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Stock Assessment for the inside population of yelloweye rockfish (*Sebastes ruberrimus*) in British Columbia, Canada for 2010

Évaluation du stock de la population de sébastes aux yeux jaunes (*Sebastes ruberrimus*) des eaux intérieures en Colombie-Britannique, Canada, pour 2010

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ABSTRACT

A new stock assessment is presented for the inside population of yelloweye rockfish (*Sebastes ruberrimus*) in British Columbia, Canada for 2010. A Bayesian state space surplus production (BSP) model is used due to the lack of sufficient age data for a fully age structured stock assessment. The model presented requires a time series of historical annual catch biomass from all fisheries (reconstructed from 1918 to 2009) and is fitted to stock trend data derived from commercial catch and effort data as well as two research survey catch indices. Prior probability distributions are required for key parameters including the maximum intrinsic rate of increase, r, initial stock size relative to unfished stock size, carrying capacity and constants of proportionality for the abundance indices. A reference case assessment model based solely on mortality from fisheries selects the most credible set of model inputs and projects results which are evaluated for a variety of model settings.

The BSP model fits the stock trend data fairly well and predicts that the stock declined in the 1980s when fishery catches increased substantially. Management advice is based on output from a reference case BSP model run which estimates that the inside yelloweye rockfish biomass in 2009 is 780 tonnes (CV 0.46) which is 12% (CV 0.43) of the initial biomass in 1918. This is below the fisheries Limit Reference Point (LRP), 0.4 B_{MSY}, consistent with the Canadian Precautionary Approach and there is a 90% probability that the stock is within the Critical Zone (DFO 2006). The fishing mortality rate in 2009 was above F_{MSY} and the total catch (15 t) is estimated to be 78% (CV 0.66) of the replacement yield.

The model predicts the stock biomass to increase over time under harvest policies similar to 2009. Projecting the stock biomass over a five year time horizon, there is low probability (<14%) that the stock biomass will exceed 0.4 B_{MSY} regardless of the harvest policy. With a total fishing mortality (TAC) of 15 t, over a 40 and 80 year time horizon the probability that the stock biomass exceeds 0.4 B_{MSY} ranges from 44% to 56%, respectively.

Since the early 1990's, abundance indices have continued to decline despite dramatic reductions in fishing mortality. This disparity may indicate the possibility of influences other than fishing on the population that cannot be accounted for in the reference case BSP model. Other possible explanations, outside of fishing effort, could be a lag in population response to the reduction in fishing effort and/or recruitment declines or failure. Another potential influence is investigated, for illustrative purposes only. This novel approach incorporates predation by pinnipeds and sets a framework for possible future analyses but, given current uncertainties in pinniped consumption, is not considered here for management advice. Should future stock biomass continue to decline, under current low fishery catches, other models should be explored to examine factors other than the fishery that could influence the inside yelloweye rockfish stock.

RÉSUMÉ

Une nouvelle évaluation du stock est présentée pour la population de sébastes aux yeux jaunes (*Sebastes ruberrimus*) des eaux intérieures en Colombie-Britannique, Canada, pour 2010. On utilise un modèle bayésien de l'espace d'états de la production excédentaire en raison du manque de données suffisantes sur l'âge pour faire une évaluation du stock selon la structure par âge complète. Le modèle présenté nécessite une série chronologique de la biomasse des captures annuelles historiques pour toutes les pêches (reconstitution de 1918 à 2009) et il est ajusté en fonction des données sur la tendance pour les stocks obtenues à partir des données sur l'effort et les captures commerciales, ainsi que des indices de capture découlant de deux études de recherche. Les répartitions théoriques antérieures sont nécessaires pour les principaux paramètres, dont le taux d'accroissement intrinsèque maximum, « r », la taille initiale du stock par rapport à la taille du stock non exploité, la capacité biotique et les constantes de proportionnalité pour les indices d'abondance. Un modèle d'évaluation du scénario de référence reposant uniquement sur la mortalité due aux pêches sélectionne l'ensemble de données d'entrée du modèle le plus crédible et fait une projection des résultats, lesquels sont évalués pour un éventail de configurations du modèle.

Le modèle bayésien de la production excédentaire ajuste assez bien les données sur la tendance du stock et prédit le déclin du stock dans les années 1980, lorsque les captures par la pêche ont augmenté considérablement. L'avis sur la gestion repose sur le résultat de l'exécution du modèle bayésien de la production excédentaire du scénario de référence qui estime que la biomasse du sébaste aux yeux jaunes des eaux intérieures en 2009 est de 780 tonnes (CV de 0,46), soit 12 % (CV de 0,43) de la biomasse initiale de 1918. Cela se situe en deçà du point de référence limite (PRL) des pêches, 0,4 B_{MSY}, ce qui est conforme à l'approche de précaution canadienne, et il y a une probabilité de 90 % que le stock se situe dans la zone critique (MPO 2006). Le taux de mortalité par la pêche en 2009 était supérieur à F_{MSY} et on estime que le total des captures (15 t) représente 78 % (CV de 0,66) du rendement de remplacement.

Le modèle prédit que la biomasse du stock augmentera au fil du temps avec des politiques de pêche semblables à celles de 2009. Avec une projection de la biomasse sur un horizon prévisionnel de cinq ans, il y a une faible probabilité (<14 %) que la biomasse du stock excède 0,4 B_{MSY}, peu importe la politique en place en matière de captures. Avec une mortalité totale due à la pêche (TAC) de 15 t, sur un horizon prévisionnel de 40 et de 80 ans, la probabilité que la biomasse du stock excède 0,4 B_{MSY} est de 44 % et 56 %, respectivement.

Depuis le début des années 1990, les indices d'abondance ont continué d'afficher un déclin, et ce, malgré une réduction considérable de la mortalité due à la pêche. Cet écart peut indiquer possiblement d'autres influences sur la population que la pêche, dont on ne peut tenir compte dans le modèle bayésien de la production excédentaire du scénario de référence. Parmi les autres explications possibles, mis à part l'effort de pêche, il pourrait y avoir un décalage entre la réponse de la population et la réduction de l'effort de pêche, ou peut-être aussi un déclin ou un échec du recrutement. On étudie une autre influence possible, aux fins de démonstration uniquement. Cette approche novatrice intègre la prédation par les pinnipèdes et établit un cadre en vue d'analyses futures, mais, étant donné les incertitudes actuelles sur la consommation par les pinnipèdes, cela n'est pas pris en considération ici pour l'avis sur la gestion. Si la biomasse future du stock continuait de subir un déclin, avec le faible taux actuel de captures par la pêche, il faudrait étudier d'autres modèles afin d'examiner quels facteurs autres que la pêche pourraient avoir des incidences sur le stock de sébastes aux yeux jaunes des eaux intérieures.

INTRODUCTION

Since 1986, yelloweye rockfish (*Sebastes ruberrimus*) have been 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, 1995, Yamanaka 1995, unpublished manuscript, PSARC G95-11, Yamanaka and Kronlund 1997, Kronlund et al. 1999, Yamanaka and Lacko 2001). The key indicator of yelloweye rockfish stock status in the 2001 stock assessment 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 (B.C.). Harvest advice to managers 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 U.S. (SSC 2000). The F, derived from Z in 1997/98 for the outside population and in 2001 for the inside population of yelloweye rockfish along the B.C. coast was in excess of M.

Recommendations for management also outlined a Rockfish Conservation Strategy to address lingering conservation concerns for inshore rockfish. Components of the Strategy included:

1). Account for all catch (landed and released) across all sectors and in all fisheries
2). Decrease fishing mortality (F<M)
3). Establish areas closed to all fishing
4). Improve stock monitoring and assessment

The Rockfish Conservation Strategy was initiated in late 2001 and worked towards improvements to catch monitoring, the dramatic reduction of allowable catches, implementation of Rockfish Conservation Areas (closed areas) and the commencement of coastwide stock monitoring surveys (Koolman et al. 2007, Yamanaka and Logan 2010). Managers adopted a harvest rate of less than 2% (F < M) in conjunction with spatial management whereby areas were closed to all harvest. No yelloweye rockfish age data were available from the inside area therefore F estimated for quillback rockfish for the inside area was applied to yelloweye rockfish. TACs were reduced for the inside management region in proportion to the required reduction in F for the 2002 fishing year.

In 2006, a stock status report was requested and prepared for the Committee on the Status of Wildlife in Canada (COSEWIC) (Yamanaka et al. 2006). COSEWIC received this status report and included new genetic analyses conducted in 2007 and recognized two designatable units (DUs) of yelloweye rockfish in British Columbia (B.C.); inside and outside (COSEWIC 2008). COSEWIC reviewed the updated status report in November 2008 and designated both DUs of yelloweye rockfish as special concern. His Excellency the Governor General in Council listed both populations of yelloweye rockfish under the *Species At Risk Act* as special concern on June 23, 2011 (http://www.gazette.gc.ca/rp-pr/p2/2011/2011-07-06/html/sor-dors128-eng.html). This stock assessment is solely concerned with the inside DU or population of yelloweye rockfish.

A request for science information and/or advice was received from managers in early 2010 (Appendix 1). This document aims to fulfill the management request to determine the current status of the stock relative to DFO's Precautionary Approach harvest default reference points. Reference points are given together with the rationale for their selection. The assessment model outputs provide forecasts of the influence of varying harvest levels on future population trends. This information is required to develop management plans for the inside yelloweye rockfish DU that has been designated as special concern by COSEWIC.

A new stock assessment methodology that explicitly accounts for trends in predation rates from harbour seals and sea lions (pinnipeds), and its results are also presented in this document. It was motivated by; 1) a continuing decline in yelloweye rockfish abundance indices in recent years despite dramatic reductions in fishing mortality, 2) a growing concern over the potential impact on B.C. rockfishes of increasing pinniped abundance in B.C. inside waters since the 1970s (e.g., about a 10-fold increase in harbour seal abundance) (Olesiuk 2009, 2010), 3) the known predation on rockfishes in B.C. waters by pinnipeds (Olesiuk 1993; Tollit et al. 2009), 4) the high bioenergetic requirements of pinnipeds (e.g., about 6 tons per year per Steller sea lion) (Winship and Trites 2003; Olesiuk, unpublished manuscript), and 5) the high vulnerability of yelloweye rockfish populations to threats such as pinniped predation due to its late age of maturity and low natural mortality rate. This new methodology treats pinniped populations as if they were different fishing fleets but subject to bioenergetic requirements, and incorporates information on diet composition and a Type I functional response (Holling 1959). The results from this new methodology are presented for illustrative purposes to evaluate the sensitivity of the stock assessment results to possible historic variation in predation by harbour seals and sea lions.

DISTRIBUTION

Yelloweye rockfish are distributed in the northeast Pacific from south of Umnak Island in the Aleutian Islands (Mecklenburg et al. 2002) to Ensenada, northern Baja California (Phillips 1957). They occur over rock habitats at depth extremes of 15 to 549 metres (Kramer and O'Connell 1995, Eschmeyer et al. 1983). Yelloweye rockfish range throughout B.C. in open coast, as well as, protected waters, exhibiting a demersal existence over hard, complex substrates such as rock reefs and boulder fields (Yamanaka et al. 2011). Observed depths for 95% of all fishery and research survey data in B.C. lie between 19 and 251 metres (Yamanaka et al. 2006).

Two genetically distinct populations of yelloweye rockfish are recognized in B.C. (Yamanaka et al. 2006, COSEWIC 2008). The outside population is panmictic and known to extend from at least Sitka, Alaska to Bowie Seamount, throughout the open coast waters of B.C. and Washington State to northern Oregon (Yamanaka et al. 2000, Yamanaka et al. 2006). The inside population is distributed throughout most of the protected marine waters East of Vancouver Island. From the sampling conducted between 2004 and 2007, the inside yelloweye rockfish population has a western boundary which lies in a straight line between the western shores of Numas and Malcolm Islands within Queen Charlotte Strait (~127^{o} W) and an approximate southern boundary, near Victoria, B.C. (~48^{o} 20' N) which coincides with the Strait of Georgia marine ecozone (COSEWIC 2008) (Figure 1). Yelloweye rockfish are rarely caught in surveys conducted in the San Juan Islands and Puget Sound area adjacent to Canadian waters and no samples are available for DNA analysis (Wayne Palsson pers. comm.).

The distribution of yelloweye rockfish, shown as catch per unit of effort (CPUE) from research longline surveys, is depicted in Figure 2. There appears to be a break between populations at the southern boundary where no yelloweye rockfish are caught on either side of the boundary. At the western boundary both populations occur in close proximity to each other.

Yelloweye rockfishes are targeted or incidentally caught by all gear types (jig, troll, set-line, and trawl) in the Aboriginal, commercial and recreational fisheries for groundfish, halibut (*Hippoglossus stenolepsis*), spiny dogfish (*Squalus acanthias*), lingcod (*Ophiodon elongatus*), and salmon (*Onchoryncus spp.*). Since the inception of the ZN licensed hook and line rockfish fishery, in 1986, fishery management has been applied over two management units: inside and outside. The inside fishery management area encompasses the Pacific States Marine Fisheries Commission (PSMFC) Major Area 4B and all other B.C. marine waters comprise the outside fishery management area, inclusive of PSMFC Major Areas 3CD and 5ABCDE (Figure 3). The inside management unit wholly encompasses the inside yelloweye rockfish population and includes, at both extremes of the management unit (more so in the West than in the South), a small portion of the outside population.

STOCK ASSESSMENT METHODOLOGY

There are insufficient age data with which to estimate fishery selectivity at age for the various Aboriginal, commercial, and recreational fisheries and gear types (jig, troll, set-line, and trawl) that have captured inside yelloweye rockfish to permit a reliable fully age structured stock assessment. Age data has been collected sporadically between 1980 and 2000 from the commercial jig fishery and since 2003 from research set-line surveys (Table 1 and Figure 4). For this reason, only a non-age structured stock assessment method has been considered. A Bayesian state space surplus production (BSP) model, similar to the one applied in the 2008 stock assessment of B.C. bocaccio rockfish (*Sebastes paucispinis*), is applied for the inside population of yelloweye rockfish (Stanley et al. 2009).

The BSP assessment model presumes that the main source of interannual variation in mortality has been from changes in fishing effort. The model requires a time series of historical annual catch biomass from all fisheries and is fitted to stock trend data derived from commercial catch data, and longline research surveys. Reconstructions of commercial, recreational and Aboriginal catch biomass were conducted for a fishery catch time series that spans from 1918 to 2009. Stock trend data were derived from the yelloweye rockfish catch data from the inside directed commercial hook and line fishery from 1986 to 2009 and from two longline research surveys conducted in the inside waters: the spiny dogfish survey in the Strait of Georgia in 1986, 1989, 2004, 2005 and 2008 and the inshore rockfish survey throughout inside waters in 2003 to 2005, and 2007 to 2009. The model also requires prior probability distributions for key parameters including the maximum intrinsic rate of increase parameter r, the initial stock size relative to unfished stock size, carrying capacity and constants of proportionality for the abundance indices to which the model is fitted.

A reference case BSP model is constructed with the “most plausible” data inputs and sensitivity tests are conducted to determine the influence of varying each of these inputs on the model outcomes. Management advice is based on these “reference case” analyses. Results from a BSP model (see below) that has been extended to included interannual variation in predation from pinnipeds, i.e., harbour seals and sea lions, are presented only for illustrative purposes to demonstrate the sensitivity of stock assessment results to alternative hypotheses about historic predation from pinnipeds.

Fisheries reference points consistent with DFO’s Precautionary Reference points are presented in this assessment (DFO 2006). For surplus production models, B_{MSY} is commonly defined at 0.5 B_0, or half of the unfished biomass. 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

Future inshore yelloweye rockfish stock projections from the BSP model are also presented at 5, 20, 40 and 80 year horizons (i.e., up to 2 generations).

SOURCES OF INFORMATION

HISTORIC CATCH

The inside yelloweye rockfish population resides within the general area considered to be inside protected waters East of Vancouver Island, referred to as PSMFC Major Area 4B. Although the boundaries of the inside yelloweye rockfish DU are slightly inside of the boundaries for PSMFC Major Area 4B, to be consistent over the historic catch time series, all catch data for the inside yelloweye population is not distinguished from the catch from the inside management area, PSMFC Major Area 4B (Figure 3).

Determining the catch of yelloweye rockfish from historic catch data sources requires the decomposition of species specific landings from a mixed species market category such as “other fish” or “rockfish”. This is accomplished by using proportions of yelloweye rockfish to other rockfish, by gear type from more recent catch data sources where complete species and gear type information are available. In some instances, published reports on the species composition of the catch or effort by a specific gear type or fishing sector is available and used to determine the inside yelloweye rockfish catch.

Historic catch of inside yelloweye rockfish is reconstructed for commercial, recreational and Aboriginal fisheries from 1918 to 2009. Reconstruction of the commercial fishery catch is generally described below and is the combined total of both commercial landings and discards (Appendix A Table A1). Detail of the procedures, R code to extract data from DFO databases and the application of species specific conversion factors is described in Haigh and Yamanaka (2011). Recreational fishery retained and released catch is derived from DFO data sources, together with anecdotal information from local recreational fishery experts to reconstruct early fishery history (Detail in Appendix B). Aboriginal catch estimates are determined from estimates of Aboriginal population size and estimates of consumption rates (Detail in Appendix C).

Commercial Fishery Landings Haigh and Yamanaka (2011), Appendix A Table A1

Commercial landings for yelloweye rockfish are estimated from aggregated species landing statistics from a variety of sources over time. Data were transcribed from books which recorded fishery statistics in B.C. from 1918 to 1951 and from sale slip records between 1952 and 1981. This sale slip system moved to an electronic format in 1982 and continued until 1994. In 1995, groundfish fisheries reported landings by species through dockside monitoring programs. In 2002, the halibut fishery began to record dockside landing data in a Fisheries Operating System (FOS). With the launch of the pilot groundfish licence integration project, in 2006, all species caught (landed and discarded) are reported through the FOS with the exception of the trawl fishery, which began reporting through FOS in 2007.

Commercial Landings (Dominion of Canada Bureau of Statistics) 1918 - 1950

Landings are reported in three districts for British Columbia: District 1 includes the Vancouver area, District II includes the area North of Cape Caution and District III includes the remainder of the province. There are discrepancies with these landing data by District with evidence that the double counting of groundfish species applied to District 1 occurred but was likely variable between Districts and years, especially after 1939 (Sandy Argue pers. comm.). Data reported here are derived directly from the annual records and the double counting problem addressed in model sensitivity analyses. The aggregated species category of fish used in this analysis varied slightly from year to year and included “red cod, etc.” from 1918 to 930, “red and rock cod” from 1931 to 1943, 1945, and 1946, “red cod” in 1944, and “rockfish” from 1947 to 1950. Landings are not separated by fishing gear type and are converted from cwt (‘00 lbs) to metric tonnes.

Yelloweye rockfish are absent from the early trawl gear landings in the Strait of Georgia (Ketchen 1979). To separate out the trawl from the hook and line landings, the rockfish landings by gear type were estimated using sale slip data (1951 to 1981). The proportion of hook and line landings was then applied to the landings data prior to 1951 to adjust the all gear landings to only hook and line landings (Rutherford, 1999). In a similar way, to adjust landings only for the inside area, area proportions were applied using sale slip data.

Landings of inside yelloweye rockfish are estimated as a portion of these hook and line landings based on the proportion of yelloweye rockfish to all other rockfish species taken by hook and line in the commercial logbook data.

<u>Commercial sale slips (B.C. Commercial Catch Statistics: Pacific Region) 1951 – 1981</u>

Sale slip reported landings by PFMA, hook and line gear type (longline, handline and troll), and categories of “red and rock cod” (1951-1975) and “rockfish” (1976-1981). The landed weights are reported as “dressed heads off”, so a conversion factor of 1.1 was applied to represent whole fish weights.

Landings of yelloweye rockfish are estimated as a portion of the total hook and line landings of all rockfish species. The total hook and line landings were estimated by combining the two rockfish categories of “red and rock cod” and “rockfish”. Based on proportions of yelloweye rockfish to all other rockfish species taken by hook and line in the commercial logbook data (1986–1995), estimates of yelloweye rockfish were derived. This was done due to the lack of species specific catch data in these early years.

<u>Commercial Sale slips (DFO sales slip database PacHarv3) 1982 – 1994</u>

Landings are reported by PFMA, hook and line gear type (longline, handline and troll), and a “red snapper” category. Red snapper landings, extracted from the PacHarv3 database, are assumed to be yelloweye rockfish.

<u>Hook and Line 1995 – 2005 and Trawl 1995 - 2006: Dockside monitoring programs and logbooks (DFO catch databases PacHarvHL and PacHarvTrawl)</u>

Landings are reported by species through Dockside Monitoring Programs (DMP) and allocated to PFMA using logbook records reported by fishermen. Records are extracted from the PacHarvHL and PacHarvTrawl databases for yelloweye rockfish.

<u>2006 - 2008 Fisheries Operations System (FOS)</u>

Through FOS, total catch of yelloweye rockfish is reported through the integration of at-sea observers and electronic video monitoring, dockside monitoring and logbook reporting. Estimates of the total catch of yelloweye rockfish from the mandatory electronic monitoring (EM) systems on the groundfish hook and line fleet, which takes the majority of the catch, are shown to be unbiased and accurate (Stanley and Olsen 2009).

Salmon Troll Catch (2001 – 2008)

Recent salmon troll catch (kept and discarded) from commercial hails and logbooks indicate extremely low catch rates (0.0017 kg yelloweye rockfish/day) with an average of 4900 fishing days per year (Commercial Salmon Logbook Program: FOS database extracted by Bruce Patton). The catch of yelloweye rockfish from the inside salmon troll fishery has averaged 8 kg annually between 2001 and 2008. This catch is negligible and was not included in further analyses.

Commercial Fishery Discards included in Appendix B Table B1

Discards from the commercial fisheries are estimated from DFO observer data and applied to landings in earlier years. The discards are considered negligible up until the institution of species specific licensing regimes for groundfish then continued 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. Shack bait is included in this estimate of discards. Shack baiting practices occur in this and other fisheries and peaked in the mid-1980's (1985-1986).

At-sea observer data collected between 2000 and 2004 onboard hook and line vessels is used to determine yelloweye rockfish discards in the hook and line rockfish (ZN license), dogfish and lingcod (Schedule II, C license) and Pacific halibut (L license) fisheries.

Hook and line rockfish fishery (ZN license) 1986 - 2005

The proportion of yelloweye rockfish discarded to landed is determined from observer records in the hook and line rockfish fishery (ZN license). This proportion is then applied to the yelloweye rockfish landed from this fishery to estimate the yelloweye rockfish discards. Discards 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 discarded) of all species is accounted for. The ZN fishery became a limited entry fishery in 1992 but this change was unlikely to change the discard rate.

Pacific halibut (*Hippoglossus stenolepis*) fishery (L license) 1979 - 2005

Similar to the ZN fishery, using observer records from the Pacific halibut (L license) fishery, discard rates are determined from the proportion of yelloweye rockfish discarded per halibut landed. Yelloweye rockfish discards are estimated for the Pacific halibut fishery from 1979, when the L licence was introduced, to 2005.

Hook and line spiny dogfish (*Squalus acanthias*) and lingcod (*Ophiodon elongatus*) fishery (C license - Schedule II) 1986 - 2005

Similar to the other fisheries, observer records are used to estimate the yelloweye rockfish discarded to the spiny dogfish or lingcod landed in the fishery. Discards 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.

Unreported commercial catches 1986 to 2005

Unreported catches since the initiation of the ZN fishery up until the implementation of the 100% monitoring program in 2006 are estimated, by industry, to be equivalent to the commercial catch estimate. For this reason the reference case model is based on double the commercial catch reported from available sources during this period 1986 - 2005.

Recreational Fishery Catch Appendix C Table C3

The Strait of Georgia Sport Fishery Creel Survey (Creel) is used to estimate catch from 1982 to 2008 (Hardie et al. 2001). Estimates of rockfish (all species) were partitioned to derive yelloweye rockfish estimates and to fill in catches for Area 12. Creel survey estimates are not corrected for missing survey months and could be considered biased low by 5% (Bill Shaw pers. comm.). The average weight of yelloweye rockfish, 2.49 kg, determined from weights collected during the Creel survey between 2000 and 2008, is applied to the total number of fish to estimate the total catch weight.

Recreational catches prior to the creel survey were reconstructed by formulating a time series of hypothesized recreational fishing effort prior to the creel survey. It is known that yelloweye rockfish have been captured by recreational anglers since the late 1800's with recreational angling effort increasing after World War II (George Bates, Bill Otway, Wayne Saito pers. comm.). Informal interviews suggest that recreational fishing effort increased steadily up to the 1960s, held steady in the 1960s, and increased in the 1970s up to the 1980s. Based on this, trend lines were formulated for historic recreational fishing effort up to 1981. Applying the Bayesian imputation method in Stanley et al. (2009), using the average Creel catch per unit effort from 1982 -1986 and the historical hypothesized fishing effort, catches were probabilistically imputed up to 1981 (Appendix C Table C3).

Aboriginal Consumption Appendix D Table D2

Consumption of yelloweye rockfish by Aboriginal populations is estimated by applying a consumption rate to population estimates for Aboriginal people who reside near, and have access to, the inside yelloweye rockfish population (Appendix D Table D2).
Population data is obtained through the Canada Census which identified Native Indians (1931 – 1971) (Statistics Canada prepared by B.C. STATS 2009) and Indian and Northern Affairs Canada for recent years (1980 – 2007).

A near-urban First Nation diet study near Victoria in British Columbia shows rockfish (all species) consumed by about 13% of the studied population (Mos et al. 2004). Of these consumers, approximately 3 meals of rockfish were eaten annually. Consumption data obtained from an Alaskan publication reports the Traditional Diet Survey median annual consumption rate of one pound (1 lb) of yelloweye rockfish consumed per Aboriginal person in Southeast Alaska (State of Alaska 2007). This estimate is higher than estimates based on confidential DFO data (M. Fetterly pers. comm.). Yelloweye rockfish is more abundant and available to SE Alaskans than Aboriginal groups in and around the Strait of Georgia, therefore, an estimate of half the Alaskan consumption was used for the Aboriginal subsistence consumption rate in B.C.. This estimate of half a pound (0.23 kg) of yelloweye rockfish per person per year was applied to the Aboriginal population estimate to determine the Aboriginal consumption in the inside waters.

LIFE HISTORY PARAMETERS

Biological samples are routinely collected during the inside longline surveys (Lochead and Yamanaka 2004, 2006 and 2007). Fresh fork lengths and wet weights are collected onboard the survey vessel together with visual assessments of sex and gonad maturity. Surveys are conducted in the late summer/early fall. Otoliths are aged, post-survey, at the Sclerochronology Lab at DFO's Pacific Biological Station using the break and burn technique (MacLellan 1997). Samples obtained from the inside yelloweye rockfish stock area only were used to estimate life history parameters for the inside yelloweye rockfish population (Figure 1).

von Bertalanffy Growth

Estimates of the von Bertalanffy growth parameters are updated using the longline survey biological sample data. While there may be some size selectivity in this research gear, the potential size selectivity remains unknown. Size selectivity of commercial fishing gears could potentially cause biases in growth estimates even when research gear has been used to sample the population (Taylor et al. 2005; Gwinn et al. 2010). However, the extent of potential bias caused by such processes is currently unknown. The length data were presumed to be lognormally distributed about the model-predictions of length at age. The priors for the growth model parameters were all non-informative ones. A Bayesian estimation model was developed and applied that computes the posterior mean and covariance of the parameters. The SIR algorithm (McAllister and Kirchner 2002) was applied here and in the estimation of the other life history parameters below to obtain approximations of the joint posterior distributions for the model parameters. The estimates are shown in Table 2 and the correlations are shown in Table 3 for males and females. While L_{inf} is estimated quite precisely (CVs of 5-7%), estimates of K and t_0 are estimated with only moderate precision (17-27%).

Length-weight relationship

The fork length to wet weight conversion parameters are estimated using a Bayesian estimation methodology. The posterior means and CVs are shown in Table 4.

Age at maturity

A Bayesian approach is applied to estimate parameters for a function of fraction mature at age for females using the inside longline research survey biological sample data. At each age where n_a yelloweye rockfish are sampled, the number of observed mature yelloweye rockfish (m_a) is modeled as a binomial random variable with the probability of being mature determined by some maturity ogive function. To account for possible non-independence in samples for yelloweye rockfish caught in the same longline sets, the sample sizes are reduced by one quarter. This did not affect the values obtained for the median age at maturity or the CV in age at maturity; it only slightly reduced their precision. The probability mature at age is modeled using a cumulative lognormal density function which appears to fit the fraction mature at age data much better than a logistic function (Figure 5). The median age and approximate CV in the age at maturity are 17.7 years and 0.50 (Table 5).

Computing a prior density function for the maximum intrinsic rate of increase (r)

The methodology developed in the 2008 B.C. bocaccio stock assessment (Stanley et al. 2009) to compute a prior density function for r is extended to include additional sources of uncertainty (see Appendix G and Cuif et al. 2009). Previously these included only the stock-recruit steepness (h) parameter and the rate of natural mortality (M). Uncertainty is now included in all of the input parameters for this Monte Carlo algorithm. The program uses the posterior means and covariances for the female growth parameter estimates (Tables 2 and 3), the length to weight conversion factors (Table 4), and parameters for the fraction maturity-at-age schedule (Table 5) (covariances not shown for the latter two functions). It is assumed that the first age-at-maturity for females is the first observed age at maturity in the longline research survey (8 years). The fraction mature at age after age 8 is made to follow the values given by the density function that were drawn from the posterior distribution of parameter estimates for the fraction mature-at-age model.

Estimates of Z for the inside population of yelloweye rockfish from Ricker catch curves (1975) is 0.036 yr^{-1} and from Schnute and Haigh (2006) methods the posterior mean of the Z distribution is 0.057 yr^{-1} (Yamanaka et al. 2006). U.S. stock assessments use M = 0.041 yr^{-1} based on estimates from Yamanaka et al. (2000) using Hoenig's equation (1983) for a maximum age of 112 yrs (outside DU). Using Hoenig's equation and the maximum age for inside yelloweye rockfish, 101 years, M = 0.045 yr^{-1}. The prior density function for M is a lognormal density function with median of 0.04 yr^{-1} and a standard deviation in the natural log of the random variable of 0.2.

In demographic modeling of r for teleosts, it is common to use estimates of the steepness parameter for the Beverton-Holt stock (B-H) recruit function. However, because yelloweye rockfish are known to be cannibalistic, we presumed a Ricker function for the reference case prior and then applied a Beverton-Holt function in a sensitivity analysis. The posterior predictive distribution for the Ricker steepness from Forrest et al. (2010) is approximated using a transformed beta density function with minimum of 0.2, mean of 0.93 and standard deviation of 0.42. The posterior predictive distribution for B-H steepness from Forrest et al. (2010) is approximated using a transformed beta density function with a minimum of 0.2, maximum of 1, a mean of 0.71 and standard deviation of 0.15. A total of 10,000 Monte Carlo simulations are carried out and values less than 0.005 are excluded from the results. The prior mean for r based on Ricker steepness that resulted from the Monte Carlo simulation is considerably lower, at 0.0465 with SD of 0.0173 (Figure 6). This was best approximated by a normal density function. When a higher mean Ricker steepness prior is applied, the prior mean for r became 0.055 with a SD of 0.0188. When a lower mean Ricker steepness prior is applied, the prior mean for r became 0.036 with a SD of 0.0156. As usual, the form of the prior density function for r from the B-H model is very well approximated by a log normal density function. The prior mean for r based on B-H steepness that resulted from the Monte Carlo simulation is 0.0680 with SD of 0.0320 (Figure 6).

STOCK TRENDS

Commercial CPUE (see Appendix E for details).

The commercial catch data for yelloweye rockfish are derived from logbook records from the directed hook and line rockfish fishery (ZN licenses) in the British Columbia Strait of Georgia management region. The hook and line fishery includes both longline gear and gear classified as handline, including rod and reel, troll, and other handline gear. As the logbook program for the hook and line rockfish (*Sebastes*) fishery began in 1986 (see Kronlund and Yamanaka 1997 for further details), data are available from 1986 to 2009. Due to periodic changes to management and logbook reporting protocol during this time period the data are split into five time series: 1986-1990 (n = 30739), 1995-2001 (n = 18082), 2003-2005 (n = 1195), 2006-2009 (n = 2015) (Table E6). 2002 is not included in the time series due to a large reduction in effort by the fleet that year in protest of the total allowable catch reductions (Tables 6 and 7). The 2006-2009 time series was also not included in the stock assessment model because of indications of possible shifts in species targeting during this period that could not be accounted for by the GLM modeling.

Catch data for yelloweye rockfish are recorded as piece counts and/or weights and are available by year, area (PFMA), gear type, and set. Where only weights were provided the count was imputed using a weight to count conversion (3.17 kg/fish) based on all catch records available. Counts were summed for all utilization codes (retained or discarded). Data for sets where non-reef species (e.g. dogfish (*Squalus acanthius*), Pacific halibut (*Hippoglossus stenolepis*) were targeted and/or duration was zero were excluded. Sets with unknown gear type were assigned to a gear category based on their maximum depth, where those with a maximum depth greater than 50 m were longline and all others were handline. Data from areas where no yelloweye were caught during the time series were discarded from all models.

Catch per unit effort (CPUE) is a commonly used metric for abundance. It is calculated as:

(1) $$CPUE_i = \frac{C_i}{E_i}$$

where C is the count of yelloweye and E is the duration (in hours) the gear was deployed during set i. In earlier years all catch is recorded as one entry per day and should be considered as a daily measure, thus differing from later time periods.

The CPUE time series are standardized using generalized linear models (GLM) where the year effects are assumed to closely follow the abundance trends (see Appendix E). Following the methodology of Babcock and McAllister (2002) a Bayesian delta lognormal model is employed with the explanatory variables (factors) year, area, and gear type. Four models using a combination of these factors were produced: year, year/area, year/gear, and year/area/gear. The area and gear factors are treated as fixed effects because there are too few levels to consider random effects. No interactions are considered. The delta lognormal model has two components, a binomial density function to model the number of positive catches of yelloweye (a binomial abundance index) and a lognormal density function to model the sets with positive catches (a lognormal abundance index) (Babcock and McAllister 2002).

Generally, the mean of the delta lognormal abundance index shows a decline over time regardless of the model (Figure 7 and Table 8). The commercial cpue abundance indices are shown in Appendix E Table E8 and Figure E9.

Longline Research Survey CPUE

Two longline research survey time series are available for use in this assessment; the Strait of Georgia spiny dogfish survey (1986 – 2008) and the inshore rockfish survey for the inside waters (2003 – 2008). In both these surveys, spiny dogfish comprise the bulk of the catch with yelloweye rockfish, in most cases, making up the largest biomass of finfish in the catch. Nominal catch per unit of effort (number of target fish per hook per minute of soak time) indices do not take into account the variability introduced by the interspecific competition for baited hooks. Somerton and Kikkawa (1995) proposed different standardization methods to take into account this competition which are based on instantaneous catch rates. An assumption of this new approach to abundance indices is that the number of baited hooks remaining as time increases conforms to an exponential decay process with hooks becoming unbaited due to fish capture and mechanical processes. New abundance indices, based on the instantaneous catch rates, are derived to not only take into account the competition for baited hooks but also to account for the return of unbaited, empty hooks (Marie Etienne pers comm).

Inshore Rockfish Longline Surveys – inside waters

Since 2003, inshore rockfish longline surveys have been conducted within the inside management area 4B on an annual basis (except 2006). The first two years of the survey, 2003 and 2004, were conducted in PFMAs 12 and 13 and in the following years moved to cover northern and southern portions of the 4B management area on a rotating basis (Lochead and Yamanaka 2004, 2006 and 2007). These 2 x 2 km grid surveys target hard-bottom areas in an area and depth stratified (40 – 70 m and 71-100 m) random design. Data for all surveys are extracted from the DFO's PBS GFBio database. An exponential model is applied to account for variation in bait competition with other species such as dogfish (Marie Etienne pers comm). The resulting indices are shown in Table 9 and Figure 8. Four of the seven time series show decreases in the relative density of yelloweye rockfish while three show no apparent change in density from 2003 to 2009.

Strait of Georgia spiny dogfish longline surveys

Spiny dogfish longline surveys are conducted at specific locations, representative of commercial fishing sites, within the Strait of Georgia in 1986, 1989, 2004, 2005 and 2008 (McFarlane et al. 2005a 2005b 2006, King and McFarlane 2009). Five depth intervals, between 0 and >220, were fished during most surveys. The shallowest depth interval 0 – 55 m was not sampled in the later years so was dropped from the analyses. A change from j-hooks to circle-hooks took place in 2004 requiring an estimate of the ratio of capture probabilities of circle-hook to j-hooks using the data for all captured rockfish combined. The exponential model was applied to the dogfish longline survey data to compute the relative density estimates for yelloweye rockfish and dogfish in inside waters. Figure 9 and Table 10 shows the nominal catch per unit effort with hook corrections and the density estimates from the application of the exponential model and gear standardization (Etienne et al. in review). With the median estimated ratio applied, this time series shows about a 4-fold decrease in abundance since the mid-1980's.

Strait of Georgia Trawl Surveys

Trawl surveys conducted by Washington State Fish and Wildlife, which covered portions of Canadian inside waters, could not be used due to the lack of yelloweye rockfish caught, and inconsistent survey coverage between years (Wayne Palsson pers. comm.). Young-of-the-year lingcod trawl surveys conducted by DFO also could not be used due to the lack of yelloweye rockfish caught.

STOCK ASSESSMENT MODELING

STATE-SPACE BAYESIAN SURPLUS PRODUCTION MODEL (BSP) APPENDIX G

The version of the BSP model applied in this assessment is the Bayesian surplus production model developed for the recent B.C. Bocaccio assessment (Prager 1994; McAllister et al. 2001; Stanley et al. 2009). It effectively assumes that the non-fishery mortality rate is constant over time. This is a non-equilibrium state-space surplus production model with a Bayesian statistical methodology for parameter estimation:

(2) $$B_y = \left(B_{y-1} + B_{y-1}\, r \left(1 - \frac{B_{y-1}}{K} \right) - F_{y-1}\, B_{y-1} \right) \exp\left(\varepsilon_y - \frac{\sigma_p^2}{2} \right)$$

where B_y is stock biomass in year y, r is the maximum intrinsic rate of increase, K is the average unfished stock size or carrying capacity, F_y is the fishing mortality rate, and the prior probability distribution for the process error term is given by $\varepsilon_t \sim \text{Normal}\left(0, \sigma_p^2\right)$. This model projects from initial conditions in 1918, when commercial catch records become available, to the current year, accounting for annual catch removals and surplus production.

The model imputes recreational catches from approximations of annual recreational fishing effort for years 1918 to 1982 when creel survey estimates of recreational catch and effort first became available. Recreational catches are predicted using the equation:

$$(3) \qquad \hat{C}_{s,y} = B_y \times \frac{g_s E_{s,y}}{Z_y}\left(1-\exp\left(-Z_y\right)\right)$$

where $g_{s=r}$ is the recreational angling catchability coefficient, $E_{s=r,y}$ is the recreational fishing effort for year y, Z_y is the total instantaneous mortality rate (without an explicit term for pinniped mortality rates) (see equation 8 below) and $\hat{C}_{s=r,y}$ is the predicted recreational catch in year y. The parameter $g_{s=r}$ is estimated by taking the average creel survey estimates of recreational catch from 1982 to 1991 and evaluating the density of this averaged observation using a lognormal likelihood function with a median value given by the average of the model-predicted recreational catch values for these years.

Aboriginal and commercial catches are treated as fixed and known and the model solves for fishing mortality rates that are consistent with the inputted total fixed annual catch (Prager 1994).

We computed the probability of each observation using a lognormal likelihood function.

$$(4) \quad I_{i,y} \sim \text{Lognormal}\left(\ln\left(q_i B_y\right), \sigma^2_{o,i}\right)$$

where $I_{i,y}$ is the observed index of abundance for series i in year y, q_i is the constant of proportionality for series i and $\sigma_{o,i}$ is the standard deviation in the error deviation between the log predicted index and the log observed index. Conditional on estimated catches but ignoring predation, the BSP model was fitted to the dogfish longline research survey data index, standardized commercial catch per unit effort (cpue) data, and indices by area for the rockfish longline research survey.

Due to the relatively few data available it was not possible to reliably estimate the observation error variance in the deviates between the predicted and observed abundance indices and the process error variance in annual stock biomass. Because the rate of natural mortality is relatively low and there appear to be many age classes present even in recent decades, we've presumed a relatively small value for the annual stock biomass process error variance. ε_t from 1918 to 2009 were treated as estimated parameters and σ_p was set at 0.05.

As in Stanley et al. (2009), an iterative approach is applied to obtain values for the SD in the log normal observation error deviates for the abundance index data that were consistent with the magnitude of the observation error deviations in each time series. A single annual index was not derived from the eight sampling strata for the research longline survey indices because the time series is short with very sparse overlap between areas in a given year due to the survey area rotation between the south and north inside waters between years. The minimum SD in the natural logarithm of observation error deviates (σ_o) was limited to 0.5, but the value is allowed to be larger if the posterior mode gave a value larger than 0.5. For the two research survey abundance series, we set the minimum σ_o to 0.15. The final values for σ_o are rounded up to the nearest multiple of 0.05 for each index series since the values obtained were based on the posterior mode and fits can be expected to deteriorate when parameter uncertainty is accounted for.

Priors are specified for the maximum intrinsic rate of increase, r (see Appendix G), the ratio of initial stock size to equilibrium unfished stock size, K, the constants of proportionality for the abundance indices, q, K, and the catchability coefficient for the recreational fishery that is used to impute recreational fishing mortality up to 1981 using values for annual recreational fishing effort. The reference case prior for the parameter r, was normally distributed with a mean value of 0.0465 and a standard deviation of 0.0173. The prior for B_{1918} /K or "α" was lognormal with a mean of 0.9 and standard deviation in the natural logarithm of α of 0.2. A small amount of depletion was presumed because a small commercial fishery for rockfish in inside waters had already been established by 1918 (i.e., catches were at about 29-71 tons 1918-1920). The prior for K was uniform between 1000 t and 350,000 t, with the bounds being well outside of the bounds of empirically based support. The priors for the constant of proportionality, q, for the abundance indices were non-informative with respect to K, i.e., uniform over the natural logarithm of q. The prior for the catchability coefficient, g, for recreational fishing, was also set to be non-informative, i.e., exponential with coefficient set equal to the average recreational fishing effort for the years where predicted catches were compared with observed catches (1982-1992).

