Ecopath with Ecosim Background

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ASMFC Atlantic Menhaden and Ecological Reference Points Review Workshop

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The Ecopath with Ecosim (EwE) Modeling Framework

- Freely available ecosystem modeling software package (www.Ecopath.org).
  - 1984 - first Ecopath model published by Polovina (1984)
  - 1992 – Ecopath II software, mass balance, network and system statistics
  - 1997 – Ecosim, dynamic biomass simulations
  - 1999 – Ecospace, spatial simulations
  - 2013/2014 – Ecospace, habitat capacity and spatial-temporal framework

- Broadly used as a research tool, with a few examples of real-world management applications in fisheries.
- Coded in VB with a GUI. R, Fortran, and CLI versions also exist.
- Large user base, training materials, approved best practices all exist (Heymans et al. 2016; Link 2010)
- Software maintenance/development is led by the Ecopath International Initiative and the Ecopath Research and Development Consortium

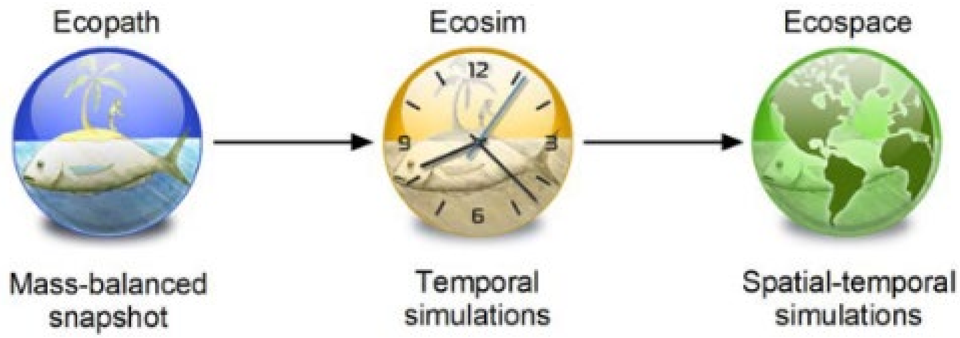
The Ecopath with Ecosim (EwE) Modeling Framework

