocaccio for the WCVI shrimp trawl survey.

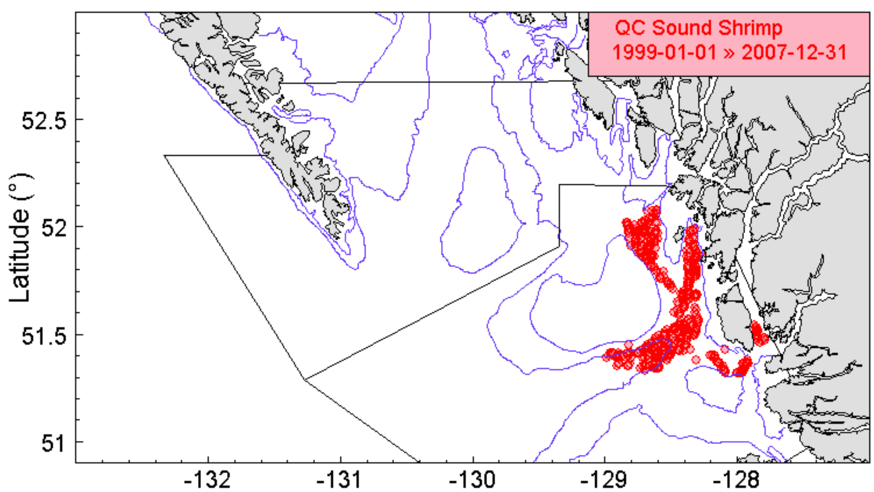

Figure 40. Map showing the locations of valid tows (Stratum numbers 109, 110, 111) conducted by the QCSd shrimp survey over the period 1999 to 2007. The tows on the inside of Calvert Island represent Stratum 111 which was not used in the analysis of this survey for bocaccio.

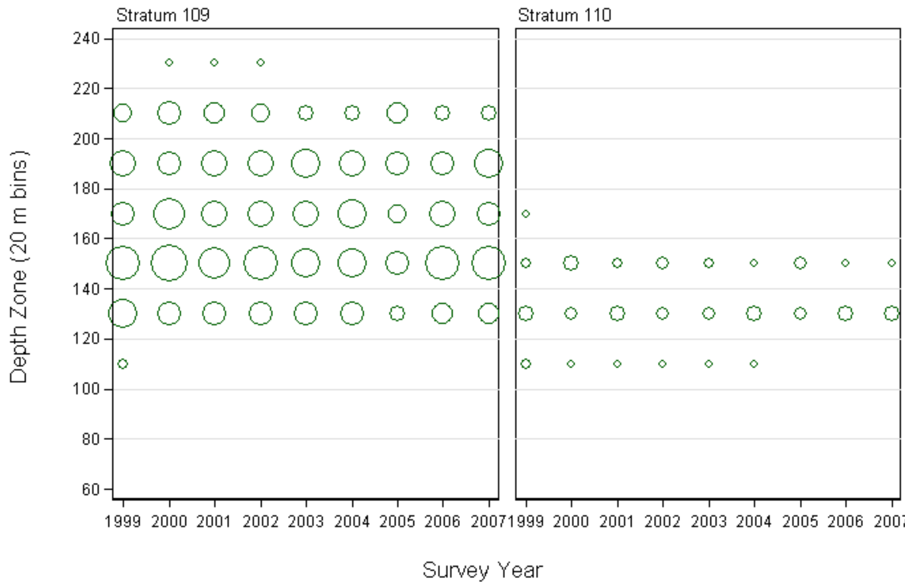

Figure 41. Distribution of tows by stratum, survey year, and 20 m depth zone in the QCSd shrimp survey. Depth zones are indicated by the centre of the depth interval, weighted by the number of tows. Maximum circle size: Stratum 109=26 tows (150 m bin); Stratum 110=5 tows (130 m bin). Depth is the mean of the start and end depths for the tow.

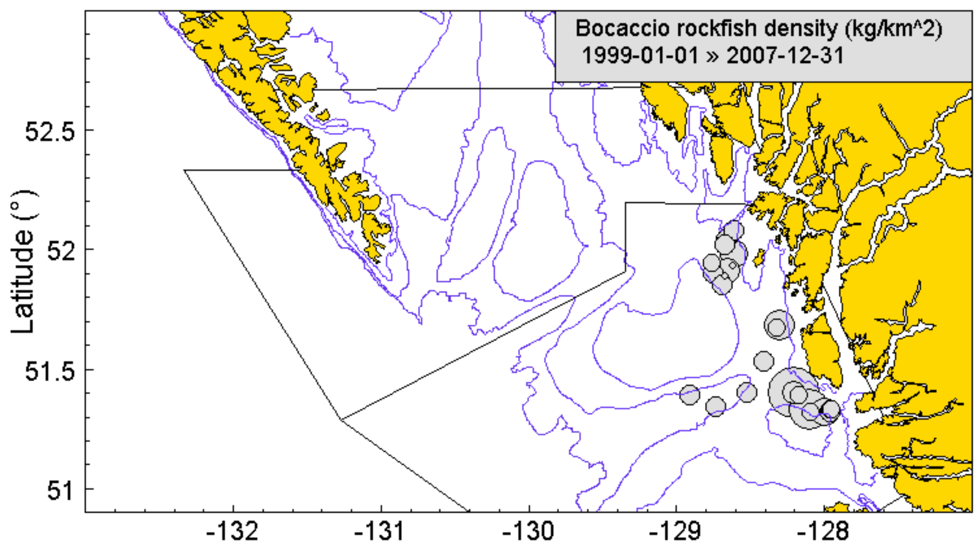

Figure 42. Map of the locations of all trawls from the Queen Charlotte Sound shrimp trawl survey (1999–2007) which caught bocaccio. Circles are proportional to catch density (largest circle=0.57 kg/km^2). Also shown are the 100, 200, and 300 m isobaths and the area stratum boundaries for the Queen Charlotte Sound synoptic survey.

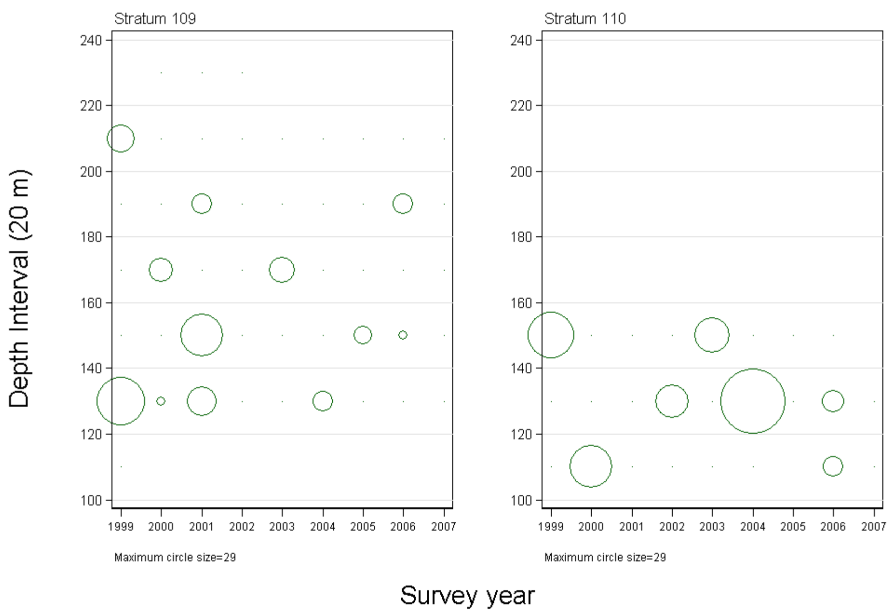

Figure 43. Distribution of catch weight of bocaccio by stratum (Table 42.), survey year, and 20 m depth zone. Depth zones are indicated by the centre of the depth interval. Maximum circle size: 29 kg (120 m bin in 2004 in Stratum 110). Minimum depth observed for bocaccio: 113 m; maximum depth observed for bocaccio: 206 m. Depth is defined as the start depth for the tow.

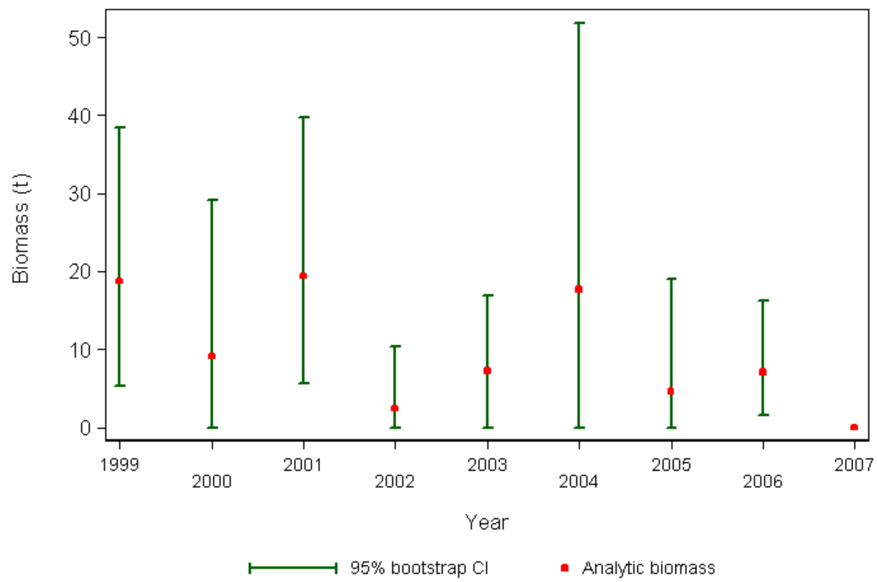

Figure 44. Plot of biomass estimates for bocaccio from the QC Sound shrimp trawl survey for 1999 to 2007. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

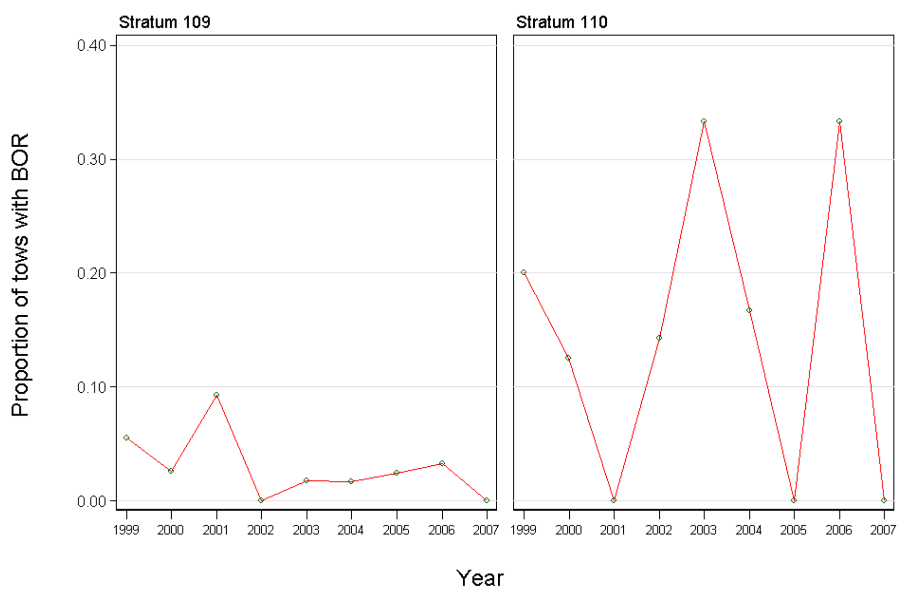

Figure 45. Proportion of tows by stratum and year which contain bocaccio for the QC Sound shrimp trawl survey.

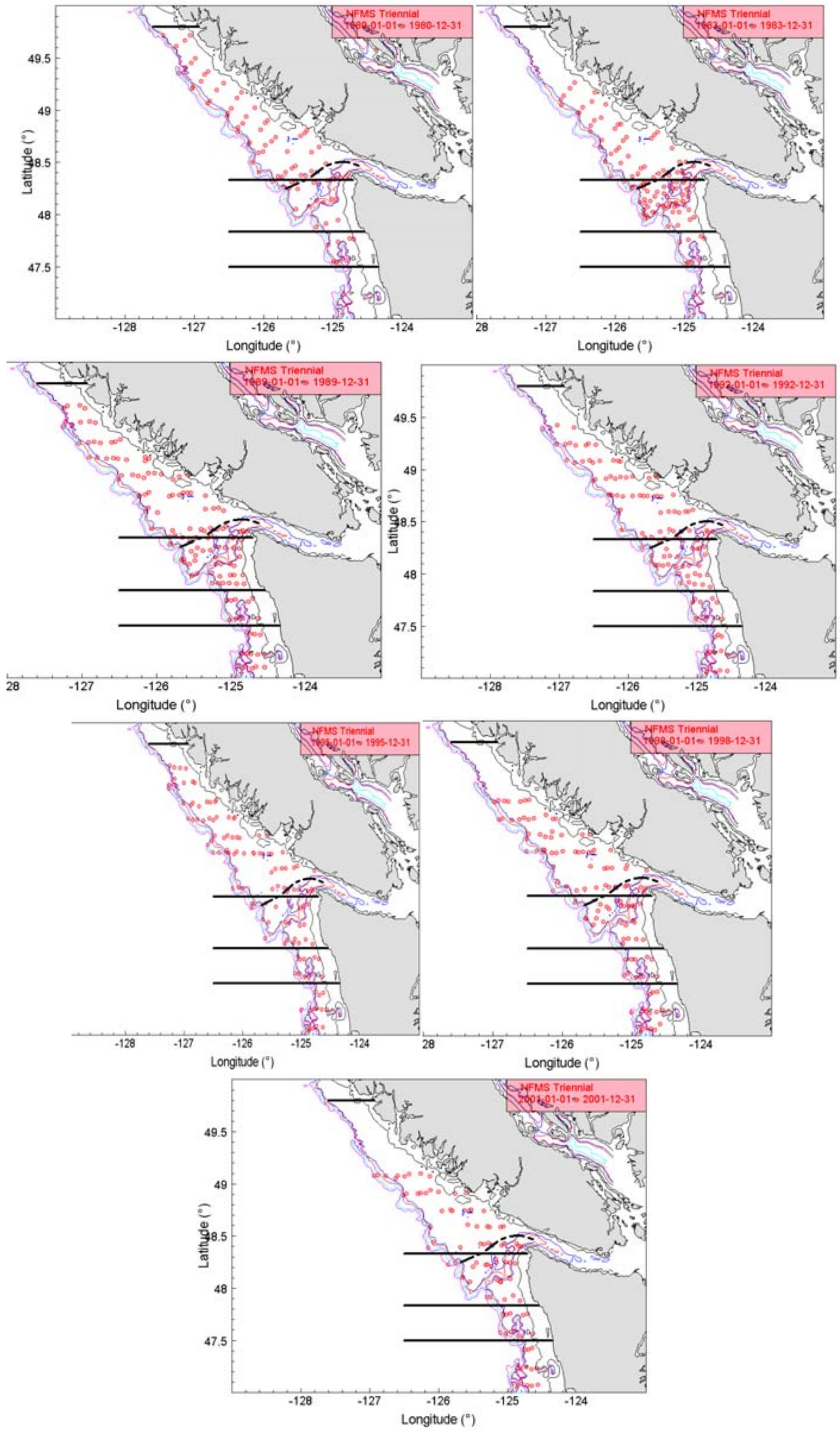

Figure 46. Plot of tow locations (in red) in the Vancouver INPFC region for each of the seven triennial surveys that surveyed Canadian waters. Dashed line shows approximate position of the US/Canada marine boundary. Horizontal lines are the stratum boundaries: 47°30′, 47°50′, 48° 20′, and 49°50′. Tows south of the 47°30′ line were not included in the analysis. Isobaths act as stratum boundaries at 55, 183, 220, 366, and 500 m.