METHOD OF BAYESIAN INTEGRATION

The BSP software that is developed for this stock assessment applies the sampling importance resampling (SIR) algorithm to integrate the joint posterior pdf of model parameters and sample from the posterior for stock projections (Rubin 1987; McAllister et al. 1994; McAllister and Ianelli 1997). Importance sampling for the state-space BSP was quite efficient with acceptably stable results obtained in a few hours of computing (i.e., no single draw having more than about 1% of the total posterior weight). See Stanley et al. (2009) for further details on the implementation of this method of integration and diagnostics applied to seek reliable approximations of the marginal posterior density functions of interest.

OUTPUT STATISTICS COMPUTED

Marginal posterior distributions were computed for all model parameters and management quantities of interest including K, r, q, g, α, the maximum sustainable yield (MSY), biomass at MSY (B_{MSY}), biomass by year (B_y), the most recent biomass (B_{2009}), the ratio of B_{2009}/B_{MSY}, fishing mortality rate at MSY (F_{MSY}), the replacement yield, the ratio of the most recent fishing mortality rate to that at MSY (F_{2009}/F_{MSY}) and the ratio of the most recent catch to replacement yield ($C_{c,2009}/RepY_{2009}$).

RESULTS

THE BAYESIAN SURPLUS PRODUCTION MODEL - REFERENCE CASE BSP

The Bayesian surplus production model (BSP) reference case utilizes the most credible set of model inputs and structures, given the available options. The reference case for this stock assessment includes the following:

1) The standard deviation in log process error deviates is to be set at 0.05, to account for uncertainty in stock dynamics processes.
2) Non-informative priors for q are to be applied due to a paucity of expert judgment on the alternative values for factors that scale swept area biomass estimates to total population biomass.

3) A uniform prior for K is the base case prior for K, to enable equal credibility for small and large possible values for K.
4) Positive lag 1 autocorrelation in process error deviates set to 0.5 and starting to be simulated in 2009, the first year for which there is no information in the data about historic process error.

In summary the reference case has the following specifications:

- prior mean r = 0.0465, SD(r)= 0.0173
- all 12 stock trend indices:
  1. a spiny dogfish research longline survey,
  2. seven areas of the inshore rockfish research longline survey, and
  3. three directed rockfish commercial catch per unit effort time series.
- the deviations between observed and predicted average annual recreational catch values are treated as lognormal in the estimation of the coefficient, g, used to impute historic recreational catch from historic fishing effort with σ_r set at 0.15
- Schaefer surplus production function ($B_{msy}/K = 0.5$)
- process error SD = 0.05
- mean α or $B_{1918}/K = 0.9$
- non-informative priors for q
- lag 1 autocorrelation starts in 2008
- σ_o for indices obtained by iterative reweighting

SENSITIVITY TESTS

The sensitivity of stock assessment and projection results to a variety of model settings is evaluated. Some of the key sensitivity tests are as follows:

A) **Prior for r** - The sensitivity of model results to the informative prior for r is evaluated with the application of priors for r with lower and higher prior means. A prior for r is applied that uses a Ricker steepness prior with a prior mean 25% below the reference case Ricker steepness prior from Forrest et al. (2010). This gave a prior mean for r of 0.0361 with SD of 0.0156. A prior for r is computed using the Beverton-Holt steepness distribution from Forrest et. al (2010) which is lognormal with a prior mean of 0.068 and SD of 0.0320. A prior for r is also computed with a prior mean for Ricker steepness at 25% higher than the reference case prior mean. This gave a prior mean for r of 0.055 with SD of 0.0188. This prior for r was lower than that obtained with the Beverton-Holt steepness prior. To cover the extremes, the low r run uses a normal distribution for r and had a prior mean value for r of 0.0361 and SD in r of 0.0156. The high r run uses a lognormal distribution for r and has a prior mean value of r of 0.068 and SD in r of 0.0320.

B) **Value assumed for B_{1918}/K_0** (or α or B_{init}/K) - α typically cannot be estimated from available data and it is commonly assumed that B_{init}/K falls at 90-100% of K, in Schaefer surplus production model applications, when the model starts near or at the beginning of the fishery. It has been found that if the catch series is more than a few decades, the final results are insensitive to the value assumed for α, providing it is over about 50%. In the BSP model, we considered alternative prior means of 0.7 and 1.2.

C) **Uncertainty in catch estimates -** The influence of uncertainty in historic catch is evaluated by conducting runs where annual fixed catch values for the commercial, Aboriginal and recreational fisheries combined are set at 50% and then 150% (i.e., 0.5 and 1.5 times higher) of the originally estimated time series of combined fixed catch values.

D) **Influence of different stock trend data on the assessment results -** The relative effect of each stock trend index on the assessment is evaluated by conducting a set of runs in which each stock trend index was left out one at a time.

Table 12 summarizes the different runs carried out and assigns run identifier numbers to the various runs carried out.

Bayes factor is the ratio of the probability of the data for an alternative model (e.g., for the low B_{1918}/K case) to the probability of the same data for the reference case model. We computed Bayes factors for each alternative model run referenced to the reference case run to indicate the relative plausibility of the different model runs when different models or models with different priors were fitted to the same data. The average of the importance function for each model run was used as an approximation of the probability of the data for each model given the model (Kass and Raftery 1995; McAllister and Kirchner 2002).

PROJECTIONS CONSIDERED

Projections are done from 2010 to 2090 (approximately two generations) to evaluate the potential future stock trends resulting from alternative fixed catch policies and alternative constant fishing effort policies. For the latter, the fixed effort was scaled to be consistent with alternative fixed quotas applied in the first future year of the projection (in this case, 2010). The median stock biomass of recruited fish (B_y) and ratio of stock biomass to stock biomass at MSY (B_y/B_{MSY}) trajectories with 90% PIs are computed for each policy option.

In summary the following statistics were computed:

1) median ratio of final stock biomass to stock biomass at MSY (B_y / B_{MSY}),
2) probability of stock size exceeding 0.4 B_{MSY},
3) probability of stock biomass meeting or exceeding 0.8 B_{MSY},
4) final stock biomass meeting or exceeding B_{2009} in 5, 20, 40 and 80 years.

EVALUATION OF STOCK STATUS

THE REFERENCE CASE

The reference case BSP model provided fairly good fits to the three sets of abundance indices (Figure 10 - A). The data in most of the time series are fairly evenly spread about the posterior median population biomass trend for inside yelloweye rockfish (Figure 10 - B). After the sharp decline in the 1980s and 1990s, there does not appear to be any apparent increase in stock biomass. The modeled stock biomass fits the longest time series, i.e., the spiny dogfish longline survey index, fairly well, with the empirical σ_o at the posterior mode at 0.31 (Table 10). The empirical values for the individual area inshore rockfish longline survey series range from about 0.02 to as high as about 1.02, with the high values largely due to relatively low catches of yelloweye rockfish in the sets and large interannual error variability in some of these series (Table 9). The three commercial CPUE series also have relatively low values for σ_o of 0.15, 0.12, and 0.17 (Table 8).

Deviations from zero in the posterior central tendencies of process error terms indicate where the stock trend data is consistently different from the model predictions. The posterior modes for the process error terms for the vast majority of the years are centered at zero and not different from the prior means. In a few of the most recent years, i.e., 2002, 2005, 2008 and 2009 the posterior means are different from zero (Figure 10 - C). This indicates that for these years, the stock trend observations from more than one of the stock trend series are consistently different from the values predicted by the deterministic equations in the BSP model.

The priors for some parameters are markedly updated by the data (Figure 11, Table 11). These included the unfished stock size (K), the constants of proportionality for the stock trend indices (q), and catchability for the recreational fishery (g_r), all of which had non-informative priors with very large CVs (> 3) and posterior CVs all of < 0.4. The prior for r was markedly updated to a posterior mean considerably lower than the prior mean. Initial stock size relative to K is only updated slightly (Figure 11).

The model shows two periods of relative steep decline in line with the two periods in which the fishery catches were largest, i.e., during the war years and during the mid 1980s to mid 1990s (Figure 12 - A). The estimated population abundance shows relatively little change since the mid-1990s when catches were very substantially reduced and this is the main reason for the considerable update in the posterior for r, i.e., with the posterior mean being considerably lower than the prior mean. The prior mean r predicted population recovery with the marked reduction in catch; the lack of recovery in the indices updated the prior so that the posterior mean was lower than the prior mean. The posterior median ratio of fishing mortality rate relative to F_{MSY} has been much higher than 1 in the 1980s and 1990s and decreased to lower levels still higher than 1 since then (Figure 12 – B). The posterior median ratio of catch to replacement yield has remained mostly above 1 and far exceeded 1 in the war years and 1980s to 1990s (Figure 12 - C). The trajectory of F_y / F_{MSY} against B_y / B_{MSY} shows that the stock has been overfished and overfishing has occurred in the last few decades (Figure 13).

For the Reference Case run, median initial stock biomass in 1918 is estimated at 6466 tonnes (CV 0.40) (Table 13). Stock biomass in 2009 is estimated to be at 780 tonnes which is 12% (CV 0.43) of the initial biomass. Replacement yield in 2009 is 19 tonnes (CV 0.49), fishing mortality (F) in 2009 exceeds that at MSY by 1.38 (CV 0.70) and the catch is 78% (CV 0.66) of the replacement yield in 2009.

SENSITIVITY TO ALTERNATIVE MODEL SETTINGS

To account for uncertainty in model outputs, the sensitivity of results to a variety of alternative input and model settings is evaluated (see Table 12 for a description of these). Results reported are for the posterior median, standard deviation and coefficient of variation (posterior mean/posterior SD). Stock assessment results from the sensitivity runs are shown in Table 13 and Figure 14.

The first sets of sensitivity analyses evaluated the sensitivity of results to alternative priors for r and B_{init}/K (Table 13). With low and high prior means, the priors are updated and the posterior SDs are considerably lower, e.g., with the prior SD going from 0.032 to a posterior SD of 0.010 for the high prior mean case (A.2). The prior median for r decreased from 0.0680 to 0.034. When the prior mean for B_{init}/K ranged from 0.7 to 1.2, the posterior medians for initial stock sizes (B_{init}) varied from about 5,700 tons to 7,800 tons and the posterior median for B_{2009} ranged from about 800 to 790 tons. Stock biomass in 1918 and 2009 is sensitive to the alternative settings for historic catches but the stock status (B_{2009}/B_{1918}) estimates are not. Results are insensitive to leaving out the commercial catch and the inshore rockfish longline survey indices but show higher stock status when leaving out the spiny dogfish survey index, because of the relatively steeper decline in this index. High r and lower initial stock size (B_{1918}/K=0.7) assumptions result in higher estimates of stock status (B_{2009}/B_{1918}), as expected.

Plots of the posterior median values from several of the sensitivity runs for the BSP model are shown in Figures 14 and 15. All show substantial depletion from the initial stock size in 1918. However, the pattern and extent of depletion varies among the runs as expected. The runs using the BSP model and with the highest prior mean for B_{init}/K (B.2) show the largest amount of depletion at 10%. The run with the smallest prior mean for B_{init}/K (B.1) shows the least amount of depletion at 19%, presumably because it compensates with a higher posterior mean estimate of r (Table 13).

For instances in which the model was fitted to the same sets of data, Bayes factor was computed for each alternative model in each set of comparable models (Table 14). The probability of the data given the model was computed using importance sampling using the method of McAllister and Kirchner (2002). In all instances, Bayes factors are not sufficiently different such that any one model is strongly down-weighted. Bayes factors were within a factor of four, indicating that the data did not strongly disfavour any one model.

STOCK DEPLETION

The posterior median values are computed for the two-generation levels of stock depletion starting in 1997 (Table 15). This could not be done for three generation levels, due to the generation time for inside yelloweye rockfish at 40 years (1/M + age of maturity where M=0.04 and the median age at maturity at 17 years, then rounded to 40 years) and the stock assessment timeframe which only goes back to 1918, which is less than 3 generations. In all instances except one, the fraction of stock size in the target year relative to two generations earlier decreases over this period to values less than 0.20. If the two generation level of depletion is less than a value of 0.20, it is plausible that the three generation level of depletion is as low or lower.

STOCK PROJECTIONS AND DECISION TABLES

For all alternative policies projected in the BSP model, the population shows varying amounts of expected increase. These results showed moderate sensitivity to alternative priors for r and alternative priors for B_{init}/ K and alternative scenarios for historic catches. The reference case BSP projection results are shown in Figure 16 and Table 16 at 5, 20, 40 and 80 year time horizons (two generations) with associated probabilities of the stock biomass exceeding 0.4 B_{MSY} and 0.8 B_{MSY} in any year in the horizon. Probabilities that the stock biomass B_{fin} at the end of the time horizon exceeds stock biomass B_{2009} in 2009 are also provided in Table 16. Managers are advised to select a policy and then evaluate the likelihood of the stock surpassing a reference point across the various model alternatives for the Reference Case (Table 16) and the sensitivity tests (Tables 17 to 19).

For the reference BSP case, the probability of the stock biomass exceeding 0.4 B_{MSY} over a 5 year horizon, for all policies, is low (<0.14) (Table 16). Given a fixed total fishing mortality policy (TAC) of 15 t over a 40 year horizon, the probability that the stock biomass exceeds 0.4 B_{MSY} increases to 44% and over an 80 year horizon increases to 56%.

Projections are also made for 5, 20 and 40 year time horizons under sets of the various alternative scenarios outlined in Table 11. Projections results are very similar to the reference case under alternative scenarios for the prior mean for r (Table 17), the prior mean for B_{init}/K

(Table 18), scenarios for low and high historic catches, scenarios for low (50% of reference case) and high (150% of reference case) (Table 19).

U.S. YELLOWEYE ROCKFISH STOCKS

In the SEO region of Alaska, adjacent to northern B.C. the yelloweye rockfish assessment for 2009 indicates a lower 95% CI of the 2010 exploitable biomass estimate at 4,321 t (Brylinsky et al. 2009). A harvest rate of 2% is applied to this biomass (lower 95% CI), together with a 3% adjustment for other species for a recommended allowable biological catch (ABC) of 295 t for demersal shelf rockfish (DSR). After a deduction of a subsistence harvest (8 t), the total allowable catch (TAC) is allocated 84% (241 t) and 16% (46 t) to the commercial and recreational fisheries. A directed DSR fishery is permitted if there is sufficient quota after deductions are made for mortality in the halibut and test fisheries.

In Washington State, to the south of B.C. a ban on the retention of yelloweye rockfish has been in place since 2003. For the outer coastal U.S., a stock assessment was conducted for Oregon and California in 2001 and the yelloweye rockfish declared overfished in 2002 (Wallace 2001). Subsequent stock assessments were conducted for the whole of the outer coastal U.S. from Washington through Oregon and California (Methot et al. 2002, Wallace et al. 2005, 2006, Wallace 2008). Rebuilding analyses followed these assessments (Methot and Piner 2002, Tsou and Wallace 2005, 2006). The most recent stock assessment, in 2009, indicated that in California, Oregon, and Washington, the yelloweye rockfish relative spawning output is estimated at 16.4%, 22.5%, and 27.3% of unexploited conditions, respectively (Stewart et al. 2009). Yelloweye rockfish, in Puget Sound/Georgia Basin were proposed by NOAA to be listed as threatened under the U.S. Endangered Species Act in April 2009 (NMFS 2009). Rockfish, in general, in Puget Sound have declined by 70% in abundance over the last 40 years with yelloweye rockfish showing greater declines (Williams et al. 2010).

SUMMARY

A Bayesian surplus production model (BSP) is presented using catch data recently derived from historic records from 1918 to 1952 together with existing catch records from 1953 to 2009, life history data, estimates of r, and abundance trends from commercial catch records and two longline research surveys. The BSP model provided fairly good fits to the stock trend data accounting for the stock decline in the 1980s and 1990s during high fishery catches. The BSP model could only account for the continued decline in abundance since the 1990s by updating the prior for r to give a posterior mean for r considerably less than the prior mean. For further discussion see Sources of Uncertainty (2) below.

Stock status for the inside yelloweye rockfish stock is evaluated using the reference case BSP model run. This model run estimates that the stock biomass in 2009 is at 780 tonnes which is 12% (CV 0.43) of the initial biomass of 6466 t in 1918 (Table 13). For all model scenarios, the stock is below the fisheries limit reference point (LRP), consistent with the Canadian Precautionary Approach of 0.4 B_{MSY} and is likely within the Critical Zone. For the reference case BSP model run, median B_{2009}/B_{1918} is 0.123 (CV 0.43), with a probability that $B_{2009} > 0.4B_{MSY}$ of 4.8% and a probability that $B_{2009} > 0.8\ B_{MSY}$ of 0.1% as illustrated in Figure 17. The inside population of Yelloweye Rockfish is likely (90% probability) in the Critical Zone (DFO 2006). Replacement yield in 2009 is estimated at 19 t (CV 0.49) with catches of 15 t in 2009 estimated at 78% (CV 0.66) of replacement yield. Fishing mortality in 2009 is estimated to be 1.38 (CV 0.70) that of the fishing mortality at MSY.

Stock projections show that the stock will increase over time. However, the probability that the stock will recover (B_{curr}>0.4 B_{MSY}) over the short term (5 years) is low (0.14) for all harvest policies. Given a fixed catch (total fishing mortality) harvest policy of15 t, this probability increases to about 44% over a 40 year time horizon and 56% over an 80 year time horizon.

SOURCES OF UNCERTAINTY

The sensitivity of model results to a variety of alternative input and model settings have been addressed earlier in the document. Discussed here are other sources of uncertainty that may have some effect on model outcomes. These remain uncertain and can not be addressed until further research is conducted or other data becomes available.

1) Trends in abundance

The longest available time series of abundance, 1986 to 2008, is from the spiny dogfish survey which is conducted at index sites in the Strait of Georgia (lower portion of the inside area). This area has experienced greater fishing pressure than other portions of the inside waters and may not be representative of the entire inside yelloweye rockfish population. The inshore rockfish longline survey, although very short in duration (2003 to 2009), does not show as great a decline in areas outside of the Strait of Georgia (Area 12, in the northern portion of the inside waters and in the mainland inlets Area 13, 15, and 28) (Figure 2 and 9). The spiny dogfish survey may indicate the most extreme declines for the inside yelloweye rockfish stock.

The inshore rockfish survey depth strata, extends from 40 to 100 m which covers the shallow portion of the entire depth range for yelloweye rockfish. Peak abundance for yelloweye rockfish in outside waters is 150 m. Although there is little rocky habitat below 100 m in the inside waters, this portion of the population is not surveyed but may represent higher densities of yelloweye rockfish than the shallower waters that are surveyed.

2) Continued decline of abundance indices in spite of decreased fishery harvests

Troubling to the authors is the observation that most abundance indices have continued to decline despite substantial declines in fishery catch since the early 1990s. The BSP model is unable to account for these declines based on fishing effort. Other possible explanations, outside of fishing effort, could be a lag in population response to the reduction in fishing effort and/or recruitment declines or failure.

Another possible influence on the yelloweye rockfish population is predation by pinnipeds. This hypothesis is investigated below and presented here as one of a number of hypothetical stock outcomes. For illustration purposes only, we develop a hypothetical Pinniped Bayesian Surplus Production (PBSP) stock assessment model, as an extension to the BSP model presented above, which accounts for systematic changes in historical predation rates on yelloweye rockfish by pinnipeds. It is known that pinniped abundance has increased substantially since the late 1960's and that rockfish are a portion of their diet. Managers are advised that this is a first step at developing a framework for integrating mortality from predators into the population model and is not used to generate management advice. These analyses are strictly exploratory and are shown below to illustrate possible influences of predation on the yelloweye rockfish population that highlight stock outcomes that are independent from the fisheries.

PBSP - SOURCES OF INFORMATION

Sources of information for the Bayesian Surplus Production model incorporating pinnipeds (PBSP) are identical to those for the BSP model presented earlier, with the addition of population trends and consumption data for pinnipeds. Pinnipeds included in the analysis are Harbour seals (*Phoca vitulina*), Steller sea lions (*Eumetopias jubatus*), and California sea lions (*Zalophus californianus*). Elephant seals (*Mirounga angustirostris*) are not included due to their small numbers, lack of diet information and their primary location at the southern stock boundary in the Strait of Juan de Fuca. Substantial increases in abundance of all of these populations have occurred in inside waters since the late 1960s when culling and bounty programs were halted. The information for pinnipeds are summarized below and detailed in Appendix F.

PINNIPED CONSUMPTION (See Appendix F Table F9 For Additional Details)

Trends in abundance of pinnipeds in inside waters

Pinnipeds, i.e., Harbour seals, Steller sea lions, and California sea lions are known predators of rockfish and their abundance in B.C. inside waters has increased markedly since the late 1960s when culling and bounty programs were halted in B.C. and the U.S (Figure 18). Temporal variation in predation on inside yelloweye rockfish from pinnipeds since 1918 is accounted for using literature based reconstructions of B.C. pinniped abundance, diet and bioenergetics studies. General methods are outlined below, see Appendix F for details.

Harbour seals

The annual abundance of Harbour seals in B.C. waters was estimated by Olesiuk (2010) using generalized logistic models fitted to time series of census estimates for the Strait of Georgia, as well as several index areas outside of the Strait of Georgia. Counts are corrected for the fraction of time hauled out (Tables F1, F2). The total abundance for inside DU waters in 2008 comes to about 60,000 animals (Table F1).
Inside abundance and total B.C. abundance of Harbour seals from 1913-2008 are provided in Tables F1 and F2). We assumed that inside waters Harbour seal abundance from 2009 does not increase any further.

Steller sea lions

Olesiuk (2009) provided census estimates of Steller sea lion abundance at various B.C. sites since 1971. Trend estimates are scaled and fitted to the B.C. total breeding population estimate of 31,900 in 2010 (Olesiuk 2009).

The historic trends in Steller sea lion abundance in inside waters are assumed to follow the same pattern as Olesiuk's (2009) reconstruction of B.C. Steller sea lion abundance between 1913 and 1970. Reconstructions of historic abundance estimates prior to 1970 are made by applying a ratio of inside waters abundance to Olesiuk's (2009) total population in 1970. See Table F4 for the reconstructed annual abundances of Steller sea lions in B.C. and inside DU waters between 1970 and 2010 (with uncertainty intervals) and Table F5 for the B.C. and total inside waters Steller sea lion abundance for years 1913-1970. The estimated abundance in inside waters was about 1000 animals in 1913 and declined to a minimum of 500 animals in 1973, presumably due to hunting and culling. In the last few decades the abundance in the inside waters DU has increased to about 1800 animals in 2010. While there is no indication from surveys that the rate of increase has been slowing in recent years, we've nevertheless assumed that the abundance remains stable after 2010.

California sea lions

Currently there exist no published estimates of California sea lion abundance in B.C. inside waters. California sea lions had not been recorded in B.C. waters prior to the late 1950s and were first sighted hauling out on Race Rocks on the southern tip of Vancouver Island in the early 1960s (Bigg 1985, 1988). Abundance estimates of California sea lion within the inside DU waters are based on unpublished DFO winter surveys off southern Vancouver Island. California sea lion abundance in inside DU waters appears to have leveled off since the early 1980s and is held constant in projections from 2009. See Table F7 for approximations of California sea lion abundance in B.C. inside waters from 1971-2009.

Figure 18 shows the reconstructed abundance estimates of inside DU waters harbour seals, Steller sea lions and California sea lions.

Consumption of all rockfish by pinnipeds

Harbour seals

Olesiuk (1993) estimated that the average bioenergetic requirement for harbour seals in the Strait of Georgia was about 700 kg per animal per year. From published and unpublished data, a weighted mean, weighting by the relative abundance of harbour seals in the Strait of Georgia and northern inside waters was used to obtain a value of 1.3% of rockfish (all species) in harbour seal diets for the inside waters (Olesiuk 1993, Peter Olesiuk pers comm).

Steller and California sea lions

Winship and Trites (2003) suggest that the average adult/subadult Steller sea lion in southeast Alaska consumes about 6.1 tons per year, and Olesiuk (unpublished manuscript) estimated average annual consumption in southern BC and Washington to be about 6.5 tonnes per year.. An estimate of daily consumption of Steller sea lions in inside waters is 17.9 kg/ day, accounting for the age and sex composition and seasonal occurrence of animals in these waters (Peter Olesiuk pers comm). Diet estimates from about 1200 scat samples take in inside waters between 1979-1989 in the Strait of Georgia and 2006-2008 in the San Juan Islands indicate the average fraction of rockfish in the diet was about 0.2% in these samples (Peter Olesiuk pers comm). More recently, 111 samples of scats of Steller sea lions collected from the largest winter haulout for sea lions in the Strait of Georgia, i.e., Norris Rocks near to Denman Island, taken in February and March 2005 (Andrew Trites pers comm, Tollit et al. 2009). These samples indicate that based on a split sample frequency analysis the fraction of rockfish in sea lion diets in the winter and spring months is 5.64%. The reason for the large difference is unknown, but suggests that the importance of rockfish can vary widely between sites and with season. Taking the mean of these estimates weighted by the number of samples, the fraction in the diet comes to 0.67%. We've applied the combined estimate for the fraction of rockfish in the diet of Steller sea lions to the winter diets of both Steller and California Sea lions in the inside waters DU.

Species specific consumption of rockfish by pinnipeds

There are no studies to estimate pinniped diet composition of rockfish by species or size/age. Therefore, it is assumed that the fraction of yelloweye rockfish in pinnipeds' diets is the same as their percentage occurrence in surveys of abundance (Appendix F Table F8). The fraction of rockfish that is yelloweye is estimated at 0.254. Table F9 provides a summary of a computation of the average mass of prey, rockfish, and yelloweye rockfish predicted to be eaten in years in which diet information was collected for harbour seals and Steller sea lions.

PBSP STOCK ASSESSMENT MODELING METHODOLOGY

The version of the Bayesian surplus production model (PBSP) presented in this section extends the BSP model to explicitly include interannual variation in pinniped predation. The populations of different pinniped species are treated as if they are different fishing fleets, using annual abundance estimates for each pinniped species as covariates for species-specific predation rates and applying a Type I functional response model of the relationships between annual predation rate by predator species on yelloweye rockfish and yelloweye rockfish density. The predation rate parameters are parameterized using literature-based estimates and unpublished data of bioenergetic requirements, diet composition studies for pinnipeds within the DU, and research survey estimates of rockfish species composition in the pelagic and benthic zones within the DU (see Appendix F).

STATE-SPACE BAYESIAN SURPLUS PRODUCTION MODEL WITH PINNIPED PREDATION INCLUDED (PBSP)

Due to data limitations, a relatively simple approach is used to include pinniped predation in the surplus production model. Predation mortality is accounted for in each year using pinniped species abundance as a covariate for the predation rate by that species, subject to a limit on the fraction of the diet that could be composed of rockfish (see below for details). The state-space surplus production equation is thus modified to the following:

$$(5) \quad B_y = \left(B_{y-1} + B_{y-1}\, r_0 \left(1 - \frac{B_{y-1}}{K_0} \right) - \left(F_{y-1} + M_{1,y} \right) B_{y-1} \right) \exp\left(\varepsilon_y - \frac{\sigma_p^2}{2} \right)$$

where r_0 in this model reflects the maximum potential rate of increase in the absence of fishing and pinniped predation, K_0 reflects the expected equilibrium stock biomass should fishing and pinniped predation be reduced to zero, $M_{1,y}$ is the total natural mortality rate from pinniped predation in year y. With only one annual consumption estimate of yelloweye rockfish for each pinniped species (Appendix F Table F9), it is necessary to impute the annual consumption for all other years within the surplus production model. Given the limited time available for the stock assessment analysis, only a Type I functional response model (Holling 1959) was applied. A Type II or Type III functional response model (e.g., Spencer and Collie 1995) to compute annual predation rates could in future work be considered, though versions with simplified data requirements (e.g., Steele and Henderson 1984; Spencer 1997; Spencer and Collie 1997) would need to be considered due to the paucity of data on search and handling times for pinniped predation on rockfish. The total annual predation for each pinniped species was computed as a function of each pinniped species' annual abundance, an estimate of the per capita risk of predation mortality per unit predator species, and the annual abundance of yelloweye rockfish. Thus, to a limit, the total amount of yelloweye rockfish consumed increased with pinniped abundance and yelloweye rockfish abundance, subject to a per capita limit on the per capita consumption rate of rockfish per predator. The Baranov catch equation was applied to probabilistically impute the annual consumption by pinniped species in each year:

(5a) $M_{j,y} = g_j N_{j,y}$ where $B_y \times \frac{M_{j,y}}{Z_y}\left(1-\exp\left(-Z_y\right)\right) < C\max_{j,y}$

(5b) $M_{j,y} = -\log\left(1-\frac{C\max_{j,y}}{B_y}\right)$ where $B_y \times \frac{M_{j,y}}{Z_y}\left(1-\exp\left(-Z_y\right)\right) \geq C\max_{j,y}$

(6a) $C_{j,y} = B_y \times \frac{M_{j,y}}{Z_y}\left(1-\exp\left(-Z_y\right)\right)$ where $B_y \times \frac{M_{j,y}}{Z_y}\left(1-\exp\left(-Z_y\right)\right) < C\max_{j,y}$

(6b) $C_{j,y} = C\max_{j,y}$ where $B_y \times \frac{M_{j,y}}{Z_y}\left(1-\exp\left(-Z_y\right)\right) \geq C\max_{j,y}$

(7) $M_{1,y} = \sum_{j=1}^{3} M_{j,y}$

(8) $Z_y = F_y + M_0 + M_{1,y}$

(9) $C\max_{j,y} = d\max_j A_j N_{j,y}$

where:

$M_{j,y}$ is the natural mortality rate from pinniped species j in year y,

B_y is the population biomass of yelloweye rockfish in year y, F_y is the total fishing mortality rate from commercial, recreational and aboriginal effort in year y,

Z_y is the total mortality rate in year y, $M_{1,y}$ is the total natural mortality rate from pinniped predation in year y, g_j is the annual per capita predation coefficient for predator species j,

$N_{j,y}$ is the abundance of pinniped species j in year y, M_0 is the average rate of natural mortality not attributed to pinniped predation,

$C\max_{j,y}$ is the maximum expected annual consumption of yelloweye rockfish by species j,

$d_{\max j}$ is the maximum average fraction of yelloweye rockfish in the predator's diet and

A_j is the predator's average annual bioenergetic requirement.

Given that the prior mean for the total average rate of natural mortality over the last several decades was 0.04 yr^{-1} (see below), we've presumed a fixed value of 0.02 yr^{-1} for M_0 and estimated g_j for each pinniped species.

Recognizing that the percentage of rockfish in the diet of the three pinniped species in B.C. is low, a fixed maximum limit, or cap to the fraction of rockfish in the diet (d_{max}) is introduced (Equation 9). This presumes that in all years, and seasons there is sufficient availability of other more desirable prey species such that rockfish remains only a small fraction of the diet. Unpublished data collected by Trites (pers. comm.) and Olesiuk indicate that the approximate frequency of occurrence of rockfish in the summer diet of B.C. Steller sea lions was at about 18% since the year 2000. Diet data collected in the late 1950s and early 1960s indicate the occurrence of rockfish in the diet of B.C. Steller sea lions was about 16% (Spalding 1964). It should be noted these are estimates of frequency of occurrence (FO), not estimates of relative contribution to diet (which would probably be somewhat less than half the FO as animals feed on multiple prey species). The Strait of Georgia is and has been one of the most resource rich areas of the B.C. coast, with very high seasonal influxes of several different fish species including the five species of Pacific salmon, herring, hake, sand lance, and eulachon. Given that these have been found to be more preferred prey items to pinnipeds than rockfish and have been at most times of year the most abundant prey items in the Strait of Georgia, it is presumed that even when rockfish abundance was higher in the past in the inside waters, that rockfishes still comprised a relatively small fraction of the diet of pinnipeds in inside waters. Based on these observations, we put a cap on the maximum fraction of yelloweye rockfish in each pinniped species' diet at no more than double the available estimates of the fraction of rockfish in the diet from the last few decades when yelloweye rockfish abundance was becoming depleted from earlier years. This Type I functional response is such that the amount consumed per predator increases linearly with rockfish density up to a maximum, and represents a "hockey stick" functional form. Caps of up to twenty times the diet fraction estimates obtained from the 1980s when inside yelloweye were at about half of the initial abundance were tried in sensitivity analyses but found to introduce no appreciable differences in stock status and projection results (see below).

The coefficient g_j is estimated for each species by placing a non-informative prior on this parameter (i.e., non-informative with respect to the fraction of stock biomass consumed) (Stanley et al. 2009) and comparing the model predicted value for consumption with the empirically derived value for a given year. The prior density function for g_j was exponential with the exponential density function parameter set to the average abundance of pinnipeds over the time period in which the diet study was taken. The model predictions are constrained to closely fit the consumption rate estimates by pinniped species derived from bioenergetics, diet composition and pinniped population abundance reconstructions. A lognormal probability model is used for deviations between the bioenergetics predictions of consumption and the surplus production model predictions of average annual consumption for each pinniped species.

$$(10) \quad \log\left(L_{d,j}\right) = -\frac{\left(\ln\left(\frac{\overline{C}_{e,j}}{\overline{C}_{m,j}}\right)\right)^2}{2\sigma_{d,j}^{\ 2}} - \log\left(\overline{C}_{e,j}\right) + \text{const}$$

where $\overline{C}_{e,j}$ is the empirically predicted average yelloweye rockfish biomass consumed in the reference year set for pinniped species j (Table F9) with the reference years determined by the years over which the diet composition study was conducted, $\overline{C}_{m,j}$ is the model predicted average yelloweye rockfish biomass consumed by pinniped species j and the annual values computed using the above equation, and $\sigma_{d,j}$ is the standard variation for log deviations between predicted and observed values. The value for $\sigma_{d,j}$ was fixed at 0.15 so that the modeled values for g_j give close fits between model predicted and empirically predicted values for yelloweye rockfish biomass consumed.

The prior for B_{1918}/K_0 or "α_0" was lognormal with a mean of 0.5 and standard deviation in the natural logarithm of α_0 of 0.2. We chose a low value for the prior mean for α_0 because the abundance of Steller sea lions were probably at or near historical highs in the earliest year of the available time series of abundance estimates, 1913, and subsequently decreasing due to culling. In contrast, harbour seals had been depleted from historic peak levels by large commercial kills between 1880 and 1910 (Olesiuk 2009, 2010; Figure 18, Tables F1, F2, F4 and F5). The seal population subsequently recovered somewhat from the low when the model started in 1918, but predator control kills prevented the population from fully recovering until it was protected in 1970 (Olesiuk 2010). Assuming that these predators have historically foraged on rockfish, the rockfish populations in 1918 when the model starts could be expected to have experienced moderate levels of pinniped predation for several decades and to be depleted relative to hypothetical levels that could be expected in the absence of any pinniped predation (K_0).

MANAGEMENT REFERENCE POINTS UNDER VARYING PINNIPED PREDATION

If there were no fishing and no pinniped predation, then we can presume that the population would fluctuate around a long-term average unfished and predation-free abundance of K_0. For any given value for pinniped predation rate, p_y, we can presume that if it were held constant, the population would equilibriate to some lower level. That equilibriated value is the carrying capacity K_y that is conditional on that particular predation rate, p_y

(11) $p_y = M_{1,y} / (Z_y)*(1 - \exp(-Z_y))$

where

(12) $Z_y = M_{1,y} + F_y + M_0$

M_0 = the long-term average rate of natural mortality resulting from sources other than pinniped predation

and

(13) $K_y = K_0 * (1-p_y/ r_0)$ for $p_y < r_0$

(14) $K_y = 0$, for $p_y \geq r_0$

(15) $\therefore$ If $p_y \geq r_0$, $MSY_y = 0$ and $B_{msy,y} = 0$

For a series of years when $p_y < r_0$ and $B_y < K_y$

(16) $K_y > 0$

(17) $MSY_y > 0$ and $MSY_y = r_y K_y / 4$

(18) $B_{msy,y} > 0$ and $B_{msy,y} = K_y/2$

The realized maximum rate of population increase in year y, conditional on predation rate p_y is given by:

(19) $r_y = r_0 - p_y$,

The realized maximum sustainable harvest rate is given by:

(20) $U_{msy,y} = r_y / 2$

Thus, with interannual variation in predation rates, potential reference points normally applied in fisheries stock assessment will be time-varying and depend upon the annual abundances of each of the different predator populations (Bell 1977). The definition of time-invariant reference points requires the specification of a fixed level of predation. We are currently unable to specify a fixed level of predation that could be considered optimal from a societal and/or ecosystem point of view. Therefore should a stock assessment model with explicit pinniped predation be considered, we cannot at this time apply these reference points. For the purpose of illustration, we have used instead the stock biomass in the initial year of the stock assessment, B_{init} or B_{1918} as a provisional stock biomass reference point for the PBSP model results. This is completely arbitrary but relatively simple in principle. We've considered 0.5 B_{init} as a target stock biomass reference point for the PBSP model. We use r_0 /2 as a time invariant mortality reference point.

METHOD OF BAYESIAN INTEGRATION

The estimation models, particularly the one that included pinniped predation, had relatively high dimensionality for importance sampling with three key population dynamics parameters (r, K, α), up to 15 nuisance parameters, i.e., four coefficients, g, for recreational fishing and predation, and 11 constants of proportionality, q, and 92 process error terms. For the pinniped model, this posed considerable challenges for seeking numerical efficiency in the importance sampling. The main techniques applied to identify a workable numerical protocol entailed developing the importance function and increasing the number of draws to be taken from the importance function. The importance function utilized was a multivariate log t distribution with 25 degrees of freedom and with the median set to the posterior modal estimate for each estimated parameter and the marginal variance set at a value the same as or slightly larger than the prior variance, and most or all covariances set to 0. The parameters K and P_0 were in most instances log transformed in the importance function to improve sampling efficiency. In some instances the standard deviation in the log of K (σ_K) for the importance function was set to a value just larger than an initial estimate of the posterior value for σ_K. In such instances, approximations of the posterior covariances (which were negative) between log(K) and log(P_0) and log(K) and r were inputted for the importance function. Values slightly larger than the prior SD for r were applied as the SD for r in the importance function. In other instances, σ_K for the importance function was set at relatively large values, e.g., 1.8 to 2.4, to ensure that the largest posterior weights (importance ratios) did not fall in the tails of the posterior. Between about 5 million and 36 million draws from the importance function were applied to obtain approximations of the posterior distributions.

OUTPUT STATISTICS COMPUTED

Marginal posterior distributions were computed for all model parameters and management quantities of interest including K, r, q, g, α, the maximum sustainable yield (MSY), biomass at MSY (B_{MSY}), biomass by year (B_y), the most recent biomass (B_{2009}), the ratio of B_{2009}/B_{MSY}, fishing mortality rate at MSY (F_{MSY}), the replacement yield, the ratio of the most recent fishing mortality rate to that at MSY (F_{2009}/F_{MSY}) and the ratio of the most recent catch to replacement yield ($C_{c,2009}/RepY_{2009}$). For the predation model, marginal posterior distributions were also computed for $C_{j,y}$, $M_{j,y}$ and $M_{1,y}$.

PBSP RESULTS

THE REFERENCE CASE PBSP

The reference case application of the pinniped surplus production model, applied the following additional settings.

- The deviations between observed and predicted average annual consumption values per predator population are treated as lognormal in the estimation of the coefficient, g, used to impute historic predator consumption from historic predator abundance with σ_d set at 0.15. Larger values led to numerical instability during importance sampling.
- For the Type I functional response model, the maximum limit on percentage of yelloweye rockfish in the diet for each pinniped was set at twice the available approximation of this percentage based on available information in the last few decades.
- The mean α_0 or $B_{1918}/ K_0 = 0.5$

SENSITIVITY TESTS

The sensitivity of stock assessment and projection results to a variety of model settings was evaluated. Table 21 summarizes the sensitivity runs for the PBSP model. The key sensitivity tests are as follows:

A) **prior for r** (as in BSP)

B) **value assumed for the prior mean for B_{1918}/K_O** (0.2 and 0.8)

C) **uncertainty in catch estimates** (as in BSP)

D) not conducted for the PBSP model

E) **Influence of alternative assumptions quantifying the amount of predation mortality** – Different multiples of the empirically derived values for the annual amount consumed by each pinniped species were evaluated but retaining the reference case estimates of annual predator abundance. The multiples for the amounts consumed are set at 1%, 10%, 25%, 50%, 150% and 200% of the reference case values for annual consumption. These alternative values account for the uncertainties and potential biases in the average annual fraction of yelloweye rockfish in each pinniped species' diet, the fraction of rockfish in the diet of each pinniped species and the average bioenergetic requirements of each pinniped species. For example, a multiple of 10% could be taken as there being only 2.5% of rockfish species biomass being yelloweye as opposed to the reference assumption of 25%. The multiple of 200% could alternatively imply that the percentage biomass of rockfish that is yelloweye in the diet is 50% instead of 25% in the reference case setting. Under the reference case, the prior mean B_{init}/ K_0 was set at 0.50. To account for plausible covariation in the magnitude of predation and $B_{init}/ K_{0,}$ the prior mean for B_{init}/ K_0 was successively reduced as the fixed assumed magnitude of predation relative to the reference case was progressively increased (see Table 21 for details).

F) **Uncertainty over the maximum fraction of rockfish in the diet**. Two alternative runs were conducted in which the maximum fraction of rockfish in the diet of pinnipeds was varied from the reference case of 200% of the observed diet fractions to 20x 5x, 3x and 1.5x the observed values for the percentage of yelloweye rockfish in the diet for the e.g., mid-

1980s for harbour seals when abundance was estimated to be about half of that in the initial year, i.e., 1918. For example, under the reference case if the observed value for the percentage of yelloweye rockfish in the diet was 0.3%, the maximum was set at 0.6%. Under the scenario with the cap set at 20x, the maximum possible for the average annual percentage of yelloweye rockfish in the entire DU in the diet was set at 6%.

