Fisheries and Oceans Canada Science
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Research Document 2009/013

Document de recherche 2009/013

Stock assessment for Canary rockfish (*Sebastes pinniger*) in British Columbia waters

Évaluation du stock de sébaste canari (*Sebastes pinniger*) dans les eaux de la Colombie-Britannique

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

Canada

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Correct citation for this publication:

Stanley, R.D., P. Starr and N. Olsen. 2009. Stock assessment for Canary rockfish (Sebastes pinniger) in British Columbia waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/013. xxii + 198 p.

ABSTRACT

The status of the B.C. population of canary rockfish (*Sebastes pinniger*) is assessed as one coastwide stock. This analysis uses a catch at age model tuned to five fishery-independent surveys, age composition data from the commercial fishery, and estimates of catch from 1940. The model was started from an equilibrium state in 1940 while the available fishery-independent survey data span a period from 1967 to 2007, although not all intervening years are represented. There is one age sample from 1978 while the remaining samples cover 1990 to 2004.

The stock assessment specifically investigated the following factors: 1) the effect of including the proportion-at-age data from the commercial fishery; 2) the impact of deterministic or stochastic recruitment; 3) the impact of estimating or fixing the commercial selectivity; and 4) the impact of steepness of values 0.55 and 0.70. Six model runs covered the above uncertainty options. A Bayesian approach, based on the Markov Chain Monte Carlo (MCMC) algorithm, was used to estimate the joint posterior distributions of model parameters and to make projections for five years from 2009 to 2013 across a range of fixed catch options.

The results were consistent in indicating that the stock has declined from its original biomass levels to between 15% and 35% of B_0. It is likely that this decline has been arrested and it is even possible that the stock is presently rebuilding at recent harvest levels, which have averaged about 875 t since 1997. What is not certain from this assessment is whether current catch levels will ensure a rebuild. Some of the runs investigated in this assessment suggest that current removals will allow a slow rebuild. The runs with lower steepness or which do not estimate the commercial selectivity suggest that this is not the case. Taken collectively, the results of this analysis indicate that to be reasonably confident of rebuilding, harvests should be lowered from current levels. The size of the reduction is dependent on the choices of 1) a target biomass, 2) a recovery timeframe, and 3) a desired certainty of reaching the biomass in the specified timeframe. It is also affected by the assumptions related to stock productivity. Decision tables are provided to assist managers in selecting the optimal harvest option for each combination of objectives under two assumptions of stock productivity.

RÉSUMÉ

La situation de la population de sébaste canari (*Sebastes pinniger*) en Colombie-Britannique fait l'objet d'une évaluation comme un stock unique pour l'ensemble de la côte ouest. Cette analyse utilise un modèle de prises selon l'âge reposant sur cinq relevés de pêches indépendants, les données de la composition par âge des pêches commerciales et les estimations des captures depuis 1940. Le modèle débute avec un état d'équilibre en 1940, tandis que les données disponibles grâce aux relevés de pêches indépendants s'échelonnent de 1967 à 2007, bien que toutes les années intermédiaires ne soient pas représentées. On dispose d'un échantillon d'âge datant de 1978, alors que les autres échantillons couvrent la période allant de 1990 à 2004.

L'évaluation du stock examine plus particulièrement les facteurs suivants : 1) l'effet d'inclure les données sur la composition par âge des pêches commerciales; 2) l'incidence du recrutement déterministe ou probabiliste; 3) l'incidence de l'estimation ou de l'établissement de la sélectivité commerciale; 4) l'incidence de taux de variation de 0,55 et de 0,70. Six séquences d'utilisation de modèle ont couvert les options susmentionnées liées à l'incertitude. Une approche bayesienne, fondée sur l'algorithme Monte Carlo-chaîne de Markov (MCMC), a servi à estimer les distributions conjuguées à postériori des paramètres du modèle et à faire des projections pour cinq ans, soit de 2009 à 2013, au sujet d'un éventail d'options quant aux captures établies.

Les résultats ont tous indiqué que le stock affichait un déclin comparativement au niveau original de la biomasse entre 15 p. 100 et 35 p. 100 de la biomasse de départ (B_0). Il est probable que ce déclin ait été stoppé et il est même possible que le stock soit présentement en reconstruction vu les niveaux de prises récents, qui s'élèvent en moyenne à environ 875 tonnes depuis 1997. L'incertitude qui persiste à l'issue de cette évaluation consiste à savoir si les niveaux de prises actuels favoriseront la reconstruction du stock. Certaines des séquences étudiées dans le cadre de cette évaluation suggèrent que les récoltes actuelles permettront une lente reconstruction. Les séquences présentant la plus petite pente ou celles qui ne font pas l'estimation de la sélectivité commerciale suggèrent que ce n'est pas le cas. Globalement, les résultats de cette analyse indiquent que pour assurer raisonnablement la reconstruction, le nombre de captures doit être abaissé comparativement aux niveaux actuels. L'importance de la réduction dépend des choix relatifs à :1) une biomasse cible; 2) un délai de rétablissement; et 3) la certitude souhaitée d'atteindre la biomasse dans un délai déterminé. Elle dépend également des hypothèses liées à la productivité du stock. Des tables de décision sont fournies afin d'aider les gestionnaires à choisir la meilleure option pour les récoltes en fonction de chaque association d'objectifs en vertu de deux hypothèses sur la productivité du stock.

INTRODUCTION

Background

The objective of this working paper is to provide a stock assessment for canary rockfish (*Sebastes pinniger*) in British Columbia waters. Additionally, it is intended to support the development of a Recovery Potential Assessment (RPA) should this response be deemed necessary (see DFO 2007 for RPA template with summary in Appendix A). Concurrent with, but independent of, the review of this document, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) met in November 2007 and recommended a "Threatened" designation for canary rockfish in BC waters. Should the Federal Minister of the Environment approve this designation, then DFO IS placed on a legislated timeline to provide a "Recovery Strategy" based on an RPA in 2009. In this document, we attempt to provide the key ingredients needed for development of an RPA.

This document follows from Stanley et al*.* (2005) which summarized key biological information and most survey indices. The present document updates the previous information but differs in a number of key areas. First, we have attempted to reconstruct a catch history of canary rockfish back to 1940 instead of starting at 1967. Second, we have used the specimen data to derive new estimates of growth, the length/weight relationship, and maturity at age. Third, we have developed a canary rockfish survey index from a Queen Charlotte Sound Pacific ocean perch (*S. alutus*) survey conducted from 1967 to 1984. Finally, we provide, for the first time, a catch-at-age analysis for the B.C. population of canary rockfish.

Stock boundaries and designatable units

Canary rockfish are found from northern Baja California to the western Gulf of Alaska (Love et al. 2002) but populations are most abundant between northern California and B.C. No genetics or tagging studies have been conducted to delineate stock boundaries within B.C. The current U.S. assessment reports that there is no genetic evidence of distinct stocks off the U.S. coast and treats the population as one stock from California to Washington (Stewart 2007).

Canary rockfish have previously been managed and assessed in B.C. as two main stocks: a West Coast Vancouver Island stock (Pacific Marine Fisheries Commission Areas 3C+3D) and a Queen Charlotte Sound stock (PMFC Area 5A+5B) (Stanley 1999, Groundfish Management Plan[1]) (Figure 1). These stock boundaries were not based on biological evidence; rather they were adopted as a precautionary measure to distribute the fishing mortality given the possibility of stock structure. PMFC Areas 4B (Strait of Georgia), 5C and 5D (southern and northern Hecate Strait, respectively) and 5E (West Coast Queen Charlotte Islands) were not assessed owing to the low catches in these areas.

Since there is no known biological basis for assigning more than one distinct population for canary rockfish, Stanley et al. (2005) suggested that when considering extinction risk of this species, that it be treated as one designatable unit. We continue with the assumption of one stock for this assessment. However, that does not preclude the use of area-specific quotas.

[1] Pacific Region Integrated Fisheries Management Plan for Groundfish, April 1, 2007 to March 31, 2008. http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/MPLANS/plans07/Groundfish0708pl.pdf.

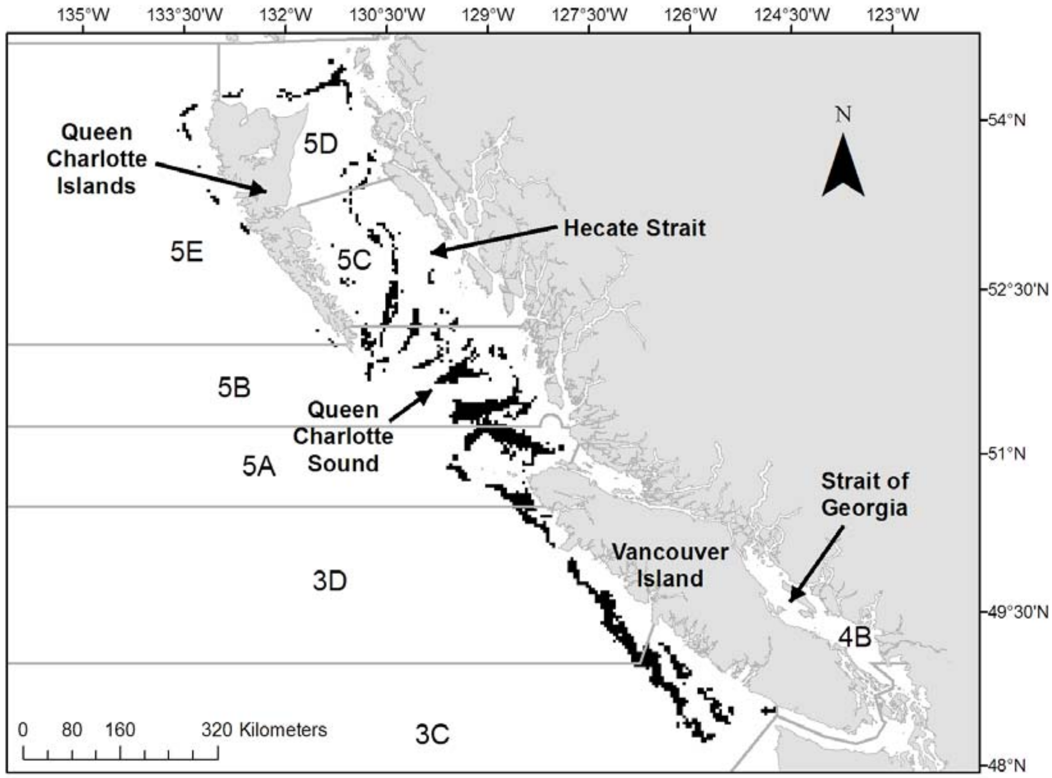

Figure 1. Spatial distribution of catches of canary rockfish in B.C. as recorded in commercial trawl observer observations (1996-2004). Also shown are the PMFC area designations.

Range and Distribution

Canary rockfish appear to be broadly distributed over the outer coast of B.C. and probably within enclosed waters (Figure 2). We know of no evidence that canary rockfish have become locally extirpated in regions within the coast of B.C.; but the available data lack the spatial resolution and temporal comparability to examine this issue. A tagging study conducted in Oregon (DeMott 1983) indicated that individual canary rockfish can move significant distances (>100 km).

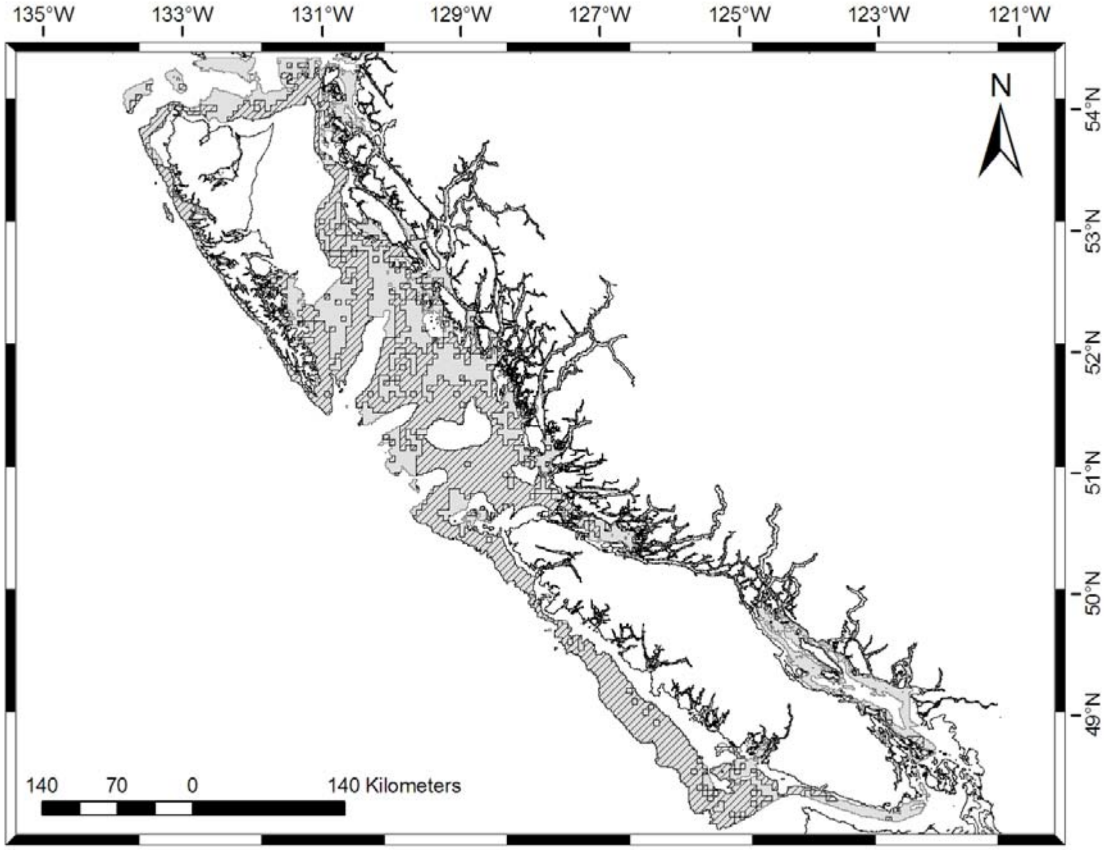

Figure 2. Canary rockfish habitat in B.C. (from Stanley et al. 2005). The gray shaded region defines the potential maximum area (=60,043 km^2) of canary rockfish habitat based on depth-of-capture in the commercial trawl fleet. The hatched zone indicates within this region, the area where canary rockfish were actually captured (presence/absence on a 25 km^2 grid =32,788 km^2 or 54.6% of the potential habitat), based on logs from the commercial trawl, and hook and line fleets.

CATCH

We present a reconstruction of canary rockfish catch from B.C. waters back to 1930 (Table 1 and Figure 3, Appendix B). Since the advent of the fishery in about 1945, total catches have averaged about 900 t, similar to the last decade.

Catch summaries in the previous assessment (Stanley et al. 2005) began with the 1967 calendar year. While landings by Canadian vessels were assumed to be negligible for earlier years, we were aware of significant landings by Washington State vessels, but did not attempt to estimate these catches. Prior to 1967, rockfish were not identified to species in Washington landings; they were grouped as “Pacific ocean perch” or “other rockfish” (ORF). Canary rockfish were a significant but unknown proportion of the latter group. Furthermore, early Washington State data did not always distinguish whether fish caught in Area 3C originated from the northern Washington State or B.C. portion of this area.

Recently, Methot and Stewart (2005) and Stewart (2007) reconstructed canary rockfish catches from U.S. waters back to 1932 for Washington-California. For Washington landings, they used the

Washington trawl ORF landings from 1930-1966 and the observed proportions of canary rockfish in 1967-1970 landings to reconstruct the 1930-1966 landings to Washington State.

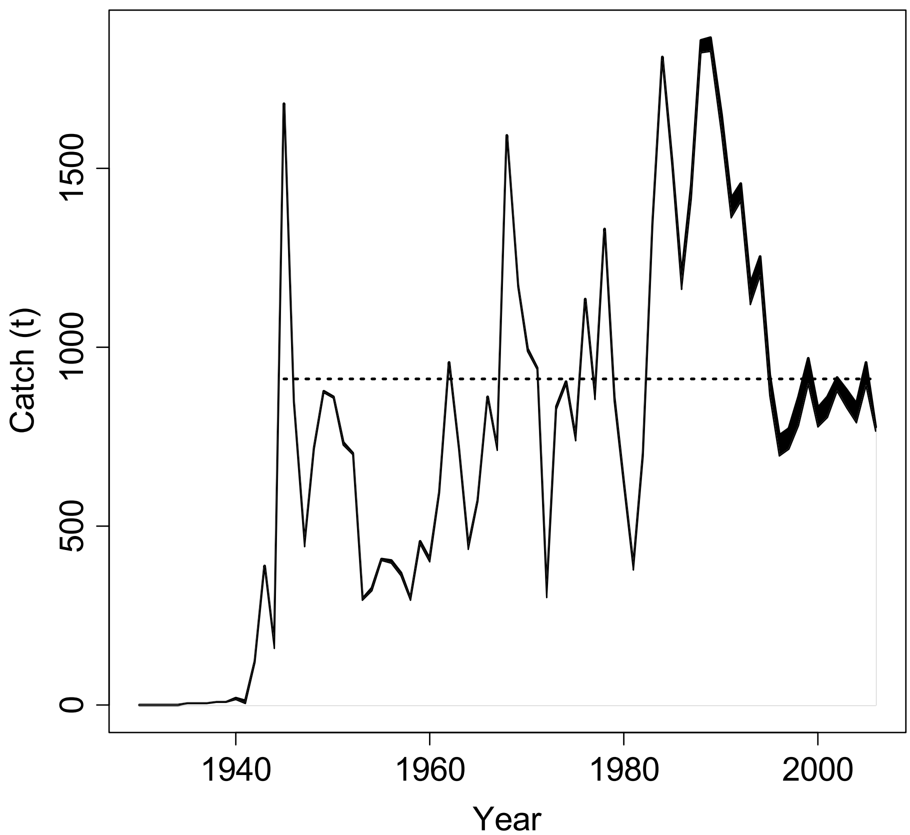

Figure 3. Total estimated canary rockfish catch from B.C. waters. Average annual catch since 1945 is approximately 900 t (dashed line). The solid black portion represents hook and line catch (Appendix B).

For this assessment, we attempted a similar reconstruction. For trawl catches, as with the U.S. reconstruction, the key element included converting ORF landings to Washington State and B.C. for 1930-1966 by first partitioning landings to those catches originating from PMFC Areas 3C-5D and second, converting ORF landings to canary rockfish landings. For the latter element, we assumed that 46% and 16% of the landings were canary rockfish for Areas 3C-3D and 5A-5D respectively. These proportions were observed in Washington State landings from these areas in 1967-1970 (Appendix B).

There were two additional minor differences from the trawl catch compilation provided in Stanley et al. (2005). In this assessment, we do not include historical catches from the U.S. portion of Area 3C. These are accommodated in the U.S. assessment. We also added an estimate of discards for 1930-1995, prior to introduction of the At-Sea-Observer-Program (ASOP). Data from the observer program (1996-2006), indicated a recent discard rate of an additional 0.6%. We assume this represents the chronic level of discarding of unmarketable sizes, which represent a very small proportion of the catch.

Table 1. Reconstruction of canary rockfish catches from B.C. waters (1930-2006) (See Appendix B for details of the reconstruction.

	Catch (t)				Catch (t)		
Year	Trawl	HL	Total	Year	Trawl	HL	Total
1930	0	0	0	1968	1587	4	1591
1931	0	0	0	1969	1168	6	1174
1932	0	0	0	1970	988	8	996
1933	0	0	0	1971	938	6	943
1934	1	0	1	1972	299	7	307
1935	4	0	4	1973	828	6	834
1936	5	0	5	1974	897	7	904
1937	5	0	5	1975	739	7	745
1938	7	0	7	1976	1128	6	1134
1939	7	0	7	1977	853	7	860
1940	16	5	21	1978	1322	8	1329
1941	6	5	11	1979	852	10	862
1942	119	4	124	1980	612	9	621
1943	385	4	389	1981	379	8	387
1944	160	4	164	1982	697	6	704
1945	1676	4	1680	1983	1344	7	1351
1946	845	4	849	1984	1800	10	1811
1947	441	5	446	1985	1508	16	1524
1948	717	5	721	1986	1163	32	1195
1949	872	5	876	1987	1415	39	1454
1950	859	4	864	1988	1822	36	1858
1951	729	5	734	1989	1826	40	1866
1952	699	5	704	1990	1596	55	1652
1953	293	6	299	1991	1360	54	1414
1954	321	6	327	1992	1409	47	1457
1955	403	7	410	1993	1121	55	1176
1956	398	6	404	1994	1201	53	1254
1957	364	7	371	1995	866	59	925
1958	292	6	298	1996	696	60	756
1959	451	6	458	1997	716	57	773
1960	401	7	408	1998	780	83	862
1961	591	7	598	1999	898	72	971
1962	951	8	959	2000	778	52	831
1963	714	7	721	2001	805	58	863
1964	437	5	443	2002	879	37	915
1965	569	5	574	2003	830	50	880
1966	857	5	862	2004	791	51	841
1967	710	5	716	2005	893	63	956
				2006	765	13	779

This added component of catch is not intended to account for any additional catch that may have been dumped, mis-reported, or landed secretly in this fishery. As noted in Stanley et al. (2005), these amounts may have been significant, particularly between about 1985 and 1995, as some harvesters attempted to circumvent trip limits and quotas. We have not attempted to account for these additional volumes in this catch reconstruction.

Reliable records of hook and line and trap (HL) landings of canary rockfish are available since 1996 with introduction of 100% dockside monitoring in these fleets. Estimates of total catch are now available from these fleets as of 2006-2007. These fleets now operate under a regulation of 100% retention of rockfish, with electronic review of discarding to confirm that discarding is negligible.

As with the trawl fishery, we also attempted to reconstruct earlier catches of the HL fishing (Appendix B). To summarize, we separated the historical HL fishery into the ZN-license component, which targeted rockfish and lingcod, and the Halibut fishery component. We used catch composition in 1995-1996 landings from logbook and dockside monitoring (DMP) (Yamanaka and Kronlund 1997) in the ZN fishery to estimate that 3% of the “rockfish” landings in this fishery (1956-1994) were composed of canary rockfish. Being a targeted rockfish fishery, we assumed discarding in this sector has always been negligible.

For the Halibut fishery, we assumed non-retention of canary rockfish but a discard rate of 0.06% based on recent bycatch in the IPHC surveys in 2003-2005 (Appendix B). The total contribution of these two fisheries appears to have been negligible until 1986. The HL fisheries currently represent about 5% of the fishery.

Note that among the many assumptions in applying a catch ratio based on recent observation so far back in time, is the requisite assumption that canary rockfish were at similar abundance levels historically. As we note subsequently in this analysis, the population may have been 3-10 times greater historically. Therefore, it is reasonable to assume that the canary rockfish bycatch in these fisheries may have been higher by a similar magnitude. However, we did not attempt to iteratively adjust the historical catch estimates.

As discussed in Stanley et al. 2005, catches of canary rockfish in the remaining commercial fisheries, recreational and First Nations’ fisheries are negligible relative to trawl and HL landings. They may, however, have significant socio-cultural importance. One possible exception to this is the salmon troll fishery. While Stanley *et al*. (2005) demonstrated that the current bycatch of canary rockfish in this fishery is negligible; the much greater troll effort in the 1950-1990 period in combination with a significantly higher canary rockfish biomass might have led to a significant bycatch.

FISHERIES MANAGEMENT

As noted earlier, DFO official management plans should be examined for details on fishing regulations. The current overall TAC is 1193 t (Table 2) with 87.70% of the canary rockfish quota allocated to trawl (T license), 11.77% to outer coast HL rockfish harvesters (ZN-outside license), and 0.53% to Pacific halibut harvesters (L license). Catches in the trawl fleet are constrained by an annual quota and vessel-specific quotas.

Hook and line catches were constrained by annual quotas and trip limits. Since 2006, there has been virtually 100% monitoring in all remaining groundfish sectors, with the exception of a small trawl fishery in the Strait of Georgia. The HL harvesters are also now constrained by sector and vessel quotas. Groundfish catches in the recreational fishery are constrained by a bag limit (for “all rockfish” combined) which varies by area.

Table 2. Canary rockfish harvest, quota, and catch (t), by year and area, 1997-2006. “Total” column also includes catches from unknown areas and Area 4B. Catches do not include HL discards until 2006/2007. Catch in the halibut fishery from “Queen Charlottes” (Queen Charlottes is a designate quota area for the HL fishery) is assigned to 5C for 2005 and 2006.

Year		Region				Total
		3C+3D	5A+5B	5C+5D	5E	
1997/98	Recommended Harvest[a]	350-525	200-400	[b]	[b]	550-925
	Trawl Quota[c]	503	345	81		929
	Quota (HL)[c]	[e]				[e]
	Catch (trawl and HL)	449	198	46	29	747
1998/99	Recommended Harvest[a]	350-525	200-400	[b]	[b]	550-925
	Trawl Quota[c]	503	345	81		929
	Quota (HL)[c]	74				74
	Catch (trawl and HL)	443	302	49	20	833
1999/00	Recommended Harvest[a]	350-525	200-400	[b]	[b]	550-925
	Trawl Quota[c]	499	342	80		921
	Quota (HL)[c]	76				76
	Catch (trawl and HL)	574	324	47	19	976
2000/01	Recommended Harvest[d]	350-700	175-350	50-150	100-200	675-1400
	Trawl Quota[c]	555	277	106	159	1097
	Quota (HL)[c]	92				92
	Catch (trawl and HL)	479	227	80	27	821
2001/02	Recommended Harvest[d]	[d]	[d]	[d]	[d]	[d]
	Trawl Quota[c]	529	265	101	151	1046
	Quota (HL)[c]	[e]				[e]
	Catch (trawl and HL)	505	239	77	20	852
2002/03	Recommended Harvest[d]	[d]	[d]	[d]	[d]	[d]
	Trawl Quota[c]	529	265	101	151	1046
	Quota (HL)[c]	140				140
	Catch (trawl and HL)	576	242	67	9	896
2003/04	Recommended Harvest[d]	[d]	[d]	[d]	[d]	[d]
	Trawl Quota[c]	529	265	101	151	1046
	Quota (HL)[c]	140				140
	Catch (trawl and HL)	514	250	73	24	865
2004/05	Recommended Harvest[d]	[d]	[d]	[d]	[d]	[d]
	Trawl Quota[c]	529	265	101	151	1046
	Quota (HL)[c]	140				140
	Catch (trawl and HL)	525	206	68	10	809
2005/06	Recommended Harvest[d]	[d]	[d]	[d]	[d]	[d]
	Trawl Quota[c]	529	265	101	151	1046
	Quota (HL)[c]	140				140
	Catch (trawl and HL)	601	231	95	11	943
2006/07	Recommended Harvest[d]	[d]	[d]	[d]	[d]	[d]
	Trawl Quota[c]	529	265	101	151	1046
	Quota (HL)[c]	147				147
	Catch (trawl and HL)	479	241	51	4.5	777
2007/08	Recommended Harvest[d]	[d]	[d]	[d]	[d]	[d]
	Trawl Quota[c]	529	265	101	151	1046
	Quota (HL)[c]	147				147
	Catch (trawl and HL)	na	na	na	na	na

[a] Stanley (1995)
[b] Not specified in Stanley (1995)
[c] see http://ops.info.pac.dfo.ca/fishman/Mgmt_plans/
[d] Stanley (1999), advice not updated for 2001/2002-2007/2008
[e] Not specified

Area specific quotas adopted by DFO were partially derived from advice provided in stock assessment documents (Table 2). The most recent advice from Stanley (1999) commented:

> "While the variety of conclusions is disappointing, they are consistent in indicating there is no massive underexploited stock of fish in the traditional grounds of 3C-5B. We see no basis for arguing for increased harvests in the traditional canary rockfish fishing grounds of Areas 3C+3D and 5A+5B… We suggest that managers do not consider yields in excess of [*average*] historical levels for these traditional fishing areas. Therefore, maximum [*defined as high risk*] recommended yields for Areas 3C+3D and 5A+5B are 700 and 350 t, respectively.
>
> In view of the expected poor 1990's' year classes, declining U.S. populations of canary rockfish, the dependency of the age analysis on the assumption of stable recruitment and the low estimates generated by Walters and Bonfil (1999), we suggest a minimum [defined as low risk] harvest no more than 50% of the average yield. This translates to 350 t and 175 t for Areas 3C+3D and 5A+5B, respectively."

Note that the expressions of risk were qualitative and intended to convey the uncertainty of the advice and thereby allow managers flexibility within the suggested range.

BIOLOGY

Biological Samples

Biological sample data were extracted from the GFBio database at the Pacific Biological Station. The extraction did not include "surface-read" ages from the 1970's. Samples sources include port samples taken from commercial landings, and at-sea observer (ASOP) samples taken during commercial fishing operations, and research samples taken during surveys. Ageing of canary rockfish is currently conducted with the break-and-burn method (MacLellan 1997). While the method is imprecise (Stanley 1999), analyses of B.C. canary rockfish specimens, using lead-radium dating and a bomb radiocarbon chronometer, indicated that the method is unbiased (Andrews et al. 2007). Details of the data sources and analyses of biological parameters are provided in Appendix C.

Growth parameters

Table 3 provides the values used for the fixed biological parameters in the catch-age stock assessment model. These include the estimated values from the base models assumed for all of 3CD5ABC (see Appendix C for details).

Age sampling information

Most of the age composition samples are from port samples taken at dockside during unloading, although there have been an increase in the number of samples taken by the ASOP in recent years (Figure 4). The latter sampling seems to have been more heavily weighted towards the WCVI than to QCSd (Figure 4). In spite of numerous samples, there is no obvious progression of specific cohorts, particularly in more recent years (Figure 5).

Table 3. Values for fixed biological parameters used in the stock assessment model.

Relationship	Equ.	Parameter	Males	Females
Length/weight	1	b_0^s	1.42E-05	1.37E-05
	1	b_1^s	3.05	3.06
Growth	2	L_∞^s	52.9	56.9
	2	k^s	0.174	0.163
	2	t_0^s	0.320	0.561

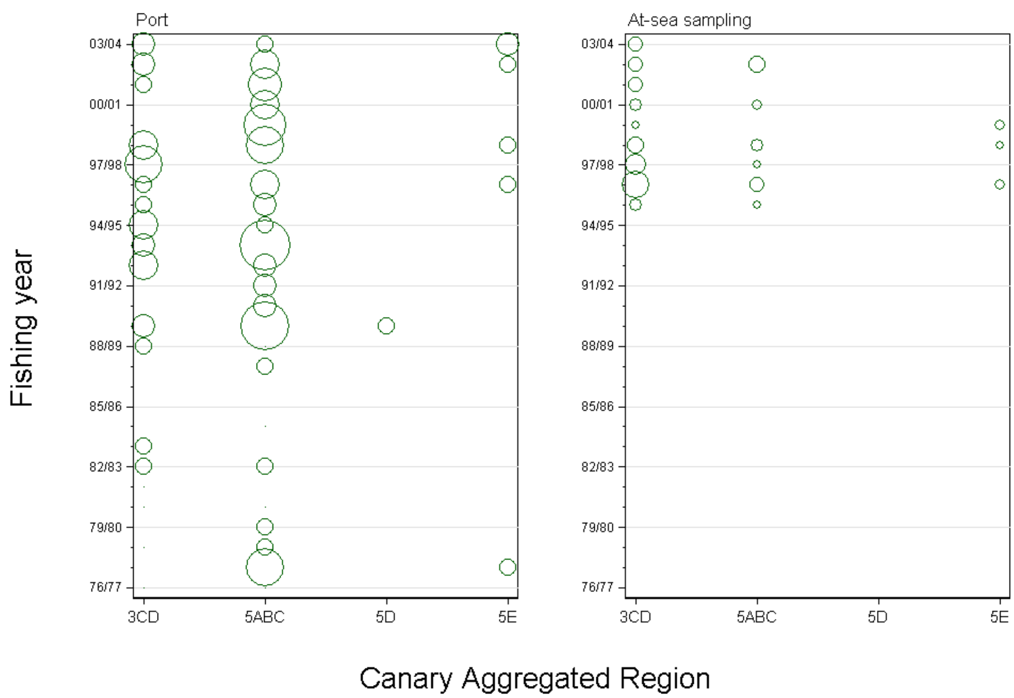

Figure 4. Number of age samples available from the commercial fishery by sample origin, aggregated DFO Region and fishing year. Maximum circle size is 16 for both graph panels.

We combined port sampling and at-sea sampling (see Appendix C). An arbitrary cut-off minimum of 4 samples in a year was selected to avoid including years which showed large variations from the patterns seen in Figure 5 and which would be heavily down-weighted in the assessment model. This resulted in omitting years from 1979-1989.

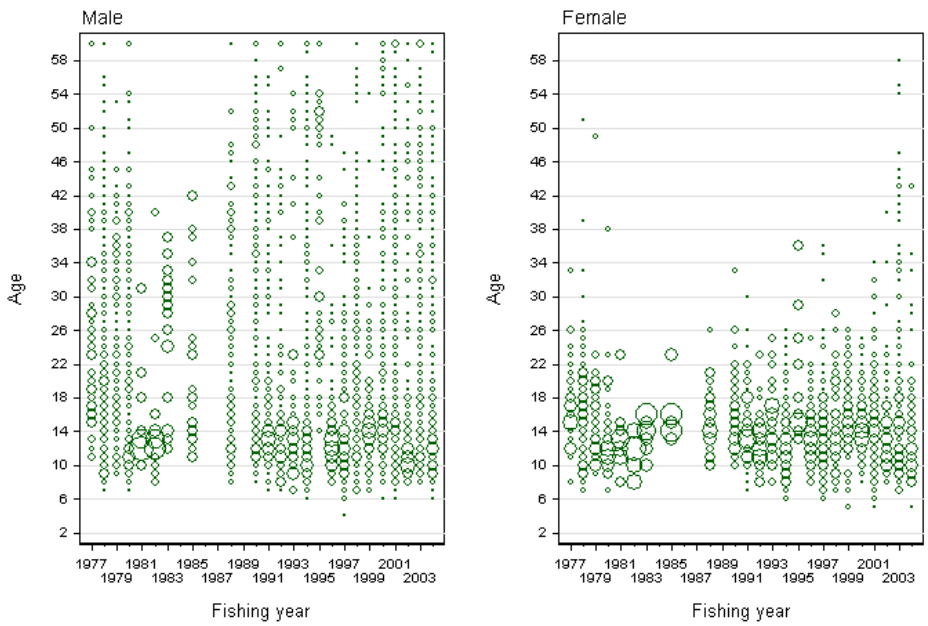

Figure 5. Relative age class size of canary rockfish by sex and fishing year over all samples for combined area 3CD5ABC. Vertical columns sum to one from age 2 to age 60, with age 60 treated as a plus-group. This plot combines port sampling with ASOP sampling without weights.

Table 4. Number of age samples available by year for the selected age compositions used to represent the coastwide canary rockfish population.

Year	**Number samples**	**Year**	**Number samples**
1978	6	1998	22
1990	5	1999	14
1991	24	2000	14
1993	4	2001	12
1994	11	2002	7
1995	5	2003	11
1996	7	2004	25
1997	10		

Maturity and fecundity

Estimation of the proportion of mature females at age was based on staged females in the database that had been aged using the break and burn method, regardless of sample origin (Figure 6, Table 5). This selection resulted in about 2,700 observations (Appendix C).

There are no published studies on the fecundity of canary rockfish. We have assumed that fecundity is linearly proportional to body weight and that there are no age-specific effects on spawn viability.

Table 5. Summary of data used to estimate the female proportion mature at age used in the catch-age model. Stages 1 and 2 were assumed to be immature fish and all other staged fish (stages 3 to 7) were assumed to be mature. Only ages with at least 10 staged observed fish sampled from January to June were used. The observed proportions and the fitted model are plotted in Figure 6.

Age	Number ages	Mean length (cm) immature	Mean length (cm) mature	Observed prop. mature	Fitted prop. mature	Model prop. mature
3	17	18.7	–	0.000	0.014	0.000
4	24	21.6	–	0.000	0.022	0.000
5	15	26.5	–	0.000	0.034	0.000
6	13	32.0	–	0.000	0.051	0.000
7	35	35.1	39.0	0.029	0.074	0.029
8	58	37.9	45.0	0.069	0.106	0.069
9	64	40.8	43.0	0.094	0.147	0.094
10	109	43.7	48.6	0.183	0.199	0.199
11	147	45.6	48.3	0.190	0.261	0.261
12	174	47.6	50.5	0.374	0.336	0.336
13	197	48.4	51.2	0.467	0.420	0.420
14	158	49.6	51.3	0.601	0.512	0.512
15	137	49.7	52.6	0.672	0.609	0.609
16	96	49.9	53.7	0.750	0.705	0.705
17	81	51.6	53.4	0.753	0.796	0.796
18	73	52.3	54.2	0.877	0.876	0.876
19	39	54.0	55.5	0.872	0.939	0.939
20	48	51.4	55.1	0.813	0.981	0.981
21	30	53.3	55.6	0.800	0.999	0.999
22	24	50.5	55.9	0.833	1.000	1.000
23	17	53.5	55.5	0.765	1.000	1.000

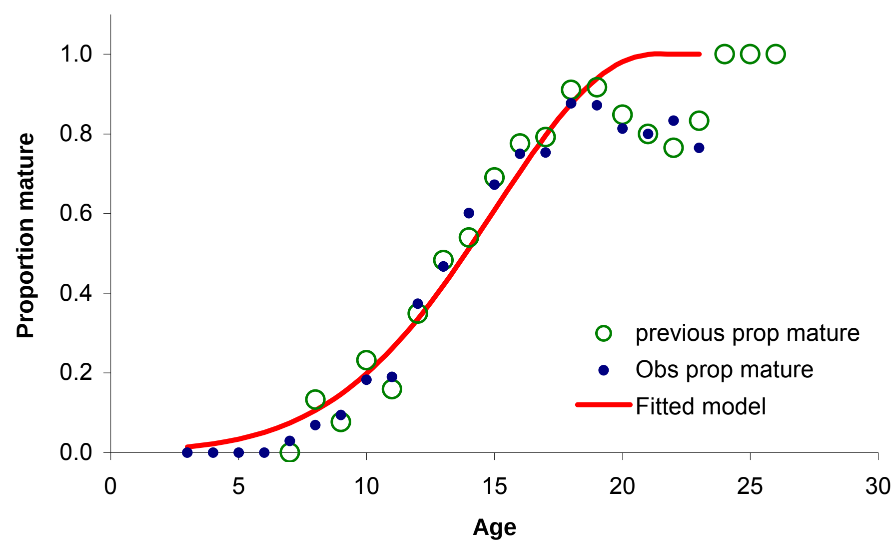

Figure 6. Three estimates of the proportion of mature females: 1) calculated by Stanley et al. (2005); 2) observed from the available data; 3) fitted model.

Natural Mortality

Stanley (1999) reviewed the existing information on estimates of *M and* suggested plausible ranges of 0.02-0.04 for males and 0.06-0.08 for females. However, most catch-at-age analyses (Methot and Piner 2001, Methot and Stewart 2005) obtain the best model fits when female *M is* allowed to increase coincident with reproductive maturation. The current U.S. assessment fixes *M for* males and young females at 0.06, and then allows the degree of increase for older females (age 14+) to be treated as an estimated parameter. The base U.S. run estimated that *M* increased from 0.06 to 0.097 at age 14. In the 2005 U.S. assessment, a generation time of 22 years for females was estimated from an age-averaged value of *M* of 0.09.

The reason for the more truncated age composition of the females is unknown. It has also been observed in yellowtail rockfish (*S. flavidus*). Early assessments of both of these species entertained the possibilities that it was caused by an increasing rate of natural mortality with age in females or, decreasing selectivity/availability/vulnerability for older females in the fishery, or both. Most recent assessments attribute the effect mostly to increasing *M* with age. Models appear to obtain their best fit if *M is* allowed to increase rapidly coincident with the age of maturation (see Methot and Stewart 2005). There is no evidence that higher *F* at earlier ages causes the absence of older females since the sexes appear to enter the fishery in equal proportions. There are also no reports of spatial refugia or a gear selectivity bias that could cause this effecting B.C. waters. In this B.C. assessment, all model runs fixed all ages for male *M* at 0.06. Female *M* was set at 0.06 to age 13 then fixed at 0.12 for age 14 and older.

FISHERY INDEPENDENT SURVEYS

The population model presented below uses the results of five surveys (Figure 7 and Figure 8; Table 6). Full details of the surveys and derivation of index values are provided in the Appendices.

1. West Coast Vancouver Island shrimp trawl survey (WCVI Shrimp) (Appendix D)
2. Queen Charlotte Sound shrimp trawl survey (QCSd Shrimp) (Appendix E)
3. G.B.Reed (QCSd groundfish bottom trawl survey (G.B.Reed survey) (Appendix F)
4. U.S. triennial groundfish bottom trawl survey (Triennial survey) (see Stanley *et al*. 2005)
5. QCSd groundfish bottom trawl survey (QCSd survey) Appendix G).

Other surveys that could have been used either capture too few canary rockfish or have just been initiated (Figure 9 and Figure 10; Table 6).

Table 6. Fishery independent trawl surveys conducted in B.C. applicable to canary rockfish.

Survey	Start	End	Ongoing	Surveys	Depth (m)	Gear Used	Included
WCVI Shrimp[1]	1975	2007	Y	30	15-258	Shrimp trawl	Yes
QCSd Shrimp	1999	2004	Y	6	15-309	Shrimp trawl	Yes
GBReed QCSd	1967	1984	N	7	147-256	Groundfish bottom trawl	Yes
U.S. Triennial[2]	1980	2001	N	8	55-477	Groundfish bottom trawl	Yes
QCSd Gfish	2003	2005	Y	3	37-543	Groundfish bottom trawl	Yes
WCVI Gfish	2004	2006	Y	2	46-750	Groundfish bottom trawl	No, two data points
Hecate Strait Gfish	2005	2007	Y	2	11-230	Groundfish bottom trawl	No, two data points
WCQCI Gfish	2006	2007	Y	2	180-1800	Groundfish bottom trawl	No, two data points, too few fish
Hecate Strait Assemblage[3]	1984	2003	N	11	18-232	Groundfish bottom trawl	No, too few fish
IPHC[4]	1995	2007	Y	13	15-300	Set line	No, too few fish
DFO longline (N and S)	2006	2007	Y	1	20-260	Set line	No, one data point in each area

Notes:

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

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

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

Start and end years refer to the surveys used in this document, not necessarily the complete survey series.

[4]From 1997-2002, only first twenty hooks of each skate were enumerated for bycatch species,
therefore, total catch numbers for canary rockfish are too low to be useful as an index over this period.
Catch is now fully enumerated (2003-2007), but numbes remain too low to be useful over the short term. However, with full enumeration,
this survey may provide a useful secondary coastwide index.

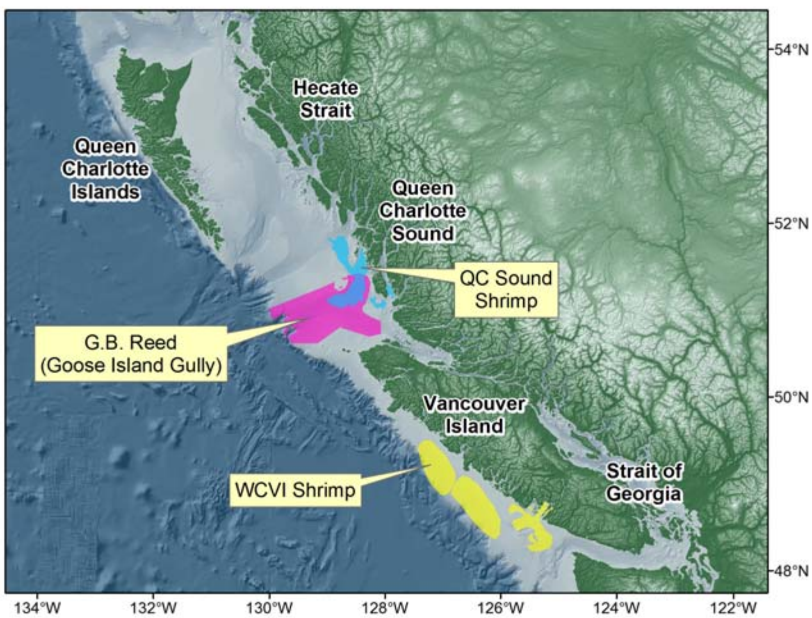

Figure 7. Locations of the QCSd and WCVI shrimp surveys, and the G.B. Reed QCSd survey.

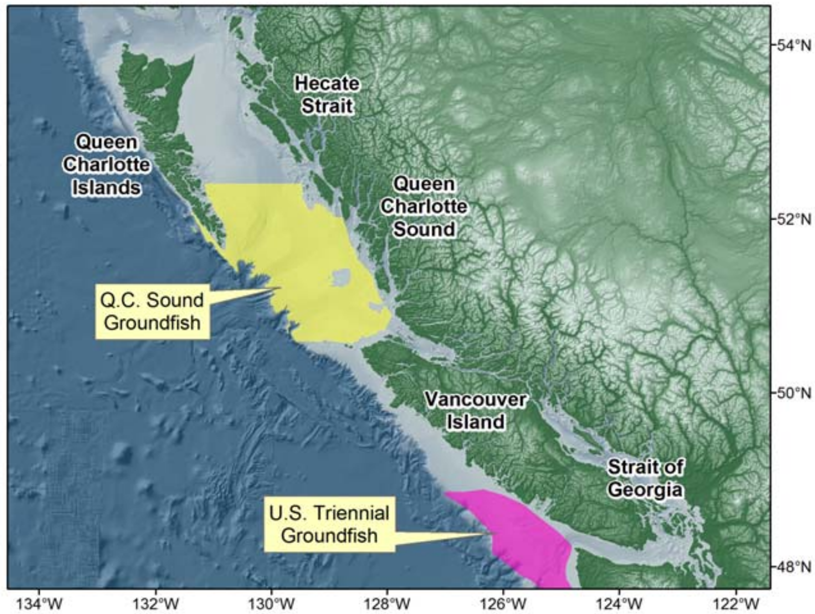

Figure 8. Locations of the QCSd and Triennial groundfish surveys.

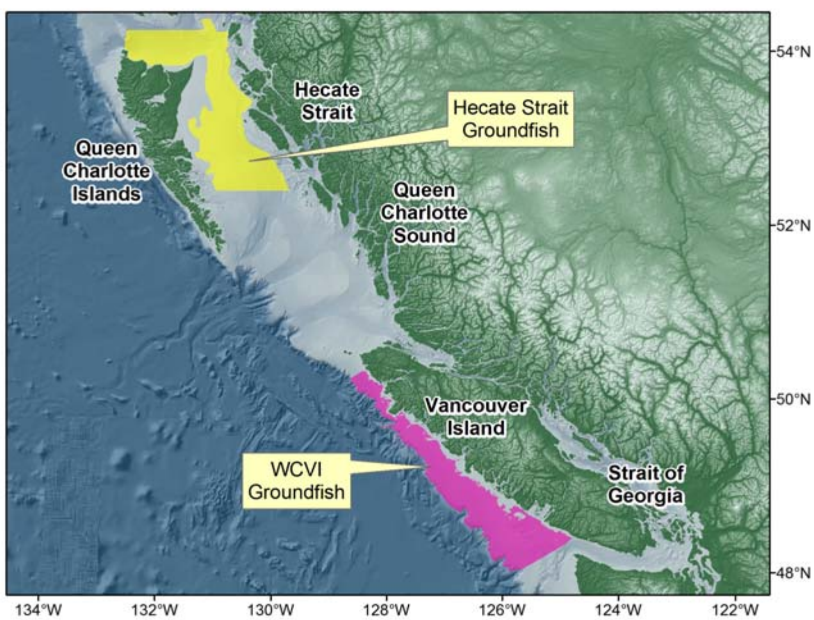

Figure 9. Locations of the “new” Hecate Strait and WCVI groundfish surveys.

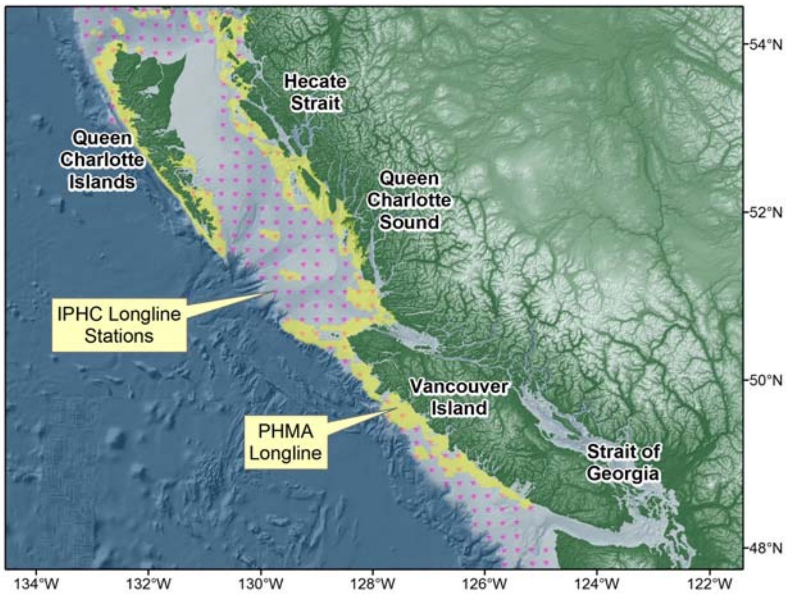

Figure 10. Locations of the PHMA longline survey (yellow shaded region) and the set locations of the IPHC longline survey.

West Coast Vancouver Island Shrimp Survey

Tow-by-tow data from the WCVI shrimp trawl survey are available for 33 years spanning the period of 1972-2007 (Appendix D). However, rockfish were not identified to the species level for the 1972 and 1973 surveys and 1974 is a missing year. Therefore, for rockfish species, this survey begins in 1975 and is the longest series available to monitor this species in Canadian waters. This survey has a limited range in terms of depth surveyed (80 to 160 m) and does not go further north than 49.5° N (Figure 11). Previous analyses had interpreted the units of the "distance traveled" field for this survey as kilometres. However, it was brought to our attention that the units were in nautical miles for the surveys prior to 2004. Therefore, the survey indices have been re-analysed using the correct formulation for the distance travelled field, although the changes relative to the indices reported in Stanley et al. (2005) are minor (Figure 12).

Canary rockfish biomass has varied substantially throughout the history of this survey, but with an apparent downward trend and there are several years which have high biomass estimates associated with high levels of relative error (e.g. 1977, 1983, 1994) (Figure 12, Table 7).

The shrimp surveys discussed above and below are clearly only indexing only a small portion of the coastwide biomass of canary rockfish. Furthermore, it can be assumed that the gear and the towing speed (~ 2 knots) result in a low catchability of the canary rockfish in that area, and the survey focuses on soft silty bottom which is not the preferred habitat of canary rockfish. These surveys were not designed to index the coastwide population of canary rockfish and the observed trends should be viewed with caution. However, this survey represents the only available long-term consistent time series on the Canadian west coast and thus merits its inclusion.

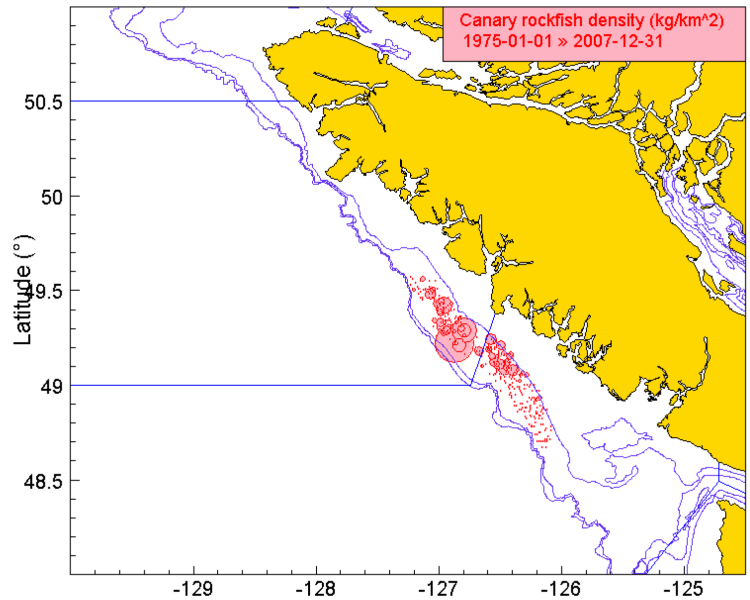

Figure 11. Map of the locations of all trawls from the WCVI shrimp trawl survey (1975–2007) that caught canary rockfish. Circles are proportional to catch density (largest circle=128 kg/km^2). Also shown are the 100, 200 and 300-m isobaths and the PMFC major area boundaries for Areas 123 and 124.

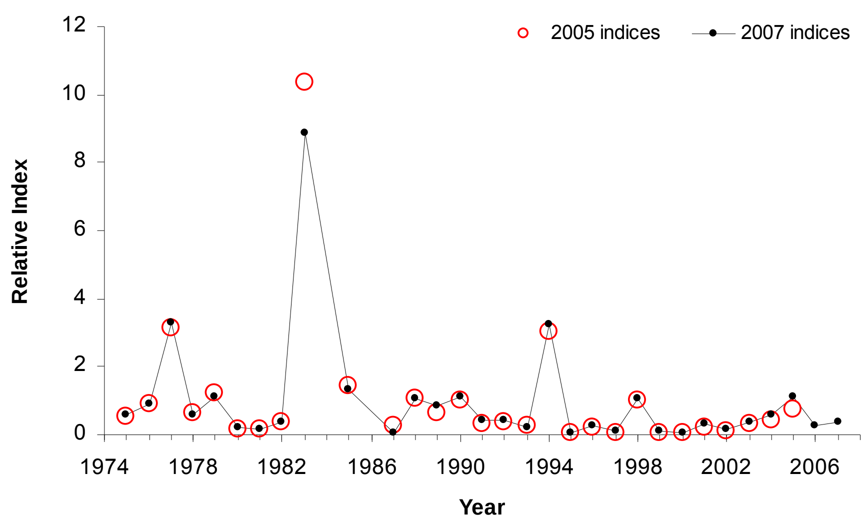

Figure 12. Plot of biomass estimates for canary rockfish from the WCVI shrimp trawl survey for 1975-2007.

Table 7. Biomass estimates for canary rockfish from the WCVI shrimp trawl survey for the survey years 1975 to 2007. Biomass estimates are based on a post-stratification of this survey into two strata and by assuming that the survey tows were randomly selected within these areas. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement. The analytic CV (Eq. 4) is based on the assumption of random tow selection within a stratum.

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
1975	557	557	330	830	0.230	0.237
1976	827	812	237	1,985	0.515	0.525
1977	3,016	3,144	201	8,623	0.667	0.666
1978	552	556	45	1,729	0.778	0.820
1979	1,030	1,014	239	2,444	0.517	0.544
1980	208	208	35	667	0.754	0.745
1981	158	157	36	367	0.532	0.542
1982	340	342	110	719	0.450	0.446
1983	8,139	8,483	17	32,461	0.983	0.996
1985	1,223	1,198	189	3,408	0.676	0.669
1987	69	71	6	188	0.684	0.696
1988	988	974	239	2,388	0.526	0.531
1989	799	810	61	2,265	0.695	0.704
1990	1,040	1,072	45	3,837	0.919	0.911
1991	366	368	40	1,243	0.806	0.881
1992	392	408	18	1,232	0.792	0.791
1993	192	192	40	523	0.594	0.587
1994	2,970	2,983	76	10,701	0.916	0.894
1995	39	39	8	85	0.484	0.490
1996	222	222	72	428	0.419	0.433
1997	82	82	30	156	0.381	0.387
1998	977	965	5	3,445	0.957	0.985
1999	81	80	44	137	0.291	0.299
2000	29	29	11	54	0.375	0.376
2001	311	312	23	1,133	0.880	0.869
2002	138	140	67	236	0.307	0.313
2003	321	324	150	614	0.359	0.381
2004	548	542	174	1,145	0.435	0.444
2005	1,010	991	77	3,321	0.886	0.881
2006	259	255	43	662	0.572	0.575
2007	320	319	218	503	0.217	0.220

Queen Charlotte Sound Shrimp Survey

This survey covers the lower half of QCSd, extending westward from Calvert Island and Rivers Inlet into Goose Island Gully (Figure 13) (Appendix E). Over 600 usable tows have been conducted by this survey over the nine available survey years.

Catches of canary rockfish tend to be distributed along the trench of Goose Island Gully and along the shelf edge of the outside islands (Figure 14). Canary rockfish were mainly taken at depths from 130 to 190 m. Estimated biomass levels for canary rockfish from the QCSd shrimp trawl survey are relatively small and variable (Figure 15 and Table 8). There are a few years with higher levels of biomass (2002, 2003 and 2005) but all years have high levels of variability, with CVs ranging between 36% and 102%).

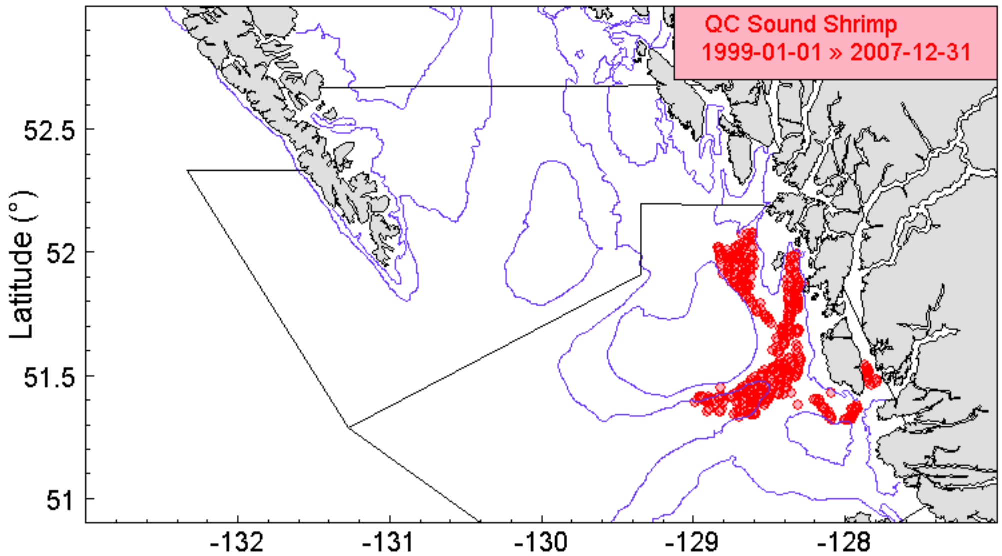

Figure 13. Map showing the locations of valid tows (Stratum numbers 109, 110, 111) conducted by the QCSd shrimp survey over the period 1999 to 2007. The tows on the inside of Calvert Island represent Stratum 111 which was not used in the analysis of this survey for canary rockfish.

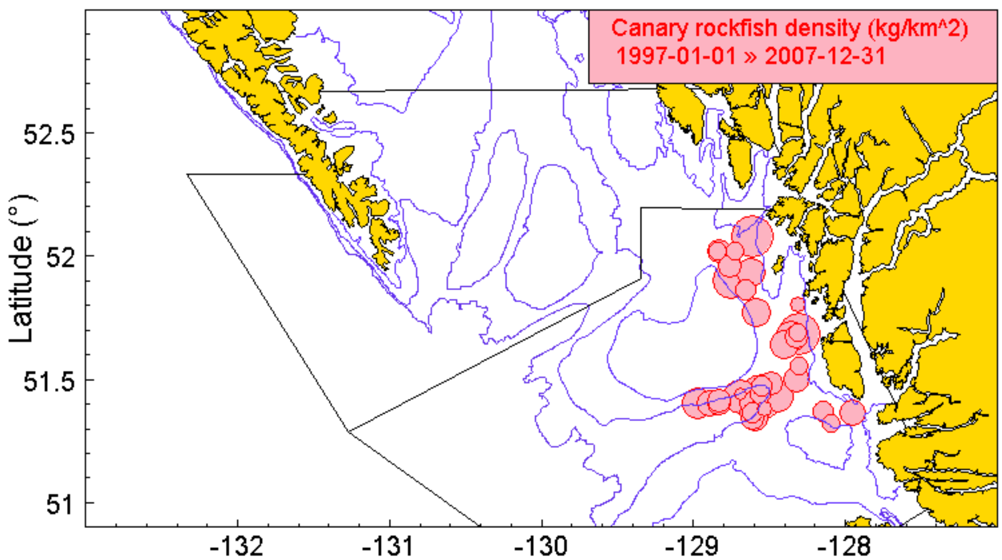

Figure 14. Map of the locations of all trawls from the QCSd shrimp trawl survey (1999–2007) which caught canary rockfish. Circles are proportional to catch density (largest circle=0.14 kg/km^2). Also shown are the 100, 200 and 300 m isobaths and the area stratum boundaries for the QCSd synoptic survey.

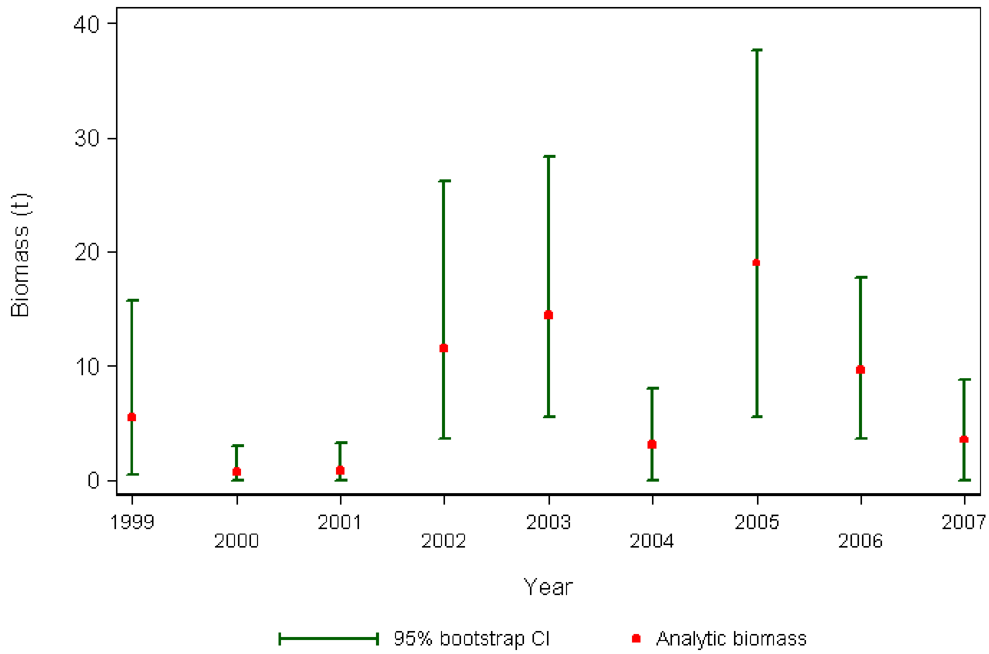

Figure 15. Plot of biomass estimates for canary rockfish from the QCSd shrimp trawl survey for 1999 to 2007 with bias corrected 95% confidence intervals from 1000 bootstrap replicates.

Table 8. Biomass estimates for canary rockfish from the QCSd shrimp trawl survey for the survey years 1999 to 2007. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement. The analytic CV is based on the assumption of random tow selection within a stratum.

Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
1999	5.5	5.6	0.5	15.7	0.681	0.691
2000	0.7	0.7	0.0	3.0	1.019	1.000
2001	0.8	0.9	0.0	3.3	0.968	1.000
2002	11.5	11.5	3.6	26.2	0.467	0.483
2003	14.4	14.1	5.5	28.3	0.385	0.397
2004	3.1	3.1	0.0	8.0	0.681	0.701
2005	19.0	18.6	5.5	37.6	0.441	0.446
2006	9.6	9.6	3.5	17.7	0.365	0.384
2007	3.5	3.5	0.0	8.8	0.605	0.601

G.B. Reed Queen Charlotte Sound Survey

We have included for the first time in a canary rockfish review an analysis of canary rockfish catch rates from the FR Vessel *G.B.Reed* - Pacific ocean perch surveys of QCSd (Appendix F). We have examined data from seven trips, which spanned the period of 1967 to 1984. A total of 204 tows in Goose Island Gully were included in the analysis (Figure 16, and Figure 17; Table 9, Table 10, and Table 11).

Table 9. Number of tows available for biomass estimation from the 7 GB Reed surveys (1967-1984) in Goose Island Gully by depth interval.

Survey year	147-183 m	184-219 m	220-256 m	Total
1967	6	11	5	22
1969	9	11	6	26
1971	4	15	8	27
1973	7	11	7	25
1976	7	13	8	28
1977	12	14	14	40
1984	11	15	10	36
Total	56	90	58	204

Table 10. Catch weight (kg) of canary rockfish for each of the 7 G.B. Reed surveys (1965-1984) by depth interval, based on the recorded depth at the beginning of each tow.

	Depth Interval					All
Survey year	66-146 m	147-183 m	184-219 m	220-256 m	257-428 m	tows
1967	5	33	56	2	0	96
1969		145	24	2	0	171
1971		463	57	2	0	522
1973		98	10	2	0	110
1976		55	110	9	0	174
1977	0	688	57	11	0	756
1984		97	121	6	11	235
Total	114	2,816	713	60	11	3,714

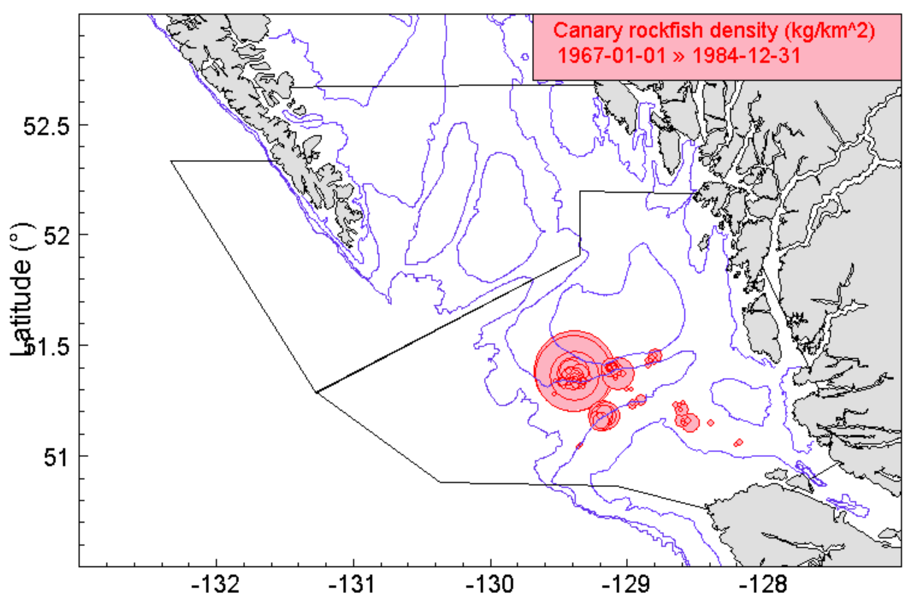

Figure 16. Map of the locations of all trawls from the GB Reed trawl survey (1967–1984) which caught canary rockfish. Only those tows in Goose Island Gully that were used in the biomass index calculation are shown. Circles are proportional to catch density (largest circle=2.42 kg/km^2). Also shown are the 100, 200 and 300-m isobaths.

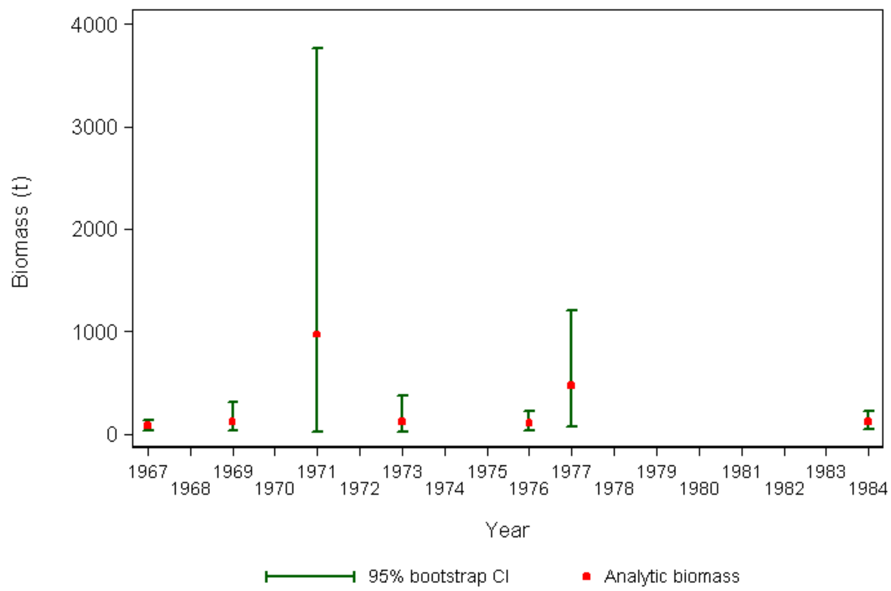

Figure 17. Plot of biomass estimates for canary rockfish from the Goose Island Gully G.B.Reed trawl surveys for the period 1967 to 1984 with bias corrected 95% confidence intervals from 1000 bootstrap replicates.

Table 11. Biomass estimates for canary rockfish from the Goose Island Gully G.B. Reed trawl surveys for the years 1967 to 1984. Biomass estimates are based on three depth strata and by assuming that the survey tows were randomly selected within these areas. Bootstrap bias corrected confidence intervals and CVs are based on 5000 random draws with replacement. The analytic CV (Eq. 4) 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 (Eq 4)
1967	79.4	79.1	32.5	137.0	0.342	0.354
1969	119.6	116.4	35.3	309.1	0.556	0.541
1971	973.2	964.2	24.9	3,768.2	0.954	0.956
1973	121.5	123.8	20.3	366.2	0.703	0.703
1976	110.4	110.8	34.4	222.6	0.410	0.415
1977	469.9	471.2	70.3	1,202.0	0.588	0.612
1984	120.2	121.8	49.3	216.1	0.348	0.351

Canary rockfish were caught primarily at the entrance to the Gully (Figure 16). Estimated biomass levels in the Goose Island Gully for canary rockfish from the G.B.Reed trawl surveys appear to have been relatively constant through the 7 years of this survey. The exception is 1971 which has a large biomass estimate associated with a very large relative error (Figure 17; Table 11). This large biomass estimate is the result of a single tow which caught 447 kg of canary, the largest single catch of this species in the 9 surveys. The 1977 survey year also has a high relative error but the biomass is somewhat lower.

Although the G.B.Reed data provide a highly uncertain tracking of the 1967-1984 period, they are useful in providing the only available index which spans the period of Soviet (1965-1976) and Japanese (1966-1978) trawling on the B.C. coast. While these fisheries are assumed to have concentrated on unfished populations of Pacific ocean perch in deeper water (Ketchen 1980), it is possible that they also harvested significant quantities of shelf rockfish. The G.B.Reed survey, such as it is, does not support the contention of a major fishing down event for canary rockfish caused directly by Soviet and Japanese fleets.

U.S. NMFS Triennial Survey

The U.S. National Marine Fisheries Service (NMFS) triennial survey began in 1977 and typically covered northern California to the U.S./Canada border in northern Washington (Weinberg et al. 2002). For the years 1980, 1983, 1989, 1992, 1995, 1998, and 2001, it was extended into southern B.C. waters. The first two of these surveys extended to 49°15' N; the latter five surveys extended further north to 49°40' N. The analyses are unchanged from Stanley et al. (2005).

The U.S. triennial survey indices for canary rockfish show a declining trend over the period of the survey, with the amount of decline depending on which area is considered (Figure 18, Table 12).

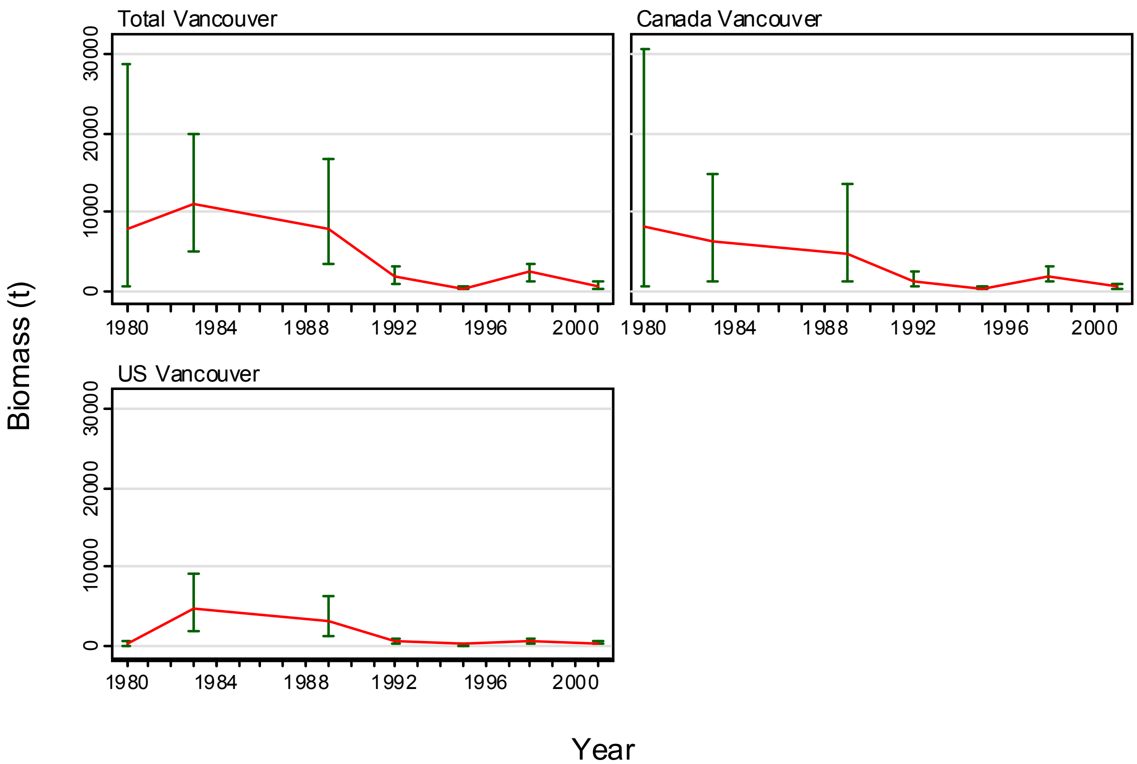

Figure 18. Three biomass estimates for canary rockfish in the INPFC Vancouver region (total region, Canadian waters only and U.S. waters only) with 95% bias corrected error bars estimated from 5,000 bootstraps.

Table 12. Biomass estimates for canary rockfish in the Vancouver INPFC region (total region, Canadian waters only and U.S. waters only) with 95% confidence regions based on the bootstrap distribution of biomass. Additional details and alternative derivations are shown in Stanley et al. (2005). The bootstrap estimates are based on 5,000 random draws with replacement.

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

Queen Charlotte Sound Groundfish Survey

The QCSd trawl survey has been conducted for four years, (2003-2005 and 2007) in QCSd and the lower part of Hecate Strait (Figure 19 and Figure 20) (Appendix G).

