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

Steven Martell, Jake Schweigert, Jaclyn Cleary, Vivian Haist

November 15, 2011

Abstract

Estimates of herring abundance in British Columbia (B.C.) waters has been based on catch-age data and spawn survey abundance information. These data are typically interpolated using a statistical catch-age framework; however, virtual methods (e.g., VPA) have been used in the past. This assessment also uses a statistical catch age model. This document is broken into two parts: Part I deals with moving the herring assessments towards Canada's sustainable fisheries framework and introduces a new integrated statistical catch-age model for jointly estimating the abundance of Pacific herring and associated reference points to be used in the sustainable fisheries framework. Part II of this document implements this new assessment framework using the data for the five major and two minor regions. Finally, we present catch advice based on decision tables that utilize poor, average, and good age-3 recruitment forecasts.

In Part I of this document we provide a very brief description of the new assessment framework (a full technical description of the model is provided in the Appendix of this document). We then conduct some simulation testing with perfect information to demonstrate that the model is capable of estimating all the parameters. We further explore precision and bias in parameter estimates based on simulation data with both observation and process errors. We then parameterize the new assessment model such that the assumptions of the previous assessment model (Herring Catch Age Model, or HCAM) are mostly met and compare parameter estimates and estimates of spawning stock biomass (using data from 1951:2010). Using data from the Strait of Georgia only, we then compare alternative assumptions about the spawn survey scaling coefficient (q), natural mortality and selectivity, and examine how these alternative assumptions influence estimates of key parameters (unfished spawning biomass, steepness, average natural mortality). Relaxing assumptions about q and natural mortality rates had the largest impacts on estimated parameters. Lastly, we compared estimates of spawning stock biomass from HCAM with the new model for all five major areas to understand the subtle differences between the assumptions in the two models.

In Part II of this document we present updated data from the herring fisheries and surveys in 2011, a brief description of the analytical methods used to construct the decision tables, and present the results of the application of the new assessment model to the 2011 data. New this year is a Bayesian prior for the dive survey spawn index (q) and the development of this prior is detailed in the appendix. The expected value of q was estimated to be 0.587 with a standard deviation of 0.155. To summarize the overall fit to the model, maximum likelihood estimates derived quantities and residuals between observed and predicted variables are used. Retrospective analysis (i.e., the sequential removal of the most recent data) is used as a diagnostic for model misspecification. Catch advice (decision tables) are based on the median values of random samples from the joint posterior distribution and not the maximum likelihood estimates. Visual inspection of the trace plots from the posterior samples and pair plots were used to judge if the samples were taken from a stationary distribution. Historically catch advice was based on cuttoff values that were derived from 1996 estimates of the unfished biomass (B_0, cuttoff values are set at $0.25B_0$). This assessment provides updated estimates of B_0 and presents catch advice based on new cuttoff values. An alternative decision table, where catch advice is based on old cuttoffs, is also presented.

Median estimates of the 2011 spawning stock biomass is as follows: Haida Gwaii (HG) –16,579 t, Prince Rupert District (PRD) – 27,046 t, Central Coast (CC) – 14,666 t, Strait of Georgia (SOG) 125,261 t, West Coast Vancouver Island (WCVI) 14,679 t. Implementation of the current harvest control rule (HCR) advises no fishing in HG under poor recruitment and no fishing in CC under poor and average recruitment. Based on the 20% harvest rate and application of the harvest control rule the estimated maximum available harvest ranges from 4,296 t in HG to 27,690t in SOG (assuming good recruitment). Catch advice for the minor areas is based on a 10% fixed exploitation rate with no cuttoffs and ranges from 91 t in Area 27 (assuming poor recruitment) to 614 t in Area 2W (assuming good recruitment).

Contents

Abstract . . . i
Contents . . . iii
List of Figures . . . viii
List of Table . . . xi

I Moving towards a sustainable fisheries framework for Pacific herring: data, models and alternative assumptions **1**
1.1 Introduction . . . 2
1.2 Methods . . . 2
1.2.1 Analytical methods . . . 2
1.2.2 Sustainable Fisheries Framework reference points . . . 4
1.2.3 Simulation testing . . . 4
1.2.4 Comparison of HCAM with ^{i}SCA$_\mathrm{M}$ . . . 5
1.3 Results . . . 7
1.3.1 Simulation testing . . . 7
1.3.2 Comparison of HCAM with ^{i}SCA$_\mathrm{M}$ . . . 10
1.3.3 Alternative assumptions about catchability, mortality & selectivity . . . 13
1.3.4 Preliminary assessments for all other areas . . . 16
1.4 Discussion . . . 18

II Stock Assessment and Management Advice for the British Columbia Pacific Herring Stocks: 2011 Assessment and 2012 Forecasts **20**
2.5 Introduction . . . 21
2.6 BC Herring Stocks . . . 21
2.7 Methods . . . 22
2.7.1 Input data & assumptions . . . 22
2.7.2 Analytical methods . . . 29
2.7.3 Retrospective analysis . . . 29
2.7.4 Abundance and recruitment forecasts . . . 29
2.7.5 Harvest control rule . . . 36
2.8 Results . . . 37
2.8.1 Maximum likelihood fits to the data . . . 37
2.8.2 Biomass estimates & reference points . . . 41
2.8.3 Estimates of mortality . . . 47
2.8.4 Selectivity . . . 51
2.8.5 Recruitment and stock-recruitment relationships . . . 54
2.8.6 Retrospective analysis . . . 57
2.8.7 Marginal posterior distributions . . . 57
2.8.8 Parameter confounding . . . 58
2.8.9 Marginal posterior distributions . . . 58
2.8.10 Forecast and catch advice based on the joint posterior distribtution . . . 58

2.9 Stock assessments for minor stock areas . . . 71
2.9.1 Maximum likelihood estimates of biomass . . . 71
2.9.2 Estimates of recruitment and reference points . . . 71
2.9.3 Retrospective analysis . . . 80
2.9.4 Marginal posterior distributions and trace plots . . . 80
2.9.5 Catch advice . . . 81
2.10 Outstanding Issues . . . 81
2.11 Acknowledgements . . . 85
References . . . 86

III Appendixes **88**
A.1 Technical description of ^{i}SCA$_{M}$ . . . 89
A.1.1 Analytic methods . . . 89
A.1.2 Equilibrium considerations . . . 89
A.1.3 MSY based reference points . . . 91
A.1.4 Dynamic age-structured model . . . 92
A.1.5 Options for selectivity . . . 95
A.1.6 Options for natural mortality . . . 97
A.1.7 Residuals, likelihoods & objective function value components . . . 98
A.1.8 Catch data . . . 98
A.1.9 Relative abundance data . . . 98
A.1.10 Age composition data . . . 99
A.1.11 Stock-recruitment . . . 100
A.1.12 Parameter Estimation and Uncertainty . . . 101
A.1.13 Negative loglikelihoods . . . 101
A.1.14 Constraints . . . 101
A.1.15 Priors for parameters . . . 102
A.1.16 Survey priors . . . 102
A.1.17 Convergence penalties . . . 103
B.2 Data and Control files . . . 104
B.2.1 Haida Gwaii . . . 104
B.2.2 Prince Rupert District . . . 105
B.2.3 Central Coast . . . 108
B.2.4 Strait of Geogia . . . 110
B.2.5 West Coast of Vancouver Island . . . 112
B.2.6 Area 2W . . . 114
B.2.7 Area 27 . . . 115
B.2.8 Control file for the simulation studies . . . 117
C.3 Bayesian prior for the dive survey spawn index proportionality constant q . . . 118
C.3.1 The process . . . 118
C.3.2 Factors affecting q and their distributions . . . 118
C.3.3 Simulating the dive survey spawn index q . . . 119
D.4 Landings and Survey data . . . 124

List of Figures

1.1 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. 3

1.2 True (thin line) and estimated (thick shaded line) spawning biomass (a), fishing mortality rates by gear (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. 8

1.3 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 (numerator) versus true (denominator) value is plotted; values of 1 and -1 correspond to a twice or half the true value, respectively. 9

1.4 Results based on trying to configure the ^{i}SCA$_{\mathrm{M}}$ model as similar as possible to the previous HCAM assessment. Maximum likelihood estimates of pre-fishery biomass (defined as the numbers-at-age times the mean weight-at-age at the start of the year) and post fishery spawning biomass in the Strait of Georgia (a), spawning biomass depletion (b), age-2 recruits (c), stock-recruitment relationship and unfished reference points (d), components of total mortality (log-scale, panel e), and observed (points) and predicted (lines) spawn survey data (f). The red line in panel (a) is the MLE estimate of spawning biomass from HCAM. . . 11

1.5 Results are based on configuring ^{i}SCA$_{\mathrm{M}}$ to be similar to HCAM. From top to bottom in the left column: the log residuals between observed and predicted catch for each gear, the residuals between the observed and predicted spawn survey index, and the annual deviations between age-2 recruitment and that predicted by the Beverton-Holt model and the estimated spawning stock biomass. Right column: residual patterns in the age-composition data (observed - predicted, where black is a positive residual) for each of the three commercial gears in the Strait of Georgia. 12

1.6 A comparison of the estimated biomass and spawning biomass and fits to the survey data when q is either fixed at 1 for Survey 2 (panels a, b), or estimated using an informative prior with an expected mean of 0 and a log standard deviation of 0.274 (panels c and d). 14

1.7 A comparison of fits to the survey data and estimated components of average mortality by year when M is allowed to vary via a random walk process or is estimated and assumed time invariant. Note that the y-axis in panels (b) and (d) are on a log scale and that the estimate of M is 0.67 in panel (d). 15

1.8 Residuals in the age-composition data when gillnet selectivity is a function of mean weight-at-age (left column with q Fixed in each caption) and or is a logistic function of age and time invariant (right column with Fixed Gillnet in each caption). 16

1.9 A comparison of estimated spawning stock biomass between HCAM and ^{i}SCA$_{\mathrm{M}}$ for the five major stock assessment regions using data from 1951 to 2010 and setting up ^{i}SCA$_{\mathrm{M}}$ similar to HCAM. 17

2.1 Historical catch of herring in the five major stock areas between 1951 and 2011 for the winter purse seine fishery (dark bars), seine-roe fishery (grey bars), and gillnet fishery (light grey bars). Units of catch are in thousands of metric tons. 23

2.2 Preliminary Spawning activity for Haida Gwaii (top panels) and Prince Rupert District (bottom) in 2011. 24

2.2 Preliminary Spawning activity for Central Coast (top left panel), Strait of Georgia (top right) in 2011 and west coast Vancouver Island (bottom). 25
2.3 Spawn survey index for Strait of Georgia between 1951 and 2011. The units are actual estimates of spawning biomass (1000s tons), but only the trend information is used in the model fitting. 26
2.4 Spatial location and sample sizes of 2011 biosamples from commercial and research-charter programs in the north coast (top panel) and south coast (lower panel). 28
2.5 Proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gillnet fishery (bottom) in Haida Gwaii. The area of the circle reflects the proportion-at-age, 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. 30
2.6 Proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gillnet fishery (bottom) in Prince Rupert District. The area of the circle reflects the proportion-at-age, 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. 31
2.7 Proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gillnet fishery (bottom) in the Central Coast region. The area of the circle reflects the proportion-at-age, 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. 32
2.8 Proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gillnet fishery (bottom) in the Strait of Georgia. The area of the circle reflects the proportion-at-age, 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. 33
2.9 Proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gillnet fishery (bottom) in the West Coast Vancouver Island region. The area of the circle reflects the proportion-at-age, 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. 34
2.10 Empirical mean weight-at-age data by cohort from 1951 to 2011 for ages 2 to 10 in the five major Stock Assessment Regions. 35
2.11 Residual for the log difference between observed and predicted catch for the five major SARs for each gear type (Gear 1 = winter seine fishery, Gear 2 = seine-roe fishery, Gear 3 = gillnet fishery). 38
2.12 Residual patterns for the log difference between observed and predicted spawn survey abundance for the five major SARs. Spawn survey data based on surface estimates are show as solid lines and data based on diver surveys is shown as dashed lines. 39
2.13 Observed (points) and predicted (lines) spawn survey abundance data scaled by the MLE estimate of q for each of the five major SARs. In each panel, the corresponding scaler (q) is presented for each of the surveys. 40
2.14 Residual difference between the observed and predicted proportions-at-age for HG for each of the three gear types (Gear 1 = winter seine, Gear 2 = seine-roe, Gear 3 = gillnet). The area of each circle is proportional to the residua, black is positive, and red is negative. The corresponding MLE estimates of the residual variance is displayed in each panel. 42
2.15 Residual difference between the observed and predicted proportions-at-age for PRD for each of the three gear types (Gear 1 = winter seine, Gear 2 = seine-roe, Gear 3 = gillnet). The area of each circle is proportional to the residua, black is positive, and red is negative. The corresponding MLE estimates of the residual variance is displayed in each panel. 43

2.16 Residual difference between the observed and predicted proportions-at-age for CC for each of the three gear types (Gear 1 = winter seine, Gear 2 = seine-roe, Gear 3 = gillnet). The area of each circle is proportional to the residua, black is positive, and red is negative. The corresponding MLE estimates of the residual variance is displayed in each panel. 44
2.17 Residual difference between the observed and predicted proportions-at-age for SOG for each of the three gear types (Gear 1 = winter seine, Gear 2 = seine-roe, Gear 3 = gillnet). The area of each circle is proportional to the residua, black is positive, and red is negative. The corresponding MLE estimates of the residual variance is displayed in each panel. 45
2.18 Residual difference between the observed and predicted proportions-at-age for WCVI for each of the three gear types (Gear 1 = winter seine, Gear 2 = seine-roe, Gear 3 = gillnet). The area of each circle is proportional to the residua, black is positive, and red is negative. The corresponding MLE estimates of the residual variance is displayed in each panel. 46
2.19 Estimates of total biomass at the start of the year (numbers times empirical weight-at-age) and spawning stock biomass (post fishery) for the five major SARs. 48
2.20 Estimates of spawning biomass depletion (B_t/B_0) for each of the five major stock areas. Horizontal dotted lines represent 25% and 40% depletion levels, and the shaded regions demarcate reference points based on <40% B_{MSY}/B_0(critical zone) and 40–80% B_{MSY}/B_0(cautious zone) and >80% B_{MSY}/B_0(healthy zone). Note that in calculating the B_{MSY} reference points, the average catch ratios over the last 20 years was used to partition fishing mortality to each of the gears. 49
2.21 Maximum likelihood estimates of the components of average total mortality for each of the five major stock assessment regions. Note that the y-axis is plotted on a log scale, natural mortality (grey) is age-independent, fishing mortality is age-specific and the average fishing mortality rate over all age-classes is plotted here. 50
2.22 Maximum likelihood estimates of age-specific selectivity coefficients for the winter seine fishery for each of the major stock areas. 51
2.23 Maximum likelihood estimates of age-specific selectivity coefficients for the seine-roe fishery for each of the major stock areas. 52
2.24 Estimates of selectivity for the gillnet fleet for each of the five major stock assessment regions. In this case selectivity is a logistic function of the empirical weight-at-age data; due to declining growth there is a tendency for selectivity to shift to older ages. 53
2.25 Maximum likelihood estimates of age-2 recruits for each of the five major stock areas. The horizontal divisions demarcate the 0.33 and 0.66 quantiles that define poor, average, and good recruitment. 54
2.26 Maximum likelihood estimates of age-2 recruits versus estimated spawning stock biomass in each of the five major assessment regions. The green and red circles indicate the start (recruits in 1952) and end (recruits in 2011) of the series, the circle plus (red) corresponds to the maximum likelihood estimate of unfished spawning biomass (B_0) and unfished age-2 recruitment R_0, the line is the Beverton-Holt stock recruitment model fitted to these data. . . 55
2.27 Log residual differences between estimated age-2 recruits and the recruitment predicted by the Beverton-Holt model and estimated spawning stock biomass. The standard deviations of the residuals along with the MLE estimate of the process error standard deviations are displayed at the top of each panel. 56
2.28 Retrospective estimates of spawning stock biomass for each of the five major stock assessment areas. The model was sequentially fitted to the full data set, then from 1951:2010, 1951:2009, ... 1951:2001. 57
2.29 A systematic sample of 2,000 from an MCMC chain of length 1,000,000 of leading parameters and derived variables used in reference point calculations for HG. Green circle corresponds to the MLE estimates and the solid line is a lowess smooth fit to the data (f=1/4), and the dashed line is the mean of the distribution. 59
2.30 A systematic sample of 2,000 from an MCMC chain of length 1,000,000 of leading parameters and derived variables used in reference point calculations for PRD. Green circle corresponds to the MLE estimates and the solid line is a lowess smooth fit to the data (f=1/4), and the dashed line is the mean of the distribution. 60

2.31 A systematic sample of 2,000 from an MCMC chain of length 1,000,000 of leading parameters and derived variables used in reference point calculations for CC. Green circle corresponds to the MLE estimates and the solid line is a lowess smooth fit to the data (f=1/4), and the dashed line is the mean of the distribution. 61
2.32 A systematic sample of 2,000 from an MCMC chain of length 1,000,000 of leading parameters and derived variables used in reference point calculations for SOG. Green circle corresponds to the MLE estimates and the solid line is a lowess smooth fit to the data (f=1/4), and the dashed line is the mean of the distribution. 62
2.33 A systematic sample of 2,000 from an MCMC chain of length 1,000,000 of leading parameters and derived variables used in reference point calculations for WCVI. Green circle corresponds to the MLE estimates and the solid line is a lowess smooth fit to the data (f=1/4), and the dashed line is the mean of the distribution. 63
2.34 Pairs plot and marginal distributions for leading parameters in HG region (200 random samples). The dotted lines correspond to the means of the distributions, circle is the mean, and the red square is the mode of the distribution. 64
2.35 Pairs plot and marginal distributions for leading parameters in PRD region (200 random samples). The dotted lines correspond to the means of the distributions, circle is the mean, and the red square is the mode of the distribution. 65
2.36 Pairs plot and marginal distributions for leading parameters in CC region (200 random samples). The dotted lines correspond to the means of the distributions, circle is the mean, and the red square is the mode of the distribution. 66
2.37 Pairs plot and marginal distributions for leading parameters in SOG region (200 random samples). The dotted lines correspond to the means of the distributions, circle is the mean, and the red square is the mode of the distribution. 67
2.38 Pairs plot and marginal distributions for leading parameters in WCVI region (200 random samples). The dotted lines correspond to the means of the distributions, circle is the mean, and the red square is the mode of the distribution. 68
2.39 Marginal posterior densities (histograms) and prior densities (lines) for the seven leading parameters and spawn survey scaler ($\ln(q)$, tan colour) for each of the five major assessment regions. 69
2.40 Top Panels: probability of the spawning stock biomass in 2013 falling below the cutoff level versus the 2012 catch option. Middle Panels: probability of the spawning stock in 2013 being less than the spawning stock biomass in 2012 versus the 2012 catch option. Bottom Panels: probability of the 2012 harvest rate (catch/3+ biomass) being greater than the target harvest rate of 0.2. 76
2.41 Catch and survey data for minor stock Areas 2W and Area 27. 77
2.42 Age composition data for Area 2W and Area 27 for the seine-roe fishery (Gear 2) and the gillnet fishery (Gear 3). 78
2.43 Maximum likelihood estimates of total biomass, spawning biomass, spawning depletion and fits to the spawn survey data for the two minor stock areas. 79
2.44 Maximum likelihood estimates of age-2 recruits, spawner-recruit relationships with the fitted Beverton Holt model and unfished reference points (B_o, R_o), and the residuals between the estimated age-2 recruits and that predicted by the Beverton-Holt model. 80
2.45 Retrospective estimates of spawning stock biomass for each of the minor stock assessment areas. The model was sequentially fitted to the full data set, then from 1951:2010, 1951:2009, ... 1951:2001. 81
2.46 A systematic sample of 2000 points from a chain of length 1,000,000 from the joint posterior distribution for areas 2W and area 27. 82
2.47 Marginal distributions for the leanding parameters based on a systematic sample of 2000 points from a chain of length 1,000,000 from the joint posterior distribution for areas 2W and area 27. 83

A.48 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. 91
A.49 Example of a natural cubic spline interpolation for 15-selectivity coefficients based on estimating 6 nodes (true selectivity was based on a logistic function). In ^{i}SCA$_M$ the user specifies the number of nodes (e.g., 6 circles) to estimate; then the 15 age-specific selectivity coefficients are interpolated using a natural cubic spline. 96
A.50 Example of a time-varying cubic spline (left) and bicubic spline (right) interpolation for selectivity based on data from the Pacific hake. 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. 97
A.51 Prior distributions used for $\ln(R_o), h, \ln(M), \ln(\bar{R}), \rho, \vartheta$ in the herring assessment models. . . 102
C.1 Distribution of the log of the simulated spawn index q estimates, overlaid with a normal distribution based on the mean and standard deviation of the simulated values. 120

List of Tables

1.1 A comparison of key parameters from ^{i}SCA$_{\mathrm{M}}$ and the HCAM model with the ^{i}SCA$_{\mathrm{M}}$ model set up like HCAM. 10
1.2 Summary statistics for alternative structural assumptions about the Strait of Georgia herring assessment from 1951 to 2010. Definitions are No. is the number of estimated parameters, f the objective function value, B_o unfished spawning biomass, h steepness, $\bar{M}$ is the average natural mortality rate, $B_{MSY}$the biomass at maximum sustainable yield, q survey scalers for pre and post 1988. 13
2.1 Summary of biological samples collected and processed from all sources from the 2010/11 herring season. 27
2.2 Summary of biological samples collected and processed from commercial catch and test fishery charters from 2002/03-2010/11. 27
2.3 Summary of maximum likelihood estimates for each of the five major stock areas. No. is the total number of estimated parameters, F_{MSY} the average instantaneous fishing rate to achieve the maximum sustainable yield (MSY), B_0 is the unfished spawning biomass, B_{MSY} is the spawning biomass that achieves maximum sustainable yield,B_t is the spawning biomass at the end of the 2011 fishing season, and B_t/B_0 is the spawning depletion level at the end of the 2011 fishing season. 47
2.4 Maximum likelihood estimates of gillnet selectivity parameters, where μ_a is the age-at-50% vulnerability, σ_a is the standard deviation in selectivity, and $\lambda^{(a)}$ is the coefficient that describes the influence of growth on selectivity ($\lambda^{(a)}$=0 implies no effect, $\lambda^{(a)} > 0$ implies a positive effect). 53
2.5 Estimates of 2011 spawning biomass, B_0, and depletion based on 2000 systematic samples from the joint posterior distribution drawn from a chain of length 1,000,000. 58
2.6 Estimated spawning stock biomass, age-4+ biomass and pre-fishery biomass for poor average and good recruitment, old cutoffs, and available harvest based on median values from the joint posterior distribution. 70
2.7 Estimated spawning stock biomass, age-4+ biomass and pre-fishery biomass for poor average and good recruitment, new cutoffs (based on median value of $0.25B_0$ estimated within the ^{i}SCA$_{\mathrm{M}}$ model), and available harvest based on the median values from the joint posterior distribution. 70
2.8 Decision table for HG where the risk level represents the probability of exceeding the quantities specified in the headers of each column. Three performance measures are considered: the probability of the spawning stock biomass in 2013 falling below the cutoff level, the probability of the spawning stock biomass in 2013 declining from 2012, and the probability of 2012 exploitation rate exceeding the 20% level that is used in the harvest control rule. To use this table, first determine the appropriate level of risk (e.g. 0.25 or 25% chance), then choose the appropriate management quantity (e.g. spawning biomass falling below the cutoff), and then read off the recommended catch (e.g., 3,060 tonnes). 71

2.9 Decision table for PRD where the risk level represents the probability of exceeding the quantities specified in the headers of each column. Three performance measures are considered: the probability of the spawning stock biomass in 2013 falling below the cutoff level, the probability of the spawning stock biomass in 2013 declining from 2012, and the probability of 2012 exploitation rate exceeding the 20% level that is used in the harvest control rule. To use this table, first determine the appropriate level of risk (e.g. 0.25 or 25% chance), then choose the appropriate management quantity (e.g. spawning biomass falling below the cutoff), and then read off the recommended catch (e.g., 1,788 tonnes). 72
2.10 Decision table for CC where the risk level represents the probability of exceeding the quantities specified in the headers of each column. Three performance measures are considered: the probability of the spawning stock biomass in 2013 falling below the cutoff level, the probability of the spawning stock biomass in 2013 declining from 2012, and the probability of 2012 exploitation rate exceeding the 20% level that is used in the harvest control rule. To use this table, first determine the appropriate level of risk (e.g. 0.25 or 25% chance), then choose the appropriate management quantity (e.g. spawning biomass falling below the cutoff), and then read off the recommended catch (e.g., 402 tonnes). 73
2.11 Decision table for SOG where the risk level represents the probability of exceeding the quantities specified in the headers of each column. Three performance measures are considered: the probability of the spawning stock biomass in 2013 falling below the cutoff level, the probability of the spawning stock biomass in 2013 declining from 2012, and the probability of 2012 exploitation rate exceeding the 20% level that is used in the harvest control rule. To use this table, first determine the appropriate level of risk (e.g. 0.25 or 25% chance), then choose the appropriate management quantity (e.g. spawning biomass falling below the cutoff), and then read off the recommended catch (e.g., 51,565 tonnes). 74
2.12 Decision table for WCVI where the risk level represents the probability of exceeding the quantities specified in the headers of each column. Three performance measures are considered: the probability of the spawning stock biomass in 2013 falling below the cutoff level, the probability of the spawning stock biomass in 2013 declining from 2012, and the probability of 2012 exploitation rate exceeding the 20% level that is used in the harvest control rule. To use this table, first determine the appropriate level of risk (e.g. 0.25 or 25% chance), then choose the appropriate management quantity (e.g. spawning biomass falling below the cutoff), and then read off the recommended catch (e.g., 184 tonnes). 75
2.13 Summary of maximum likelihood estimates for the two minor stock areas. No. is the total number of estimated parameters, F_{MSY} the average instantaneous fishing rate to achieve the maximum sustainable yield (MSY), B_0 is the unfished spawning biomass, B_{MSY} is the spawning biomass that achieves maximum sustainable yield,B_t is the spawning biomass at the end of the 2011 fishing season, and B_t/B_0 is the spawning depletion level at the end of the 2011 fishing season. 75
2.14 Estimated spawning stock biomass, age-4+ biomass and pre-fishery biomass for poor average and good recruitment, cutoffs, and available harvest. 81
A-1 Steady-state age-structured model assuming unequal vulnerability-at-age, age-specific natural mortality, age-specific fecundity and Beverton-Holt type recruitment. Note that M is the average natural mortality rate between 1951-2011. 90
A-2 Partial derivatives, based on components in Table A-1, required for the numerical calculation of F_{MSY} using (A.1). 92
A-3 Statistical catch-age model using the Baranov catch equation, where R_0 and κ are the leading parameters that define population scale and productivity, respectively. 93
A-4 An incomplete list of symbols, constants and description for variables used in ^{i}SCAM. 94
C-1 Factors affecting the q prior and their assumed distributions. 119
C-2 Estimated means and standard deviations for the simulated q prior and natural log of the q prior. 120
C-3 Summary of west coast North America herring egg loss literature. 121

C-4 Estimates of the instantaneous daily egg loss rate (Z) from herring egg loss studies conducted in the Pacific Northwest. The Z estimates for the Haegele and Schweigert (1989, 1991) studies were calculated from their reported egg loss rates over the study period. 122
C-5 Criteria for selecting herring spawn survey data records for estimating days between spawning and surveys. The "number of records" is the records retained after each successive selection criterion. 122
C-6 Average number of days between spawn deposition and spawn survey by stock assessment region and year. 123
D-1 Observed catch by gear type and year for each stock. 125
D-2 Abundance for each survey by year for each stock. 127

Part I

Moving towards a sustainable fisheries framework for Pacific herring: data, models and alternative assumptions

1.1 Introduction

There are four major objectives of this paper: (1) to describe in detail an alternative integrated statistical catch-age model (^{i}SCA$_{\mathrm{M}}$), (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 1.1). 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 $0.25B_o$, and estimates of unfished biomass were established first in 1985 (Haist et al., 1986). Estimates of B_o were updated most recently in 1996, and in last years HCAM assessment marginal posterior distributions for B_o were also presented but were not used to update cutoffs (Cleary and Schweigert, 2010). These cutoffs are currently thought to be more conservative than the current default Limit Reference Point of 0.4B$_{\mathrm{MSY}}$ (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 ^{i}SCA$_{\mathrm{M}}$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 HCAM (v2) in this paper and we refer the reader to Schweigert et al. (2009) and Cleary and Schweigert (2010). 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 estimation 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 forecasts 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.

1.2 Methods

1.2.1 Analytical methods

We present a new stock assessment platform for the assessment of BC Pacific herring. This platform is based on the general statistical catch age model first described by Fournier and Archibald (1982). The software platform used is called ^{i}SCA$_{\mathrm{M}}$, which stands for integrated Statistical Catch Age Model. The source code and documentation for ^{i}SCA$_{\mathrm{M}}$ is freely available from `https://sites.google.com/site/iscamproject/`, or from a subversion repository at `http://code.google.com/p/iscam-project/`. The subversion repository is more likely to be up to date; whereas, the project website has periodic updates with corresponding version numbers. 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 ^{i}SCA$_{\mathrm{M}}$ is provided in Appendix A.1 of this report.

At times this document reads more like a users manual for the ^{i}SCA$_{\mathrm{M}}$software and this is intentional as we expect that reviewers may wish to repeat the efforts to verify model results. The details of the analytical

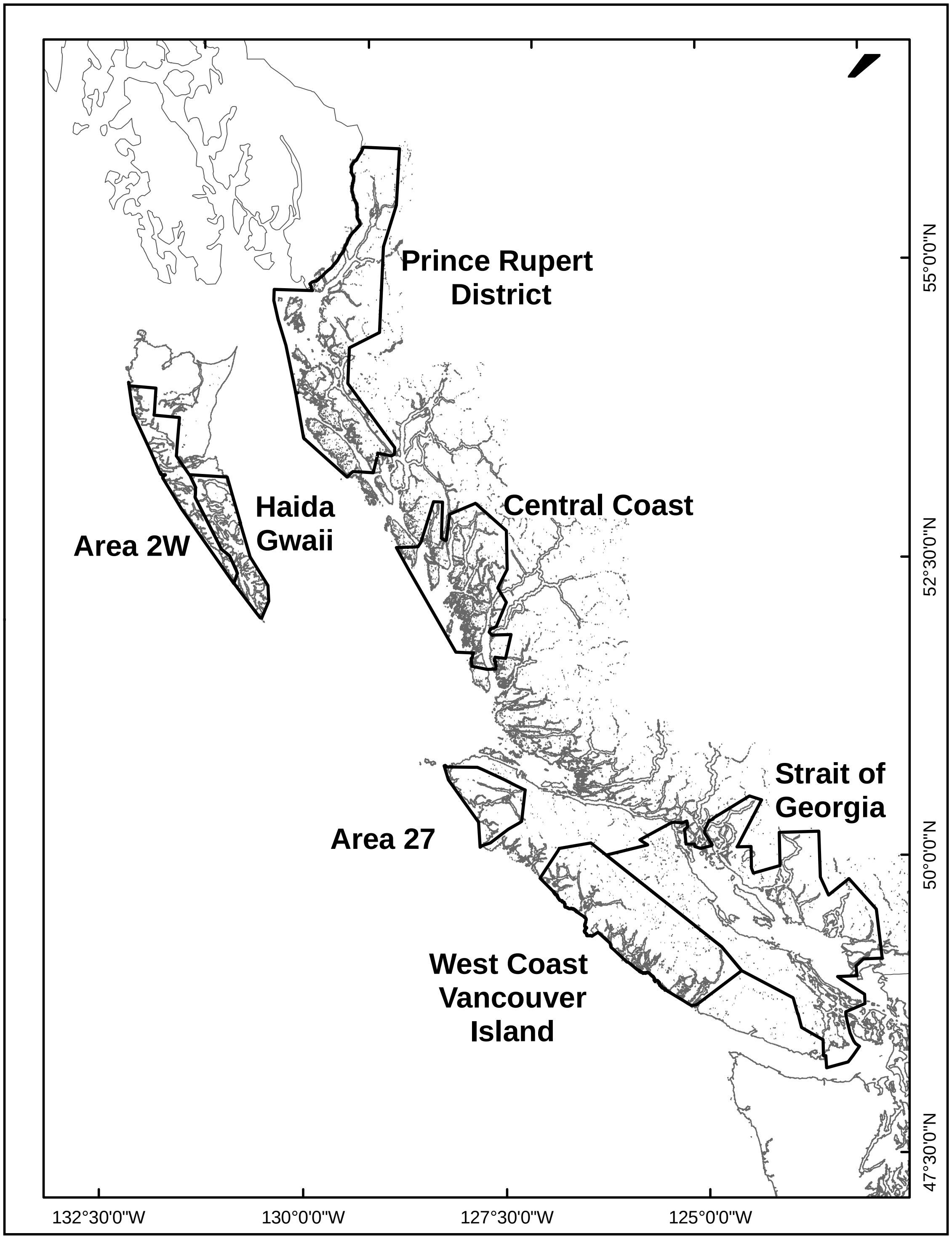

Figure 1.1: B.C. herring major stock areas: Haida Gwaii (HG or QCI 2E), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SOG), West Coast Vancouver Island (WCVI), and minor stock areas: Area 2W and Area 27.

equations are identified in Appendix A.1, and the text herein will often refer to how to implement the scenario in the software itself.

In short, for each stock two input files are required for ^{i}SCA$_{\mathrm{M}}$: (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.2 such that these results can be verified by an independent reviewer using the ^{i}SCA$_{\mathrm{M}}$ 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.

1.2.2 Sustainable Fisheries Framework reference points

The Sustainable Fisheries Framework provides the basis for ensuring Canadian fisheries are conducted in a manner which support conservation and sustainable use. The framework incorporates existing fisheries management policies along with new and evolving policies. The framework consists of two main elements: conservation and sustainable use policies, and planning and monitoring tools. The conservation and sustainable use policies incorporate the precautionary and ecosystem approaches to fisheries management.

The general framework for developing a harvest strategy that is compliant with the precautionary approach is to divide the stock into three stock status zones; healthy, cautious, and critical zones (Fisheries and Oceans Canada, 2006). In this work we define these stock status thresholds as $0.4\mathrm{B}_{\mathrm{MSY}}$ and $0.8\mathrm{B}_{\mathrm{MSY}}$ when crossing from the critical-cautious zone and cautious-healthy zone, respectively. A critical component to this interpretation is the definition of $\mathrm{B}_{\mathrm{MSY}}$. In the case of a single fishing fleet using a fixed gear, $\mathrm{B}_{\mathrm{MSY}}$ is normally defined as the spawning stock biomass that would, on average, support the largest surplus yield. In the case of multiple fishing fleets, each using a different gear with different selectivities, the definition of $\mathrm{B}_{\mathrm{MSY}}$ is more complex and is a function of allocation of mortality to each gear type. For example, if one gear harvest fish at a much younger age than the other gear, an increase in allocation to the gear that catches younger sexually immature fish will shift $\mathrm{B}_{\mathrm{MSY}}$ upwards. Also, changes in selectivity over time (perhaps due to changes in growth) will result in changing $\mathrm{B}_{\mathrm{MSY}}$. This precise definition for $\mathrm{B}_{\mathrm{MSY}}$ increases the difficulty in estimating reference points when there are non-stationary parameters in the model (i.e., time-varying natural mortality rates, selectivity, growth in the case of Pacific herring).

Estimates of reference points are based on equilibrium calculations (see Appendix A.1), where the average natural mortality rate over the time period in question is used along with the most recent empirical estimates of weight-at-age and fecundity. In lieu of any formal allocation arrangements for the gear-types that harvest herring, the ratios of average catch over the past 20 years for each gear type, in each SAR, are used for allocation purposes and calculating MSY based reference points.

1.2.3 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 ^{i}SCA$_{\mathrm{M}}$, 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 replicates precisely the true vulnerable proportions-at-age. The simulation 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.

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 Appendix B.2.8.

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 $\hat{\theta} = 2\theta$, and is -1 when $\hat{\theta} = 0.5\theta$. 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 (i.e., 1/2.50=0.4). The control file used for the Monte Carlo procedures is provided in Appendix B.2.8, on page 117.

The simulation testing presented here is not very extensive in that only a single scenario based on the catch time series in the Strait of Georgia and an arbitrary parameter set θ was used to explore bias and precision. In practicality, additional simulation testing should be conducted preferably using the MLE estimates of $\hat{\theta}$ as true parameter values to determine if the data and model structure combined are informative about the true parameter values. It is possible to obtain a spurious results based on the choice of θ that was used in simulation trials.

1.2.4 Comparison of HCAM with ^{i}SCA$_{\mathrm{M}}$

There are a number of different statistical assumptions and structural differences between the previous assessments using HCAM (Herring Catch Age Model) and ^{i}SCA$_{\mathrm{M}}$. Here we briefly summarize the differences and similarities between the two approaches, and we first attempt to formulate the ^{i}SCA$_{\mathrm{M}}$ 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. The following subsections describe how ^{i}SCA$_{\mathrm{M}}$ was set up to best approximate HCAM.

For the gillnet fishery, HCAM implements a time varying selectivity scheme as a function of the average weight-at-age. A similar implementation was also developed in ^{i}SCA$_{\mathrm{M}}$. Alternative options for changes in selectivity will be investigated later in this paper. For the remainder of this paper and especially in the Figures, the definitions for Gear is as follows: Gear 1 = winter purse seine fishery, Gear 2 = seine-roe fishery, Gear 3 = gillnet fishery.

Age-composition data

There are two alternative likelihoods specified for the age-composition data in HCAM (see Table 8 in Appendix B in Cleary and Schweigert, 2010); a multinomial likelihood (T8.1), and a robust normal approximation to the multinomial(T8.2). In ^{i}SCA$_{\mathrm{M}}$, a multivariate logistic negative log-likelihood for age-composition data is used (see equation A.10 above); this likelihood weights age-composition data based on the conditional maximum likelihood estimate of the variance. Whereas, the multinomial likelihoods weights data based on the effective sample size; the effective sample size is normally determined iteratively by examining the distributions of residuals relative to other sources of information that the model is fit to (see Gavaris and Ianelli, 2002, for full details).

In addition, ^{i}SCA$_\text{M}$ requires a minimum observed proportion in each age class to reduce the influence on the likelihood of observations from extremely weak cohorts that would be difficult to detect due to measurement errors. We assume in years and ages where the observed proportion is less than 2%, the consecutive ages are grouped into a single age-class which reduces the effective number of age-classes (this is some what analogous to a plus group). For example, assume the age-proportions in 1970 of age-2 and age-3 fish are 3.5% and 0.1%, respectively. If the user specifies a minimum proportion of 2% then ^{i}SCA$_\text{M}$ will treat these observations as 3.6% age 2-3 fish in 1970. Pooling the data this way has been shown to reduce the influence of measurement errors on weak cohorts (Richards et al., 1997).

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 gear types. To implement these assumptions in ^{i}SCA$_\text{M}$ we fix the assumed standard deviation for the catches in the last phase to 0.0707 for each of the gear-types for all years. In other words, we assume that errors in estimating the catch by gear-type is constant over the 1951-2011 time period.

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}SCA$_\text{M}$ the relative weights for the pre and post 1988 survey data were fixed at 1.0 and 1.1666, respectively. In ^{i}SCA$_\text{M}$ the total error (or precision=1/(std. dev.)) 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 ^{i}SCA$_\text{M}$ (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 $\rho = 0.35/1.15$. The total variance is calculated as $(0.35^2 + 0.8^2)^{-1}$.

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}SCA$_\text{M}$ 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. Note that the use of a lognormal prior for natural mortality rates will result in a slight downward bias in the maximum likelihood estimate of natural mortality rates. Based on the prior distribution described above, the mode of this distribution is approximately equivalent to an $M = 0.38$.

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

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

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}SCA$_{\mathrm{M}}$ 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 (i.e., a biased random walk) and long-term changes in M could have profound effects on reference point calculations. HCAM assumed an unbiased random walk and the central tendency of d_t is 0; whereas, ^{i}SCA$_{\mathrm{M}}$assumes a biased random walk and 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}SCA$_{\mathrm{M}}$, 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}SCA$_{\mathrm{M}}$ model, or treated as fixed constants; however, ^{i}SCA$_{\mathrm{M}}$ estimates the total error and partitions it into observation (σ) and process error (τ) components. To make the same assumptions about the error terms in ^{i}SCA$_{\mathrm{M}}$ as those that were used in HCAM the following values were used $\vartheta = 1/1.15 = .8695$, and $\rho = 0.3043$, 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 HCAM was based on a lognormal distribution with a log mean 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}SCA$_{\mathrm{M}}$ 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 switched 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 using an uninformative prior. Again, to emulate these assumptions in ^{i}SCA$_{\mathrm{M}}$ 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 uninformative prior for the pre-1988 data.

1.3 Results

1.3.1 Simulation testing

Model validation against perfect information

Given perfect information about trends in relative abundance and age composition information, and a deterministic stock-recruitment relationship, ^{i}SCA$_{\mathrm{M}}$ 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 1.2 estimates of spawning biomass and fishing mortality rates were exactly the same as the true values. There is no measurable difference between the observed and predicted trends in the relative abundance information (Figs. 1.2cd).

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 $\widehat{\tau}^2$ for the winter seine fishery $\widehat{\tau}^2 = 2.49e-03$, the seine roe fishery $\widehat{\tau}^2 = 1.25e-27$, and the gillnet fishery $\widehat{\tau}^2 = 1.24e-27$.

This perfect fit to the data is used only to judge if the code is syntactically correct and to determine if it

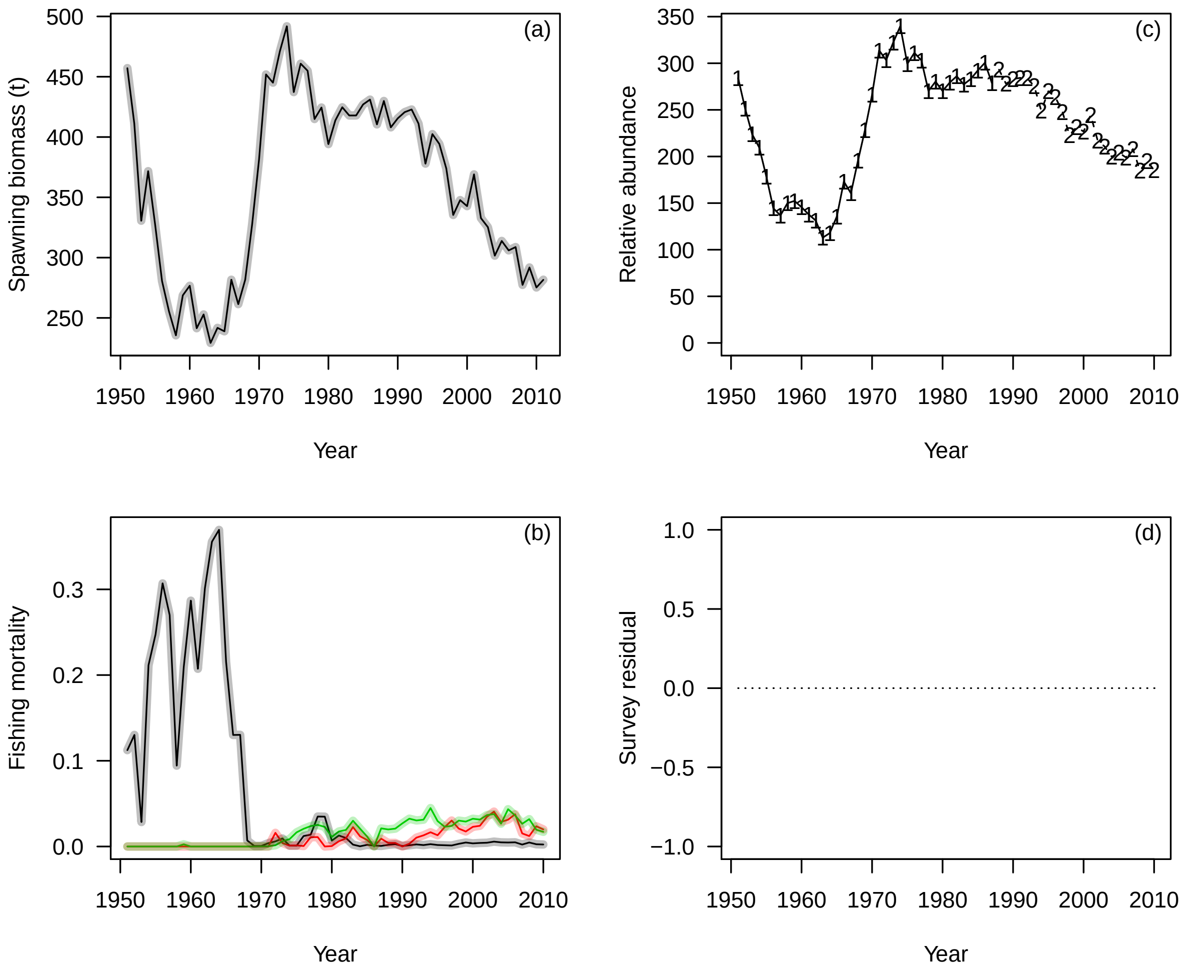

Figure 1.2: True (thin line) and estimated (thick shaded line) spawning biomass (a), fishing mortality rates by gear (b), observed and predicted relative abundance (c), and residuals between observed and predicted relative abundance (d) for the SOG herring simulation with perfect information and a deterministic stock-recruitment relationship.

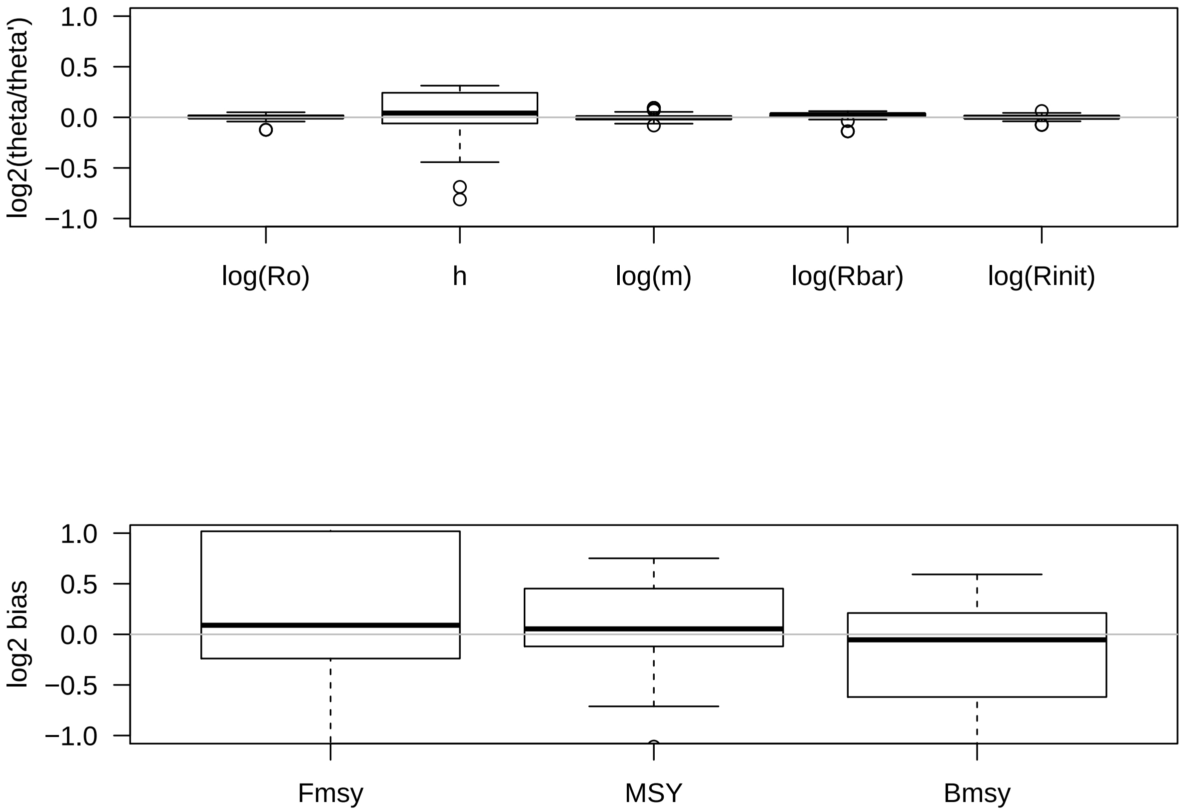

Figure 1.3: Estimates of precision and bias in key model parameters and MSY based reference points for 50 simulated data sets conditioned on the Strait of Georgia herring catch. The log2 ratio of estimated (numerator) versus true (denominator) value is plotted; values of 1 and -1 correspond to a twice or half the true value, respectively.

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.

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 recruitment ($\ln(R_o)$) and the natural mortality rate ($\ln(M)$), the average recruitment ($\ln(\bar{R})$) and the initial recruitment ($\ln(\dot{R})$), as shown in Figure 1.3. 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 ($h = 0.8$). These high values of M and h imply a very productive stock, and the spawning biomass would have to be driven to very low levels in order to generate data that would be informative about the underlying production function. Note that M and h are confounded because M is required to calculate the spawning stock biomass per recruit in unfished conditions. 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 1.3 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.

It should also be noted here that this simulation is somewhat unrealistic in comparison to applying the model to the real data. The simulated conditions have a much lower total variance in comparison to the real assessments, we assume the ratio of observation error to process error is precisely known, and M and selectivity are constant. Whereas, in the real assessments the total error is estimated and partitioned into observation error and process error using an informative prior, M and selectivity in the gill net fisheries are not constant and allowed to vary over time. These assumptions should actually be simulation tested in future work to better characterize the nature of the data and model assumptions.

1.3.2 Comparison of HCAM with ^{i}SCA$_{M}$

Based on the description of the priors and model setup in Section 1.2.4 on page 5, a comparison of the spawning stock biomass between ^{i}SCA$_{M}$ and HCAM were very similar (Figure 1.4a) for the Strait of Georgia stock. 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 difference in the assumptions about the error structure for the age-composition data.

Estimates of spawning depletion are based on the post fishery spawning biomass relative to the estimated unfished spawning biomass (Figure 1.4b). The three coloured zones demarcate the critical zone, cautious zone, and healthy zones with transitions defined by $0.4B_{MSY}$ and $0.8B_{MSY}$, respectively.

Maximum likelihood estimates of key model parameters for both ^{i}SCA$_{M}$ and HCAM are summarized in Table 1.1. The ^{i}SCA$_{M}$ model has 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. Both models assume that stock-recruitment is in the form of Beverton-Holt, only the prior for steepness differs between the two models.

Table 1.1: A comparison of key parameters from ^{i}SCA$_{M}$ and the HCAM model with the ^{i}SCA$_{M}$ model set up like HCAM.

