

Part I: Moving towards the sustainable fisheries framework
for Pacific herring: data, models, and alternative
assumptions.

Part II: Stock Assessment and Management Advice for the
British Columbia Pacific Herring Stocks

2011 Assessment and 2012 Forecasts

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Abstract

June 15, 2011. Structure of this paper has changed a bit. This document will now consist of an assessment and forecast of the five major stocks and the two minor stocks. There will be at least 5 appendixes that 1) describe the input data and the control files used for the assessment model, 2) a detailed description of $iSCAM$, 3) a description of the methods used to develop the prior distribution, 4) simulation testing of the $iSCAM$ model, 5) moving toward the sustainable fisheries framework (see Cleary and Cox paper) and include discussion of the issues of developing an MSY-based framework for a multigear fishery with changing selectivities and natural mortality rates, and finally 6) a list of research recommendations.

Summary: Three major themes of the paper: 1) a comparing HCAM and iSCAM (where iSCAM is set up with nearly the same assumptions as 2010 HCAM assessment), 2) an iSCAM assessment with several scenarios addressing (a) q with various priors, (b) time-varying versus constant M , (c) alternative selectivity models, and (d) the interactions of all three of these confounded variables, and 3) an iSCAM assessment with the test fishery and seine roe fishery data separated into specific fleets. The side by side comparison will examine similarities/differences between trends in biomass, fishing mortality rates, and residual fits to the spawn survey data an age-composition data. These two models have some fundamental differences in the statistical assumptions about the catch-at-age data, so results are likely to be slightly different. Results for all three themes will focus on reconstructing table 5 from last years assessment, with the addition of LRP and USRP to be compared with the cutoffs and catch advice for low med and high recruitment.

Contents

Abstract	i
Contents	iii
List of Figures	v
1 Introduction	1
2 Methods	1
2.1 Input data & assumptions	1
2.1.1 Catch data	1
2.1.2 Relative abundance data	3
2.1.3 Biological samples	4
2.1.4 Age composition data	4
2.1.5 Mean weight-at-age data	4
2.2 Analytical methods	14
2.3 Simulation testing	15
2.3.1 Estimation performance with perfect information	15
2.3.2 Bias & precision with observation & process errors	15
2.4 Comparison of HCAM with <i>iSCA_M</i>	16
2.4.1 Age-composition data	16
2.4.2 Commercial catch data	16
2.4.3 Spawn survey data	16
2.4.4 Specification of prior distributions	16
2.5 Forecasts of pre-fishery biomass based on SFF reference points	17
3 Results	17
3.1 Simulation testing	17
3.1.1 Estimation performance with perfect information	17
3.1.2 Bias & precision with observation & process errors	18
3.2 Comparison of HCAM with <i>iSCA_M</i>	20
3.2.1 Strait of Georgia herring assessment	25
3.2.2 Retrospective and prospective analyses	25
3.3 Alternative assumptions about catchability, mortality & selectivity	25
3.3.1 Impacts of informative priors on q 's	25
3.3.2 Implications of variable natural mortality rate M_t	25
3.3.3 Implications of variable selectivity in directed fisheries	25
3.4 Separating test fishery data from the purse seine roe fishery data	25
3.5 Preliminary assessments for all other areas	25
4 Discussion	25
References	26
A Technical description of <i>iSCA_M</i>	27
A.1 Analytic methods	27
A.1.1 Equilibrium considerations	27
A.1.2 MSY based reference points	27
A.1.3 Dynamic age-structured model	30
A.1.4 Options for selectivity	33
A.1.5 Options for natural mortality	34
A.2 Residuals, likelihoods & objective function value components	35
A.2.1 Catch data	35
A.2.2 Relative abundance data	36
A.2.3 Age composition data	36

A.2.4	Stock-recruitment	37
A.3	Parameter Estimation and Uncertainty	38
A.3.1	Negative loglikelihoods	38
A.3.2	Constraints	38
A.3.3	Priors for parameters	39
A.3.4	Survey priors	39
A.3.5	Convergence penalties	39
B	Data and Control files	41
B.1	Haida Gwaii	41
B.2	Prince Rupert District	43
B.3	Central Coast	45
B.4	Strait of Georgia	47
B.5	West Coast of Vancouver Island	50

List of Figures

1	B.C. herring major stock areas: Haida Gwaii (HG or QCI 2E), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SOG), West Coast Vancouver Island (WCVI), and minor stock areas: Area 2W and Area 27	2
2	Historical catch of herring in the five major stock areas between 1951 and 2010 for the winter purse seine fishery (dark bars), seine-roe fishery (grey bars), and gill net fishery (light grey bars). Units of catch are in thousands of metric tons.	3
3	Preliminary Spawning activity for Haida Gwaii (top panel) and Prince Rupert District (bottom) in 2011.	5
3	Preliminary Spawning activity for Central Coast (top panel) and Strait of Georgia (bottom) in 2011.	6
3	Preliminary Spawning activity in 2011 for the West Coast of Vancouver Island (includes minor stock area 27).	7
4	Spawn survey index for Strait of Georgia between 1951 and 2010. The units are actual estimates of spawning biomass (1000s tons), but only the trend information is used in the model fitting.	8
5	Bubble plots showing the proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gill net fishery (bottom) in Haida Gwaii. The area of the circle is proportional to cohort abundance, each column sums to 1, zeros are not shown, and age 10 is a plus group. Also shown is the mean age of the catch (line) and the approximate 95% distribution of ages (shaded polygon) for each year.	9
6	Bubble plots showing the proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gill net fishery (bottom) in Prince Rupert District. The area of the circle is proportional to cohort abundance, each column sums to 1, zeros are not shown, and age 10 is a plus group. Also shown is the mean age of the catch (line) and the approximate 95% distribution of ages (shaded polygon) for each year.	10
7	Bubble plots showing the proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gill net fishery (bottom) in the Central Coast region. The area of the circle is proportional to cohort abundance, each column sums to 1, zeros are not shown, and age 10 is a plus group. Also shown is the mean age of the catch (line) and the approximate 95% distribution of ages (shaded polygon) for each year.	11
8	Bubble plots showing the proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gill net fishery (bottom) in the Strait of Georgia. The area of the circle is proportional to cohort abundance, each column sums to 1, zeros are not shown, and age 10 is a plus group. Also shown is the mean age of the catch (line) and the approximate 95% distribution of ages (shaded polygon) for each year.	12
9	Bubble plots showing the proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gill net fishery (bottom) in the West Coast Vancouver Island region. The area of the circle is proportional to cohort abundance, each column sums to 1, zeros are not shown, and age 10 is a plus group. Also shown is the mean age of the catch (line) and the approximate 95% distribution of ages (shaded polygon) for each year.	13
10	Empirical mean weight-at-age data by cohort from 1951 to 2010 for ages 2 to 10 in the five major Stock Assessment Regions.	14
11	True (thin line) and estimated (thick shaded line) spawning biomass (a), fishing mortality rates (b), observed and predicted relative abundance (c), and residuals between observed and predicted relative abundance (d) for the SOG herring simulation with perfect information and a deterministic stock-recruitment relationship.	18
12	Estimates of precision and bias in key model parameters and MSY based reference points for 50 simulated data sets conditioned on the Strait of Georgia herring catch. The log2 ratio of estimated versus true value is plotted; values of 1 and -1 correspond to a twice or half the true value, respectively.	19

13	Maximum likelihood estimates of pre-fishery biomass and post fishery spawning biomass (a), spawning biomass depletion (b), observed (points) and predicted (lines) spawn survey data (c), and spawn survey residuals. These results are based on trying to configure the <i>iSCAM</i> model as similar as possible to the previous HCAM assessment; the red line in panel (a) is the MLE estimate of spawning biomass from HCAM.	21
14	Components of total mortality rate (a), residuals between the observed and predicted catch (b), the spawning stock biomass versus age-2 recruits and stock recruitment relationship (estimates of unfished spawning biomass and unfished recruitment are denoted by the circle with the + symbol inside, c), and the residuals in the stock recruitment relationship (d).	22
15	Estimates of age-2 recruits (a) and the residuals (observed-predicted, positive shown in black) in the age-composition data for the winter purse seine fishery (lower left), seine-roe fishery (upper right) and gill net fishery (lower right). The area of each circle is proportional to the residual error, and zeros are not shown. Note that observed age-proportions less than 2% were pooled into the adjacent (younger) age class and the conditional maximum likelihood estimates of the variance is displayed on the top of each panel.	23
16	A comparison of estimated spawning stock biomass between HCAM and <i>iSCAM</i> for the five major stock assessment regions.	24
17	Cap.	25
18	Equilibrium yield (a), recruits (b), biomass (c) and spawner per recruit (ϕ_e/ϕ_E) (d) versus instantaneous fishing mortality F_e for two different values of the recruitment compensation ratio ($\kappa = 12$ solid lines, $\kappa = 4$ dashed lines). Vertical lines in each panel correspond to F _{MSY} and horizontal lines correspond to various reference points that would achieve MSY.	29
19	Example of a natural cubic spline interpolation for estimating selectivity coefficients. In <i>iSCAM</i> the user specifies the number of nodes (circles) to estimate; then age-specific selectivity coefficients are interpolated using a natural cubic spline.	34
20	Example of a time-varying cubic spline (left) and bicubic spline (right) interpolation for selectivity. The panel on the left contains 165 estimated selectivity parameters and the bicubic interpolation estimates 85 selectivity parameters, or 5 age nodes and 17 year nodes. There are 495 actual nodes (selectivity parameters) being interpolated.	35
21	An example of the prior distributions used for $\ln(R_o)$, h , $\ln(M)$, $\ln(\bar{R})$, ρ , ϑ . The actual values used for the SOG herring assessment can be found in the control file in the appendix.	40

1 Introduction

There are four major objectives of this paper: (1) to describe in detail an alternative integrated statistical catch-age model (*iSCAM*), (2) examine parameter estimation performance using *iSCAM*, (3) perform a side-by-side comparison of the previous HCAM and *iSCAM* on the five major herring stocks, and (4) explore alternative assumptions about selectivity, catchability, and natural mortality using *iSCAM*. The most recent assessment of BC herring stocks was conducted in 2010 using the Herring Catch Age Model (HCAMv2) which is documented in [Cleary and Schweigert \(2010\)](#). Furthermore, a review sponsored by the Herring Research and Conservation Society (HRCS) was conducted June 17-18, 2010 in Nanaimo, BC where an expert panel addressed specific questions about the current implementation of the HCAMv2 model and suggested recommendations for each of the questions. This paper also attempts to address some of the points brought up in the review.

BC herring are currently managed as five major stocks and 2 minor stocks (Figure 1). Annual catch advice for each of these areas is based on current estimates of stock status, and a 20% exploitation rate if the stock is above the cutoff level for the five major stocks and a 10% exploitation rate for the two minor stocks. Cutoff levels for the five major stocks are based on $0.25B_o$, and estimates of unfished biomass were established first in 1985 ([Haist et al., 1986](#)). These cutoffs are currently thought to be more conservative than the current default Limit Reference Point of $0.4B_{MSY}$ ([Fisheries and Oceans Canada, 2006](#)). However, estimates of B_o and MSY based reference points have not been examined for Pacific herring for some time. In this paper we also describe the methods for updating estimates of B_o and MSY based reference points using the *iSCAM* model framework. We also compare estimates of MSY based reference points for the Strait of Georgia herring under the previously mentioned alternative assumptions (see point (4) in the previous paragraph).

We do not provide a detailed description of HCAMv2 in this paper and we refer the reader to [Schweigert et al. \(2009\)](#) and [Cleary and Schweigert \(2010\)](#) for a more detailed description. We first begin with a description of the input data required and assumptions about the data, followed by a detailed description of the analytical methods and assumptions in *iSCAM*. We then present the analytical methods and assumptions for exploring alternative hypotheses about selectivity, catchability and natural mortality, followed by a description of the elements that make up the joint posterior distribution (i.e., likelihoods, priors, and penalties). Parameter estimating and quantifying uncertainty is carried out using AD Model Builder ([ADMB Project, 2009](#)). We then explore estimation performance in *iSCAM* using simulation experiments where the model is used to generate simulated observations with known parameter values, then estimate parameter, and repeat this exercise a number of times to evaluate bias and precision in parameter estimates. Finally, we present forecast of pre-fishery biomass and available harvest options using the cutoffs (e.g., reproduce Table 5 in [Cleary and Schweigert, 2010](#)) as well as available harvest options based on the Sustainable Fisheries Framework (i.e., [Fisheries and Oceans Canada, 2006](#)) for comparison.

2 Methods

2.1 Input data & assumptions

2.1.1 Catch data

For each of the statistical areas, the required input data for *iSCAM* consists of a catch time series for each of the fishing fleets. For the BC herring fishery, the annual total removals has been partitioned into three distinct fishing fleets (or fishing periods, see Figure 2). The first fleet is a winter seine fishery that has been in operation since the start of the assessment in 1951, the second is a seine-roe fishery that commenced in 1972 in the Strait of Georgia, and the third fleet is a gillnet fishery that targets females on the spawning grounds. The model is fit to the catch time series information and assumes measurement errors are lognormal, independent and identically distributed. The assumed standard deviation in the catch observations must be specified in the control file and it is assumed that measurement errors in the catch is the same for all fishing periods. The units of the catch are given in 1000s of metric tons.

In addition to the commercial catch, removals from fisheries independent surveys must also be specified in *iSCAM*. Two additional fleets are specified to represent the spawn survey, where the spawn survey is

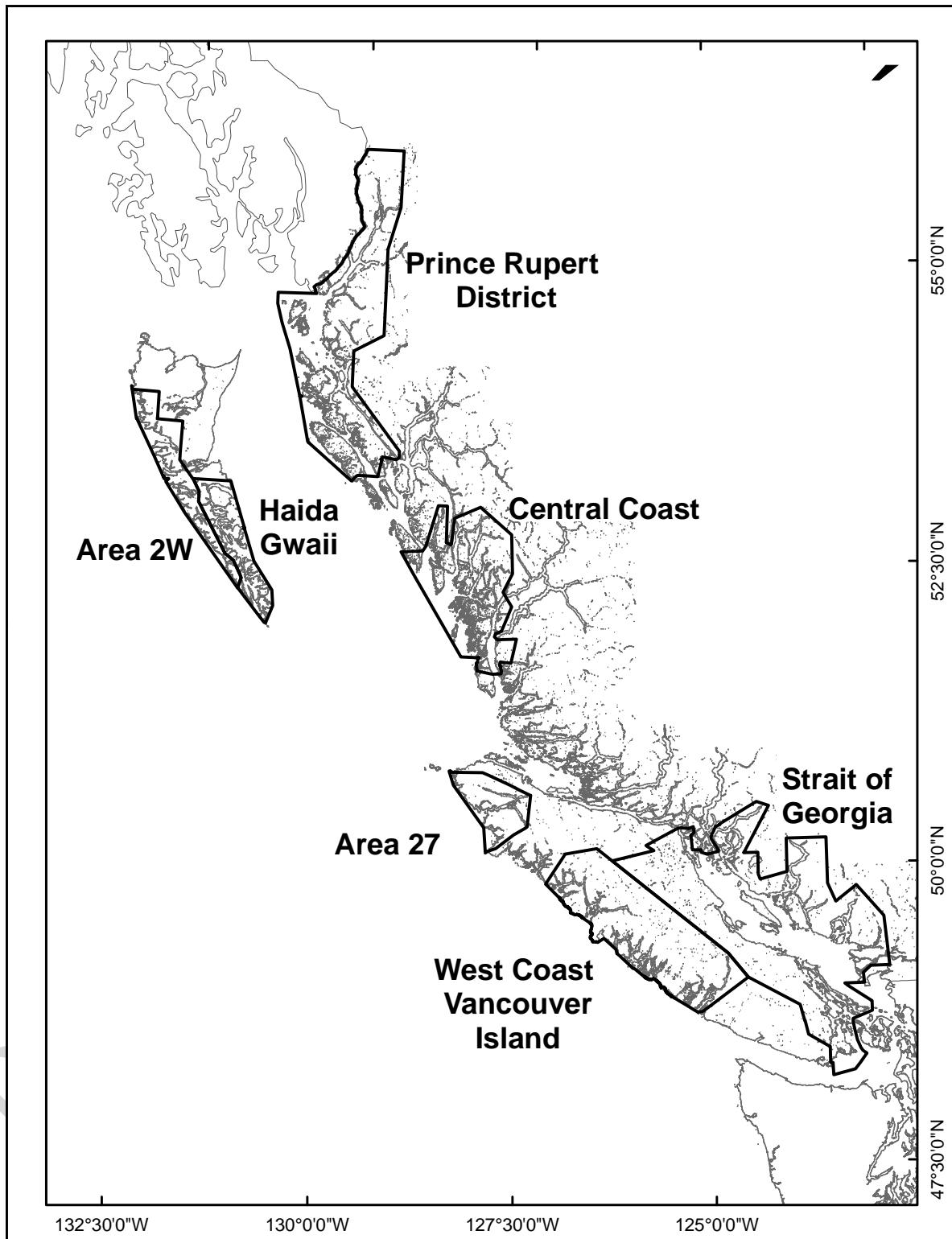


Figure 1: B.C. herring major stock areas: Haida Gwaii (HG or QCI 2E), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SOG), West Coast Vancouver Island (WCVI), and minor stock areas: Area 2W and Area 27.

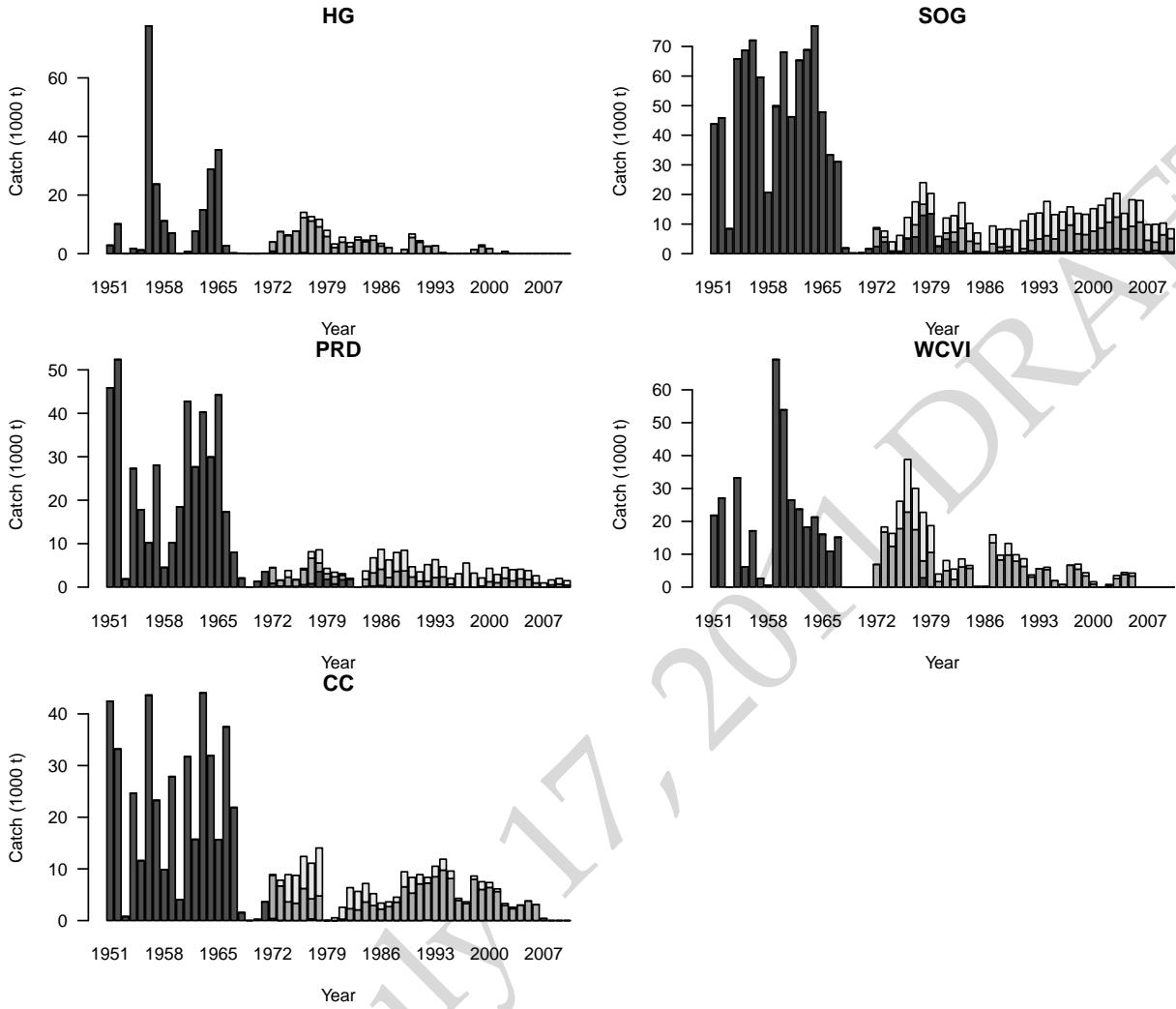


Figure 2: Historical catch of herring in the five major stock areas between 1951 and 2010 for the winter purse seine fishery (dark bars), seine-roe fishery (grey bars), and gill net fishery (light grey bars). Units of catch are in thousands of metric tons.

broken into two distinct time periods pre-1988 and post-1988, the year when the survey switched from surface surveys to dive surveys. This partitioning of the data is done for two reasons: (1) to allow for different catchability coefficients to be specified for the early and late periods, and to allow for more weight to be placed on the contemporary data due to improved precision in the estimates of egg layers.

In the case where the test fishery data has been separated from the seine roe fishery, an additional fleet is specified in the data file and fishing mortality rates for the test fishery are also estimated in years when the catch is greater than 0.

2.1.2 Relative abundance data

Herring spawn surveys have been conducted throughout the B.C. coast beginning in the 1930s. Prior to 1988, spawn surveys were conducted from the surface either by walking the beach at low tide or using a drag from a skiff to estimate the shoreline length and width of spawn. Egg layers were sampled visually and are used to calculate egg densities following the methods of Schweigert (2001). Beginning in 1988, herring spawn surveys using SCUBA methods were introduced and were implemented coastwide within a

couple of years initially being conducted by DFO staff and eventually through contract divers hired through the test fishing program. Prior to the 2006 Larocque ruling, the test fishing program was funded through an allocation of fish by industry. In years since the 2006 Larocque ruling, the availability of resources to conduct dive surveys in all areas has been reduced. For the 2010 survey, dive surveys were conducted in all major and minor assessment regions, with the exception of Area 2W where snorkeling and surface survey methods were also used. As in earlier years, a few minor spawning beds outside the main assessment areas were surveyed by SCUBA or surface methods where resources permitted.

The locations of the spawning beds for the five major and two minor stock areas are shown in Figure 3. Egg density estimates are used to calculate a fishery-independent index of herring spawning biomass, referred to as the spawn survey index hereafter (Schweigert et al., 2001).

The spawn survey is conducted after the fisheries in the area have been conducted; therefore, it is assumed that all the mortality for the year has occurred just prior to commencing the spawning survey. The fisheries independent survey estimates egg density and total spawn area, and from this information the total female spawning biomass can be estimated assuming the 227 eggs per gram of female or 114 eggs per gram of mature spawning individuals (Hardwick, 1973). The assumed selectivity for the spawn survey is fixed to the maturity schedule for herring.

2.1.3 Biological samples

Biological samples are collected from both commercial catch and from the test fishery program. Commencing in 1975, test fishery charters supplemented biological samples in areas with poor sampling that was not representative of the stock in that area (i.e., fishing solely on spawning aggregations), or in closed areas. Prior to 2006, test fishing charters were funded through an allocation of fish to the test program; the program is now fully funded by DFO. Through a contract with DFO, the Herring Conservation and Research Society (HCRS) sub-contracts a number of vessels to collect biological samples. Industry also conducts pre-season test sets for roe-quality testing in open areas and supplementary biological samples are provided as part of this program. The following data are collected for all biological samples: fish length, weight, sex, and maturity. Subsequently these sources of data are combined and information on weight-at-age and proportion-at-age become input data for the stock assessment model.

During the 2010/2011 season a total of XXX biological samples were collected, of which XXX were collected from the test fishery, XXX were collected from the roe fishery, XXX from the food & bait fishery, XXX from Spawn on Kelp (SOK) operations, and XXX from the summer trawl research survey (Table ??). Note that the definition of a sample is roughly 100 individual fish. A summary of biological samples collected from commercial and pre-fishery charters from 2002/03–2010/11 is presented in Table ??).

2.1.4 Age composition data

Ageing data, through the reading of fish scales, are collected from the biological samples taken from the commercial fisheries and test fishery charters. Age composition data is used to determine proportions-at-age and is an essential source of input data to the herring stock assessment model.

Catch-at-age data from the winter seine fishery (top panels of Figures 5-9) indicate that this fishery primarily targets younger fish in comparison to the seine-roe and gill net fleets. The winter seine fishery appears not to capture older fish in comparison to the gill net fleet. The shaded polygons in Figures 5-9 approximates the 95% distribution of ages in the catch. Roughly 90% of the fish landed in the winter seine fishery are younger than age-7, and younger than age-6 in recent years. In both the winter seine and seine-roe fishery age-2 fish are frequently landed; whereas, age-2 fish are rarely landed in the gill net fisher, and fish to appear to fully recruit to the gear until at least 4-5 years of age. The mean age of the catch appears to be increasing between 2008 and 2010 in both the gill net and winter seine fishery, and there is no obvious trend in the seine roe fishery. There is however a declining trend in the older ages caught in the seine-roe fishery since 2006 (erosion of age-structure).

2.1.5 Mean weight-at-age data

From the mid-1970s until the present, there has been a measurable decline in weight-at-age for all ages in all major stock areas (Figure 10). Samples collected during the 2009/10 fishing year indicate weights-at-age

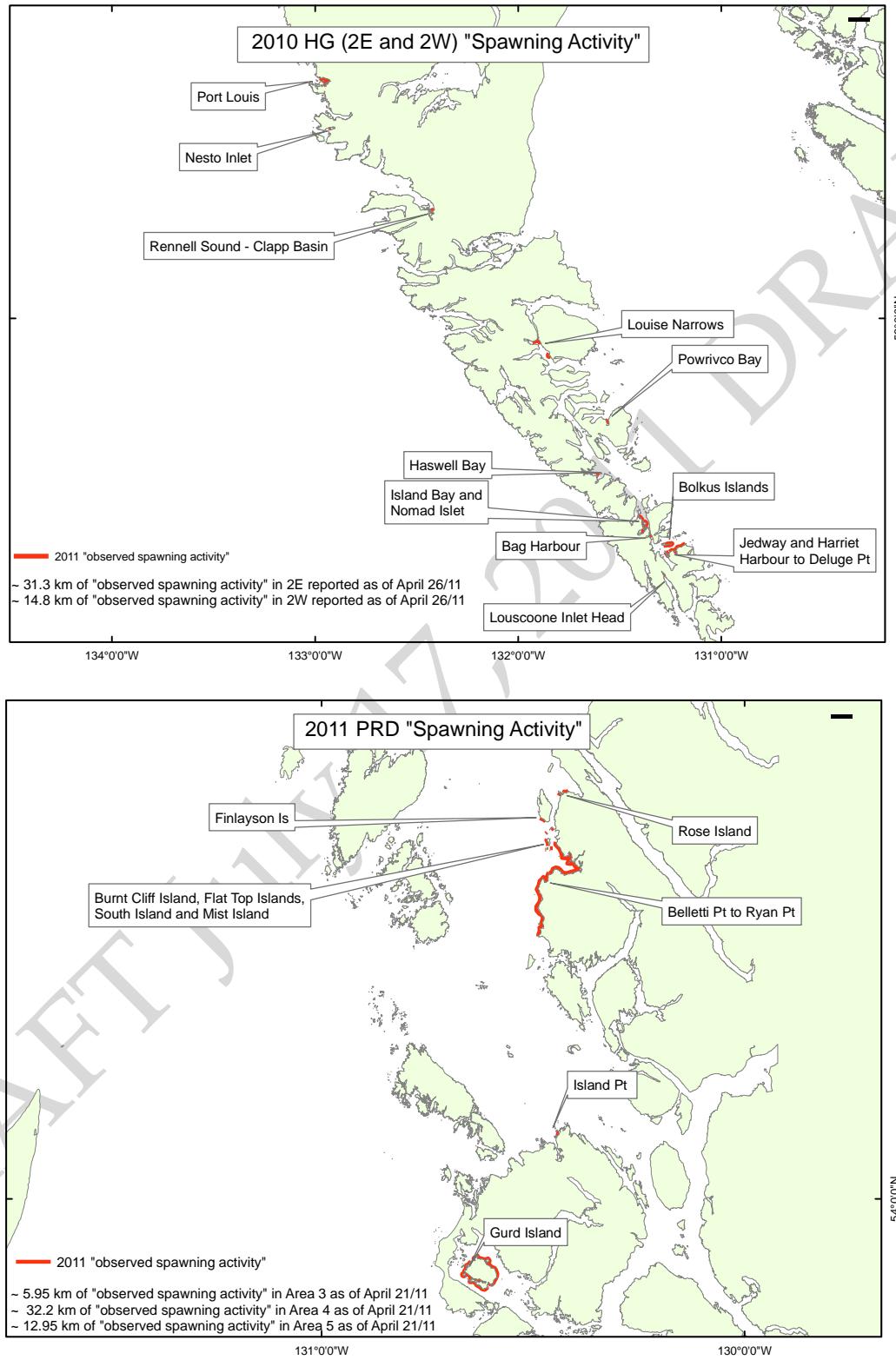


Figure 3: Preliminary Spawning activity for Haida Gwaii (top panel) and Prince Rupert District (bottom) in 2011.

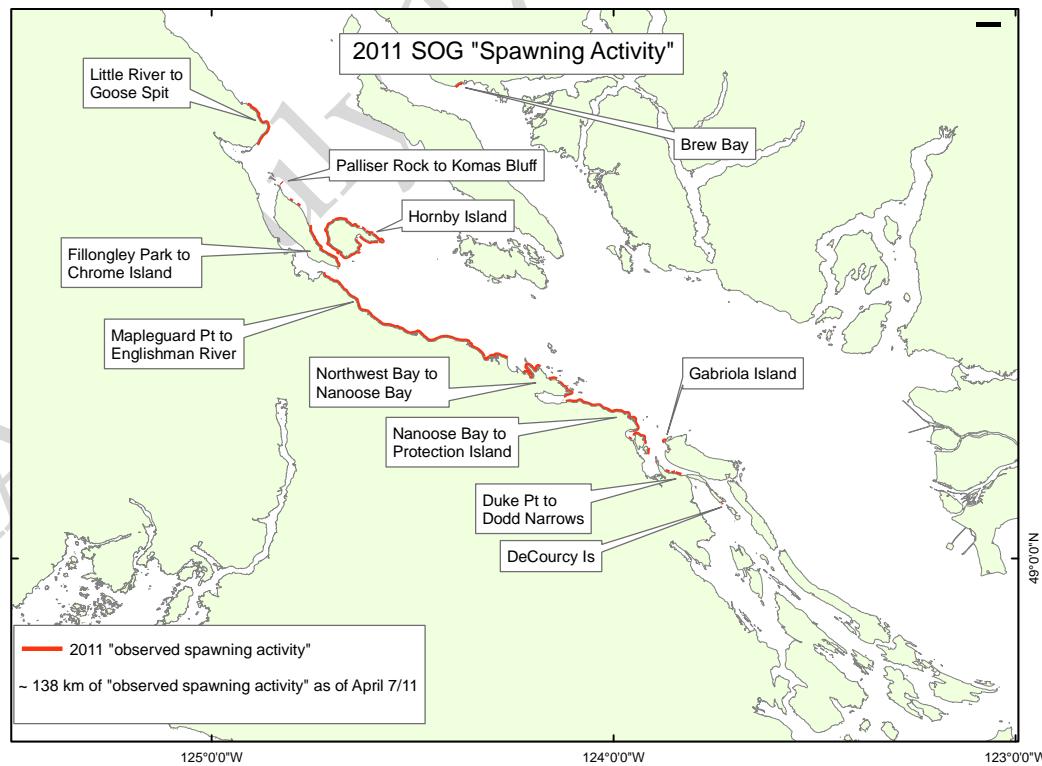
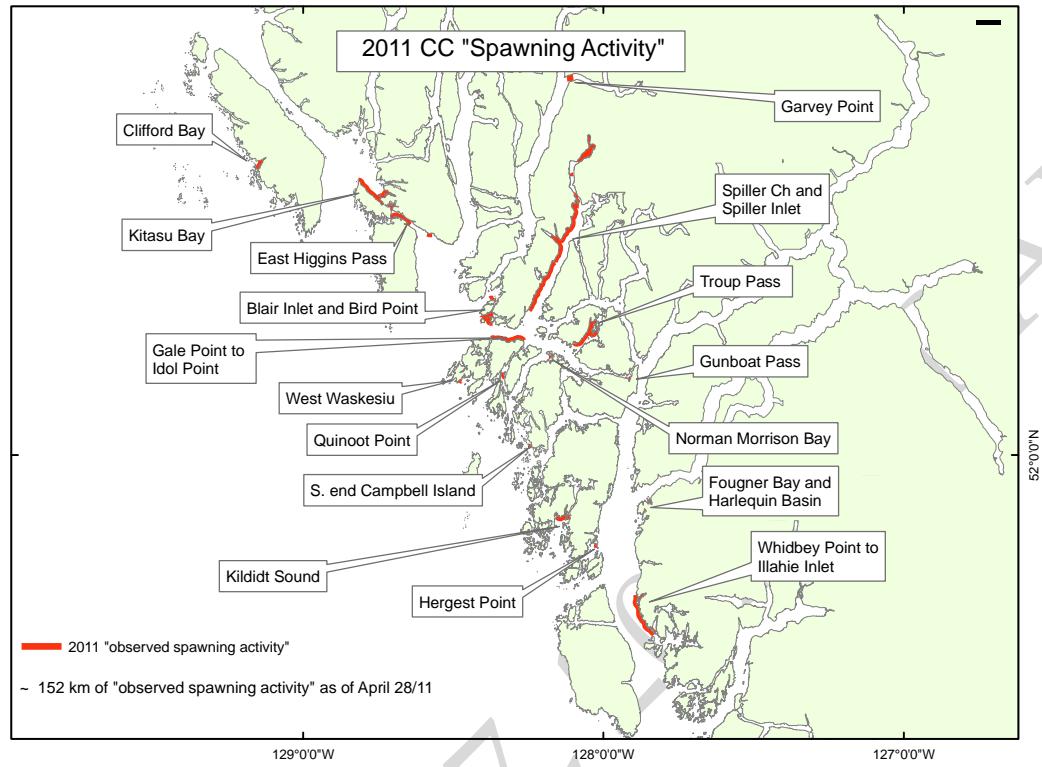


Figure 3: Preliminary Spawning activity for Central Coast (top panel) and Strait of Georgia (bottom) in 2011.