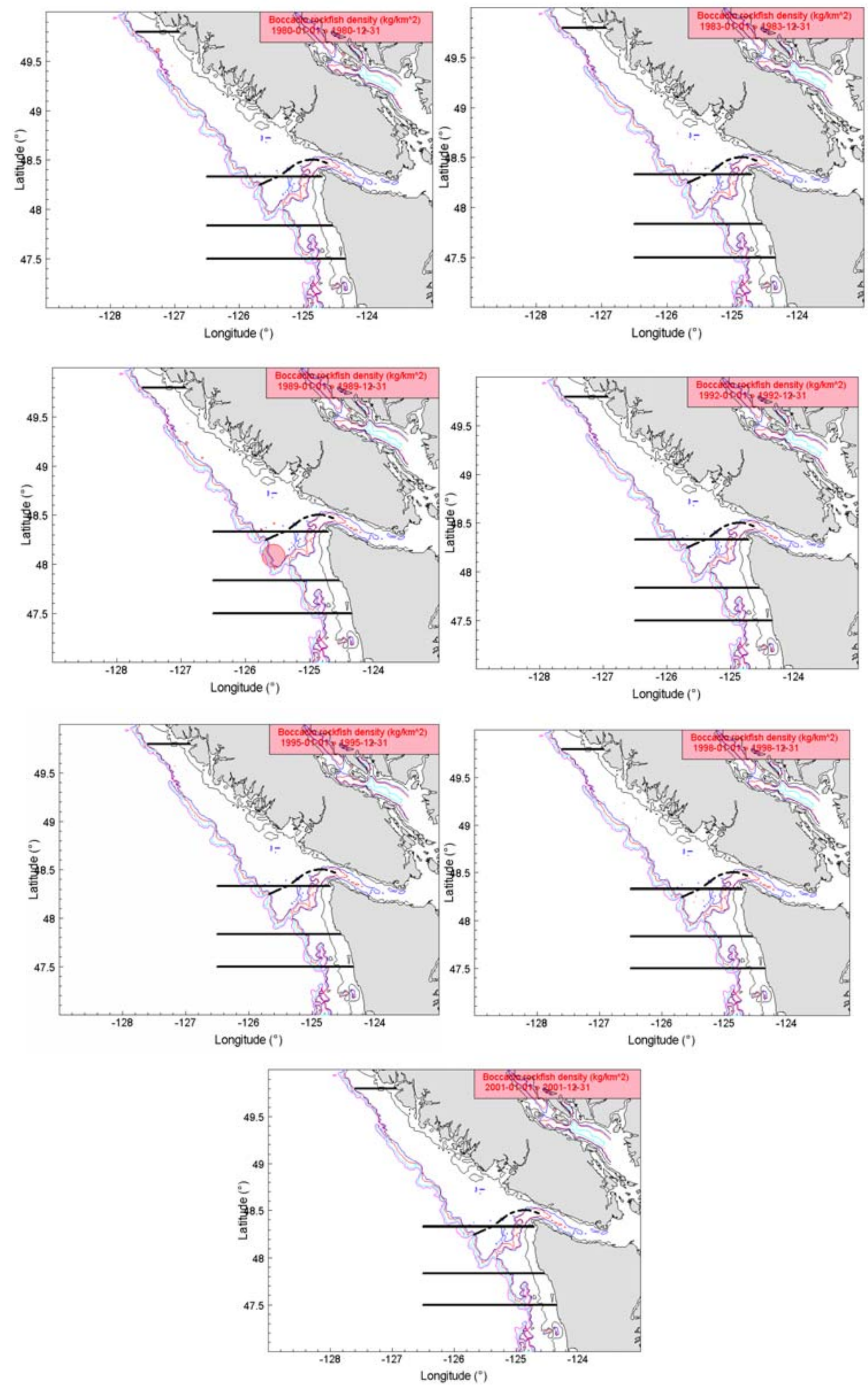

Figure 47. Plot of valid tows, weighted by the density of bocaccio, in the Vancouver INPFC region for the seven triennial surveys that surveyed Canadian waters. Catches in each year are scaled to the weight of the largest

density of bocaccio (220,761 kg/km^2 in 1989). The approximate position of the US/Canada marine boundary is shown (dashed line). The horizontal lines are the stratum boundaries: 47°30', 47°50', 48°20' and 49°50'.

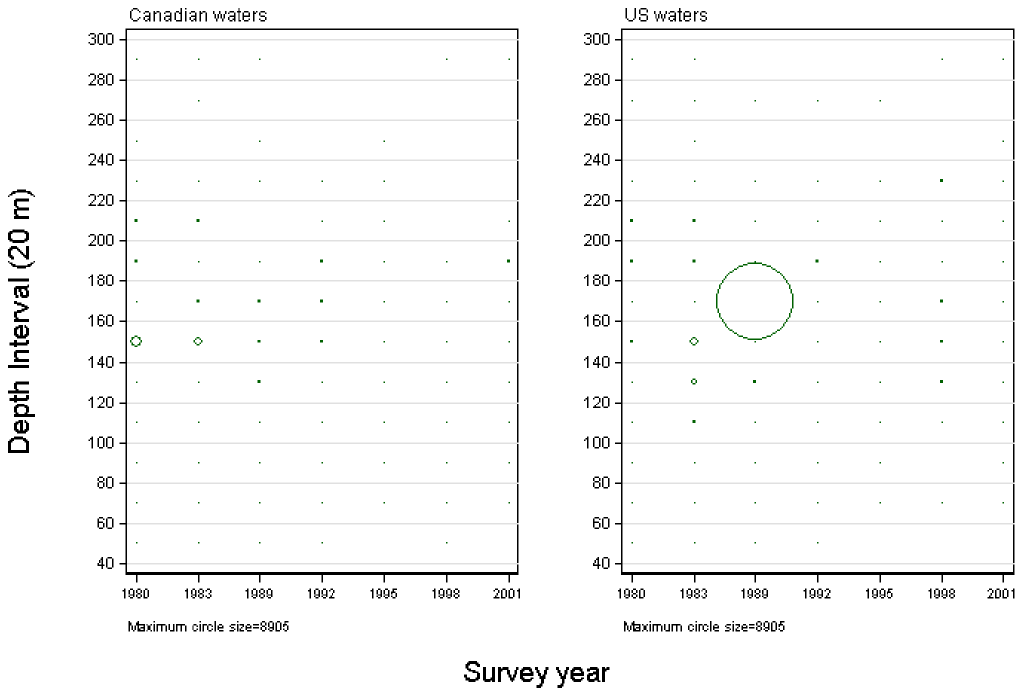

Figure 48. Distribution of bocaccio catch weights for each survey year summarised into 20 m depth intervals for all valid tows (Table 45.) in Canadian and US waters of the Vancouver INPFC area. Depth intervals are labelled with the mid-point of the interval.

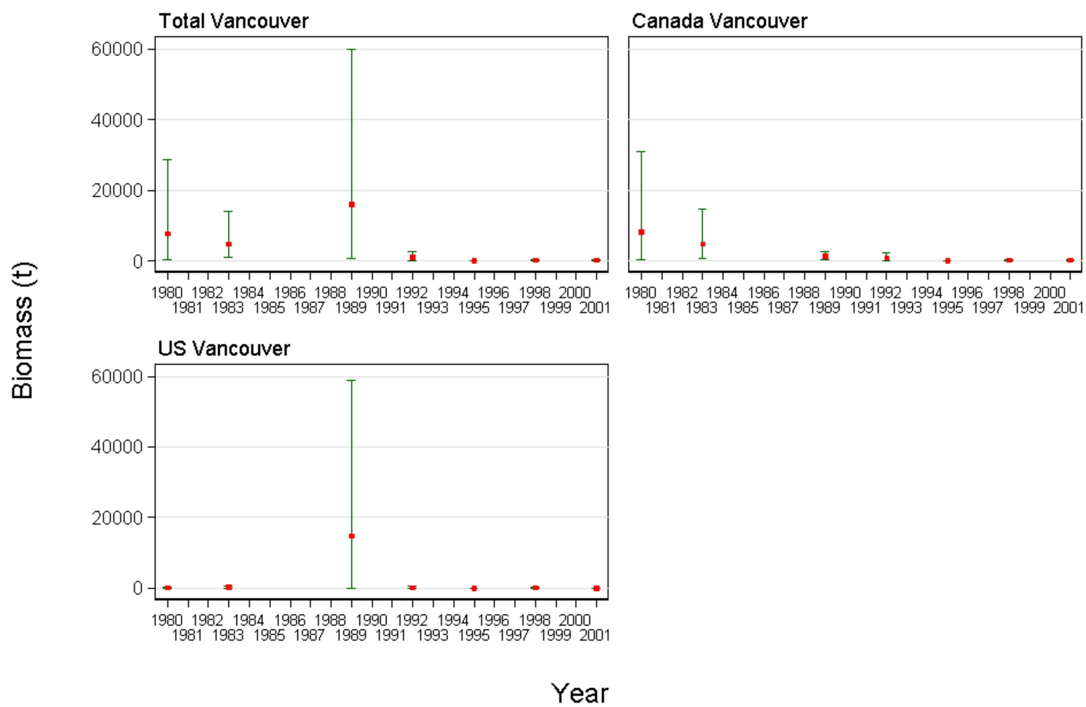

Figure 49. Three biomass estimates for bocaccio in the INPFC Vancouver region (total region, Canadian waters only, and US waters only) with 95% bias corrected error bars estimated from 1000 bootstraps

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Figure 50. Proportion of tows with bocaccio by year for the Vancouver INPFC region (total region, Canadian waters only and US waters only).

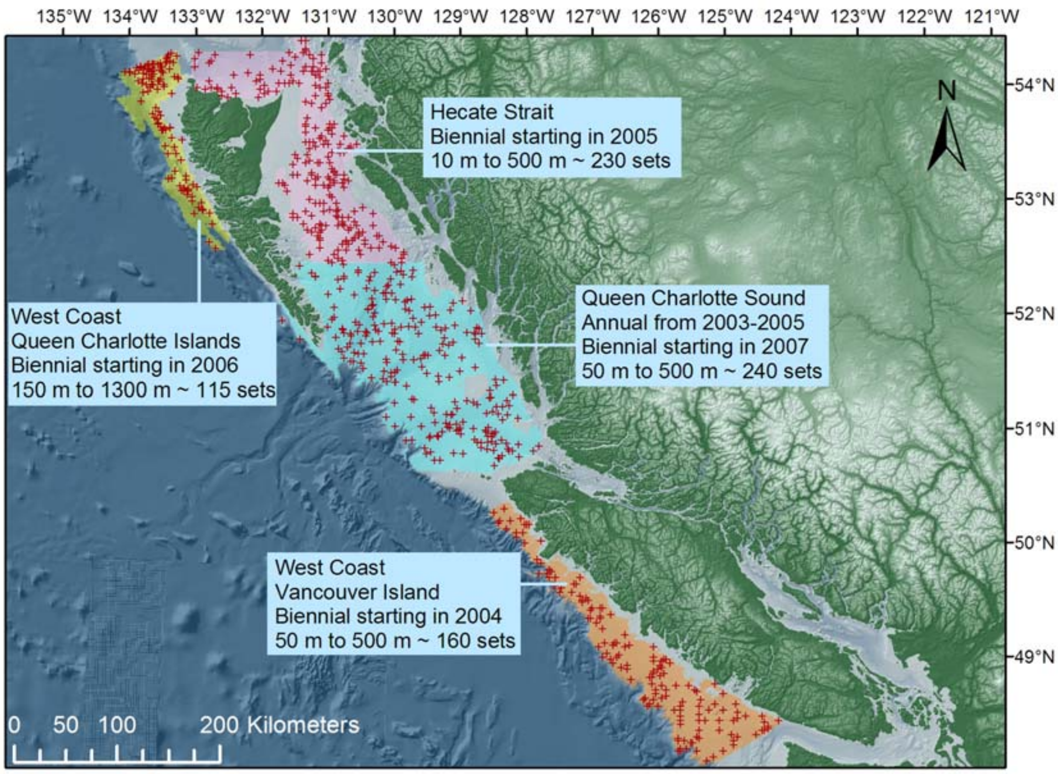


Figure 51. Location of Groundfish synoptic surveys

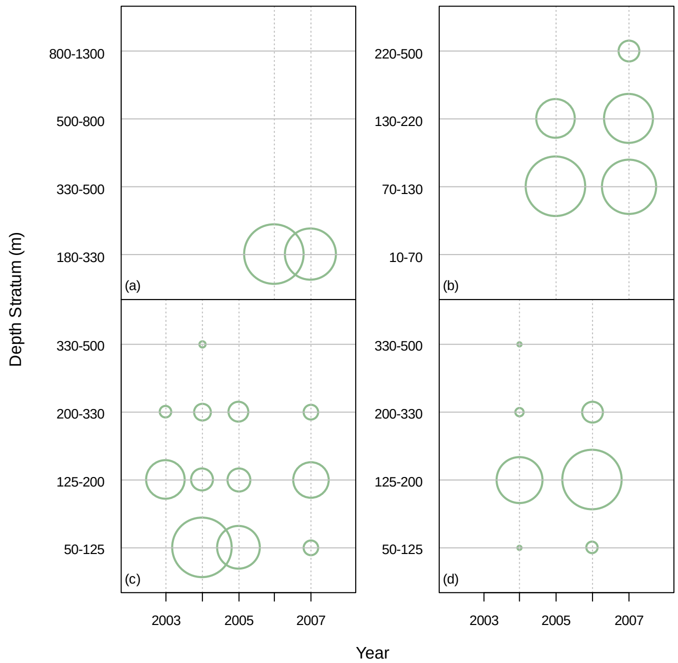


Figure 52. Total catch weight of bocaccio by stratum: (a) WCQCI; (b) HS; (c) QCSd; (d) WCVI. The vertical lines in each panel indicate the years in which the survey took place.

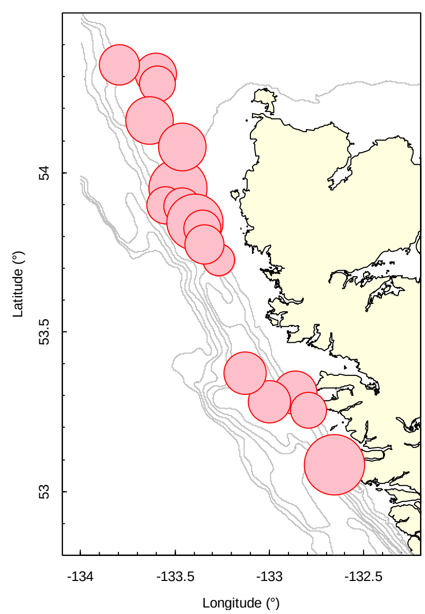


Figure 53. Locations of tows in the WCQCI survey (2006 and 2007), which captured bocaccio. The total number of completed tows was 222. Bocaccio were captured in 18 tows. The largest circle represents a catch weight of 11 kg.

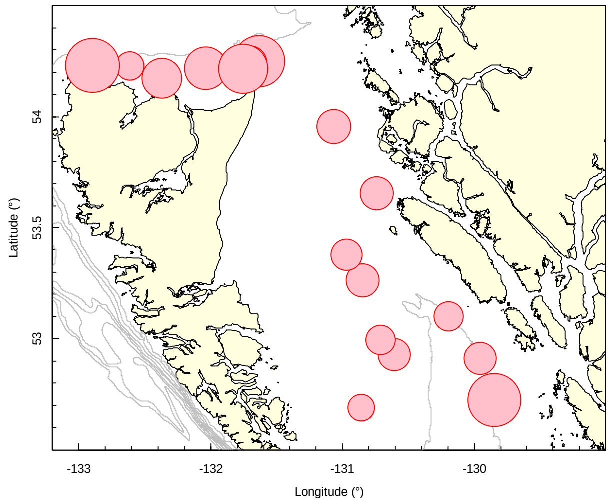


Figure 54. Locations of tows in the HS survey (2005 and 2007), which captured bocaccio. The total number of completed tows was 369. Bocaccio was captured in 18 tows. The largest circle represents a catch weight of 12 kg.

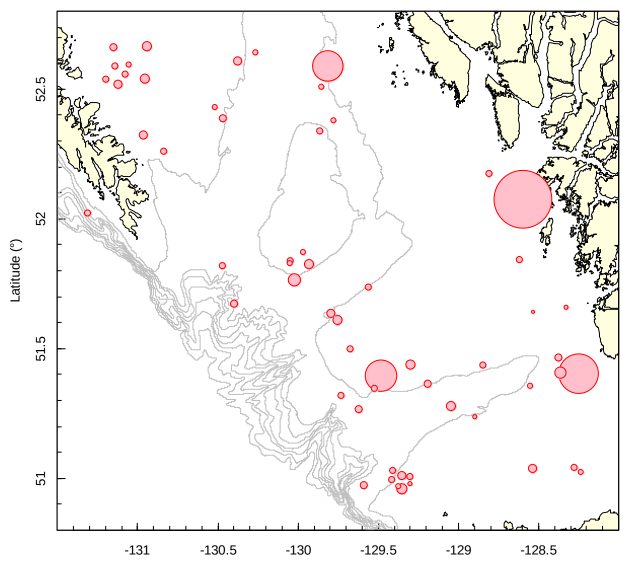


Figure 55. Locations of tows in the QCSd survey (2003-2005 and 2007), which captured bocaccio. The total number of completed tows was 949. Bocaccio was captured in 61 tows. The largest circle represents a catch weight of 321 kg.

