Evaluating Fishery Management Reference Points in a Variable Climate

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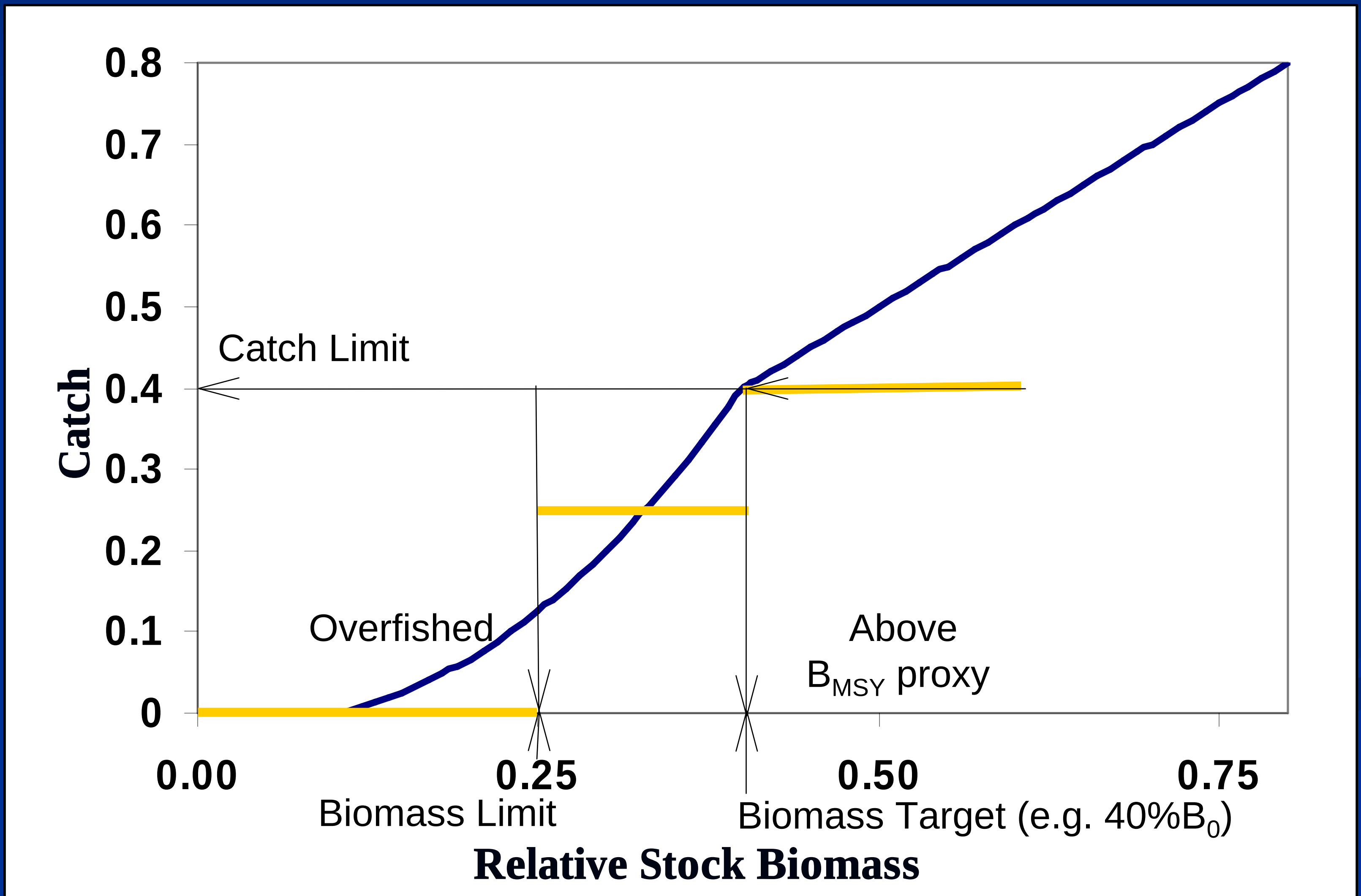
What are Biomass Reference Points?

- A fishing mortality rate or level of stock biomass used by scientists to describe current stock status in relation to a management goal.
  - typically the desired level of a stock.
- Calculated in a standard way.
- Linked to stock productivity.

Example Control Rule: West Coast Groundfish

Control rules include goals, reference points, data, and expected management actions.

Reference points are quantitative measures used in control rules.



