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Assessment of Pacific Cod in Hecate Strait (5CD) and Queen Charlotte Sound (5AB), January, 2005

Évaluation de la morue du Pacifique dans le détroit d'Hécate (5CD) et dans le détroit de la Reine-Charlotte (5AB) en janvier 2005

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Abstract

The available commercial fishery and research survey data for Pacific cod stocks in Hecate Strait (5CD) and Queen Charlotte Sound (5AB) were assembled and reviewed for this stock assessment paper. Results from a 3-year survey designed specifically to monitor Pacific cod abundance in Hecate Strait during a period of stock recovery were included. A delay-difference stock production model was used to synthesize these data. There are clear indications that the Hecate Strait population has increased in abundance and biomass since an historic low in 2001. The reduction in TAC for this stock which was introduced in the 2001/02 fishing year resulted in a decrease in exploitation rate which has contributed to the increase in stock size. However, the population has not yet recovered to the long term average biomass and continued increases may be desirable. A candidate stock biomass limit reference point is proposed based on the previous minimum biomass from which the stock had recovered. This was the stock biomass in 1971. Catch forecasts were calculated for a wide range of TAC in 2005/06. The results are presented as probabilities of specific performance measures being met or exceeded. Attention is drawn to the probability of biomass increase and the probability of the biomass being greater than the biomass in 1971. We were unable to produce an analytical assessment of the Queen Charlotte Sound population. Several reasons for this are discussed and recommendations are made for future research to address this issue.

Résumé

Dans ce rapport, nous avons regroupé les données de pêche commerciale et de relevés de recherche sur les stocks de morue du Pacifique dans le détroit d'Hécate (5CD) et dans le détroit de la Reine-Charlotte (5AB) et nous avons examiné celles-ci aux fins d'évaluation des stocks. Nous présentons les résultats d'un relevé de trois ans conçu dans le but précis de surveiller l'abondance de la morue du Pacifique dans le détroit d'Hécate au cours d'une période de rétablissement des stocks. Nous avons utilisé un modèle d'analyse de production à retardement des stocks pour faire la synthèse de ces données. Il existe des indices clairs qui portent à croire que l'abondance et la biomasse de la population du détroit d'Hécate ont augmenté depuis 2001, année où un plancher historique a été atteint. La réduction du TAC pour ce stock, mise en vigueur en 2001-2002, a entraîné une baisse du taux d'exploitation, ce qui a contribué à l'augmentation de la taille du stock. La population ne s'est cependant pas encore rétablie suffisamment pour que sa biomasse soit égale à la moyenne à long terme; la poursuite du rétablissement pourrait donc être souhaitable. Nous proposons un point de référence pour la limite de la biomasse du stock reproducteur fondé sur le minimum de biomasse précédent (1971) à partir duquel le stock s'est rétabli. Les prévisions des prises ont été établies pour une vaste gamme de TAC pour l'année 2005-2006. Les résultats sont présentés sous forme de probabilités que des objectifs de performance précis soit atteints ou dépassés. Nous prêtons une attention particulière à la probabilité d'une hausse de la biomasse et à la probabilité que la biomasse soit supérieure à la biomasse en 1971. Nous avons été incapables de réaliser une évaluation analytique de la population du détroit de la Reine-Charlotte. Dans ce rapport, nous discutons de plusieurs des raisons qui expliquent cet échec et nous présentons des recommandations relatives à la recherche future sur cette question.

Introduction

Four stocks of Pacific cod are defined for management purposes on the BC coast, Strait of Georgia (4B), west coast Vancouver Island (3AB), Queen Charlotte Sound (5AB), and Hecate Strait (5CD). This working paper focuses on the Hecate Strait and Queen Charlotte Sound stocks (Figure 1).

Pacific cod is a relatively short lived species and their stock status may change rapidly. Yields have been low in recent years due mainly to low abundance and restrictive TACs. An industry-funded stratified random bottom trawl monitoring survey in Hecate Strait was designed and implemented in 2002 and there are 3 years of results available for analysis. Reports from industry indicate increases in abundance in this area. The last assessment of Hecate Strait Pacific cod was by Sinclair et al. 2001).

There has never been a stock assessment of Pacific cod in Queen Charlotte Sound and the current TAC was based on a precautionary approach that considered historical catches. Reports from industry also indicate an increase in abundance in this area which has prompted a request for an assessment.

In July 2004, the ADM Fisheries and Aquaculture Management requested that Science assessments include candidate Limit Reference Points for groundfish and pelagic fisheries beginning in 2004. This was considered to be an important component of integrating the Precautionary Approach (PA) into Fisheries Management Renewal.

The objectives of the working paper, as specified in the Request for Working Paper (Annex 1), are to review surveys, biological sampling, catch records, logbooks, observer reports and fishing practices for Pacific cod, to recommend a biological limit reference point for each stock, and provide a basis for the management of the 2005/06 fisheries in the offshore management areas 5AB and 5CD. The main questions are

- What are the current biomass and size structure of Pacific cod stocks in 5AB and 5CD and how do these quantities relate to historical stock conditions?
- What is the expected trajectory of the Pacific cod in the 2 areas to the end of the 2005/06 fishing season and how will this be affected by a range of annual TACs?
- What are appropriate biological limit reference points that could be recommended for each of these stocks? Provide the biological considerations and rationale used to form these recommendations.

Methods

Fishery Data

Commercial fishing data are presented in this document by fishing year which includes the period April through March. Fishing year 1956-57 includes the period April 1, 1956 to March 31, 1957. Landings data are also presented separately for Canada and the USA. USA landings data were obtained from the Pacific Marine Fisheries Commission reports for 1956-1981. Canadian data were obtained from the GFCatch database for the period 1954-1995 (Rutherford 1999) and the PacHarvest database.

Survey Data

Hecate Strait Assemblage Survey

A series of multi-species groundfish bottom trawl surveys have been conducted in Hecate Strait in May-June of 1984, 1987, 1989, 1991, 1993, 1995, 1996, 1998, 2000, 2002, and 2003 (Westrheim et al. 1984, Fargo et al. 1984, Fargo et al. 1988, Wilson et al. 1991, Hand et al. 1994, Workman et al. 1996, Workman et al. 1997, Choromanski et al. 2002, Choromanski et al. 2002). The results up to 2000 were reported in the last assessment, results from 2002 and 2003 are presented here for the first time.

The original design of this survey assigned fishing locations by 10 fm depth intervals within a 10 nm grid of Hecate Strait. The survey has been post stratified for the purpose of calculating an abundance index for Pacific cod (Sinclair 1999). The post stratification used 10 fm depth intervals for the entire survey area, thereby treating each depth interval as a single stratum.

Hecate Strait Pacific Cod Monitoring Survey

The TAC for the Pacific cod in Hecate Strait was reduced considerably for the 2001/02 fishing year because of a low assessed stock size. The assessment was based largely on abundance indices derived from commercial fishing catch per unit effort (CPUE). With the reduced TAC, fishers avoided areas of high cod abundance in order to retain quota holdings for cod while fishing for other species. This potentially biased the CPUE data and reduced its utility in tracking changes in stock abundance (Sinclair et al. 2001). While the Hecate Strait Assemblage Survey is conducted biennially in Hecate Strait, the relatively low sample size in this survey coupled with the highly aggregated distribution of Pacific cod in Hecate Strait results in a high estimation variance and a reduced capacity to track changes in abundance (Sinclair 1999). Recognizing this shortfall in the traditional abundance indices, a survey optimized for Pacific cod was implemented in Hecate Strait to monitor the population as it rebuilt. The survey was planned for a three-year period with fishing carried out in areas identified by experienced fishers as being good for the species

(Figure 2). The Canadian Groundfish Research and Conservations Society covered all vessel costs for the survey while DFO covered costs of the scientific crew and dockside monitoring. The results for 2002, 2003, and 2004 are presented here. A complete description of the survey design is presented by Sinclair and Workman 2002.

Survey Indices

The stratified mean catch per unit effort weighted by the surface area of each stratum was used as the index of relative abundance for both the assemblage survey and the monitoring survey. These formulae apply for a single survey (i.e. annual for the assemblage survey and monthly for the monitoring survey)

Observations

C_{sh}	catch weight (kg) in set s in stratum h
D_{sh}	Duration (hr) of set s in stratum h
f_{lsh}	number of fish measured at length l in set s in stratum h
N	number of possible set locations in survey area
N_h	number of possible set locations in stratum h
n_h	number of fishing sets made in stratum h

Calculated values

$U_{sh} = \frac{C_{sh}}{D_{sh}}$	catch per unit effort in set s in stratum h: units $kg \cdot hr^{-1}$
$w_h = \frac{N_h}{N \cdot n_h}$	weight assigned to all sets in stratum h for calculating stratified means.
$\overline{U}_h = \frac{\sum_s U_{sh}}{n_h}$	mean catch per unit effort in stratum h
$Var_{\overline{U}_h}$	variance of the mean catch per unit effort in stratum h
$\overline{U} = \sum_h \left(w_h \cdot \sum_s U_{sh} \right)$	stratified mean catch per unit effort in the survey: units $kg \cdot hr^{-1}$
$Var_{\overline{U}} = \frac{1}{N^2} \sum_h \frac{N_h^2 \cdot Var_{\overline{U}_h}}{n_h}$	variance of the stratified mean catch per unit effort
$S_{sh} = \sum_l f_{lsh} \cdot 7.377E-06 \cdot l^{3.0963}$	calculated sample weight for set s in stratum h: units, l in cm, S in kg. Length/weight relationship from Westrheim 1996). Sample weight was only calculated for sets where there was subsampling, otherwise $S_{sh} = C_{sh}$

$F_{lsh} = \frac{C_{sh} \cdot f_{lsh}}{S_{sh} \cdot D_{sh}}$ catch per unit effort of length l fish in set s in stratum h, adjusted for subsampling: units $\# \cdot hr^{-1}$

$\overline{F}_l = \sum_h \left(w_h \cdot \sum_s F_{lsh} \right)$ catch per unit effort of length l fish caught in the survey: units $\# \cdot hr^{-1}$

$\overline{F} = \sum_l \overline{F}_l$ stratified mean catch per unit effort in the survey: units $\# \cdot hr^{-1}$

For the monitoring survey, the annual index was calculated as the stratified mean including fishing ground and month as strata. An index of abundance at length ($\overline{F}_l$) was also calculated for each survey.

Bootstrapping was used to investigate the variability of the annual stratified mean catch rates (Smith 1997). For a given survey and within a stratum, the observed catches were randomly sampled, with replacement, to obtain pseudo-replicates of size n_h. The stratified annual mean was calculated from the bootstrap replicates, and this was repeated 1000 times for each survey. The distribution of the bootstrap means was used to estimate the distribution of the annual stratified means. For the Hecate Strait surveys, the bootstrap variance was about 8% less than the stratified variance on average.

Catch per Unit Effort Analysis

The criteria used to select data for the calculation of CPUE for 5AB (Queen Charlotte Sound) and 5CD (Hecate Strait) Pacific cod are listed in Table 1. A similar analysis was also performed on the equivalent data for 3CD (west coast Vancouver Island).

Catch data are available on a tow-by-tow basis in the PacHarvest database where each tow has at least two associated depth fields (beginning and end of tow). However, data in the GFCatch database prior to 1991 are only available in summary form because vessels reported on a “trip” basis and provided “rolled-up” reports of catch for defined “localities” within approximately 10 fathom depth bands (Rutherford 1999). Most records would have two associated depth bands which were interpreted by the algorithm in Table 2. Beginning in January 1991, the data in GFCatch are reported on a tow-by-tow basis.

Four CPUE analyses (defined in Table 3) were performed on each of the 5AB and 5CD data sets. Only the first three analyses in Table 3 were performed on the 3CD data. A range of analyses was required because there had been a substantial drop in the Hecate Strait Pacific cod TAC on 1 April 2001 which altered the behaviour of fishermen and consequently affected the comparability of the later CPUE indices with those from earlier years. Three of the selected analyses attempt to adjust for this effect (B, C, D) while anaylsis A is presented as a continuation with the analysis performed for the 2001 Hecate Strait assessment.

One approach used to correct for changes in effort behaviour was to identify key localities where Pacific cod have been captured throughout the available catch history (Table 4). The areas selected for Hecate Strait were the same as those used in the Hecate Strait monitoring survey (Sinclair and Workman 2002) while the cumulative catch data were examined to identify similar areas in Queen Charlotte Sound. It appears that information about the locality of catch was not recorded for 5AB (Queen Charlotte Sound) prior to 1966 although locality information was more common in 5CD (Hecate Strait) in these early years (Figure 3). Therefore, Analysis "D" for Queen Charlotte Sound (Table 4) uses the catch and effort data from Analysis "A" for all fishing years prior to 1966/67.

All analyses were performed on total mortalities (=landed catch+discards), but this potentially may bias the analyses, given that accurate discard data have only been available since 1996 when 100% observer coverage was implemented in the trawl fleet. However, it is important to include the discard information to obtain a complete index for this species, given the low TAC for Hecate Strait Pacific cod beginning in 2001.

Catch and effort (either as total hours fished or number of tows) were summed for each analysis by 1 April to 31 March fishing year, beginning in 1 April 1956. CPUE indices were calculated for each fishing year (*y*) using the following equation:

$$\mathrm{CPUE}_y = \frac{\sum_{j=1}^{N_{jy}} \mathrm{Catch}_{jy}}{\sum_{j=1}^{N_{jy}} \mathrm{Effort}_{jy}}$$

where *j* indexes each fishing event in each data set and N_{jy} is the number of fishing events by fishing year in the data set. An index standardised by dividing by the mean CPUE index for 1996/97 to 2003/04 was selected for making comparisons between indices.

$$\mathrm{Index}_y = \frac{\mathrm{CPUE}_y}{\left(\sum_{j=96/97}^{j=03/04} \mathrm{CPUE}_j \Big/ 8 \right)}$$

Commercial Fishery Size Composition

The annual size composition of commercial catches and landings were estimated from port samples and at-sea samples collected by observers. The sample data were extracted from the GFBio database, using the criteria given in Table 5. Examination of the sample length frequencies revealed 7 samples that were coded as being Pacific cod but the size composition was uncharacteristic of the species. These samples, listed in Table 5, were eliminated from the analysis. The samples were also coded as being either from unsorted catches or from keepers. These samples were analyzed separately in order to estimate the size composition of total catches (unsorted) and landings (keepers). The numbers of samples and numbers of fish measured by sample category, fishing year, and quarter in Hecate Strait and Queen Charlotte sound are given in Annex 2 and Annex 3.

The algorithm for estimating the size composition of the catches and landings is as follows. Sample weights were not recorded. Sample weights were estimated using the sample length frequency and the length weight relationship given in Westrheim 1996. The sample length frequency was adjusted to represent the catch in the fishing event by multiplying by the ratio of catch weight divided by sample weight. For unsorted samples the catch weight was the sum of kept plus discard weight. For keeper samples, the catch weight was the landed weight. The adjusted samples were then added together, by length, within stock, sample category, fishing year, and quarter. These quarterly length frequencies thus represent the sampled fishing events. These frequencies were then adjusted to reflect the total catch in all fishing events in the stock, sample category, fishing year, and quarter. The ratio of total reported catch divided by the catch in the sampled fishing events was used. The quarterly adjusted length frequencies were then combined by stock, sample category and year. If there were quarters without samples, the combined frequency was adjusted by the ratio of total catch in the sampled stock, sample category, fishing year, and quarters divided by the catch from quarters with samples. If there were no samples taken in a year, there was no attempt made to estimate the size composition of the catches in that year. The annual mean weight of fish in the catch was estimated from the annual length frequency for the kept fraction of the catch.

Delay-difference production analysis

A delay-difference stock production model (Hilborn and Walters 1992, Quinn and Deriso 1999, Schnute 1985, Sinclair et al. 2001, Starr et al. 2002, Starr and Fargo 2004) was used to estimate stock, parameters and reference points relevant to management. The model uses two age groups, recruits and spawners. A Beverton-Holt stock-recruitment function was used to link the two groups. The stock recruitment function included an environmental component. Sea level during the spawning season (January – March) at Prince Rupert has been used as a proxy variable for transport through Hecate Strait. Years of high sea level (and high transport) have been associated with poor recruitment (Sinclair et al. 2001;Sinclair and Crawford 2005). Recruitment to the spawning population and the fishery was assumed to be knife edged at age 2, as was assumed in two previous Pacific cod assessments (Sinclair et al. 2001, Starr et al. 2002). Growth was assumed to follow a constant von-Bertalanffy function and the length-weight relationship was assumed to be constant. Input parameters for growth were taken from Westrheim 1996 and were assumed to be constant and known without error. The model is conditioned on fishing effort, estimated as the ratio of catch divided by catch per unit effort. The objective function includes terms for minimising the differences between the predicted and the observed catch, the predicted and the observed mean weight of fish in the population, the predicted and observed biomass indices from two surveys (Hecate St. assemblage survey and Hecate St. Pacific cod monitoring survey) and minimising the recruitment deviations relative to the mean recruitment. The model used in this assessment differs from the model described by Sinclair et al. 2001 by the addition of two survey indices, switching to a Beverton-Holt stock-recruitment function, and some changes to the equilibrium equations. The following tables describe the model parameters, data, dynamics and likelihoods.

Estimated Parameters

Parameter	**Description**
B_0	Unfished equilibrium population biomass
M	Instantaneous natural mortality rate
g	ratio B_1 / B_0, population biomass in year 1 relative to unfished equilibrium population biomass
h	"steepness" of the Beverton-Holt stock-recruitment curve: where fraction defines the proportion of the maximum recruitment which is available when the spawning stock size is 20% B_0 (Francis 1992) OR Single parameter defining the Ricker stock-recruitment function (steepness at the function at the origin)
q_c	Fishery catchability
q_t	Hecate Strait assemblage trawl survey catchability
q_s	Hecate Strait monitoring trawl survey catchability
d	Slope of function relating deviations from mean Prince Rupert sea level to observed recruitment
f_t	Recruitment anomalies in year *t* (there are 47 of these parameters)

Fixed parameters

Parameter	**Value**	**Description**
L_∞	89.48	Asymptotic length in von-Bertalanffy growth equation (cm) (ages 2+ only)
k	0.307	growth rate parameter in von-Bertalanffy growth equation (ages 2+ only)
t_0	-0.116	time at L_0 in von-Bertalanffy growth equation (ages 2+ only)
A	7.38E-06	slope of length – weight relationship (cm to kg)
B	3.0963	Exponent of length – weight relationship
r	2	age of knife edge recruitment to fishery and spawning population
r	0.835	slope of the Ford-Walford plot, age *r* to 20
a	1.415	Intercept of Ford-Walford plot, age *r* to 20

Annual Input Data

Data series	**Description**
E_t	Fishing effort (h) in year *t*
C_t	Catch biomass in year *t*
w_t	mean weight of individuals in the population in year *t*
$T_{index,t}$	Hecate Strait assemblage survey index in year *t*
$T_{s,t}$	Standard error for the Hecate Strait assemblage survey index in year *t*

$S_{index,t}$	Hecate Strait monitoring trawl survey index in year t
$S_{s,t}$	Standard error for the Hecate Strait monitoring trawl survey index in year t
n_t	Annual deviation in year t from mean sea level in Prince Rupert

Derived parameters:

Equation	Description
$w_r = A\left(L_\infty\left(1-e^{-k(r-t_0)}\right)\right)^B$	weight at the age of recruitment
$S = e^{-M}$	natural survival rate
$\overline{w} = \frac{Sa + w_r(1-S)}{(1-Sr)}$	average body weight in the unfished population
$N_0 = \frac{B_0}{\overline{w}}$	equilibrium population numbers at B_0
$R_0 = N_0(1-S)$	equilibrium recruitment at B_0
$a = \frac{B_0}{R_0}\left(1-\frac{(h-0.2)}{(0.8h)}\right)$	Beverton-Holt 'alpha' parameter expressed in terms of the steepness parameter (Francis 1992)
$b = \frac{5h-1}{4hR_0}$	Beverton-Holt 'beta' parameter expressed in terms of the steepness parameter (Francis 1992)
$s_0 = \frac{hR_0}{B_0}$	Maximum recruitment survival for Ricker stock-recruitment function (slope at the origin of stock recruitment curve)
$b = \frac{-\ln(1/h)}{B_0}$	Recruitment capacity for Ricker stock recruitment function

Model Equations

Equation	Description
$F_t = q_c E_t$	instantaneous fishing mortality in year t
$N_t = N_{t-1}e^{(-M-F_{t-1})} + R_{t-r+1}$	population numbers in year t
$B_t = \left(a\ N_{t-1} + r\,B_{t-1}\right)e^{(-M-F_{t-1})} + w_r R_{t-r+1}$	population biomass in year t
$\hat{w}_t = \frac{B_t}{N_t}$	predicted mean weight of individuals in the population in year t
$R_t = \frac{B_t}{(a+bB_t)}e^{f_t}e^{dn_t}$	Recruitment in year t using a Beverton-Holt stock-recruitment, including the factor for relating the deviation from mean Prince Rupert sea level
$R_t = s_0 B_t e^{(-bB_t)}e^{(f_t)}e^{dn_t}$	Recruitment in year t using a Ricker stock-recruitment, including the factor for relating the deviation from mean Prince Rupert sea level
$\hat{C}_t = \frac{B_t\left(1-e^{(-M-F_t)}\right)F_t}{M+F_t}$	Predicted catch in year t
$\hat{T}_{index,t} = q_t B_t$	Predicted Hecate Strait assemblage survey biomass index in year t
$\hat{S}_{index,t} = q_s B_t$	Predicted Hecate Strait monitoring survey biomass index in year t

Equation	Description
$C_t = \dfrac{B_t\left(1-e^{(-M-F_t)}\right)F_t}{M+F_t}$	Solve F_t for in years 2005/06
$H_t = \dfrac{(1-e^{(-M-F_t)})F_t}{M+F_t}$	Harvest rate in year t

Objective Function:
There were five terms that were minimised in the objective function. These five terms are described in the equations below:

$$\left(n\ln s_f + \frac{1}{2s_f^2}\sum(f^2)\right) + \left(n\ln s_c + \frac{1}{2s_c^2}\sum(\ln C_t - \ln\hat{C}_t)^2\right)$$
$$+\left(n\ln s_w + \frac{1}{2s_w^2}\sum(\ln w_t - \ln\hat{w}_t)^2\right) + \left(n\ln s_t + \sum\frac{(\ln T_{index,t} - \ln\hat{T}_{index,t})^2}{2s_{t,t}^2}\right)$$
$$+\left(n\ln s_V + \sum\frac{(\ln S_{index,t} - \ln\hat{S}_{index,t})^2}{2s_{V,t}^2}\right)$$

The following years were used in each component of the objective function: 1956-2002 for recruitment anomalies, 1956-2003 for the catch, 1956-2003 for mean weight, eleven survey years which occurred between 1984 and 2003 for the assemblage survey (Table 10), 2002-2004 for the monitoring survey.
The residual standard deviations used for weighting the components of the objective function were set to the values in the table below. The standard errors for the various data components were arrived at by iteratively reweighting each data set until the standard deviation of the standardized (Pearson) residuals from the model fit for that data set was reasonably near to 1.0 (as predicted if the data fit the lognormal distributional assumptions). Process error was added to the estimated survey standard errors using $s_{survey,t} = \sqrt{X_{s,t}^2 + s_{survey,2}^2}$ (where $X_{s,t}^2$ is the observed standard error for one of the three surveys included in the model and $s_{survey,2}^2$ is the additional process error added to each index to bring the standard deviation of the survey residuals to the 1.0 target (Francis et al. 2001).

Standard deviations applied to the data (NA=not applicable)

Observation error	Process error	Description
$s_w = 0.2$	NA	Standard deviations for mean weight
$s_c = 0.1$	NA	Standard deviations for catch
$T_{s,t}$	$s_{t,2} = 0.68$	Standard deviations for Hecate Strait assemblage survey
$S_{s,t}$	$s_{V,2} = 0$	Standard deviations for Hecate Strait monitoring survey

$s_f = 0.4$	NA	Standard deviations for recruitment deviations

All priors used in the model were uniform with wide bounds so that the esitmation procedure was not affected by the choice of the bounds. The exception to this was the use of an informed prior for the recruitment deviations, which was assumed to be normally distributed in log space, with a mean of zero and a standard deviation of 0.4.

Table of priors used in all model runs. NA: not applicable.

Parameter	Prior type	Lower bound	Upper bound	Mean	SD
g	uniform	0.1	2	NA	NA
B_0	uniform	500	1000000	NA	NA
q_c	uniform	5.00E-08	5.00E-03	NA	NA
q_t	uniform	5.00E-08	1	NA	NA
q_s	uniform	5.00E-08	1	NA	NA
M	uniform	0.1	1	NA	NA
h	uniform	0.01	12	NA	NA
d	uniform	-10	10	NA	NA
f_t (log space)	normal	-5	5	0	0.4

Equilibrium Predictions

Equation	**Description**
$S_e = e^{-M-F_e}$	survival rate with fishing at equilibrium
$w_e = B_e / N_e$	Weight at equilibrium
$B_e = \dfrac{a\,Sa + w_e\,r\,Sa + w_e w_r - w_e a}{w_e b - a\,Sb - w_e\,r\,Sb}$	population biomass at equilibrium
$Y_e = \dfrac{B_e\left(1-e^{(-M-F_e)}\right)F_e}{M+F_e}$	yield at equilibrium

Bayesian estimation procedure:

Bayesian procedures were used to estimate the uncertainty in model estimates of current biomass and in future projections. This procedure was conducted in the following steps:

A. Model parameters were estimated using maximum likelihood and the prior probabilities. All parameters were assumed to have uniform priors. These point estimates represent the mode of the joint posterior distributions of the parameters and are called the MPD estimates;

B. One hundred million samples from the joint posterior distribution of parameters were generated using the Markov chain - Monte Carlo procedure (MCMC) using the Hastings-Metropolis algorithm (Gelman et al. 1995), which were sampled once in every 50,000 draws;

C. For each sample of the posterior, a one-year projection was made for 2005/06 over a catch range of 0 to 2500 t, in 50 t increments. Future recruitment in the model forecasts was generated by assuming that the recruitment anomalies would be average (i.e. $f_{2003} = 0$). This anomaly was then used in the Beverton-Holt stock-recruitment equation (page 8) with the appropriate parameters for each Bayesian draw to calculate the expected recruitment. The catch in 2004/05 was assumed to be 400 t, which is the TAC;

D. A marginal posterior distribution was found for each quantity of interest by integrating the product of the likelihood and the priors over all model parameters; the posterior distributions are described by the mean, median, and 5th and 95th percentiles.

Reference points

Reference points are considered an integral part of the precautionary approach to fisheries management. The reference points define both desirable (target reference points) and undesirable (limit reference points) stock states. Stock assessments produce performance measures that indicate where the stock is relative to the reference points. Fisheries management measures such as TACs should be structured to move the stock away from limit reference points, and toward target reference points, thus maintaining fish stocks in desirable states. Scientific work concerning management frameworks, reference points, and decision rules has received much attention in Canada (Richards and Schnute 1999, Rivard and Rice 2002), and elsewhere throughout the world (NAFO 2004; ICES 1997). (This is by no means a comprehensive listing of relevant references). A common feature of these management frameworks is the consideration of spawning stock biomass and exploitation rate. Such a framework was presented as part of previous Pacific cod stock assessments (Sinclair 2000; Sinclair et al. 2001; Starr et al. 2002).

A Canadian implementation of the Precautionary Approach was developed recently through debate among several government sectors spanning human health to environment and fisheries (A Canadian Perspective on the Precautionary Approach/Principle Discussion Document, http://www.ec.gc.ca/econom/discussion_e.htm). The debate concluded that under the precautionary approach, the absence of full scientific certainty shall not be used as a reason to postpone decisions where there is a threat of serious or irreversible harm. For commercially exploited fish stocks, serious harm was linked to impaired productivity and the inability of a stock to reproduce itself. In other words, to recruitment overfishing and low spawning stock biomass (Rice and Rivard 2002).

Subsequent DFO workshops have investigated various methods of estimating limit reference points associated with recruitment overfishing and serious harm (Rivard and Rice 2002;Vermette and Rice 2004). Most of these methods involve examining stock/recruitment data and fitting both parametric and non-parametric relationships to these data. It was recognized that, in the absence of convincing evidence for decreasing per capita recruitment at low biomass, it is not possible to determine the point at which serious harm occurs without making arbitrary assumptions about the relationship of spawning stock to recruitment. Nonetheless, as an already low biomass level declines further, the risk of serious harm must increase and the options to manage such risk become more limited. Experience, judgment and knowledge of stock specific circumstances are important considerations in setting the technical basis for determining a practical, but necessarily arbitrary, limit reference point in each application. Under these circumstances, the biomass limit reference point can be an effective guide to sound risk management and the application of precaution, particularly when used in conjunction with the trends in biomass and stock productivity. It can signal a state at which the need to reduce risk to the stock should be the pre-eminent concern of management, even though it is not an objectively determined switch below which all mortality associated with fishing should be turned off.

A number of candidate limit reference points have been considered in the literature. One candidate is the biomass which produces half the maximum recruitment. While the arbitrary nature of such a limit is a clear shortcoming, an even greater one is the difficulty fitting a plausible function to stock recruitment data, especially on a stock-by-stock basis. While meta analysis provides some relief from this problem (Myers 2001), it remains daunting. Another approach involves examining the historical stock biomass trajectory to identify a previous low level from which the stock recovered ($B_{recovery}$). Concerns with this approach centre on the potential absence of a suitable biomass history from a period of full exploitation and the impacts of trends in demographic parameters. If these criticisms can be allayed, establishing a limit reference point on the basis of an empirically observed low biomass from which a stock has recovered is attractive because of its simplicity and its basis in observation.

The ADM Fisheries and Aquaculture Management requested that DFO scientific stock assessments for groundfish and pelagic stocks include candidate limit reference points. Our stock assessment model includes an explicit stock/recruitment relationship from which we can estimate the biomass associated with half maximum recruitment (BH50). We also have a reasonably long historical spawning stock biomass trajectory from which $B_{recovery}$ can be identified. We have also gone a step further by examining various biomass target reference points. The assessment model allows the estimation of the biomass that produces maximum sustainable yield (B_{msy}) and the fishing mortality associated with it (F_{msy}). We have also examined the historical mean biomass as a proxy for a target biomass reference point and the average exploitation rate as a proxy for the limit exploitation reference point. The merits and pitfalls of these traditional model-based (BH50, B_{msy}, F_{msy}) and pragmatic observation-based ($B_{recovery}$, B_{avg} and H_{avg}) reference points are discussed.