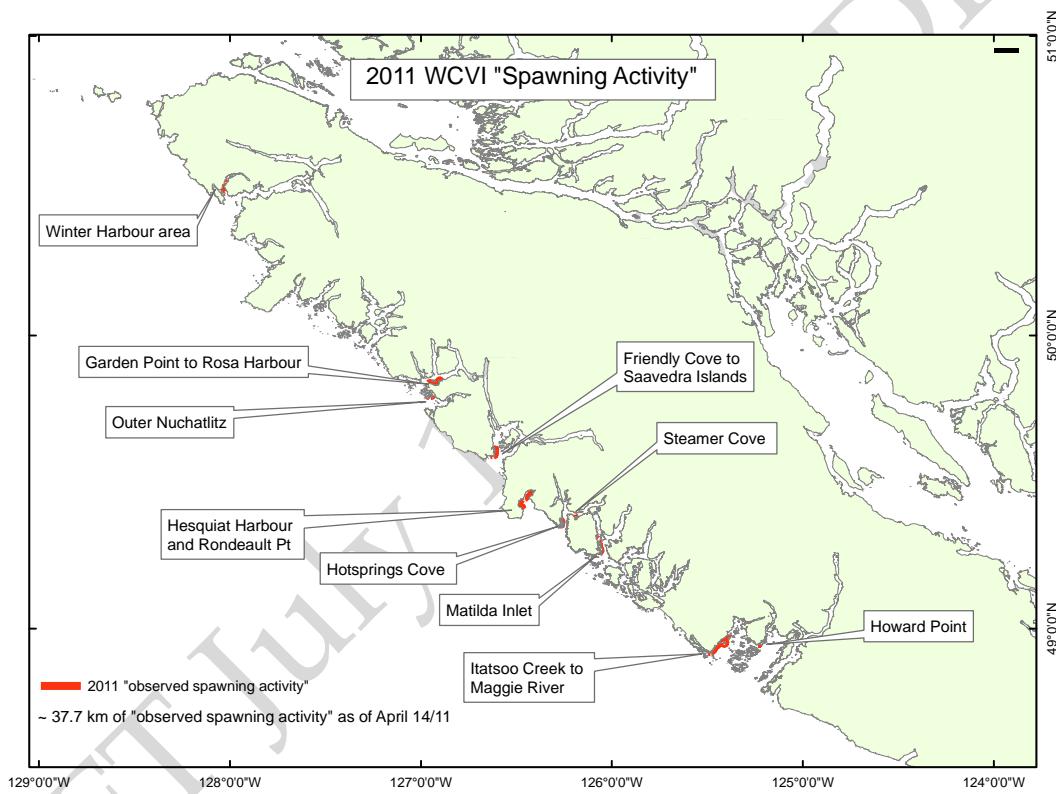


Figure 3: Preliminary Spawning activity in 2011 for the West Coast of Vancouver Island (includes minor stock area 27).

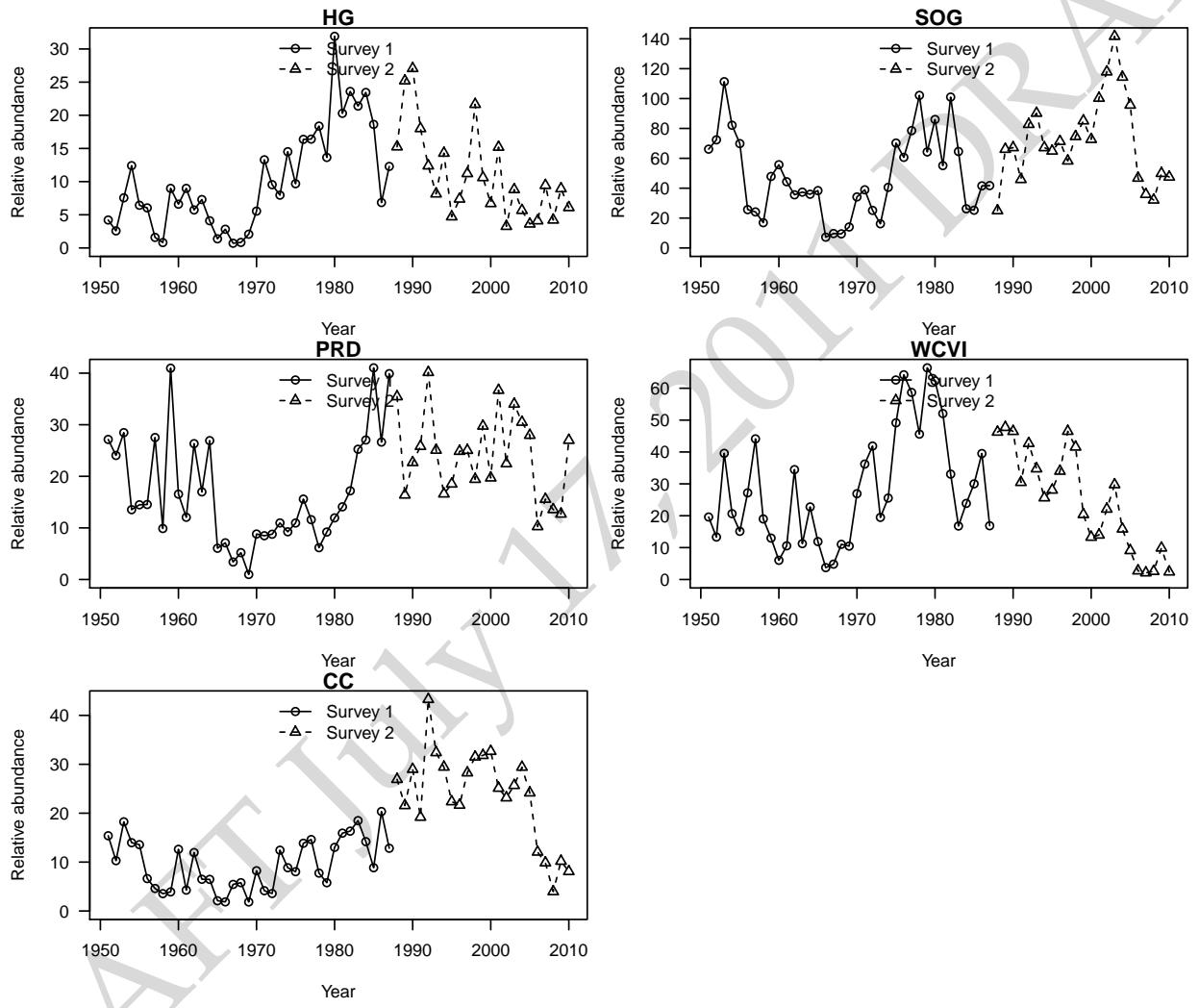


Figure 4: Spawn survey index for Strait of Georgia between 1951 and 2010. The units are actual estimates of spawning biomass (1000s tons), but only the trend information is used in the model fitting.

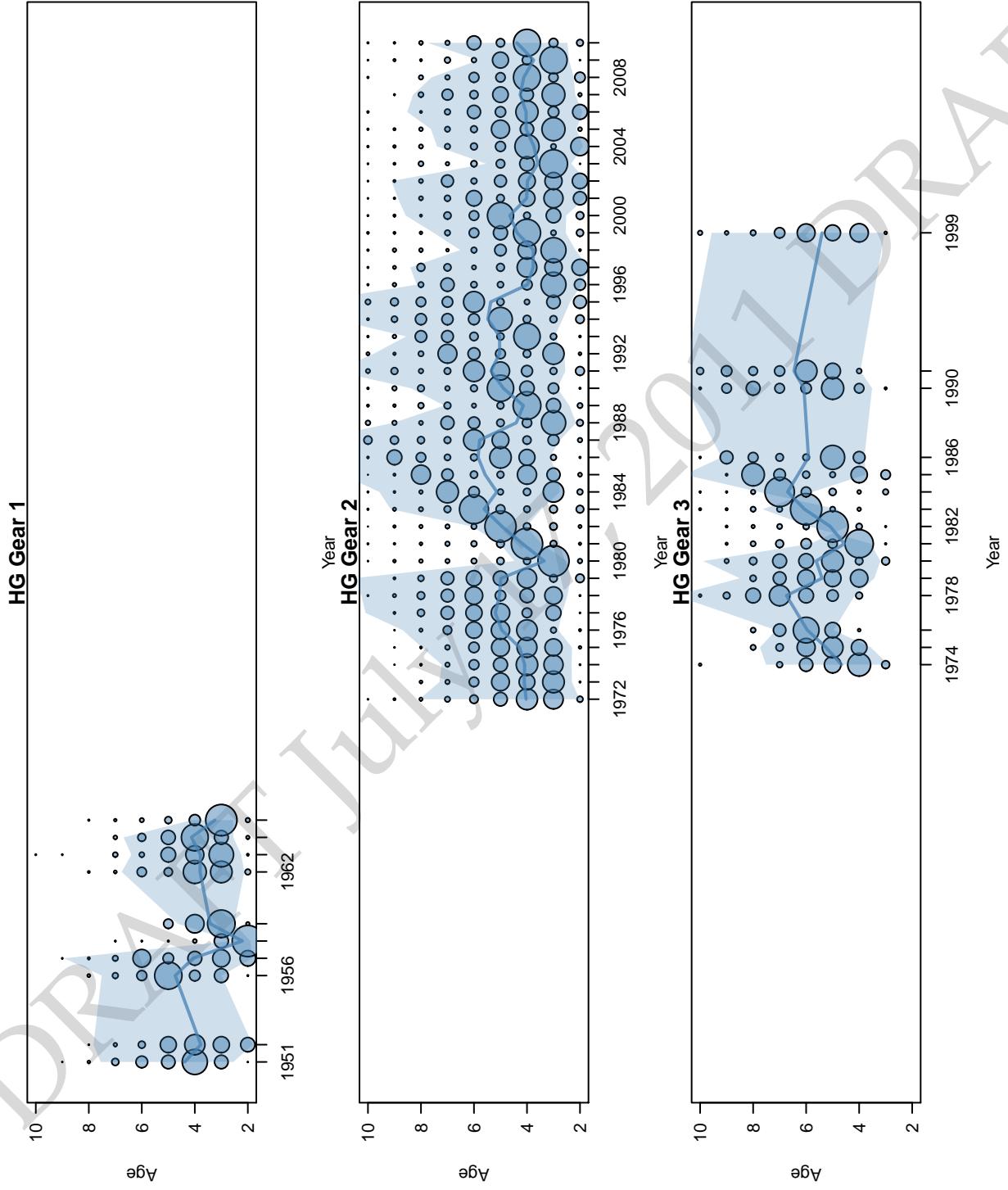


Figure 5: Bubble plots showing the proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gill net fishery (bottom) in Haida Gwaii. The area of the circle is proportional to cohort abundance, each column sums to 1, zeros are not shown, and age 10 is a plus group. Also shown is the mean age of the catch (line) and the approximate 95% distribution of ages (shaded polygon) for each year.

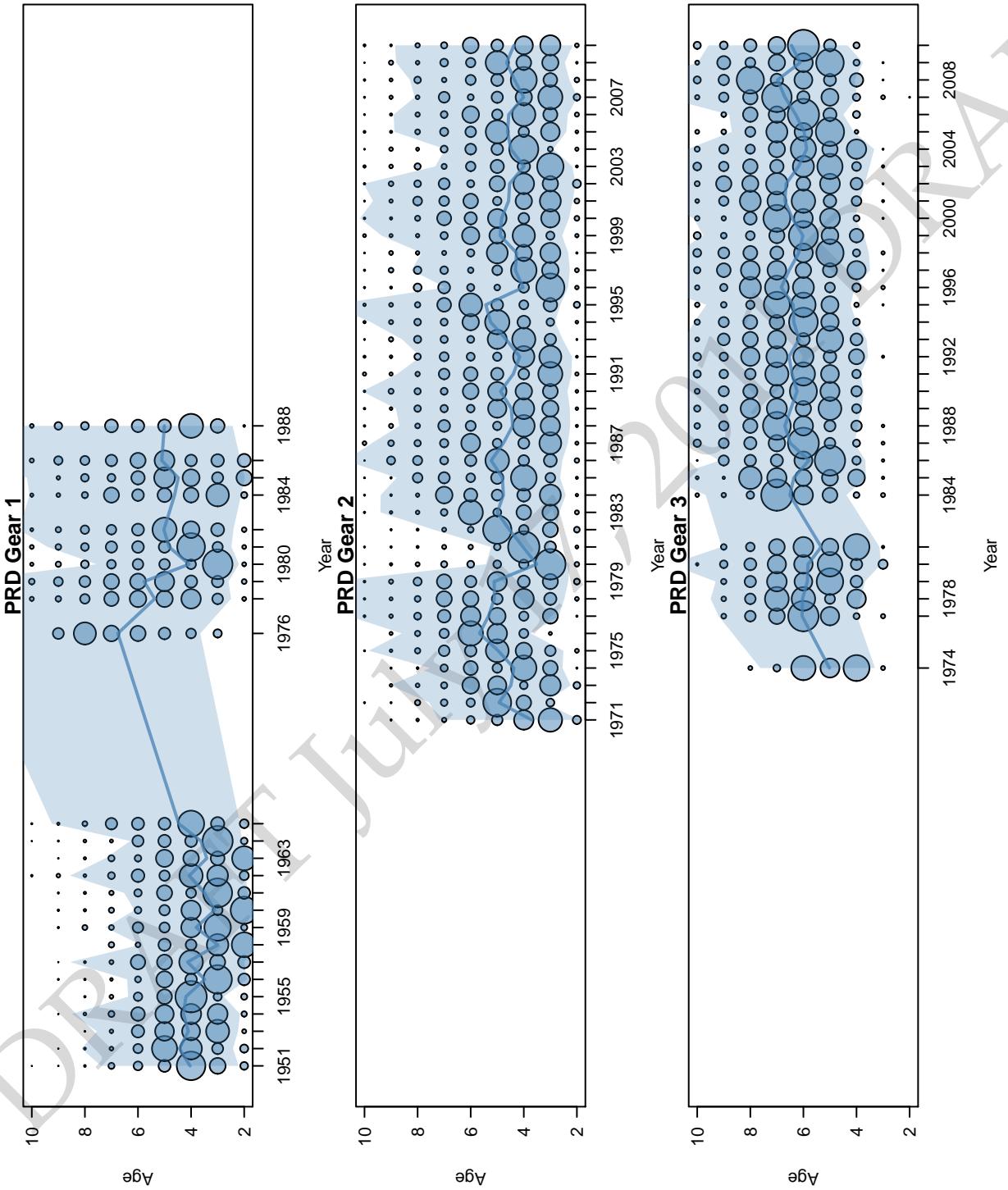


Figure 6: Bubble plots showing the proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gill net fishery (bottom) in Prince Rupert District. The area of the circle is proportional to cohort abundance, each column sums to 1, zeros are not shown, and age 10 is a plus group. Also shown is the mean age of the catch (line) and the approximate 95% distribution of ages (shaded polygon) for each year.

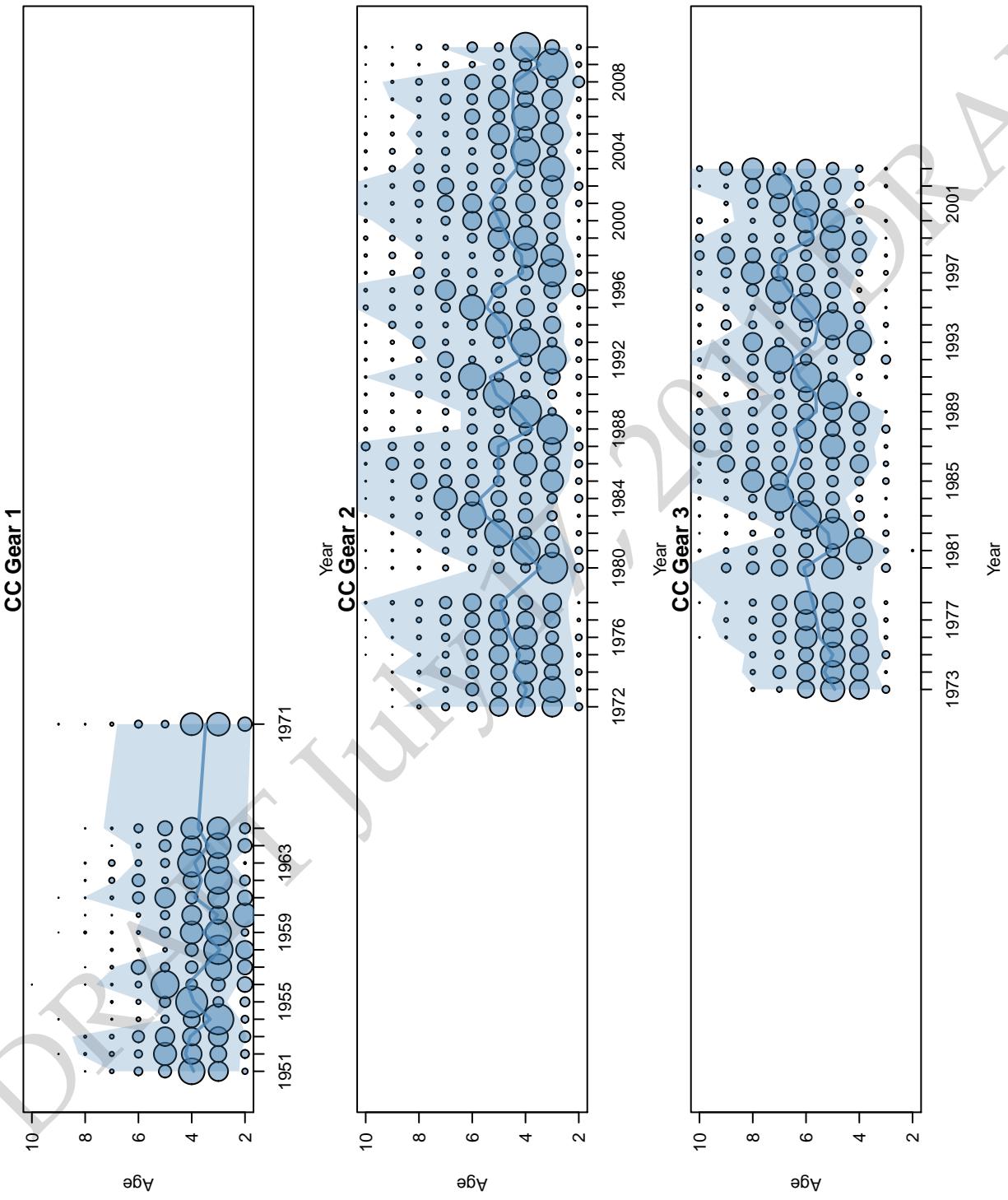


Figure 7: Bubble plots showing the proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gill net fishery (bottom) in the Central Coast region. The area of the circle is proportional to cohort abundance, each column sums to 1, zeros are not shown, and age 10 is a plus group. Also shown is the mean age of the catch (line) and the approximate 95% distribution of ages (shaded polygon) for each year.

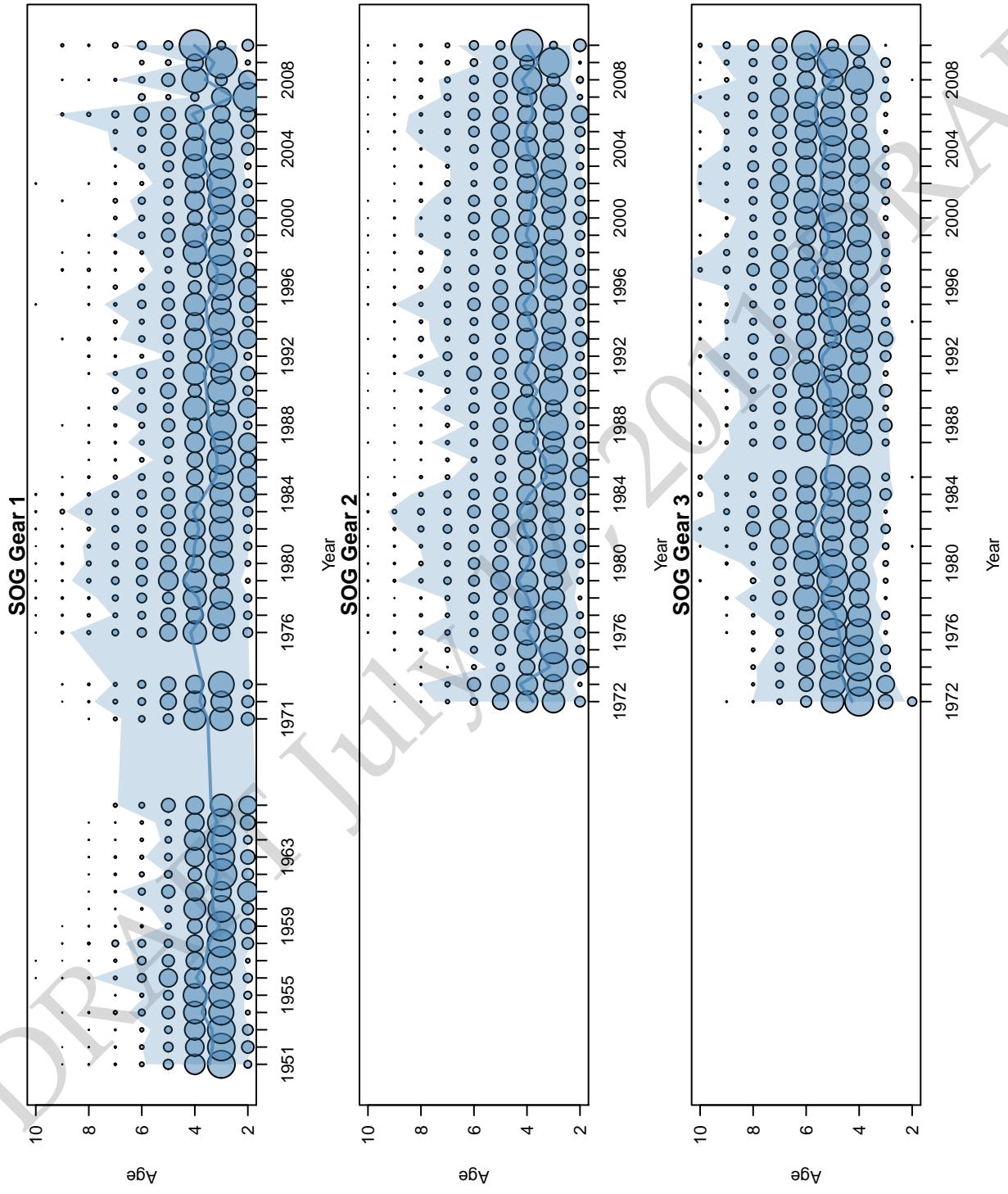


Figure 8. Bubble plots showing the proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gill net fishery (bottom) in the Strait of Georgia. The area of the circle is proportional to cohort abundance, each column sums to 1, zeros are not shown, and age 10 is a plus group. Also shown is the mean age of the catch (line) and the approximate 95% distribution of ages (shaded polygon) for each year.

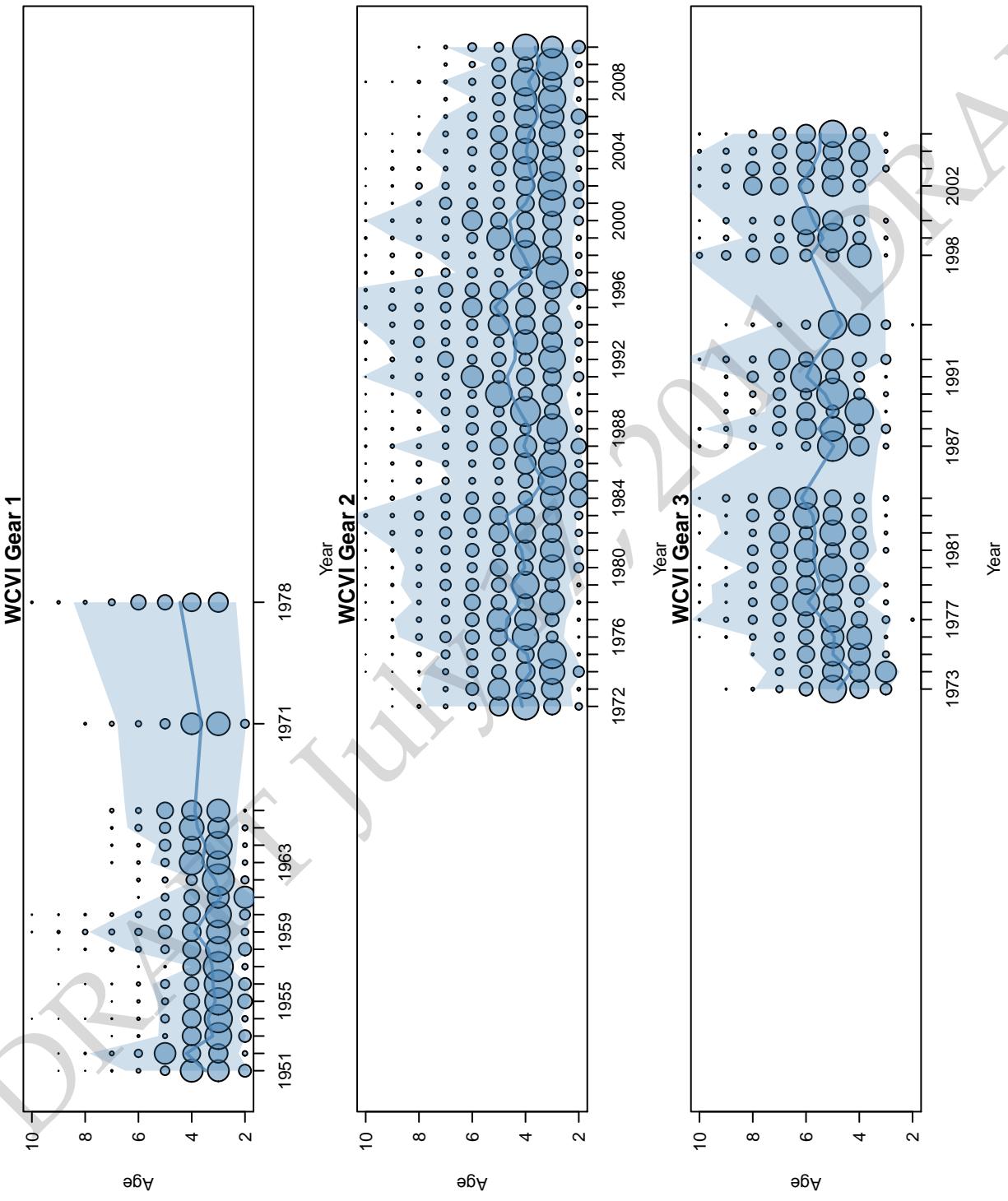


Figure 9: Bubble plots showing the proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gill net fishery (bottom) in the West Coast Vancouver Island region. The area of the circle is proportional to cohort abundance, each column sums to 1, zeros are not shown, and age 10 is a plus group. Also shown is the mean age of the catch (line) and the approximate 95% distribution of ages (shaded polygon) for each year.

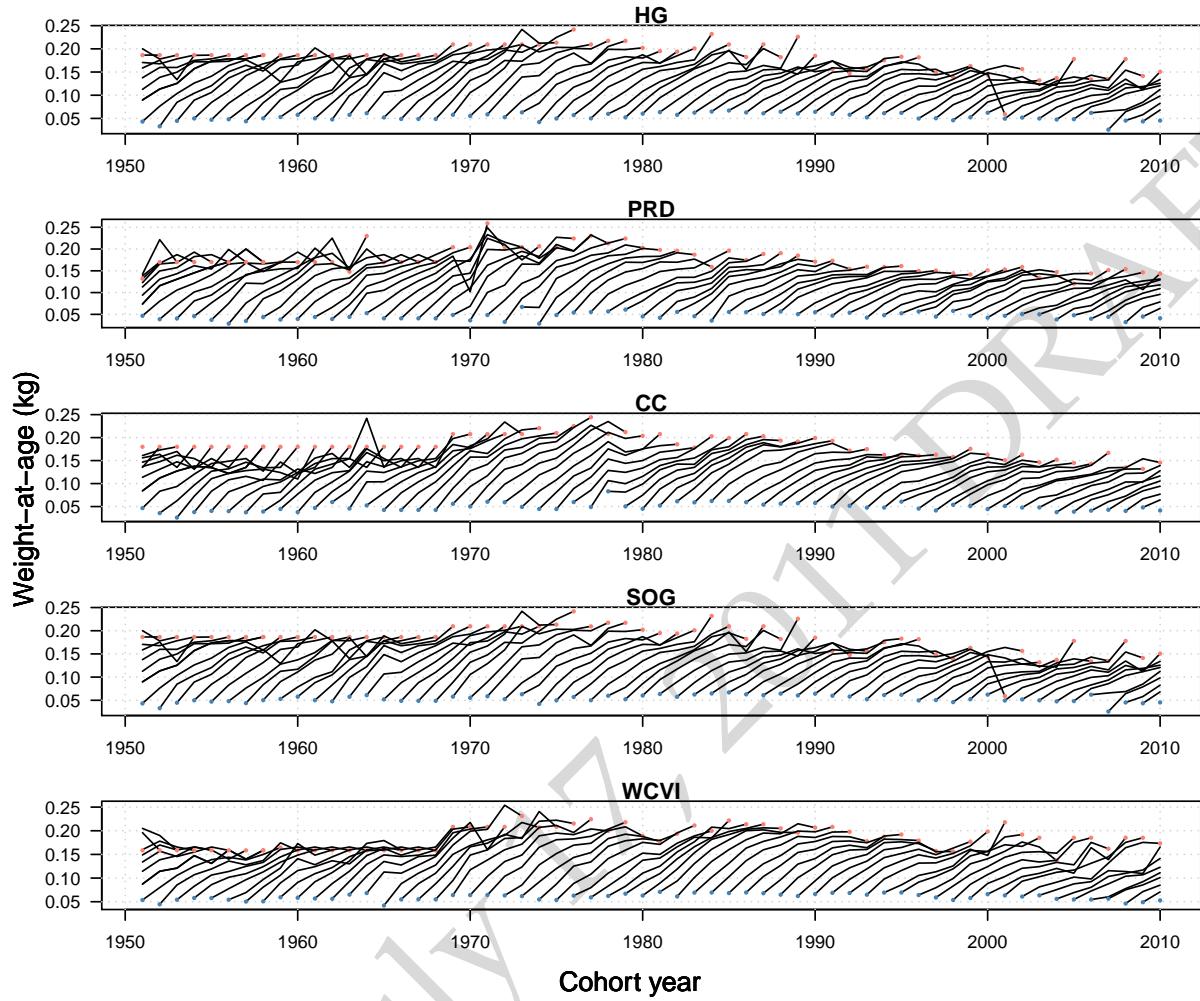


Figure 10: Empirical mean weight-at-age data by cohort from 1951 to 2010 for ages 2 to 10 in the five major Stock Assessment Regions.

that are among the lowest on record. This declining weight-at-age may be attributed to any number of factors, including: fishing effects (i.e., gear selectivity), environmental effects (changes in ocean productivity), or it may even be attributed to changes in sampling protocols (shorter time frame over which samples are collected). Declining weight-at-age has been observed in all five of the major stocks, and despite area closures over the last 10-years, has continued to occur in the QCI and WCVI stocks. Although the direct cause of this decline is still to be investigated, this trend has been observed in B.C. and U.S. waters, from California to Alaska (Schweigert, 2002), and merits further research. The observed mean weight-at-age data appear to have a few erroneous errors that need to be investigated as well; for example, see the apparently small age-10 fish in 2001 in Figure 10.

2.2 Analytical methods

A new stock assessment platform has been used for the 2011 Pacific herring assessment and this platform is based on the general statistical catch age model first described by Fournier and Archibald (1982). The software platform used is called *ⁱSCAM*, which stands for integrated Statistical Catch Age Model. The source code and documentation for *ⁱSCAM* is freely available from <https://sites.google.com/site/iscamproject/>, or from a subversion repository at <http://code.google.com/p/iscam-project/>. Ideally,

the results of this report could easily be repeated just by downloading the necessary software and using the data and control files presented in the appendix of this paper. A complete technical description of $iSCA_M$ is provided in Appendix A.

In short, for each stock a two input files are required for $iSCA_M$: (1) a data file that contains the historical catch, survey, life-history and age-composition information, and (2) a control file that specifies initial parameter values, priors, selectivity options, and various other controls that specify options for time-varying natural mortality, type of recruitment model, etc. Each major and minor stock has its own data and control file and these are provided in Appendix B such that these results can be verified by an independent reviewer using the $iSCA_M$ software.

Estimated model parameters includes the initial numbers-at-age, annual age-2 recruits, annual fishing mortality rates for each gear, selectivity parameters, natural mortality rates, parameters that describe the observation error and process error variance, and the unfished age-2 recruits and the steepness of the stock recruitment relationship. The total number of estimated parameters differs for each stock assessment region depending on the number of years of active fishing, assumptions about selectivity, and the number of assumed nodes in natural mortality rates. In general the total number of estimated parameters ranges from

2.3 Simulation testing

The purpose of conducting simulation testing is two fold: (1) to demonstrate that the model is capable of estimating model parameters given perfect information, and (2) to examine precision and bias in parameter estimates (and corresponding management quantities) in the presence of observation and process errors. To conduct simulation testing using $iSCA_M$, the following command line option `-sim 1234` is used, where 1234 is a unique random number seed. There is also a special seed number `-sim 000` that generates data with no error. That is the simulation model is deterministic, the relative abundance data are directly proportional with 0 observation error, and the age-composition data is exactly replicates the true vulnerable proportions-at-age. The model is conditioned on the historical catch data specified in the data file, and the true parameter values used to simulate the data are those that are specified in the control file.

2.3.1 Estimation performance with perfect information

When simulating data with perfect information, there are a couple of things that need to be highlighted here when trying to estimate parameters from data that contain no error. First, the phases for the precision and variance partitioning parameters (ϑ and ρ) should be set to a negative number. There are no error in the data, therefore, there is no need to estimate the variance terms for the error distributions. Second, in the control file, the initial value for the precision (ϑ) should be set to an extremely large number (e.g., 4999.999, assuming the upper bound is 5000). The reason to set this number large is to minimize the slight bias due to the lognormal bias correction in the stock recruitment relationship (i.e., the $-0.5\tau^2$ term in T3.13, or T3.14). The control file used to simulate the fake data is provided in Table ??.

2.3.2 Bias & precision with observation & process errors

To determine bias and precision of parameter estimates when the model is confronted with both observation error and process error, a series of Monte Carlo trials are performed and \log_2 ratios are used to measure the distribution of estimated parameters ($\hat{\theta}$) from the true value(θ). The \log_2 ratio

$$\log_2 \left(\frac{\hat{\theta}}{\theta} \right)$$

is zero when $\hat{\theta} = \theta$, is 1 when $2\hat{\theta} = \theta$, and is -1 when $0.5\hat{\theta} = \theta$. Box plots are used to examine the distribution of 50 trials where a unique random number seed is used for each trial. For the purposes of the simulation experiments only, we assume that the proportion of the total variance associated with observation error is known ($\rho = 0.25$) and estimate the total variance. The total precision is set to 2.50 which is equivalent to a total standard deviation of 0.4. The control file used for the Monte Carlo procedures is provided in Table ??.

