# Operating Model for Halibut ABM

# SSC Recommendations - June 2018

**Based on these criteria, the SSC recommends that the working group move forward with their proposed plan for the October 2018 meeting using Approach 2 (i.e., the “two-area” halibut simulation model) to conduct a preliminary analysis of a subset of ABM alternatives.** Approach 2 is the simplest and the closest to being developed of the three suggested approaches and will be capable of providing a preliminary analysis of ABM alternatives for the October 2018 meeting. Further, this approach is the most transparent and can explore some of the key assumptions that underlie halibut population dynamics. However, in its current form, Approach 2 still requires additional work before it can be used to evaluate ABM alternatives.

# SSC Recommendations - June 2018 cont.

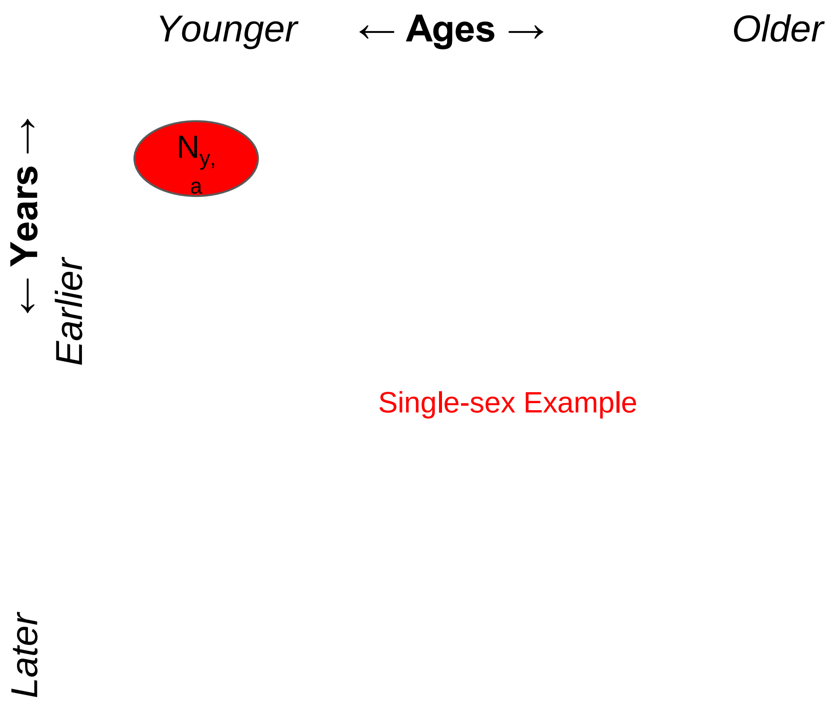
- **A management model for setting the Total Constant Exploitation Yield (TCEY) must be developed.** The SSC agrees with the working group's suggested approach of using historical observations to relate available halibut biomass and TCEY.

- **Halibut PSC limits must be tied to impacts in the groundfish and directed halibut fisheries.** The SSC was unsure of whether the suggested empirical approach of relating historical PSC limits to PSC use and groundfish harvest is appropriate since there is very little historical variation in PSC limits. A different approach for measuring impacts to the groundfish fisheries may be needed.

- **Additional thought must be given to how uncertainty will be incorporated into the model.** The working paper suggests that a halibut simulation framework with "perfect information" could be ready for the October 2018 meeting, but the SSC notes the importance of evaluating the performance of ABM alternatives under various sources of uncertainty (e.g., estimation, process, or implementation error).

# Operating Model (OM) Overview

- Sex and age-structured
- 2 Areas
  - BSAI region (4ABCDE)
  - Remaining regions in aggregate
- Common recruitment
  - Apportioned among areas
- 3 Gear types (Selectivity and $F_t$)
  - Directed Fishery, PSC Trawl, PSC Longline
- Gear-specific Selectivity
- Age-specific movement between areas



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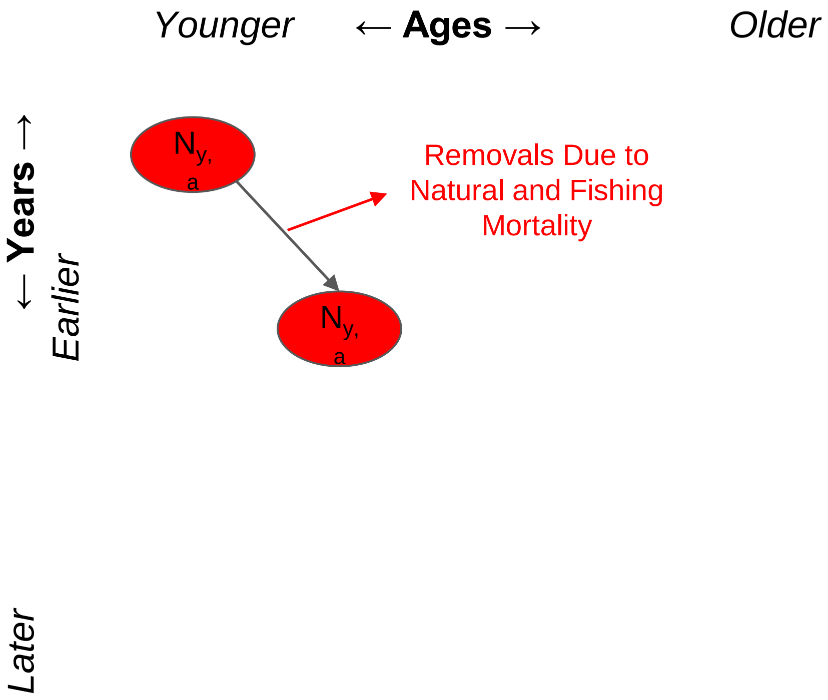

