Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

C S A S — S C C S

Canadian Science Advisory Secretariat

Secrétariat canadien de consultation scientifique

Research Document 2011/124

Document de recherche 2011/124

Pacific Region

Région du Pacifique

Lingcod (*Ophiodon elongatus*) stock assessment and yield advice for outside stocks in British Columbia

Évaluation du stock de morues-lingues (*Ophiodon elongatus*) et avis sur le rendement du stock dans les eaux extérieures de la Colombie-Britannique

J.R. King[1]
M. McAllister[2]
K.R. Holt[1]
P.J. Starr[3]

[1]Pacific Biological Station, Science Branch,
Fisheries and Oceans Canada, 3190 Hammond Bay Road,
Nanaimo, British Columbia, V9T 6N7, Canada.

[2]University of British Columbia, Fisheries Centre,
Aquatic Ecosystems Research Laboratory,
Vancouver, British Columbia, V6T 1Z4, Canada.

[3]Canadian Groundfish Research and Conservation Society,
1406 Rose Ann Drive, Nanaimo, British Columbia, V9T 4K8, Canada.

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

Canada

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Correct citation for this publication:
La présente publication doit être citée comme suit :

King, J.R., M. McAllister, K.R. Holt and P.J. Starr. 2012. Lingcod (*Ophiodon elongatus*) stock assessement and yield advice for outside stocks in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/124. viii + 177p.

ABSTRACT

Lingcod (*Ophiodon elongatus*) are unique to the west coast of North America. They are distributed in nearshore waters from California to Alaska, with the centre of abundance off the coast of British Columbia. Lingcod are found on the bottom at depths of 3-400 m, with most individuals occupying rocky areas at depths of 10-100 m. Tagging studies have shown lingcod to be largely non-migratory; however, stock delineation has not been clearly defined in British Columbia. Lingcod populations in British Columbia are assessed and managed as five separate units based on DFO Statistical Areas. These units include one inside stock in the Strait of Georgia (Area 4B) and four outside stocks: southwest Vancouver Island (Area 3C), northwest Vancouver Island (Area 3D), Queen Charlotte Sound (Areas 5A and 5B), and Hecate Strait and the west coast of Haida Gwaii (Areas 5C, 5D, and 5E). This assessment provides advice for the four outside assessment areas only (Area 3C, Area 3D, Area 5AB, and Area 5CDE).

Lingcod are an important component of both the commercial and recreational groundfish fishery off British Columbia. They are exploited primarily by trawl gear, but also by hook and line gear, including handline, longline, and troll. For the 2009-2010 fishing year, a 65 cm size limit was in place for lingcod retained in commercial fisheries. The size limits also applied to recreational fisheries in Areas 3C, 3D and 5A only. A coastwide winter closure (November 16 to March 31) was in effect for the hook and line commercial fishery, and for recreational fisheries conducted in 3C, 3D and 5A. All commercial fisheries are managed with an Individual Vessel Quota system. The total lingcod commercial catch for the outside management areas in 2009 was 2,014 tonnes. The total lingcod recreational catch in 2009 was estimated as 44 tonnes (27, 275 pieces).

We applied a Bayesian surplus production model to assess lingcod stock status within each of the four assessment areas. Data inputs for area-specific models included total annual catch since 1927, three or more abundance indices (with CV's), and prior probability distributions for estimated parameters. Area-specific parameter estimates for intrinsic rate of increase (*r*) and carrying capacity (*K*) were used to calculate management parameters such as maximum sustainable yield (MSY), the optimum fishing mortality rate at MSY (F_{MSY}), and the optimal stock size at MSY (B_{MSY}). The assessment model was projected 5 years into the future under a range of alternative constant harvest policies (e.g., total allowable catch levels) to create decision tables for each assessment area. Sensitivity analyses were used to evaluate the effect of stock assessment assumptions on the results.

Current lingcod stock status is assessed in the context of the DFO *Fishery Decision-making Framework Incorporating the Precautionary Approach*, which requires the definition of three stock status zones (Healthy, Cautious and Critical). Delineation between these zones is based on an Upper Stock Reference (USR) set at 80% of B_{MSY} that delineates the boundary between Healthy and Cautious zones and a Limit Reference Point (LRP) set at 40% of B_{MSY} that delineates the boundary between Cautious and Critical zones. For each assessment area, we present the probability that current biomass levels are within Healthy and Critical zones. In addition, we quantify stock status relative to commonly used management parameters, including: current biomass relative to B_{MSY}, current biomass relative to unfished biomass, and current fishing mortality relative to F_{MSY}. Additional management parameters reported include MSY and the replacement yield for 2010, which is the amount of yield that can be removed without leading to biomass increase or decline in 2011.

Based on the medians of the estimated posterior distributions for current biomass, the lingcod stocks in all four assessment areas are most likely in the Healthy Zone (i.e. current biomass is greater than 80% of B_{MSY}). Considerable uncertainty exists in the stock status estimates for Areas 3C and 5AB. There is high confidence in classifying stocks in both Area 3D Area 5CDE as in the Healthy Zone.

RÉSUMÉ

La morue-lingue (*Ophiodon elongatus*) est unique à la côte ouest de l'Amérique du Nord. Son aire de répartition couvre les eaux littorales depuis la Californie jusqu'en Alaska, le centre de son abondance se trouvant au large de la côte de la Colombie-Britannique. On peut observer la morue-lingue sur le fond, à des profondeurs oscillant entre 300 et 400 m, mais la plupart des individus occupent des zones rocheuses à des profondeurs allant de 10 à 100 m. Des études de marquage ont montré que la morue-lingue était essentiellement non migratoire; toutefois, la délimitation des zones fréquentées par ces stocks en Colombie-Britannique n'est pas clairement établie. Les populations de morues-lingues en Colombie-Britannique sont évaluées et gérées selon cinq unités distinctes fondées sur les zones statistiques du MPO. Ces unités comprennent le stock du détroit de Georgie (zone 4B), qui se trouve dans des eaux intérieures, et quatre stocks des eaux extérieures : sud-ouest de l'île de Vancouver (zone 3C), nord-ouest de l'île de Vancouver (zone 3D), détroit de la Reine-Charlotte (zones 5A et 5B) ainsi que détroit d'Hécate et côte ouest de Haida Gwaii (zones 5C, 5D et 5E). La présente évaluation contient des avis pour les quatre zones des eaux extérieures seulement (zone 3C, zone 3D, zone 5AB et zone 5CDE).

La morue-lingue représente une proportion importante des prises dans les pêches commerciales et sportives au poisson de fond au large de la Colombie-Britannique. L'espèce est principalement exploitée par chalutage, mais également par la pêche à la ligne, y compris la palangrotte, la palangre et la ligne traînante. Pour la saison de pêche 2009-2010, une limite de taille de 65 cm a été imposée pour toutes les morues-lingues retenues dans les pêches commerciales. La limite de taille a également été appliquée aux pêches sportives dans les zones 3C, 3D et 5A seulement. Tout le long de la côte, une fermeture hivernale (du 16 novembre au 31 mars) était en vigueur pour les pêches commerciales à la ligne, de même que pour les pêches sportives dans les zones 3C, 3D et 5A. Toutes les pêches commerciales sont gérées à l'aide d'un système de quota individuel de bateau. En 2009, les prises commerciales totales dans les zones de gestion des eaux extérieures ont été de 2 014 tonnes. Pour la même année, les prises sportives totales ont été estimées à 44 tonnes (27 275 individus).

Nous avons utilisé un modèle bayésien de production excédentaire pour évaluer l'état du stock de morues-lingues dans chacune des quatre zones d'évaluation. Les données d'entrée pour les modèles propres à une zone donnée comprenaient les prises annuelles totales depuis 1927, au moins trois indices de l'abondance relative (avec les coefficients de variation) et la distribution *a priori* des probabilités pour les paramètres estimés. On a utilisé les estimations des paramètres propres à une zone donnée relatifs au taux de croissance intrinsèque (*r*) et à la capacité biotique (*K)* pour calculer les paramètres de gestion comme le rendement maximal soutenu (*RMS*), le taux de mortalité optimal dans les pêches au RMS (F_{RMS}) et la taille optimale du stock au RMS (B_{RMS}). Nous avons effectué une projection sur cinq ans au moyen du modèle d'évaluation selon un éventail de nouvelles politiques concernant les prises constantes (p. ex., niveaux des totaux autorisés des captures) afin de créer des tables de décision pour chaque zone d'évaluation. Des analyses de sensibilité ont été menées pour permettre l'évaluation des effets de différentes hypothèses d'évaluation des stocks sur les résultats.

L'état actuel du stock de morues-lingues est évalué dans le contexte du Cadre décisionnel pour les pêches intégrant l'approche de précaution (MPO, 2009), qui requiert la définition de trois zones d'état des stocks (zone saine, zone de prudence et zone critique). La délimitation de ces zones est fondée sur un point de référence supérieur (PRS), fixé à 80 % de B_{RMS}, qui définit la limite entre la zone saine et la zone de prudence, et un point de référence limite (PRL), fixé à 40 % de B_{RMS}, qui définit la limite entre la zone de prudence et la zone critique. Pour chaque zone d'évaluation, nous présentons la probabilité que les niveaux actuels de la biomasse se situent à l'intérieur des zones saine et critique. De plus, nous quantifions l'état du stock par rapport à des paramètres de gestion utilisés communément, notamment la biomasse actuelle par rapport à B_{RMS}, la biomasse actuelle par rapport à la biomasse non exploitée, et le taux de mortalité dans les pêches par rapport à F_{RMS}. Les

paramètres de gestion additionnels rapportés incluent le RMS et le rendement de remplacement pour 2010, qui représente le rendement qui peut être retiré sans mener à une hausse ou à un déclin de la biomasse en 2011.

Selon les médianes des distributions estimées *a posteriori* pour la biomasse actuelle, les stocks de morues-lingues dans les quatre zones d'évaluation se situent fort vraisemblablement dans la zone saine (c.-à-d., que la biomasse actuelle est supérieure à 80 % de B_{RMS}). Il existe une forte incertitude quant aux estimations de l'état du stock dans les zones 3C et 5AB. Nous avons une grande confiance que le stock des zone 3D et 5CDE se situe dans la zone saine.

INTRODUCTION

The purpose of this assessment is to update management advice for outside lingcod stocks in British Columbia. These outside stocks are assessed and managed as four separate areas based on DFO Statistical Areas: 3C, 3D, 5AB and 5CDE (Figure 1). Outside stocks were last assessed at being at a moderate level of abundance (King and Surry 2000), and currently support commercial and recreational fisheries.

GENERAL BIOLOGY

Lingcod (*Ophiodon elongatus*) are unique to the west coast of North America, with a range extending from Baja, California to the Shumanagin Islands, Alaska. Adults typically inhabit nearshore waters. They can occur at depths ranging up to 450 m; however, they are most often found in rocky habitats between 10 to 100 m, especially during spawning season.

Lingcod are one of the few marine fish species in Canada that exhibit parental care for incubating eggs. Female lingcod deposit eggs masses along rocky crevices or ledges in relatively shallow (< 100 m) nearshore waters each winter (Low and Beamish 1978). While females leave the nest site once the egg mass has been fertilized by one or more males, males will remain within 1 m of the nest for an average of 7 weeks until the eggs have hatched (Low and Beamish 1978. During this time, males display aggressive behaviour towards potential predators that feed on eggs and larvae, and their presence is believed to substantially reduce egg mortality (Low and Beamish 1978). In British Columbia waters, the spawning period extends from December until March, with peak spawning occurring in late January and early February (Cass et al. 1990). Once lingcod larvae hatch in early March to April, they spend between 3 and 9 weeks as planktonic larvae (Phillips and Barraclough 1977, Marko et al. 2007). During this phase, movement is relatively passive with ocean currents affecting dispersion (Marko et al. 2007). Post-larval lingcod settle on flat bottom habitats that contain some structural complexity such as eelgrass or kelp beds (Cass et al. 1990, Petrie and Ryer 2006). By age 2, individuals move into habitats of similar relief and substrate as adults.

Tagging studies in British Columbia have shown that once lingcod reach maturity (approximately age 2 for males and age 4 for females), they tend to stay close to the reef or rocky area to which they first recruited. One study on the outer coast of Vancouver Island found that 95% of fish tagged between 1978 and 1982 stayed within 10 km of the tagging location, and that only a few individuals migrated beyond 50 km (Cass et al. 1990). Concurrent tagging studies in the Strait of Georgia (Area 4B; Figure 1) indicated that it is unlikely that stocks in the Strait of Georgia mix with outside stocks (Cass et al. 1990). Studies on smaller spatial scales have found that males display extremely high site fidelity. Individuals often return to the same spawning grounds in subsequent years; and sometimes even return to the exact same nest site (King and Withler 2005). In comparison, females display lower site fidelity than males and are believed to disperse greater distances.

Lingcod are considered a non-migratory species because they do not move long distances. They do, however, make seasonal migrations each year on and off the spawning grounds (Cass et al. 1990; Martell et al. 2000). Between May and September, both male and female lingcod are captured on nearshore trawling grounds. During the winter, trawl catches of male lingcod drop steeply as individuals begin to aggregate inshore in October. Males disaggregate in April once they have finished guarding the nest. Females spend a shorter amount of time on the spawning grounds, and are more likely to be caught by trawl fisheries in the winter than males (Cass et al. 1990). Biological sampling of winter commercial trawl catches indicated that over 75% of the catch is comprised of females.

Lingcod are well-adapted predators with large mouth gapes that allow them to consume a wide range of prey species. In British Columbia waters, lingcod are believed to feed heavily on Pacific herring and Pacific hake; however, they have also been known to consume flatfish, rockfish, sablefish, cod, salmon, crabs, shrimp, squid, and octopus (Cass et al. 1990). In the San Juan Islands of Washington State, a recent study found that lingcod diet composition was highly variable, with no single species dominating prey composition (Beaudreau and Essington 2007). An important finding of this study with implications for modelling lingcod population dynamics is that lingcod display cannibalism in the wild. For lingcod larger than 30 cm, lingcod made up 4.3% of their diet by weight (A. Beaudreau, pers. comm.) Once past their larval and early juvenile stages, marine mammals such as sea lions and harbour seals are likely the primary predators of lingcod (Cass et al. 1990).

FISHERY AND MANAGEMENT HISTORY

Commercial fishing for lingcod in British Columbia began around 1860 (Cass et al. 1990). Between 1900 and the 1940s, lingcod was ranked fourth in commercial importance after salmon, Pacific herring and Pacific sardines, and was the main source of fresh fish throughout the year (Cass et al. 1990). Prior to the 1940s, the fishery in British Columbia was focussed in the Strait of Georgia and utilized primarily hook and line gear. By the mid- to late-1940s, most areas off the British Columbia coast were being exploited by the trawl fishery, and since the 1960s, trawl landings have dominated over hook and line landings (Figure 2; Appendix B). In the 1930s and 1940s, hook and line landings averaged about 550 tonnes, but had dropped to less than 200 tonnes by the mid-1950s. At the same time, trawl landings gradually increased. By the 1950s, trawl landings averaged over 2,400 tonnes. Coastwide catches rose and peaked at 5,700 t in 1985. Catches remained high in the early 1990s, and then dropped rapidly in the late 1990s. Total coastwide catch has remained stable around 2,400 t since 2000. Catch statistics are provided in Appendix B.

In addition to the Canadian fishery, several foreign fleets captured lingcod in Canadian waters prior to 1982. United States trawlers began fishing lingcod in Canadian waters in the 1940s; however, US trawl catch was not recorded until 1954. During the 1950s and 1960s, the US trawl catch accounted for, on average, 40% of the coastwide lingcod catch, with a maximum proportion of 61% in 1959 (King and Surry, 2000). With the declaration of Canada's 200 mile Canadian Fishing Zone in 1977, US trawl catches in Canadian waters dwindled and had ceased completely by 1982. Foreign fleets from the Soviet Union, Japan and Poland also conducted fisheries within Canadian waters between 1965 and1977. Vessels from the Soviet Union and Japan conducted bottom trawl fisheries, while Polish vessels conducted mid-water trawls. Lingcod catch statistics for these foreign fleets were not recorded; however, total rockfish catches were recorded. Lingcod catch statistics were estimated by applying the ratio of lingcod to rockfish captured in DFO trawl surveys conducted on the *FRV G.B. Reed* over a similar period of years (Westrheim 1967) as per Stanley et al. (2009b). Coastwide, these foreign fleets are estimated to have captured between 11 tonnes (in 1977) and 210 tonnes (in 1966) of lingcod annually (Appendix B).

The commercial lingcod fishery has been subject to a variety of management measures including size limits, seasonal closures, and annual quotas. A coastwide size limit of 58 cm (head-on) on retained lingcod was first introduced to the commercial fishery in 1942. This limit was extended to 65 cm for the whole coast in 1996. Various winter closures have been applied to both commercial and recreational fisheries between the 1920s and the present in order to protect protect spawning fish and nest-guarding males. Prior to 1987, these closures were only in place for the Strait of Georgia stock. In 1987, winter closures were also implemented for all commercial fisheries off the west coast of Vancouver Island. Closures were from January 1 to April 15 in the offshore portions of Areas 3C and 3D and in the west coast Vancouver Island portions of Area 5A, and from November 15 to April 15 in the inshore portions of Areas 3C and 3D. In 1988 the closures were extended to the entire west coast of Vancouver Island and to Area 5A. The winter closure for the trawl fishery was removed in 1996 with the introduction of onboard vessel observers, bycatch limits for halibut, and the requirement that all catches of quota species, including discards, be counted against vessel period limits. In 2000, the winter closure for the hook and line fishery was extended coastwide.

In 1987 the first lingcod quotas was assigned for Area 3C (1,400 tonnes). In 1993, quotas were assigned for 3D (600 tonnes), 5AB (1,650 tonnes), and 5CD (1,000 tonnes). In 1997, the 5CD quota coverage was extended to include 5E. Trends in annual quota levels since 1993 are shown in Appendix B (Figures B-3 to B-6). Total lingcod catch has often remained below TAC levels in most areas since the introduction of quotas (Figures B-3 to B-6). In recent years, this trend is likely a result of the integrated management structure in place for British Columbia groundfish fisheries. In 2006, an extensive pilot plan for the integration of commercial groundfish fisheries was initiated in the Pacific Region. Under integrated management, individual vessel quotas (IVQ) were established for most commercially-valued groundfish species, including lingcod, and strong catch-monitoring systems were established so that mortality from both landed and released at sea catch could be accounted for in IVQ. Due to high uncertainty in annual catches from multi-species assemblages, vessels often reach their quota limit for one species, but still have remaining quota for other species. While additional fishing opportunities for the current year can be obtained through inter-fleet trading of IVQ or borrowing up to a given percentage of next years IVQ (30% for lingcod), limited IVQ availability and strong disincentives for individual vessels to exceed the percent overage cap causes many vessels to under-harvest their IVQ. As a result, total coast-wide catches for many species are more likely to fall below TAC limits under the current management system than they are to exceed them.

For the 2009-2010 fishing year, a 65 cm size limit was in place for all lingcod retained in the commercial fisheries and for recreational fisheries conducted in Areas 3C, 3D and 5A only. A winter closure from November 16 to March 31 was in effect for the hook and line commercial fisheries coastwide, and for recreational fisheries conducted in Areas 3C, 3D and 5A. The commercial sector quota allocations (tonnes) by Area for the 2009-2010 fishing year were:

	TAC (tonnes)	
Area	Trawl	Hook and Line
3C	800	150
3D	220	180
5AB	862	200
5CDE	580	420

PREVIOUS ASSESSMENTS

A quantitative stock assessment model was first applied to Area 3C lingcod in 1997 using a catch-age analysis (Leaman and McFarlane 1997). Interpretation of stock status for the other three outside assessment areas (Areas 3D, 5AB, and 5CDE) relied on interpretation of recent trends in simple catch statistics (e.g., CPUE, catch composition). Results suggested recent declines in biomass for all outside stocks and lead to a more conservative harvest regime. In 2000, King and Surry updated the analysis of catch statistics that had been used by Leaman and McFarlane (1997) for all outside assessment areas. The statistical catch-age assessment model was not updated at this time. The 2000 assessment concluded that there was no new information available that would justify revising the management recommendations from Leaman and McFarlane (1997).

CURRENT ASSESSMENT

In the current assessment, we develop Bayesian surplus production models for the four outside lingcod assessment areas. This assessment is that first time that a Bayesian statistical approach has been applied to lingcod stock assessment in British Columbia. A Bayesian approach is an important advancement because Bayesian assessment frameworks can improve management advice by reducing uncertainty in stock size estimates (McAllister et al. 1994). This reduction in uncertainty can be achieved through the use of informed prior distributions that incorporate existing knowledge and expert judgment about parameter values into the assessment framework (McAllister and Kirkwood 1998).

This assessment also represents the first time that management advice for British Columbia lingcod stocks has been presented in the context of DFO's new *Fishery Decision-making Framework Incorporating the Precautionary Approach* (DFO 2009 ; hereafter referred to as the *PA decision-making framework*). This framework requires the definition of three stock status zones (Healthy, Cautious and Critical) based on two reference points: an Upper Stock Reference (USR) that delineates the boundary between Healthy and Cautious zones and a Limit Reference Point (LRP) that delineates the boundary between Cautious and Critical zones. Within the Healthy zone, the Removal Reference, or the maximum acceptable harvest rate, can be applied. In the Cautious zone, the harvest rate is reduced and should progressively decrease as the stock level approaches the LRP (i.e. enters the Critical zone). Within the Cautious zone, fisheries management actions should promote rebuilding to the Healthy zone. Within the Critical zone, productivity is considered to be sufficiently impaired to cause serious harm due to over-fishing, other human induced mortality, or changes in population dynamics not related to fishing. In the Critical zone harvest levels must be kept in the lowest possible level and fishery management actions must promote stock growth.

Biomass estimates from the surplus production models are linked to USR and LRP reference points when assessing the current status of lingcod stocks. Annex 1B of the *PA Decision-making Framework* outlines default USR and LRP values that can be used for guidance when there is insufficient stock-specific information available to develop reference points (DFO 2009):

- Upper Stock Reference Point: Biomass=80% of B_{MSY}
- Limit Reference Point: Biomass=40% of B_{MSY}

These reference points mean that stocks are assessed as being in the Healthy zone if current biomass estimates are greater than $0.8 \cdot B_{MSY}$, in the Cautious zone if current biomass estimates are between $0.8 \cdot B_{MSY}$ and $0.4 \cdot B_{MSY}$, and in the Critical zone if current biomass estimates are below $0.4 \cdot B_{MSY}$. A target biomass reference point is not directly identified within the PA Decision-making Framework; however, the framework specifies that the reference removal rate should not exceed the fishing mortality at maximum sustainable yield (F_{MSY}), which implies a minimum target biomass of B_{MSY}. We have thus also chosen to include stock status relative to B_{MSY} when presenting results:

- Target Reference Point: Biomass = B_{MSY}

In addition to defining stock status zones, the *PA Decision-making Framework* includes a harvest control rule that recommends a precautionary level of fishery harvest based on current stock status. Annex 1B of the *PA Decision-making Framework* provides guidance on a provisional Removal Reference Rate (i.e. harvest rate or fishing mortality, F_{LIMIT}) to apply within each stock status zone:

- When the stock is in the Healthy zone: $F_{LIMIT} < F_{MSY}$
- When the stock is in the Cautious zone:
  $F_{LIMIT} < F_{MSY} \times [\,(\text{Biomass} - 40\%\ B_{MSY}) / (80\%\ B_{MSY} - 40\%\ B_{MSY})\,]$
- When the stock is in the Critical zone: $F_{LIMIT} = 0$.

Current status is presented relative to LRP, USR, and target reference points, with the probability of current stock status being at or above LRP and USR reference points emphazised. Second, decision tables based on five-year stock projections given a range of constant catch levels use performance measures related to the probability of stock status being at or above LRP, USR, and target reference points in 2016.

METHODS

OVERVIEW

We applied a Bayesian surplus production model that used Sampling Importance Resampling (SIR; Rubin 1987, 1988; McAllister et al. 1994) to assess lingcod stock status within each of the four assessment areas. Required data inputs for the assessment model were catch, at least one abundance index with CV's, and prior probability distributions for estimated parameters. Estimated parameters included carrying capacity (*K*), the intrinsic rate of population growth (*r*), biomass in the first modeled year defined as a ratio of K ($p = B_{1927} / K$), variance parameters for each abundance index, a catchability coefficient (*q*) for each abundance index, and a technological creep parameter (tech) used to describe a linear increase in fishery catchability for catch-per-unit-effort (CPUE) indices over time. Area-specific parameter estimates for *r* and *K* were used to calculate management parameters such as maximum sustainable yield (MSY), the optimum fishing mortality rate at MSY (F_{MSY}), and the optimal stock size at MSY (B_{MSY}). Finally, the assessment model was projected 5 years into the future under a range of alternative constant harvest policies (e.g., total allowable catch levels) to create decision tables for each assessment area. Sensitivity analyses were used to evaluate the effect of stock assessment assumptions on the results.

DATA INPUTS

Three types of data inputs were required for the assessment model, each of which is described in the following three sections: 1) historic records of total catch, 2) one or more indices of relative population abundance, and 3) biological data used to create informative prior distributions for the *r* parameter. We provide a brief overview of these three data inputs here, and then elaborate on them in the referenced appendices.

Catch Data

Catch data were available from 1927 to 2009 for input into area-specific stock assessment models. Both commercial and recreational catch were accounted for.

Commercial catch data were compiled from a variety of sources for each of the four assessment areas (3C, 3D, 5AB, and 5CDE), and included both hook and line and trawl gear. Annual records of trawl fishery catch include records from the Canadian domestic trawl fleet, the U.S. trawl fleet, and foreign fleets (Japan, Poland, and Russia). Annual catch records for all gear-types and fleets are provided in Appendix B.

Recreational catch estimates are available as pieces starting mid-way through the assessment time period (1984 for Area 3C, 1998 for Area 3D, 1993 for Area 5AB, 1992 for Area 5CDE). Missing values between 1927 and the first year of sampling for each area, as well as a period of missing data between 1990 and 1995 for Area 3C, were previously infilled by Cuif et al. (2009). We use these infilled values in the current assessment so that recreational catch is represented from 1927 to 2010 in all areas. A description of the infilling method is provided in Appendix B. Conversion of pieces to tonnes was done using an average weight of 1.6 kg, as per Leaman and McFarlane (1997). The use of this estimate was necessary because biological data collected by creel survey programs are insufficient for estimating the average weight of recreational catch. Recreational catch estimates obtained from the creel program are provided in Appendix B.

Abundance Indices

Fishery-dependent abundance indices were derived from commercial trawl fishery catch rates (catch-per-unit effort; CPUE). Commercial CPUE indices were standardized using a stepwise generalised linear model (GLM) procedure (Appendix C). For each assessment area, separate GLM analyses were performed for three different time periods: (1) series start (1954 – 1966) – 1990, (2) 1991-1995, and (3) 1996-2010 (Table 1). These time periods were chosen to reduce confounding effects of groundfish fishery changes in 1991 and 1996 on annual CPUE indices. Within the surplus production model fit, separate catchability parameters were estimated for each time series. Methods and results for the stepwise GLM procedure for all combinations of assessment area and time period are provided in Appendix C.

Fishery-independent abundance indices were available from a number of research surveys conducted along the British Columbia coast between 1975 and 2010, although the coverage of these surveys tends to be patchy through time (Appendix D). Research surveys used as data inputs included the recent groundfish synoptic surveys, the Hecate Strait multi-species trawl survey, two shrimp trawl surveys, and the US triennial survey. The number of research survey indices input to the assessment model varied among assessment areas (Table 1). Methods used to develop these indices (including a bootstrap analysis of annual variance) and the resulting values are available in Appendix D.

Biological Data

Three types of analysis were used to estimate biological parameters for lingcod stocks in each assessment area: (i) estimation of growth parameters based on length-at-age data, (ii) estimation of a maturity function, and (iii) estimation of a length-weight relationship. The methods and results for these analyses are presented in Appendix E. Parameters estimated from these biological data analyses were used to develop area-specific informative prior distributions for the intrinsic rate of increase, *r*, which was used an input into the surplus production model (Appendix F). A Ricker stock-recruitment function was assumed for the demographic analysis used to develop a prior distribution for *r* because lingcod are known to have cannibalistic behaviour (Cass et al., 1990; A. Beaudreau, University of Washington, School of Fisheries and Aquatic Sciences, pers. comm.), which is better characterized by a Ricker model.

SURPLUS PRODUCTION ASSESSMENT MODEL

Surplus production models (also called biomass dynamic models) are the simplest form of population dynamic model available for conducting a formal fisheries stock assessment. They pool the effects of recruitment, growth, and natural mortality into a single production function that ignores age, sex, and size structure (Hilborn and Walters, 1992). Surplus production is simply defined as the net change in stock biomass that would occur in the absence of fishing, (i.e., the catch that could be taken to keep stock biomass constant; Hilborn and Walters, 1992). A key characteristic of SPMs is that they do not require fish to be aged since recruitment is not explicitly modelled.

SPMs are commonly used in fisheries stock assessment, especially for populations with limited or no catch-age data. In some instances, the estimation performance of simple production model has been found to be as good, or better, than age structured models, even when catch-age data are available (Ludwig and Walters, 1985; Polacheck et al., 1993).

Key assumptions of the Schaefer SPM used in this assessment are:

(1) No large immigration or emigration of individuals to or from the population. This assumption is probably reasonable for a non-migratory species such as lingcod.
(2) The relationship between surplus production and biomass is symmetric, with surplus production being zero at a biomass of zero and at carrying capacity.
(3) The average form of the surplus production function remains stationary over time.

Analyses were conducted using a previously developed Bayesian Surplus Production model software program (BSP; McAllister and Babcock 2006). The program used a state-space modelling approach to fit the assessment model to data. Bayesian State-space modelling has been increasingly used in fisheries stock assessment in recent years (Meyer and Millar, 1999; Millar and Meyer, 2000). The state-space approach allows for deviations from model predictions (i.e., random variability) in both (i) the data (e.g., abundance or biomass indices) and (ii) the unobserved state of the system of interest (e.g., true annual biomass) (Millar and Meyer, 2000). A description of the assessment model, including the development of prior distributions for all estimated parameters, is provided in Appendix F.

For each of the four British Columbia lingcod assessment areas, we developed a reference case for which all inputs, assumptions, and settings were formulated based on the best available information and scientific judgment (Appendix F). All available indices of abundance were included in reference runs. Prior distributions were either estimated directly from data (e.g., informative prior distributions for intrinsic rates of growth) or had prior means set at values obtained from the literature (e.g., informative prior distribution on the rate of increase in fishery catchability over time). For each assessment area, the reference case was identified prior to running the stock assessment model.

Sensitivity analyses were used to examine the effect of reference case assumptions on stock status and projection results. Some analyses were conducted for all assessment areas, while others were only tested in Area 3C since it has historically sustained the largest catches and it has the largest amount of data available. A detailed list of sensitivity analyses tested is available in Appendix F, while the results are available in Appendix G.

INDICATORS OF STOCK STATUS

Stock Status in 2010

Current stock status in 2010 is quantified in several ways based on model predictions, including:

- current biomass relative to B_{MSY} (B_{2010} / B_{MSY}),
- current biomass relative to unfished biomass (B_{2010} / K),
- current biomass relative to biomass at the start of lingcod catch records (B_{2010} / B_{1927}),
- current fishing mortality relative to F_{MSY} (F_{2010} / F_{MSY}),
- the probability that stock biomass is in the Healthy zone in 2010 [P(B_{2010}>0.8B_{MSY})], and
- the probability that stock biomass is above the Critical zone in 2010 [P(B_{2010}>0.4B_{MSY})].

Additional management parameters reported include maximum sustainable yield, MSY, and the replacement yield for 2010, REPY_{2010}, which is the amount of yield that can be removed from the stock without leading to biomass increase or decline in 2011 (i.e., $\mathrm{B}_{2011} = \mathrm{B}_{2010}$).

Uncertainty in estimated parameters is summarized in two ways. First, the 90% probability interval is provided for each parameter as the 5^{th} and 95^{th} percentile of estimated posterior distributions. This interval represents the range of values within which the model is 90% certain that the true value for the quantity of interest occurs. Secondly, we provide the coefficient of variation (CV) for each parameter, which is calculated as the absolute value for the mean of the posterior distribution divided by the standard deviation of the distribution.

Uncertainty in current stock status relative to the USR and the LRP is quantified as the probability that B_{2010} is in the Healthy zone, (B_{2010}>0.8$\mathrm{B}_{\mathrm{MSY}}$), and the probability that B_{2010} is above the critical zone P(B_{2010}>0.4$\mathrm{B}_{\mathrm{MSY}}$), respectively.

Predicted population trajectories from the surplus production model between 1927 and 2010 can also be used to examine trends in stock status over time, as well as to evaluate how model predictions compare to the data sets used to fit the model.

Stock Projections for Yield Advice

Yield advice is provided by using five-year projections (2011 – 2016) to create decision tables for each individual assessment area. The range of constant TAC policies considered ranged from 500 to either 3,000 or 4,500 tonnes, depending on the area. Larger TAC quota policies were considered for Areas 3D and 5CDE since the ratio of current biomass to B_{MSY} was estimated to be larger in these areas. The upper TAC levels considered are all well above the estimated *MSY*, and illustrate the impacts of removals above this stock reference point.

The resulting decision tables show median projected biomass in 2016 relative to B_{MSY} (B_{2016}/B_{MSY}), as well as the probability of being above several stock status reference points by 2016. Stock status reference points considered include the LRP ($0.4B_{MSY}$), the USR ($0.8B_{MSY}$), and the assumed target biomass level of B_{MSY}. The probability that B_{2016} is greater than B_{2010} is also summarized in decision tables; however, this indicator is not referenced in the *PA Decision-making Framework* (DFO 2009).

Ten-year and 20-year projections using constant TAC levels were also used to create decision tables, which are provided in Appendix G. We focus on the 5-year time period when discussing yield options in this assessment based on the assumption that the current assessment will be updated within 5 years.

ASSESSMENT RESULTS

STOCK STATUS IN 2010

Detailed summaries of stock status for each of the four assessment areas are presented in Appendix G, including results for the reference case and sensitivity analyses. A sub-set of status indicators from reference case runs for each area are also summarized in Tables 2 – 5.

Stock biomass in all four assessment areas show declines in recent years; however, results based on the median of posterior distributions indicate that current biomass remains above B_{MSY}. Biomass for 2010 (B_{2010}) in all assessment areas, as estimated by posterior median values, was above the associated B_{MSY} posterior median value, indicating that all outside lingcod stocks are most likely in the Healthy Zone (Figure 3).

Posterior distributions for most stock status indicators and management parameters are imprecise. In some cases, distributions are highly skewed and / or display more than one mode (Appendix G). As a result, conclusions about current stock status relative to reference points are highly uncertain. Probability statements about stock status being in Healthy or Critical zones help communicate this uncertainty, and should be considered when interpreting results.

Area 3C

Stock biomass in Area 3C has shown a 45% decline from both biomass in 1997 and unfished biomass, *K* (Table 2). Biomass was relatively stable between 1927 and 1955, and then declined until 2010, with two slight upturns in the mid-1980s and the mid-2000s (Figure 4).

The median of the estimated posterior distribution for B_{2010} is 111% that of B_{MSY} (Table 2), indicating that this stock is most likely in the Healthy zone. Considerable uncertainty exists in stock status estimates for Area 3C. Although the median ratio of B_{2010}/B_{MSY} is 1.11, the probability that B_{2010} is in the Healthy zone is only 67% [$P(B_{2010} > 0.8B_{MSY})$]. Furthermore, the probability that B_{2010} is in the Critical zone is 10% [i.e., $1 - P(B_{2010} > 0.4B_{MSY})$].

The posterior median estimate of MSY is 1,390 tonnes. The posterior median estimate of current fishing mortality is well below the posterior median of F_{MSY} ($F_{2010}/F_{MSY} = 0.39$); however, once again this value is uncertain, as evidenced by the 90% probability interval of (0.06, 2.2). The posterior median replacement yield for 2010 ($REPY_{2010}$) is 1,099 tonnes, which represents the surplus production that could be removed in 2011 with no increase or decrease to stock biomass.

Area 3D

Stock biomass in Area 3D has shown relatively small total declines from the 1927 biomass level (22% decline) and from the unfished biomass level (Table 3). Model predictions show periods of increasing and decreasing biomass since the late-1960s when biomass estimates were at historic high levels (Figure 5). Biomass declined from 1970 to the mid-1980s, and then increased again until 2003 (Figure 5). Since 2003, the biomass has been declining, and is currently at historic low estimates.

The median of the estimated posterior distribution for B_{2010} is 156% that of B_{MSY} (Table 3), indicating that this stock is most likely in the Healthy zone. There is high confidence in classifying the Area 3D stock as "Healthy". The probability that B_{2010} is in the Healthy zone is 95%, while the probability that B_{2010} is in the Critical zone is < 1%.

The posterior median estimate of MSY is 1,888 tonnes. The posterior median estimate of current fishing mortality is well below the posterior median of F_{MSY} (F_{2010} / F_{MSY} = 0.11), with high confidence that this is the case based on the 90% probability interval (0.03-0.85). The posterior median replacement yield for 2010 ($REPY_{2010}$) is 1,118 tonnes, which represents the surplus production that could be removed in 2011 with no increase or decrease to stock biomass.

Area 5AB

Stock biomass in Area 5AB has shown a 44% decline from both biomass in 1927 and unfished biomass, which are estimated to be approximately equal ($B_{1927} \approx K$; Table 4). Biomass showed dramatic depletion between the mid-1960s and late-1970s, followed by some rebuilding in the 1980s (Figure 6). Since the mid-1980s, biomass has steadily declined to a historic low in 2010.

The median of the estimated posterior distribution for B_{2010} is 113% that of B_{MSY} (Table 4), indicating that this stock is most likely in the Healthy zone. There is considerable uncertainty in stock status estimates for Area 5AB: the probability that B_{2010} is in the Healthy zone is only 67%, while the probability that B_{2010} is in the Critical zone is 5%.

The posterior median estimate of MSY is 1,283 tonnes. The posterior median estimate of current fishing mortality is well below the posterior median of F_{MSY} (F_{2010} / F_{MSY} = 0.51); however, this value is extremely uncertain, as evidenced by the 90% probability interval of (0.08, 2.18). The posterior median replacement yield for 2010 ($REPY_{2010}$) is 1,055 tonnes, which represents the surplus production that could be removed in 2011 with no increase or decrease to stock biomass.

Area 5CDE

Stock biomass in Area 5CDE has shown a 28% decline from biomass in 1927 and a 27% decline from unfished biomass (Table 5). Changes in biomass over time for this stock have been relatively minor (Figure 7). Overall the stock appears to have remained stable between 1927 and 1970. From 1970 onwards, the stock has declined until 1980, increased until 1990, and then continued to decline up to the present time.

The median of the estimated posterior distribution for B_{2010} is 146% that of B_{MSY} (Table 5), indicating that this stock is most likely in the Healthy zone. There is high confidence in classifying the Area 5CDE stock as "Healthy". The probability that B_{2010} is in the Healthy zone is 88%, while the probability that B_{2010} is in the Critical zone is < 1%.

The posterior median estimate of MSY is 1,091 tonnes. The posterior median estimate of current fishing mortality is well below the posterior median of F_{MSY} (F_{2010} / F_{MSY} = 0.31); however, this value is somewhat uncertain, as evidenced by the 90% probability interval of (0.08, 1.42). The posterior median replacement yield for 2010 ($REPY_{2010}$) is 679 tonnes, which represents the surplus production that could be removed in 2011 with no increase or decrease to stock biomass.

YIELD ADVICE BASED ON STOCK PROJECTIONS

Decision tables based on 5-year stock projections for each assessment area are provided in Table 6. Posterior median biomass levels in Area 3D were projected to remain within the Healthy zone (B_{2016} / B_{MSY} > 0.8) at the highest level of TAC considered (4,500 tonnes). Posterior median biomass levels in Areas 3C, 5AB and 5CDE were projected to remain within the Healthy zone at TACs of between 2,000 and 2,500 tonnes. Projections were uncertain in all areas. At a constant TAC of 2,000 tonnes, the probability of each stock being in the Critical zone in 2016 ranged from 9% for Area 3D to 33% for Area 5AB (calculated as 1 – P[B_{2016} > 0.4B_{MSY}] for each area).

Projection results were particularly uncertain for Areas 3C and 5AB. For Area 3C, a TAC set at 1,000 (which is below the MSY estimate of 1,390, Table 2), resulted in only a 62% probability that B_{2016} would be in the Healthy zone, and a 17% probability that B_{2016} would be in the Critical zone. Taking no annual catch for this area (TAC = 0) still produced a 6% probability that B_{2016} would be in the Critical zone. For Area 5AB, a TAC set at 1,000 (which is below with the MSY estimate of 1,283) resulted in a 61% probability that B_{2016} would be in the Healthy zone, but a 17% probability that B_{2016} would be in the Critical zone.

DISCUSSION

DATA USED

<u>Informative *r* prior</u>

Estimation of *r* is influenced by uncertainty in age data because the development of a prior distribution for *r* uses estimates of age-at-maturity and size-at-age (Appendix F; Equation F-8). The ageing methodology for lingcod is validated, and criteria exist for determining difficult to discern annuli. Therefore the uncertainty of age estimates is likely low, perhaps as little as 1-2 years. However, some of the biological data used to estimate growth rates were obtained from commercial trawl fishery landings. The minimum size limit of the fishery (65 cm) resulted in very few fish age 1-2 years in the samples. In addition, the young fish (ages 1-4) sampled in the commercial fishery landings might represent fast-growing individuals with higher size at age.

<u>Abundance Indices</u>

The commercial CPUE time series in each assessment area were assumed proportional to the abundance of lingcod in that area, thereby providing indices of relative abundance. This assumption may not be correct because commercial CPUE might exhibit hyperstability (Hilborn and Walters, 1992) i.e. the CPUE may remain high despite declining abundance. This would reflect fisher efficiency in searching for fish, and concentrated effort on areas where lingcod are most abundant. If fish continue to aggregate in these areas, CPUE may remain high despite declining abundance. Hyperstability was also a reason for not considering the “qualified CPUE” procedure used in previous lingcod assessments. The qualifying criterion (“qualified” tows needed to have at least 25% of the catch with lingcod) could result in a hyperstable index as stock abundance declined. Consideration of a hyperstability parameter, as described in Appendix H, did not improve the goodness of fit of the model, suggesting that hyperstability in not a large concern with the commercial CPUE for this species.

Trawl research surveys were used as fishery-independent indices of abundance and we assumed that these data were also proportional to lingcod abundance. A number of the surveys exhibited high inter-annual variability in lingcod biomass estimates, and some annual CVs were >0.80. Iterative reweighting (Appendix F) downscaled the influence of annual values with high CVs so that survey time series or individual data points with high variability had less influence on biomass estimates. However, despite the re-weighting, the inclusion of multiple abundance time series, often with diverging trends among them and high inter-annual variability within a single survey series, lead to high overall uncertainty in biomass estimates.

The shrimp trawl research survey in Area 3C exhibited the most inter-annual variability and highest annual CVs suggesting that it is an uncertain index of lingcod abundance. Trends in this survey contributed to the decision to apply a technology creep parameter to the commercial CPUE time series (described below and in Appendices F and H). From 1975-1990, the commercial catch of lingcod increased. One expectation given high catches would be a decline in abundance and an eventual decline in commercial CPUE. However, during this period commercial CPUE continued to increase. The shrimp trawl research survey was the only fishery-independent survey in Area 3C spanning the 1975-1990 time period, and the survey CPUE exhibited the expected decline over this period. This decline in the shrimp trawl survey was taken as further support for the technological creep hypothesis as a means to explain why commercial CPUE increased during this period.

An alternate hypothesis increasing commercial CPUE despite high removals during this period is a true increase in abundance due to basin-wide climate impacts (e.g. Pacific Decadal Oscillation) on recruitment. The commercial CPUE exhibited an increase beginning in the early 1980s, which could relate to strong year classes in the late 1970s entering the fishery (at age 3 or 4). The 1977 climate regime-shift (Mantua et al. 1997) was concomittant with a strong year classes in several fish species, including groundfish, from California through Alaska (King 2005). This hypothesis was not investigated.

We relied only on trawl research surveys for fishery-independent indices of abundance, and did not use hook and line surveys. The International Pacific Halibut Commission has conducted an annual setline survey throughout British Columbia waters since 1997. The survey is conducted during the summer months along a standardized grid that is 10 nmi (18.5 km) by 10 nmi at depths of 45 to 500 m. In Canadian waters, the grid extends along the west coasts of Vancouver Island and Queen Charlotte Islands, throughout Queen Charlotte Sound and Hecate Strait. Between 1997 and 2002, only 20 hooks per skate, at or near the beginning of each skate, were enumerated for species composition. Since 2003, in the Canadian portion of this survey, all hooks are enumerated for species composition. This survey was not included as an index of abundance. In addition, we did not consider rockfish longline surveys that have been conducted in Area 3C 2006-2009, since the time period was short

ASSESSMENT MODEL

The simple state-space surplus production model (SPM) used fitted most of the abundance index data reasonably well for all four assessment areas when a technological creep parameter was applied to commercial CPUE indices (Appendix F and Appendix H). While surplus production models have been shown to perform well in many instances, their treatment of a stock as undifferentiated biomass limits their ability to respond to changes in age, sex, and size structure in a population in a timely manner. Catch-at-age data with moderately good coverage from the British Columbia trawl fleet are available for areas 3C and 5AB, so future stock assessments should consider applying an age-structured assessment model to these areas to see how perceptions of stock status are affected.

The methodology used to develop area-specific informative prior distributions for the *r* parameter of the surplus production model (i.e., the intrinsic rate of population growth) required assumptions about both recruitment steepness and natural mortality rate (M) for lingcod. The methodology was similar to that used for Boccaccio rockfish (Stanley et al. 2009a); however, some changes were made for the current assessment. Unlike the previous application to Boccaccio in which only M and steepness were random variables, all demographic parameter inputs were treated as random variables. In addition, a Ricker stock recruitment relationship was assumed when specifying steepness for lingcod rather than the Beverton & Holt relationship used for Bocaccio. We made the assumption of Ricker relationship because lingcod are known to have cannibalistic behaviour (Cass et al., 1990; A. Beaudreau, University of Washington, School of Fisheries and Aquatic Sciences, pers. comm.), which is better characterized by a Ricker model. Since this assumption is a significant one, diet studies of lingcod in British Columbia should be undertaken to better understand the magnitude of cannibalism, as well as its potential impacts on population demographics.

An additional source of uncertainty in the formulation of an informative prior distributions for *r* was the selection of a natural mortality rate for lingcod populations. The value of M=0.193 used in this assessment was taken from an estimate of M for female lingcod made by Leaman and McFarlane (1997), who based their estimate on Hoenig's (1983) relationship between M and natural mortality. As the *r* prior shows considerable sensitivity to the value chosen for M (Cuif et al. 2009), future assessments should consider alternative methods for estimating this parameter. The SPM used in this assessment presumed that M at the lowest population density was unchanging over time. However, this parameter under low density conditions is likely to change over time due to changes in food availability, predators, and other environmental factors (Hilborn and Walters, 1992).

The assumed relationship between CPUE and abundance is a key uncertainty in stock assessments that use fishery CPUE to index of abundance. The potential for catchability to vary over time for commercial and recreational CPUE indices is well-documented (reviewed in Wilberg and Bence 2006). Changes in catchability through space and time can result from a variety of factors including: occasional fleet-wide increases in vessel engine power, improvements to gear technology, improvements to navigational devices, adoption of improved sonar devices to locate target species and their habitat, increases in a captain's control of gear at depth, and improvements in knowledge about when and where to capture species of interest. A variety of methods have been developed to incorporate changing catchability into stock assessment models (Appendix H). In this assessment, we assumed that the catching power of the commercial trawl fishery for lingcod increased linearly over time (Appendix F). This assumption was based on the observation that standardized commercial trawl CPUE indices exhibited an increasing trend during the early portion of the time series leading up to the 1990s despite increasing total removals (Appendix C; Appendix F). One explanation for this pattern is a systematic increase in catching power over time in the British Columbia trawl fleet. A technology creep (*tech*) parameter was used to represent this systematic increase in fishing power.

Cuif et al. (2009) also used a tech parameter; however, the approach taken in this assessment differs from somewhat from Cuif et al (2009). The current assessment uses an informative prior for *tech* that was derived from a literature review (Appendix H), while Cuif et al. (2009) fixed *tech* at the posterior modal value estimated from an initial model run. Using a fixed value for the reference case would provide overly certain results. In contrast, using a prior for tech allows uncertainty in the parameter to be accounted for in the reference case results. The prior mean for the reference case scenario in all assessment areas was a 2% increase in catching power per year.

Sensitivity analyses showed that estimates of current stock status and projection results were highly sensitive to relatively small changes in the prior mean for the tech parameter (Appendix G). The large variability in the stock trend data for the different areas and relatively low overlap between commercial catch rate and survey time series in most instances gave relatively little information about the hypothesized values for the tech parameter. Given the large amount of variability in the stock trend data and the large uncertainty over the tech parameter, the wide posterior distributions for stock status in all four assessment areas are to be expected. Future lingcod assessments using commercial trawl CPUE data as an index of abundance should include a formal model selection analysis that examines a more comprehensive set of assumptions about the nature and magnitude of changes in catchability over time (e.g., Wilberg et al., 2010).

Estimates of current stock status and projection results for the different policy options were relatively insensitive to the prior mean applied for the *r* parameter in all four assessment areas (Appendix G). This may be because median biomass was above 50% of unfished biomass in all areas, and thus well above the low stock sizes at which *r* is a more important determinant of stock dynamics.

CURRENT VERSUS PREVIOUS ASSESSMENT RESULTS

Results from the current assessment differ from those of a recent 2009 analysis by Cuif et al. (2009), in which a slightly different formulation of a Bayesian SPM was applied to outside lingcod populations. The Cuif et al. (2009) analysis tended to predict that outside lingcod stocks were smaller and more productive, while our assessment predicts larger and less productive stocks. For example, in Area 3C Cuif et al. (2009) estimated an *r* of 0.231, an F_{MSY} of 0.115, a carrying capacity, *K*, of 22,150 tonnes, and a current biomass, B_{2008}, of 10, 590 tonnes (all values based on posterior medians). In contrast, our posterior median estimates for Area 3C were an *r* of 0.134, an F_{MSY} of 0.067, a *K* of 50, 434 tonnes, and a current biomass, B_{2010}, of 25, 083 tonnes.

A trade-off between *r* and *K* is common when fitting population dynamic models to data. Differences in model assumptions and input data between the Cuif et al. (2009) analysis and our current assessment likely lead to a different trade-off being made between these two parameters. Key difference include: 1) Cuif et al. (2009) applied a prior for *K* that was considerably more peaked at lower values than the one that we applied in the 2010 assessment (Appendix F). This prior would have put more weight on lower values for carrying capacity than the prior that we applied. Having a prior for *K* that strongly favours low values for *K* will lead to a posterior for *r* that favours higher values; 2) Cuif et al. (2009) used a qualified commercial CPUE series, whereas we used a GLM standardized series. Differences in trends between these two sets of commercial CPUE indices are apparent: Cuif et al.'s (2009) qualified commercial series bends up strongly since 1996 while the GLM index that we've applied shows little net change since 1996. The strong rise in the Cuif et al. (2009) qualified commercial index since 1996 is more consistent with the observed drop in catch, and would thus be less likely to update the posterior for *r* downwards from the prior mean of 0.25. In contrast, the lack of net change in the GLM CPUE index since 1996 is expected to update the *r* prior downwards, as happened in our 2010 assessment. We favour using the standardized approach due to the higher likelihood of hyperstability in the qualified CPUE indices; and 3) all of the additional 2009 and 2010 data points added since the Cuif et al. 2009 analysis either stayed low or dropped, despite catches remaining low. Once again, this pattern would be expected to lead to a further decline in the posterior for r.

While the scale of predicted biomass differs between the Cuif et al. (2009) analysis and our assessment, general perceptions about stock status relative to reference points and sustainable harvest levels are similar. For example, the posterior median estimate of B_{2008} / B_{MSY} in Area 3C from Cuif et al. (2009) was 0.97, while the posterior median estimate of B_{2010} / B_{MSY} in Area 3C from the current assessment is 1.11. The posterior median estimate of MSY in Area 3C from Cuif et al. (2009) was 1205 tonnes, while the posterior median estimate of MSY in Area 3C from the current assessment is 1390 tonnes.

Prior to 2009, a quantitative stock assessment model was last applied to outside lingcod in 1997 using a catch-age analysis of the Area 3C stock (Leaman and McFarlane 1997). Interpretation of stock status for the other three outside assessment areas at this time (Areas 3D, 5AB, and 5CDE) relied on an inspection of recent trends in simple catch statistics (e.g., CPUE, catch composition). Results from the Area 3C catch-age model was were similar to those of Cuif et al. (2009) in that they suggested a smaller, more productive stock. Exploitable biomass in Area 3C in 1996 (B_{1996}) was estimated to be 13, 000 tonnes and F_{MSY} was estimated to be 0.161.

Results from the 1997 assessment suggested recent declines in biomass for all outside stocks, and a more conservative harvest regime was recommended at that time (Leaman and McFarlane 1997). Despite similar predictions of historic biomass trends over time for the 1997 assessment and our 2010 assessment, perceptions about current biomass relative to safe biological limits differs. This difference is due to the adoption of B_{MSY}-based reference point for the current assessment. Leaman and McFarlane (1997) recommended a reduction in harvest because biomass levels in 1996 were below long-terms averages. Our results suggest that while stock biomass in all areas has continued a gradual downward trend since the start of the fishery, current biomass levels are still above B_{MSY}.

RECOMMENDATIONS FOR FUTURE ASSESSMENTS AND RESEARCH

Based on the uncertainties and limitations discussed above, future assessment and research plans should consider:

1. Development of a catch-at-age stock assessment model for Areas 3C and 5AB.
2. Examination of alternative sources of abundance time series data that were not considered in this assessment. For example, the International Pacific Halibut Commission (IPHC) has conducted a standardized longline survey in outside areas since 1997 that could be informative for future stock assessments.
3. Evaluation of a broader set of candidate models for representing time-varying catchability in commercial CPUE time series (e.g., abrupt shifts due to management or gear changes, density-dependent effects) using a formal model selection analysis.
4. Investigation of the extent of cannibalism in British Columbia lingcod populations, as well as the suitability of the Ricker stock-recruitment relationship assumed for lingcod in the current assessment.
5. Examination of alternate methods to Hoenig's (1983) method for estimating natural mortality rates in British Columbia lingcod populations.
6. Genetic investigations of stock structure for lingcod populations in BC using microsatellite DNA analyses. The current assessment uses management areas as a proxy for stock structure; however, the appropriate scale for assessment and management of outside lingcod in British Columbia is not known.

CONCLUSION

In this assessment of outside lingcod stocks in British Columbia, we formulated informative prior distributions for the intrinsic rate of population growth, *r*, for input into area-specific Bayesian surplus production assessment models. Four separate assessment models were developed for four different mnagement areas: Areas 3C, 3D, 5AB, and 5CDE. This approach took into account several data sources and allowed representation of uncertainty in both population processes and observations. The priors were similar to those obtained in a recent assessment analysis by Cuif et al. (2009), but were wider because we used a prior standard deviation in the natural logarithm of *M* that was twice as large as that used in Cuif et al. (2009). The wider prior distribution for *M* allowed us to more fully account for uncertainty in this input parameter. We also applied an informative prior to a tech parameter to account for possible increases in catching power of commercial trawlers that was likely not accounted for by GLM standardization of the CPUE data. Despite these informative prior distributions, stock assessment and projection results were imprecise. For example, most of the posterior probability for B_{2010}/ K ranged between about 0.2 and 0.9 for all areas. Under reference case settings, it appeared highly unlikely that any of the stocks were depleted below 0.4 B_{MSY}. Application of a variety of harvest policy options spanning the current range of catches and quotas in projections all gave higher than a 50% probability of maintaining stocks at above B_{MSY} up to 5 years into the future. Stock status and projection results were relatively insensitive to alternative priors for *r*. However, stock status and projection results for Areas 3C, 5AB, and 5CDE were sensitive to alternative priors for the tech parameter.

REFERENCES

Beaudreau, A.H., and Essington, T.E. 2007. Spatial, Temporal, and Ontogenetic Patterns of Predation on Rockfishes by Lingcod. *Transactions of the American Fisheries Society*, 136: 1438–1452.

Cass, A.J., Beamish, R.J., and McFarlane, G.A. 1990. Lingcod (*Ophiodon elongatus*). *Can. Spec. Pub. Fish. Aquat. Sci.*, 109: 40 p.

Cuif, M., M. McAllister, and J.R. King. 2009. Development of a surplus production model applicable to British Columbia offshore stocks of lingcod (*Ophiodon elongatus*). Canadian Technical Report of Fisheries and Aquatic Sciences 2861: xii+72 p. Available at http://www.dfo-mpo.gc.ca/Library/340571.pdf (January 27, 2010).

DFO. 2009. A fishery decision-making framework incorporating the Precautionary Approach. Available at: http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/precaution-eng.htm (January 24, 2011).

Hilborn, R., and Walters, C.J. 1992. Quantitative fisheries stock assessment. Choice, dynamics and uncertainty. Chapman and Hall, London, UK. 570 p.

King, J.R. (Ed.) 2005. Report of the Study Group on Fisheries and Ecosystem Responses to Recent Regime Shifts. PICES Scientific Report No. 28, 162 pp.

King, J.R., and Surry, A.M. 2000. Lingcod stock assessment and recommended yield options for 2001. *Can. St. Assess. Sec. Res. Doc.*,164: 50 p.

King, J.R., and Withler, R.E. 2005. Male nest site fidelity and female serial polyandry in lingcod (*Ophiodon elongatus*, Hexagrammidae). *Molecular Ecology*, 14: 653-660.

Leaman, B.M., and McFarlane, G.A.. 1997. Lingcod stock assessment and recommended yield options for 1998. *Can. St. Assess. Sec. Res. Doc.*, 97/131.

Low, C.J. and R.J. Beamish. 1978. A study of the nesting behaviour of lingcod (*Ophiodon elongates*) in the Strait of Georgia, British Columbia. *Fish. Mar. Serv. Tech. Rep.* 843: 27 p.

Ludwig, D., and Walters, C.J. 1985. Are age-structured models appropriate for catch-effort data? *Can. J. Fish. Aquat. Sci.*, 42: 1866-1072.

Marko, P.B., L. Rogers-Bennett, and A.B. Dennis. 2007. MtDNA population structure and gene flow in lingcod (*Ophiodon elongatus*): limited connectivity despite long-lived pelagic larvae. *Marine Biology* 150: 1301-1311.

Martell, S.J.D., C.J. Walters, and S.S. Wallace. 2000. The use of marine protected areas for conservation of lingcod (*Ophiodon elongatus*). *Bulletin of Marine Science* 66: 729-743.

Mantua, N.J., S.R. Hare, Y. Zhang, J.M Wallace and R.C. Francis. 1997. A Pacific inter-decadal climate oscillation with impacts on salmon production. Bull. Am. Meteor. Soc. 78: 1069-1079.

McAllister, M.K. and Babcock, E.A. 2006. Bayesian surplus production model with the Sampling Importance Resampling algorithm (BSP): A user's guide. Available from: http://www.sefsc.noaa.gov/library.jsp (January 27, 2010).

McAllister, M.K., E.K. Pikitch, A.E. Punt, and R. Hilborn. 1994. A Bayesian approach to stock assessment and harvest decisions using the sampling - importance - resampling algorithm. *Canadian Journal of Fisheries and Aquatic Sciences*, 51: 2673-2687.

McAllister, M.K., and G.P. Kirkwood, G.P. 1998. Bayesian stock assessment. A review and example application using the logistic model. *ICES Journal of Marine Science*, 55: 1031-1060.

Meyer, R., and Millar, R.B. 1999. Bayesian stock assessment using a state–space implementation of the delay difference model. *Can. J. Fish. Aquat. Sci.*, 56: 37–52.