2.4 Comparison of HCAM with $i\text{SCA}_M$

There are a number of different statistical assumptions and structural differences between the previous assessments using HCAM (Herring Catch Age Model) and $i\text{SCA}_M$. Here I briefly summarize the differences and similarities between the two approaches, and we first attempt to formulate the $i\text{SCA}_M$ model to be as similar as possible to the last implementation of HCAM used in Cleary and Schweigert (2010).

The objective function in the HCAM model has four major components to it: 1) the likelihood of the age composition data, 2) the likelihood of the commercial catch data, 3) the likelihood of the spawn data, and 4) the prior densities for estimated model parameters. In the following subsections are more detailed descriptions of how the $i\text{SCA}_M$ model was set up to best approximate the HCAM implementation.

For the GN fishery, HCAM implements a time varying selectivity scheme as a function of the average weight-at-age. At present this is not implemented in $i\text{SCA}_M$, and after a day of investigation I (SJDM) was not able to come up with a feasible solution to make the models more comparable. Alternative options for changes in selectivity will be investigated further later in this paper.

2.4.1 Age-composition data

There are two alternative likelihoods specified for the age-composition data in the HCAM model (see Table 8 in Appendix B in Cleary and Schweigert, 2010). It is unclear which likelihood is actually used, the multinomial likelihood (T8.1), or the robust normal approximation (T8.2), or both in the assessment. In any event, $i\text{SCA}_M$ implements a multivariate logistic negative log-likelihood for age-composition data (see equation 10 above), with the intention of weighting these data based on the conditional maximum likelihood estimate of the variance. In addition, we require a minimum observed proportion of at least 1% in each age class, in years and ages where the observed proportion is less than 1% the consecutive ages grouped into a single age-class which reduces the effective number of age-classes (this is somewhat analogous to a plus group).

2.4.2 Commercial catch data

In the HCAM assessment, commercial catch was assumed to be known with a high degree of certainty; observation errors were assumed lognormal, and the standard deviation specified in the code is fixed at 0.0707 (variance of 0.005) for all three periods. The analogous setup in $i\text{SCA}_M$ is to fix the assumed standard deviation for the catches in the last phase to 0.0707.

2.4.3 Spawn survey data

For the Strait of Georgia spawn survey, the assumed standard deviations in HCAM were specified at 0.35 and 0.3 for the pre and post 1988 periods. To carry out the same assumptions in $i\text{SCA}_M$ the relative weights for the pre and post 1988 survey data were fixed at 1.0 and 1.1666, respectively. In $i\text{SCA}_M$ the total error (or precision=1/variance) is estimated and partitioned into components of observation error (spawn survey residuals) and process error (recruitment deviations). To implement the same observation error and process errors in the $i\text{SCA}_M$ model (standard deviations of 0.35 and 0.8, respectively for observation errors and process errors in HCAM) the total precision was fixed at $\vartheta = 1/1.15$, and the proportion assigned to observation error was fixed at $\rho = 0.35/1.15$.

2.4.4 Specification of prior distributions

Starting with the prior density for natural mortality in HCAM, the average natural mortality rate is assumed to be normal with a mean of 0.45, and a standard deviation of 0.2 (see Table 3 in Cleary and Schweigert, 2010). The average natural mortality rate in $i\text{SCA}_M$ is estimated in the log scale; using a normal prior for the $\ln(M)$ is equivalent to a lognormal prior for M . A lognormal prior is appropriate for this parameter as natural mortality rates must be positive; however, there is no equivalent analytical transformation to the normal distribution that was used in the HCAM assessment. Here we have specified a normal prior for $\ln(M)$ with a log mean of $\ln(0.45) = -0.7985$ and a log standard deviation of 0.4 to approximate the variance specified in the normal distribution used in the previous HCAM assessment.

The base HCAM model also allows for a random walk in natural mortality rate implemented as:

$$M_t = \begin{cases} \psi, & t = t' \\ M_{t-1} \exp(d_t^M), & t > t' \end{cases}$$

where d_t^M are annual natural mortality deviations that are assumed to be normally distributed with a mean 0 and a standard deviation of 0.10, and ψ is an estimated initial value for natural mortality. The implementation of time varying natural mortality is similar in $i\text{SCA}_M$ in that it is a random walk process, but the components of the objective function include a prior for the initial value of M (as specified in the previous paragraph) and that the first differences between natural mortality deviations are normally distributed. Again, this structure allows natural mortality rates to drift away from central tendency and long-term changes in M could have profound effects on reference point calculations. For the comparison with the HCAM model, the first differences in annual natural mortality deviations were assumed to have a mean 0 and a standard deviation of 0.10.

Annual recruitment deviations in the HCAM implementation were assumed to be normally distributed on a log scale with a mean of zero and a standard deviation of 0.8. To set up an equivalent assumption in $i\text{SCA}_M$, the total variance (ϑ) and ratio of the total variance (ρ) that explains observation error in the spawn survey must be specified *a priori*. In the HCAM model the variance terms for the observation errors and process errors are not estimated and assumed to be known; the standard deviation for recruitment variation was set at 0.8 and the standard deviation for observation errors in the spawn survey was fixed at 0.35 and 0.3 for the pre and post 1988 data, respectively. These variance terms can be estimated within the $i\text{SCA}_M$ model, or treated as fixed constants; however, $i\text{SCA}_M$ estimates the total error and partitions the variance into observation (σ^2) and process error (τ^2) components. To make the same assumptions about the variance terms in $i\text{SCA}_M$ as those that were used in HCAM the following values were used $\vartheta = 1/1.15 = 0.8695652$, and $\rho = 0.3043478$, and the weights assigned to the post 1988 spawn data were set at 1.1666 and 1.0 for the pre 1988 spawn data.

The prior for steepness in the HCAM model was based on a lognormal distribution with a logmean of 0.67 and a standard deviation of 0.17. For the Beverton-Holt stock recruitment model, steepness must lie in the interval of $0.2 < h \leq 1.0$; a Beta distribution is an appropriate density function for this parameter. In the $i\text{SCA}_M$ implementation, a Beta distribution is used and to approximate the distribution used in the HCAM model, the shape and rate parameters specified are 10.0 and 4.925373, respectively. These values corresponds to a mean of 0.67 and a standard deviation of 0.1178 for the Beta prior.

The last informative prior that is not explicit in the table of priors in the HCAM model is the scaling parameter (q) for the spawn survey. The spawn survey data are broken into two separate time series, pre and post 1988 when the survey switch from a surface estimate to dive surveys for estimating total egg deposition. In the HCAM implementation, a very informative prior for q in the post 1988 period was used where the mean was fixed at $q = 1.0$ and not permitted to vary (i.e., $\sigma_q = 0$). The scaling parameter in the first period was then freely estimated. Again, to emulate these assumptions in the $i\text{SCA}_M$ implementation a normal prior for $\ln(q)$ with a mean = 0 and a standard deviation of 0.001 was used for the post 1988 data and a uniform prior for the pre 1988 data.

2.5 Forecasts of pre-fishery biomass based on SFF reference points

3 Results

3.1 Simulation testing

3.1.1 Estimation performance with perfect information

Given perfect information about trends in relative abundance and age composition information, and a deterministic stock-recruitment relationship, $i\text{SCA}_M$ was able to estimate 216 parameters without any substantial errors. Estimation performance is easily demonstrated by comparing estimates of spawning biomass and fishing mortality rates to the true values that were used to simulate the data. As shown in Figure 11 estimates of spawning biomass and fishing mortality rates were exactly the same as the true values. There is

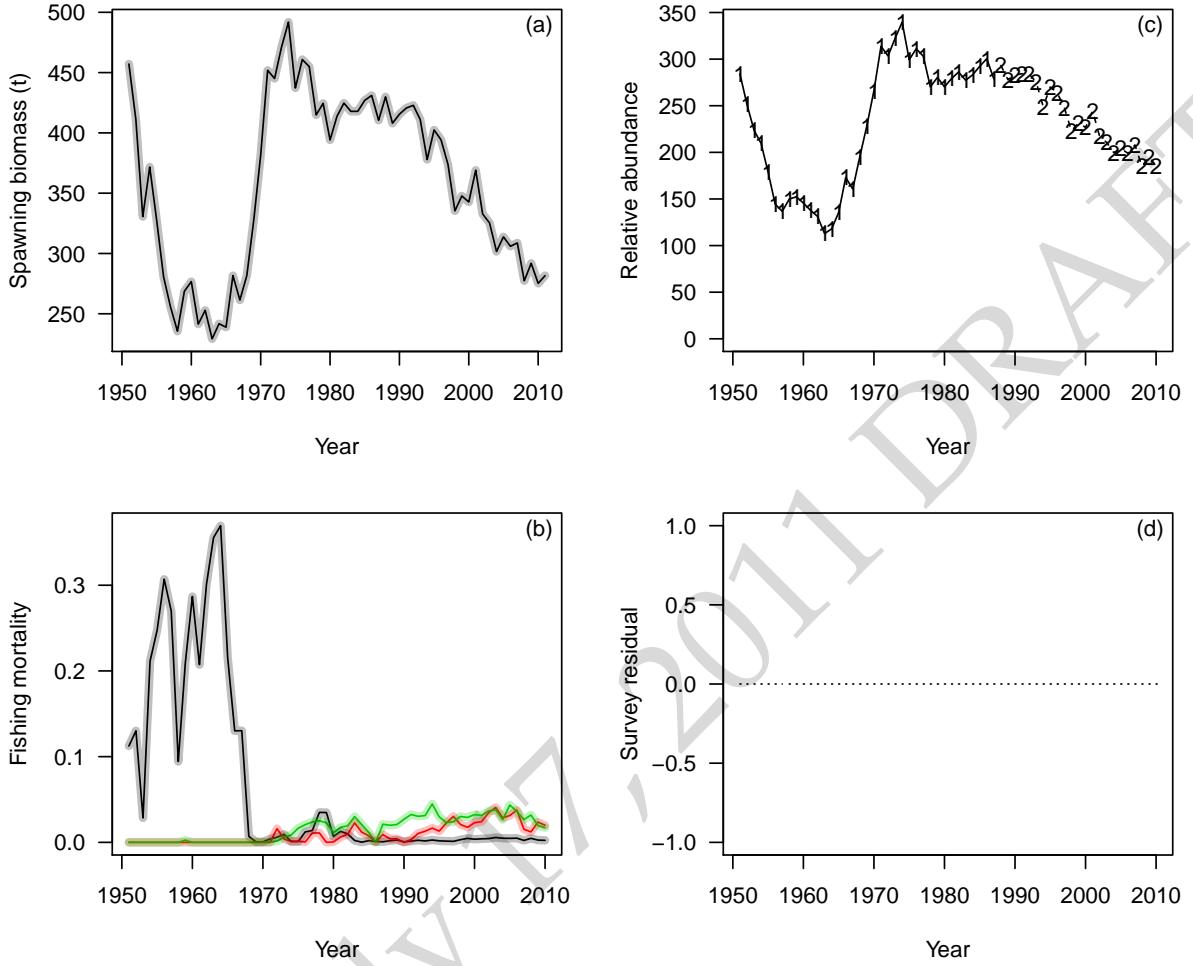


Figure 11: True (thin line) and estimated (thick shaded line) spawning biomass (a), fishing mortality rates (b), observed and predicted relative abundance (c), and residuals between observed and predicted relative abundance (d) for the SOG herring simulation with perfect information and a deterministic stock-recruitment relationship.

no measurable difference between the observed and predicted trends in the relative abundance information (Figs. 11cd).

Residuals between the observed and predicted age-composition data (not shown) were also extremely small and are easily summarized by the conditional maximum likelihood estimates of the residual variance $\hat{\tau}^2$ for the winter seine fishery $\hat{\tau}^2 = 2.49e - 03$, the seine roe fishery $\hat{\tau}^2 = 1.25e - 27$, and the gill net fishery $\hat{\tau}^2 = 1.24e - 27$.

This perfect fit to the data is used only to judge if the code is syntactically correct and to determine if it is capable of estimating model parameters exactly given perfect information. In the following section, observation errors and process errors are introduced to determine bias and precision in parameter estimates.

3.1.2 Bias & precision with observation & process errors

In the simulation experiments conducted with both observation error and process error included in the simulated data, there was no appreciable bias in the estimates of unfished biomass ($\ln(R_o)$) and the natural

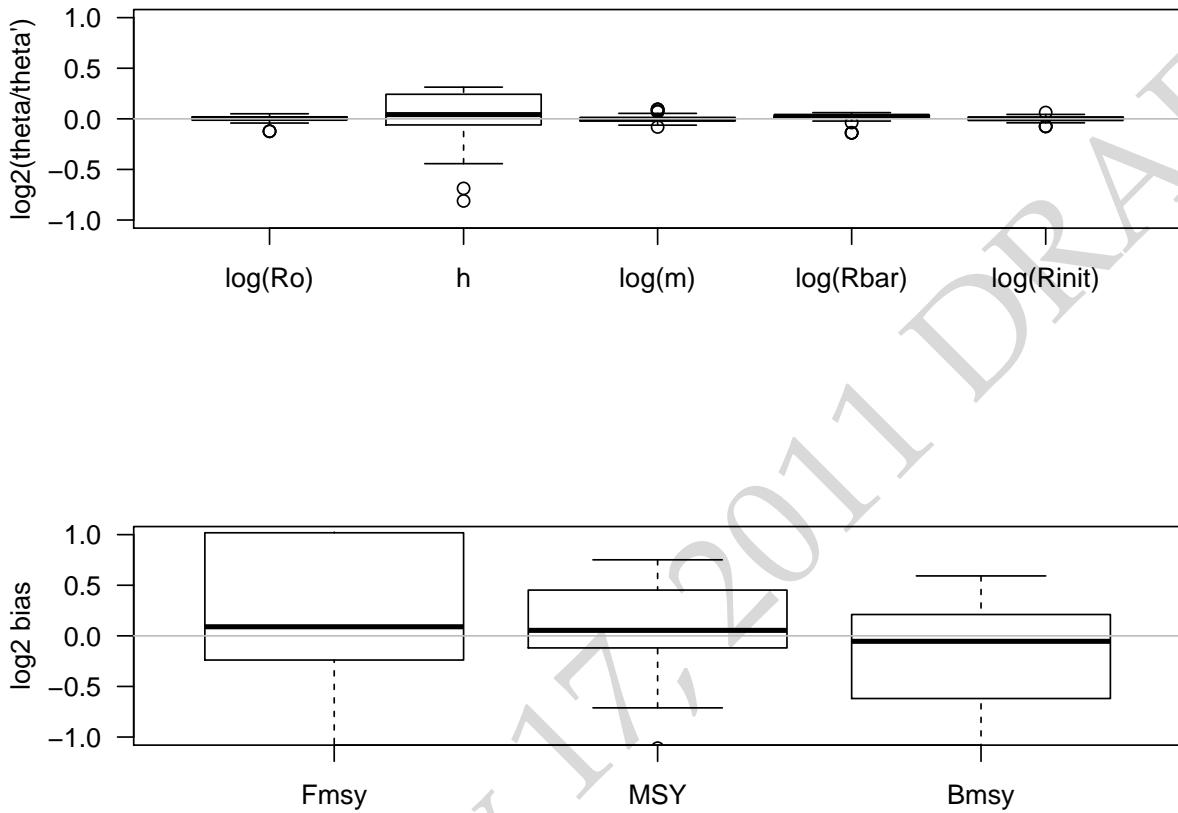


Figure 12: Estimates of precision and bias in key model parameters and MSY based reference points for 50 simulated data sets conditioned on the Strait of Georgia herring catch. The \log_2 ratio of estimated versus true value is plotted; values of 1 and -1 correspond to a twice or half the true value, respectively.

mortality rate ($\ln(M)$), the average recruitment ($\ln(\bar{R})$) and the initial recruitment ($\ln(\dot{R})$, Figure 12). There was, however, a very slight upward bias in the estimate of the steepness parameter for the Beverton-Holt stock recruitment relationship. Also, steepness was estimated with the least amount of precision. The estimability of steepness depends on many factors including the precision of the observations, but also the history of exploitation, the true value of steepness and the natural mortality rate (Conn et al., 2010).

Its not surprising to see a slight upward bias in h for these simulations because the true value of natural mortality was set quite high ($M = 0.45$) along with steepness ($h = 0.8$). Furthermore, the simulated exploitation history involved a strong depletion signal between the 1950s and 1960's followed by very light exploitation from 1970 onward. On average the assumed parameter values for the simulation and the catch time series generated sufficient contrast to reliably estimate key model parameters without the use of informative priors.

The lower panel of Figure 12 shows the apparent precision and bias in the estimates of MSY based reference points. There is a very slight upward bias in the estimate of F_{MSY} associated with the slight upward bias in steepness. Estimates of B_{MSY} are also slightly biased in a downward direction, and MSY in a slight upward direction. Overall, MSY is the most precisely estimated and F_{MSY} is the least precisely

estimated management variable.

3.2 Comparison of HCAM with $i\text{SCA}_M$

Based on the description of the priors and model setup in Section 2.4 on page 16, a comparison of the spawning stock biomass between $i\text{SCA}_M$ and HCAM were very similar (Figure 13a). Between 1951 and 1969 the absolute difference in spawning biomass is minimal and post 1970 estimates of spawning biomass are slightly higher for the HCAM model. The only real difference between the two models during this period is a structural differences in selectivity for the gill net fishery.

Estimates of spawning depletion are based on the post fishery spawning biomass relative to the estimated unfished spawning biomass (Figure 13b). Note how ever the predicted 2011 estimate is the pre-fishery spawning biomass. The three coloured zones demarcate the critical zone, cautious zone, and healthy zones which are defined by $0.4B_{MSY}$ and $0.8B_{MSY}$, respectively.

Maximum likelihood estimates of key model parameters for both $i\text{SCA}_M$ and HCAM are summarized in Table 1. Estimates of B_o and MSY based reference points are sensitive to the initial starting conditions and the phase in which some of the parameters are estimated. The $i\text{SCA}_M$ model tends to have a lower estimate of B_o in comparison to the HCAM model and a higher value of steepness (h). These two parameters are usually negatively correlated and it is expected that if B_o was higher in one model in comparison to the other, then h would normally be lower to compensate. Information to estimate B_o and h come from the apparent stock-recruitment data and the structural form of the stock recruitment relationship. In $i\text{SCA}_M$ annual recruitment is freely estimated and the residuals are based on the Beverton-Holt stock recruitment model and the estimates of spawning stock biomass. Similarly, in HCAM recruitment is a function of the spawning stock biomass and the Beverton-Holt model and the annual deviations are estimated and assumed to be normally distributed random variables.

Table 1: A comparison of key parameters from $i\text{SCA}_M$ and the HCAM model

Parameter	$i\text{SCA}_M$	HCAM
Unfished spawning biomass (B_o 1000 t)	151.492	190.817
Steepness (h)	0.763	0.683
Average natural mortality rate	0.504	0.334
Survey q for period 1	1.213	1.1105

Average natural mortality rates are similar between the two models, and the survey q for the pre-1988 spawn survey data is slightly higher in the $i\text{SCA}_M$ model. The more contemporary survey data were both forced to scale with $q = 1.0$. There is some pattern in the residuals for the overall fits to the survey data (Figure 13d), the model fails to predict the large increases in abundance in the late 1970s and early 2000s and the recent decline in the late 2000s. The assumed standard deviation for the survey errors was 0.35 and 0.3 for the pre and post 1988 survey data, the standard deviation of the residual errors in Figure 13d is 0.424 and 0.32, respectively.

Estimates of the components of total mortality for the comparison with the HCAM model are shown in Figure 14. The fishing mortality rates for each gear represent the average fishing mortality rate over all age-classes, and the natural mortality rate is assumed to be age-independent. During the 1950s through to 1968, fishing mortality rates for Pacific herring in the Strait of Georgia were extremely high; this period was almost exclusively a purse-seine fishery where fish were taken for fishmeal. After the fishery reopened in the early 1970s fishing mortality rates were greatly reduced and targeted the spawning component of the stock as the market was for herring roe.

Estimates of natural mortality are based on a random walk process, initially starting at a value of 0.367 in 1951 and declining to a very low value of 0.068 in 1959, then increasing to a maximum of 1.02 in 1970 (Figure 14a). Information to estimate natural mortality rates comes from the age-composition data, and assumptions about selectivity in the fishery. In this comparison, the $i\text{SCA}_M$ model assumes selectivity is invariant and much of the residual variation in the age-composition is explained by variation in M and

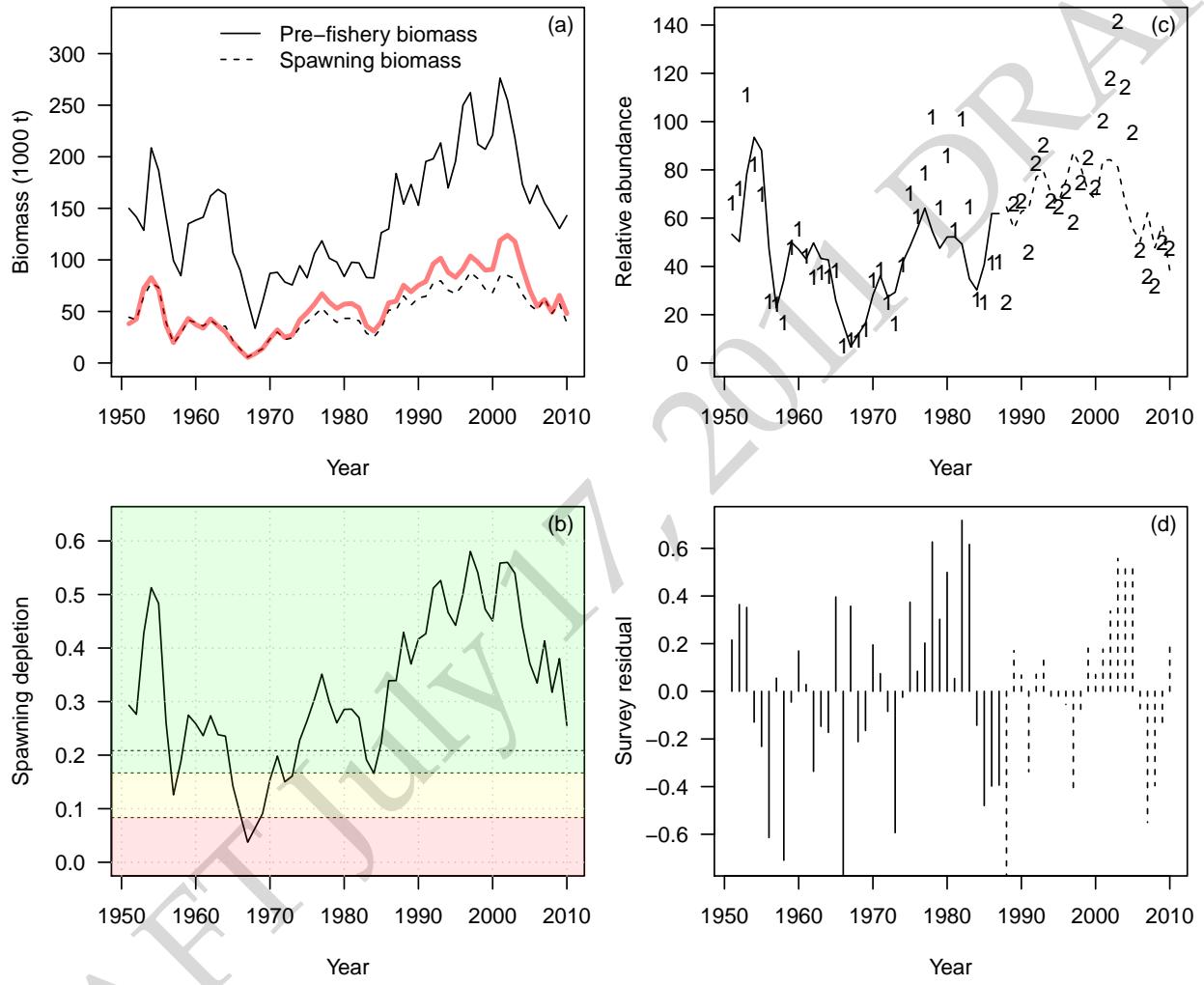


Figure 13: Maximum likelihood estimates of pre-fishery biomass and post fishery spawning biomass (a), spawning biomass depletion (b), observed (points) and predicted (lines) spawn survey data (c), and spawn survey residuals. These results are based on trying to configure the $i\text{SCA}_M$ model as similar as possible to the previous HCAM assessment; the red line in panel (a) is the MLE estimate of spawning biomass from HCAM.

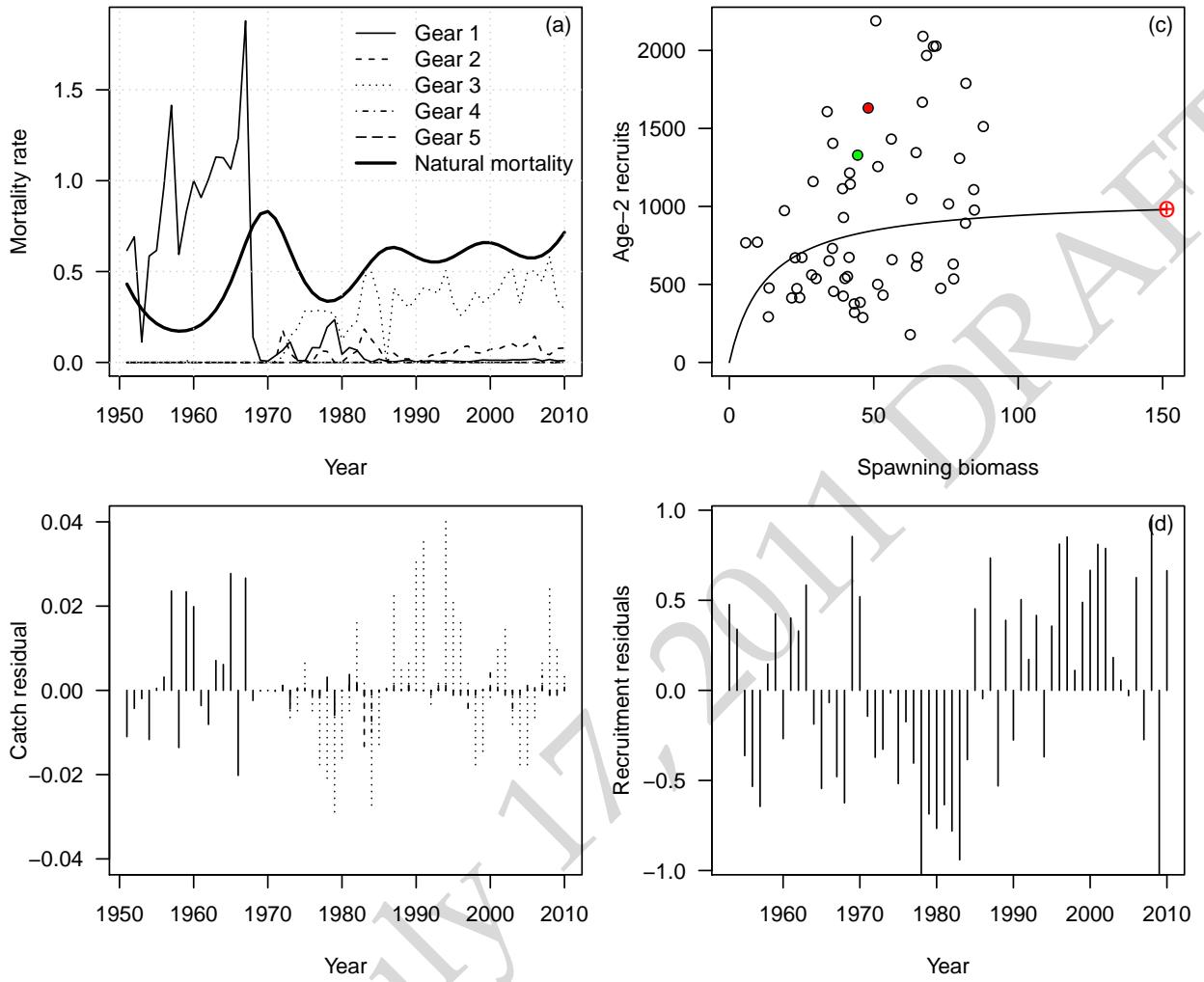


Figure 14: Components of total mortality rate (a), residuals between the observed and predicted catch (b), the spawning stock biomass versus age-2 recruits and stock recruitment relationship (estimates of unfished spawning biomass and unfished recruitment are denoted by the circle with the + symbol inside, c), and the residuals in the stock recruitment relationship (d).

variation in age-2 recruits (see Figure 15 for residual patterns and age-2 recruitment). The HCAM model has a very similar trend in the estimates of natural mortality but the variability is much less than that of the $i\text{SCA}_M$ assessment. This is almost certainly due to the changes in selectivity for the gill net fishery associated with changes in mean body weight in the HCAM implementation.

There is good correspondence between the observed and predicted catch, however, the residual patterns does not appear to be iid for each of the fleets.

There was some lack of fit to the age-composition data for the purse seine fisheries and the best fits were actually obtained for the gill net fisheries. The conditional maximum likelihood estimates of the standard deviations of the age-composition data are 0.797, 0.672, and 0.326 for the winter purse seine, seine-roe, and gill net fisheries, respectively. The smaller the standard deviation, the better correspondence between the observed and predicted age-composition data.

For the five major stock assessment regions there was very good correspondence between the estimated spawning stock biomass between the HCAM and new $i\text{SCA}_M$ models (Fig. 16). The control file used for each of the assessment regions was the same as that used for the Strait of Georgia. No additional changes

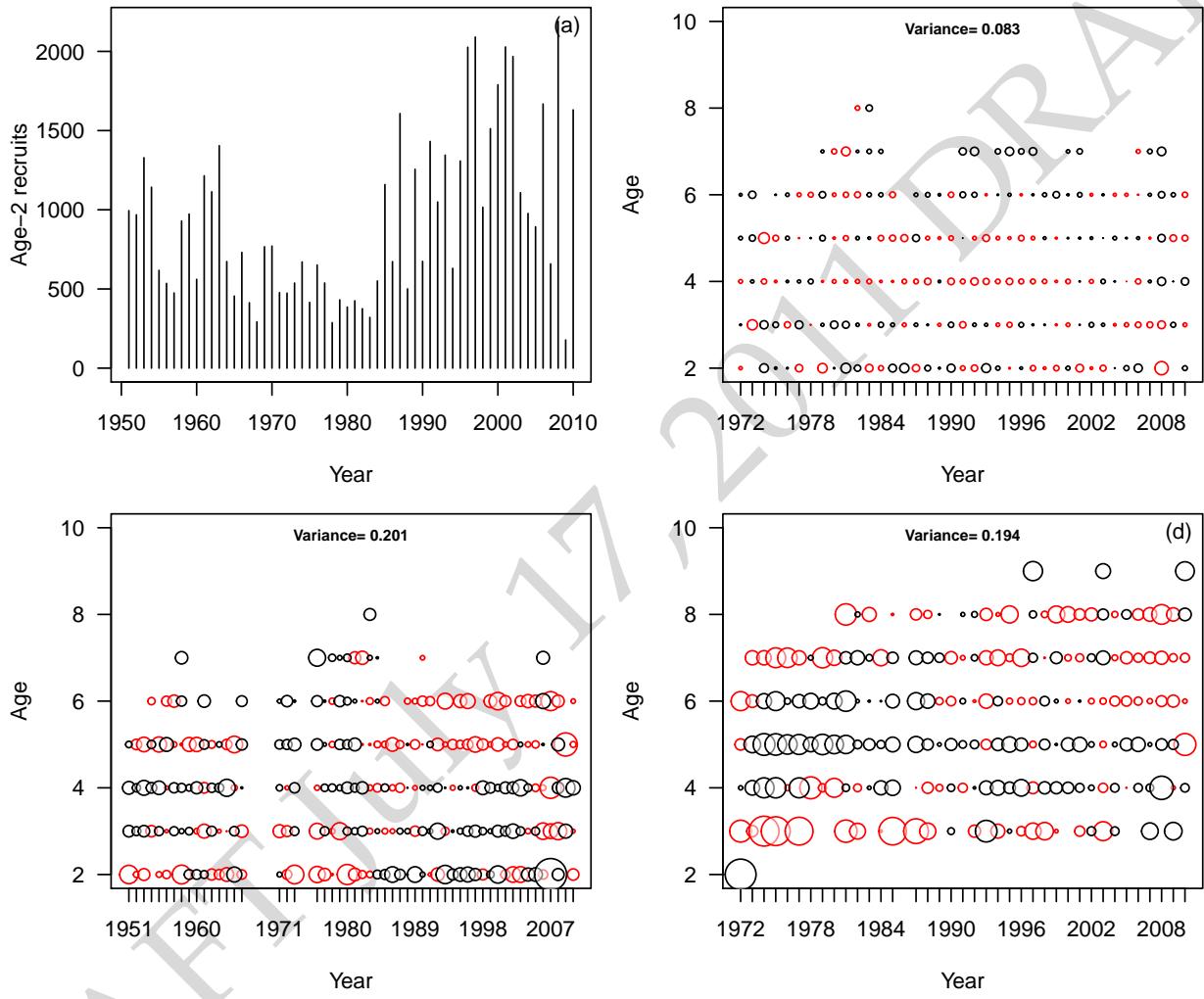


Figure 15: Estimates of age-2 recruits (a) and the residuals (observed-predicted, positive shown in black) in the age-composition data for the winter purse seine fishery (lower left), seine-roe fishery (upper right) and gill net fishery (lower right). The area of each circle is proportional to the residual error, and zeros are not shown. Note that observed age-proportions less than 2% were pooled into the adjacent (younger) age class and the conditional maximum likelihood estimates of the variance is displayed on the top of each panel.

were required (i.e., each SAR had the same initial starting parameter values etc.).

