Part I: Moving towards a sustainable fisheries framework for BC herring: data, models & alternative assumptions.
Part II: Stock assessment and management advice for BC Herring stocks (2011/2012)

Steven Martell, Jake Schweigert, Jaclyn Cleary, Vivian Haist

University of British Columbia

martell.steve@gmail.com

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Contents

June 2010: HCAM Review Workshop

Terms of Reference (paraphrased)

- Herring spawn index, is $q = 1$ assumption appropriate?
- HCR, should CUTOFF change in concert with B_0 updates?
- What is the best way to parameterize natural mortality?
- Are the priors appropriate and is uncertainty appropriately reflected in assessments?
- Preference for selectivity/availability parameterization.
- Should stock assessments be conducted on a risk-neutral or risk-averse basis?
- Appropriate assumptions for an operating model (MSE).

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Summary of Panel Recommendations

1. Assumption that $q = 1$ was inappropriate.
2. CUTOFFS can be fixed or updated annually.
3. A model based approach to estimating B_0 and B_{MSY} is appropriate.
4. Recruitment variation σ_R should be estimated within the model.
5. Issues regarding estimation of selectivity, natural mortality and q should be explored.
6. Science advice should be risk neutral.

The model parameterization of q could potentially have the single greatest effect on estimation of management parameters, and as such further investigation is recommended.

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If the intention is that the CUTOFF represents 25% B_0 then it should be updated in conjunction with stock assessment updates.

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Estimates of MSY based reference points are sensitive to the assumed form of the recruitment model and allocation to gears with different selectivities.

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Note that MLE estimates of σ_R are biased; values from the joint posterior distribution are unbiased.

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Current Harvest Control Rule

- CUTOFF set at 0.25 B_0 (last updated in 1996).
- 20% exploitation rate.
- Forecast based on poor, average, good recruitment.

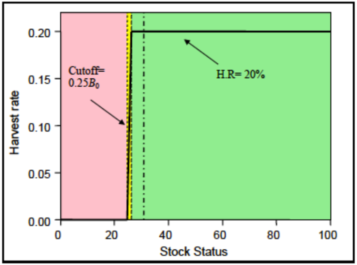

Figure: HCR for herring stocks.

Harvest Strategy Compliant with Precautionary Approach

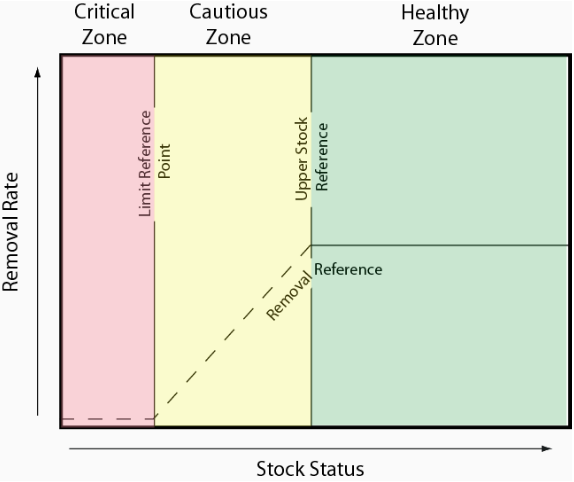

Figure: Fisheries management framework consistent with a precautionary approach.

Key elements for the new framework

Reference points

- Limit Reference Point (LRP) & Upper Stock Reference (USR) requires knowledge of stock productivity and population scale.
- Removal Rate requires knowledge of stock productivity.
- MSY-based reference points require *a priori* allocation to different gears.

Risk & Decision making

- Onus on being able to reliably determine stock status (informative data).

Contents

Input data

The input data for $^{i}\mathrm{SCA}_{\mathrm{M}}$ is the same as HCAM:

- Catch by gear,
- Spawn survey index,
- Age-composition data for all gears,
- Empirical weight-at-age data.

Integrated Statistical Catch Age Model (^{i}SCAM)

- The model is based on a statistical catch-age framework first developed by Fournier and Archibald (1982).
- Flexible options for modelling selectivity, natural mortality, & survey catchability.
- Integrated framework: joint estimation of policy parameters (e.g., reference pionts).
- Model is implemented in AD Model Builder ADMB Project (2009), and the source code is maintained at: `http://code.google.com/p/iscam-project/`

Assumptions I

Error distributions

- Observation errors in catch are lognormal & σ is known.
- Errors in spawn survey are lognormal & σ is unknown.
- Recruitment deviations are lognormal & σ is unknown.
- Age-composition residuals follow a multivariate-logistic distribution.

Selectivity

- Seine gears: asymptotic and time invariant.
- Gillnet gear: parametric logistic function with weight anomalies as a covariate.

Assumptions II

Structural assumptions

- Age-2 recruitment with a Beverton-Holt model.
- Fishing & natural mortality occur simultaneously (Baranov catch equation).
- Natural mortality is age-independent.
- Natural mortality can vary over time (random walk, $\sigma = 0.1$).
- 100% of the total mortality occurs before spawning.
- Fecundity is proportional to mature biomass.

Equilibrium & MSY-based reference points

- B_o is based on average M and average fecundity-at-age.
- B_{MSY} is based on average (M) and fecundity in terminal year.

Objective function

Major components of the objective function

1. Likelihoods for data.
2. Likelihoods for structural assumptions.
3. Phased penalties to ensure regular solution.
4. Prior densities for model parameters.

Likelihoods for data

- Normal density functions for:
  - catch residuals (log-scale) with fixed σ^2,
  - spawn survey residuals (log-scale) with estimated σ^2.

- Multivariate logistic function for age-composition evaluated at the conditional MLE of σ^2.
  - age-proportions $< 2\%$ are pooled into adjacent age class.

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Structural Assumptions

- Stock-recruitment

$$\ln \ell = n \ln(\tau) + \frac{\sum_t \delta_t^2}{2\tau^2},$$
$$\delta_t = \ln(N_{2,t}) - \ln(f(SB_t))$$

- Natural mortality (random walk)

$$M_{t+1} = M_t \exp(\varphi_t)$$
$$\ln \ell = n \ln(\sigma) + \frac{\sum_{t=2}^{T}(\varphi_t - \varphi_{t-1})^2}{2\sigma^2}$$

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Phased Penalties

- Mean fishing mortality rate:

$$\ln(\sigma_{\bar{F}}) + \frac{(\ln(\bar{F}) - \ln(0.2))^2}{2\sigma_{\bar{F}}^2}, \quad \sigma_{\bar{F}}^{(1-3)} = 0.05, \quad \sigma_{\bar{F}}^{(4)} = 2.0$$

- Deviations in average recruitment:

$$\ln(\sigma_{\omega}) + \frac{\sum_t \omega_t^2}{2\sigma_{\omega}^2}, \quad \sigma_{\omega}^{(1-3)} = 0.0707, \quad \sigma_{\omega}^{(4)} = 2.0$$

$$\ln(\sigma_{\ddot{\omega}}) + \frac{\sum_t \ddot{\omega}_t^2}{2\sigma_{\ddot{\omega}}^2}, \quad \sigma_{\ddot{\omega}}^{(1-3)} = 0.0707, \quad \sigma_{\ddot{\omega}}^{(4)} = 2.0$$

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Priors I

Table: Prior distributions for key model parameters.

Parameter	Distribution	P1	P2
$\ln(R_0)$	Uniform	-5.0	15
Steepness	Beta	10.0	4.925373
Natural mortality ($\ln(M)$)	Normal	-0.7985077	0.2
Rbar	Uniform	-5.0	15
Rinit	Uniform	-5.0	15
Variance ratio (ρ)	Beta	17.08696	39.0559
Precision	Gamma	25.0	28.75
Survey $\ln(q)$	Normal	-0.569	0.274

Priors II

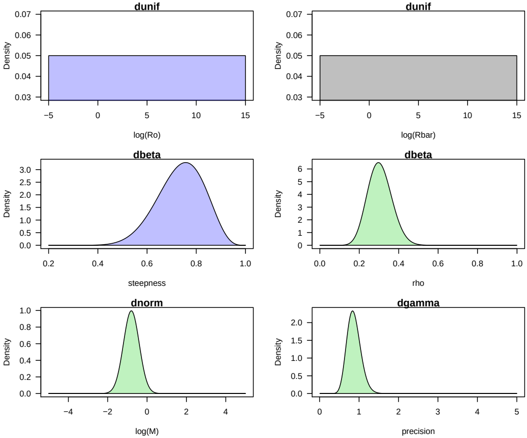
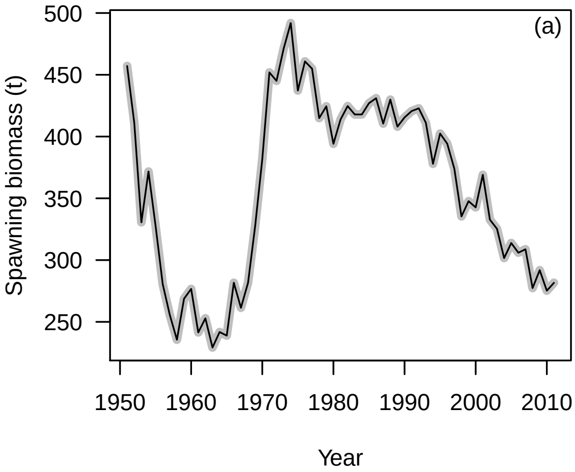


Figure: Prior densities for leading model parameters.