Results

Hecate Strait

Description of the fishery

Pacific cod are distributed throughout area 5CD mainly at depths less than 150 m. Pacific cod are caught almost entirely in the multispecies bottom trawl fishery where it is one of the principle target species. Other species commonly taken with Pacific cod include arrowtooth flounder, English sole, big skate, Dover sole, and rock sole (Figure 4). Cod density, measured by commercial catch per unit effort, is highest over the Two Peaks/Butterworth, White Rocks, Shell Ground, Reef Island, and Horseshoe fishing grounds (Figure 2).

Annual reported catches of Pacific cod show considerable variability (Figure 5, **Table 6**). There were major peaks in landings in the mid-1960s (9526 t in 1966), the mid-1970s (5521 t in 1975), in 1987 (9562 t) and 1991 (7763 t). The minimum reported catch was 214 t in 2001, which was constrained by a TAC of 200 t. Catches since 1995 have been among the lowest on record.

Discard estimates are presented in **Table 6**. It should be noted that these estimates are considered to be unrepresentative of discarding for the period 1954-1995 because they were obtained from logbooks. Beginning in 1996, the estimates are based on at sea observations by fishery observers (which cover 100% of the A-license fleet) and these are considered to be more accurate. The amounts of Pacific cod reported as discarded have increased in the most recent two or three years from less than 10% of the total catch between 1996 – 2000 to over 20% in 2002 and 2003.

Annual total allowable catches (TACs) were introduced in the 5CD area in 1992. These were managed on a calendar year basis until 1996. Beginning with the 1997-98 period, the fishing year was changed to April 1 to March 31. The original TAC was 3,400 t and landings exceeded this figure by 51% (Table 7). The TAC was increased to 5,100 t in 1993, and then reduced in steps to 1000 t in 1998/99. The low catch in relation to the TAC in 1999/00 led to a carryover of 283 t in 2000/01. The TAC was reduced to 200 t in 2001/02 due to very low assessed stock biomass and no carryovers were allowed. The TAC was maintained at 200 t in 2002/03. The 2003/04 TAC was initially set at 200 t but results from the Hecate Strait Pacific cod monitoring survey, commercial CPUE, and input from the trawl fleet indicated that cod abundance had increased in the area. Consequently, the TAC was increased to 400 t in the winter of 2003/04 and the TAC was maintained at 400 t for 2004/05. As of November 25, 2004, 66% of TAC had been landed.

Other management measures have been used to control the Pacific cod fishery in area 5CD. A voluntary increase in mesh size was suggested for this fishery in 1991 and was then regulated in 1995. There have also been a number of closures instituted in Hecate Strait to protect cod spawning biomass. The Horseshoe and Reef Island fishing grounds as well as the shallow Dogfish Bank were closed from January 1 – April 15 between 1996 and 2000. The closed area was increased in size in 2001 to include all of Hecate Strait south of a line between the latitude of Rose Spit and north of a line just south of Reef Island. This closed all of the main cod fishing grounds except Two Peaks/Butterworth.

The reduced TAC for Pacific cod and the expansion of the spawning closures was accompanied by a reduction of trawl fishing effort in Hecate Strait and a shift of fishing away from areas where cod were traditionally found. There has been considerable variation in fishing effort in waters less than 150 m in Hecate Strait over the years (Figure 6). Effort peaked in the late 1960s (10,945 hours in 1968), the late 1970s (13,108 hours in 1979), and the early 1990s (19,201 hours in 1993). Trawling effort has declined considerably since this last peak and averaged 7,700 hours between 1996 and 2000. There was a further decline to 1993 to 4,158 hours which is close to the historical minimum of 3,829 hours in 1985. Maps for fishing effort distribution indicate a considerable decline in fishing effort on traditional cod fishing grounds and in particular Shell Ground and White Rocks (Figure 7).

Commercial catch per unit effort

Plots of the CPUE indices standardized relative to the mean CPUE for the series do not show a large sensitivity to the analysis assumptions when the plots are viewed for all fishing years (Figure 8; Table 8). However, there is some variation in the most recent (2003/04) index point depending on the analysis, A to D (Figure 9; Table 8). We elected to use analysis D as the best representation of Pacific cod relative biomass in 5CD.

Commercial catch size composition

There was good spatial coverage of at-sea sampling of Pacific cod in the Hecate Strait bottom trawl fishery from 1996 – 2003 (Figure 10). There was also an indication of segregation by size with smaller fish (< 45 cm mean length) dominating samples from the Shell Ground area, intermediate sized fish (45 – 60 cm mean length) in the Two Peaks-Butterworth area, and larger fish (>60 cm mean length) on the Horseshoe.

Samples were taken from both unsorted and the landed portions of catches of Pacific cod in Hecate Strait in all years since 1996. The landed samples were taken both at sea and at shore when the vessels were unloaded. It was possible to estimate the size composition of both the unsorted catch and the landings (kept) in each year. It was also possible to weight these estimated size compositions by the total catch weight of each size category. The unsorted samples would represent the total catch of the vessels while the kept samples would represent those fish retained and landed for sale. In principle, size compositions should match for the size range of fish retained for sale. For Pacific cod, smaller fish are often discarded at sea because of their low commercial value.

There was a reasonable correspondence in the size compositions in most years with the most notable exception in 2001 (Figure 11). In most years, the size composition of fish greater than approximately 45 cm lined up fairly well. However, there were many smaller fish in the unsorted samples that in the kept samples.

A rough estimate of the numbers of cod discarded at each length interval and in each fishing year was derived from the size composition data shown in Figure 11 as follows. First, it was assumed that, if the estimated number of kept fish was greater than the number of unsorted fish, the number of discards was zero and the number of kept fish was equal to the number of unsorted fish. This avoided having a negative estimate of discards. Second, it was assumed that all fish caught over 55 cm in length were kept. The estimated numbers of discarded fish were greatest in 1999, 2002 and 2003 (Figure 12). In each of these years the discard estimates exceeded the kept estimates.

The mean weight of fish in the catch varied between 1.56 kg (1987) and 3.28 kg (1997) (Figure 13). The low mean weight in 1987 corresponds to the recruitment of the very large 1985 year-class. The mean weights in the mid 1990s were the highest in the time series, possibly reflecting low recruitment or a shift to larger mesh size in the commercial fishery.

Hecate Strait Assemblage survey

Two more Hecate Strait assemblage surveys have been conducted since the last assessment document was produced, in 2002 and 2003. The CPUE index from the 2002 survey was the fourth largest in the time series (Figure 14). However, the 95% confidence interval of this estimate overlaps all other estimates except for the very low value in 2000. The 2003 CPUE index was the third lowest in the time series. The 95% confidence interval of this estimate overlaps all others except the high values in 1987 and 1989. As has been noted in past assessments (Sinclair 1999), the Pacific cod abundance indices derived from this survey have a high sampling variance making their interpretation very difficult. This is reflected in the large amount of variability between successive survey mean indices and the large degree of overlap in the individual 95% confidence intervals. In addition, the coefficients of variation of the means range from 21% in 2003 and 52% in 1998.

There were three modes in the cod size composition in the 2002 Hecate Strait assemblage survey, at 30 cm, 47 cm, and 64 cm (Figure 15). The first mode is probably age-1 fish. It is difficult to tell how old the fish in the subsequent modes are because we do not have a reliable age-determination method for Pacific cod at this time. The number of fish near the 30 cm mode in 2002 was comparable to the modes seen in 1991 and 1993 which were not considered to be large year-classes in Hecate Strait. There was again a dominant mode around 30 cm in the 2003 size composition. This appeared to be larger than in 2002 and was similar to that seen in 1995 and 1998.

Hecate Strait Pacific Cod Monitoring Survey

The Hecate Strait Pacific cod monitoring survey was successfully carried out according to its initial plan. There were 544 survey tows, 36 in each month except March, 2002 when there were 40. There were also 56 skipper tows; four each month except March, 2002 when there were none. A summary of results by year, month, and stratum are given in (Annex 4).

The monthly and annual results of the survey are given in Table 9. There was a tendency for surveys in May, June and July to have higher CPUE than surveys in March and April of the same year. An exception occurred in March, 2003. Sampling variation was acceptable. While the monthly CVs varied between 20% - 54% (average 35%), the annual CV was close to 20%. There was a statistically significant increase in the survey index between 2002 and 2003, a factor of almost 3 (Figure 16). There was a further increase in 2004, + 8%. However, given the sampling variability, this is not a statistically significant increase.

The survey caught cod over a range of lengths from 20 – 90 cm. There was a dominant mode at 30 cm in the 2002 and 2003 surveys as was noted in the Hecate Strait assemblage survey (Figure 17). These are likely to be 1-year old fish. There was a much smaller mode at this length in 2004. The 2004 size frequency had 2 modes, at 45 cm and 65 cm. There was a clear increase in abundance of all sizes between 2002 and 2003. This continued to 2004 at the larger sizes (> 40 cm). This pattern is similar to what occurred in the unsorted size composition in the bottom trawl fishery (Figure 11).

Stock Assessment Analysis

Input data for the Hecate Strait model are given in Table 10.

Preliminary "Mode of the Posterior Distribution" (MPD) fits

A range of assumptions were made over six runs to test model performance and to choose candidate runs to move forward into the Bayesian phase of the assessment. These runs ranged from one which was made to emulate the model run used in the previous Hecate St. Pacific cod assessment (Sinclair et al. 2001) to runs which tested the sensitivity of the model to the fixing or estimation of key parameters. In general, it is often best to estimate key parameters in a Bayesian model because the act of fixing a parameter will necessarily remove that parameter from the uncertainty calculations in the MCMC procedure.

The run which emulated the 2001 Hecate Strait Pacific cod assessment model assumed a Ricker stock-recruitment function, estimated the M, h and sea level parameters, and assumed equal variances between the weight and catch input data (Table 11; Table 12). This run was made to provide continuity with the previous assessment but was not carried forward because it was decided that a declining stock-recruitment function at high biomass levels was inappropriate for this species as was the equal weighting between the catch and average weight data. All further investigations used a Beverton-Holt stock-recruitment function which does not decline with increased abundance and increased the effective weight of the catch data relative to the average weight data.

The sensitivity of model results to alternative formulations involving *M* (the natural mortality rate), *h* (the Beverton-Holt "steepness"), *d* (the sea level slope), and the relative weighting of the residuals for catch and mean weight was investigated. The sea level parameter is estimated from data and was only fixed in one run to establish whether the use of this parameter significantly improved the overall model fit. The M parameter is weakly linked to the mean weight data and the assumed growth function. The *h* parameter was not directly linked to the model data and it is unlikely that the available data have information which pertains directly to it. Therefore, estimating either or both of M and *h* can potentially be misleading as the parameters may alias for model mis-specifications or other model-related problems. The sensitivity runs involved either fixing or estimating these parameters. M was fixed at 0.4, a value found for other gadoid stocks (Sinclair 2001). *h* was fixed at 0.75, a value suggested by Myers et al. 2002 for marine fish with life histories similar to Pacific cod. The sea level parameter was fixed at 0.0 (i.e. no effect). Most of the runs used a sigma of catch of 0.10. One trial run was made with a sigma for catch of 0.15 but is not reported.

Model fits were similar for the models which estimated both *M* and *h* (Estimate M,h), fixed *h* (Fixed h) or *M* (Fixed M), or fixed both (Fixed M,h;Table 12; Figure 18; Figure 19). Therefore it is difficult to use model performance to select between these models. The models which estimated the Beverton-Holt "steepness" parameters tended to estimate quite low values for this parameter (less than 0.6; Table 12). It was felt that estimates for the *h* parameter in this range were more appropriate for species which are known to have a strong stock-recruitment effect, such as a salmon species, rather than for a marine fish which has, in the past, recovered quickly to high levels from relatively low levels (Figure 20; Figure 21). It is likely that the low estimates for this parameter are compensating for some model mis-specification such as the knife-edge recruitment assumption. Such compensation may also account for the relatively high estimate for the *M* parameter, but it was thought that this estimate is more realistic than the estimates for the *h* parameter. On the other hand, the model fit improved significantly with the addition of the sea level slope parameter (*d*: by about 19 likelihood units; Table 12), indicating that there is good justification for preferring the models which include this parameter.

Although the model fits were similar between these four models, the management advice which would result from these four models would be quite different, particularly for the model-based traditional reference points. The ratio B_{2005}/B_{msy} ranged from 55% to 184% and the ratio B_{2005}/BH_{50} ranged from 106% to 668% depending on which parameters were estimated and the relative weighting of the catch and mean weight residuals (Table 12). The range in the estimated values of the pragmatic observation-based reference points was much less. In each run, the minimum biomass from which the stock had previously recovered was in 1971. The ratio of B_{2005}/B_{avg} ranged from 48% to 59% and the ratio of B_{2005}/B_{1971} ranged from 71% to 116%. The high sensitivity of the ratios based on model-based reference points and the high degree of uncertainty about the key model parameters that determine them (e.g. *M*, *h*, B_0) indicate their limited utility to provide consistent management advice. However, the robust nature of the observation-based reference points to variations in model formulation and assumptions, coupled with their firm empirical basis, means that the observation-based reference points are more capable of providing consistent management advice.

On the basis of these runs, it was decided to go forward to the Bayesian assessment phase with two runs, the Fixed h and the Estimate M, h runs (Table 12). Population biomass, numbers, recruitment and recruitment deviation estimates from the two models are given in Table 15.

Retrospective analysis

An MPD retrospective analysis was performed on the Fixed h model run (Table 11; Table 12) to test for the effect of the stepwise removal the historical catch and weight data, one year at a time. This was done to test for any large changes in model performance, indicating sensitivity to specific data inputs.

The retrospective analysis did not reveal any major issues with the estimates for the key parameters (Figure 22) or in any of the time series trajectories (Figure 23; Figure 24; Figure 25). The parameter estimates for the *Binit_ratio* and B_0 show reverse trends (one is raising while the other is falling) but this is expected since these parameters are highly correlated. There was a reduction in the *M* parameter between the runs terminating in 2001 and 2000. This was accompanied by an increase in the catchability parameter and an increase in the sea level parameter.

The biomass trends are similar for all the retrospectives for the overlapping years, primarily because these trends are driven by the catch history (Figure 23). There is a downward shift in the biomass series associated with the reduction in the *M* parameter. The shift to lower biomass levels is mirrored by a shift to higher exploitation rates (Figure 24), lower overall recruitments (Figure 25). However, none of these changes indicate a large change or a shift in model behaviour.

It was hoped that this analysis might show whether there was a detectable shift in the data resulting from a change in mesh size regulations that were initiated in Hecate Strait in the early- to mid-1990s (Haist and Fournier 2002; Annex 5). Such a change in mesh size would likely cause a shift in the selectivity by the net gear but a delay-difference model does not accommodate such changes very easily, given the knife-edge recruitment assumption that is required in this formulation. Therefore, it was possible that a shift in the data that could not be accommodated in the model dynamics would result in a shift in the parameter estimates coincident with the regulation change. However, there is no evidence of such a shift in Figure 22.

Bayesian MCMC results

Traces of the MCMC draws for the seven (Fixed h; Figure 26) or eight (Estimate M, h; Figure 27) primary parameters have been plotted to see if the MCMC procedure has reasonably sampled the available parameter space. The lack of trends or sudden shifts in these traces is taken as evidence that the MCMC procedure was successful.

Posterior distributions for the seven (Fixed h; Figure 28) or eight (Estimate M, h; Figure 29) primary parameters show that the distributions are well formed and are centered in most cases near the MPD estimate. The B_0 and the h parameters are skewed while the sea level and M parameters are symmetrical. Note that the posterior distribution for M is shifted to the left of the MPD estimate for both of the model runs investigated, indicating that lower values of M are also consistent with the available data.

Table 16 provides the pairwise correlation coefficients for the main parameters of the Fixed h and Estimate M,h models. This table indicates that there are significant correlations between the M and g parameters with the catch (q_c) and the monitoring survey (q_s) scaling parameters. Such correlations are common in models such as the one developed for this assessment. However, Figure 30 and Figure 31 show that these correlations do not have a significant impact on the estimates of derived parameters of management interest, such as the ratio of the current biomass (B_{2005}) relative to the candidate limit reference biomass (B_{1971}). These figures show that there is no significant correlation between these derived parameters and any of the main model parameters. This is an expected result if the Bayesian search procedure has fully explored the available parameter space.

Posterior distributions for the recruitment deviation parameters (Fixed h; Figure 32; Estimate M, h; Figure 33) show that the data have considerable influence on some of the years while having little effect on others. For both models, the recruitment deviation for the last year (2002) has a broad distribution centered about zero, as would be expected. On the other hand, the recruitment deviation distributions from 1995 to 2000 are all well below zero for both model runs, indicating that recruitment in these years was lower than was predicted by the stock/recruitment relationship mediated through the sea level parameter.

Box plots of the biomass trends for both model runs (Fixed h; Figure 34; Estimate M, h; Figure 35) show very similar trends, indicating that it is the data that are driving this assessment, particularly the catch data. The Estimate M, h (Figure 35) model shows a somewhat less optimistic upturn in the most recent three to four years, compared to the Fixed h model run (Figure 34), probably due to the low value estimated for the Beverton-Holt steepness parameter. Box plots of the surplus production (Fixed h; Figure 36; Estimate M, h; Figure 37) show the same direction of difference between the two model runs. The mean and median values of the parameter estimates are similar, indicating that skewness is not great for either of these model runs (Table 13 and Table 14). Comparison of the biomass levels indicate that the current (2005/06) biomass is similar in level to the 1971/72 biomass level which was the lowest biomass from which the stock had previously recovered.

Projections were made for a single year, starting with the beginning year biomass in 2005/06. This was done in the model by assuming that the current TAC of 400 t will be fully caught. The model is tuned to a biomass estimate collected for the current fishing year from the Hecate Strait monitoring survey. A wide range (0 to 2500 t in 50 t steps) of possible catches for 2005/06 was applied to each of the 2000 MCMC trajectories available for the two model runs. The subsequent beginning year biomass for 2006/07 resulting from each of the catch trials was then tested against five performance indicators to judge the effect of the catch level. These five performance indicators are:

a) Harvest rate in 2005/06 relative to the average harvest rate (1956/57-2003/04);

b) Beginning year biomass in 2006/07 compared to the average biomass (1956/57-2003/04);

c) Beginning year biomass in 2006/07 compared to the beginning year biomass in 2005/06;

d) Beginning year biomass in 2006/07 compared to the beginning year biomass in 1971/72, the lowest biomass in the time series from which the population recovered to a level higher than the average biomass over the period of model reconstruction;

e) Beginning year biomass in 2006/07 compared to the beginning year biomass in 2001/02, the year the TAC was reduced and the lowest biomass in the entire time series.

These pragmatic performance indicators were selected over more traditional reference points such as B_0 or B_{MSY} because these latter indicators are very sensitive to model assumptions for which there is relatively little information.

The results of the catch projections are summarized in the decision tables (Table 17 and Table 18) for the Fixed *h* and Estimate *M, h* models. Cumulative probabilities for desired outcomes of the performance indicators in relation to the 2005/06 TAC are presented. Results for the Fixed *h* model (Table 17) are discussed below to illustrate the utility of the decision tables. The first column gives the probability of the harvest rate being below the long term average. The probability is 100% up to a TAC of 1300 t. The probability then declines to 50% at a TAC of 1800 t. The second column indicates there is 0% probability of the biomass at the beginning of 2006/07 exceeding the long term average for all catches. The third column gives the probability of the stock biomass increasing from 2005/06 to 2006/07. At a TAC of 0 t, there is a 98% probability of an increase. A TAC of 850 t gives an 80% chance of an increase, and a TAC of between 1050 – 1100 t gives a 50% chance. The fourth column gives the probability of the 2006/07 biomass being greater than that in 1971/72, the proposed limit reference point. This is the flattest of the cumulative probability curves indicating that it has the greatest uncertainty. A TAC of 0 t has a 90% probability of the 2006/07 biomass being larger than in 1971/72, declining to 80% at a TAC of 600 t, and to 50% at a TAC of 1850 t. The last column indicates that there is 100% probability of the 2006/07 biomass being greater than in 2001/02 for the entire catch range. The cumulative probabilities for the 2 performance measures of biomass increase and biomass being above that in 1971 from the Fixed *h* and Estimate *M, h* models are compared in Figure 38. The probabilities of the desired outcome (i.e. biomass increasing and biomass greater than 1971) were greater for the Fixed *h* model than for the Estimate *M, h* model for all catches. This indicates the Fixed *h* model was the more optimistic of the two.

We prefer the Fixed *h* model run over the Estimate M, h model run because the low estimated steepness in the latter model is not realistic for a fast-growing marine species such as Pacific cod and that the low estimate for this parameter is probably a function of model misspecification or of data anomalies. It appears that the Hecate Strait Pacific cod biomass has increased since the observed low in 2001/02 and continued growth is possible at TACs below about 1000 t in 2005/06. However, the projected biomass was below the long-term average at all TACs, indicating the stock has not yet recovered to the target. There is also a risk that the 2006/07 biomass will be below that in 1971/72, the proposed limit reference point and this risk increases as the TAC increases.

Model uncertainties

There are two levels of uncertainty in these model results. The uncertainty in the parameter estimates associated with the observed data along with the assumed process error described in Table 11 is explicitly addressed using the Bayesian procedure. Unfortunately, this uncertainty only applies to a single model with one set of model assumptions. Two model runs have been presented in detail but they only represent a small subset of the possible set of "realities" that could have been modeled for this stock.

It is this wide range of potential "realities" which comprises the other major source of model uncertainty. Some examples of this range have presented in Table 11 and were partially explored in Table 12, although there are many other options which would probably give an even much wider range of results. Examples of such further exploration could include different weighting between the catch and average weight data, other types of stock recruitment functions, or even a substantially different modeling approach, such as employing a statistical catch-at-length model.

The potential for alternative interpretations of the Hecate Strait Pacific cod data observations is large and clearly we have not explored very many of these possibilities. The Bayesian methodology works well within a model, allowing for an explicit handling of the uncertainties associated with a specific model run. We have adopted this methodology and applied it to two candidate runs which we feel have some validity as credible interpretations of the available data.

Unfortunately, a procedure that explicitly combines uncertainty across different model runs has not yet been developed. We acknowledge that there is greater uncertainty in this assessment than is presented in Table 13 to Table 18. However, we are not able to do more than to note the existence of this uncertainty at this time.

The assessment model used a fixed growth equation which was initially derived from tagging experiments done in the 1960s. We have assumed that growth is fixed over the time series and that the growth parameters are known without error. It would be worthwhile to reanalyze the historical tagging results and to investigate whether the growth analysis could be integrated into the assessment model, thus capturing the uncertainty associated with the estimation of the growth parameters.

We have also assumed that recruitment to the spawning population and the fishery is knife-edged at age 2. Another way to interpret this assumption is that we have assumed that mortality rates between spawning and age 2 have been constant. This is potentially a serious shortcoming of this model, given the evidence of substantial catches of younger fish (Figure 11) and that the harvest rate has varied considerably over time. It would be illustrative to investigate the possible effects violations of the knife edged recruitment assumption might have on the assessment results.

Queen Charlotte Sound (5AB)

Stock Definition

Queen Charlotte Sound (area 5AB) has been a designated management area for Pacific cod since the late 1970s. While there has been little stock delineation research conducted on Pacific cod in this area, the stock designation was inferred from results of studies conducted in adjacent areas. Pacific cod are considered to be relatively sedentary with little movement among the principle groundfish fishing areas of Hecate Strait (5CD), Queen Charlotte Sound, west coast Vancouver Island (3CD), and the Strait of Georgia (4B). There was a considerable amount of tagging in Hecate Strait, West Coast Vancouver Island, the Strait of Georgia, Puget Sound, and western Washington. But, there has been no tagging in Queen Charlotte Sound (Westrheim 1996). There were 13,086 Pacific cod tagged in Hecate Strait between 1954-1968. Of the 3,588 recoveries 99.7% were reported from Hecate Strait and only 0.1% was reported from Queen Charlotte Sound. There were 24,512 Pacific cod tagged in West Coast Vancouver Island, Strait of Georgia, Puget Sound, and western Washington between 1954 – 1979. Of the 4,380 recoveries 95% came from the area of tagging and 0.2% came from Queen Charlotte Sound. There was some movement of tagged fish among adjacent areas (e.g. Strait of Georgia and Puget Sound), but there was very little to no movement into Queen Charlotte Sound in all of these tagging experiments.

Spawning sites and seasons have been identified for Pacific cod in Hecate Strait, West Coast Vancouver Island, and the Strait of Georgia. No spawning site has been identified in the literature or by fishermen in Queen Charlotte Sound. Various other genetic, meristic and morphometric studies have resolved differences on a much wider spatial scale than the BC coast and very few of these studies have included samples from Queen Charlotte Sound.

There is some evidence of stock differences within 5AB. Westrheim 1987 reported different incidence rates of parabranchial tumors thought to be caused by parasitic infection in 5A and 5B. The incidence was greater in 5A. It was suggested that some stock separation was needed to establish this difference in infection rate. However, the current stock definition has persisted.

Description of the fishery

Pacific cod are caught mainly around the edge of Goose Island Bank in area 5B and on Cape Scott and Mexicana Banks north of Vancouver Island in 5A (Figure 1). The depth range of capture is from 60 – 160 m. Pacific cod are caught almost entirely in the multispecies bottom trawl fishery. Other species caught with Pacific cod include arrowtooth flounder, yellowtail rockfish, Pacific Ocean perch, lingcod, silvergray rockfish, yellowmouth rockfish, and rock sole (Figure 4).

Annual reported catches of Pacific cod in Queen Charlotte Sound show considerable variability (Figure 5, Table 19). There were major peaks in 1957 (3795 t), 1965 (2670 t), 1976 (3926 t), 1979 (4026 t), 1987 (3209 t), and 1991 (2206 t). These peak years may be contrasted with years of low landings in 1961 (423 t), 1970 (359 t), 1983 (184 t), and the minimum on record in 2000 (67 t). Reported catches have increased since 2000 to 351 t in 2003. There was a substantial catch reported by USA vessels from 1955 to 1981. The USA portion of the total catch was over 50% for all of these years.

As was noted in the section on Hecate Strait, the discard estimates for the period 1954-1995 are unrepresentative of true discarding because they were obtained from logbooks. Since then, the discard estimates come from at-sea observers and are considered more accurate. The proportion of the total catch reported as discarded was consistent between 1996 and 2003 between 7% - 17% with no trend.

Annual TACs were introduced for Pacific cod in Queen Charlotte Sound in fishing year 1997 (Table 20). There was no scientific advice for this area. The TAC was initially established at the low end of the range of observed catches. The TAC remained unchanged until 2003/04 when it was increased to 390 t based on input from the fishing industry to Fisheries Management that cod abundance had increased. There were also carryforward amounts in the 1999 – 2004 fishing years. The TACs plus carryforward was not caught between 1997 and 2002, with as low as 18% taken in 2000 and 56% in 2002. The TAC plus carryforward was exceeded by 16% in 2003.

Bottom trawling by Canadian vessels in Queen Charlotte Sound began in the early 1950s. Annual reported fishing effort at depths equal to or less than 150m varied between 1,500 – 5,000 hours between 1956 and 1975 (Figure 39). There was an increase in the mid-1970s to over 6,000 hours. Fishing effort declined to 3,500 hours in the mid-1980s followed by a substantial increase to a maximum of 12,000 hours in 1991. Fishing effort declined again to 4,000 hours in 1997, then increased again to close to 8,000 hours in 2002 and 2003. Bottom trawl fishing effort in Queen Charlotte Sound in the 1 – 150m depth range was always less than that in Hecate Strait, except for 2002 and 2003 (Figure 6). There was also considerable fishing effort by vessels from the USA in the years prior to 1981, however we do not have access to these data at the present time. There was also bottom trawl fishing by Japanese and Soviet vessels in the late 1960s and early 1970s. They were targeting mainly rockfish and likely at depths greater than 150 m. The by-catch of Pacific cod in these fisheries is not known.

Commercial catch per unit effort

Plots of the CPUE indices standardized relative to the mean CPUE for the series based on all effort (Analysis A) and the effort only from key localities (Analysis D) are very similar, while Analyses B and C show lesser peaks in CPUE for the peak years in the 1970s and the early 1990s (Figure 8; Table 8). The CPUE indices for Analysis A are higher for those for Analysis D in 2001/02 and 2002/03, suggesting some movement away from traditional Pacific cod fishing grounds in those years (Figure 9; Table 8).

Commercial catch size composition

There was considerably less sampling of the Pacific cod catches in Queen Charlotte Sound than in Hecate Strait (Annex 3). In addition, there were many more time periods (year and quarter) with no samples or very low numbers of samples (3 or less). There was also a switch from shore-based sampling to at sea sampling, and from kept samples to unsorted samples. The relatively low sampling frequency in Queen Charlotte Sound and the rapid transition between sampling regimes precluded comparisons of length composition estimates from these two types of sampling.

The mean weight of fish in the catch varied between 1.22 kg (2001) and 3.70 kg (1962) (Figure 40). There was an initial increase in mean weight to the maximum in 1962. This was followed by a decline until the early 1970s. Mean weights were variable without trend since then. There were 4 years for which no samples were taken, 1984, 1988, 1992, and 1995.

Analysis

Failure to obtain reasonable results

A model similar to that presented for Hecate Strait (5CD) Pacific cod was attempted for Queen Charlotte Sound (5AB) Pacific cod. This model used an equivalent set of data as was available for the Hecate Strait Pacific cod, including catch data, a CPUE series (expressed as equivalent effort) and a series of average weights. There are no biomass surveys in this area that would be useful for Pacific cod, except for a developing survey which has been run now for two years (in June-July 2003 and 2004). However, two survey points are not sufficiently informative to justify including this information in the model. The Queen Charlotte Sound model did not include likelihood elements associated with surveys and it did not have a sea level effect in the recruitment function. Otherwise the Hecate Strait and Queen Charlotte Sound models were identical.

We were unable to obtain sensible parameter estimates from this model using the 5AB data set. Either the model would estimate a very low overall biomass, with a consequent average harvest rate in excess of 80-90% or the model would estimate that the stock size was so large that the catch was having no effect at all on the underlying biomass. The average harvest rate for this scenario would be less than 1%.

