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Stock Assessment for the Outside Population of Yelloweye Rockfish (*Sebastes ruberrimus*) for British Columbia, Canada in 2014

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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ABSTRACT

A new stock assessment is presented for the Outside population of Yelloweye Rockfish (*Sebastes ruberrimus*) in British Columbia, Canada for 2014. This assessment considers a single Outside stock based on genetic analyses. A non-equilibrium, age-aggregated Bayesian surplus production (BSP) model was used in this assessment, employing catch data derived from historic commercial, recreational and Aboriginal catch records reconstructed back to 1918, life history data to estimate the intrinsic rate of increase (r), and abundance trends derived from research surveys and commercial hook and line catch records. Sensitivity analyses considered six different sources of uncertainty: assumptions about the historic catch, priors for the intrinsic rate of increase and carrying capacity, the amount of process error standard deviation, the accuracy in different abundance indices, the form of the surplus production function, and the form of the stock assessment model.

The BSP model fits the stock trend data well and predicts a steep stock decline in the mid-1980s to the mid-1990's, coincident with a substantial increase in fishery catches and also the more gradual decline seen in most of the indices since then. Management advice is based on output from a model run proposed by the CSAP review committee and estimates that the Outside Yelloweye Rockfish biomass in 2014 (B2014) is at 3,821 t (90% credibility interval of 2,428 – 7,138 t), which is 18% (90% credibility interval 10 – 33 %) of the estimated initial biomass in 1918 (B1918) of 21,955 t (90% credibility interval 13,747 – 37,694 t). Fisheries reference points consistent with DFO's Precautionary Reference Points are presented for this assessment. There is a 63% probability that B2014 is below the Limit Reference Point (LRP) of 0.4 BMSY and a 99% probability that it is below the Upper Stock Reference (USR) of 0.8 BMSY.

Advice to management is presented in the form of decision tables, using 5, 10, and 15 year projections, for constant catch policies between 0 and 300 t/year. Replacement yield or surplus production in 2014 is estimated at 162 t (90% credibility interval 80 – 258 t). The current catch of 287 t in 2014 is estimated at 178% (90% credibility interval 114 – 360%) of replacement yield.

Évaluation du stock de sébastes aux yeux jaunes (Sebastes ruberrimus) des eaux extérieures de la Colombie-Britannique, Canada, 2014

RÉSUMÉ

Nouvelle évaluation du stock de sébastes aux yeux jaunes (Sebastes ruberrimus) des eaux extérieures de la Colombie-Britannique, Canada, 2014. La présente évaluation examine un stock unique dans les eaux extérieures d'après les analyses génétiques. Un modèle bayésien de production excédentaire non équilibré avec regroupement par âge a été utilisé pour cette évaluation, à partir des données sur les prises tirées des dossiers de prises antérieurs provenant des pêches commerciales, récréatives et autochtones reconstituées jusqu'en 1918, des données sur le cycle biologique pour estimer le taux d'augmentation intrinsèque (r) et les tendances relatives à l'abondance tirées des relevés de recherche et des dossiers de prises commerciales à la ligne et à l'hameçon. Les analyses de sensibilité tenaient compte de six sources différentes d'incertitude : hypothèses concernant les prises antérieures, données antérieures pour le taux d'augmentation intrinsèque et la capacité biotique, écart-type de l'erreur de traitement, l'exactitude de divers indices d'abondance, forme de la fonction de production excédentaire et forme du modèle d'évaluation d'un stock.

Le modèle bayésien de production excédentaire s'ajuste bien aux données sur les tendances du stock et prévoit une diminution abrupte du stock dans le milieu des années 1980 et le milieu des années 1990, qui coïncide avec une augmentation importante des prises de pêche et également le déclin graduel observé dans la plupart des indices depuis. Les conseils de gestion s'appuient sur les résultats d'un modèle d'exécution proposé par le comité d'examen du CASP et évaluent que la biomasse de la population des eaux extérieures de sébastes aux yeux jaunes en 2014 (B2014) est estimée à 3 821 t (intervalle de crédibilité de 90 %, de 2 428 à 7 138 t), c'est-à-dire 18 % (intervalle de crédibilité de 90 %, 10 à 33 %) de la biomasse initiale estimée (B1918) de 21 955 t (intervalle de crédibilité de 90 %, 13 747 à 37 694 t) en 1918. Les points de référence des pêches conformes aux points de référence de précaution du MPO sont présentés aux fins de cette évaluation. Il y a une probabilité de 63 % que B2014 soit inférieure au point de référence limite (PRL) de 0,4 de la BRMS et une probabilité de 99 %, elle est inférieure au point de référence supérieur du stock (PRS) de 0,8 de la BRMS.

L'avis de gestion est présenté sous la forme de tables de décisions, à l'aide des projections sur 5, 10 et 15 ans, pour les politiques sur les prises constantes entre 0 et 300 t/année. Le rendement de remplacement ou la production excédentaire de 2014 est estimé à 162 t (intervalle de crédibilité de 90 %, 80 à 258 t). Les prises actuelles de 287 t en 2014 sont estimées à 178 % (intervalle de crédibilité de 90 %, 114 à 360 %) du rendement de remplacement.

INTRODUCTION

Yelloweye Rockfish (*Sebastes ruberrimus*) was previously assessed together with other inshore rockfish species; Quillback (*S. maliger*), Copper (*S. caurinus*), China (*S. nebulosus*), Tiger (*S. nigrocintus*) and Black (*S. melanops*) (Richards 1986, Yamanaka and Richards 1992, 1993, 1994, and 1995, Yamanaka 1995 published manuscript, Yamanaka and Kronlund 1997, Kronlund et al. 1999, Yamanaka and Lacko 2001). The key indicator of Yelloweye Rockfish stock status in the last assessment, in 2001, was the estimate of total mortality (Z) and implied fishing mortality (F) from simple catch curve analyses (Ricker 1975) applied to research survey and commercial age data collected at various locations throughout British Columbia (BC). Harvest advice to managers in 2002, was to consider an optimal harvest rate, less than or equal to half of the natural mortality rate, $F_{opt} \leq 0.5\ M$ as proposed by Walters and Parma (1996) and risk-neutral proxies and precautionary harvest rates of 0.75 M to 0.5 M recommended in the United States (SSC 2000). The F, derived from Z in 1997/98 for the outside Yelloweye Rockfish population was in excess of M. Recommendations for management included dramatic reductions to F and also outlined a Rockfish Conservation Strategy to address conservation concerns for inshore rockfish (Koolman et al. 2007, Yamanaka and Logan 2010).

A Yelloweye Rockfish stock status report was prepared for the Committee on the Status of Wildlife in Canada (COSEWIC) in 2006 (Yamanaka et al. 2006b). Research on genetic population structure revealed two distinct populations of Yelloweye Rockfish in BC; these are recognized by COSEWIC as two designatable units and referred to as “Inside” and “Outside” (COSEWIC 2008). This stock assessment is solely concerned with the Outside population of Yelloweye Rockfish. The Inside population was assessed in 2010 (Yamanaka et al. 2011a).

This document fulfils a request from groundfish managers to determine the current status of the Outside Yelloweye Rockfish population in 2014 relative to DFO’s Precautionary Approach default harvest reference points (DFO 2009). The assessment model employed in this assessment was used for the coastwide Quillback Rockfish and Inside Yelloweye Rockfish stock assessments (Yamanaka et al. 2011a and 2011b) as well as the Bocaccio assessments in 2009 and 2012 (Stanley et al. 2009, 2012). Outputs provide forecasts of the influence of varying fixed harvest levels on future Outside Yelloweye Rockfish population trends. This information will assist managers in the development of management plans for the BC groundfish fishery.

1.1 DISTRIBUTION AND STOCK STRUCTURE

Yelloweye Rockfish is widely distributed along the northeast Pacific coast from the Aleutian Islands in Alaska to northern Baja California (Mecklenburg et al. 2002, Philips 1957) (Figure 1 from Love et al. 2002). They occur in high-relief rock habitats at depths between 15 and 549 metres, but adults are commonly found at depths between 91 and 180 metres (Kramer and O’Connell 1995, Eschmeyer et al. 1983, Love et al. 2002). In BC Yelloweye Rockfish exhibit a demersal existence over hard, complex substrates such as rock reefs and boulder fields. This species is caught in both hook and line and trawl fisheries throughout BC (Yamanaka et al. 2006b) (Figure 2). The depth of capture for 95% of all BC fishery data (1996-2015) is between 35 and 267 metres (Figure 3). Observations from submersibles in BC show juvenile Yelloweye Rockfish occur at depths from 30 to 168 metres, generally shallower than the adults which range from 30 to 232 metres (Yamanaka et al. 2006b). In some areas, juveniles were observed coexisting with adults in the same steep rock reef habitat. Both juveniles and adults commonly associate with corals and sponges that also occur in these rock habitats.

Two genetically distinct populations of Yelloweye Rockfish exist in B.C. (Yamanaka et al. 2000; 2006, COSEWIC 2008, Siegle et al. 2013). The Outside population is widespread and is known to extend from fishing grounds near Sitka in Southeast Alaska, West to Bowie Seamount, and

South into Washington State and Northern Oregon. The Inside population is generally confined to the protected marine waters East of Vancouver Island from approximately Malcolm Island (~127^{o}W) in Queen Charlotte Strait through to the Juan de Fuca sill (~48^o 20’ N) (Figure 4). New analyses suggest that the Inside population also extends into Puget Sound (Andrews et al. *in review*).

Figure 1. Global distribution of Yelloweye Rockfish highlighted in yellow. Reproduced with permission from Love et al. 2002.

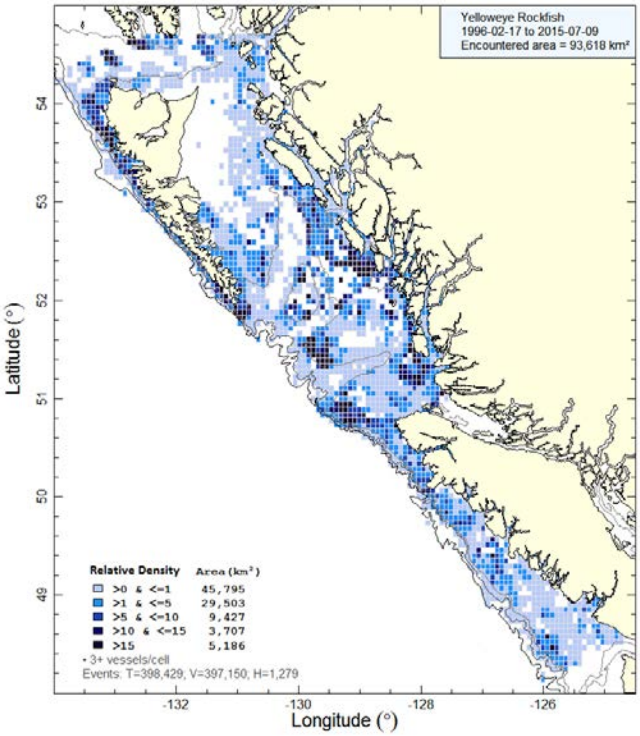

Figure 2. Coastwide distribution of Outside Yelloweye Rockfish shown as relative densities using grid cells approximately 5 square kilometres (km) in size from hook and trawl fisheries from 1996 to 2015. The total area of occupancy over the 1996 to 2015 time period is 93,618 km^2.

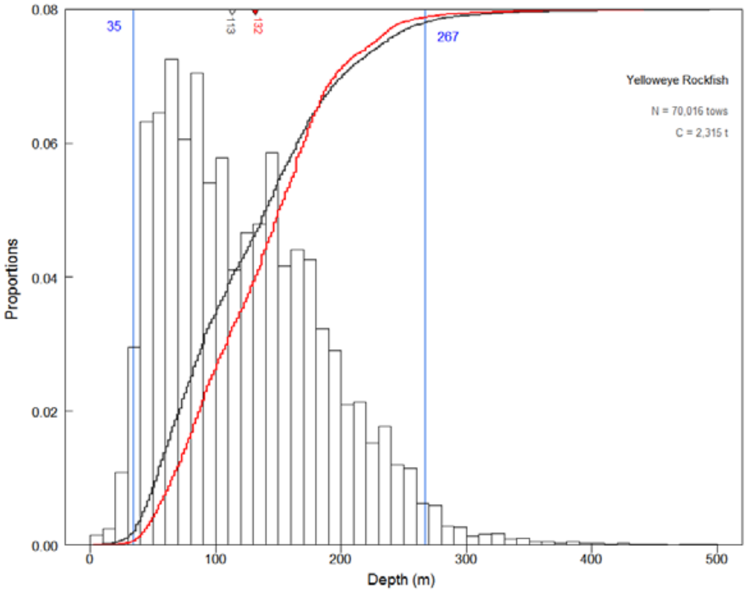

Figure 3. Depth frequency of fishing events that capture Outside Yelloweye Rockfish from commercial hook and line and trawl fisheries from 1996 to 2015 with the blue vertical lines denoting the 5% and 95% quantiles. The black curve shows the cumulative frequency of tows that encounter Yelloweye while the red curve shows the cumulative catch of Yelloweye at depth (scaled from 0 to 1). The median depth of cumulative catch (inverted red triangle) is indicated along the upper axis. The total number of tows (N) and the total catch in tonnes (C) are shown.

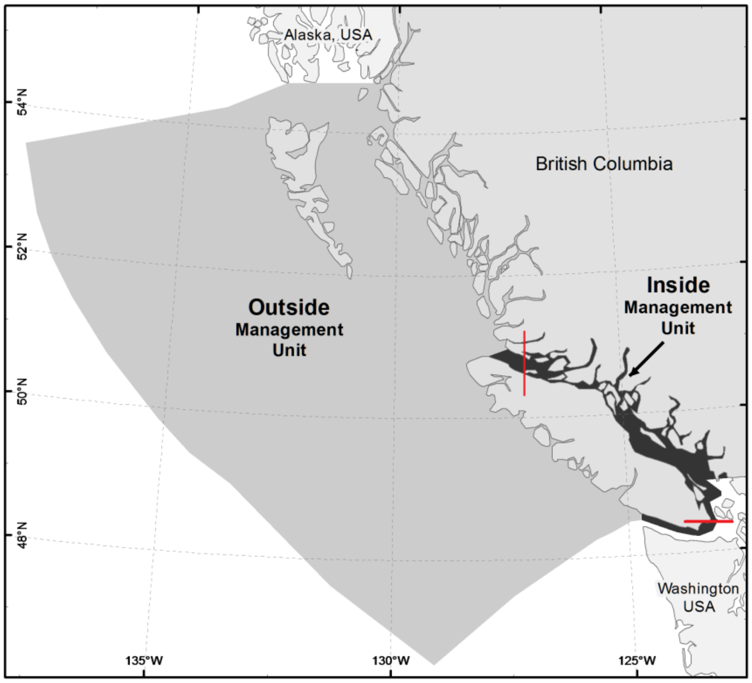

Figure 4. Map of BC showing the Outside and Inside management areas and the boundaries (lines shown in red) of the two genetically distinct Yelloweye Rockfish populations. The Inside population is confined to the protected waters east of Vancouver Island with approximate boundaries at 127^{o} W and 48^{o} 20' N (lines shown in red). The Outside population extends from at least Southeast Alaska through B.C. to at least Northern Oregon.

1.2 LIFE HISTORY

Yelloweye Rockfish is one of the oldest and largest rockfish in the genus *Sebastes*. In BC, an age of 121 years and a length of 88 cm are recorded from research survey sampling (DFO GFBio database, Accessed December 1, 2016). Juveniles have been observed as small as 5 cm in length and coloured a dark crimson-red with two brilliant white horizontal stripes along the body (Figure 5 upper left). The red body colour and white stripes fade with age and after sexual maturity Yelloweye Rockfish appear more uniformly pinkish-orange with bright yellow eyes (Figure 5 lower left and right). Under water, this species sometimes appears with a pale lateral line and white spots at the insertion of the dorsal fins (Figure 5 upper right).

The life history of Yelloweye Rockfish is not well known and is probably similar to other rockfishes. Courtship behaviour and mating have been observed for some species of rockfish (Love et al. 2002). After mating, females store sperm and can fertilize their eggs months after mating. Rockfishes are viviparous, providing nutrients to the developing embryos and releasing free swimming larvae. Once sexually mature, female Yelloweye Rockfish produce between 1.2 and 2.7 million eggs annually, with fecundity and egg quality increasing with female rockfish weight (Berkeley 2004, Palumbi 2004, Dick 2009). The gestation period for rockfishes is generally between one and two months followed by a post-parturition larval period of one to two months (Love et al. 2002). Larvae and juveniles occur in the upper mixed layer (<300 m) and are dispersed by physical transport processes (Loeb et al. 1995, Kokita and Omori 1999, Lotterhos 2014). Juveniles settle to benthic habitats between 3–9 cm in size and 6-9 months of age (Love et al. 2002).

Figure 5. Yelloweye Rockfish: upper left – early juvenile, upper right – sub adult, lower left – adults, and lower right – adults caught on longline gear and showing the effects of barotrauma.

In BC, Yelloweye Rockfish males are in a mating condition (running ripe) from November through the winter months. Eyed larvae are observed in females from April to September with the highest proportion of females in this stage in May and June. Hence, parturition peaks in May and June. Young juveniles (5 cm) have been observed in rock habitats associated with sponges, crinoids and other emergent fauna. Similar to other rockfishes, Yelloweye show an ontogenic shift to deeper habitats within their depth range (Lea et al. 1999). Juveniles have been observed occupying shallower depths than the adults (Yamanaka et al. 2006b).

Yelloweye Rockfish have been observed as largely sedentary, demersal and showing some site fidelity. In Oregon, where tagged fish were studied for over a year, vertical movements of 3 to 7 metres and minimal horizontal movements led authors to concluded high site fidelity for this species (Hannah and Rankin 2011). Shorter-term experiments in Alaska also show high site fidelity for this species (Hochhalter and Reed 2011). There is also some evidence, through the examination of Yelloweye Rockfish otolith growth chronologies, that the high levels of synchrony within sampling sites compared to among sites, indicate that these fish do not migrate long distances (Black et al. 2008).

Rockfishes are physoclistic with closed swim bladders that are not connected to the digestive tract by a duct. To regulate the swim bladder, rockfishes diffuse gases from body fluids through capillaries in the bladder membrane. Therefore, rockfishes suffer barotrauma injuries when brought up rapidly from depth because they cannot quickly deflate the swim bladder (Figure 5). Rockfish vary by species in their ability to submerge themselves after surfacing rapidly from depth during fishing. Yelloweye Rockfish have a low submergence rate of 22% as estimated by Hochhalter and Reed in Alaska (2011) and suffer mortalities as a result of this barotrauma.

Sperm Whales (*Physeter macrocephalus*) and Killer Whales (*Orcinus orca*) are known to consume adult Yelloweye Rockfish; Harbour Seals (*Phoca vitulina*) and Steller Sea Lions (*Eumetopias jubatus*) are also known to consume rockfishes, some of which may be Yelloweye

(Olesiuk et al. 1990, Ford and Ellis 2006, Lance et al. 2012, Ford 2014). Juvenile Yelloweye Rockfish are preyed upon by Chinook Salmon (*Oncorhynchus tshawytscha*), rockfishes, Lingcod (*Ophiodon elongatus*), and marine birds (Mills et al. 2007).

Yelloweye Rockfish is an aggressive piscivore that feeds on rockfishes, Herring (*Clupea palliasi*), juvenile Cod (Gadidae), Sand lance (*Ammodytes hexapterus*), flatfishes (Pleuronectiformes), Opal Squid (*Loligo opalescens*), shrimps (*Caridea spp*., *Pandalus spp*.) and crabs (*Acantholithodes hispidus*, *Cancer oregonensis*) (Rosenthal et al. 1988, Steiner 1978, Love et al. 2002). Given its piscivory, longevity, size, and sedentary habit, this species likely plays an important role in the rock reef ecosystem.

1.3 FISHERY AND MANAGEMENT HISTORY

Zooarchaeological data provide evidence of regular harvests of rockfish (*Sebastes spp.*) by Aboriginal inhabitants of Barkley Sound on the west coast of Vancouver Island that span at least 1500 years at sites where habitation is traced back to at least 5000 years (McKechnie 2007). Many rockfish species are harvested and Yelloweye Rockfish is a valued traditional food in many coastal First Nations (Stewart 1977, Turner and Turner 2007).

Early commercial fisheries developed in BC in the 1800's with salted and dried fish products used by Aboriginal people (Parsons 1993). The demand for fish expanded with the influx of fur traders and again with miners in the 1850's (Parsons 1993). After confederation, marine fisheries were administered by Canada and the collection of statistics on the fisheries developed. Anecdotal records from fishery inspectors in 1888 explained that of the 28 varieties of rockfish known at the time, "the most abundant and highly prized is what is known as the red cod or snapper" (Canada, 1988). A consistent collection of fishery statistics was assembled by the Canada Dominion Bureau of Statistics in 1917, hence the quality of data prior to 1917 is not high (Morse 1983). Yelloweye Rockfish have a long history in commercial fisheries and the early days of fishery statistics.

Rockfishes together with other species such as Lingcod (*Ophiodon elongatus*) and North Pacific Spiny Dogfish (*Squalus acanthias*) were caught using hook and line gears. The first fishery input control for this hook and line fishery was established in the form of a limited entry "C" licence in 1977. At this time, there were 1128 "C" licence entitlements (DFO). The market demand for hook and line rockfish began to expand in the late 1970's to early 1980's with catches of Yelloweye Rockfish beginning to increase (Figure 6). In 1986, the "ZN" licence was established which allowed directed fishing for rockfishes with hook and line gear. The number of "ZN" licences issued increased from 1362 in 1986 to 2396 by 1990 (Yamanaka and Kronlund 1997). Catch of Yelloweye Rockfish peaked in 1990 at 1716 t. In 1991, "ZN" licences were split by area for Inside (4B) and Outside (remainder of the coast) waters with 592 and 1595 licences, respectively. Limited entry licencing was implemented for the Inside "ZN" in 1992 and the following year, for the Outside "ZN" in 1993. This resulted in 70 Inside and 178 Outside licences in 1993.

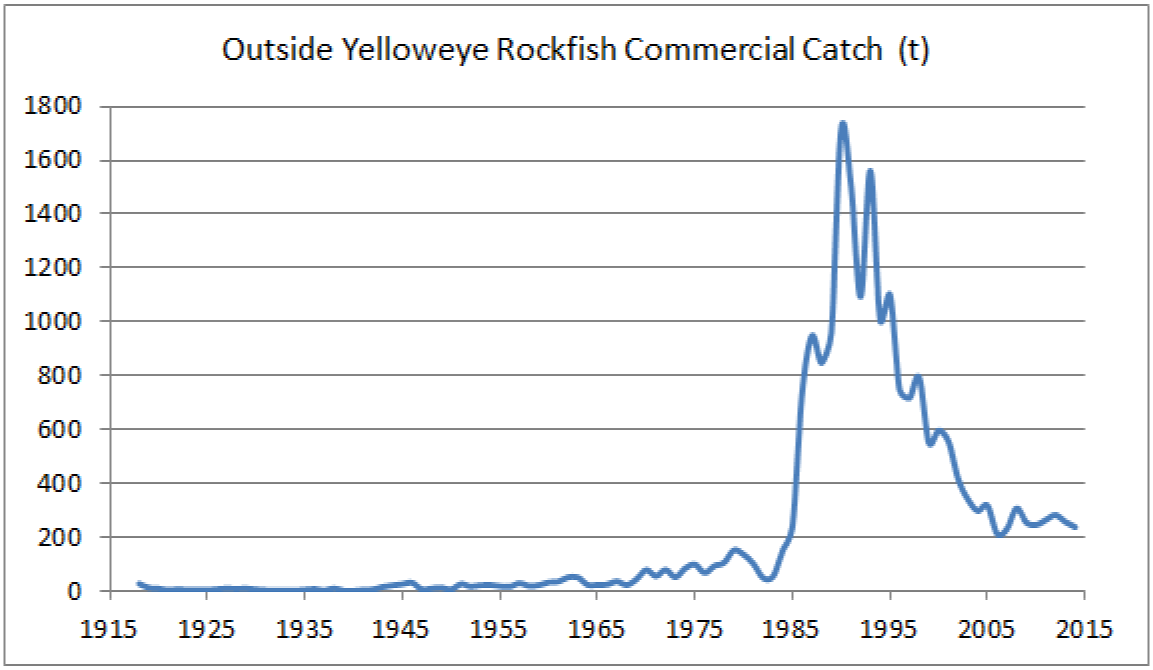

Figure 6. Outside Yelloweye Rockfish reconstructed catch history for combined commercial groundfish fisheries from 1918 to 2006 and recorded fishery catches from the Fishery Operations System from 2007 to 2014 in tonnes.

Fishery output controls, in the form of catch quotas were introduced for Yelloweye Rockfish in 1991. Catch quotas have continued as the main fishery management tool for Yelloweye Rockfish since license limitation coastwide for the "ZN" fishery. Quotas have declined for the outside Yelloweye Rockfish fishery from a high of 923 tonnes (t) in 1993, to 277 t in 2014 (Table 1). Reconstructed catches have declined from an average of 1331 t between 1990 to 1995, to 625 t between 1996 to 2002, and 254 t between 2006 to 2014 (Figure 6).

*Table 1. Overall catch quotas for Outside Yelloweye Rockfish from 1991 to 2014 by management area for commercial groundfish fisheries. Integrated groundfish fishery management initiated in the 2006/07 fishing year. Outside Yelloweye Rockfish commercial catch from 1991 to 2014 by calendar year (Jan-Dec). + unknown allocations for Trawl and Halibut in some years prior to 2000 and includes research allocations, * January 1 to December 31, CC Central Coast, PFMA 6 to 10 and 106 to 110, NC North Coast, PFMA 3 to 5 and 103 to 105, HG Haida Gwaii, PFMA 1, 2, 101 and 102, WCVI West Coast Vancouver Island, PFMA 21 to 27, 11, 121 to 127 and 111,*

Fishing Year	Trawl Coastwide	Rockfish Outside				Halibut Coastwide	Outside Total
		CC	NC	HG	WCVI		
1991*	-	100	80	200	250	-	680
1992*	-	100	80	200	250	-	689
1993*	-	138	94	308	313	-	923
1994*	-	113	60	302	236	-	781
1995*	-	118	60	291	231	-	762
1996*	-	139	48	242	187	-	647
1997*	16.2	112	36	123	146	-	441
1998/99	19	99	32	117	133	-	404
1999/00	13.4	86	27	91	111	-	338
2000/01	14	73	27	58	95	175	465
2001/02	13	71	27	46	97	169	446
2002/03	7	40	13	42	52	90	250
2003/04	7	38	12	40	50	76	229
2004/05	7	38	12	40	50	76	229
2005/06	7	40	13	42	52	76	229

Fishing Year	Trawl Coastwide	Hook and Line TAC (L & ZN Outside)					Outside Total
		3C/D, 5A	5B	5C/D	5E		
2006/07	7	83	60	64	70	-	290
2007/08	7	83	60	64	70	-	290
2008/09	7	83	60	64	70	-	290
2009/10	7	83	60	64	70	-	290
2010/11	7	83	60	64	70	-	290
2011/12	7	83	60	64	70	-	290
2012/13	7	83	60	64	70	-	290
2013/14	7	83	60	64	70	-	290

In 1998, DFO developed a Rockfish Conservation Strategy aimed at halting inshore rockfish population declines and to allow an opportunity for these populations to rebuild (Yamanaka and Logan 2010). This strategy is based on four specific conservation measures:

- account for all catch
- decrease fishing mortality
- establish areas closed to all fishing
- improve stock assessment and monitoring

DFO implemented the strategy in 2002 (Koolman et al. 2007, Yamanaka and Logan 2010). Fishing mortality was reduced by 75% for the Inside and 50% for the Outside. New stock monitoring surveys were initiated in 2003 and in 2006 and 164 Rockfish Conservation Areas (RCAs) were established between 2002 and 2007, to protect and conserve inshore rockfish and Lingcod, as well as their habitat. RCAs are designed to eliminate rockfish and Lingcod mortality related to fishing activity within their boundaries. The RCAs were monitored, using visual survey tools, between 2009 and 2011, and 100% catch monitoring and license integration were implemented in groundfish fisheries in 2006. New stock assessments were conducted for Inside Yelloweye Rockfish in 2010 and for coastwide Quillback Rockfish in 2011 (Yamanaka et al. 2011a, 2011b). The current stock assessment herein for the Outside Yelloweye Rockfish continues to support the Conservation Strategy.

Yelloweye Rockfish was designated as Special Concern in November 2008 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and listed as Special Concern under Canada's Species at Risk Act (SARA) in July 2011 (COSEWIC 2008). This listing describes the species as one that may become Threatened or Endangered due to biological characteristics and identified threats, and requires periodic monitoring to detect declines in abundance. A Yelloweye Rockfish SARA management plan is in development.

1.4 UNITED STATES FISHERIES FOR YELLOWEYE ROCKFISH

Alaska

At the northern end of the species' range, in Alaska, Yelloweye Rockfish is managed as part of multiple rockfish species assemblages in three distinct areas, the Eastern Bering Sea and Aleutian Islands (BSAI), the Gulf of Alaska (GOA) not including the Southeast Outside District (SEO), and the SEO District. In the two western areas (excluding SEO), Yelloweye Rockfish is included with 24 other species of rockfish in the "Other Rockfish" stock complex and the complex is managed in accordance with the North Pacific Fishery Management Council (NPFMC) harvest rules (Spies and Spencer 2013, Tribuzio and Echave 2013). The Other Rockfish complex is classified as a Tier 5 stock and the average of the three most recent Aleutian Islands (AI) and Eastern Bering Sea (EBS) slope trawl surveys and the GOA trawl survey are used to estimate exploitable biomass and determine the recommended Allowable Biological Catch (ABC) for the Other Rockfish stock complex in the AI and BSAI, and GOA, respectively.

In the SEO district, adjacent to BC waters, the Demersal Shelf Rockfish (DSR) assemblage which includes Yelloweye Rockfish, is managed using a harvest rate that is lower than the maximum allowed by the NPFMC harvest rules in recognition of the low productivity of the stock, the uncertainty of the biomass estimates, and the vulnerability of this assemblage to overfishing (Green et al. 2014). The DSR complex in SEO is considered a Tier 4 stock and assessed using annual visual surveys to derive an available biomass estimate for Yelloweye Rockfish (Green, et al. 2014). However, the recommended harvest rates are lower than that for Tier 4; F=M=0.02. For the 2014 fishery, the recommended ABC for DSR is calculated by applying the harvest rate (F=0.02) to the Yelloweye Rockfish biomass estimated from visual surveys then increasing this by 3% to account for other rockfishes in the DSR assemblage. The 2014 ABC for the SEO District DSR complex was 274 t.

Stocks in Alaska are considered healthy and are not subject to overfishing (ADFG 2015).

Washington, Oregon and Califonia

The coastal Yelloweye Rockfish population has been considered overfished since 2002 (Wallace 2001; Wallace 2007). The 2011 stock assessment of the coastal Yelloweye Rockfish population (California, Oregon, and Washington) estimated that the stock's spawning potential ratio (SPR) had been depleted to 21.4% relative to unexploited conditions (Taylor and Wetzel 2011). Relative depletion also varies by state, with California estimated to be at 17.3% of unexploited conditions, Oregon, 23.9%, and Washington, 27.2%. Fishing mortality rates are estimated to have been in excess of the SPR50% (the current F-target for rockfish) from 1976 through 1999. Relative exploitation rates (catch/biomass of age-8 and older fish) peaked at 12.7% in 1992 and have been at or less than 1.1% after 2001. The US coastal Yelloweye

Rockfish under the SPR=76% rebuilding strategy, estimates the Annual Catch Limit (ACL) values for 2013 and 2014 at 17.7, and 18.0 tonnes, respectively.

STOCK ASSESSMENT

1.5 FISHERY DEPENDENT DATA

Catch Data (Appendix A)

Yelloweye Rockfish is a highly prized food fish species that is primarily caught by hook and line gear types. Their widespread distribution along the nearshore coast of British Columbia (BC) makes them vulnerable to capture by all fisheries. Catch from commercial, recreational and Aboriginal fisheries were amalgamated for this stock assessment. Calendar year is used in this assessment to summarize annual catch. Catch data are not easily amalgamated for all outside areas and the methods used to estimate catch for Yelloweye Rockfish, in all fisheries, in this assessment are detailed in Appendix A. A brief description follows below.

The Outside Yelloweye Rockfish population occurs within Pacific Marine Fisheries Commission (PMFC) major areas 3CD and 5ABCDE. Although the boundaries of the Outside Yelloweye Rockfish Designatable Unit (COSEWIC terminology) are slightly inside the boundaries of PMFC major area 4B, we exclude 4B to be consistent with the management boundaries over the historic catch time series (Figure 4). That is, all catch data for the Outside Yelloweye Rockfish population includes coastwide catch except for that in PMFC major area 4B, which is occupied by the Inside Yelloweye population.

1.5.1.1 Reconstructed commercial catches

Commercial fisheries investigated are the groundfish hook and line (Pacific Halibut *Hippoglossus stenolepis*, rockfish, Lingcod and North Pacific Spiny Dogfish *Squalus suckleyi*, and Sablefish *Anoplopoma fimbria*), groundfish and shrimp (Family Pandalidae) trawl, Pacific Salmon (Genus *Oncorhynchus*) troll, and Sablefish, Dungeness Crab (*Cancer magister*) and Spot Prawn (*Pandalus platyceros*) trap. The catch of Outside Yelloweye Rockfish is reconstructed for commercial fisheries from 1918 to 2006 for the hook and line fleet and from 1918 to 2007 for the trawl fleet. Modern catch data sources are then used to 2014. Determining the catch of Yelloweye Rockfish from historic sources requires the decomposition of landings from mixed-species market categories such as “other rockfish” or “rockfish”. This is accomplished by using proportions of Yelloweye Rockfish to rockfish other than Pacific Ocean Perch (*S. alutus*) by gear type from modern catch data sources where complete species and gear type information are available. Commercial catch reconstructions have been used in previous stock assessments and this reconstruction has been conducted following the general procedures published in Haigh and Yamanaka (2011) and modified after consultations with industry representatives. See Appendix A for further details.The catch of Outside Yelloweye Rockfish is reconstructed for commercial fisheries from 1918 to 2006, catches from 2007 to 2014 are assumed to be fully reported (Figure 7). Commercial groundfish catch reconstructions have been used in previous stock assessments for the Inside population of Yelloweye Rockfish (Yamanaka et al. 2011a), Coastwide Quillback Rockfish (*S. maliger*, Yamanaka et al. 2012), Pacific Ocean Perch , Edwards et al. 2012, 2014a, 2014b), Yellowmouth Rockfish (*S. reedi*, Edwards et al. 2012b), and Silvergray Rockfish (*S. brevispinis*, Starr et al. 2016). The 2015 reconstruction of Yelloweye Rockfish commercial catch has been conducted following the general procedures published in Haigh and Yamanaka (2011), which have undergone significant changes since its publication, and results in the combined total of both commercial landings and discards. ‘Official’ or ‘merged’ catch numbers are used where present and include data from seven DFO databases that are merged to best represent catch. The catch reconstruction procedures were modified through consultations with the commercial industry at two meetings to discuss catch data on March 27th and May 14th, 2015 (see letters from the Pacific Halibut Management Association (PHMA) dated April 7 and June 12). These modifications and correspondence are included in the commercial catch reconstruction details outlined in Appendix A.

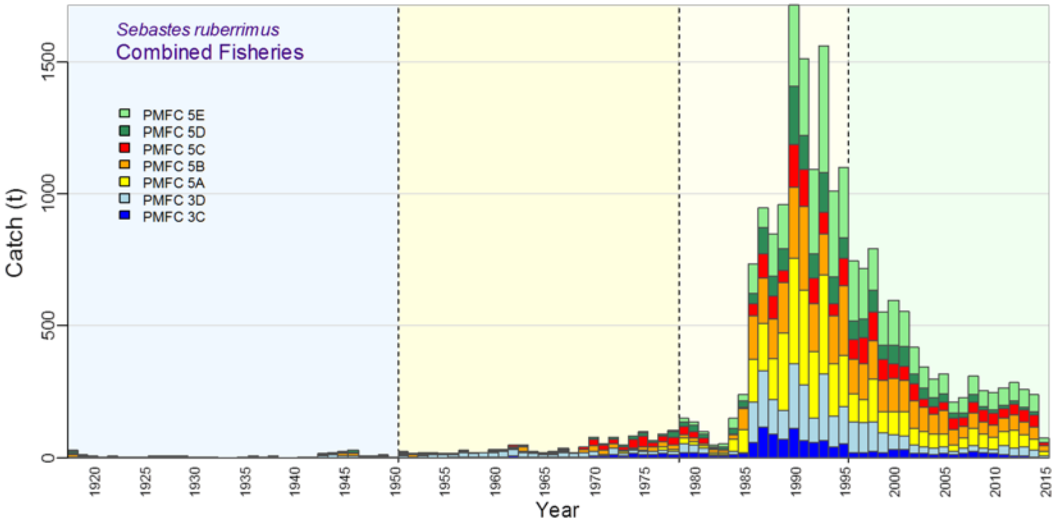

Figure 7. Outside Yelloweye Rockfish reconstructed groundfish commercial catch from 1918 to 2005 and Fishery Operations System catch from 2006 to 2014. Annual catches indicated by coloured stacked bars by PMFC management area. Vertical dotted lines denote time periods of fishery data sources explained in Appendix A.

Commercial Pacific Salmon troll fishery catch of Yelloweye Rockfish is estimated by DFO fishery managers and since 2001 has been estimated to be less than 1 t. (Appendix A). Using recorded effort and catches in the fishery from 2001 to 2014 and effort data from DFO Commercial Catch Stats Blue Books for the years 1952 to 1981, salmon troll fishery catch of Yelloweye Rockfish was estimated from 1918 to 2014 using methods detailed in Stanley et al. (2012) and Yamanaka et al. (2011b) (Appendix A).

Commercial invertebrate fishery landings of Yelloweye Rockfish were investigated. Catches in the shrimp by trawl (beam and otter), and the Spot Prawn and Dungeness Crab by trap fisheries are undetermined or low and not considered further in the assessment (Appendix A).

1.5.1.2 Recreational catches

Recreational hook and line catch (retained and released) is monitored by DFO creel surveys and lodge/guide logbook programs for some PFMAs (Lewis 2004, VanTongeren and Winther 2010, K. Hein, DFO South Coast, Nanaimo unpublished data, K. Wong, DFO North Coast, Bella Coola unpublished data) and through the iRec email survey of recreational license holders coastwide (DFO 2015).

Catch data from the West Coast Vancouver Island (WCVI) Creel Survey and the Central Coast lodge/logbook program were combined and scaled with the iRec information to estimate recreational catches for Outside Yelloweye Rockfish from 2000 to 2014. Recreational catch was estimated from 1918 to 2014 using recent catch/effort data together with effort data for the WCVI Creel Survey from 1984 to 1999 and earlier effort data compiled by Yamanaka et al. (2011a) (Appendix A). Confidential iRec data were available to view for years 2012 to 2014.

Recreational invertebrate by trap fisheries are monitored in some areas but there is no information to assess the catch of Yelloweye Rockfish in these fisheries.

1.5.1.3 Aboriginal catches

An estimate of the Food Social and Ceremonial (FSC) catch of Outside Yelloweye Rockfish was derived by applying Aboriginal consumption rates to estimates of the BC Outside Coastal Aboriginal population (Appendix A). A similar technique was used to estimate the FSC Inside Yelloweye Rockfish catch (Yamanaka et al. 2011a). These estimates were then compared to the “Dual Fishing” estimates derived from the Fishery Operations System (FOS) data which reports fishing trips in which a combined commercial and FSC fishing trip is landed. These estimates were similar and hence we used Dual fishing trips as reported through FOS as the estimate for Aboriginal FSC catches. These catches are included in our data extractions of commercial catch.

Commercial Logbook Records for Index Data

When the “ZN” licence was instituted in 1986, commercial logbook records were a mandatory requirement (Hand et al. 1990). Changes to the recording of catch and effort have occurred over time but the basic catch and effort by location data have been maintained in databases (Haigh and Richards 1997, Yamanaka and Kronlund 1997). For this reason, temporal breaks are made in the compilation of the commercial logbook indices to avoid potential bias from these periodic changes in the logbook format as well as groundfish management actions. The resulting time periods or stanzas of stable logbook formats and management actions are: 1986-88, 1989-1993, 1994-95, 1996-2001, 2002-2005, 2006-2014. Problems in 1994 and 1995 with recording catch and effort in a new logbook format are evident in the data and this stanza is not used in the stock assessment.

The standardization of commercial fisher logbook data is detailed in Appendix A and the resulting abundance indices are shown in Table 2.

Table 2. Standardized abundance indices from commercial longline catch per unit effort. The data were standardized by M. Etienne. Proc sigma refers to the standard deviation (SD) in the natural logarithm between the index and the model predicted index based on some annual systematic process affecting the scaling between the index and stock size. The values shown were obtained with the state-space parameter σ_p *set at 0.05. It should be noted that the Proc sigma values were updated with each new estimation in the sensitivity analyses. Obs sigma refers to the SD in the natural logarithm of the index computed based on the processing of the commercial catch and effort data that produced the index. Index is relative. The FOS index is derived from fisherlogs within the Fisheries Operations System, the PHL series is derived from fisherlogs within the PacHarvHL database. These data are broken into four different series to eliminate biases caused by various management changes over the years. Indices obtained from M. Etienne were rescaled to the same order as the survey indices.*

Series	Counter	Year	Index	Proc sigma	Obs sigma
PHL 1	9	1986	0.887	0.2	0.055
PHL 1	9	1987	1.05	0.2	0.0501
PHL 1	9	1988	1.06	0.2	0.0533
PHL 2	10	1989	0.957	0.3	0.0565
PHL 2	10	1990	0.889	0.3	0.031
PHL 2	10	1991	1.03	0.3	0.0331
PHL 2	10	1992	0.952	0.3	0.0365
PHL 2	10	1993	1.17	0.3	0.0348
PHL 3	11	1996	1.11	0.2	0.1346
PHL 3	11	1997	1.02	0.2	0.1324
PHL 3	11	1998	1.11	0.2	0.1315
PHL 3	11	1999	1.02	0.2	0.1345
PHL 3	11	2000	0.861	0.2	0.1359
PHL 3	11	2001	0.884	0.2	0.1274
PHL 4	12	2002	1.01	0.2	0.062
PHL 4	12	2003	1.03	0.2	0.0582
PHL 4	12	2004	1	0.2	0.0599
PHL 4	12	2005	0.965	0.2	0.0563
FOS	8	2006	5.21	0.2	0.095
FOS	8	2007	4.725	0.2	0.093
FOS	8	2008	4.375	0.2	0.092
FOS	8	2009	3.56	0.2	0.108
FOS	8	2010	4.981	0.2	0.11
FOS	8	2011	3.881	0.2	0.108
FOS	8	2012	3.631	0.2	0.102
FOS	8	2013	3.898	0.2	0.101
FOS	8	2014	3.503	0.2	0.109

1.6 FISHERY INDEPENDENT DATA

Fishery independent research surveys conducted by DFO that have caught Yelloweye Rockfish are shown in Table 3. The longline hook surveys provide the highest catch rate of Yelloweye Rockfish (number of sets encountering Yelloweye Rockfish) and are used to derive abundance indices for the assessment. In addition, some trawl surveys also provide consistent catch rates of Yelloweye Rockfish and are used as relative abundance indices for the assessment. Survey abundance indices were only included for stock assessment from series in which there was at least three observations in a time series that had at least three sets containing Yelloweye Rockfish. Although the Sablefish Stratified Random survey consistently catches Yelloweye Rockfish, this survey was not used in the assessment on the advice of industry (27 March 2015, 14 May 2015).

Table 3. Summary of all DFO research surveys which caught Yelloweye Rockfish from DFO's GFBio database (DFO Gfaster output) detailing the first year and last year of the survey and number of survey years, number of years Yelloweye Rockfish were caught in the survey, number of sets in the survey series and the number of sets that caught Yelloweye Rockfish.

SURVEY	First Year	Last Year	# Years	# Years w/ YE	# Sets	# Sets w/ YE
Queen Charlotte Sound Synoptic Survey	2003	2013	7	7	1,670	209
Hecate Strait Synoptic Survey	2005	2015	6	6	1,000	30
West Coast Vancouver Island Synoptic Survey	2004	2014	6	6	848	107
Hecate Strait Pacific Cod Monitoring Survey	2002	2004	3	3	600	16
West Coast Haida Gwaii Synoptic Survey	2006	2014	6	5	652	16
Historic GB Reed Goose Island Gully Surveys	1967	1995	9	5	463	18
Queen Charlotte Sound Shrimp Survey	1998	2013	16	11	1,103	32
West Coast Vancouver Island Shrimp Survey	1975	2014	38	21	2,994	30
West Coast Van. Island Thornyhead Survey	2001	2003	3	0	199	0
Strait of Georgia Synoptic Survey	2012	2012	1	1	51	1
IPHC Longline Survey	2003	2014	11	11	1,866	722
PHMA Rockfish Longline Survey - North	2006	2012	4	4	762	553
PHMA Rockfish Longline Survey - South	2007	2014	4	4	724	443
Sablefish Inlet Standardized	1995	2013	19	2	378	2
Sablefish Offshore Standardized	1990	2010	21	3	1,041	8
Sablefish Stratified Random	2003	2013	11	11	983	64

Longline hook surveys

The stock assessment model was fitted to three standardized research survey longline abundance indices and three synoptic trawl survey biomass series. The standardization of the research longline is detailed in Appendix A. These abundance indices and their standard deviations can be found for longline surveys in Table 4.

1.6.1.1 International Pacific Halibut Commission (IPHC) standardized stock assessment (SSA) survey

The IPHC's SSA survey is the longest times series of longline survey data in BC. This survey is a fixed station survey that has been conducted annually, with chartered commercial fishing vessels deploying fixed gear, in Canadian waters (IPHC Area 2B), since 1963 (Figure 8). It provides distribution, biomass, age, growth and maturity data that are used in the annual assessment of Pacific Halibut (*Hippoglossus stenolepis*). In 2003, the IPHC provided the opportunity to deploy an additional technician to enumerate and identify catch to species on a hook by hook basis and to collect biological data on rockfishes, during their 2B survey operations (e.g. Flemming et al. 2012). The complete enumeration of species during the SSA survey was recorded in 1995, 1996, and in all survey years beginning in 2003. In the years between 1995 and 2003, regular species composition sampling occurred over the first 20 hooks (20%) on each survey skate of gear. Although the species composition sampling, configuration of the survey stations, and the areas surveyed in BC have changed over the time series, the nominal survey series from 1995 to 2014 (except 2013) has shown to reflect abundance trends over the entire BC coast (Appendix B).

A multinomial exponential model is used with all available IPHC SSA data from 1995 to 2014 to develop an abundance index for this time series. Noting here that no adjustments were made to the nominal series used for the multinomial exponential model. As discussed in Appendix B, the exclusion of the WCVI portion of the IPHC survey series, compared with years when the WCVI is included, shows that the WCVI portion of the survey shows similar trends to the overall survey but the catch rates are generally lower. Similar comparisons with sets north of Vancouver Island show that the catch rates are somewhat higher for the north. Overall, all areas studied showed similar trends to the coastwide dataset. Multinomial exponential model methods were also used by Yamanaka et al. (Appendix E in 2011b) for the construction of a coastwide Quillback Rockfish abundance index (Appendix C). This model incorporates the presence of empty hooks and bait competition to produce robust abundance indices.

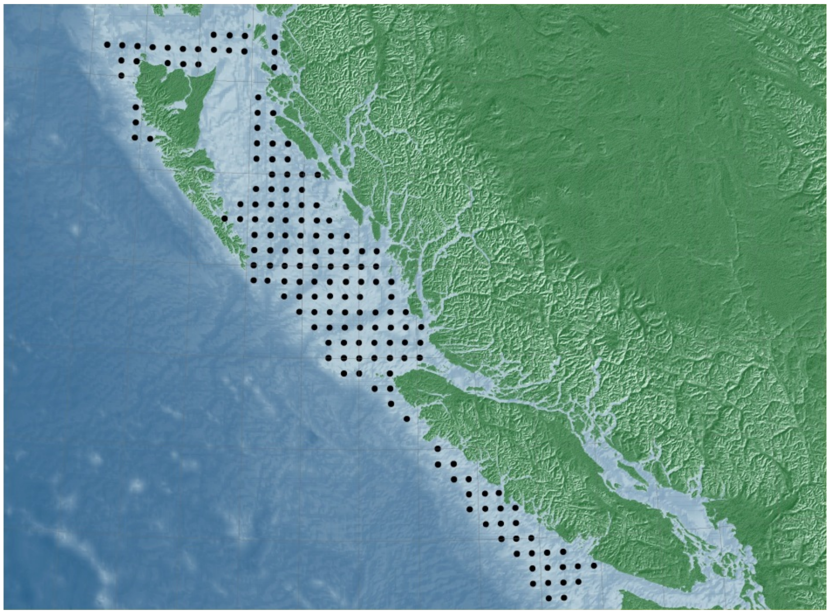

Figure 8. International Pacific Halibut Commission (IPHC) standardized stock assessment (SSA) survey stations in 2014. 170 stations are sampled annually.

Table 4. Standardized abundance indices from different long line surveys. IPHC refers to the International Pacific Halibut Commission Standardized Stock Assessment long line survey. The counter reflects the index series identifier in the stock assessment model. Proc sigma refers to the standard deviation (SD) in the natural logarithm between the index and the model predicted index based on some annual systematic process affecting the scaling between the index and stock size. The values shown were obtained with the state-space parameter σ_p set at 0.05. It should be noted that the Proc sigma values were updated with each new estimation in the sensitivity analyses. Obs sigma refers to the SD in the natural logarithm of the index computed based on the processing of the survey data (or commercial catch and effort data) that produced the index. Index is a relative biomass. IPHC indices were rescaled to the same order as the survey indices.

Series	Counter	Year	Index	Proc sigma	Obs sigma
IPHC	5	1995	2.331	0.25	0.0272
IPHC	5	1996	3.067	0.25	0.0309
IPHC	5	1997	2.351	0.25	0.0545
IPHC	5	1998	2.887	0.25	0.0483
IPHC	5	1999	1.752	0.25	0.0475
IPHC	5	2000	3.132	0.25	0.0539
IPHC	5	2001	2.625	0.25	0.0615
IPHC	5	2002	2.035	0.25	0.0883
IPHC	5	2003	1.57	0.25	0.0296
IPHC	5	2004	1.974	0.25	0.0268
IPHC	5	2005	1.7	0.25	0.0308
IPHC	5	2006	1.803	0.25	0.0321
IPHC	5	2007	1.415	0.25	0.0369

Series	Counter	Year	Index	Proc sigma	Obs sigma
IPHC	5	2008	0.9775	0.25	0.0347
IPHC	5	2009	1.217	0.25	0.0295
IPHC	5	2010	1.417	0.25	0.0246
IPHC	5	2011	1.286	0.25	0.033
IPHC	5	2012	1.266	0.25	0.0351
IPHC	5	2013	1.307	0.25	0.0753
IPHC	5	2014	1.143	0.25	0.0372

1.6.1.2 Pacific Halibut Management Association (PHMA) survey

The PHMA, in consultation with Fisheries and Oceans Canada (DFO), initiated a depth-stratified, random-design research longline survey conducted with chartered commercial fishing vessels in 2006. The survey employs standardized longline snap gear and fishing methods and alternates annually between the northern and southern portions of BC (Figure 9). The project is designed to provide catch rates of all species and biological samples of inshore rockfish from the outside coastal waters of BC for stock assessment. The data series used in this assessment spans the northern area in 2006, 2008, 2010, 2012 and 2015, and the southern area in 2007, 2009, 2011, and 2014. A multinomial exponential model is used to develop an abundance index for these times series of data similar to that used by Yamanaka et al. (2011) (Appendix C).

