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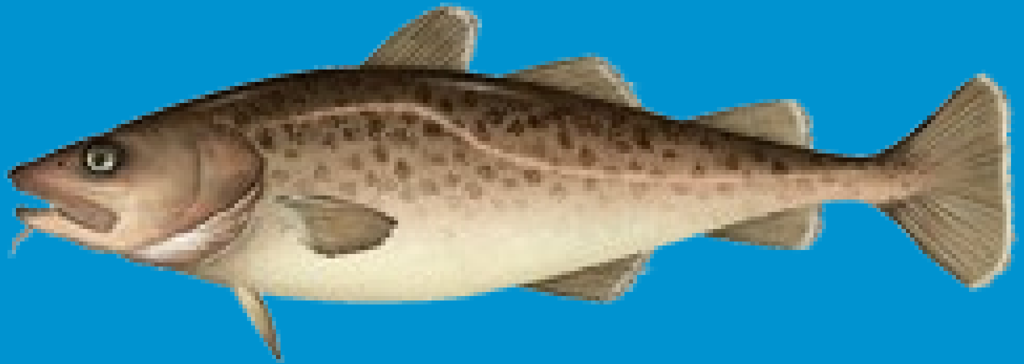
Pacific Cod Management 201

Steven Barbeaux

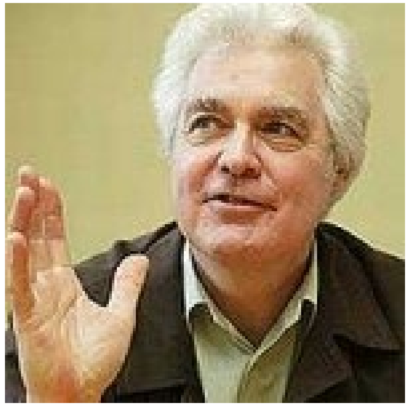
Factory Longline Coalition
May 8, 2023



Stock Assessment is Hard...but Does it Need to be?

- "Managing fisheries is hard: it's like managing a forest, in which the trees are invisible and keep moving around"
  - John Shepherd

(except maybe salmon!)

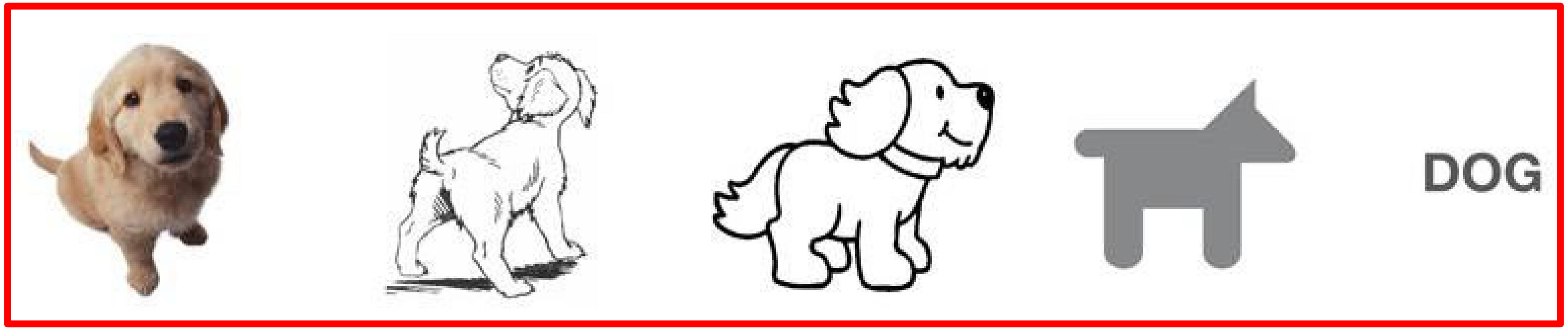


- "Stock assessment isn't rocket science...but you all sure make it seem harder."
  - David Goethel (dinner conversation)

- Assessment scientists have a tendency to make things more difficult than they need to be...
  - Today will probably be no different

Models are abstractions of reality

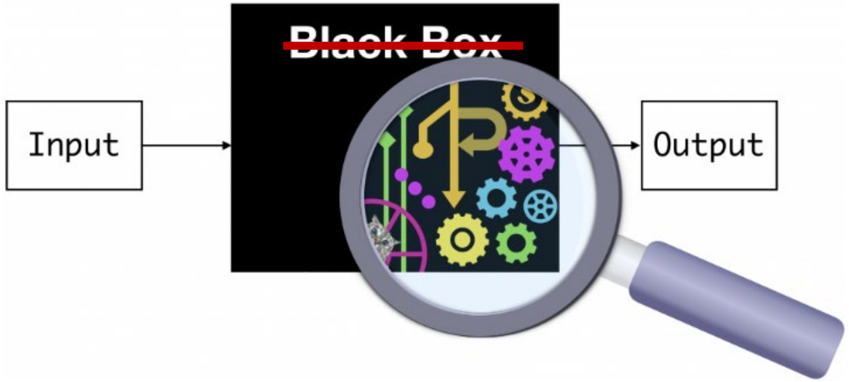
Realistic → Abstract



Source: https://sheilapontis.wordpress.com/2013/12/09/visualisations-the-process-of-abstraction/

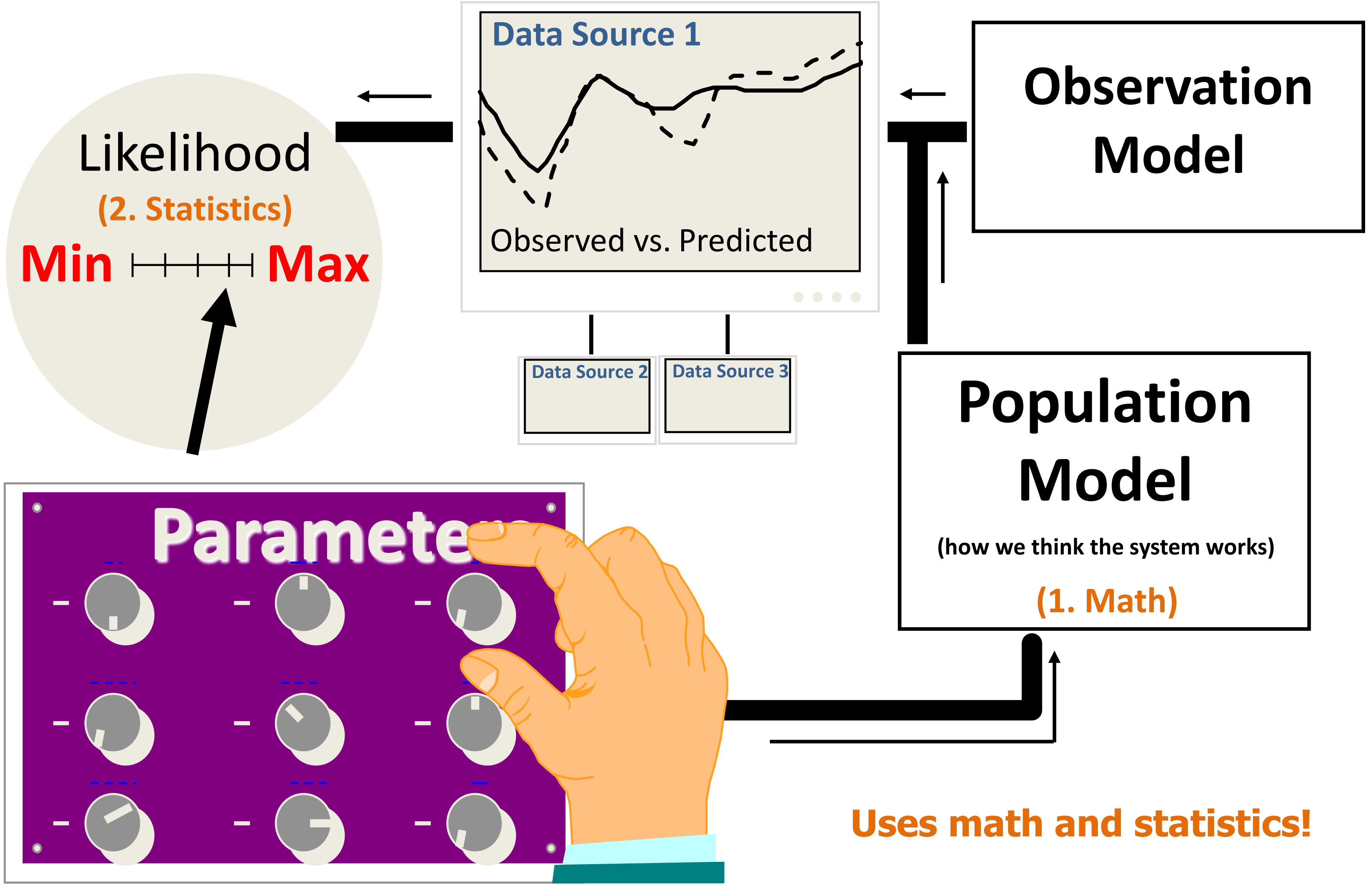
Applying models

- Understand simplifications/assumptions
- Provides appropriate output
- As much of a black box as an engine



“All models are wrong; some models are useful”- G.E.P. Box

Stock Assessment (not really a ‘black box”)



Stock assessment terminology

Stock - Biological unit being analyzed, and its fishery

Abundance (N), Biomass (B) - How many (N) or total weight (B) of fish

Recruitment (R) - Number of young fish entering stock each year

Natural mortality (M) - Mortality each year due to natural causes

Fishing mortality (F) - Mortality each year from fishing

Total Mortality (Z) = M + F

Maximum Sustainable Yield (MSY) – The largest average catch that the stock can produce over the long-term

Overfishing Limit (OFL) – The level of catch above which overfishing is occurring, generally corresponds to MSY

Acceptable Biological Catch (ABC) – The level of catch that prevents OFL from being exceeded

Total Allowable Catch (TAC) – Council-specified upper limit on catch (cannot exceed ABC)

Stock assessment terminology

Biological Reference Point - a biologically-based metric of stock status

B_{MSY} – Stock biomass associated with MSY

F_{MSY} – Fishing mortality associated with MSY (F_{OFL})

Spawning Stock Biomass (SSB, FSB) – Egg producing portion of the stock, can be basis for B_{MSY}

Spawners per Recruit (SPR) –Ratio between two lifetime egg productions (fished/unfished)

$B_{100\%}$ – Biomass of unfished stock

$F_{35\%}$ – A fishing mortality rate that, in the long term, under average recruitment would result in 35% of unfished biomass. Proxy for F_{MSY} (F_{OFL}) for stocks above B_{MSY}

$F_{40\%}$ – A fishing mortality rate that, in the long term, under average recruitment would result in 40% of unfished biomass. Proxy for F_{MSY} (F_{OFL}) for stocks below B_{MSY}

$B_{35\%}$ – Long-term average biomass expected under average recruitment and **$F_{35\%}$** . Proxy when B_{MSY} cannot be directly estimated

Population dynamics

- The study of change in an animal or fish population.
  - The simplest useful population model is the logistic, in which a population has sigmoidal growth to the carrying capacity.
  - More complex models may include age and/or length structure, natural and harvesting mortality, recruitment of new individuals into the population, individual growth, reproductive parameters, species interactions, spatial structure, and movement.
  - A common feature of realistic models that have an equilibrium carrying capacity is that there is density-dependence in some population process that causes a reduction in the rate of increase as the population gets large.