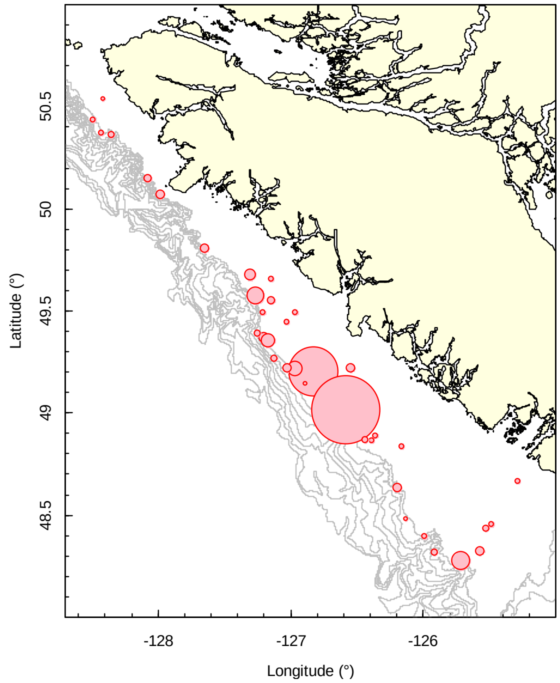


Figure 56. Locations of tows in the WCVI survey (2004 and 2006), which captured bocaccio. The total number of completed tows was 255. Bocaccio was captured in 39 tows. The largest circle represents a catch weight of 449 kg.

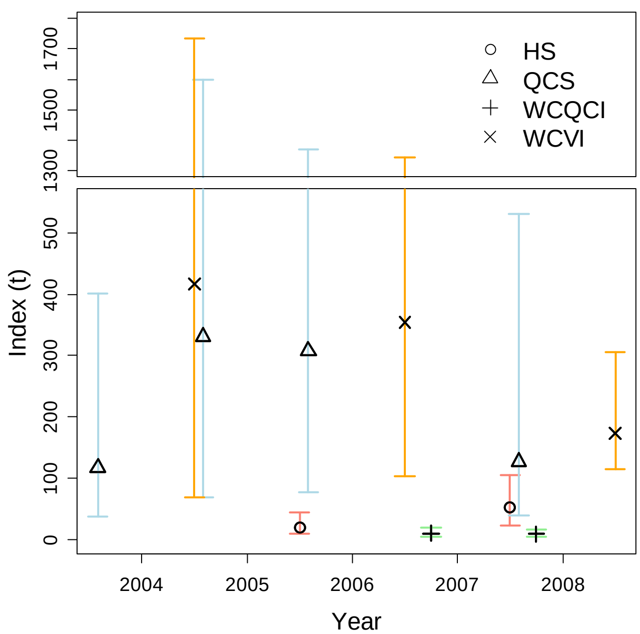


Figure 57. Biomass indices plotted by year and month.

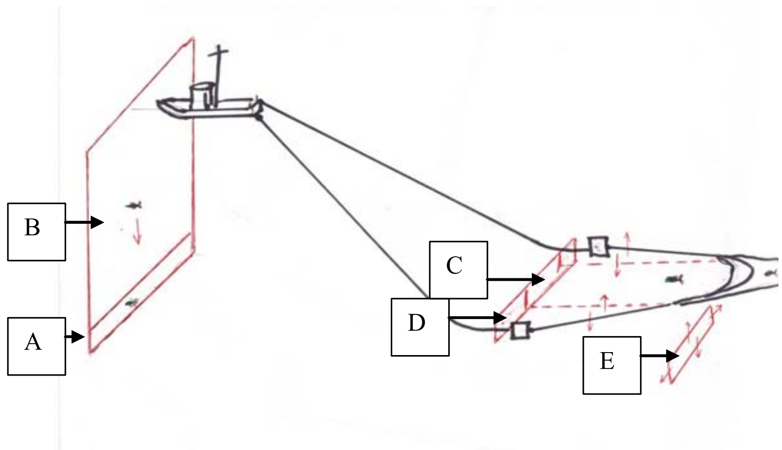


Figure 58. Diagram of fishing zones in the path of the bottom trawl

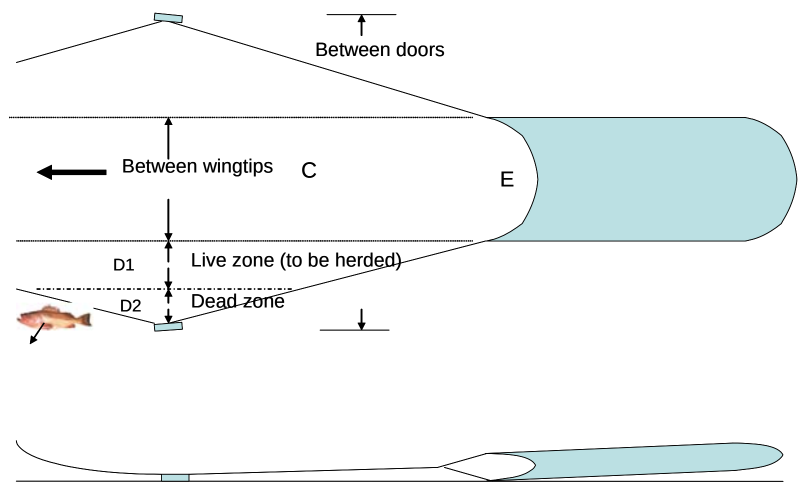


Figure 59. Top view and side views showing the trawl warps, sweeps and net configuration.

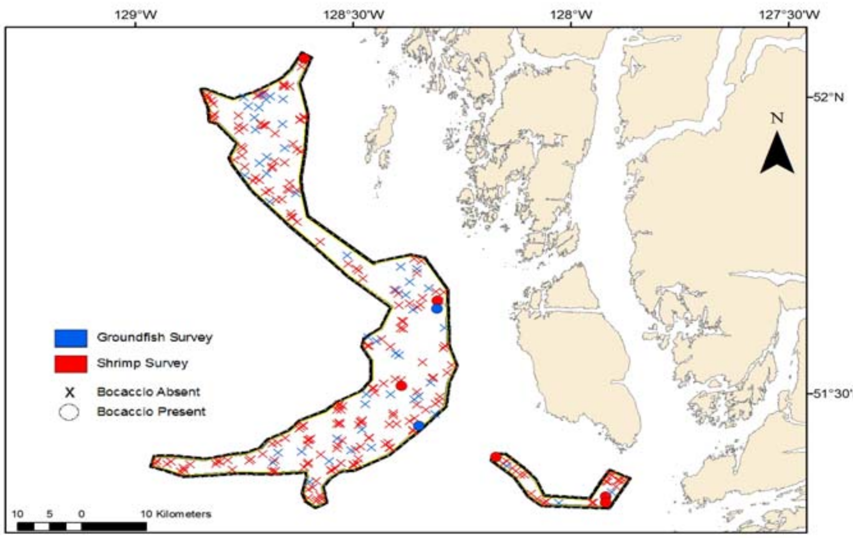


Figure 60. Spatial mask of the overlapped QCSd groundfish and shrimp surveys. Polygons were connected by hand to delimit the outer boundaries.

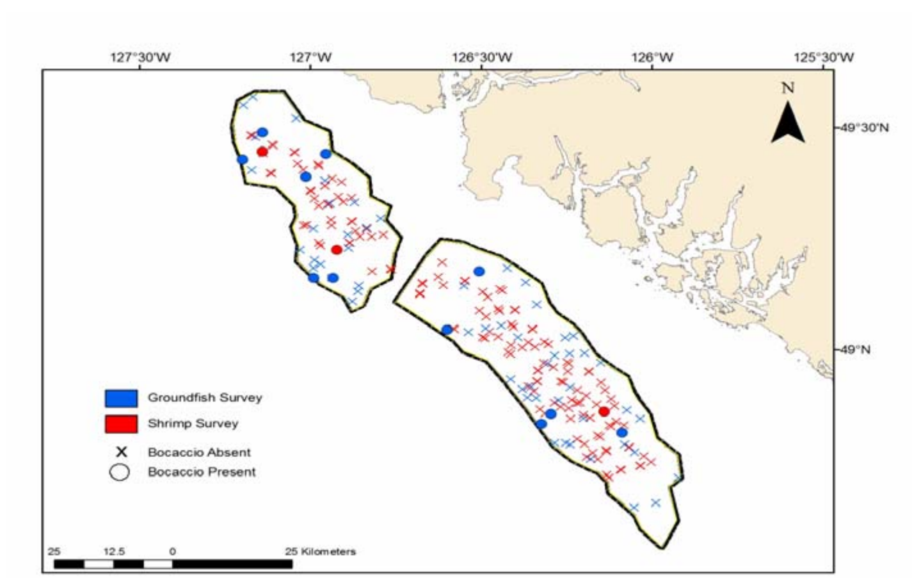


Figure 61. Spatial mask of the overlapped WCVI groundfish and shrimp surveys. Polygons were connected by hand delimit the outer boundaries.

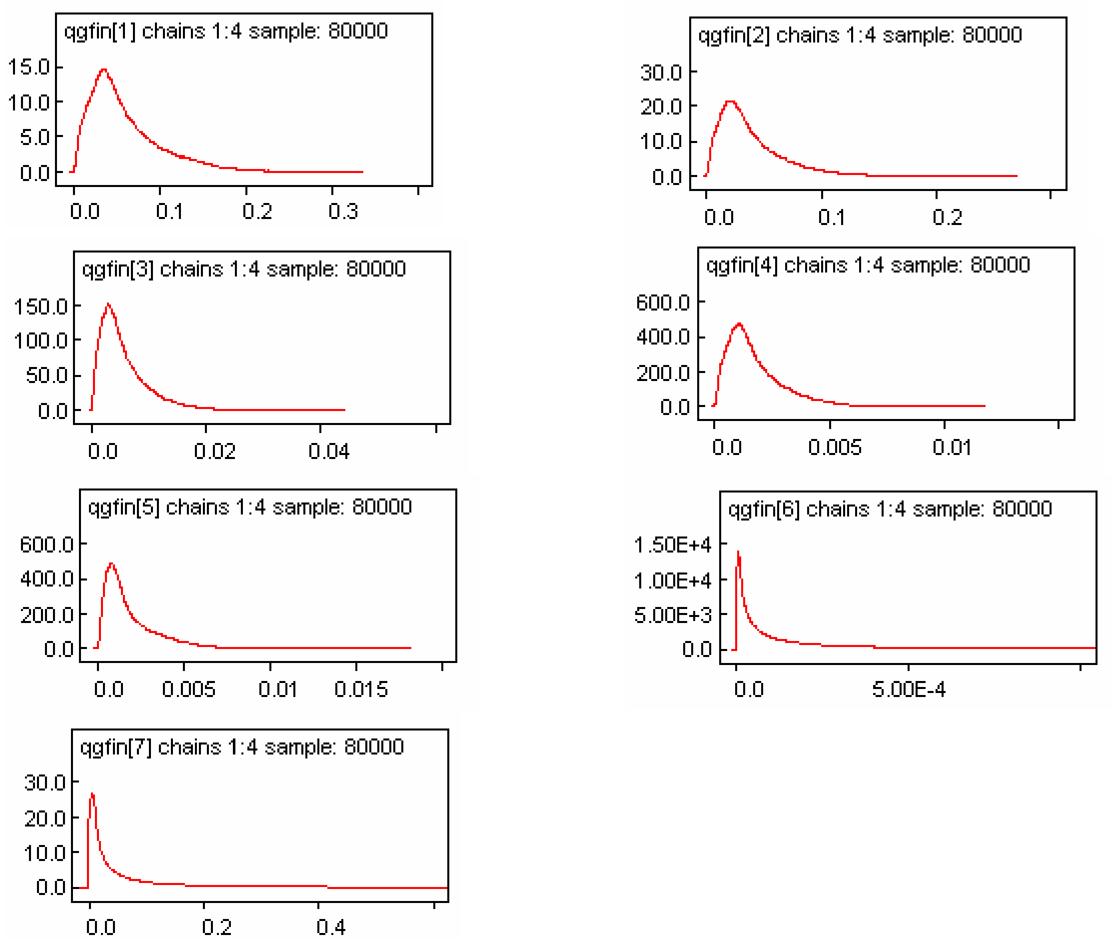


Figure 62. Marginal density functions for *q-gross*.

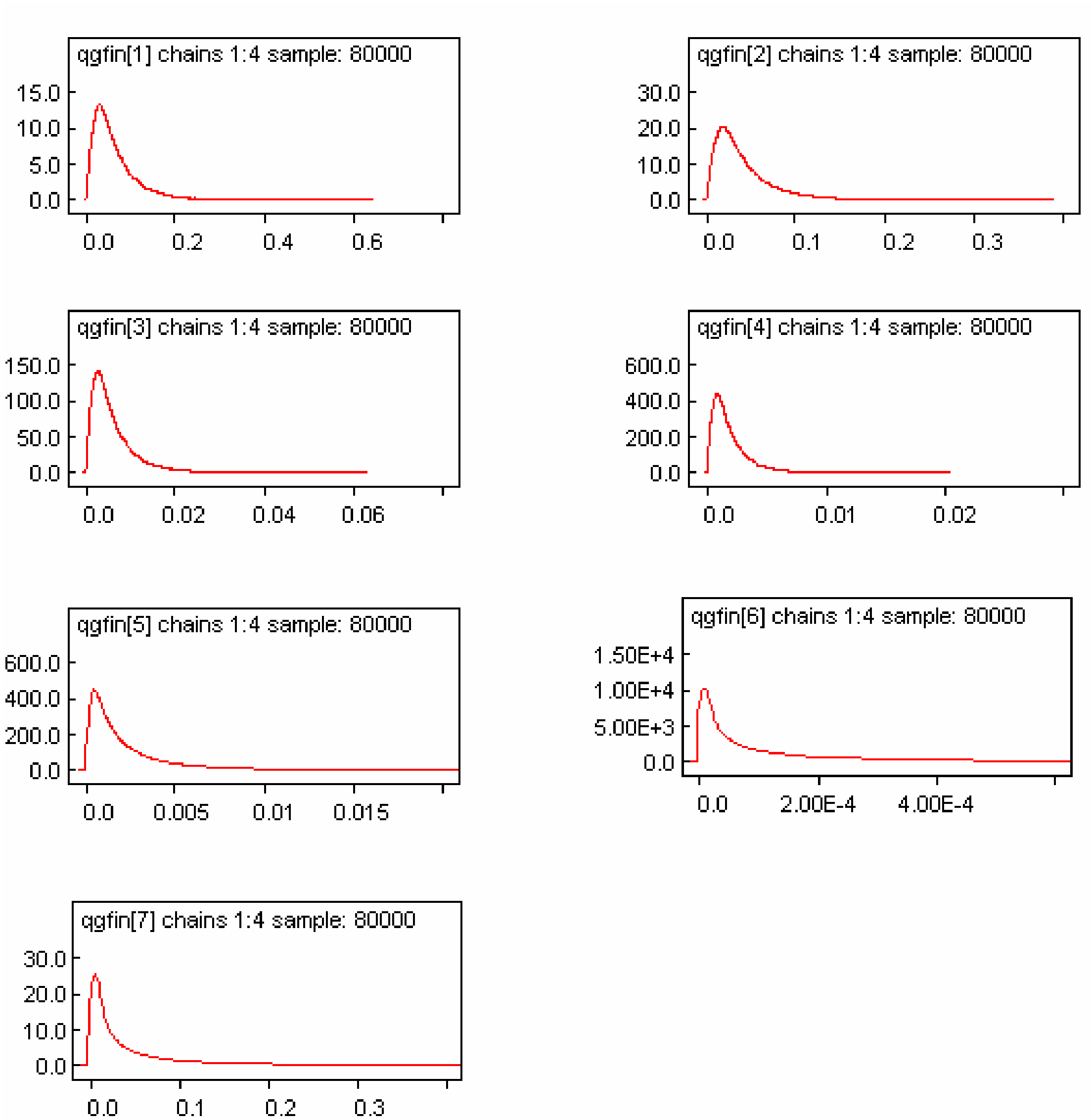


Figure 63. Marginal density functions for *q-gross* (*qgfin*) for the seven different surveys when Bayesian updating and uncertainty factors are applied to the *q-net* factors.