Figure 9. Pacific Halibut Management Association (PHMA) research longline survey coastwide grid in greyscale (shading depicts depth intervals). The coastwide grid is divided into northern and southern portions that are sampled over two years. The survey plans 198 sets per year.

Table 5. Standardized abundance indices from different long line surveys. IPHC refers to the International Pacific Halibut Commission Standardized Stock Assessment long line survey. PHMA_S refers to the Pacific Halibut Management Association –southern area longline survey, PHMA_N refers to Pacific Halibut Management Association –northern area longline survey. The counter reflects the index series identifier in the stock assessment model. Proc sigma refers to the standard deviation (SD) in the natural logarithm between the index and the model predicted index based on some annual systematic process affecting the scaling between the index and stock size. The values shown were obtained with the state-space parameter σ_p set at 0.05. It should be noted that the Proc sigma values were updated with each new estimation in the sensitivity analyses. Obs sigma refers to the SD in the natural logarithm of the index computed based on the processing of the survey data (or commercial catch and effort data) that produced the index. Index is a relative biomass. Indices obtained from M. Etienne were rescaled to the same order as the survey indices.

Series	Counter	Year	Index	Proc sigma	Obs sigma
PHMA_S	6	2007	4.828	0.5	0.0177
PHMA_S	6	2009	4.225	0.5	0.018
PHMA_S	6	2011	6.396	0.5	0.0161
PHMA_S	6	2014	2.112	0.5	0.0238
PHMA_N	7	2006	5.067	0.2	0.0166
PHMA_N	7	2008	5.909	0.2	0.0163
PHMA_N	7	2010	5.054	0.2	0.0169
PHMA_N	7	2012	6.055	0.2	0.0158

Synoptic trawl surveys

DFO’s groundfish section conducts trawl surveys over a grid comprising 2 km by 2 km grid cells throughout BC’s trawlable substrates in the Hecate Strait/Dixon Entrance, West Coast Haida Gwaii, Queen Charlotte Sound, and West Coast Vancouver Island regions. These surveys cover the continental shelf and upper slope and are stratified by area and depth. In each survey year, grid blocks are selected at random for sampling. Three trawl surveys have been useful for indexing Yelloweye Rockfish as they catch these fish consistently over the time series; the Hecate Strait, Queen Charlotte Sound and West Coast Vancouver Island. (Table 6).

The stock assessment model was fitted to these three synoptic trawl survey biomass series. The standardization of the trawl survey series is detailed in Appendix A. These abundance indices and their standard deviations can be found for trawl surveys in Table 7.

Table 6. Synoptic research trawl surveys that consistently caught Outside Yelloweye Rockfish and are used in the stock assessment. Surveys are listed by year, relative index in tonnes with lower and upper 95% confidence intervals, relative error, total catch of Outside Yelloweye Rockfish, number of sets in the survey, and the number of sets that caught Yelloweye Rockfish.

Trawl Surveys	**Year**	**Index (t)**	**Lower 95% CL**	**Upper 95% CL**	**Rel. Error**	**Total Catch (kg)**	**Num. of Sets**	**Num. Sets With Yelloweye**
Hecate Strait Synoptic Survey	2005	16	6	30	0.38	44	203	9
Hecate Strait Synoptic Survey	2007	25	5	47	0.44	35	134	5
Hecate Strait Synoptic Survey	2009	10	0	24	0.61	14	156	3
Hecate Strait Synoptic Survey	2011	14	3	28	0.50	21	186	4
Hecate Strait Synoptic Survey	2013	20	6	37	0.41	30	175	6
Queen Charlotte Sound Synoptic Survey	2003	205	81	402	0.40	256	233	20
Queen Charlotte Sound Synoptic Survey	2004	313	139	561	0.35	391	230	33
Queen Charlotte Sound Synoptic Survey	2005	271	154	414	0.24	327	224	38
Queen Charlotte Sound Synoptic Survey	2007	150	94	211	0.21	237	257	35
Queen Charlotte Sound Synoptic Survey	2009	134	75	207	0.25	180	233	22
Queen Charlotte Sound Synoptic Survey	2011	251	56	595	0.57	312	252	22
Queen Charlotte Sound Synoptic Survey	2013	161	104	227	0.20	209	241	39
West Coast Vancouver Island Synoptic Survey	2004	177	57	321	0.40	144	89	11
West Coast Vancouver Island Synoptic Survey	2006	90	47	143	0.28	153	164	17
West Coast Vancouver Island Synoptic Survey	2008	150	62	259	0.33	236	159	20
West Coast Vancouver Island Synoptic Survey	2010	159	84	254	0.28	228	136	25
West Coast Vancouver Island Synoptic Survey	2012	145	65	238	0.32	214	153	16
West Coast Vancouver Island Synoptic Survey	2014	63	24	112	0.36	90	147	18

Table 7. Swept area abundance indices obtained from synoptic trawl trawl surveys. QCSS (Queen Charlotte Sound Synoptic), HSS (Hecate Strait Synopti)c, and WCVIS (West Coast Vancouver Island Synoptic). The counter reflects the index series identifier in the stock assessment model. Proc sigma refers to the standard deviation (SD) in the natural logarithm between the index and the model predicted index based on some annual systematic process affecting the scaling between the index and stock size. The values shown were obtained with the state-space parameter σ_p set at 0.05. The Proc sigma values are updated with each new estimation in the sensitivity analyses. Obs sigma refers to the SD in the natural logarithm of the index computed based on the processing of the survey data that produced the index. Relative biomass values are in tonnes.

Series	Counter	Year	Index (t)	Proc sigma	Obs sigma
QCSS	1	2003	205	0.1	0.4
QCSS	1	2004	312.8	0.1	0.35
QCSS	1	2005	271.2	0.1	0.24
QCSS	1	2007	149.5	0.1	0.21
QCSS	1	2009	134.3	0.1	0.25
QCSS	1	2011	251.1	0.1	0.57
QCSS	1	2013	160.9	0.1	0.2
HSS	2	2005	16.58	0	0.38
HSS	2	2007	25.45	0	0.44
HSS	2	2009	10.52	0	0.61
HSS	2	2011	13.89	0	0.5
HSS	2	2013	19.82	0	0.41
WCVIS	3	2004	176.6	0.3	0.4
WCVIS	3	2006	89.8	0.3	0.28
WCVIS	3	2008	149.8	0.3	0.33
WCVIS	3	2010	158.5	0.3	0.28
WCVIS	3	2012	145	0.3	0.32
WCVIS	3	2014	62.7	0.3	0.36

1.6.1.3 Hecate Strait

The Hecate Strait (and Dixon Entrance) Synoptic (HSS) trawl survey is conducted by the *CCGS W.E. Ricker* every two years and started in 2005 (Figure 10 and Figure 11).

Figure 10. Hecate Strait (including Dixon Entrance) Synoptic survey grid in greyscale (shading depicts depth intervals).

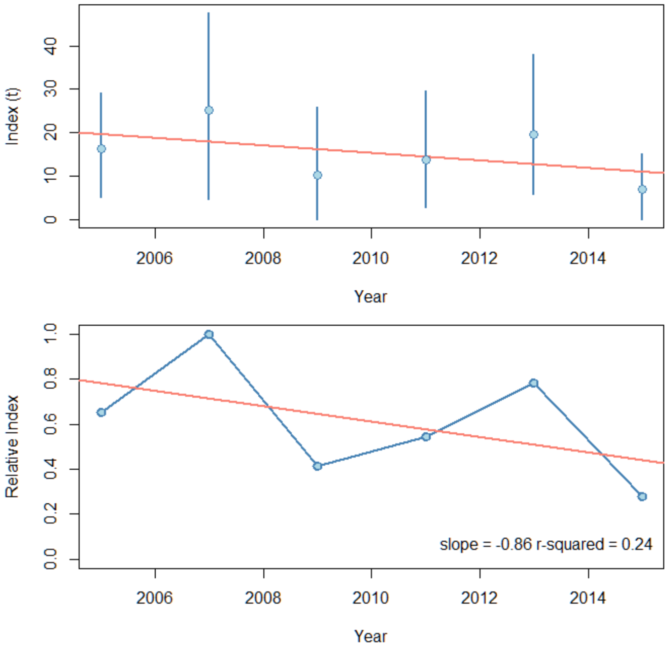

Figure 11. Hecate Strait Synoptic trawl survey abundance index. Top panel, survey mean with 95% bootstrapped confidence interval and regression line plotted to show the survey trend. Bottom panel, relative index means scaled from 0 to 1 with regression line slope and R-squared values shown (Starr and Fargo 2004).

1.6.1.4 Queen Charlotte Sound

The Queen Charlotte Sound Synoptic (QCSS) trawl survey is conducted by chartered commercial fishing vessels every two years and started with three annual surveys in 2003, 2004 and 2005 (Figure 12 and Figure 13).

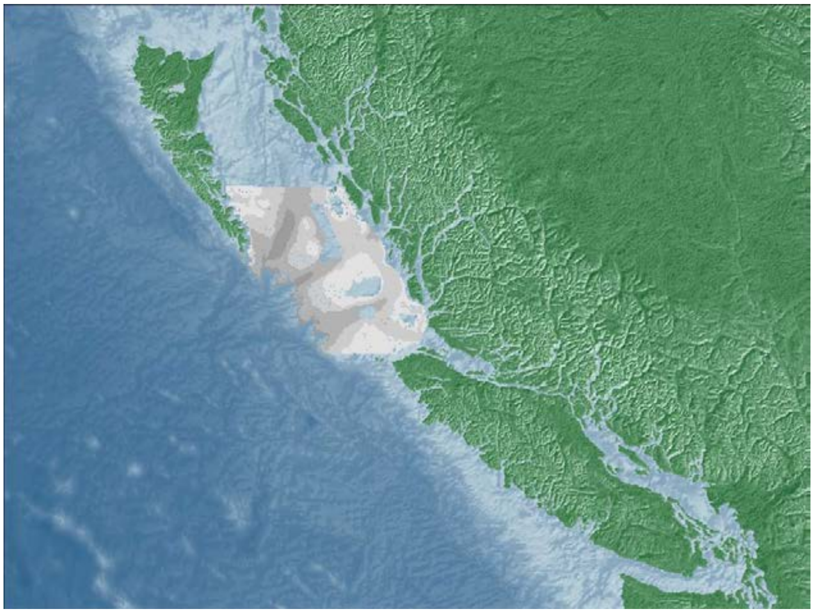

Figure 12. Queen Charlotte Sound synoptic Survey grid in greyscale (shading depicts depth intervals).

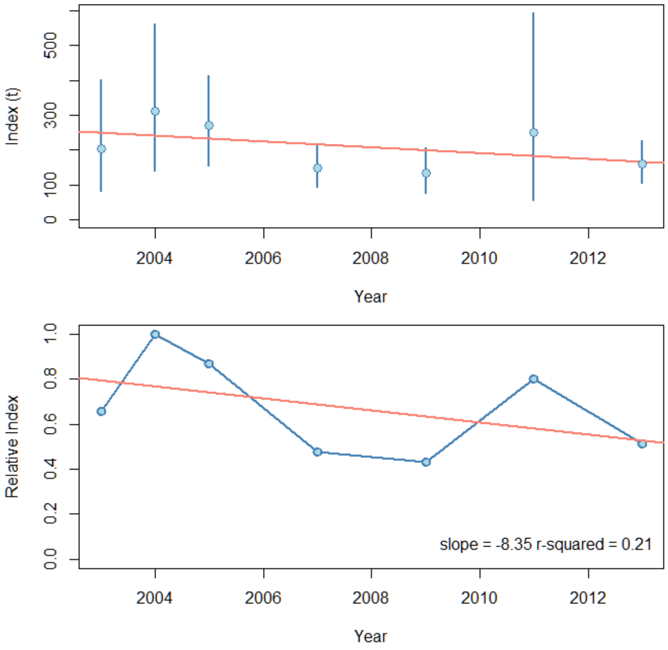

Figure 13. Queen Charlotte Sound Synoptic trawl survey abundance index. Top panel, survey mean with 95% bootstrapped confidence interval and regression line plotted to show the survey trend. Bottom panel, relative index means scaled from 0 to 1 with regression line slope and R-squared values shown (Starr and Fargo 2004).

1.6.1.5 West Coast Vancouver Island

The West Coast Vancouver Island Synoptic (WCVIS) trawl survey is conducted by the *CCGS W.E. Ricker* every two years and started in 2004 (Figure 14 and Figure 15).

Figure 14. West Coast Vancouver Island Synoptic survey shown in greyscale (shading depicts depth intervals).

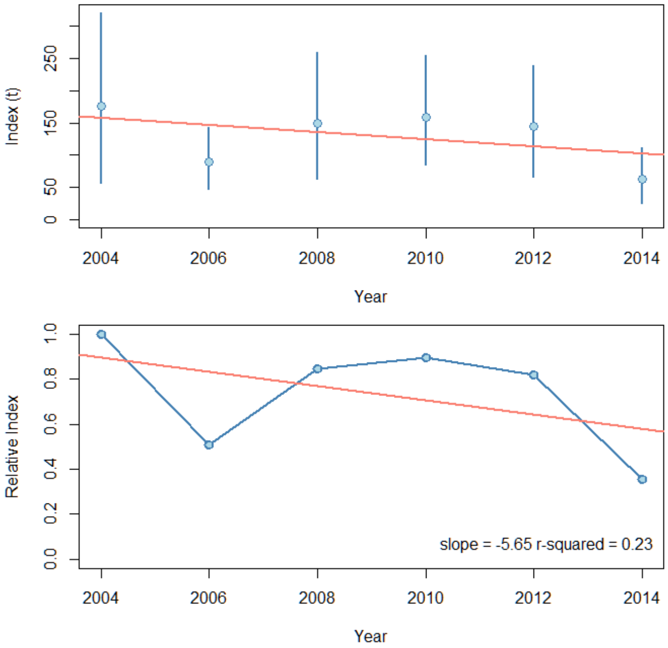

Figure 15. West Coast Vancouver Island Synoptic trawl survey abundance index Top panel, survey mean with 95% bootstrapped confidence interval and regression line plotted to show the survey trend. Bottom panel, relative index means scaled from 0 to 1 with regression line slope and R-squared values shown (Starr and Fargo 2004).

1.7 BIOLOGICAL DATA

Natural mortality rate and growth

Yelloweye Rockfish are long-lived with ages of up to 121 years for females and 115 years for males recorded in B.C. (Table 8). Using Hoenig's method on the oldest female and male, the rate of natural mortality is predicted to be 0.038 y^{-1} and 0.039 y^{-1}, respectively (Hoenig 1983, Hewitt and Hoenig 2005). Females attain older ages and longer lengths than the males but males display 23% higher growth rates than females (Figure 16). Growth rate parameters by sex were estimated using the methods reported in Stanley et al. (2012) and King et al. (2012) (Figure 17). The estimates of L_{inf} for males and females were similar and very precisely estimated due to the large number of samples (Table 8).

Table 8. Outside Yelloweye Rockfish maximum length (maxLen) and age (maxAge), von Bertalanffy (vonB) growth and length-weight (lenwt) parameter estimates for female and males. Lengths in centimeters (cm) and weight in kilograms (kg).

Sex	maxLen	maxAge	vonB	Mean	SD	LenWt	Mean	SD
females	*N=13,225* 81.0 cm	*N=9,590* 121	*N=2279*			*N=6,165*		
			L_{inf} (cm)	63.82	0.45	*a*	1.25E-08	7.41E-10
			k (yr^{-1})	0.047	0.0019	*b*	3.067	0.0094
			t_0 (yr)	-3.72	0.108			
males	*N=12,575* 78.3 cm	*N=10,000* 115	*N=2443*			*N=6,289*		
			L_{inf} (cm)	66.82	0.34	*a*	1.65E-08	9.62E-10
			k (yr^{-1})	0.0433	0.0016	*b*	3.022	0.011
			t_0 (yr)	-1.15	0.57			

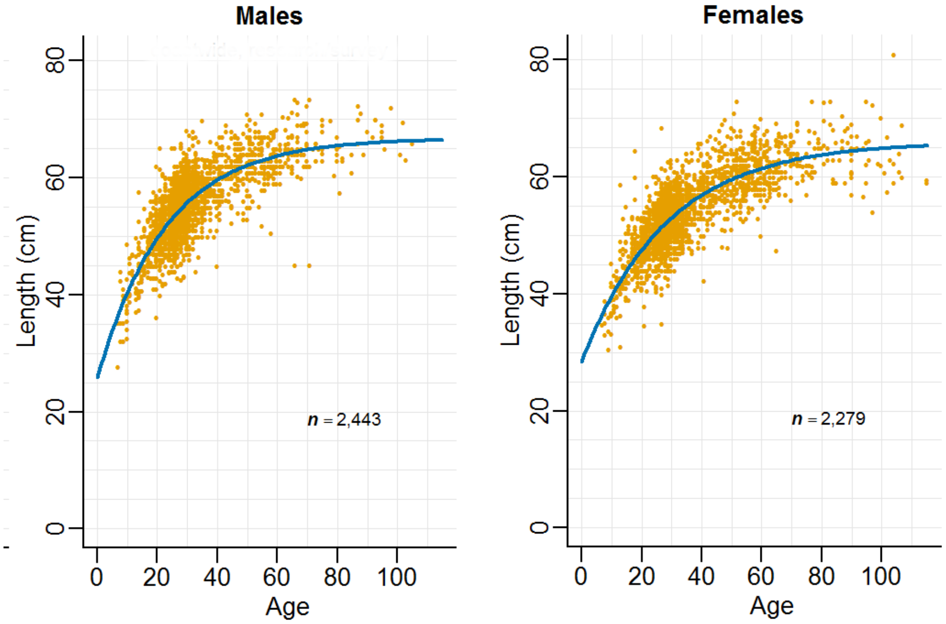

Figure 16. Fitted von Bertalanffy model to Outside Yelloweye Rockfish age (years) and length (cm) data by sex.

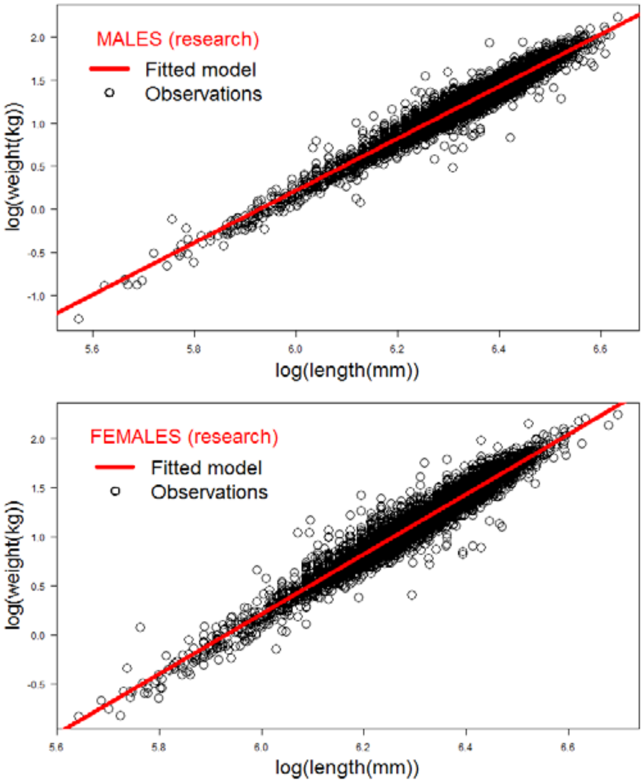

Figure 17. Fitted log length to mass model to Outside Yelloweye Rockfish length (mm) and mass (kg) data by sex.

Maturity

The fraction mature at age was estimated using a normalized cumulative lognormal density function as this provided a better fit to the data than the conventional logistic function. The same method was applied and documented in Yamanaka et al (2011). Females have a lower mean age at maturity than males (Table 9). Age at 50% sexual maturity is 15.2 years for females and 17.5 years for males (Figure 18). These estimates are based on visual or macroscopic evaluation of the gonad which may over-represent immature female Yelloweye Rockfish when compared to microscopic maturity assessments due to the difficulty of assessing maturity in ovaries (Hannah et al. 2009).

Table 9. Outside Yelloweye Rockfish posterior mean and posterior CV in the median age at maturity and the standard deviation in the natural log of the age at maturity (approximate CV in age at maturity).

Sex	Parameter	Mean	Std
females	median age (yr)	15.21	0.32
	approx. CV in age at maturity	0.46	0.014
males	median age (yr)	17.55	0.45
	approx. CV in age at maturity	0.56	0.018

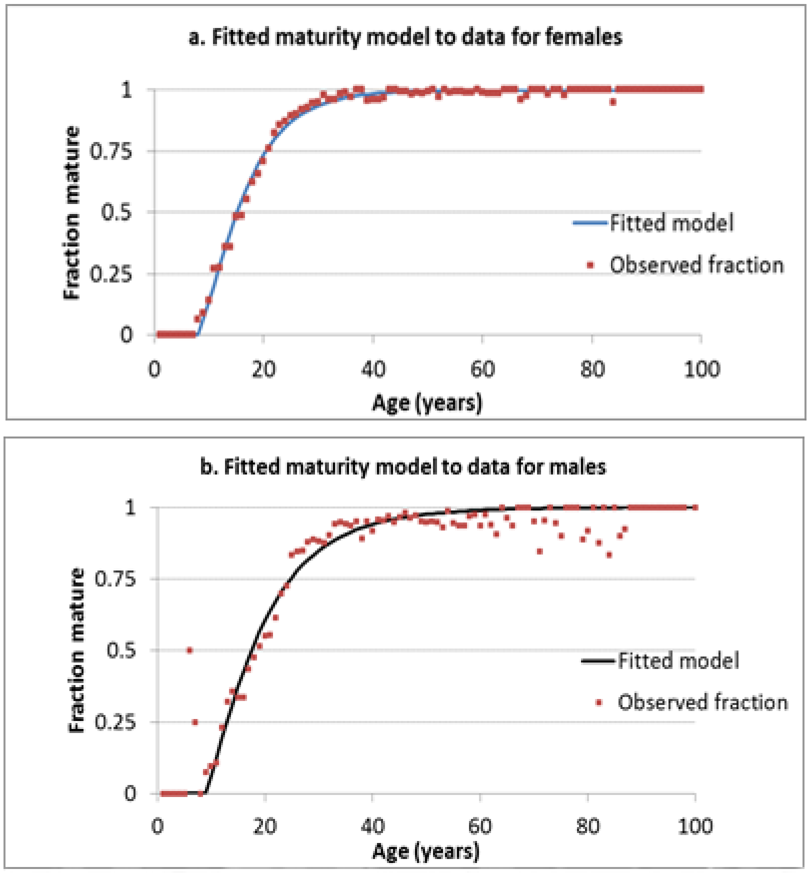

Figure 18. Outside Yelloweye Rockfish Maturity model fitted to research survey data by sex.

1.8 BAYESIAN SURPLUS PRODUCTION MODEL DESCRIPTION

The stock assessment methodology was chosen based on the types of data available and a requirement to assess stock status using stock biomass (e.g., B_{msy}) reference points. Due to the lack of a time series of age-structured fishery catch-age data, paucity of survey catch-age data, and availability of catch biomass records and abundance indices for recent years, an age-aggregated stock assessment methodology was chosen for application. This was a non-equilibrium Bayesian state-space surplus production model (Stanley et al. 2009) in which the following key parameters were estimated: maximum rate of increase, r, carrying capacity (K), constants of proportionality for abundance indices (q), and the ratio of initial stock size to K (B_{init} /K). Annual deviates from the biomass dynamics equation were also estimated to account for variation in stock biomass introduced by interannual variability, e.g., in recruitment and somatic growth. The approach uses life history data to form an informative prior distribution for r and enables estimation of maximum sustainable yield (MSY) management reference points and annual stock biomass. Uncertainty is accounted for with the computation of probability distributions for model outputs and probability statements on the status of the stock with respect to the management reference points.

This assessment used for the reference case stock assessment model the non-equilibrium, age-aggregated Bayesian surplus production (BSP) model described in Stanley et al. (2009). The BSP applied is a state-space version which incorporates both observation error and stochastic process error in the fish stock dynamics (Meyer and Millar 1999). The process error permits a more thorough accounting of uncertainty in estimates of model parameters, stock biomass, stock projections, and models deviations from model predictions as compared to a deterministic surplus production model. A Bayesian statistical approach was adopted to fit the model to data, allowing for the use of informed prior probability distributions for model parameters that incorporated information and expert judgment. The BSP model was fitted to four sets of survey abundance indices: three trawl survey indices (Table 3) and three longline hook survey series (Table 4) and five commercial CPUE series to reconstruct historical trends in abundance of outside Yelloweye Rockfish (Table 2). The fitted model was then used to evaluate the future trends in abundance based on alternative total catch policies. Total catch refers to total combined catch from all modelled fisheries, including commercial, recreational and Aboriginal catch.

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

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

where B_t is stock biomass in year *t*, *r* is the maximum intrinsic rate of increase, *K* (or B_0), is the average unfished stock size or carrying capacity, and F_t is the instantaneous fishing mortality rate in year *t*.

To evaluate whether the BSP estimation model can estimate management quantities of interest with acceptable accuracy and precision a number of different simulation evaluation exercises have been performed. For example, McAllister et al. (2009) evaluated the estimation performance of a Bayesian version of this model applied to a Pacific rockfish life history type. In those tests, a stochastic state-space production model with a CV in process error of 10% was applied to simulate stock biomass dynamics and fishery independent index time series. The latter had fairly large CVs in observation error (e.g., 0.3-0.7 per data set) and became available in the latter part of the stock's depletion history and when the final depletion of the stock had reached about 0.2 B_{msy}. The state-space BSP estimation model was found to perform acceptably in estimation of stock biomass, and stock status with absolute bias being 14% or less. When applied in a variety of harvest rate-based management procedures, the stock recovered successfully to over 0.4 B_{msy} within the 40-year horizon in about 60% of the simulation trials and the estimation method correctly identified true recoveries in about 80% of the trials and true failed recoveries also in about 80% of the trials. It was also found that the state-space version of the BSP model far outperformed a deterministic, non-state-space version of the BSP model in estimation and when applied in the same types of management procedures.

Earlier simulation testing of a deterministic version of the BSP when the underlying true population model had process error in stock biomass of 10% and fishery independent abundance indices were simulated with different magnitudes of observation error variance also showed acceptable performance of the BSP method in estimation and in feedback control evaluations of management procedures that incorporated BSP estimation results (McAllister and Kirkwood 1998). This testing included misspecification of the priors, and the model estimates tended to track actual stock biomass as long as the priors for key parameters (e.g., *r* and constants of proportionality for stock trend indices, *q*) were not overly precise or strongly biased (McAllister and Kirkwood 1998). Recent simulation testing using fishery-independent abundance index data generated from an age-structured population dynamics model showed that a state-space BSP estimation method used in conjunction with importance sampling yielded acceptably precise and accurate estimates of depletion relative to unfished stock size (e.g., all of the estimated 90% intervals for depletion from 20 simulated data sets included the true value for depletion, the cross-data set coefficient of variation in the estimate was 7% and bias in the estimate of depletion was 1.9%, Charles Edwards, NIWA, Wellington, NZ and Murdoch McAllister, UBC, Vancouver, B.C., unpublished data).

In a study where the state-space BSP model was applied to actual catch and mostly fishery independent abundance index data from 10 different New Zealand fish stocks, the BSP estimates of depletion and BSP projections yielded very similar results to those obtained when fully age-structured stock assessment models (i.e., CASAL) had been fitted to the same abundance index data and other data (McAllister and Edwards 2016). In summary, several different evaluations of the BSP methodology suggest that a state-space BSP model applied to fishery independent abundance index data can provide estimation performance for stock biomass and stock status no worse than if a fully-age structured model had been fitted to the same data and estimation of stock biomass and depletion could be expected to be reliable, even when the abundance data are available for only the latter part of the depletion history.

The version used in this assessment provides more accurate representations of fish stock dynamics than a deterministic version or discrete harvest rate version, especially when fishing mortality occurs throughout the year and when exploitation rates are high. It is slightly more cumbersome because the annual fishing mortality rate (F_t) must be solved numerically rather than analytically as in the discrete version (see McAllister and Babcock 2002 and McAllister et al. 1999; 2001 for additional details on the model).

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

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

where the prior probability distribution for the process error term is given by $\varepsilon_t \sim \mathrm{Normal}\left(0, \sigma_p^2\right)$. Values for ε_t from 1918 to 2014 were treated as estimated parameters and σ_p was set at 0.05 in the reference case run. Applications of a semi-age structured delay difference model (see below) to data for outside Yelloweye Rockfish gave posterior means for σ_p of about 0.025-0.035 under a fairly wide range of assumed values for the standard deviations in stock-recruit function deviates ($0.3 \leq \sigma_r \leq 0.8$). In the delay difference model, σ_p was computed from the average annual deviation between the deterministic model prediction and stochastic prediction of stock biomass. No attempt was made to estimate the process error variance or the observation error variance in the BSP model, owing to the paucity of time series data that could inform estimates of variance in ε_t and observation error deviates for different time series and the low precision in most of the indices.

The reference case prior distributions for *K*, *r*, the ratio of stock size in 1918 to *K* (B_{1918}/K), and the constants of proportionality (*q*) for the stock trend indices are provided in Table 10 (see appendix G of Stanley et al. 2009 for the methodology used to develop these priors). As was done in Stanley et al. (2009), the prior for the maximum intrinsic rate of increase, *r*, was developed using a demographic approach (McAllister *et al.* 2001). This approach was based on available life history data on growth, the natural mortality rate (*M*), maturity-at-age, and the Ricker stock-recruit steepness parameter, developed from a hierarchical meta-analysis of rockfish stock-recruit data (Forrest et al. 2010). The posterior predictive distribution for the Ricker steepness from Forrest et al. (2010) was approximated using a transformed beta density function with minimum of 0.2, mean of 0.93, and standard deviation of 0.42.

A lognormal likelihood function of the stock trend data was applied as it was in Yamanaka et al. (2011a). As in Stanley et al. (2009) and subsequent applications of this methodology, an iterative reweighting method was applied to arrive at values for abundance index sigma values for the process error associated with each abundance index (Table 7).

An index of recreational fishing effort formulated for years 1918-2014 was applied as a covariate for recreational fishing mortality rate. This assessment extended the same recreational fishing effort series for outside waters as was applied in the 2012 Bocaccio assessment (Stanley et al. 2012). Creel survey records for recreational angling effort on the WCVI and creel survey estimates of catch on the WCVI and CC were used to impute annual indices of recreational angling effort for 2001-2014. The total annual recreational catch for 2002-2014 was obtained by summing the creel catch records for the CC and WCVI and applying a factor of two to obtain the outer coast recreational catch biomass for these years. Where records were available for the total outer coast and also WCVI and CC, it was found that the sum of catches for WCVI and CC was about half of that for records on the entire outer coast. See Appendix A for the records of recreational effort and catch that were used in this assessment. Recreational catch records increased by a factor of 3.4 from 2002-2006 to 2007-2014 despite there being no change in average recreational effort. For reasons explained further in Appendix A, the catchability coefficient for the recreational catch was estimated using recreational catch data from 2007 to 2014. A lognormal likelihood function was applied to the imputed average value for recreational catch biomass for the years 2007-2014 and this was predicted using the model stock biomass and the catchability coefficient, k_1 (see Stanley et al. 2009 for further details).

An index of commercial salmon troll fishing effort formulated for years 1918-2014 was applied as a covariate for salmon troll fishing mortality rate. This assessment extended the same salmon troll fishing effort series for outside waters as was applied in Stanley et al. (2012) using effort records for years up to 2014 (Appendix A). Records of total annual west coast salmon troll catch biomass of Yelloweye Rockfish were available only for 2001-2014 (Appendix A). A lognormal likelihood function was applied to the average of the records of salmon troll catch biomass for the years 2001-2014 and this was predicted using the model-predicted stock biomass and the catchability coefficient, k_2 (see Stanley et al. 2009 for further details).

The method of integration of the joint posterior distribution was the Sampling/Importance Resampling (SIR) algorithm, as in recent implementations of the BSP model to Canadian groundfish stocks (e.g., Stanley et al. 2009; 2012, Yamanaka et al. 2012). For years following the last year with the abundance index data and in projections, annual process error terms were modelled using a one-year-lag autoregressive model. The correlation coefficient, ρ, was set at 0.5 to account for the likelihood that process error terms are positively auto correlated between years. For details see Stanley et al. (2009). Projections were carried out only for 5, 10 and 15 year horizons.

Prior distribution for the maximum rate of population increase,

A similar methodology was applied to formulate a prior distribution for r in this assessment as in Yamanaka et al. (2011a), except that the CV of the M-*prior* was increased from 0.20 to 0.25 yr ^{1}.The methodology includes empirical uncertainty in the parameter estimates for growth, the length-weight relationship, the proportion mature at age, and the Ricker steepness parameter (from Forrest et al. 2010 and see Yamanaka et al. 2011a). A Ricker stock-recruit function was adopted in preference to the Beverton-Holt stock formulation because cannibalism occurs in Yelloweye Rockfish (Love et al. 2002). The prior for *r* was then developed from a simulation model which included these life history parameters, represented as priors by their posterior mean and covariance matrix (see Eq. 26 to Eq. 32 in Appendix G of Stanley et al. 2012, Stanley et al. 2009). The mean and standard deviation (SD) for the *r*-prior used in this assessment were

0.0523 and 0.0197 (Figure 19), which are similar to the mean of 0.117 and SD of 0.035 used in the 2009 assessment. The prior distribution for *r* is approximated in the model by using this mean and SD to describe a normal distribution.

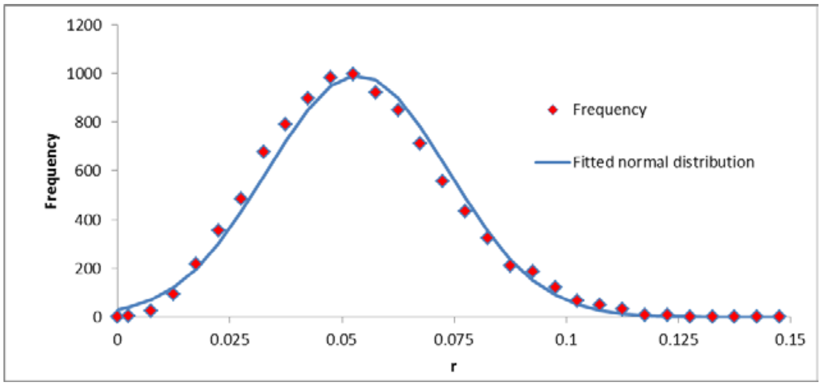

Figure 19. Fitted normal density function and simulated density function of values for r generated from a Monte Carlo simulation of r from life history parameter distributions.

Post-model pre-data diagnostics

In Bayesian analysis, it is common to compare the posterior distributions with prior distributions for key model parameters to evaluate the extent to which posteriors are updated from their prior distributions. This is done either visually (e.g., Myer and Millar 1999) or by taking the ratio of posterior precision (i.e., 1/variance) to prior precision for estimated parameters (e.g., Tolwinski-Ward et al. 2013). Posterior results have been considered to have updated priors when the ratio of posterior precision to prior precision for quantities of interest has been larger than about 1.2 (e.g., Muller 2012; Tolwinski-Ward et al. 2013); however there doesn't appear to be have been any conventions established for this in the literature. It should be noted that for those parameters for which informative priors have been developed, e.g., *r* in the BSP model, either no update or only a slight posterior update is to be expected. For parameters having either non-informative or diffuse priors, posterior updates are in contrast expected. The comparison of posterior distributions with priors, however, cannot be done for model variables of interest that are functions of the parameter values (e.g., B_y/B_{msy}, replacement yield, F_y/F_{msy}) and fixed inputs such as catch and fishing effort since priors aren't placed on these variables in the first place and these quantities can only be computed by running the model. Post-model pre-data (PMPD) distributions in contrast can serve as intermediary diagnostic distributions for all model quantities of interest to indicate the amount of information imparted about quantities of interest from the fitting of the model to abundance indices (Punt and Butterworth 2000; Brandon et al. 2007). The PMPDs were thus computed to serve as a diagnostic tool to show how the priors interact with the population dynamics model, fixed inputs for catch, and fishing effort before the model is fitted to the abundance index data. If posterior distributions are found to be nearly identical to the PMPDs for all quantities of interest it could be concluded that there is insufficient information in the abundance index data to support the stock assessment. When the mode of the posterior departed from that of the PMPD or the posterior precision became greater than the PMPD precision for quantities of interest it could be concluded that the abundance index data were sufficiently informative to support a stock assessment (McAllister and Edwards 2016).

The PMPDs for BSP model quantities of interest were computed using importance sampling and the fixed catch and effort inputs but with the likelihood functions for the abundance indices deactivated. Due to model structure and stability issues, it was necessary to run the model with the likelihood function activated for the observed catches for the recreational and salmon troll fisheries. However, the influence of this likelihood function on the model output distributions was minimized by inflating the likelihood function’s coefficient of variation for the observed mean catch for these two fisheries from 0.6 per year to 100 per year.

1.9 REFERENCE CASE MODEL SETTINGS

In the reference case stock assessment model setting, the prior for *K* was uniform on log *K* and the standard deviation in the state space process error term, σ_p was set at 0.05, as it was in assessments for other long-lived rockfishes (Yamanaka et al. 2011a,b). The prior probability density functions for estimated model parameters in the reference case run are shown in Table 10.

Table 10. Prior probability distributions for stock assessment model parameters.

Parameter	**Prior Density function**	**Comments**
K	Uniform (log(500), log(300,000))	Units in tonnes. The prior density of proportional to 1/K and is applied here to convey the idea that in the absence of empirical analysis credibility rating for hypothesized values for K are more consistent on a log scale than a uniform scale.
q for commercial CPUE and survey indices	Proportional to 1/*q*	This prior is non-informative with respect to *K* and stock biomass (McAllister et al. 1994).
P_0	Lognormal(ln(1.0), 0.2^2)	This indicates that the stock was near to carrying capacity in 1918.
r	Normal(0.0523, 0.0197^2)	The relatively low prior mean comes largely from the late median age at maturity of 15 years. It also comes from the relatively low estimates of recruits per tonne of spawner biomass at the origin of the stock-recruit function which in turn derives partly from the low prior mean for steepness obtained from the meta-analysis of rockfish stock recruit data (Forrest et al. 2010).
K	Exponential($\bar{E}_j$)	This prior is non-informative with respect to harvest rate from recreational fishing and salmon troll bycatch where E_j is the average effort for fishery *j* in outside waters for the years where catch records were available (see Stanley et al. 2009 for the derivation).

1.10 REFERENCE CASE MODEL RESULTS

The posterior results obtained by fitting the BSP model to the data were well-behaved and showed distinct updates from the priors and PMPDs for all management quantities of interest (see below). The posteriors for quantities of interest had well-formed posterior distributions that had no bimodality or multi-modality and where there had been thick tails in the priors and PMPDs, the posteriors showed well-defined sharpened tails. Also there was no significant auto-correlation in deviations between predicted and observed abundance index data for the fishery dependent and fishery independent data. This indicates that all data series were consistent with model predictions and consistent with each other (see also below). In summary, all diagnostics suggested that the BSP model could satisfactorily predict the abundance index data and that the data were informative about BSP model parameters.

Importance sampling as a numerical algorithm for posterior integration was moderately efficient for this implementation of the BSP. For example, the maximum weight from the importance sampling in all BSP runs was down to less than 1% in no more than about 30 minutes of computing, i.e., after a few million draws were taken from the importance function. The maximum percentage weight of any one draw in forming the posterior distributions dropped progressively with more importance samples and dropped to 0.5% in the reference case run with 6,344,536 samples taken and used from the importance function. For applications of SIR to stock assessment, importance sampling is deemed be sufficient when the maximum weight drops below 1% (McAllister et al. 1994). The coefficient of variation (CV) (i.e., standard deviation in importance weights divided by their mean) in the importance weights was far less than the CV in the product of likelihood and prior, signifying stable and efficient importance sampling (McAllister and Kirchner 2002).

In the reference BSP case analysis, the prior for K was uniform on the natural logarithm of K and value for σ_p of 0.05 was applied. The fit of estimated population biomass to the indices and a plot of the total catch biomass by year is shown in Figure 20a and 20b. Total catches were relatively small up to the mid-1980s and the stock abundance estimates show relatively little decline up till then. The largest catches occurred in the late 1980s and early 1990s. Two of the standardized commercial catch per unit indices, PHL1 and PHL2, starting in 1986 and 1989, respectively are very short and noisy and don’t precisely conform to the model projected decline in this period Figure 20b. The abundance index with the longest time series, IPHC, which runs from 1995 to 2014, initiates after total catches began to decline. The model gives a close fit to this index (Figure 20). This index together with the other abundance indices, which start after 1995, are consistent with a pronounced decline in the stock from the mid-1990s to about 2005 and a lesser decline since then. The 90% posterior probability interval for stock biomass supports a very substantial decline since the 1980s, indicating that the catch and stock trend data are informative about the trend in abundance.

The trajectory of estimates of the ratio of fishing mortality rate in 2014 to F_{msy} show a marked increase in the 1980s and a decline to values still well in excess of 2 in the last decade (Figure 20c). The posterior results for process error suggest a declining trend in process error after 2000 followed by a brief rebound after 2005 and final down turn in the most recent five years (Figure 20d).

The marginal posterior probability density functions (pdfs) were informative for the carrying capacity parameter, K, with a strong update in the prior distribution for K (Figure 21a). However, the posterior for r showed a relatively small update from the prior for r with the posterior centered slightly lower than the prior (Figure 21b). The post model, pre-data distributions (PMPDs) for several stock status quantities are also shown in Figure 21. The PMPD distributions indicate that the priors for model parameters, when applied in combination with the inputted values for catch and effort, provide quite vague information about most of the model parameters and quantities of interest. The PMPD distribution is practically identical to the prior for *r*. The PMPD for *K* however is slightly more informative than the prior for *K* but less informative than the posterior (Figure 21a). The priors on the catchability coefficient for the imputed fishery catches provided this slight update in the prior for *K* because when combined with the fishery effort, they were originally formulated to give an approximately uniform distribution for harvest rate (see Stanley et al. 2012). For the PMPD distributions of stock biomass in 2014, MSY and depletion in 2014 appear to be slightly informed by the model inputs and model structures with higher densities at lower values and positively skewed distributions extending over higher values (Figure 21c, d, f and h). The PMPD distributions for replacement yield, F/F_{MSY} and catch/ replacement yield in 2014 are however relatively flat (Figure 21e, g, and i).

The posteriors for all other estimated quantities in Figure 21 show a marked update from the PMPDs suggesting that the abundance index data are informative for all of these quantities. The posterior for current depletion, for example, spans a narrow range of possible values with the 5th and 95th percentiles at 9% and 27% of *K* (Table 11). The 90% probability interval for the ratio of catch to replacement yield in 2014 spans 107% to 360%. The 90% interval for the ratio of fishing mortality rate to F_{MSY} in 2014 spans an interval from 162% to 645%. The assessment suggests that there a 0.6% probability that stock biomass in 2014 is above 80% of B_{MSY} and an 18% probability that stock biomass in 2014 is above 40% of B_{MSY} (Table 11). The median posterior estimates of the ratio of stock biomass in 2014 to 2002 when rockfish conservation measures were widely adopted were 0.61 with a 90% interval of 0.49-0.76. This suggests that the stock has continued to decline, despite more than a decade of rockfish conservation measures.

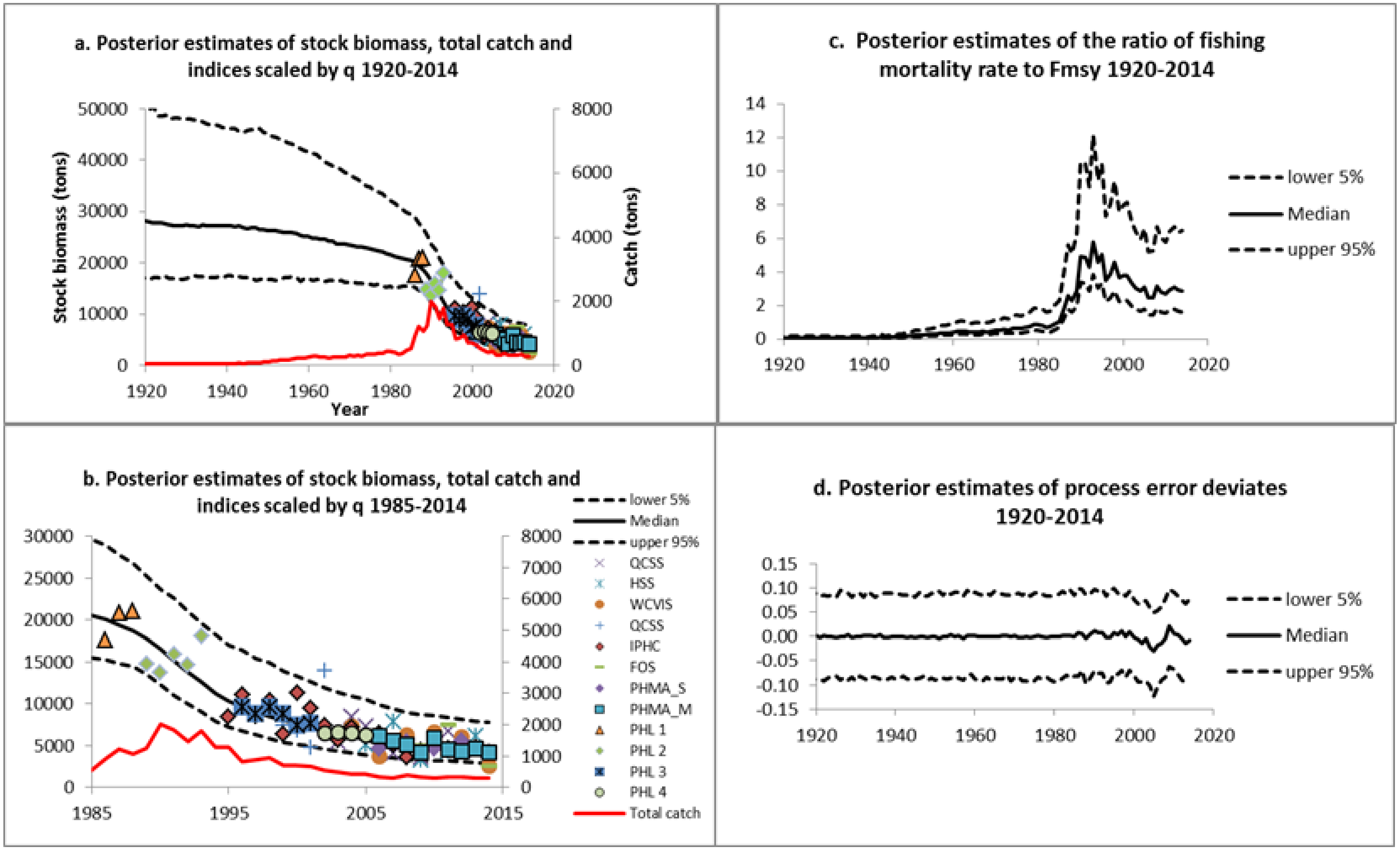

Figure 20. Reference case run. Plots of posterior median estimates of stock biomass and total catch and 90% intervals for stock biomass and abundance indices rescaled by their constants of proportionality (q) for a) 1920-2014 and b 1985-2014, and posterior medians and 90% intervals for c) the ratio of fishing mortality rate 1920-2014, and d) process error deviates 1920-2014.

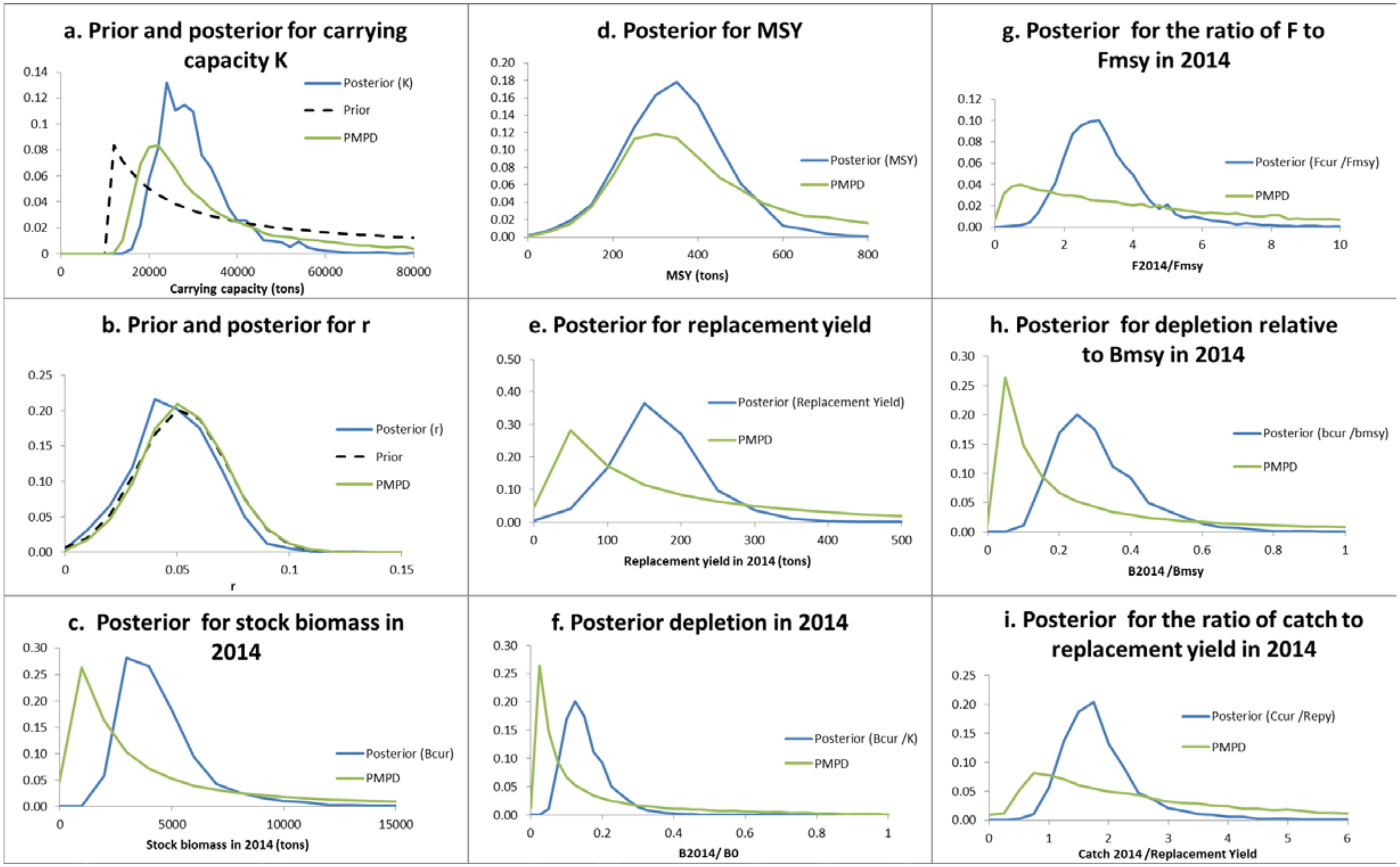

Figure 21. Reference case plots of prior, post-model pre-data (PMPD), and posterior distributions for a) carrying capacity K and b) r, and PMPD and posterior distributions for c) stock biomass in 2014, d) maximum sustainable yield (MSY), e) replacement yield in 2014, f) depletion in 2014, g) the ratio of fishing mortality rate (F) to fishing mortality rate at MSY (Fmsy) in 2014, h) the ratio of stock biomass to stock biomass at msy (Bmsy) in 2014, and i) the ratio of catch to replacement yield in 2014.

