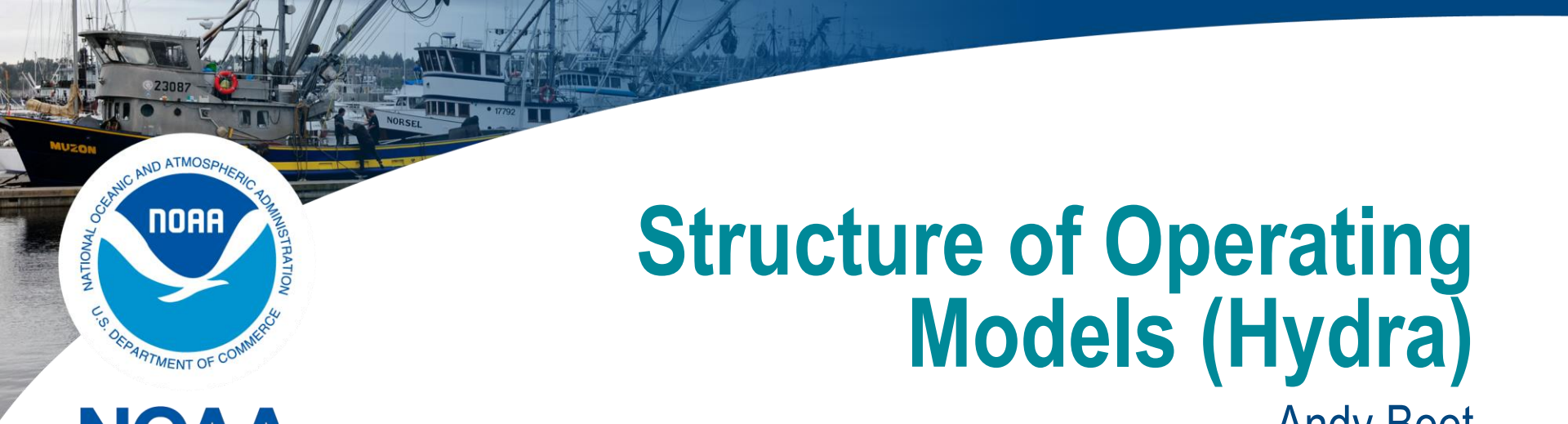


NOAA FISHERIES
Northeast Fisheries Science Center

Structure of Operating Models (Hydra)

Andy Beet

Michael Fogarty

Ecosystem Based Fishery Management Strategy Review

TOR 7: Review the structure and application of operating models for Georges Bank.

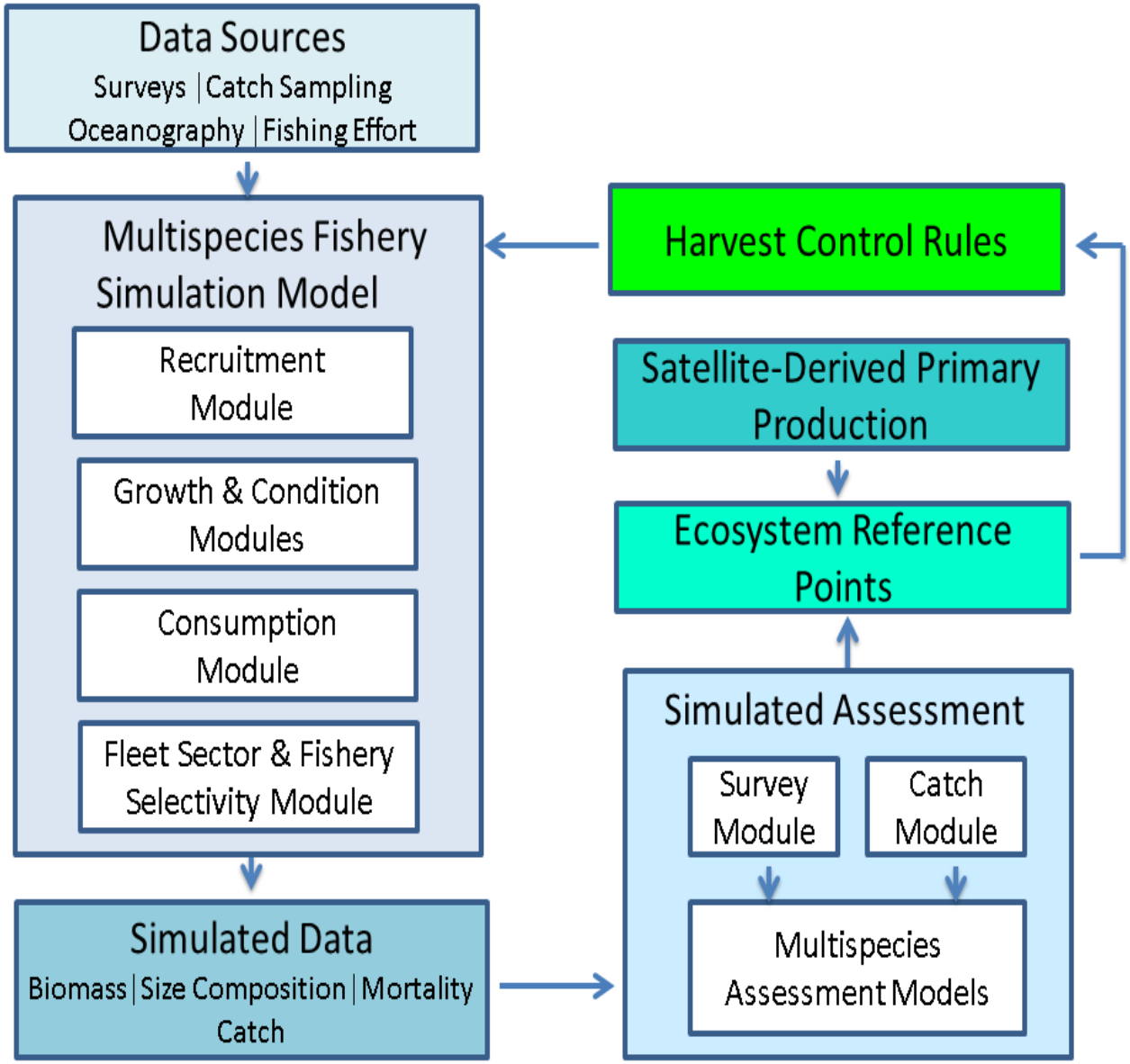
April 30-May 2 ,2018

Woods Hole MA

Hydra Operating Model

Multispecies Model (Biological and Technological Interactions	• 10 fish species: 2 elasmobranchs, 3 piscivores, 2 planktivores, 3 benthivores
Size structured	• 5 variable width size categories for each species
Estimates predation mortality	• Size specific predation mortality
Environmental covariates on growth, maturity, fecundity	• 2 growth forms, exponential and von Bertalanffy • Temperature covariate on both growth forms
Generalized recruitment function	• Species specific recruitment
Multiple fishing fleets	• 3 fleets: bottom & pelagic trawls, fixed gear. • Size specific fishing mortality
Implemented in ADMB	• Simulation mode only, operating model
Fishery Functional Groups	• Account for Technical and Biological interactions