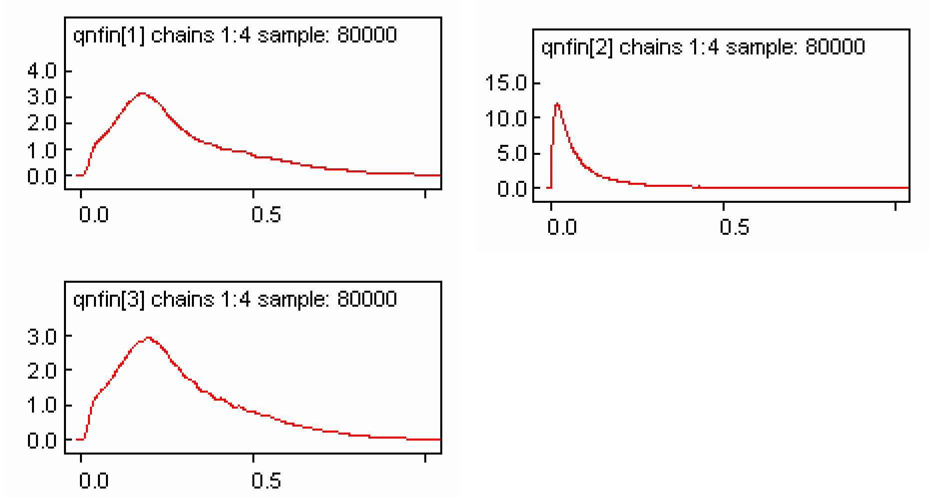


Figure 64. Output density functions for *q-net* for the AWII (1), shrimp (2) and Nor'Eastern trawl (3) nets when the uncertainty factor and Bayesian updating are applied (reference case)

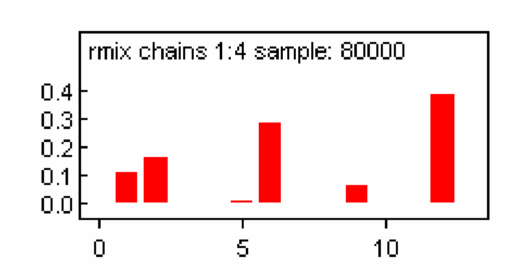


Figure 65. Marginal posteriors placed on the results of each of the 12 different captains based on the Bayesian updating using the catch rate ratio observations for the DFO AWII and shrimp trawl nets when the uncertainty factors are applied.

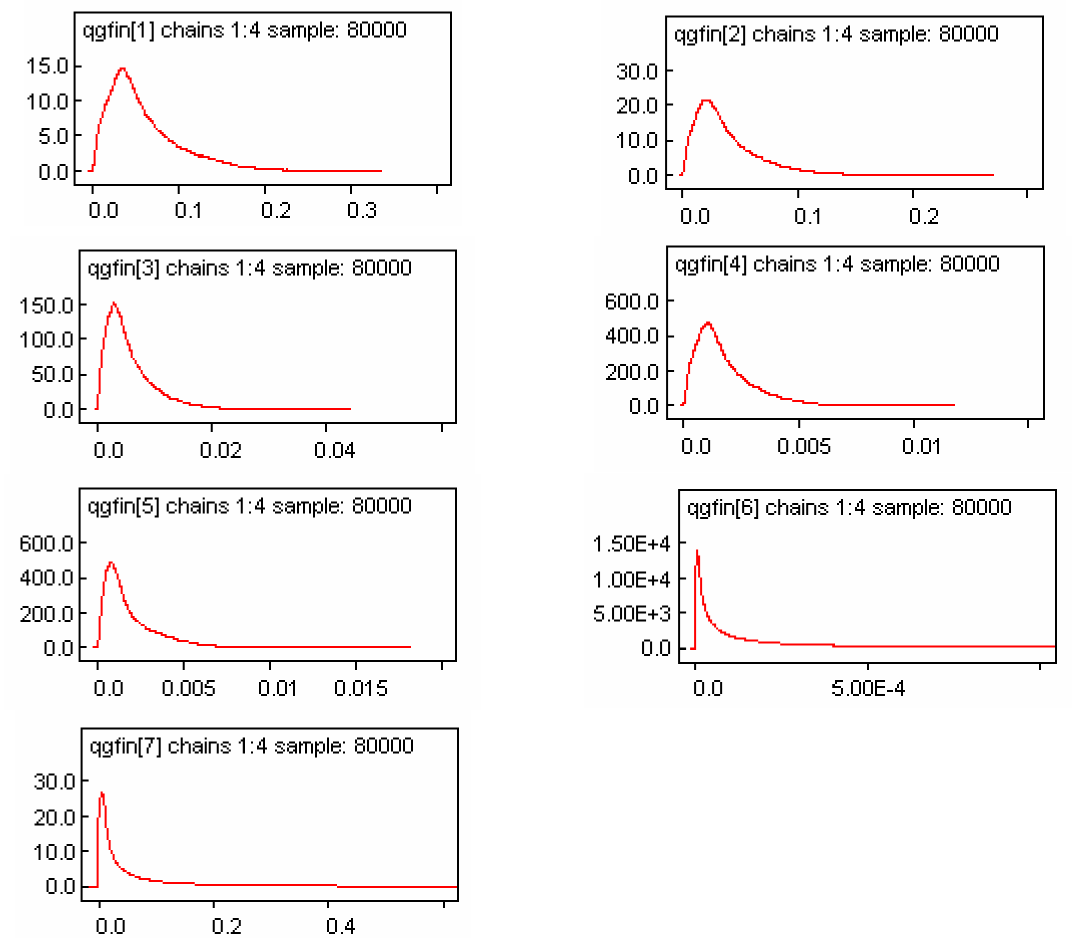


Figure 66. Marginal density functions for *q-gross* for the seven different surveys nets when the uncertainty factor is not applied and Bayesian updating is still applied.

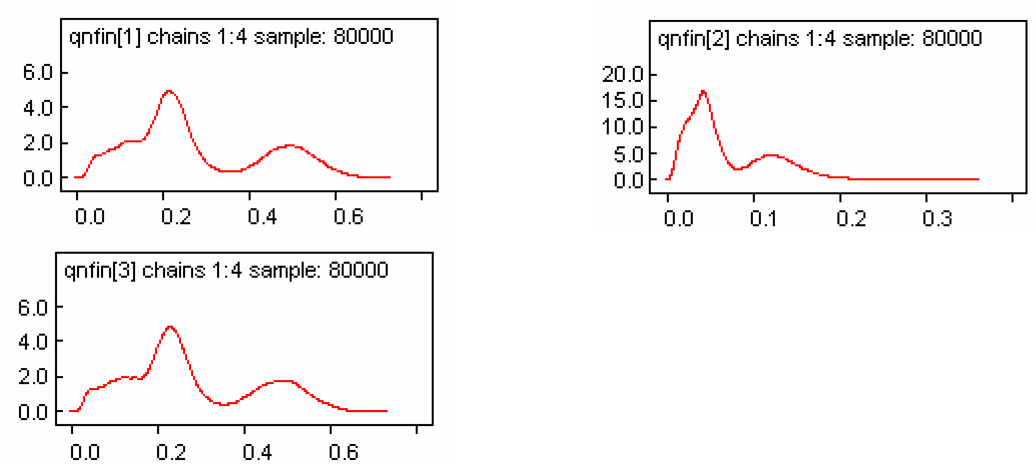


Figure 67. *q-net* output distributions for the AWII (1), shrimp (2), and Nor'Eastern trawl (3) nets when the uncertainty factor is not applied and Bayesian updating is still applied.

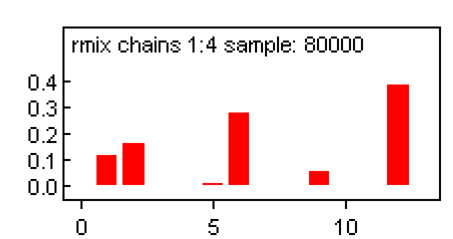


Figure 68. Marginal posteriors placed on the results of each of the 12 different captains based on the Bayesian updating using the catch rate ratio observations for the DFO AWII and shrimp trawl nets when the uncertainty factors are not applied.

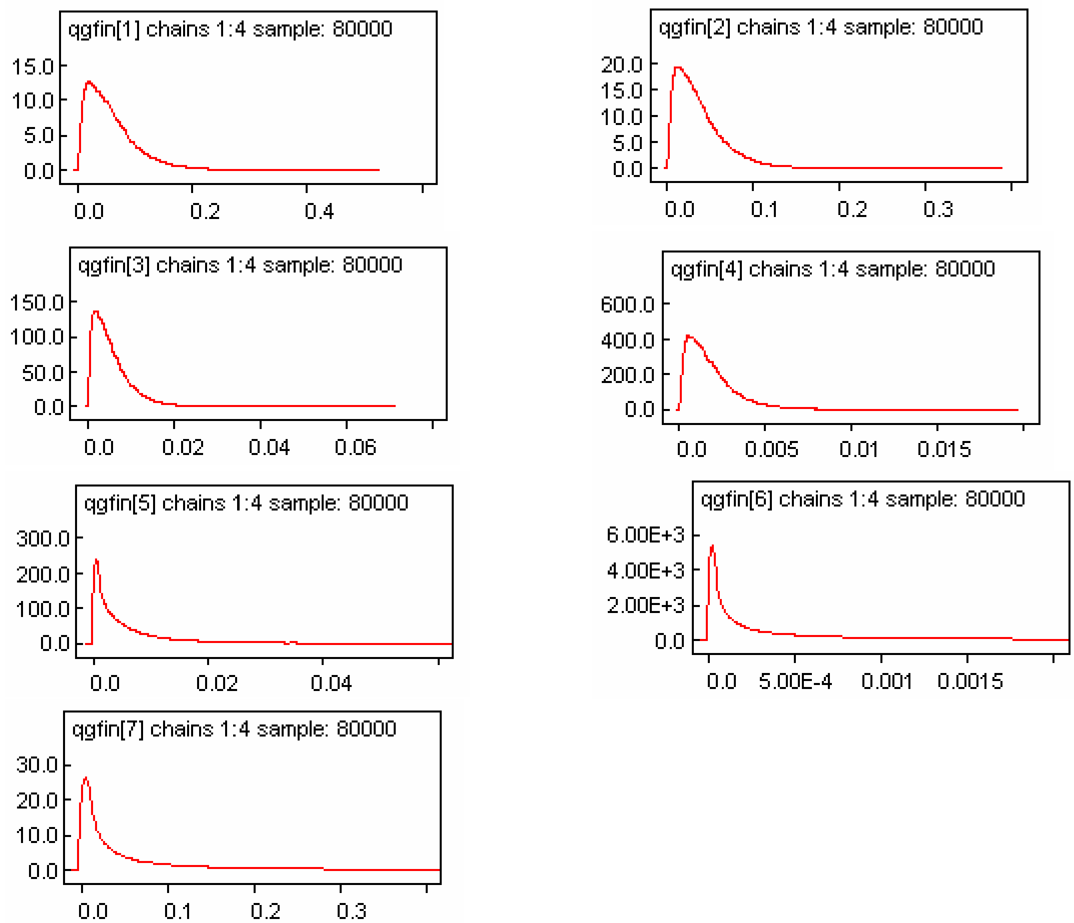


Figure 69. Marginal density functions for *q-gross* for the seven different surveys when the uncertainty factor is applied but there is no Bayesian update with the observed catch rate ratios for the AWII and shrimp trawl nets.

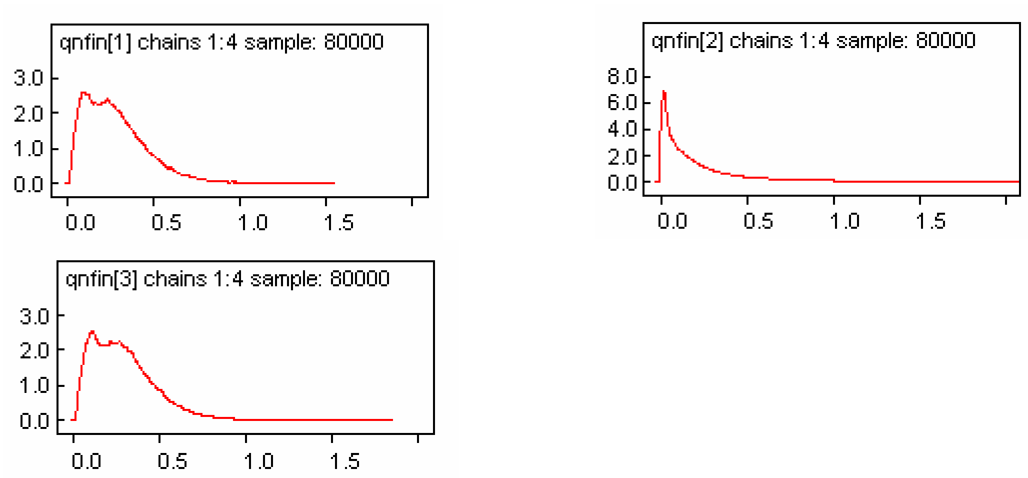


Figure 70. *q-net* output distributions for the AWII (1), shrimp (2) and Nor'Eastern trawl (3) nets when the uncertainty factor is applied but there is no Bayesian update with the observed catch rate ratios for the AWII and shrimp trawl nets

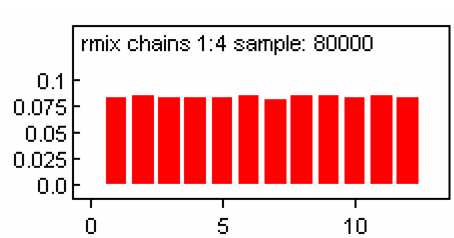


Figure 71. Marginal posteriors placed on the results of each of the 12 different captains based on the Bayesian updating using the catch rate ratio observations for the DFO AWII and shrimp trawl nets when the uncertainty factors are applied and there is no Bayesian update.

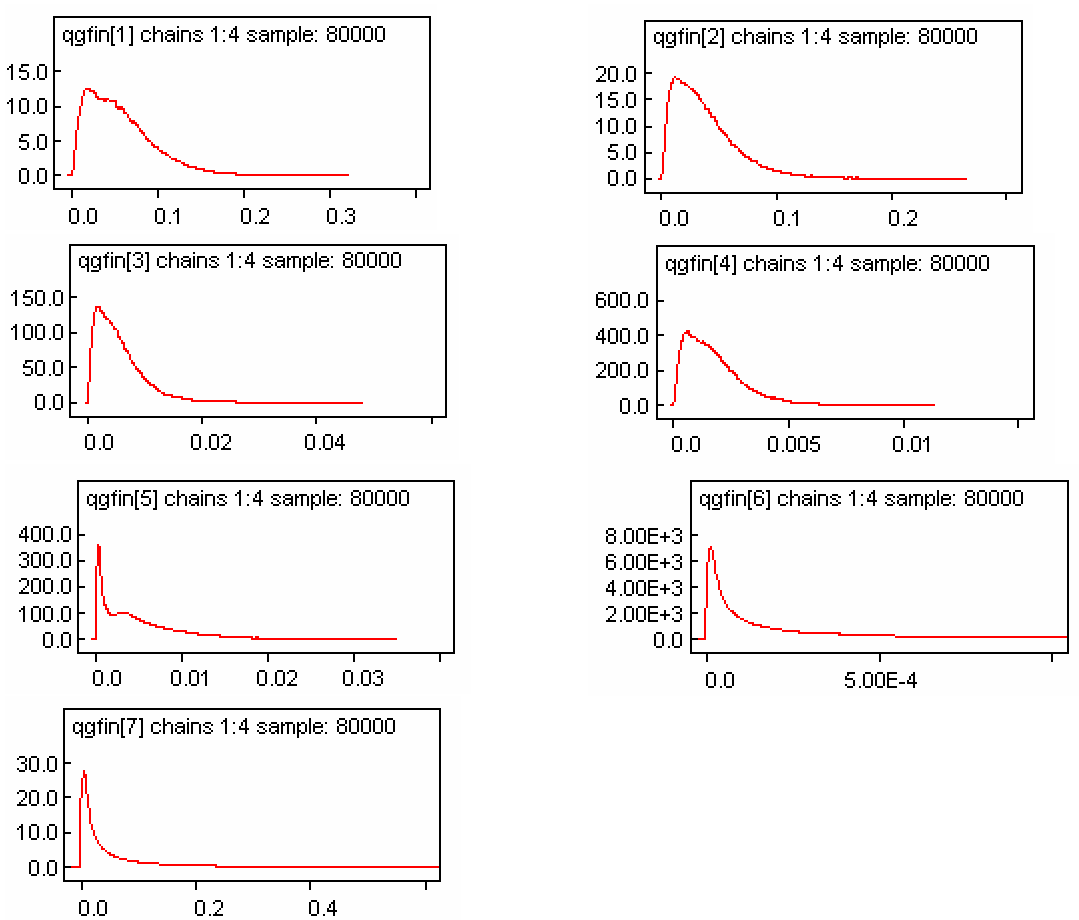


Figure 72. Marginal density functions for *q-gross* for the seven different surveys when the uncertainty factor is not applied and there is no Bayesian update with the observed catch rate ratios for the AWII and shrimp trawl nets.