Parameter	^{i}SCA$_{M}$	HCAM
Unfished spawning biomass (B_o 1000 t)	108.492	190.817
Steepness (h)	0.811	0.683
Average natural mortality rate	0.563	0.334
Survey q for period 1	0.985	1.1105

Average natural mortality rate is higher in the ^{i}SCA$_{M}$ model (Table 1.1), and the survey q for the pre-1988 spawn survey data is nearly identical in the two models (Figure 1.4f). The more contemporary survey data were forced to scale with $q = 1.0$. There is some pattern in the residuals for the overall fits to the

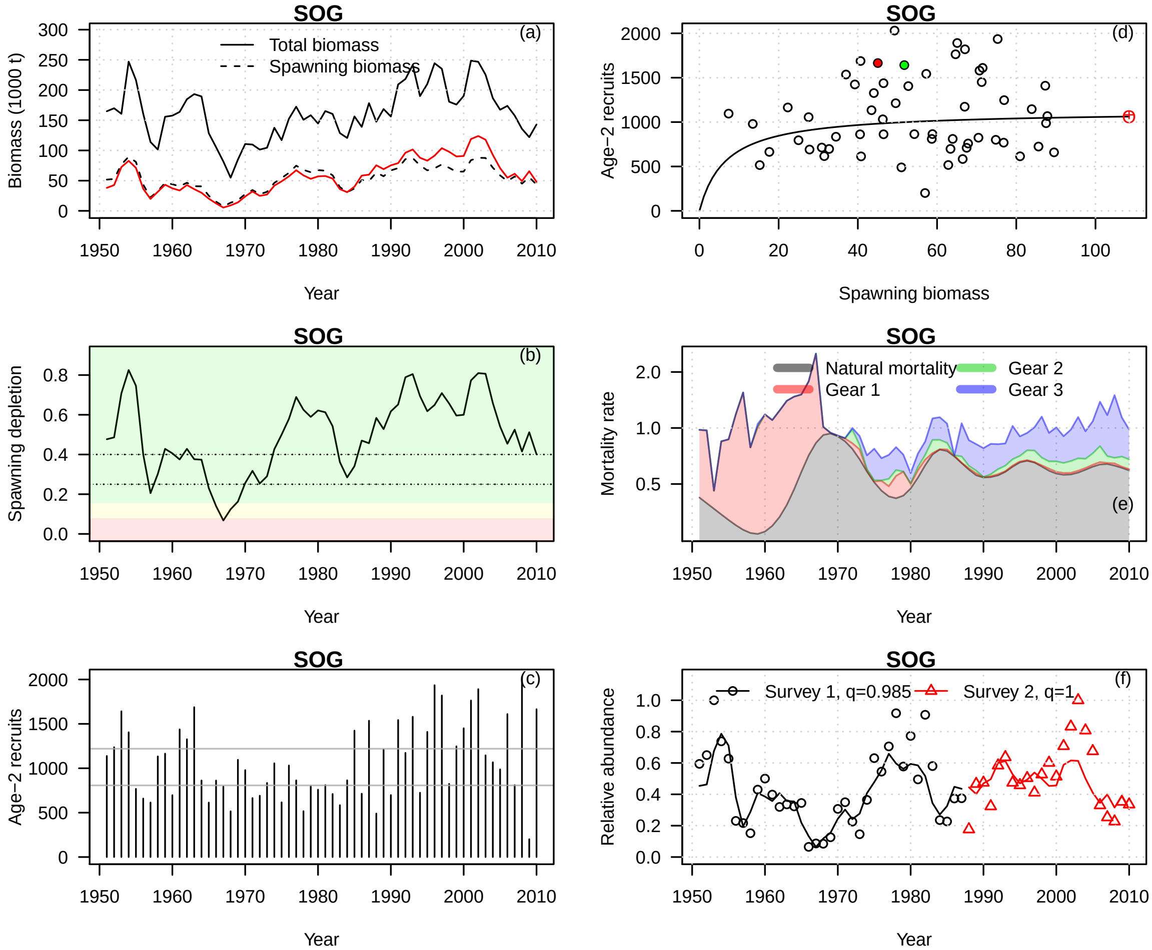

Figure 1.4: Results based on trying to configure the $^{i}\text{SCA}_{\text{M}}$ model as similar as possible to the previous HCAM assessment. Maximum likelihood estimates of pre-fishery biomass (defined as the numbers-at-age times the mean weight-at-age at the start of the year) and post fishery spawning biomass in the Strait of Georgia (a), spawning biomass depletion (b), age-2 recruits (c), stock-recruitment relationship and unfished reference points (d), components of total mortality (log-scale, panel e), and observed (points) and predicted (lines) spawn survey data (f). The red line in panel (a) is the MLE estimate of spawning biomass from HCAM.

survey data (Figure 1.4f), the model fails to predict the large increases in abundance in the late 1970s and early 2000s and the recent sharp decline in the mid 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 1.4f is 0.335 and 0.334, respectively.

Estimates of the components of total mortality for the comparison with the HCAM model are shown in Figure 1.4e. 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 winter purse-seine fishery where fish were taken for fishmeal (the reduction fishery). After the fishery reopened in the early 1970s fishing mortality rates were greatly reduced and targeted the spring spawning aggregations as the market was for herring roe.

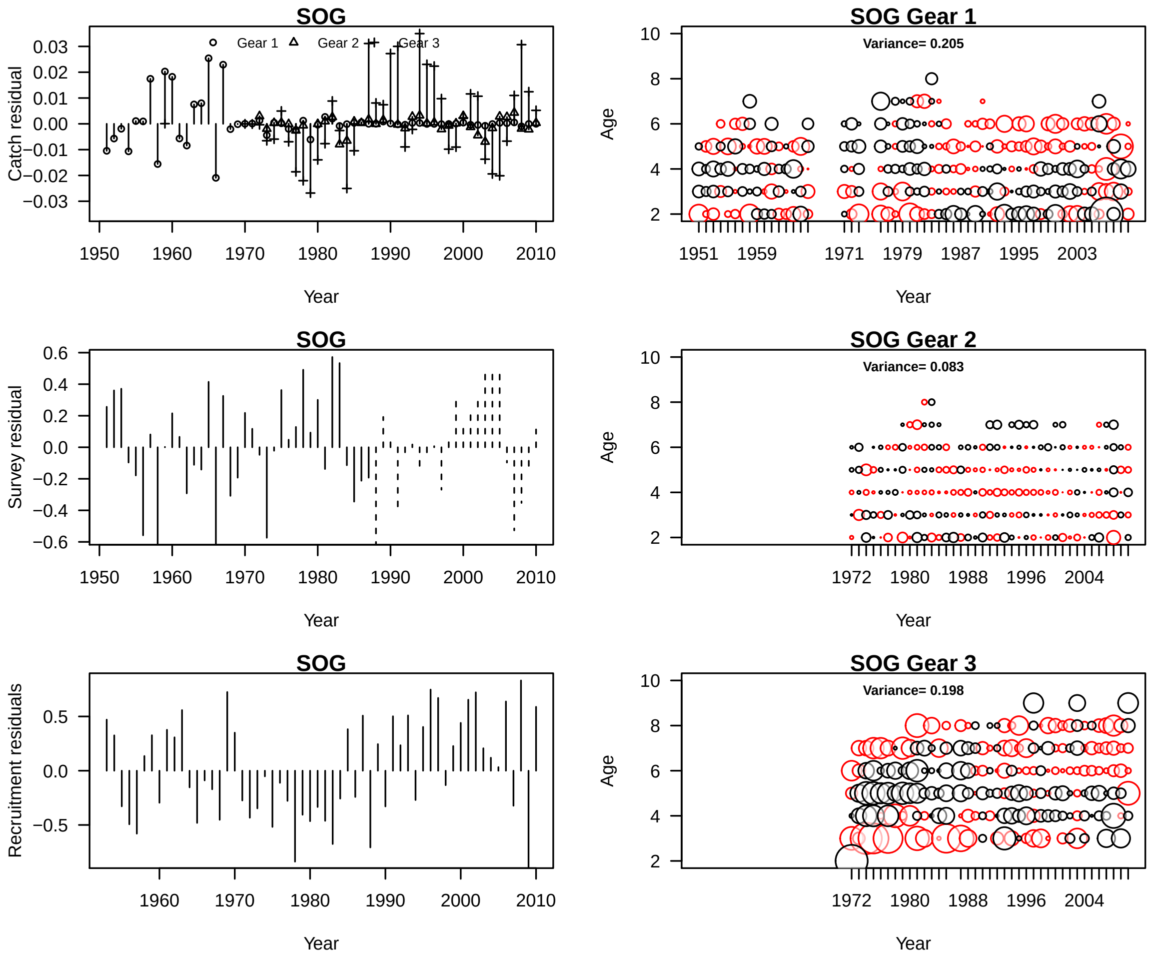

Figure 1.5: Results are based on configuring $^{i}\mathrm{SCA}_{\mathrm{M}}$ to be similar to HCAM. From top to bottom in the left column: the log residuals between observed and predicted catch for each gear, the residuals between the observed and predicted spawn survey index, and the annual deviations between age-2 recruitment and that predicted by the Beverton-Holt model and the estimated spawning stock biomass. Right column: residual patterns in the age-composition data (observed - predicted, where black is a positive residual) for each of the three commercial gears in the Strait of Georgia.

Estimates of natural mortality are based on a random walk process, initially starting at a value of 0.401 in 1951 and declining to a very low value of 0.217 in 1959, then increasing to a maximum of 0.915 in 1969 (Figure 1.4e). Information to estimate natural mortality rates comes from the age-composition data, and assumptions about selectivity in the fishery. In this comparison, the $^{i}\mathrm{SCA}_{\mathrm{M}}$ model assumes selectivity is invariant for the purse seine gears and is a function of weight-at-age for the gillnet gear. Much of the residual variation in the age-composition is explained by variation in M and variation in age-2 recruits (see Figures 1.4c & d for and age-2 recruitment and stock recruitment relationship). The HCAM model has a very similar trend in the estimates of natural mortality but the variability is much less than that of the $^{i}\mathrm{SCA}_{\mathrm{M}}$ assessment. This is almost certainly due to the differences in the assumptions about the error structure in the age-composition data (or relative weights associated with the age-composition).

There is good correspondence between the observed and predicted catch, however, the residual patterns do not appear to be iid for each of the fleets (Fig. 1.5). Recall that the fit to the catch data is largely determined by an assumed variance for the observation errors in the reported catch ($\sigma_C^2 = 0.005$).

The fit to the spawn survey data in Strait of Georgia is nearly iid for the 1951:1987 time period. There is some pattern in the residuals post 1988 that appears to be in contradiction with other information (i.e., age-composition data and structural assumptions about selectivity) (Fig. 1.5). The pattern in the recruitment residuals for the Strait of Georgia suggest periods of below average-recruitment in the 1970s and early 1980s and above average recruitment starting in the early 1990s.

Fits to the age-composition data for the purse seine-roe fishery were best in comparison to the winter seine and gillnet fisheries. The conditional maximum likelihood estimates of the variance of the age-composition data are 0.205, 0.083, and 0.198 for the winter purse seine, seine-roe, and gillnet fisheries, respectively. The smaller the standard deviation, the better correspondence between the observed and predicted age-composition data. Also the pattern of residuals does indicate some model mis-specification (e.g., the gillnet fishery in the Strait of Georgia).

1.3.3 Alternative assumptions about catchability, mortality & selectivity

Here we briefly explore the differences between relaxing the informative prior on catchability for the survey, reducing the number of natural mortality parameters being estimated and exploring alternative selectivity options to try and reduce the residual pattern in the gillnet fishery age-composition data. For the comparisons, we only examine the maximum likelihood fits to the data and the overall objective function value. Table 1.2 presents a few summary statistics for the following sub sections for easier comparison.

Table 1.2: Summary statistics for alternative structural assumptions about the Strait of Georgia herring assessment from 1951 to 2010. Definitions are No. is the number of estimated parameters, f the objective function value, B_o unfished spawning biomass, h steepness, $\bar{M}$ is the average natural mortality rate, B_{MSY} the biomass at maximum sustainable yield, q survey scalers for pre and post 1988.

Model	No.	f	B_o	h	$\bar{M}$	B_{MSY}	q_1	q_2
Fixed q	279	-1166.62	108.49	0.812	0.56	20.962	0.985	1.0
Prior q	279	-1161.83	110.57	0.798	0.59	21.964	0.912	0.912
Fixed M	219	-1055.48	128.06	0.687	0.67	25.727	0.688	0.796
Gillnet Selectivity	279	-1196.06	121.65	0.76	0.655	25.27	0.817	0.683

Impacts of informative priors on q's

The implication of relaxing the informative prior on q for the contemporary spawn survey data was examined by using a less informative prior for the spawn survey q. The results shown in Fig. 1.6 is a comparison of the HCAM parameterized version of the model as shown in previous sections with a version where the prior on $\ln(q)$ was assumed normal ($\mu = 0, \sigma = 0.274$) for both the contemporary and surface survey data.

The net result of relaxing this prior on q is a slight increase in the global scaling (the spawn biomass increases by roughly 12%) in comparison to the fixed $q = 1$ scenario. There is no appreciable difference in the overall fits to the data (see objective function value in Table 1.2).

Implications of variable natural mortality rate M_t

In this next scenario we use the less informative prior for $\ln(q)$ as in the previous section but do not allow natural mortality rates to vary over time (i.e., fixed M). The natural mortality rate and q are confounded so it does not make sense to fix q and estimate M because the corresponding estimate of M would simply be conditional on the assumed value of q.

In the case where M is assumed to be time invariant, estimates of average M over the entire time series does increase slightly as well as the overall scaling of population size (Table 1.2). There are 60 fewer estimated parameters in this case but the overall fit to the data is slightly degraded (Fig 1.7, and see objective function values in Table 1.2).

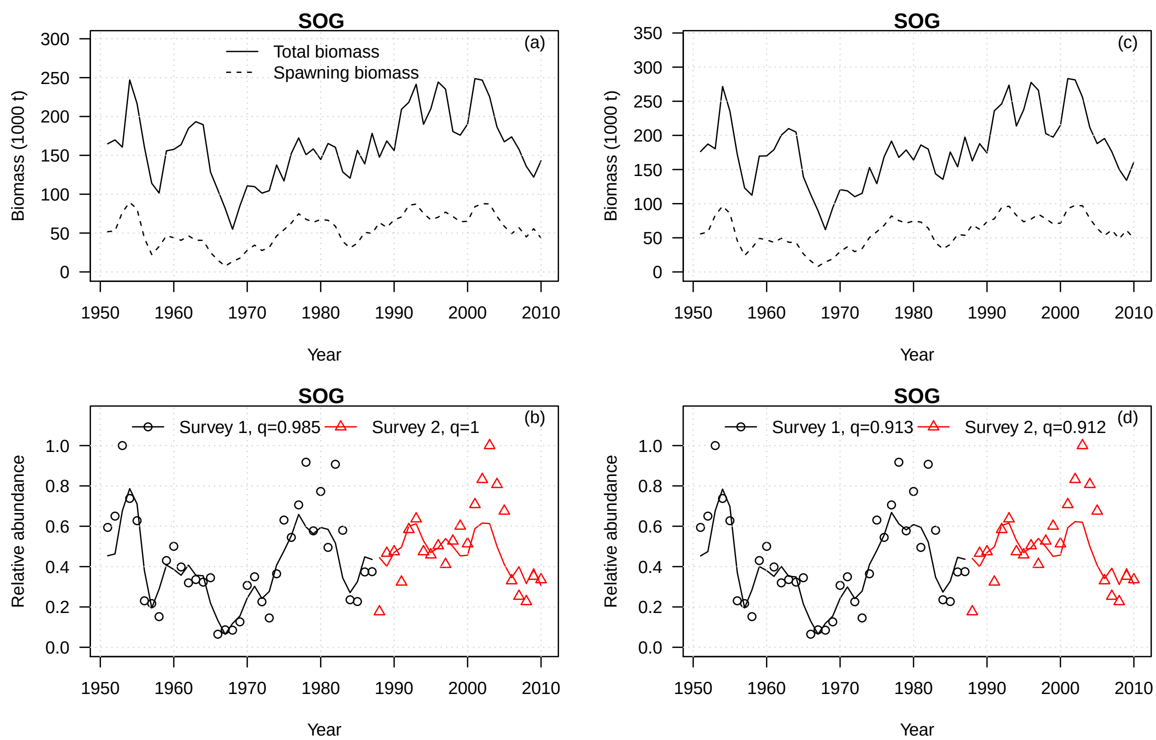

Figure 1.6: A comparison of the estimated biomass and spawning biomass and fits to the survey data when q is either fixed at 1 for Survey 2 (panels a, b), or estimated using an informative prior with an expected mean of 0 and a log standard deviation of 0.274 (panels c and d).

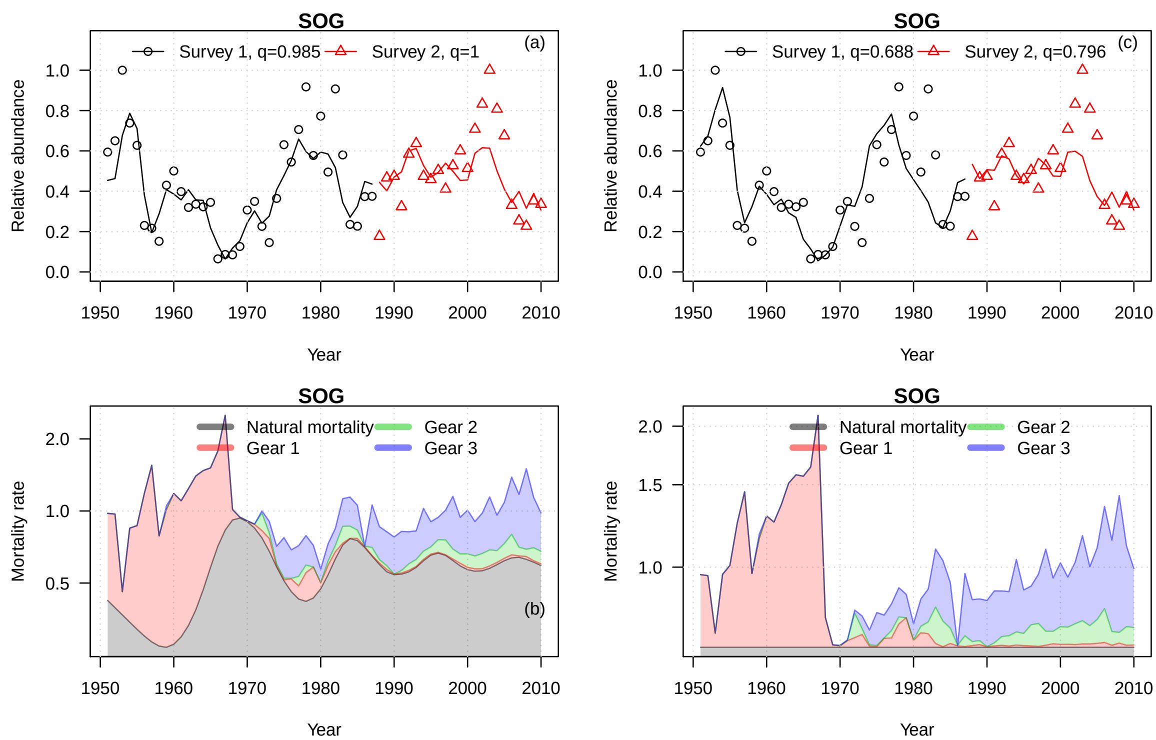

Figure 1.7: A comparison of fits to the survey data and estimated components of average mortality by year when M is allowed to vary via a random walk process or is estimated and assumed time invariant. Note that the y-axis in panels (b) and (d) are on a log scale and that the estimate of M is 0.67 in panel (d).

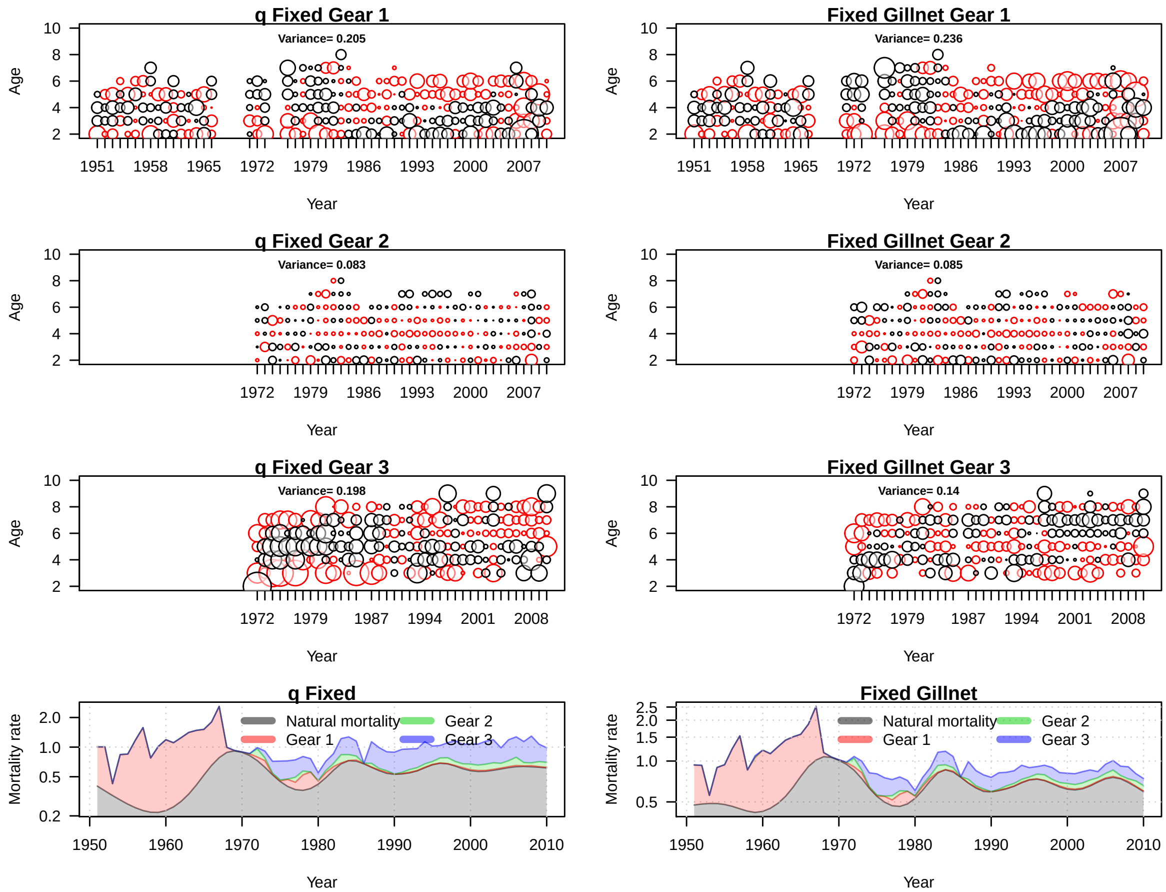

Figure 1.8: Residuals in the age-composition data when gillnet selectivity is a function of mean weight-at-age (left column with q Fixed in each caption) and or is a logistic function of age and time invariant (right column with Fixed Gillnet in each caption).

Implications of variable selectivity in directed fisheries

Finally, we also explored the option of treating the gillnet selectivity as time invariant and estimated two parameters that describe age-specific selectivity using a logistic curve. In this case we also allowed for a random walk process in natural mortality rates so the total number of estimated parameters remains the same.

Better fits to the gillnet fishery age-composition data were obtained with constant selectivity, and the residual pattern also appears to improve under the assumption of constant selectivity (Fig. 1.8). There was also a slight degradation to the age composition data in the winter purse seine fishery (Gear 1), but residual patterns were nearly identical in both the seine fisheries (Fig. 1.8). The same number of model parameters were estimated and there was a slight improvement in the overall objective function with constant selectivity (Table 1.2). Trends in the estimates of natural mortality rates are similar when the gillnet selectivity is assumed constant.

1.3.4 Preliminary assessments for all other areas

For the five major stock assessment regions there was very good correspondence between the estimated spawning stock biomass between the HCAM and new ^{i}SCA$_{\text{M}}$ models (Fig. 1.9). The control file used for each of the assessment regions was the same as that used for the Strait of Georgia. No additional changes were required (i.e., each SAR had the same initial starting parameter values etc.). In some areas there are minor differences in the trends and overall scaling (e.g., SOG, PRD), these were also identified as cases that had persistent negative residuals in the HCAM model.

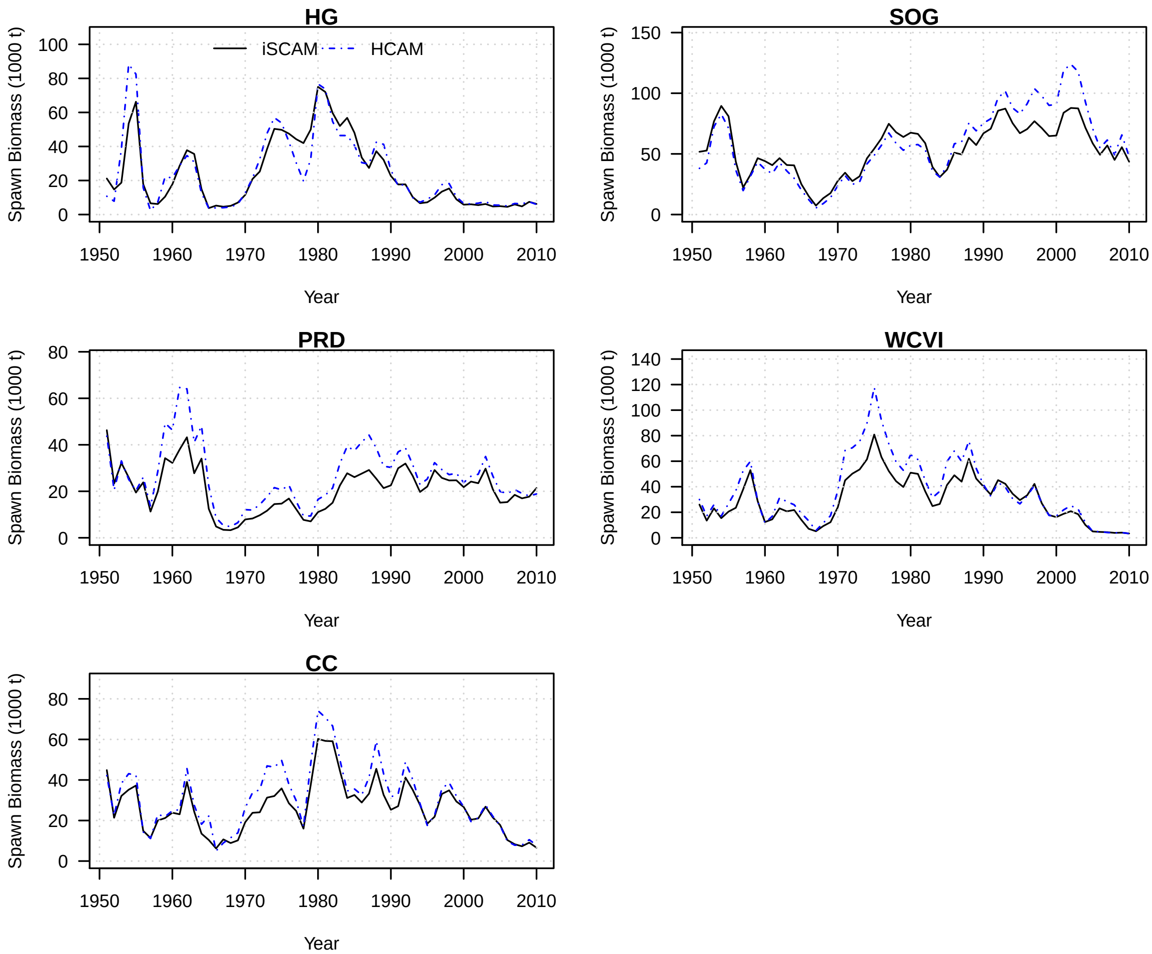

Figure 1.9: A comparison of estimated spawning stock biomass between HCAM and ^{i}SCA$_{\text{M}}$ for the five major stock assessment regions using data from 1951 to 2010 and setting up ^{i}SCA$_{\text{M}}$ similar to HCAM.

1.4 Discussion

The simulation studies showed a minor upward bias in the estimates of F_{MSY}, MSY and a slight bias in steepness. Unfortunately, the true parameter values used in the simulation study did not provide significant contrast in the data to generate information over a wide range of spawning depletion. In general, such widely contrasting data are required to resolve parameter confounding (Hilborn and Walters, 1992). The simulated fishing mortality rates were extremely low (i.e., less than 0.3 between 1951 and 1969, and less than 0.1 post 1970.) and the stock was never depressed to a level where, on average, recruitment would be limited by spawner abundance. Future simulation studies should impose a more severe mortality schedule to see if this resolves the slight parameter bias.

There are a few significant differences between ^{i}SCA$_{M}$ and the previous assessment using HCAM, despite efforts to parametrize ^{i}SCA$_{M}$ as close as possible to HCAM. These differences include: different likelihood function for the age-composition data, using the conditional maximum likelihood estimate of q, estimation of variance, and jointly estimating parameters for the stock recruitment relationship. Here we briefly discuss how these structural differences influence model results.

In our attempts to parametrize the ^{i}SCA$_{M}$ model to reproduce the results of last years HCAM assessment, we fixed the variance and variance partitioning parameters such that the same weights were placed on the spawn observation errors and variation in annual recruitment. The age-composition data, however, were not given the same weight as the multinomial samples sizes that were used in the HCAM model. In this case, the ^{i}SCA$_{M}$ model assumes a homogenous variance in the age-composition data and the weight assigned to each observation is based on the conditional maximum likelihood estimate of the variance (i.e., this is akin to using concentrated likelihoods for the age-composition data). The main affect of this difference in likelihood formulations is that in the ^{i}SCA$_{M}$ model each year is given the same weight regardless of sample size (i.e., small and large sample sizes are given too much or too little weight, respectively, in comparison to the multinomial likelihood used in HCAM). That being said, there is also much debate about what the effective sample size should be when using the multinomial likelihood due to correlation structure in the samples (e.g., Francis, 2011). Another subtle difference between the two approaches is the pooling of samples that are less than 2% of the age-composition into the adjacent year class.

A second major difference between the two modelling platforms is the how q for the dive survey data is treated. In the previous HCAM model, the dive survey q was fixed at 1, and was not treated as a latent variable. As a result the residuals between the observed and predicted survey data did not have a mean of 0 due to contradictions between the spawn survey data and the age-composition data in the SOG assessment. The residuals for the spawn survey data post 1988 were nearly all negative. In the ^{i}SCA$_{M}$ model, the conditional maximum likelihood estimate of q was used to scale the spawn survey data along with a very informative prior for q was used to force $q = 1$ for the post 1988 spawn survey. In ^{i}SCA$_{M}$ model the sum of the residuals between the observed and predicted spawn survey data did have a mean equal to zero and there is no apparent bias in scaling parameters (q's) associated with contradictions in data sources.

In the comparison between HCAM and ^{i}SCA$_{M}$ models, the variance parameters in the ^{i}SCA$_{M}$ model were fixed such that the same observation error and process error were used in both models. The fixed variance and fixed q values could also partially explain the persistent negative residual patterns observed in the HCAM model; these data may be weighted less relative to the age-composition data. Moreover, fixing these variance parameters (specifically the ratio of observation to process errors) is also likely to bias estimates of uncertainty in spawning biomass, and other variables. We also explored the possibility of estimating the total variance and the fraction associated with observation error for the SOG model. In this case, reasonable estimates of the variance parameters were obtained and this is only possible because there is information on relative abundance and age-composition in this fishery. We further estimate all the variance parameters in Part II of this document for all major and minor stock areas. Estimates of uncertainty are likely to be less biased now that the variance parameters are jointly estimated.

Lastly, another less subtle difference between the two modelling approaches was the estimation of the stock recruitment parameters. In the HCAM model an improper prior was used for the steepness parameter, where steepness was bound between 0.2-0.99 and a lognormal prior was used. In ^{i}SCA$_{M}$, we used a Beta distribution as the prior rescaled for values in the range of 0.2-1.0 for the Beverton-Holt model. Estimating the stock-recruitment parameters is critical in establishing reference points and moving towards the Sustainable Fisheries Framework (SFF). If there are no information in the data to reliably estimate steepness, then the form of the prior distribution will influence derived reference points.

The default reference points suggested in the SFF are based on the concept of Maximum Sustainable Yield (e.g., the suggested LRP is $0.4\mathrm{B}_{\mathrm{MSY}}$, and the USR is $0.8\mathrm{B}_{\mathrm{MSY}}$). Such a default requires that we can accurately calculate $\mathrm{B}_{\mathrm{MSY}}$. In order to calculate $\mathrm{B}_{\mathrm{MSY}}$, precise estimates of population parameters (B_0, h), life-history parameters ($M, L_\infty, k, t_o, a, b, \dot{a}, \dot{\gamma}$), and selectivity parameters ($\hat{a}, \hat{\gamma}$) are required. See parameters defined in Table A-1 for a full explanation of how these are related to $\mathrm{B}_{\mathrm{MSY}}$. Estimating these parameters is one of the major goals of a fisheries stock assessment model, but calculating reference points based on the concept of MSY has a potential problem when there are multiple fleets involved that have very different selectivity curves. That problem relates to allocation of yield to each of the fleets. If each fleet has the same selectivity curve, then each fleet imposes the same age-specific mortality and there will be no impacts on the MSY estimates. If however one or more fleets harvest fish at a much younger (or older) age, then estimates of MSY (and the corresponding removal rate reference point) will shift up or down depending on the ratio of maturity to vulnerability. In general, the later the fish recruit to the fishing gear, the higher the sustainable fishing mortality rate.

Calculating reference points for the SFF is more about determining allocation of herring to the purse seine and gillnet fleets. The gillnet gear tends to catch older herring in comparison to the winter seine and seine roe fisheries. Larger allocations to the seine fisheries come at a tradeoff of reducing potential yield for the gillnet fishery. There is a real optimization problem here that goes just beyond the biology of the species, namely, profitability of each fishery. Furthermore, the calculation of reference points assumes that these data come from a unit-stock and not a collection of mixed sub-stocks that may differ in productivity.

Part II

Stock Assessment and Management Advice for the British Columbia Pacific Herring Stocks: 2011 Assessment and 2012 Forecasts

cutoff

2.5 Introduction

The objectives of this section of the report are: (1) present the data used in the 2011 assessment, (2) provide a summary overview of the integrated statistical catch-age model (hereafter, ^{i}SCA$_\mathrm{M}$), (3) present the 2011 stock assessment and forecast for 2012, and (4) describe in detail the decision table used to provide advice to fisheries management.

BC herring are currently managed as five major stocks and 2 minor stocks (Figure 1.1). Annual catch advice for each of these areas is based on current estimates of stock status, and a 20% exploitation rate if the post-fishery 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 historically were based on the 1996 estimate of $0.25B_o$. These cutoffs are currently thought to be more conservative than the suggested default Limit Reference Point of $0.4\mathrm{B}_\mathrm{MSY}$ (Fisheries and Oceans Canada, 2006). For example, B_MSY is normally in the range of 35% of the unfished biomass for many fish stocks; therefore, 40% of $\mathrm{B}_\mathrm{MSY}$is roughly 14% of unfished which is significantly lower than the $25\% B_o$ that is currently used for Pacific herring. Alternative cutoffs based on updated estimates of B_o are also provided in this document.

This years assessment is based on a new model, ^{i}SCA$_\mathrm{M}$, where alternative assumptions about survey q, and the form of the error distribution for the age-composition data are the major differences in comparison to the 2010 assessment using HCAM. In addition to the changes in likelihoods, we also present an alternative parametrization of the gillnet selectivity to determine if the residual variation in gillnet age-composition data are better explained by systematic changes in the empirical weight-at-age data or selectivity has been relatively constant and natural mortality rates have varied over time.

In this part of the document, we first describe the five major and two minor Stock Assessment Regions (SARS) that comprise the BC herring stocks. We then present the input data used in this years assessment, briefly describe the analytical methods and diagnostics, describe the recruitment and catch forecasts, and the Harvest Control Rule (HCR) used for generating catch advice. We then present the maximum likelihood estimates of residual patterns and overall fits to the observations, summarize MSY based reference points and maximum likelihood estimates of B_0. Lastly, we present the results of integrating the joint posterior distribution, diagnostics for ensuring convergence, marginal parameter distributions (with prior distributions overlaid), and catch advice based on the median values of the joint posterior distribution. The last section presents the data, MLE results, marginal distributions and catch advice for the two minor areas (the HCR in the minor area differs from the major areas).

2.6 BC Herring Stocks

The geographic boundaries used to delineate the B.C. herring stock assessment regions have remained consistent since 1993. Boundaries and locations of the major stock and minor stock areas are identified in Figure 1.1. The Haida Gwaii (HG) or Queen Charlotte Islands (QCI2E) stock assessment region includes most of Statistical Area 2E, spanning from Cumshewa Inlet in the north to Louscoone Inlet in the south. The Prince Rupert District (PRD) stock assessment region encompasses Statistical Areas 03 to 05. The Central Coast (CC) assessment region separates the major migratory stocks from the minor spawning populations in the mainland inlets. The Central Coast assessment region includes Statistical Area 07 plus Kitasu Bay in Area 06, Kwakshua Channel in Section 085 and Fitz Hugh Sound in Section 086. The Strait of Georgia (SOG) stock assessment region includes all of Statistical Areas 14 to 19, 28, and 29 (excluding Section 293), Deepwater Bay and Okisollo Channel, both in Section 132, and Section 135. The west coast of Vancouver Island (WCVI) assessment region encompasses Statistical Areas 23 to 25. The minor stocks include all of Area 27 and Area 2W (excluding Louscoone Inlet in Section 006). Current geographic stock boundaries are outlined in Midgley (2003), although note that SOG sections 280 and 291 do not appear as they were added in 2006.

2.7 Methods

2.7.1 Input data & assumptions

Catch data

For each of the statistical areas, the required input data for ^{i}SCA$_{\mathrm{M}}$ 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 2.1). 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 log-normal, independent and identically distributed. The assumed standard deviation in the catch observation data 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 ^{i}SCA$_{\mathrm{M}}$. Two additional fleets are specified to represent the spawn survey, where the spawn survey is 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.

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 2011, dive surveys were conducted in all major and minor assessment regions, with the exception of Area 2W where snorkelling 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 2.2. Egg density estimates are used to calculate a fishery-independent index of herring spawning biomass, referred to as the spawn survey index hereafter (Schweigert, 2001).

The spawn survey is conducted after the fisheries in the area have been completed; 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 200 eggs per gram of female body weight or 100 eggs per gram of mature body weight of both sexes (Hay, 1985; Hardwick, 1973). The assumed selectivity for the spawn survey is fixed to the maturity schedule for herring and the mean weight-at-age data comes from empirical observations based on biological samples.

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 where catch 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

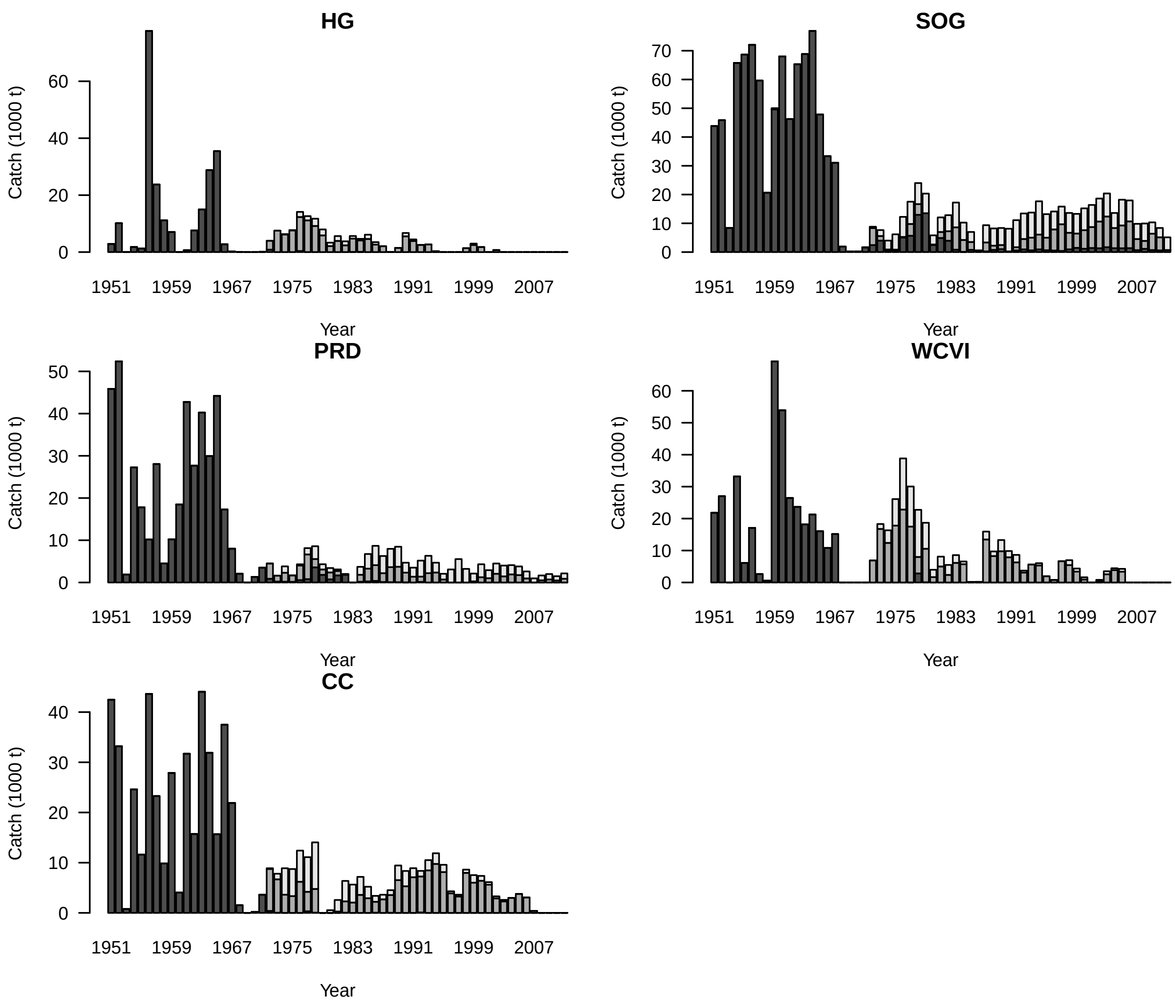

Figure 2.1: Historical catch of herring in the five major stock areas between 1951 and 2011 for the winter purse seine fishery (dark bars), seine-roe fishery (grey bars), and gillnet fishery (light grey bars). Units of catch are in thousands of metric tons.

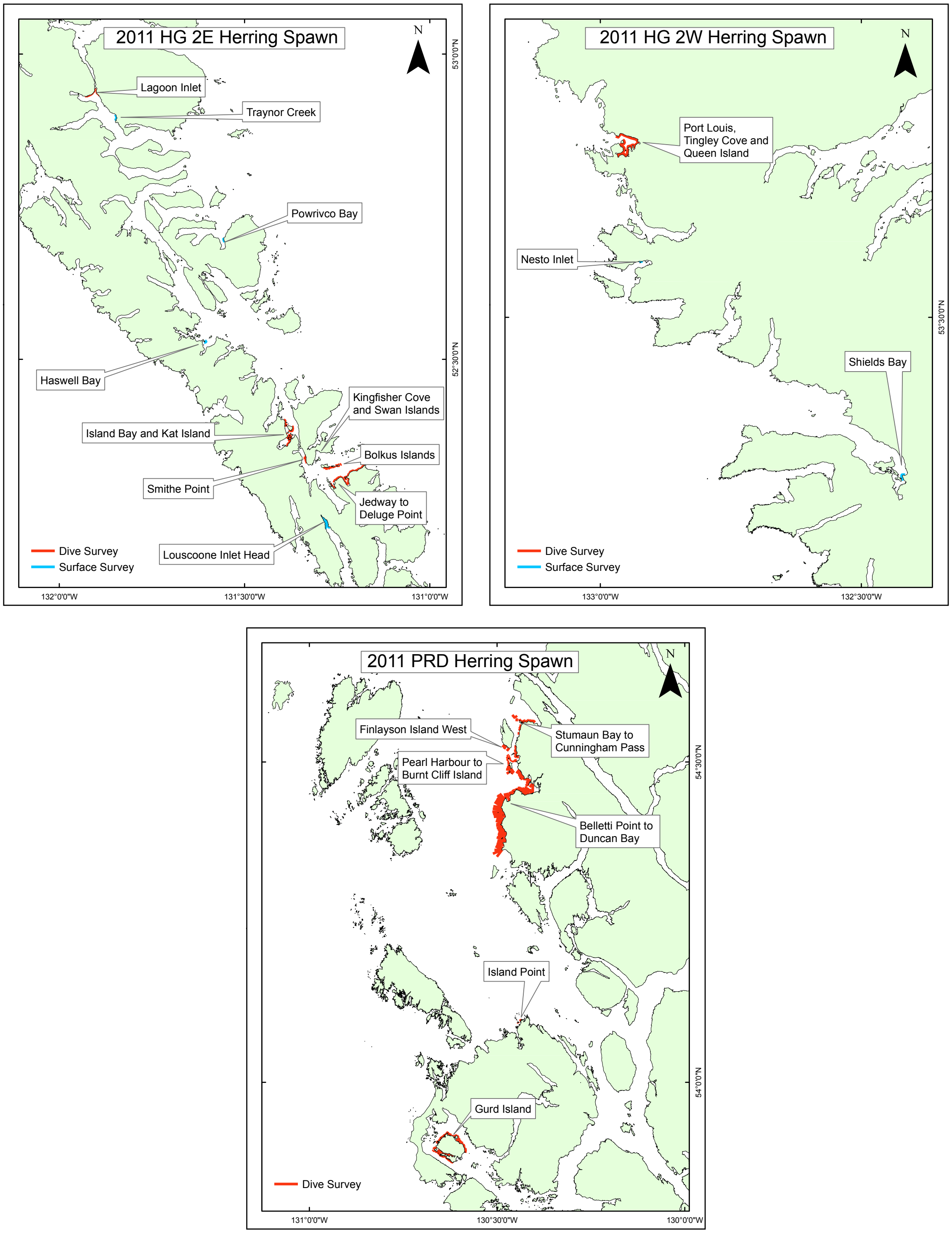

Figure 2.2: Preliminary Spawning activity for Haida Gwaii (top panels) and Prince Rupert District (bottom) in 2011.

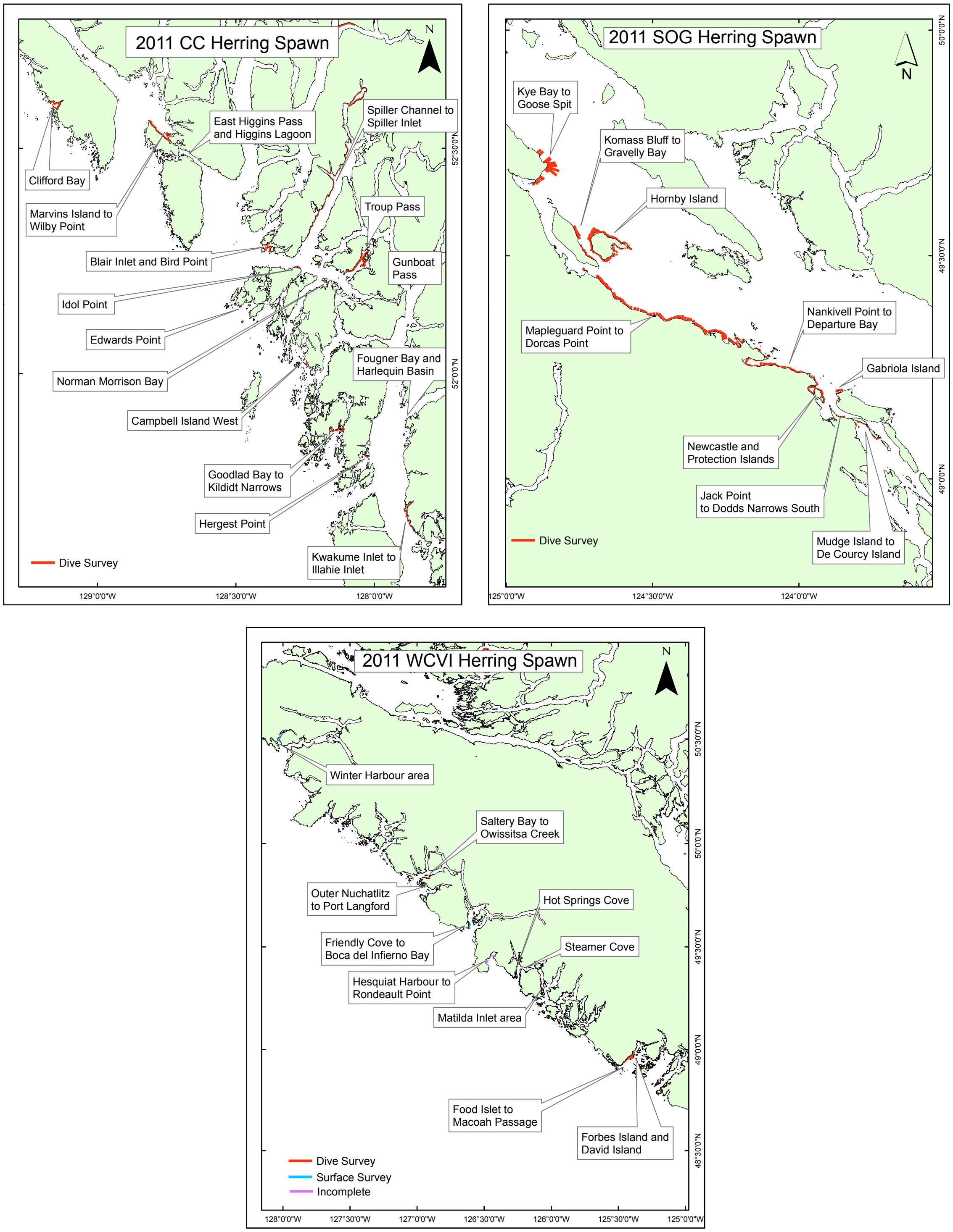

Figure 2.2: Preliminary Spawning activity for Central Coast (top left panel), Strait of Georgia (top right) in 2011 and west coast Vancouver Island (bottom).

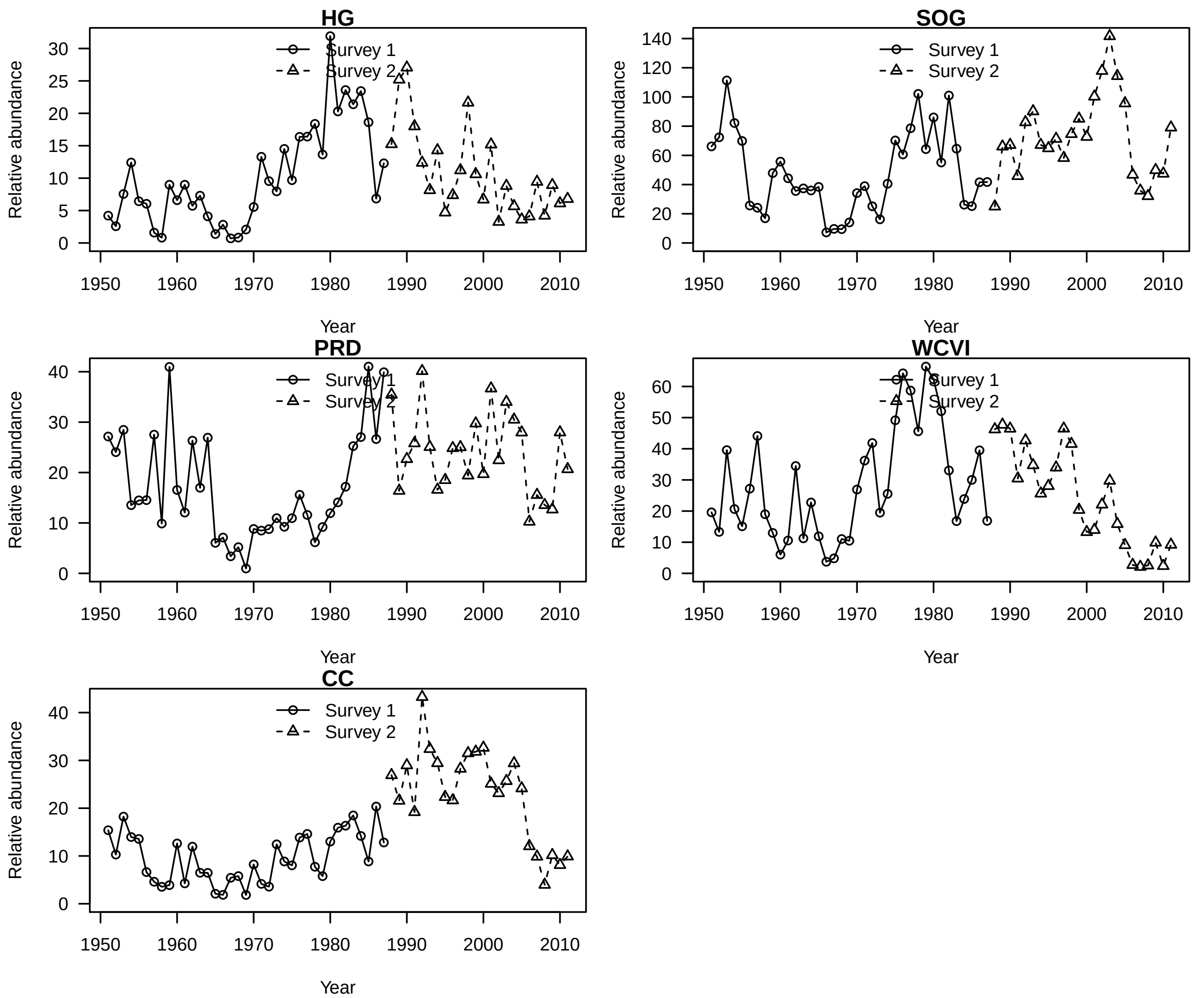

Figure 2.3: Spawn survey index for Strait of Georgia between 1951 and 2011. The units are actual estimates of spawning biomass (1000s tons), but only the trend information is used in the model fitting.

