# 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)

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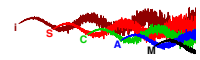
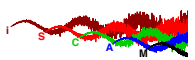


# Contents





# 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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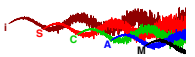
# Summary of Panel Recommendations

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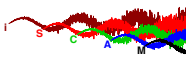
Note that MLE estimates of $\sigma_R$ are biased; values from the joint posterior distribution are unbiased.



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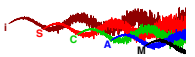

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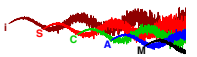


# Current Harvest Control Rule

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

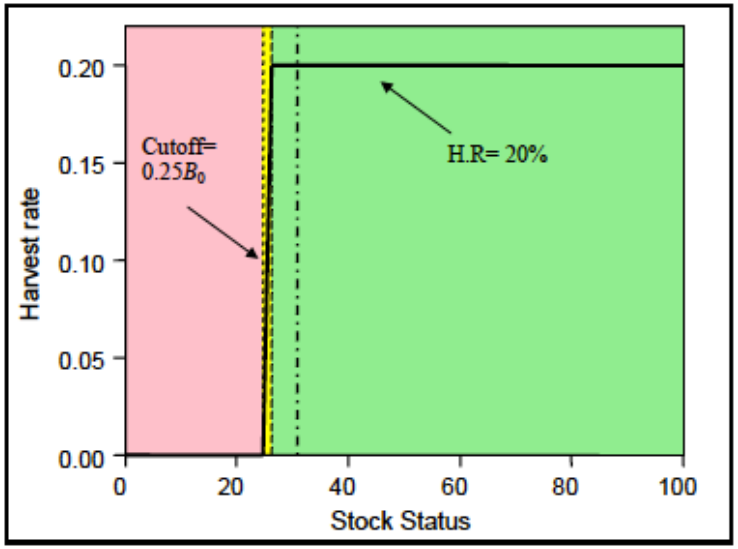



Figure: HCR for herring stocks.

# Harvest Strategy Compliant with Precautionary Approach

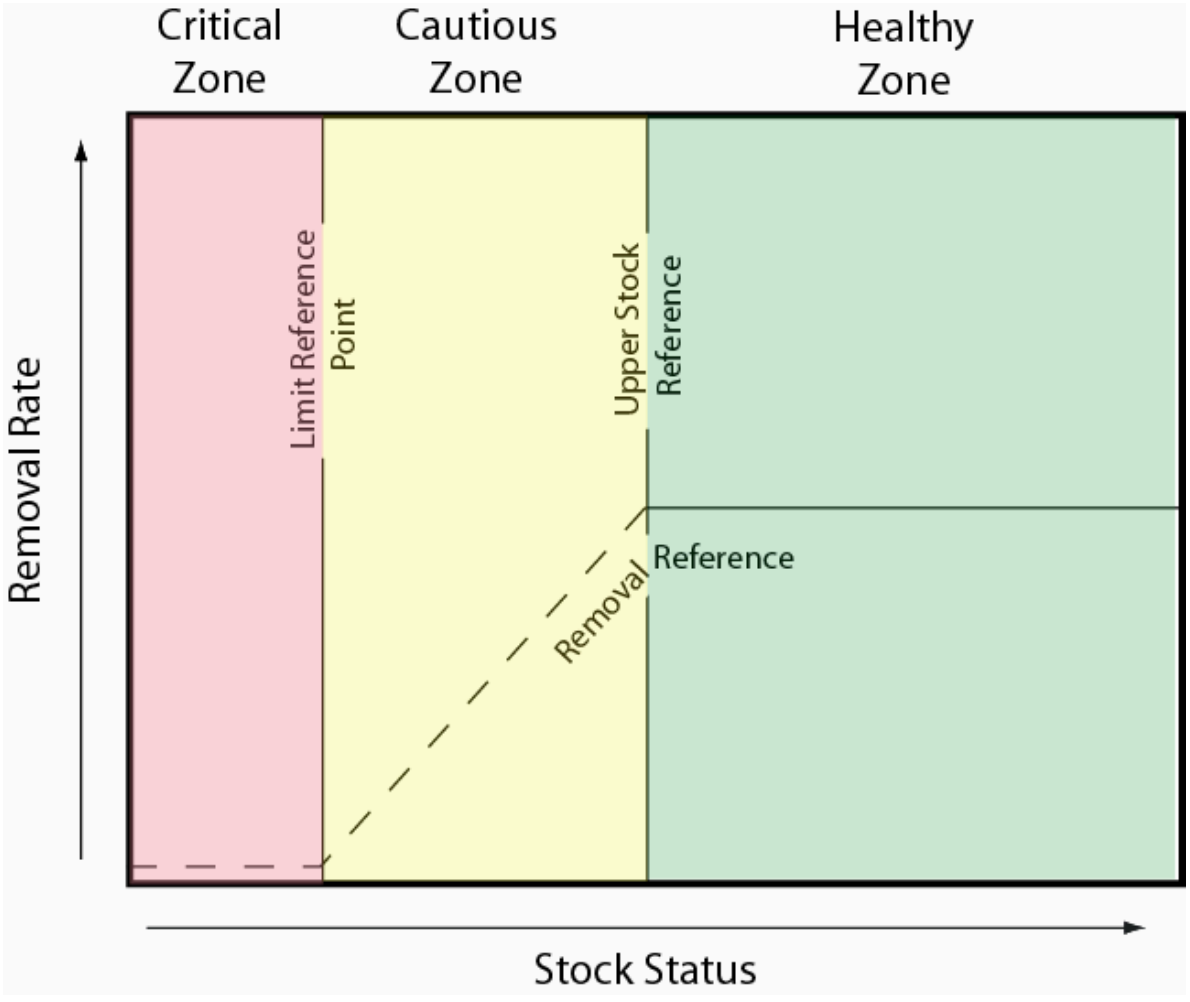



Figure: Fisheries management framework consistent with a precautionary approach.

# 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

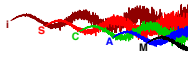
# Input data

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 **?**.
- 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 **?**, and the source code is maintained at:
  `http://code.google.com/p/iscam-project/`



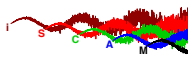
# Assumptions I

## Error distributions

- Observation errors in catch are lognormal & $\sigma$ is known.
- Errors in spawn survey are lognormal & $\sigma$ is unknown.
- Recruitment deviations are lognormal & $\sigma$ 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.



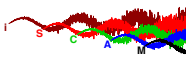
# Assumptions II

## 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

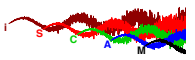
- $B_o$ is based on average $M$ and average fecundity-at-age.
- $B_{MSY}$ is based on average ($M$) and fecundity in terminal year.



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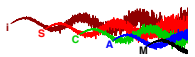
- Multivariate logistic function for age-composition evaluated at the conditional MLE of $\sigma^2$.
  - age-proportions $< 2\%$ are pooled into adjacent age class.



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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)

$$M_{t+1} = M_t \exp(\varphi_t)$$
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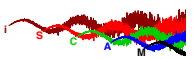


# Phased Penalties

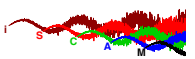
- Mean fishing mortality rate:

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

- 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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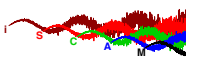
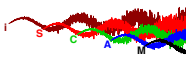


# Priors I

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 ($\rho$) | Beta | 17.08696 | 39.0559 |
| Precision | Gamma | 25.0 | 28.75 |
| Survey $\ln(q)$ | Normal | -0.569 | 0.274 |



# Priors II

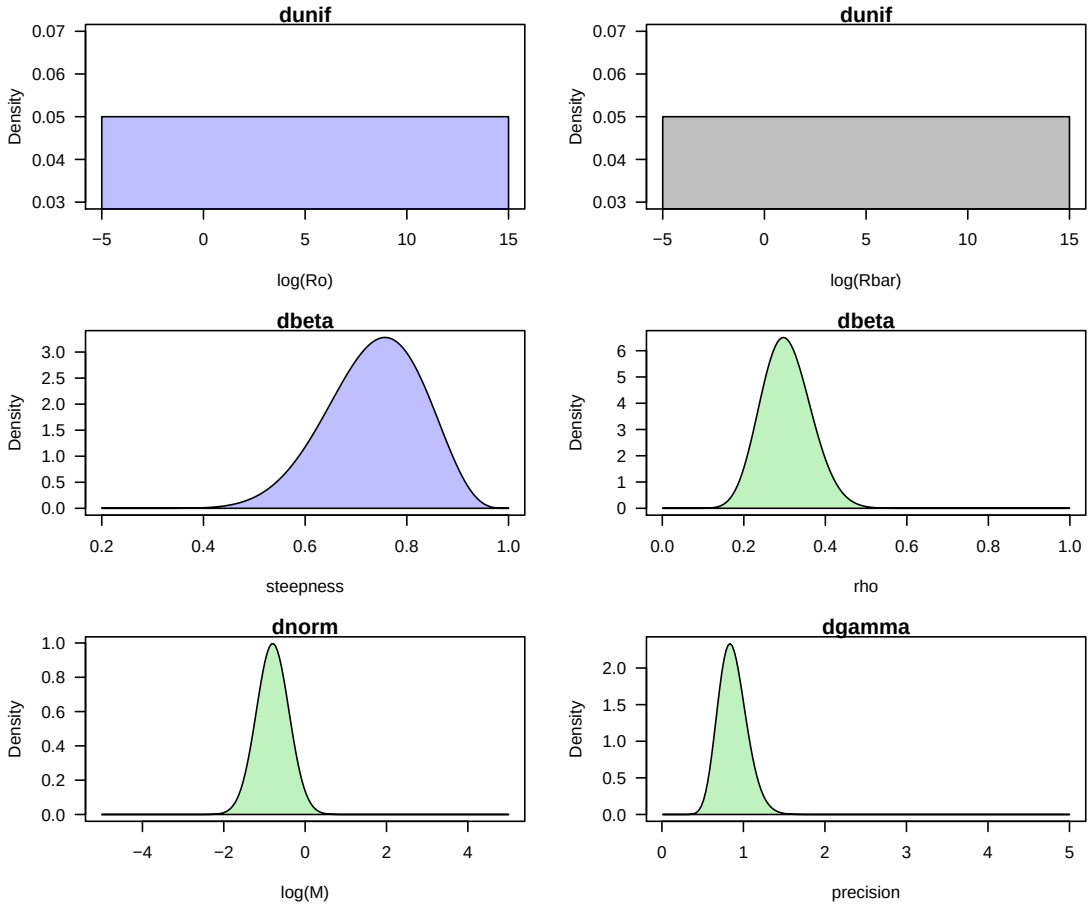
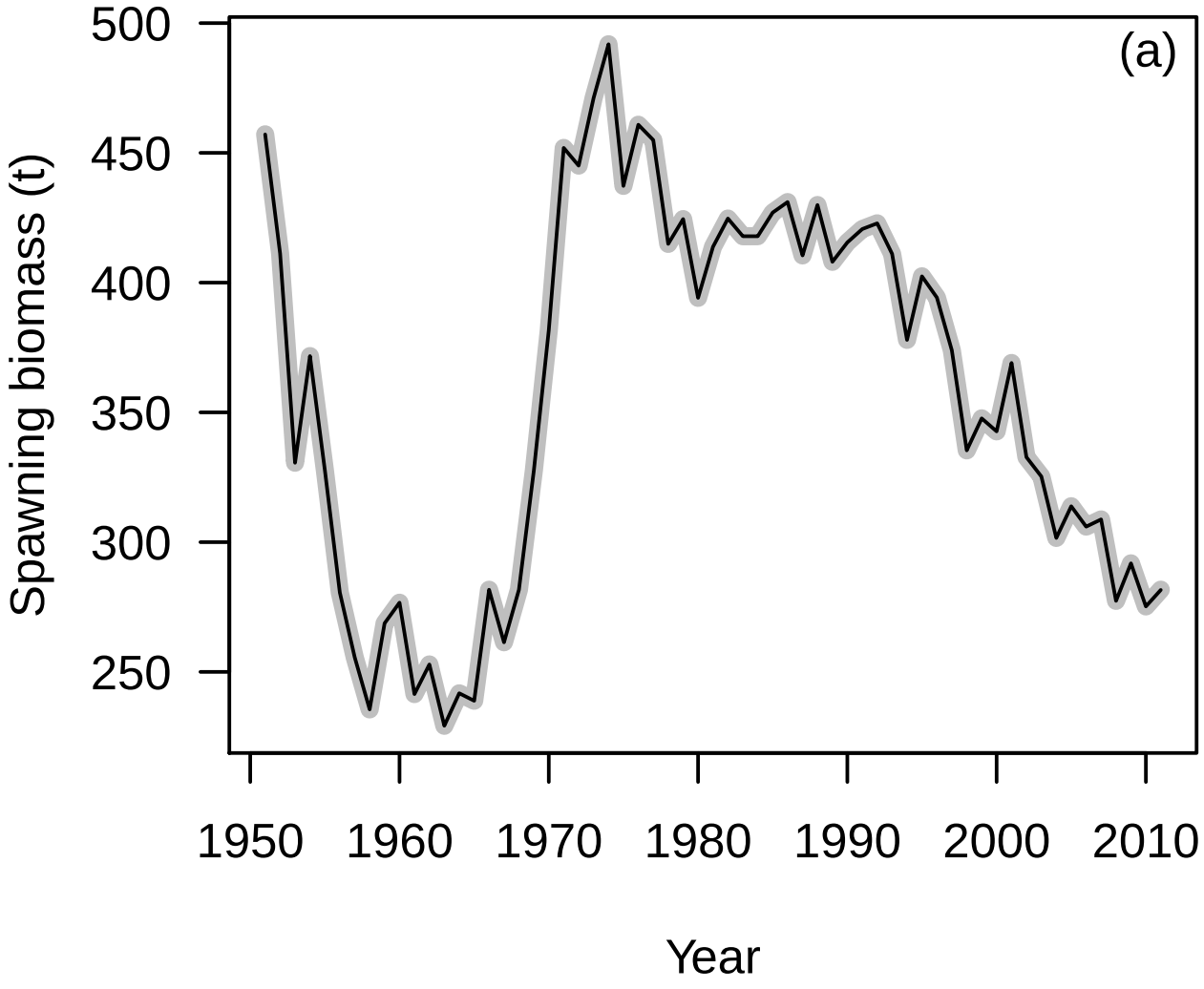



Figure: Prior densities for leading model parameters.

# Simulation testing

Estimation performance with perfect information.



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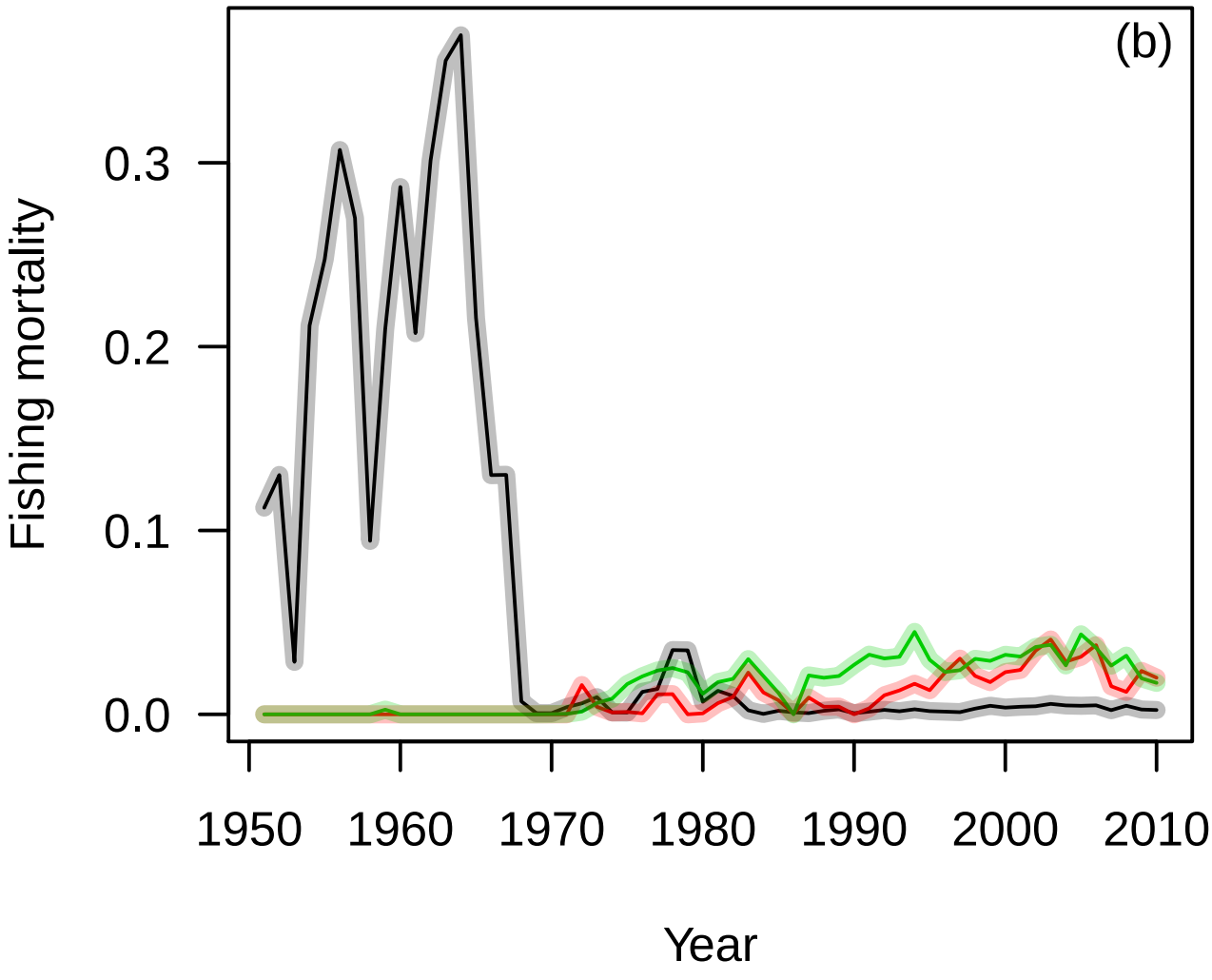

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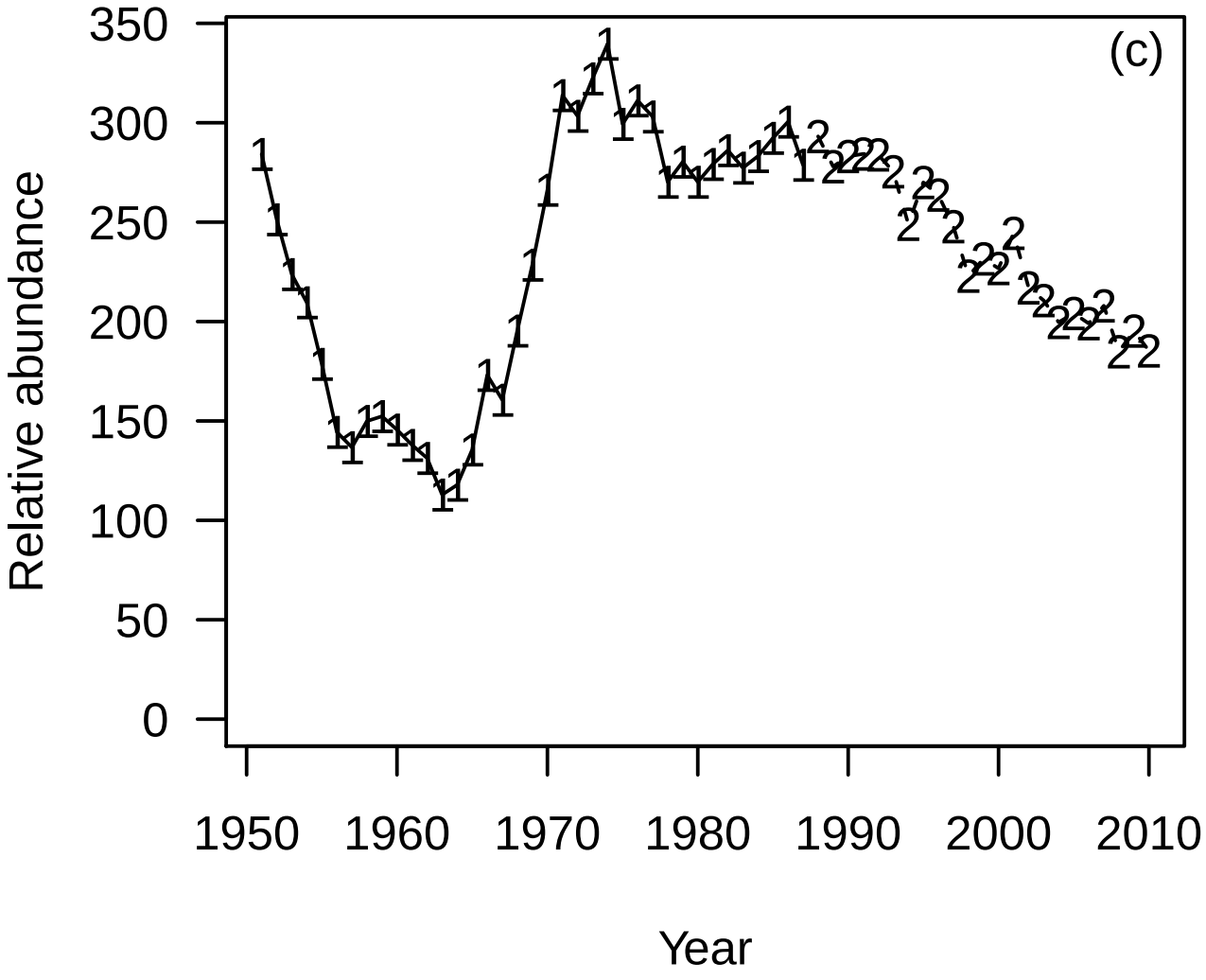
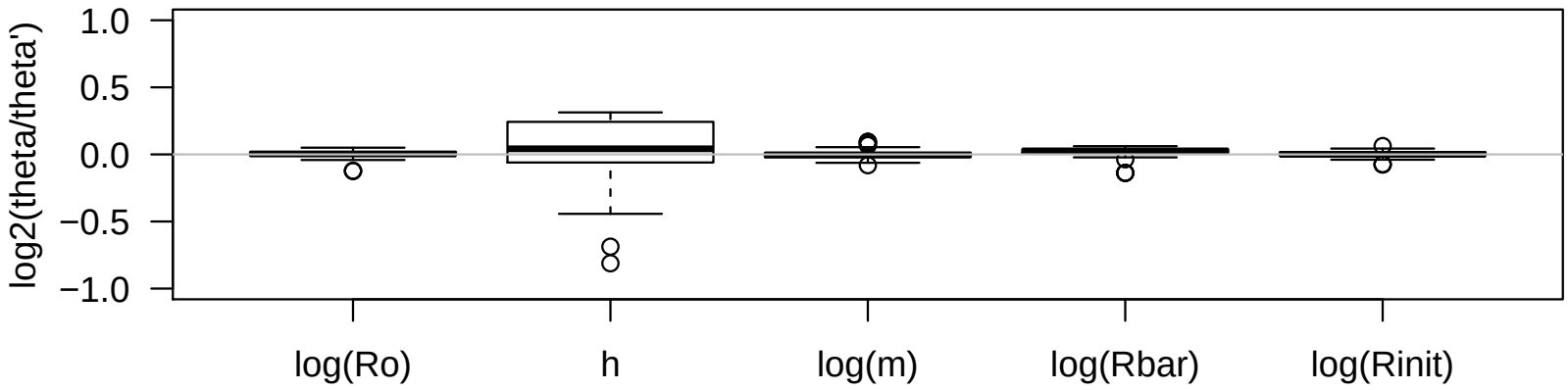


# Precision & Bias

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



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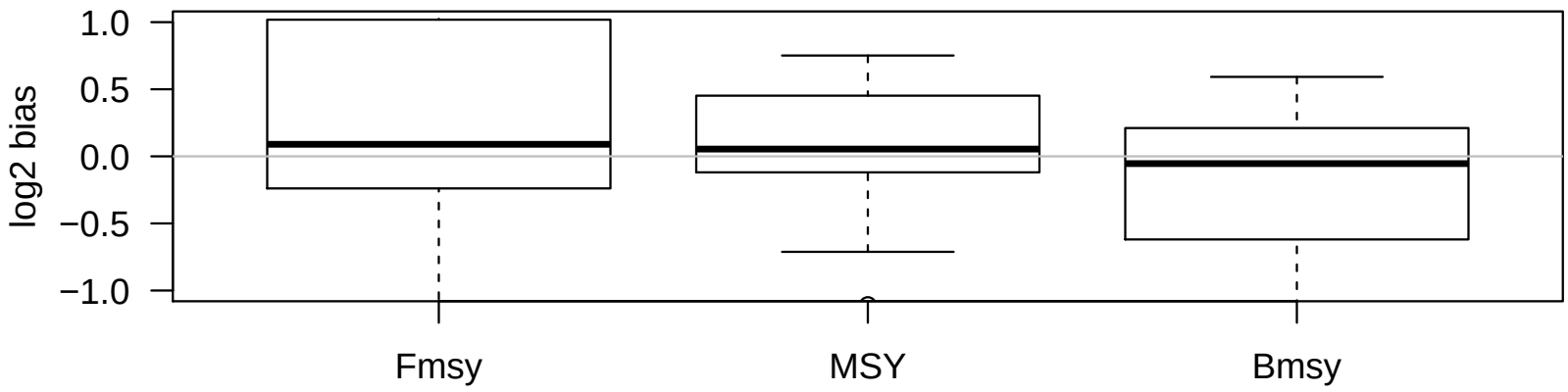
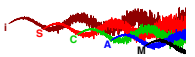


# Strait of Georgia

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 $(\vartheta, \rho)$.
- Prior for steepness ($h \sim$ Beta in ${}^{i}\mathrm{SCA}_{\mathrm{M}}$)



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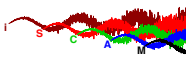

# SOG Spawning biomass

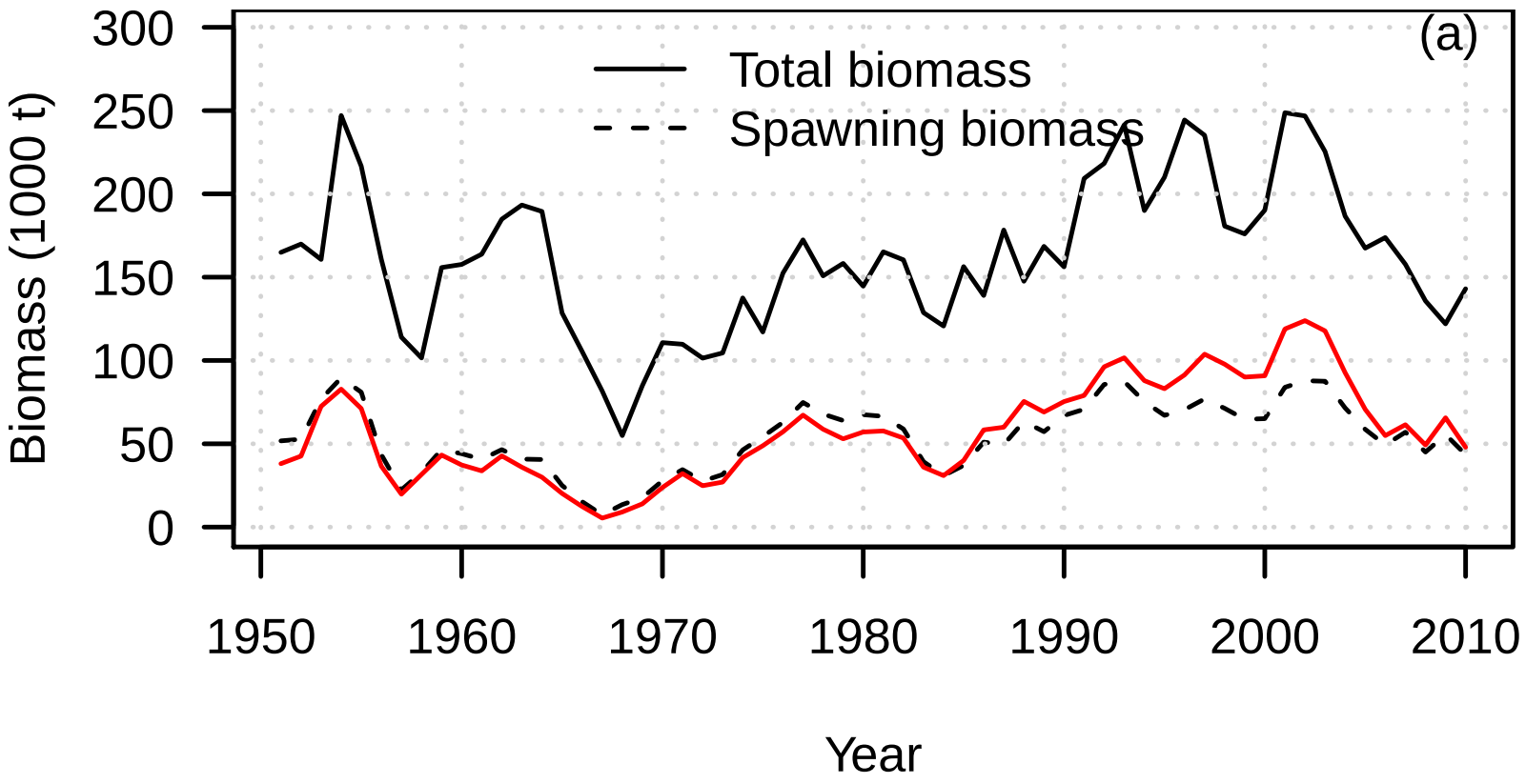


Figure: Total biomass at the start of the year, spawning biomass after fishing. HCAM (2010) spawning biomass shown in red.