Estimated biomass levels for canary rockfish from this trawl survey appeared to be increasing up to the 2005 survey, but the 2007 survey showed a drop contrary to this trend (Figure 21; Table 13). The estimated relative errors lie between 30 and 40% with the exception of the 2005 survey where the relative error is 60% (Table 13). The proportion of tows which captured canary rockfish is variable, with both aerial strata showing similar trends. Approximately 15-25% of the survey tows contain canary rockfish.

While we have not had a chance to explore the cause, we note that virtually all of the species observed in the survey, many of which are relatively long-lived and include flatfish, showed significantly lower catch rates in 2007 as compared with the average from 2003-2005 (Figure 22). Since it is doubtful that all of these species underwent a true decline over this period, it is reasonable to postulate that some year-specific effect reduced availability or catchability in 2007. Note the matching decline above in the QCSd shrimp survey.

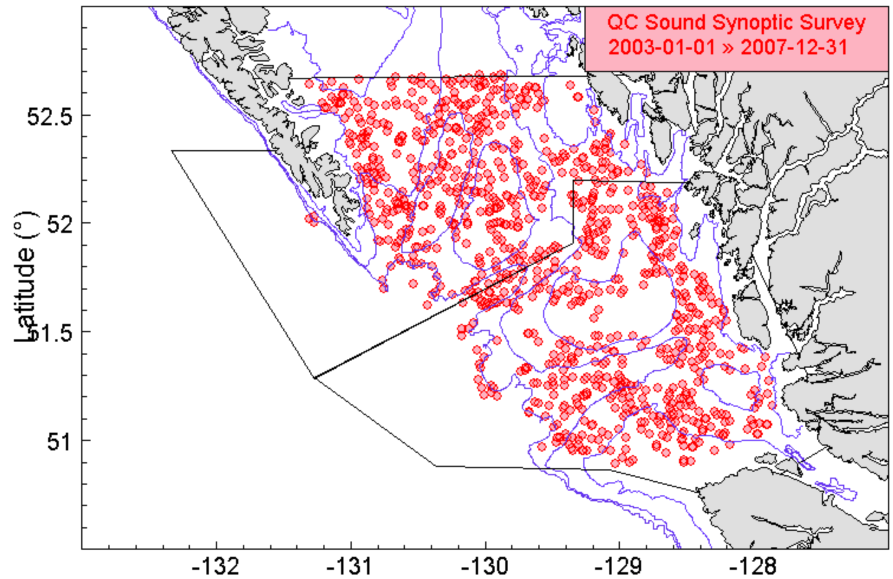

Figure 19. Chart showing the locations of valid tows conducted by the QCSd synoptic trawl survey over the period 2003 to 2007. The boundaries of the two aerial strata (5AB-South and 5AB North) are shown.

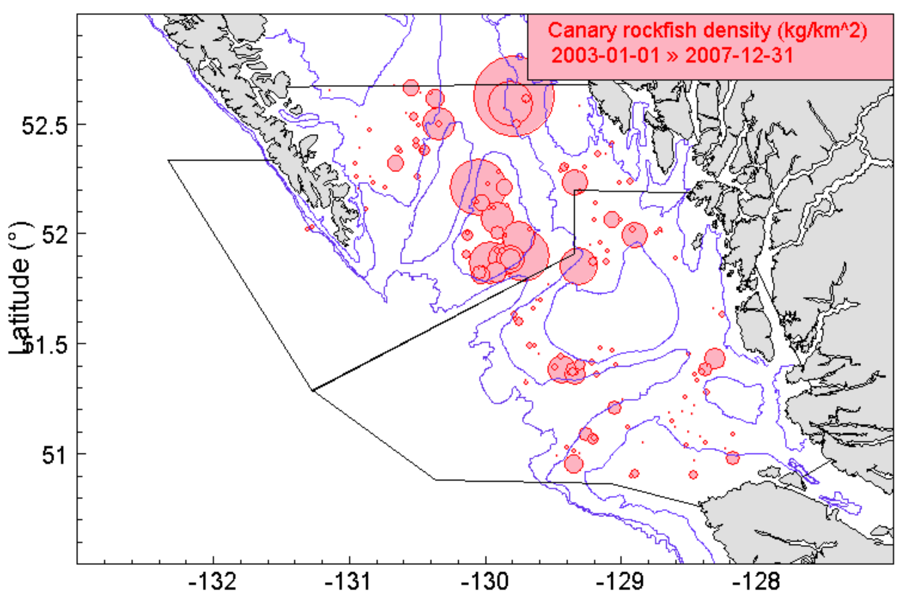

Figure 20. Map of the locations of all trawls from the QCSd synoptic trawl survey (2003–2007) which caught canary rockfish. Circles are proportional to catch density (largest circle=8671 kg/km^2). Also shown are the 100, 200 and 300 m isobaths and the area stratum boundaries.

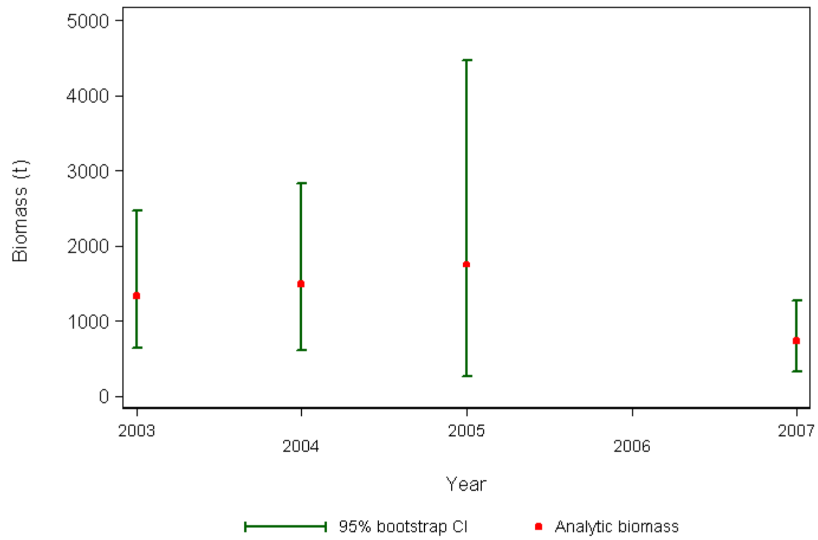

Figure 21. Plot of biomass estimates for canary rockfish from the QC Sound synoptic trawl survey for 2003 to 2007 with bias corrected 95% confidence intervals from 1000 bootstrap replicates.

Table 13. Biomass estimates for canary rockfish from the QC Sound synoptic trawl survey for the survey years 2003 to 2007. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement. The analytic CV is based on the assumption of random tow selection within a stratum.

Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
2003	1,337	1,346	635	2,464	0.335	0.346
2004	1,494	1,491	607	2,831	0.380	0.382
2005	1,748	1,833	268	4,475	0.596	0.602
2007	737	735	322	1,277	0.343	0.342

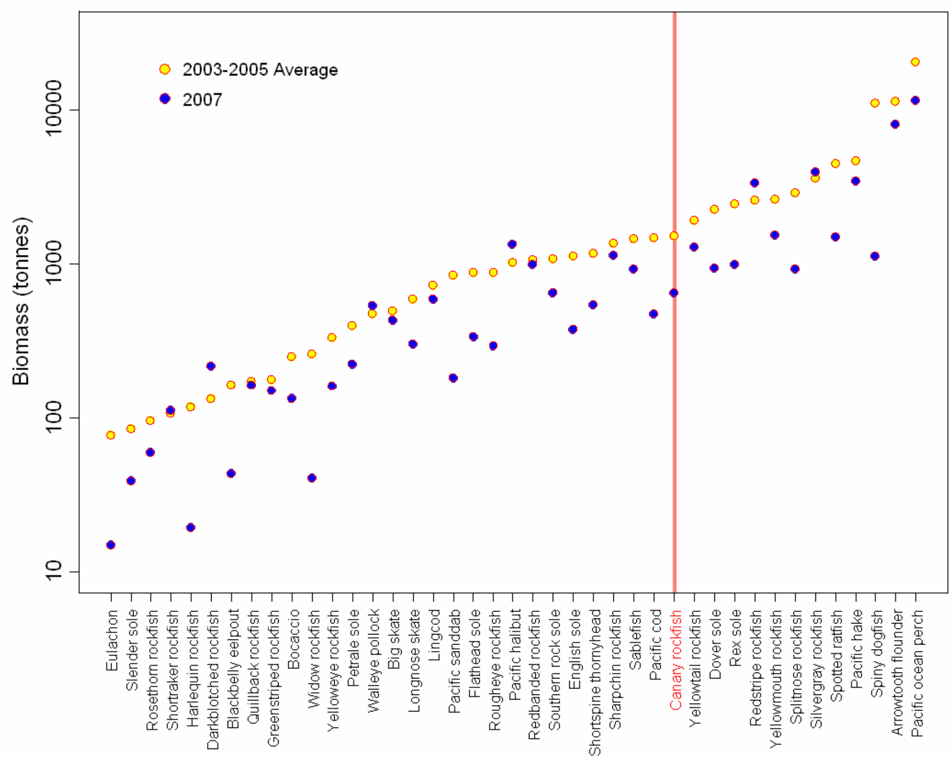

Figure 22. Biomass indices of selected fish species caught in the QCSd groundfish survey. A comparison of 2003-2005 average values to the 2007 estimates. Canary rockfish is highlighted.

Other surveys

Relatively high-density groundfish surveys were also initiated by DFO and Industry off the West Coast of Vancouver Island in 2004 and Hecate Strait in 2005, to parallel the QCSd groundfish survey. Both have been repeated once and each will be conducted every two years. We did not include the results in our modeling because there are only two data points but have summarized the results below (Figure 23 and Table 14).

Table 14. Biomass estimates from the first two Hecate Strait and West Coast Vancouver Island Groundfish synoptic surveys. Note that 2006* values refer to additional estimation for the 2006 WCVI survey after removal of one large tow 4,000 kg.

Survey	Year	Biomass (mt)	Lower CI (mt)	Upper CI (mt)	Relative Error	Number of Sets	Non zero Sets
Hecate Strait Groundfish	2005	19	8	55	0.48	226	14
	2007	34	18	73	0.34	143	15
WCVI groundfish	2004	709	395	1,397	0.32	98	39
	2006	3,935	1,556	12,906	0.52	166	48
	2006*	2,076	899	4,678	0.39	165	47

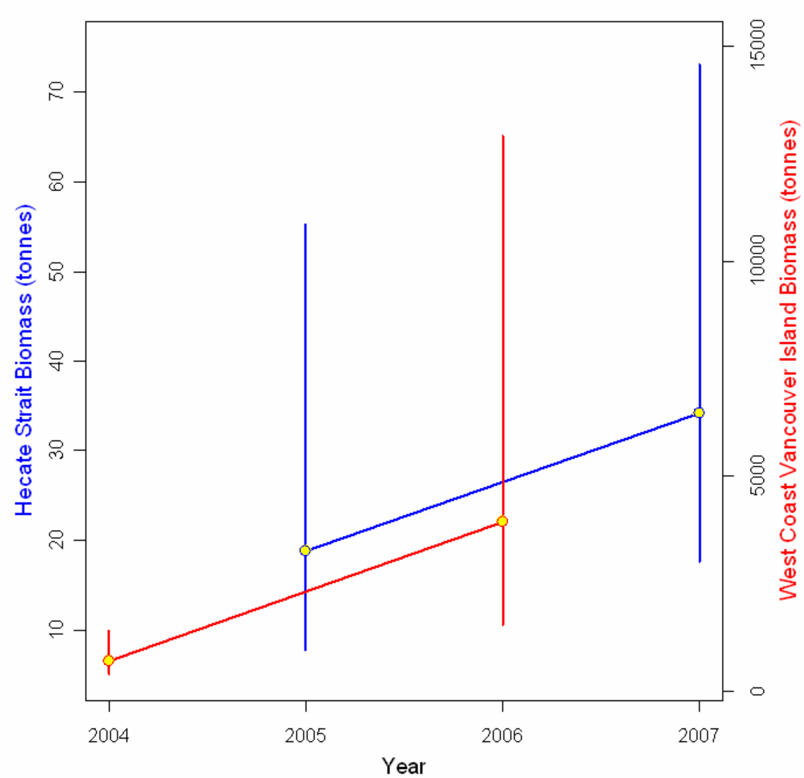

Figure 23. Canary rockfish biomass estimates from the Hecate Strait and WCVI groundfish surveys.

Both indicate larger biomasses in the second year of the survey, albeit with high imprecision. One tow of over 4,000 kg exerts leverage in the 2006 WCVI survey. However, even if this catch were omitted, the biomass estimate would be 2,076 t. The large variance in these surveys will render each of these surveys and the QCSd groundfish survey relatively imprecise for canary rockfish. However, as a group they will provide much better tracking of canary rockfish in the future, in comparison with the output of the two shrimp surveys and U.S. triennial survey which largely drive the current assessment.

We also did not include the results of the IPHC and DFO longline surveys (Figure 10). The former survey was initiated in 1995, but only recently have all non-halibut catches been enumerated. While relatively few canary rockfish are caught, over the long term this survey will provide a useful secondary index. The same applies to the new DFO longline surveys, which have just been initiated.

COMMERCIAL TRAWL CPUE

We updated the previous analysis of commercial trawl CPUE to include the period of April 1996 through March 2007 (Appendix H). The beginning date of this analysis corresponds to the start of ASOP records and ignores the prior catch history that relied on fisher logs and sales slips. We argue that catch rate data prior to April 1996 are not comparable over time, owing largely to the significant and varying degrees of mis-reporting. As noted before, our concerns about this period are based on the reporting of a large number of landing events, known to the senior author and others, for which the fishing logs and sales slips were obviously falsified. Furthermore, the trip limits were varied over time; thus the directions of the biases would vary from one year to the next, or over groups of years. The dysfunction in the catch reporting system and the resulting inability to manage to quotas was the primary reason that the Department imposed 100% observer coverage on the trawl fishery in 1996. While we acknowledge that the degree of misreporting was never documented in a manner that would support these concerns, we suggest that presenting catch rates as being reliable from this period would not be useful.

The commercial CPUE analysis in Appendix H is confined to the period 1996-2007, which marked the beginning of 100% observer coverage and the collection of more reliable data. However, this analysis is included with the caveat that CPUE can be expected to be hyperstable within the context of an IVQ (Individual Vessel Quota) fishery which was introduced in 1997. As canary rockfish abundance varies, fishers in an IVQ fishery are likely to alternate between targeting and avoiding this species in response to changes in abundance and other factors, such as market requirements or quota availability. This behaviour should cause hyperstability in reported CPUE. However, there clearly will be an abundance signal in CPUE as at some point, CPUE will respond to large-scale changes in abundance, particularly if the stock is declining. Therefore, the analyses presented in Appendix H were conducted to examine whether there was evidence of a decline large enough to overcome the hyperstability suspected in CPUE data.

The lognormal series show a general increasing trend in the Area 3CD, while the equivalent series for 5A-5C, showed an initial decline to a lower stable period from 2000/2001-2004/2005, then an increase over the last two years (Figure 24). The overall trends indicate an increasing catch rate since 2000/2001. The binomial series in both areas show an initial decline followed by a generally increasing trend since 2001, with a decline in the most recent fishing year.

These series of relative abundance indices should be interpreted with caution as they are derived from fishery dependent data and are subject to among-year effects which may originate from sources other than fish abundance. Nevertheless, these data, with their limitations, do not indicate a substantial decline in abundance in these areas since 1996; in fact, they indicate a rising catch rate since 2000/2001-2001/2002.

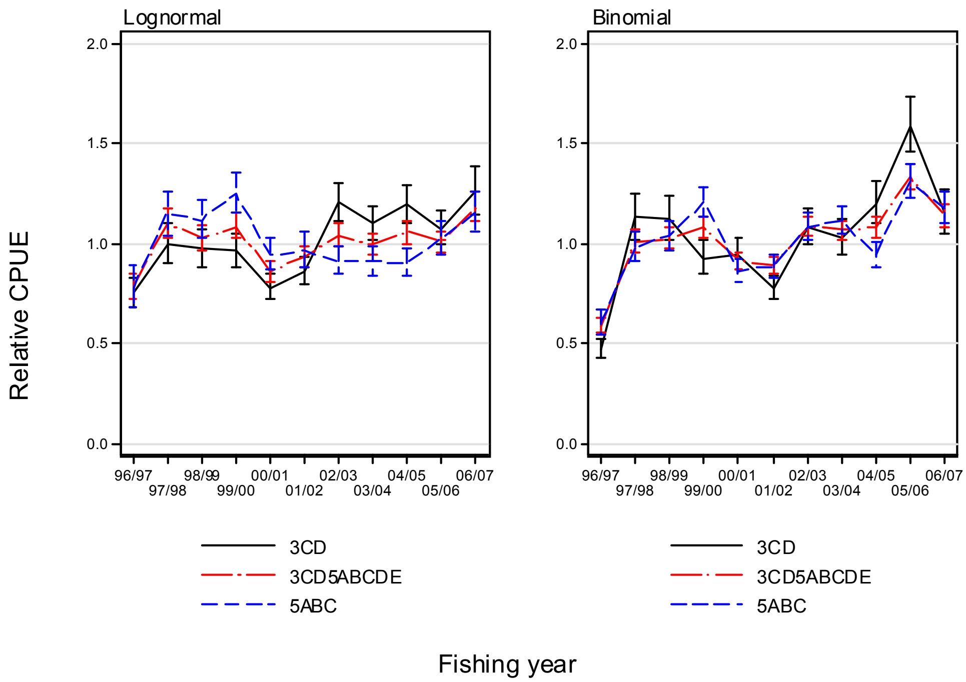

Figure 24. Comparison of standardised CPUE indices among the two regions as well as for the total B.C. (labeled “3CD5ABCDE”) analysis for each of the regression model assumptions (lognormal and binomial). Each series has been standardised relative to the geometric mean of the period 1996/97 to 2006/07. The error bars show ± 95% confidence bounds.

U.S. ASSESSMENTS

The population of canary rockfish off the coast of Washington-California was assessed again for 2007 (Stewart 2007) (Figure 25). A rebuilding analysis will be completed in the fall of 2007. The current status of the stock is summarized in a draft version as:

> “Canary rockfish were relatively lightly exploited until the early 1940s, when catches increased and a decline in biomass began. The rate of decline in spawning biomass accelerated during the late 1970s and finally reached a minimum (13% of unexploited) in the mid 1990s. The canary rockfish spawning biomass is estimated to have been increasing since that time, in response to reductions in harvest and above average recruitments in the preceding decade. However this trend is very uncertain. The estimated relative depletion level in 2007 is 32.4% (p. 6).”

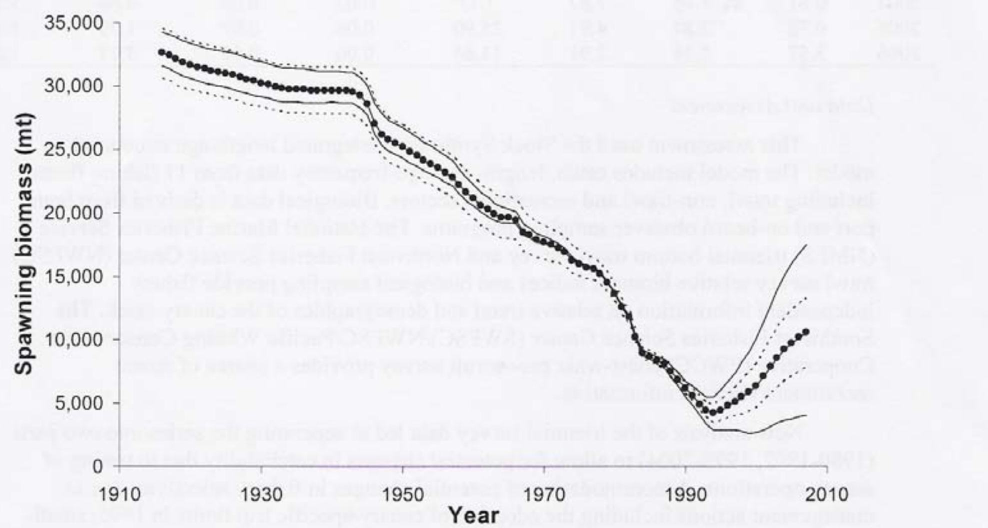

Figure b. Estimated spawning biomass time-series (1916-2007) for the base case model (round points) with approximate asymptotic 95% confidence interval (dashed lines) and alternate states of nature (light lines).

Figure 25. Modelled status of canary rockfish in U.S. waters (draft version from Stewart 2007, p. 6).

STOCK ASSESSMENT MODEL FOR CANARY ROCKFISH

Catch-age model

A coastwide assessment of canary rockfish was undertaken using a catch at age model tuned to five fishery-independent surveys and age composition data from the commercial fishery (Appendix J). A Bayesian approach, based on the Markov Chain Monte Carlo (MCMC) algorithm (Gelman et al. 1995), was used to estimate the joint posterior distribution of model parameters, thus attempting to explicitly incorporate some of the model and data uncertainty in the assessment results. The model was started from an equilibrium state in 1940 while the available fishery-independent survey data span a period from 1967 to 2007(Table 15), although not all intervening years are represented. There is one age sample from 1978 while the remaining samples cover the period from 1990 to 2004.

Table 15. Data used in canary rockfish catch-age model.

Data type	Years	Reference
Catch	1940–2006	Appendix B
Age composition from commercial trawl fishery	1978–2004	Appendix C
WCVI shrimp trawl survey	1975–2007	Appendix D
QCSd shrimp trawl survey	1999–2007	Appendix E
GB Reed trawl survey	1967–1984	Appendix F
QCSd synoptic trawl survey	2003–2007	Appendix G
NFMS Triennial trawl survey	1980–2001	Stanley et al. (2005)

Model equations, assumptions, the fitting procedure followed, and results are presented in detail in Appendix J. The model incorporated a Beverton-Holt stock recruitment function with fixed steepness parameters and estimated the selectivity ogive for the commercial fishery only; the survey selectivity functions were fixed due to lack of data. Catchability parameters were estimated for all stock abundance indices. Growth and maturity at age were assumed to be constant over time and these biological models were estimated outside of the model fitting procedure (Appendix C). The age composition data were fitted as proportions at age and sex. Process error was added to the various data components of the model to achieve apparent equal weighting between data sets, as determined by the standard deviation of the normalised residuals (*sdnr*).

The commercial and survey selectivities used in this model were derived from equivalent selectivity ogives published in a recent assessment of the canary rockfish stock off Washington, Oregon and California (Stewart 2007). The selectivity ogives in the U.S. assessment were length-based, requiring the conversion of the ogives using the imputed age from the mean lengths (Appendix I). The derived commercial selectivity parameters were either used as fixed parameter estimates for two of the model runs or as an informed prior in the model runs where the commercial selectivity parameters were estimated. This latter approach was used to constrain the model parameter estimates to plausible values and to allow for the simultaneous estimation of the commercial selectivity and recruitment deviations. The U.S. assessment also provided fixed selectivity parameter estimates which were used for all surveys, given that none of the Canadian surveys had adequate sample information to allow for an independent estimation of the selectivity ogives. The derivation of these parameter estimates is documented in Appendix I.

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

1. The effect of including the proportion-at-age data from the commercial fishery;
2. The effect of assuming a deterministic or stochastic recruitment;

3. The effect of estimating or fixing the commercial selectivity;
4. The effect varying of the steepness assumption: two values were tested (0.70 and 0.55).

Six model runs were made (Table 16) which covered the above uncertainty options. These runs are described in detail in Appendix J. Summary results are presented below.

Table 16. Description of the six stock assessment runs made by the canary rockfish catch-age model. All models used the same catch vector and were fitted to the five surveys referenced in Table 15.

Run number	Catch-at-age data	Recruitment	Commercial selectivity	Steepness
Run 02	Not used	Deterministic	Fixed	0.70
Run 05	Used	Stochastic	Fixed	0.70
Run 08	Used	Deterministic	Estimated	0.70
Run 11	Used	Stochastic	Estimated	0.70
Run 14	Used	Deterministic	Estimated	0.55
Run 17	Used	Stochastic	Estimated	0.55

Stock assessment projections

The Bayesian approach was extended to make projections for five years from 2009 to 2013 across a range of fixed catch options. Five year projections were made from the posterior distribution of the terminal biomass with recruitments drawn randomly from a distribution in log-space of mean=0 and standard deviation=0.6 (which is the assumption for recruitment variation during the fitting phase). The projections are made starting from the 2008 beginning year biomass across a number of fixed catch options, ranging from 0 to 1200 t in 100 t steps. The resulting biomass levels for each year from 2009 were evaluated against four performance indicators to generate decision tables that can be used to provide management advice.
The performance indicators selected for this stock assessment are:

1. The probability that $\tilde{B}_y$ is greater than or equal to 0.2 B_0: $\mathrm{P}\left(\tilde{B}_y \geq 0.2B_0\right)$;
2. The probability that $\tilde{B}_y$ is greater than or equal to 0.4 B_0: $\mathrm{P}\left(\tilde{B}_y \geq 0.4B_0\right)$;
3. The probability that $\tilde{B}_y$ is greater than B_{2008}:: $\mathrm{P}\left(\tilde{B}_y > B_{2008}\right)$.

Model-based reference points were used for this assessment because no biological reference points have been specified for canary rockfish, nor are there good candidates for reference points that can be inferred from the biomass trajectory. This is because most of the stock reconstruction shows a steady declining trend (a "one-way trip"). The model-based reference points are based on the equilibrium spawning biomass consistent with the model estimate of R_0 (the female spawning B_0: Eq. J.6). These suggested reference points are 0.$4B_0$ and half this value or 0.2B_0. These values are consistent with reference points used by the National Marine Fisheries Service in the United States (Stewart 2007)[2].

[2] As a result of the November 2007 PSARC review of this document, the results were recast to be consistent with the Draft DFO policy on the Precautionary Approach (DFO 2006, DFO 2008) which recommended Limit Reference and Upper Reference points of 0.4*B_{msy} and 0.8*B_{msy}. These results were published in a Recovery Potential Assessment (RPA) (see Stanley and Starr, in press). B_{msy} in the RPA corresponds approximately to 0.296*B_0 and 0.356*B_0 for Runs 11 and 17 respectively, in the present document. The RPA also provides harvests rates (*F*) implied by the fixed harvests rates summarised in the decision tables.

Results

Appendix J provides decision tables for all six model runs summarised in Table 16. They show the probabilities for each performance indicator described above and the expected values for the ratio of each year with B_0 and B_{2008} (Table J.12 to Table J.23) by projection year at catch levels that range from 0 to 1200 t per year in 100 t steps.

All of the sources of model uncertainty investigated in the canary assessment appear to affect the management advice. The inclusion of the proportion-at-age data appears to exclude the possibility of very large biomass levels. This is indicated by the relatively restricted range of MCMC traces from the models which included these data (Runs 05 to 17) compared to the wide excursions seen in the MCMC traces and the long right-hand tail in the R0 marginal posterior distribution for Run 02 (Figure J.21 and J.22). Run 02 is quite pessimistic, lying to the left (along with Run 05) of the other model runs in each of the decision table graphs (see Figure 26, Figure 27, and Figure 28), resulting in the lowest levels of catches.

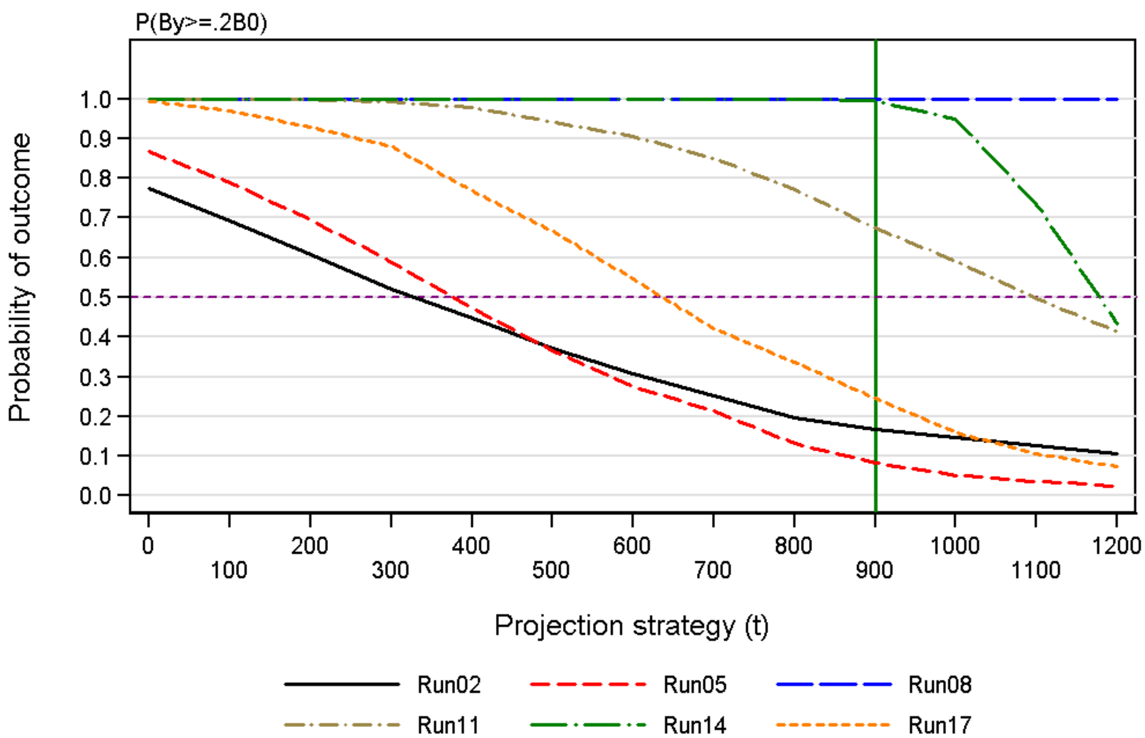

Figure 26. Comparison of the probability of $\tilde{B}_y$ exceeding $0.2B_0$ by the end of the projection period (2013) for the six model runs in Table 16. The green vertical line indicates the approximate position of the mean average catch over the past 5 and 10 years.

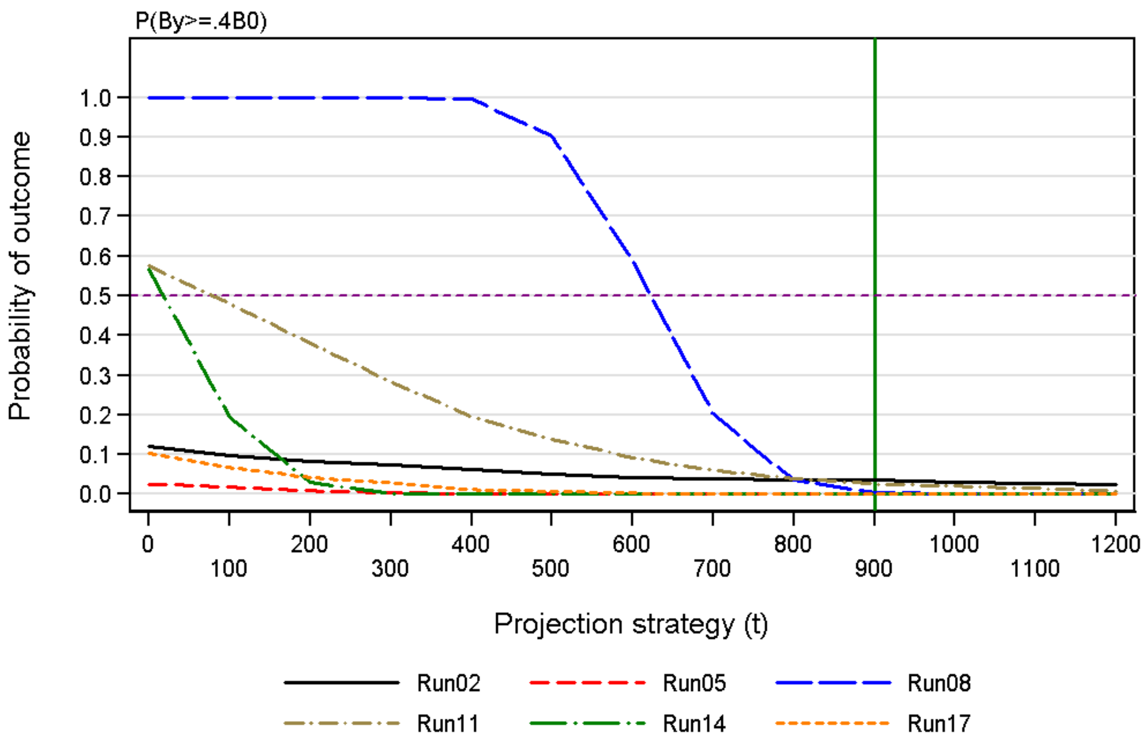

Figure 27. Comparison of the probability of $\tilde{B}_y$ exceeding $0.4B_0$ by the end of the projection period (2013) for the six model runs in Table 16. The green vertical line indicates the approximate position of the mean average catch over the past 5 and 10 years.

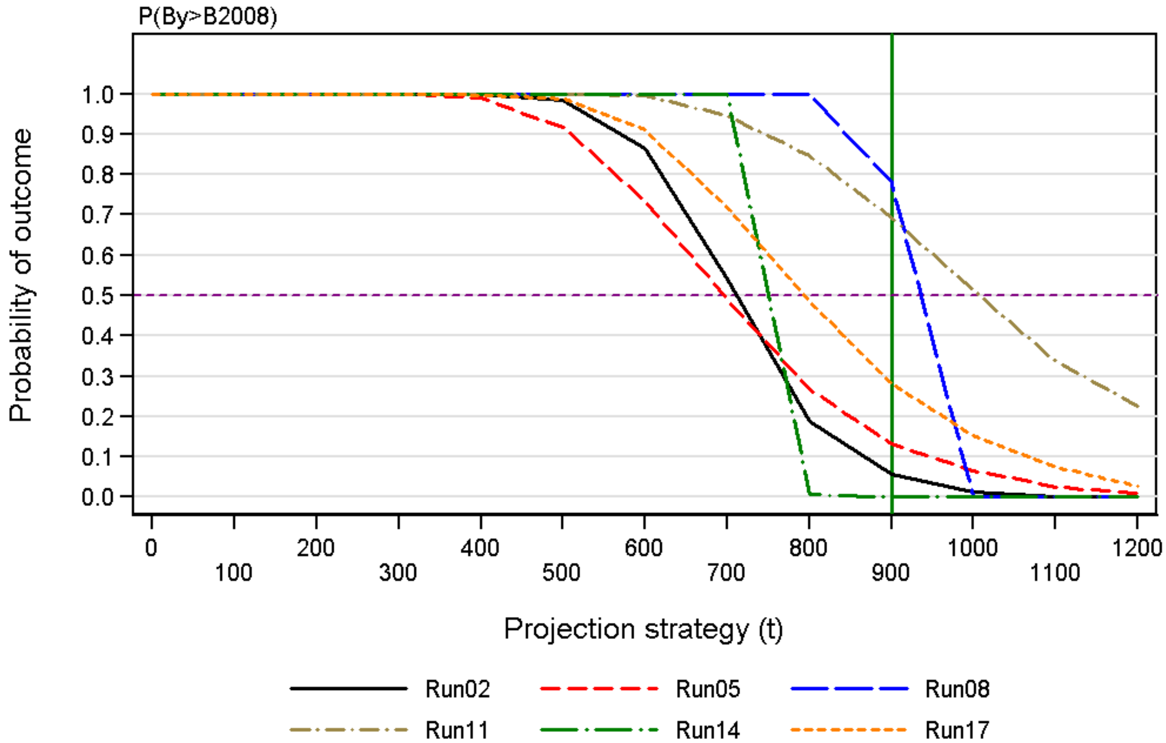

Figure 28. Comparison of the probability of $\tilde{B}_y$ exceeding B_{2008} by the end of the projection period (2013) for the six model runs in Table 16. The green vertical line indicates the approximate position of the mean average catch over the past 5 and 10 years.

Run 05 is also instructive. It uses the proportion-at-age data but does not estimate the commercial selectivities. Instead, the age data are used to estimate stochastic recruitment. The decision curves generated by this run are very similar to those for Run 02, suggesting that the pessimism generated by Runs 02 and 05 compared to the other four runs is related to the commercial selectivities, rather than whether the recruitment is stochastic or deterministic. The age at full selectivity for Runs 02 and 05 (based on an interpretation of length-based selectivity ogives provided in Stewart 2007: see Appendix I this document) for females is 12.4 compared to about age 14 for the four model runs which estimate this parameter (Table J.7). The male age of full selectivity is 14.3 in the ogives based on the US assessment (12.4+1.9; Table J.7) while the equivalent estimated parameter in this assessment is about 13.6 (14-0.4; Table J.7). Therefore, these two differences in the selectivity ogives (given that the left-hand variance parameter estimates are largely unchanged; Table J.7) are sufficient to generate the differences between Runs 02 and 05 compared to the four other runs (Figure 26, Figure 27, and Figure 28).

The effect of stochastic or deterministic recruitment is also pronounced when model runs which estimate the selectivity parameters are compared. There are two such comparisons: Run 08 and Run 11 (with steepness=0.70) and Run 14 and Run 17 (with steepness=0.55). In general, the two deterministic recruitment runs are more optimistic than the equivalent stochastic runs. In fact, this effect seems to be stronger than the difference caused by changing steepness in some instances, with both Run 08 and Run 14 being much more optimistic than any of the other runs for the $\mathrm{P}\left(\tilde{B}_y \geq 0.2B_0\right)$ indicator (Figure 26).

The effect of the steepness parameter is reasonably clear. The two steepness pairs behave similarly for the $\mathrm{P}\left(\tilde{B}_y > B_{2008}\right)$ indicator, with the two runs using steepness=0.70 (Runs 08 and 11) shifted to the right of the steepness=0.55 runs (Runs 14 and 17) (Figure 28). Each of these run pairs appears to behave similarly within the same steepness for this indicator. However, the $\mathrm{P}\left(\tilde{B}_y \geq 0.2B_0\right)$ indicator shows a similar behaviour, but it is confounded with the recruitment assumption. The steepness=0.70 runs are still to the right of the equivalent steepness=0.55 runs, but the stochastic runs are both to the left of the deterministic runs (Figure 26). Finally, the $\mathrm{P}\left(\tilde{B}_y \geq 0.4B_0\right)$ indicator is the least informative, given that there is only a low probability that the stock size will exceed this indicator in any of the runs (Figure 27). However, the two steepness=0.70 runs lie to the right of both of the steepness=0.55 runs for this indicator.

The authors have examined the six runs presented in Table 16 and feel that Run 11 is the most credible. This run uses all the available data (the five surveys plus the proportion-at-age data) and estimates both the commercial selectivity ogive and the recruitment deviations. It appears that the proportion-at-age data supplied to the model are consistent in suggesting that an age at full selectivity near age 14 is required for both males and females in all instances when these parameters are estimated (Table J.7). This is in spite of a reasonably strong informed prior which should tend this parameter to a younger age for females (Appendix I).

The most vexing issue is the selection of the “steepness” parameter, which is the subject of some disagreement amongst fishery scientists. It appears that the choice in this parameter is often a function of the culture from which the assessment stems rather than strong information which persuasively indicates that specific values are preferred. For instance, a steepness of 0.75 is used without comment in sensitivity trials in all New Zealand orange roughy assessments, a species with low productivity and a maximum age similar to that for west coast rockfish species (Ministry of Fisheries 2007). However, west coast rockfish assessments in the US tend to use much lower values for steepness (Stewart 2007). This situation is not easily resolved and the authors acknowledge the uncertainty in this parameter. It is not known which of the two steepness values investigated in these two runs is the more plausible. Managers will have to consider both productivity assumptions as plausible in their decisions.[3]

Of note for canary rockfish is that recruitment to the fishery precedes maturity (Figure 29). This added morality on juveniles would tend to favour selection of a lower *F* for fully recruited ages than would be the case if maturity were delayed relative to recruitment. This impact however is accommodated in the model.

[3] Following the PSARC review in November 2007, and while revisions were being made to the present document, Forrest et al. (in prep) provided preliminary results of a hierarchical meta-data analysis of steepness for rockfish. This work, which updated an earlier analysis by Dorn (2002), indicates a mean estimate for *h* of 0.74 for the Washington-California population of canary rockfish. The “cross-stock” (generic rockfish) estimate is currently 0.71 with a range among all rockfish species/stocks of 0.56-0.89.

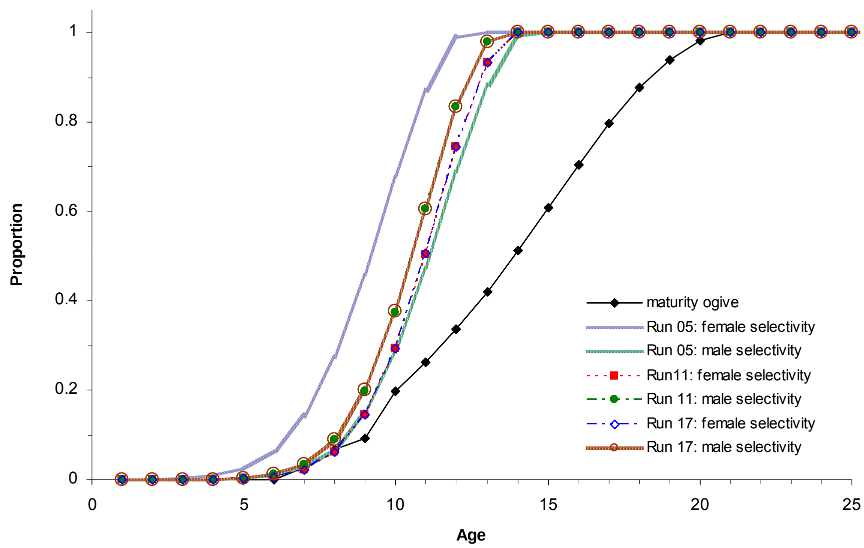

Figure 29. Fishery selectivity at age by sex and among runs in comparison with age at maturity.

Limitations of this stock assessment

The survey data used in this assessment are disparate, in that they come from a variety of sources and the only long term series is the WCVI shrimp trawl survey, a survey that was not designed to monitor rockfish species and which has a limited range, both in terms of depth (it is limited to 80 to 160 m) and areal coverage (it does not venture beyond 49° 36' N). The surveys in QCSd (GB Reed and QCSd synoptic) are more promising, but the former ended in the mid-1980s and latter has only just begun.

Since the two longer-term indices only index abundance for the west coast of Vancouver Island, the indices on relative abundance for this area have a disproportionate impact on the long-term trends. As well, the age composition data are based on relatively few samples and are potentially not very representative of the fishery.

This above information demonstrates that this assessment is based on relatively little data and it is surprising that it shows the level of consistency that it does. This consistency is heartening, but should not be interpreted as indicating a high level of certainty. Instead, this assessment, should be viewed as an approximation of the trajectory of this stock, particularly in the years prior to 1967, which is the initial survey year. It is clear that the stock has declined from its original biomass levels, particularly from the mid-1980s to the mid-1990s, when catch levels increased to above 1200 t per year and rose to nearly 2000 t in some years (Appendix B). It is likely that this decline has been arrested and it is even possible that the stock is presently rebuilding at harvest levels which have averaged near 875 t since 1997. What is not certain from this assessment is whether current catch levels will ensure a rebuild. Some of the runs investigated in this assessment (Runs 08 and 11) suggest that current removals will allow a slow rebuild. The runs with lower steepness or which do not estimate the commercial selectivity suggest that this is not the case.

Taken collectively, the results of this analysis indicate that to be reasonably confident that a significant increase will occur within a 5 to 10 year time frame, annual harvests should be reduced from current levels. Whether an increase in abundance is required depends on the management objectives of this population with respect to a target spawning biomass. If an increase in spawning biomass is considered necessary, management will not only need to choose a target spawning biomass but select a time frame over which the rebuilding will occur, and specify a desired probability that the rebuilding will reach the target biomass. Furthermore, the discussion of rebuilding targets (biomass, timeframe and probability) must be conditioned by the assumptions related to productivity, as discussed above.

The decision tables provided in this paper give guidance to the selection of short-term TAC recommendations and describe a range of possible future outcomes over the projection period at fixed levels of annual catch. The accuracy of the projections is predicated on the model being correct. Uncertainty in the parameters is explicitly addressed using the Bayesian approach but this only reflects the specified model, including the weights assigned to the various data components. Projection accuracy also depends on highly uncertain future recruitment values and the adoption of static harvest policies. For instance, it is likely that the data and the stock assessment will be updated during the time period covered by the projections which in turn would lead to different levels of catch through revised decision tables. A simple projection based on the assumption of a fixed catch policy provides an evaluation of alternative management decisions without any form of feedback. More complex feedback management evaluations are potentially possible but are beyond the scope of this analysis. However, there is value in continuing with this type of analysis in the short term because it can identify possible approaches that can be expanded into the more complex formal feedback evaluations. Analyses such as this one also can identify the strengths and weaknesses of the available data.

GENERAL COMMENTS

We are not aware of any significant and imminent anthropogenic threat to canary rockfish habitat. Most of the population is distributed over the continental shelf, which is not currently exposed to extensive human activities. We assume that fishing gear has some impact, although trawl activity continues to be concentrated on virtually the same areas as it has for a few decades and there is evidence that the areal extent of this impact is reducing. Future oil and gas exploration may have some impact, but there is currently a moratorium on this activity.

Large-scale environmental change owing to shorter-term regime shifts or possibly resulting from global warming may be having, or will have, an influence on canary productivity but we have no basis for predicting these factors. Under current conditions, we do not see a need to explicitly consider habitat issues within an RPA or Recovery Strategy. We have therefore confined the recommendations to a discussion of the total commercial fishery quota.

As the results of the above analyses are evaluated in light of the various assumptions and data limitations, so should any decision about harvest strategies be conditioned by the relevant management objectives. These include, for example, the choice of various target or reference biomass levels and the rate and degree of certainty in approaching a target. In the case of canary rockfish, the desired abundance and catch rates might also be defined by the role that canary rockfish harvesting plays in a complex multispecies, multi-gear and IVQ fishery. How would a specific canary rockfish quota affect the ability of harvesters to catch the other non-canary rockfish quotas? Ideally, the model and the objectives should be examined in an integrated simulation such as proposed in a “Operational Management Procedure” (OMP) (Butterworth 2007). A comprehensive OMP should incorporate the timing and quality of future updates on stock information, explicit consideration of whether past “threats” to the population are still present, and include a wide range of model uncertainty similar to that presented in Table 16.

We emphasize that, with respect to canary rockfish and most other B.C. groundfishes, the risk-environment has changed dramatically in the last decade. First, with past improvements in trawl monitoring and recent improvements in the HL monitoring, total commercial harvest is now well monitored. Second, while any one survey will only provide imprecise tracking of canary rockfish abundance, the large number of surveys currently being conducted on either an annual or biennial frequency provide assurance that significant changes in abundance should be tracked in the future for most key groundfish species. The large number of groundfish populations that require monitoring should preclude any expectation from managers and stakeholders that comprehensive reviews and assessments will be done frequently. However, updates on key indices can be produced on an annual or biennial basis that will allow tracking of key populations.

It is also worth noting that the virtual moratorium on canary rockfish fishing in U.S. waters that has been in place since about 1999 has removed whatever threat or impact this fishery imposed on the B.C. population. Not only has that threat been removed, there is evidence that the U.S. population has started to recover, coincident with some recent indices in B.C. waters

Finally, if a reduced canary rockfish quota will make it difficult for harvesters to catch the quotas of other species, managers may take advantage of the flexibility offered by the assumption of one coastwide stock, and allocate more quota to those areas that require more canary rockfish as bycatch.

RESEARCH AND DATA REQUIREMENTS

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

1. Single species stock assessments are limited in value when considered in the context of multi-species nature of the fisheries which take these species. More thought should be given to management of the aggregates of species that are taken in the commercial fisheries and what information needs to be collected to accomplish this management.

2. DFO and their research collaborators should continue the suite of fishery-independent trawl and longline surveys which have been established across the B.C. coast. This includes obtaining age and length composition samples which will allow the estimation of survey-specific selectivity ogives.

3. The heavy emphasis DFO and Industry has placed on initiating large scale synoptic trawl surveys demands an early review of the results to ascertain how effective these surveys will be in monitoring these populations. In particular, we suggest that the results should be examined to obtain some understanding of the sources and magnitude of the “process” error.

4. Review and potentially improve the commercial sampling programme for canary rockfish age composition with the goal of obtaining representative samples of this fishery.

5. All B.C. groundfish assessments would benefit from a dedicated study to reconstruct the historical catches for all groundfishes on the B.C. coast. This study should attempt to examine all groundfish at the same time and should be conducted in conjunction with U.S. researchers. Future canary rockfish assessments should consider the possibility that bycatch in the salmon troll fleet may have had significant impact on the population.

6. The use of survey catchabilities within stock assessment analyses should receive more attention. It may be possibly to provide meaningful bounds on catchability, which in turn would help scale actual biomass levels in assessments. This approach has been adopted in other jurisdictions (e.g., New Zealand) where informed priors are constructed for survey catchability parameters which are then used in Bayesian models like the catch-age model presented in this report.

ACKNOWLEDGEMENTS

The present analysis benefited from the assistance of Kate Rutherford in updating the trawl and HL catch data. Allan Hicks (Univ. of Washington) kindly altered the software in the Awatea version of Coleraine stock assessment model to allow *M* to vary between young and old females.

APPENDIX A. CONTENTS OF A RECOVERY POTENTIAL ASSESSMENT

(*excerpts from DFO 2007*)

Phase I: Assess current/recent species status

1. Evaluate **present species status** for abundance, range and number of populations
2. Evaluate **recent species trajectory** for abundance, range, and number of populations
3. Estimate, to the extent that information allows, the current or recent **life history parameters** for the species (total mortality [*Z*], natural mortality[m], fecundity, maturity, recruitment, etc) or reasonable surrogates; and associated uncertainties for all parameters.
4. Address the separate Terms of Reference for describing and quantifying (to the extent possible) the **habitat requirements and habitat use patterns** of the species.
5. Estimate expected **population and distribution targets** for recovery, according to DFO guidelines.
6. Project **expected population trajectories** over three generations (or other biologically reasonable time), and trajectories over **time to the recovery target** (if possible to achieve), given current population dynamics parameters and associated uncertainties (step 3) using DFO guidelines on long-term projections.
7. Evaluate **residence requirements** for the species, if any.

Phase II: scope for management to facilitate recovery. In all steps below taking account of associated uncertainties.

8. Assess the **probability that the recovery targets can be achieved** under current rates of population dynamics parameters, and **how that probability would vary with different mortality (**especially lower**) and productivity (**especially higher**) parameter**s
9. Quantify to the extent possible the **magnitude of each major potential source of mortality** identified in the pre-COSEWIC RAP, and considering information in COSEWIC Status Report, from DFO sectors, and other sources.
10. Quantify to the extent possible the **likelihood that the current quantity and quality of habitat is sufficient** to allow population increase, and would be sufficient to support a population that as reached its recovery targets (using methods in step 4)
11. Assess to the extent possible the magnitude by which current **threats to habitats have reduced habitat quantity and quality.**

Phase III: Scenarios for mitigation and alternative to activities

12. Using input from all DFO sectors and other sources as appropriate, develop an **inventory of all feasible measures to minimize/mitigate** the impacts of activities in Steps 9 and 11.
13. Using input from all DFO sectors and other sources as appropriate, develop an inventory of all reasonable **alternatives to the activities** in tasks 9 and 11, but with potential for less impact. (e.g. changing gear in fisheries causing bycatch mortality, relocation of activities harming critical habitat)
14. Using input from all DFO sectors and other sources as appropriate, develop an inventory of all **reasonable and feasible activities that could increase the productivity or survivorship parameters** in steps 3 and 8.
15. Estimate, to the extent possible, the **reduction in mortality rate expected** by each of the mitigation measures in 12 or alternatives in 13. and **the increase in productivity or survivorship** associated with each measure in 14
16. Project **expected population trajectory** (and uncertainties) over three generations (or other biologically reasonable time), and to the time of reaching recovery targets when recovery is feasible; given mortality rates and productivities from 15 that are **associated with specific scenarios** identified for exploration. Include scenarios which provide as high a probability of survivorship and recovery as possible for biologically realistic parameter values.
17. Recommend **parameter values for population productivity and starting mortality rates,** and where necessary, specialized features of population models that would be required to allow exploration of additional scenarios as part of the assessment of economic, social, and cultural impacts of listing the species.

APPENDIX B. CANARY ROCKFISH CATCH RECONSTRUCTION

Spatial scope of catch history

We have provided catch reconstructions for canary rockfish from 1930-2006 for commercial trawl and from 1940-2006 for the HL fishery (Tables B.1, B.6, and Table B.7). The catch history includes the area covered by the outer coast of B.C. waters from the U.S. border off the southwest coast of Vancouver Island to the Alaska border. We did not include the few trawl and HL observations from records from Major Area 4B (Strait of Georgia and Strait of Juan de Fuca). We also omitted catches from commercial salmon, shellfish, recreational and First Nations catches. We assumed these were negligible relative to trawl and HL fisheries and few observations are available.

Commercial Trawl

1930-1949 Landings

“Other” rockfish (ORF) landings to Washington State were partitioned back to PMFC Area of original catch (3C/CDN-5E) and then converted to canary rockfish landings using a canary rockfish proportion of 46% for 3C-3D and 16% for 5A-5E (Table B.1) following the steps below:

Step 1:
Total ORF landings (t) to Washington State for 1930-1949 were taken from the working tables of the U.S. assessment (Ian Stewart, pers. comm. cols. R and AE, Table B.1: Col. 1). Stewart obtained the landings estimates from Pacific States Fish Commission Annual Reports and the Pacific Fisherman Yearbook.

Step 2:
As total ORF landings to Washington State could have originated anywhere from Oregon-B.C., we reduced total ORF landed by 29% to account for catch from south of Area 3C (CDN and US) (Table B.1: col. 3). This proportion was estimated by comparing total landings of ORF caught only in Areas 3C-5E in 1950-1953 from (Ketchen 1976) with all ORF landings to Washington in 1950-1953 from the Stewart working tables.

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

Step 4:
We then separated 3C landings from 1930-1949 into catches originating either in the U.S. or Canadian portions of 3C (Table B.1: Col. 17). We used the proportions observed in trawl landings to Washington pooled over 1966-1970 (Tagart and Kimura 1982: p. 20) (Table B.4) to estimate that 29% of the landings from all of 3C originated from the Canadian portion of 3C (3C/CDN).

Step 5:
Total ORF landings by area of catch (Areas 3C/CDN to 5E) were then converted to canary rockfish by using a proportion of 0.46 for Areas 3C/CDN and 3D or 0.16 for Areas 5A-5E (Table B.5: Col. 21 and 22). These proportions were observed in landings to Washington State from 1967-1970 (Fraidenburg et al. 1977; p.12 and p.14).

Table B.1. Reconstruction of canary rockfish trawl landings (t) (1930-1966).

Year	Total ORF landings to Washington State	Total ORF landings to Washington State	Total ORF landings from 3C-5E	3C		3D		5A		5B		5C	
	(mt)	('000 lbs)	('000 lbs)	('000 lbs) CDN	('000 lbs) USA	('000 lbs) CDN	('000 lbs) USA	('000 lbs) CDN	('000 lbs) USA	('000 lbs) CDN	('000 lbs) USA	('000 lbs) CDN	('000 lbs) USA
	1	2	3	4	5	6	7	8	9	10	11	12	13
1930	0	0	0	0	0	0	0	0	0	0	0	0	0
1931	0	0	0	0	0	0	0	0	0	0	0	0	0
1932	0	0	0	0	0	0	0	0	0	0	0	0	0
1933	0	0	0	0	0	0	0	0	0	0	0	0	0
1934	4	8	6	0	1	0	1	0	1	0	2	0	0
1935	29	63	45	0	10	0	7	0	9	0	17	0	0
1936	37	81	58	0	13	0	9	0	12	0	22	0	0
1937	33	73	52	0	11	0	8	0	11	0	20	0	0
1938	49	107	76	0	17	0	12	0	16	0	29	0	0
1939	51	112	80	0	18	0	13	0	17	0	31	0	0
1940	113	249	177	0	39	0	29	0	37	0	68	0	0
1941	42	93	66	0	15	0	11	0	14	0	26	0	0
1942	821	1809	1284	0	282	0	209	0	268	0	498	0	3
1943	2652	5848	4152	0	913	0	677	0	867	0	1609	0	11
1944	1102	2430	1725	0	379	0	281	0	360	0	669	0	5
1945	11552	25468	18082	0	3977	0	2947	0	3777	0	7006	0	49
1946	5824	12839	9115	0	2005	0	1486	0	1904	0	3532	0	25
1947	3042	6707	4762	0	1047	0	776	0	995	0	1845	0	13
1948	4940	10891	7733	0	1701	0	1260	0	1615	0	2996	0	21
1949	6008	13246	9405	0	2068	0	1533	0	1964	0	3644	0	25
1950				31	1919	7	1654	15	2246	26	2736	0	35
1951				48	1867	10	1056	10	1266	76	3774	2	13
1952				124	1439	4	1174	28	1439	200	2987	1	15
1953				35	739	0	536	2	713	20	1011	0	10
1954				118	769	10	614	6	568	116	1065	0	19
1955				65	695	13	821	8	1417	135	788	0	7
1956				27	630	2	892	0	1485	84	696	6	18
1957				22	843	0	956	40	626	91	708	1	8
1958				13	635	2	652	50	918	94	429	12	0
1959				29	2331	0	782	169	1037	326	300	5	0
1960				16	2350	4	821	28	459	48	535	1	3
1961				36	2392	6	1530	29	902	86	573	0	1
1962				36	2943	31	2428	56	1394	401	1459	0	0
1963				25	1308	1	1862	58	1237	168	1785	0	27
1964				26	1237	13	755	358	975	207	1077	3	17
1965				20	1453	72	1065	225	1291	210	1437	10	56
1966				46	1405	24	1772	119	3174	168	1846	8	3

Table B.1. (continued). Reconstruction of canary rockfish trawl landings (t) (1930-1966).

Year	5D		3C+3D	3C+3D	5A:5D	Prop. canary rockfish		Canary rockfish landings for 3C-CDN+3D	Canary rockfish landings for 5A-5D	Total canary rockfish landings from 3C-CDN- 5D		Total canary rockfish landings plus discards (0.0063)
	('000 lbs)	('000 lbs)	('000 lbs)	('000 lbs)	('000 lbs)	3C-3D	5A-5D	('000 lbs)	('000 lbs)	('000 lbs)	(mt)	(mt)
	CDN	USA	CDN+USA	3D+3C/CDN	CDN							
	14	15	16	17	18	19	20	21	22	23	24	25
1930	0	0	0	0	0	0.46	0.16	0	0	0	0	0
1931	0	0	0	0	0	0.46	0.16	0	0	0	0	0
1932	0	0	0	0	0	0.46	0.16	0	0	0	0	0
1933	0	0	0	0	0	0.46	0.16	0	0	0	0	0
1934	0	0	2	1	4	0.46	0.16	1	1	1	1	1
1935	0	1	17	10	28	0.46	0.16	5	4	9	4	4
1936	0	1	22	13	36	0.46	0.16	6	6	12	5	5
1937	0	1	20	12	32	0.46	0.16	5	5	10	5	5
1938	0	1	29	17	47	0.46	0.16	8	8	15	7	7
1939	0	1	31	18	49	0.46	0.16	8	8	16	7	7
1940	0	3	68	40	109	0.46	0.16	18	17	36	16	16
1941	0	1	25	15	41	0.46	0.16	7	7	13	6	6
1942	0	23	492	291	793	0.46	0.16	134	127	261	118	119
1943	0	75	1590	941	2562	0.46	0.16	433	410	843	382	385
1944	0	31	661	391	1065	0.46	0.16	180	170	350	159	160
1945	0	327	6924	4100	11159	0.46	0.16	1886	1785	3672	1665	1676
1946	0	165	3490	2067	5625	0.46	0.16	951	900	1851	840	845
1947	0	86	1823	1080	2939	0.46	0.16	497	470	967	439	441
1948	0	140	2961	1753	4772	0.46	0.16	807	763	1570	712	717
1949	0	170	3601	2133	5804	0.46	0.16	981	929	1910	866	872
1950	91	214	3611	2227	5363	0.46	0.16	1024	858	1882	854	859
1951	80	98	2981	1621	5319	0.46	0.16	746	851	1597	724	729
1952	97	112	2741	1631	4879	0.46	0.16	750	781	1531	694	699
1953	7	66	1310	760	1829	0.46	0.16	350	293	642	291	293
1954	13	74	1511	881	1861	0.46	0.16	405	298	703	319	321
1955	17	115	1594	1054	2487	0.46	0.16	485	398	883	401	403
1956	9	31	1551	1085	2329	0.46	0.16	499	373	872	395	398
1957	9	33	1821	1207	1516	0.46	0.16	555	243	798	362	364
1958	9	63	1302	842	1575	0.46	0.16	387	252	639	290	292
1959	39	85	3142	1466	1961	0.46	0.16	675	314	988	448	451
1960	21	55	3191	1511	1150	0.46	0.16	695	184	879	399	401
1961	44	21	3964	2240	1656	0.46	0.16	1030	265	1295	588	591
1962	106	52	5438	3323	3468	0.46	0.16	1529	555	2083	945	951
1963	27	10	3196	2250	3312	0.46	0.16	1035	530	1565	710	714
1964	53	34	2031	1134	2724	0.46	0.16	522	436	958	434	437
1965	25	40	2610	1564	3294	0.46	0.16	720	527	1247	565	569
1966	45	0	3247	2217	5363	0.46	0.16	1020	858	1878	852	857

Notes:

1 Col. 1: 1930-1949: Total ORF landings (mt) to Washington State from Ian Stewart's personal spreadhseet. Columns R and AE

2 Col. 3: 1930-1949: Total ORF landings ('000's pounds) to Washington State that originated in 3C-5D (Col. 2 * 0.74) (see Table 2 below)

3 Col. 4-16: 1930-1949: Total ORF landings ('000's lbs) to Washington State that originated in each PMFC Area (Col. D * proportions in Table 3)

4 Col. 4-15: 1950-1966 from Ketchen 1976

5 Col. 17: 1930-1966: Convert total ORF landings from 3C to 3C-CDN only.

Table B.2. Proportion of Washington State trawl landings ('000 lbs) originating from 3C-5D in 1950-1953 (79%).

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

Notes:
1 Total "Other rockfish" (ORF) from Stewart 2007

Table B.3. PMFC Area of catch (t) for US vessels landing ORF to Washington State.

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

Table B.4. Proportion of ORF caught in Canadian portion of 3C in US vessel landings to Washington State (29%) (from Tagart and Kimura 1982 (p.20)).

Year	3C-US	3C-CDN	3C-Total
	lbs.	lbs.	lbs.
1966	724,501	562,352	1,286,853
1967	356,402	286,304	642,706
1968	944,492	159,066	1,103,558
1969	1,057,437	373,953	1,431,390
1970	818,097	214,954	1,033,051
Total	3,900,929	1,596,629	5,497,558

Table B.5. Proportion (P) of canary rockfish in US trawl vessel ORF landings to Washington from 3C-3D and 5A-5D in 1967-1969 (from Fraidenburg et al. 1977; p12 and p14).

	Area 3C-3D			Areas 5A-5E		
	Canary rockfish	ORF	P-Canary rockfish	Canary rockfish	ORF	P-Canary rockfish
1967	772	1210	0.64	374	2068	0.18
1968	1081	2599	0.42	1029	2754	0.37
1969	1350	3500	0.39	529	4949	0.11
1970	1384	2614	0.53	172	3636	0.05
Total	**4587**	**9923**	**0.46**	**2104**	**13407**	**0.16**

Step 6:
Landings from the two regions were then added (Table B.1: Col. 23 and converted to t, Col. 24).

<u>1950-1966 Landings</u>

The process for reconstructing 1950-1966 trawl landings was similar to that used for 1930-1949, except we took advantage of published ORF landings from US and CDN vessels by Major Area (Ketchen 1976: Table B.1: 1950-1966).

Step 1:
From Ketchen (1976) we obtained ORF landings catch by Major Area 3C to 5E (Table B.1: Columns 4-15 for 1950-1966).

Step2:
As for 1930-1949, we partitioned 3C landings into those originating from the U.S. and CDN portions of 3C, again assuming that 29% came from 3C/CDN.

Step 3:
We converted ORF landings to canary rockfish and converted to mt as for the 1930-1949 period.

<u>1967-2006 Landings</u>

Trawl landings by Major area for 1967-2006 were obtained from the DFO-PacHarvTrawl databases as in Stanley et al. (2005), except that this analysis excluded landings from the U.S. portion of 3C for the years of 1967-1980 (prior to the 200 mile limit) (Table B.6 from 1967-2006 Trawl catch reconstruction). The catches could be sorted because the logbook noted the locality of capture. For example, catches by Canadian vessels from “Ollie Spot” and “Cape Flattery Spit” were assigned to U.S. waters (see Rutherford 1999, p. 61). We used the same proportion to split U.S. vessel landings.

Table B.6. Catches of canary rockfish by trawl gear (1967-2006).

	4B							
	Bottom Trawl			Midwater trawl				Total
Year	Can landed	US landed	Can discarded	Can landed	Can discarded	J/V	N/S	
1967	0.4	-				-	-	0.4
1968	0.0	-				-	-	0.0
1969	1.1	-				-	-	1.1
1970	1.7	-				-	-	1.7
1971	0.8	-				-	-	0.8
1972	0.1	-				-	-	0.1
1973	0.0	-				-	-	0.0
1974	2.3	-				-	-	2.3
1975	2.1	-				-	-	2.1
1976	tr.	-				-	-	0.0
1977	0.4	-				-	-	0.4
1978	0.1	-				-	-	0.1
1979	0.6	-				-	-	0.6
1980	0.0	-				-	-	0.0
1981	0.3	-				-	-	0.3
1982	0.5	-				-	-	0.5
1983	tr.	-				-	-	0.0
1984	0.6	-				-	-	0.6
1985	0.0	-				-	-	0.0
1986	0.1	-				-	-	0.1
1987	0.0	-				-	-	0.0
1988	tr.	-				0.0	0.0	0.0
1989	tr.	-				0.0	0.0	0.0
1990	0.0	-				0.0	0.0	0.0
1991	tr.	-				0.0	0.0	0.0
1992	0.9	-				0.0	-	0.9
1993	0.0	-		tr.		0.0	-	0.0
1994	tr.	-		tr.		0.0	-	0.0
1995	tr.	-		tr.		0.0	-	0.0
1996	tr.	-	tr.	0.0	0.0	0.0	-	0.0
1997	0.0	-	tr.	0.0	0.0	0.0	-	0.0
1998	0.0	-	0.0	0.0	0.0	0.0	-	0.0
1999	0.0	-	0.0	0.0	0.0	0.0	-	0.0
2000	0.0	-	0.0	0.0	0.0	0.0	0.0	0.0
2001	tr.	-	0.0	0.0	0.0	0.0	-	0.0
2002	tr.	-	tr.	0.0	tr.	-	-	0.0
2003	0.0	-	tr.	0.0	0.0	-	-	0.0
2004	0.0	-	tr.	0.0	0.0	0.0	0.0	0.0
2005	0.0	-	0.0	tr.	tr.	0.0	-	0.0
2006	0.0	-	0.0	0.0	tr.	0.0	-	0.0

Table B.6. (continued).

	3C-CDN only							
	Bottom Trawl			Midwater trawl				Total
Year	Can landed	US landed	Can discarded	Can landed	Can discarded	J/V	N/S	
1967	6.2	85.0				-	-	91.2
1968	4.0	67.0				-	-	71.0
1969	4.4	22.0				-	-	26.4
1970	5.6	0.0				-	-	5.6
1971	51.7	113.0				-	-	164.7
1972	0.2	41.0				-	-	41.2
1973	0.0	45.0				-	-	45.0
1974	9.9	27.0				-	-	36.9
1975	6.7	55.0				-	-	61.7
1976	51.0	199.0				-	-	250.0
1977	58.0	46.0				-	-	104.0
1978	15.0	3.0				-	-	18.0
1979	29.0	0.0				-	-	29.0
1980	17.7	-				-	-	17.7
1981	12.1	-				-	-	12.1
1982	40.8	-				-	-	40.8
1983	151.0	-				-	-	151.0
1984	307.2	-				-	-	307.2
1985	177.3	-				-	-	177.3
1986	200.9	-		0.3		-	-	201.2
1987	215.7	-		2.3		-	-	218.0
1988	480.9	-				0.1	5.8	486.8
1989	435.4	-		1.4		1.3	8.4	446.5
1990	226.9	-		4.2		1.6	tr.	232.7
1991	166.1	-		2.7		2.4	0.4	171.6
1992	296.3	-		4.7		1.3	-	302.3
1993	244.5	-		tr.		3.3	-	247.8
1994	212.3	-		3.2		14.7	-	230.2
1995	171.5	-		2.5		2.5	-	176.5
1996	137.0	-	2.7	1.0	tr.	4.3	-	145.0
1997	122.9	-	1.7	0.3	tr.	1.7	-	126.6
1998	75.4	-	0.4	7.7	0.0	2.2	-	85.7
1999	92.2	-	0.8	3.1	0.0	1.0	-	97.1
2000	90.6	-	0.2	0.8	0.0	0.5	tr.	92.1
2001	137.2	-	0.6	1.3	0.1	2.0	-	141.2
2002	120.3	-	0.3	5.8	tr.	-	-	126.4
2003	157.1	-	0.5	6.6	tr.	-	-	164.2
2004	120.5	-	0.2	10.2	tr.	0.9	0.0	131.8
2005	185.8	-	1.2	2.3	tr.	0.2	-	189.5
2006	97.6	-	0.4	0.9	tr.	tr.	-	98.9

Table B.6. (continued).

	3D								
	Bottom Trawl			Midwater trawl				Total	US 3C+3D from Stanley
Year	Can landed	US landed	Can discarded	Can landed	Can discarded	J/V	N/S		
1967	3.9	351.9				-	-	355.8	
1968	18.7	502.1				-	-	520.8	
1969	46.1	597.4				-	-	643.5	
1970	17.8	713.1				-	-	730.9	
1971	14.5	524.5				-	-	539.0	
1972	0.0	192.9				-	-	192.9	
1973	0.0	443.3				-	-	443.3	
1974	16.3	577.7				-	-	594.0	
1975	7.0	452.6				-	-	459.6	
1976	137.6	186.9				-	-	324.5	
1977	96.5	222.2				-	-	318.7	
1978	53.0	860.6		1.1		-	-	914.7	
1979	100.4	250.7				-	-	351.1	
1980	107.5	-				-	-	107.5	477.0
1981	50.7	-				-	-	50.7	249.0
1982	215.0	-				-	-	215.0	133.0
1983	694.9	-				-	-	694.9	
1984	882.4	-				-	-	882.4	
1985	726.9	-				-	-	726.9	
1986	462.1	-		57.4		-	-	519.5	
1987	415.2	-		94.2		-	-	509.4	
1988	543.7	-		31.4			tr.	575.1	
1989	704.6	-		16.7		tr.	3.1	724.4	
1990	502.5	-		30.4		1.2	0.3	534.4	
1991	470.8	-		8.3		0.1	0.1	479.3	
1992	450.1	-		16.2		0.0	-	466.3	
1993	553.6	-		25.9		0.1	-	579.6	
1994	512.8	-		36.9		0.3	-	550.0	
1995	423.5	-		25.2		0.0	-	448.7	
1996	255.2	-	0.8	50.6	0.4	0.0	-	307.0	
1997	230.9	-	3.5	82.5	2.4	0.0	-	319.3	
1998	267.1	-	0.8	81.7	0.4	0.0	-	350.0	
1999	283.6	-	0.3	151.6	0.4	0.0	-	435.9	
2000	271.5	-	0.4	89.0	4.6	0.0	0.0	365.5	
2001	319.6	-	2.6	34.8	0.0	0.0	-	357.0	
2002	399.5	-	0.8	48.0	tr.	-	-	448.3	
2003	284.3	-	0.3	44.8	tr.	-	-	329.4	
2004	357.3	-	0.3	36.0	0.1	0.0	-	393.7	
2005	330.1	-	8.1	37.0	0.0	0.0	-	375.2	
2006	294.9	-	0.6	81.4	0.1	0.0	-	377.0	

Table B.6. (continued).

	5A							
	Bottom Trawl			Midwater trawl				Total
Year	Can landed	US landed	Can Discarded	Can landed	Can discarded	J/V	N/S	
1967	29.5	88.1	-		-	-	-	117.6
1968	44.9	607.0	-		-	-	-	651.9
1969	58.4	355.0	-		-	-	-	413.4
1970	3.0	90.2	-		-	-	-	93.2
1971	11.7	35.5	-		-	-	-	47.2
1972	0.4	33.5	-		-	-	-	33.9
1973	17.5	113.5	-		-	-	-	131.0
1974	2.7	180.1	-		-	-	-	182.8
1975	2.8	4.7	-		-	-	-	7.5
1976	20.1	208.3	-		-	-	-	228.4
1977	23.5	60.0	-		-	-	-	83.5
1978	106.3	8.1	-	2.3	-	-	-	116.7
1979	48.5	18.8	-	0.0	-	-	-	67.3
1980	20.3	-	-	0.0	-	-	-	20.3
1981	46.0	-	-	0.0	-	-	-	46.0
1982	158.6	-	-	0.0	-	-	-	158.6
1983	119.3	-	-	0.0	-	-	-	119.3
1984	215.6	-	-	0.0	-	-	-	215.6
1985	140.6	-	-	0.0	-	-	-	140.6
1986	96.2	-	-	0.0	-	-	-	96.2
1987	181.3	-	-	0.2	-	-	-	181.5
1988	186.5	-	-	0.0	-	0.0	0.0	186.5
1989	137.9	-	-	0.2	-	0.0	0.0	138.1
1990	164.8	-	-	1.8	-	0.0	0.0	166.6
1991	204.3	-	-	0.4	-	0.0	0.0	204.7
1992	212.2	-	-	3.0	-	0.0	-	215.2
1993	80.6	-	-	2.2	-	0.0	-	82.8
1994	101.4	-	-	4.0	-	0.0	-	105.4
1995	66.0	-	-	2.7	-	0.0	-	68.7
1996	53.6	-	0.2	5.5	0.0	0.0	-	59.3
1997	75.0	-	0.3	1.4	0.0	0.0	-	76.7
1998	147.0	-	0.3	5.6	0.0	0.0	-	152.9
1999	105.4	-	0.2	2.9	tr.	0.0	-	108.5
2000	66.3	-	0.1	4.7	0.0	0.1	0.0	71.2
2001	78.6	-	0.5	7.3	tr.	0.0	-	86.4
2002	73.8	-	0.9	17.5	tr.	-	-	92.2
2003	76.2	-	0.3	10.4	0.2	-	-	87.1
2004	92.3	-	0.1	7.6	0.0	0.0	-	100.0
2005	88.2	-	tr.	11.0	tr.	0.0	-	99.2
2006	119.4	-	0.5	5.8	tr.	tr.	-	125.7

Table B.6. (continued).