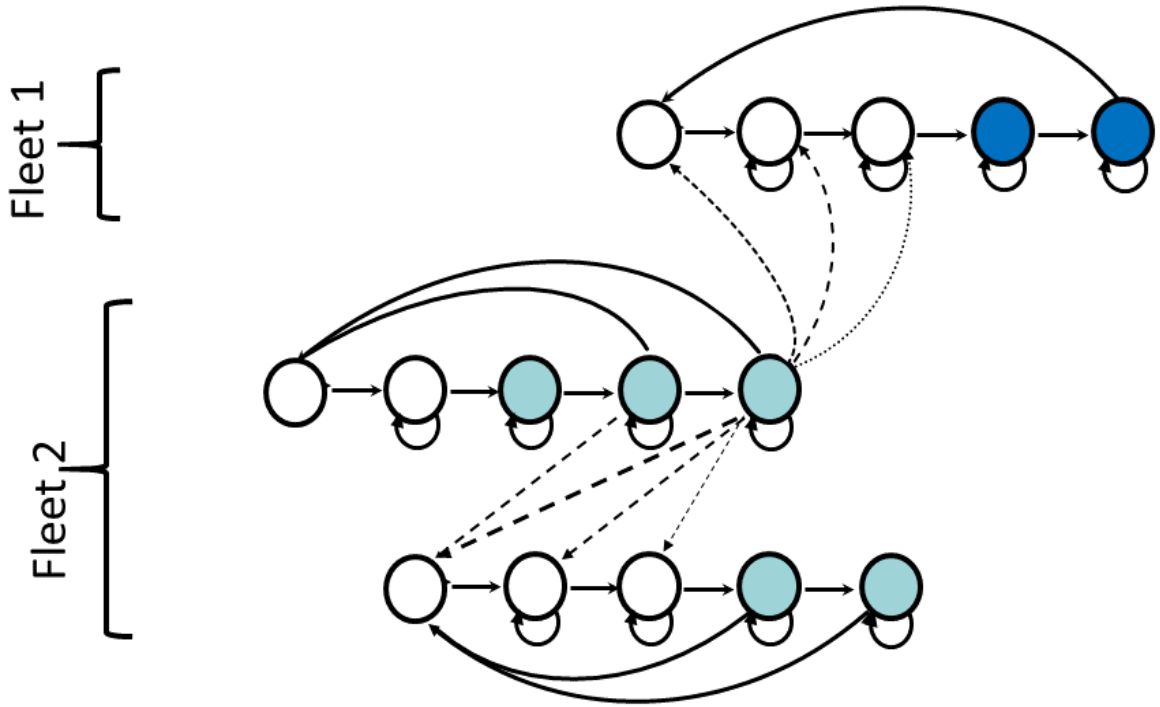
Hydra Operating Model



Basic Model Structure

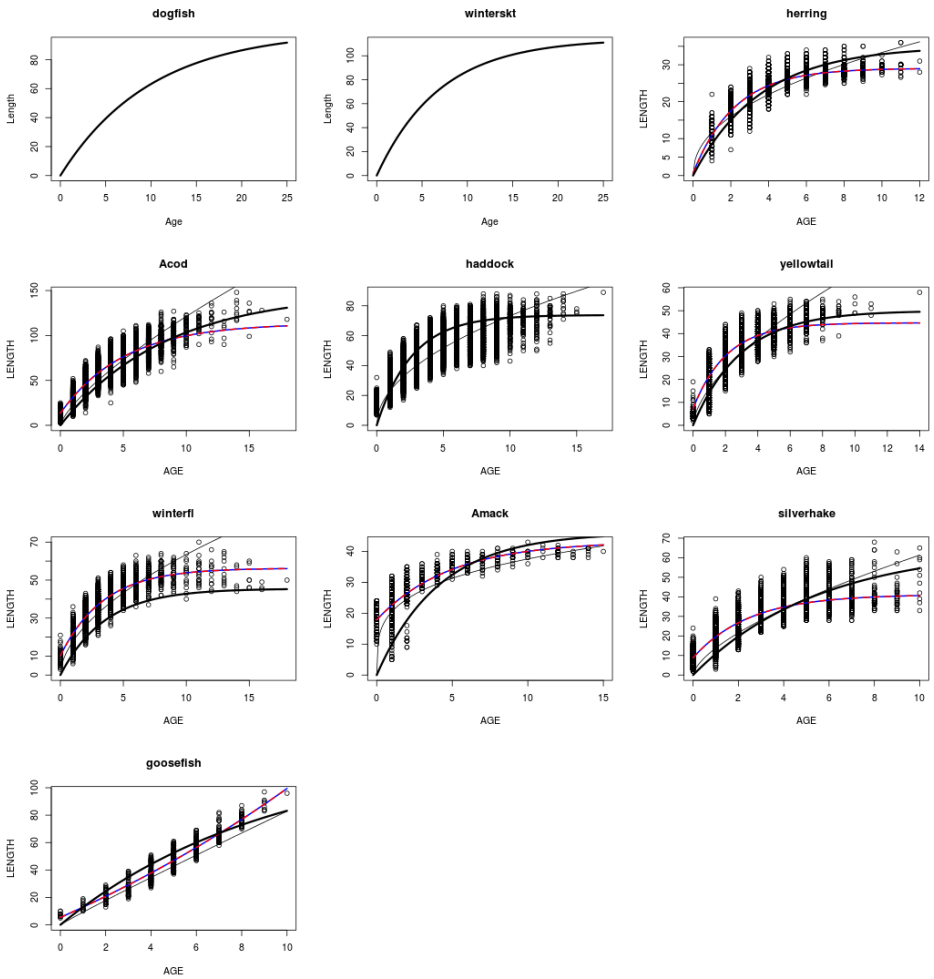
$$N_{i,j,t+1} = \phi_{i,j\to j,t} S_{i,j,t}\, N_{i,j,t} + R_{i,1,t} \qquad \mathrm{j} = 1$$

$$N_{i,j,t+1} = \sum_{j'=j-1}^{j} \phi_{i,j'\to j,t}\, S_{i,j',t} N_{i,j',t} \qquad \mathrm{j} = 2, \ldots, J$$



Growth

- Two forms of growth possible (von Bertalanffy, power function)
- Parameter estimates used in model were assumed fixed throughout the simulation.
- Fitted to length at age data from fishery independent surveys of GB (shown)
- Growth functions were discretized to calculate the time taken for a species to grow from the lower end of a size class to the upper end.
- The model timestep is based on time takes fastest growing species to grow into the next size class interval
- ~ 73 days per time step



Recruitment

$$\mathrm{R}_t = f(S_{t-1}, \underline{\theta})e^{\varepsilon_t}$$

where e^{ε_t} are IID lognormal random variables such that $\varepsilon_t \sim N(-\sigma^2/2, \sigma^2)$

$f(S_{t-1}, \underline{\theta})$ is a predetermined functional form for recruitment

$\underline{\theta}$ is a vector of model parameters.

R_t, recruitment (millions) and has been scaled to represent age 0 individuals.

S_t, spawning stock is defined in metric tons.

For segmented linear stock recruitment model we define $\underline{\theta} = (\alpha, \beta, \delta)$

(hockey stick, and over compensatory form)

α is the slope at origin (recruits/spawning biomass)

δ is the change-point (the value of spawning stock biomass at which the slope changes)

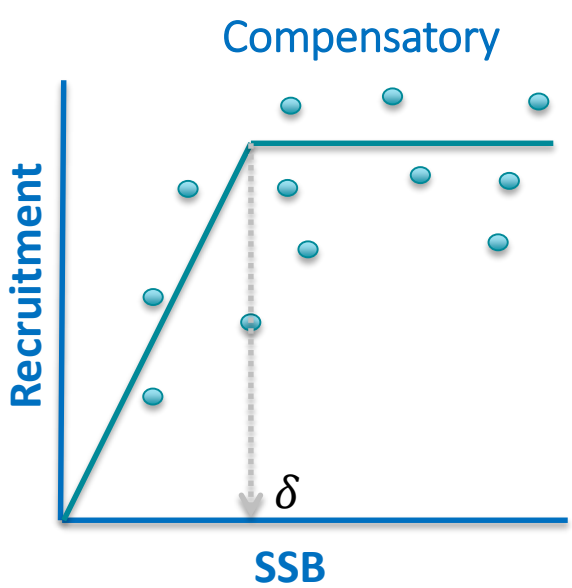
β is the change in slope after the change-point.