Neither of these scenarios is realistic and we decided to abandon the assessment of this stock. As described above, it is unclear whether this stock should be grouped with either 5CD or 3CD. The time series of CPUE indices are similar between the stocks but this may reflect similar ocean conditions rather than stock synchrony. The historical tagging data indicate that there is little movement between these areas, but this may reflect differential exploitation or tag recovery effort rather than true isolation of stocks.

Comparison of trends between areas

The purpose of this section is to compare time trends in the stock biomass indices (commercial CPUE) and mean weights of fish in the catch. Similar patterns might indicate that similar forces are driving the dynamics of these populations, or that the populations are related.

Commercial catch per unit effort

The CPUE indices for Hecate Strait and Queen Charlotte Sound Pacific cod show a similar trend and produced a highly significant correlation ($r = 0.70$, $p < .0001$). Both series showed peaks in the late 1950s, mid-1960s, early 1970s, and late 1980s. They also had low values in the intervening periods. The largest discrepancy between the two series occurred in the late 1970s when the Hecate Strait CPUE values declined and those from Queen Charlotte Sound remained high. Both series reached historic lows in the early 2000s.

Size composition 5AB 5CD

The mean weight of Pacific cod in the commercial catch was of similar scale, particularly during the period 1965 – 1990. However, the mean weights in 5AB were considerably higher than those in 5CD in the early 1960s, and lower during the latter part of the time series. Overall, there was a decreasing trend in mean weight in 5AB (slope = -0.024 kg yr-1, $p = 0.013$) and an increasing trend in 5CD (slope = 0.007, $p = .044$). The correlation between the two time series was positive but weak ($r = 0.093$, $p = 0.093$).

Discussion and Conclusions

The history of the Hecate Strait Pacific cod fishery is one of pulse fishing with wide variations in harvest rate coinciding with large variations in stock size. There have been three distinct episodes of substantial increases in stock size which followed periods when the harvest rate was low. These increases in stock size were then tracked with an increasing harvest rate. Inevitably the harvest rate peaked after the peak in stock size and the continued high harvest rates exacerbated the subsequent decline in stock size. Of particular note is the period of very high harvest rate in the early 1990s which was followed by the lowest biomass on record during the late 1990s and early 2000s.

There are clear indications of recent increases in stock biomass in Hecate Strait. The reduced TAC for the stock and a shift in fishing pattern has resulted in a reduction in exploitation rate. The increased monitoring effort associated with the Hecate Strait Pacific cod monitoring survey has indicated an increase in stock size between 2002-2004. This is corroborated by an increase in catch per unit effort in the commercial fishery and by the many reports of increased abundance from the fishing industry. The size composition data from the monitoring survey and the commercial fishery are consistent, showing a good abundance of 1-year old fish in 2002 and 2003, which in turn contributed to an increase in spawning stock size. However, the abundance of young fish in 2004 was lower than in the previous 2 years, suggesting that recruitment to the commercial sizes in 2005/06 may be lower. While there has been an increase in stock size, it has not yet reached the long term average biomass level.

One of the objectives of the working paper was to propose candidate limit reference points for this fishery. We have extended this discussion to include both target and limit reference points and examined a number of alternatives. Traditional model-based reference points such as B_{msy} and F_{msy} as well as reference points derived from a stock recruitment relationship (e.g. BH_{50}) were shown to be very sensitive to minor changes in model formulation or assumptions and thus were too unstable to be of practical use to provide consistent management advice. Pragmatic observation-based reference points based on estimates taken from the historical reconstruction of the stock, such as B_{avg}, H_{avg}, and $B_{recovery}$, were shown to be more robust to changes in model assumptions and thus could provide more consistent management advice. These reference points have an intuitive appeal since they are based on empirical observations which can be easily explained to managers and fishermen.

It is also evident from the time series of biomass and harvest rates that stock conditions have varied considerably but there has been no long term trend. This argues in favor of using historical reference levels to guide current management. A possible caveat to this approach is the fact that the extended period of low biomass in the recent years followed a period of very high harvest rates in the early 1990s. Thus, it would seem prudent to manage the TAC so that harvest rates stay away from the high levels observed in the 1990s.

A desirable state (target) would be to have stock biomass near the long term average. This would buffer against potentially dangerous stock declines during periods of poor recruitment and should result in higher production from the stock. The previous minimum biomass from which the stock has recovered to above the long term average occurred in 1971. The estimated stock biomass in 1971 was sensitive to the model formulation. However, the observation that the minimum biomass from which the stock recovered occurred in 1971 was robust to model formulation. The stock reached an historic low in 2001. While there has been some stock growth since then, the population has yet to reach the long term average. Thus, it would be premature to conclude that the stock has recovered from the low biomass in 2001. Based on these observations, we suggest that the biomass in 1971 be used as a candidate limit reference point for this stock. We recommend against using a fixed biomass as the limit since this number will change depending on the assessment model formulation. Rather, we recommend using the biomass in 1971 as the limit from whatever model formulation is used.

How the decision table (Table 17) is used to inform a management decision on the TAC for this stock in 2005/06 will depend on the management objectives and risk tolerance. The limit reference point specifies a stock biomass below which serious harm to the stock may result. In principle, a management decision regarding a limit reference point should be made in a risk averse manner. In other words, the probability that the stock biomass will remain above the limit should be well above 50%. No standard has been set for how high this probability should be. Many will argue it should be close to 90%, while others may choose a lower probability such as 75%. A reasonable short term objective for this stock would be to promote stock rebuilding, given that the current biomass is still below the long term average. The probability that stock size will increase should be above 50% in order to achieve this objective and the rate of rebuilding will be faster with higher rebuilding probabilities.

It was not possible to produce a stock assessment for Pacific cod in Queen Charlotte Sound (5AB). We used a similar modeling approach and input data for this stock as was used for Hecate Strait but numerous attempts to produce a credible result failed. The reasons for this result are unclear at present. One observation is that the time series of catch and catch per unit effort for this stock do not follow a normal pattern for fish stocks. In particular, there was considerable variation in the annual catch during the first 30 years of the time series, but the estimated fishing effort was relatively constant during this period. It is possible that the commercial catch per unit effort time series is biased because we were not able to properly identify those fishing events which were the most likely to indicate variation in cod abundance. There was also a substantial catch by vessels from the USA for which we have no effort data so the Canadian CPUE series was to estimate the effort. Essentially we were forced to assume that the Canadian and USA CPUE were the same. However, if the USA CPUE was higher during those years, then the effort estimates would be biased. The new bottom trawl survey in Queen Charlotte Sound may provide a useful index of cod abundance in the area for future assessments. A second problem is that the stock structure in Queen Charlotte Sound is not well known. There have been no tagging experiments conducted in the area nor have any spawning areas been identified. While there are similarities in CPUE and total catch trends among all three offshore management areas, this is not sufficient to warrant grouping Queen Charlotte Sound with either of the other two.

Recommendations

Management

Hecate Strait

- It is recommended that the stock biomass in 1971/72 be used as a candidate limit reference point for management. This is the previous minimum biomass from which the stock has recovered to a level above the long term average.

- It is recommended that the decisions table from the Fixed *h* model (Table 17) be used as the basis for management decisions regarding TAC for the Hecate Strait stock. Attention should be focused on the probability that the stock biomass will continue to increase and that the biomass after the fishing year will be greater than the biomass in 1971/72, the proposed limit reference point.

Queen Charlotte Sound

It was not possible to produce a stock assessment for Pacific cod in Queen Charlotte Sound. Consequently, there is no management advice for this stock.

Research

- It is recommended that the historical tagging results for Pacific cod be reanalyzed with emphasis on re-estimating growth rates. The incorporation of this analysis in the stock assessment model should be investigated. This analysis would also be useful in planning any future tagging experiments.
- There was a substantial amount of Pacific cod catch reported in Canadian waters by vessels from the USA in the years prior to the extension of fisheries jurisdiction. It is recommended that the original disaggregated catch and effort data be solicited from the USA authorities and analyzed as part of future assessments, particularly for Queen Charlotte Sound.
- It is recommended that further stock identification work be undertaken for the Queen Charlotte Sound area. An initial project would be to document spawning grounds in the area.

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Tables

Table 1. List of data selection criteria used to filter data for the calculation of Pacific cod CPUE indices.

GFCatch (1 April 1956–31 December 1995)		
1.	**“Source”=1 or “Source”=2**	1=“Trawl trip report” 2=“Trawl sales slip or landing record only”
2.	**“Gear” <>4**	4=“Shrimp trawl”
PacHarvest (16 February 1996–31 March 2004)		
3.	“Success code”<=1 and “Success_code”<>NULL	0=“Unknown” 1=“Fully usable”
4.	Dropped all data from Hecate St. monitoring survey (2002-2004)	11 trips dropped representing 412 tows
Both data sources		
5.	All tows or event records with no catch or discard of any species	Includes some tows with “success_code”=0 or “success_code”=1 in PacHarvest
6.	All tows or event records with where depth=NULL or depth=0 or depth>150 m	In GFCatch, all three depth fields (min_depth, avg_depth & max_depth) =0
7.	All tows or event records with where hours_fished=NULL or hours_fished=0	Field names: GFCatch=“time” PacHarv=“duration”

Table 2. Algorithm used to convert depth information in GFCatch into a single usable field.

$\text{Depth}=\frac{(\text{min\_depth}+\text{max\_depth})}{2}$ if min_depth<>0&min_depth<>NULL &max_depth<>0&max_depth<>NULL
Depth=min_depth if max_depth==0||max_depth==NULL
Depth=max_depth if min_depth==0||min_depth==NULL
Depth (m)=Depth(fathoms) * 1.8288

Table 3. Description of the four CPUE analyses performed on Pacific cod catches from Hecate Strait (5CD) and Queen Charlotte Sound (5AB). Analyses A to C were performed on catch and effort data from all of 5AB or 5CD while Analysis D was performed on the areas listed in Table 4.

A.	Catch and effort are summed without regard to target species or location of capture. This analysis is a continuation of the CPUE analysis provided for the 2001 Hecate St. assessment.
B.	Catch and effort are summed as in Analysis A up to 31 March 2001 (the end of the 2000/01 fishing year). After that date (when the TAC was dropped to 200 t) only tows which captured pacific cod are included in the analysis to allow for the fact that fishermen were actively avoiding Pacific cod after that date.
C.	Only catch and effort from tows or events which actually caught Pacific cod are included in the analysis.
D.	All catch and effort in the key pacific cod localities (Table 4) were included in the analysis.

Table 4. DFO localities used to define “key Pacific cod areas” for Queen Charlotte Sound and Hecate Strait Pacific cod.

DFO Major Stat	DFO Minor Stat	DFO Locality Name	DFO Locality
Queen Charlotte Sound (5AB)			
5	11	Cape Scott Spit	2
5	11	Mexicana	3
5	11	Topknot	4
6	8	NE Goose	1
6	8	SE Goose	2
6	8	NW Goose	3
6	8	SW Goose	4
Hecate Strait (5CD)			
7	2	Reef Island	3
7	2	West Horseshoe	1
7	6	East Horseshoe	10
8	4	Two Peaks	2
8	4	Butterworth	1
8	5	White Rocks	1
8	5	Shell Ground	3

Table 5: Criteria used to select length frequency samples of Pacific cod from the GFBio database to estimate the size composition of bottom trawl catches.

1.	**TRIP_SUB_TYPE = 1 or 4**	1=Non-observed domestic 4=observed domestic
2.	**SPECIES_CODE = 222**	Pacific cod
3.	**ACTIVITY_CODE is null**	To avoid samples taken during the Hecate Strait Pacific cod monitoring survey
4.	**GEAR_CODE = 1**	Bottom trawl
5.	**SPECIES_CATEGORY_CODE = 1 or 3**	1=unsorted 3=keepers
6.	**SAMPLE_TYPE_CODE = 1 or 2 or 6 or 7**	1=total catch 2=random 6=random from randomly assigned set 7=random from set after randomly assigned set
7.	**SAMPLE_ID <> 173726, 173740, 191471, 184243, 184159, 215903, 223726**	These samples were coded as being from Pacific cod but have a size composition inconsistent with the species. These samples were therefore excluded from further analysis.

Table 6: Reported catch of Pacific cod in area 5CD by Canada and the USA, 1954-2003. The reported discards for the period 1954-1995 are unrepresentative of true discarding because the estimates were taken from logbooks. Discard estimates since 1996 are based on at-sea observations and are considered to be more representative of true discarding.

	Canada			USA	
FYear	Discard	Landed	Catch	5CD	Total
1954	0	847	847	0	847
1955	0	549	549	283	833
1956	0	1299	1299	998	2297
1957	0	2041	2041	1573	3614
1958	0	2800	2800	2789	5589
1959	0	1887	1887	1816	3703
1960	0	1647	1647	606	2254
1961	0	1376	1376	206	1582
1962	0	1897	1897	231	2128
1963	0	2421	2421	333	2754
1964	0	6093	6093	465	6558
1965	0	8622	8622	474	9096
1966	172	8756	8928	598	9526
1967	343	5585	5928	481	6409
1968	101	3932	4033	56	4088
1969	8	2557	2565	18	2583
1970	0	1189	1190	13	1203
1971	21	1315	1336	1	1337
1972	0	2900	2900	5	2905
1973	7	3826	3833	9	3842
1974	65	5320	5385	0	5385
1975	99	5422	5521	0	5521
1976	24	4172	4196	0	4196
1977	128	3460	3587	0	3587
1978	101	2301	2402	0	2402
1979	231	5517	5748	0	5748
1980	53	4237	4291	0	4291
1981	29	2657	2686	0	2686
1982	6	2526	2531	0	2531
1983	66	2301	2366	0	2366
1984	7	1722	1728	0	1728
1985	6	1049	1055	0	1055
1986	103	3723	3826	0	3826
1987	36	9526	9562	0	9562
1988	2	6188	6190	0	6190
1989	36	3434	3469	0	3469
1990	201	3407	3608	0	3608
1991	59	7705	7763	0	7763
1992	35	5234	5269	0	5269
1993	2	3386	3388	0	3388
1994	1	1170	1171	0	1171
1995	1	1022	1024	0	1024

	Canada			USA	
FYear	Discard	Landed	Catch	5CD	Total
1996	69	1070	1139	0	1139
1997	78	1115	1193	0	1193
1998	33	843	876	0	876
1999	39	577	616	0	616
2000	20	495	515	0	515
2001	31	183	214	0	214
2002	72	199	270	0	270
2003	101	357	458	0	458

Table 7: Summary of recommended yields, TACs and landings for Pacific cod in area 5D

Year	Assessment Advice	TAC	Carryover	Landings	Percent of TAC+Carryover Landed
2004/05	No new advice	400		152	38% Jun. 30
2003/04	increased to 400t in Jan 2004	400		357	89%
2002/03	Decision table	200		199	100%
2001/02	Substantial reduction in catch	200		183	92%
2000/01	No new advice	1000	283	495	39%
1999/00	600-1500	1000	230	577	47%
1998/99	No directed fishery	1000		843	84%
1997/98	L: 1075 H:2165	1620		1115	69%
1996	0	by-catch only		660	
1995	L: 1870 M: 3040 H: 5520	1870		1329	71%
1994	L: 1670 M: 3850 H: 7790	3850		1566	41%
1993	L: 3200 H: 6500	5100		3986	78%
1992	L: 600 M: 2800 H: 3800	3400		5138	151%

Table 8. CPUE indices (kg/h) for Queen Charlotte Sound and Hecate Strait Pacific cod. The analyses in this table are described in Table 3.

	Queen Charlotte Sound (5AB)				Hecate Strait (5CD)			
Fishing year	**Analysis A**	**Analysis B**	**Analysis C**	**Analysis D**	**Analysis A**	**Analysis B**	**Analysis C**	**Analysis D**
56/57	99	99	151	99	195	195	369	228
57/58	213	213	294	213	316	316	543	279
58/59	107	107	200	107	465	465	655	569
59/60	160	160	231	160	354	354	397	470
60/61	85	85	129	85	284	284	328	300
61/62	45	45	73	45	210	210	254	231
62/63	58	58	97	58	273	273	313	311
63/64	51	51	87	51	496	496	545	545
64/65	176	176	275	176	875	875	964	940
65/66	263	263	372	263	894	894	925	873
66/67	210	210	316	213	825	825	917	896
67/68	119	119	198	117	651	651	753	691
68/69	99	99	152	100	330	330	382	308
69/70	50	50	72	51	253	253	290	298
70/71	35	35	67	36	122	122	151	158
71/72	78	78	113	79	157	157	193	182
72/73	202	202	228	205	425	425	453	514
73/74	216	216	246	215	649	649	725	782
74/75	255	255	281	255	823	823	860	958
75/76	280	280	303	279	559	559	607	652
76/77	258	258	275	252	348	348	394	397
77/78	167	167	191	161	313	313	355	345
78/79	254	254	298	253	244	244	308	263
79/80	275	275	332	271	405	405	464	464
80/81	198	198	237	200	331	331	388	377
81/82	130	130	165	129	266	266	318	297
82/83	94	94	133	94	365	365	420	421
83/84	28	28	48	27	342	342	408	384
84/85	52	52	78	49	238	238	287	267
85/86	44	44	70	45	203	203	246	175
86/87	35	35	52	34	644	644	743	724
87/88	314	314	374	316	1035	1035	1157	1110
88/89	204	204	257	203	613	613	721	681
89/90	87	87	115	87	307	307	377	374
90/91	63	63	90	63	317	317	409	374
91/92	185	185	348	187	438	438	643	440
92/93	144	144	268	137	292	292	458	358
93/94	110	110	224	103	172	172	309	209
94/95	47	47	116	43	97	97	192	129
95/96	18	18	53	18	100	100	205	115
96/97	20	20	51	21	111	111	148	141
97/98	27	27	57	28	166	166	206	200
98/99	19	19	39	20	114	114	154	156
99/00	15	15	37	15	75	75	105	83
00/01	7	7	25	7	74	74	110	102
01/02	15	54	54	6	32	58	58	43

Fishing year	Queen Charlotte Sound (5AB) Analysis A	Analysis B	Analysis C	Analysis D	Hecate Strait (5CD) Analysis A	Analysis B	Analysis C	Analysis D
02/03	20	54	54	13	49	71	71	70
03/04	33	82	82	32	93	131	131	149

Table 9: Monthly and annual mean catch per unit effort (kg hr-1), standard deviation, lower and upper bounds of the 90% confidence interval and coefficient of variation from the Hecate Strait Pacific cod monitoring survey, 2002-2004.

YEAR	MONTH	MEAN	STD	LOW	HI	CV
2002	Mar	25.05	5.90	15.95	35.39	24%
2002	Apr	61.51	22.95	30.04	100.73	37%
2002	May	182.26	84.56	62.48	312.79	46%
2002	Jun	143.33	65.59	62.57	248.84	46%
2002	Jul	111.02	33.35	61.21	167.25	30%
	Annual	104.63	22.91	70.71	141.96	22%
2003	Mar	268.46	124.31	84.00	476.23	46%
2003	Apr	95.39	24.87	63.52	130.80	26%
2003	May	165.44	73.15	69.61	282.95	44%
2003	Jun	253.58	138.05	55.44	465.07	54%
2003	Jul	729.80	295.60	312.40	1224.20	41%
	Annual	302.53	71.52	198.53	419.58	24%
2004	Mar	120.57	24.44	85.35	160.47	20%
2004	Apr	81.22	16.71	57.87	108.97	21%
2004	May	531.91	131.49	350.53	739.41	25%
2004	Jun	377.24	96.57	232.23	532.25	26%
2004	Jul	526.29	204.60	240.90	859.71	39%
	Annual	327.45	52.67	247.12	408.67	16%

Table 10: Input data for delay difference model of Pacific cod in Hecate Strait.

Year	C_t	E_t	w_t	n_t	$T_{index,t}$	$T_{s,t}$	$S_{index,t}$	$S_{s,t}$
1956	2297	10072	2.550	0.000				
1957	3614	12952	2.281	0.000				
1958	5589	9822	2.409	0.000				
1959	3703	7879	2.320	0.000				
1960	2254	7513	2.403	0.000				
1961	1582	6848	2.472	0.000				
1962	2128	6843	2.271	-1.123				
1963	2754	5053	2.123	-0.627				
1964	6558	6976	2.011	-0.439				
1965	9096	10419	2.493	-1.217				
1966	9526	10632	2.637	0.108				
1967	6409	9276	2.383	-0.382				
1968	4088	13274	2.660	0.676				
1969	2583	8668	2.526	-0.226				
1970	1203	7612	2.697	0.163				
1971	1337	7348	2.169	-1.597				
1972	2905	5652	1.724	-0.904				
1973	3842	4913	2.177	0.442				
1974	5385	5621	2.063	-0.721				
1975	5521	8467	2.272	-0.764				
1976	4196	10569	2.203	-0.380				
1977	3587	10398	1.817	-0.049				
1978	2402	9133	2.325	0.746				
1979	5748	12389	1.991	-0.838				
1980	4291	11382	2.102	0.079				
1981	2686	9042	2.066	1.480				
1982	2531	6013	2.404	-0.658				
1983	2366	6162	2.595	2.285				
1984	1728	6473	2.262	1.008	27	0.34		
1985	1055	6028	2.705	-1.180				
1986	3826	5285	2.324	0.000				
1987	9562	8614	1.560	0.951	100	0.37		
1988	6190	9090	2.268	-0.306				
1989	3469	9276	2.663	-1.596	105	0.43		
1990	3608	9648	2.166	-0.451				
1991	7763	17644	2.170	-0.746	25	0.30		
1992	5269	14717	2.550	2.854				
1993	3388	16212	2.951	1.692	29	0.26		
1994	1171	9077	3.201	-0.267				
1995	1024	8900	2.992	0.254	36	0.48		
1996	1139	8081	2.829	-0.399	29	0.39		
1997	1193	5967	3.283	-0.528				
1998	876	5615	2.836	2.033	101	0.52		
1999	616	7421	2.730	0.418				
2000	515	5044	2.808	-0.018	12	0.23		
2001	214	4973	2.386	-0.415				
2002	270	3864	2.000	-0.098	56	0.30	105	0.22

$Year$	C_t	E_t	w_t	n_t	$T_{index,t}$	$T_{s,t}$	$S_{index,t}$	$S_{s,t}$
2003	458	3076	2.296	0.353	26	0.22	303	0.24
2004	400			0.389			328	0.16

Table 11. List of model assumptions tested with alternative model runs.

Run name	Parameters	Data weight (CVs)
All models	Estimate B_0, g, q_c, q_t, q_s, and 47 * f_t	$s_w = 0.2$; $s_{t,2} = 0.68$; $s_{V,2} = 0$
Fixed h	$h = 0.75$; estimate M, d	$s_c = 0.1$
Estimate M, h	estimate h, M, d	$s_c = 0.1$
Fixed d	$h = 0.75$; $d = 0$; estimate M	$s_c = 0.1$
Fixed M	$M = 0.4$; estimate h, d	$s_c = 0.1$
Fixed M, h	$h = 0.75$; $M = 0.4$; estimate d	$s_c = 0.1$
Ricker S-R	estimate h, M, d	$s_c = 0.2$

Table 12. MPD results for alternative model runs of the Hecate Strait Pacific cod delay-difference model based on model runs to 2004/05 and a projection over a range of catches for 2005/06. All biomass estimates are expressed as beginning year. Fixed parameters are shown in grayed cells. NA: not applicable or not calculated. NP: no catch will raise B_{fyear} above B_{msy}. –; not reported.

	Fixed h	**Estimate** M, h	**Fixed** d	**Fixed** M	**Fixed** M, h	**Ricker S-R**
Parameters						
g	0.695	0.610	0.758	0.331	0.390	0.410
B_0	23006	23175	30593	26024	21726	33179
M	0.596	0.567	0.621	0.400	0.400	0.321
q_c	2.192E-05	2.519E-05	1.487E-05	4.239E-05	4.250E-05	3.350E-05
q_t	2.888E-03	3.348E-03	1.984E-03	5.685E-03	5.645E-03	4.782E-03
q_s	2.660E-02	3.269E-02	1.826E-02	5.700E-02	5.329E-02	4.639E-02
h	0.75	0.53	0.75	0.57	0.75	3.56
d	-5.612E-01	-5.297E-01	0.000E+00	-5.340E-01	-5.783E-01	-4.885E-01
Likelihoods						
Weight	25.766	24.609	18.825	21.176	22.341	-20.241
Catch	-4.984	-2.419	7.056	3.899	1.237	32.929
Hecate St_assemblage	12.494	12.651	12.078	13.045	12.959	12.526
Hecate St_monitoring	-0.889	-0.728	-0.661	-0.497	-0.652	1.650
Recruitment deviations	89.111	85.604	103.187	85.259	89.594	30.407
Total likelihood	121.496	119.717	140.484	122.881	125.479	57.270
ratio: obs_catch/pred_catch	1.041	1.041	1.053	1.040	1.040	1.094
Derived Reference Parameters						
F_{msy}	0.656	0.354	0.703	0.259	0.384	0.193
B_{msy}	7,584	8,861	10,053	9,681	7,207	15,388
F_{crash}	0.000	1.586	0.000	1.031	0.000	0.464
B_{2005}/B_0	61%	46%	68%	25%	35%	22%
B_{2005}/B_{msy}	184%	120%	206%	67%	105%	46%
U_{avg}	13%	15%	9%	25%	25%	21%
B_{avg}	24,924	21,685	35,950	12,794	12,774	14,272
B_{1971}	12,674	11,165	18,309	6,630	6,541	11,321
B_{2001}	4,297	3,695	6,652	2,207	2,238	3,387
B_{2005}/B_{avg}	56%	49%	57%	50%	59%	50%
B_{2005}/B_{1971}	110%	95%	113%	97%	116%	63%
B_{2005}/B_{2001}	325%	288%	311%	292%	338%	211%
Standard deviation of standardised residuals from data fit						
SD_{weight}	1.146	1.123	1.137	1.150	1.175	0.641
SD_{catch}	1.600	1.633	1.750	1.712	1.679	1.659
$SD_{hecate\_assemblage}$	1.029	1.044	0.987	1.081	1.073	1.032
$SD_{hecate\_monitoring}$	1.069	1.142	1.171	1.239	1.175	1.917

Table 13. Model parameter and derived parameter estimates (mean, median and 90% confidence bounds) for the "Fixed h "model based on 100,000,000 MCMC draws sampled every 50,000 iterations.

	p(5%)	Median	Mean	p(95%)
Total likelihood	140.48	148.26	148.58	157.97
Model Parameters				
g	0.477	0.675	0.678	0.893
B_0	18,912	21,078	22,242	29,457
M	0.450	0.557	0.555	0.657
q_c	1.400E-05	2.510E-05	2.520E-05	3.740E-05
q_t	1.755E-03	3.447E-03	3.611E-03	5.913E-03
q_s	1.667E-02	3.147E-02	3.225E-02	5.088E-02
d	-0.719	-0.558	-0.559	-0.403
Derived biomass indicators				
B_{1971}	7,204	11,150	12,031	20,108
B_{2001}	2,548	3,761	4,101	6,840
B_{2005}	7,871	12,164	13,079	21,401
$B_{\mathrm{Avg}_{56\text{-}03}}$	14,681	21,703	23,555	38,579
$U_{\mathrm{Avg}_{56\text{-}03}}$	0.08	0.15	0.15	0.22
$B_{2005}/B_{\mathrm{Avg}_{56\text{-}03}}$	0.44	0.55	0.56	0.70
B_{2005}/B_{1971}	0.84	1.09	1.10	1.43
B_{2005}/B_{2001}	2.54	3.17	3.22	4.07
$\sum_{t=1}^{N} C_t / \sum_{t=1}^{N} \hat{C}_t$	1.01	1.04	1.04	1.07
B_{2005}/B_0	0.40	0.57	0.58	0.77
$B_{2005}/B_{\mathrm{MSY}}$	1.21	1.73	1.75	2.34
B_{MSY}	6,273	6,979	7,343	9,617
Standard deviation of normalised residuals				
SD_{weight}	1.12	1.20	1.20	1.27
SD_{catch}	1.61	1.75	1.76	1.92
$SD_{hecate\_assemblage}$	0.98	1.04	1.04	1.09
$SD_{hecate\_monitoring}$	0.79	1.18	1.18	1.58

Table 14. Model parameter and derived parameter estimates (mean, median and 90% confidence bounds) for the “Estimate M, h ”model based on 100,000,000 MCMC draws sampled every 50,000 iterations.

	p(5%)	Median	Mean	p(95%)
Total likelihood	138.93	146.92	147.30	156.92
Model Parameters				
g	0.383	0.609	0.615	0.865
B_0	20,033	22,818	23,358	28,268
M	0.434	0.541	0.540	0.643
q_c	1.570E-05	2.680E-05	2.700E-05	3.920E-05
q_t	1.928E-03	3.753E-03	3.907E-03	6.322E-03
q_s	1.960E-02	3.557E-02	3.649E-02	5.668E-02
h	0.418	0.539	0.554	0.739
d	-0.685	-0.521	-0.524	-0.367
Derived biomass indicators				
B_{1971}	7,085	10,536	11,302	18,057
B_{2001}	2,352	3,490	3,749	6,007
B_{2005}	6,368	9,974	10,714	17,914
$B_{\mathrm{Avg}_{56\text{-}03}}$	13,966	20,272	21,801	34,559
$U_{\mathrm{Avg}_{56\text{-}03}}$	0.09	0.16	0.16	0.23
$B_{2005}/B_{\mathrm{Avg}_{56\text{-}03}}$	0.38	0.49	0.49	0.63
B_{2005}/B_{1971}	0.72	0.94	0.96	1.26
B_{2005}/B_{2001}	2.21	2.82	2.87	3.70
$\sum_{t=1}^{N} C_t / \sum_{t=1}^{N} \hat{C}_t$	1.01	1.04	1.04	1.07
B_{2005}/B_0	0.27	0.45	0.46	0.67
$B_{2005}/B_{\mathrm{MSY}}$	0.69	1.17	1.22	1.94
B_{MSY}	6,963	8,714	8,825	10,986
Standard deviation of normalised residuals				
SD_{weight}	1.10	1.17	1.18	1.25
SD_{catch}	1.63	1.79	1.79	1.94
$SD_{hecate\_assemblage}$	0.99	1.05	1.05	1.11
$SD_{hecate\_monitoring}$	0.80	1.24	1.24	1.70

Table 15: Mature population biomass and numbers, recruitment, and recruitment deviations from the MPDfits for the Fixed h and Estimate M,h delay difference models for Hecate Strait.