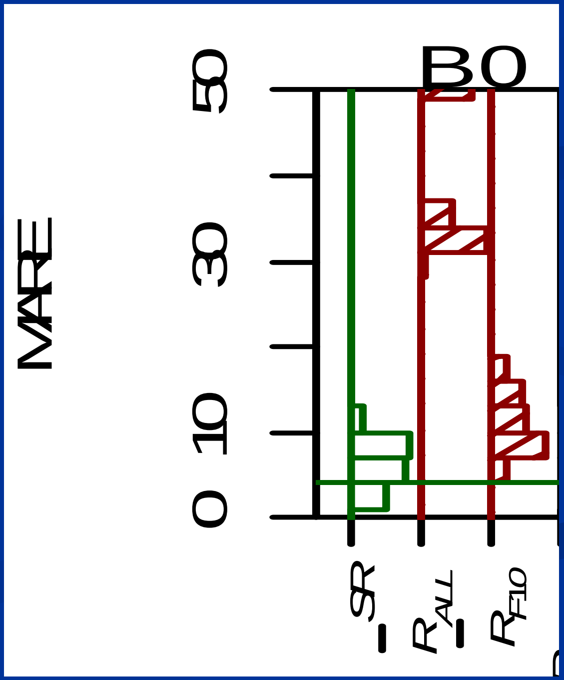
Introduction

- Control rules require estimates of:
  - B_0 (average SSB @ F=0)
  - Current spawning biomass relative to B_0
  - F_{MSY}
- **Low frequency environmental variability, as well as fishing, can impact population abundance, often via recruitment.**
- 2 common ways to estimate B_0 depend upon:
  - Average Recruitment
  - Stock-Recruitment relationship
- BRPs are often treated as exact but realistically BRPs have some level of uncertainty.
- Need measures of BRPs which are robust to environmental forcing (i.e. unbiased and precise)

Previous Simulation Study:
Predicated upon a stationary stock-recruitment relationship
Fit the stock-recruitment model inside the stock assessment model

- Factors
  - Life history, Recruitment Variation
  - Data Quantity and Quality:
    - Observation Error, Age-composition sample size, length of the catch time series, and length of the survey.

- Main Conclusion
  - B_0 and stock depletion are best estimated with the stock recruitment estimators.
  - B_0 and stock depletion are poorly estimated with the average recruitment estimators



Objective

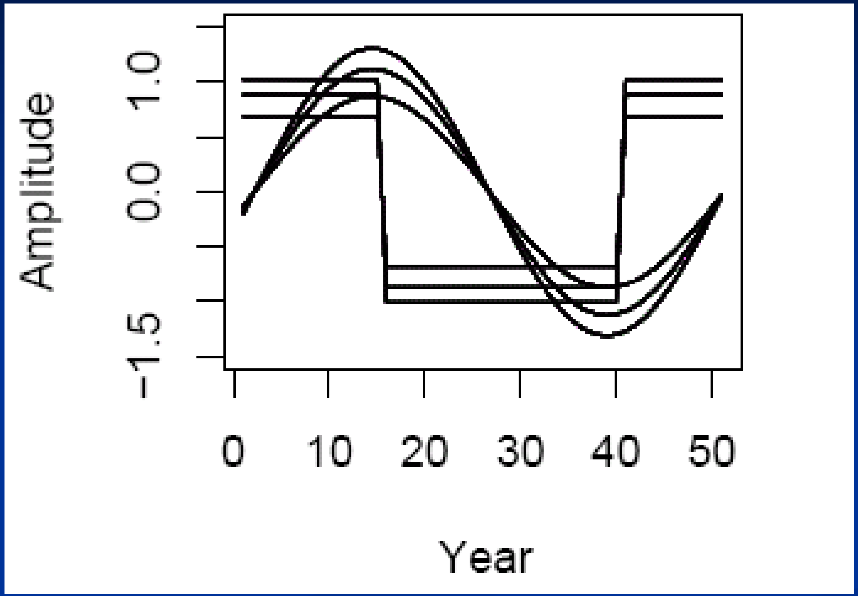
- Explore the performance of alternative estimators given climate forcing via the stock-recruitment function:
  - B_0 (average unfished biomass)
  - Stock Depletion: Current biomass relative to B_0 (B_{last} / B_0)
  - h
  - F_{MSY}
- Groundfish life histories
  - Rockfish
  - Flatfish
  - Semi-pelagic Gadid

