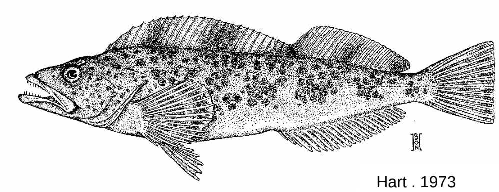
LINGCOD (*OPHIODON ELONGATUS*) STOCK ASSESSMENT AND YIELD ADVICE FOR OUTSIDE STOCKS IN BRITISH COLUMBIA



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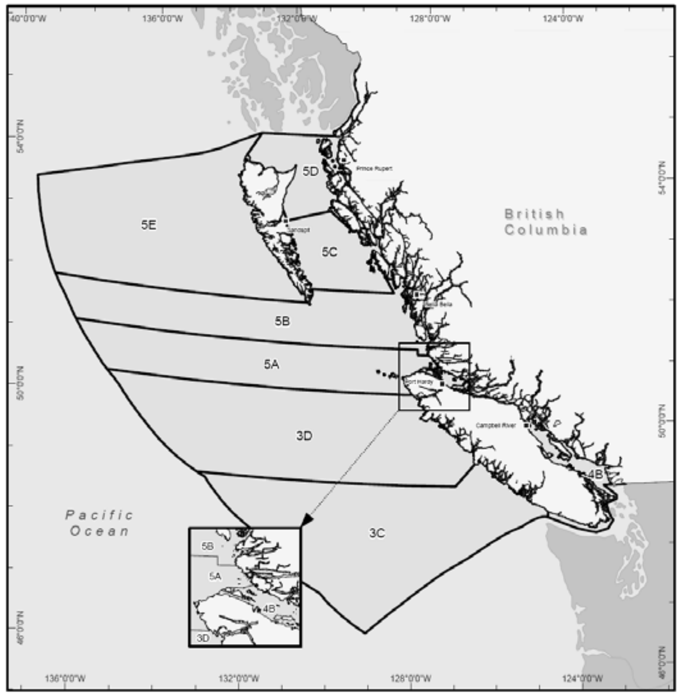

Figure 1. Map of groundfish management areas that are used to delineate four offshore lingcod assessment areas in British Columbia (Area 3C, Area 3D, Areas 5AB, and Areas 5CDE).

Context :

Lingcod (Ophiodon elongatus) are an important component of both the commercial and recreational groundfish fisheries off British Columbia, Canada. They are exploited primarily by trawl, but also by hook and line, including handline, longline and troll. They have a long history of exploitation as food fish, starting with First Nations as early as 5,000 years ago, and it known that they were fished by early settlers in the inshore waters around Victoria by the mid-1800s.

In the context of DFO's new Fishery Decision-making Framework Incorporating the Precautionary Approach, advice was requested by Fisheries and Oceans Canada (DFO) Fisheries Management on the current stock status and potential yields for the four management units of lingcod in the outside waters of British Columbia (Figure 1).

This Science Advisory Report has resulted from a Fisheries and Oceans Canada, Canadian Science Advisory Secretariat Regional Advisory Process. Additional publications resulting from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

SUMMARY

- Lingcod (*Ophiodon elongatus*) are an important component of both the commercial and recreational groundfish fisheries off British Columbia, Canada. They are exploited primarily by trawl, but also by hook and line, including handline, longline and troll. They have a long history of exploitation as food fish, starting with First Nations as early as 5,000 years ago, and it known that they were fished by early settlers in the inshore waters around Victoria by the mid-1800s. Catch data are available from 1927.

- Outside lingcod populations in British Columbia are assessed and managed as four separate units based on DFO Statistical Areas: 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).

- A Bayesian surplus production model was used to assess lingcod stock status within each of the four assessment areas. Data inputs included at least three relative abundance (trawl survey or CPUE) 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 produce decision tables for each assessment area. Sensitivity analyses were used to evaluate the effect of stock assessment assumptions on the results.

- For Area 3C, the median of the estimated posterior distribution for B_{2010} is 111% of B_{MSY}, indicating that this stock is most likely in the Healthy Zone. Greater uncertainty exists in stock status estimates for Area 3C than other Areas because the probability that B_{2010} is in the Healthy Zone is only 67% and the probability that B_{2010} is in the Critical Zone is 10%.