Theory of surplus production

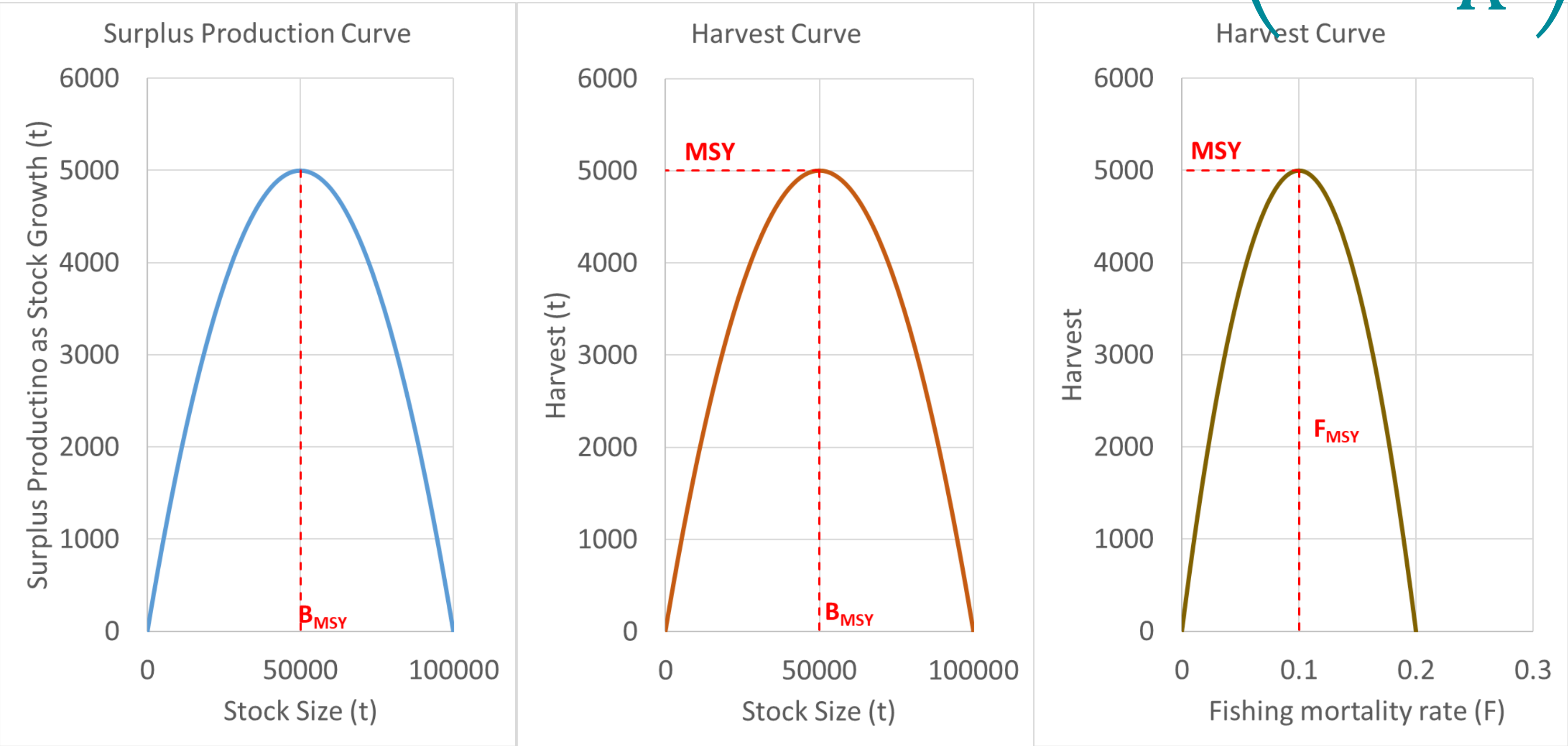
- Stocks respond to sudden new causes of mortality with additional productivity to compensate.
  - Fishing mortality reduces the biomass below carrying capacity, reduced competition and greater relative abundance of resources at this lower level allows the stock to increase productivity.

- Theoretically, the biomass of a stock can be held indefinitely at a level below carrying capacity, and the fishery can continue to operate on the corresponding surplus production.
  - This entails a lot of assumptions, but in effect is the basis for current fisheries management practices.

Surplus production model

- Schaefer model or logistic production model:

$$B_{t+1} = B_t + rB_t\left(1 - \frac{B_t}{K}\right) - C_t$$



$$B_{MSY} = K/2$$

$$C_{MSY} = rK/4$$

Carrying capacity K = 100,000t = $B_{100\%}$

Growth rate r = 0.2

B_{MSY} = 50,000t

C_{MSY} = 5,000t

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Surplus production model

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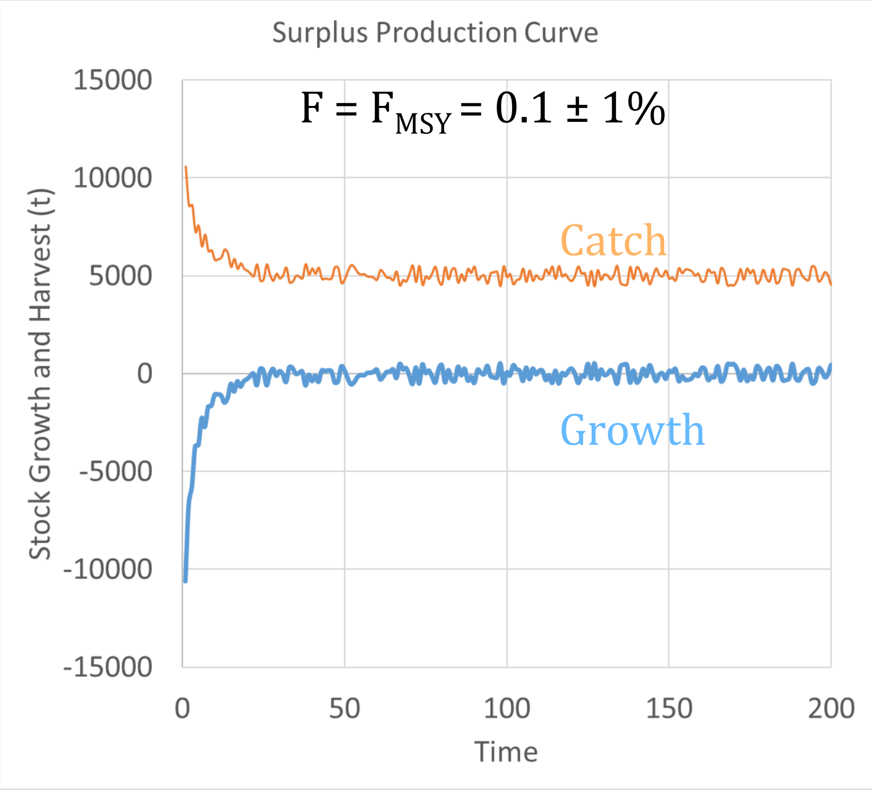
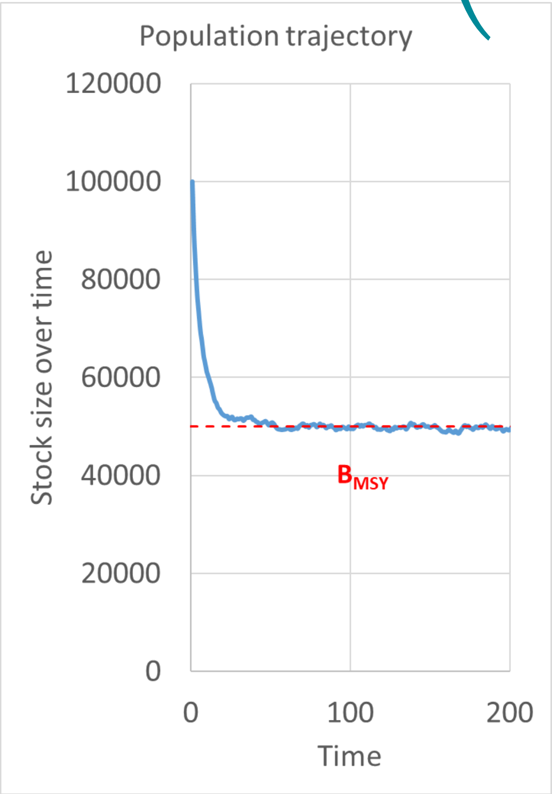




$$B_{MSY} = K/2$$

$$C_{MSY} = rK/4$$

Carrying capacity K = 100,000t = $B_{100\%}$
Growth rate r = 0.2
B_{MSY} = 50,000t
C_{MSY} = 5,000t