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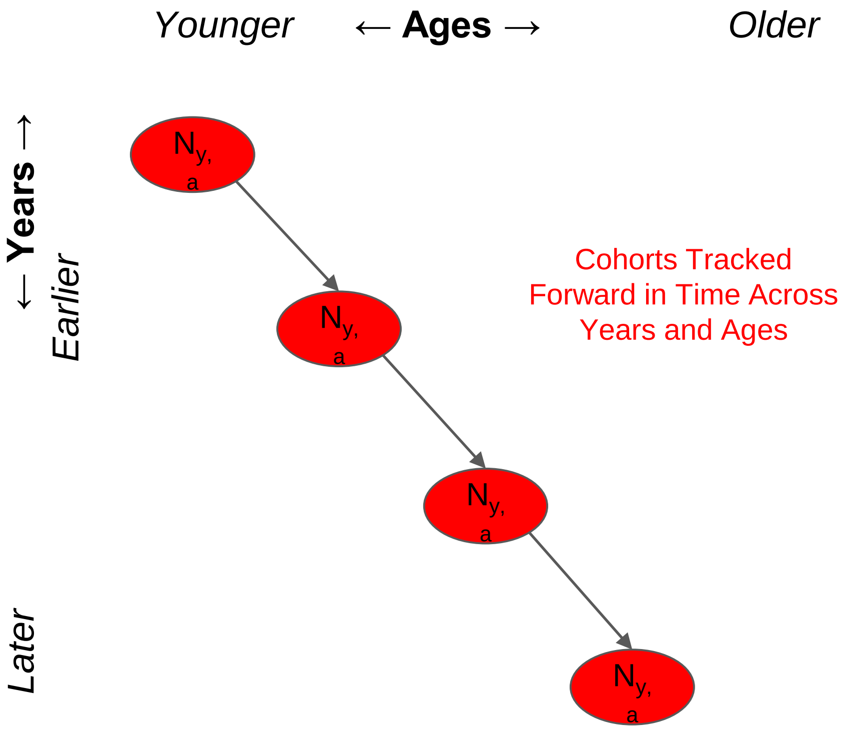

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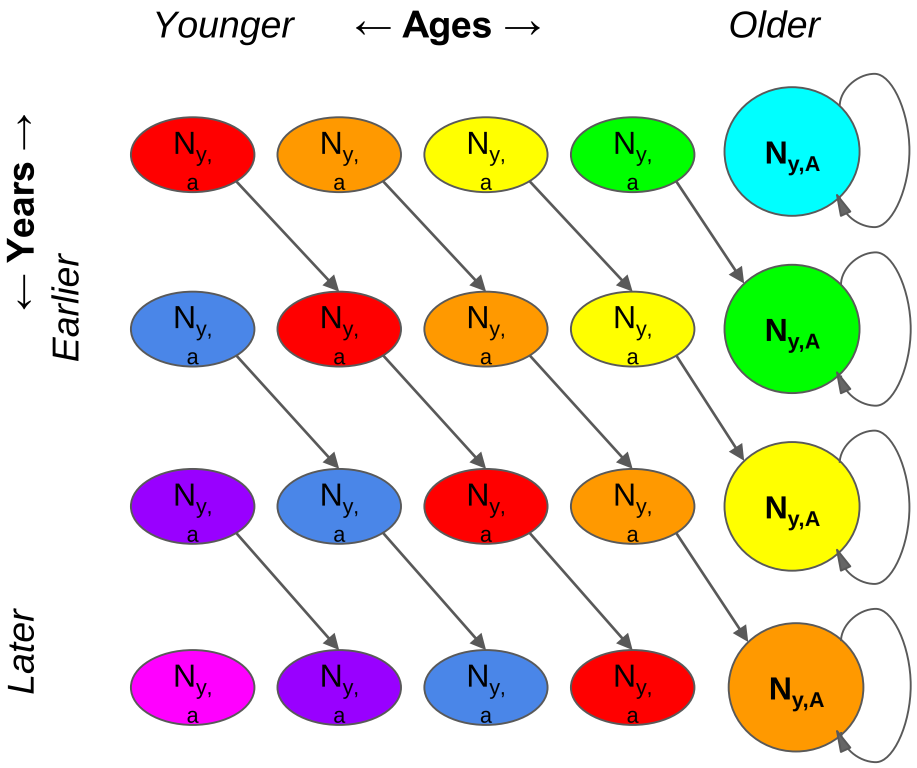
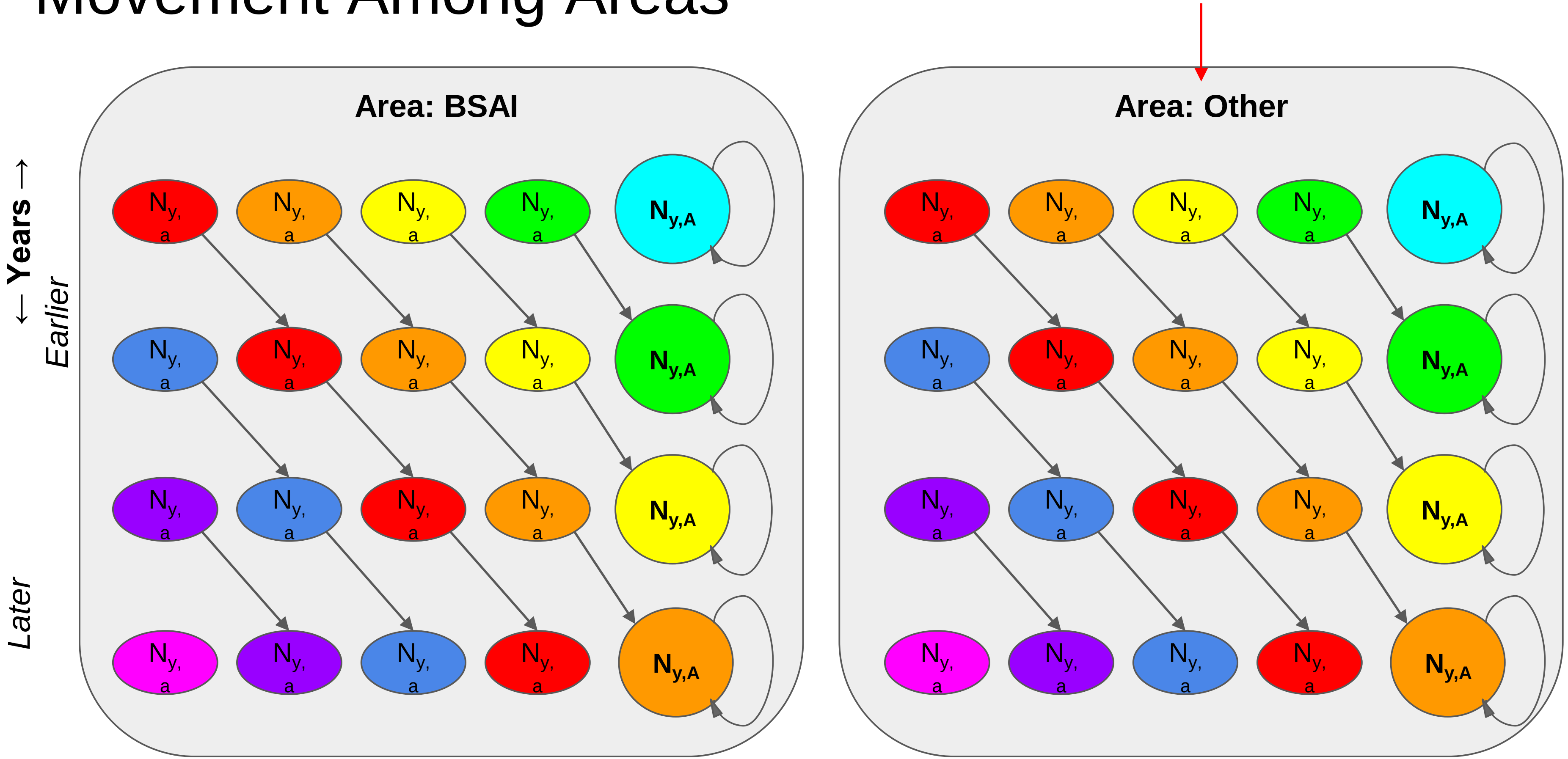