Millar, R.B., and Meyer, R. 2000. Non-linear state space modeling of fisheries biomass dynamics by using Hastings–Metropolis within-Gibbs sampling. *Appl. Stat*., 49: 327–342.

Petrie, M.E. and C.H. Ryer. 2006. Laboratory and field evidence for structural affinity of young-of-the-year lingcod. *Transactions of the American Fisheries Society* 135: 1622-1630.

Phillips, A.C. and W.E. Barraclough. 1977. One the early life history of lingcod, *Ophiodon elongates*. *Fish. Mar. Serv. Tech. Rep*. 756: 35 p.

Polacheck, T., Hilborn, R., and Punt, A.E. 1993. Fitting surplus production models: comparing methods and measuring uncertainty. *Can. J. Fish. Aquat. Sci.*, 50: 2597-2607.

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

Rubin, D. B. 1988. Using the SIR algorithm to simulate posterior distributions. Pages 385–402 in J. M. Bernardo, M. H. Degroot, D. V. Lindley and A. M. Smith, eds. Bayesian statistics 3: Proceedings of the Third Valencia International Meeting, June 1–5, 1987. Clarendon Press, Oxford. 805 p.

Stanley, R. D., M. McAllister, P. Starr and N. Olsen, 2009a. Stock assessment for bocaccio (*Sebastes paucispinis*) in British Columbia waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/055. 200p.

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

Westrheim, S.J. 1967. *G.B. Reed* Groundfish Cruise Reports, 1963-66. Fish Res. Bd. Can. Tech. Rep. 30: 288 p.

Wilberg, M. J., and J. R. Bence. 2006. Performance of time-varying catchability estimators in statistical catch-at-age analysis. *Canadian Journal of Fisheries and Aquatic Sciences* 63: 2275–2285.

Wilberg, M.J., J.T. Thorson, B.C. Linton, and J. Berkson. 2010. Incorporating time-varying catchability in population dynamic stock assessment models. *Reviews in Fisheries Science* 18: 2-24.

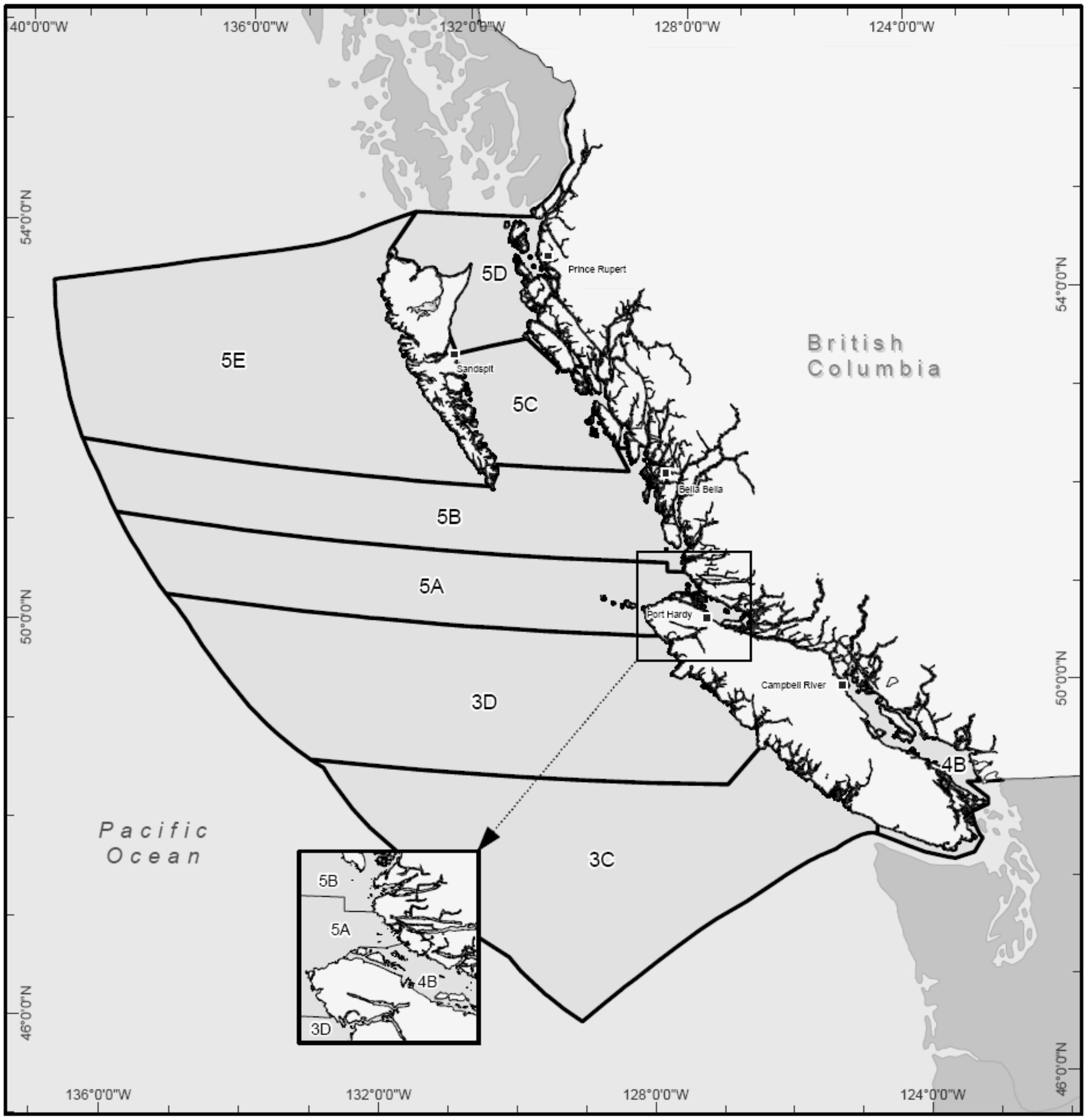

Figure 1. Map of groundfish management areas that are used to delineate four outside lingcod assessment areas in British Columbia (Area 3C, Area 3D, Areas 5AB, and Areas 5CDE).

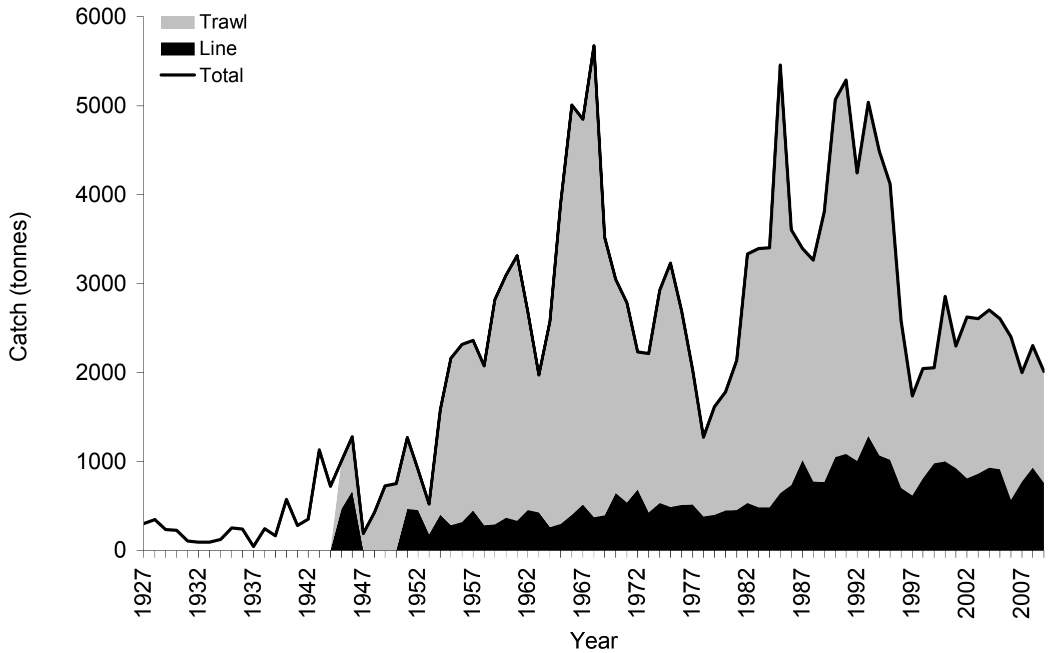

Figure 2. Coastwide hook and line, trawl and total commercial catch (tonnes) of lingcod in Canadian waters. Data available in Appendix B. Annual trawl fishery and hook and line fishery catches are shown as stacked values.

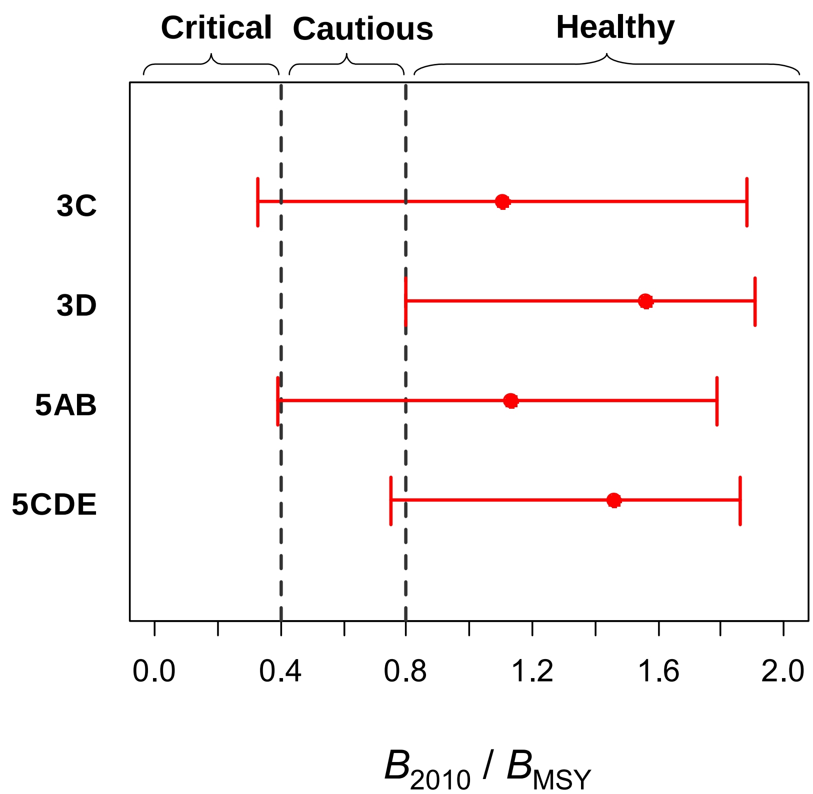

Figure 3. Current stock status (represented as the ratio of B_{2010} to B_{MSY}) relative to the Limit Reference Point (LRP) and Upper Stock Reference (USR) point for each of the four outside lingcod assessment units. Dots show the posterior median of the ratio of B_{2010} to B_{MSY} and error bars show the 95% probability intervals of the ratio. Vertical dashed lines indicate the LRP ($0.4B_{MSY}$) and USR ($0.8B_{MSY}$). The three stock status zones delineated by these reference points (Healthy, Cautious, and Critical) are indicated at the top of the figure.

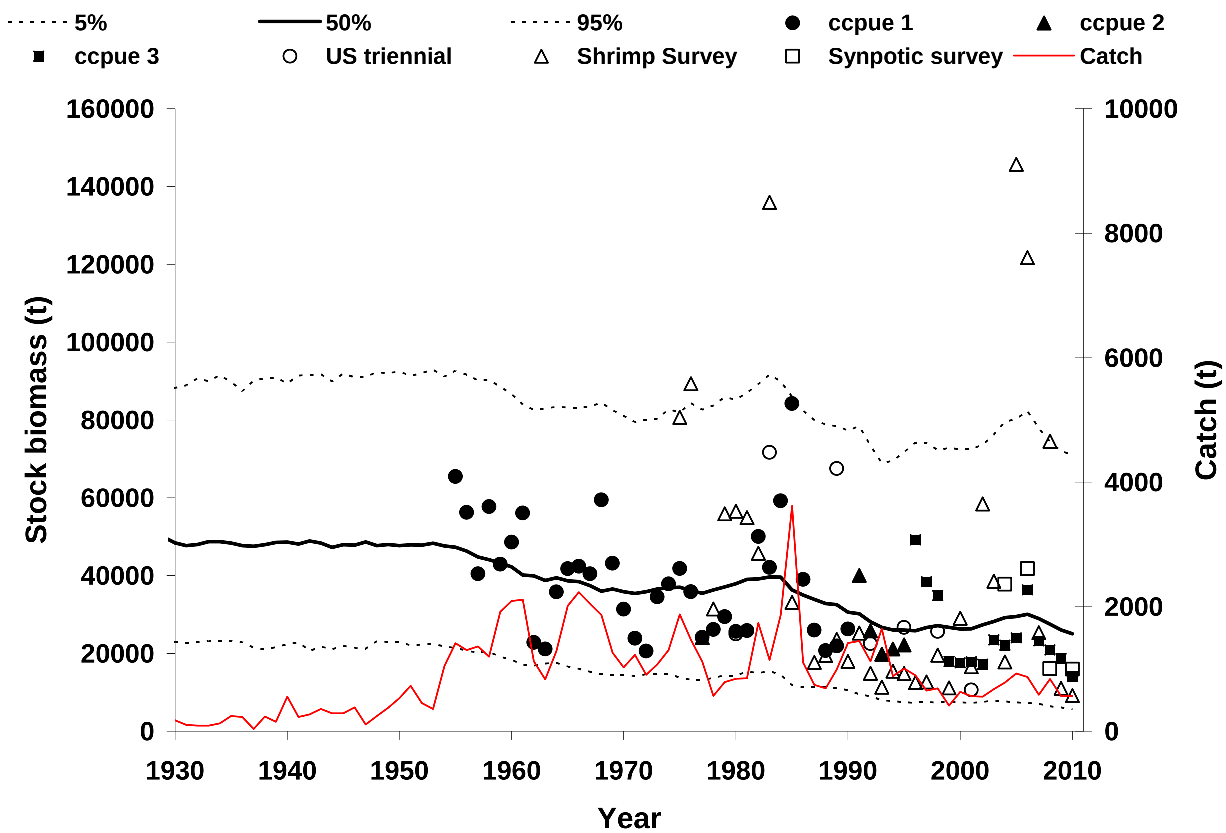

Figure 4. Catch, estimated biomass in tonnes (represented as the posterior median (50%) and 90% probability interval), and observed stock trend indices divided by their posterior median value for the catchability coefficient for Area 3C between years 1927 and 2010. Results are shown for the reference case. The abbreviations ccpue 1, ccpue 2 and ccpue 3 are the commercial stock trend indices for 1954-1990, 1991-1995 and 1996-2001. The plotted ccpue indices are divided by the posterior median tech creep value for each year.

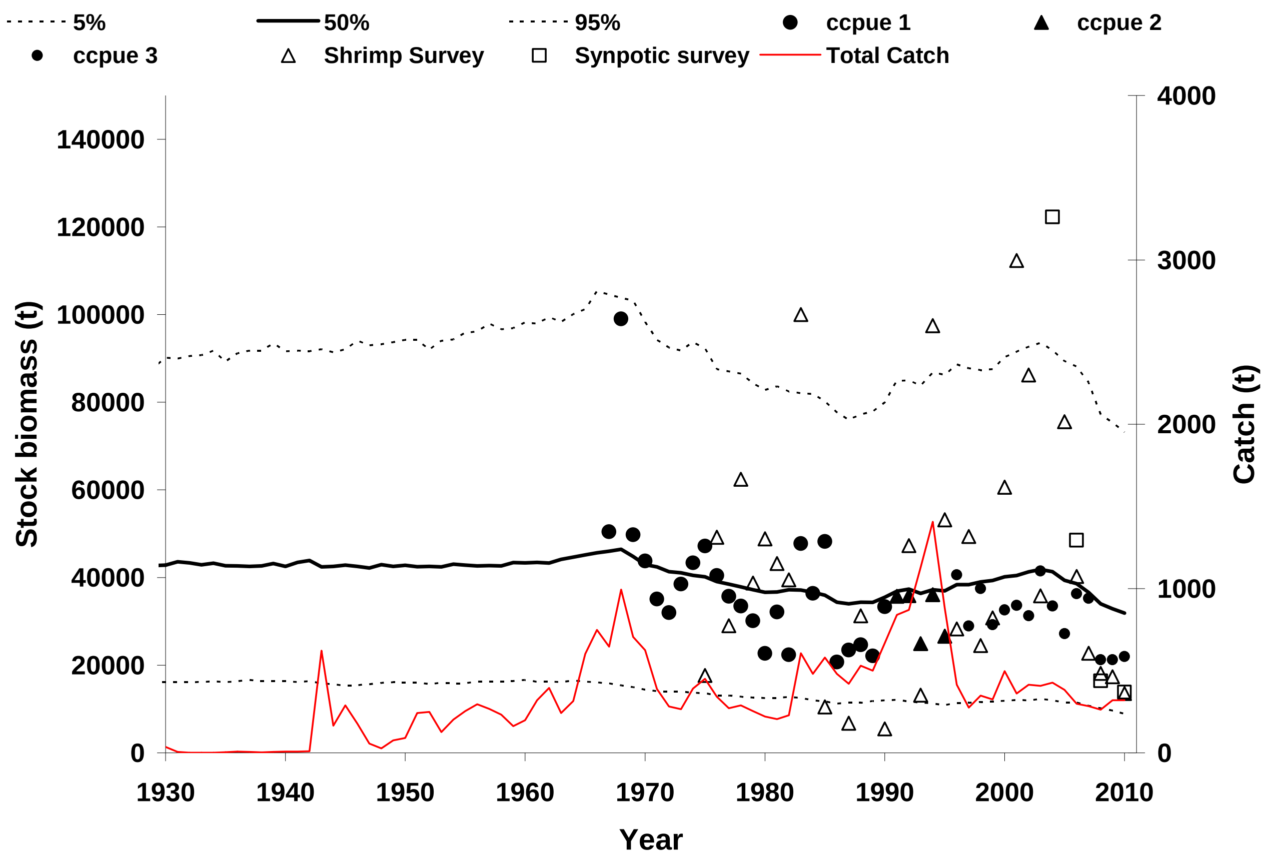

Figure 5. Catch, estimated biomass in tonnes (represented as the posterior median (50%) and 90% probability interval), and observed stock trend indices divided by their posterior median value for the catchability coefficient for Area 3D between years 1927 and 2010. Results are shown for the reference case. The abbreviations ccpue 1, ccpue 2 and ccpue 3 are the commercial stock trend indices for 1966-1990, 1991-1995 and 1996-2001. The plotted ccpue indices are divided by the posterior median tech creep value for each year.

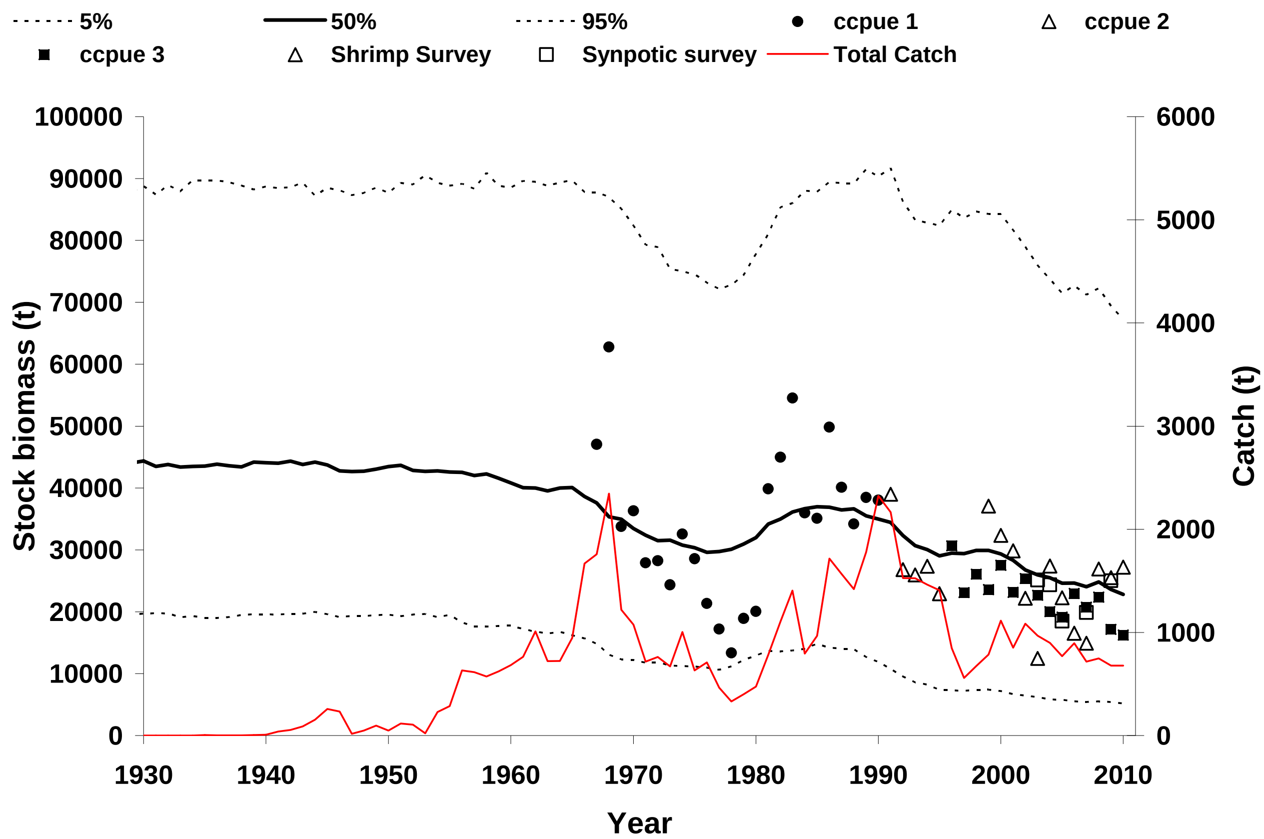

Figure 6. Catch, estimated biomass in tonnes (represented as the posterior median (50%) and 90% probability interval), and observed stock trend indices divided by their posterior median value for the catchability coefficient for Area 5AB between years 1927 and 2010. Results are shown for the reference case. The abbreviations ccpue 1, ccpue 2 and ccpue 3 are the commercial stock trend indices for 1966-1990, 1991-1995 and 1996-2001. The plotted ccpue indices are divided by the posterior median tech creep value for each year.

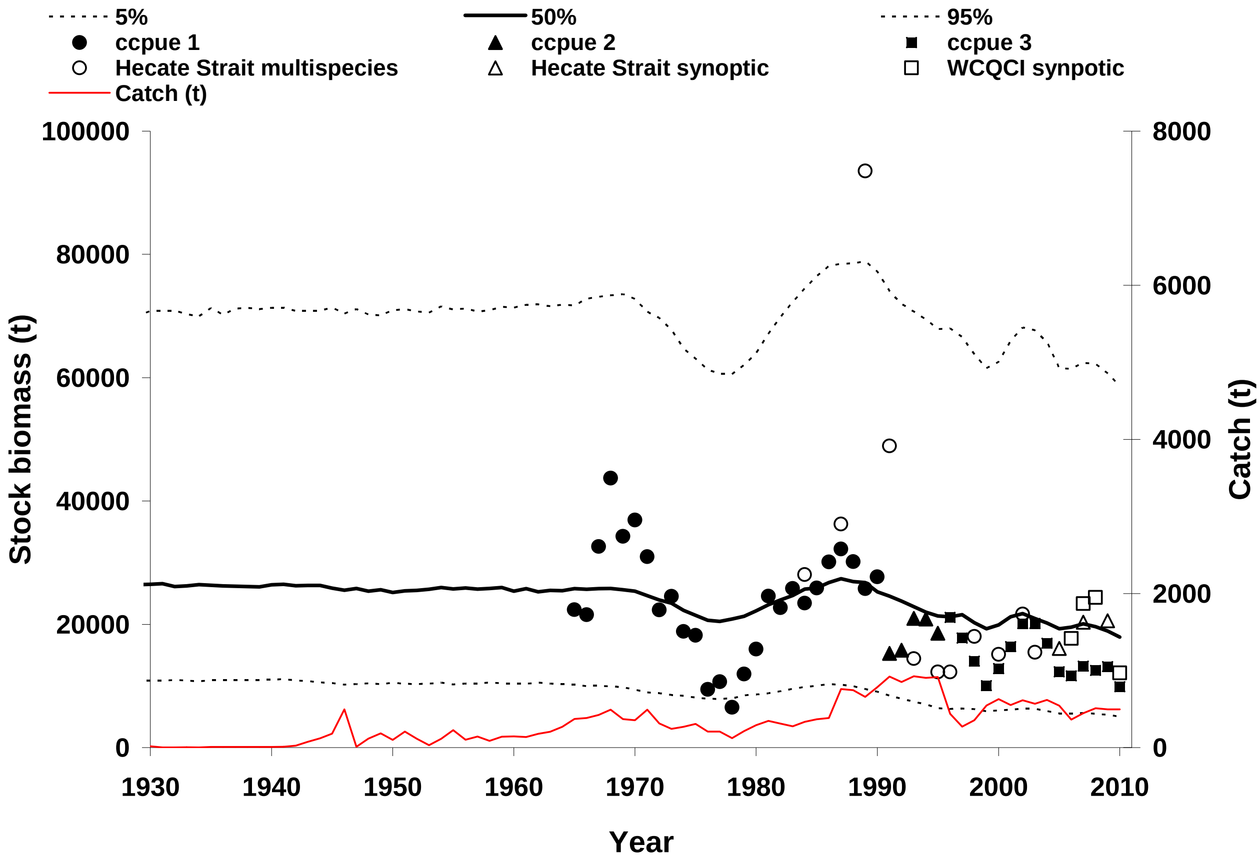

Figure 7. Catch, estimated biomass in tonnes (represented as the posterior median (50%) and 90% probability interval), and observed stock trend indices divided by their posterior median value for the catchability coefficient for Area 5CDE between years 1927 and 2010. Results are shown for the reference case. The abbreviations ccpue 1, ccpue 2 and ccpue 3 are the commercial stock trend indices for 1964-1990, 1991-1995 and 1996-2001. The plotted ccpue indices are divided by the posterior median tech creep value for each year.

Table 1. Summary of abundance indices used for the stock assessment in the four areas (com = commercial trawl fishery CPUE, tri = US triennial survey, sh = shrimp survey, sy = groundfish synoptic survey, multi = Hecate Strait multispecies assemblage survey).

Area	**Series *j***	**Time period**	**Source**	**Comment**
3C	*com*	1954 to 2010	Commercial trawl data (3 series: up to 1990, 1991-1995, 1996-2010)	GLM standardized
	tri	1980 to 2001 missing 1986	NMFS trawl surveys	Triennial CPUE in tonnes
	sh	1975 to 2010 not 1984 and 1986	DFO trawl surveys: West Coast Vancouver Island Shrimp Survey	Relative biomass in tonnes
	3C sy	2004 - 2006 - 2008 - 2010	DFO trawl surveys: West Coast Vancouver Island Synoptic Survey for Area 3C only	Relative biomass in tonnes
3D	*com*	1966 to 2010	Commercial trawl data (3 series: up to 1990, 1991-1995, 1996-2010)	GLM standardized
	sh	1975 to 2008 not 1984 and 1986	DFO trawl surveys: West Coast Vancouver Island Shrimp Survey	Relative biomass in tonnes
	3D sy	2004 - 2006 - 2008 - 2010	DFO trawl surveys: West Coast Vancouver Island Synoptic Survey	Relative biomass in tonnes
5AB	*com*	1966 to 2010	Commercial trawl data (3 series: up to 1990, 1991-1995, 1996-2010)	GLM standardized
	sh	1999 to 2010	DFO trawl surveys: Queen Charlotte Sound Shrimp Survey	Relative biomass in tonnes
	sy	2003 - 2004 - 2005 - 2007 - 2009	DFO trawl surveys: Queen Charlotte Sound Synoptic Survey	Relative biomass in tons
5CDE	*com*	1964 to 2010	Commercial trawl data (3 series: up to 1990, 1991-1995, 1996-2010)	GLM standardized
	HS sy	2005 - 2007 - 2009	DFO trawl surveys: Hecate Strait (HS) Synoptic Survey	Relative biomass in tonnes
	WCQCI sy	2006, 2007, 2008, 2010	DFO trawl surveys: West Coast Queen Charlotte Islands (WCQCI) Synoptic Survey	Relative biomass in tonnes
	multi	1984 - 1987 - 1989 - 1991 - 1993 - 1995 - 1996 - 1998 - 2000 - 2002 - 2003	DFO trawl surveys: Hecate Strait Multispecies Assemblage Survey	Tonnes / hour

Table 2. Parameter estimates and stock status indicators for lingcod in Area 3C. Posterior medians, 90% probability intervals (5th and 95th percentiles of posterior distribution), and coefficient of variations (CV) are provided for all parameter estimates. The two quantiles represent the probability that biomass in 2010 is above the critical zone [P(B_{2010}> 0.4B_{MSY})] and the probability that biomass in 2010 is in the healthy zone [P(B_{2010}> 0.8B_{MSY})]. All biomass and yield values are in tonnes.

Estimated Parameters				
Variable	Median	5th Percentile	95th Percentile	CV
r	0.1339	0.0448	0.3339	0.59
K	50434	25626	93648	0.38
MSY	1390	663	5498	0.77
B_{MSY}	25217	12813	46824	0.38
B_{1927}	49221	23010	87553	0.38
B_{2010}	25083	5580	71078	0.67
B_{2010}/ B_{MSY}	1.106	0.327	1.884	0.47
B_{2010}/ B_{1927}	0.551	0.162	1.084	0.52
B_{2010}/K	0.5532	0.1636	0.9421	0.47
F_{MSY}	0.067	0.0224	0.1669	0.59
F_{2010}	0.0215	0.0078	0.0914	1.03
F_{2010}/ F_{MSY}	0.39	0.059	2.1651	1.12
$REPY_{2010}$	1099	350	2962	0.65
Estimated Quantiles				
P(B_{2010}> 0.4B_{MSY})	0.90			
P(B_{2010}> 0.8 B_{MSY})	0.67			

Table 3. Parameter estimates and stock status indicators for lingcod in Area 3D. Posterior medians, 90% probability intervals (5th and 95th percentiles of posterior distribution), and coefficient of variations (CV) are provided for all parameter estimates. The two quantiles represent the probability that biomass in 2010 is above the critical zone [$P(B_{2010} > 0.4B_{MSY})$] and the probability that biomass in 2010 is in the healthy zone [$P(B_{2010} > 0.8B_{MSY})$]. All biomass and yield values are in tonnes.

Estimated Parameters				
Variable	Median	5th Percentile	95th Percentile	CV
r	0.184	0.051	0.347	0.49
K	44135	17346	91045	0.47
MSY	1888	417	5388	0.71
B_{MSY}	22068	8673	45523	0.47
B_{1927}	43288	15812	86899	0.48
B_{2010}	31869	8880	73192	0.55
B_{2010}/ B_{MSY}	1.56	0.80	1.91	0.21
B_{2010}/ B_{1927}	0.78	0.39	1.14	0.28
B_{2010}/K	0.78	0.40	0.95	0.21
F_{MSY}	0.09	0.03	0.17	0.49
F_{2010}	0.010	0.004	0.033	0.80
F_{2010}/ F_{MSY}	0.11	0.03	0.85	1.63
$REPY_{2010}$	1118	226	3252	0.72
Estimated Quantiles				
$P(B_{2010} > 0.4B_{MSY})$	>0.99			
$P(B_{2010} > 0.8\ B_{MSY})$	0.95			

Table 4. Parameter estimates and stock status indicators for lingcod in Area 5AB. Posterior medians, 90% probability intervals (5th and 95th percentiles of posterior distribution), and coefficient of variations (CV) are provided for all parameter estimates. The two quantiles represent the probability that biomass in 2010 is above the critical zone [$P(B_{2010} > 0.4B_{MSY})$] and the probability that biomass in 2010 is in the healthy zone [$P(B_{2010} > 0.8B_{MSY})$]. All biomass and yield values are in tonnes.

Estimated Parameters				
Variable	Median	5^{th} Percentile	95^{th} Percentile	CV
r	0.142	0.050	0.295	0.50
K	44117	21303	88109	0.43
MSY	1283	620	4675	0.75
B_{MSY}	22058	10651	44054	0.43
B_{1927}	44726	19603	86663	0.44
B_{2010}	22824	5179	67220	0.72
B_{2010}/B_{MSY}	1.13	0.39	1.79	0.43
B_{2010}/B_{1927}	0.56	0.20	1.03	0.48
B_{2010}/K	0.56	0.20	0.90	0.43
F_{MSY}	0.07	0.03	0.15	0.50
F_{2010}	0.028	0.010	0.124	0.90
F_{2010}/F_{MSY}	0.51	0.08	2.18	0.96
$REPY_{2010}$	1055	429	2924	0.63
Estimated Quantiles				
$P(B_{2010} > 0.4B_{MSY})$	0.95			
$P(B_{2010} > 0.8B_{MSY})$	0.67			

Table 5. Parameter estimates and stock status indicators for lingcod in Area 5CDE. Posterior medians, 90% probability intervals (5th and 95th percentiles of posterior distribution), and coefficient of variations (CV) are provided for all parameter estimates. The two quantiles represent the probability that biomass in 2010 is above the critical zone [$P(B_{2010} > 0.4B_{MSY})$] and the probability that biomass in 2010 is in the healthy zone [$P(B_{2010} > 0.8B_{MSY})$]. All biomass and yield values are in tonnes.

Estimated Parameters				
Variable	Median	5th Percentile	95th Percentile	CV
r	0.183	0.078	0.301	0.45
K	27316	11538	72682	0.67
MSY	1091	431	3661	0.91
B_{MSY}	13658	5769	36341	0.67
B_{1927}	26384	11009	70163	0.67
B_{2010}	17929	5051	58666	0.83
B_{2010}/B_{MSY}	1.46	0.75	1.86	0.29
B_{2010}/B_{1927}	0.72	0.39	1.04	0.35
B_{2010}/K	0.73	0.38	0.93	0.29
F_{MSY}	0.09	0.04	0.15	0.45
F_{2010}	0.026	0.008	0.094	0.98
F_{2010}/F_{MSY}	0.31	0.08	1.42	1.13
$REPY_{2010}$	679	287	1847	0.80
Estimated Quantiles				
$P(B_{2010} > 0.4B_{MSY})$	> 0.99			
$P(B_{2010} > 0.8B_{MSY})$	0.88			

Table 6. Decision table with median posterior estimates of biomass after five years (B_{2016}) in relation to the target biomass (B_{MSY}) at various levels of constant annual total allowable catch (TAC). Probabilities (P) are presented for 4 stock status indicators: B_{2016} will be above the Limit Reference Point (40% of B_{MSY}), B_{2016} will be above the Upper Stock Reference (80% of B_{MSY}), B_{2016} will be above the target biomass of B_{MSY}, and B_{2016} will be above the current biomass (B_{2010}). For comparison purposes, median estimates of maximum sustainable yield for each area (in tonnes) are: 3C = 1390, 3D = 1888, 5AB = 1283, and 5CDE = 1091.

TAC (tonnes)	B_{2016}/B_{MSY}	$P(B_{2016} > 0.4B_{MSY})$	$P(B_{2016} > 0.8B_{MSY})$	$P(B_{2016} > B_{MSY})$	$P(B_{2016} > B_{2010})$
Area 3C					
0	1.20	0.94	0.73	0.61	0.69
500	1.15	0.89	0.69	0.57	0.57
1000	1.07	0.83	0.62	0.53	0.37
1500	0.97	0.76	0.58	0.48	0.24
2000	0.90	0.71	0.54	0.42	0.18
2500	0.79	0.66	0.50	0.39	0.12
3000	0.70	0.61	0.45	0.36	0.08
Area 3D					
0	1.60	1.00	0.95	0.91	0.58
500	1.55	0.99	0.93	0.89	0.49
1000	1.46	0.97	0.91	0.85	0.36
1500	1.36	0.94	0.87	0.76	0.27
2000	1.27	0.91	0.79	0.69	0.21
2500	1.17	0.88	0.73	0.61	0.16
3000	1.08	0.84	0.67	0.55	0.11
3500	0.99	0.76	0.61	0.49	0.08
4000	0.89	0.72	0.55	0.44	0.06
4500	0.80	0.67	0.50	0.39	0.04
Area 5AB					
0	1.19	0.98	0.77	0.63	0.71
500	1.12	0.93	0.69	0.57	0.55
1000	1.02	0.83	0.61	0.51	0.35
1500	0.93	0.75	0.55	0.46	0.23
2000	0.83	0.67	0.51	0.42	0.16
2500	0.71	0.63	0.47	0.37	0.12
3000	0.61	0.57	0.43	0.34	0.09
Area 5CDE					
0	1.50	1.00	0.93	0.87	0.64
500	1.39	0.97	0.84	0.74	0.41
1000	1.24	0.86	0.73	0.65	0.22
1500	1.09	0.77	0.64	0.55	0.14
2000	0.94	0.70	0.56	0.48	0.10
2500	0.78	0.62	0.49	0.41	0.07
3000	0.61	0.55	0.44	0.36	0.05
3500	0.41	0.50	0.39	0.32	0.04
4000	0.23	0.47	0.35	0.28	0.03
4500	0.06	0.43	0.32	0.24	0.02

APPENDIX A. REQUEST FOR SCIENCE ADVICE

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: Gary Logan	Telephone Number: 604-666-9033
Email:Gary.Logan@dfo-mpo.gc.ca	Fax Number:

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

Lingcod, coast-wide abundance and updated science advice on the status of the stock with respect to the new precautionary approach policy.

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

There is currently a commercial and recreational fishery for lingcod in outside waters along the coast of British Columbia. There is also a limited recreational fishery, fishing mortality cap in place, within the Strait of Georgia. Lingcod abundance and catch limits require review. In addition, the Strait of Georgia lingcod rebuilding model requires an update with specific reference to rebuilding of lingcod abundance within Areas 28 and 29. The last assessment for lingcod in outside waters was completed in 2002 while the Strait of Georgia was last assessed in 2005. Lingcod is becoming more important to the recreational fishery along the entire coast of BC with reduced salmon opportunity and a reduced TAC for halibut.

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

Groundfish management is submitting several species for review. Hopefully these can all be addressed within the multi-species survey.

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?

Inform management decisions for commercial and recreational users for the following season.

Date Advice Required: Opening of the 2009 groundfish fishery.

Latest possible date to receive Science advice: Strait of Georgia, model review, March 2010, coast-wide assessment, December 2009.

Rationale justifying this date: Advice for 2010 commercial fishery with a common season (opening/closing date) of late February 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: X Date: January 2, 2009

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.

APPENDIX B. CATCH DATA

Lingcod catch data has been recorded from a variety of sources since 1927 (Table B - 1). Prior to 1927, lingcod landings were grouped with other groundfish species into a 'cod' category, though there is some suggestion that lingcod comprised almost all of the catch (Ketchen et al. 1983). Hook and line catch of lingcod dominated the total coastwide catch until the late-1950s (Figure B - 1). Since the late-1950s, the trawl catch has accounted for the majority of lingcod landings (Figure B - 1). Since the initiation of a quotas in all Areas in 1993, the coastwide trawl catch has averaged 1,869 tonnes annually; the annual hook and line coastwide catch has averaged 914 tonnes (Figure B - 2 to Table B - 5). Since 1954, the majority of the total commercial catch of lingcod has been in Area 3C, although during the late-1980s to early-1990s and in some recent years, the total commercial catch of lingcod in 5AB has been equivalent or greater than that in 3C (Figure B - 2). Since 1993, Areas 3D and 5CDE have had similar levels of annual lingcod catch (17% and 20% of the coastwide total, respectively (Table B - 3 and Table B - 5). However, since 1999, the commercial catch of lingcod in 5E has developed from virtually non-existent to accounting for almost 10% of the coastwide lingcod catch, which has resulted in a 5CDE lingcod catch that is consistently higher than the catch in 3D. Estimates of discard mortality were not included in catch statistics (Tables B-2 to B-5).

In 1996, the commercial groundfish trawl fishery began a 100% at-sea onboard observer program. All fishing events were observed by an independent on-board observer, who records estimates of retained and discarded catch for quota species including lingcod. The longline fishery was only partially covered through logbook records and at-sea observers (DFO 2007). In 2006, an extensive pilot plan for the integration of commercial groundfish fisheries was initiated (DFO 2006). The Integrated Fisheries Management Plan (IFMP) implemented individual transferable quotas (ITQs) in all groundfish fisheries not currently under a quota regime. This system allows fishers to account for their bycatch by considering discard mortality of individual species – including lingcod - in commercial quota recommendations for all groundfish. Since 2006, 100% at-sea electronic- and video-monitoring systems have been in place for all commercial trap and longline vessels.

Lingcod are captured by the recreational fishery throughout British Columbia waters. Creel survey programs do not have complete geographic or seasonal coverage; both of which vary by year. Since 1984, creel surveys have been conducted in and around Barkley and Clayoquot Sounds of Area 3C. Creel survey programs have been conducted since 1992 and 1998 in Areas 3D and 5DE, respectively. Recreational fishing in Areas 5AB and 5C are mainly conducted through lodges with catch estimates available through voluntary logbook submission since 1993. Due to the patchy coverage of the creel survey programs, recreational catch estimates are available starting mid-way through the assessment time period (1984 for Area 3C, 1998 for Area 3D, 1993 for Area 5AB, 1992 for Area 5CDE; Table B - 6). Missing values between 1927 and the first year of sampling for each area, as well as a period of missing data between 1990 and 1994 for Area 3C, were previously infilled by Cuif et al. (2009). We use these infilled values in the current assessment so that recreational catch is represented from 1927 to 2010 in all areas. The steps taken by Cuif et al. to infill missing values are as follows:

(i) Set recreational catch in all areas to zero in 1927.
(ii) For each area, infill 1970 to the start year (i.e., the first year of available data, ranging from 1984 to 1998 depending on the area) as a constant annual catch set at the average value between the start year and 2008.
(iii) Infill 1928 to 1969 as a linear increase from zero in 1927 to the infilled 1970 level.
(iv) For area 3C only, infill the years between 1990 and 1994 using lingcod recreational catch estimates from the Barkely Sound creel survey survey alone. Note that this final step likely causes an underestimate for this area in these five years.

Recreational lingcod catch estimates were available as pieces (Table B - 6); conversion to tonnes was done by applying an average weight of 1.6 kg as per Leaman and McFarlane (1997). There are insufficient biological data collected by creel survey programs to update this estimate average weight.

Table B - 1. Sources of lingcod commercial catch data (1927-2009).

Years and Data Type	Sources and Notes
1927-1946 Total Catch	Dominion Bureau of Statistics, Fisheries Division (in Waddell and Ware 1995). Catches were reported as dressed weight, DW (head and viscera removed; Wilby 1937), and converted to round weight, RW, using the formula RW = 1.39 * DW (K. Rutherford, pers. comm., DFO, Pacific Region, Nanaimo, BC). Catch was not reported by gear type, but is known to be primarily from the line fishery, especially in nearshore waters (Forrester et al. 1978).
1945-1953 Trawl	Thomson and Yates (1960, 1961a, 1961b). Data obtained by Port Observers and supplemented with sales slip records.
1945-1946 Line	Calculated as difference between Total Catch and Canadian Trawl (above).
1945-1946 Area 3D Catch	Total Catch for these years in Area 3D was less than Canadian Trawl Catch suggesting that an error may have occurred when data was tabulated. Trawl catch is assumed to be correct, as it is based on two DFO sources (port observers and sales slip records). Total catch and line catch are not available.
1947-1950 Line and Total Catch	No area totals available for line or total catch. Coastwide total catch reported in Dominion Bureau of Statistics, Fisheries Division.
1951-1993 Line	Obtained from Fisheries and Oceans Canada, British Columbia Catch Statistics Annual Reports which summarize catch from sales slip records. Catches were reported as dressed weight, DW (head and viscera removed; Wilby 1937), and converted to round weight, RW, using the formula RW = 1.39 * DW (K. Rutherford, pers. comm., DFO, Pacific Region, Nanaimo, BC). Catches for 1982-1993 were reported as round weight, but included the conversion factor for reference.
1954-1955 United States Trawl	Ketchen (1976).
1956-1982 United States Trawl	Pacific States Marine Fisheries Commission, PSMFC (Will Daspit, pers. comm.). Prior to 1975 PSMFC reported Canadian and U.S. trawl data in combined format; therefore for 1954-1974, U.S. catch was determined by subtracting Canadian catch from the combined catch.
1965-1977 Russian, Japanese and Polish Trawl	Estimated by applying area-specific lingcod to rockfish catch ratios in research trawl surveys (Westrheim 1967) to rockfish catches reported in INPFC Statistical Yearbooks, Ketchen (1980) and Stanley et al. (2009a).
1954-1995 Trawl	Obtained from the groundfish catch database, GFCatch (Fisheries and Oceans Canada, Pacific Region, Groundfish Data Unit, Nanaimo, BC). Catch data based on logbook records and/or sales slip records.
1994-1995 Line	Obtained from the sales slip database, PacHarv3 ((Fisheries and Oceans Canada, Pacific Region, Groundfish Data Unit, Nanaimo, BC).
1996-March 31, 2006 Line	Obtained from the sales slip database, PacHarv3 (Fisheries and Oceans Canada, Pacific Region, Groundfish Data Unit) and from the Dock-Side Monitored Hook and Line database, PacHarvHL (Fisheries and Oceans Canada, Pacific Region, Groundfish Data Unit, Nanaimo, BC).
1996-March 31 2007 Trawl	Obtained from the groundfish trawl observer database, PacHarvest (Fisheries and Oceans Canada, Pacific Region, Groundfish Data Unit).
April 1 2006-2009 Line	GFFOS database (DFO, Pacific Region, Catch Statistics Unit, Vancouver, BC)
April 1 2007-2009 Trawl	GFFOS database (DFO, Pacific Region, Catch Statistics Unit, Vancouver, BC)

Table B - 2. Commercial catch (tonnes) of lingcod in Area 3C.

Year	Line	Trawl				Total	Year	Line	Trawl				Total
		Canada	U.S.	Foreign	Total	Catch			Canada	U.S.	Foreign	Total	Catch
1927	--	--	0	0	--	245	1969	171	618	465	3	1086	1257
1928	--	--	0	0	--	259	1970	286	537	193	4	734	1020
1929	--	--	0	0	--	186	1971	230	732	252	4	988	1218
1930	--	--	0	0	--	174	1972	267	517	112	7	636	903
1931	--	--	0	0	--	101	1973	184	786	94	2	882	1066
1932	--	--	0	0	--	89	1974	226	956	89	25	1070	1296
1933	--	--	0	0	--	89	1975	216	1225	424	6	1655	1871
1934	--	--	0	0	--	125	1976	253	701	506	1	1208	1461
1935	--	--	0	0	--	243	1977	267	628	216	0	844	1111
1936	--	--	0	0	--	228	1978	200	355	6	0	361	561
1937	--	--	0	0	--	35	1979	181	592	10	0	602	783
1938	--	--	0	0	--	235	1980	213	622	1	0	623	836
1939	--	--	0	0	--	153	1981	240	604	0	0	604	844
1940	--	--	0	0	--	553	1982	220	1510	0	0	1510	1730
1941	--	--	0	0	--	229	1983	170	971	0	0	971	1141
1942	--	--	0	0	--	267	1984	128	1737	0	0	1737	1865
1943	--	--	0	0	--	354	1985	192	3416	0	0	3416	3608
1944	--	--	0	0	--	286	1986	268	834	0	0	834	1102
1945	79	206	0	0	206	285	1987	234	492	0	0	492	726
1946	246	135	0	0	135	381	1988	118	565	0	0	565	683
1947	--	107	0	0	107	107	1989	131	848	0	0	848	979
1948	--	240	0	0	240	240	1990	238	1177	0	0	1177	1415
1949	--	375	0	0	375	375	1991	181	1265	0	0	1265	1446
1950	--	526	0	0	526	526	1992	145	976	0	0	976	1121
1951	212	514	0	0	514	726	1993	215	1428	0	0	1428	1643
1952	190	259	0	0	259	449	1994	187	688	0	0	688	875
1953	83	269	0	0	269	352	1995	198	805	0	0	805	1003
1954	241	416	387	0	803	1044	1996	112	784	0	0	784	896
1955	169	572	667	0	1239	1408	1997	160	483	0	0	483	643
1956	156	730	411	0	1141	1297	1998	150	528	0	0	528	678
1957	295	550	512	0	1062	1357	1999	139	269	0	0	269	408
1958	156	493	545	0	1038	1194	2000	156	477	0	0	477	633
1959	181	358	1371	0	1729	1910	2001	149	409	0	0	409	558
1960	218	468	1399	0	1867	2085	2002	124	416	0	0	416	540
1961	136	706	1266	0	1972	2108	2003	158	516	0	0	516	674
1962	228	224	666	0	890	1118	2004	145	635	0	0	635	780
1963	180	197	448	0	645	825	2005	151	773	0	0	773	924
1964	101	426	757	0	1183	1284	2006	47	821	0	0	821	868
1965	122	764	1125	0	1889	2011	2007	75	496	0	0	496	571
1966	158	685	1368	17	2070	2228	2008	107	713	0	0	713	820
1967	246	794	990	12	1796	2042	2009	64	497	0	0	497	561
1968	162	974	719	9	1702	1864							

Table B - 3. Commercial catch (tonnes) of lingcod in Area 3D.

Year	Line	Trawl				Total	Year	Line	Trawl				Total
		Canada	U.S.	Foreign	Total	Catch			Canada	U.S.	Foreign	Total	Catch
1927	--	--	0	0	--	44	1969	78	513	106	4	623	701
1928	--	--	0	0	--	64	1970	159	379	77	5	461	620
1929	--	--	0	0	--	13	1971	115	214	50	4	268	383
1930	--	--	0	0	--	36	1972	182	65	19	9	93	275
1931	--	--	0	0	--	4	1973	84	114	58	3	175	259
1932	--	--	0	0	--	0	1974	113	129	113	31	273	386
1933	--	--	0	0	--	0	1975	90	146	200	8	354	444
1934	--	--	0	0	--	0	1976	91	110	135	1	246	337
1935	--	--	0	0	--	3	1977	108	96	62	0	158	266
1936	--	--	0	0	--	7	1978	88	185	12	0	196	284
1937	--	--	0	0	--	4	1979	101	92	54	0	147	248
1938	--	--	0	0	--	1	1980	88	86	40	0	127	215
1939	--	--	0	0	--	3	1981	113	75	12	0	87	200
1940	--	--	0	0	--	6	1982	175	49	0	0	49	224
1941	--	--	0	0	--	6	1983	153	447	0	0	447	600
1942	--	--	0	0	--	8	1984	153	322	0	0	322	475
1943	--	--	0	0	--	620	1985	194	380	0	0	380	574
1944	--	--	0	0	--	164	1986	229	246	0	0	246	475
1945	--	287	0	0	287	287	1987	327	88	0	0	88	415
1946	--	175	0	0	175	175	1988	242	283	0	0	283	525
1947	--	53	0	0	53	53	1989	196	300	0	0	300	496
1948	--	24	0	0	24	24	1990	241	421	0	0	421	662
1949	--	73	0	0	73	73	1991	284	549	0	0	549	833
1950	--	88	0	0	88	88	1992	310	554	0	0	554	864
1951	168	73	0	0	73	241	1993	673	448	0	0	448	1121
1952	185	61	0	0	61	246	1994	552	847	0	0	847	1399
1953	89	34	0	0	34	123	1995	373	502	0	0	502	875
1954	140	36	24	0	60	200	1996	186	222	0	0	222	408
1955	93	66	90	0	156	249	1997	173	97	0	0	97	270
1956	125	55	112	0	167	292	1998	186	162	0	0	162	348
1957	135	83	45	0	128	263	1999	197	127	0	0	127	324
1958	120	49	59	0	108	228	2000	220	277	0	0	277	497
1959	94	10	53	0	63	157	2001	167	187	0	0	187	354
1960	106	37	50	0	87	193	2002	220	183	0	0	183	403
1961	116	71	128	0	199	315	2003	178	227	0	0	227	405
1962	104	52	233	0	285	389	2004	194	230	0	0	230	424
1963	122	52	64	0	116	238	2005	166	214	0	0	214	380
1964	85	199	27	0	226	311	2006	124	168	0	0	168	292
1965	90	423	82	0	505	595	2007	148	126	0	0	126	274
1966	136	526	59	22	607	743	2008	136	111	0	0	111	247
1967	167	375	85	15	475	642	2009	158	149	0	0	149	307
1968	108	719	150	11	880	988							

Table B - 4. Commercial catch (tonnes) of lingcod in Area 5AB.

Year	Line	Trawl				Total Catch
		Canada	U.S.	Foreign	Total	
1927	--	--	0	0	--	0
1928	--	--	0	0	--	0
1929	--	--	0	0	--	0
1930	--	--	0	0	--	1
1931	--	--	0	0	--	0
1932	--	--	0	0	--	0
1933	--	--	0	0	--	0
1934	--	--	0	0	--	0
1935	--	--	0	0	--	3
1936	--	--	0	0	--	1
1937	--	--	0	0	--	1
1938	--	--	0	0	--	1
1939	--	--	0	0	--	3
1940	--	--	0	0	--	7
1941	--	--	0	0	--	39
1942	--	--	0	0	--	54
1943	--	--	0	0	--	86
1944	--	--	0	0	--	153
1945	224	32	0	0	32	256
1946	175	56	0	0	56	231
1947	--	16	0	0	16	16
1948	--	47	0	0	47	47
1949	--	95	0	0	95	95
1950	--	46	0	0	46	46
1951	35	80	0	0	80	115
1952	32	71	0	0	71	103
1953	4	17	0	0	17	21
1954	10	51	166	0	217	227
1955	19	50	215	0	265	284
1956	35	236	359	0	595	630
1957	12	252	345	0	597	609
1958	2	309	258	0	567	569
1959	4	369	247	0	616	620
1960	23	307	351	0	658	681
1961	49	366	345	0	711	760
1962	69	497	441	0	938	1007
1963	77	242	400	0	642	719
1964	33	373	315	0	688	721
1965	23	226	671	22	919	942
1966	59	478	1056	71	1605	1664
1967	40	413	1247	54	1714	1754
1968	41	766	1503	32	2301	2342
1969	57	377	756	23	1156	1213
1970	82	268	712	11	991	1073
1971	58	287	367	2	656	714
1972	109	267	373	9	649	758
1973	67	166	415	18	599	666
1974	84	253	618	46	917	1001
1975	75	320	212	21	553	628
1976	92	415	186	11	612	704
1977	78	300	78	3	381	459
1978	39	273	15	0	288	327
1979	54	320	21	0	341	395
1980	58	399	14	0	413	471
1981	49	730	0	0	730	779
1982	54	1047	0	0	1047	1101
1983	57	1345	0	0	1345	1402
1984	75	716	0	0	716	791
1985	85	877	0	0	877	962
1986	61	1651	0	0	1651	1712
1987	131	1431	0	0	1431	1562
1988	125	1291	0	0	1291	1416
1989	159	1616	0	0	1616	1775
1990	200	2119	0	0	2119	2319
1991	305	1857	0	0	1857	2162
1992	262	1262	0	0	1262	1524
1993	102	1421	0	0	1421	1523
1994	129	1334	0	0	1334	1463
1995	166	1239	0	0	1239	1405
1996	187	659	0	0	659	846
1997	143	411	0	0	411	554
1998	216	454	0	0	454	670
1999	200	583	0	0	583	783
2000	189	919	0	0	919	1108
2001	206	641	0	0	641	847
2002	190	892	0	0	892	1082
2003	156	807	0	0	807	963
2004	188	706	0	0	706	894
2005	199	567	0	0	567	766
2006	140	750	0	0	750	890
2007	206	505	0	0	505	711
2008	324	419	0	0	419	743
2009	245	428	0	0	428	673

Table B - 5. Commercial catch (tonnes) of lingcod in Area 5CDE.

Year	Line	Trawl				Total Catch
		Canada	U.S.	Foreign	Total	
1927	--	--	0	0	--	13
1928	--	--	0	0	--	26
1929	--	--	0	0	--	35
1930	--	--	0	0	--	17
1931	--	--	0	0	--	1
1932	--	--	0	0	--	3
1933	--	--	0	0	--	4
1934	--	--	0	0	--	1
1935	--	--	0	0	--	6
1936	--	--	0	0	--	6
1937	--	--	0	0	--	6
1938	--	--	0	0	--	7
1939	--	--	0	0	--	8
1940	--	--	0	0	--	7
1941	--	--	0	0	--	8
1942	--	--	0	0	--	22
1943	--	--	0	0	--	72
1944	--	--	0	0	--	117
1945	163	16	0	0	16	179
1946	247	245	0	0	245	492
1947	6	9	0	0	9	15
1948	--	115	0	0	115	115
1949	--	182	0	0	182	182
1950	--	94	0	0	94	94
1951	53	136	0	0	136	189
1952	47	62	0	0	62	109
1953	5	22	0	0	22	27
1954	9	25	75	0	100	109
1955	3	38	178	0	216	219
1956	5	38	54	0	92	97
1957	6	57	71	0	128	134
1958	9	35	39	0	74	83
1959	17	57	59	0	116	133
1960	22	82	34	0	116	138
1961	34	63	33	0	96	130
1962	54	100	13	0	113	167
1963	47	117	29	0	146	193
1964	43	192	23	0	215	258
1965	64	234	21	37	292	356
1966	47	258	7	59	324	371
1967	62	256	69	20	345	407
1968	65	378	5	35	418	483
1969	92	244	0	14	258	350
1970	120	207	1	7	215	335
1971	136	265	58	10	333	469
1972	128	154	0	13	167	295
1973	93	123	0	9	132	225
1974	113	119	1	10	130	243
1975	107	170	0	9	179	286
1976	74	98	1	14	113	187
1977	63	120	0	8	128	191
1978	56	48	0	0	48	104
1979	64	128	0	0	128	192
1980	89	170	0	0	170	259
1981	52	265	0	0	265	317
1982	84	192	0	0	192	276
1983	108	144	0	0	144	252
1984	128	145	0	0	145	273
1985	176	138	0	0	138	314
1986	177	136	0	0	136	313
1987	324	367	0	0	367	691
1988	290	349	0	0	349	639
1989	286	272	0	0	272	558
1990	371	304	0	0	304	675
1991	317	528	0	0	528	845
1992	290	445	0	0	445	735
1993	296	456	0	0	456	752
1994	203	546	0	0	546	749
1995	284	555	0	0	555	839
1996	218	213	0	0	213	431
1997	143	125	0	0	125	268
1998	257	91	0	0	91	348
1999	445	93	0	0	93	538
2000	439	178	0	0	178	617
2001	403	135	0	0	135	538
2002	277	322	0	0	322	599
2003	370	194	0	0	194	564
2004	405	203	0	0	203	608
2005	396	140	0	0	140	536
2006	261	92	0	0	92	353
2007	348	98	0	0	98	446
2008	366	126	0	0	126	492
2009	293	180	0	0	180	473

Table B - 6. Estimated recreational catch (pieces) available from creel survey programs or voluntary lodge/charter logbook submissions.