	5B								
	Bottom Trawl			Midwater trawl				Total	US 5A+5B from Stanley
Year	Can landed	US landed	Can discarded	Can landed	Can discarded	J/V	N/S		
1967	8.8	126.5	-		-	-	-	135.3	
1968	1.9	330.3	-		-	-	-	332.2	
1969	8.5	63.4	-		-	-	-	71.9	
1970	3.2	129.4	-		-	-	-	132.6	
1971	6.5	147.0	-		-	-	-	153.5	
1972	0.0	27.6	-		-	-	-	27.6	
1973	11.6	184.1	-		-	-	-	195.7	
1974	0.5	77.4	-		-	-	-	77.9	
1975	20.0	184.0	-		-	-	-	204.0	
1976	71.8	238.4	-		-	-	-	310.2	
1977	95.7	228.0	-	1.9	-	-	-	325.6	
1978	154.1	0.0	-	0.0	-	-	-	154.1	
1979	230.0	43.3	-	tr.	-	-	-	273.3	
1980	257.1	-	-	0.0	-	-	-	257.1	88.0
1981	138.7	-	-	0.0	-	-	-	138.7	
1982	200.8	-	-	0.0	-	-	-	200.8	
1983	240.8	-	-	0.2	-	-	-	241.0	
1984	297.7	-	-	0.0	-	-	-	297.7	
1985	254.3	-	-	0.0	-	-	-	254.3	
1986	183.8	-	-	0.0	-	-	-	183.8	
1987	381.8	-	-	0.0	-	-	-	381.8	
1988	391.5	-	-	7.7	-	0.0	0.0	399.2	
1989	337.9	-	-	26.3	-	0.0	0.0	364.2	
1990	428.6	-	-	5.9	-	0.0	0.0	434.5	
1991	312.3	-	-	0.7	-	0.0	0.0	313.0	
1992	265.0	-	-	tr.	-	0.0	-	265.0	
1993	107.4	-	-	0.8	-	0.0	-	108.2	
1994	188.5	-	-	0.0	-	0.0	-	188.5	
1995	101.8	-	-	1.0	-	0.0	-	102.8	
1996	76.5	-	6.6	1.9	0.1	0.0	-	85.1	
1997	114.3	-	1.6	1.6	0.0	0.0	-	117.5	
1998	135.8	-	0.2	0.7	0.0	0.0	-	136.7	
1999	200.3	-	0.4	0.7	0.0	0.0	-	201.4	
2000	147.6	-	1.2	0.1	0.0	tr.	0.0	148.9	
2001	134.7	-	0.2	2.3	tr.	0.0	-	137.2	
2002	134.0	-	0.1	5.5	0.0	-	-	139.6	
2003	143.7	-	tr.	13.3	0.0	-	-	157.0	
2004	91.6	-	0.1	tr.	0.0	0.0	-	91.7	
2005	119.4	-	1.0	0.2	0.0	0.0	-	120.6	
2006	109.4	-	0.3	0.5	tr.	tr.	-	110.2	

Table B.6. (continued).

	5C							
	Bottom Trawl			Midwater trawl				Total
Year	Can landed	US landed	Can discarded	Can landed	Can discarded	J/V	N/S	
1967	0.0	-				-	-	0.0
1968	0.7	-				-	-	0.7
1969	4.0	-				-	-	4.0
1970	0.3	-				-	-	0.3
1971	0.2	-				-	-	0.2
1972	0.4	-				-	-	0.4
1973	0.0	-				-	-	0.0
1974	tr.	-				-	-	0.0
1975	0.0	-				-	-	0.0
1976	0.9	-		1.9		-	-	2.8
1977	6.9	-		0.0		-	-	6.9
1978	93.3	-		0.0		-	-	93.3
1979	115.8	-		0.0		-	-	115.8
1980	202.1	-		0.0		-	-	202.1
1981	115.9	-		0.0		-	-	115.9
1982	57.0	-		0.0		-	-	57.0
1983	114.9	-		0.0		-	-	114.9
1984	68.9	-		0.0		-	-	68.9
1985	187.1	-		0.0		-	-	187.1
1986	44.1	-		0.0		-	-	44.1
1987	90.8	-		0.0		-	-	90.8
1988	79.8	-		0.0		0.0	0.0	79.8
1989	111.3	-		0.0		0.0	0.0	111.3
1990	134.8	-		0.0		0.0	0.0	134.8
1991	113.8	-		0.0		0.0	0.0	113.8
1992	107.1	-		0.0		0.0	-	107.1
1993	52.2	-		0.0		0.0	-	52.2
1994	102.8	-		0.0		0.0	-	102.8
1995	53.9	-		tr.		0.0	-	53.9
1996	53.2	-	0.1	tr.	0.0	0.0	-	53.3
1997	34.2	-	0.2	tr.	0.0	0.0	-	34.4
1998	39.6	-	1.4	0.0	0.0	0.0	-	41.0
1999	32.7	-	0.1	tr.	0.0	0.0	-	32.8
2000	69.3	-	0.1	0.0	0.0	0.0	0.0	69.4
2001	71.9	-	0.1	0.0	0.0	0.0	-	72.0
2002	62.6	-	tr.	tr.	0.0	-	-	62.6
2003	68.8	-	tr.	0.0	0.0	-	-	68.8
2004	59.4	-	0.2	tr.	0.0	0.0	-	59.6
2005	80.1	-	tr.	0.0	0.0	0.0	-	80.1
2006	39.1	-	tr.	0.0	0.0	0.0	-	39.1

Table B.6. (continued).

	5D							
	Bottom Trawl			Midwater trawl				Total
Year	Can landed	US landed	Can discarded	Can landed	Can discarded	J/V	N/S	
1967	6.1	-	-		-	-	-	6.1
1968	0.0	-	-		-	-	-	0.0
1969	1.4	-	-		-	-	-	1.4
1970	19.1	-	-		-	-	-	19.1
1971	27.1	-	-		-	-	-	27.1
1972	1.5	-	-		-	-	-	1.5
1973	8.1	-	-		-	-	-	8.1
1974	0.0	-	-		-	-	-	0.0
1975	1.2	-	-		-	-	-	1.2
1976	4.8	-	-		-	-	-	4.8
1977	8.5	-	-		-	-	-	8.5
1978	7.6	-	-	0.6	-	-	-	8.2
1979	9.2	-	-	tr.	-	-	-	9.2
1980	3.1	-	-	0.0	-	-	-	3.1
1981	11.3	-	-	0.0	-	-	-	11.3
1982	2.6	-	-	0.0	-	-	-	2.6
1983	4.0	-	-	0.0	-	-	-	4.0
1984	4.7	-	-	0.0	-	-	-	4.7
1985	3.3	-	-	0.0	-	-	-	3.3
1986	0.4	-	-	0.0	-	-	-	0.4
1987	12.1	-	-	0.0	-	-	-	12.1
1988	3.8	-	-	0.0	-		0.0	3.8
1989	10.7	-	-	0.0	-	0.0	0.0	10.7
1990	18.9	-	-	0.0	-	0.0	0.0	18.9
1991	39.0	-	-	1.5	-	0.0	0.0	40.5
1992	18.4	-	-	0.0	-	0.0	-	18.4
1993	21.3	-	-	0.3	-	0.0	-	21.6
1994	9.1	-	-	0.1	-	0.0	-	9.2
1995	6.2	-	-	0.2	-	0.0	-	6.4
1996	15.2	-	0.1	0.1	0.0	0.0	-	15.4
1997	6.6	-	0.1	tr.	0.0	0.0	-	6.7
1998	3.2	-	0.1	tr.	0.0	0.0	-	3.3
1999	8.0	-	0.1	tr.	0.0	0.0	-	8.1
2000	8.5	-	tr.	tr.	0.0	0.0	0.0	8.5
2001	2.8	-	tr.	tr.	0.0	0.0	-	2.8
2002	1.9	-	tr.	tr.	0.0	-	-	1.9
2003	2.3	-	tr.	0.4	0.0	-	-	2.7
2004	5.7	-	0.1	0.5	0.0	0.0	-	6.3
2005	4.7	-	0.1	0.1	0.0	0.0	-	4.9
2006	7.4	-	tr.	1.0	0.0	0.0	-	8.4

Table B.6. (continued).

	5E							
	Bottom Trawl			Midwater trawl				Total
Year	Can landed	US landed	Can discarded	Can landed	Can discarded	J/V	N/S	
1967	0.0	-	-		-	-	-	0.0
1968	0.0	-	-		-	-	-	0.0
1969	0.0	-	-		-	-	-	0.0
1970	0.0	-	-		-	-	-	0.0
1971	0.0	-	-		-	-	-	0.0
1972	0.0	-	-		-	-	-	0.0
1973	0.0	-	-		-	-	-	0.0
1974	0.0	-	-		-	-	-	0.0
1975	0.0	-	-		-	-	-	0.0
1976	0.0	-	-	0.0	-	-	-	0.0
1977	0.6	-	-	0.0	-	-	-	0.6
1978	8.3	-	-	0.0	-	-	-	8.3
1979	0.4	-	-	0.1	-	-	-	0.5
1980	0.5	-	-	0.0	-	-	-	0.5
1981	2.4	-	-	0.0	-	-	-	2.4
1982	18.3	-	-	0.0	-	-	-	18.3
1983	10.4	-	-	0.0	-	-	-	10.4
1984	12.7	-	-	0.0	-	-	-	12.7
1985	9.4	-	-	0.0	-	-	-	9.4
1986	110.5	-	-	0.0	-	-	-	110.5
1987	12.6	-	-	0.0	-	-	-	12.6
1988	79.1	-	-	0.0	-		0.0	79.1
1989	19.5	-	-	0.0	-	0.0	0.0	19.5
1990	64.3	-	-	0.1	-	0.0	0.0	64.4
1991	29.0	-	-	0.0	-	0.0	0.0	29.0
1992	26.3	-	-	0.0	-	0.0	-	26.3
1993	21.7	-	-	tr.	-	0.0	-	21.7
1994	7.7	-	-	0.0	-	0.0	-	7.7
1995	3.5	-	-	tr.	-	0.0	-	3.5
1996	10.1	-	tr.	0.5	0.0	0.0	-	10.6
1997	19.6	-	0.5	0.0	0.0	0.0	-	20.1
1998	2.5	-	0.0	0.0	0.0	0.0	-	2.5
1999	7.0	-	0.1	0.1	0.0	0.0	-	7.2
2000	14.2	-	tr.	0.4	0.0	0.3	0.6	15.5
2001	2.0	-	0.0	0.0	0.0	0.0	-	2.0
2002	3.1	-	0.0	0.1	0.0	-	-	3.2
2003	18.6	-	tr.	0.1	0.0	-	-	18.7
2004	3.9	-	0.0	tr.	0.0	0.0	-	3.9
2005	7.5	-	0.0	3.1	tr.	0.0	-	10.6
2006	1.5	-	0.0	1.0	0.0	0.0	-	2.5

Table B.6. (continued).

	5U Unknown trawl		Total
Year	Can landed	Can discarded	
1967	0.0	-	0.0
1968	0.0	-	0.0
1969	0.0	-	0.0
1970	0.0	-	0.0
1971	0.0	-	0.0
1972	0.0	-	0.0
1973	0.0	-	0.0
1974	0.0	-	0.0
1975	0.0	-	0.0
1976	0.0	-	0.0
1977	0.0	-	0.0
1978	0.0	-	0.0
1979	0.0	-	0.0
1980	0.0	-	0.0
1981	0.0	-	0.0
1982	0.0	-	0.0
1983	0.0	-	0.0
1984	0.0	-	0.0
1985	0.0	-	0.0
1986	0.0	-	0.0
1987	0.0	-	0.0
1988	0.0	-	0.0
1989	0.0	-	0.0
1990	0.0	-	0.0
1991	0.0	-	0.0
1992	0.0	-	0.0
1993	0.0	-	0.0
1994	0.0	-	0.0
1995	0.0	-	0.0
1996	9.4	0.0	9.4
1997	4.0	0.0	4.0
1998	4.0	0.0	4.0
1999	4.8	0.0	4.8
2000	0.7	0.0	0.7
2001	1.8	0.0	1.8
2002	2.5	0.0	2.5
2003	1.2	0.0	1.2
2004	2.5	0.0	2.5
2005	2.5	0.0	2.5
2006	1.5	0.0	1.5

Table B.6. (continued).

	All areas									
	Bottom Trawl			Midwater trawl				Unknown trawl	
Year	Can landed	US landed	Can discarded	Can landed	Can discarded	J/V	N/S	Can landed	Can discarded
1967	54.9	651.5	0.0	0.0	0.0	0.0	0.0	0.0	-
1968	70.2	1506.4	0.0	0.0	0.0	0.0	0.0	0.0	-
1969	123.9	1037.8	0.0	0.0	0.0	0.0	0.0	0.0	-
1970	50.7	932.7	0.0	0.0	0.0	0.0	0.0	0.0	-
1971	112.5	820.0	0.0	0.0	0.0	0.0	0.0	0.0	-
1972	2.6	295.0	0.0	0.0	0.0	0.0	0.0	0.0	-
1973	37.2	785.9	0.0	0.0	0.0	0.0	0.0	0.0	-
1974	31.7	862.2	0.0	0.0	0.0	0.0	0.0	0.0	-
1975	39.8	696.3	0.0	0.0	0.0	0.0	0.0	0.0	-
1976	286.2	832.6	0.0	1.9	0.0	0.0	0.0	0.0	-
1977	290.1	556.2	0.0	1.9	0.0	0.0	0.0	0.0	-
1978	437.7	871.7	0.0	4.0	0.0	0.0	0.0	0.0	-
1979	533.9	312.8	0.0	0.1	0.0	0.0	0.0	0.0	-
1980	608.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
1981	377.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
1982	693.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
1983	1335.3	0.0	0.0	0.2	0.0	0.0	0.0	0.0	-
1984	1789.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
1985	1498.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
1986	1098.1	0.0	0.0	57.7	0.0	0.0	0.0	0.0	-
1987	1309.5	0.0	0.0	96.7	0.0	0.0	0.0	0.0	-
1988	1765.3	0.0	0.0	39.1	0.0	0.1	5.8	0.0	-
1989	1757.3	0.0	0.0	44.6	0.0	1.3	11.5	0.0	-
1990	1540.8	0.0	0.0	42.4	0.0	2.8	0.3	0.0	-
1991	1335.3	0.0	0.0	13.6	0.0	2.5	0.5	0.0	-
1992	1376.3	0.0	0.0	23.9	0.0	1.3	0.0	0.0	-
1993	1081.3	0.0	0.0	29.2	0.0	3.4	0.0	0.0	-
1994	1134.6	0.0	0.0	44.2	0.0	15.0	0.0	0.0	-
1995	826.4	0.0	0.0	31.6	0.0	2.5	0.0	0.0	-
1996	600.8	0.0	10.5	59.6	0.5	4.3	0.0	9.4	0.0
1997	603.5	0.0	7.9	85.8	2.4	1.7	0.0	4.0	0.0
1998	670.6	0.0	3.2	95.7	0.4	2.2	0.0	4.0	0.0
1999	729.2	0.0	2.0	158.4	0.4	1.0	0.0	4.8	0.0
2000	668.0	0.0	2.0	95.0	4.6	0.9	0.6	0.7	0.0
2001	746.8	0.0	4.0	45.7	0.1	2.0	0.0	1.8	0.0
2002	795.2	0.0	2.1	76.9	0.0	0.0	0.0	2.5	0.0
2003	751.0	0.0	1.1	75.6	0.2	0.0	0.0	1.2	0.0
2004	730.7	0.0	1.0	54.3	0.1	0.9	0.0	2.5	0.0
2005	815.8	0.0	10.4	53.7	0.0	0.2	0.0	2.5	0.0
2006	669.3	0.0	1.8	90.6	0.1	0.0	0.0	1.5	0.0

Table B.6. (continued).

Year	Total landings and reported discards for BC waters	Total landings and reported discards for BC waters, not including 4B	Reported discards (1996-2006)	Reported landings (minus discards)	Discard rate (D/(L)	Estimated discards (1967-1995)	Total BC Trawl Catch (not including 4B)
	All areas						
1967	706.4	706.0			0.0063	4.4	710.4
1968	1576.6	1576.6			0.0063	9.9	1586.5
1969	1161.7	1160.6			0.0063	7.3	1167.9
1970	983.4	981.7			0.0063	6.2	987.9
1971	932.5	931.7			0.0063	5.9	937.6
1972	297.6	297.5			0.0063	1.9	299.4
1973	823.1	823.1			0.0063	5.2	828.3
1974	893.9	891.6			0.0063	5.6	897.2
1975	736.1	734.0			0.0063	4.6	738.6
1976	1120.7	1120.7			0.0063	7.1	1127.8
1977	848.2	847.8			0.0063	5.3	853.1
1978	1313.4	1313.3			0.0063	8.3	1321.6
1979	846.8	846.2			0.0063	5.3	851.5
1980	608.3	608.3			0.0063	3.8	612.1
1981	377.4	377.1			0.0063	2.4	379.5
1982	693.6	693.1			0.0063	4.4	697.5
1983	1335.5	1335.5			0.0063	8.4	1343.9
1984	1789.8	1789.2			0.0063	11.3	1800.5
1985	1498.9	1498.9			0.0063	9.4	1508.3
1986	1155.8	1155.7			0.0063	7.3	1163.0
1987	1406.2	1406.2			0.0063	8.9	1415.1
1988	1810.3	1810.3			0.0063	11.4	1821.7
1989	1814.7	1814.7			0.0063	11.4	1826.1
1990	1586.3	1586.3			0.0063	10.0	1596.3
1991	1351.9	1351.9			0.0063	8.5	1360.4
1992	1401.5	1400.6			0.0063	8.8	1409.4
1993	1113.9	1113.9			0.0063	7.0	1120.9
1994	1193.8	1193.8			0.0063	7.5	1201.3
1995	860.5	860.5			0.0063	5.4	865.9
1996	685.1	685.1	11.0	674.1	0.0163		696.1
1997	705.3	705.3	10.3	695.0	0.0148		715.6
1998	776.1	776.1	3.6	772.5	0.0047		779.7
1999	895.8	895.8	2.4	893.4	0.0027		898.2
2000	771.8	771.8	6.6	765.2	0.0086		778.4
2001	800.4	800.4	4.1	796.3	0.0051		804.5
2002	876.7	876.7	2.1	874.6	0.0024		878.8
2003	829.1	829.1	1.3	827.8	0.0016		830.4
2004	789.5	789.5	1.1	788.4	0.0014		790.6
2005	882.6	882.6	10.4	872.2	0.0119		893.0
2006	763.3	763.3	1.9	761.4	0.0025		765.2

Notes:

1 CDN landed: 1967-1995 GFCatch; 1996-2006 PacharvTrawl. Calendar year until 1995. 1996 contains Jan-Mar

2 Fishing year (Apr-Mar) from 1997-2006

3 US landed: 1967-1979 Tagart & Kimura; 1980-1982 are amounts from Stanley 1995.

4 Can discarded: 1996-2006 PacharvTrawl. Calendar year until 1995. 1996 contains Jan-Mar 1997. Fishing year Apr-Mar from 1997-2006.

5 J/V: only available from 1988, by calendar year but fishery generally occurs May-Sep (GFBio)

6 N/S: National or Supplemtal direct for trawling. Occurred in 1988-1991, 2000, 2004, by calendar year but fishery generally occurs May-Sep (GFBio)

7 Shrimp trawl: no records of canary or other rockfish; used excluders since 2000

Trawl Discards (1930-1995; 1996-2006)

Estimates of trawl discards of canary rockfish are available from observer coverage since 1996. Discards ranged from 1-11 t/y from 1996-2006. This represented an additional catch (and mortality) of 0.6% over this period. These discards are predominantly the result of discarding undersized and/or unmarketable specimens.

We have no means for estimating discards prior to 1996. Trawl net mesh sizes are assumed to be similar over the whole period of the fishery so we assume mesh selectivity has been relatively constant, thus there was no period when we would assume the higher or lower catch rates of small fish. We also assume that the minimum size for sorting at sea has remained similar over time. Therefore, we have assumed a chronic underlying discard rate of 0.6% to represent the discarding of undersized fish for 1930-1995, the same as for 1996-2006 (Table B.1)[4].

Prior to the early 1980's, there were no regulations so any discarding would have been market driven. We are not currently aware of any evidence that marketable canary rockfish were differentially discarded over other rockfish. Nor do we know that large amounts of rockfish were dumped prior to the 1980's. However, market conditions or possibly the delivery of "bad" fish in these earlier years might have led some catches of canary rockfish to be dumped without being recorded as landings.

Anecdotal comments have indicated that from the early-mid1980's until 1995, significant catches of rockfish were discarded at sea, mis-identified or even secretly sold on a black market as harvesters attempted to circumvent quota and trip limit constraints. However, we have no means of estimating these amounts. Our model runs assume no additional unreported catch of marketable fish in this period. If this assumption requires further investigation, we recommend that it be explored as a modeling or sensitivity analysis using alternative/hypothetical catch histories for 1985-1995.

Commercial HL

Consistent with our reconstruction of the trawl history, we attempted a reconstruction of HL landings and discards where possible. The HL fisheries have been separated into ZN license fishery which tended to target rockfish and the Halibut fishery which targeted halibut.

[4] Note: we incorrectly did not add the additional 0.6% discard rate to the 1930-1967 period. Thus total trawl catches used in the assessment modeling for the 1930-1967 period were underestimated by 0.6% or 0-5 t/y during this period. However, this increment was applied for 1967-1995; see Table B.6., last page.

Table B.7. Hook and line cary rockfish reconstruction (1940-2006).

Year	Halibut Fishery		ZN fishery			HL Integrated fishery	Total HL catch
	Halibut Landings (from IPHC website)	Canary rockfish discards (*0.0006)	ZN landings (all rockfish)	ZN landings of canary (*0.030)	ZN DMP (from PacHarv)		
	mt	mt	mt	mt	mt	mt	mt
1940	8016	4.8					5
1941	8077	4.8					5
1942	7497	4.5					4
1943	6517	3.9					4
1944	7244	4.3					4
1945	6837	4.1					4
1946	6613	4.0					4
1947	8334	5.0					5
1948	8014	4.8					5
1949	8014	4.8					5
1950	7413	4.4					4
1951	7919	4.8					5
1952	9091	5.5					5
1953	9360	5.6					6
1954	10795	6.5					6
1955	11322	6.8					7
1956	8460	5.1	33.7	1.0			6
1957	9098	5.5	59.9	1.8			7
1958	8023	4.8	45.6	1.4			6
1959	8387	5.0	46.1	1.4			6
1960	7634	4.6	67.3	2.0			7
1961	8236	4.9	74.9	2.2			7
1962	7292	4.4	105.1	3.2			8
1963	6818	4.1	94.2	2.8			7
1964	7039	4.2	41.0	1.2			5
1965	5377	3.2	42.9	1.3			5
1966	5429	3.3	47.1	1.4			5
1967	5006	3.0	71.4	2.1			5
1968	4586	2.8	56.8	1.7			4
1969	4602	2.8	103.4	3.1			6
1970	5816	3.5	148.2	4.4			8
1971	4653	2.8	94.4	2.8			6
1972	4467	2.7	155.2	4.7			7
1973	4597	2.8	97.7	2.9			6
1974	3052	1.8	159.8	4.8			7
1975	2096	1.3	181.3	5.4			7
1976	3234	1.9	133.5	4.0			6
1977	3302	2.0	175.2	5.3			7
1978	2463	1.5	202.0	6.1			8
1979	2091	1.3	290.5	8.7			10
1980	2204	1.3	263.0	7.9			9
1981	2563	1.5	201.3	6.0			8
1982	2563	1.5	161.3	4.8			6
1983	2513	1.5	177.4	5.3			7
1984	2468	1.5	291.9	8.8			10
1985	4105	2.5	451.6	13.5			16
1986	4713	2.8	966.3	29.0			32
1987	5089	3.1	1182.0	35.5			39
1988	5557	3.3	1101.6	33.0			36
1989	5833	3.5	1216.4	36.5			40
1990	4731	2.8	1746.0	52.4			55
1991	3887	2.3	1714.5	51.4			54
1992	3025	1.8	1519.8	45.6			47
1993	3447	2.1	1757.3	52.7			55
1994	4808	2.9	1668.0	50.0			53
1995	4491	2.7			56.0		59
1996	4309	2.6			57.4		60
1997	4289	2.6			54.9		57
1998	5589	3.4			79.2		83
1999	5849	3.5			68.8		72
2000	5540	3.3			48.9		52
2001	4822	2.9			55.5		58
2002	4630	2.8			33.9		37
2003	5437	3.3			46.8		50
2004	5318	3.2			47.4		51
2005	5483	3.3			60.2		63
2006						13.4	13

Notes:

1 Halibut landings from International Pacific Halibut Commission website (http://www.iphc.washington.edu/halcom/default.htm)

2 Ratio of canary rockfish catch tohalibut catch in the IPHC surveys

1930-1994 ZN fishery landings

Records of total rockfish landings for the ZN HL fishery for rockfish and lingcod in Areas 3C-5E are available back to 1956 in Yamanaka and Kronlund (1997, p. 25: note we excluded catches from the Strait of Georgia) (Table B.7). We converted these total rockfish estimates to canary rockfish by assuming a constant proportion of 0.03 (3%). This proportion was derived from 1996 logbook species composition in the same report (Yamanaka and Kronlund 1997, p. 24). Note the reconstructed amounts for the early 1990's are similar to the DMP records starting in 1995.

1930-2005 ZN fishery discards

We have no information with which to estimate canary rockfish discards in the ZN fishery from 1930-2005. We have assumed it has been negligible over the course of the fishery. If these amounts are considered to have been significant, then subsequent model runs could conduct sensitivity tests using hypothetical time series but we suggest that these values are probably negligible compared with total catches.

1995-2006 ZN fishery Landings

Commercial hook and line landings for 1995-2006 were taken from PacHarvHL as for the previous assessment (Table B.8). They represent landings only.

Table B.8. Landings of canary rockfish from dockside monitoring program (1995-2004).

	4B					3C				
Year	ZN LL Landed[1]	Troll[2]	Sched II Line gear	Halibut Landed[3]	Total	ZN LL Landed	Troll	Sched II Line gear	Halibut Landed	Total
1995	0.3		-	tr.	0.3	1.8			tr.	1.8
1996	0.2	0.0	-	tr.	0.2	3.0	0.0		tr.	3.0
1997	0.7	0.0	-	0.0	0.7	1.2	0.0		tr.	1.2
1998	0.2	0.0	-	tr.	0.2	2.9	0.0		tr.	2.9
1999	0.5	0.0	-	tr.	0.5	1.6	0.3		0.1	2.0
2000	1.0	0.0	-	tr.	1.0	4.1	tr.		-	4.1
2001	1.2	0.0	-	tr.	1.2	4.0	1.1		-	5.1
2002	0.1	0.0	-	0.0	0.1	1.7	0.6		-	2.3
2003	0.8	0.0	-	0.0	0.8	1.6	8.6		-	10.2
2004	0.2	0.0	-	tr.	0.2	0.8	2.3	0.1	-	3.2
2005	tr.	0.0	-	0.0	0.0	0.5	3.1	0.5	-	4.1
2006	0.2	-	tr.	0.1	0.3	0.9	-	0.2	0.4	1.5

[1]ZN landed: 1995-2005 from PacharvHL D_Official_Catch. Calendar year 1995-1996. 1997 from Jan 1/97 to Mar 31/98. Fishing year (Mar-Apr) 1998-2006. 2006 from FOS.

[2]Troll: from Pacharv3 (Regional Data Unit). Calendar year 1996-2005, incidental to salmon fishery.

[3]Halibut landed: from DMP. Calendar year 1995-2004. 1995-1999 reported by PFMA, 2000-2005 reported by rockfish management regions. 2006 from FOS, manual merge of logs and DMP.

Rockfish mgmt regions: SG included with 4B, NC included with 5D. WC, CC and QC are separate columns.

Table B.8. (continued).

	3D					WC	5A				
Year	ZN LL Landed	Troll	Sched II Line gear	Halibut Landed	Total	Halibut Landed	ZN LL Landed	Troll	Sched II Line gear	Halibut Landed	Total
1995	7.3			tr.	7.3		8.9			tr.	8.9
1996	17.3	0.0		tr.	17.3		7.3	0.0		0.1	7.4
1997	8.7	0.0		tr.	8.7		5.5	0.0		0.1	5.6
1998	18.5	0.0		0.3	18.8		10.6	0.0		0.4	11.0
1999	29.4	0.9		0.7	31.0		6.1	0.0		0.3	6.4
2000	12.9	0.1		-	13.0	2.1	6.8	0.0		-	6.8
2001	5.9	tr.		-	5.9	3.4	11.7	0.0		-	11.7
2002	2.9	4.0		-	6.9	5.5	3.2	0.1		-	3.3
2003	1.7	7.1		-	8.8	7.1	6.8	tr.		-	6.8
2004	1.9	8.5	0.5	-	10.9	5.9	11.2	0.4	0.6	-	12.2
2005	1.9	23.8	1.1	-	26.8	5.5	7.6	0.2	0.5	-	8.3
2006	0.4	-	0.2	1.0	1.6		1.2	-	0.1	1.2	2.5

Table B.8. (continued).

	5B					CC	5C				
Year	ZN LL Landed	Troll	Sched II Line gear	Halibut Landed	Total	Halibut Landed	ZN LL Landed	Troll	Sched II Line gear	Halibut Landed	Total
1995	1.7			0.1	1.8		4.3			0.1	4.4
1996	2.4	0.0		0.4	2.8		3.2	0.0		0.3	3.5
1997	2.9	0.0		0.2	3.1		3.3	0.0		0.2	3.5
1998	2.9	0.0		0.3	3.2		4.8	0.0		0.4	5.2
1999	3.4	0.0		1.0	4.4		3.0	0.0		0.2	3.2
2000	3.2	0.0		-	3.2	0.5	0.3	0.0		-	0.3
2001	3.1	tr.		-	3.1	0.8	1.9	0.2		-	2.1
2002	1.4	0.0		-	1.4	1.3	1.4	0.0		-	1.4
2003	1.5	0.0		-	1.5	1.6	0.2	0.0		-	0.2
2004	2.1	0.0	0.1	-	2.2	1.0	1.2	0.0	tr.	-	1.2
2005	1.4	0.0	tr.	-	1.4	1.4	0.1	0.0	tr.	-	0.1
2006	0.3	-	tr.	1.9	2.2		1.1	-	tr.	1.5	2.6

Table B.8. (continued).

	5D					5E					QC
Year	ZN LL Landed	Troll	Sched II Line gear	Halibut Landed	Total	ZN LL Landed	Troll	Sched II Line gear	Halibut Landed	Total	Halibut Landed
1995	1.2			tr.	1.2	5.5			tr.	5.5	
1996	1.0	tr.		0.1	1.1	10.7	0.0		0.4	11.1	
1997	1.1	0.0		0.1	1.2	8.7	0.0		0.3	9.0	
1998	0.7	tr.		0.6	1.3	17.9	0.0		1.0	18.9	
1999	1.7	0.0		0.4	2.1	11.9	0.0		0.9	12.8	
2000	1.2	0.0		0.1	1.3	7.3	0.0		-	7.3	4.1
2001	2.1	0.1		0.1	2.3	10.7	0.9		-	11.6	7.0
2002	1.5	2.3		0.2	4.0	0.2	0.7		-	0.9	5.7
2003	1.0	1.7		0.2	2.9	0.1	1.1		-	1.2	4.2
2004	0.5	2.4	0.0	0.2	3.1	0.1	1.0	0.0	-	1.1	5.8
2005	0.1	0.4	tr.	0.3	0.8	tr.	0.1	0.0	-	0.1	9.4
2006	0.1	-	tr.	0.8	0.9	0.6	-	0.1	1.3	2.0	

Table B.8. (continued).

	Unknown area					All areas				
Year	ZN LL Landed	Troll	Sched II Line gear	Halibut Landed	Total	ZN LL Landed	Troll	Sched II Line gear	Halibut Landed	Total
1995	25.1			0.0	25.1	56.1	0.0	0.0	0.2	56.3
1996	11.2	0.0		0.0	11.2	56.3	0.0	0.0	1.3	57.6
1997	22.6	0.0		tr.	22.6	54.7	0.0	0.0	0.9	55.6
1998	17.9	0.0		0.0	17.9	76.4	0.0	0.0	3.0	79.4
1999	6.9	0.0		0.0	6.9	64.5	1.2	0.0	3.6	69.3
2000	6.2	0.0		tr.	6.2	43.0	0.1	0.0	6.8	49.9
2001	2.4	0.1		0.0	2.5	43.0	2.4	0.0	11.3	56.7
2002	1.2	0.0		0.0	1.2	13.6	7.7	0.0	12.7	34.0
2003	2.3	0.0		0.0	2.3	16.0	18.5	0.0	13.1	47.6
2004	0.8	0.0	tr.	0.0	0.8	18.8	14.6	1.3	12.9	47.6
2005	1.9	-	0.4	0.0	2.3	13.5	27.6	2.5	16.6	60.2
2006	0.1	-	tr.	tr.	0.1	4.9	0.0	0.6	8.2	13.7

1930-2005 Halibut Fishery discards

We used observations of canary rockfish catch relative to halibut catch in the IPHC halibut survey for 2003-2005 to estimate a bycatch ratio of 0.006 (0.6%). We then estimate the incidental catch (discarded and retained) by applying this ratio to total halibut landings from B.C.

The total piece counts of halibut and canary were obtained from the IPHC surveys in 2003, 2004, and 2005. The mean weight for halibut (17.2 kg) was obtained from the 2003 IPHC survey, the only survey of the three years for which halibut weights and counts were recorded. Mean canary length of 48.1 was obtained from 29 samples taken from the 2003-2005 IPHC surveys. A length-weight relationship was derived from data in GFBio and used it to calculate the weight of a 48.1 cm canary at 1.9 kg. Having obtained mean piece weight for halibut and canary rockfish, we converted the IPHC piece counts to total catch weight for the years 2003-2005 and calculated the ratio of canary weight to halibut weight at 0.0055 or 0.6%

2006 Total HL canary rockfish catches

The Pilot Groundfish Integration Project introduced 100% retention of all rockfish for 2006, we therefore assume HL landings represent total canary rockfish catch for all hook and line vessels for 2006.

Additional Data Sources Used in the Catch Summary

AKFIN. U.S. commercial landings from Alaska, 1991-1998 (www.psmfc.org/akfin/Reports/reports.html).

PACFIN. U.S. commercial landings from Washington, Oregon and California, 1981-2000 (www.psmfc.org/pacfin/data.html).

GFCatch. Canadian trawl landings, 1954-1995 (Rutherford 1999).

PacHarvTrawl. Canadian trawl landings, 1996-2000. SQL Server database, Groundfish Section, Stock Assessment Division, Science Branch, Fisheries and Oceans, Canada. Pacific Biological Station.

PacHarvHL. Canadian hook and line landings, 1995-2001. SQL Server database, Groundfish Section, Stock Assessment Division, Science Branch, Fisheries and Oceans, Canada. Pacific Biological Station.

Pacharv3. Canadian troll landings from sales slips, 1982-2001. Oracle database, Regional Data Unit, Information Management, Corporate Services Branch, Fisheries and Oceans, Canada.

South Coast Creel Database. Estimates of recreational catches (caught and released) from the Strait of Georgia. South Coast Stock Assessment, Fisheries and Oceans, Canada.

U.S. trawl landings from Canada and Washington, 1967-1979 (from Tagart and Kimura 1982).

U.S. trawl landings from Canada and Washington, 1980, unpublished data from Washington State Department of Fish and Wildlife (Jack Tagart, pers. comm. Appendix 1)

Washington Department of Fish and Wildlife. Commercial trawl landings for 1980.

APPENDIX C. BIOLOGICAL ANALYSES FOR CANARY ROCKFISH

Estimation of length-weight parameters

Every record with canary rockfish data was extracted from the biological sample data available in GFBio (extract obtained 27 August 2007). This resulted in recovering 28,089 records distributed by year, sex and combined major area as reported in Table C.1. An additional 11,559 records are missing either sex, length, or date of sampling information.

A linear regression model (Eq. C.1) was fitted to available length-weight pairs categorised by sex and major combined DFO region (Table C.2, see Table J.2 for a list of parameters) to see if there were major differences in the estimated parameters between the areas for each sex. The length data were trimmed to the 1 and 99 percentiles in each area to drop potential out-of-range lengths. The weight-length pairs were trimmed further by fitting the model twice, with the second pass dropping large outliers (where the absolute value of the standardised residual was greater than 4).

Eq. C.1

$$W_i^s = b_0^s L_i^{b_1^s}$$

$$\ln\left(W_i^s\right) = \ln(b_0^s) + b_1^s \ln\left(L_i\right) + \varepsilon_i$$

$$\hat{b}_0^s = \exp\left[\ln(b_0^s)\right]$$

Model fits and residual plots are provided for the fit to the total B.C. data (males: Figure C.1; females: Figure C.2). Parameter estimates and some diagnostics from the fitted models are presented in Table C.3 and are plotted for comparison by sex and area in Figure C.3. Residuals for both models show reasonable fits to the data but there are many anomalous outliers. These may be caused by data errors, given the long period over which the data have been collected and the variety of sample type origins (Table C.2). Examination of the parameter estimates by major DFO region shows similar values between the sexes (Table C.3). There is a suggestion that the β parameter is larger on the west coast of Vancouver Island than in the more northerly regions (approximately 3.1 for 3CD compared to 2.9 for 5ABC; Table C.3). The confidence bounds do not overlap, indicating that this difference is probably statistically significant. However, the differences are small and do not constitute a substantial difference in these parameters.

Table C.1. Distribution of length records by sex and combined major DFO reporting region for canary rockfish as recorded in the GFBio database (current to 27 August 2007). These records all have a valid sex code, major DFO area code and a length observation. Records missing one of these values are not included in this table.

Year	**Males**						**Females**					
	3CD	**4B**	**5ABC**	**5D**	**5E**	**Total**	**3CD**	**4B**	**5ABC**	**5D**	**5E**	**Total**
1962				73		73				17		17
1966			88			88			17			17
1967	28		20			48	6		5			11
1968	27	17	8			52	29	17	2			48
1969	183		140			323	61		116			177
1971			2			2			4			4
1976	196					196	73					73
1977	452		183			635	149		108			257
1978	83		1,644		120	1,847	28		813		161	1,002
1979	573		287			860	135		120			255
1980			1,215		3	1,218			566		2	568
1981			182			182			95			95
1982	407		59			466	219		21			240
1983	361		352			713	231		178			409
1984	248					248	165					165
1985	684		232			916	415		67			482
1986	417					417	324					324
1988	305	1	315			621	170		135			305
1989	170					170	132		2			134
1990	45		291			336	21		124			145
1991	380		168	37		585	304		85	17		406
1992		2	104			106			53			53
1993	73		76			149	78	1	73			152
1994	77		306			383	75		233			308
1995	119		68			187	92		16			108
1996	127		202			329	76		184			260
1997	61		118		123	302	57		100		80	237
1998	614	3	159		278	1,054	421		50		63	534
1999	291		171			462	259		115			374
2000	347		258		192	797	102		151		97	350
2001	82		273		128	483	83		181		31	295
2002	140		129			269	130		99			229
2003	192	2	476	26		696	129		268	14		411
2004	418	8	347	3	77	853	369	7	181		57	614
2005	368	26	351			745	215	26	252			493
2006	530	4	196	35	52	817	510	1	170	15	69	765
2007	46		13	10		69	58		9	8		75
Total	8,044	63	8,433	184	973	17,697	5,116	52	4,593	71	560	10,392

Table C.2. Distribution of available length-weight pairs for canary rockfish by year, sex and combined major DFO areas.

	Males						Females					
Year	**3CD**	**4B**	**5ABC**	**5D**	**5E**	**Total**	**3CD**	**4B**	**5ABC**	**5D**	**5E**	**Total**
1988		1				1						0
1989	47					47	33					33
1991	152					152	124					124
1992		2				2						0
1996			71			71			48			48
1997					93	93					59	59
1998		3				3						0
1999			12			12			17			17
2000			20		38	58			28		12	40
2002	26					26	33					33
2003	124	2	364	25		515	67		195	13		275
2004	157	8	249		7	421	167	7	119		28	321
2005	42	26	220			288	28	26	153			207
2006	286	4	137	35	25	487	289	1	118	15	30	453
2007				3		3			3	5		8
Total	834	46	1,073	63	163	2,179	741	34	681	33	129	1,618

Table C.3. Length-weight parameter estimates for canary rockfish by sex and major combined area (3CD,5ABC,5D,5E) and for combined areas 3CD5ABC. All available length-weight pairs were used, regardless of data origin except that the each length distribution was truncated at the 1% and 99% of the empirical distribution to reduce the effect of outliers.

Area	Parameter	N	Estimate	Transformed	SE	LB	UB
Males							
3CD	$\hat{b}_1^m$	815	3.10	3.10	0.009	3.09	3.12
	$\hat{b}_0^m$		-11.36	1.17E-05	0.034	-11.42	-11.29
5ABC	$\hat{b}_1^m$	1,044	2.93	2.93	0.019	2.89	2.97
	$\hat{b}_0^m$		-10.72	2.21E-05	0.073	-10.87	-10.58
5D	$\hat{b}_1^m$	63	2.97	2.97	0.102	2.77	3.17
	$\hat{b}_0^m$		-10.88	1.89E-05	0.391	-11.64	-10.11
5E	$\hat{b}_1^m$	159	2.84	2.84	0.081	2.68	2.99
	$\hat{b}_0^m$		-10.32	3.29E-05	0.320	-10.95	-9.70
Total[1]	$\hat{b}_1^m$	1,859	3.05	3.05	0.008	3.03	3.06
	$\hat{b}_0^m$		-11.16	1.42E-05	0.031	-11.22	-11.10
Females							
3CD	$\hat{b}_1^f$	726	3.10	3.10	0.014	3.07	3.13
	$\hat{b}_0^f$		-11.37	1.16E-05	0.053	-11.47	-11.26
5ABC	$\hat{b}_1^f$	666	2.93	2.93	0.020	2.89	2.97
	$\hat{b}_0^f$		-10.72	2.22E-05	0.079	-10.87	-10.56
5D	$\hat{b}_1^f$	33	2.95	2.95	0.070	2.81	3.09
	$\hat{b}_0^f$		-10.78	2.09E-05	0.268	-11.30	-10.25
5E	$\hat{b}_1^f$	127	2.91	2.91	0.051	2.81	3.01
	$\hat{b}_0^f$		-10.65	2.38E-05	0.202	-11.04	-10.25
Total[1]	$\hat{b}_1^f$	1,388	3.06	3.06	0.011	3.03	3.08
	$\hat{b}_0^f$		-11.20	1.37E-05	0.043	-11.28	-11.11

[1] Combined areas 3CD5ABC

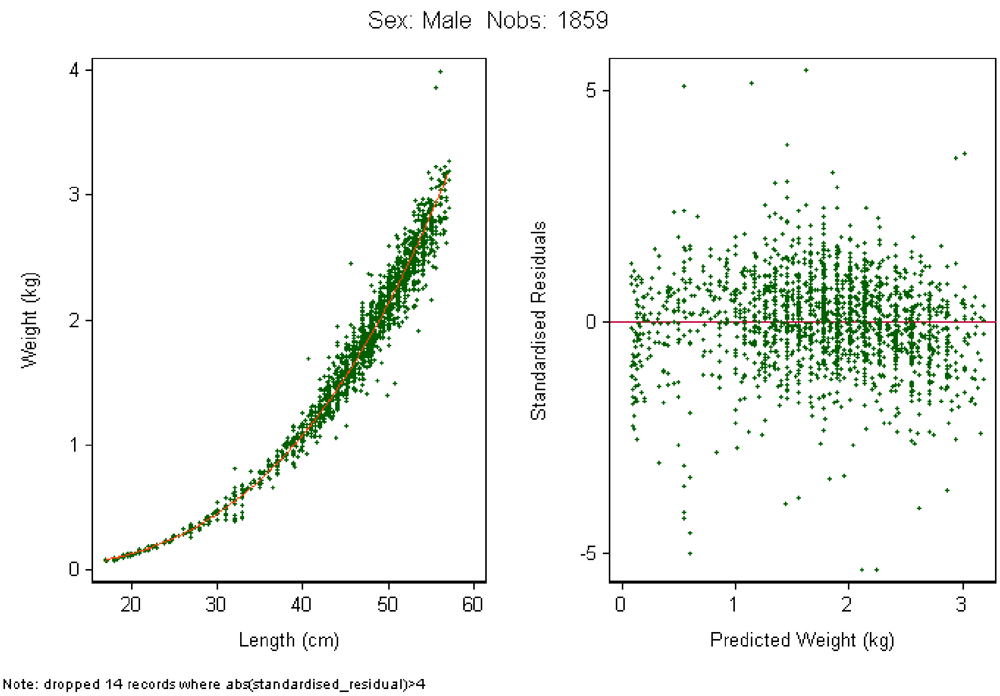

Figure C.1. Plot of the fit for length-weight data for males in combined areas 3CD5ABC. All available length-weight pairs for the area were used in the analysis, regardless of data origin or sample type.

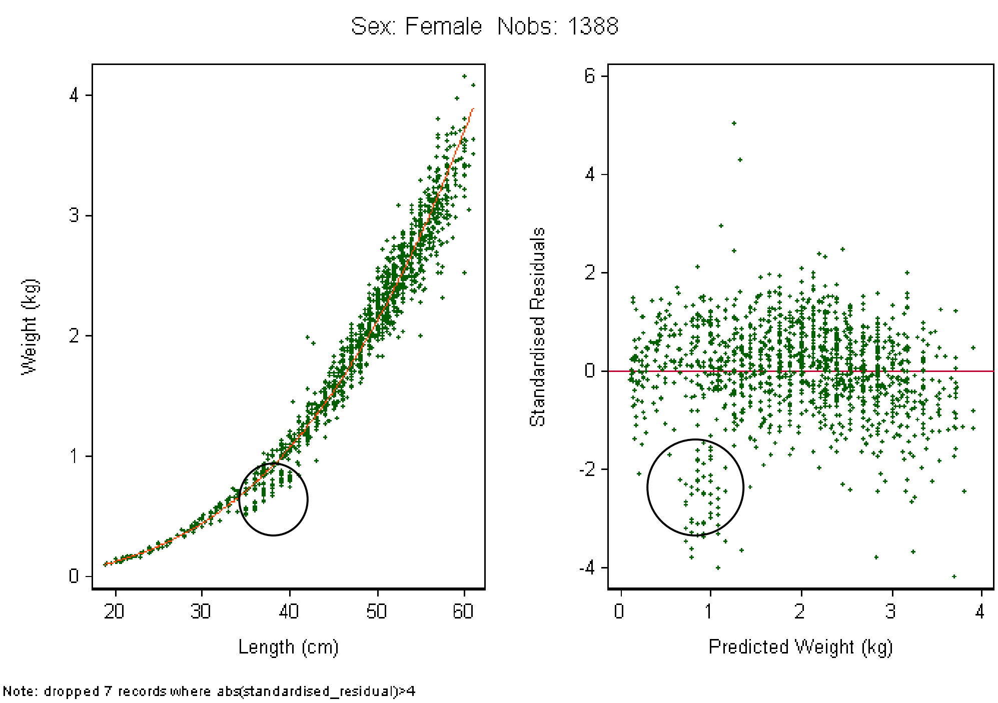

Figure C.2. Plot of the fit for length-weight data for females in combined areas 3CD5ABC. All available length-weight pairs for the area were used in the analysis, regardless of data origin or sample type.[Note: subsequent to the analysis, the circled and outlying cluster of points were found to be a sample of redstripe rockfish (*S. proriger*) incorrectly coded as canary rockfish]. Removal of these observations were found to have a negligible effect on the results.

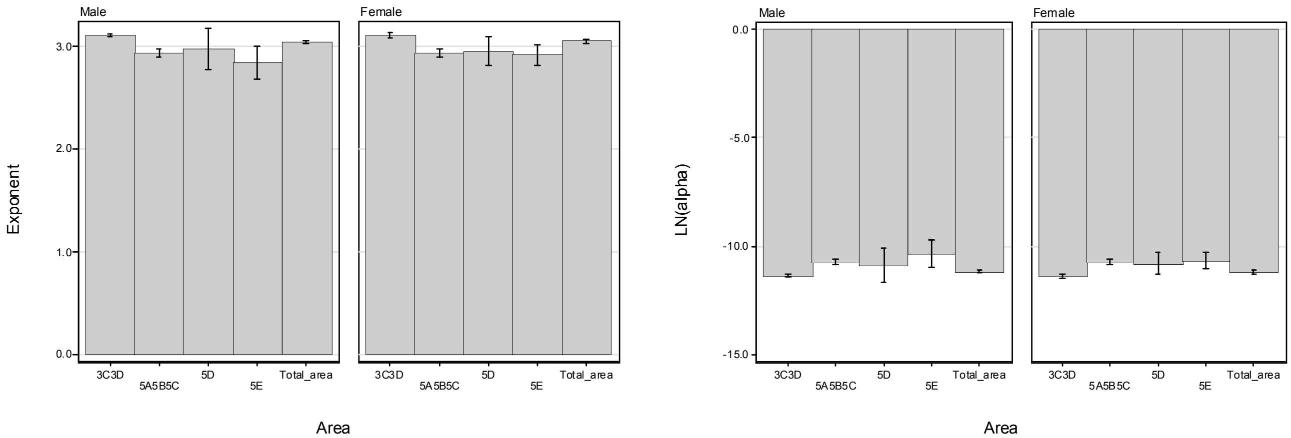

Figure C.3. Comparison of the estimates for each of the parameters in Eq. C.1 by combined major area and for total B.C. by sex, showing the 95% confidence bounds.

Estimation of von-Bertalanffy growth parameters

A non-linear von-Bertalanffy model (Eq. C.2) was fitted to age-length pairs categorised by sex and major combined DFO region (Table C.4) as well as to a model using data from the combined areas of 3CD5ABC to see if there were major differences in the estimated parameters between the areas for each sex. Neither the length nor the age data were trimmed to remove outliers prior to the analysis and all fish had been aged using the break and burn method.

Eq. C.2 $$L_i^s = L_\infty^s e^{\left(-k^s\left[a_i^s - t_0^s\right]\right)}$$

Model fits and residual plots are provided for the fit to the combined data from Areas 3CD5ABC (males: Figure C.4; females: Figure C.5). Parameter estimates and some diagnostics from models fitted to data to various combinations of the PMFC major areas are presented in Table C.5 and are plotted for comparison by sex and area in Figure C.6. Residuals for these models show reasonable fits to the data, except at the youngest ages where there appear to be some minor patterns in the residuals for males (e.g., Figure C.4) while there is less pattern in the female residuals (e.g., Figure C.5). These patterns may be caused by the lack of a full range of samples at these younger ages or the failure of the model to match the growth at these ages. The parameter estimates differ somewhat from earlier estimates made by Archibald et al. (1981), although it should be noted that the area selection is different.

Examination of the parameter estimates by combined major DFO regions shows little difference in the L_∞ parameter between regions for either sex, but there were discrepancies in the k and t_0 parameters between areas for both sexes (Table C.5; Figure C.6), with the more northerly areas showing lower values for both k and t_0. The unrealistically low values for t_0 for these northerly models are probably an artefact of the lack of observations at younger age classes in Area 5ABC compared to the 3CD samples (Figure C.7). Note that the estimates of these parameters when all data are combined are much closer to the 3CD estimates even though there are more data observations from the 5ABC, indicating the value of these observations at younger ages (Table C.5).

Plots of the effect of extending the maximum age used when estimating the von-Bertalanffy parameters shows stabilisation of the estimates after about age 50 (Figure C.8). A plot comparing the effect of constraining the data to age samples collected in the first half (January to June) of the calendar year compared to the estimates made from the entire year shows little sensitivity to this constraint (Figure C.9). There is some difference in the parameter estimates obtained when the data are separated by sample origin (Commercial or Research) (Figure C.10). However, the number of research samples is low and there are discrepancies in the distribution of observations by age, with younger ages predominating in the research samples while older ages predominate in the commercial samples (Figure C.11). This lack of representation in these data sets means that neither set of samples will adequately represent the full range of ages for this species and that combining the sample type origins is the preferred choice. Finally, there seems to relatively little sensitivity to estimating the von-Bertalanffy parameters using the mean length at each age or to using the total data set (Figure C.12), indicating that the range of observations in this data set is reasonably well balanced across the available ages.

Table C.4. Distribution of available age-length pairs for canary rockfish by year, sex and combined major DFO areas.

	Males					**Females**				
Year	**3CD**	**5ABC**	**5D**	**5E**	**Total**	**3CD**	**5ABC**	**5D**	**5E**	**Total**
1977	90	64			154	25	35			60
1978		537		47	584		237		53	290
1979	162	136			298	39	53			92
1980		228			228		72			72
1981		13			13		11			11
1982	30	22			52	20	5			25
1983	144	16			160	81	9			90
1984	120				120	92				92
1985	221	23			244	150	7			157
1986	44				44	31				31
1988	30	120			150	20	46			66
1989	13				13	12				12
1990	20	205			225	13	87			100
1991	260	168	37		465	180	85	17		282
1992		104			104		53			53
1993	73	49			122	78	32			110
1994	25	306			331	27	233			260
1995	119	39			158	92	11			103
1996	124	96			220	73	89			162
1997	60	118		30	208	57	100		21	178
1998	500	122		81	703	366	35		12	413
1999	239	134			373	189	99			288
2000	169	258		117	544	73	151		36	260
2001	82	266		127	475	83	132		31	246
2002	90	129			219	82	98			180
2003	126	230			356	81	127			208
2004	253	292		74	619	197	138		51	386
Total	2,994	3,675	37	476	7,182	2,061	1,945	17	204	4,227

Table C.5. Von-Bertalanffy parameter estimates for canary rockfish by sex and combined areas (3CD, 5ABC and 5E). A combined analysis for 3CD5ABC is also provided. All available break & burn age-length pairs were used, regardless of data origin or sample type, beginning with age 2.

Area	Parameter	Males N	Males Estimate	Males SE	Males LB	Males UB	Females N	Females Estimate	Females SE	Females LB	Females UB
3CD	L_∞^s	2,994	53.04	0.104	52.84	53.24	2,061	57.1	0.267	56.6	57.6
	k^s		0.18	0.002	0.18	0.19		0.17	0.004	0.17	0.18
	t_0^s		0.73	0.07	0.59	0.87		0.95	0.107	0.74	1.16
5ABC	L_∞^s	3,675	53.62	0.115	53.4	53.85	1,945	58.5	0.531	57.5	59.6
	k^s		0.12	0.003	0.11	0.12		0.12	0.007	0.10	0.13
	t_0^s		-4.18	0.385	-4.93	-3.42		-2.20	0.518	-3.21	-1.18
5E	L_∞^s	476	53.68	0.216	53.25	54.1	204	60.0	1.274	57.5	62.5
	k^s		0.13	0.011	0.11	0.16		0.12	0.018	0.09	0.16
	t_0^s		-3.93	1.116	-6.12	-1.74		-1.20	1.206	-3.56	1.17
Combined	L_∞^s	6,669	52.9	0.067	52.8	53.0	4,006	56.9	0.215	56.5	57.3
3CD5ABC	k^s		0.17	0.002	0.17	0.18		0.16	0.003	0.16	0.17
	t_0^s		0.32	0.074	0.17	0.47		0.56	0.118	0.33	0.79
3D5AB[1]	L_∞^s		54.1					55.3			
	k^s		0.114					0.209			
	t_0^s		-3.98					2.0			
5CD[1]	L_∞^s		52.8					62.1			
	k^s		0.137					0.095			
	t_0^s		-0.45					-1.05			

[1] Archibald, Shaw and Leaman (1981)

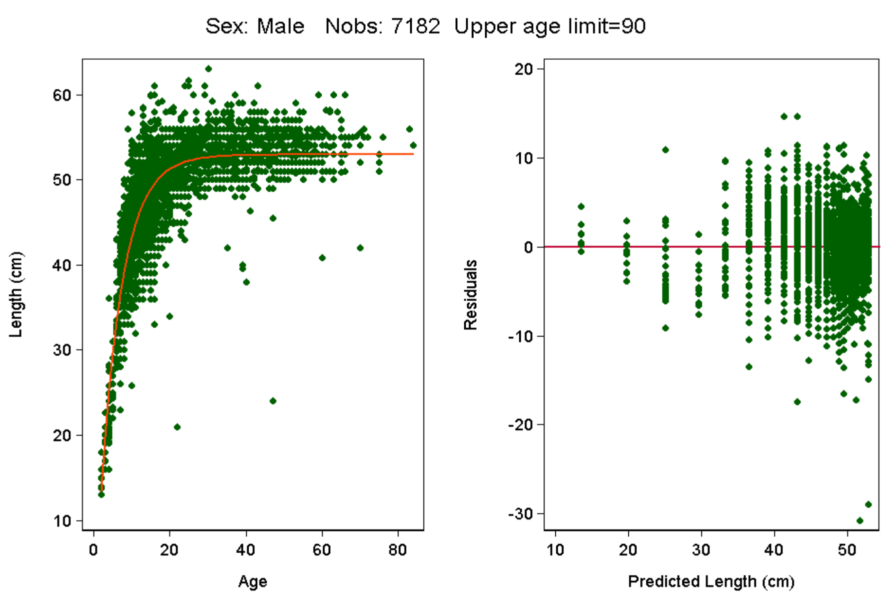

Figure C.4. Plot of the fit for age-length data for males in combined areas 3CD5ABC. All available age-length pairs were used in the analysis, regardless of data origin, starting with age 2.

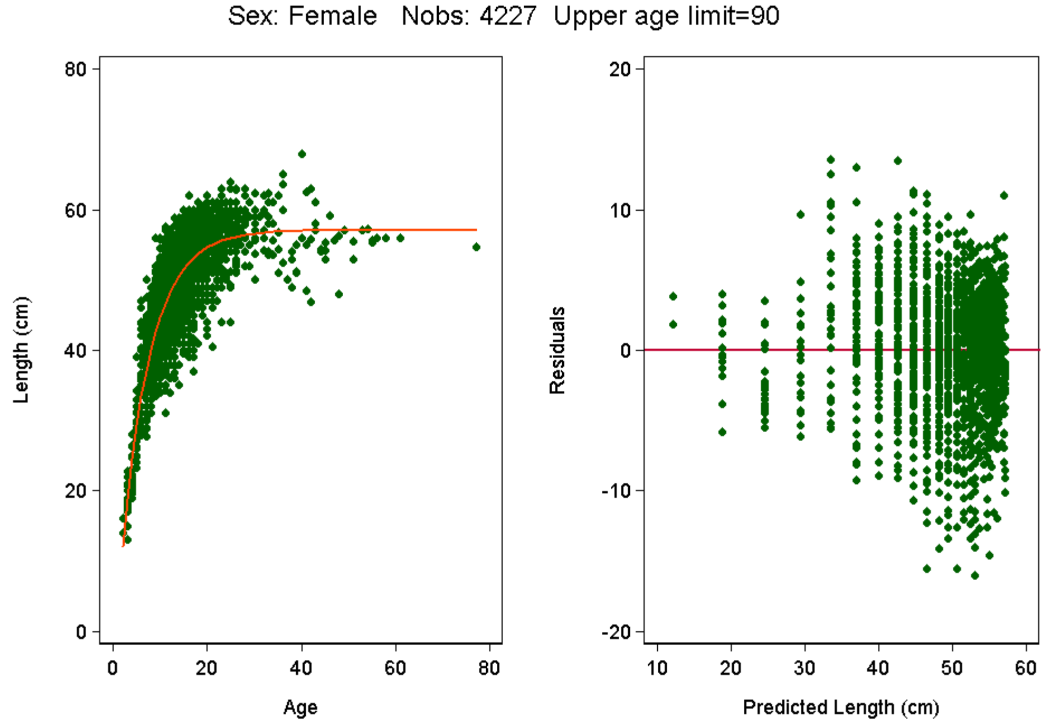

Figure C.5. Plot of the fit for age-length data for females in combined areas 3CD5ABC. All available age-length pairs were used in the analysis, regardless of data origin, starting with age 2.

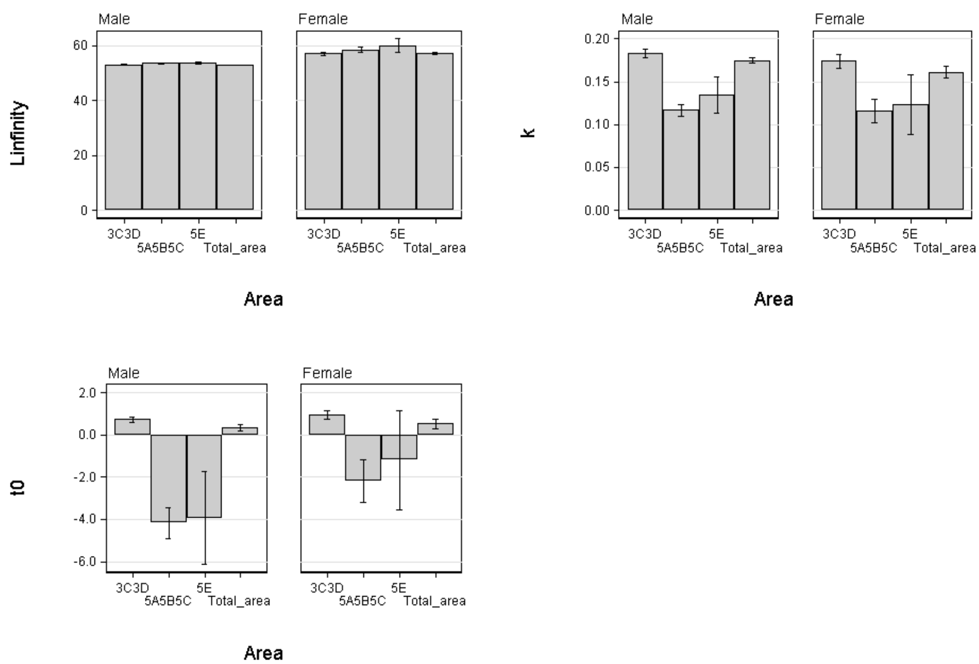

Figure C.6. Comparison of the von-Bertalanffy model estimates for each of the model parameters in Eq. C.2 across combinations of the major PMFC areas and by sex, showing the 95% confidence bounds. All sample origins have been combined across the entire year of data up to the maximum age.

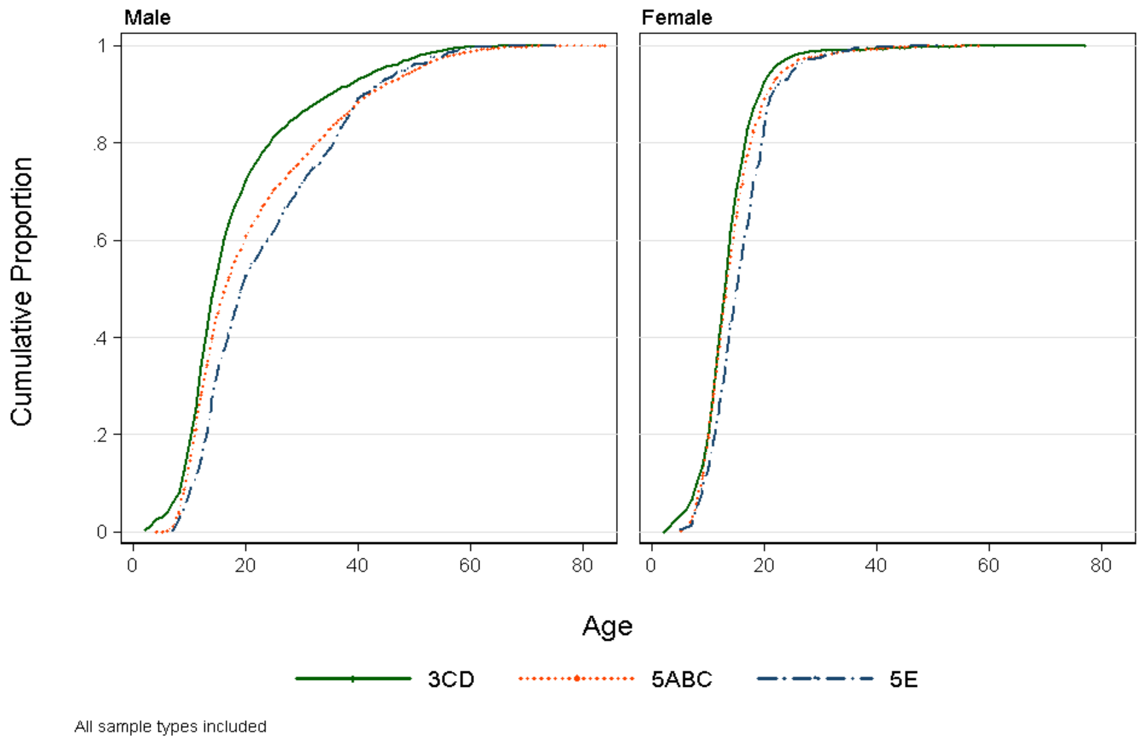

Figure C.7. Empirical cumulative age frequency proportions for three combined DFO major regions by sex for all sampling data.

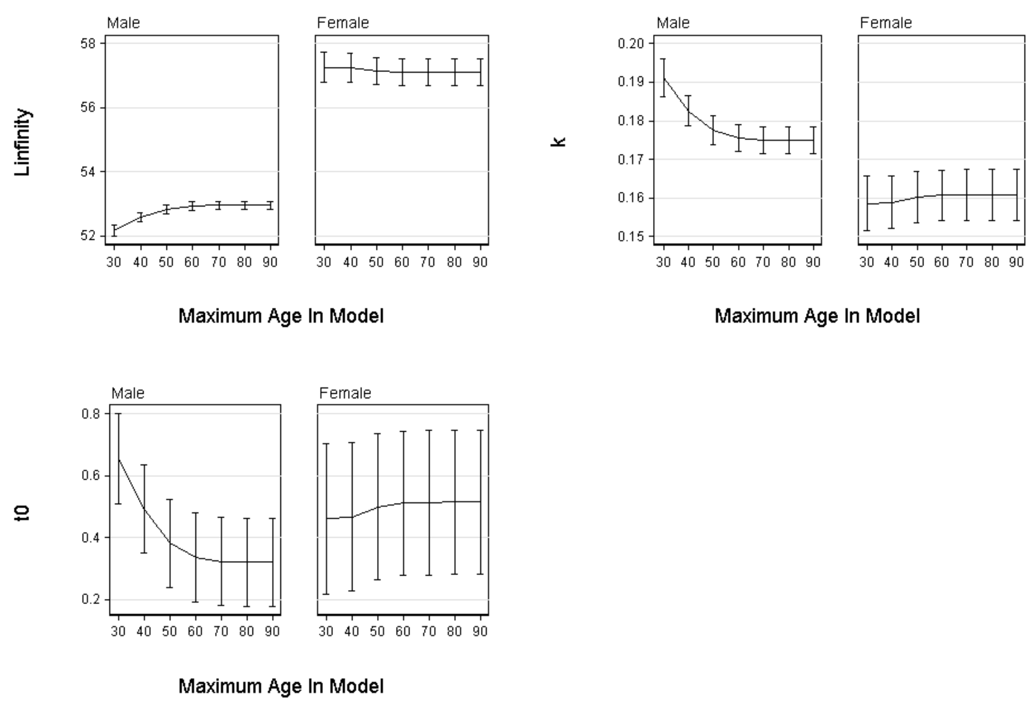

Figure C.8. Sensitivity of the von-Bertalanffy model estimates to the last age in the model for each of the parameters in Eq. C.2 by sex, showing the 95% confidence bounds. All areas and sample origins have been combined across the entire year.

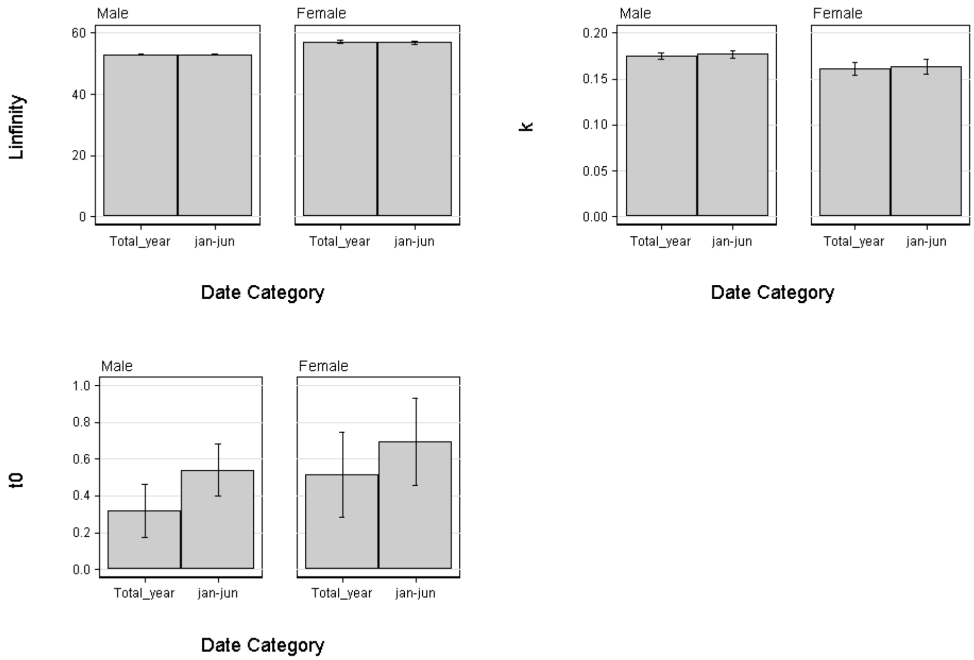

Figure C.9. Sensitivity of the von-Bertalanffy model estimates to using the entire year's worth of data compared to the first half of the year for each of the parameters in Eq. C.2 by sex, showing the 95% confidence bounds. All areas and sample origins have been combined using data from the entire year up to the maximum age.

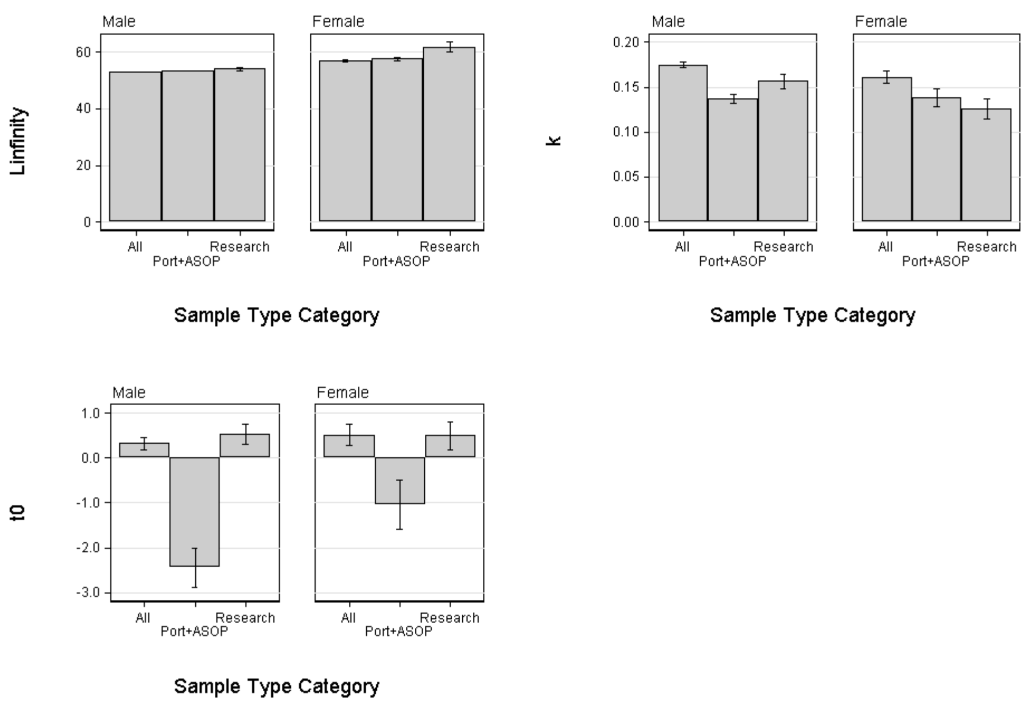

Figure C.10. Sensitivity of the von-Bertalanffy model estimates to sample type origin for each of the parameters in Eq. C.2 by sex, showing the 95% confidence bounds. All areas and sample origins have been combined using data from the entire year up to the maximum age.

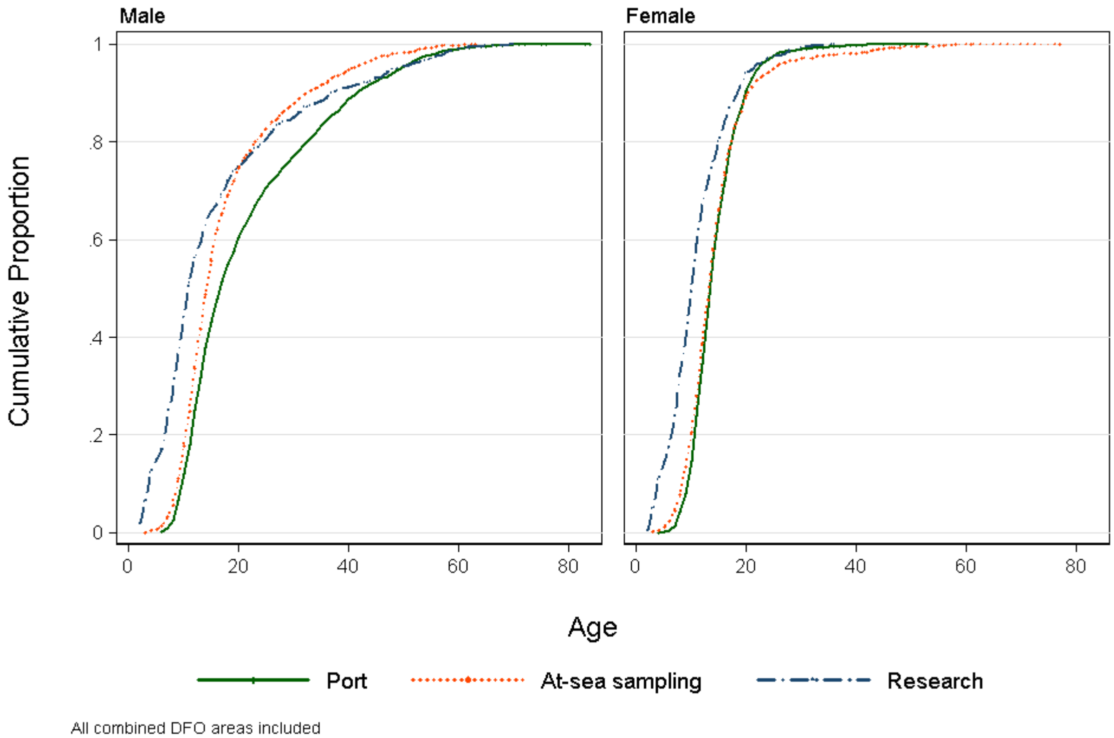

Figure C.11. Empirical cumulative age frequency proportions for three sampling types by sex for all regions combined.