Three main components

Ecopath: Static mass-balanced model

Ecosim: Temporal dynamics

Ecospace: Spatial-temporal dynamic



Additional modules

Policy analysis: MSE, policy optimization, MPAs

Uncertainty: Monte Carlo, EcoSampler

Ecotracer: contaminant tracing

Automation: Multisim, script-based console application

EwE

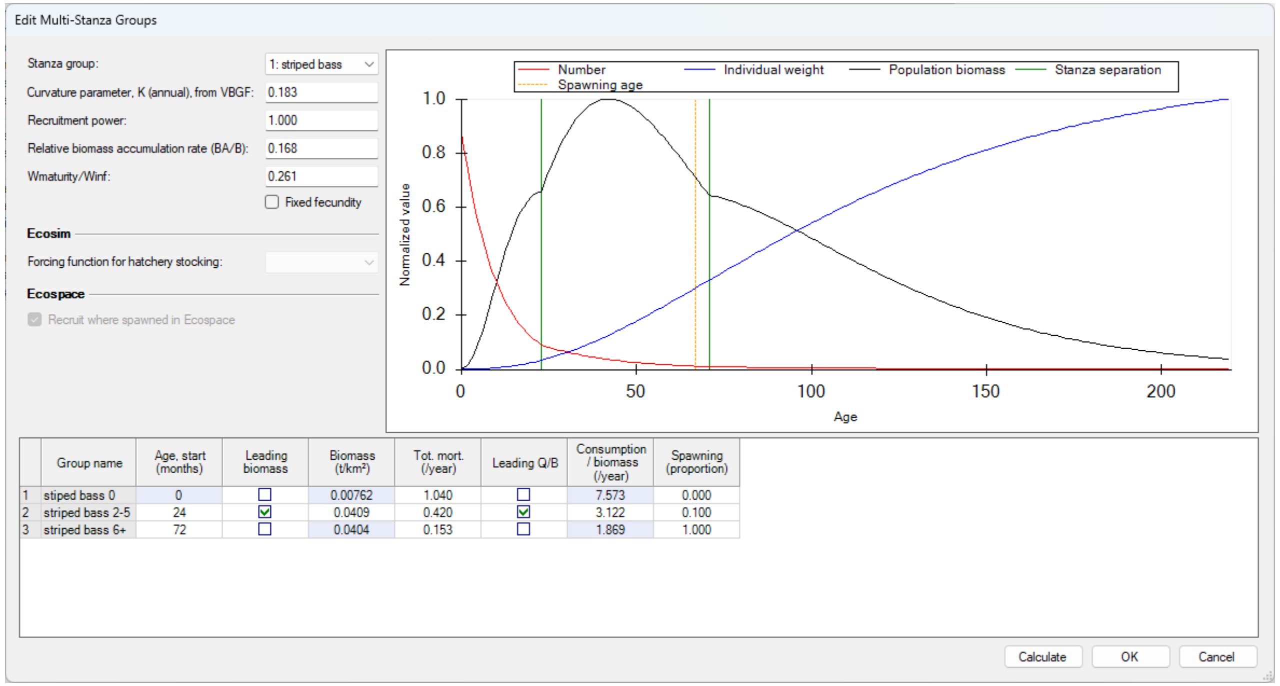
Ecopath Basics – Input requirements

For each species, functional group, or age stanza

- Biomass (mt/km2)
- Production rate (P/B yr)
- Consumption rate (Q/B yr)
- Ecotrophic Efficiency (EE) – usually calculated from above inputs
- Biomass accumulation rate (yr) – optional input; can be calculated if all of the above are entered
- Diet matrix
- Landings and discards

Ecopath Multi-stanza groups

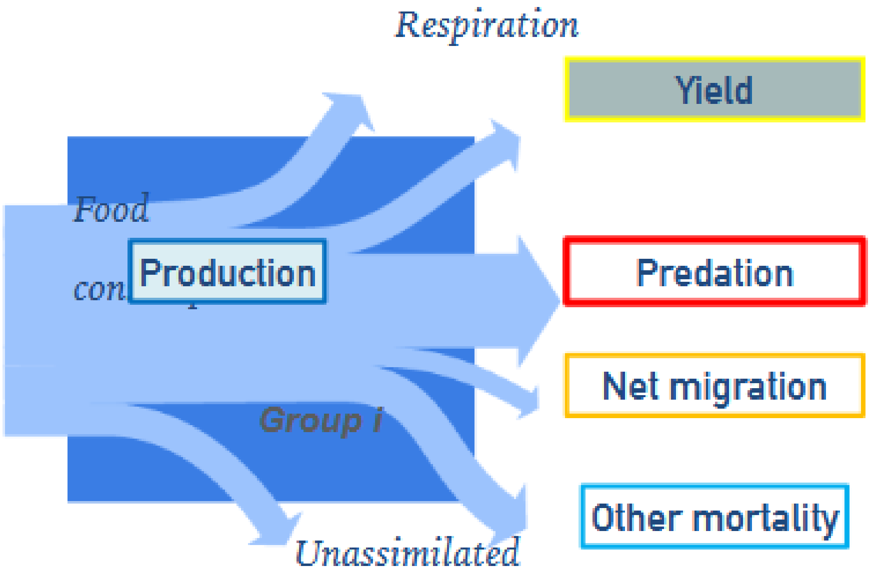
- Multistanza groups used to represent ontogeny in feeding, habitat, and fishery selectivity for focal species
- Requires growth parameter K and relative maturity
- Input B and Q/B for one ‘leading’ stanza and Z for all stanzas
- B and QB calculated for non-leading stanzas



ECOPATH MASTER EQUATIONS

1. $$\left(\frac{Q}{B}\right)_i \cdot B_i = \boxed{\left(\frac{P}{B}\right)_i \cdot B_i} + R_i + UN_i$$

2. $$\boxed{\left(\frac{P}{B}\right)_i \cdot B_i} = \boxed{\sum_{Pred\_j=1}^{n} \left(\frac{Q}{B}\right)_j \cdot B_j \cdot DC_{ij}} + \boxed{E_i} + \boxed{Y_i} + BA_i + \boxed{\left(\frac{P}{B}\right)_i \cdot B_i \cdot (1 - EE_i)}$$



B_i	Biomass
P_i/B_i	Production
Q_i/B_i	Specific consumption
DC_{ij}	Fraction of prey *i* in diet of
B_iA_i	Biomass accumulation
EE_i	Production used in the system
$1\text{-}EE_i$	Unexplained mortality

Polovina, J.J. 1984. Coral Reefs, 3:1-11; Christensen and Walters. 2004. Ecol. Model., 172(2-4): 109-139