G) **Upper and lower uncertainty bounds accounting for joint uncertainty in all quantities determining predation mortality**. Approximations for the prior standard deviations were formulated for the annual abundance of each of the three pinnipeds in the DU, bioenergetic requirements, and fraction of rockfish in the diet, fraction of rockfish in the diet that are yelloweye (See Table F9 for details). All of the standard deviations are for the logarithm of each quantity of interest. The joint uncertainty was modeled using the law of the additivity of variances. When the logarithms of each of the quantities are added, as they are to determine predation mortality, the total variance is the sum of the variances for the logarithm of each quantity. The prior variances were thus added to compute the joint variance in the predation mortality. These values and the multipliers for the 2.5th and 97.5th percentiles of the lognormal distribution for total predation by pinniped species are given in Table F9b.

H) **Alternative set of diet reference years for harbour seals**. In the final round of revision it was found that the reference year set for harbour seal diets applied in the population modeling should have been set at 1982-1988 instead of 1988 only. It was not expected that this would influence results since the population model scales the predicted diet to the selected reference year abundance of harbour seals. A further model run was carried out to evaluate the sensitivity of results to modifications to the reference year set for the diet study.

PBSP EVALUATION OF STOCK STATUS

THE REFERENCE CASE PBSP

When the PBSP model was fitted to the combined stock trend data the posterior median stock biomass indicates that the stock declined slightly between the 1920s and the 1960s and increased slightly between the 1960s and mid-1970s. This increase in stock size is presumably due to a slight reduction in predation with the large drops in harbour seal and Steller abundance in the 1950s and 1960s (Figure 18). Due to the lack of stock trend data up to the mid 1980s, the posterior probability intervals for stock biomass progressively widen as we go further back in time. From the late 1970s as pinniped abundance and fishing mortality rates increased the population showed a steady decline right through to 2009 with the decline slowing in recent years (Figure 19 A and B). The estimated process error deviates become estimable after 2000 due to there being more stock trend available for these years. While there was a positive spike in 2002, the deviates were strongly negative in 2008 and 2009 (Figure 19 C). The priors for parameters such as r and the initial stock size relative to K_0 do not appear to have been updated (Figure 20 and Table 20). This is because the prior for r and is empirically based, i.e.,, was based on available life history data for inside waters yelloweye rockfish, e.g., survey catch-age, and length-age data for inside yelloweye rockfish, and sensitivity analyses (see below) showed that the PBSP results were not sensitive to different specifications for these priors.

Using 50% of the initial stock biomass in 1918 as a provisional target reference point, the stock has declined to well below this point in recent years with the median at about 22% of the target (CV 52%) (Table 20, Figure 12A). The posterior median ratio of fishing mortality rate relative to F_{msy} was mostly less than 1 up to the mid-1980s and much less than the estimates under the BSP model (Figures 12B and 21B). This ratio increased to well over 1 for some years from the mid-1980s to mid-1990s and has decreased to below 1 since then. The posterior median ratio of catch to replacement yield has remained below 1, except for the years from the mid-1980s to 2001 when catches were at their highest values (Figure 21 - C). The total estimated predation under the reference case BSP model has exceeded the total catch in most historic years up to 1965. Since mid-1990s when the total catch dropped from about 400 t to about 15 tons in 2009, the posterior median estimate of total predation has decreased from a recent peak of about 125 t in the mid-1980s to about 45 t in 2009 (Figure 22). This is still a very small fraction of the total amount of fish consumed by pinnipeds. In inside waters in 2010, pinnipeds have consumed about 62,000 tons of marine organisms to meet their bioenergetic requirements. Thus, yelloweye rockfish have made up on average about 0.3% of the total biomass of prey consumed by pinnipeds in inside waters. The trajectory of F(y) / F_{msy} against B(y) / B_{msy} shows that in the last few years the stock has not been overfished but that the stock has remained depleted well below the provisional target reference point level since 1988 (Figure 23).

The posterior median 2009 abundance of inside yelloweye rockfish from the PBSP model is at about 11% (CV=0.52) of the initial stock size in 1918 and current abundance is at about 732 tons (CV=0.38) (Table 20). The 2009 total catch is estimated to be about 47% of the replacement yield (CV=0.62) and the 2009 harvest rate is estimated at about 89% of the MSY harvest rate (CV=0.66). However, pinniped predation at 45 t in 2009 (CV=0.27) exceeds the replacement yield of 32 t (CV=0.45) and total fishery yield of 15 tons in 2009 (Figure 22). Estimates in 2009 of the amount eaten by Steller sea lions, harbour seals and California sea lions are 6 t (CV=0.24), 31 t (CV=0.31), and 8 t (CV=0.27), respectively.

The rate of natural mortality from predation by harbour seals (M_{HS}) has in all historic years exceeded that of Steller sea lions and California sea lions (Figure 25b). The posterior median M_{HS} varied from under 0.01 to 0.02 yr^{-1} from 1918 until about 1965 and then decreased to a low of about 0.003 yr^{-1} in the late 1960s when harbour seal abundance was a historic low. M_{HS} began to increase in the 1970s when the population began to increase. Since then, M_{HS} has increased and then leveled out at about 0.04 yr^{-1} since about 2005.

The total rate of natural mortality from pinniped predation, M_1, tracks the changes in pinniped abundance in inside waters (Figures 18 and 24). The posterior median for the long-term average value obtained for M_1 was about 0.02 yr^{-1} (Table 20) and about half of the value for M provided earlier (0.04 yr^{-1}). In the past three decades M_1 has increased substantially from a low of about 0.003 yr^{-1} in the early 1970s and since about 1980s has become considerably higher than the posterior median value for r (Figure 24). The posterior median for the long-term average predation rate (0.024 yr^{-1}) was considerably less than the posterior median for r (0.046). M_1 has been considerably higher than F in most years up to the mid-1960s and then again in the last decade (Figure 24). These and other statistics on stock status indicate that inside yelloweye rockfish is heavily depleted relative to stock biomass in the early 1900s and that the depletion may be due large increases in catches in the 1980s and possibly also to increases in pinniped predation since the 1970s.

EVALUATION OF SENSITIVITY OF PBSP MODEL RESULTS TO UNCERTAINTY IN MODEL INPUTS

As the PBSP model is a new formulation to account for potential impacts of pinniped predation on yelloweye rockfish, numerous sensitivity runs were conducted to evaluate the sensitivity of results to plausible alternative inputs and assumptions. To identify lower and upper credibility bounds for the predation inputs, we formulated prior distributions for each of them. We computed the total uncertainty in the values for the total yelloweye rockfish consumption for each pinniped species assuming that all sources of uncertainty were independent. With an estimates of the total prior uncertainty in the total consumption by pinniped species, we formulated lower and upper 95% bounds for the consumption and abundance for each pinniped species. Since the numerical procedures for computing posterior distributions in model outputs became unstable when variances in the consumption inputs were large, we instead carried out two additional PBSP model runs with the consumption and predator abundance estimates set at their 2.5th and 97.5th prior distribution percentiles.

Figure 22 shows the reference case, and 2.5th and 97.5th uncertainty bound run historic trajectories for total predation as compared to total catch. These plots show considerable uncertainty over the amount of total predation on inside yelloweye rockfish with the upper bound being well over an order of magnitude larger than the lower bound. These show that under the full range of uncertainty, that historic pinniped predation could conceivably be in most years less than the total catch or in all years larger than the total catch. However, even under the lower bound run, in recent years the total predation approaches the total catch.

Figure 24 shows the reference case, and 2.5th and 97.5th uncertainty bound run historic trajectories for total predation rate as compared to total fishing mortality rate. These plots also show considerable uncertainty over the relative magnitude of predation rates, though the general historic trends are similar between the different runs with major increases in predation rates occurring in the last few decades and the maximum predation rate occurring in the most recent year. The lower bound trajectory has predation rates keeping mostly below fishing mortality rates and always below the posterior median value for r, with predation rates exceeding fishing mortality rates after 2005. In contrast, under the 97.5% bound run, the predation rate exceeds the fishing morality rate in most years, with predation rates far exceeding fishing mortality rates since about 1995.

Figure 25 shows the reference case, and 2.5th and 97.5th uncertainty bound run historic trajectories for natural mortality rate associated with each pinniped species. These plots also show considerable uncertainty over the relative magnitude of predation mortality rates, though with harbour seal predation rates in most years far exceeding the predation rates of the two other species and the maximum predation rate occurring in the most recent year. The maximum predation rate by harbour seals varies from about 0.02 to about 0.06 yr^{-1} in the most recent year. The relative predation rates for the two sea lion species vary more due to larger uncertainty in their diet and abundance and range from very low percentages up to about 0.02- 0.03 yr^{-1} in the most recent year under the low and high bound runs.

Plotted in Figures 26 and 27 are the posterior median values for the ratio of stock biomass to the provision target stock biomass and stock biomass from several of the sensitivity runs for the PBSP model. All show substantial depletion from the initial stock size in 1918. The runs using the PBSP model and with the lower 2.5% bound and the highest prior mean for B_{init}/K_0 (B.4) show the largest amount of depletion. The run with the smallest prior mean for B_{init}/K_0 (B.3) shows the least amount of depletion, presumably because it compensates with a posterior distribution supporting higher values for r_0 (Table 22).

Most results are sensitive to alternative settings for the uncertainty bounds, the prior for r and the initial stock size relative to K. Except for the estimates of the provisional target stock size and to some extent stock size in 2009, results are relatively insensitive to alternative settings for the priors for r and B_{init}/K_0 (Table 22). For example, results from a run with the low prior mean for r, target stock size is about 8600 tons. This is about 7100 tons under the prior for r with the high prior mean.

PBSP model results are relatively insensitive to the different scenarios for historic catches (C.3 and C.4) (Table 22). Results are also insensitive to different scenarios for the maximum percentage of rockfish in pinnipeds' diets (F.1 to F.4) (Table 22). Under all scenarios the stock is still strongly depleted relative to the initial stock size in 1918 and the ratios of F_{2009}/F_{msy} and $Catch_{2009}/RepY_{2009}$ are still relatively low (Table 22).

The sensitivity analyses that had one of the strongest influences on the PBSP results had to do with the factors affecting total predation, i.e., the runs with different inputs for total yelloweye rockfish consumption (E.1 to E.6) and the runs with the upper and lower bounds on consumption and predator abundance (G.1 and G.2). In runs E.1 to E.6 we varied the inputted yelloweye rockfish consumption rates for each pinniped species to a one hundredth, one tenth, one quarter, one half, and 1.5 and 2 times the reference case estimates of total consumption by pinniped species and refitted the surplus production model to these alternative values. The results are qualitatively similar for consumption rates set at 1.5 times down to as low as one half of the reference case estimates (Table 22). For the run with yelloweye rockfish consumption set to one quarter of the reference case level (E.3) and less, the results start to become substantially different. For example, the posterior median for the provisional target biomass and F_{2009}/F_{msy} change from about 7100 tons and 0.88 under the reference case to 4200 tons 1.3 under run E.3. Run E.2 with consumption set at 1/10th of the reference case gives results most similar to the lower bound run G.1. The upper bound run G.2 gives results more extreme than the most consumption sensitivity run E.6 where consumption was set at double the reference case. Applying a slightly expanded set of reference years for the harbour seal diet (1982-1988) (run H.1) as opposed to only 1988 in the reference case produced no noticeable difference in stock assessment (Table 22) and projection results (not shown).

While there is some sensitivity in results to different inputs for the prior for r, the prior for initial stock size, catch records, and the maximum % rockfish in the diet, Bayes factors in none of these instances assigned very low credibility to any of these scenarios. The run with catches set at 1/2 the reference case however had 10 times the credibility of the reference case. This may indicate that when predation is included, it is easier to explain the stock trend indices with somewhat lower historical catches. However, Bayes factors with values of around 10 are still considered not to provide strong support for a model (Kass and Raftery 1995). All of the Bayes factors in this analysis should be interpreted in a conservative manner since the variance inputs to the likelihood functions for pinniped predation were set at values that were on the low side. In contrast, the lower consumption rate runs tended to be assigned considerably lower credibility than the high consumption rate runs (Table 23). For example the 2.5% lower bound run had 2% of the credibility of the reference case and the upper bound scenario had 12 times the credibility of the reference case. Note that the uncertainty bound analysis was different from the diet uncertainty analysis in a few different respects. For example, in the uncertainty bound analysis, the abundance time series for the three pinniped populations and several other factors affecting the total amount of yelloweye rockfish were set at different values based on their error variances. In contrast, in the diet uncertainty analyses only the total amount eaten in the reference years were varied while the abundance values were kept constant. Thus the Bayes factors while tending in the same direction over these two sensitivity analyses should not be expected to behave in the same way as the predation factors are increased. Similarly, the run with 1/10th of the reference case consumption of yelloweye by pinnipeds had 4/1000ths the credibility of the reference case run. The run with consumption at twice the reference case was 5 times more credible than the reference case run. The greater credibility of runs with high pinniped predation may be attributable to the fact they better explain the continued decline in yelloweye rockfish abundance in recent years despite the reduction in fishing mortality.

PBSP STOCK DEPLETION

The posterior median values are computed for the two-generation levels of stock depletion starting in 1997 (Table 24). For the reference case, the fraction of stock size in the target year relative to two generations earlier decreases from 0.39 in 1997 to 0.17 in 2009. It is plausible that the three generation level of depletion is low or lower than these values. The various sensitivity runs show higher levels of depletion over two generations (Table 24).

PBSP STOCK PROJECTIONS AND DECISION TABLES

When the population is projected assuming that pinniped abundance stays the same at 2009 levels, inside yelloweye abundance continues to decrease to varying extents depending on the harvest policy option (Table 25, Figure 28 - A). Projection results are very similar to the reference case under alternative scenarios for the prior mean for r, the prior mean for B_{init}/K_0, scenarios for low and high historic catches, scenarios for high (150% of reference case) yelloweye rockfish consumption by pinnipeds, and the run with the 97.5% upper bound for predation inputs (Tables 26 - 30). However, under the low consumption run (Table 29) and the lower predation bound run (Table 30) all but the harvest policies with the highest harvest rates resulted in population persistence (i.e., maintained the population at values of at least 1% of the initial stock size) as far as 80 years into the future.

If the predation by each pinniped species was lowered to about 1/5 of the 2009 levels, by the year 2021, and then were to remain at the same level after that, the rate of decrease in the median values for inside yelloweye rockfish abundance slowed considerably and then showed increases under all policy options (Table 31, Figure 28 - B).

PBSP SUMMARY AND DISCUSSION

A substantial literature on complex interactions between predators, prey and fisheries already exists (e.g., May et al. 1979; Yodzis 1994; 2000; 2001; Spencer 1997; Spencer and Collie 1996; 1997; Fulton et al. 2003; Essington 2004; Walters et al. 1997; 2000; 2005; Walters and Kitchell 2001; Walters and Martell 2004). Many of these papers discuss issues such as the possibility of multiple stable states and complex and diffuse effects in food webs due to direct and indirect trophic interactions. In particular, there have been a number of papers considering interactions among marine mammals, their prey and fisheries (May et al. 1979; Punt and Butterworth 1995; Constable 2001; Yodzis 2000; 2001; Lessard et al. 2005). The main conclusions of these papers have tended to be: i) interactions among mammal predators, fish and fisheries tend to be complex and often mitigated by other components of the ecosystem; and ii) maximum sustainable yield changes its definition when predators are explicitly taken into account.

The PBSP model presented in this report extends previous work dealing with the interactions of pinnipeds and fisheries by explicitly accounting for long term trends in pinniped predation within the context of a Bayesian stock assessment approach that explicitly accounts for uncertainty given available data and other key information (Punt and Hilborn 1997; McAllister and Kirchner 2002). As noted above, there has been much theoretical attention given to considering the potential forms of the interactions between pinnipeds and fisheries as noted above and some empirical studies on this issue (e.g., Punt and Butterworth 1995). However, there has been relatively little attention focused on developing an empirical basis to include pinniped predation within the context of contemporary stock assessment approaches that could be more generally applied. This is particularly important for the purposes of providing fisheries management advice that takes into account the potential impacts of historic trends in pinniped predation on fish stocks of interest and potential future scenarios for pinniped predation on fish stocks. Development of stock assessment methodologies that explicitly account for pinniped predation are especially needed given the recent exponential increases in pinniped populations in many different regions (e.g., in eastern Canada (Bowen et al. 2003), Australia (T. Smith, pers commn), South Africa and Namibia (Punt and Butterworth 1995)) and recent concerns about the potential growing impacts of pinniped predation on fish populations, especially those that are very low in abundance compared to historic levels (e.g., Chouinard et al. 2005; Bundy et al. 2010).

In this report, alternative hypotheses on the relative magnitude of pinniped predation on the fish stock of interest are considered using a stock assessment methodology developed within a Bayesian estimation and decision analytic framework (Punt and Hilborn 1997). The alternative models representing alternative hypotheses on the potential competing impacts of pinniped predation and fishing are constructed and their credibility was evaluated by fitting the models to available data and computing Bayes factors for the alternative models. This would permit the potential consequences of alternative policy options to be presented within fully specified decision tables (Hilborn et al. 1993), i.e., that include a set of key alternative hypotheses, e.g. on the impacts of pinniped predation, represented in columns across the top of such tables, and also a representation of the credibility for each alternative hypothesis obtained from fitting the models to the data which reflects the relative credibility of each hypothesis given the available data, i.e., Bayes factor. The Pinniped Bayesian Surplus Production (PBSP) model adds ecological realism into the yelloweye rockfish stock dynamics and provides a sound theoretical and empirical basis for it. It also offers a Bayesian stock assessment framework and potential new reference points with which to consider ecosystem based fisheries management (Pikitch et al. 2004), particularly with respect to dealing with pinniped-fishery interactions.

The PBSP model is presented here as an extension of the BSP model and has been applied for illustrative purposes only. It was motivated by a growing concern over the potential impact on B.C. rockfishes of the substantial increases in pinniped abundance in B.C. and inside waters since the 1970s, the known predation on rockfishes by pinnipeds in B.C. waters, the high bioenergetic requirements of harbour seals and sea lions, and the high vulnerability of the yelloweye rockfish population to threats such as pinniped predation due to its late age of maturity and low natural mortality rate. The PBSP analysis provides indications of the sensitivity of stock assessment results to explicitly modeling long term trends in predation from seals and sea lions. In contrast to the BSP model that presumes that predation rates are constant, the PBSP model attributes the decline in the 1980s to the present to result partly from pinniped predation. However, at this point, given the uncertainties in pinniped predation on yelloweye rockfish, no management advice can be provided from this version of the surplus production model. Nevertheless, under most scenarios considered, the BSP model projects future stock increases with fisheries management while the PBSP model projects continued stock declines unless pinniped predation decreases. If the stock does not appear to respond to fishery management (low fishery catches) sometime into the future (e.g., within 5 years), the provision of management advice using alternative models such as the new one presented in this document and extensions of it may need to be further explored.

The form of the functional response determines the degree to which density of the prey controls predation rates and, therefore, determines key prey population dynamics (Holling 1959; Yodzis 1994). The assessment only considered a Type I (capped linear) functional response with the maximum cap on the percentage of yelloweye rockfish consumed per predator set in the reference case at double the average consumption estimated within the last three decades. There are other areas, even in BC, where rockfish comprise a significant portion of the diet of sea lions, indicating that they will be consumed when abundant and accessible. This probably also holds for seals, although to a lesser extent. Setting the upper limit at twice the low levels observed in the last three decades may have artificially constrained pinniped consumption of yelloweye when they were more abundant. However, it is conceivable that the high abundance of other more desirable prey species in inside waters compared to other areas historically and in recent years may have limited the extent to which pinnipeds in inside waters have consumed rockfishes even when rockfish abundances were considerably higher in the past. It is also likely that the application of a ceiling that could be too low would have little effect on the results, especially in recent and future years because yelloweye stocks are depressed and the ceilings do not come into play. But even when much higher maximum caps were applied, the stock status and projection results obtained did not differ much at all from the reference case. This is likely due to the fact that the estimated abundance when the diet of the main predator, i.e., harbour seals, was sampled was at about half of the initial abundance. Under the Type I functional response model, the maximum modeled predation during the time series would thus go no higher than about double the consumption estimated in the 1980s and thus still remain well below caps ranging higher than double the observed values.

A Type III functional response predicts depensatory predation rates at low prey density and can occur as a result of a large number of mechanisms including inability of predators to detect prey at lower densities (predator inefficiency); prey switching by the predator when prey densities become low; spatial refuges, or by changes in prey foraging behaviour at low densities, where prey at low densities do not have to engage in risky foraging excursions that expose them to predators (foraging arena theory: Walters and Juanes 1993; Walters and Korman 1999; Walters and Martell 2004). Foraging arena theory is thought to be a ubiquitous stabilizing mechanism in marine ecosystems. It has been used to derive the Beverton-Holt stock-recruitment function (Walters and Korman 1999; Walters and Martell 2004) and to explain the observations that chaotic predator-prey cycles and extinction of marine fish species appear to be rare in nature (Walters et al. 1997; 2000). In its true form, the equation describing the Type III functional response includes parameters for search time and handling time (Holling 1959). However, it is not uncommon for these parameters to be expressed in simpler terms (e.g., Steele and Henderson 1984; Spencer 1997; Spencer and Collie 1997). In contrast, a Type II functional response would result in predation rates remaining disproportionately high as prey density dropped and would result in accelerated decline in the prey species. Due to time constraints, it was not possible to consider the implementation of Type II and Type III variants of the functional response within the stock assessment framework that was adopted.

SOURCES OF UNCERTAINTY IN THE PINNIPED STOCK ASSESSMENT MODEL

1) Pinniped consumption

Although the amount of predation mortality and the maximum fraction of rockfish in the diet are addressed in the sensitivity analyses, there is still uncertainty associated with the inputs to the pinniped predation parameters.

a) Diet composition

Detailed areal and seasonal diet studies have not been conducted for each pinniped species in the entire inside waters but are required to improve estimates of diet composition. Some of the existing data is several decades old, and needs to be updated. The portion of the overall rockfish estimate that is actually yelloweye rockfish, as well as, associated digestions rates also need to be detailed together with some indication of size or age.

b) Annual abundance of sea lions

The total inside waters annual abundances of California sea lions and Steller sea lions are uncertain due to the infrequent counts, and uncertainty in the average fraction of California sea lions hauled out and counted during surveys. Pinnipeds often congregate to feed on prey that are seasonally or locally abundant, so the distribution as well as abundance of pinnipeds can influence consumption levels.

c) Rates of consumption per animal

It is possible that each pinniped species will exhibit a type II or III functional responses to variations in the availability of preferred prey species. Without more information on predator-prey relationships it is difficult to predict how consumption rates of yelloweye rockfish might change as yelloweye rockfish abundance and the abundance of more preferred prey species change over time. Most pinnipeds are opportunistic predators such that the relative availability of other prey species will likely influence the rockfish consumption.

d) Size and age composition of yelloweye rockfish consumed.

The PBSP model only considers the exploitable or fishable biomass which for the different fisheries involved, i.e.,, recreational aboriginal and commercial fisheries. The modeled exploitable biomass thus includes the mixture of immature, subadult and adult yelloweye rockfish. In contrast, pinnipeds may feed on a different range of fish sizes than any of the fisheries, for example, down to age one fish. It is also conceivable that pinnipeds may primarily consume juvenile and subadult rockfish and large numbers of pre-recruits. Should this be the case pinnipeds could still have an impact on the population and the fishery by affecting recruitment and the smaller sized component of the exploitable biomass. Should this be the case it could be questioned whether pinnipeds could be considered to behave as “just another fishing fleet”; pinnipeds could behave instead more similarly to a bycatch fishery that impacts juveniles of an economically important fish stock. For example, pinnipeds could behave similarly to how the Gulf of Mexico shrimp fishery behaves with respect to its bycatch of juvenile red snapper (*Lutjanus campechanus*); this appears to have severely impacted red snapper recruitment and the red snapper fishery (Brooks and Powers 2007). Should this be the case, the estimates of pinniped predation rates and fishing mortality rates could still be comparable providing that the average values for non-pinniped sources of natural mortality rates were similar for fish consumed by pinnipeds and those taken by the different fisheries. In contrast, the consumption by pinnipeds of the same biomass of smaller-sized fish would translate into higher total mortality rates than the harvest of the same biomass of larger sized individuals. Given the paucity of age composition data (for each of the fisheries and pinnipeds) differences in size selectivity between pinnipeds and fishing fleets is obviously something that cannot be incorporated into the existing model. It is nevertheless an important consideration that deserves further attention. See Appendix F for further discussion.

2) Factors other than fishery catches and pinniped consumption

a) continued low / declining recruitment of yelloweye rockfish

Factors affecting the recruitment of yelloweye rockfish are unknown and the possibility of declining or continued poor recruitments will contribute to declining abundance. Setting poor recruitment apart from the fishery and pinniped consumption is difficult and a source of uncertainty in the stock assessment.

b) large unreported catches

Large unreported catches are a menace to all stock assessments and could contribute to a decline in abundance. Given the increased monitoring of the fisheries, this is not considered plausible (>150%) in recent years of the fishery but remains uncertain.

SUGGESTIONS FOR FURTHER RESEARCH

Further research to address the uncertainty in the above mentioned trend indices and pinniped consumption inputs would serve to improve the stock assessment. Other research to improve the stock assessment includes:

1. Variations in recruitment of yelloweye rockfish are currently unknown. This information could inform future stock projections. Suggested research includes using visual tools to assess pre-recruits *in situ,* and assessing other fisheries or research surveys for juvenile fish.
2. Future efforts to construct a delay-difference or an age structure model may help to evaluate whether employing all other data sources such as length and age frequency distributions would be valuable in understanding trends in abundance for yelloweye rockfish.
3. Histological evaluation of yelloweye rockfish sexual maturity is suggested to determine the proportion of mature fish, particularly at smaller sizes (younger ages) which may update stock productivity and sustainable yield.
4. In the short-term, it may be possible to investigate the influence of pinnipeds on rockfish by surveying densities and the depth distribution of rockfishes within RCAs that are near to and far away from pinniped haulouts. Provided that fishery effects are removed within RCAs direct pinniped predation effects may be observed in existing rockfish populations.
5. Key structural uncertainties in the PBSP model need to be addressed before management advice can be based on the outputs. These include:
    a. Improved estimates of pinniped diets
    b. Formulation or evaluation of the sensitivity of the functional response
    c. Selectivity associated with pinnipeds and the fisheries and their relationship to the age of maturity for yelloweye rockfish
    d. Reassessment of Fishery Reference Points.

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TABLES

Table 1. Total number of inside yelloweye rockfish aged (break and burn) by year, gear type and fishery. Ages range from 5 to 101 years.

year	number aged	gear type	fishery
1980	37	jig	commercial
1984	68	jig	commercial
1985	122	jig	survey
1986	43	jig	survey
1988	225	jig	survey
1989	74	jig	survey
1994	50	jig	survey
2000	2	jig	commercial
2003	181	longline	survey
2004	146	longline	survey
2005	276	longline	survey
2006	131	longline	survey
2007	115	longline	survey
2008	201	longline	survey

*Table 2. Posterior means and CVs for the von Bertalanffy growth parameters for inside yelloweye rockfish (*Sebastes ruberrimus*) derived from samples collected between 2003 and 2008 during the inside research longline survey.*

	Yelloweye rockfish *(Sebastes ruberrimus)*			
	Female n=455		Male n=431	
	mean	CV	mean	CV
L_{inf}	690.89	0.065	680.87	0.05
t_0	-12.856	0.27	-12.126	0.236
K	0.0297	0.2	0.0308	0.171

Table 3. Posterior correlations for the von Bertalanffy growth parameters for inside yelloweye rockfish (Sebastes ruberrimus).

Yelloweye rockfish (*Sebastes ruberrimus*)		
	female	male
corr (L_{inf}, K)	-0.933	-0.934
corr (L_{inf}, t_0)	-0.874	-0.798
corr (K, t_0)	0.945	0.925

Table 4. Posterior means and CVs for the length (L in mm) to weight (W in kg) conversion constants a and b where $W=aL^b$ for inside yelloweye rockfish (Sebastes ruberrimus).

	Yelloweye rockfish (*Sebastes ruberrimus*)			
	Female n=455		Male n=431	
	mean	CV	mean	CV
a	9.41 e-9	0.12	1.03 e-8	0.11
b	3.10	0.006	3.09	0.006

Table 5. 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).

Yelloweye rockfish (*Sebastes ruberrimus*)		
	mean	CV
median age (yr)	17.68	0.088
approx CV in age at maturity	0.498	0.211

Table 6. History of management changes for the directed hook and line rockfish (Sebastes) fishery from 1986-2009.

Year	Management Change
<1986	open fishery
1986	ZN licence introduced, requirement for logbooks
1991	total allowable catch (TAC) restrictions introduced, 592 licenses
1992	limited entry licensing, 74 licenses
	fishing periods with species based catch limits and TACs
1995	aggregate species management, TACs
	mandatory dockside monitoring of landings
2002	TACs reduced by 75%, rockfish conservation areas (RCAs) introduced
2006	groundfish fishery integration and 100% monitoring

Table 7. Yelloweye rockfish total allowable catch (TAC) for the inside management area (4B) by management year.

Yelloweye rockfish Inside management area 4B			
Management Year	Catch Quota tonnes	Management Year	Catch Quota tonnes
1986	-	1998	23
1987	-	1999	20
1988	-	2000	20
1989	-	2001	20
1990	-	2002	7
1991	50	2003	7
1992	59	2004	7
1993	70	2005	7
1994	70	2006	7
1995	62	2007	7
1996	26	2008	7
1997	24	2009	7
		2010	7

Table 8. Abundance indices for inside waters derived from a Bayesian generalized linear model of the inside commercial catch per unit effort data (CCPUE). The series number shows the CCPUE time series used in the parameter estimation of each index. All values could not be treated as a single series for parameter estimation because of occasional changes in management and protocols for recording data. The CV is the posterior coefficient of variation in each index value from the Bayesian model. σ_o is the fixed value for the standard deviation (SD) in the natural logarithm of deviates between these observed and model predicted values that were applied. The empirical estimates obtained from the reference case run (see below) are also shown.

Year	Index	Serie	CV	σ_o (fixed)	σ_o
1986	2.837	1	0.041	0.25	0.15
1987	2.108	1	0.042	0.25	0.15
1988	2.229	1	0.038	0.25	0.15
1989	1.414	1	0.034	0.25	0.15
1990	1.626	1	0.033	0.25	0.15
1995	1.720	2	0.051	0.15	0.12
1996	1.737	2	0.045	0.15	0.12
1997	1.286	2	0.053	0.15	0.12
1998	1.290	2	0.047	0.15	0.12
1999	1.125	2	0.046	0.15	0.12
2000	1.095	2	0.047	0.15	0.12
2001	0.969	2	0.052	0.15	0.12
2003	0.476	3	0.28	0.20	0.17
2004	0.334	3	0.31	0.20	0.17
2005	0.411	3	0.36	0.20	0.17
2006	0.376	4	0.176	0.20	0.17

Table 9. Abundance indices for Pacific Fisheries Management Areas 12-17 and 28 derived from the inside waters rockfish research longline survey from 2003 to 2009. The fixed values for the standard deviation (SD) in the natural logarithm of deviates between these observed and model predicted values that were applied and the empirical estimates obtained from the reference case run (see below) are also shown. -1 indicates no data available.

	Area 12	Area 13	Area 14	Area 15	Area 17	Area 16	Area 28
fixed σ_o	0.50	0.50	0.50	0.50	1.00	0.50	0.50
estimated σ_o	0.16	0.58	0.27	0.02	1.02	0.63	0.04
Year	index	index	index	index	index	index	index
2003	7.6	34.1	-1	-1	-1	-1	-1
2004	10.5	34.2	-1	-1	-1	-1	-1
2005	-1	-1	30.1	28.9	15.8	20.2	2.9
2006	-1	-1	-1	-1	-1	-1	-1
2007	10.4	11.0	-1	-1	-1	-1	-1
2008	8.8	13.4	20.4	29.5	30.0	8.2	-1
2009	-1	-1	-1	-1	4.0	-1	3.0

Table 10. Abundance indices for inside yelloweye rockfish derived from the Strait of Georgia dogfish research longline survey from 1986 to 2008. The CV is the posterior coefficient of variation in each index value from the Bayesian model. σ_o is the fixed value for the standard deviation (SD) in the natural logarithm of deviates between these observed and model predicted values that were applied. The empirical estimates obtained from the reference case run (see below) are also shown.

Year	Index	CV	σ_o (fixed)	σ_o (empirical)
1986	1.22E-04	0.35	0.20	0.31
1989	1.87E-04	0.34	0.20	0.31
2004	5.72E-05	0.18	0.20	0.31
2005	4.59E-05	0.20	0.20	0.31
2008	3.83E-05	0.17	0.20	0.31

Table 11. For the reference case Bayesian surplus production model (BSP) run, the posterior median, standard deviation (SD), coefficient of variation (CV) (standard deviation/ mean) for key parameters and stock status indicators for inside yelloweye rockfish. K_0 is the equilibrium stock size in absence of fishing. r is the maximum rate of population increase in absence of fishing. The maximum sustainable yield (MSY) reflects the maximum sustainable total biomass that can be captured by fishermen. B_{2009} and C_{2008} are the recruited stock biomass and catch biomass in 2009, RepY is the replacement yield in 2009. F_{MSY} refers to the fishing mortality rate at MSY. B_{init} is the stock biomass in the first year of the model, i.e., 1918. Biomass values are in tons. q is the constant of proportionality for each different stock trend index. LL refers to research longline survey. CCPUE refers to the standardized commercial catch per unit effort index. Recr_g is the catchability coefficient to predict recreational catches from recreational fishing effort.

Variable	Median	SD	CV
K_0 (t)	7385	3201	0.40
r	0.027	0.014	0.48
MSY (t)	50	20	0.38
B_{2009} (t)	780	391	0.46
B_{init} (t)	6466	2787	0.40
B_{2009}/K	0.108	0.047	0.41
B_{init}/K	0.872	0.186	0.21
B_{2009}/B_{init}	0.123	0.057	0.43
F_{2009}/F_{MSY}	1.38	1.18	0.70
C_{2009}/RepY	0.78	0.62	0.66
RepY (t)	19	10	0.49
q - dogfish LL	0.00065	0.00017	0.26
q - rockfish LL Area 12	0.0110	0.0036	0.31
q - rockfish LL Area 13	0.024	0.0079	0.31
q - rockfish LL Area 14	0.030	0.0100	0.32
q - rockfish LL Area 15	0.035	0.0117	0.32
q - rockfish LL Area 17	0.0152	0.0051	0.32
q - rockfish LL Area 16	0.0156	0.0052	0.32
q - rockfish LL Area 28	0.0036	0.0012	0.32
q - CCPUE 86-90	0.00071	0.00014	0.19
q - CCPUE 95-01	0.00119	0.00037	0.30
q -CCPUE 03-05	0.00046	0.00015	0.31
Recr_g	0.00190	0.00042	0.22
$P(B_{2009} > 0.4B_{MSY})$	0.048		
$P(B_{2009} > 0.8B_{MSY})$	0.001		

Table 12. Summary of the sensitivity runs in the inside yelloweye rockfish stock assessment indicating a category code, category description, table code for use in other tables and a description of the run. The reference case model is the Bayesian Surplus Production model (BSP).

Category Code	Category Description	Table Code	Run Description
Ref	Reference run	Ref.1	Reference run BSP
A	r prior mean	A.1	low r (mean = 0.0361, SD=0.0156) BSP
		A.2	high r (mean = 0.0680, SD= 0.0320) BSP
B	Initial stock size assumptions	B.1	prior mean B_{init}/ K_0 = 0.7 BSP
		B.2	prior mean B_{init}/ K_0 = 1.2 BSP
C	Uncertainty over commercial catch records (note that recreational catches were presumed constant)	C.1	fixed commercial catches are 50% of the reference case BSP
		C.2	fixed commercial catches are 150% of the reference case BSP
D	Effect of data	D.1	Leave out CCPUE data BSP
		D.2	Leave out dogfish research longline BSP
		D.3	Leave out rockfish research longline BSP

Table 13. Stock assessment results for alternative settings to the Bayesian surplus production (BSP) stock assessment model. B_{1918} and B_{2009} refer to the stock size in 1918 and 2009, $RepY_{2009}$ refers to the replacement yield in 2009. F_{2009} refers to the fishing mortality rate in 2009. All biomass values are in tonnes. The posterior median (Med), standard deviation (SD) and coefficient of variation (CV) are shown for each estimated quantity. See Table 12 for more details on the runs associated with the run code numbers.

	r			B_{1918}			B_{2009}			$RepY_{2009}$			B_{2009}/B_{init}			F_{2009}/F_{msy}			$Catch_{2009}/RepY_{2009}$		
Code	**Med**	**SD**	**CV**	**Med**	**SD**	**CV**	**Med**	**SD**	**CV**	**Med**	**SD**	**CV**	**Med**	**SD**	**CV**	**Med**	**SD**	**CV**	**Med**	**SD**	**CV**
Reference run																					
Ref.1.	0.027	0.014	0.48	6466	2787	0.40	780	391	0.46	19	10	0.49	0.123	0.057	0.43	1.38	1.18	0.70	0.78	0.62	0.66
r prior																					
A.1	0.022	0.012	0.50	7066	2783	0.37	828	340	0.38	16	9	0.50	0.118	0.054	0.42	1.68	1.36	0.67	0.95	0.71	0.64
A.2	0.034	0.014	0.38	5889	2006	0.32	765	296	0.36	23	10	0.38	0.131	0.056	0.40	1.13	0.56	0.45	0.65	0.29	0.41
Initial stock size assumptions																					
B.1	0.026	0.015	0.50	5665	2529	0.41	804	328	0.38	19	10	0.48	0.143	0.066	0.43	1.43	1.22	0.70	0.80	0.63	0.66
B.2	0.028	0.014	0.46	7825	2847	0.34	787	389	0.45	19	11	0.49	0.103	0.046	0.41	1.34	1.13	0.69	0.77	0.61	0.66
Uncertainty over historic catches																					
C.1	0.027	0.014	0.47	3227	1370	0.39	377	236	0.55	10	5	0.50	0.123	0.056	0.42	1.37	1.14	0.69	0.78	0.60	0.65
C.2	0.027	0.014	0.48	9699	4114	0.39	1183	537	0.42	29	16	0.49	0.123	0.057	0.42	1.38	1.17	0.70	0.78	0.61	0.66
Effect of different data sets																					
D.1	0.028	0.015	0.49	6567	2564	0.37	925	486	0.47	22	12	0.49	0.143	0.068	0.44	1.15	0.99	0.70	0.67	0.52	0.65
D.2	0.037	0.017	0.41	6788	6707	0.78	1687	7112	1.93	26	73	1.53	0.191	0.319	1.12	1.20	3.12	1.47	0.61	1.73	1.54
D.3	0.031	0.016	0.46	6261	2630	0.39	884	379	0.40	24	12	0.46	0.142	0.064	0.41	1.08	0.94	0.71	0.63	0.50	0.66

Table 14. Posterior probabilities for the BSP stock assessment model with A. low (A.1), reference case (Ref) and high (A.2) prior means for r; B. alternative prior means for initial stock size relative to unfished, unpredated stock size (B_{init}/K) representing cases low (B.1), Ref and high (B.2); and C. low (C.1), reference case (Ref) and high (C.2) variants for historic catches. In each of these comparisons, the prior probability on each model alternative is set to be equal across the alternative models.

Category Description	Code	**Run Description**	**Bayes Factor**
r prior mean	A.1	low r (mean = 0.0361, SD=0.0156)	0.7
	Ref.1	Reference run BSP	1
	A.2	high r (mean = 0.0680, SD= 0.0320)	0.2
Initial stock size assumptions	B.1	prior mean B_{init}/ K_0 = 0.70	0.45
	Ref.1	prior mean B_{init}/ K_0 = 0.90	1
	B.2	prior mean B_{init}/ K_0 = 1.20	0.99
Uncertainty over catch records	C.1	fixed commercial catches are lower by 50%	0.8
	Ref.1	Reference case commercial catches	1
	C.2	fixed commercial catches are higher by 50%	1.2

Table 15. BSP Posterior median estimates of two generation levels of population decline (B_{fin}/ B_{init}) for the years 1997-2009 under a number of the key alternative scenarios highlighted in Table 14.

	Bayesian Surplus Production model						
Year	Ref.1	Low r	High r	B_{init}/K=0.7	B_{init}/K=1.2	Low catch	High Catch
1997	0.20	0.20	0.21	0.22	0.19	0.20	0.20
1998	0.19	0.19	0.20	0.20	0.18	0.19	0.19
1999	0.18	0.18	0.18	0.19	0.17	0.18	0.18
2000	0.16	0.17	0.17	0.18	0.16	0.16	0.16
2001	0.16	0.15	0.16	0.17	0.15	0.15	0.15
2002	0.15	0.15	0.16	0.16	0.14	0.15	0.15
2003	0.15	0.15	0.16	0.16	0.15	0.15	0.15
2004	0.16	0.16	0.17	0.17	0.15	0.16	0.16
2005	0.16	0.16	0.17	0.17	0.15	0.16	0.16
2006	0.16	0.16	0.17	0.17	0.15	0.16	0.16
2007	0.16	0.15	0.17	0.17	0.15	0.15	0.16
2008	0.16	0.15	0.17	0.17	0.15	0.15	0.15
2009	0.16	0.15	0.16	0.16	0.15	0.15	0.16

Table 16. Projection results for the reference case BSP model at 5, 20, 40 (one-generation) and 80 (two-generation) year horizons. Horizon refers to the time period over which the projections were developed. Policy refers to the various harvest strategies. TAC refers to fixed catch policies that are harvested annually over the time horizon. F refers to constant fishing effort policies that are set at TAC levels in 2010. Median(B_{fin}/B_{MSY}) refers to the posterior median for the ratio of the stock biomass at the end of the horizon to that at B_{MSY}. P(B>0.4 B_{MSY} in Hz) is the probability that stock biomass in any year in the horizon exceeds 40% of stock biomass at B_{MSY}. P(B>0.8 B_{MSY} in Hz) is the probability that stock biomass in any year in the horizon exceeds 80% of stock biomass at B_{MSY}. P(B_{fin}>B_{2009}) refers to the probability that stock biomass at the end of the horizon exceeds stock biomass in 2009.