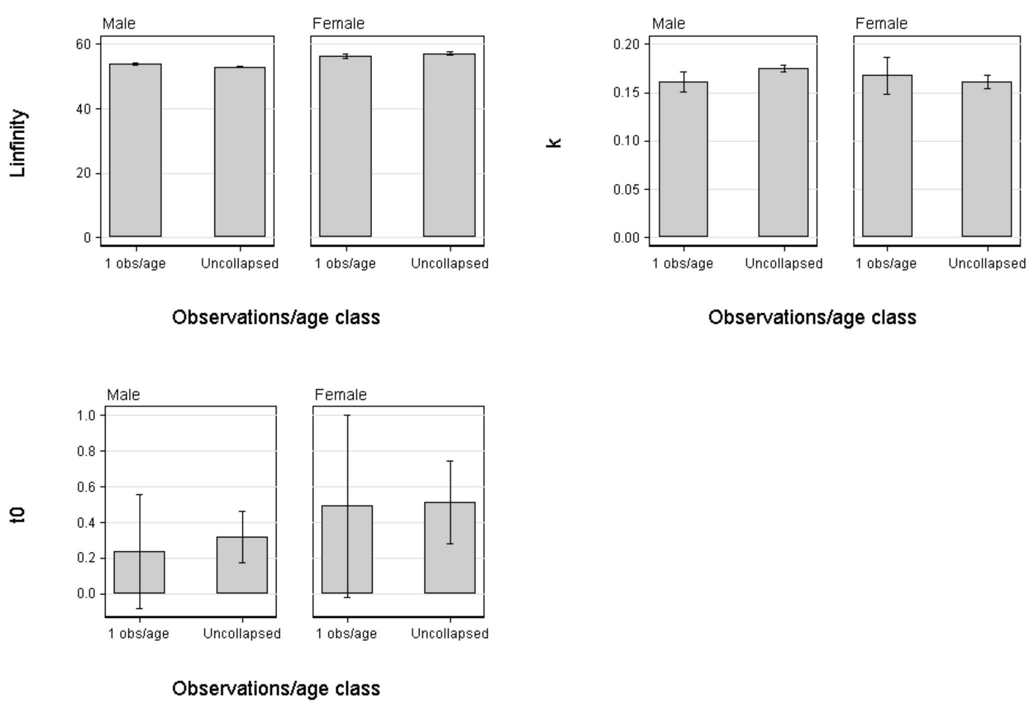

Figure C.12. Sensitivity of the von-Bertalanffy model estimates to weighting of observations at each age class for each of the parameters in Eq. C.2 by sex, showing the 95% confidence bounds. All areas and sample origins have been combined using data from the entire year up to the maximum age.

Table C.6. Number of age-length pairs used in each of the categories plotted in Figure C.6 to Figure C.12.

Category	Males	Females
3C3D	2,994	2,061
5A5B5C	3,675	1,945
5E	476	204
Jan-Jun	4,484	2,553
Port+At-sea observer	6,622	3,841
Research	560	386
Maximum age		
30	5,777	4,161
40	6,494	4,197
50	6,906	4,217
60	7,123	4,225
70	7,173	4,226
80	7,180	4,227
90	7,182	4,227

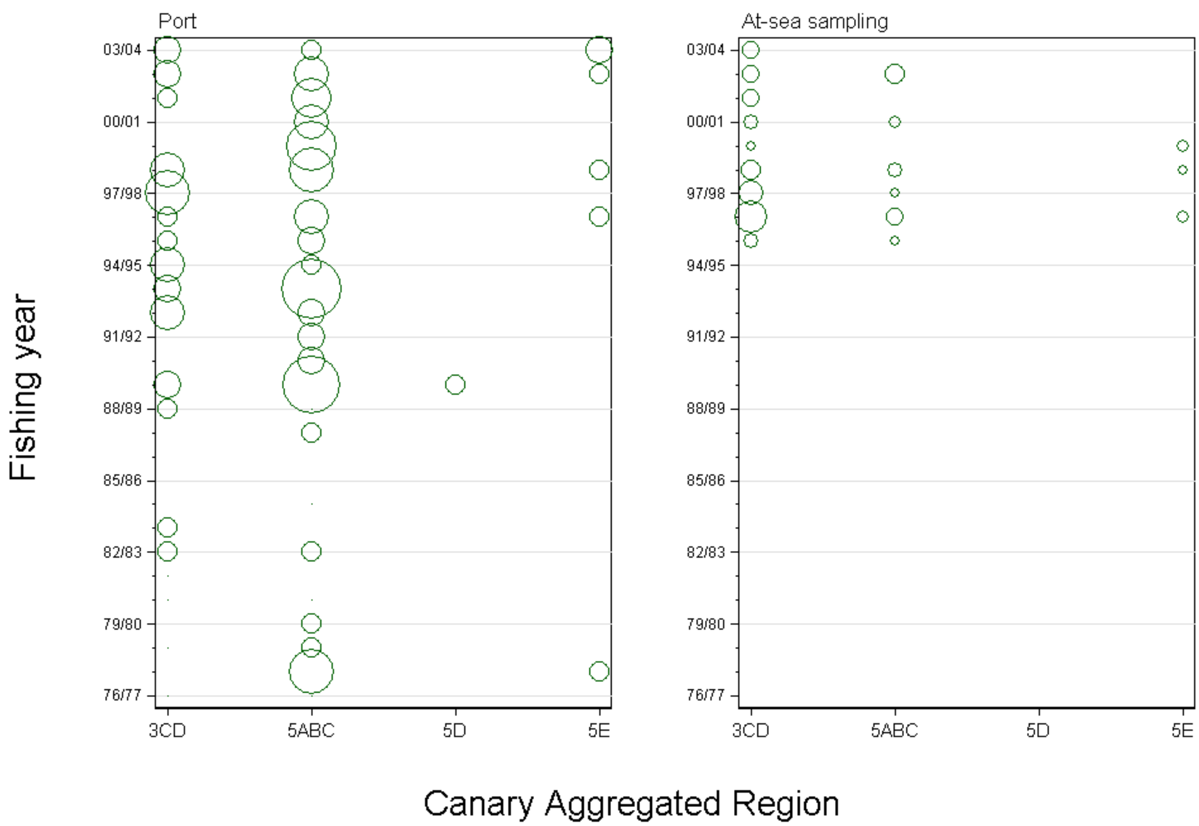

Figure C.13. Number of age samples available from the commercial fishery by sample origin, aggregated DFO Region and fishing year. Maximum circle size is 16 for both panels.

Biological parameters used in the catch-age stock assessment model

Table C.7 provides the values used for the fixed biological parameters in the canary rockfish catch-age stock assessment model. These include the estimated values from the base models assumed for all of 3CD5ABC (Table C.3 and Table C.5) as well as alternative parameter estimates which are used in different parameterisations of the von-Bertalanffy model. Also included are the standard deviations of the length at minimum and maximum ages in the model.

Parameter	Males	Females
b_0^s	1.42E-05	1.37E-05
b_1^s	3.05	3.06
L_∞^s	52.9	56.9
k^s	0.174	0.163
t_0^s	0.320	0.561
$\overline{L}_{a=1}^s$	5.91	3.93
$\overline{L}_{a=60}^s$	52.9	56.9
$\sigma_{\overline{L}_{a=1}^s}$	1.41	1.41
$\sigma_{\overline{L}_{a=60}^s}$	2.02	0.68

Canary rockfish age sampling information

Most of the age composition samples are from port samples taken at dockside, although there has been an increase in the number of samples taken by at-sea observers in recent years (Figure C.13). The latter sampling seems to have been more heavily weighted towards the WCVI than to QCSd. The sample age distributions by year and sex for total B.C. canary rockfish from combined at-sea and port samples are presented in Figure C.14. There is a considerable amount of data, but the progression of cohorts is not obvious, particularly in more recent years.

Direct comparisons of the age composition information derived from port sampling and at-sea sampling shows a varied response by year, with no systematic trend by sample origin for either males (Figure C.15) or females (Figure C.16), with the at-sea sampling showing younger fish in some years and in other years, it is the port sampling which has the younger fish. On this basis, it was decided that it would be acceptable to combine the samples across these two types of sampling. This is helpful, because the number of available samples is low, even with the combining of sample origin (Table C.8). It is also for this reason that weighting by area and time period was not attempted. There were too few samples to justify this approach. A plot of age frequencies by sex is provided in Figure C.17, which shows no strong trend or change over time. An arbitrary cut-off minimum of 4 samples in a year was selected to avoid including years which showed large variations from the patterns seen in Figure C.17 and which would be heavily down weighted in the assessment model.

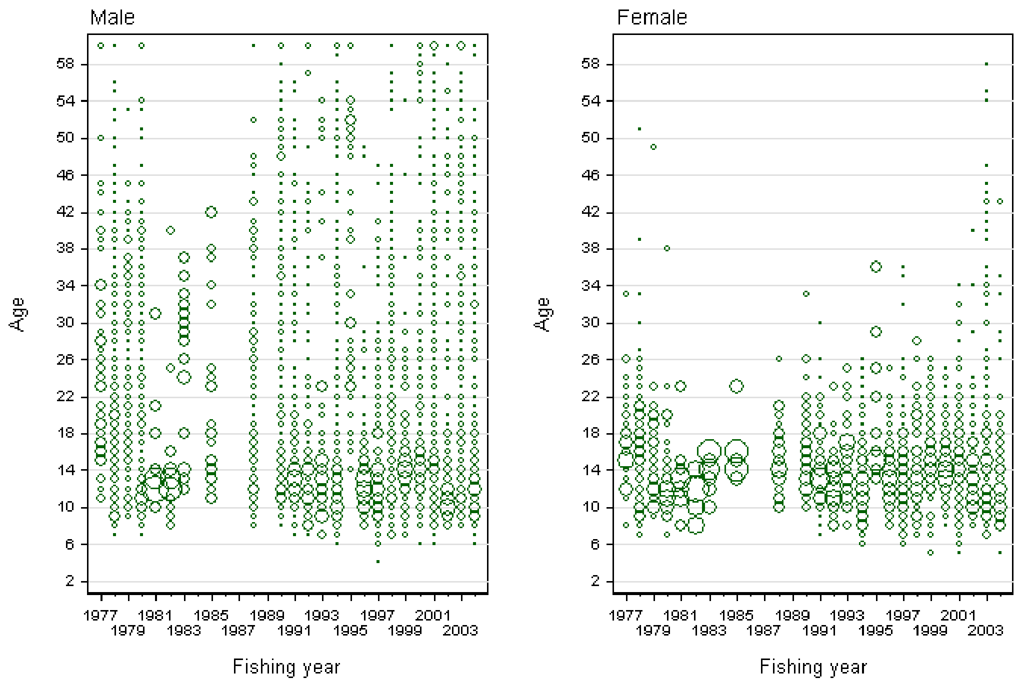

Figure C.14. Relative size of each age class of canary rockfish by sex and fishing year over all available samples for combined area 3CD5ABC. Vertical columns sum to one from age 2 to age 60, with age 60 treated as a plus-group. This plot combines port-sampling with at-sea observer sampling without weights.

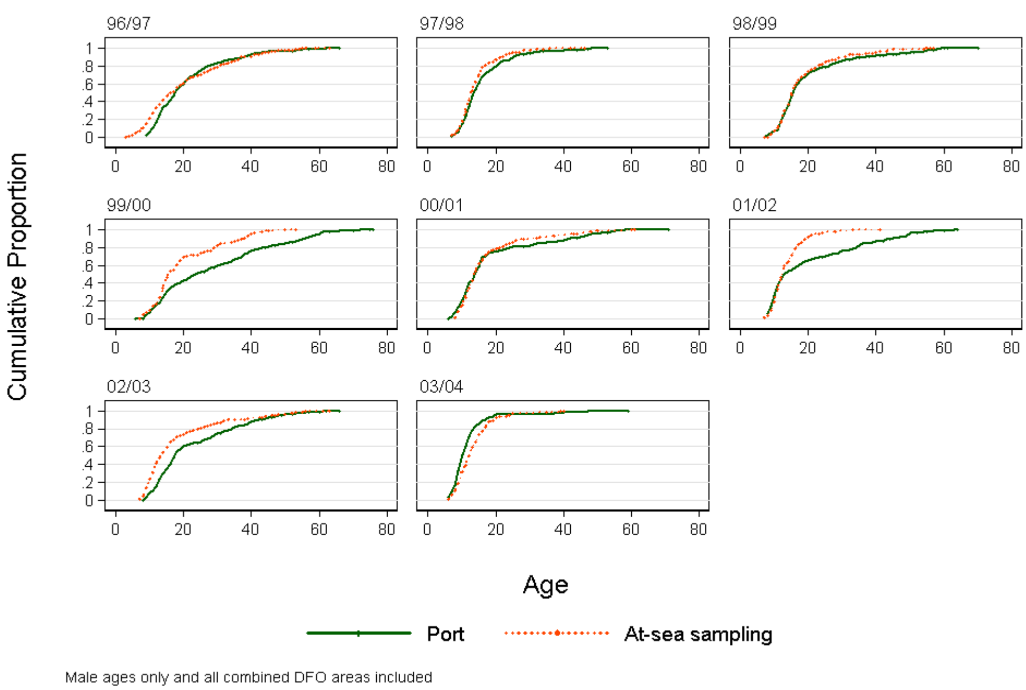

Figure C.15. Empirical cumulative age frequency proportions by fishing year for port and at-sea sampling types for males in all areas combined.

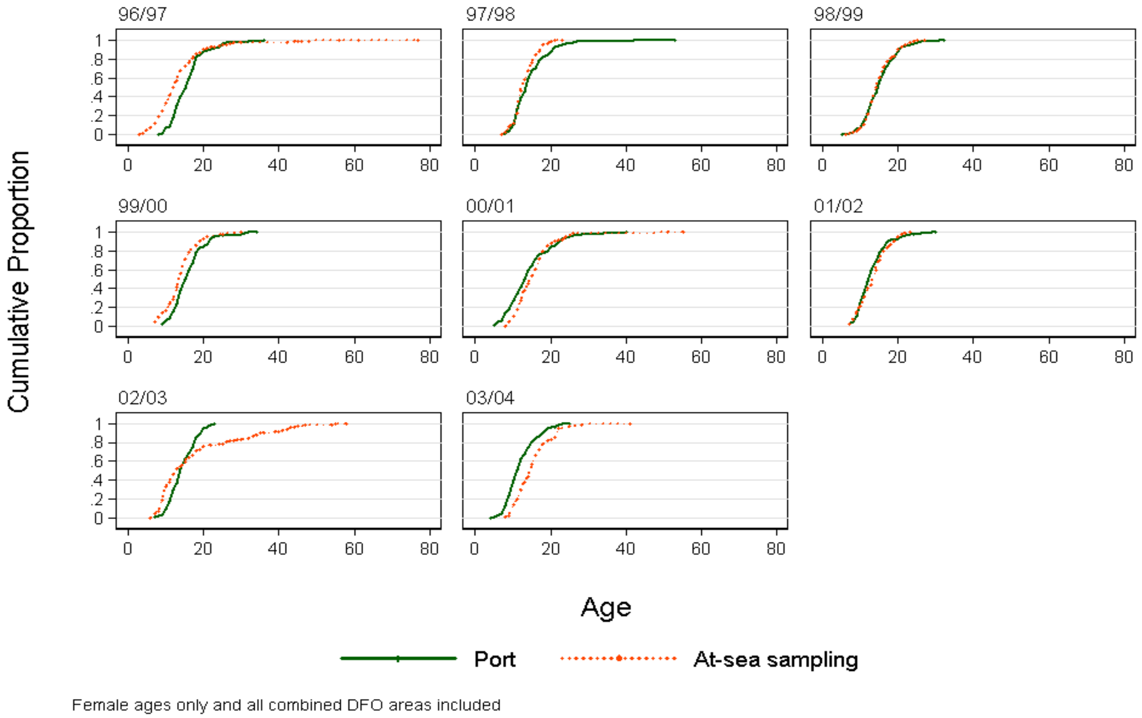

Figure C.16. Empirical cumulative age frequency proportions by fishing year for port and at-sea sampling types for females in all areas combined.

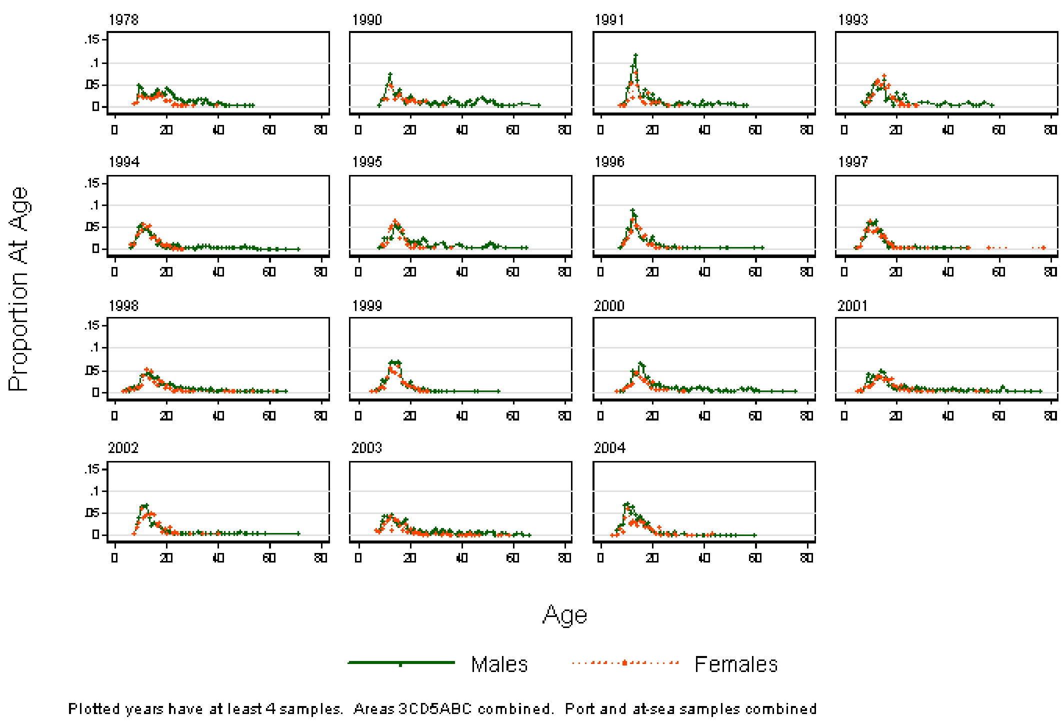

Figure C.17. Age frequency distributions for males and females by calendar year for all commercial samples (port and at-sea) for the combined 3CD5ABC areas.

Table C.7. Number of age samples available by year for the selected age compositions used to represent the coastwide canary rockfish population.

Year	Number samples	Year	Number samples
1978	6	1998	22
1990	5	1999	14
1991	24	2000	14
1993	4	2001	12
1994	11	2002	7
1995	5	2003	11
1996	7	2004	25
1997	10		

Estimation of proportion of mature females by age

This analysis was based on all staged females in the database that had been aged using the break and burn method, regardless of sample origin. This selection resulted in about 2,700 observations (Table C.9). Only females sampled from January to June were used in creating the maturity curve because in these months it is easier to distinguish between immature and maturing females (Table C.10). The proportion of mature females at each age with at least 10 observations was calculated, assuming that stage 1 and 2 females were immature and that the remaining staged females would spawn or had spawned in that year (Table C.11). A double-normal function (Eq.J.D.3) was fitted to the observed proportions mature at age to smooth the observations to obtain an increasing monotonic function for use in the stock assessment model (Figure C.18). This fitted curve corresponded well to the maturity function for canary rockfish presented by Stanley et al. (2005), except for ages less than 10, where the fitted line appeared to overestimate the proportion of mature females (Figure C.18). Accordingly, the maturity ogive used in the stock assessment model was based on the observed proportions of mature females from ages 3 to 9 and then switched to the fitted monotonic function for ages 10 to 22, after which it was assumed that all females were mature (Table C.11). This approach is reasonable as it is not necessary for the maturity function to be highly accurate in the stock assessment model as its only function is to calculate the spawning biomass used in the Beverton-Holt stock recruitment function.

Table C.8. Number of aged females using the break and burn method available by maturity stage and sample origin for the period 1978 to 2004. Maturity stages 1 and 2 are considered immature or “resting”. Stages greater than 2 are considered to apply to mature who either will spawn or have spawned in the year of sampling.

	Sample origin				
Maturity stage	Port	At-sea	Research	Other	Total
1	70	8	156	0	234
2	805	33	68	0	906
3	800	24	99	0	923
4	104	0	4	0	108
5	75	0	0	0	75
6	28	2	21	6	57
7	381	21	29	3	434
Total	2,263	88	377	9	2,737

Table C.9. Proportion of staged females by month and maturity category.

Month	Stage 1+2 Immature	Stages 3+4 Mature	Stage 5 Spawning	Stages 6+7 Spent
Jan	0.39	0.57	0.01	0.04
Feb	0.45	0.36	0.12	0.07
Mar	0.43	0.27	0.05	0.26
Apr	0.56	0.07	0.02	0.34
May	0.58	0.10	0.00	0.32
Jun	0.49	0.19	0.33	0.00
Jul	0.37	0.44	0.19	0.00
Aug	0.30	0.46	0.24	0.00
Sep	0.40	0.46	0.00	0.14
Oct	0.51	0.47	0.02	0.00
Nov	0.20	0.74	0.00	0.05
Dec	0.31	0.64	0.05	0.00

Table C.10. Summary of data used to estimate the female proportion mature used in the catch-age model. Stages 1 and 2 were assumed to be immature fish and all other staged fish (stages 3 to 7) were assumed to be mature (Table C.9). Only ages with at least 10 staged observed fish sampled from January to June were used. The observed proportions and the fitted model are plotted in Figure C.18.

Age	Number ages	Mean length (cm) immature	Mean length (cm) mature	Observed prop. immature	Observed prop. mature	Fitted prop. mature	Model prop. mature
3	17	18.7	–	1.000	0.000	0.014	0.000
4	24	21.6	–	1.000	0.000	0.022	0.000
5	15	26.5	–	1.000	0.000	0.034	0.000
6	13	32.0	–	1.000	0.000	0.051	0.000
7	35	35.1	39.0	0.971	0.029	0.074	0.029
8	58	37.9	45.0	0.931	0.069	0.106	0.069
9	64	40.8	43.0	0.906	0.094	0.147	0.094
10	109	43.7	48.6	0.817	0.183	0.199	0.199
11	147	45.6	48.3	0.810	0.190	0.261	0.261
12	174	47.6	50.5	0.626	0.374	0.336	0.336
13	197	48.4	51.2	0.533	0.467	0.420	0.420
14	158	49.6	51.3	0.399	0.601	0.512	0.512
15	137	49.7	52.6	0.328	0.672	0.609	0.609
16	96	49.9	53.7	0.250	0.750	0.705	0.705
17	81	51.6	53.4	0.247	0.753	0.796	0.796
18	73	52.3	54.2	0.123	0.877	0.876	0.876
19	39	54.0	55.5	0.128	0.872	0.939	0.939
20	48	51.4	55.1	0.188	0.813	0.981	0.981
21	30	53.3	55.6	0.200	0.800	0.999	0.999
22	24	50.5	55.9	0.167	0.833	1.000	1.000
23	17	53.5	55.5	0.235	0.765	1.000	1.000

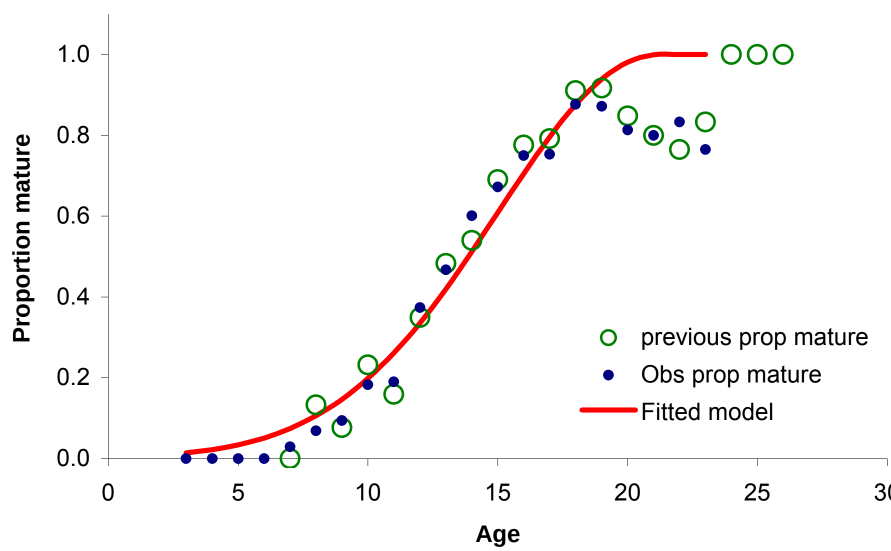

Figure C.18. Three estimates of the proportion of mature females: 1) calculated by Stanley et al. (2005); 2) observed from the available data Table C.11); 3) a double normal curve fitted to the observed proportions in Table C.11).

APPENDIX D. WEST COAST VANCOUVER ISLAND SHRIMP TRAWL SURVEY

Data selection

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

These survey data were analysed following the recommendations made by Starr and Sinclair (2002) in their re-analysis of the data from the same survey for WCVI Pacific cod, with some modifications. These recommendations and modifications include:

- post-stratifying the data into two areas, Areas 124 and 125 (Figure D.1) because these are the areas that have been monitored the most consistently over the history of the survey. The main modifications applied included dropping some tows which occurred in the most northerly part of Area 125 in 1975 and 1976 because these tows were not repeated in later surveys.

- moving tows east of the longitude 125° 54' from Area 124 to 123 as these tows were made in inshore waters and were spatially more closely associated with Area 123.

- only using tows made by the following vessels: *G.B. Reed*, *Ricker*, *Sharlene K*. and the *Frosti* (Table D.1). The latter two vessels are included because they are the only vessels which operated in 1989 and 2005 respectively. This vessel selection also rules out tows made in September 1977 and September 1978 which appear to be outside the scope of this survey.

The number of tows available for use in the analysis and the area weights in square kilometres for the defined strata are presented in Table D.2. There are almost no tows at depths shallower than 100 m in Area 125 (Figure D.2) although there is reasonable coverage in the 80-100 m depth zone in Area 124. Coverage is continuous in all survey years up to the 140-160 m depth zone in both of the area strata, but the coverage in the 160-180 m depth zone is sporadic in many of the survey years. This analysis used 80 m to 160 m as the depth range for all survey years. This should not affect the comparability of Area 125 because there is a consistent lack of tows in depths less than 100 m across all surveys (Figure D.2). Stratum area weights were used which reflect the reduced area associated with the truncated depth range.
No tows were recorded in Area 125 for the 1989 and 1991 survey years (Table D.2). The catch rates estimated for Area 124 were also applied to the Area 125 stratum to ensure that the indices for these survey years were comparable to the indices in the years when Area 125 was surveyed.

Table D.1. Number of sets made by each vessel involved in the west coast Vancouver Island shrimp trawl by month and survey year. All sets south of 50°N are included, not just sets used in the analysis.

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

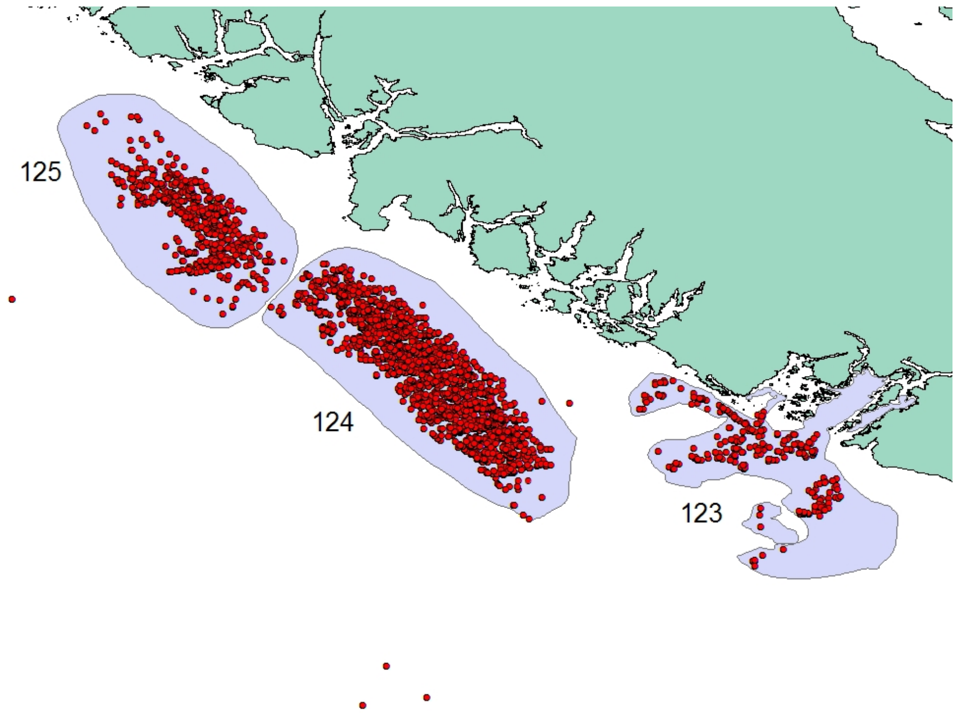

Figure D.1. Map of the locations of all trawls in areas 123, 124 and 125 that were associated with the WCVI shrimp trawl survey. Areas 124 and 125 are the strata that have been surveyed consistently over the history of the survey and which are in locations most likely to catch canary rockfish.

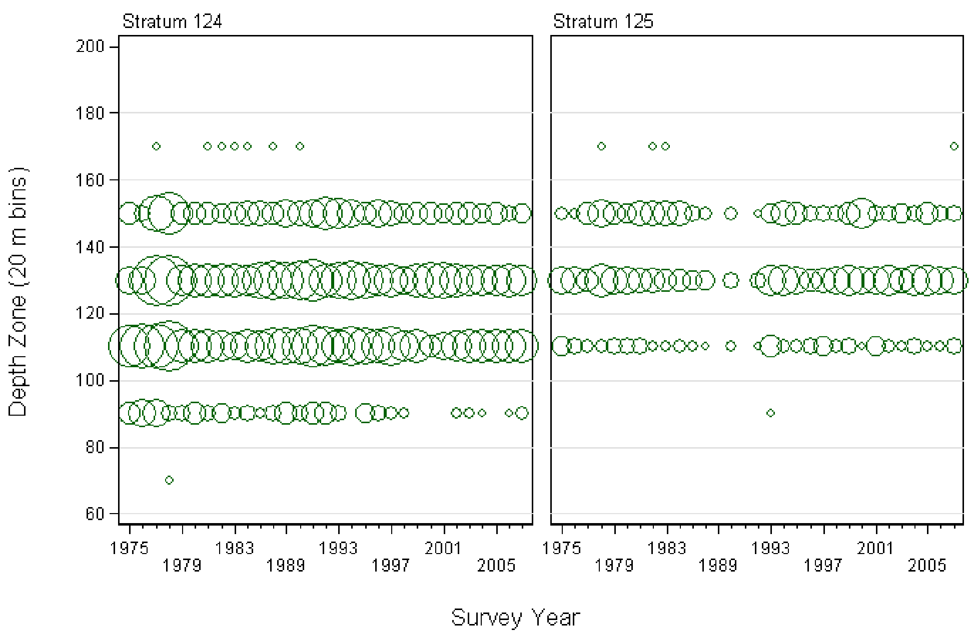

Figure D.2. Distribution of tows in 20 m depth zones by survey year and area stratum for all tows. Each 20 m depth bin is indicated by the mid-point of the bin (i.e.: 110 m= 100-120 m). Tow depth determined by the start depth. Circles are weighted by the number of sets observed in each depth bin. Maximum circle size: stratum 124=48 tows and stratum 125=20 tows, both in the 130 m depth bin.

Methods

These data were analysed using the following equations which assume that tow locations were selected randomly within a stratum relative to the biomass of canary rockfish. This was not an assumption made by the original survey design and the area stratification definition in Figure D.1 was not used when conducting the survey. The original survey design used latitudinal transects and selected the stations randomly along the transect. The biomass in any year *y* was obtained by summing the product of the CPUE and the area surveyed across the surveyed strata *i*:

Eq. D.1 $$B_y = \sum_{i=1}^{k} C_{y_i} A_i = \sum_{i=1}^{k} B_{y_i}$$

where C_{y_i} = mean CPUE density (kg/km^2) for species *s* in stratum *i*

A_i = area of stratum *i* (km^2), and

B_{y_i} = biomass of canary rockfish in stratum *i* for year *y*.

k = number of strata

CPUE $\left(C_{y_i}\right)$ for canary rockfish in stratum *i* for year *y* was calculated as a density in kg/km^2 by

Eq. D.2 $$C_{y_i} = \frac{\sum_{j=1}^{n_{y_i}} \left(W_{y_i j} \big/ D_{y_i j} w_{y_i j} \right)}{n_{y_i}}$$

where $W_{y_i j}$ = catch weight (kg) for canary rockfish in stratum *i* for year *y* and tow *j*

$D_{y_i j}$ = distance travelled (km) by tow *j* in stratum *i* for year *y*

$w_{y_i j}$ = net opening (km) by tow *j* in stratum *i* for year *y*

n_{y_i} = number of tows in stratum *i*

The variance of the survey biomass estimate V_y for canary rockfish in year *y* is calculated in kg^2 as follows:

Eq. D.3 $$V_y = \sum_{i=1}^{k} \sigma_{y_i}^2 A_i^2 \big/ n_{y_i} = \sum_{i=1}^{k} V_{y_i}$$

where $\sigma_{y_i}^2$ = variance of CPUE (kg^2/km^4) for species *s* in stratum *i*

V_{y_i} = variance of canary rockfish in stratum *i* for year *y*

The CV for canary rockfish for each year *y* was calculated as follows:

Eq. D.4 $$CV_y = \frac{\sqrt{V_y}}{B_y}$$

One thousand bootstrap replicates with replacement were made on the survey data to estimate bias corrected 95% confidence regions for each survey year (Efron 1982).

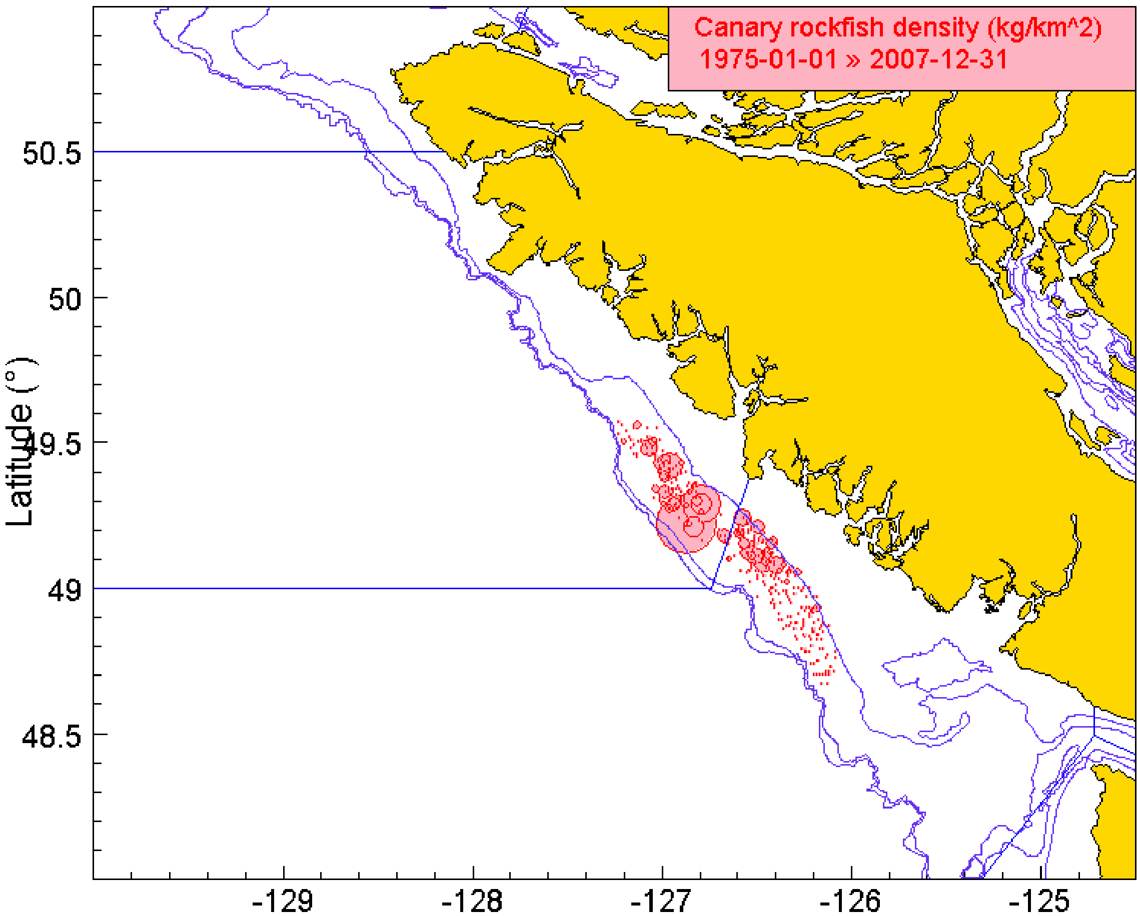

Figure D.3. Map of the locations of all trawls from the WCVI shrimp trawl survey (1975–2007) which caught canary rockfish. Circles are proportional to catch density (largest circle=128 kg/km^2). Also shown are the 100, 200 and 300 m isobaths and the PMFC major area boundaries for Areas 123 and 124.

Table D.2. List of tows used from the WCVI shrimp trawl survey by survey year and stratum, including the number and weight of canary rockfish for tows dropped from the analysis and tows shifted from 124 to 123. All tows with starting depths >160 m have been excluded.

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

[1] Area out to 160 m maximum depth

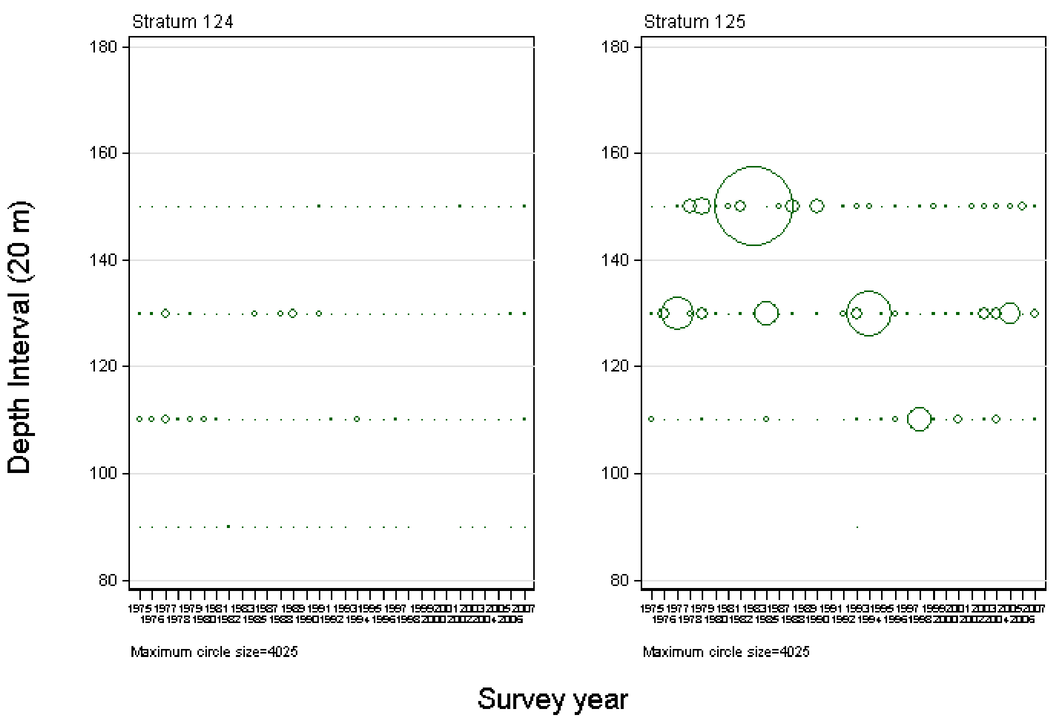

Figure D.4. Distribution of catch weight of canary rockfish by stratum (Table D.2), survey year and 20 m depth zone. Depth zones are indicated by the centre of the depth interval. Minimum depth observed for canary rockfish: 91 m; maximum depth observed for canary rockfish: 164 m. Depth is the start depth for the tow.

Results

Catches of canary rockfish have been recorded along the shelf for the full range of the usable tows, with greater apparent abundance in Area 125 relative to Area 124 (Figure 11). The distribution of canary rockfish catches by depth is concentrated between 100 and 160 m (Figure D.4). Estimated biomass levels for canary rockfish from the WCVI shrimp trawl survey appear to have been relatively consistent throughout the history of this survey, with the exception of some years with high biomass estimates associated with high levels of relative error (e.g. 1977, 1983, 1994; Figure D.5; Table D.3). The incidence of canary rockfish is relatively common, but variable, in this survey (Figure D.6). The incidence of tows with canary in Stratum 125 (32%) is nearly twice as high as in Stratum 124 (18%) over the 31 survey years.

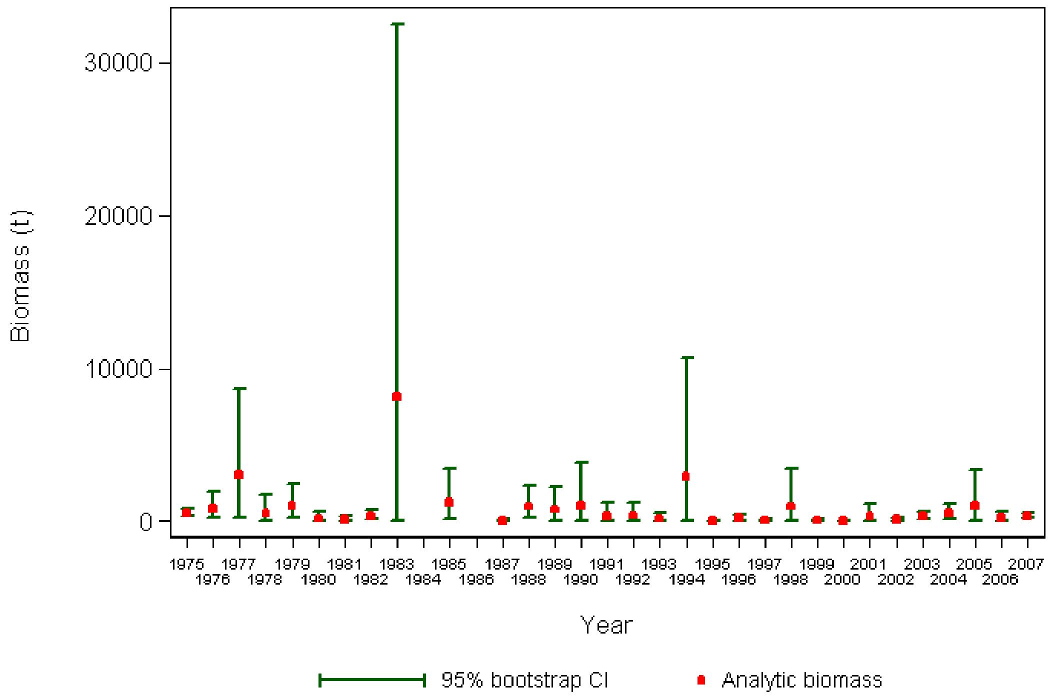

Figure D.5. Plot of biomass estimates for canary rockfish from the WCVI shrimp trawl survey for the period 1975 to 2007 with bias corrected 95% confidence intervals from 1000 bootstrap replicates.

Table D.3. Biomass estimates for canary rockfish from the WCVI shrimp trawl survey for the survey years 1975 to 2007. Biomass estimates are based on a post-stratification of this survey into two strata (Figure D.1) and by assuming that the survey tows were randomly selected within these areas. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement. The analytic CV (Eq. D.4) 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 (Eq. D.4)
1975	557	557	330	830	0.230	0.237
1976	827	812	237	1,985	0.515	0.525
1977	3,016	3,144	201	8,623	0.667	0.666
1978	552	556	45	1,729	0.778	0.820
1979	1,030	1,014	239	2,444	0.517	0.544
1980	208	208	35	667	0.754	0.745
1981	158	157	36	367	0.532	0.542
1982	340	342	110	719	0.450	0.446
1983	8,139	8,483	17	32,461	0.983	0.996
1985	1,223	1,198	189	3,408	0.676	0.669
1987	69	71	6	188	0.684	0.696
1988	988	974	239	2,388	0.526	0.531
1989	799	810	61	2,265	0.695	0.704
1990	1,040	1,072	45	3,837	0.919	0.911
1991	366	368	40	1,243	0.806	0.881
1992	392	408	18	1,232	0.792	0.791
1993	192	192	40	523	0.594	0.587
1994	2,970	2,983	76	10,701	0.916	0.894
1995	39	39	8	85	0.484	0.490
1996	222	222	72	428	0.419	0.433
1997	82	82	30	156	0.381	0.387
1998	977	965	5	3,445	0.957	0.985
1999	81	80	44	137	0.291	0.299
2000	29	29	11	54	0.375	0.376
2001	311	312	23	1,133	0.880	0.869
2002	138	140	67	236	0.307	0.313
2003	321	324	150	614	0.359	0.381
2004	548	542	174	1,145	0.435	0.444
2005	1,010	991	77	3,321	0.886	0.881
2006	259	255	43	662	0.572	0.575
2007	320	319	218	503	0.217	0.220

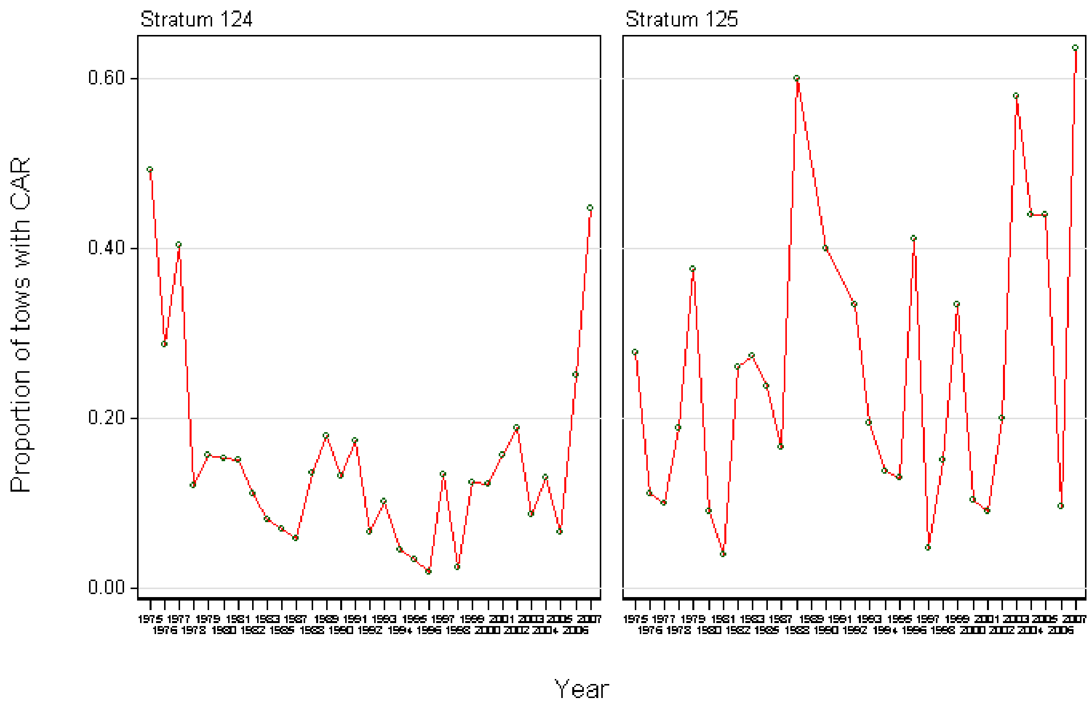

Figure D.6. Proportion of tows by stratum and year which contain canary rockfish for the WCVI shrimp trawl survey.

APPENDIX E. QUEEN CHARLOTTE SOUND SHRIMP TRAWL SURVEY

Data selection

This survey covers the lower half of QCSd extending westward from Calvert Island and Rivers Inlet into Goose Island Gully (Figure 19). There is also a stratum providing coverage between Calvert Island and the mainland. Five vessels took part in the first year (1998) and the timing in that year was slightly later than in subsequent years (Table E.1). It was decided to discard this survey year, given the exploratory nature of the first survey year and that five different vessels collected the data. Subsequent to that year, the survey has been conducted routinely by the CCGS W.E.Ricker (except in 2005 when the *Frosti* was used) in April or May and all years are reported. The survey is divided into three aerial strata: stratum 109 lying to the west of the outside islands and extending into Goose Island Gully; stratum 110 lying to the south of Calvert Island and stratum 111 lying between Calvert Island and the mainland (Figure 19). Stratum 111 has been discarded as its location is not considered good habitat for rockfish species and no canary rockfish has ever been taken in that stratum. The majority of tows occur in the larger of the two remaining strata (109) while only a few are placed in Stratum 110 (Table E.2). Only tows with usability codes of 1 (useable), 2 (fail, but all data useable), and 6 (gear torn, but all data useable) were included in the biomass estimate. Over 600 useable tows have been conducted by this survey over the nine available survey years (Table E.2).

Table E.1. Number of sets made by each vessel involved in the QCSd shrimp trawl by month and survey year. All QCSd sets are included, not just sets used in the analysis.

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

As described in Appendix D, a doorspread density value (catch density based on area covered between the trawl doors) was generated for each tow based on the catch of canary rockfish, an arbitrary doorspread (25 m) for the tow, and the distance travelled. The distance travelled was determined at the time of the tow, based on the bottom contact time (J. Boutillier, pers. comm.). The two missing values for this field were filled in by multiplying the vessel speed and the tow time. All tows were used regardless of depth because this survey, unlike the WCVI shrimp survey, has consistently sampled depths up to about 220 m (Figure E.2). Thus, there was no need to truncate the tows at depth to ensure comparability across survey years.

Table E.2. Stratum designations, area covered, and number of useable tows, for the QCSd shrimp survey from 1999 to 2007.

	Stratum		
Survey year	**109**	**110**	**Total**
1999	72	10	82
2000	76	8	84
2001	65	7	72
2002	65	7	72
2003	57	6	63
2004	59	6	65
2005	41	6	47
2006	61	6	67
2007	60	5	65
Total	556	61	617
Area (km^2)	2,142	159	2,301

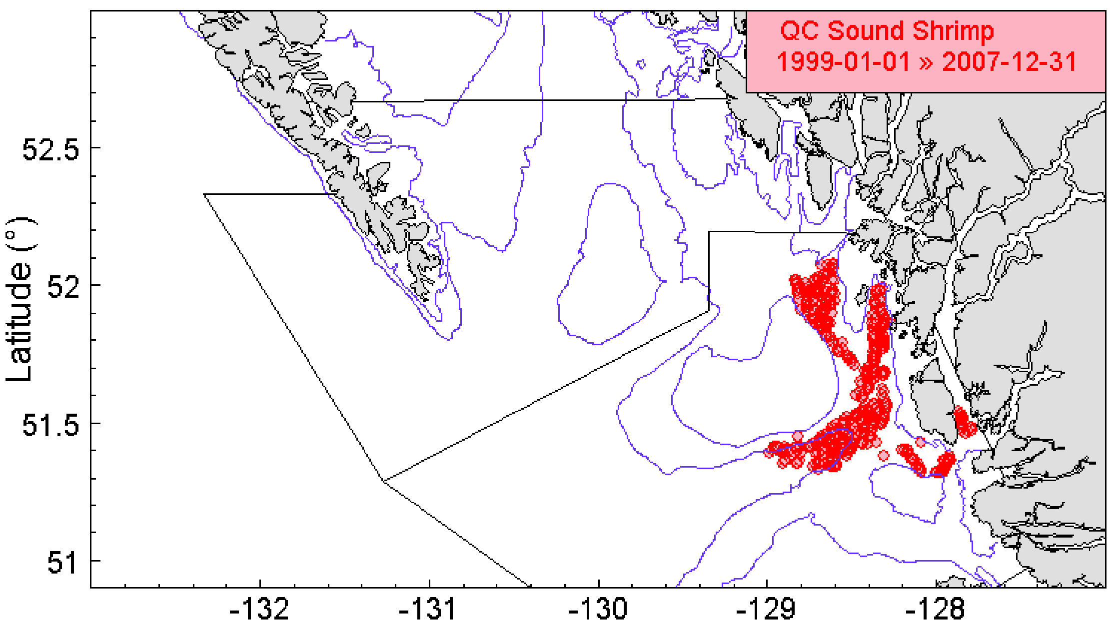

Figure E.1. Map showing the locations of valid tows (Stratum numbers 109, 110, 111) conducted by the QCSd shrimp survey over the period 1999 to 2007. The tows on the inside of Calvert Island represent Stratum 111 which was not used in the analysis of this survey for canary rockfish.

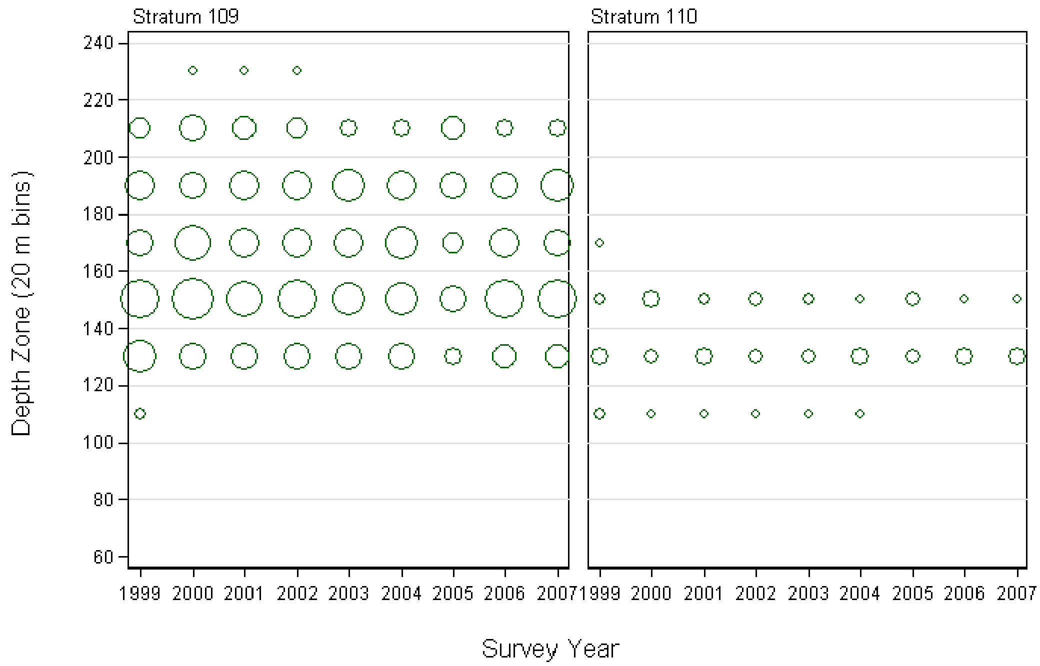

Figure E.2. Distribution of tows by stratum, survey year and 20 m depth zone. Depth zones are indicated by the centre of the depth interval, weighted by the number of tows. Maximum circle size: Stratum 109=26 tows (150 m bin); Stratum 110=5 tows (130 m bin). Depth is the mean of the start and end depths for the tow.

Methods and Results

Catches of canary rockfish tend to be distributed along the trench of Goose Island Gully and along the shelf edge of the outside islands (Figure E.1). Canary rockfish were mainly taken at depths from 130 to 190 m and very few canaries were taken in Stratum 110 at any depth (Figure E.4).

Estimated biomass levels for canary rockfish from the QC Sound shrimp trawl survey are relatively small and variable (Figure E.5, Table E.3). There are a few years with higher levels of biomass (2002, 2003 and 2005) but all years have high levels of variability, with CVs ranging between 36% and 102%. The proportion of tows which took canary rockfish is consistently low in Stratum 109, with values from 2-10% of the tows containing canaries (Figure E.6). There are usually less than 10 tows in Stratum 110 (and this stratum tends to sample more shallow depths (Figure E.2). Therefore, it is unlikely that this stratum will provide much useful information for this species, as demonstrated by the substantial variability in the proportion of non-zero tows (Figure E.6).

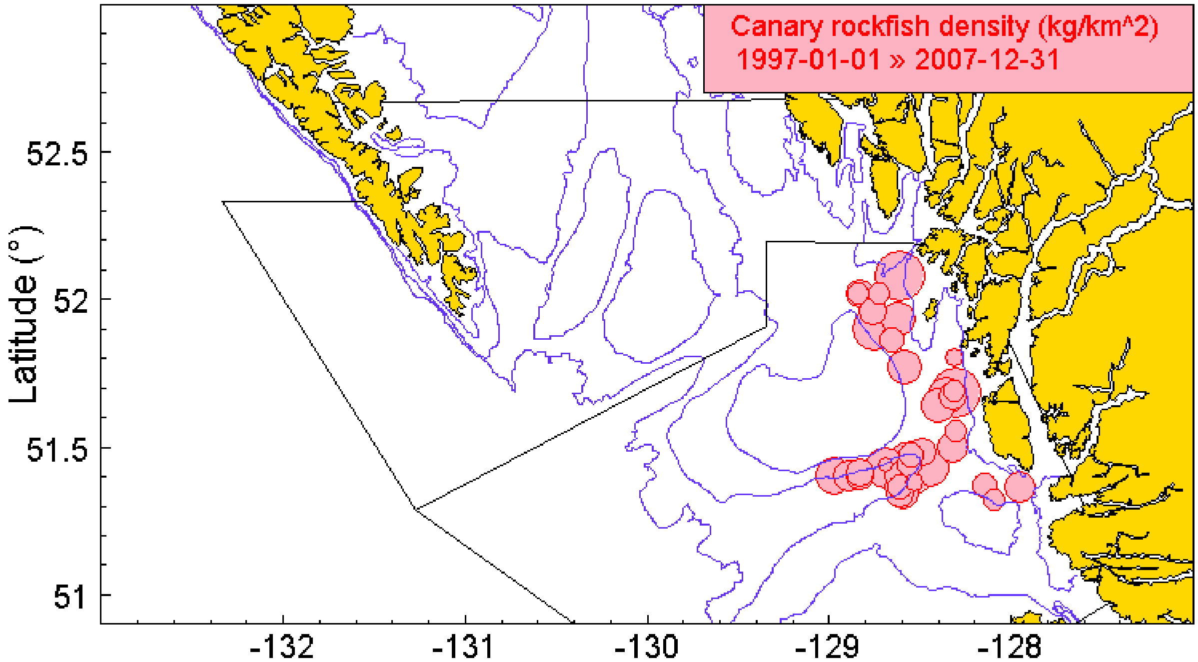

Figure E.3. Map of the locations of all trawls from the QCSd shrimp trawl survey (1999–2007) which caught canary rockfish. Circles are proportional to catch density (largest circle=0.14 kg/km^2). Also shown are the 100, 200 and 300 m isobaths and the area stratum boundaries for the QCSd groundfish synoptic survey.

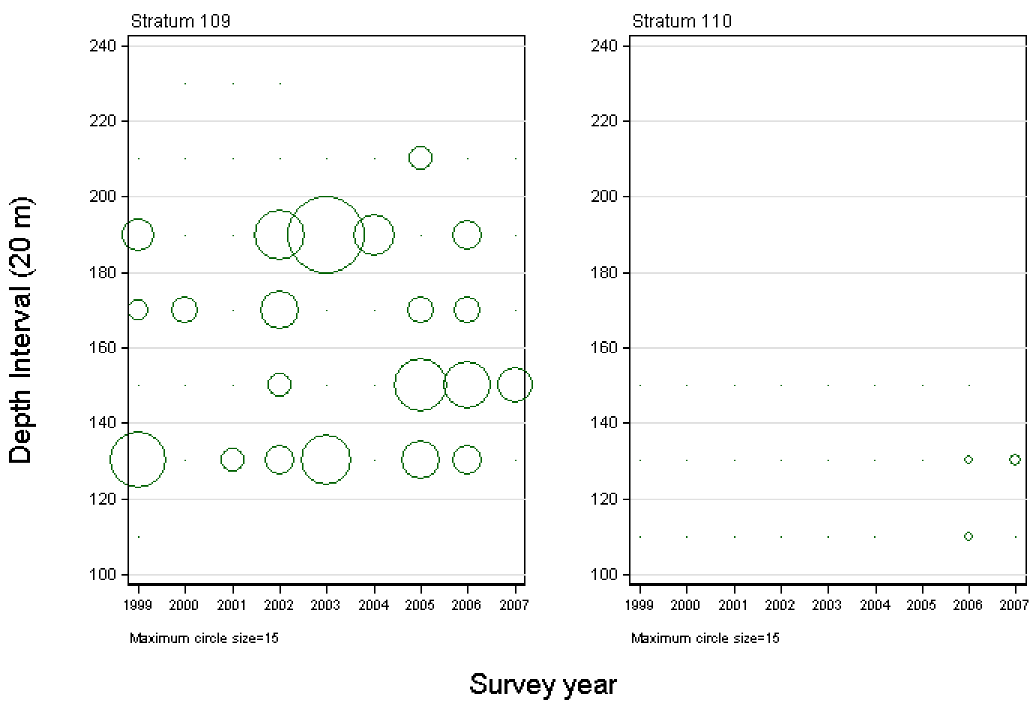

Figure E.4. Distribution of catch weight of canary rockfish by stratum (Table E.2), survey year and 20 m depth zone. Depth zones are indicated by the centre of the depth interval. Maximum circle size: Stratum 109=15 kg (190 m bin). Minimum depth observed for canary rockfish: 120 m; maximum depth observed for canary rockfish: 210 m. Depth is the mean of the start and end depths for the tow.

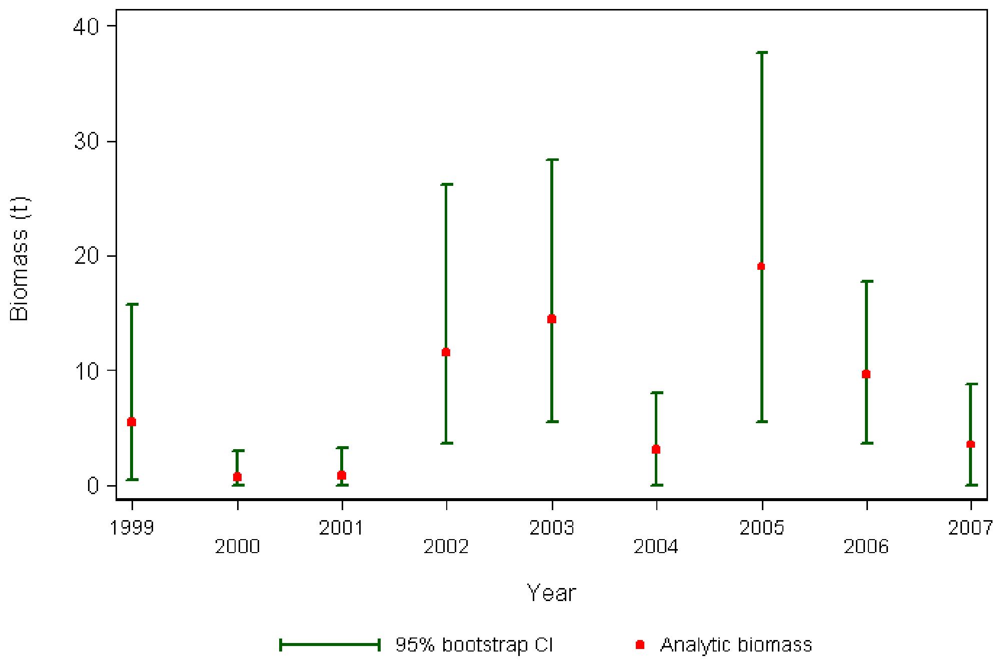

Figure E.5. Plot of biomass estimates for canary rockfish from the QCSd shrimp trawl survey for 1999 to 2007. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

Table E.3. Biomass estimates for canary rockfish from the QCSd shrimp trawl survey for the survey years 1999 to 2007. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement. 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 (Eq. D.4)**
1999	5.5	5.6	0.5	15.7	0.681	0.691
2000	0.7	0.7	0.0	3.0	1.019	1.000
2001	0.8	0.9	0.0	3.3	0.968	1.000
2002	11.5	11.5	3.6	26.2	0.467	0.483
2003	14.4	14.1	5.5	28.3	0.385	0.397
2004	3.1	3.1	0.0	8.0	0.681	0.701
2005	19.0	18.6	5.5	37.6	0.441	0.446
2006	9.6	9.6	3.5	17.7	0.365	0.384
2007	3.5	3.5	0.0	8.8	0.605	0.601

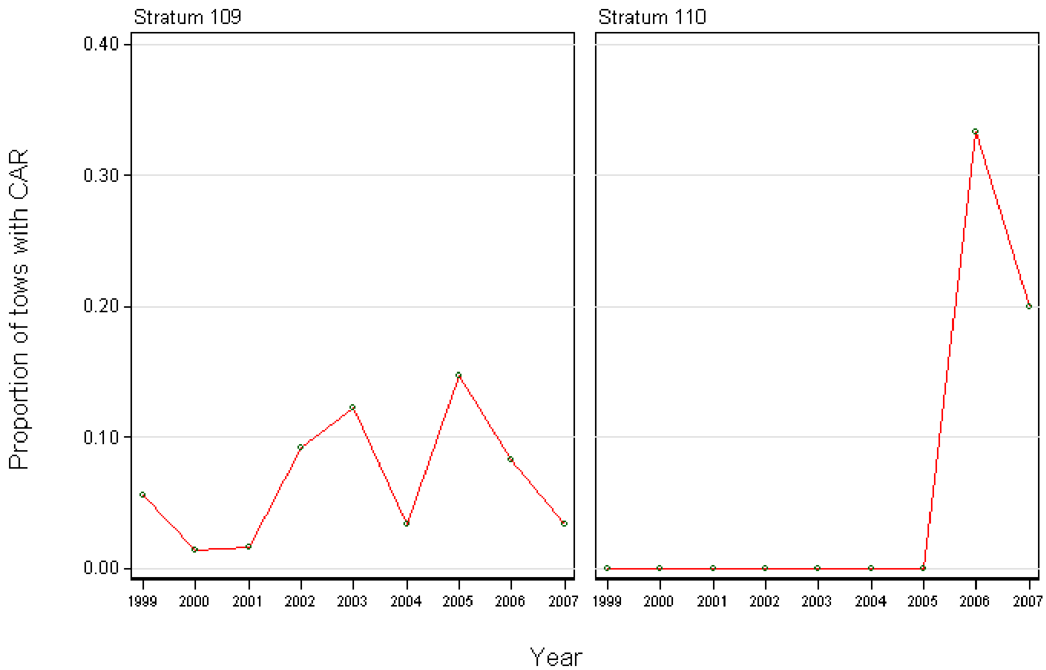

Figure E.6. Proportion of tows by stratum and year which contain canary rockfish for the QCSd shrimp trawl survey.

APPENDIX F. GB REED HISTORICAL TRAWL SURVEYS

Data selection

Tow-by-tow data from a series of FRV *G.B. Reed* historical trawl surveys were available for 9 years spanning the period from 1965 to 1984. However, the first two surveys, in 1965 and 1966, were quite wide ranging, with the 1965 survey extending from near San Francisco to halfway up the Alaskan panhandle (Figure F.1:left panel). The 1966 survey was only slightly less ambitious, ranging from the southern US-Canada border in Juan de Fuca Strait into the Alaskan panhandle (Figure F.1: right panel). It was decided that the implicit design of these two surveys was likely to have been exploratory and that these surveys would not be comparable to the seven subsequent surveys which were much narrower in scope. The 1967 (Figure F.2: left panel) and 1969 (Figure F.2:centre panel) surveys had tows on the west coast of Vancouver Island, the Queen Charlotte Islands and SE Alaska, but both of these surveys had a considerable number of tows in the Goose Island Gully grounds. The 1971 survey (Figure F.2:right panel) was entirely confined to the Goose Island Gully while the following four surveys covered both Goose Island and Mitchell Gullies in QCSd (Figure F.3 and Figure F.4). On the basis of these plots, it was decided to use only the tows from the Goose Island Gully grounds for the 1967 to 1984 surveys to ensure comparability. These grounds were defined as all tows lying between 50.9°N and 51.6°N latitude (Figure F.5).

The original depth stratification of these surveys was in 20 fathom intervals, with the important strata for canary rockfish ranging from 80 fathoms (146 m) to 140 fathoms (256 m). The most shallow tows recorded for this survey were 66 and 67 m and there were only 12 tows (from a total of 497 tows) less than 146 m over the 9 surveys. About one-quarter of all tows (128 tows) were deeper than 256 m (Table F.1).

Table F.1. Number of tows, minimum, mean and maximum depths by depth interval, based on the recorded depth at the beginning of each tow over all 9 historical GB Reed surveys (1965 to 1984).

Depth interval	Mean depth (m)	Minimum depth (m)	maximum depth (m)	N depth
66-146 m	122	66	146	12
147-183 m	167	148	183	88
184-219 m	201	185	219	163
220-256 m	235	220	256	106
257-428 m	300	260	428	128
All tows	226	66	428	497

Almost all canary rockfish were taken in the central three strata, ranging from 147 m to 256 m (Table 10). Canary catches in the outermost strata were sporadic. Including these rare catches would greatly increase the associated variance of the biomass estimates; therefore, these strata were not included in the analysis of the relative biomass estimates. A total of 204 tows in Goose Island Gully were included in the analysis of these 7 historical surveys (Table 9).

Table F.2. Catch weight (kg) of canary rockfish for each of the 9 historical GB Reed surveys (1965 to 1984) by depth interval, based on the recorded depth at the beginning of each tow.

	Depth Interval					
Survey year	**66-146 m**	**147-183 m**	**184-219 m**	**220-256 m**	**257-428 m**	**All tows**
1965	5	634	38	25	0	702
1966	105	603	240	2	0	950
1967	5	33	56	2	0	96
1969		145	24	2	0	171
1971		463	57	2	0	522
1973		98	10	2	0	110
1976		55	110	9	0	174
1977	0	688	57	11	0	756
1984		97	121	6	11	235
Total	114	2,816	713	60	11	3,714

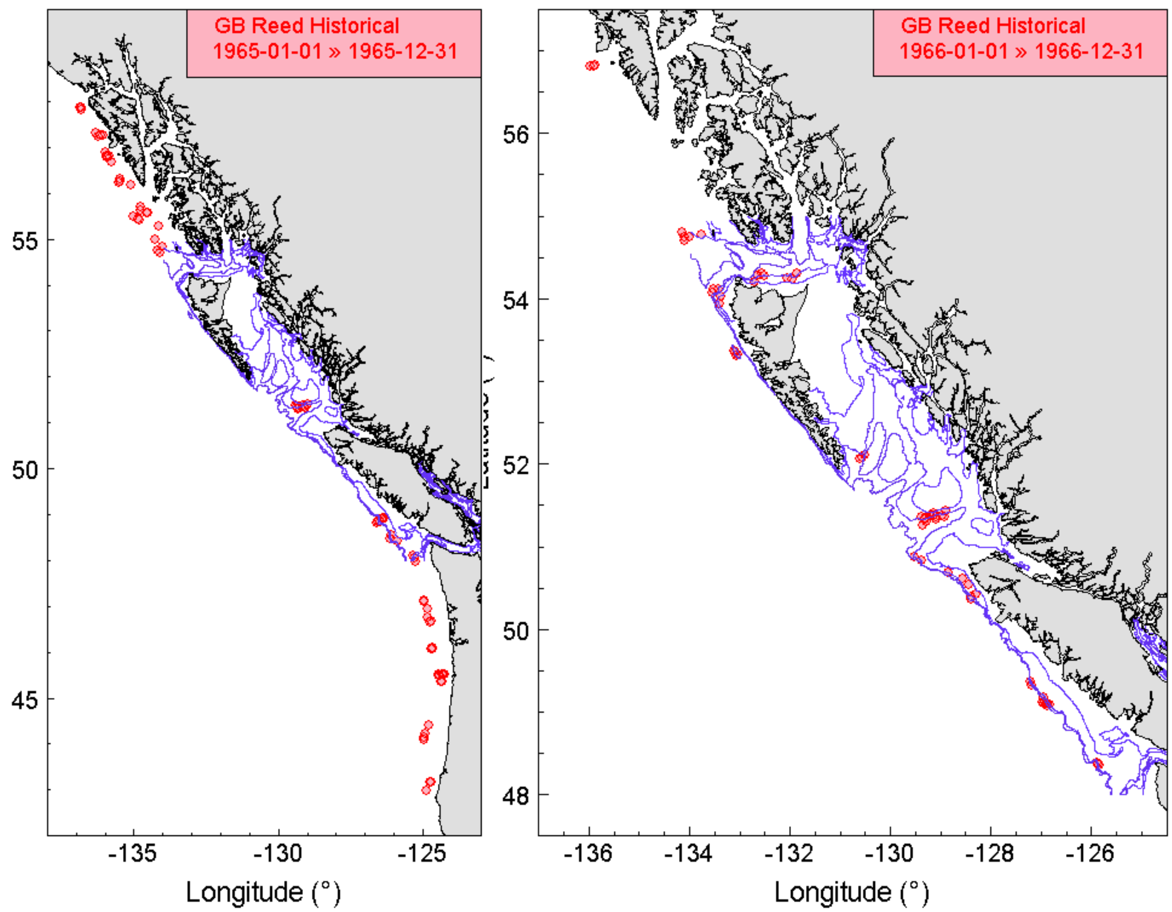

Figure F.1. Extent of the first two GB Reed surveys: [left panel] tow locations for the 1965 survey; [right panel] tow locations for the 1966 survey.

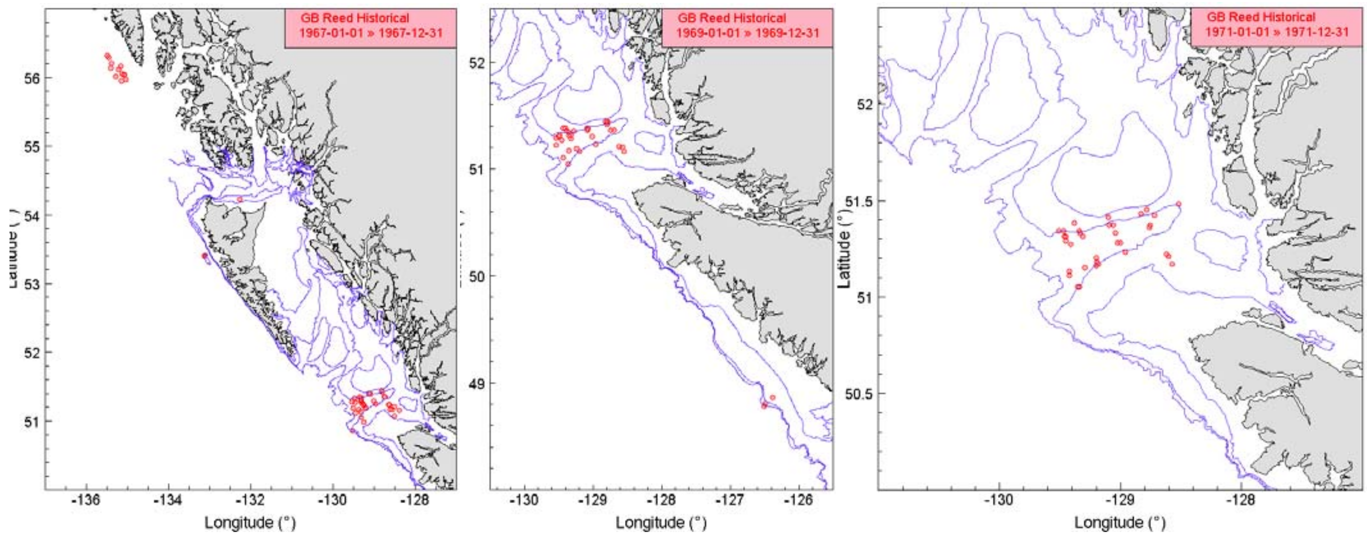

Figure F.2. Extent of the next three historical GB Reed surveys. [left panel] location of tows from the 1967 survey; [centre panel] location of tows from the 1969 survey; [right panel] location of tows from the 1971 survey.