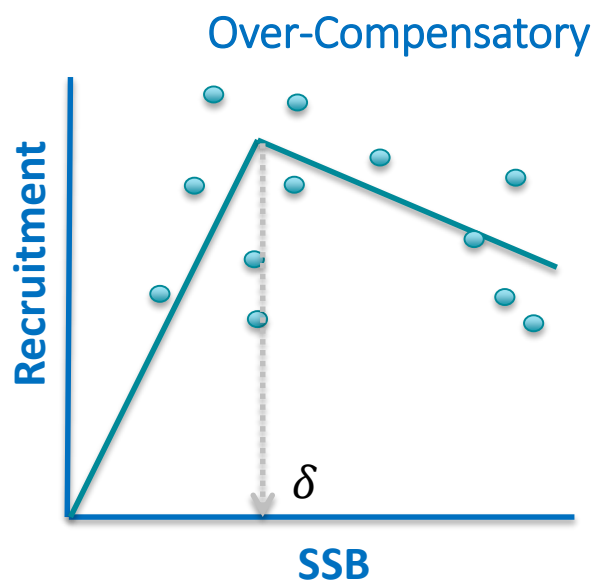
Recruitment

$$f(S_{t-1}, \underline{\theta}) = \alpha S_{t-1} \qquad \text{if } S_{t-1} \leq \delta$$

$$= \alpha S_{t-1} + \beta(S_{t-1} - \delta) \qquad \text{if } S_{t-1} > \delta$$

Note: when $\beta = -\alpha$, the above equation simplifies to the hockey stick model.





Stock-Recruitment sampling regime

Starting point-
Based on life histories (cannibalism)

Hockey stick model fitted to herring, haddock, yellowtail flounder, winter flounder, mackerel

Over compensatory model fitted to dogfish, winter skate, cod, silver hake, monkfish

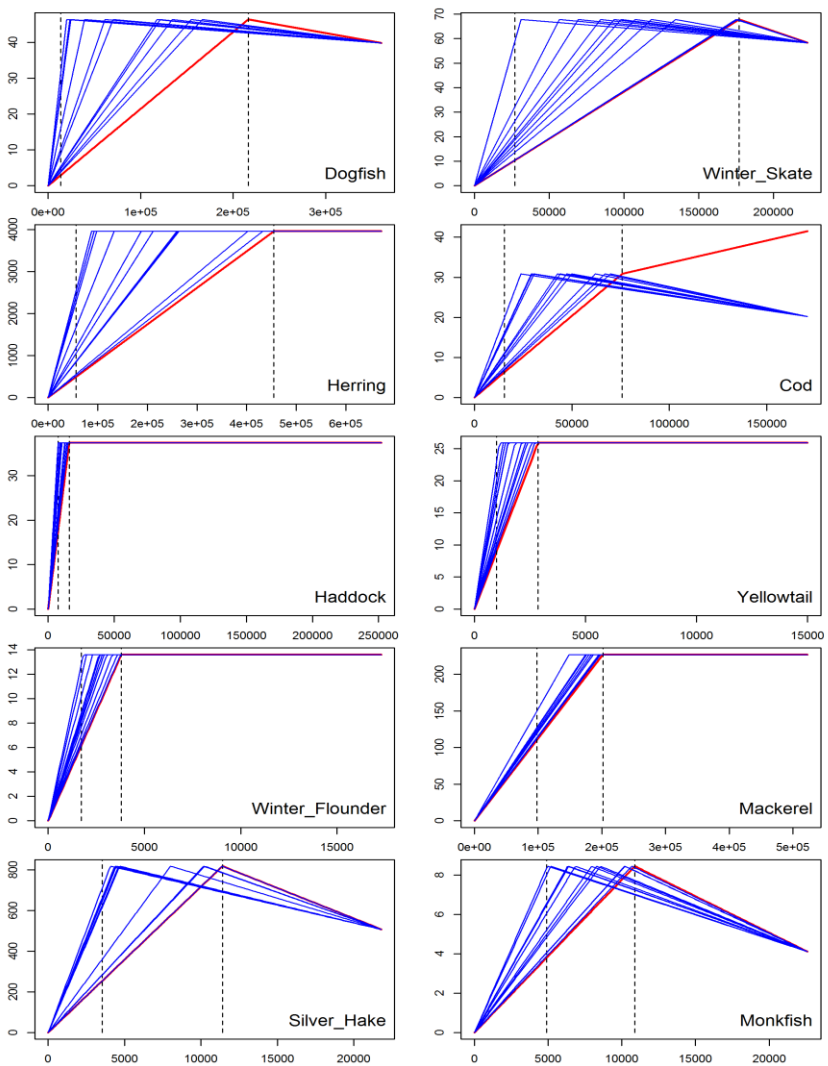
To account for uncertainty in the S-R data and to tackle the issue of "missing" data for lower levels of spawning stock we adopt a simple sampling regime to select variants of these fitted models.

Rules:

1. Breakpoint [min(SSB)/2, δ] (dotted lines)
2. Asymptote unchanged (for hockey stick)
3. Slope after the breakpoint calculated to pass through fitted value of largest SSB (over compensatory)

Criteria:

mean biomass > min (survey data) (after period of no fishing)
0.5 min(survey data) < mean biomass < 2x max(survey data)
min(reported landings) < mean landings < max (reported landings)



Consumption/Predation

Prey suitability (size preference & vulnerability)

Predator requirements (how much pred needs to consume to account for its growth. Function of mean stomach content)

Number of Predators (account for total consumption)

$$M2_{m,n,t} = \sum_i \sum_j \frac{\rho_{i,j,m,n} I_{i,j,t} N_{i,j,t}}{\sum_a \sum_b \rho_{i,j,a,b} \overline{W}_{a,b} N_{a,b,t} + \Omega}$$

Other food

Mean weight of Prey

Number of Prey

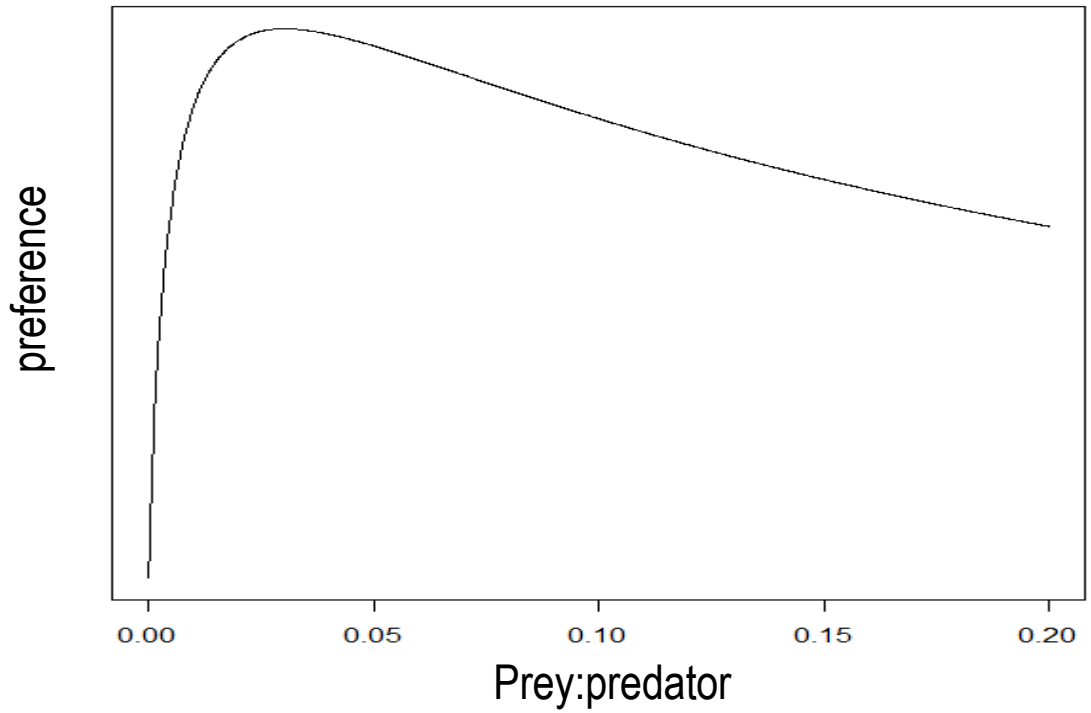
Consumption: Size preference

$$\vartheta_{n,j} = \frac{1}{(w_n/w_j)\sigma_j\sqrt{2\pi}} exp\left(-\frac{1}{2{\sigma_j}^2}\left(ln(w_n/w_j) - \Psi_j\right)^2\right)$$