Slide: Marta Coll

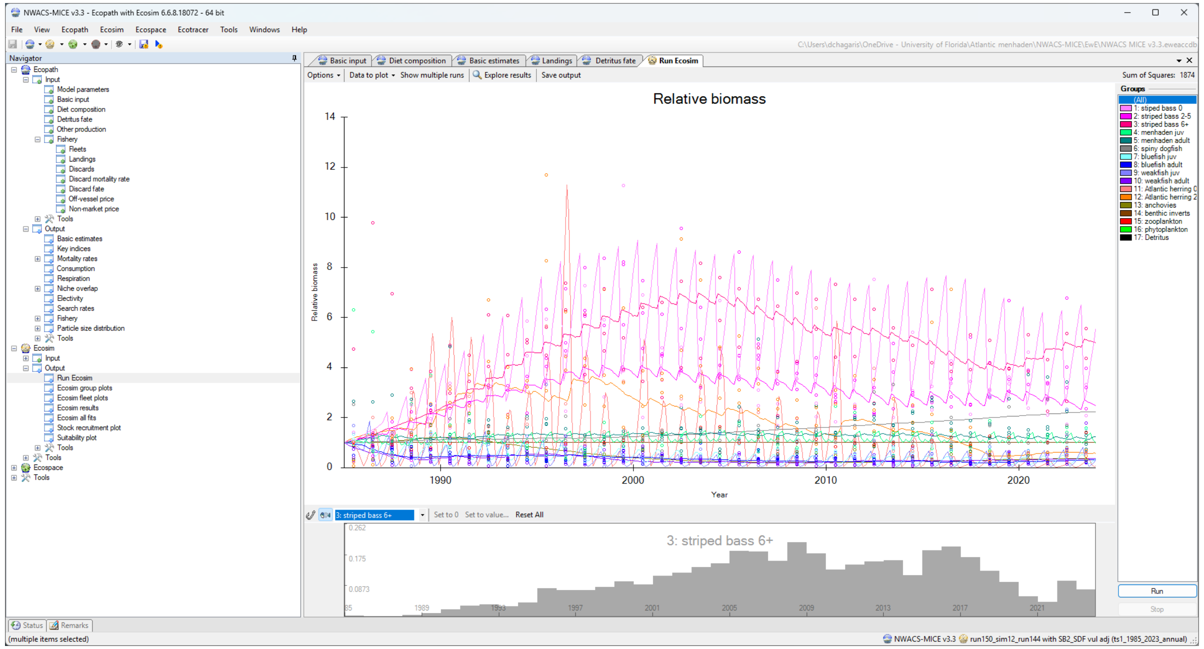
Ecosim Basics

- **Biomass dynamics modeled on monthly time step starting at Ecopath base year values**

$$\frac{dB_i}{dt} = g_i \sum_j Q_{ji} - \sum_j Q_{ij} - (M0_i + F_i + e_i) \cdot B_i + I_i$$

Biomass = Consumption – predation – (other mortality+fishing+~~emigration~~) + ~~immigration~~

- Fishing mortality is either forced directly for functional group/species/stanza or proportional to fleet efforts
- Environmental forcing and mediation functions for PP, egg production, v_{ij}, a_{ij}, A, M0

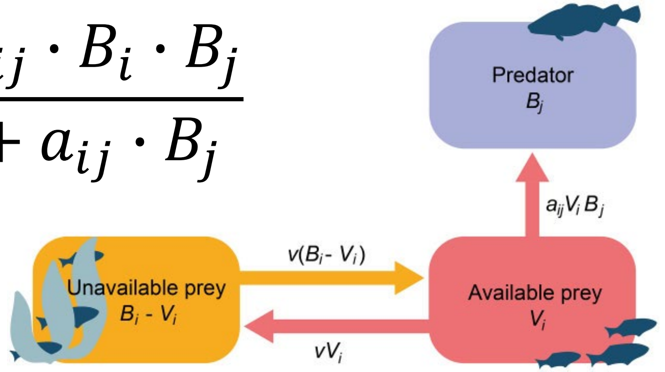


Ecosim Consumption Model

Consumption (Qij) is based on foraging arena theory

- A simple mass-action model, modified to account for density dependence and risk-sensitive foraging behavior
- Transfer of prey in/out of foraging arenas governed by exchange rates (v_{ij}) that regulate consumption by predator

$$Q_{ij} = \frac{a_{ij} \cdot v_{ij} \cdot B_i \cdot B_j}{2v_{ij} + a_{ij} \cdot B_j}$$



$$Q_{ij} = \frac{v_{ij} a_{ij} B_i B_j T_i T_j S_{ij} M_{ij} / D_j}{v_{ij} + v_{ij} T_i M_{ij} + a_{ij} M_{ij} B_i S_{ij} T_j / D_j / A} \times f(Env_t)$$