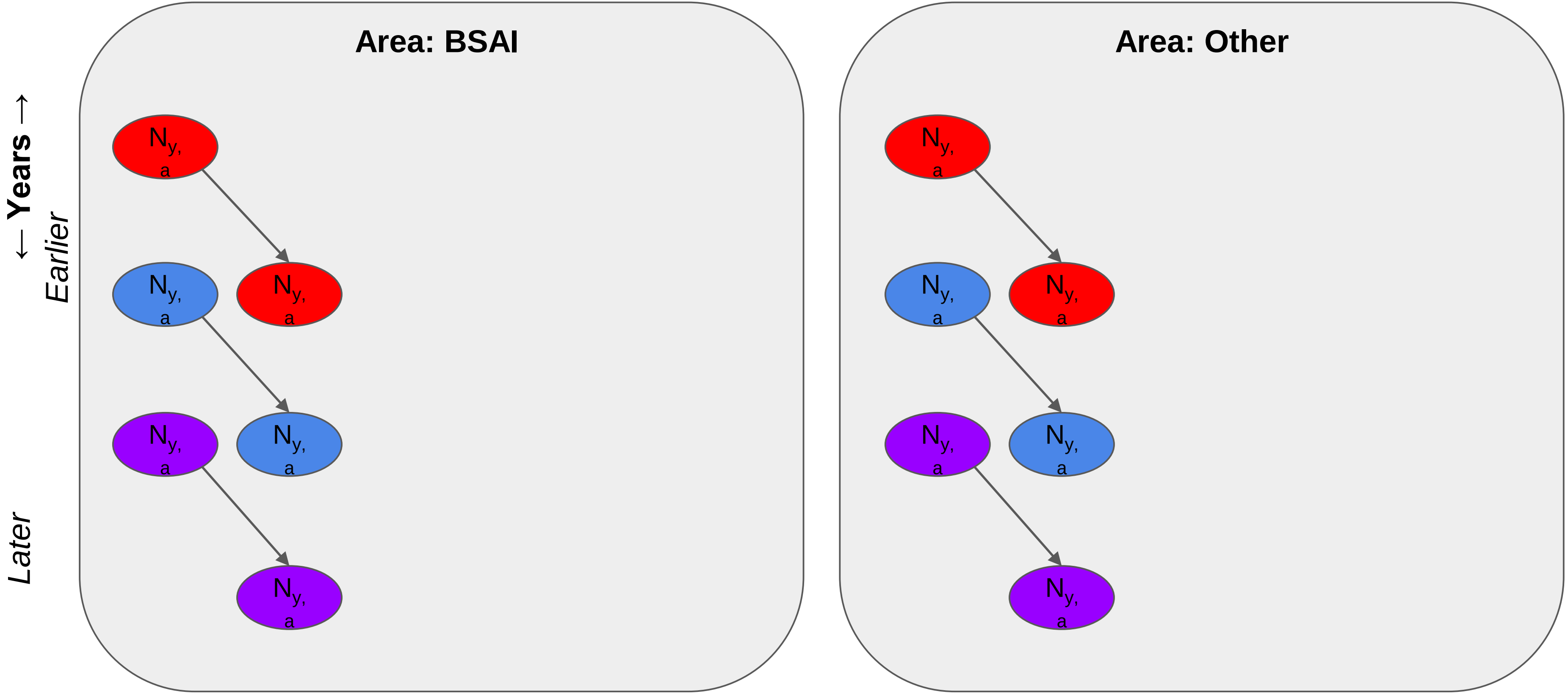
# Movement Among Areas

Remaining regions in aggregate



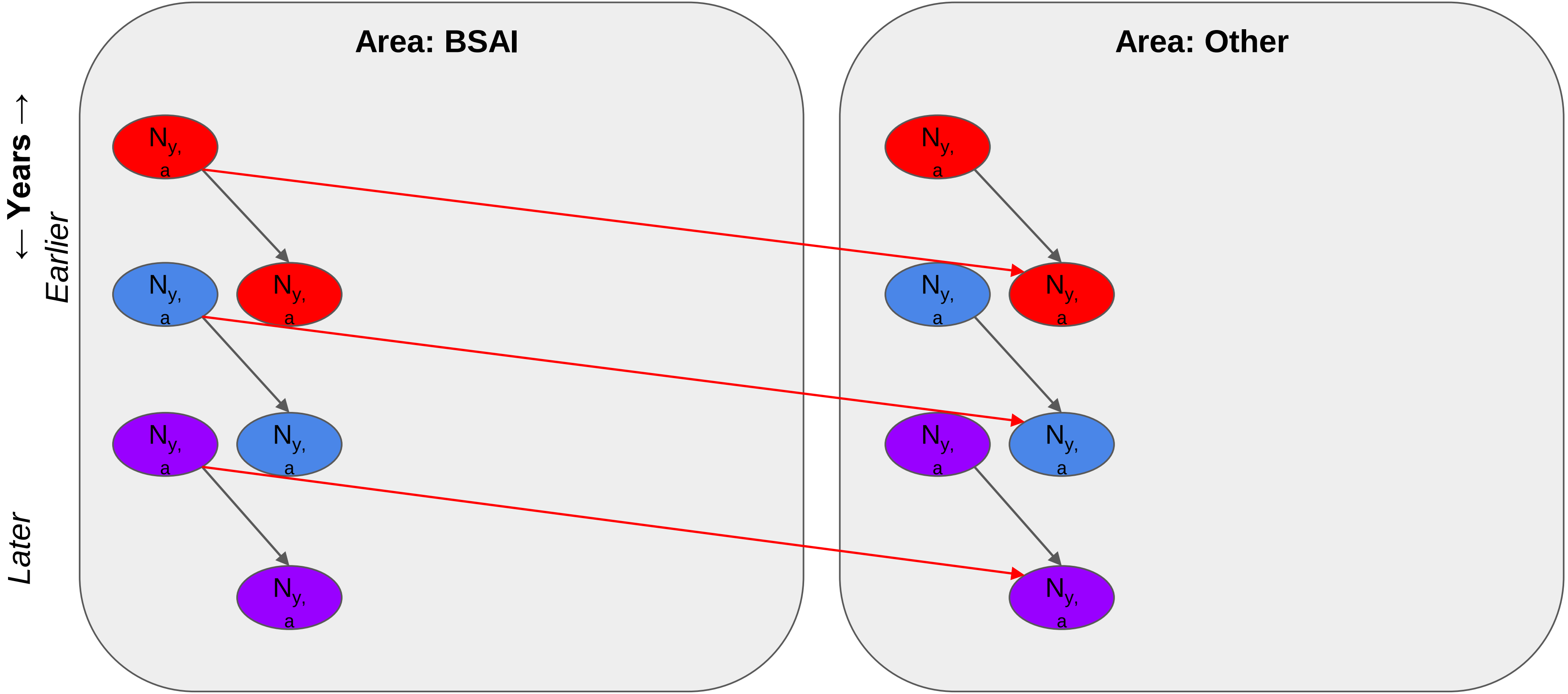
# Movement Among Areas

Survival



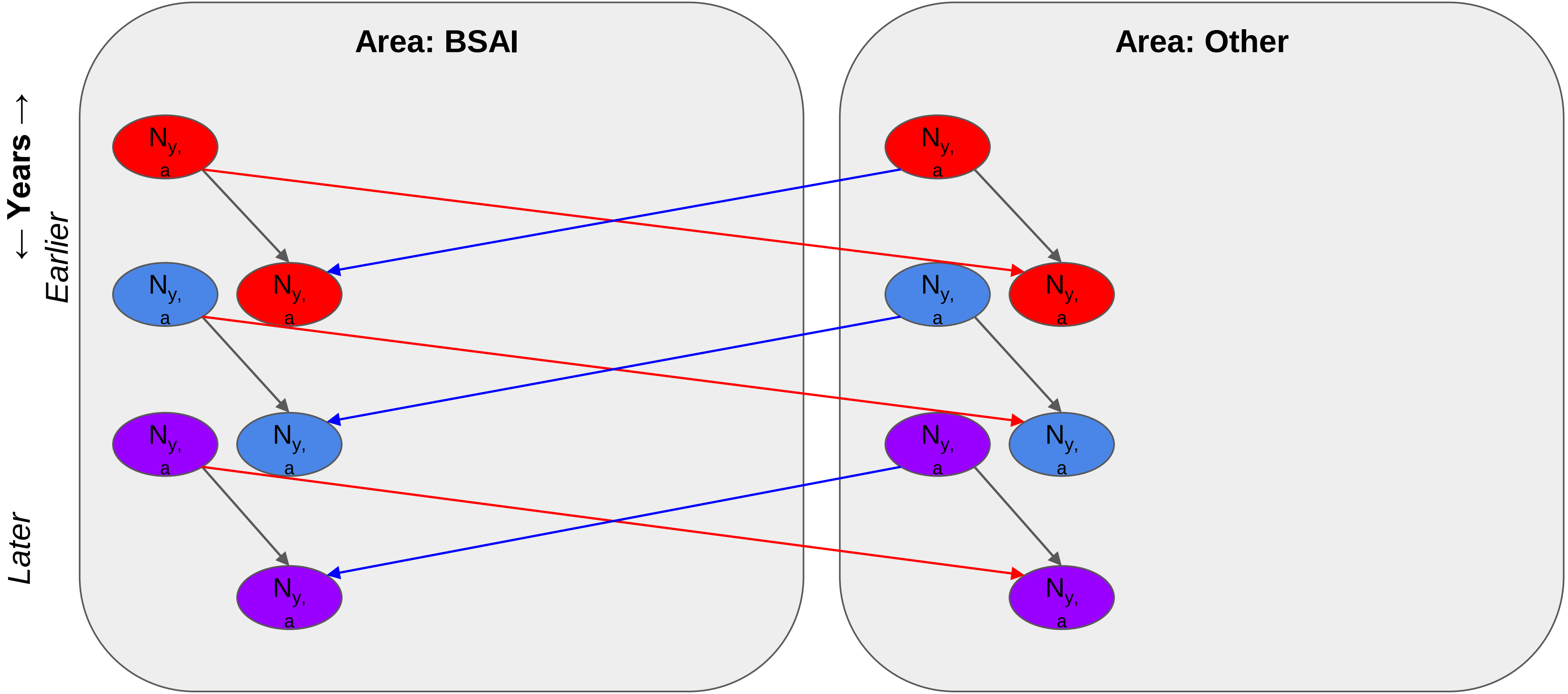
# Movement Among Areas

**Survival**
**Movement Out of BSAI**



# Movement Among Areas

Survival
Movement **Out** of BSAI
Movement **Into** BSAI



# Sources of Operating Model ***Variation***

- Current
  - Log-normal process variation in recruitment
- Potential
  - Temporal variation in weight at age
  - Temporal variation in mean recruitment (periodic, PDO-like)

# Operating model major uncertainties

- Recruitment distribution between GOA and BS
- Migration rates
- Weight-at-age regime
- Recruitment regime (e.g. high or low period for R0)

