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Updated stock assessment for Bocaccio (*Sebastes paucispinis*) in British Columbia waters for 2012

Mise à jour de l'évaluation des stocks de bocaccio (*Sebastes paucispinis*) dans les eaux de la Colombie-Britannique en 2012

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ABSTRACT

This document provides a stock assessment for Bocaccio in British Columbia waters using data current to 2011. Results of the work are intended to serve as advice over the short term to managers and stakeholders on current stock status, and likely impacts of different harvest options. As in previous work, a Bayesian surplus production model was used. It was fit to one fishery dependent and eight fishery independent biomass indices, and a reconstructed catch history back to 1935 when the population was assumed to be near to an unfished equilibrium. Catch histories for some sectors were imputed from limited data. For the first time in a Bocaccio assessment, recreational catch was included as in input to the model. As in the previous work, this analysis indicates that Bocaccio exploitable stock biomass has declined significantly from the 1930s, with the steepest decline occurring from 1985 to 1995. The rate of decline slowed after 1995. While there is considerable uncertainty in estimating recent trends, there is no sign that the population has started to increase, and, more than likely, has continued to decline in the most recent decade. Based on the reference case results, the median estimate of stock size relative to its unfished stock size (B_{2012}/K) is 3.5%. The median estimate of current abundance relative to B_{msy} (biomass at maximum sustainable yield) is 7.0% with 90% confidence limits of 2.9% and 18.2% leaving little or no likelihood that the stock is currently above the lower Precautionary Approach reference point of $0.4*B_{msy}$, based on the reference case. Current harvests are approximately equal to the estimate of replacement yield. The impacts of alternative model assumptions from those used in the reference case were explored in 18 additional sensitivity runs but these results were similar to those of the reference case. Long term biomass projections were made for the reference case and a selection of the sensitivity runs over 5, 20, and 60 year scenarios under varying fixed harvest assumptions from 0-200 t/y. Results of the forecasts were presented relative to the DFO draft policy target references points of $0.4*B_{msy}$ and $0.8*B_{msy}$. 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 herein.

RÉSUMÉ

Le présent document contient une évaluation des stocks de bocaccio dans les eaux de la Colombie-Britannique, réalisée à partir de données de 2011. Les résultats du travail serviront aux gestionnaires et aux intervenants d'avis à court terme à propos de l'état actuel du stock et des effets probables des différents niveaux de prélèvement. Comme dans les travaux précédents, un modèle bayésien de production excédentaire a été employé. Il a été ajusté à partir d'un indice de biomasse dépendant de la pêche et de huit indices indépendants de l’indice de la biomasse, ainsi que des données de captures reconstituées de l'année 1935, à laquelle la population aurait été non exploitée et proche d'un équilibre naturel. Les données historiques sur les prises de certains secteurs ont été imputées à partir d'une information limitée. Pour la première fois dans une évaluation des stocks de bocaccio, la pêche récréative a été incluse dans les intrants du modèle. Comme le travail précédent, cette analyse montre que la biomasse du stock exploitable de bocaccio a considérablement diminué depuis les années 1930 et enregistré une chute brutale de 1985 à 1995. Le taux de déclin a ralenti après 1995. Malgré d'importantes incertitudes quant à l'estimation des tendances récentes, aucun signe n'indique un début de croissance de la population et cette dernière a, plus probablement, continué de décliner pendant la décennie passée. Compte tenu des résultats du scénario de référence, la médiane estimée de la taille du stock par rapport à la taille du stock non exploité (B_{2012}/K) est de 3,5 %. La médiane estimée de l'abondance relative actuelle par rapport à la B_{rms} (biomasse au rendement maximal soutenu) est de 7 %, avec des limites de confiance de 90 % à 2,9 % et 18,2 %, ce qui rend peu ou pas probable que le stock soit actuellement au-dessus du point de référence de l'approche de précaution, établi à $0,4*B_{rms}$ à partir du scénario de référence. Les captures actuelles sont à peu près égales au rendement de remplacement estimé. Les effets d'autres hypothèses du modèle que celles utilisées dans le scénario de référence ont été examinés dans 18 exécutions supplémentaires du modèle aux fins d'analyse de la sensibilité. Les résultats obtenus sont similaires à ceux du scénario de référence. Des projections à long terme de la biomasse ont été réalisées pour le scénario de référence et certaines des exécutions aux fins d'analyse de la sensibilité sur une période de 5, 20 et 60 ans, pour différentes hypothèses de prélèvement fixe variant de 0 à 200 tonnes/an. Les résultats des prévisions ont été présentés en comparaison des points de référence cibles de l'ébauche de politique du MPO, établis à $0,4*B_{rms}$ et $0,8*B_{rms}$. Bien que l'approche bayésienne utilisée dans le cadre de la présente évaluation offre un mécanisme formel pour inclure les incertitudes dans les résultats du modèle (y compris les prévisions), les gestionnaires et les intervenants doivent savoir que toutes les sources d'incertitude n'ont pas été étudiées et qu'il est probable que le degré d'incertitude réel soit plus important qu'il n'est indiqué dans le présent document.

1 INTRODUCTION

1.1 CONTEXT

In January, 2004, the Minister of the Environment received a document on Bocaccio (*Sebastes paucispinis*) from the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). This document assessed the Bocaccio population in British Columbia (BC) waters as "threatened" (COSEWIC 2002). This prompted the Department of Fisheries and Oceans Canada (DFO) to conduct extended consultations with the government of BC, Aboriginal peoples, stakeholders, and the public on whether or not the Bocaccio population should be added to the List of Wildlife Species at Risk (Schedule 1) under the Species at Risk Act (SARA). Results of these consultations led the Governor in Council, through the Minister of the Environment, to refer the assessment back to COSEWIC in April 2006 for further information and consideration[1].

In December 2006, COSEWIC reaffirmed the original assessment without reassessing the species, citing an absence of new information that would lead to a change in the status of this species. In 2010, the Government of Canada, on the recommendation of the Minister of the Environment, acknowledged receipt of the COSEWIC Bocaccio assessment conducted under subsection 23(1) of SARA.

Following extensive review, the Governor in Council decided in 2011 not to add Bocaccio to the List of Wildlife Species at Risk. This decision was based on the recommendation of the Minister of the Environment and advice from the Minister of Fisheries and Oceans, taking into account the assessments provided by COSEWIC and those provided by DFO (DFO 2009a, Stanley et al. 2009a). It was determined that the costs of protection under SARA would likely outweigh the benefits to Canadians. However, the statement noted that protective measures would be taken under existing legislative tools such as the *Fisheries Act*, as well as non-legislative tools such as government programs and actions by non-governmental organizations.

Among the steps taken to provide protection to the Bocaccio population, an updated DFO assessment of Bocaccio was scheduled for 2011. In addition to updating the advice and enhancing the analysis, it would coincide with a COSEWIC re-assessment scheduled for 2011-2012.

1.2 OBJECTIVES

This assessment updates the previous Bocaccio assessment which used data current to 2007 (DFO 2009a, Stanley et al. 2009a). We refer readers to those documents for many of the background details on distribution, basic biology, data inputs, and modelling details. The basic objectives of this document are to:

- update the previous assessment with four more years of data (2008-2011);
- enhance the previous model;
- provide, with rationale, a Limit Reference Point, an Upper Stock Reference, guided by the DFO Sustainable Fisheries Framework (DFO 2009b);
- assess the status of the stock relative to the recommended reference points;
- predict the consequences of varying harvest levels on future population trends.

[1] Species at Risk Public Registry page for Bocaccio (including links to recommendations and decisions): http://www.sararegistry.gc.ca/species/speciesDetails_e.cfm?sid=740

The resulting information and advice may be used to assist development of groundfish management plans.

2 STOCK STRUCTURE

Consistent with previous documents, we treat Bocaccio as a single coastwide stock in BC waters. From the most recent US assessment of Bocaccio, Field 2011 notes that:

> "*from a population genetic perspective, all Bocaccio from British Columbia, Canada to Baja, Mexico, should probably be considered to be a single, panmictic unit*".

Buonaccorsi et al. (2012) note:

> *"We maintain that there is not enough evidence to reject the single homogeneous gene pool hypothesis for bocaccio rockfish… The lack of genetic divergence in this study does not support subdivision of the species' range into separate management units, but does not necessarily refute division as moderate levels of population exchange may be sufficient to homogenize allele frequencies (e.g. Buonaccorsi et al. 2001), yet may not be sufficient for populations to quickly recolonize extirpated areas…*
>
> *…The findings of this study are concordant with an early allozyme study of bocaccio stock structure from southern to northern California which detected no significant allele frequency differences at two polymorphic loci (Wishard et al. 1980)…*

We note that Bocaccio in the Puget Sound/Georgia Basin is considered by US sources as a "distinct population segment", based on life-history, environmental, ecological, and genetic information (Drake et al. 2010). The genetics conclusion is based on observations on "sister" species (Alexandra Valentin, COSEWIC, personal communication, 2012).

Field et al. (2009) note in the 2009 US assessment that:

> *"The National Marine Fisheries Service (NMFS) recently issued a proposed rule (and request for comment) to list the population of Bocaccio in the Georgia Basin (Puget Sound, Washington and the Strait of Georgia in BC as endangered (at high risk of extinction) under the Endangered Species Act (ESA). This proposed rule came about as a result of a petition to enlist this and several other population units of rockfish in this region (the other four species were canary, yelloweye, greenstriped and redstripe rockfish). Of these five only bocaccio is proposed to be listed as endangered…*
>
> *The proposed rule is based on the evaluation of abundance trends, spatial structure of the populations, and the suite of somewhat unique threats in this ecosystem. Among the factors related directly to bocaccio are the rapid decline and current total absence of bocaccio in recreational rockfish catches within the Georgia Basin (consistent with a substantial overall decline in the catch rates of all rockfish, but of a greater magnitude), the highly variable nature of bocaccio recruitment, and the observation that historical length composition data were indicative of multiple strong cohorts (interpreted as evidence that fish present in the ecosystem were unlikely to be infrequent strays from the coastal population).***"**

Our interpretation of the COSEWIC guidelines for recognizing Designatable Units (Guidelines for Recognizing Designatable Units: http://www.cosewic.gc.ca/eng/sct2/sct2_5_e.cfm) is that the US work provides only a partial justification for assuming a separate Puget Sound/Georgia Basin population. Certainly no genetics research work has been conducted on this issue, nor are there any biological data for the BC portion of this area for comparing life history parameters.

Presumably, the virtual absence of catch and sample data as well as the lack of relative abundance indices for the BC portion of the Puget Sound/Georgia Basin would render such an assessment “data limited”. However, given the possibility that there is a separate population and the sparseness of the data from this area, we exclude these data from the analysis as in the previous assessment. No separate assessment has been conducted on the BC portion of the Puget Sound/Georgia Basin Bocaccio population.

3 DISTRIBUTION

The distribution of Bocaccio catch observations in BC waters is provided in Figure 1. This figure shows the location of capture for all observations of Bocaccio in the most recent 10 years (2002-2011). We did not attempt to examine whether distribution has changed over time. The commercial data are not comparable over time and the time series of the various surveys are relatively short (see below).

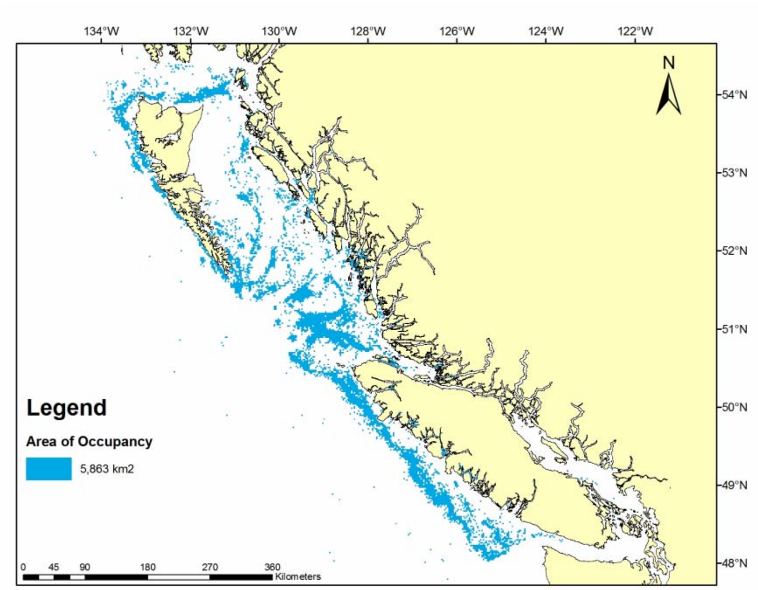


Figure 1. Area of occupancy for Bocaccio based on survey and commercial observations from 2002-2011 (commercial trawl 2002-2011; commercial HL 2006-2011). Figure indicates all 2 km x 2 km cells with at least one record of Bocaccio capture.

4 LIFE HISTORY PARAMETERS

4.1 SAMPLE SOURCES

The estimates of size-at-age and maturity-at-age were derived from 1,212 aged specimens collected between 2001-2010; these included 940 used in the previous assessment (DFO Groundfish GFBio database). These samples came from both research survey and commercial fishery catches. The commercial samples were obtained from at-sea observer and port samples of both midwater and bottom trawl catches. As noted in Stanley et al. 2009a, 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. An updated summary of the age composition is provided in Figure 2.

There are more males than females in the age-length samples for all ages, but it is not known whether this reflects higher natural mortality, higher fishing mortality, or a combination of both. It may also represent different selectivities between sexes in these samples which were collected from surveys and commercial fishing since 2001.

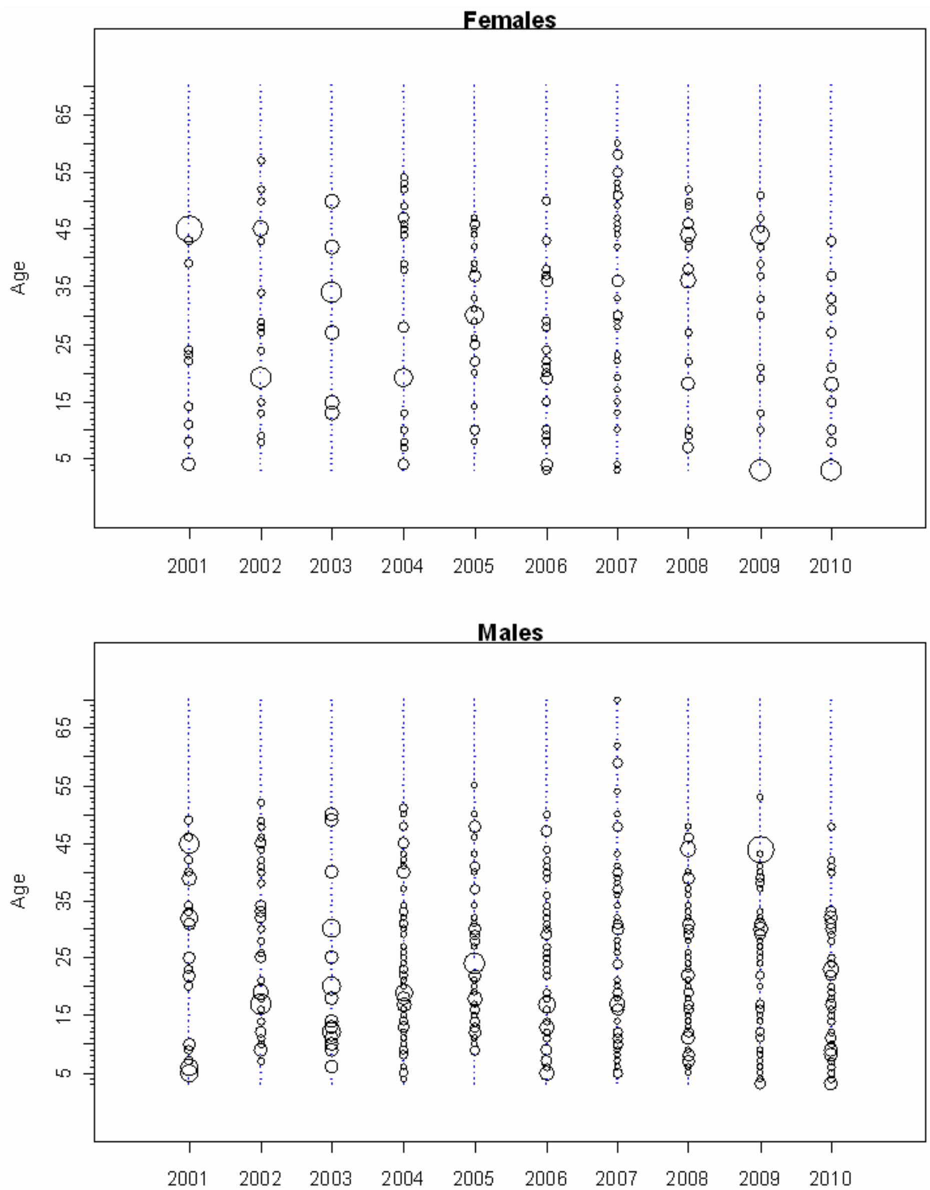


Figure 2. Bubble plot of proportions-at-age for female and male Bocaccio for 2001-2010, all sources combined. Area of the bubble is proportional to proportion-at-age within each sex. Youngest age showing in 2009 and 2010 corresponds to 3-year-olds. No age data are available from prior to 2001.

4.2 GROWTH, AGE-AT-MATURITY, AND NATURAL MORTALITY

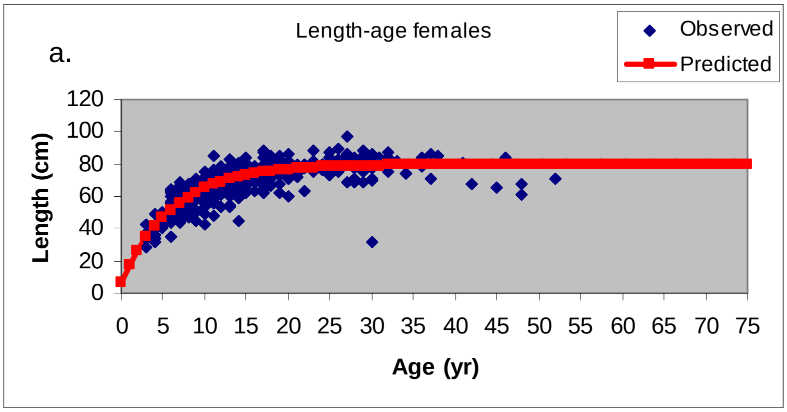
Growth was estimated using same methods as before (Stanley et al. 2009a), using the updated data. A von Bertalanffy growth model was fitted to the length-age observations (Figure 3 and Table 1). The estimates of k and L_{inf} are precisely determined owing to the fairly large sample sizes. The estimate of t_0 is poorly determined because there was only one observation below age seven for males and three observations below age six for females.

The estimates of maturity-at-age for female Bocaccio were updated with a subset of the additional data (n=321)[2] (Figure 4). However, we used a different method in which proportion mature at age was estimated by applying a cumulative, renormalized lognormal density function. The age at which the maturity-at-age function intersects with zero mature was set at the oldest immature age at which zero animals were found to be mature. The number found to be mature in each set of samples at each age was modeled to be a binomial random variable with the probability predicted by the renormalized cumulative lognormal density function. The parameters estimated included the median value and standard deviation in the natural logarithm of age for the lognormal density function (see King et al. 2012 for details on the methodology). The median estimate of age at 50% maturity for females was estimated to be 7.1 years as opposed to the 8.5 years estimated previously (Stanley et. al. 2009a). The advantage of applying the cumulative renormalized lognormal function over the logistic function is that it provides a much better fit to the maturity data for Bocaccio. The best fitting logistic function (not shown) markedly under-predicted the observed positive fraction of mature values for the youngest ages.

Table 1. Updated growth parameters for Bocaccio.

Sex	Parameter	2012		2009
		Mean	SD	Mean
Females				
	L_{inf} (cm)	79.520	0.630	78.32
	k (yr^{-1})	0.162	0.002	0.163
	t_0 (yr)	-0.510	0.380	-1.20
Males				
	L_{inf} (cm)	69.180	0.150	69.98
	k (yr^{-1})	0.177	0.001	0.108
	t_0 (yr)	-1.970	0.400	-8.46
Females				
	a	8.57E-09	1.0E-09	3.58E-05
	b	3.10	0.028	2.754

[2] As in previous work, we used observations on female maturity from months of February-July owing to difficulty in field-staging of rockfish maturity (see Stanley and Kronlund, 2004 for an explanation of the methodology).



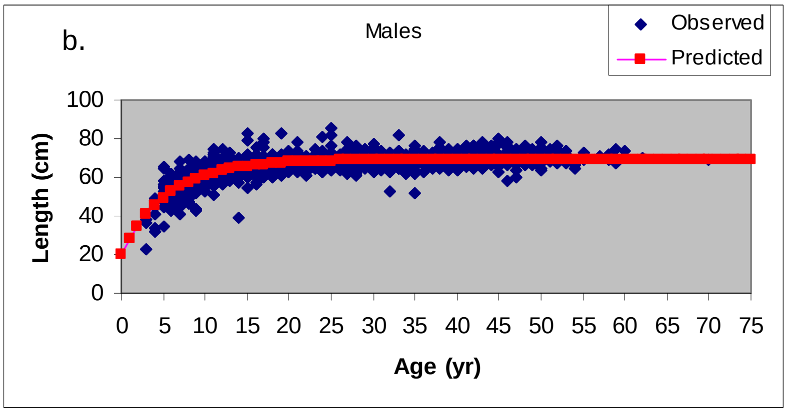


Figure 3. Observed and estimated length-at-age for a. female and b. male Bocaccio.

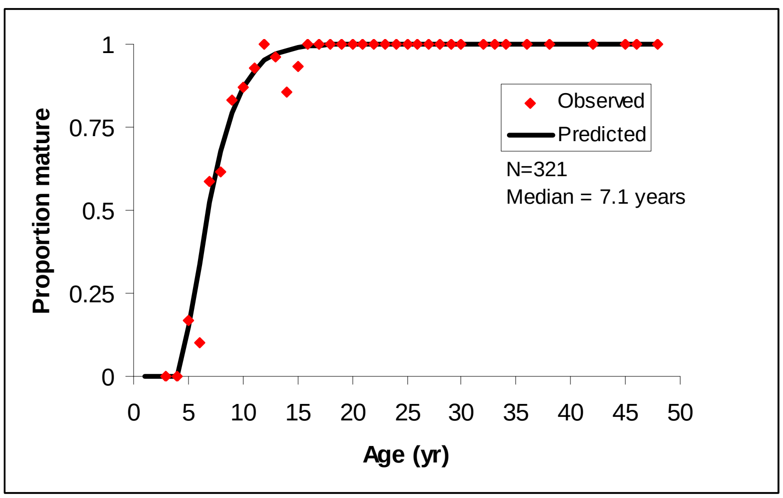


Figure 4. Observed and estimated proportion mature-at-age for female Bocaccio. The median refers to the age at which 50% of females are predicted to be mature.

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 juvenile females (Figure 5).

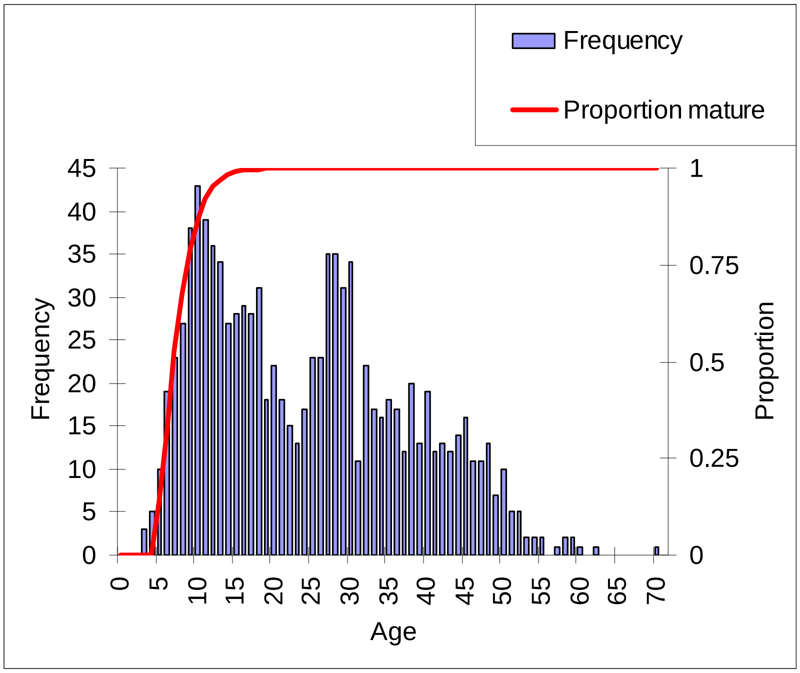


Figure 5. Female Bocaccio proportion mature-at-age (line) compared with histogram of age frequency of females, for all samples combined.