Size preference

variance

preferred ratio of prey:pred weight



Consumption: Prey Suitability

prey vulnerability

Size preference

$$\rho_{i,j,m,n} = \lambda_{m,i}\vartheta_{n,j}$$

Predator

Prey	Dogfish	Winter Skate	Herring	Cod	Haddock	Yellowtail Fl	Winter Fl	Mackerel	Silver Hake	Monkfish
Dogfish	●									●
Winter Skate	●									
Herring	●	●		●	●				●	●
Cod	●	●		●	●					●
Haddock	●	●								●
Yellowtail Fl	●									●
Winter Fl	●									●
Mackerel	●	●		●					●	●
Silver Hake	●	●		●	●				●	●
Monkfish										●

Vulnerability Matrix (Food web)

Consumption: Annual Food Intake

$$I_{i,j,t} = 365 * 24\underbrace{\left[\alpha_i e^{\beta_i \mathrm{T}_t}\right]}_{\text{Hourly Gastric Evacuation Rate}}\bar{C}_{i,j,t}$$

Mean Stomach Weight for Predator i of size j

Consumption

Size preference

$$\vartheta_{n,j} = \frac{1}{(w_n/w_j)\sigma_j\sqrt{2\pi}} exp\left(-\frac{1}{2{\sigma_j}^2}\left(ln(w_n/w_j) - \Psi_j\right)^2\right)$$

preferred ratio of prey:pred weight

prey suitability

vulnerability

$$\rho_{i,j,m,n} = \vartheta_{n,j}\lambda_{m,i}$$

$$\rho_{i,j,m,n}\bar{W}_{m,n}N_{m,n,t}$$

Prey weight population

Available prey

$$\rho_{i,j,m,n}I_{i,j,t}N_{i,j,t}$$

Intake population

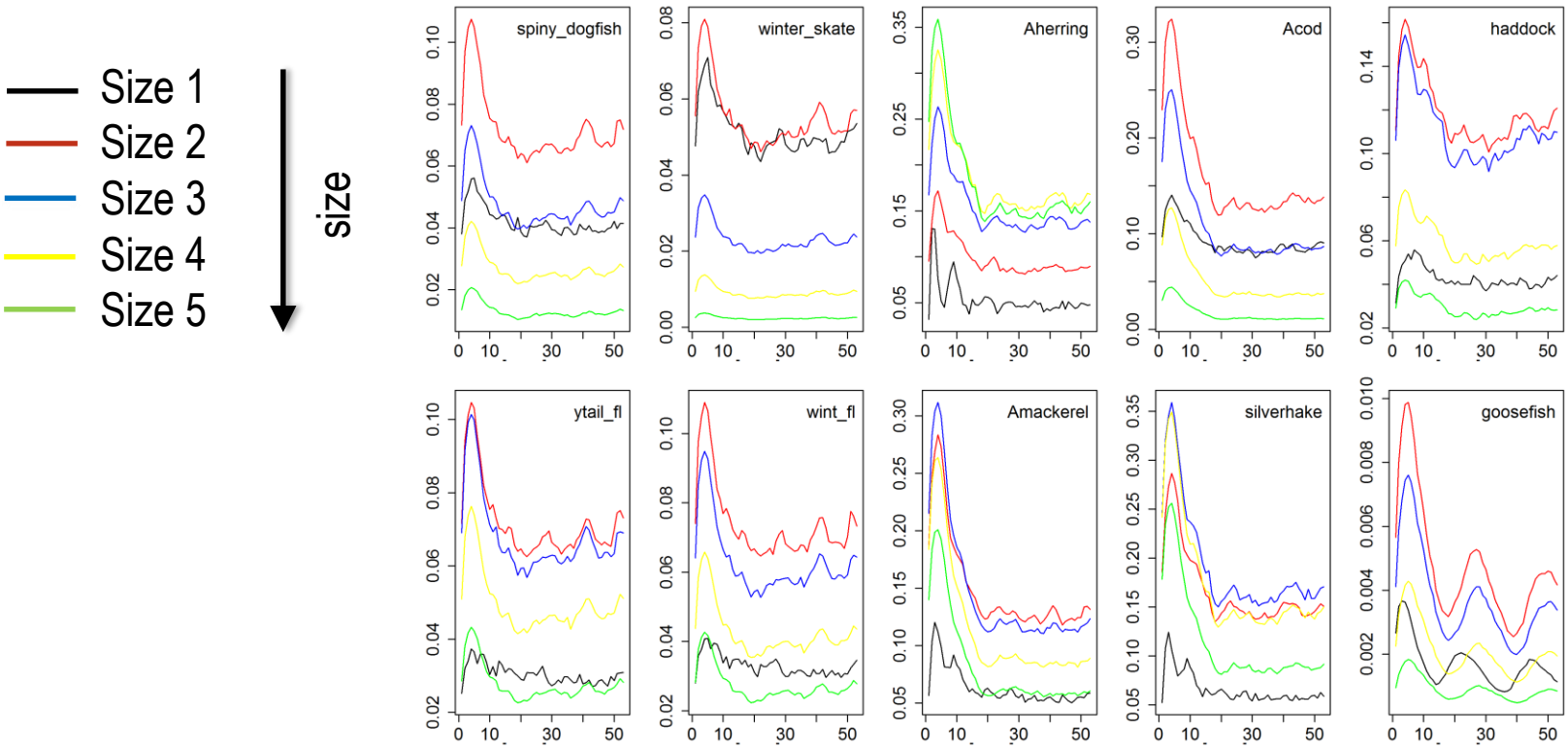
Total requirement by Predator i, size j

$$M2_{m,n,t} = \sum_i \sum_j \frac{\rho_{i,j,m,n}I_{i,j,t}N_{i,j,t}}{\sum_a \sum_b \rho_{i,j,a,b}\bar{W}_{a,b}N_{a,b,t} + \Omega}$$