Simulation testing

Estimation performance with perfect information.



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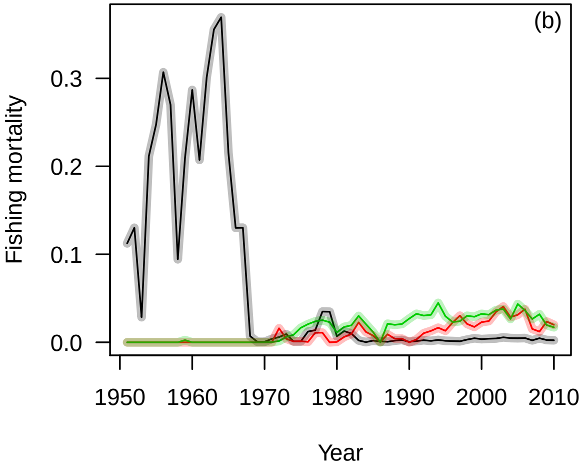

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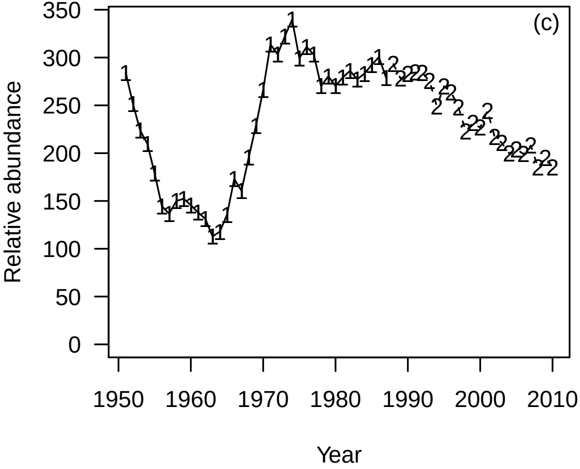
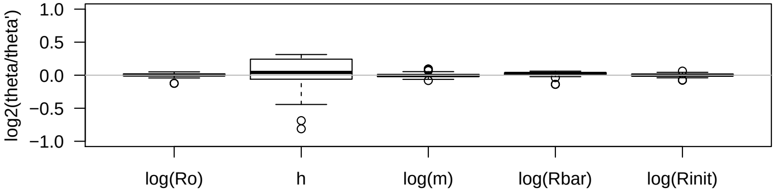


Precision & Bias

Bias ratios for key model parameters based on 50 simulated data sets.



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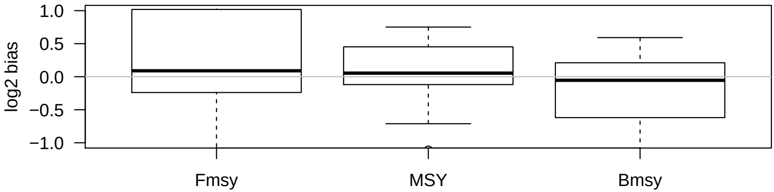

Strait of Georgia

Objective: set up ${}^{i}\mathrm{SCA}_{\mathrm{M}} \sim$ HCAM & compare.

Significant differences between ${}^{i}\mathrm{SCA}_{\mathrm{M}}$ & HCAM

- Likelihood for age-comps.
- Pooling of age-proportions less than 2% into adjacent cohort.
- Conditional MLE for survey q.
- Estimation of total variance and variance partitioning parameter (ϑ, ρ).
- Prior for steepness ($h \sim$ Beta in ${}^{i}\mathrm{SCA}_{\mathrm{M}}$)

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SOG Spawning biomass

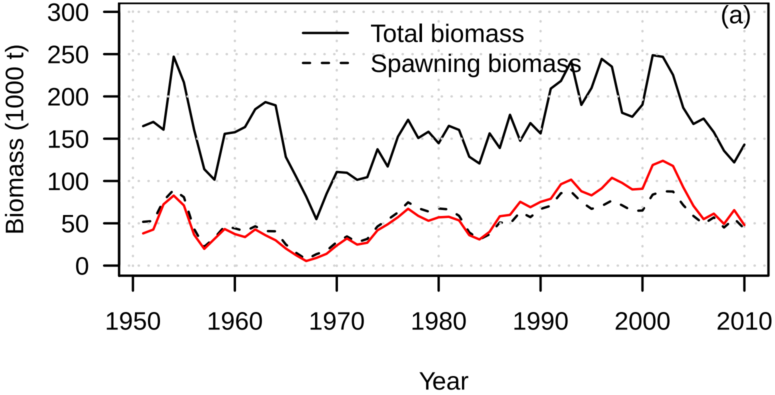


Figure: Total biomass at the start of the year, spawning biomass after fishing. HCAM (2010) spawning biomass shown in red.

SOG Spawning biomass

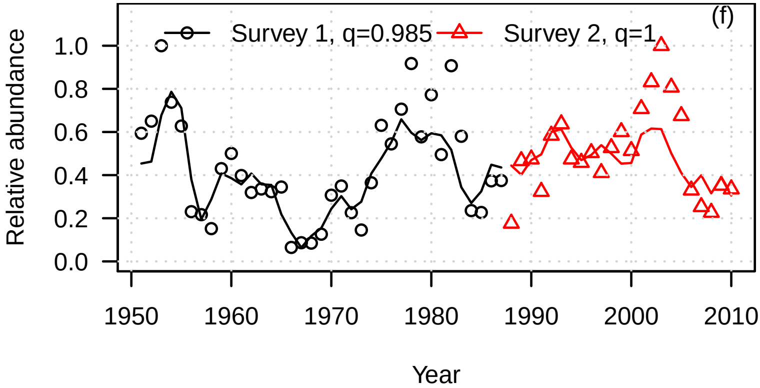
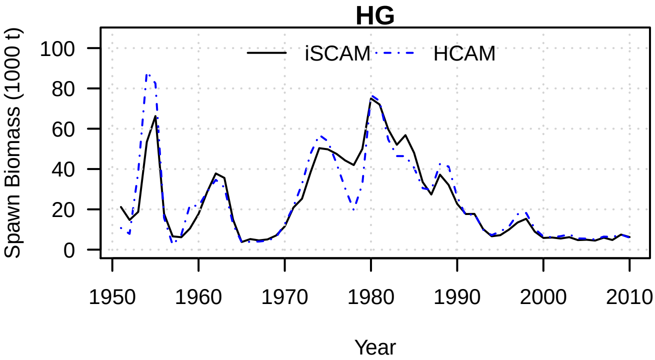
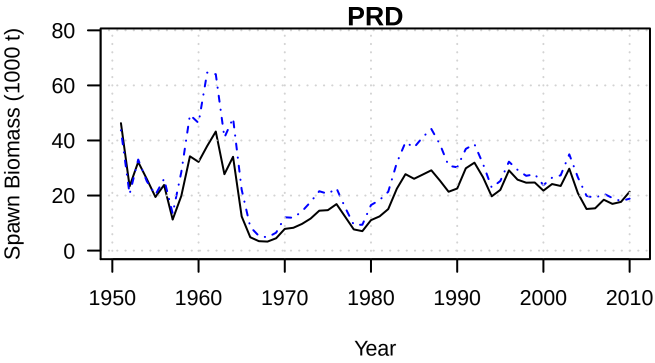


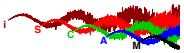
Figure: Observed and predicted spawn survey data for surface (black) and dive (red) surveys.

Spawning biomass in HG

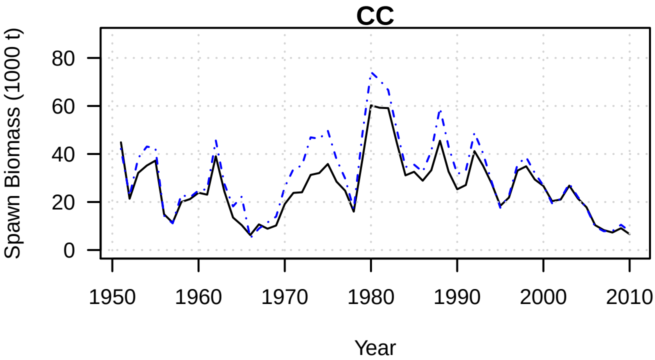


Spawning biomass in PRD

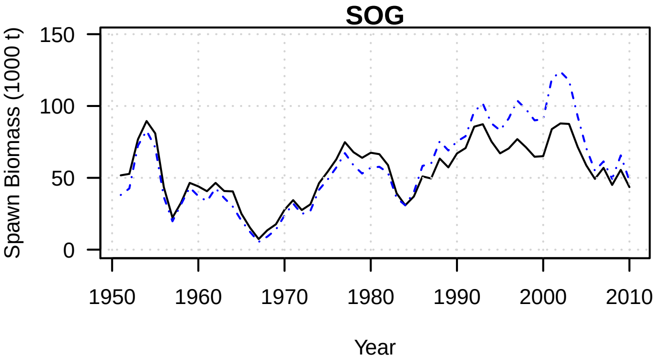




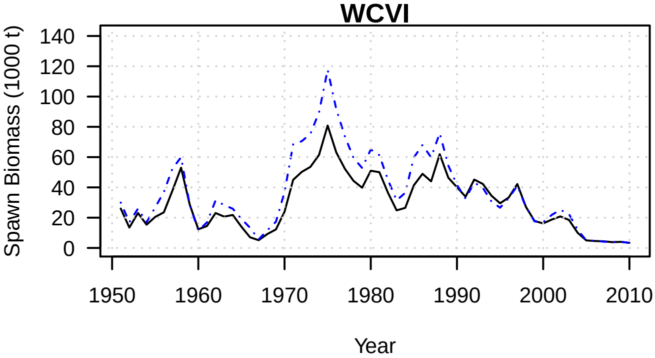
Spawning biomass in CC



Spawning biomass in SOG



Spawning biomass in WCVI



Discussion

- Slight bias in MSY reference points and steepness; likely due to lack of contrast in simulated data.
- Despite differences between assessment platforms there is a remarkable correspondence in spawning biomass estimates.
- Significant differences in:
  - weighting of age-composition data,
  - pooling of age-composition samples (<2%),
  - conditional MLE for dive survey q with a very informative prior,
  - prior for steepness.
- MSY based reference points require unbiased estimates of selectivity parameters, and allocation of catch to each gear must be established *a priori*.