As in Stanley et al. 2009a, we treated instantaneous rate of natural mortality for females, *M*, as a lognormal random variable with a median of 0.075 yr^{-1} and standard deviation in log space equal to 0.25. Generation time is treated as approximately 20 years.

5 CURRENT MANAGEMENT AND MONITORING OF BOCACCIO CATCHES

Bocaccio are captured incidentally in all commercial groundfish trawl and most hook-and-line fisheries, as well as the salmon troll and recreational. There is currently no directed fishing for Bocaccio in any fishery. Some targeting took place during earlier decades of the groundfish trawl fishery.

There are currently no regulations that specifically limit trawl catches of Bocaccio although landings of non-quota rockfish in the trawl fleet (including Bocaccio), are limited to a maximum of 15,000 lbs per trip, all non-quota species combined[3]. However, to address the concerns for Bocaccio, a voluntary program for the trawl fleet was developed and implemented in 2004 in which groundfish trawl vessels relinquished all landed Bocaccio catches and directed the proceeds for research and management purposes. These actions resulted in an approximate halving of Bocaccio trawl landings after 2004 relative to level of landings prior to that year (Figure 6, Appendix Table 1 and Appendix Table 2). This voluntary relinquishment program remains in place at this time.

In the commercial groundfish hook-and-line and trap fisheries (HL fisheries), Bocaccio is managed as part of an aggregate of "other" rockfish which is applied to non-quota rockfish. For Inside ZN rockfish fishing (i.e., inside waters of Vancouver Island), the combined catch in a trip of “other” rockfish must be less than or equal to the combined catch of Yelloweye, Quillback, Copper, China, and Tiger Rockfish. For HL fishing in outside waters, there is a trip limit of 5,000 pounds for non-quota rockfish combined. Recreational catches are constrained by “rockfish” daily bag limits of 0 to 5, depending on the area.

[3] See the 2011-2013 Integrated Fishery Management Plan for Groundfish at http://www.pac.dfo-mpo.gc.ca/fm-gp/mplans/ground-fond_2012-13.pdf

Trawl catches (not including those from inside waters) have been monitored since 1991 with independent 100% dockside coverage of landings and, since 1996, with 100% observer coverage of at sea catches. Total catches from this fishery are considered accurate since 1996.

Catches in the groundfish HL fishery have been monitored with 100% independent dockside monitoring for all sub-sectors since 1996 (ZN rockfish in 1995) and with a 100% electronic monitoring of catches at sea since 2006. Catches for this fishery are considered accurate since 2006 (see Stanley et al. 2009b).

Rockfish catches in the recreational fishery, depending on the area, are monitored primarily through a combination of creel surveys, aerial flights to estimate effort, and harvester logs. The program is primarily designed to estimate the catches of salmonids, but there has been a concerted effort to improve the monitoring of groundfish species in recent years.

6 COMMERCIAL CATCH DATA

This assessment uses catch data from the same fisheries as were modelled in the previous assessment, with four additional years of observations (2007/2008-2010/2011). This assessment also models the recreational catches for the first time in a Bocaccio assessment (Table 2).

Table 2. The seven fisheries modelled in this stock assessment, showing the years these fisheries were included. Catches from four of these fisheries were assumed known without error ("Fixed"). Catches from the remaining fisheries were estimated as described in Stanley et al. 2009a and below.

Gear	Sector	Years	Fixed or Estimated
Trawl	US domestic	1935-1980	Fixed
Trawl	CDN domestic	1950-2011	Fixed
Trawl	Soviet and Japanese	1965-1977	Fixed
HL	CDN Rockfish ZN	1940-2011	Fixed
HL	CDN and US Halibut	1935-2011	Estimated
Troll	CDN Salmon troll	1935-2011	Estimated
Handline	Recreational	1935-2011	Estimated

In this document, "catch" refers to total removals by fishing gear, summing both the retained (landed) catch and the discarded catch. We assume that all Bocaccio die after capture, so this sum is equivalent to total fishery-generated mortality. Bocaccio have been predominantly a non-directed (or bycatch) species in all BC fisheries.

6.1 TRAWL CATCH

Catch for all trawl fisheries were input as fixed values, known without error (Figure 6, (Appendix Table 1 and Appendix Table 2). Details on how historical catches were reconstructed are provided in Stanley et al 2009a. Data were updated for 2008-2011. Catch estimates for 2012 were assumed to be equal to 2011.

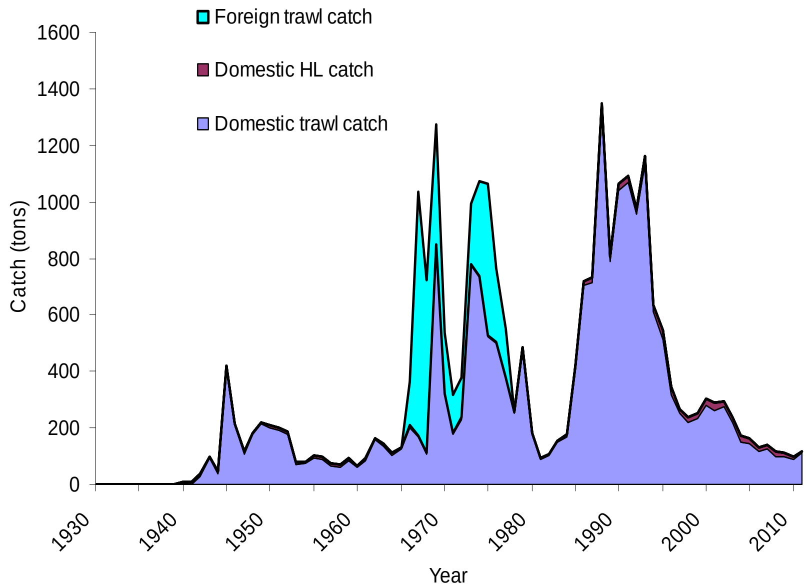


Figure 6. Domestic (U.S. and Can.) and foreign (Soviet, Japanese, and Polish) trawl landings (1930 to 2011).

6.2 HOOK-AND-LINE CATCH

As in the previous assessment, we divided the HL and trap fisheries into three sectors: rockfish ZN (set-line, and handline and lingcod troll), halibut (set-line), and salmon troll. Catches for the rockfish ZN fishery, which primarily targets rockfish and lingcod, were taken directly from DFO catch databases as fixed values, known without error (Figure 6, Appendix Table 1 and Appendix Table 2).

Catches of Bocaccio in the halibut, salmon troll, and recreational fisheries were estimated with the same methodology described in the previous assessment for halibut and salmon troll (Appendix Table 1, Appendix Table 2, and Appendix Table 3). The time series of halibut catch is estimated as a function of fishing effort in outside waters. This effort series was updated for this assessment with an additional four years, ending in 2011 (Figure 7).

The model predicted annual catches in the halibut fishery from the observed halibut effort ($E_{f,y}$) (see Eq. B1 in Stanley et al. 2009a, Appendix B).The catchability coefficient, k_f, was estimated from the observed halibut catches during the years 2006-2011, with a non-informative prior for k_f (Stanley et al. 2009a) and with updated catch records ending in 2011. The imputed values of catch for these fisheries are provided below in the section on model results (Section 11.4 and Figure 21). The salmon troll effort series was extended up to 2010; 2011 data were not available at the time of report preparation. Effort values for 2011 and 2012 were assumed to be equal to 2010.

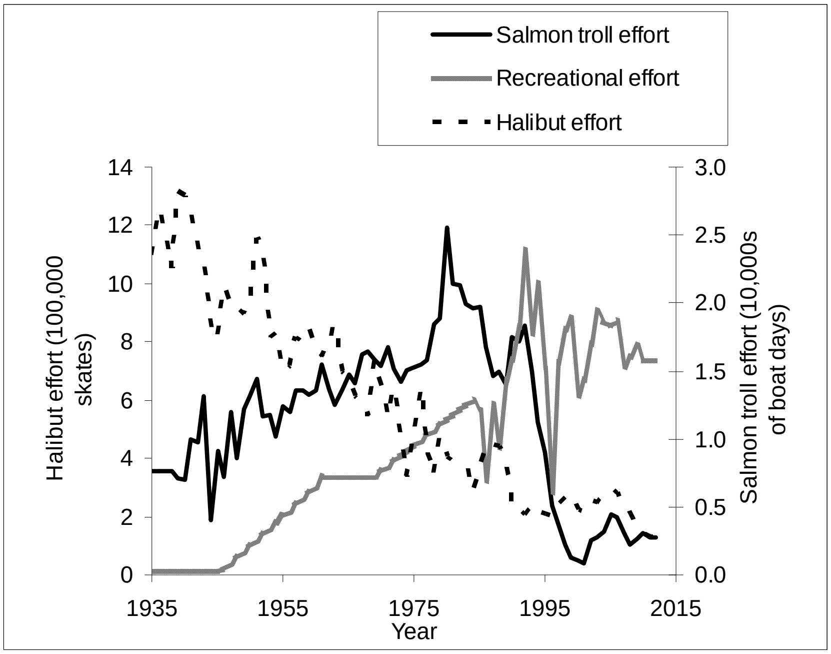


Figure 7. Time series of annual effort used for imputation of total catch in the salmon troll, halibut, and recreational fisheries.

6.3 RECREATIONAL CATCH

Earlier Bocaccio assessments treated recreational catches as negligible relative to other fisheries and were not included in the analyses. However, the relative importance of this fishery has increased, given the reduced catches in the trawl fishery and the low estimates of current biomass. This means that the impact of recreational exploitation rates needs also to be considered.

Similar arguments could be made for the inclusion of exploitation of catches of Bocaccio by other fisheries (e.g., salmon seine and gillnet, prawn trap and First Nations); however, this was not attempted for this assessment. The exploitation by each of these fisheries is assumed to be lower than that for the recreational fishery, although considered collectively, there may be having an impact. However, the lack of available data precludes the sensible inclusion of these fisheries.

Consistent with the rest of the assessment, we did not include recreational catch from the inside waters of Vancouver Island (Strait of Georgia, Juan de Fuca Strait, and Queen Charlotte Strait), although catches of Bocaccio have been reported from Area 12, Queen Charlotte Strait (Table 3). The appearance of Bocaccio in 2008 in Table 3 reflects ongoing effort to improve monitoring of non-salmonids in this fishery.

Table 4 summarizes available recreational catch estimates of Bocaccio from outside waters of the BC. South Coast data exclude catches and effort from waters inside of Vancouver Island (i.e., Area 20-Juan de Fuca Strait, the Strait of Georgia, and Areas 11 and 12-Queen Charlotte Strait). Note that although effort units are collected as angler days in the Central Coast data, they were treated as “boat days” in the discussion below. North coast estimates were only available for “Rockfish”, so we converted these to pieces of Bocaccio by using the observed yearly bycatch ratio (Bocaccio/Rockfish) for the South and Central Coasts combined.

Table 3. Estimates of Bocaccio catch from Minor Area 12 (Inside waters of Vancouver Island – north) (DFO, unpublished data).

Year	Minor Area 12		
	Rockfish (pieces)	Bocaccio (pieces)	Boat Trips
2000	11136		18083
2001	7670		10825
2002	1415		5016
2003	4918		14059
2004	5924		16367
2005	4762		18682
2006	9370		15901
2007	5407		16737
2008	7028	127	12914
2009	9827	107	15080
2010	9335	41	14981
2011	8298	11	15623

Assuming that Bocaccio catches were underestimated for the north coast in 2007 (3 pieces), we used the 2008-2010 data for all areas. This indicated a mean annual reported catch of 250 pieces coastwide. This equates to about 1 t using the mean weight of 4.3 kg observed in commercial fisheries. Assuming a recent coastwide fishing effort of about 100,000 days (including an extra 14,000 days for the North Coast), this catch rate would correspond to about 0.0025 Bocaccio/day coastwide. This implies a Bocaccio/Rockfish catch ratio of 0.66%, which is consistent with the ratios shown in Table 4.

We used simple methods to combine recreational data sources by area; however, the intent was only to develop a starting minimum assumption of coastwide catch. The resulting value of 1 t per year was so low relative to other fisheries we suggest no additional work is warranted.

Table 4. Estimates of recreational catch of Bocaccio 2000-2010 (unpublished DFO data). Note that "total boat days" does not include a north coast estimate. Values in italics were estimated from monitoring data.

Year	Total			South Coast (excl. SoG)			Central coast and Area 11			North coast		
	Rockf. (pieces)	Boc. (pieces)	Boat days	Rockf. (pieces)	Boc. (pieces)	Boat days	Rockf. (pieces)	Boc. (pieces)	Angler Days	Rockf. (pieces)	*Catch Ratio from SC, Area 11 and CC combined*	*Boc. (pieces) (est.)*
2000	34093	0	55788	14100		55788	0	0	0	19993		
2001	39481	0	60811	21048		60811	0	0	0	18433		
2002	50466	0	102511	30437		75262	4603	0	27249	15426		
2003	33386	2	113384	21965		84124	4234	2	29260	7187		
2004	42516	4	115518	29620		81825	4952	4	33693	7944		
2005	55601	0	112316	43157		79202	4713	0	33114	7731		
2006	52129	14	114891	37293		79401	7556	14	35490	7280		
2007	44503	87	99082	32460	78	64632	10422	9	34447	1622	***0.0020***	***3***
2008	69653	279	95184	39829	243	66908	8798	36	28155	21026	***0.0057***	***120***
2009	62127	261	93027	31452	220	71768	7238	41	21101	23437	***0.0067***	***158***
2010	65379	212	86580	30035	117	66208	7076	95	20210	28268	***0.0057***	***162***

For comparison, the commercial HL (non-trap and non-dogfish) fisheries catch about 0.31 Bocaccio/day (2006-2011), or 100 times greater and the catch ratio (Bocaccio/Rockfish) is about 1% (50% higher).

While it is obvious that monitoring has improved in recent years, we suggest the true recreational catch is likely underestimated. This can be inferred from the large number of unidentified “Rockfish”. Therefore, we suggest that 1 t/y is suitable as a minimum current (2010) coastwide estimate of the recreational catch of Bocaccio. There is no analytical basis for deriving a maximum estimate but we proposed a theoretical upper limit of about 10 t/y (about 2,300 pieces/y). This translates to a catch rate of 0.023 Bocaccio/day, or 1 fish for every 43 boat days of sport fishing (100,000 days/ (10 t/4.3 kg)).

The historical recreational catch of Bocaccio in outside waters was estimated using the same methodology as in the halibut and salmon troll fisheries. We used the outside waters recreational fishing effort series, compiled for the 2011 Quillback Rockfish assessment (Yamanaka et al. 2012) (Figure 7 and Appendix Table 3). Data for 2011 were not available at the time of report preparation; consequently, recreational effort for 2011 and 2012 was assumed to be the same as that in 2010.

As indicated above, a single approximation of the bycatch of Bocaccio in recreational fisheries was formulated for the year 2010. This was originally specified as a triangular distribution with a minimum of 1 ton, a peak at 5 tons and a maximum at 10 tons (Figure 8). This prior was treated as a pseudo data point just as the one for the average catch in outside waters salmon troll fisheries had been treated as a pseudo data point. To allow for improved numerical performance in the Bayesian model, the triangular distribution was replaced by a truncated normal density function for the estimated catch in 2010, with the minimum value set to 1.0 ton. The closest fit between the normal and initial triangular distribution was obtained by setting the mean of the normal density function (without truncation) to 5.2 tons and CV to 0.4 (Figure 8). The probability density of the data point was computed using the model predicted value for the recreational catch in year 2010 as follows:

$$C_{r,2010} \sim Normal\left(\hat{C}_{r,2010}, \left(CV \times \hat{C}_{r,2010} \right)^2 \right)$$

where $C_{r,2010}$ is the data point for the recreational catch in 2010 and $\hat{C}_{r,2010}$ is the model-predicted recreational catch in 2010. This is predicted in the same way that the halibut and troll catch is predicted (i.e., by assuming that the fishing mortality rate from recreational fishing is directly proportional to the annual recreational fishing effort):

$$\hat{C}_{r,2010} = B_{2010}\left(1 - \exp\left(-k_r E_{r,2010}\right)\right)$$

where B_{2010} is the model predicted biomass in 2010, k_r is the recreational catchability coefficient, and $E_{r,2010}$ is the recreational fishing effort in 2010. The estimated recreational catch by year is provided below in model output (Section 11.4 and Figure 21, Appendix Table 1, Appendix Table 2 and Appendix Table 3).

Note that the above process, which bases catchability on 2010 results, leads to estimates of higher catches going backwards over time, reaching a peak median estimate of 33 t in 1984 then slowly declining to near 0 by 1945. This trend simply reflects the effect of greater Bocaccio abundance in combination with the trend in recreational effort. These estimates are highly uncertain (Figure 21), dependent on the assumed prior based on the 2010 estimated catch (Figure 8) and the additional assumption that catchability has been constant in time (e.g., constant fishing behaviour and gear). While it is extremely unlikely that catchability has been constant during the past 60 years for these effort-driven fisheries (recreational, salmon troll, and halibut fisheries), we lack any basis for estimating changes in catchability for these fisheries and feel that this methodology is a reasonable means for accounting for the impact of these fisheries.

In the case of recreational fishery, annual current catches which lie between 1 and 10 t seem to be a reasonable range; however, there is little basis to defend the modal choice of 5 t, other than being the approximate midpoint. The true mean could be as low as 2-3 t, which would reduce the historical series by half. However, the mean could be closer to 10 t, leading to the opposite effect.

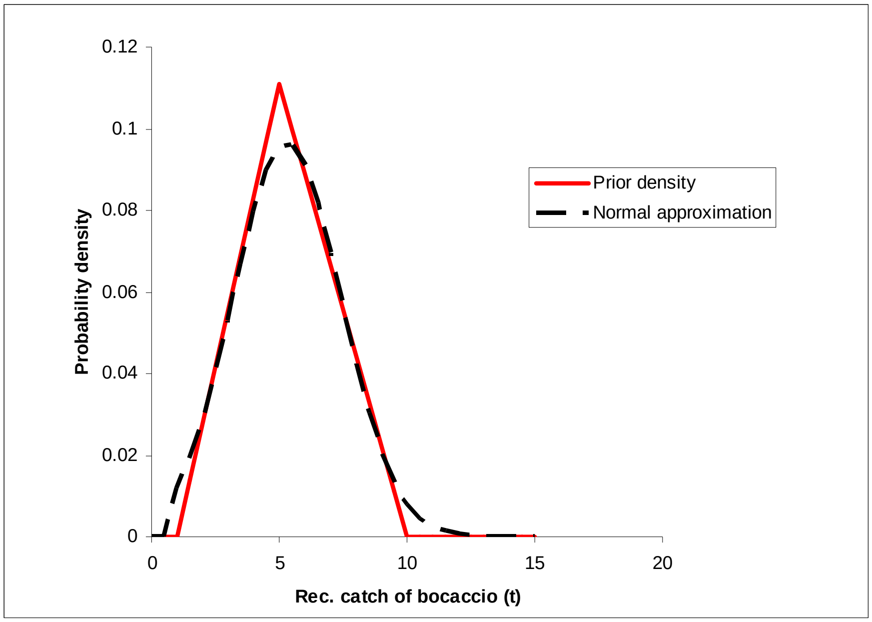


Figure 8. Plot of the initial prior distribution for recreational catch of Bocaccio in BC in 2010 from a qualitative interpretation based on recreational catch data and interviews. A normal approximation of the prior is also shown. This latter distribution was used to compute the probability of this prior approximation of recreational catch given model predicted catches of Bocaccio in 2010.

7 ABUNDANCE TRENDS - COMMERCIAL CPUE

We included the same commercial bottom trawl CPUE index for 1996/1997 to 2003/2004 used previously (Stanley et al. 2009a) as an index of abundance in the assessment model. 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 Stanley et al. (2009a), we did not 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 was the end of the “fishing year” at that time. After this date, in response to concerns expressed about the status of Bocaccio, as noted earlier, most participants in the trawl fishery voluntarily agreed to relinquish[4] the value of all Bocaccio landings. This initiative not only removed the incentive to target Bocaccio, but also encouraged harvesters to avoid Bocaccio. Trawl catches in this sector declined from around 200-250 t annually to nearly 100 t per year by the 2006/2007 fishing year. Consequently, we believe that Bocaccio catch rates after the 2003/2004 fishing year are not comparable with the earlier period and ended the series in 2003/2004. The standardized and nominal trends

[4] The individual harvester did not receive any payment for Bocaccio landings. Revenue was “relinquished” to the Canadian Groundfish Research and Conservation Society.

indicate there was little change in CPUE from 1996/1997 to 2003/2004 (Figure 9 and Appendix Table 4).

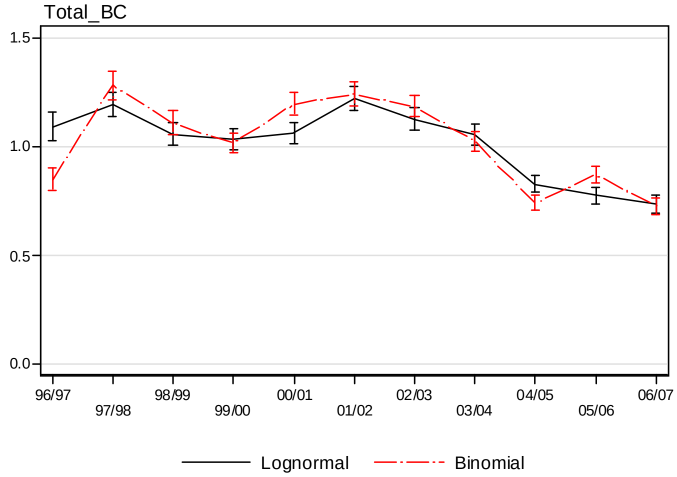


Figure 9. Comparison of the lognormal and binomial standardised commercial trawl CPUE indices for Bocaccio. The error bars show ± 95% confidence bounds.

Catch data were standardized using Generalized Linear modelling (GLM) methods (Stanley et al. 2009a). The nominal and standardized indices, as well as other treatments of the data, provided similar trends over the selected time period, probably indicating that fishing practices changed little over this period. This stability across treatments does not validate the series as an index of abundance, but indicates that alternative methods are unlikely to provide a significantly different signal.

Concerns over comparability in fishing behaviour have led us to exclude the use of commercial catch rates from the groundfish HL fisheries. Improved monitoring, starting in 2006, has provided accurate estimates of catch (landings and discards) of Bocaccio from that year forward. However, we think it is likely that fishing behaviour has changed and continues to change as the fleet adapts to Individual Vessel Quotas (introduced in 2006), thus rendering it unlikely catch rates in this fishery will provide usable indices of relative abundance for Bocaccio.

8 ABUNDANCE TRENDS - SURVEYS

We used the results from eight surveys in this stock assessment (Figure 10 and Figure 11, Table 5 - Table 7). Results for the two shrimp surveys, and the four Groundfish synoptic surveys were updated with 2008-2011 results using the methodology described in Stanley et al. (2009a) (Figure 12 and Figure 13, Appendix Table 5 - Appendix Table 10). We again used biomass indices from the US NMFS Triennial survey which ended surveying in BC waters in 2001 (Figure 12 and Appendix Table 11).

We included results from the West Coast Haida Gwaii Groundfish Synoptic Survey (WCHG) for the first time (Figure 13 and Appendix Table 7). This survey was excluded previously because there were only two data points. Abundance indices for this survey were derived in the same manner as followed for the other synoptic trawl surveys (see Stanley et al. 2009a).

We also included the International Pacific Halibut Commission (IPHC) longline survey results for the first time (Figure 12 and Appendix Table 12). The method of calculating the index for this longline surveys is provided in Section 21, Appendix B. The IPHC survey is a fixed station longline survey of approximately 170 stations. Although initiated before 2003, we have only used results from 2003-2011 because this was the first year that groundfish catch (in pieces) was fully enumerated. In previous years, non-halibut catch was enumerated for only the first 100 hooks in each skate, leading to very low numbers of Bocaccio in the enumerated data. We made no attempt to adjust for gear saturation in this longline survey (Ricker 1975). However, a preliminary analysis did not indicate a strong negative correlation between overall catch of all species and Bocaccio[5]. This index is based on catch in pieces, unlike all of the other surveys.

We continue to exclude use of historical G.B. Reed Queen Charlotte Sound survey, and all DFO longline surveys because they did not capture enough Bocaccio to be reliable. There are additional DFO longline surveys but these are currently to 2-3 survey points. They could be considered for future Bocaccio assessments.

Table 5. Fishery independent surveys used in this assessment (BT= bottom trawl).