3.2.1 Strait of Georgia herring assessment

3.2.2 Retrospective and prospective analyses

3.3 Alternative assumptions about catchability, mortality & selectivity

3.3.1 Impacts of informative priors on q 's

3.3.2 Implications of variable natural mortality rate M_t

3.3.3 Implications of variable selectivity in directed fisheries

3.4 Separating test fishery data from the purse seine roe fishery data

3.5 Preliminary assessments for all other areas

4 Discussion

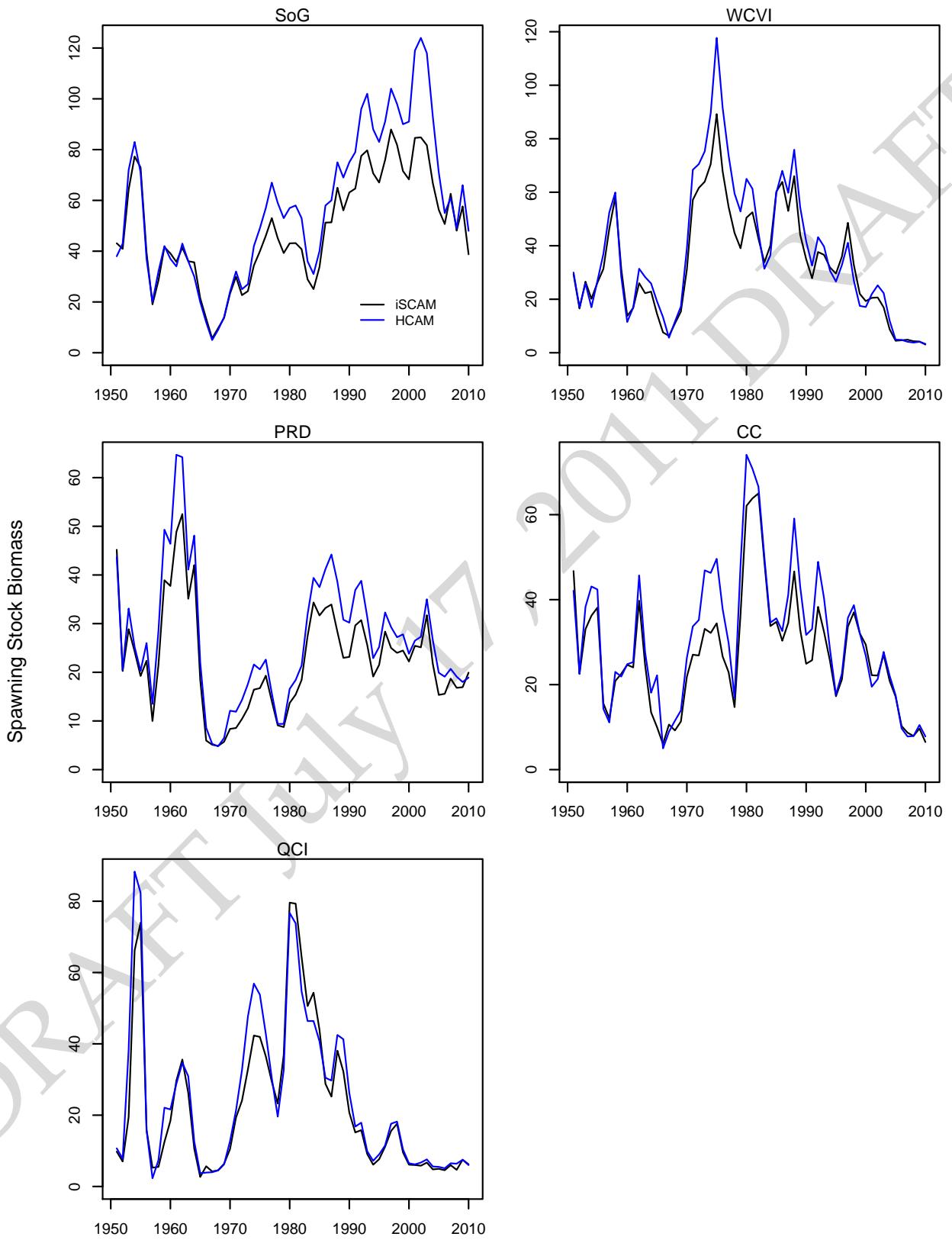


Figure 16: A comparison of estimated spawning stock biomass between HCAM and *iSCAM* for the five major stock assessment regions.

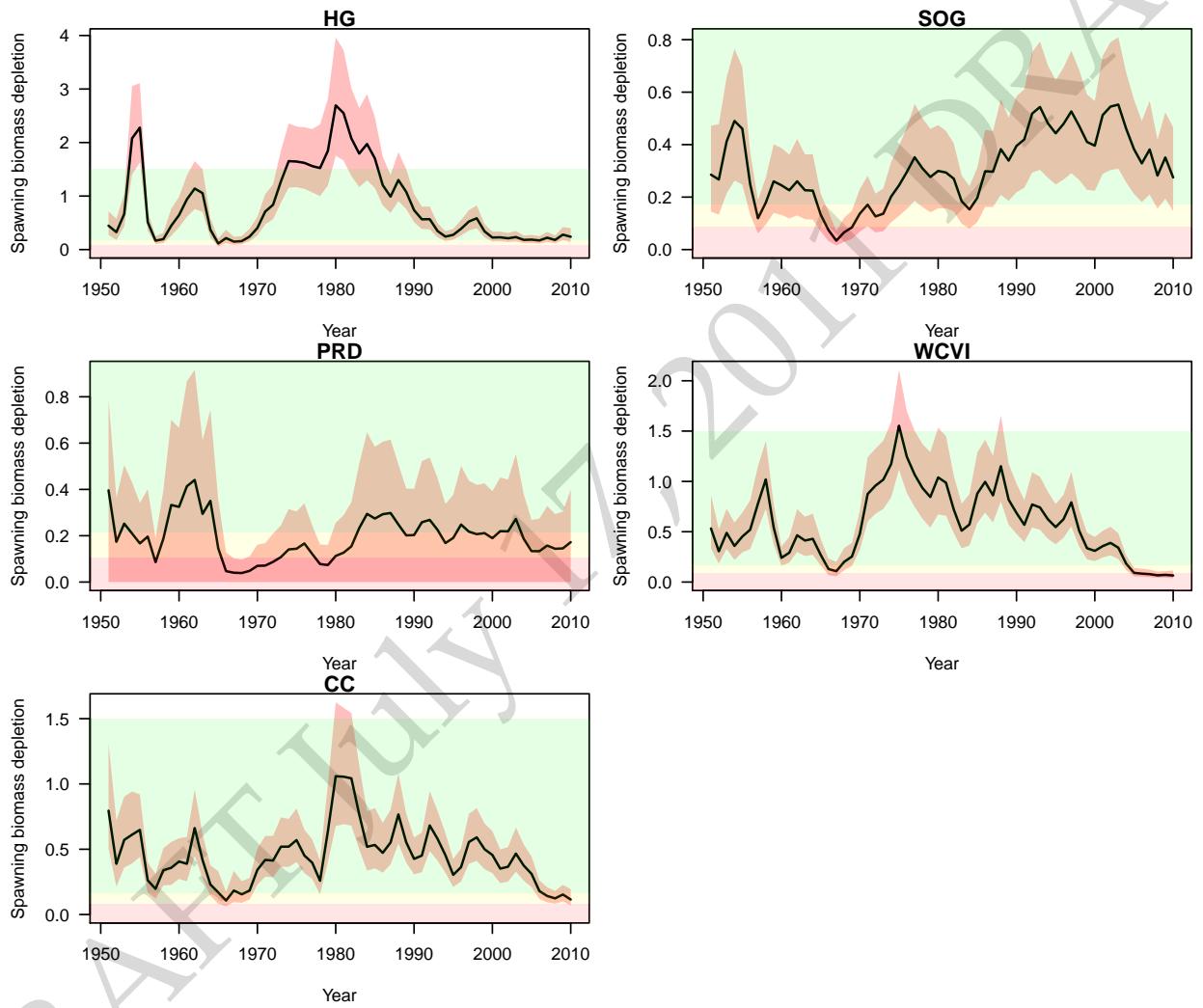


Figure 17: Cap.

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A Technical description of $i\text{SCAM}$

A.1 Analytic methods

The section contains the documentation in mathematical form of the underlying age structured model, and its steady state version that is used to calculate MSY-based reference points, the observation models used in predicting observations, and the components of the objective function that formulate the statistical criterion that is used to estimate model parameters. All of the model equations are laid out in tables and are intended to represent the order of operations, or pseudocode, in which to implement the model. $i\text{SCAM}$ was implemented in AD Model Builder version 10.1 [ADMB Project \(2009\)](#). This appendix also describes some of the optional features in $i\text{SCAM}$ for estimating nonparametric selectivities.

A.1.1 Equilibrium considerations

Steady-state conditions are presented in Table A-1, in here we assume the parameter vector Θ in (T1.1) is unknown and would eventually be estimated by fitting $i\text{SCAM}$ to time series data. For a given set of growth parameters and maturity-at-age parameters defined by (T1.3), growth is assumed to follow the von Bertalanffy model (T1.4), mean weight-at-age is given by the allometric relationship in (T1.5), and the age-specific vulnerability is given by a logistic function (T1.6). Note, however, there are alternative selectivity functions implemented in $i\text{SCAM}$, the logistic function used here is simply for demonstration purposes. Mean fecundity-at-age is assumed to be proportional to the mean weight-at-age of mature fish, where maturity at age is specified by the parameters a and γ for the logistic function.

Survivorship for unfished and fished populations is defined by (T1.8) and (T1.9), respectively. It is assumed that all individuals ages A and older (i.e., the plus group) have the same total mortality rate. The incidence functions refer to the life-time or per-recruit quantities such as spawning biomass per recruit (ϕ_E) or vulnerable biomass per recruit (ϕ_b). Note that upper and lower case subscripts denote unfished and fished conditions, respectively. Spawning biomass per recruit is given by (T1.10), the vulnerable biomass per recruit is given by (T1.11) and the per recruit yield to the fishery is given by (T1.12). Unfished recruitment is given by (T1.13) and the steady-state equilibrium recruitment for a given fishing mortality rate F_e is given by (T1.14). Note that in (T1.14) we assume that recruitment follows a Beverton-Holt model of the form:

$$R_e = \frac{s_o R_e \phi_e}{1 + \beta R_e \phi_e}$$

where

$$\begin{aligned} s_o &= \kappa / \phi_E, \\ \beta &= \frac{(\kappa - 1)}{R_o \phi_E}, \end{aligned}$$

which simplifies to (T1.14). The equilibrium yield for a given fishing mortality rate is (T1.15). These steady-state conditions are critical for determining various reference points such as F_{MSY} and B_{MSY} .

A.1.2 MSY based reference points

$i\text{SCAM}$ calculates MSY-based reference points by finding the value of F_e that results in the zero derivative of the steady-state catch equation (T1.15). This is accomplished numerically using a Newton-Raphson method where an initial guess for F_{MSY} is set equal to $1.5M$, then use (1) to iteratively find F_{MSY} . Note that the partial derivatives in (1) can be found in Table A-2.

Table A-1: Steady-state age-structured model assuming unequal vulnerability-at-age, age-specific natural mortality, age-specific fecundity and Beverton-Holt type recruitment.

Parameters	
$\Theta = (B_o, \kappa, M_a, \hat{a}, \dot{\gamma})$	(T1.1)
$B_o > 0; \kappa > 1; M_a > 0$	(T1.2)
$\Phi = (l_\infty, k, t_o, a, b, \dot{a}, \dot{\gamma})$	(T1.3)
Age-schedule information	
$l_a = l_\infty(1 - \exp(-k(a - t_o)))$	(T1.4)
$w_a = a(l_a)^b$	(T1.5)
$v_a = (1 + \exp(-(\hat{a} - a)/\gamma))^{-1}$	(T1.6)
$f_a = w_a(1 + \exp(-(\dot{a} - a)/\dot{\gamma}))^{-1}$	(T1.7)
Survivorship	
$\iota_a = \begin{cases} 1, & a = 1 \\ \iota_{a-1}e^{-M_{a-1}}, & a > 1 \\ \iota_{a-1}/(1 - e^{-M_a}), & a = A \end{cases}$	(T1.8)
$\hat{\iota}_a = \begin{cases} 1, & a = 1 \\ \hat{\iota}_{a-1}e^{-M_{a-1}-F_e v_{a-1}}, & a > 1 \\ \hat{\iota}_{a-1}e^{-M_{a-1}-F_e v_{a-1}}/(1 - e^{-M_a - F_e v_a}), & a = A \end{cases}$	(T1.9)
Incidence functions	
$\phi_E = \sum_{a=1}^{\infty} \iota_a f_a, \quad \phi_e = \sum_{a=1}^{\infty} \hat{\iota}_a f_a$	(T1.10)
$\phi_B = \sum_{a=1}^{\infty} \iota_a w_a v_a, \quad \phi_b = \sum_{a=1}^{\infty} \hat{\iota}_a w_a v_a$	(T1.11)
$\phi_q = \sum_{a=1}^{\infty} \frac{\hat{\iota}_a w_a v_a}{M_a + F_e v_a} \left(1 - e^{(-M_a - F_e v_a)}\right)$	(T1.12)
Steady-state conditions	
$R_o = B_o/\phi_B$	(T1.13)
$R_e = R_o \frac{\kappa - \phi_E/\phi_e}{\kappa - 1}$	(T1.14)
$C_e = F_e R_e \phi_q$	(T1.15)

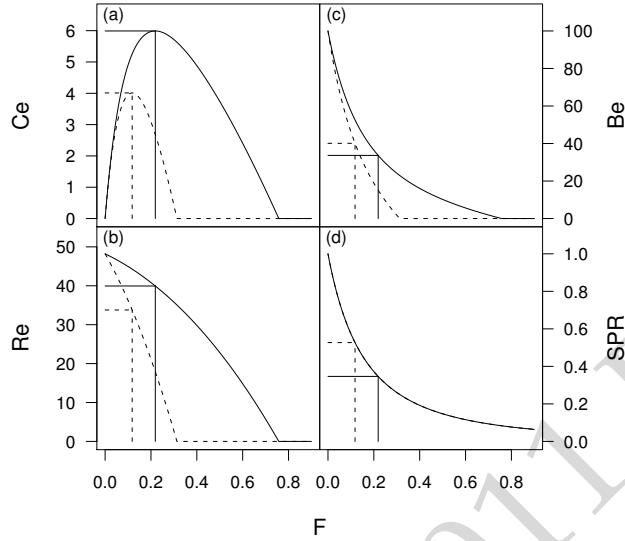


Figure 18: Equilibrium yield (a), recruits (b), biomass (c) and spawner per recruit (ϕ_e/ϕ_E) (d) versus instantaneous fishing mortality F_e for two different values of the recruitment compensation ratio ($\kappa = 12$ solid lines, $\kappa = 4$ dashed lines). Vertical lines in each panel correspond to F_{MSY} and horizontal lines correspond to various reference points that would achieve MSY.

$$F_{e+1} = F_e - \frac{\frac{\partial C_e}{\partial F_e}}{\frac{\partial^2 C_e}{\partial F_e}} \quad (1)$$

where

$$\begin{aligned} \frac{\partial C_e}{\partial F_e} &= R_e \phi_q + F_e \phi_q \frac{\partial R_e}{\partial F_e} + F_e R_e \frac{\partial \phi_q}{\partial F_e} \\ \frac{\partial^2 C_e}{\partial F_e} &= \phi_q \frac{\partial R_e}{\partial F_e} + R_e \frac{\partial \phi_q}{\partial F_e} \end{aligned}$$

The algorithm usually converges in less than 10 iterations depending on how close the initial guess of F_{MSY} is to the true value. A maximum of 20 iterations are allowed in $iSCA_M$, however, if $\frac{\partial C_e}{\partial F_e} < 10^{-5}$ the algorithm stops. Note also, that this is only performed on data type variables and not differentiable variables within AD Model Builder.

Given an estimate of F_{MSY} , other reference points such as MSY are calculated use the equations in Table A-1 where each of the expressions is evaluated at F_{MSY} . A graphical representation of MSY based reference points for two alternative values of the recruitment compensation parameter κ is show in Figure 18.

There are some additional technical details about calculating MSY based reference points when considering multiple fishing gears with different selectivities. The maximum sustainable yield summed over all fishing gears is a function of the selectivities of each gear type and what fraction of the total catch is allocated to each gear. In the Pacific herring fishery, there are three distinct fleets that all have different selectivities; the purse-seine gears tend to catch smaller younger fish, while the gill net fishery tends to target larger mature females. The optimum fishing mortality rate for each gear that would maximize the yield depends on what the other gears are removing; this in itself is another optimization problem that fisheries management must contend with. For the purposes of this assessment, $iSCA_M$ requires an allocation of the total catch (summed across gear type) to each gear before it proceeds with calculating reference points.

Table A-2: Partial derivatives, based on components in Table A-1, required for the numerical calculation of F_{MSY} using (1).

Mortality & Survival	
$Z_a = M_a + F_e v_a$	(T2.1)
$S_a = 1 - e^{-Z_a}$	(T2.2)
Partial for survivorship	
$\frac{\partial \hat{v}_a}{\partial F_e} = \begin{cases} 0, & a = 1 \\ e^{-Z_{a-1}} \left(\frac{\partial \hat{v}_{a-1}}{\partial F_e} - \hat{v}_{a-1} v_{a-1} \right), & 1 < a < A \\ \frac{\partial \hat{v}_{a-1}}{\partial F_e} - \frac{\hat{v}_{a-1} e^{-Z_{a-1}} v_a e^{-Z_a}}{(1 - e^{-Z_a})^2}, & a = A \end{cases}$	(T2.3)
Partials for incidence functions	
$\frac{\partial \phi_e}{\partial F_e} = \sum_{a=1}^{\infty} f_a \frac{\partial \hat{v}_a}{\partial F_e}$	(T2.4)
$\frac{\partial \phi_q}{\partial F_e} = \sum_{a=1}^{\infty} \frac{w_a v_a S_a}{Z_a} \frac{\partial \hat{v}_a}{\partial F_e} + \frac{\hat{v}_a w_a v_a^2}{Z_a} \left(e^{-Z_a} - \frac{S_a}{Z_a} \right)$	(T2.5)
Partial for recruitment	
$\frac{\partial R_e}{\partial F_e} = \frac{R_o}{\kappa - 1} \frac{\phi_E}{\phi_e^2} \frac{\partial \phi_e}{\partial F_e}$	(T2.6)

For this herring assessment, the average catch over the past 20 years was arbitrarily used to determine the allocation scheme for each of the stock assessment regions. For the Strait of Georgia this corresponds to 6.9% for the winter seine fishery, 41.4% for the seine roe fishery, and 51.8% for the gill net fishery. We further assume that 100% of the total mortality takes place prior to spawning.

A.1.3 Dynamic age-structured model

The estimated parameter vector in ${}^i\text{SCA}_M$ is defined in (T3.1), where R_0 , κ and M are the leading unknown population parameters that define the overall population scale in the form of unfished recruitment and productivity in the form of recruitment compensation and natural mortality. The total variance ϑ^2 and the proportion of the total variance that is associated with observation errors ρ are also estimated, then the variance is partitioned into observation errors (σ^2) and process errors (τ^2) using (T3.2).

The unobserved state variables (T3.3) include the numbers-at-age year year t ($N_{t,a}$), the spawning stock biomass (B_t) and the total age-specific total mortality rate ($Z_{t,a}$).

The initial numbers-at-age in the first year (T3.4) and the annual recruits (T3.5) are treated as estimated parameters and used to initialize the numbers-at-age matrix. Age-specific selectivity for gear type k is a function of the selectivity parameters γ_k (T3.6), and the annual fishing mortality for each gear k in year t ($F_{k,t}$). The vector of log fishing mortality rate parameters $F_{k,t}$ is a bounded vector with a minimum value of -30 and an upper bound of 3.0. In arithmetic space this corresponds to a minimum value of 9.36e-14 and a maximum value of 20.01 for annual fishing mortality rates. In years where there are 0 reported catches for a given fleet, no corresponding fishing mortality rate parameter is estimated and the implicit assumption is there was no fishery in that year.

There is an option to treat natural mortality as a random walk process (T3.7), where the natural mortality rate in the first year is the estimated leading parameter (T3.1) and in subsequent years the mortality rate deviates from the previous year based on the estimated deviation parameter φ_t . If the mortality deviation

Table A-3: Statistical catch-age model using the Baranov catch equation and C^* and F^* as leading parameters.

Estimated parameters	
$\Theta = \left(R_0, \kappa, M, \bar{R}, \ddot{R}, \rho, \vartheta, \vec{\gamma}_k, F_{k,t}, \{\ddot{\omega}_a\}_{a=\dot{a}+1}^{a=A}, \{\omega_t\}_{t=1}^{t=T}, \{\varphi_t\}_{t=2}^T \right)$	(T3.1)
$\sigma = \rho/\vartheta, \quad \tau = (1 - \rho)/\vartheta$	(T3.2)
Unobserved states	
$N_{t,a}, B_t, Z_{t,a}$	(T3.3)
Initial states ($t = \dot{t}$)	
$N_{t,a} = \ddot{R} e^{\ddot{\omega}_a} \exp(-M_t)^{(a-\dot{a})}; \quad t = \dot{t}; \dot{a} \leq a \leq A$	(T3.4)
$N_{t,a} = \bar{R} e^{\omega_t}; \quad \dot{t} \leq t \leq T; a = \dot{a}$	(T3.5)
$v_{k,a} = f(\vec{\gamma}_k)$	(T3.6)
$M_t = M_{t-1} \exp(\varphi_t), \quad t > 1$	(T3.7)
$F_{k,t} = \exp(F_{k,t})$	(T3.8)
State dynamics ($t > \dot{t}$)	
$B_t = \sum_a N_{t,a} f_a$	(T3.9)
$Z_{t,a} = M_t + \sum_k F_{k,t} v_{k,t,a}$	(T3.10)
$\hat{C}_{k,t} = \sum_a \frac{N_{t,a} w_a F_{k,t} v_{k,t,a} (1 - e^{-Z_{t,a}})^{\eta_t}}{Z_{t,a}}$	(T3.11)
$N_{t,a} = \begin{cases} N_{t-1,a-1} \exp(-Z_{t-1,a-1}) & a > \dot{a} \\ N_{t-1,a} \exp(-Z_{t-1,a}) & a = A \end{cases}$	(T3.12)
Recruitment models	
$R_t = \frac{s_o B_{t-k}}{1 + \beta B_{t-k}} e^{\delta_t - 0.5\tau^2} \quad \text{Beverton-Holt}$	(T3.13)
$R_t = s_o B_{t-k} e^{-\beta B_{t-k} + \delta_t - 0.5\tau^2} \quad \text{Ricker}$	(T3.14)

parameters are not estimated, then M is assumed to be time invariant.

State variables in each year are updated using equations T3.9–T3.12, where the spawning biomass is the product of the numbers-at-age and the mature biomass-at-age (T3.9). The total mortality rate is given by (T3.10), and the total catch (in weight) for each gear is given by (T3.11) assuming that both natural and fishing mortality occur simultaneously throughout the year. The numbers-at-age are propagated over time using (T3.12), where members of the plus group (age A) are all assumed to have the same total mortality rate.

Recruitment to age k can follow either a Beverton-Holt model (T3.13) or a Ricker model (T3.14) where the maximum juvenile survival rate (s_o) in either case is defined by $s_o = \kappa/\phi_E$. For the Beverton-Holt model, β is derived by solving (T3.13) for β conditional on estimates of κ and R_o :

$$\beta = \frac{\kappa - 1}{R_o \phi_E},$$

Table A-4: List of symbols, constants and description for variables used in $iSCA_M$.

Symbol	Constant value	Description
<u>Indexes</u>		
a		index for age
t		index for year
k		index for gear
<u>Model dimensions</u>		
\acute{a}, A	2, 10	youngest and oldest age class (A is a plus group)
\acute{t}, T	1951, 2010	first and last year of catch data
K	5	Number of gears including survey gears
<u>Observations (data)</u>		
$C_{k,t}$		catch in weight by gear k in year t
$I_{k,t}$		relative abundance index for gear k in year t
$p_{k,t,a}$		observed proportion-at-age a in year t for gear k
<u>Estimated parameters</u>		
R_o		Age- \acute{a} recruits in unfished conditions
κ		recruitment compensation
M		instantaneous natural mortality rate
\bar{R}		average age- \acute{a} recruitment from year \acute{t} to T
\ddot{R}		average age- \acute{a} recruitment in year $\acute{t} - 1$
ρ		fraction of the total variance associated with observation error
ϑ		total precision (inverse of variance) of the total error
$\vec{\gamma}_k$		vector of selectivity parameters for gear k
$F_{k,t}$		logarithm of the instantaneous fishing mortality for gear k in year t
$\ddot{\omega}_a$		age- \acute{a} deviates from \ddot{R} for year \acute{t}
ω_t		age- \acute{a} deviates from \ddot{R} for years \acute{t} to T

and for the Ricker model this is given by:

$$\beta = \frac{\ln(\kappa)}{R_o \phi_E}$$

A.1.4 Options for selectivity

At present, there are six alternative age-specific selectivity options in $i\text{SCA}_M$. The simplest of the selectivity options is a simple logistic function with two parameters where it is assumed that selectivity is time-invariant. The more complex selectivity options assume that selectivity may vary over time and may have as many as $(A-1) \cdot T$ parameters. For time-varying selectivity, cubic and bicubic splines are used to reduce the number of estimated parameters. Prior to parameter estimation, $i\text{SCA}_M$ will determine the exact number of selectivity parameters that need to be estimated based on which selectivity option was chosen for each gear type. It is not necessary for all gear types to have the same selectivity option. For example it is possible to have a simple two parameter selectivity curve for say a survey gear, and a much more complicated selectivity option for a commercial fishery.

Logistic selectivity The logistic selectivity option is a two parameter model of the form

$$v_a = \frac{1}{1 + \exp(-(a - \mu_a)/\sigma_a)}$$

where μ_a and σ_a are the two estimated parameters representing the age-at-50% vulnerability and the standard deviation, respectively.

Age-specific selectivity coefficients The second option also assumes that selectivity is time-invariant and estimates a total of $A-1$ selectivity coefficients, where the plus group age-class is assumed to have the same selectivity as the previous age-class. For example, if the ages in the model range from 1 to 15 years, then a total of 14 selectivity parameters are estimated, and age-15+ animals will have the same selectivity as age-14 animals.

When estimating age-specific selectivity coefficients, there are two additional penalties that are added to the objective function that control how much curvature there is and limit how much dome-shaped can occur. To penalize the curvature, the square of the second differences of the vulnerabilities-at-age are added to the objective function:

$$\lambda_k^{(1)} \sum_{a=2}^{A-1} (v_{k,a} - 2v_{k,a-1} + v_{k,a-2})^2 \quad (2)$$

The dome-shaped term penalty as:

$$\begin{cases} \lambda_k^{(2)} \sum_{a=1}^{A-1} (v_{k,a} - v_{k,a+1})^2 & (if) v_{k,a+1} < v_{k,a} \\ 0 & (if) v_{k,a+1} \geq v_{k,a} \end{cases} \quad (3)$$

For this selectivity option the user must specify the relative weights $(\lambda_k^{(1)}, \lambda_k^{(2)})$ to add to these two penalties.

Cubic spline interpolation The third option also assumes time-invariant selectivity and estimates a selectivity coefficients for a series age-nodes (or spline points) and uses a natural cubic spline to interpolate between these nodes (Figure 19). Given $n+1$ distinct knots x_i , selectivity can be interpolated in the intervals defined by

$$S(x) = \begin{cases} S_0(x) & x \in [x_0, x_1] \\ S_1(x) & x \in [x_1, x_2] \\ \dots \\ S_{n-1}(x) & x \in [x_{n-1}, x_n] \end{cases}$$

where $S''(x_0) = S''(x_n) = 0$ is the condition that defines a natural cubic spline.

The same penalty functions for curvature and dome-shaped selectivity are also invoked for the cubic spline interpolation of selectivity.

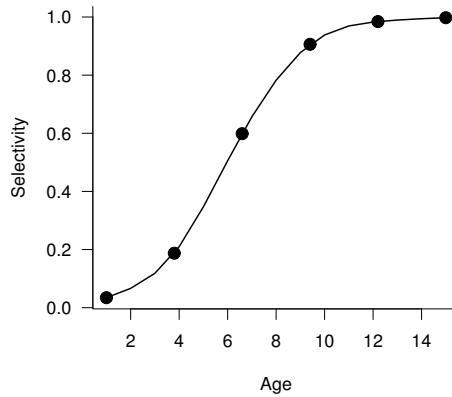


Figure 19: Example of a natural cubic spline interpolation for estimating selectivity coefficients. In $i\text{SCAM}$ the user specifies the number of nodes (circles) to estimate; then age-specific selectivity coefficients are interpolated using a natural cubic spline.

Time-varying selectivity with cubic spline interpolation A fourth option allows for cubic spline interpolation for age-specific selectivity in each year. This option adds a considerable number of estimated parameters but the most extreme flexibility. For example, given 40 years of data and estimated 5 age nodes, this amounts 200 (40 years times 5 ages) estimated selectivity parameters. Note that the only constraints at this time are the dome-shaped penalty and the curvature penalty; there is no constraint implemented for say a random walk (first difference) in age-specific selectivity. As such this option should only be used in cases where age-composition data is available for every year of the assessment.

Bicubic spline to interpolate over time and ages The fifth option allows for a two-dimensional interpolation using a bicubic spline (Figure 20). In this case the user must specify the number of age and year nodes. Again the same curvature and dome shaped constraints are implemented. It is not necessary to have age-composition data each and every year as in the previous case, as the bicubic spline will interpolate between years. However, it is not advisable to extrapolate selectivity back in time or forward in time where there are no age-composition data unless some additional constraint, such as a random-walk in age-specific selectivity coefficients is implemented (as of July 17, 2011, this has not been implemented).

A.1.5 Options for natural mortality

There is an option in $i\text{SCAM}$ to estimate a time series of deviations in natural mortality rates (φ_t). If not estimated, natural mortality M is assumed to be invariant over time and age. If, however, M is thought to vary over time, then $i\text{SCAM}$ models natural mortality as a random walk process (T3.7). In such cases where M is allowed to freely vary over time, the user must specify two additional components in the control file. First, the phase in which the vector of deviations φ_t is estimated must be specified (use a -ve phase to turn off the estimation), and the user must also specify a standard deviation in the deviation parameters. If estimated, then an additional component is added to the objective function to constrain the first differences in the deviation parameters. This first difference constraint only limits how quickly M may increase or decrease over time and does not penalize deviations from an underlying mean. Thus it is possible for M to drift (increase or decrease) away from some central tendency. This drifting can have profound effects on reference point calculations as it also allows for non-stationarity in the underlying production function.

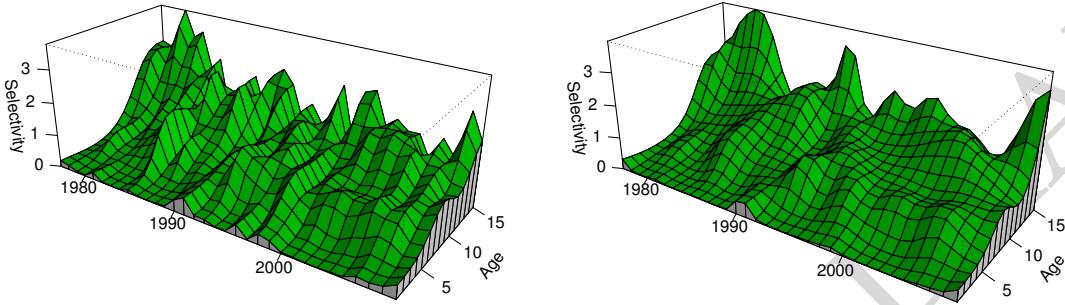


Figure 20: Example of a time-varying cubic spline (left) and bicubic spline (right) interpolation for selectivity. The panel on the left contains 165 estimated selectivity parameters and the bicubic interpolation estimates 85 selectivity parameters, or 5 age nodes and 17 year nodes. There are 495 actual nodes (selectivity parameters) being interpolated.

A.2 Residuals, likelihoods & objective function value components

There are 3 major components to the overall objective function that are minimized. These components consist of the likelihood of the data, prior distributions and penalty functions that are invoked to regularize the solution during intermediate phases of the non-linear parameter estimation. This section discusses each of these in turn, starting first with the residuals between observed and predicted states followed by the negative loglikelihood that is minimized for the catch data, relative abundance data, age-composition, and stock-recruitment relationships.

A.2.1 Catch data

It is assumed that the measurement errors in the non-zero catch observations are log-normally distributed, and the residuals is given by:

$$\eta_{k,t} = \ln(C_{k,t}) - \ln(\hat{C}_{k,t}), \quad (4)$$

The residuals are assumed to be normally distributed with a user specified standard deviation σ_C . At present, it is assumed that observed catches for each gear k is assumed to have the same standard deviation. To aid in parameter estimation, two separate standard deviations are specified in the control file: the first is the assumed standard deviation used in the first, second, to N-1 phases, and the second is the assumed standard deviation in the last phase. The negative loglikelihood (ignoring the scaling constant) for the catch data is given by:

$$\ell_C = \sum_k \left[T_k \ln(\sigma_C) + \frac{\sum_{t \in \hat{C}_{k,t} \neq 0} (\eta_{k,t})^2}{2\sigma_C^2} \right], \quad (5)$$

where T_k is the total number of non-zero catch observations for gear type k .

A.2.2 Relative abundance data

The relative abundance data are assumed to be proportional to biomass that is vulnerable to the sampling gear:

$$V_{k,t} = \sum_a N_{t,a} e^{-\lambda_{k,t} Z_{t,a}} v_{k,a} w_{a,t}, \quad (6)$$

where $v_{k,a}$ is the age-specific selectivity of gear k , and w_a is the mean-weight-at-age. A user specified fraction of the total mortality $\lambda_{k,t}$ adjusts the numbers-at-age to correct for survey timing. In the case of Pacific herring spawn surveys, the vulnerability is fixed to the assumed maturity ogive and the empirical weight-at-age data are used to construct the predicted relative abundance. Also, it was assumed that all the mortality (post-fishing) had occurred during the time the survey took place (i.e., $\lambda_{k,t} = 1$). The residuals between the observed and predicted relative abundance index is given by:

$$\epsilon_{k,t} = \ln(I_{k,t}) - \ln(q_k) + \ln(V_{k,t}), \quad (7)$$

where $I_{k,t}$ is the observed relative abundance index, q_k is the catchability coefficient for index k , and $V_{k,t}$ is the predicted vulnerable biomass at the time of sampling. The catchability coefficient q_k is evaluated at its conditional maximum likelihood estimate:

$$q_k = \frac{1}{N_k} \sum_{t \in I_{k,t}} \ln(I_{k,t}) - \ln(V_{k,t}),$$

where N_k is the number of relative abundance observations for index k (see Walters and Ludwig, 1994, for more information). The negative loglikelihood for relative abundance data is given by:

$$\ell_I = \sum_k \sum_{t \in I_{k,t}} \ln(\sigma_{k,t}) + \frac{\epsilon_{k,t}^2}{2\sigma_{k,t}^2} \quad (8)$$

where

$$\sigma_{k,t} = \frac{\rho\vartheta^2}{\omega_{k,t}},$$

where $\rho\vartheta^2$ is the proportion of the total error that is associated with observation errors, and $\omega_{k,t}$ is a user specified relative weight for observation t from gear k . The $\omega_{k,t}$ terms allow each observation to be weighted relative to the total error $\rho\vartheta^2$; for example, to omit a particular observation, set $\omega_{k,t} = 0$, or to give 2 times the weight, then set $\omega_{k,t} = 2.0$. To assume all observations have the same variance then simply set $\omega_{k,t} = 1$. Note that if $\omega_{k,t} = 0$ then equation (8) is undefined; therefore, $i\text{SCA}_M$ adds a small constant to $\omega_{k,t}$ (1.e-10, which is equivalent to assuming an extremely large variance) to ensure the likelihood can be evaluated.