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Introduction

Objectives:

1. Data used in the 2011 assessment.
2. Overview of the analytical methods.
3. Present the 2011 stock assessment.
4. Describe & present the catch forecasts for 2012.

Data used in the 2011 stock assessment

- Catch by gear type.
- Spawn survey data.
- Age-composition data.
- Empirical weight-at-age data.

Catch by gear (1950:2011)

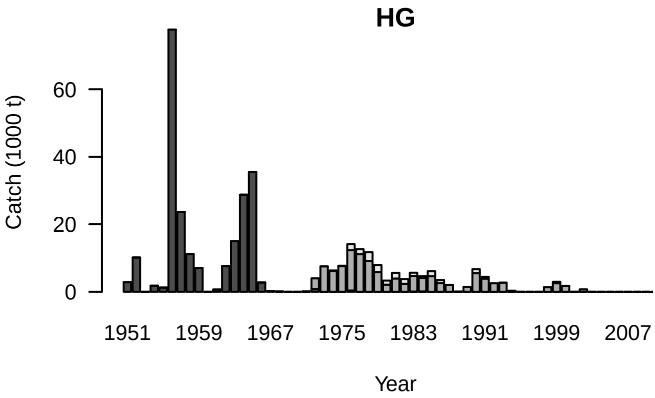

Figure: Catch by gear for Haida Gwaii.

Catch by gear (1950:2011)

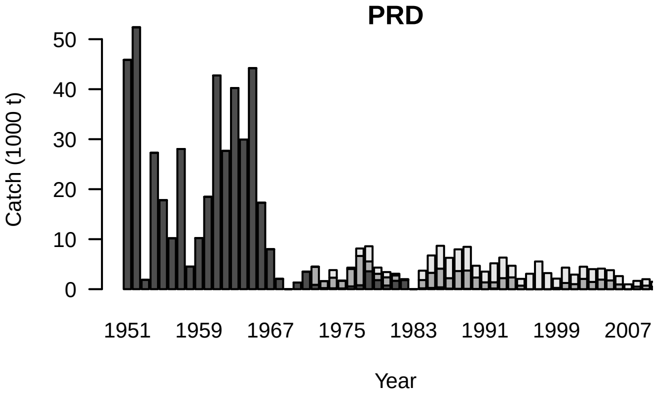

Figure: Catch by gear for Prince Rupert District.

Catch by gear (1950:2011)

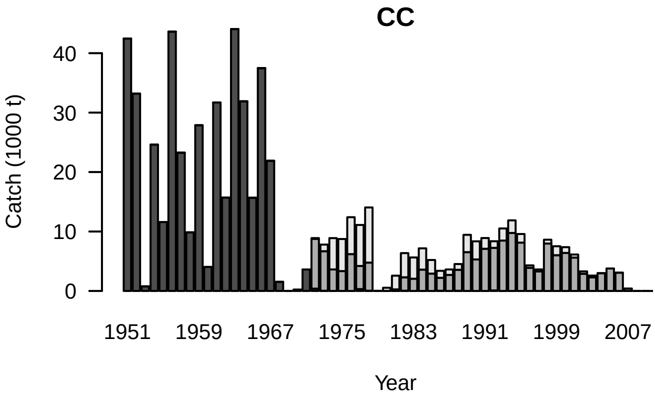

Figure: Catch by gear for Central Coast.

Catch by gear (1950:2011)

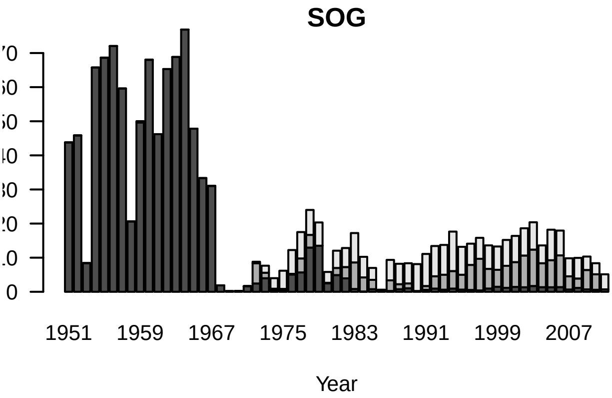

Figure: Catch by gear for Strait of Georgia.

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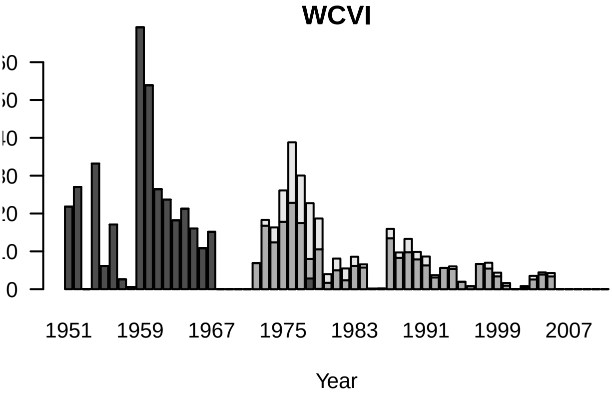

Figure: Catch by gear for West Coast of Vancouver Island.

Spawning activity in 2010

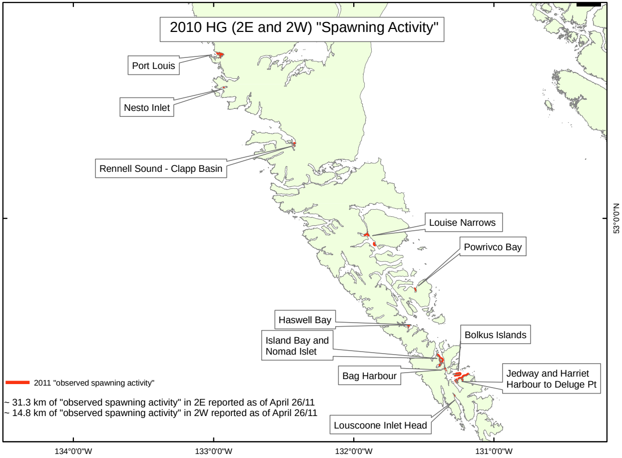

Figure: 2010 Spawning activity in Haida Gwaii.

Spawning activity in 2010

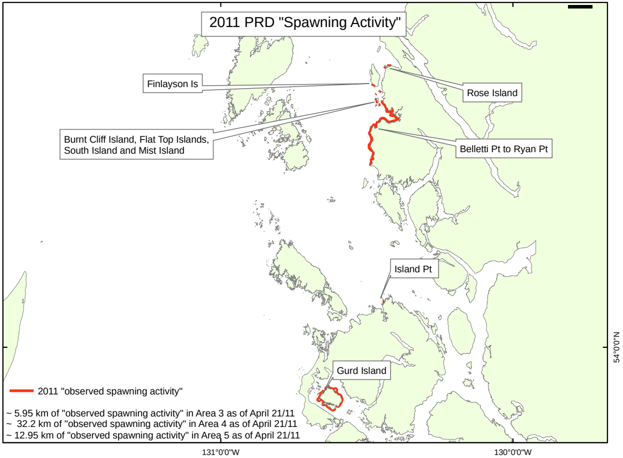

Figure: 2010 Spawning activity in Prince Rupert District.

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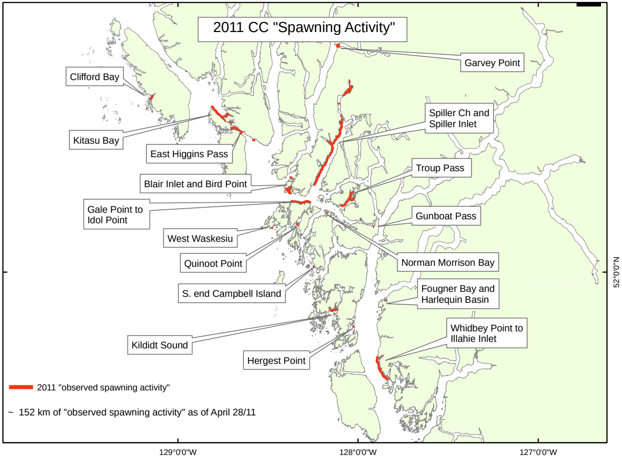

Figure: 2010 Spawning activity in Central Coast.