- a_{ij} = effective search rate
- B_i = prey biomass; V_i = vulnerable prey biomass; B_j = predator biomass
- v_{ij} = vulnerability exchange rate
- Ecosim consumption equation is far more elaborate, with terms for feeding time, handling time, mediation, and forcing

Ecosim Parameters

- Vulnerability exchange rate multipliers (k_{ij}): [1,∞]
  - most sensitive parameters in the model
  - $v_{ij} = k_{ij}*M2_{ij}$
- Feeding time adjustment rate (FTA): [0,1]
  - Increase growth (FTA=0)
  - Improve survival (FTA=1) at high food density or low B
  - with predator effect >0 simulates ‘risk sensitive foraging’
- M0 varying with FTA: [0,1]
  - Allows M0 to vary in proportion to feeding time (1) leading to increased density dependence in M (↑ biomass - ↑ feeding time - ↑ mortality)
- Prey switching: [0,2]
  - modifies effective search rate a_{ij} ; slow (<1) and fast (>1) response to prey densities
- Handling time: [>1], places additional limits on consumption

Ecosim Vulnerability Multiplier (k_{ij}) Parameters

JOURNAL ARTICLE EDITOR'S CHOICE

Calibrating ecosystem models to support ecosystem-based management of marine systems

Jacob W Bentley, David Chagaris, Marta Coll, Johanna J Heymans, Natalia Serpetti, Carl J Walters, Villy Christensen

ICES Journal of Marine Science, Volume 81, Issue 2, March 2024, Pages 260–275, https://doi.org/10.1093/icesjms/fsad213

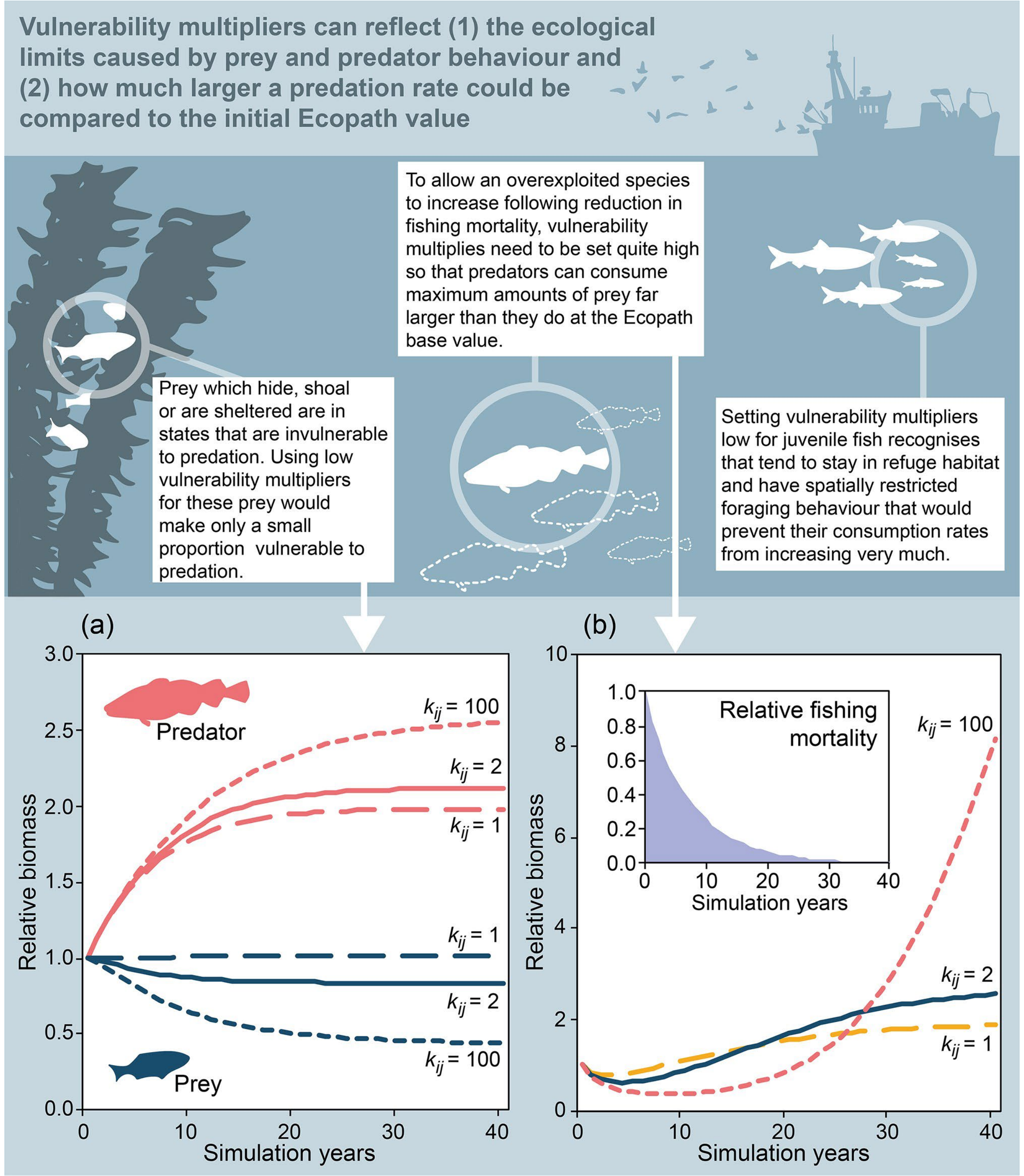
Published: 24 January 2024 **Article history** ▾