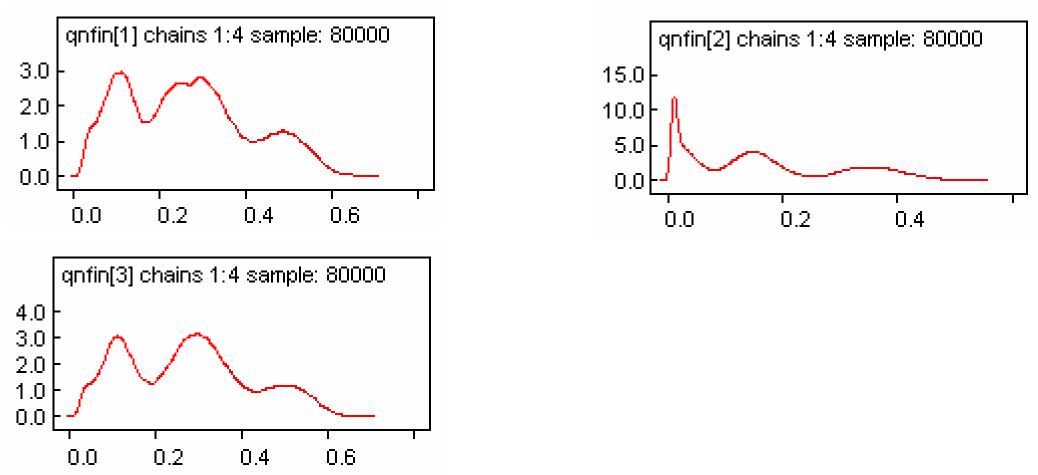


Figure 73. *q-net* output distributions for the AWII (1), shrimp (2) and Nor'Eastern trawl (3) nets when the uncertainty factor is not applied and there is no Bayesian update with the observed catch rate ratios for the AWII and shrimp trawl nets.

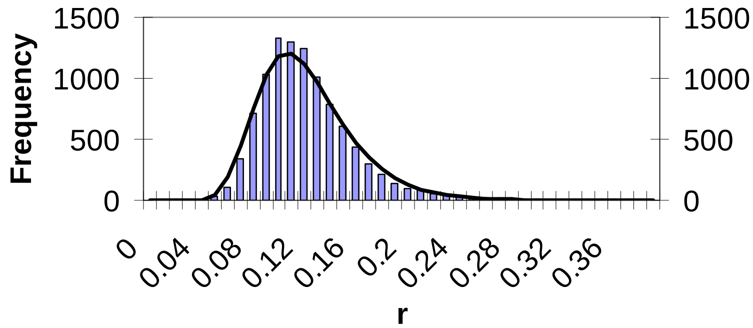


Figure 74. Monte Carlo results from stochastic demographic analysis to compute a prior for *r*. A normal approximation with the same mean and SD as the Monte Carlo results is also shown.

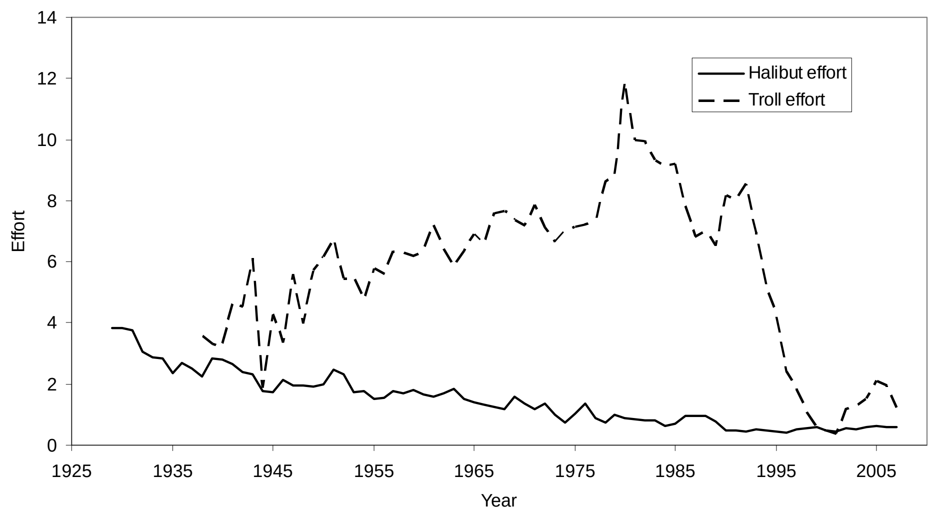


Figure 75. Historic time series of fishing effort in the B.C. halibut and salmon troll fisheries (halibut effort in total skates and troll effort in days fished).

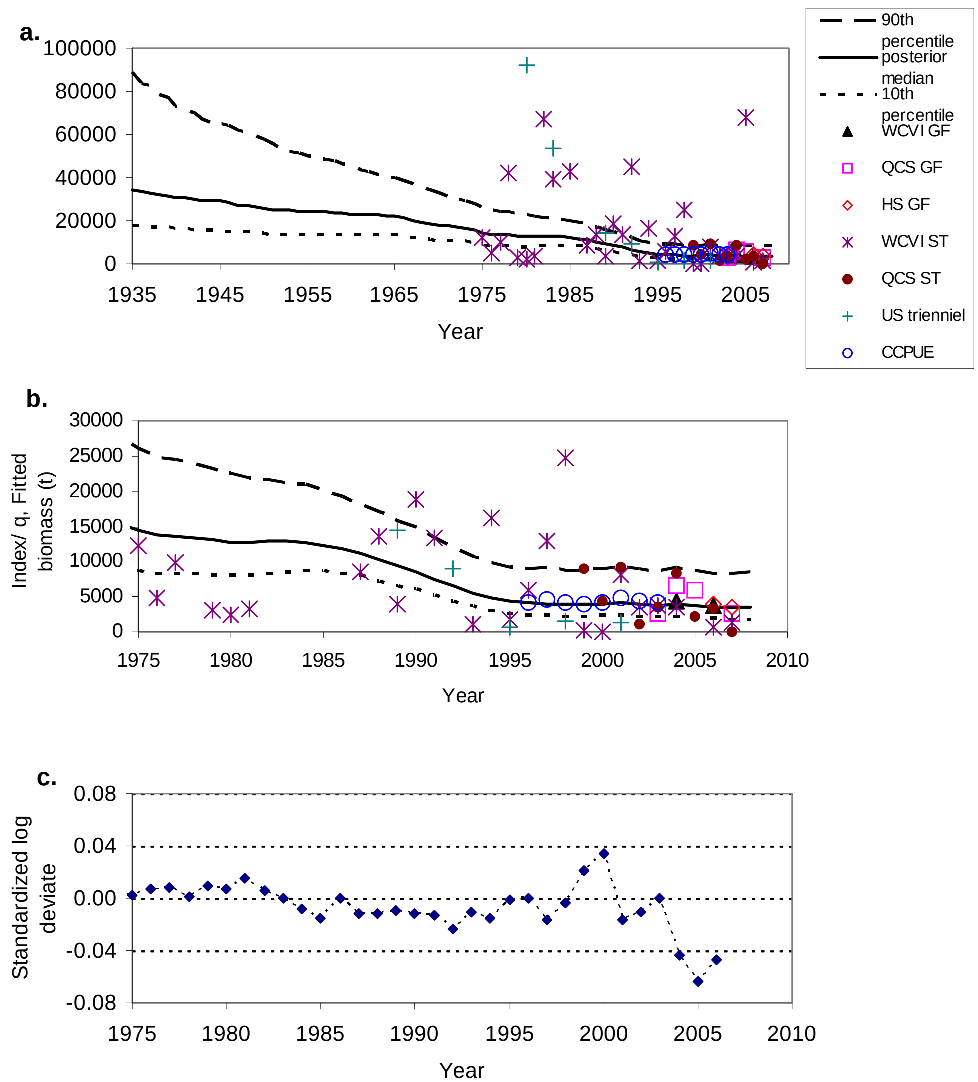


Figure 76. For the reference case, a. posterior median and 80% probability intervals for stock biomass (t), and the stock trend indices divided by their posterior modal value for of constants of proportionality for years 1935-2008, b. the same as a. but with high values cut off and for years from 1975 to 2008; and c. log standardized annual deviates in surplus production for years from 1975 to 2006. WCVI refers to west coast Vancouver Island, TS refers to trawl survey, QCS refers to QCSd, SS refers to synoptic survey, HS refers to Hecate Strait, GF refers to groundfish survey. a. full trend; b. last part, cut off high values.

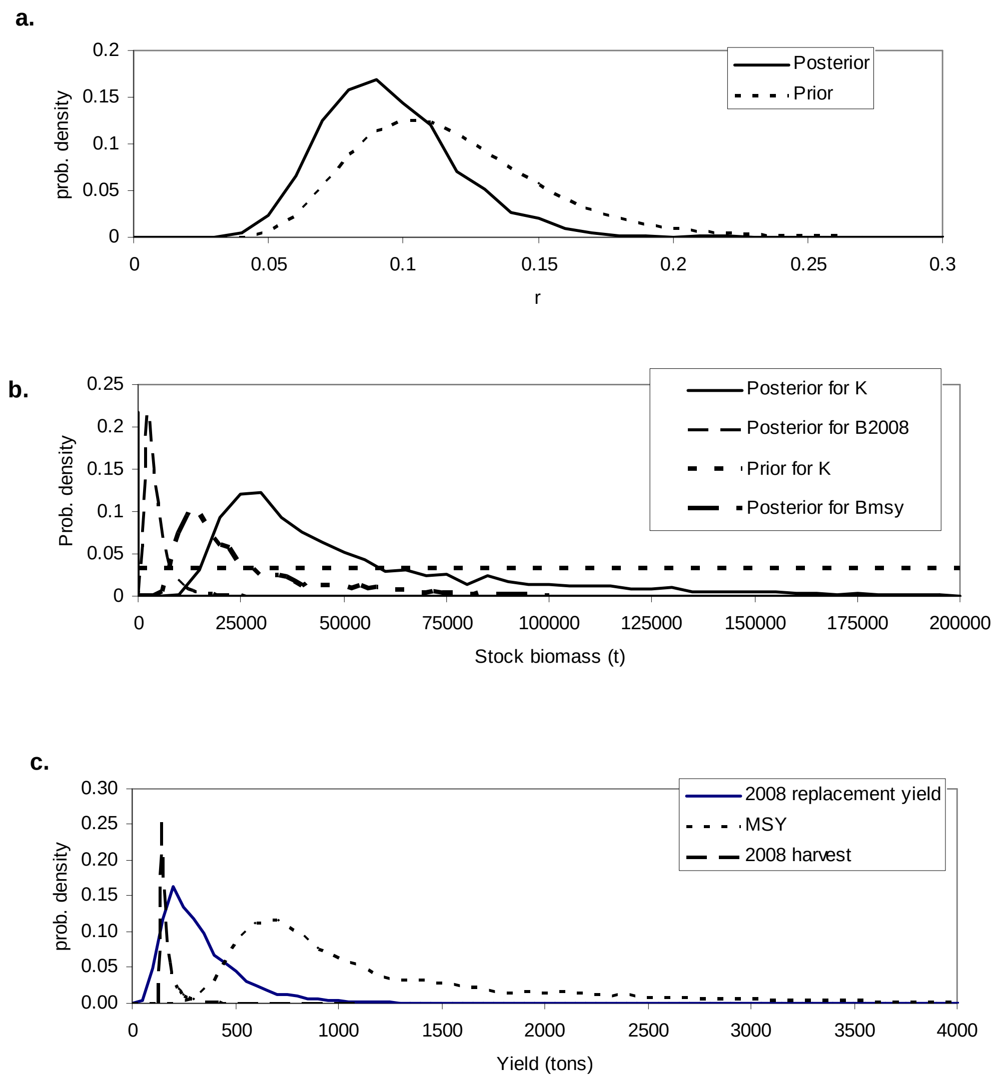


Figure 77. For the reference case the marginal prior and posterior densities for r, stock biomass and yield. a. prior and posteriors for r. b. prior for carrying capacity (*K*) and posteriors for *K*, stock biomass in 2008 (B_{2008}), and B_{MSY}. c. posteriors for *MSY*, 2008 replacement yield, and 2008 harvest (catch in 2008 plus the random variables for halibut and troll catch in 2008).

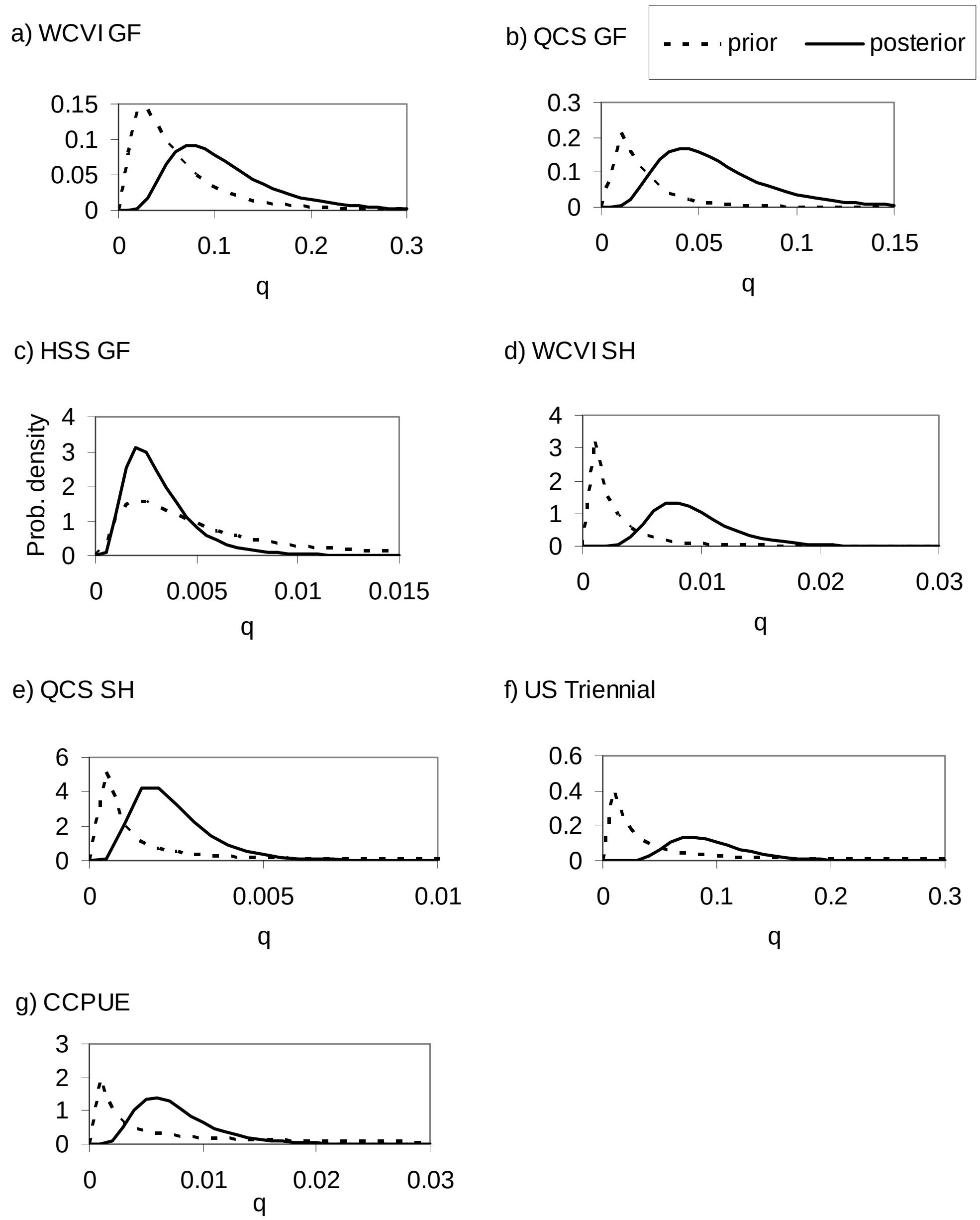


Figure 78. For the reference case, the posterior densities for the constants of proportionality for the survey indices. The posterior densities are computed assuming a lognormal density function using the posterior mean and SD obtained from importance sampling.