In the case of the Pacific herring assessment, the spawn survey data post-1988 were assumed to be twice as precise as the pre-dive survey data (1951-1987). To implement this, weights for the 1951-1987 data were set equal to $\omega_{k,t} = 1.0$ and the contemporary data was assigned $\omega_{k,t} = 2.0$. The standard deviation in the observation errors is conditional on estimated values of ρ and φ^2 .

A.2.3 Age composition data

Sampling theory suggest that age composition data are derived from a multinomial distribution (Fournier and Archibald, 1982); however, $i\text{SCA}_M$ assumes that age-proportions are obtained from a multivariate logistic distribution (Schnute and Richards, 1995; Richards et al., 1997). The main reason $i\text{SCA}_M$ departs from the traditional multinomial model has to do with how the age-composition data are weighted in the objective function. First, the multinomial distribution requires the specification of an effective sample size; this may be done arbitrarily or through iterative re-weighting (McAllister and Ianelli, 1997; Gavaris and Ianelli, 2002), and in the case of multiple and potentially conflicting age-proportions this procedure may fail to converge properly. The assumed effective sample size can have a large impact on the overall model results.

A nice feature of the multivariate logistic distribution is that the age-proportion data can be weighted based on the conditional maximum likelihood estimate of the variance in the age-proportions. Therefore,

the contribution of the age-composition data to the overall objective function is “self-weighting” and is conditional on other components in the model.

Ignoring the subscript for gear type for clarity, the observed and predicted proportions-at-age must satisfy the constraint

$$\sum_{a=1}^A p_{t,a} = 1$$

for each year. The multivariate logistic residuals between the observed ($p_{t,a}$) and predicted proportions ($\widehat{p}_{t,a}$) is given by:

$$\eta_{t,a} = \ln(p_{t,a}) - \ln(\widehat{p}_{t,a}) - \frac{1}{A} \sum_{a=1}^A [\ln(p_{t,a}) - \ln(\widehat{p}_{t,a})]. \quad (9)$$

The conditional maximum likelihood estimate of the variance is given by

$$\widehat{\tau}^2 = \frac{1}{(A-1)T} \sum_{t=1}^T \sum_{a=1}^A \eta_{t,a}^2,$$

and the negative loglikelihood evaluated at the conditional maximum likelihood estimate of the variance is given by:

$$\ell_A = (A-1)T \ln(\widehat{\tau}^2). \quad (10)$$

In short, the multivariate logistic likelihood for age-composition data is just the log of the residual variance weighted by the number observations over years and ages.

There is also a technical detail in (9), where observed and predicted proportions-at-age must be greater than 0. It is not uncommon in catch-age data sets to observe 0 proportions for older, or young, age classes. *iSCAM* adopts the same approach described by Richards et al. (1997) where the definition of age-classes is altered to require that $p_{t,a} \geq 0.02$ for every age in each year. This is accomplished by grouping consecutive ages, where $p_{t,a} < 0.02$, into a single age-class and reducing the effective number of age-classes in the variance calculation ($\widehat{\tau}^2$) by the number of groups created. The choice of 2% is arbitrary and the user can specify the minimum proportion (including 0) to consider when pooling age-proportion data. In the case of an exact 0 in the observed age-proportions the pooling of the adjacent age-class still occurs, this ensures that (9) is defined.

In the Strait of Georgia herring example, we set the minimum proportion to 2% to reduce the influence of the large numbers of 0 proportions in the purse-seine fleets, especially prior to 1970 during the reduction fishery.

A.2.4 Stock-recruitment

There are two alternative stock-recruitment models available in *iSCAM*: the Beverton-Holt model and the Ricker model. Annual recruitment and the initial age-composition are treated as latent variables in *iSCAM*, and residuals between estimated recruits and the deterministic stock-recruitment models are used to estimate unfished spawning stock biomass and recruitment compensation. The residuals between the estimated and predicted recruits is given by

$$\delta_t = \ln(\bar{R}e^{w_t}) - f(B_{t-k}) \quad (11)$$

where $f(B_{t-k})$ is given by either (T3.13) or (T3.14), and k is the age at recruitment. Note that a bias correction term for the lognormal process errors is included in (T3.13) and (T3.14).

The negative log likelihood for the recruitment deviations is given by the normal density (ignoring the scaling constant):

$$\ell_\delta = n \ln(\tau) + \frac{\sum_{t=1+k}^T \delta_t^2}{2\tau^2} \quad (12)$$

Equations (11) and (12) are key for estimating unfished spawning stock biomass and recruitment compensation via the recruitment models. The relationship between (s_o, β) and (B_o, κ) is defined as:

$$s_o = \kappa / \phi_E \quad (13)$$

$$\beta = \begin{cases} \frac{\kappa - 1}{B_o} & \text{Beverton-Holt} \\ \frac{\ln(\kappa)}{B_o} & \text{Ricker} \end{cases} \quad (14)$$

where s_o is the maximum juvenile survival rate, β is the density effect on recruitment, and B_o is the unfished spawning stock biomass. Unfished steady-state spawning stock biomass per recruit is given by ϕ_E , which is the sum of products between age-specific survivorship and relative fecundity. In cases where the natural mortality rate is allowed to vary over time, the calculation of ϕ_E , and the corresponding unfished spawning stock biomass (B_o) is based on the average natural mortality rate over the entire time period. This subtle calculation has implications for reference point calculations in cases where there are increasing or decreasing trends in natural mortality rates over time; as estimates of natural mortality rates trend upwards, estimates of B_o decrease.

For the Strait of Georgia Pacific herring example, only the Beverton-Holt recruitment model was considered. The description of the Ricker model is included here for the sake of completely documenting the features in the $i\text{SCAM}$ platform.

A.3 Parameter Estimation and Uncertainty

Parameter estimation and quantifying uncertainty was carried out using the tools available in AD Model Builder (ADMB Project, 2009). AD Model Builder (ADMB) is a software for creating computer programs to estimate the parameters and associated probability distributions for nonlinear statistical models. The software is freely available from <http://admb-project.org/>. This software was used to develop $i\text{SCAM}$, and the source code and documentation for $i\text{SCAM}$ is freely available from <https://sites.google.com/site/iscamproject/>, or from a subversion repository at <http://code.google.com/p/iscam-project/>.

Suffice it to say that there is a lot more going on in the $i\text{SCAM}$ software than just minimizing the sum of the four negative loglikelihood functions defined in the previous section. There are actually five distinct components that make up the objective function that ADMB is minimizing:

$$f = \text{negative loglikelihoods} + \text{constraints} + \text{priors for parameters} + \text{survey priors} + \text{convergence penalties}.$$

The purpose of this section is to completely document all of the components that make up the objective function. Such transparency is absolutely necessary to better understand estimation performance, as well as, to ensure the results are repeatable.

A.3.1 Negative loglikelihoods

The negative loglikelihoods pertain specifically elements that deal with the data and variance partitioning and have already been described in detail in section A.2. There are four specific elements that make up the vector of negative loglikelihoods:

$$\vec{\ell} = \ell_C, \ell_I, \ell_A, \ell_\delta. \quad (15)$$

To reiterate, these are the likelihood of the catch data ℓ_C , likelihood of the survey data ℓ_I , the likelihood of the age-composition data ℓ_A and the likelihood of the stock-recruitment residuals ℓ_δ . Each of these elements are expressed in negative log-space, and ADMB attempts to estimate model parameters by minimizing the sum of these elements.

A.3.2 Constraints

There are two specific constraints that are described here: 1) parameter bounds, and 2) constraints to ensure that a parameter vector sums to 0. In $i\text{SCAM}$ the user must specify the lower and upper bounds for the leading parameters defined in the control file $(\ln(R_o), h, \ln(M), \ln(\bar{R}), \rho, \vartheta)$. All estimated selectivity parameters

$\vec{\gamma}_k$ are estimated in log space and have a minimum and maximum values of -5.0 and 5.0, respectively. These values are hard-wired into the code, but should be sufficiently large/small enough to capture a wide range of selectivities. Estimated fishing mortality rates are also constrained (in log space) to have a minimum value of -30, and a maximum value of 3.0. Log annual recruitment deviations are also constrained to have minimum and maximum values of -15.0 and 15.0 and there is an additional constraint to ensure the vector of deviations sums to 0. This is necessary in order to be able to estimate the average recruitment \bar{R} . Finally, the annual log deviations in natural mortality rates are constrained to lie between -2.0 and 2.0.

An array of selectivity parameters (i.e., `init_bounded_matrix_vector`) is estimated within $i\text{SCA}_M$ where each matrix corresponds to a specific gear type, and the number of rows and columns of each depends on the type of selectivity function assumed for the gear and if that selectivity changes over time. In cases where the nodes of a spline are estimated these nodes also have an additional constraint to sum to 0. This is effectively implemented by adding to the objective function:

$$1000 \left(\frac{1}{N_{\vec{\lambda}_k}} \sum \vec{\lambda}_k \right)^2.$$

This additional constraint is necessary to ensure the model remains separable and the annual fishing mortality rates are less confounded with selectivity parameters.

A.3.3 Priors for parameters

Each of the six leading parameters specified in the control file ($\ln(R_o)$, h , $\ln(M)$, $\ln(\bar{R})$, ρ , ϑ) are declared as bounded parameters and in addition the user can also specify an informative prior distribution for each of these parameters. Five distinct prior distributions can be implemented: uniform, normal, lognormal, beta and a gamma distribution. For the Strait of Georgia herring, a bounded uniform prior was specified for the log of unfished recruitment $U(-5.0, 15)$, a non-informative beta prior was assumed for steepness Beta(1.01, 1.01), a normal prior was specified for the log of natural mortality rate $N(-1.0966, 0.05)$, a bounded uniform prior for the log of average recruitment $U(-5.0, 15.0)$, a beta prior for the variance partitioning parameter ρ Beta(15, 60), and a gamma prior for the precision parameter ϑ , Gamma(156.25, 125.0). An example of these prior distributions based on the parameter specified above is show in Figure 21.

In addition to the priors specified for the six leading parameter, there are several other informative distributions that are invoked for the non-parametric selectivity parameters. In cases were age-specific selectivity coefficients are estimated, or nodes of a spline function are estimated, two additional penalties are added to the objective function to control how smooth the selectivity changes (2) and how much dome-shape is allowed in the nonparametric selectivities (3).

A.3.4 Survey priors

The scaling parameter q for each of the surveys is not estimated; rather, the maximum likelihood estimate for q conditional on all other parameters is used to scale the predicted spawning biomass to the observed spawn survey index. In the case of Pacific herring, the relationship between fecundity and mature female biomass is relatively invariant at about 227 eggs per gram (Hardwick, 1973). This relationship has been used to convert total egg deposition from the spawn survey to total female spawning biomass, and assuming all spawning was accounted for, then a reasonable estimate for q should be 1.0.

In the Strait of Georgia herring assessment, we specified an informative normal prior on $\ln(q)$ with a mean of 0, and a standard deviation of 0.05 for the contemporary data. For the pre-1988 spawn survey data, we explored three alternative priors including a non-informative prior, and a normal prior with a mean 0 and standard deviations of 0.05, or 0.1. The informative prior for the contemporary data implies a 95% confidence interval of 0.82 to 1.22 for q .

A.3.5 Convergence penalties

For the Strait of Georgia herring assessment, there are well over 200 estimated parameters, the exact number depends on the model configuration. Needless to say, non-linear parameter estimation is often very sensitive to the initial starting conditions, and the end results may differ depending on the initial values of the

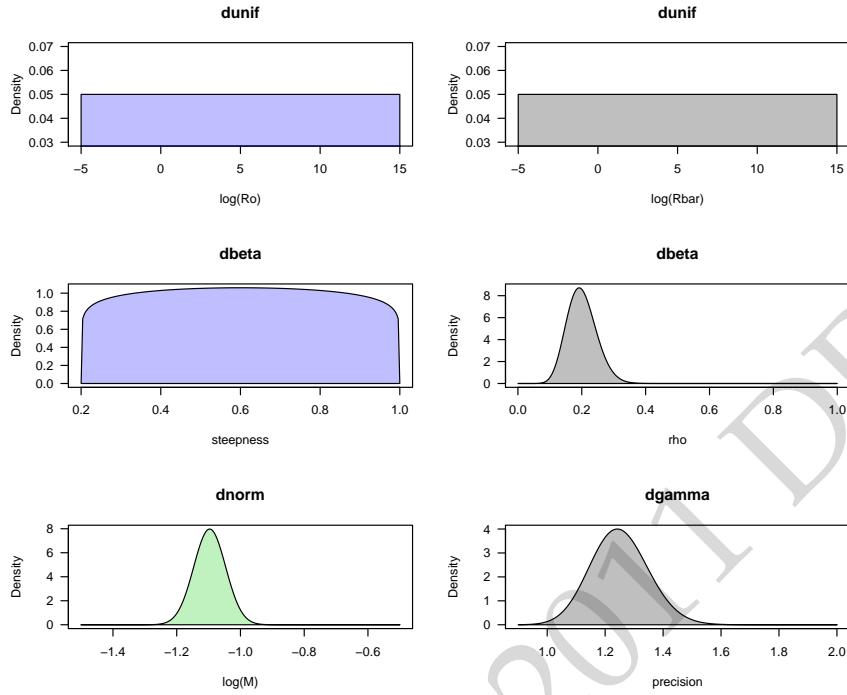


Figure 21: An example of the prior distributions used for $\ln(R_o)$, h , $\ln(M)$, $\ln(\bar{R})$, ρ , ϑ . The actual values used for the SOG herring assessment can be found in the control file in the appendix.

model parameters or even the phase at which parameters are included into the estimation problem. There is no guarantee that the algorithm will converge to the global minimum every time. AD Model Builder is unique in that the estimation process can be conducted in a series of phases where more and more parameters are ‘freed up’ as the model progress through each phase. Furthermore, the actual objective function can change between phases such that during the initial phases large penalties can be used to, as Dave Fournier would say, “regularize the solution”. For example, in the initial phases of parameter estimation $i\text{SCA}_M$ uses fairly steep quadratic penalties for the annual recruitment deviations and average fishing mortality rates to initially aid in finding reasonable values of the average recruitment, natural mortality and selectivity parameters. In the final phase, these quadratic penalties are relaxed.

In the case of the annual recruitment deviations, the quadratic penalty term is:

$$100 \sum_{t=1-A}^T \omega_t^2,$$

which is approximately a normal density with a standard deviation equal to 0.07. In the last phase this constraint is relaxed with a large standard deviation of 5.0.

A similar penalty (a normal distribution for the log mean fishing rate) is also invoked for the mean fishing mortality rate, but in this case the user specifies the mean fishing mortality rate and the standard deviations in the initial phases and the last phase. Normally, a rather small standard deviation is used in the initial phases (e.g., 0.01) and this is then relaxed to a much larger value (e.g., 5.0) in the last phase. These standard deviations are specified by the user in the control file.

B Data and Control files

B.1 Haida Gwaii

```

#NB The data herein were taken from qci2010_final.dat for the HCAM model.
## -----
## ____Model Dimensions_____
1951      #first year of data
2010      #last year of data
2       #age of youngest age class
10      #age of plus group
5       #number of gears (ngear)
## flags for fishery (1) or survey (0) in ngears
#1 1 0 0
0.100 0.400 0.495 0.0 0.0
## -----
## _____
##Age-schedule and population parameters
#natural mortality rate (m)
0.334
#growth parameters (linf,k,to) (from fishbase)
27.0, 0.48, 0
#length-weight allometry (a,b)
4.5e-6, 3.1270
#saturation at age (am=log(3)/k) & gm=std for logistic
2.055, 0.05
## -----
##Time series data
#Observed catch (1951-2010, 1000s metric t)
#Year P1 P2 P3 S1 S2
1951 2.847 0.000 0.000 0 0
1952 10.147 0.000 0.000 0 0
1953 0.000 0.000 0.000 0 0
1954 1.786 0.000 0.000 0 0
1955 1.234 0.000 0.000 0 0
1956 77.681 0.000 0.000 0 0
1957 23.711 0.000 0.000 0 0
1958 11.168 0.000 0.000 0 0
1959 7.027 0.000 0.000 0 0
1960 0.000 0.000 0.000 0 0
1961 0.653 0.000 0.000 0 0
1962 7.632 0.000 0.000 0 0
1963 14.980 0.000 0.000 0 0
1964 28.777 0.000 0.000 0 0
1965 35.448 0.000 0.000 0 0
1966 2.746 0.000 0.000 0 0
1967 0.213 0.000 0.000 0 0
1968 0.080 0.000 0.000 0 0
1969 0.000 0.000 0.000 0 0
1970 0.000 0.000 0.000 0 0
1971 0.102 0.000 0.000 0 0
1972 0.849 3.124 0.000 0 0
1973 0.000 7.520 0.000 0 0
1974 0.000 6.191 0.127 0 0
1975 0.000 7.619 0.105 0 0
1976 0.374 11.939 1.802 0 0
1977 0.000 11.146 1.489 0 0
1978 0.000 9.172 2.553 0 0
1979 0.000 5.867 2.086 0 0
1980 0.000 2.106 1.210 0 0
1981 0.000 3.926 1.705 0 0
1982 0.000 2.371 1.407 0 0
1983 0.067 4.661 0.929 0 0
1984 0.096 4.016 0.535 0 0
1985 0.000 4.616 1.493 0 0
1986 0.000 2.613 0.890 0 0
1987 0.000 2.061 0.000 0 0
1988 0.000 0.032 0.000 0 0
1989 0.000 1.461 0.000 0 0
1990 0.000 5.542 1.170 0 0
1991 0.000 3.899 0.543 0 0
1992 0.000 2.524 0.000 0 0
1993 0.000 2.699 0.000 0 0
1994 0.000 0.299 0.000 0 0
1995 0.000 0.000 0.000 0 0
1996 0.000 0.000 0.000 0 0
1997 0.000 0.000 0.000 0 0
1998 0.000 1.372 0.000 0 0
1999 0.000 2.500 0.473 0 0
2000 0.000 1.764 0.000 0 0
2001 0.000 0.000 0.000 0 0
2002 0.000 0.706 0.000 0 0
2003 0.000 0.000 0.000 0 0
2004 0.000 0.000 0.000 0 0
2005 0.000 0.000 0.000 0 0
2006 0.000 0.000 0.000 0 0
2007 0.000 0.000 0.000 0 0
2008 0.000 0.000 0.000 0 0
2009 0.000 0.000 0.000 0 0
2010 0.000 0.000 0.000 0 0
#Relative Abundance index from fisheries independent survey (it) 1970-2008
#it
#60
#2
#n_it_nobs
37 23
#survey type
## 1 = survey is proportional to vulnerable numbers
## 2 = survey is proportional to vulnerable biomass
## 3 = survey is proportional to spawning biomass (e.g., herring spawn survey)
3 3
#ityr it gear wt survey timing
1951 4.213 4 1 1
1952 2.578 4 1 1
1953 7.555 4 1 1
1954 12.408 4 1 1
1955 6.437 4 1 1
1956 6.042 4 1 1
1957 1.592 4 1 1
1958 0.815 4 1 1
1959 8.981 4 1 1
1960 6.599 4 1 1
1961 8.981 4 1 1
1962 5.730 4 1 1
1963 7.297 4 1 1
1964 4.104 4 1 1
1965 1.378 4 1 1
1966 2.824 4 1 1
1967 0.710 4 1 1
1968 0.833 4 1 1
1969 2.075 4 1 1
1970 5.552 4 1 1
1971 13.291 4 1 1
1972 9.542 4 1 1
1973 7.960 4 1 1
1974 14.510 4 1 1
1975 9.666 4 1 1
1976 16.374 4 1 1
1977 16.408 4 1 1
1978 18.371 4 1 1
1979 13.649 4 1 1
1980 31.904 4 1 1
1981 20.294 4 1 1
1982 23.593 4 1 1
1983 21.391 4 1 1
1984 23.439 4 1 1
1985 18.625 4 1 1
1986 6.847 4 1 1
1987 12.289 4 1 1
1988 15.245 5 1.1666 1
1989 25.201 5 1.1666 1
1990 27.058 5 1.1666 1
1991 17.998 5 1.1666 1
1992 12.376 5 1.1666 1
1993 8.152 5 1.1666 1
1994 14.293 5 1.1666 1
1995 4.701 5 1.1666 1
1996 7.377 5 1.1666 1
1997 11.215 5 1.1666 1
1998 21.649 5 1.1666 1
1999 10.610 5 1.1666 1
2000 6.698 5 1.1666 1
2001 15.195 5 1.1666 1
2002 3.257 5 1.1666 1
2003 8.801 5 1.1666 1
2004 5.668 5 1.1666 1
2005 3.614 5 1.1666 1
2006 4.097 5 1.1666 1
2007 9.436 5 1.1666 1
2008 4.213 5 1.1666 1
2009 8.935 5 1.1666 1
2010 6.091 5 1.1666 1
#Age composition data by year, gear (ages 2-15+)
#na_gears
3
#na_nobs
10 39 15
#a_sage
2 2 2
#a_page
10 10 10
#yr gear V2 V3 V4 V5 V6 V7 V8 V9 V10 #Number aged.
1951 1 1 226 781 226 170 62 9 1 0
1952 1 381 485 760 479 92 25 2 0 0
1956 1 2 216 130 838 113 37 10 0 0
1957 1 901 1116 718 423 1167 111 21 5 0
1958 1 2259 462 35 5 4 4 0 0 0
1959 1 1 60 27 7 0 0 0 0 0
1962 1 7 106 120 16 20 2 1 0 0
1963 1 3 402 218 146 17 16 0 1 1
1964 1 5 78 294 81 26 6 0 0 0
1965 1 17 833 105 41 15 6 2 0 0
1972 2 36 386 454 190 72 29 11 5 1
1973 2 3 700 372 471 138 29 13 0 0
1974 2 2 471 593 255 125 25 5 1 0
1975 2 38 1521 2056 1677 573 117 22 6 0
1976 2 18 114 1495 1186 940 260 39 3 0
1977 2 3 625 258 944 728 466 141 13 0
1978 2 2 308 202 112 311 165 58 11 2
1979 2 57 45 298 167 186 130 28 4 0
1980 2 70 3361 168 179 100 62 46 26 3
1981 2 34 234 5380 322 177 111 45 18 11
1982 2 30 165 158 2973 87 54 35 19 1
1983 2 96 103 69 135 1434 77 31 18 4
1984 2 94 1268 158 100 352 1455 39 12 6
1985 2 47 531 1132 144 161 404 1119 16 1
1986 2 10 134 1041 1902 191 155 380 905 15
1987 2 57 342 192 799 1239 126 142 190 190
1988 2 61 855 126 80 197 249 23 28 32
1989 2 81 622 2364 143 56 139 99 22 15
1990 2 11 487 918 3033 199 93 193 86 14
1991 2 227 140 361 972 1303 125 61 135 51

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1992 2 23 1243 159 270 402 992 77 19 27
1993 2 12 128 2240 165 225 448 436 43 9
1994 2 75 52 61 590 129 133 132 39 5
1995 2 68 75 11 21 178 46 38 25 11
1996 2 103 515 89 31 32 149 23 11 2
1997 2 372 430 549 86 25 73 88 14 3
1998 2 10 1470 758 315 73 18 33 30 7
1999 2 108 58 1610 433 204 64 16 10 9
2000 2 107 398 84 1270 171 97 9 10 3
2001 2 175 363 256 58 240 35 16 3 1
2002 2 602 750 706 369 86 371 42 13 3
2003 2 2 1685 453 159 80 28 52 10 3
2004 2 248 20 428 74 34 22 12 5 2
2005 2 17 606 205 374 51 31 16 6 3
2006 2 136 72 305 67 108 20 3 0 2
2007 2 6 247 78 114 32 56 12 1 0
2008 2 86 68 583 70 79 17 15 0 2
2009 2 1 645 76 222 20 29 4 5 1
2010 2 39 70 644 62 170 18 13 3 2
1974 3 0 9 76 40 26 5 0 0 1
1975 3 0 0 9 16 12 2 1 0 0
1976 3 0 0 1 29 81 19 3 0 0
1978 3 0 0 6 17 29 56 29 6 1
1979 3 0 0 48 44 46 26 6 0 0
1980 3 0 29 27 229 104 93 27 9 0
1981 3 0 2 583 61 77 44 19 4 0
1982 3 0 1 16 425 16 11 5 2 0
1983 3 0 0 7 14 532 16 14 3 3
1984 3 0 11 5 18 35 313 7 1 1
1985 3 0 20 59 7 11 30 113 1 0
1986 3 0 0 41 172 13 17 29 49 1
1990 3 0 2 32 174 39 33 68 33 2
1991 3 0 0 8 79 153 34 25 36 16
1999 3 0 4 185 137 175 60 16 8 11
#n_wt_obs
60
#Mean weight-at-age in kilograms (interpolated: from HCAM.rep)
#$yr V1 V2 V3 V4 V5 V6 V7 V8 V9
1951 0.0417 0.0897 0.1126 0.1376 0.1586 0.1706 0.2001 0.1865 0.1865
1952 0.0432 0.0896 0.1133 0.1385 0.1599 0.1756 0.1677 0.1780 0.1865
1953 0.0329 0.0763 0.0988 0.1255 0.1498 0.1599 0.1334 0.1784 0.1865
1954 0.0447 0.0847 0.1038 0.1278 0.1571 0.1721 0.1751 0.1860 0.1865
1955 0.0498 0.0893 0.1048 0.1262 0.1448 0.1738 0.1728 0.1784 0.1865
1956 0.0471 0.0845 0.1060 0.1205 0.1410 0.1587 0.1785 0.1733 0.1865
1957 0.0481 0.0828 0.1089 0.1371 0.1505 0.1640 0.2100 0.1784 0.1865
1958 0.0438 0.0763 0.1081 0.1421 0.1535 0.1647 0.1762 0.1885 0.1865
1959 0.0502 0.0836 0.0993 0.1314 0.1596 0.1677 0.1523 0.1580 0.1865
1960 0.0530 0.0902 0.1125 0.1279 0.1597 0.1290 0.1770 0.1784 0.1865
1961 0.057 0.0786 0.1111 0.1170 0.1372 0.1650 0.1720 0.1784 0.1865
1962 0.0501 0.0880 0.0993 0.1366 0.1449 0.1530 0.2028 0.1784 0.1865
1963 0.0477 0.0832 0.1048 0.1116 0.1494 0.1778 0.1794 0.1784 0.1865
1964 0.0576 0.0993 0.1159 0.1378 0.1588 0.1850 0.1400 0.1784 0.1865
1965 0.0611 0.1051 0.1224 0.1451 0.1452 0.1770 0.1440 0.1784 0.1865
1966 0.0520 0.1067 0.1487 0.1681 0.1783 0.1888 0.1720 0.1784 0.1865
1967 0.0488 0.0880 0.1104 0.1332 0.1530 0.1677 0.1720 0.1784 0.1865
1968 0.0488 0.0880 0.1108 0.1332 0.1530 0.1677 0.1720 0.1784 0.1865
1969 0.0488 0.0880 0.1108 0.1332 0.1530 0.1677 0.1720 0.1784 0.1865
1970 0.0578 0.0888 0.1175 0.1399 0.1609 0.1733 0.1871 0.1927 0.2096
1971 0.0553 0.1056 0.1319 0.1537 0.1742 0.1895 0.1693 0.1927 0.2096
1972 0.0586 0.0897 0.1298 0.1478 0.1671 0.1778 0.1973 0.1850 0.2096
1973 0.0525 0.0993 0.1274 0.1588 0.1749 0.1928 0.1977 0.2010 0.2096
1974 0.0630 0.0677 0.1392 0.1653 0.2093 0.1733 0.2420 0.1927 0.2096
1975 0.0421 0.0828 0.1115 0.1423 0.1694 0.1934 0.1995 0.2122 0.2096
1976 0.0498 0.0849 0.1238 0.1455 0.1743 0.1914 0.2033 0.2248 0.2133
1977 0.0571 0.0888 0.1173 0.1389 0.1616 0.1910 0.2010 0.2027 0.2418
1978 0.0501 0.0853 0.1098 0.1321 0.1513 0.1672 0.1689 0.1999 0.2095
1979 0.0597 0.0848 0.1178 0.1405 0.1609 0.1754 0.1991 0.2051 0.2174
1980 0.0522 0.0780 0.1083 0.1352 0.1584 0.1718 0.1831 0.1984 0.2172
1981 0.0602 0.0857 0.1085 0.1348 0.1561 0.1706 0.1873 0.1802 0.2022
1982 0.0635 0.0945 0.1153 0.1292 0.1551 0.1618 0.1696 0.1688 0.1950
1983 0.0576 0.0898 0.1174 0.1349 0.1431 0.1580 0.1707 0.1851 0.1941
1984 0.0624 0.0881 0.1148 0.1388 0.1586 0.1590 0.1666 0.1762 0.2010
1985 0.0647 0.0867 0.1141 0.1345 0.1564 0.1703 0.1869 0.1926 0.2320
1986 0.067 0.0895 0.1108 0.1324 0.1495 0.1700 0.1971 0.1954 0.2096
1987 0.0628 0.0874 0.1056 0.1226 0.1366 0.1522 0.1660 0.1580 0.1823
1988 0.0609 0.0900 0.1138 0.1302 0.1423 0.1547 0.1642 0.2006 0.2096
1989 0.0644 0.0841 0.1068 0.1273 0.1390 0.1474 0.1561 0.1580 0.1820
1990 0.060 0.0851 0.1060 0.1283 0.1468 0.1582 0.1609 0.1453 0.2260
1991 0.064 0.0894 0.1101 0.1280 0.1428 0.1553 0.1634 0.1508 0.1850
1992 0.0598 0.0905 0.1118 0.1319 0.1494 0.1592 0.1738 0.1739 0.1563
1993 0.0579 0.0922 0.1118 0.1286 0.1411 0.1529 0.1566 0.1600 0.1475
1994 0.0522 0.0809 0.1047 0.1207 0.1350 0.1405 0.1512 0.1609 0.1563
1995 0.0612 0.0856 0.1108 0.1314 0.1446 0.1617 0.1631 0.1791 0.1753
1996 0.0619 0.0829 0.1061 0.1264 0.1457 0.1557 0.1719 0.1694 0.1830
1997 0.0497 0.0826 0.1017 0.1197 0.1368 0.1463 0.1541 0.1670 0.1817
1998 0.0504 0.0726 0.0939 0.1086 0.1194 0.1331 0.1438 0.1559 0.1485
1999 0.0460 0.0795 0.0991 0.1134 0.1255 0.1341 0.1434 0.1508 0.1390
2000 0.0523 0.0724 0.0948 0.1110 0.1291 0.1387 0.1532 0.1599 0.1630
2001 0.0622 0.0853 0.0990 0.1197 0.1332 0.1483 0.1552 0.1454 0.1440
2002 0.0494 0.0793 0.0959 0.1076 0.1254 0.1324 0.1413 0.1640 0.0590
2003 0.0518 0.0772 0.0930 0.1050 0.1113 0.1282 0.1401 0.1280 0.1563
2004 0.0498 0.0729 0.0888 0.0993 0.1091 0.1125 0.1241 0.1219 0.1320
2005 0.0476 0.0741 0.0910 0.1064 0.1175 0.1257 0.1305 0.1218 0.1373
2006 0.0483 0.0714 0.0882 0.1023 0.1113 0.1208 0.1279 0.1394 0.1780
2007 0.0620 0.0753 0.0831 0.0994 0.1154 0.1230 0.1301 0.1432 0.1340