Year	3C	3D	5AB	5CDE
1984	2818			
1985	6478			
1986	645			
1987	9959			
1988	4372			
1989	8853			
1990				
1991				
1992				2469
1993			625	2914
1994			617	2949
1995	4016		1284	4654
1996	1830		1270	4605
1997	5993		2595	3652
1998	7002	588	2244	3650
1999	2574	1531	2079	4723
2000	138	248	2772	6770
2001	3415	4168	2532	9675
2002	9172	7789	2481	8461
2003	1964	2176	2370	5224
2004	1664	2102	2601	6675
2005	2347	2574	2403	5207
2006	4037	4954	3683	6337
2007	9253	6191	4191	1151
2008	11772	10689	2685	13145
2009	3564	7531	2177	14003

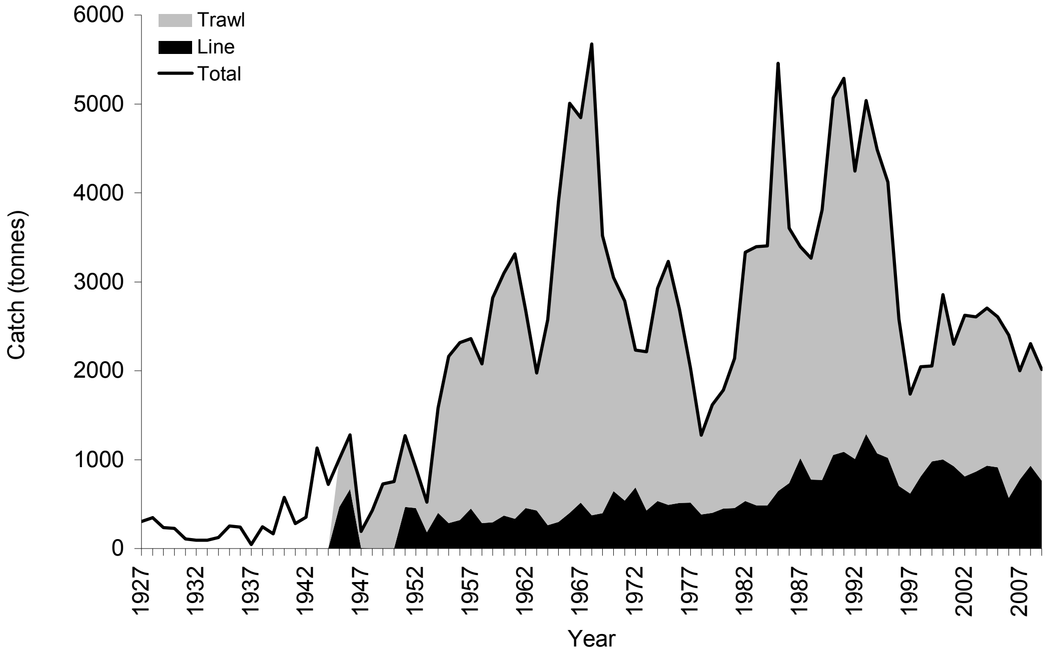

Figure B - 1. Coastwide hook and line, trawl and total commercial catch (tonnes) of lingcod in Canadian waters.

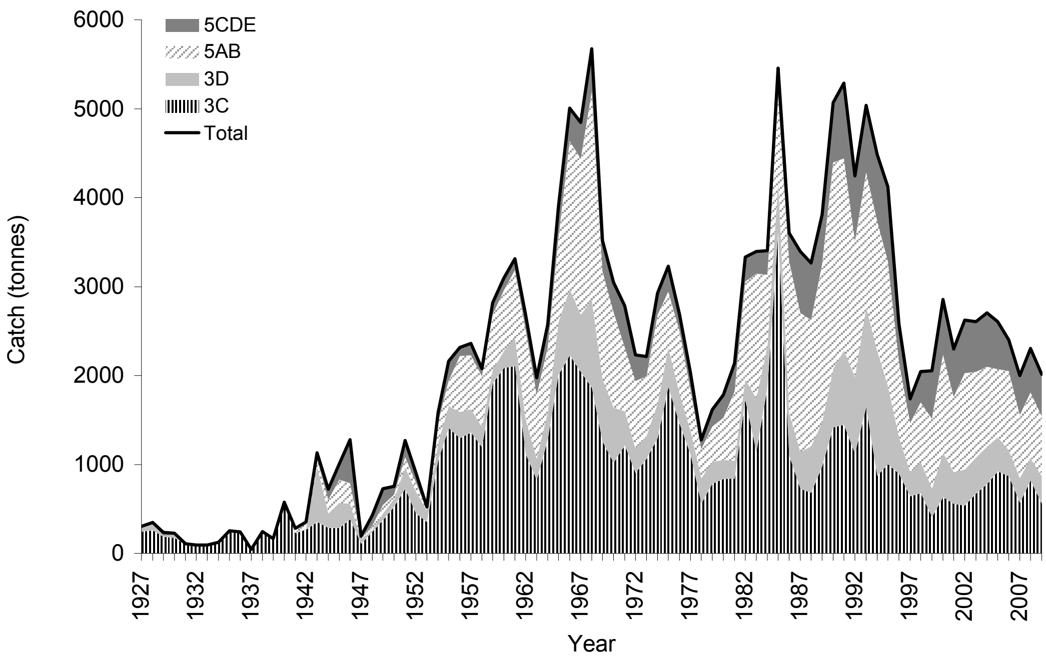

Figure B - 2. Total commercial catch (tonnes) of lingcod by assessment Area.

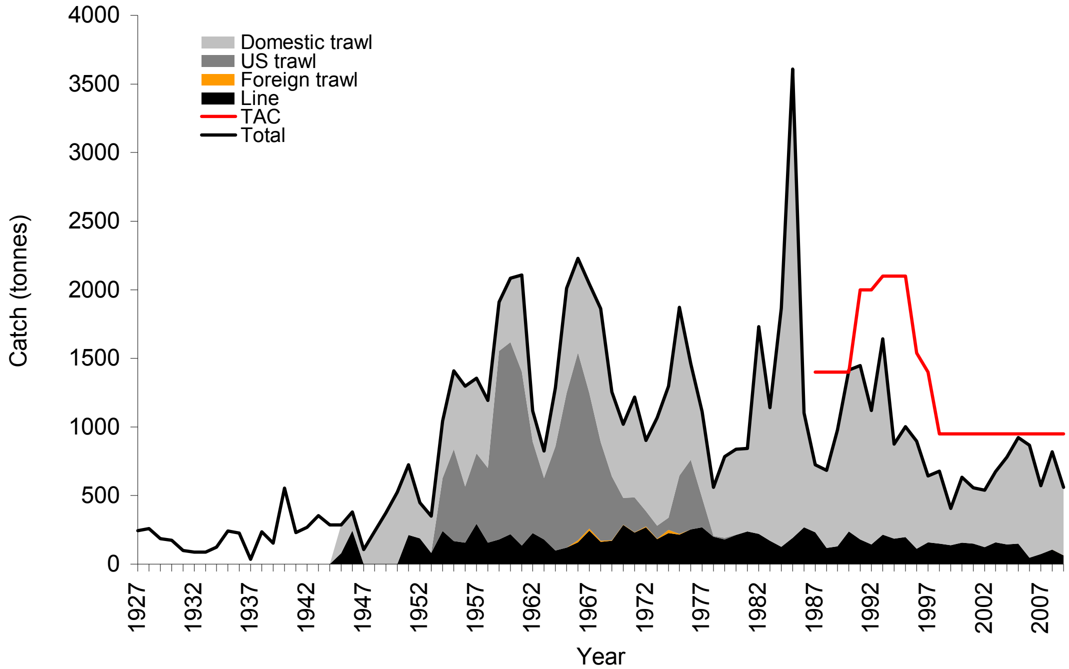

Figure B - 3. Area 3C lingcod commercial catch (tonnes) by hook and line (1945-2009), domestic trawl (1945-2009), US trawl in 3C waters (1954-1981), foreign (Japan, Poland, Russia) trawl in 3C waters (1963-1977). Total commercial catch (1927-2009) represents all gear and nation catch; prior to 1945 commercial lingcod catch was not recorded by gear type but was predominantly hook and line. Total Allowable Catch (all gear) was implemented in 1987. Sources of data outlined in Table B - 6.

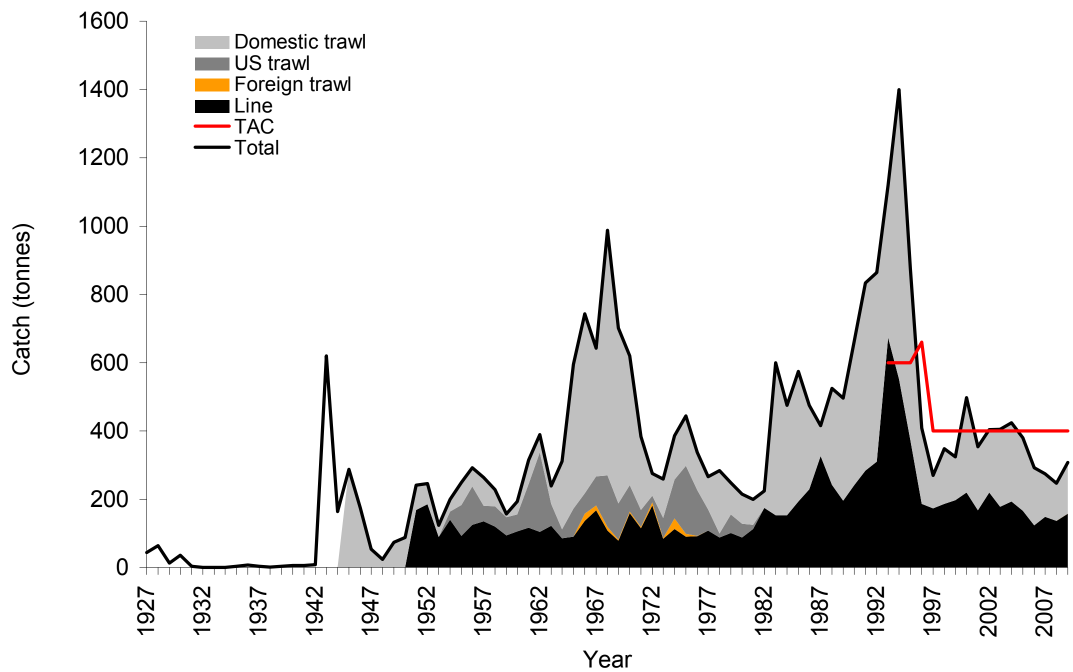

Figure B - 4. Area 3D lingcod commercial catch (tonnes) by hook and line (1945-2009), domestic trawl (1945-2009), US trawl in 3D waters (1954-1981), foreign (Japan, Poland, Russia) trawl in 3D waters (1963-1977). Total commercial catch (1927-2009) represents all gear and nation catch; prior to 1945 commercial lingcod catch was not recorded by gear type but was predominantly hook and line. Total Allowable Catch (all gear) was implemented in 1993. Sources of data outlined in Table B - 6.

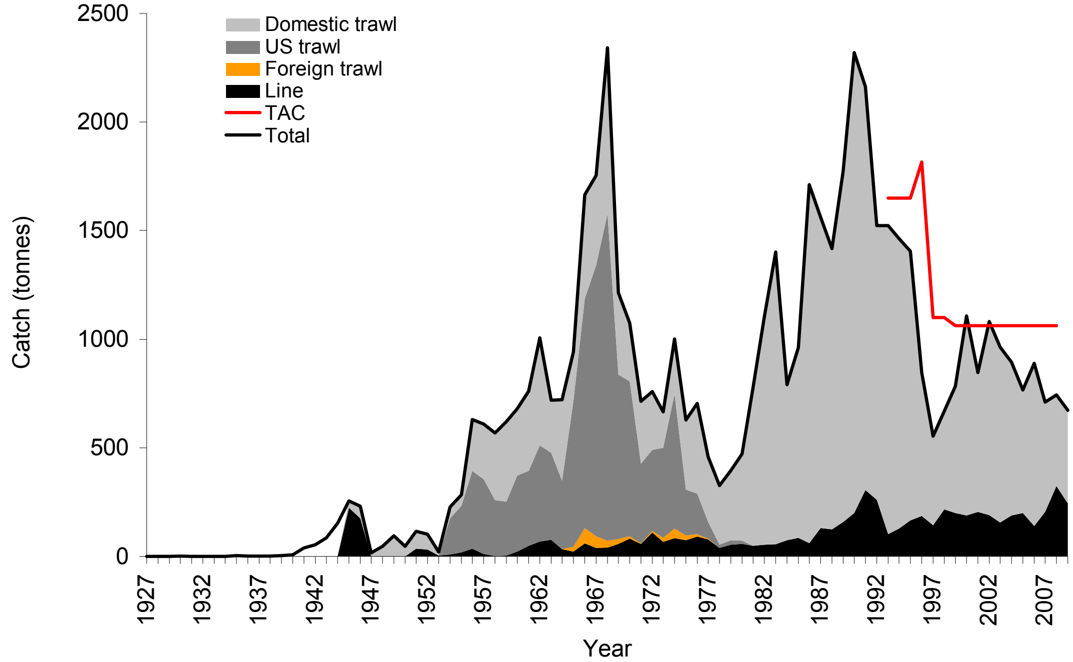

Figure B - 5. Area 5AB lingcod commercial catch (tonnes) by hook and line (1945-2009), domestic trawl (1945-2009), US trawl in 5AB waters (1954-1981), foreign (Japan, Poland, Russia) trawl in 5AB waters (1963-1977). Total commercial catch (1927-2009) represents all gear and nation catch; prior to 1945 commercial lingcod catch was not recorded by gear type but was predominantly hook and line. Total Allowable Catch (all gear) was implemented in 1993. Sources of data outlined in Table B - 6.

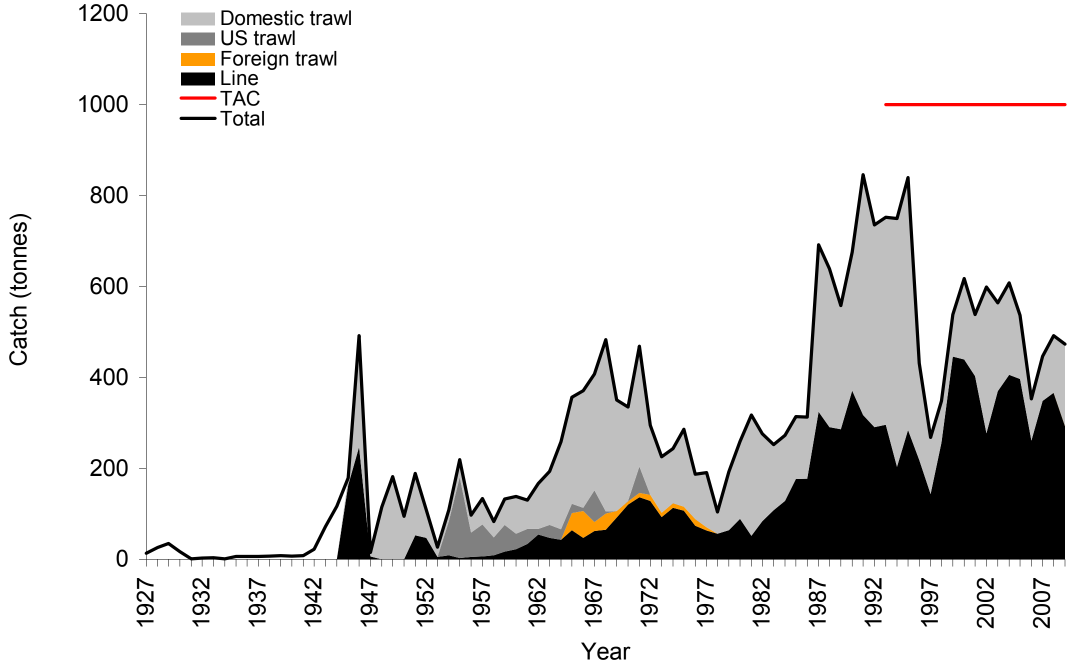

Figure B - 6. Area 5CDE lingcod commercial catch (tonnes) by hook and line (1945-2009), domestic trawl (1945-2009), US trawl in 5CDE waters (1954-1981), foreign (Japan, Poland, Russia) trawl in 5CDE waters (1963-1977). Total commercial catch (1927-2009) represents all gear and nation catch; prior to 1945 commercial lingcod catch was not recorded by gear type but was predominantly hook and line. Total Allowable Catch (all gear) was implemented in 1993. Sources of data outlined in Table B - 6.

APPENDIX C. FISHERY CPUE

A stepwise general linear model (GLM) regression procedure was used to estimate a time series of relative annual changes in catch-per-unit-effort (CPUE) based on the relationship between CPUE and available predictive variables (factors). Data were derived from the DFO GFFOS, PacHarvestTrawl and GFCatch commercial catch and effort databases. This approach is commonly used to analyse fisheries catch and effort data and has been described in Hilborn and Walters (1992) and Quinn and Deriso (1999).

Quinn and Deriso (1999; page 19) described a general linear model based on the lognormal distribution:

(*Eq. C-1*) $$U_{ijk} = U_0 \prod_i \prod_j P_{ij}^{X_{ij}} e^{\varepsilon_{ijk}}$$

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

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

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

(*Eq. C-2*) or

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

where, p is the total number of predictive factors included in the model and n_i is the number of levels (or categories) for predictive factor i. In the second form of the model, β_0 is the intercept of the model and β_{ij} is the logged coefficient of the factor j at level i under consideration.

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

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

(*Eq. C-3*) $$\beta_j^{'} = \beta_j \big/ \overline{\beta}$$

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

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

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

A range of predictive factors (P_{ij}) are available in the databases that can be used to account for variability in observed CPUE. These factors include the date of capture (usually year and month), the capturing vessel, the depth of capture, and the location of capture. The year of capture is usually given special significance in these analyses because between-year variation in the year effect is interpreted as relative changes in the annual stock abundance. The resulting series of 'year' or 'year' canonical coefficients is termed the "Standardised" annual CPUE index $\left[Y_j^{'}\right]$ in this report.

A selection procedure (Vignaux 1993, Vignaux 1994; Francis 2001) was applied to determine the relative importance of these predictive factors in the model. The procedure involves a forward stepwise fitting algorithm which generates regression models iteratively, starting with the simplest model (one response variable and one predictive variable [factor]) and building in complexity subject to a stopping rule designed to include only the most important predictive factors.

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

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

Model diagnostic tools were used to ensure that residuals from the final model fit were generally consistent with the underlying lognormal assumption.

In addition to the Standardized index described above, two other methods are available for calculating annual CPUE indices from catch and effort data. Although only the Standardized index was used as input to the surplus production model in the current assessment (Appendix F), we present the other two indices in this Appendix for the sake of comparison. The first alternative method, termed the "Arithmetic" CPUE index in this report, uses a simple mean annual CPUE specified as:

(*Eq. C-5*)
$$R_j = \frac{\sum_{k=1}^{M_j} C_{jk}}{\sum_{k=1}^{M_j} E_{jk}}$$

where C_{jk} denotes that catch and E_{jk} denotes the effort for each record *k* in year *j*. The second alternative index, termed the "Unstandardized" CPUE index in this report, is specified by:

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

where U_j is the annual geometric mean of the CPUE observations. Annual estimates obtained using Eq. C-6 are equivalent to the results obtained from a linear model where year is the only predictive factor.

Like the scaling described for the standardised index, the series specified by Eq. C-5 and Eq. C-6 can be scaled relative to their geometric means. This is done to provide comparability with the standardised indices. Given *n* years in each series, the geometric means of the arithmetic and unstandardised series are given by $\bar{R} = \sqrt[n]{\prod_1^n R_j}$ and $\bar{U} = \sqrt[n]{\prod_1^n U_j}$, respectively. Thus, each series can be scaled to the corresponding geometric mean as:

(Eq. C-7)
$$R_j^{'} = {R_j}/{\bar{R}}$$

and

(Eq. C-8)
$$U_j^{'} = {U_j}/{\bar{U}}$$

The procedures described by Eq. C-1, Eq. C-2 and Eq. C-6 are necessarily confined to the positive catch observations in the data set as ln(0) is undefined. Observations with zero catch were dropped from this analysis.

Limitations of GLM standardization

There are two limitations with respect to the use of GLMs to standardize CPUE time series that should be noted:

1. The standardisation procedure operates under the assumption that the variable effects (other than the year or abundance effect) included in the model are constant across all years and can be estimated by the model. If this assumption is incorrect, there will be a [year]:[effect] interaction which will invalidate the model.
2. A potentially more serious problem is the underlying assumption that the CPUE series tracks abundance. This is an extension of the previous concern. If there exist effects independent of abundance which change over time that are inadequately standardised or are unknown, the annual abundance indices will include these as changes in the "year" variable and consequently will be interpreted as a change in abundance. These effects will include the [year]:[effect] interactions described above or any other effects for which the data are incomplete or unavailable. Unless supporting data that allow for the quantification of these effects are available, these effects will be confounded with the abundance index and will lead to a biased index of abundance. If these additional effects are sufficiently large, the CPUE index will not be a reliable index of abundance and should not be used in stock assessment.

Despite these limitations, the GLM stadardization approach was determined to be a better alternative to arithmetic or unstandardized time CPUE time series for input into the current stock assessment model.

DATA SELECTION

Data were selected from three DFO catch/effort databases using the following criteria:

GFCatch (tow start date): 1 January 1954 to 31 December 1995 PacHarvTrawl (tow start date): 16 February 1996 to 31 March 2007 GFFOS (tow best date): 1 April 2007 to 30 June 2010
Bottom trawl type (in GFFOS: hard and soft bottom type)
Fished in a valid outside DFO Major region
PacHarvTrawl and GFFOS: Fishing success code <=1 (code 0= unknown; code 1= useable)
Catch of at least one fish or invertebrate species (no water hauls)
Valid depth field
GFCatch: vessel information not used PacHarvTrawl and GFFOS: vessel had been in the fishery for at least 3 years with a minimum of 5 trips in each of those years
PacHarvTrawl and GFFOS: valid latitude and longitude co-ordinates
GFCatch: valid estimate of time towed that was greater than 0 hours PacHarvTrawl and GFFOS: valid estimate of time towed that was greater than 0 hours and less than 24 hours

Total annual landings and discards for lingcod are presented for DFO major regions from 1954 to the end of June 2010 (Table C - 1). Landings are generated from dockside monitoring programmes which have been in place since 1995. Prior to that year, landings are available from logbooks maintained by fishermen which have been cross-validated with landing slips issued by the receiving processing plant. Discard estimates are considered to be unreliable prior to 1996 because they were based on voluntary reporting and are known to be incomplete. Discards since February 1996 are based on estimates made by an independent at-sea observer and are considered more reliable than those obtained from logbooks.

Table C - 1. Total landed and discarded trawl catches for lingcod in the GFCatch-PacHarvestTrawl-GFFOS databases, summarised by calendar year for major DFO reporting areas. Data from 1 January 1954 to 27 December 1995 are from the GFCatch database (Rutherford 1995). Data from 16 February 1996 to 31 March 2007 are from the PacHarvestTrawl database. Data from 1 April 2007 onwards are from the DFO GFFOS database. The groundfish fishery was closed from 28 December 1995 to 15 February 1996. These catches have been summarised without data selection criteria.

		DFO Major Region									
Year	**Other[1]**	**4B**	**3B**	**3C**	**3D**	**5A**	**5B**	**5C**	**5D**	**5E**	**Total**
	Landed catch (t)										
1954		69.2	0.0	416.1	35.5	12.5	38.9	1.6	23.4		597.2
1955		50.6		571.8	65.6	12.8	37.2	0.2	37.7		775.9
1956		55.7	0.0	730.2	55.2	78.1	158.0	22.8	15.6		1,115.6
1957		42.0	0.0	550.2	83.4	124.1	128.5	30.7	26.3		985.1
1958		74.6	0.2	493.5	48.7	80.4	228.7	11.5	23.6		961.3
1959		336.4	0.0	358.4	10.4	67.2	301.9	18.3	39.1		1,131.7
1960		184.1	0.0	467.7	37.2	85.0	222.2	45.1	36.8		1,078.1
1961		102.1	0.7	706.0	71.2	195.9	170.4	17.2	45.9		1,309.3
1962		75.4	1.1	223.9	52.4	273.9	223.6	65.9	34.6		950.8
1963		39.6	1.8	197.1	51.6	143.9	98.4	68.7	48.6		649.6
1964		90.3	1.6	426.3	198.8	279.1	93.6	142.0	49.7		1,281.5
1965		93.7		764.6	423.0	137.2	88.7	145.7	88.7		1,741.7
1966	0.0	53.7		685.3	526.1	276.4	201.2	158.7	99.0	0.0	2,000.5
1967		51.2	2.7	793.9	374.9	263.9	149.0	182.1	73.9		1,891.6
1968	0.0	83.9	1.4	974.4	718.7	560.3	205.7	233.3	144.6		2,922.3
1969		65.6	1.8	618.1	512.9	263.3	114.3	123.7	120.5		1,820.1
1970	0.3	48.1	0.2	536.7	378.9	230.1	38.1	106.1	101.1	0.0	1,439.6
1971		55.5	0.1	732.5	214.5	161.2	126.0	175.1	89.8		1,554.7
1972		34.5		517.4	65.3	98.3	168.7	62.2	91.7		1,038.2
1973		14.8		785.8	114.3	132.0	34.3	44.4	78.5		1,204.1
1974		49.4		955.7	129.3	157.0	96.1	37.7	81.5		1,506.7
1975		33.2		1,224.8	146.5	61.6	258.6	36.8	133.2		1,894.6
1976	0.2	43.4	0.0	700.9	110.0	176.1	239.2	36.8	61.2	0.0	1,367.8
1977		27.2	0.0	627.7	95.8	95.9	204.0	18.2	101.7	4.6	1,175.2
1978		42.5		355.4	184.7	118.9	154.5	11.8	36.2	3.4	907.5
1979		25.2		592.2	92.4	92.7	227.9	45.0	82.6	1.2	1,159.1
1980		33.5		622.3	86.4	102.8	296.1	55.4	114.9	3.8	1,315.1
1981		63.1		603.9	75.1	182.9	547.7	57.8	207.6	1.2	1,739.2
1982		79.1		1,509.8	48.6	467.3	579.9	96.0	95.6	1.9	2,878.1
1983	0.0	85.3		970.7	446.9	572.8	772.4	49.3	94.2	1.3	2,992.9
1984		42.7		1,737.0	321.8	261.0	454.9	23.2	122.0	8.8	2,971.5
1985		27.1		3,416.3	380.3	407.8	469.3	45.4	92.3	15.0	4,853.5
1986		44.5		834.3	245.8	639.6	1,012.0	52.8	83.2	13.1	2,925.2
1987		17.0		492.2	87.6	675.7	755.8	180.0	186.7	5.8	2,400.8
1988		13.0		565.4	282.8	553.7	737.4	166.6	182.9	19.6	2,521.4
1989		2.9		848.6	299.6	879.0	737.6	128.4	143.5	20.0	3,059.5
1990		0.2		1,176.9	420.7	983.1	1,136.0	136.4	168.2	27.8	4,049.0
1991		1.5		1,265.1	549.3	704.6	1,152.3	332.9	195.7	10.3	4,211.6
1992		2.0		976.4	553.9	552.9	709.7	162.3	283.0	8.8	3,249.1
1993		1.0		1,427.9	448.4	673.1	748.6	207.1	248.7	10.1	3,764.9
1994		4.0		687.9	847.5	771.7	562.3	398.8	147.8	11.8	3,431.8
1995		0.9		805.2	501.8	682.1	557.6	389.3	165.8	8.4	3,111.0
1996	6.2	0.6		784.7	222.3	249.2	409.9	127.0	76.7	9.0	1,885.4
1997	2.2	1.5		482.4	96.6	132.9	278.2	39.3	73.4	12.6	1,119.0
1998	1.7	1.4		527.4	161.6	184.0	270.1	15.0	69.9	6.3	1,237.3
1999	2.5	1.0		268.5	126.9	230.8	353.0	30.1	57.2	5.9	1,075.8
2000	1.8	1.3		477.5	276.7	163.3	754.9	60.1	112.8	5.6	1,854.0

Year	Other[1]	4B	3B	3C	3D	5A	5B	5C	5D	5E	Total
		DFO Major Region									
2001	0.7	0.4		412.2	188.4	175.3	465.8	61.7	68.0	5.1	1,377.7
2002	1.1	0.0		413.4	181.2	314.0	577.8	120.4	195.3	6.1	1,809.4
2003	2.4	0.0		516.5	227.3	278.1	529.2	49.8	142.0	6.1	1,751.5
2004	2.2	0.0		634.5	229.8	356.1	349.7	34.2	152.2	13.2	1,771.9
2005	8.1	0.0		772.8	214.0	186.2	380.6	22.9	106.3	9.8	1,700.6
2006	6.0	0.0		821.7	167.9	249.2	500.9	35.1	47.2	9.6	1,837.5
2007	6.7	0.0		679.0	276.6	310.0	300.5	62.4	58.2	8.0	1,701.4
2008	5.3	0.1		712.8	110.8	143.2	276.3	33.4	85.5	7.3	1,374.8
2009	9.9	0.0		496.6	148.8	162.4	266.0	90.4	84.4	4.9	1,263.4
2010[2]	0.5	0.0		128.1	100.5	44.3	59.1	17.9	6.2	5.4	362.1
Total[3]	57.8	2,266.1	11.5	42,074.9	13,123.3	16,467.0	21,008.9	5,122.7	5,632.6	291.7	106,056.3
	Discarded catch (t)										
1996	0.0	0.2		16.2	6.5	21.5	26.0	6.9	2.6	0.1	80.1
1997	0.0	0.0		18.8	7.2	25.7	57.3	4.7	3.1	0.4	117.2
1998	0.0	0.0		28.2	13.3	47.5	106.7	1.4	2.7	0.1	199.9
1999	0.0	0.0		14.6	5.5	25.3	56.8	1.2	2.8	0.3	106.5
2000	0.0	0.0		16.1	7.4	16.4	60.9	1.9	8.1	0.1	110.9
2001	0.0	0.1		21.2	9.9	12.7	48.6	2.5	7.5	0.1	102.5
2002	0.0	0.6		29.8	15.3	27.2	105.3	4.3	10.3	0.1	192.9
2003	0.0	1.1		32.8	26.7	26.1	65.6	1.9	5.5	0.1	159.7
2004	0.0	0.6		31.9	16.8	17.3	29.6	0.7	1.7	0.1	98.9
2005	0.0	0.1		31.7	17.1	5.3	14.4	0.6	1.2	0.1	70.4
2006	0.0	0.0		28.3	2.9	5.3	20.3	1.4	0.6	0.1	59.1
2007	0.0	0.5		29.9	3.4	10.7	29.0	2.3	1.4	0.3	77.5
2008	0.0	0.8		32.0	3.2	5.5	39.2	1.1	3.3	0.1	85.1
2009	0.0	0.6		34.2	4.0	7.7	19.7	10.6	3.0	0.0	79.7
2010[2]	0.0	0.2		11.6	5.4	4.1	5.4	0.9	0.4	0.1	28.2
Total[4]	0.0	4.6		377.2	144.5	258.5	685.0	42.4	54.2	2.3	1,568.7
	Landed + Discarded catch (t)										
1996	6.2	0.8		800.9	228.8	270.7	435.9	133.8	79.3	9.1	1,965.5
1997	2.2	1.5		501.2	103.8	158.6	335.5	44.0	76.5	12.9	1,236.3
1998	1.7	1.4		555.6	174.9	231.5	376.8	16.4	72.6	6.4	1,437.3
1999	2.5	1.0		283.1	132.4	256.1	409.8	31.3	60.0	6.2	1,182.4
2000	1.8	1.3		493.6	284.1	179.7	815.8	62.0	120.9	5.7	1,964.9
2001	0.7	0.5		433.4	198.3	188.0	514.4	64.2	75.5	5.2	1,480.2
2002	1.2	0.6		443.2	196.6	341.2	683.0	124.7	205.6	6.2	2,002.3
2003	2.4	1.1		549.3	254.0	304.2	594.8	51.7	147.5	6.2	1,911.1
2004	2.2	0.6		666.4	246.6	373.4	379.3	35.0	153.9	13.3	1,870.8
2005	8.1	0.1		804.5	231.0	191.5	395.1	23.5	107.4	9.9	1,771.0
2006	6.0	0.0		850.1	170.8	254.5	521.2	36.6	47.8	9.6	1,896.6
2007	6.7	0.5		708.9	280.0	320.7	329.5	64.7	59.6	8.3	1,778.9
2008	5.3	0.9		744.8	114.0	148.7	315.5	34.5	88.8	7.5	1,459.9
2009	9.9	0.6		530.8	152.8	170.0	285.7	101.0	87.4	5.0	1,343.2
2010	0.5	0.2		139.7	105.9	48.4	64.5	18.8	6.7	5.5	390.3
Total[3]	57.9	2,270.7	11.5	42,452.1	13,267.7	16,725.5	21,693.8	5,165.1	5,686.8	293.9	107,625.0

[1] includes catches in unknown areas and areas outside of Canadian waters
[2] incomplete year: 01 January to 30 June
[3] 01 January 1954 to 30 June 2010
[4] 16 February 1996 to 30 June 2010

A map showing the distribution of mean lingcod CPUE (kg/h), over grids summarising the B.C. bottom trawl fishery from 1996 to 2010, indicates that high catch rates for lingcod are centred over most of the west coast of Vancouver Island plus some sporadic high catch rates in Queen Charlotte Sound and Hecate Strait (Figure C - 1).

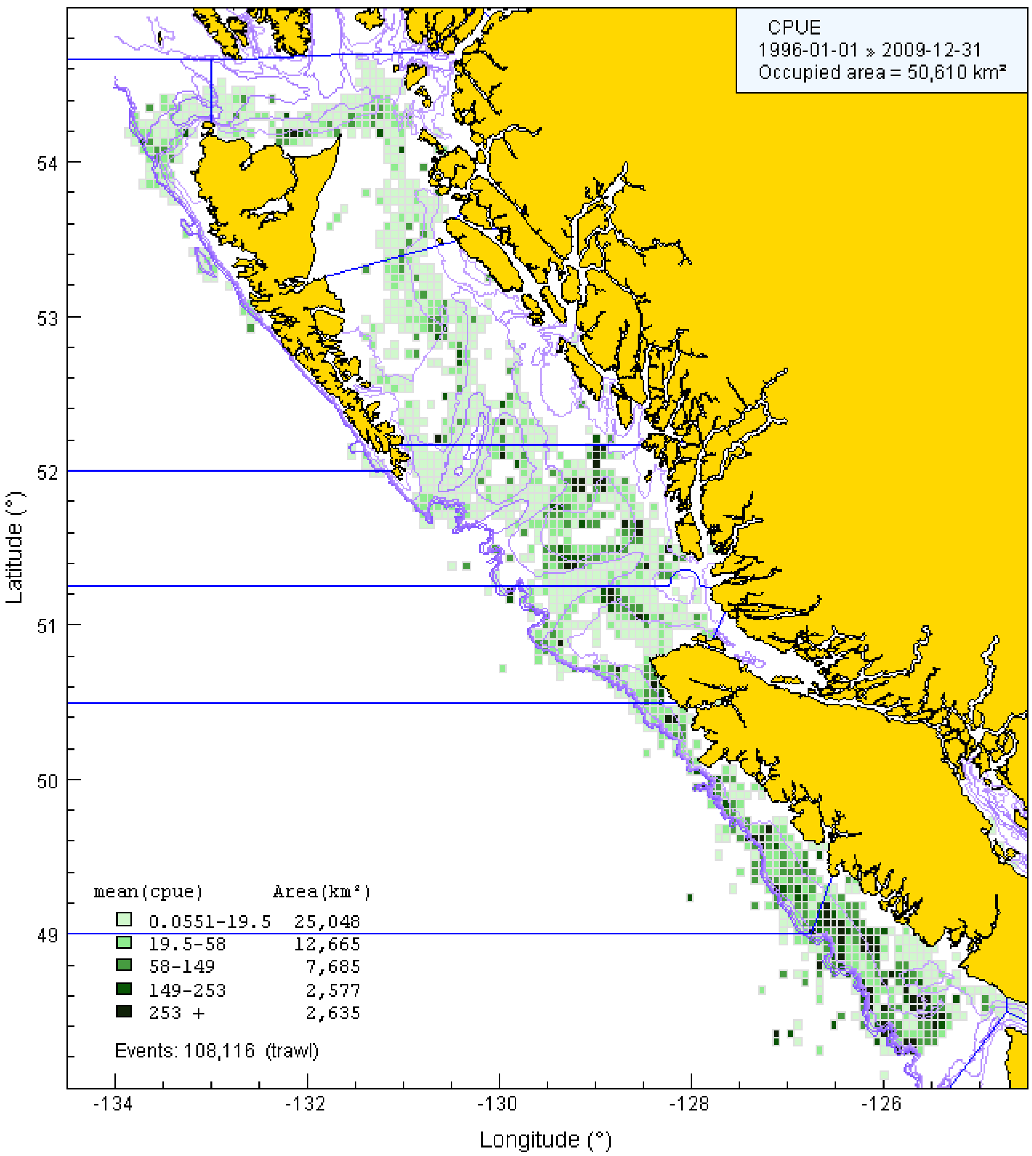

Figure C - 1. Distributional plot of lingcod CPUE (kg/h) allocated across 0.075°W X 0.055°N grids for the period 16 February 1996 to 30 June 2010 (each cell represents approximately 34 km^2). Grid cells have been colour coded to indicate the range in which the mean CPUE for the cell falls over the entire period. The indicated CPUE ranges correspond to these approximate quantiles: 0-50%, 50%–75%, 75–90%, 90–95%, and 95%+.

MODEL SPECIFICATION

Standardization analyses using the stepwise GLM approach were conducted for 5 spatial units: the 4 BC offshore assessment regions (3C, 3D, 5AB, and 5CDE) as well as all four regions combined (COAST). For each spatial unit considered, separate GLM analyses were performed for three different time periods: (1) 1954 – 1990, (2) 1991-1995, and (3) 1996-2010. A total of 15 different analyses were therefore done (5 spatial areas x 3 time periods). We use the notation Area: Time Period (e.g., Area 3C: 1954-1990) to denote each of the 15 models.

Each break between time periods represents a significant change in data collection or fishery management, which are described below. A larger set of predictive factors were available for each successive time period due to increased data availability through time.

(1) The first time period (1954 – 1990) used amalgamated long-term historical data starting in the earliest year possible for each area. CPUE was estimated as landed catch per hour fished because reliable discard estimates are unavailable for this period. All CPUE data in this time period were "rolled up" into daily records stratified by DFO locality and aggregated depth band. Analysis start years for some DFO major regions (e.g., 3D) were postponed to 1956 or 1966 because the locality data for earlier years had a high proportion of localities entered as "Unknown".

Response and predictive variables used in the stepwise GLM for 1954 – 1990 time period*:

Variable Name	Description
Response Variable	
CPUE	Landed catch/hours towed (catch prorated for PacHarvTrawl and GFFOS)
Predictive Variables	
Year	Calendar year (1 January–31 December)
Month	Month
Locality	DFO locality (Rutherford 1995)
Depth	Depth aggregated into 25 m depth bands

* Data obtained from GFCatch, PacHarvTrawl and GFFOS databases.

(2) The second time period (1991 – 1995) used tow-by-tow data, which became available starting in 1991. CPUE was estimated as landed catch per hour fished because reliable discard estimates are unavailable for this period.

Response and predictive variables used in the stepwise GLM for 1991 – 1995 time period*:

Variable Name	Description
Response Variable	
CPUE	Landed catch / hours towed (catch prorated for PacHarvTrawl and GFFOS)
Predictive Variables	
Year	Calendar year (1 January–31 December)
Month	Month
Locality	DFO locality (Rutherford 1995)
Depth	Depth aggregated into 25 m depth bands
Vessel	Unique fishing vessel identification number (coded)

* Data obtained from GFCatch, PacHarvTrawl and GFFOS databases. All data were available on a tow-by-tow basis.

(3) The third time period (1996 – 2010) also used tow-by-tow data. The year 1996 represents the start of quota-management for the fishery. The change to quota management was accompanied by the start of latitudinal data for fishing events, the

inclusion of discards in catch records, and an increase in the minimum size limit for retained lingcod.

Response and predictive variables used in the stepwise GLM for 1991 – 1995 time period*:

Variable Name	Description
Response Variable	
CPUE	Combined (landed [prorated] and discarded catch) / hours towed
Explanatory Variables	
Year	Calendar year (1 January–31 December) **
Month	Month
Locality	DFO locality (Rutherford 1995)
Depth	Depth aggregated into 25 m depth bands
Vessel	Unique fishing vessel identification number (coded)
Latitude	Latitude separated in 0.1° bands beginning with 48°N

* Data obtained from PacHarvTrawl and GFFOS databases. All data were available on a tow-by-tow basis.
** Start date for 1996 was February 16 instead of January 1 due to fishery closure.

For all three time periods, locality and latitude categories (levels) with relatively few observations were pooled into a single "Plus" category to reduce the number of parameters estimated. Vessel and depth bands were not pooled. Instead the vessel selection criteria were tightened to reduce the number of vessel categories and effort records at depths which were unsuitable for lingcod were not used. Vessels were included in the analysis only if they had completed at least 5 trips in at least 3 of the 15 years in the data set. All data for qualifying vessel were included, regardless of the number of trips in a year. An additional requirement for vessel qualification of at least 100 positive lingcod catch tows was added to exclude vessels that did not actively fish lingcod.

AREA 3C CPUE

Area 3C: 1954 - 1990

The depth distribution of the majority of successful catch records (between the 1^{st} and 99^{th} percentiles) ranged from 22 m to 218 m, with only a few observations at deeper or shallower depths. The GLM model used all valid tows occurring between 0 and 225 m.

The stepwise GLM analysis selected the factors of month (12 categories), DFO locality (19 categories), and depth band (9 categories) as predictive variables in the final lognormal model, in addition to the year factor which was forced as the first variable. These four factors accounted for 51% of the total model variation (Table C - 2). All explanatory variables offered to the model were selected for the final model. The effect of the standardization procedure on the CPUE index was not strong, as indicated by the similarity of the final model (model Y+M+L+D in Figure C - 2) with the initial model (model Y in Figure C - 2, which is equivalent to the Unstandardized index from Equation 6). Standardization drove down the CPUE peak in the mid-1980's and slightly elevated catch rates prior to 1980.

Annual patterns in the Standardized index (i.e., the final, selected lognormal model) were similar to the Arithmetic and Unstandardized indices over the entire time period (Table C - 3). The standardized index varied considerably between 1954 – late 1970's, with no long-term trend in any one direction (Figure C - 2). This relatively stable period was followed by an increase in CPUE to a high point in 1985, which was about 3 times the average value between 1954 and 1990. The series then quickly dropped to near the long-term average in the final four years (1987–1990).

Table C - 2. Order of acceptance of variables into the 3C: 1954 - 1990 model of lingcod CPUE by core vessels (based on the vessel selection described in text) with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.

Step	Variable	R^2
1	Year*	0.091
2	Month*	0.427
3	DFO locality *	0.499
4	Depth bands*	0.510
Final		**0.510**

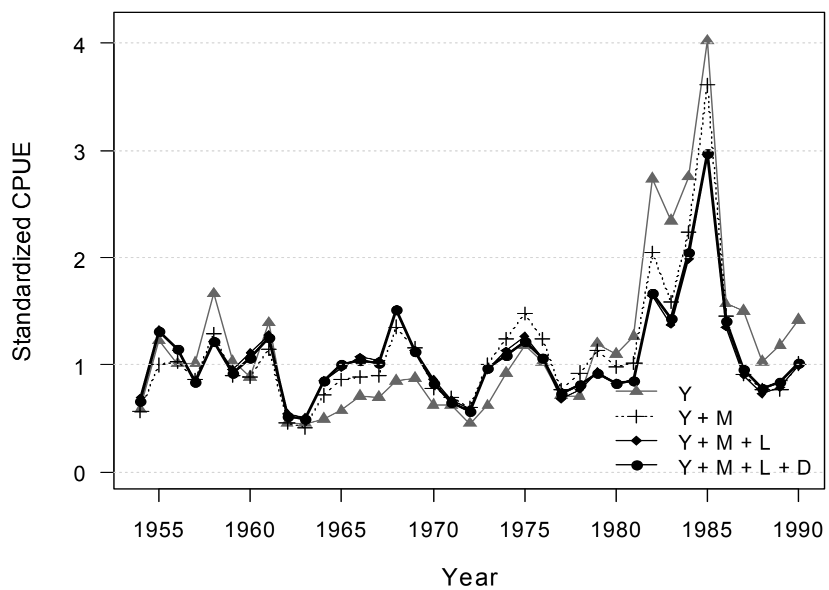

Figure C - 2. Change in year coefficients after adding each successive predictive factor to the Area 3C: 1954-1990 GLM analysis (Y = year, M = month, L = locality, D = depth). The final model, which represents the Standardized index used in the stock assessment, is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

Table C - 3. Arithmetic, unstandardised, and standardised CPUE indices for the Area 3C: 1954-1990 analysis. Upper and lower bounds are provided for the standardized index, as is the associated standard error. The geometric mean of the standardised series has been scaled so that it equals the geometric mean of the arithmetic series.

Year	Arithmetic Series	Unstandardized Series	Standardized Series			
			Series	Lower	Upper	S.E.
1954	68.9	95.4	108.1	93.5	125.1	0.073
1955	150.8	200.6	213.9	183.8	249.0	0.076
1956	168.1	165.0	187.2	160	219.0	0.078
1957	159.1	166.3	137.3	114.4	164.8	0.091
1958	224.4	272.8	199.6	161.2	247.0	0.107
1959	168.3	169.8	151.3	121.9	187.8	0.108
1960	142.6	144.8	174.6	144.2	211.4	0.096
1961	184.3	228.0	205.3	174.2	242.0	0.082
1962	95.6	75.4	85.2	70.4	103.1	0.095
1963	111.2	73.8	80.3	65.0	99.3	0.106
1964	137.4	80.8	138.8	115.3	167.2	0.093
1965	151.8	93.9	165.0	138.5	196.7	0.088
1966	140.0	116.3	170.7	146.2	199.3	0.077
1967	198.1	113.7	166.0	141.1	195.4	0.082
1968	305.9	139.1	248.6	209.4	295.2	0.086
1969	150.8	143.5	183.9	151.4	223.4	0.097
1970	130.5	102.6	136.1	114.3	162.1	0.087
1971	142.4	102.1	105.7	91.5	122.2	0.072
1972	72.8	73.7	93.1	81.3	106.6	0.068
1973	173.7	101.4	158.6	131.4	191.5	0.094
1974	166.2	150.9	177.5	147.8	213.1	0.091
1975	206.8	193.7	199.7	170.5	234.0	0.079
1976	128.3	167.3	174.6	147.7	206.4	0.084
1977	110.1	116.5	119.7	101.8	140.9	0.081
1978	98.8	115.9	132.4	109.4	160.3	0.095
1979	152.1	196.3	151.6	122.5	187.8	0.107
1980	146.4	179.9	134.5	109.9	164.8	0.101
1981	163.1	207.1	138.4	111.5	171.9	0.108
1982	331.3	448.3	273.0	224.9	331.3	0.097
1983	293.1	383.9	234.2	184.5	297.3	0.119
1984	365.7	450.5	335.6	271.6	414.7	0.106
1985	479.2	659.2	486.5	398.7	593.6	0.100
1986	232.3	256.8	229.8	185.1	285.2	0.108
1987	154.7	246.3	155.9	125.4	193.7	0.109
1988	134.4	168.4	126.6	103.6	154.7	0.100
1989	186.8	194.0	136.6	112.2	166.4	0.099
1990	168.9	232.8	167.0	135.6	205.7	0.104

Area 3C: 1991 – 1995

The depth distribution of the majority of successful catch records (between the 1st and 99th percentiles) ranged from 49 m to 349 m, with only a few observations at deeper or shallower depths. The GLM model used all valid tows occurring between 25 and 350 m.

All predictive variables offered to the model were selected for the final model: locality (19 categories), month (12 categories), vessel (16 categories) and depth band (12 categories), in addition to the year factor which was forced as the first variable. These five factors accounted for 50% of the total model variation (Table C - 4). The effect of the standardization procedure on the CPUE index was not strong, as indicated by the similarity of the final model (model Y+M+L+D in Figure C - 2) with the initial model (model Y in Figure C - 2, which is equivalent to the Unstandardized index from Equation C6). Standardization drove down the CPUE peak in the mid-1980's and slightly elevated catch rates prior to 1980

The effect of the standardization procedure on the CPUE series was to slightly decrease the index in the first three years (1991-1993), and to eliminate the downward spike in 1994 by increasing the index for this one year (Figure C - 3). Examination of changes in the annual index as successive predictive variables were added to the model indicated that the downward spike in 1994 was eliminated with the addition of the first explanatory term of locality (Figure C - 3). All predictive variables selected to the final model contributed to the dampening of the initial decline in standardized CPUE by decreasing the 1991 value.

Annual patterns in the Standardized index (i.e., the selected lognormal model) were similar to the Unstandardized index over the entire time period, with both showing a decline over the first three years (Table C - 5). In contrast, the Arithmetic index was relatively stable throughout the time period.

*Table C - 4. Order of acceptance of variables into the 3C: 1991 - 1995 model of lingcod CPUE with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.*

Step	Variable	R^2
1	Year*	0.048
2	DFO locality*	0.386
3	Month*	0.442
4	Vessel*	0.487
5	Depth bands*	0.497
Final		**0.497**

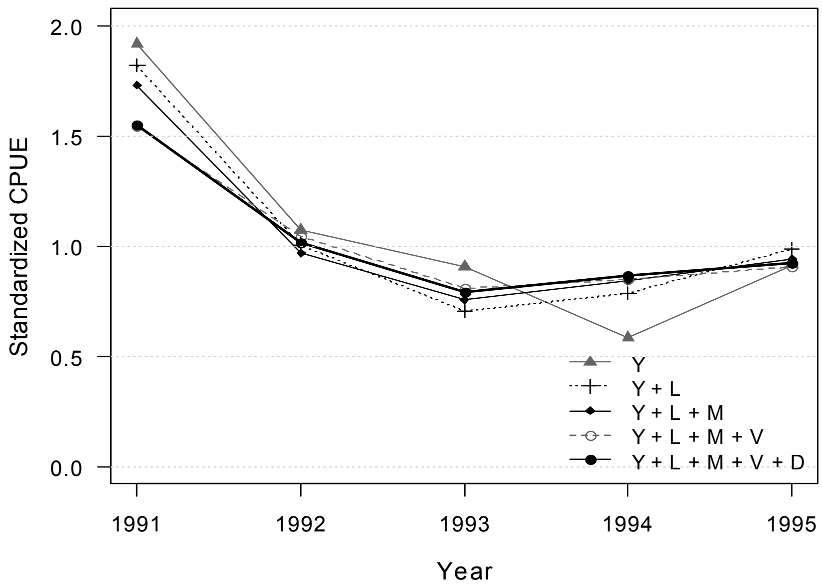

Figure C - 3. Change in year coefficients after adding each successive predictive factor to the Area 3C: 1991-1995 GLM analysis (Y = year, M = month, L = locality, D = depth, V = vessel). The final model, which represents the Standardized index used in the stock assessment, is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

Table C - 5. Arithmetic, unstandardised, and standardised CPUE indices for Area 3C: 1991-1995 analysis. Upper and lower bounds are provided for the standardized index, as is the associated standard error. The geometric mean of the standardised series has been scaled so that it equals the geometric mean of the arithmetic series.

Year	Arithmetic Series	Unstandardized Series	Standardized Series			
			Series	Lower	Upper	S.E.
1991	279.5	442.0	356.9	325.4	391.3	0.046
1992	255.5	247.3	234.3	216.1	254.1	0.041
1993	255.1	208.9	182.8	167.1	200.0	0.045
1994	166.1	135.0	199.0	183.7	215.5	0.040
1995	214.6	210.6	213.3	197.0	231.0	0.040

Area 3C: 1996-2010

The depth distribution of the majority of successful catch records (between the 1st and 99th percentiles) ranged from 60 m to 410 m, with only a few observations at deeper or shallower depths. The GLM model for this area and time period used all valid tows occurring between 50 and 425 m.

All predictive variables offered to the stepwise procedure were selected for the final model: locality (21 categories), depth band (15 categories), vessel (35 categories), month (12 categories), and latitude (11 categories), in addition to the year factor which was forced as the first variable. These six factors accounted for 31% of the total model variation (Table C - 6).

The effect of the standardization procedure was not strong (Figure C - 4). Standardisation lifted the first half of the series and depressed the second half (with the exception of the final year), but maintained the overall pattern of the series. Examination of changes to the annual CPUE index as successive predictive variables were added shows that the biggest shift away from the initial year effect model (i.e., the Unstandardised index) occurred with the addition of locality.

The effect of the standardization procedure was not strong (Figure C - 4). Standardisation lifted the first half of the series and depressed the second half (with the exception of the final year), but maintained the overall pattern of the series. Examination of changes to the annual CPUE index as successive predictive variables were added shows that the biggest shift away from the initial year effect model (i.e., the Unstandardised index) occurred with the addition of locality.

Annual patterns in the Standardized index (i.e., the selected lognormal model) were similar to the Arithmetic and Unstandardized indices over the entire time period (Table C - 7). The standardized index declined by over 50% in the first four years after 1996, and then stayed steady at that level up to 2002. Between 2002 and 2006 the index rose to a peak in 2006 which was nearly as high as at the beginning of the series in 1996 (Figure C - 4, Table C - 7). CPUE dropped again after 2006, reaching a level similar to that observed in the late-1990s/early 2000s by 2010. Interviews with active fishermen confirm that CPUE has declined in the past three to five years and the decline observed in this index is consistent with the drop in relative abundance for lingcod in the west coast Vancouver Island synoptic survey (see Appendix D).

*Table C - 6. Order of acceptance of variables into the 3C:1996 - 2010 model of lingcod CPUE with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.*

Step	Variable	R^2
1	Year*	0.040
2	DFO locality*	0.158
3	Depth bands*	0.235
4	Vessel*	0.277
5	Month*	0.298
6	Latitude*	0.312
Final		**0.312**

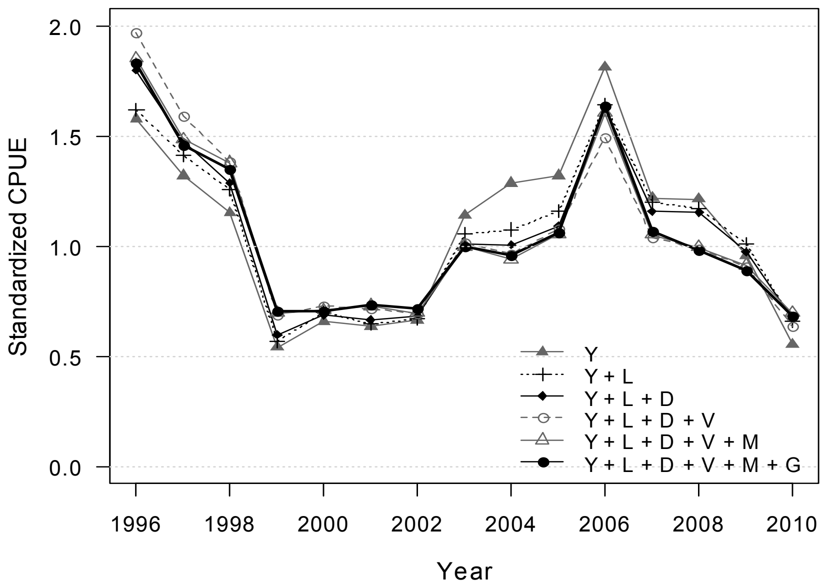

Figure C - 4. Change in year coefficients after adding each successive predictive factor to the Area 3C: 1996-2010 GLM analysis (Y = year, M = month, L = locality, D = depth, V = vessel, G = latitude). The final model, which represents the Standardized index used in the stock assessment, is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

Table C - 7. Arithmetic, unstandardised, and standardised CPUE indices for Area 3C: 1996-2010 analysis. Upper and lower bounds are provided for the standardized index, as is the associated standard error. The geometric mean of the standardised series has been scaled so that it equals the geometric mean of the arithmetic series.

Year	Arithmetic Series	Unstandardized Series	Standardized Series			
			Series	Lower	Upper	S.E.
1996	391.4	349.3	405.0	358.2	457.8	0.061
1997	327.1	292.4	322.7	284.9	365.6	0.062
1998	265.2	254.6	298.4	267.6	332.8	0.054
1999	136.7	119.5	156.4	141.6	172.8	0.050
2000	175.3	145.7	156.1	143.5	169.8	0.042
2001	155.6	140.9	162.1	149.2	176.1	0.041
2002	146.9	147.3	158.8	146.5	172.2	0.040
2003	233.9	252.0	220.9	203.3	240.1	0.042
2004	287.9	284.7	212.2	195.8	229.9	0.040
2005	244.6	292.3	234.4	217.4	252.6	0.038
2006	341.1	400.9	361.6	333.3	392.4	0.041
2007	274.5	269.7	236.1	216.7	257.3	0.043
2008	268.4	268.3	216.4	199.3	235	0.041
2009	183.1	212.1	197.2	181.3	214.4	0.042
2010	105.5	122.7	151.4	135.3	169.6	0.057

AREA 3D CPUE

Area 3D: 1966 - 1990

The depth distribution of the majority of successful catch records (between the 1st and 99th percentiles) ranged from 37 m to 311 m, with only a few observations at deeper or shallower depths. The GLM model used all valid tows occurring between 50 and 325 m.

All predictive variables offered to the stepwise procedure were selected for the final model: month (12 categories), depth band (12 categories), and locality (12 categories), in addition to the year factor which was forced as the first variable. These four factors accounted for 31% of the total model variation (Table C - 8).

The effect of the standardization procedure was not strong (Figure C - 5). Standardisation slightly depressed time series prior to 1980 and increased the time series after 1985. Examination of changes to the annual CPUE index as successive predictive variables were added shows that the biggest shift away from the initial year effect model (i.e., the Unstandardised index) occurred with the addition of month, although depth band also contributed to the final pattern. The addition of the month effect substantially increased the index in 1985. Annual patterns in the Standardized index (i.e., the selected lognormal model) were similar to those of the Unstandardised index over the entire time period (Figure C - 9). The Arithmetic index showed higher peaks in CPUE in a small subset of years (1973, 1974, and 1978) compared to the other two indices.

*Table C - 8. Order of acceptance of variables into the 3D: 1966 - 1990 model of lingcod CPUE by core vessels (based on the vessel selection described in text) with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.*

Step	**Variable**	**R^2**
1	Year*	0.114
2	Month*	0.229
3	Depth bands *	0.290
4	DFO locality *	0.311
Final		**0.311**

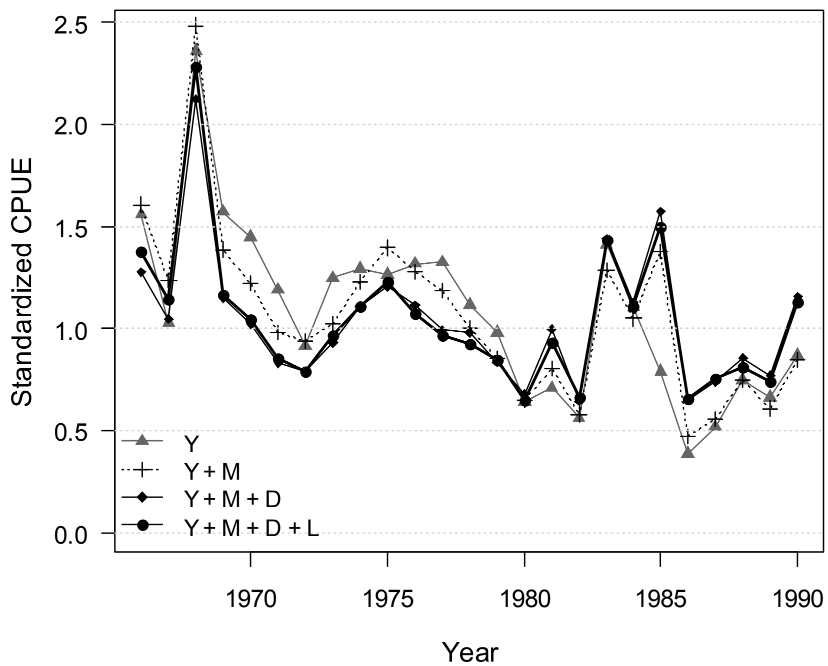

Figure C - 5. Change in year coefficients after adding each successive predictive factor to the Area 3D: 1966-1990 GLM analysis (Y = year, M = month, L = locality, D = depth). The final model, which represents the Standardized index used in the stock assessment, is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

Table C - 9. Arithmetic, unstandardised, and standardised CPUE indices for Area 3D: 1966 - 1990 analysis. Upper and lower bounds are provided for the standardized index, as is the associated standard error. The geometric mean of the standardised series has been scaled so that it equals the geometric mean of the arithmetic series.