Survey	Depth range (m)	Gear used	Used in assess. (09/12)
West Coast Vanc. Isl. Shrimp[a] (Starr et al. 2002)	80–160[b]	Shrimp Trawl	Yes/Yes
Qu. Char. Sound Shrimp (Boutillier 1998)	100–235	Shrimp Trawl	Yes/Yes
US NMFS Triennial[c] (Weinberg et al. 2001)	55–366[b]	Gfish BT	Yes/Yes
Qu. Char. Sound Syn. Gfish (Olsen et. al. 2007)	37–543	Gfish BT	Yes/Yes
West Coast Vanc. Isl. Syn. Gfish (Workman et. al. 2008b)	46–750	Gfish BT	Yes/Yes
Hecate Strait Syn. Gfish (Workman et. al. 2008a)	11–230	Gfish BT	Yes/Yes
West Coast Haida Gwaii Syn. Gfish (Workman et al. 2007)	180–1800	Gfish BT	No/Yes
IPHC[d]	20-500	Longline	No/Yes

[a] Survey began in 1972 but rockfish catch by species not recorded until 1975
[b] indicates depth range analyzed for indices used in assessment
[c] index from Canadian waters only
[d] Data obtained from the IPHC (survey descriptions can be found at http://www.iphc.int/research/surveys.html)

Table 6. Observations by year for the abundance indices used in the assessment.

Survey/Index	Year																																
	75-79	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	08	09	10	11
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	x	x	x	x
US NMFS Tri		x			x						x			x			x			x			x										
QCSd Syn Gfish																									x	x	x		x		x		x
WCVI Syn Gfish																										x		x		x		x	
HS Syn Gfish																											x		x		x		x
WCHG Syn Gfish																												x	x	x		x	
Comm trawl CPUE																		x	x	x	x	x	x	x	x	x							
IPHC																									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/Sets	Tows/Sets With Bocaccio	Mean Length (cm)
WCVI Shrimp	35	16	2,801	170	61.1
QCSd Shrimp	14	7	969	32	65.7
US NMFS Triennial	7	391	878	91	-
WCHG Syn Gfish	4	17	468	39	71.8
HS Syn Gfish	4	14	679	29	67.8
QCSd Syn Gfish	6	50	1,429	81	67.2
WCVI Syn Gfish	4	90	556	102	62.9
IPHC Longline Survey	9	24	1,530	116	72.1

[5] Note that an analytical approach and supporting software application to accommodate hook saturation in HL surveys is nearly finished and will be available for future DFO assessments by the end of 2012.

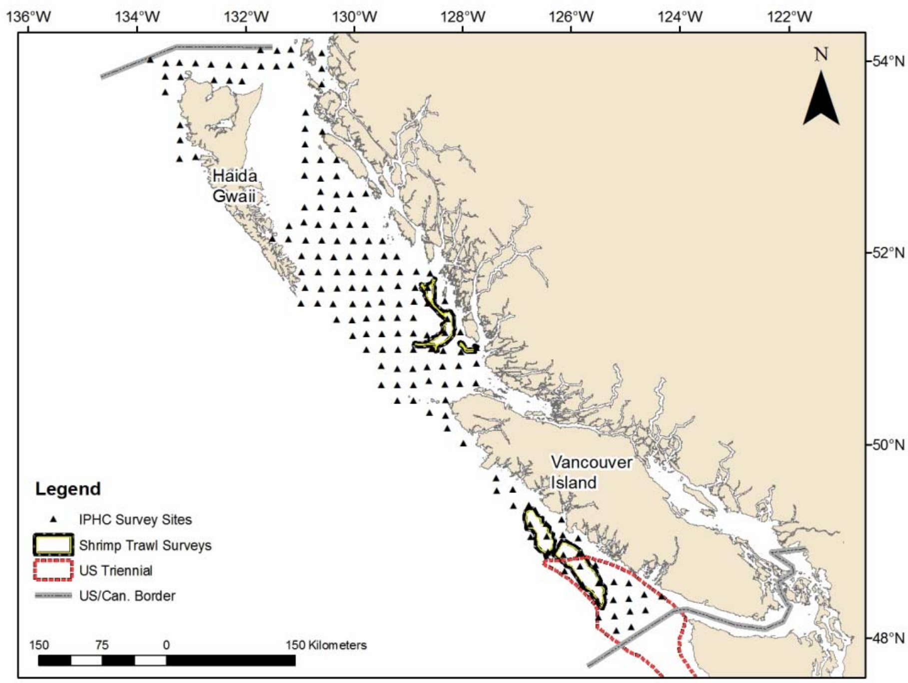


Figure 10. Locations of Shrimp trawl, US NMFS Triennial bottom trawl, and IPHC HL longline surveys.

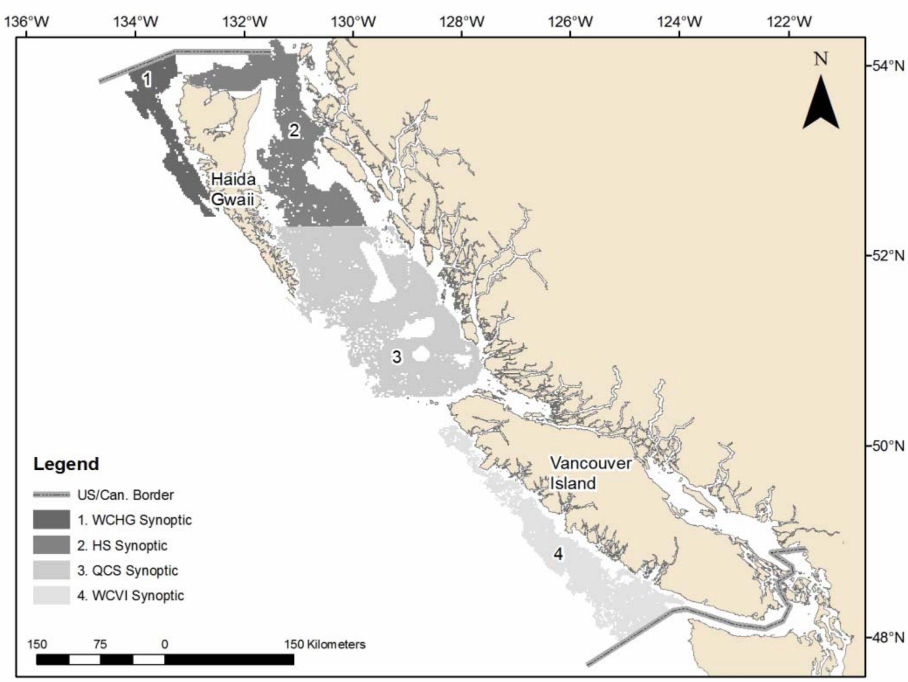


Figure 11. Locations of Groundfish Synoptic bottom trawl surveys.

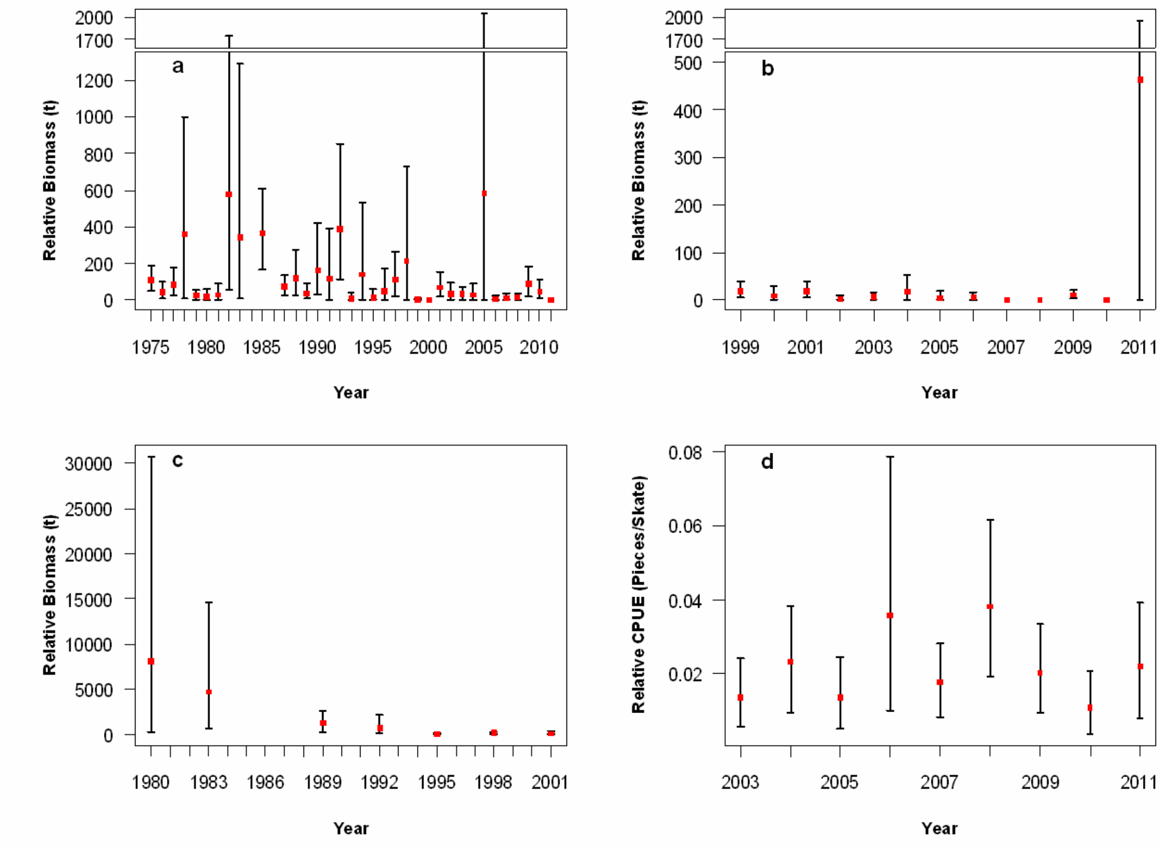


Figure 12. Plots of biomass estimates for Bocaccio from the a. West Coast Vancouver Island shrimp trawl, b. Queen Charlotte Sound shrimp trawl, c. U.S. Triennial survey, and d. IPHC longline surveys. Bias corrected 95% confidence intervals from 1,000 bootstrap replicates are plotted.

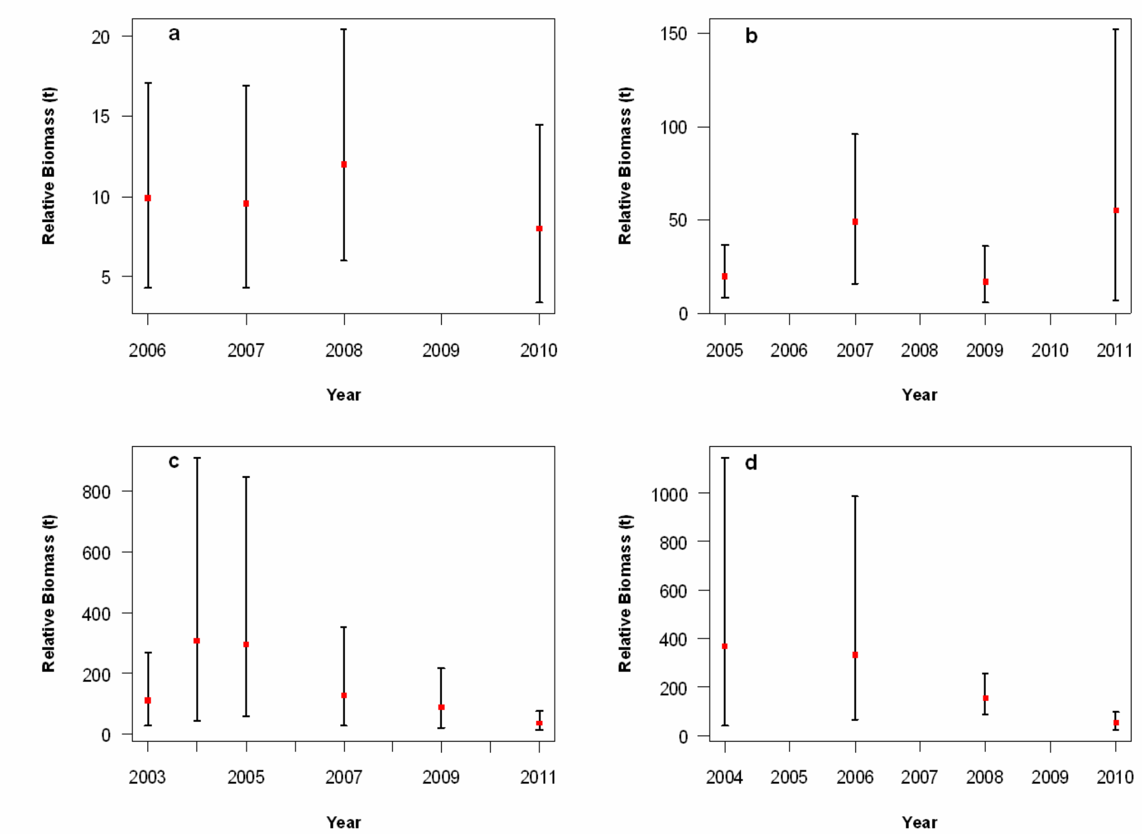


Figure 13. Plots of biomass estimates for Bocaccio from the a. West Coast Haida Gwaii; b. Hecate Strait, c. Queen Charlotte Sound and, d. West Coast Vancouver Island Groundfish Synoptic trawl surveys for 2003 to 2011. Bias corrected 95% confidence intervals from 1,000 bootstrap replicates are plotted.

9 TRAWL SURVEY CATCHABILITY

As in the 2009 assessment, an informative prior for trawl survey catchability, *q*, was applied to improve the precision in estimates about stock biomass (Stanley et al. 2009a, McAllister et al. 2010). In this assessment, one additional trawl survey index of abundance for from the WCHG survey was included so the informative prior for *q* was extended to include this survey (Table 8) (see Appendix Figure 1 and Appendix Table 13 for the confidence limits and marginal density functions for *q-gross*).

Results from a rockfish gillnetting experiment (Matthews et al. 1989) were also compiled to provide an estimate of the ratio of the density of Bocaccio in untrawlable and trawlable areas. The value for the ratio of the mean catch rate means across 21 sets in untrawlable and 20 sets in trawlable areas was 1.44. The lognormal standard deviation of the ratio was 0.28. A lognormal density function was used to compute the probability of the experimental observation given the *q* model predictions of the ratio (McAllister et al. 2010). The updated prior for the ratio of catch rate between untrawlable and trawlable areas caused the prior median values for *q* to increase slightly in value and for the joint prior distribution for *q* to become slightly more precise than that used in the 2009 assessment. The higher *q* is associated with an overall downward scaling of biomass.

The joint prior for survey catchability was approximated by a seven dimensional lognormal density function (one dimension for each of the seven trawl 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 and CVs for q-gross (qgfin) for the current and 2009 assessments

Survey	2012		2009	
	Mean	CV	Mean	CV
#1 - WCVI groundfish	0.1110	0.69	0.0703	0.77
#2 - QCSd-groundfish	0.0720	0.72	0.0459	0.80
#3 - HS - groundfish	0.0105	0.76	0.0067	0.83
#4 - WCHG - groundfish	0.0034	0.71	0.0021	0.79
#5 - WCVI Shrimp	0.0048	1.40	0.0030	1.46
#6 - QCSd Shrimp	0.0005	2.64	0.0004	2.74
#7 - US Triennial groundfish	0.0605	1.56	0.0474	1.73

10 BAYESIAN SURPLUS PRODUCTION MODEL

This assessment used the non-equilibrium, age-aggregated Bayesian surplus production (BSP) model described in Stanley et al. (2009a). It is a state-space version which incorporates stochastic process error in the fish stock dynamics (Meyer and Millar 1999) and thereby permits a more thorough accounting of uncertainty in estimates of stock biomass, stock projections, and deviations as compared to a deterministic surplus production model. A Bayesian statistical approach was adopted to fit the model to data, allowing for the use of informed priors which incorporated information and expert judgements. The BSP model was fitted to eight sets of survey abundance indices and the one commercial CPUE series to reconstruct historical trends in abundance of Bocaccio. The fitted model was then used to evaluate the future trends in abundance based on alternative total allowable catch (TAC) policies. TAC refers to total combined catch from all modelled fisheries, including recreational catch for the first time.

We use a version of the Schaefer surplus production function (Hilborn and Walters 1992) that applies continuous fishing mortality rate equations (Prager 1994, and see Stanley et al. 2009a):

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

where B_t is stock biomass in year *t*, *r* is the maximum intrinsic rate of increase, *K* (or B_0), is the average unfished stock size or carrying capacity, and F_t is the instantaneous fishing mortality rate 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 using simulation testing of the state space version of this model (unpublished work by first and second author). Earlier simulation testing of a deterministic version also produced acceptable performance (McAllister and Kirkwood 1998). This testing included misspecification of the priors, as long as the priors for key parameters (e.g., *r* and constants of proportionality for stock trend indices, *q*) were not overly precise or strongly biased (McAllister and Kirkwood 1998). The version used in this assessment provides more accurate representations of fish stock dynamics than a deterministic version or 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 rather than analytically as in the discrete version (see McAllister and Babcock 2002 and McAllister et al. 1999; 2001a for additional details on the model).

We applied a state-space version of the BSP that incorporates lognormal deviates from total annual biomass predictions:

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

where the prior probability distribution for the process error term is given by $\varepsilon_t \sim \text{Normal}\left(0, \sigma_p^2\right)$. Values for ε_t from 1935 to 2011 were treated as estimated parameters and σ_p was set at 0.1. In the 2009 assessment, sensitivity tests showed that stock status and projection results were insensitive to two alternative settings of 0.05 and 0.15 for σ_p. Consequently, these sensitivity runs were not repeated in this assessment. No attempt was made to estimate the process error variance or the observation error variance, owing to the paucity of time series data that could inform estimates of variance in ε_t and the low precision in most of the indices.

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 of Stanley et al. 2009a for the methodology used to develop these priors). As was done in 2009, the prior for the maximum intrinsic rate of increase, *r*, was developed using a demographic approach (McAllister *et al.* 2001b). This approach was based on available life history data on growth, the natural mortality rate (*M*), maturity-at-age, and the Ricker stock-recruit steepness parameter, developed from a hierarchical meta-analysis of rockfish stock-recruit data (Forrest et al. 2010). The posterior predictive distribution for the Ricker steepness from Forrest et al. (2010) was approximated using a transformed beta density function with minimum of 0.2, mean of 0.93, and standard deviation of 0.42.

The method used to develop the prior for *r* in the 2009 assessment only accounted for uncertainty in *M* and steepness. A similar methodology was applied in this assessment, except that the CV of the *M-prior* was increased from 0.20 to 0.25 yr^{-1}. In addition, the methodology was expanded to include empirical uncertainty in the parameter estimates for growth, the length-weight relationship, the proportion mature at age, and the Ricker steepness parameter (from Forrest et al. 2010 and see Yamanaka et al. 2012). A Ricker stock-recruit function was adopted in preference to the Beverton-Holt stock formulation because there has been a report of cannibalism in Bocaccio (Love et al. 2002). The prior for *r* was then developed from a simulation model which included these life history parameters, represented as priors by their posterior mean and covariance matrix (see Eq. 26 to Eq. 32 in Appendix G, Stanley et al. 2009a). The mean and standard deviation (SD) for the *r*-prior used in this assessment were 0.1067 and 0.039 (Figure 14), which are similar to the mean of 0.117 and SD of 0.035 used in the 2009 assessment. The prior distribution for *r* is approximated in the model by using this mean and SD to describe a normal distribution. Prior distributions for *r*, representing higher and lower levels of productivity, were developed in the same manner for use in model sensitivity runs (Figure 14).

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

Parameter	**Prior Density function**	**Comments**
K	Uniform (500, 200,000)	Units in tons
q for commercial cpue and the IPHC index	Proportional to 1/*q*	This prior is non-informative with respect to *K* and stock biomass (See Stanley et al. 2009a: Table 4, Appendix F11 and F13 for key details on the informative prior for the survey *q*s).
P_0	Lognormal(ln(0.9), 0.2^2)	This indicates that the stock was near to carrying capacity in 1935.
r	Normal(0.1067, 0.0391^2)	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 rockfish stock recruit data (Forrest et al. 2010).

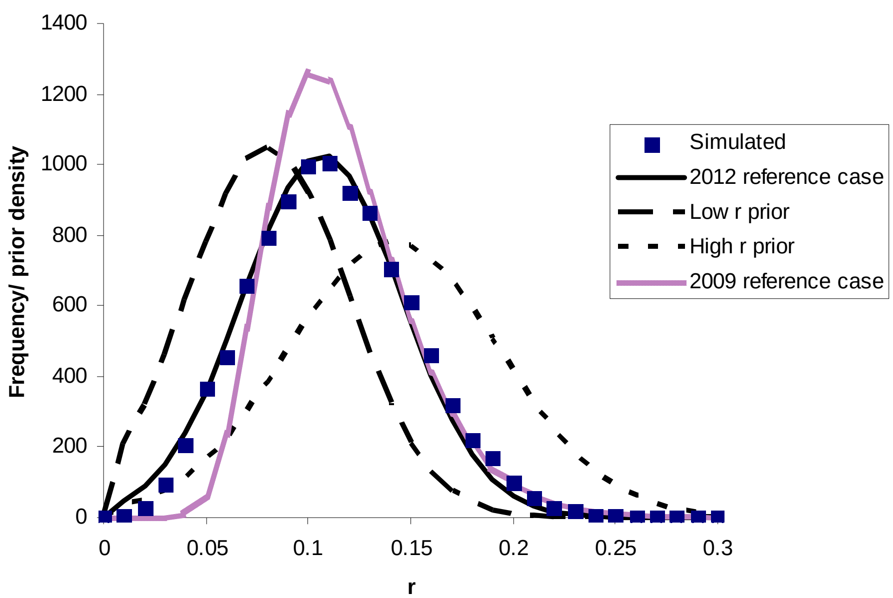


Figure 14. Fitted normal prior density function of the maximum intrinsic rate of increase, r, for BC Bocaccio. The square dots show the frequency distribution of values simulated from the stochastic demographic model for r. The 2009 reference case and 2012 reference or base case, and low and high prior r cases, are shown.

The Schaefer surplus production model assumes that B_{msy}/K (or B_{msy}/B_0) occurs at 50% of *K*. This is a property of the model parameterisation and does not reflect the productivity or other biological characteristics of Bocaccio. However, we have chosen this parameterisation for our reference case because we believe that this ratio is a credible representation of Bocaccio for a number of reasons. One reason is that a recent hierarchical meta-analysis of stock-recruit data for rockfish (Forrest et al. 2010) indicated that the credible range for the median B_{msy}/K by species spanned 0.15 to 0.5 for the Beverton-Holt stock-recruit function and 0.35 to 0.5 when the Ricker stock-recruit function was fitted to the same data (Figure 15). Furthermore, when the steepness parameter for either stock-recruit function approaches lower values, which tend to be more consistent with the low value for r estimated for Bocaccio, the estimated value for B_{msy}/B_0 tends to approach 0.5 (Figure 15) (Forrest et al. 2010).

Nevertheless, recognising that the choice of B_{msy}/K=50% was arbitrary; we investigated three alternative forms of the surplus production function as sensitivity tests, wherein we fixed the B_{msy}/K ratio at 0.3, 0.4, and 0.6. We used a variant of the Fletcher generalized surplus production function (Quinn and Deriso 1999), which allowed the value of B_{msy}/K to take on any value between 0 and 1. We use this form because the classical forms of the Pella-Tomlinson and Fletcher generalized surplus production functions have the property where *r* and the value for B_{msy}/K are negatively correlated, with *r* becoming infinity when B_{msy}/K decreases below the value of 1/*e* (~ 0.37) (Quinn and Deriso 1999). The variant employed in these sensitivities uses a parabolic Schaefer production form for the portion of the production function below B_{msy}/K, thus allowing the Schaefer production function to be continuous with the Fletcher form at *MSY* (McAllister et al. 1999). This also permits the prior for *r* to be incorporated directly into the generalized model, which is not permitted in the classic generalized form. The corresponding Fletcher functions (dotted curves in Figure 16) are shown for B_{msy}/K implementations of 0.3 and 0.4. Note that the Schaefer model is a special case of the Fletcher model, when B_{msy}/K is fixed at 0.5.