```

B.2 Prince Rupert District

```

#NB The data herein were taken from qci2010_final.dat for the HCAM model.
## -----
## Model Dimensions-----
1951 #first year of data
2010 #last year of data
2 #age of youngest age class
10 #age of plus group
5 #number of gears (ngear)
## flags for fishery (1) or survey (0) in ngears
#1 1 0 0
0.0446192 0.3503630 0.6050178 0.0000000 0.0000000 #Based on last 30 years of catch.
## -----
## Age-schedule and population parameters
#natural mortality rate (m)
0.334
#growth parameters (linf,k,to) (from fishbase)
27.0, 0.48, 0
#length-weight allometry (a,b)
4.5e-6, 3.1270
#maturity at age (am=log(3)/k) & gm=std for logistic
2.055, 0.05
## -----
#Time series data
#Observed catch (1951-2010, 1000s metric t)
#Year P1 P2 P3 S1 S2
1951 45.865 0.000 0.000 0 0
1952 52.379 0.000 0.000 0 0
1953 1.865 0.000 0.000 0 0
1954 27.277 0.000 0.000 0 0
1955 17.803 0.000 0.000 0 0
1956 10.182 0.000 0.000 0 0
1957 28.035 0.000 0.000 0 0
1958 4.523 0.000 0.000 0 0
1959 10.224 0.000 0.000 0 0
1960 18.476 0.000 0.000 0 0
1961 42.746 0.000 0.000 0 0
1962 27.660 0.000 0.000 0 0
1963 40.228 0.000 0.000 0 0
1964 29.930 0.000 0.000 0 0
1965 44.211 0.000 0.000 0 0
1966 17.295 0.000 0.000 0 0
1967 7.998 0.000 0.000 0 0
1968 2.068 0.000 0.000 0 0
1969 0.000 0.000 0.000 0 0
1970 1.330 0.000 0.000 0 0
1971 3.500 0.000 0.000 0 0
1972 0.877 3.613 0.004 0 0
1973 0.218 1.388 0.000 0 0
1974 0.182 2.122 1.515 0 0
1975 0.155 1.536 0.011 0 0
1976 0.564 3.466 0.276 0 0
1977 0.792 5.858 1.494 0 0
1978 3.588 1.974 3.031 0 0
1979 1.810 1.271 1.236 0 0
1980 0.738 1.641 1.046 0 0
1981 1.682 1.051 0.356 0 0
1982 1.815 0.170 0.000 0 0
1983 0.000 0.000 0.000 0 0
1984 0.173 1.653 1.880 0 0
1985 0.253 3.018 3.476 0 0
1986 0.375 3.732 4.573 0 0
1987 0.122 2.077 4.071 0 0
1988 0.079 3.550 4.340 0 0
1989 0.071 3.657 4.745 0 0
1990 0.043 2.285 2.361 0 0
1991 0.000 1.366 2.143 0 0
1992 0.142 1.233 3.797 0 0
1993 0.000 2.208 4.112 0 0
1994 0.000 2.363 2.324 0 0
1995 0.000 0.706 1.355 0 0
1996 0.000 0.000 3.086 0 0
1997 0.000 0.000 5.541 0 0
1998 0.000 0.000 3.217 0 0
1999 0.000 0.266 1.859 0 0
2000 0.000 1.239 3.076 0 0
2001 0.000 1.012 1.906 0 0
2002 0.000 2.061 2.432 0 0
2003 0.000 1.451 2.562 0 0
2004 0.000 1.919 2.192 0 0
2005 0.000 1.750 2.050 0 0
2006 0.000 0.957 1.661 0 0
2007 0.000 0.000 0.969 0 0
2008 0.000 0.513 1.148 0 0
2009 0.000 0.713 1.286 0 0
2010 0.000 0.475 1.010 0 0
#Relative Abundance index from fisheries independent survey (it) 1970-2008
#nit
#60
2
#nit_nobs
37 23
#Survey type
## 1 = survey is proportional to vulnerable numbers
## 2 = survey is proportional to vulnerable biomass
## 3 = survey is proportional to spawning biomass (e.g., herring spawn survey)
3 3
#it gear wt survey timing
1951 27.149 4 1 1
1952 24.047 4 1 1
1953 28.468 4 1 1
1954 13.535 4 1 1
1955 14.482 4 1 1
1956 14.533 4 1 1
1957 27.518 4 1 1
1958 9.882 4 1 1
1959 40.961 4 1 1
1960 16.545 4 1 1
1961 12.059 4 1 1
1962 26.329 4 1 1
1963 16.981 4 1 1
1964 26.919 4 1 1
1965 6.055 4 1 1
1966 7.105 4 1 1
1967 3.386 4 1 1
1968 5.197 4 1 1
1969 0.965 4 1 1
1970 8.814 4 1 1
1971 8.480 4 1 1
1972 8.774 4 1 1
1973 10.959 4 1 1
1974 9.244 4 1 1
1975 10.949 4 1 1
1976 15.587 4 1 1
1977 11.589 4 1 1
1978 6.164 4 1 1
1979 9.195 4 1 1
1980 11.937 4 1 1
1981 14.087 4 1 1
1982 17.186 4 1 1
1983 25.247 4 1 1
1984 27.041 4 1 1
1985 41.028 4 1 1
1986 26.638 4 1 1
1987 39.905 4 1 1
1988 35.444 5 1.1666 1
1989 16.379 5 1.1666 1
1990 22.679 5 1.1666 1
1991 25.811 5 1.1666 1
1992 40.145 5 1.1666 1
1993 25.071 5 1.1666 1
1994 16.589 5 1.1666 1
1995 18.516 5 1.1666 1
1996 24.854 5 1.1666 1
1997 25.037 5 1.1666 1
1998 19.420 5 1.1666 1
1999 29.745 5 1.1666 1
2000 19.694 5 1.1666 1
2001 36.684 5 1.1666 1
2002 22.449 5 1.1666 1
2003 34.007 5 1.1666 1
2004 30.493 5 1.1666 1
2005 27.956 5 1.1666 1
2006 10.251 5 1.1666 1
2007 15.562 5 1.1666 1
2008 13.553 5 1.1666 1
2009 12.684 5 1.1666 1
2010 26.988 5 1.1666 1
#Age composition data by year, gear (ages 2-15+)
#na_gears
3
#na_nobs
25 40 33
#a_sage
2 2 2
#a_page
10 10 10
#yr gear V2 V3 V4 V5 V6 V7 V8 V9 V10 #Number aged.
1951 1 203 852 2739 486 263 124 12 2 1
1952 1 282 522 1994 2679 364 61 18 2 0
1953 1 17 541 327 361 158 14 1 0 0
1954 1 56 753 772 638 351 69 16 1 0
1955 1 31 55 795 177 59 12 2 0 0
1956 1 169 978 160 319 43 9 3 2 0
1957 1 401 610 1482 597 558 45 12 1 0
1958 1 339 256 64 82 13 17 0 0 0
1959 1 54 973 539 144 157 34 35 3 0
1960 1 1903 252 972 286 119 71 16 7 0
1961 1 400 2348 276 649 155 54 16 5 0
1962 1 30 153 190 38 58 17 3 5 1
1963 1 1326 434 550 673 100 89 13 2 0
1964 1 109 2174 339 371 300 23 20 4 1
1965 1 184 412 1603 336 350 312 58 14 4
1976 1 0 8 11 16 27 29 57 14 0
1978 1 11 80 265 188 191 145 64 22 12
1979 1 22 125 140 348 234 216 113 75 31
1980 1 13 708 76 90 90 62 48 23 9
1981 1 69 459 3366 586 603 562 266 145 68
1982 1 37 288 485 1005 246 161 124 52 16
1984 1 18 237 103 91 64 107 18 7 5
1985 1 92 48 110 165 69 24 23 5 0
1986 1 198 182 155 451 266 152 95 82 20
1988 1 1 53 159 46 43 42 17 16 4
1971 2 39 309 211 64 34 11 4 1 0
1972 2 0 38 128 460 42 27 17 1 1
1973 2 37 336 47 262 219 31 12 6 0
1974 2 1 113 336 47 104 28 2 1 0
1975 2 41 298 695 1362 355 306 78 20 4
1976 2 0 6 49 226 357 52 17 6 0
1977 2 3 327 125 406 564 240 72 20 6
1978 2 10 100 269 79 163 152 23 7 2
1979 2 27 181 113 290 104 166 53 14 3
1980 2 57 2507 239 164 129 104 45 17 5
1981 2 36 494 3840 170 79 68 20 10 6
1982 2 42 290 114 1024 44 21 6 3 0
1983 2 62 954 813 241 2253 171 52 27 9

```

```

1984 2 17 1138 436 314 448 721 31 9 4
1985 2 18 330 2288 528 268 439 329 8 4
1986 2 99 778 534 2616 611 298 401 313 3
1987 2 42 1904 490 327 1423 281 165 136 59
1988 2 19 1303 1638 251 351 485 82 61 10
1989 2 22 784 1307 1001 178 162 129 23 8
1990 2 33 920 1143 1431 1040 203 168 109 13
1991 2 39 1979 391 519 649 391 68 36 39
1992 2 16 1699 1587 251 228 287 146 26 17
1993 2 5 432 1783 1216 162 177 175 63 4
1994 2 44 325 885 3248 1487 276 248 96 31
1995 2 140 673 297 495 1898 692 107 56 25
1996 2 29 1763 241 76 115 316 140 10 5
1997 2 35 615 1447 216 68 133 128 50 5
1998 2 4 702 465 768 94 30 23 27 2
1999 2 17 95 706 350 425 76 18 15 13
2000 2 77 1111 381 1132 496 646 89 20 10
2001 2 79 1430 875 235 702 315 260 39 4
2002 2 240 867 1553 871 187 442 167 82 10
2003 2 16 2387 538 605 313 92 131 47 20
2004 2 23 50 2700 273 238 98 19 28 2
2005 2 21 856 268 1297 279 166 59 13 10
2006 2 29 327 887 176 460 78 32 9 2
2007 2 27 355 161 78 22 72 9 7 1
2008 2 69 578 2062 448 310 65 138 29 9
2009 2 11 847 703 1723 286 197 45 59 2
2010 2 41 1095 888 377 676 108 54 10 12
1974 3 0 1 41 22 36 3 1 0 0
1977 3 0 3 6 56 152 41 19 4 0
1978 3 0 0 31 9 49 50 10 2 0
1979 3 0 0 24 120 54 66 22 5 0
1980 3 0 13 20 92 52 51 22 9 1
1981 3 0 1 105 44 62 39 12 5 0
1984 3 0 5 10 65 108 290 17 6 4
1985 3 0 2 90 82 87 120 164 2 3
1986 3 0 5 54 713 249 115 101 80 1
1987 3 0 10 55 125 1041 293 163 108 60
1988 3 0 3 46 51 153 318 83 36 13
1989 3 0 0 22 145 65 112 104 16 11
1990 3 0 0 34 116 231 56 63 33 8
1991 3 0 0 39 171 288 287 61 40 28
1992 3 0 3 123 85 219 236 183 37 31
1993 3 0 0 62 302 71 138 99 61 7
1994 3 0 0 24 160 434 110 101 54 15
1995 3 0 1 10 144 295 334 35 16 10
1996 3 0 4 21 29 132 167 135 16 6
1997 3 0 1 123 73 88 128 130 70 15
1998 3 0 7 33 466 222 107 122 76 40
1999 3 0 0 78 119 357 97 33 14 21
2000 3 0 1 17 187 166 342 76 9 10
2001 3 0 3 58 97 337 215 266 55 9
2002 3 0 1 87 243 117 285 161 145 16
2003 3 0 3 40 323 226 92 107 46 32
2004 3 0 1 244 151 412 172 55 53 17
2005 3 0 0 6 350 136 195 44 10 7
2006 3 0 0 17 58 332 90 72 8 0
2007 3 1 11 40 208 108 630 150 65 14
2008 3 0 1 126 102 224 108 519 77 36
2009 3 0 1 20 406 187 144 53 92 9
2010 3 0 0 19 72 492 145 78 31 26
##n_wt_obs
60
#Mean weight-at-age in kilograms (interpolated: from HCAM.rep)
##$yr V1 V2 V3 V4 V5 V6 V7 V8 V9
1951 0.0383 0.0737 0.0940 0.1128 0.1229 0.1316 0.1420 0.1380 0.1320
1952 0.0467 0.0838 0.1158 0.1308 0.1498 0.1657 0.1672 0.2215 0.1700
1953 0.0388 0.0803 0.1108 0.1307 0.1433 0.1572 0.1698 0.1871 0.1700
1954 0.0405 0.0724 0.1057 0.1308 0.1453 0.1617 0.1826 0.1930 0.1700
1955 0.0458 0.0808 0.1013 0.1215 0.1429 0.1593 0.1540 0.1871 0.1700
1956 0.0373 0.0764 0.0944 0.1136 0.1405 0.1518 0.1700 0.1990 0.1700
1957 0.0287 0.0752 0.1041 0.1225 0.1368 0.1654 0.1887 0.2000 0.1700
1958 0.0346 0.0758 0.1216 0.1414 0.1398 0.1679 0.1698 0.1871 0.1700
1959 0.0436 0.0857 0.1022 0.1205 0.1494 0.1547 0.1659 0.1480 0.1700
1960 0.0386 0.0674 0.1038 0.1211 0.1398 0.1545 0.1689 0.1700 0.1700
1961 0.0395 0.0740 0.1074 0.1306 0.1443 0.1594 0.1554 0.1930 0.1700
1962 0.0439 0.0791 0.1086 0.1388 0.1641 0.1797 0.1807 0.2020 0.1700
1963 0.0393 0.0662 0.1042 0.1281 0.1545 0.1664 0.1902 0.2250 0.1700
1964 0.0442 0.0724 0.0932 0.1224 0.1333 0.1890 0.1520 0.1560 0.1480
1965 0.0527 0.0983 0.1143 0.1400 0.1568 0.1637 0.1797 0.2001 0.2300
1966 0.0408 0.0774 0.1058 0.1270 0.1442 0.1599 0.1698 0.1871 0.1700
1967 0.0408 0.0774 0.1058 0.1270 0.1442 0.1599 0.1698 0.1871 0.1700
1968 0.0408 0.0774 0.1054 0.1270 0.1442 0.1599 0.1698 0.1871 0.1700
1970 0.0485 0.0831 0.1134 0.1382 0.1571 0.1734 0.1836 0.1913 0.2042
1971 0.0362 0.0688 0.1104 0.1517 0.1445 0.1766 0.1720 0.1020 0.2042
1972 0.0485 0.1004 0.1370 0.1628 0.1991 0.2247 0.2331 0.2490 0.2590
1973 0.0328 0.0826 0.1172 0.1641 0.1791 0.1976 0.2103 0.2158 0.2042
1974 0.0670 0.0863 0.1212 0.1655 0.1845 0.1947 0.2040 0.1750 0.2042
1975 0.0280 0.0658 0.1138 0.1375 0.1648 0.1673 0.1827 0.1786 0.2063
1976 0.0485 0.0887 0.1325 0.1583 0.1734 0.2029 0.2106 0.2270 0.2042
1977 0.0540 0.0862 0.1178 0.1510 0.1688 0.1838 0.1955 0.1956 0.2242
1978 0.0554 0.0984 0.1249 0.1491 0.1701 0.1856 0.2022 0.2323 0.2304
1979 0.0566 0.0966 0.1289 0.1483 0.1661 0.1844 0.1911 0.2136 0.2129
1980 0.0609 0.0807 0.1165 0.1471 0.1697 0.1792 0.1879 0.2094 0.2241
1981 0.0452 0.0811 0.0999 0.1306 0.1551 0.1692 0.1827 0.2014 0.2028
1982 0.0421 0.0775 0.1084 0.1162 0.1483 0.1703 0.1778 0.1833 0.1978
1983 0.0558 0.0795 0.1042 0.1222 0.1349 0.1536 0.1697 0.1914 0.1961
1984 0.0457 0.0752 0.0897 0.1112 0.1237 0.1351 0.1568 0.1769 0.1870
1985 0.0356 0.0787 0.0975 0.1095 0.1219 0.1336 0.1490 0.1766 0.1590
1986 0.0555 0.0919 0.1185 0.1369 0.1472 0.1578 0.1685 0.1795 0.1963
1987 0.0549 0.0835 0.1070 0.1283 0.1418 0.1526 0.1596 0.1719 0.1746
1988 0.0507 0.0742 0.0967 0.1165 0.1385 0.1514 0.1519 0.1642 0.1887
1989 0.0565 0.0751 0.0965 0.1156 0.1368 0.1471 0.1658 0.1596 0.1906
1990 0.0504 0.0890 0.1078 0.1222 0.1376 0.1524 0.1658 0.1763 0.1850
1991 0.0548 0.0763 0.1058 0.1205 0.1298 0.1413 0.1483 0.1601 0.1711
1992 0.0470 0.0764 0.0933 0.1201 0.1334 0.1405 0.1486 0.1671 0.1732
1993 0.0538 0.0767 0.0964 0.1093 0.1264 0.1367 0.1417 0.1514 0.1543
1994 0.0425 0.0717 0.0935 0.1061 0.1160 0.1340 0.1375 0.1413 0.1594

1995 0.0480 0.0741 0.0920 0.1123 0.1207 0.1309 0.1487 0.1577 0.1589
1996 0.0524 0.0723 0.0947 0.1111 0.1290 0.1343 0.1429 0.1485 0.1608
1997 0.0565 0.0677 0.0839 0.1038 0.1190 0.1308 0.1377 0.1454 0.1496
1998 0.0448 0.0679 0.0799 0.0926 0.1018 0.1208 0.1303 0.1462 0.1505
1999 0.0579 0.0791 0.0956 0.1044 0.1155 0.1181 0.1363 0.1390 0.1443
2000 0.0465 0.0691 0.0852 0.1042 0.1099 0.1185 0.1303 0.1308 0.1416
2001 0.0424 0.0674 0.0917 0.1051 0.1245 0.1264 0.1368 0.1376 0.1513
2002 0.0466 0.0660 0.0847 0.1047 0.1176 0.1287 0.1334 0.1476 0.1532
2003 0.0505 0.0701 0.0853 0.1096 0.1262 0.1400 0.1457 0.1521 0.1588
2004 0.0500 0.0641 0.0865 0.1003 0.1148 0.1312 0.1432 0.1524 0.1340
2005 0.0382 0.0641 0.0709 0.1001 0.1059 0.1194 0.1376 0.1392 0.1470
2006 0.0479 0.0631 0.0796 0.0908 0.1097 0.1213 0.1309 0.1434 0.1205
2007 0.0399 0.0581 0.0702 0.0902 0.1069 0.1103 0.1196 0.1274 0.1440
2008 0.0442 0.0582 0.0816 0.0947 0.1078 0.1175 0.1316 0.1323 0.1516
2009 0.0322 0.0725 0.0823 0.1017 0.1134 0.1198 0.1292 0.1374 0.1540
2010 0.0449 0.0661 0.0869 0.0985 0.1121 0.1180 0.1266 0.1368 0.1464
##eofc
999

## -----
## SOG HERRING CONTROLS
## -----
## Prior descriptions:
## -0 uniform (0,0)
## -1 normal (p1=mu,p2=sig)
## -2 lognormal (p1=log(mu),p2=sig)
## -3 beta (p1=alpha,p2=beta)
## -4 gamma(p1=alpha,p2=beta)
## -----
## npar
## ival lb ub phz prior p1 p2 parameter name
## 7
## 1 7.60 -5.0 15 4 0 -5.0 15 #log_ro
## 2 0.67 0.2 1.0 4 3 10.0 4.925373 #steepness
## 3 -0.7985077 -5.0 5.0 3 1 -0.7985077 0.4 #log_m
## 4 7.40 -5.0 15 1 0 -5.0 15 #log_avgrec
## 5 7.20 -5.0 15 1 0 -5.0 15 #log_recinit
## 6 0.3043478 0.001 0.999 -3 3 15.0 60.0 #rho
## 7 0.8695652 0.01 5.0 -3 4 156.25 125.0 #kappa (precision)
## -----
## SELECTIVITY PARAMETERS
## -----
## OPTIONS FOR SELECTIVITY:
## 1) logistic selectivity parameters
## 2) selectivity coefficients
## 3) a constant cubic spline with age-nodes
## 4) a time varying cubic spline with age-nodes
## 5) time varying cubic bicubic spline with age & year nodes.
## 6) fixed logistic (set isel_type=6, and estimation phase to -1)
## 7) logistic function of body weight.
## sign=0.10 0.15 0.20 0.30 0.40 0.50
## wt=200. 50.0 22.2 12.5 5.56 3.12 2.00
## Gear 1:3 fishery: Gear 4-5 survey
## isel_type
## 1 1 7 6 6
## Age at 50% selectivity (logistic)
## 2 0.30 0.6 2.055 2.055
## STD at 50% selectivity (logistic)
## 0.25 0.25 0.15 0.05 0.05
## No. of age nodes for each gear (0 to ignore).
## 5 5 0 0
## No. of year nodes for each gear (0 to ignore).
## 12 3 10 0 0
## Estimation phase
## 2 2 2 -1 -1
## Penalty weight for 2nd differences w1/(2*sig^2)
## 125. 125. 12.5 12.5 12.5
## Penalty weight for dome-shaped selectivity 1/(2*sig^2)
## 50.0 50.0 200.0 200.0 200.0
## -----
## Priors for Survey q
## -----
## nits number of surveys
## 2
## priors 0=uniform density 1=normal density
## 0 1
## prior log(mean)
## 0 -0.662
## prior sd
## 1.0 0.226
## -----
## OTHER MISCELLANEOUS CONTROLS
## 0 ## 1 verbose ADMB output (0=off, 1=on)
## 1 ## 2 recruitment model (1=beverton-holt, 2=ricker)
## 0.100 ## 3 std in observed catches in first phase.
## 0.0707 ## 4 std in observed catches in last phase.
## 0 ## 5 Assume unfished in first year (0=FALSE, 1=TRUE)
## 0.02 ## 6 Minimum proportion to consider in age-proportions for dmvlogistic
## 0.20 ## 7 Mean fishing mortality for regularizing the estimates of Pt
## 0.01 ## 8 std in mean fishing mortality in first phase
## 2.00 ## 9 std in mean fishing mortality in last phase
## 3 ## 10 phase for estimating m_deviations (use -1 to turn off mdevs)
## 0.1 ## 11 std in deviations for natural mortality
## 12 ## 12 number of estimated nodes for deviations in natural mortality
## 1.00 ## 13 fraction of total mortality that takes place prior to spawning
## 1 ## 14 switch for age-composition likelihood (1=dmvlogistic, 2=dmultinom)
## -----
## eofc
999

```

B.3 Central Coast

```

#NB The data herein were taken from qci2010_final.dat for the HCAM model.
## -----
## Model Dimensions-----
1951 #first year of data
2010 #last year of data
2 #age of youngest age class
10 #age of plus group
5 #number of gears (ngear)
## flags for fishery (1) or survey (0) in ngears
#1 1 0 0
0.004190067 4.493316190 0.794911714 0.000000000 0.000000000
## -----
## age-schedule and population parameters
#natural mortality rate (m)
0.334
#growth parameters (linf,k,to) (from fishbase)
27.0, 0.48, 0
#length-weight allometry (a,b)
4.5e-6, 3.1270
#maturity at age (am=log(3)/k) & gm=std for logistic
2.055, 0.05
## -----
#Time series data
#Observed catch (1951-2010, 1000s metric t)
#Year P1 P2 P3 S1 S2
1951 42.458 0.000 0.000 0 0
1952 33.195 0.000 0.000 0 0
1953 0.768 0.000 0.000 0 0
1954 24.616 0.000 0.000 0 0
1955 11.594 0.000 0.000 0 0
1956 43.627 0.000 0.000 0 0
1957 23.261 0.000 0.000 0 0
1958 9.849 0.000 0.000 0 0
1959 27.870 0.000 0.000 0 0
1960 4.037 0.000 0.000 0 0
1961 31.704 0.000 0.000 0 0
1962 15.709 0.000 0.000 0 0
1963 44.054 0.000 0.000 0 0
1964 31.895 0.000 0.000 0 0
1965 15.670 0.000 0.000 0 0
1966 37.482 0.000 0.000 0 0
1967 21.890 0.000 0.000 0 0
1968 1.528 0.000 0.000 0 0
1969 0.009 0.000 0.000 0 0
1970 0.209 0.000 0.000 0 0
1971 3.614 0.000 0.000 0 0
1972 0.388 8.367 0.137 0 0
1973 0.035 6.653 1.112 0 0
1974 0.000 3.621 5.267 0 0
1975 0.000 3.343 5.395 0 0
1976 0.000 6.198 6.213 0 0
1977 0.322 3.881 6.904 0 0
1978 0.048 4.723 9.277 0 0
1979 0.000 0.005 0.000 0 0
1980 0.010 0.000 0.528 0 0
1981 0.000 0.269 2.304 0 0
1982 0.041 2.258 4.071 0 0
1983 0.000 2.061 3.579 0 0
1984 0.000 3.588 3.582 0 0
1985 0.000 2.915 2.294 0 0
1986 0.038 2.173 1.176 0 0
1987 0.000 2.695 0.920 0 0
1988 0.028 3.529 0.970 0 0
1989 0.000 6.531 2.911 0 0
1990 0.000 5.305 3.046 0 0
1991 0.000 7.097 1.806 0 0
1992 0.084 7.163 1.111 0 0
1993 0.000 8.478 2.038 0 0
1994 0.000 9.757 2.122 0 0
1995 0.000 8.131 1.451 0 0
1996 0.000 3.897 0.402 0 0
1997 0.000 3.276 0.344 0 0
1998 0.000 7.976 0.646 0 0
1999 0.000 6.013 1.511 0 0
2000 0.000 6.394 0.972 0 0
2001 0.000 5.613 0.517 0 0
2002 0.000 2.894 0.399 0 0
2003 0.000 2.299 0.289 0 0
2004 0.000 2.988 0.000 0 0
2005 0.000 3.778 0.000 0 0
2006 0.000 3.072 0.000 0 0
2007 0.000 0.398 0.000 0 0
2008 0.000 0.000 0.000 0 0
2009 0.000 0.000 0.000 0 0
2010 0.000 0.000 0.000 0 0
#Relative Abundance index from fisheries independent survey (it) 1970-2008
#nit
#60
2
#nit_nobs
37 23
#Survey type
## 1 = survey is proportional to vulnerable numbers
## 2 = survey is proportional to vulnerable biomass
## 3 = survey is proportional to spawning biomass (e.g., herring spawn survey)
3 3
#it gear wt survey timing
1951 15.390 4 1 1
1952 10.295 4 1 1
1953 18.237 4 1 1
1954 13.967 4 1 1
1955 13.564 4 1 1
1956 6.626 4 1 1
1957 4.607 4 1 1
1958 3.549 4 1 1
1959 3.904 4 1 1
1960 12.615 4 1 1
1961 4.265 4 1 1
1962 11.948 4 1 1
1963 6.485 4 1 1
1964 6.464 4 1 1
1965 2.097 4 1 1
1966 1.863 4 1 1
1967 5.434 4 1 1
1968 5.790 4 1 1
1969 1.837 4 1 1
1970 8.230 4 1 1
1971 4.156 4 1 1
1972 3.572 4 1 1
1973 12.434 4 1 1
1974 8.852 4 1 1
1975 8.037 4 1 1
1977 14.613 4 1 1
1978 7.747 4 1 1
1979 5.779 4 1 1
1980 13.012 4 1 1
1981 15.919 4 1 1
1982 16.333 4 1 1
1983 18.482 4 1 1
1984 14.185 4 1 1
1985 8.850 4 1 1
1986 20.342 4 1 1
1987 12.827 4 1 1
1988 26.916 5 1.1666 1
1989 21.561 5 1.1666 1
1990 28.980 5 1.1666 1
1991 19.183 5 1.1666 1
1992 43.274 5 1.1666 1
1993 32.392 5 1.1666 1
1994 29.432 5 1.1666 1
1995 22.348 5 1.1666 1
1996 21.646 5 1.1666 1
1997 28.255 5 1.1666 1
1998 31.503 5 1.1666 1
1999 31.813 5 1.1666 1
2000 32.652 5 1.1666 1
2001 25.109 5 1.1666 1
2002 23.147 5 1.1666 1
2003 25.679 5 1.1666 1
2004 29.407 5 1.1666 1
2005 24.158 5 1.1666 1
2006 12.051 5 1.1666 1
2007 9.857 5 1.1666 1
2008 3.971 5 1.1666 1
2009 10.183 5 1.1666 1
2010 8.075 5 1.1666 1
#Age composition data by year, gear (ages 2-15+)
#na_gears
3
#na_nobs
16 38 30
#_sage
2 2 2
#_page
10 10 10
#yr gear V2 V3 V4 V5 V6 V7 V8 V9 V10 #Number aged.
1951 1 129 1518 2693 638 269 66 3 0 0
1952 1 267 1035 1551 1966 232 79 23 2 0
1953 1 274 822 779 297 39 13 0 0
1954 1 126 2198 640 147 41 5 0 2 0
1955 1 156 181 1749 213 36 9 0 0 0
1956 1 852 683 458 2862 145 17 2 0 1
1957 1 758 2357 501 284 688 33 1 0 0
1958 1 880 2272 439 45 20 17 0 0 0
1959 1 189 2430 1831 401 40 22 21 1 0
1960 1 545 309 364 77 16 1 1 0 0
1961 1 450 902 301 826 276 22 3 1 0
1962 1 43 303 117 16 64 13 1 0 0
1963 1 4 324 604 58 30 30 2 0 0
1964 1 164 549 320 118 17 1 0 0 0
1965 1 143 637 591 277 95 6 1 0 0
1971 1 137 377 351 36 40 9 1 1 0
1972 2 75 530 494 448 120 76 19 1 0
1973 2 15 615 228 198 150 26 6 2 0
1974 2 44 278 602 287 187 100 14 3 0
1975 2 103 2932 2269 2477 764 283 60 6 2
1976 2 163 637 2234 1132 912 246 80 13 1
1977 2 18 492 587 818 408 221 51 10 1
1978 2 3 356 212 278 322 151 49 15 5
1980 2 186 2303 214 266 121 76 21 13 1
1981 2 197 751 3325 408 314 145 35 19 6
1982 2 59 543 376 2112 182 160 51 17 0
1983 2 29 381 840 582 3109 274 169 40 11
1984 2 274 460 637 1143 1016 2563 142 52 6
1985 2 149 2052 410 457 698 638 987 24 7
1986 2 240 972 2378 516 384 404 367 697 25
1987 2 256 1169 744 1626 289 230 294 235 275
1988 2 59 3528 606 326 370 87 76 78 44
1989 2 72 266 4300 517 202 158 42 45 36
1990 2 66 383 346 4973 511 256 202 51 28
1991 2 144 1337 480 440 3947 453 166 105 23
1992 2 146 4241 828 199 250 1362 155 44 34
1993 2 252 586 5608 848 177 225 916 98 28
1994 2 85 1538 620 3888 549 148 199 257 22

```

```

1995 2 74 581 2250 894 4604 609 192 220 155
1996 2 667 1114 323 926 388 1696 325 83 43
1997 2 146 3892 1161 249 422 274 583 106 27
1998 2 34 2393 2793 553 155 202 198 192 41
1999 2 39 440 2141 1709 326 81 106 97 55
2000 2 16 865 490 1572 1186 263 53 41 26
2001 2 112 340 1194 517 1173 831 181 38 15
2002 2 269 1851 579 971 338 1124 475 78 13
2003 2 22 2144 1138 365 400 183 317 120 24
2004 2 37 225 2085 542 112 147 75 70 17
2005 2 42 2311 1037 2101 566 125 112 60 30
2006 2 53 702 3246 585 967 199 44 31 3
2007 2 32 700 444 739 190 185 37 10 1
2008 2 144 146 659 184 246 44 43 8 1
2009 2 60 2059 308 238 67 63 8 10 2
2010 2 41 387 1597 133 189 51 52 2 6
1973 3 0 4 28 43 21 2 1 0 0
1974 3 0 2 106 184 116 58 8 0 0
1975 3 0 16 99 171 59 21 9 0 0
1976 3 0 10 230 364 431 144 37 5 1
1977 3 0 5 59 161 143 61 18 6 0
1978 3 0 7 74 277 345 149 30 3 1
1980 3 0 6 1 39 24 21 13 7 0
1981 3 4 22 722 194 213 155 74 27 7
1982 3 0 31 75 944 84 71 28 8 1
1983 3 0 9 124 224 1177 87 67 11 4
1984 3 0 3 34 141 190 655 51 12 6
1985 3 0 43 84 137 303 349 558 18 13
1986 3 0 18 248 126 101 166 134 219 6
1987 3 0 8 76 440 115 77 97 80 84
1988 3 0 23 56 80 144 72 37 51 46
1989 3 0 2 180 159 107 91 33 23 16
1990 3 0 8 529 133 50 62 9 12
1991 3 0 3 13 34 377 51 38 19 5
1992 3 0 66 87 61 101 659 98 35 10
1993 3 0 2 342 112 44 45 211 17 8
1994 3 0 30 94 1287 237 69 83 135 12
1995 3 0 3 112 101 823 135 23 29 37
1996 3 0 2 8 102 65 306 59 12 7
1997 3 0 7 15 32 117 99 197 37 7
1998 3 0 5 149 142 90 183 164 217 62
1999 3 0 1 123 382 151 51 44 46 35
2000 3 0 3 14 277 285 71 11 6 14
2001 3 0 0 39 46 422 225 57 9 0
2002 3 0 3 30 105 38 237 83 7 1
2003 3 0 4 33 103 238 104 306 114 20
#n_wt_obs
60
#Mean weight-at-age in kilograms (interpolated: from HCAM.rep)
#>$yr V1 V2 V3 V4 V5 V6 V7 V8 V9
1951 0.0480 0.0842 0.1138 0.1371 0.1465 0.1559 0.1610 0.1352 0.1800
1952 0.0468 0.0869 0.1121 0.1311 0.1476 0.1578 0.1630 0.1730 0.1800
1953 0.0358 0.0833 0.1078 0.1273 0.1474 0.1616 0.1699 0.1352 0.1800
1954 0.0260 0.0626 0.0937 0.1167 0.1378 0.1330 0.1545 0.1310 0.1800
1955 0.0380 0.0725 0.0966 0.1204 0.1429 0.1347 0.1545 0.1352 0.1800
1956 0.0400 0.0834 0.1107 0.1269 0.1436 0.1581 0.1220 0.1352 0.1800
1957 0.0400 0.0821 0.1082 0.1222 0.1322 0.1487 0.1730 0.1352 0.1800
1958 0.0374 0.0725 0.0958 0.1157 0.1280 0.1465 0.1545 0.1352 0.1800
1959 0.0391 0.0774 0.0938 0.1098 0.1068 0.1316 0.1345 0.1270 0.1800
1960 0.0447 0.0639 0.0810 0.1034 0.1078 0.1470 0.1240 0.1352 0.1800
1961 0.0379 0.0771 0.0985 0.1206 0.1241 0.1317 0.1223 0.1100 0.1800
1962 0.0470 0.0808 0.1074 0.1314 0.1436 0.1554 0.1220 0.1352 0.1800
1963 0.0598 0.0825 0.1035 0.1236 0.1425 0.1543 0.1655 0.1352 0.1800
1964 0.0457 0.0858 0.1081 0.1271 0.1282 0.1540 0.1545 0.1352 0.1800
1965 0.0526 0.1037 0.1271 0.1474 0.1675 0.1757 0.2420 0.1352 0.1800
1966 0.0426 0.0799 0.1038 0.1240 0.1365 0.1497 0.1545 0.1352 0.1800
1967 0.0426 0.0799 0.1039 0.1240 0.1365 0.1497 0.1545 0.1352 0.1800
1968 0.0426 0.0799 0.1039 0.1240 0.1365 0.1497 0.1545 0.1352 0.1800
1969 0.0426 0.0799 0.1039 0.1240 0.1365 0.1497 0.1545 0.1352 0.1800
1970 0.0559 0.0897 0.1165 0.1386 0.1573 0.1713 0.1850 0.1978 0.2077
1971 0.0502 0.0934 0.1275 0.1576 0.1712 0.1819 0.1760 0.1780 0.2077
1972 0.0609 0.0945 0.1172 0.1418 0.1570 0.1654 0.1973 0.1930 0.2077
1973 0.0594 0.0986 0.1312 0.1560 0.1730 0.1834 0.1972 0.2340 0.2077
1974 0.0492 0.0869 0.1209 0.1416 0.1658 0.1788 0.1974 0.2167 0.2077
1975 0.0448 0.0836 0.1187 0.1444 0.1662 0.1862 0.1988 0.2037 0.2205
1976 0.0445 0.0814 0.1081 0.1356 0.1553 0.1754 0.1913 0.2004 0.2100
1977 0.0598 0.0891 0.1164 0.1382 0.1660 0.1839 0.1987 0.2219 0.2250
1978 0.0490 0.0856 0.1142 0.1338 0.1612 0.1864 0.2160 0.2269 0.2442
1979 0.0832 0.1065 0.1281 0.1534 0.1755 0.1913 0.2116 0.2350 0.2077
1980 0.0501 0.0818 0.0998 0.1244 0.1440 0.1614 0.1688 0.1981 0.2120
1981 0.0452 0.0749 0.0990 0.1156 0.1388 0.1500 0.1755 0.1747 0.2040
1982 0.0521 0.0880 0.1094 0.1300 0.1392 0.1519 0.1683 0.1824 0.2077
1983 0.0614 0.0907 0.1107 0.1292 0.1424 0.1493 0.1567 0.1727 0.1855
1984 0.0590 0.0900 0.1082 0.1223 0.1352 0.1419 0.1556 0.1761 0.1782
1985 0.0620 0.0951 0.1234 0.1399 0.1502 0.1653 0.1734 0.1753 0.2029
1986 0.0623 0.0989 0.1268 0.1422 0.1551 0.1667 0.1734 0.1802 0.1992
1987 0.0594 0.0918 0.1221 0.1491 0.1683 0.1790 0.1848 0.1957 0.2077
1988 0.0541 0.0842 0.1143 0.1390 0.1711 0.1844 0.1889 0.1957 0.2031
1989 0.0563 0.0830 0.1032 0.1301 0.1465 0.1728 0.1797 0.1804 0.1936
1990 0.0572 0.0843 0.1065 0.1262 0.1476 0.1685 0.1787 0.1877 0.1916
1991 0.0577 0.0846 0.1062 0.1288 0.1447 0.1650 0.1784 0.1868 0.1992
1992 0.0500 0.0860 0.1055 0.1236 0.1362 0.1511 0.1683 0.1874 0.1932
1993 0.0517 0.0858 0.1052 0.1201 0.1330 0.1404 0.1538 0.1674 0.1716
1994 0.0474 0.0831 0.1068 0.1225 0.1339 0.1481 0.1588 0.1630 0.1750
1995 0.0474 0.0796 0.1057 0.1233 0.1348 0.1438 0.1522 0.1561 0.1624
1996 0.0607 0.0781 0.1028 0.1258 0.1397 0.1476 0.1582 0.1655 0.1617
1997 0.0458 0.0761 0.0888 0.1054 0.1320 0.1432 0.1493 0.1596 0.1607
1998 0.0415 0.0716 0.0874 0.1006 0.1173 0.1404 0.1462 0.1540 0.1629
1999 0.0538 0.0681 0.0902 0.1054 0.1138 0.1292 0.1478 0.1545 0.1582
2000 0.0514 0.0771 0.0881 0.1127 0.1268 0.1377 0.1450 0.1660 0.1756
2001 0.0445 0.0734 0.0974 0.1061 0.1255 0.1358 0.1468 0.1569 0.1631

2002 0.0512 0.0670 0.0878 0.1084 0.1187 0.1295 0.1366 0.1414 0.1507
2003 0.0478 0.0773 0.0885 0.1111 0.1264 0.1371 0.1433 0.1508 0.1629
2004 0.0481 0.0694 0.0912 0.0961 0.1125 0.1248 0.1362 0.1461 0.1461
2005 0.0378 0.0675 0.0752 0.1061 0.1091 0.1258 0.1360 0.1404 0.1521
2006 0.0388 0.0605 0.0786 0.0916 0.1106 0.1147 0.1281 0.1347 0.1447
2007 0.0410 0.0651 0.0750 0.0956 0.1025 0.1184 0.1202 0.1397 0.1430
2008 0.0430 0.0606 0.0757 0.0873 0.1034 0.1153 0.1260 0.1344 0.1670
2009 0.0405 0.0664 0.0727 0.0921 0.1035 0.1219 0.1346 0.1315 0.1350
2010 0.0481 0.0667 0.0841 0.0928 0.1046 0.1034 0.1228 0.1540 0.1320
##eofc
999
## -----
SOC HERRING CONTROLS
CONTROLS FOR ESTIMATED PARAMETERS
## Prior descriptions:
## -0 uniform (0,0)
## -1 normal (p1=mu,p2=sig)
## -2 lognormal (p1=log(mu),p2=sig)
## -3 beta (p1=alpha,p2=beta)
## -4 gamma(p1=alpha,p2=beta)
## -----
7 ## npar
## ival lb ub phz prior p1 p2 parameter name
## -----
7.60 -5.0 15 4 0 -5.0 15 #log_ro
0.67 0.2 1.0 4 3 10.0 4.925373 #steepness
-0.7985077 -5.0 5.0 3 1 -0.7985077 0.4 #log_m
7.40 -5.0 15 1 0 -5.0 15 #log_avgrec
7.20 -5.0 15 1 0 -5.0 15 #log_recinit
0.3043478 0.001 0.999 -3 3 15.0 60.0 #rho
0.8695662 0.01 5.0 -3 4 156.25 125.0 #kappa (precision)
## -----
## -----
SELECTIVITY PARAMETERS
## OPTIONS FOR SELECTIVITY:
## 1) logistic selectivity parameters
## 2) selectivity coefficients
## 3) a constant cubic spline with age-nodes
## 4) a time varying cubic spline with age-nodes
## 5) a time varying bicubic spline with age & year nodes.
## 6) fixed logistic (set isel_type=6, and estimation phase to -1)
## 7) logistic function of body weight.
## sig=0.05 0.10 0.15 0.20 0.30 0.40 0.50
## wt =200. 50.0 22.2 12.5 5.5 3.12 2.00
## Gear 1:3 fishery: Gear 4-5 survey
## isel_type
1 1 7 6 6
## Age at 50% selectivity (logistic)
2.0 3.0 0.6 2.055 2.055
## STD at 50% selectivity (logistic)
0.25 0.25 0.15 0.05 0.05
## No. of age nodes for each gear (0 to ignore).
5 5 5 0 0
## No. of year nodes for each gear (0 to ignore).
12 3 10 0 0
## Estimation phase
2 2 -1 -1
## Penalty weight for 2nd differences w=1/(2*sig^2)
125. 125. 12.5 12.5 12.5
## Penalty weight for dome-shaped selectivity 1=1/(2*sig^2)
50.0 50.0 200.0 200.0 200.0
## -----
## Priors for Survey q
## -----
## nits #number of surveys
2
## priors 0=uniform density 1=normal density
0 1
## prior log(mean)
0 -0.662
## prior sd
1.0 0.226
## -----
## OTHER MISCELLANEOUS CONTROLS
0 ## 1 verbose ADMB output (0=off, 1=on)
1 ## 2 recruitment model (1=beverton-holt, 2=ricker)
0.100 ## 3 std in observed catches in first phase.
0.0707 ## 4 std in observed catches in last phase.
0 ## 5 Assume unfished in first year (0=FALSE, 1=TRUE)
0.02 ## 6 Minimum proportion to consider in age-proportions for dmlogistic
0.20 ## 7 Mean fishing mortality for regularizing the estimates of Ft
0.01 ## 8 std in mean fishing mortality in first phase
2.00 ## 9 std in mean fishing mortality in last phase
3 ## 10 phase for estimating m_deviations (use -1 to turn off mdevs)
0.1 ## 11 std in deviations for natural mortality
12 ## 12 number of estimated nodes for deviations in natural mortality
1.00 ## 13 fraction of total mortality that takes place prior to spawning
1 ## 14 switch for age-composition likelihood (1=dmvlogistic, 2=dmultinom)
## -----
## eofc
999