Spawning activity in 2010

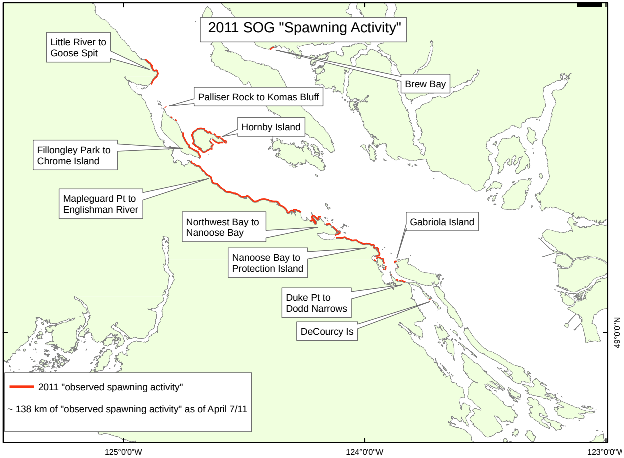

Figure: 2010 Spawning activity in Strait of Georgia.

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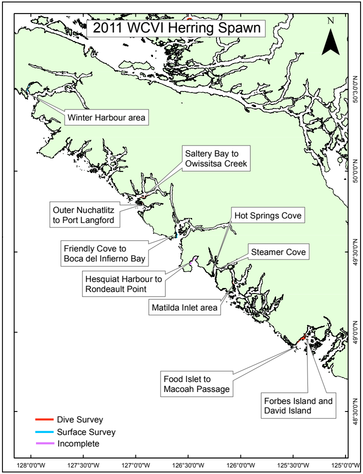

Figure: 2010 Spawning activity in West Coast Vancouver Island.

Spawn survey time series

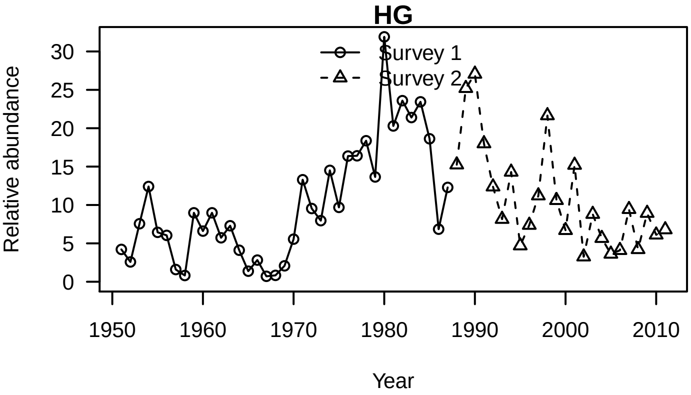

Figure: Spawn survey series in Haida Gwaii.

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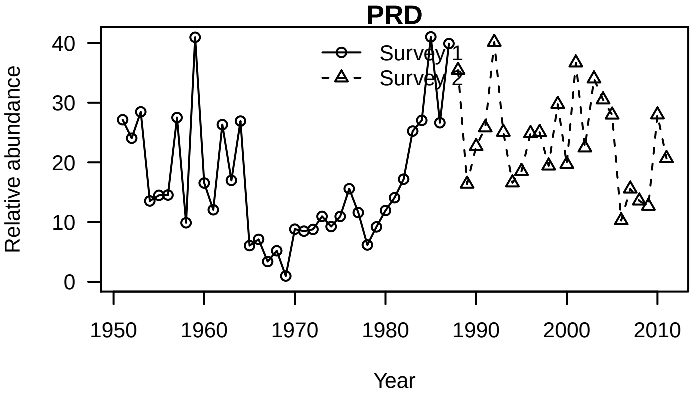

Figure: Spawn survey series in Prince Rupert District.

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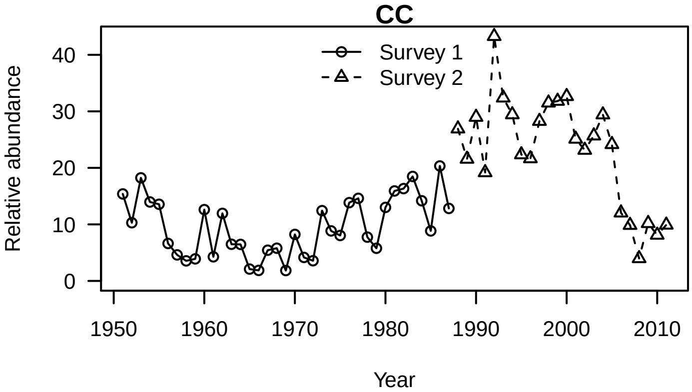

Figure: Spawn survey series in Central Coast.

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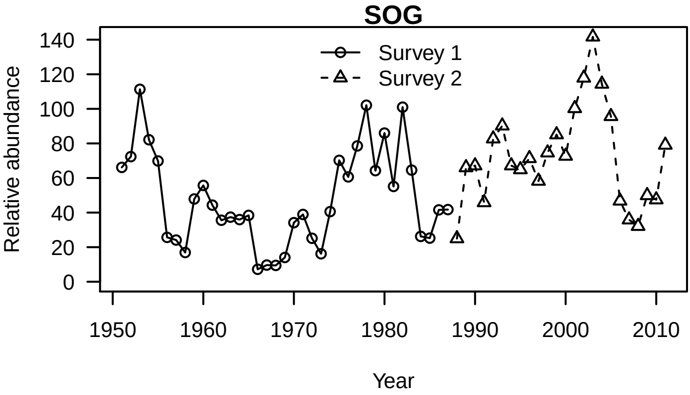

Figure: Spawn survey series in Strait of Georgia.

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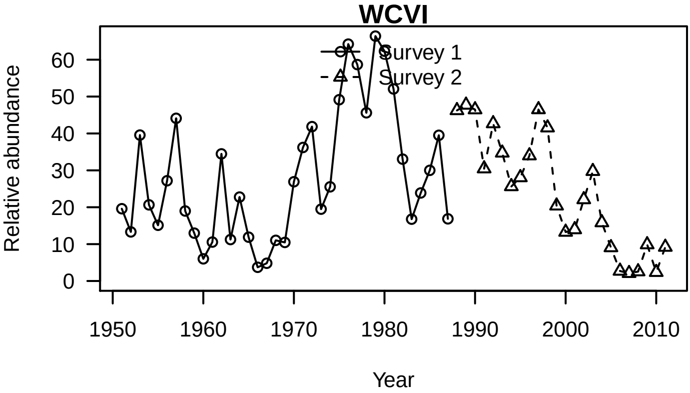

Figure: Spawn survey series in West Coast of Vancouver Island.

Age-composition data

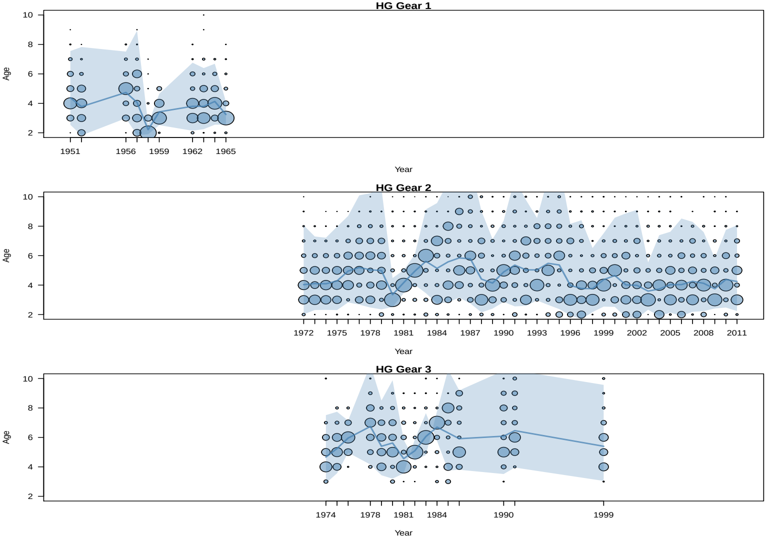

Figure: Haida Gwaii: winter seine, seine-roe, gillnet.

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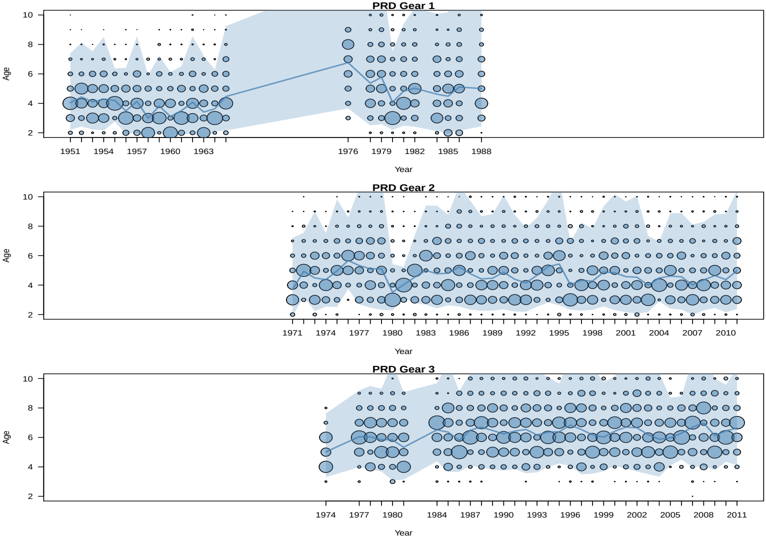

Figure: Prince Rupert District: winter seine, seine-roe, gillnet.