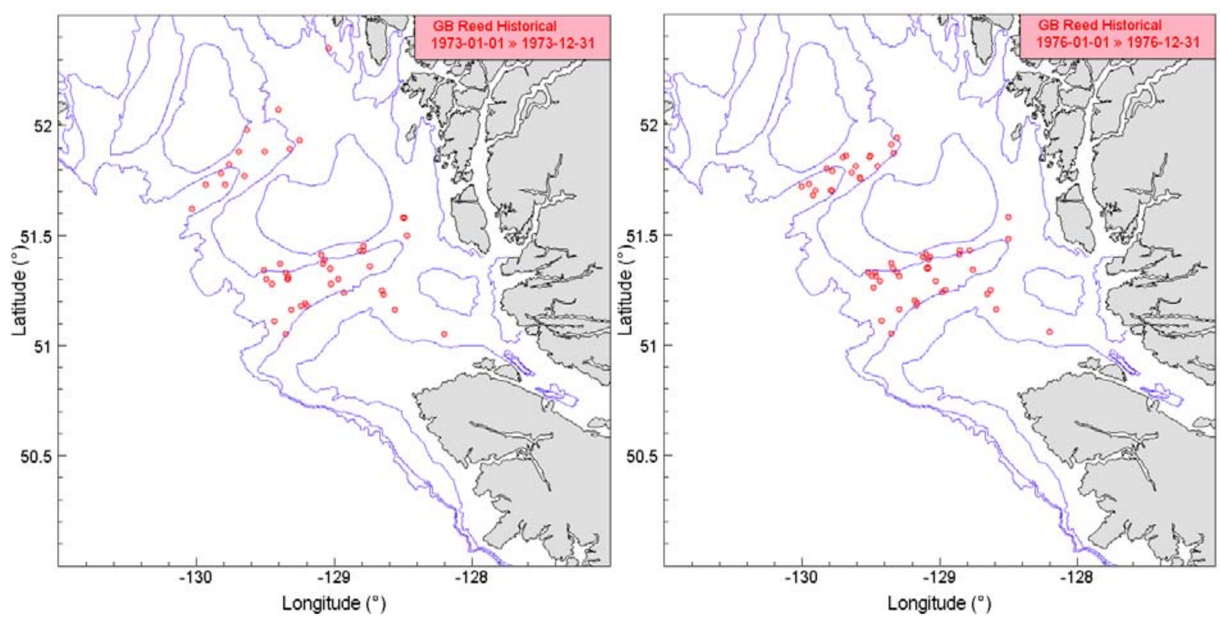

Figure F.3. Extent of the following two historical GB Reed surveys. [left panel] location of tows from the 1973 survey; [right panel] location of tows from the 1976 survey.

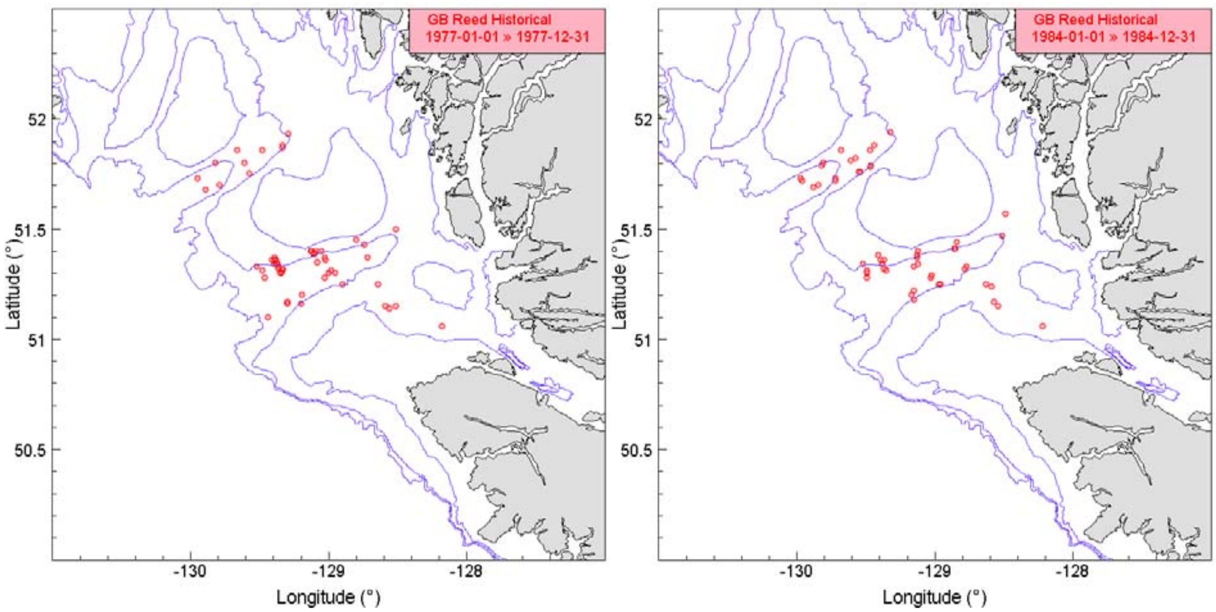

Figure F.4. Extent of the final two historical GB Reed surveys. [left panel] location of tows from the 1977 survey; [right panel] location of tows from the 1984 survey.

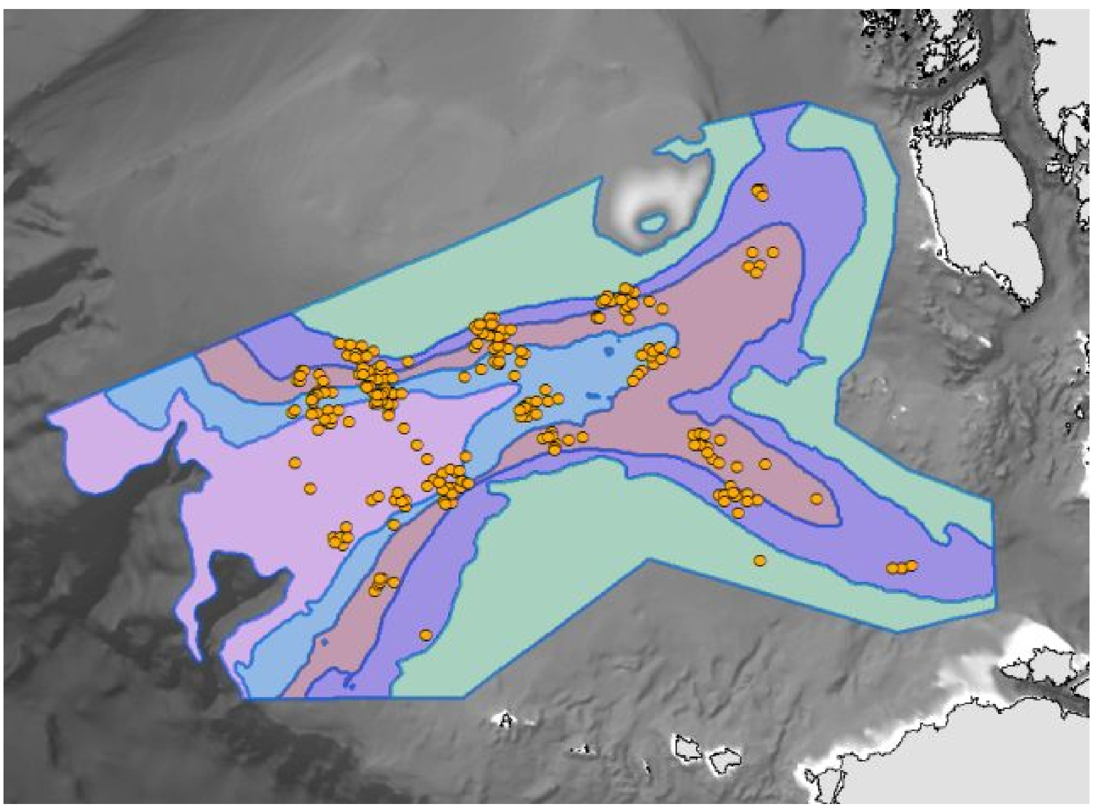

Figure F.5. The full range of selected tows for the historical GB Reed surveys, showing the stratum depth contours of 256 m (140 fathoms), 219 m (120 fathoms), 183 m (100 fathoms) and 146 m (80 fathoms). The deep edge of the survey area is 549 m (300 fathoms) and the shallow cut-off is 37 m (20 fathoms). Only the tows lying between 146 m and 256 m were used in the analysis.

Table F.3. Number of tows available for biomass estimation from the 7 historical GB Reed surveys (1967 to 1984) in Goose Island Gully by depth interval.

Survey year	147-183 m	184-219 m	220-256 m	Total
1967	6	11	5	22
1969	9	11	6	26
1971	4	15	8	27
1973	7	11	7	25
1976	7	13	8	28
1977	12	14	14	40
1984	11	15	10	36
Total	56	90	58	204

Methods

These data were analysed using the following equations which assume that tow locations were selected randomly within a stratum relative to the biomass of canary rockfish. This was not an assumption made by the original survey design and the area stratification definition in Table F.1 was not used when conducting the survey. The original survey design used latitudinal transects and selected the stations randomly along the transect. The biomass in any year *y* was obtained by summing the product of the CPUE and the area surveyed across the surveyed strata as described in appendix D.

Results

A map showing the locations where canary rockfish were caught in Goose Island Gully indicates that this species was primarily caught at the entrance to the gully (Figure 16). Estimated biomass levels in the Goose Island Gully for canary rockfish from the historical GB Reed trawl surveys appear to have been relatively constant through the 7 years of this survey, with the exception of 1971 which has a large biomass estimate associated with a very large relative error (Figure F.7). This large biomass estimate is the result of a single tow which caught 447 kg of canary, the largest single catch of this species in the 9 surveys. The 1977 survey year also has a high relative error but the biomass is somewhat lower. The proportion of tows which contain canary rockfish decreased over the first 10 years spanned by the survey, and then showed strong variability (Figure F.8). The proportion of tows which held canary is relatively high, ranging between 30 and 60%.

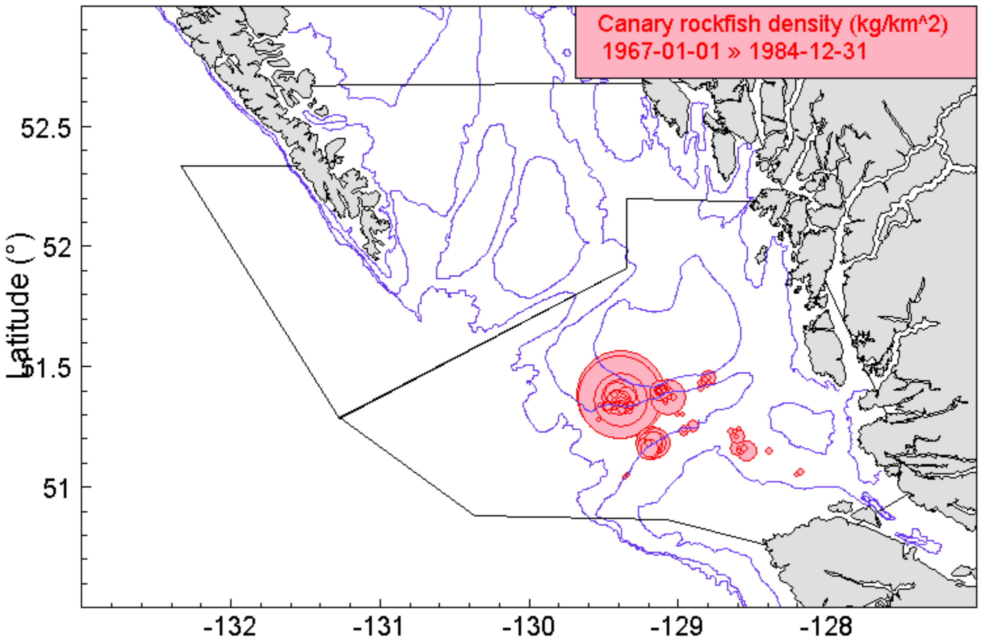

Figure F.6. Map of the locations of all trawls from the historical GB Reed trawl survey (1967–1984) which caught canary rockfish. Only tows in Goose Island Gully which were used in the biomass index calculation are shown. Circles are proportional to catch density (largest circle=2.42 kg/km^2). Also shown are the 100, 200 and 300 m isobaths.

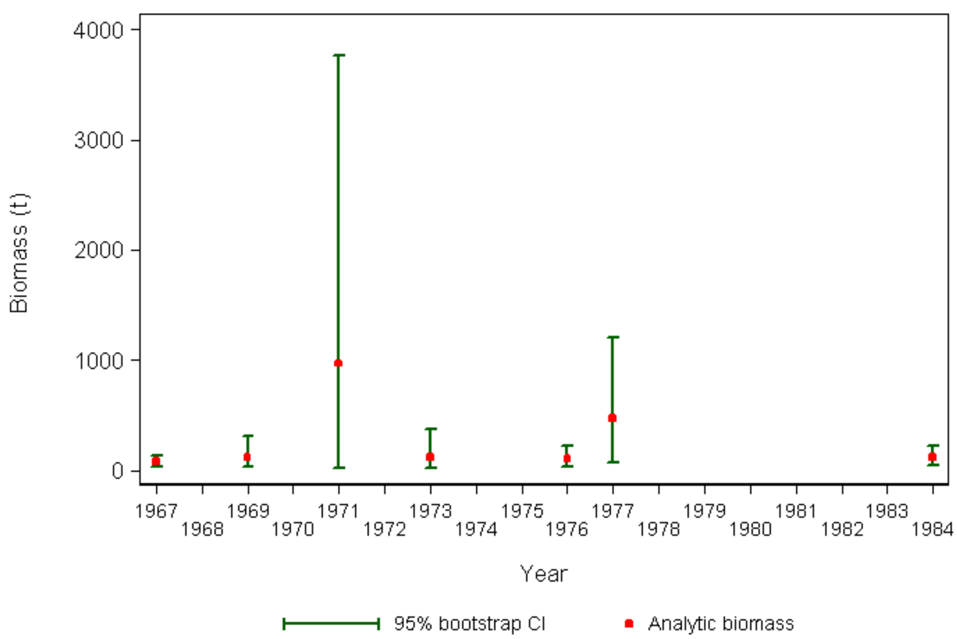

Figure F.7. Plot of biomass estimates for canary rockfish from the historical Goose Island Gully GB Reed trawl surveys for the period 1967 to 1984 with bias corrected 95% confidence intervals from 1000 bootstrap replicates.

Table F.4. Biomass estimates for canary rockfish from the historical Goose Island Gully GB Reed trawl surveys for the years 1967 to 1984. Biomass estimates are based three depth strata (Table 9) and by assuming that the survey tows were randomly selected within these areas. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement. 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 (Eq. D.4)
1967	79.4	79.1	32.5	137.0	0.342	0.354
1969	119.6	116.4	35.3	309.1	0.556	0.541
1971	973.2	964.2	24.9	3,768.2	0.954	0.956
1973	121.5	123.8	20.3	366.2	0.703	0.703
1976	110.4	110.8	34.4	222.6	0.410	0.415
1977	469.9	471.2	70.3	1,202.0	0.588	0.612
1984	120.2	121.8	49.3	216.1	0.348	0.351

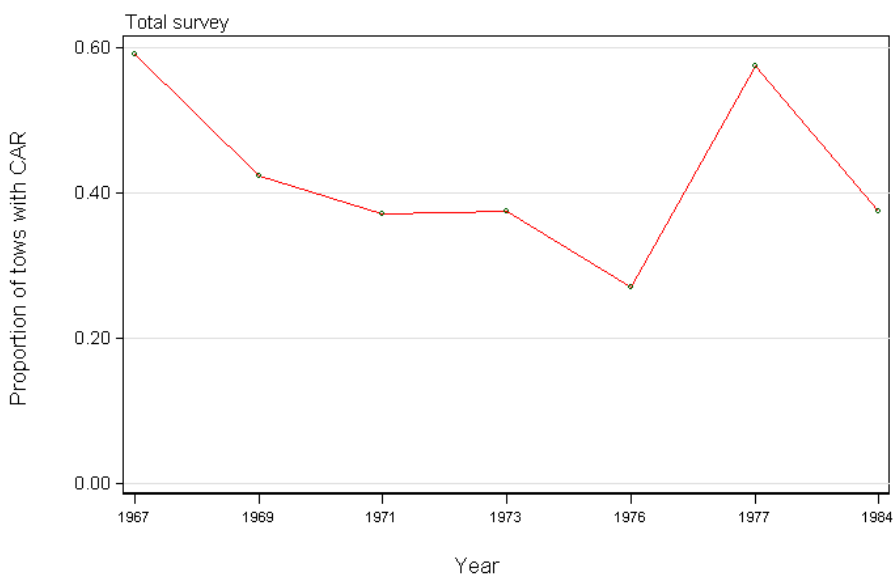

Figure F.8. Proportion of valid tows by year which contain canary rockfish from the valid Goose Island Gully tows used to analyse the historical GB Reed trawl survey.

APPENDIX G. QUEEN CHARLOTTE SOUND SYNOPTIC TRAWL SURVEY

Data Selection

This survey has been conducted in four years over the period 2003 to 2007 in Queen Charlotte Sound (QCSd) between Vancouver Island and Moresby Island and extending into the lower part of Hecate Strait between Moresby Island the mainland. It is divided into two large areal strata which roughly correspond to the DFO Regions 5A and 5B (Figure 19). Each of these two areas is divided into four depth strata: 50–120 m; 120–250 m; 250–370 m; and 370–500 m (Table G.1; Figure 19).

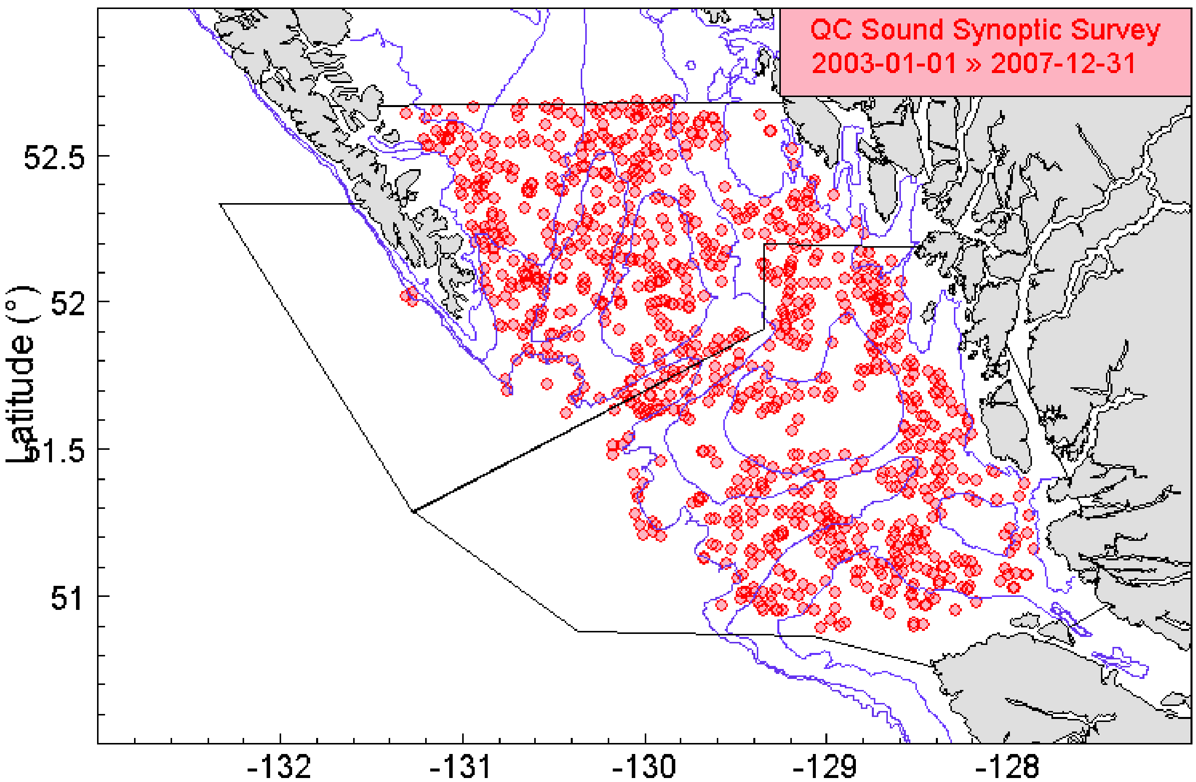

Figure G.1. Map showing the locations of valid tows conducted by the QCSd synoptic trawl survey over the period 2003 to 2007. The boundaries of the two areal strata (5AB-South and 5AB North) are shown.

A doorspread density value (catch density based on area cover between the trawl doors)) was generated for each tow based on the catch of canary rockfish, the mean doorspread for the tow and the distance travelled. The distance travelled was calculated by multiplying the mean vessel speed for the tow by the total time on the bottom as determined from the bottom contact sensor. Missing values for the doorspread field were filled in using the mean doorspread for the stratum in the survey year (26 values over all years). Missing values in the vessel speed field were filled in using the mean value for the entire survey in that year (3 values over all years). Missing values in the bottom contact time field substituted the winch time (time from winch lockup to winch retrieval; 7 values over the first three survey years and for all tows in the 2007 survey[5]). The data from the 2007 survey are preliminary and have not been subjected to the

[5] Unpublished analyses indicated that set time derived from winch lockup-retrieval provides an unbiased estimate derived from the bottom contact sensor.

same level of error checking as for the other three survey years and some fields (such as the bottom contact time field) are not available. This is because this survey was only recently completed in early August 2007 but it was considered important to include this survey observation in the modelling.

Table G.1. Stratum designations, number of useable tows, for each of the four years of the QCSd synoptic survey. Also shown is the area of each stratum.

Area name:	5AB-South				5AB-North				
Depth zone:	**50-125 m**	**125-200 m**	**200-330 m**	**330-500 m**	**50-125 m**	**125-200 m**	**200-330 m**	**330-500 m**	**Total**
Stratum no.:	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**tows**
2003	30	56	29	6	5	39	52	19	236
2004	42	49	31	8	20	38	39	7	234
2005	29	60	29	8	8	45	37	8	224
2007	32	62	23	7	19	57	48	7	255
Area (km^2)	5,334	5,873	3,134	625	2,279	4,926	4,688	1,343	28,202

Methods

These data were analysed using the following equations which assume that tow locations were selected randomly within a stratum relative to the biomass of canary rockfish. This was an assumption made by the original survey design using the area stratification definition in Figure 19 and Figure G.1. The biomass in any year *y* was obtained by summing the product of the CPUE and the area surveyed across the surveyed strata *I* as described in Appendix D.

Results

Catch densities of canary rockfish from this survey are higher in the 5AB-North areal stratum in Mitchell Gully and extending up to the northern boundary of the stratum (Figure G.1). Catch densities are lower in 5AB-South stratum (Figure G.2). Canary rockfish were mainly taken at depths from 130 to 190 m, but there are sporadic observations at depths up to about 300 m (Figure G.3).

Estimated biomass levels for canary rockfish from this trawl survey appeared to be increasing up to the 2005 survey, but the 2007 survey dropped to the lowest value in the series (Figiure G.4, Table G.2). The estimated relative errors lie between 30 and 40% with the exception of the 2005 survey where the relative error is 60% (Table G.2 and Table D.3). The proportion of tows which took canary rockfish is variable, with both areal strata showing similar trends (Figure G.5). Approximately 15-25% of the survey tows contain canary rockfish.

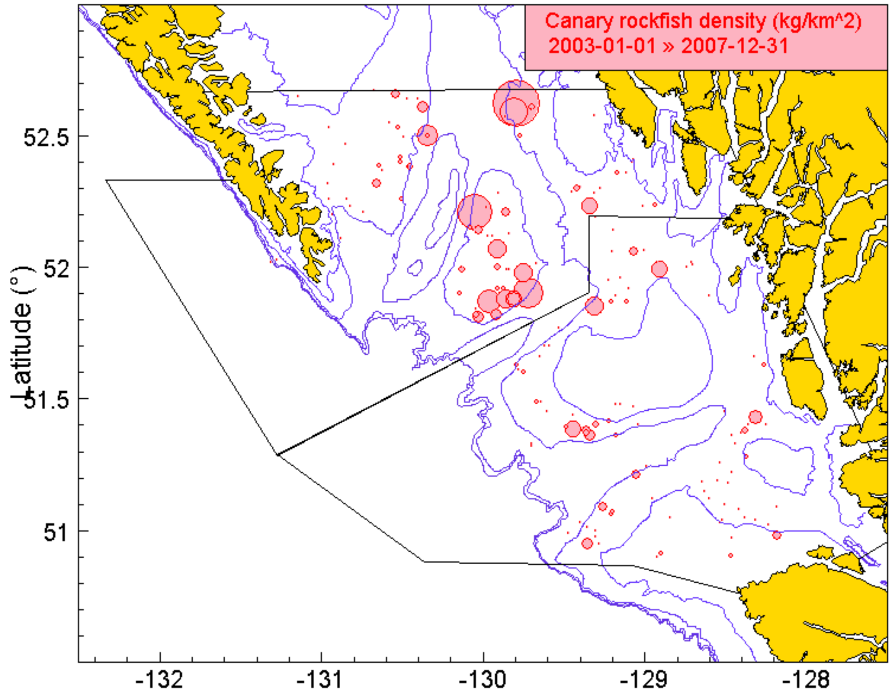

Figure G.2. Map of the locations of all trawls from the QCSd synoptic trawl survey (2003–2007) which caught canary rockfish. Circles are proportional to catch density (largest circle=8.7 kg/km^2). Also shown are the 100, 200, 300 and 400 m isobaths and the area stratum boundaries.

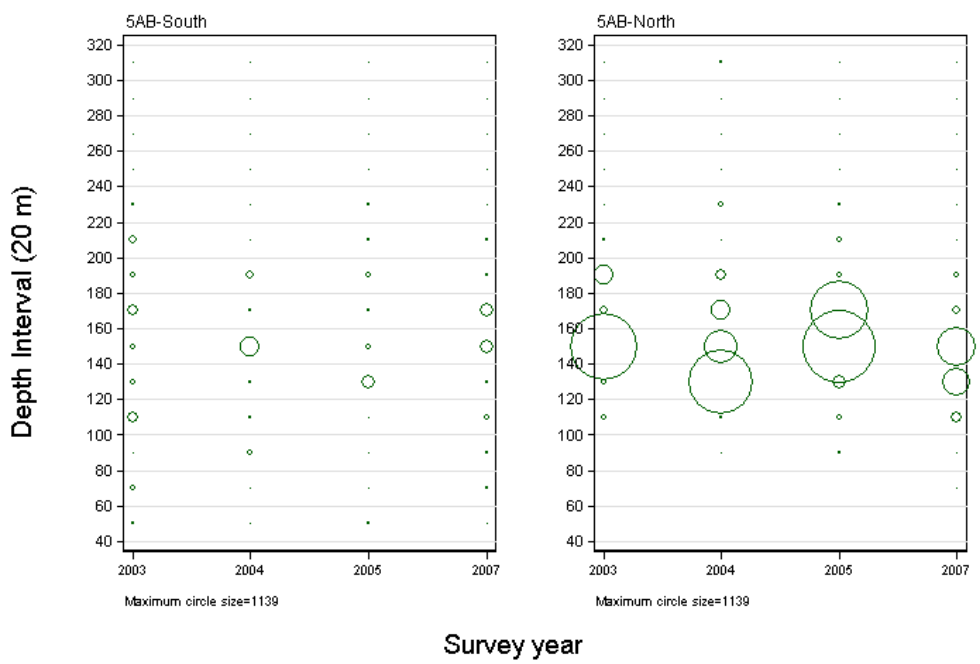

Figure G.3. Distribution of observed weights of canary rockfish by the two areal strata (Table G.1), survey year and 20 m depth zone. Depth zones are indicated by the centre of the depth interval and circles in the each panel are scaled to the maximum value in 5AB-North (1139 kg – 150 m bin). Minimum depth observed for canary rockfish: 45 m; maximum depth observed for canary rockfish: 310 m. Depth is taken at the start position for each tow.

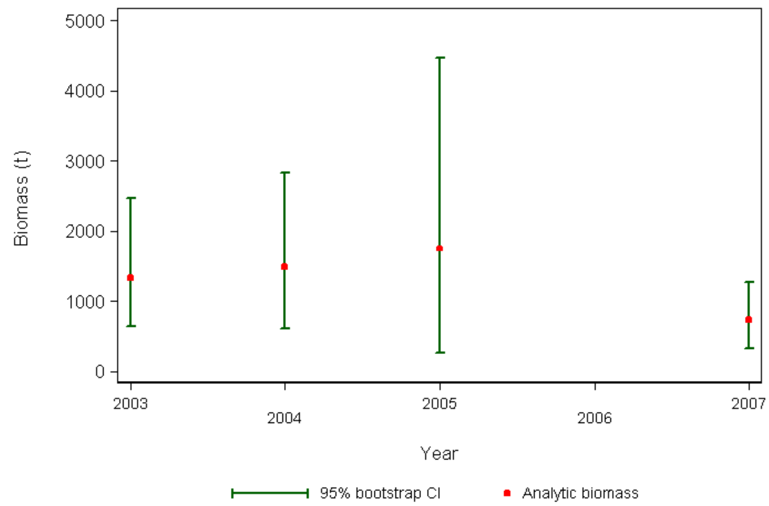

Figure G.4. Plot of biomass estimates for canary rockfish from the QCSd synoptic trawl survey for 2003 to 2007. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

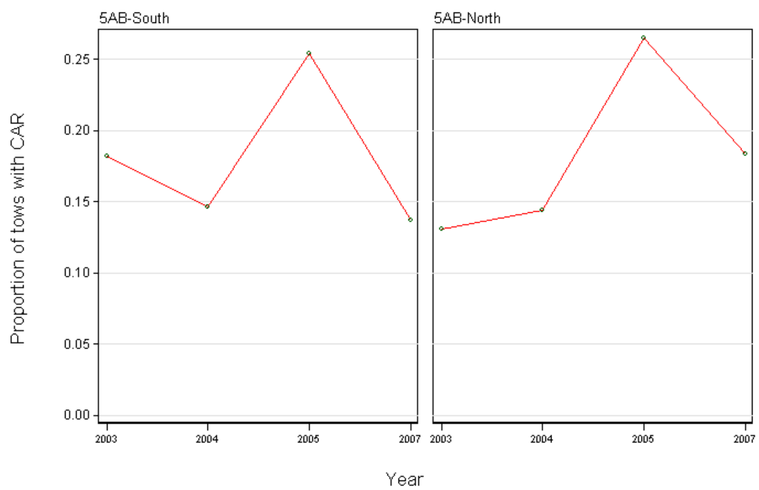

Figure G.5. Proportion of tows by stratum and year which contain canary rockfish for the QCSd synoptic trawl survey.

Table G.2. Biomass estimates for canary rockfish from the QCSd trawl survey for the survey years 2003 to 2007. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement. The analytic CV is based on the assumption of random tow selection within a stratum.

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV (Eq. D.4)
2003	1,337	1,346	635	2,464	0.335	0.346
2004	1,494	1,491	607	2,831	0.380	0.382
2005	1,748	1,833	268	4,475	0.596	0.602
2007	737	735	322	1,277	0.343	0.342

APPENDIX H. CANARY ROCKFISH CPUE ANALYSIS

Methods

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

Eq. H.1
$$U_{ijk} = U_0 \prod_i \prod_j P_{ij}^{X_{ij}} e^{\varepsilon_{ijk}}$$

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

Taking the logarithm of Eq. H.1 yields an additive linear regression model:

Eq. H.2
$$\ln U_{ijk} = \ln U_0 + \sum_{i=1}^{p} \sum_{j=1}^{n_i - 1} X_{ij} \ln P_{ij} + \varepsilon_{ijk}$$

or

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

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

The model described by Eq. H.1 and Eq. H.2 is over-parameterised and constraints must be imposed to allow estimation of model parameters. A common solution is to create a reference level by setting a factor coefficient to zero, usually the first. The remaining n_i-1 coefficients of each factor *i* represent incremental effects relative to the reference level.

The estimated factor coefficients are not unique: coefficients obtained by fixing a factor level will differ with the choice of reference level. However, the relative differences among the estimated coefficients will not be affected by the choice of constraint. Following the suggestion of Francis (1999), coefficients for factor *i* were transformed to "canonical" coefficients over all levels *j* calculated relative to their geometric mean $\bar{\beta} = \sqrt[n]{\prod_1^n \beta_j}$ (including the level where β_j=0), so that

Eq. H.3
$$\beta_j' = \beta_j / \bar{\beta}$$

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

Eq. H.4 $$b_j^{'} = \mathrm{e}^{(\beta_j - \bar{\beta})}$$

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

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

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

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

1. Calculate a regression for each predictive factor (variable) against the natural log of CPUE (kg/h).

2. Generate the Akaike Information Criterion (AIC) (Akaike 1974) and select the predictor variable that has the lowest AIC. The AIC is used for model selection to account for variables which may have equivalent explanatory power in terms of residual deviance but require fewer degrees of freedom for the model (Francis 2001).

3. Repeat Steps 1 and 2, accumulating the number of selected predictor variables and increasing the model degrees of freedom, until the increase in residual deviance (as measured by R^2) for the final iteration is less than 0.01. The selection of 0.01 as the threshold is arbitrary but adding factors which explain small amounts of the total variance has little effect on the year coefficients and other coefficients of interest.

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

Eq. H.5 $$R_j = \frac{\sum_{k=1}^{M_j} C_{jk}}{\sum_{k=1}^{M_j} E_{jk}}$$

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

Another annual index is specified by

Eq. H.6
$$U_j = \exp\left[\frac{\sum_{k=1}^{M_j} \ln\left(\frac{C_{jk}}{E_{jk}}\right)}{M_j}\right]$$

where U_j is the annual geometric mean of the CPUE observations. The resulting annual index is termed the "Unstandardised" CPUE index in this report. Annual estimates obtained using Eq. H.6 are equivalent to the results obtained from a linear model where year is the only predictive factor.

Like the scaling described for the standardised index, the series specified by Eq. H.5 and Eq. H.6 can be scaled relative to their geometric means. This is done to provide comparability with the standardised index. Given *n* years in each series, the geometric means of the arithmetic and unstandardised series are given by $\bar{R} = \sqrt[n]{\prod_{1}^{n} R_j}$ and $\bar{U} = \sqrt[n]{\prod_{1}^{n} U_j}$, respectively. Thus, each series can be scaled to the corresponding geometric mean as:

Eq. H.7
$$R_j^{'} = R_j / \bar{R}$$

and

Eq. H.8
$$U_j^{'} = U_j / \bar{U}$$

The procedures described by Eq. H.1, Eq. H.2 and Eq. H.6 are necessarily confined to the positive catch observations in the data set as $\ln(0)$ is undefined. Observations with zero catch can be handled in a number of ways:

1. Zero catch records are frequently dropped from further consideration, usually because they are not accurately recorded. This is particularly true for catch records which are maintained by fishermen who frequently discount small amounts of catch as being inconsequential.

2. A small increment can be added to the zero catch records so that ln(0) can be calculated. This is not a satisfactory solution because model parameter estimates have been shown to be sensitive to the value selected for the increment.

3. A linear regression model based on a binomial distribution and using the presence/absence of the fish species as the dependent variable can be estimated using the same data set. Explanatory factors are estimated in this model in the manner described in Eq. H.1 and Eq. H.2. Such a model will provide another series of standardised coefficients of relative annual changes that may be analogous to the series estimated from the lognormal regression, depending on whether the probability of presence/absence can be considered an index of abundance. Such an approach should only be used for data sets where zero catch records are known to have good reliability, which is not the case for the long term series presented here.

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

Eq. H.9
$$C_i = \frac{L_i}{\left(1 - P_0\left[1 - \frac{1}{B_i}\right]\right)}$$

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

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

Data selection and model specification

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

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

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

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

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

Catches

Total annual landings and discards for canary rockfish are presented by major DFO region from 1979–80 to 2006–07 (Table H.1). Landings from the PacHarvestTrawl database are considered more reliable than earlier landings from the GFCatch database as they are verified by the presence of an observer. Discard estimates are not available prior to 1996 and the establishment of the independent observer program.

The majority of canary catches have been from the west coast of Vancouver Island (Areas 3C and 3D), primarily in the northern part of the island (Area 3D). However, there have been consistent catches from QCSd (Areas 5A and 5B) and there were significant canary landings in the early 1990s in the lower part of Hecate Strait (Area 5C). Catches in Area 5E (west coast Queen Charlotte Islands) are minor (generally less than 20 t per year) with the exception of 1985–86, when over 100 t were recorded. Discards for this species are minor, with generally less than 10 t per year recorded since 1996–97 for all areas (Table H.1).

Combined Areas 3C and 3D (West coast Vancouver Island):

The depth distribution of the majority of successful catch records data ranged from about 70 m to under 400 m, with sporadic observations at deeper depths (Figure H.1). The GLM model used all valid tows occurring between 50 and 400 m.

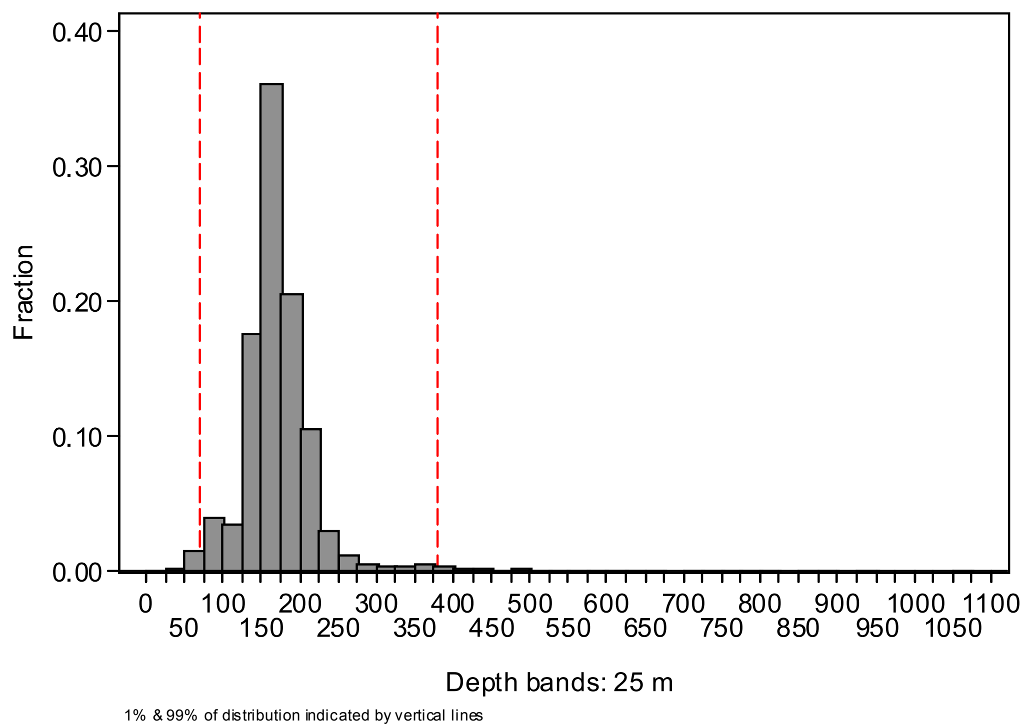

Figure H.1. Depth distribution of canary rockfish for tows with landed catch in the combined Areas 3C and 3D from 1996/97 to 2006/07 in 25 m intervals. Each bin interval is labelled with the upper bound of the interval. Vertical lines: 1%=69 m; 99%=379 m.

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

Fish. Year	3C	3D	5A	5B	5C	5D	5E	Total
Landed catch								
79/80	33.7	103.7	51.1	270.4	116.4	8.7	0.5	584.6
80/81	16.6	109.1	33.9	243.7	202.0	1.7	0.5	607.4
81/82	12.9	49.3	30.2	169.2	115.3	11.3	2.4	390.6
82/83	100.5	215.9	172.8	165.9	57.6	2.6	18.3	733.6
83/84	196.6	770.5	111.4	250.6	116.9	4.1	10.8	1461.0
84/85	274.9	965.5	241.9	282.7	68.3	4.6	12.2	1850.0
85/86	169.5	694.7	132.8	272.3	189.0	3.3	116.7	1578.4
86/87	208.4	498.2	79.4	168.8	43.5	0.9	13.8	1013.1
87/88	226.1	482.3	200.3	383.0	90.5	13.0	8.1	1403.4
88/89	503.4	552.4	170.5	421.8	86.1	2.3	76.6	1813.2
89/90	464.7	842.4	157.4	437.1	125.4	15.6	21.4	2064.0
90/91	209.6	521.5	227.1	412.5	126.6	28.0	85.1	1610.4
91/92	197.4	439.8	177.1	315.6	117.8	32.8	27.1	1307.7
92/93	284.2	496.2	185.8	197.8	100.2	17.7	35.0	1316.8
93/94	253.4	557.7	74.7	123.0	65.2	22.2	20.1	1116.4
94/95	221.7	541.8	107.0	182.1	88.7	8.7	8.7	1158.8
95/96	141.8	396.2	63.7	93.3	46.4	2.0	10.1	753.6
96/97	141.3	303.2	50.8	81.2	52.9	15.3	2.9	647.7
97/98	114.0	314.3	77.1	111.1	34.6	6.6	19.6	677.2
98/99	81.0	336.4	151.7	136.3	39.3	3.2	2.5	750.3
99/00	95.4	445.1	108.4	205.6	33.8	8.0	7.1	903.3
00/01	91.7	362.4	71.5	143.3	70.1	8.5	14.6	762.1
01/02	140.7	348.4	85.4	136.8	70.1	2.9	2.0	786.2
02/03	123.6	441.7	95.5	139.7	62.5	1.9	3.2	868.2
03/04	172.8	329.4	82.5	156.8	68.8	2.7	18.6	831.7
04/05[1]	121.7	392.9	99.9	91.6	59.4	6.1	3.9	775.5
05/06	192.3	373.4	99.6	119.6	80.1	4.8	10.5	880.2
06/07	98.2	371.6	124.7	109.9	39.1	8.5	2.5	754.5
	4,888.2	12,256.2	3,264.3	5,821.7	2,366.4	248.1	555.0	29,399.9
96/97	2.6	1.2	0.2	7.0	0.1	0.1	0.0	11.3
97/98	1.7	5.8	0.3	1.3	0.4	0.1	0.5	10.0
98/99	0.4	1.1	0.3	0.2	1.2	0.1	0.0	3.3
99/00	0.8	0.6	0.2	0.4	0.1	0.1	0.1	2.3
00/01	0.3	4.9	0.1	1.2	0.1	0.0	0.0	6.5
01/02	0.7	2.6	0.5	0.2	0.1	0.0	0.0	4.1
02/03	0.3	0.8	0.9	0.1	0.0	0.0	0.0	2.1
03/04	0.5	0.3	0.5	0.0	0.0	0.0	0.0	1.3
04/05	0.3	0.3	0.1	0.1	0.2	0.1	0.0	1.1
05/06	1.3	8.1	0.1	1.0	0.0	0.1	0.0	10.5
06/07	0.5	0.7	0.5	0.3	0.0	0.0	0.0	1.9
	9.4	26.4	3.7	11.8	2.2	0.4	0.6	54.5

[1] Cells marked with grey are greater than the equivalent totals reported in Appendix 5, Table 1 in Stanley et al. (2006).

The GLM analysis for the combined areas 3C and 3D selected 0.1° degree of latitude (23 categories), depth band (14 categories), DFO locality (33 categories) and vessel (38 categories) as explanatory variables in addition to fishing year in the final model and accounted for 29% of the variation (Table H.2). Neither month nor DFO Major Area entered the model. Fishing year explained very little of the total variance. The analysis was performed on total landed catch (verified landings plus discards) but the level of discards for this species is extremely low (Table H.1). The selected lognormal model shows little trend from the beginning of the series to 2000/01, after which it rose over two years to a new level which is about 20-25% higher than the previous level (Figure H.2; Table H.3). The standardised model does not vary much from the simple arithmetic mean CPUE or the geometric mean of the non-zero catches, possibly indicating that the fishery has remained reasonably consistent across the eleven years of available data (Figure H.2). The estimated coefficients for the selected explanatory variables appear to be reasonable, with high catch rates concentrated in a narrow band in the upper part of Vancouver Island (top left panel; Figure H.3–note that the good catch rates in the "plus" group are based on a very small number of records). The depth categorical variable shows a peak between 150 and 200 m and the localities with the better catch rates are concentrated in the upper part of Vancouver Island (Figure H.3). The vessel coefficients do not show a great deal of variation, with the range generally lying between 0.5 and 1.5 relative index units lower and higher than the overall mean.

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

Variable	1	2	3	4	5	6
Fishing year*	**0.009**					
0.1° Latitude bands*	0.162	**0.168**				
Depth bands*	0.123	0.135	**0.252**			
DFO locality*	0.154	0.162	0.214	**0.274**		
Vessel*	0.038	0.045	0.191	0.272	**0.293**	
Month	0.010	0.018	0.177	0.262	0.284	0.299
DFO Major region	0.036	0.044	0.168	0.252	0.275	0.293
Improvement in deviance	0.000	0.159	0.084	0.023	0.018	0.006

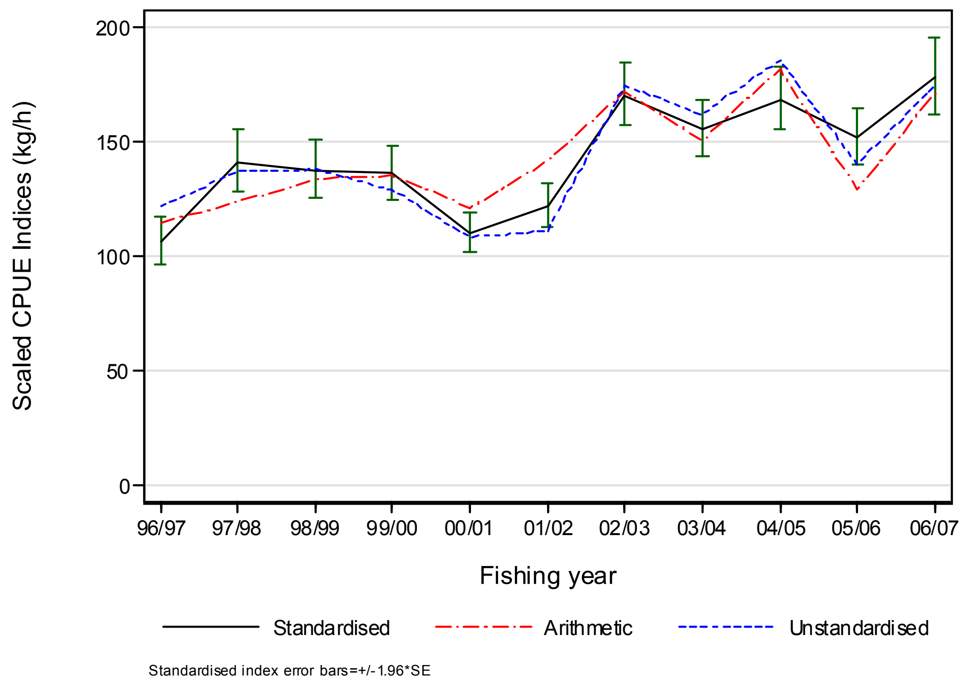

Figure H.2. Three CPUE series for 3C/3D landed canary rockfish catches for the 1996/97 to 2006/07 fishing years. The solid line is a standardised analysis correcting for 0.1° latitude band, 25 m depth band, DFO locality and vessel effects. The arithmetic series is the sum of the non-zero catch divided by the sum of the associated effort (Eq. H.5) and the unstandardised series is the geometric mean of all positive CPUE observations (Eq. H.6).

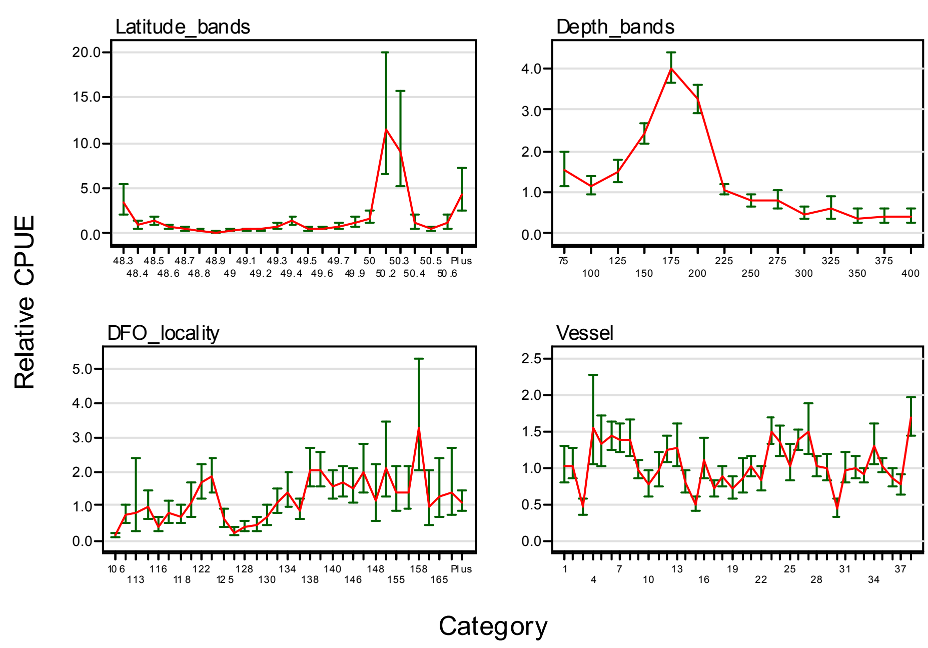

Figure H.3. Plots of the coefficients for the categorical explanatory variables included in the standardised GLM analysis presented in Figure H.2. (locality 138: Father Charles Canyon; 158=Esperanza West)

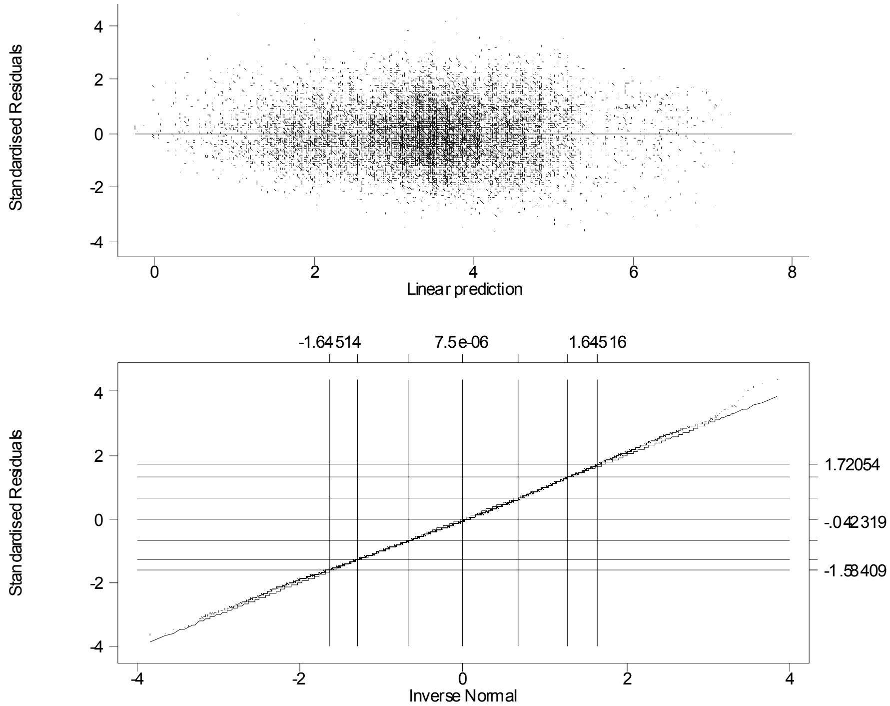

Figure H.4. Standardised (Pearson) residuals for the 3C/3D GLM analysis presented in Figure H.2. The outside horizontal and vertical lines represent the 5th and 95th percentiles of the theoretical and observed distributions.

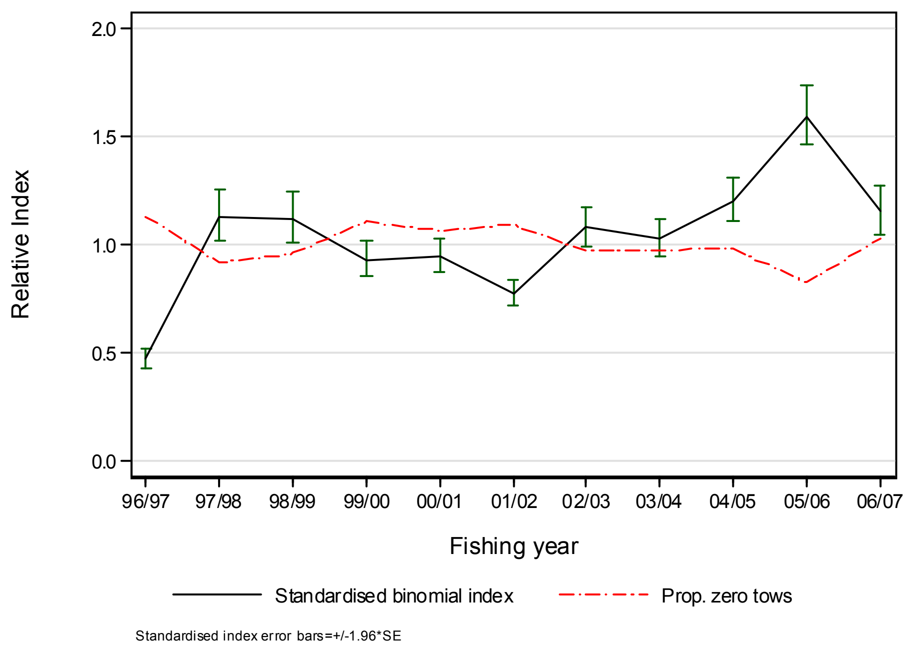

Figure H.5. Year effects from a standardised binomial logit model fit to the presence/absence of canary rockfish using the same dataset that provided the lognormal regression model (Figure H.2). Also shown is the relative proportion of tows with zero canary rockfish by fishing year (mean=0.51). Each series has been normalised to its geometric mean.

Table H.3. Arithmetic and standardised CPUE indices with upper and lower bounds of the standardised indices and the associated standard error for the 3C/3D model of non-zero catches of canary rockfish. 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	St. error
96/97	114.8	106.3	96.1	117.6	0.052
97/98	123.6	141.0	127.9	155.3	0.050
98/99	133.6	137.5	125.4	150.9	0.047
99/00	135.1	136.1	124.7	148.6	0.045
00/01	121.1	110.2	101.7	119.5	0.041
01/02	141.5	121.8	112.7	131.6	0.040
02/03	171.8	170.3	157.4	184.2	0.040
03/04	150.6	155.2	143.5	167.8	0.040
04/05	181.6	168.6	155.6	182.8	0.041
05/06	128.9	152.1	140.5	164.6	0.040
06/07	171.2	178.3	162.3	196.0	0.048

Model residuals fit the model assumption of log-normal error well throughout the entire distribution, with little deviation at either tail (Figure H.4). A binomial model fit to the presence/absence of canary rockfish using the same dataset which provided the lognormal model shows a big jump in the annual effects between the first and second year of the series, followed by a declining trend to 2001/02 (Figure H.5). After that year, the index increased to 2005/06 and has fallen in the most recent fishing year. There has been little variation in the proportion to tows reported with zero catch (Figure H.5).

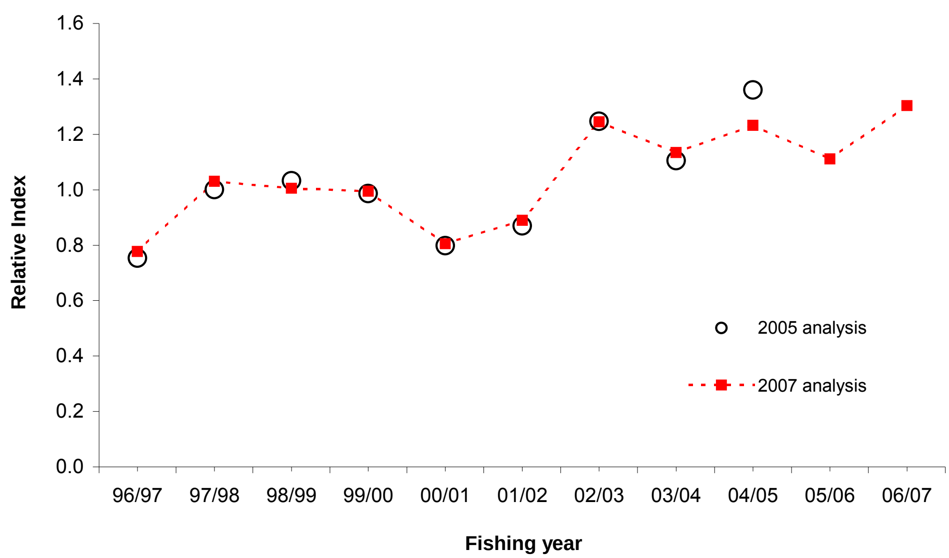

Figure H.6. Comparison of the 3CD lognormal standardised index calculated for the 2005 canary rockfish report (Stanley et al. 2006) with the equivalent index from this report (Table H.3). Both series are presented relative to the 1996/97 to 2004/05 geometric mean.

A comparison of the 3CD series presented in Table H.3 with the equivalent series calculated in 2005 (Stanley et al. 2006) shows that the two sets of series are consistent, with the exception of the index for 2004/05 which is lower than the equivalent 2005 index (1.23 compared to 1.36;

Figure H.6). This difference may be related to the fact the data set obtained in 2005 appears to have been incomplete for 2004/05, with a total catch of 351 t for Areas 3C+3D in 2004/05 compared to the 515 t for the same year shown in Table H.1 (compare with Table 1 in Appendix 5 in Stanley et al. 2006).

Combined Areas 5A, 5B and 5C (Queen Charlotte Sound and lower Hecate Strait)

The depth distribution of the majority of successful catch records data ranged from about 60 m to 300 m, with only sporadic observations at deeper and shallower depths (Figure H.7). The GLM model used all valid tows occurring between 50 and 325 m.

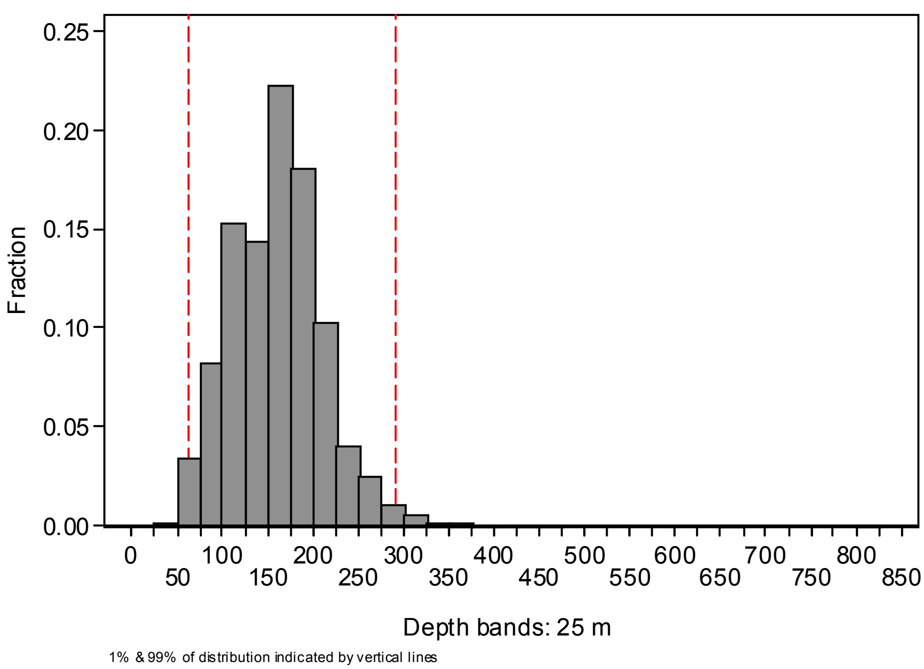

Figure H.7. Depth distribution of tows with landed canary rockfish catch in the combined Areas 5A, 5B and 5C from 1996/97 to 2006/07 in 25 m intervals. Each bin interval is labelled with the upper bound of the interval. Vertical lines: 1%=62 m; 99%=292 m.

The GLM analysis for combined Areas 5A, 5B and 5C selected DFO locality (27 categories), depth band (11 categories), 0.1° latitude bands (27 categories), and vessel (30 categories) in addition to fishing year as explanatory variables in the final model and accounted for 27% of the variation (Table H.4). These are the same explanatory variables selected by the 3CD model, with the order for the localities and latitude bands reversed (compare Table H.4 with Table H.2). As for the 3CD model, neither month nor DFO Major Area entered the model and fishing year explained very little of the total variance. The analysis was performed on total landed catch (verified landings plus discards) but the level of discards for this species is extremely low (Table H.1). The selected lognormal model shows a rising trend from the beginning of the series which peaked in 1999/00 (Figure H.8; Table H.5). After this year, the index dropped 20-25% to a level which was maintained to 2005/06, when the index returned over two years back to the level observed from 1997/98 to 1999/00 (Figure H.8; Table H.5). As seen in the 3CD model, the standardised model does not vary much from the simple arithmetic mean CPUE or the geometric mean of the non-zero catches, except for two years, 2000/01 and 2001/02, where the standardised and geometric mean index dropped while the arithmetic index stayed at the higher levels observed in the preceding years (Figure H.8). The estimated coefficients for the selected explanatory variables appear to be reasonable, with the highest catch rates occurring in localities in the lower sections of Hecate Strait, including a known “hot spot” which straddles the line between 5B and 5C (top left panel; Figure H.9). The depth categorical variable shows a peak between 150 and 200 m (again as seen in the 3CD analysis) and the latitudes with peak catch rates are not distant from the equivalent categories in the 3CD analysis (Figure H.3). The vessel coefficients do not show a large amount of variation, except for one vessel with a coefficient of about 2 and a few vessels dropping to a relative CPUE index near 0.5. Vessel acceptance criteria were set higher in this model compared to the 3CD model because too many vessels were accepted into the model when the 3CD vessel acceptance criteria were applied. The explanatory variables, although increasing the amount of deviance explained by the model, do little to modify the overall trend generated by the unstandardised annual means. This indicates that the fishery has been relatively stable with respect to canary rockfish over the 11 years.

Table H.4: Order of acceptance of variables into the 5A/5B/5C model of successful total mortalities (verified landings plus discards) of canary rockfish by core vessels (based on the vessel selection criteria of at least 8 trips in five or more fishing years) with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an asterisk (*). Fishing year was forced as the first variable.

Variable	1	2	3	4	5	6
Fishing year*	**0.004**					
DFO locality*	0.113	**0.119**				
Depth bands*	0.100	0.104	**0.218**			
0.1° Latitude bands*	0.092	0.098	0.176	**0.254**		
Vessel*	0.042	0.045	0.145	0.239	**0.270**	
Month	0.015	0.020	0.127	0.222	0.258	0.275
DFO Major region	0.011	0.014	0.120	0.219	0.257	0.273
Improvement in deviance	0.000	0.115	0.099	0.036	0.017	0.005

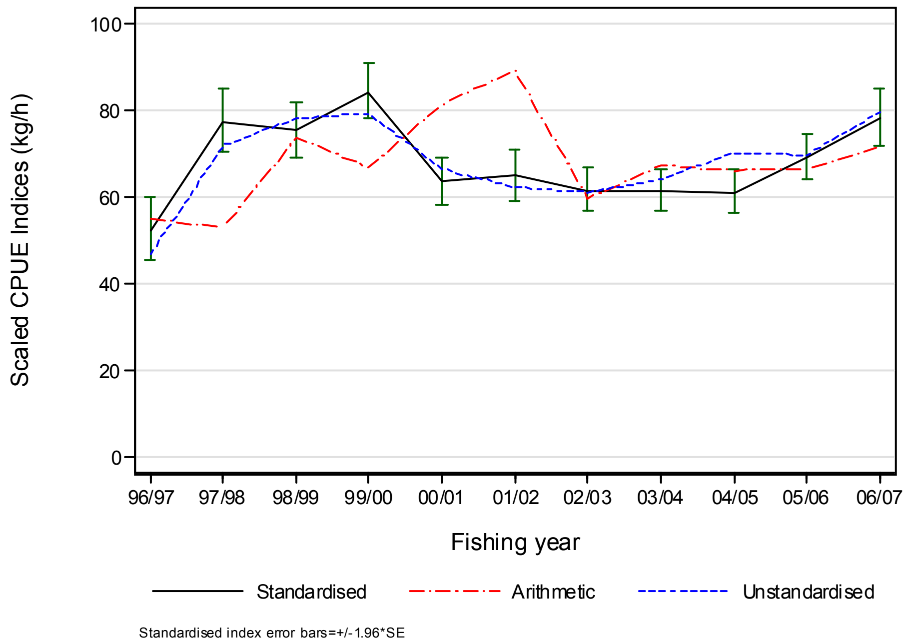

Figure H.8. Three CPUE series for 5A/5B/5C landed canary rockfish catches for the 1996/97 to 2006/07 fishing years. The solid line is a standardised analysis correcting for fishing year, DFO locality, depth band category, 0.1° latitude bands and vessel effects. The arithmetic series is the sum of the non-zero catch divided by the sum of the associated effort (Eq. H.5) and the unstandardised series is the geometric mean of all positive CPUE observations (Eq. H.6).

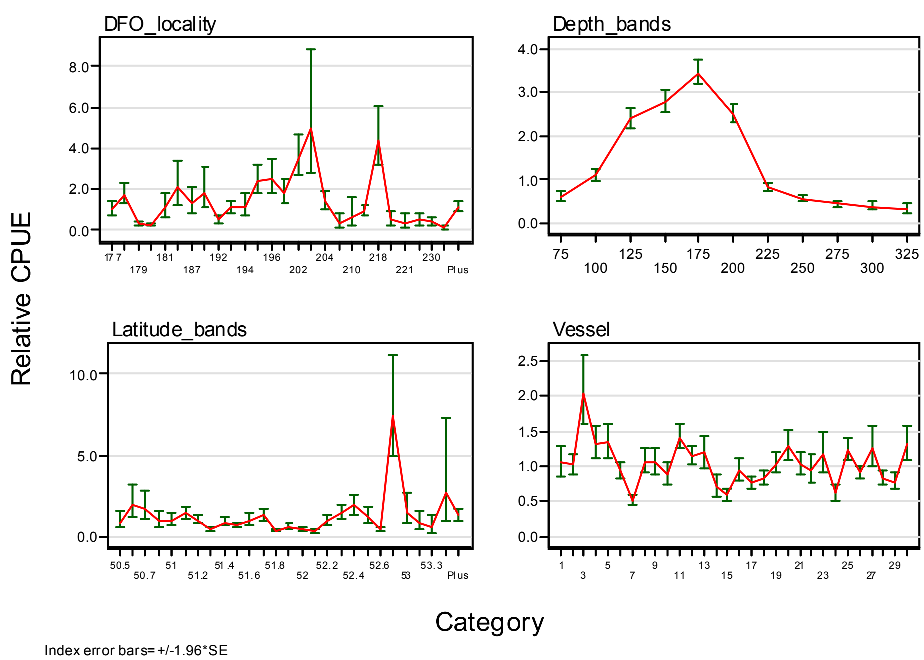

Figure H.9. Plots of the coefficients for the categorical explanatory variables included in the standardised GLM analysis presented in Figure H.8. Locality codes: 202: SW Middle Bank; 203: outside Cape St. James; 218: NW Middle Bank.

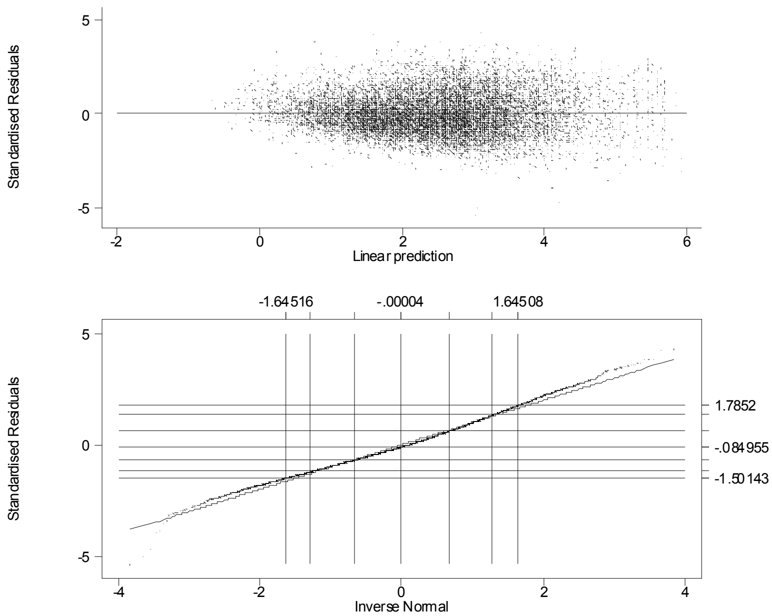

Figure H.10. Standardised (Pearson) residuals for the 5A/5B/5C GLM analysis presented in Figure H.8. The outside lines represent the 5th and 95th percentiles of the theoretical and observed distributions.

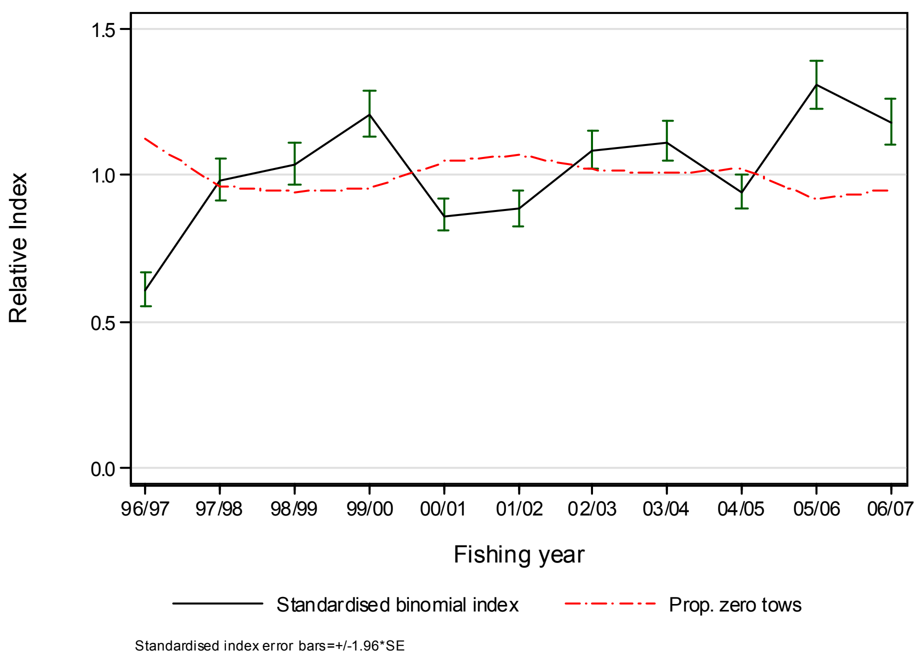

Figure H.11. Year effects from a standardised binomial logit model fit to the presence/absence of canary rockfish using the same dataset that provided the lognormal regression model (Figure H.8). Also shown is the relative proportion of tows with zero canary rockfish by fishing year (mean=0.71). Each series has been normalised to its geometric mean.

Model residuals fit the model assumption of log-normal error reasonably well, with some minor deviations at the tails of the distribution (Figure H.10). A binomial model fit to the presence/absence of canary rockfish using the same dataset which was used for the lognormal model shows little trend over the eleven-year period (Figure H.11). There has been no change in the proportion to tows reported with zero catch (Figure H.11).

Table H.5. Arithmetic and standardised CPUE indices (kg/h) with standard errors and upper and lower bounds of the standardised indices for the 5A/5B/5C model of non-zero catches of canary rockfish. The standardised series has been scaled to the geometric mean of the arithmetic series.

Fishing year	Arithmetic	Standardised	Lower bound	Upper bound	Standard error
96/97	54.9	52.3	45.7	59.9	0.069
97/98	53.0	77.3	70.4	84.8	0.047
98/99	73.7	75.3	69.2	82.0	0.043
99/00	66.8	84.3	78.1	91.1	0.039
00/01	81.3	63.5	58.4	69.1	0.043
01/02	89.2	64.9	59.3	71.1	0.047
02/03	59.7	61.6	56.9	66.6	0.040
03/04	67.3	61.3	56.8	66.2	0.039
04/05	66.0	61.0	56.3	66.1	0.041
05/06	66.6	69.1	64.0	74.6	0.039
06/07	71.6	78.0	71.8	84.7	0.042

Comparison of trend lines

Each of the analysed areas have had two types of CPUE analysis applied: one looking at non-zero catches (lognormal GLM) and the other looking at the change in the proportion of successful catches (binomial GLM). A comparison of the two areas for each type of GLM analysis shows that the binomial series are very similar for the two areas, with each area showing a strong increase between 1996/97 to 1997/98, followed by fairly similar trends, although the 2005/06 peak is stronger for the 3CD analysis than for the 5ABC analysis (Figure H.12). Both series show a drop in 2006/07, although the index for that year is above the 11-year average. The two sets of lognormal series are somewhat different, with the 5ABC series being above the 3CD in the first part of the series, while the relative positions of the two series are reversed in the latter part of the 1990s and early 2000s (Figure H.12). However, both series show an upturn in 2006/07 which tends to make the two lognormal series appear somewhat similar. Note that the 3CD fishery has a higher absolute catch rate (Table H.3 and Table H.5) and a higher proportion of non-zero tows (Figure H.2 and Figure H.8) than the 5ABC fishery.

A map showing the distribution of canary CPUE (kg/h) over all of BC indicates that canary rockfish are widely distributed from southern US/Canada border to part way up Hecate Strait (Figure H.19). High catch rates are found all along the entire length of the west coast shelf of Vancouver Island, with a greater concentration of “hot spots” in the more northerly sections of this coast. Good catch rates for canary are found at the top of Vancouver Island and sporadically in QCSd. There is an extension of high catch rates into the lower part of Hecate Strait, but there is a considerable lessening in the concentration of this species in the more northerly parts of Hecate Strait, Dixon Entrance and the west coast of the QC Islands. The continuous nature of these regions of high catch rates and the reasonable conformity of the CPUE trends across the two analysed areas of the coast seem to support an hypothesis of a single coastal stock.