Table 2.1: Summary of biological samples collected and processed from all sources from the 2010/11 herring season.

	Commercial samples				
Stock	Roe fishery	SOK fishery	F&B	Test fishery	Research
HG (QCI 2E)				13	
PRD	29	1		24	
CC				30	
SOG	18		20	60	
WCVI				14	16
Area 2W				10	
Area 27		3			
Other Areas					
Total	57	4	16	151	16

Table 2.2: Summary of biological samples collected and processed from commercial catch and test fishery charters from 2002/03-2010/11.

Fishing season	Commercial fishery samples	Charter and research samples	Total
2002/03	120	287	407
2003/04	79	222	301
2004/052	83	191	274
2005/06	46	164	210
2006/07	114	85	199
2007/08	116	103	219
2008/09	87	136	223
2009/10	78	135	213
2010/11	81	167	248

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 compiled and used as the information on mean weight-at-age and catch-at-age data that are the essential input data for the stock assessment model.

During the 2010/2011 season a total of 248 biological samples were collected, of which 151 were collected from the test fishery, 57 were collected from the roe fishery, 16 from the food & bait fishery, 4 from Spawn on Kelp (SOK) operations, and 16 from the summer trawl research survey (Table 2.1). 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 2.2 and the spatial locations of the biosamples are presented in Figure 2.4.

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. At present, the biological samples from the test fisheries are pooled with the seine-roe fisheries. Future analyses may further disaggregate these data to determine if the test fishery and the seine-roe fishery have very different age-compositions. Age composition data is used to determine proportions-at-age and is an essential source of input data to the herring stock assessment model.

In all of the major SARS, catch-at-age data from the winter seine fishery (top panels of Figures 2.5-2.9)

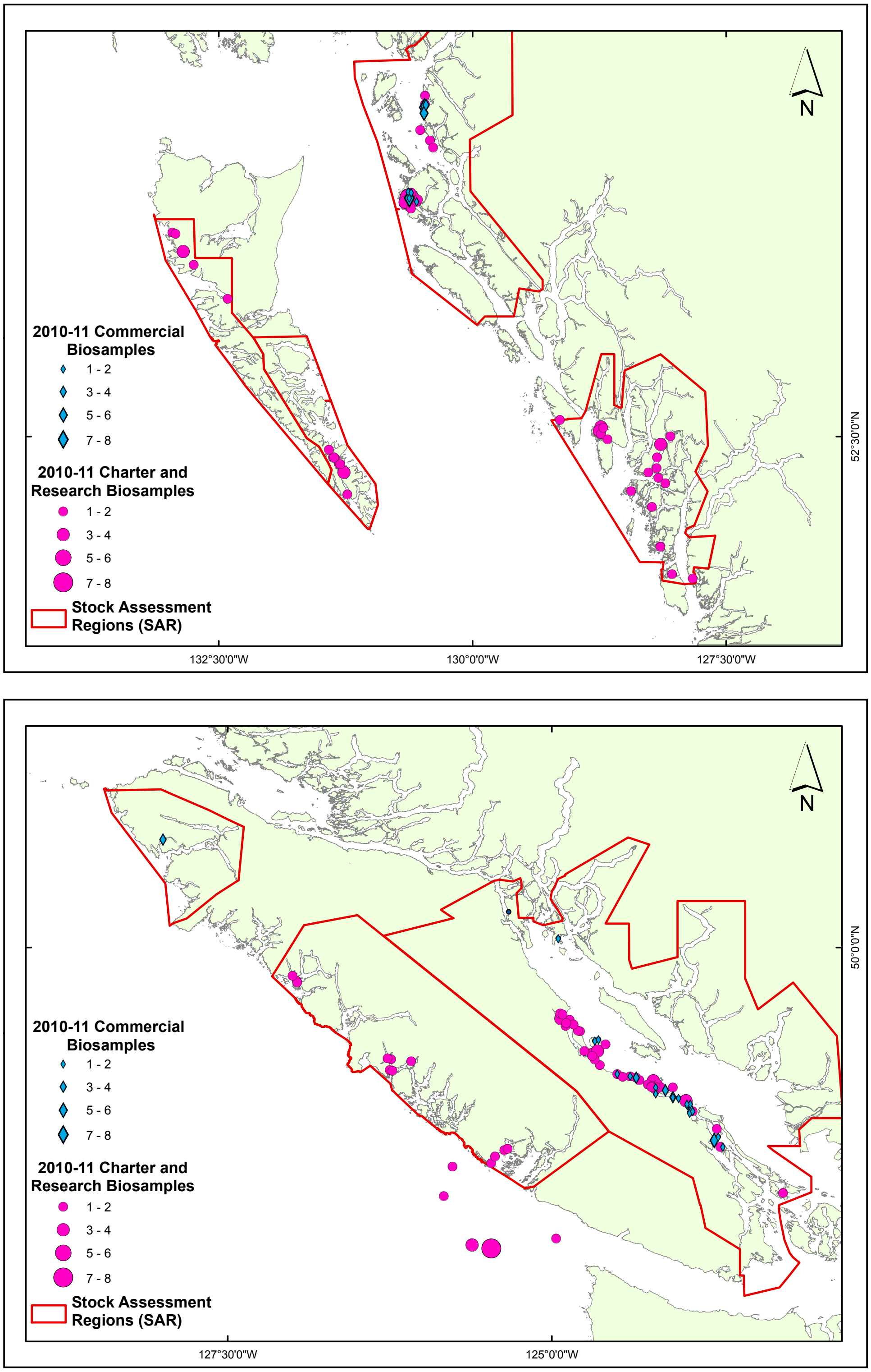

Figure 2.4: Spatial location and sample sizes of 2011 biosamples from commercial and research-charter programs in the north coast (top panel) and south coast (lower panel).

tend to consist of younger fish in comparison to the age composition data from the seine-roe and gillnet fleets post 1970. The shaded polygons in Figures 2.5-2.9 approximates the 95% distribution of ages in the catch. Roughly 90% of the fish landed in the winter seine fishery were 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 gillnet fishery, and fish do not appear to fully recruit to the gillnet 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 gillnet 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).

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 2.10). Samples collected during the 2009/10 fishing year indicate weights-at-age 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 et al., 2002), and merits further research. The observed mean weight-at-age data appear to have a few errors that need to be investigated as well; for example, see the apparently small age-10 fish in 2001 in Figure 2.10.

Mean weight-at-age data are based on the biological samples taken from the fisheries and test fishery data. The spatial distribution of the biological samples from 2011 are shown in Figure 2.4.

2.7.2 Analytical methods

For the 2011 BC herring assessment, ^{i}SCA$_{\mathrm{M}}$was used to conduct the stock assessment for each of the five major Stock Assessment Regions (SAR) and two minor assessment areas (Area 2W and Area 27). The technical details of this model can be found in Appendix A.1.

2.7.3 Retrospective analysis

A retrospective analysis was conducted for each of the major and minor SARs. The retrospective analysis successively removes the last 10-years of data and examines changes in estimates of terminal spawning biomass. The results are then plotted on a single panel to compare how estimates of spawning biomass change as successive years of data are omitted from the analysis.

2.7.4 Abundance and recruitment forecasts

The abundance forecast for the upcoming fishing season, also referred to as pre-fishery biomass, is defined as the predicted biomass of age-4 fish and older plus the number of age-3 fish recruiting in year $T + 1$. The abundance estimates are based on the median values from the sampled posterior distribution. Age-3 recruits are based on poor, average, and good recruitment scenarios; see next paragraph for definitions of poor, average and good.

The recruitment forecasts are based on the surviving number of age-3 fish at the start of the fishing season times the average weight-at-age 3 in the last 5 years. The definitions of poor, average, and good recruitment are as follows: **Poor** is the average recruitment from the 0-33 percentile, **Average** is the average recruitment from the 33-66 percentile, and **Good** is the average recruitment from the 66-100 percentile. Note that all cohorts from 1951 to 2011 were included in the calculation of recruitment quantiles.

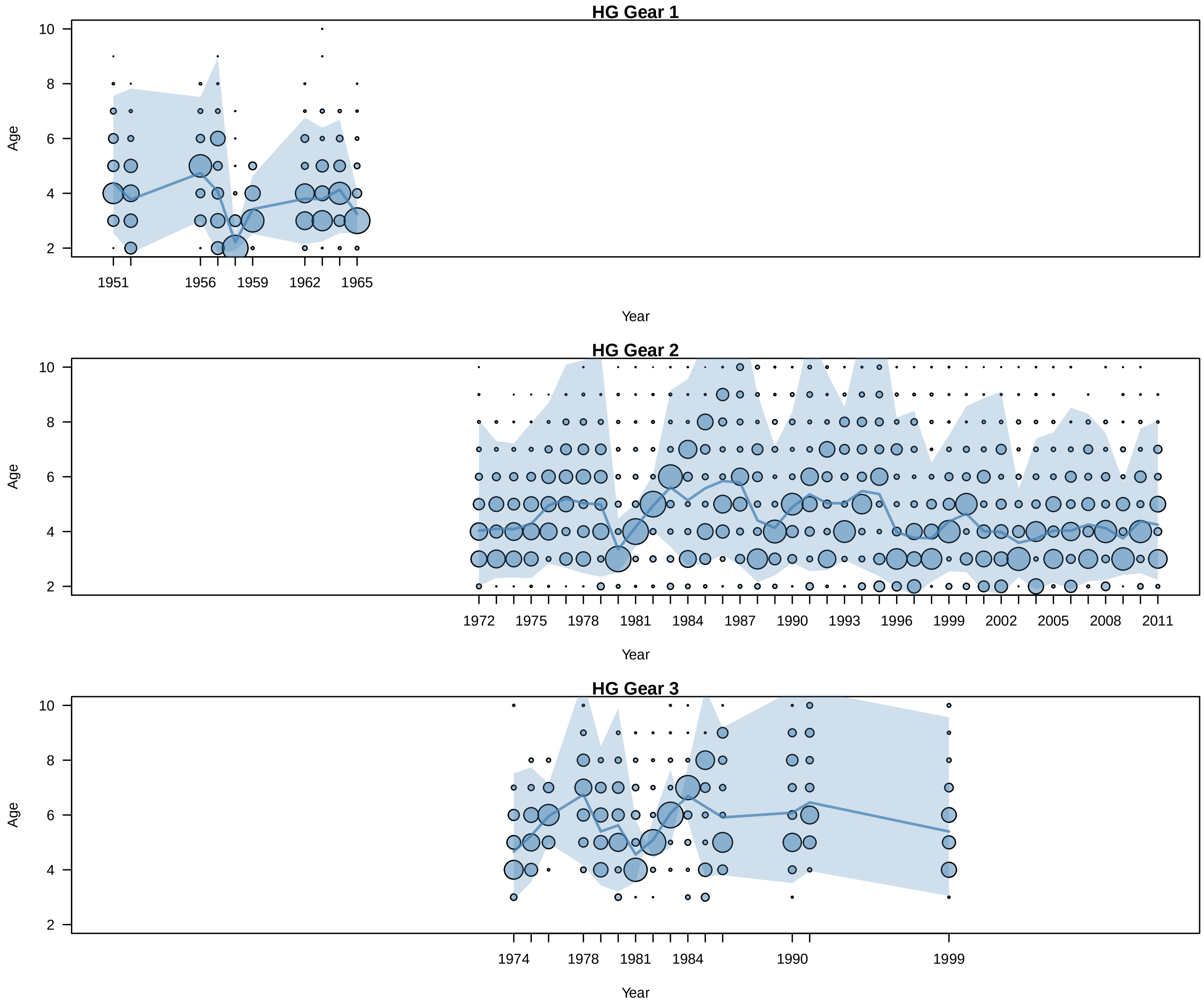

Figure 2.5: Proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gillnet fishery (bottom) in Haida Gwaii. The area of the circle reflects the proportion-at-age, each column sums to 1, zeros are not shown, and age 10 is a plus group. Also shown is the mean age of the catch (line) and the approximate 95% distribution of ages (shaded polygon) for each year.

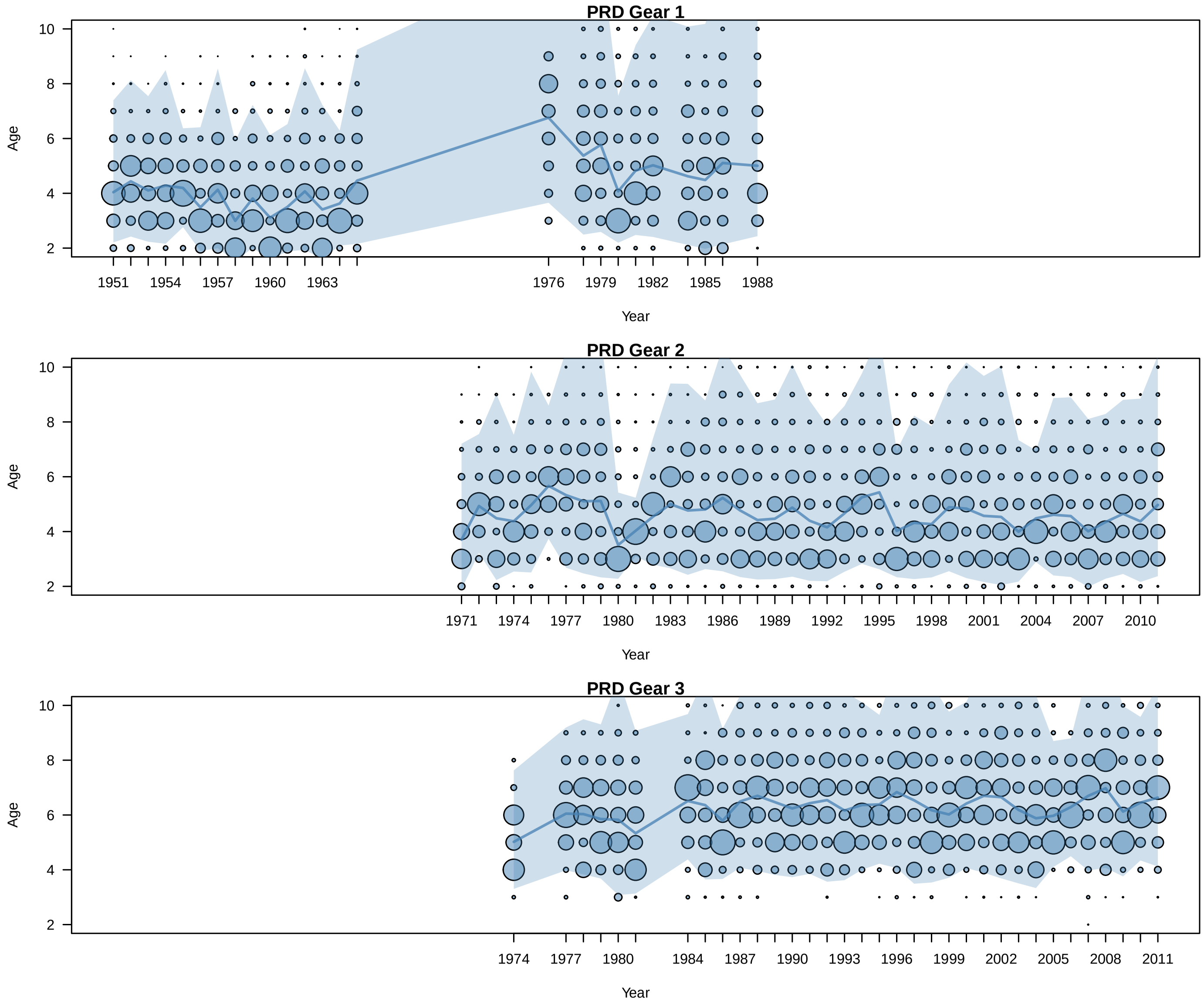

Figure 2.6: Proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gillnet fishery (bottom) in Prince Rupert District. The area of the circle reflects the proportion-at-age, each column sums to 1, zeros are not shown, and age 10 is a plus group. Also shown is the mean age of the catch (line) and the approximate 95% distribution of ages (shaded polygon) for each year.

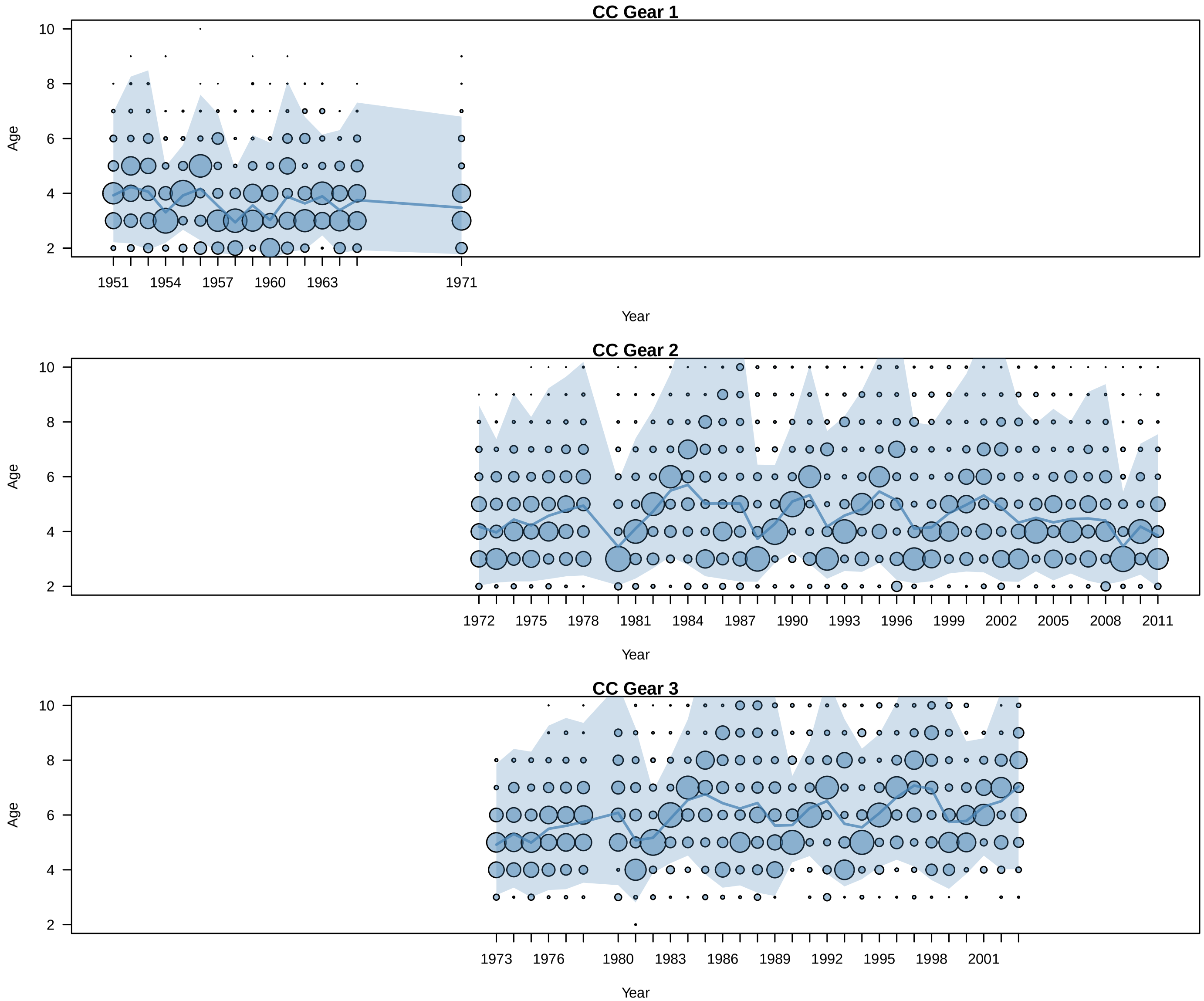

Figure 2.7: Proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gillnet fishery (bottom) in the Central Coast region. The area of the circle reflects the proportion-at-age, each column sums to 1, zeros are not shown, and age 10 is a plus group. Also shown is the mean age of the catch (line) and the approximate 95% distribution of ages (shaded polygon) for each year.

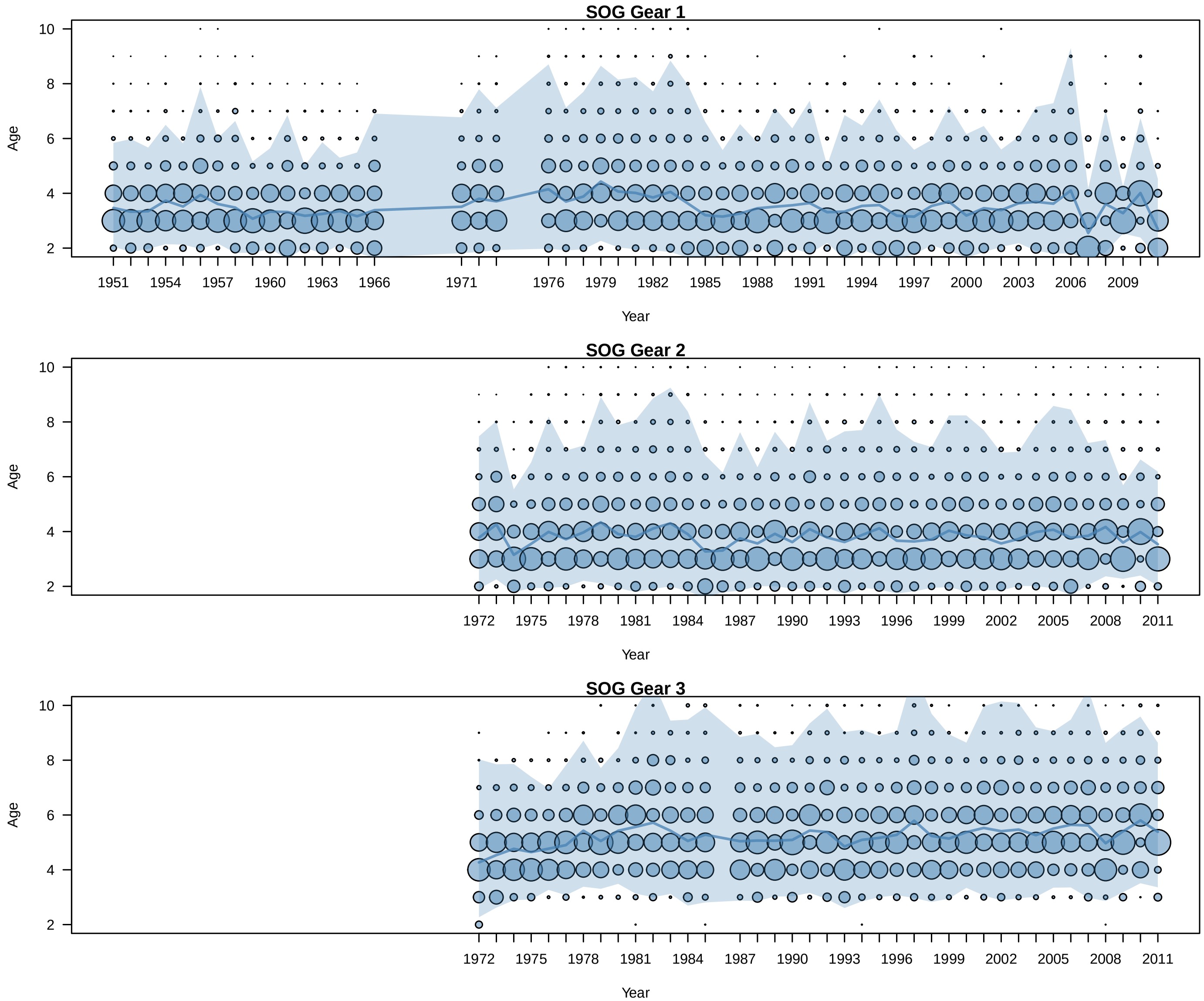

Figure 2.8: Proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gillnet fishery (bottom) in the Strait of Georgia. The area of the circle reflects the proportion-at-age, each column sums to 1, zeros are not shown, and age 10 is a plus group. Also shown is the mean age of the catch (line) and the approximate 95% distribution of ages (shaded polygon) for each year.

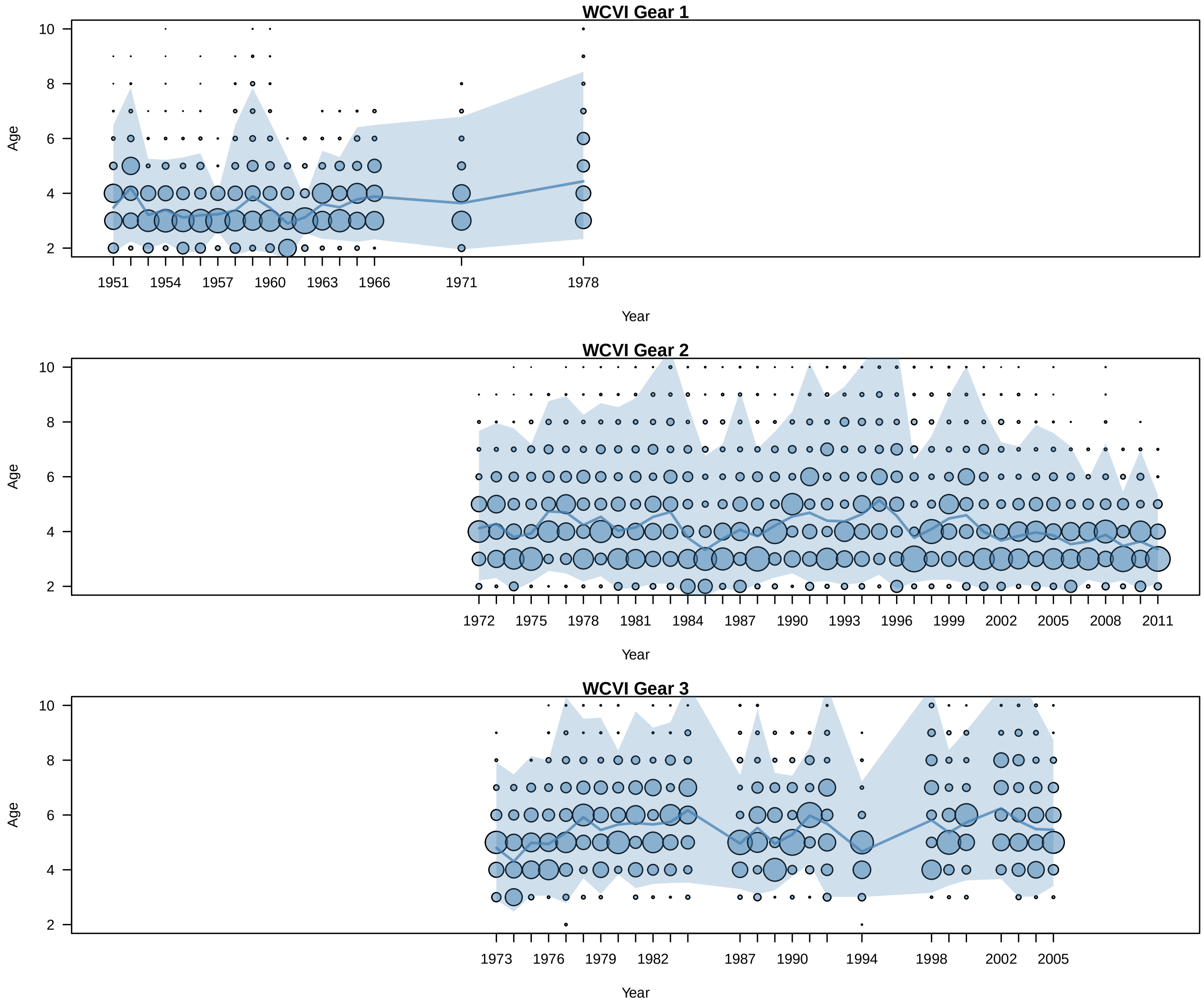

Figure 2.9: Proportions-at-age versus time for the winter purse seine fishery (top), seine roe fishery (middle) and the gillnet fishery (bottom) in the West Coast Vancouver Island region. The area of the circle reflects the proportion-at-age, each column sums to 1, zeros are not shown, and age 10 is 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.

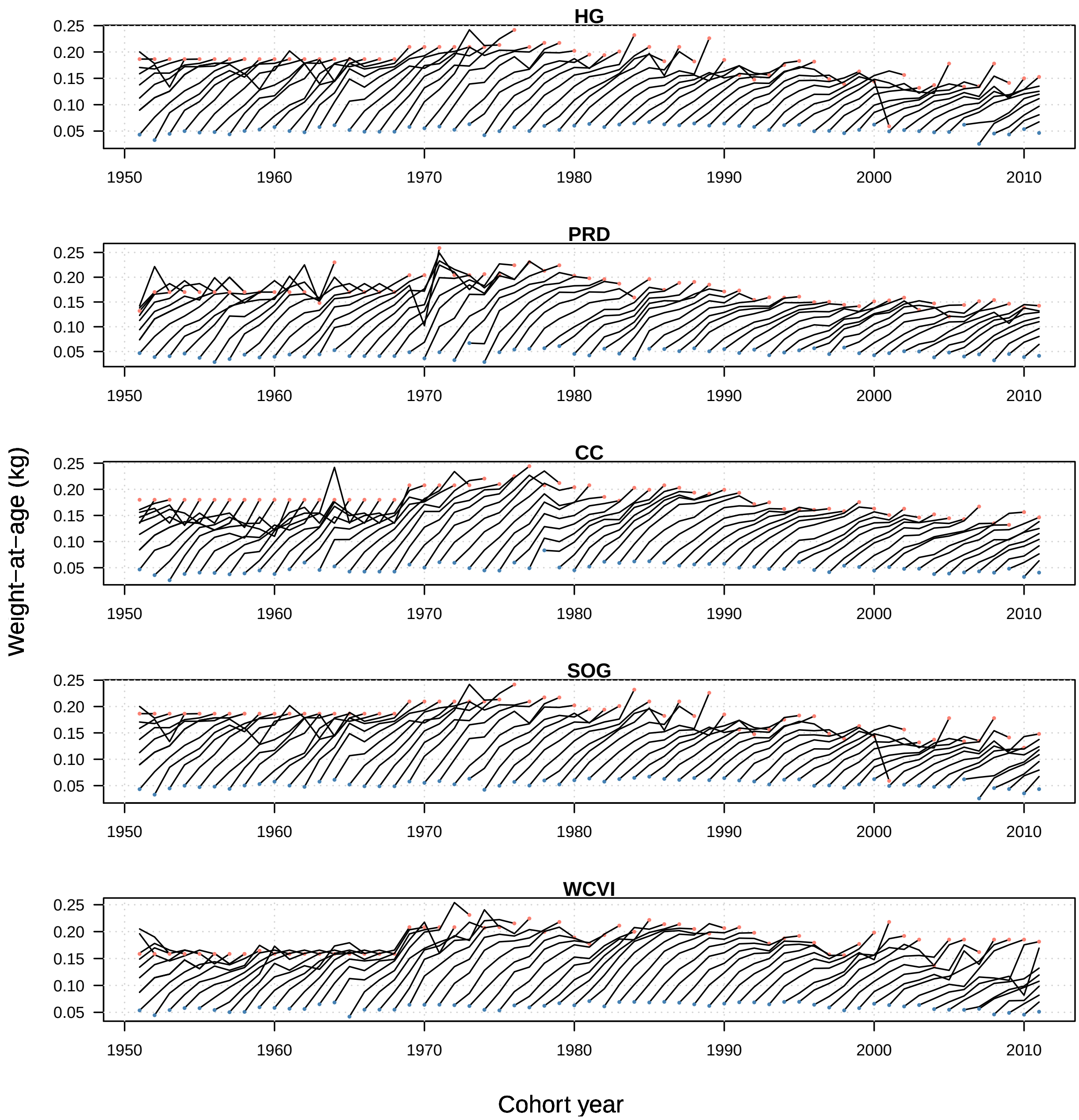

Figure 2.10: Empirical mean weight-at-age data by cohort from 1951 to 2011 for ages 2 to 10 in the five major Stock Assessment Regions.

2.7.5 Harvest control rule

Catch advice is based on the application of the harvest control rule (HCR). A formal HCR as been used to provide management advice for the major BC herring stocks since 1986 (Stocker, 1993). The herring HCR has three components:

1. Reference points
2. Harvest rate
3. Decision rules

These three components are consistent with the DFO harvest strategy that is compliant with the precautionary approach (Fisheries and Oceans Canada, 2006). In this strategy, there are two reference points: 1) the limit reference point (LRP) which is a minimum stock size where fishing activity is ceased if the stock falls below the LRP into the critical zone, and (2) the upper stock reference (USR) that defines the boundary between the cautious zone and healthy zones.

Reference Points

The harvest control rule that is currently used to provide catch advice for the five major BC herring stocks is a hybrid between a fixed escapement policy and a fixed exploitation rate policy. For each of the major stocks, the reference point is defined as a cutoff level (or escapement target)and is set at 25% of the unfished spawning stock biomass. The cutoff is intended to maintain a minimum spawning stock biomass of 25% of the estimated unfished biomass. Simulation studies in the past (Haist et al., 1986; Hall et al., 1988) suggest that 25% of the unfished spawning biomass leaves a sufficient spawning reserve to ensure long-term sustainability of the resource.

At present, there are no formal definitions for LRP and USR for the five major herring stocks. The cutoff values for each of the stocks are thought to be more conservative than the default LRP of $0.4\mathrm{B}_{\mathrm{MSY}}$. For example, surplus production in most fish stocks is usually maximized when the stock is depleted in a range of 30%-45% of its unfished state. If we assume that herring production was maximized at a depletion level of 45% or $\mathrm{B}_{\mathrm{MSY}}$=$0.45B_o$, then the default LRP for herring would be equal to 18% of the unfished biomass (i.e. 40% of $\mathrm{B}_{\mathrm{MSY}}/B_o$). This document also presents the maximum likelihood estimates of spawning biomass depletion, and these results are over-laid on coloured panels that define the default $0.4\mathrm{B}_{\mathrm{MSY}}$ and $0.8\mathrm{B}_{\mathrm{MSY}}$ LPR and USR, respectively (see Figure 2.20).

Critical to the HCR is the estimate of unfished spawning biomass (B_o). The cutoff levels were last revised in 1996 (Schweigert et al., 1996), and these same values have been used to provide catch advice ever since. In this assessment, we provide updated estimates of B_o and the associated cutoff values based on $0.25B_o$.

In the case of the minor stock areas, the harvest control rule consist of a fixed exploitation rate and there are now cutoff values associated with these stock assessment regions.

Harvest rate

The Pacific Science Advice Review Committee (PSARC) has reviewed the biological basis for target exploitation rate, considering both the priority of assuring conservation of the resource and allowing sustainable harvesting opportunities (Schweigert and Ware 1995). The review concluded that 20% is an appropriate exploitation rate for those major stock areas that are well above cutoff levels of 25% of the estimated unfished biomass.. The recommended 20% harvest rate is based on an analysis of stock dynamics which indicates this level will stabilize both catch and spawning biomass while foregoing minimum yield over the long term (Hall et al., 1988; Zheng et al., 1993).

In the case of minor stock areas, data-limitations present a challenge in providing reliable estimates of unfished biomass, required for the calculation of stock-specific cutoffs. Consequently, the PSARC recommended harvest rate of 10% is applied to the currently estimated biomass for the following year for these areas.

Decision rules

For the major stock areas, the harvest control rule combines both constant exploitation rate and constant escapement policies, allowing for smaller fisheries in areas where the 20% harvest rate would bring the escapement down to levels below the cutoff. The rule operates as follows:

- If the forecast is less than the cutoff: the area is closed to all commercial harvest.
- If the forecast run (B_{t+1}) is greater than the cutoff: A commercial harvest is permitted and the harvest rate is based on the following rules:
  - If $0.8B_{t+1} >$ Cutoff, then harvest rate u= 20%.
  - If $0.8B_{t+1} <$ Cutoff, then harvest rate $u = \frac{B_{t+1} - \text{Cutoff}}{B_{t+1}}$

In the case of the minor stock areas, the decision to allow for a commercial harvest has been at the discretion of Fisheries Management. In years where a commercial harvest is permitted, a harvest rate of 10% is applied to the estimated biomass for the area.

2.8 Results

The results section is broken down into three major subsections, Maximum likelihood fits to the data, marginal posterior distributions, and stock forecasts and catch advice based on samples from the joint posterior distribution.

2.8.1 Maximum likelihood fits to the data

Although the maximum likelihood estimates are not explicitly used for constructing the catch advice, we do present the MLE estimates of the residual patterns and fits to the data for comparisons.

Catch residuals

Residuals between the observed and predicted catch are largely determined by the user specified standard deviation in each of the control files. In this assessment, the assumed variance for all regions (including minor regions) was set at 0.005, which corresponds to a standard deviation of approximately 0.0707. Overall the residuals for each fishery in each stock assessment region are unremarkable (Fig. 2.11), with exception of a major outlier in the Haida Gwaii in the mide 1950s. In 1956, the reported catch in Haida Gwaii was extremely large ($>$ 60,000 mt) and the model has a difficult time explaining this large catch. In order to explain this large catch in a single year, a large biomass in the region is required.

Fits to the spawn survey data

The residuals between the observed and predicted spawn survey index (on a log scale) are shown in Figure 2.12. Recall that the spawn survey data are treated as two independent time series where data between 1951–1987 were based on surface estimates of spawn deposition and data post 1988 are based on diver surveys of spawn deposition. More weight was assigned to the contemporary data. Also, you might be tempted to compare the estimated values of q in Figure 2.12 with those estimated in Part I of this document (e.g., Table 1.2 on page 13). The results in Table 1.2 are based on data from 1951 to 2010 (i.e., omit the 2011 data) and use a different parameterization of the selectivity function for the gillnet fishery (type 7 as opposed to type 8, see Appendix A.1.5 on page 95).

For most areas, there is little pattern in the residuals between the observed and predicted survey data (Fig 2.12). For the HG, PRD and CC regions, there is very good correspondence between the observed and predicted survey data post 1988. In the SOG, there is a period of positive residuals between 1999 and 2005 where the predicted spawn biomass fails to increase as much as indicated by the survey. Similary 3–4 year trends also exist in the WCVI spawn survey data after the year 2000.

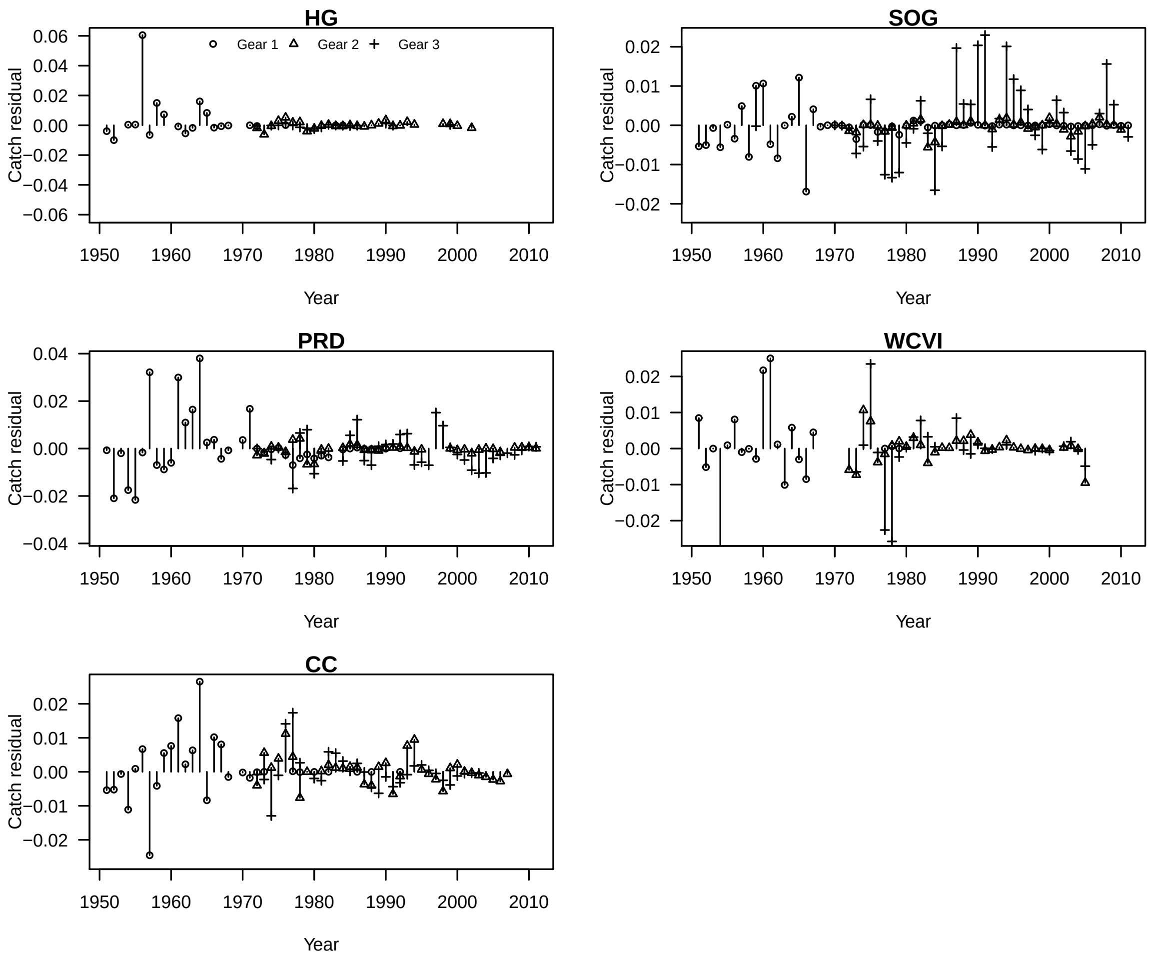

Figure 2.11: Residual for the log difference between observed and predicted catch for the five major SARs for each gear type (Gear 1 = winter seine fishery, Gear 2 = seine-roe fishery, Gear 3 = gillnet fishery).

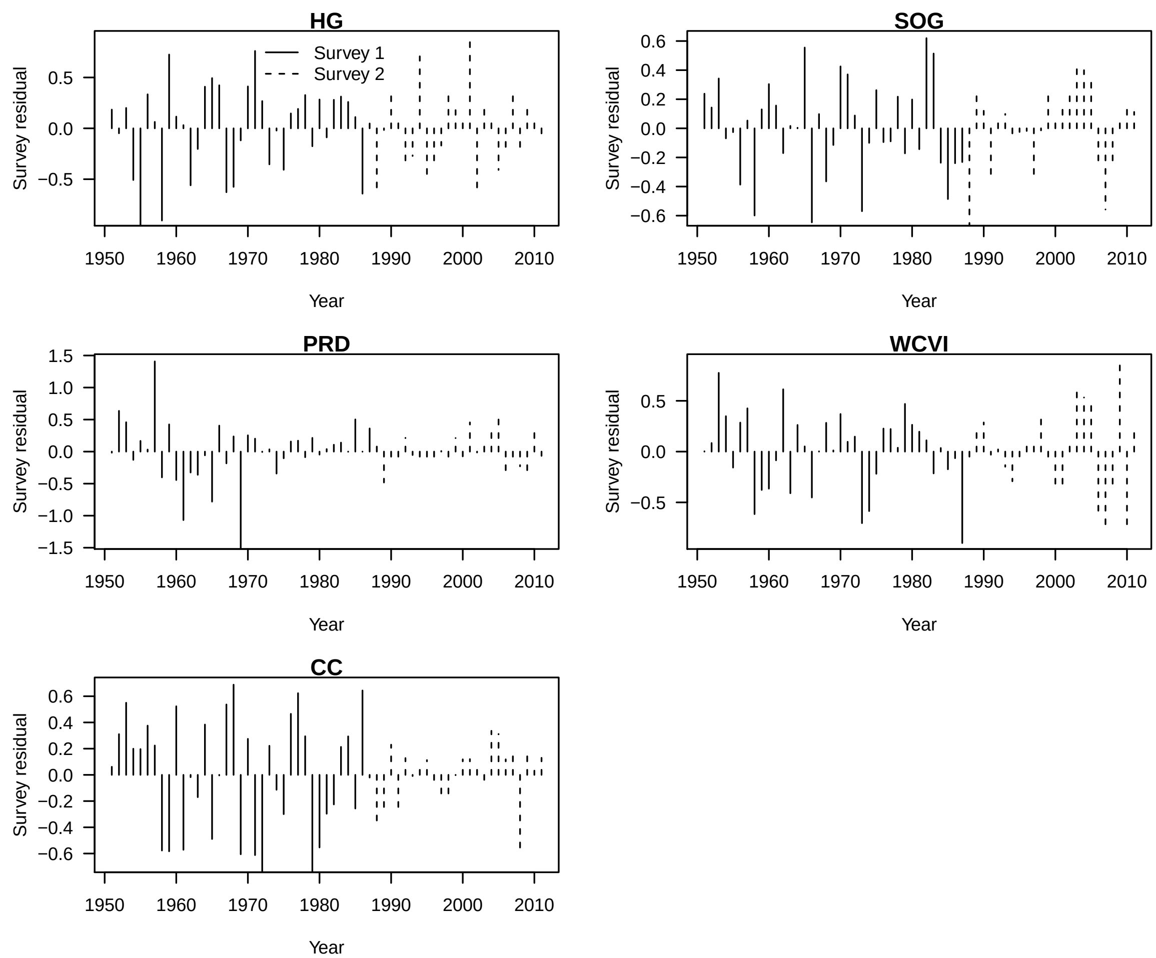

Figure 2.12: Residual patterns for the log difference between observed and predicted spawn survey abundance for the five major SARs. Spawn survey data based on surface estimates are show as solid lines and data based on diver surveys is shown as dashed lines.

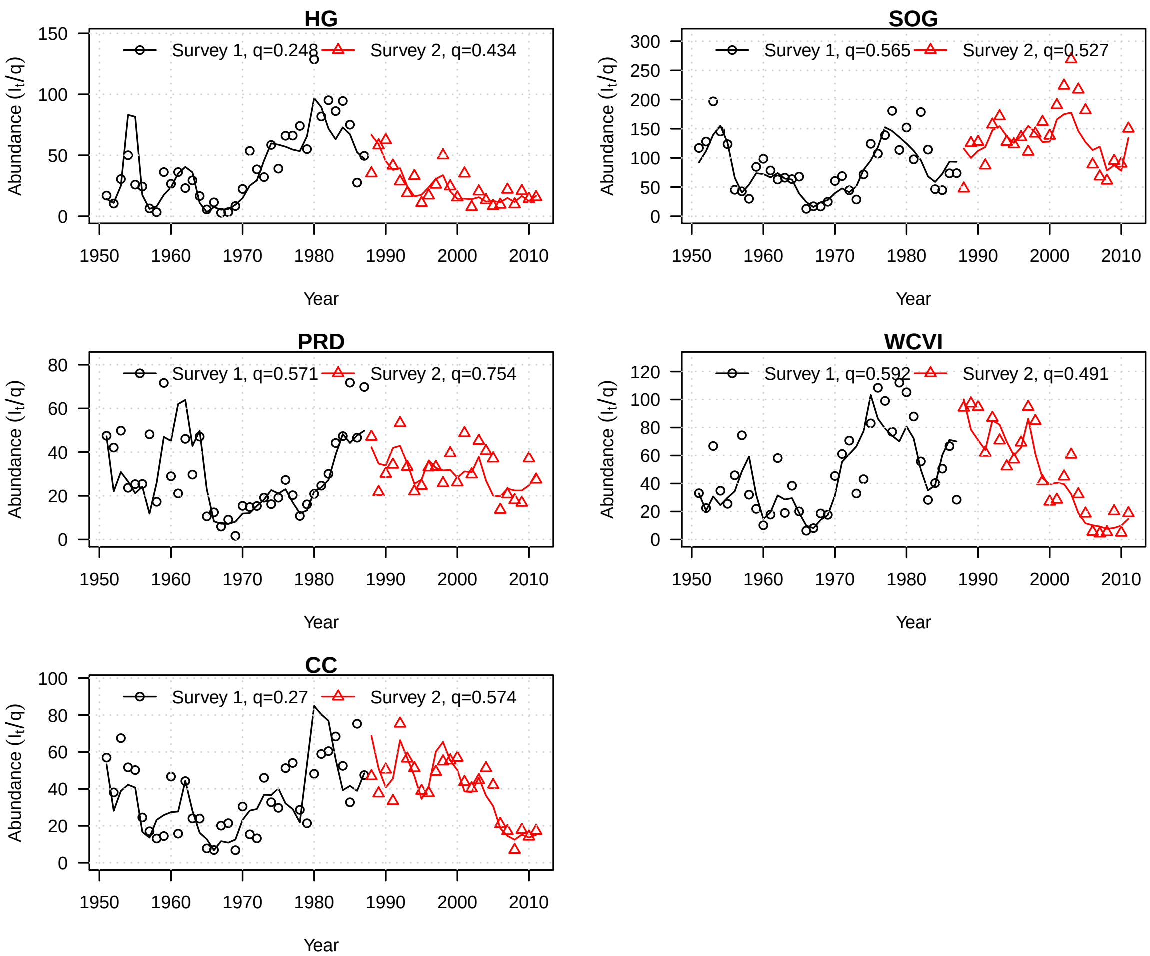

Figure 2.13: Observed (points) and predicted (lines) spawn survey abundance data scaled by the MLE estimate of q for each of the five major SARs. In each panel, the corresponding scaler (q) is presented for each of the surveys.

In comparison to the previous assessment for Pacific herring using the HCAM model, estimates of the catchability coefficient are very different (HCAM assumed q=1 for post 1988 data). In each of the five major assessment regions (and the two minor regions) a less informative prior for the catchability coefficient was used (see Appendix C.3). Maximum Likelihood Estimates (MLE) of the catchability coefficients are presented for each region in Fig. 2.13 along with the observed and predicted trends in the spawn index. Estimates of q in both time periods are less than 1.0 for all regions. The interpretation of $q = 1$ is that the spawn survey data is an absolute measure of spawn abundance, $q < 1$ implies that the survey under-estimates the spawn abundance and $q > 1$ implies an over-estimate. For example, in the HG region the MLE values for q are 0.248 and 0.434 for the pre- and post-1988 data, respectively. This could be interpreted as the spawn survey, on average, sees 24.8% and 43.4% of the deposited spawn each year. This interpretation however is conditional on the specification of mature biomass in the stock assessment model and the methods used to extrapolate egg density to spawning biomass. Values of $q < 1$ could also be interpreted as the fraction of eggs remaining at the time the spawn survey was conducted (i.e., (1-q) of the eggs survived predation, storms, etc.)

Age composition residuals

The assumed error distribution for the age-composition data has changed in this assessment from a multinomial distribution implemented in HCAM to a multivariate-logistic distribution. In the former implementation the age-composition data were weighted by the annual samples sizes in each region for each age and year. In the ^{i}SCA$_{\mathrm{M}}$ implementation the age-composition data for all years is given the same weight (i.e., we assume the observation errors is homogenous) based on the conditional maximum likelihood estimate of the variance (see Appendix A.1 for full details). We further pool age-proportions that are less than 2% into the adjacent younger year class to reduce the influence of small outliers and weak cohorts.

In HG the MLE estimates of the variance for each gear is 0.102, 0.106 and 0.306, for the winter seine, seine-roe and gillnet fleets, respectively (Fig. 2.14). In general there is fairly good agreement between the observed and predicted age-composition data in this region, with poorer fits to the gillnet age-composition data. There is no persistent pattern in the residuals.