North Pacific Groundfish Tier System

Data quality

OFL

Tier 1

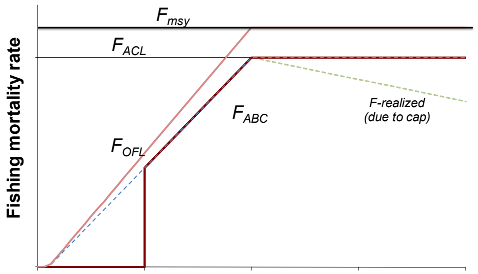
Tier 2

Tier 3

Reliable stock recruitment relationship

Reliable estimates of spawners, age-structured model

ABC



Scientific uncertainty explicitly considered in buffering ABC from OFL

HCR provides additional buffer below BMSY

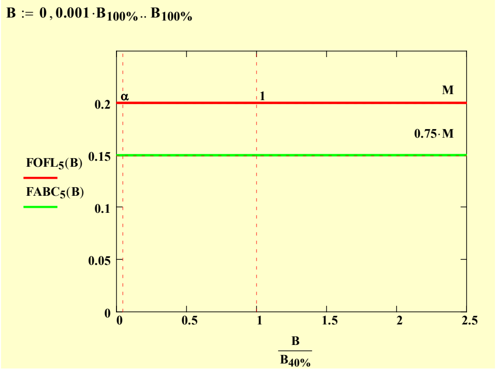
Tier 4

Tier 5

Tier 6

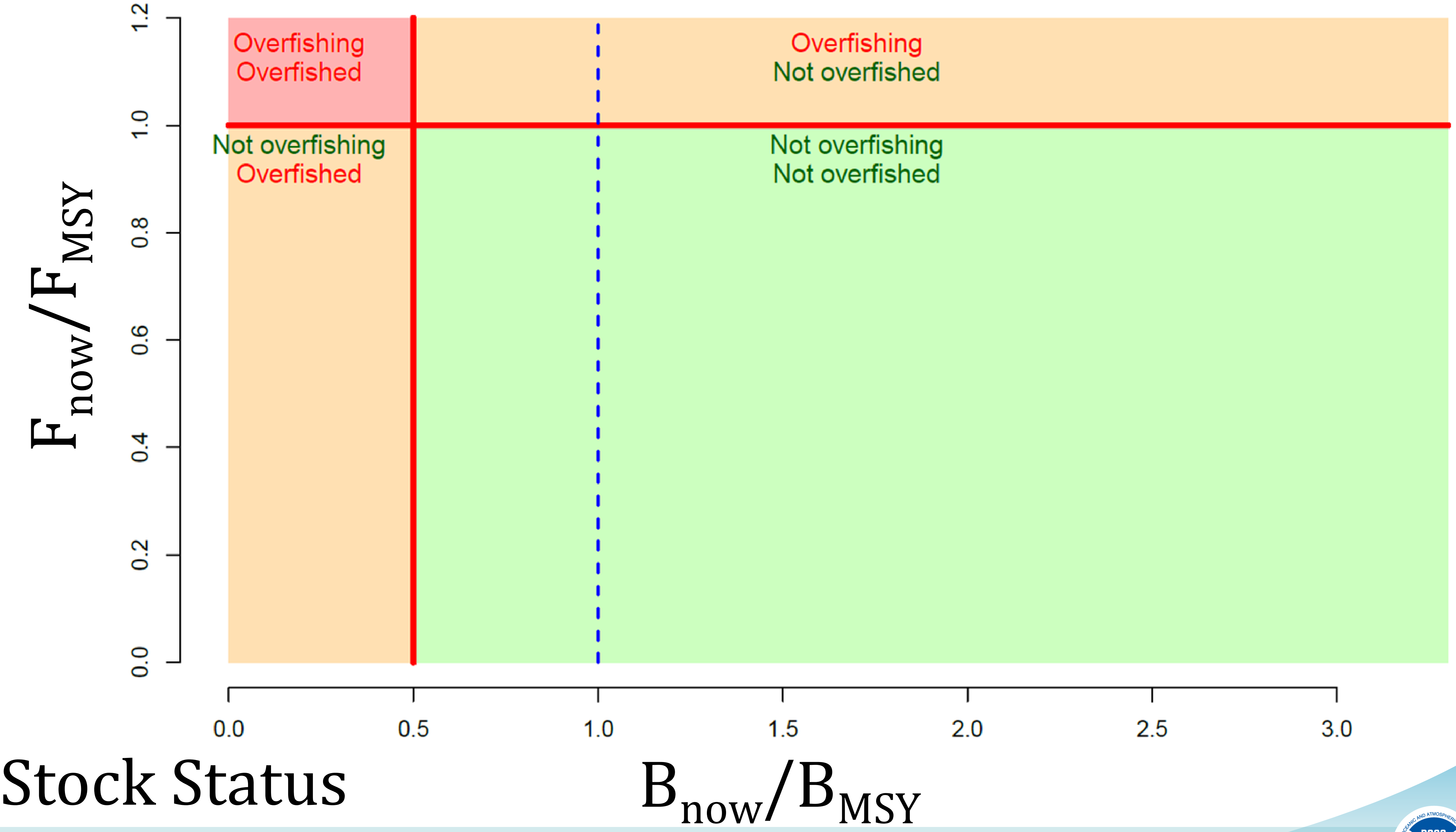
OFL based on survey biomass estimates and natural mortality