Year	Arithmetic Series	Unstandardized Series	Standardized Series			
			Series	Lower	Upper	S.E.
1966	364.8	278.9	246.3	191.0	317.7	0.127
1967	305.3	184.2	204.3	154.8	269.7	0.139
1968	464.0	422.0	408.3	319.6	521.6	0.122
1969	265.7	280.7	208.7	168.8	258.0	0.106
1970	225.1	258.9	187.0	149.7	233.5	0.111
1971	159.4	212.6	152.5	118.8	195.8	0.125
1972	154.8	163.6	141.4	94.4	211.7	0.202
1973	340.7	222.8	173.4	107.0	280.9	0.241
1974	358.5	231.1	198.5	145.0	271.9	0.157
1975	224.0	225.9	219.8	159.4	303.2	0.161
1976	208.9	235.4	191.9	141.8	259.7	0.151
1977	226.0	237.0	172.3	129.0	230.2	0.145
1978	327.9	199.4	164.7	125.4	216.2	0.136
1979	135.1	175.3	150.7	104.2	217.9	0.184
1980	75.4	114.9	115.5	84.4	158.2	0.157
1981	113.6	126.7	166.6	117.1	237.0	0.176
1982	68.7	100.4	118.0	78.2	178.2	0.206
1983	198.2	252.4	256.2	201.0	326.6	0.121
1984	172.8	197.9	198.5	149.4	263.8	0.142
1985	218.9	141.1	267.8	194.5	368.7	0.160
1986	65.3	69.3	117.2	93.2	147.3	0.115
1987	77.6	92.4	134.9	102.3	177.8	0.138
1988	141.0	133.8	144.4	113.2	184.3	0.122
1989	137.1	118.5	131.7	103.4	167.7	0.121
1990	107.1	155.3	202.1	149.1	274.1	0.152

Area 3D: 1991 - 1995

The depth distribution of the majority of successful catch records (between the 1^{st} and 99^{th} percentiles) ranged from 59 m to 311 m, with only a few observations at deeper or shallower depths. The GLM model used all valid tows occurring between 50 and 325 m.

All predictive variables offered to the stepwise procedure were selected for the final model: depth band (11 categories), vessel (21 categories), month (12 categories), and locality (19 categories), in addition to the year factor which was forced as the first variable. These five factors accounted for 29% of the total model variation (Table C - 10).

The effect of the standardization procedure was not strong, and did not change the pattern in CPUE over time (Figure C - 6). Annual patterns in the Standardized index (i.e., the selected lognormal model) were similar to those of the Arithmetic and Unstandardized index over the entire time period (Table C – 11)

*Table C - 10. Order of acceptance of variables into the 3D: 1991 - 1995 model of lingcod CPUE by core vessels (based on the vessel selection described in text) with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.*

Step	Variable	R^2
1	Year*	0.014
2	Depth bands *	0.132
3	Vessel *	0.214
4	Month*	0.269
5	DFO locality*	0.286
Final		**0.286**

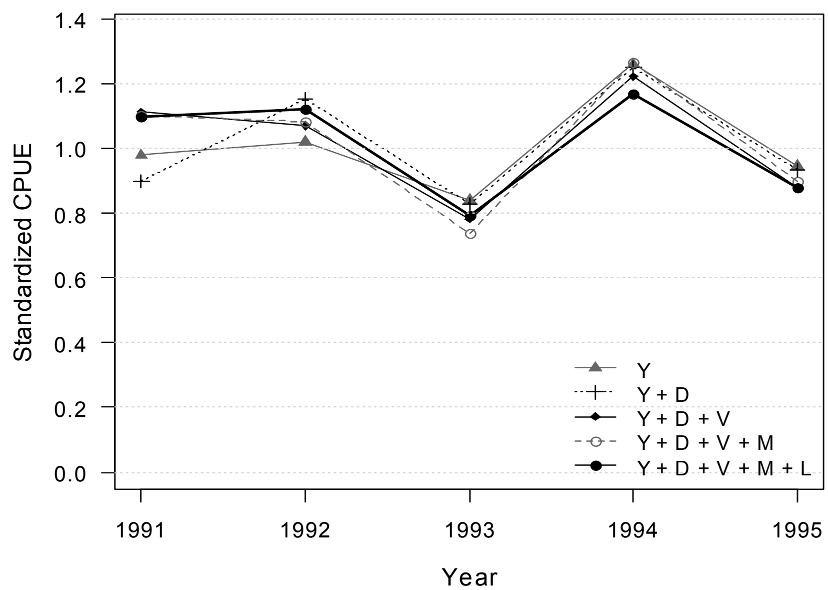

Figure C - 6. Change in year coefficients after adding each successive predictive factor to the Area 3D: 1991-1995 GLM analysis (Y = year, M = month, L = locality, D = depth, V = vessel). The final model, which represents the Standardized index used in the stock assessment, is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

Table C - 11. Arithmetic, unstandardised, and standardised CPUE indices for Area 3D: 1991-1995 analysis. Upper and lower bounds are provided for the standardized index, as is the associated standard error. The geometric mean of the standardised series has been scaled so that it equals the geometric mean of the arithmetic series.

Year	Arithmetic Series	Unstandardized Series	Standardized Series			
			Series	Lower	Upper	S.E.
1991	154.6	141.9	159.3	143.4	176.9	0.052
1992	163.1	148.0	162.7	150.2	176.3	0.040
1993	104.2	121.8	114.9	106.7	123.7	0.037
1994	180.0	182.8	169.4	158.1	181.6	0.035
1995	135.7	137.2	127.2	118.0	137.2	0.038

Area 3D: 1996 - 2010

The depth distribution of the majority of successful catch records (between the 1st and 99th percentiles) ranged from 80 m to 384 m, with only a few observations at deeper or shallower depths. The GLM model used all valid tows occurring between 75 and 400 m.

Four of the five predictive variables offered to the stepwise procedure were selected for the final model: locality (11 categories), vessel (34 categories), depth band (13 categories), and latitude (16 categories), in addition to the year factor which was forced as the first variable. The month effect was excluded from the final model. The final five factors accounted for 28% of the total model variation (Table C - 12).

The effect of the standardization procedure was not strong (Figure C - 7). Standardisation lifted the first half of the series and depressed the last three years, but maintained the overall pattern of the series. Examination of changes to the annual CPUE index as successive predictive variables were added shows that the shift away from the initial year effect model (i.e., the Unstandardised index) in the last three years occurred with the addition of vessel. Annual patterns in the Standardized index (i.e., the selected lognormal model) were similar to the Arithmetic and Unstandardized indices over the most of time period (Table C - 13). The one exception was 2008 when the Arithmetic Index showed a large jump in CPUE. Although small increases and decreases in the Standardized index occurred over time, it showed an overall stable trend for the entire time period (Figure C - 7; Table C - 13).

*Table C - 12. Order of acceptance of variables into the 3D: 1996 - 2010 model of lingcod CPUE by core vessels (based on the vessel selection described in text) with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.*

Step	**Variable**	**R^2**
1	Year*	0.011
2	DFO locality*	0.137
3	Vessel*	0.201
4	Depth bands*	0.255
5	Latitude*	0.276
6	Month	0.283
Final		**0.276**

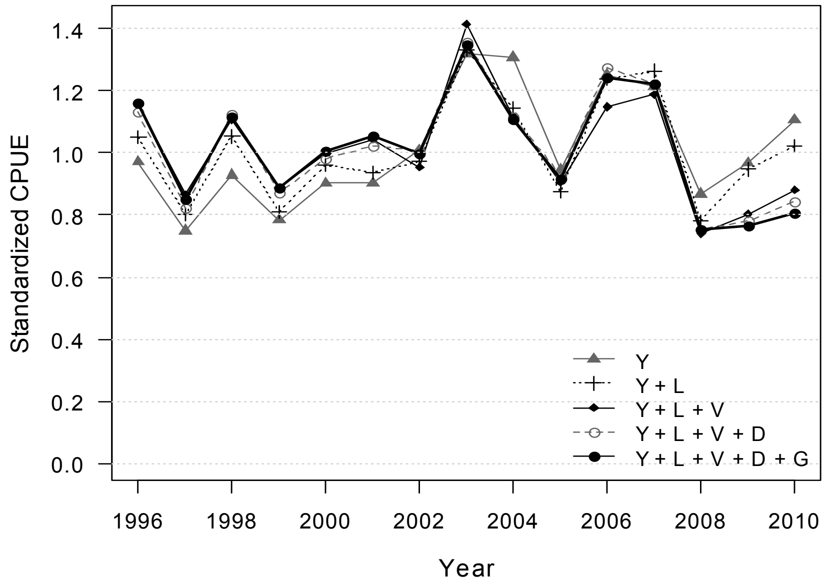

Figure C - 7. Change in year coefficients after adding each successive predictive factor to the Area 3D: 1996-2010 GLM analysis (Y = year, M = month, L = locality, D = depth, V = vessel, G = latitude). The final model, which represents the Standardized index used in the stock assessment, is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

Table C - 13. Arithmetic, unstandardised, and standardised CPUE indices for Area 3D: 1996-2010 analysis. Upper and lower bounds are provided for the standardized index, as is the associated standard error. The geometric mean of the standardised series has been scaled so that it equals the geometric mean of the arithmetic series.

Year	Arithmetic Series	Unstandardized Series	Standardized Series			
			Series	Lower	Upper	S.E.
1996	87.1	103.9	124.4	110.6	140.0	0.059
1997	76.0	80.2	91.0	80.0	103.4	0.064
1998	94.4	99.4	119.5	107.5	133.0	0.053
1999	86.1	83.9	95.0	85.7	105.3	0.052
2000	129.2	96.6	107.7	98.9	117.4	0.043
2001	91.7	96.7	112.7	103.8	122.4	0.041
2002	97.8	108.0	106.7	97.9	116.2	0.043
2003	139.2	141.1	144.2	132.3	157.3	0.043
2004	151.4	140.1	118.6	108.5	129.8	0.045
2005	90.2	101.1	97.9	90.1	106.4	0.041
2006	144.2	133.8	133.1	119.4	148.4	0.054
2007	218.9	129.9	130.7	118.0	144.7	0.051
2008	84.7	92.8	80.7	72.6	89.6	0.053
2009	94.1	103.6	82.0	74.3	90.3	0.049
2010	93.2	118.4	86.4	76.9	97.0	0.058

AREA 5AB CPUE

Area 5AB: 1966 - 1990

The depth distribution of the majority of successful catch records (between the 1st and 99th percentiles) ranged from 61 m to 277 m, with only a few observations at deeper or shallower depths. The GLM model used all valid tows occurring between 25 and 350 m.

All predictive variables offered to the stepwise procedure were selected for the final model: depth band (10 categories), month (12 categories), and locality (13 categories), in addition to the year factor which was forced as the first variable. These four factors accounted for 29% of the total model variation (Table C - 14).

The effect of the standardization procedure was not strong (Figure C - 5). Standardisation had little effect on the time series prior to 1984, and only slightly increased CPUE in the last 7 years. Examination of changes to the annual CPUE index as successive predictive variables were added shows that the biggest shift away from the initial year effect model (i.e., the Unstandardised index) occurred with the addition of depth bands. The remaining variables had very minor effects. Annual patterns in the Standardized index (i.e., the selected lognormal model) were similar to those of the Arithmetic and Unstandardized index over the entire time period (Table C - 15). The standardized CPUE index declined between 1966 and 1978, with 1978 being a historic low (Figure C - 8). The standardized index then increased rapidly between 1978 and 1983. CPUE levels at the end of the time period are generally larger than those at the beginning.

*Table C - 14. Order of acceptance of variables into the 5AB: 1996 - 2010 model of lingcod CPUE by core vessels (based on the vessel selection described in text) with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.*

Step	Variable	R^2
1	Year*	0.053
2	Depth bands *	0.220
3	Month *	0.258
4	DFO locality *	0.285
Final		**0.285**

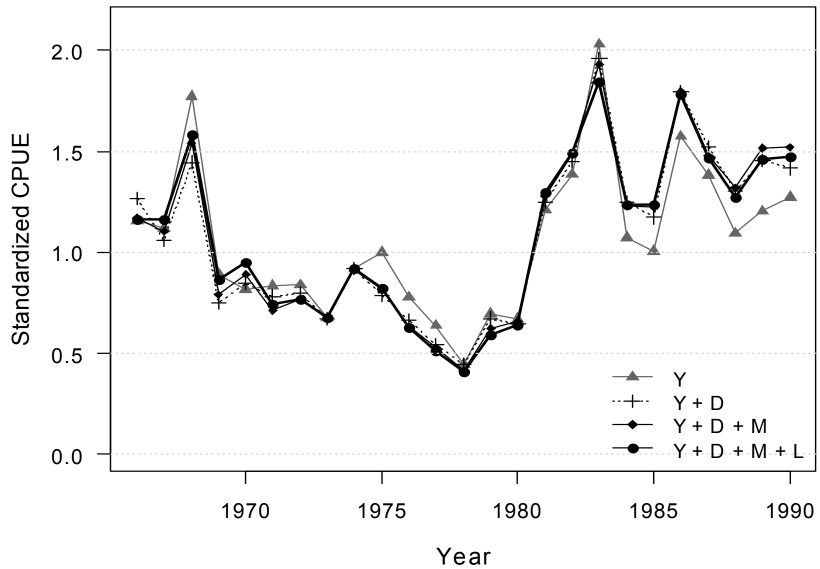

Figure C - 8. Change in year coefficients after adding each successive predictive factor to the Area 5AB: 1966-1990 GLM analysis (Y = year, M = month, L = locality, D = depth). The final model, which represents the Standardized index used in the stock assessment, is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

Table C - 15. Arithmetic, unstandardised, and standardised CPUE indices for Area 3D: 1996-2010 analysis. Upper and lower bounds are provided for the standardized index, as is the associated standard error. The geometric mean of the standardised series has been scaled so that it equals the geometric mean of the arithmetic series.

Year	Arithmetic Series	Unstandardized Series	Standardized Series			
			Series	Lower	Upper	S.E.
1966	149.3	140.2	141.8	119.7	167.9	0.085
1967	138.2	135.4	140.5	118.7	166.4	0.084
1968	199.9	214.5	191.2	163.3	223.9	0.079
1969	84.4	108.1	104.8	88.8	123.6	0.083
1970	103.4	98.9	115.2	95.7	138.8	0.093
1971	88.6	101.3	91.2	74.5	111.6	0.101
1972	83.6	101.6	93.5	75.1	116.4	0.110
1973	87.7	81.7	81.8	63.4	105.4	0.127
1974	106.7	111.3	111.8	84.3	148.3	0.141
1975	83.4	121.0	99.7	81.3	122.2	0.102
1976	78.4	94.3	76.0	63.3	91.2	0.091
1977	65.8	77.2	62.4	51.2	76.1	0.099
1978	57.8	54.1	49.4	41.3	59.1	0.090
1979	62.8	84.2	70.8	59.1	84.9	0.091
1980	82.0	81.3	78.1	66.8	91.2	0.078
1981	162.5	146.6	157.4	134.3	184.5	0.079
1982	178.5	167.7	180.9	156.3	209.3	0.073
1983	238.8	245.8	223.3	190.4	261.8	0.080
1984	122.1	129.8	150.4	125.5	180.2	0.090
1985	167.1	121.8	148.9	122.5	181.0	0.098
1986	281.0	190.8	215.3	181.3	255.7	0.086
1987	159.7	167.5	178.0	155.5	203.7	0.068
1988	149.0	132.5	154.6	133.4	179.1	0.074
1989	192.1	145.8	176.9	153.2	204.4	0.072
1990	208.8	154.2	175.0	153.8	199.1	0.065

Area 5AB: 1991 - 1995

The depth distribution of the majority of successful catch records (between the 1st and 99th percentiles) ranged from 59 m to 393 m, with only a few observations at deeper or shallower depths. The GLM model used all valid tows occurring between 50 and 400 m.

Three of the four predictive variables offered to the stepwise procedure were selected for the final model: depth band (10 categories), vessel (36 categories), and month (12 categories), in addition to the year factor which was forced as the first variable. The locality variable was excluded by the stepwise procedure. The four final factors accounted for 31% of the total model variation (Table C - 16).

The effect of the standardization procedure was not strong, and did not change the pattern in CPUE over time (Figure C - 9). Annual patterns in the Standardized index (i.e., the selected lognormal model) were similar to those of the Arithmetic and Unstandardized index over the entire time period (Table C - 16).

*Table C - 16. Order of acceptance of variables into the 5AB: 1991 - 1995 model of lingcod CPUE by core vessels (based on the vessel selection described in text) with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.*

Step	Variable	R^2
1	Year*	0.014
2	Depth bands *	0.175
3	Vessel *	0.300
4	Month*	0.314
5	DFO locality	0.324
Final		**0.314**

Table C - 17. Arithmetic, unstandardised, and standardised CPUE indices for Area 5AB: 1991-1995 analysis. Upper and lower bounds are provided for the standardized index, as is the associated standard error. The geometric mean of the standardised series has been scaled so that it equals the geometric mean of the arithmetic series.

Year	Arithmetic Series	Unstandardized Series	Standardized Series			
			Series	Lower	Upper	S.E.
1991	243.2	240.7	224.9	211.7	239.0	0.030
1992	156.7	157.8	157.7	149.9	166.0	0.025
1993	172.5	159.9	155.9	148.5	163.6	0.024
1994	154.0	149.4	167.5	159.1	176.3	0.026
1995	130.8	146.0	143.1	136.0	150.4	0.025

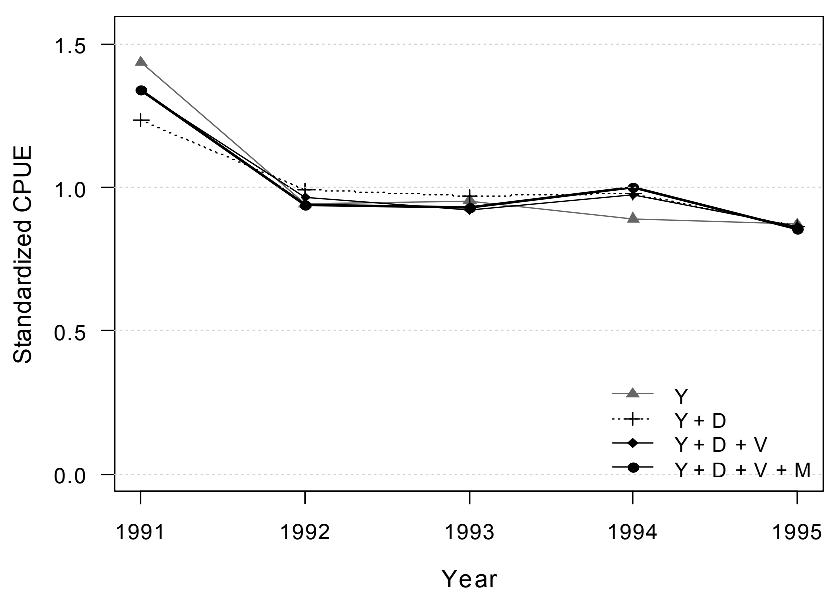

Figure C - 9. Change in year coefficients after adding each successive predictive factor to the Area 5AB: 1991-1995 GLM analysis (Y = year, M = month, L = locality, D = depth, V = vessel). The final model, which represents the Standardized index used in the stock assessment, is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

Area 5AB: 1996 - 2010

The depth distribution of the majority of successful catch records (between the 1st and 99th percentiles) ranged from 57 m to 326 m, with only a few observations at deeper or shallower depths. The GLM model used all valid tows occurring between 50 and 350 m.

Four of the five predictive variables offered to the stepwise procedure were selected for the final model: depth band (12 categories), locality (19 categories), month (12 categories), and vessel (47 categories), in addition to the year factor which was forced as the first variable. The latitude effect was excluded from the final model. The final five factors accounted for 41% of the total model variation (Table C - 18).

The effect of the standardization procedure was not strong (Figure C - 10). Examination of changes to the annual CPUE index as successive predictive variables were added shows that the largest shift away from the initial year effect model (i.e., the Unstandardised index) occurred with the addition of depth bands. Annual patterns in the Standardized index (i.e., the selected lognormal model) were similar to the Unstandardized indices over the most of time period (Table C - 19). The Arithmetic index was comparable in most years, with the exception of a few large increases in CPUE in the years 200, 2008, and 2009. Although small increases and decreases in the Standardized index occurred over time, it showed an overall stable trend (Figure C - 10; Table C - 19).

*Table C - 18. Order of acceptance of variables into the 5AB: 1996 - 2010 model of lingcod CPUE by core vessels (based on the vessel selection described in text) with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.*

Step	Variable	R^2
1	Year*	0.007
2	Depth bands *	0.334
3	DFO locality *	0.377
4	Month *	0.393
5	Vessel *	0.407
6	Latitude	0.413
Final		**0.407**

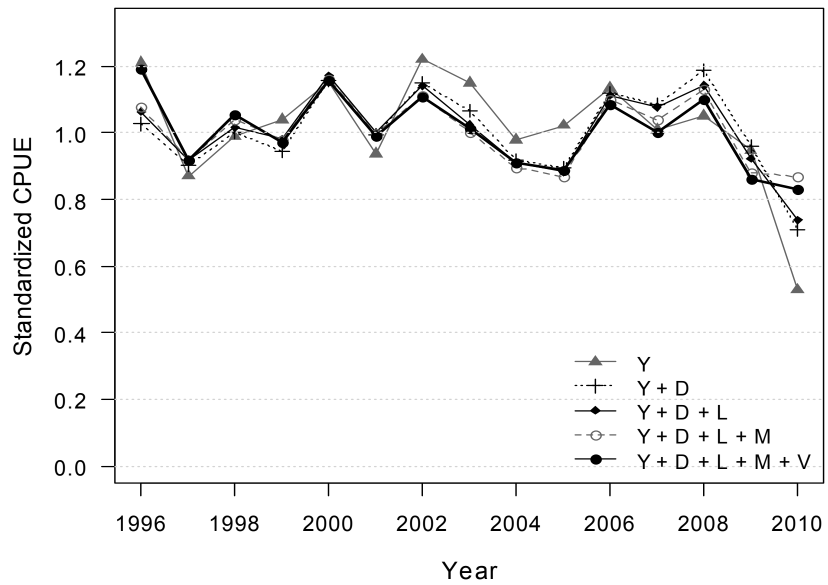

Figure C - 10. Change in year coefficients after adding each successive predictive factor to the Area 5AB: 1996-2010 GLM analysis (Y = year, M = month, L = locality, D = depth, V = vessel, G = latitude). The final model, which represents the Standardized index used in the stock assessment, is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

Table C - 19. Arithmetic, unstandardised, and standardised CPUE indices for Area 5AB: 1996-2010 analysis. Upper and lower bounds are provided for the standardized index, as is the associated standard error. The geometric mean of the standardised series has been scaled so that it equals the geometric mean of the arithmetic series.

Year	Arithmetic Series	Unstandardized Series	Standardized Series			
			Series	Lower	Upper	S.E.
1996	98.4	109.9	108.2	101.7	115.2	0.031
1997	78.4	79.0	83.2	79.0	87.6	0.026
1998	81.2	89.8	95.8	91.3	100.4	0.024
1999	79.0	94.4	88.3	84.5	92.4	0.022
2000	124.8	104.9	105.0	100.5	109.7	0.022
2001	88.9	85.1	90.0	86.0	94.2	0.023
2002	103.4	110.9	100.7	96.6	105.0	0.021
2003	87.7	104.4	91.8	88.1	95.6	0.020
2004	91.2	88.9	82.7	79.2	86.3	0.022
2005	77.2	92.8	80.6	77.0	84.3	0.022
2006	97.4	103.0	98.6	94.2	103.2	0.023
2007	92.6	91.7	90.9	86.6	95.3	0.024
2008	132.2	95.5	99.8	93.7	106.4	0.032
2009	104.6	86.0	78.2	73.8	82.8	0.029
2010	53.4	48.0	75.4	69.2	82.2	0.043

AREA 5CD CPUE

Area 5CD: 1964 - 1990

The depth distribution of the majority of successful catch records (between the 1st and 99th percentiles) ranged from 29 m to 206 m, with only a few observations at deeper or shallower depths. The GLM model used all valid tows occurring between 25 and 225 m.

All predictive variables offered to the stepwise procedure were selected for the final model: locality (21 categories), month (12 categories), and depth band (8 categories), in addition to the year factor which was forced as the first variable. These four factors accounted for 31% of the total model variation (Table C - 20).

The effect of the standardization procedure was not strong (Figure C - 11). Standardisation had little effect on the time series prior to 1983, and tended to increase CPUE from 1983 onwards. The remaining variables had very minor effects. Annual patterns in the Standardized index (i.e., the selected lognormal model) were similar to those of the Arithmetic and Unstandardized index over the entire time period (Table C - 21). The standardized CPUE index increased in the earliest years (1964 to 1968) and then declined between 1968 and 1978, with 1978 being a historic low (Figure C - 11). The standardized index then increased rapidly between 1978 and 1987. CPUE levels at the end of the time period are larger than those at the beginning.

*Table C - 20. Order of acceptance of variables into the 5CD: 1964 - 1990 model of lingcod CPUE by core vessels (based on the vessel selection described in text) with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.*

Step	Variable	R^2
1	Year*	0.065
2	DFO locality *	0.203
3	Month *	0.289
4	Depth bands *	0.305
Final		**0.305**

Figure C - 11. Change in year coefficients after adding each successive predictive factor to the Area 5CD: 1964-1990 GLM analysis (Y = year, M = month, L = locality, D = depth). The final model, which represents the Standardized index used in the stock assessment, is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

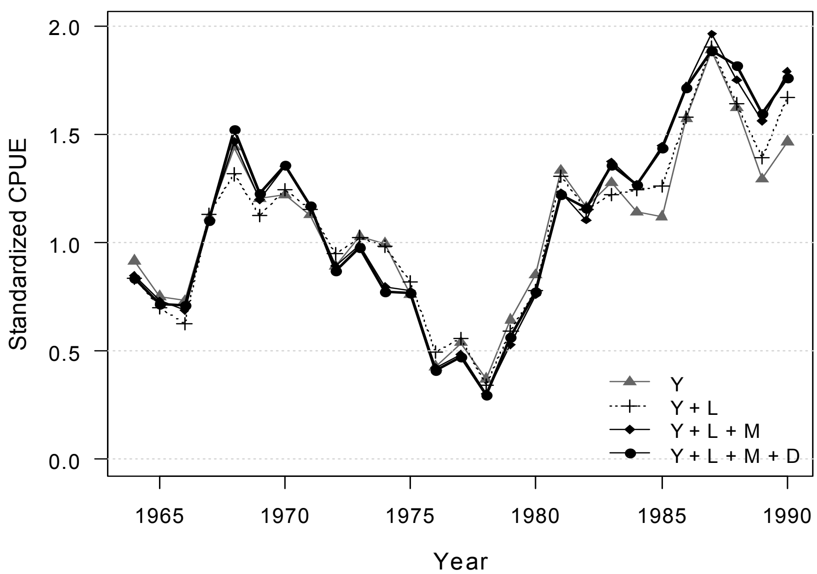

Table C - 21. Arithmetic, unstandardised, and standardised CPUE indices for Area 5CD: 1964-1990 analysis. Upper and lower bounds are provided for the standardized index, as is the associated standard error. The geometric mean of the standardised series has been scaled so that it equals the geometric mean of the arithmetic series.

Year	Arithmetic Series	Unstandardized Series	Standardized Series			
			Series	Lower	Upper	S.E.
1964	42.9	27.7	25.1	21.5	29.4	0.078
1965	34.5	22.7	21.5	18.7	24.8	0.071
1966	32.4	22.1	21.4	18.8	24.5	0.066
1967	49.2	33.8	33.3	28.6	38.8	0.076
1968	49.0	43.5	45.7	40.1	52.0	0.065
1969	32.1	36.3	37.0	32.5	42.1	0.064
1970	31.0	36.8	41.0	35.8	47.0	0.068
1971	40.2	34.0	35.3	30.9	40.2	0.066
1972	26.0	27.0	26.2	22.3	30.7	0.080
1973	27.5	31.1	29.6	25.2	34.7	0.080
1974	28.3	30.1	23.3	19.6	27.9	0.088
1975	27.2	23.0	23.2	19.9	27.1	0.077
1976	11.1	13.0	12.3	10.6	14.3	0.075
1977	16.8	16.2	14.3	12.5	16.5	0.071
1978	11.1	11.2	9.0	7.7	10.6	0.082
1979	16.8	19.4	17.0	15.0	19.3	0.063
1980	20.1	25.7	23.3	20.6	26.3	0.060
1981	35.4	40.2	36.8	32.1	42.3	0.069
1982	37.9	35.1	35.5	30.4	41.5	0.078
1983	36.6	38.6	40.9	34.7	48.3	0.083
1984	29.8	34.5	38.2	32.5	44.8	0.080
1985	30.1	33.8	43.4	36.2	51.9	0.090
1986	38.3	47.6	52.2	44.4	61.5	0.081
1987	45.8	57.0	57.3	50.0	65.7	0.068
1988	45.9	49.0	54.4	47.5	62.3	0.068
1989	34.9	39.1	48.8	42.6	55.8	0.068
1990	42.1	44.3	52.6	46.0	60.0	0.066

Area 5CD: 1991 - 1995

The depth distribution of the majority of successful catch records (between the 1^{st} and 99^{th} percentiles) ranged from 26 m to 206 m, with only a few observations at deeper or shallower depths. The GLM model used all valid tows occurring between 25 and 225 m.

All predictive variables offered to the stepwise procedure were selected for the final model: locality (23 categories), vessel (29 categories), month (12 categories), and depth band (8 categories), in addition to the year factor which was forced as the first variable. The four final factors accounted for 40% of the total model variation (Table C - 22).

The effect of the standardization procedure was not strong. Standardization slightly increased the CPUE index in the first couple years and depressed it in the last few, but it did not change the general pattern over time (Figure C - 12). The Standardized CPUE series showed an increase over the 5-year time period. Annual patterns in the Standardized index (i.e., the selected lognormal model) were similar to those of the Arithmetic and Unstandardized index (Table C - 23).

*Table C - 22. Order of acceptance of variables into the 5CD: 1991 - 1995 model of lingcod CPUE by core vessels (based on the vessel selection described in text) with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.*

Step	Variable	R^2
1	Year*	0.031
2	DFO locality *	0.257
3	Vessel *	0.359
4	Month*	0.384
5	Depth bands*	0.400
Final		**0.400**

Table C - 23. Arithmetic, unstandardised, and standardised CPUE indices for Area 5CD: 1991-1995 analysis. Upper and lower bounds are provided for the standardized index, as is the associated standard error. The geometric mean of the standardised series has been scaled so that it equals the geometric mean of the arithmetic series.

Year	Arithmetic Series	Unstandardized Series	Standardized Series			
			Series	Lower	Upper	S.E.
1991	61.0	54.8	64.8	61.3	68.5	0.028
1992	77.2	62.7	68.9	65.7	72.2	0.024
1993	78.1	106.6	93.5	88.9	98.3	0.025
1994	100.0	103.7	95.6	90.6	100.8	0.027
1995	94.8	91.7	87.4	82.8	92.2	0.027

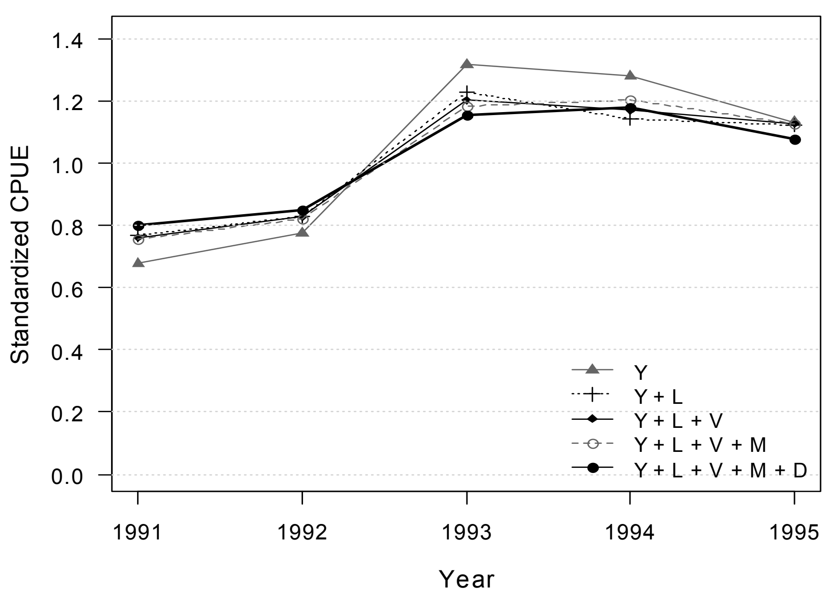

Figure C - 12. Change in year coefficients after adding each successive predictive factor to the Area 5CD: 1991-1995 GLM analysis (Y = year, M = month, L = locality, D = depth, V = vessel). The final model, which represents the Standardized index used in the stock assessment, is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

Area 5CD: 1996 - 2010

The depth distribution of the majority of successful catch records (between the 1st and 99th percentiles) ranged from 33 m to 302 m, with only a few observations at deeper or shallower depths. The GLM model used all valid tows occurring between 25 and 325 m.

All predictive variables offered to the stepwise procedure were selected for the final model: locality (24 categories), month (12 categories), depth band (12 categories), vessel (27 categories), and latitude (24 categories), in addition to the year factor which was forced as the first variable. These six factors accounted for 31% of the total model variation (Table C - 24).

The effect of the standardization procedure was not strong (Figure C - 13). Standardisation lifted the first few years of the series and depressed some years in the latter half, but maintained the overall pattern of the series. Annual patterns in the Standardized index (i.e., the selected lognormal model) were similar to the Unstandardized indices over the entire time period (Table C - 25). The Arithmetic series differed from the other two in some years; it showed relatively low CPUE value near the start of the series and some high value near the end (especially 2007-2009).

*Table C - 24. Order of acceptance of variables into the 5CD: 1996 - 2010 model of lingcod CPUE by core vessels (based on the vessel selection described in text) with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.*

Step	Variable	R^2
1	Year*	0.038
2	DFO locality *	0.172
3	Month *	0.220
4	Depth bands*	0.241
5	Vessel *	0.262
6	Latitude *	0.277
Final		**0.277**

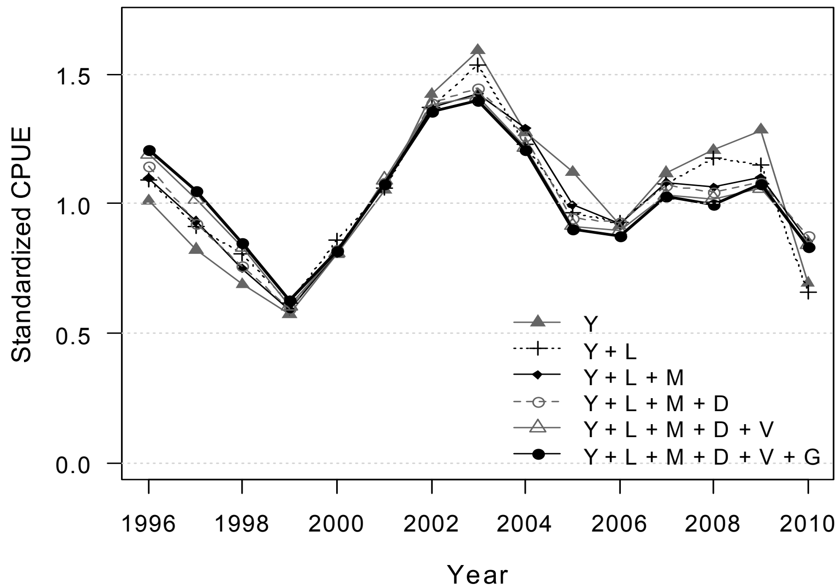

Figure C - 13. Change in year coefficients after adding each successive predictive factor to the Area 5CD: 1996-2010 GLM analysis (Y = year, M = month, L = locality, D = depth, V = vessel, G = latitude). The final model, which represents the Standardized index used in the stock assessment, is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

Table C - 25. Arithmetic, unstandardised, and standardised CPUE indices for Area 5CD: 1996-2010 analysis. Upper and lower bounds are provided for the standardized index, as is the associated standard error. The geometric mean of the standardised series has been scaled so that it equals the geometric mean of the arithmetic series.

Year	Arithmetic Series	Unstandardized Series	Standardized Series			
			Series	Lower	Upper	S.E.
1996	42.4	44.8	53.7	49.3	58.5	0.043
1997	28.8	36.5	46.4	43.2	49.9	0.036
1998	22.9	30.5	37.7	35.1	40.4	0.035
1999	20.4	25.5	27.8	26.1	29.6	0.032
2000	36.0	35.8	36.3	34.3	38.4	0.028
2001	37.6	46.6	47.8	44.9	50.9	0.031
2002	81.4	63.1	60.2	56.8	63.9	0.030
2003	73.4	70.5	62	58.0	66.4	0.034
2004	65.7	56.6	53.7	50.2	57.4	0.034
2005	50.2	49.8	40	37.3	43.0	0.036
2006	38.8	40.6	38.9	36.0	42.0	0.039
2007	65.6	49.6	45.5	41.9	49.4	0.041
2008	66.7	53.5	44.3	40.8	48.1	0.041
2009	73.2	57.0	47.7	44.3	51.3	0.037
2010	26.6	30.7	36.9	33.0	41.4	0.057

COASTWIDE CPUE

Coast: 1966 - 1990

The depth distribution of the majority of successful catch records (between the 1st and 99th percentiles) ranged from 31 m to 261 m, with only a few observations at deeper or shallower depths. The GLM model used all valid tows occurring between 25 and 275 m.

All predictive variables offered to the stepwise procedure were selected for the final model: locality (83 categories), month (12 categories), and depth band (10 categories), in addition to the year factor which was forced as the first variable. These four factors accounted for 44% of the total model variation (Table C - 26).

The effect of the standardization procedure was not strong (Figure C - 14). Annual patterns in the Standardized index (i.e., the selected lognormal model) were similar to those of the Arithmetic and Unstandardized index over the entire time period (Table C - 27). The Standardized CPUE index declined over the first half of the time series until 1978, and then increased until 1984 (Figure C - 14; Table C - 27). The standardized index was stable between 1984 and 1990. CPUE levels at the end of the time period are generally larger than those at the beginning.

*Table C - 26. Order of acceptance of variables into the COAST: 1966 - 1990 model of lingcod CPUE by core vessels (based on the vessel selection described in text) with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.*

Step	Variable	R^2
1	Year*	0.036
2	DFO locality *	0.353
3	Month *	0.418
4	Depth bands *	0.443
Final		**0.443**

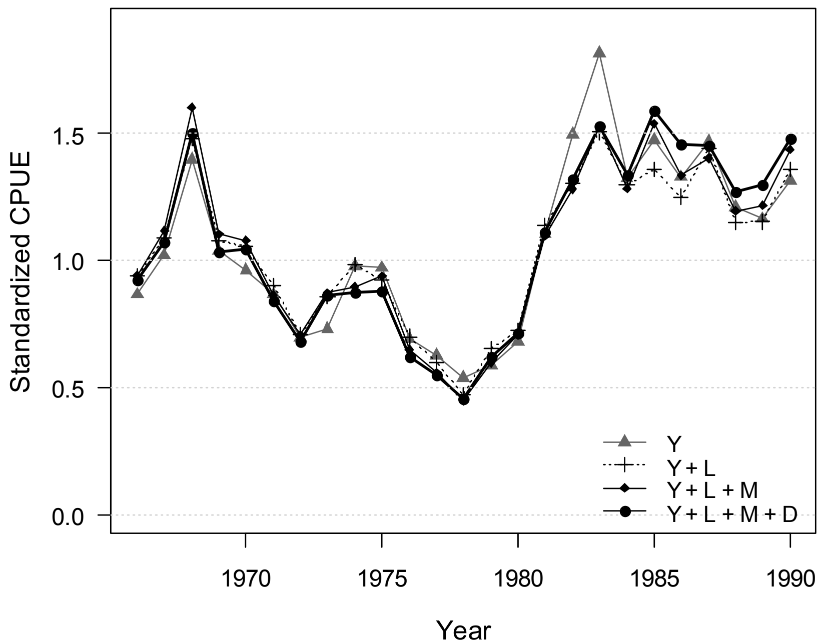

Figure C - 14. Change in year coefficients after adding each successive predictive factor to the COAST: 1966-1990 GLM analysis (Y = year, M = month, L = locality, D = depth, V = vessel, G = latitude). The final model, which represents the Standardized index used in the stock assessment, is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

Table C - 27. Arithmetic, unstandardised, and standardised CPUE indices for Area COAST: 1991-1995 analysis. Upper and lower bounds are provided for the standardized index, as is the associated standard error. The geometric mean of the standardised series has been scaled so that it equals the geometric mean of the arithmetic series.

Year	Arithmetic Series	Unstandardized Series	Standardized Series			
			Series	Lower	Upper	S.E.
1966	111.7	93.3	99.5	91.5	108.2	0.042
1967	137.4	109.9	115.3	105.3	126.3	0.045
1968	173.4	150.5	161.6	148.7	175.7	0.042
1969	94.2	111.6	111.0	101.9	120.8	0.042
1970	93.0	103.6	112.5	103.0	122.8	0.044
1971	90.3	93.3	90.4	83.0	98.5	0.043
1972	62.2	74.8	73.2	66.6	80.5	0.047
1973	101.6	78.6	93.0	83.4	103.8	0.055
1974	115.1	105.4	93.9	83.9	105.1	0.056
1975	115.9	104.5	94.6	86.0	104.1	0.048
1976	71.4	74.6	66.7	60.7	73.2	0.047
1977	63.8	67.5	58.9	53.7	64.5	0.046
1978	63.4	57.9	49.1	44.5	54.2	0.049
1979	57.4	63.4	67.0	61.2	73.5	0.046
1980	62.0	73.4	77.0	70.8	83.8	0.042
1981	103.7	118.7	119.3	108.8	130.8	0.046
1982	166.7	161.2	142	129.4	155.8	0.046
1983	179.7	195.4	164.9	149.6	181.7	0.049
1984	143.5	142.5	143.7	130.0	158.8	0.050
1985	224.2	158.7	171.0	153.8	190.1	0.053
1986	176.5	142.9	157.2	142.8	173.0	0.048
1987	115.2	158.2	156.5	143.9	170.3	0.042
1988	105.1	130.2	136.8	125.7	148.9	0.042
1989	120.1	125.3	139.5	128.2	151.7	0.042
1990	137.8	141.5	159.1	146.5	172.7	0.041

Coast: 1991 - 1995

The depth distribution of the majority of successful catch records (between the 1st and 99th percentiles) ranged from 33 m to 289 m, with only a few observations at deeper or shallower depths. The GLM model used all valid tows occurring between 25 and 300 m.

All predictive variables offered to the stepwise procedure were selected for the final model: locality (76 categories), vessel (90 categories), month (12 categories), and depth band (11 categories), in addition to the year factor which was forced as the first variable. These five factors accounted for 43% of the total model variation (

Table C - 28).

The standardization procedure stabilized the 5-year time series (Table C - 15). Standardisation tended to stabilize the time series. Examination of changes to the annual CPUE index as successive predictive variables were added shows that the biggest shift away from the initial year effect model (i.e., the Unstandardised index) occurred with the addition of locality. Annual patterns in the Standardized index (i.e., the selected lognormal model) differed from both the Arithmetic and Unstandardised indices (Table C - 29).

*Table C - 28. Order of acceptance of variables into the COAST: 1991 - 1995 model of lingcod CPUE by core vessels (based on the vessel selection described in text) with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.*

Step	**Variable**	R^2
1	Year*	0.004
2	DFO locality *	0.301
3	Vessel *	0.378
4	Month*	0.417
5	Depth bands*	0.433
Final		**0.433**

Table C - 29. Arithmetic, unstandardised, and standardised CPUE indices for COAST: 1991-1995 analysis. Upper and lower bounds are provided for the standardized index, as is the associated standard error. The geometric mean of the standardised series has been scaled so that it equals the geometric mean of the arithmetic series.

Year	Arithmetic Series	Unstandardized Series	Standardized Series			
			Series	Lower	Upper	S.E.
1991	164.1	141	165.1	159.8	170.6	0.016
1992	143.5	134.4	145.1	141.2	149.1	0.014
1993	175.4	178.4	151.8	147.7	155.9	0.014
1994	154.6	164.8	165.1	160.7	169.7	0.014
1995	138.8	159.1	147.6	143.7	151.7	0.014

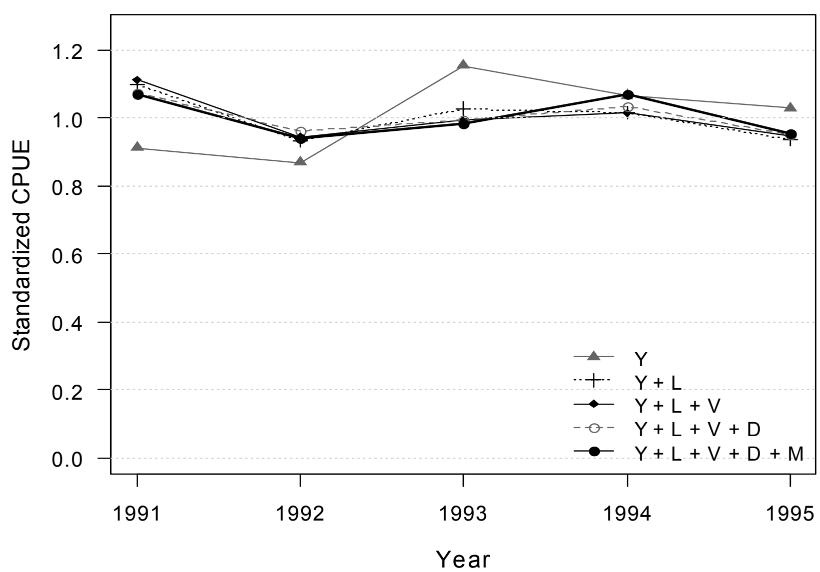

Figure C - 15. Change in year coefficients after adding each successive predictive factor to the COAST: 1990-1995 GLM analysis (Y = year, M = month, L = locality, D = depth, V = vessel). The final model, which represents the Standardized index used in the stock assessment, is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

Coast: 1996 - 2010

The depth distribution of the majority of successful catch records (between the 1st and 99th percentiles) ranged from 46 m to 356 m, with only a few observations at deeper or shallower depths. The GLM model used all valid tows occurring between 25 and 375 m.

All predictive variables offered to the stepwise procedure were selected for the final model: locality, depth band, vessel, latitude, and month, in addition to the year factor which was forced as the first variable. These six factors accounted for 34% of the total model variation (Table C - 30).

The standardization procedure had a moderate effect on the overall time series (Figure C - 16). Standardisation lifted the first half of the series and depressed the second half (with the exception of the final year), resulting in an overall stabilization of the series. Examination of changes to the annual CPUE index as successive predictive variables were added shows that the biggest shift away from the initial year effect model (i.e., the Unstandardised index) occurred with the addition of locality. Trends in the Arithmetic index were more consistent with the Unstandardised index than with the Standardized Index (Table C - 31).

*Table C - 30. Order of acceptance of variables into the COAST: 1996 - 2010 model of lingcod CPUE by core vessels (based on the vessel selection described in text) with the amount of explained deviance (R^2) for each variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.*

Step	**Variable**	**R^2**
1	Year*	0.012
2	DFO locality *	0.215
3	Depth bands *	0.291
4	Vessel *	0.316
5	Latitude *	0.332
6	Month*	0.344
Final		**0.344**

Table C - 31. Arithmetic, unstandardised, and standardised CPUE indices for COAST: 1996-2010 analysis. Upper and lower bounds are provided for the standardized index, as is the associated standard error. The geometric mean of the standardised series has been scaled so that it equals the geometric mean of the arithmetic series.

Year	Arithmetic Series	Unstandardized Series	Standardized Series			
			Series	Lower	Upper	S.E.
1996	114.3	105.7	135.1	129.8	140.7	0.020
1997	86.3	80.8	102.4	98.8	106.2	0.018
1998	91.4	88.4	109.4	105.7	113.2	0.017
1999	70.0	74.9	85.4	82.7	88.3	0.016
2000	106.2	89.8	99.9	97.0	103.0	0.015
2001	84.7	88.9	96.1	93.1	99.2	0.016
2002	102.9	110.3	108.0	104.9	111.3	0.015
2003	108.5	125.1	116.3	112.7	119.9	0.015
2004	118.7	117.3	103.1	99.9	106.4	0.016
2005	106.4	122.2	98.4	95.3	101.5	0.016
2006	133.7	133.1	118.8	114.8	122.9	0.017
2007	135.3	118.8	108.0	104.3	111.8	0.018
2008	150.8	131.9	104.1	100.1	108.3	0.020
2009	114.8	116.5	97.1	93.6	100.8	0.018
2010	69.1	79.7	84.3	80.0	88.9	0.026

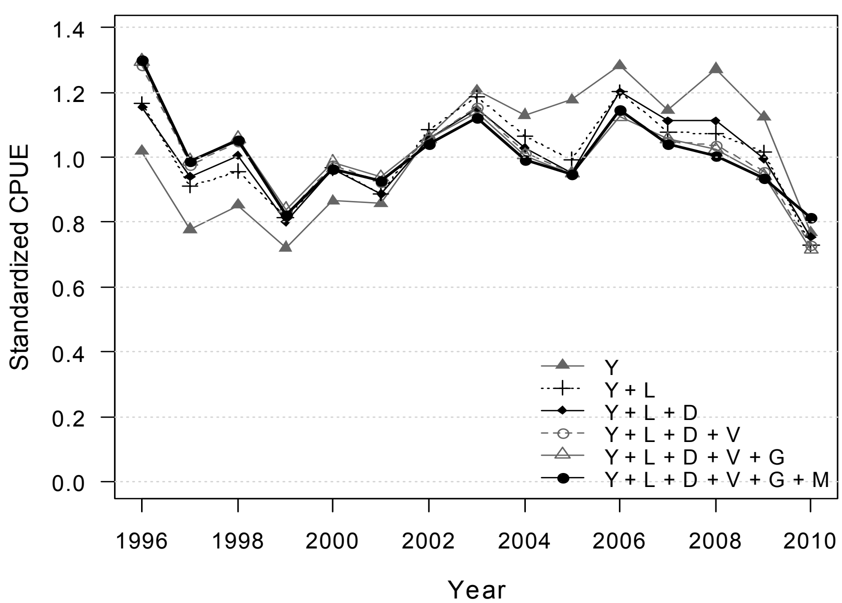

Figure C - 16. Change in year coefficients after adding each successive predictive factor to the COAST: 1996-2010 GLM analysis (Y = year, L = locality, D = depth, V = vessel, G = latitude, M = month). The final model, which represents the Standardized index used in the stock assessment, is shown with a thick solid black line. Each line has been scaled so that the geometric mean equals 1.0.

REFERENCES

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

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

Francis, R.I.C.C. 2001. Orange roughy CPUE on the South and East Chatham Rise. New Zealand Fishery Assessment Report 2001/26. 30 p.

Hilborn, R. and C. J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics. Routledge, Chapman & Hall, Inc. New York. 570 p.

Quinn, T.R. and R.B. Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press. 542 p.

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

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

APPENDIX D. RESEARCH SURVEYS

There exist ten surveys with potential for providing information about lingcod (LIN) relative abundance which have operated in British Columbia waters since 1967 (Table D - 1). All but two of these surveys (historical Queen Charlotte Sound and Hecate Strait Pacific cod monitoring) were used in this assessment. The two surveys which covered the west coast Vancouver Island (shrimp survey and synoptic survey) were split to accommodate the two assessment areas (3C and 3D) which required independent assessments. The US NMFS triennial was only applied to the 3C assessment area because it did not extend beyond 49°N.

Table D - 1. List of surveys available to be used as a series of relative biomass estimates and how they were incorporated into this assessment.

	Assessment Region				
Survey	3C	3D	5AB	5CDE	Total BC
US NMFS triennial	used				used
West coast Vancouver Island shrimp	used (Area 124)	used			used (Total WCVI)
West coast Vancouver Island synoptic	used (Area 3C)	used (Area 3D)			used (Total WCVI)
Historical Queen Charlotte Sound			not used		not used
Queen Charlotte Sound synoptic			used		used
Queen Charlotte Sound shrimp			used		used
Hecate St multi-species				used	used
Hecate St synoptic				used	used
West coast Haida Gwaii synoptic				used	used
Hecate St Pacific cod				not used	not used

ANALYTICAL METHODS

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

(Eq. D - 1)
$$U_{yi} = \frac{1}{n_{yi}} \sum_{j=1}^{n_{yi}} \frac{C_{yij}}{E_{yij}},$$

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

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

(Eq. D - 2)
$$\delta_{yi} = \frac{1}{vw} U_{yi},$$

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

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

(Eq. D - 3)
$$\delta_{yi} = \frac{1}{n_{yi}} \sum_{j=1}^{n_{yi}} \frac{C_{yij}}{D_{yij} w_{yij}},$$

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

The annual biomass estimate $\left(B_y\right)$ is then the sum of the product of CPUE densities and bottom areas across m strata:

(Eq. D - 4)
$$B_y = \sum_{i=1}^{m} \delta_{yi} A_i = \sum_{i=1}^{m} B_{yi},$$

where δ_{yi} = mean CPUE density (kg/km^2) for stratum i, year y;
A_i = area (km^2) of stratum i;
B_{yi} = biomass (kg) for stratum i, year y;
m = number of strata.

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

(Eq. D - 5)
$$V_y = \sum_{i=1}^{m} \frac{\sigma_{yi}^2 A_i^2}{n_{yi}} = \sum_{i=1}^{m} V_{yi},$$

where σ_{yi}^2 = variance of CPUE density (kg^2/km^4) for stratum i, year y;
V_{yi} = variance of the biomass estimate (kg^2) for stratum i, year y.

The coefficient of variation $\left(CV_y\right)$ of the annual biomass estimates $\left(B_y\right)$ is

(Eq. D - 6)
$$CV_y = \frac{\sqrt{V_y}}{B_y}.$$

For all research survey indices described below, analytical estimates of annual biomass (Eq. D - 4) and bootstrap estimates of CV (described below) were used for input to the surplus production model (Appendix F). Analytical estimates of CV and bootstrap mean estimates of biomass are included in this appendix for comparison purposes only.

Additional details on methods used to calculate research survey indices, as well as maps showing the distribution of sample locations and survey catch rates, are available from P. Starr (contact information with author affiliations).

US NMFS TRIENNIAL TRAWL SURVEY

Methods

Tow-by-tow data from the NMFS triennial survey covering the Vancouver INPFC region were provided by Mark Wilkins (NMFS) for the seven years that the survey worked in BC waters (Table D - 2). These tows were assigned to strata by the NMFS, but the size and definition of these strata have changed over the life of the survey (Table D - 3). The NMFS survey database also identified in which country the tow was located.

All usable tows have an associated net width and distance travelled, allowing for the calculation of the area swept by the tow. Biomass indices and the associated analytical CVs for lingcod were calculated for the total Vancouver INPFC region and for each of the Canadian- and US-Vancouver sub-regions, using appropriate area estimates for each stratum and year (Table D - 3). Strata that were not surveyed consistently in all seven years of the survey were dropped from the analysis (Table D - 2; Table D - 3), allowing the remaining data to provide a comparable set of data for each year from 1989 onwards. US tows taking placing south of the 47.5° line have been excluded because these tows are outside the Vancouver INPFC region. The strata definitions used in the 1980 and 1983 surveys were considerably different than those used in subsequent surveys, particularly in Canadian waters. Therefore, the 1980 and 1983 indices were scaled up by the ratio (1.24=9169 km^2/7399 km^2) of the total stratum areas relative to the 1989 and later surveys so that the coverage from the first two surveys would be comparable to the surveys conducted from 1989 onwards.

The data were analysed using equations D-1 to D-6. When calculating the variance for this survey, it was assumed that the variance and CPUE within any stratum was equal, even for strata that were split by the presence of the US/Canada border. The total biomass $\left(B_{y_i}\right)$ within a stratum which straddled the border was split between the two countries $\left(B_{y_{i_c}}\right)$ by the ratio of the relative area within each country. The variance $V_{y_{i_c}}$ for that part of stratum *i* within country *c* was calculated as being in proportion to the ratio of the square of the area within each country *c* relative to the total area of stratum *i*. The partial variance $V_{y_{i_c}}$ for country *c* was used instead of the total variance in the stratum V_{y_i} when calculating the variance for the total biomass in US or Canadian waters. CVs were calculated as in Equation D-6.

The biomass estimates and the associated standard errors were adjusted to a constant area covered using the ratios of area surveyed provided in Table D - 4. This was required to adjust the Canadian biomass estimates for 1980 and 1983 to account for the smaller area surveyed in those years compared to the succeeding surveys. The biomass estimates from Canadian waters were consequently multiplied by the ratio 1.24 (=9166/7399) to make them equivalent to the coverage of the surveys from 1989 onwards.

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

Results

The biomass estimates obtained from the above methods show an apparent decreasing trend for the Canada-Vancouver sub-region (Figure D - 1), although the estimates are very uncertain (particularly 1983 and 1998; Figure D - 1; Table D - 6). Biomass estimates from US waters are lower by an order of magnitude relative to those calculated for the Canadian strata.

All seven surveys have imprecise CVs, ranging to a high of 55% in the Canada Vancouver region for 1983 (Table D - 6). Only the 1980 and 2001 surveys have CVs less than 30%. Note that the bootstrap estimates of CV do not include any uncertainty with respect to the ratio expansion required to make the 1980 and 1983 survey estimates comparable to the 1989 and later surveys. Therefore, it is likely that the true uncertainty for this series is even greater than estimated.

WEST COAST VANCOUVER ISLAND SYNOPTIC TRAWL SURVEY

Methods

This survey has been conducted four times during the period 2004 to 2010 off Vancouver Island. It consists of a single areal stratum and four depth strata. Although no explicit spatial strata were included in the design of the WCVI synoptic survey, tows occurring in the two PFMC Major Areas 3C and 3D have been coded so that separate biomass indices were calculated for each of these areas.

A doorspread density value (Eq. D - 4) was generated for each tow based on the catch of lingcod, the mean doorspread for the tow and the distance travelled. The distance travelled was calculated by multiplying the mean vessel speed for the tow by the total time on the bottom as determined from the bottom contact sensor. Missing values for the doorspread field were filled in either using the mean doorspread for the stratum in the survey year or a default value of 73 m (159 of the 421 valid tows had missing doorspread values replaced with mean value for the year/stratum cell; a further 90 tows were replaced with the default value as there were no observations in the year/stratum cell). Missing values in the vessel speed field were filled in using the mean value for the entire survey in that year (77 values over all years, including 67 in 2008). Missing values in the bottom contact time field substituted the winch time (time from winch lockup to winch retrieval; 70 values were missing over the three survey years, including 38 in 2004 and 30 in 2008).

Results

Estimated biomass levels for lingcod were lower in the 2008 and 2010 surveys compared to the 2004 and 2006 surveys, but the relative error for the 2004 survey estimate is so high that it is not possible to consider it larger than any of the other survey estimates (Figure D - 2; Table D - 7). The estimated relative errors (CV) were reasonable for three of four survey years of the survey (15–22%), but, as mentioned, the relative errors for both of the 2004 estimates were so large (69%) to render the estimates for that year useless (Table D - 7).

WEST COAST VANCOUVER ISLAND SHRIMP SURVEY

Methods

Tow-by-tow data from a west coast Vancouver Island shrimp trawl survey are available for 35 years spanning the period from 1972 to 2010. These survey data were analysed following the recommendations made by Starr et al. (2002) in their reanalysis of the data from the same survey for west coast Vancouver Island Pacific cod, with some modifications.

Biomass estimates are based on a post-stratification of this survey into two strata (Stratum 124 and Stratum 125) and by assuming that the survey tows were randomly selected within these areas. The data were analysed using equations D-1 to D-6, which assume that tow locations were selected randomly within a stratum relative to the biomass of lingcod. This was not an assumption made by the original survey design. The original survey design used latitudinal transects and selected the stations randomly along the transect. One thousand bootstrap replicates with replacement were made on the survey data to estimate bias corrected 95% confidence regions for each survey year (Efron 1982).