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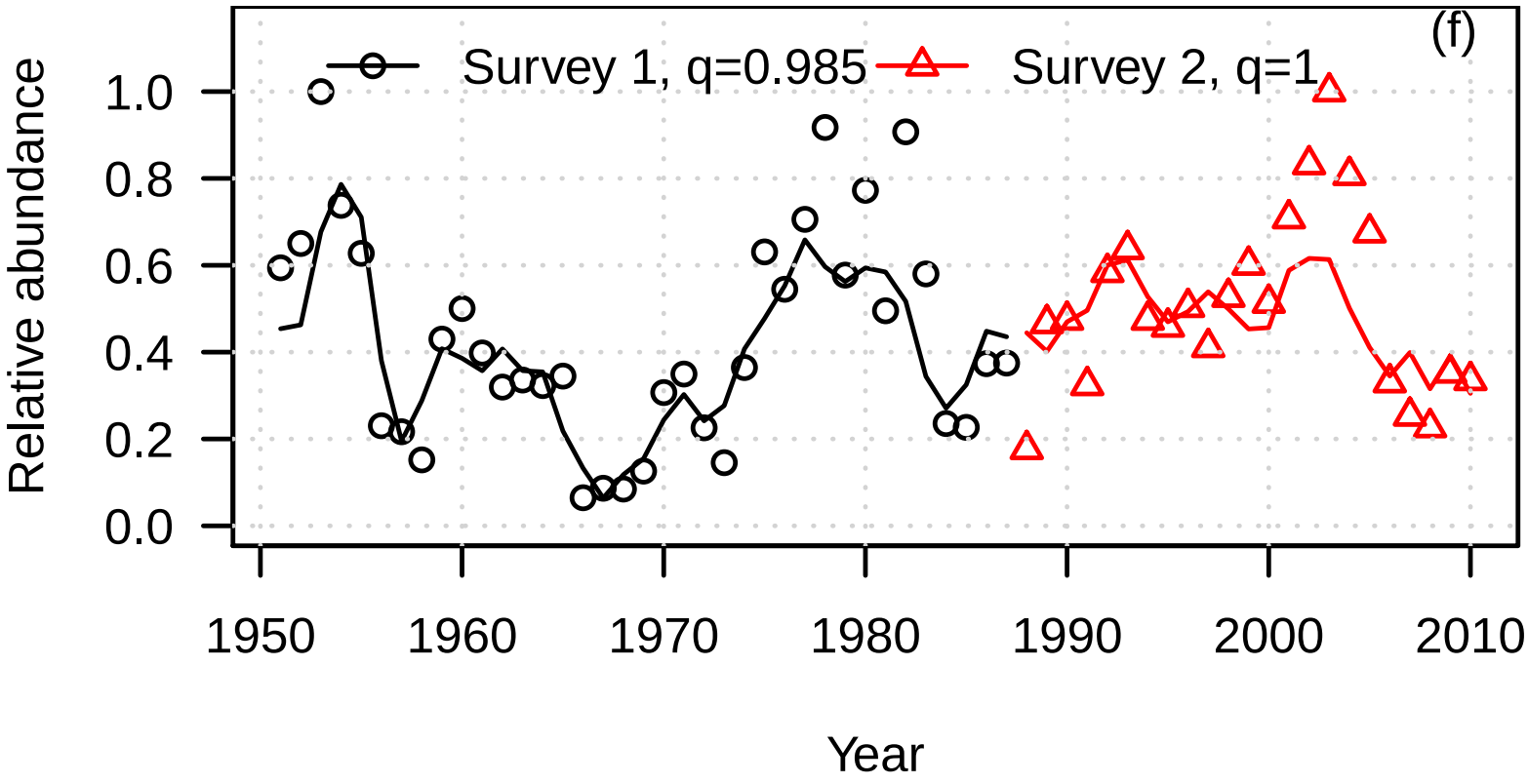
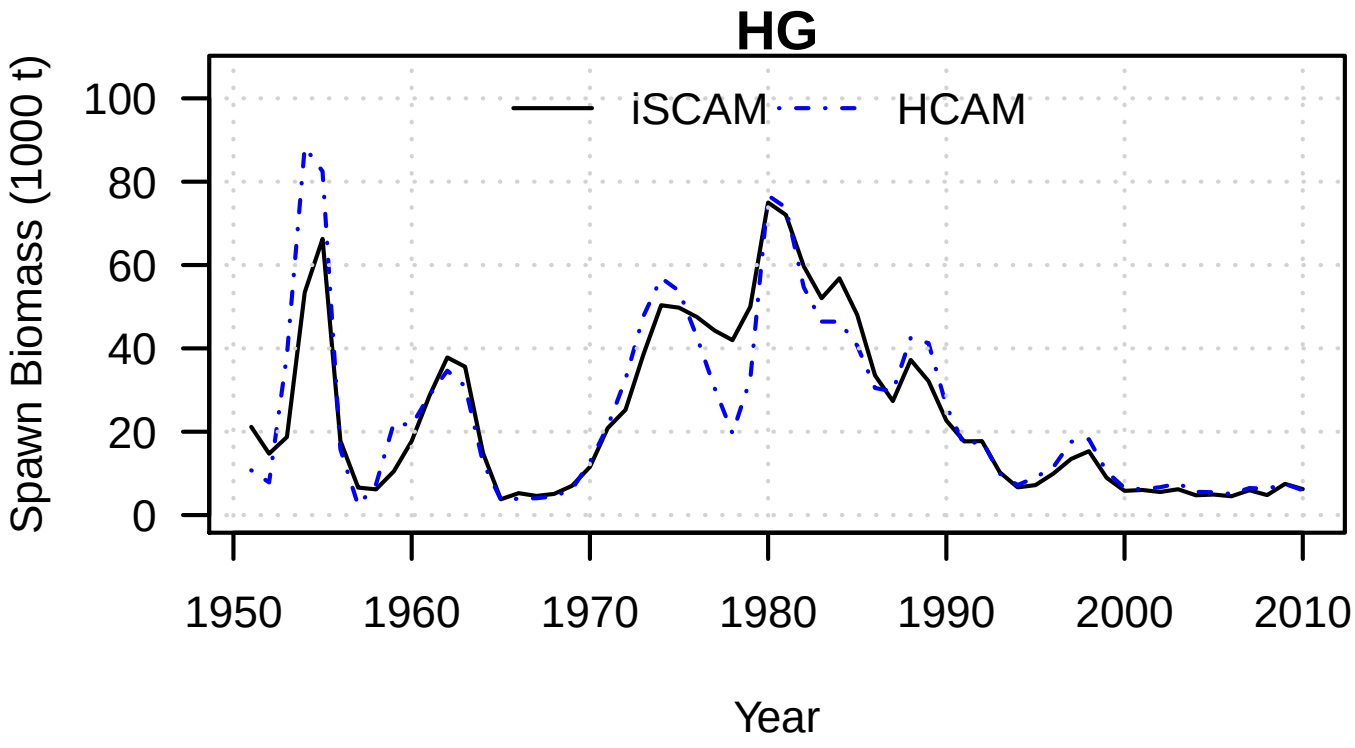
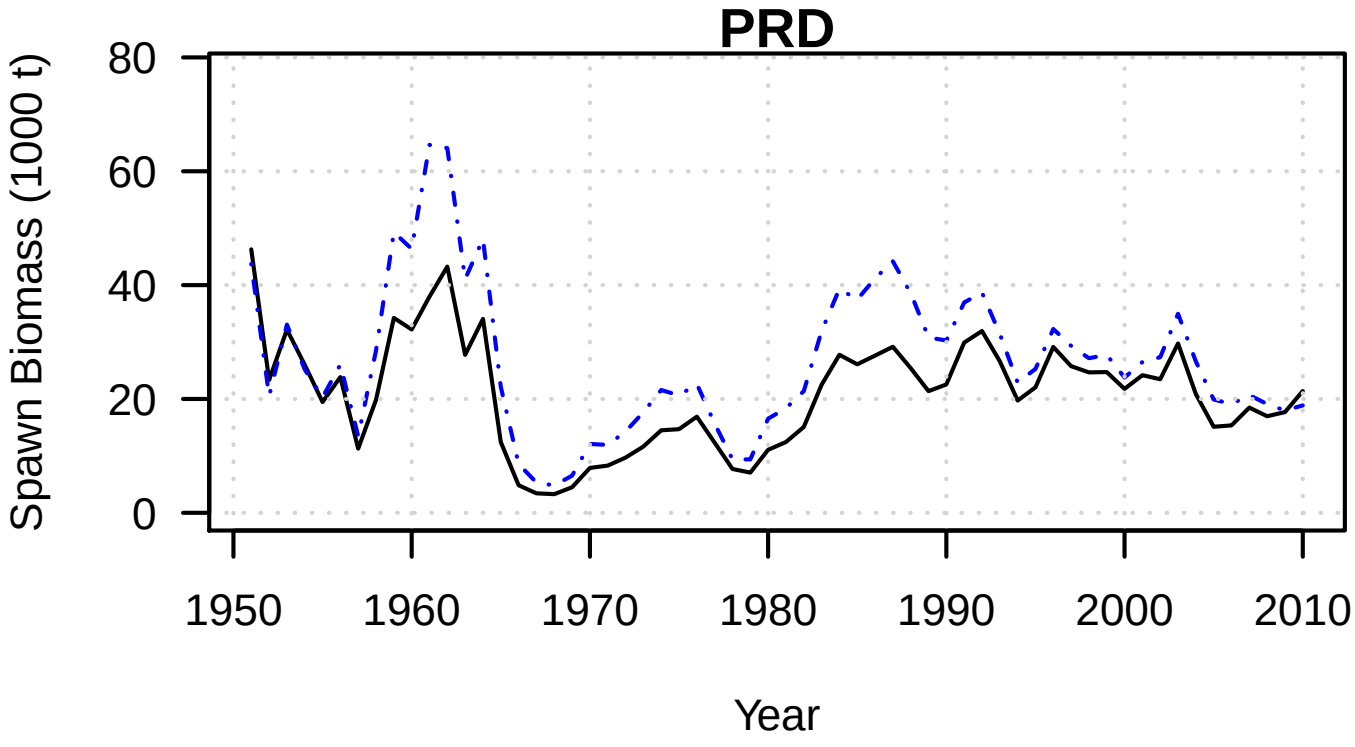



Figure: Observed and predicted spawn survey data for surface (black) and dive (red) surveys.

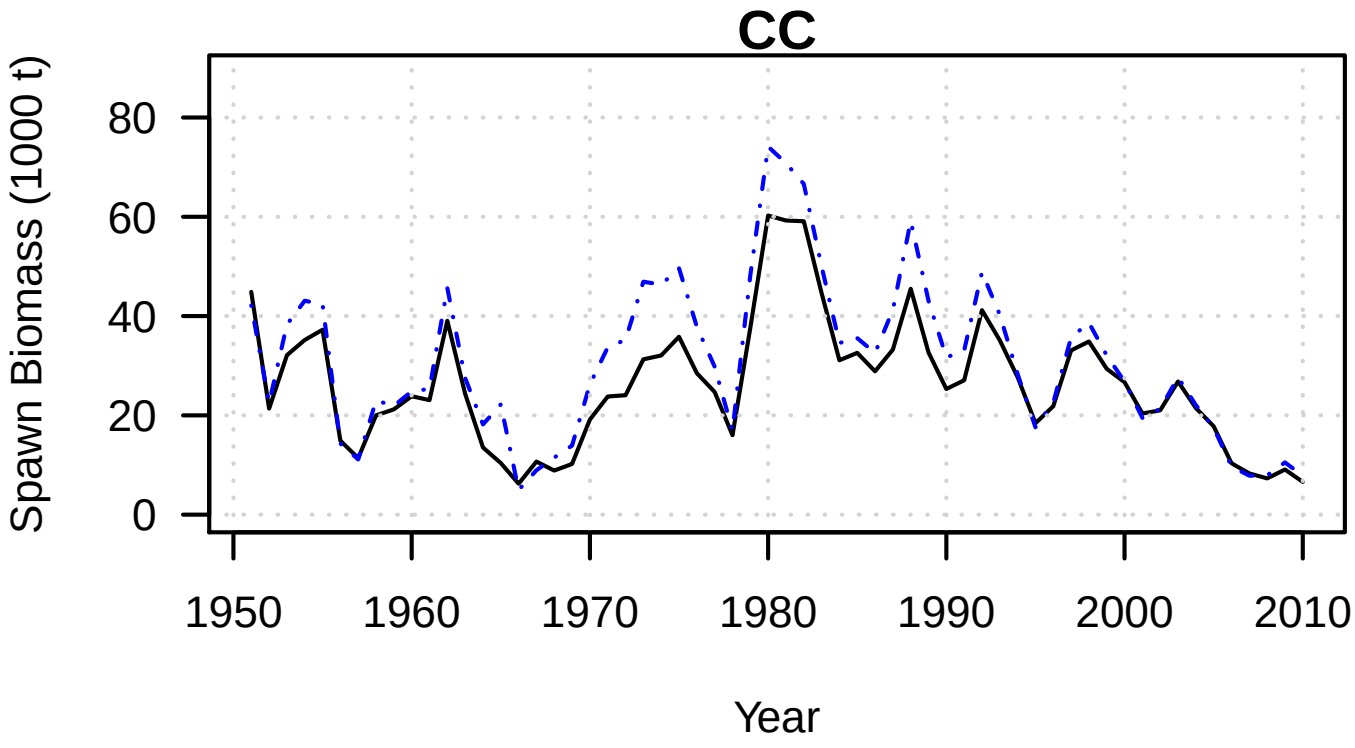
# Spawning biomass in HG



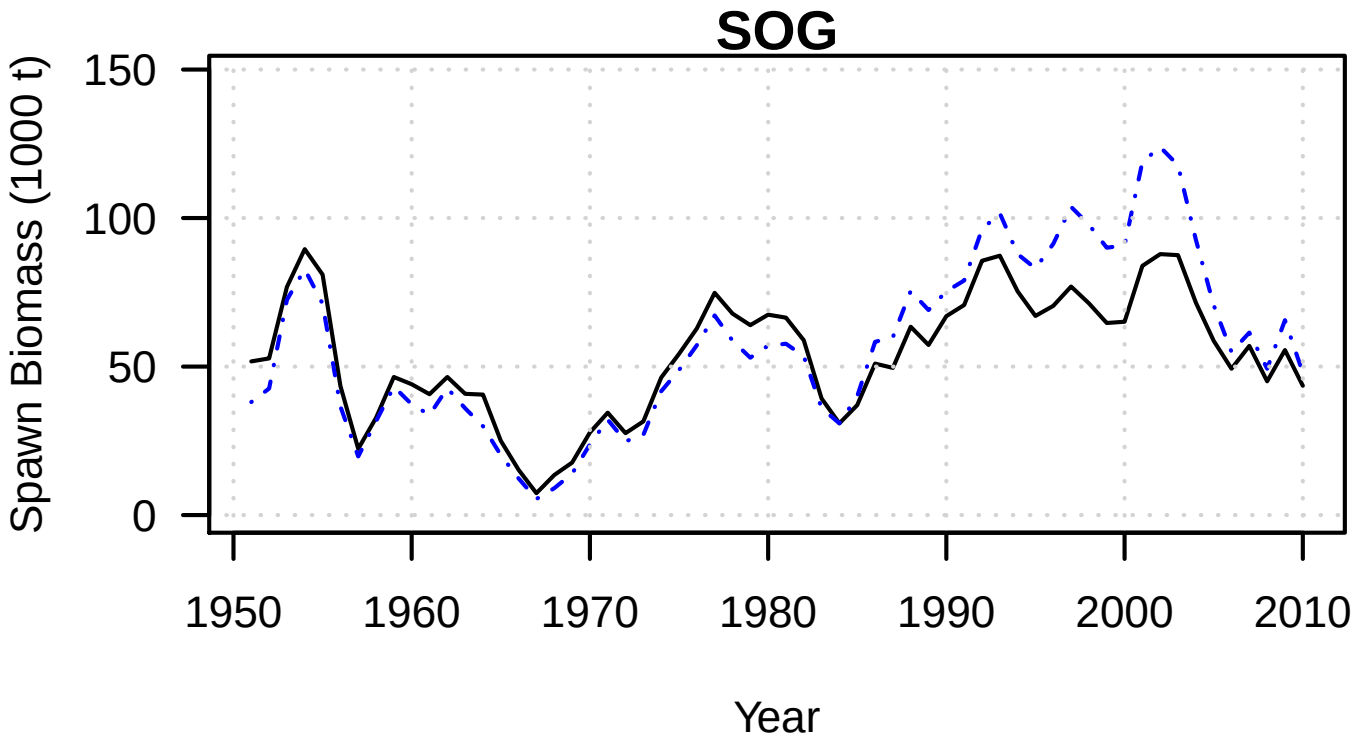
# Spawning biomass in PRD



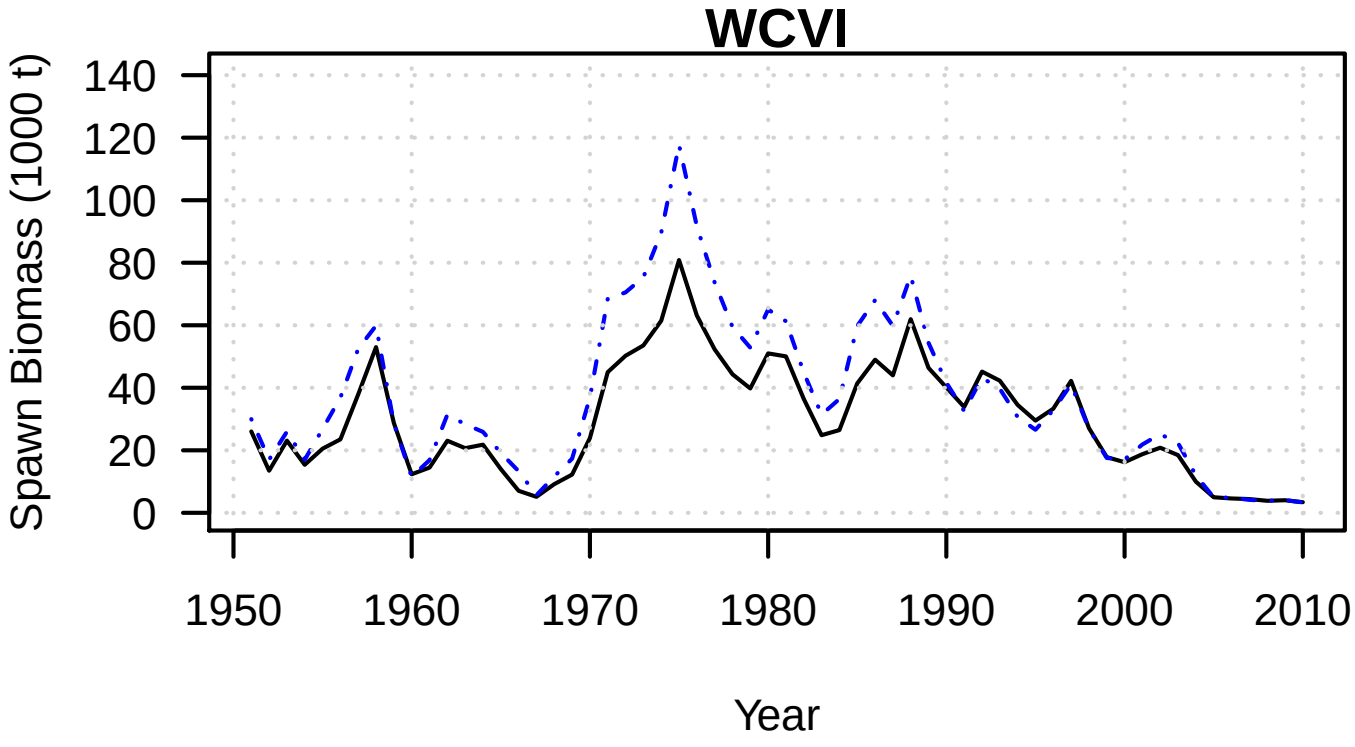
# Spawning biomass in CC



# 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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# 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:
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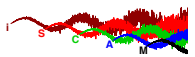
# Contents





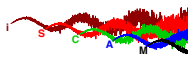
# Introduction

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)

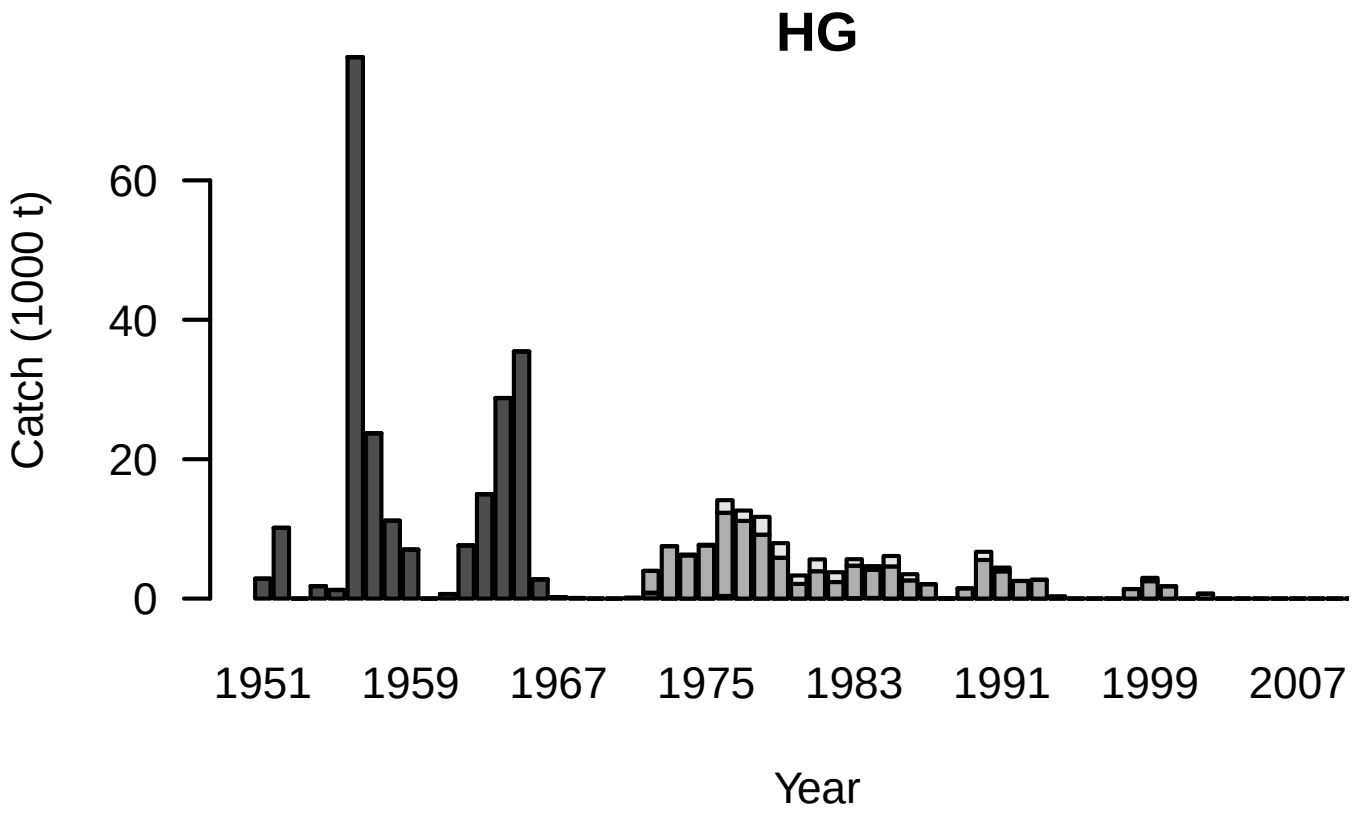



Figure: Catch by gear for Haida Gwaii.

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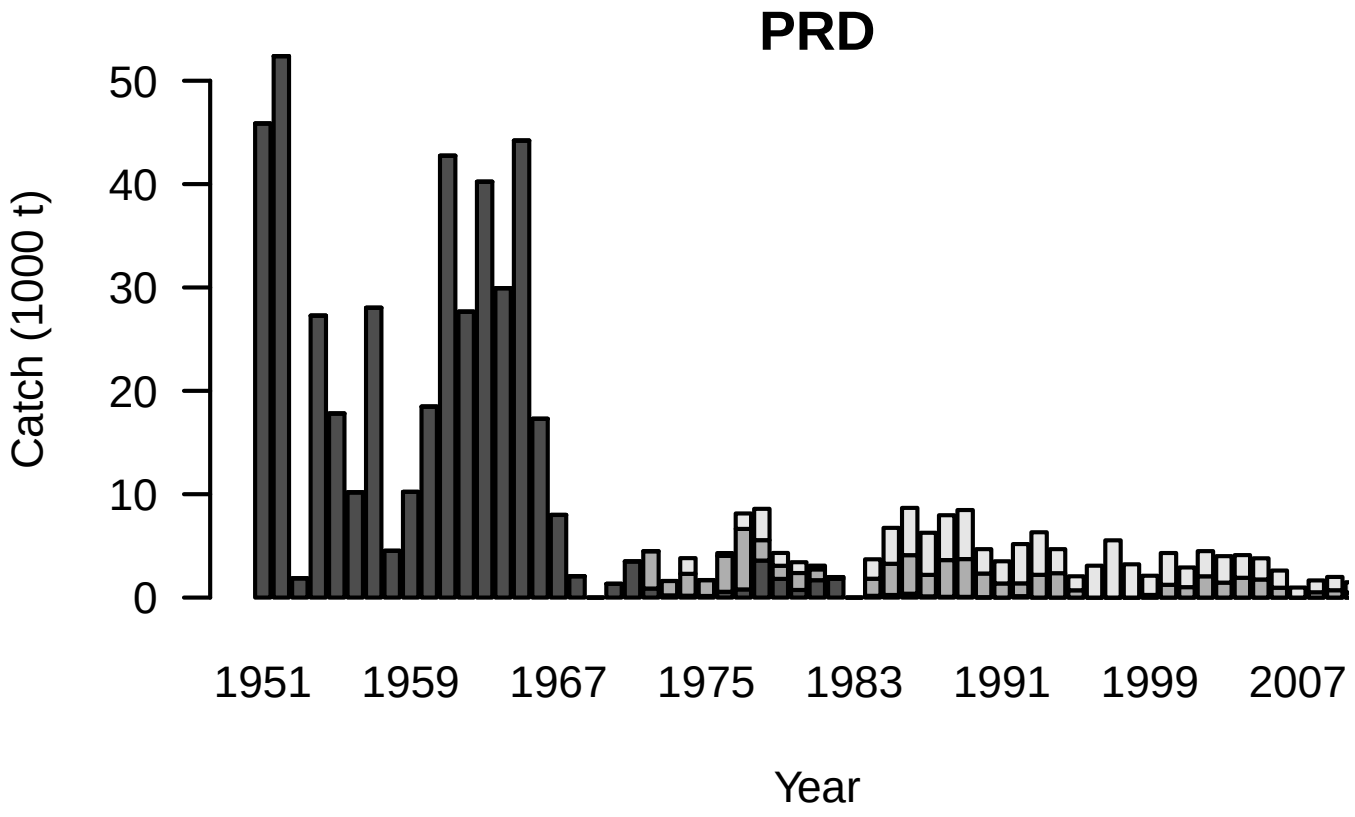


Figure: Catch by gear for Prince Rupert District.

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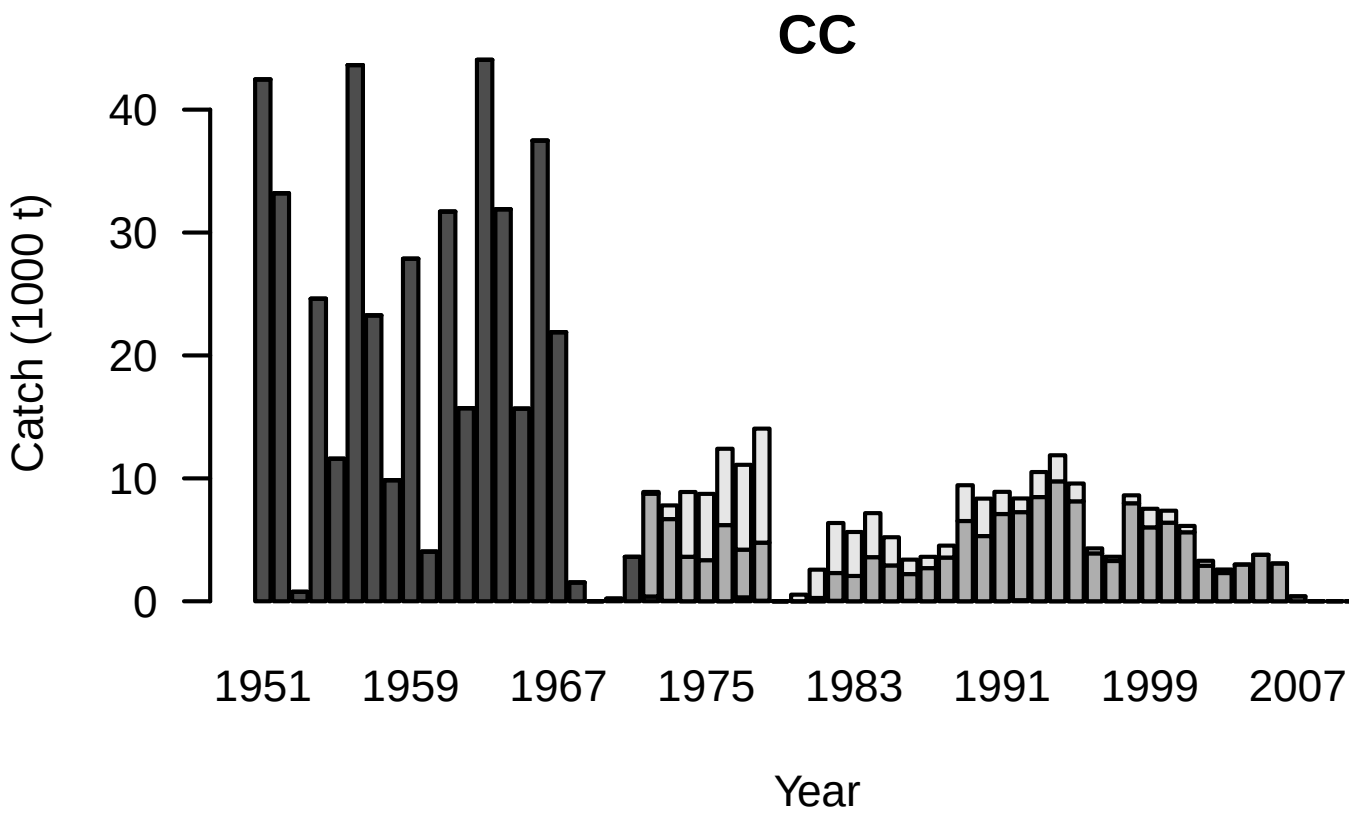


Figure: Catch by gear for Central Coast.