	Fixed *h*				Estimate *M,h*			
Year	B_t	N_t	R_t	f_t	B_t	N_t	R_t	f_t
1956	15984	7496	13961	1.095	14141	6411	12208	1.120
1957	22137	17275	3625	-0.286	19293	15031	3190	-0.311
1958	29362	21129	3218	-0.427	25407	18364	2891	-0.472
1959	27180	13016	3994	-0.205	23552	11327	3570	-0.245
1960	21724	9254	9108	0.637	18999	8162	7934	0.605
1961	17903	8320	17460	1.306	15826	7403	14909	1.285
1962	20209	13055	34026	1.331	17877	11470	28704	1.312
1963	31213	23653	10292	0.380	27216	20388	9178	0.338
1964	57522	45697	8226	0.232	49517	38891	7571	0.154
1965	61814	31907	6216	-0.487	53470	27693	5511	-0.585
1966	49243	22222	2860	-0.511	42853	19660	2646	-0.590
1967	36817	15918	3287	-0.634	32169	14047	2962	-0.694
1968	26319	10019	1996	-0.518	23183	8957	1819	-0.558
1969	17613	7415	4848	-0.101	15461	6601	4115	-0.115
1970	13135	5375	25175	1.801	11654	4831	21933	1.857
1971	12674	7355	18957	0.534	11165	6378	15003	0.561
1972	30677	28626	8910	0.081	26800	24941	7888	0.042
1973	47880	32897	3379	-0.156	40796	27279	3192	-0.219
1974	50189	25190	5219	-0.376	42959	21568	4688	-0.458
1975	40579	15654	6480	-0.174	35338	13816	5752	-0.248
1976	29965	12385	5414	-0.121	26367	11023	4775	-0.179
1977	23959	11895	15243	1.116	21113	10546	13401	1.077
1978	20642	10634	3434	0.084	18165	9381	3106	0.073
1979	27175	20041	8654	0.097	23910	17631	7494	0.050
1980	24284	11853	7880	0.527	21224	10430	6703	0.451
1981	23070	13745	1978	-0.065	20036	11937	1823	-0.096
1982	24018	14094	3906	-0.588	20738	12098	3370	-0.622
1983	20957	8787	1234	-0.077	18302	7724	1141	-0.115
1984	17643	8138	38932	2.675	15522	7124	33659	2.639
1985	13572	5126	11359	0.247	12050	4575	9032	0.247
1986	41187	41408	3959	-0.239	35910	35889	3692	-0.289
1987	55038	31685	2726	-0.090	47593	26861	2636	-0.161
1988	44701	18419	8297	0.325	38566	15963	7317	0.222
1989	30876	11044	13029	0.073	26906	9841	11755	0.074
1990	25484	13264	3941	-0.467	22400	11738	3646	-0.451
1991	28643	18946	3102	-0.880	25441	16980	2810	-0.896
1992	22249	11034	851	-0.134	19487	9825	812	-0.170
1993	16214	7507	1872	0.033	14143	6658	1637	0.006
1994	10037	3752	5334	0.049	8680	3324	4462	0.153
1995	7731	3567	1968	-0.606	6749	3138	1594	-0.485
1996	9629	6951	1378	-1.371	8260	5885	1156	-1.245
1997	9881	5178	1157	-1.623	8367	4319	981	-1.484
1998	8672	3882	586	-0.843	7351	3265	498	-0.747
1999	7162	3049	853	-1.333	6111	2589	711	-1.155
2000	5306	2014	2295	-0.512	4538	1717	1886	-0.245

	Fixed h				Estimate M,h			
Year	B_t	N_t	R_t	f_t	B_t	N_t	R_t	f_t
2001	4297	1847	5365	0.179	3695	1569	4358	0.508
2002	4963	3207	4014	0.022	4216	2672	2552	0.059
2003	8835	6989	3505		7364	5733	2561	
2004	12217	7615	3626		9601	5563	2821	
2005	13964	7522	4595		10648	5548	3610	

Table 16. Pairwise correlation coefficients for the main parameters of the Fixed *h* and Estimate *M,h* models calculated from the 2000 draws which form the posterior distributions for each model. Parameters pairs with correlations greater than ABS(0.8) have been coloured grey.

	g	B_0	q_c	q_t	q_s	M	h	d
Fixed *h* model								
g	1.000							
B_0	0.630	1.000						
q_c	-0.840	-0.777	1.000					
q_t	-0.627	-0.599	0.744	1.000				
q_s	-0.725	-0.696	0.883	0.664	1.000			
M	0.774	0.687	-0.903	-0.695	-0.815	1.000		
d	0.031	0.199	-0.131	-0.091	-0.114	0.053	NA	1.000
Estimate *M,h* model								
g	1.000							
B_0	0.268	1.000						
q_c	-0.875	-0.435	1.000					
q_t	-0.646	-0.341	0.739	1.000				
q_s	-0.775	-0.355	0.879	0.659	1.000			
M	0.823	0.367	-0.914	-0.682	-0.815	1.000		
h	0.166	-0.210	-0.043	-0.027	-0.131	0.036	1.000	
d	-0.027	0.263	-0.087	-0.051	-0.030	0.027	-0.187	1.000

Table 17. Probabilities associated with five performance measures for the "Fixed h "model resulting from the range of simulated catch levels applied in 2005 based on 100,000,000 MCMC draws sampled every 50,000 iterations.

Catch (t)	$U_{2005} < U_{avg}$	$B_{2006} > B_{avg}$	$B_{2006} > B_{2005}$	$B_{2006} > B_{1971}$	$B_{2006} > B_{2001}$
0	1.00	0.00	0.98	0.90	1.00
50	1.00	0.00	0.98	0.89	1.00
100	1.00	0.00	0.98	0.89	1.00
150	1.00	0.00	0.98	0.88	1.00
200	1.00	0.00	0.98	0.88	1.00
250	1.00	0.00	0.97	0.87	1.00
300	1.00	0.00	0.97	0.86	1.00
350	1.00	0.00	0.97	0.85	1.00
400	1.00	0.00	0.96	0.84	1.00
450	1.00	0.00	0.95	0.83	1.00
500	1.00	0.00	0.94	0.83	1.00
550	1.00	0.00	0.93	0.81	1.00
600	1.00	0.00	0.91	0.80	1.00
650	1.00	0.00	0.90	0.79	1.00
700	1.00	0.00	0.87	0.78	1.00
750	1.00	0.00	0.85	0.78	1.00
800	1.00	0.00	0.83	0.77	1.00
850	1.00	0.00	0.80	0.76	1.00
900	1.00	0.00	0.75	0.75	1.00
950	1.00	0.00	0.69	0.74	1.00
1000	1.00	0.00	0.63	0.73	1.00
1050	1.00	0.00	0.55	0.71	1.00
1100	1.00	0.00	0.46	0.70	1.00
1150	1.00	0.00	0.36	0.69	1.00
1200	1.00	0.00	0.26	0.68	1.00
1250	1.00	0.00	0.18	0.67	1.00
1300	0.99	0.00	0.12	0.65	1.00
1350	0.98	0.00	0.07	0.64	1.00
1400	0.97	0.00	0.05	0.62	1.00
1450	0.94	0.00	0.03	0.61	1.00
1500	0.91	0.00	0.02	0.60	1.00
1550	0.85	0.00	0.02	0.59	1.00
1600	0.79	0.00	0.02	0.57	1.00
1650	0.72	0.00	0.01	0.56	1.00
1700	0.64	0.00	0.01	0.55	1.00
1750	0.55	0.00	0.01	0.53	1.00
1800	0.47	0.00	0.00	0.52	1.00
1850	0.38	0.00	0.00	0.51	1.00
1900	0.31	0.00	0.00	0.49	1.00
1950	0.26	0.00	0.00	0.48	1.00
2000	0.20	0.00	0.00	0.46	1.00
2050	0.15	0.00	0.00	0.45	1.00
2100	0.12	0.00	0.00	0.44	1.00
2150	0.09	0.00	0.00	0.43	1.00
2200	0.07	0.00	0.00	0.42	1.00
2250	0.05	0.00	0.00	0.41	1.00
2300	0.04	0.00	0.00	0.39	1.00
2350	0.03	0.00	0.00	0.39	1.00
2400	0.02	0.00	0.00	0.37	1.00
2450	0.01	0.00	0.00	0.36	1.00
2500	0.01	0.00	0.00	0.34	1.00

Table 18. Probabilities associated with five performance measures for the "Estimate M, h" model resulting from the range of simulated catch levels applied in 2005 based on 100,000,000 MCMC draws sampled every 50,000 iterations.

Catch (t)	$U_{2005} < U_{avg}$	$B_{2006} > B_{avg}$	$B_{2006} > B_{2005}$	$B_{2006} > B_{1971}$	$B_{2006} > B_{2001}$
0	1.00	0.00	0.99	0.57	1.00
50	1.00	0.00	0.99	0.56	1.00
100	1.00	0.00	0.98	0.54	1.00
150	1.00	0.00	0.98	0.53	1.00
200	1.00	0.00	0.97	0.52	1.00
250	1.00	0.00	0.97	0.50	1.00
300	1.00	0.00	0.95	0.49	1.00
350	1.00	0.00	0.94	0.47	1.00
400	1.00	0.00	0.93	0.46	1.00
450	1.00	0.00	0.91	0.45	1.00
500	1.00	0.00	0.89	0.43	1.00
550	1.00	0.00	0.85	0.42	1.00
600	1.00	0.00	0.82	0.40	1.00
650	1.00	0.00	0.75	0.39	1.00
700	1.00	0.00	0.68	0.38	1.00
750	1.00	0.00	0.60	0.37	1.00
800	1.00	0.00	0.52	0.36	1.00
850	1.00	0.00	0.43	0.35	1.00
900	1.00	0.00	0.34	0.34	1.00
950	1.00	0.00	0.27	0.32	1.00
1000	1.00	0.00	0.20	0.32	1.00
1050	1.00	0.00	0.15	0.30	1.00
1100	0.99	0.00	0.11	0.29	1.00
1150	0.98	0.00	0.08	0.28	1.00
1200	0.97	0.00	0.05	0.27	1.00
1250	0.94	0.00	0.04	0.26	1.00
1300	0.90	0.00	0.03	0.25	1.00
1350	0.84	0.00	0.02	0.24	1.00
1400	0.78	0.00	0.01	0.23	1.00
1450	0.69	0.00	0.01	0.22	1.00
1500	0.60	0.00	0.01	0.20	1.00
1550	0.52	0.00	0.00	0.20	1.00
1600	0.44	0.00	0.00	0.19	1.00
1650	0.35	0.00	0.00	0.18	1.00
1700	0.28	0.00	0.00	0.17	1.00
1750	0.22	0.00	0.00	0.17	1.00
1800	0.17	0.00	0.00	0.16	1.00
1850	0.14	0.00	0.00	0.16	1.00
1900	0.11	0.00	0.00	0.14	1.00
1950	0.08	0.00	0.00	0.14	1.00
2000	0.06	0.00	0.00	0.13	1.00
2050	0.05	0.00	0.00	0.12	1.00
2100	0.04	0.00	0.00	0.12	1.00
2150	0.03	0.00	0.00	0.11	1.00
2200	0.02	0.00	0.00	0.11	1.00
2250	0.02	0.00	0.00	0.11	1.00
2300	0.01	0.00	0.00	0.10	1.00
2350	0.01	0.00	0.00	0.10	1.00
2400	0.01	0.00	0.00	0.10	1.00

Catch (t)	$U_{2005} < U_{avg}$	$B_{2006} > B_{avg}$	$B_{2006} > B_{2005}$	$B_{2006} > B_{1971}$	$B_{2006} > B_{2001}$
2450	0.00	0.00	0.00	0.09	1.00
2500	0.00	0.00	0.00	0.09	1.00

Table 19: Reported catch of Pacific cod in Queen Charlotte Sound (5CD) by Canada and the USA, 1954-2003. The reported discards for the period 1954-1995 are unrepresentative of true discarding because the estimates were taken from logbooks. Discard estimates since 1996 are based on at-sea observations and are considered to be more representative of true discarding.

	Canada			USA	
Fyear	Discard	Landed	Catch	5AB	Total
1953	0	0	0	0	0
1954	0	92	92	0	92
1955	0	59	59	283	342
1956	0	370	370	1711	2080
1957	0	1170	1170	2625	3795
1958	0	481	481	1122	1603
1959	0	595	595	937	1532
1960	0	385	385	589	974
1961	0	164	164	259	423
1962	0	247	247	392	639
1963	0	161	162	703	864
1964	0	575	575	1254	1829
1965	0	687	687	1983	2670
1966	3	696	699	1811	2510
1967	0	461	461	1486	1948
1968	5	403	408	980	1388
1969	0	265	265	652	917
1970	0	81	81	278	359
1971	2	230	232	944	1176
1972	0	748	748	2416	3164
1973	2	445	447	1862	2308
1974	0	698	698	2238	2936
1975	2	1329	1331	2468	3799
1976	6	1655	1660	2265	3926
1977	51	916	968	1315	2283
1978	21	1785	1806	1941	3747
1979	51	1956	2008	2018	4026
1980	22	1259	1280	1269	2550
1981	6	811	817	795	1611
1982	11	581	593	0	593
1983	0	184	184	0	184
1984	1	395	396	0	396
1985	0	291	291	0	291
1986	9	304	313	0	313
1987	5	3204	3209	0	3209
1988	5	1843	1849	0	1849
1989	6	786	793	0	793
1990	28	842	870	0	870

	Canada			USA	
Fyear	Discard	Landed	Catch	5AB	Total
1991	3	2203	2206	0	2206
1992	0	1863	1864	0	1864
1993	5	1487	1492	0	1492
1994	1	589	590	0	590
1995	2	273	274	0	274
1996	24	201	225	0	225
1997	27	144	170	0	170
1998	27	141	169	0	169
1999	14	116	130	0	130
2000	8	59	67	0	67
2001	8	112	120	0	120
2002	37	183	219	0	219
2003	49	302	351	0	351

Table 20: Summary of recommended yields, TACs and landings for Pacific cod in area 5AB.

Year	Assessment Advice	TAC	Carryover	Landings	Percent of TAC+Carryover Landed
2004/05	No Advice	390	9	68	17% as of Jun 30
2003/04	No Advice	260		302	116%
2002/03	No Advice	260	67	183	56%
2001/02	No Advice	260	76	112	33%
2000/01	No Advice	260	75	59	18%
1999/00	No Advice	260	74	116	35%
1998/99	No Advice	260		141	54%
1997/98	No Advice	260		144	55%

Figures

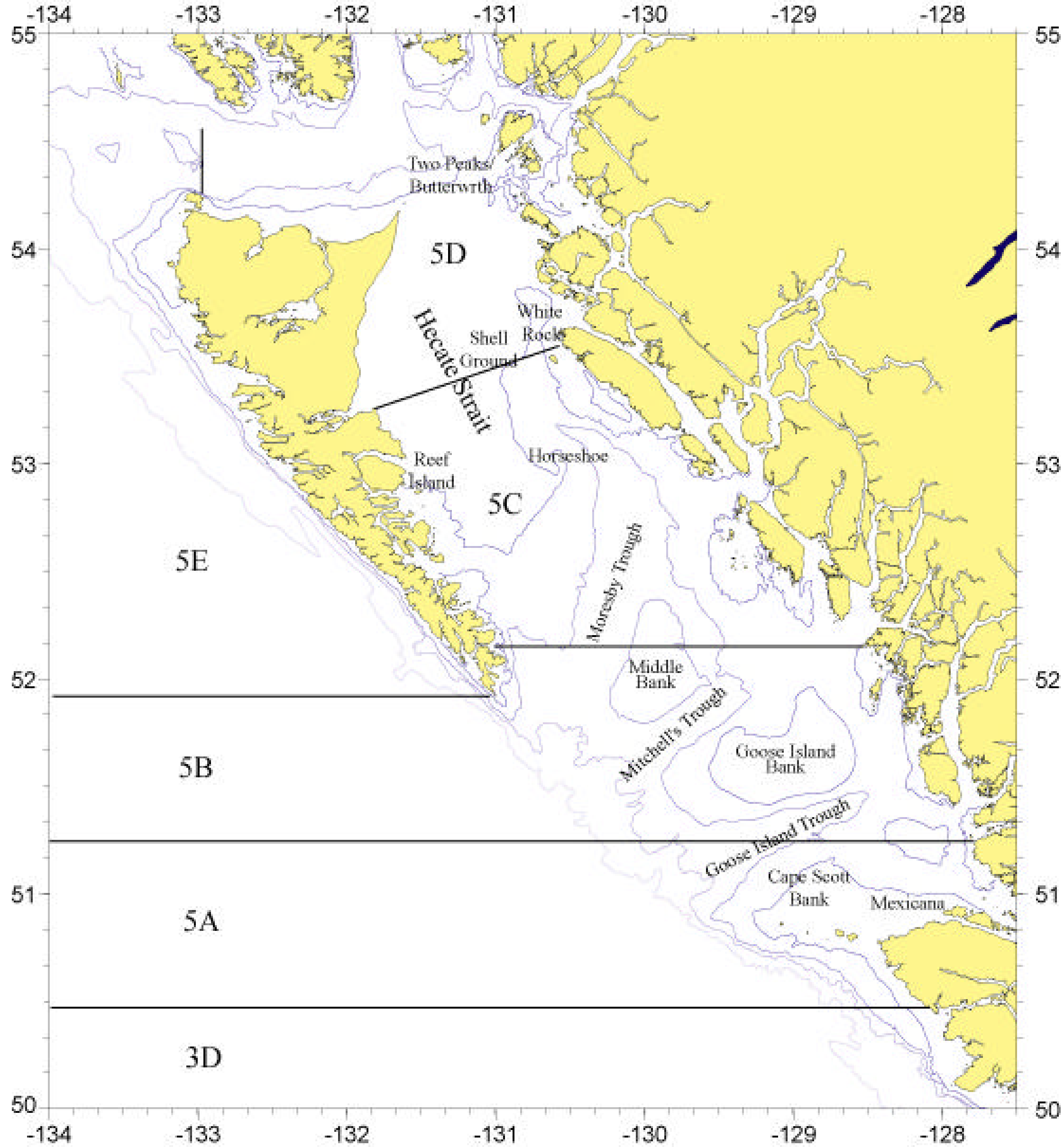


Figure 1: This assessment documents deals with Pacific cod in 2 management areas, 5AB (Queen Charlotte Sound) and 5CD (Hecate Strait).

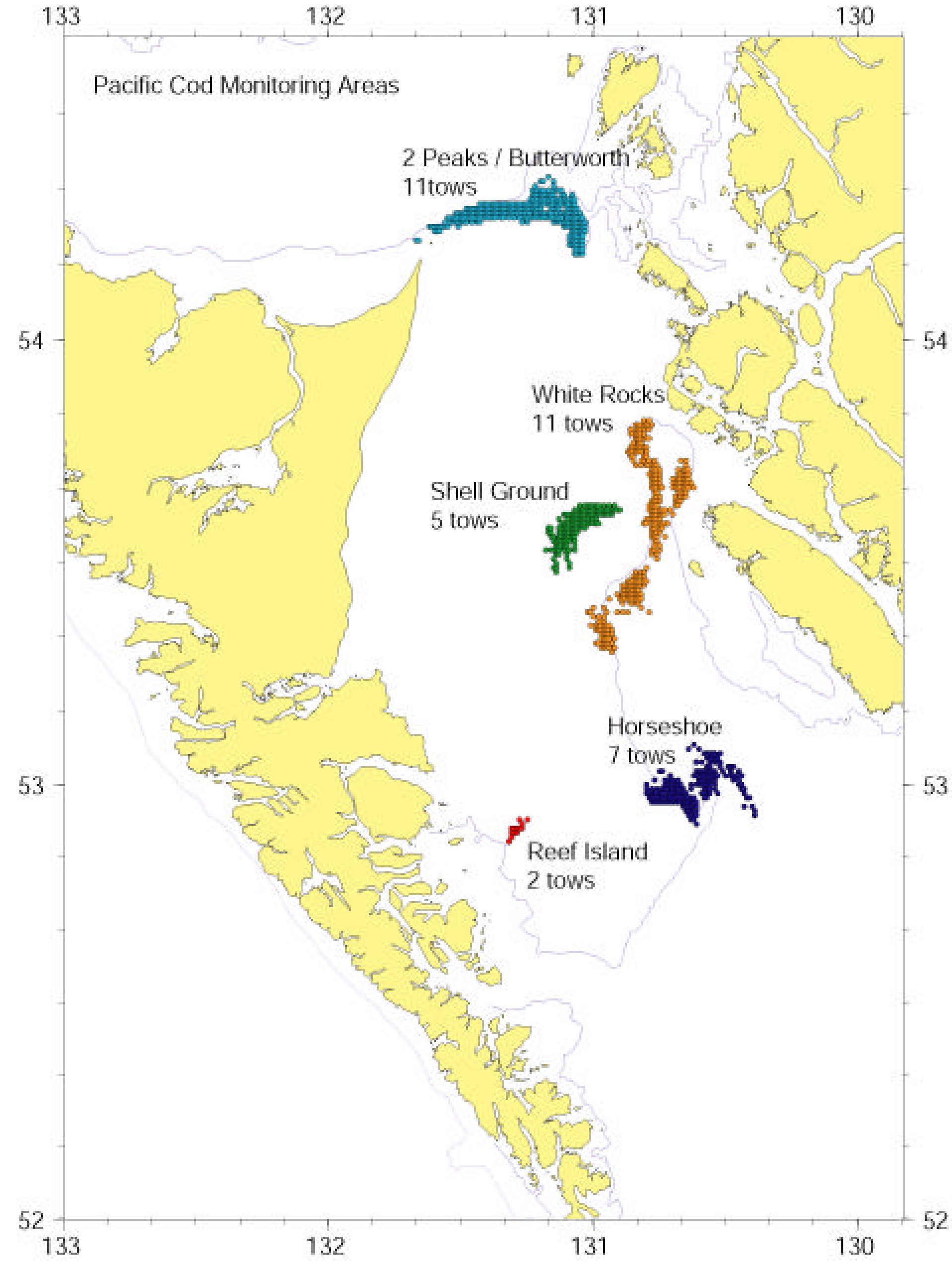


Figure 2: Tow locations for monitoring survey

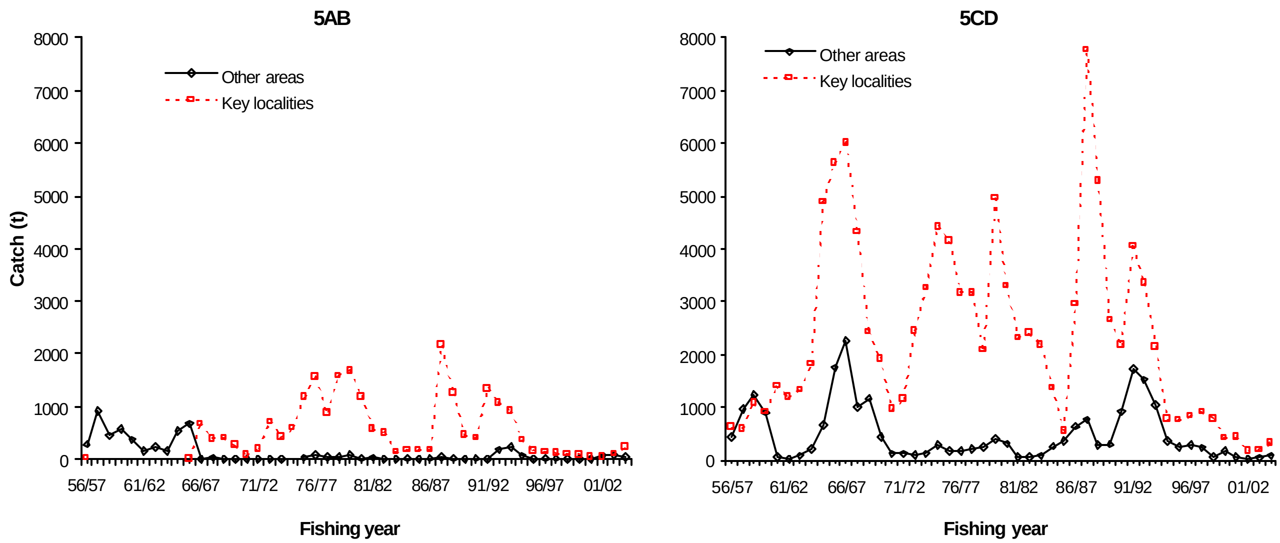


Figure 3. Plots of the relative catch of Pacific cod between the “key localities” identified in Table 4 and the remaining localities (including the designation “unknown”) for 5AB and 5CD.

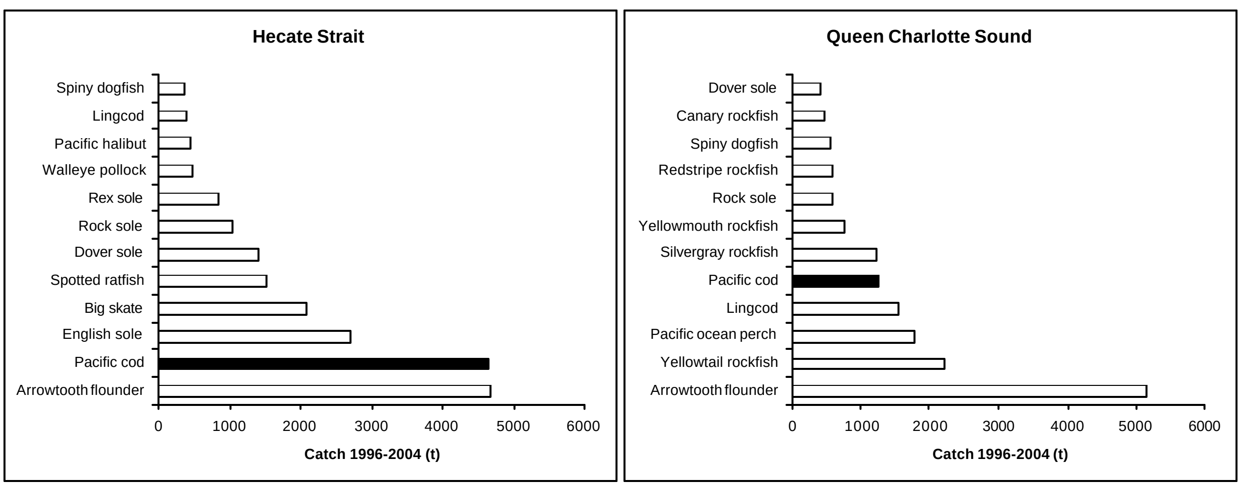
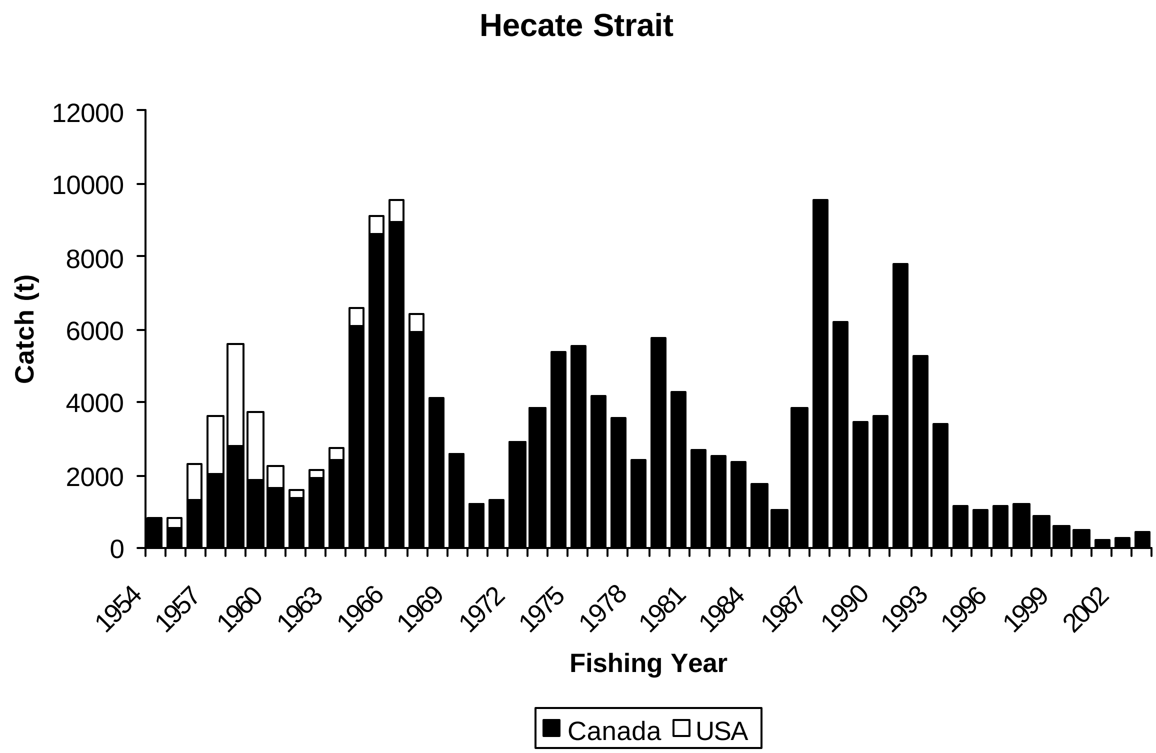


Figure 4: Total catches (t) of species caught in fishing tows that yielded 90% of the Pacific cod catch in the period 1996-2004 in Hecate Strait and Queen Charlotte Sound.