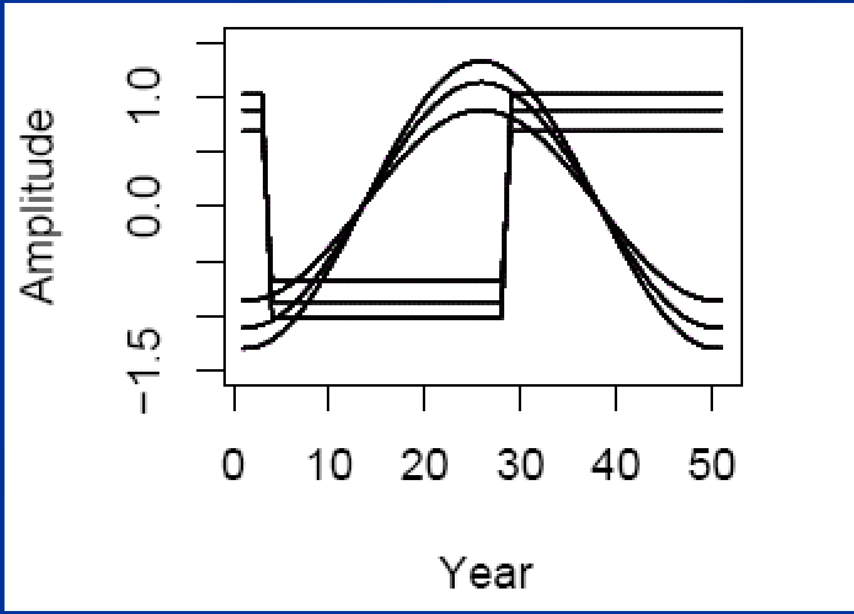
The Operating Model: Defining the True State of the System

- Age-structured
- B-H Recruitment (with variability & climate forcing)
- Biological Information –
  - Selectivity (logistic), Weight, and Fecundity at Age
  - Natural mortality (M)
  - Steepness (h)
  - Stock depletion (Bcurr/B0)
- Burn-in = 400 years
- Sampling (with variability)
  - Survey Index of Abundance
  - Survey and Fishery Age Compositions

The Operating Model: Climate Forcing Function

- Deterministic
  - Sine or Step Function
  - Vary where data begin to be collected in relation to the climate forcing function
- 25 year period
- Calculate B_0 using 4 full cycles of the climate forcing function





The Operating Model: Climate Impact on Recruitment

- Allow the deviation about the stock-recruitment relationship to be a function of an environmental variable.

$$N_{y,0} = \frac{4\,h\,R_0\,B_y}{(1-h)B_* + (5h-1)B_y} e^{\varepsilon_y - \sigma_R^2/2}$$

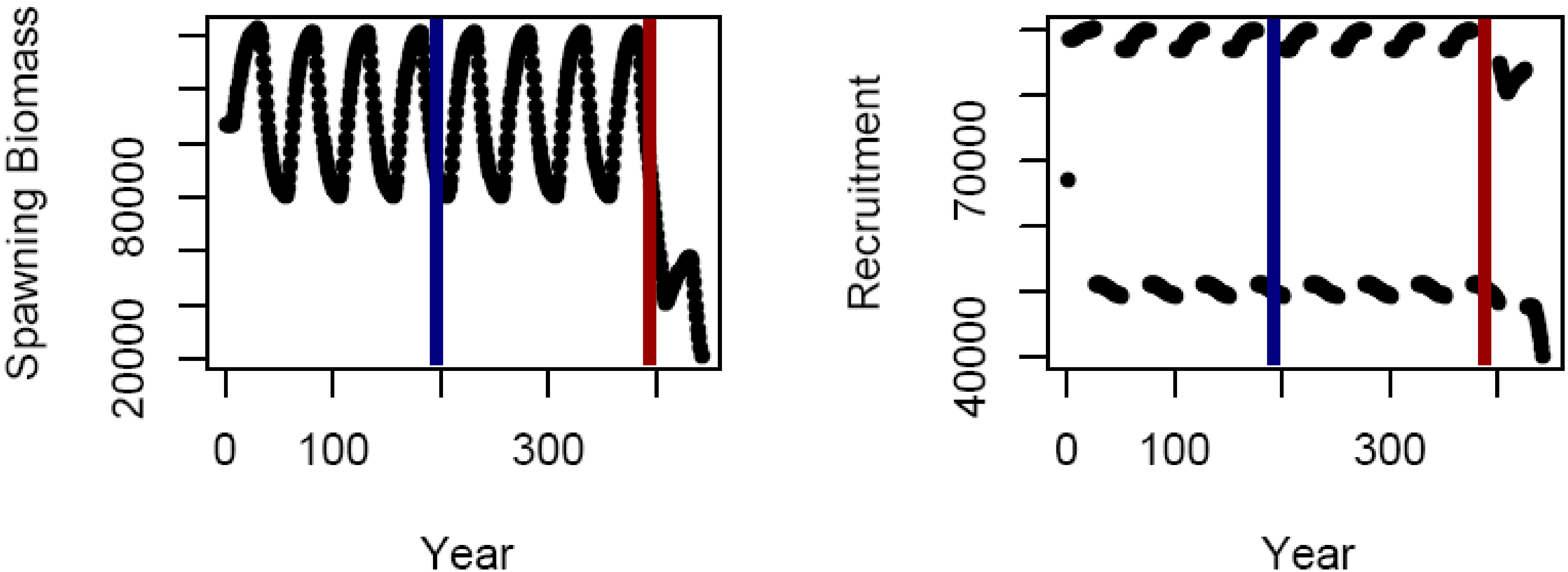
$$\varepsilon_y = \overline{p}E_{y-1} + \eta_y \qquad \eta_y : \quad N(0, \sigma_R)$$