- For Area 3D, the median of the estimated posterior distribution for B_{2010} is 156% of B_{MSY}, indicating that this stock is most likely in the Healthy Zone. There is high confidence in classifying the Area 3D stock as "Healthy" because the probability that B_{2010} is in the Healthy Zone is 95% and the probability that B_{2010} is in the Critical Zone is $< 1\%$.

- For Area 5AB, the median of the estimated posterior distribution for B_{2010} is 113% of B_{MSY}, indicating that this stock is most likely in the Healthy Zone. There is greater uncertainty in stock status estimates for Area 5AB than in Area 3D and 5CDE because the probability that B_{2010} is in the Healthy Zone is only 67%, and the probability that B_{2010} is in the Critical Zone is 5%.

- For Area 5CDE, the median of the estimated posterior distribution for B_{2010} is 146% of B_{MSY}, indicating that this stock is most likely in the Healthy Zone. There is high confidence in classifying the Area 5CDE stock as "Healthy" because the probability that B_{2010} is in the Healthy Zone is 88% and the probability that B_{2010} is in the Critical Zone is $< 1\%$.

INTRODUCTION

Biology

Lingcod are endemic to the west coast of North America. They are distributed in the nearshore waters from California to Alaska, with the centre of abundance off the coast of British Columbia. They 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, and it is thought that multiple stocks likely exist within British Columbia. However, stock delineation has not been clearly defined. 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 the four outside stocks assessed here.

Lingcod live up to a maximum of about 20 years for females and 14 years for males, reaching a maximum size of approximately 120 cm and 90 cm, respectively. Females and males are reproductively mature at age 3-5 years (61-75 cm) and age 2 years (50 cm), respectively. Spawning takes place from December to March. Females deposit eggs in nests which males actively defend until hatching in mid-March or April. The larvae are pelagic until late May or early June when they settle to the bottom as juveniles. Juveniles may be found on flat bottom areas that are not typical habitat of older lingcod. They eventually settle in habitats of similar relief and substrate as older lingcod, but remain at shallower depths for several years. In general, the dispersion of juveniles is spatially limited, with colonization and recruitment occurring in localized areas only. Lingcod begin recruiting to the commercial fishery at age 2 and are fully recruited at age 6.

Role in the Ecosystem

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 modeling lingcod population dynamics, is that lingcod display cannibalism in the wild. 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).

The Fishery

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 in the local market throughout the year (Cass et al. 1990). Prior to the 1940s, the fishery in British Columbia was dominated by the Strait of Georgia hook and line fishery. By the 1940s, most areas off the British Columbia coast were being exploited by the trawl fishery, and, since the 1960s, trawl landings dominated (Figure 2). The total coastwide catch has remained stable around 2,400 tonnes since 2000 (Figure 2). 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 3C, 3D and 5A. A winter closure from November 16 to March 31 was in effect for the coastwide hook and line commercial fisheries and for recreational fisheries conducted in 3C, 3D and 5A.

The Total Allowable Catch (TAC) was 950 tonnes for Area 3C; 400 tonnes for Area 3D; 1062 tonnes for Area 5AB and 1000 tonnes for Area 5CDE.

ASSESSMENT

Sources of Information

Catch data were available from 1927 to 2009 for input into stock assessment models, accounting for both the commercial and recreational catch. Commercial catch data included both hook and line and trawl gear. Recreational catch estimates are available from creel programs beginning in the early 1980s. 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 for each management area. For each area, separate GLM analyses were performed for three different time periods: (1) series start (1954 – 1966) – 1990, (2) 1991-1995, and (3) 1996-2010 with separate catchability parameters estimated for each time series. These time periods were chosen to reduce confounding effects of groundfish fishery changes in 1991 and 1996 on annual CPUE indices. Fishery-independent abundance indices were available from several research surveys including the recent groundfish synoptic trawl surveys, the Hecate Strait multi-species trawl survey, two shrimp trawl surveys, and the US triennial survey.