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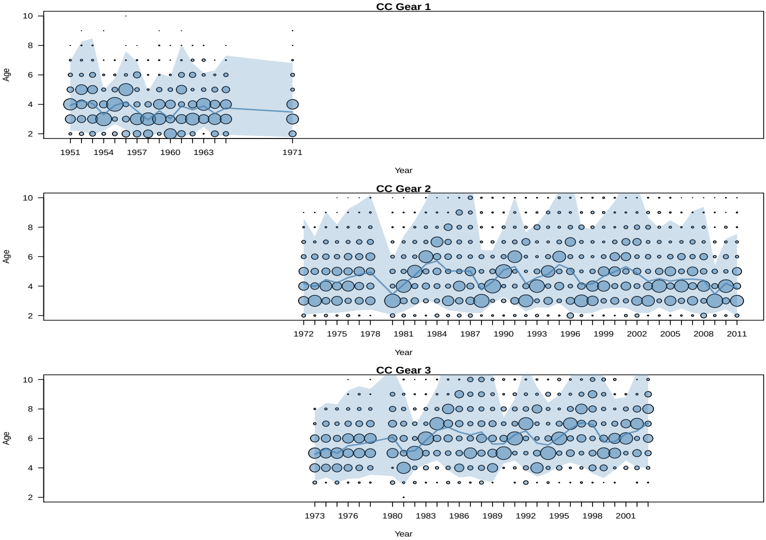

Figure: Central Coast: winter seine, seine-roe, gillnet.

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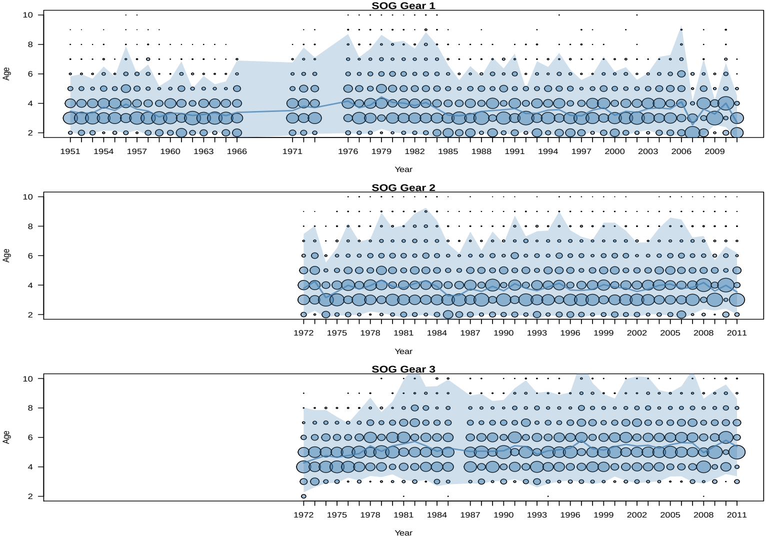

Figure: Strait of Georgia: winter seine, seine-roe, gillnet.

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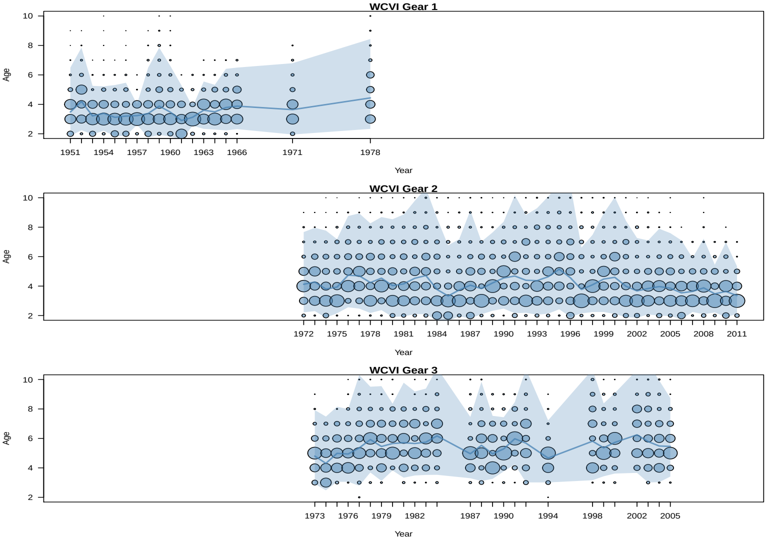

Figure: West Coast Vancouver Island: winter seine, seine-roe, gillnet.

Weight-at-age

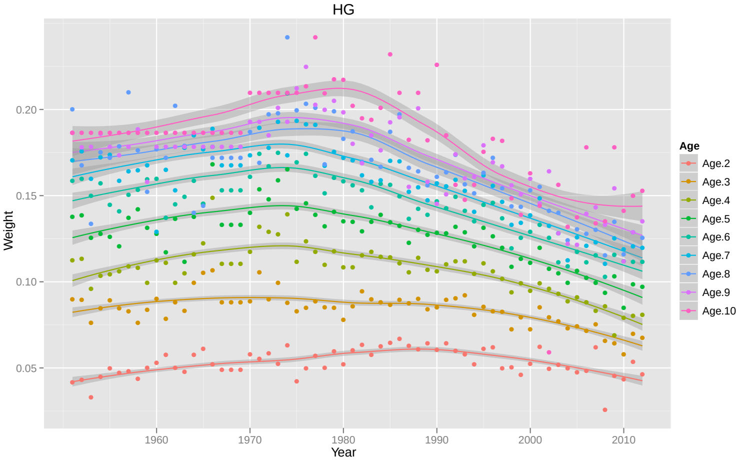

Figure: Haida Gwaii: empirical weight-at-age (kg).

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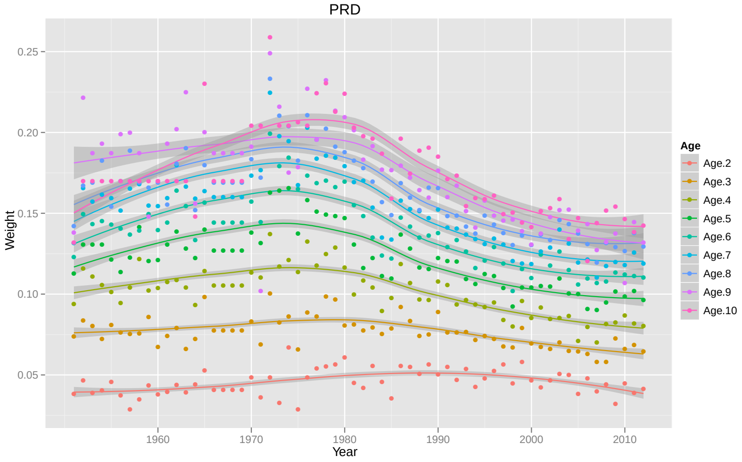

Figure: Prince Rupert District: empirical weight-at-age (kg).

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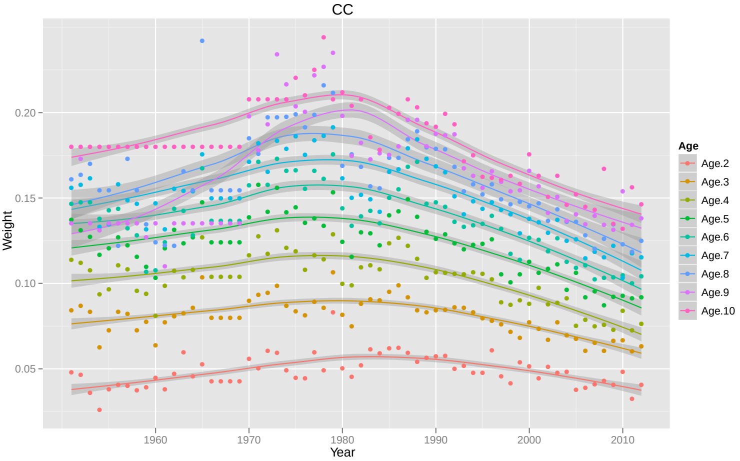

Figure: Central Coast: empirical weight-at-age (kg).