For the PRD region, the fits to the age-composition data are slightly poorer, with MLE estimates of the variance ranging from 0.164 to 0.269 for the gillnet and winter seine fleets (Fig. 2.15). There is no remarkable pattern in the winter seine fishery, the seine-roe fishery tends to have positive residuals for age-3 and age 7+ fish, and negative residuals for ages 5-6 fish. Residuals in the gillnet fishery are mostly negative for age-4 fish post 1988. The gillnet gear tends to catch older fish than both seine gears.

For the Central Coast (CC) region, there is also good correspondence between the observed and predicted age-composition data, with MLE estimates of the variance ranging from 0.135 to 0.201 (Fig. 2.16). There is no striking temporal pattern in the residuals for any of the fishing fleets. There is a tendency to overestimate the proportion-at-age 4 in the seine-roe fishery.

For the Strait of Georgia, there is also very good correspondence between the observed and predicted age-composition data for all three gears (Fig 2.17). The MLE estimates of the variance range from 0.089 to 0.263 for the seine-roe and winter seine fleets, respectively. In the gillnet fleet there has been a tendency to under-estimate the proportions-at-age 6-7 between the 1996 to 2011. Recall that selectivity for the gillnet fishery can be influenced by the empirical weight-at-age data, which has been trending to small fish in recent years. In this case, the age-composition data do not suggest that changes in mean weight-at-age has influenced the selectivity patterns (see results for selectivities).

In the case of WCVI, there is good correspondence between the observed and predicted age composition data for the seine fisheries and less so for the gillnet fishery (Fig 2.18). The MLE estimates of the variance range from 0.092 to 0.237 for the seine-roe and gillnet fisheries, respectively. Residual patterns in the seine fisheries and gillnet fisheries are unremarkable. The size of the residuals are fairly homogenous over time for all gears.

2.8.2 Biomass estimates & reference points

Maximum likelihood estimates of total biomass (age 2+) and the spawning stock biomass for each of the five major assessment regions in summarized in Figure 2.19. Estimates of spawning stock depletion (B_t/B_0) for the five major regions is summarized in Figure 2.20 along with estimates of the sustainable fisheries framework reference points. With the exceptions of CC and WCVI, estimates of spawning stock depletion in 2011 are all currently at or above 40% of their estimated unfished state. In the CC and WCVI, spawning stock depletion is estimated to be 25% and 25% of their unfished state, respectively (Fig 2.20).

Maximum likelihood estimates of spawning stock biomass in 2011 were as follows: HG – 16,723 tonnes, PRD – 27,288 tonnes, CC – 14,624 tonnes, SOG – 129,070 tonnes, and WCVI – 14,909 tonnes (Table 2.3). These estimates are considerably higher in comparison to last years HCAM estimates; the difference largely owes to the substantial change in spawn survey scaling coefficient (q).

In addition to the current estimates of spawning biomass, Table 2.3 also summarizes estimates of reference points and the total number of estimated parameters for each of the five major stock assessment regions. Each region contained data from 1951 to 2011, and the number of estimated parameters ranges from 159 in HG to 235 in SOG. The difference in the number of estimated parameters owes to the difference in the number of years of catch data for each region.

Estimates of unfished spawning biomass for each region is as follows: HG – 40,684 tonnes, PRD – 68,761 tonnes, CC – 59,365 tonnes, SOG – 135,523 tonnes, and WCVI – 57,462 tonnes. Applying the same cutoff

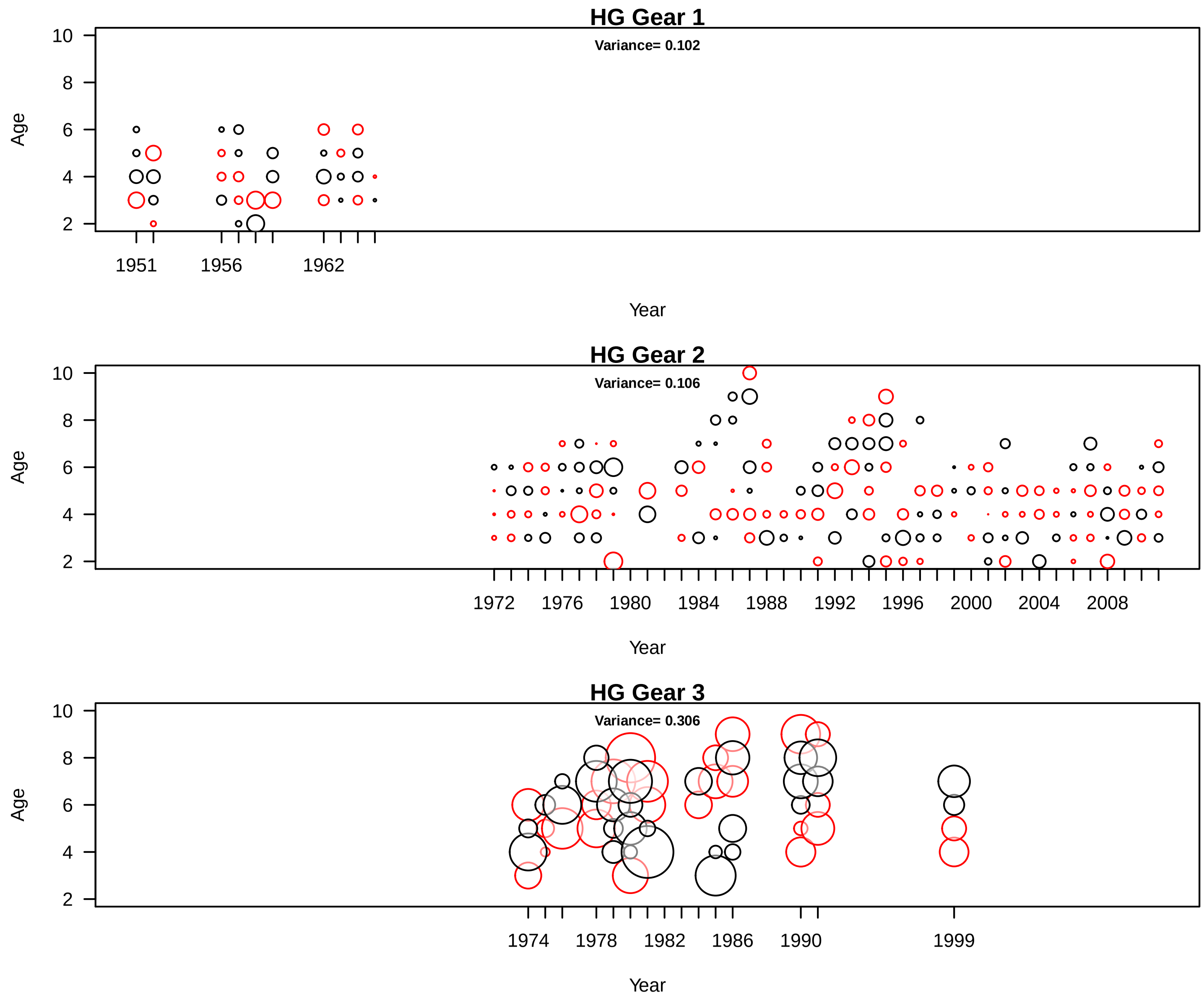

Figure 2.14: Residual difference between the observed and predicted proportions-at-age for HG for each of the three gear types (Gear 1 = winter seine, Gear 2 = seine-roe, Gear 3 = gillnet). The area of each circle is proportional to the residua, black is positive, and red is negative. The corresponding MLE estimates of the residual variance is displayed in each panel.

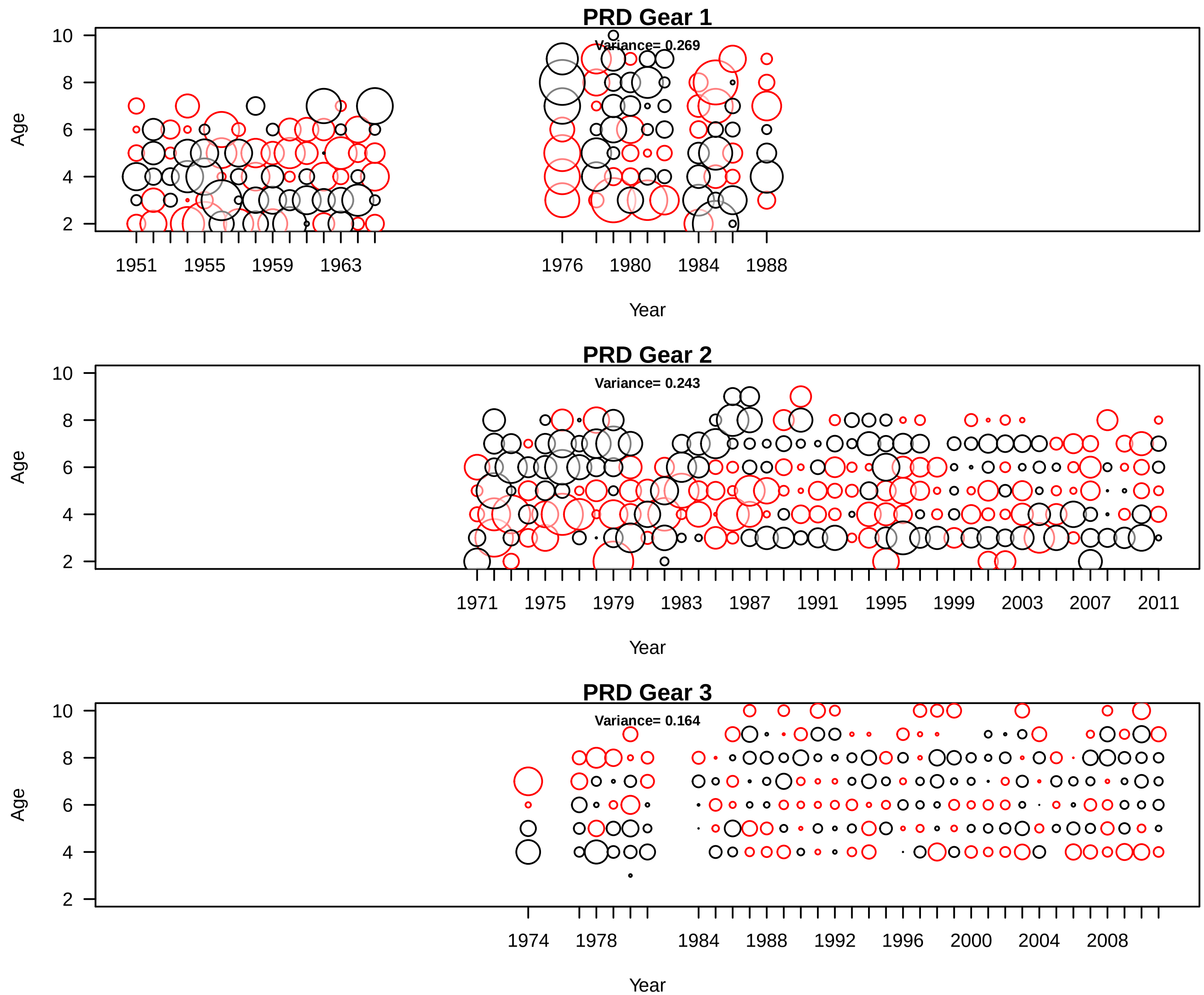

Figure 2.15: Residual difference between the observed and predicted proportions-at-age for PRD for each of the three gear types (Gear 1 = winter seine, Gear 2 = seine-roe, Gear 3 = gillnet). The area of each circle is proportional to the residua, black is positive, and red is negative. The corresponding MLE estimates of the residual variance is displayed in each panel.

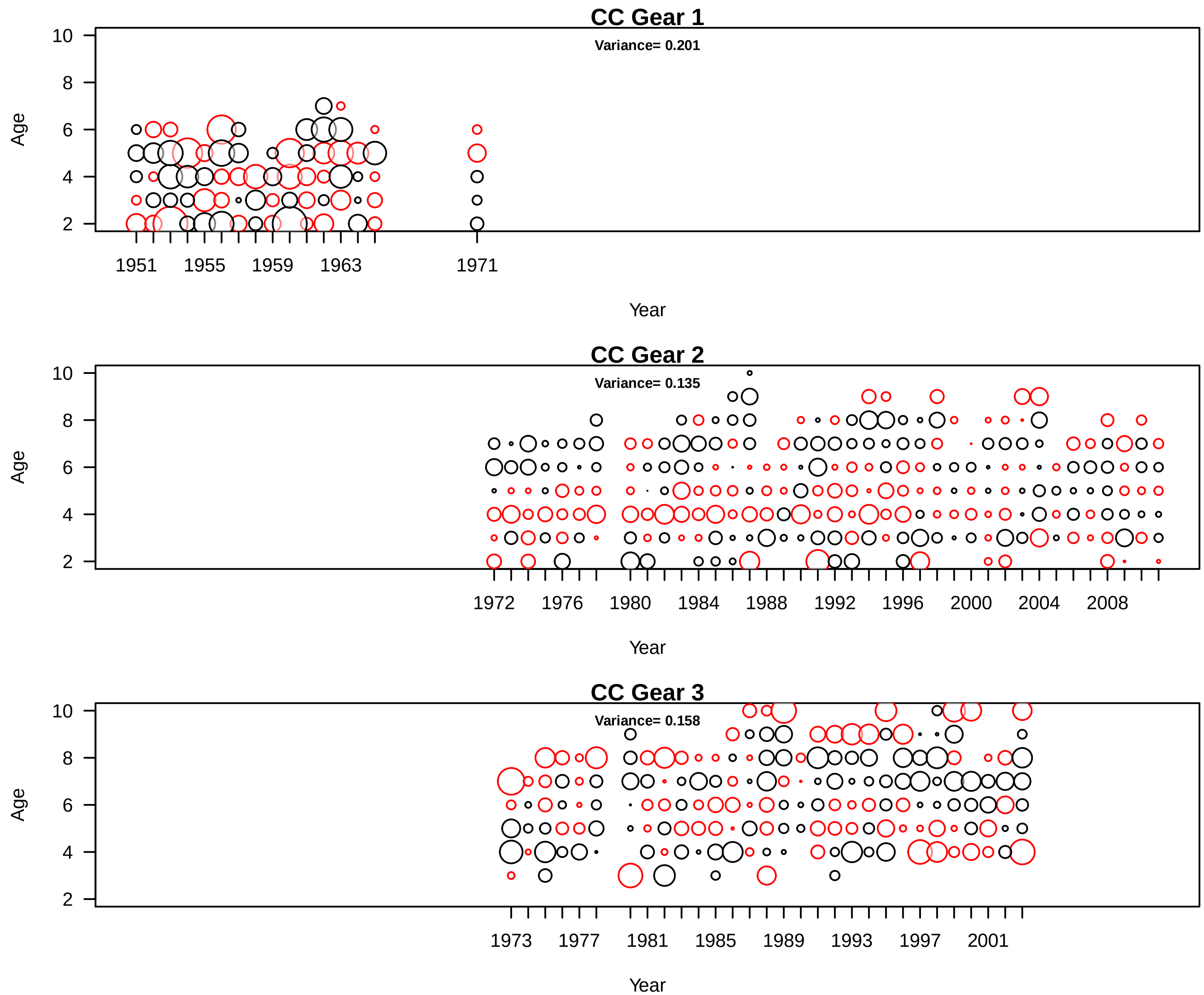

Figure 2.16: Residual difference between the observed and predicted proportions-at-age for CC for each of the three gear types (Gear 1 = winter seine, Gear 2 = seine-roe, Gear 3 = gillnet). The area of each circle is proportional to the residua, black is positive, and red is negative. The corresponding MLE estimates of the residual variance is displayed in each panel.

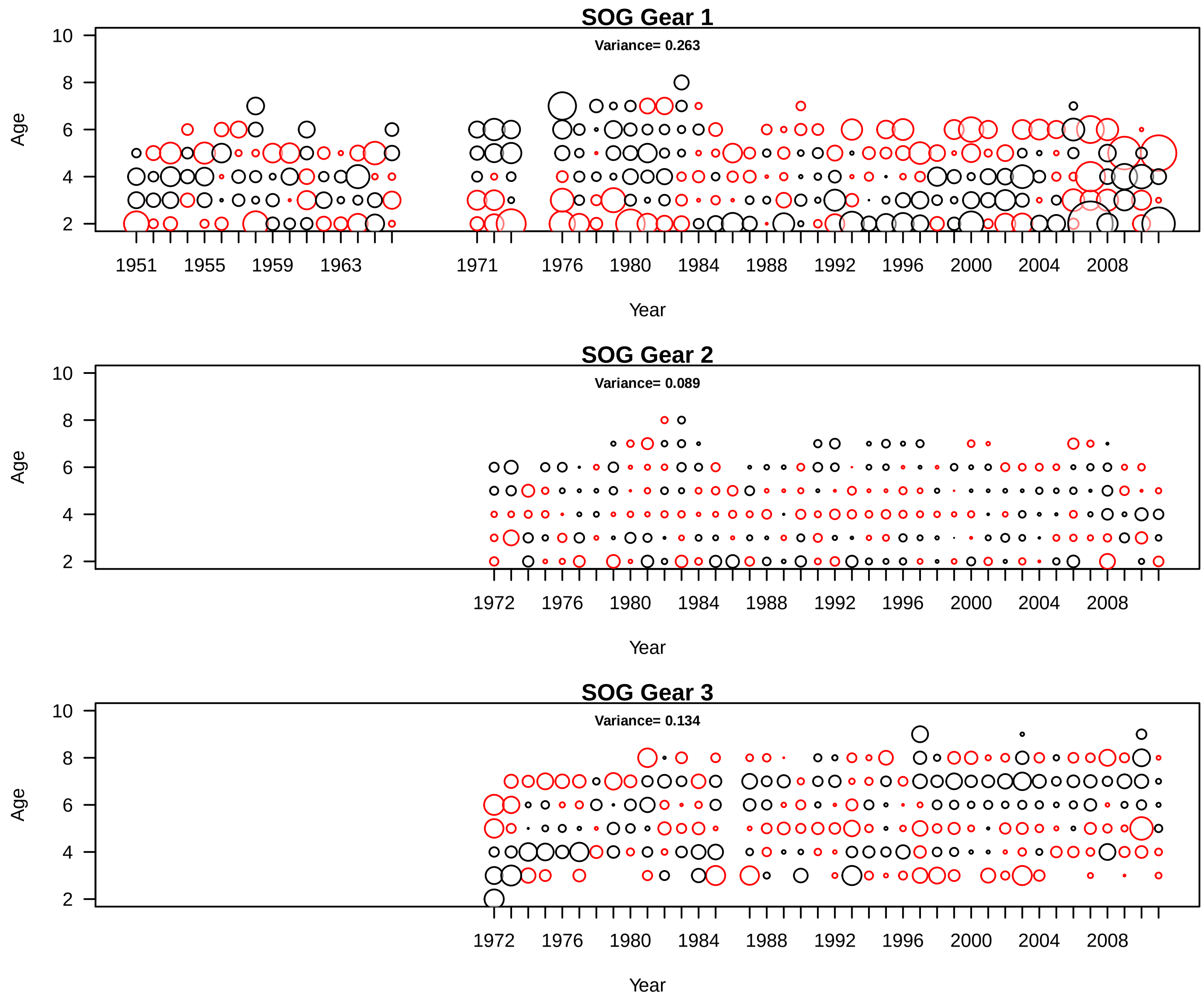

Figure 2.17: Residual difference between the observed and predicted proportions-at-age for SOG for each of the three gear types (Gear 1 = winter seine, Gear 2 = seine-roe, Gear 3 = gillnet). The area of each circle is proportional to the residua, black is positive, and red is negative. The corresponding MLE estimates of the residual variance is displayed in each panel.

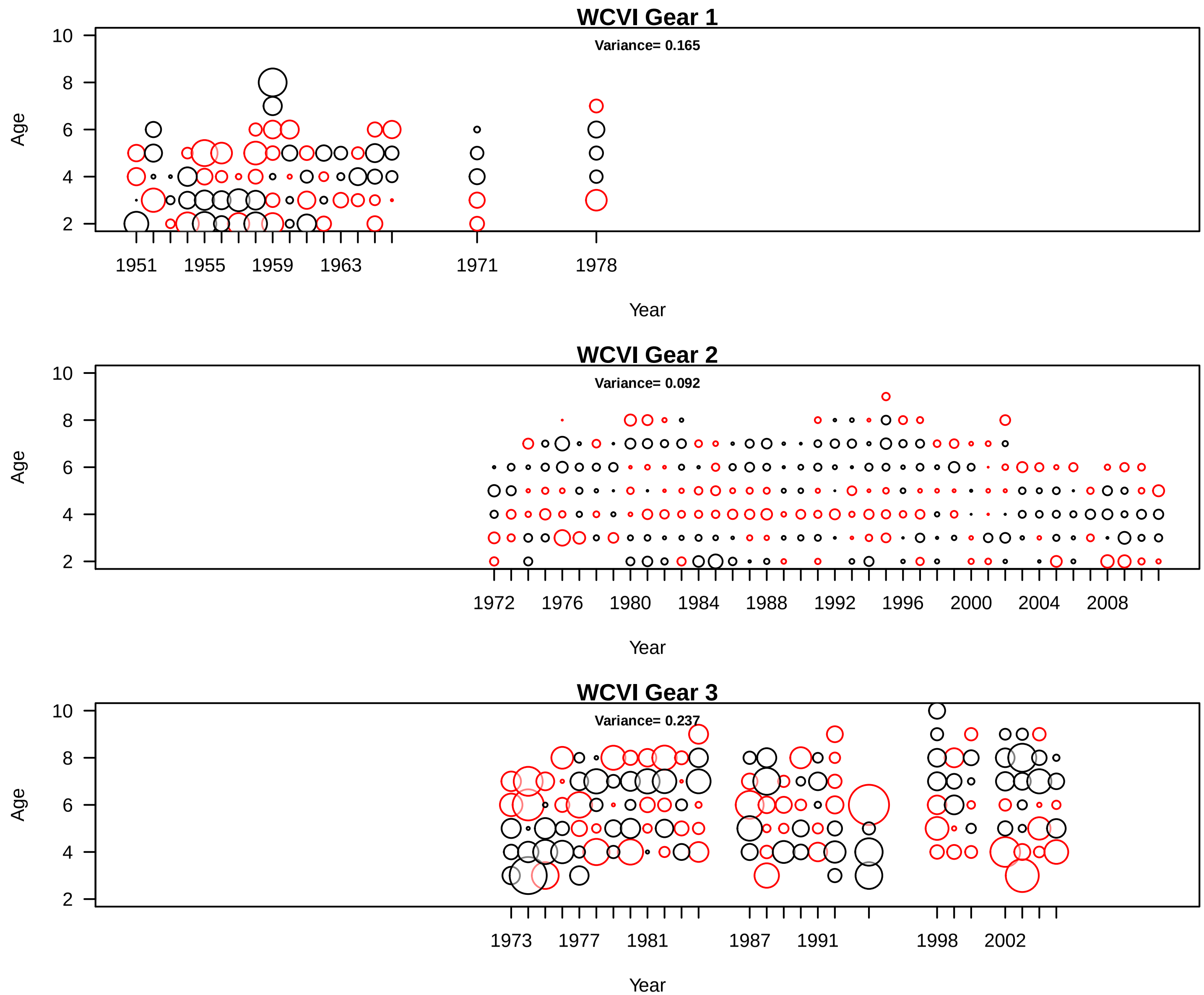

Figure 2.18: Residual difference between the observed and predicted proportions-at-age for WCVI for each of the three gear types (Gear 1 = winter seine, Gear 2 = seine-roe, Gear 3 = gillnet). The area of each circle is proportional to the residua, black is positive, and red is negative. The corresponding MLE estimates of the residual variance is displayed in each panel.

Table 2.3: Summary of maximum likelihood estimates for each of the five major stock areas. No. is the total number of estimated parameters, F_{MSY} the average instantaneous fishing rate to achieve the maximum sustainable yield (MSY), B_0 is the unfished spawning biomass, B_{MSY} is the spawning biomass that achieves maximum sustainable yield,B_t is the spawning biomass at the end of the 2011 fishing season, and B_t/B_0 is the spawning depletion level at the end of the 2011 fishing season.

Stock	HG	PRD	CC	SOG	WCVI
No.	159	206	190	235	174
F_{MSY}	2.36	0.54	1.31	1.4	0.98
MSY	8,761	6,669	9,104	27,442	10,260
B_0	40,684	68,761	59,365	135,523	57,462
$0.25B_0$	10,171	17,190	14,841	33,881	14,366
B_{MSY}	8,708	18,600	11,514	28,211	11,281
$0.8B_{MSY}$	6,966	14,880	9,211	22,568	9,025
$0.4B_{MSY}$	3,483	7,440	4,605	11,284	4,512
B_t	16,723	27,288	14,624	129,070	14,909
B_t/B_0	0.41	0.4	0.25	0.95	0.26

rule used in previous assessments (25% of B_0), results in a substantial change in the cutoff levels for PRD, CC, SOG, and WCVI. The previoucutoffs cutoff level for HG was estimated at 10,700 tonnes, and in this assessment there is a minor downward revision to 10,171 tonnes. In the case of PRD, the previous cutoff was 12,100 tonnes and in this assessment is now 17,190 tonnes. For the CC, the previous cutoff was 17,600 tonnes and now 14,841 tonnes. For the SOG, the previous cutoff was 21,200 tonnes, and in this assessment it has been revised upwards to 33,881 tonnes. Lastly, for the WCVI the cutoff has decreased from 18,800 tonnes to 14,366 tonnes. Note however, that these revised B_0's and cutoffs are Maximum Likelihood Estimates (MLE) and not median values from the joint posterior distribution (see section 2.8.10)

2.8.3 Estimates of mortality

The most recent HCAM assessment model allowed for annual estimates of M_t where natural mortality was modelled as a random walk process. The same random walk model has been adopted in this ^{i}SCA$_M$ implementation; however, a reduced number of parameters (12 nodes instead of 60 annual deviations) was estimated and interpolated using a bicubic spline. The number of estimated nodes does have minor influences on the various trends in natural mortality; we came to arrive at estimating 12 nodes by ensuring the estimated trends were very similar to trends in M when estimating 60 annual natural mortality rate deviations (NB. the use of formal model selection criterion should be used to determine the optimal number of nodes).

For all of the five major stock assessment regions, estimates of natural mortality rates have trended upwards since the 1950s (Figure 2.21). Trends in estimates of natural mortality are also consistent with the trends in natural mortality from last years HCAM model (see Figure 18 in Cleary and Schweigert, 2010). There was no relationship between trends in natural mortality and trends in the empirical mean weight-at-age data. Information about natural mortality comes from the age-composition data; therefore, changes in natural mortality rates over time is not necessarily linked with changes in growth rates, and vice versa. In the mid to late 1970s, estimates of natural mortality rates were very low during a time when most of the stocks were recovering from the earlier reduction fishery. In the last decade, estimates of natural mortality rates for herring have been at an all time high, and in all locations there is indication that natural mortality rates may be starting to decline. Estimates of M_t in the most recent years, however, are highly suspect because there are incomplete cohorts to infer estimates of total mortality rates and M_t is also confounded with selectivity.

Estimates of fishing mortality rates in each of the regions, between 1951 and 1970 were very high due to the reduction fishery by the winter purse seine (Gear 1). After the fishery re-opened in the early 1970s fishing mortality rates have been greatly reduced and periodic since the early 1990s due to the implementation

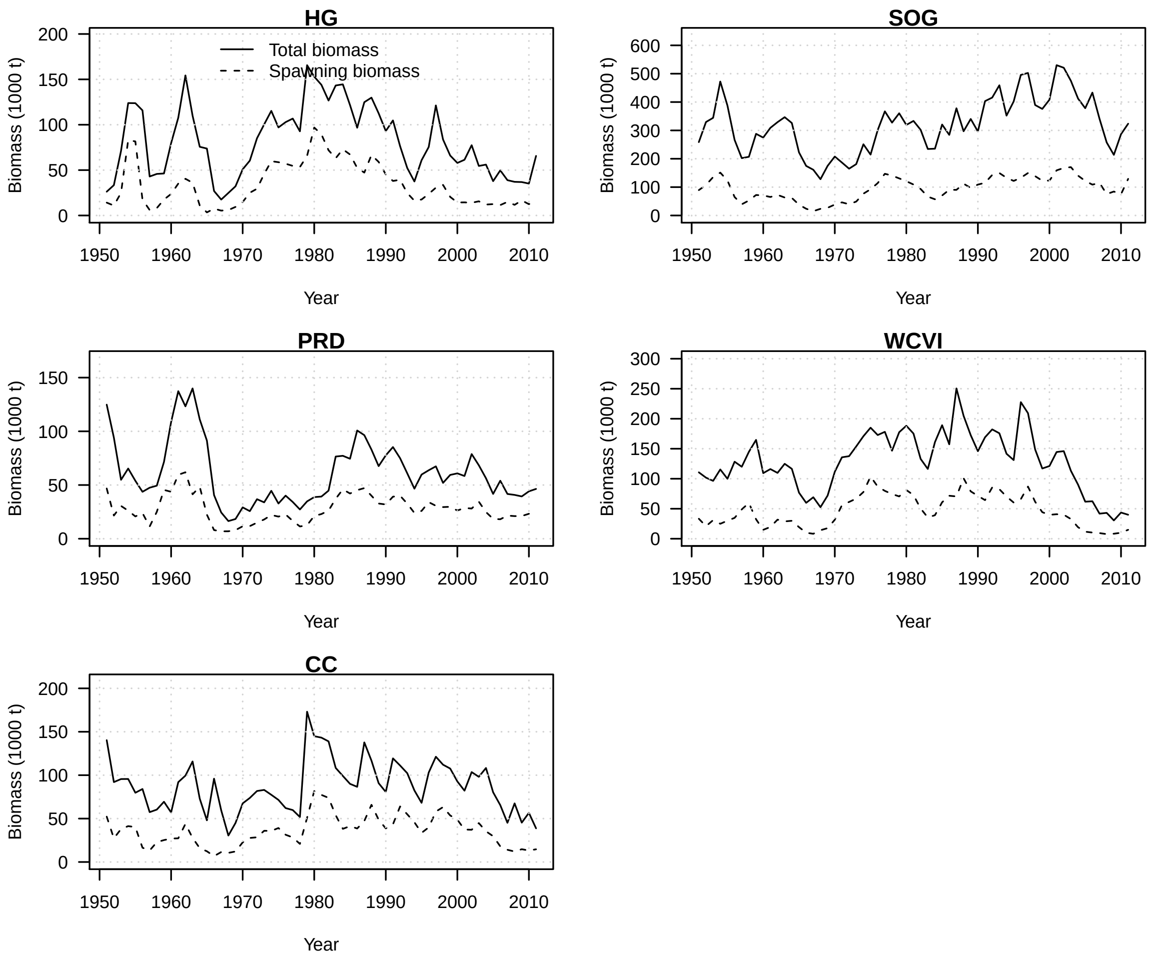

Figure 2.19: Estimates of total biomass at the start of the year (numbers times empirical weight-at-age) and spawning stock biomass (post fishery) for the five major SARs.

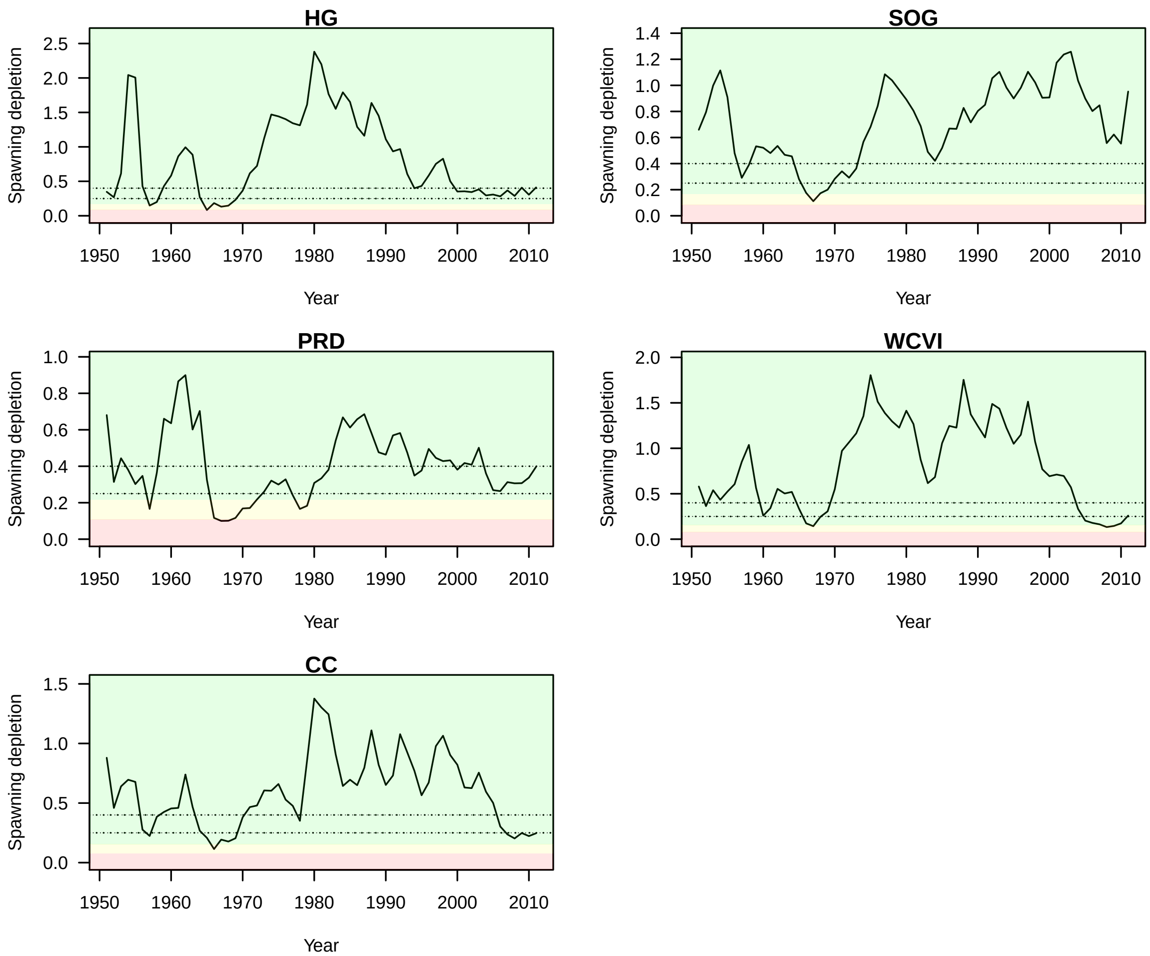

Figure 2.20: Estimates of spawning biomass depletion (B_t/B_0) for each of the five major stock areas. Horizontal dotted lines represent 25% and 40% depletion levels, and the shaded regions demarcate reference points based on <40% B_{MSY}/B_0(critical zone) and 40–80% B_{MSY}/B_0(cautious zone) and >80% B_{MSY}/B_0(healthy zone). Note that in calculating the B_{MSY} reference points, the average catch ratios over the last 20 years was used to partition fishing mortality to each of the gears.

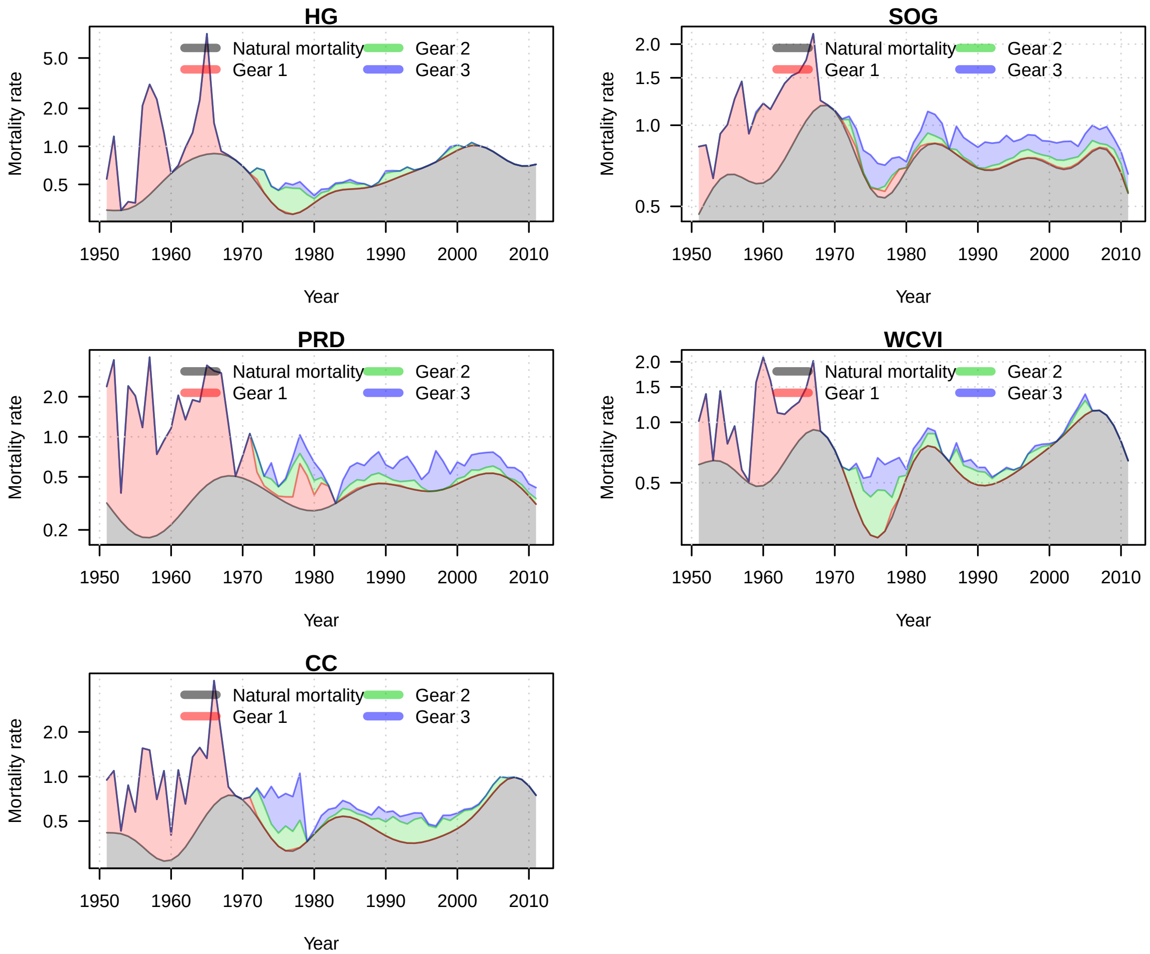

Figure 2.21: Maximum likelihood estimates of the components of average total mortality for each of the five major stock assessment regions. Note that the y-axis is plotted on a log scale, natural mortality (grey) is age-independent, fishing mortality is age-specific and the average fishing mortality rate over all age-classes is plotted here.

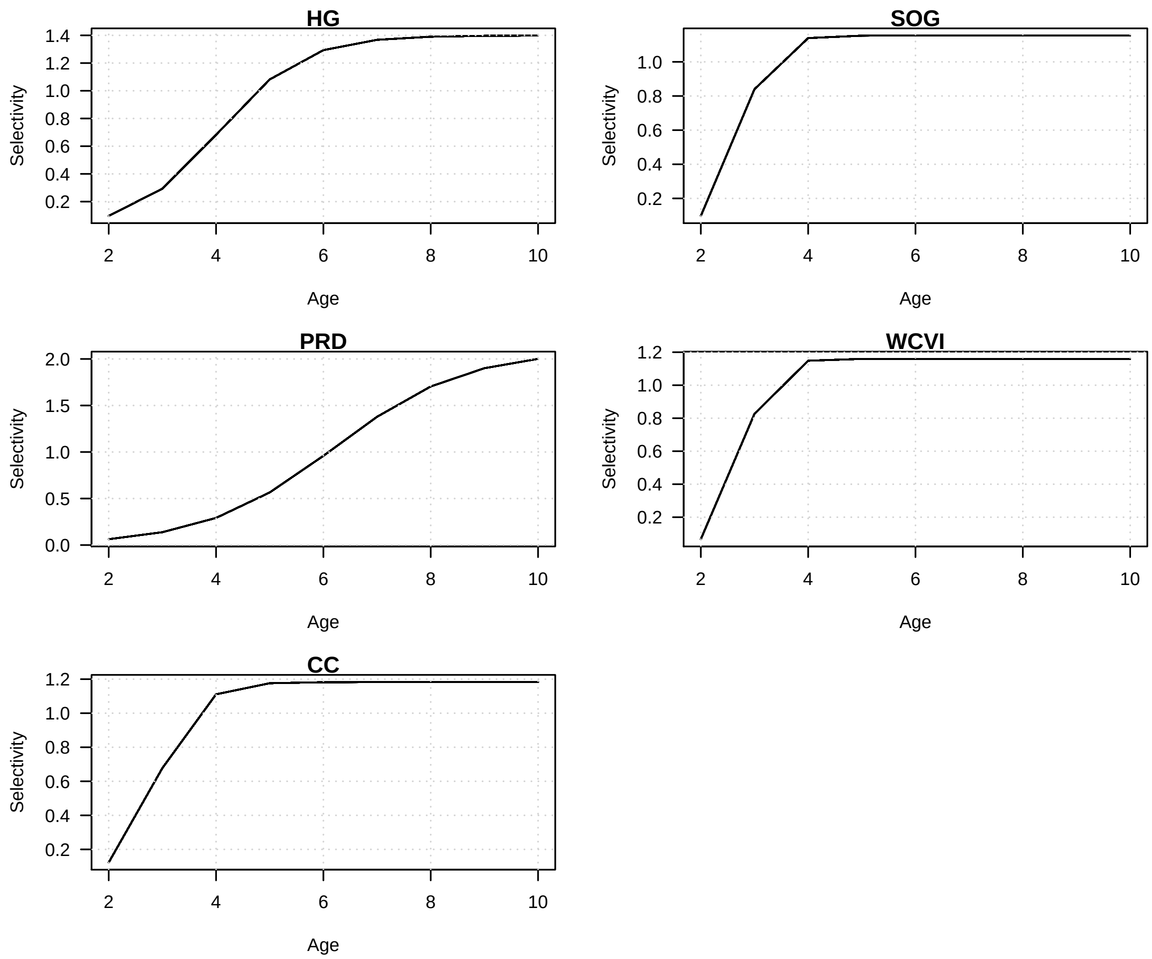

Figure 2.22: Maximum likelihood estimates of age-specific selectivity coefficients for the winter seine fishery for each of the major stock areas.

of a harvest control rule with target escapements (cutoffs). Of notable exceptions are the fishing mortality rates for the gillnet fishery in PRD and SOG have been substantially higher than other regions and consistently open each and every year (Fig. 2.21). Note that fishing mortality rates for each gear in Fig. 2.21 reflect the average fishing mortality over all age-classes and are not comparable among gears due to differences in gear selectivity. Fishing mortality rates for the gillnet fishery tend to be higher than the seine-roe fishery because recruitment to the gillnet gear is much older in comparison to the seine-roe gear.

2.8.4 Selectivity

Maximum likelihood estimates of selectivity for the winter seine fishery, seine-roe fishery and the gillnet fishery for each of the five major SARs are shown in Figures 2.22, 2.23, and 2.24, respectively. Selectivities for the seine fisheries were assumed time-invariant, and selectivity for the gillnet fishery varies over time due to changes in the mean weight-at-age data.

For the winter seine fishery, age-specific selectivity coefficients were somewhat variable among the assessment regions (Fig. 2.22). The age at which herring were fully recruited to the gear was roughly age 5 for CC, SOG, and WCVI. Age at full recruitment for HG and PRD was much older, 9- and 10-years, respectively.

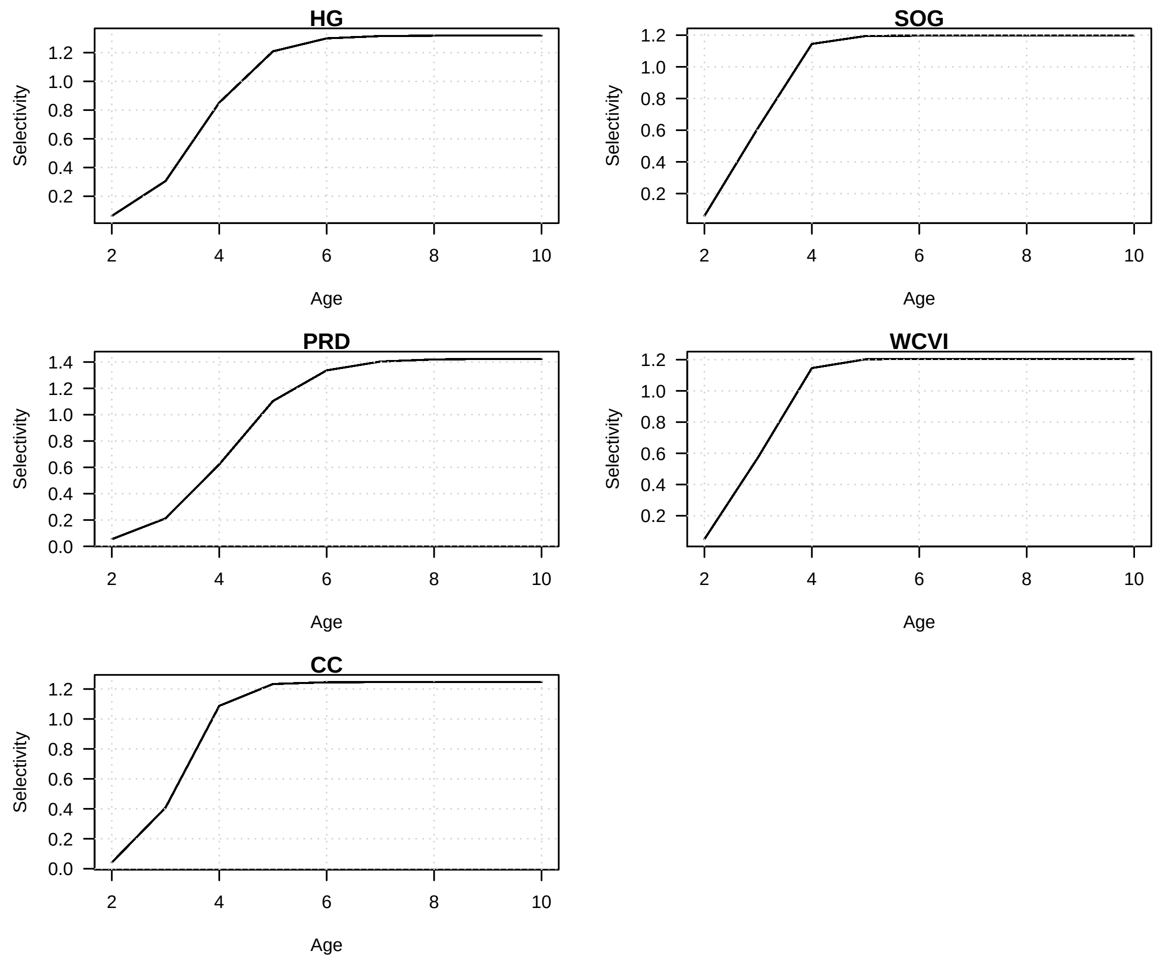

Figure 2.23: Maximum likelihood estimates of age-specific selectivity coefficients for the seine-roe fishery for each of the major stock areas.

For the seine-roe fishery, maximum likelihood estimates of selectivity were much more consistent among regions than the winter seine fishery (Fig. 2.23). Age at full recruitment to this gear type was roughly 5-6 years, and roughly the age at 50% vulnerability was roughly 3-4 years, with a tendency to recruit to the fishery at a younger age in the southern regions.

In the case of the gillnet fishery, selectivity was allowed to vary over time according to variation in the empirical weight-at-age data (Fig. 2.24). Recall that selectivity for the gillnet fishery was modelled as a logistic function of age with the addition of age-specific deviations where selectivity can increase if the weight-at-age is above average for that year. This selectivity function consists of three latent variables: two that describe the age-at-50% vulnerability and standard deviation in vulnerability-at-age, and a third parameter that describes the influence of variation in weight-at-age on departures from the logistic selectivity function ($\lambda^{(a)}$). Maximum likelihood estimates for these parameters for the gillnet fishery are presented in Table 2.4. With the exception of PRD and WCVI, estimates of $\lambda^{(a)}$ are negative and close to 0 implying no affect of variation in weight-at-age on selectivity or a slight negative effect (i.e., vulnerability to the gear declines for fish that are larger than the average weight). In the case of PRD and WCVI, the variation in weight-at-age explains approximately 4.1% and 8.7% of the residual variation in the age-composition data (Table 2.4).

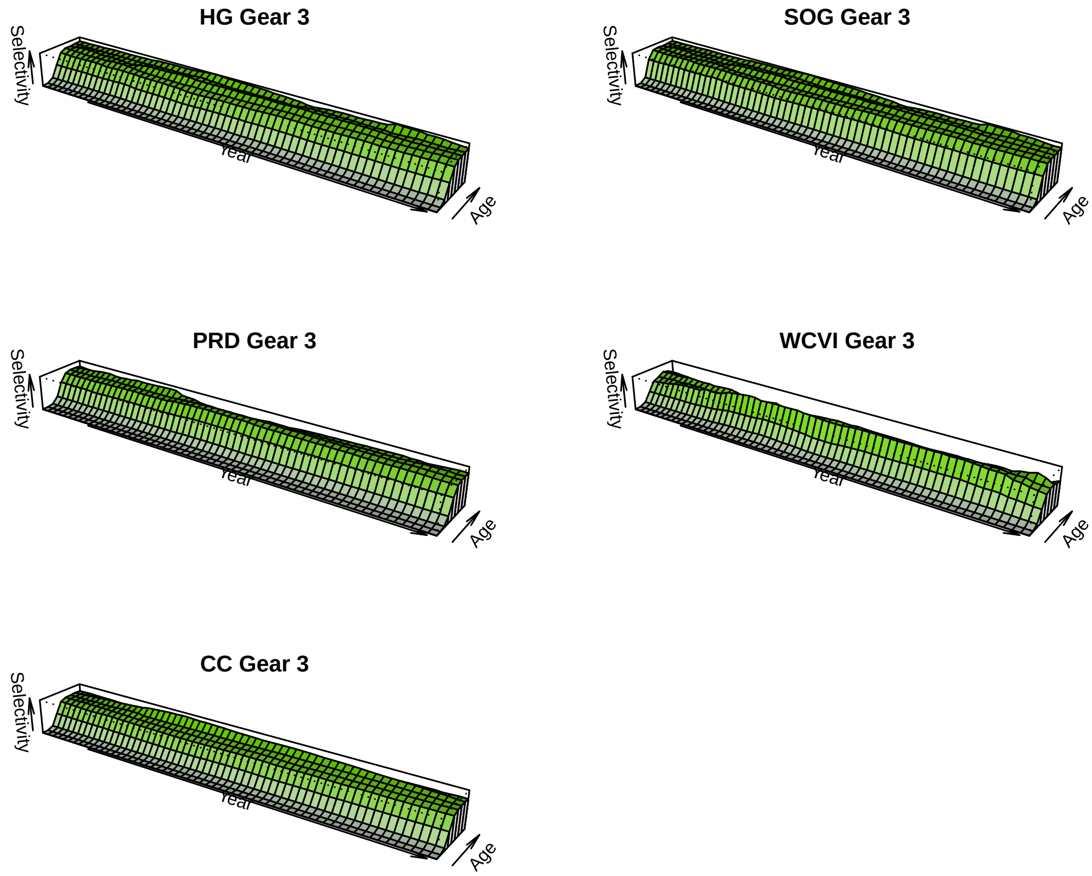

Figure 2.24: Estimates of selectivity for the gillnet fleet for each of the five major stock assessment regions. In this case selectivity is a logistic function of the empirical weight-at-age data; due to declining growth there is a tendency for selectivity to shift to older ages.

Table 2.4: Maximum likelihood estimates of gillnet selectivity parameters, where μ_a is the age-at-50% vulnerability, σ_a is the standard deviation in selectivity, and $\lambda^{(a)}$ is the coefficient that describes the influence of growth on selectivity ($\lambda^{(a)}$=0 implies no effect, $\lambda^{(a)} > 0$ implies a positive effect).