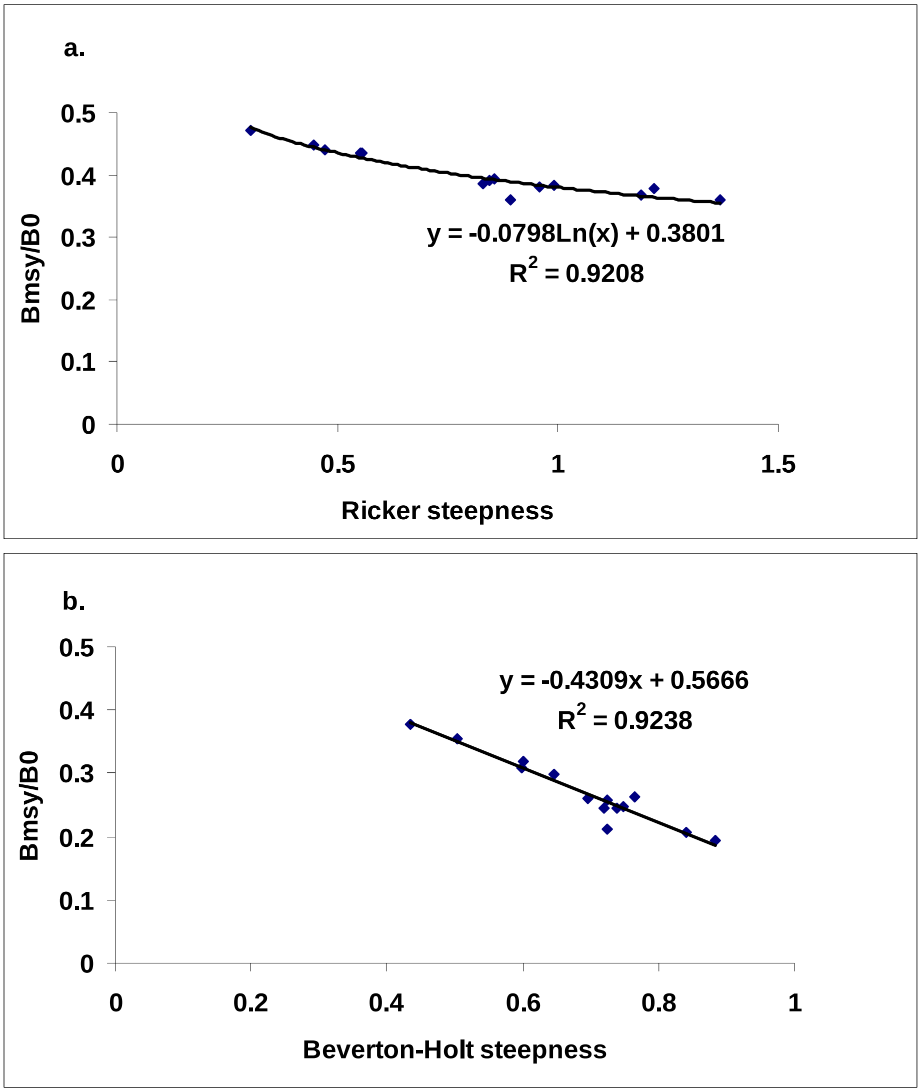


Figure 15. Estimated values for B_{msy}/B_0 under the Ricker and Beverton-Holt stock-recruit models as a function of the steep parameter in the a) Ricker and b) Beverton-Holt stock-recruit functions (Forrest et al. 2010).

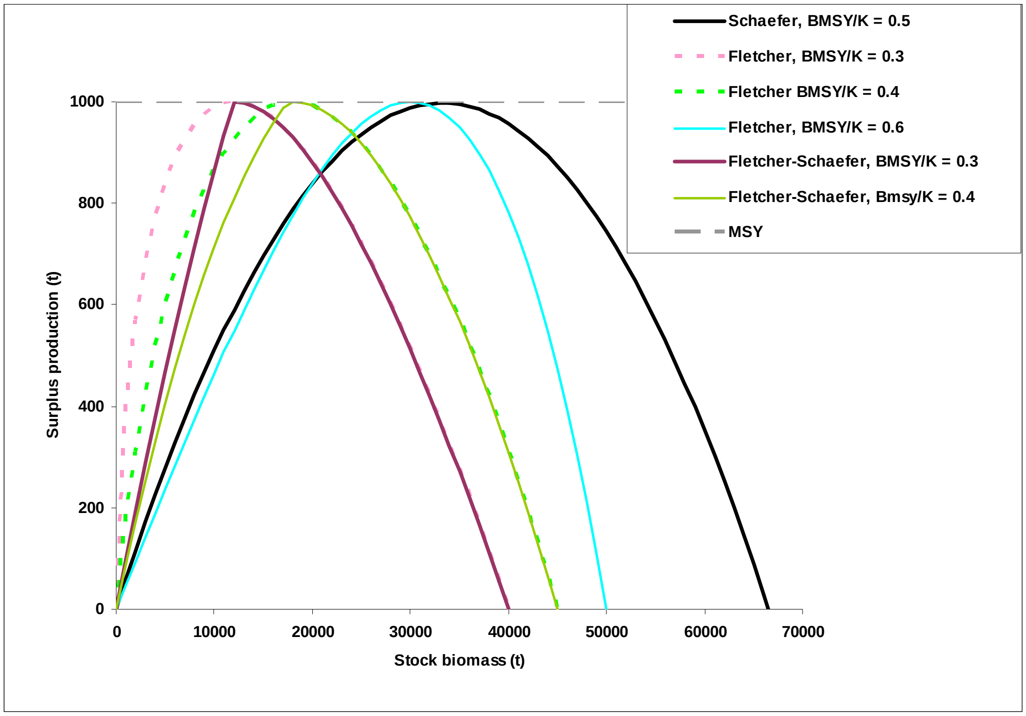


Figure 16. A plot of the reference case Schaefer and three alternative production functions applied in evaluations of the sensitivity of results to different model settings. All plotted production functions are referenced to approximately the same MSY value.

11 REFERENCE CASE

11.1 REFERENCE CASE INPUTS

For the reference case runs, all inputs, assumptions, and settings were formulated based on the best available information and scientific judgment. The key settings and any changes from the 2009 reference runs are presented in Table 10. It is important to note that all model runs assumed that Bocaccio productivity, as well as catchability and availability in the surveys and fisheries, were treated as constant over time. While this is not a good assumption for time series that extend over 60 years in some cases (i.e., the halibut fishery effort series), there is no additional information with which to hypothesize credible assumptions on how these parameters varied over time. Where possible, however, we have conducted sensitivity tests to explore the impact of the assumption of stationarity.

11.2 REFERENCE CASE RESULTS

As in the previous work (DFO 2009a)[6], the results of the reference case indicates that Bocaccio exploitable stock biomass has declined significantly from the 1930s, with the steepest decline occurring from 1985 to 1995 (Table 11, Table 12, Table 13, and Figure 17). The rate of decline slowed after 1995, coincident with lower catches of the early 1990s. The decline appears to have continued after 2000 (Figure 17c).

The posterior mean and median estimates for exploitable biomass in 2012 are 2,205 t and 1,879 t (CV=55%), respectively (Table 11). The posterior median estimate of stock size relative to its unfished stock size (B_{2012}/K) is 3.5% (CV=84%). Current abundance relative to B_{msy} (B_{2012}/B_{msy}) is 7% (CV=84%). The 80% confidence limits (10% and 90% percentiles) of the

[6] Note that methodology and input for the previous assessment are provided in Stanley et al. 2009a, while final results of the corrected reference run are provided in DFO 2009a.

median estimate of B_{2012}/B_{msy} lie between 0.029 and 0.182 leaving little likelihood that the stock is above the lower PA reference point of $0.4*B_{msy}$ (Figure 18).

The posterior median of F_{2012}/F_{msy} is 1.9 (CV=91%). The maximum rate of increase, *r*, in the Schaefer model is equal to $2*F_{msy}$, therefore, the population can not sustain values for F_{2012}/F_{msy} of greater than 2. The posterior median for the replacement yield (*RepY*) in 2012 is 143 tons (CV=55%). The posterior median ratio of the total harvest in 2012 relative to replacement yield *(Catch/RepY*) is 99% (CV=87%). Values for this ratio greater than 1 should lead to further stock decline, if sustained.

The reference case median estimates of 2012 biomass and replacement yield are about 80% and 72%, respectively, of those indicated for 2008 (DFO 2009a), with the current of these estimates being more precise (Table 14). The level of depletion (to 2012) is greater than that reported for 2008 (DFO 2009), with the median estimate of stock biomass down to 3.5% of the average unfished level as opposed to 5.6% reported earlier (DFO 2009a). The posterior median ratio of stock size in 2011 relative to 2001 is 0.66 with 10th and 90th percentiles at 0.46 and 0.97 (Table 11). The 90% probability interval for this statistic was 0.42 and 1.09. These results thus indicate that there is more than a 90% probability that stock size is lower in 2011 than it was 10 years previous. The more pessimistic estimates of the current assessment result from a number of reasons. First, the updated priors for survey *q* were slightly larger owing to the update from the gillnet experiment. The higher and more precise priors for *q* translate into lower and more precise biomass estimates.

Second, in the 2009 assessment, the survey index values of zero were ignored due to the use of a lognormal likelihood function in that assessment. In the current assessment, we applied a different likelihood function (normal with a constant standard deviation for each index of abundance) that allowed evaluation of zero biomass values. Predictably, the inclusion of zero biomass values for 2000 and, 2011 in the WCVI shrimp survey and for 2007, 2008, and 2010 in the QCSd shrimp survey gives more weight to smaller stock sizes as well as increasing precision.

Error distributions for trawl survey catch rate data are often considered to be more closely approximated by a lognormal distribution than by a normal distribution. In this assessment, we were forced to reject the lognormal density function since it cannot accommodate zero values for observations and there were more than a few of them (five in total). A normal distribution truncated at zero still provided an adequate fit to the abundance indices, as the model converged consistently under a non-linear minimization function. While there were some large positive outliers for some of the time series, the values obtained and applied for the SDs were large enough to accommodate the wide scatter in the deviations between observed and model predicted indices of abundance (Figure 17). In the 2009 assessment, when there were only two zero survey values that were excluded, runs with lognormal versus normal likelihood functions yielded very similar posterior distributions for parameters and stock status.

Table 10. Key parameter choices for the current reference case and significant changes from the 2009 reference case (DFO 2009a, Stanley et al. 2009a).

Parameter	Value (2012)	Value (2009)	Comments
Prior mean *r*	0.1067, SD= 0.039;	0.117; SD=0.035	Discussed above
Survey values of 0	Included 0 values	Excluded one 0 value	The 2009 assessment applied a lognormal likelihood function for the abundance index data with a constant standard deviation in the deviation between the logarithms of observed and model predicted abundance index values. For 2012, to accommodate the zero values, we applied a normal distribution for the likelihood function with a constant standard deviation (SD) for each time series of abundance.
Recreational catch	Included	Excluded	Described above
CVs for indices	Same as 2009		As in the 2009 assessment, we applied iterative re-weighting to arrive at values for the standard deviations in deviations between model-predicted and observed abundance index values.
Likelihood function for catch	CV=0.6 for troll CV=0.5 for halibut CV=0.4 for recreational	Same for troll and halibut	We applied a truncated normal distribution as the likelihood function for the observed halibut, recreational, and salmon troll catches. We applied a constant fixed CV for each likelihood function. The CVs for the halibut and salmon troll catch values were the same as those applied in the 2009 assessment. The CV for the recreational catch was the value that lead to the closest normal distribution approximation of the expert derived prior for the recreational catch of Bocaccio in 2010.
Schaefer surplus production function	(B_{msy}/K=0.5);	Same	Discussed above
Salmon troll daily catch	10	15	Maximum fleet-wide limit on average daily troll catch set at 10 Bocaccio per day.
Process error SD	0.1	same	
Prior mean B_{1935}/K	0.9	same	
Informative priors for survey *q*	Updated	same	
Density in trawlable area < untrawlable area	Triangular prior updated with experimental data with a median of 1.4.	Triangular prior with mode of 3 but no data used to update it.	Discussed above
Process error deviates	Lag = 1 Autocorrelation coeff. = 0.7	Autocorrelation coeff. = 0.67	Estimated from posterior median process error deviates, starts in 2012.

Third, most of the surveys and, particularly the ones that fit the model best, indicate decreases since 2008, despite total catches among the lowest in the history of the fishery. Fourth, exploitation from a fourth sector, the recreational sector, was added in this assessment. As recreational effort has not changed substantially from the 1980s, this fishery is estimated to have exerted a low fishing mortality rate since the 1980s that was not previously included. The addition of this previously unaccounted source of fishing mortality, although relatively small, acts to intensify the estimated decline in stock size.

Table 11. Reference case 2012 stock assessment statistics. Biomass values are in metric tons and the referenced current year is 2012.

Variable	Mean	SD	CV	10th Percentile	Median	90th Percentile
r	0.084	0.033	0.391	0.0397	0.084	0.1254
B_0	63,240	38,639	0.611	26,461	52,330	116,664
MSY	1,234	904	0.733	540	981	2,227
B_{msy}	31,620	19,319	0.611	13,231	26,165	58,332
B_{msy}/B_0	0.5	.	.	0.5	0.5	0.5
B_{init}	55,922	36,070	0.645	21,907	43752	98,206
B_{2012}	2,205	1,214	0.55	1,031	1,879	3,625
B_{2012}/B_{msy}	0.093	0.078	0.835	0.029	0.07	0.182
B_{2012}/B_{init}	0.054	0.048	0.885	0.016	0.041	0.106
B_{2012}/K	0.047	0.039	0.835	0.0144	0.0351	0.0911
F_{msy}	0.0422	0.0165	0.391	0.0199	0.042	0.0627
F_{2012}	0.0808	0.0359	0.444	0.041	0.0742	0.1289
F_{2012}/F_{msy}	2.2835	2.0839	0.913	1.03	1.9037	3.5758
RepY	163	90	0.552	75	143	287
Catch/RepY	1.1806	1.0267	0.87	0.5705	0.9898	1.811
B_{2011}/B_{2001}	0.6989	0.2091	0.299	0.46	0.66	0.97
$P(B_{2012}>0.4B_{msy})$	0.01					
$P(B_{2012}>0.8B_{msy})$	0.001					

Table 12. Posterior 10th, 50th, and 90th percentiles of stock biomass (t) 1935-2012 from the reference case run.

Year	Lower 10%	Median	Upper 90%	Year	Lower 10%	Median	Upper 90%
1935	21907	43752	98206	1974	9813	14442	24362
1936	21226	41662	89542	1975	9223	13394	23080
1937	20514	40226	86141	1976	8556	12812	22068
1938	19873	38530	81513	1977	8514	12939	21815
1939	19151	37378	80921	1978	8816	12815	21613
1940	18697	34925	75919	1979	8586	12868	21257
1941	18386	33731	66959	1980	8369	13031	21236
1942	17717	33074	68540	1981	8650	12822	20570
1943	17250	31801	61479	1982	8810	12708	20311
1944	16862	31125	59523	1983	8695	12730	19853
1945	16925	30524	58881	1984	8489	12407	18751
1946	16222	29843	57254	1985	8512	11886	17679
1947	15891	28407	54899	1986	8278	11095	16151
1948	15565	27689	53313	1987	7540	10351	14590
1949	15046	26894	52294	1988	6706	9123	12871
1950	14438	26449	51442	1989	5957	8023	11385
1951	13948	25297	49527	1990	5275	7153	10404
1952	13618	24702	47783	1991	4672	6202	9207
1953	13809	24445	45886	1992	3914	5327	7900
1954	13992	24667	44708	1993	3090	4401	6705
1955	14039	24184	44839	1994	2498	3638	5773
1956	13587	23946	44413	1995	2149	3240	5203
1957	13314	23410	43870	1996	1917	2930	4864
1958	13290	23189	41641	1997	1843	2829	4810
1959	12828	22328	41258	1998	1843	2709	4650
1960	12873	22438	40503	1999	1832	2728	4537
1961	13014	21777	39103	2000	1842	2749	4526
1962	13193	21277	38402	2001	1825	2718	4596
1963	12938	21363	37243	2002	1726	2599	4484
1964	12805	21415	36138	2003	1609	2502	4253
1965	13015	20672	35076	2004	1558	2475	4236
1966	12561	20286	33724	2005	1458	2428	4233
1967	12024	18819	32355	2006	1443	2365	4157
1968	11845	18224	31859	2007	1339	2278	4030
1969	11307	17697	30050	2008	1270	2230	3941
1970	11103	16759	28693	2009	1178	2071	3676
1971	11026	16194	27682	2010	1082	1935	3435
1972	10971	16118	26671	2011	1052	1911	3506
1973	10463	15279	26040	2012	1031	1879	3625

Table 13. Posterior 10th, 50th, and 90th percentiles of the ratio of stock biomass in each recent year to the stock biomass sixty years prior.

Year	10%	50%	90%
1994	0.03	0.07	0.15
1995	0.03	0.07	0.15
1996	0.03	0.07	0.15
1997	0.04	0.07	0.15
1998	0.04	0.07	0.15
1999	0.04	0.08	0.16
2000	0.04	0.08	0.16
2001	0.04	0.08	0.16
2002	0.04	0.08	0.16
2003	0.04	0.08	0.16
2004	0.04	0.08	0.17
2005	0.04	0.07	0.16
2006	0.04	0.07	0.16
2007	0.04	0.07	0.15
2008	0.04	0.07	0.15
2009	0.03	0.07	0.16
2010	0.03	0.07	0.16
2011	0.03	0.07	0.15
2012	0.03	0.07	0.15

Table 14. Comparison of key results from the 2009 (DFO 2009a) and 2012 analyses. B_{cur} refers either to 2012 or 2008.

	2012			2009		
Variable	**Mean**	**CV**	**Median**	**Mean**	**Mean CV**	**Median**
B_0	63,240	0.611	52,330	54,042	0.66	45,053
B_{msy}	31,620	0.611	26,165	27,021	0.662	22,526
B_{cur}	2,205	0.55	1,879	3,022	0.83	2,324
B_{cur}/B_{msy}	0.093	0.835	0.070	0.155	0.973	0.111
B_{cur}/K	0.047	0.835	0.0351	0.078	0.973	0.056
RepY	163	0.552	143	236	0.649	198

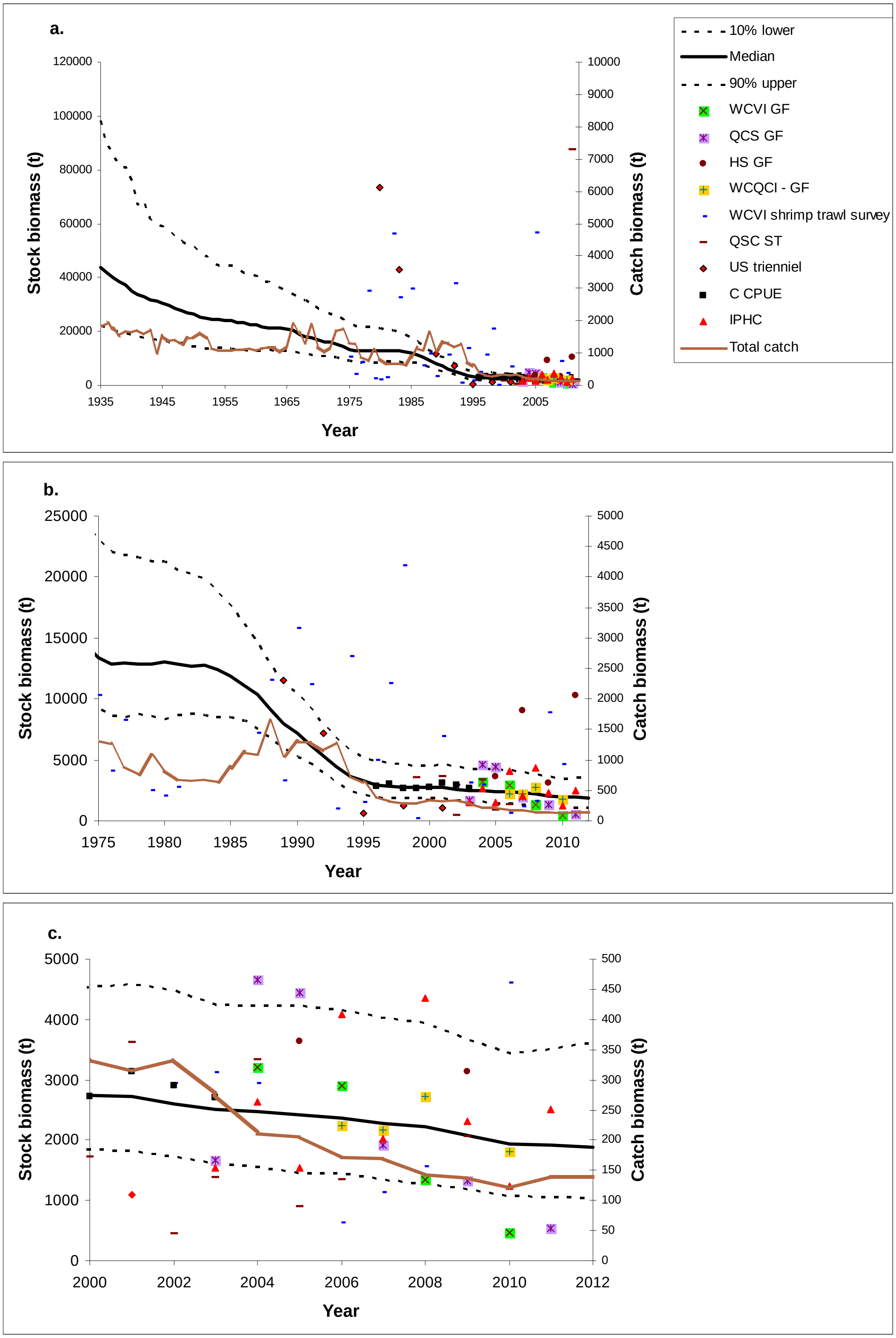


Figure 17. Plots of median and 80% probability intervals and indices rescaled by their median a. 1935-2012; b. 1975-2012; c. 2000-2012. Note that some of the very large values for some of the indices are not shown in panels b. and c. to permit closer inspection of more recent trends.

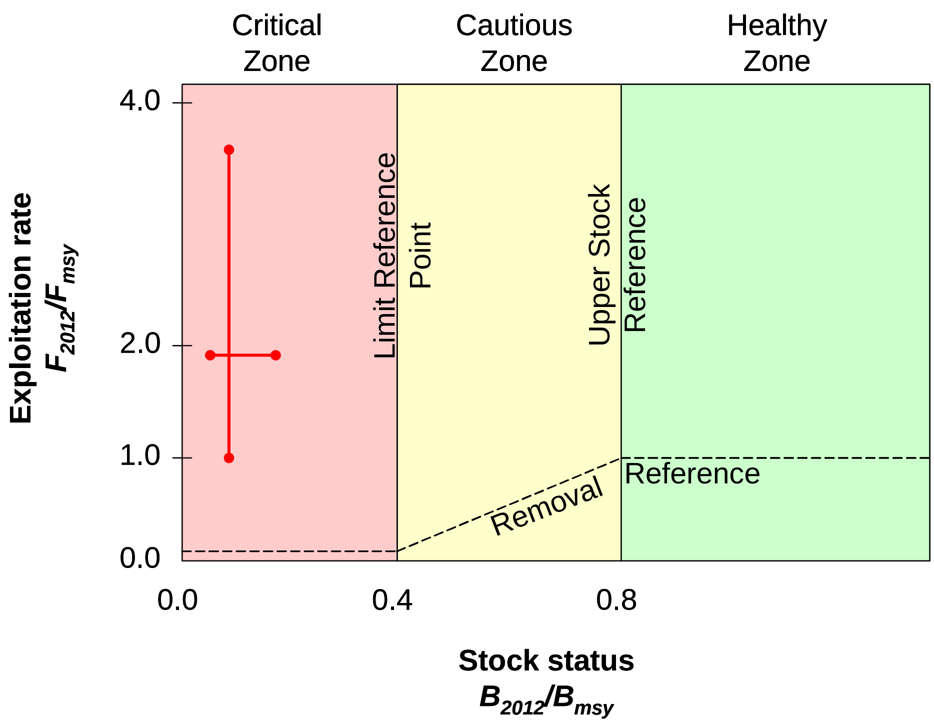


Figure 18. Estimated stock status in 2012 and exploitation rate relative to reference points (from Table 11). Range indicates 10th and 90th percentiles.

11.3 REFERENCE CASE MODEL PERFORMANCE AND UNCERTAINTY

Posterior distributions for most quantities show an update from the prior distributions (Figure 19). The post model, pre-data distributions were also shown in Figure 19. The post model, pre-data distribution shows how the priors interact with the BSP model, fixed inputs for catch, and fishing effort for the different imputed fisheries before the model is fitted to the abundance index data. The post model, pre-data distributions indicate that the priors for model parameters, when applied in combination with the inputted values for catch and effort, provide quite vague information about most of the model parameters and quantities of interest. While the post model, pre-data distribution for catch to replacement yield in 2012 appears to be informed by the model inputs and model structures, the range is still quite wide with most outputted values ranging between about 0.1 and 2 and is not updated after fitting to the abundance indices (Figure 19). This is the only posterior distribution that is not significantly updated by the abundance data.

Model fits to the survey and CPUE data are poor, with large deviations between observed and predicted indices. CVs for the predicted to observed fits to the abundance indices are greater than 0.5 for seven out of nine series (Table 15; Figure 17). This outcome is caused by some large outlier values in both shrimp trawl series and in the US Triennial series (Figure 12). Autocorrelation is apparent in the deviates for some of the indices, as, for example, in the US Triennial series (Figure 17). The posterior mean for the intrinsic rate of increase (*r*) was 0.084 (CV=39%), less than the prior of 0.107 (CV=37%) (Figure 19c). This decrease in the mean value for *r* suggests that the model reduced the average underlying stock productivity in order to fit the recent declines in biomass.