- Specify the total variance to be composed of two components:
  - Deterministic climate function
  - Random variability

$$\sigma_\eta^2 = \sigma_E^2 + \sigma_R^2$$

- Each component contributes ½ of the total variance.

The Operating Model:
Example Population (without error)



The Estimation Model

- Age structured estimation model with an integrated stock-recruitment relationship
  (i.e. same structure as the operating model)

- Estimated quantities
  - B_0, h, environmental link to the stock-recruitment relationship, F_{MSY}
  - Time series of spawning biomass, recruitment and fishing mortality
  - Selectivity functions for the survey and fishery

Alternative Estimation Methods

Three alternative methods of stock assessment are considered:

1. Estimate the annual recruitments, use the estimates of spawning biomass and recruitment to estimate the parameters of a stock recruitment relationship external to the stock assessment. (abbreviation “M_0”)
2. Include the fit of a stock-recruitment relationship inside the stock assessment model. (abbreviation “M_{SR}”)
3. Include the fit to a stock-recruitment relationship which includes the environmental data inside the stock assessment model (Maunder and Watters 2003). (abbreviation “M_{SRE}”)

Alternative Reference Point Estimators

Estimator Description	B_0 and Depletion
Stock-recruitment relationship, B_0 equilibrium	SR
Average recruitment during the whole period of catches (* spawning biomass-per-recruit at F_{MSY} for B_{MSY})	$\bar{R}_{ALL}$
Average recruitment during the first 10 years of catches (* spawning biomass-per-recruit at F_{MSY} for B_{MSY})	$\bar{R}_{F10}$

Simulation Trials:
Parameters constant between simulations

Species	Rockfish	Flatfish	Semi-pelagic Gadid
Length of catch time series	50 years	50 years	50 years
Extent of observation error	0.2	0.2	0.2
Age-composition sample size	200	200	200
Period of Climate Function	25 years	25 years	25 years
Amplitude of Climate Function	½ total	½ total	½ total
Natural mortality (yr^{-1})	0.12	0.2	0.23

Simulation Trials:
Parameters varying between simulations

Species	Rockfish	Flatfish	Semi-pelagic Gadid
Depletion	0.2, 0.4, 0.6	0.2, 0.4, 0.6	0.2, 0.4, 0.6
Steepness (*h*)	0.2, 0.3, 0.5	0.6, 0.8, 1	0.55, 0.75, 0.95
Extent of recruitment variation	0.2, 0.4, 0.6	0.3,0.5,0.7	0.9, 1.13, 1.3
Shape of the environmental function	Step, Sine	Step, Sine	Step, Sine
Position of the environmental function at the start of data collection	Peak, Middle, Trough	Peak, Middle, Trough	Peak, Middle, Trough

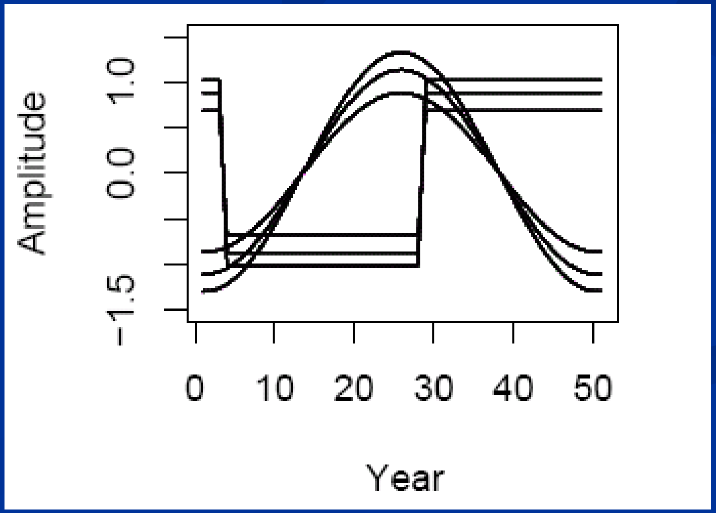
- Full Factorial Design
- 100 simulations for each trial.