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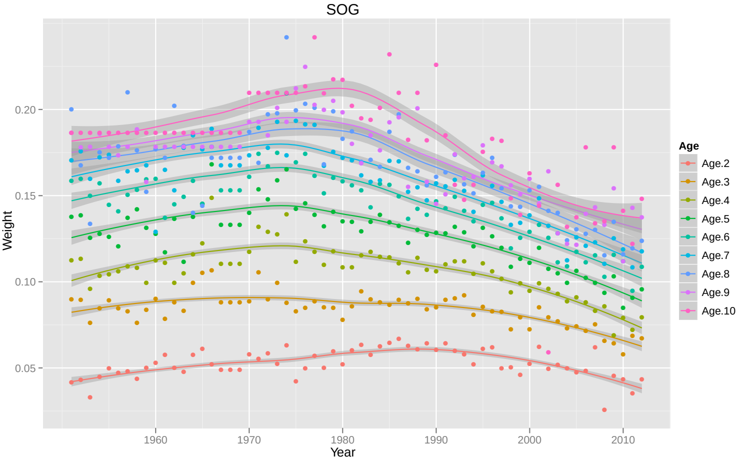

Figure: Strait of Georgia: empirical weight-at-age (kg).

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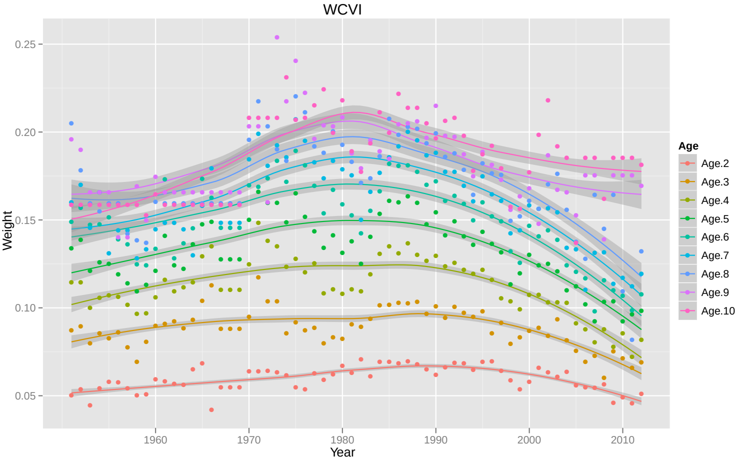

Figure: West Coast Vancouver Island: empirical weight-at-age (kg).

Analytics & assumptions

- All major and minor areas were assessed using ^{i}SCA$_{\text{M}}$.
- Reported catch: CV $= 0.005$
- Spawn survey: proportional & 100% of Z_t.
- Dive survey more precise than surface survey.
- Fecundity $\propto$ mature weight-at-age.
- Seine gears: selectivity is asymptotic and time-invariant.
- Gillnet gear: logistic selectivity with weigth-at-age covariates.
- $P(\ln(q_1), \ln(q_2)) \sim \text{Normal}(\mu = -0.569, \sigma = 0.274)$.
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Diagnostics, Forecasts & Catch Advice

Diagnostics Retrospective analysis (sequential removal of the last 10 years of data).

Forecasts One-year projection of 3+ biomass with poor, average, good age-3 recruitment.

Catch advice Based on HCR with 20% harvest rate if above cutoff.

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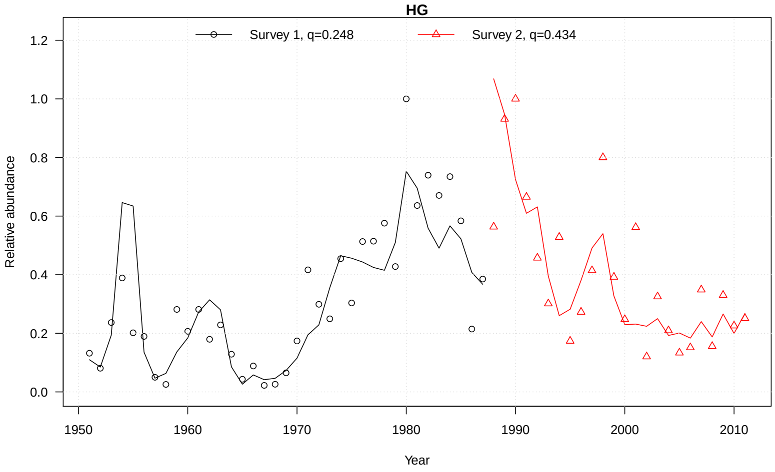

Figure: Haida Gwaii

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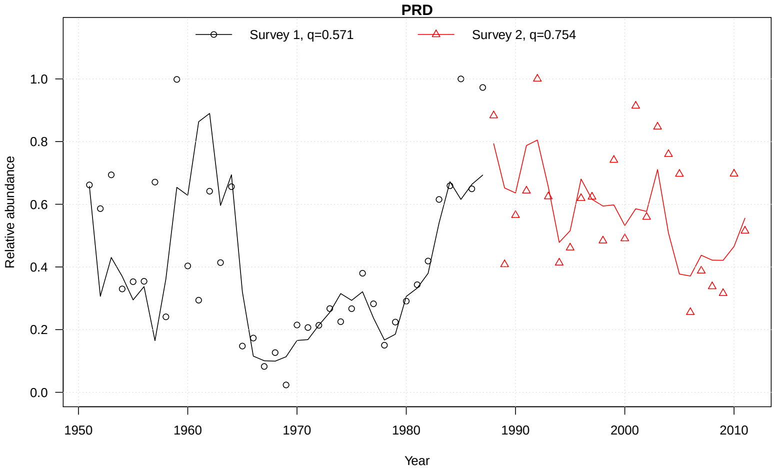

Figure: Prince Rupert District

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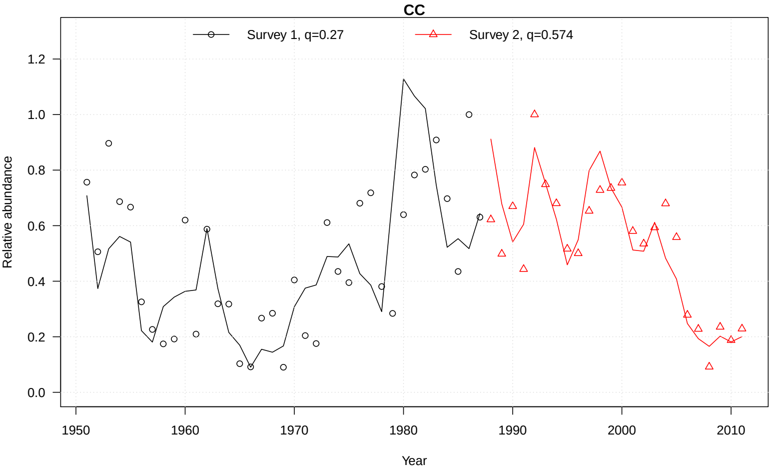

Figure: Central Coast

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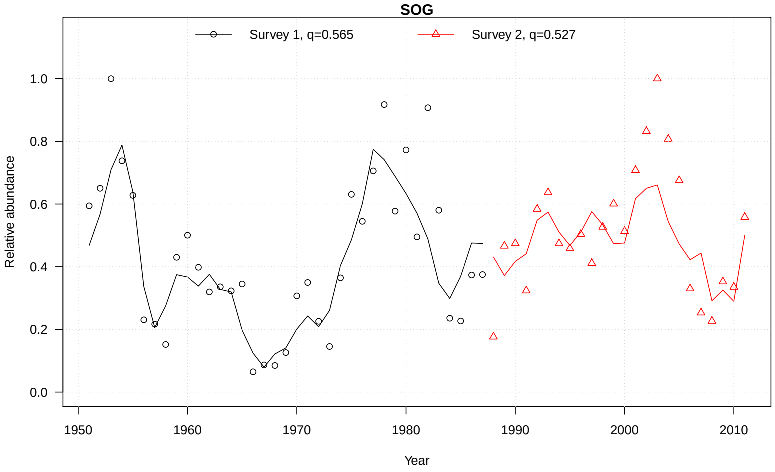

Figure: Strait of Georgia

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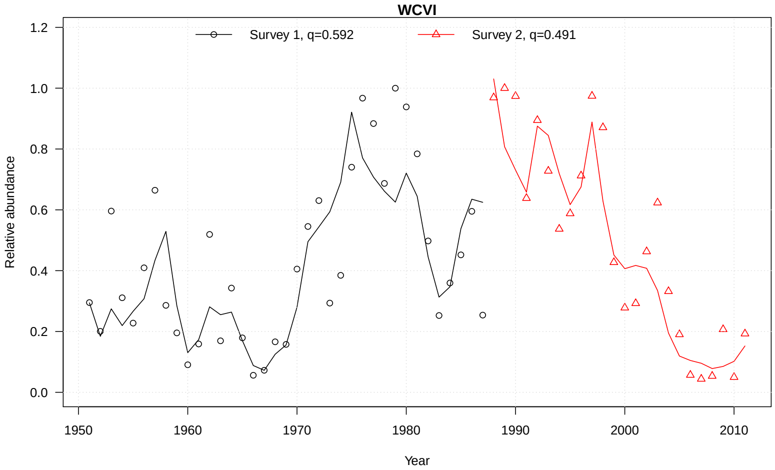
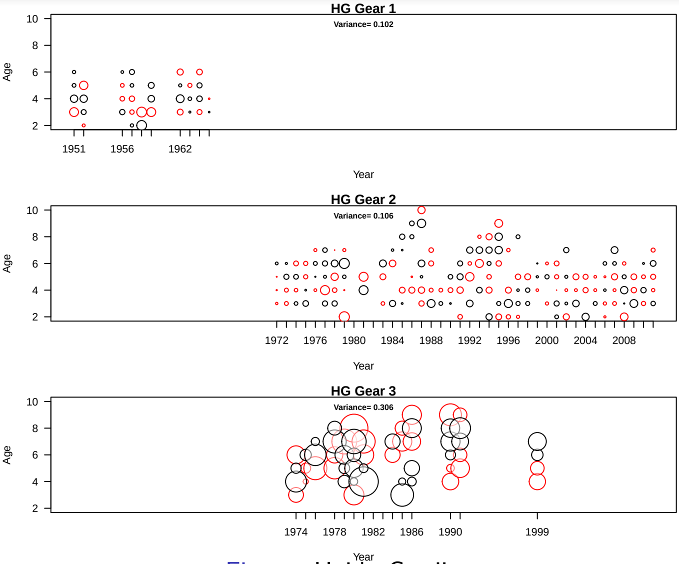