Table 11. Posterior mean, standard deviation (SD), coefficient of variation (CV), Median and 90% intervals for parameters and stock status indicators for B.C. Outside Yelloweye Rockfish from the reference case run of the Bayesian surplus production model in which the σ_p was fixed at 0.05 and the model was fitted to the abundance index data.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
r	0.049	0.018	0.372	0.0185	0.0483	0.0778
B0	30485	9719	0.319	20031	28373	48457
MSY	349	118	0.339	165	345	548
Bmsy	15242	4860	0.319	10016	14186	24228
Bmsy/B0	0.5	0	0	0.5	0.5	0.5
Binit	30476	11187	0.367	17174	28306	51224
B2014	4585	2195	0.479	2774	4046	7742
B2014/Bmsy	0.313	0.122	0.388	0.169	0.288	0.529
B2014/Binit	0.163	0.073	0.446	0.079	0.146	0.300
B2014/K	0.157	0.061	0.388	0.085	0.144	0.265
FMSY	0.024	0.009	0.372	0.009	0.024	0.039
F2014	0.071	0.020	0.284	0.037	0.070	0.104
F2014/FMSY	3.451	3.315	0.961	1.618	2.896	6.447
REPY	175	63	0.361	77	171	281
Catch2014/REPY>0	2.00	1.80	0.90	1.07	1.69	3.61
B2014/B2002	0.650	0.073	0.113	0.493	0.612	0.756
P(B2014> 0.4Bmsy)	0.18	-	-	-	-	-
P(B2014> 0.8Bmsy)	0.006	-	-	-	-	-

1.11 UNCERTAINTY AND SENSITIVITY ANALYSIS

The model settings for the 31 sensitivity runs are summarized in Table 12, and includes the management advice run (MA in the table). Six different sources of uncertainty were considered: A-series - assumptions about the catch reconstruction, B-series - priors, C-series - process error and standard deviation, D-series - influence of different abundance index data sources, E-series - the form of the surplus production function, and F-series - the form of the stock assessment model.

There were numerous assumptions required for the reconstruction of catches for the contributing fisheries; the sensitivity of results to six initial scenarios for historic catches were thus considered: (A.1) applying a fixed historic catch time series determined from outputs of the reference case run, (A.2) reconstructing halibut catches from bycatch ratio estimates from recent years, (A.3) imputing halibut catches using a reconstruction of historic halibut effort and recent records of Yelloweye Rockfish non-directed catch, (A.4 and A.5) halving or doubling historic catches prior to 2006, and (A.6) replacing the reference case fixed catch series with that formulated by consultation with the PHMA. A further four scenarios were also considered: (A.7) adjusting the recreation effort to zero prior to 1975 and ramping effort up exponentially to 2002, (A.8) Removing the salmon troll catch prior to 1950 and using ¼ of the salmon troll catch data values after 1950, (A.9) Implementing both A.7 and A.8 together, (A.10) Starting the BSP model in 1951 (not 1918), and otherwise the same as the reference case.

The sensitivity of results to the prior mean for *r* (B.1 and B.2) and the form of the prior for *K* was evaluated (B.3). Different settings for the process error standard deviation were considered (C.1 and C.2).

The influence of the different abundance index data sources were evaluated in six initial scenarios by removing different groups of the indices or only using selected indices: (D.1) removed the IPHC index, (D.2) removed the FOS and PHL logbook indices, (D.3) removed the trawl indices, (D.4) only using the PHMA and IPHC indices, (D.5)leaving out the Queen Charlotte Sound shrimp trawl index, and (D.6) only using the PHMA and IPHC indices but with IPHC index starting in 1998 (removing 1995 to 1997 IPHC data), (D.7) only using an unadjusted southern PHMA index, (D.8) only using an unadjusted northern PHMA index, and (D.9) only using unadjusted southern and northern PHMA indices.

Uncertainty in the form of the surplus production function was evaluated using different settings for a generalized production model (McAllister et al. 1999) (E.1-E.3). Sensitivity of results to the form of the stock assessment model was evaluated by applying four different settings of a Bayesian delay-difference model (F.1-F.4).

To compare the credibility of each model given the data, we computed Bayes factors (Kass and Raftery 1995) for the reference case and for each of the related sensitivity runs. Bayes factors account for both the relative goodness of fit of the model to the data and the parsimony for each of the alternative models. They are calculated as the ratio of the marginal probability of the data for one model to that for another model. We used the mean value for the importance weights from a given model run as an approximation of the probability of the data given the model (Kass and Raftery 1995, McAllister and Kirchner 2002). This is known to be a numerically stable approximation for the probability of the data, given the model and approximations obtained through importance sampling. For example, the CV in the mean weight was less than 0.02 after several million draws from the importance function.

In all instances, we compared Bayes factors to our reference case model settings. In other words, the probability of the data for the reference case model was placed in the denominator and that for the model run to which it was compared in the numerator. It is commonly held that the Bayes factor must depart substantially from 1.0 for anything to be inferred from the exercise but even fairly large or small departures in Bayes factors can result from random chance in the data and/or misspecification of probability models. Intermediate values for Bayes factor (e.g., between about 0.001 and 100) should be interpreted with caution. For example, models that had Bayes factors of between about 0.1 and 0.01 could be interpreted as unlikely but not discredited. When the Bayes factor for a model is less than 0.001, the model could be viewed as highly unlikely relative to the other.

Sensitivity to the historic catch reconstruction

Results were quite sensitive to the catch scenario applied but none of the scenarios considered suggested stock status results very different from the reference case run (Table 13). The posterior medians for the total catch by year for runs A.1-A.6 and the reference run can be viewed in Figure 22.

In run A.1 the recreational and salmon troll catches were fixed at the posterior median values from the reference case run. This gave posterior results for stock status quantities that were considerably more uncertain than those for the reference case run with much wider probability intervals and slightly less pessimistic in terms of the posterior medians (Table 13, Table 15). This implies that the scenario for doubling the historic catch is about 20 times less credible than that for halving the catches. However, the scenario for halving the catch was only about twice as credible as the reference case run suggesting that the reference case run still remained credible.

Results were most sensitive to an attempt to impute non-directed catch in the halibut fishery using the full time series of reconstructed halibut effort and records of catches in recent years (A.3). A workable implementation was achieved by adopting the assumption that there has been a gradual increase in the catching power of halibut gear for Yelloweye Rockfish. A net average increase of 2% per year in catching power for the halibut fishery was applied. Halibut effort was several times higher at the beginning of the time series than in recent years. With higher abundance and much higher effort, the imputed halibut catch for early years was extraordinarily high putting the posterior median for total catch up to about 12,000 t, compared to about 50 t under the reference case (Figure 22). The effect of this was for the estimate of carrying capacity and B_{MSY} to be extraordinarily high to support these high catches and for depletion relative in 2014 to be extremely low, e.g., with the posterior median at only 2% relative to B_0. Given the extraordinarily high catches imputed in early years for run A.3, the results for this run were judged to be implausible.

Sensitivity tests on the recreational catch A.7 and A.8 resulted in replacement yield, $Rep_{\mathrm{Y},}$ dropping slightly from the reference case, current biomass $B_{cur,}$ similar to the reference case, B_{cur}/B_0 up from 0.14 to 0.18 and 0.15 for A.7 and A.8, respectively. Combining A.7 and A.8 in a new sensitivity test lowered B_{MSY} from 14,000 to 11,000 t. B_{cur} is similar to the reference case and Rep_Y is a bit lower. B_{cur}/B_0 median increased to 0.189 from 0.140. P(B_{cur}>0.4B_{MSY}) is still low, though up to 0.43 from 0.18, however, for A.7, A.8, and A.9, P(B_{cur}>0.4B_{MSY}) remains low and there is still a >50% probability that the stock is below the LSR of 0.4B_{MSY}.

Starting the model in 1951 for test A.10 had very similar outputs to the reference case. B_{MSY} and B_{curr} are slightly less and Rep_Y slightly more than the reference case. P(B_{cur}>0.4B_{MSY}) is the same as the reference case.

Sensitivity to priors

Results were relatively insensitive to the different settings for the priors for r and K (Table 13).

Sensitivity to process error standard deviation

Results were relatively insensitive to the lower and higher values applied for the inputted process error standard deviation, though slightly less pessimistic with the application of the larger value for this term (Table 13).

Sensitivity to the abundance indices

Results were relatively insensitive to the set of abundance indices applied. The posterior medians for all of the quantities considered were similar between the reference case and all four sensitivity runs (Table 13). The largest effect was caused by removing the IPHC index in D.1. The posterior median values for most of the listed variables became slightly less pessimistic compared to the reference case. The posterior 90% intervals however widened for most of the quantities considered, especially for stock biomass in 2014.

The tests using unadjusted PHMA abundance indices (D.7, D.8, and D.9) were all too short to inform the stock assessment model. Results were very close to the priors and PMPDs and hence the results are not valid.

Sensitivity to the form of the surplus production function

Results were moderately sensitive to the form of the surplus production function. For example, when the B_{MSY}/K ratio was varied over the range from 0.3 to 0.6 the posterior median depletion relative to B_0 ranged from 0.23 to 0.12 and the posterior medians for the stock biomass in 2014 to B_{MSY} ranged from 0.45 to 0.25 (Table 13).

Sensitivity to the type of stock assessment model

The BSP model is an age-aggregated model that models biomass dynamics with a simple surplus production function that implicitly models the combined effects on surplus production of annual recruitment, annual growth, and natural mortality in the recruited portion of the population. The surplus production is made to be a direct function of the biomass in the previous year. Given that the median age of maturity of female Yelloweye rockfish is 15 years, and that recruitment is a major component of surplus production, the single-year lag in surplus production may introduce bias in model predictions of stock biomass, replacement yield and MSY–based reference points. To evaluate the sensitivity of stock assessment results to the choice of the type of biomass dynamic model additional runs were carried out by applying a delay-difference stock assessment model (Walters and Martell 2004. In contrast to BSP, the delay difference model includes an explicit stock-recruit function, and explicitly models fish growth and natural mortality. It is much simpler than a conventional age-structured model, however, in that it presumes that the vulnerability of fish to capture for all fishing fleets is knife edged at the median age of maturity.

For the delay-difference model, it was trickier to get the nonlinear optimization, one of the steps prior to importance sampling, to locate satisfactorily the joint posterior mode for all parameters especially the stock-recruit deviates. Extension of the range between the lower and upper bounds for some parameters (e.g., the catchability parameters for catch imputation), and using a larger number of different starting points in the parameter space for the search, helped to avoid suboptimal solutions.

The delay-difference implementations in SIR ran fairly quickly with convergence diagnostics for most runs satisfied after about 20-30 minutes of computing. Diagnostics indicated that importance sampling was highly efficient. For example, the maximum importance weight from any one draw from the importance function was no more than about 0.7% of the total cumulative weight of values drawn, meeting the conventional requirement in stock assessment applications of SIR for this figure to be no more than 1% (McAllister et al. 1994).

The Bayesian delay-difference (BDD) model gave less optimistic and more precise posterior results than the Bayesian surplus production model (Figure 24 and Figure 26, Table 13, Table 15 to Table 18). The posterior median results for depletion were all lower relative to B_{MSY} and B_0 compared the BSP reference case. For example, under run F.1, the posterior 90% interval for the ratio of stock biomass in 2014 to B_0 was 0.05, 0.20 with a median of 0.11 (Table 13), lower than the BSP median of 0.14, and 90% interval of 0.08, 0.26 (Table 11). B_{MSY}, exploitable stock biomass, and replacement yield were estimated to be consistently less than the estimates given by the reference case BSP model. The posterior median replacement yield was 156 t from run F.1 for the BDD model (Table 13), compared to 171 t from the BSP (Table 11). Estimates of the ratios of fishing mortality rate in 2014 to F_{MSY} and catch in 2014 to replacement yield in 2014 were all higher for the delay-difference model (e.g., the posterior median was 5.7 compared to 2.9 for the reference case BSP model). All runs of the BDD showed patterns in stock recruit deviates over the last 15 years similar to the patterns in the process error deviates from the BSP model (Figure 21d, Figure 23d, Figure 24d, Figure 25f, Figure 26f).

The BDD run F.2 in which the variance in stock-recruit deviates was increased from 0.5 to 0.8 gave a higher posterior median for steepness, lower posterior median for stock biomass and replacement yield, a lower ratio of F_{2014} to F_{MSY}, and higher catch to replacement yield in 2014 (Table 13). The Bayes factor for run F.2 was insignificantly different from that for run F.1. When the BDD model was fitted to the mean weight data from the commercial longline fishery results were similar to run F.1 when the mean weight data were given similar weight to the abundance index data (i.e., run F.3 with a CV of 0.3 for the mean weight data). In run F.4 the weighting of the mean weight index relative to that for the abundance indices was increased by reducing the CV on the mean weight data by half. Here the posterior median values for all quantities considered remained very similar to runs F.1 and F.3 but became slightly more precise (Table 13, Figure 25 and Figure 26).

The posterior median estimates of the ratio of B_{MSY}/B_0 for all of the BDD runs ranged between 0.44 and 0.45, which is quite close to the value of 0.5 for B_{MSY}/B_0 that is presumed in the reference case BSP model (Table 16, Table 17 and Table 18).

The BDD model provided estimates of the standard deviation in stock biomass process error. The posterior median estimates for σ_p ranged from 0.025 when the standard deviation in stock recruit deviates σ_R was set at 0.5, and to 0.04 when σ_R was set at 0.8. These estimates of σ_p suggest that the value of 0.05 is not unreasonable especially given that there exist other contributing sources of process error in stock biomass, e.g., interannual fluctuations in somatic growth and natural mortality rate.

1.12 APPLICATION OF THE BAYESIAN SURPLUS PRODUCTION AND DELAY-DIFFERENCE MODELS TO SIMULATED DATA

To test whether the Bayesian surplus production and delay difference models could provide estimates close to the true underlying stock biomass, data were simulated from the delay difference model using its posterior modal results from run F.1 and using the reference case catch and effort data. An assumed 10% CV in observation error in the data for each of the 12 data sets was applied. The reference case settings for the BSP model were applied and the settings for the BDD model under run F.1 were applied for estimation. Some of the assumed parameter values are shown in Table 20. For example, the true assumed value for B_0 was 28,820 t, steepness was 0.674, the ratio of initial stock biomass to B0 was 0.98, and σ_r was set at 0.5.

The posterior median estimate of B_0 from the delay difference model was 22,584 t. The posterior median from the BSP model was 25,485 t, both reasonably close to the true value. The delay difference model, however, came closer to the true estimate of stock biomass for the latter 30 years of the trajectory and overestimated the amount of depletion for the latter part of the trajectory. In contrast the BSP model underestimated stock biomass for the first half of the trajectory and over-estimated stock biomass for the latter half of the trajectory (Figure 27). Both models over-estimated the ratio of final stock biomass to actual stock biomass for the latter half of the trajectory, but with the delay difference model providing estimates closer to the true ones than the BSP model. For both methods, the true values lay on or just below the lower bound of the 90% interval for some parts of the biomass and depletion trajectories. Estimates of quantities of interest for the delay difference and BSP models based on the simulated data and true values for these quantities can be found in Table 19 and Table 20.

1.13 RETROSPECTIVE ANALYSIS OF THE BSP MODEL

To evaluate whether there was serious bias in the BSP model, a retrospective analysis was performed. In this analysis, five additional runs of the reference case BSP model were performed. In the first new run, the BSP model was fitted to abundance indices to 2009 and projected to 2014 using the catch and effort data up to 2014. In the second run, the BSP model was fitted to data to 2007, and projected to 2014 using the catch and effort data up to 2014. In the third run, the BSP model was fitted to abundance indices to 2005 where seven of the 12 data sets were used but excluding HSS, PHMA S, PHMA N, FOS and WCVISS, and projected to 2014 using the catch and effort data up to 2014. In the fourth run, the BSP model was fitted to abundance indices to 2003 where seven of the 12 data sets were used as in run three, and projected to 2014 using the catch and effort data up to 2014. In the fifth run, the BSP model was fitted to abundance indices to 2001 where five of the 12 data sets were used but excluding HSS, PHMA S, PHMA N, FOS, WCVISS, PHL4 and QC Synoptic, and projected to 2014 using the catch and effort data up to 2014. Figure 28 shows the trajectories of stock biomass from 1985-2014 and ratio of fishing mortality rate to F_{msy} from 1920 to 2014. There is a slight tendency for the magnitude of the biomass to increase and for the fishing mortality rate trajectories to decrease as abundance data are progressively removed (Fig. 28). This suggests that the model has had a tendency to be slightly over-optimistic when it is fitted to fewer data.

Table 12. A summary list of sensitivity runs conducted for the Outside Yelloweye Rockfish stock assessment. The Reference Run (Ref) is followed by Codes summarized by a Category Description (A-F) and details on the sensitivity Run Description (1-9)

Code	Category Description	Code	Run Description
Ref	Reference run	Ref	BSP(φ=0.5) reference run with s_p = 0.05
MA	Management Advice run		A.9 and D.2
A	Catch scenarios BSP (φ=0.5).	A.1	No catch imputation, troll and recreational catch values from medians in base case run
		A.2	Halibut catch series obtained from bycatch ratio estimate in recent years
		A.3	Halibut catches imputed using halibut effort data and an estimate of halibut bycatch q
		A.4	Catches before 2006 (catch inputs including combined, rec. and troll) set at 0.5 of base case
		A.5	Catches before 2006 (catch inputs including combined, rec. and troll) set at 2x base case
		A.6	PHMA catch series
		A.7	Adjusted recreational effort – zero prior to 1975, ramping up exponentially to 2002
		A.8	Removal of salmon troll catch prior to 1950 and use ¼ of salmon troll catch data values
		A.9	Implementing both A.7 and A.8 together
		A.10	Starting BSP model in 1951, otherwise the same as the reference case
B	Priors	B.1	prior mean *r* set at 2/3 base case
		B.2	prior mean *r* set at 1 1/3 of base case
		B.3	uniform on *K* prior rather than uniform on log *K* prior
C	Process error standard deviation	C.1	s_p = 0.025, (close to the estimate of SD in process error in stock biomass from BDD model with sigmar = 0.5)
		C.2	s_p = 0.075, (about double the SD in process error in stock biomass from the BDD model with sigmar=0.8)
D	Abundance index data	D.1	no IPHC index, but including the rest
		D.2	no FOS and no PHL index, but including the rest (no logbook-based indices)
		D.3	no trawl indices, but including the rest
		D.4	only with IPHC and PHMA index
		D.5	Leaving out the Queen Charlotte Sound shrimp trawl index, otherwise same as reference case
		D.6	Only with IPHC and PHMA index but with IPHC starting in 1998 (removing 1995-1997 IPHC data)
		D.7	Only with unadjusted PHMA south index
		D.8	Only with unadjusted PHMA north index
		D.9	Only with unadjusted PHMA south and north indices

Code	Category Description	Code	Run Description
E	Generalized surplus production model	E.1	B_{MSY}/K set at 0.3
		E.2	B_{MSY}/K set at 0.4
F	Bayesian delay-difference model	F.1	sigma R set at 0.5, fitted to same data as BSP
		F.2	sigma R set at 0.8, fitted to same data as BSP
		F.3	sigma R set at 0.5, fitted to same data as BSP and also mean commercial longline length data 1986-2002, CV=0.3
		F.4	sigma R set at 0.5, fitted to same data as BSP and also mean commercial longline length data 1986-2002, CV=0.15

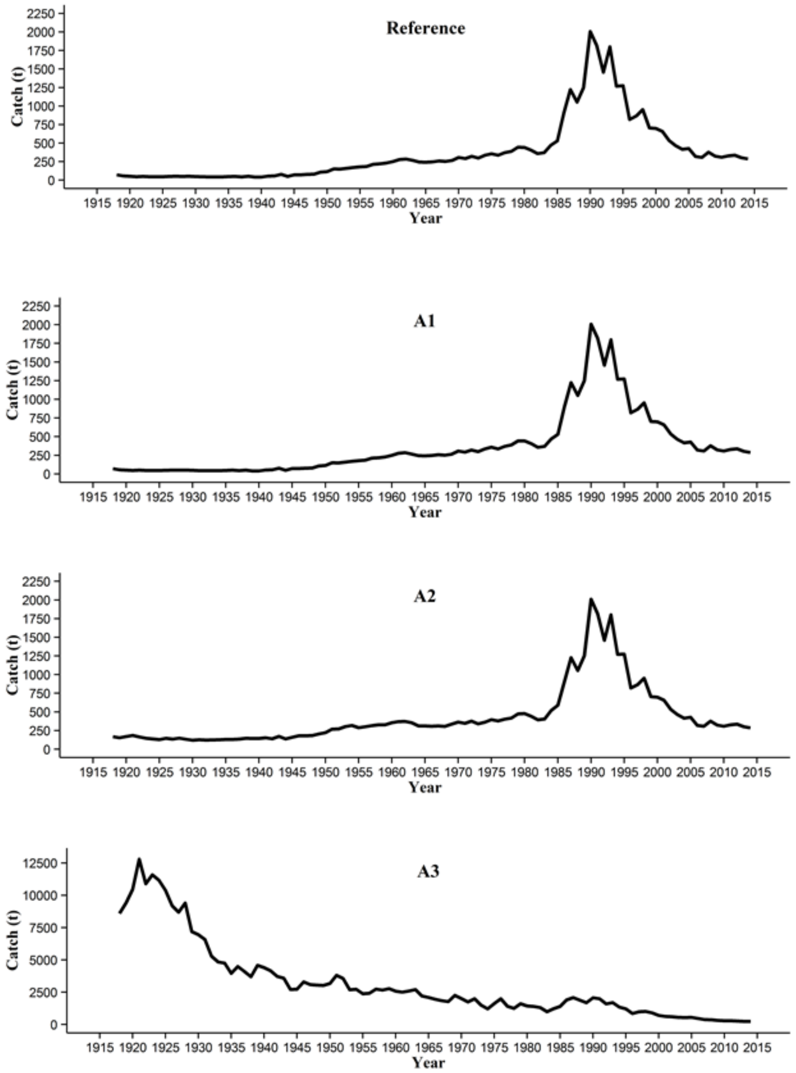

Figure 22. Plots of posterior median total catches for the reference run (top panel) and sensitivity runs A1 to A6 (see Table 11). The trajectories for runs A1, A6 and the reference run are very similar and not visibly distinguishable. The maximum for the trajectory for run A3 was much higher than the others. A1, A2, A6 and the reference plots are on the same y-axis scale, and A3, A4 and A5 are scaled differently.

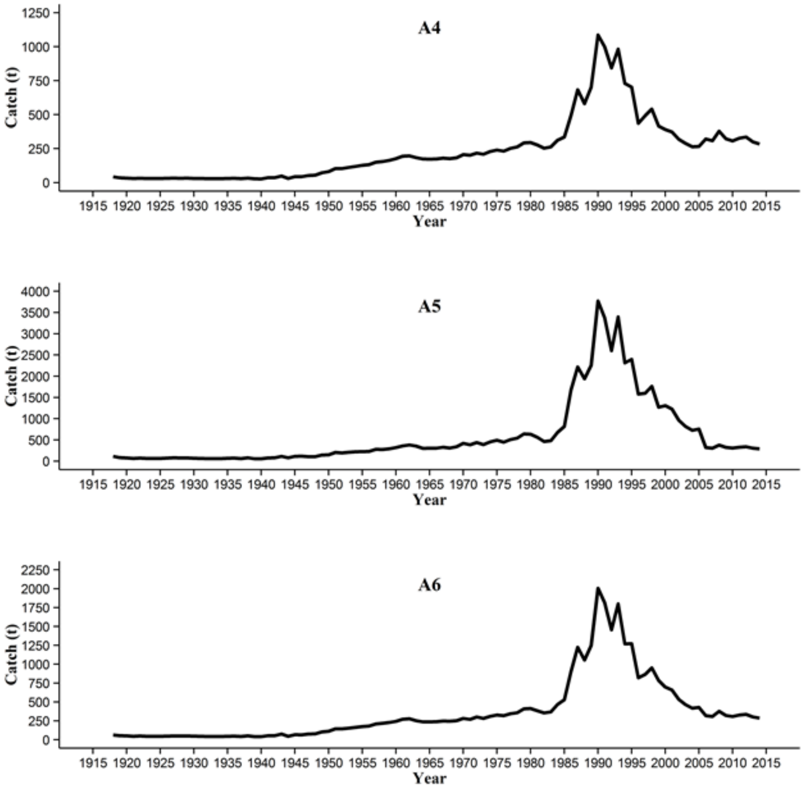

Figure 22. Continued.

Table 13. Posterior median and 90% interval results for evaluations of the sensitivity of stock assessment results for Outside Yelloweye Rockfish to different stock assessment model settings and inputs (continued on next page).

Catch scenarios BSP

Run	***r***			B_{MSY}			$B_{current}$			***RepY***			$B_{current}$ / B_{MSY}		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
-	**Reference run**														
Ref	0.018	0.048	0.078	10,016	14,186	24,228	2,774	4,046	7,742	77	171	281	0.17	0.29	0.53
A.1	0.01	0.039	0.07	11,041	18,466	301,379	3,110	7,597	423,380	72	210	4251	0.21	0.45	1.65
A.2	0.02	0.048	0.078	10,662	15,279	25,150	2,794	3,939	7,808	85	172	274	0.16	0.27	0.5
A.3	0.022	0.052	0.081	34,565	97,460	218,999	2,582	4,149	8,168	116	210	350	0.02	0.04	0.15
A.4	0.021	0.05	0.079	6,210	9,091	15,572	2,078	3,223	6,403	66	133	215	0.2	0.37	0.66
A.5	0.014	0.041	0.068	17,647	24,731	41,340	4,990	7,045	14,575	104	254	440	0.18	0.29	0.55
A.6	0.018	0.048	0.078	9,966	14,322	24,173	2,830	4,050	8,382	79	172	281	0.17	0.3	0.55
A.7	0.02	0.048	0.079	8,137	11,288	18,094	2,780	4,066	7,796	77	166	267	0.24	0.37	0.62
A.8	0.019	0.048	0.077	9,758	13,695	22,216	2,542	4,029	8,206	78	165	275	0.17	0.30	0.57
A.9	0.019	0.048	0.079	8,012	10,916	17,323	2,559	4,076	8,178	79	161	269	0.237	0.378	0.651
A.10	0.018	0.05	0.086	9,456	13,953	22,785	2,617	3,976	7,650	76	176	278	0.174	0.301	0.545

Priors

Run	***r***			B_{MSY}			$B_{current}$			***RepY***			$B_{current}$ / B_{MSY}		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
-	**Reference run**														
Ref	0.018	0.048	0.078	10,016	14,186	24,228	2,774	4,046	7,742	77	171	281	0.17	0.29	0.53
B.1	0.008	0.033	0.062	10,707	16,069	27,854	3,230	4,771	9,631	39	138	251	0.17	0.3	0.58
B.2	0.033	0.064	0.095	9,484	12,894	19,835	2,487	3,486	6,327	117	200	301	0.17	0.27	0.49
B.3	0.015	0.045	0.077	10,544	15,371	28,676	2,835	4,111	9,788	67	167	284	0.15	0.28	0.59

Process error standard deviation

Run	***r***			B_{MSY}			$B_{current}$			***RepY***			$B_{current}$ / B_{MSY}		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
-	**Reference run**														
Ref	0.018	0.048	0.078	10,016	14,186	24,228	2,774	4,046	7,742	77	171	281	0.17	0.29	0.53
C.1	0.018	0.047	0.077	10,941	14,072	20,097	2,741	3,816	6,064	72	158	238	0.18	0.28	0.42
C.2	0.019	0.05	0.079	9,116	15,160	30,094	2,788	4,238	13,103	85	186	368	0.15	0.3	0.74

Abundance index data

Run	***r***			B_{MSY}			$B_{current}$			***RepY***			$B_{current}$ / B_{MSY}		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
-	**Reference run**														
Ref	0.018	0.048	0.078	10,016	14,186	24,228	2,774	4,046	7,742	77	171	281	0.17	0.29	0.53
D.1	0.021	0.049	0.080	10,061	14,508	25,790	2,696	4,713	21,976	92	195	464	0.17	0.35	1.18
D.2	0.021	0.051	0.082	10,137	14,172	23,181	2,582	3,733	7,004	82	169	271	0.16	0.27	0.49
D.3	0.019	0.048	0.078	9,947	14,288	23,711	2,770	4,032	8,066	80	171	280	0.17	0.29	0.56
D.4	0.022	0.052	0.083	10,121	14,130	22,752	2,574	3,753	7,131	86	172	292	0.16	0.27	0.51
D.5	0.019	0.048	0.078	9,998	14,231	23,315	2,703	3,936	7,800	76	168	274	0.17	0.28	0.516
D.6	0.023	0.053	0.084	10,341	14,560	23,769	2,183	3,111	5,657	70	151	248	0.123	0.22	0.418
D.7	0.022	0.052	0.083	10,476	15,445	28,069	1,543	2,733	12,691	53	134	366	0.07	0.19	0.86

Run	***r***			***B_{MSY}***			***$B_{current}$***			***RepY***			***$B_{current}$ / B_{MSY}***		
-	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
D.8	0.026	0.057	0.089	9,823	14,155	27,442	2,811	6,707	30,979	107	270	568	0.16	0.51	1.48
D.9	0.024	0.054	0.084	9,944	14,339	25,966	2,410	4,533	22,360	89	201	490	0.14	0.34	1.20

Generalized surplus production model

Run	***r***			***B_{MSY}***			***$B_{current}$***			***RepY***			***$B_{current}$ / B_{MSY}***		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
-	**Reference run**														
Ref	0.018	0.048	0.078	10,016	14,186	24,228	2,774	4,046	7,742	77	171	281	0.17	0.29	0.53
E.1	0.019	0.048	0.079	6,514	9,997	17,401	2,977	4,347	9,335	71	166	276	0.23	0.45	1.01
E.2	0.018	0.048	0.078	8,648	12,272	21,358	2,808	4,090	8,504	74	170	279	0.19	0.34	0.68
E.3	0.019	0.047	0.077	10,482	14,187	23,097	2,455	3,483	6,351	82	172	269	0.16	0.25	0.42

Bayesian delay-difference model

Run	***r***			***B_{MSY}***			***$B_{current}$***			***RepY***			***$B_{current}$ / B_{MSY}***		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
-	**Reference run**														
Ref	0.018	0.048	0.078	10,016	14,186	24,228	2,774	4,046	7,742	77	171	281	0.17	0.29	0.53
F.1	0.300	0.480	0.820	8,790	11,678	16,940	1,425	2,383	4,502	42	158	350	0.10	0.22	0.42
F.2	0.326	0.553	1.05	7,360	10,352	14,711	1,440	2,618	6,187	1	112	426	0.12	0.27	0.72
F.3	0.306	0.491	0.797	8,917	11,780	18,713	1,286	2,263	4,334	50	155	373	0.09	0.20	0.42
F.4	0.32	0.52	0.84	8,803	11,672	17,001	1,175	2,018	3,565	51	154	381	0.09	0.18	0.35

Table 14 (continued) Posterior median and 90% interval results for evaluations of the sensitivity of stock assessment results for Outside Yelloweye Rockfish to different stock assessment model settings and inputs.

Catch scenarios BSP

Run	***$B_{current}$ / B_0***			***$F_{current}$ / F_{MSY}***			***$Catch_{cur}$ / RepY***			***$P(B_{cur} > 0.4 B_{MSY})$***	***$P(B_{cur} > 0.8 B_{MSY})$***	**Bayes** Factors	Posteriors updated?
	5%	50%	95%	5%	50%	95%	5%	50%	95%				
-	**Reference run**												
Ref	0.08	0.140	0.26	1.62	2.9	6.45	1.07	1.69	3.61	0.18	0.006	1	Yes
A.1	0.1	0.220	0.83	0.03	2.11	6.4	0.063	1.35	3.87	0.57	0.29	-	No
A.2	0.08	0.130	0.25	1.68	2.91	6.08	1.084	1.68	3.37	0.14	0.004	0.93	Yes
A.3	0.01	0.020	0.08	1.5	2.18	3.69	0.811	1.13	1.89	0.001	0.000	-	Yes
A.4	0.1	0.180	0.33	1.96	3.57	7.39	1.364	2.17	4.24	0.40	0.02	2.16	Yes
A.5	0.09	0.150	0.27	1.05	1.96	5.01	0.678	1.15	2.85	0.19	0.011	0.12	Yes
A.6	0.09	0.150	0.28	1.59	2.88	6.31	1.035	1.68	3.57	0.18	0.009	0.98	Yes
A.7	0.12	0.184	0.31	1.62	2.85	6.03	1.10	1.74	3.68	0.39	0.012	1.12	Yes
A.8	0.08	0.149	0.28	1.60	3.00	6.39	1.06	1.75	3.61	0.22	0.009	0.95	Yes
A.9	0.118	0.189	0.326	1.59	2.87	6.04	1.101	1.78	3.65	0.43	0.017	1.05	Yes
A.10	0.087	0.150	0.273	1.67	2.84	6.48	1.067	1.65	3.684	0.18	0.007	-	Yes

Priors

Run	$B_{current} / B_0$			$F_{current} / F_{MSY}$			$Catch_{cur} / RepY$			$P(B_{cur} > 0.4\ B_{MSY})$	$P(B_{cur} > 0.8\ B_{MSY})$	Bayes Factors	Posteriors updated?
	5%	50%	95%	5%	50%	95%	5%	50%	95%				
-	**Reference run**												
Ref	0.08	0.140	0.26	1.62	2.9	6.45	1.07	1.69	3.61	0.18	0.006	1	Yes
B.1	0.08	0.150	0.29	1.81	3.57	12.46	1.19	2.09	7.37	0.23	0.012	1.12	Yes
B.2	0.09	0.140	0.25	1.54	2.52	4.41	0.99	1.45	2.44	0.14	0.005	0.80	Yes
B.3	0.08	0.140	0.29	1.5	3.03	7.61	1.04	1.75	4.24	0.17	0.018	-	Yes

Process error standard deviation

Run	$B_{current} / B_0$			$F_{current} / F_{MSY}$			$Catch_{cur} / RepY$			$P(B_{cur} > 0.4\ B_{MSY})$	$P(B_{cur} > 0.8\ B_{MSY})$	Bayes Factors	Posteriors updated?
	5%	50%	95%	5%	50%	95%	5%	50%	95%				
-	**Reference run**												
Ref	0.08	0.140	0.26	1.62	2.9	6.45	1.07	1.69	3.61	0.18	0.006	1	Yes
C.1	0.09	0.140	0.21	2.05	3.19	7.08	1.25	1.83	3.92	0.07	0.002	0.88	Yes
C.2	0.08	0.150	0.37	1	2.65	5.95	0.78	1.55	3.32	0.28	0.037	0.35	Yes

Abundance index data

Run	$B_{current} / B_0$			$F_{current} / F_{MSY}$			$Catch_{cur} / RepY$			$P(B_{cur} > 0.4\ B_{MSY})$	$P(B_{cur} > 0.8\ B_{MSY})$	Bayes Factors	Posteriors updated?
	5%	50%	95%	5%	50%	95%	5%	50%	95%				
-	**Reference run**												
Ref	0.08	0.140	0.26	1.62	2.9	6.45	1.07	1.69	3.61	0.18	0.006	1	Yes
D.1	0.08	0.170	0.59	0.54	2.48	5.5	0.63	1.51	3.14	0.41	0.123	-	Yes
D.2	0.08	0.130	0.24	1.71	3.0	6.26	1.08	1.72	3.43	0.13	0.002	-	Yes
D.3	0.08	0.150	0.28	1.57	2.89	6.3	1.04	1.69	3.55	0.19	0.009	-	Yes
D.4	0.08	0.140	0.25	1.61	2.92	6.04	1.03	1.68	3.31	0.15	0.005	-	Yes
D.5	0.09	0.141	0.26	1.68	3.00	6.56	1.09	1.73	3.71	0.17	0.005	-	Yes
D.6	0.06	0.110	0.21	1.961	3.46	7.43	1.18	1.91	3.94	0.07	0.001	-	Yes
D.7	0.04	0.092	0.43	0.86	3.95	10.3	0.78	2.14	5.22	0.16	0.06	-	No
D.8	0.08	0.257	0.74	0.33	1.56	4.62	0.51	1.10	2.62	0.64	0.27	-	No
D.9	0.07	0.170	0.60	0.49	2.42	5.69	0.60	1.46	3.19	0.41	0.14	-	No

Generalized surplus production model

Run	$B_{current} / B_0$			$F_{current} / F_{MSY}$			$Catch_{cur} / RepY$			$P(B_{cur} > 0.4\ B_{MSY})$	$P(B_{cur} > 0.8\ B_{MSY})$	Bayes Factors	Posteriors updated?
	5%	50%	95%	5%	50%	95%	5%	50%	95%				
-	**Reference run**												
Ref	0.08	0.140	0.26	1.62	2.9	6.45	1.07	1.69	3.61	0.18	0.006	1	Yes
E.1	0.12	0.230	0.51	1.36	2.67	6.47	1.08	1.73	4.01	0.62	0.106	0.95	Yes
E.2	0.09	0.170	0.34	1.54	2.9	6.67	1.05	1.70	3.90	0.32	0.027	0.85	Yes
E.3	0.08	0.120	0.21	1.55	2.45	5.04	1.10	1.69	3.43	0.061	0.001	1.00	Yes

Bayesian delay-difference model

Run	$B_{current} / B_0$			$F_{current} / F_{MSY}$			$Catch_{cur} / RepY$			$P(B_{cur} > 0.4 B_{MSY})$	$P(B_{cur} > 0.8 B_{MSY})$	Bayes Factors	Posteriors updated?
	5%	50%	95%	5%	50%	95%	5%	50%	95%				
-	**Reference run**												
Ref	0.08	0.140	0.26	1.62	2.9	6.45	1.07	1.69	3.61	0.18	0.006	1	Yes
F.1	0.05	0.11	0.21	2.57	5.60	12.17	0.86	1.90	6.30	0.06	0.002	0.93	Yes
F.2	0.06	0.13	0.36	0.95	3.83	12.12	0.42	2.31	15.20	0.23	0.04	1.00	Yes
F.3	0.05	0.10	0.21	2.49	5.78	12.34	0.81	1.95	5.61	0.06	0.010	0.005	Yes
F.4	0.04	0.09	0.17	2.78	5.73	12.14	0.80	1.94	5.58	0.02	0.000	1.00	Yes

Table 15. Bayes factors computed for comparable stock assessment model runs where the model was fitted to the same data. Entries marked " "- indicate that the Bayes factor could not be computed due to the model being fitted to different data than the reference case model in the denominator of the ratio of model probabilities or due to the prior for one or more parameters being so different in form (e.g., normalizing constants in the joint prior being more than an order of magnitude different) from the priors in the second model that it would not be meaningful to compute Bayes factors. log(mean weight) gives the natural logarithm of the mean importance ratio for the specified model run. φ is the assumed value for B_{MSY}/K.

-	Run category	-	Description	log(mean weight)	Bayes factor
A	Catch scenarios BSP (*φ*=0.5).	A.1	No catch imputation, troll and recreational catch values from medians in base case run	-	-
		A.2	Halibut catch series obtained from bycatch ratio estimate in recent years	97.18	0.93
		A.3	Halibut catches imputed using halibut effort data and an estimate of halibut bycatch *q*	-	-
		A.4	Catches before 2006 (catch inputs including combined, rec. and troll) set at 0.5 of base case	98.02	2.16
		A.5	Catches before 2006 (catch inputs including combined, rec. and troll) set at 2x base case	95.16	0.12
		A.6			
		A.7			
		A.8	PHMA catch series		
		A.9			
		A.10		97.23	0.98
		Ref	Catch imputation of catches in salmon troll and recreational fisheries	97.25	1.00
B	Priors	B.1	prior mean r set at 2/3 base case	97.36	1.12
		B.2	prior mean r set at 1 1/3 of base case	97.03	0.80
		B.3	uniform on *K* prior rather than uniform on log *K* prior	-	-
		Ref	Prior median for r set at 0.0523	97.25	1.00
C	Process error standard deviation	C.1	$\sigma_p = 0.025$	97.13	-
		C.2	$\sigma_p = 0.075$	96.22	0.35

-	Run category	-	Description	log(mean weight)	Bayes factor
		Ref	σ_p = 0.05	97.25	1.00
D	Abundance index data	D.1	no IPHC index, but including the rest	-	-
		D.2	no FOS and no PHL index, but including the rest (no logbook-based indices)	-	-
		D.3	no trawl indices, but including the rest only with IPHC and PHMA index	-	-
		D.4	-		
		D.5			
		D.6			
		D.7			
		D.8			
		D.9		-	-
		Ref	-	97.25	-
E	Generalized surplus production model	E.1	*φ* set at 0.3	97.21	0.95
		E.2	*φ* set at 0.4	97.09	0.85
		Ref	*φ* set at 0.5	97.25	1.00
		E.3	*φ* set at 0.6	96.91	0.71
F	Bayesian delay-difference model	F.1	sigma *R* set at 0.5, fitted to same data as BSP	55.71	0.93
		F.2	sigma *R* set at 0.8, fitted to same data as BSP	55.79	1.00
		F.3	sigma *R* set at 0.5, fitted to same data as BSP and also mean commercial longline length data 1986-2002, CV=0.3	59.34	0.005
		F.4	sigma *R* set at 0.5, fitted to same data as BSP and also mean commercial longline length data 1986-2002, CV=0.15	64.64	1.00

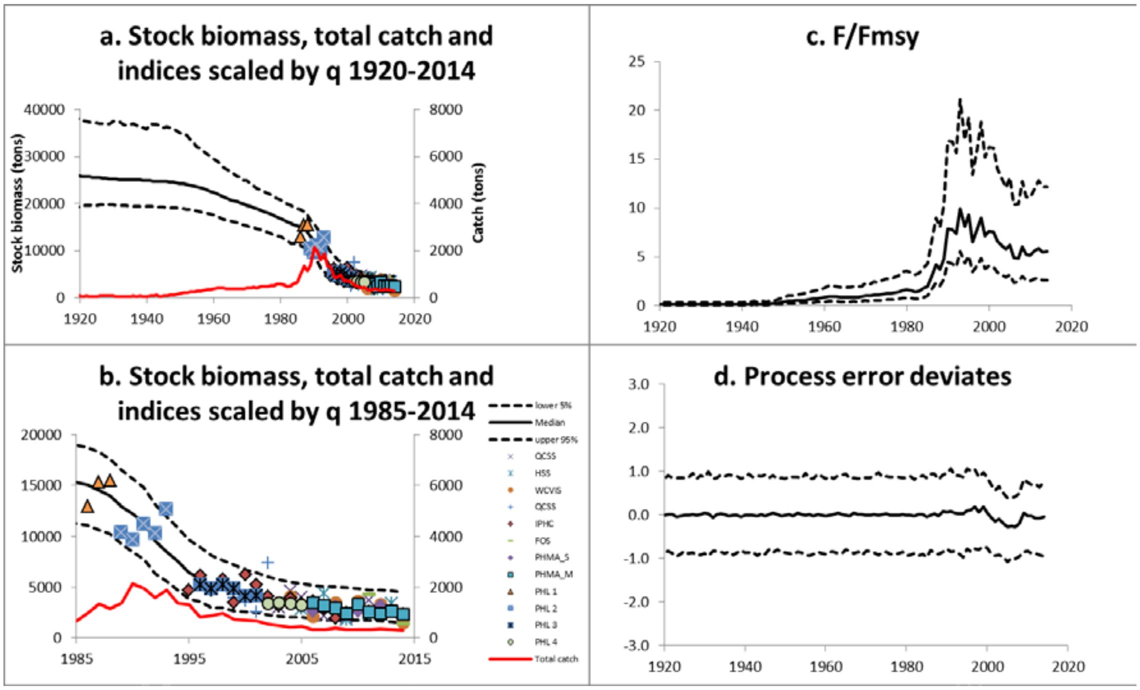

Figure 23. Posterior medians and 90% posterior interval for stock biomass from 1920-2014 (panel a), and from 1985-2014 (panel b), catch is also shown in red. Posterior medians and 90% posterior intervals for F/F_{MSY} (panel c) and process error deviates for run F.1, the BDD model with σ_R set at 0.5 (panel d).

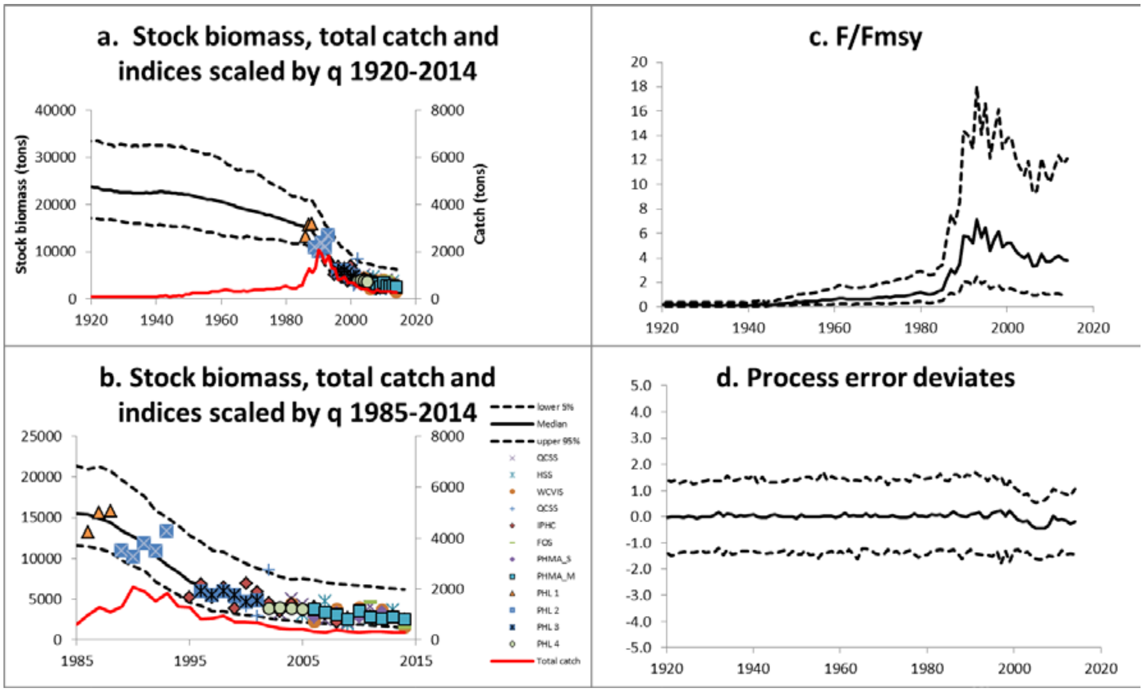

Figure 24. Posterior medians and 90% posterior interval for stock biomass from 1920-2014 (panel a), and from 1985-2014 (panel b), catch is also shown in red. Posterior medians and 90% posterior intervals for F/F_{MSY} (panel c) and process error deviates for run F.2, the BDD model with σ_R set at 0.8 (panel d).

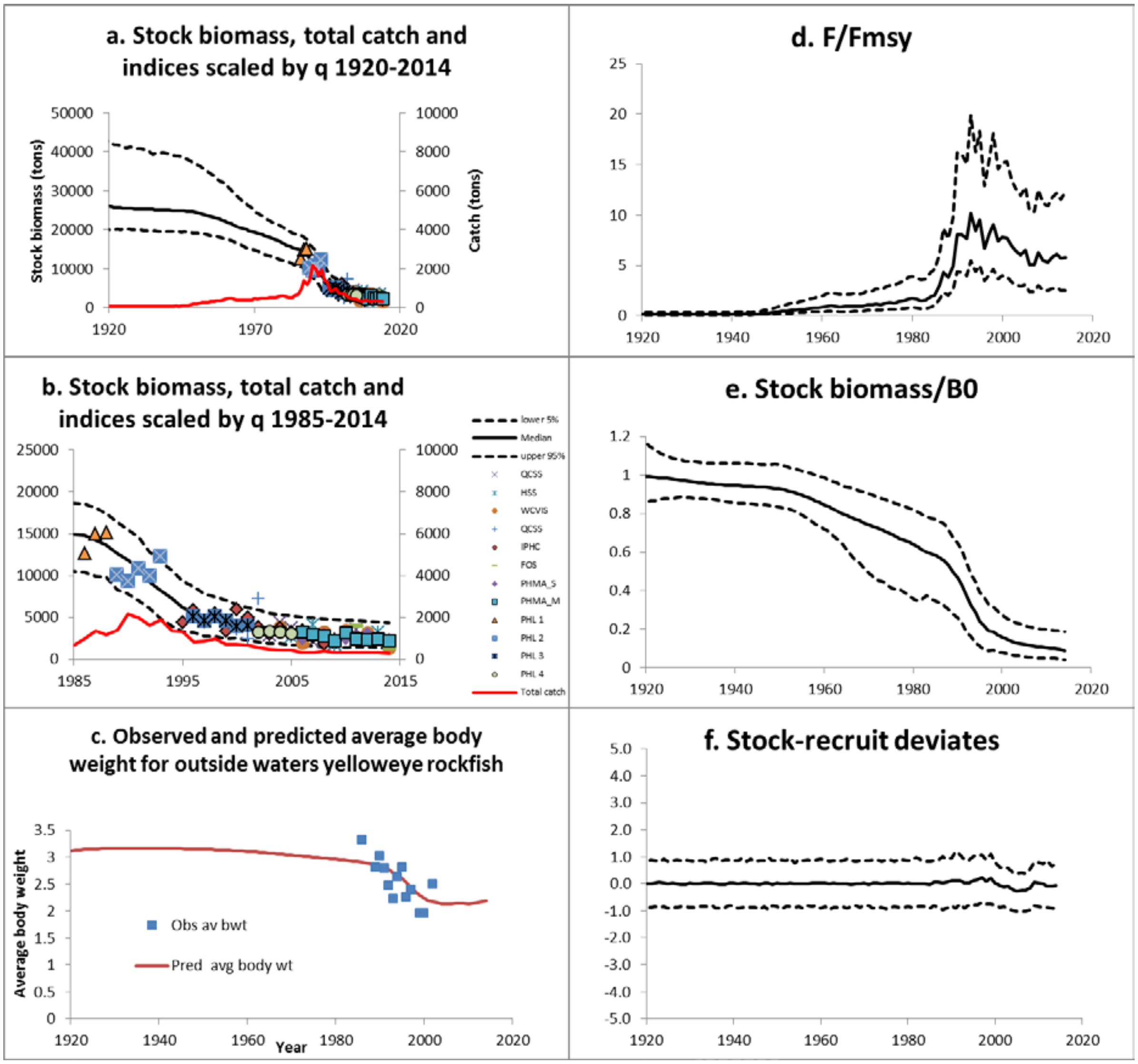

Figure 25. Posterior medians for stock biomass, and total catch and a 90% posterior interval for stock biomass 1920-2014, (panel a) and 1985-2014 (panel b). Posterior medians and 90% posterior intervals for F/F$_{MSY}$ (panel d) and process error deviates for run F.3, the BDD model with σ_R set at 0.5 and fitted to both abundance index and commercial longline mean weight data with the likelihood function CV for the latter set at 0.3.