Performance Evaluation

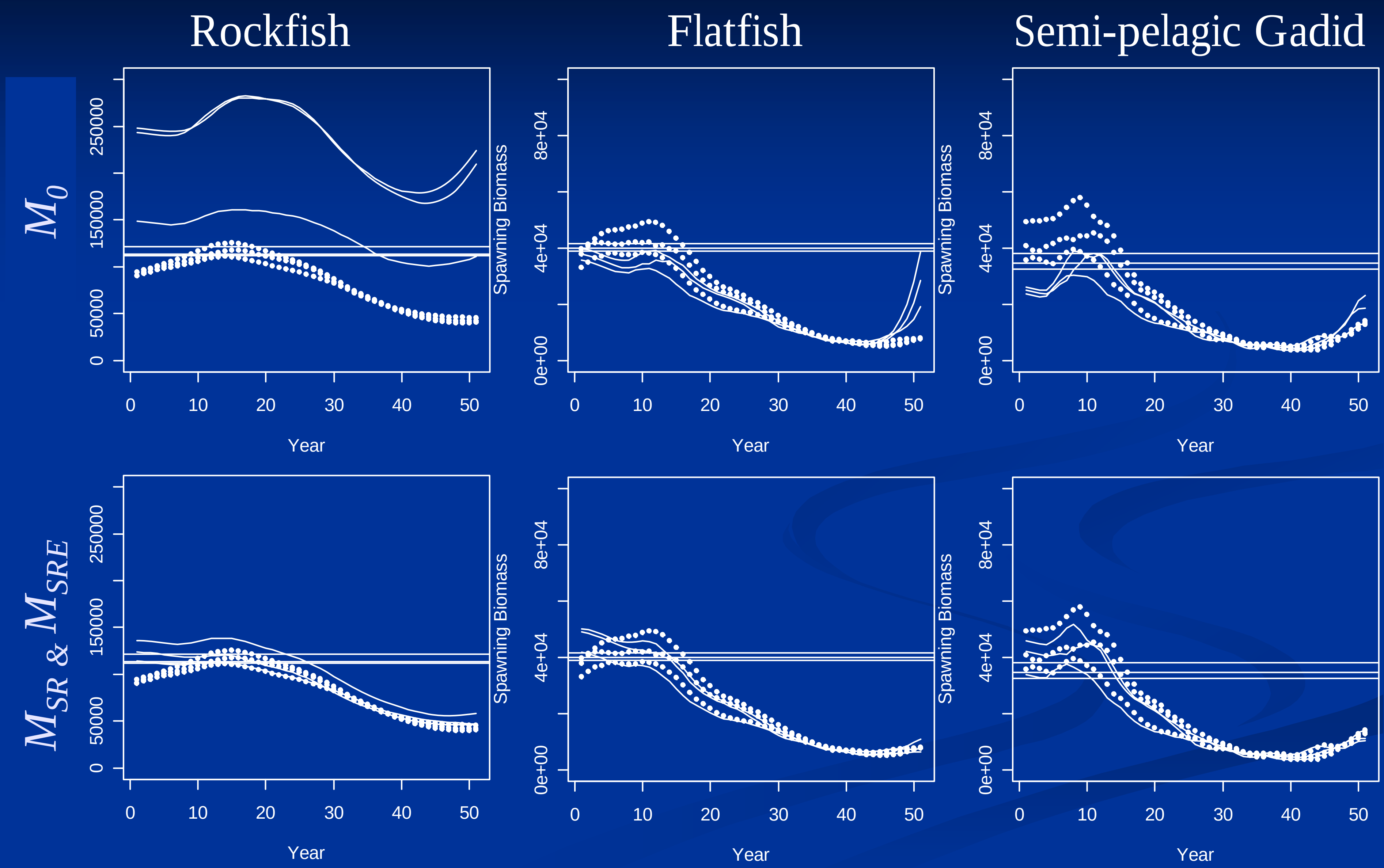
- Estimates of B_0, stock depletion, h , and F_{MSY} are compared to the true values from the operating model.
- Performance statistics:
  - For Each Simulation Within A Trial
    - Percent Relative Error = $\left(\frac{(O-T)}{T}\right)*100$

Preliminary Individual Trial Results

- All life histories
- Lowest level of both recruitment variability and observation error.
- Middle value for steepness.
- Target level of stock depletion (40%B_0).
- Sine shaped climate forcing function.
- Collection of data beginning at the peak of the climate forcing function.