OFL usually based on historical catch

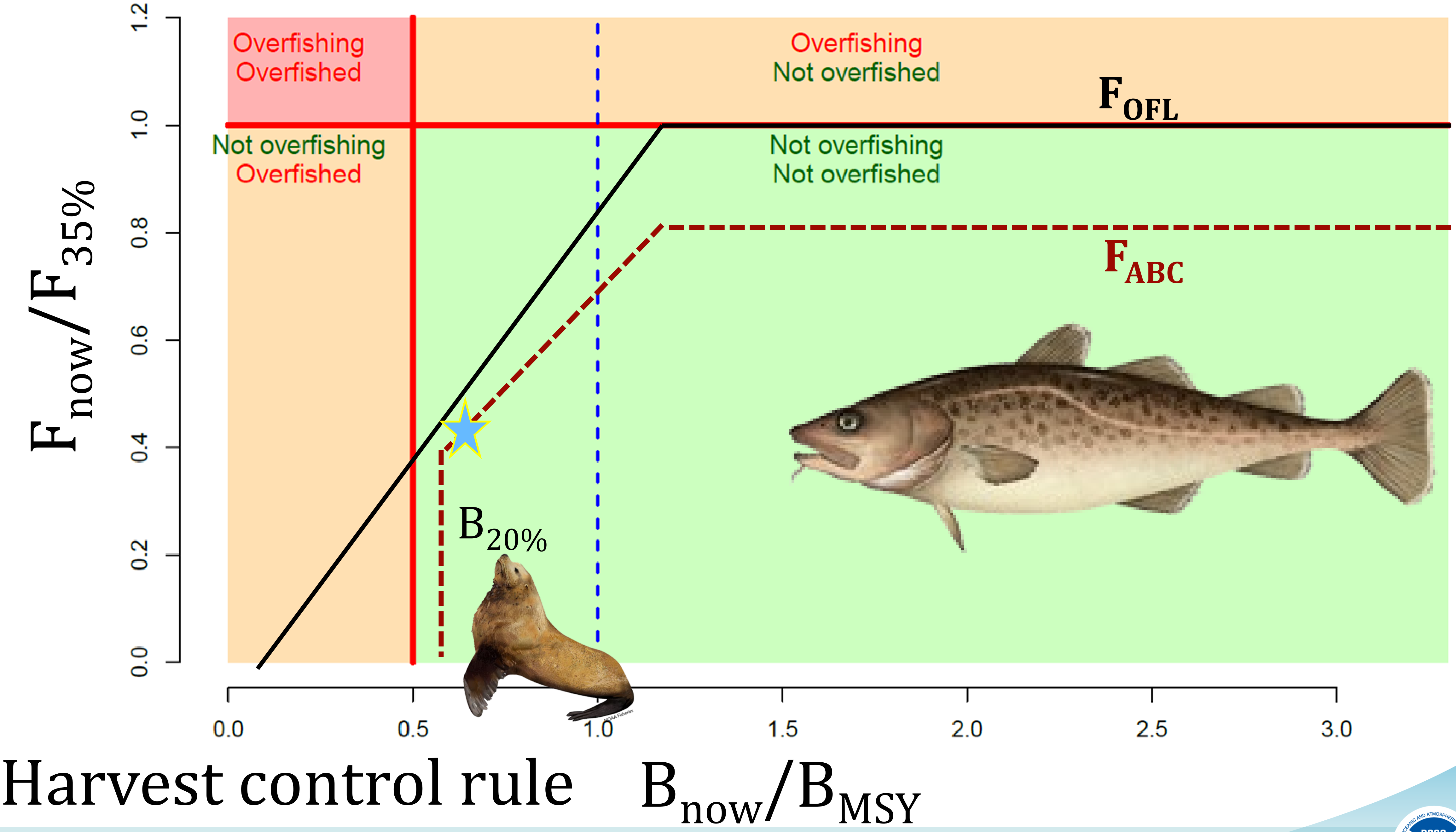


Flat CR based on estimate of natural mortality

Flat CR based on 25% buffer from OFL



Stock Status



Harvest control rule

Life history modeling

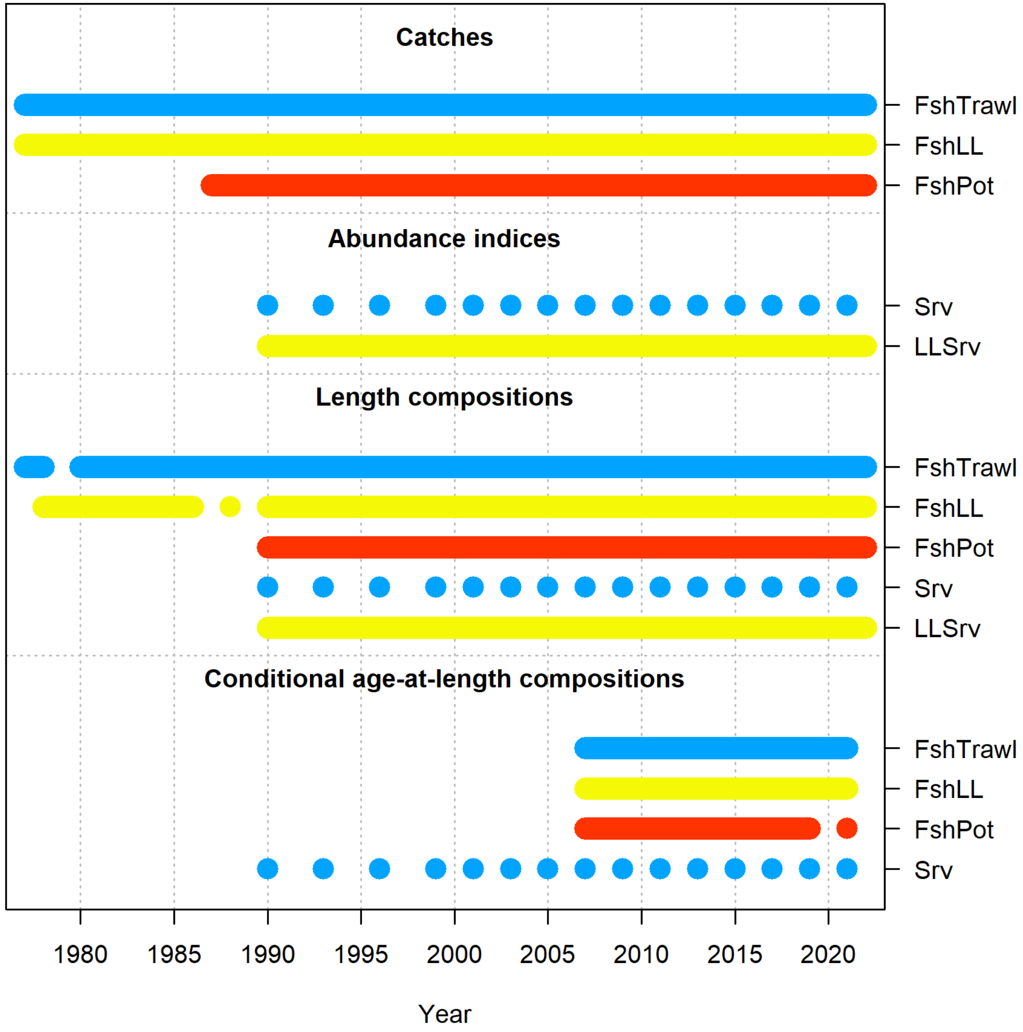
- Population dynamics modeling in which the life history characteristics such as recruitment, natural mortality, and growth are used to assess an appropriate management strategy
- Compensation remains a fundamental assumption, but origins and shape of production in relation to population size, mortality, growth, and recruitment is modeled

Single Species Age-based Stock Assessment

- Statistical catch-at-age model
  - Analyzes data on the age of fish captured in scientific surveys and by fisheries to provide management advice. Requires a large amount of data.
    - At least one index of stock size, such as a survey index or record of commercial fishery catch and effort.
    - Records of the total catch from each fishery targeting a stock over time.
    - Information on the number of fish caught at each age during annual surveys and by all relevant fisheries.
  - Performance depends on information on a stock's natural mortality, growth, and reproduction.
  - Estimates a stock's current size, harvest rate, and its management reference points associated with maximum sustainable yield (MSY) and forecasts of catch and biomass that managers can use to evaluate the risk associated with a range of harvest options.

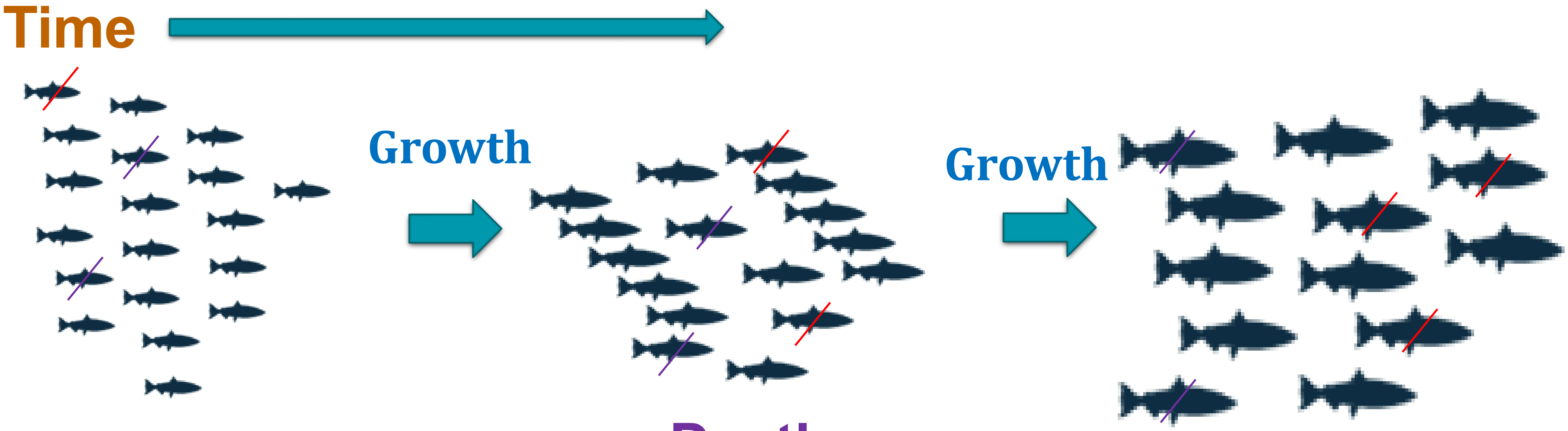
Current GOA Pacific cod Stock Assessment

- Data
  - Abundance indices
  - Catch
  - Length composition
  - Conditional age-at-length composition



Modelling fish populations: How do we do it?

A population model is developed to represent the stock accounting for all components of population growth.



- Deaths
- Catches

- Deaths
- Catches

- Deaths
- Catches

Year-class scale

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Pacific cod operating model

- Statistical catch-at-age

$$N_{a,t+1}\begin{cases} N_{0,t+1} & a = 0 \\ N_{a-1,t}e^{-M-s_{f,a-1}F_t} & a \geq 1 \; to \; A-1 \\ \left(N_{A-1,t}+N_{A,t}\right)e^{-M-s_{f,A}F_t} & a = A \end{cases}$$

  - $N_{a,t+1}$ is the number of fish at age a at the start of the year t
  - $s_{f,a}$ is the fishery gear selectivity by age
  - A is the maximum age in the model, a ‘plus group’
  - F_t is the instantaneous fishing mortality rate
  - M is the instantaneous natural mortality rate

Recruitment - $N_{0,t+1}$

- The addition of new individuals to a population through the birth process
- Most important component in population dynamics
- Stock recruitment models predict the number of recruits in a coming year based on the current number of spawners and assumptions on the nature of mortality and compensation.

Recruitment Models

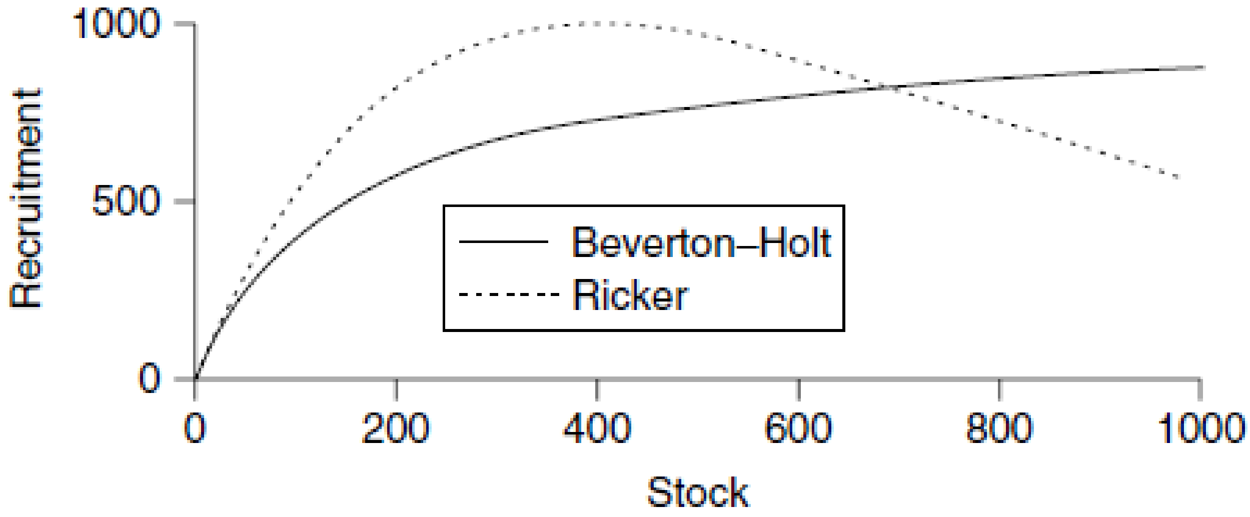
- Beverton-Holt model
  - Density-dependent effect is related to the juvenile population itself

$$N_{0,t+1} = \alpha S_t / 1 + \beta S_t$$

- Ricker model
  - Density dependent effect is related to the stock rather than juvenile population

$$N_{0,t+1} = \alpha e^{-\beta S_t}$$

  - S_t is the spawning biomass in year t
  - α is the productivity parameter
  - β is the density dependence parameters

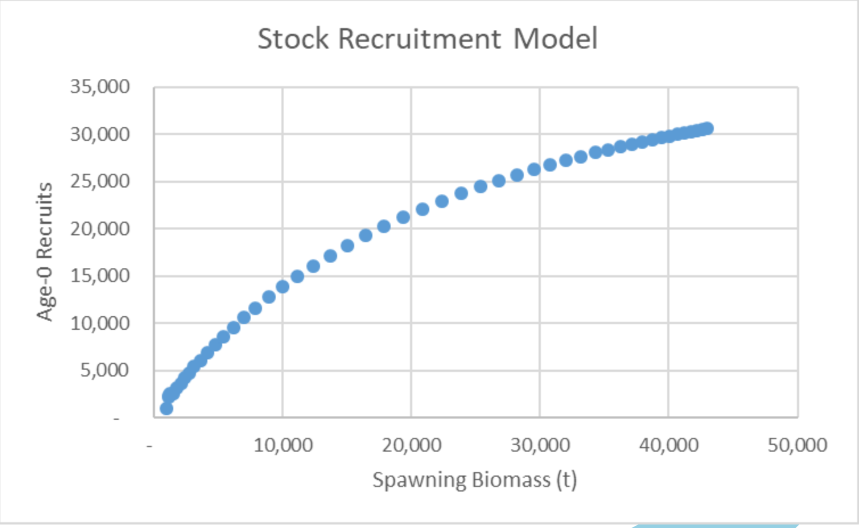


Recruitment Models

- Beverton-Holt reparamaterization

$$N_{0,t} = \frac{4hR_0S_t}{S_0(1-h)+S_t(5h-1)} e^{-0.5\sigma_R^2+\bar{R}_t}$$

  - h=steepness or recruitment compensation
  - S_0 = unfished equilibrium spawning biomass
  - S_t = spawning biomass at the start of the season
  - R_0 = number of age-0 fish at unfished equilibrium
  - σ_R^2= standard deviation of recruitment
  - $\bar{R}_t$= lognormal recruitment deviation for year t