Represents behavioral traits.

- low kij for prey that hide, shoal, or shelter in invulnerable states
- low kij for juv fish that are spatially restricted to refuge habitat

Relates to carrying capacity and stock recovery.

- High kij needed for recovery of overexploited stocks
- Low kij implies a species is near it’s carrying capacity



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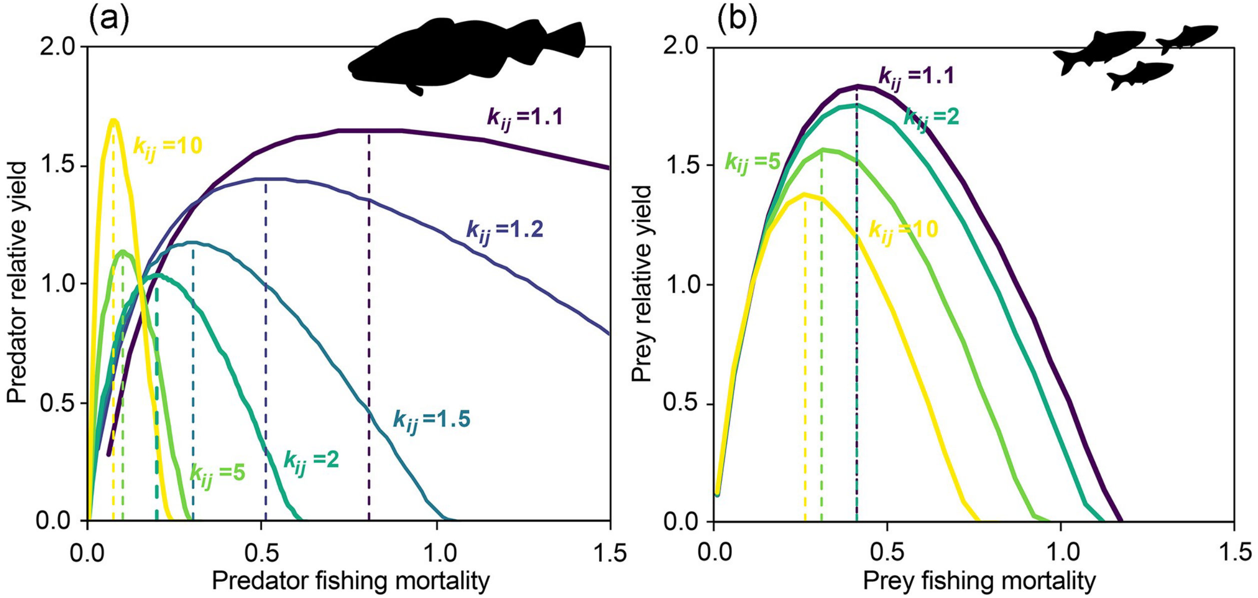