Stock	$\ln(\mu_a)$	$\ln(\sigma_a)$	$\lambda^{(a)}$
HG	1.598	-0.68125	-0.030581
PRD	1.727	-0.66217	0.040988
CC	1.604	-0.8050	-0.019404
SOG	1.540	-0.9797	-0.02835
WCVI	1.608	-0.6647	0.08677

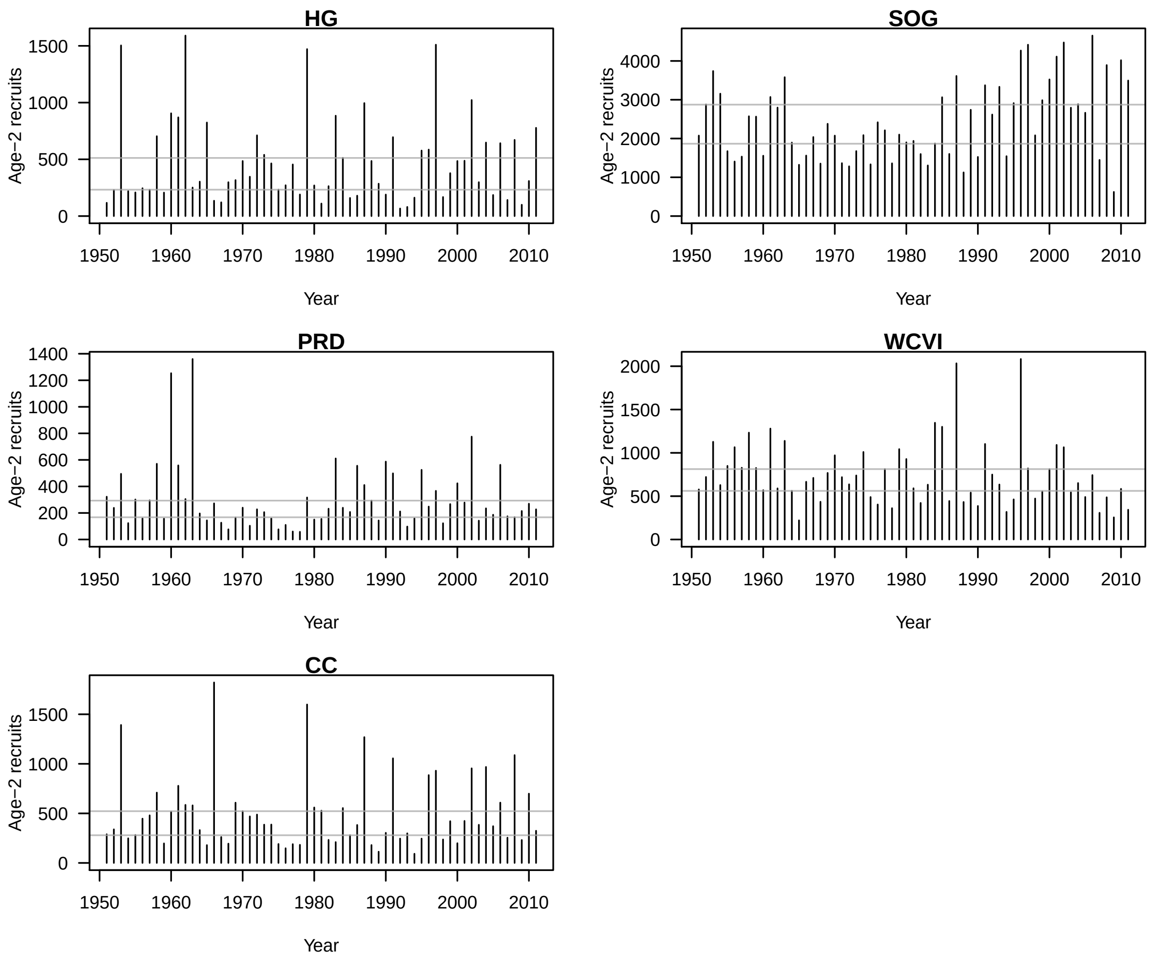

Figure 2.25: Maximum likelihood estimates of age-2 recruits for each of the five major stock areas. The horizontal divisions demarcate the 0.33 and 0.66 quantiles that define poor, average, and good recruitment.

2.8.5 Recruitment and stock-recruitment relationships

Recruitment to each stock is defined as the number of age-2 fish entering the population at the beginning of each year. Age-2 recruitment is estimated as a free parameter within ^{i}SCA$_{\text{M}}$, subject to the constraint that annual estimates vary around a Beverton-Holt stock recruitment relationship with an estimated standard deviation. Maximum likelihood estimates of age-2 recruits are shown in Figure 2.25 along with horizontal lines that demarcate the 0.33 and 0.66 quantiles that was traditionally used to categorize recruitment as poor, average, and good in previous assessments.

Estimates of age-2 recruits for 2010 and 2011 were average and good in HG, average in PRD, good and average in CC, good in SOG, and average and poor in the WCVI region.

The underlying stock-recruitment relationship is key for determining reference points for this stock. Maximum likelihood estimates of the age-2 recruits versus spawning biomass, along with the corresponding Beverton-Holt stock recruitment model are shown in Figure 2.26. The Beverton-Holt stock recruitment model was jointly fitted to these data by estimating the steepness of the stock recruitment relationship (h) and the unfished age-2 recruits (R_0). The unfished spawning biomass was determined by using the average fecundity and average natural mortality rates (from 1951-2011) to calculate the average spawning biomass

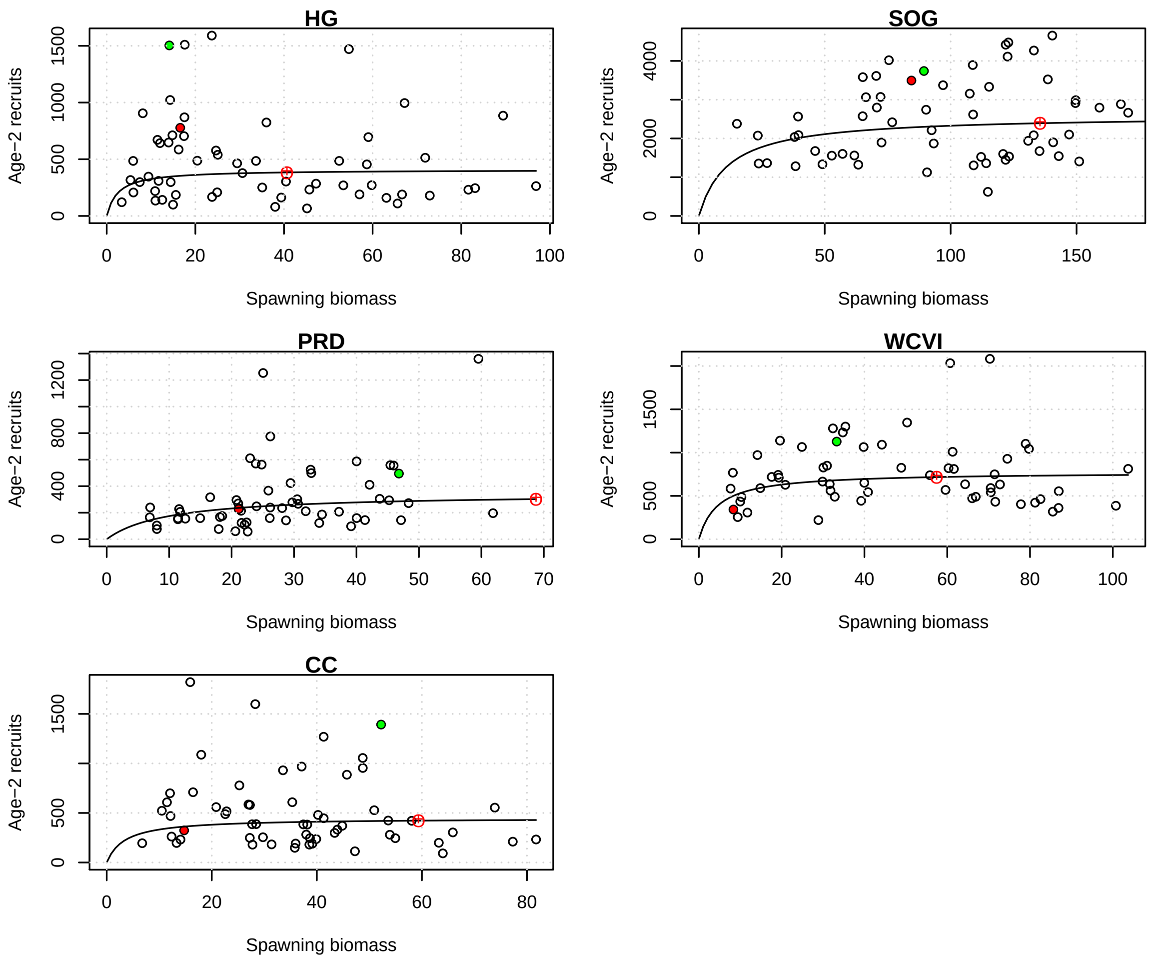

Figure 2.26: Maximum likelihood estimates of age-2 recruits versus estimated spawning stock biomass in each of the five major assessment regions. The green and red circles indicate the start (recruits in 1952) and end (recruits in 2011) of the series, the circle plus (red) corresponds to the maximum likelihood estimate of unfished spawning biomass (B_0) and unfished age-2 recruitment R_0, the line is the Beverton-Holt stock recruitment model fitted to these data.

per recruit. Alternative stock-recruitment models (e.g., Ricker model) were not explored to determine if they provided a better fit.

Between 1951 and 2011, four of the five major stock areas have fluctuated above the estimate of unfished spawning biomass; the exception is the PRD area. In HG, age-2 recruitment has been remarkably stable over a very wide range of spawner abundance. This is also the case for CC and WCVI. In PRD and SOG, variation in recruitment appears to be lower at low spawning abundance and the average recruitment rate tends to drop. Maximum likelihood estimates for steepness for these five stocks are as follows: HG – 0.81, PRD – 0.66, CC – 0.82, SOG – 0.76, WCVI – 0.77.

The log residual differences between the estimated age-2 recruits and that predicted by the estimated spawning-biomass and Beverton-Holt model for each of the major stock areas is shown in Figure 2.27. There is no strong autocorrelation in recruitment, except perhaps 5-8 year periods of poor and good recruitment in SOG. There is good correspondence between the standard deviations of the residuals and the estimated standard deviation of the process error variance (τ).

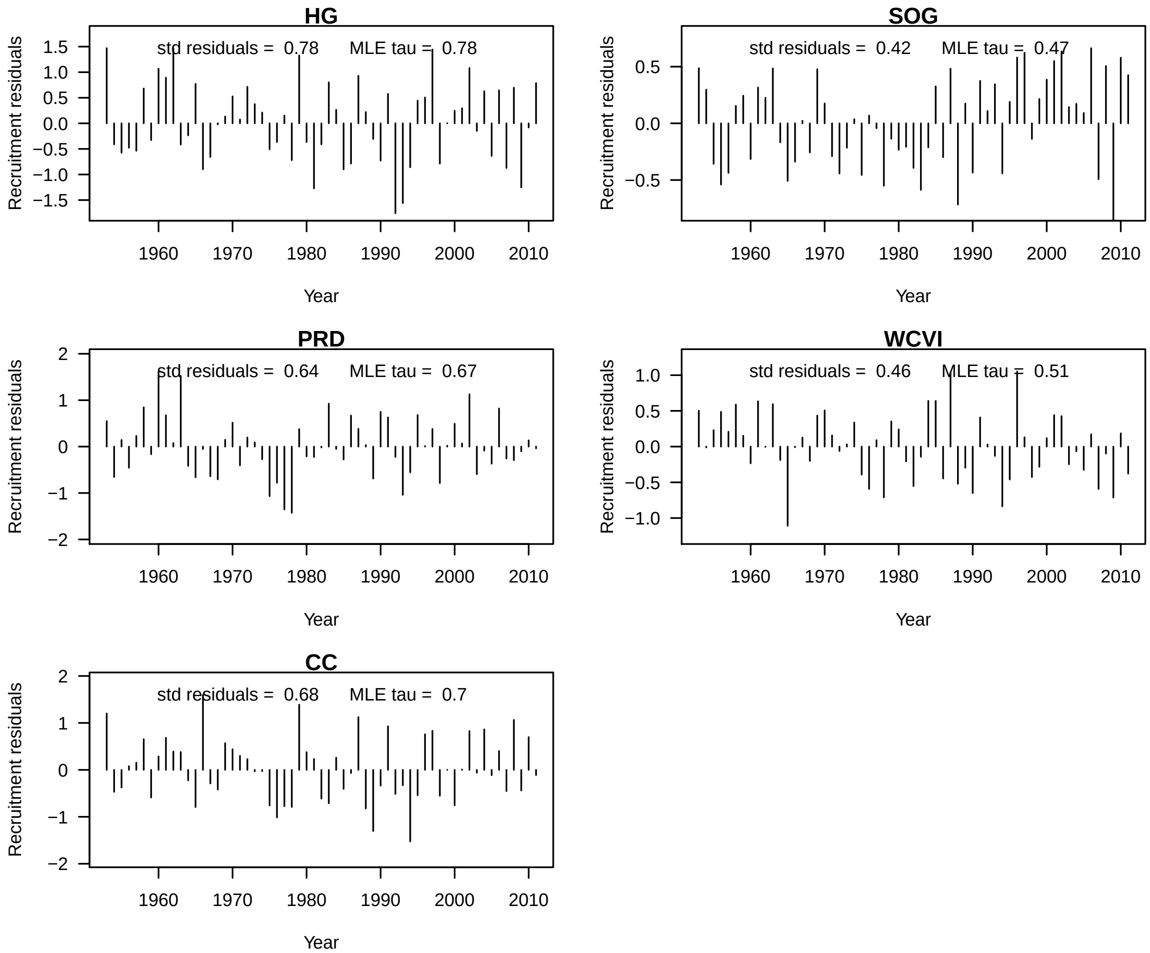

Figure 2.27: Log residual differences between estimated age-2 recruits and the recruitment predicted by the Beverton-Holt model and estimated spawning stock biomass. The standard deviations of the residuals along with the MLE estimate of the process error standard deviations are displayed at the top of each panel.

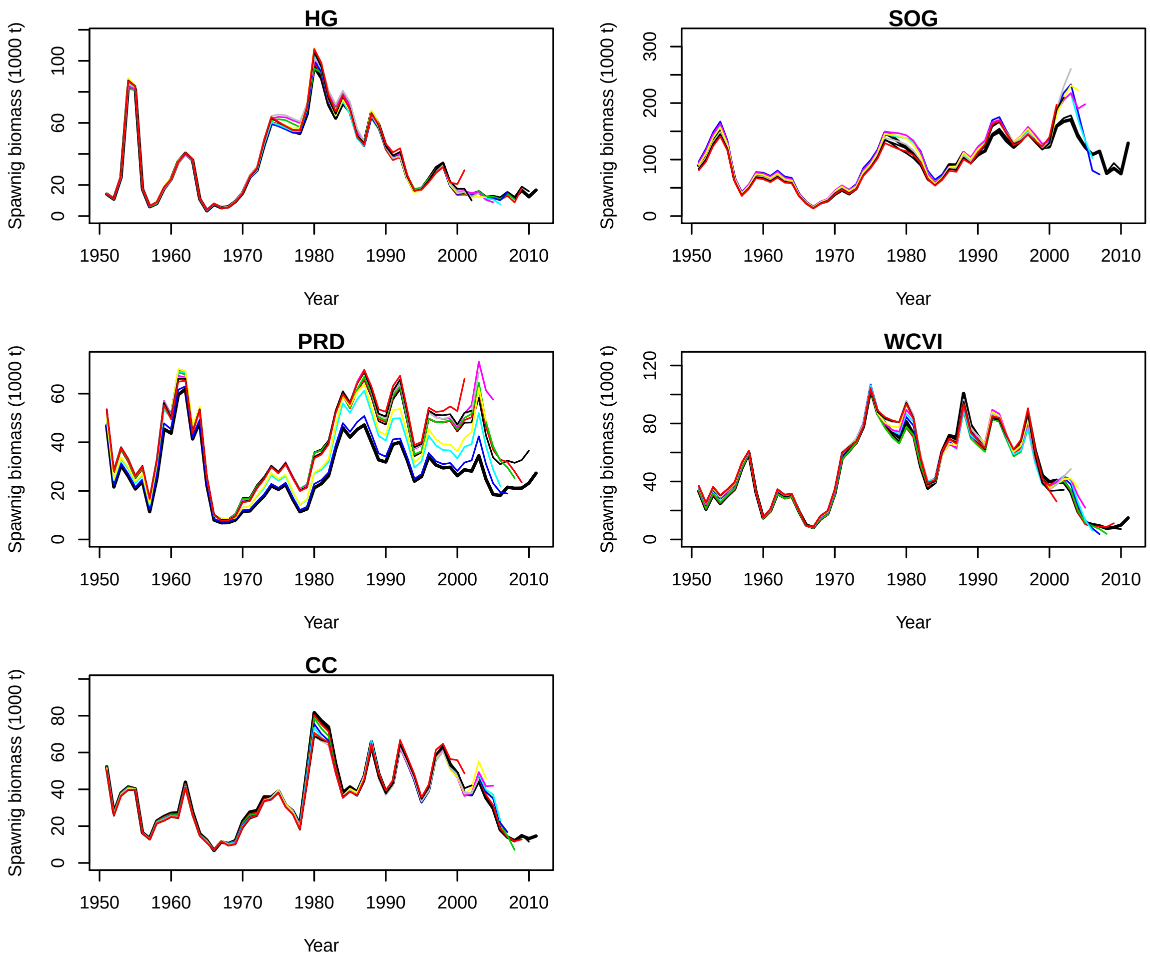

Figure 2.28: Retrospective estimates of spawning stock biomass for each of the five major stock assessment areas. The model was sequentially fitted to the full data set, then from 1951:2010, 1951:2009, ... 1951:2001.

2.8.6 Retrospective analysis

Four of the five major regions contained little to no retrospective bias in the estimates of spawning stock biomass when fitting the data back to 2001 (10 years, Figure 2.28). The PRD region does show a strong retrospective bias; as each year of data is removed estimates of the terminal spawning biomass that year increase. This pattern of declining estimates of biomass as data are added is persistent for all of the years in which the retrospective estimates were examined.

2.8.7 Marginal posterior distributions

Marginal posterior distributions for estimated model parameters were constructed using AD Model Builders built in Metropolis-Hastings algorithm (Gelman, 2004). For each of the major and minor assessment areas, a systematic sample of 2,000 points from a chain of length 1,000,000 and is intended to represent a random sample from the joint posterior distribution. These samples were then used to construct marginal distributions for derived quantities (e.g., B_0). All areas with the exception of the SOG used the inverse Hessian matrix as the jumping distribution. In the case of SOG, the hessian matrix had to be re-scaled (using the

Table 2.5: Estimates of 2011 spawning biomass, B_0, and depletion based on 2000 systematic samples from the joint posterior distribution drawn from a chain of length 1,000,000.

	SB_{2011}			B_0			SB_{2011}/B_0		
Stock	**Median**	2.5%	97.5%	**Median**	2.5%	97.5%	**Median**	2.5%	97.5%
HG	**16.58**	7.70	33.63	**41.74**	30.05	61.51	**0.39**	0.19	0.75
PRD	**27.05**	14.45	50.59	**78.56**	54.15	150.18	**0.34**	0.15	0.68
CC	**14.67**	7.28	27.28	**62.40**	48.47	85.06	**0.23**	0.12	0.41
SOG	**125.14**	70.43	217.95	**140.05**	110.47	184.24	**0.89**	0.53	1.45
WCVI	**14.68**	6.99	27.63	**59.58**	46.84	78.53	**0.24**	0.12	0.43

`-mcmult 2.0` option in ADMB) in order to invert the Hessian matrix.

Diagnostic trace plots

No formal statistical tests were carried out to determine if the samples from the joint posterior distribution were taken from a converged distribution. Visual inspection was used to determine overall convergence and the trace plots for each of the five major regions are shown in Figures 2.29–2.33.

2.8.8 Parameter confounding

To examine the level of confounding among the estimated parameters, 200 randomly selected points from the joint posterior distribution for the seven leading parameters were plotted against each other in a pairs plot (e.g., Fig. 2.34). Only 200 points were plotted to reduce the file size. Among the seven leading estimated parameters ($R_0, h, M, \bar{R}, \ddot{R}, \rho, \vartheta$) there was very little confounding (Figures 2.34 – 2.38).

There is, however, some strong confounding between the estimated parameters and a few of the derived reference points. In all major areas, there was a strong positive correlation between steepness (h) and F_{MSY}; similarly there is a strong positive correlation between $B_0$and R_0. Among the reference points alone, there is a negative correlation between $B_{MSY}$and F_{MSY}, and a positive correlation between $F_{MSY}$and MSY. This level of confounding among the derived variables is not cause for concern from a parameter estimation standpoint; it does, however, highlight the tradeoffs that must be made from a decision makers perspective.

2.8.9 Marginal posterior distributions

Marginal posterior distributions and along with the prior densities for the seven leading parameters are shown in Figure 2.39. In all cases, the steepness parameter, followed by the instantaneous natural mortality rate appears to be the most influenced by the prior density. Uniform prior distributions were assumed for the scaling parameters ($R_0, \bar{R}$, and $\ddot{R}$). There were good posterior updates for the total variance and variance portioning parameters (ϑ, ρ).

Median estimates of the 2011 spawning stock biomass and the 95% credible interval for each of the five major assessment regions are summarized in Table 2.5. Current estimates of depletion and the corresponding uncertainty is based on the ratio of the 2011 spawning biomass divided by the corresponding estimate of B_0. Depletion levels less that 0.25 would be considered to be below the cutoff level.

2.8.10 Forecast and catch advice based on the joint posterior distribtution

Catch advice has historically been provided in the form of a decision table based on median values of the joint posterior distribution. The decision table contains columns specifying the 2011 SSB the age 4+ total biomass, estimates of age-3 recruit biomass for poor, average, and good recruitment, cutoff levels, and the available harvest under poor, average, and good recruitment scenarios. Moving towards DFO's sustainable fisheries framework (SFF) is a necessary next step.

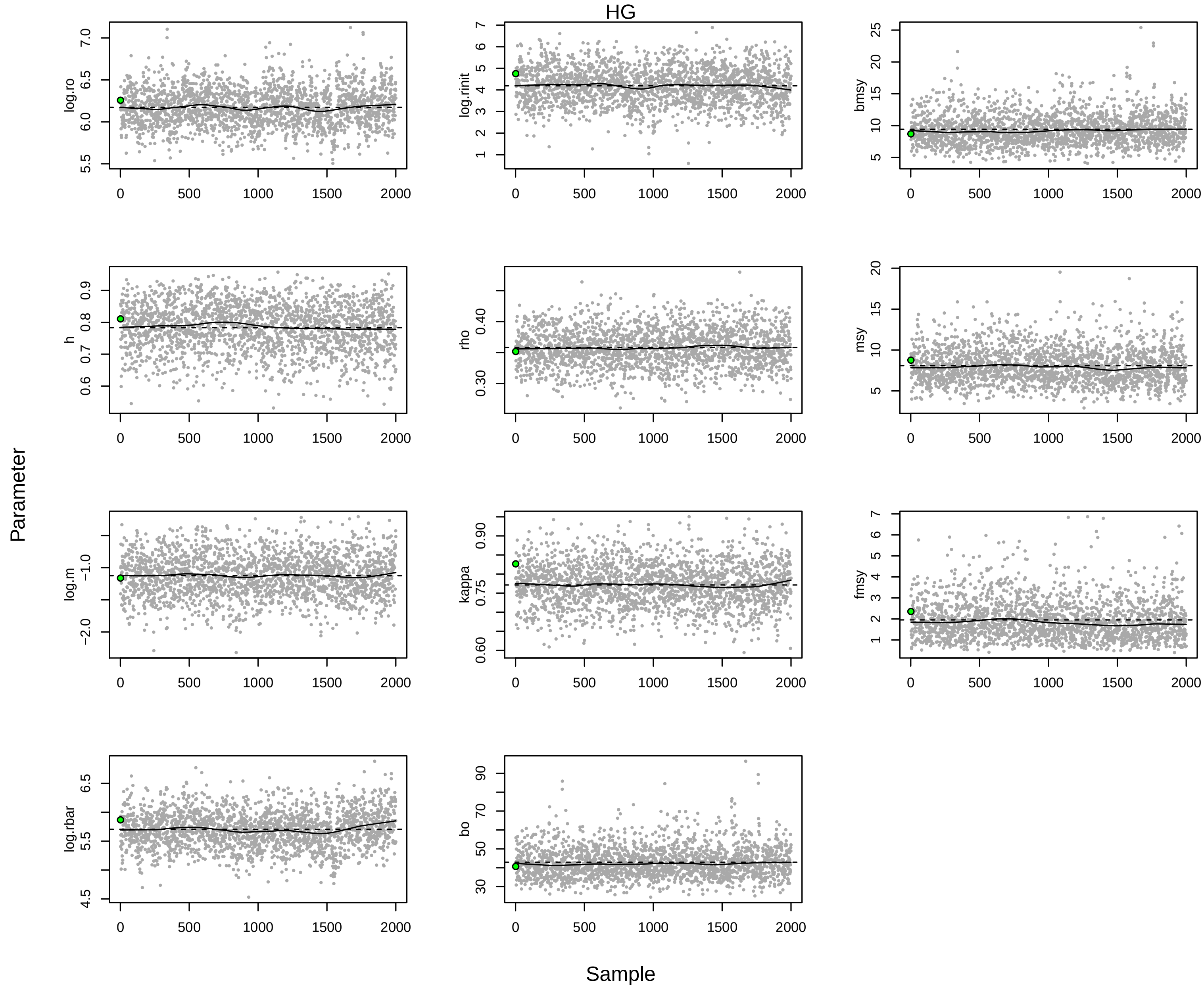

Figure 2.29: A systematic sample of 2,000 from an MCMC chain of length 1,000,000 of leading parameters and derived variables used in reference point calculations for HG. Green circle corresponds to the MLE estimates and the solid line is a lowess smooth fit to the data (f=1/4), and the dashed line is the mean of the distribution.

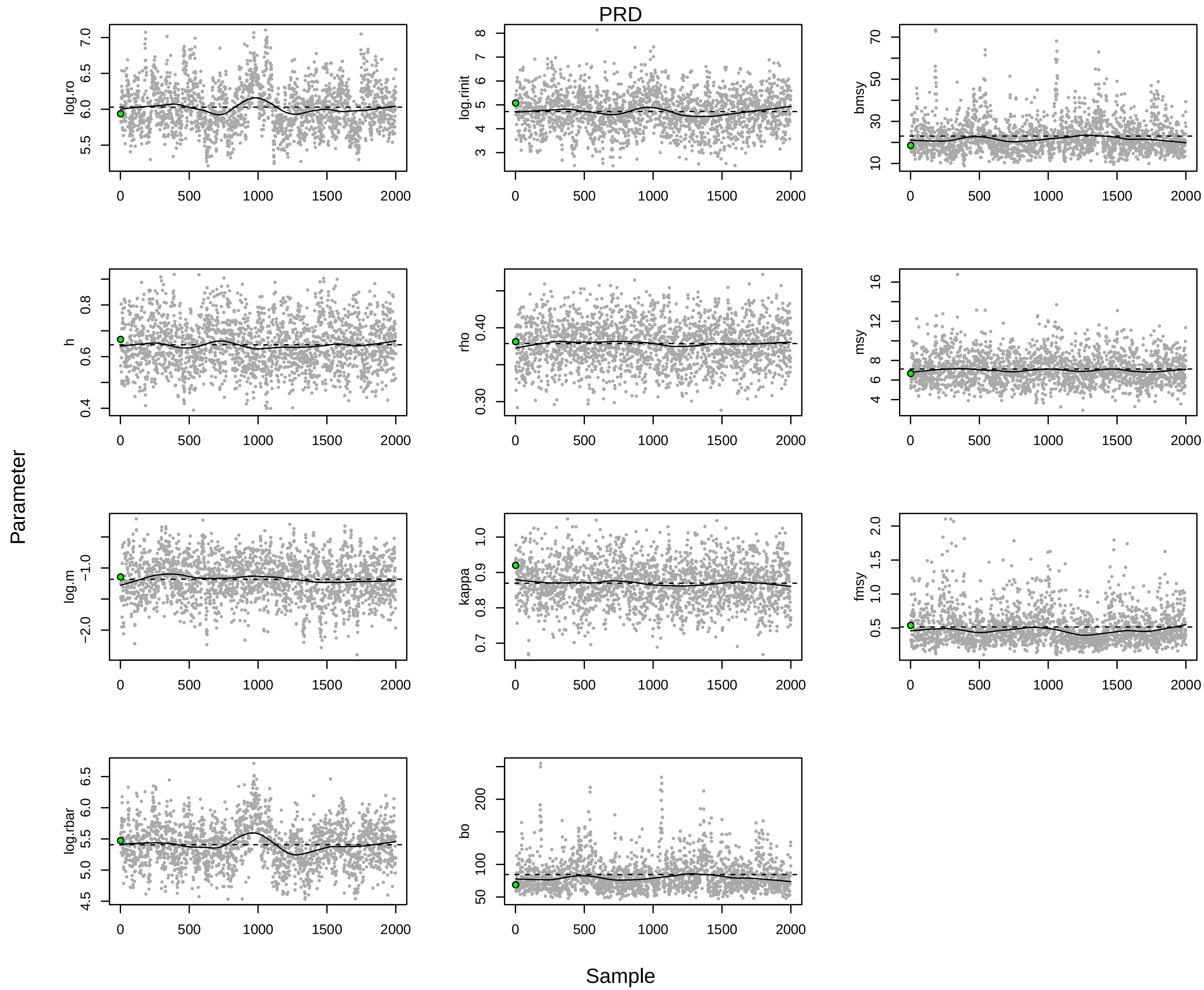

Figure 2.30: A systematic sample of 2,000 from an MCMC chain of length 1,000,000 of leading parameters and derived variables used in reference point calculations for PRD. Green circle corresponds to the MLE estimates and the solid line is a lowess smooth fit to the data (f=1/4), and the dashed line is the mean of the distribution.

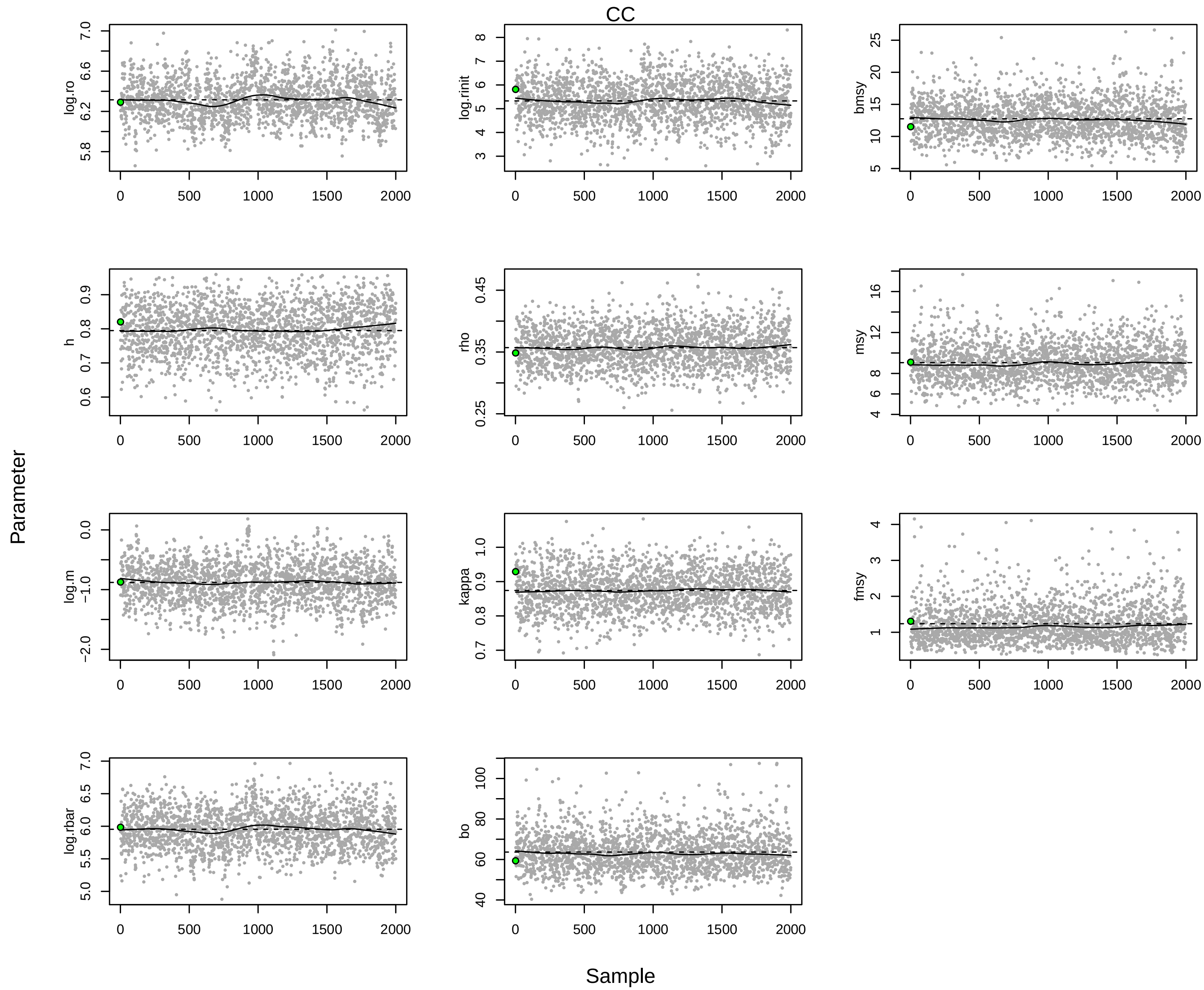

Figure 2.31: A systematic sample of 2,000 from an MCMC chain of length 1,000,000 of leading parameters and derived variables used in reference point calculations for CC. Green circle corresponds to the MLE estimates and the solid line is a lowess smooth fit to the data (f=1/4), and the dashed line is the mean of the distribution.

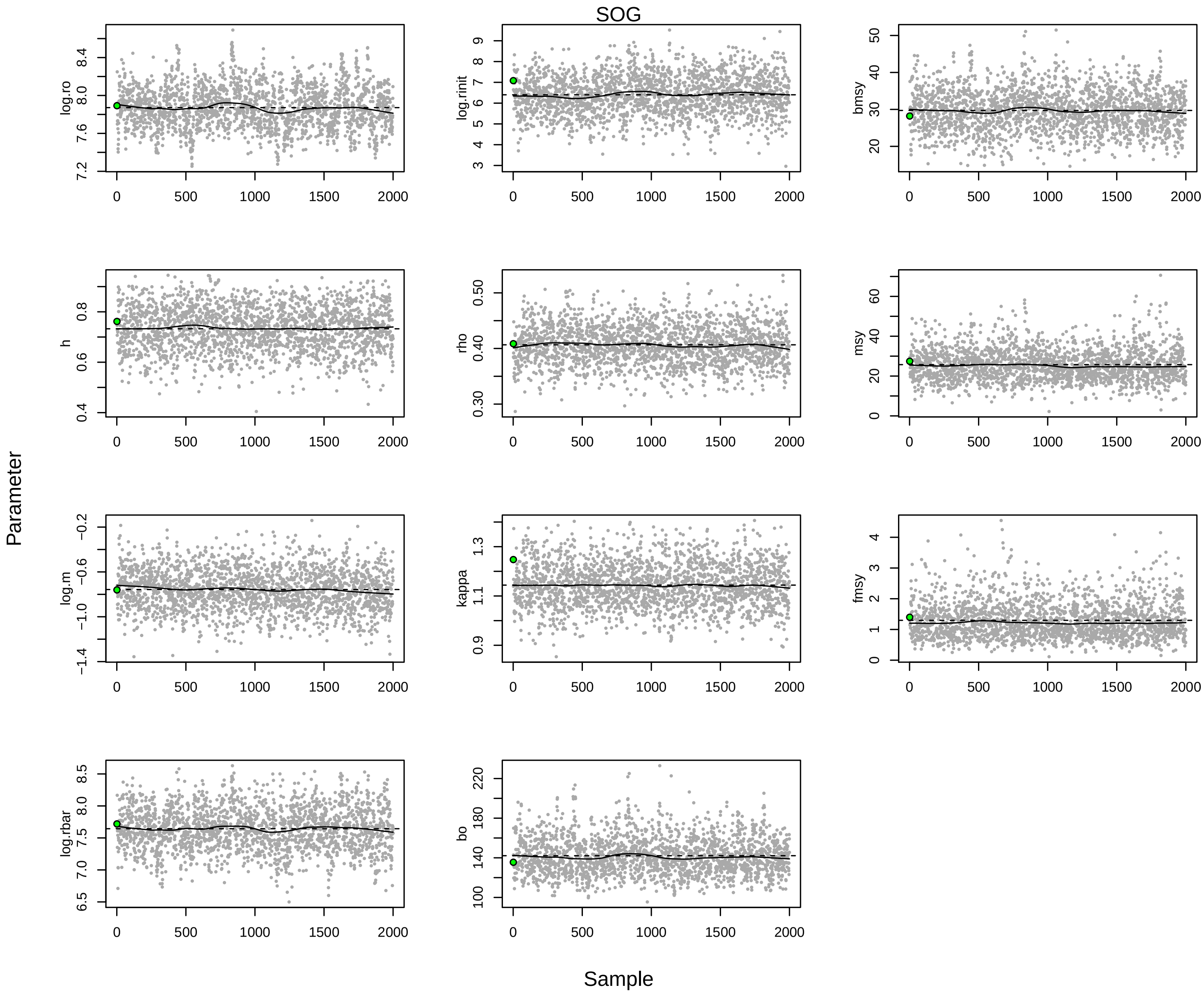

Figure 2.32: A systematic sample of 2,000 from an MCMC chain of length 1,000,000 of leading parameters and derived variables used in reference point calculations for SOG. Green circle corresponds to the MLE estimates and the solid line is a lowess smooth fit to the data (f=1/4), and the dashed line is the mean of the distribution.

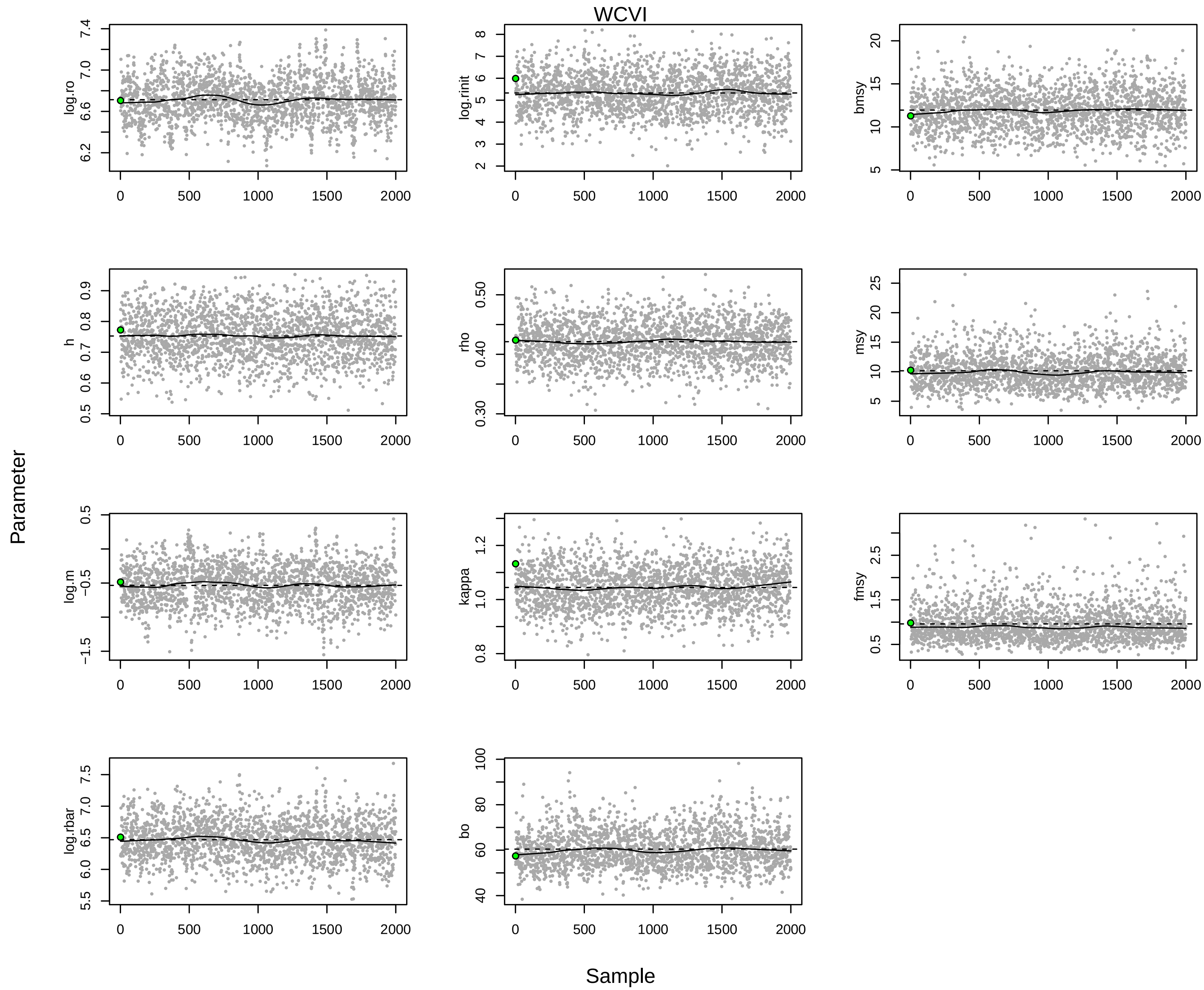

Figure 2.33: A systematic sample of 2,000 from an MCMC chain of length 1,000,000 of leading parameters and derived variables used in reference point calculations for WCVI. Green circle corresponds to the MLE estimates and the solid line is a lowess smooth fit to the data (f=1/4), and the dashed line is the mean of the distribution.

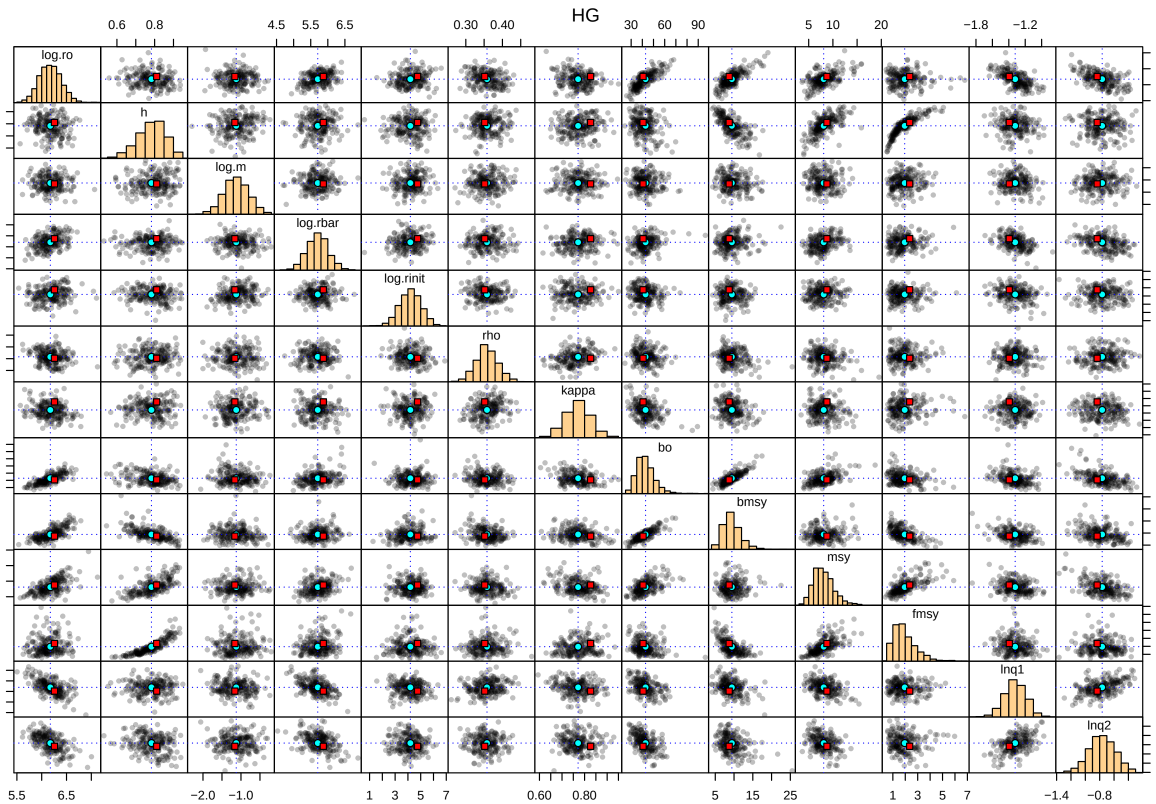

Figure 2.34: Pairs plot and marginal distributions for leading parameters in HG region (200 random samples). The dotted lines correspond to the means of the distributions, circle is the mean, and the red square is the mode of the distribution.

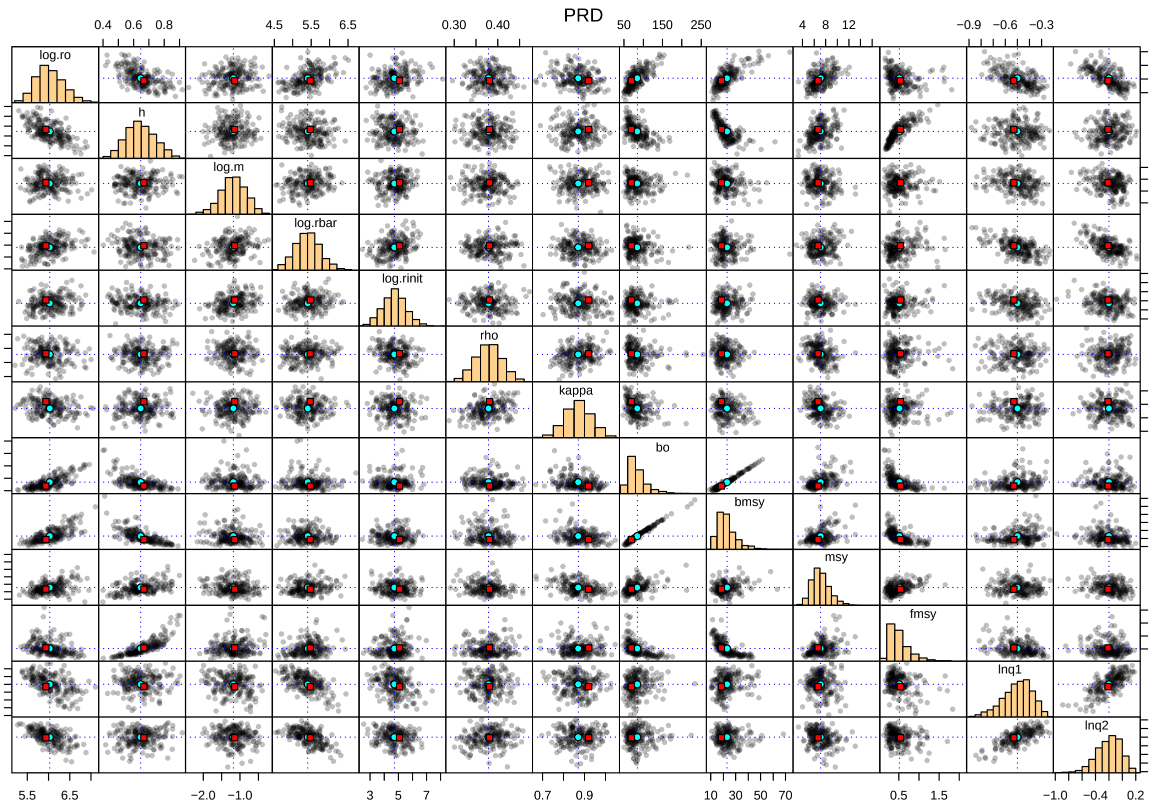

Figure 2.35: Pairs plot and marginal distributions for leading parameters in PRD region (200 random samples). The dotted lines correspond to the means of the distributions, circle is the mean, and the red square is the mode of the distribution.

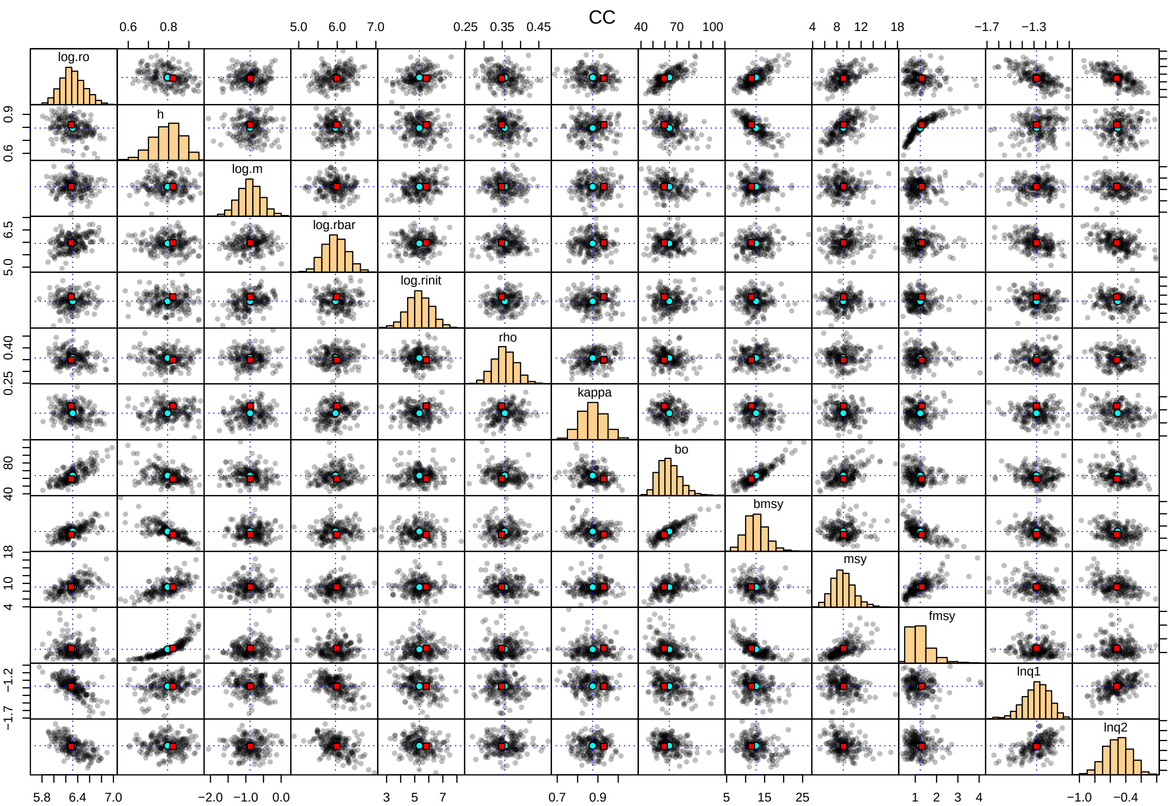

Figure 2.36: Pairs plot and marginal distributions for leading parameters in CC region (200 random samples). The dotted lines correspond to the means of the distributions, circle is the mean, and the red square is the mode of the distribution.