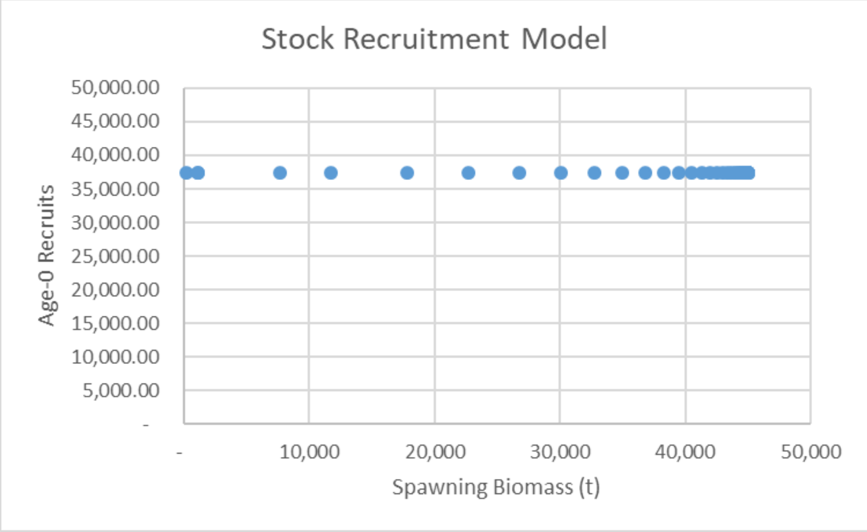


Recruitment Models

- Beverton-Holt reparamaterization with h=1 (Mean recruitment)

$$N_{0,t} = R_0 e^{-0.5\sigma_R^2 + \bar{R}_t}$$

  - R_0 = number of age-0 fish at unfished equilibrium
  - σ_R^2= standard deviation of recruitment
  - $\bar{R}_t$= lognormal recruitment deviation for year t



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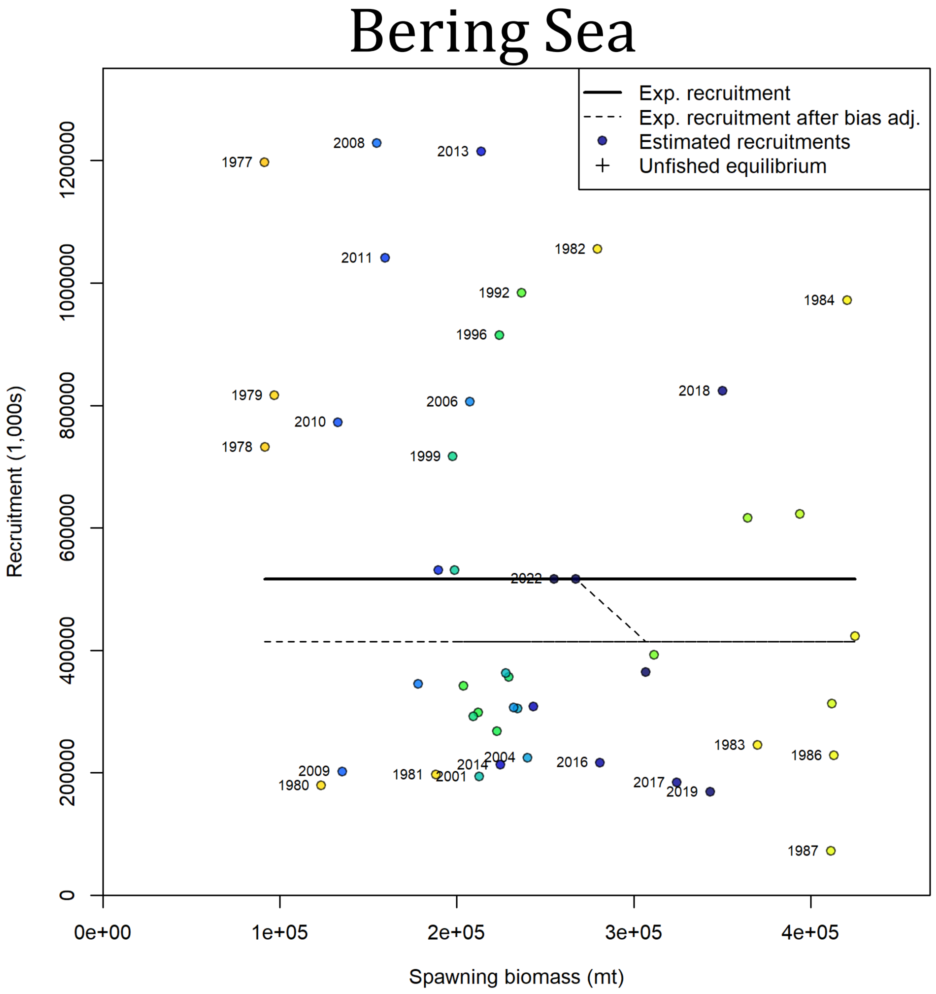
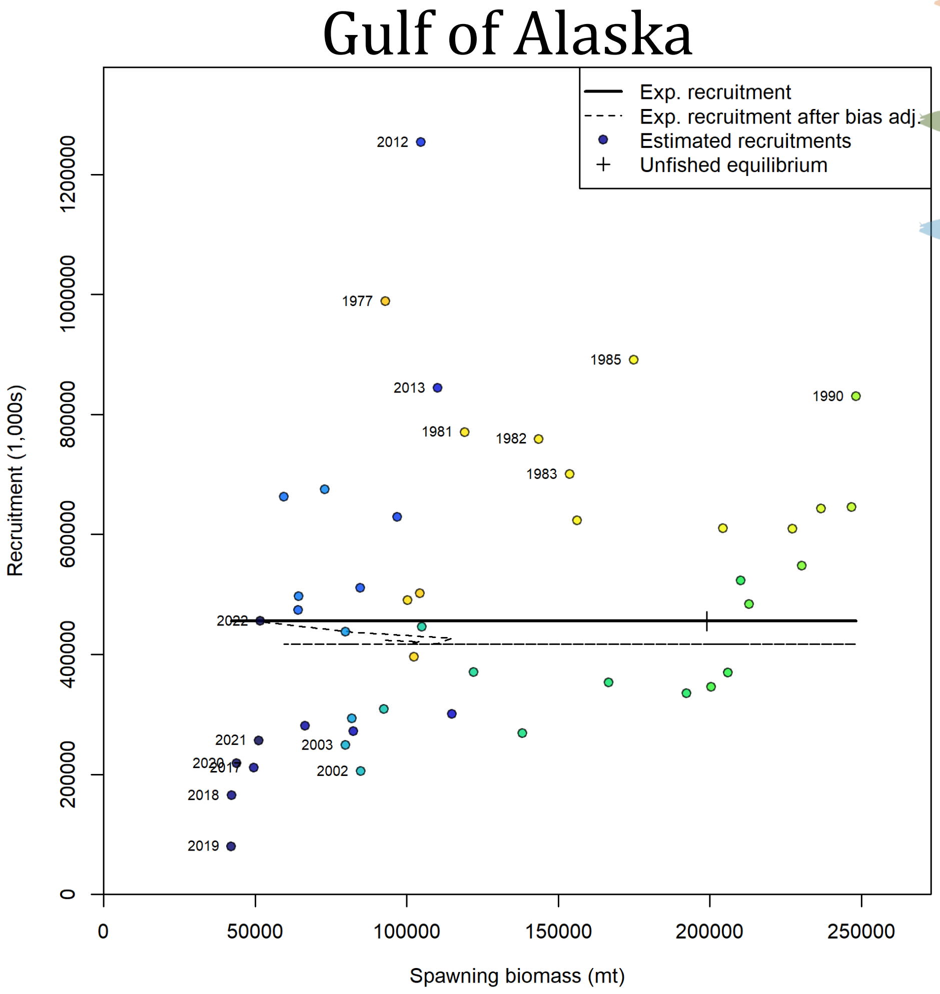
Pacific cod Recruitment





h=1.0

Survey Observation Model

- The biomass that is available for observation at each year *t* for the survey at age *a* and length *l* is:

$$\widetilde{\boldsymbol{B}}_{t,a,l} = \emptyset_{a,l} w_l s_{s,a,t} \left(\widetilde{N}_{a,t} e^{\left(-surveytiming\left(M_a + F_{f,a} F_t\right)\right)} \right)$$

  - $\emptyset_{a,l}$ is the proportion of fish at age *a* at length *l*
  - w_l is the weight at length *l*
  - $S_{s,a,t}$ is the survey selectivity at age a in year *t*.
  - $e^{\left(-surveytiming\left(M_a + F_{f,a} F_t\right)\right)}$ takes into account the fish removed from the population prior to the survey through natural and fishery mortality

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Survey Observation Model

- The expected observed survey is related to the available population abundance by:

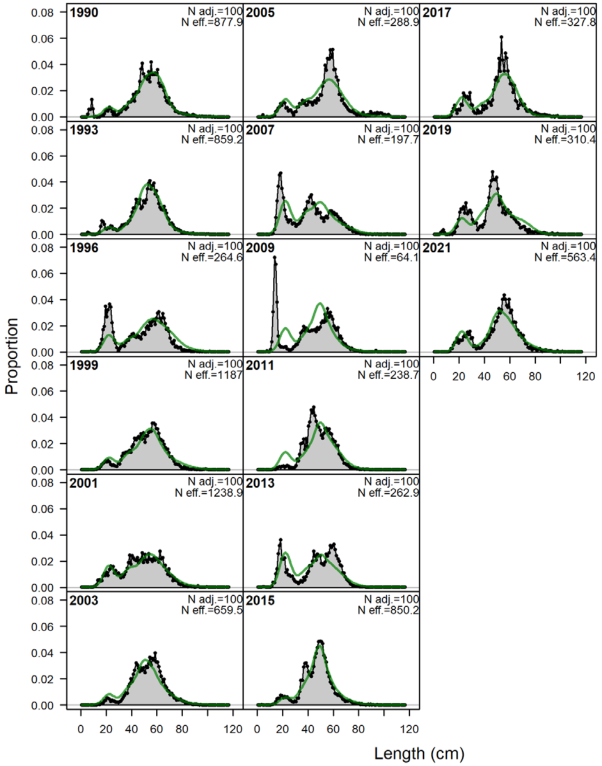
$$B^{obs}_{t,a,l} = \mathbf{Q}\tilde{B}_{t,a,l}e^{\varepsilon^s_t-((\sigma_s)^2/2)} \quad \varepsilon^S_t \sim N(0,(\sigma_s)^2)$$

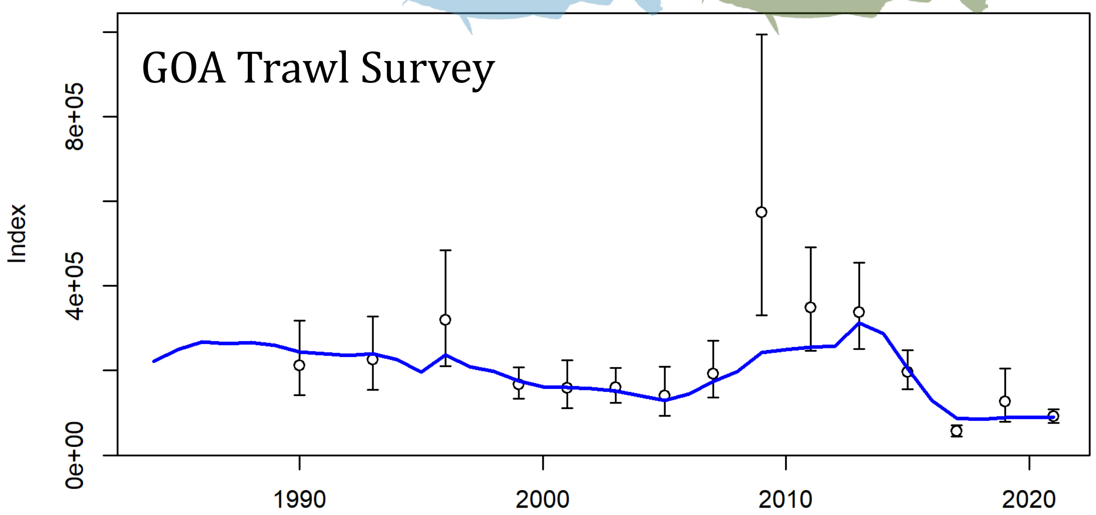
  - **Q** is the catchability coefficient for the survey
  - σ_s is the standard deviation of the survey catchability in log space.

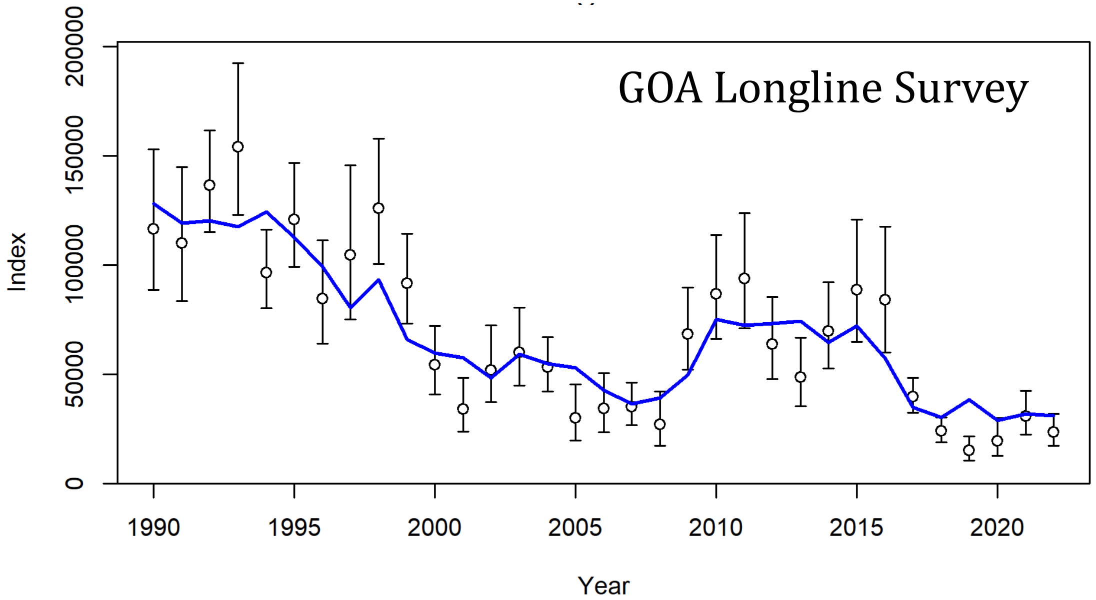
The catchability parameter scales the survey biomass to the population and is highly influential in the model results

Surveys

- GOA bottom trawl surveys
  - 1991-2021
- GOA longline survey
  - 1990-2022

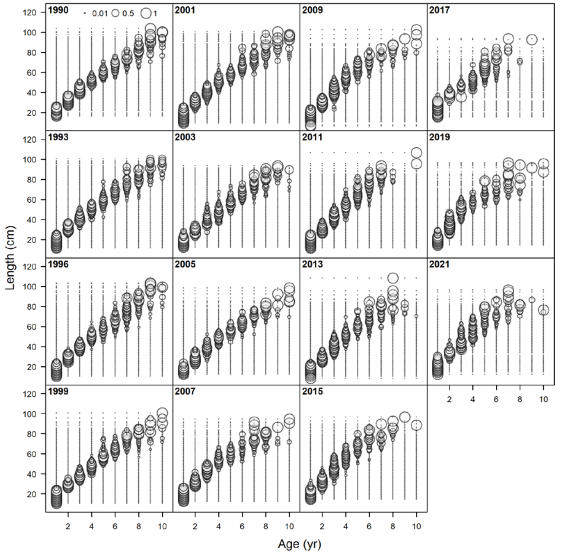


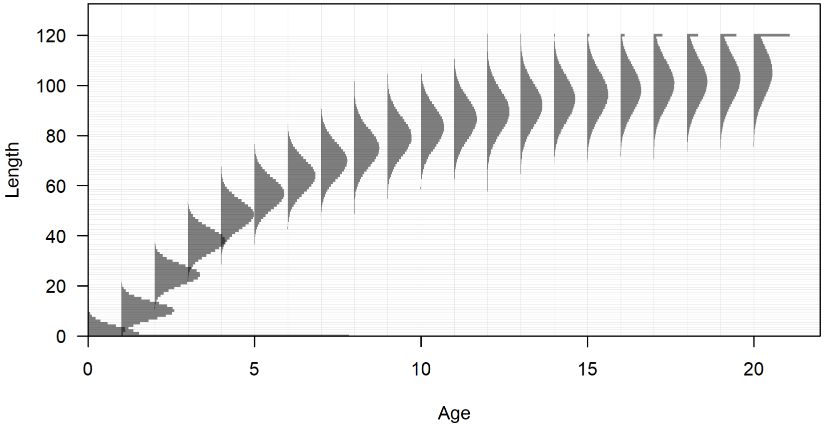


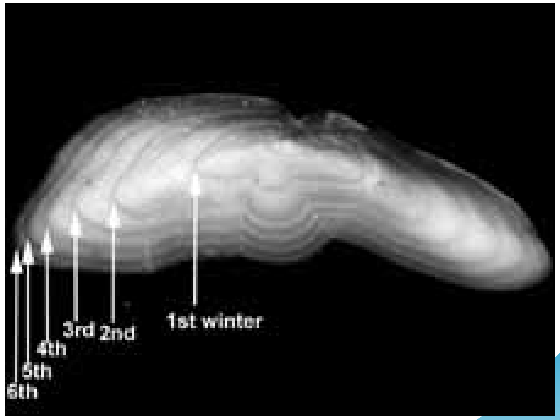


Age at length, $\emptyset_{a,l}$

- Otoliths age determination
  - Traditional 'break and burn' with manual interpretation of bands
- Age at length key used to develop age composition for survey and fishery