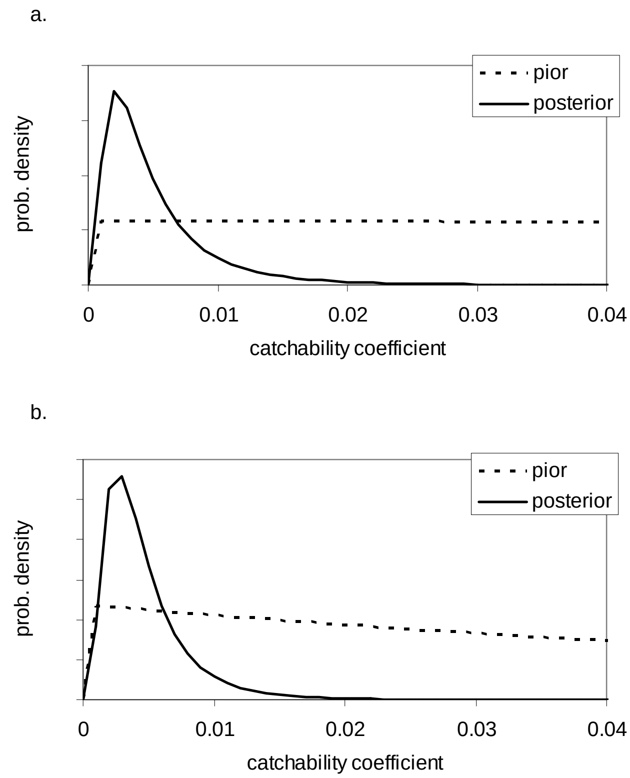
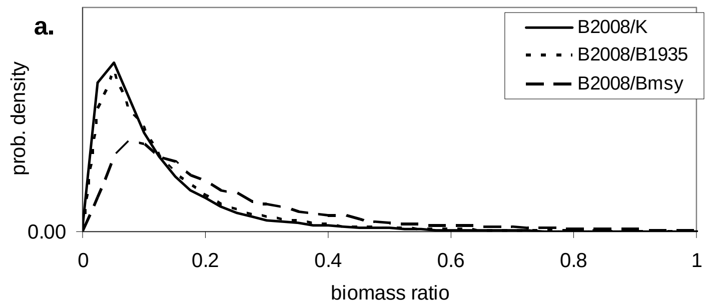


Figure 79. For the reference case, the prior and posterior densities for the catchability coefficients for the a. halibut and b. troll fisheries. The posterior densities are computed assuming a lognormal density function using the posterior mean and SD obtained from importance sampling.

a.



b.

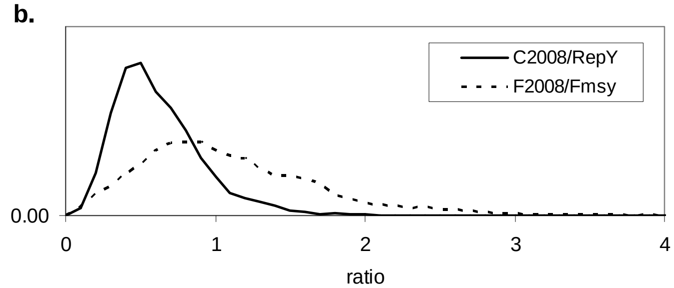


Figure 80. For the reference case, the posterior densities are computed assuming a lognormal density function using the posterior mean and SD obtained from importance sampling

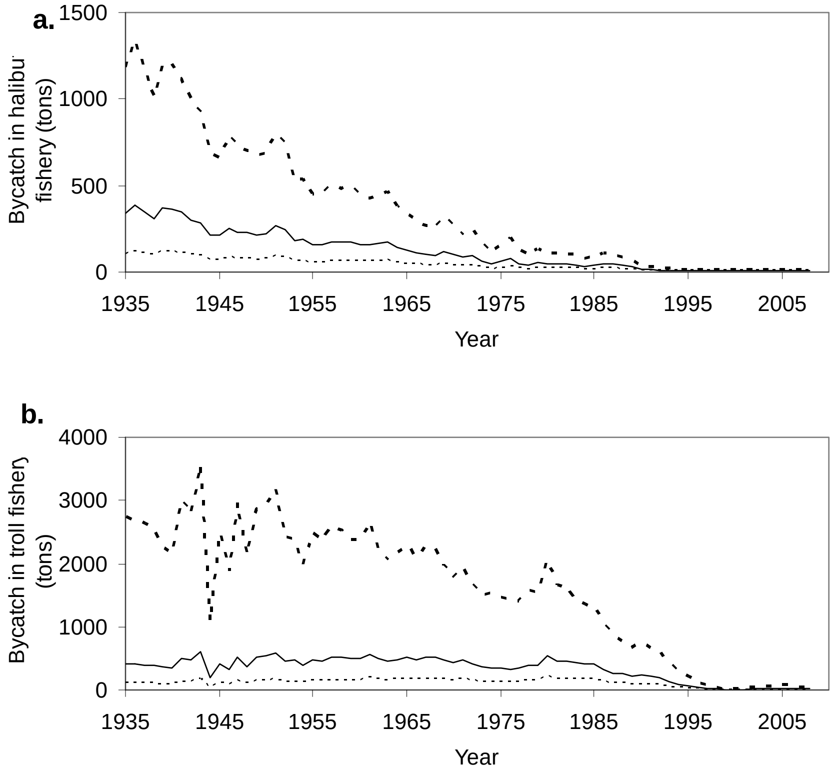
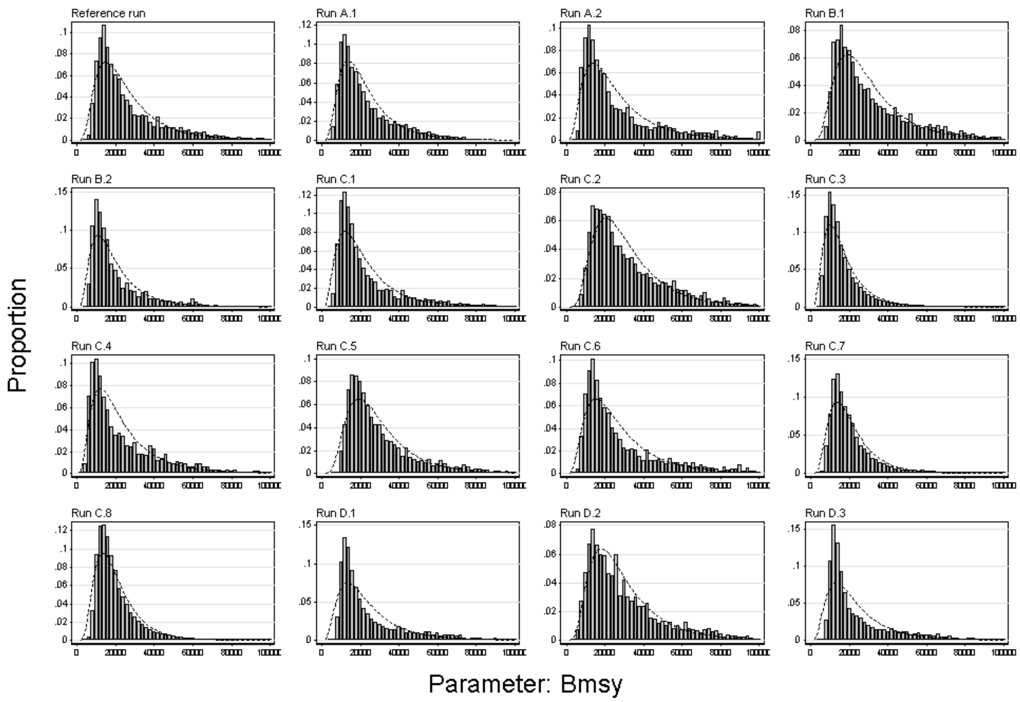


Figure 81. For the reference case, the posterior medians and 80% probability intervals for bocaccio catch in the a. halibut and b. troll fisheries

a.



b.

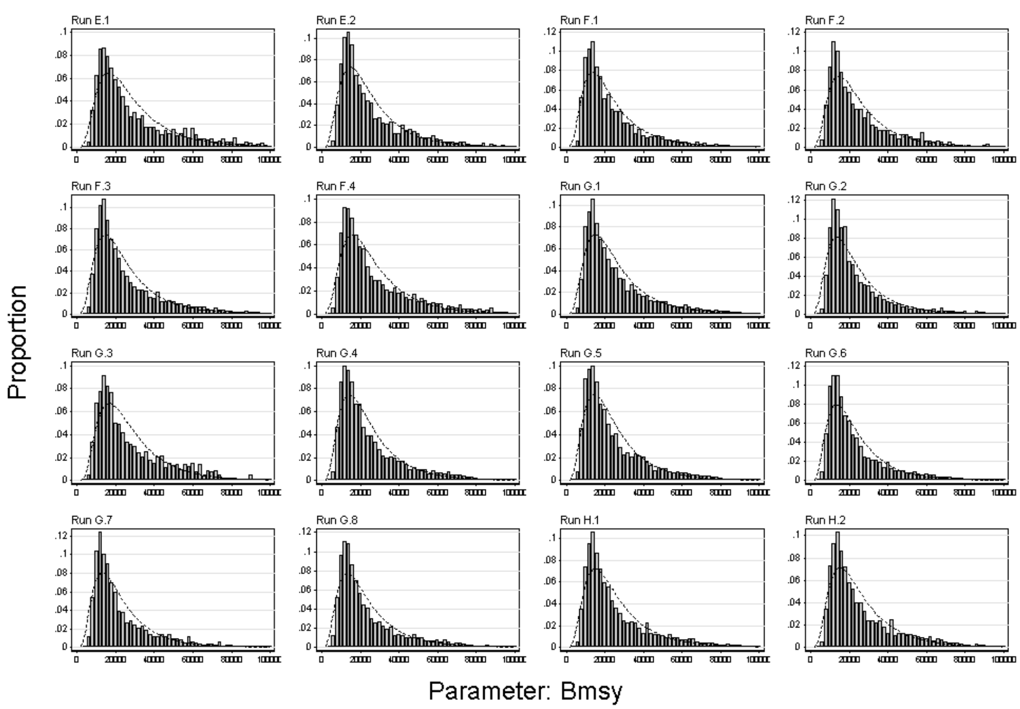
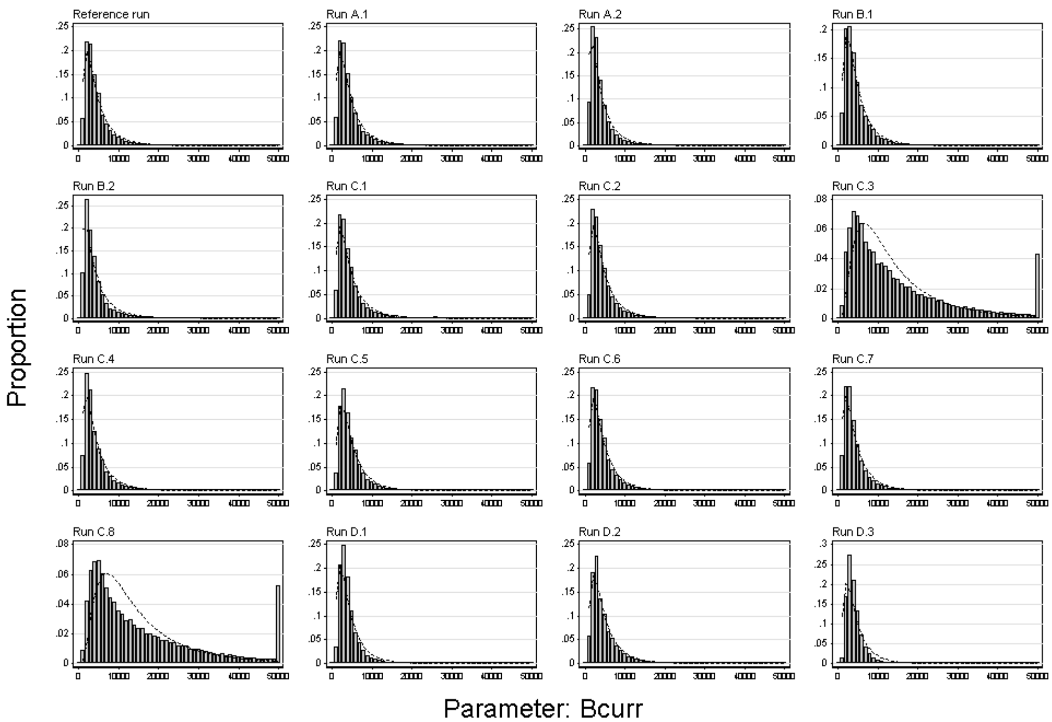


Figure 82. Posterior distributions of the parameter B_{MSY} for a. the reference run and the first 15 sensitivities. b. Posterior distributions of the parameter B_{MSY} for the final 16 sensitivities. Dashed line is a lognormal distribution with same mean and standard deviation as the posterior distribution.

a.



b.

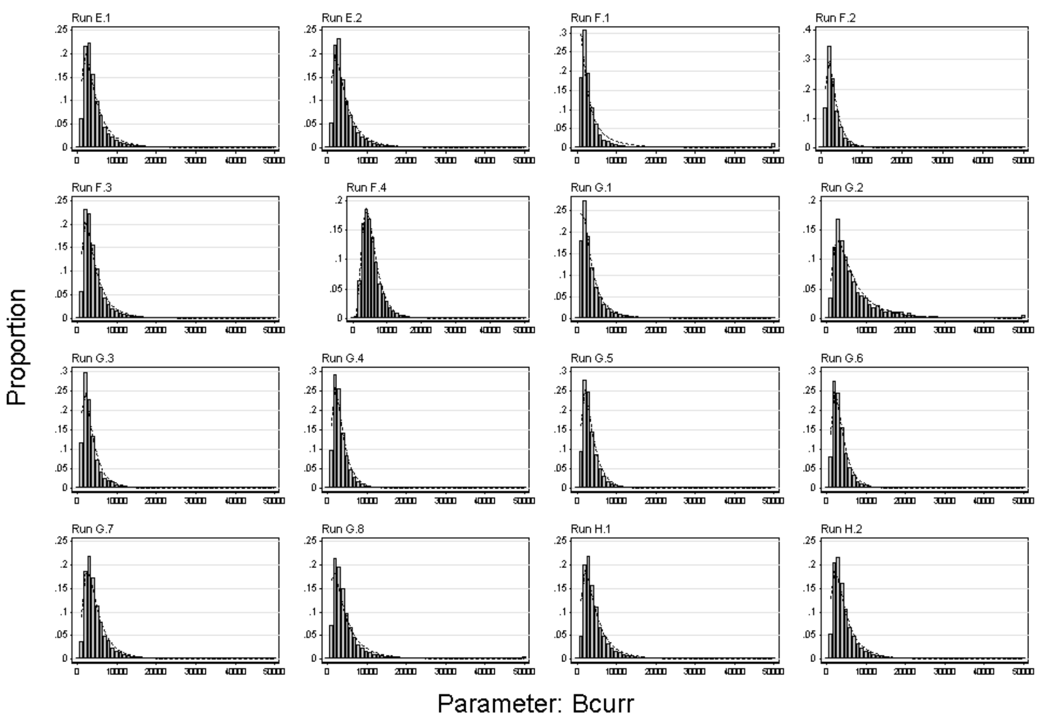
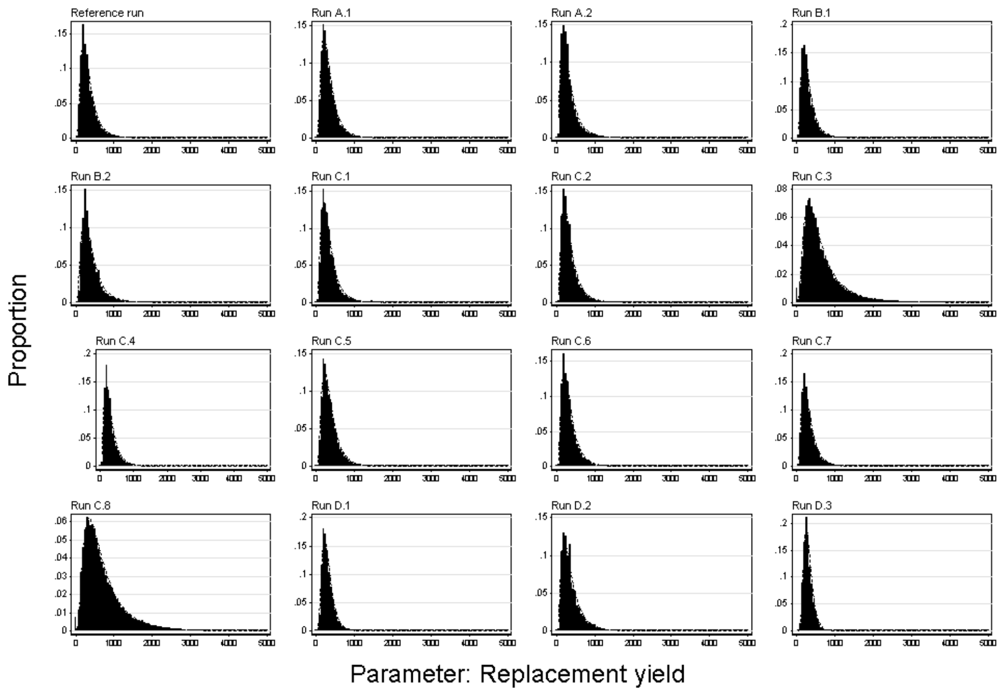


Figure 83. Posterior distributions of the parameter $B_{current}$ for a. the reference run and the first 15 sensitivities. b. the final 16 sensitivities. Dashed line is a lognormal distribution with same mean and standard deviation as the posterior distribution.

a.



b.