Results

Estimated biomass levels for lingcod from the WCVI shrimp trawl survey have been variable over the history of the survey, with variable relative error (ranging from 0.14 to 0.79 for Stratum 124 and 0.10 to 0.82 for Stratum 125) (Figure D - 3; Table D - 8). There has been a substantial drop in biomass levels in Stratum 124 since 2008, but this is not mirrored in Stratum 125. A total biomass index for WCVI (Stratum 124 + Stratum 125) is shown in Table D - 9.

QUEEN CHARLOTTE SOUND (QCS) SYNOPTIC TRAWL SURVEY

Methods

This survey has been conducted in five years over the period 2003 to 2009 in QCS between Vancouver Island and Moresby Island and extending into the lower part of Hecate Strait between Moresby Island and the mainland. The design divided the survey into two large aerial strata (5AB North and 5AB South), which roughly corresponded to the PMFC regions 5A and 5B while also incorporating part of 5C. Each of these two areas was divided into four depth strata: 50–120 m; 120–250 m; 250–370 m; and 370–500 m.

A doorspread density value (Eq. D - 4) was generated for each tow based on the catch of lingcod, the mean doorspread for the tow, and the distance travelled. The latter was calculated by multiplying the mean vessel speed for the tow by the total time on the bottom as determined from the bottom contact sensor. Missing values for the doorspread field used the mean doorspread for the stratum in the survey year (53 values over all years). Missing values in the vessel speed field used the mean value for the entire survey in that year (24 values over all years). Missing values in the bottom contact time field substituted the winch time (time from winch lockup to winch retrieval; 42 values over the four survey years).

Results

Estimated lingcod biomass from this trawl survey shows no real trend, with the biomass estimates for 2004 and 2009 being nearly identical (Figure D - 4; Table D - 10). The estimated relative errors are moderate, lying between 17 and 28% (Table D - 10).

QCS SHRIMP SURVEY

Methods

This survey covers the SE corner of QCS extending westward from Calvert Island and Rivers Inlet into the Goose Island Gully. There is also a stratum providing coverage between Calvert Island and the mainland. Five vessels took part in the first year that the survey was conducted (1998) and the timing in that year was later than in subsequent years (July instead of April/May). It was decided to discard this initial survey year, given the apparent exploratory nature of the design and the potential for non-comparability among vessels in the same year and with subsequent surveys. After the initial year, the survey has been conducted routinely by the *W.E. Ricker* (except in 2005 when the *Frosti* was used) in April or May. This assessment uses all years from1999 onwards.

The survey is divided into three aerial strata: stratum 109 lying to the west of the outside islands and extending into Goose Island Gully; stratum 110 lying to the south of Calvert Island and stratum 111 lying between Calvert Island and the mainland. Stratum 111 has been discarded as its location does not provide good habitat for lingcod.

These data were analysed using equations D-1 to D-6, which assume that tow locations were selected randomly within a stratum relative to the biomass of lingcod. One thousand bootstrap replicates with replacement were made on the survey data to estimate bias corrected 95% confidence regions for each survey year (Efron 1982).

A doorspread density value (Eq. D - 4) was generated for each tow based on the catch of LIN, an arbitrary doorspread (25 m) for the tow, and the distance travelled. The distance travelled was determined at the time of the tow, based on the bottom contact time (James Boutillier, DFO, *pers. comm.*). The few missing values for this field were filled in by multiplying the vessel speed and the tow time. All tows were used regardless of depth because this survey, unlike the west coast Vancouver Island shrimp survey, has consistently sampled depths up to about 240 m, so there was no need to truncate the tows at depth to ensure comparability across survey years.

Results

Estimated biomass levels for lingcod from the QCS shrimp trawl survey are low but have been consistent across years, without showing a trend and with CVs ranging between 22% and 58% (Figure D - 5; Table D - 11).

WEST COAST HAIDA GWAII SYNOPTIC TRAWL SURVEY

Methods

This survey has been conducted four times over the period 2006 to 2010 off the west and north coasts of Haida Gwaii. It comprises a single areal stratum and four depth strata: 180–330 m; 330–500 m; 500–800 m; and 800–1300 m. The deepest stratum (800–1300 m) has not been consistently monitored over the four survey years and consequently has been omitted from the analysis.

A doorspread density value (Eq. D - 4) was generated for each tow based on the catch of lingcod, the mean doorspread for the tow and the distance travelled. The distance travelled was calculated by multiplying the mean vessel speed for the tow by the total time on the bottom as determined from the bottom contact sensor. Missing values (26 of the 459 valid tows) for the doorspread field were populated using the mean doorspread for the stratum in the survey year. Missing values in the vessel speed field were populated using the mean value for the entire survey in that year (11 values over all years). Missing values in the bottom contact time field used the winch time instead (time from winch lockup to winch retrieval; 35 values missing over the three survey years, including 17 in 2008).

Results

Estimated lingcod biomass from this trawl survey show no obvious trend, with the first three survey years nearly the same, followed by a halving of the index in 2010 (Figure D - 6; Table D - 12). The estimated relative errors are moderate, lying between 23 and 39% (Table D - 12).

HECATE STRAIT MULTISPECIES TRAWL SURVEY

Data from the Hecate Strait multispecies trawl survey for every year in each tow were available for analysis (N. Olsen DFO *pers. comm.*). The recommendations by Sinclair (1999) were used to analyse these data.

The distribution of tows by depth zone and survey year as presented by Sinclair (1999) could not be duplicated exactly, but differences were small. These differences may be due to different conversion assumptions as the depth data are provided in metres and the depth intervals are defined in fathoms. Alternatively, the original data may have been recorded in fathoms and there may be a loss in precision when converting from fathoms to metres and back to fathoms. These data were analysed using equations D-1 to D-6, which assume that tow locations were selected randomly within a stratum relative to the biomass of lingcod. This was not an assumption made by the original survey design.

Sinclair (1999) suggested calculating lingcod survey CPUE $\left(C_{y_i}\right)$ in stratum *i* for year *y* using (Eq. D - 7 to obtain a density in kg/km^2 instead of Equation D-2 because there were insufficient data available to use the latter formulation.

(Eq. D - 7)

$$C_{y_i} = \frac{\sum_{j=1}^{n_{y_i}} \left(W_{y_i j} \Big/ E_{y_i j}\, 0.0486 \right)}{n_{y_i}}$$

where,

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

$E_{y_i j}$ = effort (h) by tow *j* in stratum *i* for year *y*

0.0486 = constant factor (km^2/h) applied to convert CPUE in kg/h to swept area (kg/km^2)

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

Results

Estimated biomass levels for lingcod from the Hecate Strait multispecies trawl survey do not show much contrast, but the first four surveys may be generally a bit stronger with respect to lingcod than the final seven (Figure D - 7; Table D - 13). This is particularly true for the 1989 index, which had two of the three largest catch weights for lingcod for the entire series located in the 20-29 fm stratum. Relative errors for this species in this survey are moderate, with the estimated CVs ranging from 0.20 to 0.43 (Table D - 13).

HECATE STRAIT SYNOPTIC TRAWL SURVEY

Data selection

To date, this survey has been conducted in 2005, 2007 and 2009 within Hecate Strait and the eastern parts of Dixon Entrance. It comprises a single areal stratum and four depth strata: 10-70m, 70-130m, 130-220m, and 220-500m.

A doorspread density value (Eq. D - 4) was generated for each tow based on the catch of lingcod, the mean doorspread for the tow and the distance travelled. The distance travelled was calculated by multiplying the mean vessel speed for the tow by the total time on the bottom as determined from the bottom contact sensor. Missing values (198 of the 493 valid tows) for the doorspread field were populated using the mean doorspread for the stratum in the survey year. Missing values in the vessel speed field were populated using the mean value for the entire survey in that year (12 values over all years). Missing values in the bottom contact time field used the winch time instead (time from winch lockup to winch retrieval; 6 values missing over the three survey years, 3 in 2007 and 3 in 2009).

Results

Estimated lingcod biomass from this trawl survey show no trend, with the last two survey years being nearly identical and the 2005 survey estimate about 20% lower (Figure D - 8; Table D - 14). The estimated relative errors are low, with all three less than 20% (Table D - 14).

Table D - 2. Number of tows by stratum and by survey year for the NFMS triennial survey. Strata which are coloured grey have been excluded from the analysis due to incomplete coverage across the seven survey years, or were from locations outside of the Vancouver INPFC area (Table D-3).

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

Table D - 3. Stratum definitions by year used in the NFMS triennial survey to separate the survey results by country and by INPFC area. Stratum definitions in grey are those strata which have been excluded from the final analysis due to incomplete coverage across the seven survey years or because the locations were outside of the Vancouver INPFC area.

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

Table D - 4. Number of usable tows performed and area surveyed in the INPFC Vancouver region separated by the international border between Canada and the United States.

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

Table D - 5. Catch weight (kg) of lingcod by survey year and stratum, separated by the country of capture. Strata which were excluded (see Table D - 3) from the analysis are marked in grey.

Stratum	Survey Year							Total
	1980	1983	1989	1992	1995	1998	2001	
	Canadian strata							
11	546.4							546.4
12		1,392.0						1,392.0
18N			185.2	5.1				190.3
19N			2,046.8	686.2	836.3	737.3	212.1	4,518.7
28N			0.0	0.0	0.0	1.7		1.7
29N			114.7	35.1	44.6	31.8	1.3	227.5
31	208.4							208.4
32		8.6						8.6
38N					0.0			0.0
51	40.4							40.4
52		11.8						11.8
	US strata							
10	172.1	16.3						188.5
11		551.9						551.9
17N			7.0	33.1	11.4	10.6	16.3	78.5
17S			186.2	940.8	92.2	82.4	243.2	1,544.8
18S			408.1	35.4	52.5	192.3	86.3	774.7
19S			6.1	0.5	5.0	14.8	3.4	29.8
27N			11.1	1.7	7.6	3.8	0.0	24.2
27S			168.2	20.9	18.4	544.4	1,443.1	2,195.0
28S			24.0	15.2	10.3	1.8	4.6	56.0
29S			0.0	0.0	0.0	0.0	0.0	0.0
30	116.6	0.0						116.6
31		234.8						234.8
37N					0.0	0.0	0.0	0.0
37S					0.0	0.0	0.0	0.0
38S					0.0		0.0	0.0
50	3.4	0.0						3.4
51		235.2						235.2

Table D - 6. Biomass estimates for lingcod in the Vancouver INPFC region (total region, Canadian waters only and US waters only) with 95% confidence regions based on the bootstrap distribution of biomass. The bootstrap estimates are based on 1000 random draws with replacement.

Estimate type	Year	Biomass	Mean bootstrap biomass	Lower bound biomass	Upper bound biomass	CV Bootstrap	CV Analytic
Total Vancouver	1980	4,345	4,359	2,536	6,460	0.222	0.224
	1983	10,320	10,197	4,683	22,564	0.434	0.444
	1989	9,792	9,846	5,281	16,188	0.286	0.286
	1992	3,226	3,214	1,581	6,116	0.342	0.340
	1995	3,838	3,852	2,221	6,525	0.271	0.279
	1998	3,936	3,978	1,761	9,377	0.474	0.462
	2001	1,826	1,833	1,117	2,688	0.222	0.225
Canada Vancouver	1980	3,125	3,120	1,832	4,895	0.238	0.243
	1983	8,956	8,832	2,944	22,522	0.540	0.552
	1989	8,436	8,500	4,145	14,622	0.317	0.317
	1992	2,821	2,814	1,226	5,609	0.372	0.371
	1995	3,335	3,361	1,782	5,807	0.298	0.304
	1998	3,207	3,258	1,193	8,480	0.553	0.541
	2001	1,326	1,329	695	2,108	0.276	0.280
US Vancouver	1980	1,281	1,297	316	2,529	0.444	0.462
	1983	1,805	1,796	1,170	2,613	0.201	0.208
	1989	1,355	1,346	900	2,018	0.208	0.206
	1992	405	399	231	633	0.256	0.252
	1995	502	491	291	912	0.287	0.292
	1998	730	719	451	1,132	0.235	0.236
	2001	500	504	280	853	0.275	0.276

Table D - 7. Biomass estimates for lingcod from the WCVI synoptic trawl survey for the survey years from 2004 to 2010. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement. Note that the total survey stratum areas were used for the 3C and 3D biomass calculations as these values were not available by subarea.

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
	Area 3C					
2004	1,739.9	1,765.0	373.1	4,921.8	0.690	0.677
2006	1,922.1	1,923.7	1,381.6	2,528.7	0.149	0.152
2008	738.5	737.1	523.1	959.9	0.154	0.148
2010	734.6	731.5	532.3	983.6	0.155	0.157
	Area 3D					
2004	5,420.5	5,314.1	712.0	14,600.5	0.689	0.717
2006	2,150.0	2,159.6	1,464.8	3,088.9	0.191	0.191
2008	729.0	723.3	504.0	1,024.3	0.178	0.172
2010	614.8	615.8	388.7	925.2	0.216	0.221
	Total survey					
2004	3,136.1	3,236.5	687.4	7,017.0	0.511	0.522
2006	2,194.2	2,199.7	1,673.8	2,842.1	0.134	0.134
2008	732.2	732.5	591.2	913.5	0.114	0.113
2010	709.1	706.0	533.6	898.6	0.132	0.134

Table D - 8. Biomass estimates for Lingcod from the WCVI shrimp trawl survey by stratum for the survey years 1975 to 2010. Biomass estimates are based on a post-stratification of this survey into two strata (Stratum 124 and Stratum 125) and by assuming that the survey tows were randomly selected within these areas. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement. The analytic CV is based on the assumption of random tow selection within a stratum.

	Stratum 124						Stratum 125					
Survey Year	Bio-mass (t)	Boot-strap bio-mass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Boot-strap CV	Anal-ytic CV	Bio-mass (t)	Boot-strap bio-mass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Boot-strap CV	Anal-ytic CV
1975	1,371.5	1,365.0	873.8	2,025.1	0.220	0.226	181.3	182.3	90.1	286.4	0.274	0.275
1976	1,519.2	1,507.0	688.6	3,046.8	0.453	0.461	505.3	505.2	236.0	876.6	0.317	0.314
1977	408.6	414.7	292.4	519.3	0.148	0.153	297.7	299.8	126.7	486.9	0.316	0.331
1978	534.0	538.7	394.4	732.2	0.158	0.162	640.9	631.2	235.5	1,343.0	0.415	0.428
1979	950.7	955.7	698.4	1,212.1	0.136	0.137	397.8	394.4	125.6	829.4	0.445	0.473
1980	962.2	959.3	595.7	1,373.9	0.214	0.222	501.3	508.1	268.8	821.0	0.281	0.291
1981	934.2	939.1	647.7	1,235.5	0.162	0.166	443.3	440.5	214.8	824.9	0.349	0.348
1982	778.4	776.7	537.3	1,133.6	0.197	0.207	405.1	411.1	182.7	851.8	0.407	0.413
1983	2,311.5	2,303.0	636.4	6,800.7	0.658	0.664	1,026.3	1,025.9	693.4	1,394.5	0.175	0.186
1985	562.6	556.1	288.2	1,157.7	0.365	0.361	107.7	107.8	46.2	186.8	0.322	0.333
1987	301.2	302.3	112.3	743.8	0.527	0.524	69.4	69.5	1.0	205.1	0.666	0.712
1988	330.6	331.0	221.2	456.4	0.181	0.179	320.8	317.9	138.3	598.3	0.358	0.368
1989	401.1	400.0	294.2	533.5	0.155	0.152	–	–	–	–	–	–
1990	304.8	303.6	222.6	413.5	0.151	0.153	56.4	60.5	0.0	169.3	0.627	0.712
1991	429.1	429.0	274.3	610.4	0.200	0.198	–	–	–	–	–	–
1992	253.0	258.6	133.2	439.2	0.310	0.305	485.2	487.6	338.4	669.7	0.176	0.201
1993	193.1	190.4	128.2	291.2	0.211	0.214	135.5	131.3	64.9	272.9	0.376	0.369
1994	262.2	260.7	182.1	365.3	0.172	0.172	1,000.6	1,008.6	790.2	1,216.0	0.108	0.110
1995	251.8	254.2	170.3	353.9	0.184	0.185	545.9	564.6	264.0	938.3	0.317	0.337
1996	213.2	214.4	122.8	346.3	0.262	0.268	290.2	288.5	154.1	450.1	0.263	0.272
1997	216.1	218.1	121.8	355.8	0.269	0.269	506.9	513.6	243.3	888.6	0.327	0.319
1998	333.1	333.8	210.7	468.7	0.193	0.201	251.7	253.1	152.3	361.9	0.218	0.223
1999	190.0	192.3	104.1	317.5	0.279	0.289	316.3	318.2	201.8	441.0	0.191	0.201
2000	494.0	497.0	229.4	1,105.8	0.430	0.423	622.4	623.7	424.2	860.4	0.178	0.178
2001	281.9	274.9	110.0	650.4	0.480	0.478	1,153.1	1,156.3	623.1	1,827.4	0.273	0.279
2002	992.5	994.6	394.5	2,474.9	0.507	0.500	884.7	881.7	326.9	1,875.4	0.429	0.444
2003	655.9	654.3	164.1	1,483.4	0.513	0.514	367.5	367.4	176.0	583.4	0.282	0.290
2004	303.0	305.9	165.2	520.7	0.298	0.303	4,312.9	4,232.6	479.1	11,902.8	0.816	0.864
2005	2,476.9	2,502.7	395.6	8,425.5	0.792	0.806	775.4	772.7	412.8	1,186.8	0.247	0.252
2006	2,069.6	2,050.3	1,259.8	3,295.7	0.245	0.254	413.3	414.7	220.8	661.1	0.264	0.275
2007	431.1	435.4	250.8	647.3	0.239	0.234	233.3	232.6	97.0	424.0	0.363	0.372
2008	1,268.2	1,223.3	277.1	3,829.7	0.697	0.694	186.2	183.8	90.0	340.2	0.331	0.353
2009	188.4	190.1	108.4	316.2	0.275	0.274	178.1	177.7	78.0	292.8	0.313	0.322
2010	156.0	156.1	101.1	232.2	0.209	0.218	139.1	138.9	95.2	188.4	0.174	0.181

Table D - 9. Biomass estimates for lingcod from the total WCVI shrimp trawl survey for the survey years 1975 to 2010.

Survey	Biomass	Boot-strap	Lower bound	Upper bound	Bootstrap	Analytic
1975	1,552.8	1,558.7	1,026.9	2,259.2	0.196	0.203
1976	2,024.5	2,061.8	1,082.5	3,822.5	0.347	0.355
1977	706.3	715.9	511.8	943.1	0.159	0.165
1978	1,174.8	1,177.5	674.8	1,774.9	0.243	0.245
1979	1,348.5	1,350.0	965.8	1,900.8	0.176	0.170
1980	1,463.5	1,462.8	984.9	1,974.1	0.175	0.177
1981	1,377.5	1,390.6	984.6	1,842.6	0.157	0.159
1982	1,183.5	1,182.6	819.3	1,775.9	0.195	0.196
1983	3,337.8	3,267.1	1,563.6	7,368.8	0.460	0.464
1985	670.3	672.0	390.0	1,185.4	0.302	0.307
1987	370.5	372.1	143.9	773.4	0.424	0.446
1988	651.4	644.5	445.3	954.7	0.192	0.203
1989	704.7	707.3	513.5	919.8	0.146	0.146
1990	361.2	361.6	257.1	510.6	0.172	0.171
1991	753.9	757.3	498.7	1,080.5	0.202	0.207
1992	738.2	742.1	515.2	1,021.8	0.169	0.168
1993	328.6	328.2	218.5	484.2	0.202	0.198
1994	1,262.8	1,266.2	1,047.4	1,507.6	0.095	0.095
1995	797.8	789.1	488.8	1,223.2	0.231	0.238
1996	503.4	500.4	342.7	701.7	0.187	0.193
1997	723.0	723.3	450.2	1,115.3	0.233	0.238
1998	584.8	585.3	423.0	754.6	0.149	0.149
1999	506.3	501.4	359.2	699.3	0.166	0.166
2000	1,116.3	1,109.4	762.4	1,766.4	0.215	0.212
2001	1,435.0	1,447.3	838.9	2,147.3	0.236	0.243
2002	1,877.2	1,866.6	889.7	3,645.9	0.355	0.337
2003	1,023.4	1,032.8	438.9	1,843.9	0.343	0.346
2004	4,615.9	4,874.5	710.1	14,156.2	0.766	0.807
2005	3,252.3	3,314.1	1,015.0	8,585.4	0.618	0.617
2006	2,482.9	2,455.7	1,653.0	3,707.3	0.214	0.217
2007	664.4	666.7	424.2	944.5	0.199	0.200
2008	1,454.5	1,486.6	435.1	3,921.4	0.595	0.607
2009	366.5	361.1	242.0	541.4	0.206	0.211
2010	295.2	293.7	219.6	379.7	0.139	0.143

Table D - 10. Biomass estimates for LIN from the QCS synoptic trawl survey for the survey years 2003 to 2009. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement.

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
2003	728.9	731.5	431.4	1240.6	0.273	0.279
2004	707.2	704.9	507.1	971.1	0.168	0.166
2005	536.9	541.6	321.9	844.6	0.234	0.241
2007	577.4	577.5	392.8	869.3	0.202	0.193
2009	726.1	722.2	376.1	1211.6	0.280	0.287

Table D - 11. Biomass estimates for lingcod from the QCS shrimp trawl survey for the survey years 1999 to 2010. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement. The analytic CV is based on the assumption of random tow selection within a stratum.

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
1999	69.3	67.4	31.1	139.7	0.382	0.396
2000	60.5	61.1	38.5	90.5	0.216	0.224
2001	55.8	54.7	26.6	97.1	0.315	0.325
2002	41.5	40.8	20.2	81	0.359	0.353
2003	23.3	23.2	10.4	43.8	0.357	0.373
2004	51.2	50.9	19.3	106.8	0.419	0.408
2005	41.6	42.1	7.8	91.5	0.495	0.502
2006	30.9	30.7	7.5	81.2	0.575	0.585
2007	27.9	27.5	10.2	52.2	0.388	0.386
2008	50.3	51.3	22.8	90	0.335	0.342
2009	47.7	47.5	25.5	81.9	0.297	0.307
2010	50.9	52.3	21.3	104.2	0.421	0.424

Table D - 12. Biomass estimates for lingcod from the WCHG synoptic trawl survey for the survey years 2006 to 2010. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement.

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
2006	42.0	42.0	25.6	63.1	0.230	0.237
2007	55.4	54.7	35.7	82.9	0.227	0.219
2008	57.7	58.8	24.8	111.0	0.367	0.380
2010	28.7	28.7	13.3	62.0	0.393	0.395

Table D - 13. Biomass estimates for lingcod from the Hecate Strait multispecies trawl survey for the survey years 1984 to 2003. Biomass estimates are based on a post-stratification of this survey into 10-fathom depth zones and by assuming that the survey tows were randomly selected within these depth zones. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement. The analytic CV is based on the assumption of random tow selection within a stratum.

Survey year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
1984	2,055.8	2,056.1	1,331.6	3,120.6	0.215	0.225
1987	2,656.3	2,673.1	1,550.1	3,950.2	0.230	0.234
1989	6,852.7	6,948.5	2,368.7	12,382.1	0.378	0.385
1991	3,585.7	3,582.4	1,653.1	7,077.3	0.373	0.371
1993	1,058.2	1,079.4	421.6	2,037.9	0.382	0.384
1995	899.9	896.7	601.5	1,317.5	0.198	0.194
1996	898.0	896.0	531.0	1,456.2	0.268	0.261
1998	1,320.8	1,333.8	516.4	2,707.8	0.427	0.437
2000	1,107.8	1,120.3	628.0	1,912.6	0.280	0.273
2002	1,586.8	1,587.4	1,027.2	2,281.6	0.203	0.207
2003	1,133.7	1,147.9	559.4	2,103.0	0.341	0.350

Table D - 14. Biomass estimates for lingcod from the Hecate Strait synoptic trawl survey for the survey years 2005, 2007 and 2009. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement.

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
2005	190.0	190.5	129.3	263.4	0.184	0.193
2007	240.5	240.7	165.2	342.9	0.186	0.183
2009	243.1	242.8	167.0	348.4	0.188	0.191

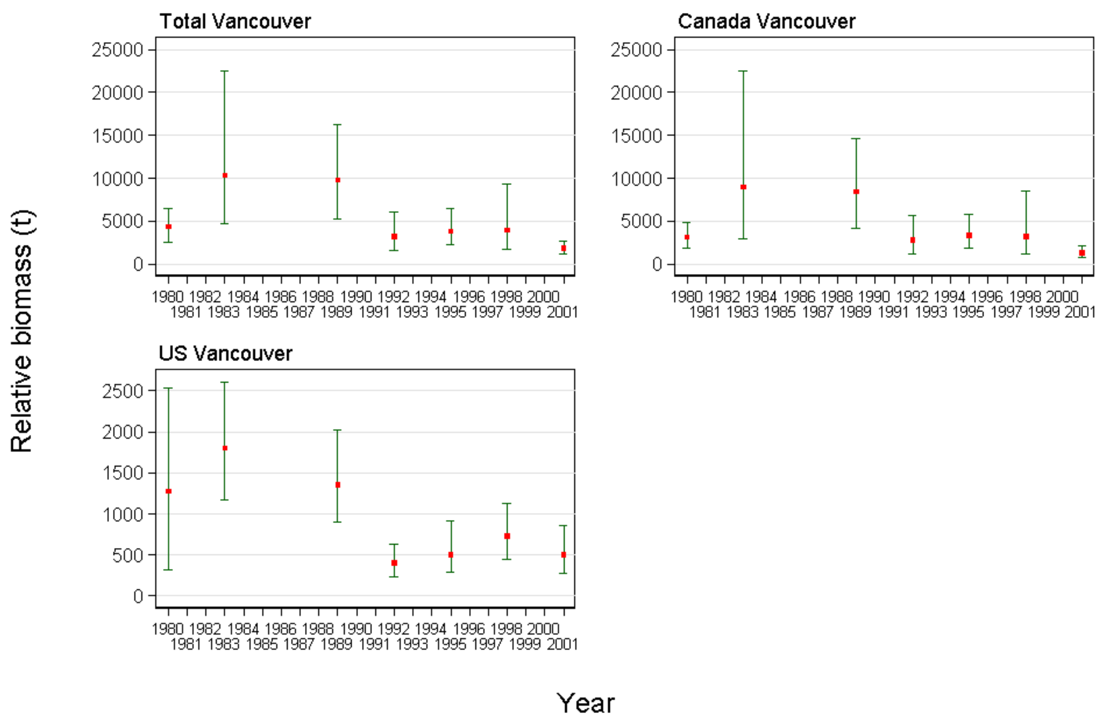

Figure D - 1. Three biomass estimates for lingcod in the INPFC Vancouver region (total region, Canadian waters only and US waters only) with 95% bias corrected error bars estimated from 1000 bootstraps. Note that the plot for US Vancouver has a different scale.

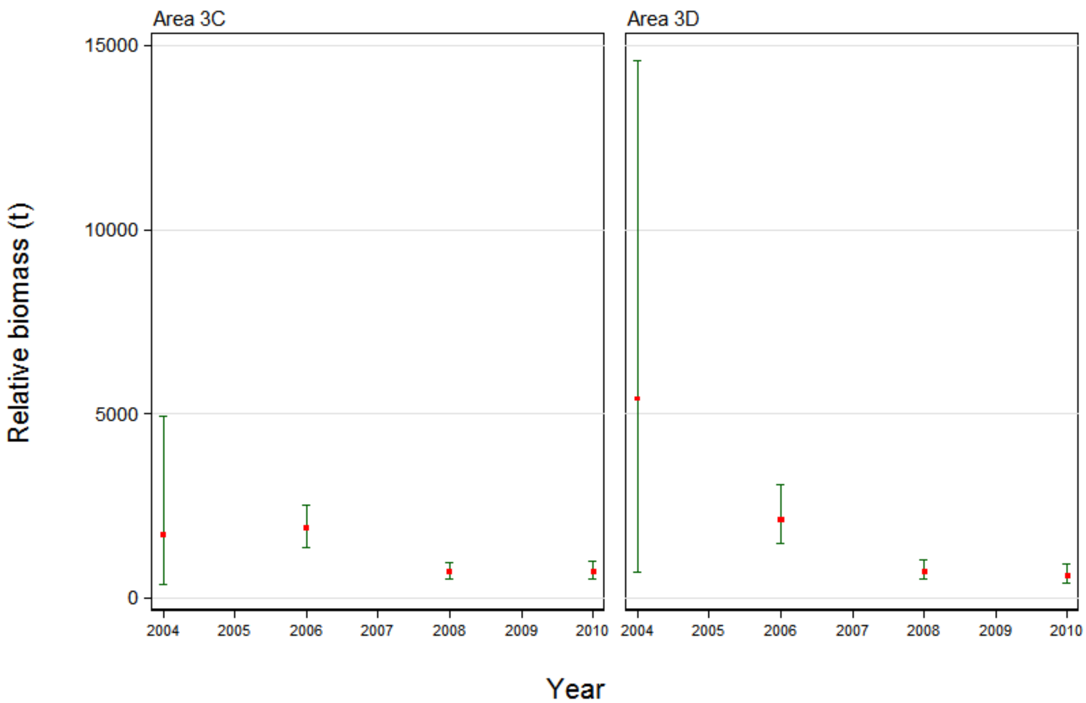

Figure D - 2. Plot of biomass estimates for lingcod from the west coast Vancouver Island synoptic trawl survey from 2004 to 2010. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

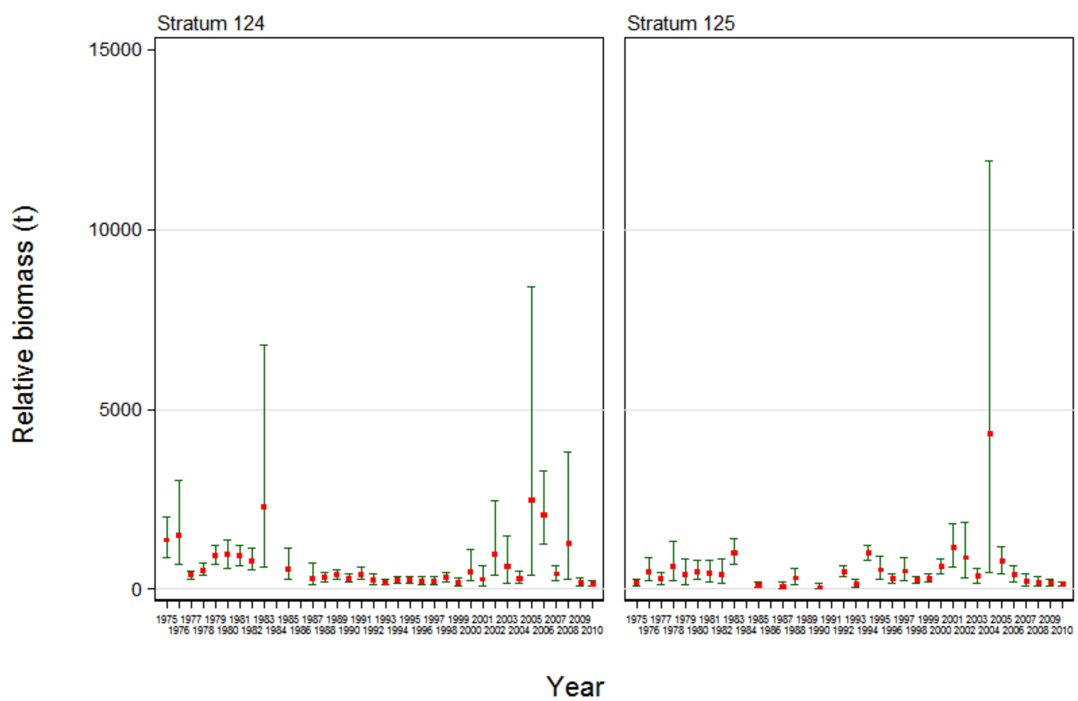

Figure D - 3. Plot of biomass estimates for Stratum 124 [left panel] and Stratum 125 [right panel] for lingcod from the WCVI shrimp trawl survey for the period 1975 to 2010. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

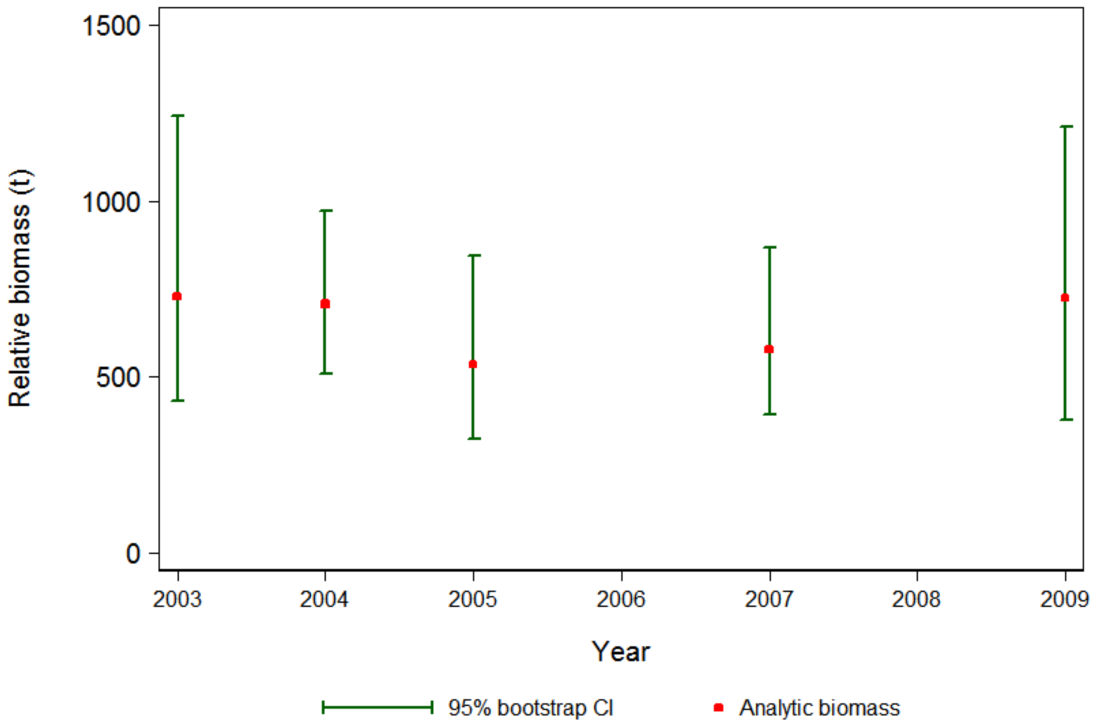

Figure D - 4. Plot of biomass estimates for LIN from the QCS synoptic trawl survey from 2003 to 2009. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

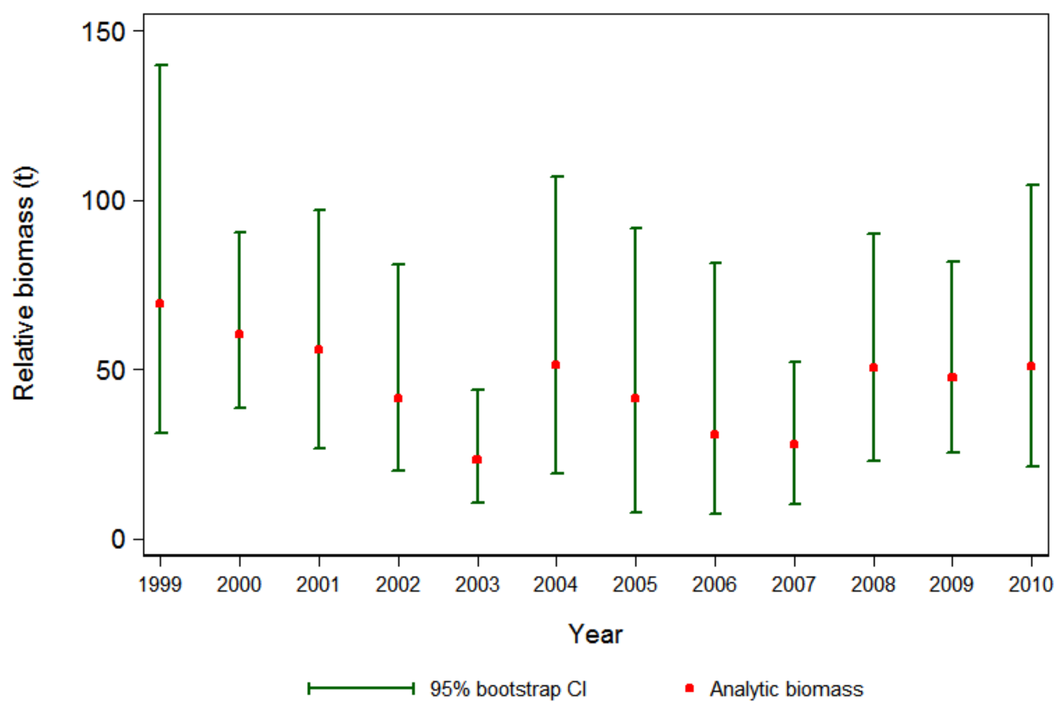

Figure D - 5. Plot of biomass estimates for lingcod from the QCS shrimp trawl survey for 1999 to 2010. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

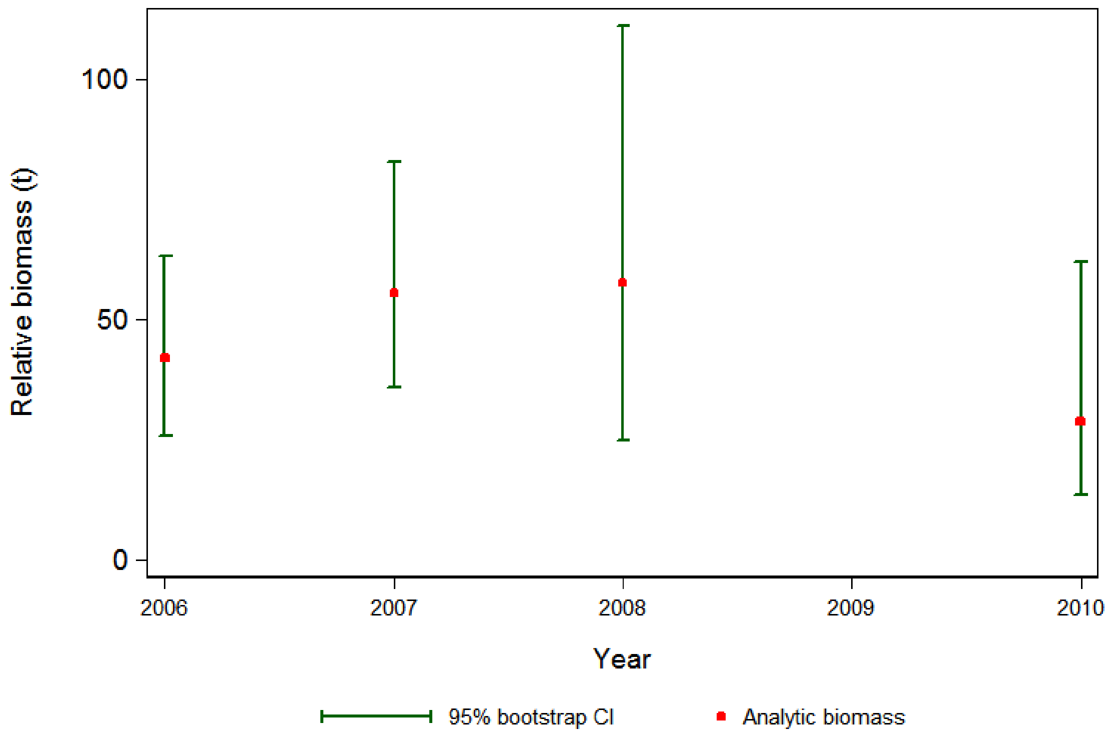

Figure D - 6. Plot of biomass estimates for lingcod from the west coast Haida Gwaii synoptic trawl survey for 2006 to 2010. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

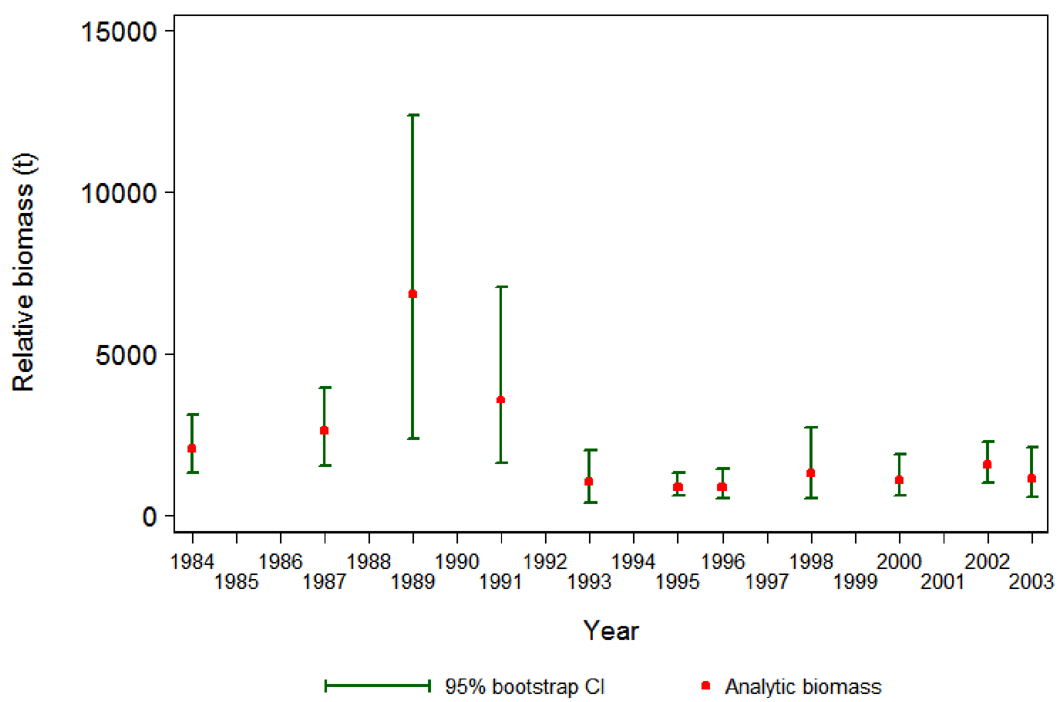

Figure D - 7. Plot of biomass estimates for lingcod from the Hecate Strait multispecies trawl survey for the period 1984 to 2003. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

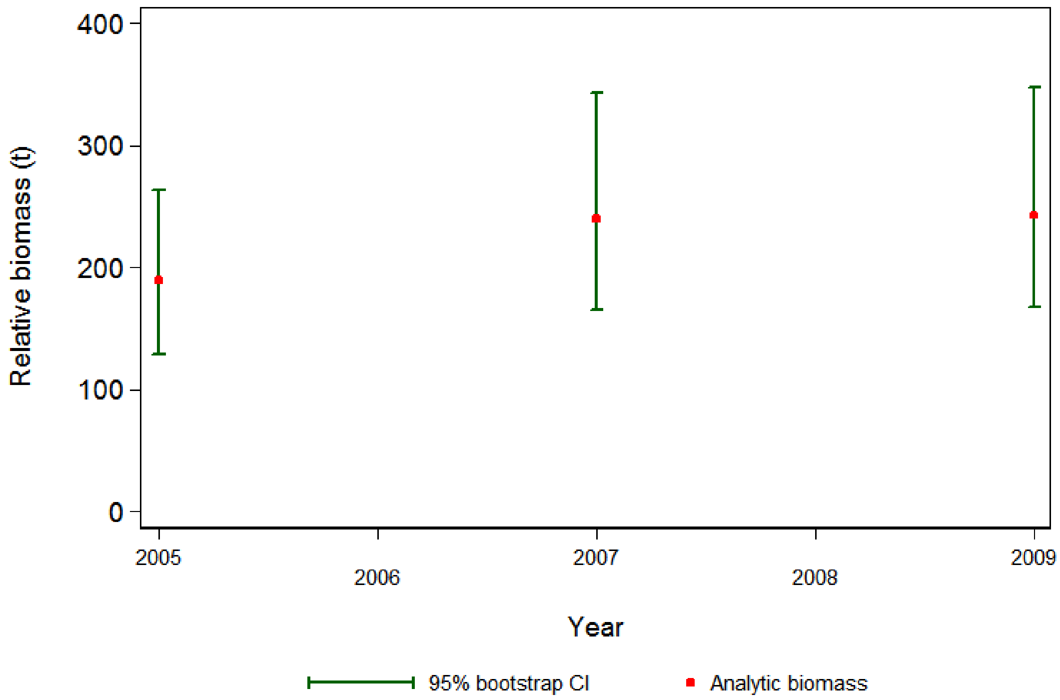

Figure D - 8. Plot of biomass estimates for lingcod from the Hecate Strait synoptic trawl survey for 2006 to 2010. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

REFERENCES

Sinclair, A.F. 1999. Survey design considerations for Pacific cod in Hecate Strait. Canadian Stock Assessment Secretariat Research Document 99/196: 42p.

Starr, P.J., A.S. Sinclair, and J. Boutillier. 2002. West coast Vancouver Island Pacific cod assessment: 2002. Can. Sci. Advis. Sec. Res. Doc. 2002/113. 67p.

Efron, B. 1982. The jackknife, the bootstrap, and other resampling plans. Society of Industrial and Applied Mathematics CBMS-NSF Monographs, 38.

APPENDIX E. BIOLOGICAL DATA ANALYSIS

Three types of biological analysis are presented in this appendix: (i) estimation of growth parameters based on length-at-age data, (ii) estimation of a maturity function, and (iii) estimation of a length-weight relationship. Outputs from these analyses were used to develop informative prior distributions for the intrinsic rate of population growth parameter ,*r*, in the Bayesian surplus production model (Appendix F).

Biological samples were collected from research surveys and commercial and recreational fisheries between 1977 and 2008. Samples were obtained from a variety of gear types, including bottom trawl, trap, gillnet, handline, longline, midwater trawl, shrimp trawl, and recreational rod and reel. Aging was conducted using fin ray methodology developed in 1977 (Cass et al., 1990). Samples from the late 1980's and early 1990's were re-aged in 1997 to correct errors made during this period (Leaman and McFarlane, 1997). Annual sample sizes for age data are shown in Table E - 1. Sample sizes for each analysis are available by age class, area, and sex in Cuif et al. 2009.

Table E - 1. Number of lingcod aged in the four areas from 1977 to 2008.

	3C	3D	5AB	5CDE
1977	752	0	443	121
1978	338	0	305	0
1979	871	193	275	0
1980	287	0	0	0
1981	439	0	586	0
1982	783	0	412	0
1983	334	0	576	0
1984	694	0	0	0
1985	216	105	199	0
1986	376	0	200	0
1987	200	0	0	0
1988	165	70	312	0
1989	211	78	210	0
1990	196	0	255	0
1991	175	0	299	0
1992	0	100	150	0
1993	100	0	100	0
1994	50	0	150	96
1995	740	447	100	100
1996	64	0	145	0
1997	150	0	50	103
1998	161	50	0	0
1999	100	50	250	0
2000	0	0	145	50
2001	1	100	100	0
2002	0	50	150	133
2003	69	31	107	128
2004	150	100	200	117
2005	50	100	92	50
2006	246	120	100	0
2007	0	0	50	50
2008	180	0	0	50
Total	**8098**	**1594**	**5961**	**998**

A Bayesian approach to parameter estimation was used for all three biological analyses. Marginal posterior distributions for biological parameters were obtained using importance sampling (SIR). The SIR algorithm used was based on McAllister and Ianelli (1997). Its application to the current lingcod analysis is described in Cuif et al. (2009). All sampling was determined to be efficient based on the maximum importance ratio. For all model runs, the maximum weight for a single draw (expressed as a percentage of the total cumulative posterior weight) dropped below 0.40% within one million draws from the importance function.

GROWTH PARAMETERS

The growth of individual lingcod was estimated by fitting a Bayesian version of the Von Bertalanffy growth model to individual length-at-age observations for male and female lingcod. The Von Bertalanffy model is based on three parameters: L_∞ is the mean asymptotic length of old fish, k is the growth rate coefficient, and t_o is the theoretical age at length zero. A normal probability density function was used to represent the probability of the observation given the model prediction of the length at age t, L_t:

(*Eq.* E-1)
$$L_t \sim \mathrm{Normal}\left(L_\infty\left(1-e^{-k\left(t-t_0\right)}\right),\sigma_g^2\right)$$

Relatively uninformative priors were placed on k, L_∞ and t_o for all areas (Table E - 2).

Table E - 2. Prior distributions for Von Bertalanffy growth parameters. The first three parameters where estimated while the σ_g parameter was fixed.

Parameter	Prior density function
k (year^{-1})	Normal(0.5,10^2)
L_∞ (mm)	Normal(2000,2000^2)
t_o (year)	Normal(0,500^2)
σ_g	Uniform(log(0.000001),log(100))

Results show that female and male lingcod have different growth patterns (Table E - 3, Figure E - 1). The results for the female growth parameters are similar for the four areas. Estimates for all parameters are quite precise (i.e., have low CVs). The posterior mean of L_∞ for males remains lower than that for females in all areas, which is consistent with previous studies (Cass et al., 1990, Jagielo and Wallace, 2005). For males, estimates for Areas 3C and 5CDE tended to be similar to each other. Estimates for Areas 3D and 5AB were also similar to each other, but differed from those of Areas 3C and 5CDE. Estimates of k were very low for males in Areas 3D and 5AB (k = 0.09 year^{-1}), compared to those for Areas 3C and 5CDE (0.23 year^{-1} and 0.28 year^{-1}, respectively). This difference is likely due to the lack of data for the lower ages for Areas 3D and 5AB, and is reflected in the relatively high CV for the k estimate in Area 3D. Fortunately, only female growth parameter estimates were used to develop the r prior for input into the assessment model.

Table E - 3. Posterior means and coefficient of variation (CV) for the Von Bertalanffy growth parameters for each sex and each area.

	3C		3D		5AB		5CDE	
Female	mean	CV	mean	CV	mean	CV	Mean	CV
Sample size	*5088*		*1303*		*4403*		*875*	
L_∞ (mm)	**1141**	0.01	**1245**	0.03	**1331**	0.02	**1254**	0.02
k (year^{-1})	**0.14**	0.05	**0.10**	0.09	**0.10**	0.05	**0.13**	0.07
t_o (year)	**-2.17**	-0.08	**-3.62**	-0.11	**-3.30**	-0.06	**-1.97**	-0.15
Male	mean	CV	mean	CV	mean	CV	Mean	CV
Sample size	*2963*		*285*		*1534*		*123*	
L_∞ (mm)	**844**	0.01	**1012**	0.10	**1086**	0.05	**841**	0.02
k (year^{-1})	**0.23**	0.06	**0.09**	0.29	**0.09**	0.13	**0.28**	0.12
t_o (year)	**-1.83**	-0.12	**-7.76**	-0.25	**-5.76**	-0.12	**-1.00**	-0.39

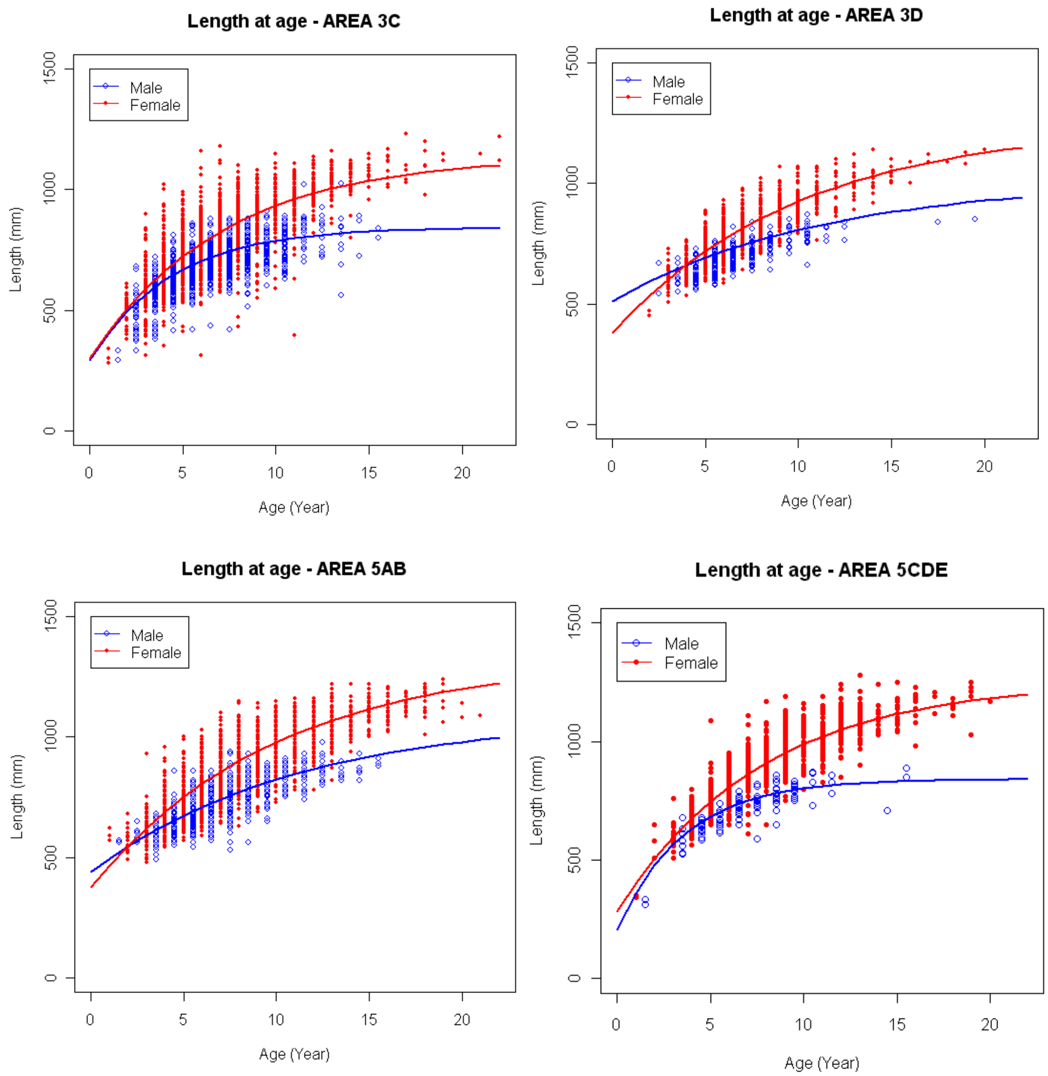

Figure E - 1. Plots of the observed length at age for both female (red circles) and male (blue circles) and the Von Bertalanffy curves fitted to data for each area.

MATURITY PARAMETERS

The proportion mature at age was modelled using a normalized and discretized cumulative lognormal density function. Initial analyses indicated that this form of a maturity function provided a better fit to proportion mature at age data than a logistic function. The maturity function includes two parameters: the median age mature (*med_age*) and the standard deviation in the log fraction maturing at age (σ_{mat}). Uninformative prior distributions were used for both parameters (Table E - 4).

Table E - 4. Prior distributions for maturity parameters.

Parameter	Prior density function
Med_age (year)	Uniform(1,20)
σ_{mat}	Uniform(log(0.000001),log(100))

The posterior mode for median age of maturity for females ranged from 3.79 to 4.18 years (Table E - 5; Figure E - 2), which is consistent with the range reported by Cass et al. (1990) of 3 to 5 years. The posterior mode for median age of maturity for males ranged from 3.52 to 3.79 years (Table E - 5; Figure E - 2), which is higher than the value reported by Cass et al. (1990) of only 2 years.

Table E - 5. Posterior modes and standard deviation (SD) of the maturity parameters for each sex and each area.

	3C		3D		5AB		5CDE	
Female	mode	SD	mode	SD	mode	SD	mode	SD
Sample size	*3339*		*1300*		*3434*		*875*	
med_age (year)	**4.17**	0.014	**3.79**	0.035	**4.18**	0.022	**3.79**	0.046
σ_{mat}	**0.329**	0.039	**0.357**	0.080	**0.493**	0.046	**0.360**	0.097
Male	mode	SD	mode	SD	mode	SD	mode	SD
Sample size	*1604*		*0*		*1098*		*123*	
med_age (year)	**3.79**	0.018	no data		**3.52**	0.045	**3.64**	0.060
σ_{mat}	**0.304**	0.054			**0.487**	0.086	**0.187**	0.260

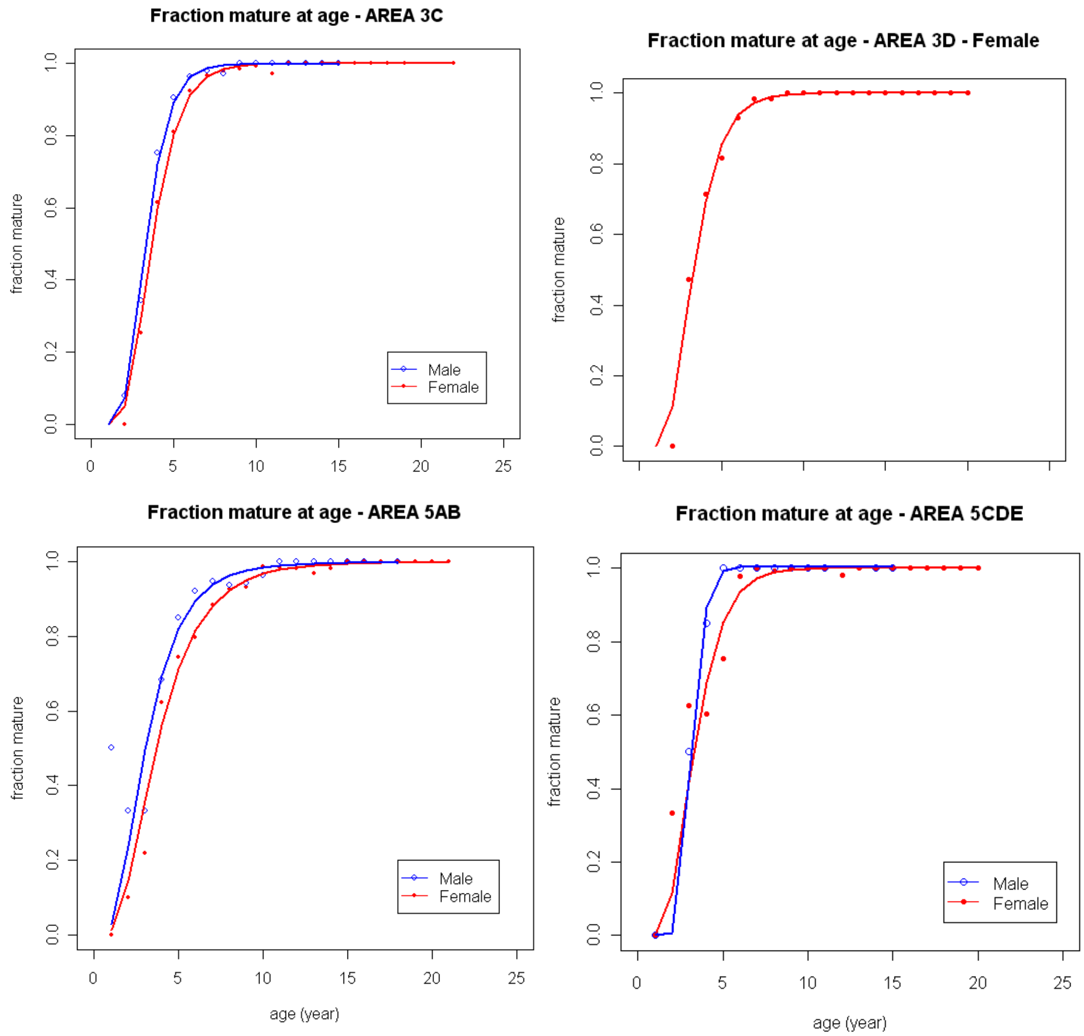

Figure E - 2. Plots of the observed fraction mature at age in AREA 3C for both female (red) and male (blue) lingcod and the cumulative lognormal curves fitted to the data.