# Operating model major uncertainties

- Recruitment distribution between other regions and BSAI
- Migration rates
- Weight-at-age regime
- Recruitment regime (e.g. high or low period for R0)

# Recruitment allocation

IPHC research on larval distribution (past and current)

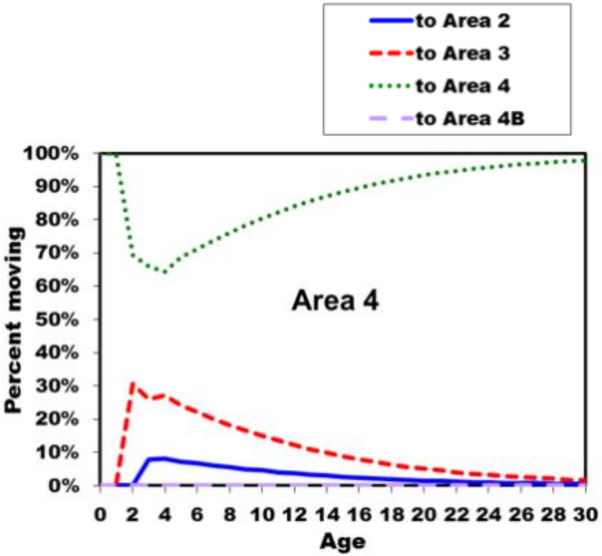
https://iphc.int/management/science-and-research/biological-and-ecosystem-science-research-program-bandesrp/bandesrp-migration/larval-distribution

IPHC-2018-SRB012-09, page14

- Prevailing currents transport larvae from east to west
- NOAA ichthyoplankton surveys in GOA and BS
  - 1972-2015
  - Larval flow through Unimak Pass
- Space-time modelling of Pacific halibut larval observations