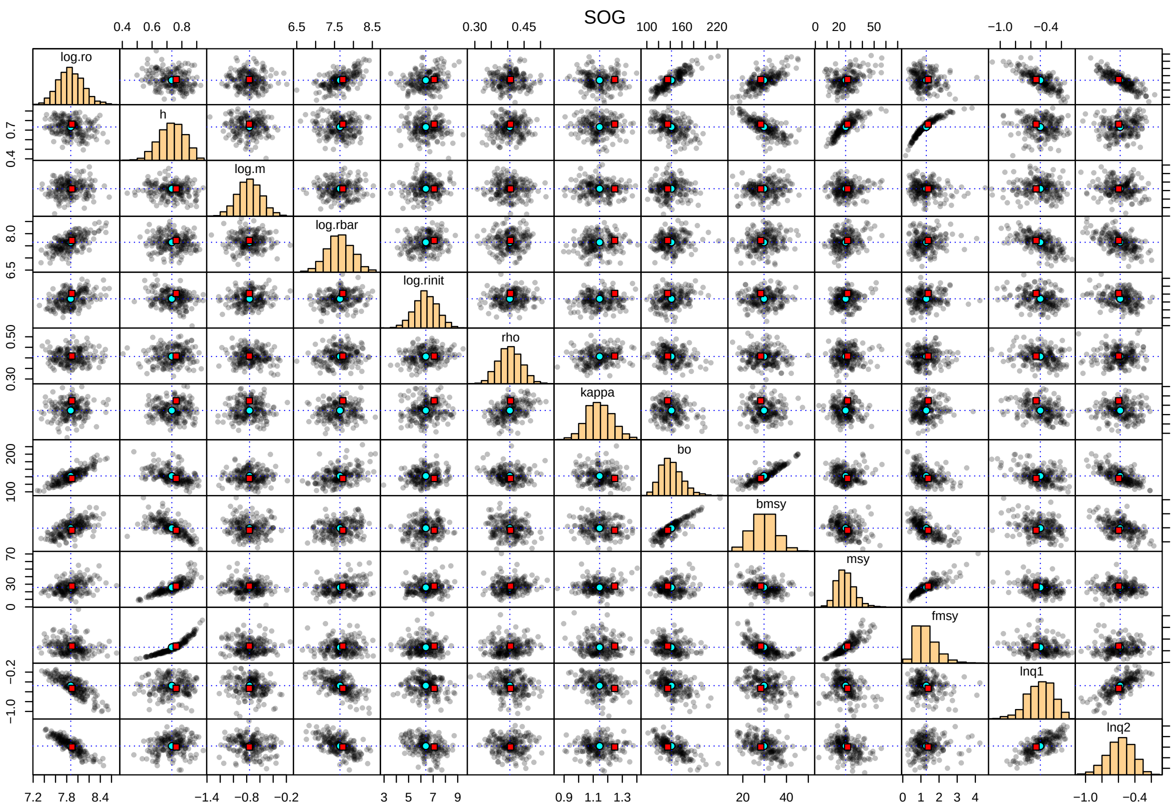

Figure 2.37: Pairs plot and marginal distributions for leading parameters in SOG region (200 random samples). The dotted lines correspond to the means of the distributions, circle is the mean, and the red square is the mode of the distribution.

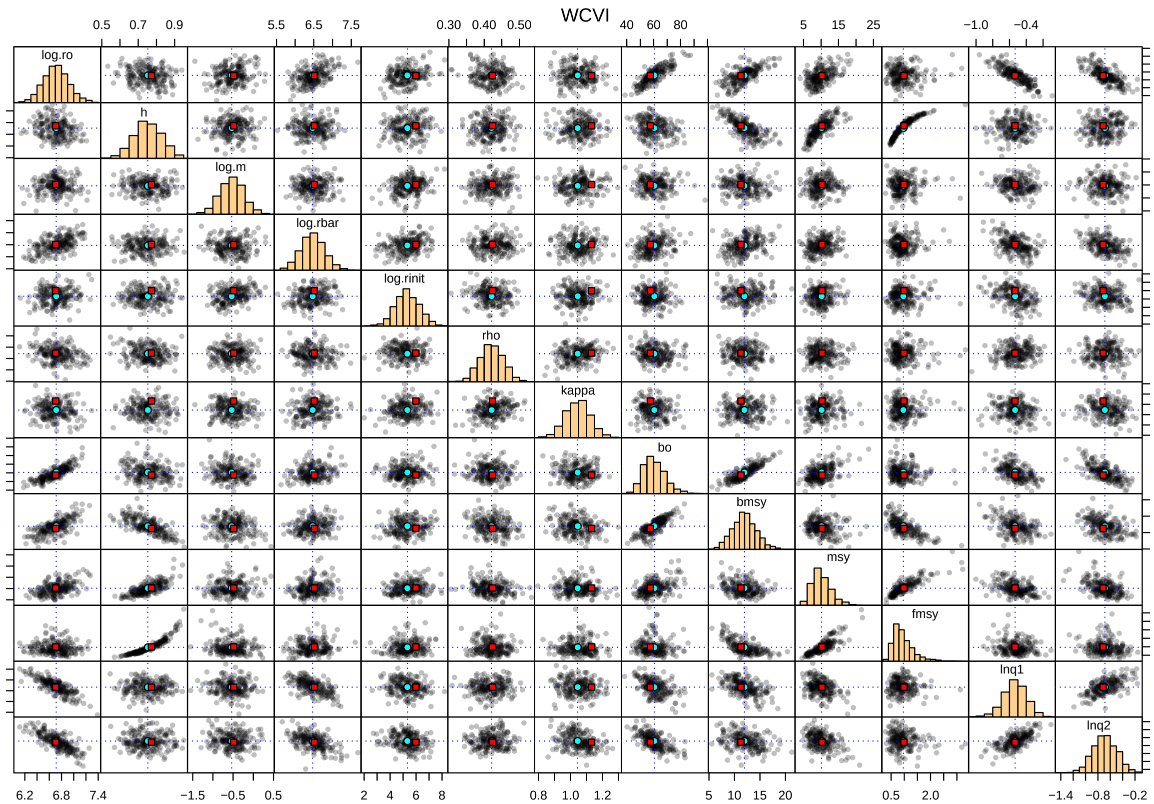

Figure 2.38: Pairs plot and marginal distributions for leading parameters in WCVI region (200 random samples). The dotted lines correspond to the means of the distributions, circle is the mean, and the red square is the mode of the distribution.

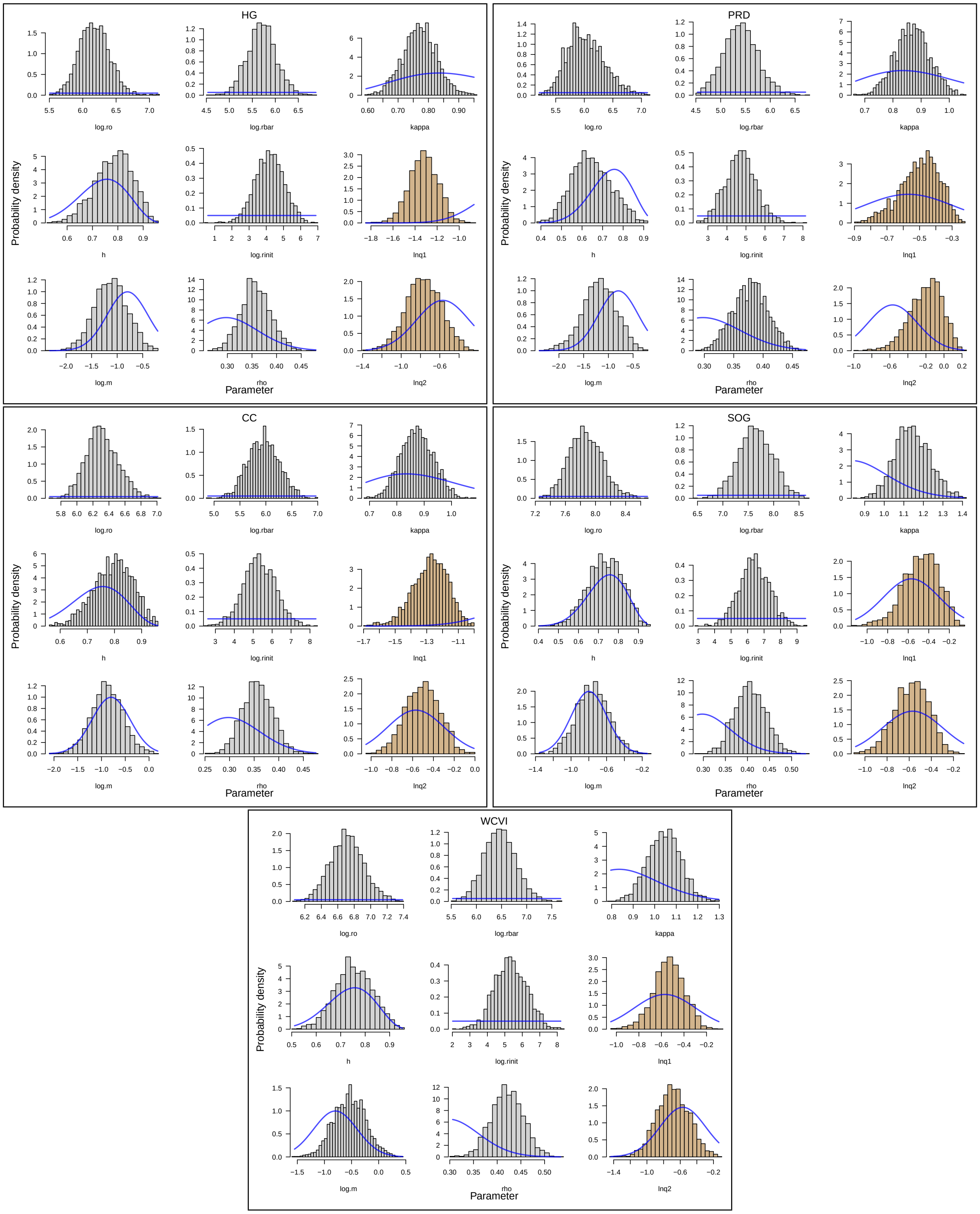

Figure 2.39: Marginal posterior densities (histograms) and prior densities (lines) for the seven leading parameters and spawn survey scaler ($\ln(q)$, tan colour) for each of the five major assessment regions.

Table 2.6: Estimated spawning stock biomass, age-4+ biomass and pre-fishery biomass for poor average and good recruitment, old cutoffs, and available harvest based on median values from the joint posterior distribution.

			Pre-fishery forecast biomass				**Available harvest**		
Stock	SSB	4+ Biomass	Poor	Average	Good	Cutoff	Poor	Average	Good
HG	16,579	7,089	9,618	12,892	21,478	10,700	0	2,192	4,296
PRD	27,046	20,593	24,150	27,492	37,286	12,100	4,830	5,498	7,457
CC	14,666	7,809	11,357	14,709	22,883	17,600	0	0	4,577
SOG	125,261	72,937	94,703	112,856	138,448	21,200	18,941	22,571	27,690
WCVI	14,679	8,267	15,321	20,906	31,130	18,800	0	2,106	6,226

Table 2.7: Estimated spawning stock biomass, age-4+ biomass and pre-fishery biomass for poor average and good recruitment, new cutoffs (based on median value of $0.25B_0$ estimated within the ^{i}SCA$_{M}$ model), and available harvest based on the median values from the joint posterior distribution.

			Pre-fishery forecast biomass				**Available harvest**		
Stock	SSB	4+ Biomass	Poor	Average	Good	Cutoff	Poor	Average	Good
HG	16,579	7,089	9,618	12,892	21,478	10,436	0	2,456	4,296
PRD	27,046	20,593	24,150	27,492	37,286	19,641	4,510	5,498	7,457
CC	14,666	7,809	11,357	14,709	22,883	15,600	0	0	4,577
SOG	125,261	72,937	94,703	112,856	138,448	35,013	18,941	22,571	27,690
WCVI	14,679	8,267	15,321	20,906	31,130	14,894	427	4,181	6,226

Cutoff levels for the BC herring stocks is defined as $0.25B_0$. The historical cutoff levels have not been updated for over 10 years now (1996/1997). Recent stock assessments (since 2001) for BC herring have assumed $q = 1$ for the spawn survey data. In this assessment we have relaxed this assumption and as a consequence estimates of herring biomass have increased substantially. Due to significant changes in population scaling it would not make sense to continue to use the previous cutoff levels as this may lead to policies that would result in overfishing or under utilization of the resource. We therefore present catch advice based on both the old cutoffs and the new cutoffs in Tables 2.6-2.7

In addition to Tables 2.6 and 2.7 we also provide an additional risk-based decision table that attempts to integrate over all of the uncertainty in the model (Tables 2.10-2.12). This decision table is also represented graphically in Figure 2.40. Figure 2.40 should be interpreted as follows: the probability of the spawning stock biomass falling below the cutoff level is determined by drawing a vertical line that intersect the cumulative probability curve and reading off the corresponding probability level. The reverse of this process was used to construct Tables 2.10-2.12.

Table 2.8: Decision table for HG where the risk level represents the probability of exceeding the quantities specified in the headers of each column. Three performance measures are considered: the probability of the spawning stock biomass in 2013 falling below the cutoff level, the probability of the spawning stock biomass in 2013 declining from 2012, and the probability of 2012 exploitation rate exceeding the 20% level that is used in the harvest control rule. To use this table, first determine the appropriate level of risk (e.g. 0.25 or 25% chance), then choose the appropriate management quantity (e.g. spawning biomass falling below the cutoff), and then read off the recommended catch (e.g., 3,060 tonnes).

Risk level	$P(SB_{2013})$<Cutoff	$P(SB_{2013} < SB_{2012})$	$P(U_{2012} < 0.2)$
0.05	0	0	2,228
0.1	0	0	3,552
0.15	583	0	4,372
0.2	1,940	0	4,989
0.25	3,060	0	5,498
0.3	4,039	0	5,944
0.35	4,928	0	6,348
0.4	5,760	0	6,727
0.45	6,558	0	7,090
0.5	7,340	0	7,445
0.55	8,121	0	7,801
0.6	8,919	907	8,164
0.65	9,751	2,547	8,542
0.7	10,640	4,299	8,947
0.75	11,619	6,229	9,392
0.8	12,740	8,439	9,902
0.85	14,096	11,113	10,519
0.9	15,898	14,666	11,338
0.95	18,809	20,404	12,662

2.9 Stock assessments for minor stock areas

Abundance estimates for the minor stock areas, Area 2W and Area 27 were also obtained using the ^{i}SCA$_{M}$ model. For these minor areas, there were some minor differences in the treatment of the data and model assumptions. Also, the gillnet selectivity in area 27 was not allowed to vary over time due to the sparse amount of information (and presumably biological samples) available to reliably estimate minor changes in selectivity for this fishery. Selectivity for area 27 gillnet fishery was assumed to be a logistic function of age and invariant over time.

The input data (Catch and relative abundance) for the minor areas is shown in Figure 2.41. As in the previous assessments of Area 2W, the spawn survey data is treated as a single continuous series from 1978 to 2011. Area 27 however, the time series is split into two series between 1978-1987 and 1988-2011. The age-composition data used in fitting the model is shown in Figure 2.42.

2.9.1 Maximum likelihood estimates of biomass

Spawning biomass in 2011 for Area 2W and Area 27 was estimated at 4,671 tonnes and 928 tonnes, respectively (Table **??**). The time series of total biomass and spawning biomass for these two areas is presented in Figure 2.43

2.9.2 Estimates of recruitment and reference points

Maximum likelihood estimates of age-2 recruitment, stock-recruitment relationships and residuals in the stock-recruitment model is shown in Figure 2.44. Estimates of age-2 recruits in area 2W have been poor-

Table 2.9: Decision table for PRD where the risk level represents the probability of exceeding the quantities specified in the headers of each column. Three performance measures are considered: the probability of the spawning stock biomass in 2013 falling below the cutoff level, the probability of the spawning stock biomass in 2013 declining from 2012, and the probability of 2012 exploitation rate exceeding the 20% level that is used in the harvest control rule. To use this table, first determine the appropriate level of risk (e.g. 0.25 or 25% chance), then choose the appropriate management quantity (e.g. spawning biomass falling below the cutoff), and then read off the recommended catch (e.g., 1,788 tonnes).

Risk level	$P(SB_{2013})$<Cutoff	$P(SB_{2013} < SB_{2012})$	$P(U_{2012} < 0.2)$
0.05	0	0	3,743
0.1	0	0	4,914
0.15	0	0	5,639
0.2	655	182	6,185
0.25	1,788	787	6,636
0.3	2,777	1,315	7,030
0.35	3,675	1,795	7,388
0.4	4,516	2,244	7,722
0.45	5,322	2,675	8,043
0.5	6,112	3,097	8,358
0.55	6,902	3,518	8,673
0.6	7,708	3,949	8,994
0.65	8,549	4,398	9,328
0.7	9,447	4,878	9,686
0.75	10,437	5,406	10,080
0.8	11,569	6,011	10,531
0.85	12,940	6,743	11,077
0.9	14,761	7,716	11,802
0.95	17,702	9,287	12,973

Table 2.10: Decision table for CC where the risk level represents the probability of exceeding the quantities specified in the headers of each column. Three performance measures are considered: the probability of the spawning stock biomass in 2013 falling below the cutoff level, the probability of the spawning stock biomass in 2013 declining from 2012, and the probability of 2012 exploitation rate exceeding the 20% level that is used in the harvest control rule. To use this table, first determine the appropriate level of risk (e.g. 0.25 or 25% chance), then choose the appropriate management quantity (e.g. spawning biomass falling below the cutoff), and then read off the recommended catch (e.g., 402 tonnes).

Risk level	$P(SB_{2013})$<Cutoff	$P(SB_{2013} < SB_{2012})$	$P(U_{2012} < 0.2)$
0.05	0	0	2,450
0.1	0	1,521	3,195
0.15	0	4,063	3,657
0.2	0	5,977	4,005
0.25	402	7,557	4,292
0.3	994	8,938	4,543
0.35	1,530	10,192	4,770
0.4	2,033	11,366	4,984
0.45	2,515	12,491	5,188
0.5	2,987	13,593	5,388
0.55	3,459	14,696	5,589
0.6	3,940	15,821	5,793
0.65	4,443	16,995	6,006
0.7	4,980	18,249	6,234
0.75	5,571	19,629	6,485
0.8	6,247	21,210	6,772
0.85	7,067	23,124	7,119
0.9	8,155	25,665	7,581
0.95	9,913	29,771	8,327

Table 2.11: Decision table for SOG where the risk level represents the probability of exceeding the quantities specified in the headers of each column. Three performance measures are considered: the probability of the spawning stock biomass in 2013 falling below the cutoff level, the probability of the spawning stock biomass in 2013 declining from 2012, and the probability of 2012 exploitation rate exceeding the 20% level that is used in the harvest control rule. To use this table, first determine the appropriate level of risk (e.g. 0.25 or 25% chance), then choose the appropriate management quantity (e.g. spawning biomass falling below the cutoff), and then read off the recommended catch (e.g., 51,565 tonnes).

Risk level	$P(SB_{2013})$<Cutoff	$P(SB_{2013} < SB_{2012})$	$P(U_{2012} < 0.2)$
0.05	32,082	0	32,080
0.1	39,969	0	37,840
0.15	44,852	0	41,406
0.2	48,528	0	44,091
0.25	51,565	0	46,308
0.3	54,218	0	48,246
0.35	56,627	0	50,005
0.4	58,882	0	51,651
0.45	61,043	0	53,230
0.5	63,161	0	54,777
0.55	65,280	0	56,324
0.6	67,441	0	57,902
0.65	69,696	0	59,549
0.7	72,105	0	61,308
0.75	74,758	0	63,245
0.8	77,794	0	65,463
0.85	81,471	0	68,148
0.9	86,354	0	71,714
0.95	94,241	8,031	77,474

Table 2.12: Decision table for WCVI where the risk level represents the probability of exceeding the quantities specified in the headers of each column. Three performance measures are considered: the probability of the spawning stock biomass in 2013 falling below the cutoff level, the probability of the spawning stock biomass in 2013 declining from 2012, and the probability of 2012 exploitation rate exceeding the 20% level that is used in the harvest control rule. To use this table, first determine the appropriate level of risk (e.g. 0.25 or 25% chance), then choose the appropriate management quantity (e.g. spawning biomass falling below the cutoff), and then read off the recommended catch (e.g., 184 tonnes).

Risk level	$P(SB_{2013})$<Cutoff	$P(SB_{2013} < SB_{2012})$	$P(U_{2012} < 0.2)$
0.05	0	907	2,269
0.1	0	6,355	3,125
0.15	0	9,728	3,655
0.2	0	12,267	4,054
0.25	184	14,365	4,384
0.3	969	16,197	4,671
0.35	1,682	17,861	4,933
0.4	2,349	19,418	5,178
0.45	2,989	20,912	5,412
0.5	3,616	22,375	5,642
0.55	4,243	23,838	5,872
0.6	4,882	25,331	6,106
0.65	5,549	26,888	6,351
0.7	6,262	28,552	6,613
0.75	7,047	30,385	6,900
0.8	7,946	32,482	7,230
0.85	9,034	35,022	7,629
0.9	10,478	38,395	8,159
0.95	12,812	43,842	9,015

Table 2.13: Summary of maximum likelihood estimates for the two minor stock areas. No. is the total number of estimated parameters, F_{MSY} the average instantaneous fishing rate to achieve the maximum sustainable yield (MSY), B_0 is the unfished spawning biomass, B_{MSY} is the spawning biomass that achieves maximum sustainable yield,B_t is the spawning biomass at the end of the 2011 fishing season, and B_t/B_0 is the spawning depletion level at the end of the 2011 fishing season.

Stock	A2W	A27
No.	74	79
F_{MSY}	0.34	1.9
MSY	265	304
B_0	2,915	2,084
$0.25B_0$	729	521
B_{MSY}	705	447
$0.8B_{MSY}$	564	358
$0.4B_{MSY}$	282	179
B_t	4,671	924
B_t/B_0	1.6	0.44

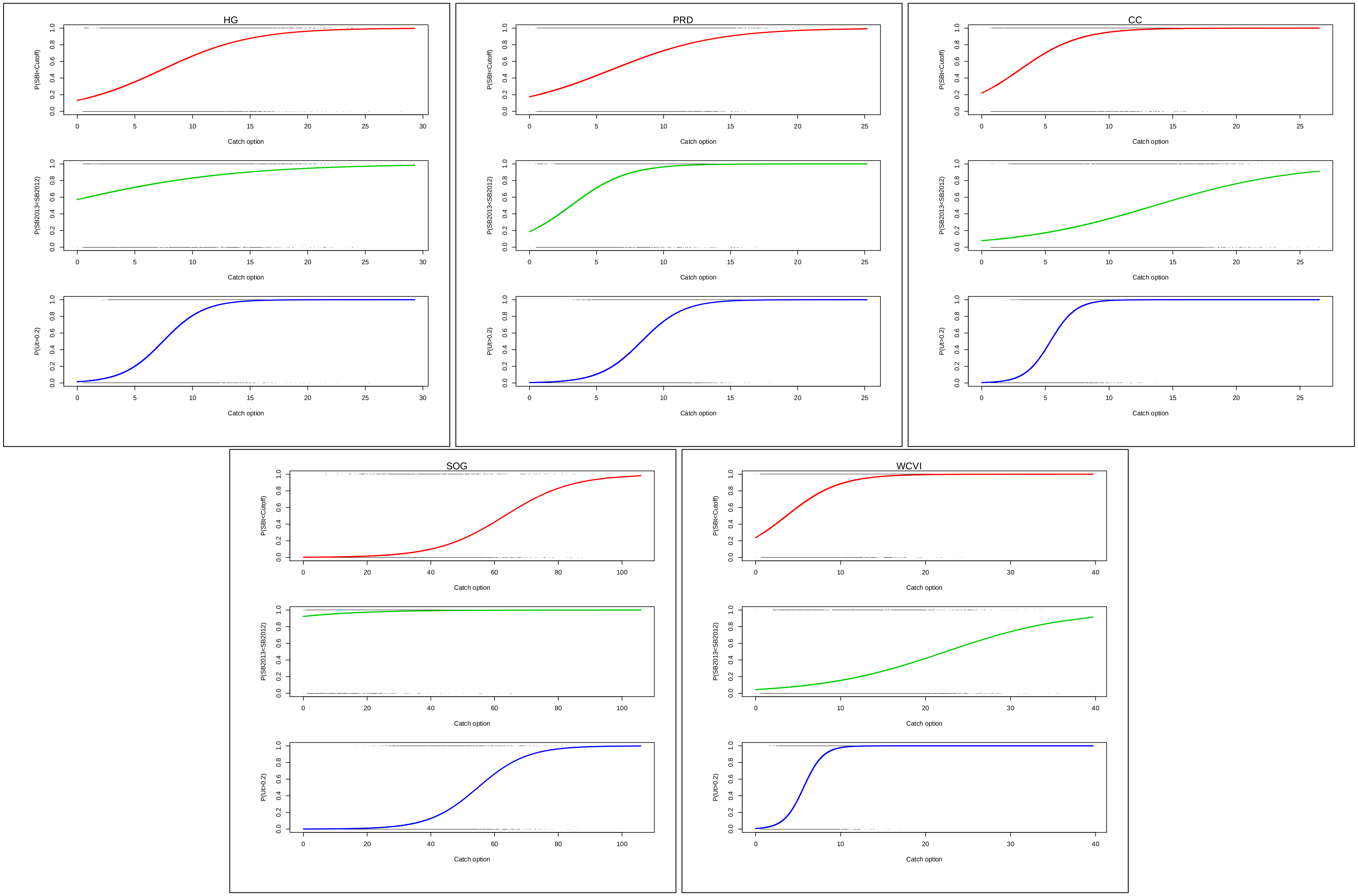

Figure 2.40: Top Panels: probability of the spawning stock biomass in 2013 falling below the cutoff level versus the 2012 catch option. Middle Panels: probability of the spawning stock in 2013 being less than the spawning stock biomass in 2012 versus the 2012 catch option. Bottom Panels: probability of the 2012 harvest rate (catch/3+ biomass) being greater than the target harvest rate of 0.2.

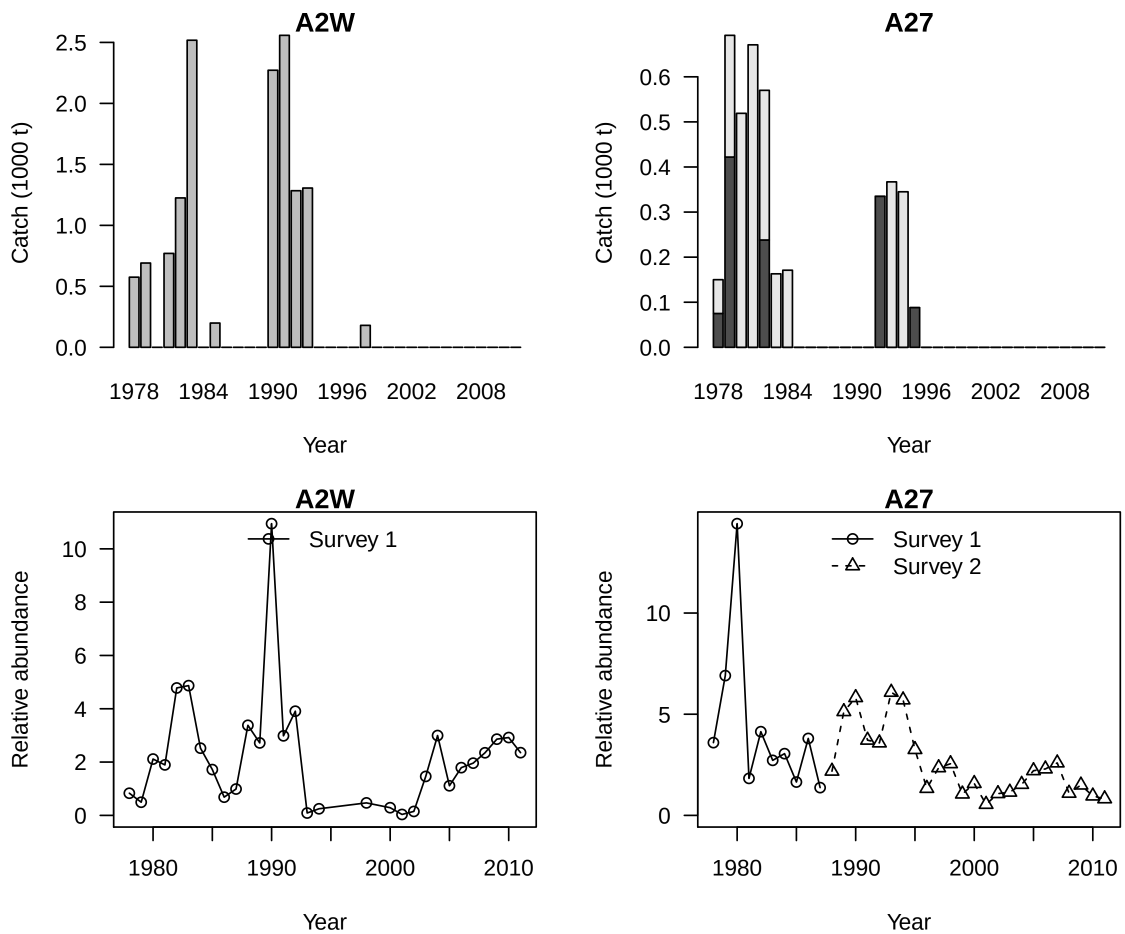

Figure 2.41: Catch and survey data for minor stock Areas 2W and Area 27.

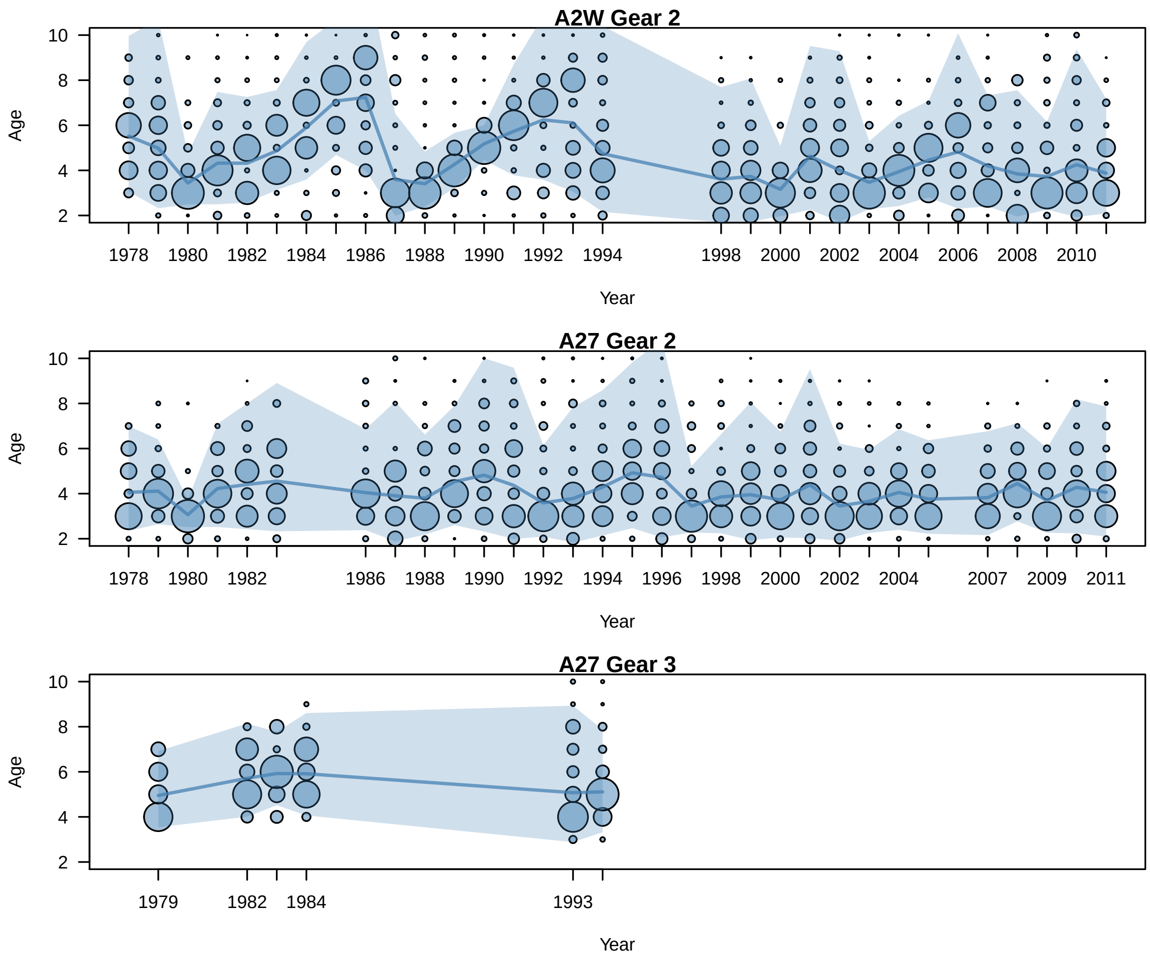

Figure 2.42: Age composition data for Area 2W and Area 27 for the seine-roe fishery (Gear 2) and the gillnet fishery (Gear 3).

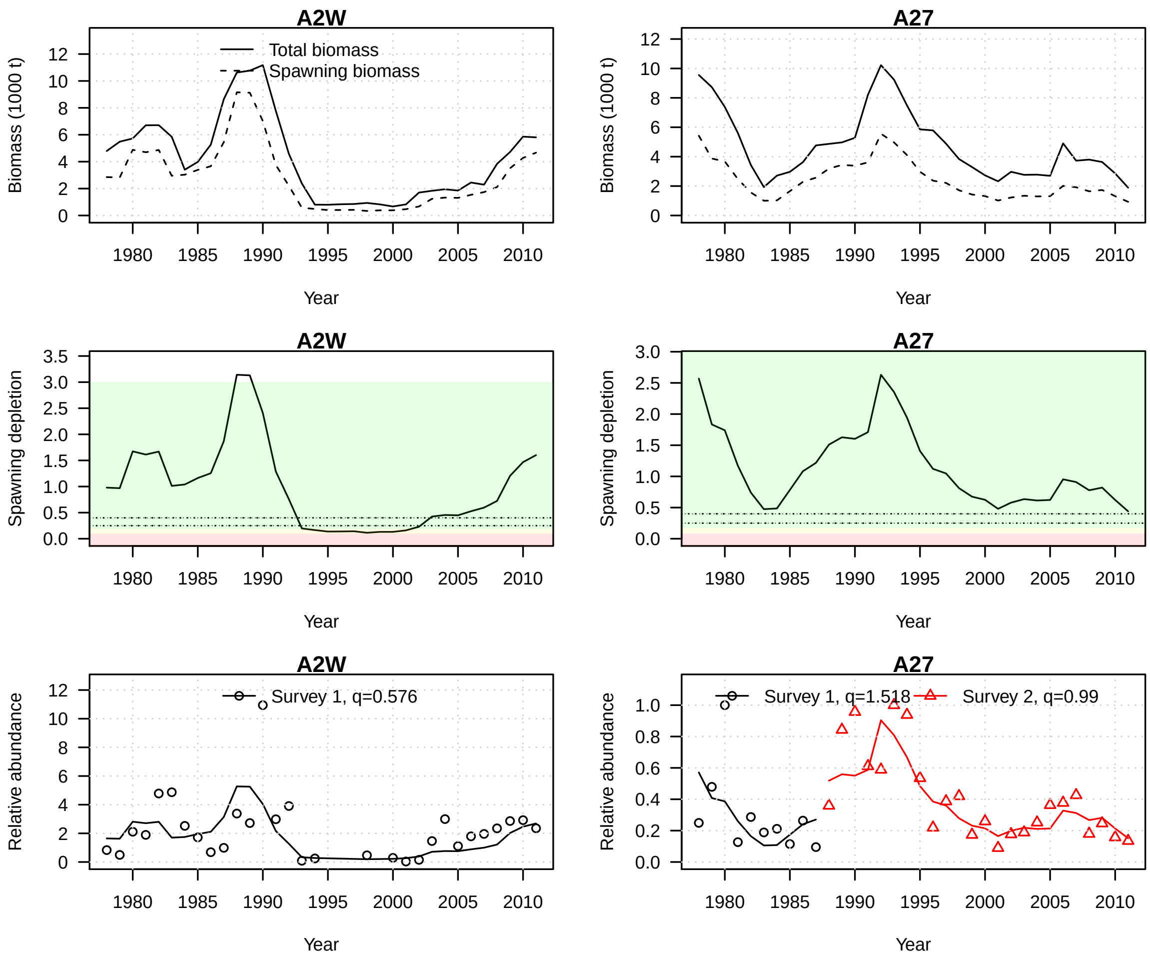

Figure 2.43: Maximum likelihood estimates of total biomass, spawning biomass, spawning depletion and fits to the spawn survey data for the two minor stock areas.

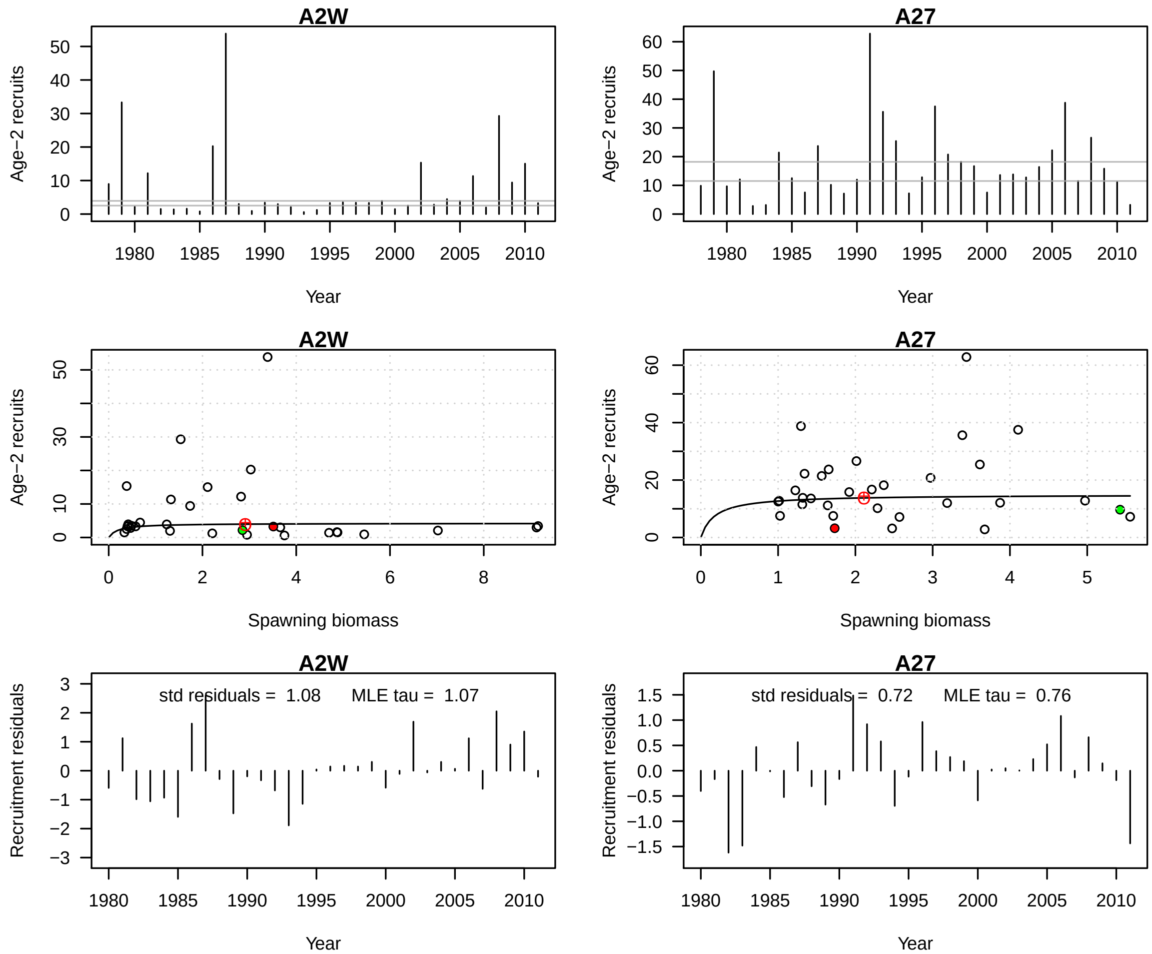

Figure 2.44: Maximum likelihood estimates of age-2 recruits, spawner-recruit relationships with the fitted Beverton Holt model and unfished reference points (B_o, R_o), and the residuals between the estimated age-2 recruits and that predicted by the Beverton-Holt model.

to average for much of the time-series. There have been 4 periods of above average recruitment for area 2W (late 1970s, mid 1980s, 2002, and 2008-2010. Recruitment in area 27 has been much more consistent by comparison. Estimates of unfished spawning biomass for ares 2W and 27 are 2,915 tonnes and 2,112 tonnes.

2.9.3 Retrospective analysis

There is almost no retrospective bias for the estimates of spawning stock biomass in area 27 using data between 1951:2001 and 1951:2011 (Fig. 2.45). In Area 2W, there is a slight retrospective bias in the estimates of spawning stock biomass. As the more recent data are fit in the model estimates of spawning biomass in the mid 2000s are revised downwards.

2.9.4 Marginal posterior distributions and trace plots

Information for the catch advice for the two minor areas is based on the median values of the joint posterior distribution. Therefore, it is important to show posterior samples to ensure proper convergence and

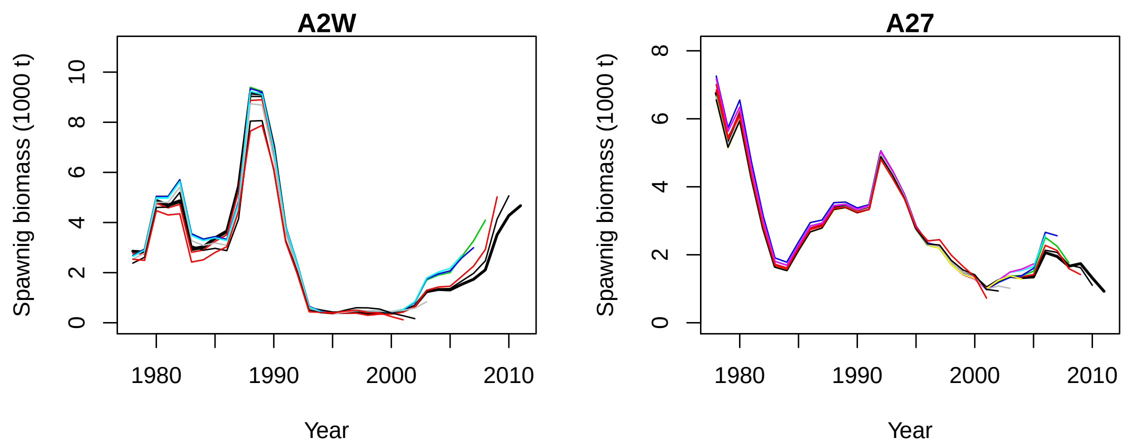

Figure 2.45: Retrospective estimates of spawning stock biomass for each of the minor stock assessment areas. The model was sequentially fitted to the full data set, then from 1951:2010, 1951:2009, ... 1951:2001.

Table 2.14: Estimated spawning stock biomass, age-4+ biomass and pre-fishery biomass for poor average and good recruitment, cutoffs, and available harvest.

			Pre-fishery forecast biomass				**Available harvest**		
Stock	SSB	4+ Biomass	Poor	Average	Good	Cutoff	Poor	Average	Good
A2W	5,448	5,204	5,294	5,398	6,141	809	529	540	614
A27	1,077	692	909	1,123	1,736	602	91	112	174

the marginal posterior distributions for the leading parameter estimates and derived variables that are of management interest.

The trace plots for the two minor areas are summarized in Figure 2.46, and the marginal distributions for the leading parameters is shown in Figure 2.47. Again, no formal convergence statistics were examined to determine if MCMC chain converged to a stable distribution. Visual inspection of the trace plots appear to have a homogenous distribution over the course of the 2000 samples. In both of the statistical areas, the posterior updates did occur (Figure 2.47. The marginal posterior for steepness in area 27 does appear to be influenced considerably by the assumed prior distribution.

2.9.5 Catch advice

Catch advice for the minor areas differs from that of the major areas in that there are not cuttoffs for these two areas and the reference exploitation rate is reduced from 20% to 10%. The same decision table format is provided with catch advice based on poor, average, and good recruitment. Catch advice for the two minor areas is summarized in Table **??**.

2.10 Outstanding Issues

The catch advice provided this year is based on the old $0.25B_0$rule for establishing Cutoffs for each SAR. Also, in moving towards a Sustainable Fisheries Framework and perhaps adopting the suggested MSY-based reference points, presents technical issue with regard to setting these reference points when pop-

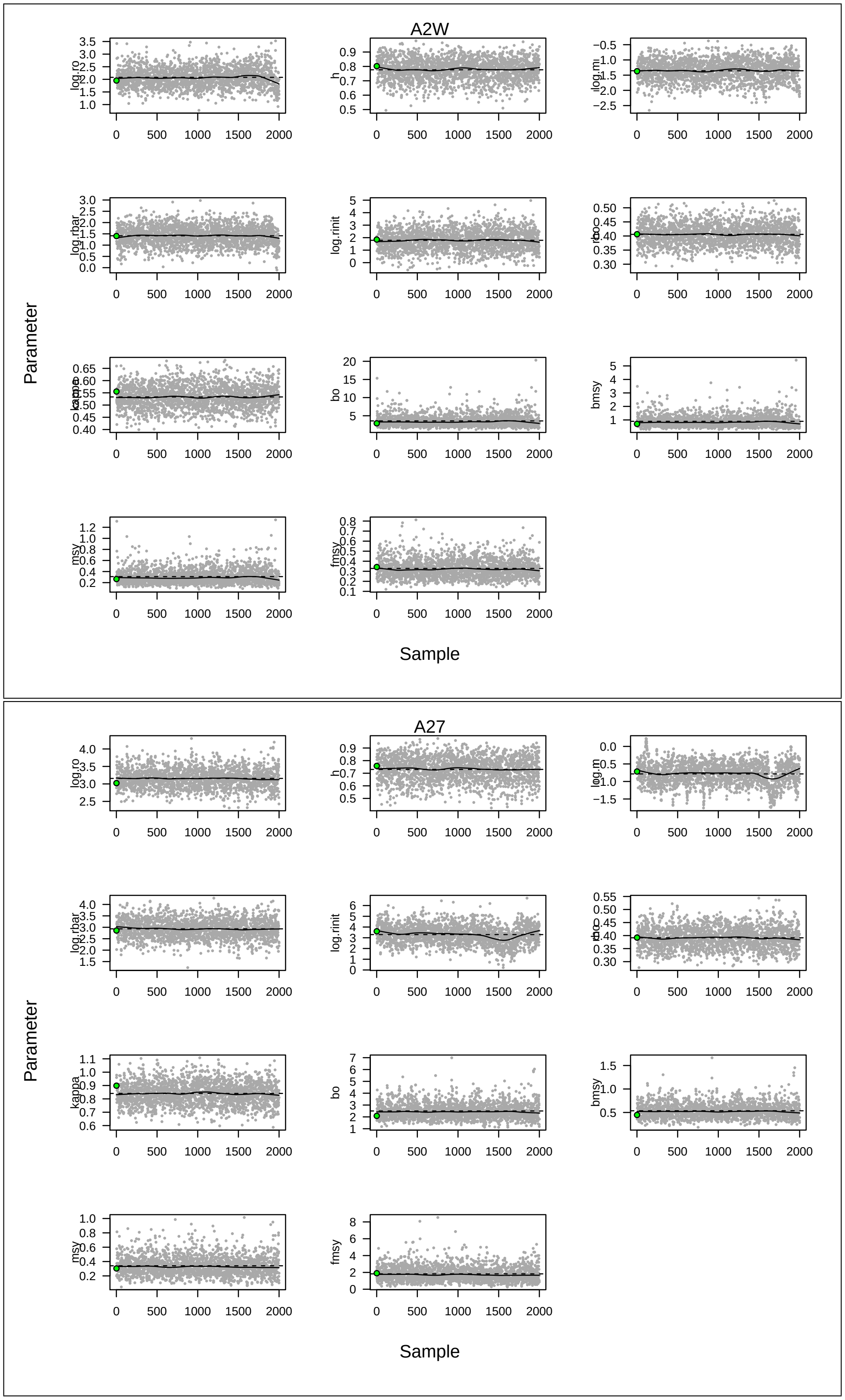

Figure 2.46: A systematic sample of 2000 points from a chain of length 1,000,000 from the joint posterior distribution for areas 2W and area 27.

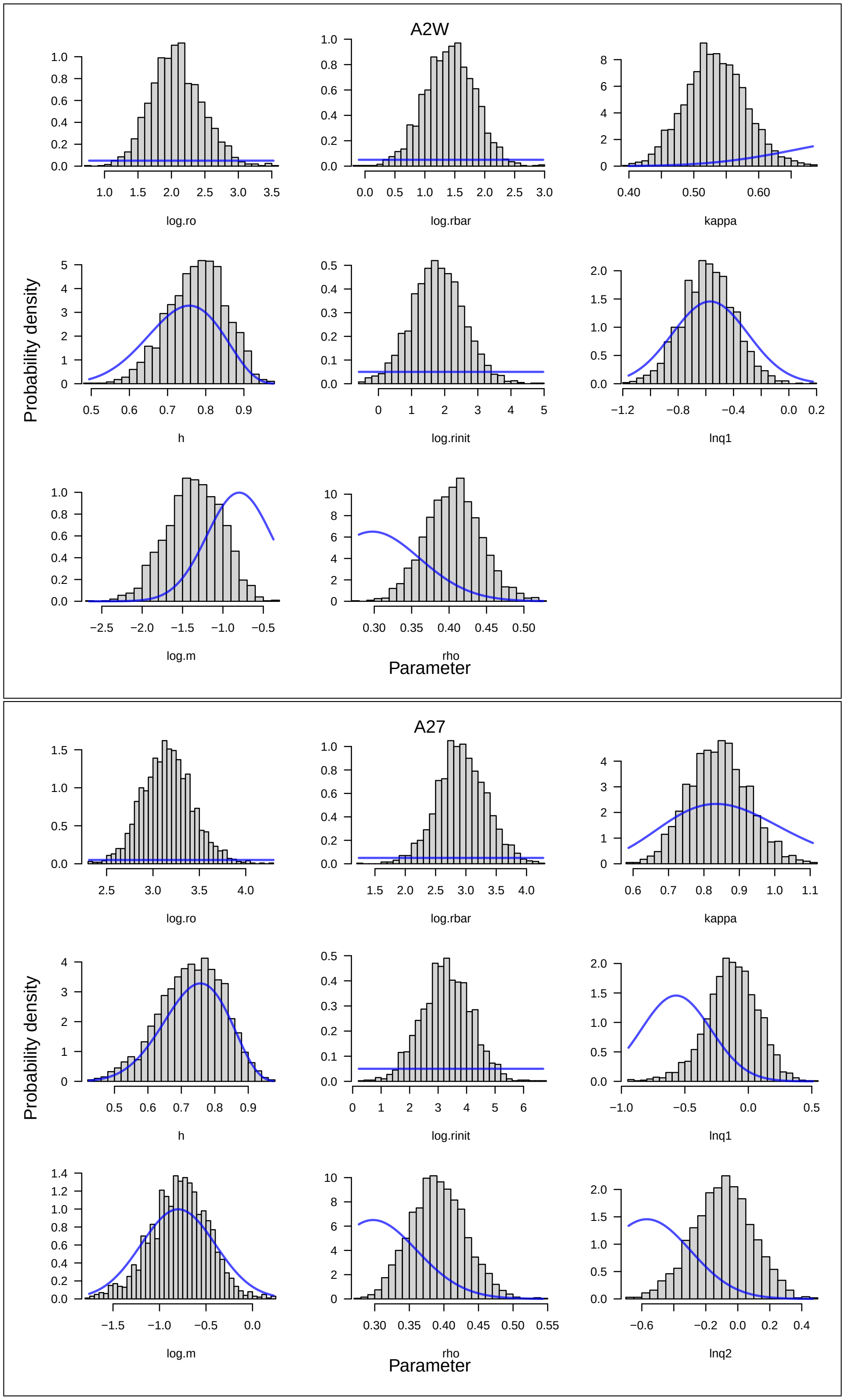

Figure 2.47: Marginal distributions for the leanding parameters based on a systematic sample of 2000 points from a chain of length 1,000,000 from the joint posterior distribution for areas 2W and area 27.

ulation parameters are changing over time. In this assessment, we have used the average weight-at-age to calculate B_0. Then in an inconsistent manner, we subsequently use the average weight-at-age age (and fecundity-at-age) over the last 5 years to determine $B_{MSY}$and F_{MSY}reference points. This outstanding issue should be examined more carefully before moving towards the SFF.