Horizon	Policy	Median (B_{fin}/B_{MSY})	P(B>0.4 B_{MSY} in Horizon)	P(B>0.8 B_{MSY} in Horizon)	P(B_{fin}>B_{2009})
5 -year	TAC= 0	0.232	0.137	0.008	0.658
	TAC= 5 t	0.228	0.134	0.008	0.617
	TAC= 10 t	0.221	0.129	0.008	0.542
	TAC= 15 t	0.215	0.125	0.008	0.468
	F=F(5 t TAC(2010))	0.228	0.134	0.008	0.616
	F=F(10 t TAC(2010))	0.221	0.129	0.008	0.543
	F=F(15 t TAC(2010))	0.215	0.123	0.008	0.469
20 -year	TAC= 0	0.336	0.421	0.069	0.847
	TAC= 5 t	0.305	0.373	0.058	0.772
	TAC= 10 t	0.271	0.320	0.047	0.674
	TAC= 15 t	0.237	0.278	0.039	0.563
	F=F(5 t TAC(2010))	0.299	0.359	0.055	0.774
	F=F(10 t TAC(2010))	0.265	0.304	0.043	0.676
	F=F(15 t TAC(2010))	0.234	0.260	0.028	0.564
40 -year	TAC= 0	0.519	0.699	0.289	0.885
	TAC= 5 t	0.446	0.619	0.232	0.824
	TAC= 10 t	0.358	0.527	0.182	0.734
	TAC= 15 t	0.275	0.435	0.137	0.577
	F=F(5 t TAC(2010))	0.414	0.595	0.206	0.822
	F=F(10 t TAC(2010))	0.328	0.488	0.135	0.733
	F=F(15 t TAC(2010))	0.260	0.391	0.087	0.595
80 -year	TAC= 0	1.008	0.848	0.658	0.942
	TAC= 5	0.816	0.782	0.566	0.862
	TAC= 10	0.605	0.685	0.474	0.757
	TAC= 15	0.383	0.557	0.377	0.597
	F=F(TAC(icur+1)) 5	0.673	0.766	0.507	0.869
	F=F(TAC(icur+1)) 10	0.456	0.634	0.371	0.763
	F=F(TAC(icur+1)) 15	0.304	0.517	0.251	0.622

Table 17. Projection results at 5, 20 and 40 year horizons under low, BSP reference case and high prior means for r. Horizon refers to the time period over which the projections were developed. Policy refers to the various harvest strategies. TAC refers to fixed catch policies that are harvested annually over the time horizon. F refers to constant fishing effort policies that are set at TAC levels in 2010. Results are shown only for Median(B_{fin}/B_{MSY}) which refers to the posterior median for the ratio of the stock biomass at the end of the horizon to that at B_{MSY}.

		Alternative hypotheses		
Horizon		Low prior mean for r (A.1)	Ref.1	High prior mean for r (A.2)
	Bayes Factor	0.8	1	0.2
	Policy			
5 -year	TAC= 0	0.220	0.232	0.256
	TAC= 5	0.217	0.228	0.252
	TAC= 10	0.210	0.221	0.245
	TAC= 15	0.204	0.215	0.237
	F=F(5 t TAC(2010))	0.216	0.228	0.252
	F=F(10 t TAC(2010))	0.210	0.221	0.245
	F=F(15 t TAC(2010))	0.204	0.215	0.238
20 -year	TAC= 0	0.296	0.336	0.396
	TAC= 5	0.269	0.305	0.361
	TAC= 10	0.240	0.271	0.323
	TAC= 15	0.208	0.237	0.285
	F=F(5 t TAC(2010))	0.265	0.299	0.354
	F=F(10 t TAC(2010))	0.235	0.265	0.314
	F=F(15 t TAC(2010))	0.208	0.234	0.277
40 -year	TAC= 0	0.417	0.519	0.639
	TAC= 5	0.349	0.446	0.559
	TAC= 10	0.276	0.358	0.465
	TAC= 15	0.205	0.275	0.365
	F=F(5 t TAC(2010))	0.336	0.414	0.517
	F=F(10 t TAC(2010))	0.265	0.328	0.414
	F=F(15 t TAC(2010))	0.208	0.260	0.328

Table 18. Projection results at 5, 20 and 40 year horizons under low, BSP reference case and high prior means for initial stock size in 1918 relative to the average expected unfished, B_{init}/K. Horizon refers to the time period over which the projections were developed. Policy refers to the various harvest strategies. TAC refers to fixed catch policies that are harvested annually over the time horizon. F refers to constant fishing effort policies that are set at TAC levels in 2010. Results are shown only for Median(B_{fin}/B_{MSY}) which refers to the posterior median for the ratio of the stock biomass at the end of the horizon to that at B_{MSY}.

		Alternative hypotheses		
Horizon		Prior mean for B_{init}/K = 0.7 (B.1)	Prior mean for B_{init}/K = 0.9 Ref.1	Prior mean for B_{init}/K = 1.2 (B.2)
	Bayes Factor	0.45	1	0.99
	Policy			
5 -year	TAC= 0	0.215	0.232	0.258
	TAC= 5	0.211	0.228	0.255
	TAC= 10	0.205	0.221	0.247
	TAC= 15	0.199	0.215	0.240
	F=F(5 t TAC(2010))	0.210	0.228	0.255
	F=F(10 t TAC(2010))	0.205	0.221	0.247
	F=F(15 t TAC(2010))	0.199	0.215	0.240
20 -year	TAC= 0	0.302	0.336	0.379
	TAC= 5	0.276	0.305	0.346
	TAC= 10	0.244	0.271	0.311
	TAC= 15	0.214	0.237	0.274
	F=F(5 t TAC(2010))	0.272	0.299	0.341
	F=F(10 t TAC(2010))	0.239	0.265	0.303
	F=F(15 t TAC(2010))	0.212	0.234	0.268
40 -year	TAC= 0	0.456	0.519	0.594
	TAC= 5	0.390	0.446	0.508
	TAC= 10	0.316	0.358	0.419
	TAC= 15	0.239	0.275	0.327
	F=F(5 t TAC(2010))	0.369	0.414	0.478
	F=F(10 t TAC(2010))	0.290	0.328	0.382
	F=F(15 t TAC(2010))	0.228	0.260	0.304

Table 19. Projection results at 5, 20 and 40 year horizons under low (50% of reference case), BSP reference case and high (150% of reference case) scenarios for total catches. Horizon refers to the time period over which the projections were developed. Policy refers to the various harvest strategies. TAC refers to fixed catch policies that are harvested annually over the time horizon. F refers to constant fishing effort policies that are set at TAC levels in 2010. Results are shown only for Median(B_{fin}/B_{MSY}) which refers to the posterior median for the ratio of the stock biomass at the end of the horizon to that at B_{MSY}.

		Alternative hypotheses		
Horizon		Fixed catches set at 50% of reference case (C.1)	Ref. case catches Ref.1	Fixed catches set at 150% of reference case (C.2)
	Bayes factor	0.8	1	1.2
	Policy			
5 -year	TAC= 0	0.233	0.232	0.234
	TAC= 5	0.222	0.228	0.233
	TAC= 10	0.208	0.221	0.228
	TAC= 15	0.195	0.215	0.224
	F=F(5 t TAC(2010))	0.222	0.228	0.233
	F=F(10 t TAC(2010))	0.209	0.221	0.228
	F=F(15 t TAC(2010))	0.196	0.215	0.224
20 -year	TAC= 0	0.333	0.336	0.343
	TAC= 5	0.266	0.305	0.325
	TAC= 10	0.200	0.271	0.301
	TAC= 15	0.131	0.237	0.28
	F=F(5 t TAC(2010))	0.264	0.299	0.322
	F=F(10 t TAC(2010))	0.204	0.265	0.296
	F=F(15 t TAC(2010))	0.156	0.234	0.271
40 -year	TAC= 0	0.520	0.519	0.526
	TAC= 5	0.355	0.446	0.469
	TAC= 10	0.178	0.358	0.414
	TAC= 15	0.007	0.275	0.361
	F=F(5 t TAC(2010))	0.323	0.414	0.448
	F=F(10 t TAC(2010))	0.197	0.328	0.385
	F=F(15 t TAC(2010))	0.118	0.260	0.329

Table 20. For the reference case Pinniped-Bayesian surplus production model (PBSP) run, the posterior median, standard deviation (SD), coefficient of variation (CV) (standard deviation/ mean) for key parameters and stock status indicators for inside yelloweye rockfish. K_0 is the equilibrium stock size in absence of fishing and predation from pinnipeds. r is the maximum rate of population increase in absence of fishing and pinniped predation. The maximum sustainable yield (MSY) reflects the maximum sustainable total biomass that can be captured by fishermen and pinnipeds. B_{2009} and C_{2008} are the recruited stock biomass and catch biomass in 2009, RepY is the replacement yield in 2009. F_{MSY} refers to the combined predation and fishing mortality rate at MSY. B_{init} is the stock biomass in the first year of the model, i.e., 1918. Biomass values are in tons. q is the constant of proportionality for each different stock trend index. LL refers to research longline survey. CCPUE refers to the standardized commercial catch per unit effort index. Recr_g, Seal_g, Stell_g, and Calsl_g are the coefficients for imputing recreational catch, and harbour seal, Steller sea lion and California sea lion consumption. Seal_2009_C, Stell_2009_C, Calsl_2009_C, and Pinniped_2009_C are estimates of the tons of inside yelloweye rockfish consumed by harbour seals, Steller sea lions, California sea lions and all pinnipeds combined.

Variable	Median	SD	CV
K_0 (t)	14264	7617	0.47
r_0	0.0465	0.018	0.38
MSY (t)	162	40	0.25
B_{2009} (t)	732	314	0.38
B_{init} (t)	7000	3549	0.45
B_{init}/K_0	0.485	0.11	0.21
B_{2009}/B_{init}	0.108	0.06	0.52
F_{2009}/F_{MSY}	0.875	0.69	0.66
C_{2009}/RepY	0.465	0.35	0.62
RepY (t)	32	16	0.45
q - dogfish LL	0.00059	0.00015	0.24
q - rockfish LL Area 12	0.0106	0.0036	0.33
q - rockfish LL Area 13	0.0234	0.0080	0.33
q - rockfish LL Area 14	0.030	0.0107	0.34
q - rockfish LL Area 15	0.035	0.0126	0.34
q - rockfish LL Area 17	0.016	0.0057	0.35
q - rockfish LL Area 16	0.0156	0.0056	0.34
q - rockfish LL Area 28	0.0037	0.0013	0.35
q - CCPUE 86-90	0.0006	0.0001	0.15
q - CCPUE 95-01	0.00096	0.00025	0.26
q -CCPUE 03-05	0.00043	0.00014	0.31
Recr_g	0.00148	0.00029	0.19
Seal_g	0.0007	0.0001	0.17
Stell_g	0.0064	0.0020	0.30
Calsl_g	0.004	0.001	0.27
Av. annual Predation rate	0.024	0.004	0.17
Av. annual M pinnipeds	0.026	0.005	0.18
Seal_2009_C (t)	31	10	0.31
Stell_2009_C (t)	6	2	0.24
Calsl_2009_C (t)	8	2	0.27
Pinniped_2009_C (t)	45	13	0.27
P(B2009> $0.4B_{MSY}$)	0.102		
P(B2009> $0.8B_{MSY}$)	0.004		

Table 21. Summary of sensitivity runs in the inside yelloweye rockfish stock assessment, including their categorization. The reference case model is Bayesian Surplus Production model with pinniped predation (PBSP). In the reference case pinniped run the maximum percentage rockfish in the diet was set to 200% of the observed percentages (e.g., if the observed was at 2%, the maximum was set at 4%). Note that consumption at e.g. 10% of reference case is equivalent to a sensitivity test where the percentage of yelloweye rockfish relative to total rockfish in the diet was at 2.5% as opposed to 25% in the reference case. 200% would be equivalent to an upper bound of 50% yelloweye of the rockfish in the diet. Under the reference case, the prior mean B_{init}/K_0 was set at 0.50. To account for plausible covariation in the magnitude of predation and B_{init}/K_0, the prior mean for B_{init}/K_0 was successively reduced as the assumed magnitude of predation in runs E was progressively increased.

Category Code	**Category Description**	**Table Code**	**Run Description**
Ref	Reference run	Ref.2	Reference run PBSP
A	r_0 prior mean	A.3	low r_0, PBSP
		A.4	high r_0, PBSP
B	Initial stock size assumptions	B.3	prior mean B_{init}/K_0 = 0.10 (PBSP)
		B.4	prior mean B_{init}/K_0 = 0.80 (PBSP)
C	Uncertainty over catch records	C.3	fixed catches are 50% of the reference case (PBSP)
		C.4	fixed catches are 150% of the reference case (PBSP)
E	Magnitude of predation (PBSP)	E.1	Consumption at 1/100x reference case, prior mean B_{init}/K_0 = 0.90
		E.2	Consumption at 1/10x reference case, prior mean B_{init}/K_0 = 0.80
		E.3	Consumption at 1/4x reference case, prior mean B_{init}/K_0 = 0.70
		E.4	Consumption at 1/2x reference case, prior mean B_{init}/K_0 = 0.60
		E.5	Consumption at 1.5x of reference case, prior mean B_{init}/K_0 = 0.40
		E.6	Consumption at 2x of reference case, prior mean B_{init}/K_0 = 0.30
F	Maximum percentage of rockfish in the diet (PBSP) (Ref. case is set at 200% of values observed in the 1980s for harbour seals but from 1979-2007 for sea lions)	F.1	Max. % rockfish in diet at 0.75 x ref. case maximum
		F.2	Max. % rockfish in diet at 1.5 x ref. case maximum
		F.3	Max. % rockfish in diet at 2.5 x ref. case maximum
		F.4	Max. % rockfish in diet at 10 x ref. case maximum
G	Lower and upper bounds from the combined uncertainty in all of the predation input variables	G.1	2.5^{th} percentile lower bound for all inputs to predation, prior mean B_{init}/K_0 = 0.90
		G.2	97.5^{th} percentile upper bound for all inputs to predation, prior mean B_{init}/K_0 = 0.30
H	Harbour seal diet reference years	H.2	These were extended to 1982-1988 (Olesiuk 1993) (compared to only 1988 in the reference case run)

Table 22. Stock assessment results for alternative settings to the Bayesian surplus production with pinnipeds (PBSP) stock assessment models. B_{2009} refers to the stock size in 2009, $RepY_{2009}$ refers to the replacement yield in 2009. F_{2009} refers to the fishing mortality rate in 2009. B_{2009}/B_{MSY} refers to ratio of yelloweye rockfish stock biomass in 2009 to the stock biomass at B_{MSY}. All biomass values are in tonnes. The posterior 5th, median (50th), and 95th percentile are shown for each estimated quantity. See Table 11 for more details on the runs associated with the run code numbers.

	r_0			B_{MSY}			B_{2009}			$RepY_{2009}$			B_{2009}/B_{MSY}			F_{2009}/F_{MSY}			$Catch_{2009}/RepY_{2009}$		
Code	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
	Reference runs																				
Ref.2	0.023	0.044	0.069	4684	7132	13067	469	781	1188	16	32	54	0.116	0.219	0.403	0.494	0.875	1.835	0.278	0.465	0.945
	r prior																				
A.3	0.016	0.036	0.057	5590	8616	15347	483	765	1292	14	27	47	0.101	0.193	0.37	0.583	1.059	2.15	0.323	0.559	1.113
A.4	0.03	0.052	0.085	3929	6378	10806	455	726	1159	20	37	64	0.127	0.247	0.461	0.413	0.754	1.424	0.237	0.408	0.742
	Initial stock size assumptions																				
B.3	0.024	0.044	0.066	6641	12341	23426	467	730	1204	18	32	53	0.165	0.316	0.65	0.522	0.897	1.661	0.285	0.47	0.848
B.4	0.026	0.048	0.07	4315	5975	9261	471	730	1185	17	33	55	0.089	0.163	0.293	0.479	0.833	1.694	0.272	0.451	0.881
	Uncertainty over historic catches																				
C.3	0.026	0.048	0.072	3354	5108	8782	266	446	767	11	21	37	0.094	0.189	0.372	0.359	0.666	1.332	0.201	0.356	0.69
C.4	0.024	0.046	0.067	6053	9076	15587	558	939	1567	20	40	70	0.109	0.215	0.417	0.571	1.051	2.176	0.321	0.559	1.117
	Uncertainty over YE consumption (0.01, 0.10, 0.25, 0.50, 1.5, 2.0 times the reference case consumption for each pinniped)																				
E.1	0.021	0.043	0.067	2527	3383	5158	284	487	820	8	19	35	0.087	0.157	0.301	0.754	1.504	3.392	0.437	0.813	1.779
E.2	0.022	0.043	0.064	2753	3711	5854	331	527	860	10	21	36	0.094	0.178	0.323	0.729	1.362	2.864	0.417	0.735	1.488
E.3	0.023	0.044	0.064	3126	4216	6801	328	541	906	11	22	39	0.099	0.183	0.347	0.679	1.297	2.621	0.388	0.695	1.354
E.4	0.023	0.046	0.068	3411	5060	8678	357	586	970	12	24	43	0.103	0.191	0.371	0.617	1.152	2.429	0.348	0.617	1.252
E.5	0.024	0.047	0.07	5862	9731	17753	441	777	1360	18	35	64	0.105	0.214	0.437	0.428	0.817	1.626	0.237	0.43	0.837
E.6	0.023	0.045	0.07	8080	13958	32956	578	945	1418	21	41	71	0.121	0.229	0.487	0.388	0.707	1.394	0.212	0.371	0.712
	Uncertainty over the maximum percentage of rockfish in each pinniped species' diet																				
F.1	0.024	0.046	0.069	4531	6730	11774	459	734	1206	17	33	56	0.126	0.235	0.428	0.48	0.859	1.742	0.271	0.461	0.9
F.2	0.025	0.045	0.066	4840	7445	13511	485	773	1237	18	33	56	0.113	0.218	0.425	0.476	0.853	1.652	0.268	0.455	0.854
F.3	0.023	0.044	0.065	4813	7616	15151	491	795	1251	17	33	57	0.105	0.218	0.433	0.472	0.856	1.688	0.266	0.458	0.872
F.4	0.022	0.044	0.065	4657	7746	15834	496	789	1260	16	33	56	0.096	0.213	0.425	0.481	0.874	1.816	0.271	0.464	0.936
	Lower 2.5% and upper 97.5% bounds applied																				
G.1	0.02	0.043	0.066	3028	4069	6393	318	531	898	10	21	38	0.08	0.144	0.284	0.685	1.331	2.977	0.399	0.723	1.531
G.2	0.032	0.051	0.071	13648	24279	40014	886	1410	2380	43	73	121	0.113	0.218	0.468	0.229	0.393	0.678	0.125	0.207	0.35
	Harbour seal diet reference years																				
H.1	0.023	0.046	0.067	4665	7222	13048	465	751	1247	15	33	55	0.118	0.221	0.416	0.492	0.86	1.905	0.276	0.461	0.978

Table 23. Posterior probabilities for PBSP stock assessment models with A. low (A.3), reference case (Ref) and high (A.4) prior means for r; B. alternative prior means for initial stock size relative to unfished, unpredated stock size (B_{init}/K) representing cases B.3-B.4 and Ref; C. low (C.3), reference case (Ref) and high (C.4) variants for historic catches; D. alternative settings for the reference amount of yelloweye rockfish biomass consumed by each pinniped species (E.1-E.5 and Ref); E. alternative settings for the maximum percentage of yelloweye rockfish in the diet (F.1, F.2 and Ref.)), and alternative settings for the fraction of the rockfish biomass in the diet that is yelloweye (G.1 and G.2). In each of these comparisons, the prior probability on each model alternative is set to be equal across the alternative models.

Category Description	**Code**	**Run Description**	**Bayes factor**
r prior mean	A.3	low r_0 (mean = 0.0361, SD=0.0156)	1.0
	Ref.2	Reference run BSP	1
	A.4	high r_0 (mean = 0.0680, SD= 0.0320)	0.9
Initial stock size assumptions	B.3	prior mean $B_{init}/K_0 = 0.20$	1.5
	Ref.2	prior mean $B_{init}/K_0 = 0.50$	1
	B.4	prior mean $B_{init}/K_0 = 0.80$	0.9
Uncertainty over catch records	C.3	fixed catches are lower by 50%	10
	Ref.2	Reference case catches	1
	C.4	fixed catches are higher by 50%	1.1
Uncertainty over consumption parameters (e.g., fraction of rockfish eaten that are yelloweye and fraction of the diet that is rockfish)	E.1	Consumption of yelloweye rockfish at 1/100 of reference case	0.00001
	E.2	Consumption at 1/10 of reference case	0.004
	E.3	Consumption at 1/4 of reference case	0.1
	E.4	Consumption at 1/2 of reference case	0.5
	Ref.2	Consumption at reference case	1
	E.5	Consumption at 1.5x of reference case	7
	E.6	Consumption at 2x of reference case	5
Uncertainty over the maximum % rockfish in the diet	F.1	Max. % rockfish in diet at 0.75 x reference case	3
	Ref.2	Max. % rockfish in diet at reference case	1
	F.2	Max. % rockfish in diet at 1.5 x reference case	0.5
	F.3	Max. % rockfish in diet at 2.5 x reference case	0.5
	F.4	Max. % rockfish in diet at 5 x reference case	0.5
2.5% and 97.5% uncertainty bounds on predation	G.1	2.5^{th} percentile lower bound for all inputs to predation, prior mean $B_{init}/K_0 = 0.90$	0.02
	Ref.2	Reference Case	1
	G.2	97.5^{th} percentile upper bound for all inputs to predation, prior mean $B_{init}/K_0 = 0.30$	12

Table 24. PBSP Posterior median estimates of two generation levels of population decline (B_{fin}/ B_{init}) for the years 1997-2009 under a number of the key alternative scenarios highlighted in Table 20.

	Bayesian Surplus Production model with predation				
Year	Ref.2	10% of ref. case pred.	150% of ref. case pred.	2.5% bound for predation	97.5% bound for predation
1997	0.39	0.13	0.21	0.12	0.24
1998	0.36	0.12	0.20	0.11	0.22
1999	0.33	0.12	0.18	0.11	0.21
2000	0.30	0.11	0.17	0.10	0.19
2001	0.29	0.10	0.16	0.09	0.18
2002	0.27	0.10	0.15	0.09	0.17
2003	0.26	0.10	0.14	0.09	0.16
2004	0.25	0.10	0.13	0.08	0.15
2005	0.23	0.09	0.13	0.08	0.15
2006	0.22	0.09	0.12	0.08	0.14
2007	0.20	0.09	0.11	0.08	0.13
2008	0.19	0.09	0.11	0.08	0.12
2009	0.17	0.09	0.11	0.08	0.12

Table 25. Projection results for the reference case PBSP model at 5, 20, and 80 (two-generation) year horizons. Horizon refers to the time period over which the projections were developed. Policy refers to the various harvest strategies. TAC refers to fixed catch policies that are harvested annually over the time horizon. F refers to constant fishing effort policies that are set at TAC levels in 2010. Median(B_{fin}/B_{MSY}) refers to the posterior median for the ratio of the stock biomass at the end of the horizon to stock biomass at B_{MSY}. P(B>0.4 B_{MSY} in Hz) is the probability that stock biomass in any year in the horizon exceeds 40% of stock biomass at B_{MSY}. P(B>0.8 B_{MSY} in Hz) is the probability that stock biomass in any year in the horizon exceeds 40% of stock biomass at B_{MSY}. P(B_{fin}>B_{2009}) refers to the probability that stock biomass at the end of the horizon exceeds stock biomass in 2009. This run presumes that the abundance of all three pinniped species will remain at 2009 levels in future years.

Horizon	Policy	Median (B_{fin}/B_{MSY})	P(B>0.4 B_{MSY} in Horizon)	P(B>0.8 B_{MSY} in Horizon)	P(B_{fin}>B_{2009})
5 -year	TAC= 0	0.187	0.121	0.007	0.186
	TAC= 5 t	0.186	0.122	0.007	0.179
	TAC= 10 t	0.180	0.119	0.007	0.147
	TAC= 15 t	0.174	0.116	0.007	0.116
	F=F(5 t TAC(2010))	0.186	0.122	0.007	0.179
	F=F(10 t TAC(2010))	0.180	0.119	0.007	0.147
	F=F(15 t TAC(2010))	0.175	0.115	0.007	0.116
20 -year	TAC= 0	0.139	0.149	0.015	0.125
	TAC= 5 t	0.118	0.145	0.014	0.084
	TAC= 10 t	0.095	0.135	0.012	0.055
	TAC= 15 t	0.071	0.126	0.011	0.038
	F=F(5 t TAC(2010))	0.124	0.145	0.014	0.085
	F=F(10 t TAC(2010))	0.109	0.135	0.012	0.056
	F=F(15 t TAC(2010))	0.095	0.126	0.011	0.038
80 -year	TAC= 0	0.036	0.171	0.030	0.060
	TAC= 5	0.000	0.154	0.024	0.029
	TAC= 10	0.000	0.140	0.018	0.012
	TAC= 15	0.000	0.129	0.015	0.006
	F=F(5 t TAC(2010))	0.022	0.156	0.023	0.033
	F=F(10 t TAC(2010))	0.013	0.140	0.018	0.015
	F=F(15 t TAC(2010))	0.007	0.129	0.015	0.007

Table 26. Projection results at 5, 20 and 80 year horizons under low, PBSP reference case and high prior means for r_0. Horizon refers to the time period over which the projections were developed. Policy refers to the various harvest strategies. TAC refers to fixed catch policies that are harvested annually over the time horizon. F refers to constant fishing effort policies that are set at TAC levels in 2010. Results are shown only for Median(B_{fin}/B_{MSY}) which refers to the posterior median for the ratio of the stock biomass at the end of the horizon to stock biomass at B_{MSY}. The projections presume that the abundance of all three pinniped species stays the same as in 2009.

		Alternative hypotheses		
Horizon		Low prior mean for r_0 (A.3)	Ref.2	High prior mean for r_0 (A.3)
	Bayes factor	1.0	1	0.9
	Policy			
5 -year	TAC= 0	0.163	0.187	0.216
	TAC= 5	0.160	0.186	0.216
	TAC= 10	0.155	0.180	0.208
	TAC= 15	0.149	0.174	0.200
	F=F(5 t TAC(2010))	0.160	0.186	0.215
	F=F(10 t TAC(2010))	0.156	0.180	0.208
	F=F(15 t TAC(2010))	0.150	0.175	0.202
20 -year	TAC= 0	0.109	0.139	0.169
	TAC= 5	0.092	0.118	0.145
	TAC= 10	0.075	0.095	0.118
	TAC= 15	0.056	0.071	0.092
	F=F(5 t TAC(2010))	0.098	0.124	0.150
	F=F(10 t TAC(2010))	0.087	0.109	0.131
	F=F(15 t TAC(2010))	0.076	0.095	0.116
80 -year	TAC= 0	0.023	0.036	0.064
	TAC= 5	0.000	0.000	0.001
	TAC= 10	0.000	0.000	0.000
	TAC= 15	0.000	0.000	0.000
	F=F(5 t TAC(2010))	0.014	0.022	0.039
	F=F(10 t TAC(2010))	0.008	0.013	0.022
	F=F(15 t TAC(2010))	0.005	0.007	0.013

Table 27. Projection results at 5, 20 and 80 year horizons under low, PBSP reference case and high prior means for initial stock size in 1918 relative to the average expected unfished, unpredated abundance, B_{init}/K_0. Horizon refers to the time period over which the projections were developed. Policy refers to the various harvest strategies. TAC refers to fixed catch policies that are harvested annually over the time horizon. F refers to constant fishing effort policies that are set at TAC levels in 2010. Results are shown only for Median(B_{fin}/B_{MSY}) which refers to the posterior median for the ratio of the stock biomass at the end of the horizon to the stock biomass at B_{MSY}. The projections presume that the abundance of all three pinniped species stays the same as in 2009.

		Alternative hypotheses		
Horizon		Prior mean for B_{init}/K_0 = 0.2 (B.3)	Prior mean for B_{init}/K_0 = 0.5 Ref.2	Prior mean for B_{init}/K_0 = 0.8 (B.4)
	Bayes factor	1.5	1	0.9
	Policy			
5 -year	TAC= 0	0.278	0.187	0.142
	TAC= 5	0.275	0.186	0.140
	TAC= 10	0.266	0.180	0.135
	TAC= 15	0.256	0.174	0.131
	F=F(5 t TAC(2010))	0.276	0.186	0.141
	F=F(10 t TAC(2010))	0.268	0.180	0.136
	F=F(15 t TAC(2010))	0.259	0.175	0.132
20 -year	TAC= 0	0.195	0.139	0.101
	TAC= 5	0.167	0.118	0.086
	TAC= 10	0.136	0.095	0.070
	TAC= 15	0.105	0.071	0.054
	F=F(5 t TAC(2010))	0.177	0.124	0.090
	F=F(10 t TAC(2010))	0.158	0.109	0.080
	F=F(15 t TAC(2010))	0.139	0.095	0.070
80 -year	TAC= 0	0.050	0.036	0.031
	TAC= 5	0.001	0.000	0.000
	TAC= 10	0.001	0.000	0.000
	TAC= 15	0.001	0.000	0.000
	F=F(5 t TAC(2010))	0.029	0.022	0.019
	F=F(10 t TAC(2010))	0.017	0.013	0.011
	F=F(15 t TAC(2010))	0.011	0.007	0.007

Table 28. Projection results at 5, 20 and 80 year horizons for PBSP model <u>under low (50% of reference case), reference case and high (150% of reference case) scenarios for total catches</u>. Horizon refers to the time period over which the projections were developed. Policy refers to the various harvest strategies. TAC refers to fixed catch policies that are harvested annually over the time horizon. F refers to constant fishing effort policies that are set at TAC levels in 2010. Results are shown only for Median(B_{fin}/B_{MSY}) which refers to the posterior median for the ratio of the stock biomass at the end of the horizon to stock biomass at B_{MSY}. The projections presume that the abundance of all three pinniped species stays the same as in 2009.

		Alternative hypotheses		
Horizon		Fixed catches set at 50% of reference case (C.3)	Ref. case catches Ref.2	Fixed catches set at 150% of reference case (C.4)
	Bayes factor	10	1	1.1
	Policy			
5 -year	TAC= 0	0.143	0.187	0.197
	TAC= 5	0.138	0.186	0.196
	TAC= 10	0.130	0.180	0.190
	TAC= 15	0.122	0.174	0.185
	F=F(5 t TAC(2010))	0.139	0.186	0.196
	F=F(10 t TAC(2010))	0.132	0.180	0.191
	F=F(15 t TAC(2010))	0.126	0.175	0.186
20 -year	TAC= 0	0.069	0.139	0.173
	TAC= 5	0.046	0.118	0.157
	TAC= 10	0.021	0.095	0.137
	TAC= 15	0.001	0.071	0.114
	F=F(5 t TAC(2010))	0.058	0.124	0.160
	F=F(10 t TAC(2010))	0.046	0.109	0.144
	F=F(15 t TAC(2010))	0.037	0.095	0.130
80 -year	TAC= 0	0.004	0.036	0.100
	TAC= 5	0.000	0.000	0.035
	TAC= 10	0.000	0.000	0.000
	TAC= 15	0.000	0.000	0.000
	F=F(5 t TAC(2010))	0.002	0.022	0.067
	F=F(10 t TAC(2010))	0.001	0.013	0.044
	F=F(15 t TAC(2010))	0.000	0.007	0.029

Table 29. PBSP projection results at 5, 20 and 80 year horizons for PBSP model under <u>low (1/4 of reference case), reference case and high (2x of reference case) scenarios for inputted total consumption of yelloweye rockfish by each pinniped species</u>. Horizon refers to the time period over which the projections were developed. Policy refers to the various harvest strategies. TAC refers to fixed catch policies that are harvested annually over the time horizon. F refers to constant fishing effort policies that are set at TAC levels in 2010. Results are shown only for Median(B_{fin}/B_{MSY}) which refers to the posterior median for the ratio of the stock biomass at the end of the horizon to stock biomass at B_{MSY}. The projections presume that the abundance of all three pinniped species stays the same as in 2009. See Table 21 for details on the priors used for B_{init}/K_0 in each of the alternative cases.

		Alternative hypotheses		
Horizon		Low fraction of rockfish in the diet (E.2)	Ref. case Ref.2	High fraction of rockfish in the diet (E.4)
	Bayes factor	0.1	1	5
	Policy			
5 -year	TAC= 0	0.187	0.187	0.153
	TAC= 5	0.183	0.186	0.154
	TAC= 10	0.175	0.180	0.151
	TAC= 15	0.167	0.174	0.148
	F=F(5 t TAC(2010))	0.183	0.186	0.154
	F=F(10 t TAC(2010))	0.175	0.180	0.152
	F=F(15 t TAC(2010))	0.168	0.175	0.150
20 -year	TAC= 0	0.242	0.139	0.059
	TAC= 5	0.207	0.118	0.052
	TAC= 10	0.168	0.095	0.044
	TAC= 15	0.131	0.071	0.036
	F=F(5 t TAC(2010))	0.206	0.124	0.056
	F=F(10 t TAC(2010))	0.171	0.109	0.053
	F=F(15 t TAC(2010))	0.145	0.095	0.050
80 -year	TAC= 0	0.329	0.036	0.001
	TAC= 5	0.247	0.000	0.000
	TAC= 10	0.155	0.000	0.001
	TAC= 15	0.065	0.000	0.001
	F=F(5 t TAC(2010))	0.237	0.022	0.001
	F=F(10 t TAC(2010))	0.168	0.013	0.001
	F=F(15 t TAC(2010))	0.115	0.007	0.001

Table 30. Projection results at 5, 20 and 40 year horizons for PBSP under 2.5%, reference case and 97.5% uncertainty bounds for pinniped predation on yelloweye rockfish. Horizon refers to the time period over which the projections were developed. Policy refers to the various harvest strategies. TAC refers to fixed catch policies that are harvested annually over the time horizon. F refers to constant fishing effort policies that are set at TAC levels in 2010. Results are shown only for Median(B_{fin}/B_{MSY}) which refers to the posterior median for the ratio of the stock biomass at the end of the horizon to stock biomass at B_{MSY}. The projections presume that the abundance of all three pinniped species stays the same as in 2009.

		Alternative hypotheses		
Horizon		2.5% bound for predation factors (G.1)	Ref. case Ref.2	97.5% bound for predation factors (G.2)
	Bayes factor	0.02	1	12
	Policy			
5 -year	TAC= 0	0.166	0.187	0.153
	TAC= 5	0.164	0.186	0.154
	TAC= 10	0.159	0.180	0.151
	TAC= 15	0.154	0.174	0.148
	F=F(5 t TAC(2010))	0.164	0.186	0.154
	F=F(10 t TAC(2010))	0.159	0.180	0.152
	F=F(15 t TAC(2010))	0.154	0.175	0.150
20 -year	TAC= 0	0.271	0.139	0.059
	TAC= 5	0.242	0.118	0.052
	TAC= 10	0.214	0.095	0.044
	TAC= 15	0.186	0.071	0.036
	F=F(5 t TAC(2010))	0.241	0.124	0.056
	F=F(10 t TAC(2010))	0.215	0.109	0.053
	F=F(15 t TAC(2010))	0.188	0.095	0.050
80 -year	TAC= 0	0.329	0.036	0.001
	TAC= 5	0.235	0.000	0.000
	TAC= 10	0.129	0.000	0.001
	TAC= 15	0.000	0.000	0.001
	F=F(5 t TAC(2010))	0.190	0.022	0.001
	F=F(10 t TAC(2010))	0.105	0.013	0.001
	F=F(15 t TAC(2010))	0.056	0.007	0.001

Table 31. Projection results for the PBSP reference case model at 5, 20 and 80 year horizons. Horizon refers to the time period over which the projections were developed. Policy refers to the various harvest strategies. TAC refers to fixed catch policies that are harvested annually over the time horizon. F refers to constant fishing effort policies that are set at TAC levels in 2010. Median(B_{fin}/B_{MSY}) refers to the posterior median for the ratio of the stock biomass at the end of the horizon to stock biomass at B_{MSY}, stock biomass in 1918. P(B>0.4 B_{init} in Hz) is the probability that stock biomass in any year in the horizon exceeds 40% of B_{MSY}. P(B>0.8 B_{init} in Hz) is the probability that stock biomass in any year in the horizon exceeds 80% of B_{MSY}. P(B_{fin}>B_{2009}) refers to the probability that stock biomass at the end of the horizon exceeds stock biomass in 2009. <u>This run presumes that the abundance of all three pinniped species is reduced by about 15% per year from 2012 to 2021 (to about one fifth the 2010 level) and then kept at this level from then on</u>.

Horizon	Policy	Median(Bfin/B_{MSY})	P(B>0.4 B_{MSY} in Horizon)	P(B>0.8 B_{MSY} in Horizon)	P(B_{fin}>B_{2009})
	pinnipeds to 1/5 of 2009 levels by 2020				
5 -year	TAC= 0	0.193	0.123	0.007	0.230
	TAC= 5	0.191	0.125	0.008	0.218
	TAC= 10	0.185	0.121	0.007	0.178
	TAC= 15	0.178	0.118	0.007	0.143
	F=F(5 t TAC(2010))	0.191	0.125	0.008	0.218
	F=F(10 t TAC(2010))	0.185	0.121	0.007	0.178
	F=F(15 t TAC(2010))	0.180	0.118	0.007	0.145
20 -year	TAC= 0	0.281	0.341	0.072	0.694
	TAC= 5	0.250	0.305	0.064	0.592
	TAC= 10	0.216	0.259	0.051	0.466
	TAC= 15	0.178	0.221	0.044	0.356
	F=F(5 t TAC(2010))	0.252	0.302	0.061	0.605
	F=F(10 t TAC(2010))	0.222	0.253	0.049	0.484
	F=F(15 t TAC(2010))	0.196	0.220	0.039	0.380
80 -year	TAC= 0	1.181	0.804	0.653	0.916
	TAC= 5	0.942	0.722	0.562	0.828
	TAC= 10	0.626	0.609	0.456	0.675
	TAC= 15	0.253	0.472	0.360	0.509
	F=F(TAC(icur+1)) 5	0.782	0.710	0.522	0.844
	F=F(TAC(icur+1)) 10	0.504	0.604	0.405	0.736
	F=F(TAC(icur+1)) 15	0.304	0.486	0.309	0.588

FIGURES

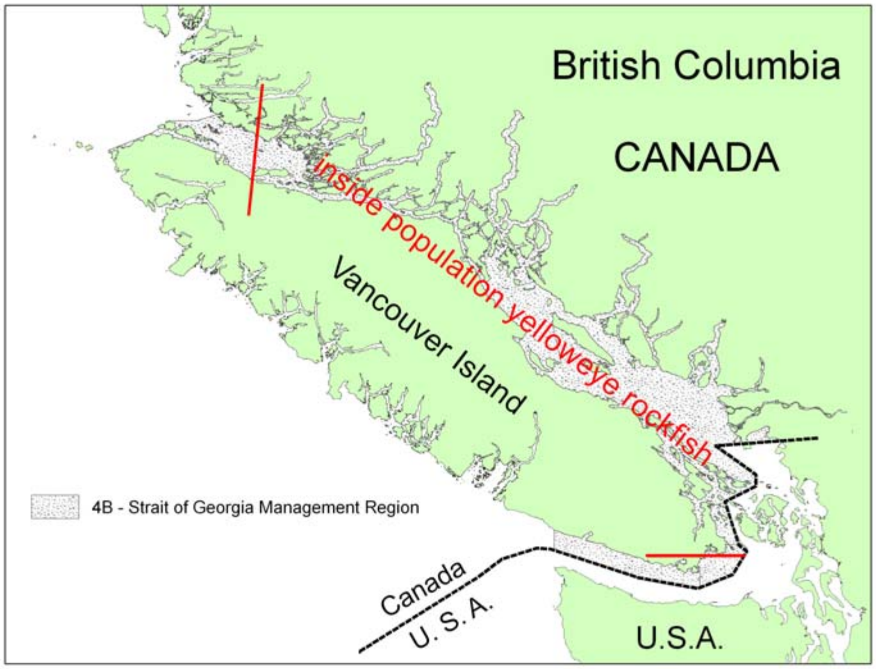

*Figure 1. Yelloweye rockfish (*Sebastes ruberrimus*) designatable unit (DU) boundaries (solid lines), inside management area 4B (stipled area) including Pacific Fishery Management Areas (PFMAs) 12 to 20, 28 and 29.*

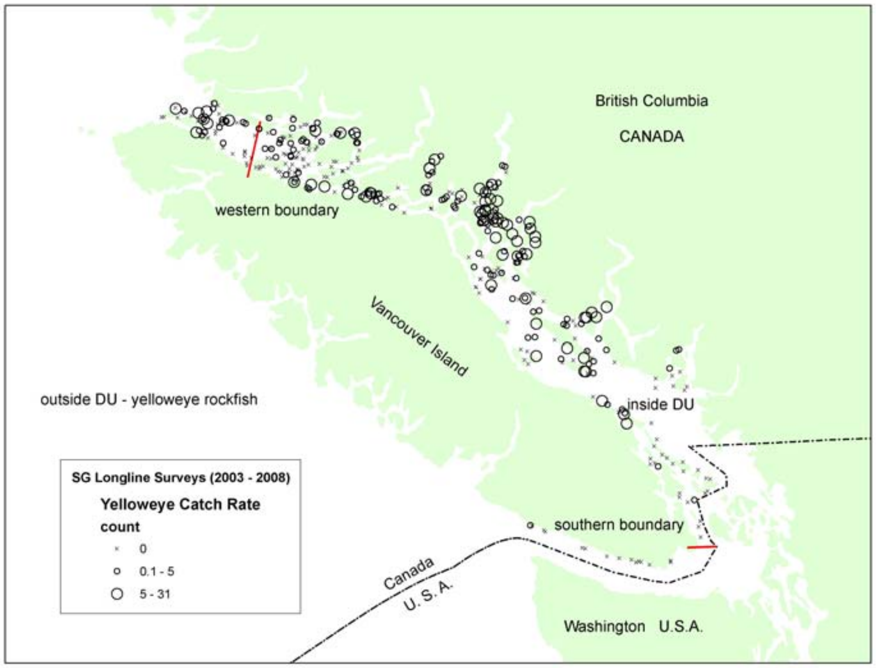

*Figure 2. Distribution of yelloweye rockfish (*Sebastes ruberrimus*) catch rates for the inside research longline surveys from 2003 to 2008. Inside and outside designatable unit (DU) boundaries for yelloweye rockfish in British Columbia are shown as solid lines.*

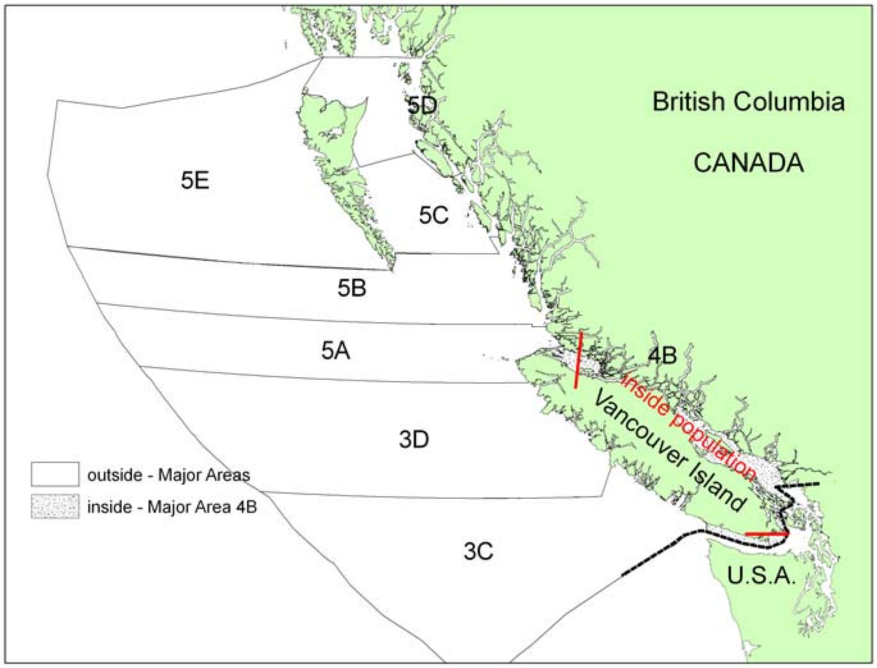

Figure 3. British Columbia coast showing the Pacific Fishery Major Areas. Major Area 4B is shown as the stipled area. The inside yelloweye rockfish DU resides within Major Area 4B and is separated from the outside yelloweye rockfish DU by the solid lines.