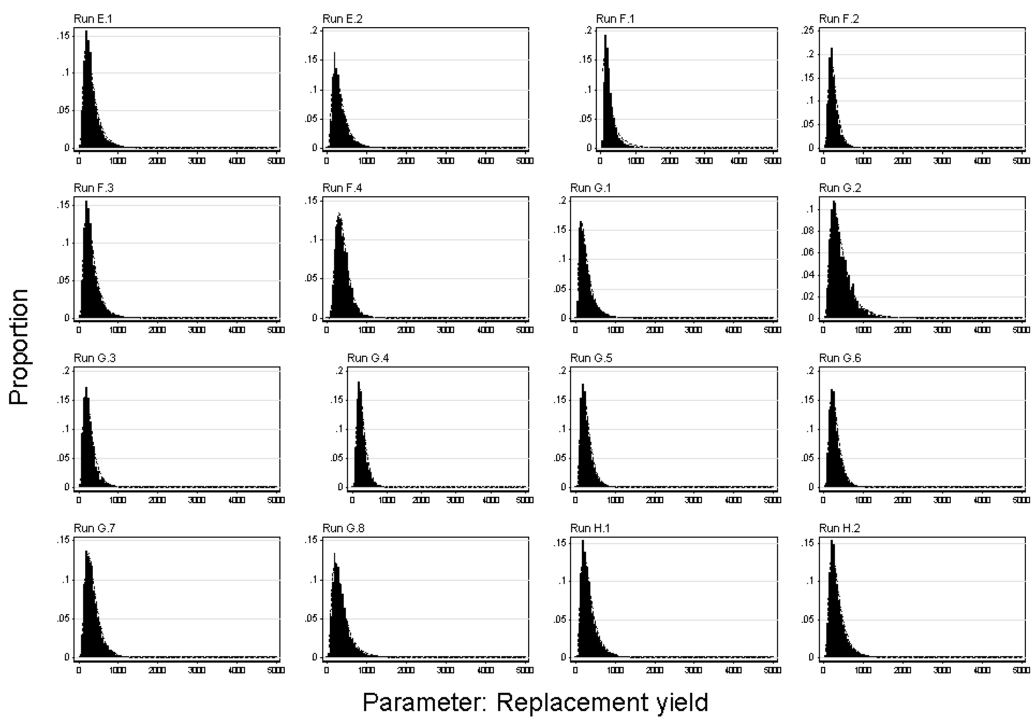
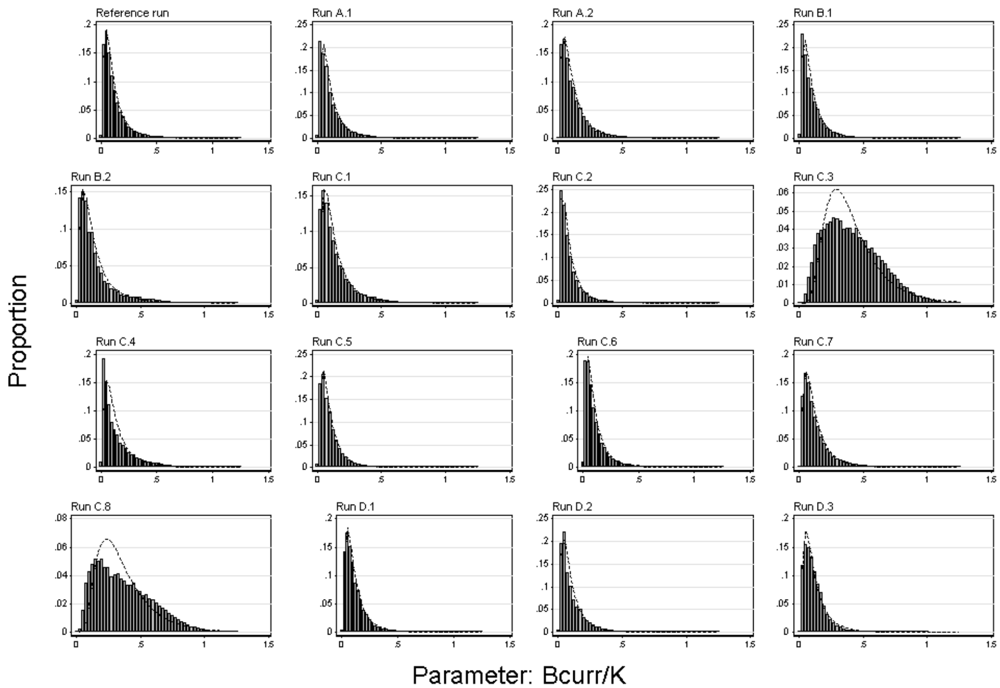


Figure 84. Posterior distributions of the parameter *Replacement_yield* for a. the reference run and the first 15 sensitivities and b. for the final 16 sensitivities. Dashed line is a lognormal distribution with same mean and standard deviation as the posterior distribution.

a.



b.

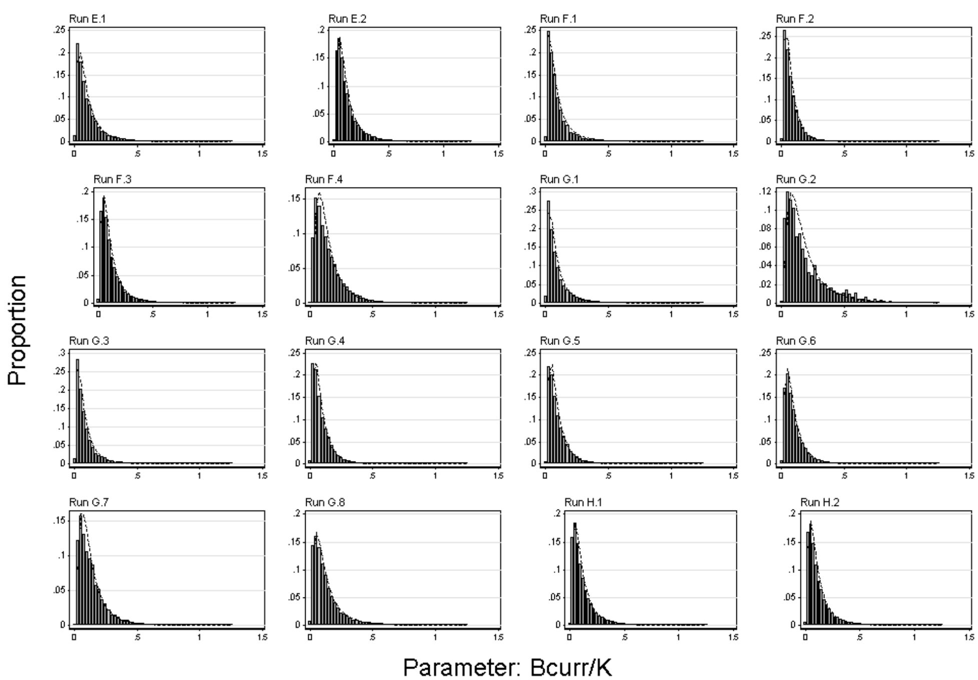
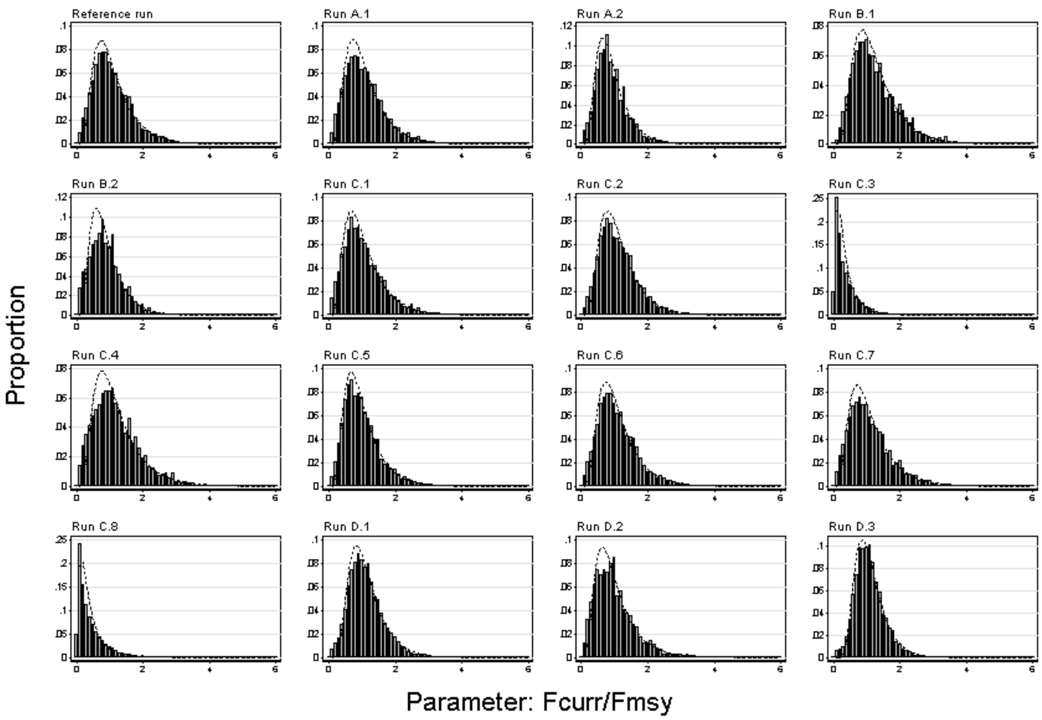


Figure 85. Posterior distributions of parameter $B_{current}/K$ for a. the reference run and the first 15 sensitivities and b. for the final 16 sensitivity runs. Dashed line is a lognormal distribution with same mean and standard deviation as the posterior distribution.

a.



b.

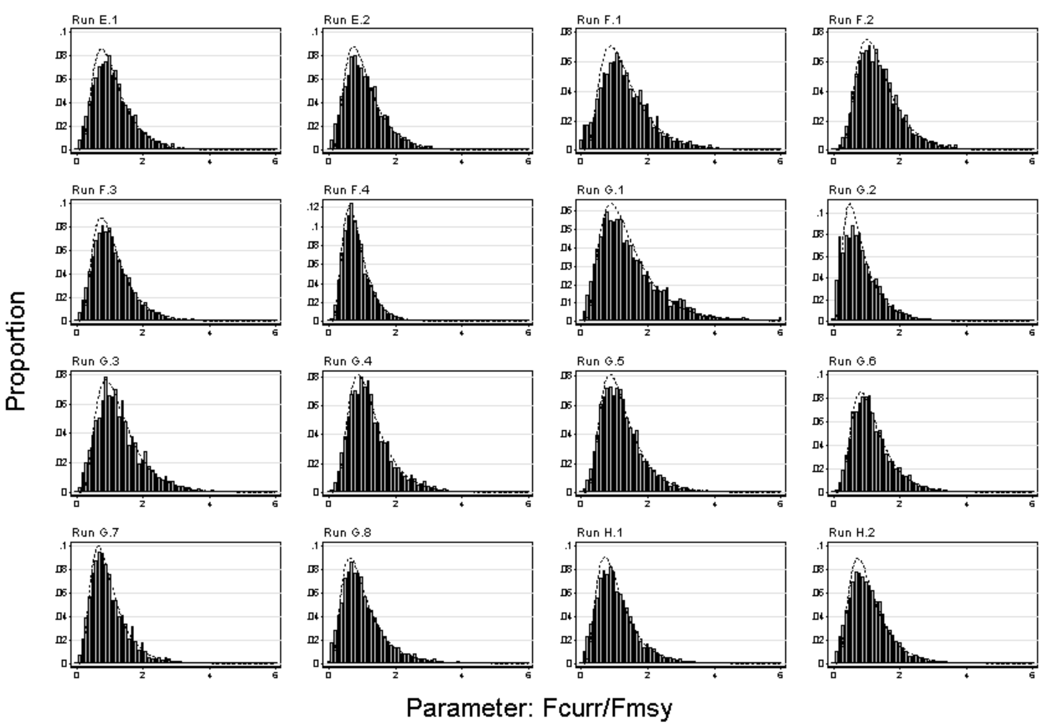
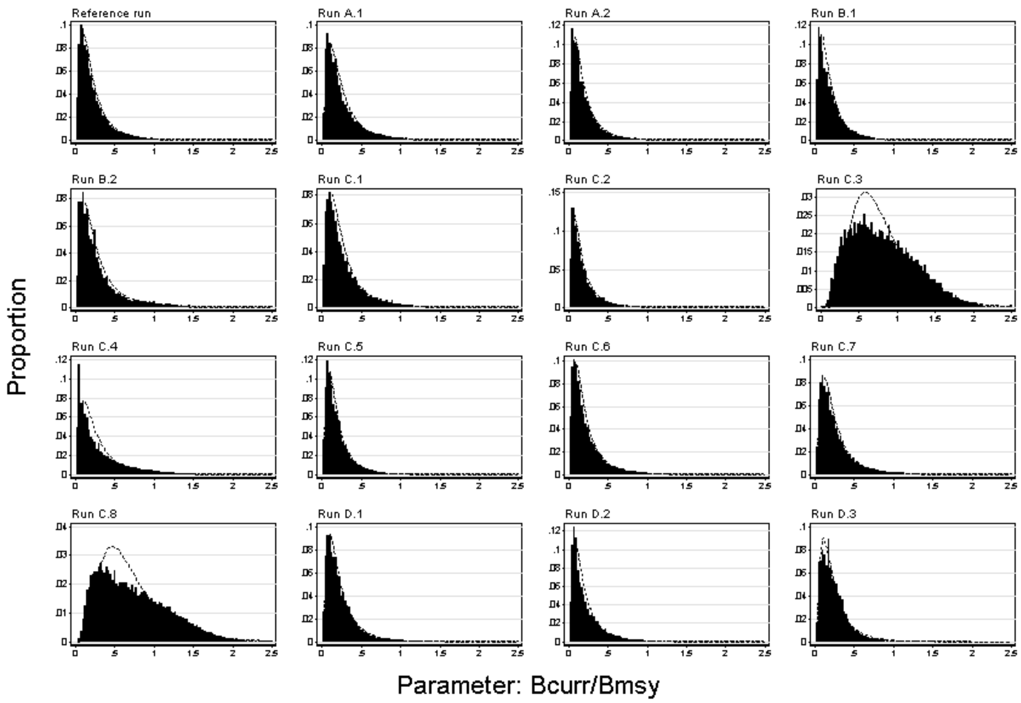


Figure 86. Posterior distributions of the parameter $F_{current}/F_{MSY}$ for a. the reference run and the first 15 sensitivities and b. the final 16 sensitivities. Dashed line is a lognormal distribution with same mean and standard deviation as the posterior distribution.

a.



b.