  - Comparison of distribution in warm years (2001-2005) and cold years (2007-2013)
- Collaboration with NOAA/EcoFOCI
  - Larval transport model to examine currents and larval advection

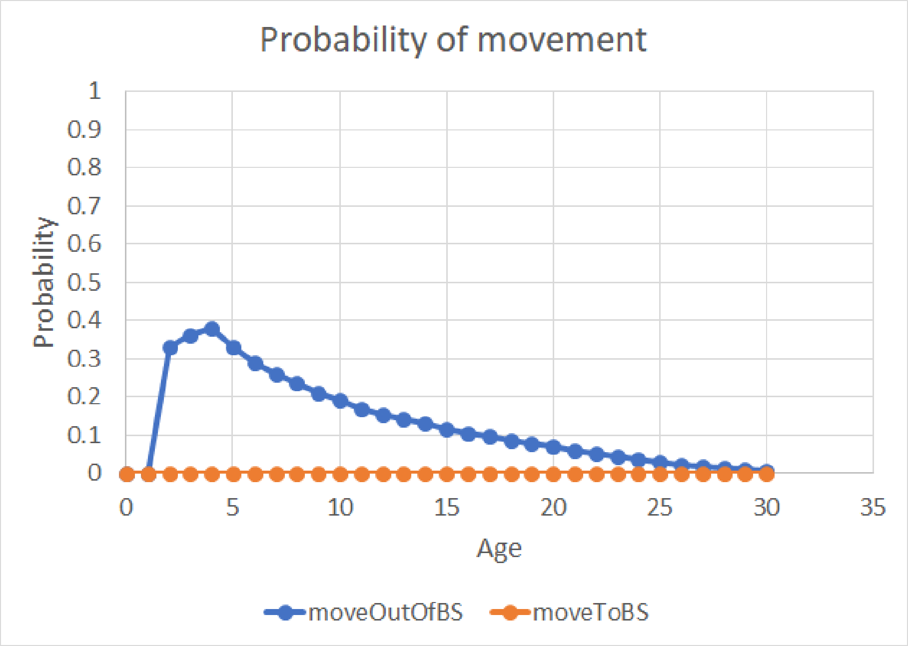
# Movement data and rates

- Current knowledge of migration (IPHC-2018-AM094-09, pags 46-47)
- Adult movement rates reasonably well understood
  - Historical and recent PIT tagging studies
- Less than age 5, trawl gear tagging studies
- Less data from IPHC Reg Area 4
  - Appreciable movement out of Area 4 between ages 5-10
  - Paucity of data for ages 2-4
- Assumptions
  - Ages 0-1 do not move
  - Age 2 cannot move from Area 4 to Area 2
  - Ages 2-4 in/out of Area 4 based relative estimates of migration from Area 3 to Area 2