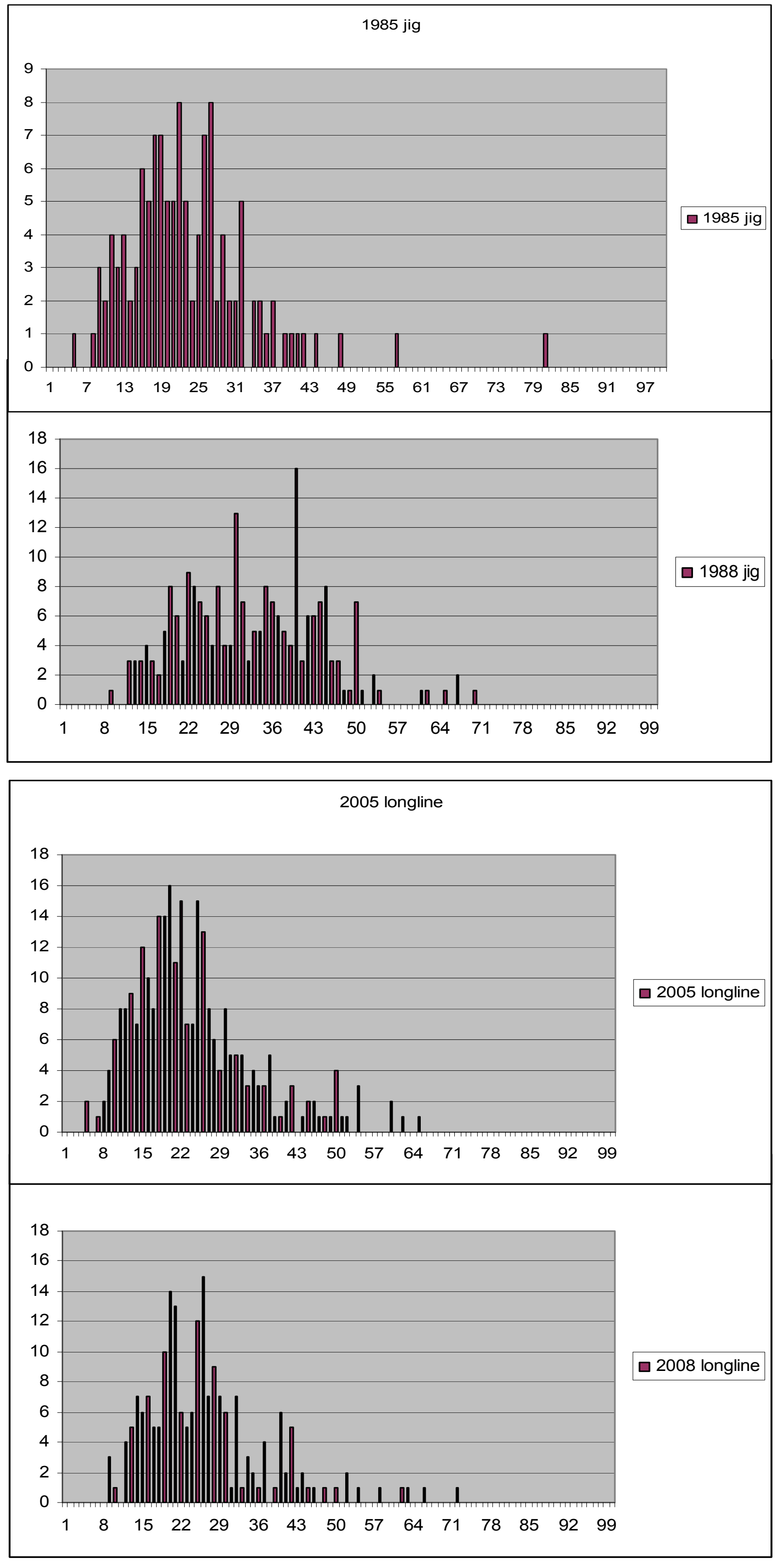

*Figure 4. Inside population of yelloweye rockfish (*Sebastes ruberrimus*) age frequencies by year and gear. See Table 1.*

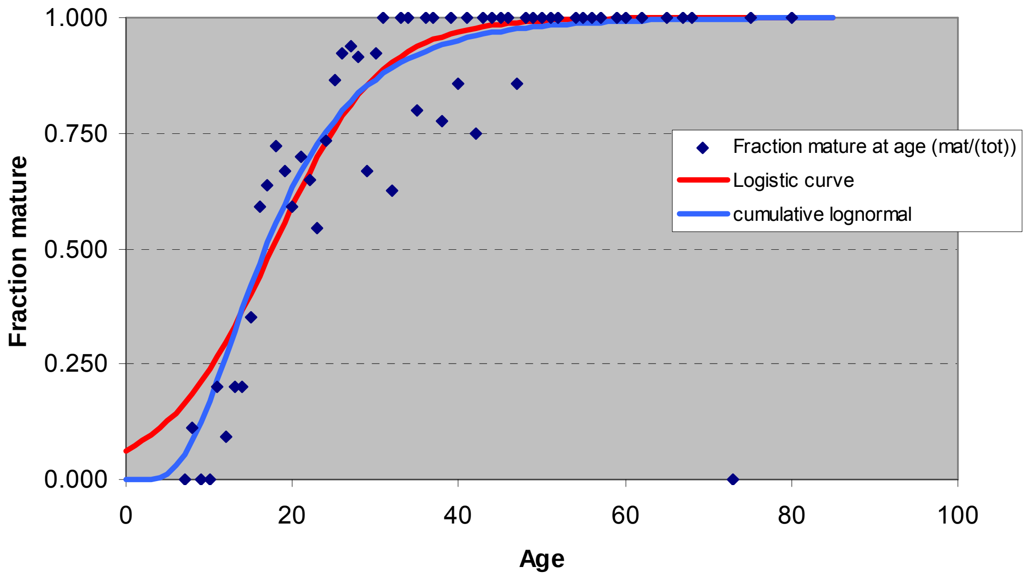

*Figure 5. Plot of the observed fraction of the inside population of yelloweye rockfish (*Sebastes ruberrimus*) mature females at age, the cumulative lognormal curve and the logistic curve fitted to the data.*

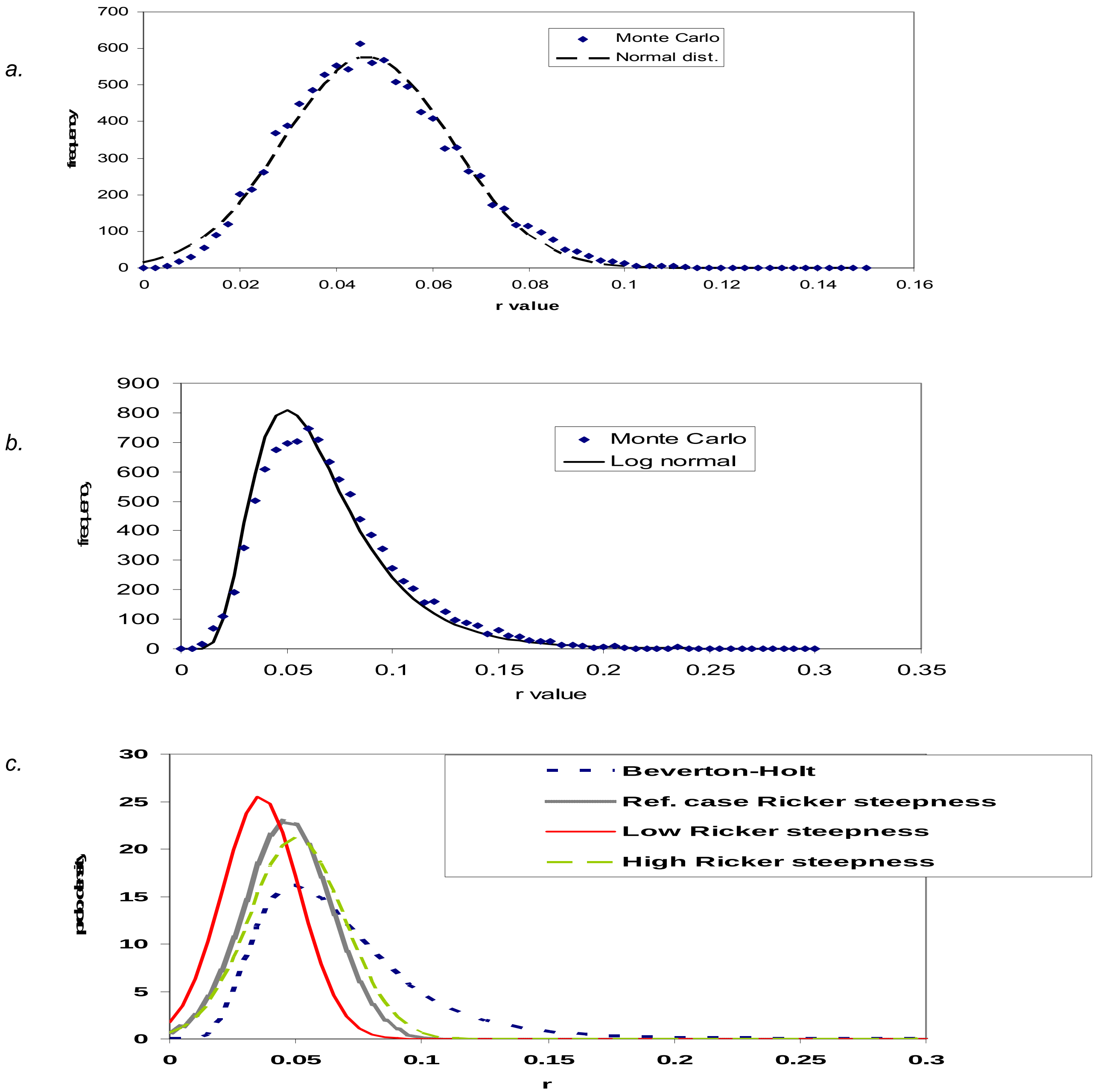

Figure 6. Frequency distribution of r values drawn from the Monte Carlo method to generate a prior density function for r for inside yelloweye rockfish. a. a normal approximation of the frequency distribution of values for r using Ricker steepness. b. lognormal approximation of the frequency distribution for r using Beverton-Holt steepness c. alternative priors for r from the Ricker and B-H steepness inputs.

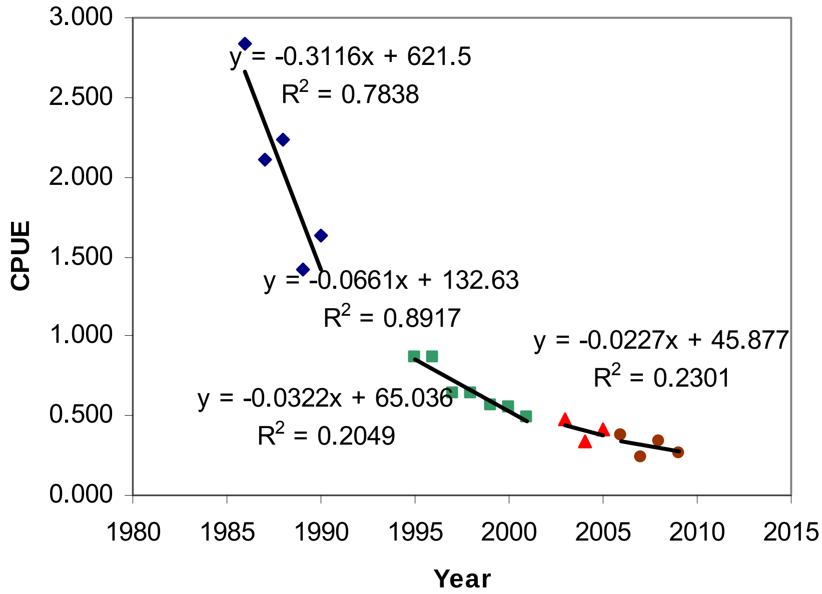

*Figure 7. Plots of the four commercial catch per unit effort abundance indices for the inside population of yelloweye rockfish (*Sebastes ruberrimus*) together with plots of the fitted linear models to each of these time segments (1992 – 1994 excluded).*

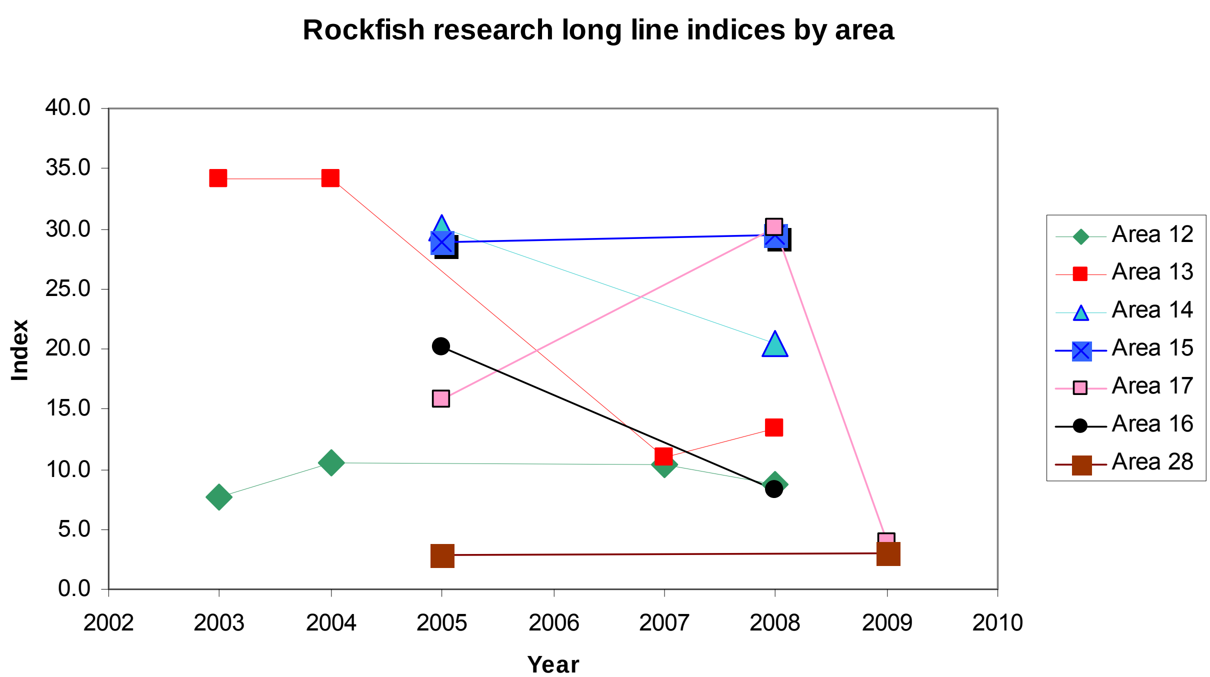

Figure 8. Plots of the density estimates of yelloweye rockfish in inside waters Pacific Fishery Management Areas (Areas) from the rockfish research longline survey. Estimates were obtained with an application of the exponential model.

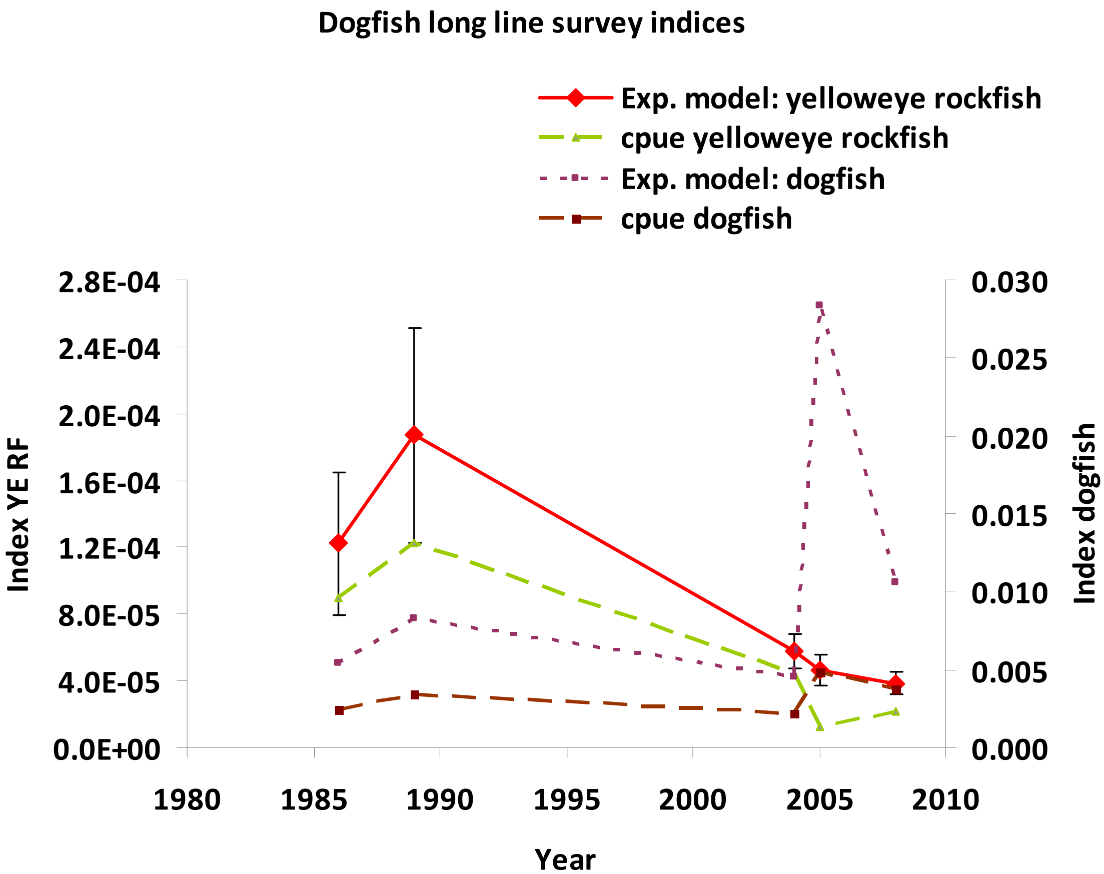

Figure 9. Nominal catch rates and exponential model indices from the Strait of Georgia spiny dogfish longline research survey, both with the circle to j-hook efficiency ratio applied. Exp. refers to exponential and cpue refers to catch per unit effort. Standard error bars are shown only for the standardized inside yelloweye rockfish series that was produced with the exponential model.

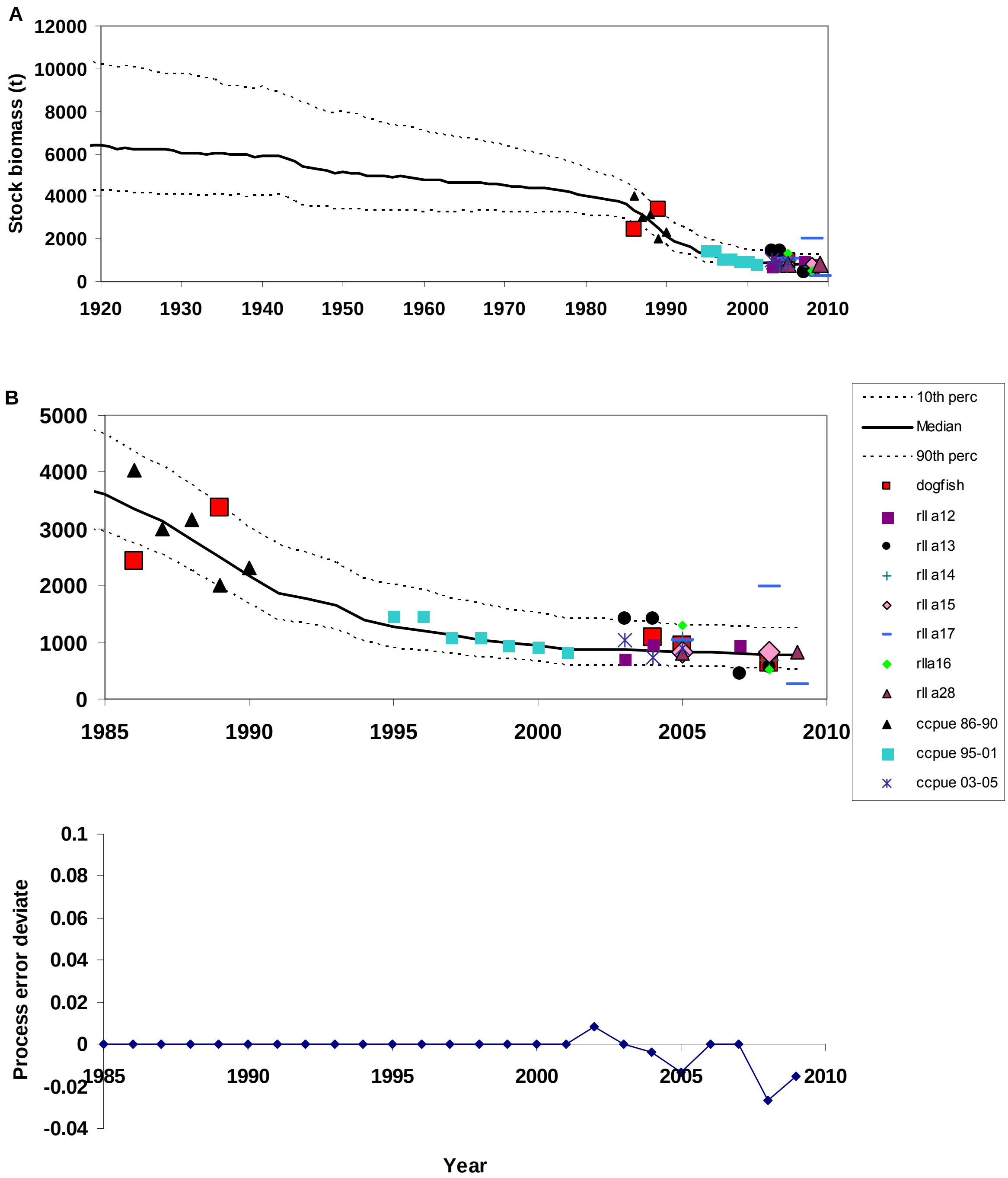

Figure 10. Plots of the posterior median inside yelloweye rockfish stock biomass and 80% probability intervals obtained after fitting the BSP model to the inside yelloweye abundance indices obtained from the Strait of Georgia spiny dogfish research longline survey (dogfish), the inside rockfish longline survey (rll) and GLM standardized inside commercial catch per unit (ccpue) effort data. The inside rockfish longline survey dataset is aggregated by Pacific Fishery Management Area from 12 to 17 and 28 (rll a12 to rll a17 and rll a28). The commercial catch per unit effort data is parsed into three stanzas for the years 1986 to 1990 (ccpue 86-90), 1995 to 2001 (ccpue 95-01), and 2003 to 2005 (ccpue 03-05). Years 1920-2009. B. Years. 1985-2009.

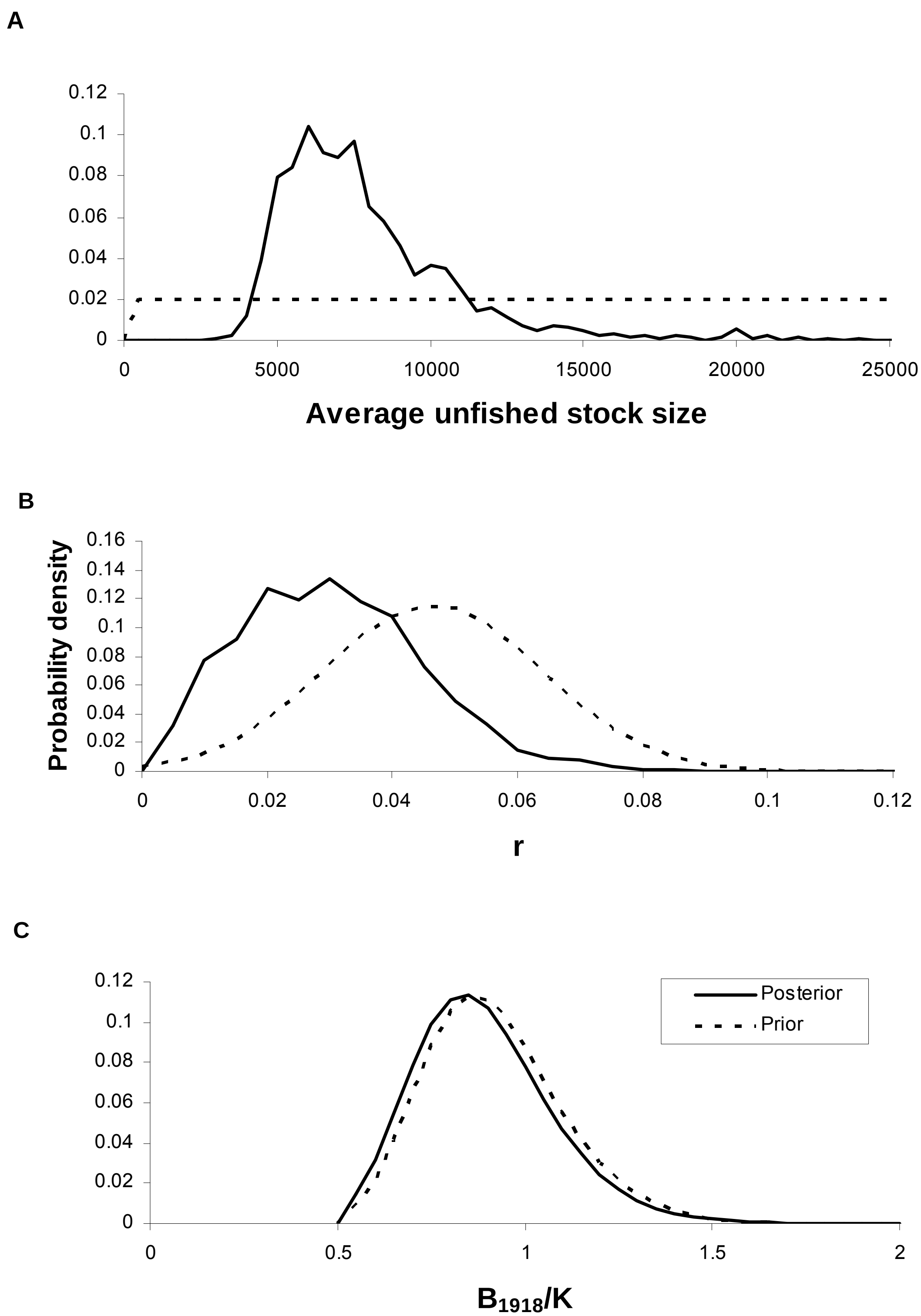

Figure 11. Plots of prior and posterior distributions for the equilibrium unfished stock size (K), the maximum rate of population increase in absence of fishing (r), and the ratio of stock size in 1918 to unfished stock size (B_{1918}/K).

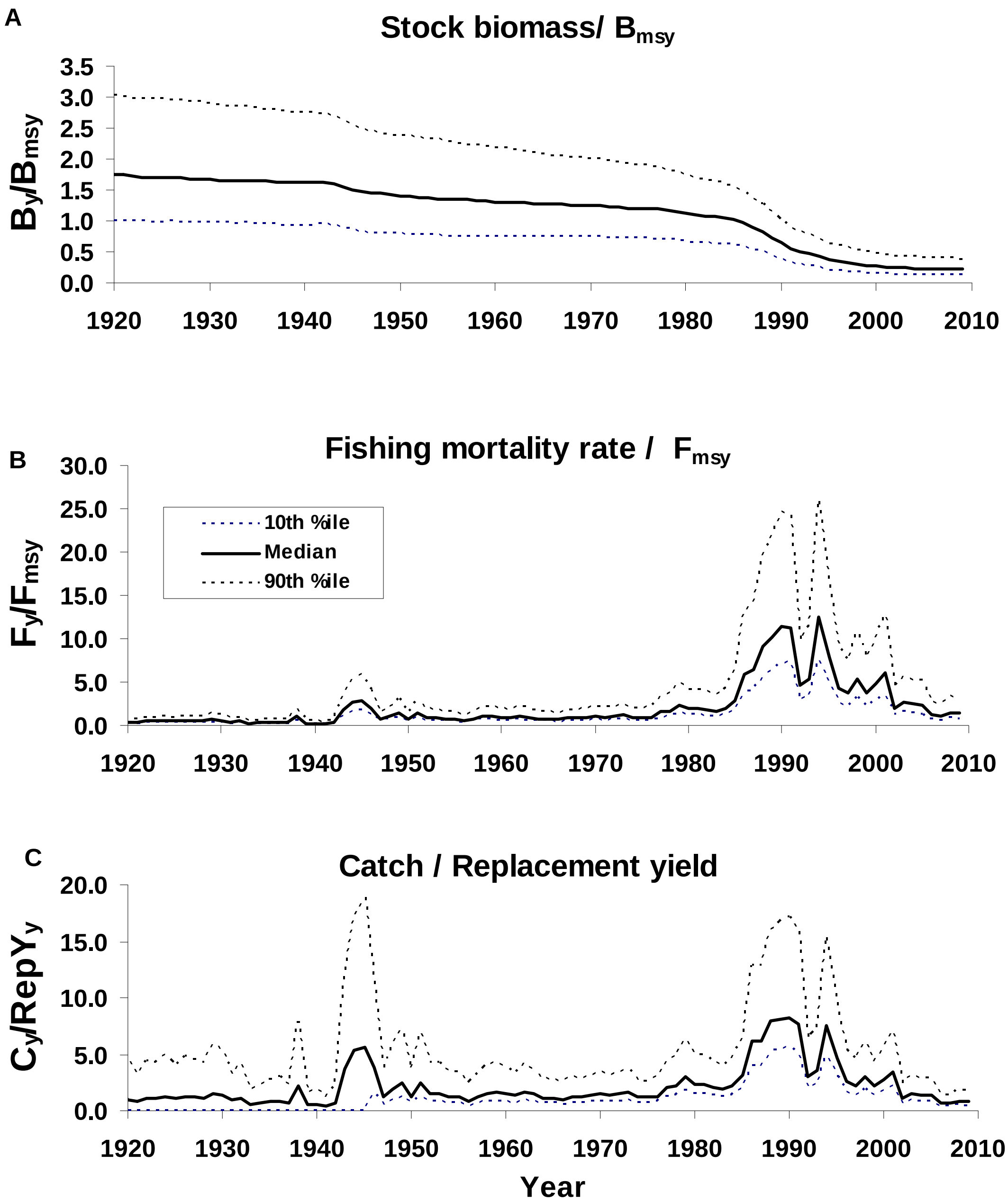

Figure 12. Time series estimates for the reference case BSP model of A) stock biomass relative to 50% of stock size in 1918 (B_y/ B_{MSY}), B) harvest rate divided by harvest rate at MSY, and C) catch relative to replacement yield for inside yelloweye rockfish. Posterior medians (solid lines) and 80% probability intervals (dotted lines) are shown.

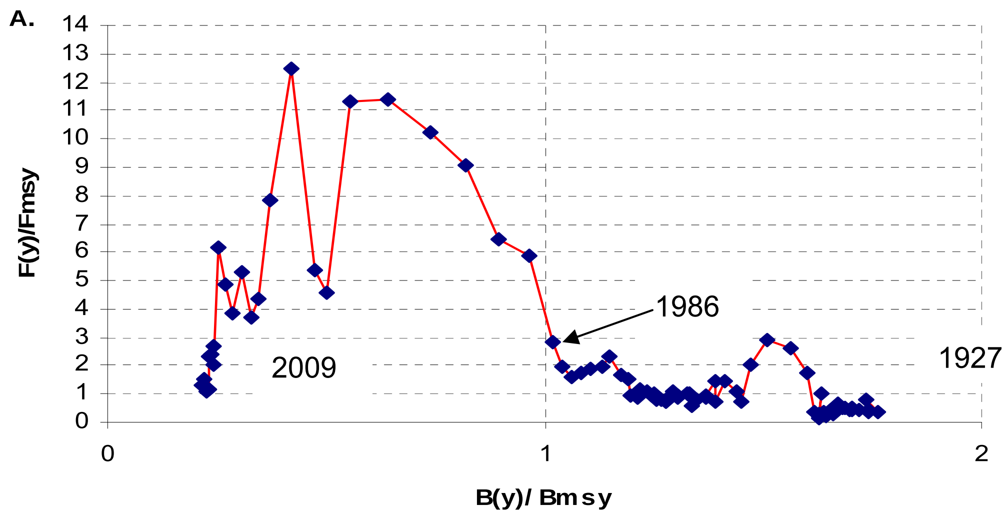

Figure 13. Time series estimates of the ratio of posterior median F /F_{MSY} to stock biomass relative to 50% of stock size in 1918 (B_y/ 0.5 B_{init}) for the reference case BSP model. Trajectories start on the right and proceed to the left.

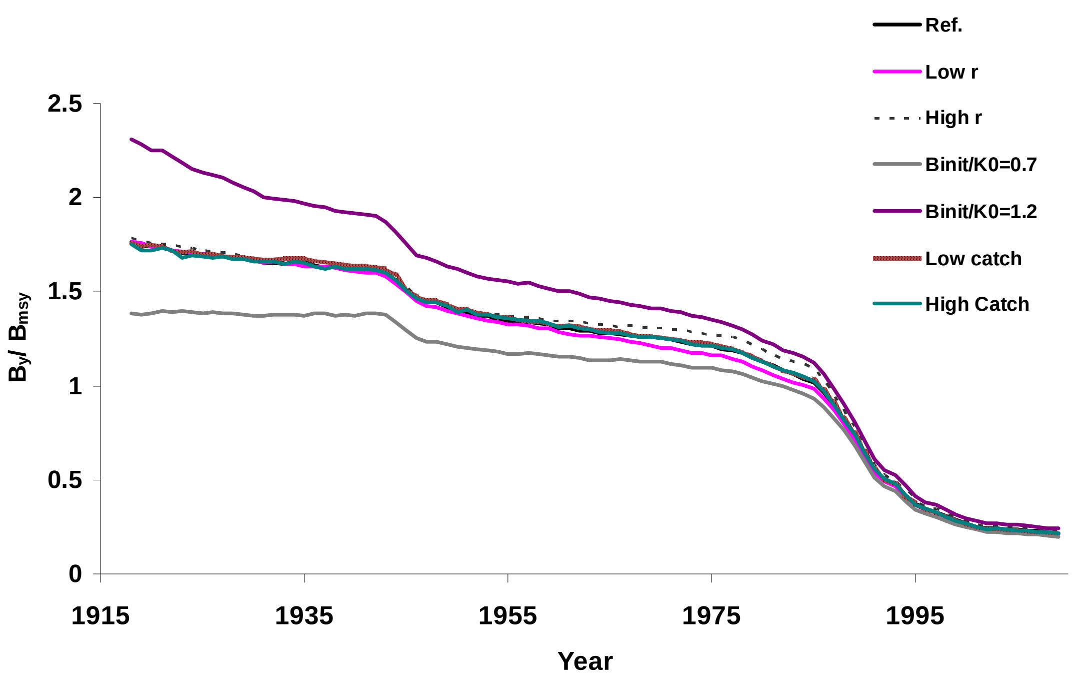

Figure 14. Plots of the BSP posterior median estimates of the ratio of stock biomass to 50% of initial stock biomass in 1918 taken from a range of the various sensitivity runs and the original reference case runs.

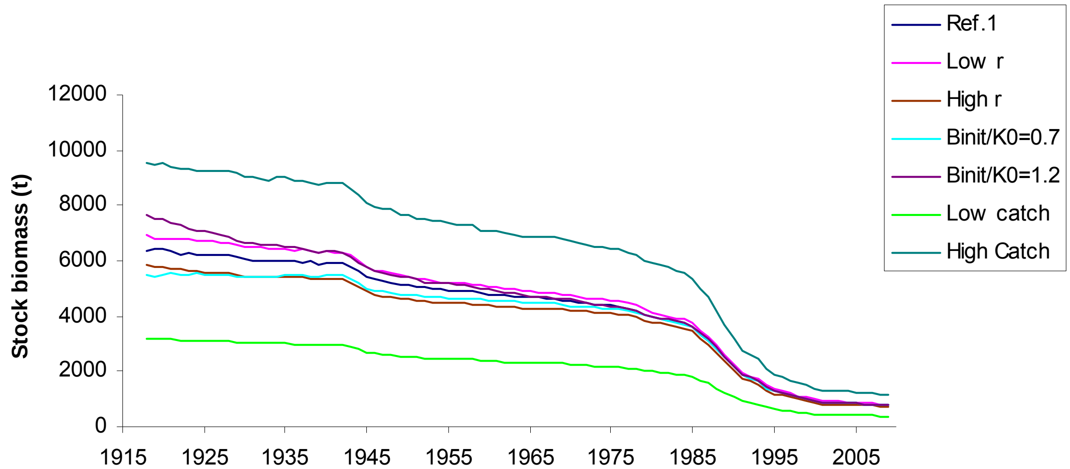

Figure 15. Plots of the BSP posterior median estimates of the ratio of stock biomass taken from a range of the various sensitivity runs and the original reference case runs.

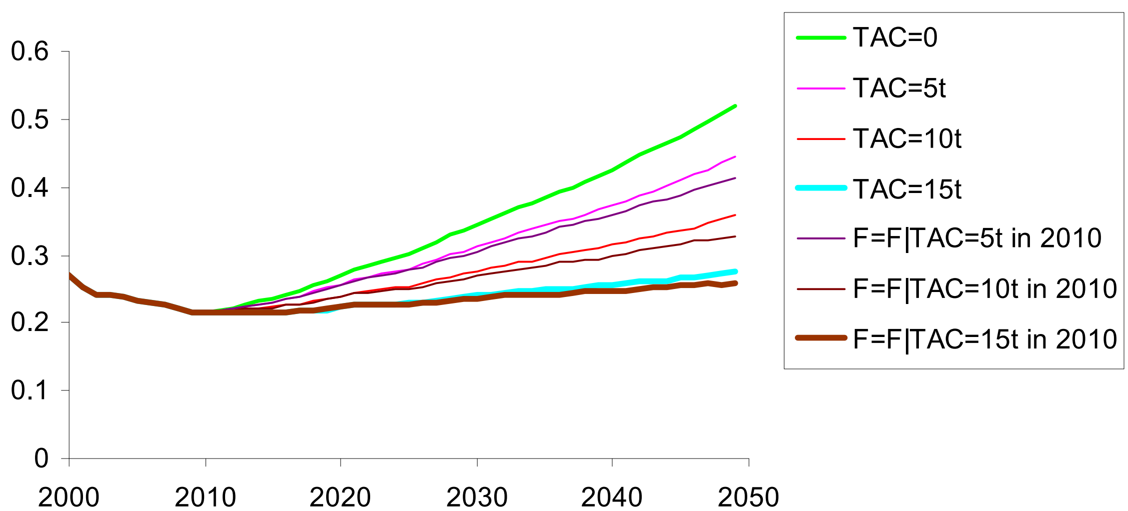

Figure 16. Projection results showing the median ratio of stock biomass to 0.5 stock biomass in 1918 for the reference case BSP model.

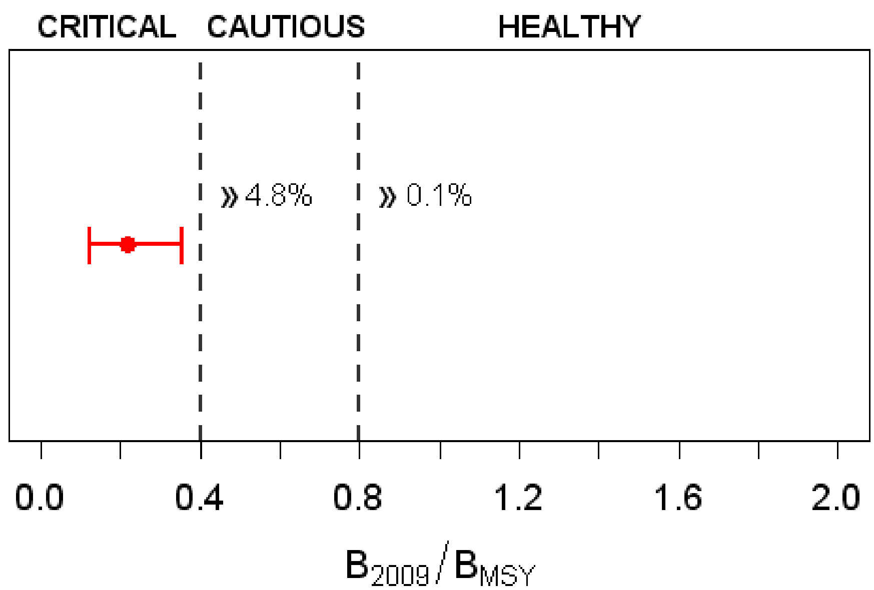

Figure 17. For the inside population of yelloweye rockfish reference case Bayesian surplus production model (BSP) run, median (point) and 90% confidence intervals for the ratio of B_{2009} relative to B_{MSY}. Vertical dashed lines indicate the limit reference point (0.4 B_{MSY}) and upper stock reference 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.