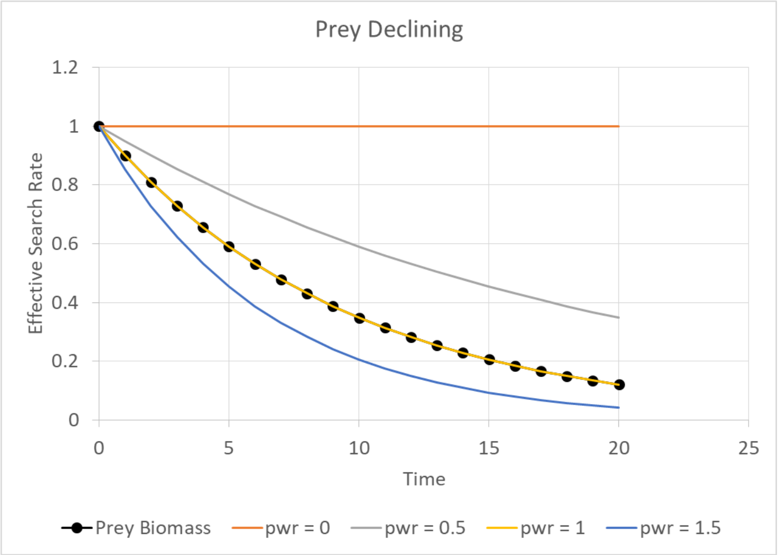
k_{ij} parameters have implications on sustainable harvest policies

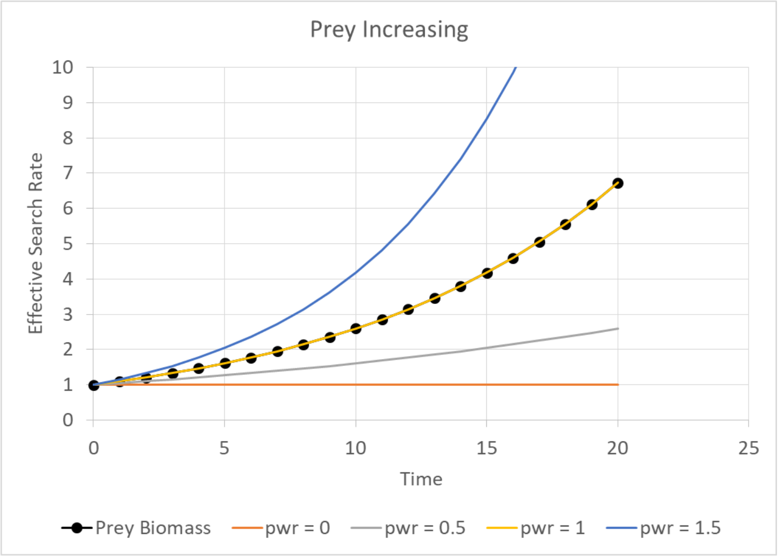
- High k_{ij} increases the sensitivity to fishing, lowering Fmsy
- High k_{ij} also reduces productivity of prey

Prey Switching in Ecosim

- When predator diet proportions change more rapidly (or slowly) than relative abundance of prey
  - "Apparent" switching away from prey that are declining in abundance, due to density dependent foraging time of prey [FTA>0]
    - This is implied for all juv stanzas
  - "Explicit" switching caused by modifying the rate of effective search (a_{ij}) in relation to changes in abundance of prey
    - A power function where P_j = *[0,2]*, and K_{ij} is a scaling constant

$$a_{ijt} = a_{ij} \cdot B_i^{P_j} \cdot K_{ij}$$





Ecosim Forcing Functions

Ecosim forcing functions can be included to drive fishing mortality, bottom-up processes, and predator-prey interactions.

Typically applied as a timeseries of multipliers on baseline rates.

- Fishing effort, F
- Nutrient loading
- **Primary production**
- Predator-prey search rates
- Predator-prey vulnerability exchange rates
- **Environmental drivers on foraging arena area**

Forcing functions can be **annual, monthly, or seasonal** (monthly repeating FF).

Mediating forcing functions involve a 3rd party functional group.

Ecosim Calibration

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- Ecosim uses a Marquardt nonlinear search algorithm to iteratively solve for the best fitting k parameters by reducing the sum of squared (SS) residuals between predicted and observed timeseries data.
- Ecosim can also estimate a time series of primary production anomalies
- Incorporates a sensitivity search to identify which k parameters to estimate
- There are several approaches to calibrating Ecosim model (Bentley et al. 2024)
  - Estimate kj by predator, or predators with timeseries
  - **Estimate kij by prey-predator interaction**
  - **Repeated searches**
  - Stepwise addition of k parameters
- Only the vulnerability multipliers are estimable by the model, and they are conditioned on Ecopath inputs and any forcing functions

~6 Different ways to calibrate Ecosim

Ecosim Calibration Procedure

The repeated kij search approach was developed and used in the previous ERP assessment.