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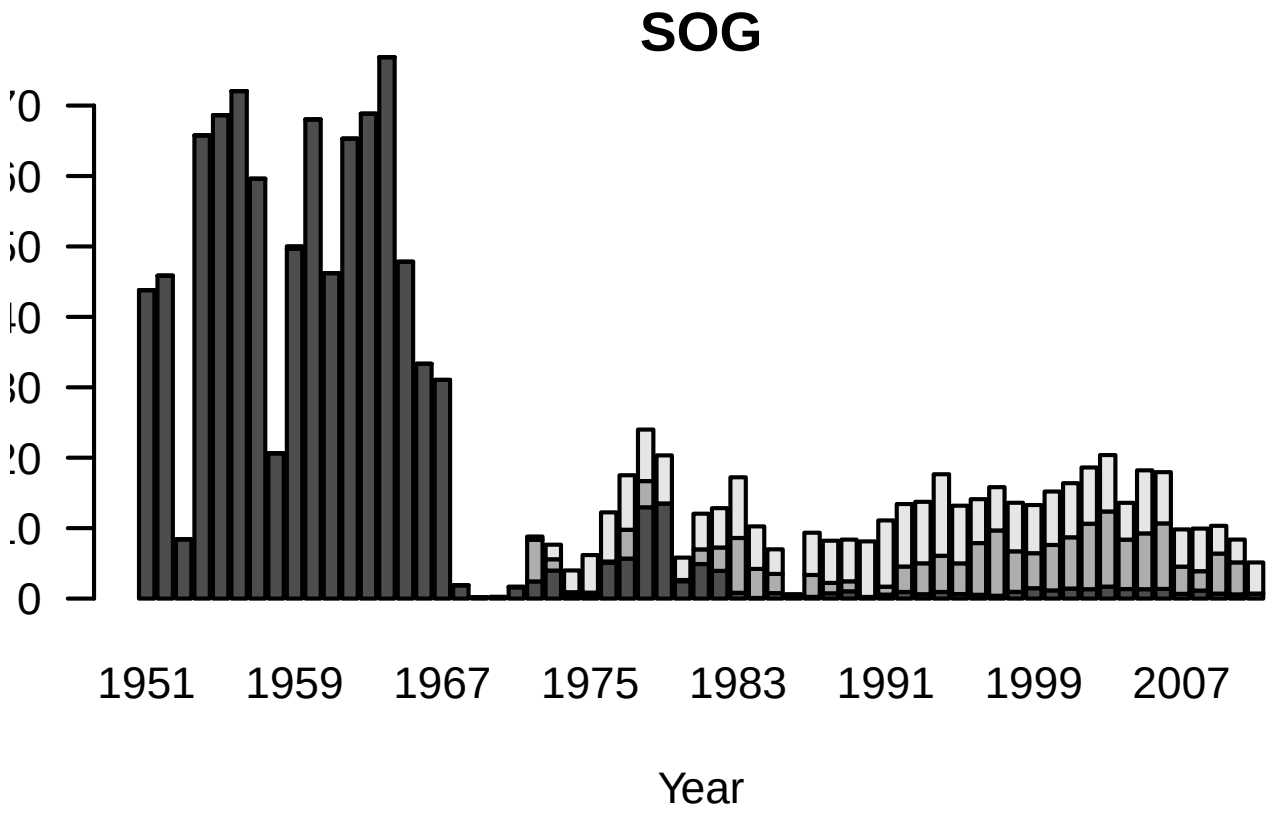


Figure: Catch by gear for Strait of Georgia.

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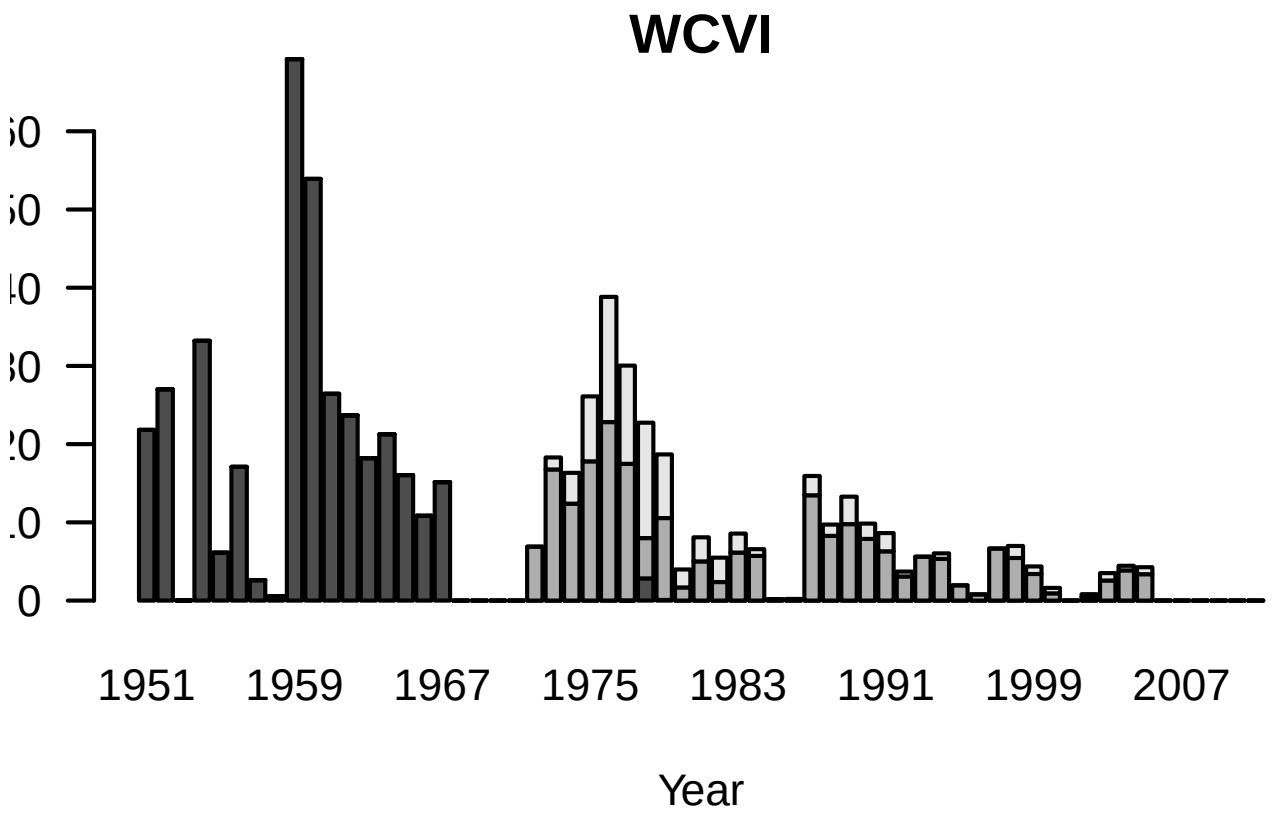


Figure: Catch by gear for West Coast of Vancouver Island.

# Spawning activity in 2010

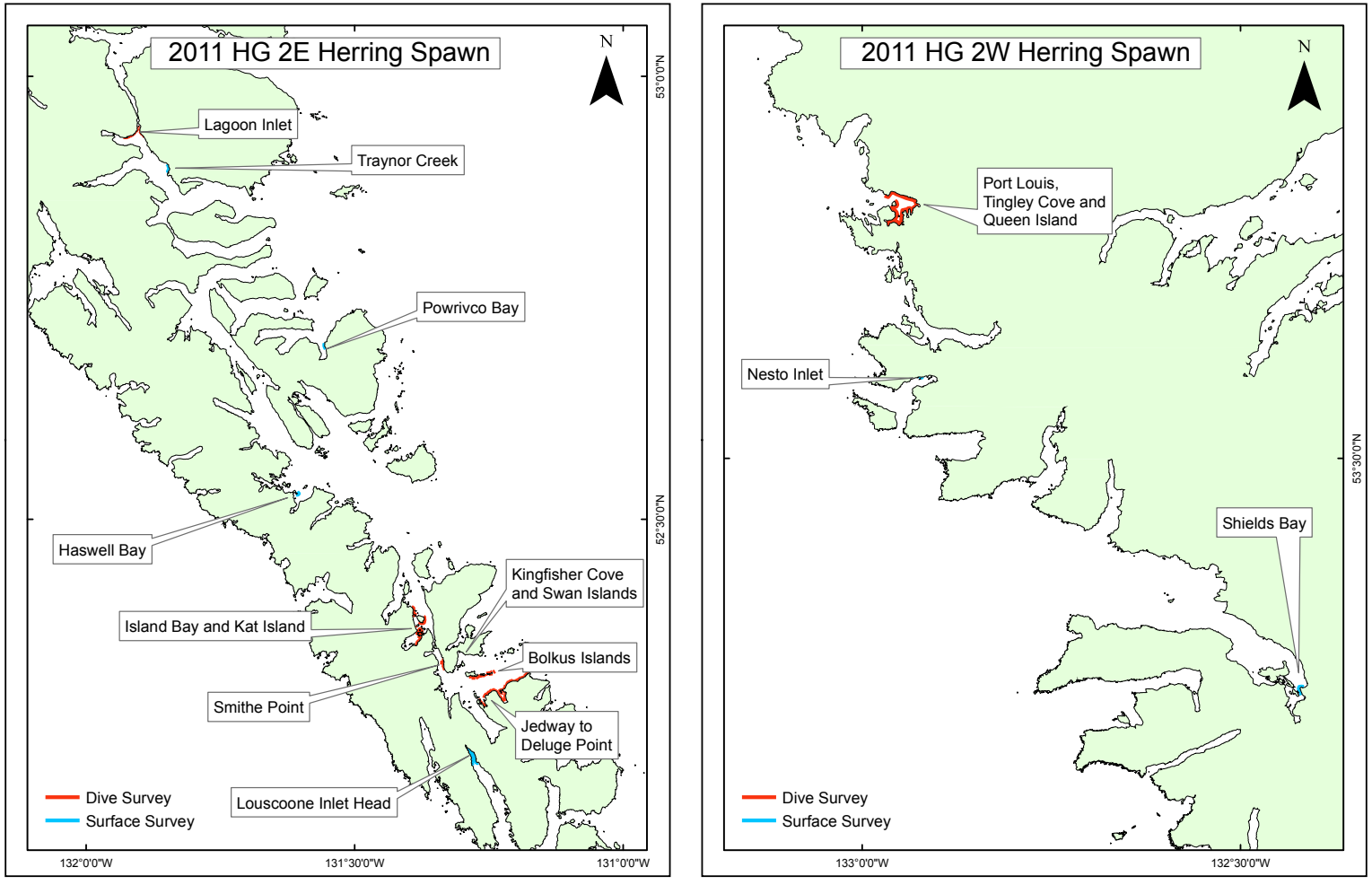


Figure: 2010 Spawning activity in Haida Gwaii.

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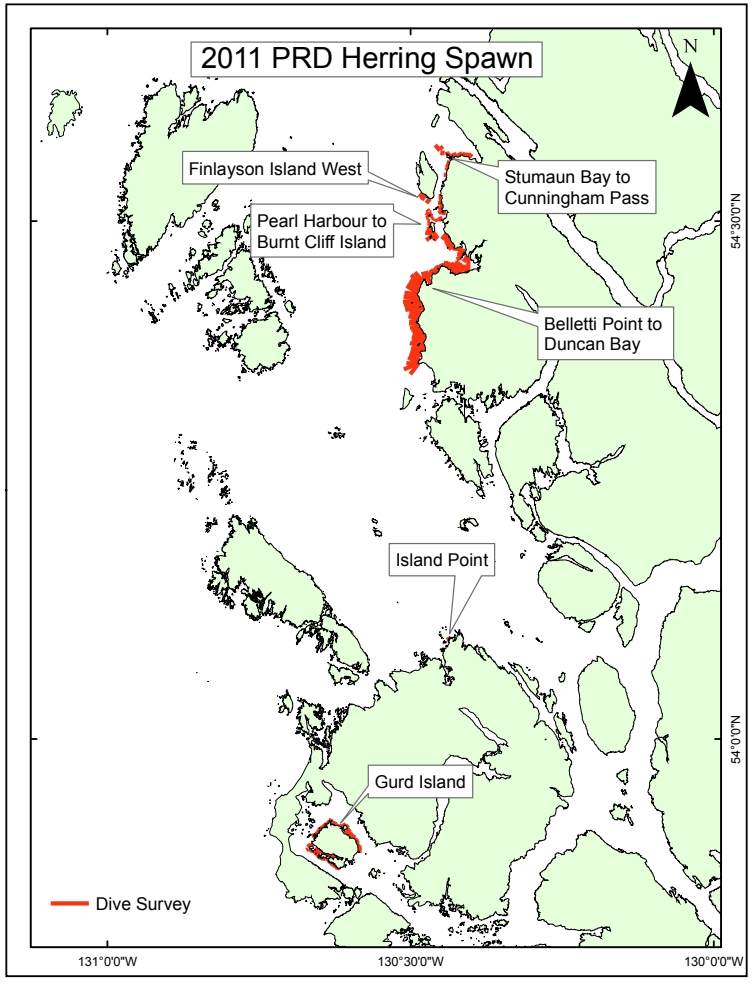


Figure: 2010 Spawning activity in Prince Rupert District.

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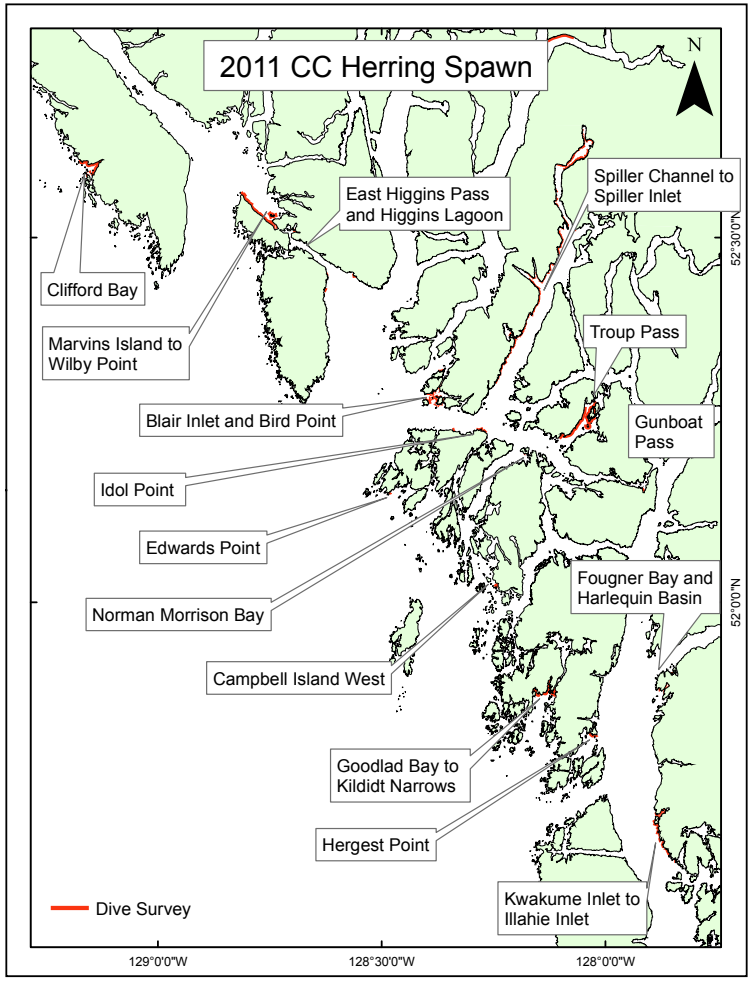


Figure: 2010 Spawning activity in Central Coast.

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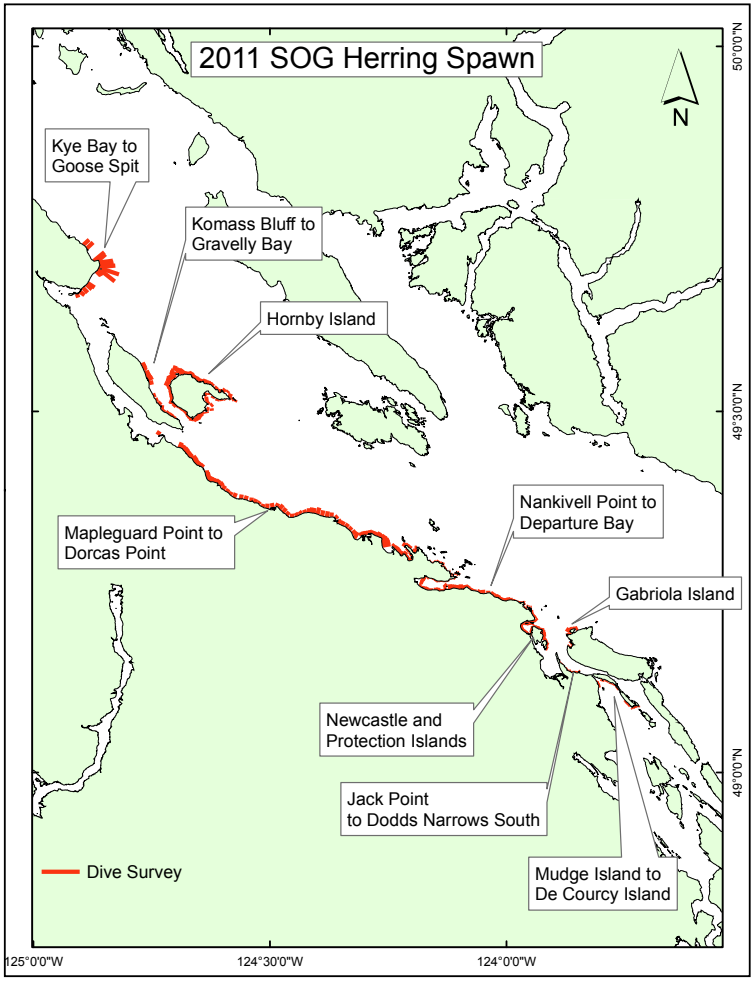



Figure: 2010 Spawning activity in Strait of Georgia.

# Spawning activity in 2010

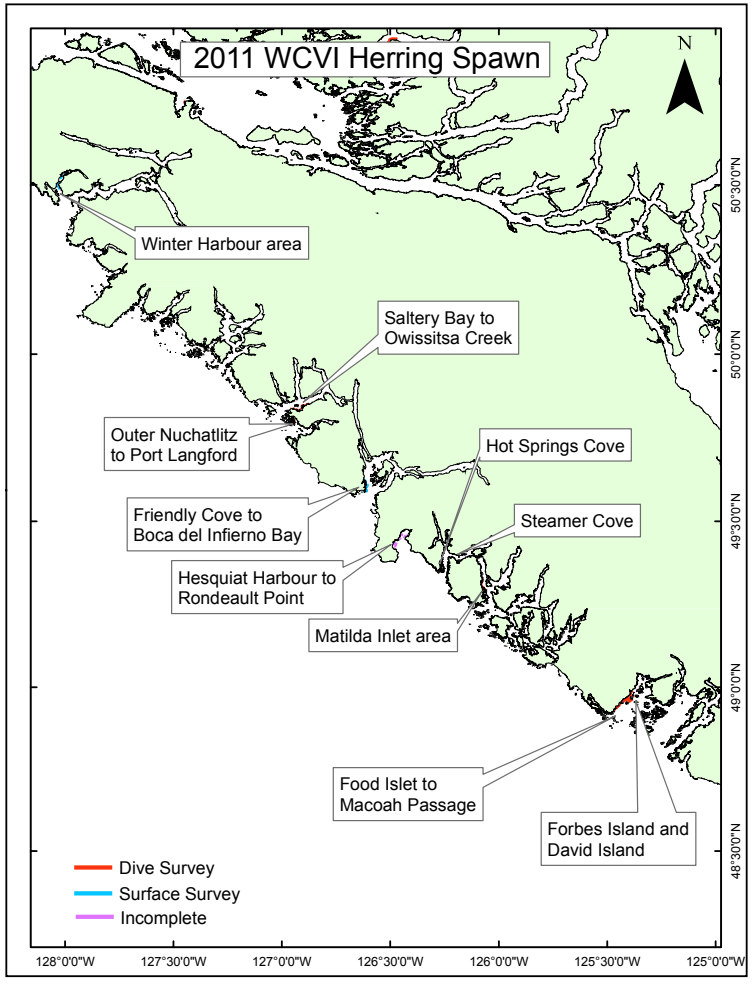
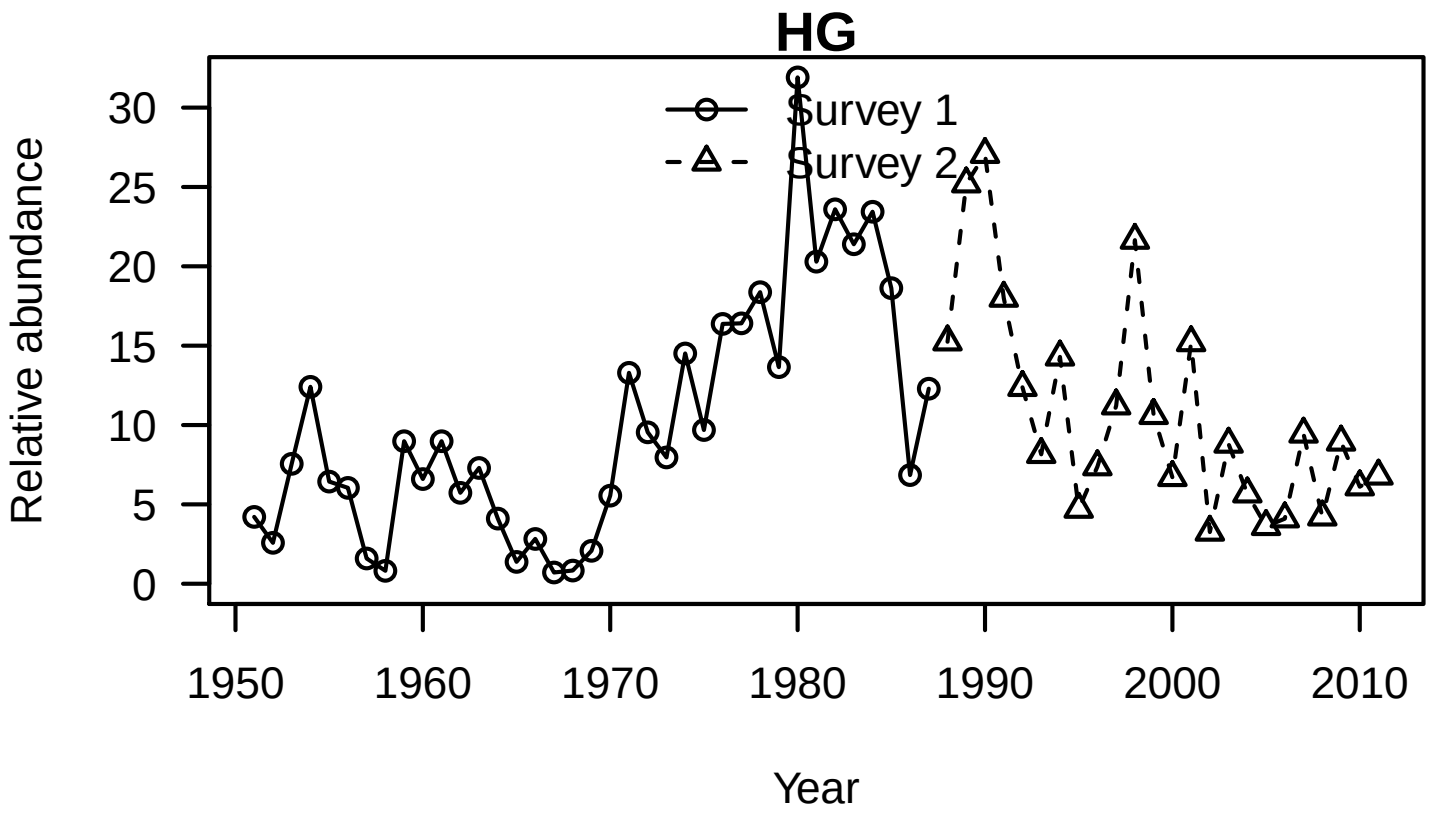



Figure: 2010 Spawning activity in West Coast Vancouver Island.

# Spawn survey time series

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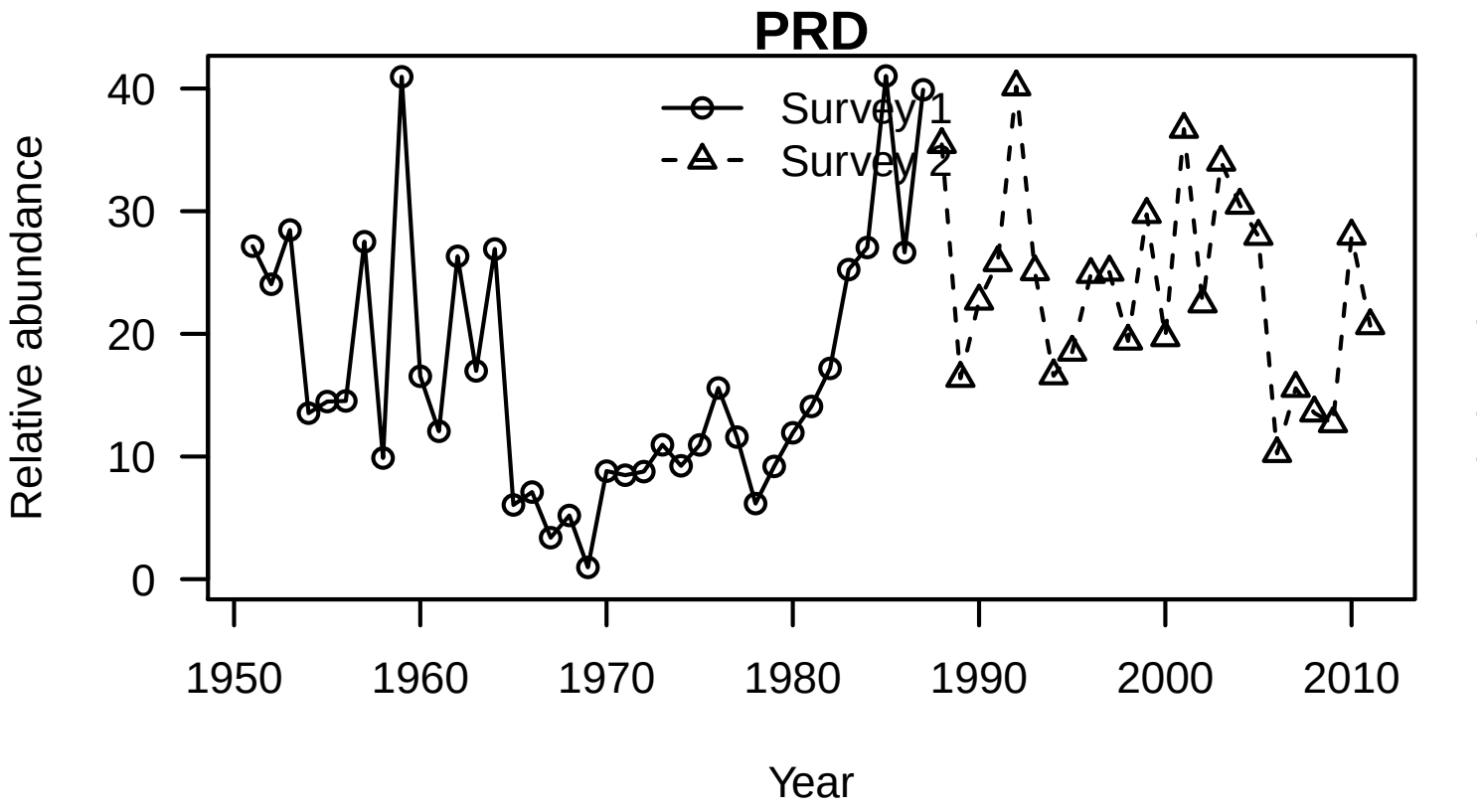


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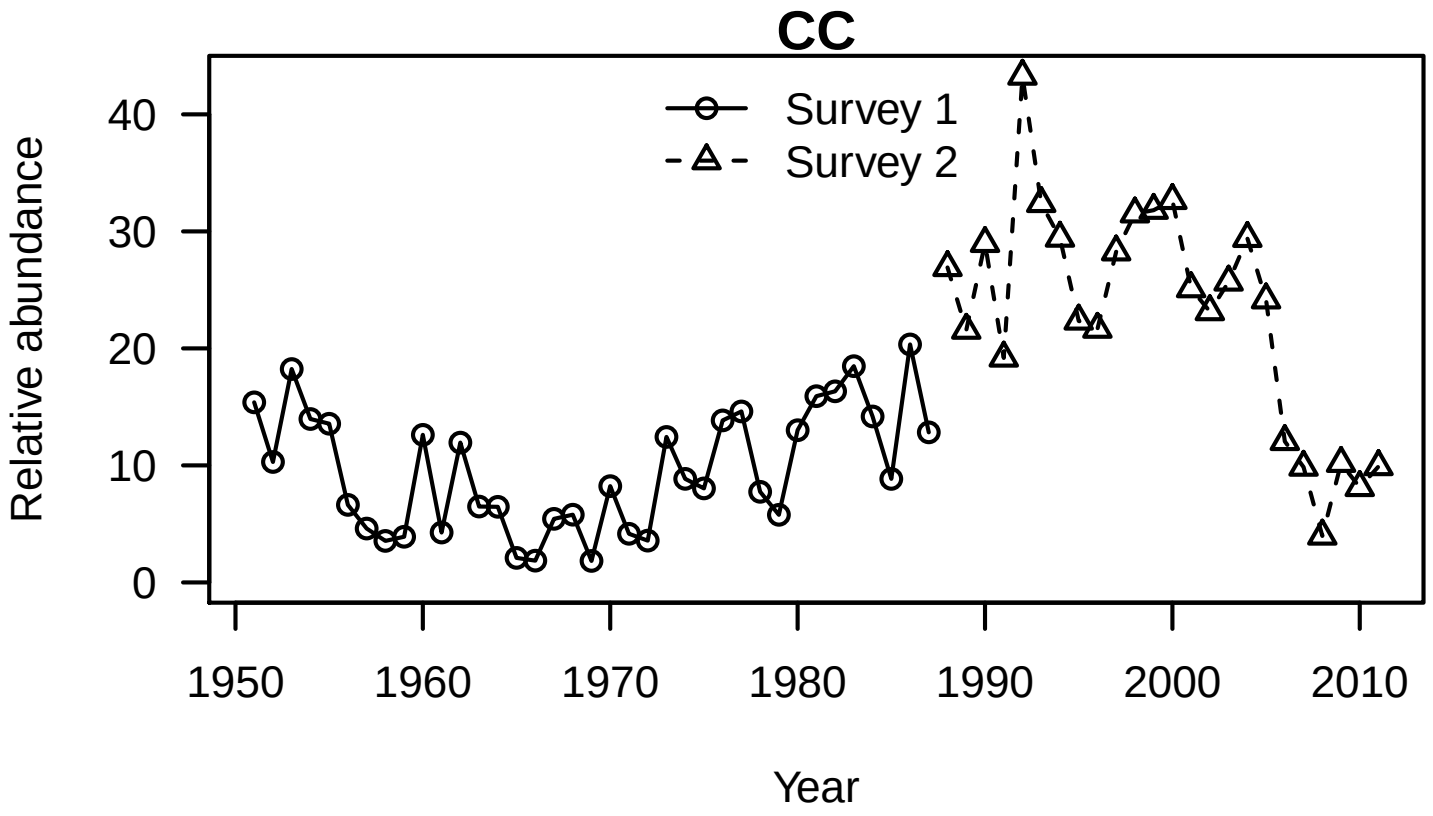


Figure: Spawn survey series in Central Coast.