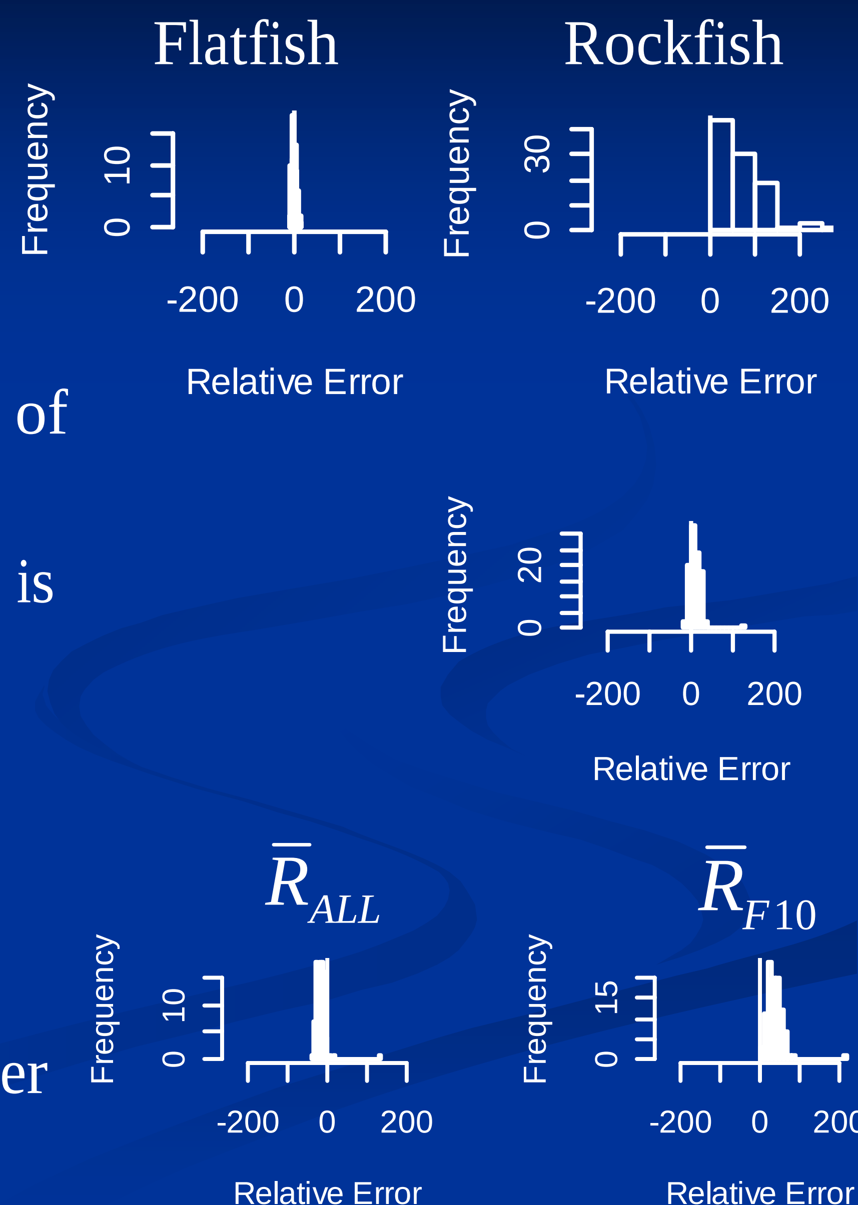


Estimation of Spawning Biomass



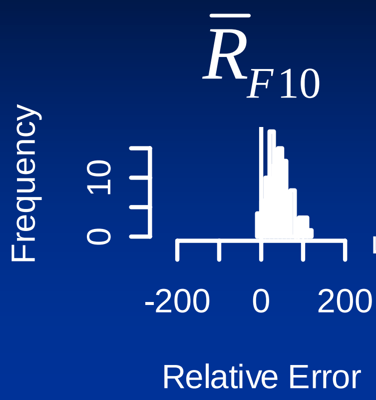
Estimation of Virgin Spawning Biomass

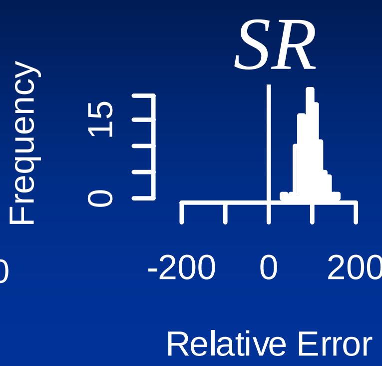
- M_0 - Estimation ability is worst for rockfish
- M_{SR} & M_{SRE}
  - Estimation improves with inclusion of S-R model in assessment
  - Fitting the stock-recruitment model is similar to using average recruitment over the full time period of catches
  - average over 10 years more variable and typically poorer
  - Estimation is less variable with inclusion of environmental parameter

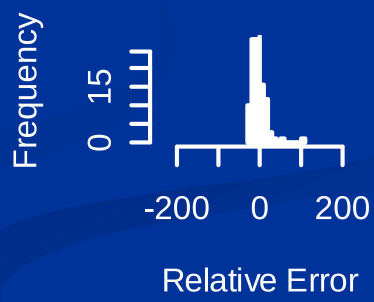