Contribution to the mortality of prey m size n by species I, size j

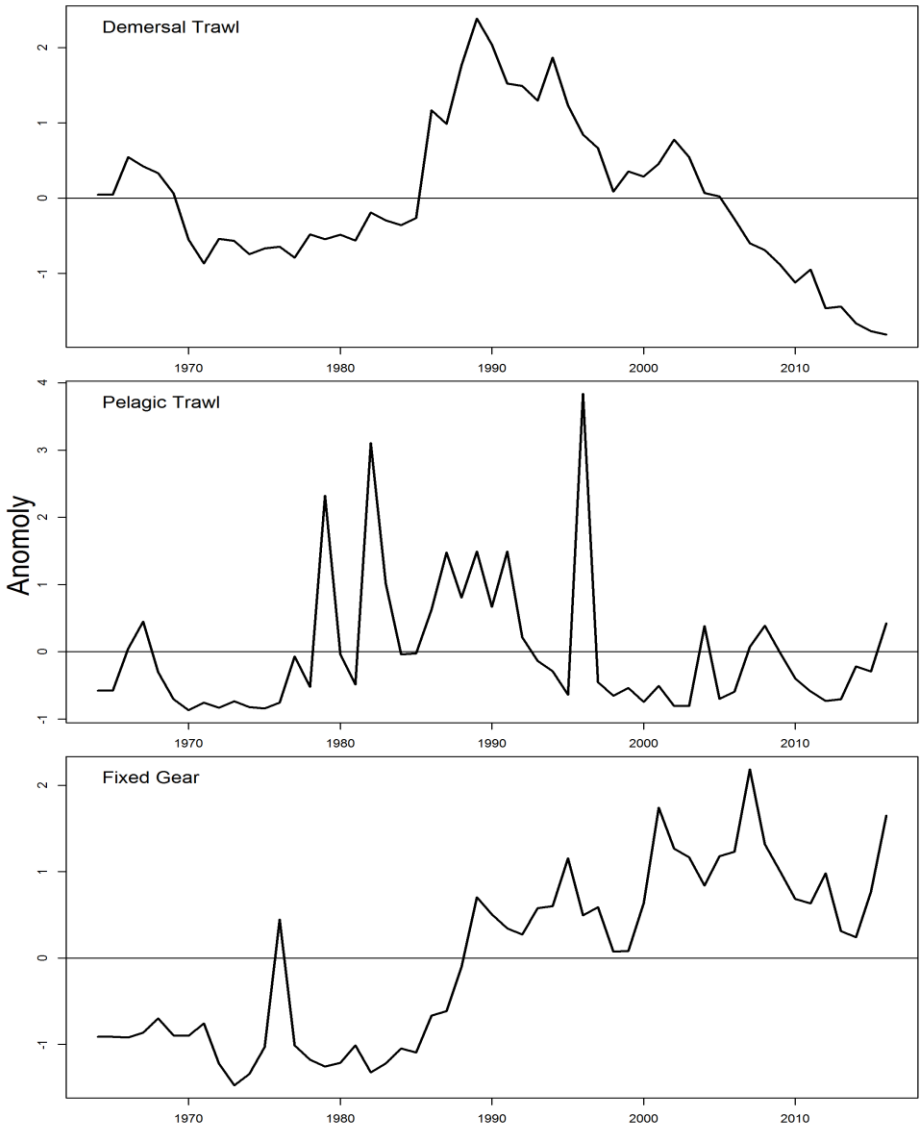
Predation Mortality

$$M2_{m,n,t} = \sum_i \sum_j \frac{I_{i,j,t} N_{i,j,t} \rho_{i,j,m,n}}{\sum_a \sum_b \rho_{i,j,a,b} \overline{W}_{a,b} N_{a,b,t} + \Omega}$$



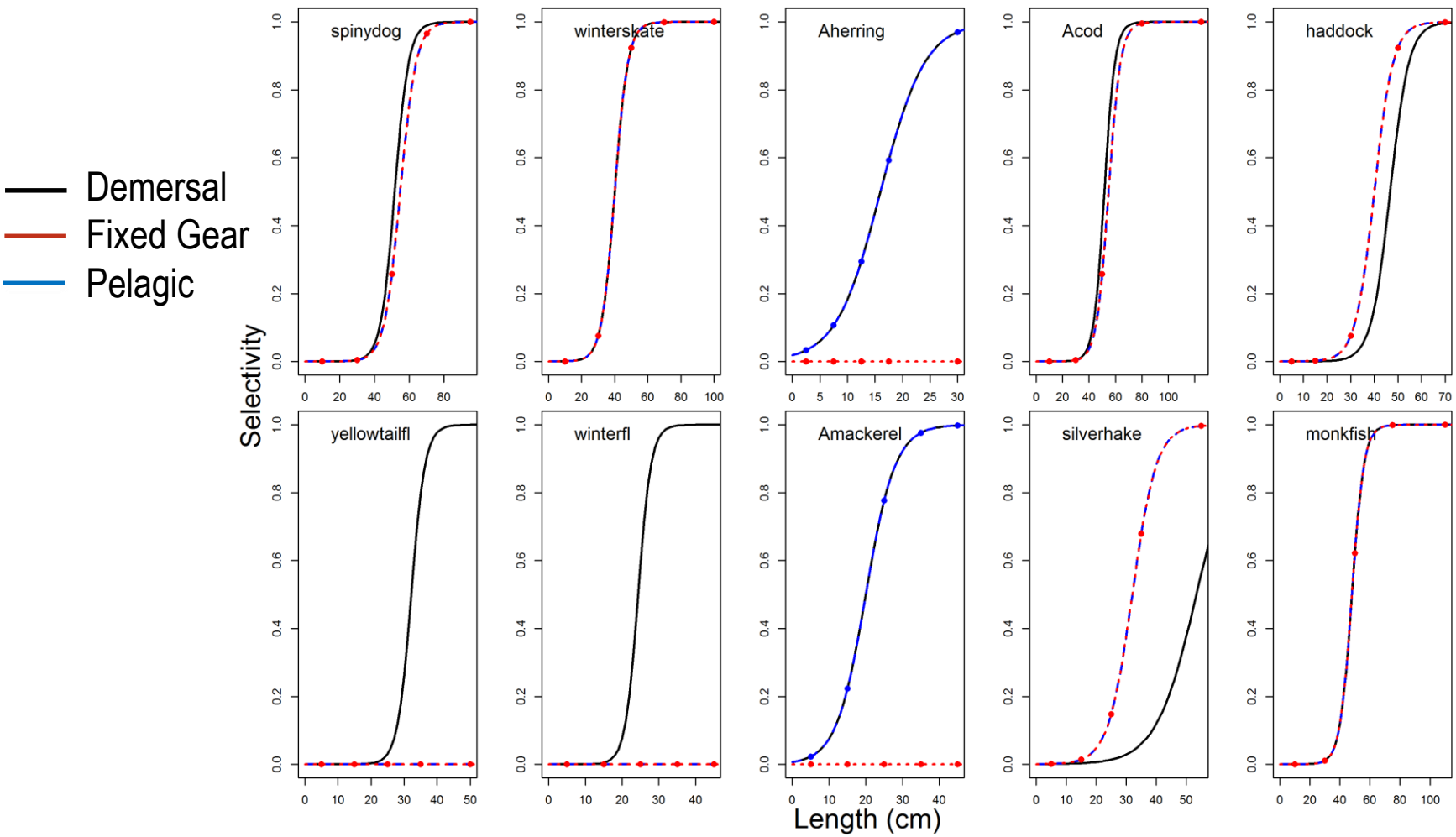
Fleets: Fishing Effort

- 3 fleets
  - demersal trawls
  - pelagic trawls
  - fixed gear (longline, gillnet)
- Historical domestic effort on Georges Bank. Standardized to account for vessel size and specific gear type (see plot)
- Have provisions to expand model to accommodate additional fleets
- Selectivity of species by fleet
- Catchability of species by fleet



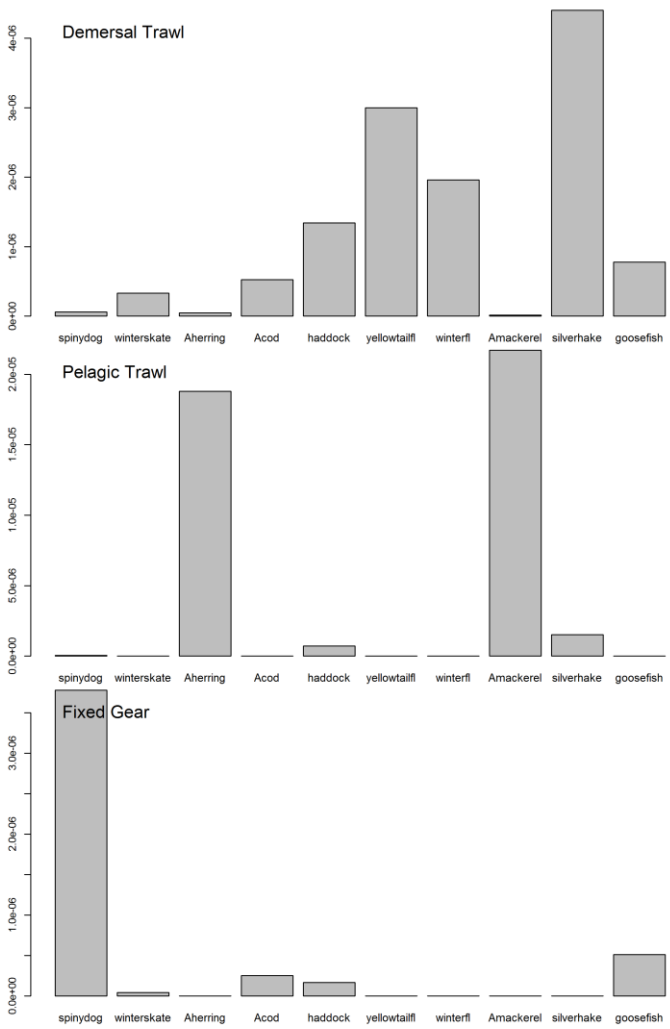
Fleets: Selectivity

$$s_{i,j,g} = \left[1 + e^{-(c_{i,g} + d_{i,g} L_{i,j})}\right]^{-1}$$



Fleets: Catchability

- Demersal trawl catches a broad selection of species
- Pelagic trawl catches primarily planktivores (herring and mackerel), some haddock and silver hake
- Fixed gear catches cod, haddock, goosefish, spiny dogfish, winter skate
- Note: Elasmobranchs caught in demersal and logline are all discarded (with high survival probability). Exception (largest size class are kept in longline with some regularity)