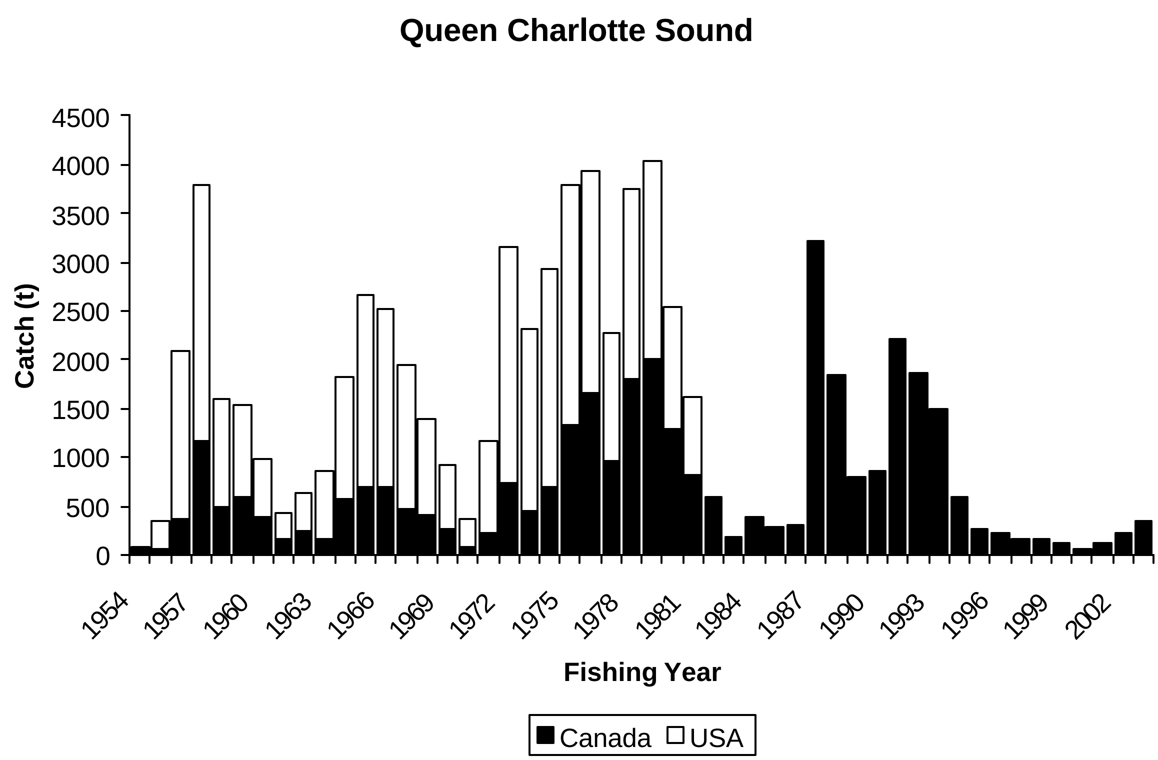


Figure 5: Reported catch of Pacific cod reported by Canada and the USA in Hecate Strait and Queen Charlotte Sound for fishing years 1954-2003.

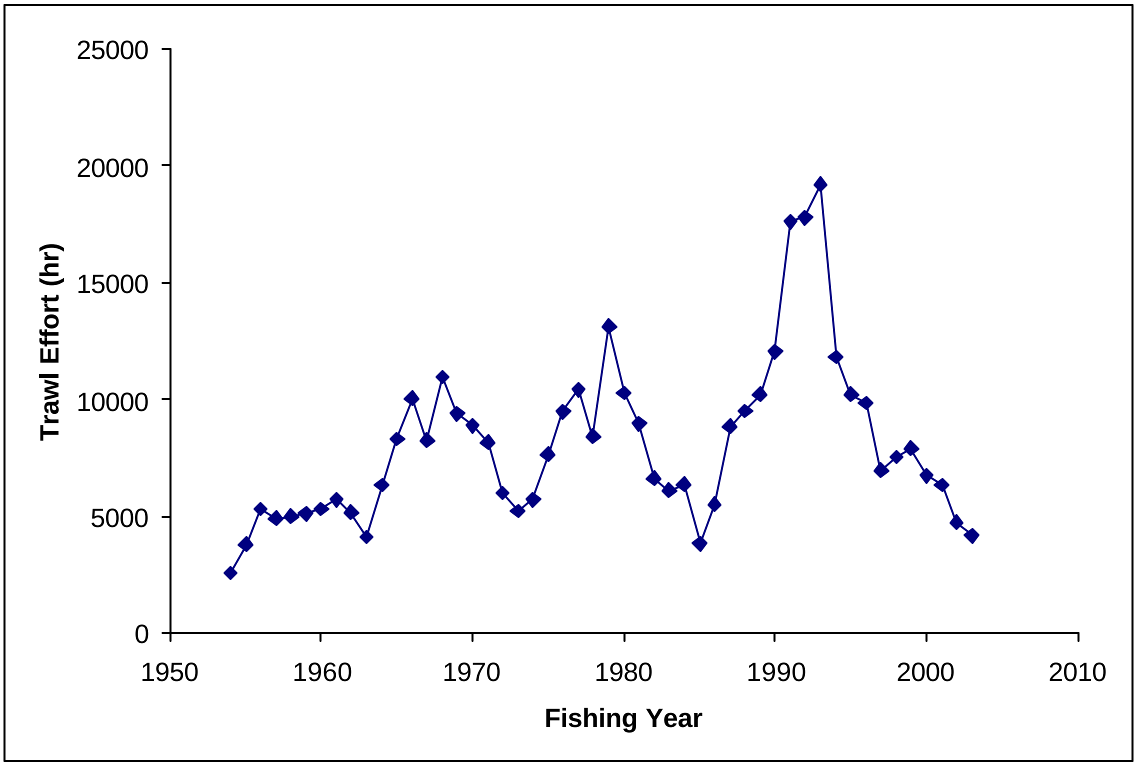


Figure 6: Annual fishing effort (hours) reported by Canadian bottom trawlers in Hecate Strait (5CD), 1954-2003.

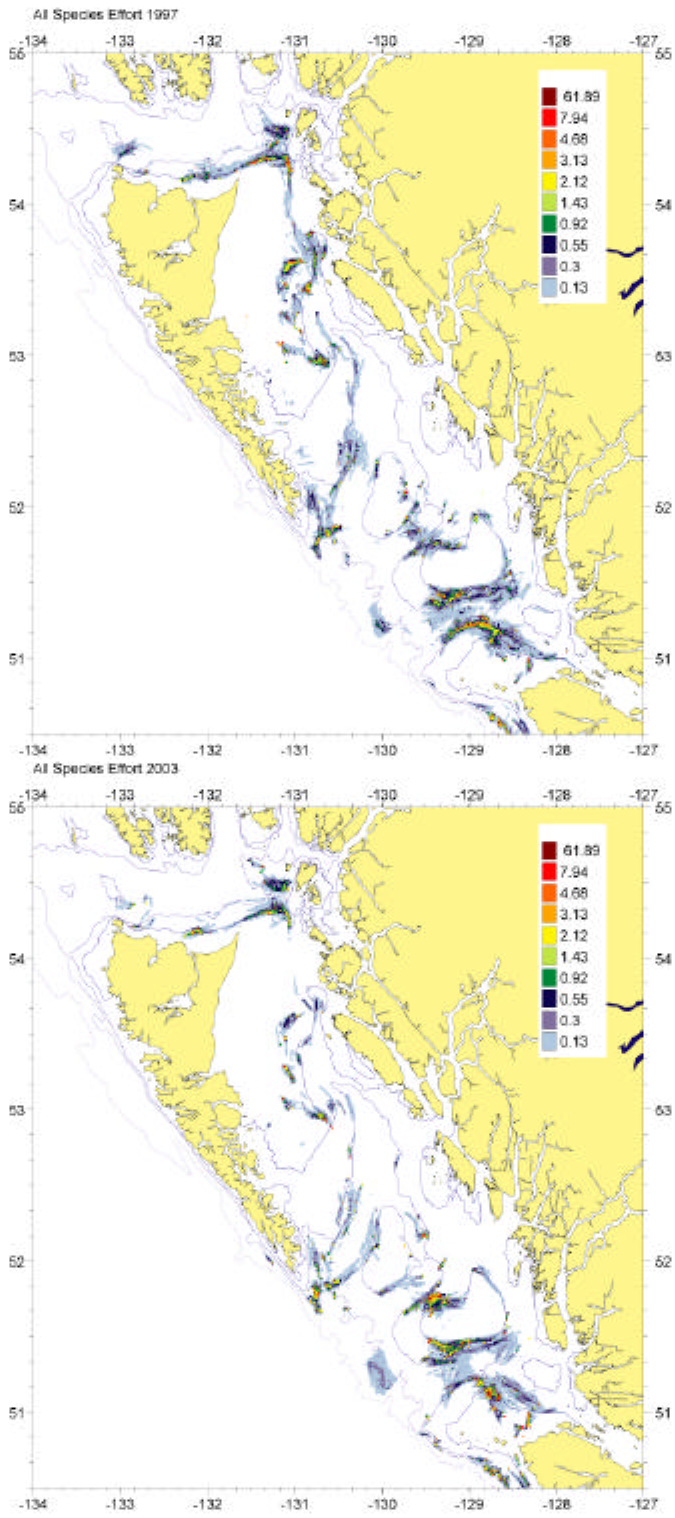


Figure 7: Bottom trawl fishing effort distribution in Hecate Strait and Queen Charlotte Sound in 1997 and 2003.

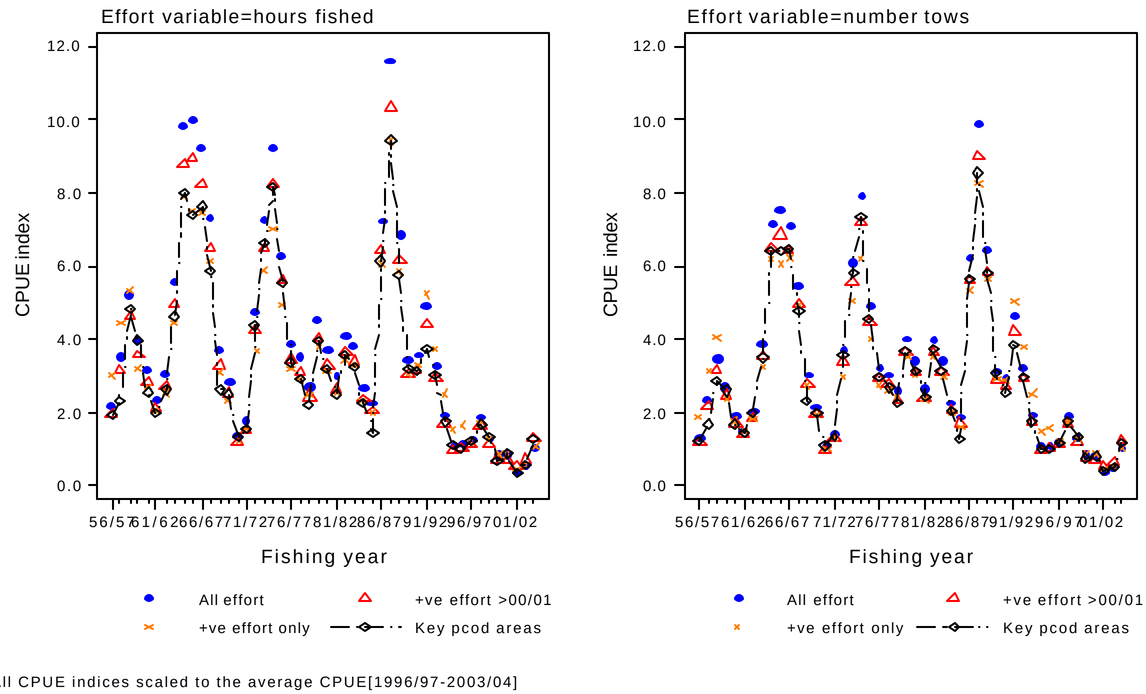


Figure 8. Plot of four CPUE indices for Hecate St. (5CD) pacific cod using two measures of effort (hours fished and number of tows): all effort=all qualified effort; +ve effort>00/01=all effort <=2000/01 & positive effort>2000/01; +ve effort only=effort with positive catches only; key pcod areas=all qualified effort in key pcod localities.

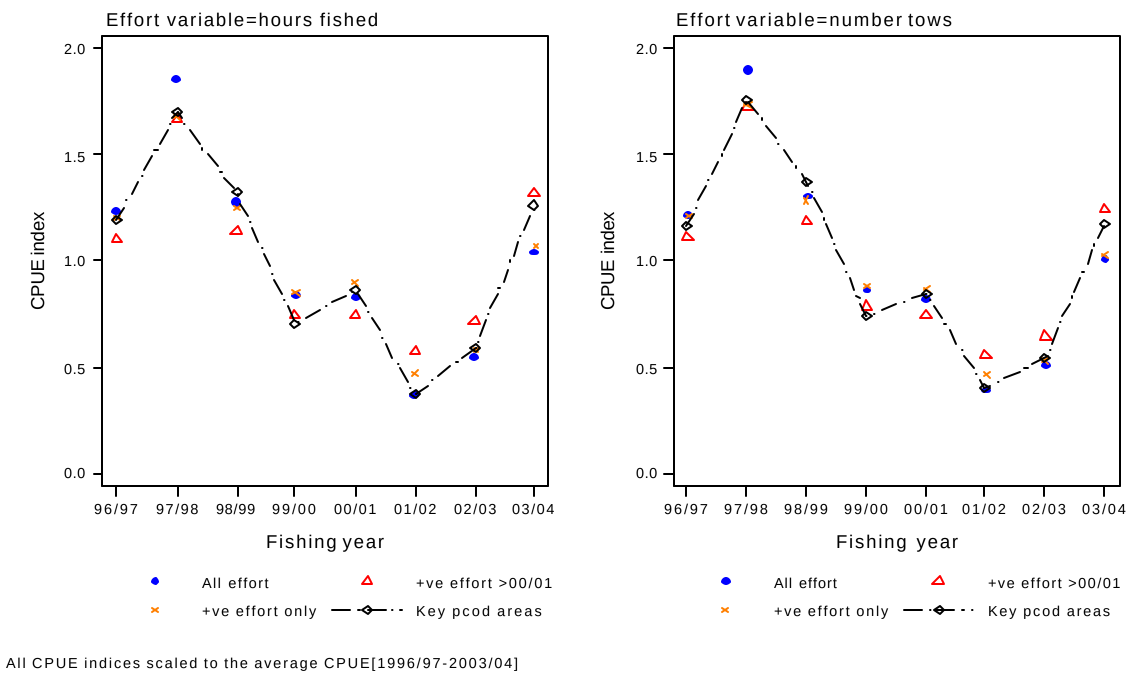


Figure 9. Plot of four CPUE index series for Hecate Strait Pacific cod from 1996/97 to 2003/04. Two measures of effort are presented: total hours fished and number of tows. Index series are as described in Figure 8.

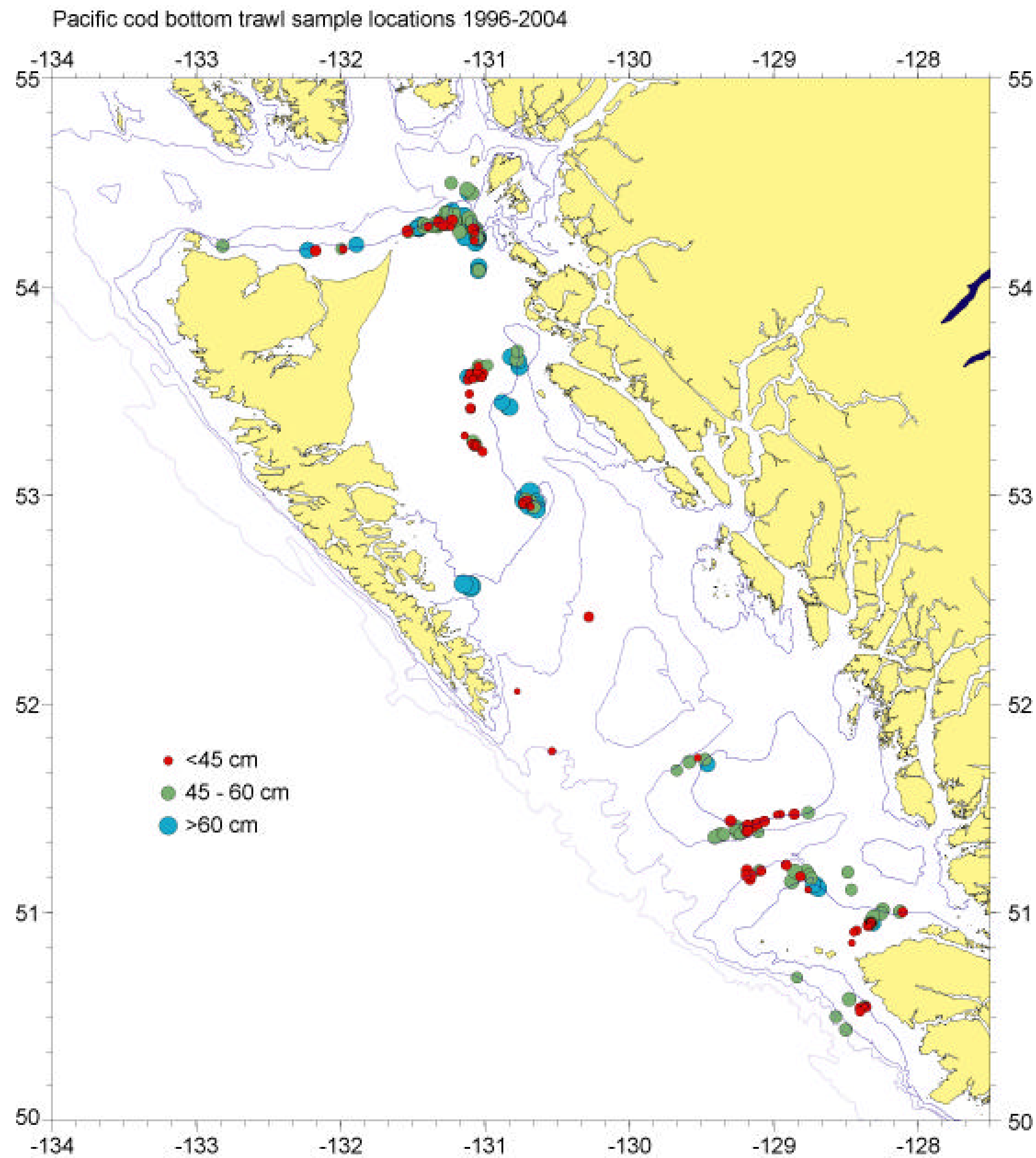


Figure 10: Locations of unsorted at-sea samples of Pacific cod in Hecate Strait and Queen Charlotte Sound 1996-2004. The symbols are sized and coloured according to the mean fish length in the sample.

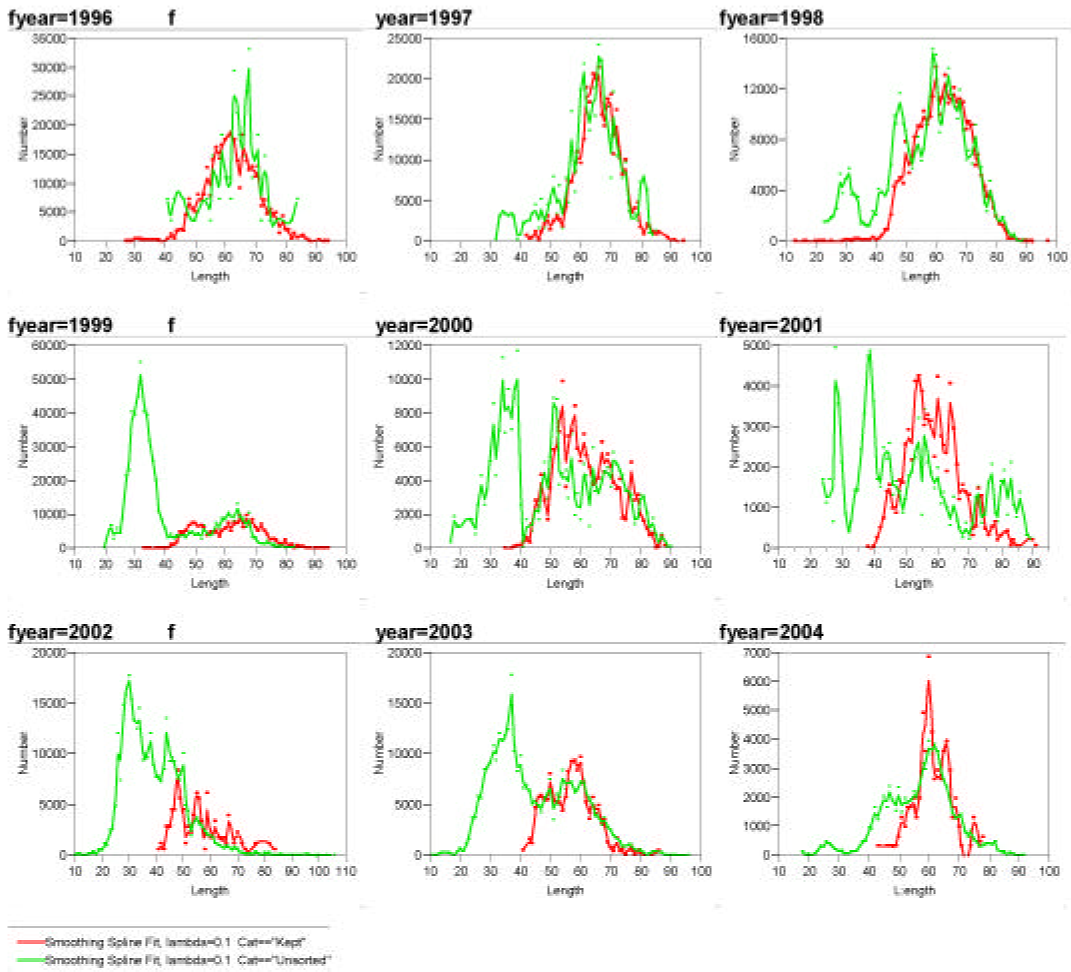


Figure 11: Length composition of Pacific cod from the bottom trawl fishery in Hecate Strait 1996-2004. The green lines are for unsorted samples collected at sea. The red lines are for kept samples taken at sea and on shore. The y-axis indicates numbers of fish at each length interval. Samples were combined and ultimately weighted by the estimated weight caught or landed in the respective catch categories.

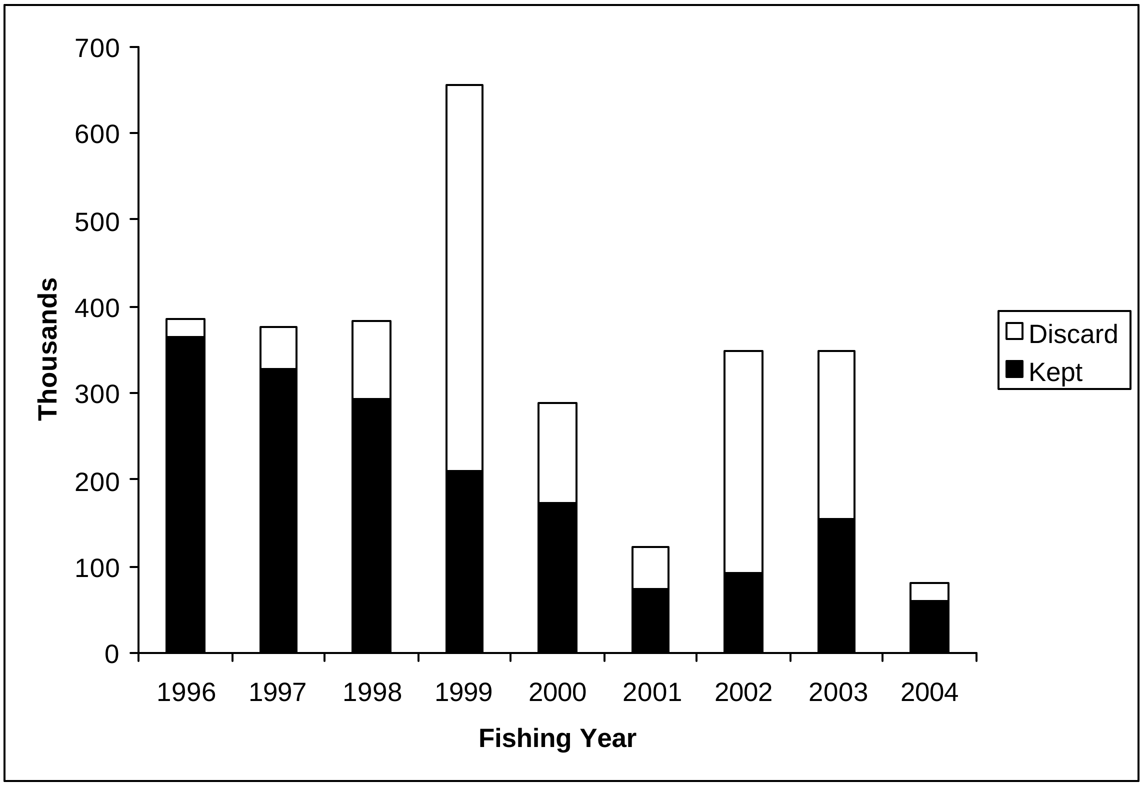


Figure 12: Estimated number of Pacific cod kept and discarded in the Hecate Strait bottom trawl fishery, 1996-2004. It should be noted that the estimates for 2004 are only for the April-June period.

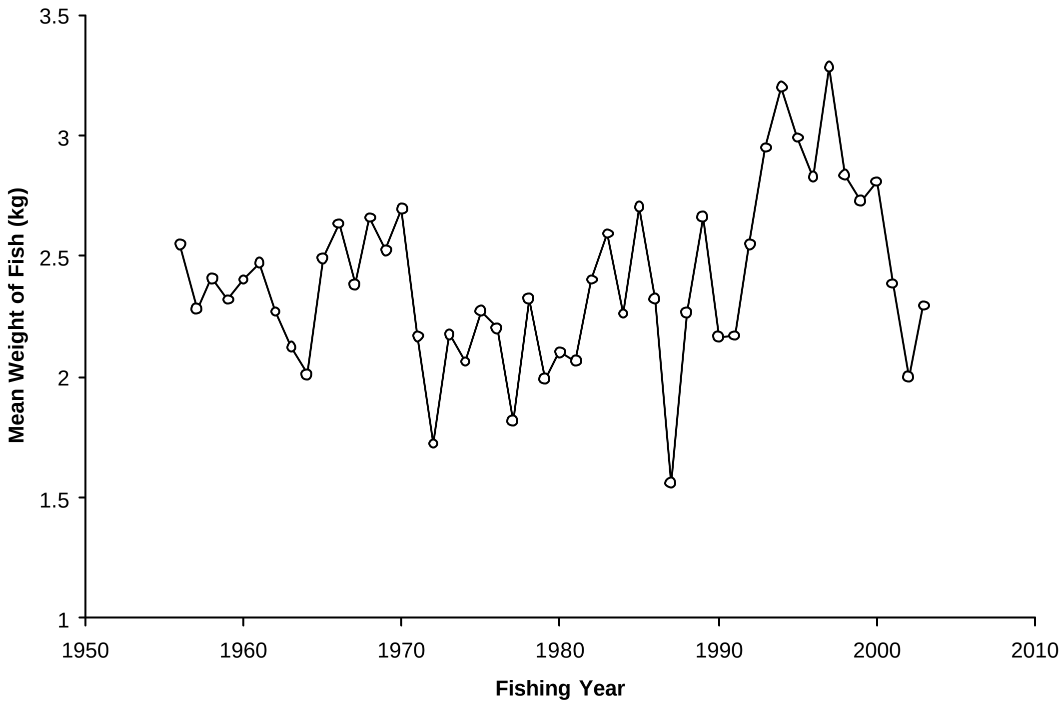


Figure 13: Mean weight of Pacific cod in the bottom trawl fishery in Hecate Strait, 1956-2003.

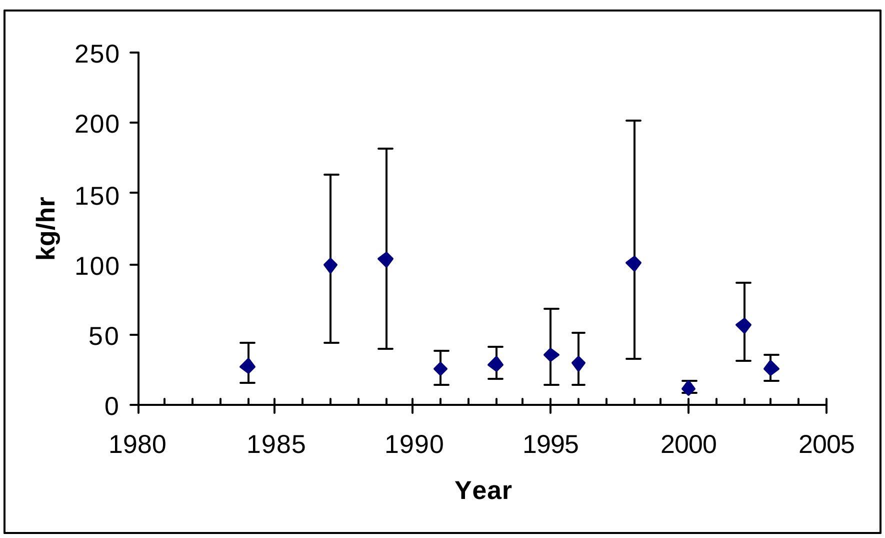


Figure 14: Mean catch per unit effort (kg·hr-1) of Pacific cod in the Hecate Strait groundfish assemblage surveys (1984-2003). The distributions of the means were determined by bootstrapping. The vertical lines give the 95% confidence limits.