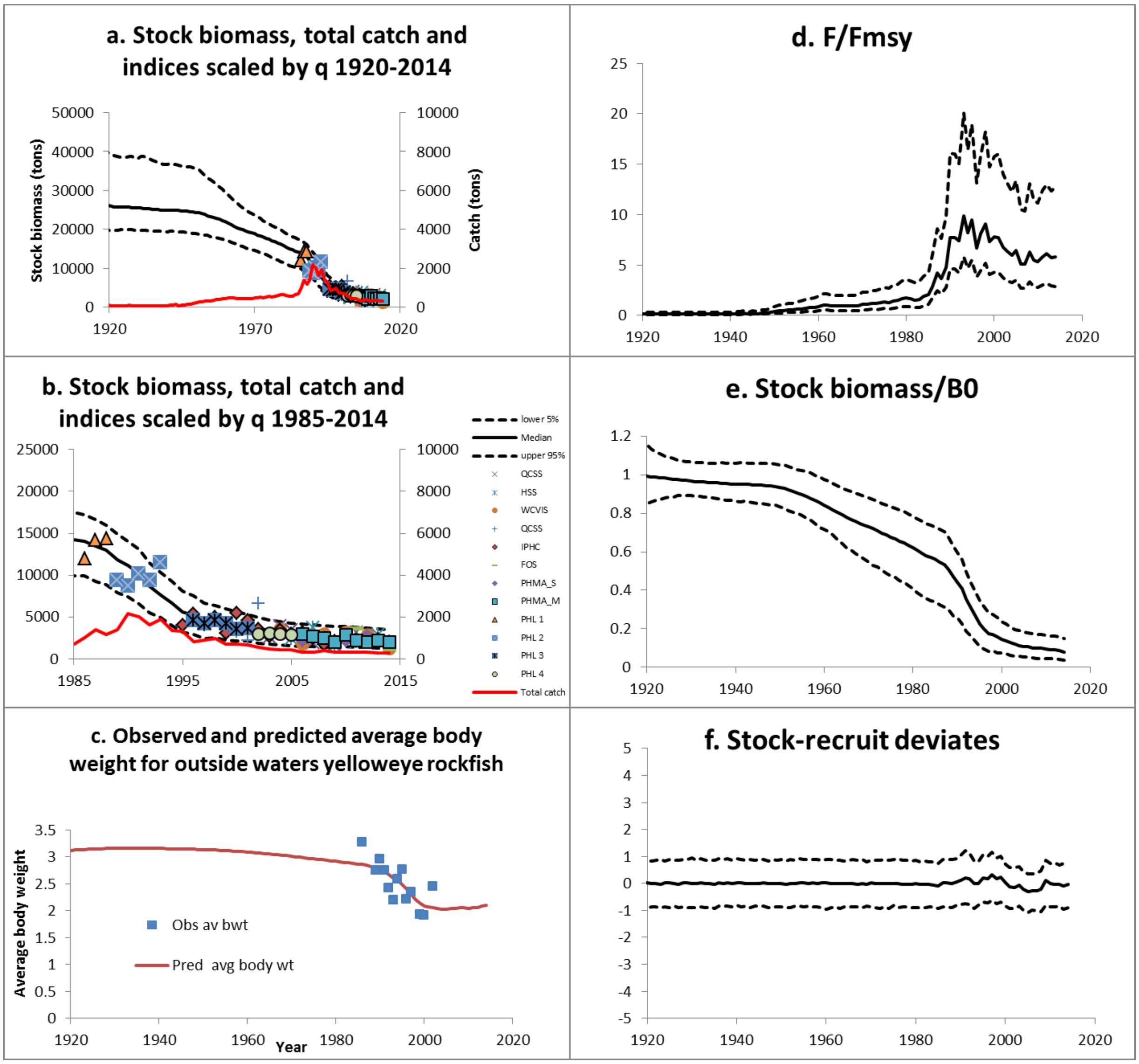

Figure 26. Posterior medians for stock biomass, and total catch and a 90% posterior interval for stock biomass 1920-2014, (panel a) and 1985-2014 (panel b). Posterior medians and 90% posterior intervals for F/F_{MSY} (panel d) and process error deviates for run F.4, the BDD model with σ_R set at 0.5 and fitted to both abundance index and commercial longline mean weight data with the likelihood function CV for the latter set at 0.15.

Table 16. Posterior mean, standard deviation (SD), coefficient of Variation (CV), median and 90% intervals for quantities of interest from run F.1 of the Bayesian delay difference model in which the σ_R was fixed at 0.5 and the model was fitted to the abundance index data. "Stdev stock bio" refers to the standard deviation in process error in the natural logarithm of stock biomass and is analogous to σ_p in the BSP model.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
Steepness	0.50	0.16	0.32	0.30	0.48	0.82
B0	27261	7997	0.293	20624	26069	37732
MSY	283	143	0.504	114	263	498
Bmsy	12123	3629	0.299	8790	11678	16940
Bmsy/B0	0.444	0.019	0.043	0.408	0.445	0.47
Binit	27196	8186	0.301	19211	25939	38550
B2014	2655	1111	0.418	1425	2383	4502
B2014/Bmsy	0.23	0.11	0.46	0.10	0.22	0.42
B2014/Binit	0.10	0.05	0.46	0.05	0.10	0.19
B2014/K	0.10	0.05	0.45	0.05	0.11	0.21
FMSY	0.02	0.01	0.48	0.01	0.02	0.05
F2014	0.13	0.05	0.36	0.07	0.12	0.21
F2014/FMSY	6.25	3.17	0.51	2.57	5.60	12.17
REPY	174	104	0.597	42	158	350
Catch/REPY	3.26	30.42	9.33	0.86	1.90	6.30
B2014/B2002	0.70	0.08	0.11	0.53	0.65	0.82
Stdev stock bio	0.03	0.01	0.38	0.02	0.03	0.05
P(B2014> 0.4Bmsy)	0.061	-	-	-	-	-
P(B2014> 0.8Bmsy)	0.002	-	-	-	-	-

Table 17. Posterior mean, standard deviation (SD), coefficient of Variation (CV), median and 90% intervals for quantities of interest from run F.2 of the Bayesian delay difference model in which the σ_R was fixed at 0.5 and the model was fitted to the abundance index data. Stdev stock bio refers to the standard deviation in process error in the natural logarithm of stock biomass and is analogous to σ_p in the BSP model.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
Steepness	0.60	0.24	0.40	0.33	0.55	1.05
B0	24401	4760	0.195	17439	23744	32792
MSY	312	143	0.459	125	293	530
Bmsy	10615	2365	0.223	7360	10352	14711
Bmsy/B0	0.43	0.02	0.06	0.39	0.44	0.47
Binit	24447	5503	0.225	16968	23805	33781
B2014	3233	2256	0.698	1440	2618	6187
B2014/Bmsy	0.32	0.21	0.66	0.12	0.27	0.72
B2014/Binit	0.14	0.08	0.61	0.05	0.12	0.28
B2014/K	0.14	0.08	0.61	0.06	0.13	0.36
FMSY	0.03	0.02	0.55	0.01	0.03	0.06
F2014	0.11	0.04	0.40	0.05	0.11	0.19
F2014/FMSY	4.88	3.96	0.81	0.95	3.83	12.12
REPY	155	151	0.978	1	112	426
Catch/REPY	13	124	10	0.4	2	15
B2014/B2002	0.66	0.09	0.13	0.46	0.63	0.83
Stdev stock bio	0.04	0.01	0.30	0.03	0.04	0.06
P(B2014> 0.4Bmsy)	0.233	-	-	-	-	-
P(B2014> 0.8Bmsy)	0.04	-	-	-	-	-

Table 18. Posterior mean, standard deviation (SD), coefficient of Variation (CV), median and 90% intervals for quantities of interest from run F.4 of the Bayesian delay difference model in which the σ_R was fixed at 0.5 and the model was fitted to the abundance index data. Stdev stock bio refers to the standard deviation in process error in the natural logarithm of stock biomass and is analogous to σ_p in the BSP model.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
Steepness	0.55	0.16	0.30	0.32	0.52	0.84
B0	27866	9736	0.349	20788	26381	38927
MSY	326	161	0.496	137	301	564
Bmsy	12242	4379	0.358	8803	11672	17001
Bmsy/B0	0.44	0.02	0.04	0.41	0.44	0.47
Binit	27778	10018	0.361	19522	26209	40099
B2014	2220	841	0.379	1175	2018	3565
B2014/Bmsy	0.19	0.08	0.43	0.09	0.18	0.35
B2014/Binit	0.09	0.04	0.45	0.04	0.08	0.15
B2014/K	0.08	0.04	0.43	0.04	0.09	0.17
FMSY	0.03	0.01	0.43	0.01	0.03	0.05
F2014	0.15	0.05	0.34	0.08	0.14	0.25
F2014/FMSY	6.4	3.1	0.5	2.8	5.7	12.1
REPY	177	108	0.614	51	154	381
Catch/REPY	2.7	10.2	3.8	0.8	1.9	5.6
B2014/B2002	0.68	0.08	0.12	0.50	0.64	0.80
Stdev stock bio	0.033	0.013	0.385	0.018	0.030	0.058
P(B2014> 0.4Bmsy)	0.024	-	-	-	-	-
P(B2014> 0.8Bmsy)	0.000	-	-	-	-	-

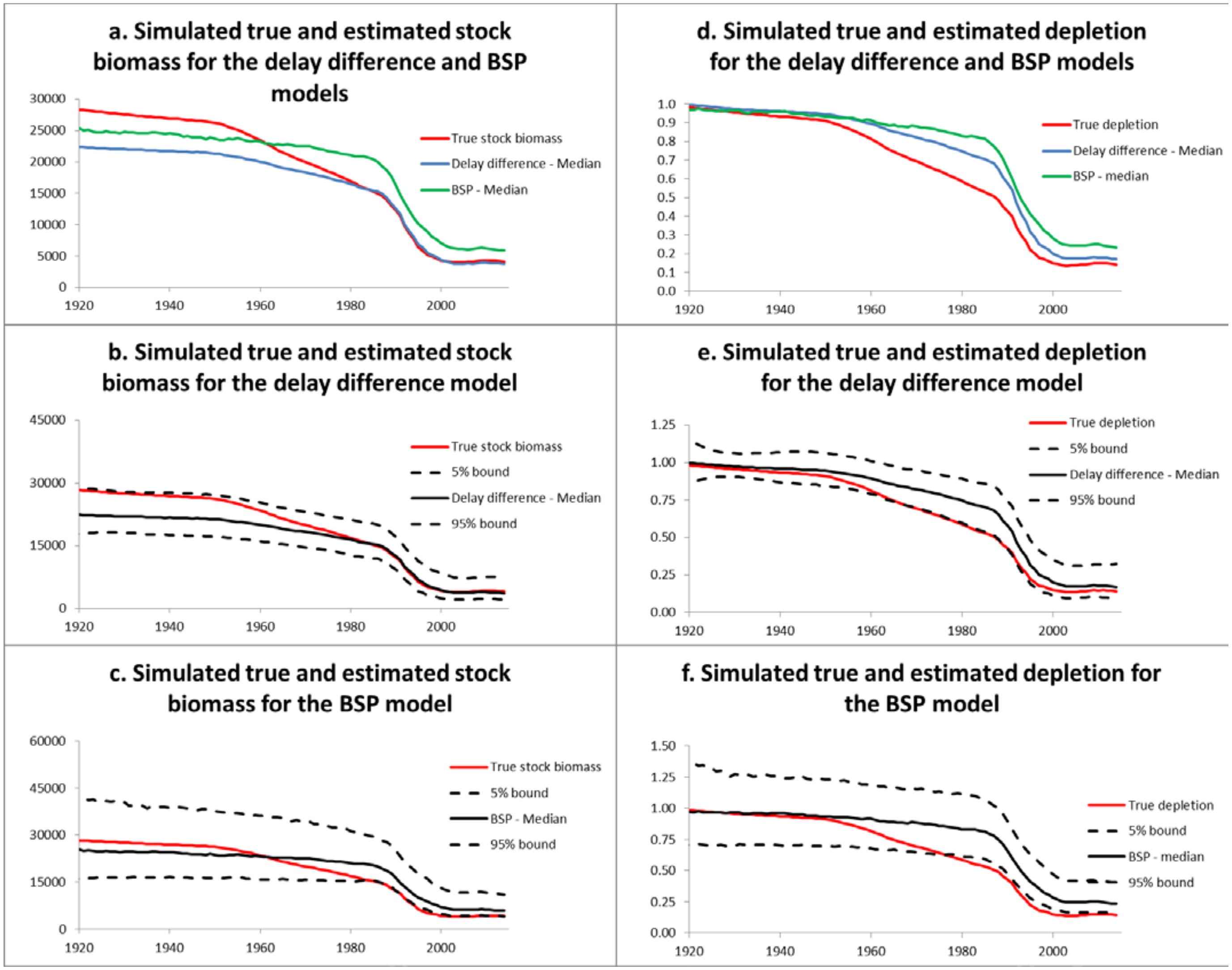

Figure 27. Simulated true and estimated stock biomass and depletion relative to B_0 for the delay difference and BSP models.

Table 19. Simulated true values for key parameters that were applied in the BDD model to simulate data.

Parameter	True values	units
B0	28820	tons
B1918/B0	0.984	-
Ricker steepness	0.67	-
SigmaR	0.5	-

Table 20. Estimates of quantities of interest obtained from the delay difference model applied to the simulated data.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile	True values
Steepness	0.65	0.19	0.29	0.40	0.63	0.97	0.67
B0	22959	3165	0.138	18964	22584	28139	28820
MSY	333	99	0.299	184	328	504	448
Bmsy	9830	1594	0.162	7712	9629	12461	12123
Bmsy/B0	0.43	0.02	0.05	0.40	0.43	0.46	0.42
Binit	23063	4071	0.177	17563	22467	29922	28372
B2014	4252	2216	0.521	2120	3737	7546	4123
B2014/Bmsy	0.43	0.18	0.41	0.22	0.40	0.76	0.34
B2014/Binit	0.19	0.08	0.42	0.09	0.17	0.32	0.15
B2014/K	0.18	0.07	0.40	0.11	0.20	0.38	0.14
FMSY	0.035	0.013	0.375	0.017	0.034	0.057	0.037
F2014	0.08	0.03	0.39	0.04	0.08	0.14	0.088
F2014/FMSY	2.62	1.27	0.48	0.97	2.46	4.84	2.39
REPY	235	143	0.609	64	210	502	293
Catch/REPY	2.05	5.01	2.45	0.59	1.43	4.47	0.81
B2014/B2002	0.93	0.08	0.09	0.81	0.95	1.13	1.02
Stdev stock bio	0.02	0.01	0.31	0.02	0.02	0.04	-
P(B2014> 0.4Bmsy)	0.494	-	-	-	-	-	-
P(B2014> 0.8Bmsy)	0.037	-	-	-	-	-	-

Table 21. Estimates of quantities of interest obtained from the BSP model applied to the simulated data.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile	True values
r	0.059	0.018	0.303	0.030	0.059	0.089	NA
B0	26834	7520	0.28	18958	25435	38972	28820
MSY	380	104	0.273	219	374	542	448
Bmsy	13417	3760	0.28	9479	12717	19486	12123
Bmsy/B0	0.5	-	-	0.5	0.5	0.5	0.42
Binit	27017	9412	0.348	16218	25095	43507	28372
B2014	6636	3054	0.46	4039	5916	11030	4123
B2014/Bmsy	0.50	0.16	0.32	0.31	0.47	0.81	0.34
B2014/Binit	0.26	0.10	0.39	0.14	0.24	0.44	0.15
B2014/K	0.25	0.08	0.32	0.15	0.23	0.403	0.14
FMSY	0.030	0.009	0.303	0.015	0.030	0.045	0.037
F2014	0.049	0.014	0.280	0.026	0.049	0.072	0.088
F2014/FMSY	1.804	0.897	0.498	0.972	1.683	2.923	2.39
REPY	271	76	0.282	157	267	400	293
Catch/REPY	1.19	0.60	0.50	0.75	1.11	1.85	0.81
B2014/B2002	0.91	0.08	0.09	0.79	0.93	1.09	1.02
P(B2014> 0.4Bmsy)	0.74	-	-	-	-	-	-
P(B2014> 0.8Bmsy)	0.05	-	-	-	-	-	-

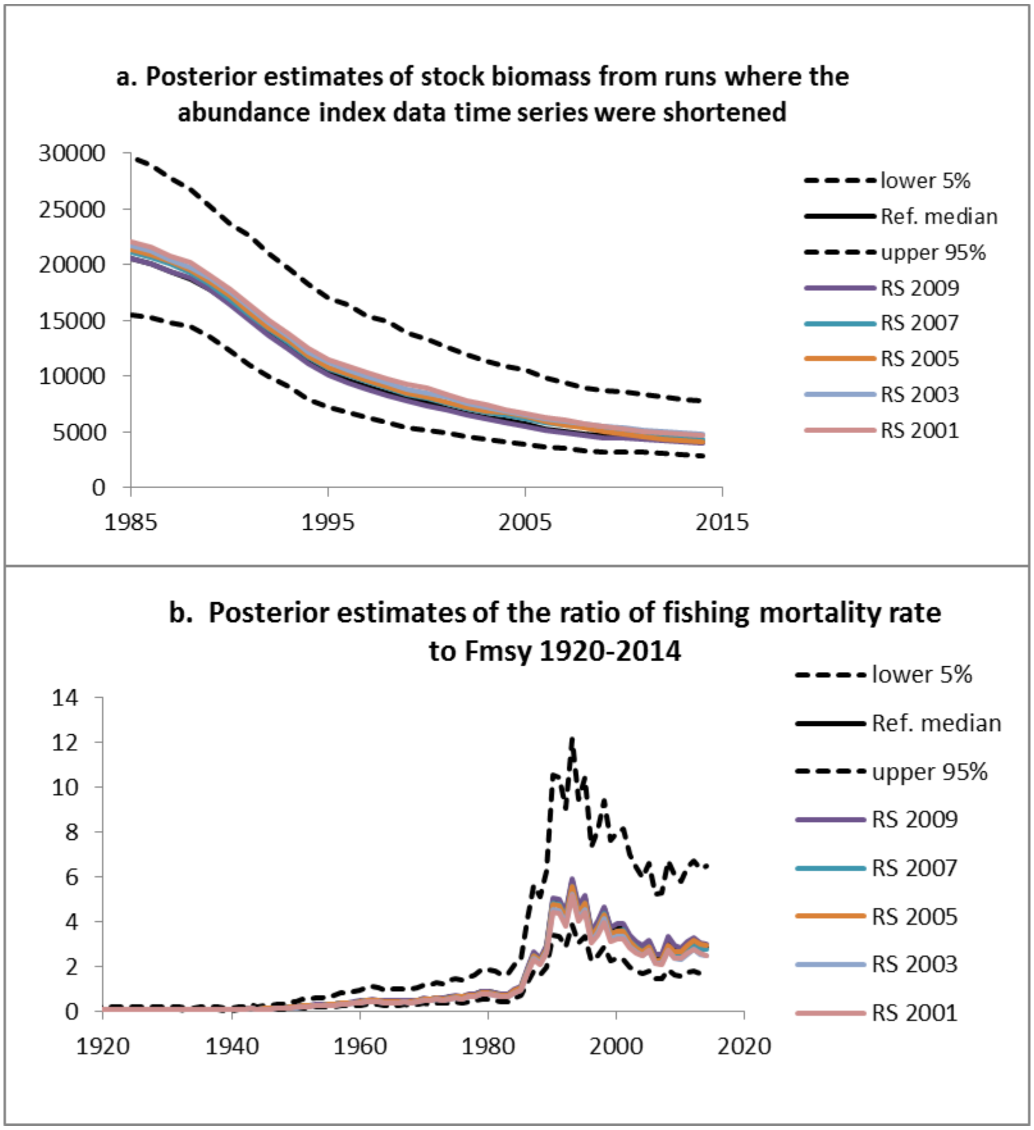

Figure 28. Plots of the estimates of a. stock biomass and b. the ratio of fishing mortality rate to F_{msy} in a retrospective analysis in which the model was fitted to successively fewer abundance index data.

MANAGEMENT ADVICE RUN

The reference case was initially proposed as the model run on which management advice would be formulated. However, after consideration of concerns over the estimated recreational and salmon troll catches in early years and the challenges of using fishery dependent abundance indices, a new model run was proposed by the review committee for use in formulating management advice (see MA Run in Table 12). For this management advice run the recreational fisheries catch time series was initiated in 1975 (zero catches prior to 1975) and increased exponentially to 2000 at which time species specific data became available; the Salmon troll fishery catch time series prior to 1950 was set to zero, 1/4 of the salmon troll catches from 1950 were used and the fishery dependent abundance index derived from logbook data was excluded in the model run over concerns that management influence and spatial considerations were not accounted for in the construction of the abundance index.

While it is acknowledged that historical catch was not zero in the recreational and salmon troll fisheries in the early years, data to establish alternate catch estimates are limited. Logbook data, unlike fishery independent survey indices, spans all years of the fishery for all participants in the directed hook and line rockfish fishery and exists as the largest data set for this assessment. Because of the significant changes in the management of the fishery over time, fisher behavior in response to these changes is difficult to account for when interpreting the catch indices from the logbook records.

REFERENCE POINTS

As part of an overall Sustainable Fisheries Framework for Canadian fisheries, a decision-making framework that incorporates the Precautionary Approach requires (DFO 2009):

1. Reference point and stock status zones (Healthy, Cautious, and Critical).
2. Harvest strategy and harvest decision rules.
3. Accounting for uncertainty and risk when developing reference points and developing and implementing decision rules.

Fisheries reference points consistent with DFO's Precautionary Reference Points are presented here for this assessment (DFO 2006). For surplus production models, B_{msy} is commonly defined at 0.5 B_0 or half of the unfished biomass for the stock. In the BSP assessment model, B_0, is defined as the carrying capacity parameter, K. Hence, for the reference case BSP model

Limit Reference Point (LRP) = $0.4\ B_{MSY} = 0.2\ B_0$
Upper Stock Reference (USR) = $0.8\ B_{MSY} = 0.4\ B_0$
Target Reference Point (TRP) = $B_{MSY} = 0.5\ B_0$

MANAGEMENT ADVICE RUN STOCK PROJECTIONS

The following results are derived from the review committee proposed management advice run. The 90% credibility interval for stock biomass supports a very substantial decline since the 1980s (Figure 29), indicating that the catch and stock trend data are informative about the trend in abundance.

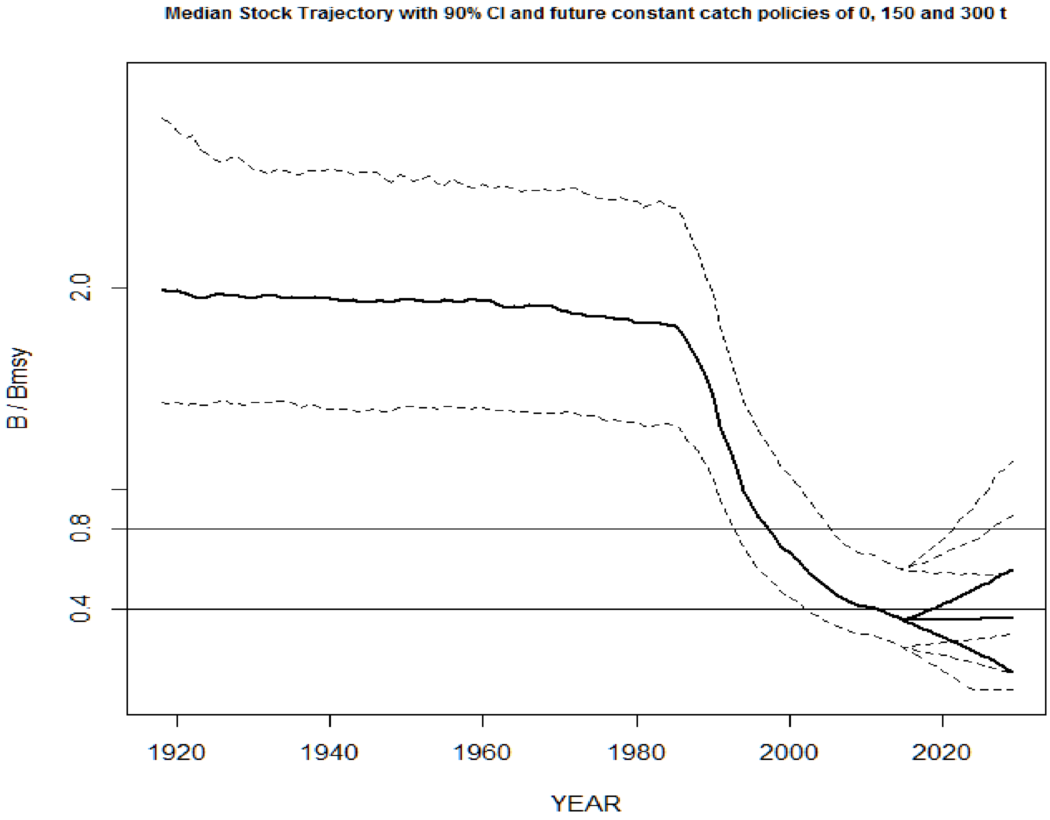

Figure 29. Outside Yelloweye Rockfish estimated historical median stock biomass and stock trajectory under various total catch scenarios of 0, 150 and 300 tonnes for the management advice run. Solid lines indicate the median and dashed lines show the 90% credibility intervals. Stock projections from 2015 onward show increases given a 0 t catch policy, little change given a 150 t catch policy and further declines given a 300 t catch policy.

Stock status for the Outside population of Yelloweye Rockfish is shown in Figure 30. The biomass in 2014 (B_{2014}) is estimated at 3,821 t (90% credibility interval of 2,428 – 7,138 t), which is 18% (90% credibility interval 10 – 33 %) of the estimated initial biomass (B_{1918}) of 21,955 t (90% credibility interval 13,747 – 37,694 t) in 1918. There is a 63% probability that stock biomass in 2014 is below the Limit Reference Point (LRP) of 0.4 B_{MSY} and a 99% probability that it is below the Upper Stock Reference (USR) of 0.8 B_{MSY}.

The median B2014/BMSY is 0.36 (Table 22) and falls within the Critical zone with the upper bound of the 90% credibility interval spanning into the Cautious zone (Figure 30). There is a 63% probability that stock status is below the LRP and a 1% probability that stock status is above the USR, i.e., a 99% probability that the stock is below the USR. Replacement yield or surplus production in 2014 is estimated at 162 t (90% credibility interval 80 – 258 t). The current catch of 287 t in 2014 is estimated at 178% (90% credibility interval 114 – 360%) of replacement yield.

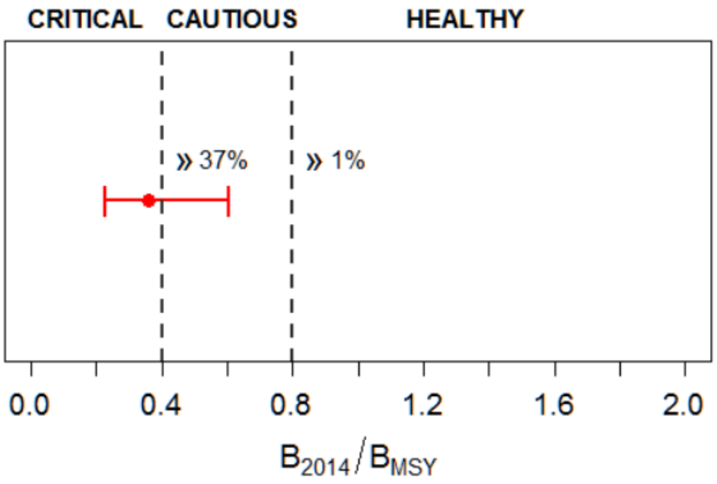

Figure 30. Stock status for the Outside population of Yelloweye Rockfish from the Reference Case Bayesian surplus production model run, median (point) and 90% confidence interval for the ratio of B_{2014} relative to B_{MSY} . Vertical dashed lines indicate the limit reference point (0.4 B_{MSY}) and upper stock reference point (0.8 B_{MSY}). The three stock status zones delineated by these reference points (Healthy, Cautious, and Critical) are indicated at the top of the figure. The arrows show the probabilities that stock status is within the Cautious Zone and the Healthy Zone.

Table 22. The 5th, 50th and 95th percentiles from the posterior distributions of quantities for stock status indicators for BC Outside Yelloweye Rockfish. Variables: r is the maximum intrinsic rate of increase, B0 is the average unfished stock size or carrying capacity, MSY is the maximum sustained yield, BMSY is the biomass at MSY, B_{1918} is the biomass in 1918, the start of the model, B_{2014} is the biomass at the beginning of 2014, F is the fishing mortality rate, REPY$_{2014}$ is the replacement yield at the beginning of 2014, Catch$_{2014}$ is the catch in 2014, P is the probability.

Variable		Percentile	
-	5	50	95
r	0.021	0.051	0.082
B0	15833	21544	33972
MSY	135	276	422
BMSY	7917	10772	16986
BMSY/B0	0.5	0.5	0.5
B1918	13747	21955	37694
B2014	2428	3821	7138
B2014/BMSY	0.227	0.360	0.604
B2014/B1918	0.104	0.182	0.33
FMSY	0.011	0.025	0.041
F2014	0.041	0.075	0.115
F2014/FMSY	1.695	2.913	6.050
REPY$_{2014}$	80	162	258
Catch$_{2014}$/REPY$_{2014}$>0	1.140	1.776	3.604
B2014/B2002	0.473	0.599	0.758
P(B_{2014}> 0.4B_{MSY})	0.369	-	-
P(B_{2014}> 0.8B_{MSY})	0.009	-	-

PROJECTION RESULTS AND DECISION TABLES

A harvest strategy is presented in the form of a decision table with stock status indicators, time horizons and probabilities of reaching the precautionary reference points (see section above). This table is designed to assist managers in their approach to managing the harvest of Outside Yelloweye Rockfish within the groundfish fishery and Sustainable Fisheries Framework. Managers requested fixed catch policies ranging from 0 to 300 tonnes per year with stock projections over 5, 10, and 15 year horizons.

For a catch policy of 0 t, the probability of the biomass exceeding the LRP of 0.4 B_{MSY} any time during a 5 year or 15 year horizon is 55% and 75%, respectively. Similarly for a catch policy of 150 t, the probability of the biomass exceeding the LRP during a 5 year or 15 year horizon is 43% and 50%, respectively. For a catch policy of 300 t, the probability of the stock exceeding the LRP during a 5 year or 15 year horizon is 33% and 35%, respectively.

The probability of the stock exceeding the USR of 0.8 B_{MSY} at a catch policy of 0 t any time during a 5 year or 15 year horizon is 3% and 11%, respectively. Similarly, for a catch policy of 150 t, the probability of the stock exceeding the USR during a 5 year or 15 year horizon is 2% and 4%, respectively. For a catch policy of 300 t, the probability of the stock exceeding the USR during a 5 year or 15 year horizon is 1.5% and 1.9%, respectively.

Table 23. Stock status indicators for Outside Yelloweye Rockfish after 5, 10 and 15 year time horizons (Hz) under various constant catch policies (total fishing mortality) in tonnes. Bfin and Ffin are the biomass and fishing mortality, respectively, in the final year of the time horizon, B0 is the average unfished stock size or carrying capacity B2014 is the biomass at the beginning of 2014, and BMSY and FMSY are the biomass and fishing mortality, respectively, at maximum sustainable yield. Probabilities are presented for six stock status indicators: P(Bfin>0.4 BMSY) is the probability of the biomass in the final year of the time horizon being above the Limit Reference point of 0.4 BMSY. P(Bfin>0.8 BMSY) is the probability of the biomass in the final year of the time horizon being above the Upper Stock Reference of 0.8 BMSY. P(B>0.4 BMSY in Hz) is the probability of the biomass being above the Limit Reference Point (0.4 BMSY) at any time within the given time horizon (Hz), with a similar definition for P(B>0.8 BMSY in Hz). P(Ffin<FMSY) is the probability of the fishing mortality in the final year of the Hz (Ffin) being below the fishing mortality at MSY

5- year Horizon

Policy	Median(Bfin/B0)	P(Bfin>Bcur)	P(B>0.4 Bmsy in Hz)	P(B>0.8 Bmsy in Hz)	P(Ffin<Fmsy)
Tot. catch= 0	0.204	0.743	0.545	0.027	1
Tot. catch= 50	0.197	0.659	0.518	0.025	0.925
Tot. catch= 75	0.191	0.595	0.495	0.024	0.742
Tot. catch= 100	0.186	0.532	0.468	0.023	0.506
Tot. catch= 125	0.180	0.474	0.446	0.02	0.297
Tot. catch= 150	0.174	0.418	0.427	0.019	0.159
Tot. catch= 200	0.163	0.307	0.386	0.018	0.04
Tot. catch= 250	0.152	0.208	0.359	0.017	0.013
Tot. catch= 300	0.140	0.143	0.333	0.015	0.006

10-year Horizon

Policy	Median(Bfin/B0)	P(Bfin>Bcur)	P(B>0.4 Bmsy in Hz)	P(B>0.8 Bmsy in Hz)	P(Ffin<Fmsy)
Tot. catch= 0	0.25	0.856	0.745	0.107	1
Tot. catch= 50	0.229	0.768	0.668	0.084	0.928
Tot. catch= 75	0.215	0.7	0.623	0.067	0.76
Tot. catch= 100	0.203	0.619	0.572	0.055	0.567
Tot. catch= 125	0.19	0.526	0.54	0.048	0.368
Tot. catch= 150	0.175	0.452	0.497	0.042	0.224
Tot. catch= 200	0.149	0.31	0.441	0.029	0.066

Policy	Median(Bfin/B0)	P(Bfin>Bcur)	P(B>0.4 Bmsy in Hz)	P(B>0.8 Bmsy in Hz)	P(Ffin<Fmsy)
Tot. catch= 250	0.122	0.198	0.382	0.023	0.017
Tot. catch= 300	0.096	0.1	0.348	0.019	0.009

15-year Horizon

Policy	Median(Bfin/B0)	P(Bfin>Bcur)	P(B>0.4 Bmsy in Hz)	P(B>0.8 Bmsy in Hz)	P(Ffin<Fmsy)
Tot. catch= 0	0.299	0.909	0.842	0.258	1
Tot. catch= 50	0.264	0.808	0.768	0.199	0.923
Tot. catch= 75	0.243	0.736	0.709	0.157	0.774
Tot. catch= 100	0.221	0.649	0.646	0.123	0.588
Tot. catch= 125	0.199	0.562	0.596	0.100	0.415
Tot. catch= 150	0.178	0.46	0.544	0.084	0.271
Tot. catch= 200	0.133	0.29	0.464	0.054	0.084
Tot. catch= 250	0.089	0.161	0.392	0.031	0.032
Tot. catch= 300	0.045	0.083	0.351	0.024	0.014

SOURCES OF UNCERTAINTY

The primary sources of uncertainty in this assessment are the catch histories. With the exception of the commercial groundfish fishery since 2006, reconstruction of the commercial, recreational and Aboriginal catch is uncertain. This uncertainty can be attributed to a lack of species identification in landings, and inconsistent regional catch monitoring and catch data reporting. This uncertainty was explored against the initial reference case through multiple sensitivity runs which indicate that the model is sensitive to the catch scenario applied but none of the scenarios considered suggest stock status results dramatically different from the reference case, including the management advice run. The stock has declined with the removal of catches beginning in the mid 1980's and is estimated to be below the LRP.

The fishery independent abundance indices available for use in the assessment are all short time series, with the exception of the International Pacific Halibut Commission Standardized Stock Assessment Survey. All surveys were initiated after the largest fishery removals in the 1980s. All abundance indices show overall declining trends, with the exception of one or two data points. Fishery-dependant abundance indices span the time period of high fishery catches and exist for all years. However, these data were not used to formulate management advice because of the influence that management actions have on the fishery together with the spatial component of fishing, and these influences were not explicitly accounted for in the analysis.

Rockfish Conservation Areas (RCAs), which account for 15% of habitat, were not explicitly considered in this assessment. Research using remotely operated vehicles between 2009 and 2011 has shown that densities of Yelloweye Rockfish in the RCAs are not different from densities in open areas. It is not expected, at this time, that the assessment would be affected by these closed areas. Future Yelloweye Rockfish assessments may need to consider population trends in the RCAs to avoid any potential bias that could be introduced when fish abundance in the RCAs becomes different from those in open areas. Monitoring populations in the RCAs and understanding how to incorporate RCAs into stock assessments may be an important area for future research.

CONCLUSIONS AND ADVICE

The BC Yelloweye Rockfish is characterized as a long-living and slow growing fish with low productivity. Fishery removals from the Outside population peaked in the mid to late 1980s and have declined since. Model results estimates the stock biomass in 2014 to be 18% of the unfished biomass B_0. There is a 63% probability that stock biomass in 2014 is below the LRP of 0.4 B_{MSY} and a 99% probability that stock biomass in 2014 is below the USR of 0.8 B_{MSY}.

Harvest advice is presented in the form of decision tables, using 5, 10 and 15 year projections, for constant catches between 0 and 300 t/year. Predicted outcomes of harvest decisions depend upon the choice of time horizon, harvest policy, and reference point. In general, the median B_{fin}/B_0 increases with the time horizon and with lower catches. Total catches greater than the replacement yield or surplus production of 162 t (90% credibility interval of 80 – 258 t) in 2014 have a higher probability of resulting in further population declines. Catches in 2015 of 150 t or less show no net population declines over the stock projections to 2029 (Figure 3).

This assessment assumes a single Outside stock. Further analysis to develop more spatially explicit harvest advice is recommended to assist with the management of the fisheries considering various factors:

1. the sedentary characteristics of Yelloweye Rockfish;

2. current spatial management which includes conservation areas where direct commercial and recreational fishing is prohibited; and
3. area-based individual transferable quotas in commercial groundfish hook and line and trap fisheries. Spatially explicit commercial catch and several fishery-independent survey data sets are available and could be used to develop area-based harvest plans.

Monitoring of Rockfish Conservation Areas (RCAs) would need to continue to enable an assessment of whether the population of Yelloweye Rockfish is increasing inside versus outside of the RCAs. While research between 2009 and 2011 has not shown evidence of increases in fish density in the RCAs, the benefits of closed areas are not expected to be detected for at least 10 years after their closure given the low productivity of this species.

Reassessment of Outside Yelloweye Rockfish is recommended in 10 years; however, research into new spatial assessment methods may be conducted within a shorter timeframe. Both the Inside and Outside stocks are scheduled for COSEWIC status reassessment in 2018.

RESEARCH NEEDS

There is a need to resolve catch to species for all groundfish species where categories of mixed species are recorded in landing statistics (see Haigh and Yamanaka 2011). For this assessment, the reconstruction of commercial catch for Yelloweye Rockfish was time consuming, requiring consultations with industry to clarify situations specific to inshore rockfish. The reconstruction of commercial catch for all groundfish species is a project that will be beneficial for assessments in the future for other species of rockfish, flatfish, roundfish, and could be implemented more efficiently if resolved for the whole, groundfish fishery. Understanding external factors (strength of the US dollar, salmon catches, markets) as well management actions (license limitation, onboard observers, license integration, and 100% monitoring) are important factors affecting any catch reconstruction. Industry can play a key role in resurrecting historic details. To expedite assessment work in the future, one official catch reconstruction matrix or array would belay much of the consternation and debate experienced leading up to this assessment.

With low and declining research survey catches, there is a need to consider the problem of modelling count data with an excess of zeros (zero inflation). Specifically, we need to investigate the use of zero-inflated regression models.

Visual assessment data exist for Yelloweye Rockfish densities over habitat type in BC (Yamanaka et al. 2012, Yamanaka and Flemming 2013). Applying density estimates (collected between 2009 and 2011 on the west coast of Vancouver Island) to an estimate of habitat for the Outside waters yields a theoretical biomass at 4,037 tonnes, an estimate not presented in the assessment but is similar to the BSP B_{2014} estimate of 4,046 t. This ‘back of the envelope’ calculation is crude but indicates that there is value in pursuing visual surveys of Yelloweye Rockfish densities and habitat classifications throughout BC for stock assessment purposes. Strategic visual surveys, coupled with the collection and interpretation of multibeam bathymetry and backscatter data could yield scientifically defensible biomass estimates that would improve stock assessments, especially for data-poor species. US assessments for Yelloweye Rockfish in SE Alaska (Green et al. 2013) and Cowcod (*Sebastes levis*) assessments in southern California (Yoklavich et al. 2007) have relied on visual methods for stock assessments.

To apply age-structured methods for assessment of this stock in the future, biological sampling programs for the commercial, recreational and Aboriginal fisheries are required. Age data from recent research surveys show population age structure, featuring a progression of age modes through time (Figure 28). However, existing biological data from the fisheries consist of sparse commercial fishery lengths from the longline fishery since 1986 and no consistently collected biological data from the commercial trawl, recreational or Aboriginal fisheries (Figure 30 and Figure 31).

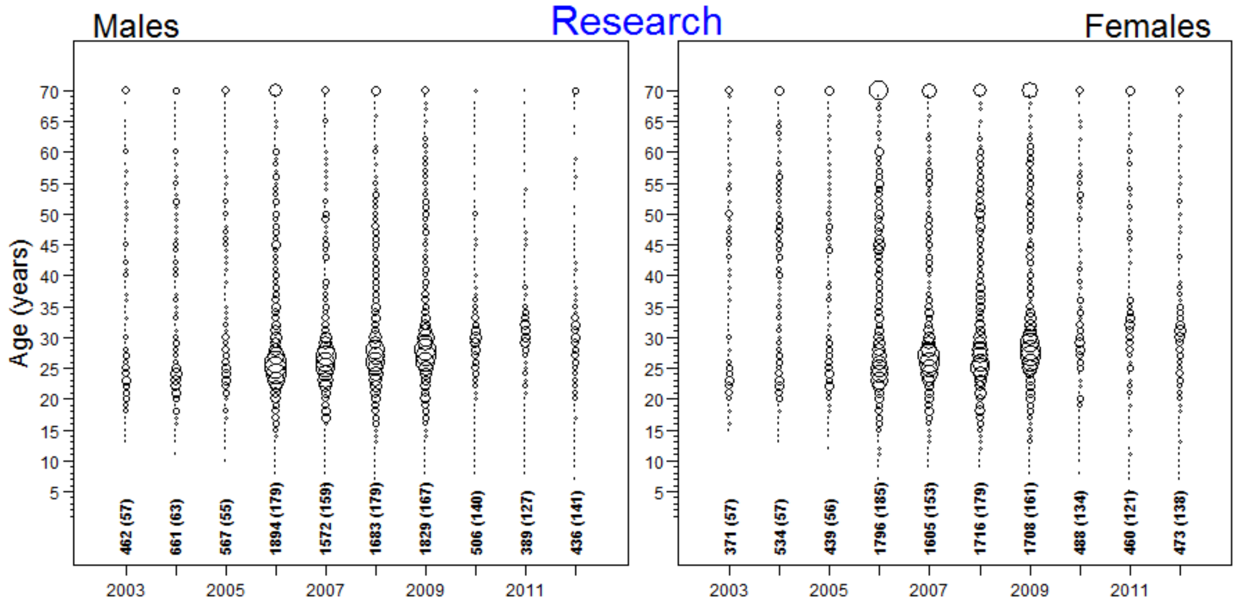

Figure 28. Outside Yelloweye Rockfish ages, by sex and year from the International Pacific Halibut Commission Standardized Stock Assessment (2003 to 2012) and Pacific Halibut Management Association longline research surveys (2007 to 2012). Numbers at the bottom of the panels represent the total number of samples by year and the number of sampling events by year (in brackets).

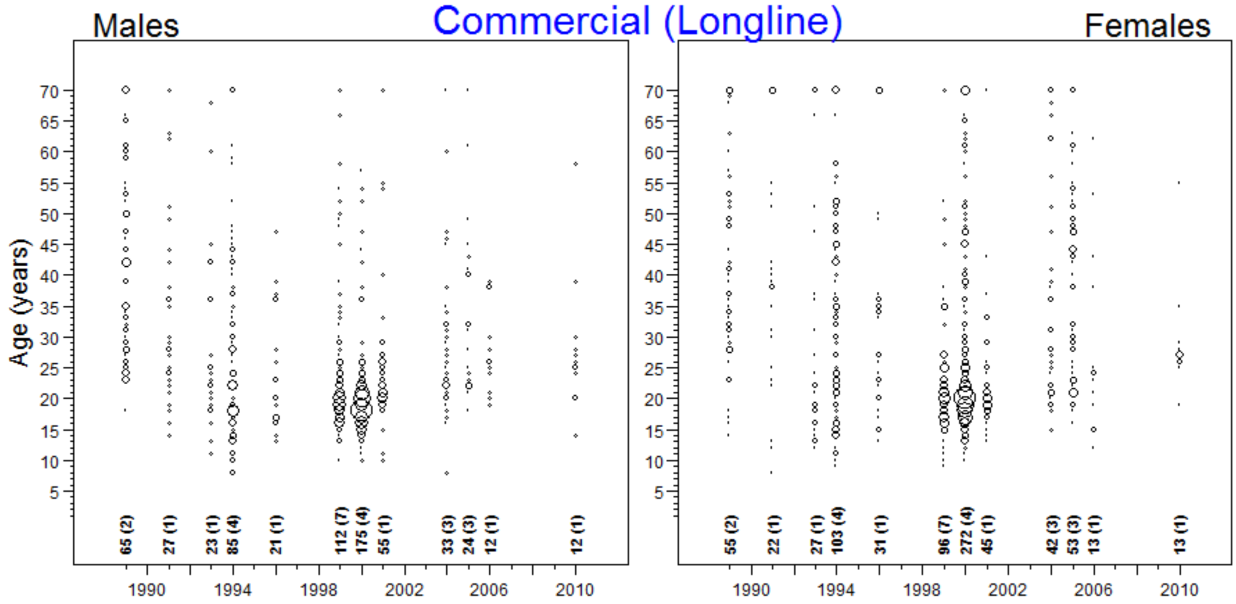

Figure 29. Outside Yelloweye Rockfish ages, by sex and year for samples (number of ages: number of samples) from the commercial longline fishery. Numbers at the bottom of the panels represent the total number of samples by year and the number of sampling events by year (in brackets).

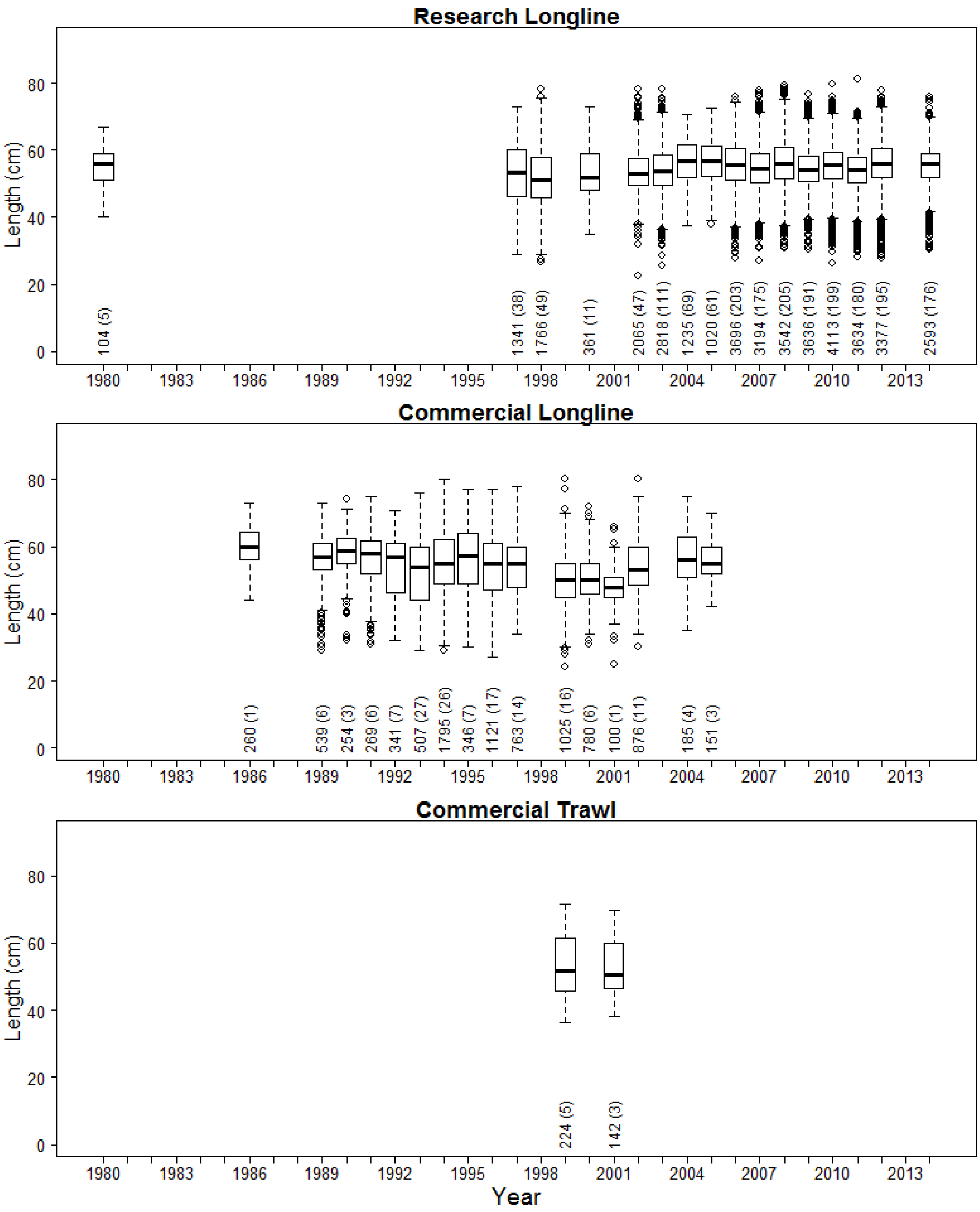

Figure 30. Boxplots of mean length (cm) for Outside Yelloweye Rockfish from research longline surveys (top panel), the commercial longline fishery (middle panel) and the commercial trawl fishery (bottom panel). Numbers at the bottom of the panels represent the total number of samples (100+ specimens) by year and the number of sampling events by year (in brackets).