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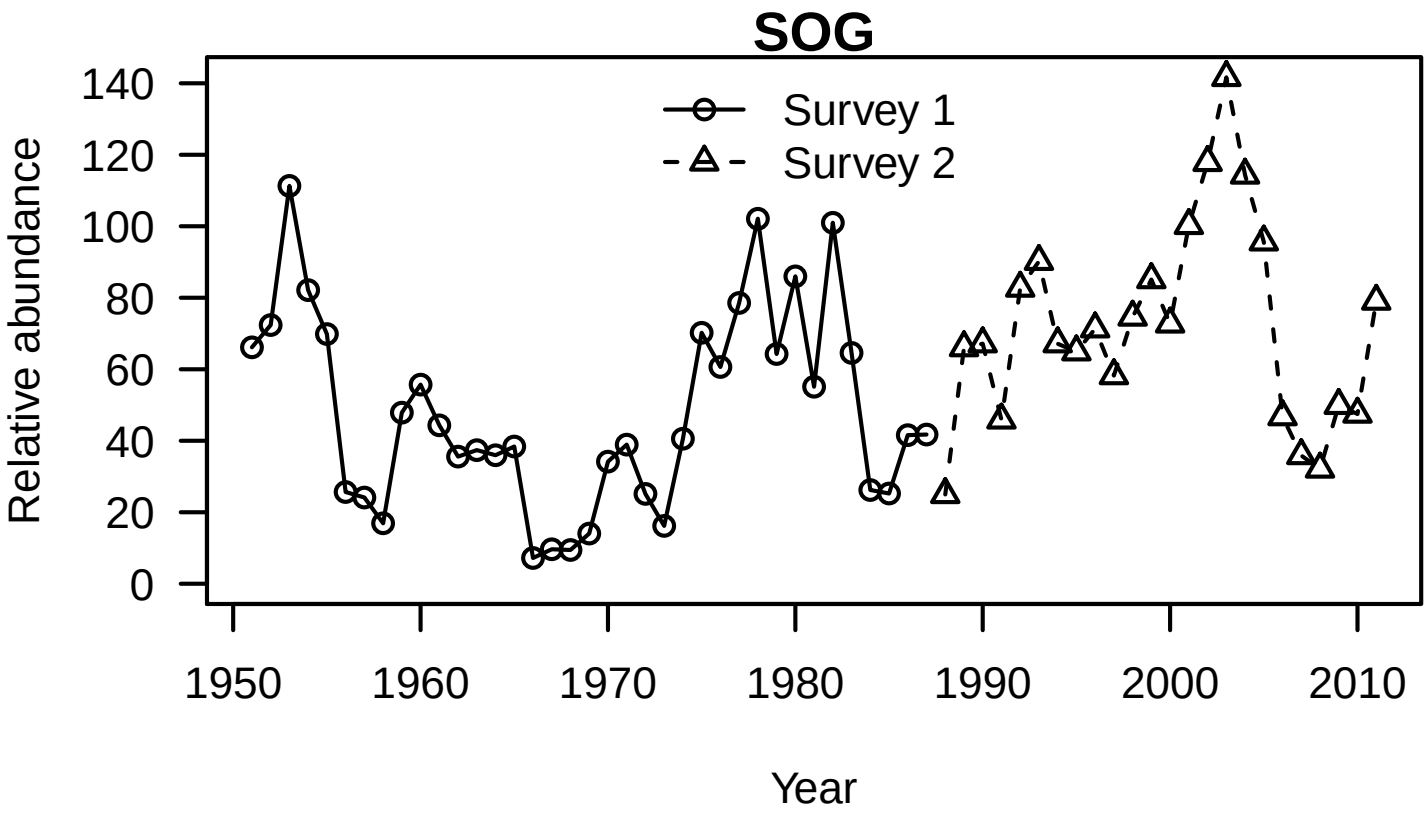


Figure: Spawn survey series in Strait of Georgia.

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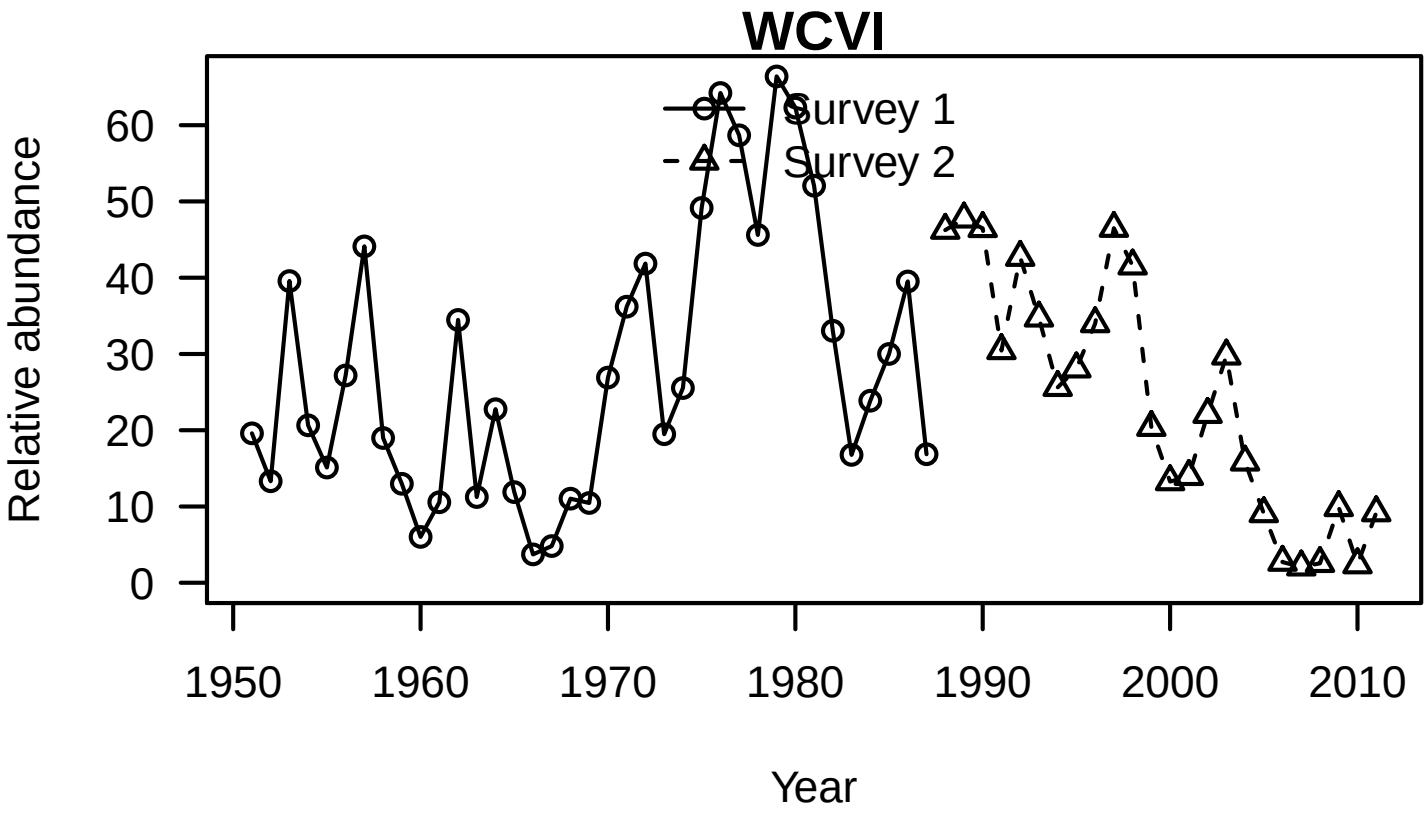


Figure: Spawn survey series in West Coast of Vancouver Island.

# Age-composition data

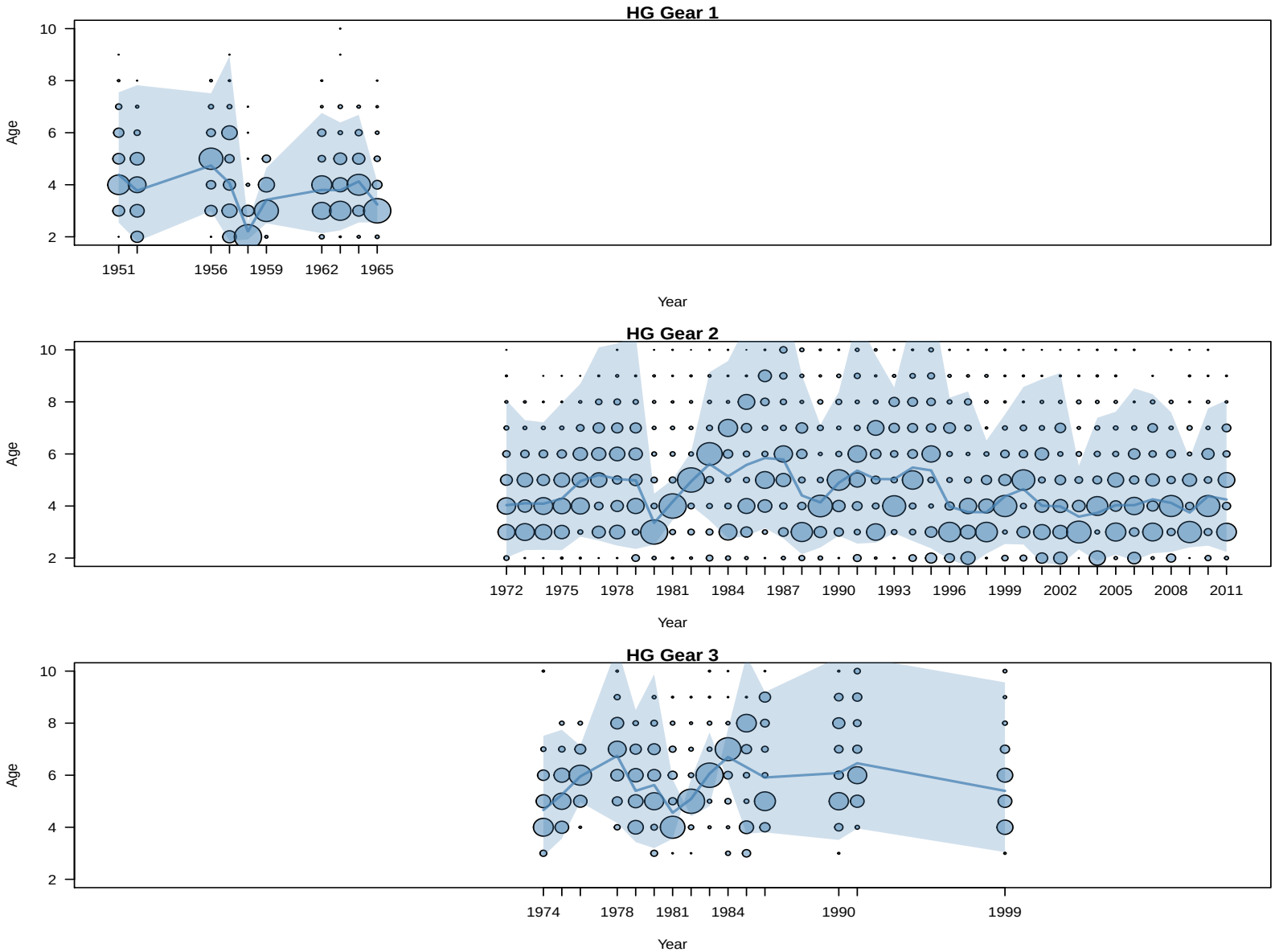


Figure: Haida Gwaii: winter seine, seine-roe, gillnet.

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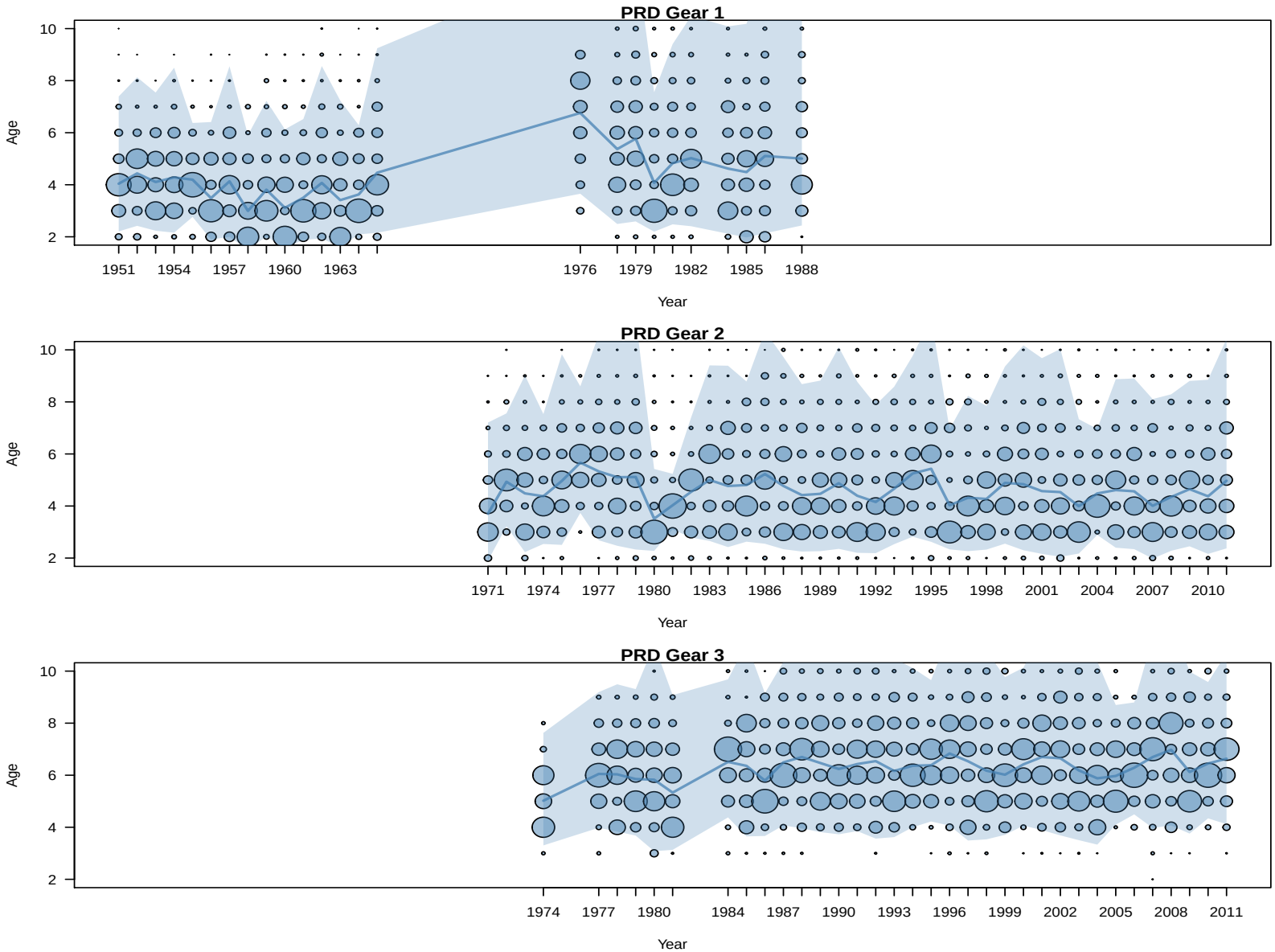


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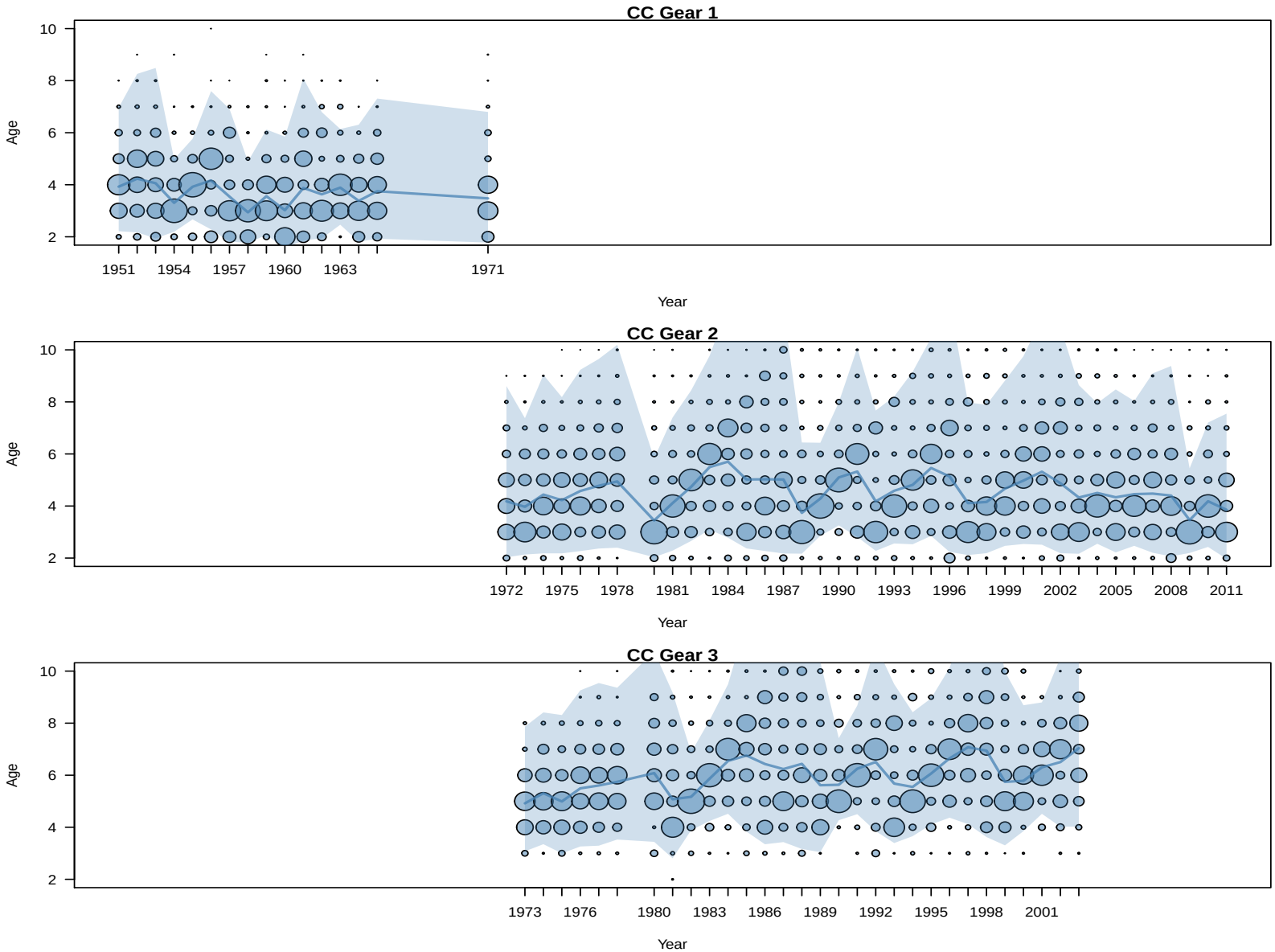


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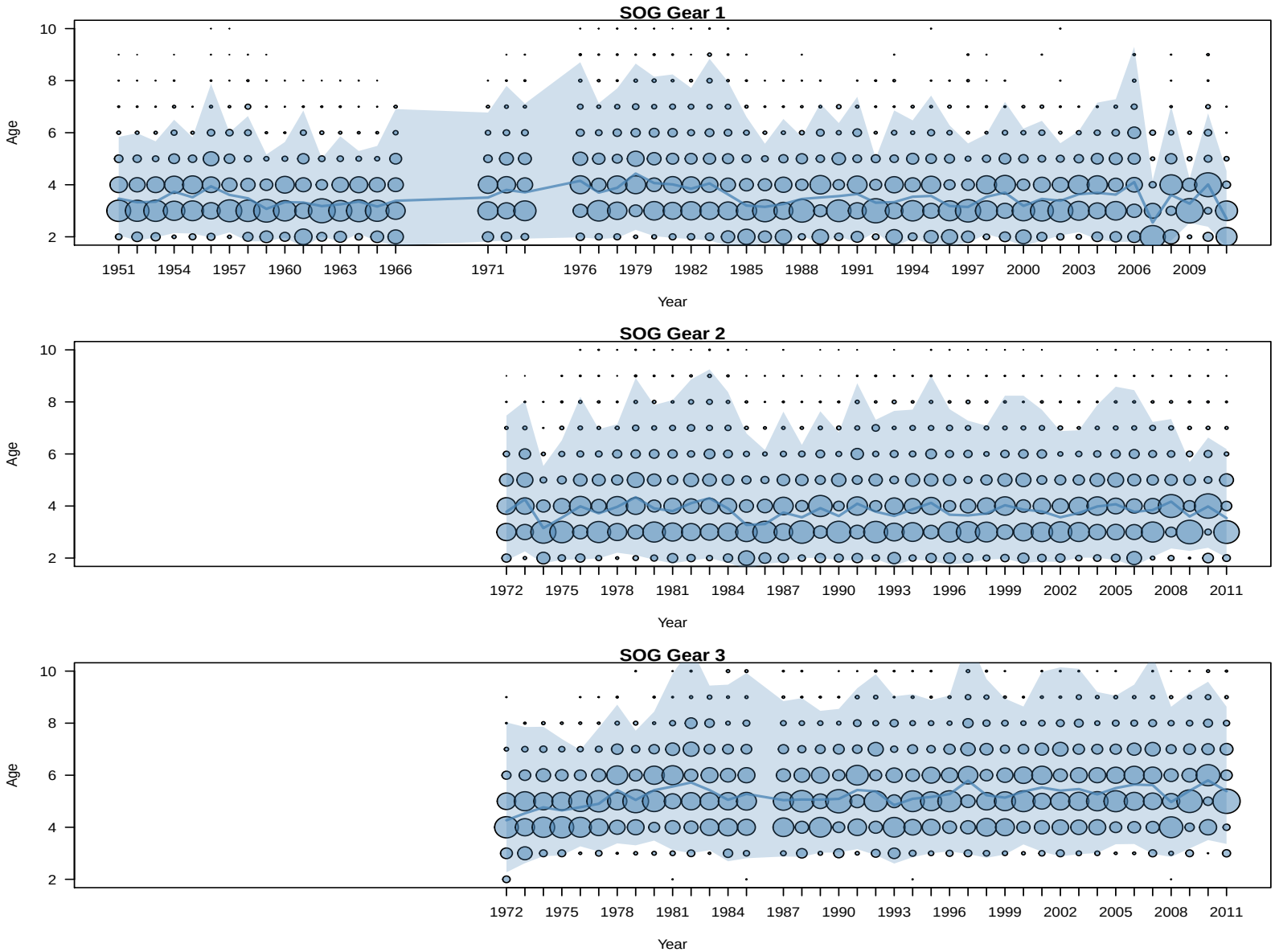


Figure: Strait of Georgia: winter seine, seine-roe, gillnet.