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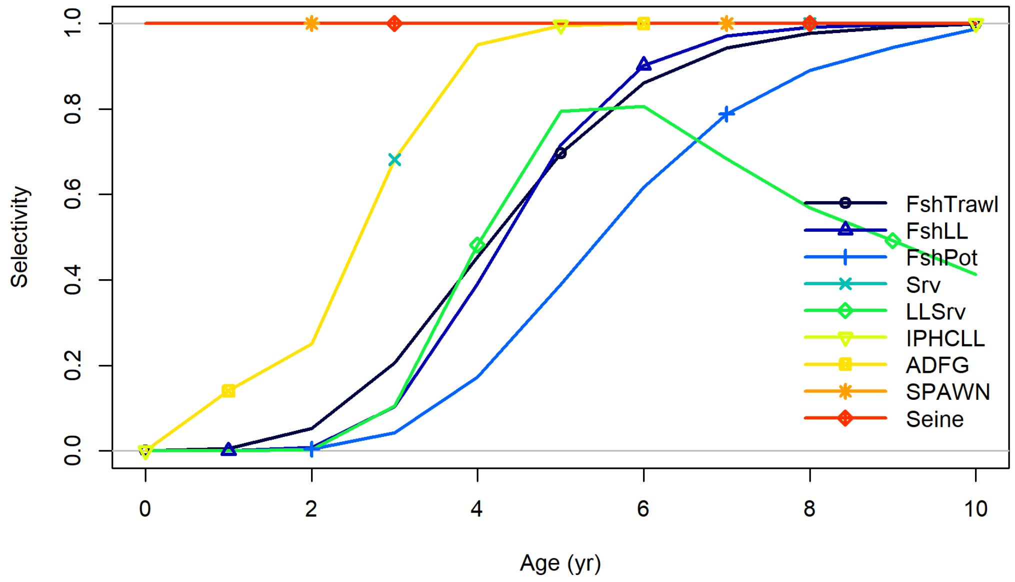
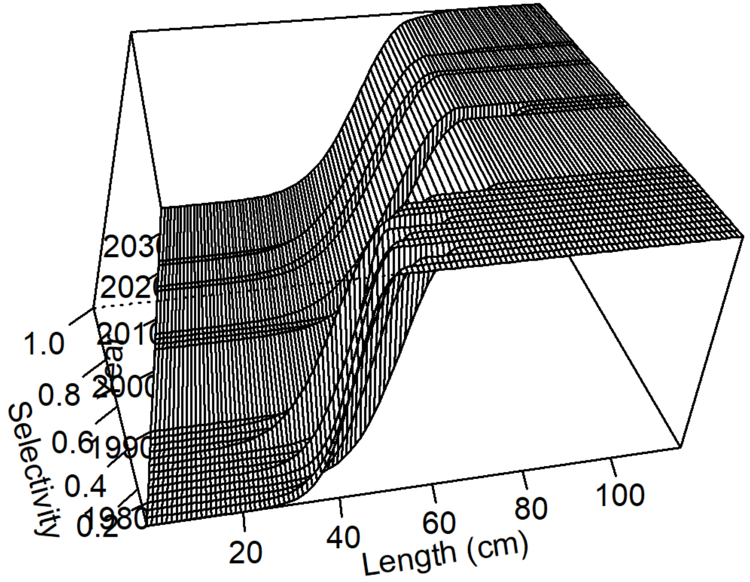
Population selectivity $S_{s,a,t}$

- The differential vulnerability to fishing of the demographic components of an exploited fish population, as a result of the gear used (e.g. mesh or hook size) and availability (choice of fishing timing or location).

GOA Pacific cod selectivity



GOA Pacific cod trawl fishery



Catch-at-age

- Baranof catch equation

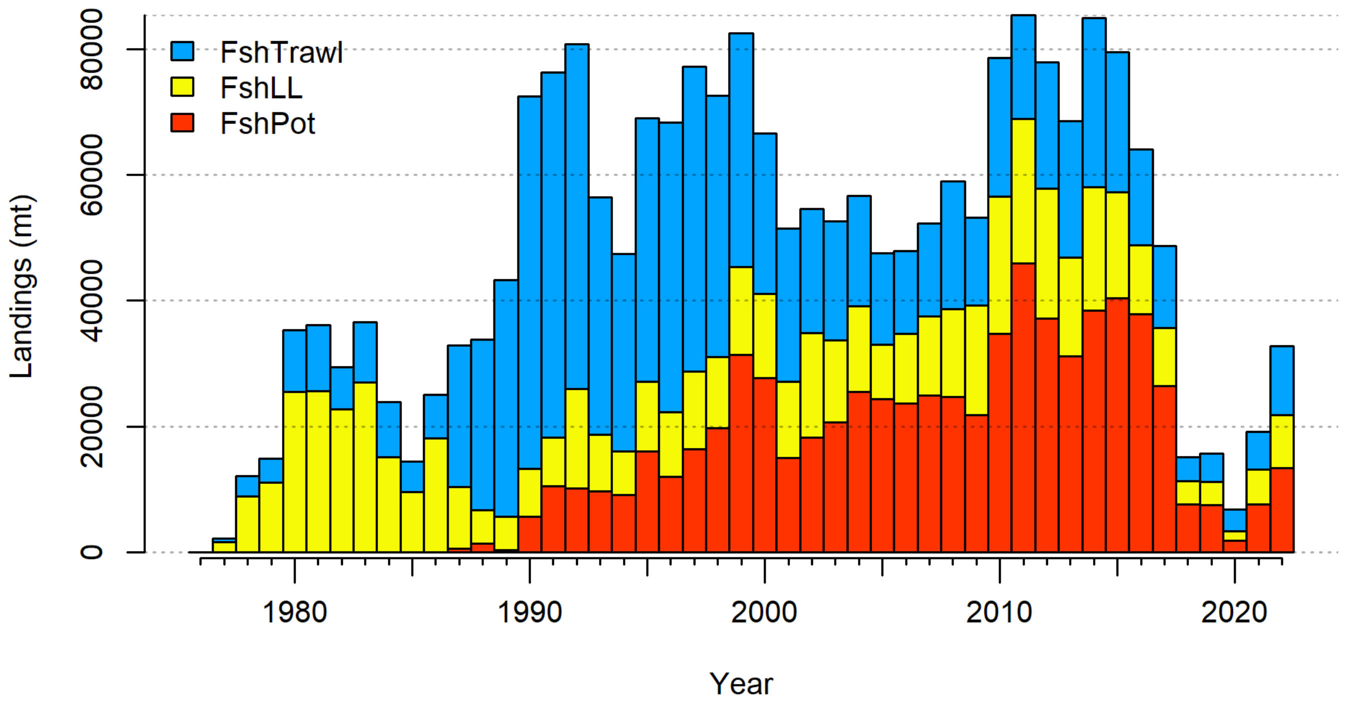
$$C_{a,t} = \frac{S_{f,a,t} F_t}{M + S_{f,a,t} F_t} N_{a,t} \left(1 - e^{(-M - S_a F_t)}\right)$$

- $C_{a,t}$ is the catch in numbers at age a year t
- $N_{a,t}$ is the number of fish at age a at the start of the year t
- $S_{f,a,t}$ is the gear selectivity by age a and year t
- A is the maximum age in the model, a ‘plus group’
- F_t is the instantaneous fishing mortality rate
- M is the instantaneous natural mortality rate

Catch Accounting

- Blend of foreign reports, fish tickets, observer data, and log books
  - Foreign and joint venture fishery 1977-1989
  - Domestic fishery 1989- present

Gulf of Alaska Catch

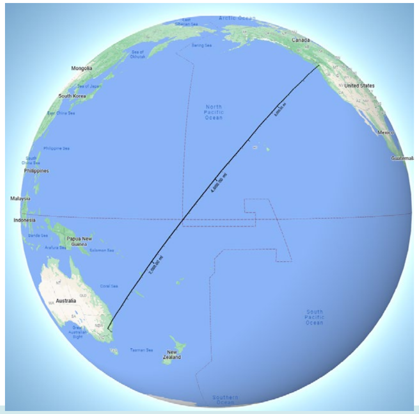


Catch-at-size and Catch-at-age

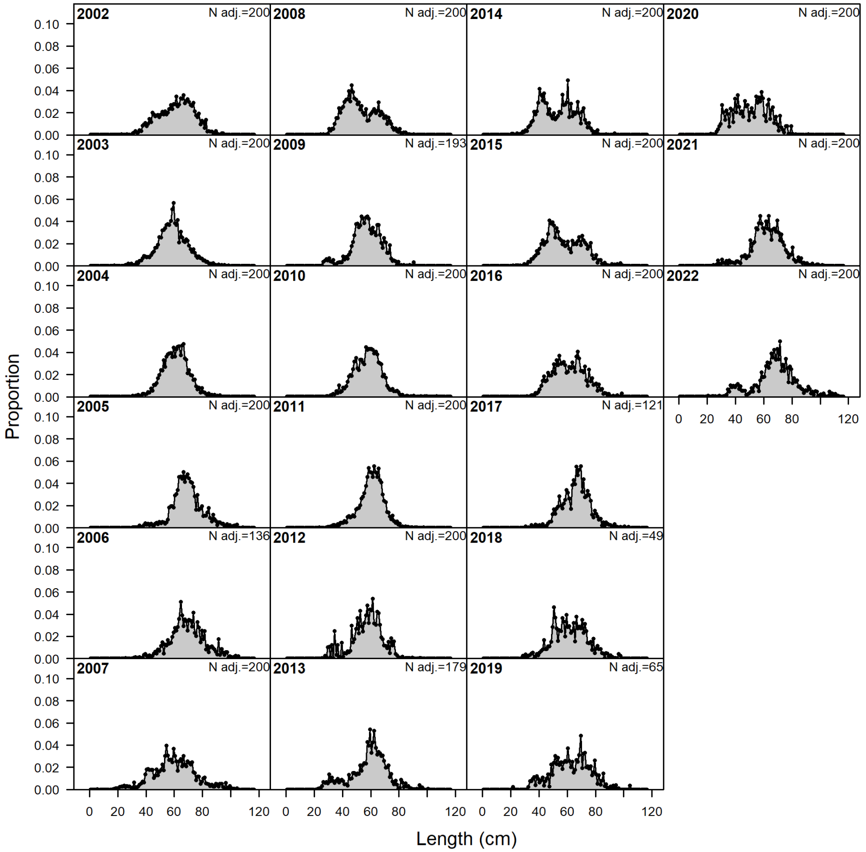
- Collected by observers
  - ~40,000 at sea hours/year
  - Bering Sea 1977-Present
    - Size measurements = 8,840,045
    - Otolith pairs for aging = 169,464
  - Gulf of Alaska 1977-Present
    - Size measurements = 2,334,225
    - Otoliths pairs for aging = 163,422

7,916 KM of cod

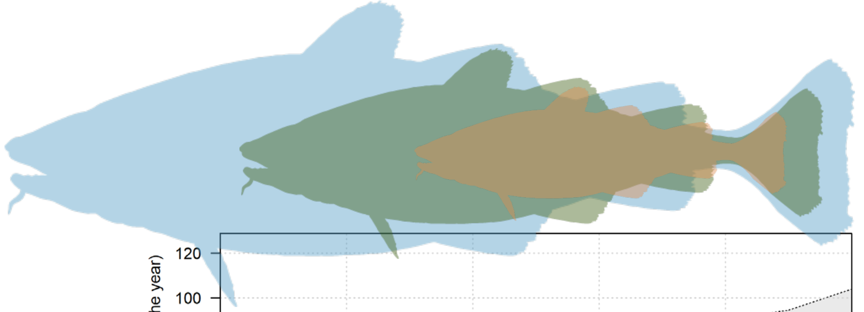
Seattle to Canberra



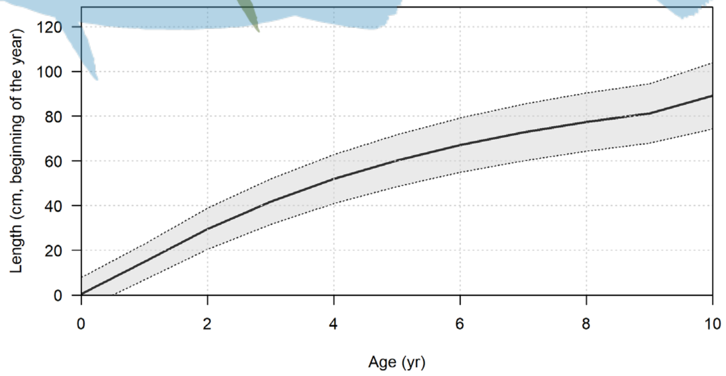
Gulf of Alaska Trawl Fishery Length Composition