Fleets: Mortality

selectivity effort

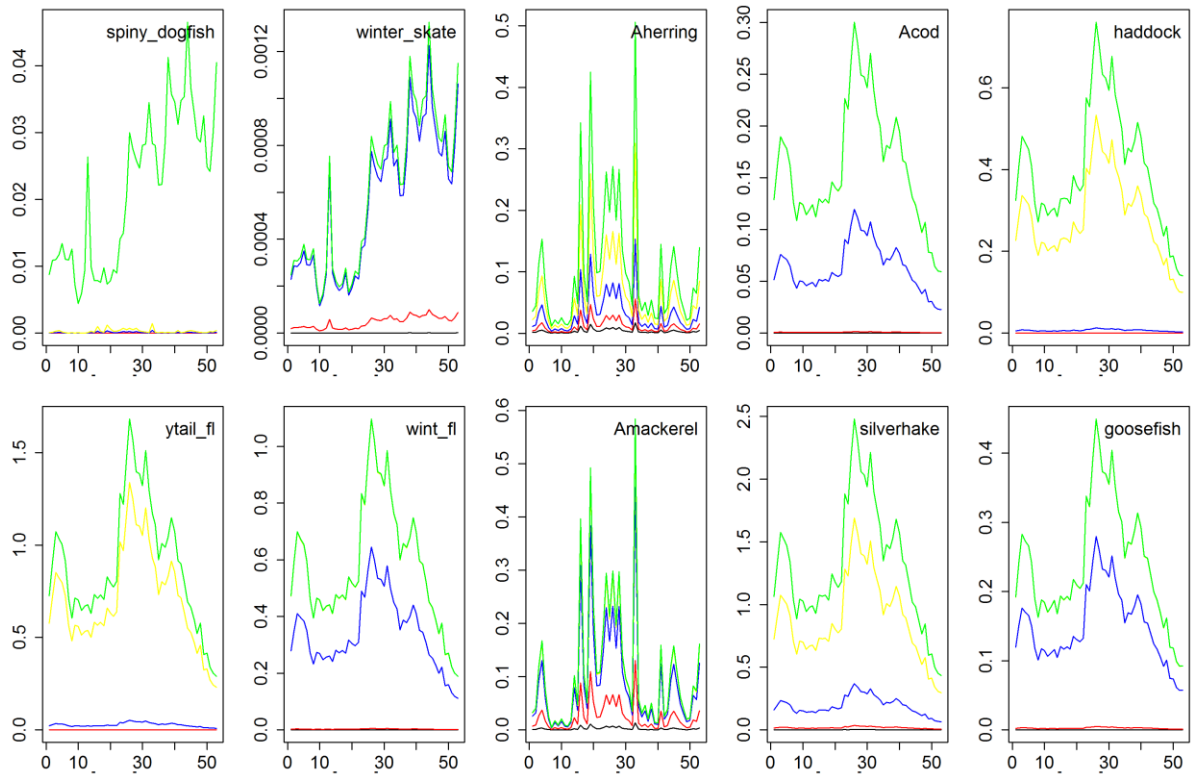
$$F_{i,j,g,t} = s_{i,j,g} q_{i,j,g} E_{g,t} \underbrace{\left[1 - p(D_{i,j,g,t}) p\left(Surv_{i,j,g,t} \middle| D_{i,j,g,t}\right)\right]}_{\text{Adjusted rate for elasmobranchs}}$$

catchability

Size 1
Size 2
Size 3
Size 4
Size 5

size

Larger sizes getting caught



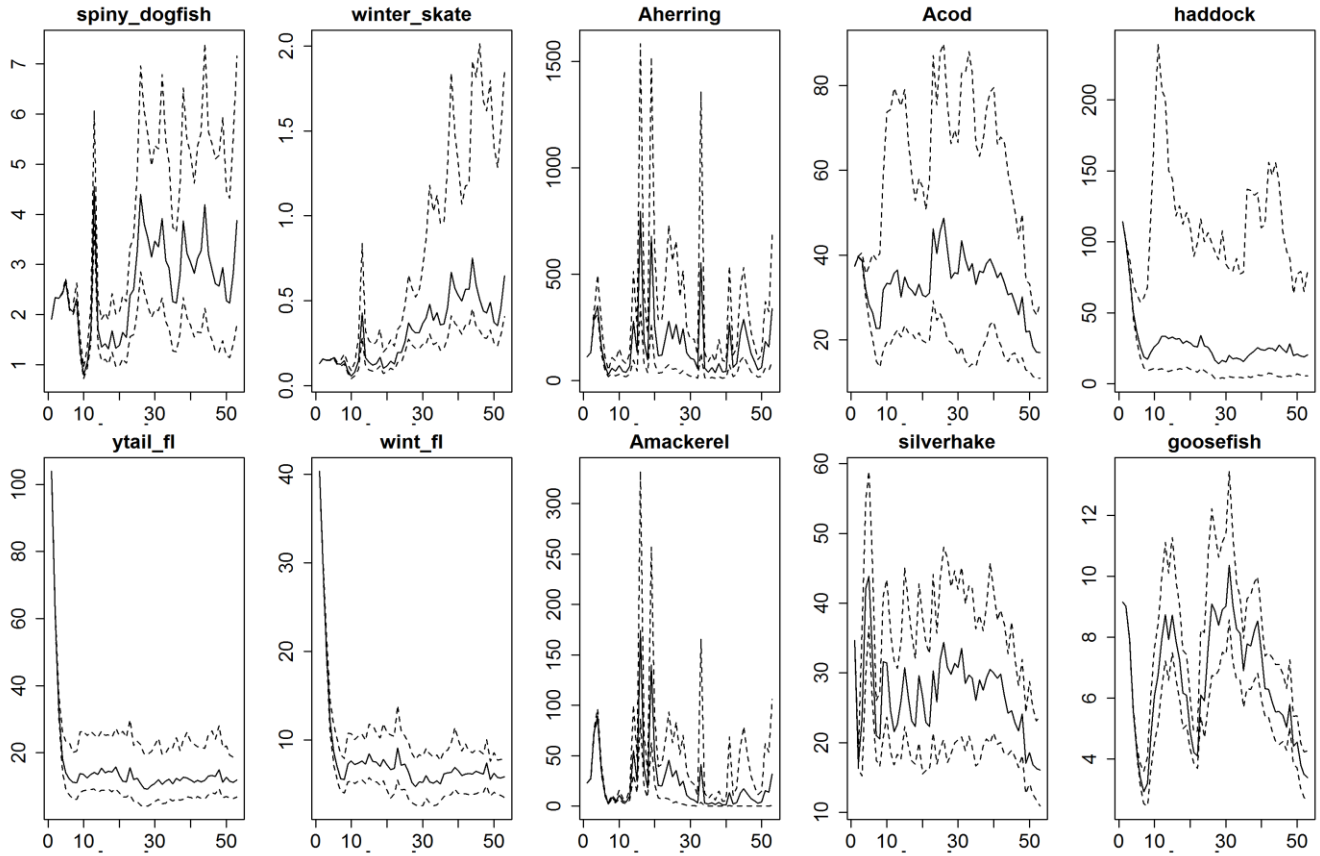
Fleets: Yield

$$Y_{i,t} = \sum_j \sum_g \frac{F_{i,j,g,t}}{Z_{i,j,g,t}} \left[1 - e^{-Z_{i,j,t}}\right] N_{i,j,t} w_{i,j}$$