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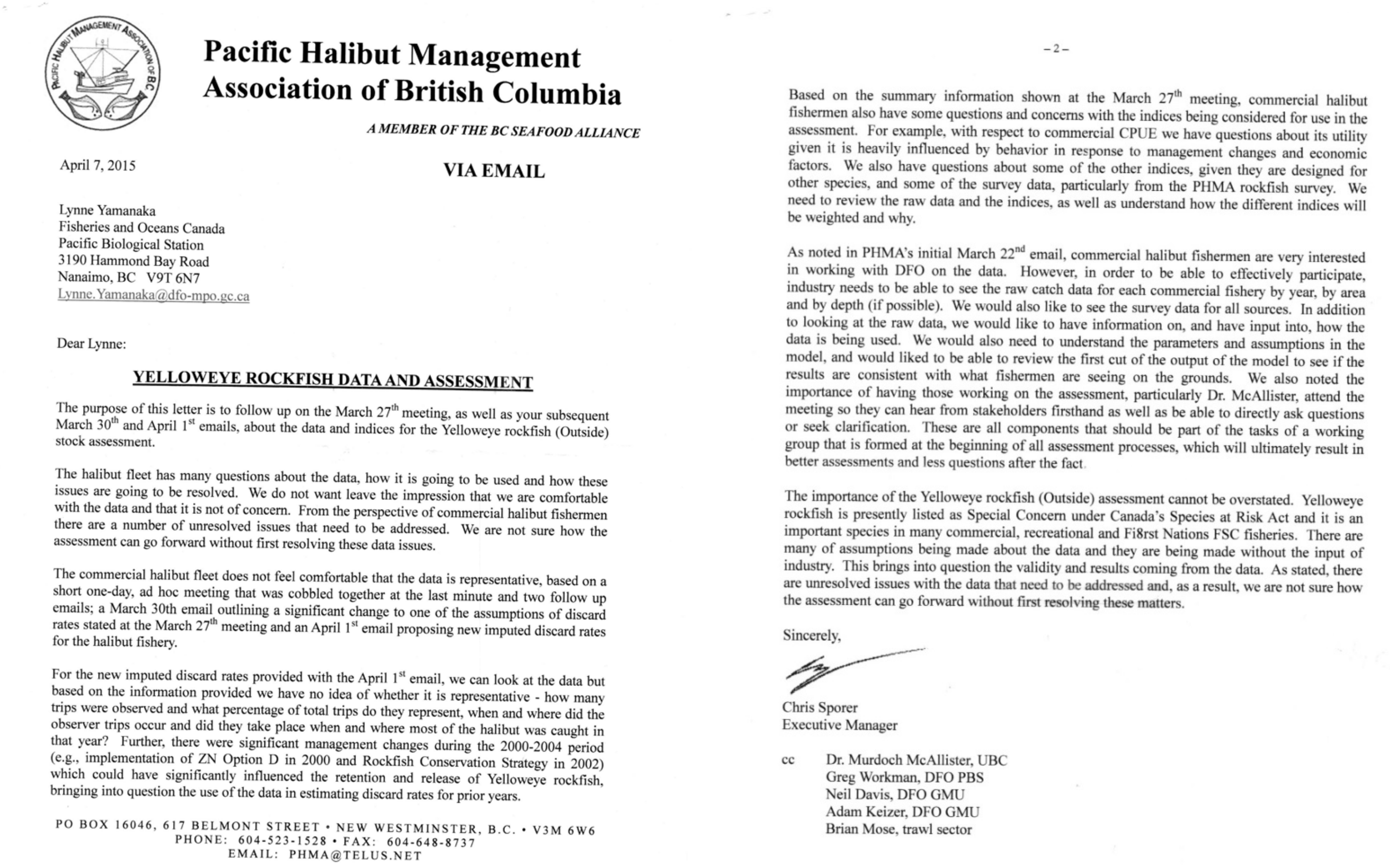
APPENDIX A. FISHERY- DEPENDENT DATA

Yelloweye Rockfish is a highly prized food fish species that is primarily caught by hook and line gear types and because of its widespread distribution along the British Columbia (BC) coast, it is incidentally caught by all fisheries. Catch from commercial, recreational and Aboriginal fisheries are amalgamated for this stock assessment. Commercial fisheries investigated are the groundfish hook and line (Pacific Halibut, rockfish, Lingcod and Spiny Dogfish, and Sablefish), groundfish and shrimp trawl, salmon troll, and Sablefish, crab and prawn trap. Recreational fisheries investigated are the West Coast Vancouver Island Creel Survey, Central Coast lodges and guides logbook program and the iRec electronic survey program. Catch estimates are also included for the Aboriginal fisheries in BC. Catch data are not easily amalgamated for all Outside areas and the methods used to estimate catch for Yelloweye Rockfish in this assessment are detailed in this Appendix. Fisherlog data, or logbook data recorded by commercial fishery participants are also described in this Appendix.

The Outside Yelloweye Rockfish population occurs within Pacific Marine Fisheries Commission (PMFC) major areas 3CD and 5ABCDE. Although the boundaries of the Outside Yelloweye Rockfish Designatable Unit (COSEWIC terminology) are slightly inside the boundaries of PMFC major area 4B, we exclude 4B to be consistent with the management boundaries over the historic catch time series. That is, all catch data for the Outside Yelloweye Rockfish population includes coastwide catch except for that in PMFC major area 4B, which is occupied by the Inside Yelloweye population.

The catch of Outside Yelloweye Rockfish is reconstructed for commercial, recreational and Aboriginal fisheries from 1918 to 2014. Determining the catch of Yelloweye Rockfish from historic catch data sources requires the decomposition of landings from mixed-species market categories such as “other rockfish” or “rockfish” to derive species-specific landings. In years prior to fully reported landings, this is accomplished by using proportions of Yelloweye Rockfish to rockfish other than Pacific Ocean Perch (herein referred to as “other rockfish” or ORF) by gear type from modern catch data sources where complete species and gear type information are available. If modern landings by species are reported by fishing sector or gear type, these data are used to report the Outside Yelloweye Rockfish catch. Calendar year is used in this assessment to summarize annual catch.

Commercial catch reconstructions have been used in previous stock assessments for the Inside population of Yelloweye Rockfish (Yamanaka et al. 2012a), Coastwide Quillback Rockfish (*S. maliger*, Yamanaka et al. 2012b), Pacific Ocean Perch (*S. alutus*, Edwards et al. 2012a, 2014a , 2014b), Yellowmouth Rockfish (*S. reedi*, Edwards et al. 2012b), and Silvergray Rockfish (*S. brevispinis*, Starr et al.,2016). The 2015 reconstruction of Yelloweye Rockfish commercial catch has been conducted following the general procedures published in Haigh and Yamanaka (2011), which have undergone significant changes since its publication, and results in the combined total of both commercial landings and discards. ‘Official’ or ‘merged’ catch numbers are used where present and include data from seven DFO databases that are merged to best represent catch. The catch reconstruction procedures were modified through consultations with the commercial industry at two meetings to discuss catch data on March 27th and May 14th, 2015 (see attached letters from the Pacific Halibut Management Association (PHMA) dated April 7 and June 12)(Figures A 1 and A 2). These modifications are included in the commercial catch reconstruction outlined below. The reconstructed commercial groundfish catches are shown in Figure A 3 and Table A 1.



Pacific Halibut Management Association of British Columbia

A MEMBER OF THE BC SEAFOOD ALLIANCE

April 7, 2015

VIA EMAIL

Lynne Yamanaka
Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7
Lynne.Yamanaka@dfo-mpo.gc.ca

Dear Lynne:

YELLOWEYE ROCKFISH DATA AND ASSESSMENT

The purpose of this letter is to follow up on the March 27th meeting, as well as your subsequent March 30th and April 1st emails, about the data and indices for the Yelloweye rockfish (Outside) stock assessment.

The halibut fleet has many questions about the data, how it is going to be used and how these issues are going to be resolved. We do not want leave the impression that we are comfortable with the data and that it is not of concern. From the perspective of commercial halibut fishermen there are a number of unresolved issues that need to be addressed. We are not sure how the assessment can go forward without first resolving these data issues.

The commercial halibut fleet does not feel comfortable that the data is representative, based on a short one-day, ad hoc meeting that was cobbled together at the last minute and two follow up emails; a March 30th email outlining a significant change to one of the assumptions of discard rates stated at the March 27th meeting and an April 1st email proposing new imputed discard rates for the halibut fishery.

For the new imputed discard rates provided with the April 1st email, we can look at the data but based on the information provided we have no idea of whether it is representative - how many trips were observed and what percentage of total trips do they represent, when and where did the observer trips occur and did they take place when and where most of the halibut was caught in that year? Further, there were significant management changes during the 2000-2004 period (e.g., implementation of ZN Option D in 2000 and Rockfish Conservation Strategy in 2002) which could have significantly influenced the retention and release of Yelloweye rockfish, bringing into question the use of the data in estimating discard rates for prior years.

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Based on the summary information shown at the March 27th meeting, commercial halibut fishermen also have some questions and concerns with the indices being considered for use in the assessment. For example, with respect to commercial CPUE we have questions about its utility given it is heavily influenced by behavior in response to management changes and economic factors. We also have questions about some of the other indices, given they are designed for other species, and some of the survey data, particularly from the PHMA rockfish survey. We need to review the raw data and the indices, as well as understand how the different indices will be weighted and why.

As noted in PHMA's initial March 22nd email, commercial halibut fishermen are very interested in working with DFO on the data. However, in order to be able to effectively participate, industry needs to be able to see the raw catch data for each commercial fishery by year, by area and by depth (if possible). We would also like to see the survey data for all sources. In addition to looking at the raw data, we would like to have information on, and have input into, how the data is being used. We would also need to understand the parameters and assumptions in the model, and would liked to be able to review the first cut of the output of the model to see if the results are consistent with what fishermen are seeing on the grounds. We also noted the importance of having those working on the assessment, particularly Dr. McAllister, attend the meeting so they can hear from stakeholders firsthand as well as be able to directly ask questions or seek clarification. These are all components that should be part of the tasks of a working group that is formed at the beginning of all assessment processes, which will ultimately result in better assessments and less questions after the fact.

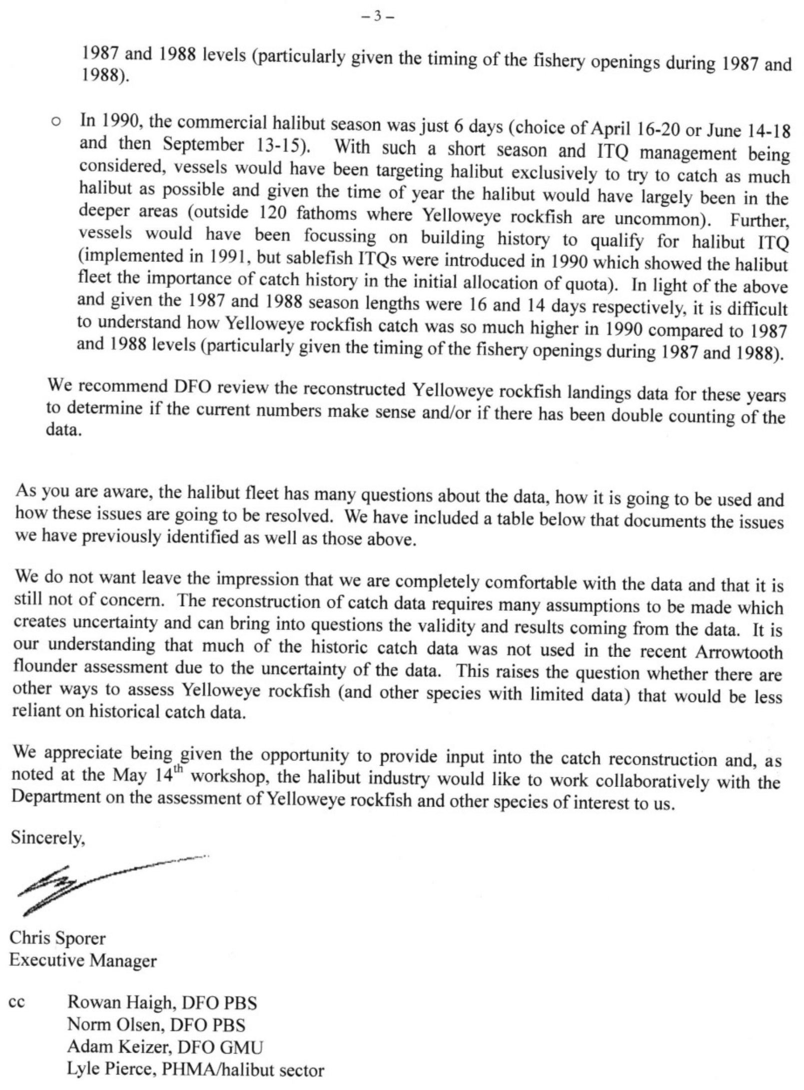
The importance of the Yelloweye rockfish (Outside) assessment cannot be overstated. Yelloweye rockfish is presently listed as Special Concern under Canada's Species at Risk Act and it is an important species in many commercial, recreational and Fi8rst Nations FSC fisheries. There are many of assumptions being made about the data and they are being made without the input of industry. This brings into question the validity and results coming from the data. As stated, there are unresolved issues with the data that need to be addressed and, as a result, we are not sure how the assessment can go forward without first resolving these matters.

Sincerely,

Chris Sporer
Executive Manager

cc Dr. Murdoch McAllister, UBC
Greg Workman, DFO PBS
Neil Davis, DFO GMU
Adam Keizer, DFO GMU
Brian Mose, trawl sector

Figure A 1. Letter to Lynne Yamanaka from Chris Sporer to follow up on the March 27th meeting, as well as subsequent emails from March 30th and April 1st, 2015, about the data and indices for the Yelloweye Rockfish (Outside) stock assessment. They discuss unresolved issues with data that need to be addressed and their concern of going forward with the assessment without first resolving these matters



– 3 –

1987 and 1988 levels (particularly given the timing of the fishery openings during 1987 and 1988).

- ○ In 1990, the commercial halibut season was just 6 days (choice of April 16-20 or June 14-18 and then September 13-15). With such a short season and ITQ management being considered, vessels would have been targeting halibut exclusively to try to catch as much halibut as possible and given the time of year the halibut would have largely been in the deeper areas (outside 120 fathoms where Yelloweye rockfish are uncommon). Further, vessels would have been focussing on building history to qualify for halibut ITQ (implemented in 1991, but sablefish ITQs were introduced in 1990 which showed the halibut fleet the importance of catch history in the initial allocation of quota). In light of the above and given the 1987 and 1988 season lengths were 16 and 14 days respectively, it is difficult to understand how Yelloweye rockfish catch was so much higher in 1990 compared to 1987 and 1988 levels (particularly given the timing of the fishery openings during 1987 and 1988).

We recommend DFO review the reconstructed Yelloweye rockfish landings data for these years to determine if the current numbers make sense and/or if there has been double counting of the data.

As you are aware, the halibut fleet has many questions about the data, how it is going to be used and how these issues are going to be resolved. We have included a table below that documents the issues we have previously identified as well as those above.

We do not want leave the impression that we are completely comfortable with the data and that it is still not of concern. The reconstruction of catch data requires many assumptions to be made which creates uncertainty and can bring into questions the validity and results coming from the data. It is our understanding that much of the historic catch data was not used in the recent Arrowtooth flounder assessment due to the uncertainty of the data. This raises the question whether there are other ways to assess Yelloweye rockfish (and other species with limited data) that would be less reliant on historical catch data.

We appreciate being given the opportunity to provide input into the catch reconstruction and, as noted at the May 14th workshop, the halibut industry would like to work collaboratively with the Department on the assessment of Yelloweye rockfish and other species of interest to us.

Sincerely,

Chris Sporer
Executive Manager

cc Rowan Haigh, DFO PBS
Norm Olsen, DFO PBS
Adam Keizer, DFO GMU
Lyle Pierce, PHMA/halibut sector

– 4 –

Yelloweye Catch in the Halibut Fishery – Identified Potential Data Issues

Issue:	**Description:**	**Status:**
DFO GMU Sector Summary reports, 2006-2014	Difference in 2006-2014 data between reconstructed catch data set and DFO GMU Sector Summary reports	Resolved: reconstructed catch data set includes L/K combination trips
Canada Dominion Bureau of Statistics data	Determine if the data includes landings by US vessels fishing in Canadian waters (e.g., see footnote under Fish Caught and Market Table I in 1918 data set).	May 14: DFO to follow up
1991-2005 Halibut Season Summary DMP data	Differences in 1991-2005 data between reconstructed catch data set and 1991-2005 Halibut Season Summary DMP data • Does this affect YE landings by halibut fleet in previous years - does the 1982-1990 data have the same issue, is this data overstated • Does this affect gamma (YE landed/ORF landed) and therefore reconstructed data that uses gamma.	May 25/26: DFO queries database, data similar, following up to see if discrepancy result of analysis to perform data reconstruction
Reconstructed data (ver. May 25)	Significant differences in total YE catch for 2000-2005 compared to Reconstructed data (ver. May 13)	June 11: DFO reports found double counting in data set, may address this issue; follow up with DFO to confirm
Gamma	Halibut industry representatives conclude the YE landed to Other Rockfish landed ratios seem high for certain PMFC areas.	June 12: sent to DFO for consideration
1999	Total catch of Yelloweye rockfish (retained and released) in the halibut fishery could be low.	June 12: sent to DFO for consideration
1989 and 1990	Yelloweye rockfish landings estimates for 1989 and 1990 in the reconstructed catch data seemed high.	June 12: sent to DFO for consideration

Figure A 2. Continued.

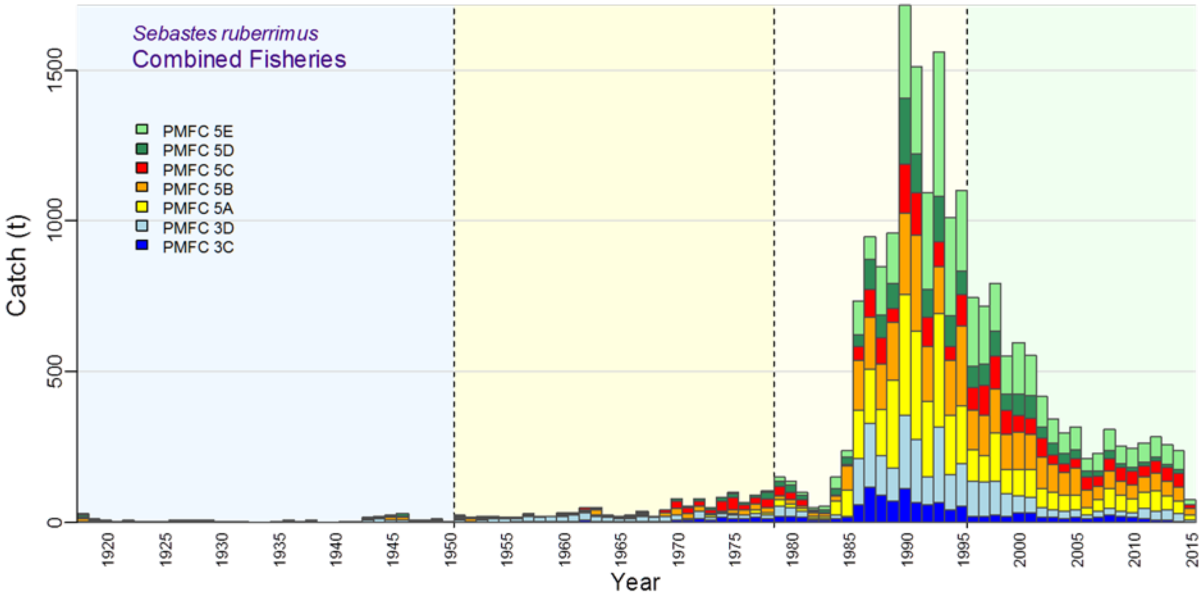


Figure A 3. Reconstructed Outside Yelloweye Rockfish commercial groundfish catch history, in tonnes, from 1918 to 2005 and catches from the Fishery Operating System (FOS) from 2006 to 2014. Coloured bars indicate PMFC area of fishing (see legend).

Table A 1. Reconstructed Outside Yelloweye Rockfish commercial groundfish catch history in tonnes by fishing sector and in total from 1918 to 2005 and catches from the Fishery Operations System (FOS) from 2006 to 2014.

Year	Trawl	Halibut	Sablefish	Dogfish/Lingcod	H&Lrockfish	TOTAL
1918	0.0	18.0	0.0	0.3	8.6	26.8
1919	0.0	6.6	0.0	0.2	4.1	10.9
1920	0.0	5.1	0.0	0.1	2.9	8.2
1921	0.0	1.6	0.0	0.1	1.1	2.8
1922	0.0	3.5	0.0	0.1	2.4	6.1
1923	0.0	1.7	0.0	0.1	1.1	2.9
1924	0.0	2.0	0.0	0.1	1.3	3.4
1925	0.0	1.8	0.0	0.0	1.0	2.9
1926	0.0	3.9	0.0	0.1	2.1	6.1
1927	0.0	5.9	0.0	0.1	3.2	9.3
1928	0.0	4.7	0.0	0.1	2.7	7.5
1929	0.0	5.6	0.0	0.1	3.0	8.7
1930	0.0	3.2	0.0	0.1	1.7	5.0
1931	0.0	1.7	0.0	0.1	1.1	2.8
1932	0.0	0.8	0.0	0.0	0.5	1.4
1933	0.0	0.5	0.0	0.0	0.3	0.8
1934	0.0	0.6	0.0	0.0	0.4	1.0
1935	0.0	2.6	0.0	0.0	1.3	3.9
1936	0.0	4.5	0.0	0.1	2.3	6.9
1937	0.0	0.8	0.0	0.0	0.4	1.2
1938	0.0	5.4	0.0	0.2	3.7	9.3
1939	0.0	0.3	0.0	0.0	0.3	0.6
1940	0.0	0.3	0.0	0.0	0.2	0.6
1941	0.0	2.1	0.0	0.0	1.3	3.4
1942	0.1	2.7	0.0	0.1	2.2	5.1
1943	0.4	7.9	0.0	0.3	6.5	14.9
1944	0.2	10.9	0.0	0.3	8.9	20.2
1945	1.8	13.6	0.0	0.3	9.2	25.0
1946	0.9	18.0	0.0	0.4	10.9	30.1
1947	0.4	2.9	0.0	0.1	2.1	5.4
1948	0.7	4.6	0.0	0.1	3.3	8.7
1949	0.9	6.4	0.0	0.2	4.5	11.9
1950	0.9	2.5	0.0	0.1	1.7	5.1
1951	0.9	14.8	0.0	0.3	9.0	25.0
1952	0.8	9.3	0.0	0.2	5.9	16.3
1953	0.7	11.7	0.0	0.3	8.0	20.7
1954	0.9	12.2	0.0	0.3	8.6	22.0
1955	0.9	8.7	0.0	0.3	7.6	17.5
1956	0.6	7.6	0.0	0.3	7.1	15.5
1957	0.8	14.9	0.0	0.6	12.1	28.3
1958	0.9	8.0	0.0	0.4	9.1	18.3
1959	1.2	9.5	0.0	0.5	10.1	21.2
1960	1.1	16.3	0.0	0.6	14.0	32.0
1961	1.3	16.4	0.0	0.7	16.0	34.5

Year	Trawl	Halibut	Sablefish	Dogfish/Lingcod	H&Lrockfish	TOTAL
1962	1.8	25.5	0.0	1.0	22.1	50.4
1963	1.3	28.1	0.0	0.8	20.1	50.3
1964	1.0	11.1	0.0	0.4	10.0	22.5
1965	1.1	11.3	0.0	0.4	9.1	21.9
1966	1.4	11.9	0.0	0.4	10.0	23.7
1967	1.2	18.7	0.0	0.6	14.5	35.0
1968	1.6	10.3	0.0	0.4	9.7	22.0
1969	2.7	22.5	0.0	0.6	16.6	42.4
1970	2.2	45.8	0.0	1.1	29.2	78.2
1971	2.1	33.5	0.0	0.6	18.5	54.6
1972	2.5	44.8	0.0	1.2	30.2	78.7
1973	2.7	30.2	0.0	0.7	17.5	51.1
1974	1.7	51.7	0.0	1.2	28.8	83.4
1975	1.4	61.3	0.0	1.3	34.3	98.3
1976	2.0	40.7	0.0	0.9	23.1	66.8
1977	2.3	57.2	0.0	1.3	32.3	93.1
1978	3.2	65.9	0.0	1.3	34.5	104.9
1979	14.5	85.8	0.0	2.0	48.9	151.2
1980	9.0	80.4	0.0	1.8	44.0	135.2
1981	5.8	60.8	0.0	1.4	32.6	100.6
1982	2.0	27.5	0.0	17.7	0.8	48.0
1983	1.8	18.7	0.0	26.8	4.9	52.3
1984	37.4	31.3	0.0	44.7	35.4	148.9
1985	8.9	72.6	0.0	85.9	69.8	237.2
1986	13.4	147.3	0.0	177.6	396.8	735.1
1987	31.6	235.2	0.0	225.4	455.5	947.7
1988	15.9	220.9	0.0	286.4	324.4	847.5
1989	36.6	402.9	0.0	222.4	298.8	960.7
1990	48.4	424.9	0.0	135.7	1106.4	1715.5
1991	32.2	273.5	0.0	193.7	1011.1	1510.4
1992	38.5	242.1	0.0	103.3	709.1	1093.1
1993	45.3	524.4	0.0	34.3	956.5	1560.6
1994	81.7	278.4	0.0	56.4	591.4	1007.9
1995	45.9	384.3	1.5	109.4	560.0	1101.1
1996	16.5	274.5	1.1	28.2	426.1	746.4
1997	17.5	240.6	1.5	21.1	435.2	715.9
1998	13.5	326.5	2.3	23.8	427.3	793.4
1999	14.1	192.4	2.2	33.7	307.4	549.9
2000	14.2	295.0	1.1	38.9	247.4	596.6
2001	11.3	303.7	1.4	18.7	221.0	556.1
2002	10.4	246.0	1.4	14.3	144.4	416.5
2003	12.0	217.3	1.2	25.9	83.8	340.2
2004	8.6	205.0	1.9	17.5	64.5	297.6
2005	9.2	204.3	3.8	15.5	84.5	317.4
2006	7.1	140.8	0.1	7.9	55.9	211.8
2007	6.4	168.1	1.1	16.9	37.5	230.0
2008	6.6	223.9	0.8	17.0	59.0	307.3

Year	Trawl	Halibut	Sablefish	Dogfish/Lingcod	H&Lrockfish	TOTAL
2009	8.0	174.9	0.4	20.0	50.9	254.3
2010	11.4	159.0	0.5	12.6	61.6	245.1
2011	8.3	170.7	4.1	10.6	70.1	263.8
2012	7.5	191.8	2.1	12.0	68.4	281.9
2013	4.5	174.8	3.5	8.3	65.4	256.5
2014	5.0	151.4	0.7	7.1	72.9	237.0

COMMERCIAL GROUNDFISH FISHERY LANDINGS

The historical data comprise landings statistics for two broad categories of rockfish – Pacific Ocean Perch (POP) and rockfish other than POP which we refer to as Other Rockfish (ORF). Noteworthy foreign fisheries for rockfishes in BC waters, primarily from the United States (US), the Soviet Union and Japan occurred prior to the declaration of the 200 nmi limit in 1977. Challenges arise when reconstructing Yelloweye Rockfish catches from these fisheries and broad landing categories prior to the implementation of the groundfish dockside monitoring program in 1994, at-sea observer program for the Option A trawl fleet in 1996, and the integrated groundfish catch monitoring and at-sea observer program for the non-trawl sectors in 2006.

Commercial landings for Outside Yelloweye Rockfish are estimated from aggregated species landing statistics from a variety of sources over time.

There are three major eras in the gathering of catch data: historic 1918 – 1950, early electronic (compiled from various sources) 1951 – 2005, and modern from 2006 onwards. ORF landings were compiled from historic and early electronic data up until credible reported landings of Yelloweye Rockfish by fishery sector became available. Conversion of ORF landings toYelloweye Rockfish landings by fishery sector and PMFC major area is calculated using ratios of Yelloweye Rockfish to ORF (see below) from credible landings data (1997-2005). The transition to using reported (not calculated) Yelloweye Rockfish catches varies by fishery sector based on when verified landings by species could be established. All reported catches from 2006 onwards are used.

The ORF landings are converted to Yelloweye Rockfish landings using fishery- and area-specific ratios of Yelloweye Rockfish to ORF called gamma (γ_{jk}, where area $j = 3,\ldots,9$ and fishery $k = 1,\ldots,5$). For each fishery and PMFC area, landings records were stratified by reference year ($i = 1997,\ldots,2005$) and 100-m depth interval. Within each depth stratum, records that contained a non-zero ORF landing were used to calculate a ratio of total Yelloweye Rockfish to total ORF and then weighted by the number of observations within each year-depth stratum to derive a stratified-weighted gamma for each fishery-area combination. Within any given year, area, and fishery, at least 10% of the records had to contain a non-zero depth value to be stratified by depth. Otherwise, the year-area-fishery stratum was assumed to contain one depth zone. During the May 14th workshop, only records with a non-zero Yelloweye Rockfish catch were used in the depth-stratified gamma calculation and industry pointed out that this would likely bias the estimation of Yelloweye Rockfish landings. Therefore, this assessment uses all records that contain a non-zero ORF landing. The gamma ratios calculated for the assessment appear in Table A 2.

Table A 2. Ratios gamma (γ_{jk}) that show the depth-stratified and weighted calculation of Yelloweye Rockfish landed to "Other Rockfish" (ORF) landed by PMFC area (j) and fishery (k).

Fishery → PMFC ↓	**Trawl**	**Halibut**	**Sablefish**	**Dogfish+ Lingcod**	**H&L Rockfish**
3C, *j*=3	0.00035	0.81925	0	0.23130	0.18220
3D, *j*=4	0.00022	0.73106	0	0.45066	0.33300
5A, *j*=5	0.00022	0.77184	0	0.70559	0.21536
5B, *j*=6	0.00072	0.69926	0	0.63202	0.33552
5C, *j*=7	0.00100	0.83568	0	0.64554	0.46662
5D, *j*=8	0.00020	0.64871	0	0.42211	0.30451
5E, *j*=9	0.00002	0.49593	0	0.46367	0.19250

Industry also requested a few tweaks to the base case reconstruction (not presented here):

fix gamma for the halibut fishery by area (5A=0.25, 5B=0.25, 5C=0.375, 5D=0.3), and

set the 1999 halibut fishery catch of Yelloweye Rockfish to be 17.5% less than that for the 1998 catch.

These changes affected the base catch reconstruction minimally but are included as the sensitivity test series A.

Historic (1918 – 1950)

Canadian Dominion Bureau of Statistics (reported ORF landings by domestic vessels (does not include foreign/US catches in Canadian waters)). Yelloweye Rockfish landings were calculated from ORF using gamma (γ_{jk}).

Catch prior to World War II (1918 – 1938) was fixed to be 90% hook and line and 10% trawl landings.

During and Post-WWII catch, gear distribution is calculated from sale-slip landings in 1951 and 1952, by PMFC area (~49% h&l, ~51% trawl).

Landed ORF catch fished in BC are gathered; where years overlap, the higher catch is adopted.

Stewart (2009) US landings 1930 – 1964

GFCatch table [B3_Catch_Pre54] 1945 – 1953

Ketchen (1976) Canada + US landings 1950 – 1975

Obradovich (2000) PacHarvHL [B22_Historic_Area_Catch] 1951 – 1981

GFCatch logbook and landings trawl and trap only 1954 – 1995

PacHarv3 sale-slip landings 1982 – 1995

The following foreign landed ORF catch fished in BC is not used. Discussion with industry at the May 14th workshop revealed that these catches were likely POP with no Yelloweye Rockfish bycatch.

Ketchen (1980a) estimated Japan catch (1965-1977)

Ketchen (1980b) Soviet Union and Japan catches (1965-1976)

Partial Early Electronic (1951 – 2005)

Yelloweye catch by fishery sector is compiled using a combination of these seven databases:

PacHarv3 sales slips (from 1982 to 1995) – hook and line only

GFCatch – trawl and trap

PacHarvest observer trawl – trawl

PacHarvHL merged data table – halibut, Dogfish+Lingcod, H&L rockfish

PacHarvSable fisherlogs – Sablefish

GFFOS groundfish subset from Fishery Operation System – all fisheries

GFBio joint-venture hake and research survey catches – multiple gear types

Starting in 2015, all official catch tables from databases above (except PacHarv3) have been merged into one catch table called “GF_MERGED_CATCH”, which is available in DFO’s GFFOS database.

Complete Modern (2006 – present)

All reported landings and releases are available on DFO’s Groundfish Fisheries Operations System (GFFOS) after 2006 (hook and line) and 2007 (trawl).

Through the Fisheries Operations System (FOS), which theoretically tracks all official catch of marine fish on the BC coast, groundfish catch records are extracted into the GFFOS database. Within GFFOS, an ‘official’ merged catch table (see above) resolves catches from dockside monitoring and observer logs or logbooks, whichever records are available. The total catch (landed and released) of Yelloweye Rockfish by the hook and line fleet is reported through the integration of dockside monitoring and logbook reporting with a sub-set of electronic monitoring (EM) verification records. Estimates of the total catch of Yelloweye Rockfish from the mandatory EM systems (partial coverage) on the groundfish hook and line fleet, which takes the majority of the catch, are shown to be unbiased and accurate (Stanley et al. 2009).

COMMERCIAL GROUNDFISH FISHERY RELEASES

At-sea releases from the commercial fisheries are estimated from ratios based on DFO observer data and applied to landings in earlier years. The releases are considered negligible up until the institution of species-specific licensing regimes for groundfish and calculated up to 2005, a year prior to the Pilot Groundfish License Integration in 2006. With single-species licensing, incentives to discard fish increased, either from regulatory non-retention and/or high-grading practices, and peaked between 1995 and 2005.

At-sea observer data were used to derive release ratios (delta, δ_{jk}, by PMFC area j = 3,…,9 and fishery k = 1,…,5). For each fishery and PMFC area, observer records were stratified by reference year (i = 1997,…,2006 for trawl and i = 2000,…,2004 for non-trawl) and 100-m depth interval. Within each depth stratum, records that contained a non-zero target catch (TAR) landing were used to calculate a ratio of total Yelloweye Rockfish released to total TAR landed and then weighted by the number of observations within each year-depth stratum to derive a stratified-weighted delta for each fishery-area combination. Within any given year, area, and fishery, at least 10% of the records had to contain a non-zero depth value to be stratified by depth. Otherwise, the year-area-fishery stratum was assumed to contain one depth zone. During the May 14th workshop, only records with a non-zero Yelloweye Rockfish released were used in the depth-stratified delta calculation and industry pointed out that this would likely bias the estimation of Yelloweye Rockfish releases. Therefore, this assessment uses all records that contain a non-zero TAR landing. Also on the advice of industry, no calculated releases of Yelloweye Rockfish are used for the trawl fishery. For the non-trawl fisheries, calculated releases were used only for the years 1986-2005. The TAR landings by fishery used to calculate delta were: H&L rockfish (ZN license) = Yelloweye Rockfish landed, Halibut (L license) = Pacific Halibut, Sablefish (K license) = Sablefish, and Dogfish/Lingcod

(Schedule II, C license) = Spiny Dogfish + Lingcod. The delta ratios calculated for the assessment appear in Table A 3.

Table A 3. Ratios delta (δ_{jk}) that show the depth-stratified and weighted calculation of Yelloweye Rockfish released to TAR landed by PMFC area (j) and fishery (k).

Fishery → PMFC ↓	**Trawl**	**Halibut**	**Sablefish**	**Dogfish+ Lingcod**	**H&L Rockfish**
3C, j=3	0.03273	0.00018	0.00114	0.00260	0.01035
3D, j=4	0.06458	0.00737	0.00075	0.00185	0.01489
5A, j=5	0.07444	0.01112	0.00100	0.00829	0.00100
5B, j=6	0.17236	0.00709	0	0.01993	0.00369
5C, j=7	0.03493	0.00824	0	0.00897	0.00559
5D, j=8	0.18603	0.00305	0	0.01146	0.07540
5E, j=9	0.02517	0.01868	2.1E-06	0.03207	0

Groundfish Trawl fishery (T license) 1954 – 2005

No calculated release ratios (YE released to Yelloweye Rockfish landed, delta: $\delta_{j=3,\ldots,9\ k=1}$) were used for the trawl fishery on the advice of industry.

Pacific Halibut (*Hippoglossus stenolepis*) fishery (L license) 1986 – 2005

The Pacific Halibut (L license) fishery release ratios were determined from the Yelloweye Rockfish released per Pacific Halibut landed from observer log records from 2000 to 2004 by PMFC Major Area (stratified and weighted as above). The release ratios (delta: $\delta_{j=3,\ldots,9\ k=2}$) were then applied to the Pacific Halibut landings from 1986 to 2005.

Sablefish (*Anoplopoma fimbria*) fishery (K license) 1986 – 2005

Observer log records from 2000 to 2004 were used to determine the release ratios of Yelloweye Rockfish released per Sablefish landed by PMFC Major Area (stratified and weighted as above). The release ratios (delta: $\delta_{j=3,\ldots,9\ k=3}$) were applied to the Sablefish landed for the years 1986 to 2005.

Spiny Dogfish (*Squalus suckleyi*) and Lingcod (*Ophiodon elongatus*) fishery (C license - Schedule II) 1986 – 2005

Observer log records from 2000-2004 are used to determine the release ratios (delta: $\delta_{j=3,\ldots,9\ k=4}$) of Yelloweye Rockfish released to Spiny Dogfish + Lingcod landed in the fishery. Releases for Yelloweye Rockfish are estimated for this fishery from 1986, when the hook and line rockfish fishery became licensed (ZN), up until 2005. We assume that with the introduction of the ZN licence to fish for rockfish by hook and line gear, the regulation of 100% non-retention of rockfish in the Schedule II (Dogfish and Lingcod) fishery was instituted. Prior to 1986, it is assumed that the rockfish were retained and landed in this fishery.

Hook and line rockfish (Genus *Sebastes*) fishery (ZN license) 1986 – 2005

The release ratio (delta: $\delta_{j=3,\ldots,9\ k=5}$) of Yelloweye Rockfish released to Yelloweye Rockfish landed is determined from observer records from 2000-2004 by PMFC major area (stratified and weighted as above). Releases are estimated for the ZN fishery from 1986, the year that the directed ZN fishery license was instituted, up until 2005. In 2006 the groundfish license integration was initiated and the total catch (landed and released) of all species is accounted for. The outside ZN fishery became license limited in 1992 but this change was unlikely to change the release rate.

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ILLEGAL, UNREPORTED, AND UNREGULATED (IUU) CATCHES

On the advice of industry, there are no adjustments made to reconstructed commercial catches to account for illegal, unreported, and unregulated catch. There are no IUU groundfish fisheries in BC.

COMMERCIAL SALMON TROLL FISHERY LANDINGS

Yelloweye Rockfish catch and effort for the Outside Salmon Troll fishery has been estimated by DFO fishery managers and shown in Table A 4. Post-season amalgamated data from DFO fishery managers obtained from Bruce Patten (Feb 2015). Outside Salmon Troll Fishery effort was obtained from the DFO Catch Stats Unit (J. Davidson Mar 2015) for the year 1982 to 2000 and from DFO Commercial Catch Stats Blue Book for years 1952-1981.

Table A 1. Yelloweye Rockfish catch (tonnes) and effort (troll days) in the commercial Outside Salmon Troll Fishery. Weights converted from numbers of fish using 3.192 kg per fish.

Year	Outside Effort (Boat Days)	Yelloweye Rockfish (Tonnes)	Year	Outside Effort (Boat Days)	Yelloweye Rockfish (Tonnes)	Year	Outside Effort (Boat Days)	Yelloweye Rockfish (Tonnes)
1952	129472	-	1973	104406	-	1994	56996	-
1953	120397	-	1974	99214	-	1995	42262	-
1954	108909	-	1975	95976	-	1996	26202	-
1955	112970	-	1976	102631	-	1997	14587	-
1956	107140	-	1977	114642	-	1998	7653	-
1957	123266	-	1978	115619	-	1999	5157	-
1958	132849	-	1979	128651	-	2000	3707	-
1959	130126	-	1980	160132	-	2001	4223	0.0
1960	132101	-	1981	140076	-	2002	9025	0.8
1961	148342	-	1982	136760	-	2003	8539	0.5
1962	133413	-	1983	139801	-	2004	8815	0.6
1963	84250	-	1984	118349	-	2005	10478	0.7
1964	100938	-	1985	104412	-	2006	10263	0.3
1965	106827	-	1986	92428	-	2007	8032	0.6
1966	107855	-	1987	74523	-	2008	7593	0.2
1967	108817	-	1988	76812	-	2009	7895	0.3
1968	121669	-	1989	65185	-	2010	7024	0.9
1969	110625	-	1990	79201	-	2011	7459	0.8
1970	114087	-	1991	80541	-	2012	7074	0.5
1971	116948	-	1992	75514	-	2013	6406	0.3
1972	109606	-	1993	59991	-	2014	8067	0.8

The salmon troll effort was extended to 1918 from Stanley et al. (2012) by taking the average ratio of the above records to those in Stanley et al. (2012) for 1952-1961 and applying the average ratio to the troll effort records from 1918-1951 in Stanley et al. (2012) (Table A5). Yelloweye Rockfish catches were imputed using the analytical approach documented for imputing catches from effort in Yamanaka et al (2012) and Stanley et al. (2012). The model predicted the catch biomass in the troll fishery in each year given the stock biomass, the salmon troll fishery effort, and an estimated catchability coefficient for the troll fishery. The catch coefficient was estimated using a likelihood function of the average troll bycatch for years 2001-

2014. The probability density of the data point was computed using the model predicted value for the average troll catch as follows:

$$\overline{C}_T \sim Normal\left(\hat{\overline{C}}_T, \left(CV_T \times \hat{\overline{C}}_T\right)^2\right)$$

where $\overline{C}_T$ is the average recorded troll catch of Yelloweye Rockfish for years 2001-2014 and $\overline{C}_T$ is the average model-predicted troll catch of Yelloweye Rockfish for years 2001-2014. This is predicted in the same way that the recreational catch was predicted (i.e., by assuming that the fishing mortality rate from trolling is directly proportional to the annual troll fishing effort):

$$\hat{C}_{T,y} = B_y\left(1-\exp\left(-c_T E_{T,y}\right)\right)$$

where B_y is the model predicted biomass in year *y*, C_T is the salmon troll catchability coefficient, and $E_{T,y}$, is the recreational fishing effort in 2010. This estimation and imputation was done within the BSP modeling software so that c was estimated simultaneously with all of the other BSP model parameters.

Table A5. Commercial salmon trolling effort in boat fishing days from 1918 to 1951.

Year	Effort	Year	Effort	Year	Effort
1918	75130	1930	75130	1942	95680
1919	75130	1931	75130	1943	128600
1920	75130	1932	75130	1944	39540
1921	75130	1933	75130	1945	89900
1922	75130	1934	75130	1946	70370
1923	75130	1935	75130	1947	117740
1924	75130	1936	75130	1948	83880
1925	75130	1937	75130	1949	119840
1926	75130	1938	75130	1950	129250
1927	75130	1939	69800	1951	141800
1928	75130	1940	68260	-	-
1929	75130	1941	98120	-	-

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COMMERCIAL INVERTEBRATE FISHERY LANDINGS

Catch monitoring is present in the commercial shrimp trawl, Spot Prawn (*Pandalus platyceros*) trap and Dungeness Crab (*Cancer magister*) trap fisheries (see below for details). The catch of Yelloweye Rockfish in these commercial fisheries is a rare and random event, which makes it impossible to accurately assess the overall catch. Recreational invertebrate fisheries are monitored through the iRec program, which emails recreational licence holders with recall surveys on their activities, including catch. Catches of Yelloweye Rockfish are assumed to be insignificant and not specifically used in the assessment but these catches could be considered generally in the model sensitivity test which increases catch (A.5).

Commercial shrimp (Family Pandalidae) trawl fishery

A bycatch monitoring program (BMP) has provided at-sea catch composition observations on the shrimp trawl fishery in BC since 2002 (Olsen et al. 2000). Coastwide observer coverage, ranged from a low of 0.5% and 0.3% to a high of 2.6% and 3.4% for beam and otter trawl types, respectively, between 2002 and 2011 (Rutherford et al. 2013). Yelloweye Rockfish have not yet been observed by the BMP in the Outside areas of BC for the shrimp trawl fisheries, and few Yelloweye Rockfish were observed in the beam trawl fishery in the Inside areas. Total commercial shrimp beam trawl effort has decreased coastwide from a high in 2002 of 31,989 hours to a low in 2011 of 12,717 hours. Trawl effort has continued to decrease from 2011 through to 2014 (K. Fong, DFO, pers. comm. Feb 19 2015). The declining trend in effort combined with low observer coverage in the fisheries, provided insufficient data to estimate the overall Yelloweye Rockfish catch in the Outside shrimp trawl fisheries, but it is expected to be low and has not been included as catch in the assessment.

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Rutherford, D.T., Barton, L.L., Clark, D.G., and Fong, K. 2013. Catch composition data from the British Columbia commercial shrimp trawl bycatch monitoring program, 2002-2011. Can. Data Rep. Fish. Aquat. Sci. 1246: iii + 114 p.

Commercial Spot Prawn (*Pandalus platyceros*) trap fishery

A third-party monitoring program for in-season management of the ‘spawner index’ collects rockfish catch data in the Spot Prawn trap fishery. From 2002 to 2008, the commercial season averaged 62 days with an estimated peak coastwide rockfish catch estimated at 22,792 rockfish (all species, upper 95% CI). An estimated 5% (*n*=112) of these rockfish were Yelloweye that averaged 0.25 kg in weight and approximately 1 year of age (Rutherford et al. 2010). Of this 5% coastwide catch, just under 20% (*n*=21) Yelloweye Rockfish were from the Outside areas. From 2002 to 2014, a total number of 77 Yelloweye Rockfish have been observed in this program for the Outside areas (K. Fong, unpublished data). This Yelloweye Rockfish catch in the commercial Spot Prawn fishery is extremely low and not possible to assess; however, a simple extrapolation yields an average of 0.06 t in total between 2002 and 2008 in the Outside areas. This small amount is not included as catch in the assessment.

References

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Commercial Dungeness Crab (*Cancer magister*) trap fishery

Fishery-independent research monitoring of crab traps was undertaken between 2001 and 2011 (L. Barton, DFO Shellfish, unpublished data 25 March 2015). The 2004 survey in Statistical Area 9 recorded 3 Yelloweye Rockfish caught in 3365 traps set and sampled. The average weight of these fish was 1.35 kg. Information is insufficient to properly assess the catch of Yelloweye Rockfish in the BC crab trap fishery. The above data do show that the catch of Yelloweye Rockfish is a rare occurrence and likely contributes insignificantly to the overall BC catch of Yelloweye Rockfish; therefore, this component is not included as catch in the assessment.

RECREATIONAL FISHERY CATCH

Recreational catches in BC are monitored by creel surveys and lodge/guide logbook programs for some PFMAs (Lewis 2004, Van Tongeren and Winther 2010, K. Hein, DFO, unpublished data, K. Wong, DFO, unpublished data) and through the iRec email survey of recreational licence holders coastwide (DFO 2015). The longest times series of recreational catch for rockfish, recorded by species (kept and released) are for the Outside fishing areas West Coast of Vancouver Island (WCVI) through creel surveys (Lewis 2004, K. Hein unpublished data) and the Central Coast (CC) through lodge/guide logbooks (K. Wong unpublished data) (Table A 6). The iRec survey is relatively new, launched in 2012, and recent results are not yet published (DFO 2015).

Table A 6. DFO West Coast Vancouver Island Creel Survey Areas 21, 23, 24, 25, 27, 121, 123, 124, 125, 127 (1984 to 1999 from Lewis 2004, 2001 to 2014 summarized from Kris Hein data files, May 2015). Fish in numbers are converted to weight using 3.192 kg/fish.

Year	Effort (boat days)	YE Catch (number of fish)	YE Catch (tonnes)
1984	62311	-	-
1985	57966	-	-
1986	32555	-	-
1987	59958	-	-
1988	44822	-	-
1989	69241	-	-
1990	75804	-	-
1991	87779	-	-
1992	115076	-	-
1993	84591	-	-
1994	102845	-	-
1995	72676	-	-
1996	29297	-	-
1997	71022	-	-
1998	81864	-	-
1999	83478	-	-
2000	56044	1744	5.6
2001	59874	4464	14.2
2002	73219	1456	4.6
2003	82365	1777	5.7
2004	79302	1315	4.2
2005	78027	2666	8.5
2006	76377	3519	11.2
2007	61878	6497	20.7
2008	63600	9384	30
2009	68528	6880	22
2010	63286	7245	23.1
2011	69084	10892	34.8
2012	60730	10068	32.1
2013	49079	4956	15.8
2014	57211	4249	13.6

Table A 7. DFO Central Coast Lodge/Guide logbook program in Areas 7, 8 and 9 (summarized from Kristen Wong's data files, May 2015). Fish in numbers are converted to weight using 3.192 kg/fish.

Year	Effort (angler days)	YE Catch (number of fish)	YE Catch (tonnes)
2002	27249	1079	3.4
2003	29260	1079	3.4
2004	33693	1356	4.3
2005	33114	1379	4.4
2006	35490	1719	5.5
2007	33211	2548	8.1
2008	26776	1950	6.2
2009	19902	1134	3.6
2010	19172	889	2.8
2011	18889	941	3.0
2012	16889	1272	4.1
2013	17682	1344	4.3
2014	19551	1255	4.0

Reviewing the iRec catch records for Yelloweye Rockfish in 2012 to 2014 (unpublished, confidential data from R. Houtman, DFO, March 2015) reveals that the estimated iRec catch (retained and released by boat angling) from the WCVI and CC areas from 2012 to 2014 are, on average, 56% of the total iRec Outside area catch estimate. To estimate the total recreational catch of Yelloweye Rockfish for the entire Outside Area for use in the assessment, the catch from the WCVI creel and CC lodge/guide logbook surveys (2002 - 2014) were combined and then expanded (2X), based on the estimated proportion of the these two areas to the total Outside catch in the iRec survey.

Comparing the catch numbers in 2012, WCVI creel and CC lodge/guide comprised 99.7% of that reported through iRec for the same PFMAs. In later years, WCVI creel and CC lodge/guide numbers fall dramatically to 26%, in comparison to iRec for 2014, and may reflect a decline in survey effort for the WCVI creel survey (R. Houtman, pers comm). In the future, iRec figures should be blended with the creel and logbook programs and used for stock assessment.

Effort in the recreational fishery for the WCVI was used to impute Yelloweye Rockfish catches back to 1918 in a similar way to Yamanaka et al. (2012) and Stanley et al. (2012) (Table A 8). Catches from the WCVI creel survey (2000-2014) and the CC lodge/guide survey (2002-2014) are used to estimate a catchability coefficient. Effort data for the WCVI creel survey from 1984 to 2000 from Lewis (2004) and further extended back to 1918 using methods developed by Yamanaka et al. 2012 and used by Stanley et al. (2012). Only the estimated coast-wide catch records from 2007-2014 were used to estimate the catchability coefficient for recreational catch imputation. The nominal recreational catch per unit effort given by the catch and effort records was much lower (i.e., twice to six times lower) for 2000-2006 than for 2007-2014. In contrast, apart from a gradual decline, all of the abundance indices show no marked change in abundance 2002-2014. It is speculated that the low recreational catch records 2002-2006 were due to underestimates of Yelloweye Rockfish recreational catch in the creel survey in this period due to a change in the creel sampling protocol from recording rockfish without mention of species to recording rockfish by species starting in 2001. There was a delay or learning curve, of at least a few years in the effective implementation of this change in protocol. Therefore only the catch records from 2007-2014 were applied to estimate the catchability coefficient for the recreational fishery for recreational catch imputation for the full time series 1918-2014.

Table A 8. Yelloweye Rockfish (YE) recreational effort for the entire outer coast, catch biomass records for west coast Vancouver Island (WCVI) and the central coast (CC) and imputed catch biomass for the entire outer coast. The recreational effort was extended from that in Stanley et al. (2012) and extended with creel survey based estimates of effort from 2002 onwards.