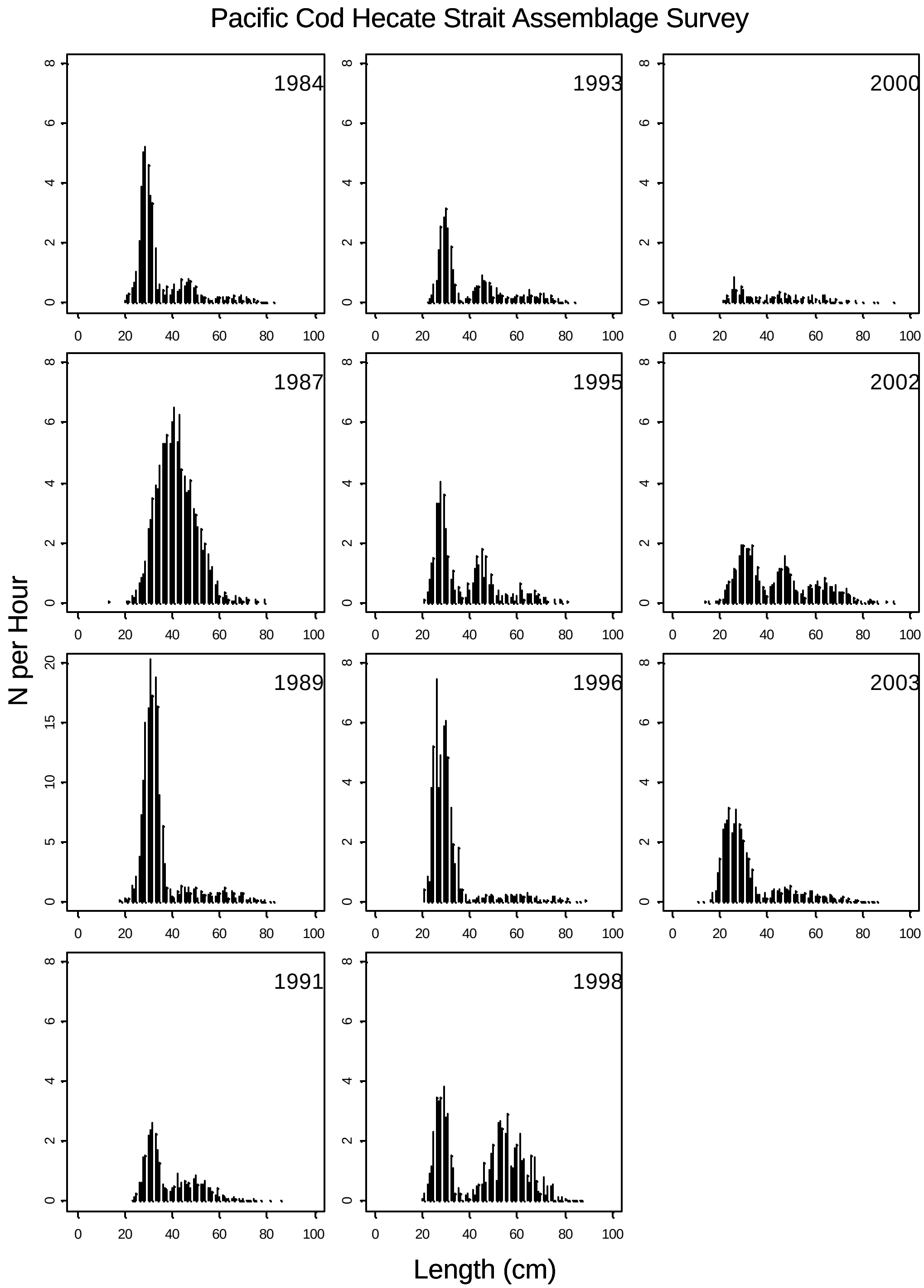


Figure 15: Length composition of Pacific cod in the groundfish assemblage surveys 1984-2003. The graphs are scaled to numbers per hour fished and indicate both size composition and relative abundance. Note that the scale of the 1989 panel is different that the others.

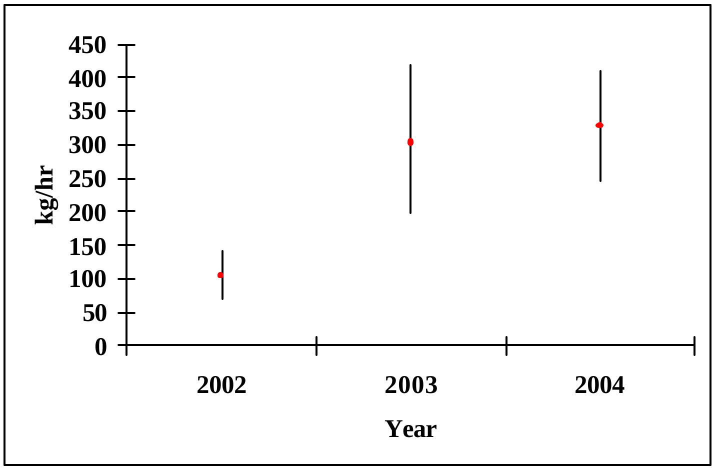


Figure 16: Annual catch per unit effort (kr hr-1) index from the Hecate Strait Pacific cod monitoring survey, 2002-2004. The error bars indicate the 90% confidence interval.

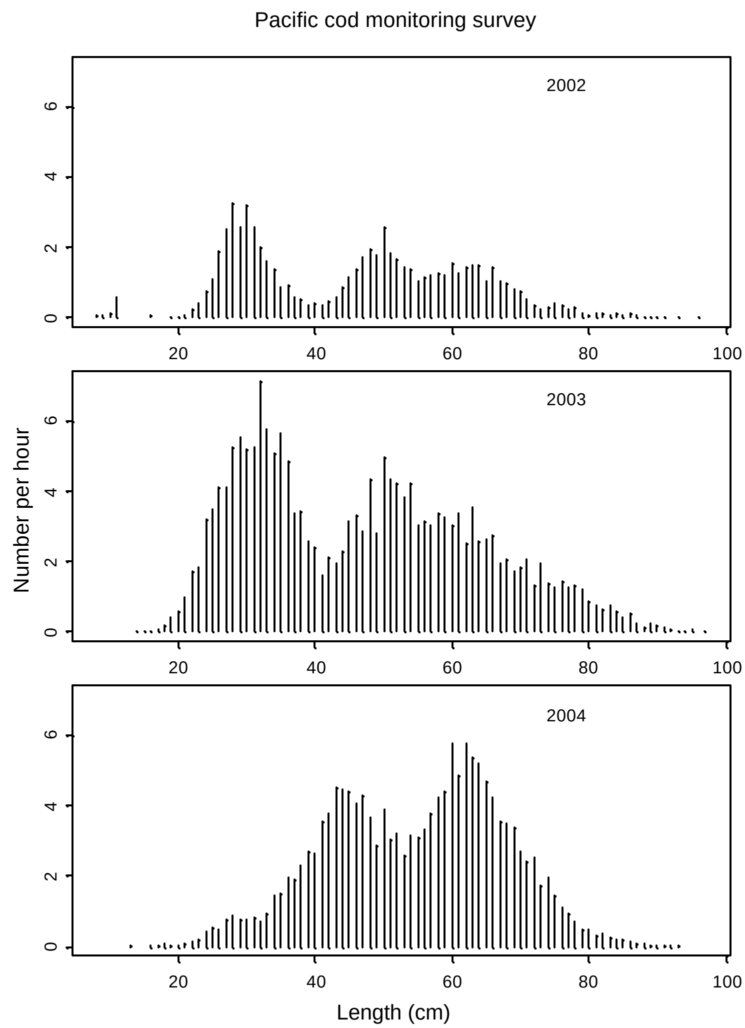


Figure 17: Size composition of Pacific cod in the Hecate Strait monitoring survey 2002-2004. The graph presents mean number per hour fishing and thus represents both the size distribution and abundance.

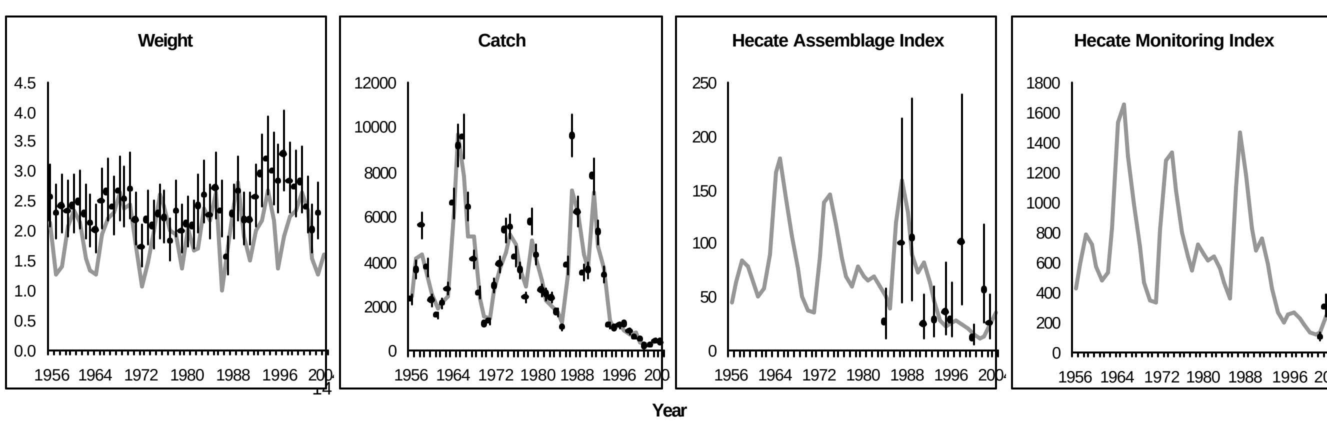


Figure 18. Model fits to the observed data for the "Fixed h "model run (Table 12).

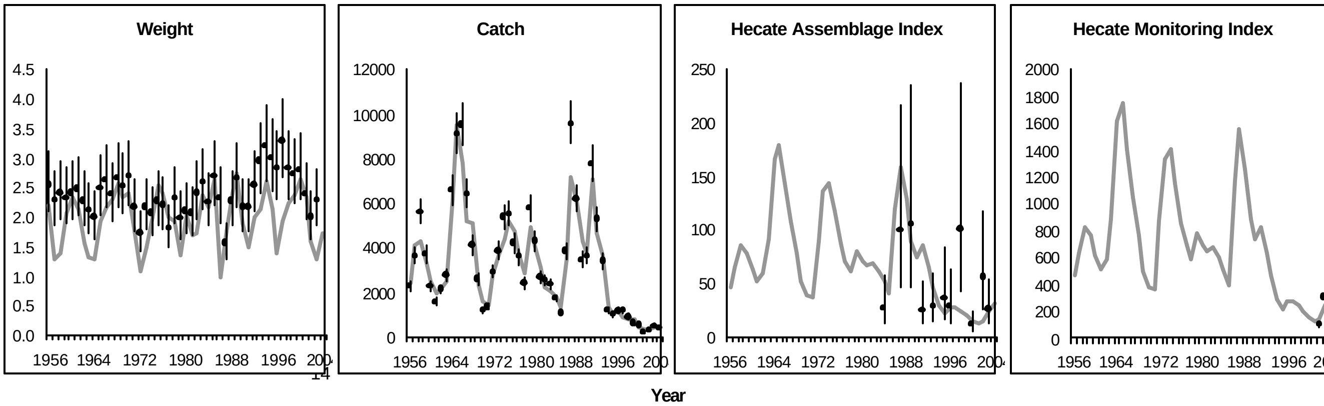


Figure 19. Model fits to the observed data for the "Estimate M, h "model run (Table 12).

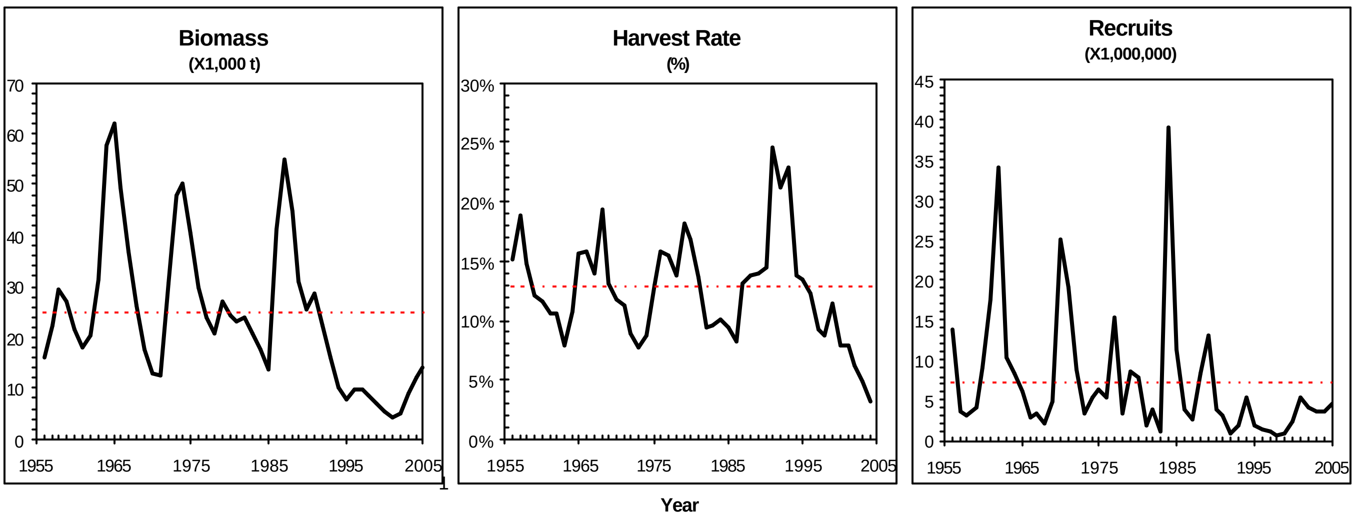


Figure 20. Population (total biomass, annual harvest rate, and number of recruits) trends for the "Fixed h "model run (Table 12). Average biomass level, average harvest rate and average number of recruits over the model period are indicated by a dashed line.

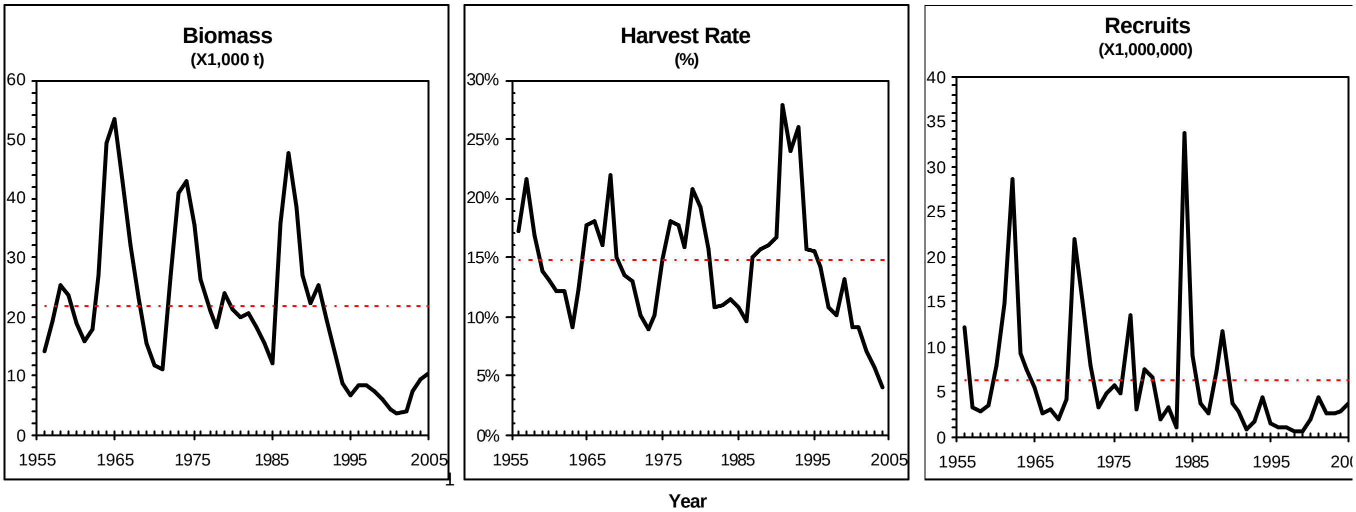


Figure 21. Population (total biomass, annual harvest rate, and number of recruits) trends for the "Estimate M, h "model run (Table 12). Average biomass level, average harvest rate and average number of recruits over the model period are indicated by a dashed line.

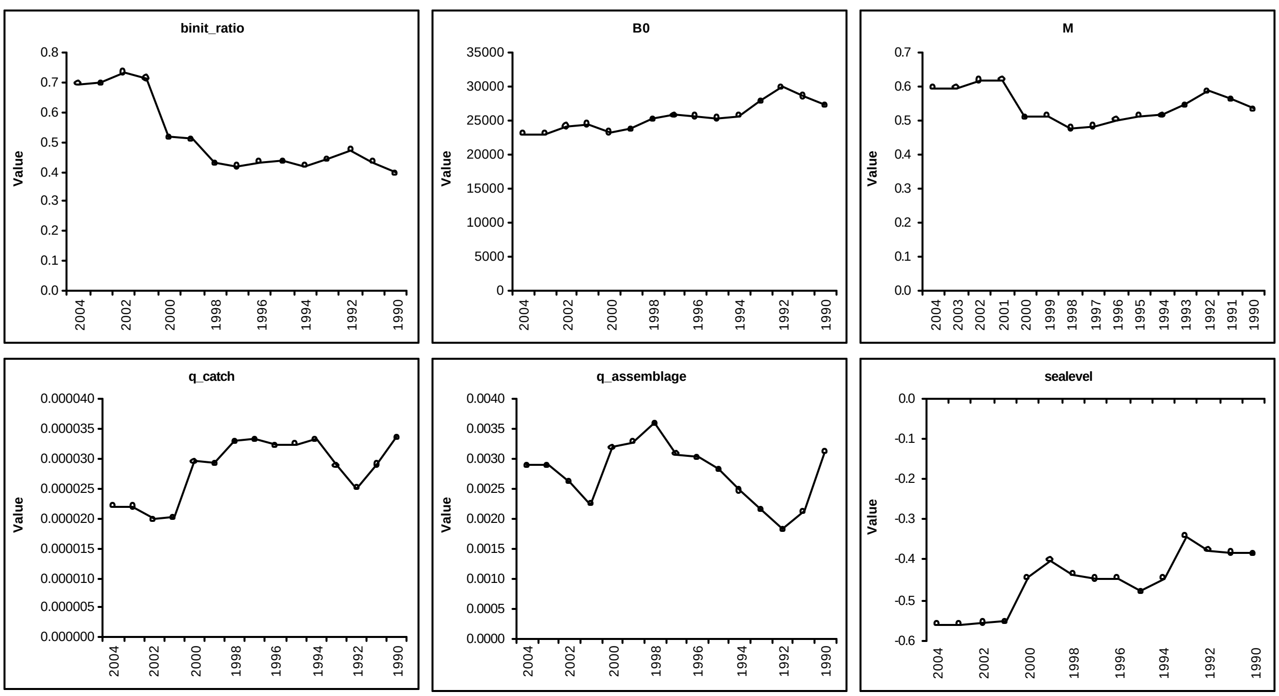


Figure 22. Estimates for key parameters by year from the Hecate St. Pacific cod retrospective analysis, based on the assumptions for the "Fixed h "model run (Table 12).

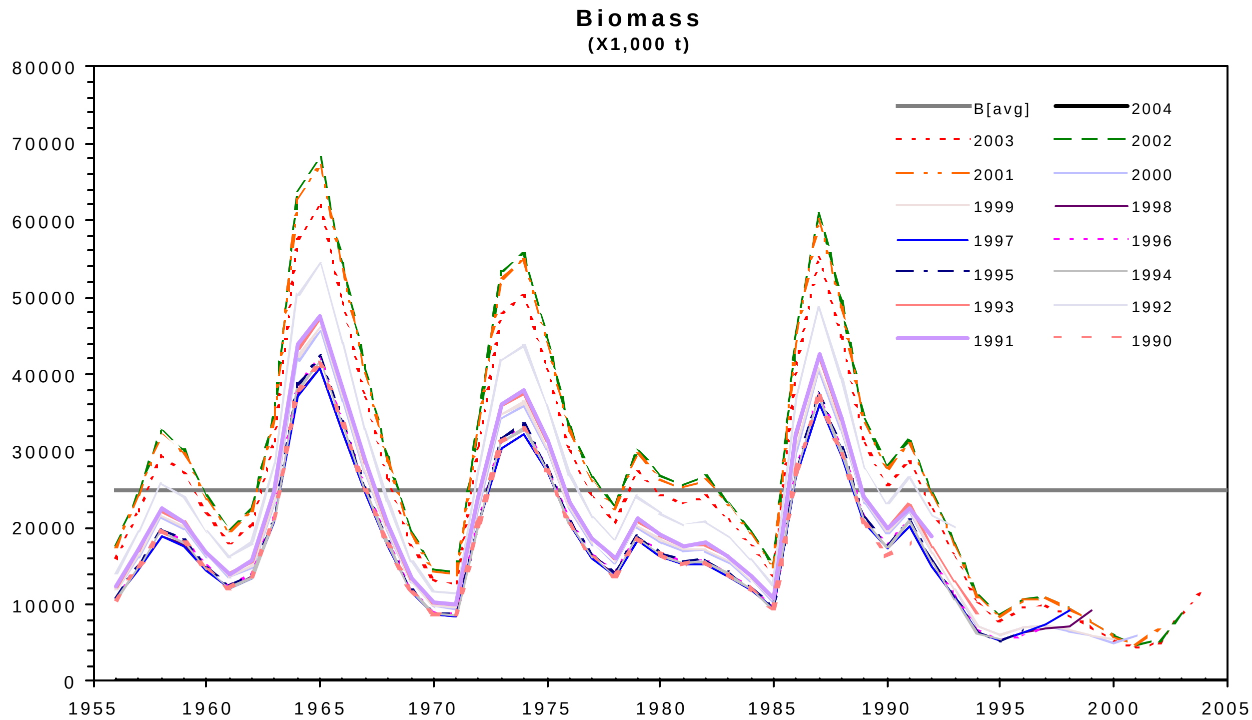


Figure 23. Biomass trajectories for Hecate St. Pacific cod from the retrospective analysis based on the assumptions for the "Fixed h "model run (Table 12).

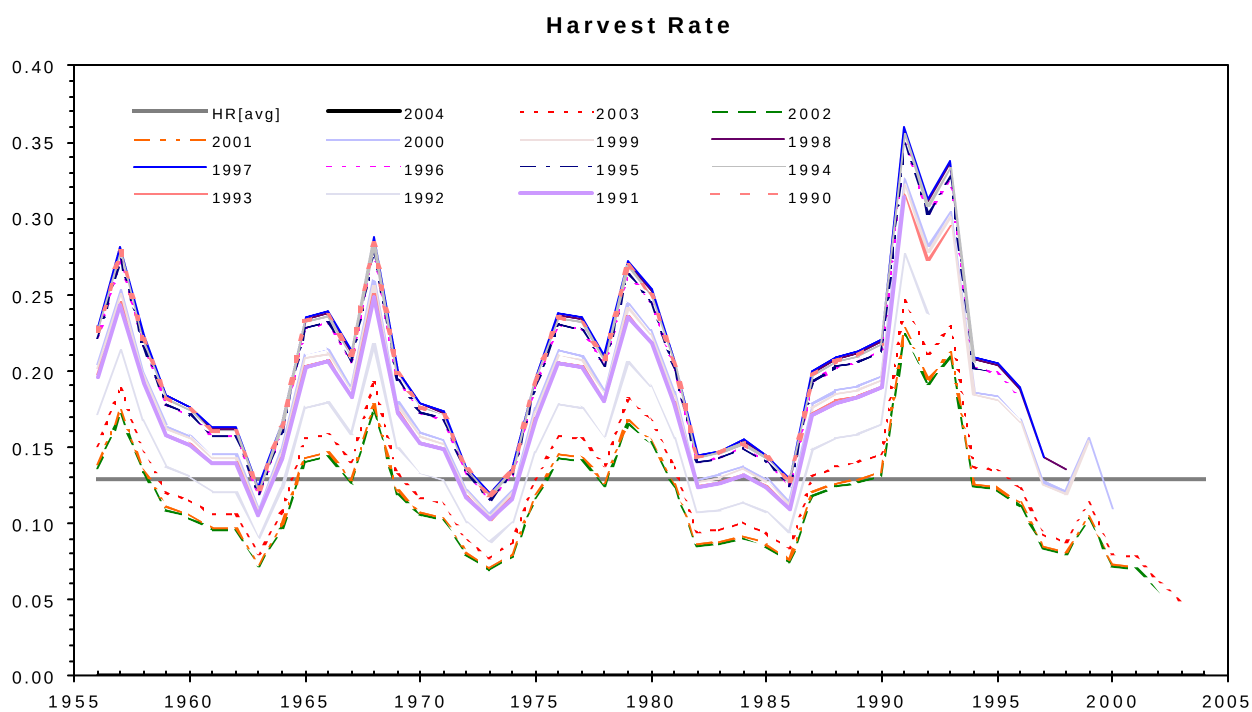


Figure 24. Annual total harvest rate trajectories for Hecate St. Pacific cod from the retrospective analysis based on the assumptions for the "Fixed h "model run (Table 12).

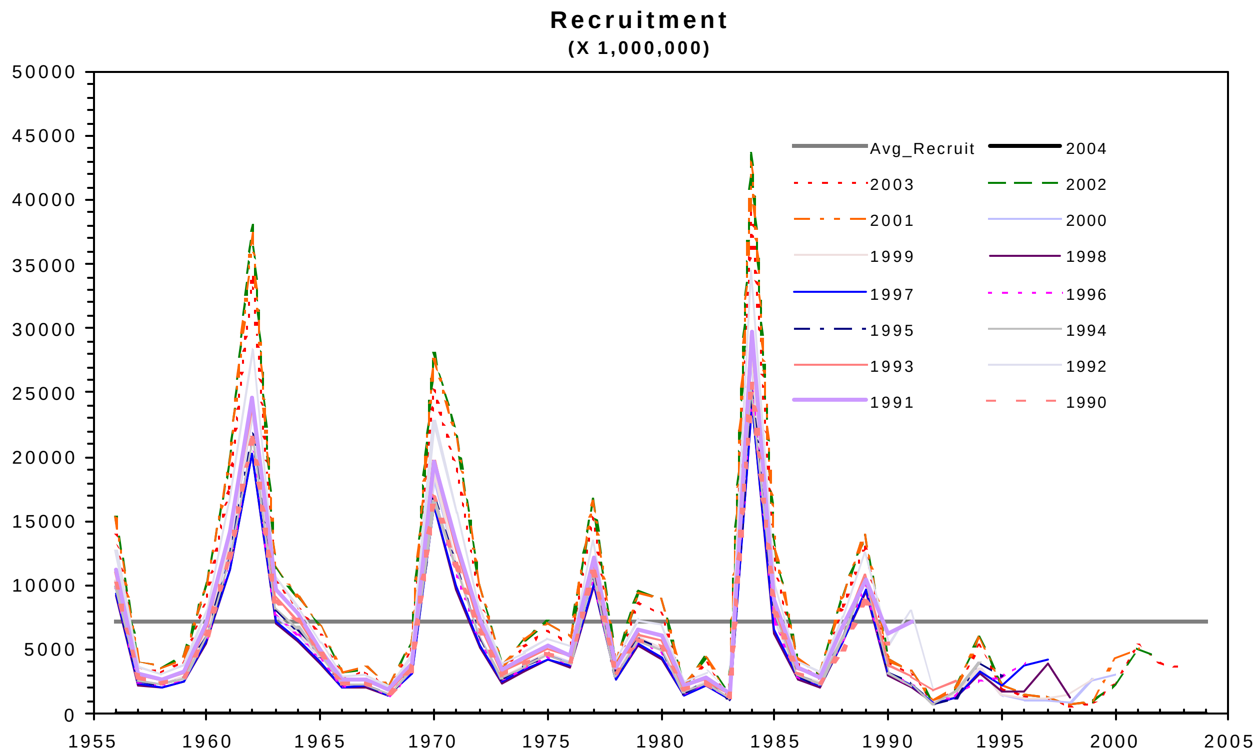


Figure 25. Trajectories of recruitment for Hecate St. Pacific cod from the retrospective analysis based on the assumptions for the “Fixed h “model run (Table 12).

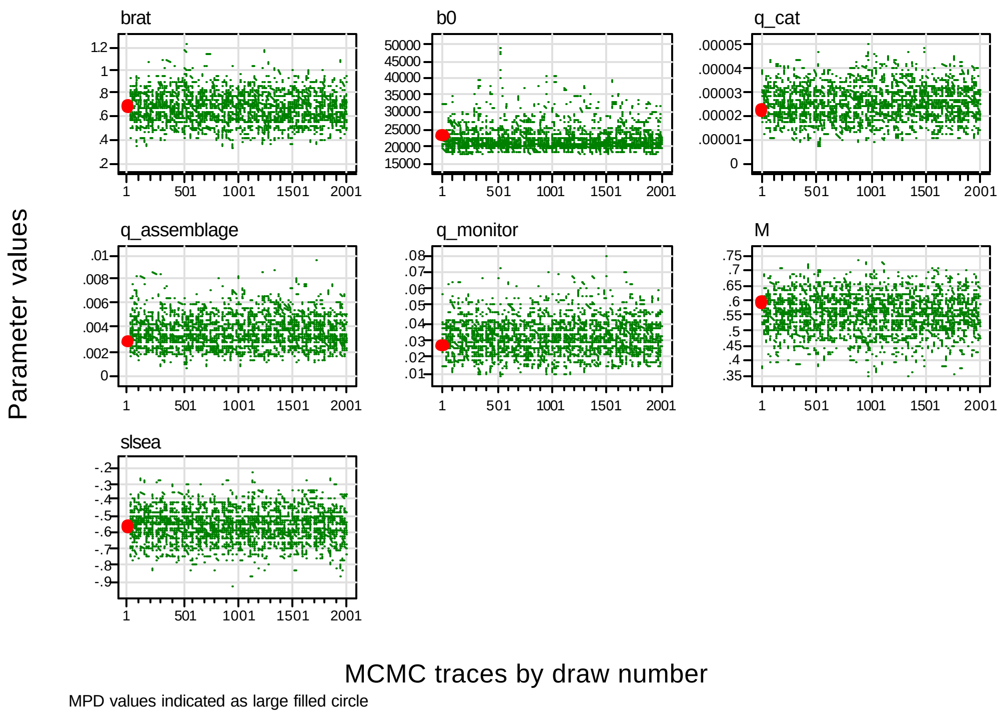


Figure 26. MCMC traces of the seven main model parameters for the “Fixed *h*” model based on 100,000,000 MCMC draws sampled every 50,000 iterations.