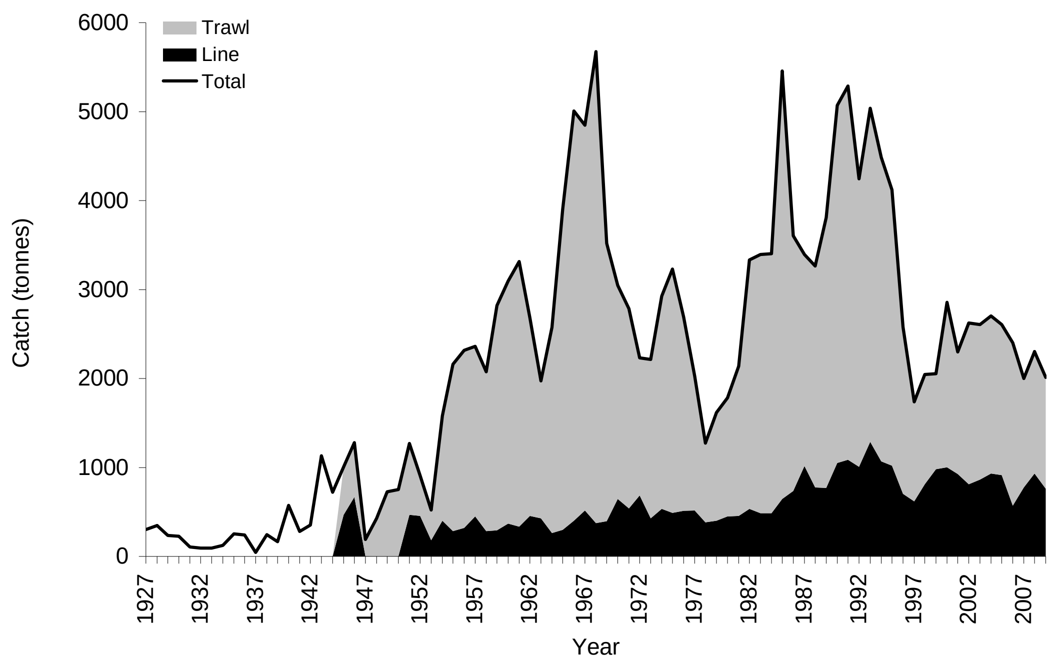

Figure 2. Coastwide hook and line, trawl, and total commercial catch (tonnes) of lingcod in outside British Columbia waters. Hook and line catches and trawl catches are shown using stacked areas.

Three sets of biological parameters for lingcod stocks in each area were estimated outside of the assessment model: (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 resulting parameters estimated were used as inputs to a demographic analysis to develop area-specific informative prior distributions for the intrinsic rate of increase, *r*. These prior distributions were then used to fit the assessment model to data.

Stock Trends

Bayesian surplus production models for each assessment area extended analyses previously reported by Cuif et al. (2009), using a state-space modelling approach which 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). Required inputs were catch and at least one index of abundance (either CPUE or trawl survey) with coefficients of variation (CV). Estimated parameters included carrying capacity (*K*), the intrinsic rate of population growth (*r)*, the ratio of biomass in 1927 (i.e., the first year of data) to *K*, the unfished equilibrium biomass, variance parameters for each abundance index, and the associated catchability parameter (*q*) for each abundance index. Prior probability distributions were specified for all of the estimated parameters.

For each of the four British Columbia lingcod assessment areas, a reference case was developed for which all inputs, assumptions, and settings were formulated based on the best available information and scientific judgment. 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).

The medians of estimated posterior distributions from the reference run are used to characterize both biomass (Figure 3) for stock trends and the ratio of biomass in 2010 to B_{MSY} (Figure 4) for current status. Stock biomass in Area 3C was relatively stable from 1927-1955 and then declined until 2010, with two small upturns in the mid-1980s and the mid-2000s (Figure 3). Overall the stock biomass has exhibited a 45% decline from the 1927 biomass level (Figure 3; Table 1). Stock biomass in Area 3D has shown a 22% decline from the 1927 biomass level (Figure 3; Table 1). Model estimates show periods of increasing and decreasing biomass since the late-1960s when biomass estimates were at historic high levels (Figure 3). Biomass then declined from 1970 to the mid-1980s, followed by an increase to 2003 (Figure 3). Since 2003, the biomass has been declining, and is currently estimated to be at an historic low. Stock biomass in Area 5AB has shown a 44% decline from 1927 (Figure 3; Table 1). Biomass showed a depletion between the mid-1960s and late-1970s, followed by some rebuilding in the 1980s (Figure 3). Since the mid-1980s, biomass has steadily declined to a historic low in 2010. Stock biomass in Area 5CDE has shown a 28% decline from the initial biomass in 1927 (Figure 3; Table 1). Changes in biomass over time for this stock are estimated tohave been relatively minor (Figure 3). Overall the stock appears to have remained stable from 1927-1970, declined until 1980, increased until 1990 and has continued to decline since then.