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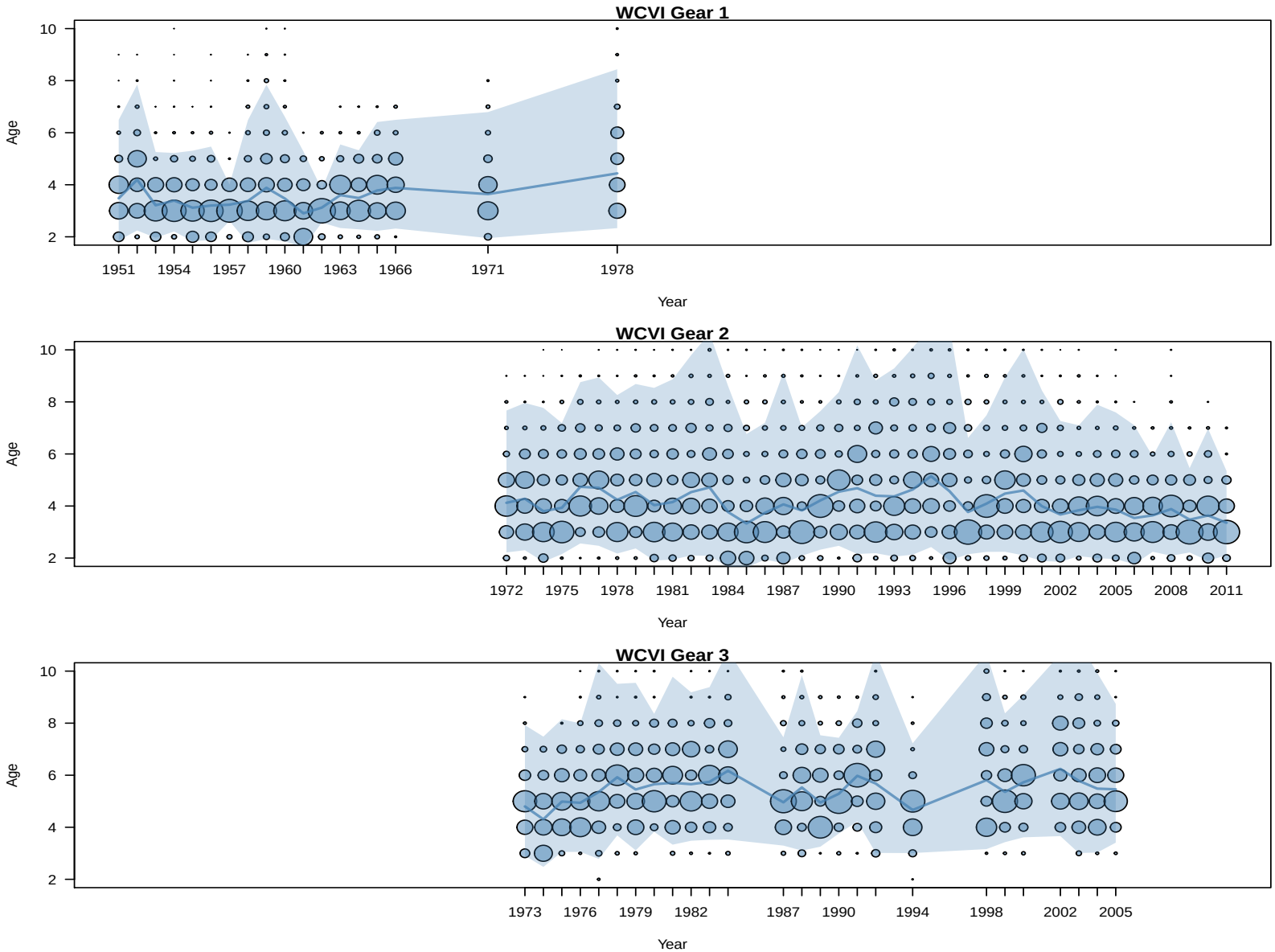


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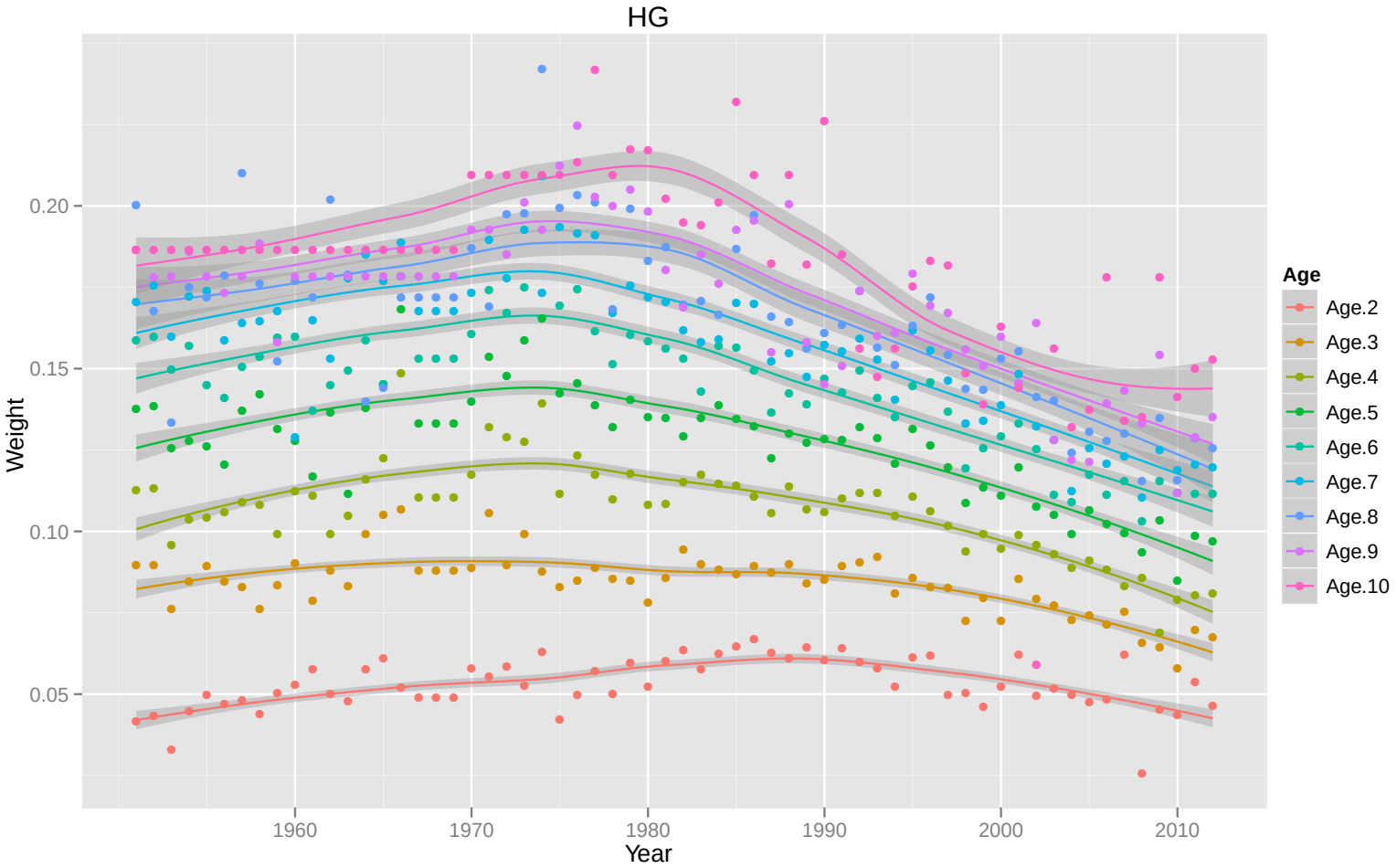
# Weight-at-age

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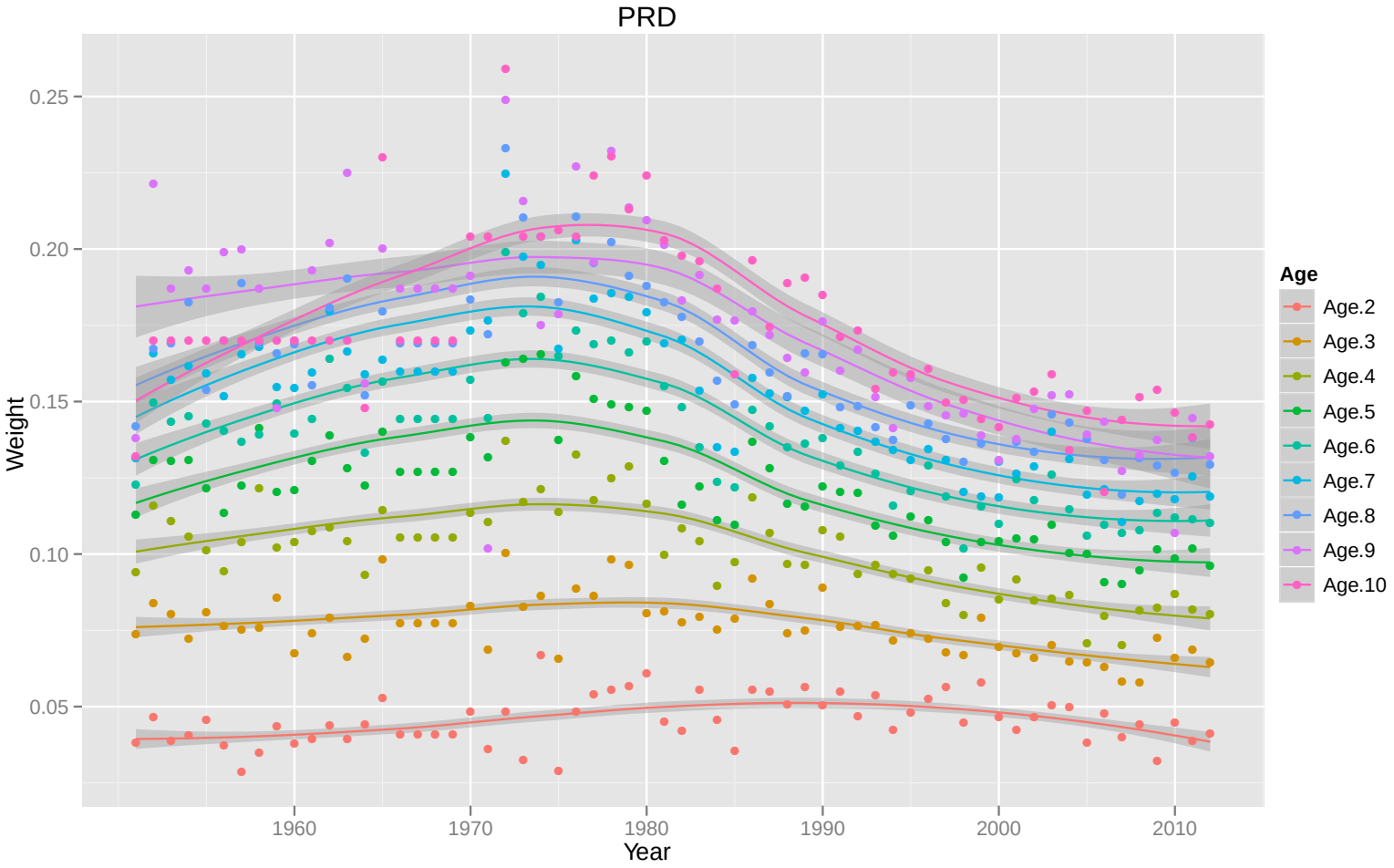


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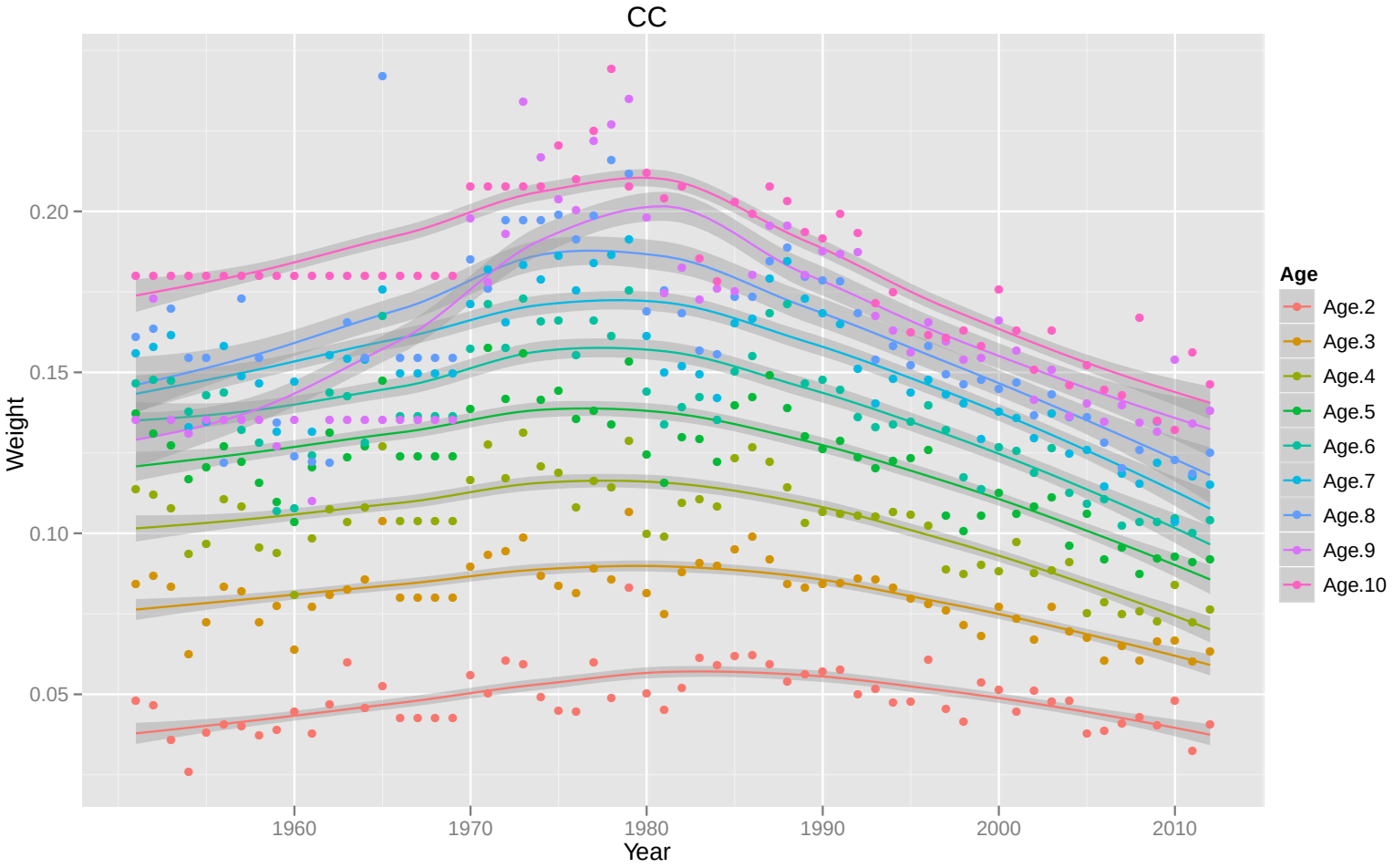


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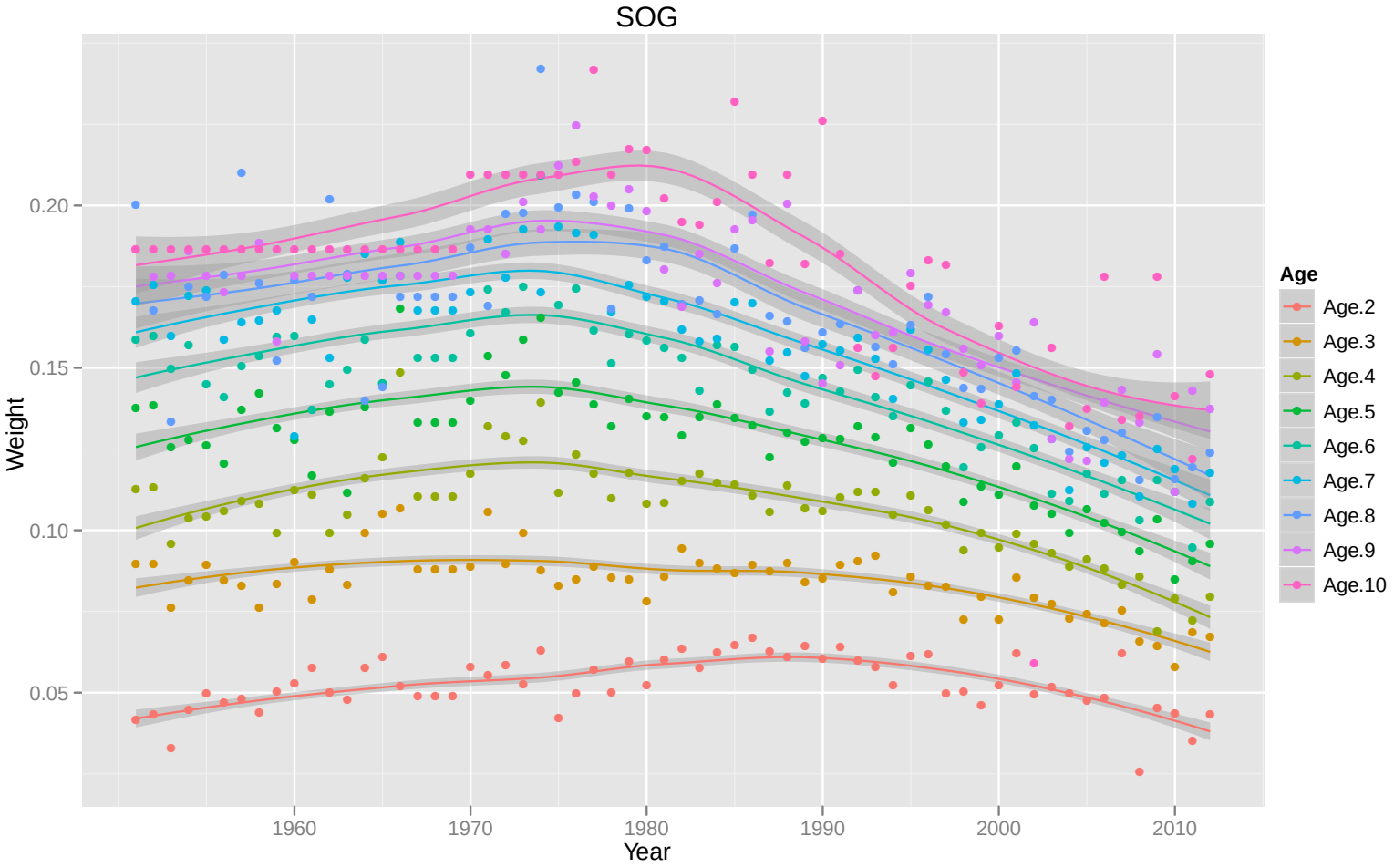


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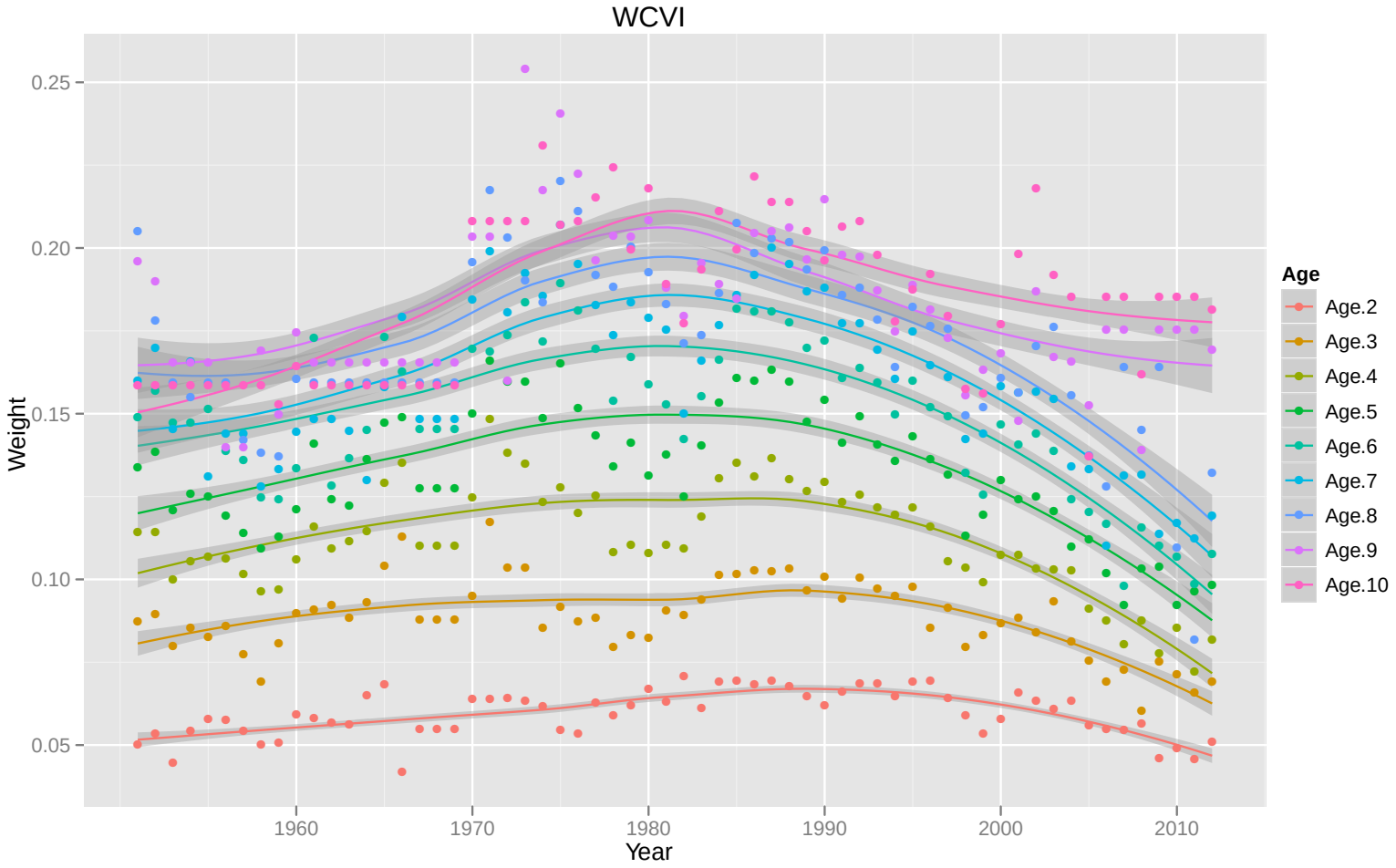


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# Analytics & assumptions

- All major and minor areas were assessed using ${}^{i}\mathrm{SCA}_{\mathrm{M}}$.
- 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.
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- $P(\ln(q_1), \ln(q_2)) \sim \mathrm{Normal}(\mu = -0.569, \sigma = 0.274)$.
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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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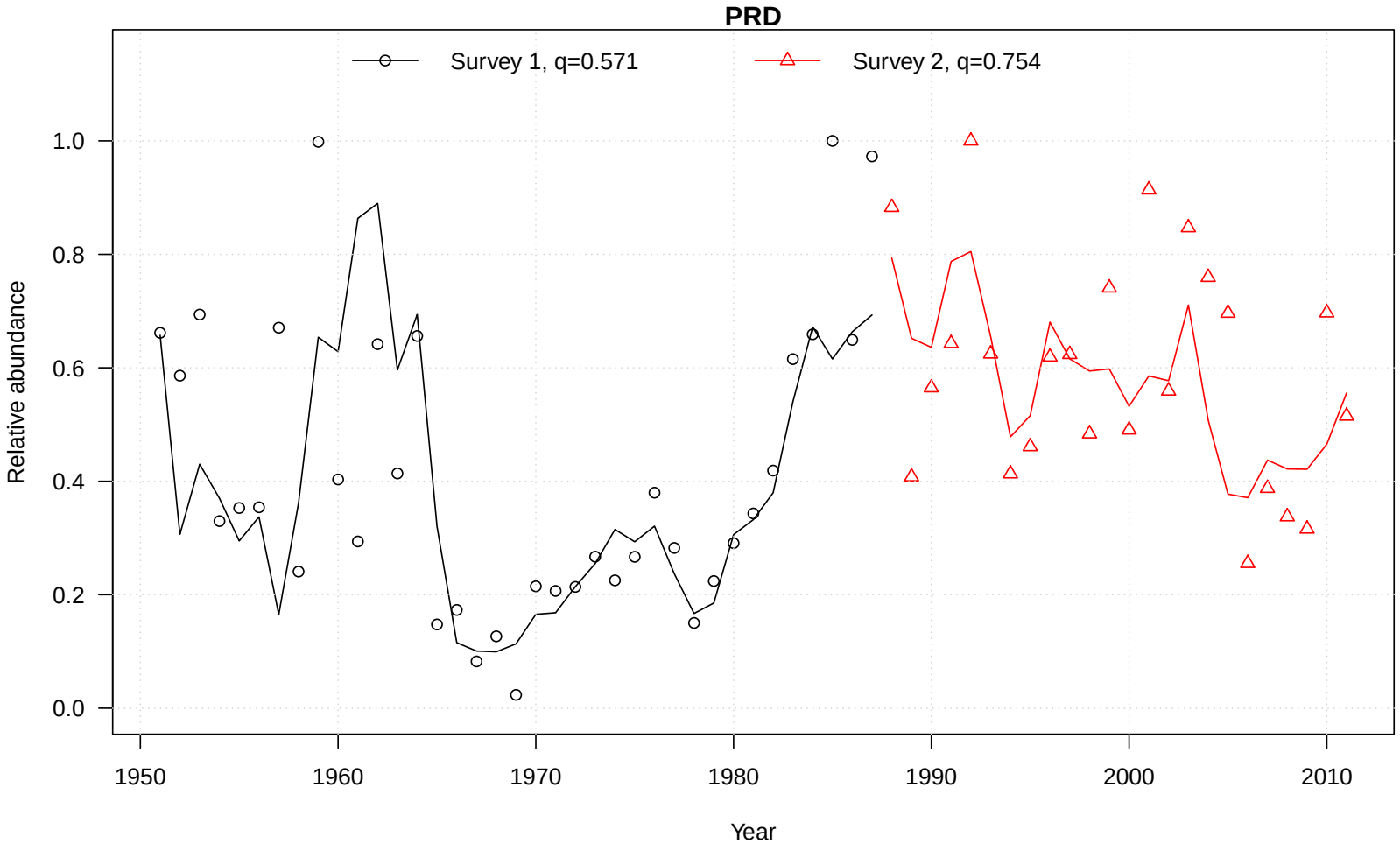


Figure: Prince Rupert District

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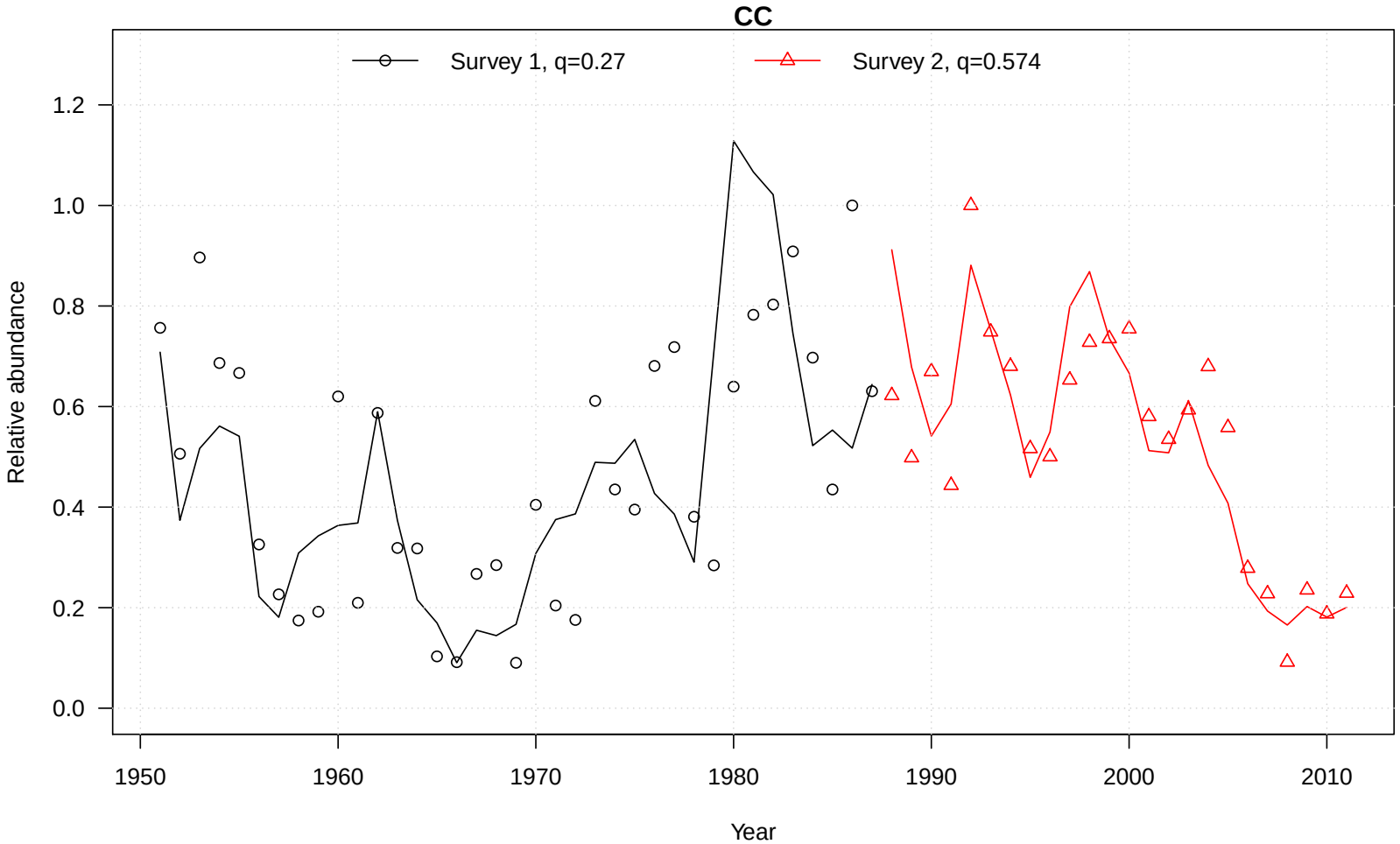


Figure: Central Coast

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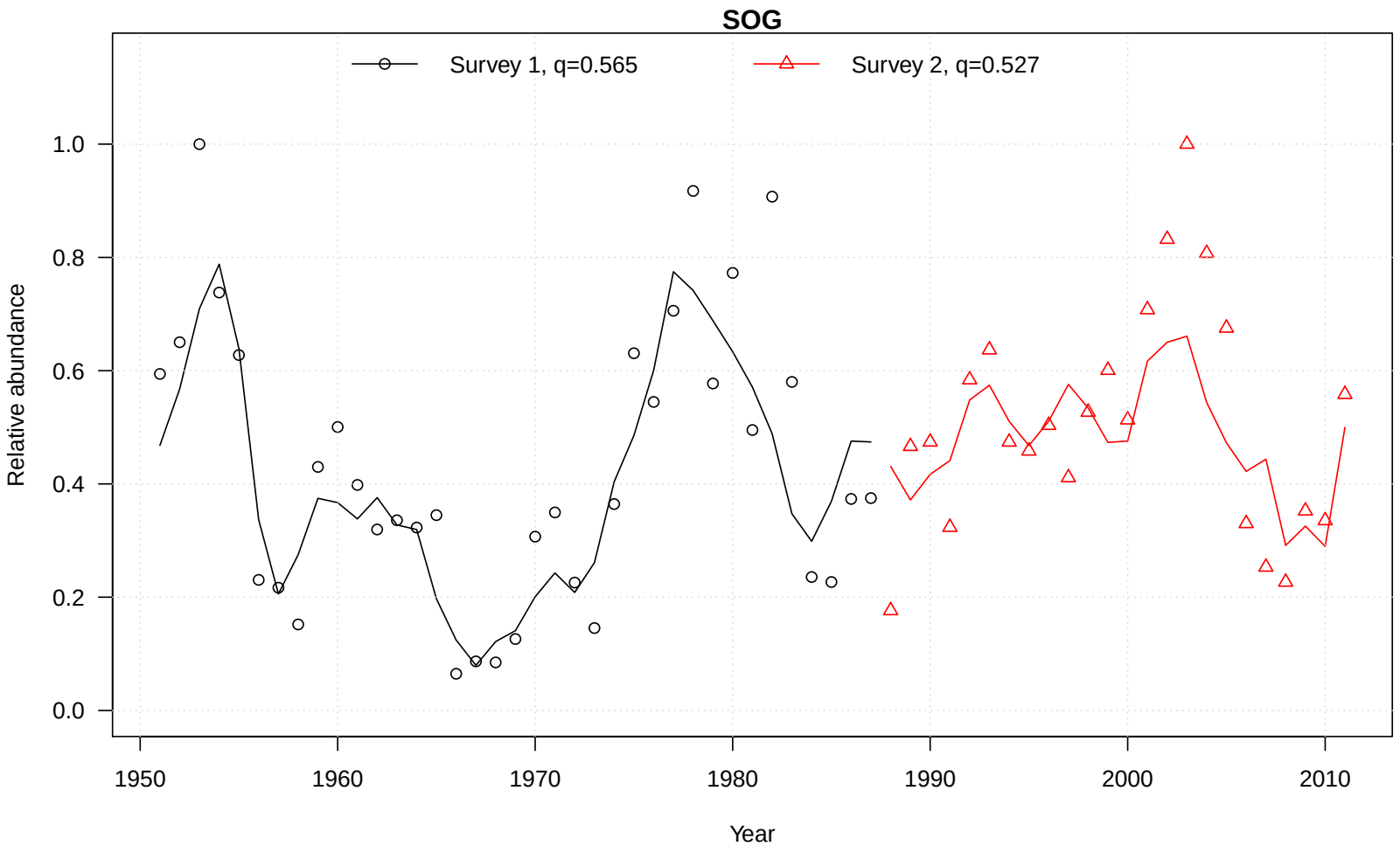