LENGTH-WEIGHT RELATIONSHIP

Length and weight data collected during the spawning season of October 1 to March 31 were excluded from this analysis due to changes in body shape during spawning. The relationship between length and weight was described using a power function with two parameters, *a* and *b*. The Bayesian analysis assumed that the probability of observing a fish with log weight at age, log (W_t), followed the normal probably density function:

(*Eq.* E-2)
$$\log(W_t) \sim \text{Normal}\left(\log(a) + b\log(L_t), \sigma^2_{ab}\right)$$

where, *a* is the intercept or proportionality constant and *b* is the length exponent. Uninformative prior distributions were used for all parameters (Table E - 6).

Table E - 6. Prior distributions for parameters of the length-weight relationship. The first two parameters where estimated while the σ_{ab} parameter was fixed.

Parameter	**Prior density function**
log(*a*)	Normal(0,100^2)
b	Normal(0,100^2)
σ_{ab}	Uniform(log(0.000001),log(10))

Estimated posterior models for length-weight parameters were similar among areas for both males and females; however, standard deviations varied (Table E - 7; Figure E - 3 to Figure E - 6). For example, Areas 3D and 5AB tended to have higher standard deviations for the *b* parameter estimates than the other two areas, regardless of sex.

Table E - 7. Posterior modes and standard deviations (SD) of the length (mm) to weight (kg) conversion parameters for each sex and each area.

	3C		**3D**		**5AB**		**5CDE**	
Female	mode	SD	mode	SD	mode	SD	mode	SD
Sample size	*494*		*366*		*396*		*120*	
log(*a*)	-19.99	0.11	-20.36	0.16	-19.99	0.13	-20.29	0.06
a	**2.08E-09**	-	**1.44E-09**	-	**2.08E-09**	-	**1.54E-09**	-
b	**3.227**	0.017	**3.285**	0.024	**3.232**	0.020	**3.275**	0.01
Male	mode	SD	mode	SD	mode	SD	mode	SD
Sample size	*237*		*66*		*156*		*33*	
log(*a*)	-21.04	0.06	-20.35	0.45	-21.39	0.37	-20.57	0.07
a	**7.28E-10**	-	**1.46E-09**	-	**5.16E-10**	-	**1.16E-09**	-
b	**3.405**	0.009	**3.288**	0.070	**3.462**	0.057	**3.328**	0.012

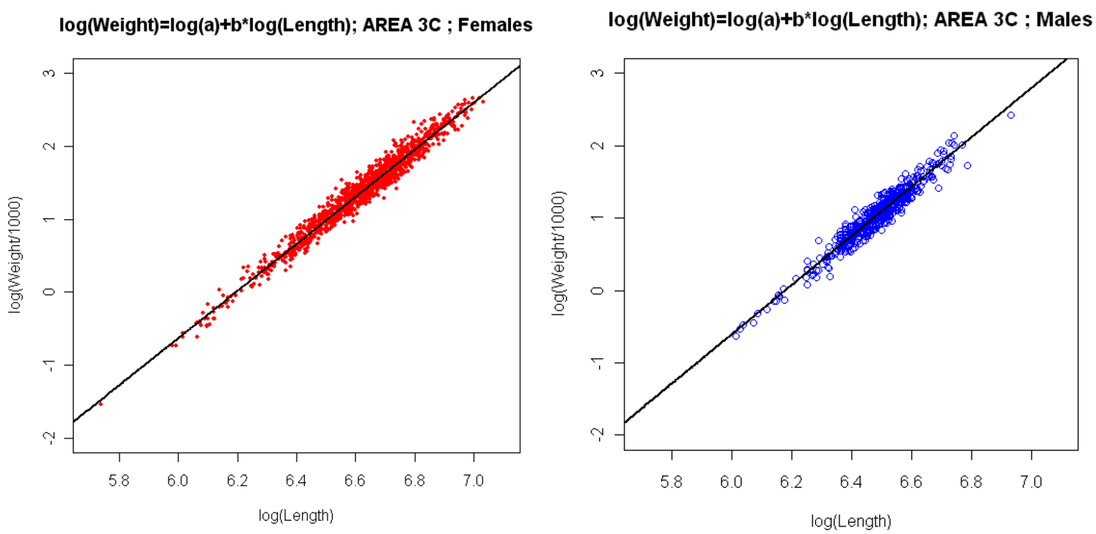

Figure E - 3. Plots of the observed length and weight at age in Area 3C without outliers for both female (red, on the left) and male (blue, on the right) lingcod and the curves ($log(W_t) = log(a) + b*log(L_t)$) fitted to the data.

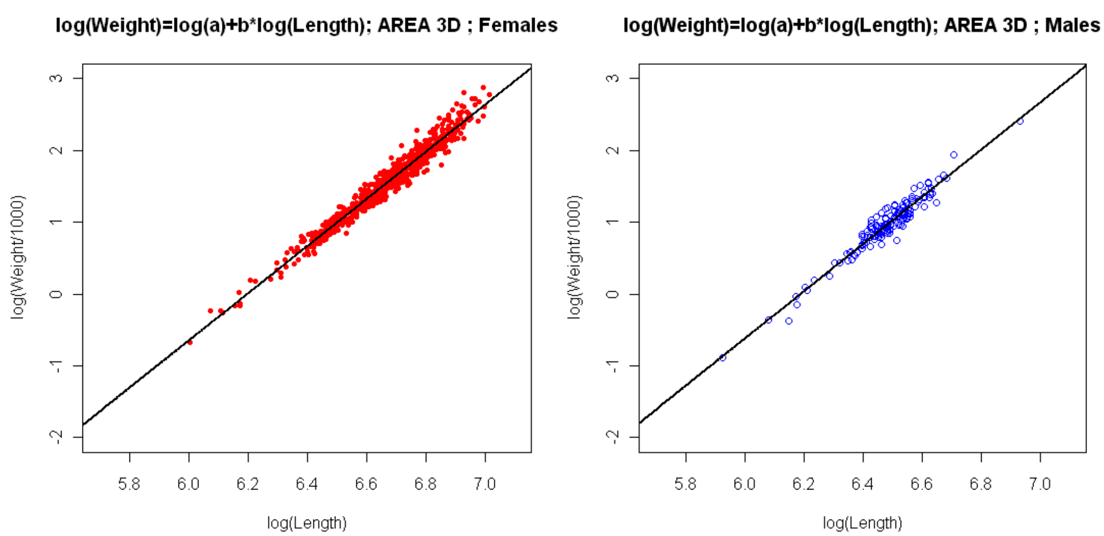

Figure E - 4. Plots of the observed length and weight at age in Area 3D without outliers for both female (red, on the left) and male (blue, on the right) lingcod and the curves ($log(W_t) = log(a) + b*log(L_t)$) fitted to the data.

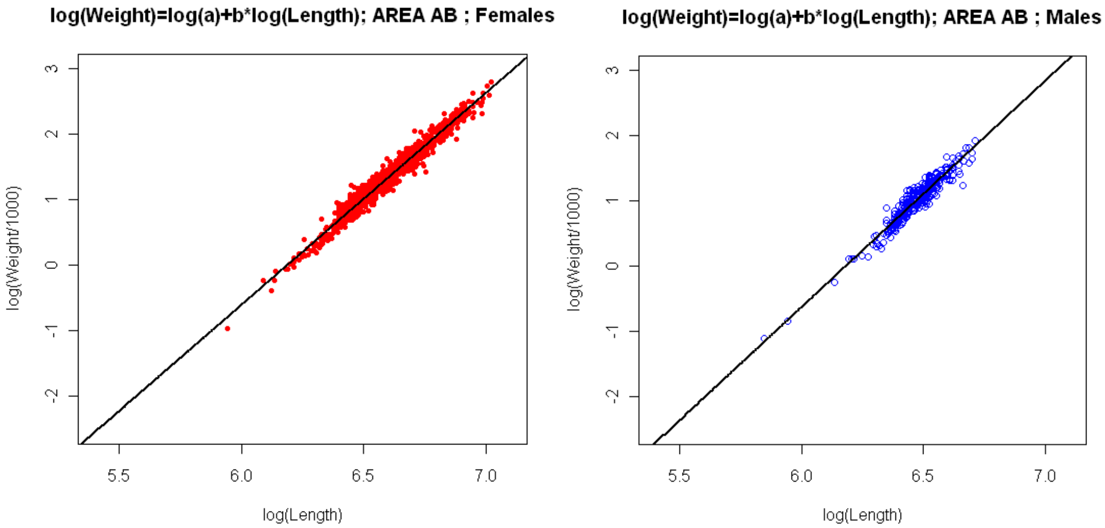

Figure E - 5. Plots of the observed length and weight at age in Area 5AB without outliers for both female (red, on the left) and male (blue, on the right) lingcod and the curves ($log(W_t) = log(a) + b*log(L_t)$) fitted to the data.

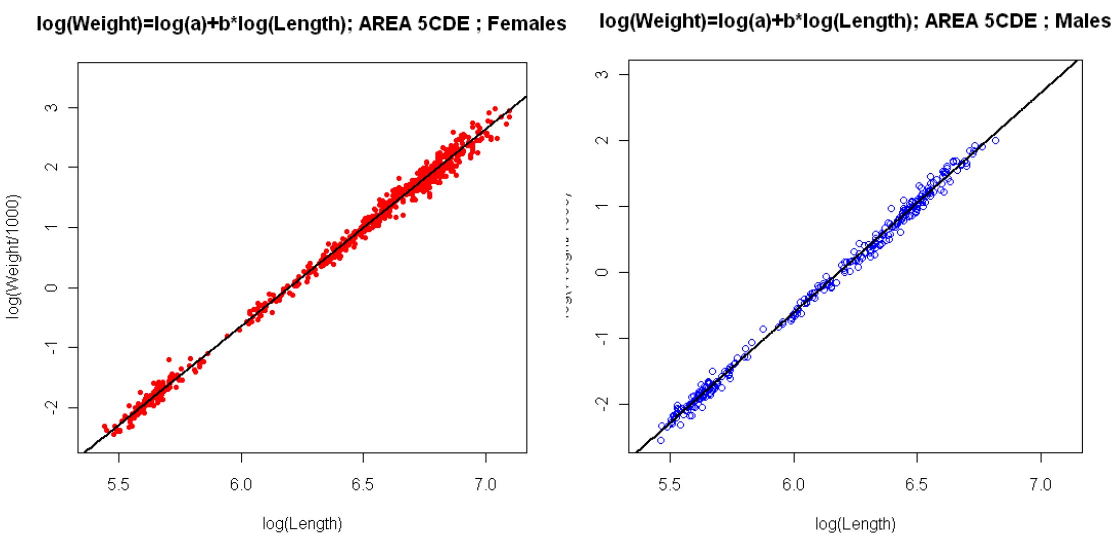

Figure E - 6. Plots of the observed length and weight at age in Area 5CDE without outliers for both female (red, on the left) and male (blue, on the right) lingcod and the curves ($log(W_t) = log(a) + b*log(L_t)$) fitted to the data.

REFERENCES

Cass, A.J., Beamish, R.J., and McFarlane, G.A. 1990. Lingcod (*Ophiodon elongatus*). *Can. Spec. Pub. Fish. Aquat. Sci.*, 109: 40 p.

Cuif, M., M. McAllister, and J.R. King. 2009. Development of a surplus production model applicable to British Columbia offshore stocks of lingcod (*Ophiodon elongatus*). Canadian Technical Report of Fisheries and Aquatic Sciences 2861: xii+72 p.

Leaman, B.M., and McFarlane, G.A.. 1997. Lingcod stock assessment and recommended yield options for 1998. *Can. St. Assess. Sec. Res. Doc.*, 97/131.

McAllister, M.K., and Ianelli, J.N. 1997. Bayesian stock assessment using catch-age data and the sampling – importance – resampling algorithm. *Can. J. Fish. Aquat. Sci.*, 54: 284-300.

Jagielo, T.H., and Wallace, F.R. 2005. Assessment of lingcod (*Ophiodon elongatus*) for the Pacific Fishery Management Council. Washington Department of Fish and Wildlife, Montesano, Washington.

APPENDIX F. ASSESSMENT MODEL SPECIFICATION

SURPLUS PRODUCTION MODEL EQUATIONS

We applied a Bayesian surplus production model that utilized Sampling Importance Resampling to assess lingcod stock status within each of the four assessment areas. Analyses were conducted using a previously developed Bayesian Surplus Production model program (BSP; McAllister and Babcock 2006). Required inputs for the program were catch and at least one index of abundance with coefficients of variation (CV). Estimated parameters included carrying capacity (*K*), the intrinsic rate of population growth (*r*), the biomass in the first modeled year defined as a ratio of K (p_0), variance parameters for each abundance index, and catchability (*q*) for each abundance index. Prior probability distributions (priors) were specified for all of the estimated parameters as part of the Bayesian analysis.

Deterministic Model Components

The surplus production model used is Prager's instantaneous *F* version of the Schaefer production model (Schaefer 1954; Prager 1994). This version of an SPM has been applied in other recent assessments of British Columbia groundfish stocks, including bocaccio rockfish and yelloweye rockfish (Stanley et al. 2009; Yamanaka et al. 2012.). State dynamics are modelled by assuming that biomass in a given year is a function of biomass in the previous year, the instantaneous fishing mortality rate, and two parameters that describe the impact of earlier biomass in growth, *r* and *K*:

(*Eq.* F-1) $$B_{y+1} = B_y + rB_y\left(1 - \frac{B_y}{\mathrm{K}}\right) - F_y B_y$$

where *y* is the year, B_y the stock biomass at the start of year *y*, *r* the intrinsic rate of increase, *K* the carrying capacity and F_y the instantaneous fishing mortality rate during year *y*. For the initial year, an additional parameter, p_0, is estimated which gives the ratio of initial stock biomass to carrying capacity ($p_0 = B_{1927}/K$).

Abundance indices in BSP are typically assumed to be directly proportional to stock biomass. The deterministic observation equation is:

(*Eq.* F-2a) $$E\left(I_{j,y}\right) = q_j B_y$$

where q_j is the constant of proportionality for the abundance index *j*, $I_{j,y}$ the observed abundance index *j* in year *y,* and $E\left(I_{j,y}\right)$ is the model predicted value for $I_{j,y}$.

In this assessment, equation F-2a was used for abundance indices from fishery-independent research surveys (Appendix D). An alternative version of equation F-2a was used for the abundance indices derived from fishery-dependent data (Appendix C) to account for potential long-term increases in the catchability of commercial CPUE time series due to technological advances,

(*Eq.* F-2b) $$E\left(I_{j,y}\right) = \left(q_0 \exp\left(tech * \left(y - y_0\right)\right)\right) B_y\,,$$

where, q_0 represents catchability at time y_0 (with y_0 referenced to the first year with commercial catch rate data, e.g., 1954 for area 3C) and the technological creep parameter (*tech*) represents a constant annual rate of change in *q*. A more thorough discussion of time-varying catchability, as well as a rationale for the approach taken in the current assessment, is provided when specifying the prior distribution for *tech* below, as well as in Appendix H.

Stochastic Model Components

The state-space approach allows for deviations from model predictions (i.e., random variability) in both (i) the data (e.g., relative abundance indices) and (ii) the unobserved state of the system of interest (e.g., annual population biomass) (Millar and Meyer, 2000). These two components of the system are modelled within a single probabilistic framework that can be highly flexible (Rivot et al., 2004). Fisheries modellers tend to choose multiplicative lognormal errors (Millar and Meyer 2000), which is what we choose for the current assessment. The abundance index data were assumed to be lognormally distributed:

(*Eq.* F-3a)
$$I_{j,y} \sim \text{lognormal}\left(\ln\left(E\left(I_{j,y}\right)\right), \sigma^2_{\text{obs},j,y}\right)$$

where $I_{j,y}$ is the observed index of abundance for series *j* in year *y* and $\sigma_{\text{obs},j,y}$ is the standard deviation in the error deviation between the log predicted index and the log observed index *j* in year *y*.

The full log likelihood function for a given management area was as follows:

(*Eq.* F-3b)
$$Log(L_a) = c - \sum_{j=1}^{n_a} \sum_{y=i_j}^{f_j} \frac{\ln\left(\frac{I_{j,y}}{E\left(I_{j,y}\right)}\right)^2}{2\sigma^2_{\text{obs},j,y}}$$

where, *c* is a constant, n_a is the number of stock trend indices for area *a*, i_j is the initial year for abundance index *j*, and f_j is the final year for abundance index *j*.

The stochastic form equation F-1 (i.e., the process equation) is:

(*Eq.* F-4)
$$\log\left(B_{y+1}\right) = \log\left(B_y + rB_y\left(1 - \frac{B_y}{\text{K}}\right) - C_y\right) + \varepsilon_{process,y}$$

where, $\varepsilon_{process,y} \sim \text{Normal}\left(0, \sigma^2_{process}\right)$ and F_yB_y has been replaced with the total catch in year *y*, C_y.

The stochastic form of equation F-2a (i.e., the observation equation) was:

(*Eq.* F-5)
$$\log\left(I_{j,y}\right) = \log\left(q_j\right) + \log\left(B_y\right) + \varepsilon_{obs,j,y}$$

where , q_j is the constant of proportionality for series *j* and $\varepsilon_{obs,j} \sim \text{Normal}\left(0, \sigma^2_{\text{obs},j}\right)$.

The $\varepsilon_{process}$ terms are i.i.d. random variables in all modelled years up to 2010. All $\varepsilon_{obs,j,y}$ are considered to be independent, but may have different variances between years since annual variance computed for each index in the initial processing of the data was added to a model-fit error variance term (see below). For each future year in stock projections, we modelled $\varepsilon_{process}$ as positively autocorrelated with a correlation coefficient ρ (see Stanley et al. (2009) for details on the autocorrelation equations). There were too few years in which it was possible to estimate the autocorrelation in process error deviates (ρ) because estimates only became non-zero after 2000. We therefore applied the commonly used default value for ρ of 0.5.

A summary of key parameters estimated by the surplus production model is provided in Table F - 1. A summary of derived management parameters is provided inTable F - 2.

Table F - 1. Summary of estimated parameters.

Parameter	Description
r	Intrinsic rate of increase
K	Carrying Capacity
p_0	Ratio of initial stock biomass in first year to carrying capacity
$\{q_{j=1}, q_{j=2}, \ldots q_{j=J}\}$	Vector of catchability parameters for J abundance indices (where, J is Area-specific as described in Table 1 of main document)
tech	Annual rate of change in q for commercial CPUE indices

Table F - 2. Summary of derived management parameters for the Schaefer model.

Maximum Sustainable Yield (MSY)	$rK/4$
Stock size for MSY	K/2
Rate of exploitation at MSY	$r/2$
Maximum rate of exploitation	r

PRIOR DISTRIBUTIONS

A summary of prior distributions for estimated parameters is given in Table F - 3. A more detailed description of the methods used to determine each prior is provided below.

Table F - 3. Prior distributions for surplus production model parameters.

Parameter	Prior density function
ln(K)	Uniform(log(5000),log(100000))
$\ln(q_j)$	Uniform(-20,20)
p_0	Lognormal(log(1),0.2^2)
r (3C)	Normal(0.255,0.102^2)
r (3D)	Normal(0.260,0.108^2)
r (5AB)	Normal(0.258,0.106^2)
r (5CDE)	Normal(0.236,0.0899^2)
tech	Normal(0.02,0.005^2)
$\varepsilon_{process,y}$	Normal(0, 0.075^2)

Intrinsic Rate of Increase (r)

For each assessment area, an informative prior distribution for the intrinsic rate of increase, *r*, was approximated using the Euler-Lotka demographic method. This method has previously been defined in Brandao et al. (2000) and McAllister et al. (2001), and reformulated in Stanley et al. (2009). The method was recently applied to stock assessments for British Columbia bocaccio rockfish (Stanley et al. 2009) and yelloweye rockfish (Yamanaka et al. 2012). A Bayesian demographic analysis of the intrinsic rate of growth for British Columbia offshore lingcod stocks was previously done by Cuif et al. (2009). For the current assessment, we updated the input for the rate of natural mortality compared to the Cuif et al. (2009) analysis, which in turn updated prior distributions for *r*. We provide an overview of the steps taken by Cuif et al. (2009), as well as our updates, in the following section.

Demographic Model Applied to Lingcod

The input data for the demographic model used to develop a prior distribution for *r* includes the posterior distributions obtained from the biological data analysis (Appendix E), as well as probability density functions that describe uncertainty in natural mortality and steepness parameters (Table F - 4).

Table F - 4. Prior distributions for natural mortality (M) and steepness (h) parameters used in demographic analysis for Lingcod.

Parameter	Prior density function
M (*year*$^{-1}$)	Lognormal(0.193,0.4^2)
h' (*h'* ϵ [0;1]) *h* = *h'*(208 -0.2) + 0.2 (*h* ϵ [0.2;208])	Beta(3.191,661.534)

Prior distributions for *M* and *h*

The median of the lognormal probability distribution used to describe *M* was 0.193 yr $^{-1}$, which is the value previously used for British Columbia outside lingcod stock assessment (Leaman and McFarlane, 1997). This value is similar to the *M* value of 0.2 yr $^{-1}$ used by Logan et al. (2005) for the most recent assessment of the inside lingcod stock in British Columbia. The standard deviation of the distribution was set at 0.4, which was updated from a value of 0.2 in Cuif et al. (2009) to more thoroughly account for uncertainty in this parameter. *M* was assumed equal for all age classes.

The steepness parameter, *h*, used in equation F-10 (below) is defined as the ratio of recruitment at 20% of the unexploited stock biomass to recruitment in the unfished state (Hilborn and Liermann 1998; Myers et al. 2002). Spawner recruitment data are not available for British Columbia lingcod stocks, which made it necessary to construct a distribution for *h* from the literature. A Ricker recruitment function was selected for the current assessment because lingcod have been observed to display cannibalistic behaviour, which is consistent with a Ricker-shaped recruitment curve.

There are no published meta-analyses from which to obtain an informative prior for a Ricker steepness parameter for lingcod; however, some estimates of a Beverton-Holt (B&H) steepness parameter for lingcod have been developed. It was therefore necessary to base the Ricker steepness estimate on previously estimated ratios of Ricker steepness parameters to B&H steepness parameters from other fish species. A review of two meta-analyses showed that, on average, steepness for the Ricker model is 1.5 times higher than that of the B&H model (Table F - 5). Jagielo and Wallace (2005) used a steepness of 0.9 for Washington State lingcod in a Beverton-Holt (B&H) relationship, while Martell (1999) assumed a steepness of 0.8 for a B&H relationship. A meta-analysis by Myers et al. (1999) found a median steepness of 0.84 for Atlantic cod and a median steepness of 0.77 for the family Hexagrammidae. In the current assessment, we assumed a mean value of 0.8. The mean Ricker steepness for lingcod was therefore set to1.2 (0.8 for B&H steepness x 1.5).

Table F - 5. Steepness values obtained from meta-analysis under B&H and Ricker assumptions.

References	Species	Mean B&H *h*	Mean Ricker *h*	Ratio $\frac{h(\text{Ricker})}{h(\text{B \& H})}$
Forrest et al. (2010)	Rockfish	0.71 (CV = 0.22)	0.93 (CV = 0.45)	1.31
Michielsens & McAllister (2004)	Baltic salmon	0.70 (CV = 0.23)	1.24 (CV = 0.48)	1.77

The mean of the CVs of the two available posterior predictive distributions for the Ricker steepness parameter were used to approximate the uncertainty in this parameter for lingcod (average CV = 0.465; Table F - 5). The updated posterior predictive distribution for rockfish conforms to a Beta distribution. The two shape parameters of the beta distribution, *alpha* and *beta*, were estimated by renormalizing the updated posterior predictive distribution for steepness so that the minimum was 0 and maximum was 1, and then fitting a beta density function to the discretized renormalized histogram. The theoretical limit for *h* under Ricker recruitment is infinity but there appears to be a natural constraint on its value (Forrest et al. 2010). In fitting a beta density function to the updated posterior predictive distribution of Ricker steepness, the value of 208 was the best fitting upper limit for *h* under Ricker recruitment.

The reference case probability distribution for *h* chosen for lingcod was a Beta distribution with *alpha* of 3.2 and *beta* of 661.5. Ten-thousand random values of *h* between 0 and 1 were generated from this Beta distribution. Then these values were transformed so that the Ricker steepness may be contained in the interval [0.2; 208] (Figure F - 1):

(Eq F-6)
$$h = h'(208 - 0.2) + 0.2$$

where *h'* ϵ [0;1] and *h* ϵ [0.2;208].

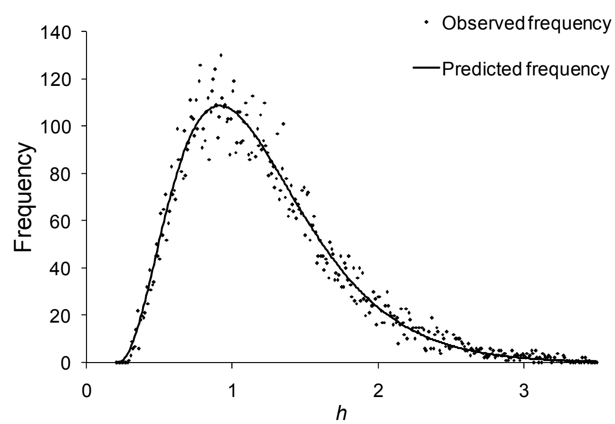

Figure F - 1. Plot of the observed steepness from Forrest et al*. (2010) updated so that mean h = 1.2, and of the fitted Ricker steepness Beta distribution.*

Demographic equations

The Lotka equation is numerically solved for r with the integration over ages starting at age 0. Assuming that there is no reproduction in the first year, a computation in which the integration starts at age 1 is analytically equivalent to an integration starting at age 0 (Stanely et al. 2009):

(*Eq.* F-7) $$1 = \sum_{t=1}^{t_p} l_t m_t e^{-tr}$$

where l_t is the survivorship at age t (i.e., the fraction of animals surviving from age 1 to age t), m_t the number of age 1 recruits expected to be produced by adult females of age t, r the intrinsic rate of increase, and t_p the age of the plus group, which was set at 30 years for lingcod. At this age only 0.3% of individuals are still alive.

Survivorship for equation F-7 was computed with the following equation:

(*Eq.* F-8) $$l_t = l_1 \exp\left(-\sum_{i=1}^{t-1} M_i\right)$$

where l_1 is set to 1 and M is the natural mortality rate for lingcod. The number of age 1 recruits expected to be produced by adult females of age t (m_t in equation F-7) is the product of the number of age 1 recruits produced per ton of spawners when spawner abundance approaches zero (R_s), the weight at age t (W_t), and the fraction mature at age t ($fmat_t$):

(*Eq.* F-9) $$m_t = R_s W_t \, fmat_t$$

Probability distributions for W_t and $fmat_t$ were taken from the posterior distributions obtained from the biological data analysis (Appendix E). Specific details of the methods used to obtain marginal posterior distributions for these parameters are available in Cuif et al. (2009).

The R_s in equation F-9 can be expressed as a function of spawner biomass produced per single age-1 recruit (S) and recruitment steepness (h), as shown in equations F-10 and F-11. In the case of a Ricker stock-recruitment relationship,

(*Eq.* F-10) $$R_s = \frac{(5h)^{5/4}}{S}$$ (Michielsens and McAllister 2004).

The S parameter in equation F-10 (spawner biomass per single age-1 recruit) is defined as:

(*Eq.* F-11) $$S = \left(\sum_{t=1}^{t_p-1}\left(W_t \, fmat_t e^{-tM}\right)\right) + W_{t_p} \, fmat_{t_p} \frac{e^{-t_p M}}{1-e^{-M}}$$

where t_p is the age of the plus group and W_{tp} the expected weight of animals in the plus group. The weight of animals in the plus group (W_{tp}) was computed from the relative number (*nagep*) and weight (W) of animals in ages above the plus group. For lingcod populations in which we assume the plus group extends from t = 30 to 50 years, (*Eq.* F-12) $$nagep_t = \frac{e^{-M(t-30)}}{\sum_{i=30}^{50} e^{-M(i-30)}}$$

(Eq. F-13) $$W_{t_p} = \sum_{t=30}^{50} nagep_t W_t$$

Formulation of *r* prior

Three candidate probability density functions (*pdf*) were considered to represent the frequency distribution of *r* values drawn from the Monte Carlo method when creating a prior for *r*: lognormal, normal, and gamma. Model selection analysis was applied to results from Area 3C to determine which *pdf* best described the Monte Carlo frequency distribution. The sum of squares of the deviations between the Monte Carlo frequency and the predicted frequency was minimized in each case so that the best fit was obtained for each distribution. The normal *pdf* had the lowest sums of squares, and was thus used to represent prior distributions for all four assessment areas. A more thorough description of this analysis is available in Cuif et al. (2009).

The prior distributions for *r* that were used as inputs to the SPM were similar for all four areas (Table F - 6, Figure F - 2).

Table F - 6. Mean, SD and CV of r prior for each area.

	3C	3D	5AB	5CDE
Mean (r)	0.219	0.220	0.215	0.224
SD (r)	0.090	0.094	0.0962	0.097
CV (r)	0.411	0.429	0.447	0.433

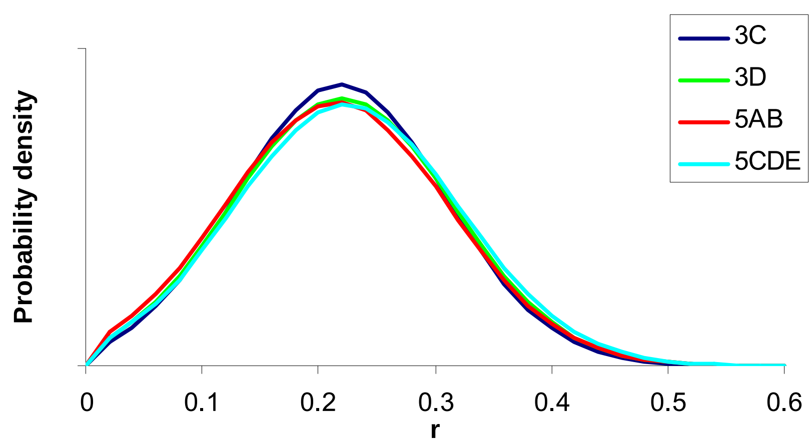

Figure F - 2. Prior normal distributions for r for each Area.

Carrying Capacity (*K*)

The prior for *K* in each assessment area was first assumed uniform over a large range of values between 5,000 tonnes and 100,000 tonnes in order to enable equal credibility for small and large possible values for *K*. The upper bound for each assessment area was set at about two times the pre-fishery stock biomass estimates of assessed US lingcod (Jagielo and Wallace, 2005). However, this uniform prior on *K* appeared unsuitable because posterior distributions for most quantities were very flat. This problem has previously been noted by Millar and Meyer (2000). We therefore chose an alternative approach in which we applied a uniform prior over the log of *K* with the same upper and lower bounds. This alternative tended to reduce the very flat tail in posteriors for *K* and initial stock size, but had relatively little influence on posterior median results. The uniform prior over the log of *K* was used in the reference case.

Ratio of Initial Biomass to Carrying Capacity (p_0)

The first year of the total catch time series considered is 1927. Our prior distribution suggested the offshore lingcod stock biomass in 1927 (B_{1927}) was at unfished conditions since the offshore trawl fishery was not widely developed at this time. The prior for p_0 was assumed to be log-normal with a mean of log(1) and a SD in the natural logarithm of p_o of 0.2.

Process Error Variance

The value of σ_{process}, which is the standard deviation of $\varepsilon_{process}$ from equation F-4, was set at 0.075 to account for potentially large interannual variability in biomass arising from variable stock dynamic processes not explicitly modeled (e.g. interannual variation in movement between areas, recruitment, growth).

Observation Error Variance

Values for $\sigma_{\text{obs},j}$, which are the standard deviation of $\varepsilon_{obs,j}$ from equation F-5, were obtained by iterative reweighting for each model run. Values obtained tended to be quite stable across different model runs for the same stock (Table F - 7 for reference case values). We presumed that values for $\sigma^2_{\text{obs},j}$ were the sum of (i) the variance for each index j, determined from the construction of the survey indices as described in Appendix D ($\sigma^2_{\text{ind},j}$) and (ii) the variance presumably due to interannual processes ($\sigma^2_{\text{int},j}$) (e.g., variation in the spatial distribution, $\sigma^2_{\text{obs},j} = \sigma^2_{\text{ind},j} + \sigma^2_{\text{int},j}$). Thus in the iterative reweighting, the values for $\sigma^2_{\text{ind},j}$ were set at the analytical variances estimated in Appendix D and the values for $\sigma^2_{\text{int},j}$ were adjusted so that $\sigma^2_{\text{ind},j}$ and $\sigma^2_{\text{int},j}$ summed to the values of $\sigma^2_{\text{obs},j}$ estimated from the stock assessment model (rounding up to the nearest 0.05 or 0.1).

Catchability (*q*)

The prior distribution for q_j is uniform over the log of q_j over the interval [-20,20]. This prior is the same for each abundance index *j*.

Table F - 7. Square root of the average variance of the observation error for each abundance index j*,* $\sigma_{obs,j}$*, by assessment area and for all areas combined (COAST), obtained from preliminary analyses and used in the assessment models. Indices are denoted as followed:* j=com1 *for the Commercial CPUE series before 1996,* j=com2 *for the Commercial CPUE series after 1996,* j=tri *for the Triennial Survey series,* j=sh *for the Shrimp Survey series,* j=sy *for the Synoptic Survey series and* j=multi *for the Multispecies Assemblage Survey series. The area where the survey took place is given between parenthesis (WCVI= West coast Vancouver Island, QCS= Queen Charlotte Sound, HS= Hecate Strait, WCQCI = West coast Queen Charlotte Islands).*

	$\sigma_{obs,com1}$	$\sigma_{obs,com2}$	$\sigma_{obs,com3}$	$\sigma_{obs,tri}$	$\sigma_{obs,sh}$	$\sigma_{obs,sy}$	$\sigma_{obs,multi}$
3C	0.509	0.254	0.452	0.629	0.87 (WCVI)	0.48 (WCVI)	--
3D	0.381	0.204	0.206	--	1.16 (WCVI)	1.17 (WCVI)	--
5AB	0.459	0.152	0.152	--	0.393 (QCS)	0.237 (QCS)	--
5CD	0.465	0.295	0.171	--	--	0.184 (HS)	0.471 (HS)
5E	--	--	--	--	--	0.252 (WCQCI)	
COAST	0.358	0.199	0.394	0.523	0.748 (WCVI) 0.317 (QCS)	0.731 (WCVI) 0.140 (QCS) 0.150 (HS) 0.294 (WCQCI)	0.473 (HS)

Technological Creep (*tech*)

The assumption of proportionality between abundance indices derived from commercial catch rates and stock biomass may not be accurate because of the potential for long term changes in catchability and variation of catchability with stock size (McAllister et al., 2001). Cuif et al. (2009) tried fitting a simple hyperstability model for commercial CPUE (ccpue) data but found that this model could not be made to fit available catch time series and abundance indices.

As shown in Appendix C, three of the four ccpue series show net increases between the 1970s and 1990. This pattern is uniformly the case between 1975 and 1990. For the years 1975 – 1990 in areas 3C, 5AB and 5CDE, the estimated slopes for ccpue are positive despite these being the years in which the largest catches occurred (Table F - 8). The positive trend in ccpue during this period is in contrast to the negative trends observed for abundance indices derived from survey data (e.g., shrimp survey). These differences in the inclination between ccpue and survey data are indicative of potential increases in catching power of the commercial trawl fishing fleet.

Table F - 8. Estimated slopes and regression R^2 values for abundance indices for comparable blocks of years where possible.

Area	Index	Years	slope	R^2
3C	ccpue	1954-1974	-0.005	1%
	ccpue	1975-1990	+0.019	2%
	shrimp survey	1975-1990	-0.053	18%
	US triennial	1980, 1983, 1989, 1992	-0.038	0%
	ccpue	1996-2010	-0.029	13%
	shrimp survey	1996-2010	+0.048	9%
	US triennial	1995, 1998, 2001	-0.33	80%
	Synoptic	2004, 6, 8, 10	-0.21	73%
3D	ccpue	1966-1974	-0.08	25%
	ccpue	1975-1990	-0.007	2%
	shrimp survey	1975-1990	-0.018	11%
	ccpue	1996-2010	-0.01	6%
	shrimp survey	1996-2010	-0.02	9%
	Synoptic	2004, 6, 8, 10	-0.79	83%
5AB	ccpue	1966-1974	-0.07	45%
	ccpue	1975-1990	+0.07	56%
	ccpue	1996-2010	-0.01	20%
	shrimp survey	1999-2010	-0.14	15%
	synoptic	2003-2009	-0.03	1%
5CDE	ccpue	1964-1974	+0.01	2%
	ccpue	1975-1990	+0.10	85%
	ccpue	1996-2010	-0.002	0%
	Hecate MS survey	1984, 1987, 1989	-0.22	75%
	HS synoptic	2005, 7, 9	+0.066	79%
	WCQCI synoptic	2006-2010	-0.10	27%

In response to the above differences in survey and ccpue trends, we considered the following as a key hypothesis in this stock assessment: the ability of fishermen to catch lingcod (i.e., fishing power per unit effort) has improved annually since 1954. We formulated a prior for a technological creep parameter (*tech*) based on a review of literature that provided estimates of rates of increase in catchability in commercial catch per unit effort data (Appendix H). The reference case prior for *tech* was specified as *tech* ~ Normal $(0.02, 0.005^2)$. The rationale for this choice is provided in Appendix H. We applied the same prior distribution for *tech* to the ccpue data in all assessment areas and for each of the three different time periods used to develop ccpue indices (prior to 1991, 1991-1995 and 1996-2010).

The total objective function or log of Bayes rule (i.e., the log the prior density function and log likelihood function) for each area *a* is thus given by:

(*Eq.* F-14)

$$\log(Bayes\ rule_a) = \log(L_a) + \sum_{j=1}^{n_a} \log\left(prior\left(q_{j,a}\right)\right) + \log\left(prior(K_a)\right) + \log\left(prior(r_a)\right) + \log\left(prior\left(p_{o,a}\right)\right)$$
$$+ \log\left(prior(tech_a)\right) + \sum_{y=1927}^{2010} \log\left(prior\left(\varepsilon_y\right)\right)$$

where n_a is the number of abundance indices in area *a*.

POSTERIOR APPROXIMATION

The SIR algorithm was used to compute marginal posterior distributions for BSP model parameters and quantities of interest (McAllister et al. 1994; Stanley et al. 2009). The key output statistics computed included marginal posterior distributions of current stock biomass (B_{2010}), the ratio of current stock biomass to carrying capacity (B_{2010}/K), the ratio of current stock biomass to stock biomass at MSY (B_{2010}/B_{MSY}), the replacement yield in 2010 ($RepY_{2010}$), and the ratio of fishing mortality rate in 2009 to fishing mortality rate at *MSY* (F_{2010}/F_{MSY}).

Due to extreme high variability in some time series, sampling was relatively inefficient and runs of 36 million draws from the importance function were taken (approximately 7-9 hours of computing on 2 GHz IBM PCs). The marginal posteriors for the quantities of interest were reliably estimated with the maximum importance ratio for any one draw taking no more than about 2% in each of the runs conducted. Runs using alternative importance functions, (e.g., with different variances in the key parameters), yielded practically identical marginal posterior estimates. The marginal prior and posterior *pdf*s of *r* and *K* are plotted in Appendix G to show the extent to which priors were updated.

DEFINITION OF REFERENCE CASE

For the reference case runs, all inputs, assumptions and settings were formulated based on the best available information and scientific judgment. Prior distributions used in the reference case have been described above. The following list summarizes the key settings:

- Prior mean *r* formulated for each of the four assessment areas using the Ricker steepness prior distribution and life history parameter estimates for each area
- All stock trend indices used for each stock
- Likelihood function for catch data follows a lognormal distribution
- Schaefer surplus production function (B_{MSY}/K=0.5)
- Prior mean $B_{1927}/ K = 1$
- Uninformative priors for *q*
- Lag 1 autocorrelation with the autocorrelation coefficient, ρ, set at 0.5 starts in 2011
- CVs for stock trend indices obtained by iterative reweighting, with fixed observation error from survey imprecision and process error components determined by fitting the BSP model to data
- Technological creep in commercial CPUE time series was constant over all years

We allowed for the possibility of updating the reference case settings based on results obtained after fitting the model to the data in the different sensitivity analyses. However, we applied conservative criteria for updating the reference case settings to reduce the possibility of making excessively frequent or poorly justified changes that could appear beneficial due to random variation in the data alone. The pre-specified criteria were that (i) we would consider revising reference case settings only if there was a very strong weight of evidence (e.g., a Bayes factor of less than 1/10 against the reference case setting compared to the most credible alternative setting for some model component) in the posterior results, and (ii) this weight of evidence held for all four assessment areas.

SENSITIVITY ANALYSES

Sensitivity tests were conducted to evaluate the effect of stock assessment model assumptions on stock status and projection results. Some analyses were conducted for all assessment areas, while others were only tested in Area 3C since it has historically sustained the largest catches and has the largest amount of data available. A summary of these analyses is provided in Table F - 9, and a brief description of each analysis is provided below.

Table F - 9. Summary of the sensitivity runs applied. The values of the mean and standard deviation (sd) of prior distributions for low r *and high* r *scenarios are provided in Table F - 10.*

Category code	Category description	Run number	Runs for all four areas (Order of Areas: 3C, 3D, 5AB, 5CDE)	Other single area sensitivity runs
Ref	Reference run	1-4	Reference case runs	
A	*r* prior mean	1-4	prior for *r* centred over low values	
		5-8	prior for *r* centred over high values	
B	*tech* prior mean	1-4	prior mean for *tech* = 1%, sd=0.5%	
		5-8	prior mean for *tech* = 3%, sd=0.5%	
		9-12	prior mean for *tech* = 4%, sd=0.5%	
C	*tech* prior SD	1		Area 3C: prior mean for *tech*= 1%, sd=0.25%
		2		Area 3C: prior mean for *tech*= 3%, sd=0.75%
D	Effect of 1996-2010 commercial cpue data	1		Area 3C: Leave out 1996-2010 ccpue
		2		Area 3C: Don't apply *tech* to 1996-2010 ccpue
E	Prior for *K*	1		Area 3C Prior for K Uniform(5t, 100000t)
F	Fixed *tech* values	0		*tech* = 0%
		1		*tech = 1%*
		2		*tech* = 2%
		3		*tech* = 3%
		4		*tech* = 4%
G	Outer coast single stock hypothesis	1		Fit one model to catches summed and all indices for Areas 3C, 3D, 5AB, 5CD, 5E.

Prior distribution on *r* - To evaluate the sensitivity of model results to the informative prior distribution for *r*, two additional runs were conducted for each of the four assessment areas: one with high *r* and one with low *r*. The low *r* prior was obtained by using a low steepness value in the demographic analysis described above, while the high *r* value was obtained by using a high steepness value in the analysis (Table F-10). The range of plausible prior *r* distributions to be tested in sensitivity analyses was determined by examining the effect of prior assumptions about natural mortality and steepness on the shape and magnitude of the *r* prior (see Cuif et al. 2009 for details). Since Cuif et al. (2009) found that varying steepness had a larger impact on estimated *r* distributions than varying natural mortality over the range of values tested, we choose to used the two extreme Ricker steepness values posed by Cuif et al. (2009) to develop low *r* and high *r* scenarios for sensitivity analyses. These high and low values represented a 25% increase and a 25% decrease, respectively, compared to the reference case mean steepness value of 0.9 (Table F - 11).

Table F - 10. The prior mean and SD (in parenthesis) of r *under alternative input priors for Ricker steepness (h; Table F-11) for each area. The 'median* h*' column represents the reference case for each assessment area, while the 'low* h*' column represents the low* r *scenario and the 'high* h*' column represents the high* r *scenario.*

Area	low *h*	median *h*	high *h*
3C	**0.174 (0.080)**	**0.219 (0.090)**	**0.258 (0.098)**
3D	**0.174 (0.083)**	**0.220 (0.094)**	**0.259 (0.103)**
5AB	**0.170 (0.087)**	**0.215 (0.096)**	**0.254 (0.209)**
5CDE	**0.178 (0.085)**	**0.224 (0.097)**	**0.263 (0.107)**

Table F - 11. Different steepness (h) probability distributions tested in sensitivity analyses.

Recruitment assumption	**Mean steepness**	**Steepness probability distribution**
med *h* (reference case)	1.2	Beta(3.191, 661.534)
low *h*	0.9	Beta(2.785, 825.872)
high *h*	1.5	Beta(3.446, 548.636)

Prior distribution on *tech* – To evaluate the sensitivity of the model to alternative priors for *tech*, priors with three different mean values were applied to all four assessment areas (i.e., with prior means of 0.01, 0.03 and 0.04, where 0.02 was the reference case). In all of these cases the prior standard deviation was fixed at 0.005. We also tried two additional runs for Area 3C only, in which the prior coefficient of variation was held constant at 0.25, while the prior mean was set at 0.01 and 0.03.

Commercial CPUE index - We evaluated the sensitivity of results to different ways of treating the third leg of the commercial catch rate time series for Area 3C only. Since 1996, it appears that trawler fishing fleet behaviour has successively evolved as trawlers have got better at cooperating to find or avoid lingcod aggregations. Since the trawl quota for Area 3C is the highest across the different areas and the majority of the trawl live lingcod fishery is in Area 3C, trawlers have incentive to share information on the location of lingcod aggregations. One fisherman indicated that since 1996, trawl fishermen have cooperated in Area 3C which could cause the commercial cpue index to behave differently from previous periods. To evaluate the impact of the 1996-2010 commercial cpue (ccpue) time series on the stock assessment results for Area 3C we have thus carried out two additional model runs. We have tried one run in which we've left out the 1996-2010 ccpue series. We have carried out a second sensitivity run in which we did not apply *tech* to the 1996-2010 ccpue series.

Prior for *K* – An alternative to the reference case prior for *K* is presented as a sensitivity analysis for Area 3C only. The alternative formulation uses a uniform distribution between 5,000 tonnes and 100,000 tonnes. As described above, this prior was originally considered for all assessment areas; however, the reference case was switched to the log of *K* with the same upper and lower bounds due to flat posterior distributions. We include the original formulation in sensitivity analyses for comparison purposes.

Fixed *tech* values – To examine the effect of choosing to estimate the technology creep parameter (*tech*) for commercial CPUE indices, five runs for Area 3C were conducted in which the parameter was fixed at five different levels (0%, 1%, 2%, 3%, and 4%). The 0% level represents the case in which catchability is assumed constant through time.

Single stock hypothesis – Historically outside lingcod populations in British Columbia have been considered to be four distinct stocks. This choice has been based on management boundaries rather than on biological evidence of stock structure. Given what is known about lingcod life history and movement patterns, it has previously been proposed that British Columbia populations have a highly localized stock structure (Smith and McFarlane, 1990; Matthews, 1992; King and Withler, 2005) suggesting that the current use of four assessment and management areas is reasonable. Recent genetic studies of lingcod population structure from California to Alaska found that Puget Sound lingcod were genetically distinct from outside coastal lingcod (Jagielo et al. 1996, Marko et al. 2007), suggesting that at least retention of separate inside and outside assessments for British Columbia is warranted. These studies were unable to detect genetic differences in lingcod populations along the coast. However, Marko et al. (2007) used only mitochondrial DNA analyses, which are known to have a low power to detect evolutionary differences; and Jagielo et al. (1996) utilized allozymes which, although more powerful than mitochondrial DNA analyses, is not as useful as microsattellite DNA analyses for determining stock delineation in populations.

Initial examinations of correlations among British Columbia outside assessment areas in catch, standardized commercial CPUE indices, and survey indices were not conclusive in their support for or against the single stock hypothesis (Table F - 12 to Table F - 14). Though it is unlikely that outside British Columbia lingcod act as one intermixing breeding population, we investigate uncertainty about the appropriate scale of stock assessment for British Columbia outside lingcod by considering a set of sensitivity runs in which we fit a single surplus production model to the sum of the annual catches across the four areas and abundance indices from all four areas (Reference run G in Table F - 9). We refer to this sensitivity analysis as the “single stock” scenario in this document.

Additional analyses were required to produce stock trend indices for the single stock scenario. A coastwide GLM analysis was performed to produce ccpue indices from catch and effort data from all areas combined for three time periods: 1966-1990, 1991-1995 and 1996-2010. Survey indices for the west coast of Vancouver Island (WCVI) that combined Areas 3C and 3D were produced for each of the synoptic and shrimp surveys. The single stock model was also fit to synoptic survey indices from Hecate Strait, Queen Charlotte Sound, and West Coast Queen Charlotte Islands, as well as the Queen Charlotte Sound shrimp trawl survey and the Hecate Strait multi-species assemblage survey.

Table F - 12. Correlations in catches between areas for years (a) 1966-1990, (b) 1991-1995, and (c) 1996-2010.

a. 1966-1990				
	3C	*3D*	*5AB*	*5CDE*
3C	1			
3D	0.44	1		
5AB	0.21	0.78	1	
5CDE	-0.04	0.43	0.72	1
b. 1991-1995				
	3C	*3D*	*5AB*	*5CDE*
3C	1			
3D	0.16	1		
5AB	0.61	0.39	1	
5CDE	0.48	0.77	0.77	1
c. 1996-2009				
	3C	*3D*	*5AB*	*5CDE*
3C	1			
3D	0.06	1		
5AB	-0.02	0.78	1	
5CDE	-0.20	0.66	0.72	1

Table F - 13. Correlations in the standardized commercial catch rate index between areas for years, (a) 1966-1990, (b) 1991-1995, and (c) 1996-2010.

a. 1966-1990				
	3C	*3D*	*5AB*	*5CDE*
3C	1			
3D	0.44	1		
5AB	0.40	0.24	1	
5CDE	0.25	0.06	0.80	1
b. 1991-1995				
	3C	*3D*	*5AB*	*5CDE*
3C	1			
3D	0.42	1		
5AB	0.91	0.46	1	
5CDE	-0.83	-0.43	-0.61	1
c. 1996-2010				
	3C	*3D*	*5AB*	*5CDE*
3C	1			
3D	0.39	1		
5AB	0.34	0.42	1	
5CDE	0.11	0.38	0.15	1

Table F - 14. Correlations in survey indices between Areas 3C and 3D and between Areas 5AB and 5CDE.

Areas	Survey	Years	Correlation
3C, 3D	Shrimp	1975-1990	0.72
3C, 3D	Shrimp	1992-1995	0.85
3C, 3D	Shrimp	1996-2010	-0.07
3C, 3D	Synoptic	2004, 6, 8, 10	0.73
5AB, 5CDE	Synoptic	2003, 7, 9	0.70

Evaluation of Credibility of Sensitivity Analysis Scenarios

To compare the credibility of each model given the data in sensitivity analyses, we computed Bayes factors (Kass and Raftery 1995) for the reference case and for each of the related sensitivity runs. Bayes factors account for both the relative goodness of fit of the model to the data and the parsimony for each of the alternative models. They are calculated as the ratio of the marginal probability of the data for one model to that for another model. We used the mean value for the importance weights from a given model run as an approximation of the probability of the data given the model (Kass and Raftery 1995; McAllister and Kirchner 2002). This is known to be a numerically stable approximation for the probability of the data given the model and approximations obtained through importance sampling were obtained with high precision (i.e., the CV in the natural logarithm in the mean weight was less than 0.05 after several million draws from the importance function). In all instances we referenced Bayes factors to our reference case model settings, i.e., the probability of the data for the reference case model was placed in the denominator and that for the model to which it was compared in the numerator. It is commonly held that nothing should be made of Bayes factor unless the value for it departs substantially from 1. Even fairly large or small Bayes factors can come from random chance in the data and possible misspecification of probability models for the data, e.g., treating errors for each observed index value as independent when they may not be independent. Thus, while a factor of 1/10 may appear to provide strong evidence against a model, the difference in fits of the model to the data could still have resulted from random chance in the data. Intermediate values for Bayes factor (e.g., between about 1/100 and 100) should be interpreted with restraint. Models with Bayes factors of between about 1/10 and 1/100 could be interpreted as unlikely but not discredited. When Bayes factor is less than 1/1000, the model with lower credibility can be viewed as highly unlikely relative to the other.

REFERENCES

Brandao, A., D. S. Butterworth, and M. R. Brown. 2000. Maximum possible humpback whale increase rates as a function of biological parameter values. Journal of Cetacean Research and Management (Suppl.) 2:192 ‑ 193.

Cuif, M., M. McAllister, and J.R. King. 2009. Development of a surplus production model applicable to British Columbia offshore stocks of lingcod (*Ophiodon elongatus*). Canadian Technical Report of Fisheries and Aquatic Sciences 2861: xii+72 p. Available at http://www.dfo-mpo.gc.ca/Library/340571.pdf (January 27, 2010).

Forrest, E., McAllister, M.K., Dorn, M., Martell, S., and Stanley, R., D., 2010. Hierarchical Bayesian estimation of recruitment parameters and reference points for Pacific rockfishes (*Sebastes* spp.) under alternative assumptions about the stock-recruit function. Canadian Journal of Fisheries and Aquatic Sciences 67: 1611-1634.

Hilborn, R., and Liermann, M. 1998. Standing on the shoulders of giants: learning from experience in fisheries. Rev. Fish. Biol. Fish. 8:273-283.

Jagielo, T.H., and Wallace, F.R. 2005. Assessment of lingcod (*Ophiodon elongatus*) for the Pacific Fishery Management Council. Washington Department of Fish and Wildlife, Montesano, Washington.

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

King, J.R., and R.E. Withler. 2005. Male nest site fidelity and female serial polyandry in lingcod (*Ophiodon elongatus*, Hexagrammidae). *Molecular Ecology* 14: 653–660.

Logan, G., W. de la Mare, J. King and D. Haggarty. 2005. Management Framework for Strait of Georgia Lingcod. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/048. 102p.

Leaman, B.M., and McFarlane, G.A.. 1997. Lingcod stock assessment and recommended yield options for 1998. Can. St. Assess. Sec. Res. Doc. 97/131.

Marko, P.B., L. Rogers-Bennett, and A.B. Dennis. 2007. MtDNA population structure and gene flow in lingcod (*Ophiodon elongatus*): limited connectivity despite long-lived pelagic larvae. *Marine Biology* 150: 1301-1311.

Martell, S.J.D. 1999. Reconstructing lingcod biomass in Georgia Strait and the effect of marine reserves on lingcod populations in Howe Sound. M.Sc. Thesis, Univ. British Columbia, Vancouver. 89 p.

Matthews, K.R. 1992. A telemetric study of the home ranges and homing routes of lingcod (*Ophiodon elongatus*) on shallow rocky reefs off Vancouver Island, British Columbia. *Fishery Bulletin* 90: 784–790.

McAllister, M.K. and Kirchner, C.H. 2002. Accounting for structural uncertainty to facilitate precautionary fishery management: illustration with Namibian orange roughy. *In* Targets, Thresholds, and the Burden of Proof in Fisheries Management, Mangel, M. (Ed.) Bull. Mar. Sci. 70(2):499-540.

McAllister, M.K. and Babcock, E.A. 2006. Bayesian surplus production model with the Sampling Importance Resampling algorithm (BSP): A user's guide. Available from: http://www.sefsc.noaa.gov/library.jsp (January 27, 2010).

McAllister, M.K., Pikitch, E.K., and Babcock, E.A. 2001. Using demographic methods to construct Bayesian priors for the intrinsic rate of increase in the Schaefer model and implications for stock rebuilding. Canadian Journal of Fisheries and Aquatic Sciences, 58: 1871–1890

Michielsens, C. and McAllister, M.K. 2004. A Bayesian hierarchical meta-analysis of stock-recruitment functions for Atlantic salmon: quantifying structural and parameter uncertainties. Canadian Journal of Fisheries and Aquatic Sciences, 61:1032-1047.

Millar, R.B., and Meyer, R. (2000). Non-linear state space modeling of fisheries biomass dynamics by using Hastings–Metropolis within-Gibbs sampling. *Appl. Stat*., 49: 327–342.

Myers, R.A., Bowen, K.G., and Barrowman, N.J. 1999. Maximum reproductive rate of fish at low population sizes. Canadian Journal of Fisheries and Aquatic Sciences, 56: 2404–2419.

Myers, R.A., Barrowman, N.J., Hilborn, R., and Kehler, D.G. 2002. Inferring Bayesian priors with limited direct data: applications to risk analysis. North Am. J. Fish. Manag. 22: 351–364.

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

Rivot, E., Prévost, E., Parent, E., and Baglinière, J.L. 2004. A Bayesian state-space modelling framework for fitting a salmon stage-structured population dynamic model to multiple time series of field data. *Ecological Modelling.*, 179: 463–485.

Schaefer, M.B. 1954. Some aspects of the dynamics of populations important to the management of commercial marine fisheries. Bulletin of the Inter-American Tropical Tuna Commission, 1: 27-56.

Smith, B. D., and G. A. McFarlane. 1990. Movements and mortality of tagged male and female lingcod in the Strait of Georgia, British Columbia. Transactions of the American Fishery Society 119: 813-824.

Stanley, R. D., M. McAllister, P. Starr and N. Olsen, 2009. Stock assessment for bocaccio (*Sebastes paucispinis*) in British Columbia waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/055. 200p.

Yamanaka, K. L., McAllister, M. K., Olesiuk, P. F., Etienne, M.-P., Obradovich, S. and Haigh, R. 2012. Stock Assessment for the inside population of yelloweye rockfish (*Sebastes ruberrimus*) in British Columbia, Canada for 2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/129. xii + 133 p.

APPENDIX G. MODEL RESULTS

STOCK STATUS IN 2010

Area 3C

Results for the full suite of parameters estimated from the reference case run for Area 3C are summarized in Table G - 1. Predicted posterior median biomass levels from the surplus production model between 1927 and 2010, as well as catch and observed stock trend indices, are shown in Figure 3 of the main assessment document. Annual predicted posterior median biomass levels between 1927 and 2010, as well as 90% probability intervals, are also provided in Table G - 2.

Posterior distributions for most quantities of interest are imprecise (Table G - 1, Figure G - 1, Figure G - 2). This result is due to the many large outlier values in some of the stock trend indices, particularly the US Triennial and shrimp survey indices (Appendix D and Figure 2 in main assessment document). The posterior distribution for *tech* is updated from the prior distribution. The posterior median for the intrinsic rate of increase r (0.134) was lower than the prior median (0.255). Catchability coefficients for stock trend indices (q_j) all had fairly large posterior CVs (0.52-0.98). These large CVs are mainly due to high interannual variation in the standardized trawl fishery CPUE indices.

Estimates of process error terms for Area 3C were zero up to the year 2000 but were updated to deviate from zero for most years since 2000 (Figure G - 3). In the last few years, estimates of process error deviates are negative.

Table G - 1. Posterior mean, median, SD, and CV for parameters and stock status indicators for B.C. offshore lingcod in Area 3C. Posterior medians for C_{2010}/MSY, $C_{2010}/Repy_{2010}$, B_{1927}/K, all 6 catchability parameters (q) and tech were calculated using a lognormal approximation based on the posterior mean and SD. All other posterior medians were obtained directly from a resample from the importance draws.

Variable	Mean	Median	SD	CV
K	53638	50434	20145	0.38
r	0.152	0.134	0.089	0.59
MSY	1978	1390	1506	0.76
B_{2010}	30651	25083	20675	0.67
B_{2010}/K	0.547	0.553	0.259	0.47
B_{1927}	52450	49221	19650	0.37
B_{1927}/K	0.990	0.975	0.176	0.18
B_{2010}/B_{1927}	0.572	0.551	0.299	0.52
C_{2010}/MSY	0.430	0.371	0.252	0.59
F_{2010}/F_{MSY}	0.677	0.39	0.751	1.11
B_{2010}/B_{MSY}	1.09	1.106	0.52	0.47
$C_{2010}/Repy_{2010}$	0.653	0.350	1.028	1.57
B_{MSY}	26819	25217	10072	0.38
$Repy_{2010}$	1267	1099	807	0.64
54-90 ccpue q	2.21E-05	1.96E-05	1.16E-05	0.52
91-95 ccpue q	2.33E-05	1.93E-05	1.56E-05	0.67
96-2010 ccpue q	2.10E-05	1.68E-05	1.57E-05	0.75
Triennial survey q	1.49E-04	1.21E-04	1.08E-04	0.73
Shrimp survey q	2.04E-05	1.64E-05	1.53E-05	0.75
Synoptic q	5.96E-05	4.26E-05	5.82E-05	0.98
tech	0.017	0.017	0.005	0.31

Table G - 2. Posterior median (50th percentile) stock biomass and 90% probability intervals (5th and 95th percentiles) for Area 3C lingcod computed from the reference case run.