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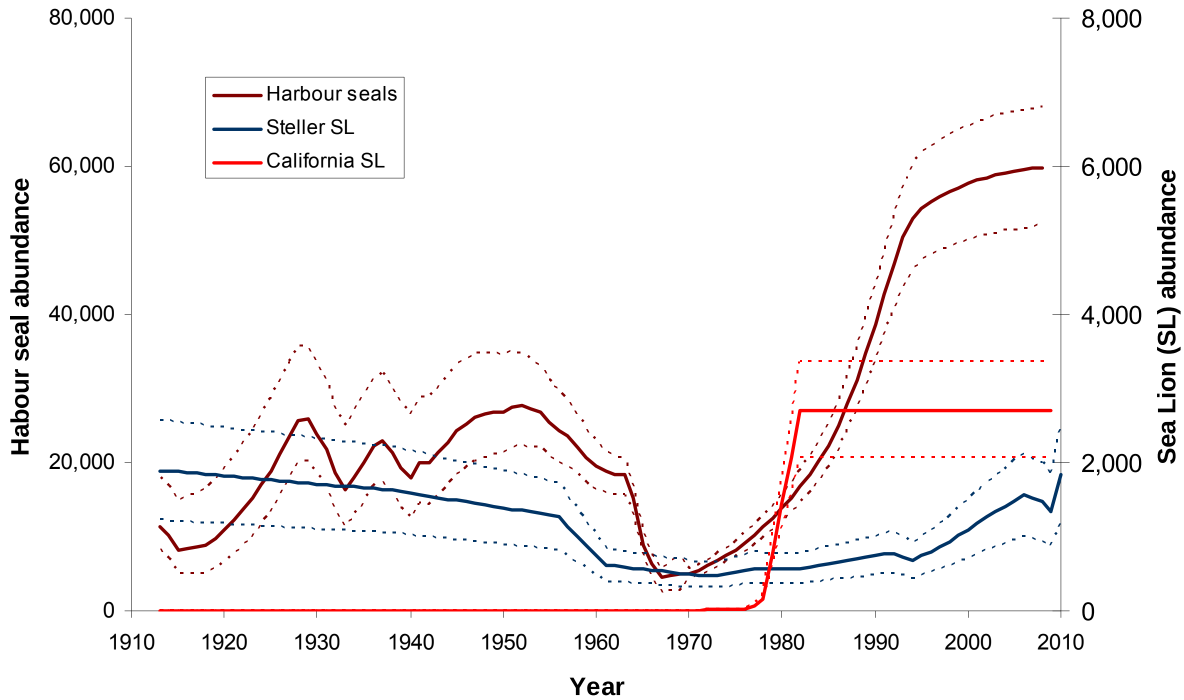

Figure 18. Trends in the abundance of harbour seals, Steller sea lions and California sea lions in inside B.C. waters. Best estimates (solid lines) and upper and lower bounds (dotted lines) are shown for each species.

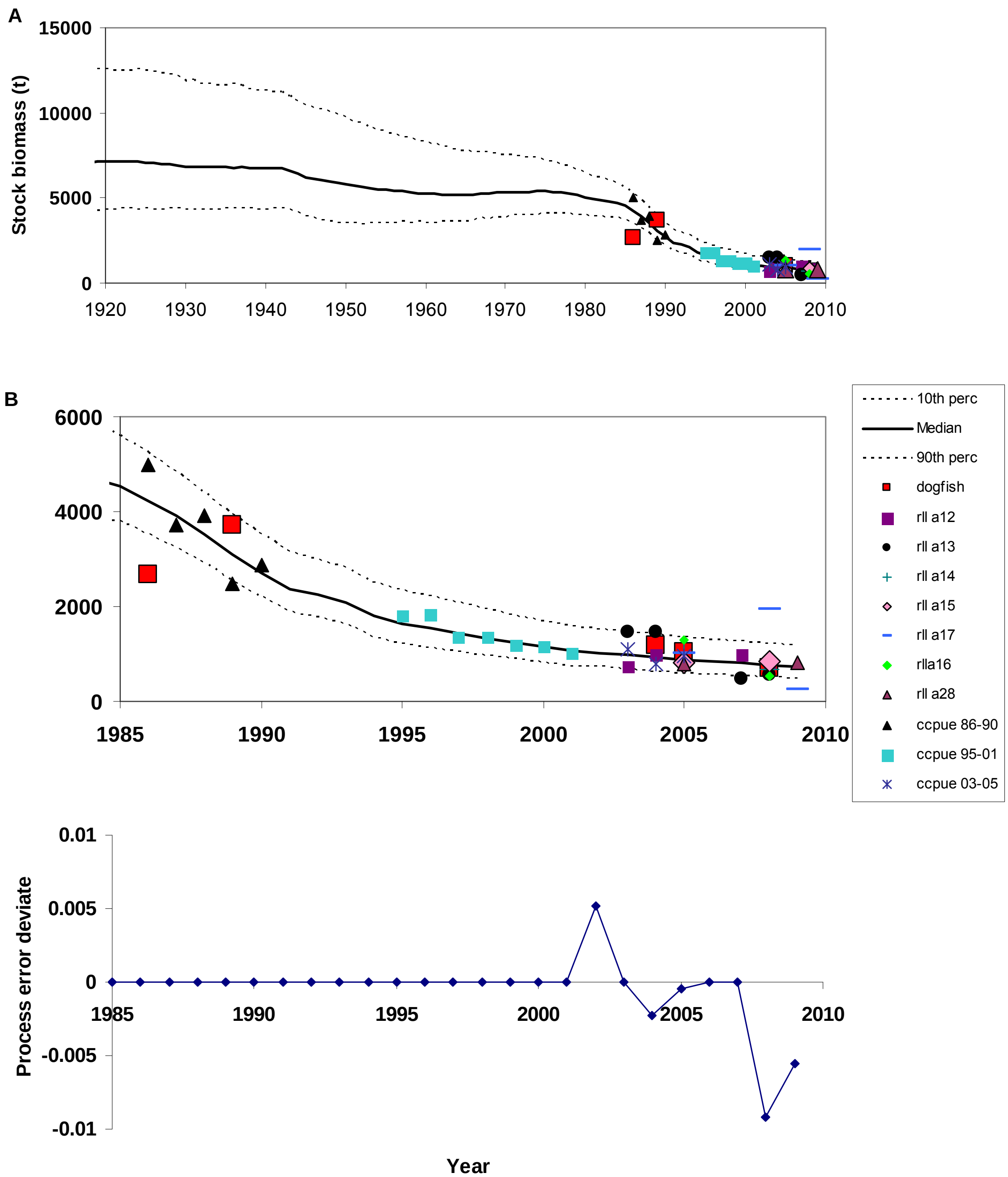

Figure 19. Plots of the posterior median yelloweye rockfish inside population stock biomass and 80% probability intervals obtained after fitting the pinniped-BSP model to the inside yelloweye abundance indices obtained from the Strait of Georgia dogfish research longline survey, the inside rockfish longline (rll) survey and GLM standardized inside commercial catch per unit (ccpue) effort data. A. Years 1920-2009. B. Years. 1985-2009.

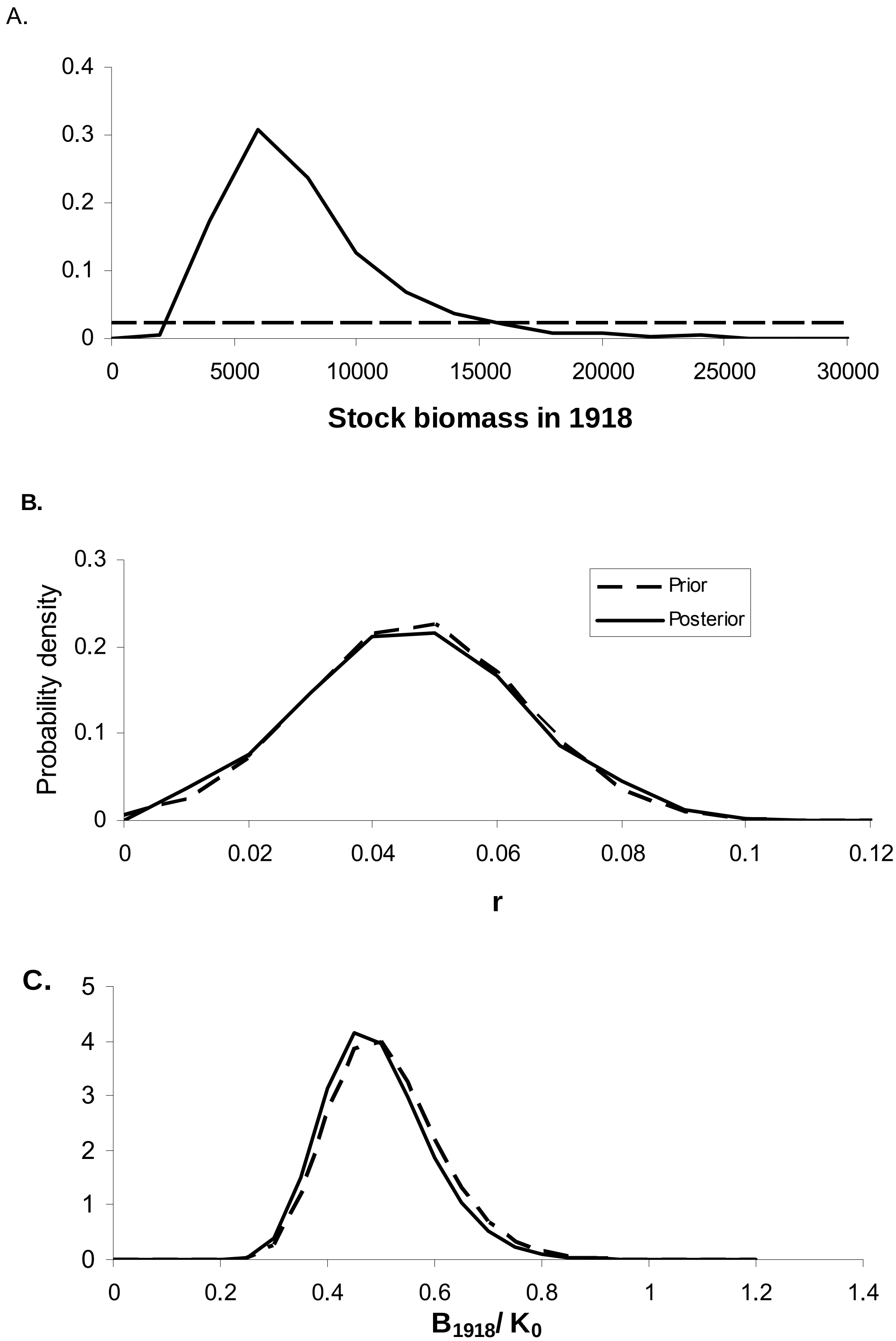

Figure 20. Plots for the yelloweye rockfish inside population PBSP model of prior and posterior distributions for the A. equilibrium unfished stock size (K), B. the maximum rate of population increase in absence of fishing (r), and C. the ratio of stock size in 1918 to unfished stock size (B_{1918}/K_0).

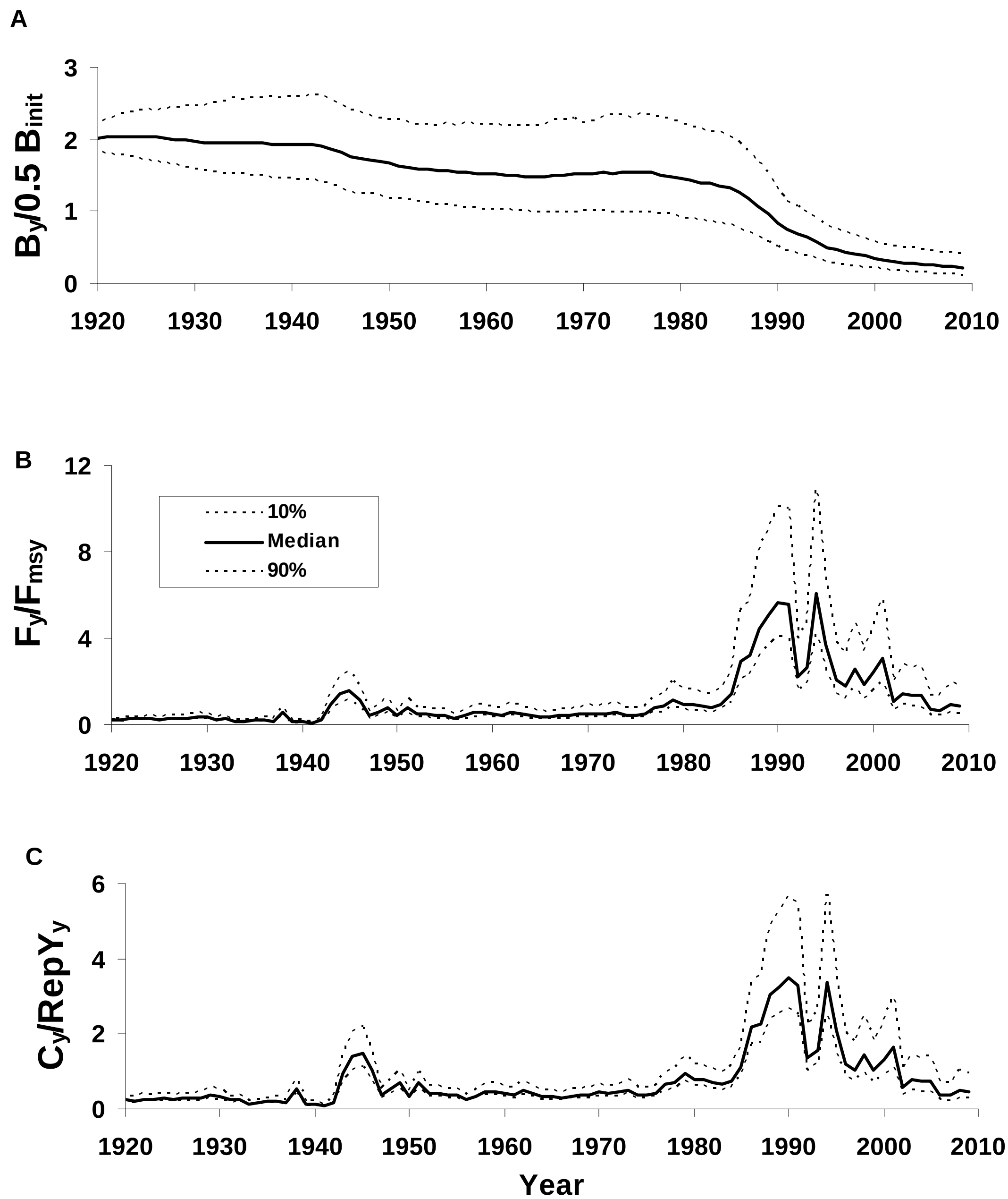

Figure 21. Time series estimates for the yelloweye rockfish inside population reference case BSP model of A) stock biomass relative to 50% of stock size in 1918 (B_y/ 0.5 B_{init}), B) harvest rate divided by harvest rate at MSY, and C) catch relative to replacement yield for inside yelloweye rockfish. Posterior medians (solid lines) and 80% probability intervals (dotted lines) are shown.

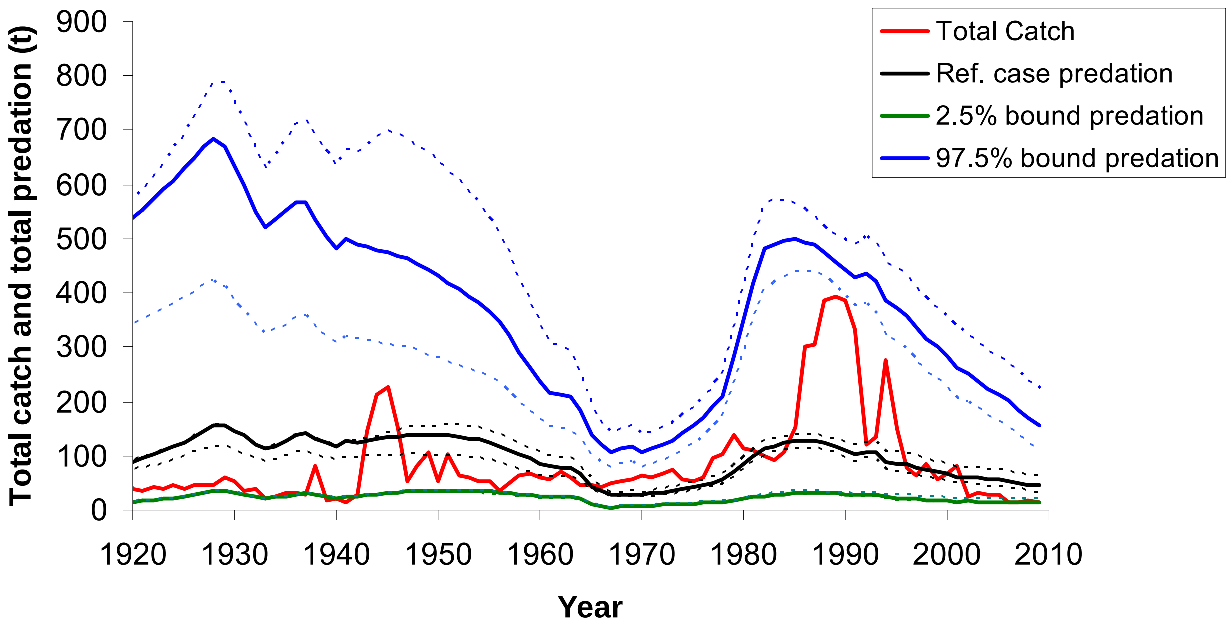

Figure 22. Plots of total annual catch and posterior median predation from pinnipeds from the yelloweye rockfish inside population reference case PBSP model and the runs with the pinniped inputs at 2.5% and 97.5 % of their reference case settings. 80% probability intervals for each model run are shown by the dotted lines.

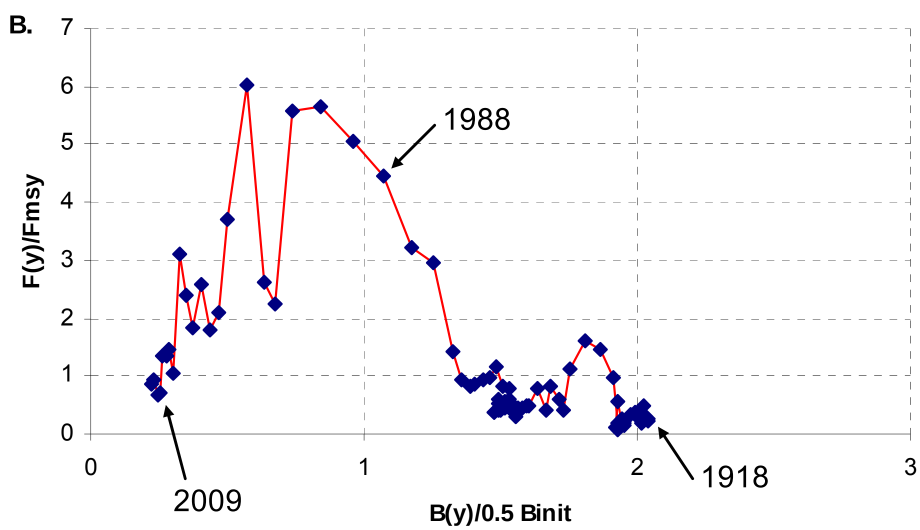

Figure 23. Inside population of yelloweye rockfish time series estimates of A) the ratio of posterior median F /F_{msy} to stock biomass relative to 50% of stock size in 1918 (B_y/ 0.5 B_{init}) for the reference case PBSP model. Trajectories start on the right and proceed to the left.

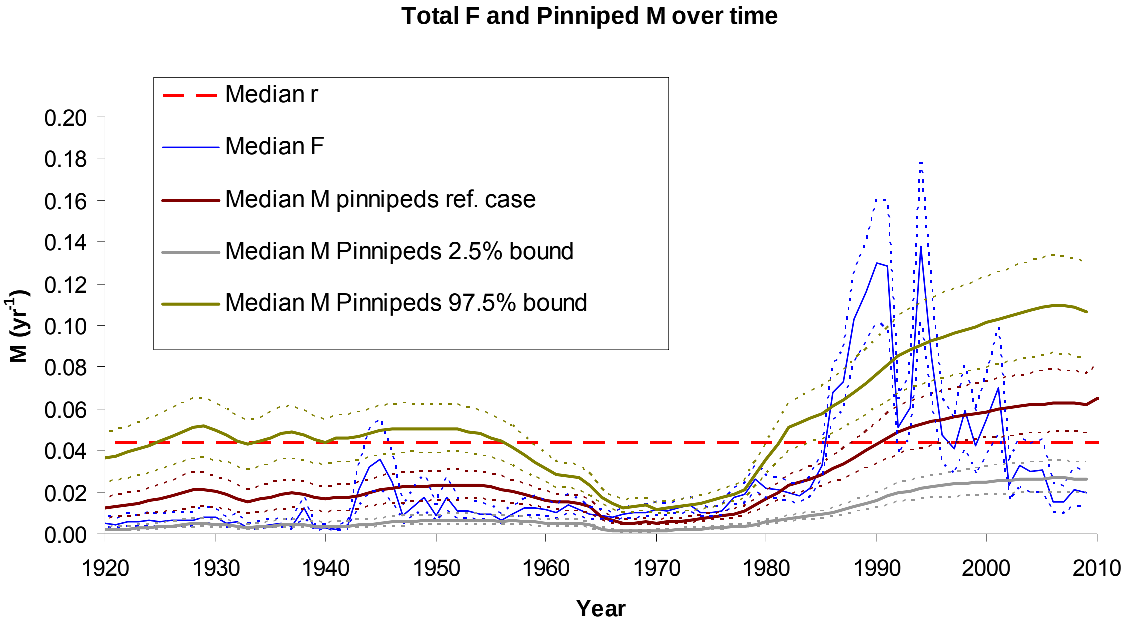

Figure 24. Trends in the rate of natural mortality for the yelloweye rockfish inside population from harbour seals, Steller sea lions, and California sea lions in B.C. inside waters. Results from the reference case PBSP model and the runs with the pinniped inputs at 2.5% and 97.5 % of their reference case settings. Medians (solid lines) and 80% probability intervals (dotted lines) for each model run are shown. Median r and F are from the reference case.

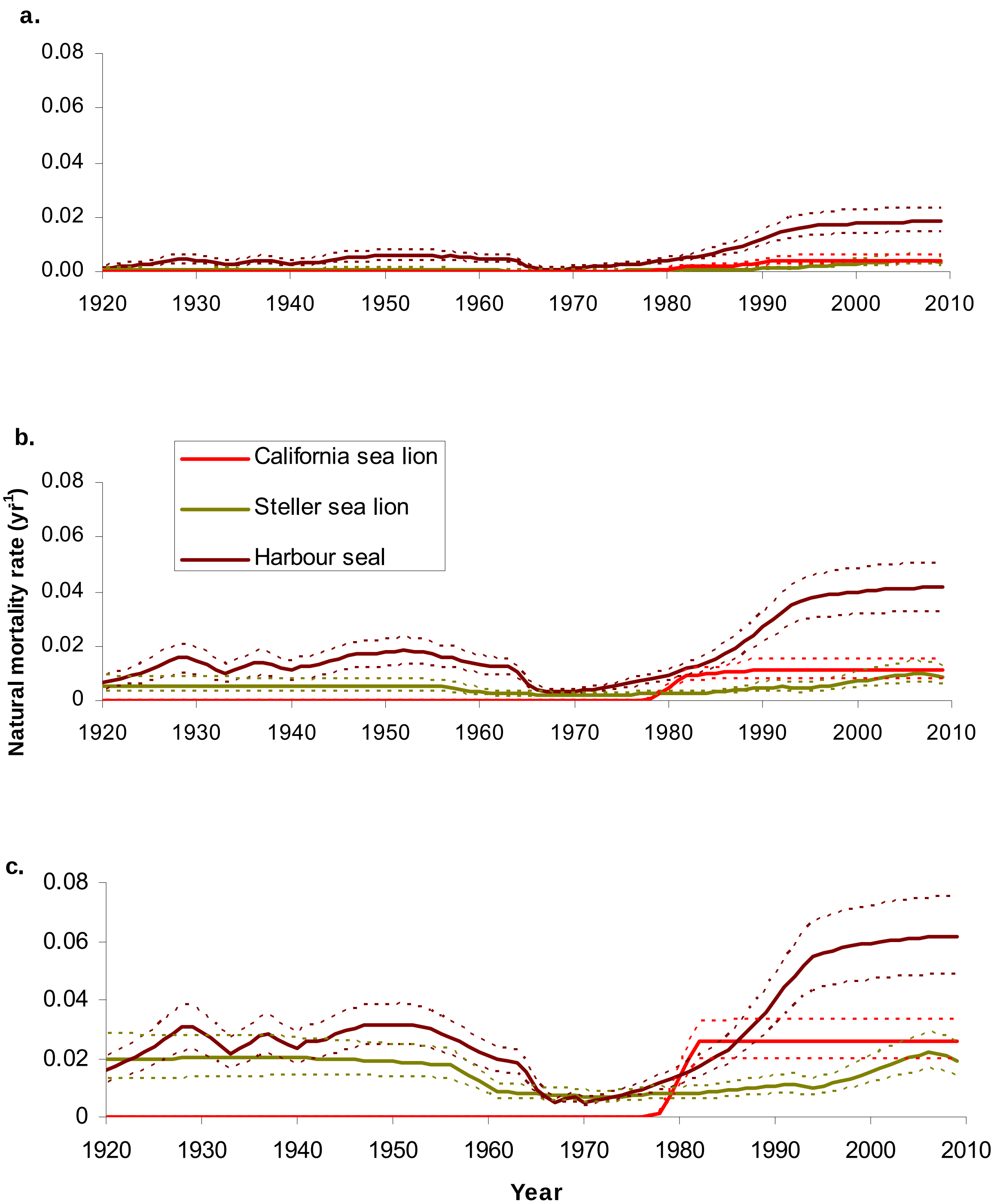

Figure 25. Trends in the total rates of natural mortality and fishing mortality for the inside population of yelloweye rockfish from pinniped predation in inside B.C. waters from the reference case run. The posterior median values are shown for F, M from pinniped predation (M_1), and the long-term average total M. 80% probability intervals for each model run are shown for $M_{1,y}$, and F_y. Results for the a., 2.5% lower bound, b. reference case and c. 97.5% upper bound scenarios for pinniped predation (runs G.1, Ref.2 and G.2, Table 23) are shown.

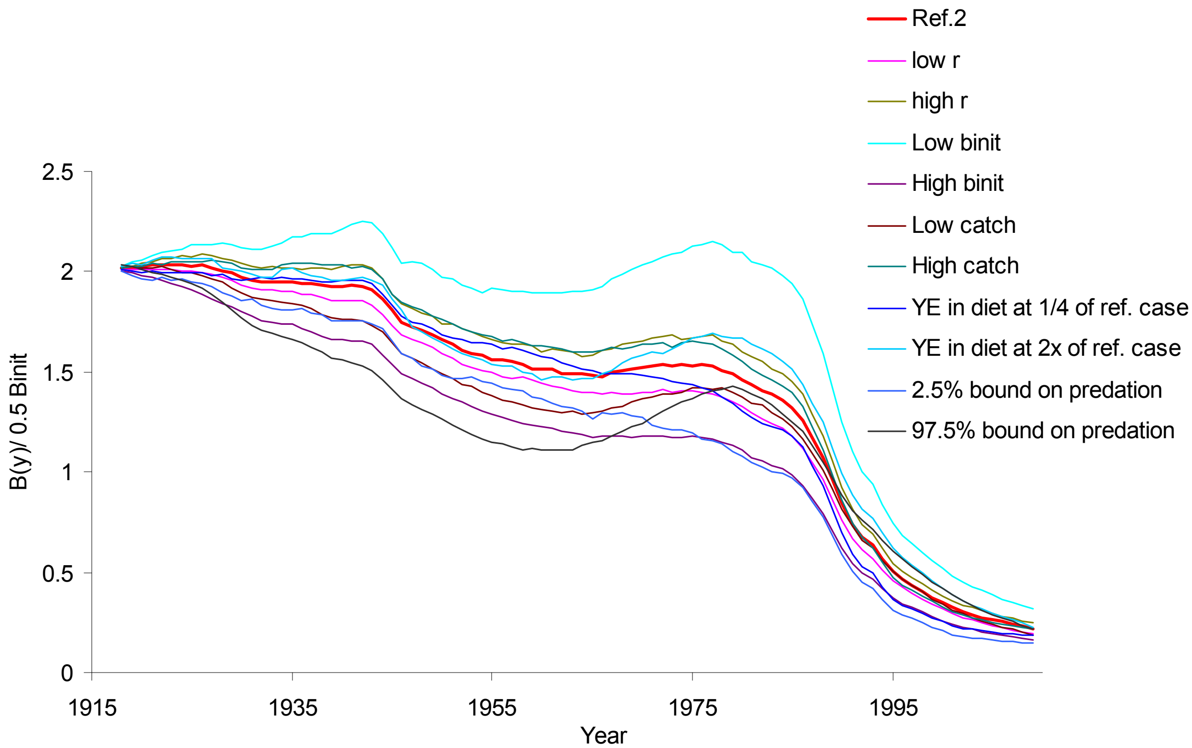

Figure 26. Plots of the yelloweye rockfish inside population PBSP posterior median estimates of the ratio of stock biomass to 50% of initial stock biomass in 1918 taken from a range of the various sensitivity runs and the original reference case runs.

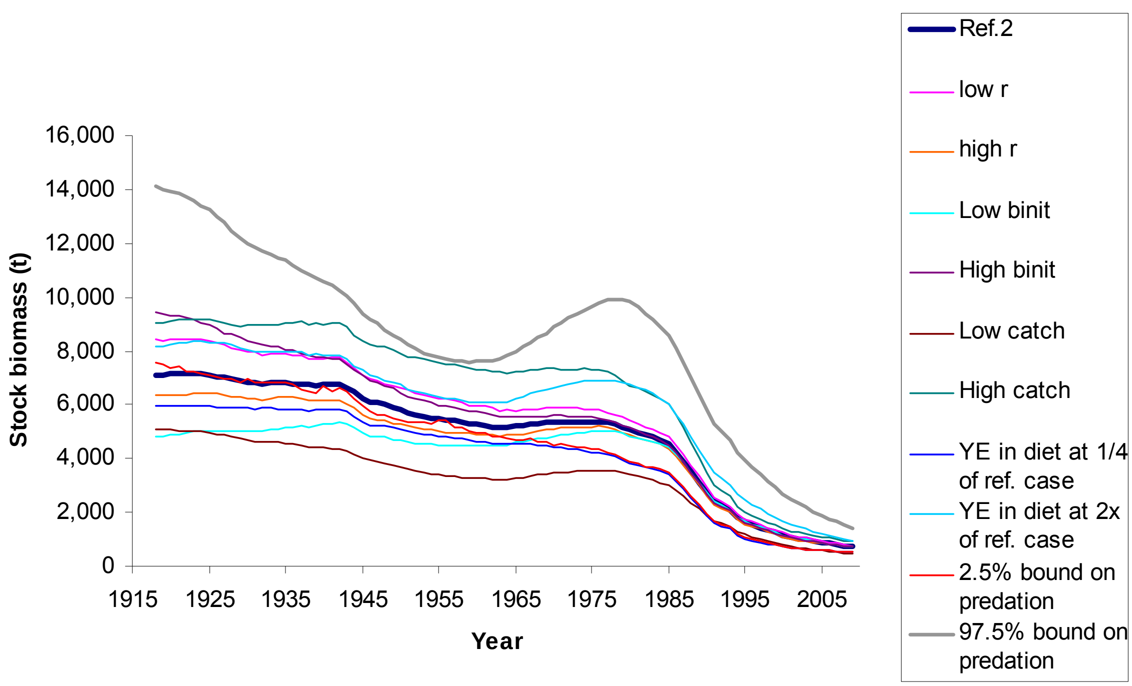

Figure 27. Plots of the yelloweye rockfish inside population PBSP posterior median estimates of the ratio of stock biomass taken from a range of the various sensitivity runs and the original reference case runs.

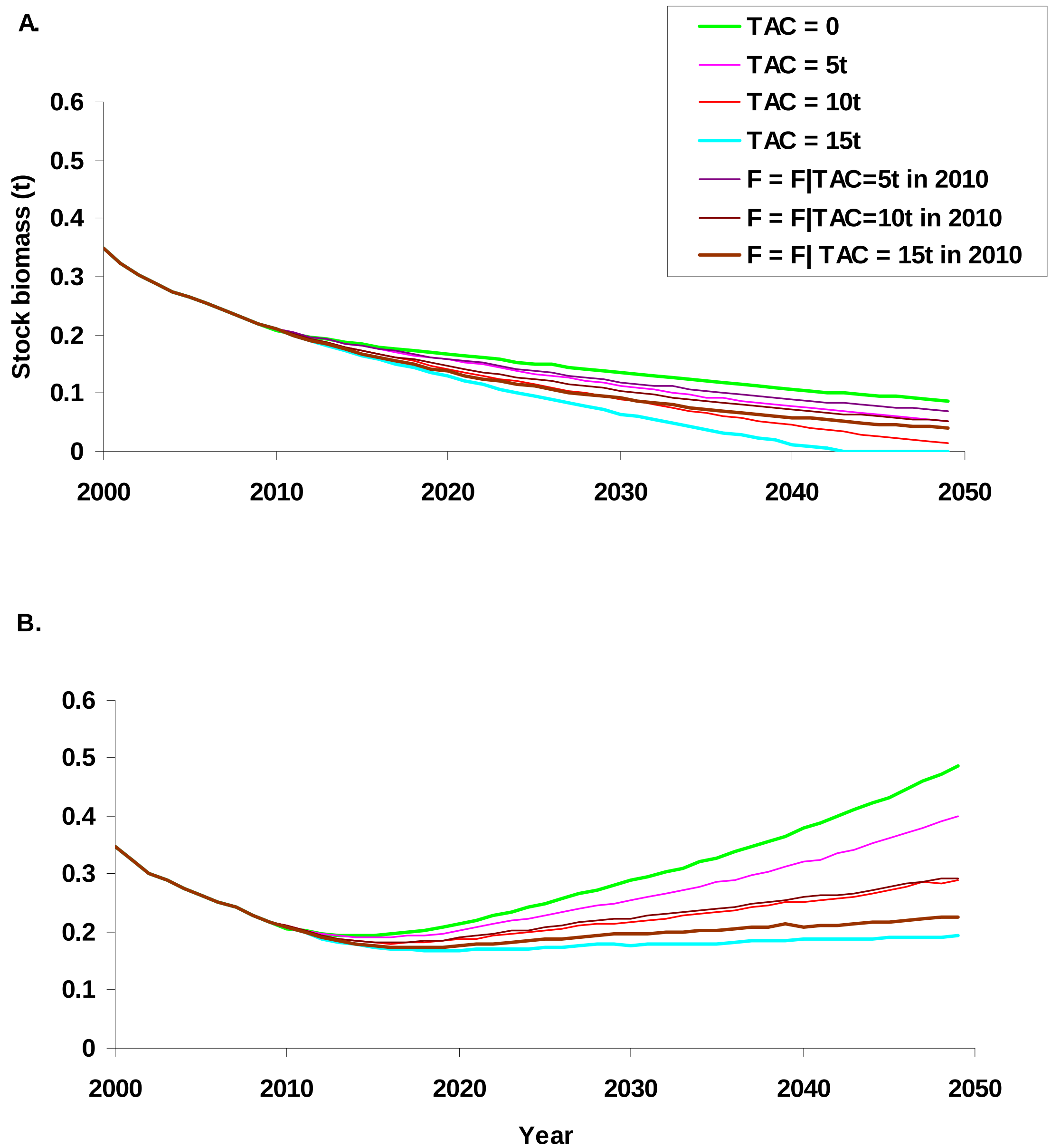

Figure 28. Yelloweye rockfish inside population projection results showing the median ratio of stock biomass to 0.5 stock biomass in 1918 for A) reference case PBSP model with pinnipeds at 2009 levels and B) reference case PBSP model with pinnipeds decreasing to about 1/5 of the 2009 levels by 2020.

APPENDIX A. REQUEST FOR SCIENCE ADVICE.

PART 1: DESCRIPTION OF THE REQUEST – TO BE FILLED BY THE CLIENT REQUESTING THE INFORMATION/ADVICE

Date (when initial client's submission is sent to Science)**:**

Directorate, Branch or group initiating the request and category of request

Directorate/Branch/Group	Category of Request
X Fisheries and Aquaculture Management	X Stock Assessment
☐ Oceans & Habitat Management and SARA	☐ Species at Risk
☐ Policy	☐ Human impacts on Fish Habitat/ Ecosystem components
☐ Science	☐ Aquaculture
☐ Other (please specify):	☐ Ocean issues
	☐ Invasive Species
	☐ Other (please specify):

Initiating Branch Contact:	
Name: Tamee Mawani/	Telephone Number: 604-666-9033
Email:Tameezan.mawani@dfo-mpo.gc.ca	Fax Number:

Issue Requiring Science Advice (i.e., "the question"):
Issue posed as a question for Science response.

In July 2004, the ADM Fisheries and Aquaculture Management agreed to work towards integrating the Precautionary Approach (PA) into Fisheries Management Renewal on groundfish fisheries. To this end staff were instructed to ensure all future Science assessments begin to include candidate Limit Reference Points for groundfish and pelagic fisheries. In this context is it appropriate to recommend a candidate Limit Reference Points Point (LRP), an Upper Stock Reference Point (USR) and target reference point (TRP) the Removal Reference for yelloweye (inside) rockfish? IF so what would the candidate points be (include biological considerations and rationale used to form these recommended candidate points.)

What is the current status of the Yelloweye inside stock relative to the DFO Precautionary Approach harvest default reference points?
I understand that the initial biomass (B_{init}) in 1918 will be used as a reference point and stock status currently (B_{curr}) relative to B_{init}.

Provide rationale for if the LRP, USR and TRP candidates differ from the PA default reference points and include decision tables which forecast the impact of varying harvest levels on future population trends.

Rationale for Advice Request:
What is the issue, what will it address, importance, scope and breadth of interest, etc.?

This species has been designated as special concern by COSEWIC and if listed will require the development of a management plan. Updated stock assessment will be an integral component of this plan.

Possibility of integrating this request with other requests in your sector or other sector's needs?

n/a

Intended Uses of the Advice, Potential Impacts of Advice within DFO, and on the Public: Who will be the end user of the advice (e.g. DFO, another government agency or Industry?). What impact could the advice have on other sectors? Who from the Public will be impacted by the advice and to what extent?
Catch advice for commercial harvesters and DFO managers.

Date Advice Required: Opening of the 2011 groundfish fishery.

Latest possible date to receive Science advice: November 2010.

Funding: Specific funds may already have been identified to cover a given issue (e.g. SARCEP, Ocean Action Plan, etc.)
Source of funding: Nil Expected amount: Nil

Initiating Branch's Approval:
Approved by Initiating Director: Date: Name of initiating Director: Sue Farlinger **Send form via email attachment following instructions below**: Regional request: Depending on the region, the coordinator of the Regional Centre for Science Advice or the Regional Director of Science will be the first contact person. Please contact the coordinator in your region to confirm the approach. National request: At HQ, the Director of the Canadian Science Advisory Secretariat (Ghislain.Chouinard@dfo-mpo.gc.ca) AND the Director General of the Ecosystem Science Directorate (Sylvain.Paradis@dfo-mpo.gc.ca) will be the first contact persons.

PART 2: **<u>RESPONSE FROM SCIENCE</u>**

In the regions: to be filled by the Regional Centre for Science Advice.
At HQ: to be filled by the Canadian Science Advisory Secretariat in collaboration with the Directors of the Science program(s) of concern.

Criteria characterising the request:	**Constraints regarding the planning of a standard peer review/Workshop:**	**Other criteria that could affect the choice of the process, the timelines, or the scale of the meeting:**
☒ Science advice is requested (rather than just information) ☐ A sound basis of peer-reviewed information and advisory precedent already exists. ☐ Inclusiveness is an issue ☐ Advice on this specific issue has been provided in the past. ☐ Urgent request. ☐ DFO is not the final advisory body. ☐ CEAA process ☐ COSEWIC process ☐ Other:	☐ External expertise required ☐ This is a scientifically controversial issue, i.e., consensus does not currently exist within DFO science. ☐ Extensive preparatory work is required. ☐ Determination of information availability is required (prior to provision of advice). ☐ Resources supporting this process are not available. ☐ Expected time needed for the preparatory work: ☐ Other (please specify):	☐ The response provided could be considered as a precedent that will affect other regions. ☐ The response corresponds to a new framework or will affect the framework currently in place. ☐ Expertise from other DFO regions is necessary. ☐ Other (please specify):

Recommendation regarding the advisory process and the timelines:

☐ Science Special Response Process (SSRP) ☐ Workshop ☐ Peer Review Meeting

Rationale justifying the choice of process:

Types of publications expected and if already known, number of report for each series:

☐ Science Advisory Report ( ) ☐ Research Document ( )

☐ Proceeding ( ) ☐ Science Response Report ( )

☐ Other:

Date Advice to be Provided:

☐ Date specified can be met.
☐ Date specified can NOT be met.