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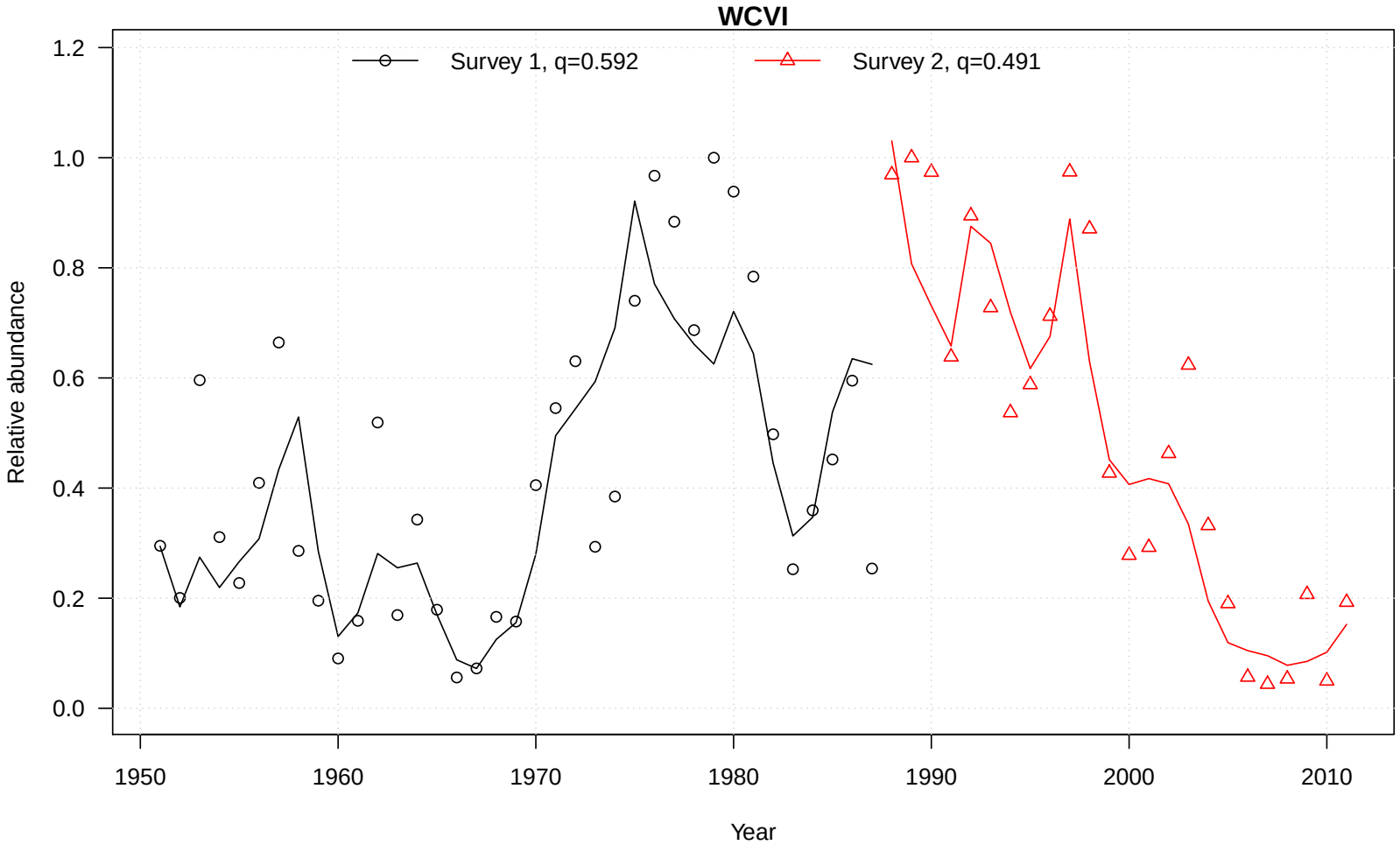
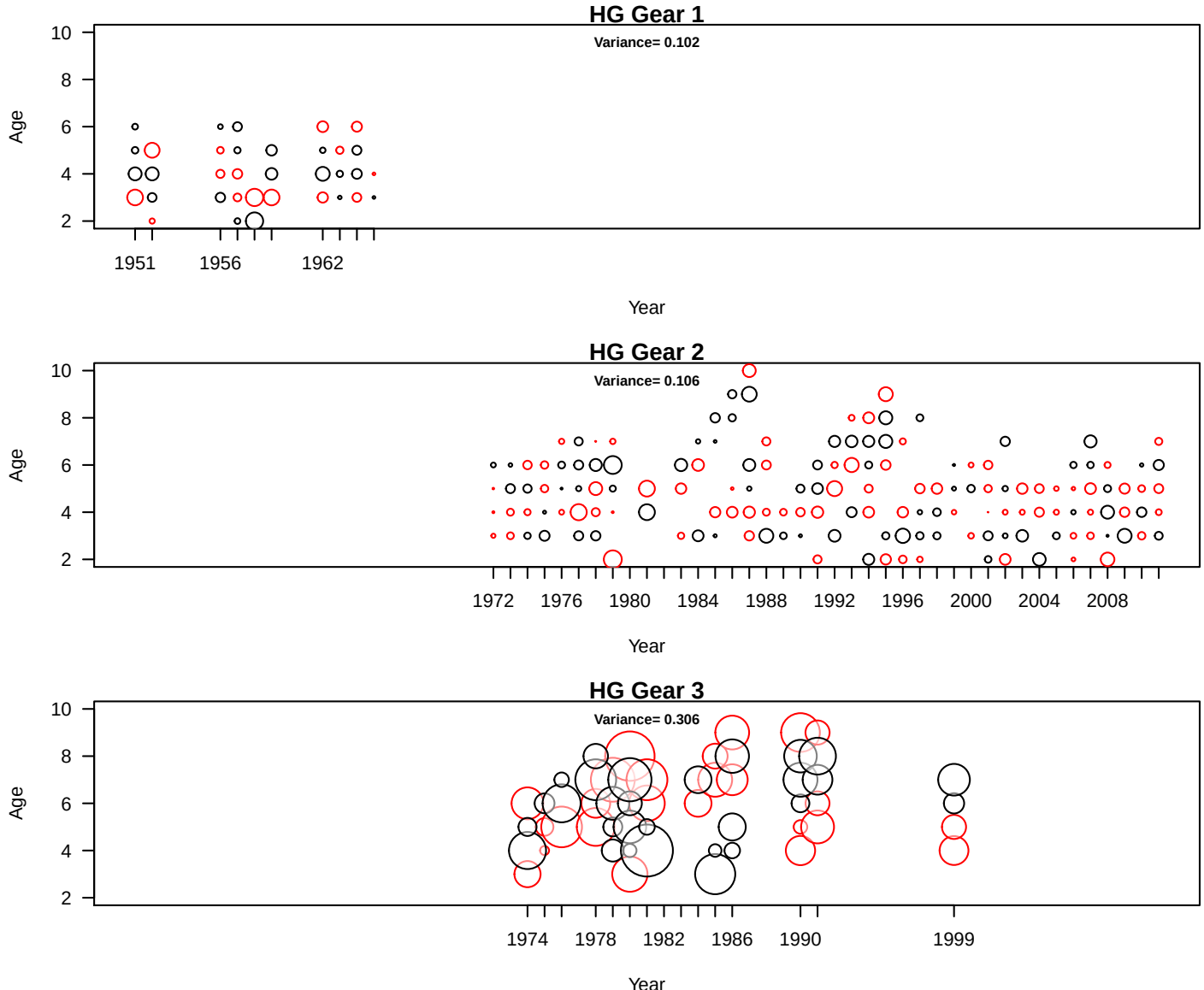



Figure: West Coast Vancouver Island

# MLE: Residuals in age composition data

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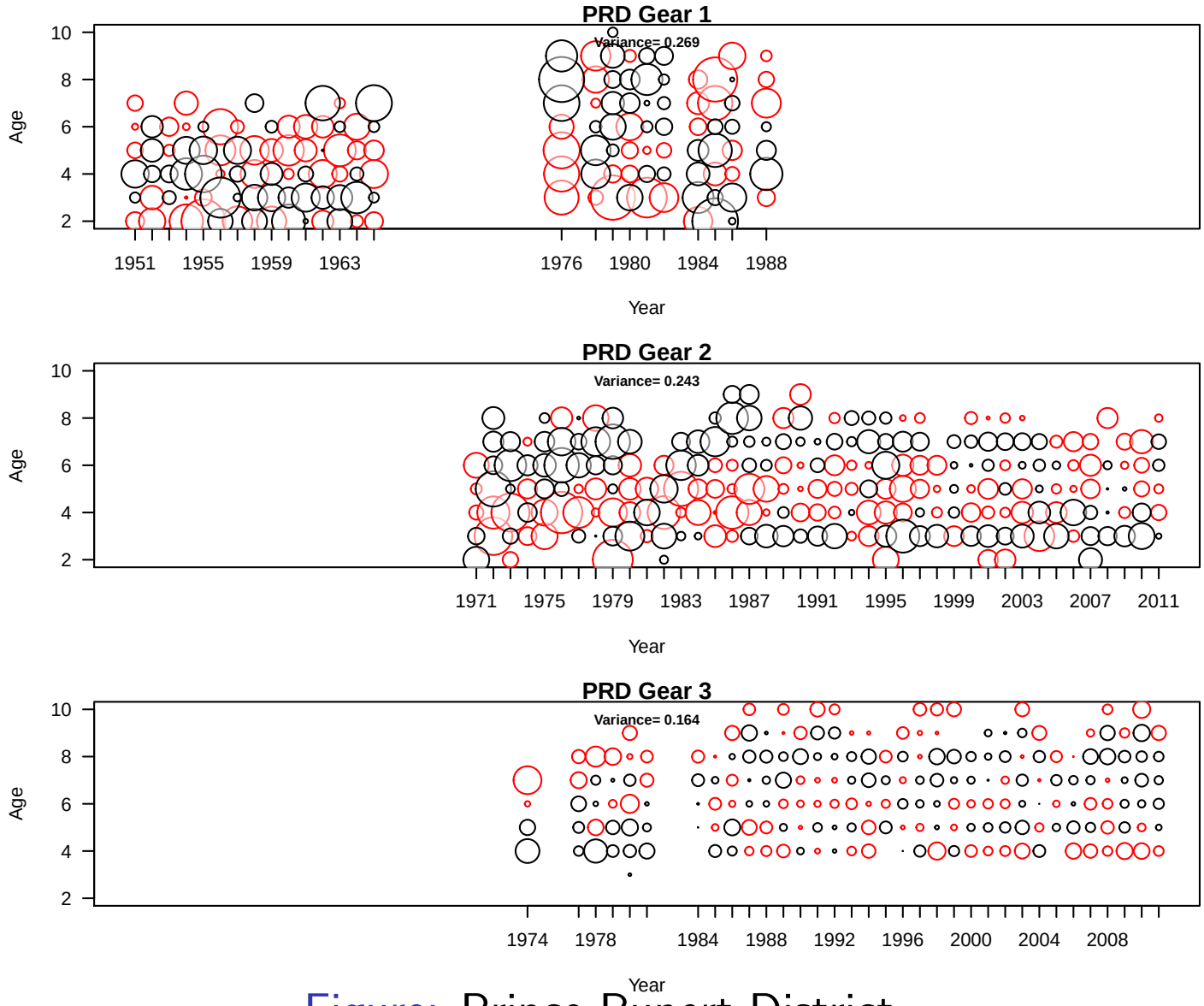


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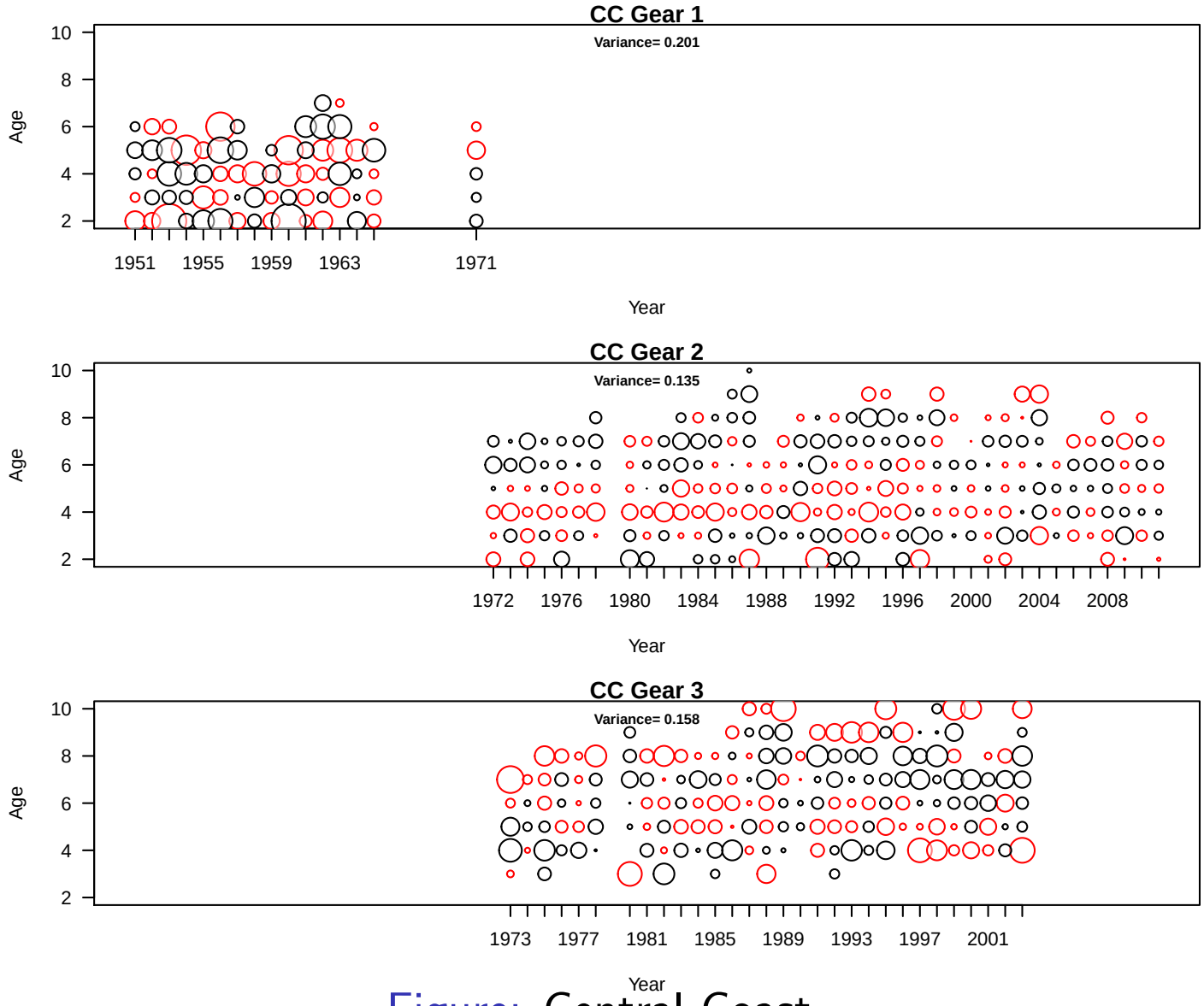


Figure: Central Coast

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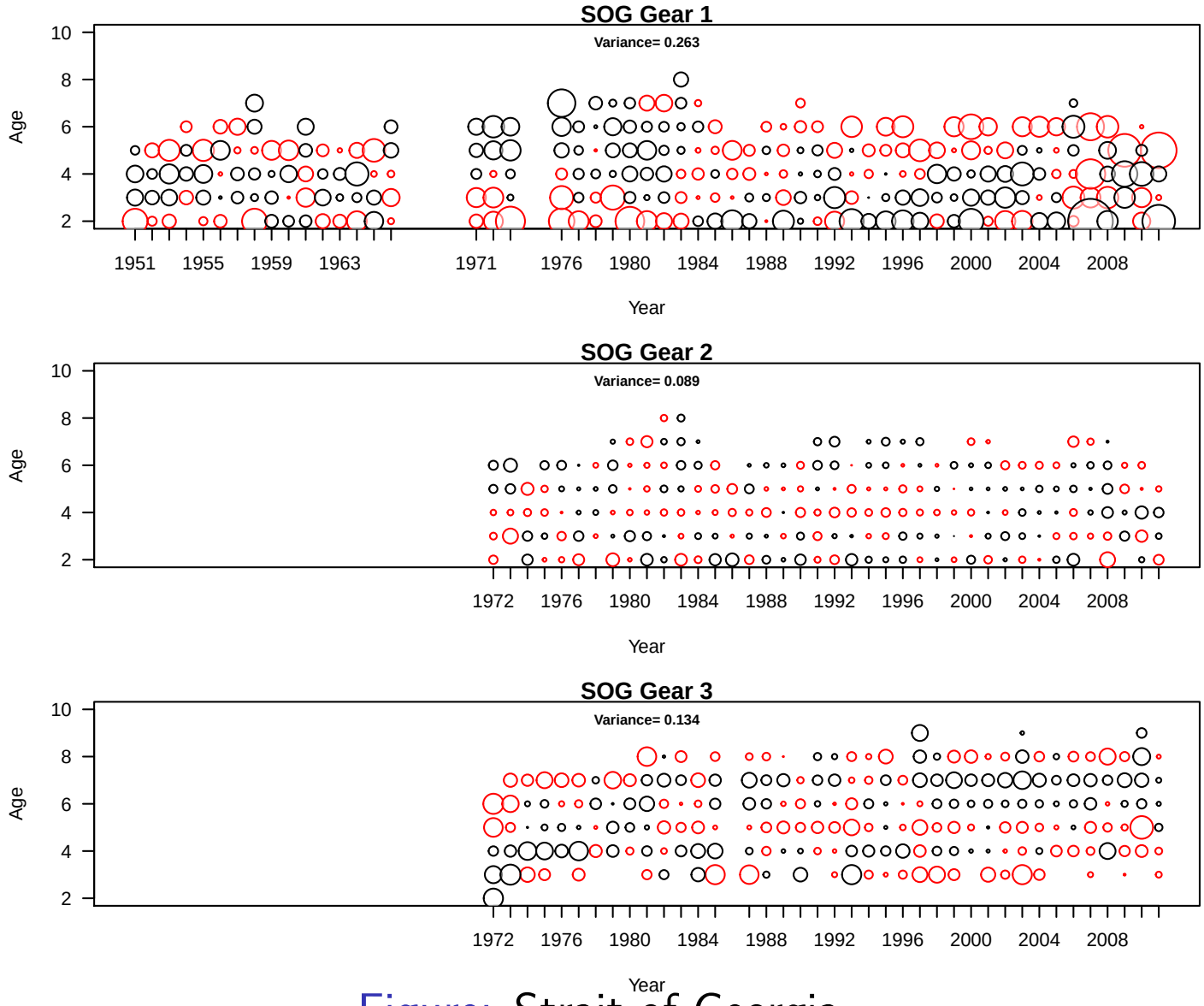


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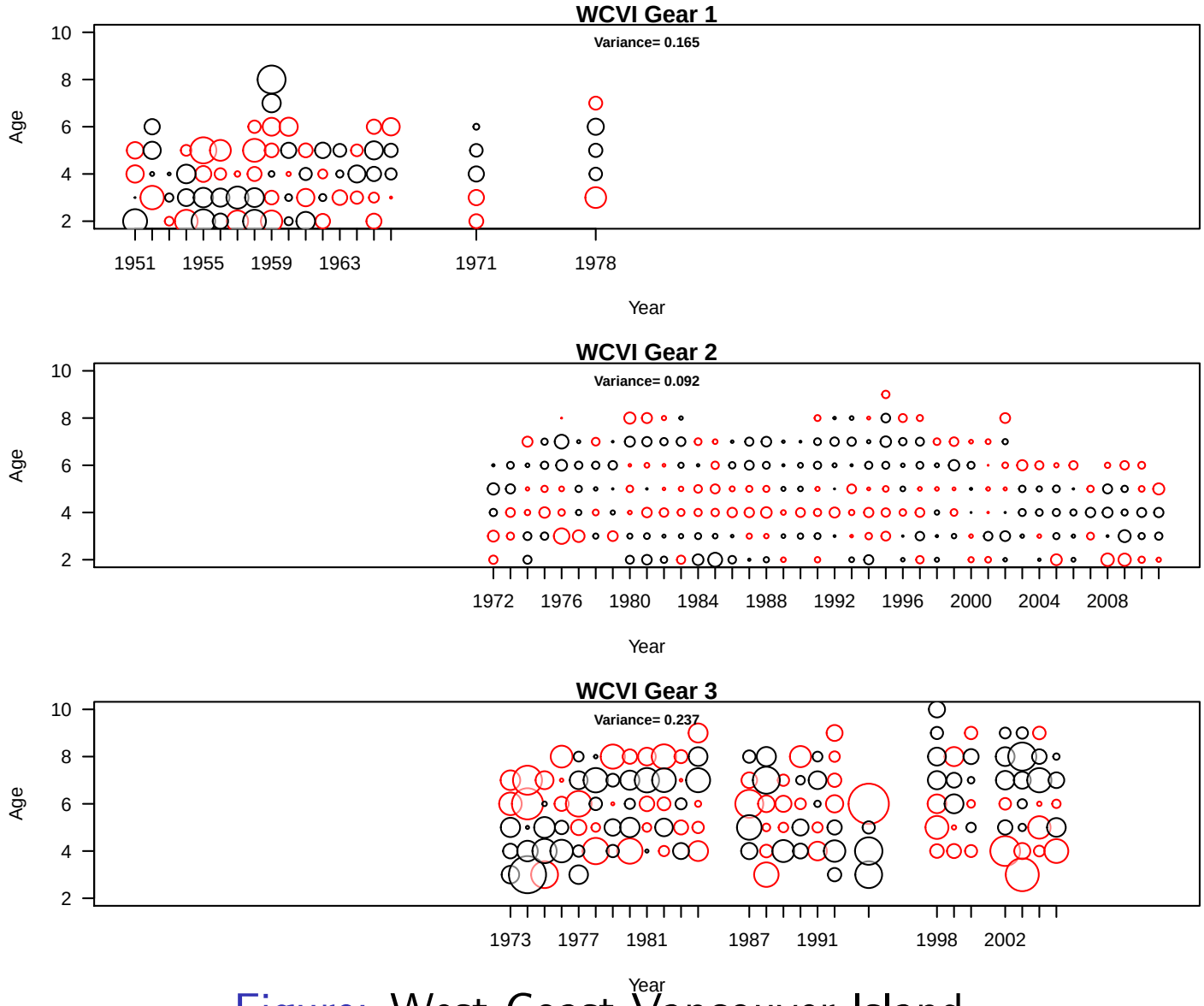