It is tempting to configure the model to fit the US Triennial index more closely because it indicates an intuitively acceptable monotonic trend. However, this is not only a circular argument but, as noted in Stanley et al. (2009a), the apparent trend is highly leveraged by one anomalous tow in the first year. We suggest that the reference case weighting of all indices is appropriate in not allowing single survey points (or surveys) to have undue influence.

The marginal posterior distributions indicated that moderate amounts of precision were obtained for most parameters (Figure 19). However, the large skews and long tails remain for some estimates. For example, much of the probability for carrying capacity lies well below 75,000 t while the tail stretches to 175,000 tonnes. Estimates for some other quantities are well defined. For example, for B_{2012}/B_0, the majority of the probability lies below 10% of B_0.

The annual process error deviates from the predicted surplus production were strongly negative for 2006-2009 (Figure 20). This indicates that the model production function predicted higher production in these years than has been reflected in the surveys. This effect is in addition to the lowering of the average stock productivity discussed in the previous paragraph, indicating that recent stock productivity has been even lower than predicted, even for an average r=0.084. Although none of the deviates was significantly different from 0, these negative deviates in 2006-2009 suggest that there was poor recruitment into exploitable age classes in these years. This relatively poor recruitment may explain, in part, why the population has not responded to the recent reduction in catches.

For the reference case and other model runs, the autocorrelation coefficient at lag 1 in the process error deviates from 1980 to 2010 was estimated at about 0.7, which was significant (p<0.05). This implies that there is a strong tendency for a poor year of surplus production to be followed by poor years.

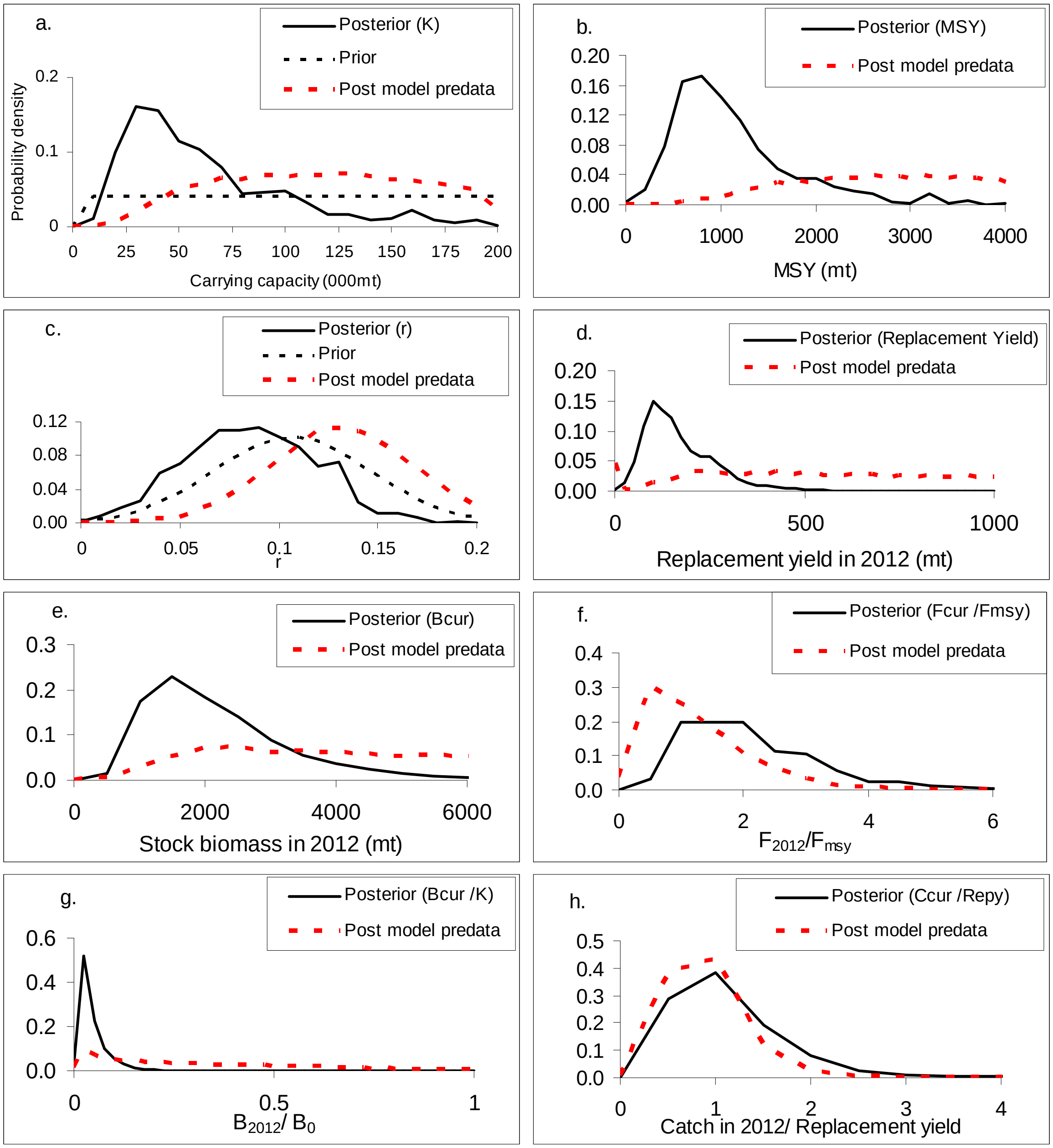


Figure 19. Marginal posterior distributions for a. carrying capacity (K or B_0); b. maximum sustainable yield (msy); c. r; d. replacement yield in 2012; e. stock biomass in 2012; f. the ratio of fishing mortality rate in 2012 to that at msy; g. the ratio of stock biomass in 2012 to average unfished stock size; and, h. the ratio of total catch biomass in 2012 to replacement yield in 2012. Priors are shown for B_0 and r. The post model, pre-data distributions are shown for derived quantities to show the influence of the catch and effort data, model structure, and prior distributions on model output distributions for quantities of interest.

Table 15. Values for the CVs applied for each of the abundance indices in the reference case and other model runs. Note that the CVs derived from iterative reweighting changed little between runs.

Index	Number of data points	Years	Standard deviation	Average value	Approx. CV
WCVI GF	4	2004-2010	135	229	0.59
QCSd GF	6	2003-2011	110	161	0.68
HS GF	4	2005-2011	25	35	0.71
WCHG GF	4	2006-2010	2	10	0.20
WCVI shrimp trawl	35	1975-2011	170	123	1.38
QCSd shrimp trawl	13	1999-2011	135	43	3.14
US Triennial	7	1981-2001	1,900	2,176	0.87
Comm. CPUE	8	1996-2003	4.5	29	0.15
IPHC	9	2003-2011	1.1	2	0.51

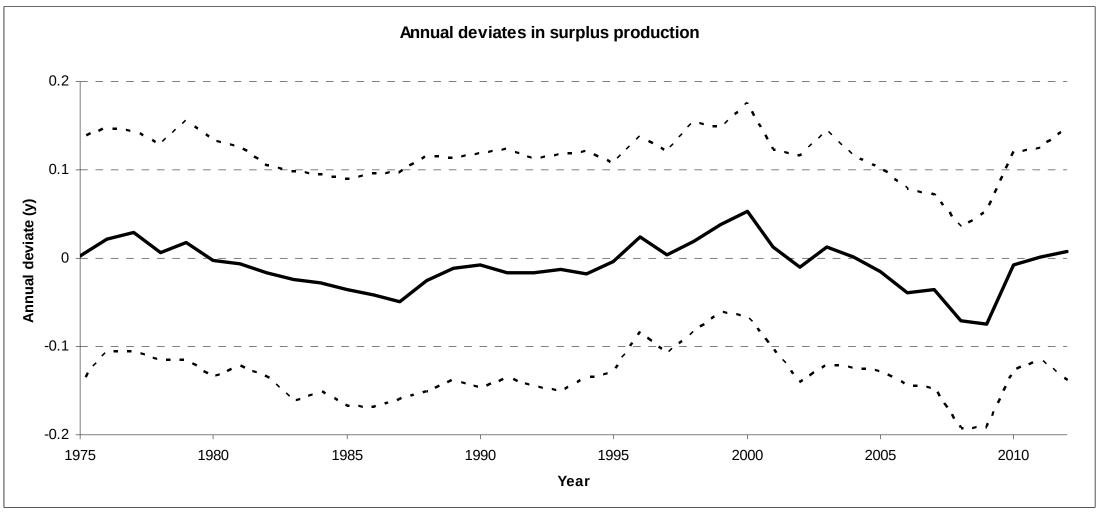


Figure 20. Annual deviates in surplus production with the median and 80% probability intervals shown. Estimates are shown only for years after 1975 because without data prior to then, the posteriors for these deviates are determined by the prior.

11.4 REFERENCE CASE RECONSTRUCTION OF HISTORICAL CATCHES

The estimated historical catch for the halibut, salmon troll, and recreational fisheries from the reference case are provided in Figure 21, with the median values and the estimated relative contributions from each sector provided in Appendix Table 1 and Appendix Table 2.

The posterior distributions for the catchability coefficients for the halibut, salmon troll, and recreational fisheries show some moderate updating from the priors to favour smaller values (Figure 22). The posterior distributions still show considerable uncertainty with long right hand tails, especially for the halibut and recreational fisheries. The more precise distribution for the salmon troll fishery results from the extremely high historic effort relative to current effort and the estimated high catches for this fishery prior to the mid-1990s.

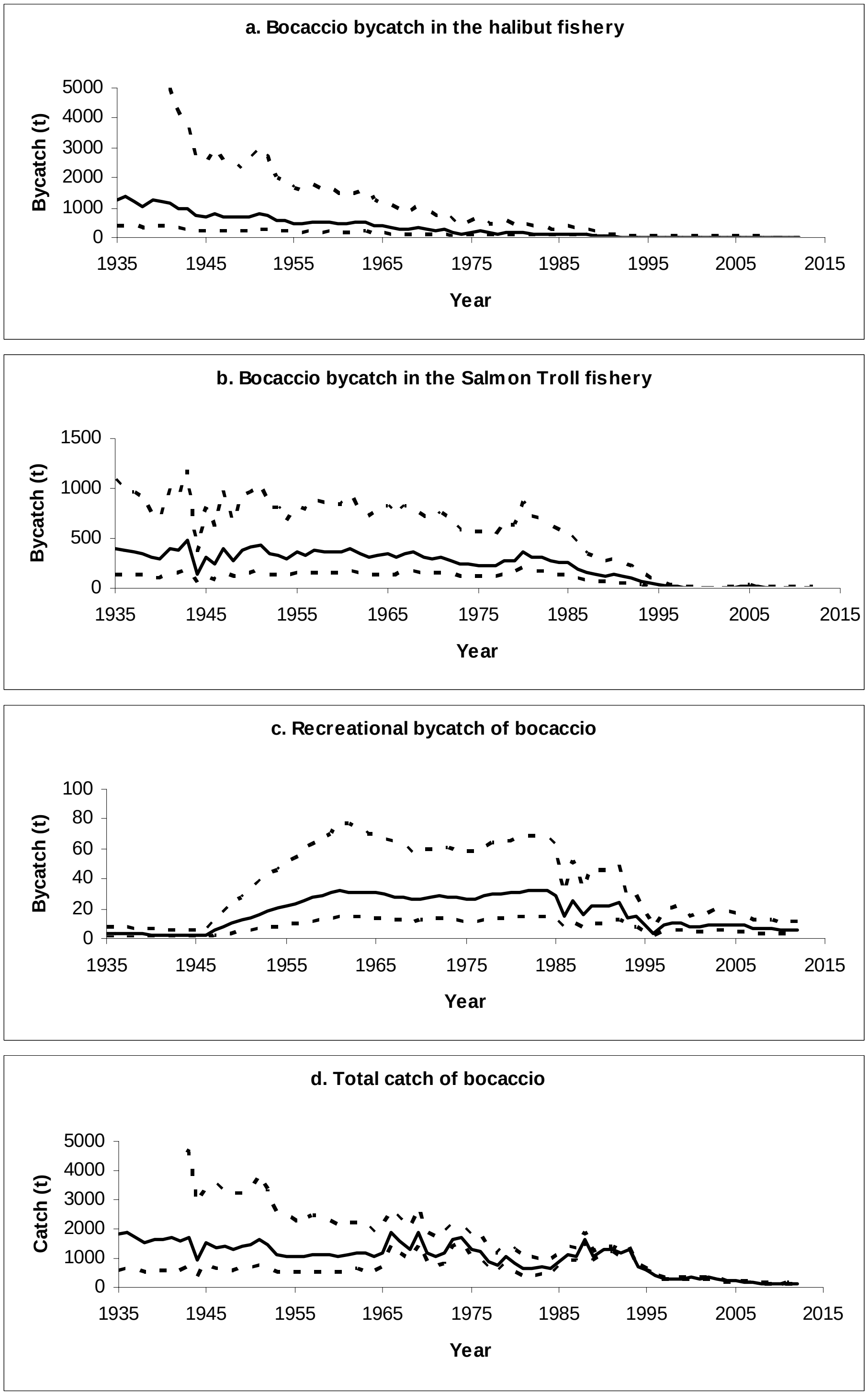


Figure 21. Median and 80% probability intervals for catch of Bocaccio in the: a. halibut fishery, b. salmon troll fishery, and c. recreational fishery, d. all sectors combined including trawl and ZN HL. Note the large variation in scale on the y-axis.

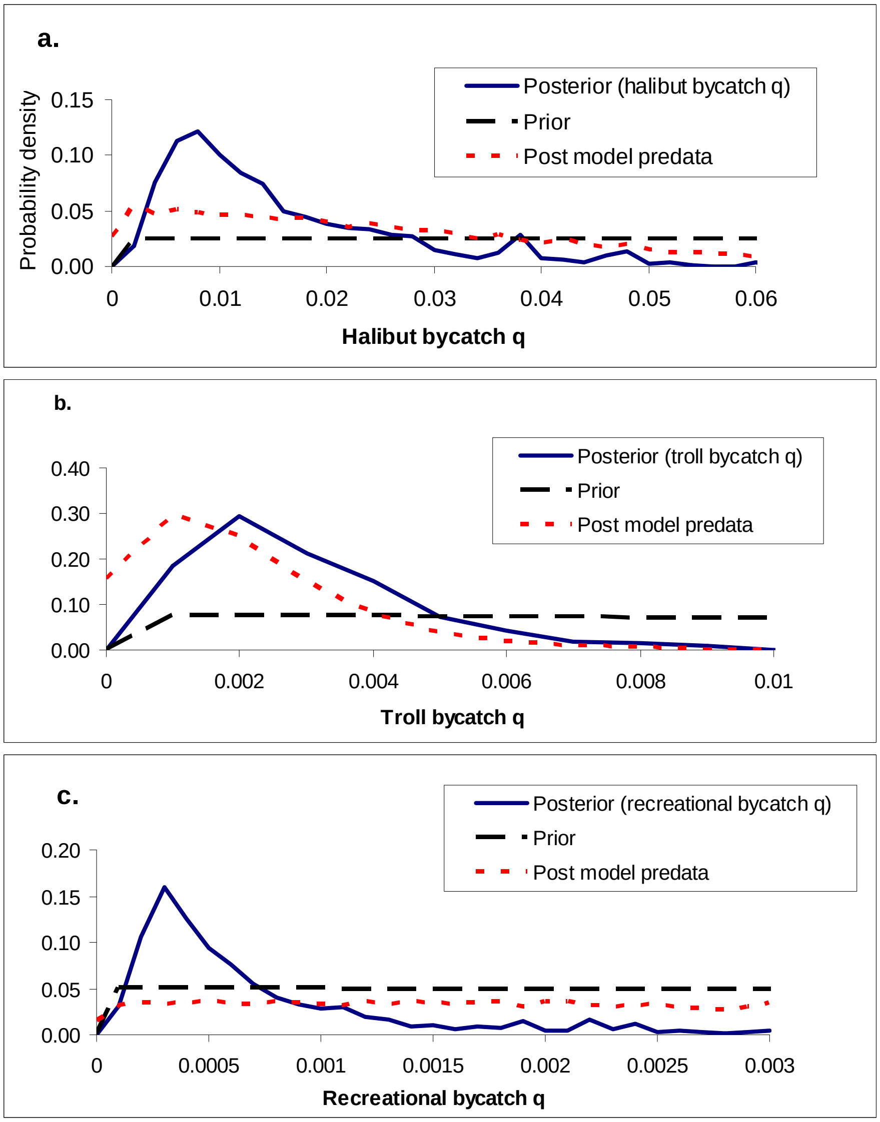


Figure 22. Prior and posterior density functions for the catchability coefficients for the a. halibut, b. salmon troll, and c. recreational sectors.

12 SENSITIVITY TESTS

12.1 SENSITIVITY RUNS

Eighteen additional runs were used to evaluate the sensitivity of the results in the reference case to alternative assumptions (Table 16) (see also Stanley et al. 2009a in which 31 additional model runs were examined).

A common point of uncertainty with the implementation of the Schaefer model is its assumption that B_{msy}/B_0 rests at 0.5. While this may be plausible for a population with very low productivity (low maximum intrinsic rate of increase), alternative values cannot be ruled out. We therefore examined runs with B_{msy}/B_0 fixed at values of 0.3, 0.4, and 0.6 (**A.1-A.3**).

The reference prior for *r*, was formed using empirically derived uncertainty distributions for all life history parameters; however, there is uncertainty in these inputs. One of these includes the posterior predictive distribution for the Ricker steepness parameter for rockfishes (Forrest et al. 2010). In DFO 2009a, two cases examined prior medians for *r* at 67% and 133% of the reference case prior. With a higher input distribution for steepness, the prior CV in *r* remained the same and the prior standard deviation increased proportionally with the mean value for *r*.

We captured the uncertainty in *r* by specifying two alternative prior distributions for *r* by setting the prior mean to 67% of the reference case prior mean (low prior *r*) and setting the prior mean to 133% of the reference case prior mean (high prior *r*). The prior CV was held constant for both cases (**B.1 and B.2**).

Table 16. Summary of sensitivity test runs.

Code	Category Description	Code	Run Description
Ref	Reference run	Ref	Reference run
A	B_{msy}/K	A.1	B_{msy}/K = 0.3
		A.2	B_{msy}/K = 0.4
		A.3	B_{msy}/K = 0.6
B	*r* prior mean	B.1	low *r* (mean = 0.0802, SD = 0.0391)
		B.2	High *r* (mean = 0.142, SD = 0.052)
C	Catch assumptions	C.1	Sum of trawl and non-halibut hook and line catch x 0.5 all yrs
		C.2	Sum of trawl and non-halibut hook and line catch x 1.5 all yrs
		C.3	Sum of trawl and non-halibut hook and line catch x 0.25 86-95
		C.4	Sum of trawl and non-halibut hook and line catch x 0.5 86-95
D	Survey *q* priors	D.1	Non-informative priors for all constants of proportionality for abundance indices (*q*); priors for the catchability coefficients for the imputed fisheries were kept the same as in the reference case, i.e., also non-informative.
E	Effect of data	E.1	Include only one data point per series and non-informative priors for all *q*s: post model, pre-data analysis of output distributions.
F	Bycatch assumptions[1]	F.1	Halibut catchability for Bocaccio decreased by 2.0% per year (implies effort in 1935 4.7 x reference effort in 1935)
		F.2	Halibut catchability for Bocaccio decreased by 1.5% per year (implies effort in 1935 3.2 x reference effort in 1935)
		F.3	Halibut catchability for Bocaccio decreased by 1% per year (implies effort in 1935 2.2 x reference effort in 1935)
		F.4	Halibut catchability for Bocaccio increased by 1% per year (implies effort in 1935 0.5 x reference effort in 1935)
		F.5	Halibut catchability for Bocaccio increased by 1.5% per year (implies effort in 1935 0.3 x reference effort in 1935)
		F.6	Halibut catchability for Bocaccio increased by 2.0% per year (implies effort in 1935 0.2 x reference effort in 1935)
		F.7	Model started in 1900 with 1900–1934 halibut effort assumed proportional to halibut catch in same year, scaled to the 1935 halibut catch and effort; other catch and effort series set=0 in 1900 and increased proportionately to 1935 observed values

[1] Sensitivity runs F.1 to F.6 were generated relative to average absolute effort observed from 2006 to 2011.

The uncertainty in the fixed catch estimates for trawl and HL fisheries was captured by investigating two alternative scenarios which set these historic catches to 50% and 150% of the reference case, respectively (**C.1 and C.2**). Two additional sensitivity runs were performed in which the fixed catch estimates for domestic trawling in 1986-1995 were decreased by a factor of 0.25 and 0.5. This was to reflect the possibility that sales slip and fisher logbook data inflated the catches of Bocaccio in this period (**C.3 and C.4**). The sensitivity of the model results to informed priors on *q* was investigated by replacing these priors with uninformative priors with wide bounds (uniform over ln(*q*)) (**D.1)**.

A question often arises in Bayesian stock assessment about the degree to which the model structure, acting with priors and the fixed inputs, influences the stock status results. To address this issue, we evaluated the influence of the reference case priors and fixed values for trawl and HL catch and fishing effort. We did this by producing what has been called the "post-model pre-data distribution" of model outputs (Punt and Butterworth 2002). We ran the model by informing it with the prior distributions for all of the estimated parameters and applying the fixed input values for catch and historic troll, halibut, and recreational effort but without fitting the model to the abundance data **(E.1)**. In other words, we effectively drew values for parameters from their prior distributions and projected the model with the fixed catch and effort values. We then compiled the frequency distribution of outputted parameter values and quantities of interest. We did so without weighting the trajectories according to how well the modelled trajectories fitted the abundance indices and the data on catch for the halibut, salmon troll, and recreational fisheries. Even without the likelihood function applied, we can expect some updates to the prior distributions. Some combinations of parameter values drawn from the prior distributions will result in population trajectories that crash the population before the current year. These runs are weeded out and not counted in tallying up the post-model, pre-data distributions.

A strong assumption in the imputation of bycatch based on a time series of effort is that the catchability (*k*) of Bocaccio in these fisheries has remained constant over time. The fishery with the largest imputed bycatch of Bocaccio is the halibut fishery therefore; we carried out a number of sensitivity runs based on assumed constant rates of change in *k* over the time series. We carried out six additional model runs where *k* was modelled to change at rates of -2%, -1.5%, -1%, 1%, 1.5%, and 2% per year (F.1-F.6). In addition, the halibut effort in the initial year, 1935, starts out high and gradually drops. Early records of halibut catches in BC (Bell et al. 1952) show that catches were very low in 1900, followed by a gradually increasing trend, peaking in the 1920s and subsequently dropping by about 40% in the 1930s (Table 17). We carried out an additional sensitivity run in which the model was started in 1900. This run imputed the values for halibut effort based on the assumption that halibut effort was directly proportional to halibut catch during the period 1900 to 1934, scaled relative to the 1935 halibut catch and effort. Other catch and effort series were filled by starting each series at zero and increasing each proportionately to reach the observed values in 1935 (F.7).

The prior mean for P_0 (i.e., the ratio of stock biomass in the initial year to B_0) was set at 0.9, with a prior coefficient of variation (CV) of about 0.2, as in the 2009 assessment. While the actual uncertainty in P_0 may be greater, numerous studies have shown that, providing the stock assessment model starts several decades in the past as this one does, the prior mean presumed for P_0, has very little effect on estimates of key parameters and stock status (e.g., Stanley et al. 2009a; King et al. 2012; Yamanaka et al. 2012). Due to this, there was no need to include different priors for P_0 in the sensitivity analyses.

No sensitivity runs were made to explore possible changes in species productivity over the model period. It is certainly plausible that average Bocaccio productivity has varied over the 60-70 years that are modelled in this analysis; however, we have no specific information to assist us in modelling time-dependent changes in the appropriate parameters. Furthermore, only if future variation in productivity was predictable, would such modelling assist in managing the Bocaccio population.

Table 17. Records of Pacific Halibut catch (t) in BC waters from 1900-1937 (Bell et al. 1952).

Year	Catch	Year	Catch
1900	3,598	1919	20,084
1901	4,998	1920	23,233
1902	7,312	1921	29,892
1903	9,062	1922	26,906
1904	12,180	1923	30,029
1905	7,200	1924	29,997
1906	9,950	1925	29,547
1907	12,915	1926	27,681
1908	15,892	1927	26,786
1909	19,460	1928	30,467
1910	19,387	1929	28,656
1911	15,854	1930	24,466
1912	21,127	1931	18,374
1913	22,347	1932	17,046
1914	21,444	1933	17,027
1915	31,769	1934	18,313
1916	26,723	1935	17,129
1917	23,030	1936	17,001
1918	17,793	1937	18,917

12.2 SENSITIVITY RESULTS

In general, the sensitivity tests did not reveal any significantly different stock status conclusions relative to the reference case (Table 18). All of the runs, except for the diagnostic run, **E.1**, continue to indicate a stock that is well below $0.4*B_{msy}$ and that current catch levels are approximately equal to estimates of replacement yield (*RepY*).