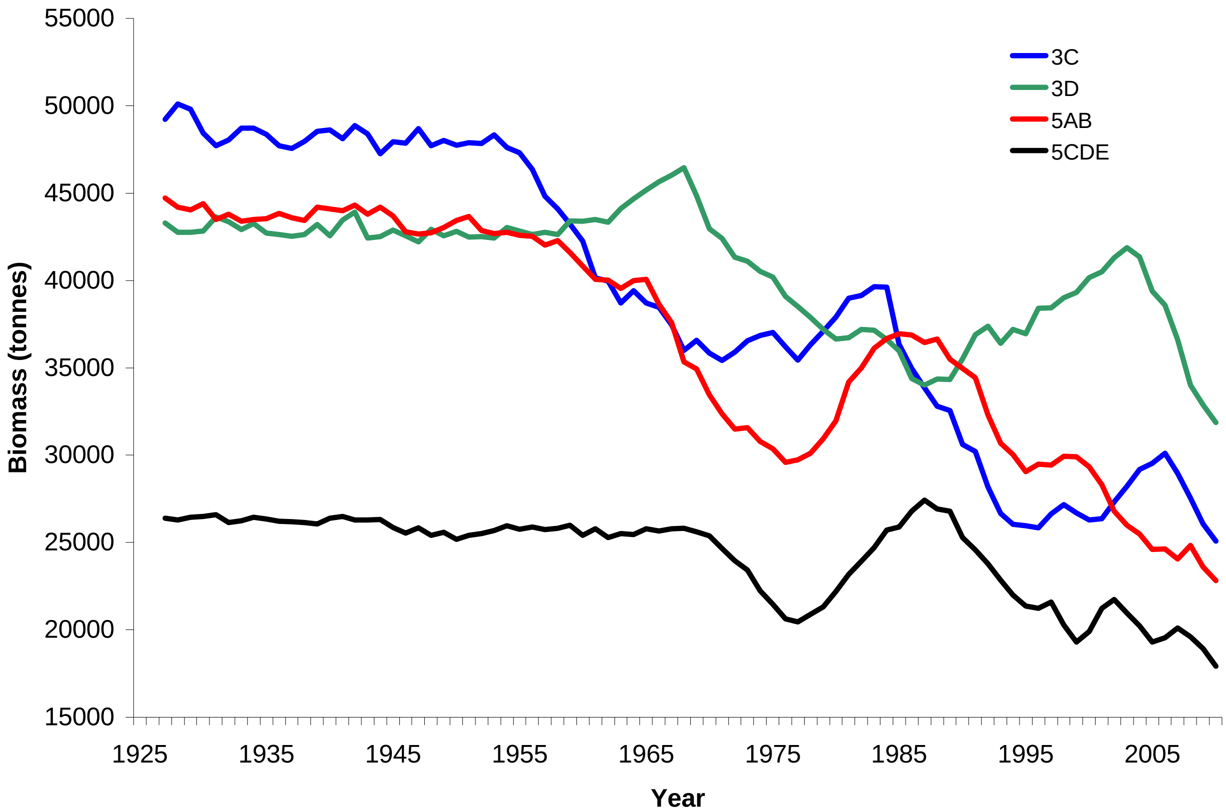

Figure 3. Estimated median stock biomass (t) from 1927-2010 for each assessment area based on results for reference cases.

Current Status

Assessment of current stock status follows the *Fishery Decision-making Framework Incorporating the Precautionary Approach* (DFO 2009) with the definition of three stock status Zones (Healthy, Cautious and Critical) based on two reference points: an Upper Stock Reference (USR; Biomass=80% of B_{MSY}) that defines the boundary between Healthy and Cautious Zones (Figure 4) and a Limit Reference Point (LRP; Biomass=40% of B_{MSY}) that defines the boundary between Cautious and Critical Zones (Figure 4). In addition, we also include stock status relative to B_{MSY} as a Target Reference Point.