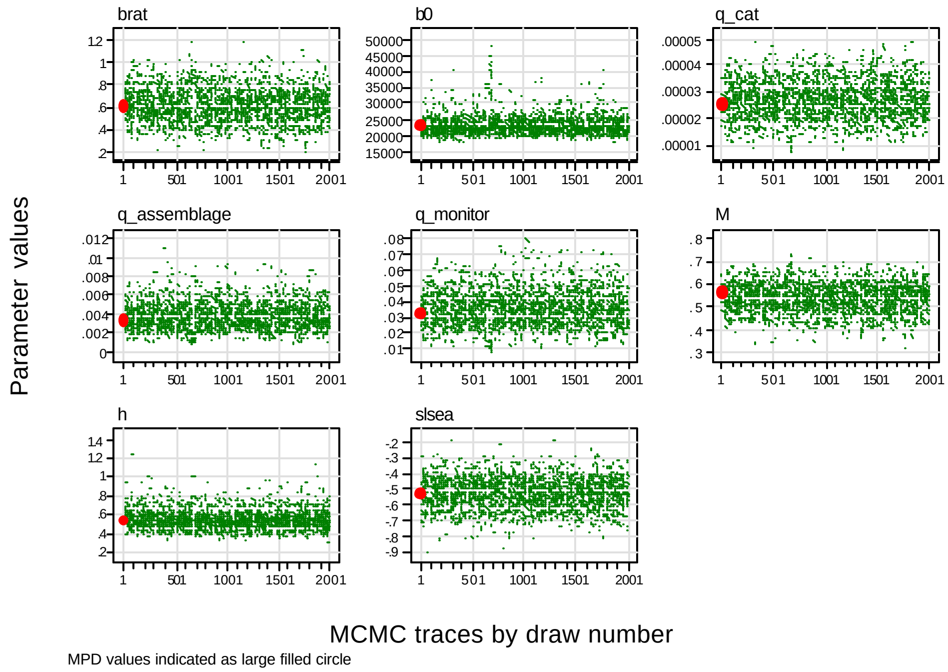


Figure 27. MCMC traces of the eight main model parameters for the “Estimate M, h ”model based on 100,000,000 MCMC draws sampled every 50,000 iterations.

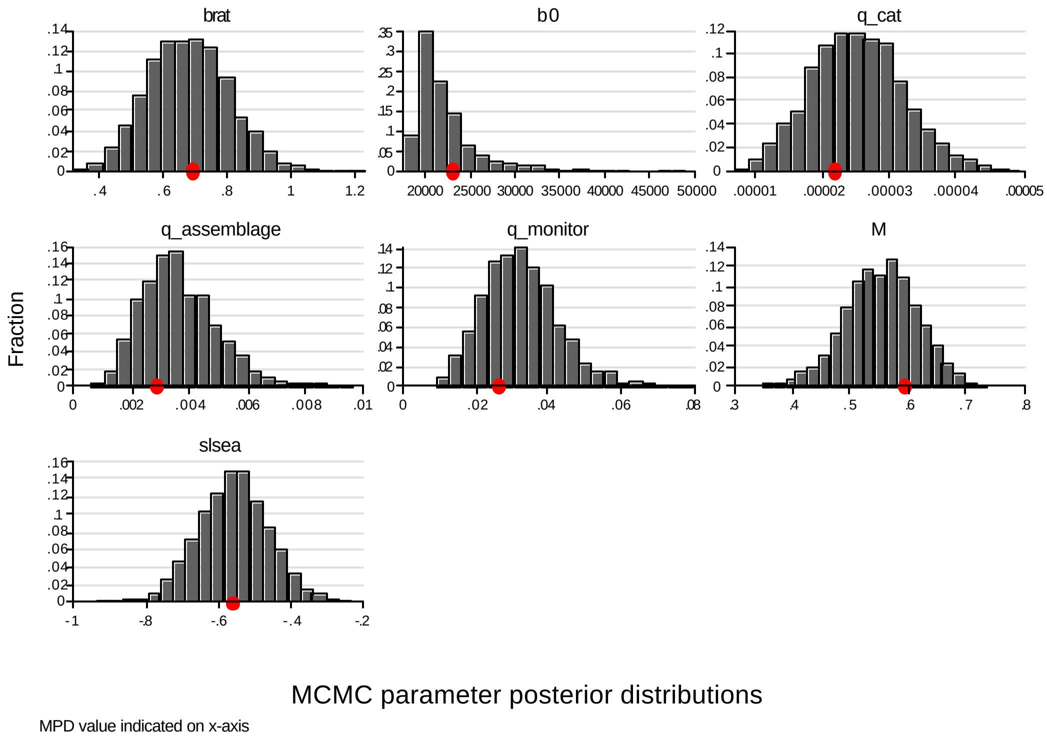


Figure 28. MCMC posterior distributions of the seven main parameters for the "Fixed h" model based on 100,000,000 MCMC draws sampled every 50,000 iterations.

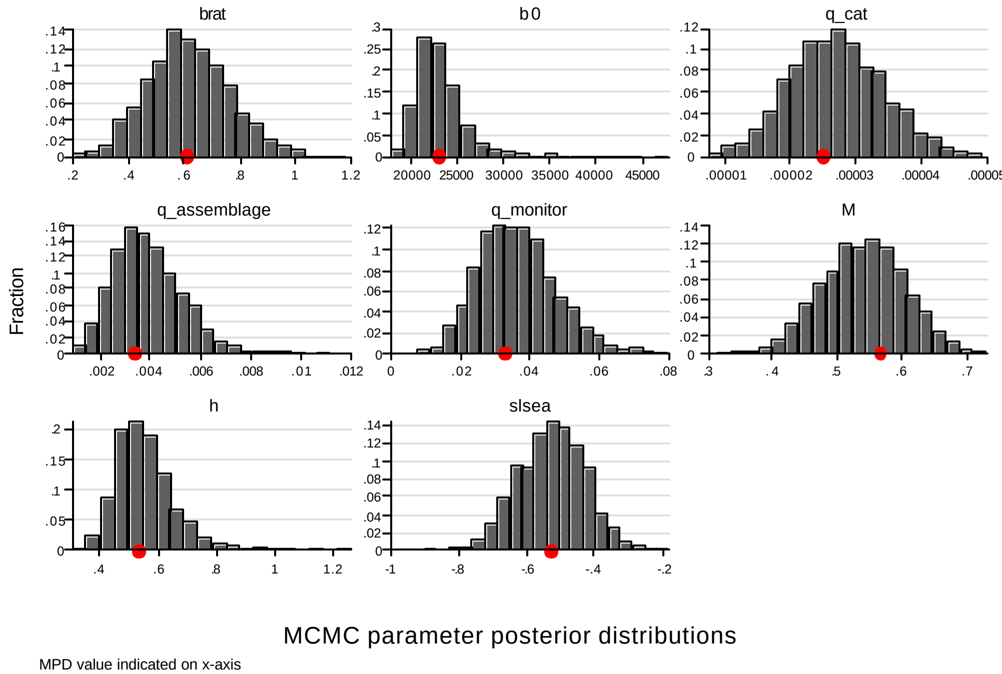


Figure 29. MCMC posterior distributions of the eight main parameters for the "Estimate M, h "model based on 100,000,000 MCMC draws sampled every 50,000 iterations.

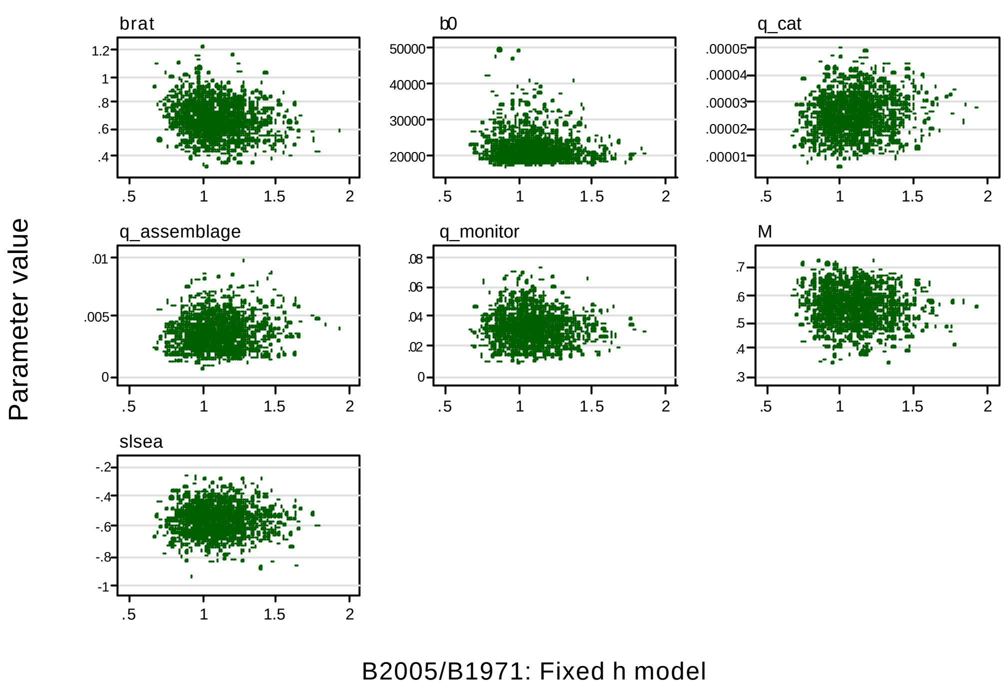


Figure 30. Joint marginal distributions of the seven main model parameters of the Fixed *h* model with the ratio of B_{2005}/B_{1971}.

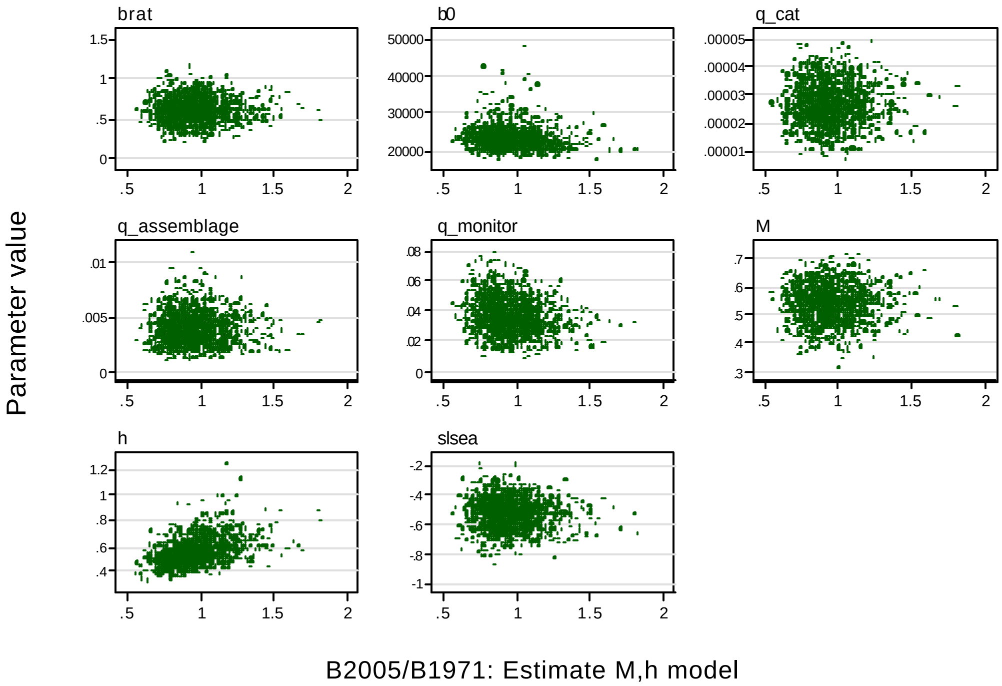


Figure 31. Joint marginal distributions of the eight main model parameters of the Estimate *M*,*h* model with the ratio of B_{2005}/B_{1971}.

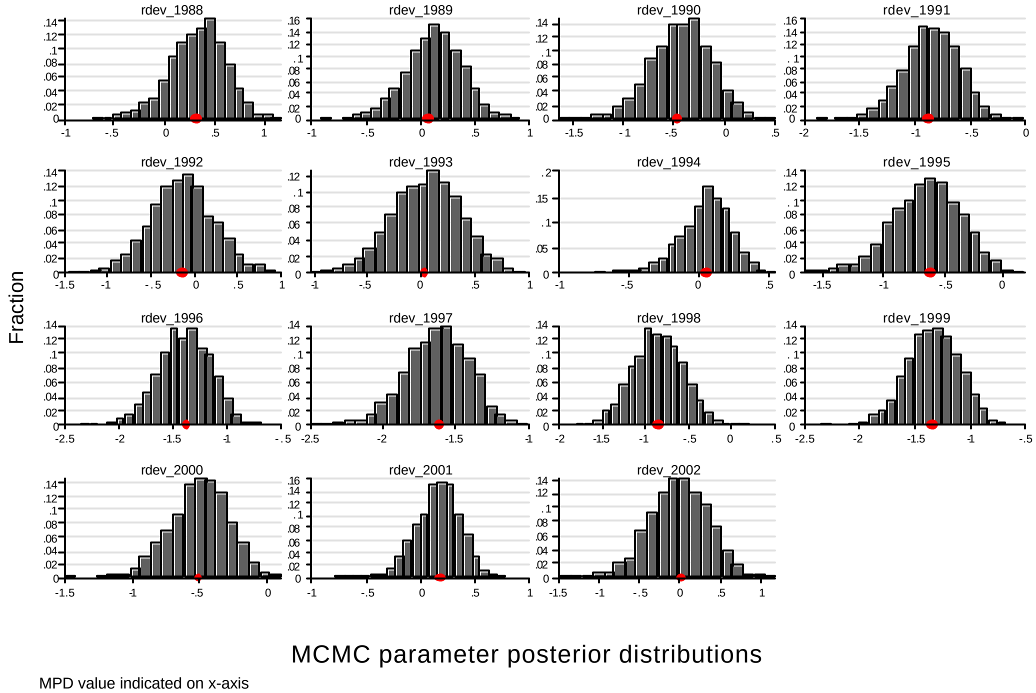


Figure 32. MCMC posterior distributions for recruitment deviation parameters from 1988 to 2002 for the "Fixed h"model based on 100,000,000 MCMC draws sampled every 50,000 iterations.

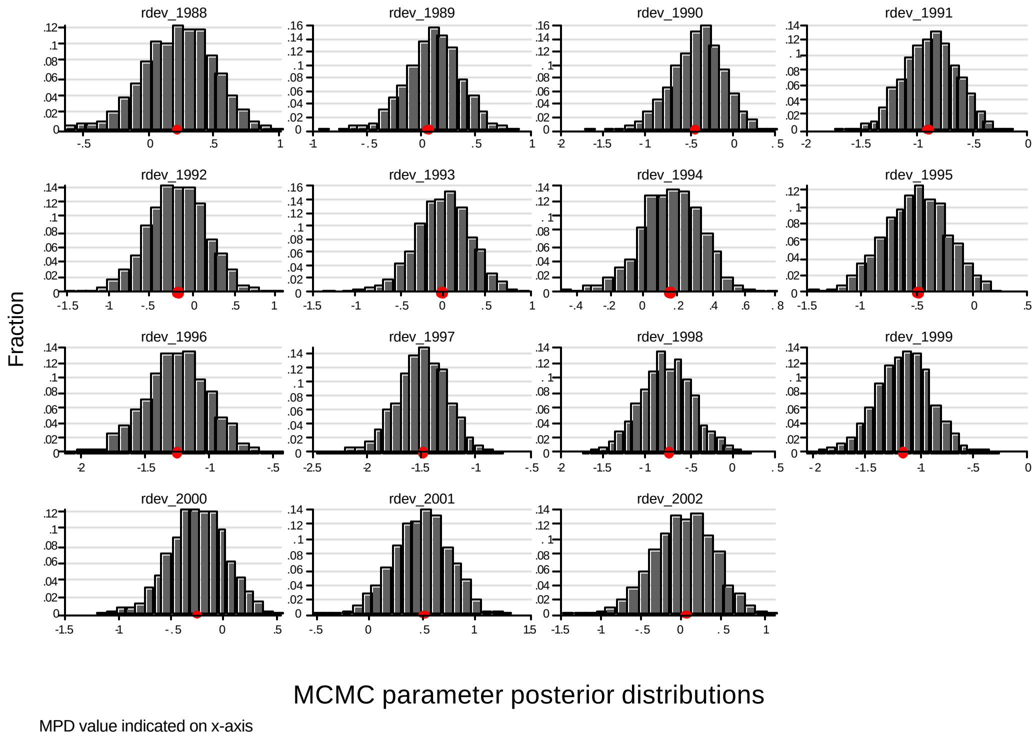


Figure 33. MCMC posterior distributions for recruitment deviation parameters from 1988 to 2002 for the “Estimate M, h ”model based on 100,000,000 MCMC draws sampled every 50,000 iterations.

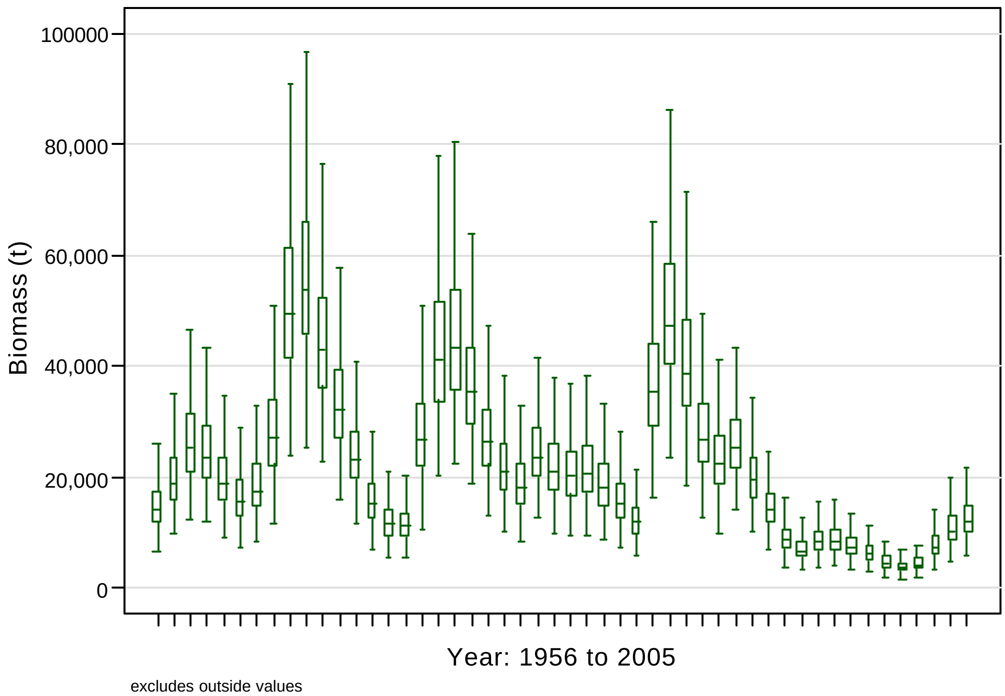


Figure 34. Box plots of beginning year biomass distributions by year for the "Fixed *h*" model based on 100,000,000 MCMC draws sampled every 50,000 iterations.

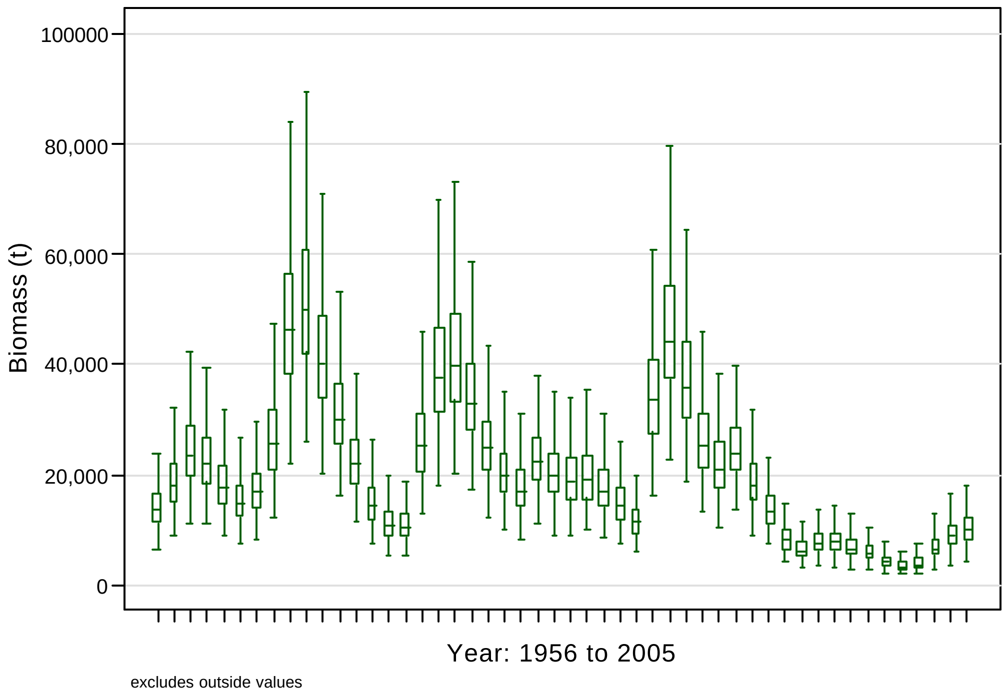


Figure 35. Box plots of beginning year biomass distributions by year for the "Estimate M, h" model based on 100,000,000 MCMC draws sampled every 50,000 iterations.

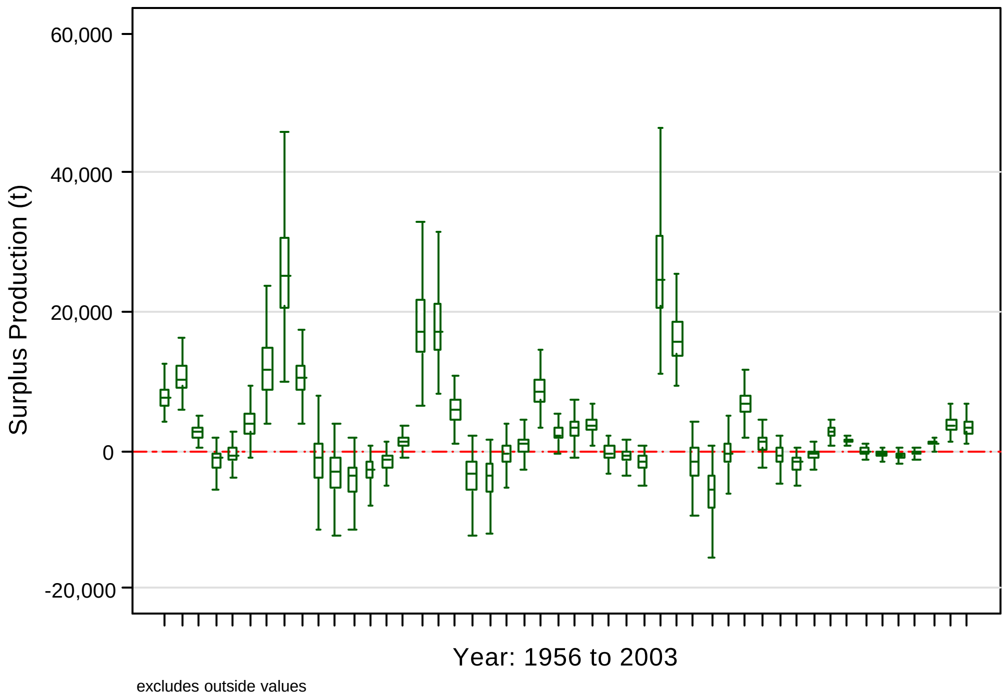


Figure 36. Box plots of surplus production distributions by year for the "Fixed *h*"model based on 100,000,000 MCMC draws sampled every 50,000 iterations.

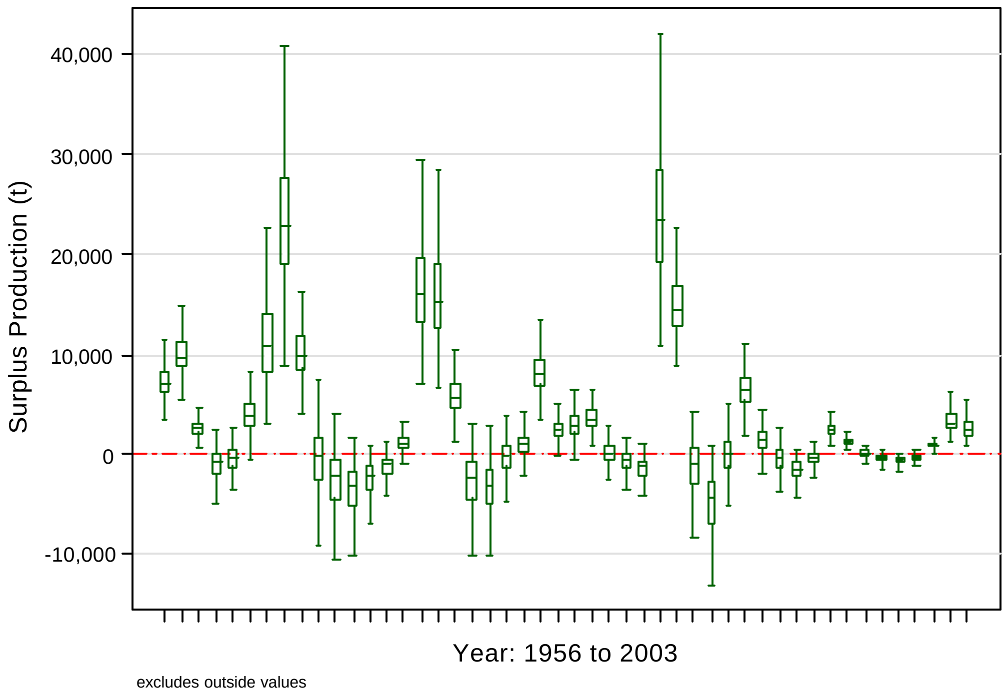


Figure 37. Box plots of surplus production distributions by year for the "Estimate M, h "model based on 100,000,000 MCMC draws sampled every 50,000 iterations.

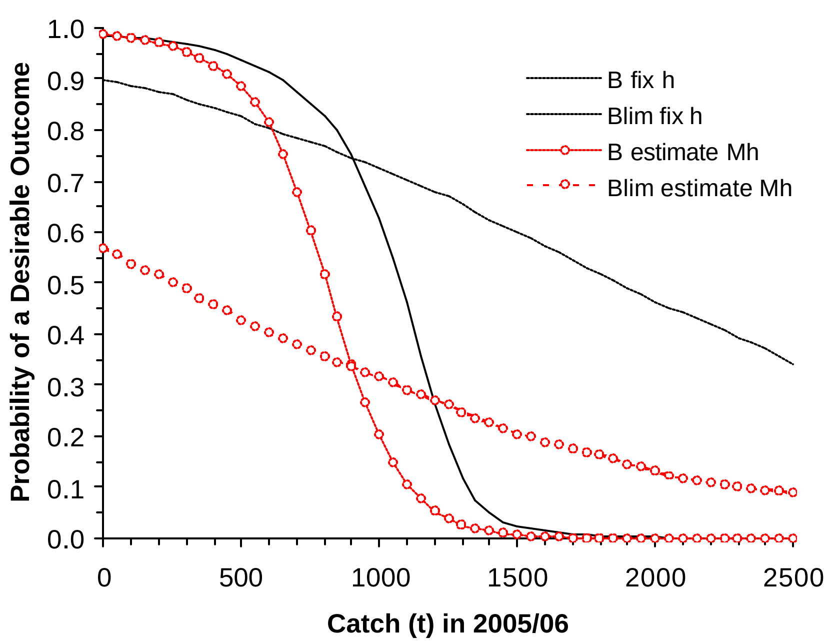


Figure 38. Cumulative probabilities of 2 performance measures, biomass increasing (B) and biomass being greater than that in 1971 (Blim) for the Fixed *h* and Estimate *M, h* models.

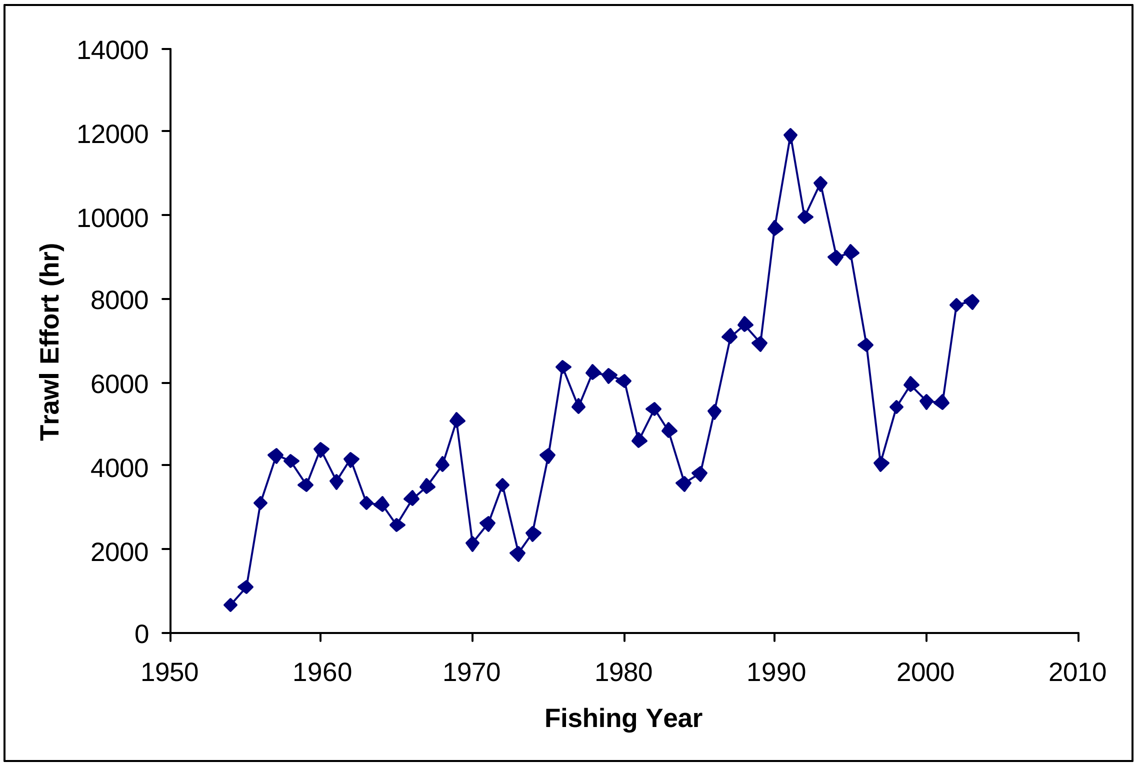


Figure 39: Annual fishing effort (hours) reported by Canadian bottom trawlers in Queen Charlotte Sound (5AB), 1954-2003.