Figure: West Coast Vancouver Island

# MLE: Mortality

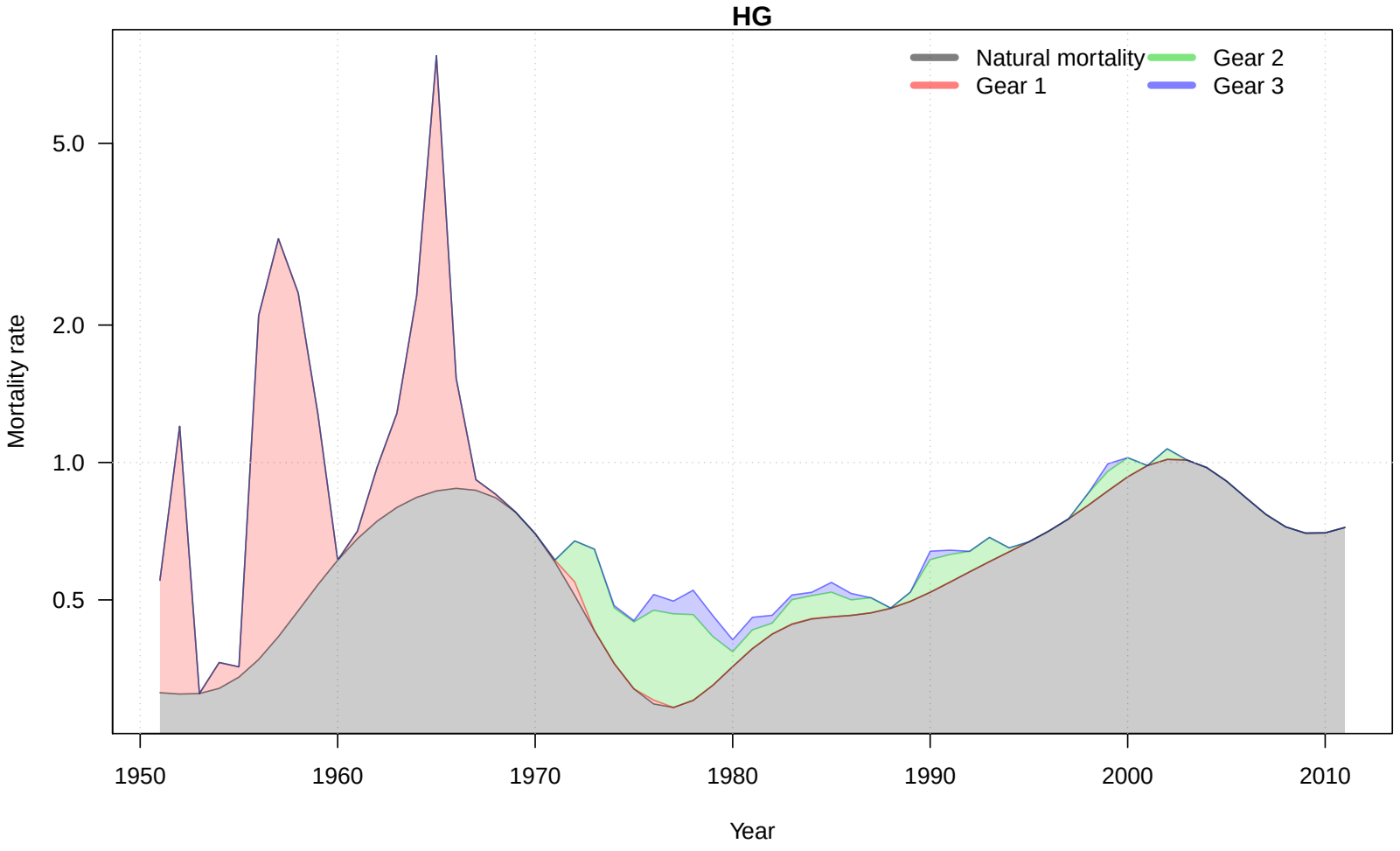



Figure: Haida Gwaii

# MLE: Mortality

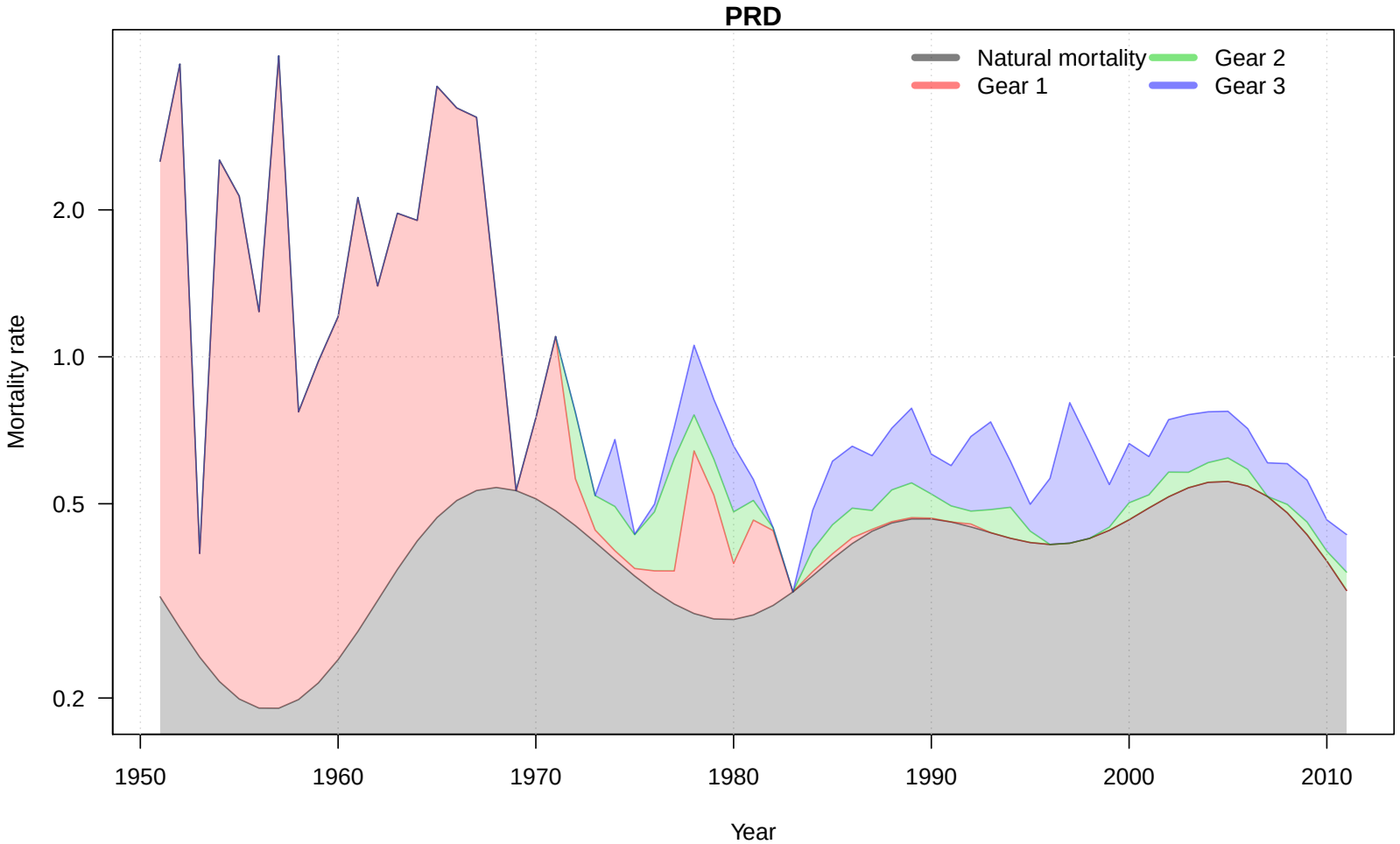



Figure: Prince Rupert District

# MLE: Mortality

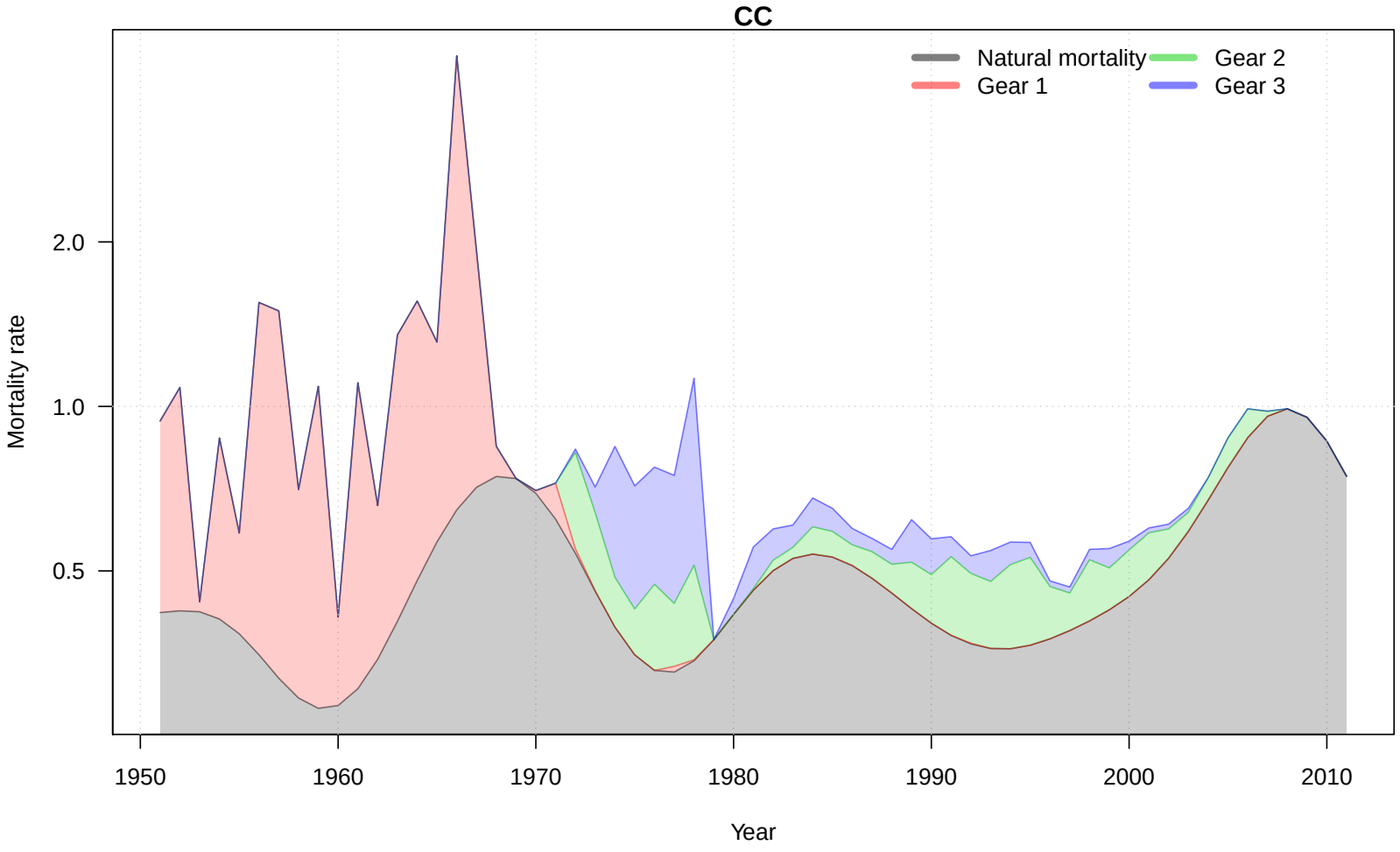



Figure: Central Coast

# MLE: Mortality

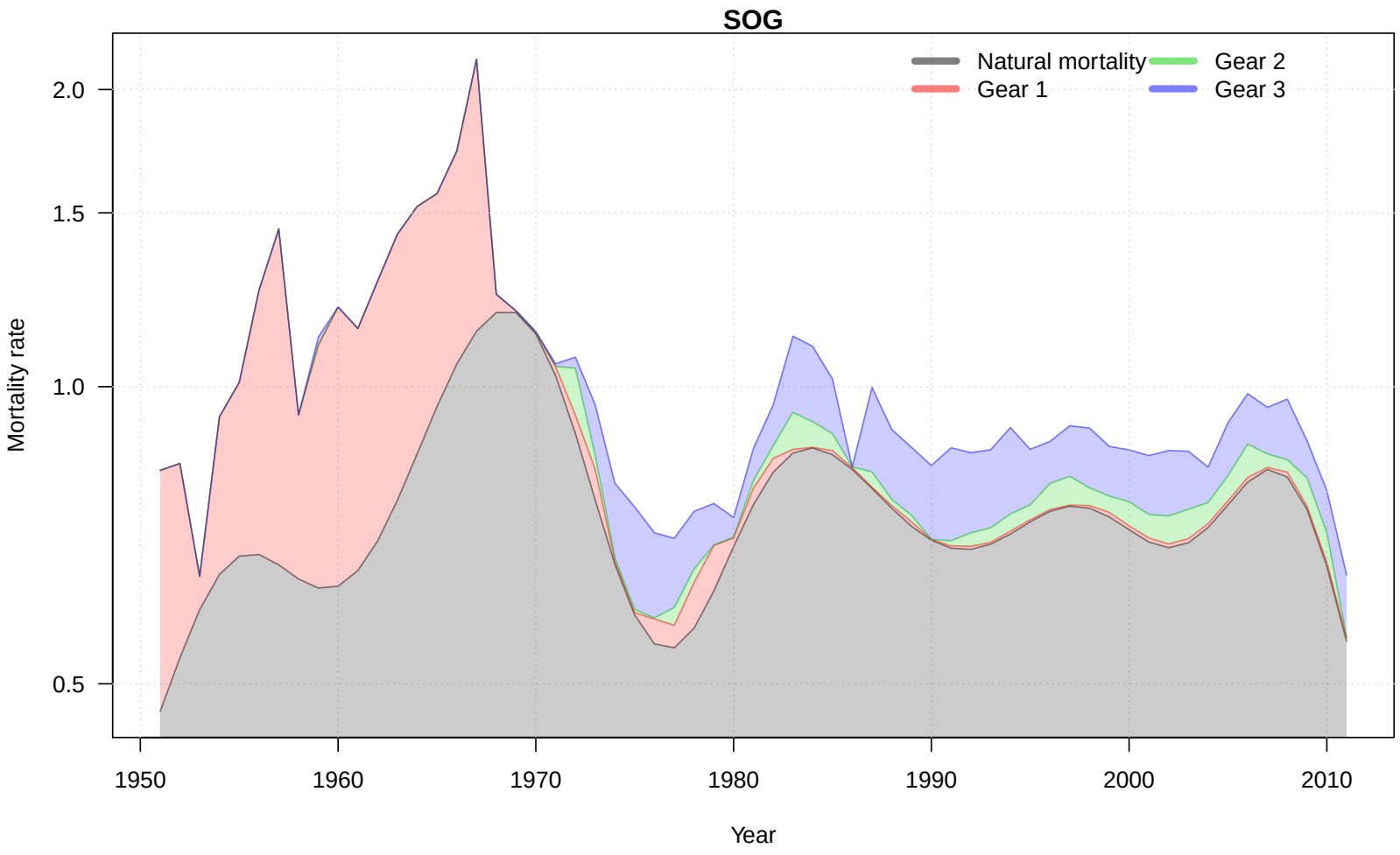



Figure: Strait of Georgia

# MLE: Mortality

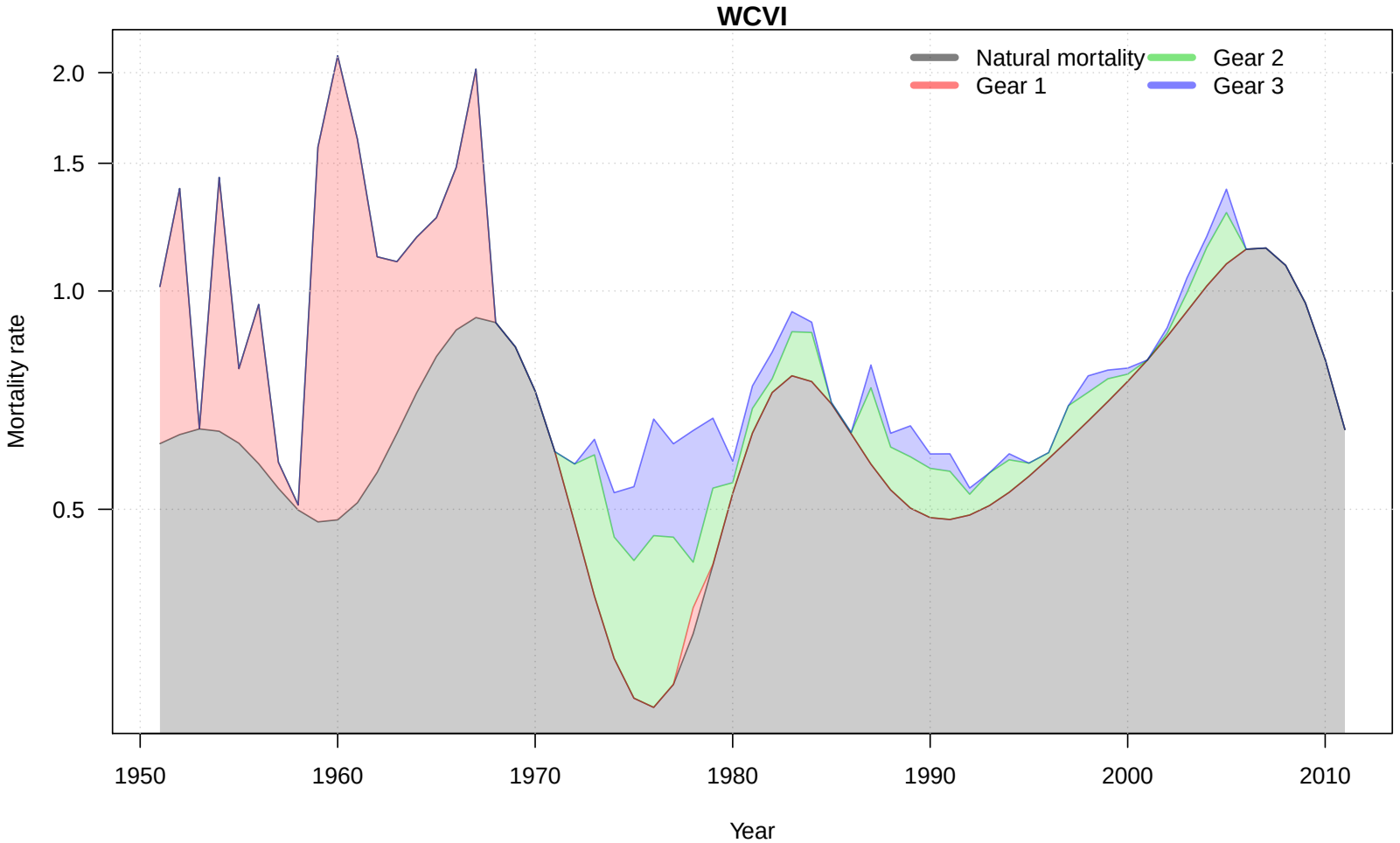



Figure: West Coast Vancouver Island

# Age-2 recruits

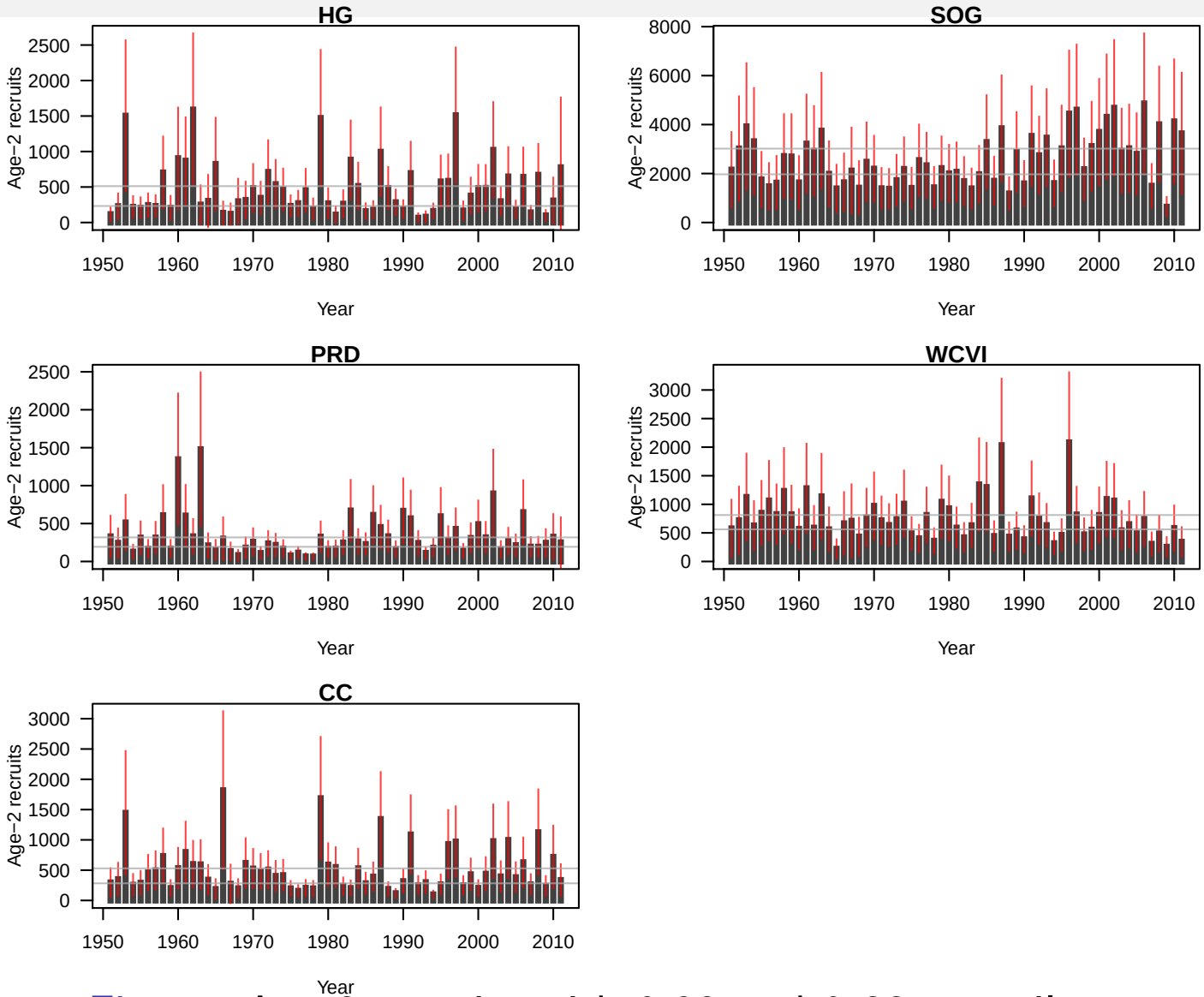



Figure: Age-2 recruits with 0.33 and 0.66 quantiles.

# Diagnostics: Retrospective plots

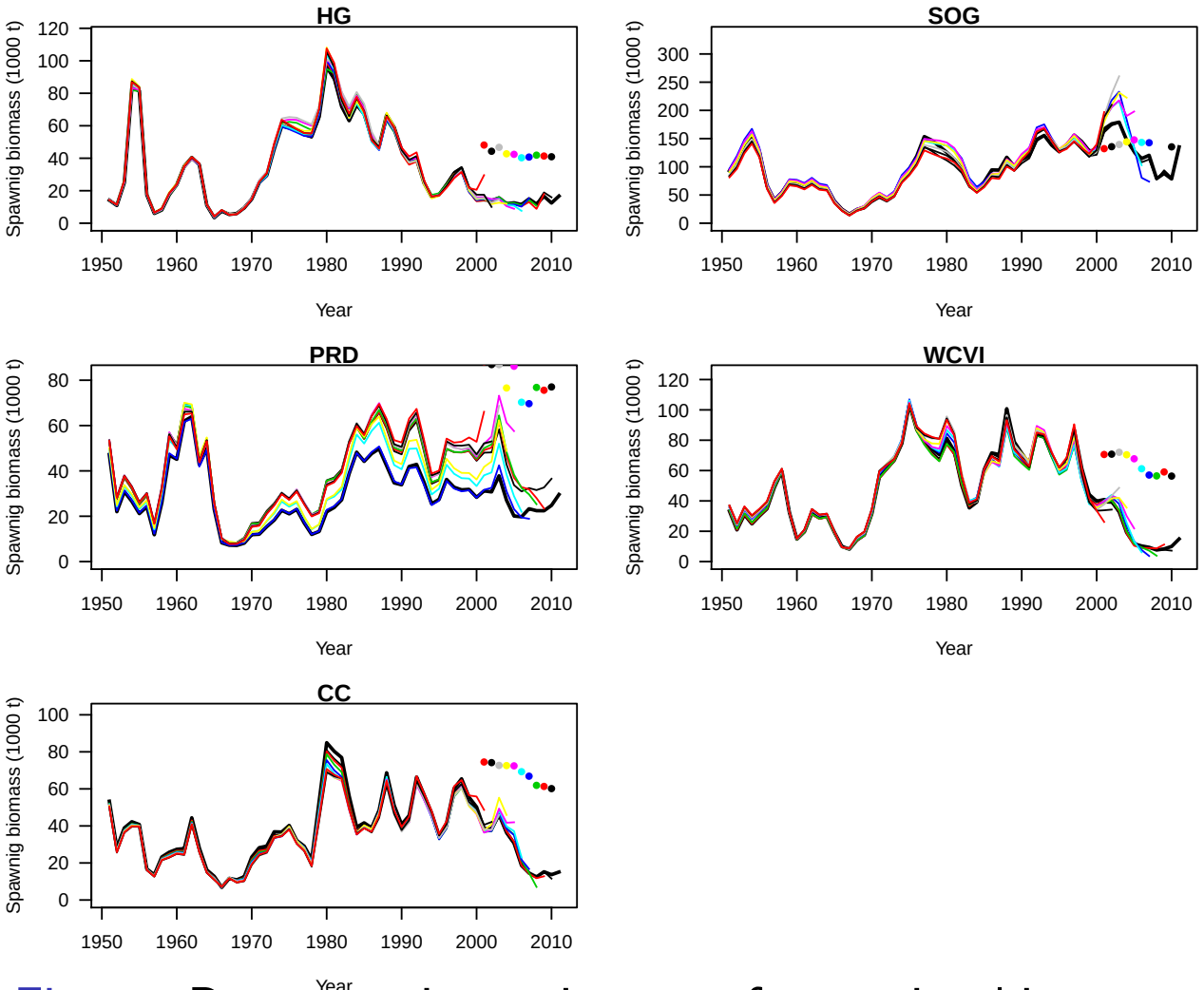



Figure: Retrospective estimates of spawning biomass.

# Diagnostics: Trace plots

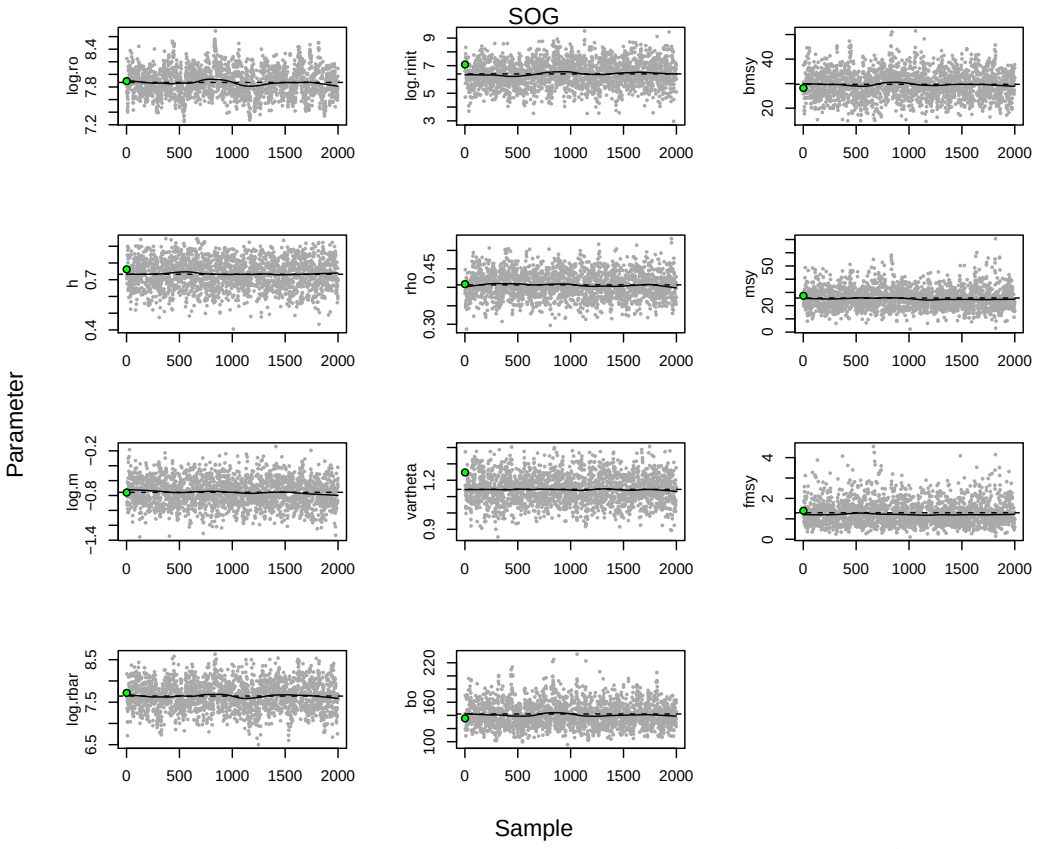



Figure: Posterior samples: 1 million, thin 500, Strait of Georgia

# Diagnostics: Pair plots

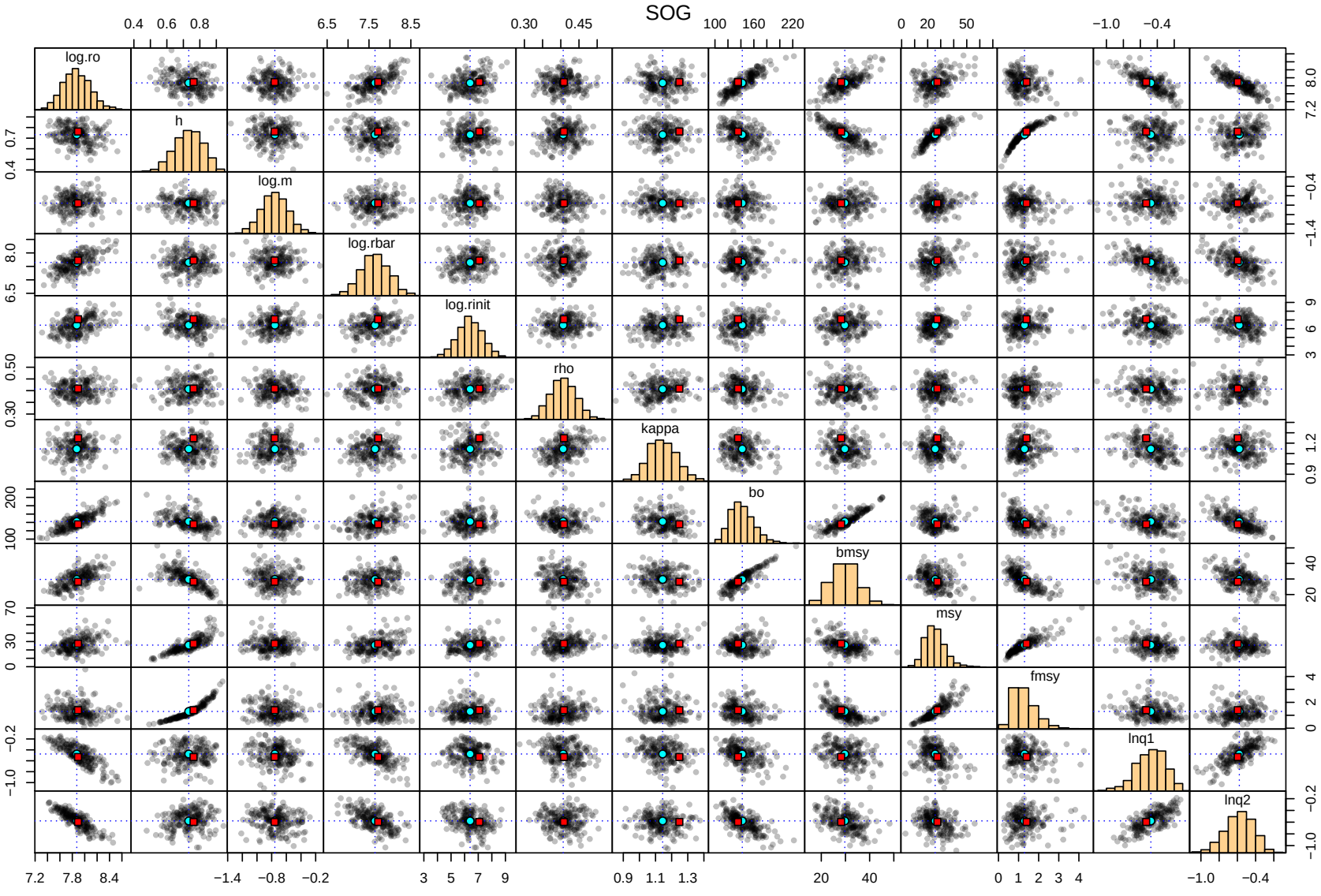



Figure: Posterior samples from leading parameters & derived variables.

# Diagnositcs: Marginal posteriors

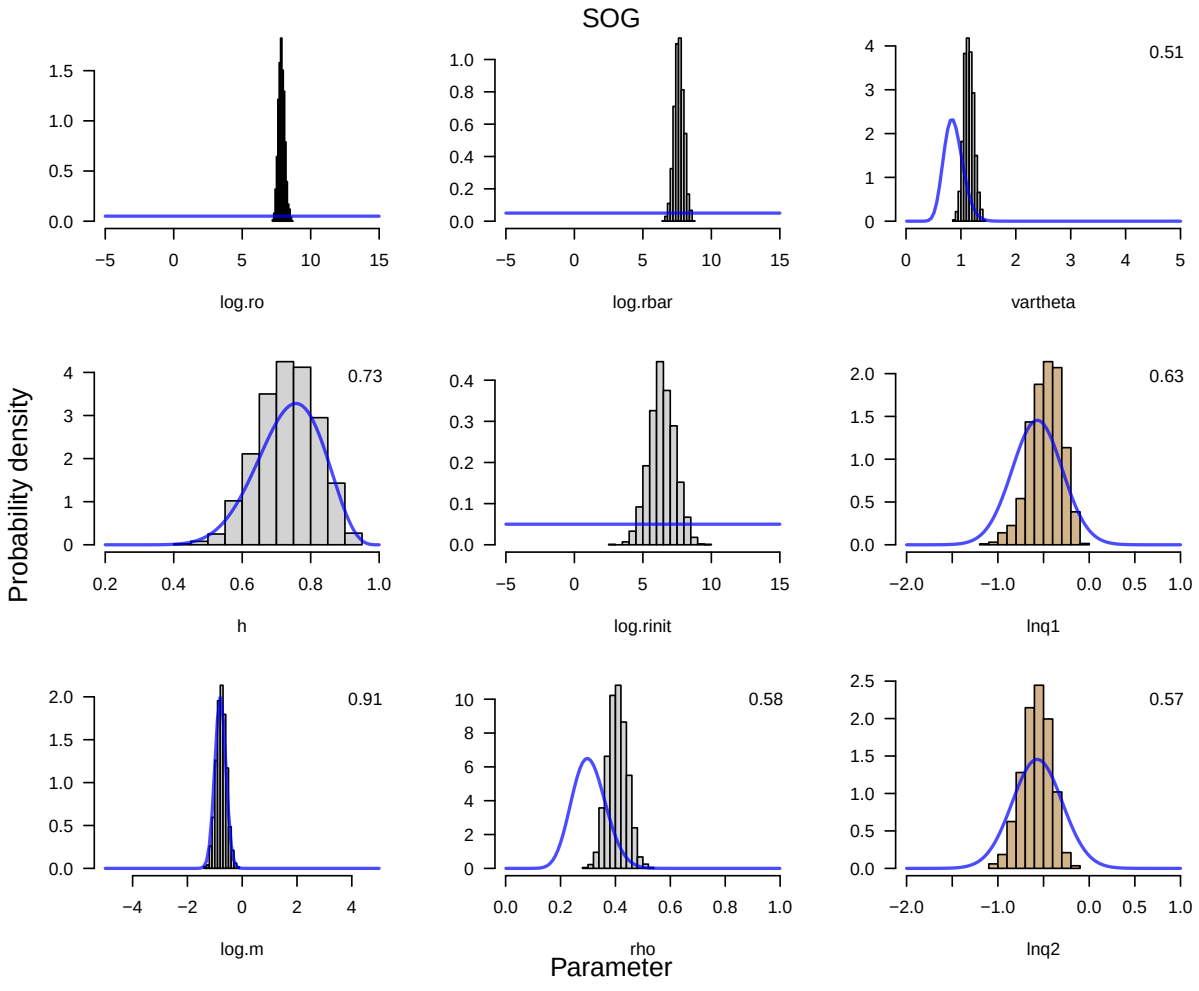



Figure: Strait of Georgia: Marginal & prior distributions.