Results were relatively insensitive to the choice of B_{msy}/K (**A.1-A.3**). Posterior median values for B_{curr}/B_{msy} increased from 0.076 to 0.110 when the B_{msy}/K ratio decreased from 0.6 to 0.3, which was the greatest range observed in stock status among the 18 sensitivities investigated. The estimates of the ratios of total catch to replacement yield *(Catch/RepY)*, and the current fishing mortality rate to F_{msy} (F_{curr}/F_{msy}) were also relatively insensitive to choice of B_{msy}/K, although these estimates were the least optimistic for the highest setting of B_{msy}/K, as expected.

The posterior median value for B_{msy} was largest for the reference case with B_{msy}/K set at 0.5. In contrast, one might think it should be largest for the run with the largest B_{msy}/K (i.e., 0.6). The smaller estimate of B_{msy} for the 0.6 run results mainly from a marked discontinuity in the shape of the Fletcher generalized production function as B_{msy}/K increases from below to above 0.5 as discussed earlier (Figure 16). The data to which the surplus production models were fitted tend to reference the different production curves to the similar *msy* values, since we see little change in abundance for several years at similar levels of low catches after strong depletion. At the same value for *msy*, the Schaefer model with B_{msy}/K at 0.5 predicts the largest values for B_{msy} and K when compared to the Fletcher model variants with different B_{msy}/K. Below the value of 0.5 for B_{msy}/K, B_{msy} decreases with B_{msy}/K. Similarly, values of B_{msy}/K above 0.5 lead to decreases in B_{msy} and *K.* This is a mathematical consequence of the Fletcher model parameterization (Quinn and Deriso 1999).

Overall results varied modestly and predictably with different priors for *r* (**B.1 and B.2**.), and high and low scenarios catch scenarios (**C.1 and C.2**). For example, lower values for *r* and higher values for catches scaled up the estimates of current stock biomass but the estimates of depletion and *Catch/RepY* in 2012 remained insensitive to these alternative input settings. The lower catch scenario slightly reduced the estimate of *Catch/RepY*. When the fixed catch inputs for 1986-1995 were lowered by factors of four and two (C.3 and C.4), the effect was to slightly reduce the posterior mean for *r,* reduce the estimated replacement yield in recent years, and lower the estimated current stock status for run C.3. It remained the same as the reference case for run C.4 (Table 18).

Application of a non-informative prior for *q* resulted in considerably lower precision in the estimates of biomass-related quantities (**D.1**). For example, the 80% probability range for biomass in 2012 was 970-5,500t versus 1,000-3,600t under the non-informative and informative priors, respectively. The posterior median values with the non-informative prior were slightly less pessimistic mainly because of the large positive skew for biomass under the non-informative prior for *q*. For example, *Catch/RepY* was 0.83 compared to 0.99 under the reference case.

The removal of all of the stock assessment data under the reference case to create a post model, pre-data run (**E.1**), yielded much wider probability distributions for all biomass derived quantities and show the influence of the priors on model output distributions when the fixed values for historic catch and effort are applied. For example, the 80% probability interval for stock biomass in 2012 widened to 3,600-81,000 t as compared with 1,000-3,600 t under the reference case. The confidence interval for B_{2012}/B_{msy} increased to 0.07-1.4 from 0.03-0.18 under the reference case. This run shows that the model structure, priors, and fixed inputs for catch and effort acting together, do not lend high precision to any of the results. Nor do they strongly bias the stock status results in one direction. The precision in the estimates of status derive mainly when the model is fitted to the abundance index data and data on catch for the three fisheries with catches estimated from effort series.

Estimated stock status showed a slight increasing trend from F.1 (catchability decreasing by 2%/year) to F.6 (catchability increasing by 2%/year) (Table 18). However, the magnitude of this increase was slight, demonstrating that the model conclusions regarding stock status were insensitive to the assumptions for the annual rate of change in the catchability coefficient, *k*. The magnitude of the estimated Bocaccio catch in the early years of the fishery varied considerably as a result of the different assumptions used for *k* and the consequent variation in the time series of effective halibut effort (Figure 23). Extending the model backwards to 1900 resulted in posterior distributions for all parameters that were nearly indistinguishable from the reference case. This implied little sensitivity to the choice of beginning year for the stock reconstruction with respect to estimates of current biomass level and relative stock status.

To provide a better understanding on how the different sensitivity runs behaved, the posterior medians for B_{init}/K, (*init*=1935), the posterior median estimated catches for the halibut, troll, and recreational fisheries, total catch, replacement yield and the posterior median for the total catch to replacement yield are also provided (Table 19). The posterior median values for the B_{init}/K ratio values were largely determined by the prior distribution and were similar across all model runs.

The posterior medians for the estimated catches were also similar across runs, except for the post model, pre-data run (**E.1**) which gave very high values for output catch and stock biomass distributions. This occurred because the reference catch data for the imputed fisheries were ignored and not used to weight the different model trajectories in the computation of model output distributions. As mentioned above, the absolute level of imputed bycatch for the halibut fishery from 1935 was sensitive to the values assumed for the catchability parameter *k*.

The posterior median for total catch was less than the posterior median for replacement yield for the instances in which the Fletcher-Schaefer model was run. In **A.1**, while the posterior median of *Catch/RepY* was about 1, the posterior median for the total catch (148 t) was less than the posterior median for the replacement yield (176 t) (Table 19, Figure 24). This was a consequence of the strong discontinuity in the shape of the Fletcher-Schaefer production function that was applied in this run (Figure 16). The same pattern and explanation applies to **A.2.** The resulting differences in the posterior distributions for *RepY* and total catch, and somewhat ragged relationship between total catch and *RepY* in these runs are illustrated in Figure 24**.** Note that median estimates of ratio *Catch/RepY* will not necessarily equal the ratio of median estimates of catch and median estimate of *RepY*.

Table 18. Medians and 80% credibility intervals drawn from the posterior distributions for seven parameters taken from the Bocaccio assessment for the reference run and 18 sensitivity runs. Codes used for each run along with a run description can be found in Table 16. Biomass values are in tons.

Run	*r*			B_{msy}			$B_{current}$			*RepY*			$B_{current}/B_{msy}$			$F_{current}/F_{msy}$			$Catch_{curr}/RepY$		
	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%	10%	Median	90%
Ref.	0.040	0.084	0.125	13231	26165	58332	1031	1879	3625	75	143	287	0.029	0.070	0.18	1.03	1.90	3.58	0.57	0.99	1.81
	B_{msy}/K																				
A.1	0.052	0.097	0.152	9677	19596	37601	1072	2077	3917	81	176	409	0.048	0.110	0.28	1.02	1.89	3.53	0.56	1.00	1.84
A.2	0.047	0.093	0.152	10665	23007	46577	1071	1969	3885	74	170	414	0.039	0.085	0.23	1.07	1.96	3.63	0.59	1.03	1.90
A.3	0.038	0.078	0.123	11512	24340	60034	916	1878	3753	63	140	291	0.028	0.076	0.21	1.06	2.10	4.58	0.57	1.05	2.17
	***r* prior mean**																				
B.1	0.022	0.06	0.104	15192	31551	65200	1228	2185	4072	48	122	241	0.030	0.067	0.17	1.14	2.20	5.58	0.63	1.15	2.85
B.2	0.04	0.094	0.157	9970	18703	39430	907	1716	3447	66	146	277	0.037	0.092	0.22	0.91	1.80	4.03	0.53	0.948	2.02
	Catch assumptions																				
C.1	0.033	0.074	0.115	9214	17717	34973	671	1205	2428	40	81	162	0.032	0.065	0.18	0.94	1.83	3.46	0.53	0.97	1.76
C.2	0.049	0.089	0.135	15977	30036	56272	1312	2297	4510	97	192	363	0.032	0.073	0.19	1.04	2.012	3.99	0.59	1.04	2.01
C.3	0.034	0.071	0.108	14406	26808	51374	1030	1735	3442	58	119	233	0.028	0.063	0.16	1.267	2.37	4.86	0.69	1.23	2.40
C.4	0.039	0.078	0.119	12970	25326	51962	1041	1897	3599	63	135	271	0.032	0.075	0.19	1.09	2.10	4.37	0.61	1.09	2.18
	Survey *q* priors																				
D.1	0.051	0.094	0.144	11629	20908	49517	969	2208	5450	82	181	404	0.036	0.098	0.30	0.697	1.53	3.37	0.42	0.83	1.68
	Effect of data																				
E.1	0.086	0.132	0.18	28358	59382	89656	3589	24012	80996	393	1944	4777	0.069	0.522	1.38	0.353	1.03	2.39	0.41	0.84	1.41
	Assumptions about catch																				
F.1	0.041	0.082	0.124	16897	34823	69233	1227	2212	4070	85	164	310	0.027	0.060	0.17	0.92	1.71	3.21	0.51	0.89	1.60
F.2	0.044	0.086	0.120	16375	32473	66401	1106	1997	3800	85	148	284	0.027	0.058	0.16	1.01	1.89	3.21	0.56	0.99	1.63
F.3	0.044	0.082	0.124	14879	29374	59814	1101	1944	3754	77	149	280	0.030	0.064	0.18	1.00	1.89	3.55	0.56	0.98	1.78
F.4	0.045	0.089	0.129	12261	21667	50526	843	1882	3519	74	145	293	0.034	0.074	0.20	1.05	1.96	3.73	0.58	1.03	1.89
F.5	0.044	0.087	0.130	11529	21187	48401	932	1840	3642	68	138	282	0.034	0.078	0.20	1.07	2.08	4.07	0.60	1.09	2.03
F.6	0.043	0.088	0.135	11477	19427	40977	976	1847	3592	70	148	282	0.040	0.089	0.21	1.04	1.94	3.90	0.59	1.03	1.96
F.7	0.044	0.086	0.132	13226	26644	60055	1000	1930	3709	76	144	296	0.030	0.068	0.19	0.98	1.87	3.65	0.55	0.98	1.83

Table 19. Posterior medians for estimated catch values and replacement yield statistics for 2012 taken from the Bocaccio assessment for the reference run and a selection of the sensitivity runs. Codes used for each run along with a run description can be found in Table 16. Catch values are in tonnes.

Run	B_{init}/K	**Halibut catch (1935)**	**Halibut catch (2012)**	**Salmon troll catch (2012)**	**Rec. catch (2012)**	**Total catch (2012)**	***RepY* (2012)**	***Catch/ RepY* (2012)**
Ref.	0.88	1,242	6	6	7	140	143	0.99
A.1	0.89	1,366	6	6	9	148	176	1.00
A.2	0.87	1,153	5	6	8	145	170	1.03
A.3	0.89	981	6	7	7	144	140	1.05
B.1	0.88	1336	6	6	6	140	122	1.14
B.2	0.87	584	4	6	6	137	146	0.95
C.1	0.88	797	4	7	6	77	81	0.97
C.2	0.89	1,247	7	6	6	200	192	1.04
C.3	0.87	1,364	6	9	7	144	119	1.23
C.4	0.87	1,172	6	8	7	144	135	1.09
D.1	0.89	992	6	8	7	146	181	0.83
E.1	0.87	2,422	127	50	964	1,407	1,944	0.84
F.1	0.88	4,872	4	7	7	141	164	0.89
F.2	0.90	3,639	5	7	8	142	148	0.99
F.3	0.89	2,422	5	7	7	141	149	0.98
F.4	0.87	620	7	6	7	146	145	1.03
F.5	0.89	434	7	6	7	146	138	1.09
F.6	0.89	294	8	7	7	147	148	1.03
F.7	0.87	910	5	5	7	142	144	0.98

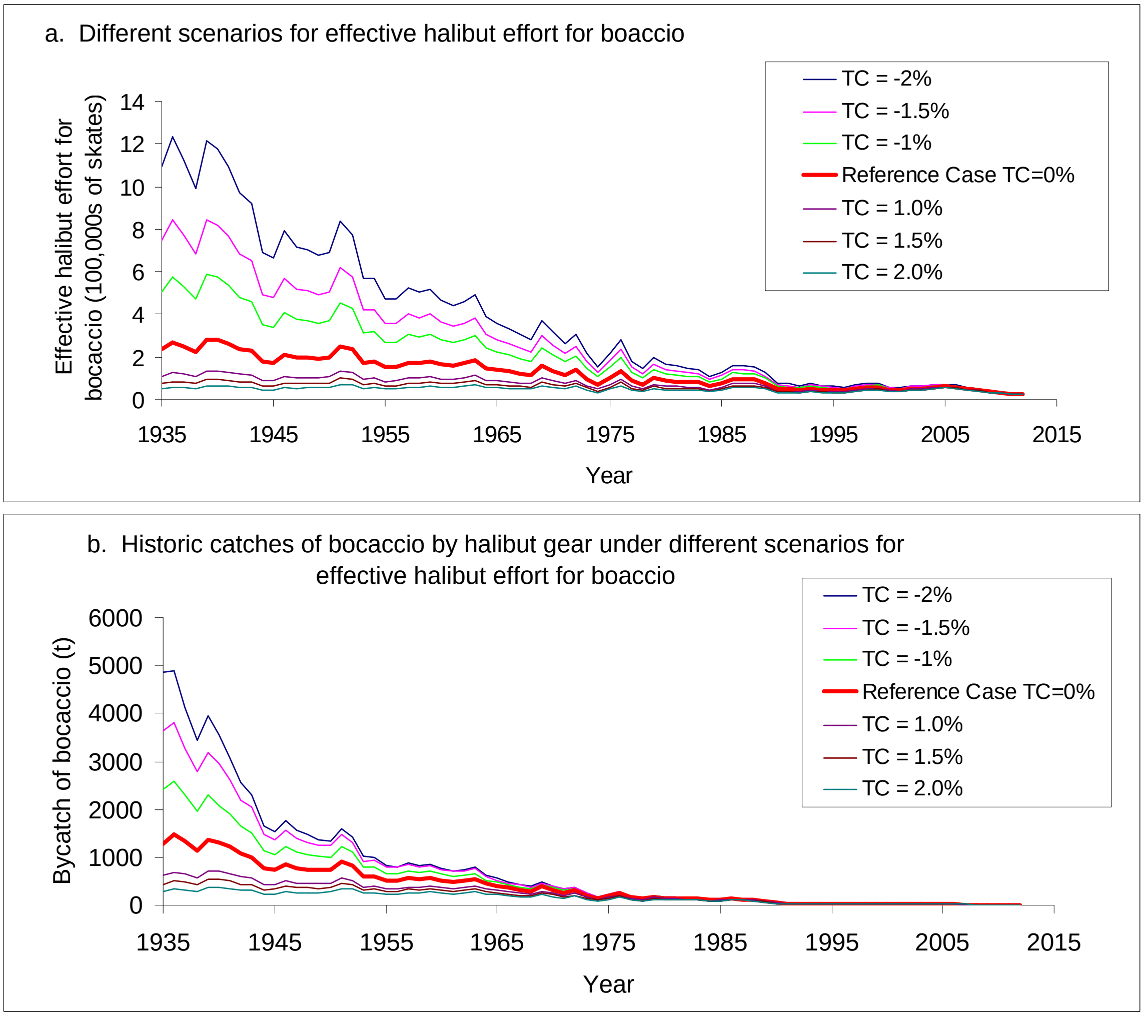


Figure 23. Plots of a. effective halibut effort in BC waters and b. posterior median catch of Bocaccio by halibut gear under different scenarios for constant percent changes in catchability of halibut gear for Bocaccio, (i.e., termed "technological creep" or "TC").

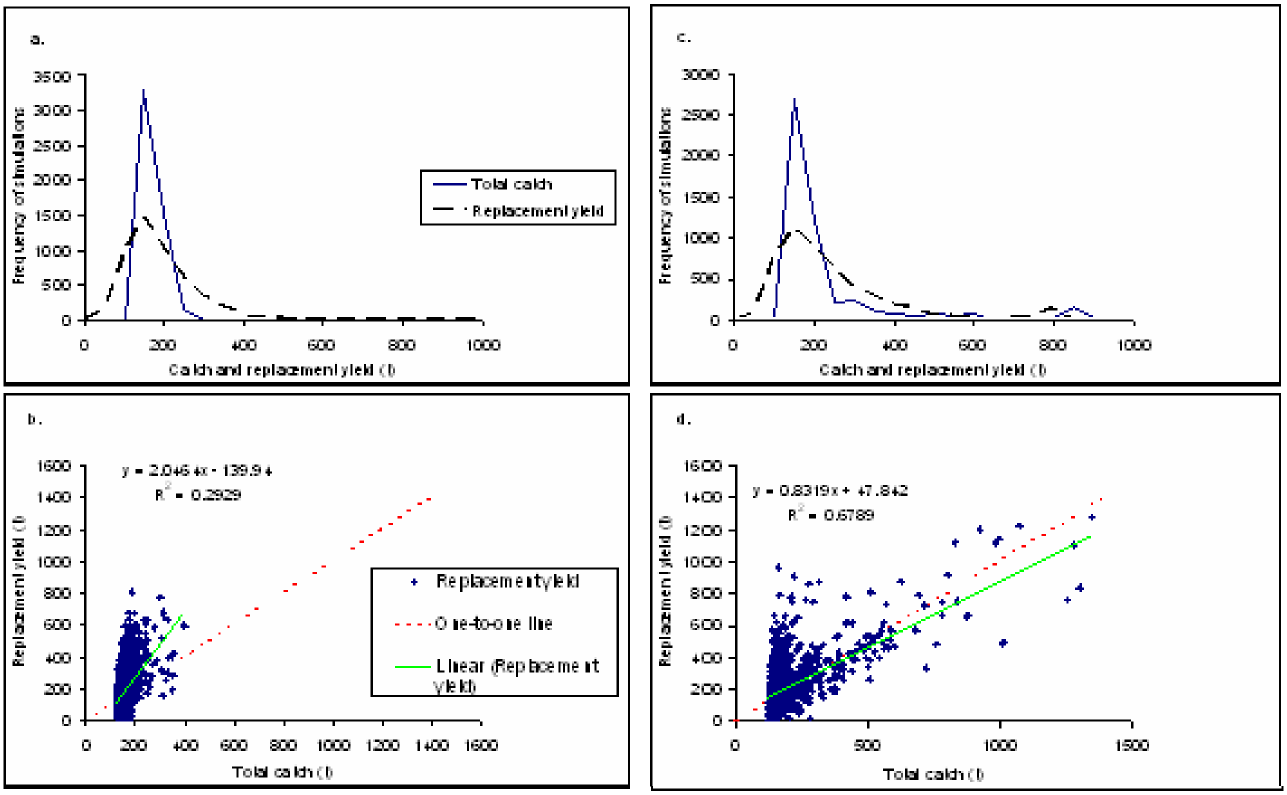


Figure 24. Plots of the a. marginal posterior distributions for total catch and replacement yield; b. draws from the posterior distribution of values for replacement yield versus total catch from the reference case run; c. marginal posterior distributions for total catch and replacement yield and d. draws from the posterior distributions of values for replacement yield versus total catch from run A.1.

12.3 SENSITIVITY RUNS EVALUATED WITH BAYES FACTORS

To compare the credibility of each model given the data, we computed Bayes factors (Kass and Raftery 1995) for the reference case and for each of the related sensitivity runs. Bayes factors account for both the relative goodness of fit of the model to the data and the parsimony for each of the alternative models. They are calculated as the ratio of the marginal probability of the data for one model to that for another model. We used the mean value for the importance weights from a given model run as an approximation of the probability of the data given the model (Kass and Raftery 1995, McAllister and Kirchner 2002). This is known to be a numerically stable approximation for the probability of the data, given the model and approximations obtained through importance sampling. For example, the CV in the natural logarithm in the mean weight was less than 0.05 after several million draws from the importance function. In all instances, we compared Bayes factors to our reference case model settings. In other words, the probability of the data for the reference case model was placed in the denominator and that for the model run to which it was compared in the numerator. It is commonly held that the Bayes factor must depart substantially from 1.0 for anything to be inferred from the exercise but even fairly large or small departures in Bayes factors can result from random chance in the data and/or misspecification of probability models. Intermediate values for Bayes factor (e.g., between about 0.001 and 100) should be interpreted with caution. For example, models that had Bayes factors of between about 0.1 and 0.01 could be interpreted as unlikely but not discredited. When the Bayes factor for a model is less than 0.001, the model could be viewed as highly unlikely relative to the other.

Except in a few instances, none of the Bayes factors indicated that one of the alternative scenarios could be considered much less, or more, plausible than the reference case (Table 20). The only scenario with a slightly higher Bayes factor than the reference case was B.1 with the low prior mean for *r.* This was consistent with the reference case because the posterior for *r* in the reference run was updated to support lower values of *r* than the prior for *r*.

The two production functions with the B_{msy}/K set at 0.3 and 0.4 had Bayes factors of about 0.2, indicating that the model with B_{msy}/K set at 0.5 provided a somewhat better fit to the data than these alternatives. This also was consistent with the reference run because in spite of the reductions in catch, the abundance indices continue to show a decline in stock size, indicating a highly unproductive stock at low stock sizes and therefore an associated high B_{msy}/K.

The production function with B_{msy}/K set at 0.6 had a Bayes factor of 0.5, also indicating that this model gives a slightly better fit to the data than the lower alternatives. The better fit could be attributed to the Fletcher model's prediction of a sharp drop in surplus production when biomass exceeds B_{msy} when, in contrast, Bocaccio appears to have sustained high exploitation rates for several decades prior to depletion below the B_{msy} level in the 1980s (Figure 17).

The two alternative scenarios which lowered the fixed catch input values for 1986-1995 by factors of 4 and 2 (C.3 and C.4) had the smallest Bayes factors relative to the reference case (0.03 and 0.05, Table 20). This is not surprising because these fixed catches span the period which showed the largest drop in available biomass indices. Consequently, the large drop in biomass levels observed in that period cannot be attributed to a time series of large fixed catches as in the reference case .

Table 20. Bayes factors for alternative mode runs. These reflect the ratio of the probability of the stock assessment data based on a sensitivity run to the probability of the data obtained from the reference case.

Category Code	**Category Description**	**Code**	**Run Description**	**Bayes factor**
A	B_{msy}/K	A.1	B_{msy}/K = 0.3	0.2
		A.2	B_{msy}/K = 0.4	0.2
		Ref	B_{msy}/K = 0.5	1.0
		A.3	B_{msy}/K = 0.6	0.5
B	*r* prior mean	B.1	low *r* (mean = 0.0802, SD = 0.039)	1.2
		Ref	reference prior (mean = 0.1067, SD = 0.039)	1.0
		B.2	high *r* (mean = 0.142, SD = 0.052)	1.0
C	Catch	C.1	Sum of trawl and non-halibut HL catch x 0.5, all yrs.’	0.9
		Ref.		1.0
		C.2	Sum of trawl and non-halibut HL catch x 1.5, all yrs.’	0.3
		C.3	Sum of trawl and non-halibut HL catch x 0.25, 86-95	0.03
		C.4	Sum of trawl and non-halibut HL catch x 0.5, 86-95	0.05
F	Catch	F.1	-2% /y change in Halibut gear q	0.4
		F.2	-1.5% /y change in Halibut gear q	0.5
		F.3	-1.0% /y change in Halibut gear q	0.6
		Ref.	0% /y change in Halibut gear q	1.0
		F.4	1% /y change in Halibut gear q	0.8
		F.5	1.5% /y change in Halibut gear q	0.8
		F.6	2% /y change in Halibut gear q	0.8

13 DECISION TABLES

We have provided forecasting scenarios over 5, 20 (1 generation) and 60 year (3 generations) time horizons for constant catch policies ranging from 0 to 200 t/y for the reference case and 5 sensitivity runs (Table 21). Graphical versions for the reference case are provided in (Figure 25). 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, 2009b), as well as additional relative metrics of stock status.

These projections are based on strong assumptions, including stationarity in model parameters, and that total stock biomass, without reference to the population age or size structure, determines annual surplus production in the following year with no lag. However, these are the same assumptions under which the model reconstruction was made. Therefore, as with most assessments, these long-term projections are provided as guidelines to distinguish between model hypotheses, rather than as true predictions of stock size.

Table 21. Decision tables are provided in the following runs for the reference case and five sensitivity runs.