Figure: West Coast Vancouver Island

MLE: Residuals in age composition data



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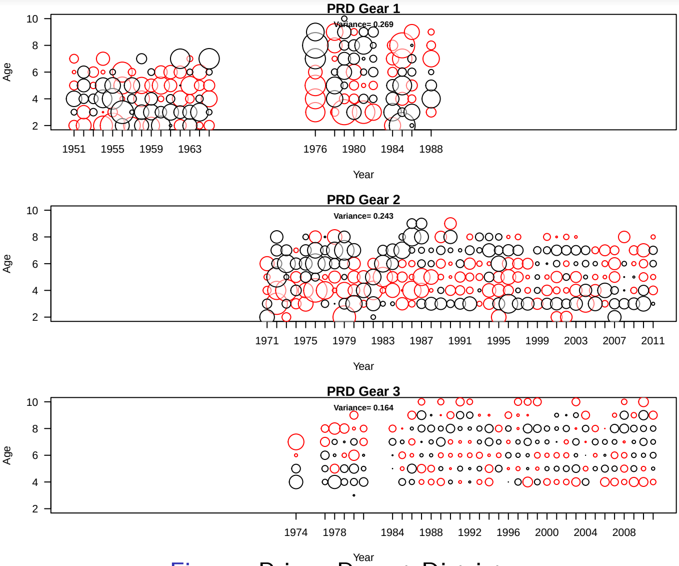

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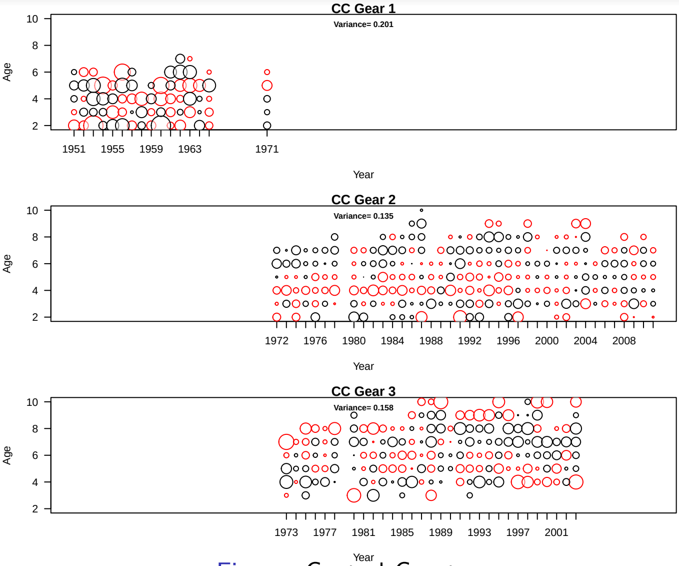

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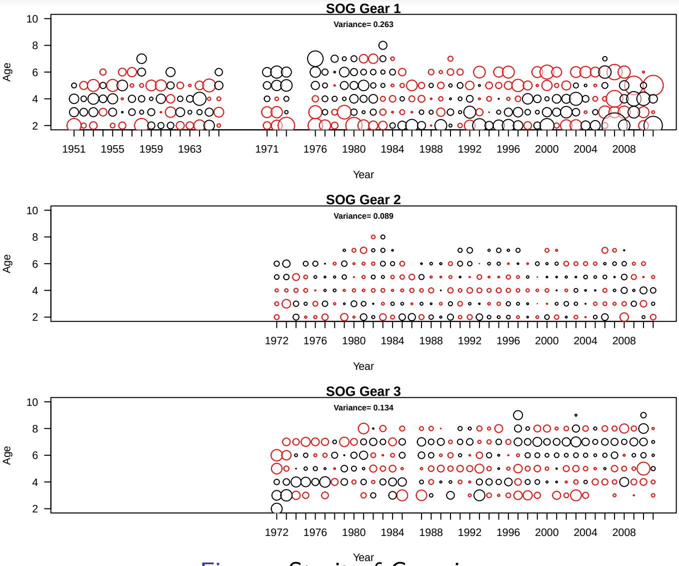

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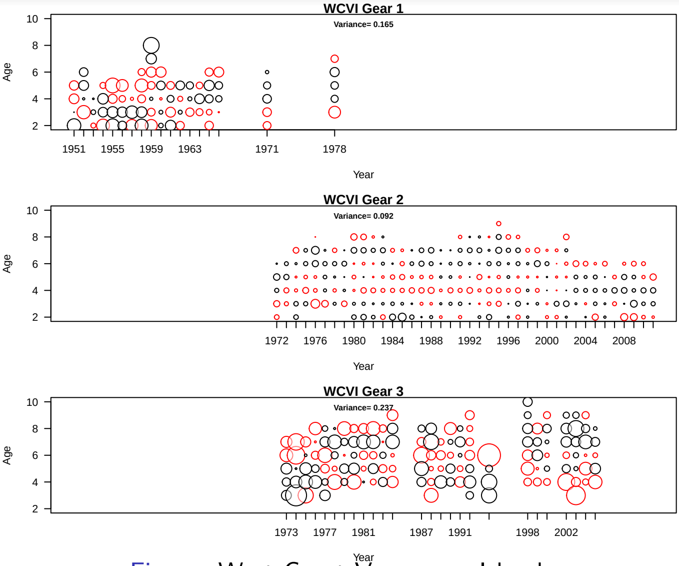

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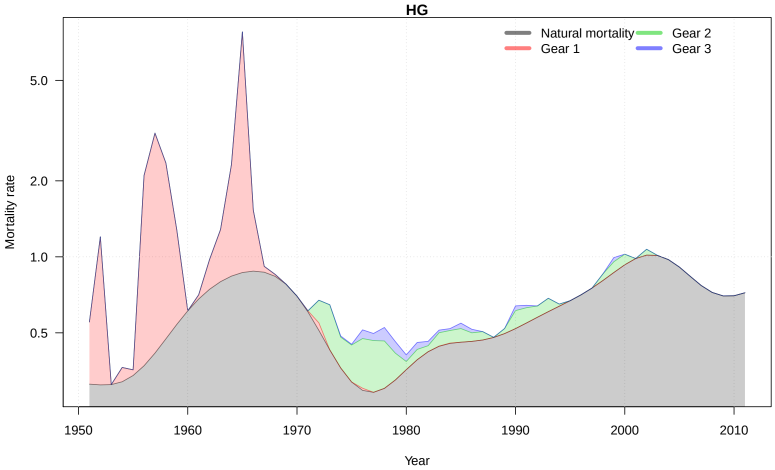
MLE: Mortality



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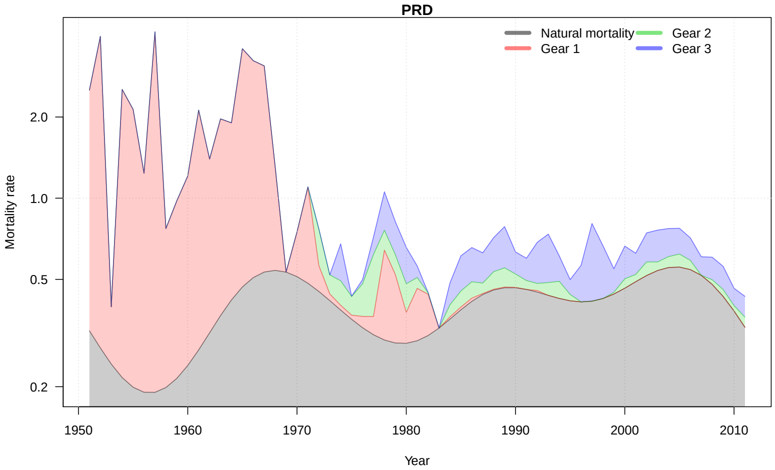