There was a strong retrospective bias for the PRD region. At this time, the sources of this bias are unknown, but likely due to two or more sources of data that contradict each-other or model misspecification. The current bias problem suggest that biomass has typically been over-estimated in recent years. The source of this bias should be investigated more closely.

There are a number of changes implemented in this ^{i}SCA$_{M}$ modelling framework that have not been formally evaluated using statistical criterion. Model selection criterion such as Analysis of Deviance (DIC) should be used when adopting new formulations. A number of alternative hypotheses (e.g., changes in selectivity, natural mortality rates) should be formally evaluated using model selection criterion.

An informative prior for the spawn survey has been used in this assessment. The marginal posterior distributions for q along with the prior distribution have been plotted and indicate that there is some information in the data to inform estimates of q. However, there are interesting geographic patterns in the estimates of q: areas to the north (HG, PRD, CC) the dive survey q is higher than the surface survey q, whereas in the south the dive survey q is less than the surface survey q. Also, in Part I of this document there was an indication that the change from selectivity based on weight-at-age to fixed, or using weight-at-age as a covariate, had a significant impact on the estimates of q in the SOG. Further work should also examine the other SARs to determine if a change in selectivity for the gillnet fishery also implies large changes in q.

2.11 Acknowledgements

The authors would like to thank Charles Fort and Kristen Daniel for their continued efforts in error checking, reviewing and updating the catch, spawn survey and biological sampling databases. We would also like to acknowledge Howard Stiff for providing programming support for the MS Access database used to summarize the assessment data time series.

Funding for the test fishing and spawn survey programs was provided by DFO through Larocque relief funds through a contract to the HCRS. The herring industry provided additional biological samples for the SOG and PRD stock areas through a modified roe testing program.

We also extend our thanks to Jim Ianelli for ideas and help with the cubic splines for selectivity and time varying natural mortality rates. Also, our huge appreciation to the members of the ADMB Foundation for continued development and support of AD Model Builder.

Bibliography

ADMB Project (2009). 2009 AD Model Builder: Automatic Differentiation Model Builder. Developed by David Fournier and freely available from admb-project.org.

Bishop, M. and Green, S. (2001). Predation on pacific herring (clupea pallasi) spawn by birds in prince william sound, alaska. *Fisheries Oceanography*, 10:149–158.

Cleary, J. and Schweigert, J. (2010). Stock Assessment and Management Advice for the British Columbia Herring Stocks: 2010 Assessment and 2011 Forecasts. *Canadian Science Advisory Secretariat*, 2010:90.

Conn, P., Williams, E., and Shertzer, K. (2010). When can we reliably estimate the productivity of fish stocks? *Canadian Journal of Fisheries and Aquatic Sciences*, 67(3):511–523.

Cordue, P. L. (in prep, 2006). Prior distributions for trawl and acoustic survey proportionality constants used in the 2006 orange roughy stock assessments. *New Zealand Fisheries Assessment Report.*, Draft:22p.

Fisheries and Oceans Canada (2006). A harvest strategy compliant with the precautionary approach. *Canadian Science Advisory Secretariat Sci. Adv. Rep. No. 2006/023.*

Fournier, D. and Archibald, C. (1982). A general theory for analyzing catch at age data. *Canadian Journal of Fisheries and Aquatic Sciences*, 39(8):1195–1207.

Francis, R. (2011). Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences*, 68(6):1124–1138.

Gavaris, S. and Ianelli, J. (2002). Statistical Issues in Fisheries' Stock Assessments*. *Scandinavian Journal of Statistics*, 29(2):245–267.

Gelman, A. (2004). *Bayesian data analysis*. CRC press.

Haegele, C. and Schweigert, J. (1989). Egg loss from pacific herring spawns in barkley sound in 1988. *Canadian Manuscript Report Fish. Aquat. Sci.*

Haegele, C. and Schweigert, J. (1991). Egg loss in herring spawns in georgia strait, british columbia. In *Proceedings of the international herring symposium. University of Alaska, Alaska Sea Grant Report*, pages 91–01.

Haist, V., Schweigert, J., Stocker, M., Station, P., of Fisheries, C. D., and Oceans (1986). *Stock assessments for British Columbia herring in 1985 and forecasts of the potential catch in 1986*. Fisheries and Oceans, Canada.

Hall, D., Hilborn, R., Stocker, M., and Walters, C. (1988). Alternative harvest strategies for pacific herring (clupea harengus pallasi). *Canadian Journal of Fisheries and Aquatic Sciences*, 45(5):888–897.

Hardwick, J. (1973). Biomass estimates of spawning herring, *Clupea harengus pallasi*, herring eggs, and associated vegetation in Tomales Bay. *Calif. Fish Game*, 59(1):36–61.

Hay, D. (1985). Reproductive biology of pacific herring (clupea harengus pallasi). *Canadian Journal of Fisheries and Aquatic Sciences*, 42(S1):111–126.

Hay, D., Fort, C., Schweigert, J. F., Hamer, L., and McCarter, P. B. (in press, 2011). Investigating changes in pacific herring spawn intensity (layers). *Canadian Stock Advisory Secretariat*, 2011(xx).

Hilborn, R. and Walters, C. J. (1992). *Quantitative fisheries stock assessment: choice, dynamics and uncertainty*, volume 2. Springer.

McAllister, M. K. and Ianelli, J. (1997). Bayesian stock assessment using catch-age data and the sampling: importance resampling algorithm. *Canadian journal of fisheries and aquatic sciences(Print)*, 54(2):284–300.

Midgley, P. (2003). Definitions and codings of localities, herring sections, stock assessment regions for british columbia herring data. *Can. MS Rep. Fish. Aquat. Sci.*, 2634:113.

Outram, D. (1958). The magnitude of herring spawn losses due to bird predation on the west coast of vancouver island. *Fisheries Research Board of Canada, Progress Reports of Pacific Biological Stations*, 111:9–13.

Palsson, W. (1984). *Egg mortality upon natural and artificial substrata within Washington state spawning grounds of Pacific herring (Clupea harengus pallasi)*. PhD thesis, University of Washington.

Richards, L., Schnute, J., and Olsen, N. (1997). Visualizing catch-age analysis: a case study. *Canadian Journal of Fisheries and Aquatic Sciences*, 54(7):1646–1658.

Rooper, C., Haldorson, L., and Quinn, T. (1999). Habitat factors controlling pacific herring (clupea pallasi) egg loss in prince william sound, alaska. *Canadian journal of fisheries and aquatic sciences*, 56(6):1133–1142.

Schnute, J. and Richards, L. (1995). The influence of error on population estimates from catch-age models. *Canadian Journal of Fisheries and Aquatic Sciences*, 52(10):2063–2077.

Schweigert, J., Christensen, L., and Haist, V. (2009). Stock Assesment for British Columbia Herring in 2008 and Forecasts of the Potential Catch in 2009. *Can. Sci. Adv. Secr.*, 2009(019):66.

Schweigert, J., Fort, C., Hamer, L., of Fisheries, C. D., Oceans, and Station, P. (1996). *Stock Assessment for British Columbia Herring in 1996 and Forecasts of the Potential Catch in 1997*. Fisheries and Oceans, Canada.

Schweigert, J., Funk, F., Oda, K., and T., M. (2002). Herring size-at-age variation in the North Pacific. In Peterson, W. and Hay, D., editors, *REX workshop on temporal variations in size-at-age for fish species in coastal areas around the Pacific Rim*, number 20, pages 47–57. PICES Sci. Rep.

Schweigert, J. F. (2001). Stock assessment for british columbia herring in 2001 and forecasts of the potential catch in 2002. *Can. Sci. Adv. Secr.*, 2001(140):84.

Stocker, M. (1993). Recent management of the british columbia herring fishery. *Perspectives on Canadian Marine Fisheries Management*, pages 267–293.

Walters, C. and Ludwig, D. (1994). Calculation of Bayes posterior probability distributions for key population parameters. *Canadian Journal of Fisheries and Aquatic Sciences*, 51(3):713–722.

Zheng, J., Funk, F., Kruse, G., and Fagen, R. (1993). Evaluation of threshold management strategies for pacific herring in alaska. In *Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations. Alaska Sea Grant College Program Report*, pages 141–165.

Part III

Appendixes

A.1 Technical description of ^{i}SCA$_{\text{M}}$

A.1.1 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}SCA$_{\text{M}}$was implemented in AD Model Builder version 10.1 (ADMB Project, 2009). This appendix also describes some of the optional features in ^{i}SCA$_{\text{M}}$ for estimating nonparametric selectivities.

It should be noted here that MSY-based reference points assume steady-state conditions, and the model structure that is implemented for the BC herring stocks is non-stationary due to time-varying changes in natural mortality rates (M_t) and selectivity. Estimates of MSY are conditional on the estimates of M, selectivity and mean weight-at-age; all of which change over time in the herring assessments. In the calculations of reference points, we use the average natural mortality between 1951-2010 and estimated selectivities and the empirical weight-at-age data in 2011.

A.1.2 Equilibrium considerations

Steady-state conditions are presented in Table A-1, in here we assume the parameter vector Θ in (T1.1) is unknown (with the exception of F_e) and would eventually be estimated by fitting ^{i}SCA$_{\text{M}}$ to time series data. The definition of F_e is the steady-state fishing mortality rate, and the value of F_e that maximizes equilibrium yield corresponds to F_{MSY} (see section A.1.3). For a given set of growth parameters (or if available empirical weight-at-age data) and maturity-at-age parameters defined by (T1.2), growth is assumed to follow the von Bertalanffy model (T1.3), mean weight-at-age is given by the allometric relationship in (T1.4), and the age-specific vulnerability is given by a logistic function (T1.5). Note, however, there are alternative selectivity functions implemented in ^{i}SCA$_{\text{M}}$, 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 $\dot{a}$ and $\dot{\gamma}$ for the logistic function.

Survivorship for unfished and fished populations is defined by (T1.7) and (T1.8), 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 (T1.9), the vulnerable biomass per recruit is given by (T1.10) and the per recruit yield to the fishery is given by (T1.11). Unfished recruitment is given by (T1.12) and the steady-state equilibrium recruitment for a given fishing mortality rate F_e is given by (T1.13). Note that in (T1.13) 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

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

which simplifies to (T1.13). The equilibrium yield for a given fishing mortality rate is (T1.14). These steady-state conditions are critical for determining various reference points such as F_{MSY} and B_{MSY}. The description of calculating steady-state yield for a given value of F_e in Table A-1 is written assuming that only one fishing fleet exists. The actual calculations are slightly more complicated for the BC herring fishery, as there are three distinct fishing fleets that each have different selectivities. The actual selectivities and calculations of survivorship involve a matrix of age-specific fishing mortalities, where each row of this matrix corresponds to one fishing fleet. In this case F_e is the total fishing mortality rate for fully selected fish summed over all fleets. In order to calculate the fleet specific fishing mortality rate, a fixed allocation of the total yield must be specified *a priori*.

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. Note that M is the average natural mortality rate between 1951-2011.

Parameters

$$\Theta = (B_o, \kappa, M, \hat{a}, \hat{\gamma}, F_e) \tag{T1.1}$$

$$B_o > 0; \kappa > 1; M > 0; F_e \geq 0$$

$$\Phi = (l_\infty, k, t_o, a, b, \dot{a}, \dot{\gamma}) \tag{T1.2}$$

Age-schedule information

$$l_a = l_\infty(1 - \exp(-k(a - t_o))) \tag{T1.3}$$

$$w_a = a(l_a)^b \tag{T1.4}$$

$$v_a = (1 + \exp(-(\hat{a} - a)/\gamma))^{-1} \tag{T1.5}$$

$$f_a = w_a(1 + \exp(-(\dot{a} - a)/\dot{\gamma}))^{-1} \tag{T1.6}$$

Survivorship

$$\iota_a = \begin{cases} 1, & a = 1 \\ \iota_{a-1}e^{-M}, & a > 1 \\ \iota_{a-1}/(1 - e^{-M}), & a = A \end{cases} \tag{T1.7}$$

$$\hat{\iota}_a = \begin{cases} 1, & a = 1 \\ \hat{\iota}_{a-1}e^{-M-F_e v_{a-1}}, & a > 1 \\ \hat{\iota}_{a-1}e^{-M-F_e v_{a-1}}/(1 - e^{-M-F_e v_a}), & a = A \end{cases} \tag{T1.8}$$

Incidence functions

$$\phi_E = \sum_{a=1}^{\infty} \iota_a f_a, \quad \phi_e = \sum_{a=1}^{\infty} \hat{\iota}_a f_a \tag{T1.9}$$

$$\phi_B = \sum_{a=1}^{\infty} \iota_a w_a v_a, \quad \phi_b = \sum_{a=1}^{\infty} \hat{\iota}_a w_a v_a \tag{T1.10}$$

$$\phi_q = \sum_{a=1}^{\infty} \frac{\hat{\iota}_a w_a v_a}{M + F_e v_a}\left(1 - e^{(-M-F_e v_a)}\right) \tag{T1.11}$$

Steady-state conditions

$$R_o = B_o/\phi_B \tag{T1.12}$$

$$R_e = R_o\frac{\kappa - \phi_E/\phi_e}{\kappa - 1} \tag{T1.13}$$

$$C_e = F_e R_e \phi_q \tag{T1.14}$$

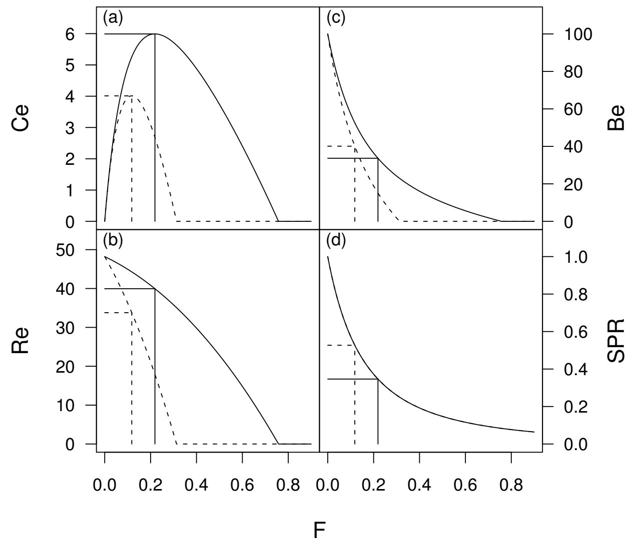

Figure A.48: Equilibrium yield (a), recruits (b), biomass (c) and spawner per recruit (ϕ_e/ϕ_E) (d) versus instantaneous fishing mortality F_e for two different values of the recruitment compensation ratio ($\kappa = 12$ solid lines, $\kappa = 4$ dashed lines). Vertical lines in each panel correspond to F_{MSY} and horizontal lines correspond to various reference points that would achieve MSY.

A.1.3 MSY based reference points

^{i}SCA$_{M}$ calculates MSY-based reference points by finding the value of F_e that results in the zero derivative of the steady-state catch equation (T1.14). This is accomplished numerically using a Newton-Raphson method where an initial guess for F_{MSY} is set equal to $1.5M$, then use (A.1) to iteratively find F_{MSY}. Note that the partial derivatives in (A.1) can be found in Table A-2.

$$F_{e+1} = F_e - \frac{\frac{\partial C_e}{\partial F_e}}{\frac{\partial^2 C_e}{\partial F_e}} \tag{A.1}$$

where

$$\frac{\partial C_e}{\partial F_e} = R_e \phi_q + F_e \phi_q \frac{\partial R_e}{\partial F_e} + F_e R_e \frac{\partial \phi_q}{\partial F_e}$$

$$\frac{\partial^2 C_e}{\partial F_e} = \phi_q \frac{\partial R_e}{\partial F_e} + R_e \frac{\partial \phi_q}{\partial F_e}$$

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 ^{i}SCA$_{M}$, 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 A.48.

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

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

Mortality & Survival

$$Z_a = M + F_e v_a \tag{T2.1}$$

$$S_a = 1 - e^{-Z_a} \tag{T2.2}$$

Partial for survivorship

$$\frac{\partial \hat{\iota}_a}{\partial F_e} = \begin{cases} 0, & a = 1 \\ e^{-Z_{a-1}}\left(\dfrac{\partial \hat{\iota}_{a-1}}{\partial F_e} - \hat{\iota}_{a-1} v_{a-1}\right), & 1 < a < A \\ \dfrac{\dfrac{\partial \hat{\iota}_{a-1}}{\partial F_e}}{(1-e^{-Z_a})} - \dfrac{\hat{\iota}_{a-1} e^{-Z_{a-1}} v_a e^{-Z_a}}{(1-e^{-Z_a})^2}, & a = A \end{cases} \tag{T2.3}$$

Partials for incidence functions

$$\frac{\partial \phi_e}{\partial F_e} = \sum_{a=1}^{\infty} f_a \frac{\partial \hat{\iota}_a}{\partial F_e} \tag{T2.4}$$

$$\frac{\partial \phi_q}{\partial F_e} = \sum_{a=1}^{\infty} \frac{w_a v_a S_a}{Z_a} \frac{\partial \hat{\iota}_a}{\partial F_e} + \frac{\hat{\iota}_a w_a v_a^2}{Z_a}\left(e^{-Z_a} - \frac{S_a}{Z_a}\right) \tag{T2.5}$$

Partial for recruitment

$$\frac{\partial R_e}{\partial F_e} = \frac{R_o}{\kappa - 1} \frac{\phi_E}{\phi_e^2} \frac{\partial \phi_e}{\partial F_e} \tag{T2.6}$$

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, ^{i}SCA$_{\mathrm{M}}$ requires an allocation of the total catch (summed across gear type) to each gear before it proceeds with calculating reference points.

For this herring assessment, the average catch over the past 20 years 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, and the start of each biological year is the month of April.

A.1.4 Dynamic age-structured model

The estimated parameter vector in ^{i}SCA$_{\mathrm{M}}$ 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 ($\digamma_{k,t}$). The vector of log fishing mortality rate parameters $\digamma_{k,t}$ is a bounded vector with a minimum value

Table A-3: Statistical catch-age model using the Baranov catch equation, where R_0 and κ are the leading parameters that define population scale and productivity, respectively.

Estimated parameters

$$\Theta = \left(R_0, \kappa, M, \bar{R}, \ddot{R}, \rho, \vartheta, \vec{\gamma}_k, \digamma_{k,t}, \{\ddot{\omega}_a\}_{a=\acute{a}+1}^{a=A}, \{\omega_t\}_{t=1}^{t=T}, \{\varphi_t\}_{t=2}^{T}\right) \tag{T3.1}$$

$$\sigma = \rho/\vartheta, \quad \tau = (1-\rho)/\vartheta \tag{T3.2}$$

Unobserved states

$$N_{t,a}, B_t, Z_{t,a} \tag{T3.3}$$

Initial states ($t = \acute{t}$)

$$N_{t,a} = \ddot{R}e^{\ddot{\omega}_a} \exp(-M_t)^{(a-\acute{a})}; \quad t = \acute{t}; \acute{a} \le a \le A \tag{T3.4}$$

$$N_{t,a} = \bar{R}e^{\omega_t}; \quad \acute{t} \le t \le T; a = \acute{a} \tag{T3.5}$$

$$v_{k,a} = f(\vec{\gamma}_k) \tag{T3.6}$$

$$M_t = M_{t-1}\exp(\varphi_t), \quad t > 1, \varphi_t \sim N(0, \sigma_M) \tag{T3.7}$$

$$F_{k,t} = \exp(\digamma_{k,t}) \tag{T3.8}$$

State dynamics ($t > \acute{t}$)

$$B_t = \sum_a N_{t,a} f_a \tag{T3.9}$$

$$Z_{t,a} = M_t + \sum_k F_{k,t} v_{k,t,a} \tag{T3.10}$$

$$\hat{C}_{k,t} = \sum_a \frac{N_{t,a} w_a F_{k,t} v_{k,t,a} \left(1 - e^{-Z_{t,a}}\right)}{Z_{t,a}} e^{\eta_t} \tag{T3.11}$$

$$N_{t,a} = \begin{cases} N_{t-1,a-1}\exp(-Z_{t-1,a-1}) & a > \acute{a} \\ N_{t-1,a}\exp(-Z_{t-1,a}) & a = A \end{cases} \tag{T3.12}$$

Recruitment models

$$R_t = \frac{s_o B_{t-k}}{1 + \beta B_{t-k}} e^{\delta_t - 0.5\tau^2} \quad \text{Beverton-Holt} \tag{T3.13}$$

$$R_t = s_o B_{t-k} e^{-\beta B_{t-k} + \delta_t - 0.5\tau^2} \quad \text{Ricker} \tag{T3.14}$$

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 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.

Table A-4: An incomplete list of symbols, constants and description for variables used in ^{i}SCA$_{M}$.

Symbol	Constant value	Description
Indexes		
a		index for age
t		index for year
k		index for gear
Model dimensions		
$\acute{a}, A$	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
Observations (data)		
$C_{k,t}$		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
Estimated parameters		
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 $\bar{R}$ for years $\acute{t}$ to T
φ_t		logarithm of annual change in natural mortality rate
Standard deviations		
σ_M	0.1	standard deviation in random walk for natural mortality
σ		standard deviation for observation errors in survey index
τ		standard deviation in process errors (recruitment deviations)
σ_C	0.0707	standard deviation in observed catch by gear
Residuals		
δ_t		annual recruitment residual
η_t		residual error in predicted catch

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:

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

and for the Ricker model this is given by:

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

A.1.5 Options for selectivity

At present, there are eight alternative age-specific selectivity options in ^{i}SCA$_\text{M}$. 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 a may have as many as (A-1)·T parameters. For time-varying selectivity, cubic and bicubic splines are used to reduce the number of estimated parameters. The last two options consider how selectivity may vary over time based on changes in mean weight-at-age. Prior to parameter estimation, ^{i}SCA$_\text{M}$ 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

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

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 at 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:

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

The dome-shaped term penalty as:

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

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

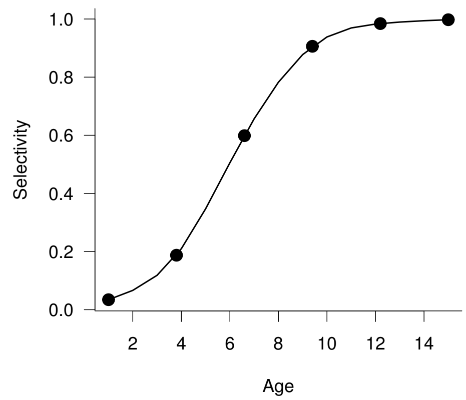

Figure A.49: Example of a natural cubic spline interpolation for 15-selectivity coefficients based on estimating 6 nodes (true selectivity was based on a logistic function). In ^{i}SCAM the user specifies the number of nodes (e.g., 6 circles) to estimate; then the 15 age-specific selectivity coefficients are interpolated using a natural cubic spline.

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 A.49). Given $n+1$ distinct knots x_i, selectivity can be interpolated in the intervals defined by

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

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.

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 A.50). 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 November 15, 2011, this has not been implemented).

Selectivity as a logistic function of weight-at-age The seventh option for selectivity is to parameterize a logistic function in terms of the weight-at-age in year t ($w_{a,t}$). In this case changes in weight-at-age over

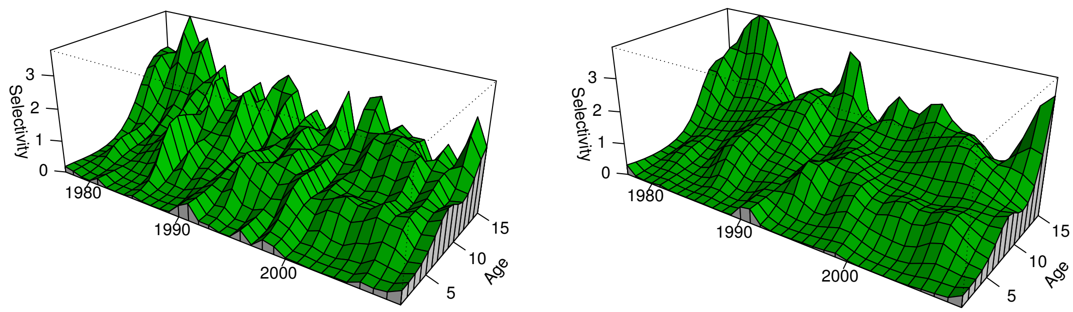

Figure A.50: Example of a time-varying cubic spline (left) and bicubic spline (right) interpolation for selectivity based on data from the Pacific hake. The panel on the left contains 165 estimated selectivity parameters and the bicubic interpolation estimates 85 selectivity parameters, or 5 age nodes and 17 year nodes. There are 495 actual nodes (selectivity parameters) being interpolated.

time allow for changes in selectivity. Such a weight-based function may be appropriate for size selective gears such as gill nets.

$$v_{a,t} = \frac{1}{1 + \exp\left(-(w_{a,t} - \mu_a)/\sigma_a\right)}$$

Using weight as a covariate The eighth option for selectivity is to use a logistic function based on age, but allow selectivity to vary based on deviations in the mean weight-at-age over time. In this case:

$$v_{a,t} = \frac{1}{1 + \exp\left(-(a - \mu_a)/\sigma_a\right)} \exp(\lambda^{(a)} \delta_{a,t})$$

where $\lambda^{(a)}$ is a latent variable that describes the residual variation in the age-composition data that is due to changes in selectivity, and $\delta_{a,t}$ is a standardized ($\mu = 0, \sigma = 1$) annual age-specific deviation in mean weight-at-age. In this case, estimates of $\lambda^{(a)} = 0$ imply that variation in the empirical weight-at-age data explain none of the residual variation in the age-composition data. Values of $\lambda^{(a)} \neq 0$ imply a positive or negative affect of variation in growth on selectivity.

A.1.6 Options for natural mortality

There is an option in ^{i}SCA$_{\mathrm{M}}$ to estimate a time series of annual changes 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}SCA$_{\mathrm{M}}$ 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 rate of change σ_M. 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.

A.1.7 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.1.8 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:

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

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:

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

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

A.1.9 Relative abundance data

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

$$V_{k,t} = \sum_a N_{t,a} e^{-\lambda_{k,t} Z_{t,a}} v_{k,a} w_{a,t}, \tag{A.6}$$

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:

$$\epsilon_{k,t} = \ln(I_{k,t}) - \ln(q_k) - \ln(V_{k,t}), \tag{A.7}$$

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:

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

where

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

where $\rho\vartheta$ 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 $\rho\vartheta$; 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 (A.8) is undefined; therefore, ^{i}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.1.10 Age composition data

Sampling theory suggest that age composition data are derived from a multinomial distribution (Fournier and Archibald, 1982); however, ^{i}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}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:

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

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:

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

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 (A.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 or weak year classes. In ^{i}SCA$_{\mathrm{M}}$ the same approach described by Richards et al. (1997) is adopted where the definition of age-classes is altered to require that $p_{t,a} \geq \dot{p}$ for every age in each year, where $\dot{p}$ is the minimum percentage specified by the user (e.g., $\dot{p} = 0.02$ corresponds to 2%). This is accomplished by grouping consecutive ages, where $p_{t,a} < \dot{p}$, 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 minimum proportion (including 0) is set by the user and can influence the results, especially in cases where there is sparse aging information. In the case of $\dot{p} = 0$, the pooling of the adjacent age-class still occurs, this ensures that (A.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.1.11 Stock-recruitment

There are two alternative stock-recruitment models available in ^{i}SCA$_{\mathrm{M}}$: the Beverton-Holt model and the Ricker model. Annual recruitment and the initial age-composition are treated as latent variables in ^{i}SCA$_{\mathrm{M}}$, 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

$$\delta_t = \ln(\bar{R}e^{w_t}) - \ln(f(B_{t-\acute{a}})) \tag{A.11}$$

where $f(B_{t-k})$ is given by either (T3.13) or (T3.14), and $\acute{a}$ 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):

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

Equations (A.11) and (A.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:

$$s_o = \kappa/\phi_E \tag{A.13}$$

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

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}SCA$_{\mathrm{M}}$ platform.

A.1.12 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}SCA$_{\mathrm{M}}$, and the source code and documentation for ^{i}SCA$_{\mathrm{M}}$ 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}SCA$_{\mathrm{M}}$ 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.1.13 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.1.7. There are four specific elements that make up the vector of negative loglikelihoods:

$$\vec{\ell} = \ell_C, \ell_I, \ell_A, \ell_\delta. \tag{A.15}$$

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.1.14 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}SCA$_{\mathrm{M}}$ 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}SCA$_{\mathrm{M}}$ 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.

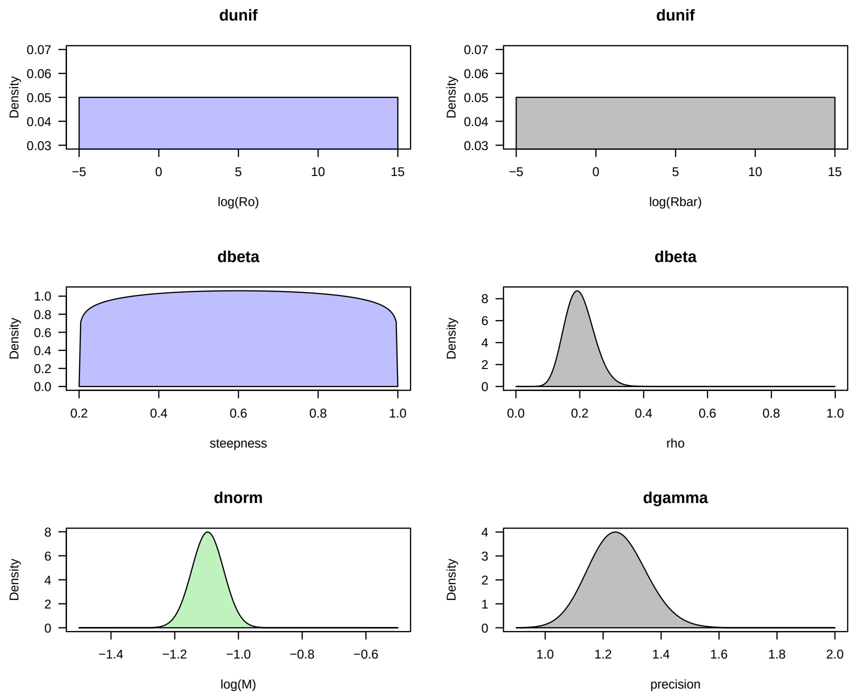

Figure A.51: Prior distributions used for $\ln(R_o), h, \ln(M), \ln(\bar{R}), \rho, \vartheta$ in the herring assessment models.

A.1.15 Priors for parameters

Each of the six leading parameters specified in the control file ($\ln(R_o), h, \ln(M), \ln(\bar{R}), \rho, \vartheta$) 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 vague 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). These prior distributions based on the parameter specified above are shown in Figure A.51.

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 (A.2) and how much dome-shape is allowed in the nonparametric selectivities (A.3).

A.1.16 Survey priors

The scaling parameter q for each of the surveys is not treated as an unknown parameter within the code; 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 200 eggs per gram (Hay, 1985; 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 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.1.17 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 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}SCA$_{\text{M}}$ 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.2 Data and Control files

B.2.1 Haida Gwaii

```
 #NB The data herein were taken from qci2010_final.dat for the HCAM model.
## _______________________
## ____Model Dimensions____
1951 #first year of data
2011 #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 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 (1951-2011, 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 11.166  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
2011  0.000  0.000 0.000 0 0
#Relative Abundance index from fisheries independent survey (it) 1970-2008
#nit
#61
2
#nit_nobs
37 24
#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
#iyr     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  9.686    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  6.113    5  1.1666  1
2011  6.792    5  1.1666  1
#Age composition data by year, gear (ages 2-15+)
#na_gears
3
#na_nobs
10 40 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  160  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
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
2011  2   21  522   90  371   65  100    9   4   0
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
61
#Mean weight-at-age in kilograms (interpolated: from HCAM.rep)
#A$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 0.0958 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 0.1751 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 0.0828 0.1089 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 0.0836 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 0.0576 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 0.0576 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 0.0880 0.1104 0.1332 0.1530 0.1677 0.1720 0.1784 0.1865
1968 0.0488 0.0880 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 0.1588 0.1749 0.1928 0.1977 0.2010 0.2096
1974 0.0630 0.0877 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 0.1234 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 0.1099 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 0.1348 0.1561 0.1706 0.1873 0.1802 0.2022
1982 0.0635 0.0945 0.1153 0.1292 0.1531 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 0.1146 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 0.1302 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 0.0604 0.0851 0.1060 0.1283 0.1468 0.1572 0.1609 0.1453 0.2260
1991 0.0642 0.0894 0.1101 0.1280 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 0.0829 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 0.0725 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 0.1530 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 0.1050 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 0.1215 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
2011 0.0536 0.0697 0.0803 0.0985 0.1116 0.1206 0.1287 0.1288 0.1500
#eof
999
```

```
 ## ___________________________________________________________________________ ##
##                             SOG 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      17.08696    39.0559    #rho
    0.8695652   0.01    5.0      3       4      25.0  28.75   #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 5.56 3.12 2.00
## Gear 1:3 fishery:  Gear 4-5 survey
## isel_type
    1        1          8       6       6
## Age at 50% selectivity (logistic)
    3.0      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           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
    1       1
## prior log(mean)
    -0.569  -0.569
## prior sd
    0.274    0.274
## ___________________________________________________________________________ ##

## ______________________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)
0.05        ## 6  Minimum proportion to consider in age-proportions for dmvlogistic
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.2.2 Prince Rupert District

```
 #NB The data herein were taken from qci2010_final.dat for the HCAM model.
## ________________________
## ____Model Dimensions____
1951 #first year of data
2011 #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 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)
#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 17.806 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 5.856 1.494 0 0
1978  3.582 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 1.238 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 0.256 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
2011  0.000 0.883 1.264 0 0
#Relative Abundance index from fisheries independent survey (it) 1970-2008
#nit
#61
2
#nit_nobs
37 24
#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
#iyr     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 27.979 5 1.1666  1
2011 20.673 5 1.1666  1
#Age composition data by year, gear (ages 2-15+)
#na_gears
3
#na_nobs
25 41 34
#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  604 562 266 145 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  46  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  163 158  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   15 1699 1587  251  228 287 146  26 17
1993  2    5  432 1783 1216  162 177 175  63  4
1994  2   44  325  885 3246 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  498 646  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 1700  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  65 135  29  9
2009  2   11  847  703 1723  286 197  45  59  2
2010  2   41 1095  888  377  676 108  54  10 12
2011  2   15 1082 1055  680  494 893 160  62 27
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
#2011  3   49  138  282 601  108  45   7  11  1
2011  3    0    2   49  138  282 601 108  45 20

#n_wt_obs
61
#Mean weight-at-age in kilograms (interpolated: from HCAM.rep)
#A$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 0.1496 0.1657 0.1672 0.2215 0.1700
1953 0.0388 0.0803 0.1108 0.1307 0.1433 0.1572 0.1690 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 0.0348 0.0758 0.1216 0.1414 0.1393 0.1679 0.1690 0.1871 0.1700
1959 0.0436 0.0857 0.1022 0.1205 0.1494 0.1547 0.1659 0.1480 0.1700
1960 0.0380 0.0674 0.1038 0.1211 0.1396 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 0.1590 0.1520 0.1560 0.1480
1965 0.0527 0.0983 0.1143 0.1400 0.1566 0.1637 0.1797 0.2001 0.2300
1966 0.0408 0.0774 0.1054 0.1270 0.1442 0.1599 0.1690 0.1871 0.1700
1967 0.0408 0.0774 0.1054 0.1270 0.1442 0.1599 0.1690 0.1871 0.1700
1968 0.0408 0.0774 0.1054 0.1270 0.1442 0.1599 0.1690 0.1871 0.1700
1969 0.0408 0.0774 0.1054 0.1270 0.1442 0.1599 0.1690 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 0.1317 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 0.0326 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 0.0288 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 0.1083 0.1162 0.1483 0.1703 0.1778 0.1833 0.1978
1983 0.0556 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 0.1351 0.1514 0.1519 0.1642 0.1887
1989 0.0565 0.0751 0.0964 0.1156 0.1361 0.1471 0.1659 0.1596 0.1906
1990 0.0504 0.0890 0.1078 0.1222 0.1379 0.1524 0.1655 0.1763 0.1850
1991 0.0548 0.0763 0.1056 0.1205 0.1290 0.1413 0.1483 0.1601 0.1711
1992 0.0470 0.0764 0.0935 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 0.1039 0.1190 0.1308 0.1377 0.1454 0.1496
1998 0.0448 0.0670 0.0799 0.0924 0.1018 0.1204 0.1303 0.1462 0.1505
1999 0.0579 0.0791 0.0956 0.1040 0.1155 0.1189 0.1363 0.1390 0.1443
2000 0.0465 0.0695 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 0.0649 0.0865 0.1003 0.1148 0.1312 0.1432 0.1524 0.1340
2005 0.0382 0.0644 0.0709 0.1000 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 0.1104 0.1196 0.1274 0.1440
2008 0.0442 0.0580 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 0.1068 0.1464
2011 0.0388 0.0687 0.0819 0.1020 0.1113 0.1256 0.1379 0.1447 0.1383
#eof
999


 ## ------------------------------------------------------------------------------ ##
##                              SOG 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       17.08696    39.0559    #rho
    0.8695652   0.01    5.0     3       4       25.0  28.75   #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 5.56 3.12 2.00
## Gear 1:3 fishery:  Gear 4-5 survey
## isel_type
    1       1         8       6       6
## Age at 50% selectivity (logistic)
    2.5     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         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
    1       1
## prior log(mean)
    -0.569  -0.569
## prior sd
    0.274    0.274
## ------------------------------------------------------------------------------ ##

## _______________________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 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.2.3 Central Coast

```
 #NB The data herein were taken from qci2010_final.dat for the HCAM model.
## ________________________
## ____Model Dimensions____
1951 #first year of data
2011 #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 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)
#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  0.000 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  0.320 3.881 6.904 0 0
1978  0.046 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  0.088 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
2011  0.000 0.000 0.000 0 0
#Relative Abundance index from fisheries independent survey (it) 1970-2008
#nit
#61
2
#nit_nobs
37 24
#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
#iyr     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
1976 13.849 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  8.121 5 1.1666 1
2011  9.906 5 1.1666 1
#Age composition data by year, gear (ages 2-15+)
#na_gears
3
#na_nobs
16 39 30
#a_sage
2 2 2
#a_page
10 10 10
#yr gear    V2   V3   V4   V5  V6  V7   V8  V9 V10  #Number aged.
1951  1 129 1518 2693  638  269   66   3   0   0
1952  1 267 1035 1551 1966  232   79  23   2   0
1953  1 274  822  702  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  308  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   25   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 2305  214  266  121   76  21  13   1
1981  2 197  759 3325  408  314  146  35  19   6
1982  2  59  548  376 2112  182  160  51  17   0
1983  2  29  381  840  589 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  260 4300  517  202  158  42  45  36
1990  2  66  383  346 4973  511  258 202  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 1698 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
2011  2 125 1359  426  671   86   64  17  17   3
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  153  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    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
61
#Mean weight-at-age in kilograms (interpolated: from HCAM.rep)
#A$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 0.0466 0.0869 0.1121 0.1311 0.1476 0.1578 0.1636 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 0.0406 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 0.0956 0.1157 0.1282 0.1465 0.1545 0.1352 0.1800
1959 0.0391 0.0774 0.0938 0.1098 0.1069 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 0.1080 0.1271 0.1282 0.1540 0.1545 0.1352 0.1800
1965 0.0525 0.1037 0.1271 0.1474 0.1675 0.1757 0.2420 0.1352 0.1800
1966 0.0426 0.0799 0.1039 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 0.0605 0.0945 0.1172 0.1418 0.1576 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 0.1989 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 0.1286 0.1534 0.1755 0.1913 0.2116 0.2350 0.2077
1980 0.0504 0.0815 0.0998 0.1244 0.1440 0.1614 0.1688 0.1981 0.2120
1981 0.0452 0.0749 0.0990 0.1156 0.1338 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 0.1845 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 0.0476 0.0831 0.1066 0.1225 0.1339 0.1481 0.1581 0.1630 0.1750
1995 0.0478 0.0796 0.1057 0.1233 0.1348 0.1438 0.1522 0.1561 0.1624
1996 0.0607 0.0781 0.1025 0.1258 0.1397 0.1476 0.1581 0.1655 0.1617
1997 0.0456 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 0.0696 0.0912 0.0962 0.1125 0.1248 0.1362 0.1365 0.1461
2005 0.0378 0.0675 0.0752 0.1062 0.1091 0.1259 0.1360 0.1404 0.1521
2006 0.0388 0.0605 0.0786 0.0919 0.1106 0.1147 0.1281 0.1347 0.1447
2007 0.0410 0.0651 0.0750 0.0955 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
2011 0.0325 0.0601 0.0724 0.0912 0.1000 0.1177 0.1185 0.1342 0.1563
#eof
999
```

```
 ## ___________________________________________________________________________ ##
##                             SOG 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       17.08696    39.0559    #rho
    0.8695652   0.01    5.0     3       4       25.0  28.75   #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 5.56 3.12 2.00
## Gear 1:3 fishery:  Gear 4-5 survey
## isel_type
   1        1          8       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           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
   1       1
## prior log(mean)
   -0.569  -0.569
## prior sd
   0.274    0.274
## ___________________________________________________________________________ ##

## _______________________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 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.2.4 Strait of Geogia

```
 #NB The data herein were taken from sog2010_final.dat for the HCAM model.
## ________________________
## ____Model Dimensions____
1951 #first year of data
2011 #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 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 45.846  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  5.988  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
2011  0.713  0.000  4.415  0  0
#Relative Abundance index from fisheries independent survey (it) 1970-2008
#nit
#61
2
#nit_nobs
37 24
#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
#iyr     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
 2011  79.070  5  1.1666  1
#Age composition data by year, gear (ages 2-15+)
#na_gears
3
#na_nobs
55 40 39
#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  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  704 3798 3502 2801  627 106  28   6  3
1957    1   98 4344 1639  782  374  44   5   1  2
1958    1  564 3278 1171  278  244 177  25   4  0
1959    1 1533 5878 1460  223   48  21  11   2  0
1960    1  398 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  190 2173 1157  110   26   4   3   0  0
1965    1  500 1703  775   73   22   3   1   0  0
1966    1  168  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   76  26  12   4  1
1978    1  110  919  958  236  166  62   9   8  3
1979    1   58  665 1545 1093  323 159  47   7  3
1980    1   84 1627  874  716  363  93  57  15  3
1981    1  340 2634 2479 1091  636 242  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
2011    1  335  371   50   19    1   1   0   0  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   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  506  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 1428 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  606  180  60  25  10  1
2010    2  583  228 3843  297  311  73  26   8  4
#2011     2 1006 3193   665 1028   109   56   21    3   1
2011    2  337 3808  642 1126  115  61  21   3  1
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
2011    3    0  103   77 1170  205 260  60  18  8
#n_wt_obs
61
#Mean weight-at-age in kilograms (interpolated: from HCAM.rep)
#A$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 0.0958 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 0.1751 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 0.0828 0.1089 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 0.0836 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 0.0576 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 0.0576 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 0.0880 0.1104 0.1332 0.1530 0.1677 0.1720 0.1784 0.1865
1968 0.0488 0.0880 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 0.1588 0.1749 0.1928 0.1977 0.2010 0.2096
1974 0.0630 0.0877 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 0.1234 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 0.1099 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 0.1348 0.1561 0.1706 0.1873 0.1802 0.2022
1982 0.0635 0.0945 0.1153 0.1292 0.1531 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 0.1146 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 0.1302 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 0.0604 0.0851 0.1060 0.1283 0.1468 0.1572 0.1609 0.1453 0.2260
1991 0.0642 0.0894 0.1101 0.1280 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 0.0829 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 0.0725 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 0.1530 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 0.1050 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 0.1215 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
2011 0.0353 0.0686 0.0721 0.0906 0.0948 0.1083 0.1194 0.1430 0.1220
#eof
999
```

```
 ## ____________________________________________________________________________ ##
##                               SOG 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
## ____________________________________________________________________________ ##
    7.20        -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 0.2    #log.m
    6.80        -5.0    15      1       0        -5.0    15       #log_avgrec
    5.80        -5.0    15      1       0        -5.0    15       #log_recinit
    0.3043478   0.001   0.999   3       3        17.08696    39.0559    #rho
    0.8695652   0.01    5.0     3       4        25.0  28.75   #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 5.56 3.12 2.00
## Gear 1:3 fishery:  Gear 4-5 survey
## isel_type
    1       1          8       6       6
## Age at 50% selectivity (logistic)
    1.5      2.0        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          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
    1       1
## prior log(mean)
    -0.569  -0.569
## prior sd
    0.274   0.274
```

```
## ___________________________________________________________________________ ##

## ______________________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 Ft
0.05        ## 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
0.99        ## 13 dfraction of total mortality that takes place prior to spawning
1           ## 14 switch for age-composition likelihood (1=dmvlogistic,2=dmultinom)
## ___________________________________________________________________________ ##


## eofc
999
```

B.2.5 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
2011 #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 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 21.821  0.000  0.000  0  0
1952 27.008  0.000  0.000  0  0
1953  0.020  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  0.029 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
2011  0.000  0.000  0.000  0  0
#
#Relative Abundance index from fisheries independent survey (it) 1970-2008
#nit
2
#nit_nobs
37 24
#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
#iyr     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 33.986    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
2011  9.196    5  1       1
#
#Age composition data by year, gear (ages 2-15+)
#na_gears
3
#na_nobs
18 40 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  508 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  575 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
1971    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   19  818 4332 1828 1196  746 251  40  0
1977    2   35  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  156 1144 1309 1244  260  454 130  65  5
1983    2  135  719  696  699  562  142 172  34 26
1984    2  669 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
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  220 251  48  2
1992    2  104 2960  662  827  362 1029 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  60 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 1295 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
2011    2   43  523  189   64    3    3   0   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  254   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
61
```

```
#Mean weight-at-age in kilograms (interpolated: from HCAM.rep)
#A$yr     V1     V2     V3     V4     V5     V6     V7     V8     V9
1951 0.0503 0.0873 0.1144 0.1339 0.1489 0.1600 0.2050 0.1960 0.1586
1952 0.0536 0.0896 0.1144 0.1386 0.1569 0.1699 0.1781 0.1900 0.1586
1953 0.0446 0.0799 0.1001 0.1210 0.1473 0.1455 0.1594 0.1656 0.1586
1954 0.0542 0.0854 0.1056 0.1258 0.1474 0.1658 0.1550 0.1656 0.1586
1955 0.0579 0.0827 0.1070 0.1249 0.1514 0.1310 0.1594 0.1656 0.1586
1956 0.0577 0.0860 0.1064 0.1192 0.1389 0.1440 0.1594 0.1400 0.1586
1957 0.0543 0.0775 0.1016 0.1139 0.1360 0.1440 0.1420 0.1400 0.1586
1958 0.0503 0.0693 0.0965 0.1093 0.1248 0.1281 0.1383 0.1690 0.1586
1959 0.0508 0.0808 0.0970 0.1130 0.1241 0.1332 0.1371 0.1499 0.1527
1960 0.0594 0.0897 0.1060 0.1212 0.1336 0.1446 0.1604 0.1745 0.1645
1961 0.0583 0.0908 0.1159 0.1410 0.1730 0.1484 0.1594 0.1656 0.1586
1962 0.0567 0.0922 0.1093 0.1241 0.1282 0.1484 0.1594 0.1656 0.1586
1963 0.0562 0.0883 0.1116 0.1222 0.1366 0.1448 0.1594 0.1656 0.1586
1964 0.0650 0.0931 0.1145 0.1362 0.1452 0.1300 0.1594 0.1656 0.1586
1965 0.0683 0.1040 0.1292 0.1474 0.1733 0.1580 0.1594 0.1656 0.1586
1966 0.0420 0.1128 0.1351 0.1489 0.1627 0.1793 0.1594 0.1656 0.1586
1967 0.0549 0.0880 0.1102 0.1275 0.1455 0.1484 0.1594 0.1656 0.1586
1968 0.0549 0.0880 0.1102 0.1275 0.1455 0.1484 0.1594 0.1656 0.1586
1969 0.0549 0.0880 0.1102 0.1275 0.1455 0.1484 0.1594 0.1656 0.1586
1970 0.0639 0.0949 0.1248 0.1501 0.1697 0.1844 0.1957 0.2034 0.2082
1971 0.0640 0.1174 0.1485 0.1660 0.1689 0.1991 0.2175 0.2034 0.2082
1972 0.0642 0.1036 0.1382 0.1596 0.1737 0.1807 0.2032 0.1600 0.2082
1973 0.0633 0.1037 0.1349 0.1598 0.1836 0.1924 0.1903 0.2540 0.2082
1974 0.0617 0.0854 0.1234 0.1487 0.1717 0.1856 0.1836 0.2175 0.2310
1975 0.0547 0.0918 0.1279 0.1652 0.1893 0.2071 0.2202 0.2406 0.2070
1976 0.0536 0.0873 0.1202 0.1518 0.1811 0.1951 0.2112 0.2223 0.2082
1977 0.0628 0.0885 0.1253 0.1435 0.1695 0.1828 0.1918 0.1962 0.2153
1978 0.0591 0.0797 0.1082 0.1341 0.1539 0.1736 0.1883 0.2038 0.2244
1979 0.0621 0.0831 0.1104 0.1412 0.1672 0.1835 0.2003 0.2034 0.1995
1980 0.0669 0.0825 0.1079 0.1314 0.1590 0.1789 0.1928 0.2083 0.2180
1981 0.0630 0.0906 0.1104 0.1377 0.1527 0.1755 0.1830 0.1879 0.1891
1982 0.0708 0.0892 0.1094 0.1251 0.1423 0.1500 0.1712 0.1795 0.1774
1983 0.0611 0.0938 0.1190 0.1405 0.1552 0.1660 0.1737 0.1954 0.1936
1984 0.0692 0.1013 0.1306 0.1535 0.1662 0.1767 0.1863 0.1891 0.2112
1985 0.0694 0.1016 0.1351 0.1609 0.1818 0.1857 0.2076 0.1848 0.1997
1986 0.0683 0.1028 0.1311 0.1601 0.1809 0.1919 0.1984 0.2045 0.2217
1987 0.0695 0.1026 0.1367 0.1634 0.1810 0.2001 0.2030 0.2050 0.2139
1988 0.0679 0.1033 0.1302 0.1597 0.1775 0.1952 0.2019 0.2062 0.2138
1989 0.0649 0.0967 0.1268 0.1476 0.1700 0.1869 0.1936 0.1966 0.2050
1990 0.0620 0.1008 0.1295 0.1542 0.1721 0.1881 0.1993 0.2148 0.1963
1991 0.0662 0.0942 0.1235 0.1412 0.1608 0.1773 0.1858 0.1978 0.2065
1992 0.0687 0.1006 0.1256 0.1493 0.1638 0.1773 0.1879 0.1973 0.2082
1993 0.0685 0.0973 0.1217 0.1406 0.1593 0.1694 0.1784 0.1873 0.1979
1994 0.0648 0.0949 0.1194 0.1358 0.1498 0.1605 0.1642 0.1748 0.1779
1995 0.0693 0.0979 0.1216 0.1432 0.1599 0.1749 0.1823 0.1888 0.1874
1996 0.0695 0.0855 0.1160 0.1363 0.1520 0.1646 0.1766 0.1814 0.1921
1997 0.0641 0.0914 0.1055 0.1316 0.1492 0.1610 0.1756 0.1729 0.1794
1998 0.0589 0.0796 0.1037 0.1133 0.1321 0.1424 0.1494 0.1557 0.1575
1999 0.0536 0.0832 0.0991 0.1195 0.1257 0.1440 0.1521 0.1634 0.1562
2000 0.0578 0.0868 0.1074 0.1301 0.1468 0.1584 0.1609 0.1681 0.1771
2001 0.0659 0.0885 0.1074 0.1242 0.1408 0.1564 0.1563 0.1478 0.1983
2002 0.0634 0.0840 0.1032 0.1249 0.1440 0.1566 0.1704 0.1868 0.2180
2003 0.0609 0.0934 0.1031 0.1207 0.1387 0.1544 0.1763 0.1670 0.1920
2004 0.0635 0.0814 0.1028 0.1100 0.1242 0.1340 0.1557 0.1657 0.1852
2005 0.0559 0.0755 0.0913 0.1122 0.1204 0.1332 0.1375 0.1525 0.1370
2006 0.0548 0.0693 0.0877 0.1020 0.1169 0.1103 0.1280 0.1754 0.1852
2007 0.0546 0.0727 0.0805 0.0924 0.0981 0.1313 0.1642 0.1754 0.1852
2008 0.0565 0.0603 0.0877 0.1034 0.1156 0.1315 0.1450 0.1390 0.1620
2009 0.0461 0.0753 0.0777 0.1038 0.1101 0.1138 0.1642 0.1754 0.1852
2010 0.0490 0.0714 0.0855 0.0923 0.1069 0.1170 0.1095 0.1754 0.1852
2011 0.0457 0.0658 0.0721 0.0963 0.0987 0.1123 0.0818 0.1754 0.1852
#
#eof
999
```

```
 ## ___________________________________________________________________________ ##
##                              PACIFIC HAKE 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       17.08696    39.0559    #rho
    0.8695652   0.01    5.0      3       4       25.0  28.75   #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 5.56 3.12 2.00
## Gear 1:3 fishery:  Gear 4-5 survey
## isel_type
   1        1 8 1 1
## Age at 50% selectivity (logistic)
```

```
    1.5      2.0 0.6 2.05 2.05
## STD at 50% selectivity (logistic)
    0.75      0.5 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 2 -2 -2
## Penalty weight for 2nd differences w=1/(2*sig^2)
    125.0     12.5 12.5 12.5 12.5
## Penalty weight for dome-shaped selectivity 1=1/(2*sig^2)
    3.125    200.0 200.0 200.0 200.0
## ___________________________________________________________________________ ##

## ___________________________________________________________________________ ##
##                              Priors for Survey q                            ##
## ___________________________________________________________________________ ##
## nits  #number of surveys
2
## priors 0=uniform density 1=normal density
1 1
## prior log(mean)
    -0.569   -0.569
## prior sd
    0.274    0.274
## ___________________________________________________________________________ ##

## _____________________OTHER MISCELLANEOUS CONTROLS_________________________ ##
0 ## verbose ADMB output (0=off, 1=on)
1 ## recruitment model (1=beverton-holt, 2=ricker)
0.100 ## std in observed catches in first phase.
0.0707 ## std in observed catches in last phase.
0 ## Assume unfished in first year (0=FALSE, 1=TRUE)
0.02 ## Minimum proportion to consider in age-proportions for dmvlogistic
0.20 ## Mean fishing mortality for regularizing the estimates of Ft
0.01 ## std in mean fishing mortality in first phase
5.00 ## std in mean fishing mortality in last phase
3 ## phase for estimating m_deviations (use -1 to turn off mdevs)
0.1 ## std in deviations for natural mortality
12 ## number of estimated nodes for deviations in natural mortality
0.99        ## fraction of total mortality that takes place prior to spawning
1           ## 14 switch for age-composition likelihood (1=dmvlogistic,2=dmultinom)
## ___________________________________________________________________________ ##


## eofc
999
```