Model Run	Decision Table
Reference case	Table 22
Case B.1 (low *r* prior)	Table 23
Case B.2 (high *r* prior)	Table 24
Case A.1 (B_{msy}/K=0.3)	Table 25
Case A.2 (B_{msy}/K=0.4)	Table 26
Case A.3 (B_{msy}/K=0.6)	Table 27

These decision tables are presented to help initiate and focus discussion of harvest strategies for Bocaccio but are not meant to endorse a constant catch policy. Table 29, and Table 30 provide summary decision tables for the probability that stock biomass exceeds 40% of B_{msy} ($0.4*B_{msy}$) within 60 years under each alternative constant TAC policy (t) and under each alternative hypothesized values for *r, Bmsy/K,* and historical catch. For example, indicates that, for the reference case, catches of less than 125 t/year are required to have at least a 50% probability of exceeding the LSR point within three generations (60 years). There is some contrast in these projections. For example, the sensitivity run which models B_{msy}/K=0.3 predicts that a constant annual harvest of 125 t/year will result in a 0.61 probability of exceeding the LRP in 3 generations while the Reference Case estimates the equivalent probability at 0.49 (Table 29).

Following Edwards et al. (2012), we have also included indicators used by COSEWIC that are based on the decline in the exploitable biomass over 3 generations (i.e., 60 years for Bocaccio) (Table 31). These are COSEWIC indicators A1 and A2 which are used for species that have been assessed as threatened[7]. These indicators are based on the decline in total numbers of mature individuals over the most recent 10 years or 3 generations, whichever is longer, defined as A1=0.5*$N_{t\text{-3Gen}}$ (a 50% decline) and A2=0.7*$N_{t\text{-3Gen}}$ (a 30% decline), where $N_{t\text{-3Gen}}$ is the number of mature individuals three generations previous to year *t*. However, we used exploitable biomass ($B_{t\text{-3Gen}}$) instead of numbers because of the configuration of the assessment model. Edwards et al. (2012) also present reference points relative to B_0 ($0.2*B_0$ and $0.4*B_0$), which are reference points used by other fishery agencies (e.g. New Zealand Ministry of Fisheries 2007, 2011). However, these have been omitted here because they are identical to the reference points labelled $0.4*B_{msy}$ and $0.8*B_{msy}$, given the Schaefer model assumption that $B_{msy}=0.5*B_0$.

[7] http://www.cosewic.gc.ca/eng/sct0/assessment_process_e.cfm, updated August 2010

Table 22. Stock status indicators for Bocaccio after 5, 20, and 60 years for the reference case. Policies are constant TAC policies in t. The statistics P(B>0.X B_{msy} in Hz) *refer to the probability that stock size exceeds 0.X B_{msy} within the stated horizon (Hz).*

Horizon	Policy	Median(B_{fin}/B_0)	Median(B_{fin}/B_{msy})	P($B_{fin}>B_{cur}$)	P($B>0.4*B_{msy}$ in Hz)	P($B>0.8*B_{msy}$ in Hz)
5 -year	0	0.05	0.10	0.76	0.05	0.01
	50	0.05	0.09	0.67	0.05	0.01
	75	0.04	0.08	0.63	0.05	0.01
	100	0.04	0.08	0.59	0.05	0.01
	125	0.04	0.07	0.53	0.04	0.01
	150	0.03	0.07	0.48	0.04	0.01
	175	0.03	0.06	0.43	0.04	0.01
	200	0.03	0.06	0.37	0.04	0.01
20 -year	0	0.16	0.33	0.88	0.43	0.21
	50	0.12	0.23	0.78	0.36	0.18
	75	0.10	0.19	0.69	0.32	0.16
	100	0.07	0.15	0.61	0.28	0.14
	125	0.05	0.10	0.52	0.25	0.12
	150	0.03	0.05	0.46	0.22	0.11
	175	0.01	0.02	0.41	0.19	0.10
	200	0.00	0.00	0.34	0.17	0.09
60 -year	0	0.65	1.29	0.95	0.86	0.77
	50	0.56	1.11	0.81	0.72	0.65
	75	0.44	0.88	0.69	0.65	0.58
	100	0.27	0.54	0.60	0.56	0.51
	125	0.06	0.11	0.50	0.49	0.44
	150	0.00	0.000	0.44	0.42	0.38
	175	0.00	0.000	0.37	0.37	0.33
	200	0.00	0.000	0.30	0.30	0.26

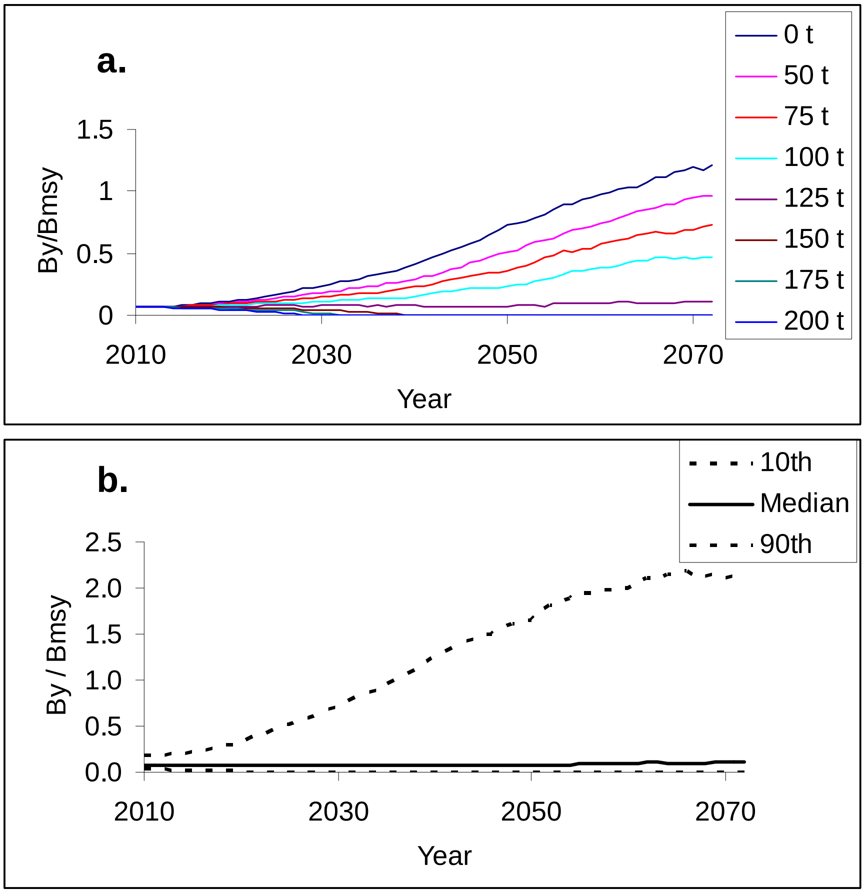


Figure 25. Reference case plots of the ratio of a. median stock biomass to B_{msy} for different constant total catch policies and b. 10^{th}, 50^{th} (median), and 90^{th} percentiles.

Table 23. Stock status indicators for Bocaccio after 5, 20, and 60 years for Case B.1 low prior r mean. Policies are constant TAC policies in tons. The statistics P($B>0.X *B_{msy}$ in Hz) refer to the probability that stock size exceeds $0.X* B_{msy}$ within the stated horizon (Hz).

Horizon	**Policy**	**Median(B_{fin}/B_0)**	**Median(B_{fin}/B_{msy})**	**P($B_{fin}>B_{cur}$)**	**P($B>0.4B_{msy}$ in Hz)**	**P($B>0.8B_{msy}$ in Hz)**
5 -year	0	0.04	0.08	0.68	0.03	0.004
	50	0.04	0.08	0.58	0.03	0.004
	75	0.04	0.07	0.52	0.03	0.004
	100	0.03	0.07	0.48	0.03	0.003
	125	0.03	0.06	0.44	0.03	0.003
	150	0.03	0.06	0.39	0.03	0.003
	175	0.03	0.06	0.36	0.02	0.003
	200	0.03	0.05	0.32	0.02	0.003
20 -year	0	0.10	0.19	0.81	0.29	0.13
	50	0.07	0.14	0.68	0.25	0.11
	75	0.05	0.11	0.60	0.22	0.10
	100	0.04	0.07	0.51	0.20	0.09
	125	0.02	0.05	0.44	0.18	0.08
	150	0.01	0.02	0.36	0.16	0.07
	175	0.00	0.00	0.31	0.14	0.06
	200	0.00	0.00	0.25	0.13	0.05
60 -year	0	0.42	0.84	0.90	0.75	0.62
	50	0.31	0.61	0.71	0.61	0.50
	75	0.18	0.35	0.60	0.54	0.43
	100	0.03	0.05	0.49	0.45	0.36
	125	0.00	0.00	0.41	0.37	0.30
	150	0.00	0.000	0.33	0.31	0.26
	175	0.00	0.000	0.27	0.27	0.22
	200	0.00	0.000	0.22	0.22	0.18

Table 24. Stock status indicators for Bocaccio after 5, 20 and 60 years for Case B.2, high prior r *mean. Policies are constant TAC policies in tons. The statistics P*(B>*0.X *B_{msy}* in Hz) *refer to the probability that stock size exceeds 0.X* B_{msy} within the stated horizon (Hz).*

Horizon	**Policy**	**Median(B_{fin}/B_0)**	**Median(B_{fin}/B_{msy})**	**P(B_{fin}>B_{cur})**	**P(B>$0.4B_{msy}$ in Hz)**	**P(B>$0.8B_{msy}$ in Hz)**
5 -year	0	0.05	0.10	0.80	0.06	0.011
	50	0.05	0.09	0.72	0.06	0.012
	75	0.04	0.09	0.61	0.06	0.012
	100	0.04	0.08	0.56	0.06	0.011
	125	0.04	0.07	0.51	0.05	0.011
	150	0.03	0.07	0.45	0.05	0.010
	175	0.03	0.06	0.40	0.05	0.010
	200	0.03	0.06	0.35	0.04	0.009
20 -year	0	0.18	0.36	0.90	0.49	0.26
	50	0.14	0.28	0.78	0.39	0.22
	75	0.10	0.19	0.71	0.36	0.20
	100	0.07	0.15	0.61	0.32	0.18
	125	0.05	0.10	0.54	0.28	0.16
	150	0.02	0.05	0.46	0.25	0.15
	175	0.00	0.00	0.37	0.23	0.13
	200	0.00	0.00	0.32	0.20	0.11
60 -year	0	0.71	1.41	0.97	0.90	0.80
	50	0.61	1.22	0.81	0.76	0.68
	75	0.52	1.03	0.73	0.68	0.62
	100	0.30	0.59	0.60	0.58	0.52
	125	0.10	0.20	0.52	0.50	0.46
	150	0.00	0.000	0.44	0.42	0.38
	175	0.00	0.000	0.35	0.34	0.31
	200	0.00	0.000	0.28	0.29	0.26

Table 25. Stock status indicators for Bocaccio after 5, 20, and 60 years for Case A.1 B_{msy}/B_0 set at 0.3. Policies are constant TAC policies in tons. The statistics P(B>0.X *B_{msy} in Hz) *refer to the probability that stock size exceeds 0.X* B_{msy} *within the stated horizon (Hz).*

Horizon	Policy	Median(B_{fin}/B_0)	Median(B_{fin}/B_{msy})	P($B_{fin}>B_{cur}$)	P($B>0.4B_{msy}$ in Hz)	P($B>0.8B_{msy}$ in Hz)
5 -year	0	0.04	0.14	0.76	0.13	0.03
	50	0.04	0.13	0.67	0.12	0.03
	75	0.04	0.12	0.63	0.11	0.03
	100	0.03	0.12	0.59	0.11	0.03
	125	0.03	0.11	0.54	0.11	0.03
	150	0.03	0.10	0.50	0.10	0.02
	175	0.03	0.10	0.46	0.10	0.02
	200	0.03	0.09	0.43	0.10	0.02
20 -year	0	0.13	0.45	0.92	0.55	0.32
	50	0.10	0.32	0.83	0.45	0.27
	75	0.08	0.27	0.74	0.42	0.26
	100	0.07	0.22	0.65	0.39	0.25
	125	0.05	0.16	0.59	0.36	0.22
	150	0.03	0.11	0.50	0.34	0.21
	175	0.02	0.06	0.43	0.31	0.19
	200	0.01	0.03	0.38	0.28	0.18
60 -year	0	0.58	1.92	0.98	0.93	0.86
	50	0.46	1.54	0.92	0.86	0.78
	75	0.41	1.36	0.83	0.77	0.69
	100	0.29	0.97	0.75	0.68	0.60
	125	0.21	0.69	0.68	0.61	0.53
	150	0.11	0.371	0.58	0.54	0.46
	175	0.01	0.045	0.49	0.47	0.40
	200	0.01	0.033	0.41	0.40	0.35

Table 26. Stock status indicators for Bocaccio after 5, 20, and 60 years for Case A.2 B_{msy}/B_0 set at 0.4. Policies are constant TAC policies in tons. The statistics P(B>0.X*B_{msy} in Hz) *refer to the probability that stock size exceeds 0.X*B_{msy} within the stated horizon (Hz).*

Horizon	Policy	Median(B_{fin}/B_0)	Median(B_{fin}/B_{msy})	P(B_{fin}>B_{cur})	P(B>0.4B_{msy} in Hz)	P(B>0.8B_{msy} in Hz)
5 -year	0	0.05	0.11	0.74	0.10	0.02
	50	0.04	0.10	0.65	0.09	0.02
	75	0.04	0.10	0.60	0.09	0.02
	100	0.04	0.09	0.54	0.09	0.02
	125	0.03	0.09	0.50	0.09	0.02
	150	0.03	0.08	0.44	0.08	0.02
	175	0.03	0.07	0.40	0.07	0.02
	200	0.03	0.07	0.37	0.07	0.02
20 -year	0	0.14	0.36	0.91	0.46	0.26
	50	0.11	0.27	0.79	0.38	0.23
	75	0.09	0.22	0.73	0.35	0.22
	100	0.07	0.18	0.65	0.33	0.20
	125	0.05	0.12	0.57	0.30	0.19
	150	0.03	0.08	0.52	0.28	0.16
	175	0.02	0.04	0.43	0.25	0.15
	200	0.01	0.03	0.38	0.22	0.14
60 -year	0	0.59	1.48	0.97	0.89	0.78
	50	0.48	1.19	0.90	0.79	0.68
	75	0.42	1.05	0.81	0.68	0.61
	100	0.31	0.78	0.69	0.60	0.55
	125	0.19	0.47	0.60	0.54	0.49
	150	0.04	0.097	0.52	0.48	0.44
	175	0.01	0.025	0.44	0.42	0.37
	200	0.01	0.025	0.37	0.36	0.32

Table 27. Stock status indicators for Bocaccio after 5, 20, and 60 years for Case A.3 B_{msy}/B_0 set at 0.6. Policies are constant TAC policies in tons. The statistics P(B>0.XB_{msy} in Hz) refer to the probability that stock size exceeds 0.X*B_{msy} within the stated horizon (Hz).*

Horizon	**Policy**	**Median(B_{fin}/B_0)**	**Median(B_{fin}/B_{msy})**	**P($B_{fin}>B_{cur}$)**	**P($B>0.4B_{msy}$ in Hz)**	**P($B>0.8B_{msy}$ in Hz)**
5 -year	0	0.06	0.10	0.78	0.10	0.02
	50	0.05	0.09	0.68	0.09	0.01
	75	0.05	0.08	0.63	0.08	0.01
	100	0.05	0.08	0.56	0.08	0.01
	125	0.04	0.07	0.50	0.08	0.01
	150	0.04	0.06	0.45	0.07	0.01
	175	0.04	0.06	0.39	0.07	0.01
	200	0.03	0.05	0.35	0.05	0.01
20 -year	0	0.19	0.31	0.89	0.46	0.28
	50	0.13	0.21	0.77	0.37	0.22
	75	0.09	0.15	0.69	0.34	0.20
	100	0.07	0.11	0.59	0.30	0.18
	125	0.04	0.07	0.52	0.27	0.16
	150	0.02	0.03	0.42	0.23	0.14
	175	0.01	0.02	0.37	0.22	0.13
	200	0.01	0.02	0.32	0.19	0.12
60 -year	0	0.74	1.24	0.97	0.85	0.77
	50	0.62	1.03	0.84	0.73	0.65
	75	0.52	0.86	0.73	0.65	0.58
	100	0.27	0.45	0.61	0.54	0.49
	125	0.06	0.09	0.52	0.47	0.43
	150	0.01	0.017	0.43	0.39	0.35
	175	0.01	0.017	0.36	0.34	0.31
	200	0.01	0.017	0.31	0.30	0.27

*Table 28. Summary decision table for the probability that stock biomass exceeds 0.4*B_{msy} within 60 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*		
	Low *r* (B.1)	**Reference *r***	**High *r* (B.2)**
Prior mean	0.0802	0.1067	0.142
Bayes factor	1.2	1.0	1.0
TAC			
0	0.75	0.86	0.90
50	0.61	0.72	0.76
75	0.54	0.65	0.68
100	0.45	0.56	0.58
125	0.37	0.49	0.50
150	0.31	0.42	0.42
175	0.27	0.37	0.34
200	0.22	0.30	0.29

*Table 29. Summary decision table for the probability that stock biomass exceeds 0.4*B_{msy} within 60 years under each alternative constant TAC policy (t) and under each alternative hypothesized value for t B_{msy}/K*

	Hypothesized B_{msy} to *K* ratio			
			Reference	
B_{msy}/K	**0.3 (A.1)**	**0.4 (A.2)**	***0.5***	**0.6 (A.3)**
Bayes factor	0.2	0.2	1.0	0.5
TAC				
0	0.93	0.89	0.86	0.85
50	0.86	0.79	0.72	0.73
75	0.77	0.68	0.65	0.65
100	0.68	0.60	0.56	0.54
125	0.61	0.54	0.49	0.47
150	0.54	0.48	0.42	0.39
175	0.47	0.42	0.37	0.34
200	0.40	0.36	0.30	0.30

*Table 30. Summary decision table for the probability that stock biomass exceeds 0.4*B_{msy} within 60 years under each alternative constant TAC policy (t) and under each alternative hypothesized scenario for the level of historic trawl and non-halibut hook and line catch.*

	Hypothesized scenario for historic catch		
	Low (C.1)	**Reference**	**High (C.2)**
Catch scenario	0.5 x ref case		1.5 x ref. case
Bayes factor	0.9	1.0	0.3
TAC			
0	0.82	0.86	0.89
50	0.62	0.72	0.82
75	0.52	0.65	0.68
100	0.40	0.56	0.61
125	0.30	0.49	0.54
150	0.23	0.42	0.49
175	0.18	0.37	0.42
200	0.14	0.30	0.37

*Table 31. Decision table showing the time to reach four reference points (RP):0.4*B_{msy}, 0.8* B_{msy} , 0.5*B_{t-3Gen}, 0.7*B_{t-3Gen} over a range of constant catch quota policies (t) for two levels of confidence for the reference case run (see text for a description of these reference points). Values are the first year that the RP is reached with the given confidence level (and the population is increasing). Declining outcomes were found for more policies under the 80% confidence level for the B_0 and B_{msy} reference points since at 80% the intervals get wider on smaller quota policies than for the medians.*

Quota Policy				
50% Confidence	**0.4*B_{msy}**	**0.8*B_{msy}**	**0.5*B_{t-3Gen}**	**0.7*B_{t-3Gen}**
0	23	41	21	24
50	30	49	24	31
75	37	58	30	34
100	46	>60	34	37
125	>60	>60	41	43
150	declining	declining	declining	declining
175	declining	declining	declining	declining
200	declining	declining	declining	declining
80% Confidence				
0	59	>60	36	38
50	>60	>60	43	52
75	declining	declining	>60	>60
100	declining	declining	>60	>60
125	declining	declining	>60	>60
150	declining	declining	declining	declining
175	declining	declining	declining	declining
200	declining	declining	declining	declining

14 STATUS OF BOCACCIO IN U.S. WATERS

Only the California and southern Oregon portion of the U.S. population of Bocaccio has been assessed in recent years. The most recent assessment was provided in November 2011, but is still only available in draft form (Field 2011). Field (2011) reports that the results are slightly more pessimistic relative to the 2009 model, with depletion of spawning biomass in the year 2011 estimated at 26% of B_0 relative to the 30% projected from the 2009 model. Continued decline in the trawl survey and hook and line survey indices were mainly responsible for this change. A young-of-the-year index suggests a flattening of what was previously an increasing trend.

Field (2011) notes further that spawning output [estimated biomass in egg production] exhibits a very moderate decline until about 1950, with a steep decline from the early 1950s followed by a sharp increase in the early 1960s. Spawning output is estimated to have exceeded the mean unfished biomass level through the early 1970s, when high fishing mortality rates again resulted in a rapid decline. Harvests declined towards the end of the 1990s, in response to management restrictions. Since the early 2000s, spawning output has been increasing steadily, largely as a result of reduced fishing mortality and a strong 1999 year class, although the rate of increase has slowed in the later half of the 2000s. Indications of strong 2009 and 2010 year classes should lead to additional increases in abundance.

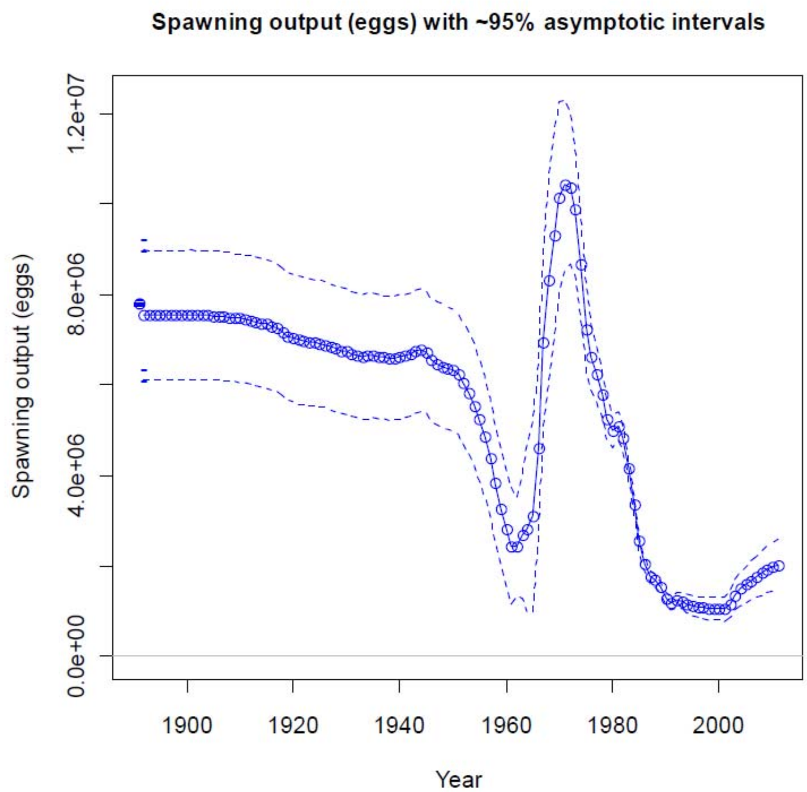


Figure 26. Estimated spawning output time series 1892-2011 for the base case fir California and southern Oregon Bocaccio population, with approximate 95% confidence intervals (figure from Field 2011).

15 SUMMARY

This document provides a stock assessment for Bocaccio in BC 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.

The reference case analysis indicates that is likely that the Bocaccio population in BC has been declining for many decades and is currently well below the LRP of $0.4*B_{msy}$. Furthermore, while there is considerable uncertainty in estimating current trends, there is no sign that the population has started to increase, and appears to have continued to decline over the most recent decade. Current harvests are approximately equal to estimates of replacement yield. The impacts on estimates of stock status of alternative model assumptions to those made in the reference case were explored with additional sensitivity runs. These runs were, in general terms, consistent with the reference case results.

Long term biomass projections were made for the reference case and a selection of the sensitivity runs over 5, 20, and 60 year scenarios under varying fixed harvest assumptions. These projections are shown relative to the DFO draft policy target references points of $0.4*B_{msy}$ and $0.8*B_{msy}$ and other reference points.

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.

16 RESPONSES TO 2009 RECOMMENDATIONS FOR FUTURE WORK

The following section summarizes the authors' responses to recommendations (in italics) made during review of the earlier work (Stanley et al. 2009a).

1. *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.*

   The authors recognize that additional work could go into the catch reconstructions for each sector. However, the model is not particularly sensitive to modest changes in historical catches. Changes in pre-1950 troll catches of Bocaccio would have little impact. Finally, there are a large number of alternative means for reconstructing catches with little objective basis for choosing amongst them.

2. *Explore the potential to work with US biologists for a coastwide assessment of Bocaccio, especially as the time series of abundance indices and ageing data expands.*

   This was not yet examined. While US assessments have so far concentrated on California data, US staff have expressed, as well, a desire to do more collaborative work, especially with ageing. Canadian and US staff have been collaborating on Bocaccio genetics work. Canadian samples were included in the genetics work noted above.

3. *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.*

   Some preliminary work on MSE work has been conducted on Bocaccio[8]. This work focussed on whether the current surveys can provide adequate monitoring of Bocaccio abundance. The unpublished work indicated that that in spite of the imprecision of each survey, when considered collectively in a modelling context, they could provide adequate monitoring. No further MSE work has been conducted or is planned.