Year	Total Outside YE recreational angling effort	WCVI recreational catch biomass	CC recreational catch biomass	Imputed recreational catch biomass for Outside YE
1918	0.241	-	-	-
1919	0.241	-	-	-
1920	0.241	-	-	-
1921	0.241	-	-	-
1922	0.241	-	-	-
1923	0.241	-	-	-
1924	0.241	-	-	-
1925	0.241	-	-	-
1926	0.241	-	-	-
1927	0.241	-	-	-
1928	0.241	-	-	-
1929	0.241	-	-	-
1930	0.241	-	-	-
1931	0.241	-	-	-
1932	0.241	-	-	-
1933	0.241	-	-	-
1934	0.241	-	-	-
1935	0.241	-	-	-
1936	0.241	-	-	-
1937	0.241	-	-	-
1938	0.241	-	-	-
1939	0.241	-	-	-
1940	0.241	-	-	-
1941	0.241	-	-	-
1942	0.241	-	-	-
1943	0.241	-	-	-
1944	0.241	-	-	-
1945	0.241	-	-	-
1946	0.283	-	-	-
1947	0.567	-	-	-
1948	0.836	-	-	-
1949	1.12	-	-	-
1950	1.403	-	-	-
1951	1.686	-	-	-
1952	1.956	-	-	-
1953	2.239	-	-	-
1954	2.523	-	-	-
1955	2.806	-	-	-
1956	3.075	-	-	-
1957	3.359	-	-	-
1958	3.642	-	-	-
1959	3.926	-	-	-
1960	4.195	-	-	-
1961	4.719	-	-	-
1962	4.719	-	-	-
1963	4.719	-	-	-
1964	4.719	-	-	-
1965	4.719	-	-	-
1966	4.719	-	-	-
1967	4.719	-	-	-
1968	4.719	-	-	-
1969	4.719	-	-	-
1970	4.96	-	-	-
1971	5.215	-	-	-

Year	Total Outside YE recreational angling effort	WCVI recreational catch biomass	CC recreational catch biomass	Imputed recreational catch biomass for Outside YE
1972	5.456	-	-	-
1973	5.711	-	-	-
1974	5.952	-	-	-
1975	6.207	-	-	-
1976	6.448	-	-	-
1977	6.703	-	-	-
1978	6.944	-	-	-
1979	7.199	-	-	-
1980	7.44	-	-	-
1981	7.681	-	-	-
1982	7.922	-	-	-
1983	8.163	-	-	-
1984	8.463	-	-	-
1985	7.872	-	-	-
1986	4.421	-	-	-
1987	8.143	-	-	-
1988	6.087	-	-	-
1989	9.404	-	-	-
1990	10.295	-	-	-
1991	11.921	-	-	-
1992	15.629	-	-	-
1993	11.488	-	-	-
1994	13.967	-	-	-
1995	9.87	-	-	-
1996	3.979	-	-	-
1997	9.646	-	-	-
1998	11.118	-	-	-
1999	11.337	-	-	-
2000	7.611	5.6	-	-
2001	8.132	14.2	-	-
2002	10.047	4.6	3.4	16.1
2003	11.163	5.7	3.4	18.3
2004	11.3	4.2	4.3	17.1
2005	11.114	8.5	4.4	25.8
2006	11.187	11.2	5.5	33.4
2007	9.509	20.7	8.1	57.7
2008	9.038	30	6.2	72.4
2009	8.843	22	3.6	51.2
2010	8.246	23.1	2.8	51.9
2011	8.797	34.8	3.0	75.6
2012	7.762	32.1	4.1	72.3
2013	6.676	15.8	4.3	40.2
2014	7.676	13.6	4.0	35.2

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Recreational invertebrate fisheries

The overall catch of Yelloweye Rockfish in the recreational Spot Prawn and Dungeness Crab trap fisheries is unknown but assumed to be low even though the gear configuration may differ slightly, given the observed catches in the commercial fishery. These catches are assumed to be insignificant and not specifically included as catch in the assessment.

ABORIGINAL FOOD, SOCIAL AND CEREMONIAL (FSC) FISHERY CATCH

One method used to estimate the FSC catch of Outside Yelloweye Rockfish was derived by applying Aboriginal consumption rates to estimates of the BC Outside Coastal Aboriginal population. A similar technique was used to estimate the FSC Inside Yelloweye Rockfish catch (Yamanaka et al. 2011).

Population estimates from the BC Native Indian (1986 and 1991) and Aboriginal (1996 and onward) population in British Columbia are derived from the Canada Census (data obtained from the BC Statistics Website). Based on the 2006 Census, 40% of the Aboriginal population in BC lived in rural areas. Selecting from rural areas in the census, an estimated 21% of the Aboriginal people live adjacent to the Outside Yelloweye Rockfish population (Table A 9).

Table A 9. Estimate of total Aboriginal population size living adjacent to Outside areas.

Year	Total BC Aboriginal Population	Rural BC Aboriginal Population (40% of Total)	Outside Coastal BC Aboriginal Population (21% of Rural)
1986	61,130	24,452	5,135
1991	169,040	67,616	14,199
1996	139,655	55,862	11,731
2001	170,020	68,008	14,282
2006	196,075	78,430	16,470

Data from Aboriginal Affairs and Northern Development Canada (AANDC) for 2013 show a total of 27 “Outside” Native Bands in BC. Using an average band size from the 15 Westcoast Vancouver Island bands (768.4 people), we apply this average to the number of Outside Native Bands for an estimate of 20,747 people in 2013 (Table A 10).

Yelloweye Rockfish consumption rates estimated from Aboriginal groups in Alaska are 0.45 kg per person per year (State of Alaska 2007). Estimates of Maa-nulth consumption rates based on population estimates and FSC landings of Yelloweye Rockfish are higher at 0.82 kg per person per year (P. Preston and P. Perebloom, DFO, pers. comm. March 2015).

This consumption estimate of FSC catch was compared with “Dual Fishing” (see next section) and was not used in the assessment.

Table A 10. Aboriginal population, by census year, in BC, rural BC, Outside Coastal areas and consumption (in tonnes) of Outside Yelloweye Rockfish based on Alaskan and BC (Maa-nulth) consumption rates.

Year	Total BC Aboriginal Population	Rural BC Aboriginal Population	Outside Coastal BC Aboriginal Population	Outside Coastal BC Aboriginal consumption (Alaska) of Yelloweye Rockfish in Tonnes	Outside Coastal BC Aboriginal consumption (Maa-nulth) of Yelloweye Rockfish in Tonnes
1986	61,130	24,452	5,135	2.3	4.2
1991	169,040	67,616	14,199	6.4	11.6
1996	139,655	55,862	11,731	5.3	9.6
2001	170,020	68,008	14,282	6.4	11.7
2006	196,075	78,430	16,470	7.4	13.5
2013			20,747	9.3	17.0

References

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Yamanaka, K. L., McAllister, M. K., Olesiuk, P. F., Etienne, M.-P., Obradovich, S. and Haigh, R. 2011. Stock assessment for the inside population of Yelloweye Rockfish (*Sebastes ruberrimus*) in British Columbia, Canada for 2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/129. xiv + 131 p.

Dual Fishing from DFO Fishery Operating System (FOS)

Yelloweye Rockfish FSC landings are recorded from DFO's FOS database for "Dual Fishing events". Dual fishing occurs when commercial and FSC landings are combined in the same trip. The FSC landings of Yelloweye Rockfish were matched to fisher logbook Trip_IDs to determine catches from the Outside areas by N. Olsen (DFO, March 2015)

Table A 11). FSC landings that are not combined with a commercial fishing trip, are not recorded in FOS and hence not easily estimated. This is a data gap when estimating FSC catches in this way.

The FOS dual fishing events in 2007 are similar to estimates based on Maa-nulth consumption rates in 2006 (Table A 10 and Table A 11). Hence, in order not to double count this catch we did not use the Aboriginal consumption estimates and only use the dual fishing landings from FOS to represent FSC catches for years 2007 to 2014.

Table A 11. Dual fishing landings, in tonnes, of Yelloweye Rockfish from the Fishery Operating System with Trip_ID matched to the Outside Areas.

Year	Number of fish	Tonnes
2007	5,575	17.0
2008	7,167	23.7
2009	3,950	12.4
2010	4,242	13.2
2011	3,022	9.1
2012	5,614	16.7
2013	5,887	18.9
2014	3,619	11.9

TOTAL CATCH OF YELLOWEYE ROCKFISH

The commercial catches from the groundfish fisheries (which include Aboriginal catches) from the reconstruction, and the salmon troll fishery imputed catches, combined with the recreational fishery imputed catches, are shown in (Figure A 4 and Table A 12). This total catch series was used for the stock assessment reference case.

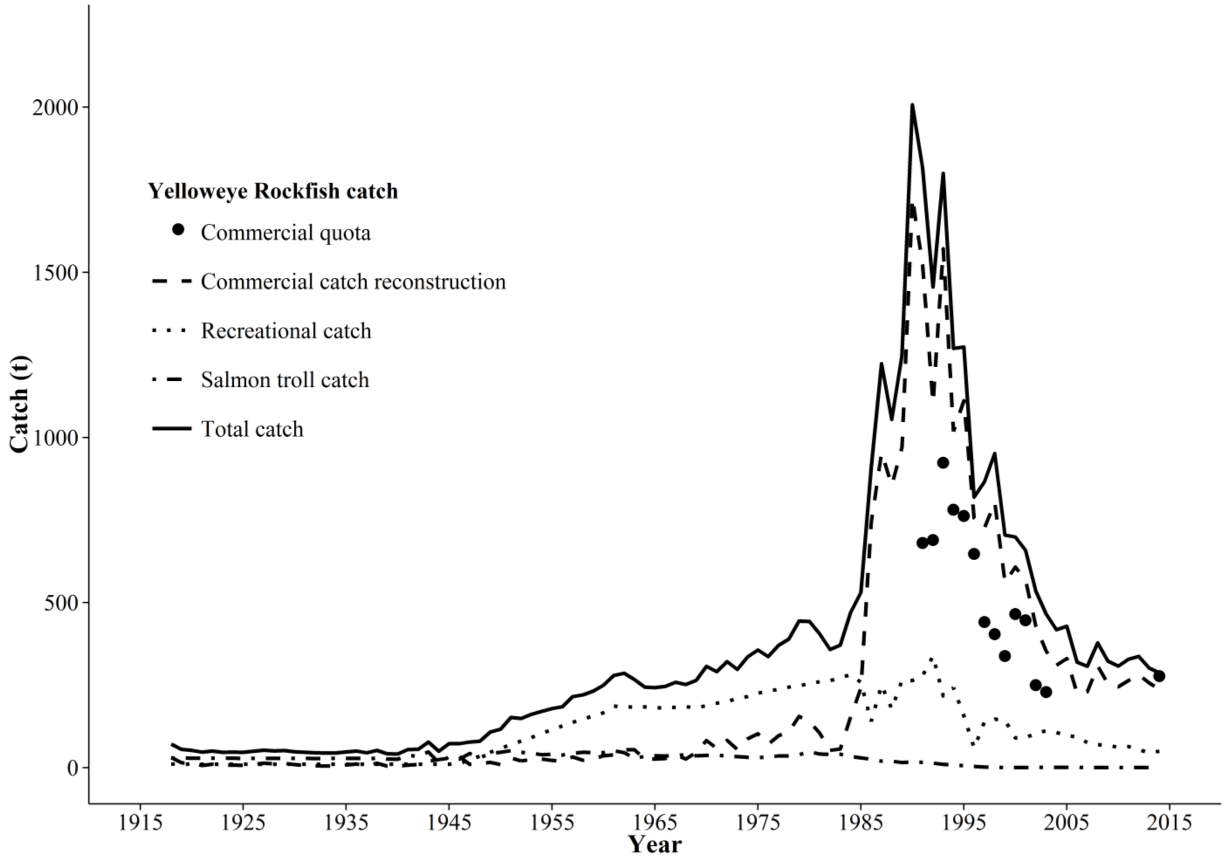

Figure A 4. Total catch of Outside Yelloweye Rockfish (red line) from 1918 to 2014 including reconstructed commercial groundfish catch (including Aboriginal catch), commercial salmon troll catch (pink line), recreational catch (black line), and overall quotas by year from 1991 to 2014 (black dots).

Table A 12. Total Outside Yelloweye Rockfish (YE) catch, by year, in tonnes (medians and 90% CI), from fixed commercial reconstructed catches for groundfish (including Aboriginal fisheries), and imputed catches for commercial salmon troll and recreational fisheries.

Year	Reconstructed commercial groundfish catch	Salmon troll imputed catch medians and 90% CI			Recreational imputed catch medians and 90% CI			TOTAL Outside YE CATCH (t) medians and 90% CI		
1918	31.0	17.7	29.2	52.4	4.8	10.9	24.5	55.0	71.3	105.3
1919	15.1	17.5	29.1	52.4	4.9	10.6	24.6	39.1	55.5	88.4
1920	12.4	17.3	28.8	51.8	4.8	10.7	24.2	36.5	52.7	85.1
1921	7.0	17.5	28.8	52.2	4.8	10.6	23.9	30.9	47.0	77.9
1922	10.3	17.5	28.6	50.1	4.8	10.6	24.2	34.4	50.1	80.9
1923	7.1	17.4	28.7	50.0	4.8	10.7	24.2	31.1	46.9	77.4
1924	7.6	17.6	28.5	50.3	4.9	10.7	24.1	31.6	47.4	77.5
1925	7.1	17.5	28.3	50.1	4.9	10.6	23.7	30.6	46.8	77.7
1926	10.3	17.3	28.2	49.8	4.8	10.5	23.3	33.7	50.0	80.4
1927	13.5	17.3	28.1	49.8	4.7	10.6	23.1	37.2	52.7	82.8
1928	11.7	17.1	28.1	49.6	4.7	10.5	23.2	35.3	51.0	81.2
1929	12.9	17.4	28.4	49.5	4.7	10.4	23.3	36.5	52.1	83.6
1930	9.2	17.7	28.1	49.7	4.8	10.3	23.6	33.1	48.3	79.8
1931	7.0	17.9	28.0	49.6	4.8	10.3	23.2	31.2	46.5	76.2
1932	5.6	17.8	27.9	49.4	4.8	10.3	22.9	29.9	45.1	73.9
1933	5.0	17.7	28.2	49.3	4.8	10.5	23.4	29.1	44.5	73.3
1934	5.2	17.9	28.1	48.7	4.9	10.4	23.0	29.4	44.6	73.5
1935	8.1	17.6	28.1	48.6	4.7	10.4	22.9	31.9	47.7	76.3
1936	11.1	17.6	28.2	48.5	4.8	10.4	22.9	34.6	50.6	79.1
1937	5.4	17.7	28.0	48.1	4.7	10.3	22.5	28.8	45.0	72.6
1938	13.5	17.7	28.1	48.0	4.7	10.3	22.1	36.7	52.6	80.9
1939	4.8	16.6	26.1	44.5	4.7	10.3	22.4	27.3	41.8	68.3
1940	4.8	16.3	25.4	43.3	4.7	10.3	22.7	27.1	41.3	68.0
1941	7.7	22.9	36.4	62.4	4.7	10.2	22.5	36.8	55.2	89.1
1942	9.3	22.6	35.8	60.1	4.7	10.3	22.3	38.1	55.8	89.3
1943	19.1	30.1	47.4	80.2	4.7	10.3	22.5	55.8	77.8	119.5
1944	24.4	9.3	14.5	24.9	4.7	10.3	22.8	39.5	49.7	69.3
1945	29.2	21.0	33.2	56.8	4.6	10.2	22.2	56.5	73.1	104.3
1946	34.3	16.0	25.9	44.3	5.4	11.9	26.0	57.9	73.1	100.8
1947	9.6	27.1	43.0	74.6	10.8	23.9	53.7	51.6	77.8	128.9
1948	12.9	19.4	30.5	52.4	16.2	35.1	78.0	52.0	80.0	137.3
1949	16.1	27.4	43.6	74.8	21.8	46.8	102.0	70.2	108.0	184.8
1950	9.3	29.7	46.7	80.0	27.0	58.0	128.9	72.4	116.3	209.2
1951	29.2	32.4	51.5	87.1	32.3	70.1	152.4	100.6	152.0	256.4
1952	20.5	29.9	46.8	78.9	38.2	80.6	175.8	94.6	149.1	263.3
1953	24.9	28.4	43.3	72.8	43.7	91.3	200.7	103.4	161.4	284.7
1954	26.2	25.8	39.2	65.3	49.0	103.6	224.5	106.4	170.3	302.2
1955	21.7	26.9	40.6	67.6	54.7	115.2	251.1	108.1	179.0	326.5
1956	19.8	25.3	38.3	63.4	59.7	126.2	272.9	110.3	184.4	346.8
1957	32.5	28.1	43.4	72.8	65.7	137.3	299.3	133.5	214.9	394.9
1958	22.6	31.2	46.5	77.6	71.6	147.1	316.3	131.9	220.4	403.2
1959	25.4	30.8	45.5	75.4	77.2	157.0	332.5	139.3	232.0	424.4
1960	36.2	30.5	45.6	75.8	81.3	166.0	353.9	156.7	249.7	455.2
1961	38.7	34.8	51.3	84.5	91.0	186.1	396.6	173.7	278.9	507.0
1962	54.6	30.9	45.8	74.8	91.8	185.5	392.5	185.5	285.9	504.5
1963	54.5	19.2	28.8	46.3	92.6	183.0	389.4	172.8	267.1	486.5
1964	26.7	23.1	34.1	55.2	92.3	184.1	386.7	146.8	244.2	458.2
1965	26.1	24.5	36.0	57.9	91.0	180.7	378.9	146.3	242.6	450.2
1966	27.9	24.6	35.7	58.3	89.1	182.8	375.6	147.0	245.9	452.5
1967	39.2	24.9	35.8	57.7	90.1	182.5	376.1	158.6	258.7	459.0

Year	Reconstructed commercial groundfish catch	Salmon troll imputed catch medians and 90% CI			Recreational imputed catch medians and 90% CI			TOTAL Outside YE CATCH (t) medians and 90% CI		
1968	26.2	27.4	40.1	63.6	90.6	184.4	369.7	151.1	251.8	442.1
1969	46.6	24.8	36.2	57.3	89.9	181.7	370.3	167.9	264.6	461.9
1970	82.4	25.8	37.0	58.2	95.9	187.6	387.8	210.9	306.8	521.0
1971	58.9	26.0	37.8	59.0	99.6	195.4	404.8	193.6	290.6	511.2
1972	82.9	24.5	35.3	54.5	104.8	201.1	410.4	221.5	321.0	537.5
1973	55.3	23.2	33.5	51.0	110.8	208.7	417.4	196.0	297.5	511.5
1974	87.6	21.8	31.5	48.0	114.2	215.5	426.0	229.4	335.8	552.2
1975	102.6	21.0	30.4	45.4	117.6	225.6	439.5	248.3	356.3	579.0
1976	71.0	22.7	32.2	48.4	120.2	232.5	450.4	222.1	336.2	561.3
1977	97.3	25.1	35.6	53.6	125.4	237.0	462.6	256.4	370.3	604.8
1978	109.1	25.1	35.6	52.9	128.3	243.8	480.9	273.1	389.3	627.6
1979	155.4	28.0	39.1	57.9	133.9	248.4	480.3	327.3	444.1	681.9
1980	139.4	33.6	48.0	70.6	139.4	254.2	483.6	321.9	443.1	681.5
1981	104.8	30.0	41.6	60.8	143.1	260.2	504.1	288.0	405.3	657.4
1982	52.2	29.8	40.1	58.3	146.4	263.5	520.3	241.4	357.8	611.8
1983	56.5	30.8	40.7	58.5	152.6	272.3	515.5	251.7	371.0	616.4
1984	153.1	25.9	34.2	49.1	157.6	282.0	530.3	344.4	469.1	719.1
1985	241.4	22.6	29.7	42.4	144.4	258.5	469.6	418.1	530.3	743.8
1986	739.3	19.5	25.5	36.1	79.3	139.5	256.3	845.1	906.0	1024.6
1987	953.4	15.3	19.9	28.2	141.6	249.7	453.2	1116.0	1223.1	1430.2
1988	854.7	15.0	19.6	27.5	101.5	177.8	319.2	977.8	1054.1	1193.1
1989	969.3	12.1	15.9	22.3	152.5	264.4	463.8	1138.9	1249.2	1450.7
1990	1725.6	13.0	17.7	25.8	154.4	264.0	468.5	1898.8	2007.3	2211.1
1991	1522.0	12.0	16.3	24.3	167.6	278.4	487.2	1707.4	1815.8	2026.1
1992	1104.3	10.7	14.2	21.4	206.0	338.1	586.2	1325.7	1455.3	1705.0
1993	1571.4	7.1	10.0	15.7	137.1	217.4	378.0	1719.6	1799.8	1959.4
1994	1018.3	6.2	8.7	14.0	156.3	242.2	414.6	1183.8	1269.5	1442.7
1995	1111.1	4.1	5.8	9.7	102.2	156.3	260.8	1220.3	1273.8	1376.1
1996	756.0	2.4	3.4	5.7	39.1	60.0	99.0	799.2	819.4	858.9
1997	725.9	1.3	1.8	3.1	92.0	138.4	230.5	820.1	865.7	958.0
1998	803.8	0.6	0.9	1.5	97.2	146.9	244.7	902.0	951.7	1049.4
1999	560.7	0.4	0.6	1.0	95.3	143.1	235.7	656.7	704.5	797.2
2000	607.9	0.3	0.4	0.7	60.7	90.3	146.9	669.0	698.6	755.2
2001	567.8	0.3	0.4	0.7	61.2	89.7	147.2	629.7	658.0	715.6
2002	428.6	0.6	0.8	1.4	71.8	105.5	171.0	501.4	534.8	600.5
2003	352.6	0.5	0.7	1.3	76.7	111.5	182.1	430.0	464.7	535.5
2004	310.3	0.5	0.7	1.3	73.4	106.3	174.0	384.5	417.5	485.1
2005	330.5	0.5	0.8	1.4	67.7	97.1	158.2	399.1	428.4	489.5
2006	225.3	0.5	0.7	1.4	65.4	93.4	150.9	291.5	319.5	376.9
2007	230.0	0.4	0.6	1.0	54.3	76.2	123.5	285.1	306.9	354.2
2008	307.3	0.4	0.5	0.9	49.3	70.0	110.9	357.1	377.8	418.7
2009	254.3	0.4	0.5	0.9	48.2	67.9	108.1	303.1	322.7	362.7
2010	245.1	0.3	0.5	0.8	44.0	61.9	98.5	289.8	307.5	344.1
2011	263.8	0.3	0.5	0.9	45.4	64.1	101.6	309.9	328.4	365.8
2012	281.9	0.3	0.4	0.8	38.8	54.6	85.9	321.2	337.0	368.2
2013	256.5	0.3	0.4	0.7	31.7	45.0	71.3	288.6	301.9	328.3
2014	237.0	0.3	0.4	0.9	34.2	49.6	80.2	271.7	287.0	317.7

FISHER LOGBOOK RECORDS

Fisher logbook records from DFO databases were used to develop abundance indices for use in the stock assessment. The PacHarvHL (PHL) dataset includes commercial fisher logbook records for the period 1986 to 2005 and the Fisheries Operations System (FOS) dataset contains the same data and covers the period from 2006 to 2014. The time series of commercial fisher logbook records is parsed into stanzas of relatively stable fishery management and logbook reporting. These stanzas are:

1986 to 1988 - initiation of the logbook program, mandatory participation (Hand et al. 1990)
1989 to 1993 - logbook format change in 1989 (Haigh and Richards 1997)
-limited entry licensing in 1993 (Yamanaka and Logan 2010)
1994 to 1995* - logbook format change in 1994 (Haigh and Richards 1997)
-dockside monitoring in 1995 (Yamanaka and Logan 2010)
1996 to 2001 - species aggregate changes in 1996 (Yamanaka and Kronlund 1997)
2002 to 2005 - reduction in TACs in 2002 (Yamanaka and Logan 2010)
2006 to 2014 - groundfish license integration and 100% monitoring (Yamanaka and Logan 2010)
-logbook records in FOS 2006

*for this period, the data reflect problems in reporting in the new logbook format and were dropped from the analysis

Generalized Linear Model (GLM) analysis

The abundance indices from the FOS and PHL datasets are produced using a classical two part generalized linear model (Pennington 1983; Lo et al. 1992; Fletcher et al. 2005). The first part of the model deals with the presence/absence data and the second part of the model deals with the counts of Yelloweye Rockfish.

This model is expressed as a mixture model and the probability to observe 0 or k is given by:

$$P(Obs=0) = (1-p) \qquad A.1$$

$$P(Obs=k) = p\,G(k), \qquad A.2$$

where: p is the probability of presence (the first part of the model) and G is the distribution of the counts when the counts are positive (the second part).

Several factors may influence the probability of presence and the expected counts when positive, at least depth and fishery. For both datasets (PHL and FOS), the fishery and depth is accounted for and treated as factors.

Fisheries are:	Halibut Lingcod Rockfish
Depth intervals are:	0-100 metres, (5-50 fathoms), 101 – 200 metres (50.5-100 fathoms), 201 – 801 meters (100.5 – 400 fathoms)

The following two sections detail the model used to produce FOS and PHL indices.

Definition of indices for the FOS dataset

P_{ydf} denotes the number of records in year y, at depth d, for fishery f, in which at least one Yelloweye Rockfish was captured, while N_{ydf} denotes the total number of records in year y, at depth d, for fishery f. P_{ydf} is assumed to follow a binomial distribution, where p_{ydf} denotes the probability of presence in year y, at depth d, and fishery f.

$P_{ydf} \sim \mathrm{Bin}(N_{ydf}, p_{ydf})$ y=2006, …, 2014; d=1,...3, f=1,...,3 A.3

$\mathrm{logit}(p_{ydf}) = m^P{}_0 + m^P{}_y + a^P{}_d + b^P{}_f$ A.4

where

- $m^P{}_0$ is the baseline,
- $m^P{}_y$ is the year y effect,
- $a^P{}_d$ is the the depth d effect,
- $b^P{}_f$ is the the fishery f effect,

expressed in logit space. The identifiability constraints use are to set the first year, first depth and first fishery equal to 0.

The dataset contains no consistent effort information over time to normalize the catch by the effort, so the effort has been assumed to be constant over all records and each record represents a fishing event.

Discrete count data are classically modeled using a Poisson distribution (Zuur 2009), however, since Yelloweye Rockfish counts in the logbook records show high variability (variance greater than the mean) there is over-dispersion in the data. Hence, the negative binomial distribution is proposed (White and Bennetts 1996) instead of a Poisson distribution. Therefore, the model for counts minus one, C_{ydf} is defined by:

$C_{ydf} \sim \mathrm{NegBin}(g_{ydf}, r)$ A.5

$\mathrm{logit}(g_{ydf}) = m^C{}_0 + m^C{}_y + a^C{}_d + b^C{}_f$, A.6

The expected value for a negative binomial distribution of parameter g and r is r/(1-g), therefore the annual index is defined by:

$p_y\, r / (1-g_y)$, with A.7

$p_y = \exp(m^P{}_0 + m^P{}_y)/(1+\exp(m^P{}_0 + m^P{}_y))$, and A.8

$g_y = \exp(m^C{}_0 + m^C{}_y)/(1+\exp(m^C{}_0 + m^C{}_y))$. A.9

A Bayesian approach is employed using a MCMC procedure to estimate parameters m, a, b, and r. Priors are chosen as non-informative (gamma distribution for r and normal distribution for other parameters, with very large variability) and a sensitivity analysis has been performed. The code used for the analysis is available on the Yelloweye GitHub site.

Definition of indices for the PHL dataset

A very similar approach has been used for defining the PHL indices. There are two differences; first the whole datasets has been split into several time periods or stanzas to account for changes in fishery and/or logbook reporting (see stanzas defined above in 1.). The same factors depth and fishery are accounted for, but the gear type is also included in the model. The model for the PHL data is then defined by:

$P_{ydfg} \sim \mathrm{Bin}(N_{ydfg}, p_{ydfg})$ A.10

$\mathrm{logit}(p_{ydfg}) = m^P{}_0 + m^P{}_y + a^P{}_d + b^P{}_f + d^P{}_g$ A.11

$C_{ydfg} \sim \mathrm{NegBin}(g_{ydfg}, r)$ A.12

$\mathrm{logit}(g_{ydfg}) = m^c{}_0 + m^c{}_y + a^c{}_d + b^c{}_f + d^c{}_g$ A.13

Similarly to the FOS analysis, the resulting index is given by:

$r * p_y / g_y$. A.14

The same priors are used to run the Bayesian analysis.

GLM results and logbook indices

The resulting standardized commercial logbook catch per unit of effort abundance indices are shown in Table A 13.

Table A13. Standardized abundance indices from commercial logbook catch per unit effort. Proc sigma refers to the standard deviation (SD) in the natural logarithm between the index and the model predicted index based on some annual systematic process affecting the scaling between the index and stock size. The values shown were obtained with the state-space parameter σ_p set at 0.05. It should be noted that the Proc sigma values were updated with each new estimation in the sensitivity analyses. Obs sigma refers to the SD in the natural logarithm of the index computed based on the processing of the commercial catch and effort data that produced the index. Index values are relative. The FOS index come from fisherlogs within the Fisheries Operating System, the PHL series come from fisherlogs within the PacHarvHL database. These data are broken into four different series to eliminate biases caused by various management changes over the years. Indices obtained from the GLM analysis are rescaled to the same order as the survey indices.

Series	Counter	Year	Index	Proc sigma	Obs sigma
PHL 1	9	1986	0.887	0.2	0.055
PHL 1	9	1987	1.05	0.2	0.0501
PHL 1	9	1988	1.06	0.2	0.0533
PHL 2	10	1989	0.957	0.3	0.0565
PHL 2	10	1990	0.889	0.3	0.031
PHL 2	10	1991	1.03	0.3	0.0331
PHL 2	10	1992	0.952	0.3	0.0365
PHL 2	10	1993	1.17	0.3	0.0348
PHL 3	11	1996	1.11	0.2	0.1346
PHL 3	11	1997	1.02	0.2	0.1324
PHL 3	11	1998	1.11	0.2	0.1315
PHL 3	11	1999	1.02	0.2	0.1345
PHL 3	11	2000	0.861	0.2	0.1359
PHL 3	11	2001	0.884	0.2	0.1274
PHL 4	12	2002	1.01	0.2	0.062
PHL 4	12	2003	1.03	0.2	0.0582
PHL 4	12	2004	1	0.2	0.0599
PHL 4	12	2005	0.965	0.2	0.0563
FOS	8	2006	5.21	0.2	0.095
FOS	8	2007	4.725	0.2	0.093
FOS	8	2008	4.375	0.2	0.092
FOS	8	2009	3.56	0.2	0.108
FOS	8	2010	4.981	0.2	0.11
FOS	8	2011	3.881	0.2	0.108
FOS	8	2012	3.631	0.2	0.102
FOS	8	2013	3.898	0.2	0.101
FOS	8	2014	3.503	0.2	0.109

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APPENDIX B. IPHC SURVEY DATA

B.1 INTRODUCTION

The International Pacific Halibut Commission (IPHC) conducts an annual stock assessment longline survey in waters from California to Alaska, including British Columbia waters (e.g. Flemming et al. 2012). The survey's main goal is to provide data on Pacific Halibut (*Hippoglosus stenolepis*) for stock assessment purposes.

At each station, the fishing gear consists of a set of skates each of about 100 hooks. Up to eight skates are on each set, with the number of skates per set varying between years. For each set the IPHC calculates an 'effective skate number', which we use here to scale the count of Yelloweye Rockfish and obtain a catch rate for each set (described below). The effective skate number "standardizes survey data in years when the number of hooks, hook spacing, or hook type varied" (Yamanaka et al., 2008). An effective skate of one represents a skate of 100 circle hooks with 18-foot spacing (Yamanaka et al., 2008).

The index 'Series AB' for Yelloweye Rockfish constructed below from the IPHC surveys consists of the mean catch rate for each year. The mean for a year is the mean of the catch rates of all sets within that year. The catch rate of a set has units of 'number of Yelloweye Rockfish caught per effective skate'. The catch rates within a year are bootstrapped, to give bootstrapped means, bias-corrected and adjusted (BCa) bootstrapped 95% confidence intervals, and bootstrapped coefficients of variation (CV).

We would like a survey index that spans as long a time period as possible, and, ideally, also covers all the coastwide waters off British Columbia (excluding the Strait of Georgia which this assessment does not consider). Although the spatial coverage and the technical details of the survey are not consistent from year to year (as described below), we are able to construct a survey index for Yelloweye Rockfish that can be considered representative of all British Columbia waters from 1995-2014.

The approach taken is described below, and extends that developed for a recent Redbanded Rockfish assessment (Edwards et al., 2017). That assessment was the first to develop an abundance index from the IPHC survey that went back to 1995, and included data up to 2012. Here we also include 2013 and 2014 data, and demonstrate that the index based on waters north of Vancouver Island can be considered representative of the coastwide population.

This work demonstrates that a consistent index can be constructed despite the survey design changing through the years. The methods could be used for other species caught by the survey. Note, however, that this work was not directly incorporated into the analysis in Appendix C that was used as the survey index in the assessment model.

Table B.1. Summary of available data from the IPHC stock assessment longline surveys. 'Data resolution' indicates at what level the data are available, and 'WCVI?' indicates whether or not the survey included locations off the west coast of Vancouver Island. 'Location of data' indicates where the data were accessed from, either our DFO `GFBio` *database or from spreadsheets.* [1] *For 1995, the biological data were in the file "1995_IPHC_SSA_Rockfish_catch_from_Kelly_Ames.xls" on DFO's Inshore Rockfish shared drive, and effective skates were obtained from Aaron Ranta (IPHC) in the file "1995EffSktValues by Station.xlsx".* [2] *For 1996-2002, the data were in the file "2B AllSpecies 96-02 roundIII.xls", which originally came from the IPHC.* [3] *For 2013 the data were in the file "2013 20-Hook Data.xls", which originally came from the IPHC.*

Year	Hooks enumerated	Data resolution	Location of data	WCVI?
1995	All	Set-by-set	Spreadsheets[1]	N
1996	All	Set-by-set	Spreadsheet[2]	N
1997-1998	First 20 of each skate	Set-by-set	Spreadsheet[2]	N
1999	First 20 of each skate	Set-by-set	Spreadsheet[2]	Y
2000	First 20 of each skate	Set-by-set	Spreadsheet[2]	N
2001-2002	First 20 of each skate	Set-by-set	Spreadsheet[2]	Y
2003-2011	All	Hook-by-hook	DFO database `GFBio`	Y
2012	All (bait experiment)	Hook-by-hook	DFO database `GFBio`	Y
2013	First 20 of each skate	Set-by-set	Spreadsheet[3]	Y
2014	All	Hook-by-hook	DFO database `GFBio`	Y

B.2 DATA

In British Columbia waters (IPHC area 2B), since 2003 a third observer has been deployed on the IPHC survey to identify all catch to the species level on a hook-by-hook basis and to conduct biological sampling (Flemming et al., 2012), although in 2013 there was no such observer. Observers were also deployed prior to 2003, although data are not available in such detail, as summarised in Table B.1. For some years only the first 20 hooks from each skate were enumerated, and for other years all hooks were enumerated but the data are only available at the set level (i.e. we do not know which hook caught which species, only how many individuals from each species were caught on the whole set). The data were extracted from various spreadsheets and the DFO database `GFBio`, and all originally came from the IPHC. For only some of the years were the locations off the west coast of Vancouver Island (WCVI) sampled. Note that, for simplicity we use the term 'first 20 hooks' since samplers on the vessels generally targetted the first 20 hooks from each skate. However, for operational reasons (particularly in areas of high catch rates), sometimes the 20 hooks would come from elsewhere within a skate, but would always consist of 20 consecutive hooks (e.g. Dykstra et al. 2002, 2003).

From Table B.1, four issues are apparent:

1. For 1997-2002 and 2013 only the first 20 hooks of each skate were enumerated, whereas for all other years all hooks were enumerated. Thus, the data from each year cannot simply be considered as comparable and analysed as one consecutive time series.
2. For the datasets for 1995, 1996, 1997-2002 and 2013, data are only available at the set-by-set level, in terms of numbers of a given species per effective skate. Which species was caught on each hook is not available, unlike for 2003-2012 and 2014. Thus, for 1995 and 1996 we cannot calculate catch rates based on the first 20 hooks (because we only have set-by-set level data), whereas we can do that for 2003-2012 and 2014, and the

Table B.2. Summary of how the four Series **A***,* **B***,* **C** *and* **D** *are constructed. Numbers in parentheses indicate the number of years for which data for each Series are available. 'Only north of WCVI' indicates Series that only consider stations north of Vancouver Island (thus excluding those off the WCVI), 'Full coast' indicates Series that use all stations from the whole coast. The rows indicate how many hooks the catch rates for each Series are based on.*

	Only north of WCVI	Full coast
First 20 hooks from each skate	**A**(18)	**D**(15)
All hooks from each skate	**B**(13)	**C**(11)

20-hook data is the only information we have for 1997-2002 and 2013.

3. In 2012 a bait experiment was conducted such that data from all skates could not be used; see Section B.4.
4. The WCVI was not visited in every year, so the spatial coverage is not consistent across years.

To address issues 1, 2 and 4 we therefore construct four time series (whose structure is summarised in Table B.2):

Series A – 1997-2014 stations north of WCVI, with catch rates based on first 20 hooks only (which is all we have for 1997-2002 and 2013).

Series B – 1995, 1996, 2003-2012 and 2014 stations north of WCVI, with catch rates based on all hooks (which is all we have for 1995 and 1996).

Series C – 2003-2012 and 2014 stations coastwide (including WCVI), with catch rates based on all hooks.

Series D – 1999 and 2001-2014 stations coastwide (including WCVI), with catch rates based on first 20 hooks only (which is all we have for 1999, 2001-2002 and 2013).

We would like to obtain an index series with as long a timespan as possible, and, ideally, over as broad a geographic region as possible. Since Series A is the longest time series, we take this and expand it to Series AB, defined as:

Series AB – for stations north of WCVI, combine the 1995 and 1996 values from Series B, based on all hooks, with the 1997-2014 values from Series A that are based on first 20 hooks only. See Section B.6.

The resulting Series AB covers the stations north of WCVI. In Sections B.6.3 and B.6.4 we show why we can consider this series to be representative of the full coast (i.e. including the WCVI), by comparing the series that exclude stations off the WCVI (Series A and B) with those that include the stations off the WCVI (Series D and B, respectively).

The absolute catch rate index for Series AB could therefore be justified as being an input to an assessment model, and be considered to be an index for the whole coast of British Columbia. Though recall that the model for this stock assessment uses the output from Appendix C, rather than from this Appendix.

B.3 SPATIAL LOCATIONS OF STATIONS

The maps in Figures B.1-B.11 show the locations of the stations of the IPHC survey since 1995. Early on, stations were not fixed between years, with the main difference being whether or not the waters off the west coast of Vancouver Island were surveyed (as summarised in Table B.2).

From 1995-1997 (Figures B.1-B.3) stations were arranged in Y-shapes; they were not exactly the same locations each year, but fairly close to each other. From 1998 onwards (Figures B.4-B.11) the stations have been positioned equidistant from one another on a 10-nautical-mile square grid (Flemming et al., 2012). In 1999 (Figure B.5) the survey first went to the WCVI. From 2001 onwards, the survey was consistently conducted at 170 regular fixed (non-random) stations (Figures B.7-B.11).

Given the difference in coverage between years, for Series A and B we exclude those stations south of 50.6° latitude, which is near the northern tip of Vancouver Island (black line in Figure B.1). This latitude was chosen so that all the stations from 1995-1997 are included (Figures B.1-B.3). The stations for 1995-1997 show good overlap (north of Vancouver Island) with the stations from 1998 onwards (Figures B.4-B.11).

For 1999 (Figure B.5) and 2001 onwards (Figures B.7-B.11), the black crosses indicate the stations off the WCVI that are below 50.6° latitude and are therefore excluded from Series A and B. Series C and D use all stations coastwide.

For Series A and D we only consider the first 20 hooks from each skate. For 2003-2012 and 2014 we have data for all hooks, and so in Figure B.10 we illustrate the stations where a Yelloweye Rockfish was never caught (in any year from 2003-2012 and 2014) on any hook, as well as the stations that caught Yelloweye Rockfish in some years but never in the first 20 hooks, and the stations that did catch it in the first 20 hooks of each skate (for at least one year).

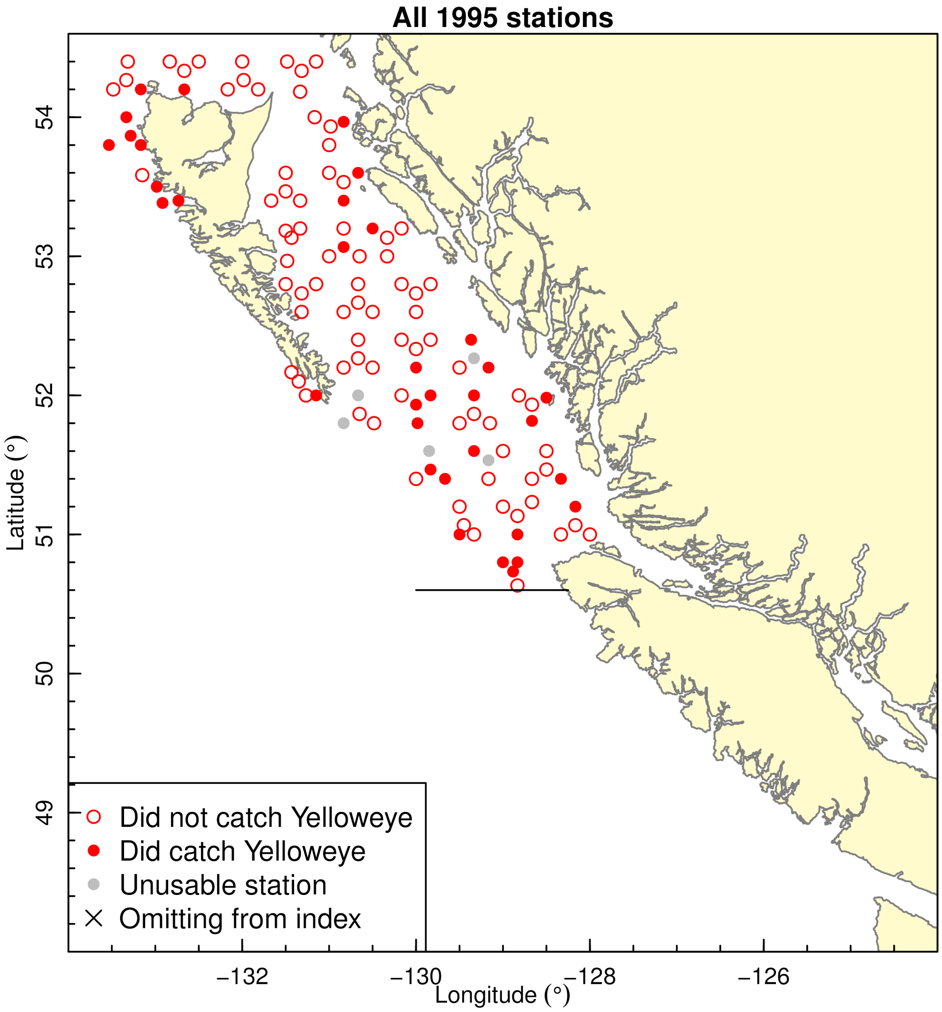

Figure B.1. Locations of the 120 stations in 1995, of which 81 did not catch Yelloweye Rockfish (red open circles), 34 stations did catch it (red closed circles), and 5 were deemed unusable by the IPHC (grey closed circles) and so are not considered further. The black line indicates the geographic cut-off, below which stations are excluded when constructing Series A and B; for this year no stations (black crosses) are excluded, since the cut-off was chosen so as to include all stations for 1995, 1996 and 1997.

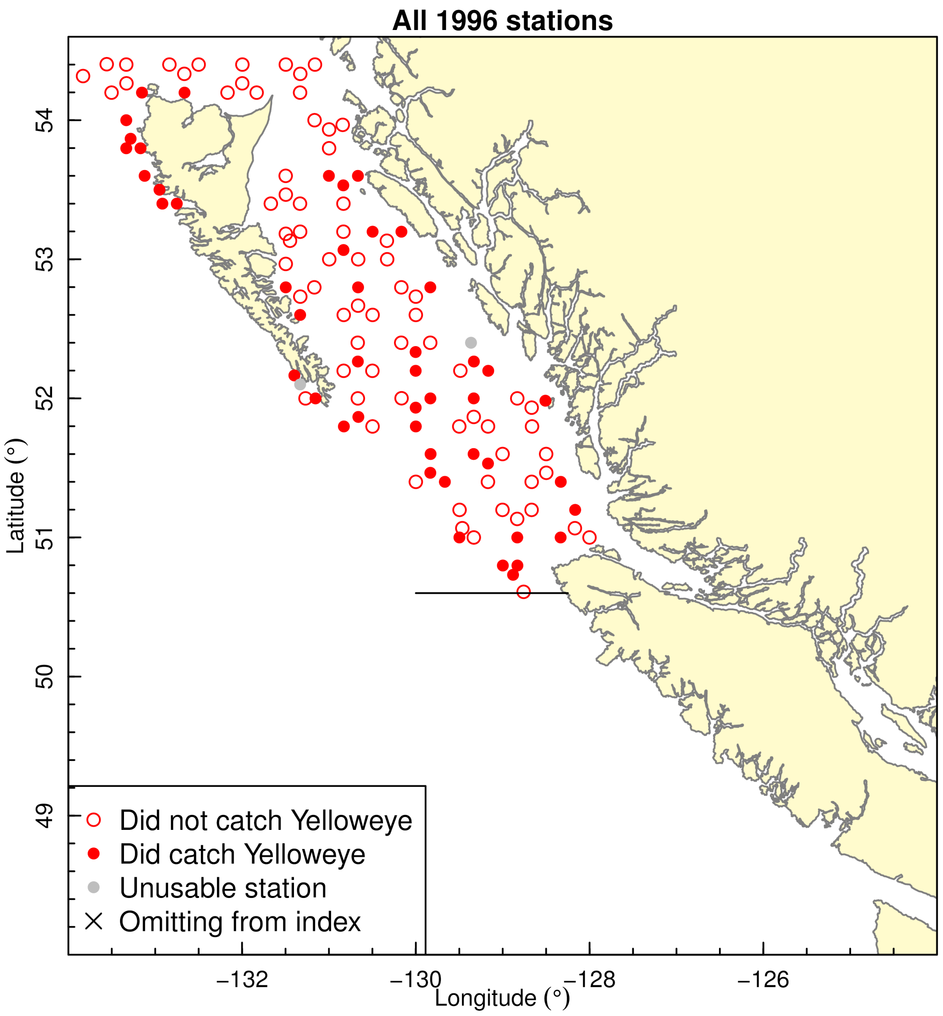

Figure B.2. Locations of the 122 stations in 1996, of which 73 did not catch Yelloweye Rockfish (red open circles), 47 stations did catch it (red closed circles), and 2 were deemed unusable by the IPHC (grey closed circles) and so are not considered further. The black line indicates the geographic cut-off, below which stations are excluded when constructing Series A and B; for this year no stations (black crosses) are excluded.

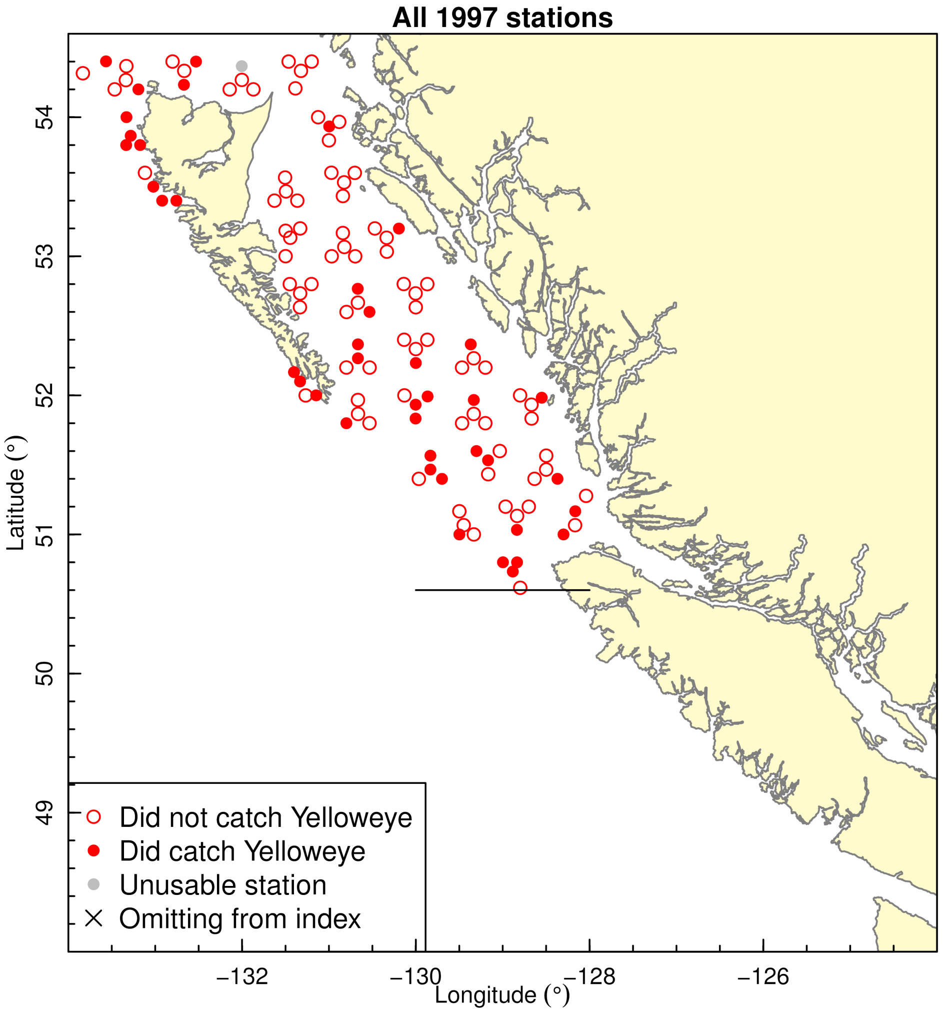

Figure B.3. Locations of the 122 stations in 1997, of which 80 did not catch Yelloweye Rockfish (red open circles), 41 stations did catch it (red closed circles), and 1 was deemed unusable by the IPHC (grey closed circles) and so are not considered further. The black line indicates the geographic cut-off, below which stations are excluded when constructing Series A and B; for this year no stations (black crosses) are excluded.

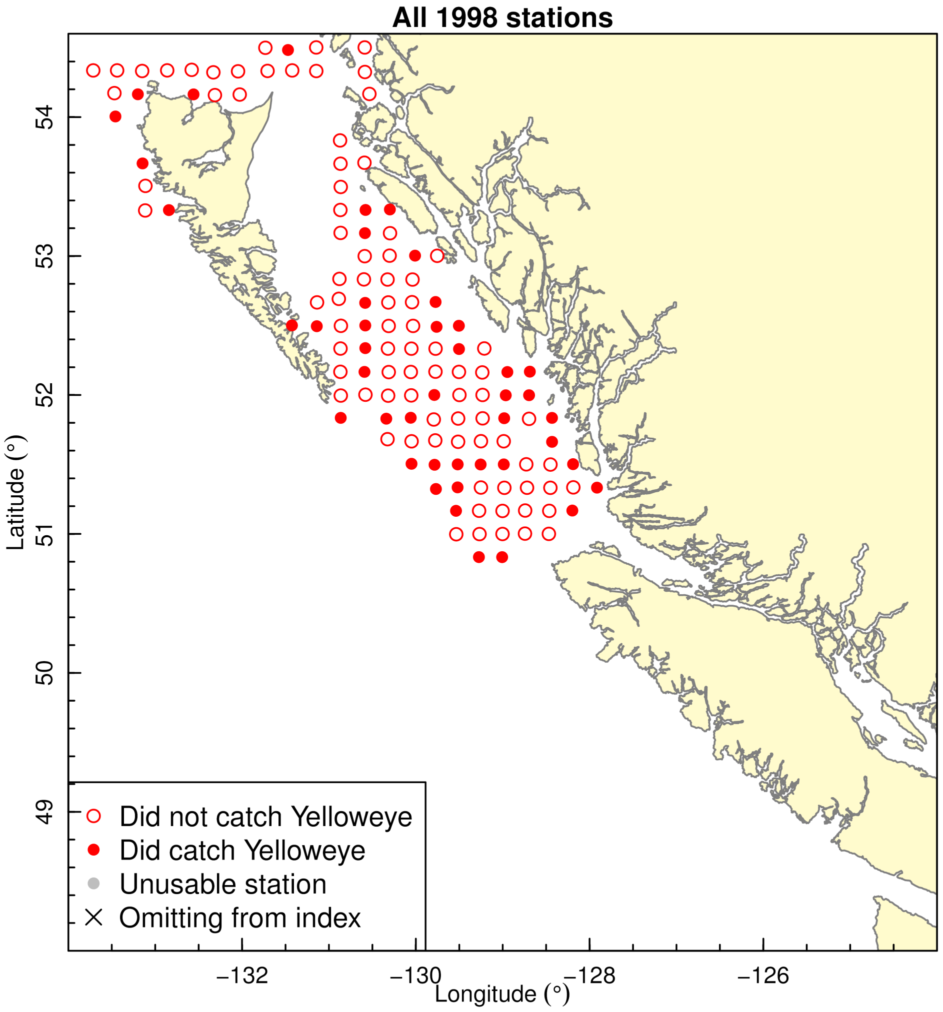

Figure B.4. Locations of the 128 stations in 1998, of which 84 did not catch Yelloweye Rockfish (red open circles), 44 stations did catch it (red closed circles), and 0 were deemed unusable by the IPHC (grey closed circles) and so are not considered further. There are no black crosses because no stations are being excluded from Series A.