Year	5%	50%	95%	Year	5%	50%	95%
1927	23010	49221	87553	**1970**	14523	35838	81015
1928	23126	50101	88445	**1971**	14177	35415	79474
1929	22995	49803	88512	**1972**	14664	35881	80069
1930	23021	48437	88277	**1973**	14575	36540	80275
1931	22765	47710	88887	**1974**	14804	36859	82715
1932	22870	48041	90633	**1975**	13765	37025	81972
1933	23224	48717	89948	**1976**	13277	36183	84292
1934	23240	48710	91460	**1977**	13080	35430	82674
1935	23227	48351	89783	**1978**	13784	36331	83684
1936	22913	47708	87385	**1979**	14294	37108	85848
1937	21454	47556	90119	**1980**	14219	37913	85213
1938	21115	47971	90722	**1981**	15338	38996	86995
1939	21585	48545	90887	**1982**	14930	39142	89204
1940	22375	48611	89374	**1983**	15394	39641	91653
1941	22876	48117	91432	**1984**	14484	39618	89926
1942	20666	48871	91557	**1985**	11878	36335	85982
1943	21702	48389	91713	**1986**	11342	34970	82344
1944	21085	47245	89915	**1987**	11408	33861	79947
1945	21954	47933	91908	**1988**	11337	32801	78787
1946	21397	47857	90944	**1989**	11103	32552	78467
1947	21213	48678	91066	**1990**	10566	30607	77239
1948	23106	47707	92256	**1991**	9493	30201	78416
1949	22986	48021	92011	**1992**	8923	28178	73361
1950	22939	47744	92471	**1993**	7978	26669	68947
1951	22054	47876	91328	**1994**	7776	26042	69514
1952	22310	47835	92086	**1995**	7400	25969	71758
1953	22475	48333	92961	**1996**	7342	25842	74213
1954	21802	47611	91130	**1997**	7486	26647	74167
1955	21410	47307	92626	**1998**	7418	27173	72177
1956	20701	46345	91628	**1999**	7589	26693	72862
1957	20251	44827	90144	**2000**	7481	26284	72420
1958	20248	44095	90316	**2001**	7292	26351	72463
1959	19148	43236	88521	**2002**	7536	27316	73605
1960	18337	42243	86611	**2003**	7864	28229	76244
1961	17035	40145	84000	**2004**	7645	29187	79559
1962	16904	39960	82534	**2005**	7443	29522	80277
1963	17431	38701	82927	**2006**	7322	30103	82245
1964	17555	39415	83372	**2007**	6997	28958	77870
1965	16609	38697	83212	**2008**	6402	27541	74439
1966	16054	38462	83174	**2009**	6160	26070	72042
1967	15308	37461	83406	**2010**	5580	25083	71078
1968	14600	36004	84493				
1969	14545	36561	82501				

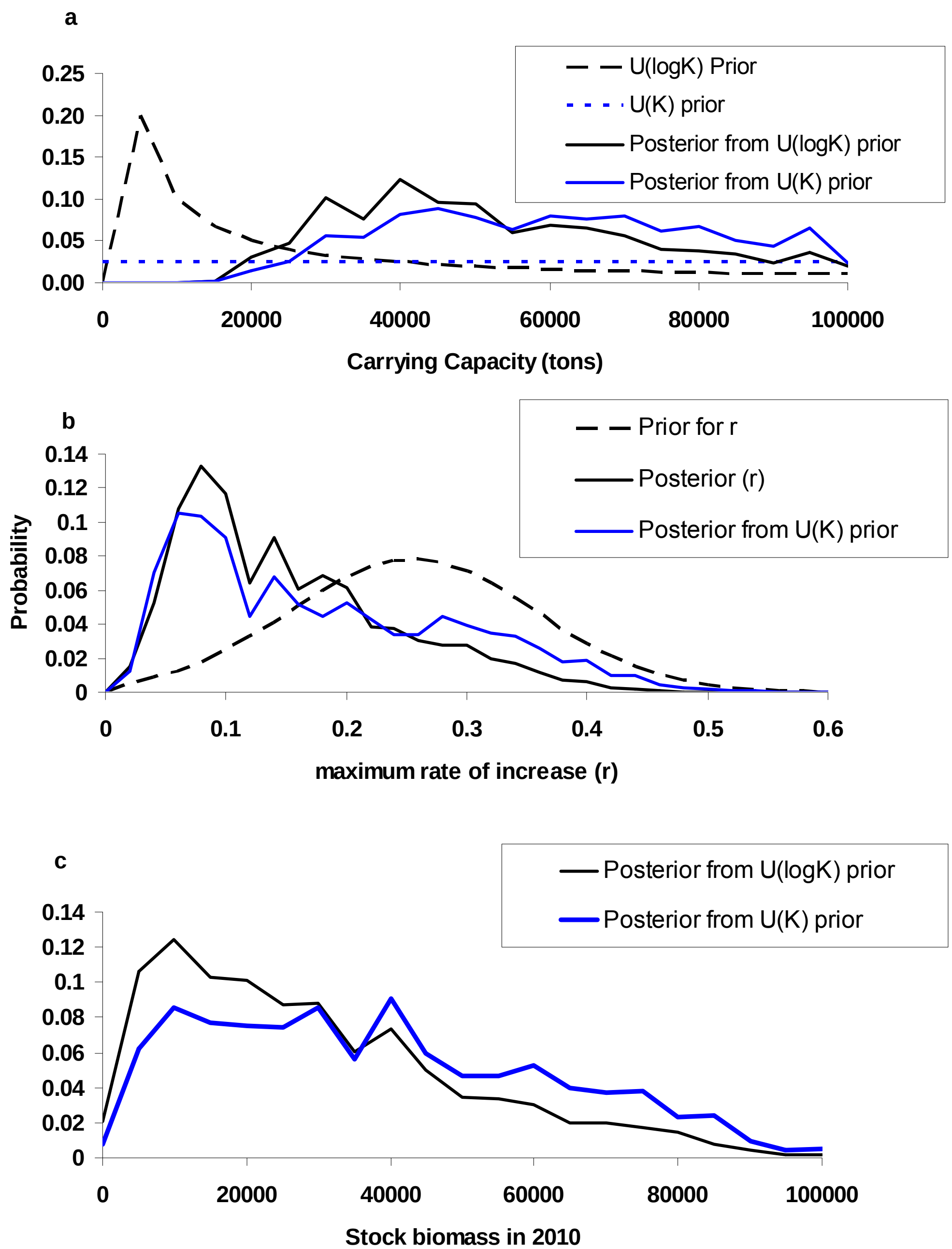

Figure G - 1. Reference case posterior distributions for (a) carrying capacity, (b) the maximum rate of increase, and (c) stock biomass in 2010 for Area 3C.

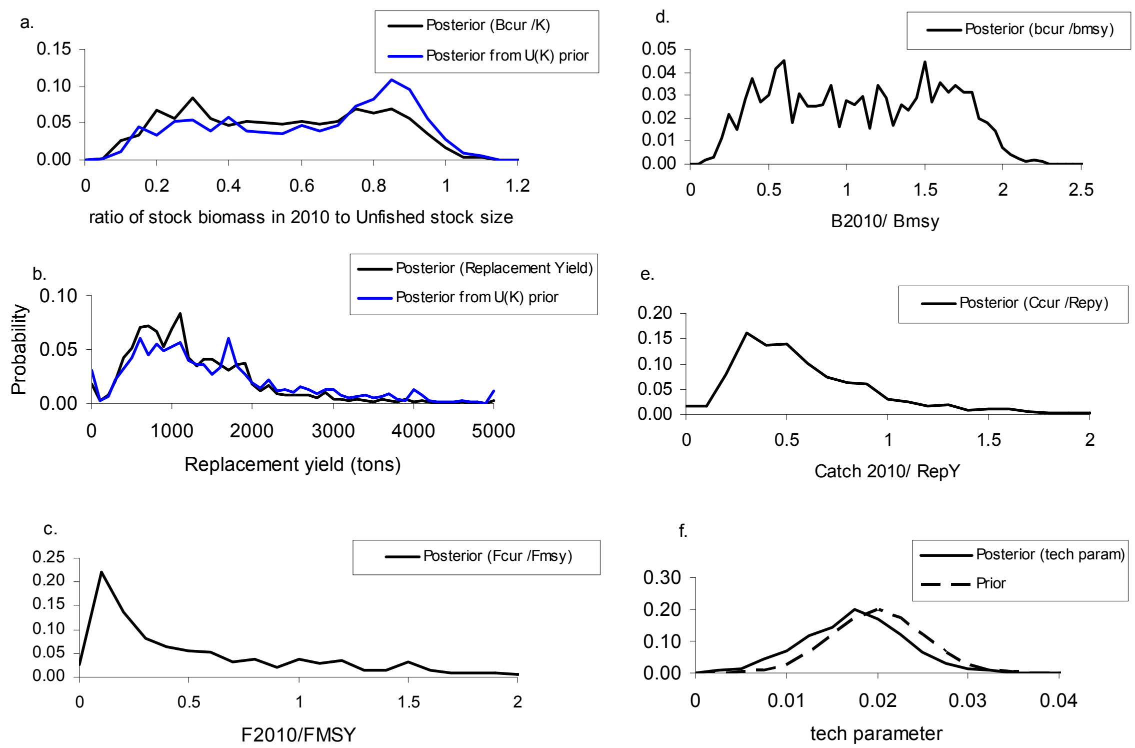

Figure G - 2. Posterior distributions for Area 3C lingcod for (a) ratio of stock biomass in 2010 to unfished stock size, (b) replacement yield in 2010, (c) ratio of fishing mortality rate in 2010 to that under F_{MSY} and tech, (d) ratio of stock biomass in 2010 to B_{MSY}, (e) catch in 2010 to replacement yield and (f) te tech (prior also shown). In some instances the marginal posterior is shown also for the sensitivity run where the uniform on log(K) prior is applied.

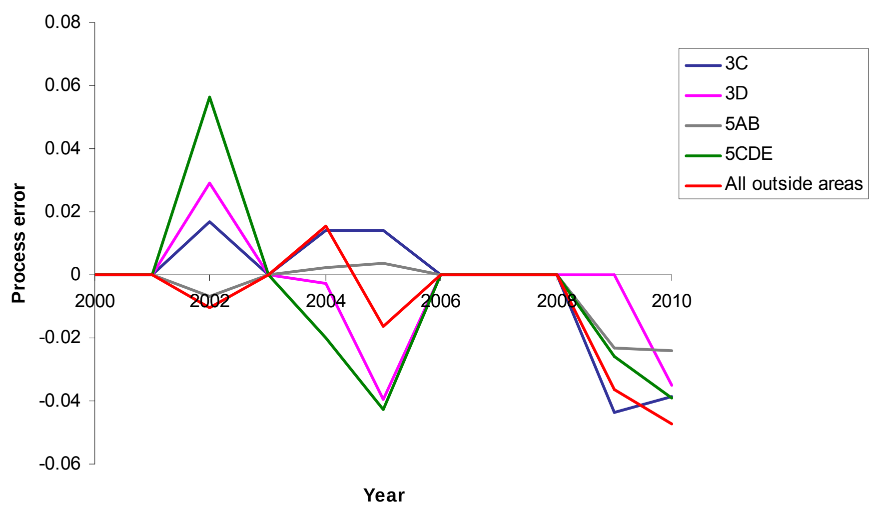

Figure G - 3. Posterior modal estimates of process error terms for the years 2000 to 2010 for each of the four assessment areas as well as all areas combined in the reference case. The BSP model accounted for uncertainty in process errors in all years. Due to large observation errors in abundance indices and few overlapping series in early years, the data did not enable updating of the prior before 2001. Thus the posterior distributions for process error terms before 2001 were no different from the prior distribution with a posterior mean of zero and standard deviation of 0.075. Posterior modes are not shown prior to 2000.

Area 3D

Results for the full suite of parameters estimated from the reference case run for Area 3D are summarized in Table G - 3. Predicted posterior median biomass levels from the surplus production model between 1927 and 2010, as well as catch and observed stock trend indices, are shown in Figure 4 of the main assessment document. Annual predicted posterior median biomass levels between 1927 and 2010, as well as 90% probability intervals, are also provided in Table G - 4.

The posterior distributions for carrying capacity (*K*), stock biomass in 2010, and most other quantities of interest are imprecise for Area 3D (Table G - 3; Figure G - 4; Figure G - 5). As noted for Area 3C, this result is likely due to large outlier values and high among-year variability in stock trend indices, as well as imprecise biomass estimates from some surveys.

As with Area 3C, estimates of process error terms for Area 3D were zero up to the year 2000 but were updated to deviate from zero for most years since 2000 (Figure G - 3). In the last few years, estimates of process error deviates are negative, although this trend was less that that of other assessment areas.

Table G - 3. Posterior mean, Median, SD, and CV for key parameters and stock status indicators for B.C. offshore lingcod in Area 3D. Posterior medians for C_{2010}/MSY, $C_{2010}/Repy_{2010}$, B_{1927}/K, all 6 catchability parameters (q) and tech were calculated using a lognormal approximation based on the posterior mean and SD. All other posterior medians were obtained directly from a resample from the importance draws.

Variable	Mean	Median	SD	CV
K	47623	44135	22563	0.47
r	0.189	0.184	0.092	0.49
MSY	2236	1888	1605	0.72
B_{2010}	36536	31869	20369	0.56
B_{2010}/K	0.748	0.78	0.159	0.21
B_{1927}	46399	43288	22162	0.48
B_{1927}/K	0.984	0.969	0.173	0.18
B_{2010}/B_{1927}	0.785	0.78	0.220	0.28
C_{2010}/MSY	0.258	0.188	0.245	0.95
F_{2010}/F_{MSY}	0.228	0.11	0.358	1.57
B_{2010}/B_{MSY}	1.50	1.56	0.32	0.21
$C_{2010}/Repy_{2010}$	0.414	0.195	0.778	1.88
B_{MSY}	23811	22068	11282	0.47
$Repy_{2010}$	1341	1118	968	0.72
54-90 ccpue q	2.74E-05	2.29E-05	1.80E-05	0.66
91-95 ccpue q	2.48E-05	2.00E-05	1.81E-05	0.73
96-2010 ccpue q	2.13E-05	1.69E-05	1.64E-05	0.77
Shrimp survey q	1.27E-05	1.04E-05	8.92E-06	0.70
Synoptic q	5.29E-05	4.18E-05	4.10E-05	0.77
tech	1.35E-02	0.013	0.005	0.34

Table G - 4. Posterior median stock biomass and 90% probability intervals for Area 3D lingcod computed from the reference case run.

Year	5%	50%	95%	Year	5%	50%	95%
1927	15812	43288	86899	**1970**	14434	42969	98318
1928	15791	42747	86056	**1971**	14116	42412	94226
1929	16084	42760	87943	**1972**	13930	41334	92467
1930	16104	42831	90119	**1973**	13974	41086	91779
1931	16122	43629	89980	**1974**	13735	40508	93728
1932	16143	43350	90583	**1975**	13617	40188	92194
1933	16188	42902	90760	**1976**	13104	39095	87542
1934	16329	43267	91722	**1977**	13077	38519	87059
1935	16131	42710	89262	**1978**	12819	37875	86546
1936	16402	42626	91179	**1979**	12612	37203	84334
1937	16620	42525	91801	**1980**	12508	36644	82807
1938	16362	42635	91797	**1981**	12583	36722	83649
1939	16331	43206	93389	**1982**	12772	37201	82446
1940	16403	42559	91647	**1983**	12569	37150	82102
1941	16178	43451	91781	**1984**	11999	36630	81952
1942	16323	43901	91649	**1985**	11754	35959	80213
1943	15877	42423	92111	**1986**	11269	34375	77705
1944	15664	42517	91421	**1987**	11436	34008	76004
1945	15287	42871	92102	**1988**	11437	34357	77232
1946	15436	42544	94034	**1989**	11841	34337	77920
1947	15650	42196	92964	**1990**	12006	35506	79886
1948	15957	42940	93254	**1991**	12079	36909	84944
1949	16124	42545	93727	**1992**	11752	37377	84969
1950	16059	42797	94251	**1993**	11484	36395	83765
1951	16023	42478	94247	**1994**	11258	37195	86776
1952	15703	42517	92022	**1995**	10916	36937	86284
1953	15954	42432	94026	**1996**	11395	38417	88651
1954	15856	43039	94333	**1997**	11425	38425	87775
1955	15889	42825	95824	**1998**	11652	39003	87378
1956	16267	42627	96176	**1999**	11754	39314	87561
1957	16206	42757	97919	**2000**	11869	40166	90239
1958	16263	42635	96641	**2001**	12052	40482	91542
1959	16391	43397	96925	**2002**	11980	41309	92694
1960	16633	43376	98204	**2003**	12282	41865	93558
1961	16243	43487	97940	**2004**	12026	41339	91826
1962	16279	43329	99374	**2005**	11432	39393	89346
1963	16201	44125	98288	**2006**	11450	38595	88106
1964	16496	44664	100123	**2007**	10728	36600	84496
1965	16276	45167	101212	**2008**	10165	34019	77213
1966	16070	45645	105367	**2009**	9646	32865	75386
1967	15885	46015	104596	**2010**	8880	31869	73192
1968	15424	46451	103856				
1969	14994	44838	103243				

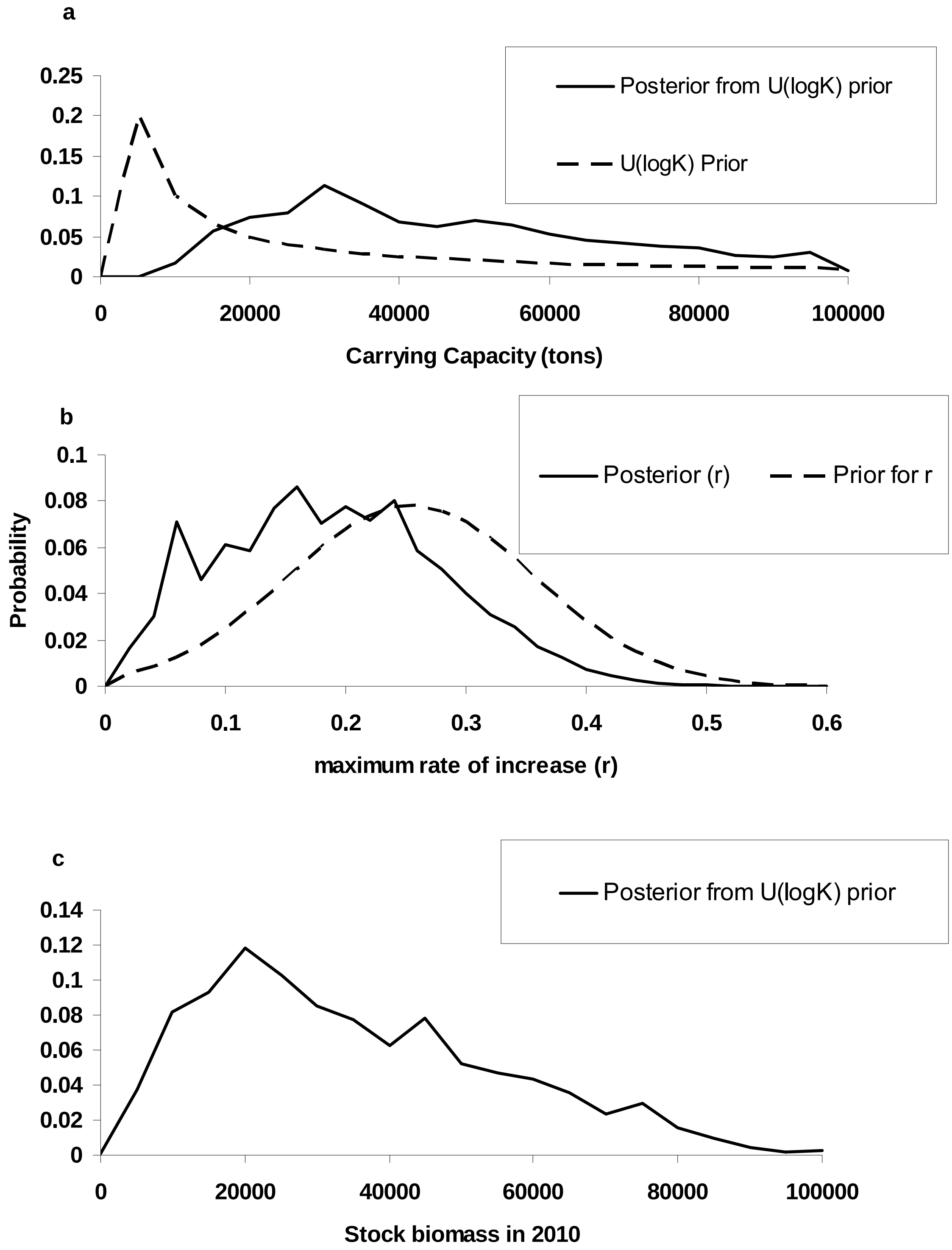

Figure G - 4. Reference case posterior distributions for (a) carrying capacity, (b) the maximum rate of increase and (c) stock biomass in 2010 for Area 3D.

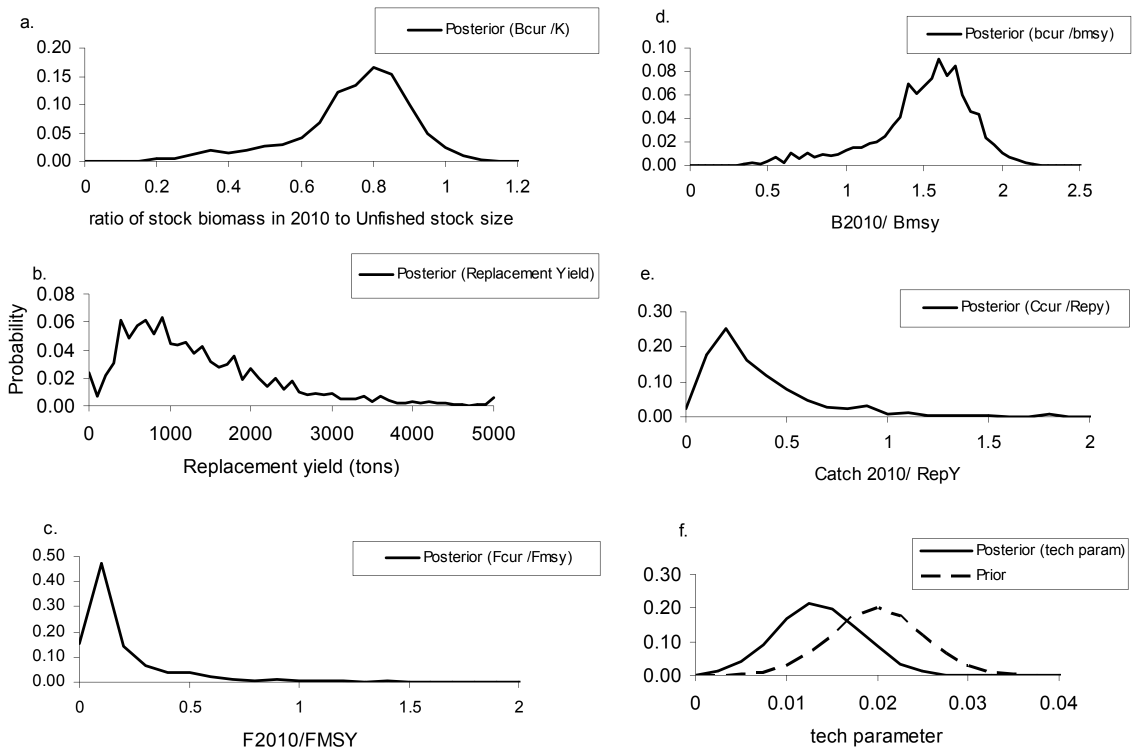

Figure G - 5. Posterior distributions for Area 3D lingcod for (a) ratio of stock biomass in 2010 to unfished stock size, (b) replacement yield in 2010, (c) ratio of fishing mortality rate in 2010 to that under F_{MSY} and tech, (d) ratio of stock biomass in 2010 to B_{MSY}, (e) catch in 2010 to replacement yield and (f) tech (prior also shown).

Area 5AB

Results for the full suite of parameters estimated from the reference case run for Area 5AB are summarized in Table G - 5. Predicted posterior median biomass levels from the surplus production model between 1927 and 2010, as well as catch and observed stock trend indices, are shown in Figure 5 of the main assessment document. Annual predicted posterior median biomass levels between 1927 and 2010, as well as 90% probability intervals, are also provided in Table G - 6.

The posterior distributions for carrying capacity (*K*), stock biomass in 2010, and most other quantities of interest are imprecise for Area 5AB (Table G - 5, Figure G - 6, Figure G - 7). As noted for Area 3C, this result is likely due to large outlier values and high among-year variability in stock trend indices, as well as imprecise biomass estimates from some surveys.

As with Area 3C, estimates of process error terms for Area 5AB were zero up to the year 2000 but were updated to deviate from zero for most years since 2000 (Figure G - 3). In the last few years, estimates of process error deviates were consistently negative.

Table G - 5. Posterior mean, Median, SD, and CV for key parameters and stock status indicators for B.C. offshore lingcod in area 5AB. Posterior medians for C_{2010}/MSY, $C_{2010}/Repy_{2010}$, B_{1927}/K, all 6 catchability parameters (q) and tech were calculated using a lognormal approximation based on the posterior mean and SD. All other posterior medians were obtained directly from a resample from the importance draws.

Variable	Mean	Median	SD	CV
K	48865	44117	20963	0.43
r	0.153	0.142	0.076	0.50
MSY	1862	1283	1402	0.75
B_{2010}	29426	22824	20847	0.71
B_{2010}/K	0.549	0.560	0.231	0.42
B_{1927}	47811	44726	20841	0.44
B_{1927}/K	0.989	0.973	0.180	0.18
B_{2010}/B_{1927}	0.576	0.560	0.269	0.47
C_{2010}/MSY	0.548	0.473	0.321	0.59
F_{2010}/F_{MSY}	0.757	0.51	0.732	0.97
B_{2010}/B_{MSY}	1.10	1.13	0.46	0.42
$C_{2010}/Repy_{2010}$	0.715	0.522	0.671	0.94
B_{MSY}	24433	22058	10482	0.43
$Repy_{2010}$	1329	1055	847	0.64
54-90 ccpue q	2.84E-05	2.44E-05	1.70E-05	0.60
91-95 ccpue q	2.68E-05	2.12E-05	2.07E-05	0.77
96-2010 ccpue q	2.87E-05	2.18E-05	2.46E-05	0.86
Shrimp survey q	2.65E-04	1.99E-04	2.34E-04	0.88
Synoptic q	3.96E-04	2.96E-04	3.52E-04	0.89
tech	0.018	0.017	0.005	0.27

Table G - 6. Posterior median stock biomass and 90% probability intervals for Area 5AB lingcod computed from the reference case run.

Year	5%	50%	95%	Year	5%	50%	95%
1927	19603	44726	86663	**1970**	12212	33457	82366
1928	19557	44182	88612	**1971**	11762	32373	79277
1929	19535	44047	87785	**1972**	11801	31496	78932
1930	19694	44386	88754	**1973**	11314	31569	75396
1931	19779	43490	87390	**1974**	11224	30778	75032
1932	19743	43777	88912	**1975**	11140	30349	74520
1933	19111	43390	87951	**1976**	10952	29581	73159
1934	19316	43482	89679	**1977**	10651	29732	72128
1935	19038	43523	89616	**1978**	11203	30098	72786
1936	18994	43850	89705	**1979**	12200	30952	74402
1937	19132	43592	89412	**1980**	12900	31975	77787
1938	19474	43428	88861	**1981**	13682	34189	80988
1939	19572	44197	88231	**1982**	13600	34998	85329
1940	19585	44084	88687	**1983**	13738	36116	86035
1941	19553	43998	88448	**1984**	14023	36662	88056
1942	19638	44326	88614	**1985**	14797	36950	87861
1943	19694	43780	89311	**1986**	14177	36874	89408
1944	19977	44199	87189	**1987**	14033	36442	89248
1945	19607	43693	88498	**1988**	13918	36644	89170
1946	19135	42774	88064	**1989**	12700	35494	91478
1947	19319	42658	87294	**1990**	11874	34974	90289
1948	19309	42724	87696	**1991**	10728	34424	91665
1949	19450	43045	88497	**1992**	9548	32289	86241
1950	19548	43446	87697	**1993**	8578	30687	83277
1951	19295	43670	89298	**1994**	8204	30037	82889
1952	19532	42847	89019	**1995**	7373	29061	82411
1953	19673	42681	90500	**1996**	7284	29485	84907
1954	19154	42745	89285	**1997**	7255	29421	83601
1955	19517	42580	88869	**1998**	7379	29938	84655
1956	18267	42522	89156	**1999**	7408	29908	84282
1957	17588	42023	88347	**2000**	7175	29329	84233
1958	17610	42272	90914	**2001**	6726	28304	81665
1959	17719	41596	88822	**2002**	6441	26787	78962
1960	17730	40819	88531	**2003**	6199	25975	75953
1961	17251	40059	89618	**2004**	5845	25491	73749
1962	16791	40020	89492	**2005**	5776	24610	71443
1963	16486	39541	88809	**2006**	5540	24640	72679
1964	16767	39990	89349	**2007**	5428	24062	71208
1965	16192	40070	89694	**2008**	5553	24832	72249
1966	15709	38624	87835	**2009**	5444	23610	69377
1967	14799	37570	87780	**2010**	5179	22824	67220
1968	13065	35332	86983				
1969	12286	34934	85097				

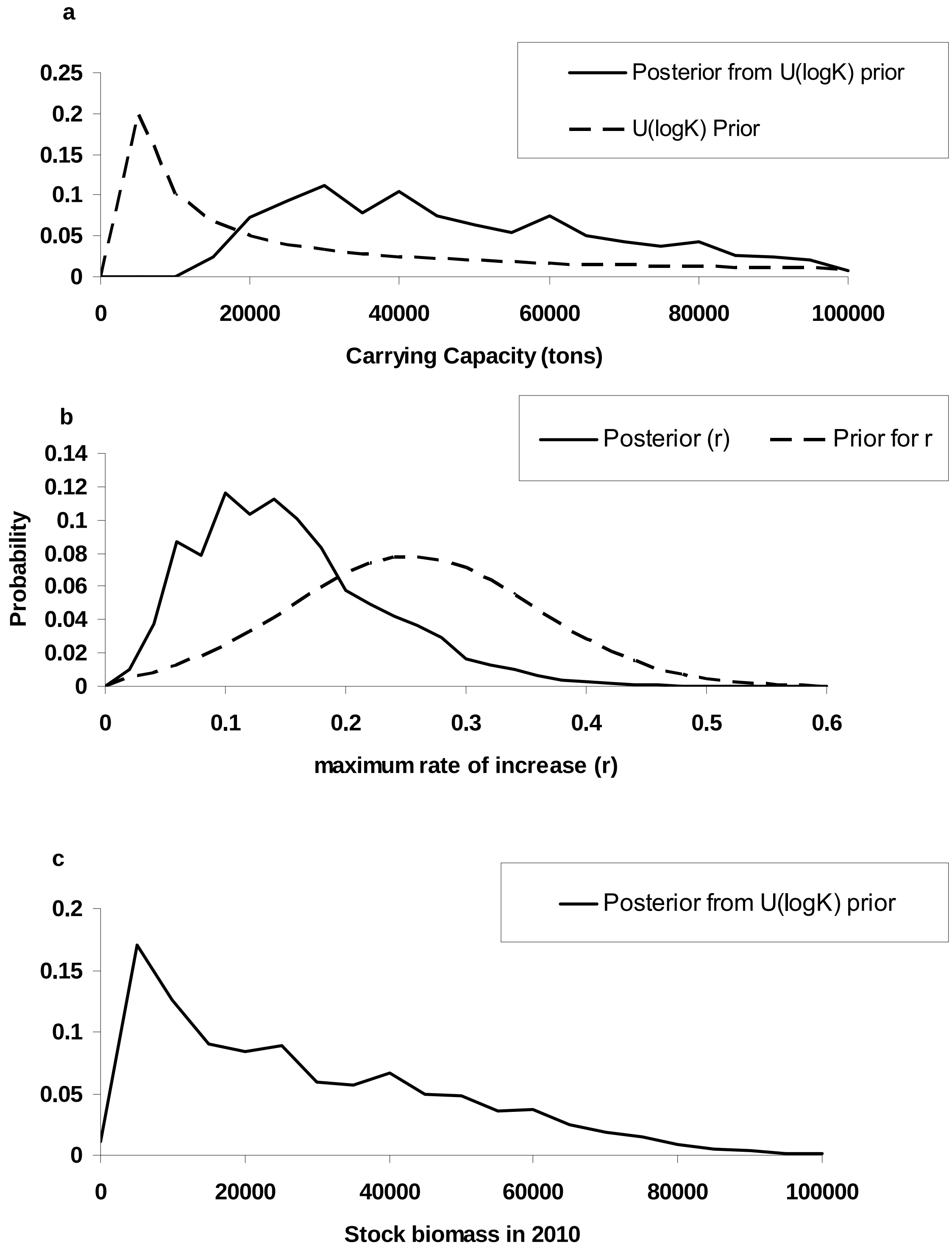

Figure G - 6. Reference case posterior distributions for (a) carrying capacity, (b) the maximum rate of increase and (c) stock biomass in 2010 for Area 5AB.

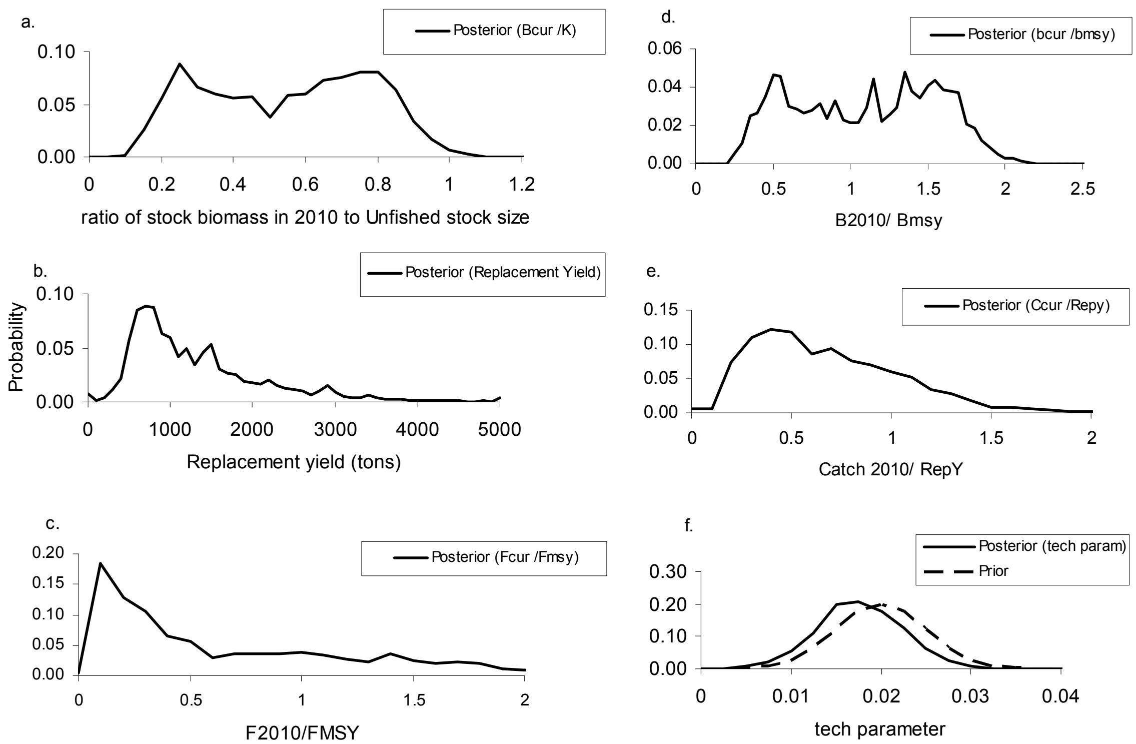

Figure G - 7. Posterior distributions for Area 5AB lingcod for (a) ratio of stock biomass in 2010 to unfished stock size, (b) replacement yield in 2010, (c) ratio of fishing mortality rate in 2010 to that under F_{MSY} and tech, (d) ratio of stock biomass in 2010 to B_{MSY}, (e) catch in 2010 to replacement yield and (f) tech (prior also shown).

Area 5CDE

Results for the full suite of parameters estimated from the reference case run for Area 5CDE are summarized in Table G - 7. Predicted posterior median biomass levels from the surplus production model between 1927 and 2010, as well as catch and observed stock trend indices, are shown in Figure 6 of the main assessment document. Annual predicted posterior median biomass levels between 1927 and 2010, as well as 90% probability intervals, are also provided in Table G - 8.

The posterior distributions for carrying capacity (*K*), stock biomass in 2010, and most other quantities of interest are imprecise for Area 5CDE (Table G - 7, Figure G - 8, Figure G - 9). Although the stock trend data have fewer outliers for this Area, estimates of all quantities remain highly imprecise.

As with Area 3C, estimates of process error terms for Area 5AB were zero up to the year 2000 but were updated to deviate from zero for most years since 2000 (Figure G - 3). In the last few years, process error deviate estimates were consistently negative.

Table G - 7. Posterior mean, Median, SD, and CV for key parameters and stock status indicators for B.C. offshore lingcod in area 5CDE. Posterior medians for C_{2010}/MSY, $C_{2010}/Repy_{2010}$, B_{1927}/K, all 6 catchability parameters (q) and tech were calculated using a lognormal approximation based on the posterior mean and SD. All other posterior medians were obtained directly from a resample from the importance draws.

Variable	Mean	Median	SD	CV
K	34675	27316	22957	0.66
r	0.190	0.183	0.085	0.45
MSY	1652	1091	1493	0.90
B_{2010}	26521	17929	21716	0.82
B_{2010}/K	0.692	0.73	0.201	0.29
B_{1927}	33933	26384	22608	0.67
B_{1927}/K	0.988	0.971	0.187	0.19
B_{2010}/B_{1927}	0.725	0.72	0.251	0.35
C_{2010}/MSY	0.570	0.458	0.424	0.74
F_{2010}/F_{MSY}	0.565	0.31	0.627	1.11
B_{2010}/B_{MSY}	1.38	1.46	0.40	0.29
$C_{2010}/Repy_{2010}$	0.842	0.462	1.284	1.53
B_{MSY}	17337	13658	11479	0.66
$Repy_{2010}$	913	679	721	0.79
64-90 ccpue q	4.06E-05	3.29E-05	2.94E-05	0.72
91-95 ccpue q	3.50E-05	2.67E-05	2.97E-05	0.85
96-2010 ccpue q	3.50E-05	2.58E-05	3.20E-05	0.91
Multi species trawl q	1.00E-04	7.69E-05	8.43E-05	0.84
Hecate Strait synoptic q	1.78E-04	1.29E-04	1.69E-04	0.95
WCQCI synoptic q	3.70E-04	2.68E-04	3.51E-04	0.95
tech	0.019	0.019	0.005	0.24

Table G - 8. Posterior median stock biomass and 90% probability intervals for Area 5CDE lingcod computed from the reference case run.

Year	5%	50%	95%	Year	5%	50%	95%
1927	11009	26384	70163	**1970**	9392	25380	72791
1928	10789	26288	70359	**1971**	8976	24666	70696
1929	10845	26445	69994	**1972**	8805	23944	69687
1930	10878	26492	70821	**1973**	8560	23424	67797
1931	10839	26595	70839	**1974**	8405	22247	64741
1932	10967	26125	70906	**1975**	8136	21455	63085
1933	10891	26236	70306	**1976**	7950	20637	61268
1934	10752	26441	69896	**1977**	7884	20448	60601
1935	10894	26345	71322	**1978**	8027	20876	60595
1936	10941	26216	70195	**1979**	8476	21318	62089
1937	10990	26183	71203	**1980**	8627	22203	63951
1938	10959	26136	71329	**1981**	8822	23182	67135
1939	10970	26074	71118	**1982**	9139	23937	69853
1940	11030	26397	71346	**1983**	9541	24694	72266
1941	11107	26490	71400	**1984**	9852	25708	74450
1942	10904	26279	70844	**1985**	10018	25888	76441
1943	10792	26288	70825	**1986**	10328	26797	78110
1944	10578	26319	70910	**1987**	10217	27408	78516
1945	10474	25866	71335	**1988**	9963	26919	78560
1946	10215	25527	70376	**1989**	9533	26798	78858
1947	10331	25828	71110	**1990**	9084	25272	77234
1948	10428	25402	70225	**1991**	8408	24566	74019
1949	10319	25591	70109	**1992**	7931	23766	71973
1950	10505	25176	70910	**1993**	7472	22847	70717
1951	10358	25408	71107	**1994**	7013	21985	69470
1952	10308	25514	70748	**1995**	6391	21362	67902
1953	10388	25684	70546	**1996**	6291	21231	67984
1954	10549	25971	71570	**1997**	6347	21576	66566
1955	10259	25764	71057	**1998**	6257	20270	63772
1956	10388	25893	71239	**1999**	5909	19299	61528
1957	10397	25725	70722	**2000**	6048	19912	62565
1958	10571	25811	70974	**2001**	6180	21240	65976
1959	10423	25977	71498	**2002**	6324	21744	68150
1960	10362	25400	71370	**2003**	6311	20957	67706
1961	10369	25797	71836	**2004**	5927	20219	65743
1962	10526	25285	71898	**2005**	5536	19294	61525
1963	10412	25512	71594	**2006**	5528	19561	61457
1964	10276	25462	71844	**2007**	5623	20103	62407
1965	10215	25777	71708	**2008**	5526	19600	62279
1966	10010	25664	72792	**2009**	5313	18929	60718
1967	10038	25786	73153	**2010**	5051	17929	58666
1968	9952	25814	73376				
1969	9795	25601	73547				

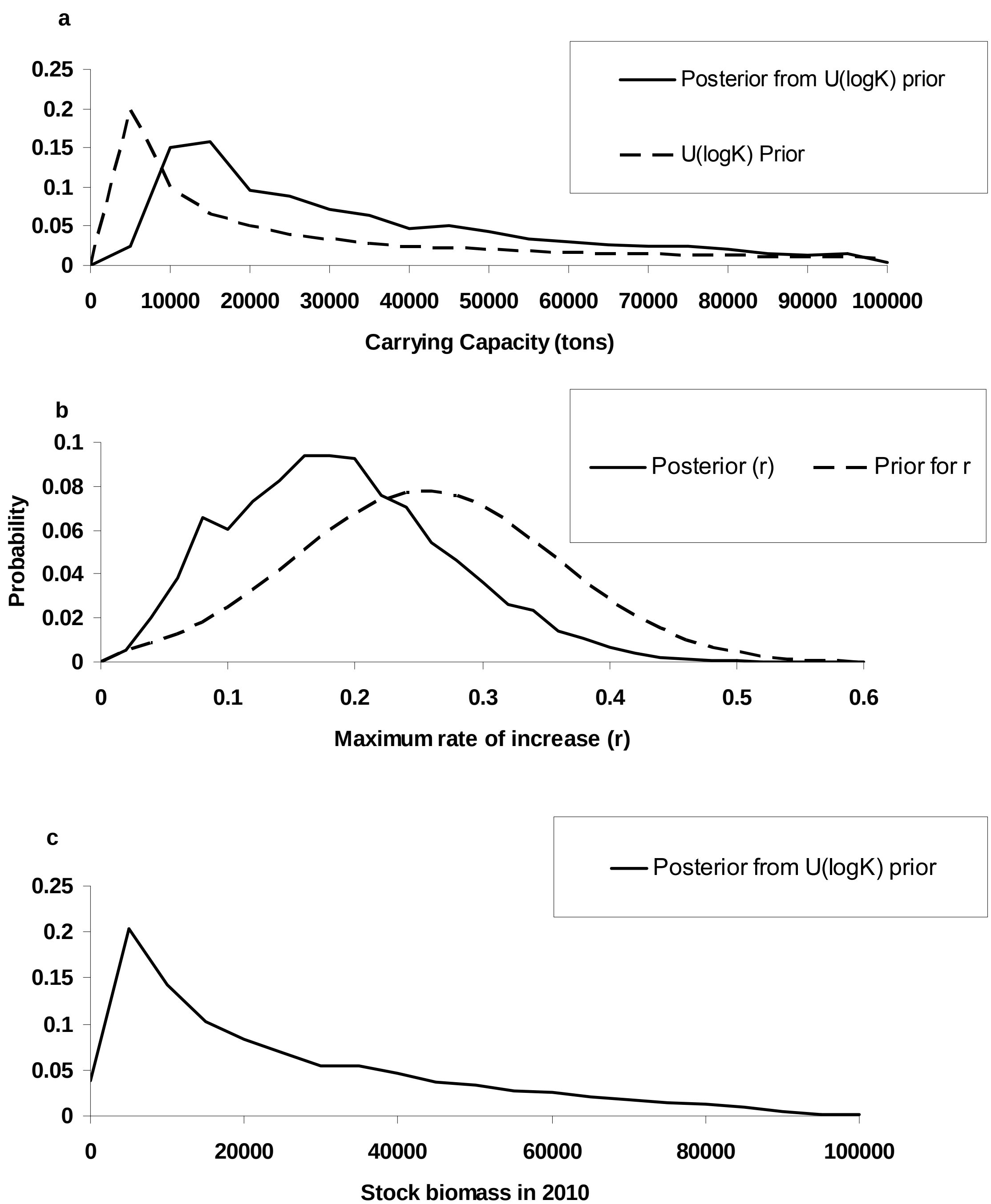

Figure G - 8. Reference case posterior distributions for (a) carrying capacity, (b) maximum rate of increase and (c) stock biomass in 2010 for Area 5CDE.

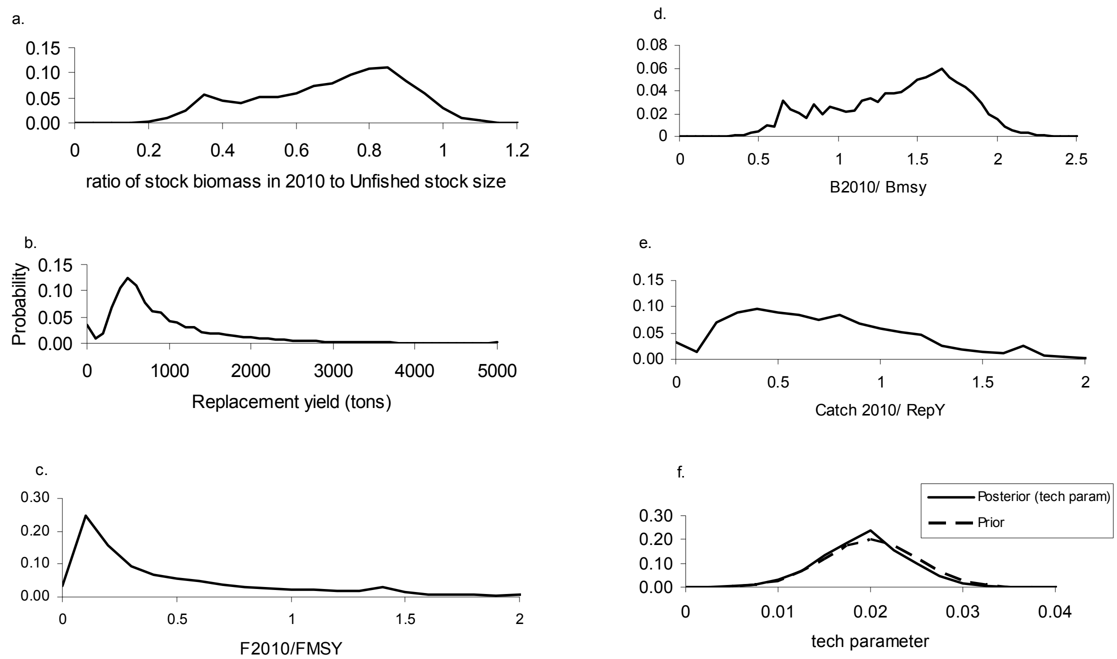

Figure G - 9. Posterior distributions for Area 5CDE lingcod for (a) ratio of stock biomass in 2010 to unfished stock size, (b) replacement yield in 2010, (c) ratio of fishing mortality rate in 2010 to that under F_{MSY} and tech, (d) ratio of stock biomass in 2010 to B_{MSY}, (e) catch in 2010 to replacement yield and (f) tech (prior also shown).

STOCK PROJECTIONS FOR YIELD ADVICE

Decision tables for constant Total Allowable Catch (TAC) policies based on 5, 10, and 20 year projections are summarized by assessment area in Table G - 9 to Table G - 12. The range of constant TAC policies considered ranged from 500 to either 3000 or 4500 tonnes, depending on the area. Larger TAC quota policies were considered for Areas 3D and 5CDE since the ratio of current biomass estimates to B_{MSY} was estimated to be larger in these areas. For all areas, upward median trajectories of B_{FINAL}/B_{MSY} occur for all policy options evaluated for TACs of 1000 tonnes and lower.

Constant effort policies were also evaluated in which the effort equivalent to some fixed quota in 2011 was applied in future years. The results for these projections in nearly all instances were similar to those for the analogous constant quota policies, though in a few instances less optimistic for the longest time horizons. Results are thus not shown for these TAC referenced effort policies.

Table G - 9. Stock status indicators for lingcod in Area 3C after 5, 10 and 20 years. Policies are constant TAC policies (tonnes). B_{FINAL} is the biomass in the final year of the projection (2016 for 5-year horizon, 2021 for 10-year horizon, and 2031 for 20-year horizon). Probabilities (P) are presented for 3 stock status indicators: B_{FINAL} will be above the Limit Reference Point (40% of B_{MSY}), B_{FINAL} will be above the target biomass of B_{MSY}, and B_{FINAL} will be above the current 2010 biomass (B_{2010}).

Horizon	TAC Policy (tonnes)	B_{FINAL}/B_{MSY}	P (B_{FINAL} > 0.4 B_{MSY})	P (B_{FINAL} > 0.8 B_{MSY})	P (B_{FINAL} > B_{MSY})	P (B_{FINAL} > B_{2010})
5 -year	0	1.20	0.94	0.73	0.61	0.69
	500	1.15	0.89	0.69	0.57	0.57
	1000	1.07	0.83	0.62	0.53	0.37
	1500	0.97	0.76	0.58	0.48	0.24
	2000	0.90	0.71	0.54	0.42	0.18
	2500	0.79	0.66	0.50	0.39	0.12
	3000	0.70	0.61	0.45	0.36	0.08
10 -year	0	1.39	0.96	0.81	0.72	0.80
	500	1.26	0.88	0.71	0.63	0.61
	1000	1.04	0.77	0.62	0.54	0.40
	1500	0.89	0.68	0.53	0.45	0.28
	2000	0.68	0.59	0.47	0.39	0.16
	2500	0.44	0.53	0.39	0.34	0.12
	3000	0.21	0.46	0.34	0.29	0.07
20 -year	0	1.65	0.98	0.90	0.84	0.84
	500	1.43	0.87	0.77	0.68	0.66
	1000	1.15	0.70	0.61	0.56	0.41
	1500	0.80	0.59	0.50	0.45	0.26
	2000	0.28	0.49	0.40	0.36	0.16
	2500	0.00	0.40	0.33	0.29	0.12
	3000	0.00	0.32	0.25	0.22	0.06

Table G - 10. Stock status indicators for lingcod in Area 3D after 5, 10 and 20 years. Policies are constant TAC policies (tonnes). B_{FINAL} is the biomass in the final year of the projection (2016 for 5-year horizon, 2021 for 10-year horizon, and 2031 for 20-year horizon). Probabilities (P) are presented for 3 stock status indicators: B_{FINAL} will be above the Limit Reference Point (40% of B_{MSY}), B_{FINAL} will be above the target biomass of B_{MSY}, and B_{FINAL} will be above the current 2010 biomass (B_{2010}).

Horizon	TAC Policy (tonnes)	B_{FINAL}/B_{MSY}	P (B_{FINAL} > 0.4 B_{MSY})	P (B_{FINAL} > 0.8 B_{MSY})	P (B_{FINAL} > B_{MSY})	P (B_{FINAL} > B_{2010})
5 -year	0	1.60	1.00	0.95	0.91	0.58
	500	1.55	0.99	0.93	0.89	0.49
	1000	1.46	0.97	0.91	0.85	0.36
	1500	1.36	0.94	0.87	0.76	0.27
	2000	1.27	0.91	0.79	0.69	0.21
	2500	1.17	0.88	0.73	0.61	0.16
	3000	1.08	0.84	0.67	0.55	0.11
	3500	0.99	0.76	0.61	0.49	0.08
	4000	0.89	0.72	0.55	0.44	0.06
	4500	0.80	0.67	0.50	0.39	0.04
10 -year	0	1.75	1.00	0.97	0.93	0.69
	500	1.62	0.98	0.92	0.88	0.57
	1000	1.47	0.93	0.85	0.77	0.40
	1500	1.32	0.87	0.76	0.68	0.29
	2000	1.16	0.78	0.66	0.57	0.21
	2500	0.98	0.70	0.57	0.49	0.15
	3000	0.79	0.62	0.49	0.41	0.10
	3500	0.56	0.55	0.42	0.34	0.08
	4000	0.33	0.48	0.35	0.28	0.06
	4500	0.05	0.41	0.30	0.24	0.04
20 -year	0	1.84	1.00	0.98	0.93	0.74
	500	1.68	0.96	0.88	0.86	0.58
	1000	1.48	0.85	0.80	0.76	0.42
	1500	1.27	0.76	0.67	0.61	0.29
	2000	0.98	0.63	0.56	0.49	0.20
	2500	0.59	0.54	0.45	0.39	0.13
	3000	0.01	0.44	0.36	0.31	0.09
	3500	0.00	0.35	0.28	0.23	0.07
	4000	0.00	0.28	0.22	0.18	0.04
	4500	0.00	0.23	0.18	0.14	0.03

Table G - 11. Stock status indicators for lingcod in Area 5AB after 5, 10 and 20 years. Policies are constant TAC policies (tonnes). B_{FINAL} is the biomass in the final year of the projection (2016 for 5-year horizon, 2021 for 10-year horizon, and 2031 for 20-year horizon). Probabilities (P) are presented for 3 stock status indicators: B_{FINAL} will be above the Limit Reference Point (40% of B_{MSY}), B_{FINAL} will be above the target biomass of B_{MSY}, and B_{FINAL} will be above the current 2010 biomass (B_{2010}).

Horizon	TAC Policy (tonnes)	B_{FINAL}/B_{MSY}	P (B_{FINAL} > 0.4 B_{MSY})	P (B_{FINAL} > 0.8 B_{MSY})	P (B_{FINAL} > B_{MSY})	P (B_{FINAL} > B_{2010})
5 -year	0	1.19	0.98	0.77	0.63	0.71
	500	1.12	0.93	0.69	0.57	0.55
	1000	1.02	0.83	0.61	0.51	0.35
	1500	0.93	0.75	0.55	0.46	0.23
	2000	0.83	0.67	0.51	0.42	0.16
	2500	0.71	0.63	0.47	0.37	0.12
	3000	0.61	0.57	0.43	0.34	0.09
10 -year	0	1.45	0.99	0.88	0.77	0.83
	500	1.27	0.92	0.74	0.64	0.66
	1000	1.04	0.76	0.60	0.51	0.40
	1500	0.79	0.64	0.50	0.44	0.27
	2000	0.56	0.56	0.44	0.38	0.19
	2500	0.33	0.49	0.38	0.33	0.14
	3000	0.06	0.43	0.34	0.29	0.09
20 -year	0	1.76	0.99	0.94	0.90	0.89
	500	1.49	0.90	0.80	0.74	0.72
	1000	1.12	0.68	0.59	0.54	0.43
	1500	0.64	0.54	0.48	0.43	0.27
	2000	0.08	0.45	0.38	0.34	0.17
	2500	0.00	0.37	0.31	0.27	0.11
	3000	0.00	0.31	0.25	0.22	0.07

Table G - 12. Stock status indicators for lingcod in Area 5CDE after 5, 10 and 20 years. Policies are constant TAC policies (tonnes). B_{FINAL} is the biomass in the final year of the projection (2016 for 5-year horizon, 2021 for 10-year horizon, and 2031 for 20-year horizon). Probabilities (P) are presented for 3 stock status indicators: B_{FINAL} will be above the Limit Reference Point (40% of B_{MSY}), B_{FINAL} will be above the target biomass of B_{MSY}, and B_{FINAL} will be above the current 2010 biomass (B_{2010}).

Horizon	TAC Policy (tonnes)	B_{FINAL}/B_{MSY}	P (B_{FINAL} > 0.4 B_{MSY})	P (B_{FINAL} > 0.8 B_{MSY})	P (B_{FINAL} > B_{MSY})	P (B_{FINAL} > B_{2010})
5 -year	0	1.50	1.00	0.93	0.87	0.64
	500	1.39	0.97	0.84	0.74	0.41
	1000	1.24	0.86	0.73	0.65	0.22
	1500	1.09	0.77	0.64	0.55	0.14
	2000	0.94	0.70	0.56	0.48	0.10
	2500	0.78	0.62	0.49	0.41	0.07
	3000	0.61	0.55	0.44	0.36	0.05
	3500	0.41	0.50	0.39	0.32	0.04
	4000	0.23	0.47	0.35	0.28	0.03
	4500	0.06	0.43	0.32	0.24	0.02
10 -year	0	1.70	1.00	0.97	0.91	0.77
	500	1.47	0.92	0.82	0.74	0.48
	1000	1.19	0.76	0.65	0.59	0.26
	1500	0.90	0.63	0.53	0.47	0.16
	2000	0.54	0.53	0.44	0.38	0.11
	2500	0.08	0.46	0.37	0.30	0.07
	3000	0.00	0.40	0.30	0.26	0.05
	3500	0.00	0.34	0.26	0.21	0.04
	4000	0.00	0.30	0.22	0.17	0.03
	4500	0.00	0.25	0.18	0.14	0.02
20 -year	0	1.85	1.00	0.98	0.95	0.82
	500	1.53	0.87	0.80	0.76	0.50
	1000	1.10	0.65	0.59	0.53	0.26
	1500	0.44	0.50	0.44	0.40	0.15
	2000	0.00	0.41	0.35	0.31	0.10
	2500	0.00	0.33	0.28	0.24	0.07
	3000	0.00	0.27	0.22	0.18	0.04
	3500	0.00	0.21	0.17	0.15	0.03
	4000	0.00	0.17	0.13	0.11	0.02
	4500	0.00	0.13	0.10	0.08	0.01

SENSITIVITY ANALYSES

Model Assumptions and Input Data

Parameter estimates from sensitivity runs for each individual assessment area are provided in Table G - 13 to Table G - 16.

Across all stocks, the estimates of stock status were affected to varying extents by the use of lower and higher prior means for the parameter *r*. For example, the posterior median for B_{2010}/B_{MSY} decreased from 1.06 (0.46) to 0.92 (0.41) going from the reference case to the low prior mean for *r* and increased to 1.22 (0.49) for the high prior mean for *r* for Area 3C (Table G - 13). However, the posterior median for F_{2010}/F_{MSY} was nearly double under the low *r* prior mean.

Across all stocks, the results were most sensitive to the different mean values inputted for *tech*, either as a fixed value or a prior mean. For example for Area 3C, the posterior median B_{2010}/B_{MSY} increased to 1.47 (0.25) when the prior mean for *tech* was set at 0.01 and decreased to 0.49 (0.72) and 0.32 (0.60) when the prior mean for *tech* was increased to 0.03 and 0.04. Maintaining a constant prior CV when the prior mean for *tech* was changed to 0.01 and 0.03 had very little impact on the results (runs B.13, B.17 versus C.1 and C.2 in Table G - 13).