4. *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.*

   As noted above, results from Matthews et al. (1989) gillnet survey were used in this assessment.

5. *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 <u>trawlable</u> block may, in fact, be untrawlable.*

   The assessment did not incorporate this 2009 reviewer's comment. However, we note that a significant portion of the area within each <u>untrawlable</u> block may, in fact, be trawlable which would act to compensate. We have no information on these two proportions.

6. *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.*

   Sufficient time was not available for the authors to consider incorporating U.S. Bocaccio survey catchability in this U.S. assessment. The use of different vessels, nets, and different bottom type, would imply that the values would not be comparable; however, the comparison could be informative.

7. *Evaluate the feasibility of a stock structure study of Bocaccio in BC and US waters using samples of chemical microconstituents in Bocaccio body parts. The presence of much older fish in recent samples from BC and Washington State in comparison with California*

[8] McAllister, M.K., Stanley, R., and Kronlund, R. 2009. Can trawl surveys tell us whether a recovery plan is working? Poster presented at ICES/PICES/UNCOVER Symposium on Rebuilding Depleted Fish Stocks –Biology, Ecology, Social Science and Management Strategies. Warnemünde/Rostock, Germany.

samples, in spite of significant fishing morality for many decades, implies the possibility of gradual migration to BC waters as US fish become older. Microconstituent analysis might reveal the source of larvae and juveniles that recruit to BC fisheries.

Resources and time were not sufficient available to conduct microconstituent analysis of Bocaccio samples.

8. *Evaluate the feasibility of acoustic studies of Bocaccio or other rockfish behaviour in response to trawl gear.*

   No rockfish acoustic studies were conducted. Rockfish acoustic work is problematic for a variety of reasons including the difficulty in identify the rockfish to species and the difficulty in using ship-based acoustics on near bottom targets, within the acoustic "dead-zone".

9. *Examine post-model pre-data distribution of model outputs*.

   This procedure was adopted and summarized above.

17 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 to work with U.S. biologists on Bocaccio research issues and, if possible, a coastwide assessment of Bocaccio.
2. Publish the nearly completed work on an MSE-based study of the adequacy of the current survey array in tracking Bocaccio abundance.
3. For the next assessment, consider incorporating end-of-summer YOY length-at-age data (Russ Markell, pers. comm., University of British Columbia) in estimation for growth parameters.
4. Conduct a review of Bocaccio surveys trends in 5 years to check for evidence of further declines in abundance and, if appropriate include results of the DFO longline surveys in this review and subsequent assessments.
5. Conduct a full assessment of Bocaccio in approximately 2022. The timing will coincide with an anticipated COSEWIC assessment.
6. We recommend continued sampling and ageing of Bocaccio. However, we note the limited amount of ageing resources and the large number of groundfish species/populations to be assessed. It might be advantageous to direct ageing resources to species for which representative time series can be developed or that currently lack sufficient material to estimate life history parameters.

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APPENDIX A CATCH

Appendix Table 1. Inputted catch values in the Reference case (1935-1975). Catches for Trawl and ZN HL are fixed; catches in the other fisheries are estimated. Note that catch values are rounded to nearest ton so percentages do not exactly match.

Year	Fixed	Estimated (Medians)			Total	Year	Proportion of Total Catch (%)			
	Trawl and ZN HL	Halibut	Salmon Troll	Recr.			Trawl and ZN HL	Halibut	Salmon Troll	Recr.
1935	1	1242	393	3	1639	1935	0%	76%	24%	0%
1936	1	1360	381	3	1745	1936	0%	78%	22%	0%
1937	1	1199	365	3	1568	1937	0%	76%	23%	0%
1938	2	1043	347	3	1396	1938	0%	75%	25%	0%
1939	2	1237	312	3	1554	1939	0%	80%	20%	0%
1940	11	1212	290	3	1516	1940	1%	80%	19%	0%
1941	8	1121	401	3	1532	1941	1%	73%	26%	0%
1942	36	981	377	3	1397	1942	3%	70%	27%	0%
1943	100	948	489	2	1540	1943	6%	62%	32%	0%
1944	45	723	145	2	915	1944	5%	79%	16%	0%
1945	418	701	317	2	1438	1945	29%	49%	22%	0%
1946	213	804	246	3	1265	1946	17%	64%	19%	0%
1947	116	700	396	5	1218	1947	10%	58%	33%	0%
1948	183	690	277	8	1158	1948	16%	60%	24%	1%
1949	221	666	385	10	1282	1949	17%	52%	30%	1%
1950	209	677	411	12	1309	1950	16%	52%	31%	1%
1951	200	795	430	14	1439	1951	14%	55%	30%	1%
1952	187	754	339	16	1296	1952	14%	58%	26%	1%
1953	78	550	336	18	982	1953	8%	56%	34%	2%
1954	81	566	291	20	959	1954	8%	59%	30%	2%
1955	104	472	356	22	954	1955	11%	49%	37%	2%
1956	98	469	334	23	923	1956	11%	51%	36%	2%
1957	74	525	372	26	997	1957	7%	53%	37%	3%
1958	70	494	364	28	955	1958	7%	52%	38%	3%
1959	91	538	354	29	1013	1959	9%	53%	35%	3%
1960	66	484	358	30	938	1960	7%	52%	38%	3%
1961	92	463	393	33	980	1961	9%	47%	40%	3%
1962	164	491	344	31	1030	1962	16%	48%	33%	3%
1963	144	541	311	31	1028	1963	14%	53%	30%	3%
1964	110	427	330	31	898	1964	12%	48%	37%	3%
1965	290	389	347	32	1058	1965	27%	37%	33%	3%
1966	1073	343	312	29	1757	1966	61%	20%	18%	2%
1967	785	315	344	28	1472	1967	53%	21%	23%	2%
1968	533	284	359	27	1204	1968	44%	24%	30%	2%
1969	1064	359	315	26	1765	1969	60%	20%	18%	1%
1970	457	304	294	26	1081	1970	42%	28%	27%	2%
1971	324	255	311	27	917	1971	35%	28%	34%	3%
1972	452	283	274	28	1038	1972	44%	27%	26%	3%
1973	1112	196	234	28	1569	1973	71%	12%	15%	2%
1974	1274	131	233	27	1665	1974	77%	8%	14%	2%

Appendix Table 2. Inputted catches in the Reference case (1976-2012). Catches for Trawl and ZN HL are fixed; catches in the other fisheries are estimated. Note that catch values are rounded to nearest ton so percentages do not exactly match

Year	Fixed	Estimated (Medians)			Total	Year	Proportion of Total Catch (%)			
	Trawl and ZN HL	Halibut	Salmon Troll	Recr.			Trawl and ZN HL	Halibut	Salmon Troll	Recr.
1975	790	184	224	26	1224	1975	65%	15%	18%	2%
1976	677	233	220	27	1157	1976	59%	20%	19%	2%
1977	399	151	228	28	807	1977	49%	19%	28%	4%
1978	255	127	273	30	684	1978	37%	19%	40%	4%
1979	486	173	274	30	962	1979	51%	18%	28%	3%
1980	183	149	364	31	726	1980	25%	21%	50%	4%
1981	95	144	310	31	580	1981	16%	25%	53%	5%
1982	105	138	304	32	580	1982	18%	24%	53%	6%
1983	154	131	282	32	599	1983	26%	22%	47%	5%
1984	176	98	260	33	566	1984	31%	17%	46%	6%
1985	418	115	252	28	814	1985	51%	14%	31%	3%
1986	720	134	196	15	1065	1986	68%	13%	18%	1%
1987	732	120	155	25	1032	1987	71%	12%	15%	2%
1988	1348	102	141	16	1607	1988	84%	6%	9%	1%
1989	808	79	123	22	1033	1989	78%	8%	12%	2%
1990	1063	43	136	21	1263	1990	84%	3%	11%	2%
1991	1093	37	116	22	1268	1991	86%	3%	9%	2%
1992	976	28	106	24	1134	1992	86%	3%	9%	2%
1993	1160	25	66	14	1266	1993	92%	2%	5%	1%
1994	635	20	44	15	714	1994	89%	3%	6%	2%
1995	545	16	31	9	601	1995	91%	3%	5%	2%
1996	343	15	17	4	378	1996	91%	4%	4%	1%
1997	267	18	12	9	306	1997	87%	6%	4%	3%
1998	236	19	7	10	273	1998	86%	7%	3%	4%
1999	251	20	4	11	286	1999	88%	7%	1%	4%
2000	303	16	3	8	330	2000	92%	5%	1%	2%
2001	288	15	3	8	313	2001	92%	5%	1%	3%
2002	295	17	7	9	328	2002	90%	5%	2%	3%
2003	237	16	8	10	270	2003	88%	6%	3%	4%
2004	170	17	9	9	205	2004	83%	8%	4%	4%
2005	162	18	12	9	201	2005	81%	9%	6%	4%
2006	131	16	11	9	167	2006	79%	10%	7%	5%
2007	139	13	8	7	166	2007	84%	8%	5%	4%
2008	118	11	5	7	140	2008	84%	8%	4%	5%
2009	114	8	6	6	134	2009	85%	6%	4%	5%
2010	99	7	6	6	118	2010	84%	6%	5%	5%
2011	119	6	6	6	137	2011	87%	4%	4%	4%
2012	119	6	6	6	137	2012	87%	4%	4%	5%

Appendix Table 3. Time series of fishery effort in the halibut, salmon troll, and recreational fisheries

Year	Halibut fishery effort	Salmon troll fishery effort	Recreational fishery effort	Catch of Bocaccio in halibut fishery	Year	Halibut fishery effort	Salmon troll fishery effort	Recreational fishery effort	Catch of Bocaccio in halibut fishery
	(100,000 skates)	(10,000 boat days)	(100,000 angler days)	(mt)		(100,000 skates)	(10,000 boat days)	(100,000 angler days)	(mt)
1935	2.35	3.57	0.17	NA	1975	1.05	7.14	4.44	NA
1936	2.70	3.57	0.17	NA	1976	1.37	7.21	4.61	NA
1937	2.51	3.57	0.17	NA	1977	0.89	7.35	4.79	NA
1938	2.26	3.57	0.17	NA	1978	0.73	8.63	4.97	NA
1939	2.83	3.32	0.17	NA	1979	1.01	8.80	5.15	NA
1940	2.79	3.25	0.17	NA	1980	0.87	11.90	5.32	NA
1941	2.65	4.67	0.17	NA	1981	0.84	9.97	5.49	NA
1942	2.39	4.55	0.17	NA	1982	0.81	9.96	5.67	NA
1943	2.32	6.11	0.17	NA	1983	0.80	9.31	5.84	NA
1944	1.77	1.88	0.17	NA	1984	0.62	9.13	6.01	NA
1945	1.75	4.27	0.17	NA	1985	0.75	9.21	5.62	NA
1946	2.12	3.35	0.20	NA	1986	0.97	7.80	3.20	NA
1947	1.96	5.60	0.41	NA	1987	0.96	6.82	5.82	NA
1948	1.96	3.99	0.60	NA	1988	0.94	6.99	4.36	NA
1949	1.92	5.70	0.80	NA	1989	0.79	6.51	6.69	NA
1950	1.99	6.15	1.00	NA	1990	0.49	8.17	7.37	NA
1951	2.48	6.74	1.21	NA	1991	0.49	8.02	8.53	NA
1952	2.34	5.44	1.40	NA	1992	0.45	8.55	11.15	NA
1953	1.75	5.48	1.60	NA	1993	0.52	6.96	8.24	NA
1954	1.78	4.74	1.80	NA	1994	0.46	5.24	9.99	NA
1955	1.51	5.79	2.01	NA	1995	0.44	4.20	7.08	NA
1956	1.54	5.59	2.20	NA	1996	0.42	2.38	2.81	NA
1957	1.75	6.35	2.40	NA	1997	0.52	1.80	7.27	NA
1958	1.71	6.31	2.61	NA	1998	0.57	1.05	8.43	NA
1959	1.81	6.20	2.81	NA	1999	0.60	0.58	8.82	NA
1960	1.66	6.33	3.00	NA	2000	0.47	0.47	6.11	NA
1961	1.60	7.21	3.38	NA	2001	0.46	0.38	6.66	NA
1962	1.70	6.40	3.38	NA	2002	0.54	1.20	7.93	NA
1963	1.84	5.84	3.38	NA	2003	0.54	1.29	9.07	NA
1964	1.50	6.35	3.38	NA	2004	0.60	1.50	8.70	NA
1965	1.40	6.89	3.38	NA	2005	0.63	2.09	8.54	NA
1966	1.31	6.60	3.38	NA	2006	0.60	1.97	8.72	8.09
1967	1.24	7.57	3.38	NA	2007	0.50	1.45	7.10	7.47
1968	1.17	7.66	3.38	NA	2008	0.45	1.04	7.46	9.90
1969	1.58	7.38	3.38	NA	2009	0.35	1.22	7.87	8.84
1970	1.37	7.19	3.55	NA	2010	0.30	1.41	7.39	3.63
1971	1.17	7.83	3.73	NA	2011	0.27	1.31	7.39	6.62
1972	1.38	7.09	3.90	NA	2012	0.27	1.31	7.39	NA
1973	0.99	6.63	4.09	NA					
1974	0.72	7.01	4.26	NA					

APPENDIX B ESTIMATION OF ABUNDANCE INDICES FROM THE IPHC SURVEY

Annual indices of catch rate (CPUE) in any year *y* were obtained by taking the overall mean of the mean Bocaccio CPUE in each of the surveyed strata *i*:

$$U_y = \frac{\sum_{i=1}^{k_y} C_{y_i}}{k_y} \qquad \textbf{Eq. 1}$$

where C_{y_i} = mean CPUE (pieces/skate) for Bocaccio in year *y* in stratum i;

k_y = number of strata in year *y;*

U_y = mean CPUE of Bocaccio for year *y.*

CPUE $\left(C_{y_i}\right)$ in stratum *i* for year *y* was calculated as pieces per skate by

$$C_{y_i} = \frac{\sum_{j=1}^{n_{y_i}} \left({}^{p_{y_i j}} / {}_{s_{y_i j}} \right)}{n_{y_i}} \qquad \textbf{Eq. 2}$$

where $p_{y_i j}$ = number of pieces of Bocaccio in year *y* in stratum *i* and set *j;*

$s_{y_i j}$ = number of skates in year *y* by set *j* in stratum *i*;

n_{y_i} = number of sets in year *y* for stratum *i*.

CPUE estimates were bootstrapped for 1000 random draws with replacement to obtain bias- corrected (Efron 1982) 95% confidence regions for each year.

APPENDIX C RELATIVE ABUNDANCE INDICES

Appendix Table 4. Arithmetic and standardised commercial bottom trawl 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

Appendix Table 5. Biomass estimates for Bocaccio from the QCSd Shrimp Trawl Survey for the survey years 1999 to 2011. Bootstrap bias corrected confidence intervals and CVs are based on 1,000 random draws with replacement. The analytic CV is based on the assumption of random tow selection within a stratum. – 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	0.0	–	–	–	0.000
2008	0.0	0.0	–	–	–	0.000
2009	10.9	10.8	3.6	21.1	0.417	0.413
2010	0.0	0.0	–	–	–	0.000
2011	462.6	467.8	0.0	1,946.0	0.988	1.000

Appendix Table 6. Biomass estimates for Bocaccio from the WCVI shrimp trawl survey for the survey years 1975 to 2011. Biomass estimates are based on a post-stratification of this survey into two strata and by assuming that the survey tows were randomly selected within these areas. Bootstrap bias corrected confidence intervals and CVs are based on 1,000 random draws with replacement. The analytic CV is based on the assumption of random tow selection within a stratum. – indicates not applicable

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	1,000.2	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	1,741.1	0.821	0.823
1983	339.6	352.4	7.3	1,293.4	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	2,050.1	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
2008	16.1	16.0	0.0	36.6	0.569	0.586
2009	91.1	92.5	19.7	181.4	0.452	0.461
2010	47.3	46.6	8.4	112.1	0.561	0.563
2011	0.0	0.0	–	–	–	0.000

Appendix Table 7. Biomass estimates for Bocaccio from the West Coast Haida Gwaii groundfish synoptic trawl survey for the years 2006 to 2010. Biomass estimates are based on a post-stratification of this survey into two strata and by assuming that the survey tows were randomly selected within these areas. Bootstrap bias corrected confidence intervals and CVs are based on 1,000 random draws with replacement. The analytic CV is based on the assumption of random tow selection within a stratum.

Survey Year	Biomass (t)	Mean bootstrap biomass	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
2006	9.9	10.0	4.3	17.1	0.329	0.345
2007	9.6	9.6	4.3	16.9	0.328	0.329
2008	12.0	12.0	6.0	20.4	0.309	0.301
2010	8.0	8.2	3.4	14.5	0.352	0.359

Appendix Table 8. Biomass estimates for Bocaccio from the Hecate Strait Groundfish synoptic trawl survey for the years 2005 to 2011. Biomass estimates are based on a post-stratification of this survey into two strata and by assuming that the survey tows were randomly selected within these areas. Bootstrap bias corrected confidence intervals and CVs are based on 1,000 random draws with replacement. The analytic CV is based on the assumption of random tow selection within a stratum

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
2005	19.5	19.4	8.3	36.4	0.376	0.369
2007	48.6	48.7	15.6	95.7	0.403	0.389
2009	16.8	16.7	5.5	35.7	0.450	0.445
2011	55.1	55.3	6.8	152.1	0.633	0.621

Appendix Table 9. Biomass estimates for Bocaccio from the Queen Charlotte Sound Groundfish synoptic trawl survey for the years 2005 to 2011. Biomass estimates are based on a post-stratification of this survey into two strata and by assuming that the survey tows were randomly selected within these areas. Bootstrap bias corrected confidence intervals and CVs are based on 1,000 random draws with replacement. The analytic CV is based on the assumption of random tow selection within a stratum

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
2003	110.1	109.5	26.4	271.0	0.591	0.606
2004	308.9	303.6	46.5	912.2	0.788	0.776
2005	295.0	302.9	57.8	849.7	0.692	0.704
2007	127.8	126.3	28.7	351.1	0.640	0.647
2009	88.5	92.9	20.1	218.0	0.585	0.613
2011	36.0	36.6	12.7	75.6	0.439	0.436

Appendix Table 10. Biomass estimates for Bocaccio from the West Coast Vancouver Island Groundfish synoptic trawl survey for the years 2006 to 2010. Biomass estimates are based on a post-stratification of this survey into two strata and by assuming that the survey tows were randomly selected within these areas. Bootstrap bias corrected confidence intervals and CVs are based on 1,000 random draws with replacement. The analytic CV is based on the assumption of random tow selection within a stratum

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
2004	370.8	390.0	40.4	1149.2	0.760	0.783
2006	336.1	337.1	69.2	989.0	0.715	0.705
2008	155.1	155.9	88.3	255.4	0.270	0.278
2010	53.2	53.6	22.1	97.7	0.371	0.385

Appendix Table 11. Biomass estimates for Bocaccio in the U.S. Triennial survey (Canadian waters only) with 95% confidence regions based on the bootstrap distribution of biomass. Biomass estimates are calculated as described earlier. The bootstrap estimates are based on 5000 random draws with replacement (from Stanley et al. 2009a).

Estimate type	Year	Biomass	Mean bootstrap biomass	Lower bound biomass	Upper bound biomass	CV bootstrap	CV Analytic
Canada	1980	8,103	8,261	296	30,812	0.923	0.937
Vancouver	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

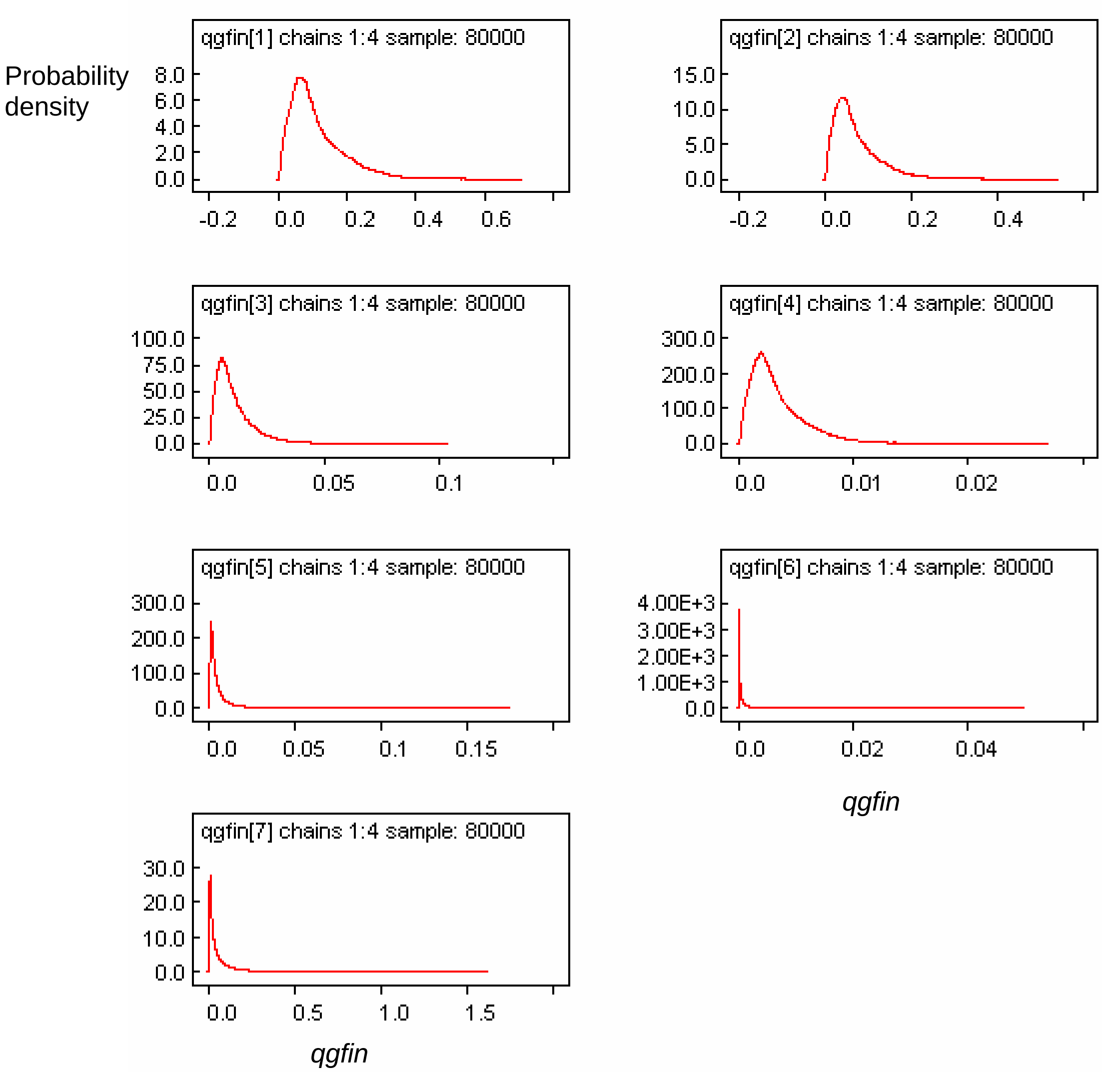
Appendix Table 12. Estimates and 95% confidence limits of relative catch rate (pieces/skate) of Bocaccio in the IPHC BC longline survey

Survey Year	CPUE		
	Bootstrap Mean	Lower bound	Upper bound
2003	0.013	0.006	0.024
2004	0.023	0.009	0.038
2005	0.013	0.005	0.024
2006	0.036	0.010	0.079
2007	0.018	0.008	0.028
2008	0.038	0.019	0.062
2009	0.020	0.009	0.034
2010	0.011	0.004	0.021
2011	0.022	0.008	0.039

APPENDIX D ADDITIONAL REFERENCE CASE RESULTS

Appendix Table 13. Posterior means, medians, standard deviations (SD), CVs and 95% probability intervals for q-gross (qgfin). The last three columns show the 2.5th, 50th, and 97.5th percentiles of the random variable qgfin. The mean and SD of the natural logarithm of qgfin 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	2.5%	Median	97.5%
#1 - WCVI groundfish	0.11100	0.0760	0.69	0.017000	0.090000	0.3050
#2 - QCSd-groundfish	0.07200	0.0520	0.72	0.010500	0.058000	0.2060
#3 - HS – groundfish	0.01050	0.0080	0.76	0.001500	0.008300	0.0315
#4 - WCHG - groundfish	0.00340	0.0024	0.71	0.000490	0.002700	0.0096
#5 - WCVI Shrimp	0.00480	0.0066	1.40	0.000300	0.002600	0.0222
#6 - QCSd Shrimp	0.00046	0.0012	2.64	0.000001	0.000107	0.0032
#7 - US Triennial groundfish	0.06050	0.0945	1.56	0.000600	0.024000	0.3360



Appendix Figure 1. 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