```

B.4 Strait of Georgia

```

#NB The data herein were taken from sog2010_final.dat for the HCAM model.
## -----
## Model Dimensions
1951 #first year of data
2010 #last year of data
2 #age of youngest age class
10 #age of plus group
5 #number of gears (ngear)
## flags for fishery (1) or survey (0) in ngears
#1 1 0 0
0.0686819 0.4137555 0.5175626 0.0000000 0.0000000
## -----
## -----
## -----
## age-schedule and population parameters
#natural mortality rate (m)
0.334
#growth parameters (linf,k,to) (from fishbase)
27.0, 0.48, 0
#length-weight allometry (a,b)
4.5e-6, 3.1270
#maturity at age (am=log(3)/k) & gm=std for logistic
2.055, 0.05
## -----
## Time series data
#Observed catch (1951-2010, 1000s metric t)
#yr p1 p2 p3 survey
1951 43.798 0.000 0.000 0 0
1952 45.849 0.000 0.000 0 0
1953 8.412 0.000 0.000 0 0
1954 65.767 0.000 0.000 0 0
1955 68.641 0.000 0.000 0 0
1956 72.062 0.000 0.000 0 0
1957 59.608 0.000 0.000 0 0
1958 20.628 0.000 0.000 0 0
1959 49.644 0.000 0.381 0 0
1960 68.037 0.000 0.000 0 0
1961 46.215 0.000 0.000 0 0
1962 65.303 0.000 0.000 0 0
1963 68.847 0.000 0.000 0 0
1964 76.881 0.000 0.000 0 0
1965 47.819 0.000 0.000 0 0
1966 33.333 0.000 0.000 0 0
1967 31.043 0.000 0.000 0 0
1968 1.891 0.000 0.000 0 0
1969 0.194 0.000 0.000 0 0
1970 0.221 0.000 0.022 0 0
1971 1.610 0.000 0.084 0 0
1972 2.434 5.921 0.456 0 0
1973 3.980 1.604 2.064 0 0
1974 0.479 0.425 3.095 0 0
1975 0.378 0.469 5.331 0 0
1976 5.061 0.202 6.975 0 0
1977 5.676 4.098 7.736 0 0
1978 12.963 3.723 7.316 0 0
1979 13.513 0.000 6.825 0 0
1980 2.470 0.169 3.180 0 0
1981 4.904 2.081 5.067 0 0
1982 3.937 3.312 5.583 0 0
1983 0.824 7.780 8.613 0 0
1984 0.087 4.126 6.039 0 0
1985 0.772 2.726 3.495 0 0
1986 0.432 0.162 0.000 0 0
1987 0.244 3.111 5.998 0 0
1988 0.756 1.471 5.968 0 0
1989 1.033 1.417 5.919 0 0
1990 0.233 0.000 7.886 0 0
1991 0.562 1.131 9.410 0 0
1992 0.939 3.610 8.870 0 0
1993 0.617 4.391 8.733 0 0
1994 0.942 5.134 11.572 0 0
1995 0.641 4.359 8.190 0 0
1996 0.541 7.338 6.233 0 0
1997 0.402 9.274 6.148 0 0
1998 0.954 5.755 6.895 0 0
1999 1.471 4.976 6.837 0 0
2000 1.156 6.455 7.593 0 0
2001 1.424 7.274 7.682 0 0
2002 1.328 9.299 7.986 0 0
2003 1.696 10.670 8.010 0 0
2004 1.356 7.019 5.226 0 0
2005 1.332 7.928 8.954 0 0
2006 1.371 9.308 7.277 0 0
2007 0.672 3.865 5.285 0 0
2008 1.139 2.752 6.046 0 0
2009 0.709 5.685 3.937 0 0
2010 0.595 4.540 3.244 0 0

##Relative Abundance index from fisheries independent survey (it) 1970-2008
#nit
#60
2
#nit_nobs
37 23
#survey type
## 1 = survey is proportional to vulnerable numbers
## 2 = survey is proportional to vulnerable biomass
## 3 = survey is proportional to spawning biomass (e.g., herring spawn survey)
3 3
#lyr it gear wt survey timing
1951 66.143 4 1 1

1952 72.376 4 1 1
1953 111.307 4 1 1
1954 82.141 4 1 1
1955 69.854 4 1 1
1956 25.667 4 1 1
1957 24.126 4 1 1
1958 16.911 4 1 1
1959 47.864 4 1 1
1960 55.709 4 1 1
1961 44.326 4 1 1
1962 35.574 4 1 1
1963 37.381 4 1 1
1964 35.954 4 1 1
1965 38.390 4 1 1
1966 7.211 4 1 1
1967 9.647 4 1 1
1968 9.442 4 1 1
1969 14.039 4 1 1
1970 34.163 4 1 1
1971 38.921 4 1 1
1972 25.139 4 1 1
1973 16.191 4 1 1
1974 40.571 4 1 1
1975 70.211 4 1 1
1976 60.642 4 1 1
1977 78.562 4 1 1
1978 102.115 4 1 1
1979 64.266 4 1 1
1980 85.991 4 1 1
1981 55.121 4 1 1
1982 100.987 4 1 1
1983 64.575 4 1 1
1984 26.227 4 1 1
1985 25.247 4 1 1
1986 41.575 4 1 1
1987 41.737 4 1 1
1988 24.976 5 1.1666 1
1989 66.052 5 1.1666 1
1990 67.152 5 1.1666 1
1991 45.830 5 1.1666 1
1992 82.714 5 1.1666 1
1993 90.198 5 1.1666 1
1994 67.144 5 1.1666 1
1995 64.899 5 1.1666 1
1996 71.326 5 1.1666 1
1997 58.232 5 1.1666 1
1998 74.616 5 1.1666 1
1999 85.095 5 1.1666 1
2000 72.688 5 1.1666 1
2001 100.248 5 1.1666 1
2002 117.864 5 1.1666 1
2003 141.651 5 1.1666 1
2004 114.352 5 1.1666 1
2005 95.643 5 1.1666 1
2006 46.752 5 1.1666 1
2007 35.865 5 1.1666 1
2008 32.103 5 1.1666 1
2009 49.909 5 1.1666 1
2010 47.480 5 1.1666 1

#Age composition data by year, gear (ages 2-15+)
#na_gears
3
#na_nobs
54 39 38
#a_sage
2 2 2
#a_page
10 10
#yr gear V2 V3 V4 V5 V6 V7 V8 V9 V10 #Number aged.
1951 1 326 4413 2371 556 110 27 8 2 0
1952 1 1008 4997 2262 608 119 24 6 1 0
1953 1 900 6177 3380 447 119 18 6 0 0
1954 1 200 6011 4845 1520 432 124 27 3 0
1955 1 233 2562 2065 355 57 6 0 0 0
1956 1 703 3798 3502 2801 627 103 28 6 3
1957 1 98 4344 1639 782 374 44 5 1 2
1958 1 561 3278 1171 278 244 177 25 4 0
1959 1 1533 5878 1460 223 48 21 11 2 0
1960 1 393 2049 1391 127 15 4 3 0 0
1961 1 1425 1395 1153 607 166 16 2 0 0
1962 1 270 2019 363 116 45 10 1 0 0
1963 1 364 1290 660 94 24 9 2 0 0
1964 1 191 2173 1157 110 26 4 3 0 0
1965 1 501 1703 775 73 22 3 1 0 0
1966 1 161 256 166 100 16 7 0 0 0
1971 1 175 568 516 101 40 13 1 0 0
1972 1 245 740 770 448 96 33 6 1 0
1973 1 58 520 253 176 48 10 4 1 0
1976 1 248 770 1463 788 225 112 37 17 2
1977 1 89 947 383 274 75 26 12 4 1
1978 1 110 919 958 236 165 62 9 8 3
1979 1 55 665 1545 1093 322 150 47 7 3
1980 1 84 1627 874 716 363 93 57 15 3
1981 1 340 2634 2479 1091 638 242 54 21 1
1982 1 223 1824 1378 625 201 131 36 2 4
1983 1 392 2093 1603 833 429 146 149 77 10
1984 1 639 1398 798 443 203 103 22 10 6
1985 1 749 1063 491 193 79 26 9 2 0
1986 1 230 832 245 60 18 4 1 0 0
1987 1 295 406 328 93 18 4 2 0 0
1988 1 77 1051 248 202 37 9 2 1 0
1989 1 331 219 532 85 73 10 2 0 0
1990 1 62 544 118 164 21 19 0 0 0

```

```

1991 1 101 223 265 51 50 7 1 0 0
1992 1 37 645 125 69 8 3 3 0 0
1993 1 252 302 316 67 26 3 6 1 0
1994 1 42 287 134 81 9 5 0 0 0
1995 1 222 311 409 123 54 8 2 0 1
1996 1 419 821 199 157 41 18 3 0 0
1997 1 52 201 50 10 3 1 2 1 0
1998 1 60 758 626 99 13 7 1 1 0
1999 1 151 361 564 176 36 5 2 0 0
2000 1 250 536 169 90 24 8 0 0 0
2001 1 77 414 223 44 28 10 0 1 0
2002 1 46 570 243 55 9 3 1 0 1
2003 1 12 189 181 36 9 1 0 0 0
2004 1 57 156 203 71 18 2 0 0 0
2005 1 22 72 36 28 9 2 0 0 0
2006 1 29 39 47 26 29 6 2 1 0
2007 1 39 17 3 1 2 0 0 0 0
2008 1 231 94 458 118 24 5 1 1 0
2009 1 4 172 49 5 3 0 0 0 0
2010 1 34 19 249 20 18 7 1 2 0
1972 2 564 2514 2354 1282 260 77 10 1 0
1973 2 51 1306 1510 1157 588 77 11 1 0
1974 2 144 533 155 37 13 1 0 0
1975 2 288 3117 1506 417 180 85 25 10 0
1976 2 183 505 1002 395 97 41 23 6 2
1977 2 100 1717 675 503 133 37 19 6 5
1978 2 30 1253 1545 423 277 53 11 1 2
1979 2 92 765 1121 898 270 126 38 15 5
1980 2 350 3800 1344 1341 694 174 93 22 7
1981 2 1230 4902 3605 1200 1002 398 87 31 6
1982 2 337 1852 1334 1124 254 273 125 29 2
1983 2 434 4122 3745 2285 1426 411 385 161 28
1984 2 604 2784 2099 936 522 244 82 35 10
1985 2 2024 3592 1519 628 268 104 46 5 1
1986 2 889 3799 1477 409 128 53 9 5 0
1987 2 781 2623 2945 1201 276 86 29 10 4
1988 2 301 3848 924 935 250 63 13 4 0
1989 2 651 1177 3491 610 460 104 20 2 1
1990 2 452 3337 652 1159 182 105 23 4 1
1991 2 542 1173 2123 476 775 116 75 10 1
1992 2 257 2762 691 843 176 260 30 16 0
1993 2 832 2096 1737 379 326 76 84 8 2
1994 2 279 2518 1594 1120 238 168 42 9 0
1995 2 580 1251 2048 1005 627 155 62 20 6
1996 2 1059 3984 1160 1192 481 280 57 19 6
1997 2 618 3806 1671 433 464 184 107 9 3
1998 2 383 4176 2784 1049 228 171 64 17 2
1999 2 268 1054 1716 792 274 75 28 7 2
2000 2 859 2759 1385 1591 627 149 21 15 1
2001 2 458 2981 1939 603 559 181 45 7 2
2002 2 490 3042 1535 673 140 116 22 4 0
2003 2 330 3994 3368 1099 322 81 35 9 0
2004 2 251 1353 1982 972 237 74 14 9 1
2005 2 353 1420 1468 1183 387 98 32 11 4
2006 2 968 1257 1134 754 448 103 33 8 1
2007 2 107 2951 1666 749 346 188 42 10 1
2008 2 160 582 3191 717 259 105 41 8 1
2009 2 20 3164 665 609 180 60 25 10 1
2010 2 583 228 3843 297 311 73 26 8 4
1972 3 46 118 468 286 68 15 2 1 0
1973 3 0 39 68 84 25 7 1 0 0
1974 3 0 45 390 283 158 39 9 0 0
1975 3 0 8 76 53 21 5 1 0 0
1976 3 0 5 322 342 89 22 5 1 0
1977 3 0 56 480 779 270 62 9 2 0
1978 3 0 2 110 165 195 59 8 2 0
1979 3 0 6 121 286 72 29 8 0 1
1980 3 0 4 26 117 90 23 2 1 0
1981 3 1 25 207 262 426 183 32 3 1
1982 3 0 27 94 180 89 123 69 5 2
1983 3 0 2 113 120 96 38 30 7 0
1984 3 0 54 229 234 144 71 12 5 7
1985 3 1 34 286 356 259 101 41 9 9
1987 3 0 48 684 642 317 163 50 11 5
1988 3 0 82 132 426 179 47 20 3 2
1989 3 0 13 331 181 213 64 18 3 0
1990 3 0 115 160 771 167 133 20 4 1
1991 3 0 14 306 187 436 79 51 13 1
1992 3 0 74 174 510 137 221 31 17 5
1993 3 0 104 363 154 196 37 49 2 2
1994 3 1 45 300 537 183 95 30 8 2
1995 3 0 21 243 341 242 52 22 4 2
1996 3 0 21 86 247 119 56 10 4 0
1997 3 0 30 113 104 202 108 54 16 6
1998 3 0 45 450 438 185 191 57 26 5
1999 3 0 18 245 307 176 56 28 5 1
2000 3 0 13 170 530 330 107 25 4 0
2001 3 0 31 190 263 345 154 34 7 2
2002 3 0 45 206 285 149 178 45 5 2
2003 3 0 30 283 439 305 137 83 28 3
2004 3 0 25 278 451 276 116 25 13 1
2005 3 0 5 91 352 207 80 28 9 1
2006 3 0 6 108 265 268 124 30 8 0
2007 3 0 140 384 760 744 512 134 36 6
2008 3 1 32 841 458 309 153 54 17 1
2009 3 0 42 63 466 166 99 29 11 1
2010 3 0 1 222 67 428 114 60 23 7

#n_wt_obs
60
##Mean weight-at-age in kilograms (interpolated: from HCAM.rep)
##$yr V1 V2 V3 V4 V5 V6 VT V8 V9
1951 0.0417 0.0897 0.1126 0.1376 0.1586 0.1706 0.2001 0.1865 0.1865
1952 0.0432 0.0896 0.1133 0.1385 0.1599 0.1756 0.1677 0.1780 0.1865
1953 0.0329 0.0763 0.0958 0.1255 0.1498 0.1599 0.1335 0.1784 0.1865
1954 0.0447 0.0847 0.1036 0.1278 0.1571 0.1721 0.1551 0.1860 0.1865
1955 0.0499 0.0893 0.1043 0.1262 0.1448 0.1738 0.1720 0.1784 0.1865

1956 0.0471 0.0845 0.1060 0.1205 0.1410 0.1587 0.1785 0.1733 0.1865
1957 0.0481 0.0822 0.1069 0.1371 0.1506 0.1640 0.2100 0.1784 0.1865
1958 0.0438 0.0763 0.1081 0.1421 0.1535 0.1647 0.1762 0.1885 0.1865
1959 0.0502 0.0838 0.0993 0.1314 0.1596 0.1677 0.1523 0.1588 0.1865
1960 0.0530 0.0902 0.1125 0.1279 0.1597 0.1299 0.1770 0.1784 0.1865
1961 0.0576 0.0786 0.1111 0.1170 0.1372 0.1650 0.1720 0.1784 0.1865
1962 0.0501 0.0880 0.0993 0.1366 0.1449 0.1530 0.2020 0.1784 0.1865
1963 0.0477 0.0832 0.1049 0.1116 0.1494 0.1778 0.1790 0.1784 0.1865
1964 0.0578 0.0993 0.1159 0.1378 0.1586 0.1850 0.1400 0.1784 0.1865
1965 0.0611 0.1051 0.1224 0.1451 0.1452 0.1770 0.1440 0.1784 0.1865
1966 0.0520 0.1067 0.1487 0.1681 0.1783 0.1888 0.1720 0.1784 0.1865
1967 0.0488 0.0881 0.1104 0.1332 0.1530 0.1677 0.1720 0.1784 0.1865
1968 0.0488 0.0881 0.1104 0.1332 0.1530 0.1677 0.1720 0.1784 0.1865
1969 0.0488 0.0880 0.1104 0.1332 0.1530 0.1677 0.1720 0.1784 0.1865
1970 0.0578 0.0888 0.1175 0.1399 0.1608 0.1733 0.1871 0.1927 0.2096
1971 0.0553 0.1056 0.1319 0.1537 0.1742 0.1895 0.1690 0.1927 0.2096
1972 0.0586 0.0897 0.1290 0.1478 0.1671 0.1778 0.1973 0.1850 0.2096
1973 0.0525 0.0993 0.1274 0.1584 0.1749 0.1928 0.1977 0.2010 0.2096
1974 0.0630 0.0877 0.1392 0.1651 0.2093 0.1733 0.2420 0.1927 0.2096
1975 0.0421 0.0828 0.1115 0.1423 0.1694 0.1934 0.1995 0.2122 0.2096
1976 0.0498 0.0849 0.1234 0.1455 0.1743 0.1914 0.2033 0.2248 0.2133
1977 0.0571 0.0888 0.1173 0.1398 0.1616 0.1910 0.2010 0.2027 0.2418
1978 0.0501 0.0853 0.1099 0.1321 0.1513 0.1672 0.1683 0.1999 0.2095
1979 0.0597 0.0848 0.1178 0.1405 0.1604 0.1754 0.1990 0.2051 0.2174
1980 0.0522 0.0780 0.1083 0.1352 0.1584 0.1718 0.1831 0.1984 0.2172
1981 0.0602 0.0857 0.1085 0.1344 0.1561 0.1708 0.1873 0.1802 0.2022
1982 0.0635 0.0947 0.1153 0.1292 0.1531 0.1618 0.1696 0.1680 0.1950
1983 0.0576 0.0894 0.1174 0.1349 0.1431 0.1580 0.1707 0.1851 0.1941
1984 0.0624 0.0881 0.1146 0.1388 0.1569 0.1590 0.1666 0.1762 0.2010
1985 0.0647 0.0867 0.1141 0.1345 0.1564 0.1703 0.1869 0.1926 0.2320
1986 0.0670 0.0895 0.1108 0.1324 0.1495 0.1700 0.1971 0.1954 0.2096
1987 0.0628 0.0874 0.1056 0.1226 0.1366 0.1522 0.1660 0.1550 0.1823
1988 0.0609 0.0900 0.1138 0.1309 0.1423 0.1547 0.1642 0.2006 0.2096
1989 0.0644 0.0841 0.1068 0.1280 0.1426 0.1390 0.1474 0.1561 0.1820
1990 0.0604 0.0851 0.1060 0.1283 0.1468 0.1572 0.1609 0.1453 0.2260
1991 0.0642 0.0894 0.1101 0.1284 0.1426 0.1553 0.1634 0.1508 0.1850
1992 0.0598 0.0905 0.1118 0.1319 0.1494 0.1592 0.1738 0.1739 0.1563
1993 0.0579 0.0922 0.1118 0.1286 0.1411 0.1529 0.1565 0.1600 0.1475
1994 0.0522 0.0809 0.1047 0.1207 0.1350 0.1405 0.1512 0.1609 0.1563
1995 0.0612 0.0856 0.1106 0.1314 0.1446 0.1617 0.1631 0.1791 0.1753
1996 0.0619 0.0826 0.1061 0.1264 0.1457 0.1557 0.1719 0.1694 0.1830
1997 0.0497 0.0826 0.1017 0.1197 0.1368 0.1463 0.1541 0.1670 0.1817
1998 0.0504 0.0724 0.0939 0.1081 0.1194 0.1333 0.1438 0.1558 0.1485
1999 0.0460 0.0795 0.0991 0.1134 0.1255 0.1341 0.1434 0.1508 0.1390
2000 0.0523 0.0724 0.0948 0.1110 0.1291 0.1387 0.1530 0.1599 0.1630
2001 0.0622 0.0853 0.0990 0.1197 0.1332 0.1483 0.1552 0.1454 0.1440
2002 0.0494 0.0793 0.0959 0.1076 0.1254 0.1324 0.1413 0.1640 0.0590
2003 0.0518 0.0772 0.0930 0.1054 0.1133 0.1282 0.1401 0.1280 0.1563
2004 0.0498 0.0724 0.0888 0.0994 0.1091 0.1122 0.1241 0.1219 0.1320
2005 0.0476 0.0741 0.0910 0.1061 0.1175 0.1257 0.1305 0.1215 0.1373
2006 0.0483 0.0714 0.0882 0.1023 0.1113 0.1208 0.1279 0.1394 0.1780
2007 0.0620 0.0753 0.0831 0.0994 0.1154 0.1230 0.1301 0.1432 0.1340
2008 0.0257 0.0658 0.0858 0.0936 0.1030 0.1105 0.1155 0.1331 0.1350
2009 0.0453 0.0644 0.0688 0.1033 0.1156 0.1251 0.1347 0.1542 0.1780
2010 0.0435 0.0580 0.0790 0.0850 0.1118 0.1189 0.1158 0.1119 0.1413

#eof
999

```

```

## -----
## SOC HERRING CONTROLS
## -----
## Prior descriptions:
## -0 uniform (0,0)
## -1 normal (p1=mu,p2=sig)
## -2 lognormal (p1=log(mu),p2=sig)
## -3 beta (p1=alpha,p2=beta)
## -4 gamma(p1=alpha,p2=beta)
## -----
## ## npar
## ival lb ub phz prior p1 p2 parameter name
## ##
7 6.60 -5.0 15 4 0 -5.0 15 #log_ro
0.67 0.2 1.0 4 3 10.0 4.925373 #steepness
-0.7985077 -5.0 5.0 3 1 -0.7985077 0.4 #log.m
7.40 -5.0 15 1 0 -5.0 15 #log_avrec
7.20 -5.0 15 1 0 -5.0 15 #log_recinit
0.3043478 0.001 0.999 -3 3 15.0 60.0 #rho
0.8695652 0.01 5.0 -3 4 156.25 125.0 #kappa (precision)
## -----
## ## SELECTIVITY PARAMETERS
## -----
## OPTIONS FOR SELECTIVITY:
## 1) logistic selectivity parameters
## 2) selectivity coefficients
## 3) a constant cubic spline with age-nodes
## 4) a time varying cubic spline with age & year nodes.
## 5) a time varying cubic spline with age & year nodes.
## 6) fixed logistic (set isel_type=6, and estimation phase to -1)
## 7) logistic function of body weight.
## sig=0.08 0.10 0.15 0.20 0.30 0.40 0.50
## wr=200. 50.0 22.2 12.5 5.5 3.12 2.00
## Gear 1:3 fishery: Gear 4-5 survey
## isel_type
1 1 7 6 6
## Age at 50% selectivity (logistic)
2.0 3.0 0.6 2.055 2.055
## STD at 50% selectivity (logistic)
0.25 0.25 0.15 0.05 0.05
## No. of age nodes for each gear (0 to ignore).
5 5 5 0 0
## No. of year nodes for each gear (0 to ignore).
12 3 10 0 0 0
## Estimation phase

```

```

2      2      2      -1     -1
## Penalty weight for 2nd differences w=1/(2*sig^2)
125.    125.    12.5   12.5
## Penalty weight for dome-shaped selectivity 1=1/(2*sig^2)
50.0    50.0   200.0  200.0  200.0
## -----
## ----- Priors for Survey q -----
## -----
## nits #number of surveys
2
## priors 0=uniform density 1=normal density
0      1
## prior log(mean)
0      -0.662
## prior sd
1.0    0.226
## -----
## ----- OTHER MISCELLANEOUS CONTROLS -----
## -----
0      ## 1 verbose ADMB output (0=off, 1=on)
1      ## 2 recruitment model (1=beverton-holt, 2=ricker)
0.100 ## 3 std in observed catches in first phase.
0.0707 ## 4 std in observed catches in last phase.
0      ## 5 Assume unfished in first year (0=FALSE, 1=TRUE)
0.02   ## 6 Minimum proportion to consider in age-proportions for dmvlogistic
0.30   ## 7 Mean fishing mortality for regularizing the estimates of Ft
0.01   ## 8 std in mean fishing mortality in first phase
2.00   ## 9 std in mean fishing mortality in last phase
3      ## 10 phase for estimating m_deviations (use -1 to turn off mdevs)
0.1    ## 11 std in deviations for natural mortality
12 ## 12 number of estimated nodes for deviations in natural mortality
1.00   ## 13 fraction of total mortality that takes place prior to spawning
1      ## 14 switch for age-composition likelihood (1=dmvlogistic, 2=dmultinom)
## -----
## eofc
999