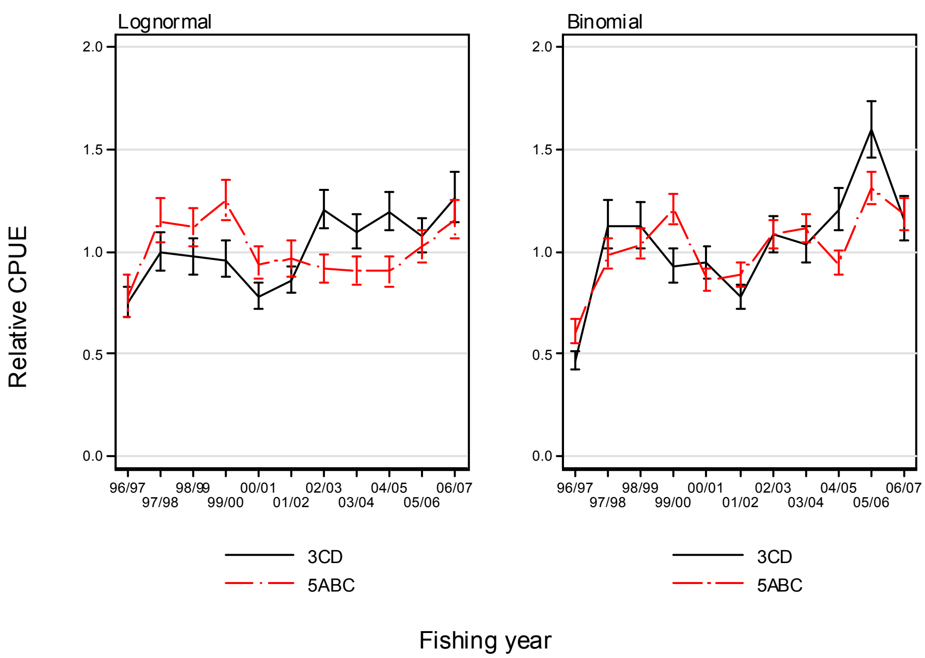

Figure H.12. Comparison of standardised CPUE indices among the two regions for each of the regression model assumptions (lognormal and binomial). Each series has been standardised relative to the geometric mean of the period 1996/97 to 2006/07. The error bars show ± 95% confidence bounds.

Total BC: Combined Areas 3C, 3D, 5A, 5B and 5C:

The depth distribution of the majority of successful catch records data ranged from about 60 m to 320 m, with only sporadic observations at deeper and shallower depths (Figure H.7). The GLM model used all valid tows occurring between 50 and 400 m (for consistency with the 3CD analysis).

The GLM analysis for Total BC (3CD5ABCDE) selected 0.1° latitude bands (43 categories), depth band (14 categories), DFO locality (39 categories), PFMC Major Area (7 categories) and vessel (40 categories) in addition to fishing year as explanatory variables in the final model and accounted for 32% of the variation (Table H.6). Apart from the PFMC Major Area variable, these are the same explanatory variables selected in the same order selected as for the 3CD model, (compare Table H.6 with Table H.2). As for the 3CD and 5ABC models, month did not enter the model and fishing year explained very little of the total variance. It is surprising that the PFMC Major Area explained some additional deviance, considering that two other area variables (DFO locality and latitude band) entered the model previously. However, the broad area definitions and the fact that there were 7 categories probably contributed to the model selection. The analysis was performed on total landed catch (verified landings plus discards) but the level of discards for this species is extremely low (Table H.1). The selected lognormal model showed an increase from the first to the second year in the series, a plateau near 100 kg/h for the next three years, followed by a drop to around 80 kg/h in 2000–01, followed by a gently rising trend to 2006–07 (Figure H.14; Table H.7).

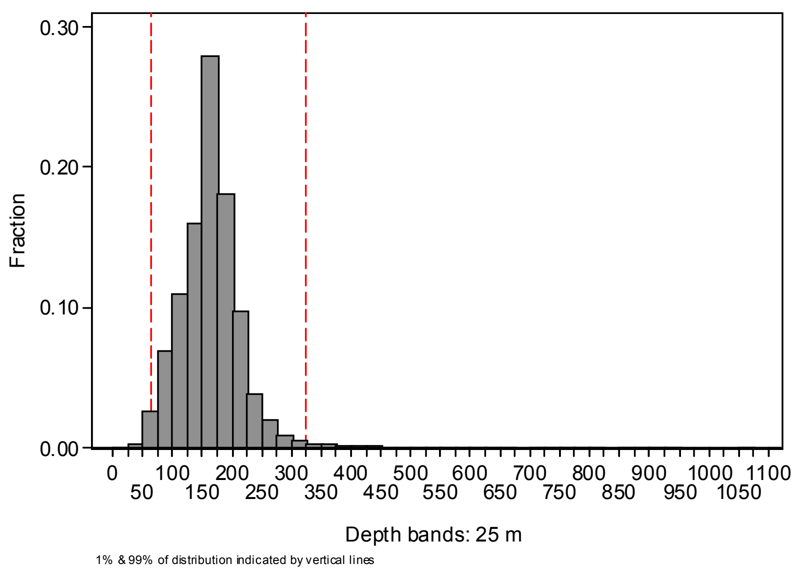

Figure H.13. Depth distribution of tows with landed canary rockfish catch in the Total BC (3CD5ABCDE) dataset from 1996/97 to 2006/07 in 25 m intervals. Each bin interval is labelled with the upper bound of the interval. Vertical lines: 1%=64 m; 99%=324 m.

As seen in both the 3CD and 5ABC models, the standardised model does not vary much from the simple arithmetic mean CPUE or the geometric mean of the non-zero catches. The exception is for three years: 2000–01 and 2001–02 where the standardised and geometric mean index dropped while the arithmetic index stayed at the higher levels observed in the preceding years and 2004–05, where both the arithmetic and geometric mean series are slightly higher in that year than the standardised index (Figure H.14). The estimated coefficients for the selected explanatory variables appear to be reasonable, with the highest catch rates occurring in localities in the southern parts of QCSd, around the southern tip of Moresby Island, and in the southern part of Hecate Strait (top left panel; Figure H.15). The depth categorical variable shows a peak between 150 and 200 m (again as seen in the both the 3CD and 5ABC analyses) and the latitudes with peak catch rates seem to be in reasonable locations (Figure H.15). The vessel coefficients do not show a large amount of variation, except for one vessel with a coefficient of about 2 and a few vessels dropping to a relative CPUE index just above 0.5. Vessel acceptance criteria were set at a high level consistent with the 5ABC model. The explanatory variables, although increasing the amount of deviance explained by the model, do little to modify the overall trend generated by the unstandardised annual means. This indicates that the fishery has been relatively stable with respect to canary rockfish over the 11 years.

Model residuals fit the model assumption of log-normal error reasonably well, with some minor deviations at the tails of the distribution (Figure H.16). A binomial model fit to the presence/absence of canary rockfish using the same dataset which was used for the lognormal model shows little trend over the eleven-year period (Figure H.17). There has been little or no change in the proportion to tows reported with zero catch (Figure H.17).

Table H.6: Order of acceptance of variables into the Total BC model of successful total mortalities (verified landings plus discards) of canary rockfish by core vessels (based on the vessel selection criteria of at least 8 trips in five or more fishing years) with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an asterisk (*). Fishing year was forced as the first variable.

Variable	1	2	3	4	5	6	7
Fishing year*	**0.002**						
0.1° Latitude bands*	0.163	**0.165**					
Depth bands*	0.139	0.143	**0.249**				
DFO locality*	0.152	0.155	0.222	**0.291**			
PFMC Major region*	0.110	0.112	0.180	0.260	**0.306**		
Vessel*	0.040	0.042	0.180	0.264	0.302	**0.319**	
Month	0.019	0.022	0.174	0.257	0.296	0.311	0.323
Improvement in deviance	0.000	0.163	0.085	0.041	0.015	0.013	0.004

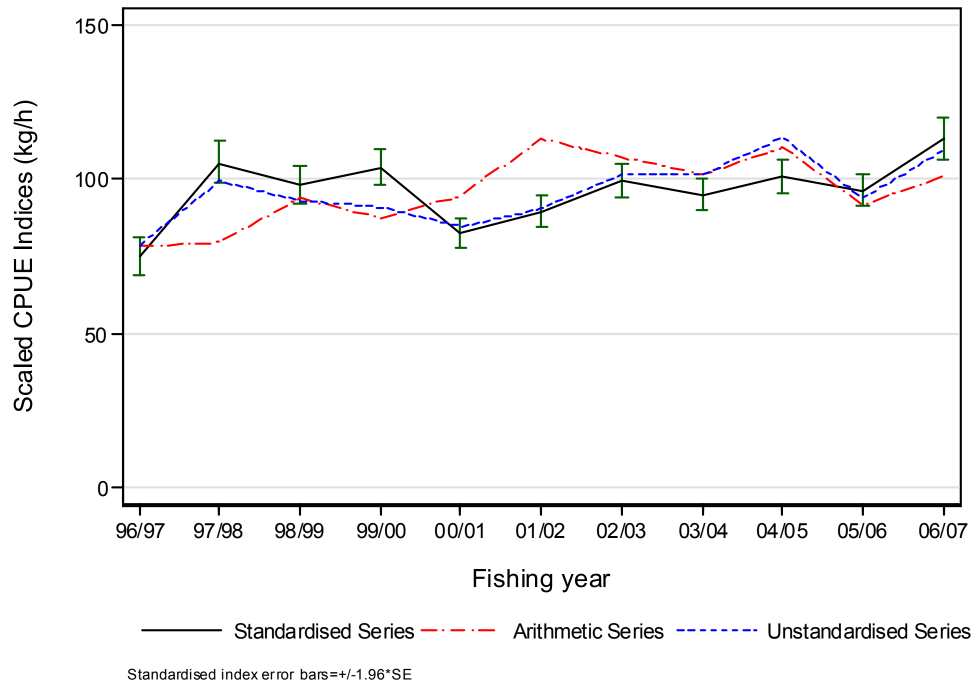

Figure H.14. Three CPUE series for Total BC landed canary rockfish catches for the 1996/97 to 2006/07 fishing years. The solid line is a standardised analysis correcting for fishing year, 0.1° latitude bands, depth band category, DFO locality, PFMC major area and vessel effects. The arithmetic series is the sum of the non-zero catch divided by the sum of the associated effort (Eq. H.5) and the unstandardised series is the geometric mean of all positive CPUE observations (Eq. H.6).

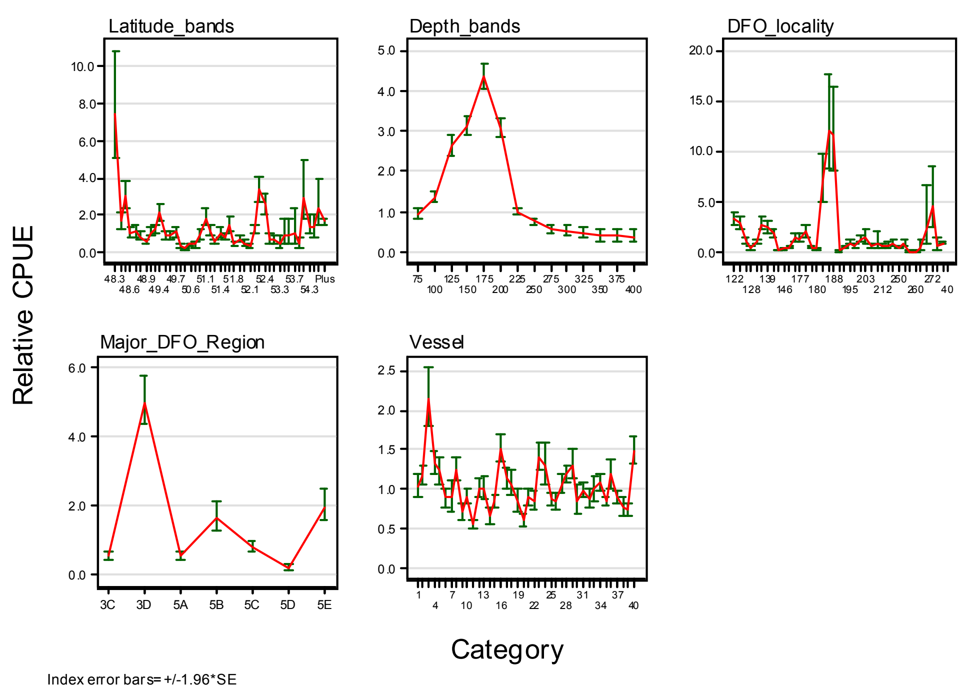

Figure H.15. Plots of the coefficients for the categorical explanatory variables included in the standardised GLM analysis presented in Figure H.8. Locality codes: 122: Deep Big Bank/Barkley Canyon; 124 Ucluelet/Loudon Canyons; 138: Father Charles canyon; 181: Topknot; 183: South Scott Islands; 188: Pisces canyon; 265: Shell Ground; 272: Frederick Island.

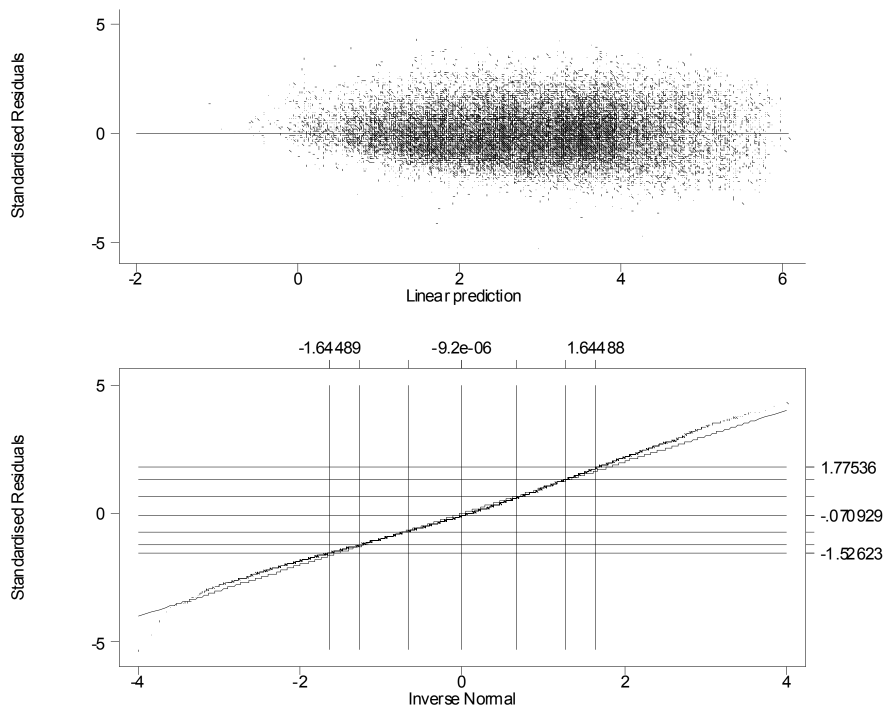

Figure H.16. Standardised (Pearson) residuals for the Total BC GLM analysis presented in Figure H.8. The outside horizontal and vertical lines represent the 5th and 95th percentiles of the theoretical and observed distributions.

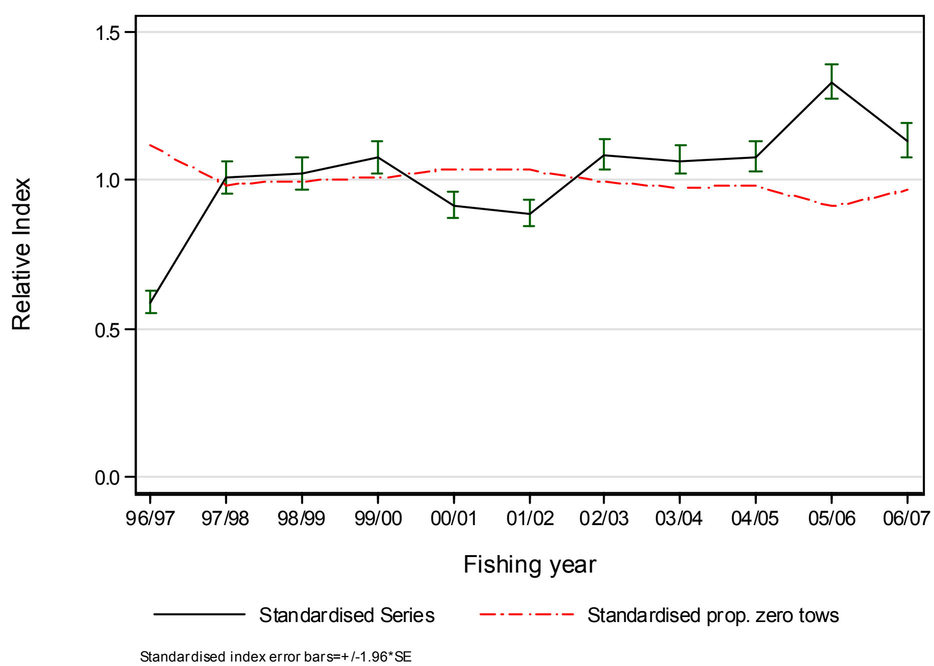

Figure H.17. Year effects from a standardised binomial logit model fit to the presence/absence of canary rockfish using the same dataset that provided the lognormal regression model (Figure H.8). Also shown is the relative proportion of tows with zero canary rockfish by fishing year (mean=0.71). Each series has been normalised to its geometric mean.

Table H.7. Arithmetic and standardised CPUE indices (kg/h) with standard errors and upper and lower bounds of the standardised indices for the Total BC model of non-zero catches of canary rockfish. The standardised series has been scaled to the geometric mean of the arithmetic series.

Fishing year	Arithmetic	Standardised	Lower bound	Upper bound	Standard error
96/97	78.4	74.7	68.9	81.0	0.041
97/98	79.5	105.2	98.6	112.3	0.033
98/99	93.8	98.0	92.1	104.3	0.032
99/00	87.6	103.8	98.1	110.0	0.029
00/01	94.7	82.3	77.7	87.1	0.029
01/02	113.1	89.2	84.2	94.6	0.030
02/03	107.1	99.5	94.2	105.0	0.028
03/04	101.5	94.7	89.8	99.9	0.027
04/05	110.3	101.1	95.7	106.8	0.028
05/06	91.8	96.2	91.3	101.4	0.027
06/07	100.9	113.3	106.7	120.3	0.031

Comparison of trend lines across all areas

A comparison plot of three lognormal regression models and the equivalent three binomial models shows that the Total BC model lies, as would be expected, in between the two distinct area models (Figure 24).

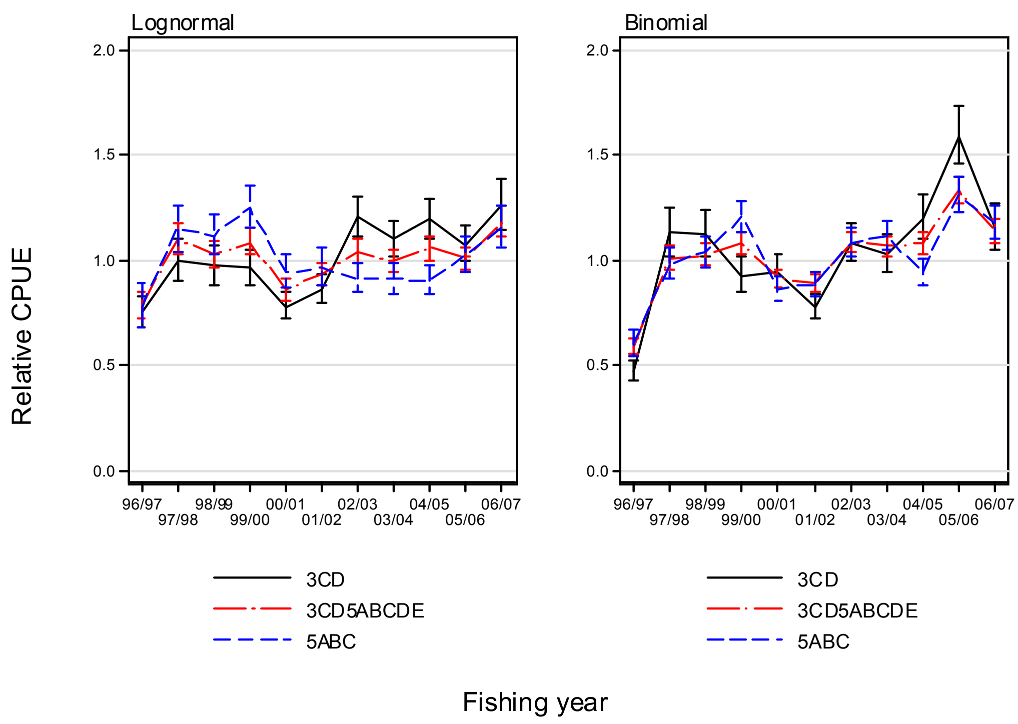

Figure H.18. Comparison of standardised CPUE indices among the two regions as well as for the Total BC (labelled "3CD5ABCDE") analysis for each of the regression model assumptions (lognormal and binomial). Each series has been standardised relative to the geometric mean of the period 1996/97 to 2006/07. The error bars show ± 95% confidence bounds.

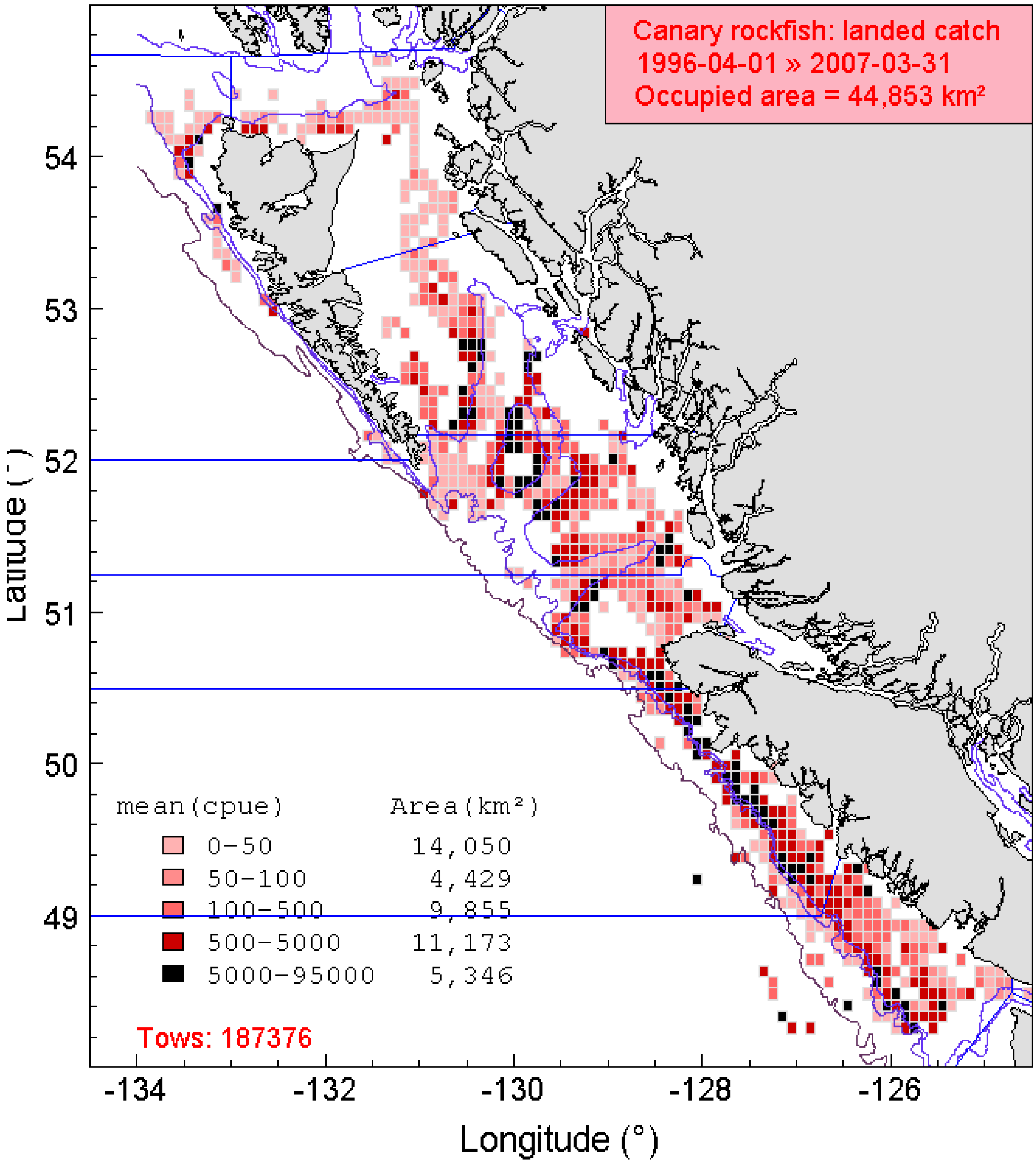

Figure H.19. Distributional plot of canary rockfish trawl CPUE (kg/h) allocated across 0.1°W X 0.075°N grids for the period 01 April 1996 to 31 March 2007. Grid cells have been colour coded to indicate the range in which the mean CPUE for the cell falls over the entire period. Isobaths are 200 m, 500 m and 1600 m. Boundaries for DFO major areas are also shown (3C: lower half of Vancouver Island; 3D: upper half of Vancouver Island; 5A: top of Vancouver Island and lower part of QCS; 5B: upper part of QCSd; 5C: lower part of Hecate Strait; 5D: upper part of Hecate Strait and Dixon Entrance; 5E: west coast Queen Charlotte Islands).

APPENDIX I. SETTING INFORMED PRIORS FOR SELECTIVITY PARAMETERS

Commercial fishery

Priors were formed for the commercial selectivity function based on the selectivity functions estimated by a recent assessment of canary rockfish off the US west coast (Stewart 2007). These selectivity functions are length-based and applied equally to each sex while the assessment model used for B.C. canary rockfish is age and sex-based. The proportions selected by length in the US assessment were converted to the imputed mean age for that length using a von-Bertalanffy growth equation specific for each sex (Appendix C).

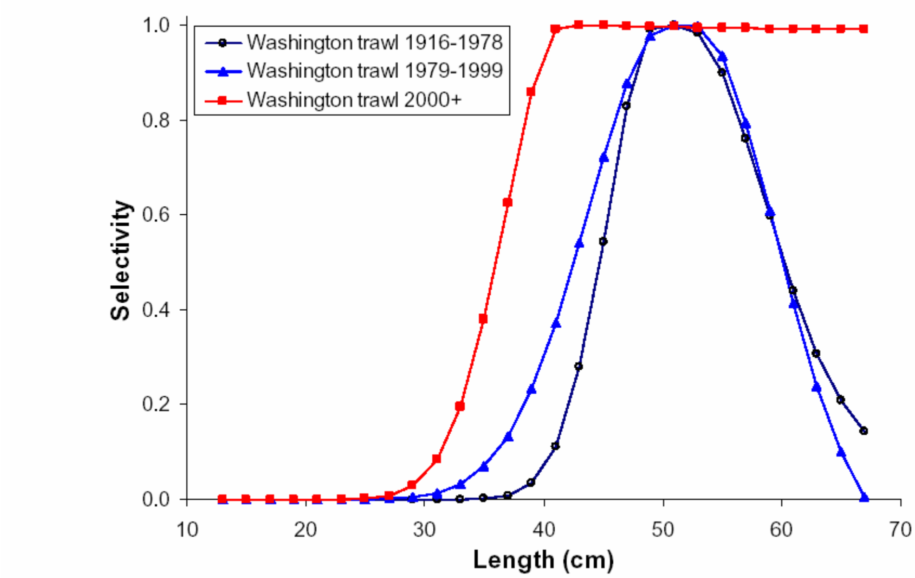

Figure I.1. Figure 66 from a recent assessment of canary rockfish off the US west coast (Stewart 2007). This figure illustrates three length-based selectivity functions developed for the Washington state trawl fishery covering three periods: 1916–1978, 1979–1999, and 2000–2006.

Parameters consistent with the form of the selectivity function used in the stock assessment model (Eq. I.1) were estimated by empirically fitting to the proportions-at-age (after conversion from lengths) selected for the Washington State commercial trawl fishery (Figure I.1; Table I.1). These estimated selectivity parameters (fitted models shown in Figure I.2) were used as the mean of the informed priors for the left-hand (ascending) $\left({}_f\nu_L^g\right)$ and age at full selectivity $\left({}_fS_{full}^g\right)$ parameters used in the assessment model for commercial trawl (Table I.2). A prior was formed for the shift parameter $\left({}_f\Delta_{S_{full}}^g\right)$ by estimating selectivity ogives for each sex and taking the difference between the male and female ${}_fS_{full}^g$ parameters. The right-hand (descending) parameter is not used in this assessment model and does not require a prior. A standard deviation consistent with a CV=0.20 was used for the ${}_fS_{full}^g$ and ${}_f\Delta_{S_{full}}^g$ parameters while the standard deviation of the ${}_f\nu_L^g$ parameter was set with CV=0.25 to reflect the more uncertain nature of this parameter (Table I.2).

Eq. I.1

$$s_a^{g,s} = \begin{cases} \exp\left\{ \dfrac{-\left(a - S_{full}^{g,s}\right)^2}{\nu_L^g} \right\} & a \le S_{full}^{g,s} \\ \exp\left\{ \dfrac{-\left(a - S_{full}^{g,s}\right)^2}{\nu_R^g} \right\} & a > S_{full}^{g,s} \end{cases}$$

where:

$$S_{full}^{g,s} = S_{full}^{g,s} + (1 - j)\Delta_{S_{full}}^{g}$$

$\left(j = 1 \text{ for females; } j = 0 \text{ for males} \right)$

Table I.1. Selectivity at age and sex $\left({}_f s_a^{g,s} \right)$ as taken from Figure 66 of Stewart (2007). The conversion from a length class to an age class was based on a von Bertalanffy growth model fitted to age-length data taken from the B.C. commercial trawl fishery (Appendix C).

Mean length class (cm)	**Imputed age**		**Proportion selected**		
	Males	**Females**	**2000+**	**1979–1999**	**1916–1978**
27	4.5	4.5	0.00	0.00	0.00
29	5.0	4.9	0.03	0.00	0.00
31	5.5	5.4	0.08	0.02	0.00
33	6.1	5.9	0.20	0.03	0.00
35	6.7	6.4	0.38	0.08	0.00
37	7.4	7.0	0.63	0.13	0.00
39	8.2	7.7	0.85	0.23	0.03
41	9.1	8.4	1.00	0.37	0.11
43	10.1	9.3	1.00	0.55	0.27
45	11.5	10.2	1.00	0.71	0.55
47	13.2	11.3	1.00	0.88	0.83
49	15.6	12.7	1.00	0.98	1.00
51	19.7	14.5	1.00	1.00	1.00
53	53.0[1]	17.0	1.00	1.00	1.00
55	53.0[1]	21.2	1.00	1.00	1.00
57	53.0[1]	40.2	1.00	1.00	1.00
59	53.0[1]	57.1[1]	1.00	1.00	1.00

[1]age at von-Bertalanffy L_∞

Table I.2. Mean estimates for the four model parameters used to describe selectivity in the canary rockfish model as derived from fitting Eq. I.1 to the age-converted length selectivities provided in Table I.1.

Parameter	Distribution	Selectivity time period 2000+	1979–1999	1916–1978	Proposed CV
${}_{f}S^{g}_{full}$	Normal	8.41	12.44	12.42	0.2
${}_{f}\Delta^{g}_{S_{full}} = {}_{f}S^{g,m}_{full} - {}_{f}S^{g,f}_{full}$	Normal	0.58	1.93	2.20	0.2
${}_{f}v^{g}_{L}$	Normal	1.36	2.72	2.02	0.25
${}_{f}v^{g}_{R}$	Not estimated	100	100	100	–

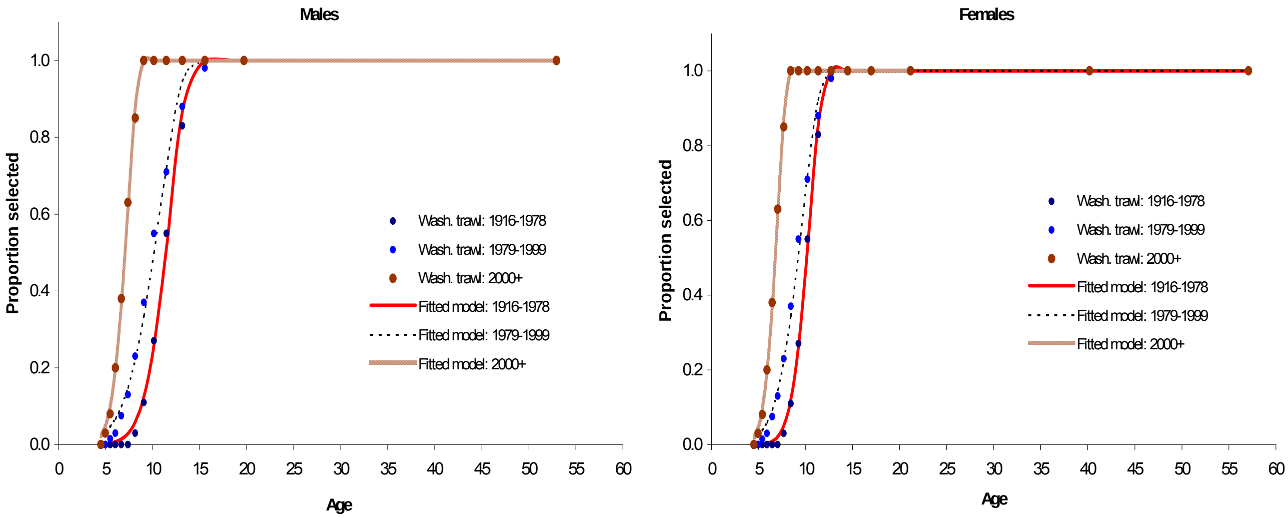

Figure I.2. Model (Eq. I.1) for male (left panel) and female (right panel) canary rockfish fitted to the selectivity at age estimates from the Washington State commercial trawl fishery over three time periods (Table I.1).

NMFS Triennial survey selectivity

Survey selectivity parameters were also estimated from the recent assessment of canary rockfish off the US west coast (Stewart 2007), using the selectivity ogive for the National Marine Fisheries Service (NFMS) triennial survey. As for the commercial fishery, this ogive is length-based and is the same for each sex while the assessment model used for B.C. canary rockfish is age-based. The proportions selected by length were consequently converted to the imputed mean age for that length using von-Bertalanffy growth equation specific for each sex (Appendix C).

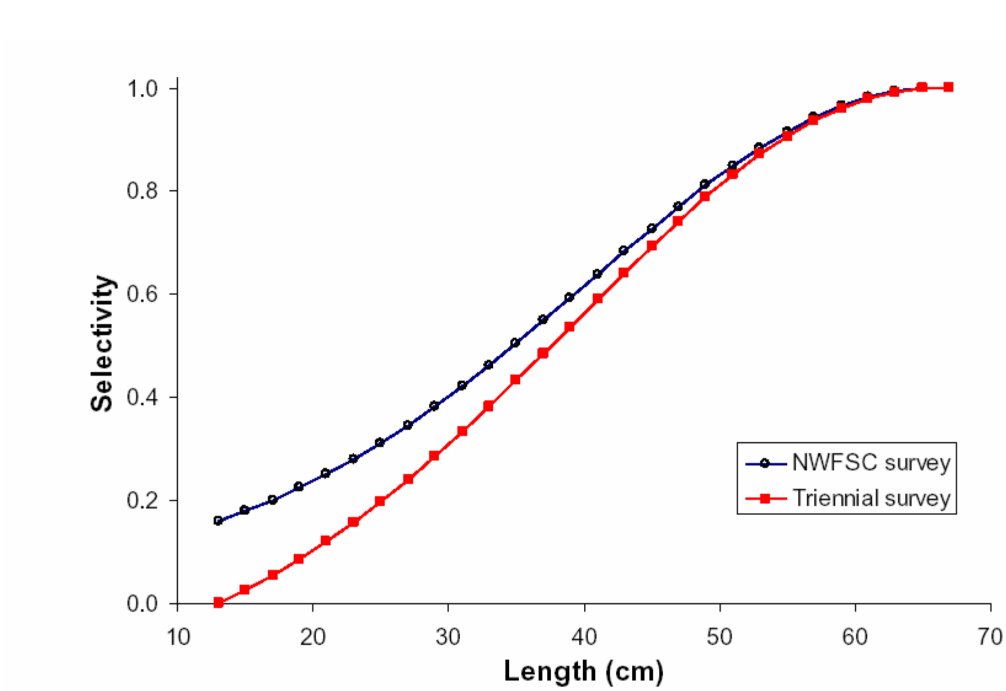

Figure I.3. Figure 63 from a recent assessment of canary rockfish off the US west coast (Stewart 2007). This figure illustrates two length-based selectivity functions developed for the NFMS Triennial and Northwest Fisheries Science Centre trawl surveys.

Parameters consistent with the form of the selectivity function used in the stock assessment model (Eq. I.1) were estimated by empirically fitting to the proportions-at-age (after conversion from lengths) selected for the NMFS triennial survey (Figure I.3; Table I.3). These estimated selectivity parameters (fitted models shown in Figure I.4) were used as the fixed parameters for the left-hand (ascending) $\left({}_{s}v_{L}^{g}\right)$ and age at full selectivity $\left({}_{s}S_{full}^{g}\right)$ parameters for all five surveys in the assessment model (Table I.4). A value for the shift parameter $\left({}_{s}\Delta_{S_{full}}^{g}\right)$ was estimated by creating survey selectivity ogives for each sex and taking the difference between the male and female ${}_{s}S_{full}^{g}$ parameters. The right-hand (descending) parameter is not used in the assessment model and does not require a value.

Note that the fitted curves are in advance of the US NFMS triennial selectivity ogive (Figure I.4). This disparity was not considered to be a serious problem given that the US selectivity ogive indicates that canary rockfish greater than 50 years in age are not fully selected. The ogives used in this model estimate that canary rockfish are fully selected to the surveys by ages 15 to 20, which seems reasonable.

Table I.3. NMFS Triennial survey selectivity at age $\left({}_{s}s_{a}^{g,s}\right)$ as taken from Figure 63 of Stewart (2007). The conversion from a length class to an age class was based on a von Bertalanffy growth model fitted to age-length data taken from the B.C. commercial trawl fishery (Appendix C).

Mean length class (cm)	Imputed age at length		Proportion selected
	Males	Females	
13	2.0	2.1	0.00
19	2.9	3.0	0.09
23	3.7	3.7	0.16
27	4.5	4.5	0.24
31	5.5	5.4	0.34
35	6.7	6.4	0.44
39	8.2	7.7	0.54
43	10.1	9.3	0.64
47	13.2	11.3	0.74
51	19.7	14.5	0.83
55	53.0[1]	21.2	0.91
59	53.0[1]	57.1[1]	0.97
63	53.0[1]	57.1[1]	1.00

[1]age at von-Bertalanffy L_∞

Table I.4. Mean estimates for the four model parameters used to describe trawl survey selectivity in the canary rockfish model as derived from fitting Eq. I-1 to the age-converted length selectivities provided in Table I.3.

Parameter	Distribution	Parameter value	Proposed CV
${}_{s}S_{full}^{g}$	Normal	16.40	0.2
${}_{s}\Delta_{S_{full}}^{g} = {}_{s}S_{full}^{g,m} - {}_{s}S_{full}^{g,f}$	Normal	1.25	0.2
${}_{s}v_{L}^{g}$	Normal	4.60	0.25
${}_{s}v_{R}^{g}$	Not estimated	100	–

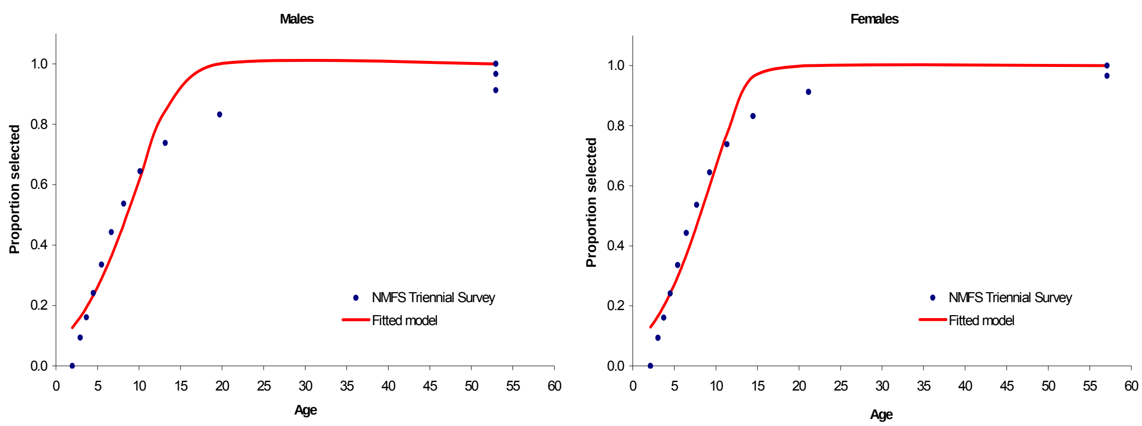

Figure I.4. Model I-1 for male (left panel) and female (right panel) canary rockfish fitted to the selectivity at age estimates from the NFMS Triennial survey (Table I.3).

APPENDIX J. CATCH AT AGE MODEL

Model assumptions

Population dynamics for canary rockfish for all of BC were analysed using a modified version of the Coleraine statistical catch-at-age model software (Hilborn et al. 2003) known as Awatea (A. Hicks, pers. comm.). This modified version retains the structure and the equations of the Coleraine software while adding some useful enhancements. The most important of these enhancements used in this canary rockfish assessment was the capability of varying *M* by age and sex.

This software was used to conduct a Bayesian analysis of the reconstruction of this stock and to perform projections under a range of fixed catch policies. The software is implemented using the AD Model Builder package (Otter Research 1999) to provide (1) maximum posterior density estimates via a function minimiser and automatic differentiation, and (2) an approximation of the posterior distribution of the parameters of interest using the Markov chain Monte Carlo (MCMC) method. The Hastings-Metropolis algorithm (Gelman et al. 1995) is used to generate the posterior distribution of the parameters of interest. Basic model assumptions are listed below and then described in detail.

1. A single coast-wide stock was assumed, taken by a single fishery. Catches were assumed to be known without error and occur in the middle of the year;

2. Beverton-Holt stock and recruitment with log-normal error structure was assumed;

3. Double-normal functions were used to model the fishery and survey selectivities with the functions constrained to an asymptote for age classes beyond the age of full selectivity. Commercial fishery and survey selectivity parameters were assumed to be constant over time, i.e., there was no process error in the selectivity;

4. An informed prior was developed for the commercial fishery based on selectivities estimated by a recent US west-coast canary rockfish assessment (Stewart 2007). Some of the assessment runs were made using this prior as fixed parameters;

5. Survey selectivity parameters were fixed at values derived for the US triennial survey from the same US west-coast canary rockfish assessment. This was done due to lack of sex-based age or length data for any of the surveys;

6. Catch at age data were assumed to be representative of the fishery if there were four or more samples in a year;

7. Fish that were aged using the otolith break and burn methodology were aged without error;

8. Catch-at-age was modelled using a robust normal likelihood modified from Fournier et al. (1998);

9. Natural mortality (*M*) was assumed to be known at a fixed value of 0.06 for male canary rockfish. Female *M* was also assumed to be 0.06 from age 1 to age 13. Females from age 14 onwards were assumed to have a higher *M* = 0.12;

10. Growth was assumed to be constant over time;

11. Maturity at age was assumed to be constant over time.

Assessment model inputs

Data used to fit the model are listed in Table J.1 and include the time series of catches, indices from five fishery independent surveys, and proportions at age from a single coastwide fishery.

Catch

Catches were estimated back to 1940 as described in Appendix B. Allowances for discards were made as described in that section and all known sources of potential mortality were included.

Biomass indices

Biomass indices from five fishery independent surveys, each spanning a different range of years, were assembled for this assessment (Table J.1). The annual biomass indices and the associated relative error from each survey year were used as model inputs.

Variable *M* with age and sex

Several species of the genus *Sebastes* exhibit a dimorphism between sexes, where there appears to be a much greater proportion of older males in the population than females. A range of hypotheses are potentially available to explain this observation; however, the approach adopted by a range of assessments for these species, including a recent assessment of canary rockfish off the coasts of Washington, Oregon and California (Stewart 2007), has been to assume that natural mortality (M) increases for mature females while it remains constant for males. The approach adopted by this assessment has been to assume that natural mortality for both males and females is 0.06 up to age 13. After that age, the female natural mortality was increased to 0.12 while the male natural mortality remained at 0.06. This approach is similar to the one adopted by the 2007 assessment of US canary rockfish (Stewart 2007), where M was fixed for both males and females at 0.06 up to age 13. After that age, males are continued with M=0.06 while M for females was allowed to be estimated by the model, with a base case model estimate of M≈0.1. The approach adopted by this stock assessment, while arbitrary, is consistent with this southern US canary stock assessment.

Proportions at age

The model was fitted to sex-specific age data summarised by year (Table J.1). Only otoliths aged using the “break and burn” method were used to construct the age samples. Practically, this meant that no age data were available prior to 1978. Plots of the age distributions by sex and sample origin are presented in Appendix C. The accumulator or plus group was set to age A=60. Annual age samples were given an initial weight in the model that represented the number of samples for that year. These weights were subsequently adjusted using the iterative procedure described below.

Weight-at-age and growth

Growth parameters were estimated from female canary rockfish length and age data from biological samples collected from 1978 to 2004 (Appendix C). Parameters for the allometric weight-length relationship were estimated for canary rockfish of both sexes, obtained from all sampling sources, with the majority being obtained from port sampling. Combining the available data sources was considered acceptable as no single source contained a wide enough range of samples in terms of age and length and fits to each of the data sources separately did not generate substantially different parameter estimates (Appendix C). Growth by sex was specified as a von Bertalanffy model with parameters specified in Appendix C and mean length at age given by:

Eq. J.1 $$L_a^s = L_\infty^s \left(1 + \mathrm{e}^{-k^s\left(a - t_0^s\right)}\right) \quad .$$

Weight at length was computed using equation Eq. J.2:

Eq. J.2 $$w_a^s = b_0^s L_a^{b_1^s} \quad .$$

The weight at age computed by the model using equations (Eq. J.1 and Eq. J.2) was assumed to be constant over time. Parameters used for equations Eq. J.1 and Eq. J.2 by sex are provided in Table C.7 in Appendix C.

Maturity at age

The proportion of females mature at age 1 through age 60 was computed from biological samples (See Appendix C Figure C.18). Maturity was assumed to be constant over time.

Model definition

<u>Selectivity</u>

Documentation for the model implemented using the Coleraine software is provided by Hilborn et al. (2003). This section describes only the subset of Coleraine model components used for the analysis of canary rockfish. The notation for the model is presented in Table J.2 and the model is stated deterministically in Table J.3 where all states and observations are defined given the parameter vector $\mathbf{\Phi}$ (D. 1). The parameters actually estimated in the analyses are defined by $\mathbf{\Theta}$ (D. 2). The model described potentially accommodates multiple fisheries, although final results are based on a model using a single fishery and five fishery-independent surveys.

Selectivity for fishery *g*, $\left\{s_a^g\right\}_{a=1}^{A}$, was allowed to vary with age class as defined by equation (D. 3). Selectivity for canary rockfish was modelled as a double half-Gaussian ("double normal") function of age *a* and fishery (or survey) *g*. The age of fully selected females in fishery *g*, ${}_{f}S_{full}^{g}$, the variance to the left of the age of full selection, ${}_{f}v_{L}^{g}$, and the male offset to the age of full selection, ${}_{f}\Delta_{S_{full}}^{g}$ were estimated in four of the six model runs investigated (and fixed in the remaining two runs). The variance to the right of the age of full selection, ${}_{f}v_{R}^{g}$, was fixed in all runs at 100 to exclude the possibility of a selectivity curve with a descending limb at ages greater than the age of full selectivity. Survey selectivity followed the same functional form, except that parameter values were fixed at values generated for the NMFS Triennial survey by a canary rockfish assessment conducted for US waters off Washington, Oregon and California (Stewart 2007). Commercial fishery and survey selectivity ogives were assumed to be constant over time.

State Moments

The vulnerable (exploitable) biomass, B_t^v, and spawning biomass, B_t, depend on the selectivity vector through equations Table J.3: (D. 4) to (D. 9). Vulnerable biomass requires application of the selectivity vector defined by equation Table J.3: (D. 3) while spawning biomass requires the additional application of the vector of proportions of females mature at age *a*, m_a. The proportion of females mature at age were supplied as data while the mean weight of females at age *a* and time *t*, w_{at}, were specified via von Bertalanffy length at age (Eq. J.1) and an allometric weight-length relationship (Eq. J.2).

Catch biomass for each fishery and year, C_t^g, is assumed to be known without error and fishing is assumed to take place in the middle of the year. The annual exploitation rate is the fraction removed from the beginning of year exploitable biomass that survives to the middle of the year as specified by equation Table J.3: (D. 4). The exploitation rate for each fishery *g* at time *t*, u_{at}^g, is given by the product of an age-specific selectivity and the exploitation rate of fully selected fish at time *t* Table J.3: (D. 5). The age-specific exploitation rate for all gears reflects the composite of all fisheries specified by the sum in equation Table J.3: (D. 6).

Recruitment

Recruitment is derived from a Beverton–Holt relationship with log-normal error structure as

Eq. J.3 $$R_{1,t+1} = N_{1,t+1} = \frac{B_t}{\alpha + \beta B_t} \exp\left({}_{R}\varepsilon_t - {}_{R}\sigma^2 / 2 \right) ,$$

where B_t is the female spawning biomass in year *t* and $\varepsilon_t \sim \left(N, {}_{R}\sigma\right)$ is the corresponding recruitment residual and ${}_{R}\sigma^2/2$ is a bias correction, i.e., the distribution of the recruitment residuals is log-normal. Mace (1994) showed that recruitment at equilibrium in the absence of fishing can be written:

Eq. J.4 $$R_0 = \frac{B^* - \alpha}{\beta B^*} \quad ,$$

where the female spawning biomass per recruit is given by

Eq. J.5 $$B^* = \sum_{a=1}^{A} w_a^f m_a e^{-M_P^f (a-1)} \quad .$$

The Beverton-Holt model can be parameterised in terms of a "steepness" parameter, *h*, defined as the proportion of unfished recruitment that will occur at a spawning biomass which is 20 % of the unfished biomass (Francis 1992). Thus Eq. J.3 can be re-parameterised as

Eq. J.6 $$\alpha = B_0 \frac{1-h}{4hR_0} \;,\; \beta = \frac{5h-1}{4hR_0} \text{, and } B_0 = \overline{R}_0 B^* .$$

where $$\overline{R}_0 = R_0 \frac{\sum_{t=1}^{T} {}_R\varepsilon_t}{T}$$

Note that the estimated recruitment deviates $\left(\left\{{}_R\varepsilon_t\right\}_{t=1}^{T}\right)$ are bias corrected so that the average of the log of all the deviates would be zero if the model were run for a sufficiently long period, as assumed in the normal distribution described above. However, the average of the estimated deviates in the assessment model is not necessarily fixed at zero (i.e., the average multiplier to recruitment is not 1) because the model is allowed to estimate the recruitments freely within the constraints of the prior. B_0 (from Eq. J.6) is the biomass that would result from average stochastic recruitment in the absence of fishing and thus incorporates the bias correction inherent in $\left\{{}_R\varepsilon_t\right\}_{t=1}^{T}$. This is not an issue when assuming deterministic recruitment because no distribution is assumed for the fixed recruitment deviates which are all fixed at zero and the estimated R_0 is always equal to the deterministic average recruitment.

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Stock Abundance Indices

Survey stock abundance indices ${}_sI_t^g$ are related to the underlying biological system by equation Table J.3: (D. 15), where estimated observations ${}_s\overline{I}_t^g$ are denoted by a bar over the quantity. Observed data are derived from research surveys as described elsewhere in this document (Table J.1). No commercial fishery indices are used in this model. Survey abundance indices are assumed to be proportional to the exploitable biomass at the middle of each time step through survey-specific catchability parameters ${}_{s}q^{g}$ (D. 15). The corresponding residuals are assumed to be log-normally distributed with $\xi_{gt} \sim N\left(0, {}_{\xi}\sigma_{g}^{2}\right)$. Thus, the equation:

Eq. J.7 $$ {}_{s}I_{t}^{g} = {}_{s}\overline{I}_{t}^{g} \exp\left(\xi_{gt}\right) \ , $$

implies the likelihood components described by equation (L. 5). The variance ${}_{\xi}\sigma_{g}^{2}$ is provided as input data and serves as a vector of initial weights for fitting the stock abundance indices.

Proportions at age

Proportions at age were obtained from port and at-sea samples of the commercial catch as described in Appendix C. An accumulator or "plus" age class *A* includes all fish equal to, or older than, the designated maximum age in the model. For canary rockfish the accumulator age class consists of all fish age 60 and older. The predicted proportion at age *a* of the catch at time *t* and gear *g* is given by equation Table J.3: (D. 16).

A robust likelihood formulation proposed by Fournier et al. (1998) was used for the proportions at age data. The corresponding likelihood function for the observed proportions at age, $p_{at}^{g,s}$, at age *a*, sex *s* and year *t* for fishery *g* is given by equation Table J.3: (L. 6) where $\overline{p}_{at}^{g,s}$ is the predicted proportion at age, *K* is the number of age classes, and τ_{t}^{g} is the inverse of the assumed sample sizes (these are entered as data and serve as initial weights for the proportions at age). The first constant $0.1/K$ reduces the weight of proportions that are close to zero as happens when age bins are empty or have only a small proportion assigned to them. The second constant 0.01 reduces the weight assigned to large residuals. The net effect is that residuals larger than three standard deviations from the fitted proportion are treated as roughly $3\left(p_{at}^{g,s}\left(1-p_{at}^{g,s}\right)\right)^{0.5}$. The use of the robust formulation is consistent with the belief that small proportions are more likely to be affected by sampling biases and random errors. Coleraine modifies the approach proposed by Fournier et al. (1998) by using the observed rather than the predicted proportions in the first term and the denominator of the second term of the likelihood function Table J.3: (L. 6).

Sequential Algorithm

The model described in Table J.3 includes a population state vector $\left\{N_{at}\right\}_{a=1}^{A}$ for each year *t* with system dynamics for these states defined by equations Table J.3: (D. 10)–(D. 14). These dynamics are a consequence of the parameter vector $\mathbf{\Phi}$ and the control data defined by catch biomass $\left(C_{t}^{g}\right)$, mean fish weight at age *a*, sex *s* and time *t* $\left(w_{at}^{s}\right)$, maturity at age *a* $\left(m_{a}\right)$ and the observed proportions in fishery *g* at age *a*, sex *s* and time *t* $\left(p_{at}^{g,s}\right)$.

The initial population in year one of the model (1940) was assumed to be in equilibrium with the average long-term recruitment, R_0, and the estimated natural mortality vector by age block *P* and sex *s*, M_P^s.

The parameter vector $\mathbf{\Phi}$ includes the recruitment residuals $\{\varepsilon_t\}_{t=1}^{T}$ that determine the initial states N_{a1} at time *t*=1 using equations Table J.3: (D. 10)–(D. 12) and the initial moments from equations Table J.3: (D. 4)–(D. 7). At time *t*=2, the states N_{a2} are determined using the dynamic equations Table J.3: (D. 13)–(D. 14) and the previously computed values (N_{a1}, u_{a1}). Iterative application of this procedure yields values N_{at} for all values of time $t = 2,\ldots,T$. Estimated observations are produced by application of equations Table J.3: (D. 15)–(D. 16) to the values of the states and moments determined at each time step.

Unit Analysis

The average unfished recruitment R_0 determines the units of the numbers of fish N_{at} by equations Table J.3: (D. 10)–(D. 14). The catch from fishery *g* as biomass, C_t^g, is input as units of metric tons of fish. The weight of individual fish, w_{at}^s, is input in units of kg. Hence, the recruitment units are in thousands of fish. Vulnerable biomass, B_t, and spawning biomass, S_t, are therefore in units of metric tons since the harvest rate is catch biomass divided by vulnerable biomass Table J.3: (D. 4).

Log-likelihood

Table J.4 defines the likelihood function $L(\mathbf{\Phi})$ for the stochastic model for the parameter vector $\mathbf{\Phi}$ (L. 1). Computation of the likelihood function begins with the values of $\overline{p}_{at}^s$ and ${}_s\overline{I}_t^g$ from equations Table J.3: (D. 15)–(D. 16) and proceeds through equations Table J.4: (L. 2)–(L. 4) so that the total likelihood corresponds to the sum of the contributions from the survey indices (L. 5) and commercial proportions at age data (L. 6). The variances serve as weighting factors specified externally to the model.

Penalties

Penalties may be added to a likelihood function and serve to constrain and stabilise the parameter estimation. The penalties correspond with prior assumptions made about some of the stochastic processes involved. For the canary rockfish model there is a penalty involved with recruitment variability:

Eq. J.8 $$Penalty_R = 0.5 \sum_{t=1}^{T} \frac{{}_R\varepsilon_t^2}{{}_R\sigma^2} \quad .$$

Informed priors (Appendix I) were used when estimating the three commercial fishery selectivity parameters $\left({}_fS_{full}^g,\ {}_f\nu_L^g,\ {}_f\Delta_{S_{full}}^g\right)$. This was done to restrict the values estimated by the model to a reasonable range. Penalties for deviating from the input prior mean were applied to the three selectivity parameters using Eq. J.9.

Eq. J.9

$$Penalty_{\text{Parameter}} = 0.5\left(\frac{\left(\hat{P} - \bar{X}\right)}{\bar{\sigma}}\right)^2$$

where

$\bar{X}$: prior mean

$\bar{\sigma}$: prior standard deviation

$\hat{P}$: estimated parameter

Estimation of model parameters and uncertainty

Bayesian Analysis

In Bayesian analysis, the objective function is defined as a negative log-posterior

Eq. J.10

$$Objective(\Theta) = -\sum_i \log\left(L(\Theta \mid D)\right) - \log\left(\pi(\Theta)\right)$$

where Θ is the vector of free parameters, L, is the likelihood function for each data source, D is the set of observations, and π is the joint prior density of parameters, Θ. Penalty functions may be added to the log-likelihood as described above. Prior distributions are specified for each model parameter (Table J.5). The negative log posterior for a uniform prior distribution is a constant, so it can be ignored in the model fitting and when computing the MCMC chain. Likewise for parameters with a uniform distribution that are bounded within a specified range, the probability is constant across the specified range and zero probability outside that range. Therefore, the log posterior contribution to the total objective function can be ignored. Note that penalties from parameters with informed priors will be added to the total objective function when computing the MCMC chain.

Model parameters were estimated and uncertainty was assessed by

1. minimising the model objective function to obtain the maximum posterior density (MPD) estimates of the parameters, and

2. generating a sample from the joint posterior probability distribution of the parameters using the Monte Carlo Markov Chain (MCMC) procedure.

The marginal distribution of any model or derived parameters can be approximated from the joint posterior density. The AD Model Builder (Otter Research Ltd. 1999) implementation of the MCMC method based on the Hastings-Metropolis algorithm (Gelman et al. 1995) was used to generate a sample from the joint posterior density. The posteriors were based on 1000 samples selected systematically from a chain of two million simulations. All chains were started from the MPD estimates.

Model fitting

Maximum posterior density estimates of model parameters were obtained by minimising the objective function in phases, with an increasing number of free parameters at each phase of the estimation process. Some model parameters were fixed, most notably the stock-recruitment steepness parameter, the natural mortality parameters, the survey selectivity parameters and the right hand variance of the fishery selectivity (Table J.5).

The unfished recruitment, R_0, and the survey catchability parameters $\left({}_{s}q^{g}\right)$ were estimated in the first phase. The recruitment residuals $\left\{\varepsilon_t\right\}_{t=1}^{T}$, when estimated by some of the models, were estimated in the second phase, followed by the fishery selectivity parameters $\left({}_{f}S_{full}^{g},\ {}_{f}\Delta_{S_{full}}^{g},\ {}_{f}\nu_{L}^{g}\right)$ which were estimated in the final phases (Table J.5).

In order to achieve an objective weighting of data sources, the standard deviations of Pearson or standard normal residuals (*sdnr*) were examined for each data source. Successive fits of a given model involved adjusting relative weights until *sdnr* values close to 1 (a standard normal distribution would have a mean of zero and standard deviation=1) were obtained for each data source. The Pearson residuals are defined as

Eq. J.11 $$r_i^{*} = \frac{\left(O_i - P_i\right)}{SD\left(O_i\right)}$$

where O_i is the observed value, P_i is the predicted value, and $SD\left(O_i\right)$ denotes the corresponding standard deviation of the *i*th observed value. For the normal, lognormal, robustified lognormal, and normal-log error distributions, the standard deviation is calculated as

Eq. J.12 $$SD\left(O_i\right) = \left(P_i\right)\left(CV_i\right) \quad ,$$

where CV_i is the coefficient of variation of the observation (Bull et al. 2005, section 6.8).

In the case of the robust normal likelihood for proportions proposed by Fournier et al. (1998), the standard deviation of the observed proportion at age *a* can be written

Eq. J.13 $$SD\left(O_{ia}\right) = \sqrt{\frac{Z_{ia}}{N_i}} \quad ,$$

where $Z_{ia} = X_{ia}\left(1 - X_{ia}\right) + 0.1/n$ and $N_i' = \min\left(N_i, 200\right)$. Observed or predicted proportions, X_{ia}, can be used depending on whether the original Fournier et al. (1998) formulation or Coleraine (Hilborn et al. 2003) formulation is used for the proportions at age. The sample size associated with the observation (a vector of proportions) is given by N_i and the number of age bins is specified by *n*. This form of the standard deviation was suggested by Bull et al. (2005) on the basis that the residuals would be equivalent to a multivariate normal with standard deviation given by ($\sqrt{X_{ia}\left(1 - X_{ia}\right)/N}$) if the constant 0.01 and $0.1/n$ were omitted from equation (16) and if $N' = N$.

The CV_i and sample sizes N_i are effectively weights associated with each data set. The strategy used during the model fitting process was to adjust the weights such that the standard deviation of the Pearson residuals (*sdnr*) for any data set was approximately 1.0, consistent with the error assumptions. If the *sdnr* was less than 1.0, the data set was judged to have too little weight while the opposite was true if the *sdnr* exceeded 1.0.

Process error can be added to each data source if required to decrease the weight given to the data in the fitting process (i.e., to achieve *sdnr* values near 1). This was accomplished by increasing the coefficient of variations or standard deviations, or by increasing the effective sample sizes in the case of proportion at age data. Where the likelihood is parameterised by the coefficient of variation, process error CV_{err}^2 can be added by

Eq. J.14 $$CV_i' = \sqrt{CV_i^2 + CV_{err}^2} \quad .$$

The sample sizes N_i used in the likelihood corresponding to proportions at age data can be adjusted using the formula for effective sample size proposed by McAllister and Ianelli (1997)

Eq. J.15 $$N_i' = \frac{\sum_{a=1}^{n} P_{ia}\left(1 - P_{ia}\right)}{\sum_{a=1}^{n}\left(O_{ia} - P_{ia}\right)^2} \quad ,$$

where O_{ia} and P_{ia} are the observed and predicted proportions at age *a* for observation *i*, respectively, and *n* is the number of age classes. For this analysis, $N_i' = \min\left(N_i, 200\right)$ was used to avoid putting excessive weight on any one set of age composition data.

<u>Projections</u>

Constant catch policies were evaluated by simulating stock trajectories into the future using the posterior distribution of the final biomass estimate in the stock reconstruction. Five year projections were conducted to allow sufficient time for the cumulative effects of annual harvests to be observed but were restricted to five years because longer projections would lack reliability

Projections were based on parameter estimates made during the stock reconstruction. The total exploitation rate was constrained to be less than 0.8 during the entire projection, but this upper limit had no effect as none of the reconstructions or the MCMC search reached this value.

Projection uncertainty was incorporated from two sources: (1) uncertainty in the current population size determined during the MCMC simulation, and (2) process uncertainty from variability in recruitment. Process uncertainty was simulated during the projection of numbers at age 1 in year *t+1* via the Beverton-Holt stock and recruitment function with ${}_R\sigma = 0.6$,

Eq. J.16 $$N_{1,t+1}^{s} = 0.5\frac{B_t}{\alpha + \beta B_t} e^{\left({}_R\varepsilon_t - {}_R\sigma^2/2\right)} \quad .$$

The female spawning biomass was used for all reconstruction and projection plots and for computation of performance measures. For each of the posterior samples, five-year projections were calculated under levels of catch ranging from 0 to 1,200 t in 100 t increments. A given catch level was held constant at the specified value in each of the projection years.

Results

MPD estimates

Models were fit to the five fishery independent survey indices and the catch-at-age data under a number of assumptions: fixed or estimated selectivities, deterministic or stochastic recruitment and two values of steepness (Table 16). One model omitted the catch-at-age data. The two values of steepness investigated were conditioned on the values used in the US canary rockfish assessment (Stewart 2007). Steepness is a parameter which is poorly estimated in these models and highly uncertain. This analysis bracketed the uncertainty by exploring values of 0.55 and 0.70, a less productive and more productive scenario, respectively. We believe that these fixed values span the range of plausible values for this parameter with canary rockfish, but it is not possible to select which of these values is the more likely.

Table J.7 provides a list of the MPD parameter estimates, *sdnr* values by data source, likelihood components by data source, and selected derived management parameters. The maximum annual exploitation rate over all years, $u_{\max}$, and the year of $u_{\max}$ are listed with the parameters. Derived management parameters are selected from the performance indicators described below.

With the exception of the model run which did not use the catch-at-age data (Run 02), the model results in terms of parameter estimates are remarkably consistent (Table J.7). The estimated values for R_0 are similar across the five model runs which used the catch-at-age data (Runs 05 to 17) and the selectivity parameters, when estimated, are also very similar between model runs. The mean value for the recruitment deviations is also similar for the three stochastic model runs. However, there is a reasonably wide range in the estimates of the status of the stock relative to B_0 (0.09 for Run 02 to 0.35 for Run 08), indicating that these quantities are sensitive to variations in model assumptions and fits to the data. All six models fit the survey data equally well and there is little difference in the fits to the commercial age data for the four model runs which estimated selectivity (Runs 08, 11, 14 and 17). However, the fit to the age data by Run 05 is much poorer than for these runs, suggesting that the selectivity prior based on the US canary assessment (Stewart 2007) is not entirely consistent with the Canadian data.

MPD trajectories

Beginning of year female spawning biomass and total vulnerable biomass (both sexes combined) are compared to the annual catches in Figure J.5, Figure J.9, and Figure J.13. These model runs are presented as examples to show variation across model runs, with Run 05 (Figure J.23) declining to relatively lower levels than the other two examples. Run 11 (Figure J.9), which assumes stochastic recruitment and the higher value of steepness, is relatively more optimistic than the run with stochastic recruitment using the lower steepness value (Run 17; Figure J.31). Note that vulnerable biomass takes into account fishery selectivity and includes both sexes while spawning biomass only tracks female mature biomass. The other three models runs (Run 02, Run 08 and Run 14) assumed deterministic recruitment which seemed less credible and are not plotted. However, these runs did not differ substantially from the stochastic model runs in terms of their fit to the data.

The perspectives on stock status differ between model runs, with the runs which assume deterministic recruitment in general indicating better stock status than the runs which estimated recruitment deviations (Table J.7). However, all model runs suggested that stock status is currently below 40% B_0 and two of the model runs estimated a stock status near to or below 10% B_0. However, the plausibility of these latter model runs is less credible, given the high exploitation rates and large catchability parameters associated with the NMFS triennial and QC Sd synoptic trawl surveys estimated by these model runs (Table J.7). However, model runs, with the possible exception of Run 02 (which omits the catch-at-age data), fit the available data almost equally well (Figure J.6, Figure J.10, and Figure J.14). Thus, it is not easy to use a "best-fit" criterion to select between model runs.

Examination of the fits to the catch-age data revealed that, in general, the deterministic fits were inferior to the stochastic fits. On this basis, we concluded that the models which assumed stochastic recruitment variation were preferred over the deterministic models. As well, the fit to the catch-age data was poorer for Run 05, which used fixed commercial selectivities (Figure J.7 and Figure J.8) than for the two runs which estimated these selectivities (Run 11 and Run 17: Figure J.11, Figure J.12, Figure J.15 and Figure J.16). For instance, note how the predicted fit to the male age proportions in Run 05 are shifted to the right of the observed proportions in many of the years, particularly in recent years (Figure J.7) while the fit is closer for the two runs with estimated selectivity (Figure J.11 and Figure J.15). This behaviour may be caused by the fact that male selectivity is shifted well to the right of the female selectivity in Run 05 while the selectivities for the two sexes are much closer when they are estimated from the catch-age data (Figure J.17). We concluded, based on the observation that the estimated selectivity functions seemed more realistic and led to a better fit to the catch-age data, that Run 05 was less credible than either Run 11 or Run 17.

The parameter estimates in Table J.7 show that the selectivity functions for the four runs which estimated these parameters were all very similar, indicating that these functions are driven by the fit to the catch-age data and are not sensitive to whether recruitment is fixed or estimated. Note that the commercial selectivity for both sexes is shifted to the left of the maturity ogive, indicating that these fisheries are exploiting immature canary rockfish. The survey selectivities are also shifted well to the right of the maturity ogive (Figure J.18).

Biomass trajectories suggest a long gradual decline in biomass into the early to mid-1990s, consistent with the relatively low productivity of this species (Figure J.5, Figure J.9, and Figure J.13). There is a suggestion of an upturn in the trajectory since then, or at least a levelling off. There is also a drop in exploitation rate in the mid-1990s which coincides with significant management changes which were implemented in the trawl fishery in the mid-1990s. Additional management changes have since been implemented in the hook and line fishery in the mid-2000s, which should also lead to reductions in exploitation on this species. While all models, particularly the models which assumed deterministic recruitment, showed a drop in exploitation rates in the mid-1990s, Run 05 and the stochastic recruitment models indicated a subsequent increase in exploitation rate until the mid-2000s, when the exploitation rate dropped (Figure J.6, Figure J.9, and Figure J.13). The stochastic model runs showed a strong drop in recruitment in the late 1980s–early 1990s, followed by an increase by the end of the estimation period (Figure J.31). This drop in recruitment must be partially responsible for the continued decline of this species in the 1990s in spite of lowered landings, although it may also have been driven by the depletion of the spawning biomass (lower right: Figure J.27 and Figure J.31).

MCMC simulations and Bayesian results

MCMC chains of 2 million samples were run to approximate the joint posterior distribution of the model parameters for all runs described in Table 16. Chains were thinned to a sub-sample of 1000 points for graphical presentations of the marginal posterior distributions, diagnostic traces and for summarising performance measures. The 5th, mean and 95% percentiles of the marginal posterior distributions of the fundamental parameters from all six MCMC model runs are presented in Table J.8. The 5th, mean and 95% percentiles of the exploitation rate in the final year of the stock reconstruction (u_{2007}), the maximum exploitation rate over the entire period 1940 to 2007 $(u_{\max})$ and the year in which $(u_{\max})$ occurred are presented in Table J.9. Finally, the 5th, mean and 95% percentiles for three derived parameters of management interest are presented in Table J.10: the ratio of the female spawning biomass at the end of the reconstruction (B_{2008}) relative to B_0; the ratio of the female spawning biomass at the end of the projection period (B_{2013}) relative to B_0; and the ratio of B_{2013} to B_{2008}.

Diagnostics focused on trace plots of the parameters through the chain and cumulative plots of selected quantiles of the distributions of parameters over the chain. Not all diagnostics for each model run are reported here. In general, the diagnostic plots indicated that all chains had converged and the plots presented here are representative of all model runs.

A reasonably complete set of diagnostic plots are presented for Run 11. Run 11 was selected as being the most plausible of the six runs presented here, making use of the catch-at-age data, estimating the commercial selectivity for each sex as well as the recruitment deviations and assuming the higher of the two steepness values investigated. Cumulative quantiles for the fundamental parameters indicate that the MCMC chain had converged quickly for this model run (Figure J.19), as do the traces for the parameters (Figure J.20), the traces for the annual biomasses (Figure J.21) and recruitments (Figure J.22). Marginal posterior distributions for the parameters (Figure J.23), the annual biomasses (Figure J.24) and recruitments (Figure J.25) all show symmetrical distributions which also show some effects from the variations in recruitment.

The model and the posterior probability density were used to conduct one to five year stock projections at a range of constant annual levels of catch (Figure J.26 and Figure J.27). Projections run from beginning of year 2008 to beginning of year 2013 for catch levels from 0 to 1200 t in increments of 100 t (the 1200 t catch level has been omitted from the plots). The annual catches at each level were held constant over the entire projection period. The projections indicate the range of expected outcomes that arise from adopting a fixed annual catch over the projection period. The projections were extended for five years so that differences between options become more apparent. The differences reflect the consequences of the uncertainty captured in the posterior density of the model parameters and the assumed recruitment uncertainty. Actual future recruitment is highly uncertain, and becomes increasingly so as the projection period increases. Performance measures were calculated for each projection to assist the selection of short-term catch recommendations.

Cumulative quantile plots for Run 02 (the run which omitted the catch-at-age data) indicate that one of the effects of including the age data in the model was to exclude the probability of very large biomass levels. Run 02 is much more variable at the upper end of R_0 and biomass levels compared to the five other model runs (Figure J.28). This is borne out by a plot of the marginal posterior distribution for R_0, which a long right hand tail which is absent in the other model runs (compare Figure J.29 with Figure J.19), as well as the biomass trajectories which show wide upper bounds in all years (Figure J.30). Run 08 shows the opposite problem, with substantially less variation than either Run 02 or Run 11 (Figure J.31).

Performance indicators

No biological reference points have been specified for canary rockfish, nor are there good candidates for sensible reference points that can be inferred from the biomass trajectory. This is because most of the stock reconstruction shows a steady declining trend (a "one-way trip"). Two arbitrary reference points have been selected based on the equilibrium spawning biomass consistent with the model estimate of R_0 (B_0: Eq. J.6). These suggested reference points are $0.4B_0$ and half this value or $0.2B_0$. These values are consistent with reference points used by the National Marine Fisheries Service in the United States (Stewart 2007).

Performance indicators are expressed in terms of the beginning of year *y* female spawning biomass, $\tilde{B}_y$, where $2009 \leq y \leq 2013$ relative to one of the biological reference points described in the previous paragraph. Each projection year is also evaluated with respect to the size of the B_{2008}, the beginning year biomass from the final year of the stock reconstruction. The implications of the full five years of projection are referenced by $\tilde{B}_{2013}$. The performance indicators evaluated for canary rockfish are listed below.

1. The probability that $\tilde{B}_y$ is greater than or equal to 0.4 B_0: $\mathrm{P}\left(\tilde{B}_y \geq 0.4B_0\right)$;
2. The probability that $\tilde{B}_y$ is greater than or equal to 0.2 B_0: $\mathrm{P}\left(\tilde{B}_y \geq 0.2B_0\right)$;
3. The expected value of the ratio of $\tilde{B}_y$ relative to B_0: $\mathrm{E}\left(\tilde{B}_y / B_0\right)$;
4. The probability that $\tilde{B}_y$ is greater than B_{2008}:: $\mathrm{P}\left(\tilde{B}_y > B_{2008}\right)$;
5. The expected ratio of $\tilde{B}_y$ relative to $B_{2008:}$ $\mathrm{E}\left(\tilde{B}_y / B_{2008}\right)$.