Z = total mortality

= predation mortality
+ fishing mortality
+ natural mortality

Yield in kilo tones



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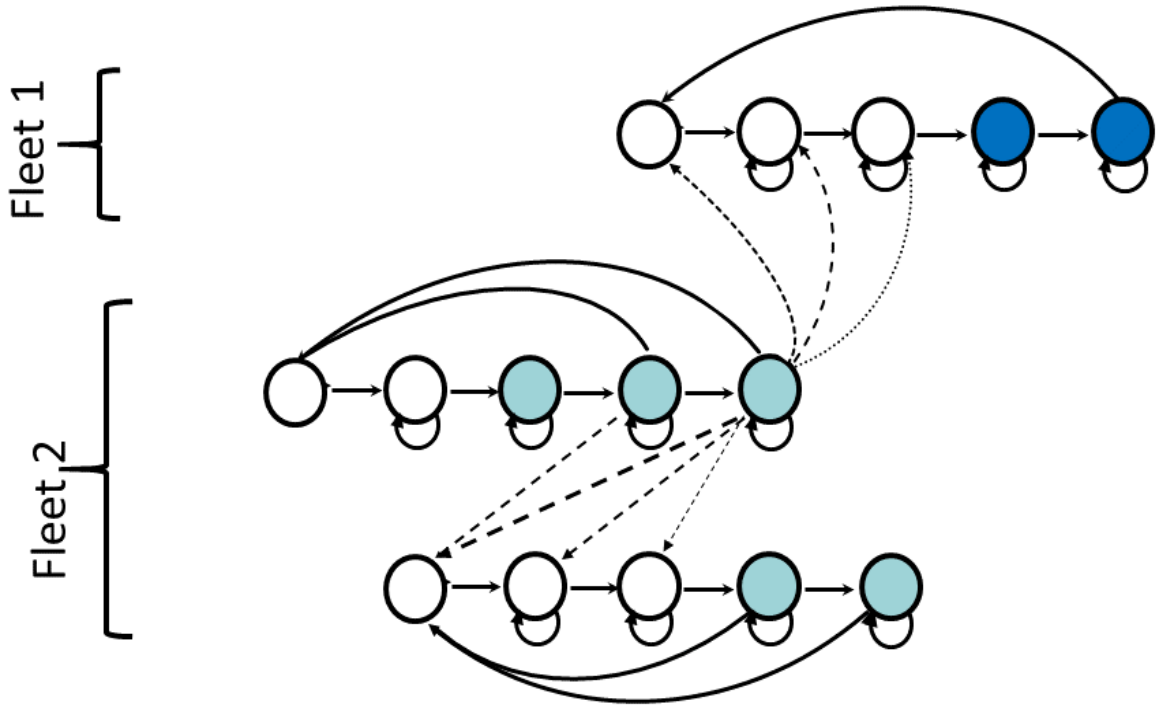


Assessment

Every 3 years: assess status of the system

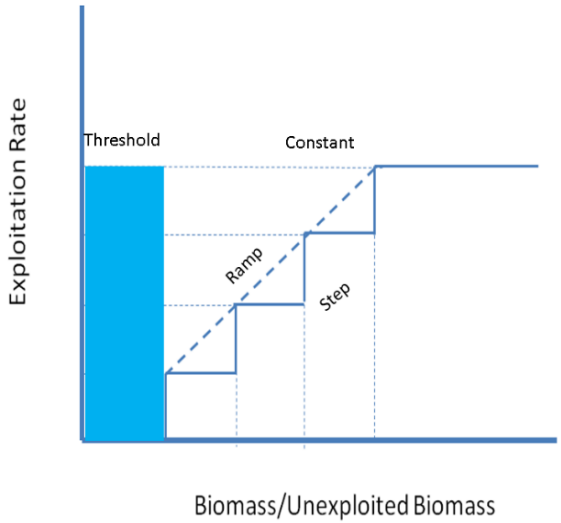
Exploitation rate determines fishing effort

If average biomass levels fall below a defined threshold - effort is reduced

If average biomass levels rise above threshold – effort is increased

8 different Harvesting strategies (shown in table)

Compare to harvesting at fixed exploitation rate throughout simulation



Threshold - %B0

Starting Rate

Exploitation	0.4	0.3	0.2	0.1
.4	0.3125	0.225	0.1375	0.05
0.35	0.275	0.2	0.125	0.05
0.3	0.2375	0.175	0.1125	0.05
0.25	0.2	0.15	0.1	0.05
0.2	0.1625	0.125	0.0875	0.05
0.15	0.125	0.1	0.075	0.05
0.1	0.0875	0.075	0.0625	0.05
0.05	0.05	0.05	0.05	0.05

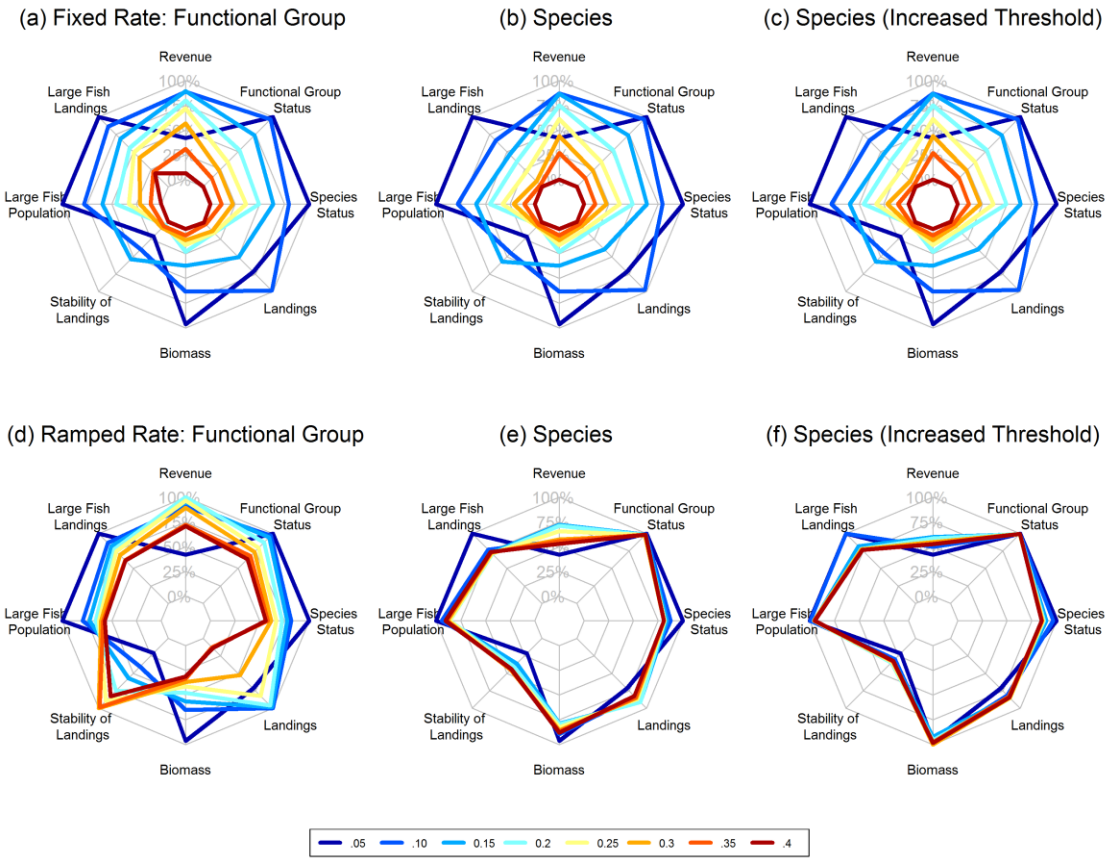
Exploitation rate reduced

Assessment: Performance Metrics

Compare simulation model results across all harvesting strategies.