Either eliminating the CPUE series from 1996-2010 or removing the *tech* from that time series had negligible impact on the results (D.1 and D2. versus Ref.1, Table G - 13).

Applying a uniform prior for *K*, rather than the reference case uniform on log *K* prior, gave slightly less precise results but overall the posterior medians for the stock status variables changed very little with some going up; for example, the posterior median for B_{2010} was 34,000 tons under a uniform on K prior versus 27,000 tons under the reference case. In contrast, the posterior median for the ratio of catch in 2010 to replacement yield was 0.35 under a uniform *K* prior versus 0.31 under the uniform log *K* reference case.

Fixing *tech* at the prior mean values, rather than treating it as a random variable with an informative prior, gave slightly more pessimistic results and as expected more precise results, particularly for estimates of stock biomass and replacement yield in 2010 (Table G - 13).

For all four assessment areas, the prior for *r* was updated slightly with posterior medians less than the prior medians by up to about one third. Even though the abundance index data show high interannual variability, they generally showed a decline over the period when the largest catches were taken in the 1970s and 1980s. Some of the indices (e.g., the shrimp survey indices) have shown an apparent increase since the 1990s after catches have remained low. However, most of the indices show decreases in the last five years when catches are also decreasing in each of the areas. This continued lack of increase and then a decrease in the abundance indices when catches are low and then decreasing is the cause of the update in the prior for *r* in the different areas and the lower value for the posterior median *for* r compared to the posterior median. This same pattern of continued low values in abundance indices after catches have declined substantially since the 1980s was also the cause of similar updates in the priors for *r* for British Columbia bocaccio (Stanley et al. 2009) and inside yelloweye rockfish (Yamanaka et al. in prep.).

Evaluation of Credibility of Sensitivity Analysis Scenarios

To evaluate the relative credibility of the alternative BSP model settings against the data, Bayes Factors were computed for some alternative sets of BSP stock assessment models and results are shown in Table G - 17. We have a slightly more liberal interpretation than Kass and Raftery (1995), to account for the relatively tight priors placed on some parameters (e.g., *tech)*. In our interpretation, ratios of marginal posterior probabilities of more than 1000: 1 could be taken as strong evidence against a particular model. Ratios of between 100:1 and 1000: 1 could be taken as moderate evidence against the less likely model. Ratios of 50:1 could be taken as weak evidence against the less likely model. In all instances the prior probabilities for the alternative models were held constant. The Bayes factors in nearly all instances were quite similar across the alternative models. For example, for Area 3C the Bayes factors for models with alternative priors for r were quite similar ranging from 1.4 to 0.8 indicating that each of the models with the alternative priors for *r* remain credible and none is more credible than any of the others with differences easily due to random patterns in the data. For Area 3C the model with a value for *tech* fixed at 0 had a probability about 7 times that for the reference case prior for *tech* (Normal $(0.02, 0.005^2)$). However, this difference could easily be explained by random patterns in the data. For Area 3C, the models with fixed alternative values for *tech* had Bayes factors ranging as high as 19 indicating none of the alternative models could be rejected. Similar results were obtained for Area 3C with alternative prior means for *tech*.

In all four areas, the model runs with the highest prior means for *tech* had the lowest Bayes factors relative to the reference case with a prior mean of 2%. The basis for updating the prior for *tech* comes from the net difference in time trend slopes between the standardized commercial catch rate series and the survey time series. For most abundance indices, the interannual variability in the indices was very high, and partly due to this there was no consistent difference in slopes between the commercial catch rate time series and the survey time series. Thus the *tech* priors with higher prior means for *tech* fitted the data more poorly, had lower values for the probability of the data given the model, and thus had lower Bayes factors. Due to the large outlier values in the shrimp trawl survey time series, particularly at the end of the time series, for Areas 3C and 3D, this gave slope estimates that were only slightly less (3D) or positive (3C) compared to the commerical catch rate time series and thus slightly higher Bayes factors for the runs with the lowest prior means for *tech*. Due to the high interannual variabiltiy in the survey data and the tendency for there to be more frequent large outliers in the latter part of the series, we caution against assigning higher credibility to the runs with the very lowest prior means for *tech*.

Decision Analysis

We show decision analysis results across two additional axes of uncertainty for Areas 3C, 3D, 5AB and 5CDE (Table G - 18 to Table G - 25). Table G - 18 shows decision analysis results for Area 3C where the low, reference case and high priors for the parameter r were applied. The results are relatively insensitive to this prior even though the posterior means for r are quite different. In all instances when different hypotheses for r for Area 3C are considered, there was at least a 50% probability of the stock staying above B_{MSY} after five years. In contrast, the results for Area 3C were more sensitive to alternative priors for *tech*, with results being considerably less optimistic when the prior mean for *tech* was 0.03 or more (Table G - 19). For Area 3D, the prior for the highest *tech* prior mean of 0.04 had very low posterior probability and thus could be discounted (Table G - 21). In all instances Bayes factor was not sufficiently low for the reference case compared to some other case such that we would consider rejecting our reference case prior for *tech* in favour of some alternative prior.

Table G - 13. Stock assessment results for alternative settings to the Bayesian surplus production (BSP) stock assessment model for Area 3C. B_{2010} refers to the stock size in 2010, $RepY_{2010}$ refers to the replacement yield in 2010. F_{2010} refers to the fishing mortality rate in 2010. All biomass values are in tons. The posterior 5th, 50th (median) and 95th percentiles are shown for each estimated quantity. See Table F - 9 for a description of each sensitivity run.

	r			***B_{MSY}***			***B_{2010}***			***$RepY_{2010}$***			***B_{2010}/B_{MSY}***			***F_{2010}/F_{MSY}***			***$Catch_{2010}/RepY_{2010}$***			***tech***		
Code	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
	***REFERENCE RUN* (E.G., *TECH* PRIOR MEAN = 0.02, SD = 0.005, R PRIOR MEAN = 0.255, SD = 0.102, UNIFORM ON LOG(K) PRIOR)**																							
Ref.1.	0.045	0.134	0.334	12813	25217	46824	5580	25083	71078	350	1099	2962	0.327	1.106	1.884	0.059	0.39	2.165	0.169	0.499	1.5	0.008	0.018	0.026
	r PRIOR (MEAN = 0.203, 0.299)																							
A.1	0.033	0.106	0.258	12758	24942	44397	4887	21699	62284	365	881	2325	0.283	0.9	1.78	0.082	0.659	2.339	0.225	0.641	1.507	0.01	0.019	0.027
A.5	0.049	0.176	0.392	11306	24148	44276	4653	27205	72664	322	1210	3406	0.316	1.327	1.918	0.049	0.237	2.128	0.139	0.442	1.402	0.008	0.017	0.025
	***tech* PRIOR MEAN (MEAN = 0.01, 0.03, 0.04, SD = 0.005)**																							
B.1	0.06	0.196	0.36	14138	28787	46835	11571	39043	82135	262	1470	3256	0.604	1.53	1.953	0.049	0.163	1.087	0.139	0.367	1.168	0.002	0.008	0.016
B.4	0.037	0.093	0.221	11617	21832	42269	2168	9802	43154	300	610	1700	0.177	0.464	1.504	0.162	1.414	3.258	0.322	0.925	1.831	0.019	0.028	0.039
B.7	0.038	0.102	0.215	11895	18701	38254	1558	5692	20563	277	463	997	0.149	0.308	0.752	0.725	2.049	3.772	0.568	1.219	2.04	0.03	0.038	0.045
	***TECH* PRIOR MEAN AND SD (MEAN = 0.01, SD = 0.0025, MEAN = 0.03, SD=0.0075)**																							
C.1	0.055	0.192	0.354	14033	28835	47022	12746	38928	78338	190	1465	3447	0.656	1.524	1.966	0.05	0.154	1.016	0.132	0.367	1.152	0.005	0.009	0.013
C.2	0.044	0.12	0.295	11580	24533	48427	2249	16817	60488	324	709	2130	0.177	0.731	1.924	0.063	0.795	2.812	0.248	0.798	1.629	0.006	0.024	0.039
	UNCERTAINTY OVER THE 1996 – 2010 CPUE INDEX																							
D.1	0.047	0.136	0.324	12029	24197	44006	6181	24137	69689	385	1066	2725	0.36	1.123	1.89	0.062	0.412	1.769	0.188	0.528	1.277	0.01	0.019	0.028
D.2	0.055	0.149	0.308	10450	21583	45373	6517	22223	70126	301	1119	2310	0.421	1.132	1.919	0.073	0.363	1.488	0.192	0.495	1.245	0.009	0.019	0.027
	UNIFORM ON K PRIOR																							
E.1	0.036	0.13	0.335	14700	29522	46359	6807	29730	76817	306	1099	3442	0.303	1.189	1.911	0.05	0.312	2.39	0.139	0.486	1.589	0.009	0.017	0.026
	FIXING *tech* AT DIFFERENT VALUES (0.00, 0.01, 0.02, 0.03, 0.04))																							
F.0	0.092	0.217	0.356	14420	29326	46650	19319	44427	80375	0	1544	3830	1.071	1.619	2.013	0.05	0.122	0.425	0	0.338	1.165	0.00	0	0
F.1	0.055	0.189	0.352	14078	28369	46844	12704	38266	76701	247	1452	3503	0.634	1.508	1.958	0.051	0.155	1.097	0.133	0.371	1.1	0.01	0	0
F.2	0.041	0.113	0.296	12413	24624	44727	5364	19199	60482	408	952	2595	0.291	0.845	1.784	0.079	0.633	2.084	0.208	0.588	1.338	0.02	0	0
F.3	0.035	0.096	0.192	11503	21591	40489	3443	8571	30987	317	619	1277	0.201	0.43	1.077	0.433	1.428	3.152	0.437	0.915	1.757	0.03	0	0
F.4	0.034	0.094	0.192	12238	20204	38021	2674	5847	17511	261	490	862	0.164	0.309	0.638	0.925	1.944	4.02	0.656	1.156	2.168	0.04	0	0

Table G - 14. Stock assessment results for alternative settings to the Bayesian surplus production (BSP) stock assessment model for Area 3D. B_{2010} refers to the stock size in 2010, $RepY_{2010}$ refers to the replacement yield in 2010. F_{2010} refers to the fishing mortality rate in 2010. All biomass values are in tons. The posterior 5th, 50th (median) and 95th percentiles are shown for each estimated quantity. See Table F - 9 for a description of each sensitivity run.

	r			***B_{MSY}***			***B_{2010}***			***$RepY_{2010}$***			***B_{2010}/B_{MSY}***			***F_{2010}/F_{MSY}***			***$Catch_{2010}/RepY_{2010}$***			***tech***		
Code	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
	REFERENCE RUN **(E.G., *TECH* PRIOR MEAN = 0.02, SD = 0.005, R PRIOR MEAN = 0.260, SD = 0.108, UNIFORM ON LOG(K) PRIOR)**																							
Ref.2.	0.051	0.184	0.347	8673	22068	45523	8880	31869	73192	226	1118	3252	0.804	1.557	1.905	0.034	0.107	0.855	0.088	0.271	1.062	0.006	0.013	0.021
	r PRIOR (MEAN = 0.206, 0.305)																							
A.2	0.034	0.141	0.297	8950	23024	45465	8891	30990	71409	224	932	2834	0.764	1.466	1.893	0.041	0.154	1.037	0.099	0.331	1.166	0.006	0.014	0.022
A.6	0.063	0.216	0.398	8151	22317	45923	9815	32620	74664	272	1250	3578	0.938	1.595	1.919	0.029	0.092	0.658	0.078	0.247	0.983	0.006	0.013	0.021
	tech **PRIOR MEAN (MEAN = 0.01, 0.03, 0.04, sd = 0.005)**																							
B.2	0.067	0.217	0.366	8216	21329	44527	10788	33251	75468	109	1114	3326	1.141	1.637	1.967	0.03	0.092	0.474	0.072	0.268	1.016	0.001	0.006	0.013
B.6	0.037	0.13	0.307	8763	21144	43195	6685	26344	67321	250	942	2990	0.564	1.401	1.836	0.041	0.17	1.505	0.102	0.337	1.189	0.014	0.022	0.03
B.10	0.027	0.071	0.24	9806	20644	43575	4308	20491	54935	151	621	2389	0.351	1.076	1.658	0.067	0.459	2.964	0.129	0.514	2.118	0.024	0.031	0.038

Table G - 15. Stock assessment results for alternative settings to the Bayesian surplus production (BSP) stock assessment model for Area 5AB. B_{2010} refers to the stock size in 2010, $RepY_{2010}$ refers to the replacement yield in 2010. F_{2010} refers to the fishing mortality rate in 2010. All biomass values are in tons. The posterior 5th, 50th (median) and 95th percentiles are shown for each estimated quantity. See Table F - 9 for a description of each sensitivity run.

	r			***B_{MSY}***			***B_{2010}***			***$RepY_{2010}$***			***B_{2010}/B_{MSY}***			***F_{2010}/F_{MSY}***			***$Catch_{2010}/RepY_{2010}$***			***tech***		
Code	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
	REFERENCE RUN **(E.G., *TECH* PRIOR MEAN = 0.02, SD = 0.005, R PRIOR MEAN = 0.249, SD = 0.105, UNIFORM ON LOG(K) PRIOR)**																							
Ref.3.	0.05	0.142	0.295	10651	22058	44054	5179	22824	67220	429	1055	2924	0.392	1.13	1.792	0.085	0.515	2.181	0.224	0.626	1.462	0.01	0.017	0.025
	r PRIOR (MEAN = 0.198, 0.292)																							
A.3	0.044	0.126	0.249	10853	22317	44487	4693	21009	66631	425	948	2681	0.375	1.001	1.722	0.104	0.622	2.32	0.244	0.706	1.541	0.011	0.018	0.026
A.7	0.053	0.157	0.344	10313	23319	44734	4809	25832	70207	429	1196	3344	0.377	1.247	1.822	0.07	0.363	2.32	0.194	0.553	1.49	0.01	0.017	0.025
	tech **PRIOR MEAN (MEAN = 0.01, 0.03, 0.04, sd = 0.005)**																							
B.3	0.067	0.169	0.321	10462	24391	46220	6519	31584	77117	423	1284	3097	0.536	1.411	1.891	0.073	0.263	1.531	0.199	0.511	1.268	0.002	0.009	0.017
B.7	0.039	0.113	0.242	9886	19421	42948	3586	10472	58531	348	702	2481	0.298	0.602	1.607	0.121	1.352	3.077	0.27	0.96	1.918	0.02	0.027	0.035
B.11	0.03	0.093	0.202	9480	18021	38238	2946	7070	34504	272	514	1454	0.25	0.424	1.167	0.387	2.132	4.023	0.461	1.317	2.47	0.029	0.036	0.045

Table G - 16. Stock assessment results for alternative settings to the Bayesian surplus production (BSP) stock assessment model for Area 5CDE. B_{2010} refers to the stock size in 2010, $RepY_{2010}$ refers to the replacement yield in 2010. F_{2010} refers to the fishing mortality rate in 2010. All biomass values are in tons. The posterior 5th, 50th (median) and 95th percentiles are shown for each estimated quantity. See Table F - 9 for a description of each sensitivity run.

	r			***B_{MSY}***			***B_{2010}***			***$RepY_{2010}$***			***B_{2010}/B_{MSY}***			***F_{2010}/F_{MSY}***			***$Catch_{2010}/RepY_{2010}$***			***tech***		
Code	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
	***REFERENCE RUN* (E.G., *TECH* PRIOR MEAN = 0.02, SD = 0.005, R PRIOR MEAN = 0.236, SD = 0.0899, UNIFORM ON LOG(K) PRIOR)**																							
Ref.4.	0.078	0.183	0.301	5769	13658	36341	5051	17929	58666	287	679	1847	0.754	1.459	1.862	0.077	0.31	1.421	0.227	0.685	1.434	0.013	0.019	0.025
	r prior (mean = 0.188, 0.274)																							
A.4	0.051	0.153	0.283	5193	14018	40573	4031	17514	65289	206	630	2071	0.642	1.368	1.913	0.077	0.402	2.026	0.192	0.747	1.928	0.012	0.02	0.027
A.8	0.073	0.206	0.39	4631	13865	41872	3717	19088	70527	140	722	2552	0.694	1.519	1.965	0.047	0.253	1.904	0.132	0.641	1.609	0.011	0.019	0.027
	***tech* prior mean (mean = 0.01, 0.03, 0.04, sd = 0.005)**																							
B.4	0.071	0.198	0.354	5074	15469	42335	5021	23375	72982	0	689	2349	0.829	1.587	2.023	0.047	0.231	1.246	0	0.636	1.84	0.004	0.011	0.019
B.8	0.051	0.158	0.323	4574	10987	38749	3071	11337	60734	253	589	2210	0.548	1.167	1.84	0.073	0.618	2.801	0.207	0.823	1.96	0.02	0.028	0.036
B.12	0.044	0.122	0.281	4599	8558	34031	2405	5770	46502	222	416	1843	0.418	0.736	1.683	0.105	1.503	3.307	0.262	1.192	2.23	0.03	0.037	0.045

Table G - 17. Bayes factors for alternative BSP stock assessment models. (a) for Area 3C with alternative priors for r; (b) for Area 3C with a value for tech fixed at 0, and the reference case prior for tech (Normal(0.02, 0.005^2)); (c) for Area 3C with fixed alternative values for tech; (d) for Area 3C alternative priors for tech; (e) for all areas treated as separate stocks versus all outside areas combined and treated as one stock; (f) all areas treated as a single stock with alternative priors for tech. In each of these comparisons, the prior probability on each model alternative is set to be equal across the alternative models. The symbol "" indicates that a hypothesis can be considered highly unlikely based on the definition that a Bayes Factor ≤ 0.01 is highly unlikely.*

Category Description	**Code**	**Run Description**	**Bayes Factor**
a. *r* prior mean	A.1	low *r* (mean = 0.203, SD=0.091)	1.5
	Ref.1	Reference run BSP (mean = 0.255, SD = 0.102)	1.0
	A.2	high *r* (mean = 0.299, SD= 0.110)	0.7
b. *tech* fixed at 0, versus estimating *tech*	F.0	*tech* fixed at 0	6.3
	Ref.1	*tech* ~ Normal(0.02, 0.005)	1.0
c. Alternative fixed values for *tech*	F.0	*tech* fixed at 0	2.9
	F.1	*tech* fixed at 0.01	2.4
	F.2	*tech* fixed at 0.02	1.0
	F.3	*tech* fixed at 0.03	0.5
	F.4	*tech* fixed at 0.04	0.2
d. Alternative priors for *tech*	C.1	*tech* ~ Normal(0.01, 0.005)	2.1
	Ref.1	*tech* ~ Normal(0.02, 0.005^2)	1.0
	C.2	*tech* ~ Normal(0.03, 0.005^2)	0.5
	C.3	*tech* ~ Normal(0.04, 0.005^2)	0.4
e. All areas as separate stocks or all outside areas as a single stock	Ref.1-4	All outside areas treated as separate stocks	NA
	G.1	All outside areas treated as a single stock	NA
f. all areas treated as a single stock with alternative priors for *tech*	G.4	*tech* ~ Normal(0.01, 0.005^2)	2.9
	G.1	*tech* ~ Normal(0.02, 0.005^2)	1.0
	G.5	*tech* ~ Normal(0.03, 0.005^2)	0.2
	G.6	*tech* ~ Normal(0.04, 0.005^2)	0.02*

Table G - 18. Summary decision table for Area 3C the probability that stock biomass exceeds 0.8 B_{MSY} after 5 years under each alternative constant TAC policy and constant harvest rate policy (in tons) and under each alternative hypothesized prior mean value for the parameter for the maximum intrinsic rate of increase, r.

	Hypothesized prior mean *r*		
	Low *r*	**Reference *r***	**High *r***
Prior mean	0.174	0.219	0.258
Posterior mean	0.119	0.152	0.189
Bayes factor	1.5	1.0	0.7
TAC Policy			
0	0.59	0.73	0.76
500	0.54	0.69	0.73
1000	0.50	0.62	0.68
1500	0.46	0.58	0.65
2000	0.41	0.54	0.61
2500	0.35	0.50	0.58
3000	0.32	0.45	0.53

Table G - 19. Summary decision table for Area 3C the probability that stock biomass exceeds 0.8 B_{MSY} *after 5 years under each alternative constant TAC policy and constant harvest rate policy (in tons) and under each alternative hypothesized prior mean values for tech.*

	Hypothesized prior mean *tech*			
Prior mean	**0.01**	**0.02**	**0.03**	**0.04**
Posterior mean	0.009	0.017	0.028	0.038
Bayes factor	2.1	1.0	0.5	0.4
TAC Policy				
0	0.92	0.73	0.30	0.09
500	0.90	0.69	0.24	0.06
1000	0.87	0.62	0.21	0.04
1500	0.83	0.58	0.17	0.03
2000	0.80	0.54	0.15	0.02
2500	0.78	0.50	0.13	0.02
3000	0.74	0.45	0.10	0.01

Table G - 20. Summary decision table for Area 3D the probability that stock biomass exceeds 0.8 B_{MSY} *after 5 years under each alternative constant TAC policy and constant harvest rate policy (in tons) and under each alternative hypothesized prior mean value for the parameter for the maximum intrinsic rate of increase,* r.

	Hypothesized prior mean *r*		
	Low *r*	**Reference *r***	**High *r***
Prior mean	0.174	0.220	0.259
Posterior mean	0.149	0.188	0.225
Bayes factor	2.1	1.0	0.8
TAC Policy			
0	0.93	0.95	0.96
500	0.90	0.93	0.95
1000	0.84	0.91	0.92
1500	0.79	0.87	0.89
2000	0.74	0.79	0.83
2500	0.66	0.73	0.78
3000	0.60	0.67	0.71
3500	0.53	0.61	0.65
4000	0.47	0.55	0.60
4500	0.43	0.50	0.55

Table G - 21. Summary decision table for Area 3D the probability that stock biomass exceeds 0.8 B_{MSY} *after 5 years under each alternative constant TAC policy and constant harvest rate policy (in tons) and under each alternative hypothesized prior mean value for tech. The symbol "*" indicates that a hypothesis can be considered highly unlikely based on the definition that a Bayes Factor ≤ 0.01 is highly unlikely.*

	Hypothesized prior mean *tech*			
Prior mean	**0.01**	**0.02**	**0.03**	**0.04**
Posterior mean	0.006	0.013	0.022	0.032
Bayes factor	16	1.0	0.1	0.01*
TAC Policy				
0	0.99	0.95	0.86	0.63
500	0.98	0.93	0.82	0.58
1000	0.96	0.91	0.78	0.50
1500	0.91	0.87	0.73	0.47
2000	0.86	0.79	0.64	0.42
2500	0.81	0.73	0.57	0.39
3000	0.73	0.67	0.52	0.34
3500	0.67	0.61	0.46	0.29
4000	0.61	0.55	0.40	0.21
4500	0.56	0.50	0.36	0.19

Table G - 22. Summary decision table for Area 5AB the probability that stock biomass exceeds 0.8 B_{MSY} *after 5 years under each alternative constant TAC policy and constant harvest rate policy (in tons) and under each alternative hypothesized prior mean value for the parameter for the maximum intrinsic rate of increase,* r*.*

	Hypothesized prior mean *r*		
	Low *r*	**Reference *r***	**High *r***
Prior mean	0.170	0.215	0.254
Posterior mean	0.130	0.153	0.175
Bayes factor	1.4	1.0	0.8
TAC Policy			
0	0.70	0.77	0.78
500	0.63	0.69	0.73
1000	0.56	0.61	0.66
1500	0.51	0.55	0.61
2000	0.45	0.51	0.58
2500	0.40	0.47	0.53
3000	0.36	0.43	0.49

Table G - 23. Summary decision table for Area 5AB the probability that stock biomass exceeds 0.8 B_{MSY} *after 5 years under each alternative constant TAC policy and constant harvest rate policy (in tons) and under each alternative hypothesized prior mean value for tech.*

	Hypothesized prior mean *tech*			
Prior mean	**0.01**	**0.02**	**0.03**	**0.04**
Posterior mean	0.009	0.018	0.027	0.037
Bayes factor	1.9	1.0	0.4	0.1
TAC Policy				
0	0.90	0.77	0.46	0.19
500	0.86	0.69	0.36	0.13
1000	0.81	0.61	0.30	0.10
1500	0.75	0.55	0.27	0.09
2000	0.71	0.51	0.24	0.07
2500	0.65	0.47	0.22	0.06
3000	0.60	0.43	0.20	0.05

Table G - 24. Summary decision table for Area 5CDE the probability that stock biomass exceeds 0.8 B_{MSY} after 5 years under each alternative constant TAC policy and constant harvest rate policy (in tons) and under each alternative hypothesized prior mean value for the parameter for the maximum intrinsic rate of increase, r.

	Hypothesized prior mean *r*		
	Low *r*	**Reference *r***	**High *r***
Prior mean	0.177	0.224	0.263
Posterior mean	0.157	0.190	0.217
Bayes factor	1.2	1.0	0.8
TAC Policy			
0	0.92	0.93	0.96
500	0.80	0.84	0.87
1000	0.67	0.73	0.76
1500	0.58	0.64	0.66
2000	0.50	0.56	0.59
2500	0.44	0.49	0.53
3000	0.39	0.44	0.49
3500	0.34	0.39	0.44
4000	0.31	0.35	0.40
4500	0.28	0.32	0.36

Table G - 25. Summary decision table for Area 5CDE the probability that stock biomass exceeds 0.8 B_{MSY} *after 5 years under each alternative constant TAC policy and constant harvest rate policy (in tons) and under each alternative hypothesized prior mean value for tech.*

	Hypothesized prior mean *tech*			
Prior mean	**0.01**	**0.02**	**0.03**	**0.04**
Posterior mean	0.011	0.019	0.028	0.037
Bayes factor	0.9	1.0	0.6	0.3
TAC Policy				
0	0.98	0.93	0.81	0.57
500	0.93	0.84	0.67	0.39
1000	0.84	0.73	0.54	0.29
1500	0.74	0.64	0.45	0.22
2000	0.66	0.56	0.39	0.19
2500	0.60	0.49	0.34	0.16
3000	0.54	0.44	0.31	0.14
3500	0.49	0.39	0.27	0.12
4000	0.44	0.35	0.24	0.11
4500	0.40	0.32	0.21	0.09

Discussion of *tech* parameter

Estimates of rates of increase in the catching power for trawl fleets from the literature have varied from 0 to 12% per year (Appendix H). However, most estimates were at the lower range of values (0-0.04), and we selected an estimate of 0.02 to use as a prior mean. We initially tried to apply prior CVs for tech that reflected large uncertainty over this value (i.e., prior CVs of 100% and then 50%). However, posterior results were very flat for all quantities of interest. When the prior CV was reduced to 25%, posterior results were less flat. We therefore applied the prior standard deviation associated with CV of 25% as the reference case. Sensitivity results showed that the biomass estimates and projection results can be highly sensitive to relatively small changes in the prior mean for the tech parameter. The large variability in the stock trend data for the different areas and relatively low overlap between commercial catch rate and survey time series in most instances gave relatively little information about the hypothesized values for the tech parameter. However, the largest values considered tended to be less likely than the lower values. For area 3D, the run with the prior mean set to 0.03 had a Bayes factor about 4500 times less than the run with the prior mean set at 0.01 and thus could be discounted relative to the other hypothesized prior means for tech. The reference case prior that we applied for tech however still gave highly imprecise results for all four outside lingcod assessment areas with a wide range of plausible values obtained for current stock size relative to initial stock size. Given the very large amount of variability in the stock trend data and the large uncertainty over the tech parameter, the very wide posterior distributions for stock status for all four stocks are to be expected.

Single Stock Hypothesis

Assessment results obtained when all offshore areas were treated as a single stock were similar to those obtained from the individual area stock assessments (Table G - 26). The median of the posterior r distribution for the single coastwide stock (r = 0.13) was within the range of those estimated for individual stocks (0.13 – 0.17). The ratios of B_{2010} / K and B_{2010} / B_{MSY} for the single stock analysis (0.47 and 0.93, respectively) were slightly lower than those for individual stocks (0.55 – 0.78 for B_{2010} / K and 1.11 – 1.56 for B_{2010} / B_{MSY}). Treating all four areas as one stock, provided similarly imprecise results compared to the four reference case runs on the individual stocks (Table G - 26; Figure G - 10; Figure G - 11). The stock biomass trend appears to track the stock trend indices and catch series similarly to the stock biomass values for the individual stocks (Figure G - 12). Projection results for the single stock hypothesis in which quota policies were quadrupled to reflect the quota for the whole coast were similar to the individual areas, and are not shown.

We could not compute posterior probabilities for the hypothesis that all areas are treated as separate stocks and the single stock hypothesis because the posterior probability for alternative models can only be computed when the different models are fitted to the same data sets. Since we used different data sets for the two alternative models, Bayes theorem can not be applied. However, the single stock hypothesis has a far more parsimonious model than using four individual stock models, and if the data had been the same, would have had a much higher posterior probability.

Table G - 26. Posterior mean, Median, SD, and CV for key parameters and stock status indicators for the single stock sensitivity analysis (i.e., all assessment areas combined). All posterior medians were calculated using a lognormal approximation based on the posterior mean and SD.

Variable	Mean	Median	SD	CV
K	198886	163885	136749	0.69
r	0.15	0.13	0.09	0.58
MSY	6561	4543	6835	1.04
B_{2010}	111107	80577	105483	0.95
B_{2010}/K	0.51	0.47	0.23	0.46
B_{1927}	194300	160922	131475	0.68
B_{1927}/K	0.99	0.98	0.18	0.18
B_{2010}/B_{1927}	0.54	0.48	0.27	0.51
C_{2010}/MSY	0.55	0.47	0.32	0.59
F_{2010}/F_{MSY}	0.78	0.59	0.67	0.86
B_{2010}/B_{MSY}	1.03	0.93	0.47	0.46
$C_{2010}/Repy_{2010}$	0.71	0.52	0.69	0.96
B_{MSY}	99443	81942	68375	0.69
$Repy_{2010}$	4281	3355	3392	0.79
66-90 ccpue q	8.61E-06	6.80E-06	6.70E-06	0.78
91-95 ccpue q	9.17E-06	6.97E-06	7.85E-06	0.86
96-2010 ccpue q	8.96E-06	6.58E-06	8.28E-06	0.92
Triennial survey q	5.41E-05	4.23E-05	4.31E-05	0.80
WCVI Shrimp survey q	1.48E-05	1.15E-05	1.20E-05	0.81
WCVI Synoptic q	2.69E-05	2.00E-05	2.41E-05	0.90
Queen Ch. Sd. Shrimp survey q	9.41E-05	7.07E-05	8.26E-05	0.88
Queen Ch. Sd. Synoptic q	1.34E-04	1.00E-04	1.19E-04	0.89
Hecate MS survey q	2.72E-05	2.11E-05	2.22E-05	0.82
Hecate synoptic survey q	4.70E-05	3.50E-05	4.20E-05	0.89
WCQCI synoptic q	9.75E-05	7.26E-05	8.75E-05	0.90
tech Parameter	0.017	1.63E-02	4.74E-03	0.28

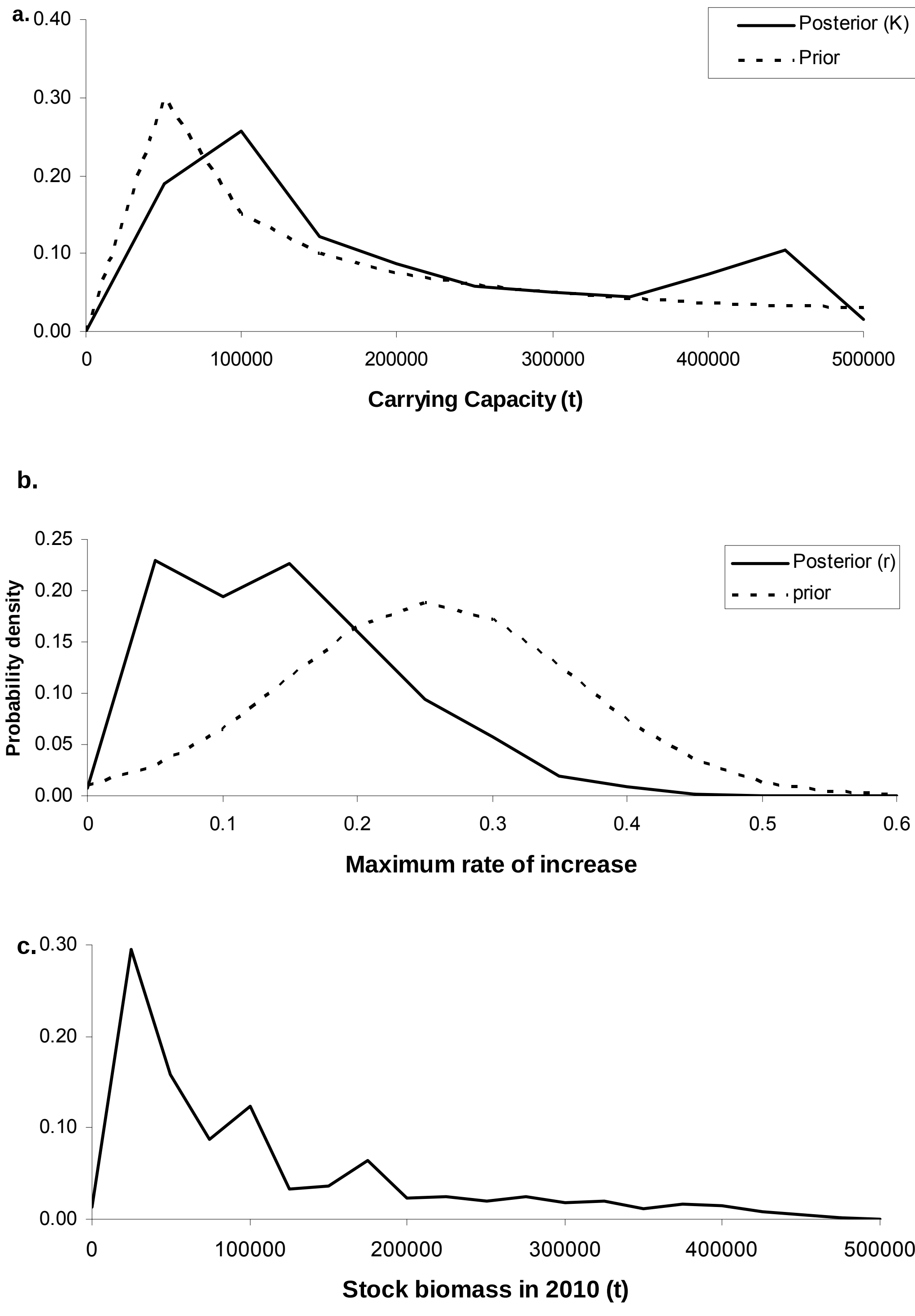

Figure G - 10. Reference case posterior distributions for (a) carrying capacity, (b) the maximum rate of increase and (c) stock biomass in 2010 for all four Areas combined.

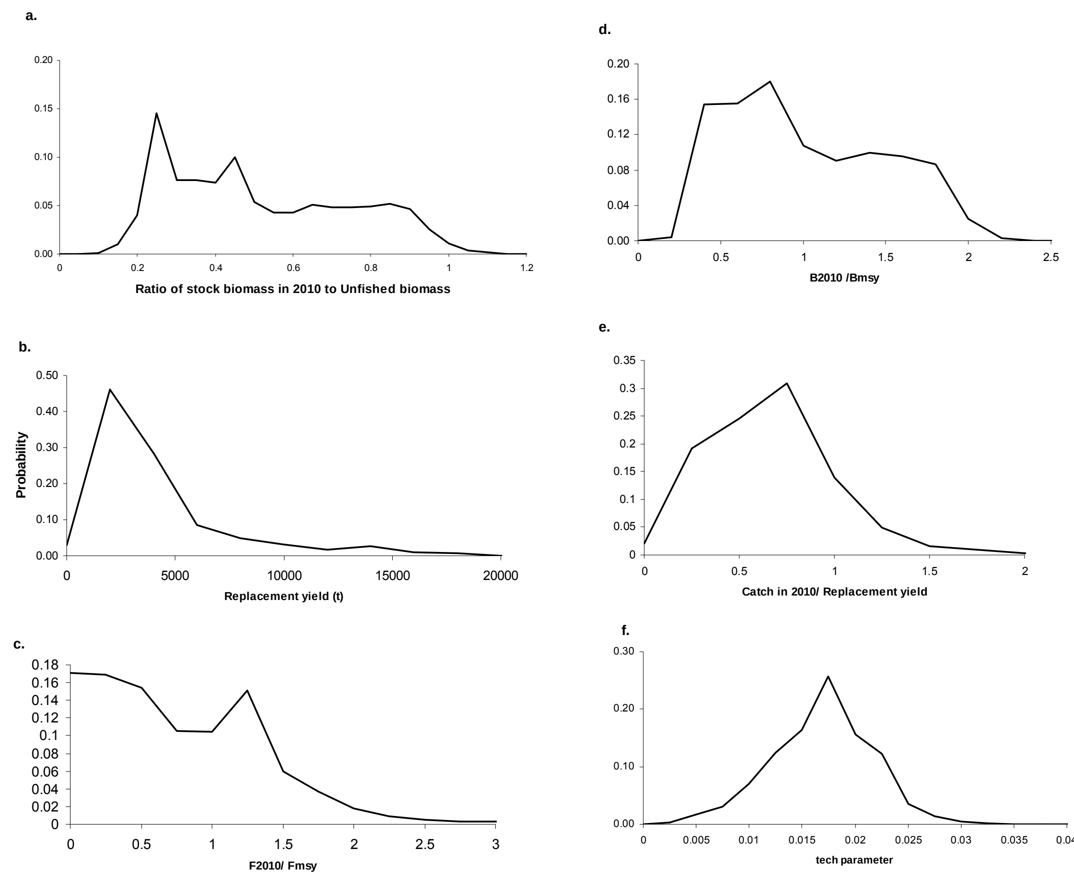

Figure G - 11. Posterior distributions for lingcod in all outside areas combined for (a) ratio of stock biomass in 2010 to unfished stock size, (b) replacement yield in 2010, (c) ratio of fishing mortality rate in 2010 to that under F_{MSY} and tech, (d) ratio of stock biomass in 2010 to B_{MSY}, (e) catch in 2010 to replacement yield and (f) tech (prior (dotted line) also shown).

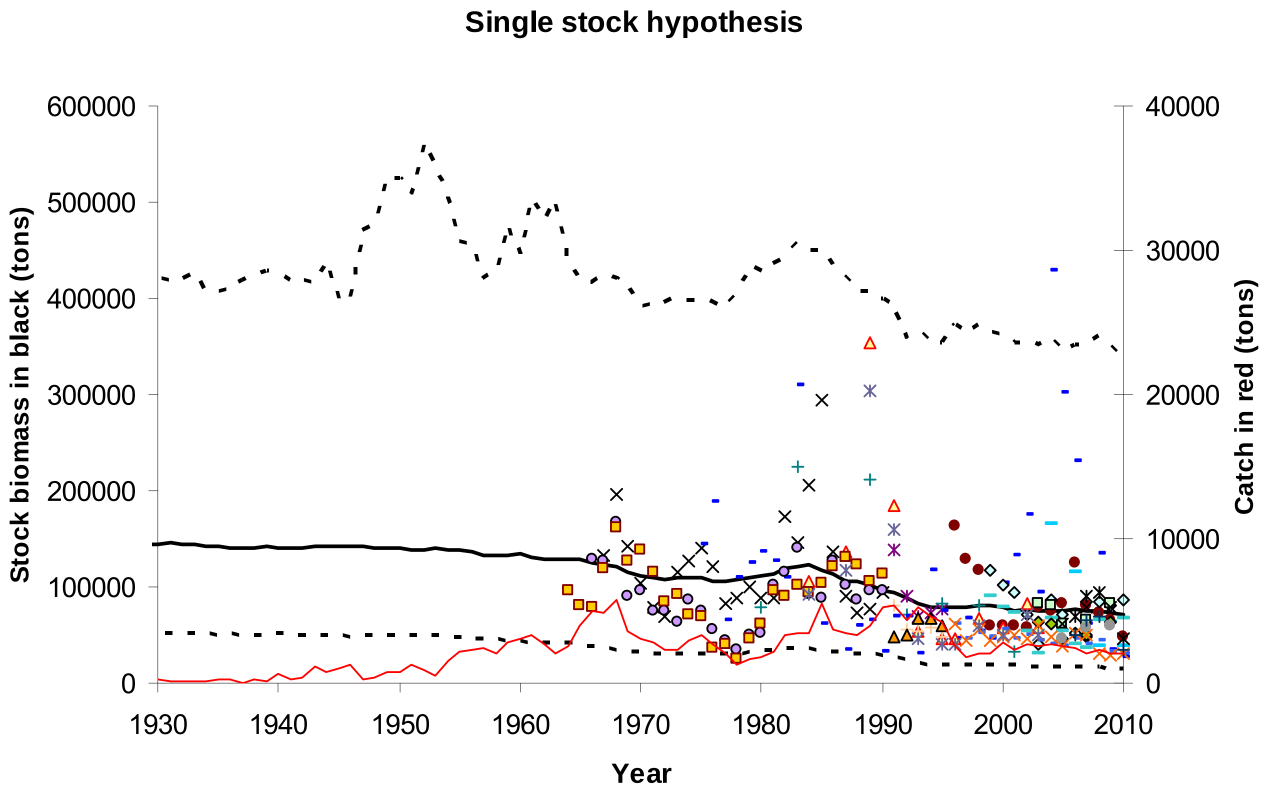

Figure G - 12. Total catch and posterior median stock biomass and 90% probability intervals for the single stock hypothesis (all four areas combined) and the stock trend index values divided by the posterior median values for q. The plotted ccpue series are adjusted using the posterior median tech creep parameter.

APPENDIX H. CHANGES IN FISHERY CATCHABILITY OVER TIME

Accounting for changes in catchability for demersal trawl fishing fleets

The constant of proportionality q describes the relationship between an observed index of abundance (I_t) and stock size (B_t) at a given point in time, t,

(*Eq. H-1*) $$I_t = qB_t \ ,$$

and is thus a common parameter in most fisheries stock assessments. Failure to properly represent variation in catchability can lead to biased assessment results (Pope and Shepherd 1985, Wilberg and Bence 2006). One factor that determines the value for q is catchability (i.e., the fraction of the present stock biomass that is, on average, caught per unit of fishing effort). The potential for catchability to vary over time for stock trend indices derived from commercial and recreational catch per unit effort (CPUE) time series is well-documented (reviewed in Wilberg and Bense, 2006), and a variety of methods have been developed to incorporate this variability into stock assessment models. In the following two sections we (1) review factors that cause catchability to vary through time and describe how these processes may affect the relationship shown in equation H-1, and (2) describe how we account for time-varying catchability for stock trend indices derived from commercial trawl CPUE in the current lingcod assessment.

Factors causing changes in catchability over time

Changes in catchability can arise from a wide range of processes including changes in the area inhabited by a stock, changes in fishing technology, changes in fisher behaviour, changes in management regulations, and changes in environmental factors that affect fish behaviour. Understanding sources of variation in any one fishery is complicated by the simultaneous occurrence of many of these factors as well as interactions among them. We provide a brief overview of some of the more commonly studied factors and describe how equation H-1 is typically modified to describe them. Summaries of additional methods for describing patterns in time-varying catchability that we do not consider are provided in Wilberg et al. (2010).

1) Density-Dependent Catchability

Co-variation in catchability with changes in the abundance of a stock is referred to as density-dependent catchability. This may result from decreases in the fraction of the area occupied by the stock as stock size decreases (i.e., range contraction). Evidence for density-dependent catchability has been well-documented for a wide range of species and fishing gear (e.g., MacCall 1976, Peterman and Steer 1981, Rose and Kulka 1999, Harley et al. 2001). Accounting for density-dependent catchability in stock assessment is best achieved by directly modelling catch rates as a function of abundance in the assessment model. The model most commonly used to describe density-dependent variability in catchability turns equation H-1 into the following power function,

(*Eq. H-2*) $$I_t = qB_t^{\beta} ,$$

where, the constant β describes the shape of the power curve. When $\beta = 1$, I_t is proportional to B_t and equation H-2 is the same as equation H-1. When $\beta > 1$, I_t will decline faster than B_t, which leads to hyperdepletion in indices of stock size. When $\beta < 1$, I_t will decline slower than B_t, which leads to hyperstability in indices of stock size. The latter case, $\beta < 1$, is the pattern most typically observed for fish populations, which means that catchability increases as abundance declines. Potential causes of this type of density-dependent relationship include gear saturation, stock aggregation during the fishing season, and non-random search patterns by fisherman.

2) Technological Creep

The tendency for catchability to gradually increase over time due to changes in fishing technology and fisher behaviour is often referred to as technological creep (Pauly and Palomares 2010). Technological creep can occur as a result of improvements in gear efficiency, increased ability to find fish due to sonar and geographic positioning systems, more efficient catch handling, learning by fishers through time, and larger horse power and boat size that allow new aggregations to be fished (Robins et al. 1998, Marchal et al. 2002).

Within stock assessment modelling, technological creep is often addressed by using GLM models to standardize CPUE time series for known sources of changing catchability through time. For example, engine horse power or boat length are often included as factors in GLM analyses (Marchal et al. 2001, 2002), which allows these effects to be removed from standardized time series before input into the assessment model. The disadvantages of this approach include the failure to correct for unmeasured factors that affect catchability and the potential presence of interactions between measured variables and year effects that complicate the interpretation of results (Wilberg et al. 2010).

Alternatively, technological creep can be directly incorporated into the assessment model by modelling catchability as a function of time. In this case, a linear model is often applied to equation H-1 in order to represent technological creep (Wilberg and Bence 2006, Pauly and Palomares 2010),

(*Eq. H-3*) $$I_t = (q_0 + bt)N_t ,$$

where q_0 represents catchability at time t=0 (i.e., the intercept) and b represents a constant annual rate of change.

3) Abrupt Steps

Abrupt steps in catchability can occur for several reasons including the rapid adoption of a more efficient technology or regulatory changes that affect fishing behaviour. As an example of how regulatory changes can impact catchability, Poos et al. (2001) found that catch efficiency for target species decreased as quota restrictions become more constraining. The application of an abrupt step model to equation H-1 would be,

(*Eq. H-4*) $$I_t = \begin{cases} q_1 N_t & \text{time period 1} \\ q_2 N_t & \text{time period 2} \end{cases}$$

where, q_1 would is applied before the abrupt step (time period 1) and q_2 is applied after the abrupt step (time period 2).

Incorporation of time-varying catchability into current assessment

Time-varying catchability in the lingcod commercial trawl fishery CPUE series has been incorporated into the assessment in two ways: (i) standardization of CPUE prior to input to the assessment model and (ii) modelling catchability as a function of time within the assessment model.

Standardization of CPUE

We use GLM's to standardize the CPUE series for measured covariates that are expected to cause changes in catchability through time. Details of the GLM analyses are presented in Appendix C. This approach allows us to account for temporal changes in fishing locality, depth, seasonality, and vessel (starting in 1991). Factors for which data are not readily available, such as technological advances and learning across years, will not be accounted for by this approach. We therefore also model catchability as a function of time within the assessment model.

Modelling Catchability as a Function of Time

Time-varying catchability is incorporated directly into the assessment model using a combination of step functions and a linear increase through time. The step functions allow separate constants of proportionality (*q* parameters) to be estimated for three different time periods representing three different management regimes (1954-1991, 1991-1995, and 1996-2010). Within each time period, a linear rate of change parameter is used to describe a gradual increase in catchability each year due to technological creep.

The technological creep parameter (*tech*) was estimated during the Bayesian model fitting procedure. A prior distribution for *tech* was constructed based on a review of empirical estimates taken from the literature. We have taken a relatively simple approach to formulate the prior for *tech.* There is considerable variation in estimates of *tech* between different demersal trawl fleets reported in Pauly and Palomares (2010) and other studies (Table H - 1). Values ranged from 0 to 12%, however most estimates were at the lower range of values (0% to 4%; Figure H - 1). We have used a prior mean of 2% for the reference case scenario, which is consistent with the mid-point of the distribution of estimates (Table H - 2). As the rate of change in *q* can conceivably be negative, we have used a normal distribution for the prior. Initial stock assessment runs with a coefficient of variation (prior SD/ Prior means) (CV) of 50% produced nearly flat posterior results for all quantities of interest. It was only when the prior CV was reduced to 25% that posterior distributions became somewhat informative. We thus chose to apply a reference case prior for *tech* as follows:

$tech \sim \text{Normal}(0.02, 0.005^2)$

We evaluated the sensitivity of results to different specifications for *tech* by carrying out stock assessment runs using the alternative prior means of 0.01, 0.03, and 0.04 for each of the four assessment areas.

Table H - 1. Empirically-derived tech parameter estimates from groundfish bottom trawl fisheries from literature sources.

No.	Location	Fishery	Time Period	Species	*tech* ($year^{-1}$)	S.E. (*tech*)	Description of Estimator	Original Reference
1	North Sea	Bottom trawl (Britain)	1886-2005	Atlantic Cod	0.0183	0.0023	Pauly and Palomares (2010) used annual estimates of fishing power from Englehard 2008 to calculate as the slope of a linear regression of log-transformed fishing power on year.	Englehard 2008 *
2	North Sea	Bottom trawl (Britain)	1886–2005	Plaice	0.0233	0.0055	Same as study 1.	Englehard 2008 *
3	Vancouver Island, Canada	Bottom trawl	1953-1976	Pacific Ocean Perch	0.0458	-	Based on direct analysis of CPUE data. A log-linear multiplicative model was used to describe relationships between CPUE and technological advances through time.	Kimura 1981 *
4	Pacific Coast, Canada	Bottom trawl	1960 -1981	Pacific Cod	0.0271 †	-	Pauly and Palomares used annual estimates of relative fishing power derived from Westerheim and Foucher (1985) to calculate *tech* as the slope of a linear regression of year on log-transformed relative fishing power.	Westrheim and Foucher 1985 *
5	Baltic Sea	Bottom otter board trawl (Danish fleet)	1987-1998	Atlantic Cod	0.02 †	-	GLM fit to index of fishing power. Year is treated as a continuous regression variable. Boat length and season are treated as explanatory factors.	Marchal et al. 2001 *
6	North Sea	Bottom otter board trawl (Danish fleet) 300+ HP	1987-1998	Atlantic Cod	0.04 †	-	GLM fit to index of fishing power. Year is treated as a continuous explanatory (regression) variable. Engine horse power, season, and area are treated as explanatory factor variables.	Marchal et al. 2002‡
7	North Sea	Bottom otter board trawl (Danish fleet) 300+ HP	1987-1998	Plaice	0.12 †	-	Same as study 6.	Marchal et al. 2002 ‡

No.	Location	Fishery	Time Period	Species	*tech* (year^{-1})	S.E. (*tech*)	Description of Estimator	Original Reference
8	North Sea	Bottom beam trawl (Dutch fleet) 300+ HP	1991-1998	Atlantic cod	0.08 †	-	Same as study 6.	Marchal et al. 2002 ‡
9	North Sea	Bottom beam trawl (Dutch fleet) 300+ HP	1991-1998	Plaice	0 †	-	Same as study 6.	Marchal et al. 2002
10	North Sea	Bottom beam trawl (Dutch fleet) 300+ HP	1991-1998	Sole	0.06 †	-	Same as study 6.	Marchal et al. 2002 ‡
11	North Sea	Bottom otter board trawl (Norwegian fleet)	1980-1998	Atlantic cod	0.08 †	-	Same as study 6.	Marchal et al. 2002 ‡
12	North Sea	Bottom otter board trawl (Norwegian fleet)	1980-1998	Haddock	0.027 †	-	Same as study 6.	Marchal et al. 2002 ‡
13	North Sea	Bottom otter board trawl (Norwegian fleet)	1980-1998	Saithe	0.023 †	-	Same as study 6.	Marchal et al. 2002 ‡
14	Pacific Coast, US	Bottom trawl	1982-1989	Multi-species groundfish	0.0279	-	Mean annual change in total factor productivity (TFP). TFP is presented as an indicator of fishing power that is calculated using a growth accounting approach. Economic indicators such as cost of labour, capital, and energy are used as inputs.	Squires 1992 *

No.	Location	Fishery	Time Period	Species	*tech* (year^{-1})	S.E. (*tech*)	Description of Estimator	Original Reference
15	Barents Sea	Bottom trawl (Norwegian fleet)	1971-1985	Arctic cod	0.02	-	A Cobb-Douglas production function is used to estimate annual technological growth.	Skjold et al. 1996
16	North Sea	Bottom beam trawl (Dutch fleet) 300+ HP	1990-2003	Sole	0.028 †	-	GLM fit to an index of partial fishing mortality, which represents catchability. Engine horse power and a year are treated as additive terms in GLM.	Rijnsdorp et al. 2006
17	North Sea	Bottom beam trawl (Dutch fleet) 300+ HP	1990-2003	Plaice	0.016 †	-	Same as Study 14.	Rijnsdorp et al. 2006

† Overall time trends may be underestimated because they have been standardized for increased engine horse power through time.

* Estimate taken directly from Pauly and Palomares (2010).

‡ Reference cited in Pauly and Palomares (2010), but results summary used here differs. We present the original species-specific values reported by Marchal et al. (2002) rather than pooling across species to get an average.

Table H - 2. Statistics describing distribution of tech parameter estimates inTable H-1. The 'Data set' column indicates whether all estimates in Table 1 were used in calculations (All estimates) or whether only a sub-sample of estimates were used (e.g., Estimates < 0.08). Sub-samples were considered because some of the larger estimates are considered unrealistically high for the BC groundfish trawl catch of lingcod.

Data set	N	Mean	Median	Standard Dev.	CV
All estimates	17	0.038	0.027	0.030	0.80
Estimates < 0.08	14	0.027	0.025	0.015	0.55
Estimates < 0.06	13	0.024	0.023	0.012	0.48
Estimates < 0.04	11	0.020	0.023	0.009	0.42

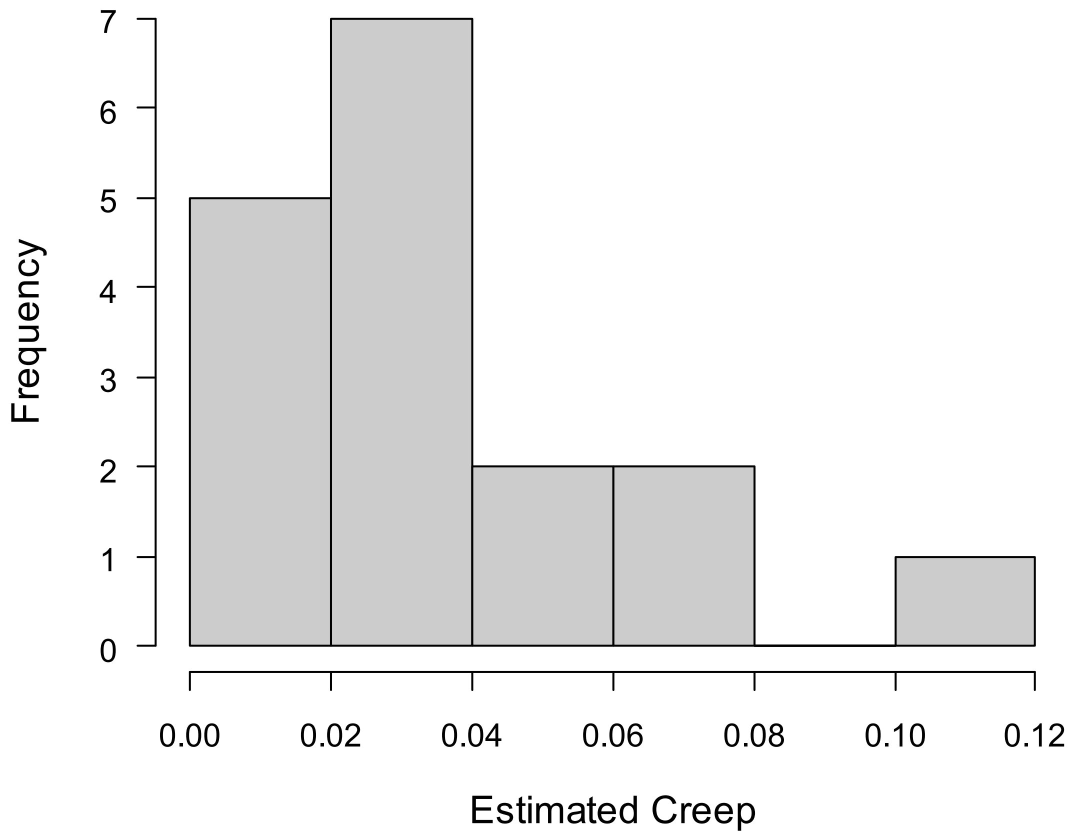

Figure H - 1. Distribution of 17 technological creep parameter estimates for demersal trawl fisheries obtained from review of published literature.

REFERENCES

Harley, S.J., R.A. Myers, and A. Dunn. 2001. Is catch-per-unit-effort proportional to abundance? *Canadian Journal of Fisheries and Aquatic Sciences* 58: 1760-1772.

MacCall, A.D. 1976. Density dependence and catchability coefficient in the California sardine, Sardinops sagax caerula, purse seine fishery. *California Cooperative Oceanic Fisheries Investigations (CalCOFI)* Report 18: 136-148. [Available at http://calcofi.org/publications/calcofireports/v18/Vol_18_MacCall.pdf Nov. 15, 2010].

Marchal, P., J.R. Neilsen, H. Hovgard, and H. Lassen. 2001. Time changes in fishin power in the Danish cod fisheries of the Baltic Sea. *ICES Journal of Marine Science* 58: 298-310.

Marchal, P., C. Ulrich, K. Korsbrekke, M. Pastoors, and B. Rackham. 2002. A comparison of three indices of fishing power on some demersal fisheries of the North Sea. *ICES Journal of Marine Science* 59: 604-623.

Pauly, D. and M.L.D. Palomares. 2010. An empirical equation to predict annual increases in fishing efficiency. *Fisheries Centre Working Paper* #2010-07. The University of British Columbia, Canada. [Available at http://www.fisheries.ubc.ca/publications/working/, Nov. 15, 2010]

Peterman, R.M. and G.J. Steer. 1981. Pelation between sport-fishing catchability coefficients and salmon abundance. Transactions of the American Fisheries Society 110: 585-593.

Poos, J. J., M.A. Pastoors, and A.D. Rijnsdorp. 2001. Quota regulation and efficiency in the Dutch beam trawl fleet. *ICES Document* CM 2001/N: 14. 16 pp. [Nov. 15, 2010]

Pope, J. G., and J. G. Shepherd. 1985. A comparison of the performance of various methods for tuning VPAs using effort data. *Journal Conceil International pour l'Exploration de la Mer* 42: 129-151.

Rijnsdorp, A.D., N. Daan, and W. Dekker. 2006. Partial fishing mortality per fishing trip: a useful indicator of effective fishing effort in mixed demersal fisheries. *ICES Journal of Marine Science* 63: 556-566.

Rose, G.A., and D.W. Kulka. 1999. Hyperaggregation of fish and fisheries: how the catch-per-unit-effort increased as the northern cod (Gadus morhua) declined. *Canadian Journal of Fisheries and Aquatic Sciences* 56 (Suppl. 1), 118–127.

Robins, C. M., Y. Wang, and D. Die. 1998. The impact of global positioning systems and plotters on fishing power in the northern prawn fishery, Australia. *Canadian Journal of Fisheries and Aquatic Sciences* 55: 1645–1651.

Squires, D. 1992. Productivity measurement in common property resource industries: and application to the Pacific coast trawl fishery. RAND Journal of Economics 23: 221-236.

Wilberg, M. J., and J. R. Bence. 2006. Performance of time-varying catchability estimators in statistical catch-at-age analysis. *Canadian Journal of Fisheries and Aquatic Sciences* 63: 2275–2285.

Wilberg, M.J., J.T. Thorson, B.C. Linton, and J. Berkson. 2010. Incorporating time-varying catchability in population dynamic stock assessment models. *Reviews in Fisheries Science* 18: 2-24.