Decision tables which evaluate each of the above performance indicators across a range of constant catch strategies over a period of five projection years are presented for the model runs in Table 16: Run 02 (Table J.12 and Table J.13), Run 05 (Table J.14 and Table J.15), Run 08 (Table J.16 and Table J.17), Run 11 (Table J.18 and Table J.19), Run 14 (Table J.20 and Table J.21), and Run 17 (Table J.22 and Table J.23). These tables indicate that there is a very low probability from any of the model runs that the stock will reach or exceed 0.4 B_0 over the next five years, even if no catch is taken. This is likely due to the relatively low productivity of this species and the generally low stock status estimated by this model. On the other hand, there is generally good agreement amongst all the model runs that the stock will increase under catch levels from 600 to 900 t per year, depending on the model run selected.

Table J.1 Data used in canary rockfish catch-age model.

Data type	Years	Reference
Catch	1940–2006	Appendix B
Age composition from commercial trawl fishery	1978–2004	Appendix C
WCVI shrimp trawl survey	1975–2007	Appendix D
QCSd shrimp trawl survey	1999–2007	Appendix E
GB Reed trawl survey	1967–1984	Appendix F
NMFS Triennial trawl survey	1980–2001	Stanley et al. (2005)
QCSd synoptic trawl survey	2003–2007	Appendix G

Table J.2 Notation for the canary rockfish catch-age model.

Symbol	Description
	Indices and Index Ranges
a	Age class, where $1 \le a \le A$ and *a*=1 corresponds to fish assigned age 1.
A	Accumulator age class or plus group of fish aged *A* and older (same value for both sexes)
P	Period index over which natural mortality $\left(M_P^s\right)$ parameter applies, where *P*=1 or *P*=2 only
C^s	Switch age for sex *x* to move from *P*=1 to *P*=2, where $1 \le a \le C^s$ for *P*=1 and $C^s + 1 \le a \le A$ for *P*=2
g	Survey or fishery index
G	Number of surveys
$s: m, f$	Indices for sex *s*: male (*m*) and female (*f*)
j	Dummy variable with value 1 for females and 0 for males
t	Time (year), where $1 \le t \le T$ and *t*=1 corresponds to the first year
T	Final year
T_g	Sets of years for survey index *g*
	Data
C_t^g	Catch in tonnes in year *t* for fishery *g*
${}_sI_t^g$	Survey index *g* in year *t*
$p_{at}^{g,s}$	Observed proportion of age class *a* for sex *s* in the catch for year *t* for fishery *g*
m_a	Proportion of females mature at age *a*
	Fixed Parameters
h	Steepness parameter from a Beverton-Holt recruitment model
M_P^s	Instantaneous rate of natural mortality for sex *s* in age period *P*
$\left(b_0^s, b_1^s\right)$	Parameters of the allometric length-weight relationship for sex *s*
$\left(t_0^s, k^s, L_\infty^s\right)$	von Bertalanffy growth model parameters for sex *s*
w_{at}^s	Weight at age *a* for sex *s* at time *t*

Table J.2. (cont.)

Symbol	Description
	Fixed Parameters (cont.)
$\left({}_{s}S_{full}^{g},{}_{s}\nu_{L}^{g},{}_{s}\nu_{R}^{g},{}_{s}\Delta_{S_{full}}^{g}\right)$	Age of full female selectivity, left (*L*), right (*R*) variances, and male offset to the full selectivity parameter for survey *g*
${}_{R}\sigma$	Standard deviation of recruitment
	Estimated Parameters
R_0	Mean unfished recruitment numbers from a Beverton-Holt model
${}_{s}q^{g}$	Catchability for the g^{th} survey (*s*)
$\left({}_{f}S_{full}^{g},{}_{f}\nu_{L}^{g},{}_{f}\nu_{R}^{g},{}_{f}\Delta_{S_{full}}^{g}\right)$	Age of full female selectivity, left (*L*), and right (*R*) variances, and male offset to the full selection parameter for fishery *g*.
${}_{R}\varepsilon_{t}\sim N(0,{}_{R}\sigma^{2})$	Recruitment deviation for year *t*
	Derived Parameters
B_t^v	Vulnerable (exploitable) biomass at the start of year *t* (combined male and female)
$N_{a,t}^{s}$	Number of age class *a* fish at the start of year *t* for sex *s*
B_t	Female spawning biomass at the start of year *t*
$s_a^{g,s}$	Selectivity for fishery *g* at age *a* for sex *s*
u_t^g	Harvest (exploitation) rate for fishery *g* in year *t*

Table J.3 Deterministic catch-age model listing calculations that define all states and observations given the parameter vector $\mathbf{\Phi}$. Vector $\mathbf{\Theta}$ defines parameters estimated by the canary rockfish catch-age model.

Parameters

(D. 1) $$\mathbf{\Phi} = \left(R_0, h, M_P^s, \left\{{}_R\varepsilon_t\right\}_{t=1}^T, {}_fS_{full}^g, {}_f\nu_L^g, {}_f\Delta_{S_{full}}^g, {}_sS_{full}^g, {}_s\nu_L^g, {}_s\Delta_{S_{full}}^g, {}_sq^g\right)$$

(D. 2) $$\mathbf{\Theta} = \left(R_0, \left\{\varepsilon_t\right\}_{t=1}^T, {}_fS_{full}^g, {}_f\Delta_{S_{full}}^g, \nu_L^g, {}_sq^g\right)$$

Selectivity (*Fishery or Survey*)

$$s_a^{g,s} = \begin{cases} \exp\left\{\dfrac{-\left(a - S_{full}^{g,s}\right)^2}{\nu_L^g}\right\} & a \le S_{full}^{g,s} \\ \exp\left\{\dfrac{-\left(a - S_{full}^{g,s}\right)^2}{\nu_R^g}\right\} & a > S_{full}^{g,s} \end{cases}$$

(D. 3) where:

$$S_{full}^{g,s} = S_{full}^{g,s} + (1-j)\Delta_{S_{full}}^g$$

State Moments

(D. 4) $$u_t^g = \frac{C_t^g}{\sum_s \sum_a \mathrm{e}^{-0.5M_P^s} s_{a,t}^{g,s} N_{a,t}^s w_{a,t}^s}$$

(D. 5) $$u_{at}^{g,s} = s_a^{g,s} u_t^g$$

(D. 6) $$u_{a,t}^s = \sum_{g=1}^G u_{a,t}^{g,s}$$

(D. 7) $$s_a^s = \sum_{g=1}^G s_a^{g,s} u_t^g \Bigg/ \sum_{g=1}^G u_t^g$$

(D. 8) $$B_t^v = \sum_{s=m}^{s=f} \sum_{a=1}^A s_a^s N_{at}^s w_{at}^s$$

(D. 9) $$B_t = \sum_{a=1}^A m_a N_{at}^f w_{at}^f$$

Table J.3. (cont.)

Initial States $(t = 1)$

(D. 10) $$N_{1,1}^s = 0.5R_0$$

(D. 11) $$N_{a,1}^s = N_{1,1} \prod_{i=1}^{a-1} \mathrm{e}^{-M_P^s(a-1)}\left(1 - s_i^s u_0^s\right) \qquad 2 \le a < A$$

(D. 12) $$N_{A,1}^{s} = N_{1,1}^{s} \frac{\prod_{a=1}^{A-1} \mathrm{e}^{-M_P^s(A-1)}\left(1-s_a^s u_0^s\right)}{1-\prod_{a=1}^{A-1} \mathrm{e}^{-M_P^s(A-1)}\left(1-s_a^s u_0^s\right)}$$

State Dynamics $\left(2 \le t \le T\right)$

(D. 13) $$N_{1,t}^{s} = 0.5 \frac{B_{t-1}}{\left(\alpha + \beta B_{t-1}\right)} e^{\left({}_R\varepsilon_t - {}_R\sigma^2/2\right)}$$

(D. 14) $$N_{a,t}^{s} = e^{-M_P^s} N_{a-1,t-1}^{s}\left(1-u_{a-1,t-1}^{s}\right) \qquad \left(2 \le a \le A\right)$$

Predicted Observations $\left(1 \le t \le T\right)$

(D. 15) $${}_s\overline{I}_t^{g} = {}_s q^{g} \sum_{s=m}^{s=f} \sum_{a=1}^{A} \mathrm{e}^{-0.5 M_P^s} s_{at}^{g,s} N_{at}^{s} w_{at}^{s} \; ; \qquad \left(t \in T_g\right)$$

(D. 16) $$\overline{p}_{at}^{g,s} = \frac{s_a^{g,s} N_{at}^{s}}{\sum_{a}^{A} s_a^{g,s} N_{at}^{s}} \; ; \qquad \left(1 \le a \le A\right)$$

Table J.4 Likelihood function for the model in Table J.3 where sequential calculations begin with the parameter vector $\mathbf{\Phi}$ and proceed to define $L(\mathbf{\Phi})$.

	Parameters
(L. 1)	$\mathbf{\Phi} = \left(R_0, h, M_P^s, \{{}_R\varepsilon_t\}_{t=1}^T, {}_fS_{full}^g, {}_f\nu_L^g, {}_f\Delta_{S_{full}}^g, {}_sS_{full}^g, {}_s\nu_L^g, {}_s\Delta_{S_{full}}^g, {}_sq^g\right)$
	Residuals
(L. 2)	${}_R\varepsilon_t = \log N_{1t} - \log R_t + \left({}_R\sigma^2/2\right); \qquad (1 \le t \le T)$
(L. 3)	$\xi_t^g = \log {}_sI_t^g - \log {}_s\bar{I}_t^g; \qquad \left(t \in \mathbf{T}_g'\right)$
	Log Likelihoods
(L. 4)	$\ln L_1^g(\mathbf{\Phi}) = \log\left(\sqrt{2\pi}\,{}_\zeta\sigma_g\right)^{-T_g} + \left[-0.5\sum_{t=1}^{T_g}\frac{\zeta_{gt}^2}{{}_\zeta\sigma_g^2}\right]$
(L. 5)	$\ln L_2^g(\mathbf{\Phi}) = -0.5\sum_{t=1}^{T}\sum_{s=m}^{s=f}\sum_{a=1}^{A}\ln\left[p_{at}^{gs}\left(1-p_{at}^{gs}\right)+\frac{0.1}{K}\right] + \sum_{t=1}^{T}\sum_{s=m}^{s=f}\sum_{a=1}^{A}\ln\left[\exp\left\{\frac{-\left(p_{at}^{gs}-\bar{p}_{at}^{gs}\right)}{2\left(p_{at}^{gs}\left(1-p_{at}^{gs}\right)+0.1/K\right)\tau_t^g}\right\}+0.01\right]$
(L. 6)	$\ln L(\mathbf{\Phi}) = \sum_{g=1}^{G}\ln L_1^g(\mathbf{\Phi}) + \sum_{g=1}^{G}\ln L_2^g(\mathbf{\Phi})$

Table J.5 Prior distributions for model parameters and values for fixed parameters. Indices for the survey (*s*) selectivity and catchability parameters are 1=GB Reed; 2=WCVI shrimp survey; 3=NMFS Triennial survey; 4=QC Sound synoptic survey; and 5=QC Sound shrimp survey. The estimation phase for the 3 selectivity parameters varied, depending on whether the model run assumed stochastic or deterministic recruitment.

Parameter	Prior Dist.	Mean/Parameters	Initial Value	Bounds	Esti. Phase
Estimated parameters					
R_0	Uniform	–	10000	[1, 1,000,000]	1
${}_R\varepsilon_t$	Log-Normal	$\mu = 0$; ${}_R\sigma = 0.6$	0	[-15, 15]	2
${}_fS^1_{full}$	Normal	$\mu = 12.44$; $\sigma = 2.44$	12.44	[5, 40]	(2,3)
${}_f\nu^1_L$	Normal	$\mu = 2.72$; $\sigma = 0.679$	2.72	[-8, 10]	(3,4)
${}_f\Delta^1_{S_{full}}$	Normal	$\mu = 1.93$; $\sigma = 0.386$	1.93	[-15, 15]	(3,4)
${}_sq^g$, $g = 1-5$	Uniform	–	-5	[-12, 5]	1
Fixed parameters					
h	–	–	(0.7 or 0.55)	–	–
$\left(M^m_1, M^m_2\right)$	–	–	(0.06, 0.06)	–	–
$\left(M^f_1, M^f_2\right)$	–	–	(0.06, 0.12)	–	–
C^f	–	–	13		
${}_f\nu^1_R$	–	–	100	–	–
${}_sS^g_{full}$, $g = 1-5$	–	–	16.4	–	–
$\left({}_s\nu^g_L,\ {}_s\nu^g_R\right)$, $g = 1-5$	–	–	(4.60, 100)	–	–
${}_s\Delta^g_{S_{full}}$, $g = 1-5$	–	–	1.25	–	–

Table J.6. Description of the six stock assessment runs made by the canary rockfish catch-age model. All models used the same catch vector and were fitted to the five surveys referenced in Table J.1.

Run number	Catch-at-age data	Recruitment	Commercial selectivity	Steepness
Run 02	Not used	Deterministic	Fixed	0.70
Run 05	Used	Stochastic	Fixed	0.70
Run 08	Used	Deterministic	Estimated	0.70
Run 11	Used	Stochastic	Estimated	0.70
Run 14	Used	Deterministic	Estimated	0.55
Run 17	Used	Stochastic	Estimated	0.55

Table J.7. MPD results for the six canary rockfish model runs described in Table 16. Fixed parameters are shaded in grey. –: not applicable.

	Run 02	Run 05	Run 08	Run 11	Run 14	Run 17
Parameters						
R_0	1,393	1,648	1,624	1,667	1,675	1,718
${}_fS^1_{full}$	12.4	12.4	14.0	13.9	14.1	13.9
${}_f\Delta^1_{S_{full}}$	1.93	1.93	-0.38	-0.42	-0.38	-0.42
${}_f\nu^1_L$	2.72	2.72	2.62	2.53	2.63	2.54
${}_sq^{\text{GB Reed}}$	0.01	0.01	0.01	0.01	0.01	0.01
${}_sq^{\text{WCVI shrimp}}$	0.07	0.05	0.04	0.05	0.04	0.05
${}_sq^{\text{NMFS Triennial}}$	0.49	0.32	0.29	0.36	0.30	0.37
${}_sq^{\text{QC synoptic}}$	0.33	0.26	0.13	0.22	0.15	0.25
${}_sq^{\text{QC shrimp}}$	0.003	0.002	0.001	0.002	0.001	0.002
mean e^{ε_t}	1	1.44	1	1.40	1	1.37
Standard deviation of normalised residuals						
$\text{sdnr}\left[{}_sq^{\text{GB Reed}}\right]$	1.05	1.01	1.00	1.01	1.00	1.01
$\text{sdnr}\left[{}_sq^{\text{WCVI shrimp}}\right]$	1.05	1.01	1.01	1.01	1.01	1.01
$\text{sdnr}\left[{}_sq^{\text{NMFS triennial}}\right]$	0.98	1.00	1.01	1.00	1.01	1.00
$\text{sdnr}\left[{}_sq^{\text{QC synoptic}}\right]$	1.06	0.98	1.01	1.00	1.01	1.00
$\text{sdnr}\left[{}_sq^{\text{QC shrimp}}\right]$	1.05	0.99	1.01	1.00	1.01	1.00
$\text{sdnr}[\text{age}]$	–	0.74	0.71	0.70	0.71	0.71
Likelihoods						
$\text{like}\left[{}_sq^{\text{GB Reed}}\right]$	2.8	2.7	2.6	2.8	2.7	2.8
$\text{like}\left[{}_sq^{\text{WCVI shrimp}}\right]$	25.4	25.7	26.1	24.1	25.6	24.3
$\text{like}\left[{}_sq^{\text{NMFS triennial}}\right]$	3.3	3.7	4.5	3.6	4.2	3.5
$\text{like}\left[{}_sq^{\text{QC synoptic}}\right]$	-2.3	-2.6	-1.6	-1.4	-1.8	-1.7
$\text{like}\left[{}_sq^{\text{QC shrimp}}\right]$	3.2	3.5	3.1	3.1	3.1	3.2
$\text{like}[\text{age}]$	–	-4,220.4	-4,270.9	-4,272.3	-4,268.6	-4,270.3
penalties	–	9.0	18.1	25.1	18.1	24.7
$\text{like}[\text{Total}]$	32.3	-4,178.5	-4,218.1	-4,215.0	-4,216.7	-4,213.5

Table J.7. (cont.)

	Run 02	Run 05	Run 08	Run 11	Run 14	Run 17
Derived parameters						
B_0 [1]	7,661	8,109	8,930	8,168	9,212	8,467
B_0^v [2]	24,229	25,743	27,411	25,169	28,290	26,092
$\left(B_{2008}/B_0\right)$	0.09	0.11	0.35	0.21	0.27	0.17
$\left(B_{2008}/B_0^v\right)$	0.12	0.13	0.33	0.22	0.26	0.17
$u_{\max}$	0.28	0.21	0.17	0.20	0.17	0.23
year of $u_{\max}$	1994	2005	1989	2005	1989	2005

[1] female spawning biomass only
[2] female plus male biomass

Table J.8. Bayesian MCMC parameter estimates for all model runs (Table 16). Summary statistics (mean, 5th and 95th percentiles) are shown for posteriors corresponding to selected parameters. –: not estimated.

	5%	Mean	95%	5%	Mean	95%	5%	Mean	95%
		R_0			${}_sq^{\text{GB Reed}}$			${}_sq^{\text{WCVI shrimp}}$	
Run02	1,361	1,477	1,709	0.007	0.012	0.018	0.030	0.057	0.085
Run05	1,427	1,612	1,811	0.006	0.009	0.014	0.035	0.049	0.065
Run08	1,582	1,628	1,678	0.006	0.010	0.014	0.027	0.036	0.047
Run11	1,457	1,632	1,822	0.006	0.010	0.015	0.035	0.047	0.062
Run14	1,639	1,679	1,724	0.006	0.009	0.014	0.030	0.039	0.051
Run17	1,518	1,695	1,883	0.007	0.010	0.015	0.038	0.050	0.065
		${}_sq^{\text{NMFS triennial}}$			${}_sq^{\text{QC synoptic}}$			${}_sq^{\text{QC shrimp}}$	
Run02	0.21	0.44	0.74	0.11	0.27	0.49	0.0008	0.0024	0.0046
Run05	0.20	0.35	0.57	0.14	0.24	0.37	0.0010	0.0020	0.0034
Run08	0.16	0.30	0.50	0.08	0.13	0.20	0.0006	0.0012	0.0020
Run11	0.21	0.37	0.59	0.13	0.22	0.37	0.0010	0.0020	0.0033
Run14	0.17	0.31	0.52	0.10	0.16	0.23	0.0008	0.0014	0.0023
Run17	0.22	0.38	0.61	0.15	0.25	0.40	0.0011	0.0022	0.0037
		${}_fS_{full}^1$			${}_f\Delta_{S_{full}}^1$			${}_f\nu_L^1$	
Run02	–	–	–	–	–	–	–	–	–
Run05	–	–	–	–	–	–	–	–	–
Run08	13.5	14.0	14.5	-0.62	-0.37	-0.10	2.43	2.61	2.79
Run11	13.3	13.8	14.3	-0.60	-0.39	-0.18	2.30	2.49	2.67
Run14	13.6	14.1	14.5	-0.62	-0.38	-0.15	2.44	2.63	2.80
Run17	13.3	13.8	14.3	-0.60	-0.39	-0.18	2.31	2.50	2.67
		$\left\{e^{R\varepsilon_t}\right\}_{t=1}^{T}$							
Run02	0	0	0						
Run05	-0.813	0.011	0.798						
Run08	0	0	0						
Run11	-0.701	0.020	0.727						
Run14	0	0	0						
Run17	-0.697	0.026	0.721						

Table J.9. Bayesian MCMC exploitation rate estimates for all model runs (Table 16). Summary statistics (mean or median, 5th and 95th percentiles) are shown for posteriors corresponding to the selected derived parameters.

	5%	Mean	95%	5%	Mean	95%	5%	Median	95%
	u_{2007}			u_{max}			year of u_{max}		
Run02	0.07	0.20	0.39	0.14	0.25	0.39	1989	1992	2007
Run05	0.10	0.17	0.28	0.15	0.20	0.28	1989	2005	2007
Run08	0.08	0.09	0.10	0.15	0.17	0.18	1989	1989	1989
Run11	0.09	0.15	0.23	0.18	0.21	0.29	1989	2005	2005
Run14	0.09	0.11	0.12	0.16	0.17	0.18	1989	1989	1989
Run17	0.11	0.18	0.27	0.18	0.23	0.32	1989	2005	2005

Table J.10. Bayesian MCMC derived parameter estimates for all model runs (Table 16). Summary statistics (mean or median, 5th and 95th percentiles) are shown for posteriors corresponding to the selected derived parameters of management interest. Five year projections assume annual catches of 900 t.

	5%	Mean	95%	5%	Mean	95%	5%	Mean	95%
	B_{2008}/B_0			B_{2013}/B_0			B_{2013}/B_{2008}		
Run02	0.05	0.15	0.34	0.01	0.12	0.34	0.18	0.68	1.00
Run05	0.07	0.15	0.23	0.02	0.12	0.22	0.31	0.75	1.13
Run08	0.32	0.35	0.38	0.32	0.35	0.38	0.99	1.00	1.01
Run11	0.14	0.22	0.31	0.12	0.24	0.37	0.78	1.10	1.46
Run14	0.24	0.27	0.30	0.22	0.25	0.28	0.89	0.92	0.94
Run17	0.10	0.17	0.25	0.06	0.16	0.27	0.51	0.88	1.22
	B_0 [1]			B_0^v [2]					
Run02	7,484	8,121	9,401	23,670	25,685	29,732			
Run05	7,766	8,401	9,122	24,630	26,619	28,904			
Run08	8,699	8,954	9,228	26,487	27,490	28,565			
Run11	7,748	8,395	9,135	23,840	25,865	28,182			
Run14	9,017	9,232	9,483	27,449	28,355	29,342			
Run17	8,058	8,747	9,568	24,831	26,955	29,484			

[1] female spawning biomass only
[2] female plus male biomass

Table J.11. Probabilities for indicated performance indicators for all model runs (Table 16). Five year projections assume annual catches of 900 t.

	Model Run Number					
	Run 02	**Run 05**	**Run 08**	**Run 11**	**Run 14**	**Run 17**
$P(B_{2008} \geq 0.2B_0)$	0.20	0.15	1.00	0.61	1.00	0.27
$P(B_{2008} \geq 0.4B_0)$	0.03	0.00	0.00	0.00	0.00	0.00
$P(B_{2013} \geq 0.2B_0)$	0.17	0.08	1.00	0.68	1.00	0.25
$P(B_{2013} \geq 0.4B_0)$	0.04	0.00	0.00	0.03	0.00	0.00
$P(B_{2013} > B_{2008})$	0.06	0.13	0.78	0.69	0.00	0.28

Table J.12 Decision tables of B_0 performance indicators for 1-5 year projections for Run 02. Statistics relate to beginning of year female spawning biomass relative to the female spawning B_0 biomass. The probability of biomass in the projection year exceeding one of the reference values (upper two tables) can be compared to the expected value of the biomass relative to B_0 (lowest table).

Annual catch strategy	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
	$\mathrm{P}\left(\tilde{B}_y \geq 0.2B_0\right)$					
0	0.199	0.294	0.400	0.521	0.661	0.773
100	0.199	0.282	0.368	0.475	0.593	0.692
200	0.199	0.267	0.338	0.430	0.515	0.609
300	0.199	0.257	0.312	0.382	0.456	0.522
400	0.199	0.240	0.293	0.336	0.393	0.448
500	0.199	0.226	0.267	0.303	0.335	0.372
600	0.199	0.217	0.238	0.266	0.291	0.308
700	0.199	0.208	0.217	0.224	0.236	0.253
800	0.199	0.197	0.195	0.195	0.195	0.196
900	0.199	0.188	0.180	0.176	0.171	0.168
1000	0.199	0.181	0.171	0.159	0.153	0.148
1100	0.199	0.177	0.159	0.151	0.140	0.127
1200	0.199	0.171	0.153	0.140	0.120	0.105
	$\mathrm{P}\left(\tilde{B}_y \geq 0.4B_0\right)$					
0	0.034	0.040	0.043	0.069	0.083	0.120
100	0.034	0.040	0.042	0.059	0.077	0.097
200	0.034	0.037	0.042	0.053	0.071	0.083
300	0.034	0.036	0.040	0.044	0.060	0.073
400	0.034	0.036	0.040	0.042	0.051	0.062
500	0.034	0.035	0.040	0.040	0.042	0.051
600	0.034	0.035	0.037	0.040	0.041	0.042
700	0.034	0.035	0.035	0.037	0.040	0.040
800	0.034	0.035	0.035	0.035	0.036	0.037
900	0.034	0.034	0.035	0.035	0.035	0.035
1000	0.034	0.033	0.033	0.032	0.031	0.030
1100	0.034	0.032	0.029	0.029	0.029	0.028
1200	0.034	0.030	0.029	0.028	0.027	0.025
	$\mathrm{E}\left(\tilde{B}_y / B_0\right)$					
0	0.152	0.174	0.198	0.225	0.253	0.282
100	0.152	0.171	0.192	0.214	0.238	0.263
200	0.152	0.167	0.185	0.204	0.224	0.244
300	0.152	0.164	0.178	0.193	0.209	0.226
400	0.152	0.161	0.172	0.183	0.195	0.207
500	0.152	0.158	0.165	0.173	0.181	0.189
600	0.152	0.155	0.159	0.163	0.167	0.172
700	0.152	0.152	0.152	0.153	0.154	0.155
800	0.152	0.149	0.146	0.143	0.141	0.138
900	0.152	0.146	0.140	0.134	0.128	0.123
1000	0.152	0.142	0.133	0.124	0.116	0.108
1100	0.152	0.139	0.127	0.115	0.105	0.095
1200	0.152	0.136	0.121	0.107	0.094	0.084

Table J.13 Decision tables of B_{2008} performance indicator for 1-5 year projections for Run 02. Statistics relate to beginning of year female spawning biomass relative to the beginning year 2008 female spawning biomass. The probability of biomass in the projection year exceeding the reference value (upper table) can be compared to the expected value of the biomass relative to B_{2008} (lower table).

Annual catch strategy	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
	$\mathrm{P}\left(\tilde{B}_y > B_{2008}\right)$					
0	0	1.000	1.000	1.000	1.000	1.000
100	0	1.000	1.000	1.000	1.000	1.000
200	0	1.000	1.000	1.000	1.000	1.000
300	0	1.000	1.000	1.000	1.000	1.000
400	0	1.000	1.000	1.000	1.000	1.000
500	0	0.979	0.982	0.986	0.986	0.983
600	0	0.816	0.839	0.856	0.863	0.864
700	0	0.485	0.506	0.519	0.535	0.542
800	0	0.171	0.176	0.180	0.185	0.188
900	0	0.053	0.054	0.055	0.056	0.056
1000	0	0.013	0.012	0.013	0.013	0.013
1100	0	0.000	0.001	0.001	0.001	0.001
1200	0	0.000	0.000	0.000	0.000	0.000
	$\mathrm{E}\left(\tilde{B}_y / B_{2008}\right)$					
0	1	1.185	1.394	1.627	1.878	2.139
100	1	1.156	1.333	1.529	1.738	1.957
200	1	1.128	1.272	1.431	1.601	1.776
300	1	1.099	1.211	1.334	1.465	1.599
400	1	1.070	1.151	1.238	1.331	1.425
500	1	1.042	1.091	1.144	1.200	1.256
600	1	1.013	1.031	1.052	1.074	1.095
700	1	0.985	0.972	0.962	0.953	0.943
800	1	0.956	0.915	0.876	0.840	0.804
900	1	0.928	0.859	0.794	0.734	0.680
1000	1	0.900	0.804	0.716	0.639	0.572
1100	1	0.872	0.752	0.645	0.555	0.482
1200	1	0.844	0.701	0.579	0.482	0.408

Table J.14 Decision tables of B_0 performance indicators for 1-5 year projections for Run 05. Statistics relate to beginning of year female spawning biomass relative to the female spawning B_0 biomass. The probability of biomass in the projection year exceeding one of the reference values (upper two tables) can be compared to the expected value the biomass relative to B_0 (lowest table).

Annual catch strategy	2008	2009	2010	2011	2012	2013
	$P(\tilde{B}_y \geq 0.2B_0)$					
0	0.152	0.253	0.374	0.568	0.740	0.867
100	0.152	0.235	0.343	0.494	0.654	0.789
200	0.152	0.219	0.308	0.415	0.560	0.696
300	0.152	0.199	0.276	0.348	0.465	0.589
400	0.152	0.186	0.242	0.299	0.374	0.473
500	0.152	0.174	0.201	0.249	0.307	0.367
600	0.152	0.163	0.175	0.204	0.233	0.275
700	0.152	0.153	0.156	0.163	0.189	0.214
800	0.152	0.136	0.135	0.125	0.125	0.132
900	0.152	0.121	0.103	0.086	0.082	0.083
1000	0.152	0.113	0.079	0.064	0.052	0.052
1100	0.152	0.102	0.062	0.047	0.039	0.037
1200	0.152	0.087	0.053	0.037	0.031	0.025
	$P(\tilde{B}_y \geq 0.4B_0)$					
0	0.000	0.000	0.001	0.004	0.010	0.026
100	0.000	0.000	0.000	0.002	0.005	0.019
200	0.000	0.000	0.000	0.001	0.004	0.009
300	0.000	0.000	0.000	0.000	0.001	0.004
400	0.000	0.000	0.000	0.000	0.000	0.002
500	0.000	0.000	0.000	0.000	0.000	0.000
600	0.000	0.000	0.000	0.000	0.000	0.000
700	0.000	0.000	0.000	0.000	0.000	0.000
800	0.000	0.000	0.000	0.000	0.000	0.000
900	0.000	0.000	0.000	0.000	0.000	0.000
1000	0.000	0.000	0.000	0.000	0.000	0.000
1100	0.000	0.000	0.000	0.000	0.000	0.000
1200	0.000	0.000	0.000	0.000	0.000	0.000
	$E(\tilde{B}_y / B_0)$					
0	0.146	0.165	0.188	0.213	0.240	0.270
100	0.146	0.162	0.181	0.203	0.226	0.252
200	0.146	0.159	0.175	0.192	0.212	0.234
300	0.146	0.156	0.168	0.182	0.199	0.216
400	0.146	0.153	0.162	0.172	0.185	0.199
500	0.146	0.149	0.155	0.162	0.171	0.181
600	0.146	0.146	0.149	0.152	0.158	0.164
700	0.146	0.143	0.142	0.143	0.144	0.147
800	0.146	0.140	0.136	0.133	0.131	0.131
900	0.146	0.137	0.130	0.123	0.119	0.115
1000	0.146	0.134	0.123	0.114	0.106	0.100
1100	0.146	0.131	0.117	0.105	0.094	0.086
1200	0.146	0.128	0.111	0.096	0.083	0.073

Table J.15 Decision tables of B_{2008} performance indicator for 1-5 year projections for Run 05. Statistics relate to beginning of year female spawning biomass relative to the beginning year 2008 female spawning biomass. The probability of biomass in the projection year exceeding the reference value (upper table) can be compared to the expected value of the biomass relative to B_{2008} (lower table).

Annual catch strategy	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
	$\mathrm{P}\left(\tilde{B}_y > B_{2008}\right)$					
0	0	1.000	1.000	1.000	1.000	1.000
100	0	1.000	1.000	1.000	1.000	1.000
200	0	1.000	1.000	1.000	1.000	1.000
300	0	0.997	0.998	1.000	1.000	1.000
400	0	0.951	0.977	0.982	0.989	0.990
500	0	0.779	0.831	0.871	0.895	0.917
600	0	0.517	0.594	0.636	0.682	0.735
700	0	0.267	0.344	0.396	0.446	0.490
800	0	0.112	0.163	0.204	0.239	0.268
900	0	0.041	0.064	0.085	0.111	0.132
1000	0	0.008	0.023	0.035	0.050	0.066
1100	0	0.001	0.008	0.011	0.022	0.026
1200	0	0.000	0.001	0.004	0.007	0.009
	$\mathrm{E}\left(\tilde{B}_y / B_{2008}\right)$					
0	1	1.142	1.313	1.506	1.720	1.953
100	1	1.118	1.262	1.426	1.610	1.811
200	1	1.094	1.211	1.347	1.501	1.670
300	1	1.070	1.161	1.269	1.393	1.530
400	1	1.045	1.111	1.191	1.286	1.393
500	1	1.021	1.060	1.114	1.180	1.257
600	1	0.997	1.011	1.037	1.075	1.124
700	1	0.973	0.961	0.961	0.973	0.994
800	1	0.948	0.912	0.887	0.873	0.869
900	1	0.924	0.863	0.814	0.776	0.750
1000	1	0.900	0.815	0.742	0.685	0.640
1100	1	0.876	0.767	0.674	0.598	0.538
1200	1	0.852	0.720	0.608	0.518	0.448

Table J.16 Decision tables of B_0 performance indicators for 1-5 year projections for Run 08. Statistics relate to beginning of year female spawning biomass relative to the female spawning B_0 biomass. The probability of biomass in the projection year exceeding one of the reference values (upper two tables) can be compared to the expected value of the biomass relative to B_0 (lowest table).

Annual catch strategy	2008	2009	2010	2011	2012	2013
			$\mathrm{P}\left(\tilde{B}_y \geq 0.2B_0\right)$			
0	1.000	1.000	1.000	1.000	1.000	1.000
100	1.000	1.000	1.000	1.000	1.000	1.000
200	1.000	1.000	1.000	1.000	1.000	1.000
300	1.000	1.000	1.000	1.000	1.000	1.000
400	1.000	1.000	1.000	1.000	1.000	1.000
500	1.000	1.000	1.000	1.000	1.000	1.000
600	1.000	1.000	1.000	1.000	1.000	1.000
700	1.000	1.000	1.000	1.000	1.000	1.000
800	1.000	1.000	1.000	1.000	1.000	1.000
900	1.000	1.000	1.000	1.000	1.000	1.000
1000	1.000	1.000	1.000	1.000	1.000	1.000
1100	1.000	1.000	1.000	1.000	1.000	1.000
1200	1.000	1.000	1.000	1.000	1.000	1.000
			$\mathrm{P}\left(\tilde{B}_y \geq 0.4B_0\right)$			
0	0.002	0.118	0.819	0.997	1.000	1.000
100	0.002	0.074	0.672	0.989	1.000	1.000
200	0.002	0.052	0.475	0.945	0.999	1.000
300	0.002	0.035	0.315	0.820	0.989	1.000
400	0.002	0.021	0.182	0.582	0.910	0.995
500	0.002	0.011	0.083	0.323	0.674	0.902
600	0.002	0.007	0.036	0.132	0.329	0.587
700	0.002	0.005	0.012	0.040	0.095	0.202
800	0.002	0.004	0.006	0.010	0.018	0.035
900	0.002	0.002	0.003	0.004	0.004	0.004
1000	0.002	0.002	0.001	0.001	0.001	0.001
1100	0.002	0.001	0.001	0.000	0.000	0.000
1200	0.002	0.001	0.000	0.000	0.000	0.000
			$\mathrm{E}\left(\tilde{B}_y / B_0\right)$			
0	0.349	0.381	0.414	0.447	0.480	0.512
100	0.349	0.377	0.407	0.436	0.465	0.493
200	0.349	0.374	0.399	0.425	0.451	0.475
300	0.349	0.370	0.392	0.414	0.436	0.457
400	0.349	0.367	0.385	0.403	0.422	0.439
500	0.349	0.363	0.378	0.392	0.407	0.421
600	0.349	0.360	0.370	0.382	0.393	0.404
700	0.349	0.356	0.363	0.371	0.378	0.386
800	0.349	0.352	0.356	0.360	0.364	0.368
900	0.349	0.349	0.349	0.349	0.350	0.350
1000	0.349	0.345	0.342	0.338	0.335	0.332
1100	0.349	0.342	0.335	0.328	0.321	0.315
1200	0.349	0.338	0.327	0.317	0.307	0.297

Table J.17 Decision tables of B_{2008} performance indicator for 1-5 year projections for Run 08. Statistics relate to beginning of year female spawning biomass relative to the beginning year 2008 female spawning biomass. The probability of biomass in the projection year exceeding the reference value (upper table) can be compared to the expected value of the biomass relative to B_{2008} (lower table).

Annual catch strategy	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
			$\mathrm{P}\left(\tilde{B}_y > B_{2008}\right)$			
0	0	1.000	1.000	1.000	1.000	1.000
100	0	1.000	1.000	1.000	1.000	1.000
200	0	1.000	1.000	1.000	1.000	1.000
300	0	1.000	1.000	1.000	1.000	1.000
400	0	1.000	1.000	1.000	1.000	1.000
500	0	1.000	1.000	1.000	1.000	1.000
600	0	1.000	1.000	1.000	1.000	1.000
700	0	1.000	1.000	1.000	1.000	1.000
800	0	1.000	1.000	1.000	1.000	1.000
900	0	0.389	0.486	0.594	0.702	0.781
1000	0	0.000	0.000	0.000	0.000	0.000
1100	0	0.000	0.000	0.000	0.000	0.000
1200	0	0.000	0.000	0.000	0.000	0.000
			$\mathrm{E}\left(\tilde{B}_y / B_{2008}\right)$			
0	1	1.092	1.186	1.281	1.375	1.467
100	1	1.082	1.165	1.250	1.333	1.415
200	1	1.071	1.145	1.218	1.292	1.363
300	1	1.061	1.124	1.187	1.250	1.311
400	1	1.051	1.103	1.156	1.208	1.260
500	1	1.041	1.082	1.125	1.167	1.208
600	1	1.030	1.062	1.094	1.125	1.157
700	1	1.020	1.041	1.062	1.084	1.105
800	1	1.010	1.020	1.031	1.043	1.054
900	1	1.000	1.000	1.000	1.002	1.003
1000	1	0.989	0.979	0.970	0.961	0.952
1100	1	0.979	0.959	0.939	0.920	0.902
1200	1	0.969	0.938	0.908	0.879	0.851

Table J.18 Decision tables of B_0 performance indicators for 1-5 year projections for Run 11. Statistics relate to beginning of year female spawning biomass relative to the female spawning B_0 biomass. The probability of biomass in the projection year exceeding one of the reference values (upper two tables) can be compared to the expected value of the biomass relative to B_0 (lowest table).

Annual catch strategy	2008	2009	2010	2011	2012	2013
	$P\left(\tilde{B}_y \geq 0.2B_0\right)$					
0	0.605	0.817	0.954	0.991	0.998	1.000
100	0.605	0.795	0.933	0.984	0.995	1.000
200	0.605	0.774	0.904	0.970	0.992	0.998
300	0.605	0.765	0.875	0.954	0.979	0.992
400	0.605	0.752	0.844	0.921	0.957	0.978
500	0.605	0.726	0.814	0.882	0.924	0.942
600	0.605	0.705	0.776	0.839	0.886	0.905
700	0.605	0.689	0.748	0.787	0.824	0.850
800	0.605	0.675	0.712	0.739	0.756	0.772
900	0.605	0.652	0.675	0.685	0.684	0.675
1000	0.605	0.628	0.630	0.624	0.609	0.592
1100	0.605	0.604	0.589	0.565	0.529	0.497
1200	0.605	0.581	0.546	0.506	0.459	0.414
	$P\left(\tilde{B}_y \geq 0.4B_0\right)$					
0	0.003	0.014	0.048	0.178	0.379	0.575
100	0.003	0.014	0.038	0.142	0.293	0.480
200	0.003	0.011	0.033	0.103	0.237	0.381
300	0.003	0.010	0.028	0.075	0.167	0.283
400	0.003	0.009	0.027	0.051	0.120	0.196
500	0.003	0.009	0.022	0.041	0.085	0.139
600	0.003	0.009	0.019	0.034	0.056	0.093
700	0.003	0.008	0.015	0.027	0.037	0.060
800	0.003	0.006	0.011	0.022	0.032	0.040
900	0.003	0.005	0.009	0.017	0.025	0.026
1000	0.003	0.004	0.008	0.011	0.018	0.021
1100	0.003	0.004	0.006	0.008	0.010	0.015
1200	0.003	0.004	0.005	0.006	0.007	0.008
	$E\left(\tilde{B}_y / B_0\right)$					
0	0.217	0.256	0.297	0.338	0.379	0.417
100	0.217	0.253	0.290	0.327	0.363	0.398
200	0.217	0.249	0.282	0.316	0.348	0.378
300	0.217	0.246	0.275	0.304	0.332	0.358
400	0.217	0.242	0.268	0.293	0.317	0.338
500	0.217	0.239	0.261	0.282	0.301	0.319
600	0.217	0.236	0.253	0.271	0.286	0.299
700	0.217	0.232	0.246	0.259	0.270	0.280
800	0.217	0.229	0.239	0.248	0.255	0.260
900	0.217	0.225	0.232	0.237	0.240	0.241
1000	0.217	0.222	0.225	0.226	0.225	0.222
1100	0.217	0.218	0.218	0.215	0.210	0.204
1200	0.217	0.215	0.210	0.204	0.195	0.185

Table J.19 Decision tables of B_{2008} performance indicator for 1-5 year projections for Run 11. Statistics relate to beginning of year female spawning biomass relative to the beginning year 2008 female spawning biomass. The probability of biomass in the projection year exceeding the reference value (upper table) can be compared to the expected value of the biomass relative to B_{2008} (lower table).

Annual catch strategy	2008	2009	2010	2011	2012	2013
	$\mathrm{P}\left(\tilde{B}_y > B_{2008}\right)$					
0	0	1.000	1.000	1.000	1.000	1.000
100	0	1.000	1.000	1.000	1.000	1.000
200	0	1.000	1.000	1.000	1.000	1.000
300	0	1.000	1.000	1.000	1.000	1.000
400	0	1.000	1.000	1.000	1.000	1.000
500	0	1.000	1.000	1.000	1.000	1.000
600	0	0.996	0.997	0.997	0.997	0.995
700	0	0.981	0.972	0.970	0.959	0.946
800	0	0.931	0.914	0.892	0.870	0.847
900	0	0.825	0.797	0.765	0.731	0.693
1000	0	0.677	0.634	0.592	0.554	0.513
1100	0	0.525	0.472	0.427	0.377	0.338
1200	0	0.360	0.329	0.295	0.258	0.227
	$\mathrm{E}\left(\tilde{B}_y / B_{2008}\right)$					
0	1	1.186	1.381	1.583	1.781	1.971
100	1	1.169	1.345	1.527	1.704	1.872
200	1	1.152	1.310	1.471	1.627	1.774
300	1	1.135	1.274	1.415	1.550	1.677
400	1	1.118	1.239	1.359	1.474	1.579
500	1	1.102	1.203	1.304	1.398	1.483
600	1	1.085	1.168	1.249	1.322	1.386
700	1	1.068	1.132	1.194	1.247	1.291
800	1	1.051	1.097	1.139	1.172	1.196
900	1	1.034	1.062	1.084	1.098	1.102
1000	1	1.017	1.027	1.030	1.024	1.009
1100	1	1.000	0.992	0.976	0.951	0.918
1200	1	0.983	0.957	0.922	0.879	0.829

Table J.20 Decision tables of B_0 performance indicators for 1-5 year projections for Run 14. Statistics relate to beginning of year female spawning biomass relative to the female spawning B_0 biomass. The probability of biomass in the projection year exceeding one of the reference values (upper two tables) can be compared to the expected value of the biomass relative to B_0 (lowest table).

Annual catch strategy	2008	2009	2010	2011	2012	2013
	$\mathrm{P}\left(\tilde{B}_y \geq 0.2B_0\right)$					
0	1.000	1.000	1.000	1.000	1.000	1.000
100	1.000	1.000	1.000	1.000	1.000	1.000
200	1.000	1.000	1.000	1.000	1.000	1.000
300	1.000	1.000	1.000	1.000	1.000	1.000
400	1.000	1.000	1.000	1.000	1.000	1.000
500	1.000	1.000	1.000	1.000	1.000	1.000
600	1.000	1.000	1.000	1.000	1.000	1.000
700	1.000	1.000	1.000	1.000	1.000	1.000
800	1.000	1.000	1.000	1.000	1.000	1.000
900	1.000	1.000	1.000	1.000	0.999	0.995
1000	1.000	1.000	1.000	0.995	0.987	0.950
1100	1.000	1.000	0.998	0.981	0.894	0.734
1200	1.000	1.000	0.991	0.908	0.693	0.434
	$\mathrm{P}\left(\tilde{B}_y \geq 0.4B_0\right)$					
0	0.000	0.000	0.000	0.000	0.081	0.566
100	0.000	0.000	0.000	0.000	0.016	0.194
200	0.000	0.000	0.000	0.000	0.000	0.030
300	0.000	0.000	0.000	0.000	0.000	0.002
400	0.000	0.000	0.000	0.000	0.000	0.000
500	0.000	0.000	0.000	0.000	0.000	0.000
600	0.000	0.000	0.000	0.000	0.000	0.000
700	0.000	0.000	0.000	0.000	0.000	0.000
800	0.000	0.000	0.000	0.000	0.000	0.000
900	0.000	0.000	0.000	0.000	0.000	0.000
1000	0.000	0.000	0.000	0.000	0.000	0.000
1100	0.000	0.000	0.000	0.000	0.000	0.000
1200	0.000	0.000	0.000	0.000	0.000	0.000
	$\mathrm{E}\left(\tilde{B}_y / B_0\right)$					
0	0.270	0.296	0.322	0.350	0.377	0.403
100	0.270	0.292	0.315	0.339	0.363	0.386
200	0.270	0.289	0.308	0.329	0.349	0.368
300	0.270	0.285	0.301	0.318	0.334	0.351
400	0.270	0.282	0.295	0.307	0.320	0.333
500	0.270	0.278	0.288	0.297	0.307	0.316
600	0.270	0.275	0.281	0.287	0.293	0.299
700	0.270	0.272	0.274	0.276	0.279	0.281
800	0.270	0.268	0.267	0.266	0.265	0.264
900	0.270	0.265	0.260	0.255	0.251	0.247
1000	0.270	0.261	0.253	0.245	0.237	0.230
1100	0.270	0.258	0.246	0.235	0.224	0.213
1200	0.270	0.254	0.239	0.224	0.210	0.196

Table J.21 Decision tables of B_{2008} performance indicator for 1-5 year projections for Run 14. Statistics relate to beginning of year female spawning biomass relative to the beginning year 2008 female spawning biomass. The probability of biomass in the projection year exceeding the reference value (upper table) can be compared to the expected value of the biomass relative to B_{2008} (lower table).

Annual catch strategy	2008	2009	2010	2011	2012	2013
	$\mathrm{P}\left(\tilde{B}_y > B_{2008}\right)$					
0	0	1.000	1.000	1.000	1.000	1.000
100	0	1.000	1.000	1.000	1.000	1.000
200	0	1.000	1.000	1.000	1.000	1.000
300	0	1.000	1.000	1.000	1.000	1.000
400	0	1.000	1.000	1.000	1.000	1.000
500	0	1.000	1.000	1.000	1.000	1.000
600	0	1.000	1.000	1.000	1.000	1.000
700	0	1.000	1.000	1.000	1.000	1.000
800	0	0.000	0.000	0.000	0.002	0.007
900	0	0.000	0.000	0.000	0.000	0.000
1000	0	0.000	0.000	0.000	0.000	0.000
1100	0	0.000	0.000	0.000	0.000	0.000
1200	0	0.000	0.000	0.000	0.000	0.000
	$\mathrm{E}\left(\tilde{B}_y / B_{2008}\right)$					
0	1	1.096	1.196	1.297	1.398	1.496
100	1	1.083	1.170	1.258	1.345	1.431
200	1	1.071	1.144	1.218	1.293	1.366
300	1	1.058	1.118	1.179	1.241	1.301
400	1	1.045	1.092	1.140	1.188	1.236
500	1	1.032	1.066	1.101	1.136	1.171
600	1	1.019	1.040	1.062	1.085	1.107
700	1	1.006	1.014	1.023	1.033	1.043
800	1	0.994	0.989	0.985	0.981	0.979
900	1	0.981	0.963	0.946	0.930	0.915
1000	1	0.968	0.937	0.907	0.879	0.852
1100	1	0.955	0.911	0.869	0.828	0.789
1200	1	0.942	0.886	0.830	0.777	0.726

Table J.22 Decision tables of B_0 performance indicators for 1-5 year projections for Run 17. Statistics relate to beginning of year female spawning biomass relative to the female spawning B_0 biomass. The probability of biomass in the projection year exceeding one of the reference values (upper two tables) can be compared to the expected value of the biomass relative to B_0 (lowest table).

Annual catch strategy	2008	2009	2010	2011	2012	2013
	$P(\tilde{B}_y \geq 0.2B_0)$					
0	0.269	0.504	0.737	0.887	0.963	0.994
100	0.269	0.480	0.685	0.847	0.922	0.970
200	0.269	0.456	0.638	0.780	0.878	0.929
300	0.269	0.427	0.576	0.725	0.803	0.880
400	0.269	0.405	0.528	0.633	0.724	0.769
500	0.269	0.378	0.477	0.547	0.616	0.667
600	0.269	0.349	0.434	0.484	0.516	0.546
700	0.269	0.329	0.381	0.422	0.429	0.421
800	0.269	0.310	0.337	0.340	0.345	0.337
900	0.269	0.283	0.295	0.291	0.280	0.246
1000	0.269	0.270	0.256	0.236	0.203	0.160
1100	0.269	0.248	0.218	0.181	0.143	0.106
1200	0.269	0.233	0.178	0.134	0.093	0.074
	$P(\tilde{B}_y \geq 0.4B_0)$					
0	0.000	0.000	0.002	0.020	0.050	0.104
100	0.000	0.000	0.001	0.011	0.033	0.068
200	0.000	0.000	0.001	0.007	0.023	0.042
300	0.000	0.000	0.000	0.005	0.013	0.029
400	0.000	0.000	0.000	0.003	0.008	0.012
500	0.000	0.000	0.000	0.000	0.005	0.008
600	0.000	0.000	0.000	0.000	0.001	0.003
700	0.000	0.000	0.000	0.000	0.001	0.001
800	0.000	0.000	0.000	0.000	0.000	0.001
900	0.000	0.000	0.000	0.000	0.000	0.000
1000	0.000	0.000	0.000	0.000	0.000	0.000
1100	0.000	0.000	0.000	0.000	0.000	0.000
1200	0.000	0.000	0.000	0.000	0.000	0.000
	$E(\tilde{B}_y / B_0)$					
0	0.173	0.204	0.235	0.267	0.297	0.326
100	0.173	0.200	0.228	0.256	0.282	0.306
200	0.173	0.197	0.221	0.245	0.267	0.287
300	0.173	0.194	0.214	0.234	0.252	0.268
400	0.173	0.190	0.207	0.223	0.237	0.249
500	0.173	0.187	0.200	0.212	0.222	0.230
600	0.173	0.184	0.193	0.202	0.208	0.211
700	0.173	0.180	0.186	0.191	0.193	0.193
800	0.173	0.177	0.179	0.180	0.178	0.174
900	0.173	0.174	0.173	0.169	0.164	0.156
1000	0.173	0.171	0.166	0.159	0.150	0.139
1100	0.173	0.167	0.159	0.148	0.136	0.121
1200	0.173	0.164	0.152	0.138	0.122	0.105

Table J.23 Decision tables of B_{2008} performance indicator for 1-5 year projections for Run 17. Statistics relate to beginning of year female spawning biomass relative to the beginning year 2008 female spawning biomass. The probability of biomass in the projection year exceeding the reference value (upper table) can be compared to the expected value the biomass relative to B_{2008} (lower table).

Annual catch strategy	2008	2009	2010	2011	2012	2013
	$P(\tilde{B}_y > B_{2008})$					
0	0	1.000	1.000	1.000	1.000	1.000
100	0	1.000	1.000	1.000	1.000	1.000
200	0	1.000	1.000	1.000	1.000	1.000
300	0	1.000	1.000	1.000	1.000	1.000
400	0	1.000	1.000	0.999	0.998	0.997
500	0	0.993	0.993	0.993	0.989	0.988
600	0	0.975	0.967	0.950	0.936	0.910
700	0	0.884	0.861	0.824	0.780	0.719
800	0	0.719	0.671	0.609	0.544	0.487
900	0	0.514	0.451	0.402	0.340	0.282
1000	0	0.347	0.292	0.239	0.201	0.152
1100	0	0.218	0.169	0.129	0.096	0.075
1200	0	0.113	0.084	0.069	0.044	0.028
	$E(\tilde{B}_y / B_{2008})$					
0	1	1.185	1.376	1.571	1.760	1.936
100	1	1.164	1.333	1.503	1.666	1.816
200	1	1.144	1.289	1.434	1.571	1.695
300	1	1.123	1.246	1.366	1.477	1.576
400	1	1.102	1.202	1.298	1.384	1.457
500	1	1.082	1.159	1.231	1.291	1.339
600	1	1.061	1.116	1.163	1.199	1.222
700	1	1.041	1.073	1.096	1.107	1.106
800	1	1.020	1.030	1.030	1.017	0.991
900	1	0.999	0.987	0.964	0.927	0.879
1000	1	0.979	0.944	0.898	0.839	0.770
1100	1	0.958	0.902	0.833	0.753	0.667
1200	1	0.937	0.859	0.769	0.671	0.572

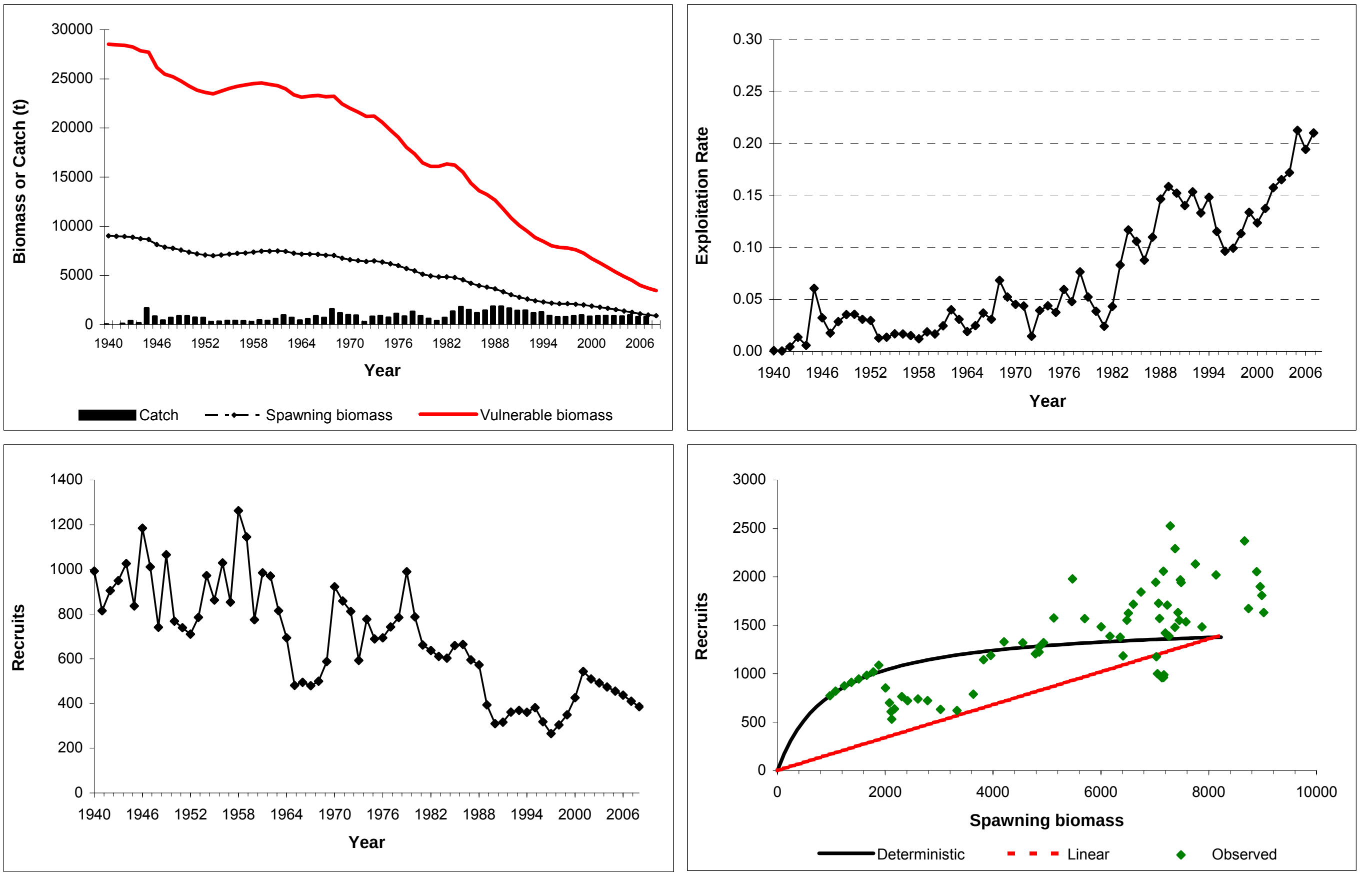

Figure J.5. Plots of Run 05 (Table 16): [top left]: vulnerable and female spawning biomass trends with annual catch; [top right]: exploitation rate (D. 4) by year; [bottom left]: female recruitment by year (male recruitment is the same); [bottom right]: stock recruitment function.

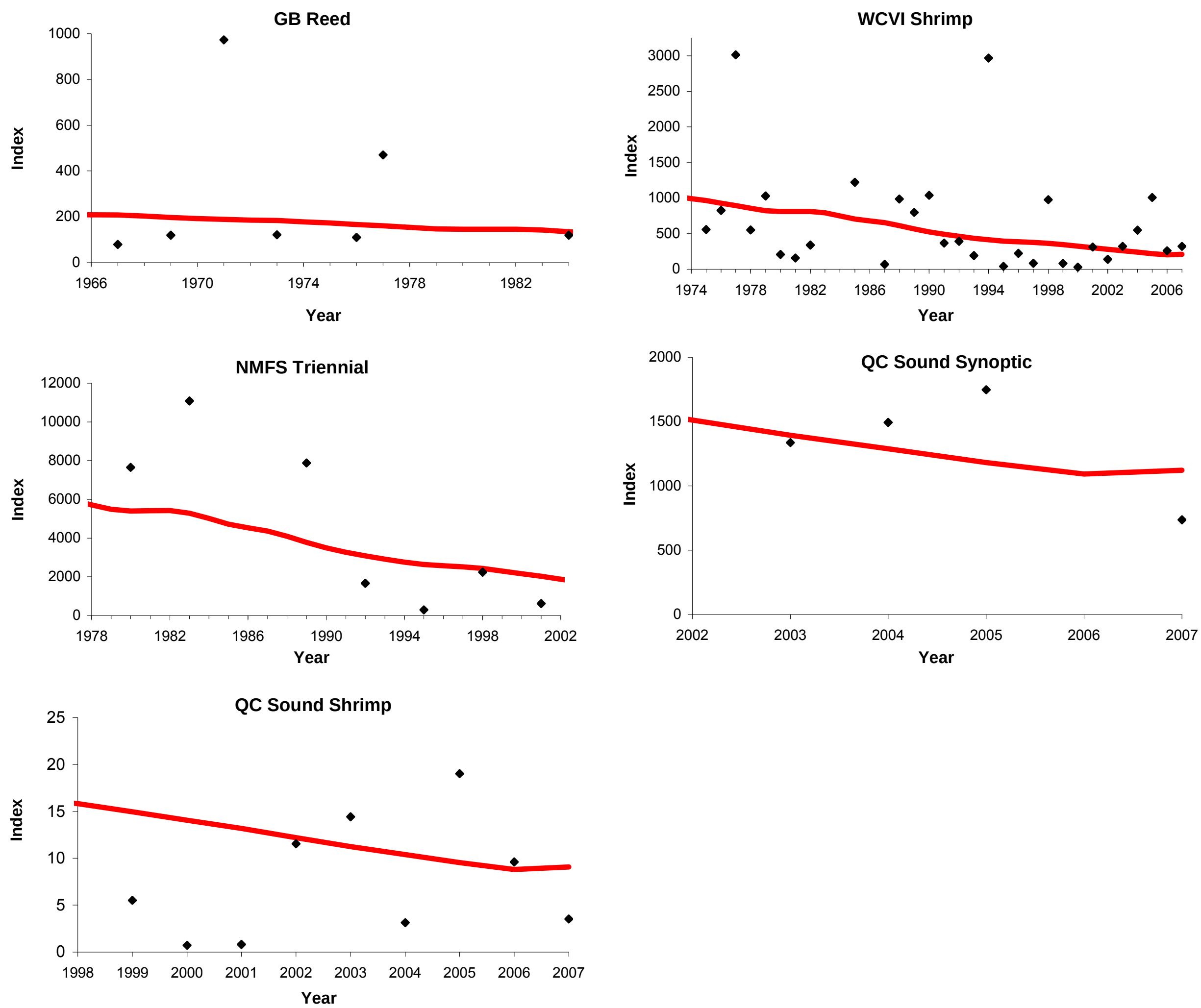

Figure J.6. Plots of the fits of Run 05 (Table 16) to the five survey data series (Table J.1). One outlying data point (1983: 8139) for the WCVI shrimp survey has been omitted to improve the clarity of the overall plot. Error bars have been omitted for the same reason.

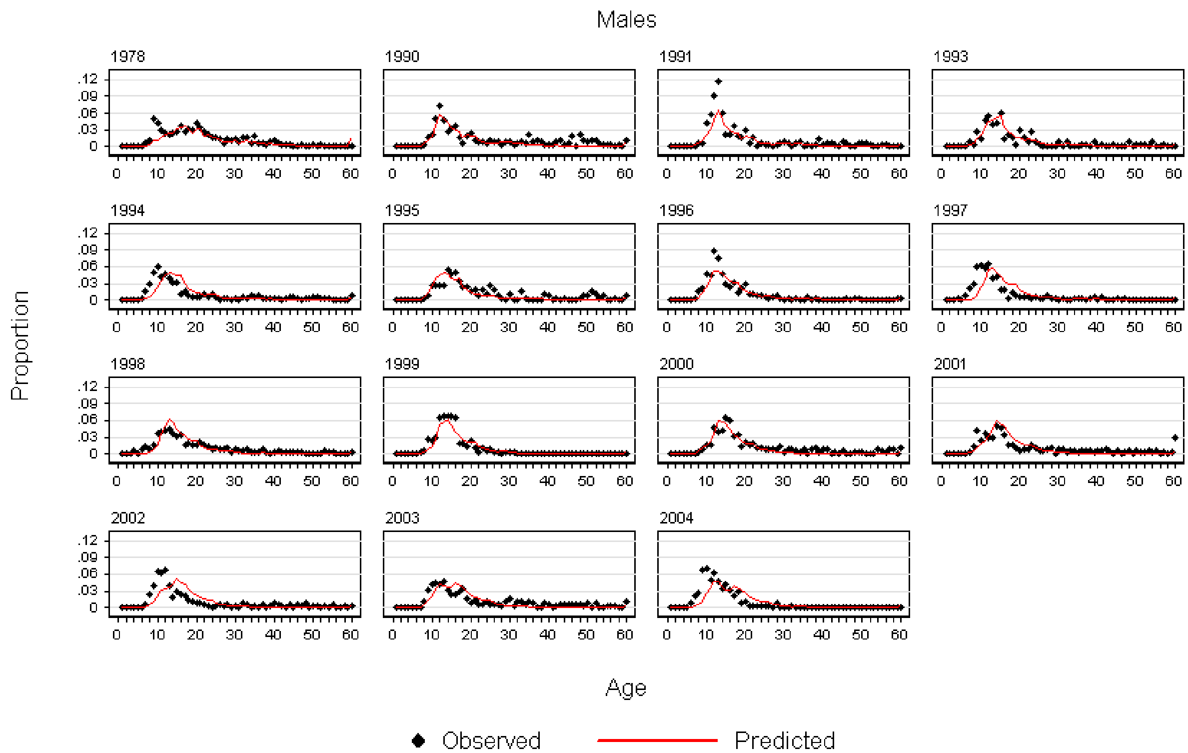

Figure J.7. Plots of the fits to the male age composition data by year for Run 05 (Table 16).

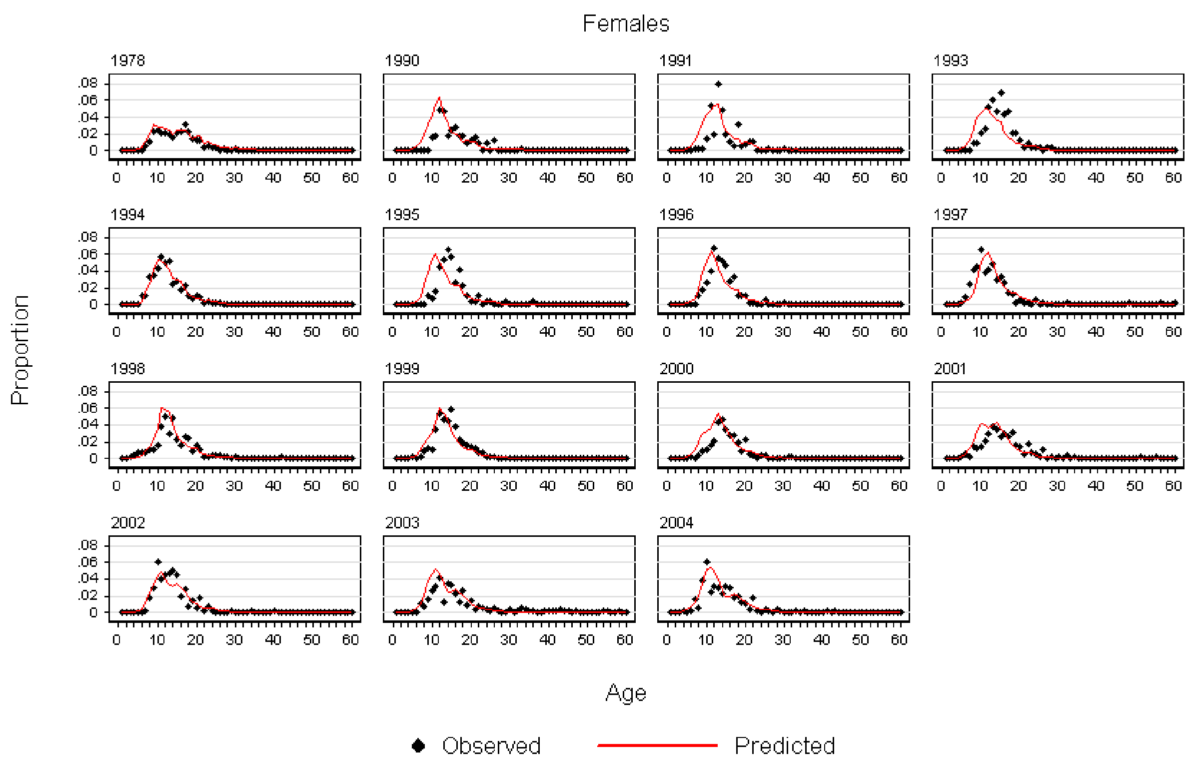

Figure J.8. Plots of the fits to the female age composition data by year for Run 05 (Table 16).

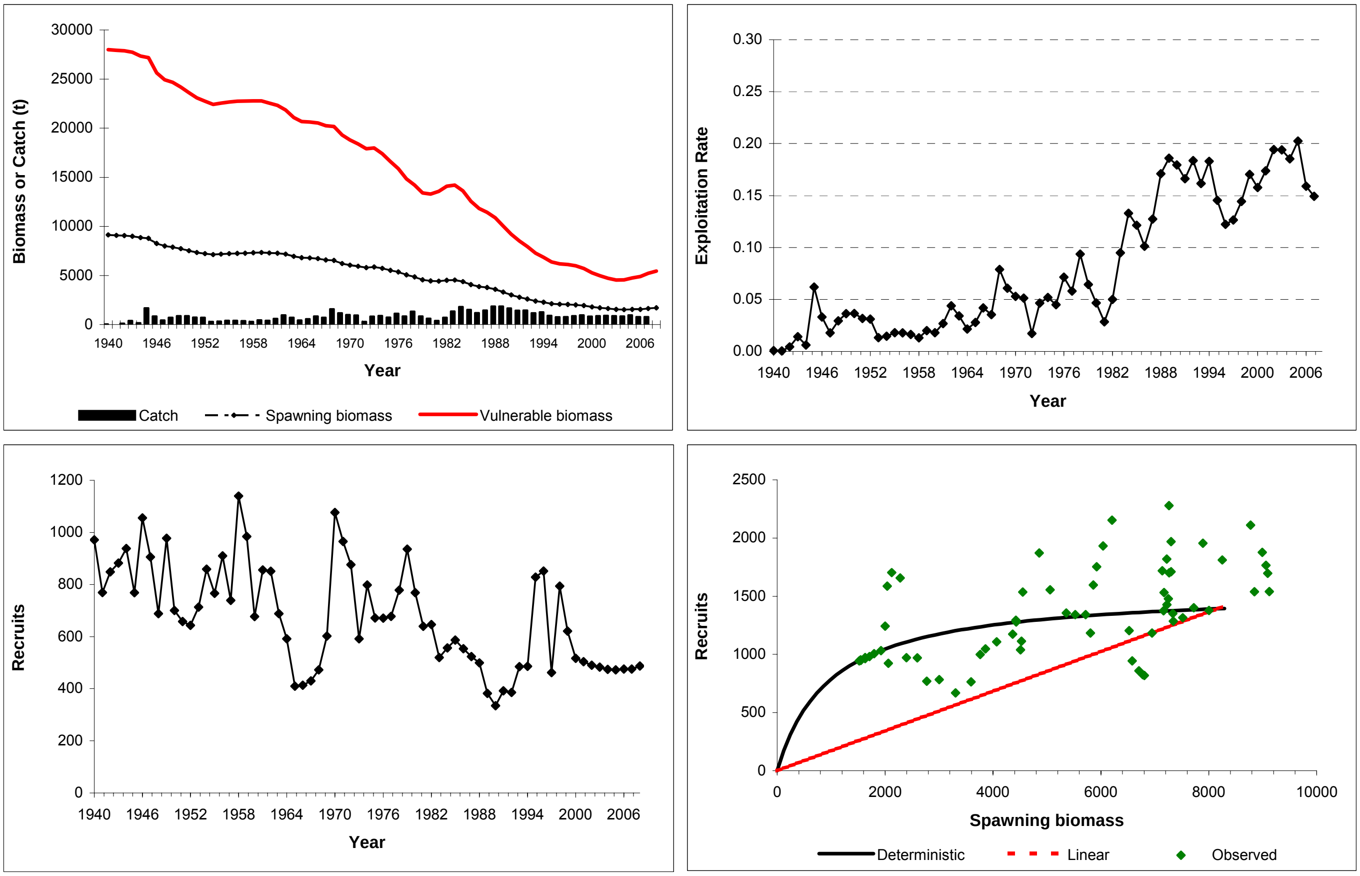

Figure J.9. Plots of Run 11 (Table 16): [top left]: vulnerable and female spawning biomass trends with annual catch; [top right]: exploitation rate (D. 4) by year; [bottom left]: female recruitment by year (male recruitment is the same); [bottom right]: stock recruitment function.

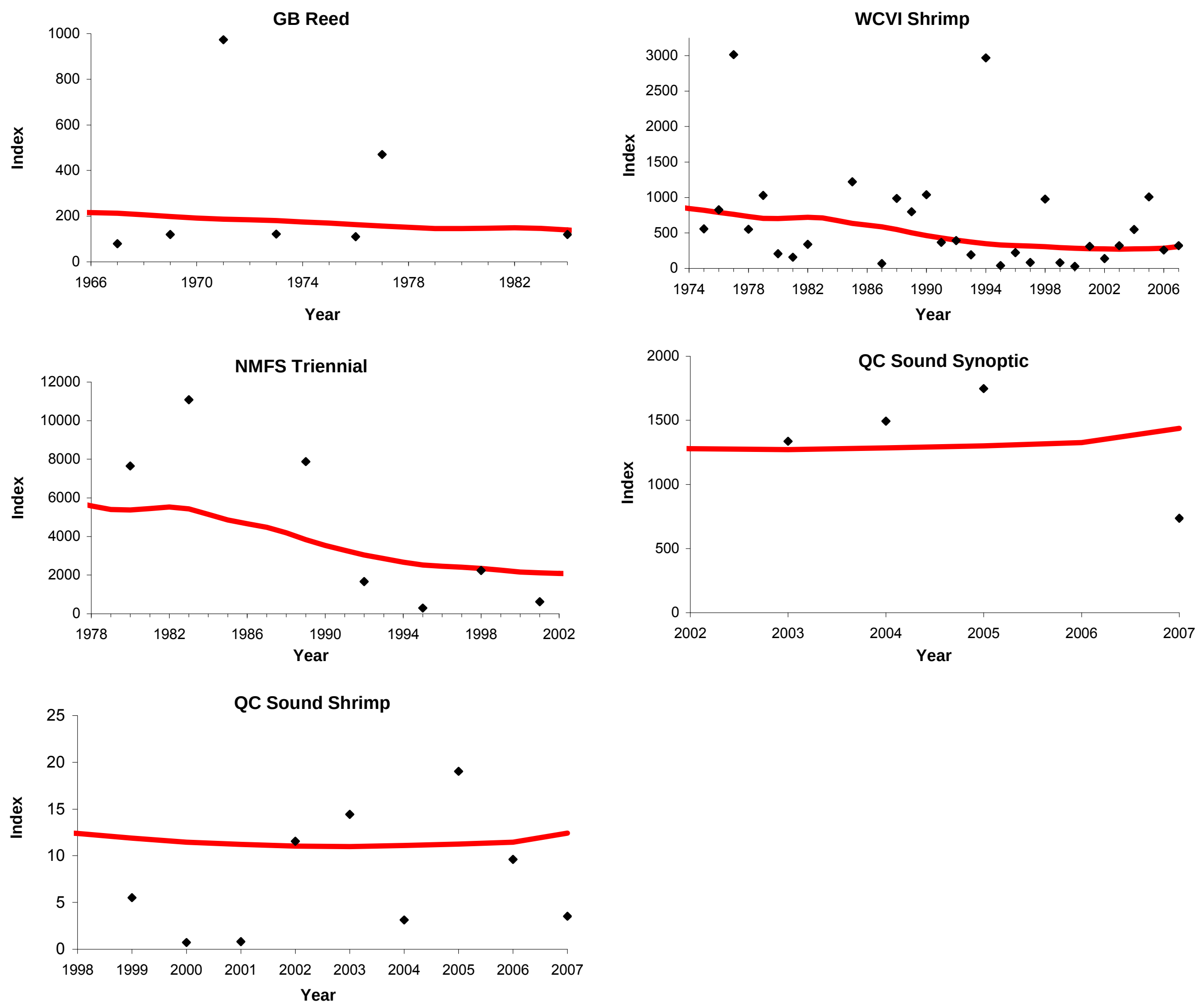

Figure J.10. Plots of the fits of Run 11 (Table 16) to the five survey data series (Table J.1). One outlying data point (1983: 8139) for the WCVI shrimp survey has been omitted to improve the clarity of the overall plot. Error bars have been omitted for the same reason.