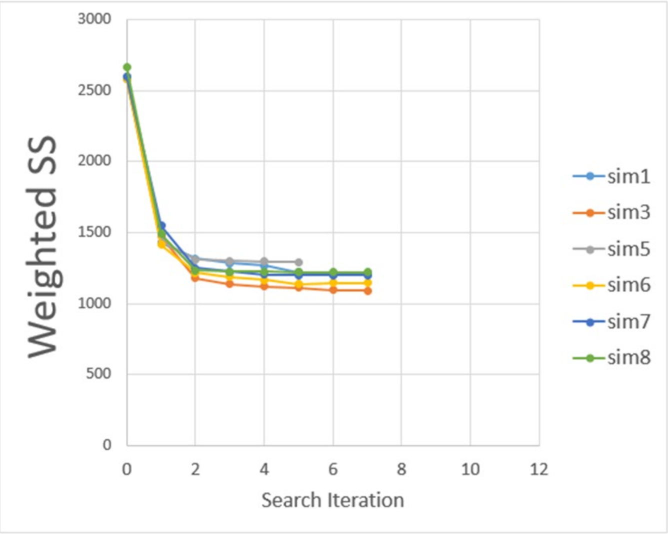
During the current NWACS-MICE development we tested several different approaches to model calibration.

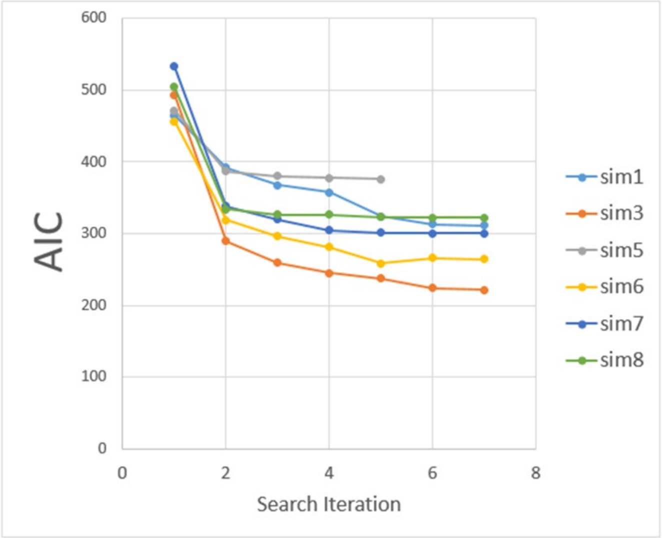
The repeated search calibration method produced the best fitting models.

Steps:

1. Search for K most sensitive k_{ij}, where K is number of reference timeseries-1
2. Estimate the K most sensitive k_{ij}
3. Repeat 1-2 until no further improvements in SS (~5)