Alternate date, as agreed to by client Branch lead and Science lead:

OR

☐ No Formal Response to be Provided by Science

Rationale:

- ☐ DFO Science Region does not have the expertise required.
- ☐ DFO Science Region does not have resources available at this time.
- ☐ The deadline can not be met.
- ☐ Not a natural science issue (e.g. socio-economic)
- ☐ Response to a similar question has been provided elsewhere:
  Reference:

Additional explanation:

Science Branch Lead:

Name: Telephone Number:
Email:

* Please contact Science Branch lead for additional details on this request.

Science Branch Approval:

Approved by Regional Director, Science (or their delegate authority):
☐ Date:

Name of the person who approved the request:

Once part 2 completed, the form is sent via email attachment to the initiating Branch contact person.

PART 3: PLANNING OF THE ADVISORY PROCESS

Science Branch Approval:

Coordinator of the event:

Potential chair(s):

Suggested date / period for the meeting:

Need a preparatory meeting:

Leader of the Steering Committee:

APPENDIX B. RECONSTRUCTION OF THE COMMERCIAL CATCH (LANDINGS AND DISCARDS) OF YELLOWEYE ROCKFISH IN B.C. INSIDE WATERS.

The reconstruction of the commercial catch of yelloweye rockfish in B.C. inside waters is described for the years 1918 to 2009 in the technical report by Haigh and Yamanaka (2011). The results of the reconstruction are shown in the following Table B1.

Table B1. Reconstructed commercial catch (landings and discards) of yelloweye rockfish (Sebastes ruberrimus) in metric tonnes (mt) for the inside management area (Major Area 4B) by fishery and total for the area (Haigh and Yamanaka 2011).

YEAR	trawl	halibut	sablefish	dogfish/lingcod	rockfish	TOTAL
1918	0.0	5.8	0.0	8.3	14.9	29.0
1919	0.0	14.4	0.0	20.4	36.9	71.8
1920	0.0	7.3	0.0	10.3	18.5	36.0
1921	0.0	6.3	0.0	8.9	16.0	31.2
1922	0.0	7.8	0.0	11.1	20.0	38.9
1923	0.0	7.6	0.0	10.8	19.4	37.8
1924	0.0	8.6	0.0	12.2	22.0	42.9
1925	0.0	7.4	0.0	10.5	19.0	36.9
1926	0.0	8.5	0.0	12.0	21.7	42.2
1927	0.0	8.5	0.0	12.0	21.7	42.2
1928	0.0	8.7	0.0	12.4	22.3	43.4
1929	0.0	11.3	0.0	16.1	29.0	56.4
1930	0.0	10.3	0.0	14.5	26.2	51.0
1931	0.0	6.7	0.0	9.5	17.2	33.5
1932	0.0	7.6	0.0	10.8	19.5	38.0
1933	0.0	3.8	0.0	5.3	9.6	18.7
1934	0.0	4.4	0.0	6.3	11.3	22.0
1935	0.0	5.7	0.0	8.1	14.5	28.3
1936	0.0	6.2	0.0	8.7	15.8	30.7
1937	0.0	4.8	0.0	6.8	12.3	24.0
1938	0.0	16.2	0.0	22.9	41.3	80.3
1939	0.0	3.2	0.0	4.5	8.2	15.9
1940	0.0	3.5	0.0	4.9	8.9	17.3
1941	0.0	2.1	0.0	3.0	5.5	10.6
1942	0.0	4.9	0.0	7.0	12.6	24.5
1943	0.0	28.3	0.0	40.0	72.3	140.6
1944	0.0	42.0	0.0	59.5	107.4	208.9
1945	0.0	45.1	0.0	63.9	115.3	224.4
1946	0.0	30.3	0.0	42.9	77.4	150.6
1947	0.0	9.7	0.0	13.8	24.8	48.3
1948	0.0	14.8	0.0	20.9	37.8	73.5
1949	0.0	19.7	0.0	27.9	50.3	97.8
1950	0.0	8.4	0.0	11.9	21.4	41.7
1951	0.0	18.1	0.0	25.6	46.2	89.8
1952	0.0	10.0	0.0	14.2	25.6	49.8
1953	0.0	9.4	0.0	13.4	24.1	46.9
1954	0.0	7.5	0.0	10.6	19.1	37.1
1955	0.0	7.1	0.0	10.1	18.2	35.5
1956	0.0	3.4	0.0	4.8	8.7	17.0
1957	0.0	5.9	0.0	8.4	15.1	29.4
1958	0.0	8.6	0.0	12.1	21.9	42.7
1959	0.0	8.8	0.0	12.5	22.6	43.9
1960	0.0	7.2	0.0	10.1	18.3	35.6
1961	0.0	5.3	0.0	7.6	13.7	26.6

1962	0.0	8.6	0.0	12.2	22.1	43.0
1963	0.0	6.6	0.0	9.3	16.9	32.8
1964	0.0	4.0	0.0	5.6	10.2	19.8
1965	0.0	3.6	0.0	5.1	9.2	17.8
1966	0.0	2.9	0.0	4.1	7.4	14.3
1967	0.0	4.5	0.0	6.3	11.4	22.1
1968	0.0	4.8	0.0	6.8	12.3	23.9
1969	0.0	5.6	0.0	7.9	14.2	27.8
1970	0.0	6.8	0.0	9.7	17.5	34.0
1971	0.0	5.8	0.0	8.3	14.9	29.0
1972	0.0	6.5	0.0	9.1	16.5	32.1
1973	0.0	7.9	0.0	11.2	20.3	39.4
1974	0.0	3.9	0.0	5.5	10.0	19.5
1975	0.0	3.1	0.0	4.4	8.0	15.6
1976	0.0	3.8	0.0	5.4	9.7	18.9
1977	0.1	10.7	0.0	15.1	27.3	53.3
1978	0.2	12.0	0.0	17.0	30.6	59.8
1979	0.0	19.2	0.7	27.1	49.0	96.0
1980	0.0	13.9	0.0	19.6	35.4	68.9
1981	0.0	16.5	0.0	23.3	42.1	81.8
1982	5.9	22.0	0.0	14.0	13.0	54.9
1983	7.9	23.3	0.0	13.6	6.6	51.5
1984	30.1	27.1	0.0	8.4	9.4	75.1
1985	68.5	34.1	0.0	7.6	9.9	120.0
1986	53.2	41.2	0.0	11.1	30.8	136.3[1]
1987	26.6	33.0	0.0	22.8	48.2	130.6[1]
1988	60.8	38.7	0.0	26.7	46.7	172.9[1]
1989	54.7	35.9	0.0	25.0	57.7	173.3[1]
1990	65.4	36.7	0.0	18.7	52.8	173.5[1]
1991	35.0	37.5	0.0	8.0	64.5	145.0[1]
1992	19.9	13.9	0.0	2.5	7.3	43.6[1]
1993	11.4	15.5	0.0	7.8	20.6	55.3[1]
1994	10.6	21.9	0.0	4.1	83.6	120.2[1]
1995	11.0	0.7	0.0	16.7	32.1	60.4[1]
1996	0.0	3.9	0.0	0.4	21.5	25.9[1]
1997	0.0	5.0	0.0	2.9	13.0	20.9[1]
1998	0.0	6.3	0.0	3.0	22.8	32.1[1]
1999	0.0	1.6	0.0	2.4	16.0	19.9[1]
2000	0.0	0.7	0.0	1.3	22.5	24.5[1]
2001	0.0	0.9	0.0	3.1	23.5	27.5[1]
2002	0.0	0.1	0.0	3.7	3.3	7.2[1]
2003	0.0	0.1	0.0	6.8	3.7	10.6[1]
2004	0.0	0.2	0.0	6.6	2.9	9.7[1]
2005	0.0	0.0	0.0	8.5	2.3	10.9[1]
2006	0.0	0.5	0.0	3.4	1.2	5.1
2007	0.0	1.3	0.0	3.7	2.9	7.9
2008	0.0	1.6	0.0	4.4	4.3	10.3
2009	0.0	0.8	0.0	5.0	2.4	8.1

[1] For the Reference Case Model run, these figures were doubled based on industry estimates of unreported catch.

APPENDIX C. RECONSTRUCTION OF THE RECREATIONAL CATCH OF YELLOWEYE ROCKFISH IN B.C. INSIDE WATERS.

There are two sources of recreational catch data compiled by Fisheries and Oceans Canada: the Strait of Georgia Sport Fishery Creel Survey (Creel) (Hardie et al. 2001) and the Survey of Recreational Fishing in Canada (Recreational) (DFO). The Creel Survey is used to estimate catch and anecdotal information from local experts to determine effort back to World War II when recreational fishing began to develop.

<u>Strait of Georgia Creel Survey 1982 - 2008</u>

The Strait of Georgia Creel survey catch estimates were obtained between 1982 and 2008 from the South Coast Creel Database in March 2009 (preliminary catch estimates for 2008). Catch in numbers of rockfish are recorded for kept fish between 1982 and 1998 and kept and released fish between 1999 and 2008. These catch estimates are in numbers of rockfish (all species) in PFMAs 13 to 20, 28 and 29 for the years 1982 to 1999 and for yelloweye rockfish in PFMAs 12 to 20, 28 and 29 for the years 2000 to 2008.

Using proportions of yelloweye rockfish to rockfish (all species) by PFMA in 2000, the number of yelloweye rockfish caught by PFMA are estimated from the rockfish (all species) catch estimates. Using proportions of yelloweye rockfish catch in PFMA12 to the rest of the Strait of Georgia in 2000 and 2001 estimates of PFMA 12 yelloweye rockfish catches are made. To estimate the weight in tonnes of the yelloweye rockfish catch, the average weight of yelloweye rockfish, 2.49 kg, determined from weights collected during the creel survey between 2000 and 2008, is applied to the total number of fish. The estimate of the inside yelloweye rockfish catch by recreational anglers is shown in Table C1. These estimates are not corrected for missing survey months and areas and could be considered biased low by 5% (Bill Shaw pers. comm.).

Table C1. Estimated yelloweye rockfish (Sebastes ruberrimus) recreational catch in numbers of fish from the "inside" Strait of Georgia Creel Survey by Statistical Area, Total catch in tonnes and Total effort in 10,000 boat trips by year from 1981 to 2008.

Number of fish by Statistical Area												Total	Total
Year	12	13	14	15	16	17	18	19	20	28	29	Tonnes[1]	Effort
1981													30.65
1982	2702	690	1418	982	8190	857	146	473	129	99	419	40.1	60.97
1983	2385	1288	1412	1010	5594	906	133	345	560	121	461	35.4	58.18
1984	1779	800	1198	1156	2445	1774	131	320	413	102	484	26.4	70.97
1985	2009	507	1028	461	5847	1047	79	303	225	68	397	29.8	68.51
1986	1746	576	1882	800	3124	1154	96	330	438	40	221	25.9	63.54
1987	2655	864	2450	750	5800	1530	111	396	574	57	638	39.4	64.27
1988	2655	864	2450	750	5800	1530	111	396	574	57	638	39.4	71.44
1989	2926	661	2640	837	7351	1640	129	653	0	56	548	43.4	65.76
1990	2369	649	1898	667	6456	790	46	363	359	59	465	35.2	57.25
1991	2693	599	1948	586	7223	1021	43	266	150	104	1418	40	49.31
1992	2125	514	1155	340	6609	897	60	300	190	68	409	31.5	50.07
1993	1375	556	770	337	3177	753	35	317	230	52	591	20.4	54.28
1994	2153	990	2062	763	4448	988	35	310	195	115	774	32	48.04
1995	1715	683	1056	599	4457	762	37	218	145	51	502	25.5	35.28
1996	1600	822	440	508	5005	340	20	280	148	65	310	23.7	31.47
1997	1265	701	513	611	3258	504	32	152	117	67	319	18.8	29.30
1998	1134	1059	304	592	2697	458	22	183	211	22	74	16.8	17.69
1999	895	765	205	155	2678	273	8	139	108	47	60	13.3	17.16
2000	1486	385	394	229	2151	866	19	322	310	66	65	15.7	19.54
2001	759	776	1331	576	3860	951	31	56	277	0	215	22	21.46
2002	84	182	1727	345	628	214	0	48	46	43	48	8.4	22.80
2003	496	4	109	126	2608	250	18	7	52	36	90	9.5	19.72
2004	176	64	1690	169	737	84	0	7	92	11	57	7.7	15.40
2005	493	115	240	13	61	343	0	19	249	20	0	3.9	12.89
2006	700	62	692	79	158	459	56	69	199	0	0	6.2	13.13
2007	380	89	16	49	104	77	0	25	198	12	1	2.4	13.42
2008	677	42	94	150	353	84	0	11	315	1	12	4.3	11.29

[1]numbers of fish converted to weight using 2.49 kg (average weight of yelloweye rockfish in the creel survey 2000-2008)

Survey of Recreational Fishing in Canada 1975 - 2005

The inside yelloweye rockfish catch in the recreational fishery can also be estimated from the Survey of Recreational Fishing in Canada (DFO) between 1975 and 2005 (Table C2). Numbers of rockfish and area of catch data from the 2000 and 2005 surveys may be used to estimate "inside" catches of rockfish using proportions of rockfish to "other fish" as well as "inside" to B.C. coast landings. These proportions could then be applied to catch and area data reported in earlier surveys conducted every five years from 1975. Proportions of rockfish caught "inside" were estimated at 94% in 1971 (Sinclair 1972) and 61% in 2000. Linear extrapolations could then used to fill in proportions between these two years. Proportions of yelloweye rockfish could be estimated by applying a 4% yelloweye to other rockfish species caught in the Strait of Georgia Creel Survey (Hardie et al. 2001). Yelloweye rockfish numbers could be converted to weights using the average weight of yelloweye rockfish in the Strait of Georgia Creel Survey Database 2009. These data, however, are derived using a small sample of post season interviews which are known for “recall bias” which inflates catch estimates. For this reason, this survey could be considered biased high and unusable (Bill Otway pers. comm.).

Table C2. Estimate of the yelloweye rockfish (Sebastes ruberrimus) catch from the inside area derived from the Survey of Recreational Fishing in Canada (DFO) between 1975 and 2005.

year	BC catch Rockfish all species	proportion inside waters	rockfish caught inside	estimate yelloweye (0.04)	tonnes mean wt 2.49 kg
1975	2340144	0.94	2199736	87989	220.0
1980	2917053	0.87	2549505	101980	255.0
1985	2038509	0.81	1647115	65885	164.7
1990	1881396	0.74	1395996	55840	139.6
1995	1763358	0.68	1192030	47681	119.2
2000	876653	0.61	530630	21225	53.1
2005	441725.6	0.45	199007	7960	19.9

Estimated recreational catch 1945 - 1981

Recreational catches prior to the creel survey were reconstructed by formulating a time series of hypothesized recreational fishing effort prior to the creel survey. It is known that yelloweye rockfish have been captured by recreational anglers since the late 1800's with recreational angling effort increasing after World War II (George Bates, Bill Otway, Wayne Seto pers. comm.). The reconstruction of fishing effort in the recreational fishery is based on a family run recreational fishing resort history; Bates Beach. George Bates supplied the following information.

> “You could consider the start of the recreational fishery right after WWII, with the fleet characterized by “putter” boats – at this time Bates Beach fleet size = 10 boats
>
> Recreational fishing effort increased steadily from WWII up to the early 1960s, at which time outboard motors became popular and allowed movement out to rock reefs further offshore.
>
> The herring population collapsed and so did the salmon fishing so people switched to groundfish, primarily lingcod and rockfish. Generally during this time there was a lull in the fishing effort – Bates Beach sold the business in 1965 fleet size = 10.
> In the early 1970’s the herring population came back and so did the salmon, effort on groundfish decreased – Bates Beach reopened second resort around 1971 – original Bates Beach still operating until 2006 with a slow decline in the original fleet to <3 boats.
>
> In the 1980’s there was good salmon fishing, effort peaked in the recreational fishery in the mid-late 1980’s – Bates Beach fleet size = 17 boats during this peak.
>
> Steady decline in effort began around 1998 to the present. During 1992 – 96 coho fishing declined and effort switched back to groundfish. Bates beach fleet size in 2009 = 3 boats.”

Based on this, trend lines were formulated for historic recreational fishing effort up to 1981. Applying the Bayesian imputation method in Stanley et al. (2009), using the average recreational catch per unit effort from 1982 -1986 and the historical hypothesized fishing effort, catches were probabilistically imputed up to 1981 (Table C3). These data are similar to effort data in Puget Sound with increases in recreational fishing effort from 1970 to a peak in 1983 followed by declines with minor peaks in 1991-92 and 1997 (Williams et al. 2010).

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Table C3. Reconstruction of the annual yelloweye rockfish effort (10,000 boat days) and catch (tonnes) in the recreational fishery from 1918 to 2008.

Year	Boat days (x10000)	Catch in tonnes	Year	Boat days (x10000)	Catch in tonnes
1918	1.66	0.9	1964	33.28	17.2
1919	1.66	0.9	1965	33.28	17.2
1920	1.66	0.9	1966	33.28	17.2
1921	1.66	0.9	1967	33.28	17.2
1922	1.66	0.9	1968	33.28	17.2
1923	1.66	0.9	1969	33.28	17.2
1924	1.66	0.9	1970	35.03	18.2
1925	1.66	0.9	1971	36.78	19.1
1926	1.66	0.9	1972	38.53	20.0
1927	1.66	0.9	1973	40.29	20.9
1928	1.66	0.9	1974	42.04	21.8
1929	1.66	0.9	1975	43.79	22.7
1930	1.66	0.9	1976	45.54	23.6
1931	1.66	0.9	1977	47.29	24.5
1932	1.66	0.9	1978	49.04	25.4
1933	1.66	0.9	1979	50.79	26.3
1934	1.66	0.9	1980	52.55	27.2
1935	1.66	0.9	1981	30.65	15.9
1936	1.66	0.9	1982	60.97	40.1
1937	1.66	0.9	1983	58.18	35.4
1938	1.66	0.9	1984	70.97	26.4
1939	1.66	0.9	1985	68.51	29.8
1940	1.66	0.9	1986	63.54	25.9
1941	1.66	0.9	1987	64.27	39.4
1942	1.66	0.9	1988	71.44	39.4
1943	1.66	0.9	1989	65.76	43.4
1944	1.66	0.9	1990	57.25	35.2
1945	1.66	0.9	1991	49.31	40.0
1946	1.98	1.0	1992	50.07	31.5
1947	3.95	2.0	1993	54.28	20.4
1948	5.93	3.1	1994	48.04	32.0
1949	7.90	4.1	1995	35.28	25.5
1950	9.88	5.1	1996	31.47	23.7
1951	11.86	6.1	1997	29.30	18.8
1952	13.83	7.2	1998	17.69	16.8
1953	15.81	8.2	1999	17.16	13.3
1954	17.78	9.2	2000	19.54	15.7
1955	19.76	10.2	2001	21.46	22.0
1956	21.74	11.3	2002	22.80	8.4
1957	23.71	12.3	2003	19.72	9.5
1958	25.69	13.3	2004	15.40	7.7
1959	27.66	14.3	2005	12.89	3.9
1960	29.64	15.4	2006	13.13	6.2
1961	33.28	17.2	2007	13.42	2.4
1962	33.28	17.2	2008	11.29	4.3
1963	33.28	17.2			

APPENDIX D. RECONSTRUCTION OF ABORIGINAL CONSUMPTION OF YELLOWEYE ROCKFISH FOR THE INSIDE WATERS.

Aboriginal consumption of yelloweye rockfish for the inside waters is estimated by using estimates of population size combined with a consumption rate. Two sources of Aboriginal population size were used, Statistics Canada Census data (prepared by B.C. STA TS 2009) and data from Indian and Northern Affairs Canada. Consumption data is estimated from a study conducted on the Aboriginal population in SE Alaska (State of Alaska 2007) together with confidential DFO data on Band allocations of groundfish (pers comm. Mark Fetterly, 2010).

Population data was obtained through Census of Canada data that identified people of Aboriginal identity (1996, 2001), population living on reserves (1986, 1991), Native peoples (1981), and Native Indians (1931 – 1971). The populations in the Census of Canada data used for the inside area between 1971 and 2001 were: Alberni Clayoquot, Comox-Strathcona, Cowichan Valley, Mount Waddington, Nanaimo, Powell River, Squamish-Lillooet, and the Sunshine Coast. For the 1931 to 1961 Census data, area Divisions 5 and 7 were used to determine inside Aboriginal populations. These data are shown in Table D1. The 1931 to 1971 data were used to project population numbers from 1918 to 1979 by linear extrapolation from 1931 to 1980 and for years prior to 1931, numbers were held constant.

Table D1. Aboriginal population estimates residing near to the inside yelloweye rockfish. Data from Statistics Canada (prepared by B.C. STATS 2009).

census year	Native population
1931	3092
1941	6221
1951	7766
1961	10505
1971	10820
1981	20710
1986	9982
1991	11944
1996	24650
2001	30305

A near-urban First Nation diet study near Victoria in British Columbia shows rockfish (all species) consumed by about 13% of the studied population (Mos et al. 2004). Of these consumers, approximately 3 meals of rockfish were eaten annually. Consumption data obtained from an Alaskan publication reports the Traditional Diet Survey median annual consumption rate of one pound (1 lb) of yelloweye rockfish consumed per Aboriginal person in Southeast Alaska (State of Alaska 2007). This estimate is higher than estimates based on confidential DFO data (M. Fetterly pers. comm.). Yelloweye rockfish is more abundant and available to SE Alaskans than Aboriginal groups in and around the Strait of Georgia, therefore, an estimate of half the Alaskan consumption was used for the Aboriginal subsistence consumption rate in B.C.. This estimate of half a pound (0.23 kg) of yelloweye rockfish per person per year was applied to the Aboriginal population estimate to determine the Aboriginal consumption in the inside waters (Table D2).

Table D2 Aboriginal consumption of yelloweye rockfish (Sebastes ruberrimus) based on population size and a consumption rate of 0.23 kg per person annually. Population estimates from Canada Census (1931 to 1971) and Indian and Northern Affairs Canada (INAC) from 1980 to 2007. Linear extrapolations were made between 5 year census data. Prior to 1931, populations were fixed at 1931 levels back to 1918.

Year	Population	Catch	Year	Population	Catch
1918	3092	0.7	1963	10568	2.4
1919	3092	0.7	1964	10600	2.4
1920	3092	0.7	1965	10631	2.5
1921	3092	0.7	1966	10663	2.5
1922	3092	0.7	1967	10694	2.5
1923	3092	0.7	1968	10726	2.5
1924	3092	0.7	1969	10757	2.5
1925	3092	0.7	1970	10789	2.5
1926	3092	0.7	1971	10820	2.5
1927	3092	0.7	1972	10926	2.5
1928	3092	0.7	1973	11032	2.6
1929	3092	0.7	1974	11138	2.6
1930	3092	0.7	1975	11244	2.6
1931	3092	0.7	1976	11350	2.6
1932	3405	0.8	1977	11456	2.7
1933	3718	0.8	1978	11562	2.7
1934	4031	0.9	1979	11668	2.7
1935	4344	1.0	1980	11774	2.7
1936	4657	1.1	1981	12007	2.7
1937	4969	1.1	1982	12244	2.8
1938	5282	1.2	1983	12511	2.8
1939	5595	1.3	1984	12687	2.9
1940	5908	1.3	1985	12950	2.9
1941	6221	1.4	1986	13728	3.1
1942	6376	1.4	1987	15689	3.6
1943	6530	1.5	1988	16883	3.8
1944	6685	1.5	1989	17620	4.0
1945	6839	1.6	1990	18526	4.2
1946	6994	1.6	1991	19209	4.4
1947	7148	1.6	1992	19977	4.5
1948	7303	1.7	1993	20574	4.7
1949	7457	1.7	1994	21047	4.8
1950	7612	1.7	1995	21564	4.9
1951	7766	1.8	1996	21943	5.0
1952	8040	1.8	1997	22446	5.1
1953	8314	1.9	1998	22895	5.2
1954	8588	1.9	1999	23328	5.3
1955	8862	2.0	2000	23745	5.4
1956	9136	2.1	2001	24131	5.5
1957	9409	2.1	2002	24480	5.6
1958	9683	2.2	2003	25105	5.7
1959	9957	2.3	2004	25995	5.9
1960	10231	2.3	2005	11774	2.7
1961	10505	2.4	2006	12007	2.7
1962	10537	2.4	2007	12244	2.8

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APPENDIX E. PRODUCING AN ABUNDANCE INDEX FROM COMMERCIAL CATCH DATA FOR YELLOWEYE ROCKFISH (*SEBASTES RUBERRIMUS*).

Methods

Data

The commercial catch data for yelloweye rockfish were derived from logbook records from the directed hook and line rockfish fishery (ZN licences) in British Columbia Strait of Georgia management region. The hook and line fishery includes both longline gear and gear classified as handline, including rod and reel, troll and other handline gear. As the logbook program for the hook and line rockfish (Sebastes) fishery began in 1986 (see Kronlund and Yamanaka 1997 for further details), data are available from 1986 to 2009. Due to management changes during this time period the data are split into five time series: 1986-1990 (n=30739), 1992-1994 (n=9492), 1995-2001 (n=18082), 2003-2005 (n=1195), 2006-2009 (n=2015) (Table E1). 2002 is not included in the time series due to a large reduction in effort by the fleet that year in protest of the total allowable catch reductions.

Catch data for yelloweye rockfish are recorded as piece counts and/or weights and are available by year, area (PFMA), gear type, and set. Where only weights were provided the count was imputed using a weight to count conversion (3.17 kg/fish) based on all catch records available. Counts were summed for all utilization codes (retained or discarded). Data for sets where non-reef species (e.g. dogfish (*Squalus acanthius*), Pacific halibut (*Hippoglossus stenolepis*) were targeted and/or duration was zero were excluded. Sets with unknown gear type were assigned to a gear category based on their maximum depth, where those with a maximum depth greater than 50 m were longline and all others were handline. Data from areas where no yelloweye were caught during the time series were discarded from all models.

Model

Catch per unit effort (CPUE) is a commonly used metric for abundance. It is calculated as:

$$\text{(E1)} \qquad CPUE_i = \frac{C_i}{E_i}$$

where C is the count of yelloweye and E is the duration (in hours) the gear was deployed during set i. In earlier years all catch is recorded as one entry per day and should be considered as a daily measure, thus differing from later time periods.

Often CPUE time series are standardized using generalized linear models (GLM) where the year effects are assumed to closely follow the abundance trends. Here, I follow the methodology of Babcock and McAllister (2002) in employing a Bayesian delta lognormal model with the explanatory variables (factors) year, area, and gear type. Four models using a combination of these factors were produced: year, year/area, year/gear, and year/area/gear. The area and gear factors are treated as fixed effects because there are too few levels to consider random effects. No interactions are considered. The delta lognormal model has two components, a binomial density function to model the number of positive catches of yelloweye (a binomial abundance index) and a lognormal density function to model the sets with positive catches (a lognormal abundance index) (Babcock and McAllister 2002). All effects are estimated relative to the reference year, area, and gear. Here that is the first year, first area, first gear and is noted as bo for the number of positive catches and ao for the positive CPUE observations.

The binomial portion of the delta lognormal model employs a logit link to linearize the binomial probabilities and takes the form:

$$\text{(E2)}\quad \log\left(\frac{py_{y,a,g}}{1-py_{y,a,g}}\right) = bo + by_y + ba_a + bg_g = \beta_{y,a,g}$$

where $py_{y,a,g}$ (the binomial abundance index) is the probability of a successful (non-zero) catch in year y and area a with gear g and the b terms are the respective effects with bo representing the mean for the reference year, area and gear. The mean of the lognormal portion of the delta lognormal model uses a log link and takes the form:

$$\text{(E3)}\quad \log(a.mu_{y,a,g}) = ao + ay_y + aa_a + ag_g = \alpha_{y,a,g}$$

where $a.mu_{y,a,g}$ (the lognormal abundance index) is the mean of the lognormal density function for year y and area a with gear g and the a terms are the respective effects with ao representing the mean for the reference year, area and gear.

The joint posterior probability density function (pdf) for the GLM model is the product of the binomial and lognormal portions of the model and the priors for the vectors of the parameters a, b, and the constant CPUE variance σ. The joint posterior pdf for the delta lognormal model is:

$$p(\sigma,\underline{a},\underline{b}|\underline{z},\underline{k},\underline{w}) \propto p(\sigma)\bullet p(bo)\bullet p(ao)$$

$$\bullet\left(\prod_{y=2}^{n_y} p(ay_y)p(by_y)\right)\bullet\left(\prod_{a=2}^{n_a} p(aa_a)p(ba_a)\right)\bullet\left(\prod_{g=2}^{n_g} p(ag_g)p(bg_g)\right)$$

$$\text{(E4)}\quad \bullet\prod_{y=1}^{n_y}\prod_{a=1}^{n_a}\prod_{g=1}^{n_g}\binom{n_{y,a,g}}{w_{y,a,g}}\left(\frac{\exp(\beta_{y,a,g})}{1-\exp(\beta_{y,a,g})}\right)^{w_{y,a,g}}\left(\frac{1}{1+\exp(\beta_{y,a,g})}\right)^{(n_{y,a,g}-w_{y,a,g})}$$

$$\bullet\prod_{s=1}^{n_{y,a,g}}\left(\frac{1}{z_{y,a,g,s}\sigma\sqrt{2\Pi}}\exp\left(-\frac{(\log(z_{y,a,g,s})-\alpha_{y,a,g})^2}{2\sigma^2}\right)\right)^{k_i}$$

where z is the CPUE observation, k is a value of 0 or 1 dependent on whether the catch is zero or non-zero respectively, w is the number of positive catches, and n is the number of sets. Further details on the derivation of the joint pdf can be found in Babcock and McAllister (2002). The priors for the $\underline{a}$ terms, $\underline{b}$ terms, and σ are non-informative and defined with mean and standard deviation as:

(E5) $ax \sim N(0,1.0E-6)$ $bx \sim N(0,1.0E-6)$ $\sigma \sim \log N(\log(0.5),1.2)$

where x represents the particular year (y), area (a) or gear (g) effect. As the first year, first area, and first gear are treated as references in the respective models, ax[1] and bx[1] are set to zero.

Year effects with the area and gear effects removed were obtained by integrating the joint posterior pdf to compute the marginal probability distributions. These integrated year effects represent the delta lognormal abundance indices. Posterior means and standard deviations are provided to summarize the central tendencies and spread in the year effects of the CPUE data.

The joint posterior pdf is estimated using the WinBUGS software (Lunn et al. 2000), employing Markov Chain Monte Carlo (MCMC). These algorithms require a stationary distribution and tests for convergence are necessary to check whether the stationary distribution has been achieved. Two Markov chains with different initial values were run for each model to allow tests for convergence on the posterior distribution. The Gelman-Rubin convergence statistic (BGR) approaches 1.0 when the pooled chain and within chain variances are similar and convergence is achieved (McCarthy 2007). Visual diagnostics for the chains were also examined to ensure that the chains were well-mixed (Figure E1). All models had a "burn-in" period of 2000 to 5000 iterations prior to convergence on the posterior distribution. The "burn-in" was discarded before posterior statistics were calculated. After removal of the "burn-in", the posterior mean and standard deviation of the first 10% and last 10% of the chains were examined to ensure that they were relatively equal. To remove autocorrelation in the chains (Figure E2 left panel) and ensure that each draw from the posterior distribution was independent, the chains were thinned and one in every 20 draws was kept (Figure E3 left panel). The chains were run until 10000 samples from the posterior distribution were produced. The deviance information criterion (DIC), given by:

(E6) $DIC = \hat{D} + 2p_D$

where $\hat{D}$ is the deviance and p_D is the effective number of estimated parameters, was used to assess model fit and select the best model for use in the stock assessment (McCarthy 2007). A lower DIC values indicates the model which provides the best fit, while minimizing the number of parameters in the model. WinBUGS was called using the R package R2WinBUGS, while convergence diagnostics were assessed with the package coda (Ihaka and Gentleman 1996).

Results

Posterior means and coefficients of variation (CVs) for the four models (year, year/area, year/gear, and year/area/gear) are presented in Table E2 and Figure E3. Generally, the mean of the delta lognormal abundance index shows a decline over time for all models in the 1986-1990, 1992-1994, 1995-2001, and 2006-2009 time periods regardless of the model (Figure E3). The 1992-1994 time period is the one exception to this trend. Variance around the posterior means is low for most time series, except for 2003-2005 and 2006-2009 where the number of observations is lower (1195 and 2015 respectively) (Table E2). The delta lognormal index mostly closely tracks trends in the lognormal index, demonstrated by the year/area/gear model plots (Figure E4). While the binomial index declines over most of the time periods, the delta lognormal index generally does not track it closely.

DIC values for the models indicate that the year/gear model best fits the data, while the year/area/gear model is the second best model in most time periods (Table E3).

While the CPUE derived delta lognormal abundance index appears to provide sensible trends, the current models ignore important variables including competition for hooks from non-target species (e.g. a dogfish abundance covariate) and depths fished, a determining factor for the species accessed. Future work will add these covariates to the model.

The systematic movement of fishermen between areas over time could potentially lead to biases in models that do not account for this behaviour (Carruthers et al. 2010). The impact of this potential source of bias on estimates of time trends in abundance using standardized commercial catch per unit effort data is expected to be relatively minor for a few reasons. First, the time periods in the analysis were relatively short and systematic shifts could have occurred within these short periods, substantial shifts that could cause biases are unlikely. Second, including versus excluding an area effect had relatively little effect on the estimated trends in the abundance indices for each time segment. Third, the best fitting models according to the DIC criterion did not include an area effect, indicating that there was relatively little variation in catch rates between areas and thus little opportunity for movement of fishermen between areas to cause potential biases in stock trend estimates in the standardized indices.

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Table E1 History of management changes for the directed hook and line rockfish (Sebastes) fishery from 1986-2009.

Year	Management Change
1986-1990	Open fishery, no fishing limits
1991	Total allowable catch (TAC) restrictions introduced, 592 licenses
1992	Limited entry reduces licenses from 592 to 74
	Fishing periods with species-based catch limits implemented, aggregate species management
1995	Mandatory dockside monitoring of landings (ZN licenses)
2002	TACs reduced by 75%, Rockfish Conservation Areas (RCAs) introduced
2006	Fishery integration and 100% monitoring

Table E2. Delta lognormal abundance index (year effects) means and coefficients of variation (CVs) for all four fixed effects models and the five time series.

	Year		Year, Area		Year, Gear		Year, Area, Gear	
Year	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**
1986	0.404	0.032	0.5279	0.038	1.676	0.031	2.836	0.040
1987	0.288	0.039	0.3858	0.042	1.286	0.036	2.106	0.042
1988	0.385	0.035	0.4491	0.037	1.528	0.033	2.228	0.038
1989	0.268	0.027	0.2986	0.032	0.883	0.026	1.414	0.033
1990	0.294	0.028	0.3583	0.031	1.096	0.028	1.625	0.032
1992	0.292	0.049	0.7177	0.055	1.446	0.047	2.599	0.053
1993	0.185	0.052	0.4853	0.051	1.566	0.055	2.600	0.056
1994	0.224	0.049	0.7785	0.050	2.104	0.054	3.949	0.057
1995	0.145	0.054	0.213	0.057	1.574	0.049	1.722	0.051
1996	0.148	0.041	0.213	0.044	1.606	0.043	1.737	0.045
1997	0.104	0.058	0.150	0.059	1.181	0.052	1.286	0.053
1998	0.108	0.049	0.143	0.048	1.239	0.046	1.290	0.047
1999	0.117	0.049	0.145	0.048	1.102	0.045	1.125	0.046
2000	0.126	0.053	0.159	0.053	1.057	0.046	1.096	0.047
2001	0.110	0.061	0.141	0.061	0.931	0.052	0.969	0.052
2003	0.166	0.134	0.085	0.166	0.663	0.149	0.473	0.267
2004	0.050	0.171	0.042	0.171	0.482	0.211	0.332	0.304
2005	0.049	0.184	0.041	0.192	0.580	0.230	0.409	0.338
2006	0.169	0.122	0.155	0.128	0.353	0.153	0.376	0.176
2007	0.179	0.117	0.147	0.125	0.261	0.126	0.243	0.142
2008	0.210	0.118	0.188	0.120	0.357	0.134	0.337	0.142
2009	0.128	0.181	0.128	0.178	0.262	0.204	0.269	0.204

Table E3 Deviance information criterion (DIC) for the four fixed effects models and the five time series. The bolded number represents the best model for that time period.

Time period	Year	Year, Area	Year, Gear	Year, Area, Gear
1986-1990	38088	38452	**35703**	36721
1992-1994	8240	11455	**7164**	7514
1995-2001	7488	7944	**5361**	6007
2003-2005	318	335	**276**	329
2006-2009	**1071**	1105	1082	1145

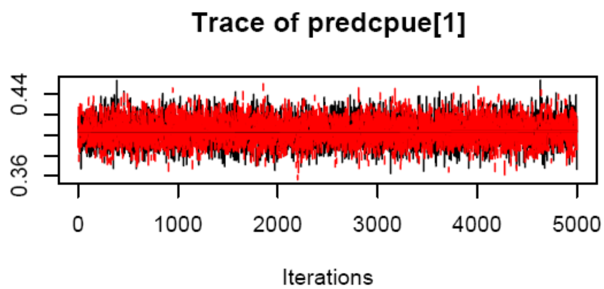

Figure E1 Trace of iterations for Markov chains of the 1986 to 1990 year, area, gear model.

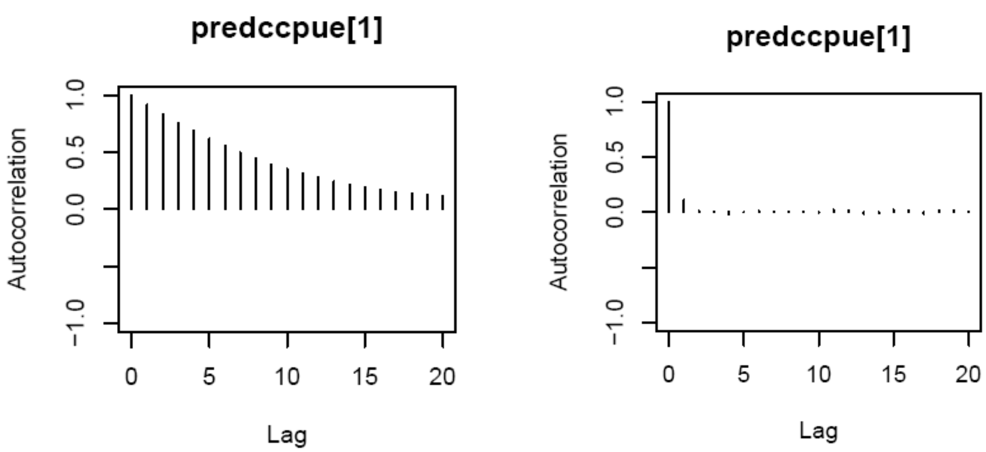

Figure E2 Autocorrelation in the year, area, gear model for 1986 to 1990 before (left) and after (right) thinning the chains in WinBUGS.

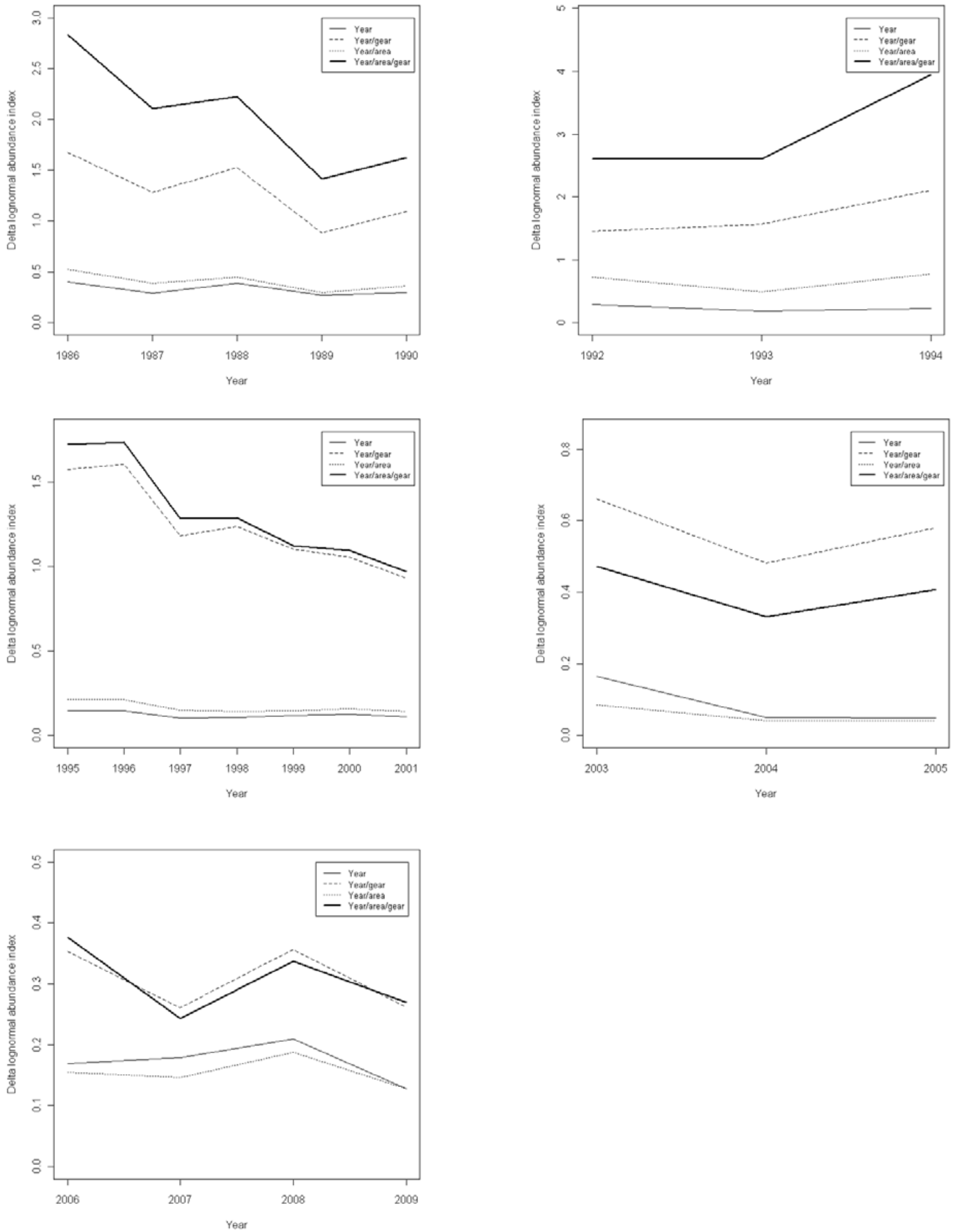

Figure E3 Delta lognormal abundance index for the four fixed effects models for the five time periods: 1986-1990 (upper panel left), 1992-1994 (upper panel right), 1995-2001 (middle panel left), 2003-2005 (middle panel right), 2006-2009 (lower panel left).