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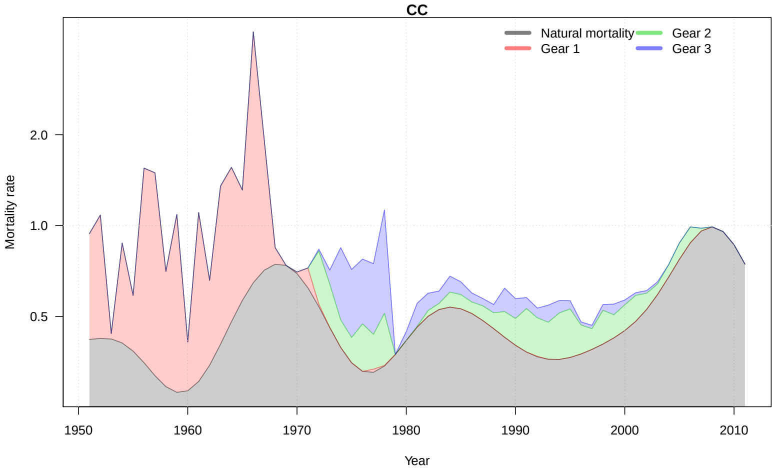

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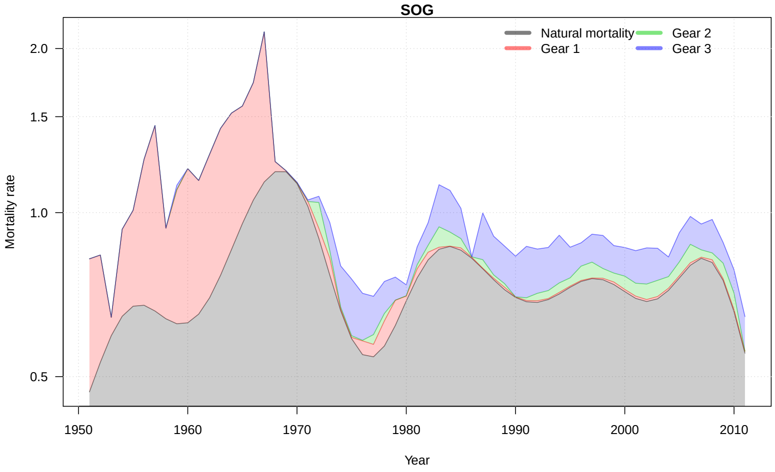

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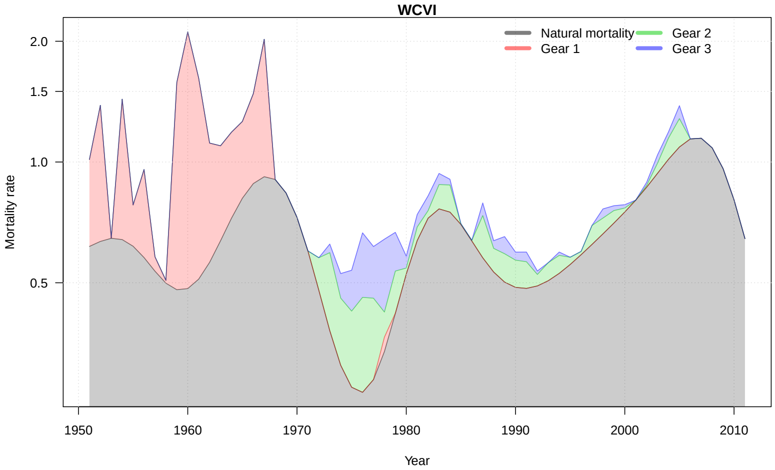

Figure: West Coast Vancouver Island

Age-2 recruits

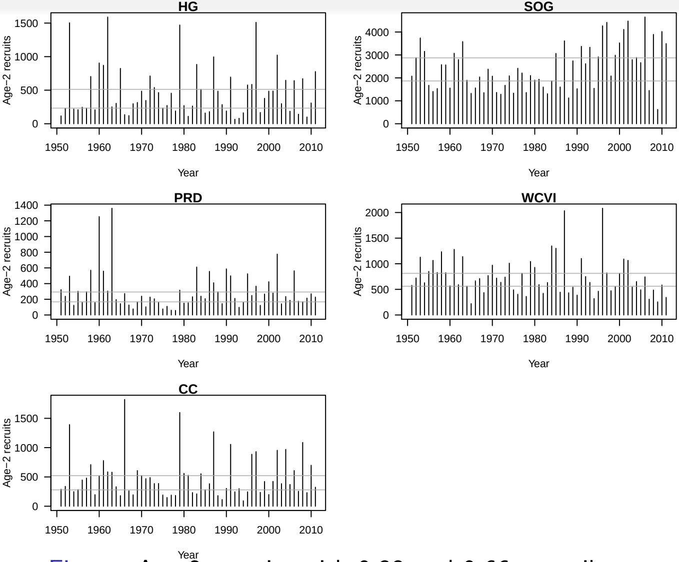

Figure: Age-2 recruits with 0.33 and 0.66 quantiles.

Diagnostics: Retrospective plots

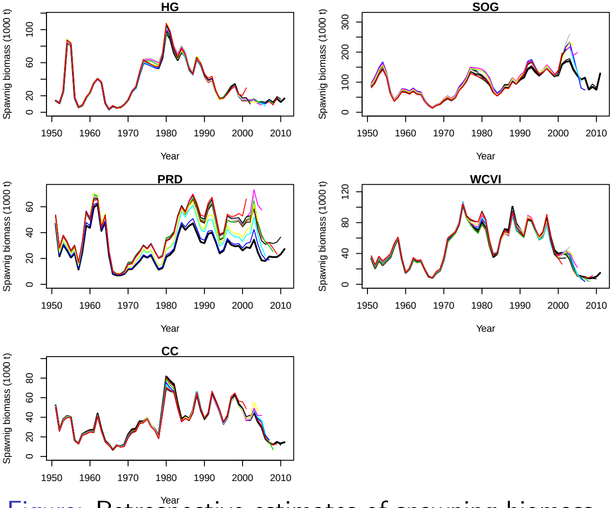

Figure: Retrospective estimates of spawning biomass.

Diagnostics: Trace plots

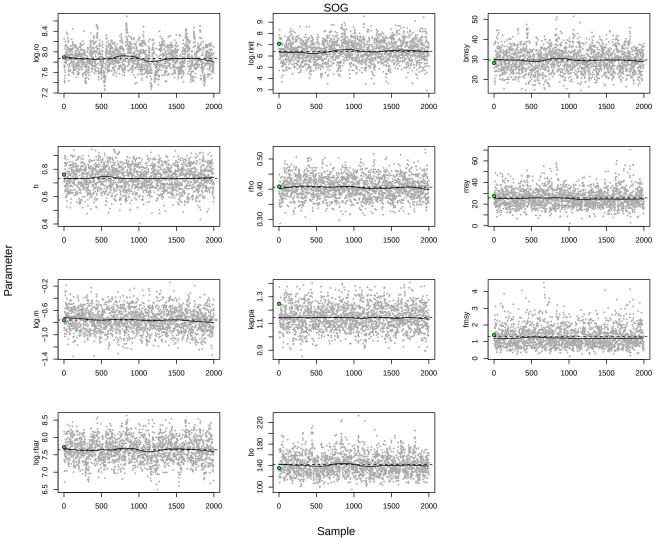

Figure: Posterior samples: 1 million, thin 500, Strait of Georgia

Diagnostics: Pair plots

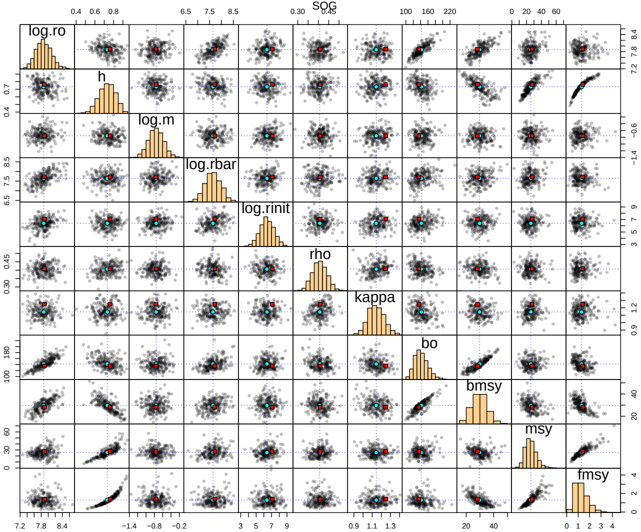

Figure: Posterior samples from leading parameters & derived variables.

Diagnositcs: Marginal posteriors

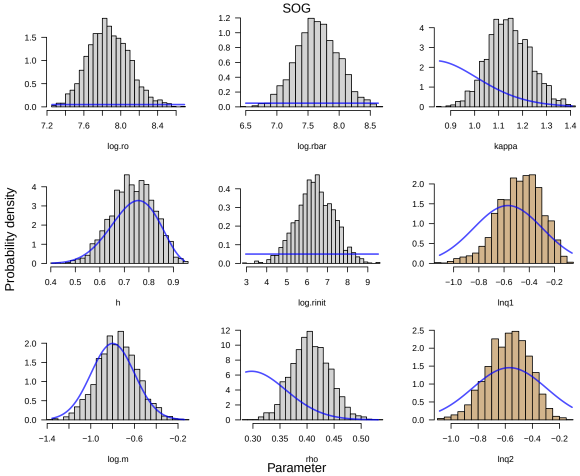

Figure: Strait of Georgia: Marginal & prior distributions.

Forecast: Old cutoffs

Table: 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

Forecast: New cutoffs

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

			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

Bibliography

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

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.