- Usually results in about 3xK parameters estimated

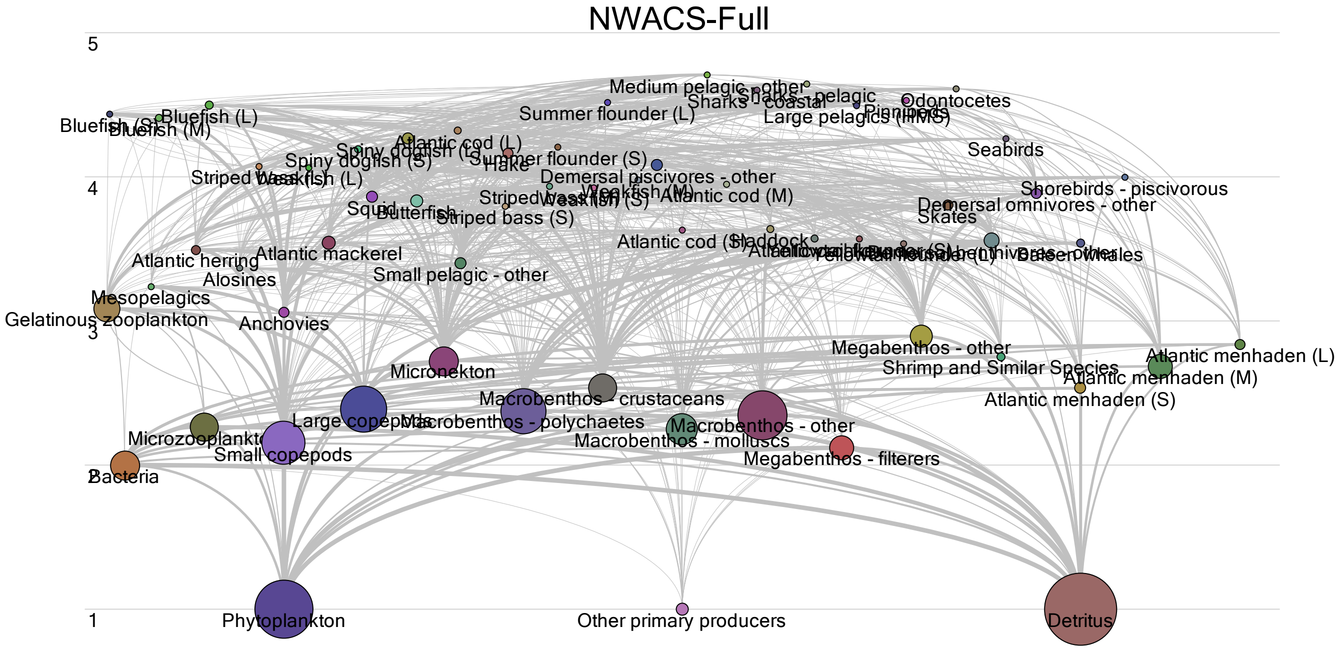


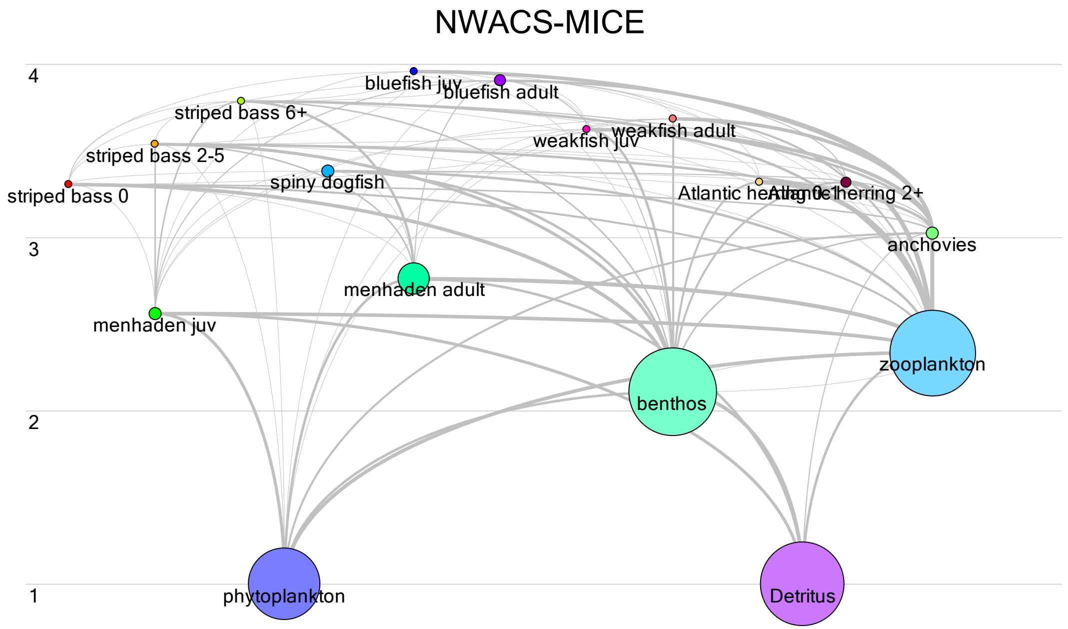


Why use EwE for Atlantic menhaden ERPs?

- It is perhaps the only tool available that can represent both top-down and bottom-up effects of predators and prey along with fishing policy explorations.
- It can handle both simple and complex model structures.
- It has the ability to incorporate environmental drivers.
- It is well documented with a long history of model developments and applications.

Northwest Atlantic Continental Shelf (NWACS) EwE Models





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Chagaris, D., Drew, K., Schueller, A., Cieri, M., Brito, J. and Buchheister, A., 2020. Ecological reference points for Atlantic Menhaden established using an ecosystem model of intermediate complexity. Frontiers in Marine Science, p.1043.