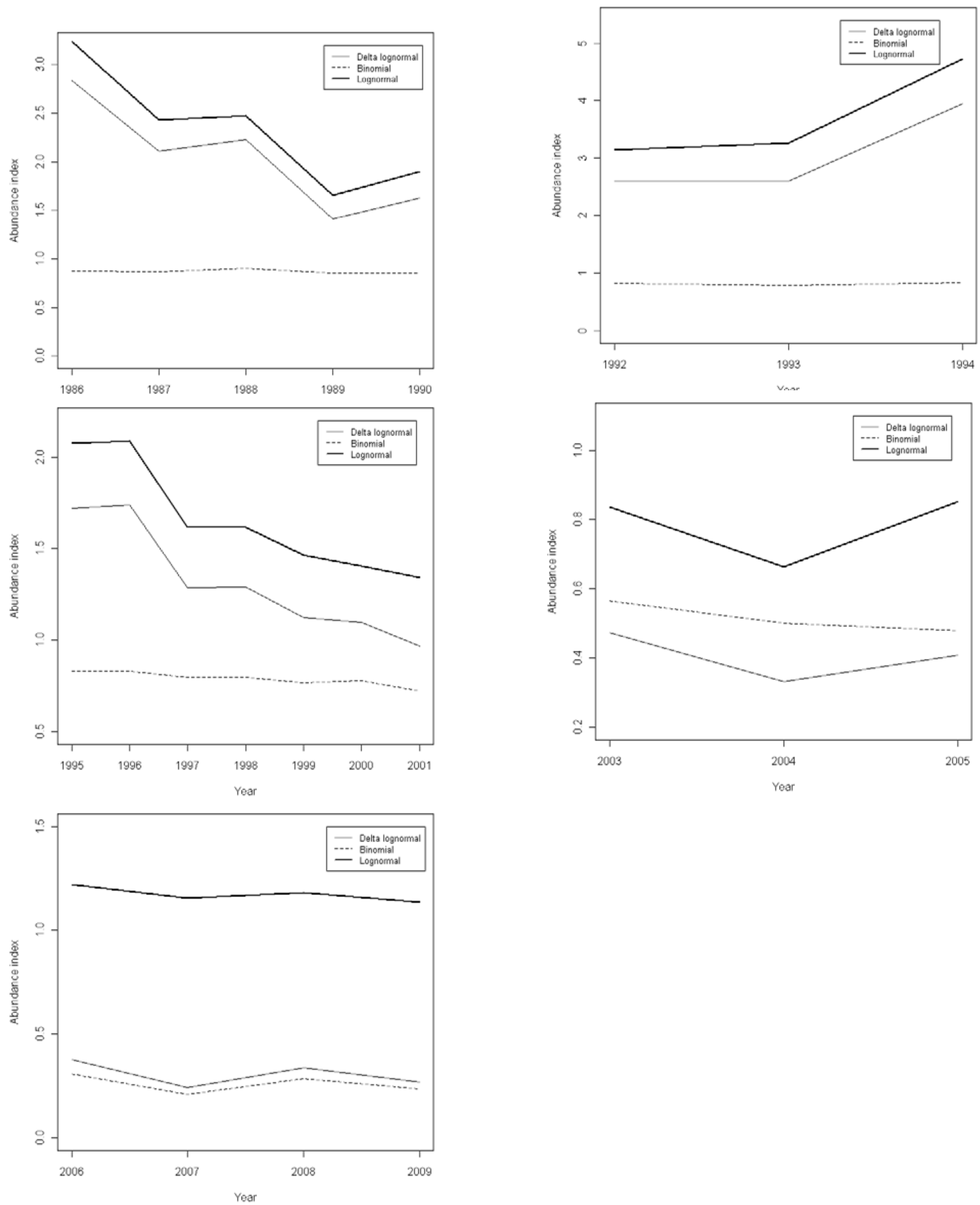

Figure E4 Delta lognormal abundance index (combination of the binomial and lognormal indices), binomial abundance index (models number of positive catches), lognormal abundance index (models positive catches) for the year/area/gear model for 1986-1990 (upper panel left), 1992-1994 (upper panel right), 1995-2001 (middle panel left), 2003-2005 (middle panel right), 2006-2009 (lower panel left).

WinBUGS code for the year/area/gear delta lognormal model with fixed effects and no interactions.

```
model;
{
for( i in 1 : nyear) {
        logit(pcy[i]) <- bo + by[i]
        la.cmu[i]<-ao + ay[i]
        a.cmu[i] <-exp(la.cmu[i])
        predccpue[i]<-pcy[i]*a.cmu[i]
for(j in 1:narea) {
for (k in 1:ngear) {
        logit(py[i,j,k]) <- bo + by[i] + ba[j] + bg[k]
        la.mu[i,j,k]<-ao + ay[i] + aa[j] + ag[k]
        a.mu[i,j,k] <-exp(la.mu[i,j,k])
        predcpue[i,j,k]<-py[i,j,k]*a.mu[i,j,k]
        }
        }
        }
##data##
for (i in 1: npres) {
        pres[i] ~ dbin(py[y[i],a[i],g[i]],ysets[i])
        }
for (j in 1: ncpue) {
         cpue_hr[j] ~ dlnorm(la.mu[yr[j],area[j],gear[j]],a.tau)
        }
##priors##
  bo ~ dnorm( 0.0,1.0E-6)
  by[1]<-0
  ba[1]<-0
  bg[1]<-0
  ao ~ dnorm( 0.0,1.0E-6)
  ay[1]<-0
  aa[1]<-0
  ag[1]<-0
for (nyr in 2:nyear) {
  by[nyr] ~ dnorm( 0.0,1.0E-6)
  ay[nyr] ~ dnorm( 0.0,1.0E-6)
        }
for (na in 2:narea) {
  ba[na] ~ dnorm( 0.0,1.0E-6)
  aa[na] ~ dnorm( 0.0,1.0E-6)
        }
for (ng in 2:ngear) {
  bg[ng] ~ dnorm( 0.0,1.0E-6)
  ag[ng] ~ dnorm( 0.0,1.0E-6)
        }
a.tau~dlnorm(lmu.tau,l.tau)
lmu.tau<-log(0.5)
l.tau<-1/(1.2*1.2)
}
```

APPENDIX F. RECONSTRUCTION OF PINNIPED CONSUMPTION OF YELLOWEYE ROCKFISH FOR THE INSIDE WATERS.

In the Pinniped-Bayesian surplus production model, reconstruction of pinniped consumption of yelloweye rockfish for the inside waters is based on determining trends in abundance of harbour seals and Steller and California sea lions, and applying diet and bioenergetics studies to estimate a consumption rate. Existing census data was used together with temporal/spatial extrapolations to estimate population trends for each pinniped species for inside waters. All abundance data are derived from published DFO assessments and unpublished data.

PINNIPED ABUNDANCE TRENDS

Harbour seals in the Strait of Georgia and northern inside waters areas of the DU

As outlined in Olesiuk (2010), harbour seal assessments in BC are based on aerial surveys of animals hauled out at low tide at the end of the pupping season. Corrections are applied to account for animals at sea and missed during surveys. As of 2008 baseline surveys had covered 82% of BC coastline and abundance of seals in unsurveyed areas was extrapolated based on the densities observed in surveyed areas. Total abundance of harbour seals in the inside DU area was estimated at 59,851 animals (95% CI 51,933 to 67,930 animals) in 2008 (see Tables 5 and 6 in Olesiuk 2010).

Recent trends in harbour seal abundance have been determined from standardized surveys conducted since the early 1970s. The most complete time-series is available for the Strait of Georgia, where seal densities are highest. Less extensive time-series are also available for select (index) areas outside the Strait of Georgia. In both cases, seal populations increased rapidly during the 1970s and 1980s, subsequently slowed during the 1990s, and have been relatively stable over the last decade. Trends can be described by generalized logistic equations (see Figure 16 in Olesiuk 2010). Overall abundance of seals in the inside DU area during 1970-2008 was derived by weighting the logistic equations by the relative proportion of seals within and outside of the Strait of Georgia (63% and 37% respectively). It was estimated that seal abundance in the inside DU area increased from a low of about 4,907 in 1970 to a peak of 59,851 in 2008 (Table F1). In stock assessment model projections, we assume that seal abundance in inside DU waters remains at 2008 levels.

Surveys were not conducted prior to the early 1970s, but harbour seal populations in BC have been reconstructed back to the 1880s based on harvest levels. The reconstruction indicates that abundance was probably near current levels in the 1880s, which was prior to any large-scale commercial kills. Intensive harvesting from 1890 to 1910 depleted populations by 1913. The population recovered somewhat by the 1930s, but control between prevented full recovery. A second period of intensive commercial harvesting in the 1960s reduced populations to very low levels until they were protected in 1970. Since the predator control programs and harvests were conducted province-wide, we assumed that trends in the inside DU area mirrored those for the total BC population (see Table F2). The total B.C. abundance has been a little less than double the DU inside waters abundance.

Table F1. Estimated harbour seal abundance in B.C. and the inside waters designatable unit (DU) for yelloweye rockfish from 1971 to 2008 (Olesiuk 2010). Abundance was estimated by fitting generalized logistic models to the survey counts adjusted for the proportion of animals hauled out during surveys. Lower and upper limits are listed based on 95% confidence intervals.

	Total Abundance in B.C.			**Abundance in Yelloweye DU Area**		
Year	**Lower Limit**	**Best Estimate**	**Upper Limit**	**Lower Limit**	**Best Estimate**	**Upper Limit**
1971	8,792	10,132	11,500	4,734	5,456	6,193
1972	9,752	11,239	12,756	5,261	6,064	6,882
1973	10,808	12,456	14,137	5,844	6,735	7,644
1974	11,968	13,792	15,654	6,488	7,477	8,486
1975	13,237	15,255	17,315	7,197	8,295	9,414
1976	14,624	16,854	19,129	7,979	9,195	10,436
1977	16,135	18,595	21,105	8,838	10,185	11,560
1978	17,774	20,484	23,249	9,780	11,271	12,793
1979	19,547	22,527	25,568	10,812	12,460	14,143
1980	21,456	24,728	28,066	11,940	13,760	15,618
1981	23,504	27,087	30,744	13,169	15,177	17,226
1982	25,689	29,605	33,602	14,506	16,718	18,975
1983	28,010	32,280	36,638	15,958	18,391	20,874
1984	30,463	35,107	39,846	17,530	20,203	22,930
1985	33,042	38,079	43,220	19,230	22,161	25,153
1986	36,944	42,576	48,323	21,596	24,889	28,249
1987	41,165	47,440	53,845	24,205	27,895	31,660
1988	45,702	52,670	59,780	27,067	31,193	35,404
1989	50,542	58,247	66,110	30,188	34,790	39,486
1990	55,645	64,128	72,785	33,550	38,664	43,884
1991	60,913	70,200	79,676	37,081	42,734	48,503
1992	66,124	76,205	86,493	40,590	46,778	53,093
1993	70,856	81,658	92,682	43,692	50,353	57,151
1994	74,597	85,969	97,575	45,916	52,916	60,060
1995	77,246	89,022	101,040	47,181	54,374	61,714
1996	79,275	91,361	103,695	47,947	55,257	62,716
1997	81,041	93,396	106,005	48,560	55,963	63,518
1998	82,627	95,224	108,079	49,104	56,590	64,229
1999	84,045	96,858	109,934	49,589	57,149	64,864
2000	85,303	98,307	111,579	50,019	57,645	65,427
2001	86,409	99,582	113,025	50,397	58,080	65,921
2002	87,373	100,693	114,287	50,727	58,461	66,353
2003	88,209	101,657	115,380	51,013	58,790	66,727
2004	88,929	102,487	116,322	51,259	59,074	67,049
2005	89,547	103,198	117,130	51,470	59,317	67,325
2006	90,073	103,805	117,818	51,651	59,525	67,561
2007	90,521	104,321	118,404	51,804	59,701	67,761
2008	90,900	104,758	118,900	51,933	59,851	67,930

Table F2. Estimated historic reconstruction of harbour seal abundance in BC and the inside waters designatable unit (DU) for yelloweye rockfish from 1913 to 1970 (Olesiuk 2010). See text for details. This table gives only the best estimates for B.C. and DU waters for years prior to 1971, and no lower and upper bounds as in Table F1 mainly to economize on space. The intervals for these earlier years were at similar relative levels as for later years.

Year	B.C.	DU Area	Year	B.C.	DU Area
1913	19,874	11,447	1942	34,894	20,098
1914	17,833	10,272	1943	36,901	21,254
1915	14,241	8,203	1944	39,426	22,709
1916	14,593	8,405	1945	42,311	24,370
1917	14,924	8,596	1946	43,781	25,217
1918	15,356	8,845	1947	45,470	26,189
1919	17,122	9,862	1948	45,995	26,492
1920	19,091	10,996	1949	46,492	26,778
1921	21,286	12,261	1950	46,743	26,923
1922	23,734	13,671	1951	47,698	27,473
1923	26,464	15,243	1952	47,969	27,629
1924	29,507	16,996	1953	47,185	27,178
1925	32,901	18,950	1954	46,659	26,874
1926	36,684	21,129	1955	44,208	25,463
1927	40,903	23,559	1956	42,198	24,305
1928	44,633	25,708	1957	40,948	23,585
1929	44,940	25,884	1958	38,405	22,120
1930	41,455	23,877	1959	36,033	20,754
1931	37,943	21,854	1960	34,083	19,631
1932	32,161	18,524	1961	32,693	18,831
1933	28,457	16,391	1962	32,127	18,505
1934	31,131	17,931	1963	31,815	18,325
1935	34,711	19,993	1964	26,602	15,322
1936	38,703	22,292	1965	15,296	8,810
1937	39,835	22,944	1966	10,990	6,330
1938	37,043	21,336	1967	7,802	4,494
1939	33,459	19,272	1968	8,347	4,808
1940	31,218	17,981	1969	8,698	5,010
1941	34,808	20,049	1970	9,128	4,907

Steller sea lions

Assessments of the status of Steller sea lion populations in BC waters are based on surveys conducted during the summer breeding season. Province-wide aerial surveys of animals on rookeries and year-round haulout sites have been conducted regularly since 1971, and counts for rookeries from boats date back to 1913 (Bigg 1985; Olesiuk 2009). The aerial surveys indicate that rookery counts provide a good index of total counts (R^2=0.987; Olesiuk 2009. We thus used the rookery counts as an index of long-term changes in Steller sea lion abundance in BC during 1913-2010. While these counts provide an index of relative change in abundance, they underestimate absolute abundance as some non-pups are at sea and missed during surveys. Absolute abundance was estimated from pup production and applying corrections to account for non-pups missed during surveys. Abundance of Steller sea lions in BC waters during the most recent survey in 2010 was estimated at 31,900 animals (95% CI 27,200 to 36,700 animals) (Olesiuk 2009; unpublished data). Abundance in prior years was estimated by scaling the 2010 estimate (and its confidence limits) to the relative changes in abundance indicated by rookery counts during 1913-2010 (Tables F4 and F5).

Steller sea lions do not breed in the inside *DU area for yelloweye rockfish* and inhabit the areas mainly during the non-breeding season when animals disperse from rookeries. Olesiuk (2009; unpublished data) recently conducted a series of aerial surveys in southern BC and Washington during spring, summer, fall and winter of 2008-2010 to document seasonal changes in sea lion abundance and distribution. They also developed and applied seasonal correction factors based on satellite telemetry to account for animals at sea and missed during surveys. The average abundance of Steller sea lion in the inside DU area in 2009 was estimated at 1,335 animals, ranging from a low of 16 animals during the summer breeding season to a peak of 2,535 during winter when animals are most widely distributed.

Winter sea lion surveys have been conducted off southern Vancouver Island periodically since the early 1970s (Bigg 1985; Olesiuk 2009; unpublished data). These surveys indicated an exponential increase in abundance (R^2=0.40; $F_{1,21}$=14.0; P=0.001) paralleling the recent increases in coast-wide breeding populations (Olesiuk unpublished data). The winter counts of Steller sea lions in the southern portion of the inside DU represented a fairly constant proportion of the total estimated abundance in BC (R^2=0.0003; $F_{1,21}$=0.007; P=0.93). We thus assumed that a constant proportion of the BC Steller sea lion population wintered in the inside DU area. The winter surveys off southern Vancouver Island indicated that that an average of 4.8% (CV=0.096) of the total BC population occurred in the southern portion of the inside DU during 1971-2009 (Table F3). The more extensive surveys conducted in 2008-2010 indicated that an additional 1.0% of the total BC population occurred in the northern portion of the inside DU (Table F3). Steller sea lion abundance (averaged over the year) for the inside DU waters during 1913-2010 are shown in Tables F4 and F5. Average annual abundance of Steller sea lions in the inside DU decreased from about 1,897 animals in 1913 to a low of 478 animals in 1973 as breeding populations were reduced by predator control. Abundance subsequently increased after populations were protected in 1970 to about 1,837 animals in 2010 (Table F4). Although the most recent survey in 2010 indicated that Steller sea lion abundance in B.C. waters was still increasing, we were hesitant to extrapolate beyond recent observations and capped the abundance after 2010 at the estimated 2010 level.

Table F3 Proportion of B.C. population of Steller sea lions wintering in the yelloweye rockfish DU Area (Olesiuk 2009; unpublished data).

	Southern Portion	Total
Mean	0.048	0.058
Lower 95% CI	0.040	0.048
Upper 95% CI	0.058	0.069

Table F4. Steller sea lion abundance supported by rookeries in B.C and estimated abundance in inside DU waters from 1971-2010. Best estimates and lower and upper limits (Olesiuk 2009, unpublished data). Bold values denote estimates based on aerial survey counts, and non-bold values are interpolated between surveys.

	Total Abundance supported by B.C. rookeries			Abundance in Yelloweye DU Area		
Year	Lower Limit	Best Estimate	Upper Limit	Lower Limit	Best Estimate	Upper Limit
1971	**7,173**	**8,413**	**9,679**	312	484	657
1972	7,125	8,356	9,614	309	481	653
1973	**7,077**	**8,300**	**9,548**	307	478	649
1974	7,448	8,735	10,050	323	503	683
1975	7,820	9,171	10,551	340	528	717
1976	8,191	9,607	11,052	356	553	751
1977	**8,563**	**10,042**	**11,553**	372	578	785
1978	8,537	10,012	11,519	371	577	782
1979	8,512	9,982	11,485	370	575	780
1980	8,486	9,953	11,450	369	573	778
1981	8,461	9,923	11,416	367	571	775
1982	**8,435**	**9,893**	**11,381**	366	570	773
1983	8,751	10,263	11,808	380	591	802
1984	9,067	10,634	12,234	394	612	831
1985	9,384	11,005	12,661	407	634	860
1986	9,700	11,376	13,087	421	655	889
1987	**10,016**	**11,746**	**13,514**	435	676	918
1988	10,333	12,119	13,942	449	698	947
1989	10,651	12,491	14,370	462	719	976
1990	10,968	12,863	14,799	476	741	1,005
1991	11,285	13,235	15,227	490	762	1,034
1992	**11,603**	**13,607**	**15,655**	504	784	1,063
1993	10,806	12,673	14,580	469	730	990
1994	**10,009**	**11,738**	**13,504**	435	676	917
1995	10,960	12,854	14,788	476	740	1,005
1996	11,912	13,970	16,073	517	805	1,092
1997	12,864	15,087	17,357	559	869	1,179
1998	**13,816**	**16,203**	**18,641**	600	933	1,266
1999	15,065	17,668	20,326	654	1,017	1,381
2000	16,314	19,133	22,011	708	1,102	1,495
2001	17,563	20,597	23,697	763	1,186	1,610
2002	**18,812**	**22,062**	**25,382**	817	1,271	1,724
2003	19,874	23,309	26,816	863	1,342	1,822
2004	20,937	24,555	28,249	909	1,414	1,919
2005	22,000	25,801	29,683	955	1,486	2,016
2006	**23,062**	**27,047**	**31,117**	1,001	1,558	2,114
2007	22,388	26,257	30,207	972	1,512	2,052
2008	**21,714**	**25,466**	**29,298**	943	1,467	1,990
2009	24,457	28,683	32,999	**858**	**1,335**	**1,812**
2010	**27,200**	**31,900**	**36,700**	1,181	1,837	2,493

Table F5. Steller sea lion abundance in B.C., and inside waters from 1913-1970 (Olesiuk 2009, unpublished data). Bold values denote estimates based on boat survey counts, and non-bold values are interpolated between surveys. This table gives only the best estimates for B.C. and DU waters for years prior to 1971, and no lower and upper bounds as in Table F4 mainly to economize on space. The intervals for these earlier years were at similar relative levels as for later years.

Year	Total B.C. abundance	Total Inside	Year	Total B.C. abundance	Total Inside
1913	**32,944**	1,897	1942	26,904	1,549
1914	32,757	1,886	1943	26,562	1,530
1915	32,570	1,876	1944	26,220	1,510
1916	32,383	1,865	1945	25,879	1,490
1917	32,196	1,854	1946	25,537	1,471
1918	32,010	1,843	1947	25,195	1,451
1919	31,823	1,833	1948	24,854	1,431
1920	31,636	1,822	1949	24,512	1,412
1921	31,449	1,811	1950	24,170	1,392
1922	31,262	1,800	1951	23,828	1,372
1923	31,075	1,790	1952	23,487	1,353
1924	30,888	1,779	1953	23,145	1,333
1925	30,701	1,768	1954	22,803	1,313
1926	30,514	1,757	1955	22,461	1,294
1927	30,327	1,747	1956	**22,120**	1,274
1928	30,140	1,736	1957	19,839	1,143
1929	29,953	1,725	1958	17,558	1,011
1930	29,766	1,714	1959	15,278	880
1931	29,579	1,703	1960	12,997	748
1932	29,392	1,693	1961	**10,716**	617
1933	29,206	1,682	1962	10,486	604
1934	29,019	1,671	1963	10,256	591
1935	28,832	1,660	1964	10,025	577
1936	28,645	1,650	1965	9,795	564
1937	28,458	1,639	1966	9,565	551
1938	**28,271**	1,628	1967	9,334	538
1939	27,929	1,608	1968	9,104	524
1940	27,587	1,589	1969	8,874	511
1941	27,246	1,569	1970	8,643	498

<u>California sea lions</u>

There is little evidence that California sea lions occurred in B.C. waters prior to the 1960s, but the species began to appear on a regular basis at Race Rocks off the southern tip of Vancouver Island in the mid 1960s, and expanded its range to many sites off southern Vancouver Island during the 1970s and 1980s (Bigg 1985). The animals are mainly adult and subadult males that have dispersed from breeding sites off California (Mate 1973). The main period of occupancy in BC extends from September-October through to April-May (Olesiuk and Bigg 1988; Olesiuk 2009; unpublished data; Olesiuk unpublished manuscript). Winter surveys off southern Vancouver Island indicate that numbers counted increased rapidly from several hundred in the early 1970s to a peak count of about 4,500 animals in 1984 (Bigg 1985), but have subsequently fluctuated between about 1,000 and 3,000 animals (Olesiuk and Bigg 1988; Olesiuk 2009; unpublished data; unpublished manuscript). The number of California sea lions counted in the Strait of Georgia (southern portion of the inside DU area) increased from 10 in 1972 to 697 in 1982, but have since shown no consistent trend (R^2=0.002; $F_{1,17}$=0.04; P=0.84), averaging about 1,451 animals. The more extensive winter surveys conducted in 2008-2010 indicate that small numbers of California sea lions also occur in the northern portion of the inside DU area, but represent less than 1% of the total DU count. We estimated overall trends of California sea lions in the inside DU area by interpolating between survey counts from 1972 to 1982 and adopting the average count for 1982 to 2010, and applying a small adjustment (1.004) to account for animals not counted in the unsurveyed northern portion of the DU area.

The California sea lion counts provide an index of changes in relative abundance, but underestimate absolute abundance as some animals will be at sea and missed during surveys. Survey correction factors to account for missed animals have not been derived for California sea lions. Following Olesiuk (unpublished manuscript), we derived very crude corrections by assuming that the haulout behaviour of California sea lions was the same as Steller sea lions, as the two species often intermingle and forage on the same prey. Based on satellite telemetry, it was estimated that about 36% (range 30-42%) of subadult and adult Steller sea lion were ashore and counted during daylight hours outside the breeding season, which corresponded with survey correction factor of 2.78 (range 2.39 to 3.31)(Table F6). Finally, based on a series of months surveys off southern Vancouver Island during 1985-1986, it was estimated that mean residency was about 8 months (Olesiuk 2009; unpublished data), so we assumed that average abundance over the year was 67% (i.e. 8/12 months) of abundance during winter surveys. (Table F7).

Table F6. Survey correction factors to adjust California sea lion counts by the fraction of time hauled out for population abundance estimation (unpublished DFO data).

Lower Limit	Best Estimate	Upper Limit
2.39	2.78	3.31

Table F7. Approximations of California sea lion abundance in inside waters since 1971 (unpublished DFO data).

Year	**Lower Limit**	**Best Estimat e**	**Upper Limit**
1971	**0**	**0**	**0**
1972	**14**	**19**	**23**
1973	14	18	22
1974	13	17	21
1975	12	16	20
1976	**11**	**15**	**19**
1977	**55**	**73**	**90**
1978	**125**	**164**	**204**
1979	610	798	993
1980	1,094	1,432	1,782
1981	1,579	2,067	2,571
1982	**2,064**	**2,701**	**3,360**
1983	2,064	2,701	3,360
1984	**2,064**	**2,701**	**3,360**
1985	**2,064**	**2,701**	**3,360**
1986	**2,064**	**2,701**	**3,360**
1987	**2,064**	**2,701**	**3,360**
1988	**2,064**	**2,701**	**3,360**
1989	**2,064**	**2,701**	**3,360**
1990	**2,064**	**2,701**	**3,360**
1991	**2,064**	**2,701**	**3,360**
1992	**2,064**	**2,701**	**3,360**
1993	2,064	2,701	3,360
1994	**2,064**	**2,701**	**3,360**
1995	2,064	2,701	3,360
1996	2,064	2,701	3,360
1997	**2,064**	**2,701**	**3,360**
1998	**2,064**	**2,701**	**3,360**
1999	**2,064**	**2,701**	**3,360**
2000	**2,064**	**2,701**	**3,360**
2001	2,064	2,701	3,360
2002	**2,064**	**2,701**	**3,360**
2003	**2,064**	**2,701**	**3,360**
2004	**2,064**	**2,701**	**3,360**
2005	2,064	2,701	3,360
2006	2,064	2,701	3,360
2007	2,064	2,701	3,360
2008	2,064	2,701	3,360
2009	**2,064**	**2,701**	**3,360**

Pinniped consumption of yelloweye rockfish

Consumption of yelloweye rockfish by harbour seals

Olesiuk (1993) estimated that the average bioenergetic requirement for harbour seals in the Strait of Georgia was about 1.9 kg per day (694 kg per animal per year). From analysis of 2,841 harbour seal scats in the Strait of Georgia collected during 1982 to 1989, about 1.1% of their diet was composed of rockfish, all species combined (Olesiuk et al. 1990). In the same study, 49 scat samples collected in Johnstone Strait in northern inside waters, the (split sample) average fraction of rockfish in the harbour seals' diet was about 1.7% (Olesiuk et al. 1990). We applied a weighted mean of these two estimates, weighting by the relative abundance of harbour seals in the Strait of Georgia and northern inside waters, to obtain a value of 1.3% for the inside DU area.

Consumption of yelloweye rockfish by Steller sea lions

Winship and Trites (2003) suggest that the average adult/ subadult Steller sea lion in southeast Alaska consumes about 6.1 tons per year. A bioenergetics model for Steller sea lions in B.C., which accounted for the age and sex composition and activity budgets for this increasing population, indicated that daily consumption of Steller sea lions in inside waters of 17.9 kg/ day, representing an annual equivalent of 6.5 tons per animal per year (Olesiuk unpublished manuscript). Diet estimates compiled from about 1,194 scat samples collected in the southern portion of the inside DU area between 1979-2008 indicated that rockfish comprised about 0.2% of the diet (Olesiuk and Bigg 1988, Olesiuk 2009; unpublished data, unpublished manuscript). In contrast, 111 scat samples of Steller sea lions collected from a major winter haul out for sea lions in the Strait of Georgia (Norris Rocks near to Denman Island) in February and March 2005 indicated that rockfish comprised 5.6% of the diet at that site during late winter (Tollit et al. 2009; Trites unpublished data). Weighting the mean of these estimates by the number of samples gives an overall estimate of rockfish comprising 0.67% of the diet. Since the two species of sea lion intermingle and utilize many of the same haul out sites from which scats were collected, we've applied the combined estimate for the fraction of rockfish in the winter diet of sea lions to both Steller and California sea lions in the inside waters DU.

Consumption of yelloweye rockfish by California sea lions

As outlined above, we've assumed that the fraction of rockfish in the diet of California sea lions in inside B.C. waters is the same as our estimates for Steller sea lions in the Strait of Georgia. Bioenergetics models have not been developed for California sea lions, but crude estimates of their requirements have been made by scaling the Steller sea lion requirements to California sea lions based on the age and size composition of animals wintering in the Pacific Northwest (Olesiuk unpublished manuscript). An estimated daily consumption of California sea lions in inside waters is 14.1 kg/ day, which gives an annual equivalent of 5.1 tonnes per animal per year (or 3.4 tonnes per animal per year when amortized over the 8 months of the year animals are present in the area) (Olesiuk 2009; unpublished data, unpublished manuscript).

Species and size composition of rockfish consumed by pinnipeds

There have been no studies to our knowledge to estimate the species composition of rockfish consumed by pinnipeds in the inside DU waters. In most cases the rockfish bone fragments recovered from scat samples cannot be visually identified to species. The only rockfish in sea lion scat in the DU waters that have been identified to species using genetic analyses came from the samples at collected at Norris Rocks. One was identified as a quillback rockfish and the other was a yelloweye rockfish (Tollit et al. 2009). Given the lack of information on rockfish species composition in pinniped diets, we've assumed that the fraction of yelloweye rockfish in pinnipeds' diets is the same as their mean percentage of their occurrence in abundance surveys with 50% weighting to pelagic and benthic survey sample estimates (Table F8). Fisheries and Oceans Canada jig surveys in Area 12 in 1988 (northern inside waters) covers depths of 5-100 m and 19% of rockfish biomass was from yelloweye. A Fisheries and Oceans dogfish longline survey covers depths of 56-280m and in 1986 and 1989 in the Strait of Georgia 51% of the rockfish biomass was yelloweye. A Fisheries and Oceans rockfish longline survey in 2004 and 2005 in Area 12 - 20, 28/29 covers depths of 41-100 m and 54% of the rockfish biomass was yelloweye. The jig survey covers shallower depths than the longline surveys. Given that both surveys are within the foraging depth ranges of pinnipeds, we've weighted the yelloweye frequencies equally between the longline and jig surveys. Given that the fraction of yelloweye in the longline surveys is similar between the two surveys and the survey periods, we've taken the average value from the longline survey estimates. The fraction of rockfish biomass that is yelloweye in the benthic zone was thus estimated at 36%. Midwater trawl survey data from the Strait of Georgia from 1983-2009 provides an average estimate of 15% of the rockfish biomass in midwater tows consisting of yelloweye rockfish. We've taken the average of the benthic and midwater yelloweye rockfish species percentages to formulate an estimate of the fraction of rockfish biomass that is on average consists of yelloweye (about 25%). Table F9 provides a summary of a computation of the average mass of prey, rockfish, and yelloweye rockfish predicted to be eaten in years in which diet information was collected for harbour seals and Steller sea lions.

There is little information on the size of rockfish consumed by pinnipeds. The PBSP model accounts for the population components of yelloweye rockfish considered to be exploitable by recreational, commercial and aboriginal fisheries in DU waters. The recreational and aboriginal fisheries in DU waters that have taken yelloweye rockfish tend to fish in the shallower portion of the depth range of yelloweye rockfish (15-549m (Yamanaka et al. 2006)) with effort tending to focus on species found in relatively shallow water, e.g., about 5-70 m. With surveys indicating that the largest oldest individuals tend to be found in the deepest part of the depth range for this species (Yamanaka et al. 2006), these fisheries are thus likely to capture a mixture of immature and mature individuals and capture a wide range of fish sizes. Commercial fisheries that take rockfish in inside waters tend to cover a wider range of depths (i.e., 19-251m (Yamanaka et al. (2006)) than the recreational and aboriginal fisheries. The commercial fisheries that take rockfish thus likely also take a mixture immature and mature individuals, but may capture on average slightly older, larger fish, than the recreational fisheries. Discarded smaller yelloweye rockfish from each of these fisheries are likely to perish, due to gas bladder expansion after being pulled up from even relatively moderate depths, e.g., over 10 m. In contrast, pinnipeds could conceivably be less selective in the size range of individuals eaten than the size range killed by recreational and commercial fishing gear. It is conceivable that pinnipeds may take on average smaller rockfish than the different fisheries. Indeed, pinnipeds may avoid the largest rockfish as the spines could be hazardous when ingested. Lance and Jeffries (2006) noted that harbour seals in the San Juan Islands preyed mainly on juvenile and sub-adult rockfish, though some larger, older specimens were also found to be eaten. Spalding (1964) suggested the typical size range of rockfish consumed by Steller sea lions was 200-350 mm (12-14”), which represents yelloweye rockfish aged up to about 10 years, which would be juvenile and sub-adults. Thus, pinnipeds may thus be consuming on average smaller sized yelloweye rockfish than those killed in the commercial fisheries and may be more similar to recreational fisheries whose catches of yelloweye rockfish have recently been approaching that of the commercial fishery. The potential decreases in size and age composition in the total mortality from an increase in the fraction of the stock biomass killed by recreational fleets and pinnipeds could to some extent cause biases in PBSP model projections.

Table F8. Fraction of rockfish biomass in surveys in inside waters that is yelloweye rockfish.

DFO research Survey	Area	Years	Depth range	% of rockfish biomass that is yelloweye
Jig	12	1988	5-100m	19%
Rockfish longline	12-20, 28, 29	2004, 2005	41-100m	54%
Dogfish longline	Strait of Georgia	1986, 1989	56-280m	51%
Average				36%
Midwater trawl	Strait of Georgia	1983 - 2009	15 – 600 m	15%
Average of benthic and midwater trawl				25%
CV*				0.32

*The CV was computed presuming the lognormal percentile of 2.5% was the midwater trawl estimate and the percentile of 97.5% as at the average of the two highest benthic estimates.

Table F9. Summary of annual consumption of rockfish and yelloweye rockfish by pinnipeds in B.C. inside waters based on bioenergetics and diet studies and estimates of abundance of each pinniped species. a. reference case. b. standard deviations in the natural logarithm of variables determining consumption of yelloweye rockfish by pinnipeds and lower and upper bound multipliers for reference case consumption estimates. c. 2.5% and 97.5% bounds based on estimates of the uncertainty variance in the contributing variables.

a. Reference case inputs to variables determining consumption of yelloweye rockfish

	Reference Years	Average abundance	Average (tonnes/ yr)	Total eaten (tonnes)	% rockfish in diet	rockfish eaten/ yr (tonnes)	yelloweye rockfish eaten/ yr (tonnes)
harbour seals	1988[1]	31193	0.69	21632	1.30%	286	72
Steller sea lions	1979-2008	909	6.5	5939	0.67%	40	10
California sea lions	1979-2008	2574	5.1	13247	0.67%	93	23

b. Standard deviations in the natural logarithm of variables determining consumption

	Variables						
	fraction rockfish in diet	fraction of rockfish that are yelloweye	bioenergetic requirements	pinniped abundance	total sigma	lower multiplier	upper multiplier
harbour seals	0.457	0.32	0.125	0.080	0.577	0.323	3.10
Steller sea lions	0.768	0.32	0.179	0.177	0.869	0.182	5.49
California sea lions	0.768	0.32	0.179	0.119	0.859	0.186	5.39

c. 95% Uncertainty bounds in pinniped abundance and biomass of yelloweye rockfish eaten

	Reference Years	Average Abundance	yelloweye rockfish eaten (tonnes)
harbour seals	1988	27067, 35404	23.4, 224.6
Steller sea lions	1979-2008	584, 1234	1.8, 55.6
California sea lions	1979-2008	1967, 3202	4.2, 121.6

[1] Note that the actual range in Olesiuk (1993) was 1982-1988. A sensitivity run was applied using modified inputs for harbour seals based on these reference years and found to produce practically identical results as the reference case run that used 1988 as the reference year for harbour seals (see Table 22, run H.1).

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APPENDIX G. APPROACH USED TO COMPUTE THE PRIOR PROBABILITY DISTRIBUTION FOR R.

We applied the demographic approach of Stanley et al. (2009) for computing an informative prior pdf for *r* in the BSP model which extended the original approach in McAllister et al. (2001) to accommodate biological inputs commonly available for teleost fish stocks. Stanley et al. (2009) accounted for uncertainty in the rate of natural mortality and the Beverton-Holt steepness parameter but treated the other biological inputs, e.g., weight at age and the fraction mature-at-age, as constants. We applied a further extension documented in Cuif et al. (2009) that included the joint posterior distribution in all of the inputted biological parameters to account for joint uncertainty in them. We also applied the variant that presumes a Ricker stock-recruit function since yelloweye have been observed to be cannibalistic. The general approach provides an approximation of the maximum expected rate of increase of the population of interest should the population be projected into the future under conditions in which all density dependent sources of natural mortality were absent. We provide an overview of the general approach below and refer readers to Cuif et al. (2009) for a more detailed version of the methodology to generate a prior for r.

The Euler-Lotka equation (Lotka 1907) provides a method to accurately approximate the maximum rate of increase for an age structured population using an integral for population increase that has an identity with 1. This equation is numerically solved for *r* with the integration over ages starting at age 0:

(G1) $$1 = \int_{a=0}^{\infty} l_a m_a \exp(-a \times r) da$$

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

(G2) $$l_a = l_0 \exp\left(-\sum_{i=0}^{a-1} M_i\right)$$

It can be shown that, providing that there is no reproduction in the first year, a computation in which the integration starts at age 1 and l_1 is set to 1 and m_a is specified in terms of age 1 recruits is analytically equivalent to equations Eq. G1. A discretized version of this is:

(G3) $$1 = \sum_{a=1}^{a_{\max}} l_a m_a \exp(-a \times r)$$

(G4) $$l_a = l_1 \exp\left(-\sum_{i=1}^{a-1} M_i\right)$$

where l_1 = 1 and a_{max} = the maximum age considered.

The formulation in equations G3 and G4 are more convenient for fisheries modelling. This is because most exploited fish species do not reproduce in their first year. Also, estimates of the number of age 1 recruits produced per unit of spawning potential (e.g., per ton of spawners) at spawner abundance approaching zero ($\tilde{R}_S$) and the expected mass-at-age of spawners, W_a, are more commonly available. In contrast, the corresponding conventional life table parameters, e.g., the annual survival rate of larval fish to 1-year-old and the expected production of larval fish per spawner, are much more difficult to estimate and estimates of these quantities are typically unavailable for fish populations.

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

(G5) $m_a = \tilde{R}_S W_a G_a$

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

The computation thus requires a value for the rate of natural mortality (*M*) for ages 1 and older (*M*), the fraction mature at age, the number of age 1 recruits produced per ton of spawners, and the mass per fish in tons for each age. A plus group was presumed at age 120 years. The *M* for females was treated as a lognormal random variable with a median of 0.04 yr^{-1} based on an analysis of proportion at age data aggregated from commercial catch and survey data. The value for the standard deviation in the natural logarithm of *M* set at 0.2. This prior density function for *M* was truncated at a minimum of 0.02 and a maximum of 0.08 yr^{-1}. $\tilde{R}_S$ was computed using the posterior predictive distribution for the Ricker steepness parameter that was obtained from an earlier draft of Forrest et al. (2010). In a sensitivity analysis, the Beverton-Holt function was presumed and the posterior predictive distribution from an earlier version of Forrest et al. (2010) was also applied. This was approximated by a lognormal density function with a median of 0.71 and a SD of 0.17. $\tilde{R}_S$ is a function of steepness and the spawner biomass produced per single age 1 recruit ($\tilde{S}$). In the Ricker model, this is given as:

(G6a) $\tilde{R}_S = \dfrac{(5h)^{5/4}}{\tilde{S}}$

For the Beverton-Holt model, this is given by:

(G6b) $\tilde{R}_S = \dfrac{4h}{\tilde{S}(1-h)}$

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

(G7) $$\tilde{S} = \left(\sum_{a=1}^{a_p - 1} \left(W_a G_a \exp(-a\,M) \right) \right) + W_{a_p} G_{a_p} \frac{\exp(-a_p M)}{1 - \exp(-M)}$$

The mean and standard deviation (SD) for *r* obtained from the Ricker steepness inputs were 0.0465 and SD of 0.0173. The histogram for *r* can be closely approximated by a normal pdf.. The mean and SD for r obtained from the Beverton-Holt steepness inputs were 0.068 and 0.0320. This prior pdf was approximated using a lognormal distribution.

A prior for r is also needed for the PBSP model. This parameter reflects the potential maximum rate of increase in the population in the absence of both fishing and pinniped predation. While we could have focused considerable effort on refining a prior distribution for this parameter, time was simply not available to do so. We thus applied the same prior distribution for r in the BSP model as for that in the PBSP model. It is difficult to predict exactly which direction the prior mean would shift should an effort have been made to account for the absence of pinniped predation in demographic analysis. For example, the possibly lowered average rate of natural mortality could lead to increased generation time, and an even lower prior mean for r for the PBSP model. If our prior was highly inconsistent with the fit of the PBSP model to the data, we'd have expected the BSP prior for r to be updated considerably. However this was not the case and currently there is no empirical basis with which to indicate how the r prior for the PBSP model may be biased without due consideration of the absence of pinniped predation. This is yet another issue that could deserve further attention for further stock assessments that consider the application of a PBPS model.

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