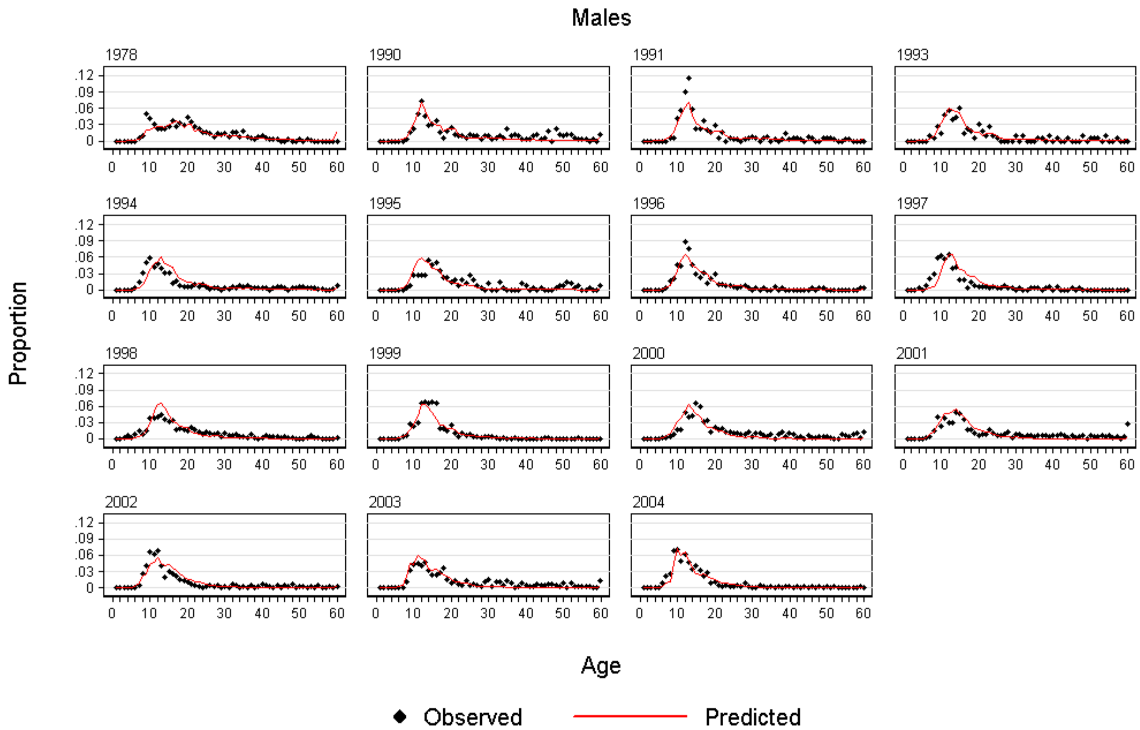

Figure J.11. Plots of the fits to the male age composition data by year for Run 11 (Table 16).

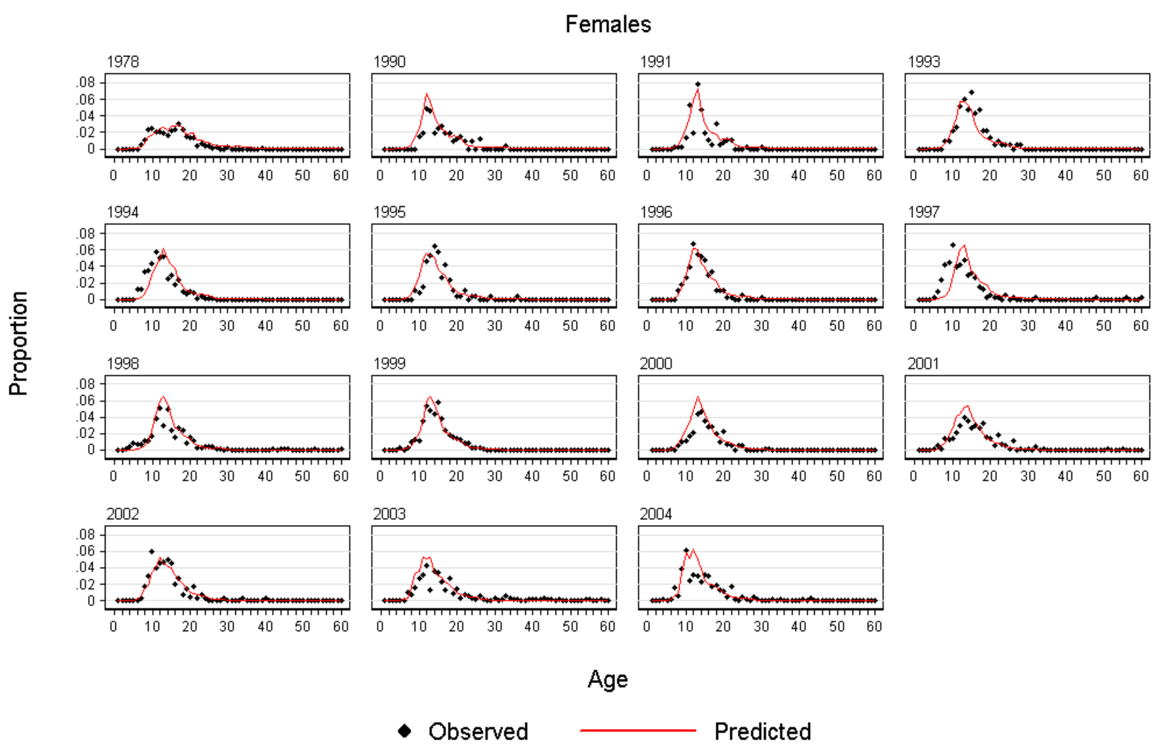

Figure J.12. Plots of the fits to the female age composition data by year for Run 11 (Table 16).

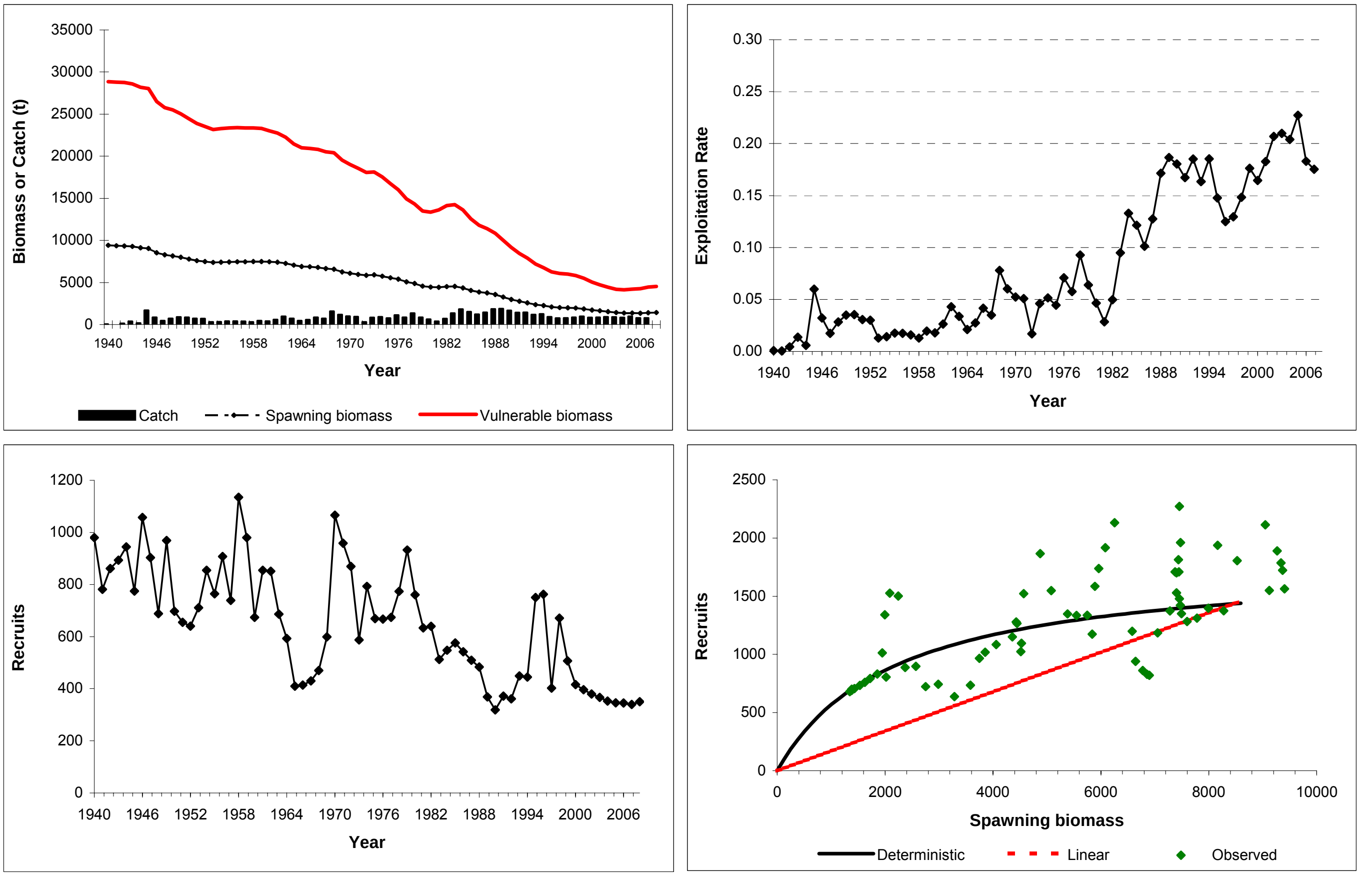

Figure J.13. Plots of Run 17 (Table 16): [top left]: vulnerable and female spawning biomass trends with annual catch; [top right]: exploitation rate (D. 4) by year; [bottom left]: female recruitment by year (male recruitment is the same); [bottom right]: stock recruitment function.

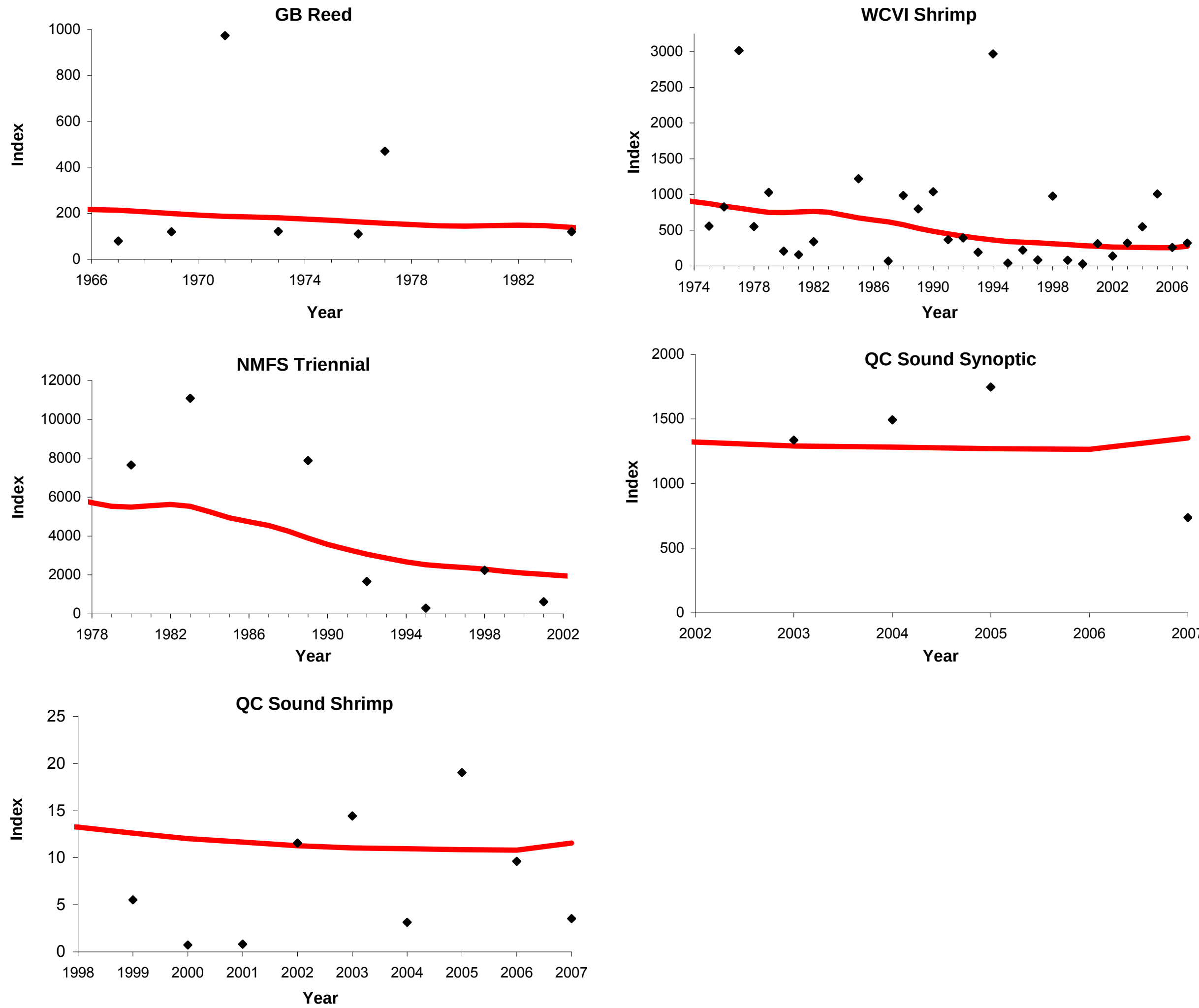

Figure J.14. Plots of the fits of Run 17 (Table 16) to the five survey data series (Table J.1). One outlying data point (1983: 8139) for the WCVI shrimp survey has been omitted to improve the clarity of the overall plot. Error bars have been omitted for the same reason.

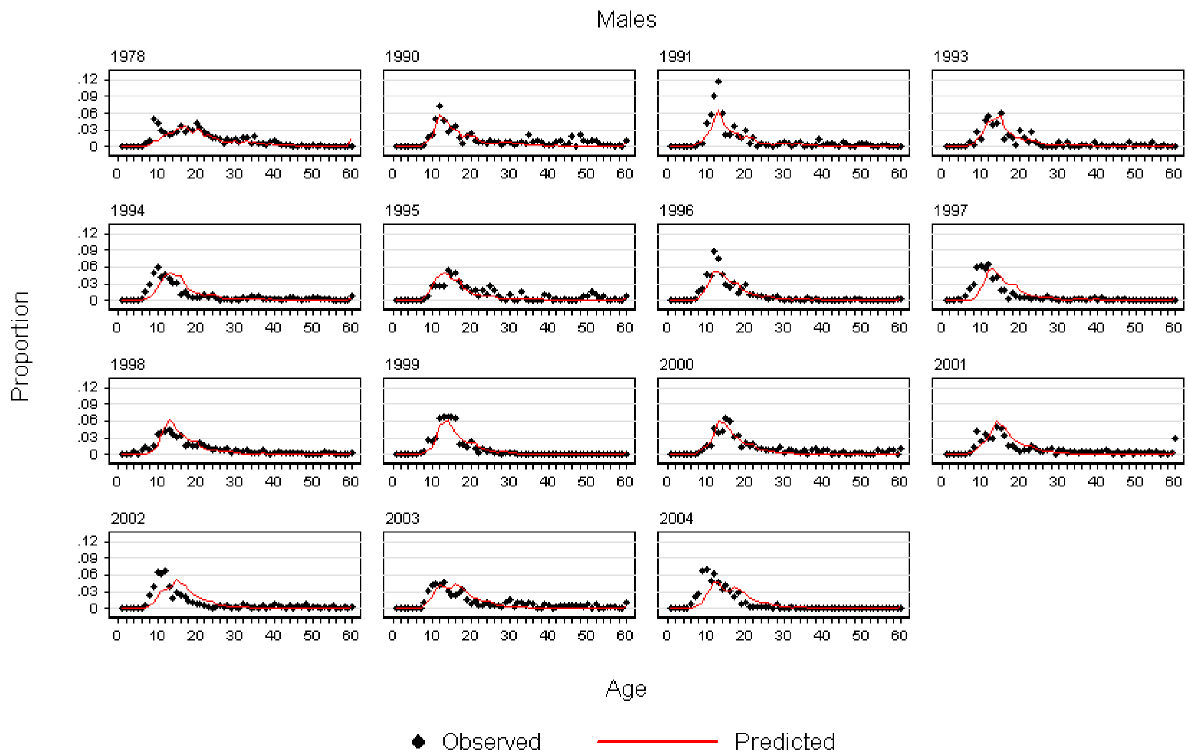

Figure J.15. Plots of the fits to the male age composition data by year for Run 17 (Table 16).

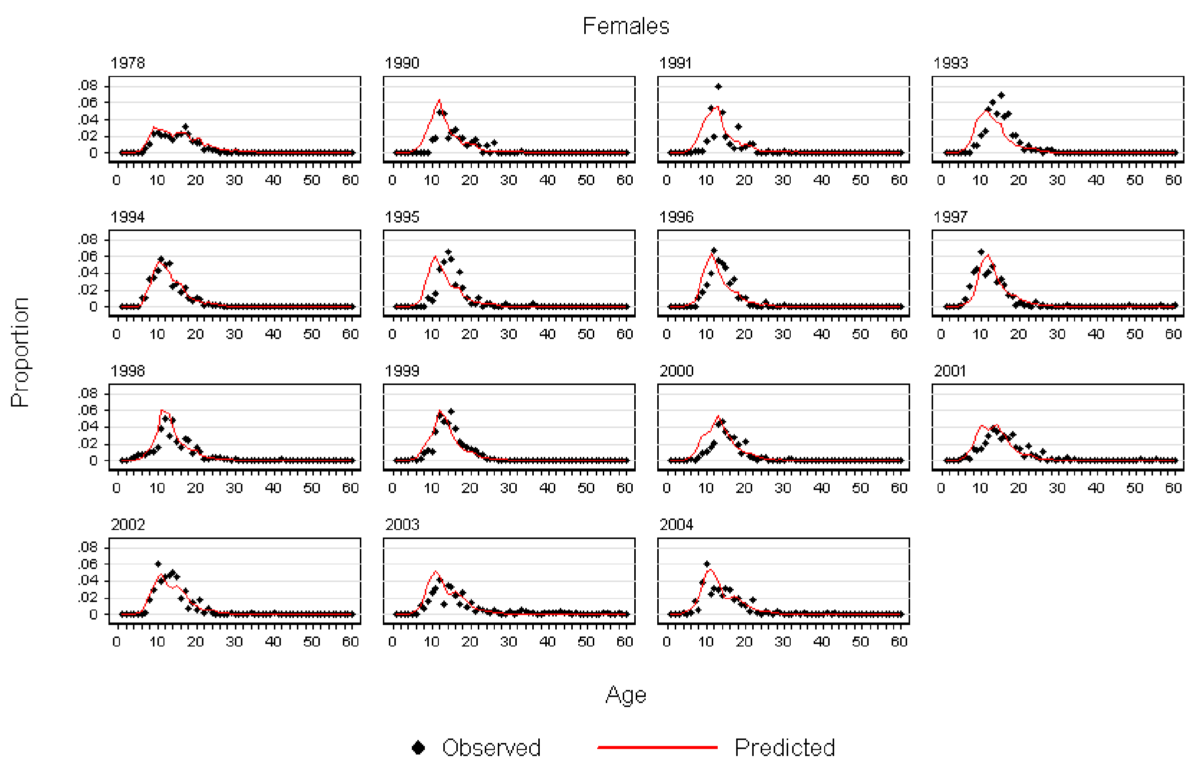

Figure J.16. Plots of the fits to the female age composition data by year for Run 17 (Table 16).

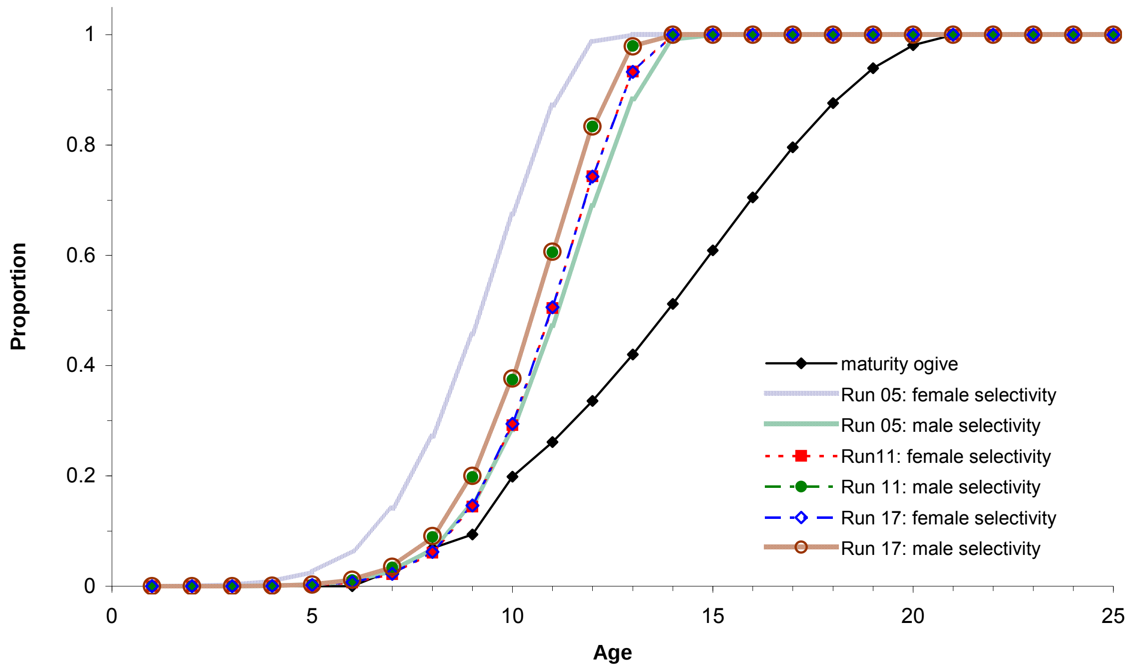

Figure J.17. Commercial selectivities by age and sex for Runs 05, 11, and 17 (Table 16). The selectivities for Run 05 were fixed as described in Appendix C. Selectivities for Runs 11 and 17 were estimated in the model. The female maturity ogive was fixed to values described in Appendix C.

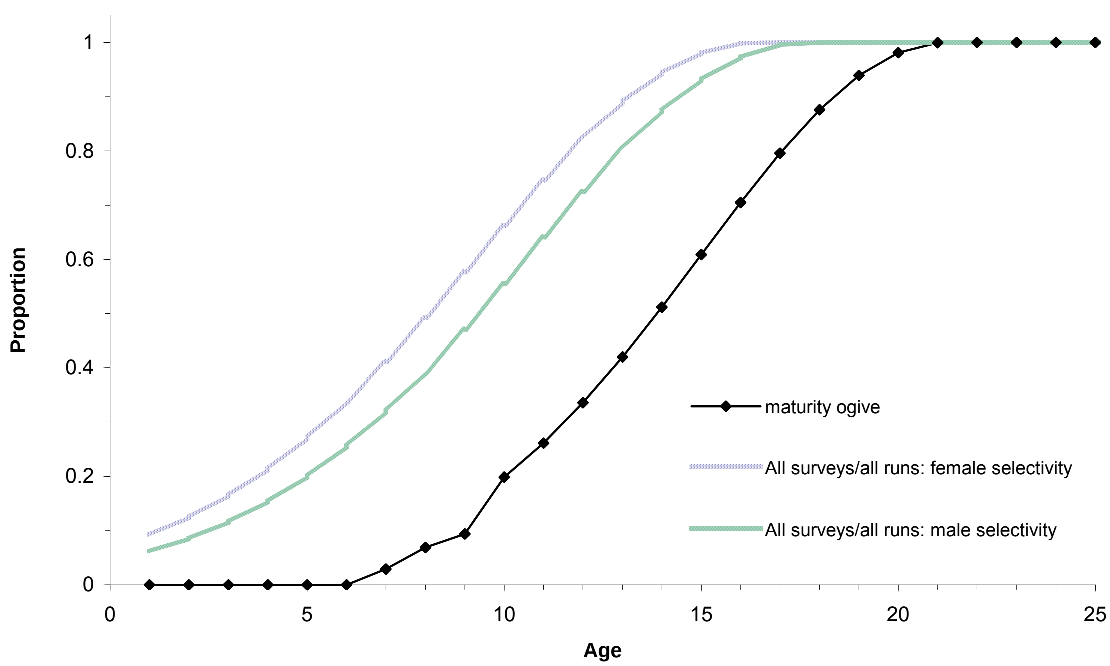

Figure J.18. Survey selectivities by age and sex for all surveys and all runs (Table 16). The survey selectivities were fixed as described in Appendix C. The female maturity ogive was fixed to values described in Appendix C.

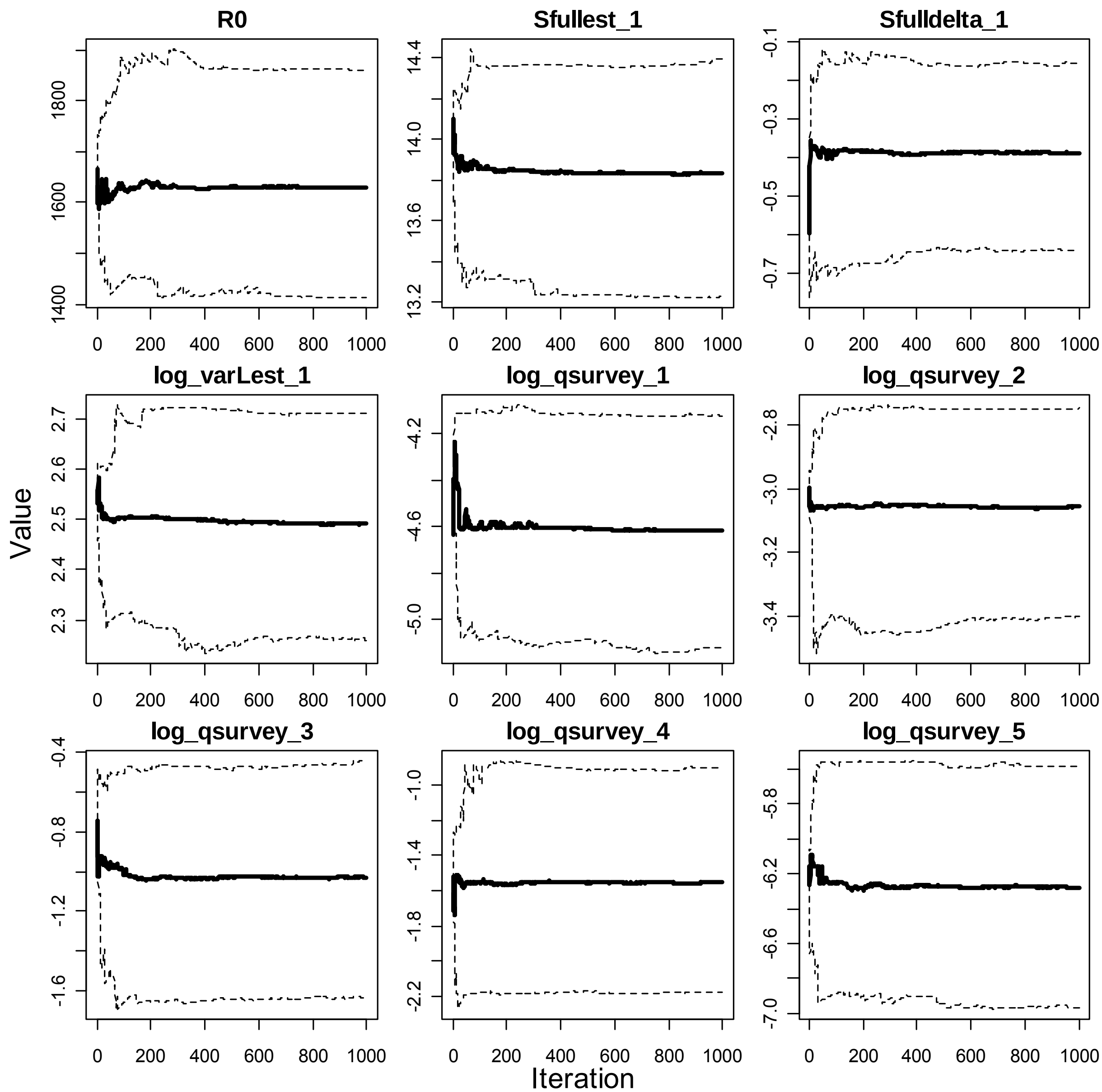

Figure J.19. MCMC cumulative quantiles for the Run 11 model parameters. The 2.5th, 50th, and 97.5th cumulative quantiles are shown.

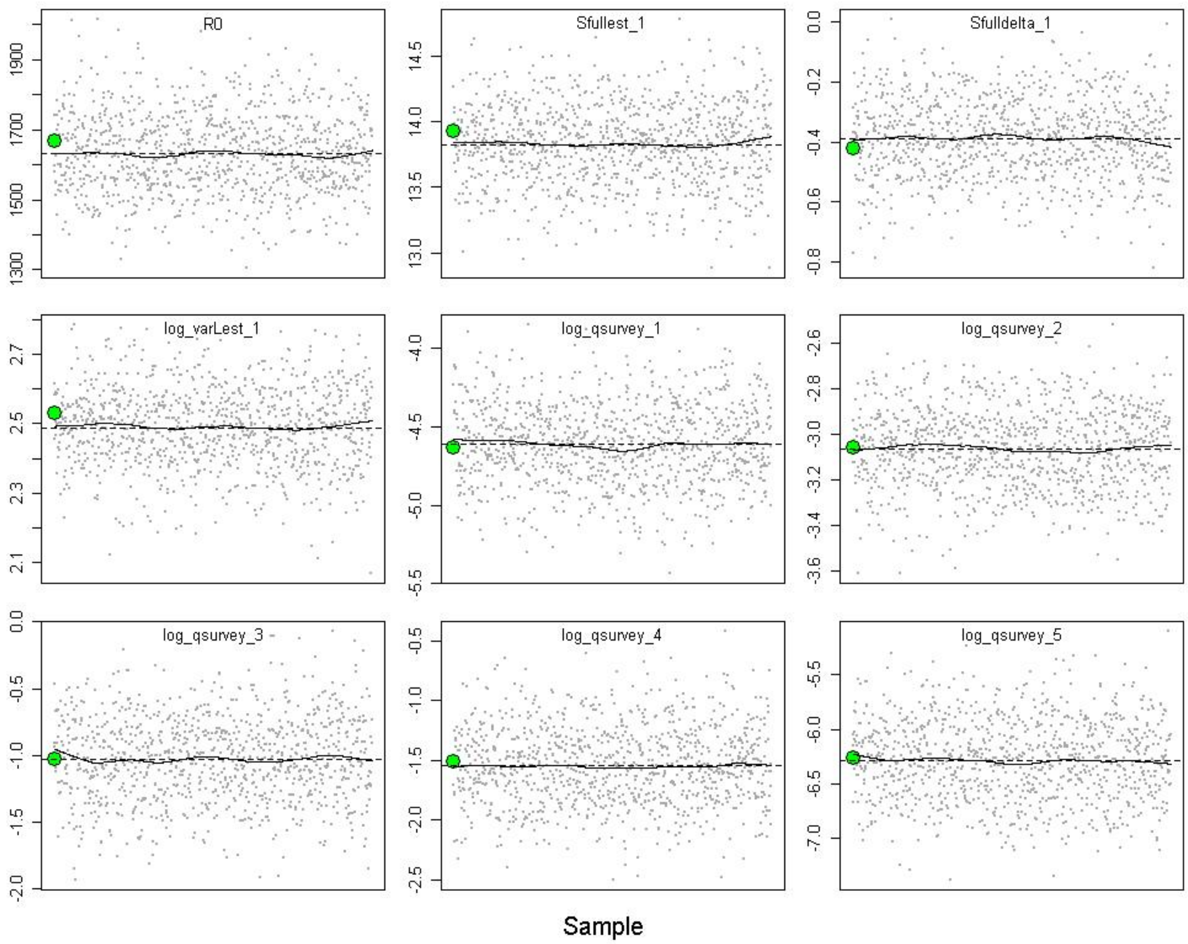

Figure J.20. MCMC traces for model parameters in Run 11. A dashed horizontal line shows the overall mean. The solid line is a regression smoother trend line. The green circles indicate the MPD estimates for the parameters.

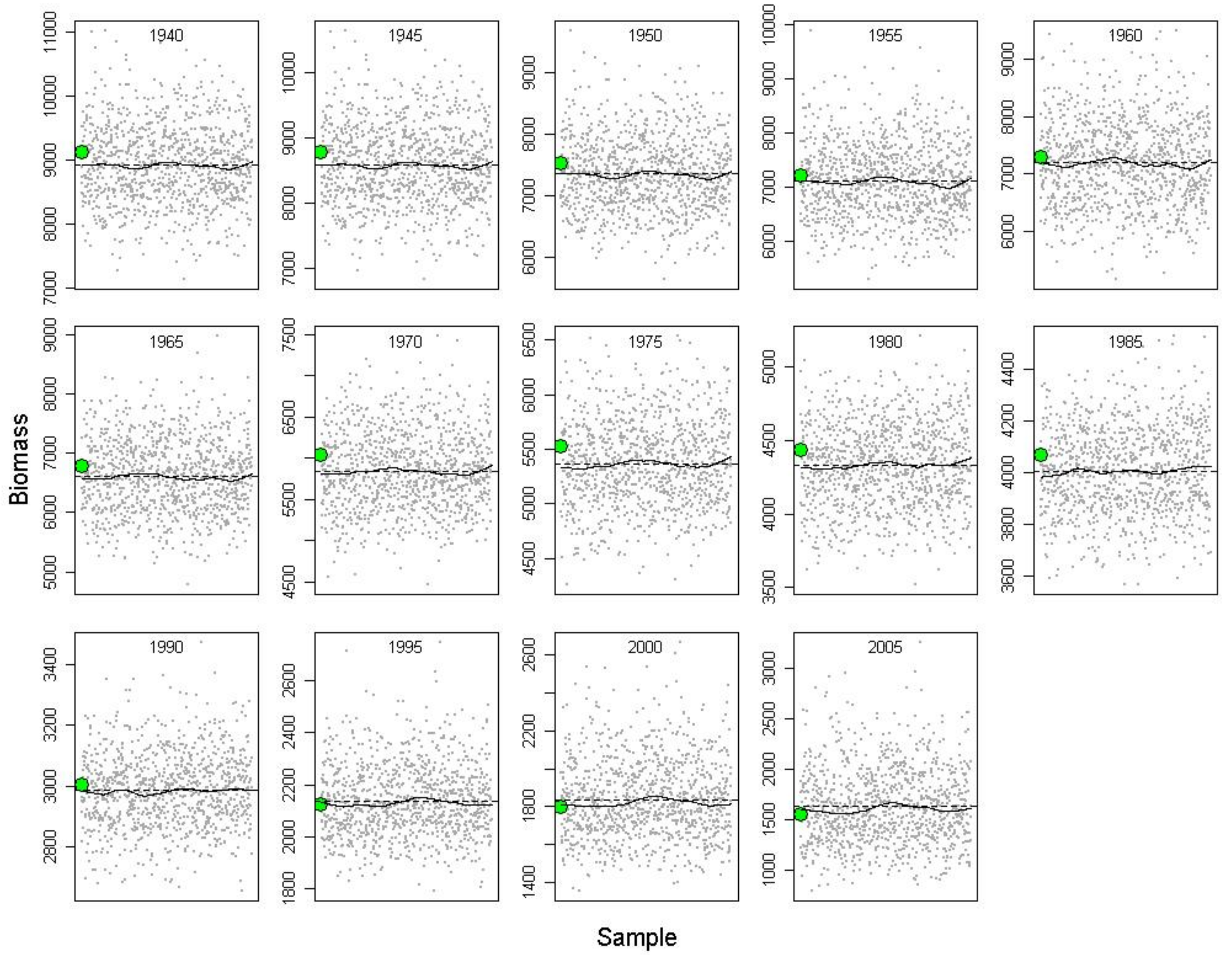

Figure J.21. MCMC female spawning biomass traces at five year intervals for Run 11. A dashed horizontal line shows the overall mean. The solid line is a regression smoother trend line. The green circles indicate the MPD estimates for the parameters.

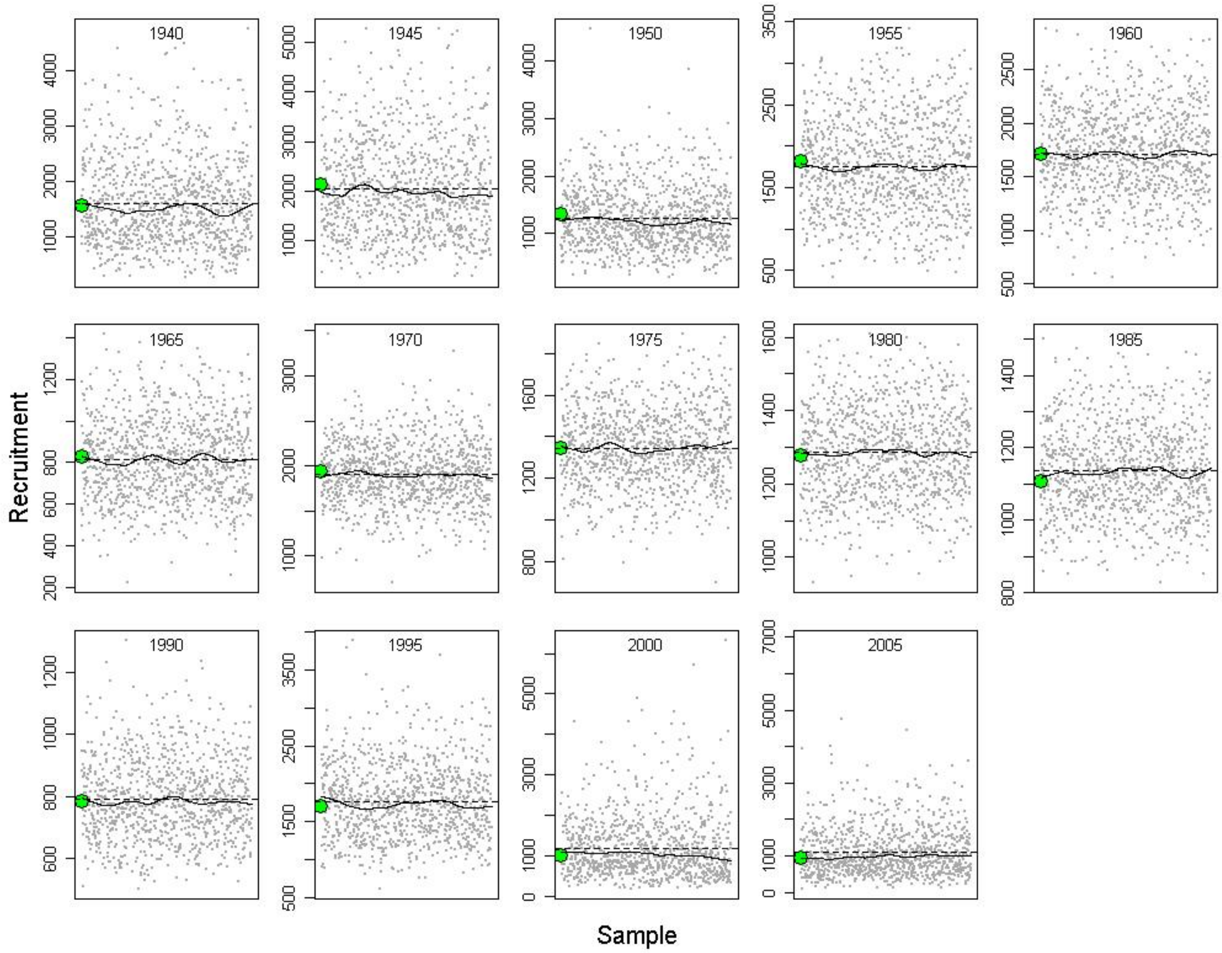

Figure J.22. MCMC recruitment traces at five year intervals for Run 11. A dashed horizontal line shows the overall mean. The solid line is a regression smoother trend line. The green circles indicate the MPD estimates for the parameters.

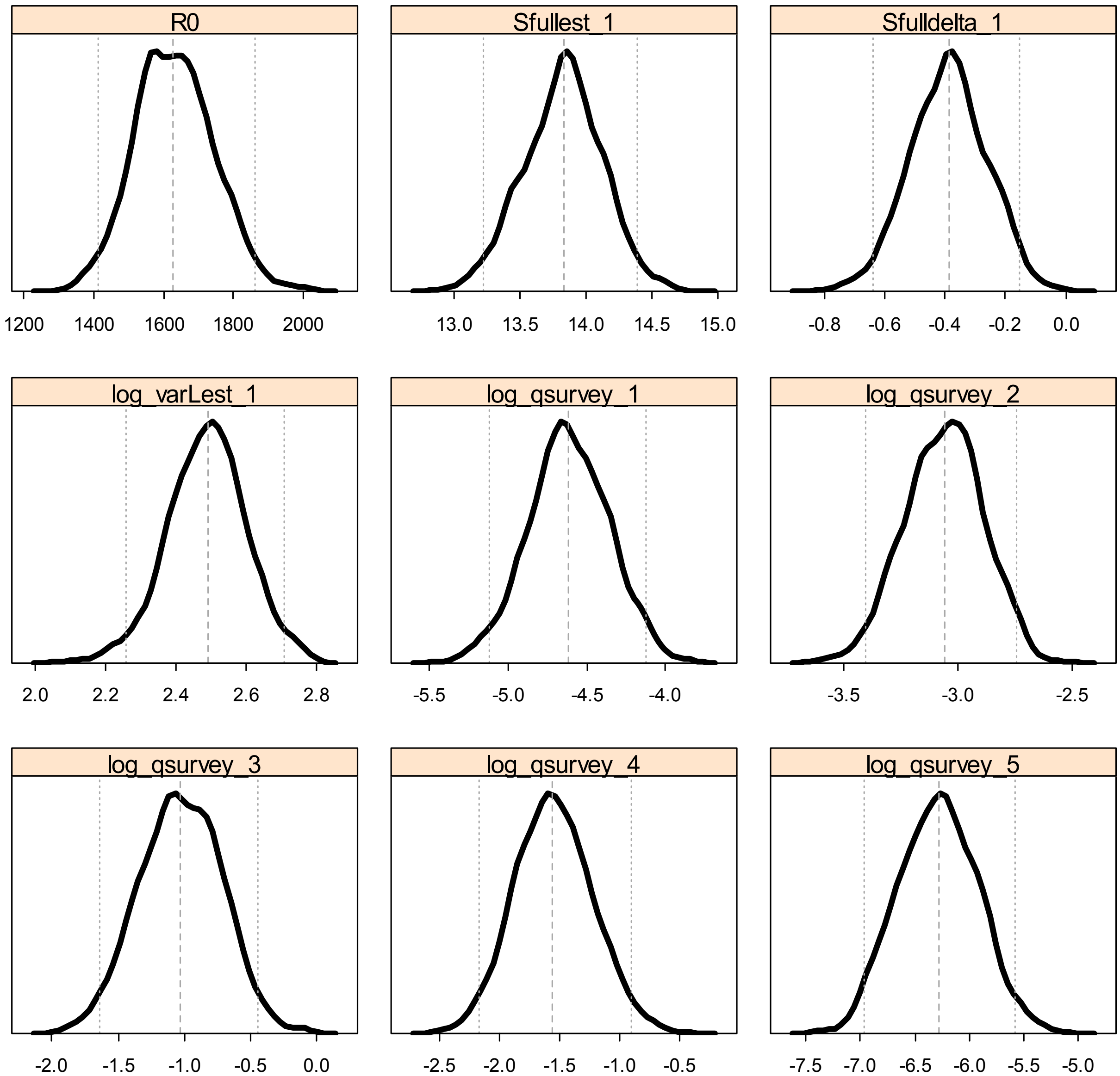

Figure J.23. Marginal posterior distributions for model parameters from Run 11. The vertical dashed lines show the 2.5th, 50th, and 97.5th percentiles.

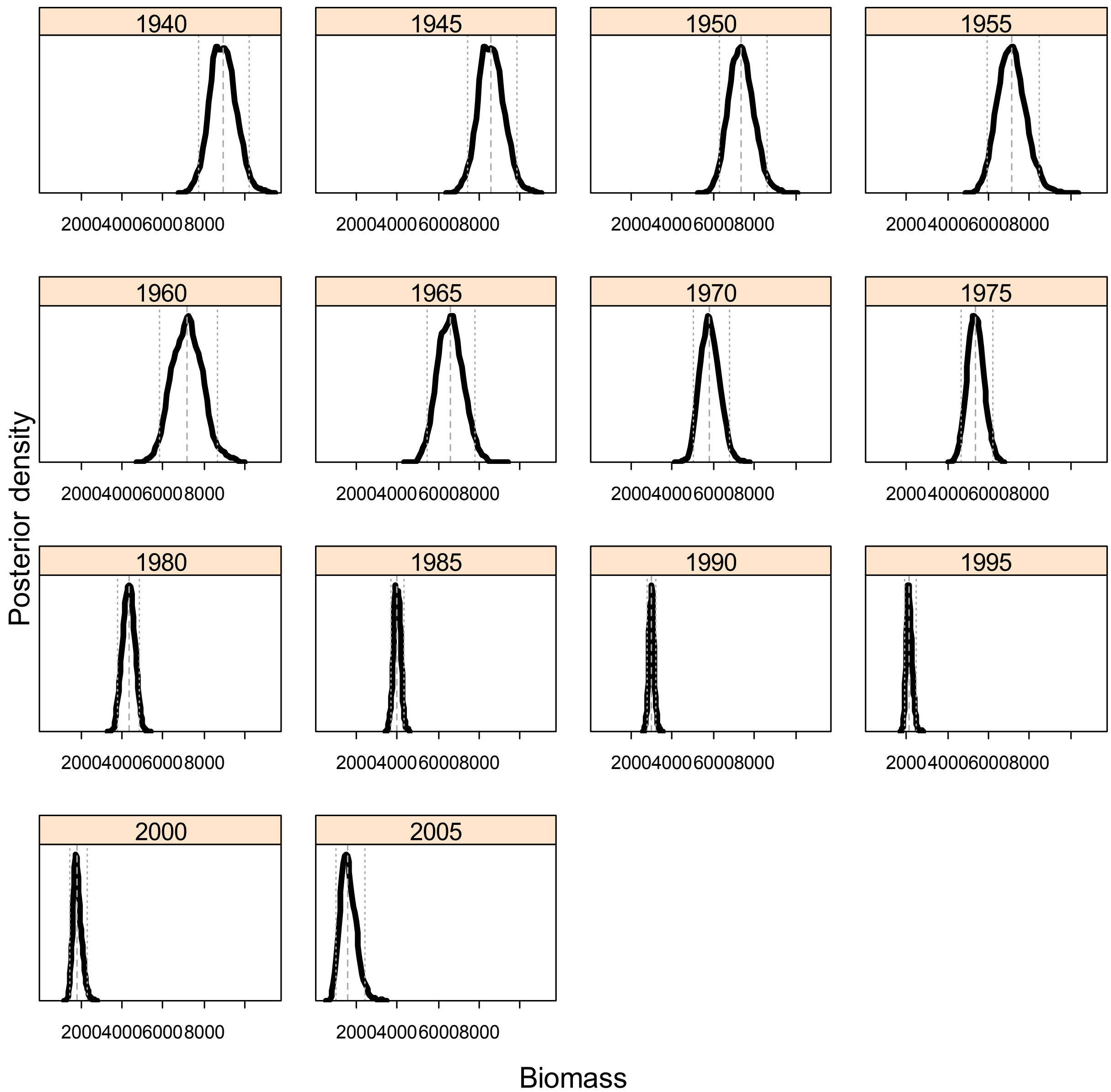

Figure J.24. Marginal posterior distributions for female spawning biomass at five year intervals for Run 11. The vertical dashed lines show the 2.5th, 50th, and 97.5th percentiles.

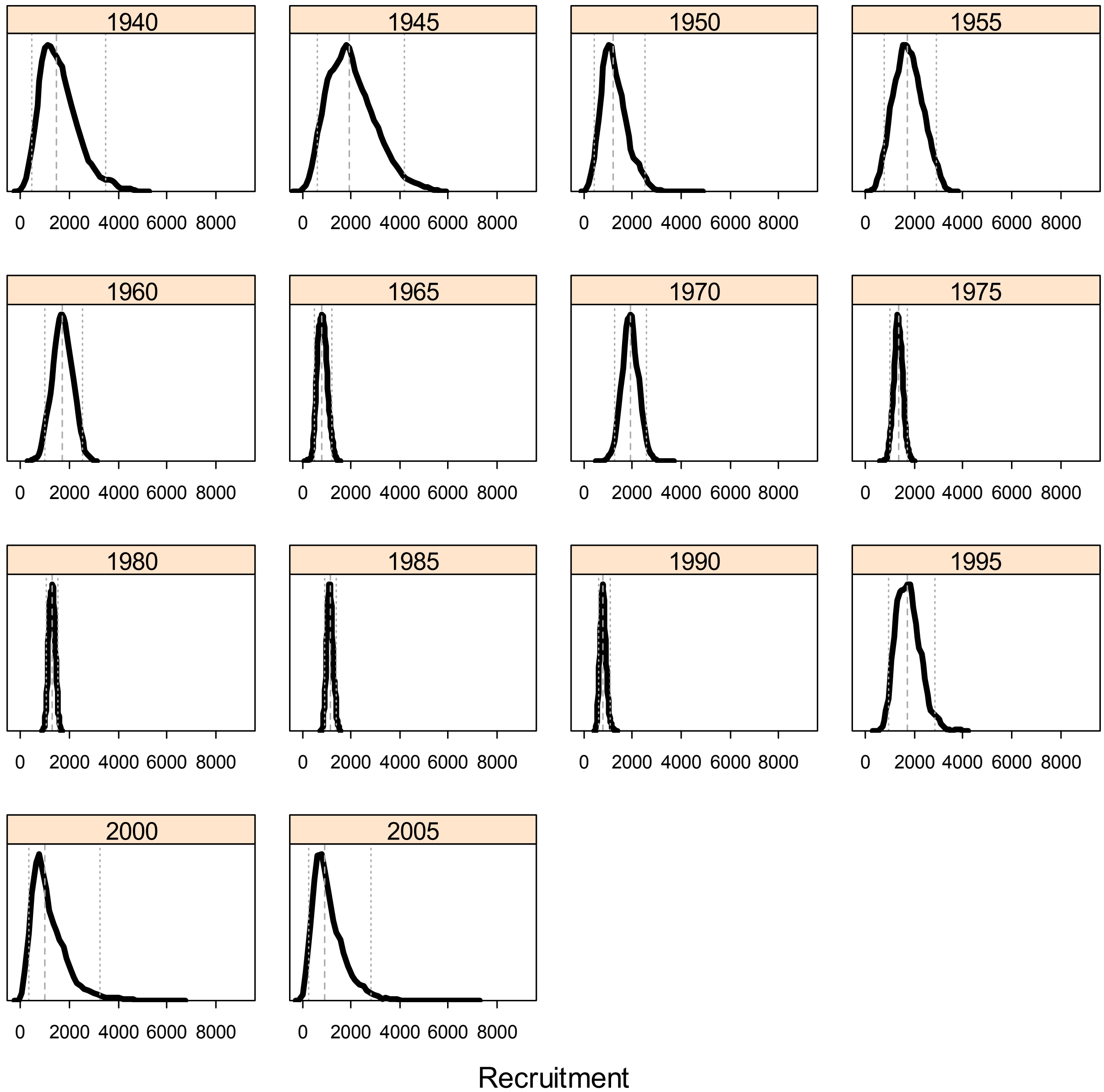

Figure J.25. Marginal posterior distributions for recruitment at five year intervals for Run 11. The vertical dashed lines show the 2.5th, 50th, and 97.5th percentiles.

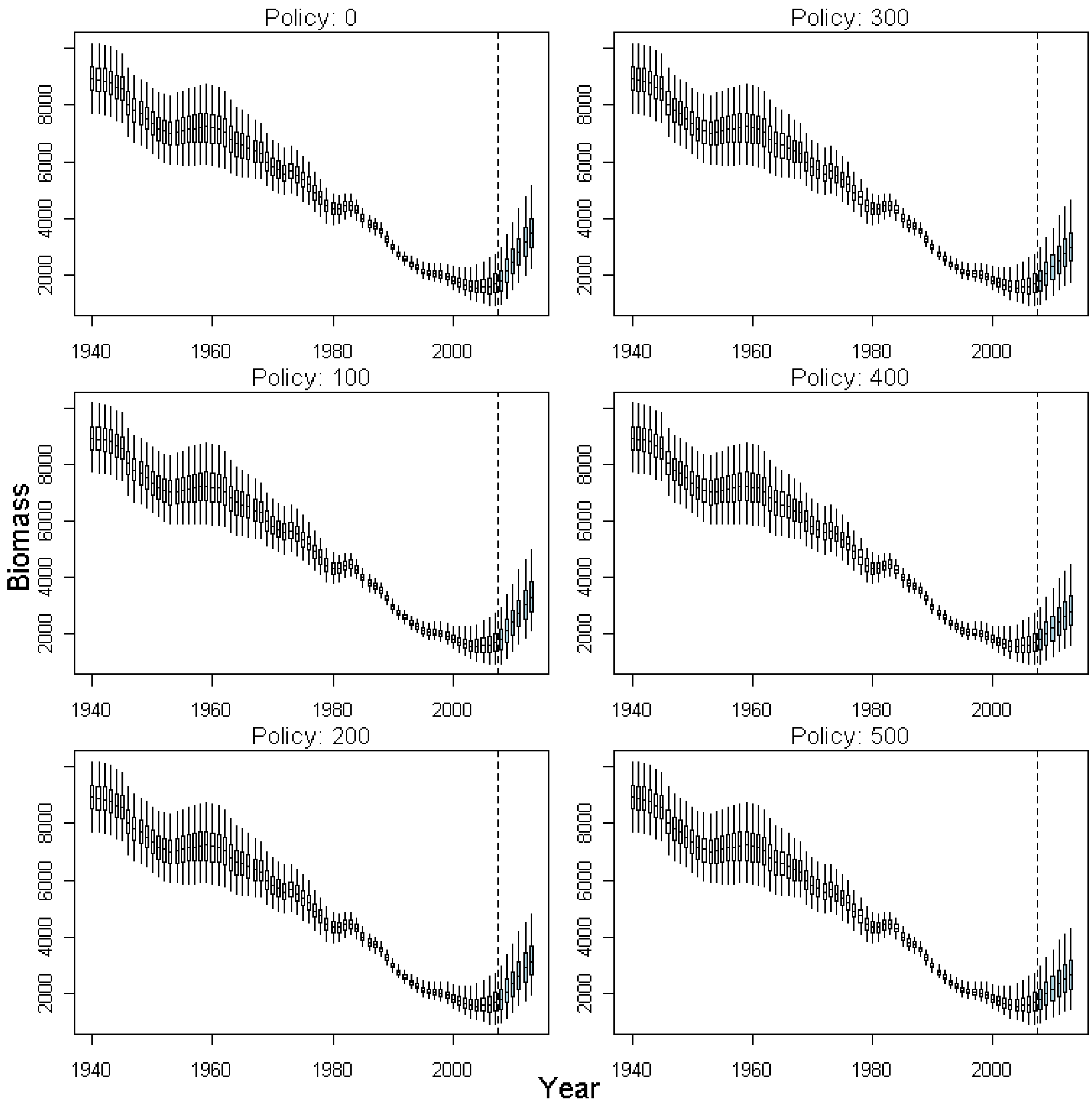

Figure J.26. Marginal posterior distributions of female spawning biomass and five-year projections using constant catch policies from 0 to 500 t per year for Run 11. The quantile-boxplots summarise the 2.5th, 25th, 50th, 75th and 97.5th percentiles of the distributions. Green boxplots indicate projection years.

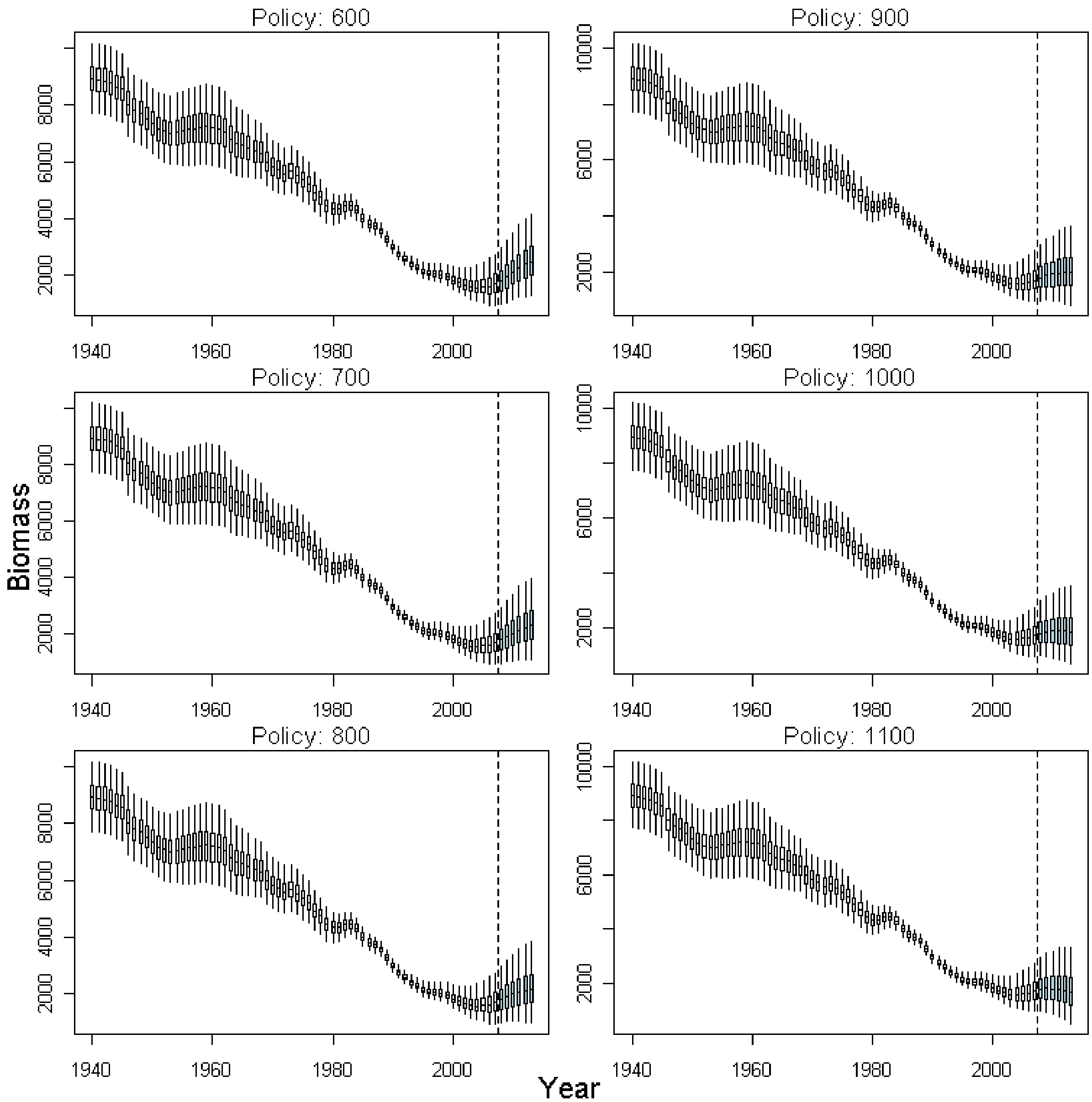

Figure J.27. Marginal posterior distributions of female spawning biomass and five-year projections using constant catch policies from 600 to 1,100 t per year for Run 11. The quantile-boxplots summarise the 2.5th, 25th, 50th, 75th and 97.5th percentiles of the distributions. Green boxplots indicate projection years.

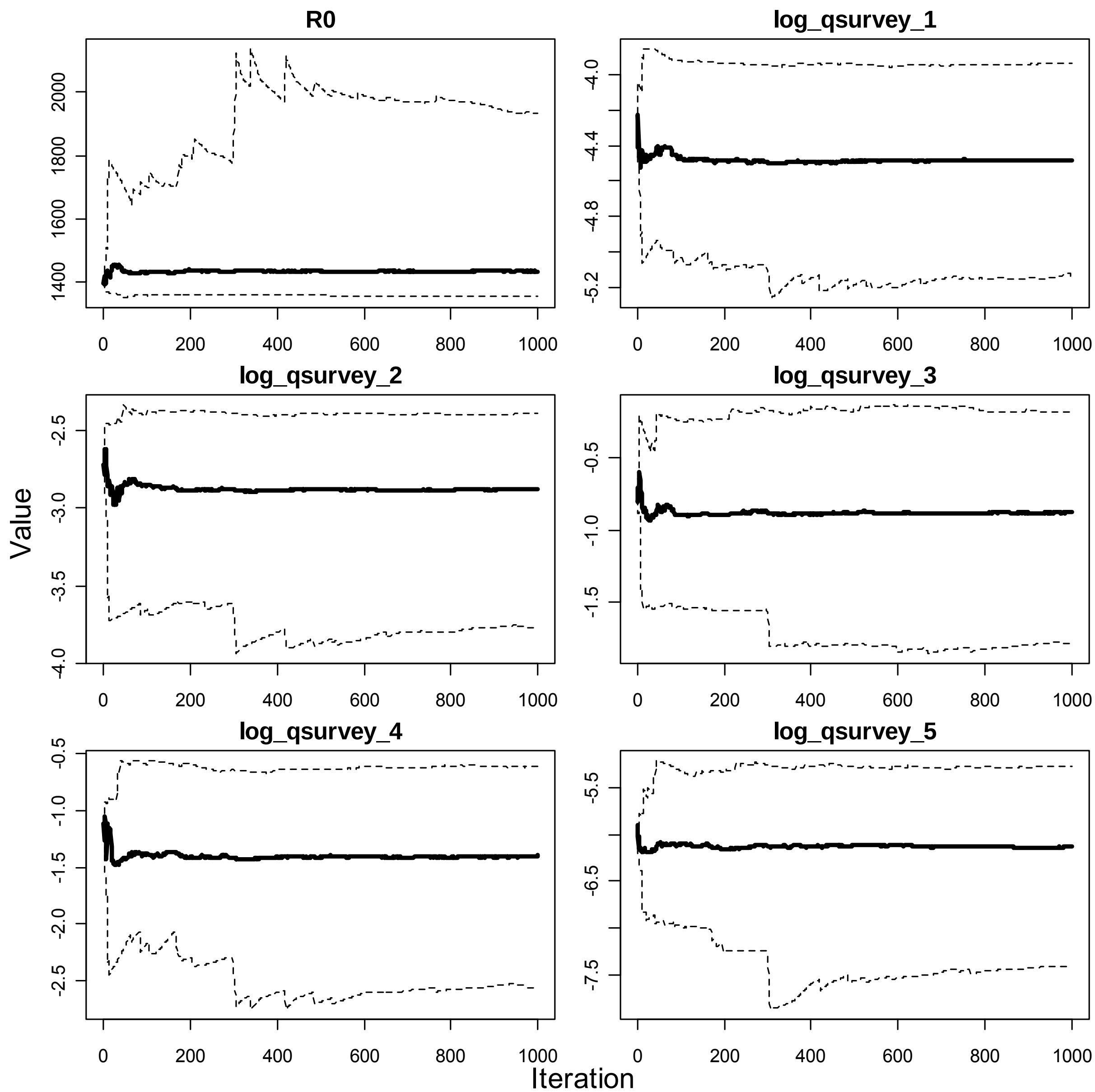

Figure J.28. MCMC cumulative quantiles for the Run 02 model parameters. The 2.5th, 50th, and 97.5th cumulative quantiles are shown.

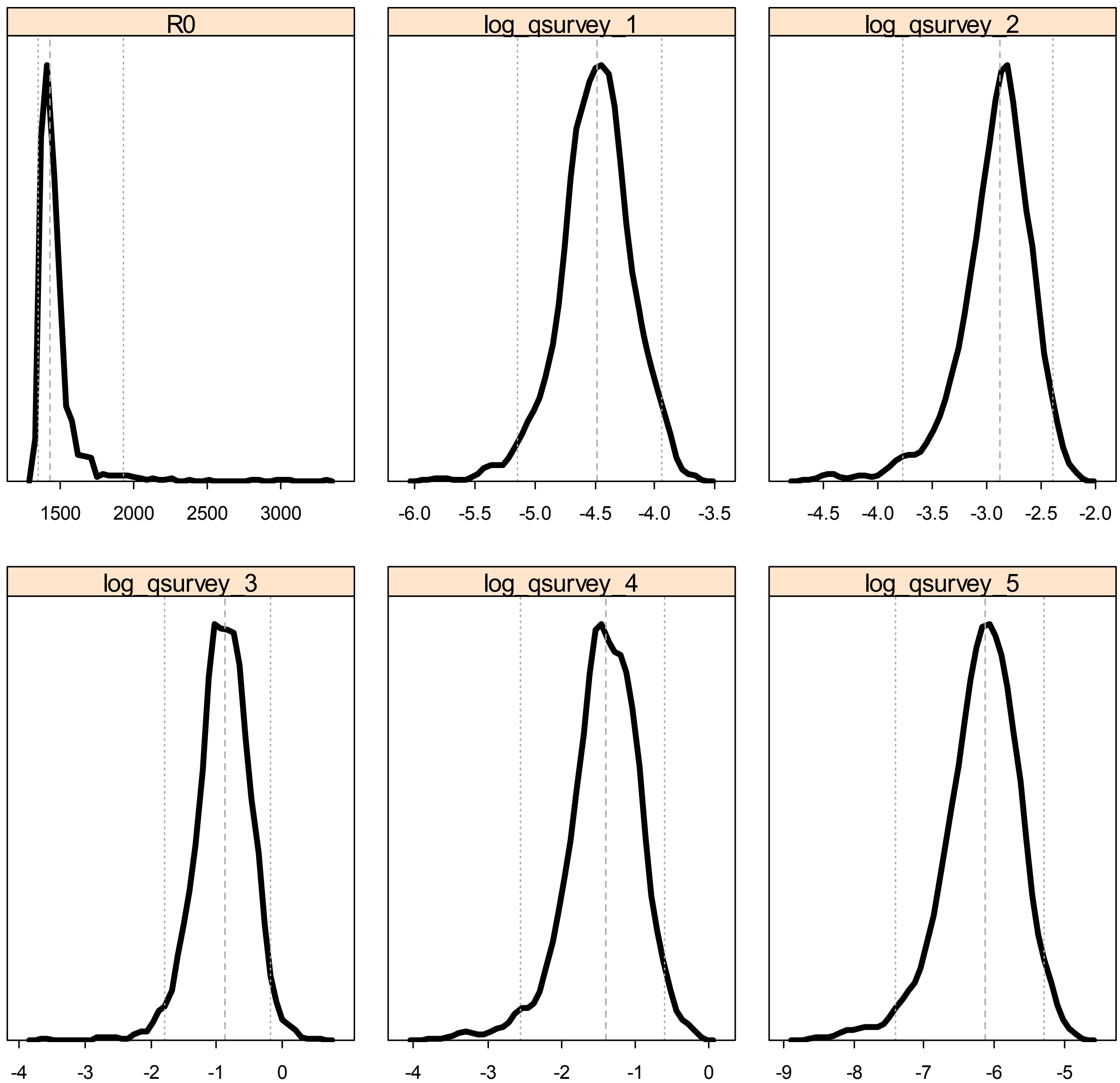

Figure J.29. Marginal posterior distributions for model parameters from Run 02. The vertical dashed lines show the 2.5th, 50th, and 97.5th percentiles.

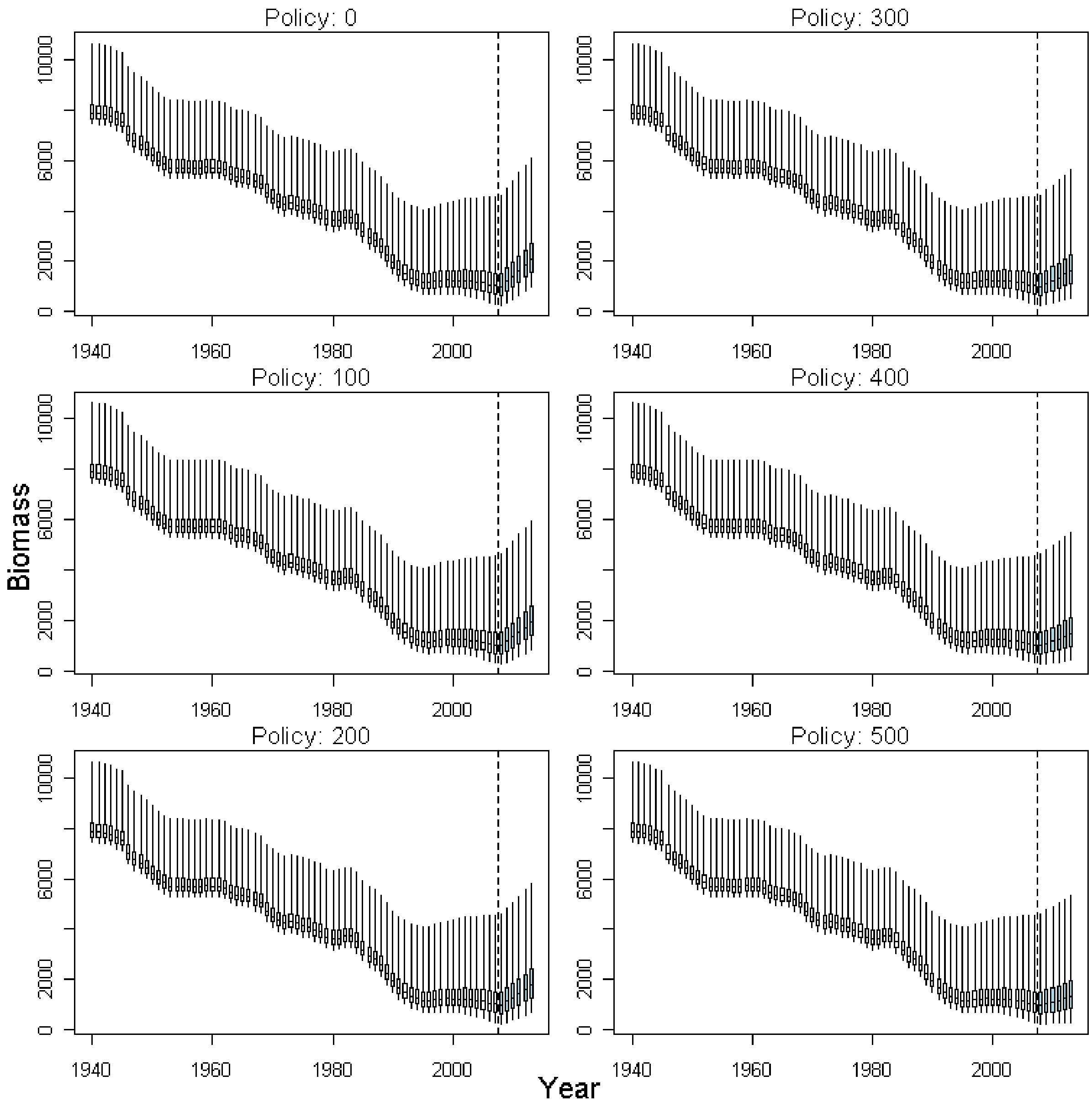

Figure J.30. Marginal posterior distributions of female spawning biomass and five-year projections using constant catch policies from 0 to 500 t per year for Run 02. The quantile-boxplots summarise the 2.5th, 25th, 50th, 75th and 97.5th percentiles of the distributions. Green boxplots indicate projection years.

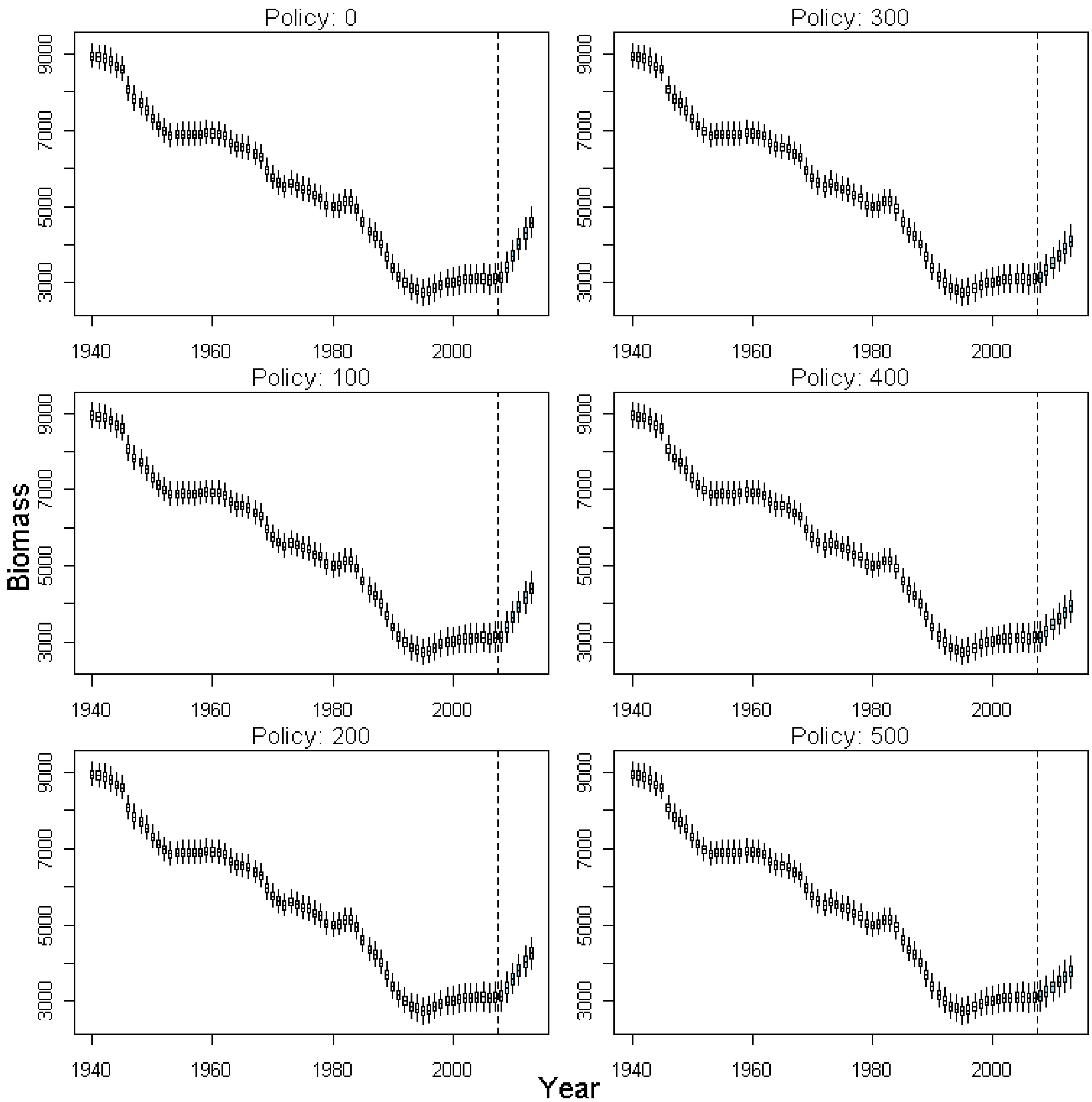

Figure J.31. Marginal posterior distributions of female spawning biomass and five-year projections using constant catch policies from 0 to 500 t per year for Run 08. The quantile-boxplots summarise the 2.5th, 25th, 50th, 75th and 97.5th percentiles of the distributions. Green boxplots indicate projection years.

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