B.2.6 Area 2W

```
 #NB The data herein were taken from a2w2010_final.dat for the HCAM model.
## _______________________
## ____Model Dimensions____
1978        #first year of data
2011        #last year of data
2           #age of youngest age class
10          #age of plus group
4           #number of gears (ngear)
## flags for fishery (1) or survey (0) in ngears
#1  1   1   0
0.100 0.405 0.495 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
#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
1978  0 0.575  0  0
1979  0 0.691  0  0
1980  0 0.000  0  0
1981  0 0.770  0  0
1982  0 1.225  0  0
1983  0 2.518  0  0
1984  0 0.000  0  0
1985  0 0.199  0  0
1986  0 0.000  0  0
1987  0 0.000  0  0
1988  0 0.000  0  0
1989  0 0.000  0  0
1990  0 2.272  0  0
1991  0 2.558  0  0
1992  0 1.284  0  0
1993  0 1.306  0  0
1994  0 0.000  0  0
1995  0 0.000  0  0
1996  0 0.000  0  0
1997  0 0.000  0  0
1998  0 0.180  0  0
1999  0 0.000  0  0
2000  0 0.000  0  0
2001  0 0.000  0  0
2002  0 0.000  0  0
2003  0 0.000  0  0
2004  0 0.000  0  0
2005  0 0.000  0  0
2006  0 0.000  0  0
2007  0 0.000  0  0
2008  0 0.000  0  0
2009  0 0.000  0  0
2010  0 0.000  0  0
2011  0 0.000  0  0
#Relative Abundance index from fisheries independent survey (it) 1970-2008
#nit
#61
1
#nit_nobs
30
#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
#iyr     it gear wt     survey timing
1978  0.832  4  1  1
1979  0.494  4  1  1
1980  2.114  4  1  1
1981  1.894  4  1  1
1982  4.781  4  1  1
1983  4.869  4  1  1
1984  2.522  4  1  1
1985  1.719  4  1  1
1986  0.684  4  1  1
1987  0.989  4  1  1
1988  3.380  4  1  1
1989  2.719  4  1  1
1990 10.946  4  1  1
1991  2.985  4  1  1
1992  3.909  4  1  1
1993  0.089  4  1  1
1994  0.248  4  1  1
1998  0.469  4  1  1
2000  0.288  4  1  1
2001  0.035  4  1  1
2002  0.149  4  1  1
2003  1.462  4  1  1
2004  2.996  4  1  1
2005  1.111  4  1  1
2006  1.791  4  1  1
2007  1.960  4  1  1
2008  2.349  4  1  1
2009  2.860  4  1  1
2010  2.921  4  1  1
2011  2.353  4  1  1
#Age composition data by year, gear (ages 2-15+)
#na_gears
1
#na_nobs
31
#a_sage
2
#a_page
10
#yr gear        V2   V3   V4   V5  V6  V7   V8 V9 V10  #Number aged.
1978 2   0   11   43   16   80   12   10   6  0
1979 2   8  101  123   87  123   74   10   6  3
1980 2   1  203   35   12    9    5    0   2  0
1981 2  67   56 1011  177   85   58   21  10  2
1982 2  31  648   25  887   71   37   20   6  1
1983 2  23   45 1893  101 1111   98   42  25 14
1984 2  32    8    3  175   12  253    9   3  1
1985 2   5   29   52   28  218   28  631   7  1
1986 2   3    1   42   43   20   76   27 152  2
1987 2  87  241    1    5    5    5   32   4 13
1988 2  27 1119  292    4    8   10   12  25  9
1989 2   6   42  934  195    6    6   12  10  9
1990 2   5   36   42 1901  412   11    5  14 10
1991 2  17  415   54   80 2163  501   26  15  8
1992 2  31  184  268   31   55 1181  243  11  6
1993 2  27  367  449  386   55  125 1097 140  9
1994 2  10   23   82   28   18    4   11  10  2
1998 2 205  385  256  207   29    7   17   2  0
1999 2 120  249  216  110   56   12    4   2  0
2000 2  13   56   16    0    2    0    1   0  0
2001 2  17   33  158   95   47   27    8   2  0
2002 2 301  250   50  227  102   72   28  16  2
2003 2  17 1214  253   56   61   19   22   6  3
2004 2  55   74  545   57   13   12    2   0  2
2005 2   4  297   96  654   45    6    9   0  2
2006 2  50   65   82   32  209   16    8   3  0
2007 2   2  374   73   42   21  120   10   3  1
2008 2  61    3   75   15    5    4   15   0  0
2009 2  21  590   20   99   18   20   18  24  4
2010 2  55  210  240   18   63   14   36  17 12
2011 2  20  455  167  212   15   32   10   1  0
#n_wt_obs
34
#Mean weight-at-age in kilograms (interpolated: from HCAM.rep)
#A$yr     V1     V2     V3     V4     V5     V6     V7     V8     V9
1978 0.0693 0.0966 0.1424 0.1688 0.1813 0.1960 0.2207 0.2303 0.2174
```

```
1979 0.0528 0.1004 0.1373 0.1557 0.1809 0.1903 0.2110 0.2030 0.1870
1980 0.0600 0.0955 0.1197 0.1686 0.1987 0.2200 0.2124 0.2465 0.2174
1981 0.0680 0.0934 0.1256 0.1572 0.1822 0.1901 0.2018 0.1900 0.2255
1982 0.0657 0.1132 0.1233 0.1559 0.1814 0.1889 0.2145 0.2100 0.2220
1983 0.0751 0.1076 0.1415 0.1579 0.1783 0.1951 0.2025 0.1962 0.2136
1984 0.0729 0.1073 0.1307 0.1563 0.1886 0.1851 0.1841 0.1867 0.2140
1985 0.0850 0.1178 0.1531 0.1791 0.2042 0.2102 0.2188 0.2191 0.2260
1986 0.0800 0.1160 0.1490 0.1623 0.1843 0.2116 0.2270 0.2315 0.2070
1987 0.0628 0.1030 0.1270 0.1702 0.2018 0.1864 0.2227 0.1958 0.2245
1988 0.0707 0.1005 0.1429 0.1583 0.1818 0.2066 0.2209 0.2391 0.2370
1989 0.0620 0.1011 0.1317 0.1579 0.1808 0.1912 0.2033 0.2161 0.2163
1990 0.0584 0.0942 0.1414 0.1638 0.1868 0.1917 0.2304 0.2070 0.2344
1991 0.0622 0.0959 0.1270 0.1676 0.1756 0.1892 0.2002 0.2123 0.2049
1992 0.0695 0.1073 0.1342 0.1460 0.1777 0.1965 0.2098 0.2066 0.2168
1993 0.0685 0.1045 0.1283 0.1460 0.1691 0.1771 0.1892 0.1979 0.1922
1994 0.0748 0.1147 0.1393 0.1514 0.1738 0.1530 0.1999 0.1985 0.1960
1995 0.0655 0.0959 0.1209 0.1482 0.1725 0.1767 0.1877 0.1996 0.2081
1996 0.0655 0.0959 0.1209 0.1482 0.1725 0.1767 0.1877 0.1996 0.2081
1997 0.0655 0.0959 0.1209 0.1482 0.1725 0.1767 0.1877 0.1996 0.2081
1998 0.0703 0.1053 0.1334 0.1677 0.1759 0.1714 0.1973 0.1940 0.2081
1999 0.0713 0.1069 0.1209 0.1476 0.1682 0.1658 0.1340 0.1870 0.2081
2000 0.0693 0.0830 0.0881 0.1482 0.2045 0.1767 0.1110 0.1996 0.2081
2001 0.0698 0.1038 0.1478 0.1717 0.1769 0.1769 0.1784 0.2155 0.2081
2002 0.0655 0.1075 0.1254 0.1747 0.1969 0.2039 0.2041 0.2041 0.2405
2003 0.0742 0.1030 0.1144 0.1337 0.1828 0.1994 0.1965 0.1922 0.1917
2004 0.0621 0.0952 0.1294 0.1437 0.1622 0.1992 0.2460 0.1996 0.2235
2005 0.0590 0.0842 0.1093 0.1392 0.1554 0.1477 0.1738 0.1996 0.1900
2006 0.0594 0.0773 0.1037 0.1374 0.1693 0.1844 0.2096 0.2113 0.2081
2007 0.0800 0.0822 0.0879 0.1174 0.1406 0.1585 0.1550 0.1753 0.2000
2008 0.0555 0.0753 0.1102 0.1286 0.1558 0.1448 0.1643 0.1996 0.2081
2009 0.0560 0.0877 0.1015 0.1393 0.1563 0.1613 0.1922 0.1903 0.1923
2010 0.0559 0.0923 0.1227 0.1347 0.1684 0.1691 0.1722 0.1852 0.2062
2011 0.0564 0.0941 0.1172 0.1411 0.1277 0.1554 0.1608 0.1570 0.2000
#eof
999
```

```
 ## ______________________________________________________________________________ ##
##                            AREA 2W 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
## ______________________________________________________________________________ ##
    2.60        -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
    2.40        -5.0    15       1        0       -5.0    15         #log_avgrec
    2.20        -5.0    15       1        0       -5.0    15         #log_recinit
    0.3043478   0.001   0.999    3        3       17.08696    39.0559    #rho
    0.8695652   0.01    5.0      3        4       25.0  28.75    #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 5.56 3.12 2.00
## Gear 1:3 fishery:  Gear 4 survey
## isel_type
   1        1          8       6
## Age at 50% selectivity (logistic)
   2.0      3.0        0.6     2.055
## STD at 50% selectivity (logistic)
   0.25      0.25      0.15    0.05
## No. of age nodes for each gear (0 to ignore).
   5        5          5       0
## No. of year nodes for each gear (0 to ignore).
   12       3          10      0
## Estimation phase
   -2        2          -2      -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
## ______________________________________________________________________________ ##

## ______________________________________________________________________________ ##
##                              Priors for Survey q                             ##
## ______________________________________________________________________________ ##
## nits  #number of surveys
   1
## priors 0=uniform density     1=normal density
   1
## prior log(mean)
   -0.569
## prior sd
   0.274
## ______________________________________________________________________________ ##

## _____________________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)
0.01        ## 6  Minimum proportion to consider in age-proportions for dmvlogistic
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.2.7 Area 27

```
 #NB The data herein were taken from a2w2010_final.dat for the HCAM model.
## ________________________
## ____Model Dimensions____
1978        #first year of data
2011        #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   0
0.100 0.405 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
#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
1978    0 0.075 0.075    0    0
1979    0 0.422 0.270    0    0
1980    0 0.000 0.519    0    0
1981    0 0.000 0.671    0    0
1982    0 0.238 0.332    0    0
1983    0 0.000 0.163    0    0
1984    0 0.000 0.171    0    0
1985    0 0.000 0.000    0    0
1986    0 0.000 0.000    0    0
1987    0 0.000 0.000    0    0
1988    0 0.000 0.000    0    0
1989    0 0.000 0.000    0    0
1990    0 0.000 0.000    0    0
1991    0 0.000 0.000    0    0
1992    0 0.335 0.000    0    0
1993    0 0.000 0.367    0    0
1994    0 0.000 0.345    0    0
1995    0 0.088 0.000    0    0
1996    0 0.000 0.000    0    0
1997    0 0.000 0.000    0    0
1998    0 0.000 0.000    0    0
1999    0 0.000 0.000    0    0
2000    0 0.000 0.000    0    0
2001    0 0.000 0.000    0    0
2002    0 0.000 0.000    0    0
2003    0 0.000 0.000    0    0
2004    0 0.000 0.000    0    0
2005    0 0.000 0.000    0    0
2006    0 0.000 0.000    0    0
2007    0 0.000 0.000    0    0
2008    0 0.000 0.000    0    0
2009    0 0.000 0.000    0    0
2010    0 0.000 0.000    0    0
2011    0 0.000 0.000    0    0
#Relative Abundance index from fisheries independent survey (it) 1970-2008
#nit
#61
2
#nit_nobs
10      24
#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
#iyr     it gear wt     survey timing
```

```
1978  3.595    4    1    1
1979  6.909    4    1    1
1980 14.419    4    1    1
1981  1.828    4    1    1
1982  4.137    4    1    1
1983  2.720    4    1    1
1984  3.051    4    1    1
1985  1.648    4    1    1
1986  3.803    4    1    1
1987  1.372    4    1    1
1988  2.184    5    1.1666    1
1989  5.128    5    1.1666    1
1990  5.821    5    1.1666    1
1991  3.717    5    1.1666    1
1992  3.581    5    1.1666    1
1993  6.084    5    1.1666    1
1994  5.707    5    1.1666    1
1995  3.254    5    1.1666    1
1996  1.333    5    1.1666    1
1997  2.354    5    1.1666    1
1998  2.553    5    1.1666    1
1999  1.054    5    1.1666    1
2000  1.576    5    1.1666    1
2001  0.544    5    1.1666    1
2002  1.075    5    1.1666    1
2003  1.147    5    1.1666    1
2004  1.532    5    1.1666    1
2005  2.209    5    1.1666    1
2006  2.295    5    1.1666    1
2007  2.592    5    1.1666    1
2008  1.093    5    1.1666    1
2009  1.498    5    1.1666    1
2010  0.957    5    1.1666    1
2011  0.818    5    1.1666    1
#Age composition data by year, gear (ages 2-15+)
#na_gears
2
#na_nobs
31  6
#a_sage
2   2
#a_page
10  10
#yr gear        V2   V3   V4   V5  V6  V7  V8 V9 V10  #Number aged.
1978 2  1   38   4  14  12   2  0  0  0
1979 2  1   10  55  10   2   1  1  0  0
1980 2 20  229  25   4   0   0  1  0  0
1981 2 15   99 435  63  98  11  0  0  0
1982 2  7  370 105 439  43  84  8  1  0
1983 2  4   21  32  11  29   0  4  0  0
1986 2  6   64 172   7   4   5  7  6  0
1987 2 48   78  45 100   3   0  3  1  4
1988 2  8  232  41  23  57   6  3  0  1
1989 2  1   59 268  38  39  53  6  2  0
1990 2 17  210 132 367  54  66 72  6  2
1991 2 33  145  33  38  83  10 18  8  0
1992 2 49 1004 158  48  41  71 14 18  6
1993 2 72  228 248  32  10   9 32  2  3
1994 2 14  300 232 292  52  20 27  5  2
1995 2 24   91 504 348 352  59 19 23  6
1996 2 58  140  45 119 101  84 18  2  2
1997 2 23  441  42   9  23  27  9  0  0
1998 2  4  112 140  14   1   8  7  2  0
1999 2 59  213 257 189  31   4  4  2  1
2000 2 15  355 158  63  49   8  1  3  0
2001 2 13   41  70  25  24  19  2  1  0
2002 2 35  293  73  47   3  11  4  1  0
2003 2  3  295 214  36  23   1  4  1  0
2004 2  5   83 209  76   4   6  3  0  0
2005 2  1   97  43  23  13   1  1  0  0
2007 2  5  209 140  72  16  10  1  0  0
2008 2  6   12 218  80  44   5  1  0  0
2009 2  9  448  73 143  23  18  0  1  0
2010 2 15   35 154  25  36   6  7  0  0
2011 2  6  105  64  74   8  10  2  1  0
1979 3  0    0  29  12  12   7  0  0  0
1982 3  0    0   5  30   8  18  2  0  0
1983 3  0    0   7  12  50   2  9  0  0
1984 3  0    0  18 182  72 144 11  5  0
1993 3  0   17 276  73  41  39 60  5  6
1994 3  0    6  91 287  46  16 18  2  3
#n_wt_obs
34
#Mean weight-at-age in kilograms (interpolated: from HCAM.rep)
#A$yr     V1     V2     V3     V4     V5     V6     V7     V8     V9
1978 0.0550 0.0778 0.1035 0.1311 0.1539 0.1520 0.1768 0.2015 0.2289
1979 0.0350 0.0827 0.1028 0.1254 0.1360 0.1510 0.1780 0.2015 0.2289
1980 0.0679 0.0833 0.0977 0.1218 0.1559 0.1657 0.1610 0.2015 0.2289
1981 0.0643 0.0928 0.1115 0.1288 0.1379 0.1498 0.1768 0.2015 0.2289
1982 0.0561 0.0929 0.1096 0.1263 0.1358 0.1469 0.1661 0.1450 0.2289
1983 0.0508 0.0884 0.1060 0.1141 0.1275 0.1657 0.1365 0.2015 0.2289
1984 0.0585 0.0932 0.1173 0.1357 0.1559 0.1657 0.1768 0.2015 0.2289
1985 0.0585 0.0932 0.1173 0.1357 0.1559 0.1657 0.1768 0.2015 0.2289
1986 0.0678 0.1139 0.1375 0.1560 0.1958 0.2048 0.1987 0.2267 0.2289
1987 0.0671 0.1072 0.1508 0.1645 0.1827 0.1657 0.2113 0.2330 0.1958
1988 0.0625 0.1002 0.1368 0.1537 0.1782 0.1897 0.1863 0.2015 0.2620
1989 0.0430 0.1039 0.1376 0.1770 0.1994 0.2127 0.1977 0.2495 0.2034
1990 0.0628 0.1014 0.1380 0.1705 0.1969 0.2162 0.2264 0.2417 0.2345
1991 0.0649 0.0944 0.1192 0.1528 0.1738 0.2005 0.2063 0.2045 0.2034
1992 0.0605 0.1020 0.1328 0.1538 0.1821 0.2035 0.2212 0.2344 0.2518
1993 0.0583 0.0894 0.1190 0.1277 0.1747 0.1848 0.1971 0.1560 0.2130
1994 0.0699 0.0948 0.1112 0.1361 0.1547 0.1680 0.1857 0.1882 0.1830
1995 0.0601 0.0998 0.1167 0.1309 0.1514 0.1682 0.1748 0.2007 0.1853
1996 0.0526 0.0907 0.1126 0.1344 0.1425 0.1643 0.1688 0.1910 0.1835
1997 0.0476 0.0820 0.1092 0.1328 0.1336 0.1494 0.1579 0.1808 0.2034
1998 0.0435 0.0751 0.0972 0.0993 0.1240 0.1328 0.1530 0.1490 0.2034
1999 0.0487 0.0720 0.0891 0.1064 0.1054 0.1390 0.1243 0.1750 0.1730
2000 0.0531 0.0798 0.0888 0.1130 0.1342 0.1356 0.1500 0.1343 0.2034
2001 0.0509 0.0743 0.0911 0.1024 0.1108 0.1142 0.1135 0.1210 0.2034
2002 0.0845 0.0917 0.0989 0.1230 0.0963 0.1192 0.1450 0.1650 0.2034
2003 0.0567 0.0995 0.1070 0.1149 0.1328 0.1490 0.1628 0.1490 0.2034
2004 0.0546 0.0816 0.1013 0.1052 0.1288 0.1277 0.1163 0.1808 0.2034
2005 0.0340 0.0684 0.0775 0.1084 0.1340 0.1300 0.1540 0.1808 0.2034
2006 0.0544 0.0845 0.1026 0.1217 0.1369 0.1505 0.1594 0.1808 0.2034
2007 0.0556 0.0675 0.0744 0.0903 0.1003 0.1171 0.1290 0.1808 0.2034
2008 0.0472 0.0660 0.0791 0.0882 0.0960 0.1114 0.1060 0.1808 0.2034
2009 0.0446 0.0735 0.0729 0.1005 0.1131 0.1141 0.1594 0.1540 0.2034
2010 0.0507 0.0677 0.0821 0.0882 0.0919 0.1037 0.0999 0.1808 0.2034
2011 0.0452 0.0642 0.0741 0.0916 0.1000 0.1020 0.1235 0.0580 0.2034
#eof
999
```

```
 ## ___________________________________________________________________________ ##
##                            AREA 2W 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
## ___________________________________________________________________________ ##
    3.60        -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
    2.40        -5.0    15       1       0      -5.0    15        #log_avgrec
    2.20        -5.0    15       1       0      -5.0    15        #log_recinit
    0.3043478   0.001   0.999    3       3      17.08696    39.0559    #rho
    0.8695652   0.01    5.0      3       4      25.0  28.75   #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 5.56 3.12 2.00
## Gear 1:3 fishery:  Gear 4-5 survey
## isel_type
   1        1          1       6       6
## Age at 50% selectivity (logistic)
   2.0      3.0        3.6     2.055   2.055
## STD at 50% selectivity (logistic)
   0.25      0.25      0.25    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          2      -1      -1
## Penalty weight for 2nd differences w=1/(2*sig^2)
   125.     50.        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
   1       1
## prior log(mean)
   -0.569  -0.569
## prior sd
   0.274   0.274
## ___________________________________________________________________________ ##

## ______________________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 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.2.8 Control file for the simulation studies

The following control file was used in the simulation study where the data were generated with absolutely no error based on catch data from the Strait of Georgia. The purpose of this simulation study was to demonstrate that ^{i}SCA$_{\mathrm{M}}$ is capable of estimating the true parameter values given perfect information.

```
## ______________________________________________________________________________ ##
##                              SOG 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/msy
    0.80        0.2     1.0     4       0       1.1     1.1     #steepness/fmsy
    -0.7985077  -5.0    0.0     -3      0       -0.7985 0.2     #log.m
    7.60        -5.0    15      3       0       -5.0    15      #log_avgrec
    7.60        -5.0    15      3       0       -5.0    15      #log_recinit
    0.05        0.001   0.999   -3      3       1.01    1.01    #rho
    4999        0.01    5000    -3      4       1.01    1.01    #vartheta
## ______________________________________________________________________________ ##

## ______________________________________________________________________________ ##
## ________________________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=1, and estimation phase to -1)
## Gear 1:3 fishery:  Gear 4-5 survey
## isel_type
    1       1           1       1       1
## Age at 50% selectivity (logistic)
    1.5     2.5         3.5     2.05    2.05
## STD at 50% selectivity (logistic)
    0.5     0.5         0.5     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          -2      -2      -2
## Penalty weight for 2nd differences w=1/(2*sig^2)
    12.5    12.5        12.5    12.5    12.5
## Penalty weight for dome-shaped selectivity 1=1/(2*sig^2)
    3.125   200.0       200.0   200.0   200.0
## ______________________________________________________________________________ ##

## ______________________________________________________________________________ ##
##                              Priors for Survey q                               ##
## ______________________________________________________________________________ ##
## nits  #number of surveys
    2
## priors 0=uniform density     1=normal density
    0       0
## prior log(mean)
    0       0
## prior sd
    1       1
## ______________________________________________________________________________ ##

## _____________________OTHER MISCELLANEOUS CONTROLS_________________________ ##
0           ## 1  verbose ADMB output (0=off, 1=on)
1           ## 2  recruitment model (1=beverton-holt, 2=ricker)
0.05        ## 3  std in observed catches in first phase.
0.01        ## 4  std in observed catches in last phase.
0           ## 5  Assume unfished in first year (0=FALSE, 1=TRUE)
0.01        ## 6  Minimum proportion to consider in age-proportions for dmvlogistic
0.05        ## 7  Mean fishing mortality for regularizing the estimates of Ft
0.01        ## 8  std in mean fishing mortality in first phase
5.00        ## 9  std in mean fishing mortality in last phase
-3          ## 10 phase for estimating m_deviations (use -1 to turn off mdevs)
0.01        ## 11 std in deviations for natural mortality
12 ## 12 number of estimated nodes for deviations in natural mortality
0.99        ## 13 fraction of total mortality that takes place prior to spawning
1           ## 14 switch for age-composition likelihood (1=dmvlogistic,2=dmultinom)
## ______________________________________________________________________________ ##


## eofc
999
```

The following control file was used in the simulation study where data were generated with observation error and process errors.

```
## ______________________________________________________________________________ ##
##              SOG HERRING CONTROLS for Monte Carlo trials
## _________________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/msy
    0.80        0.2     1.0     4       3       1.1     1.1     #steepness/fmsy
    -0.7985     -5.0    0.0     3       1       -0.7985 0.2     #log.m
    7.40        -5.0    15      1       0       -5.0    15      #log_avgrec
    7.40        -5.0    15      1       0       -5.0    15      #log_initrec
    0.25        0.001   0.999   -3      3       1.01    1.01    #rho
    2.50        0.01    15      -3      4       1.01    1.01    #vartheta
## ______________________________________________________________________________ ##

## ______________________________________________________________________________ ##
## ________________________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=1, and estimation phase to -1)
## Gear 1:3 fishery:  Gear 4-5 survey
## isel_type
    1       1           1       1       1
## Age at 50% selectivity (logistic)
    1.5     2.5         3.5     2.05    2.05
## STD at 50% selectivity (logistic)
    0.5     0.5         0.5     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           2       -2      -2
## Penalty weight for 2nd differences w=1/(2*sig^2)
    12.5    12.5        12.5    12.5    12.5
## Penalty weight for dome-shaped selectivity 1=1/(2*sig^2)
    3.125   200.0       200.0   200.0   200.0
## ______________________________________________________________________________ ##

## ______________________________________________________________________________ ##
##                              Priors for Survey q                               ##
## ______________________________________________________________________________ ##
## nits  #number of surveys
    2
## priors 0=uniform density     1=normal density
    0       0
## prior log(mean)
    0       0
## prior sd
    1       1
## ______________________________________________________________________________ ##

## _____________________OTHER MISCELLANEOUS CONTROLS_________________________ ##
0           ## 1  verbose ADMB output (0=off, 1=on)
1           ## 2  recruitment model (1=beverton-holt, 2=ricker)
0.05        ## 3  std in observed catches in first phase.
0.01        ## 4  std in observed catches in last phase.
0           ## 5  Assume unfished in first year (0=FALSE, 1=TRUE)
0.01        ## 6  Minimum proportion to consider in age-proportions for dmvlogistic
0.05        ## 7  Mean fishing mortality for regularizing the estimates of Ft
0.01        ## 8  std in mean fishing mortality in first phase
5.00        ## 9  std in mean fishing mortality in last phase
-3          ## 10 phase for estimating m_deviations (use -1 to turn off mdevs)
0.01        ## 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
```

C.3 Bayesian prior for the dive survey spawn index proportionality constant q

C.3.1 The process

A Bayesian prior for the herring dive survey spawn index proportionality constant (q) is developed using a process that combines expert knowledge (in some cases best guesses) and data associated with factors influencing the prior. The process, used to develop acoustic and trawl survey priors for New Zealand fisheries stock assessments (e.g., Cordue, 2006), is comprised of the following steps:

1. List all factors affecting q.
2. For each factor, determine the statistical distribution that best describes the uncertainty associated with that factor. Where available, the distribution is based on data (not data that will be used in the assessment); otherwise it is based on expert knowledge.
3. The prior distribution for q is estimated by integrating across the distributions for each factor. This can be approximated by generating joint random samples from the distributions.
4. Finally, a parametric model is fit to the resulting distribution of replicate random samples to approximate the q prior.

C.3.2 Factors affecting q and their distributions

The factors that contribute to the spawn index q prior include: the proportion of the total spawn that is surveyed; the amount of egg loss that occurs prior to the spawn survey; bias in the estimate of mean egg density; and drift in spawn survey observations over time. The distributions for each of these factors should reflect uncertainty in their average affect over years, not capture inter-annual variation in them.

Proportion of total spawn surveyed

The proportion of the total spawn that is surveyed has a natural upper bound of 1, though its central tendency is not known. Reasons for not surveying herring spawns include non-detection (early or late in season or very deep and not observed) or lack of resources to conduct the survey. For the latter case the spawns will be reported, and this occurrence is rare. The proportion of the total spawn that is not-detected is likely higher in more remote locations and when spawning abundance is low. With limited information, we assume a uniform distribution on 0.9 1.0 for the average proportion of total spawn surveyed.

Egg loss prior to survey

This factor accounts for egg loss due to predation (seabirds, invertebrates, marine mammals) and translocation between the time of egg deposition and the spawn surveys. The amount of egg loss prior to spawn surveys is determined by the daily egg loss rate and the number of days between a spawn and the subsequent survey.

The herring egg loss literature, recently summarized by (Hay et al., 2011, their Appendix 7), is used to estimate a distribution for daily egg loss rates. All studies conducted on the west coast of North America that estimated total egg loss over the incubation period (or daily egg loss rates) were considered for inclusion in the egg loss rate distribution. Those criteria substantially reduce the available literature (Table C-3). Egg loss estimates from the selected studies were standardized to instantaneous (daily) rates (Table C-4). A normal distribution for the daily egg loss rate, based on the mean and standard deviation of the selected estimates, is assumed.

The second component of the egg loss distribution is the average number of days between the spawn event and the surveys. Information to inform the distribution of this factor was available in the B.C. herring spawn survey database. Only dive survey records were selected, and numerous error checks imposed to remove erroneous data (Table C-4). For each spawn record, the number of days between the spawn event and subsequent survey was estimated as the difference between the mid-spawn date and the mid-survey date. The mean time between a spawn deposition event and the subsequent survey ranges from 6.4 to 9.2 days across the stock assessment regions (Table C-6). A normal distribution for the average time between egg deposition and surveys is assumed, based on the mean and standard deviation of the mean values for the stock assessment regions (mean=7.7; standard deviation =1.13).

Bias in mean egg density

The equation predicting egg density from dive survey observations was calculated from field studies conducted through much of the B.C. coast in the mid 1980s. These studies included diver observations of egg layers and percent cover by vegetation classes and subsequent laboratory egg counts of the observed quadrats. While the egg density prediction equation is unbiased, the unexplained residual error is large and the error in the mean egg densities predicted at the stock assessment region/year level were often greater than expected based on the assumption of unbiased iid observations. To allow for potential bias in predicted mean egg density at the stock assessment region level, we assume a normal distribution for this factor with mean 1 and standard deviation 0.2.

Drift in dive survey observations

The studies to calibrate field observations of herring spawns to egg density estimates were primarily conducted during the mid 1980s by research divers. Since then, Fisheries Officers and subsequently research divers have conducted the coast wide herring spawn surveys. While there is considerable effort to ensure standardization of the surveys, it is possible that there has been drift in how observations are made. There is no direct information on how survey observations may have changed over time, however Hay (in press) suggests that if drift has occurred its direction is to observations that result in lower density estimates (i.e. there has been an increase in trace observations.) For now, we do not include this factor in calculating a prior distribution for the spawn survey q.

Table C-1 summarizes the factors affecting the q prior and their assumed distributions.

Table C-1: Factors affecting the q prior and their assumed distributions.

Factor affecting the q prior	Distribution	Parameters of distribution
Proportion of total spawn surveyed (p_i)	Uniform	0.9-1.0
Egg loss prior to survey:		
Instantaneous daily egg loss rate (Z_i)	Normal	Mean 0.0642 Std. dev 0.0187
Days between spawn deposition and survey (d_i)	Normal	Mean 7.7 Std. dev. 1.13
Bias in mean egg density (b_i)	Normal	Mean 1 Std. dev. 0.2

C.3.3 Simulating the dive survey spawn index q

Monte-Carlo simulations were conducted, randomly sampling from each factors distribution. The factors will operate independently so covariance structure does not need to be considered. For each of 10,000 replicates (i), a random draw was made for each factor to generate a point in the joint distribution for the q prior ($\tilde{q}_i$):

$$\tilde{q}_i = p_i b_i \exp(-d_i Z_i)$$

For the ^{i}SCA$_{\mathrm{M}}$ herring stock assessments, a lognormal prior for the spawn index q is assumed (i.e., $\ln(q)$ is assumed normally distributed). The distribution of the simulated $\tilde{q}_i$ is reasonably approximated by a lognormal distribution (Figure C.1). Means and standard deviations for the simulated and the natural log of the $\tilde{q}_i$ are presented in Table C-2

Table C-2: Estimated means and standard deviations for the simulated q prior and natural log of the q prior.

	$\tilde{q}_i$	$\ln(\tilde{q}_i)$
Mean	0.587	-0.569
Std	0.155	0.274

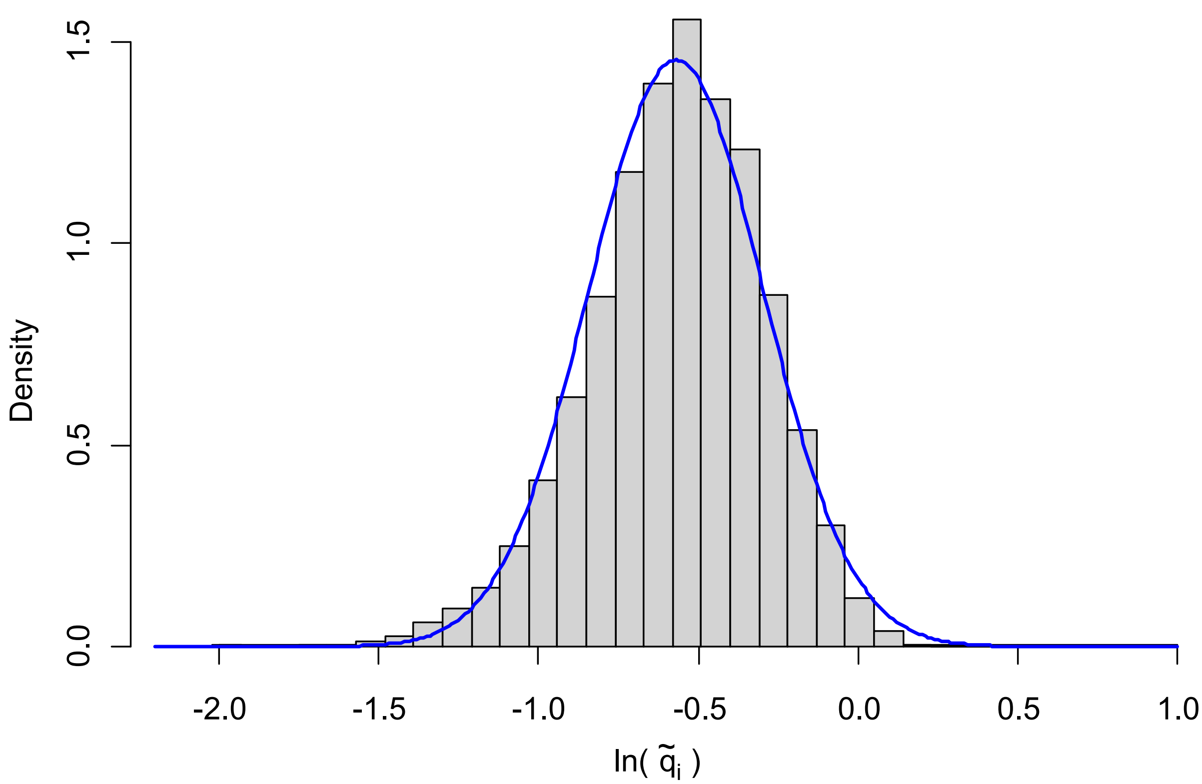

Figure C.1: Distribution of the log of the simulated spawn index q estimates, overlaid with a normal distribution based on the mean and standard deviation of the simulated values.

Table C-3: Summary of west coast North America herring egg loss literature.

Study and summary of pertinent egg loss estimates:	**Rationale for inclusion/exclusion from prior estimation:**
Bishop and Green (2001) Estimated 31% of herring egg deposition was consumed by 5 species of birds (1994, Prince William Sound), based on a bioenergetics model.	Not included because study estimated only bird predation effect.
Haegele and Schweigert (1991) Estimated 58% herring egg loss over 14 day incubation period (Lambert Channel 1989). Bird and invertebrate predation accounted for 7.1% egg loss; the remainder from physical removal and translocation could not be directly estimated.	Included because comprehensive B.C. study.
Haegele and Schweigert (1989) Estimated 19.5% egg loss from predation based on predator counts and consumption rates (birds and invertebrates). From egg counts, total egg loss estimated at 68.8% over a 14 day incubation period (their Table 3 egg loss equations). Modelled changes in observations of egg layers over the incubation period: egg layers on sea grasses= 2.17 0.07 (day); egg layers on filamentous algae= 3.47 0.13 (day). Equations result in 45% and 52% decrease in egg layers over 14 days incubation period, respectively.	Included because comprehensive B.C. study.
Outram (1958) Seabird predator exclusion study, West coast Vancouver Island (1951 1953). Overall, estimated 39% egg loss due to seabirds over the incubation period. Total egg loss over incubation period ranged from 56% to 99% (based on change in egg biomass for the control plots). Study was restricted to eelgrass beds.	Not included because study restricted to eel grass beds
Palsson (1984) Estimated daily egg loss rates from 16.9% to 51.8% (positively correlated with egg density just after spawning). Large predators account for 20% to 50% of daily egg loss. Initial egg densities were very low, ranging from 400 to 80,000 eggs/m2 across 9 study sites. Paulsons thesis cites additional egg loss literature that is not included here because the studies generally focussed on a limited range of habitat types.	Not included because study egg densities were much lower than densities generally seen in B.C. spawns.
Rooper et al. (1999) Surveys conducted 1991, 1992, 1994 and 1995. Depth is factor that best accounts for egg loss rates (higher egg loss in shallower waters). Mean daily egg loss rates (Z) were (their Table 2): • 1990 0.076 • 1991 0.042 • 1994 0.096 • 1995 0.096 Note that population was much lower in 1994 and 1995.	Comprehensive study in Prince William Sound. Estimates for 1990 and 1991 only are included because population had crashed by 1994 and abundance was low.

Table C-4: Estimates of the instantaneous daily egg loss rate (Z) from herring egg loss studies conducted in the Pacific Northwest. The Z estimates for the Haegele and Schweigert (1989, 1991) studies were calculated from their reported egg loss rates over the study period.

Publication	Study Location	Year	Z
Haegele & Schweigert (1991)	SoG	1989	0.056
Haegele & Schweigert (1989)	WCVI	1988	0.083
Rooper et al. (1999)	PWS	1991	0.076
Rooper et al. (1999)	PWS	1992	0.042
		Mean	0.0642
		Std	0.0187

Table C-5: Criteria for selecting herring spawn survey data records for estimating days between spawning and surveys. The ″number of records″ is the records retained after each successive selection criterion.

Selection criterion	Number of Records
Total dive survey records (1985-2010)	3457
Spawn and survey start/end dates completed	3188
End spawn date $\leq$ start spawn date End spawn date start spawn date $<$ 20 Survey days $\leq$ 14 3130	3130
End spawn date-end survey date$\leq$ 2 End survey date- end spawn date $<$ 20	3074

Table C-6: Average number of days between spawn deposition and spawn survey by stock assessment region and year.

Year	A2W	HG	PRD	CC	SoG	WCVI	A27
1985					5.2	6.6	8.8
1986			6.0	5.5	5.8	9.2	2.2
1987					10.6		
1988		7.4	11.2	8.3	11.0	8.2	
1989		8.2	10.8	5.8	14.5	8.6	10.7
1990	8.9	12.2	8.3	7.9	12.8	7.6	7.8
1991	10.5	5.9	7.5	11.0	12.4	9.2	2.3
1992	3.6	0.1	6.6	10.0	8.1	9.4	5.7
1993	12.2	9.3	4.9	9.1	13.1	7.6	16.8
1994	4.8	12.2	10.8	8.7	12.8	6.2	
1995		10.3	6.1	7.9	9.3	6.4	11.1
1996		7.9	5.7		10.2	4.5	7.9
1997		8.6	10.3	6.1	9.4	7.5	2.8
1998	10.5	13.3	5.5	12.4	10.4	6.4	4.2
1999		10.0	8.1	6.4	8.0	4.9	
2000	6.5	10.8	10.8	7.4	8.8	6.1	6.9
2001	9.0	7.4	8.3	6.8	8.0	6.9	3.8
2002	6.5	9.0	5.7	5.6	9.9	5.5	2.3
2003		7.5	6.2	5.0	9.5	7.0	7.3
2004	8.6	14.0	8.2	4.1	9.5	7.1	8.2
2005	6.3	9.4	8.8	9.2	5.8	5.1	3.3
2006			7.6	6.5	11.7	3.1	5.8
2007		6.0	10.8	0.7	9.3	3.4	
2008		7.4	7.2	4.3	9.5	3.8	2.0
2009	5.3	6.0	9.6	5.3	4.2	5.5	5.6
2010					7.1	5.2	
Mean	7.8	8.7	8.3	6.8	9.2	6.6	6.4

D.4 Landings and Survey data

The following tables present the herring catch by gear and year for each Stock Assessment Region and the spawn survey data. Note that the units are in 1000's of tonnes.

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

Stock	HG		PRD			CC			SOG			WCVI		
Year	Gear 1	Gear 2	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	2.860		46.000			42.700			44.200			21.600		
1952	10.200		53.200			33.300			46.100			27.200		
1953			1.870			0.769			8.420			0.020		
1954	1.780		27.400			25.000			66.300			34.300		
1955	1.230		18.000			11.600			68.600			6.110		
1956	72.600		10.100			43.000			72.100			16.900		
1957	23.700		26.600			23.800			58.900			2.620		
1958	10.900		4.550			9.870			20.900			0.556		
1959	6.970		10.300			27.500			48.900		0.381	69.200		
1960			18.500			4.000			67.000			52.100		
1961	0.654		41.200			31.000			46.500			25.500		
1962	7.680		27.300			15.700			65.900			23.700		
1963	15.000		39.400			43.500			68.500			18.400		
1964	28.200		28.900			30.800			76.400			21.100		
1965	34.900		44.100			15.800			46.800			16.100		
1966	2.750		17.100			37.000			34.000			10.900		
1967	0.213		8.030			21.700			30.600			15.000		
1968	0.080		2.080			1.530			1.890					
1969									0.194					
1970			1.330			0.209			0.221		0.022			
1971	0.102		3.450			3.620			1.610		0.084			
1972	0.849		0.878	3.620	0.004	0.388	8.360	0.137	2.430	5.900	0.456		6.940	
1973			0.218	1.390		0.035	6.610	1.110	4.000	1.610	2.080		16.900	1.540
1974		0.127	0.182	2.120	1.530		3.610	5.320	0.479	0.425	3.110		12.200	3.930
1975		0.105	0.155	1.540	0.011		3.330	5.410	0.378	0.469	5.310		17.600	8.180
1976	0.374	1.800	0.566	3.470	0.277		6.100	6.130	5.070	0.202	7.020		22.800	16.100
1977		1.490	0.797	5.820	1.520	0.320	3.850	6.790	5.690	4.110	7.860	0.029	17.400	12.800
1978		2.560	3.600	1.960	3.090	0.046	4.760	9.280	13.000	3.730	7.450	2.830	5.140	15.200
1979		2.090	1.810	1.270	1.240		0.005		13.600		6.970	0.084	10.400	8.220
1980		1.210	0.740	1.640	1.060	0.010		0.529	2.470	0.169	3.210		1.680	2.300
1981		1.710	1.690	1.050	0.357		0.269	2.300	4.890	2.080	5.100		4.980	3.070
1982		1.410	1.820	0.170		0.041	2.250	4.050	3.930	3.300	5.530		2.370	3.090
1983	0.067	0.929					2.060	3.560	0.825	7.840	8.630		6.180	2.430
1984	0.096	0.535	0.173	1.650	1.890		3.580	3.590	0.087	4.150	6.180		5.730	0.858
1985		1.490	0.253	3.010	3.470		2.910	2.290	0.772	2.730	3.530		0.177	
1986		0.890	0.375	3.730	4.540	0.038	2.170	1.170	0.432	0.162			0.203	
1987			0.122	2.080	4.090		2.710	0.924	0.244	3.110	5.870		13.400	2.450
1988			0.079	3.560	4.430	0.028	3.550	0.978	0.756	1.470	5.960		8.250	1.450
1989			0.071	3.660	4.820		6.510	2.950	1.030	1.410	5.880		9.710	3.520
1990		1.170	0.043	2.280	2.370		5.270	3.050	0.233		7.690		7.860	1.960
1991		0.543		1.360	2.140		7.130	1.820	0.562	1.130	9.130		6.300	2.340
1992			0.142	1.240	3.780	0.088	7.120	1.120	0.939	3.610	8.920		3.090	0.627
1993				2.210	4.100		8.340	2.030	0.617	4.380	8.730		5.610	
1994				2.360	2.350		9.610	2.110	0.942	5.120	11.200		5.310	0.706

Table D-1: *(continued)*

Year		Gear 1	Gear 2		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						0.706	1.370			8.150	1.450		0.641	4.360	8.030			1.950	
1996							3.100			3.910	0.403		0.541	7.340	6.120			0.790	
1997							5.420			3.290	0.345		0.402	9.300	6.110			6.670	
1998							3.170			8.060	0.650		0.954	5.760	6.970			5.450	1.550
1999			0.473			0.256	1.850			6.000	1.530		1.470	4.970	6.900			3.410	0.972
2000						1.240	3.100			6.360	0.977		1.160	6.430	7.580			0.927	0.702
2001						1.010	1.920			5.620	0.519		1.420	7.280	7.590				
2002						2.060	2.470			2.900	0.400		1.330	9.330	7.900			0.433	0.389
2003						1.450	2.590			2.300	0.289		1.700	10.700	8.100			2.570	0.950
2004						1.920	2.210			3.000			1.360	7.030	5.320			3.850	0.594
2005						1.750	2.070			3.790			1.330	7.910	9.150			3.420	0.901
2006						0.958	1.670			3.080			1.370	9.290	7.350				
2007							0.968			0.398			0.672	3.850	5.240				
2008						0.512	1.150						1.140	2.760	5.850				
2009						0.713	1.280						0.709	5.700	3.860				
2010						0.475	1.000						0.595	4.570	3.260				
2011						0.884	1.260						0.713		4.530				

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

HG				PRD				CC				SOG				WCVI			
Year	Survey 1	Year	Survey 2	Year	Survey 1	Year	Survey 2	Year	Survey 1	Year	Survey 2	Year	Survey 1	Year	Survey 2	Year	Survey 1	Year	Survey 2
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	19.597	1988	46.242
1952	2.578	1989	25.201	1952	24.047	1989	16.379	1952	10.295	1989	21.561	1952	72.376	1989	66.052	1952	13.310	1989	47.718
1953	7.555	1990	27.058	1953	28.468	1990	22.679	1953	18.237	1990	28.980	1953	111.307	1990	67.152	1953	39.571	1990	46.464
1954	12.408	1991	17.998	1954	13.535	1991	25.811	1954	13.967	1991	19.183	1954	82.141	1991	45.830	1954	20.648	1991	30.456
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
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
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
1958	0.815	1995	4.701	1958	9.882	1995	18.516	1958	3.549	1995	22.348	1958	16.911	1995	64.899	1958	18.986	1995	28.057
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
1960	6.599	1997	11.215	1960	16.545	1997	25.037	1960	12.615	1997	28.255	1960	55.709	1997	58.232	1960	6.015	1997	46.490
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
1962	5.730	1999	10.610	1962	26.329	1999	29.745	1962	11.948	1999	31.813	1962	35.574	1999	85.095	1962	34.470	1999	20.390
1963	7.297	2000	6.698	1963	16.981	2000	19.694	1963	6.485	2000	32.652	1963	37.381	2000	72.688	1963	11.245	2000	13.267
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
1965	1.378	2002	3.257	1965	6.055	2002	22.449	1965	2.097	2002	23.147	1965	38.390	2002	117.864	1965	11.891	2002	22.086
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
1967	0.710	2004	5.668	1967	3.386	2004	30.493	1967	5.434	2004	29.407	1967	9.647	2004	114.352	1967	4.813	2004	15.844
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
1969	2.075	2006	4.097	1969	0.965	2006	10.251	1969	1.837	2006	12.051	1969	14.039	2006	46.752	1969	10.465	2006	2.705
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
1971	13.291	2008	4.213	1971	8.480	2008	13.553	1971	4.156	2008	3.971	1971	38.921	2008	32.103	1971	36.206	2008	2.548
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
1973	7.960	2010	6.091	1973	10.959	2010	26.988	1973	12.434	2010	8.075	1973	16.191	2010	47.480	1973	19.481	2010	2.373
1974	14.510			1974	9.244			1974	8.852			1974	40.571			1974	25.540		
1975	9.686			1975	10.949			1975	8.037			1975	70.211			1975	49.149		
1976	16.374			1976	15.587			1976	13.849			1976	60.642			1976	64.222		
1977	16.408			1977	11.589			1977	14.613			1977	78.562			1977	58.679		
1978	18.371			1978	6.164			1978	7.747			1978	102.115			1978	45.607		
1979	13.649			1979	9.195			1979	5.779			1979	64.266			1979	66.397		
1980	31.904			1980	11.937			1980	13.012			1980	85.991			1980	62.308		
1981	20.294			1981	14.087			1981	15.919			1981	55.121			1981	52.063		
1982	23.593			1982	17.186			1982	16.333			1982	100.987			1982	33.047		
1983	21.391			1983	25.247			1983	18.482			1983	64.575			1983	16.771		
1984	23.439			1984	27.041			1984	14.185			1984	26.227			1984	23.872		
1985	18.625			1985	41.028			1985	8.850			1985	25.247			1985	30.010		
1986	6.847			1986	26.638			1986	20.342			1986	41.575			1986	39.514		
1987	12.289			1987	39.905			1987	12.827			1987	41.737			1987	16.858		