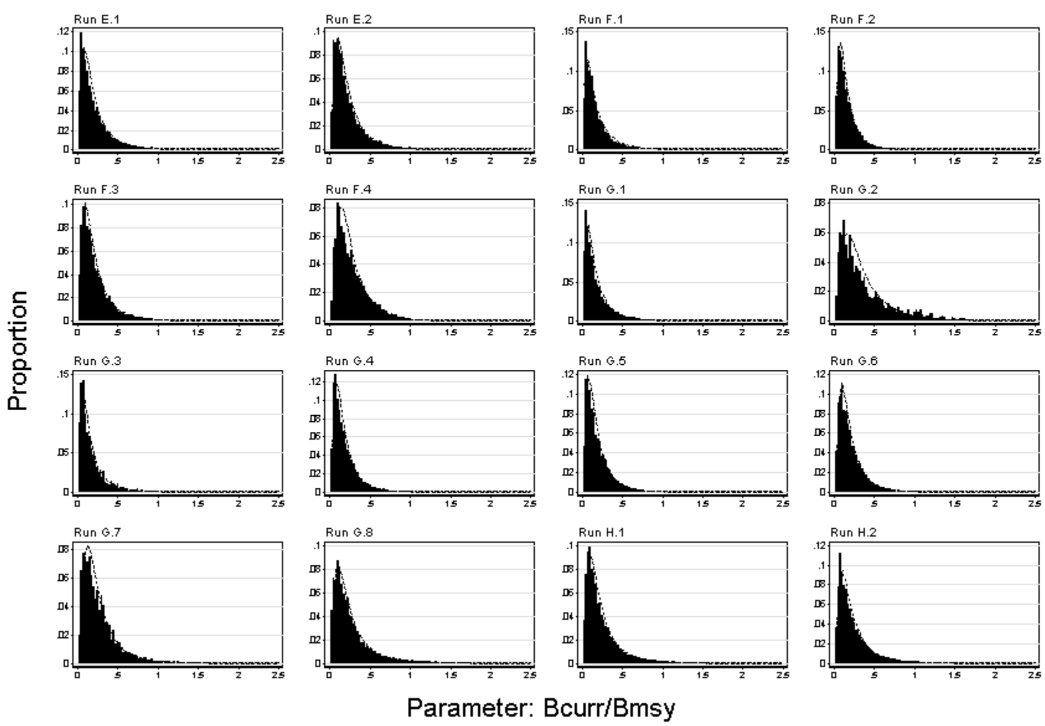
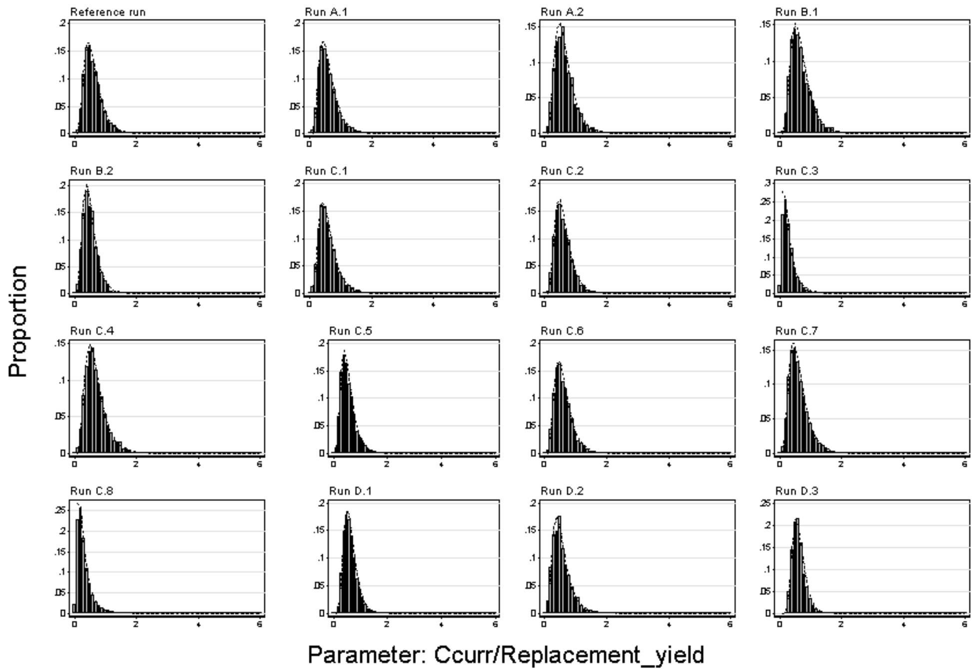


Figure 87. Posterior distributions of the parameter $B_{current}/B_{MSY}$ for a. the reference run and the first 15 sensitivities and b. the final 16 sensitivities. Dashed line is a lognormal distribution with same mean and standard deviation as the posterior distribution.

a.



b.

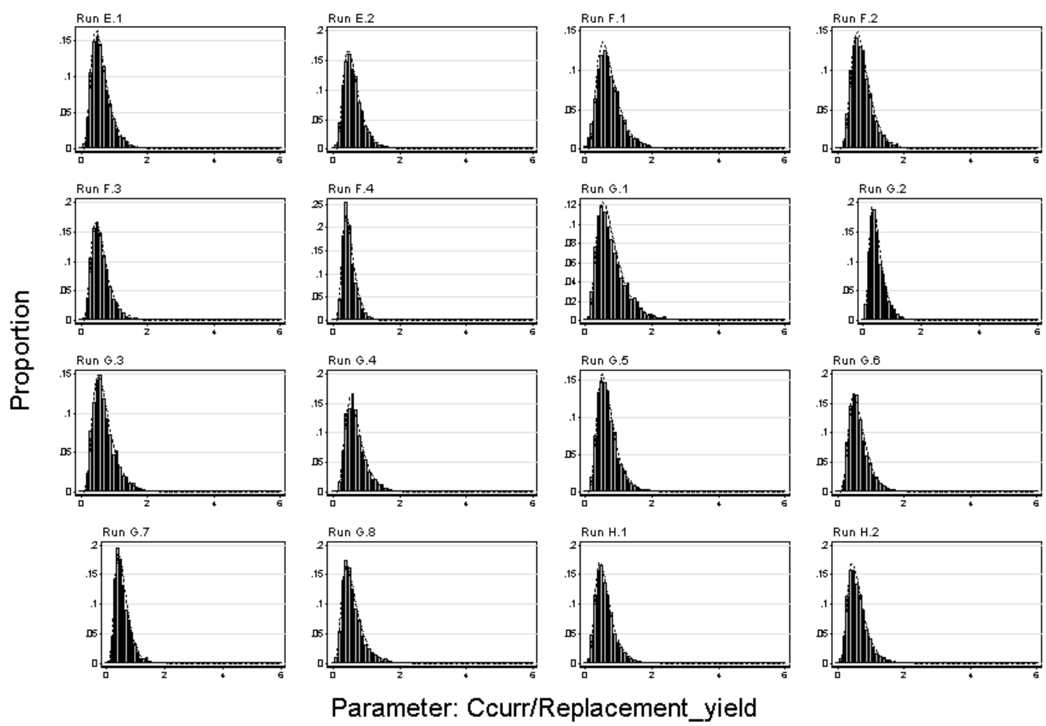
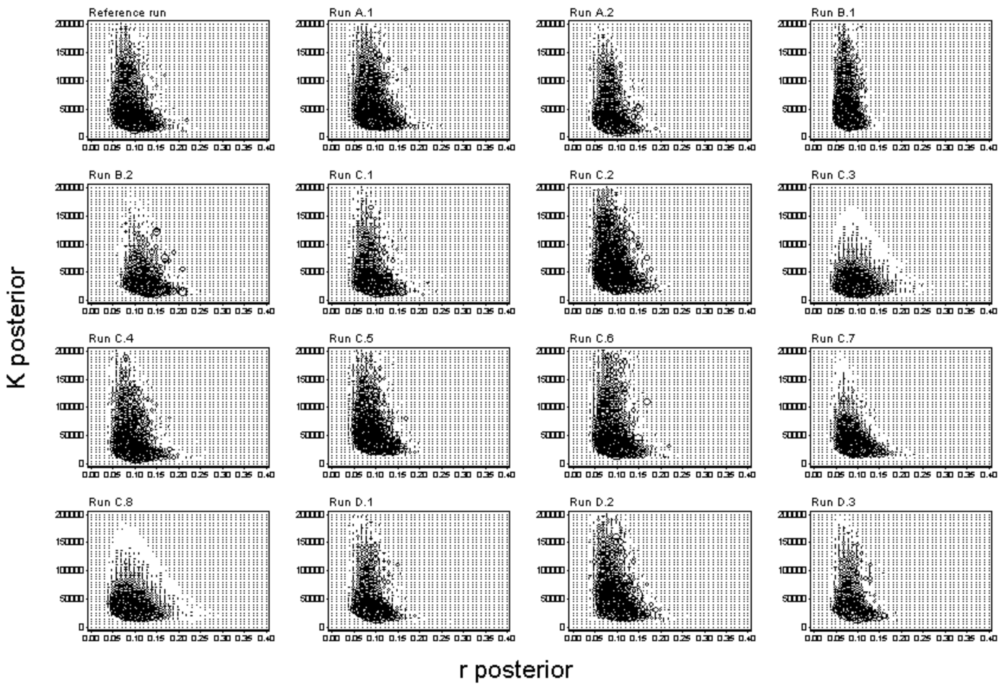


Figure 88. Posterior distributions of the parameter $Catch_{current}/Replacement\_yield$ for a. the reference run and the first 15 sensitivities and b. the final 16 sensitivities. Dashed line is a lognormal distribution with same mean and standard deviation as the posterior distribution.

a.



b.

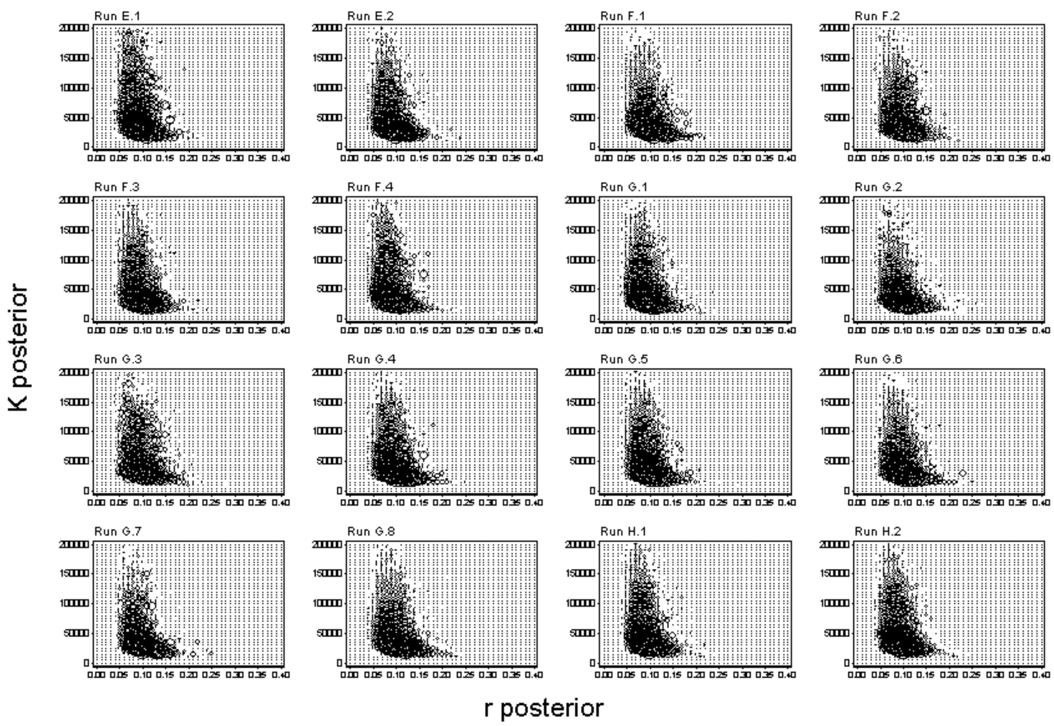


Figure 89. Joint posterior distributions of the *r* and *K* parameters for a. the reference run and the first 15 sensitivities and b. the final 16 sensitivities. Each intersection point is depicted with a hollow circle whose size is proportional to the joint probability of the two parameters**.**

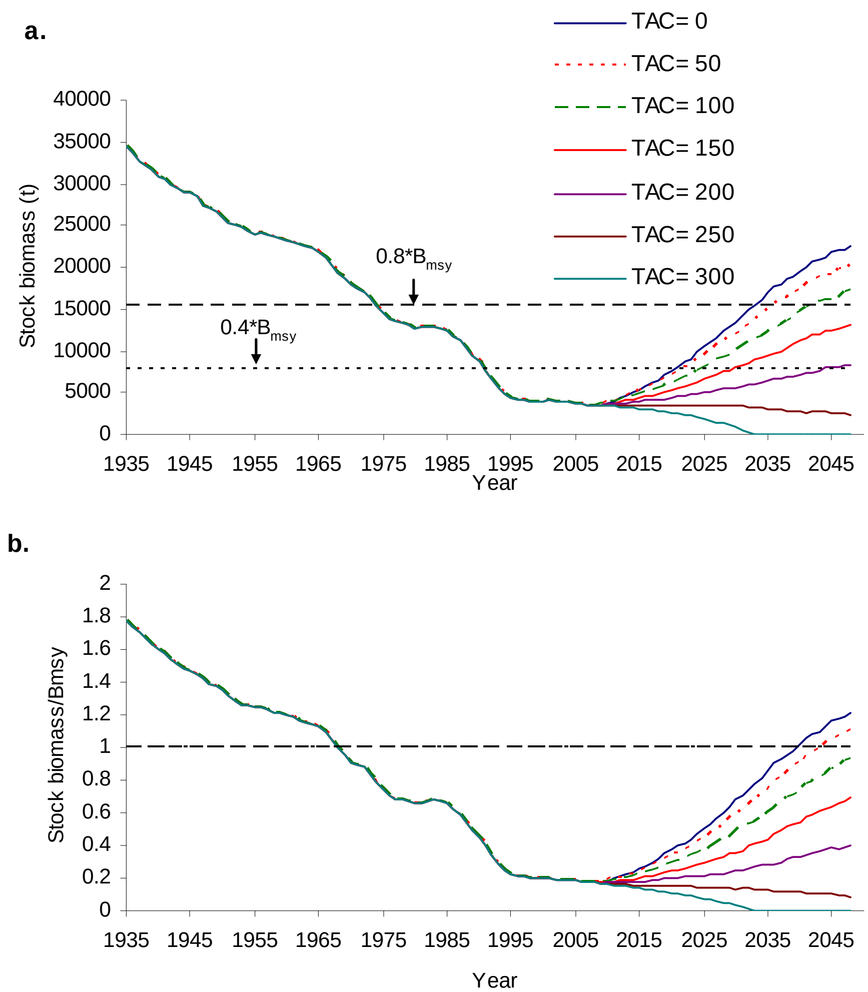


Figure 90. Reference case median stock projections of a. stock biomass relative to $0.4*B_{MSY}$ and $0.8*B_{MSY}$ and b. B/B_{MSY} for years from 2009-2048 are shown for several different constant TAC policies (in tons).

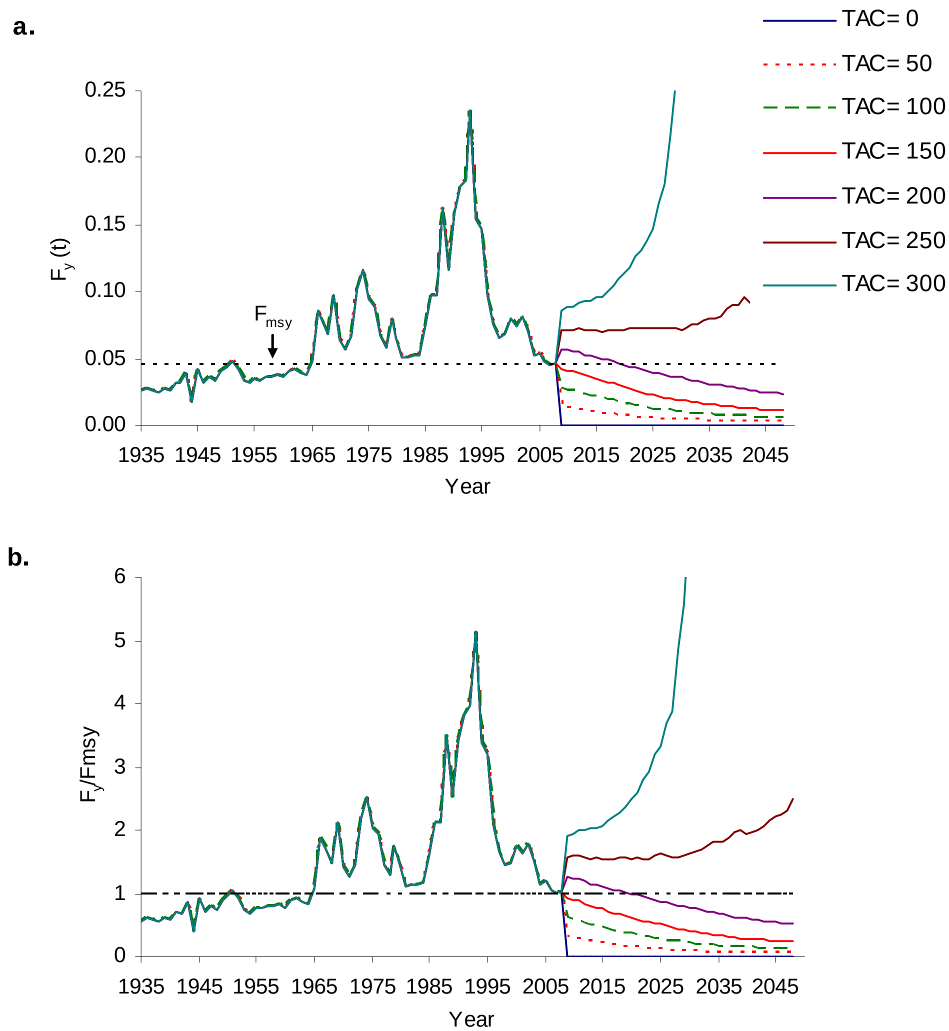


Figure 91. Reference case median stock projections of a. annual fishing mortality rate, F_y, relative to F_{MSY} and b. F_y/F_{MSY} for years from 2009-2048 are shown for several different constant TAC policies (in tons).