# Uncertainty in 2011 spawning biomass

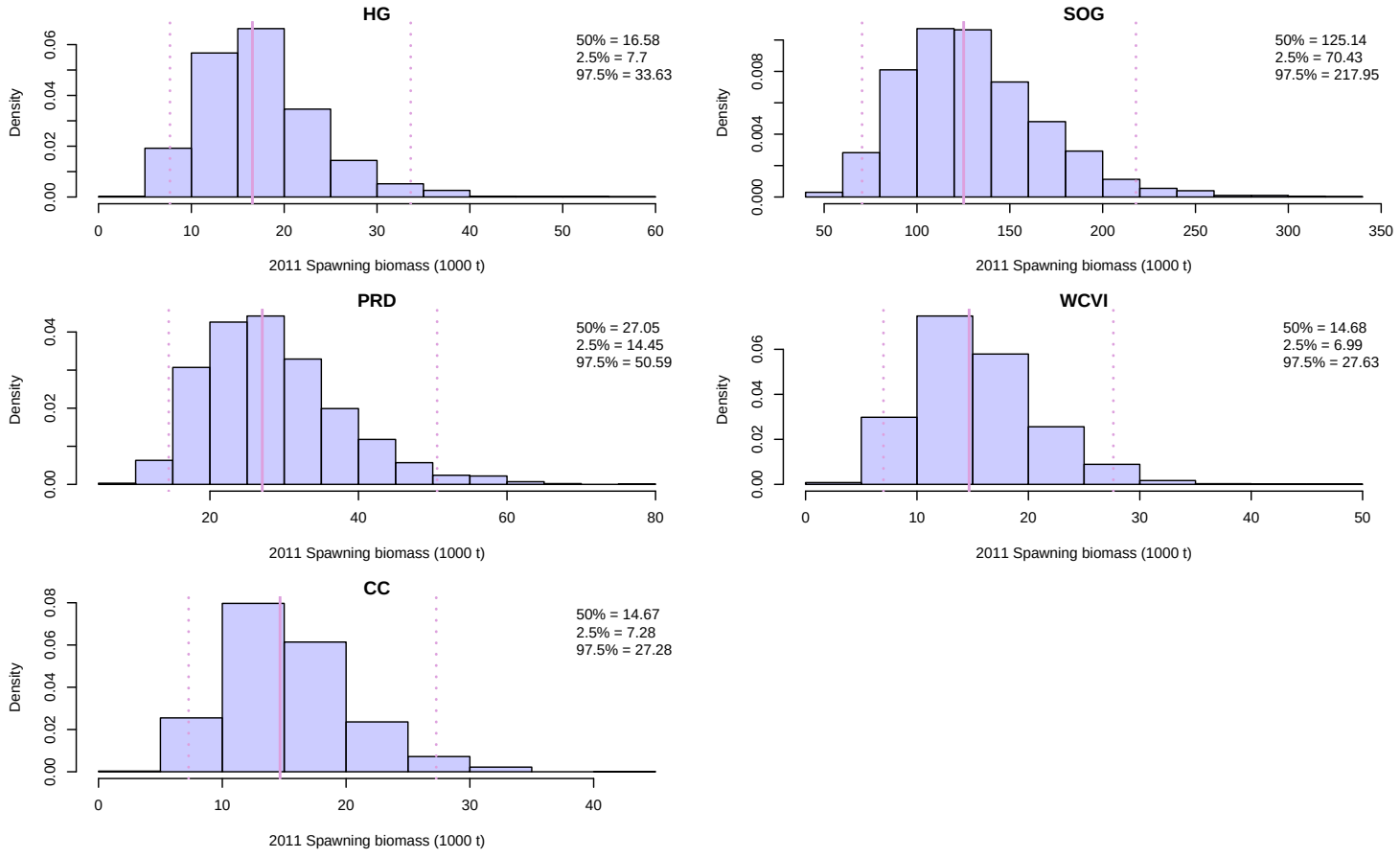



Figure: Marginal posterior distributions for 2011 spawning biomass.

# Uncertainty in 2011 spawning biomass

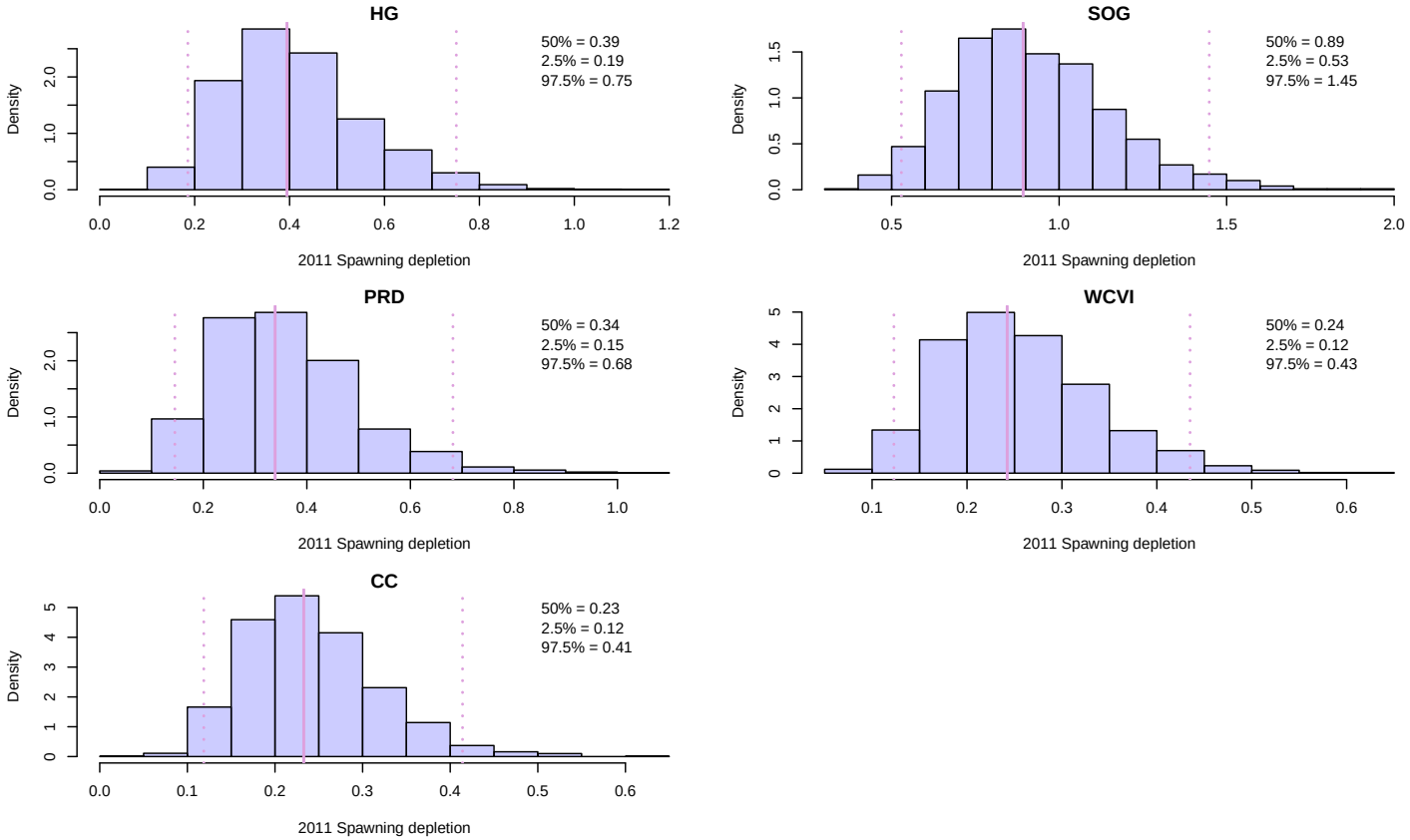
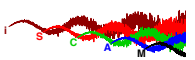



Figure: Marginal posterior distributions for 2011 spawning biomass depletion.

# Uncertainty in 2011 spawning biomass

Table: Estimates of 2011 spawning biomass, $B_0$, and depletion.

| | $SB_{2011}$ | | | $B_0$ | | | $SB_{2011}/B_0$ | | |
|---|---|---|---|---|---|---|---|---|---|
| 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 |



# Forecast: Old cutoffs

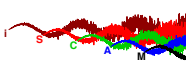
Table: Estimated spawning stock biomass, age-4+ biomass and pre-fishery biomass for poor average and good recruitment, old cutoffs, and available harvest based on median values from the joint posterior distribution.

| | | | **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 $0.25B_0$ 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 |



# Outstanding issues

- Reference points (e.g., $B_0$) based on non-stationary parameters (e.g., $M_t$, selectivity, growth).
- Strong retrospective bias in PRD.
- Formal evaluation of alternative hypotheses.

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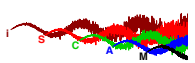

# Risk based decision making

## Considerations

- What is the probability of the stock falling below the cutoff for a given catch option?
- What is the probability of the spawning stock declining?
- What is the probability of the harvest rate exceeding 0.2?

# Probability of something bad happening

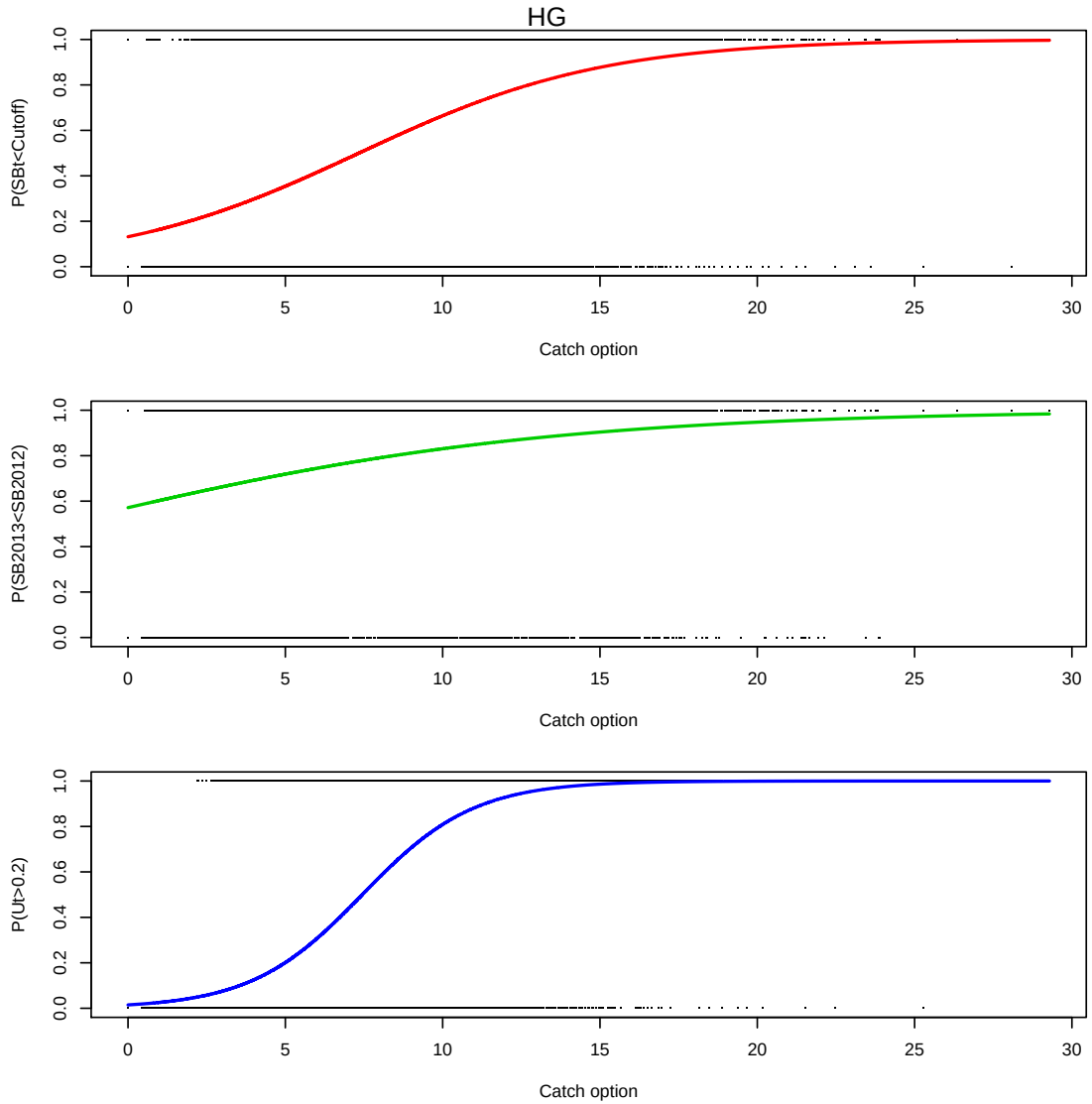


Figure: Haida Gwaii

# Probability of something bad happening

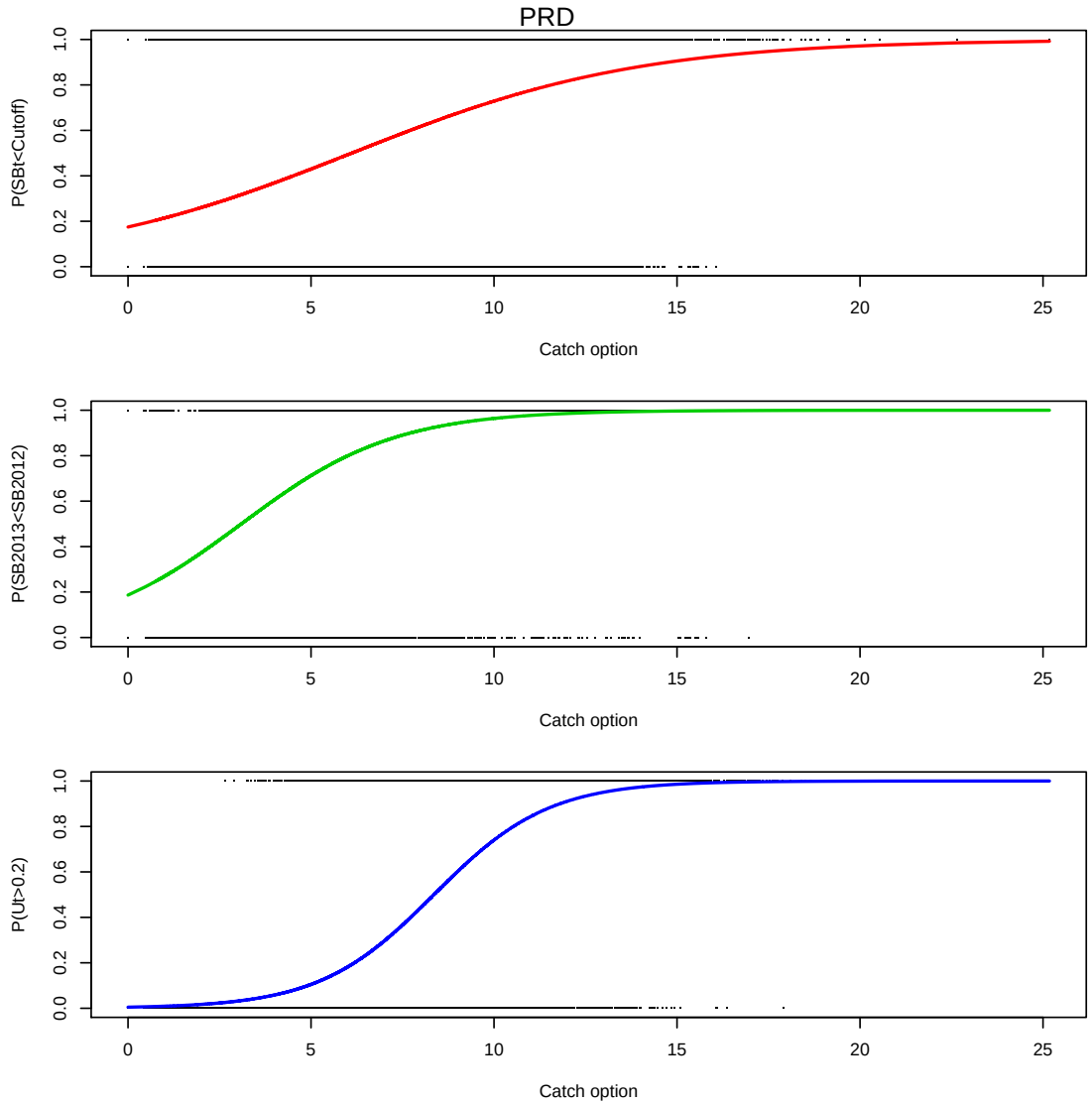


Figure: Prince Rupert District

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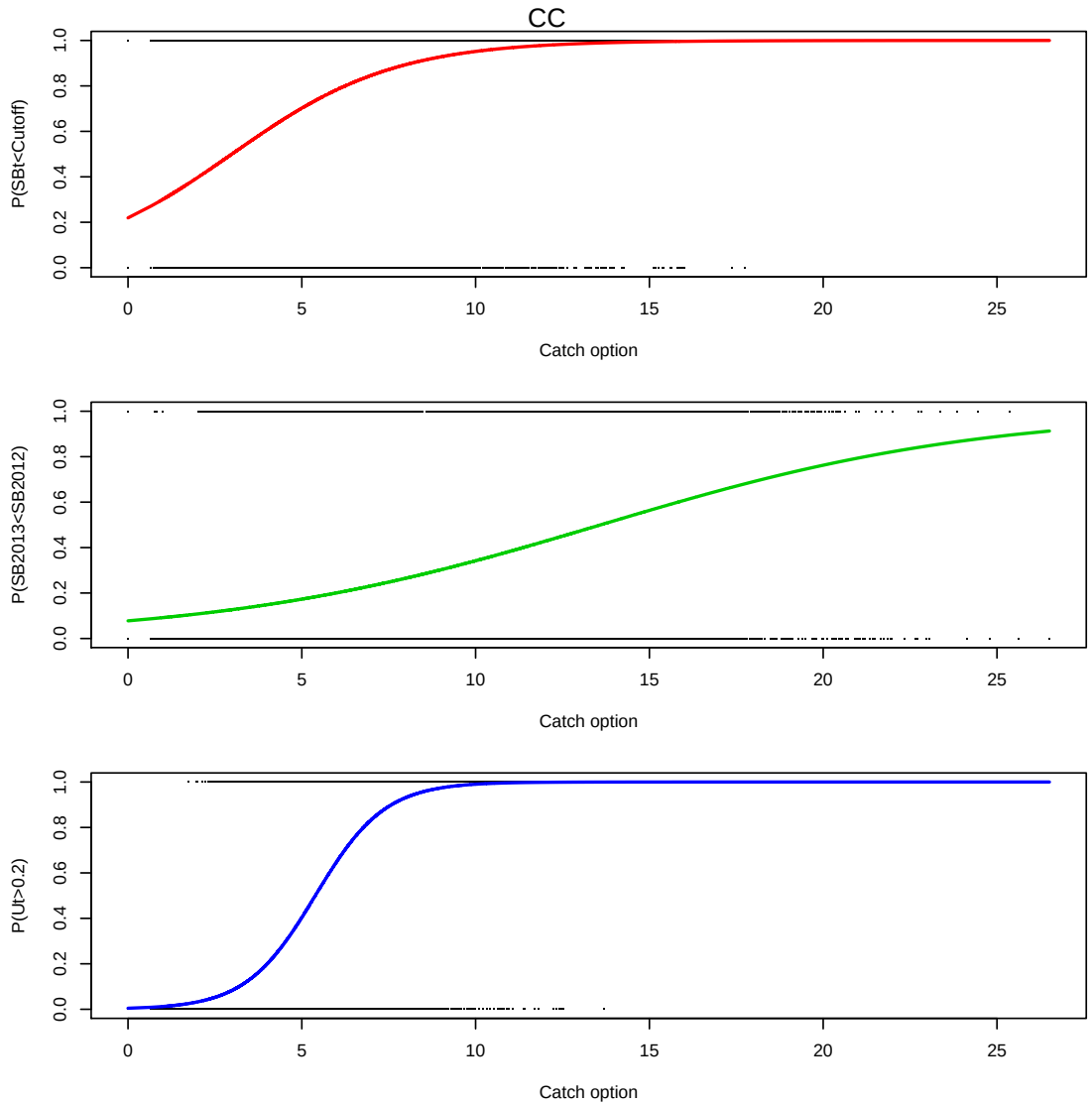


Figure: Central Coast

# Probability of something bad happening

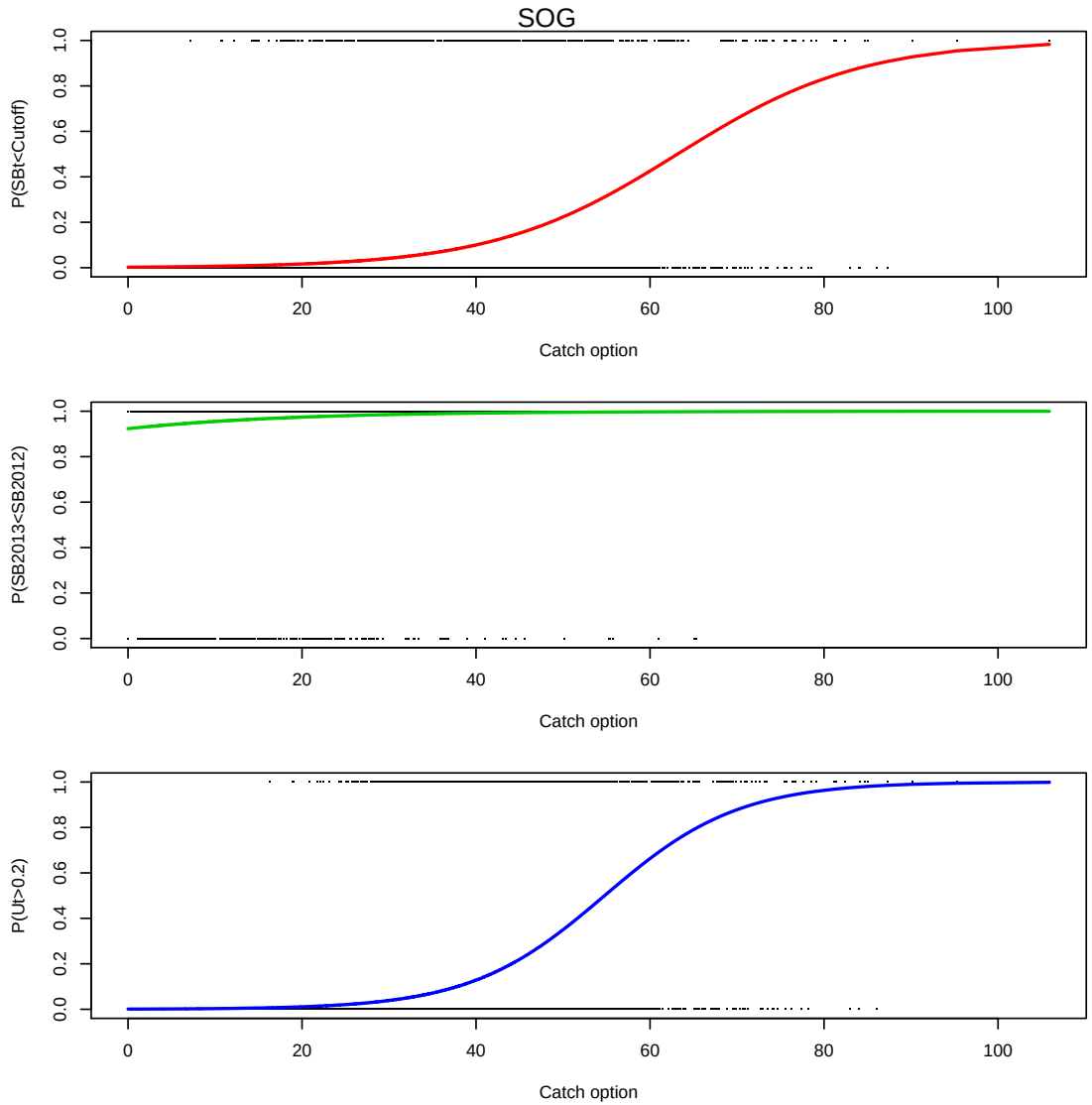


Figure: Strait of Georgia

# Probability of something bad happening

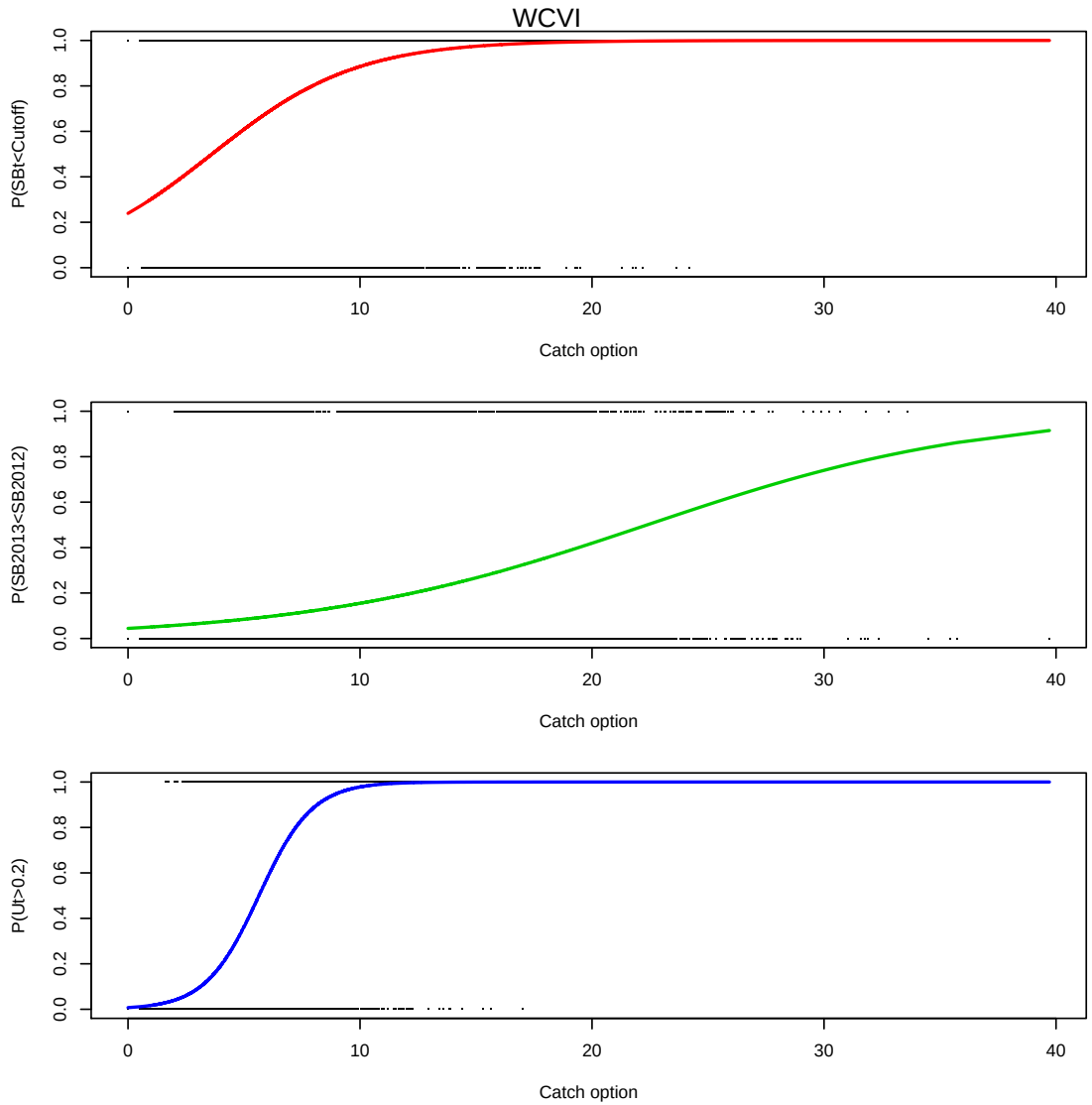


Figure: West Coast Vancouver Island

# Bibliography