# Movement from IPHC data

- Probability of movement determined from IPHC estimates of Area 4 to all other areas
  - All Areas to Area 4 is zero across all ages
- Extremely high recruitment necessary in BSAI to maintain halibut in the BSAI
- Research is being conducted on migration
  - IPHC-2018-SRB012-09, page15



# Key Operating Model ***Uncertainties***

## The Outflow Problem

- Recruitment allocation among areas – this example shows all recruitment to BSAI
- Model has age-specific movement rates among areas, but these examples show movement constant across ages and sexes

| | |
|---|---|
| Proportion of Recruitment to BSAI | 1.0 |
| Movement rate **out** of BSAI | 0.01 |
| Movement rate **into** BSAI | 0.0 |

| | |
|---|---|
| Proportion of Recruitment to BSAI | 1.0 |
| Movement rate **out** of BSAI | 0.05 |
| Movement rate **into** BSAI | 0.0 |

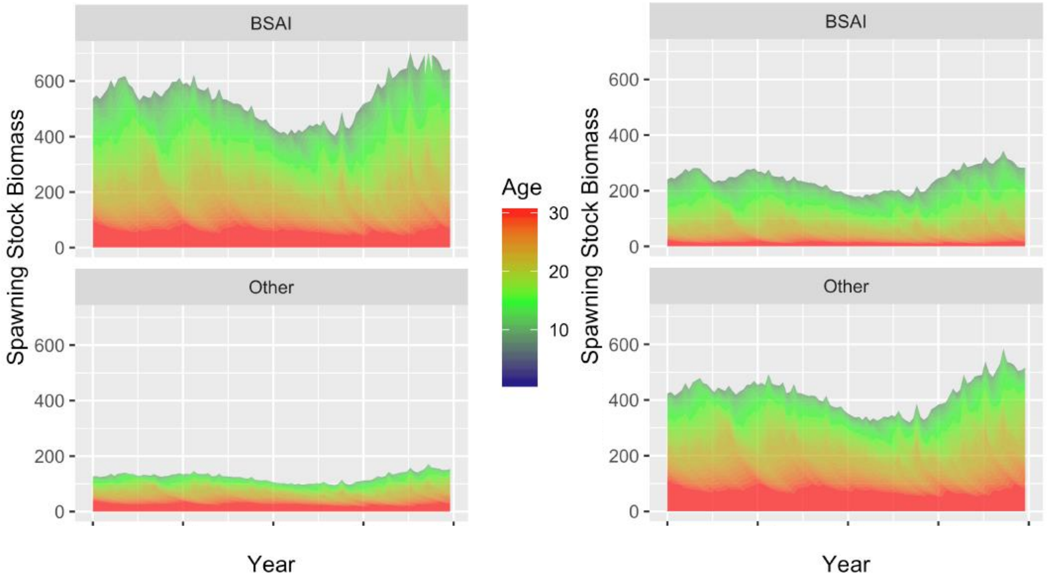
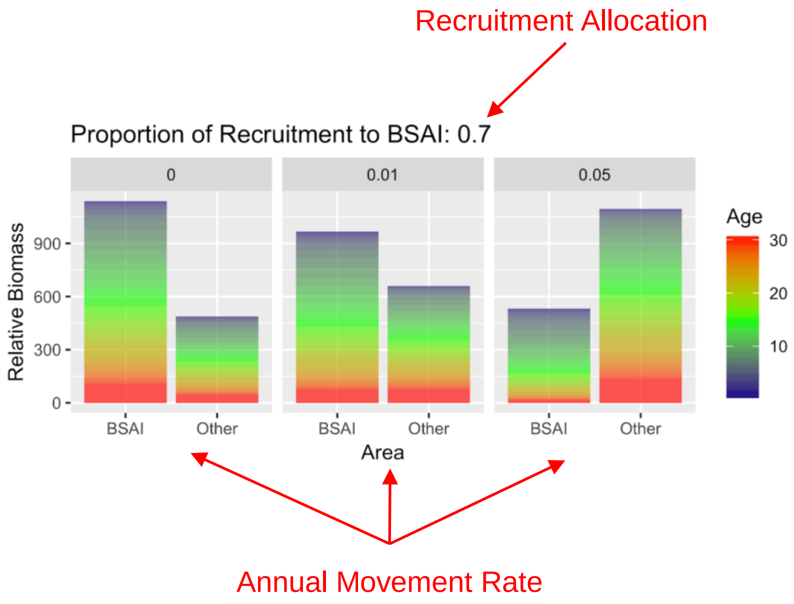



Figure 3. Simulated female spawning stock biomass at age over time under two movement scenarios, with no fishing mortality and all recruitment allocated to the BSAI area. Annual movement rates are constant across ages and sexes.

# Recruitment Allocation vs. Movement Rate

Equilibrium relative biomass at age in each area

- The combination of recruitment allocation and annual movement rate dictates both the equilibrium biomass in each region and the age-specific contribution to total biomass