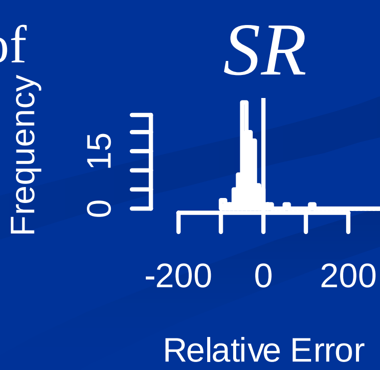
Estimation of Stock Depletion

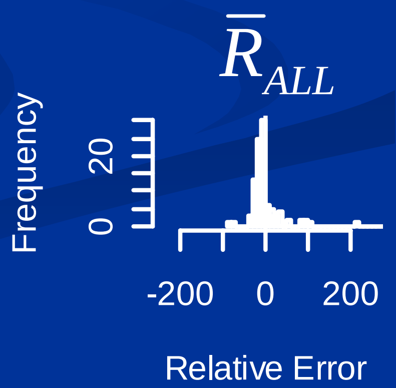
- M_0
  - Estimation ability is worst for rockfish
  - using average recruitment during the first 10 years of catches generally better than using the fit of the SR
- M_{SR} & M_{SRE}
  - Estimation improves with inclusion of SR model in assessment for rockfish
  - Estimation ability improves for rockfish
  - Negatively bias for flatfish and gadid
  - Less variable than the M_0 model
  - Estimation is less variable with inclusion of environmental parameter
  - Average recruitment better for gadid