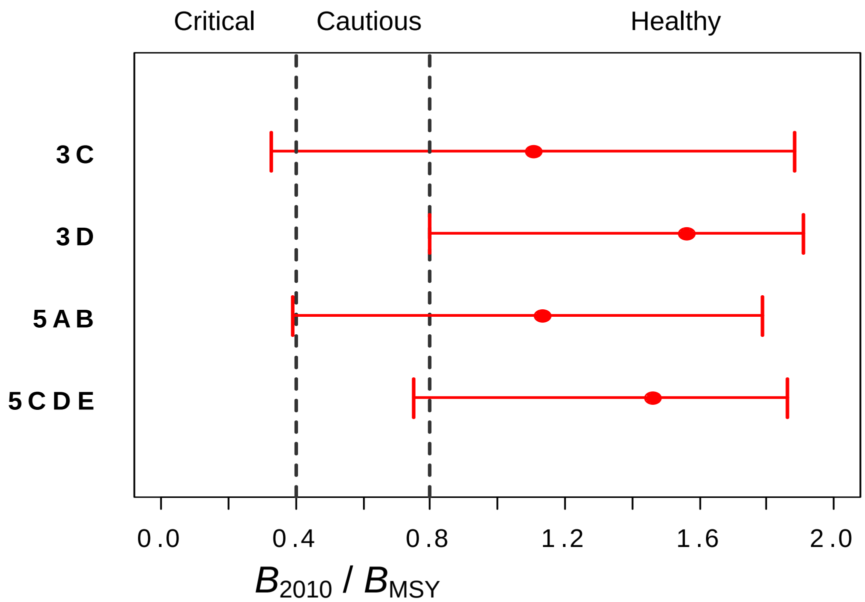

Figure 4. Current stock status (represented as the ratio of B_{2010} to B_{MSY}) relative to the limit reference point and upper stock reference point for each of the four outside lingcod assessment units in British Columbia. Dots show the posterior median of the ratio of B_{2010} to B_{MSY} and error bars show the 90% probability intervals of the ratio. Vertical dashed lines indicate the limit reference point ($0.4B_{MSY}$) and upper stock reference point ($0.8B_{MSY}$). The three stock status zones delineated by these reference points (Healthy, Cautious, and Critical) are indicated at the top of the figure.

All four assessment areas are most likely in the Healthy Zone (i.e. current biomass is greater than 80% of $B_{MSY;}$ Figure 4, Table 1). Uncertainty in current stock status relative to the USR and the LRP is quantified as the probability (P) that B_{2010} is in the Healthy Zone, $P(B_{2010}>0.8B_{MSY})$, and the probability that B_{2010} is above the critical zone $P(B_{2010}>0.4B_{MSY})$. These probabilities are based on model posterior distributions, which in some cases were highly skewed or displayed more than one mode. Greater uncertainty exists in the stock status estimates for Area 3C and for Area 5AB compared to the equivalent determinations for 3D and 5CDE.

Table 1. Stock status indicators for lingcod in each Assessment Area based on posterior median model parameter estimates. The two estimated quantiles represent the probability that biomass in 2010 is in the Healthy Zone [$P(B_{2010}> 0.8B_{MSY})$] and the probability that biomass in 2010 is above the Critical Zone [$P(B_{2010}> 0.4B_{MSY})$]. All biomass and yield values tones tonnes.

								Estimated Quantiles	
Area	*MSY*	B_{MSY}	B_{2010}	B_{2010}/B_{1927}	B_{2010}/B_{MSY}	$0.8B_{MSY}$	$0.4B_{MSY}$	$P(B_{2010}> 0.8\,B_{MSY})$	$P(B_{2010}> 0.4B_{MSY})$
3C	1390	25217	25083	0.55	1.106	20174	10087	0.67	0.90
3D	1888	22068	31869	0.78	1.56	17654	8827	0.95	> 0.99
5AB	1283	22058	22824	0.56	1.13	17646	8823	0.67	0.95
5CDE	1091	13658	17929	0.72	1.46	10926	5463	0.88	> 0.99

Sources of Uncertainty

The commercial CPUE time series associated with each assessment area were assumed to be proportional to the vulnerable biomass of lingcod in that area (i.e. they are assumed to be indices of relative abundance). While commercial CPUE may track abundance, it is also prone to hyperstability (Hilborn and Walters, 1992). Adding a hyperstability parameter to the model did not improve the goodness of fit to the available data in these four models and consequently there was little evidence to suggest that hyperstability was a concern.