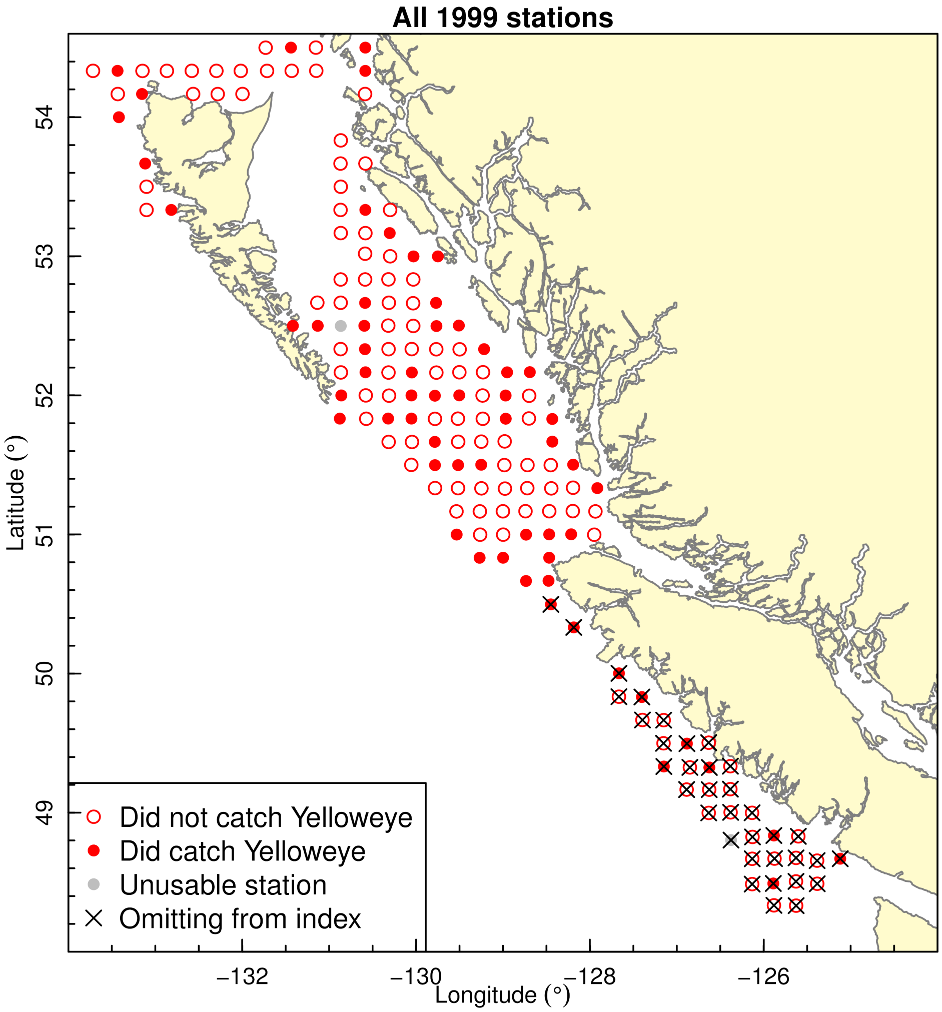

Figure B.5. Locations of the 170 stations in 1999, of which 107 did not catch Yelloweye Rockfish (red open circles), 61 stations did catch it (red closed circles), and 2 were deemed unusable by the IPHC (grey closed circles) and so are not considered further. Black crosses indicate the 35 stations being excluded from Series A because they lie south of the geographic cut-off shown on Figure B.1.

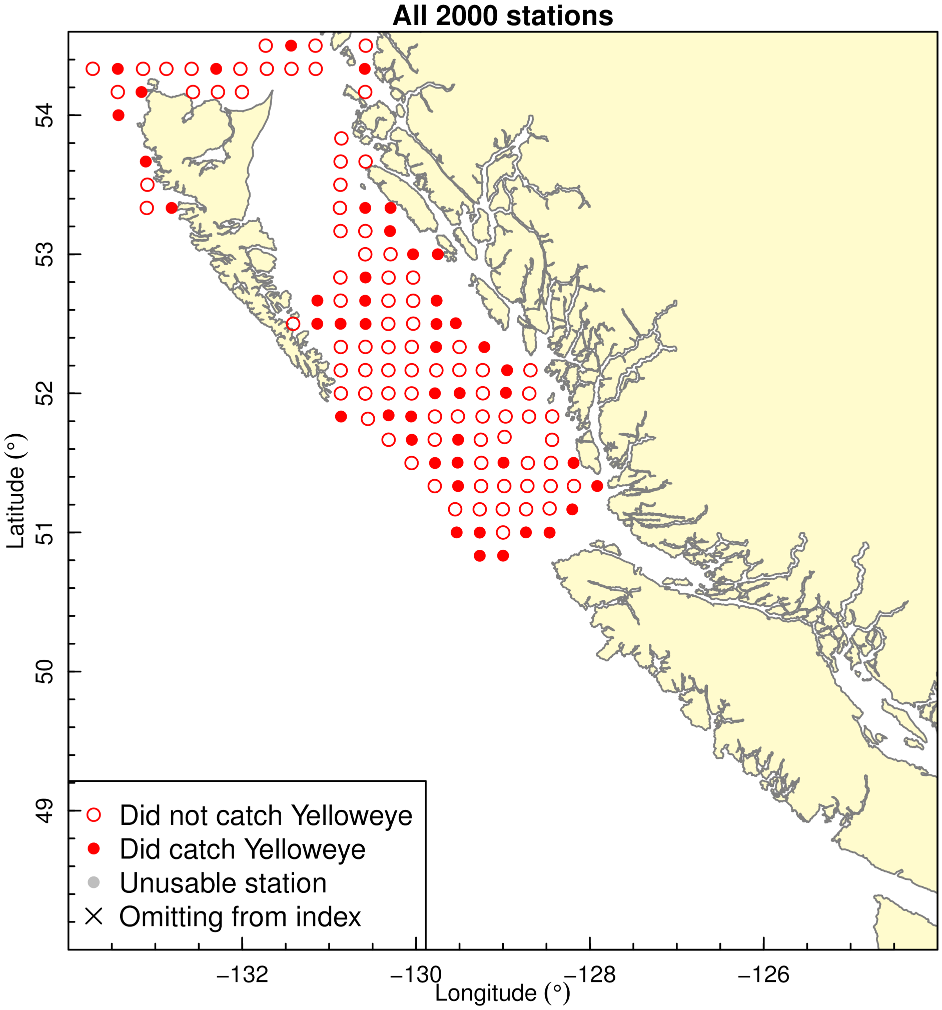

Figure B.6. Locations of the 129 stations in 2000, of which 83 did not catch Yelloweye Rockfish (red open circles), 46 stations did catch it (red closed circles), and 0 were deemed unusable by the IPHC (grey closed circles) and so are not considered further. There are no black crosses because no stations are being excluded from Series A.

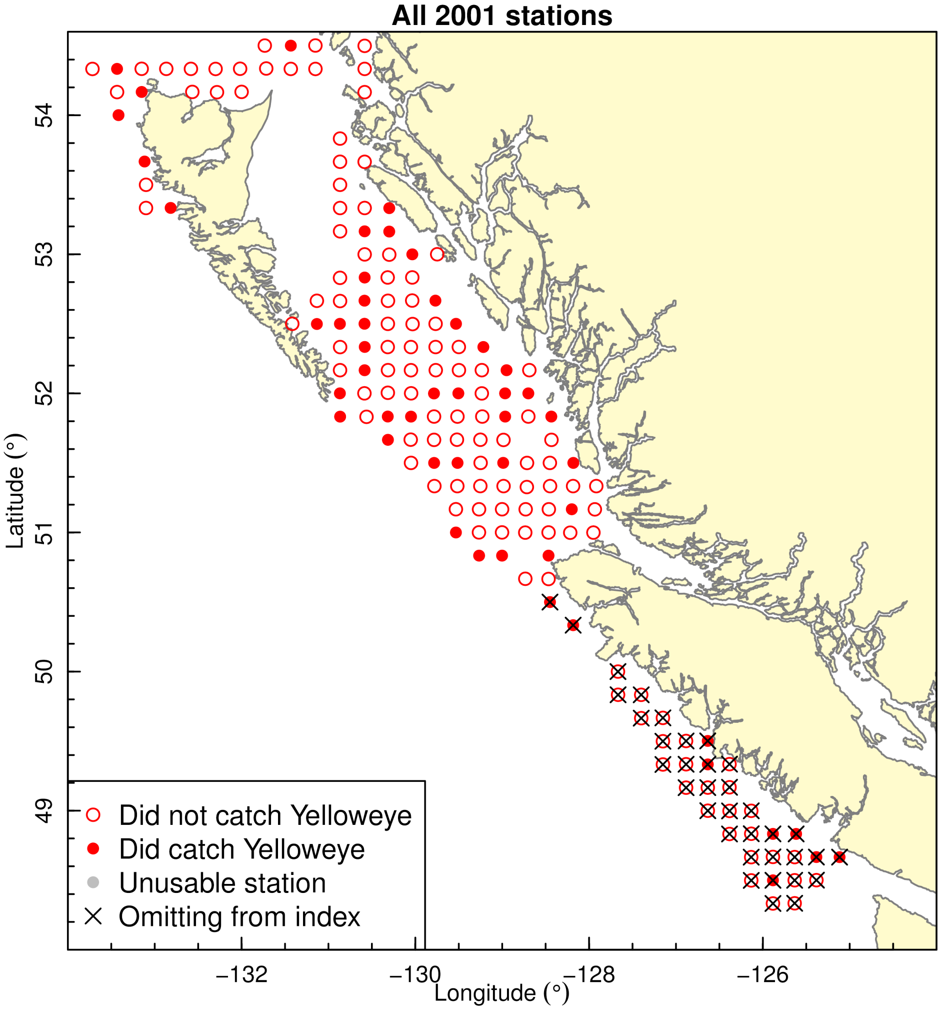

Figure B.7. Locations of the 170 stations in 2001, of which 120 did not catch Yelloweye Rockfish (red open circles), 50 stations did catch it (red closed circles), and 0 were deemed unusable by the IPHC (grey closed circles) and so are not considered further. Black crosses indicate the 35 stations being excluded from Series A.

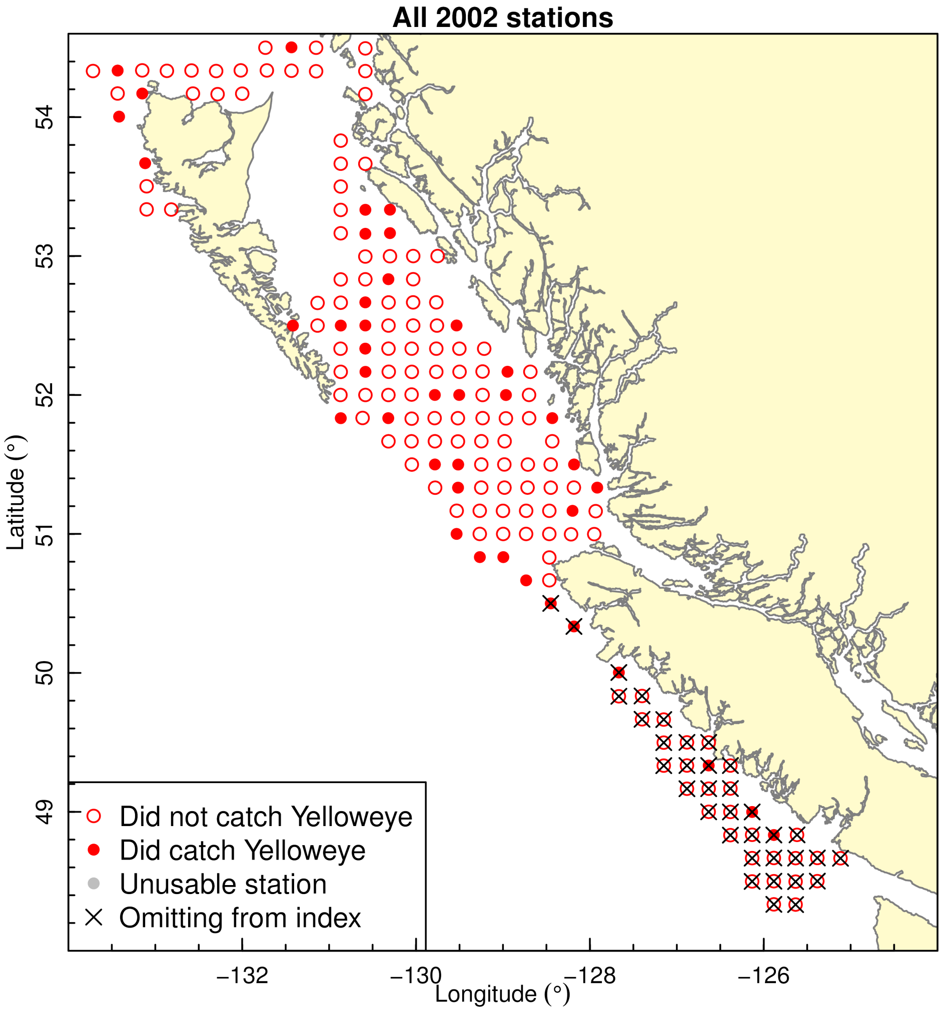

Figure B.8. Locations of the 170 stations in 2002, of which 130 did not catch Yelloweye Rockfish (red open circles), 40 stations did catch it (red closed circles), and 0 were deemed unusable by the IPHC (grey closed circles) and so are not considered further. Black crosses indicate the 35 stations being excluded from Series A.

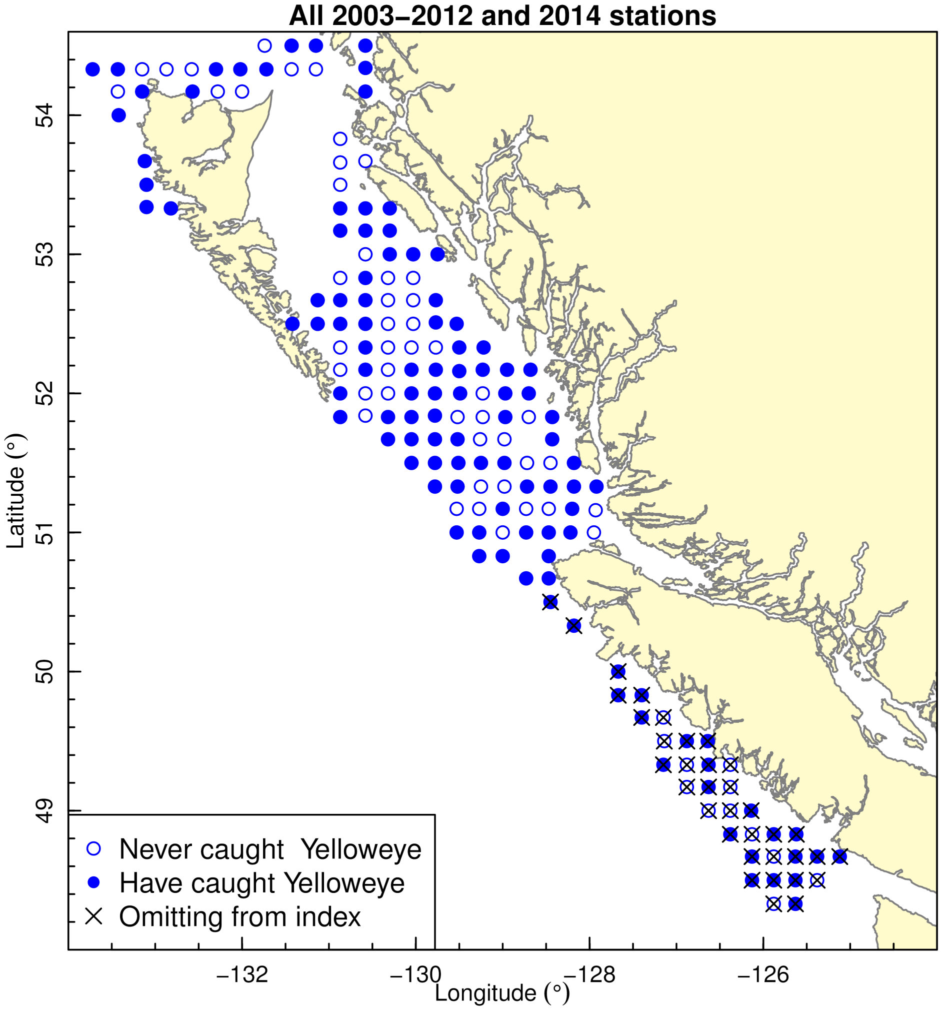

Figure B.9. Locations of all 170 stations for the IPHC survey for 2003 onwards. There are 59 stations that never caught Yelloweye Rockfish (blue open circles), and 111 stations that did catch it at least once. Black crosses indicate the 35 stations being excluded from Series A and Series B.

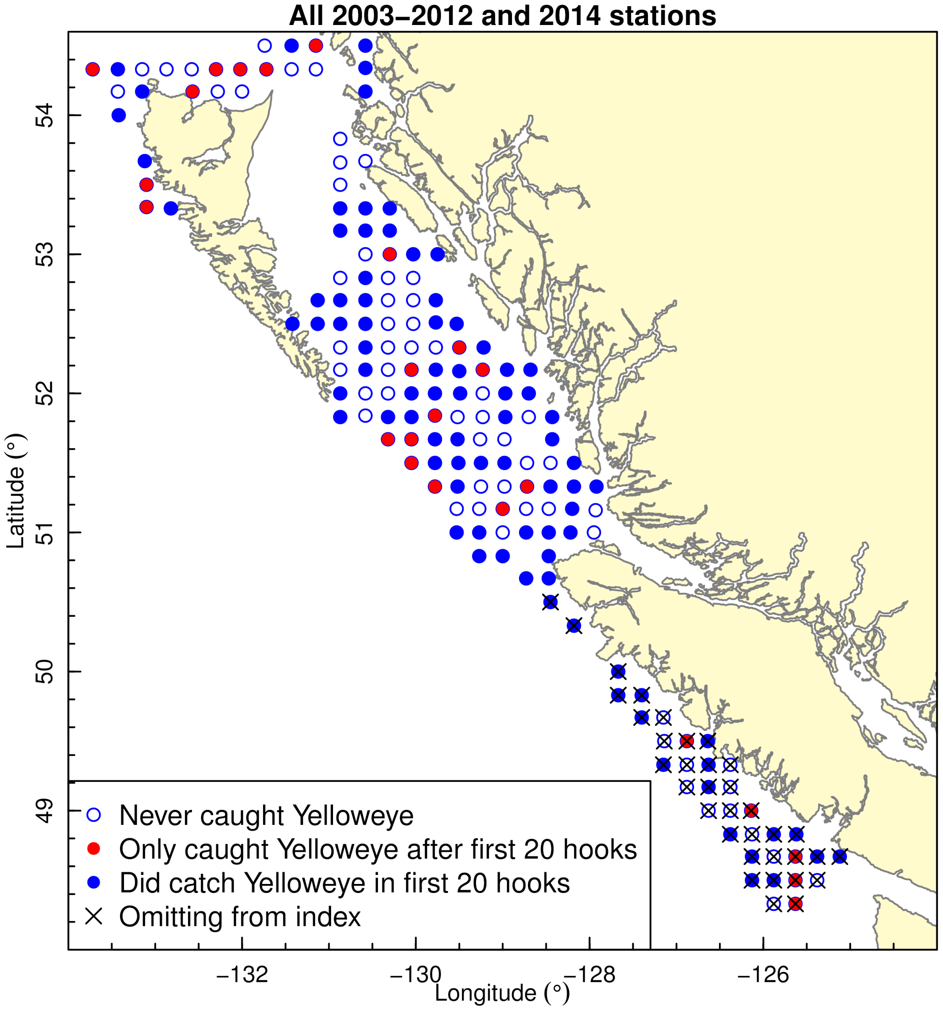

Figure B.10. Locations of all 170 stations for the IPHC survey for 2003-2012 and 2014. There are 59 stations that never caught Yelloweye Rockfish (blue open circles), 24 stations that caught Yelloweye Rockfish but never in the first 20 hooks (red closed circles), and 87 that did catch Yelloweye Rockfish within the first 20 hooks (blue closed circles). Black crosses indicate the 35 stations being excluded from Series A and B.

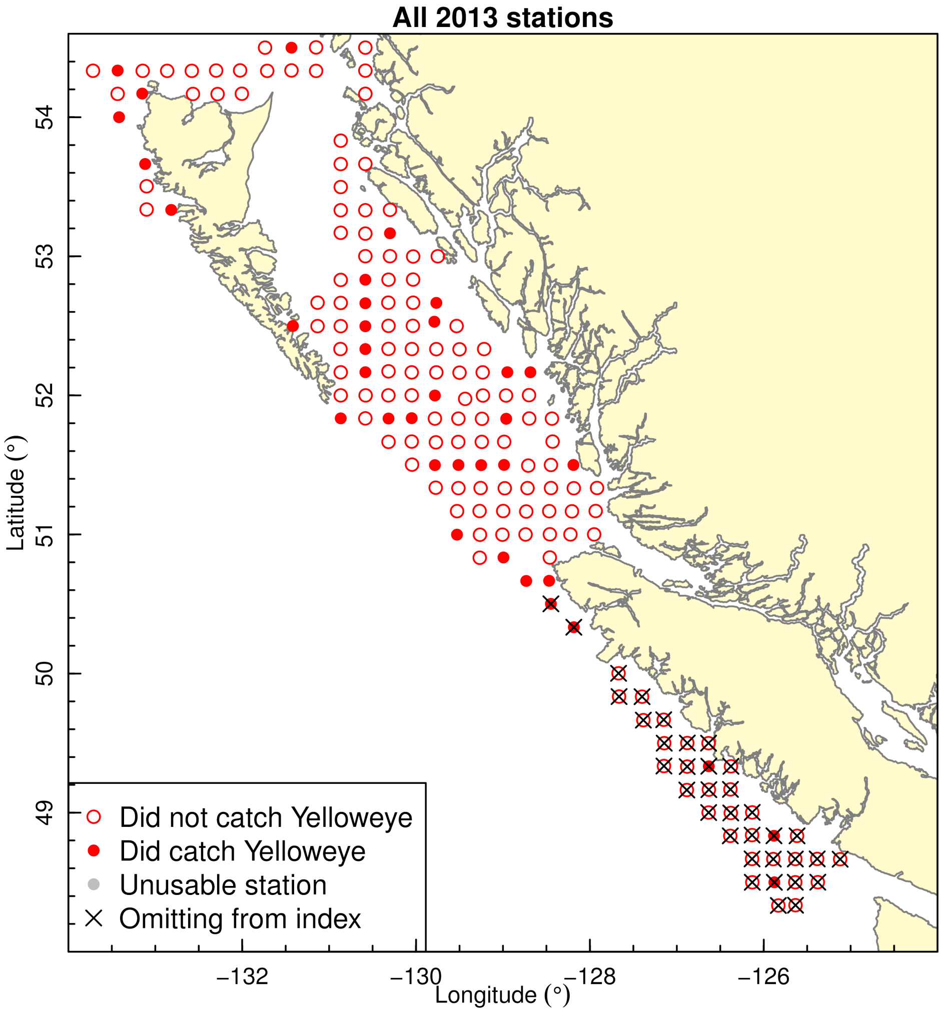

Figure B.11. Locations of the 170 stations in 2013, of which 134 did not catch Yelloweye Rockfish (red open circles), 36 stations did catch it (red closed circles), and 0 were deemed unusable by the IPHC (grey closed circles) and so are not considered further. Black crosses indicate the 35 stations being excluded from Series A.

B.4 CHUM SALMON BAIT EXPERIMENT

Prior to 2012, Chum Salmon (*Oncorhynchus keta*) was used for bait. But in 2012, a bait experiment was conducted (Henry et al., 2013). At each station three different bait types were used on the same set: a consecutive four-skate Chum Salmon treatment, a one-skate Pink Salmon (*Oncorhynchus gorbuscha*) treatment, and a one-skate Walleye Pollock (*Theragra chalcogramma*) treatment. The location of the three treatments on each set was randomized throughout the survey, and each treatment was separated by one skate (1,800 ft) of hookless groundline. For consistency with previous years, we only consider the four skates that used Chum Salmon as bait.

The effective skate number provided by the IPHC is for all skates used, which in 2012 will include skates that were not baited with Chum Salmon (Eric Soderlund, IPHC, Seattle, WA, USA, pers. comm.). But we wish to only include the Chum Salmon baited skates, and so we need to modify the effective skate number (see below). The effective skate number depends on the number of observed hooks (Eric Soderlund, IPHC, Seattle, WA, USA, pers. comm.), rather than the number of hooks that were deployed. The bait experiment was not continued for 2013 or 2014.

B.5 CATCH RATE EQUATIONS

B.5.1 CATCH RATE BASED ON ALL CHUM-BAIT HOOKS

We wish to obtain a catch rate index which, for each year, will be the mean catch rate across all sets that year. The units will be numbers of Yelloweye Rockfish caught per effective skate. We only want to consider hooks that used Chum Salmon as bait (hereafter ‘chum-bait hooks’), because we have no information as to how catch rates of Yelloweye Rockfish may change depending on the bait used. For our data, 2012 was the only year that hooks were not exclusively chum-bait hooks.

Define:

H_{it} – number of observed chum-bait hooks in set i in year t,

H^*_{it} – number of observed hooks for all bait types ($H_{it} \neq H^*_{it}$ only for 2012),

E_{it} – effective skate number of set i in year t, which needs to be based on observed chum-bait hooks,

E'_{it} – effective skate number from IPHC, which is based on all observed hooks (regardless of bait).

Thus, E_{it} is

$$E_{it} = \frac{H_{it}}{H^*_{it}} E_{it}. \tag{B.1}$$

Adapting equations on page 3 of Yamanaka et al. (2008), define:

N_{it} – the number of fish of a given species caught on set $i = 1, 2, ..., n_t$ in year t, based on observed chum-bait hooks,

n_t – the number of sets in year t,

C_{it} – catch rate (with units of numbers per effective skate) of Yelloweye Rockfish for set i in year t, based on observed chum-bait hooks, given by

$$C_{it} = \frac{N_{it}}{E_{it}}. \tag{B.2}$$

The catch rate index for year t, I_t (numbers per effective skate), is then the mean catch rate across all sets:

$$I_t = \frac{1}{n_t} \sum_{i=1}^{n_t} C_{it} = \frac{1}{n_t} \sum_{i=1}^{n_t} \frac{N_{it}}{E_{it}}. \tag{B.3}$$

B.5.2 CATCH RATE BASED THE FIRST 20 CHUM-BAIT HOOKS OF EACH SKATE

Let $\tilde{X}$ indicate a calculation of some value X that is based only on the first 20 hooks of each skate. These are the first 20 *numbered* hooks, not the first 20 *observed* hooks (so not all of the numbered hooks may have been observed). Thus we have:

$\tilde{H}_{it}$ – number of observed chum-bait hooks in the first 20 hooks of all skates in set i in year t,

$\tilde{E}_{it}$ – effective skate number of set i in year t based on the first 20 chum-bait hooks that were sent out on each skate.

Since effective skate number is a linear function of the number of hooks in a set (Yamanaka et al., 2008), we have

$$\tilde{E}_{it} = \frac{\tilde{H}_{it}}{H_{it}} E_{it} \left(= \frac{\tilde{H}_{it}}{H^*_{it}} E_{it} \right). \tag{B.4}$$

The resulting notation for the index will be:

$\tilde{I}_t$ – catch rate index for year t (in numbers of Yelloweye Rockfish per effective skate) based on only the first 20 hooks sent out for each skate,

$\tilde{N}_{it}$ – the number of Yelloweye Rockfish caught on set $i = 1, 2, ..., n_t$ in year t, based on observed chum-bait hooks and only the first 20 hooks sent out for each skate,

$\tilde{C}_{it}$ – catch rate (with units of numbers per effective skate) for set i in year t, based only on the first 20 hooks of each skate (and only skates with chum as bait), such that

$$\tilde{C}_{it} = \frac{\tilde{N}_{it}}{\tilde{E}_{it}}. \tag{B.5}$$

The catch rate index for year t, $\tilde{I}_t$ (in units of numbers per effective skate), based on only the first 20 hooks of each skate, is then the mean catch rate across all sets:

$$\tilde{I}_t = \frac{1}{\tilde{n}_t} \sum_{i=1}^{\tilde{n}_t} \tilde{C}_{it} = \frac{1}{\tilde{n}_t} \sum_{i=1}^{\tilde{n}_t} \frac{\tilde{N}_{it}}{\tilde{E}_{it}}. \tag{B.6}$$

B.5.3 EQUIVALENCY OF CATCH RATES BASED ON ALL HOOKS AND ON JUST THE FIRST 20 HOOKS

Equation (B.5) can be written as

$$\tilde{C}_{it} = \frac{\tilde{N}_{it}}{\tilde{E}_{it}} = \frac{H_{it}}{\tilde{H}_{it}} \frac{\tilde{N}_{it}}{E_{it}}. \tag{B.7}$$

If all hooks are equally likely to catch a Yelloweye Rockfish, then the catch rates based on the first 20 hooks of each skate should be an unbiased sample of the catch rates based on all the hooks. The ratio of fish caught, $\tilde{N}_{it}/N_{it}$, should equal (on average) the ratio of hook numbers, $\tilde{H}_{it}/H_{it}$, because a proportionally reduced number of fish are caught on the proportionally fewer hooks. Thus

$$\frac{\tilde{H}_{it}}{H_{it}} = \frac{\tilde{N}_{it}}{N_{it}} \tag{B.8}$$

such that

$$\tilde{C}_{it} = \frac{N_{it}}{\tilde{N}_{it}} \frac{\tilde{N}_{it}}{E_{it}} = \frac{N_{it}}{E_{it}} = C_{it}. \tag{B.9}$$

If the catch rates are greatly different, then this suggests that the catch rates from the first 20 hooks are not equivalent to the catch rates based on all the hooks. This is why we compare Series A and Series B below.

B.6 RESULTS

B.6.1 DETAILS OF SERIES A AND SERIES B

Tables B.3 and B.4 show the effective skate numbers for Series A and B. The values are lower for Series A because they are only based on 20 hooks per skate, compared to all skates for Series B (see equation B.4).

Table B.3. For series A, summary of effective skate numbers, E_{it}, for each year. Lower and Higher are the 2.5% and 97.5% quantiles, respectively.

Year	Lower	Mean	Higher
1997	1.00	1.20	1.20
1998	1.42	1.59	1.62
1999	1.59	1.60	1.61
2000	1.35	1.40	1.42
2001	0.96	1.00	1.02
2002	0.96	1.00	1.01
2003	1.59	1.61	1.64
2004	1.60	1.60	1.65
2005	1.40	1.41	1.43
2006	1.19	1.21	1.24
2007	0.98	1.01	1.03
2008	0.99	1.01	1.03
2009	1.38	1.40	1.42
2010	1.59	1.61	1.63
2011	1.18	1.20	1.24
2012	0.79	0.80	0.83
2013	1.18	1.20	1.21
2014	1.38	1.41	1.43

Table B.4. For series B, summary of effective skate numbers, E_{it}, for each year. Lower and Higher are the 2.5% and 97.5% quantiles, respectively.

Year	Lower	Mean	Higher
1995	4.76	4.99	5.08
1996	4.82	4.93	5.00
2003	7.90	7.99	8.11
2004	7.90	7.90	8.03
2005	6.96	7.00	7.03
2006	5.84	5.96	6.08
2007	4.87	4.98	5.02
2008	4.92	4.98	5.02
2009	6.89	6.98	7.10
2010	7.95	8.01	8.11
2011	5.90	5.93	6.02
2012	3.89	4.01	4.10
2014	6.92	7.01	7.17

For the overlapping years 2003-2012 and 2014, the mean effective skate numbers for series A are slightly over 20% of those for series B. This is because skates had a mean of just under 100 observed hooks, and so the first 20 hooks in each skate comprise just over 20% of the observed hooks. Thus the scaling ratio $\tilde{H}_{it}/H_{it}$ in (B.4) is just over 0.2. The lowest value, for 2012, is due to only four skates (those with Chum Salmon as bait) being usable for this analysis.

The resulting bootstrapped catch rate indices for the two Series are shown in Figure B.12. For Series A, the highest mean catch rate is at the start of the series (1997), followed by four constant years, then a drop in 2002. This is unlike the equivalent Series A for Redbanded Rockfish, which exhibited an increase in catch rates in the early years (1997-1999), followed later by a decline in 2002 to a lower level (Edwards et al., 2017). For Yelloweye, there is a period of overall increase from 2002-2010, followed by a decline that results in 2014 having the lowest average catch rate. For Series B, Figure B.12(b) shows 1995 and 1996 to be the highest years, with 2014 the lowest.

Values for the indices for Series A and Series B are given in Tables B.5 and B.6, respectively, as well as the number of sets each year and the proportion of sets in each year that did not catch Yelloweye Rockfish. The early years have slightly fewer sets than the 135 that occurred from 2001 onwards. Year 2008 has only 134 sets because for station number 2113 the hook-tally sheet was lost overboard (Yamanaka et al., 2011).

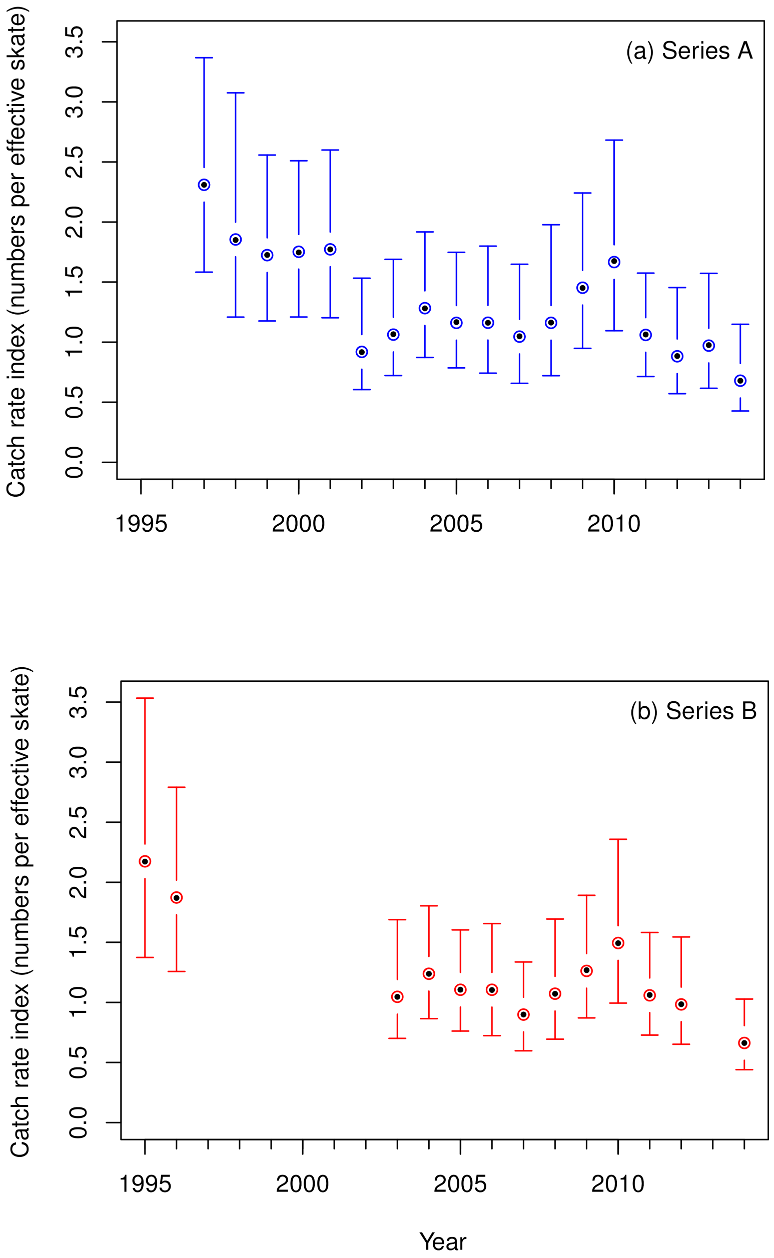

Figure B.12. Catch rate index (number of individual Yelloweye Rockfish caught per skate) for (a) Series A and (b) Series B. For a given year, the catch rate for each set is calculated from (B.2) or (B.5) as appropriate. These catch rates are then resampled for 10,000 bootstrap values, from which a bootstrapped mean (open circles) and 95% bias-corrected and adjusted confidence intervals (bars) are calculated. Small black closed circles are sample means (not bootstrapped), and essentially equal the bootstrapped means.

Table B.5. Catch rates by year for Series A. 'Sample $\bar{I}_t$' is the sample mean. B'ed means bootstrapped value. 'No YYR' is the proportion of sets that did not catch Yelloweye Rockfish that year. Lower and higher are the lower and upper bounds of the 95% bias-corrected and adjusted (BCa) confidence intervals.

Year	Sets, n_t	No YYR	Sample $\bar{I}_t$	B'ed I_t	B'ed I_t lower	B'ed I_t higher	B'ed I_t CV
1997	121	0.66	2.31	2.31	1.58	3.37	0.19
1998	128	0.66	1.85	1.85	1.21	3.08	0.23
1999	134	0.62	1.73	1.72	1.18	2.56	0.20
2000	129	0.64	1.75	1.75	1.21	2.51	0.18
2001	135	0.70	1.77	1.77	1.20	2.60	0.19
2002	135	0.75	0.92	0.92	0.61	1.53	0.23
2003	135	0.67	1.07	1.06	0.72	1.69	0.22
2004	135	0.69	1.28	1.28	0.87	1.92	0.20
2005	135	0.69	1.17	1.16	0.79	1.75	0.20
2006	135	0.76	1.16	1.16	0.74	1.80	0.22
2007	135	0.76	1.05	1.05	0.66	1.65	0.23
2008	134	0.77	1.16	1.16	0.72	1.98	0.26
2009	135	0.71	1.45	1.45	0.95	2.24	0.22
2010	135	0.68	1.67	1.67	1.10	2.68	0.23
2011	135	0.71	1.06	1.06	0.71	1.57	0.20
2012	135	0.77	0.88	0.88	0.57	1.45	0.24
2013	135	0.77	0.98	0.97	0.62	1.57	0.24
2014	135	0.76	0.68	0.68	0.43	1.15	0.25

Table B.6. Catch rates by year for Series B. 'Sample $\bar{I}_t$' is the sample mean. B'ed means bootstrapped value. 'No YYR' is the proportion of sets that did not catch Yelloweye Rockfish that year. Lower and higher are the lower and upper bounds of the 95% bias-corrected and adjusted (BCa) confidence intervals.

Year	Sets, n_t	No YYR	Sample $\bar{I}_t$	B'ed I_t	B'ed I_t lower	B'ed I_t higher	B'ed I_t CV
1995	115	0.70	2.17	2.17	1.37	3.53	0.24
1996	120	0.61	1.87	1.87	1.26	2.79	0.20
2003	135	0.55	1.05	1.05	0.70	1.69	0.22
2004	135	0.59	1.24	1.24	0.86	1.80	0.19
2005	135	0.57	1.11	1.11	0.76	1.60	0.19
2006	135	0.61	1.10	1.11	0.72	1.66	0.21
2007	135	0.67	0.90	0.90	0.60	1.34	0.21
2008	134	0.60	1.07	1.07	0.69	1.69	0.23
2009	135	0.57	1.27	1.26	0.87	1.89	0.20
2010	135	0.59	1.49	1.49	0.99	2.36	0.22
2011	135	0.61	1.06	1.06	0.73	1.58	0.20
2012	135	0.69	0.99	0.98	0.65	1.55	0.22
2014	135	0.62	0.66	0.66	0.44	1.03	0.22

B.6.2 CONSTRUCTING SERIES AB THAT COVERS ALL 20 YEARS

We wish to join up the 1995 and 1996 data from Series B (Figure B.12(b)) to the 1997-2014 data from Series A (Figure B.12(a)). The 1995 and 1996 data are only available as numbers of Yelloweye Rockfish caught for all hooks, and not as numbers caught in the first 20 hooks (Table B.1). For 1997-2002 we only have numbers caught for the first 20 hooks. But for 2003-2012 and 2014 we have hook-by-hook data, and so can compute catch rates for all hooks or based on just the first 20 hooks (i.e. these overlapping years are the only years that contribute to both Series A and Series B).

For Series A, define G_A to be the geometric mean of the bootstrapped annual means, with the geometric mean based only on the overlapping years (2003-2012 and 2014). Define G_B similarly for Series B. By dividing the bootstrapped values for each series by their respective geometric means, we obtain Figure B.13(a). This shows that the rescaled Series A and Series B are very similar for the overlapping years. Thus, on this scale, the 1995 and 1996 values from Series B can be compared to the full Series A data.

We can therefore append the 1995 and 1996 values from the rescaled Series B in Figure B.13(a) to the original Series A values (Figure B.12(a)) by multiplying them by G_A, to yield the index series in Figure B.13(b) that has units of ‘numbers per effective skate’. Equivalently, the original 1995 and 1996 values from Figure B.12(b) have thus been multiplied by G_A/G_B to give those in Figure B.13(b).

The values for the merged Series AB are given in Table B.7. We next show that Series AB can be considered as a coastwide index (despite not including the WCVI).

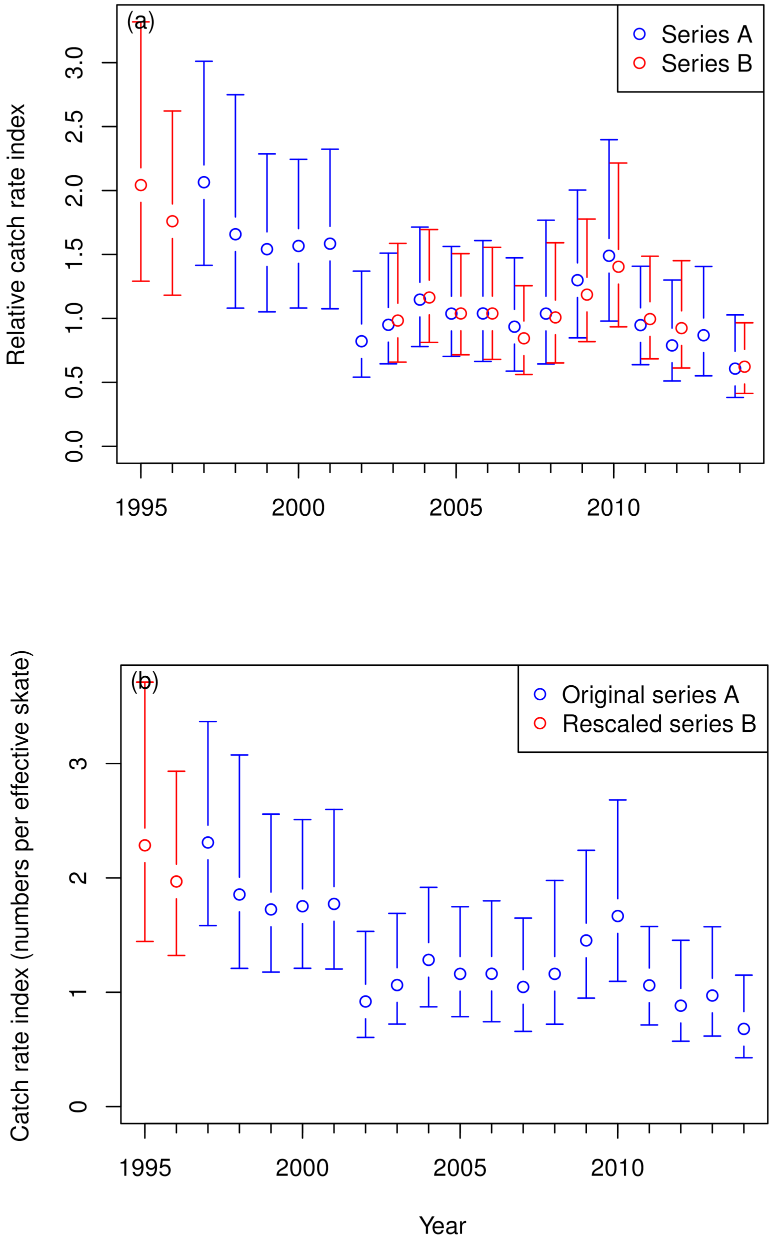

Figure B.13. (a) Each of the two catch rate series from Figure B.12 is divided by the geometric mean of its bootstrapped annual means (with the geometric mean based on the overlapping years only). (b) The catch rate index Series AB that could be used as a model input (although the index in Appendix C was used in this stock assessment). Series AB extends the original Series A by incorporating the suitably scaled 1995 and 1996 values from Series B (see text).

Table B.7. Catch rates by year for Series AB, constructed by combining 1995 and 1996 data from Series B with the full data for Series A. The 1995 and 1996 values were rescaled by multiplying them by the ratio of the geometric means of the bootstrapped means for the two series for the overlapping years, G_A/G_B*. Values are* $G_A = 1.12$ *and* $G_B = 1.06$ *such that* $G_A/G_B = 1.05$ *'Sample* $\bar{I}_t$*' is the sample mean. B'ed means bootstrapped value. 'No YYR' is the proportion of sets that did not catch Yelloweye Rockfish that year. Lower and higher are the lower and upper bounds of the 95% bias-corrected and adjusted (BCa) confidence intervals.*

Year	Sets, n_t	No YYR	Sample $\bar{I}_t$	B'ed I_t	B'ed I_t lower	B'ed I_t higher	B'ed I_t CV
1995	115	0.70	2.28	2.28	1.44	3.71	0.24
1996	120	0.61	1.96	1.97	1.32	2.93	0.20
1997	121	0.66	2.31	2.31	1.58	3.37	0.19
1998	128	0.66	1.85	1.85	1.21	3.08	0.23
1999	134	0.62	1.73	1.72	1.18	2.56	0.20
2000	129	0.64	1.75	1.75	1.21	2.51	0.18
2001	135	0.70	1.77	1.77	1.20	2.60	0.19
2002	135	0.75	0.92	0.92	0.61	1.53	0.23
2003	135	0.67	1.07	1.06	0.72	1.69	0.22
2004	135	0.69	1.28	1.28	0.87	1.92	0.20
2005	135	0.69	1.17	1.16	0.79	1.75	0.20
2006	135	0.76	1.16	1.16	0.74	1.80	0.22
2007	135	0.76	1.05	1.05	0.66	1.65	0.23
2008	134	0.77	1.16	1.16	0.72	1.98	0.26
2009	135	0.71	1.45	1.45	0.95	2.24	0.22
2010	135	0.68	1.67	1.67	1.10	2.68	0.23
2011	135	0.71	1.06	1.06	0.71	1.57	0.20
2012	135	0.77	0.88	0.88	0.57	1.45	0.24
2013	135	0.77	0.98	0.97	0.62	1.57	0.24
2014	135	0.76	0.68	0.68	0.43	1.15	0.25

B.6.3 CONSTRUCTING SERIES D (20 HOOKS, COASTWIDE) AND COMPARING IT WITH SERIES A (20 HOOKS, NORTH OF VANCOUVER ISLAND)

We now construct Series D, which is for the first 20 hooks of each skate (like for Series A) but covers the whole coast, including the WCVI (unlike Series A), as was summarised in Table B.2. We then show that Series A (north of Vancouver Island (VI)) and Series D (whole coast) show similar relative changes over the overlapping years, and so Series A can be considered representative of the whole coast, i.e. the population off the WCVI is not showing a different relative trend to the rest of the coast.

Figure B.14(a) shows the absolute catch rate index for Series A (first 20 hooks from each skate, north of VI, as in Figure B.12(a)), together with the shorter time series for Series D (first 20 hooks, coastwide, for 1999 and 2001-2014). For all overlapping years, the Series D means and confidence intervals are less than those for Series A.

For Series A, define G_A to be the geometric mean of the bootstrapped annual means, with the geometric mean based only the years that overlap with Series D (i.e. 1999 and 2001-2014). Define G_D similarly for Series D. By dividing the bootstrapped values for each series by their

Table B.8. Catch rates by year for Series D, which is first 20 hooks for all stations (coastwide) for 1999 and 2001-2014. 'Sample $\bar{I}_t$' is the sample mean. B'ed means bootstrapped value. 'No YYR' is the proportion of sets that did not catch Yelloweye Rockfish that year. Lower and higher are the lower and upper bounds of the 95% bias-corrected and adjusted (BCa) confidence intervals.

Year	Sets, n_t	No YYR	Sample $\bar{I}_t$	B'ed I_t	B'ed I_t lower	B'ed I_t higher	B'ed I_t CV
1999	168	0.64	1.55	1.55	1.09	2.22	0.18
2001	170	0.71	1.64	1.64	1.16	2.32	0.18
2002	170	0.76	0.80	0.80	0.54	1.27	0.21
2003	170	0.70	0.91	0.91	0.63	1.42	0.20
2004	170	0.70	1.15	1.15	0.80	1.70	0.19
2005	170	0.70	1.02	1.02	0.72	1.50	0.19
2006	170	0.77	0.99	0.99	0.66	1.51	0.21
2007	170	0.78	0.92	0.92	0.61	1.40	0.21
2008	169	0.77	1.08	1.08	0.72	1.71	0.22
2009	170	0.71	1.33	1.33	0.93	1.98	0.19
2010	170	0.71	1.41	1.41	0.95	2.20	0.22
2011	170	0.71	0.98	0.98	0.69	1.39	0.18
2012	170	0.78	0.80	0.81	0.53	1.24	0.22
2013	170	0.79	0.85	0.85	0.56	1.33	0.22
2014	170	0.77	0.62	0.62	0.40	0.97	0.22

respective geometric means, we obtain Figure B.14(b). The rescaled means are very close to each other, such that for the overlapping years the temporal patterns for Series A and Series D are very similar. (Values for Series A and Series D are given in Tables B.5 and B.8, respectively, and for the rescaled series in Tables B.9 and B.10).

Thus the relative patterns for Series A and Series D appear similar for the overlapping years. But the absolute catch rates in Figure B.14(a) show that inclusion of the WCVI stations in Series D consistently reduces the catch rates from those of Series A (that did not include the WCVI stations). So while inclusion of the WCVI stations does not appear to change the *relative* pattern of the index of the population, it does change the absolute values. Therefore the stations off the WCVI have to be included or excluded consistently to construct an index series; since we have more years that do not have stations off the WCVI (Table B.2), we consistently exclude these stations (giving Series A).

The stations off the WCVI have lower average catch rates than the remaining stations. Excluding them in Series A increases the (geometric and arithmetic) means of the catch rates by 12% (Table B.10) compared to Series D. Thus, in Figure B.14(a) we cannot simply join up the 1997, 1998 and 1999 Series A values with the Series D values for the other years, because the 1997, 1998 and 1999 values exclude stations off the WCVI that appear to have lower catch rates.