```

B.5 West Coast of Vancouver Island

```

#NB The data herein were taken from sog2010_final.dat for the HCAM model.
## -----
## Model Dimensions
1951 #first year of data
2010 #last year of data
2 #age of youngest age class
10 #age of plus group
5 #number of gears (ngear)
## flags for fishery (1) or survey (0) in ngears
1 1 1 0
## -----
## -----
##age-schedule and population parameters
#natural mortality rate (m)
0.334
#growth parameters (linf,k,to) (from fishbase)
27.0, 0.48, 0
#length-weight allometry (a,b)
4.5e-6, 3.1270
#maturity at age (am=log(3)/k) & gm=std for logistic
2.055, 0.05
## -----
###
#Time series data
#Observed catch (1951-2010, metric t)
#yr p1 p2 p3 survey
1951 21.621 0.000 0.000 0 0
1952 27.008 0.000 0.000 0 0
1953 0.028 0.000 0.000 0 0
1954 33.209 0.000 0.000 0 0
1955 6.123 0.000 0.000 0 0
1956 17.098 0.000 0.000 0 0
1957 2.612 0.000 0.000 0 0
1958 0.556 0.000 0.000 0 0
1959 69.223 0.000 0.000 0 0
1960 53.911 0.000 0.000 0 0
1961 26.435 0.000 0.000 0 0
1962 23.684 0.000 0.000 0 0
1963 18.206 0.000 0.000 0 0
1964 21.266 0.000 0.000 0 0
1965 16.046 0.000 0.000 0 0
1966 10.843 0.000 0.000 0 0
1967 15.145 0.000 0.000 0 0
1968 0.000 0.000 0.000 0 0
1969 0.000 0.000 0.000 0 0
1970 0.000 0.000 0.000 0 0
1971 0.000 0.000 0.000 0 0
1972 0.000 6.894 0.000 0 0
1973 0.000 16.766 1.537 0 0
1974 0.000 12.394 3.940 0 0
1975 0.000 17.799 8.309 0 0
1976 0.000 22.820 16.005 0 0
1977 0.028 17.458 12.556 0 0
1978 2.839 5.151 14.755 0 0
1979 0.084 10.472 8.138 0 0
1980 0.000 1.682 2.300 0 0
1981 0.000 5.008 3.079 0 0
1982 0.000 2.370 3.115 0 0
1983 0.000 6.141 2.434 0 0
1984 0.000 5.718 0.858 0 0
1985 0.000 0.177 0.000 0 0
1986 0.000 0.203 0.000 0 0
1987 0.000 13.463 2.471 0 0
1988 0.000 8.276 1.448 0 0
1989 0.000 9.774 3.515 0 0
1990 0.000 7.890 1.959 0 0
1991 0.000 6.299 2.336 0 0
1992 0.000 3.086 0.627 0 0
1993 0.000 5.612 0.000 0 0
1994 0.000 5.332 0.706 0 0
1995 0.000 1.947 0.000 0 0
1996 0.000 0.790 0.000 0 0
1997 0.000 6.656 0.000 0 0
1998 0.000 5.450 1.534 0 0
1999 0.000 3.405 0.968 0 0
2000 0.000 0.926 0.700 0 0
2001 0.000 0.000 0.000 0 0
2002 0.000 0.433 0.388 0 0
2003 0.000 2.571 0.945 0 0
2004 0.000 3.861 0.593 0 0
2005 0.000 3.373 0.896 0 0
2006 0.000 0.000 0.000 0 0
2007 0.000 0.000 0.000 0 0
2008 0.000 0.000 0.000 0 0
2009 0.000 0.000 0.000 0 0
2010 0.000 0.000 0.000 0 0
#
#
#Relative Abundance index from fisheries independent survey (it) 1970-2008
#nit
2
#nit_nobs
37 23
#survey type
## 1 = survey is proportional to vulnerable numbers
## 2 = survey is proportional to vulnerable biomass
## 3 = survey is proportional to spawning biomass (e.g., herring spawn survey)
3 3
#yr it gear wt survey timing
1951 19.597 4 1 1
1952 13.310 4 1 1
1953 39.571 4 1 1
1954 20.648 4 1 1
1955 15.112 4 1 1
1956 27.183 4 1 1
1957 44.114 4 1 1
1958 18.986 4 1 1
1959 12.979 4 1 1
1960 6.015 4 1 1
1961 10.556 4 1 1
1962 34.470 4 1 1
1963 11.245 4 1 1
1964 22.761 4 1 1
1965 11.891 4 1 1
1966 3.722 4 1 1
1967 4.813 4 1 1
1968 11.029 4 1 1
1969 10.465 4 1 1
1970 26.912 4 1 1
1971 36.206 4 1 1
1972 41.857 4 1 1
1973 19.481 4 1 1
1974 25.540 4 1 1
1975 49.149 4 1 1
1976 64.222 4 1 1
1977 58.679 4 1 1
1978 45.607 4 1 1
1979 66.397 4 1 1
1980 62.308 4 1 1
1981 52.063 4 1 1
1982 33.047 4 1 1
1983 16.771 4 1 1
1984 23.872 4 1 1
1985 30.010 4 1 1
1986 39.514 4 1 1
1987 16.858 4 1 1
1988 46.242 5 1 1
1989 47.718 5 1 1
1990 46.464 5 1 1
1991 30.456 5 1 1
1992 42.687 5 1 1
1993 34.728 5 1 1
1994 25.625 5 1 1
1995 28.057 5 1 1
1996 33.966 5 1 1
1997 46.490 5 1 1
1998 41.556 5 1 1
1999 20.390 5 1 1
2000 13.267 5 1 1
2001 13.955 5 1 1
2002 22.086 5 1 1
2003 29.750 5 1 1
2004 15.844 5 1 1
2005 9.075 5 1 1
2006 2.705 5 1 1
2007 2.089 5 1 1
2008 2.548 5 1 1
2009 9.876 5 1 1
2010 2.373 5 1 1
#
#Age composition data by year, gear (ages 2-15+)
#na_gears
3
#na_nobs
18 39 26
#a_sage
2 2 2
#a_page
10 10 10
#
#yr gear V2 V3 V4 V5 V6 V7 V8 V9 V10 #Number aged.
1951 1 503 1519 1666 272 58 12 1 1 0
1952 1 97 1431 1224 1809 241 72 16 2 0
1953 1 465 2220 1086 65 19 2 0 0 0
1954 1 163 3852 1681 338 42 9 5 1 1
1955 1 418 1471 484 86 16 1 0 0 0
1956 1 578 2990 743 282 52 7 2 2 0
1957 1 16 423 146 2 1 0 0 0 0
1958 1 193 770 376 81 34 20 5 1 0
1959 1 148 1607 993 519 140 88 74 21 3
1960 1 254 1561 662 246 80 27 10 4 2
1961 1 226 224 113 26 1 0 0 0 0
1962 1 56 957 112 28 10 0 0 0 0
1963 1 37 804 907 96 14 4 0 0 0
1964 1 16 677 284 118 9 3 0 0 0
1965 1 18 269 372 75 27 3 0 0 0
1966 1 1 101 78 53 6 3 0 0 0
1967 1 25 193 160 34 12 7 2 0 0
1978 1 0 180 156 105 106 20 6 4 2
1972 2 50 279 716 356 51 18 11 1 0
1973 2 18 776 620 817 276 40 7 2 0
1974 2 433 2324 1290 731 476 120 12 2 1
1975 2 60 5405 1983 1140 804 498 128 17 1
1976 2 18 818 4332 1828 1194 746 251 40 0
1977 2 38 830 2077 2487 828 294 112 18 3
1978 2 63 3164 1407 1177 1294 287 87 14 5
1979 2 30 513 1848 525 398 293 59 19 4
1980 2 232 1640 582 747 238 198 82 13 2
1981 2 232 1868 1423 499 603 261 103 29 7
1982 2 152 1144 1309 1244 261 454 130 65 5
1983 2 135 719 696 699 562 142 172 34 26
1984 2 663 1146 418 282 309 182 33 33 5
1985 2 613 1606 426 111 82 95 51 4 6
1986 2 157 2094 1233 344 130 93 73 24 3
1987 2 783 863 1709 1053 351 123 71 52 13

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1988 2 193 4587 584 1110 738 209 55 33 15
1989 2 155 960 3693 450 534 271 44 10 3
1990 2 33 1856 849 3233 307 406 125 16 4
1991 2 482 1565 1543 780 2420 226 261 48 2
1992 2 104 2960 662 827 362 1028 129 75 12
1993 2 214 1528 2255 380 416 226 423 51 27
1994 2 183 1407 1485 1875 492 311 330 98 15
1995 2 44 667 1304 1087 1335 348 226 166 31
1996 2 1079 1505 909 1457 945 968 204 85 42
1997 2 145 4109 487 266 402 294 198 32 20
1998 2 123 1224 3239 347 155 176 104 61 11
1999 2 65 960 1044 1641 325 112 63 31 14
2000 2 284 1170 984 894 1374 196 67 35 9
2001 2 165 1074 475 197 178 222 31 5 3
2002 2 348 2658 1136 371 140 157 131 15 1
2003 2 96 2191 2042 705 135 62 42 33 4
2004 2 390 1255 2431 1002 283 64 21 11 0
2005 2 157 1655 939 680 237 71 12 2 3
2006 2 174 430 387 91 62 9 1 0 0
2007 2 7 303 211 66 11 4 0 0 0
2008 2 54 255 559 119 32 8 6 1 1
2009 2 44 1202 283 230 41 10 0 0 0
2010 2 211 577 839 105 88 14 2 0 0
1973 3 0 49 131 286 68 17 4 1 0
1974 3 0 46 43 43 16 6 0 0 0
1975 3 0 7 78 88 48 19 1 0 0
1976 3 0 8 495 408 179 73 31 4 1
1977 3 2 12 58 144 56 37 17 5 1
1978 3 0 6 23 90 207 74 20 1 1
1979 3 0 5 118 136 113 86 15 2 1
1980 3 0 0 19 188 80 43 26 1 1
1981 3 0 5 59 42 102 53 20 0 0
1982 3 0 4 69 264 67 158 19 2 1
1983 3 0 2 81 136 256 37 56 2 1
1984 3 0 10 40 107 194 190 32 20 1
1987 3 0 10 135 340 30 12 16 5 2
1988 3 0 25 33 192 133 60 14 6 2
1989 3 0 1 208 42 85 36 6 4 0
1990 3 0 6 35 307 37 46 11 3 0
1991 3 0 1 21 39 198 21 25 2 0
1992 3 0 35 75 171 77 166 16 14 2
1994 3 1 35 199 340 33 7 4 1 0
1998 3 0 5 344 99 87 181 111 51 19
1999 3 0 9 113 612 193 58 38 18 2
2000 3 0 8 47 169 330 39 16 14 1
2002 3 0 0 55 154 82 110 120 12 2
2003 3 0 13 87 159 99 49 64 25 3
2004 3 0 5 179 154 158 92 24 14 5
2005 3 0 4 54 249 119 53 19 1 1
#n_wt_obs
60
#Mean weight-at-age in kilograms (interpolated: from HCAM.rep)
#$yr V1 V2 V3 V4 V5 V6 V7 V8 V9
1951 0.0503000 0.0873000 0.1144000 0.1339000 0.1498900 0.1600000 0.2050000 0.1960000 0.15860001 1 7 1 1
1952 0.0536000 0.0895000 0.1144000 0.1386000 0.1596000 0.1781000 0.1900000 0.1586000age at 50% selectivity (logistic)
1953 0.0446000 0.0799000 0.1010000 0.1210000 0.1473000 0.1455000 0.1594143 0.16562286 0.15860001.5 2.0 0.6 2.05 2.05
1954 0.0542000 0.0854000 0.1056000 0.1258000 0.1474000 0.1658000 0.1580000 0.16562286 0.1586000STD at 50% selectivity (logistic)
1955 0.0579000 0.0827000 0.1070000 0.1249000 0.1514000 0.1310000 0.1594143 0.16562286 0.15860000.75 0.5 0.15 0.05 0.05
1956 0.0577000 0.0860000 0.1064000 0.1192000 0.1389000 0.1440000 0.1594143 0.1400000 0.15860000. of age nodes for each gear (0 to ignore).
1957 0.0543000 0.0775000 0.1016000 0.1139000 0.1360000 0.1440000 0.1420000 0.1400000 0.15860005 5 5 0 0
1958 0.0503000 0.0693000 0.0965000 0.1093000 0.1248000 0.1281000 0.1383000 0.1690000 0.15860000. of year nodes for each gear (0 to ignore).
1959 0.0508000 0.0808000 0.0970000 0.1130000 0.1241000 0.1352000 0.1371000 0.1499000 0.152700012 3 10 0 0
1960 0.0594000 0.0897000 0.1060000 0.1212000 0.1336000 0.1446000 0.1604000 0.1745000 0.1645000Estimation phase
1961 0.0583000 0.0908000 0.1159000 0.1410000 0.1730000 0.1484429 0.1594143 0.16562286 0.15860002 2 2 -2 -2
1962 0.0567000 0.0922000 0.1093000 0.1241000 0.1282000 0.1484429 0.1594143 0.16562286 0.1586000Penalty weight for 2nd differences w=1/(2*sig^2)
1963 0.0562000 0.0883000 0.1116000 0.1222000 0.1366000 0.1448000 0.1594143 0.16562286 0.1586000125.0 12.5 12.5 12.5
1964 0.0650000 0.0931000 0.1145000 0.1362000 0.1452000 0.1300000 0.1594143 0.16562286 0.1586000Penalty weight for dome-shaped selectivity 1=1/(2*sig^2)
1965 0.0653000 0.1040000 0.1292000 0.1474000 0.1733000 0.1580000 0.1594143 0.16562286 0.15860003.125 200.0 200.0 200.0 200.0
1967 0.0549750 0.0880875 0.1102875 0.1275375 0.1455187 0.1484429 0.1594143 0.16562286 0.1586000Priors for Survey q
1968 0.0549750 0.0880875 0.1102875 0.1275375 0.1455187 0.1484429 0.1594143 0.16562286 0.1586000##
1969 0.0549750 0.0880875 0.1102875 0.1275375 0.1455187 0.1484429 0.1594143 0.16562286 0.1586000##
1970 0.0639778 0.0949000 0.1248556 0.1501222 0.1697500 0.1844389 0.1957944 0.2034412 0.2082571##
1971 0.0640000 0.1174000 0.1485000 0.1660000 0.1689000 0.1894400 0.2175000 0.2034412 0.2082571# number of surveys
1972 0.0642000 0.1036000 0.1382000 0.1596000 0.1737000 0.1807000 0.2032000 0.1600000 0.2082571
1973 0.0633000 0.1037000 0.1349000 0.1598000 0.1836000 0.1924000 0.1903000 0.2504000 0.2082571# priors 0=uniform density 1=normal density
1974 0.0617000 0.0854000 0.1234000 0.1467000 0.1717000 0.1856000 0.1836000 0.2175000 0.231000# prior log(means)
1975 0.0547000 0.0918000 0.1279000 0.1652000 0.1893000 0.2071000 0.2202000 0.2406000 0.207000# prior log(means)
1976 0.0536000 0.0873000 0.1202000 0.1518000 0.1811000 0.1951000 0.2112000 0.2223000 0.20825710.662
1977 0.0628000 0.0885000 0.1253000 0.1435000 0.1695000 0.1828000 0.1918000 0.1962000 0.2153000# prior sd
1978 0.0591000 0.0797000 0.1082000 0.1341000 0.1539000 0.1736000 0.1883000 0.2038000 0.2244000226
1979 0.0621000 0.0831000 0.1104000 0.1412000 0.1672000 0.1835000 0.2030000 0.2034412 0.1995700##
1980 0.0669000 0.0825000 0.1079000 0.1314000 0.1599000 0.1789000 0.1928000 0.2083000 0.2180000##
1981 0.0630000 0.0906000 0.1104000 0.1377000 0.1527000 0.1755000 0.1830000 0.1879000 0.1894400##
1982 0.0708000 0.0892000 0.1094000 0.1251000 0.1423000 0.1500000 0.1712000 0.1795000 0.1774000## recruitment model (1=beverton-holt, 2=ricker)
1983 0.0611000 0.0933800 0.1190000 0.1405000 0.1582000 0.1660000 0.1723000 0.1954000 0.1938000## std in observed catches in first phase.
1984 0.0692000 0.1013000 0.1306000 0.1535000 0.1662000 0.1767000 0.1863000 0.1891000 0.2112000## std in observed catches in last phase.
1985 0.0694000 0.1016000 0.1351000 0.1609000 0.1818000 0.1857000 0.2027600 0.1848000 0.1997000## Assume unfished in first year (0=FALSE, 1=TRUE)
1987 0.0695000 0.1026000 0.1367000 0.1634000 0.1810000 0.2001000 0.2030000 0.2050000 0.2139000## Minimum proportion to consider in age-proportions for dmvlogistic
1988 0.0679000 0.1033000 0.1302000 0.1597000 0.1775000 0.1952000 0.2019000 0.2062000 0.2138000## Mean fishing mortality for regularizing the estimates of Ft
1989 0.0649000 0.0967000 0.1268000 0.1476000 0.1700000 0.1869000 0.1936000 0.1966000 0.2050000## std in mean fishing mortality in first phase
1990 0.0620000 0.1008000 0.1295000 0.1542000 0.1721000 0.1881000 0.1993000 0.2148000 0.1965000## std in mean fishing mortality in last phase
1991 0.0662000 0.0942000 0.1235000 0.1412000 0.1608000 0.1773000 0.1858000 0.1978000 0.2068500## phase for estimating m_deviations (use -1 to turn off mdevs)
1992 0.0687000 0.1060000 0.1256000 0.1493000 0.1638000 0.1773000 0.1879000 0.1973000 0.2082000## std in deviations for natural mortality
1993 0.0685000 0.0973000 0.1217000 0.1406000 0.1593000 0.1694000 0.1784000 0.1873000 0.1979000## number of estimated nodes for deviations in natural mortality
1994 0.0648000 0.0949000 0.1194000 0.1358000 0.1498000 0.1605000 0.1642000 0.1748000 0.1779000## fraction of total mortality that takes place prior to spawning
1995 0.0693000 0.0979000 0.1216000 0.1432000 0.1599000 0.1749000 0.1823000 0.1888000 0.1874000## 14 switch for age-composition likelihood (1=dmvlogistic, 2=dmultinom)
1996 0.0695000 0.0855000 0.1160000 0.1363000 0.1520000 0.1646000 0.1766000 0.1814000 0.1924000##
1997 0.0641000 0.0914000 0.1055000 0.1316000 0.1492000 0.1610000 0.1756000 0.1729000 0.1794000
1998 0.0589000 0.0796000 0.1037000 0.1133000 0.1321000 0.1424000 0.1494000 0.1557000 0.1575000
1999 0.0536000 0.0832000 0.0991000 0.1195000 0.1257000 0.1440000 0.1521000 0.1634000 0.1562000## ofc
2000 0.0578000 0.0868000 0.1074000 0.1301000 0.1468000 0.1584000 0.1609000 0.1681000 0.1771000

```

Table B-1: Observed catch by gear type and year for each stock.

Stock	Year	HG			PRD			CC			SOG			WCVI		
		Gear 1	Gear 2	Gear 3	Gear 1	Gear 2	Gear 3	Gear 1	Gear 2	Gear 3	Gear 1	Gear 2	Gear 3	Gear 1	Gear 2	Gear 3
1951	1951	2.850	45.900	42.700	53.400	1.870	27.900	33.400	0.768	24.900	11.600	44.300	46.100	21.600	27.100	0.020
1952	1952	10.200	45.900	42.700	53.400	1.870	27.900	33.400	0.768	24.900	11.600	44.300	46.100	21.600	27.100	0.020
1953	1953	1.790	27.900	18.200	18.200	10.200	27.200	43.400	23.800	9.900	27.700	72.000	66.600	68.700	58.500	34.300
1954	1954	1.230	27.900	18.200	18.200	10.200	27.200	43.400	23.800	9.900	27.700	72.000	66.600	68.700	58.500	6.120
1955	1955	74.700	23.800	11.200	4.560	10.300	10.300	4.560	10.300	27.700	48.700	0.381	16.900	2.610	0.556	16.900
1956	1956	7.000	7.000	7.000	18.600	18.600	18.600	41.400	31.300	15.700	43.800	68.700	66.800	66.800	66.800	6.120
1960	1960	0.653	0.653	0.653	41.400	27.200	39.400	28.700	28.700	31.100	31.100	76.600	46.600	46.600	46.600	52.400
1961	1961	7.650	14.900	28.500	44.000	17.100	8.050	21.700	15.800	37.200	21.700	34.000	30.500	30.500	30.500	25.600
1962	1962	14.900	35.100	2.750	44.000	8.050	2.070	1.530	1.530	1.530	1.530	1.890	0.194	0.221	0.221	23.700
1963	1963	2.750	0.213	0.080	1.320	0.218	0.218	0.218	0.218	0.209	0.209	0.137	1.610	1.610	1.610	1.610
1964	1964	0.080	1969	1.320	3.420	0.877	3.640	0.004	0.388	8.360	0.360	2.430	5.900	5.900	5.900	5.900
1970	1970	0.102	1971	0.850	3.140	7.650	0.218	1.400	0.035	6.620	1.110	4.000	1.610	1.610	1.610	1.610
1971	1971	0.850	1972	0.850	3.140	6.210	0.127	0.182	2.120	1.520	0.320	0.479	0.425	3.110	3.110	3.110
1972	1972	0.850	1973	0.850	3.140	7.600	0.105	0.155	0.011	0.011	3.330	5.420	0.378	0.469	0.469	5.300
1973	1973	0.850	1974	0.374	7.650	11.900	1.800	0.565	0.276	0.276	6.130	6.160	5.070	0.202	0.202	7.020
1974	1974	0.374	1975	0.374	6.210	0.127	0.182	0.182	2.120	1.520	0.320	0.320	0.690	4.110	4.110	4.110
1975	1975	0.374	1976	0.374	7.600	11.900	1.800	0.565	0.565	0.565	0.565	0.565	13.000	3.730	3.730	3.730
1976	1976	0.374	1977	0.374	11.900	11.200	1.490	0.798	0.798	0.510	0.046	4.750	9.350	12.900	12.900	12.900
1977	1977	0.374	1978	0.067	11.200	1.490	0.798	0.798	0.510	0.510	0.046	4.750	9.350	12.900	12.900	12.900
1978	1978	0.067	1979	0.096	9.190	2.560	3.610	1.950	3.020	0.046	0.046	4.750	9.350	12.900	12.900	12.900
1979	1979	0.096	1980	0.096	5.920	2.100	1.810	1.270	1.240	1.240	0.005	0.005	13.600	6.990	6.990	6.990
1980	1980	0.096	1981	0.096	2.110	1.210	0.741	1.660	1.060	0.010	0.010	0.529	2.470	0.169	3.220	3.220
1981	1981	0.096	1982	0.067	3.930	1.710	1.690	1.050	0.357	0.357	0.0269	2.300	4.890	0.087	4.160	4.160
1982	1982	0.067	1983	0.067	2.370	1.410	1.830	0.170	0.170	0.041	2.250	4.050	3.930	3.300	5.510	5.510
1983	1983	0.067	1984	0.096	4.650	0.929	0.173	1.650	1.890	2.170	1.170	0.432	0.162	0.162	2.840	2.840
1984	1984	0.096	1985	0.096	4.010	0.535	0.253	0.253	0.310	3.490	0.038	2.170	1.170	0.244	3.110	3.110
1985	1985	0.096	1986	0.096	4.610	1.490	0.433	0.433	0.375	4.530	0.038	2.170	1.170	0.244	3.110	3.110
1986	1986	0.096	1987	0.070	2.620	0.890	0.375	3.720	4.530	0.038	2.170	1.170	0.244	3.110	3.110	3.110
1987	1987	0.070	1988	0.070	2.070	0.122	0.2080	4.070	2.070	2.710	0.923	0.923	0.756	1.470	1.470	1.470
1988	1988	0.070	1989	0.070	0.032	0.079	3.550	4.440	0.028	3.540	0.975	1.030	1.030	1.420	5.880	5.880
1989	1989	0.070	1990	0.070	1.460	0.071	3.660	4.860	6.520	6.520	3.060	0.233	0.233	7.710	7.710	7.710
1990	1990	0.070	1991	0.070	5.510	1.170	0.043	2.280	2.380	5.290	5.290	0.562	1.130	1.130	1.130	1.130
1991	1991	0.070	1992	0.070	3.900	0.543	1.360	2.140	7.140	1.820	0.939	3.620	8.960	9.180	6.300	6.300
1992	1992	0.070	1993	0.070	2.530	1.240	3.740	4.080	0.088	7.150	1.120	0.617	4.380	8.790	8.790	3.090
1993	1993	0.070	1994	0.070	2.690	2.210	4.080	2.370	2.370	2.360	9.660	2.120	0.942	5.120	5.320	5.320

Table B-1: (continued)

Year	Gear 1	Gear 2	Gear 3	Gear 1	Gear 2	Gear 3	Gear 1	Gear 2	Gear 3	Gear 1	Gear 2	Gear 3
1995				0.707	1.370	3.110	8.130	1.450	0.641	4.360	8.070	1.950
1996						3.900	0.402	0.541	7.340	6.140	0.790	
1997				0.256	5.370	3.180	3.290	0.344	0.402	9.290	6.130	6.670
1998	1.370	0.473	0.256	1.240	1.850	3.050	8.030	0.648	0.954	5.760	6.990	5.460
1999	2.500			1.010	1.900	5.620	6.010	1.520	1.470	4.980	6.920	3.410
2000	1.770			2.070	2.460	2.900	0.289	0.400	1.160	6.440	7.620	0.927
2001	0.707			1.450	2.610	2.300		1.360	1.420	7.280	7.640	0.433
2002				1.920	2.220	2.990		1.360	1.330	9.330	7.970	0.949
2003				1.750	2.050	3.790		1.360	1.700	10.700	8.140	2.570
2004				0.958	1.640	3.080		1.360	7.030	5.330	3.860	0.594
2005				0.949	0.949	0.398		1.330	1.330	9.170	3.420	0.902
2006				0.513	1.140			1.370	1.370	9.300	7.390	
2007				0.713	1.290			0.672	0.672	3.850	5.280	
2008				0.475	1.010			1.140	1.140	2.760	5.930	
2009								0.709	0.709	3.900	3.900	
2010								0.595	0.595	4.540	3.230	

Table B-2: Abundance for each survey by year for each stock.

Year	HG	Survey 1		Survey 2		PRD		Survey 1		Survey 2		CC		Survey 1		Survey 2		SOG		Survey 1		Survey 2		WCVI	
		Year	Year	Year	Year	Year	Year	Year	Year	Year	Year	Year	Year	Year	Year	Year	Year	Year	Year	Year	Year	Year	Year	Year	Year
1951	4.213	1988	15.245	1951	27.149	1988	35.444	1951	15.390	1988	26.916	1951	66.143	1988	24.976	1951	19.567	1988	46.242	1951	19.567	1988	47.718	1951	19.567
1952	2.578	1989	25.201	1952	24.047	1989	16.379	1952	19.52	1989	21.561	1952	72.376	1989	66.052	1952	13.310	1989	47.718	1952	13.310	1989	47.718	1952	13.310
1953	7.555	1990	27.058	1953	19.54	1990	22.679	1953	18.237	1990	28.980	1953	11.130	1990	67.152	1953	39.571	1990	46.464	1953	39.571	1990	46.464	1953	39.571
1954	12.408	1991	17.998	1954	13.535	1991	19.54	1954	13.967	1991	19.183	1954	82.141	1991	45.830	1954	20.648	1991	30.456	1954	20.648	1991	30.456	1954	20.648
1955	6.437	1992	12.376	1955	14.482	1992	40.145	1955	13.564	1992	43.274	1955	69.854	1992	82.714	1955	15.112	1992	42.687	1955	15.112	1992	42.687	1955	15.112
1956	6.042	1993	8.152	1956	14.533	1993	25.071	1956	6.626	1993	32.392	1956	25.667	1993	90.198	1956	27.183	1993	34.728	1956	27.183	1993	34.728	1956	27.183
1957	1.592	1994	14.293	1957	27.518	1994	16.589	1957	4.607	1994	29.432	1957	24.126	1994	67.144	1957	44.114	1994	25.625	1957	44.114	1994	25.625	1957	44.114
1958	0.815	1995	4.701	1958	9.832	1995	18.516	1958	3.549	1995	22.348	1958	16.911	1995	64.899	1958	18.986	1995	28.057	1958	18.986	1995	28.057	1958	18.986
1959	8.981	1996	7.377	1959	40.961	1996	24.854	1959	3.904	1996	21.646	1959	47.864	1996	71.326	1959	12.979	1996	33.986	1959	12.979	1996	33.986	1959	12.979
1960	6.599	1997	11.215	1960	16.545	1997	25.037	1960	12.615	1997	28.255	1960	55.709	1997	58.252	1960	6.015	1997	46.490	1960	6.015	1997	46.490	1960	6.015
1961	8.981	1998	21.649	1961	12.059	1998	19.420	1961	4.265	1998	31.503	1961	44.326	1998	74.616	1961	10.556	1998	41.556	1961	10.556	1998	41.556	1961	10.556
1962	5.730	1999	10.610	1962	19.92	1999	26.329	1962	11.948	1999	31.813	1962	35.574	1999	85.095	1962	34.470	1999	20.390	1962	34.470	1999	20.390	1962	34.470
1963	7.297	2000	6.698	1963	16.981	2000	19.694	1963	6.485	2000	32.652	1963	19.633	2000	72.688	1963	11.245	2000	13.267	1963	11.245	2000	13.267	1963	11.245
1964	4.104	2001	15.195	1964	26.919	2001	36.684	1964	6.464	2001	25.109	1964	35.954	2001	100.248	1964	22.761	2001	13.955	1964	22.761	2001	13.955	1964	22.761
1965	1.378	2002	3.257	1965	21.965	2002	22.449	1965	2.097	2002	23.147	1965	38.390	2002	117.864	1965	11.891	2002	22.086	1965	11.891	2002	22.086	1965	11.891
1966	2.824	2003	8.801	1966	7.105	2003	34.007	1966	1.863	2003	25.679	1966	7.211	2003	141.651	1966	3.722	2003	29.750	1966	3.722	2003	29.750	1966	3.722
1967	0.710	2004	5.668	1967	3.386	2004	30.493	1967	1.967	2004	5.434	1967	9.647	2004	114.352	1967	4.813	2004	15.844	1967	4.813	2004	15.844	1967	4.813
1968	0.833	2005	3.614	1968	5.197	2005	27.956	1968	5.790	2005	24.158	1968	9.442	2005	95.643	1968	11.029	2005	9.075	1968	11.029	2005	9.075	1968	11.029
1969	2.075	2006	10.497	1969	0.965	2006	10.251	1969	1.837	2006	12.051	1969	14.039	2006	46.752	1969	10.465	2006	2.706	1969	10.465	2006	2.706	1969	10.465
1970	5.552	2007	9.436	1970	8.814	2007	15.562	1970	8.230	2007	9.857	1970	34.163	2007	35.865	1970	26.912	2007	2.089	1970	26.912	2007	2.089	1970	26.912
1971	13.291	2008	4.213	1971	8.480	2008	13.553	1971	7.711	2008	4.156	1971	3.971	2008	38.921	1971	32.103	2008	2.548	1971	32.103	2008	2.548	1971	32.103
1972	9.542	2009	8.935	1972	8.774	2009	12.684	1972	3.572	2009	10.183	1972	25.139	2009	49.909	1972	41.857	2009	9.876	1972	41.857	2009	9.876	1972	41.857
1973	7.960	2010	6.091	1973	10.959	2010	26.988	1973	12.434	2010	8.075	1973	1.974	2010	47.480	1973	19.481	2010	2.373	1973	19.481	2010	2.373	1973	19.481
1974	14.510	2011	1.974	1974	9.244	2011	17.474	1974	8.852	2011	9.571	1974	40.571	2011	19.74	25.540	1974	25.540	1974	19.74	25.540	1974	19.74	25.540	
1975	9.686	2012	1.975	1975	10.949	2012	15.587	1975	8.037	2012	13.849	1975	17.76	2012	70.211	1975	49.149	2012	49.149	1975	49.149	2012	49.149	1975	49.149
1976	16.374	2013	1.976	1976	15.587	2013	11.589	1976	17.77	2013	14.613	1976	17.77	2013	78.642	1976	64.222	2013	64.222	1976	64.222	2013	64.222	1976	64.222
1977	16.408	2014	1.977	1977	11.589	2014	17.78	1977	6.164	2014	7.747	1977	17.78	2014	78.567	1977	58.679	2014	58.679	1977	58.679	2014	58.679	1977	58.679
1978	18.371	2015	1.978	1978	9.195	2015	17.79	1978	1.195	2015	5.779	1978	17.79	2015	102.115	1978	45.607	2015	45.607	1978	45.607	2015	45.607	1978	45.607
1979	13.649	2016	1.979	1979	11.937	2016	19.80	1979	13.012	2016	15.919	1979	16.266	2016	19.80	1979	66.308	2016	62.308	1979	66.308	2016	62.308	1979	66.308
1980	31.904	2017	1.980	1980	14.087	2017	17.186	1980	1.982	2017	16.333	1980	16.333	2017	19.82	1980	55.991	2017	52.063	1980	55.991	2017	52.063	1980	55.991
1981	20.294	2018	1.981	1981	14.087	2018	17.186	1981	1.982	2018	18.482	1981	18.482	2018	19.84	1981	55.121	2018	52.063	1981	55.121	2018	52.063	1981	55.121
1982	23.593	2019	1.982	1982	17.186	2019	25.247	1982	1.983	2019	18.482	1982	18.482	2019	19.84	1982	100.987	2019	108.047	1982	100.987	2019	108.047	1982	100.987
1983	21.391	2020	1.983	1983	25.247	2020	27.041	1983	1.984	2020	18.482	1983	18.482	2020	19.84	1983	64.575	2020	19.84	1983	64.575	2020	19.84	1983	64.575
1984	23.439	2021	1.984	1984	27.041	2021	18.052	1984	1.985	2021	18.482	1984	18.482	2021	19.84	1984	26.227	2021	23.872	1984	26.227	2021	23.872	1984	26.227
1985	18.625	2022	1.985	1985	18.052	2022	26.638	1985	1.986	2022	20.342	1985	20.342	2022	19.86	1985	25.247	2022	30.010	1985	25.247	2022	30.010	1985	25.247
1986	6.847	2023	1.986	1986	26.638	2023	39.905	1986	1.987	2023	12.827	1986	12.827	2023	19.87	1987	41.737	2023	16.858	1987	41.737	2023	16.858	1987	41.737

Table B-3: Reference points

Stock	F_{MSY}	MSY	B_0	$0.25B_0$	B_{MSY}	$0.8B_{MSY}$	$0.4B_{MSY}$	Spawn depletion
HG	1.92	5,829	34,773	8,693	6,864	5,492	2,746	0.32
PRD	0.75	6,917	78,601	19,650	20,598	16,479	8,239	0.26
CC	0.87	8,021	56,732	14,183	10,750	8,600	4,300	0.11
SOG	1.11	18,126	117,444	29,361	24,339	19,471	9,736	0.43
WCVI	0.93	7,928	45,844	11,461	9,536	7,629	3,814	0.08

Table B-4: Estimated spawning stock biomass, age-4+ biomass and pre-fishery biomass for poor average and good recruitment, cutoffs, and available harvest based on a normal prior ($\mu = 0, \sigma = 0.274$) for q in both surveys.

Stock	SSB	4+ Biomass	Pre-fishery forecast biomass			Cutoff	Available harvest		
			Poor	Average	Good		Poor	Average	Good
HG	10,474	7,147	9,241	12,159	19,292	10,700	0	1,459	3,858
PRD	17,754	11,125	13,092	15,210	21,643	12,100	992	3,042	4,329
CC	6,441	2,486	4,366	6,487	11,538	17,600	0	0	0
SOG	50,927	26,807	38,502	49,288	65,667	21,200	7,700	9,858	13,133
WCVI	3,835	1,284	4,447	7,688	13,333	18,800	0	0	0

Table B-5: Estimated spawning stock biomass, age-4+ biomass and pre-fishery biomass for poor average and good recruitment, cutoffs based on 25% of the median B_0 estimate, and available harvest based on a normal prior ($\mu = 0, \sigma = 0.274$) for q in both surveys.

Stock	SSB	4+ Biomass	Pre-fishery forecast biomass			Cutoff	Available harvest		
			Poor	Average	Good		Poor	Average	Good
HG	10,474	7,147	9,241	12,159	19,292	9,032	209	2,432	3,858
PRD	17,754	11,125	13,092	15,210	21,643	25,055	0	0	0
CC	6,441	2,486	4,366	6,487	11,538	14,969	0	0	0
SOG	50,927	26,807	38,502	49,288	65,667	31,256	7,246	9,858	13,133
WCVI	3,835	1,284	4,447	7,688	13,333	11,970	0	0	1,363

Table B-6: Reference points

Stock	F_{MSY}	MSY	B_0	$0.25B_0$	B_{MSY}	$0.8B_{MSY}$	$0.4B_{MSY}$	Spawn depletion
HG	2.14	7,461	41,309	10,327	8,178	6,543	3,271	0.38
PRD	1.01	7,321	73,708	18,427	19,989	15,991	7,996	0.35
CC	0.97	9,050	57,502	14,375	11,312	9,050	4,525	0.15
SOG	1.26	20,194	118,712	29,678	24,941	19,953	9,976	0.5
WCVI	1.02	9,618	50,569	12,642	10,673	8,538	4,269	0.11

Table B-7: Estimated spawning stock biomass, age-4+ biomass and pre-fishery biomass for poor average and good recruitment, cutoffs, and available harvest based on a normal prior ($\mu = -0.569, \sigma = 0.274$) for q in both surveys.

Stock	SSB	4+ Biomass	Pre-fishery forecast biomass			Cutoff	Available harvest		
			Poor	Average	Good		Poor	Average	Good
HG	15,244	10,395	13,285	17,149	27,002	10,700	2,585	3,430	5,400
PRD	22,828	13,037	15,574	18,263	25,897	12,100	3,115	3,653	5,179
CC	8,696	3,458	5,890	8,437	14,690	17,600	0	0	0
SOG	59,247	30,220	45,204	57,184	75,655	21,200	9,041	11,437	15,131
WCVI	5,587	1,893	6,308	10,303	17,272	18,800	0	0	0

Table B-8: Estimated spawning stock biomass, age-4+ biomass and pre-fishery biomass for poor average and good recruitment, cutoffs based on 25% of the median B_0 estimate, and available harvest based on a normal prior ($\mu = -0.569, \sigma = 0.274$) for q in both surveys.

Stock	SSB	4+ Biomass	Pre-fishery forecast biomass			Cutoff	Available harvest		
			Poor	Average	Good		Poor	Average	Good
HG	15,244	10,395	13,285	17,149	27,002	10,546	2,657	3,430	5,400
PRD	22,828	13,037	15,574	18,263	25,897	21,386	0	0	4,511
CC	8,696	3,458	5,890	8,437	14,690	15,341	0	0	0
SOG	59,247	30,220	45,204	57,184	75,655	31,659	9,041	11,437	15,131
WCVI	5,587	1,893	6,308	10,303	17,272	13,127	0	0	3,454

Were not completely comfortable with the q estimates, but we believe the approach used to develop the informative prior for q is better than the ad hoc $q=1$ assumption. Assuming $q=1$ is more conservative.