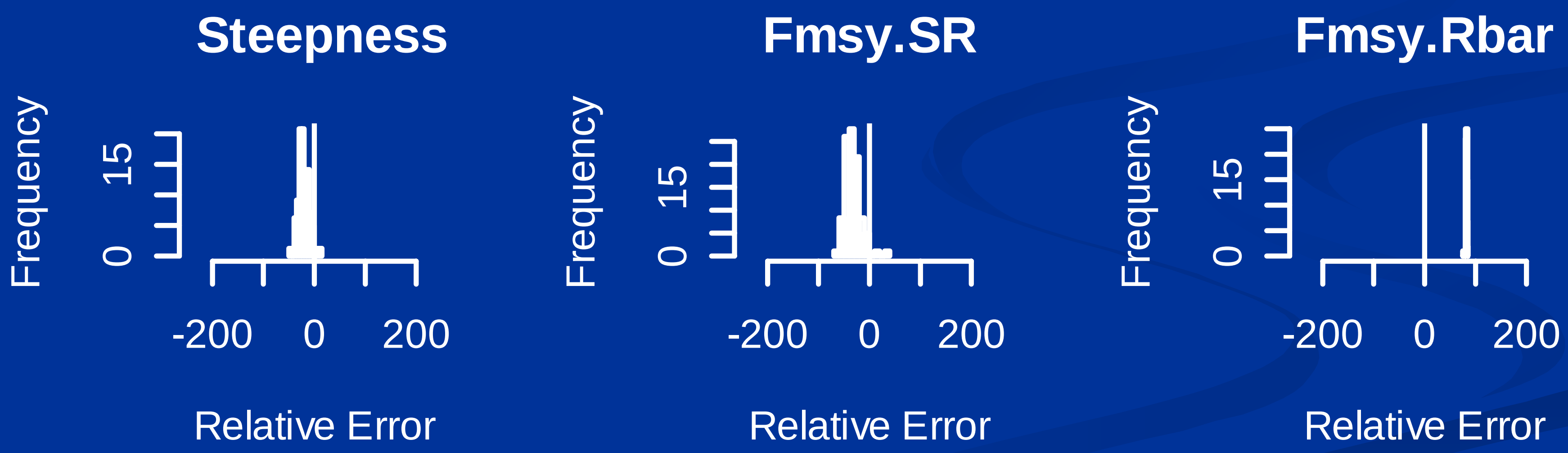






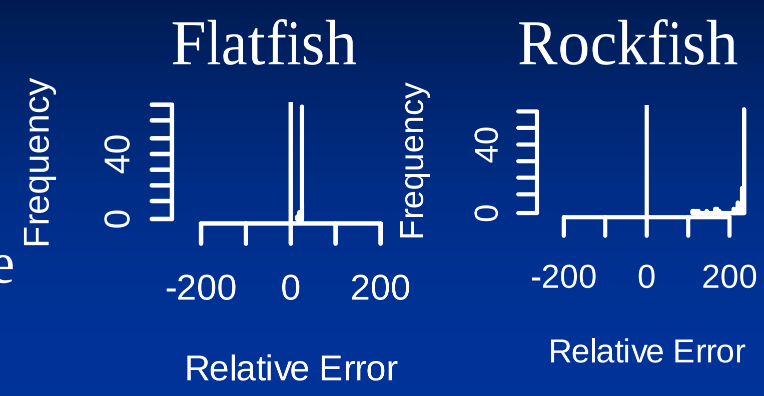
Estimation of Stock-Recruitment Steepness & F_{MSY}

- The ability to estimate F_{MSY} is directly linked to the ability to estimate h
- Fitting the SR generally underestimates h and F_{MSY}
- Using average recruitment to calculate F_{MSY} always over estimated F_{MSY}

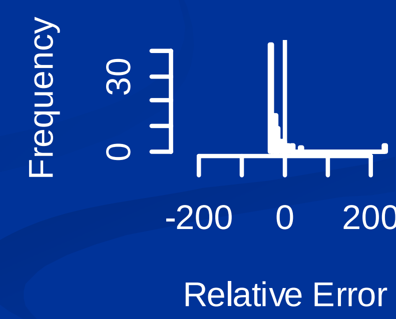


Estimation of Stock-Recruitment Steepness & F_{MSY}

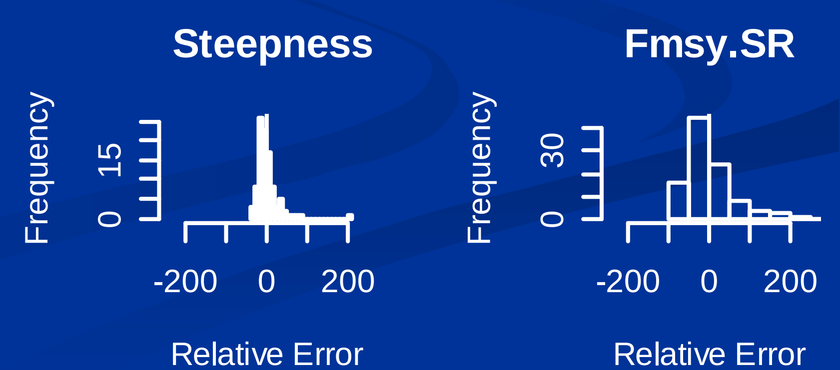
- M_0
  - Estimation ability is poor for rockfish, better for flatfish and gadid
  - Using average recruitment results in a huge positive bias for estimates of F_{MSY}



- M_{SR} & M_{SRE}
  - Improved estimation of h



  - M_{SRE} slightly improves estimators for the flatfish and gadid
  - M_{SRE} greatly improves the estimator performance for rockfish



Preliminary Conclusions

- Estimation of F_{MSY} most conservative using the fit of the stock-recruitment relationship and can be grossly over estimated using average recruitment, depending upon the model structure.
- Unclear if fitting S-R model or average recruitment over the observed time series is better for estimating virgin biomass.
- Using the fit of the S-R model to estimate stock depletion is generally better than using average recruitment (same as the previous study).
- M_0 - worst for the long lived unproductive rockfish
- M_{SR} - showed improved estimation of most quantities of interest
- M_{SRE}
  - Preferred for estimating stock depletion, better estimation of recruitments at the end of the time series.
  - Preferred for estimation of h and F_{MSY}

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