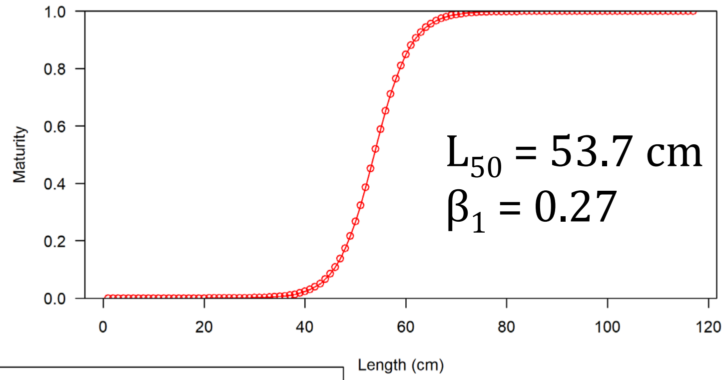
Pacific Cod Growth and Maturity



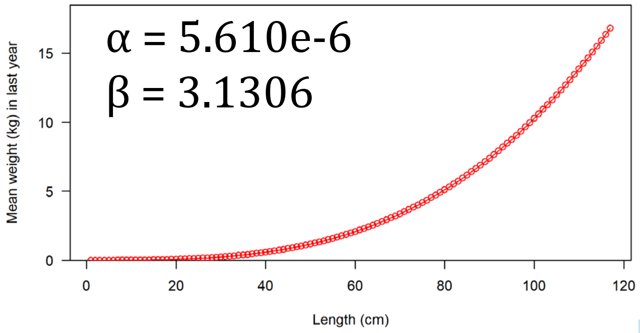
- Length-at-age (Survey data 1991-2021)
  - Von Bertalanffy growth equation
  - $L_a = L_\infty\{1 - e^{-k(a-a_0)}\}$
    - L_∞ is the asymptotic length
    - k is the growth parameter
    - a_0 is the hypothetical age were length =0
    - a is age



- Maturity-at-length (Stark 2007)
  - Proportion mature at length $P_L = \frac{1}{1+e^{-(\beta_1 L_{50}+\beta_1 L)}}$
  - β_1 is the slope
  - L_{50} is the length at 50% mature
  - L is length



- Weight-at-length (Survey data 1991-2021)
  - $W = \alpha L^\beta$



Back to the Future: Projecting Catch

- The stock assessment is only the **first half** (the easy half!) of developing scientific advice
- Once current stock sizes are estimated, then levels of sustainable harvest must be calculated using *projections/forecasts* that are based on:
  - **Desired 'sustainable' biomass** (a.k.a. **biological reference points** or 'target' biomass)
  - **Expected dynamics** of the fish and fishermen, using recent past
  - **Management actions**, known as harvest control rules (HCRs), which specify catch based on expected population size (relative to a reference point, the 'stock status')

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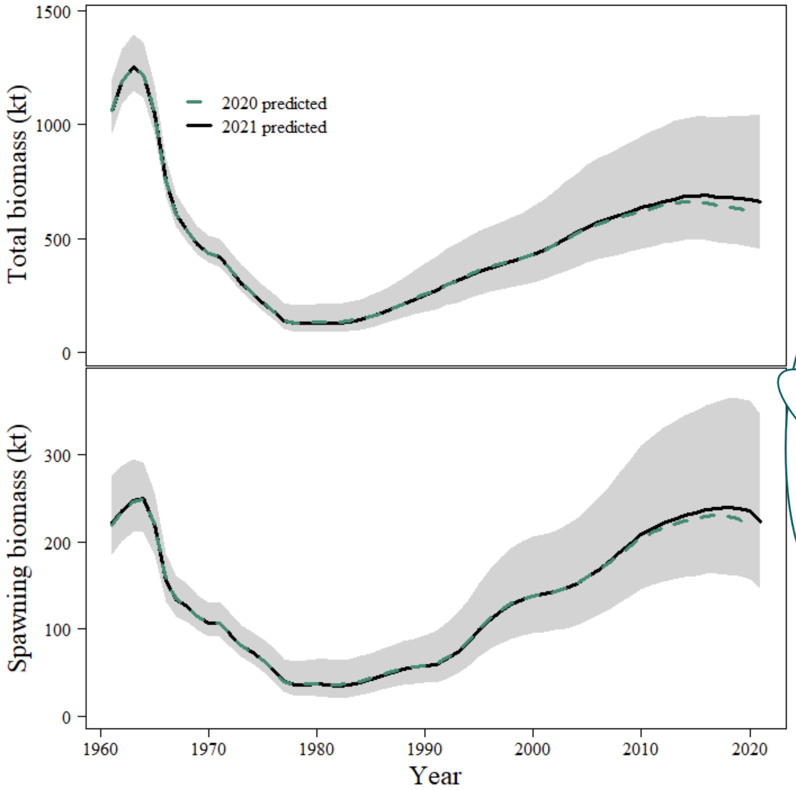
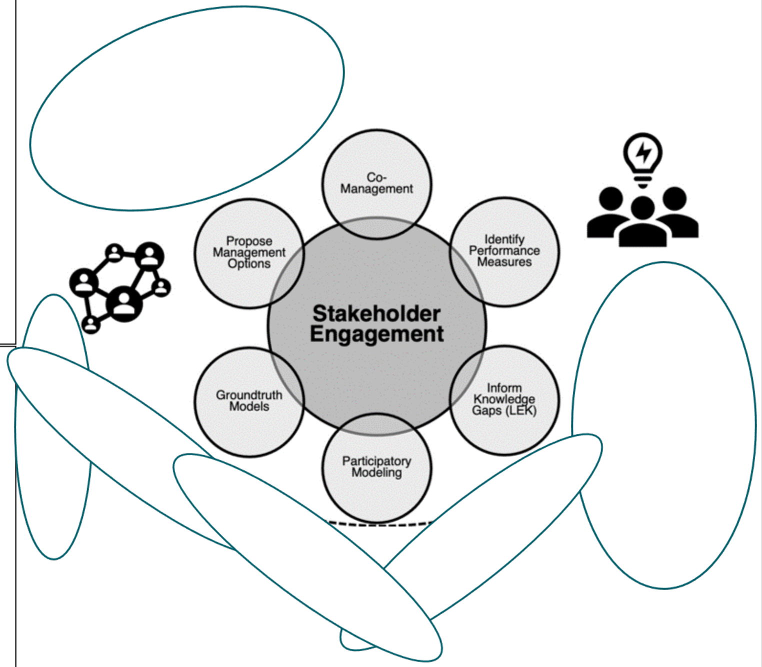
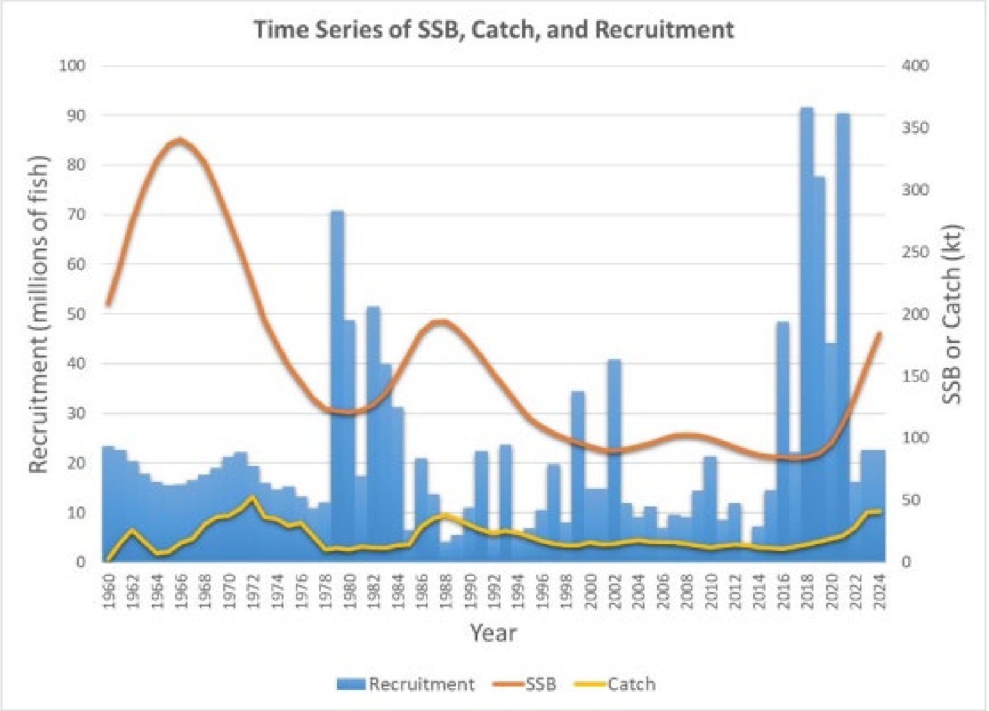
Interpreting stock assessment: look at the output – does it make sense?







Differing Perceptions of Reality

"No individual experiences the average condition"

- Fishermen
  - Real-time observations
  - Clustered
  - Small areas
  - Direct involvement
  - Year-round sampling
  - Goal-oriented sampling
  - High sample size
  - Sample the fishery
- Scientists
  - Lagged observations
  - Synoptic
  - Large areas
  - Indirect involvement
  - Intermittent snapshots
  - Probabilistic sampling
  - Low sample size
  - Sample populations