Trawl research surveys were used as fishery-independent indices of abundance, also assuming that these indices were proportional to lingcod biomass. Several of the surveys exhibited high inter-annual variability in the lingcod biomass estimates, and in some cases, the CVs associated with the index value were >0.80. These observations suggest that this species is poorly monitored using trawl surveys. Iterative reweighting downscaled the influence of the annual indices with high CVs so that survey time series or individual data points with high variability had relatively 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, led 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. However, from 1975-1990, the commercial catch and CPUE of lingcod increased and one expectation given high catches, would be a decline in abundance and CPUE. 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 a decline over this period. This decline in the shrimp trawl survey was considered to be more credible and was used to support a technological creep hypothesis as a means to explain why commercial CPUE increased during this period. An alternate hypothesis for the increase in abundance (i.e. increasing commercial CPUE) despite high removals (i.e. catch) would be basin-wide climate impacts (e.g. Pacific Decadal Oscillation) on recruitment. The commercial CPUE exhibited an increase beginning in the early 1980s, which may have related 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 concomitant with a strong year class in several fish species, including groundfish, from California through Alaska (King 2005).

Based on the observation that standardized commercial trawl CPUE indices exhibited an increasing trend during a period of increasing total removals we assumed that the catching power of the commercial trawl fishery for lingcod increased linearly over time. A technology creep (*tech*) parameter was used to represent this systematic increase in fishing power. 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. The current assessment uses an informative prior for *tech* (a 2% increase per year) that was derived from a literature review. 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. 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 reasonable.

CONCLUSIONS AND ADVICE

Decision tables based on 5-year stock projections for each assessment area are provided in Table 2. The constant TAC policies considered ranged from 500 to 3,000 or 4,500 tonnes, depending on the area. Larger TAC quota policies were considered for Areas 3D and 5CDE because the estimated ratio of current biomass relative to B_{MSY} was large in these areas.

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 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 (calculated as 1 – PB_{2016} > 0.4B_{Msy})) in 2016 ranged from 9% for Area 3D to 33% for Area 5AB.

Projection results were most uncertain for Areas 3C and 5AB. For Area 3C, a TAC set at 1,000 (which is below the median *MSY* estimate of 1,390, Table 1), 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 t(which is below with the median *MSY* estimate of 1,283 t, Table 1) 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.

Table 2. Decision table with median posterior estimates of biomass after five years (B2016) in relation to the target biomass (BMSY) 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 BMSY), B_{2016} will be above the Target Reference Point of BMSY, and B_{2016} will be above the current biomass (B_{2010}).

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

TAC (tonnes)	B_{2016}/B_{MSY}	$P\ (B_{2016} > 0.4B_{MSY})$	$P\ (B_{2016} > 0.8B_{MSY})$	$P\ (B_{2016} > B_{MSY})$	$P\ (B_{2016} > B_{2010})$
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

SOURCES OF INFORMATION

This Science Advisory Report has resulted from a Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, Regional Advisory Meeting of April 7-8, 2011 on *Reviews of stock assessments for outside stocks of lingcod and inside stocks of yelloweye rockfish in British Columbia*. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

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FOR MORE INFORMATION

Contact: Dr. Jacquelynne King
Pacific Biological Station
Nanaimo, BC V9T 6N7
Tel: 1-250-756-7176
Fax: 1-250-756-7053
E-Mail: Jackie.King@dfo-mpo.gc.ca

This report is available from the:

Centre for Science Advice (CSA)
Pacific Region
Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

Telephone: 250-756-7208
Fax: 250-756-7209
E-Mail: CSAP@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs

ISSN 1919-5079 (Print)
ISSN 1919-5087 (Online)

La version française est disponible à l'adresse ci-dessus.

CORRECT CITATION FOR THIS PUBLICATION

DFO 2012. Lingcod (*Ophiodon Elongatus*) Stock Assessment and Yield Advice for Outside Stocks in British Columbia. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/051.