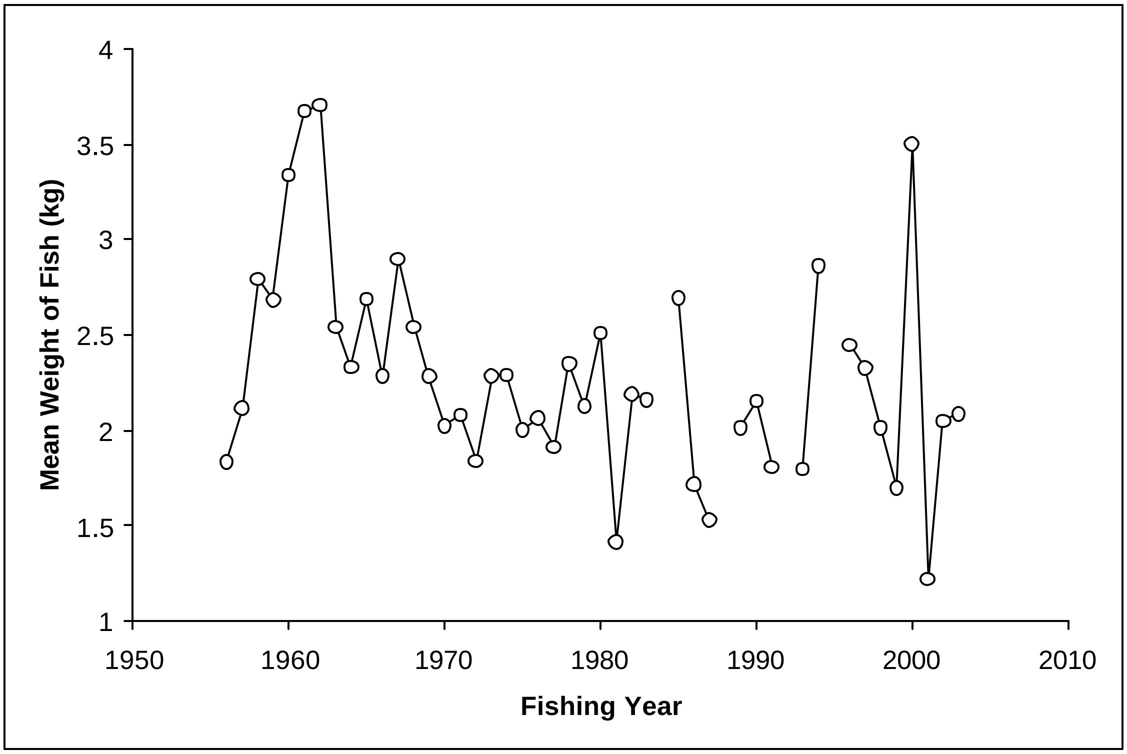


Figure 40: Mean weight of Pacific cod in the bottom trawl fishery in Queen Charlotte Sound, 1956-2003

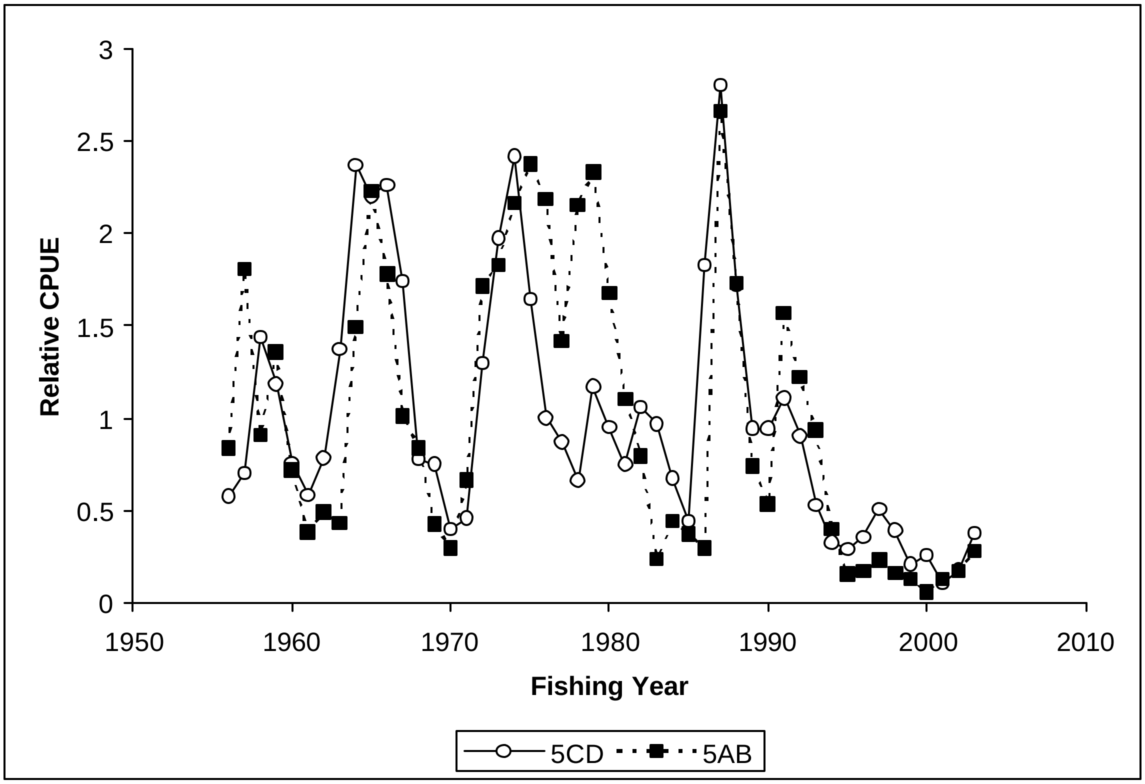


Figure 41: Comparison of CPUE time series for Pacific cod in Hecate Strait (5CD) and Queen Charlotte Sound (5AB). Both series were scaled by their respective means.

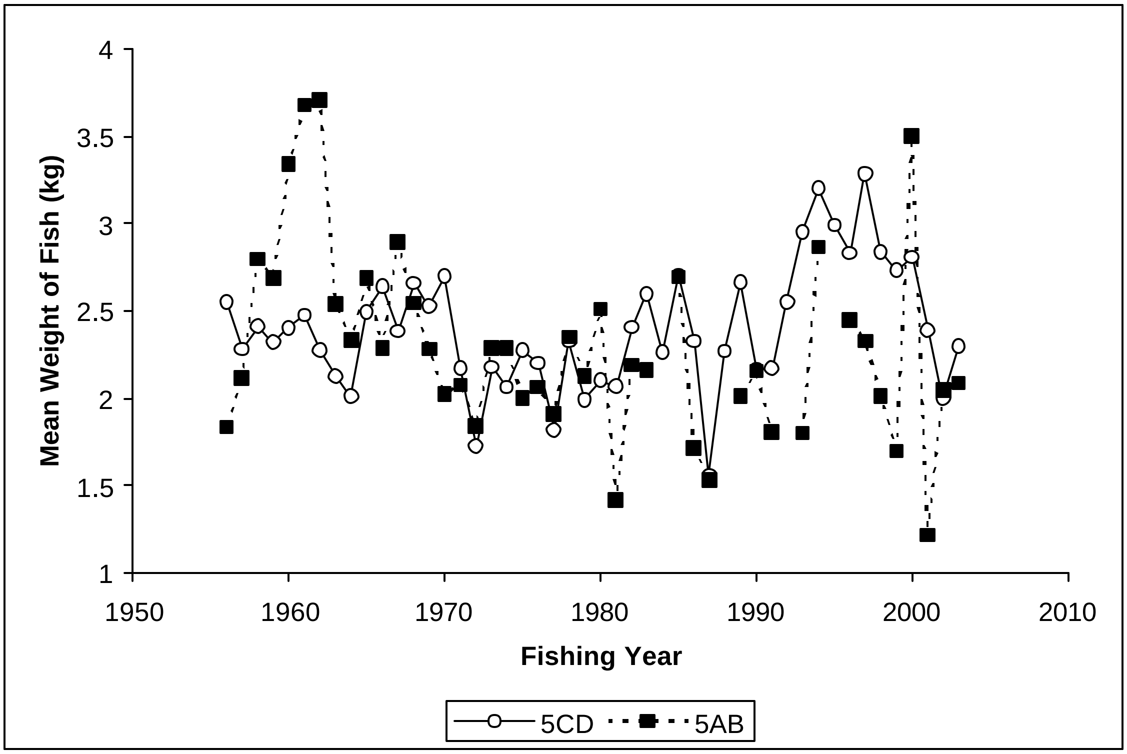


Figure 42: Comparison of mean weight of Pacific cod in the commercial catches, 1956 – 2003.

Annex

Annex 1: Request for Working paper

PSARC Request for Working Paper
Date Submitted: Finalized October 7, 2004

Individual or group requesting advice: DFO Fisheries Management, GTAC

Proposed PSARC Presentation Date: November, 2004

Subject of Paper (title if developed): Assessment of Pacific cod in Queen Charlotte Sound (5AB) and Hecate Strait (5CD) with Catch and Limit Reference Point Recommendations for 2005-06

Science Lead Author: Alan Sinclair

Resource Management Lead Author: Barry Ackerman

Rationale for request:

Pacific cod is a relatively short lived species and their stock status may change rapidly. Yields have been relatively low in recent years due mainly to low abundance and restrictive TACs. Stock assessments are possible when new information on stock status is obtained. An industry-funded stratified random bottom trawl monitoring survey in Hecate Strait was designed and implemented in 2002 and there will be 3 years of results available for analysis in the fall of 2004. Reports from industry indicate increases in abundance in this area. The TAC in area 5CD (Hecate Strait) was reduced from 1000 t to 200 t for the 2001/02 fishing year and subsequently increased to 400 t for 2004/2005.

There has never been a stock assessment of Pacific cod in area 5AB (Queen Charlotte Sound) and the current TAC was established based on a precautionary approach that considered historical catches. Reports from industry indicate an increase in abundance in this area and there has been a request for an assessment in this area.

In July 2004, the ADM Fisheries and Aquaculture Management agreed to work towards integrating the Precautionary Approach (PA) into Fisheries Management Renewal this Year by focusing initially on groundfish and pelagic fisheries. To this end NHQ has requested that Science assessments begin to include candidate Limit Reference Points for groundfish and pelagic fisheries starting this year.

Objective of Working Paper:
(To be developed by FM, StAD, Habitat Science, HEB/Oceans for internal papers)

To review surveys, biological sampling, catch records, logbooks, observer reports and fishing practices for Pacific cod to recommend biological limit reference point for each stock and provide a basis for management for the 2005/06 fisheries in the offshore management areas 5AB and 5CD.

Question(s) to be addressed in the Working Paper:
(To be developed by initiator)

What is the current biomass and size structure of Pacific cod stocks in 5AB and 5CD and how does this relate to historical stock conditions?

What is the expected trajectory of the Pacific cod in the 2 areas to the end of the 2005/06 fishing season and how will this be affected by a range of annual TACs?

What is an appropriate biological limit reference point recommended for each of these stocks? Include biological considerations and rationale used to form these recommendations.

Stakeholders Affected:
GTAC

How Advice May Impact the Development of a Fishing Plan:

The catch advice will directly affect TAC's set in the IFMP for 2004/2005 and beyond.

Timing Issues Related to When Advice is Necessary:

Catch advice is required before February 2005

Approved:

Science Manager: ______________________________;
Date:_____________________

Fisheries/Habitat/Oceans
Manager: ______________________________;
Date:_____________________

Annex 2: Numbers of length frequency samples (N sam.) and numbers of fish measured (N meas.) from bottom trawl catches of Pacific cod in Hecate Strait by sample category, fishing year, and quarter, 1954-2004.

		Apr. - Jun.		Jul. - Sep.		Oct. - Dec.		Jan. - Mar.		Total	
Sample Category	F YEAR	N sam.	N meas.	N sam.	N meas.	N sam.	N meas.	N sam.	N meas.	N sam.	N meas.
unsorted	1980							3	310	3	310
unsorted	1981	26	3313					7	1015	33	4328
unsorted	1982	10	1159	14	1300	2	231	1	56	27	2746
unsorted	1983	3	441	13	1257					16	1698
unsorted	1990							11	3181	11	3181
unsorted	1996							1	95	1	95
unsorted	1997	2	271					1	125	3	396
unsorted	1998	16	2181					3	271	19	2452
unsorted	1999	5	882	3	722			1	136	9	1740
unsorted	2000			3	142	3	310	2	240	8	692
unsorted	2001	4	298	4	599	4	123	2	85	14	1105
unsorted	2002	3	346	9	1367	12	1529	6	589	30	3831
unsorted	2003	9	1117	16	1714	5	367	14	1885	44	5083
unsorted	2004	15	1921							15	1921
Landed	1954	4	808			5	1260	9	2136	18	4204
Landed	1955	4	781			1	212	4	685	9	1678
Landed	1956	5	756	1	90			3	426	9	1272
Landed	1957	3	461			1	227	12	2314	16	3002
Landed	1958	6	1209	3	664	10	2033	20	4213	39	8119
Landed	1959	10	1949	13	3623	2	404	9	1851	34	7827
Landed	1960	6	1840	15	3604	12	2031	12	2778	45	10253
Landed	1961	17	4430	7	2488	6	1330	17	4972	47	13220
Landed	1962	6	1488	4	1215	4	1093	20	5105	34	8901
Landed	1963	8	2472	6	1767	5	1265	19	4077	38	9581
Landed	1964	24	6229	15	3967	6	1449	24	5993	69	17638

Sample Category	F YEAR	Apr. - Jun. N sam.	N meas.	Jul. - Sep. N sam.	N meas.	Oct. - Dec. N sam.	N meas.	Jan. - Mar. N sam.	N meas.	Total N sam.	N meas.
Landed	1965	21	5732	16	4040	11	2524	15	3826	63	16122
Landed	1966	30	7390	14	3480	10	2131	16	4341	70	17342
Landed	1967	9	2424	15	3784	14	2881	17	3842	55	12931
Landed	1968	20	4528	7	1589	4	858	12	2547	43	9522
Landed	1969	15	3414	5	1008	1	196	6	1193	27	5811
Landed	1970	5	964	3	713	1	172	10	1914	19	3763
Landed	1971	8	1501	1	135			2	458	11	2094
Landed	1972	3	804	2	548	6	1228	3	683	14	3263
Landed	1973	11	2854	11	2727	7	1595	2	451	31	7627
Landed	1974	9	2097	9	2031	10	2133	13	2443	41	8704
Landed	1975	14	3206	1	120	5	884	12	1590	32	5800
Landed	1976	15	1845	9	1054	4	457	5	650	33	4006
Landed	1977	12	1913	20	2372	9	1080	7	816	48	6181
Landed	1978	23	2909	11	1316	7	797	13	1656	54	6678
Landed	1979	23	3643	17	2500	5	635	26	3774	71	10552
Landed	1980	16	2191	5	596	1	120			22	2907
Landed	1981	1	120	7	777	2	240	11	1622	21	2759
Landed	1982	16	2923	10	2062	1	228	15	2807	42	8020
Landed	1983	20	3959	4	923			8	1874	32	6756
Landed	1984	9	2170	7	1640	5	1259	8	1723	29	6792
Landed	1985	5	1174	4	907			8	1844	17	3925
Landed	1986	17	4113	2	416	1	244	15	6051	35	10824
Landed	1987	7	2847	3	1406	2	540	5	1688	17	6481
Landed	1988	4	1464	2	416	2	395	8	3058	16	5333
Landed	1989	3	808			2	491	10	3335	15	4634
Landed	1990	1	231	2	656	7	1390	6	955	16	3232
Landed	1991	14	2596	4	756	2	317	11	1697	31	5366
Landed	1992	11	1776	2	292			8	898	21	2966
Landed	1993	13	1650	3	301	1	25	8	946	25	2922
Landed	1994	3	348	1	116			5	558	9	1022
Landed	1995	5	558	1	123					6	681
Landed	1996	3	404	2	179			9	912	14	1495
Landed	1997	2	225	1	130			11	1135	14	1490
Landed	1998	29	3918	12	1271			8	676	49	5865
Landed	1999	11	1332	7	901			4	461	22	2694
Landed	2000	8	1002					1	178	9	1180
Landed	2001			1	226	2	330	1	85	4	641
Landed	2002							1	164	1	164
Landed	2003							3	484	3	484
Landed	2004	1	179							1	179

Annex 3: Numbers of length frequency samples (N sam.) and numbers of fish measured (N meas.) from bottom trawl catches of Pacific cod in Queen Charlotte Sound by sample category, fishing year, and quarter, 1954-2004.

Sample Category	F YEAR	Apr. - Jun. N sam.	N meas.	Jul. - Sep. N sam.	N meas.	Oct. - Dec. N sam.	N meas.	Jan. - Mar. N sam.	N meas.	Total N sam.	N meas.

Sample Category	F YEAR	Apr. - Jun. N sam.	Apr. - Jun. N meas.	Jul. - Sep. N sam.	Jul. - Sep. N meas.	Oct. - Dec. N sam.	Oct. - Dec. N meas.	Jan. - Mar. N sam.	Jan. - Mar. N meas.	Total N sam.	Total N meas.
unsorted	1978					4	209			4	209
unsorted	1980							14	1388	14	1388
unsorted	1981	1	173	3	261			2	462	6	896
unsorted	1982	10	1182			1	85			11	1267
unsorted	1983	1	85							1	85
unsorted	1996			1	72					1	72
unsorted	1997			1	213					1	213
unsorted	1998	4	441			1	50	1	59	6	550
unsorted	1999	2	359							2	359
unsorted	2000			1	61					1	61
unsorted	2001	1	164					1	199	2	363
unsorted	2002	4	661	5	695			1	114	10	1470
unsorted	2003	11	1277	12	1428	3	228	3	394	29	3327
unsorted	2004	26	3282							26	3282
Landed	1950			1	94					1	94
Landed	1951			1	267					1	267
Landed	1953			2	227					2	227
Landed	1954			2	356					2	356
Landed	1955	1	103	1	110					2	213
Landed	1956	4	815	2	367			1	158	7	1340
Landed	1957	12	3526	11	2757			1	196	24	6479
Landed	1958	17	3669	3	819					20	4488
Landed	1959	12	3292	4	1145					16	4437
Landed	1960	11	2374	10	2541	1	259			22	5174
Landed	1961	14	3974	3	470			1	321	18	4765
Landed	1962	9	2036	5	1451			2	441	16	3928
Landed	1963	9	2439	2	571					11	3010
Landed	1964	10	2360	12	2828	2	352			24	5540
Landed	1965	11	2812	4	1027	1	253	2	373	18	4465
Landed	1966	12	2891	12	2753			2	450	26	6094
Landed	1967	14	3504	6	1617	6	1158	1	323	27	6602
Landed	1968	15	3478	5	1096			1	284	21	4858
Landed	1969	11	2360	1	220	2	316			14	2896
Landed	1970	4	943							4	943
Landed	1971	3	637	4	751					7	1388
Landed	1972	4	668	1	172					5	840
Landed	1973	3	428	1	241					4	669
Landed	1974	1	323	3	634					4	957
Landed	1975	2	379	3	435					5	814
Landed	1976	5	597	8	1004			1	122	14	1723
Landed	1977	12	1387	7	816	1	120			20	2323
Landed	1978	11	1604	12	1431					23	3035
Landed	1979	5	929	2	240			2	240	9	1409
Landed	1980	6	743	1	120			1	131	8	994
Landed	1981	1	120	1	120			1	91	3	331
Landed	1982	10	1794	1	186					11	1980
Landed	1983	2	207							2	207
Landed	1985			2	437	1	305			3	742

Sample Category	F YEAR	Apr. - Jun. N sam.	Apr. - Jun. N meas.	Jul. - Sep. N sam.	Jul. - Sep. N meas.	Oct. - Dec. N sam.	Oct. - Dec. N meas.	Jan. - Mar. N sam.	Jan. - Mar. N meas.	Total N sam.	Total N meas.
Landed	1986	1	203			1	200			2	403
Landed	1987	2	829	2	577	1	400			5	1806
Landed	1989			1	198					1	198
Landed	1990			1	211	1	348	1	331	3	890
Landed	1991	1	278	2	534	1	313	1	174	5	1299
Landed	1993							1	182	1	182
Landed	1994	2	336			3	311	1	114	6	761
Landed	1996			1	43					1	43
Landed	1997					1	107			1	107
Landed	1998	3	245	6	733					9	978
Landed	1999	3	174	5	655					8	829
Landed	2000	1	67							1	67
Landed	2002							2	363	2	363

Annex 4: Monthly strata mean catch per unit effort (kg hr-1) in survey and skipper sets from the Hecate Strait Pacific cod monitoring survey, 2002-2004. Strata codes are HS – Horseshoe, RI – Reef Island, SG – Shell Ground, TPB – Two peaks Butterworth, WR – White Rock.

			Survey Sets		Skipper Sets	
YEAR	MONTH	AREA	NSET	MEAN	NSET	MEAN
2002	Mar	HS	8	7.35		
2002	Mar	RI	2	0.00		
2002	Mar	SG	8	1.68		
2002	Mar	TPB	11	45.60		
2002	Mar	WR	11	27.89		
2002	Apr	HS	7	3.75		
2002	Apr	RI	2	10.40		
2002	Apr	SG	5	74.19		
2002	Apr	TPB	11	105.74	3	317.49
2002	Apr	WR	11	50.87	1	73.08
2002	May	HS	7	1.67		
2002	May	RI	2	5.44		
2002	May	SG	5	65.82		
2002	May	TPB	11	501.15	3	1353.13
2002	May	WR	11	47.03	1	11.64
2002	Jun	HS	7	58.19		
2002	Jun	RI	2	3.62		
2002	Jun	SG	5	146.89		
2002	Jun	TPB	11	316.49	4	1265.11
2002	Jun	WR	11	33.30		
2002	Jul	HS	7	16.88	1	0.00
2002	Jul	RI	2	17.69		
2002	Jul	SG	5	0.72	1	1052.34
2002	Jul	TPB	11	255.27	2	156.03
2002	Jul	WR	11	84.43		

			Survey Sets		Skipper Sets	
YEAR	MONTH	AREA	NSET	MEAN	NSET	MEAN
2003	Mar	HS	7	67.78		
2003	Mar	RI	2	565.17		
2003	Mar	SG	5	11.43		
2003	Mar	TPB	11	173.86	4	78.93
2003	Mar	WR	11	587.88		
2003	Apr	HS	7	1.43	1	0.90
2003	Apr	RI	2	2736.84		
2003	Apr	SG	5	40.10		
2003	Apr	TPB	11	69.74	3	51.41
2003	Apr	WR	11	89.56		
2003	May	HS	7	7.94		
2003	May	RI	2	104.33		
2003	May	SG	5	235.14		
2003	May	TPB	11	365.18	4	346.78
2003	May	WR	11	40.76		
2003	Jun	HS	7	2.98	1	146.96
2003	Jun	RI	2	80.74		
2003	Jun	SG	5	722.48		
2003	Jun	TPB	11	381.84	3	457.95
2003	Jun	WR	11	77.50		
2003	Jul	HS	7	786.66		
2003	Jul	RI	2	150.14		
2003	Jul	SG	5	304.63		
2003	Jul	TPB	11	1088.54	4	876.35
2003	Jul	WR	11	568.35		
2004	Mar	HS	7	29.14		
2004	Mar	RI	2	84.30		
2004	Mar	SG	5	73.25		
2004	Mar	TPB	11	169.06	3	545.47
2004	Mar	WR	11	153.33	1	50.40
2004	Apr	HS	7	15.42	1	987.02
2004	Apr	RI	2	32.20		
2004	Apr	SG	5	29.03		
2004	Apr	TPB	11	185.71	3	516.19
2004	Apr	WR	11	47.00		
2004	May	HS	7	10.11		
2004	May	RI	2	39.01		
2004	May	SG	5	173.09		
2004	May	TPB	11	1212.57	4	1378.72
2004	May	WR	11	382.60		
2004	Jun	HS	7	59.61		
2004	Jun	RI	2	102.06		
2004	Jun	SG	5	2.90		
2004	Jun	TPB	11	1103.55	4	867.51
2004	Jun	WR	11	55.92		
2004	Jul	HS	7	608.60		

			Survey Sets		Skipper Sets	
YEAR	MONTH	AREA	NSET	MEAN	NSET	MEAN
2004	Jul	RI	2	44.91		
2004	Jul	SG	5	52.62		
2004	Jul	TPB	11	1160.30	4	1453.57
2004	Jul	WR	11	101.86		

Annex 5: Potential effect of changing mesh size on selectivity of Pacific cod

Haist & Fournier (1998) point out that there was a major change in the mesh size regulations affecting Pacific cod which was initially suggested in 1991 and regulated in 1995. Haist & Fournier (1998) suggest that many fishermen changed their nets in the period between 1991 and 1995 and they modeled a selectivity change beginning in 1993.

The delay-difference formulation used in this model assumes knife-edge selectivity at age two. This approach assumes that all age one fish are not available to the fishery and that all age two fish are. This approach is probably not completely realistic as there will be fish in either age class which will not meet these criteria. However, more importantly, the knife-edge approach will have difficultly accommodating the change in selectivity implied by this mesh size change.

We looked at the available length frequency data to determine if there was a signal which would indicate that there had been a shift in the selectivity during that period. We conclude that there is some evidence from the data that there was a shift in selectivity, given that the cumulative length frequency distributions by quarter show a shift to the left over the critical period (Figure 43 and Figure 44)

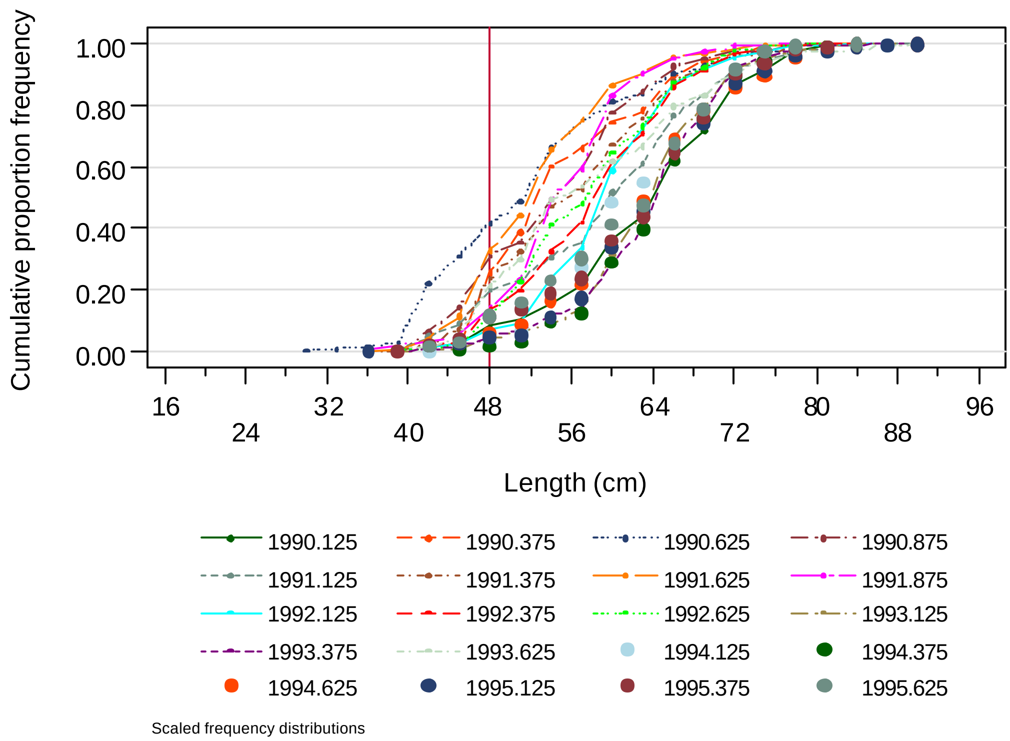


Figure 43. Sorted length frequency distributions of number of fish for Area 5CD Pacific cod by quarter for the years 1990 to 1995 (inclusive), plotted as empirical cumulative frequency distributions. Vertical line plotted at 48 cm.

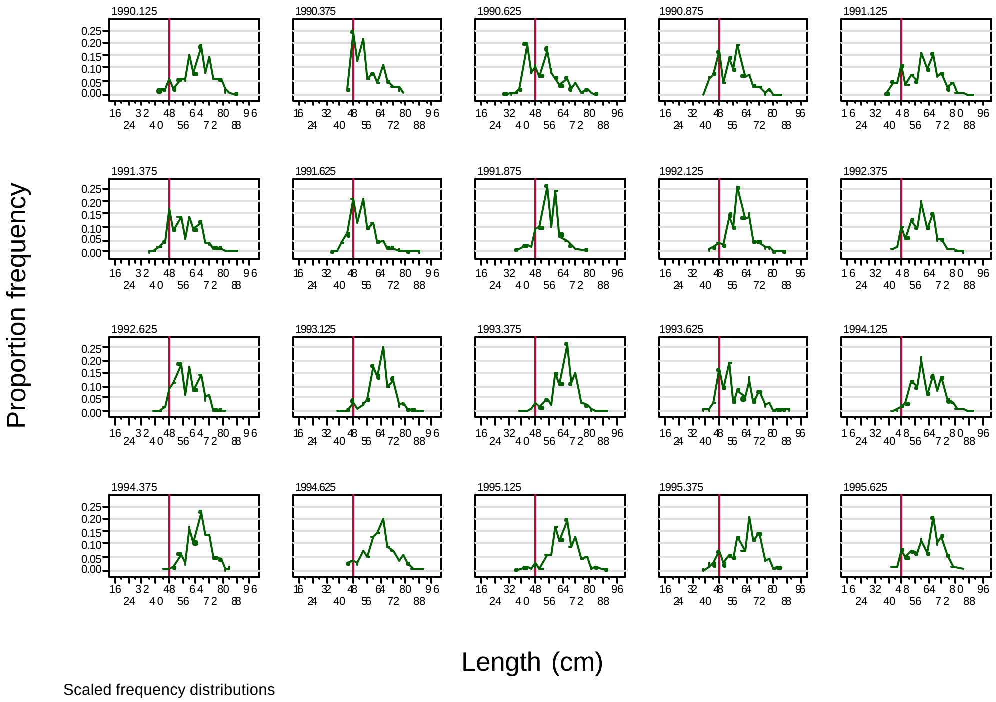


Figure 44. Sorted length frequency distributions for Area 5CD Pacific cod by quarter for the years 1990 to 1995 (inclusive), plotted as normalised frequency distributions. Vertical line plotted at 48 cm.