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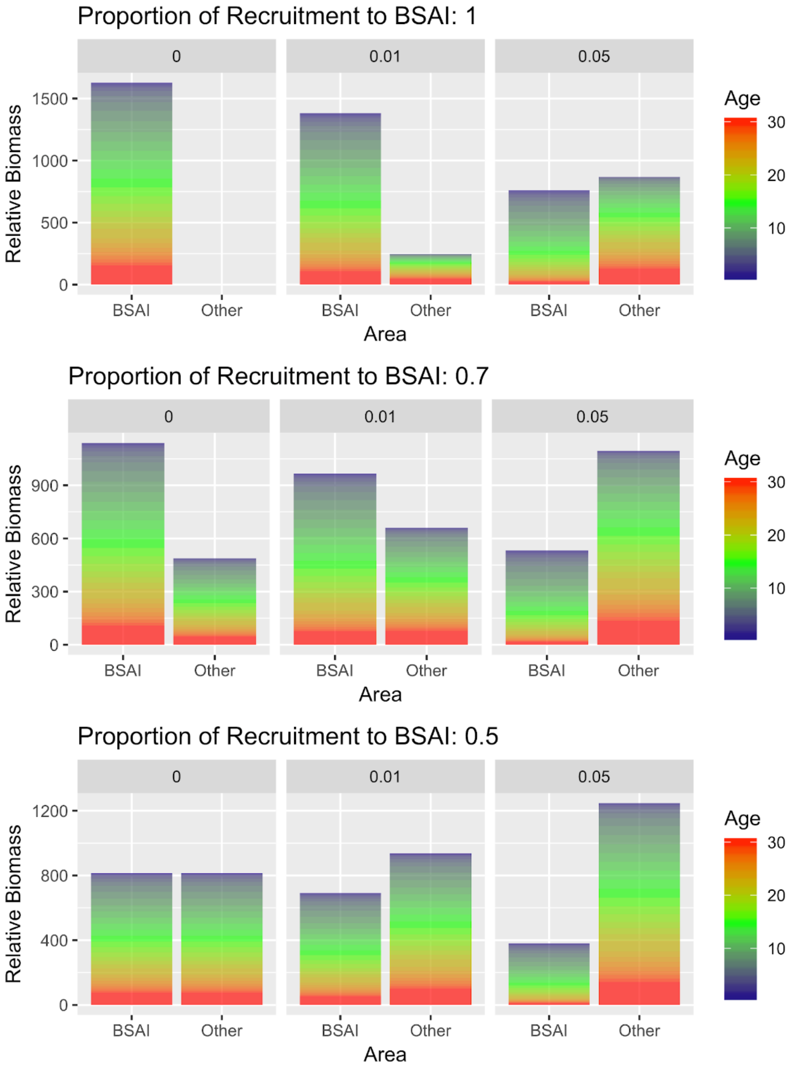


# Future Work Plan

- Identify (realistic and stable) trial values for parameters describing
  - Recruitment apportionment
  - Movement among areas
- Quantify TCEY -> FCEY pathway and harvest allocation procedure
- Add estimation (model) uncertainty to the management process
- Define selectivity for all gears (within areas)
- Add weight-at-age scenarios
  - Through variation in weight-at-age vector
- Add recruitment regime scenarios or periodic regime shifts
- Use sensitivity scenarios (high, low) for growth and recruitment or time-varying simulation?

# Supplementary Slides

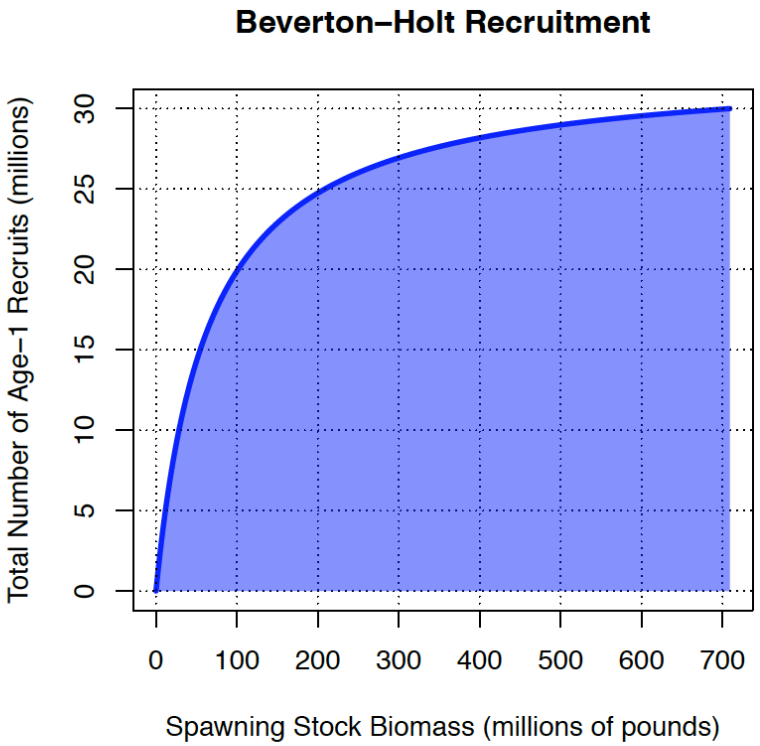
# Recruitment: Beverton-Holt with Steepness h=0.75

## Recruitment by Area and Year

$$R_{l,y} = \delta_l \frac{SSB_y 4hR_0}{SSB_0(1-h) + SSB_y(5h-1)} e^{\varepsilon_y - \frac{\sigma_r^2}{2}}$$