Radar plots:
- Revenue
- Large fish in landings
- Large fish in population
- Stability of landings
- Biomass of population
- Biomass of landings
- Indicator of species/group status

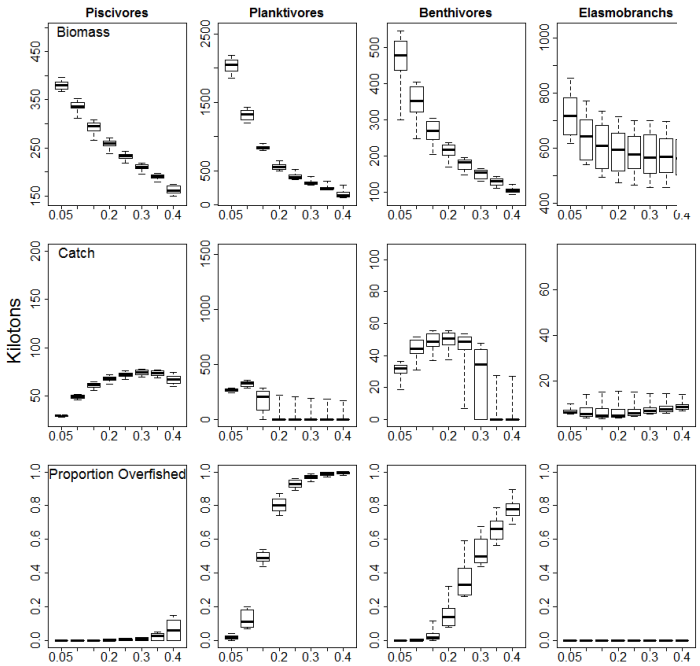
Analyzed results for 2 time periods
- Last 10 years
- Mid 10 years

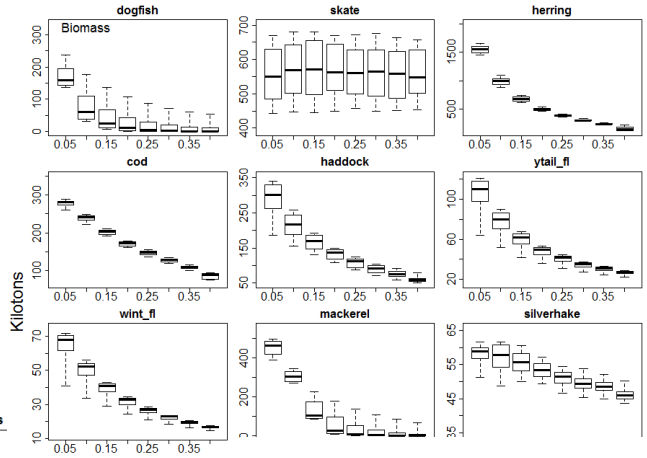


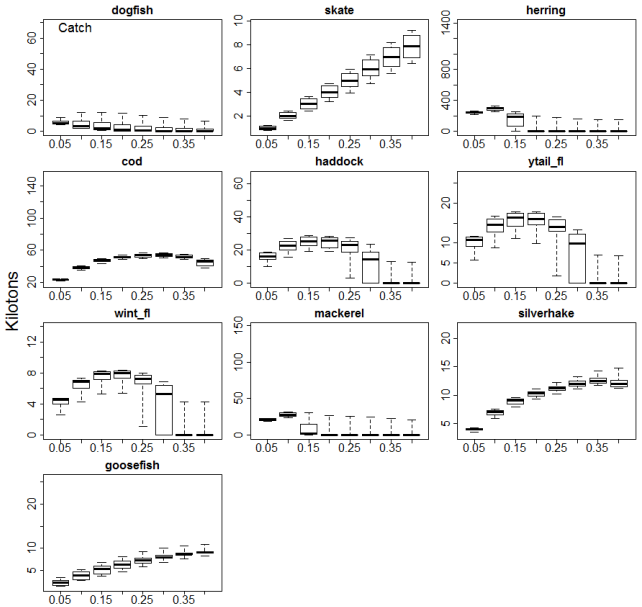
Assessment: Diagnostics

Functional Group level and species level plots for any of the 6 scenarios

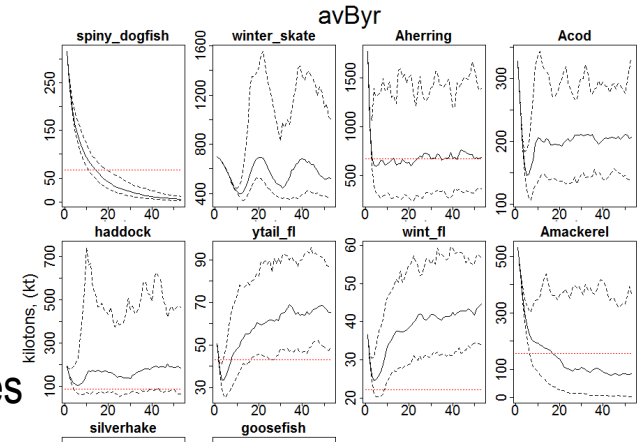
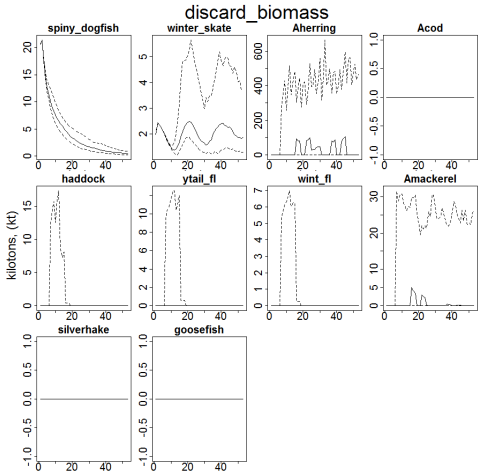
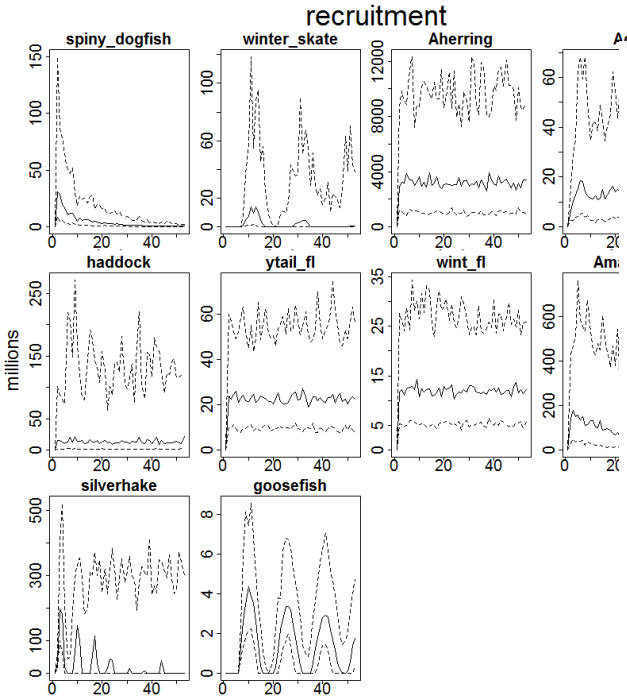
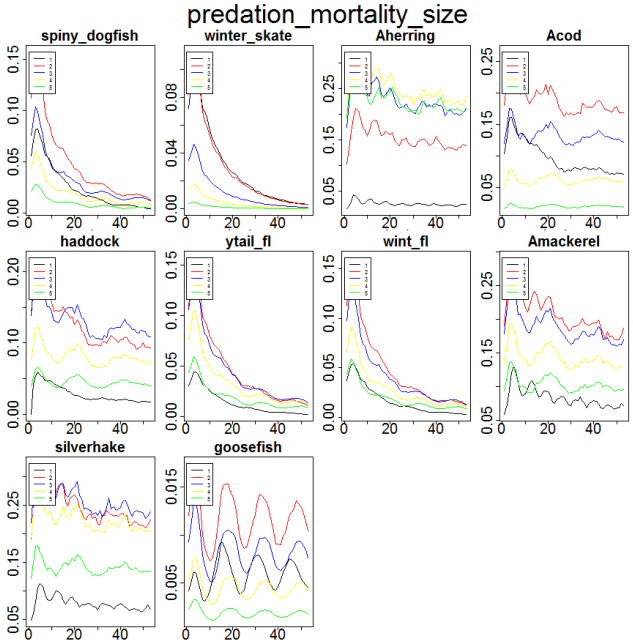
- Biomass
- Landings
- Status







Assessment: Diagnostics

Plots for any of the designated harvesting strategies

- Biomass (species, group, discards)
- Landings (fleet, group, species
- F (species, size)
- M2
- N
- Recruitment
- SSB
- Health indices
  - large fish
  - diversity
  - ratio of pred:prey
  - stability of landings
  - stability of biomass