So the population off the WCVI appears to be changing in the same way as the rest of the coast for the overlapping years (1999, 2001-2014), it just has lower catch rates in the IPHC survey than for the rest of the coast. Thus, Series A can be considered to be an index of the coastwide population for the overlapping years.

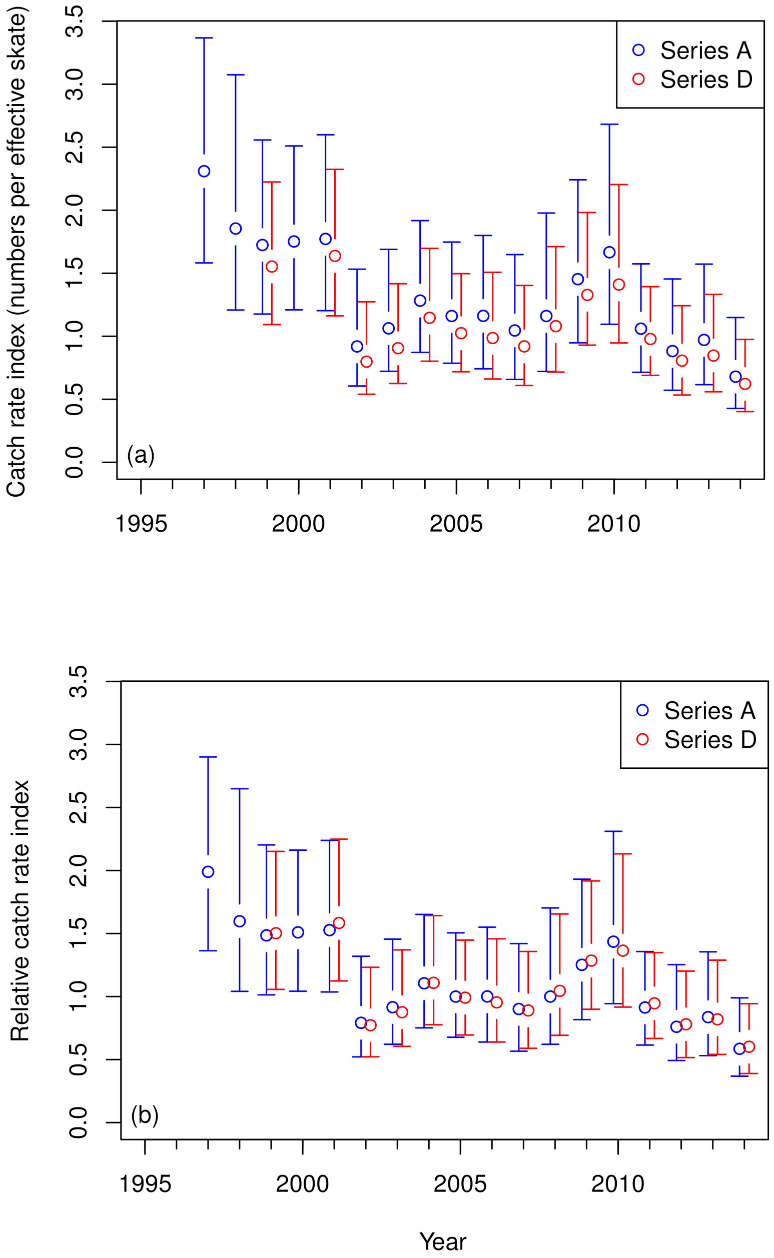

Figure B.14. (a) Catch rate index (number of individual Yelloweye Rockfish caught per effective skate) for Series A (20 hooks, north of Vancouver Island) and Series D (20 hooks, coastwide) for 1999 and 2001-2014 (plus 1997, 1998 and 2000 for Series A). For a given year, the catch rate for each set is calculated from (B.5). These catch rates are then resampled for 10,000 bootstrap values, from which a bootstrapped mean (open circles) and 95% bias-corrected and adjusted confidence intervals (bars) are calculated. (b) Each series is divided by the geometric mean of its bootstrapped annual means (with the geometric mean based on the overlapping years only), to enable comparison in the overlapping years.

Table B.9. As for Table B.5 for Series A, but with catch rates rescaled by dividing by $G'_A = 1.16$, the geometric mean of the bootstrapped means for the years that overlap with Series D, for plotting in Figure B.14(b). 'Sample $\bar{I}_t$' is the rescaled sample mean. B'ed means bootstrapped value. 'No YYR' is the proportion of sets that did not catch Yelloweye Rockfish that year. Lower and higher are the lower and upper bounds of the rescaled 95% bias-corrected and adjusted (BCa) confidence intervals.

Year	Sets, n_t	No YYR	Sample $\bar{I}_t$	B'ed I_t	B'ed I_t lower	B'ed I_t higher	B'ed I_t CV
1997	121	0.66	1.99	1.99	1.36	2.90	0.19
1998	128	0.66	1.59	1.60	1.04	2.65	0.23
1999	134	0.62	1.49	1.49	1.01	2.20	0.20
2000	129	0.64	1.50	1.51	1.04	2.16	0.18
2001	135	0.70	1.53	1.53	1.04	2.24	0.19
2002	135	0.75	0.79	0.79	0.52	1.32	0.23
2003	135	0.67	0.92	0.92	0.62	1.46	0.22
2004	135	0.69	1.10	1.11	0.75	1.65	0.20
2005	135	0.69	1.01	1.00	0.68	1.51	0.20
2006	135	0.76	1.00	1.00	0.64	1.55	0.22
2007	135	0.76	0.90	0.90	0.57	1.42	0.23
2008	134	0.77	1.00	1.00	0.62	1.70	0.26
2009	135	0.71	1.25	1.25	0.82	1.93	0.22
2010	135	0.68	1.44	1.44	0.94	2.31	0.23
2011	135	0.71	0.92	0.91	0.61	1.36	0.20
2012	135	0.77	0.76	0.76	0.49	1.25	0.24
2013	135	0.77	0.84	0.84	0.53	1.35	0.24
2014	135	0.76	0.58	0.59	0.37	0.99	0.25

Table B.10. As for Table B.8 for Series D, but with catch rates rescaled by dividing by $G_D = 1.03$, the geometric mean of the bootstrapped means for the years that overlap with Series A, for plotting in Figure B.14(b). 'Sample $\bar{I}_t$' is the rescaled sample mean. B'ed means bootstrapped value. 'No YYR' is the proportion of sets that did not catch Yelloweye Rockfish that year. Lower and higher are the lower and upper bounds of the rescaled 95% bias-corrected and adjusted (BCa) confidence intervals. The ratio of the geometric means is $G'_A/G_D = 1.12$; the respective arithmetic means are 1.20 and 1.07, with a ratio of 1.12.

Year	Sets, n_t	No YYR	Sample $\bar{I}_t$	B'ed I_t	B'ed I_t lower	B'ed I_t higher	B'ed I_t CV
1999	168	0.64	1.50	1.50	1.06	2.15	0.18
2001	170	0.71	1.58	1.58	1.12	2.25	0.18
2002	170	0.76	0.77	0.77	0.52	1.23	0.21
2003	170	0.70	0.88	0.88	0.60	1.37	0.20
2004	170	0.70	1.11	1.11	0.78	1.64	0.19
2005	170	0.70	0.99	0.99	0.70	1.45	0.19
2006	170	0.77	0.96	0.95	0.64	1.46	0.21
2007	170	0.78	0.89	0.89	0.59	1.36	0.21
2008	169	0.77	1.04	1.04	0.69	1.66	0.22
2009	170	0.71	1.28	1.29	0.90	1.92	0.19
2010	170	0.71	1.37	1.36	0.92	2.13	0.22
2011	170	0.71	0.95	0.95	0.67	1.35	0.18
2012	170	0.78	0.78	0.78	0.52	1.20	0.22
2013	170	0.79	0.82	0.82	0.54	1.29	0.22
2014	170	0.77	0.60	0.60	0.39	0.94	0.22

B.6.4 CONSTRUCTING SERIES C (ALL HOOKS, COASTWIDE) AND COMPARING IT WITH SERIES B (ALL HOOKS, NORTH OF VANCOUVER ISLAND)

We now construct Series C, which is for all hooks from each skate (like for Series B) but covers the whole coast, including the WCVI (unlike Series B), as was summarised in Table B.2. We then show that Series B (north of VI) and Series C (whole coast) are similar over the overlapping years, and so Series B can be considered representative of the whole coast, i.e. the population off the WCVI is not showing a different relative trend to the rest of the coast, as demonstrated above for Series A and D.

Figure B.15(a) shows the absolute catch rate index for Series B (all hooks, north of VI), together with the shorter time series for Series C (all hooks, coastwide, for 2003-2012 and 2014). For all overlapping years, the Series C means and confidence intervals are less than those for Series B.

For Series B, define G_B to be the geometric mean of the bootstrapped annual means, with the geometric mean based only the years that overlap with Series C (i.e. 2003 to 2012 and 2014). Define G_C similarly for Series C. By dividing the bootstrapped values for each series by their respective geometric means, we obtain Figure B.15(b). The rescaled means are very close to each other, such that for the overlapping years the temporal patterns for Series B and Series C are very similar. (Values for Series B and Series C are given in Tables B.6 and B.11, respectively, and for the rescaled series in Tables B.12 and B.13).

Thus the relative patterns for Series B and Series C appear similar for the overlapping years. But the absolute catch rates in Figure B.15(a) show that inclusion of the WCVI stations in Series C consistently reduces the catch rates from those of Series B (that did not include the WCVI stations). So while inclusion of the WCVI stations does not appear to change the *relative* pattern of the index of the population, it does change the absolute values. Therefore the stations off the WCVI have to be included or excluded consistently to construct an index series; since we have more years that do not have stations off the WCVI (Table B.2), we consistently exclude these

Table B.11. Catch rates by year for Series C, which is all hooks for all stations (coastwide) from 2003-2012 and 2014. 'Sample $\bar{I}_t$' is the sample mean. B'ed means bootstrapped value. 'No YYR' is the proportion of sets that did not catch Yelloweye Rockfish that year. Lower and higher are the lower and upper bounds of the 95% bias-corrected and adjusted (BCa) confidence intervals.

Year	Sets, n_t	No YYR	Sample $\bar{I}_t$	B'ed I_t	B'ed I_t lower	B'ed I_t higher	B'ed I_t CV
2003	170	0.58	0.90	0.90	0.62	1.43	0.21
2004	170	0.59	1.13	1.13	0.81	1.60	0.17
2005	170	0.59	1.00	1.00	0.71	1.40	0.17
2006	170	0.61	0.99	0.99	0.69	1.44	0.19
2007	170	0.67	0.82	0.82	0.56	1.18	0.19
2008	169	0.62	1.00	1.00	0.68	1.49	0.20
2009	170	0.56	1.18	1.17	0.85	1.69	0.18
2010	170	0.61	1.28	1.28	0.88	1.98	0.21
2011	170	0.62	0.94	0.94	0.66	1.37	0.19
2012	170	0.71	0.89	0.89	0.61	1.34	0.20
2014	170	0.64	0.60	0.60	0.42	0.89	0.19

stations (giving Series B).

The stations off the WCVI have lower average catch rates than the remaining stations. Excluding them in Series B increases the (geometric and arithmetic) means of the catch rates by 11% (Table B.13) compared to Series C. Thus, in Figure B.15(a) we cannot simply join up the 1995 and 1996 Series B values with the Series C values for the other years, because the 1995 and 1996 values exclude stations off the WCVI that appear (at least for the later years that we have data for) to have lower catch rates.

So the population off the WCVI appears to be changing in the same way as the rest of the coast for the overlapping years (2003-2012 and 2014), it just has lower catch rates in the IPHC survey than for the rest of the coast. Thus, Series B can be considered to be an index of the coastwide population for the overlapping years.

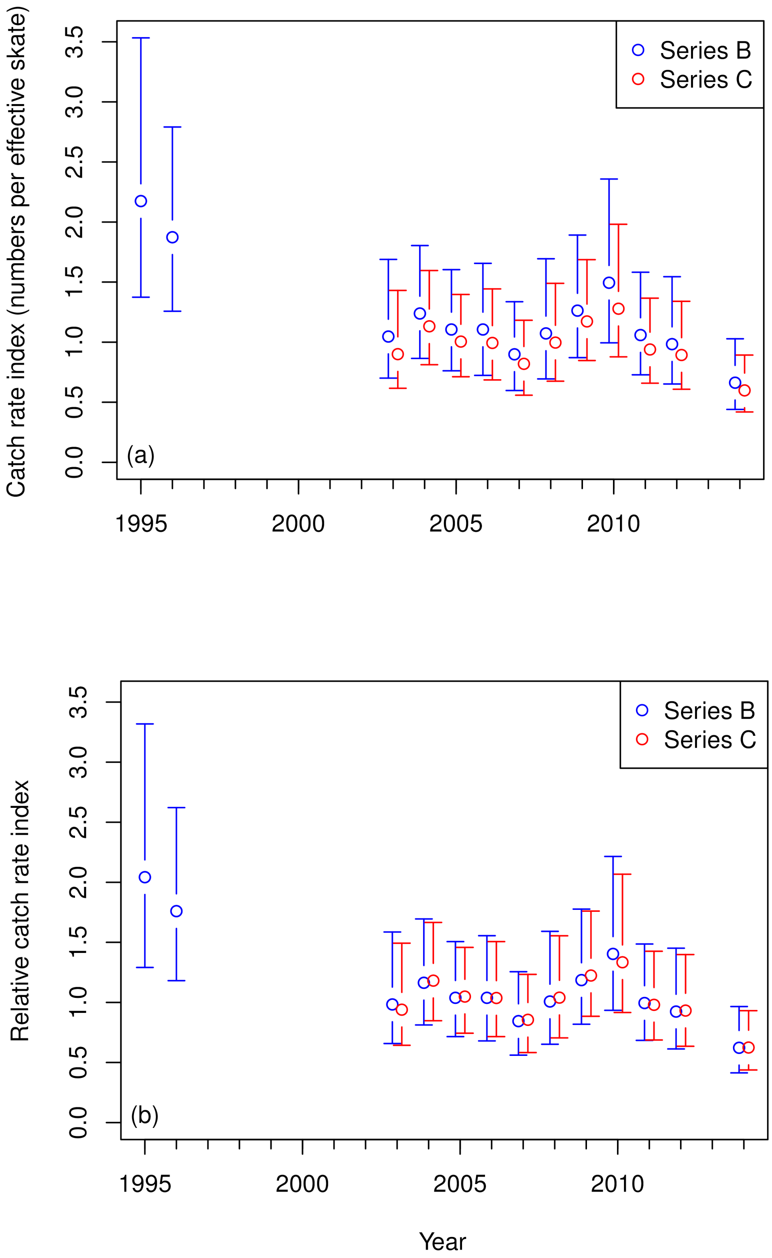

Figure B.15. (a) Catch rate index (number of individual Yelloweye Rockfish caught per effective skate) for Series B (all hooks, north of Vancouver Island) and Series C (all hooks, coastwide) from 2003-2012 and 2014 (plus 1995 and 1996 for Series B). For a given year, the catch rate for each set is calculated from (B.2). These catch rates are then resampled for 10,000 bootstrap values, from which a bootstrapped mean (open circles) and 95% bias-corrected and adjusted confidence intervals (bars) are calculated. (b) Each series is divided by the geometric mean of its bootstrapped annual means (with the geometric mean based on the overlapping years only), to enable comparison in the overlapping years.

Table B.12. As for Table B.6 for Series B, but with catch rates rescaled by dividing by $G'_B = 1.06$, the geometric mean of the bootstrapped means for the years that overlap with Series C, for plotting in Figure B.15(b). 'Sample $\bar{I}_t$' is the rescaled sample mean. B'ed means bootstrapped value. 'No YYR' is the proportion of sets that did not catch Yelloweye Rockfish that year. Lower and higher are the lower and upper bounds of the rescaled 95% bias-corrected and adjusted (BCa) confidence intervals.

Year	Sets, n_t	No YYR	Sample $\bar{I}_t$	B'ed I_t	B'ed I_t lower	B'ed I_t higher	B'ed I_t CV
1995	115	0.70	2.04	2.04	1.29	3.32	0.24
1996	120	0.61	1.76	1.76	1.18	2.62	0.20
2003	135	0.55	0.98	0.98	0.66	1.59	0.22
2004	135	0.59	1.16	1.16	0.81	1.69	0.19
2005	135	0.57	1.04	1.04	0.72	1.51	0.19
2006	135	0.61	1.04	1.04	0.68	1.56	0.21
2007	135	0.67	0.84	0.84	0.56	1.26	0.21
2008	134	0.60	1.01	1.01	0.65	1.59	0.23
2009	135	0.57	1.19	1.19	0.82	1.78	0.20
2010	135	0.59	1.40	1.40	0.93	2.21	0.22
2011	135	0.61	1.00	0.99	0.68	1.49	0.20
2012	135	0.69	0.93	0.92	0.61	1.45	0.22
2014	135	0.62	0.62	0.62	0.41	0.97	0.22

Table B.13. As for Table B.11 for Series C, but with catch rates rescaled by dividing by $G_C = 0.96$, the geometric mean of the bootstrapped means for the years that overlap with Series B, for plotting in Figure B.15(b). 'Sample $\bar{I}_t$' is the rescaled sample mean. B'ed means bootstrapped value. 'No YYR' is the proportion of sets that did not catch Yelloweye Rockfish that year. Lower and higher are the lower and upper bounds of the rescaled 95% bias-corrected and adjusted (BCa) confidence intervals. The ratio of the geometric means is $G'_B/G_C = 1.11$; the respective arithmetic means are 1.08 and 0.98 , with a ratio of 1.11 .

Year	Sets, n_t	No YYR	Sample $\bar{I}_t$	B'ed I_t	B'ed I_t lower	B'ed I_t higher	B'ed I_t CV
2003	170	0.58	0.94	0.94	0.64	1.49	0.21
2004	170	0.59	1.18	1.18	0.85	1.67	0.17
2005	170	0.59	1.05	1.05	0.74	1.46	0.17
2006	170	0.61	1.04	1.04	0.72	1.51	0.19
2007	170	0.67	0.86	0.86	0.58	1.23	0.19
2008	169	0.62	1.04	1.04	0.70	1.55	0.20
2009	170	0.56	1.23	1.22	0.88	1.76	0.18
2010	170	0.61	1.34	1.33	0.92	2.07	0.21
2011	170	0.62	0.98	0.98	0.69	1.43	0.19
2012	170	0.71	0.93	0.93	0.63	1.40	0.20
2014	170	0.64	0.63	0.62	0.44	0.93	0.19

B.7 CONCLUSION – SERIES AB IS THE LONGEST IPHC SERIES WE CAN CONSTRUCT AND CAN BE CONSIDERED A COASTWIDE INDEX

For all years that comparisons could be made, the two Series that exclude stations off the WCVI (Series A and B) demonstrated the same relative temporal patterns as the two Series that included the stations off the WCVI (Series D and B, respectively), and so we assume that the same holds for the few years for which we are unable to make such a comparison (namely 1995-1998 and 2000). Since Series AB is the longest that we are able to construct it would be a suitable index for the assessment model, and we consider it to be an index of the coastwide population for all years.

We would therefore recommend that the absolute catch rate index for Series AB in Figure B.13(b), with values in Table B.7, could be used an input to an assessment model. But for this stock assessment of Yelloweye Rockfish the index from Appendix C was used.

We note that Series AB does show a somewhat abrupt drop in catch rates between 2001 and 2002 (a 48% drop in the sample mean from 1.77 to 0.92). The survey report for 2002 (Dykstra et al., 2003) suggests no methodological reason for such a decline, since 'survey station design and most sampling protocols were left unchanged from 2001'. Indeed, when comparing the design and sampling protocols with those from 2001 (Dykstra et al., 2002), we see no alterations that would lead to a drop in catch rates of Yelloweye Rockfish. For Pacific Halibut, Figure 2 of Dykstra et al. (2003) only shows an 8% drop in catch rates (pounds per skate) from 2001 to 2002 (and a 6% increase from 1999 to 2002), further suggesting that there is not a methodological reason for the survey to have lower catch rates (in general) in 2002 compared to 2001.

B.8 DISCUSSION

Future uses of the IPHC survey data for Canadian Pacific groundfish stock assessments could investigate the use of, for example, generalised linear models. There was not time to do so for this assessment, but the extensive data processing and associated R code developed for this work should prove useful for such work.

Also, further methods could be considered, such as the delta-gamma method (e.g. Lecomte et al. 2013) that would explicitly model the zero catch rates seen for some sets. For the Redbanded Rockfish assessment, it was not clear *a priori* whether or not the delta-gamma method would lead to reduced coefficients of variation for the catch rates (Jean-Baptiste Lecomte, Pacific Biological Station, Nanaimo, BC, pers. comm.). The method used here does not explicitly account for the expected increased number of sets with zero catches in 2012 compared to other years (recall that the bait experiment in 2012 meant that only four skates could be used from each set). However, 2012 did not have the highest proportion of zero catches (Table B.7) and does not look anomalous (Figure B.13), and so the methods used here appear to be suitable.

B.9 REFERENCES

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APPENDIX C. LONGLINE SURVEY ABUNDANCE INDICES

MULTINOMIAL EXPONENTIAL ANALYSIS FOR IPHC AND PHMA DATA

IPHC and PHMA data sets are analyzed using a Multinomial Exponential Model (Somerton and Kikkawa 1995, Etienne 2015). These methods account for empty hooks and the competition for hooks between species and have been applied to develop abundance indices for Yelloweye and Quillback Rockfishes in their respective stock assessments (Yamanaka et al. 2012a and Yamanaka et al. 2012b).

The MEM approach requires information on:

N_T, the total number of target species caught (Yelloweye Rockfish),
N_{NT}, the total number of non-target species caught,
N_E, the number of hooks with returned with no bait (referred to as empty hooks),
N_B, the number of baited hooks returned,
S, the total time the fishing set is in the water (referred to as soaktime).

MEM assumes:

the vector (N_B, N_T, N_{NT}, N_E) has a multinomial distribution, M(N, a), with $a=(a_1, a_2, a_3, a_4)$ and

$a_1 = \exp(-\lambda S)$,
$a_2=[1-\exp(-\lambda S)]\ \lambda_T/\lambda\ (1-p_T)$,
$a_3=[1-\exp(-\lambda S)]\lambda_{NT}/\lambda\ (1-p_{NT})$,
$a_4=[1-\exp(-\lambda S)]\ (\lambda_T p_T+\lambda_{NT}\ p_{NT})/\lambda$.

λ is interpreted as the global pressure on a hook and is an index of the total relative abundance of fish, while λ_T is the relative abundance of the target species, Yelloweye Rockfish.

To account for differences between various depths, λT (resp λNT) the relative abundance of Yelloweye Rockfish (with respect to other species) in year y, at depth d, has been split as

$\log(\lambda T_{yd})= m_0 + m_y + a_d$,

Depth intervals split as in the PHMA survey: 20 – 70, 71-150, 151-250 metres.

The Yelloweye Rockfish relative abundance, for year y, is then given by $\exp(m_0 + m_y)$.

An additional parameter is the probability of a fish escaping from the hooks, this probability may be considered fixed over years, reflecting the notion that this probability only depends on the gear and not on the conditions or considered as variable over years and depth to account for weather conditions or local conditions, the ability of the fish at escaping from the hooks may vary.

The indices presented used this second version.

As mentioned in (Yamanaka et al. 2012b), in this form the MEM is not identifiable, therefore an additional biological assumption is required to identify the source of empty hooks. Here, we make the assumption that the probability of Yelloweye Rockfish escaping from the hook once caught is insignificant and hence have used the version MEM1. This assumption is reflected in empirical data collected from a project comparing visual abundance estimates with CPUE (S. Obradovich PhD research, UBC).

A Bayesian approach is used for the estimation. A uniform prior distribution between 0 and 1 is used for the probability of escape, while a normal distribution with large standard deviation (1000) is used as the prior distribution for all others parameters.

The code used to run this analysis is available on the Yelloweye GitHub website, with the longline package available on the Longline Analysis GitHub website.

LONGLINE SURVEY CATCH INDICES

The combined survey indices are shown together in Table C 1 (see Tables 4 and 5 on pages 15 to 17 of the main document).

Table C 1. Standardized abundance indices from three different longline research surveys. IPHC refers to the International Pacific Halibut Commission Standardized Stock Assessment long line survey. PHMA_S refers to the Pacific Halibut Management Association –southern area longline survey, PHMA_N refers to Pacific Halibut Management Association –northern area longline survey. The counter reflects the index series identifier in the stock assessment model. Proc sigma refers to the standard deviation (SD) in the natural logarithm between the index and the model predicted index based on some annual systematic process affecting the scaling between the index and stock size. The values shown were obtained with the state-space parameter σ_p *set at 0.05. The Proc sigma values were updated with each new estimation in the sensitivity analyses. Obs sigma refers to the SD in the natural logarithm of the index computed based on the processing of the longline survey data that produced the index. Index values are relative. Indices are rescaled to the same order as the survey indices.*

Series	Counter	Year	Index	Proc sigma	Obs sigma
IPHC	5	1995	2.331	0.25	0.0272
IPHC	5	1996	3.067	0.25	0.0309
IPHC	5	1997	2.351	0.25	0.0545
IPHC	5	1998	2.887	0.25	0.0483
IPHC	5	1999	1.752	0.25	0.0475
IPHC	5	2000	3.132	0.25	0.0539
IPHC	5	2001	2.625	0.25	0.0615
IPHC	5	2002	2.035	0.25	0.0883
IPHC	5	2003	1.57	0.25	0.0296
IPHC	5	2004	1.974	0.25	0.0268
IPHC	5	2005	1.7	0.25	0.0308
IPHC	5	2006	1.803	0.25	0.0321
IPHC	5	2007	1.415	0.25	0.0369
IPHC	5	2008	0.9775	0.25	0.0347
IPHC	5	2009	1.217	0.25	0.0295
IPHC	5	2010	1.417	0.25	0.0246
IPHC	5	2011	1.286	0.25	0.033
IPHC	5	2012	1.266	0.25	0.0351
IPHC	5	2013	1.307	0.25	0.0753
IPHC	5	2014	1.143	0.25	0.0372
PHMA_S	6	2007	4.828	0.5	0.0177
PHMA_S	6	2009	4.225	0.5	0.018
PHMA_S	6	2011	6.396	0.5	0.0161
PHMA_S	6	2014	2.112	0.5	0.0238
PHMA_N	7	2006	5.067	0.2	0.0166
PHMA_N	7	2008	5.909	0.2	0.0163
PHMA_N	7	2010	5.054	0.2	0.0169
PHMA_N	7	2012	6.055	0.2	0.0158

COMPARING MEAN CPUE AND THE EXPONENTIAL MODEL

Comparing the two treatment methods of the IPHC SSA data, the exponential model takes into account the fate of the empty hooks and is better described than the mean CPUE. The trends are the same with the exponential model being slightly more conservative.

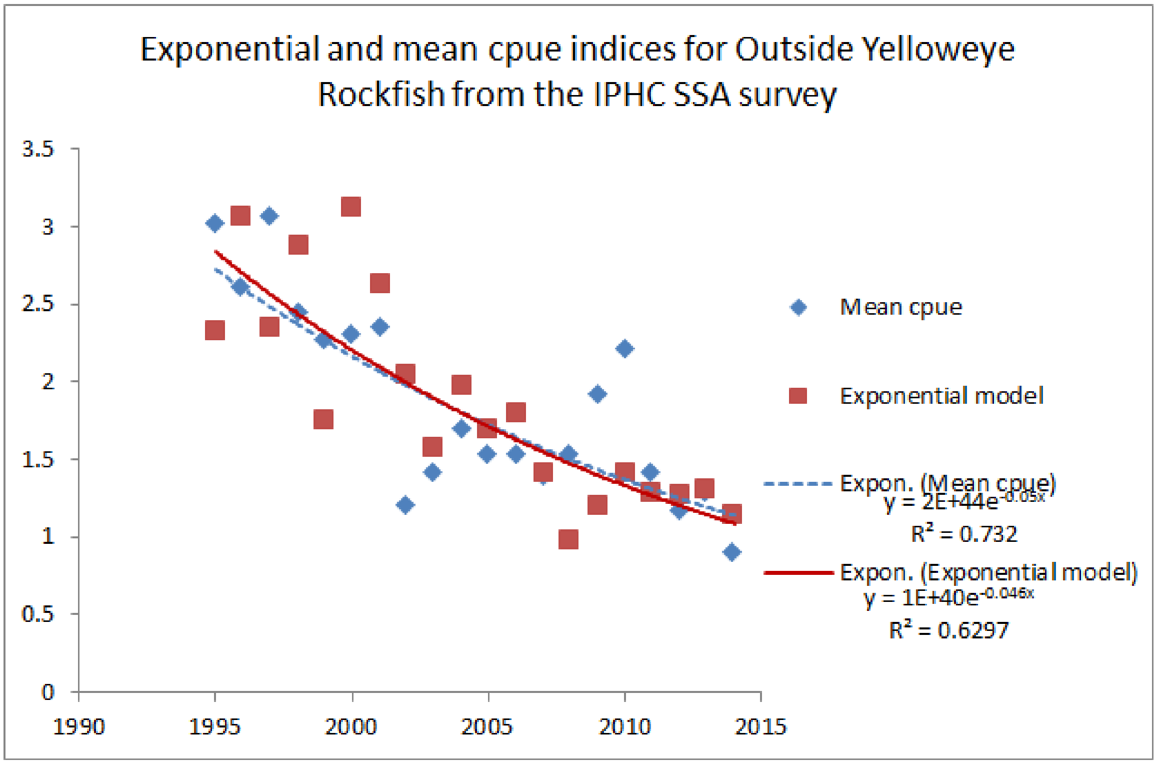

Figure C 1. A comparison of the exponential model (Appendix C.1) and mean CPUE (Appendix B) abundance indices from the International Pacific Halibut Commission (IPHC) Standardized Stock Assessment (SSA) survey data for Outside Yelloweye Rockfish from 1995 to 2014.

References

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APPENDIX D. TRAWL SURVEY ABUNDANCE INDICES

Yelloweye Rockfish are incidentally caught in the Hecate Strait/Dixon Entrance, Queen Charlotte Sound and West Coast Vancouver Island synoptic trawl research surveys. All data were retrieved from GFBio and the following algorithm used to estimate biomass from tow data (N. Olsen, DFO, pers. comm.). The Yelloweye Rockfish biomass in any year *y* was obtained by summing the product of the CPUE and the area surveyed across the surveyed strata *i*:

$$\text{Appendix A. } B_y = \sum_{i=1}^{k} C_{y_i} A_i = \sum_{i=1}^{k} B_{y_i} \qquad \textbf{D. 1}$$

where C_{y_i} = mean CPUE density (kg/km^2) of Yelloweye Rockfish in stratum *i*

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

B_{y_i} = biomass of Yelloweye Rockfish in stratum *i* for year *y*.

k = number of strata

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

$$\text{Appendix B. } C_{y_i} = \frac{\sum_{j=1}^{n_{y_i}} \left(W_{y_i j} \middle/ D_{y_i j} w_{y_i j} \right)}{n_{y_i}} \qquad \textbf{D. 2}$$

where $W_{y_i j}$ = catch weight (kg) for Yelloweye 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 (doorspread; km) by tow *j* in stratum *i* for year *y*

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

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

Table D 2. Swept area abundance indices obtained from synoptic trawl surveys. QCSS stands for Queen Charlotte Sound Synoptic, HSS stands for Hecate Strait Synoptic, and WCVIS stands for West Coast Vancouver Island Synoptic. The counter reflects the index series identifier in the stock assessment model. Proc sigma refers to the standard deviation (SD) in the natural logarithm between the index and the model predicted index based on some annual systematic process affecting the scaling between the index and stock size. The values shown were obtained with the state-space parameter σ_p set at 0.05. The Proc sigma values were updated with each new estimation in the sensitivity analyses. Obs sigma refers to the SD in the natural logarithm of the index computed based on the processing of the trawl survey data for the index. Biomass values are in tonnes.

Series	Counter	Year	Index (t)	Proc sigma	Obs sigma
QCSS	1	2003	205	0.1	0.4
QCSS	1	2004	312.8	0.1	0.35
QCSS	1	2005	271.2	0.1	0.24
QCSS	1	2007	149.5	0.1	0.21
QCSS	1	2009	134.3	0.1	0.25
QCSS	1	2011	251.1	0.1	0.57
QCSS	1	2013	160.9	0.1	0.2

Series	Counter	Year	Index (t)	Proc sigma	Obs sigma
HSS	2	2005	16.58	0	0.38
HSS	2	2007	25.45	0	0.44
HSS	2	2009	10.52	0	0.61
HSS	2	2011	13.89	0	0.5
HSS	2	2013	19.82	0	0.41
WCVIS	3	2004	176.6	0.3	0.4
WCVIS	3	2006	89.8	0.3	0.28
WCVIS	3	2008	149.8	0.3	0.33
WCVIS	3	2008	149.8	0.3	0.33
WCVIS	3	2010	158.5	0.3	0.28
WCVIS	3	2012	145	0.3	0.32
WCVIS	3	2014	62.7	0.3	0.36

References

Efron, B. 1982. The Jackknife, the Bootstrap and Other Resampling Plans. CBMS-NSF Regional Conference Series in Applied Mathematics, Monograph 38, SIAM, Capital City Press, Montpelier, Vermont, U.S.A. 92 p.

APPENDIX E. BAYESIAN DELAY-DIFFERENCE MODEL METHODOLOGY

A delay-difference model was applied in the sensitivity analysis to evaluate the sensitivity of stock assessment results to the form of the stock assessment model. The surplus production model which was used as the reference case model assumes that all dynamics are determined at the lag of one year and has no explicit age-structured features except in the derivation of the prior for r. To evaluate the sensitivity of results to applying a model that includes a key age-structured feature, i.e., the median age of maturity, such that the lag in recruitment of mature fish to the fishery is accounted for, a Bayesian version of a delay difference model was formulated, coded up and applied. The version adopted was formulated to include a minimum of assumptions and additional parameters to estimate so as to be relatively easy to apply but also be put into an MSY-based stock assessment framework analogous to that of the BSP model.

The delay difference model methodology was not adopted as the reference case methodology because the version adopted is a newly coded beta version of the software that has never before been applied in any stock assessment nor peer-reviewed. The version also makes a number of unrealistic assumptions about which parameters can be considered to be treated as fixed and known. For example, the age of recruitment is assumed to be same for all fisheries and equal to the posterior median estimate of the age at which 50% of the females mature and known without error, and the rate of natural mortality and the Ford-Walford growth parameters are also presumed to be known without error and equal to the posterior median estimates for outside Yelloweye Rockfish. Furthermore, the BSP model has been simulation tested for accuracy and performance in management procedures in a number of different studies and found to perform adequately in a wide-variety of circumstances. The Bayesian delay-difference model described here, in contrast, has not undergone any simulation testing to date, except to fit the model to data simulated from a single scenario to ensure that it could recover, satisfactorily, the true parameters and stock biomass values in the model used to simulate the data.

The delay difference model form applied was that reported in Walters and Martell (2004), p. 107. Stock biomass at the beginning of year t (B_t) and the recruited abundance in year t (N_t) are predicted from the previous year as follows:

$$B_{t+1} = S_t(\alpha N_t + \rho B_t) + w_{a_R} R_{t+1} \; if \; t > t_{init} \tag{E.1}$$

$$B_{t+1} = S_M(\alpha N_{init} + \rho B_{init}) + w_{a_R} R_{t+1} \; if \; t = t_{init} \tag{E.2}$$

$$N_{t+1} = S_t N_t + R_{t+1} \tag{E.3}$$

$$S_t = \left(1 - \frac{C_{C,t}}{B_t}\right) exp\left(-\left(M + k_r E_{r,t} + k_T E_{T,t}\right)\right) \tag{E.4}$$

where S_t is the annual fraction surviving from fishing and natural mortality, α and ρ are the Ford-Walford (F-W) growth parameters, R_t is the number of recruits in year t, w_{a_R} is fish body mass at the age of recruitment to the fishery a_R, k_r, k_t, $E_{r,t}$, and $E_{T,t}$ are the catchability coefficients for outside Yelloweye Rockfish and annual fishing effort in the recreational and salmon troll fisheries, and $C_{C,t}$ is the inputted value for the sum of directed commercial fishery, halibut fishery and Aboriginal catches of outside waters Yelloweye Rockfish. The F-W equation uses a linearity assumption to predict body weight at the current age from the previous age: $W_a = \alpha + \rho W_{a-1}$. S_t for outside Yelloweye Rockfish was computed annually using the inputed catch biomass for the year, and the imputed values for salmon troll catch, and recreational catch (E.4).

A Ricker stock-recruit function was assumed for outside Yelloweye Rockfish, since as mentioned above, this species is known to be cannibalistic (Love et al. 2002). The annual number of recruits is given by

$$R_{t+a_R} = aB_t exp(-bB_t + e_t - \sigma_R^2/2)\ if\ t > t_{init} + a_R \qquad \text{E.5}$$

$$R_{t+a_R} = R_{init} exp(e_t - \sigma_R^2/2)\ if\ t \le t_{init} + a_R \qquad \text{E.6}$$

where *a* and *b* are the Ricker stock-recruit parameters, t_{init} is the first year of the stock assessment model (i.e. 1918 for outside Yelloweye Rockfish), σ_R is the standard deviation in the natural logarithm of deviates from stock-recruit model predictions and

$$R_{init} = aB_{init} exp(-bB_{init}). \qquad \text{E.7}$$

A normal prior density function was assumed for e_t:

$$e_t \sim Normal(0, \sigma_R^2).$$

e_t were modeled to be independent in years up to the current year of the stock assessment. However, in projections, e_t were assumed to be positively autocorrelated at a lag of one year with a fixed autocorrelation coefficient of 0.5 (see Stanley et al. 2009 for details).

Initial conditions were given as follows. It was assumed that the abundance of recruited fish in the initial year deviated from the average unfished equilibrium abundance. The prior density function for the ratio of abundance to average unfished abundance in the initial year t_{init}, *g*, was lognormal:

$$g \sim logNormal(\ln(1), 0.1^2\ )$$

$$N_{init} = gN_0 \qquad \text{E.8}$$

$$B_{init} = gB_0 \qquad \text{E.9}$$

The lead parameters to estimate were the average unfished stock biomass, B_0, and the Ricker steepness parameter, *h*. The Ricker parameters *a* and *b* in equations E.5 and E.7 were computed as follows:

$$a = \frac{(5h)^{(5/4)}}{\tilde{S}} \qquad \text{E.10}$$

$$b = \frac{1}{B_0} ln\left(a\tilde{S}\right) \qquad \text{E.11}$$

where $\tilde{S}$ is the spawner biomass per recruit under average unfished conditions. This can be obtained in the following equation (Walters and Martell 2004):

$$\tilde{S} = \frac{\frac{S_M \times \alpha}{1-S_M} + w_{a_R}}{1-(\rho \times S_M)} \qquad \text{E.12}$$

The average unfished recruitment and average abundance of recruited fish under unfished conditions are given by:

$$R_0 = \frac{B_0}{\tilde{S}}$$

E.13

$$N_0 = \frac{R_0}{1-S_M} \qquad \text{E.14}$$

where

$$S_M = exp(-M)$$

E.15

a_{max} is the maximum age considered in the model (150 years) and *M* is the instantaneous rate of natural mortality.

A Bayesian estimation approach was implemented for parameter estimation in which only the steepness (*h*), average unfished stock biomass (B_0), ratio of initial stock size to unfished stock size, *g*, and stock-recruit function deviates e_t were estimated. The prior for B_0 was uniform on the natural logarithm of B_0. The prior pdfs for e_t and *g* were normal and lognormal as described above. The prior distribution for the Ricker steepness parameter was obtained from Forrest et al. (2010); these authors obtained a posterior predictive distribution for the Ricker steepness parameter from a hierarchical meta-analysis of rockfish stock-recruit data. The prior density function applied was lognormal with a minimum of 0.24:

$$h \sim logNormal(\ln(0.797), 0.4179^2) \qquad h \geq 0.24$$

It should be noted that unlike the Beverton-Holt steepness parameter which has a maximum of 1, the Ricker steepness parameter is not constrained by this upper bound due to the domed-shape of the Ricker function. While the absolute minimum value for *h* is 0.2, the value of 0.24 was applied as a minimum to avoid numerical instability. The rate of natural mortality was presumed to be fixed and known without error. The value applied was the estimate obtained for this stock assessment, i.e., 0.03802 yr^{-1}. The age of recruitment, a_R, was assumed to be fixed and known without error and was taken as 15 years, the posterior median estimate of the age in which 50% of the females reach maturity that was obtained for this stock assessment.

The Ford-Walford (F-W) growth parameter values were obtained before running the BDD model. ρ and α were obtained by transforming the estimates of von Bertalanffy (vonB) growth parameters and length to weight parameters obtained for this stock assessment. The posterior median values for the vonB parameters were used to predict the length-at-age and these values were transformed to weight-at-age using the posterior median values for the “a” and “b” length to weight (len-wt) conversion parameters. A sums-of-squares deviations objective function (O_{fn}) was applied to estimate the F-W parameters by predicting the mass-at-age from the previous age starting with two years younger than the age at recruitment.

$$O_{fn} = \sum_{a=a_R}^{a_{max}} \left(w_a|vonB - w_a|(F-W)\right)^2 \qquad \text{E.17}$$

where

w_a | vonB and w_a | (F-W) are the weights-at-age predicted by the vonB and length weight parameters and the F-W equations.

The maximum sustainable yield fishing mortality rate (F_{msy}), stock biomass at MSY (B_{msy}), and MSY values associated with each parameter value set drawn during importance sampling were found using the bi-section nonlinear minimization function which searched for the value of *F* that could maximize long-term equilibrium yield.

Replacement yield for year *t* was computed by taking the difference in the initial stock biomass between year t and the previous year and summing this with the total catch biomass taken in year *t*.

$$RepY_t = B_t - B_{t-1} + C_{C,t} + C_{r,t} + C_{T,t} \qquad \text{E.18}$$

Table E.1. Fixed parameter values used in the Bayesian delay difference models for the outside Yelloweye Rockfish assessment. NA indicates that the parameter is unitless.

Parameter	Value	Units
$L_{\infty,VonB}$	638.232	mm
K_{VonB}	4.70E-02	yr^{-1}
$t_{0,VonB}$	-8.366	yr
$a_{len\text{-}wt}$	1.25E-08	kg/mm

Parameter	Value	Units
$b_{len\text{-}wt}$	3.06718	NA
α_{FW}	0.176758	kg
ρ_{FW}	0.96505	NA

The same likelihood functions of the abundance index and salmon troll and recreational fishery catch data as were applied in the BSP model (see the main text section on the BSP model).

In two sensitivity runs, the BDD model was fitted to commercial longline mean length data also. Delay difference models can predict mean weight of fish in the recruited population since they explicitly model the number of recruits, and total mortality and somatic growth effects on an annual basis. Incorrect assumptions about vulnerability at age for different fleets, however, can result in systematic differences in predictions of mean weights.

Both mean length and mean weight data records are available for the longline and trawl fisheries. However, sampled years and sample numbers are fewer for the trawl fishery. Sample sizes are generally considerably greater and records are available in more years for mean length data than for mean weight data. Also the sample sizes have varied considerably over the years for both mean length and weight data from samples of only 29 fish in 2003 up to 1804 fish in 1994. A plot of the mean weights against the mean lengths in years where both are available shows close conformity to a linear relationship with an r-squared value of 82% (Figure E.1). We thus decided to transform the mean length data to mean weight data using the empirically-derived MLE for the linear conversion of mean length to mean weight. We also fitted the model to mean weight values that had no less than 200 samples taken to avoid situations in which samples may have been taken in a non-representative fashion from the outside waters commercial longline fishery. A plot of the time series of the mean weight values to which the BDD model was fitted is shown in Figure E.2.

To account for possible incorrect assumptions about vulnerability at age in the BDD model, a constant of proportionality parameter was applied in fitting the model to the mean weight values. A lognormal likelihood function was applied but using a fixed value for the standard deviation in log deviates.

$$W_{o,t} \sim logNormal(\ln(q_w W_t), \sigma_w^2) \qquad \text{E.19}$$

where q_w is the constant of proportionality between the mean weight "observations", $W_{o,t}$, and the model predicted mean weights, W_t, of recruited fish, and σ_w is the standard deviation in deviates between model predicted and "observed" mean weight values. In the sensitivity runs, σ_w was fixed at 0.3 in one run (F.3) and 0.15 in another run (F.4).

To verify whether the delay difference model formulated and coded up could provide parameter estimates without any serious mistakes in the implementation of the delay difference equations, data were simulated using the delay difference model that had been coded up. A depletion scenario was chosen that was similar to that given by the BSP model and abundance index data were simulated using a lognormal observation error model for these data, i.e., "true" values for the B_0 and h parameters were chose such that the depletion in 2014 relative to unfished biomass was 0.14 and stock biomass in 2014 was about 4000 tons. The observation error standard deviations were set to be relatively small, i.e., 0.11 for all of the abundance index data sets included in the simulation. The intention was to simulate data with relatively little observation error to find out whether the newly coded estimation method could recover the underlying abundance and parameter estimates that generated the data. The same number of data sets with the same representation of years as in the actual reference case abundance index time series were simulated. Also, the same catch records and effort records as went into the reference case were also applied in simulating abundance index data. Only one set of abundance index data were simulated. The delay difference estimation model used the same catch and effort records as were used to simulate the abundance index data.

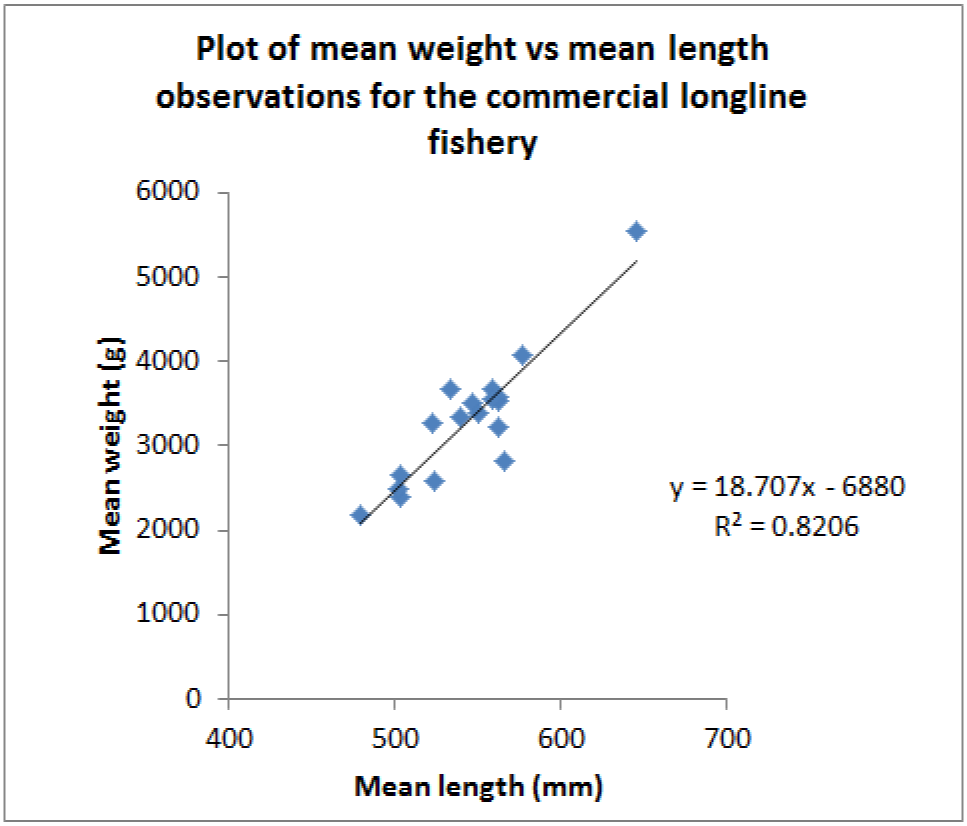

Figure E.1. Plot of mean weight against mean length observations from samples taken from the B.C. outside waters commercial longline fishery for years 1986-2010.

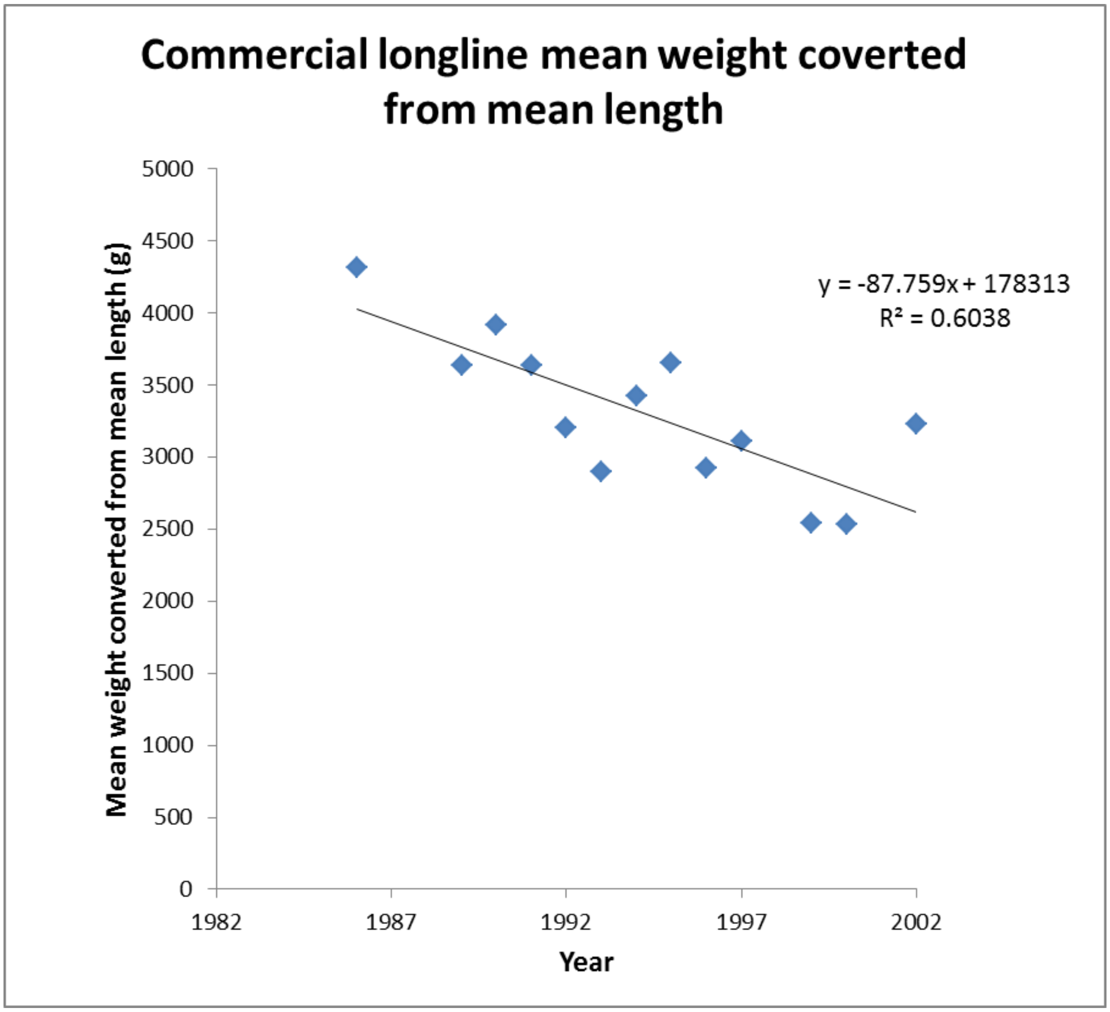

Figure E.2. Plot of the time series of mean weight values converted from mean length sample means for the commercial longline fishery. Values are plotted on for years in which sample sizes were at least 200 fish.

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