## Recruitment Process Error

$$\varepsilon_y \sim Normal(0, \sigma_r)$$



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Equilibrium Recruitment

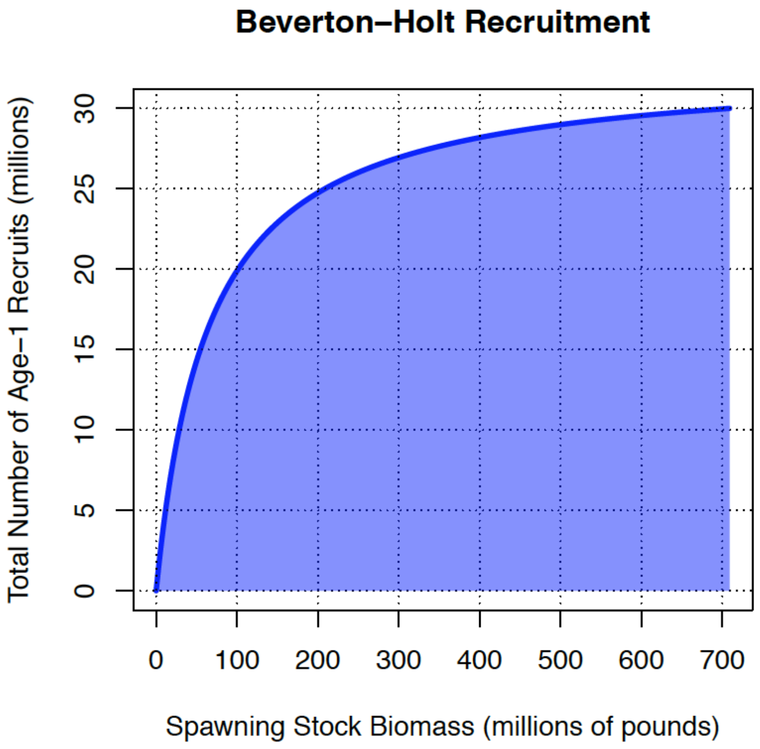
Proportion of Recruitment by area

Equilibrium Spawning Stock Biomass

## Recruitment Process Error

$$\varepsilon_y \sim Normal(0, \sigma_r)$$

Process Error Standard Deviation: 0.6



# Recruitment: Spawning Stock Biomass Calculation

- Product of female biomass at age and maturity at age, summed across areas and ages

Biomass by area, sex, year, and age

$$SSB_y = \sum_l \sum_a N_{l,s,y,a} w_{s,a} m_{s,a} = \sum_l \sum_a B_{l,s,y,a} m_{s,a}$$

Abundance by area, sex, year, and age

Weight by sex and age

Maturity by sex and age
*Note: m=0 for males at all ages*

- Recruitment at to age-1 assumes a 50/50 sex ratio

Recruitment from previous year

$$N_{l,s,y,a=1} = 0.5 R_{l,y-1}$$

# Updating Numbers (Abundance) at Age

Total Instantaneous Mortality

Fishing Mortality by area, gear, and year

$$Z_{l,s,y,a} = M_s + \sum_g v_{g,s,a} F_{l,g,y}$$

Natural Mortality by sex

Selectivity by gear, sex, and age

Numbers at age for all ages 1 < a < A (plus age group A: 30)

$$N_{l,s,y,a} = N_{l,s,y-1,a-1} e^{-Z_{l,s,y-1,a-1}}$$

# Updating Numbers at Age: Plus Age Group

Plus age group A=30

$$N_{l,s,y,a=A} = N_{l,s,y-1,a=A} e^{-Z_{l,s,y-1,a=A}} + N_{l,s,y-1,a-1} e^{-Z_{l,s,y-1,a-1}}$$

Surviving Individuals in Plus Age Group

New Entrants to Plus Age Group

# Harvest Calculations

Age-specific total catch in numbers by year

$$C_{l,s,y,a} = \left(\frac{f_{l,s,y,a}}{Z_{l,s,y,a}}\right) N_{l,s,y,a}\left(1 - e^{-Z_{l,s,y,a}}\right)$$

Total Instantaneous Mortality

Sum of Fishing Mortality Across Gear Types

$$f_{l,s,y,a} = \Sigma_g \, v_{g,s,a} F_{l,g,y}$$

Gear-specific annual catch

$$c_{l,s,y,a,g} = \left(\frac{v_{g,s,a} F_{l,g,y}}{Z_{l,s,y,a}}\right) N_{l,s,y,a}\left(1 - e^{-f_{l,s,y,a}}\right)$$

Gear-specific annual harvest in units of biomass

$$H_{l,y,g} = \sum_{s} \sum_{a} c_{l,s,y,a,g} w_{s,a}$$

# Movement Among Areas

- Movement *may* be age-specific
- Occurs after natural and fishing mortality, but prior to SSB calculations

Number of migrants from area ***i*** to area ***j***

$$\tau_{i,j,s,y,a} = N_{l=i,s,y,a}\pi_{i,j,a}$$

Transition Probability at age

Updating abundance by area, sex, year, and age

Immigrants ***into*** area a

Emigrants ***out*** of area a

$$N_{l,s,y,a} = N_{l,s,y,a} + \sum_{k\in areas} \tau_{i=k,j=l,s,y,a} - \sum_{k\in areas} \tau_{i=l,j=k,s,y,a}$$

# Notation: Symbols

| Symbol | Description |
|---|---|
| $\boldsymbol{l}$ | Area or location (Bering Sea and Aleutian Islands and remaining West Coast halibut range) |
| $\boldsymbol{y}$ | Year |
| $\boldsymbol{s}$ | Sex |
| $\boldsymbol{a}$ | Age |
| $\boldsymbol{g}$ | Gear type or fishing sector |
| $\boldsymbol{i}$ | Area migrating **from** |
| $\boldsymbol{j}$ | Area migrating **to** |

# Notation: Derived Parameters

| Parameter | Description |
|---|---|
| $\boldsymbol{R_{l,y}}$ | Recruitment |
| $\boldsymbol{SSB_y}$ | Spawning stock biomass |
| $\boldsymbol{N_{l,s,y,a}}$ | Numbers at age |
| $\boldsymbol{B_{l,s,y,a}}$ | Biomass at age |
| $\boldsymbol{Z_{l,s,y,a}}$ | Total mortality |
| $\boldsymbol{F_{l,g,y}}$ | Fishing mortality rate |
| $\boldsymbol{f_{l,s,y,a}}$ | Age and sex-specific fishing mortality rate |
| $\boldsymbol{C_{l,s,y,a}}$ | Total catch in numbers |
| $\boldsymbol{c_{l,s,y,a,g}}$ | Catch in numbers by gear type |
| $\boldsymbol{H_{l,y,g}}$ | Harvest in biomass by gear type |

# Notation: Input Parameters

| Parameter | Description |
|---|---|
| $\boldsymbol{M_s}$ | Natural mortality by sex |
| $\boldsymbol{w_{s,a}}$ | Weight at age by sex |
| $\boldsymbol{m_{s,a}}$ | Maturity at age (note this is equal to zero for males) |
| $\boldsymbol{v_{g,s,a}}$ | Selectivity |
| $\boldsymbol{B_{start}}$ | Initial biomass |
| $\boldsymbol{p_{l,s,a}}$ | Initial biomass proportions at age by area |

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