**Chapter 2**

**Use simulation testing to evaluate estimation performance of a length-based multispecies stock assessment model with different structural assumptions about the magnitude of trophic relationships.**

## **Introduction**

Historically, scientific advice for fisheries management has been based on single species population dynamics (Skern-Mauritzen et al., 2016; Karp et al., 2023), even when this approach assumes that changes in abundance are only due to fishing exploitation and natural mortality as general sources of mortality with no interaction between species, ignoring strong trophic interactions can lead to a bias in the state of populations (Trijoulet et al., 2020). Multispecies fisheries stock assessment models can improve accuracy in estimation of population dynamics by explicitly including the effect of predator-prey interactions (Wooton et al., 2021) unfortunately, multispecies models have had limited use within the management process. Early attempts to apply ecosystem approaches in assessment models include incorporating ecosystem and environmental factors into single-species stock assessments such us oceanographic and physical variables and species interaction through predation mortality in age-based and length-based assessment models (Hunsicker et al., 2011; Skern-Mauritzen et al., 2016). Models of Intermediate Complexity for Ecosystem Assessment (MICE) account for ecological processes among a limited number of components or species (Plaganyi et al., 2014), providing a link between full ecosystem models and single-species assessment models typically used to provide tactical fisheries management advice (Punt et al., 2016).

Hydra is a multispecies-multifleet, length-structured MICE (Gaichas et al., 2017) developed to simulate population dynamics in the Georges Bank ecosystem for performance testing of simpler multispecies assessment models and management procedures. Applying Hydra as an estimation model helps address long-term multiple management objectives in the context of ecosystem-based fisheries management and provides multi-species assessment and catch advice. Simulation testing has been broadly used in fisheries science management and proposed to evaluate model performance, the ability of stock assessment models to reproduce population dynamics and stock conditions under different scenarios (ICES, 2012; Basson, 2002) and, to evaluate if an assessment model is capable of produce robust catch advice. This approach is easy to implement when it is possible to simulate data from different scenarios in a short time. To evaluate the potential use of Hydra as an estimation model we evaluated the performance and robustness under different scenarios, to determine how the model respond to different parametrization, input data and scenarios and to evaluate their ability to accurately estimate model parameters and important variables such as catch, biomass and recruitment.

Understanding the consequences of uncertainty in structural assumptions (i.e., the magnitude of trophic interactions) can improve the operational management use of multispecies models and the integration of ecosystem information into the fisheries management process, and simulation testing is a crucial step to verify model consistency and robustness of the dynamics of our system under known initial conditions. To understand how the strength of trophic interactions affects model performance and the ability to estimate key management quantities, the goal of this chapter was to perform simulation testing of a multispecies statistical size-structured integrated assessment model for a subset of stocks in the Georges Bank ecosystem in the Northwest Atlantic for three different scenarios varying the amount of other food available and a base scenario assuming “historical trends” to compare the results.

## **Methods**

“Hydra” is a multispecies-multifleet length-structured model (Gaichas et al., 2017) developed to simulate population dynamics from the Georges Bank ecosystem for performance testing of simpler multispecies assessment models and management procedures. Hydra includes 10 species interaction; three fleets; multiple forms of growth; recruitment and environmental covariates; and predation mortality is included to account for mortality on preys. Hydra simulation model was already applied as a basis for testing EBFM procedures and was reviewed as part of an Ecosystem Based Management Strategy for Georges Bank. Hydra was later modified to be used as an estimation model by fitting the model to data from the Georges Bank ecosystem (total catch, catch size compositions, annual Fall and Spring NEFSC bottom trawl survey abundance indices, survey size compositions, survey, and stomach content diet compositions).

**Operating model description**

The operating model Hydra (Gaichas et al., 2017) describes population dynamics, including various forms of growth, reproduction, and mortality; biological interactions between species, such as predation and competition, and their effects on population structure; models different fishing fleets, considering effort, catch, and management. This allows for the evaluation of how fishing activity affects fish populations. The main components of the model include initial states, recruitment, predation M2, fishing effort, survey biomass, movement, ecosystem indices, and assessment (model structure equations in **Table 1**).

Originally, Hydra includes 10 key commercial species with 5 length bins each and a length-structure population dynamics and predation over 42 years, including 3 effort driven multispecies fleets. In this study we simplified the model including 2 predator species (Atlantic cod and Spiny dogfish) two preys (Atlantic mackerel and Atlantic herring), two fleets demersal and pelagic, and one survey (NEFSC spring survey), considering an equal number of size bins for each species in centimeters. Parameterizations for growth, recruitment, and fishery size selection were based on Georges Bank survey and fishery data; fishery selectivity, catchability and fishing effort were parametrized to follow the stock trends from stock assessment reports.

Hydra uses a substantial amount of input data to calibrate the model, including size specific mean stomach weights from Bowman & Michaels (1984), bottom water temperature for Georges Bank from the Northeast Fisheries Science Center Ecosystem Status Report (NEFSC, 2012). Growth parameters estimated by fitting the length at age data from fishery independent surveys of Georges Bank for Atlantic cod, Atlantic herring and Atlantic mackerel and taken from Hall et al. (2006) for spiny dogfish. Observed times series of survey biomass, survey size compositions, fishery catches, fishery size compositions, survey diet proportion observations. Additionally, it incorporates simulated data, such as environmental predictions and growth rates, for more details about the operating model structure see the supplemental material of Hydra Multispecies Size Structured Model (Gaichas et al., 2017).

The multispecies portion of this model is dominated by five main equations and includes the total consumption by predators, the suitability of that prey to each predator, and the total suitable prey biomass available to each of its predators:

Survival rate:

including two sources of natural mortality: residual mortality M1 due to all unmodeled factors and predation mortality M2.

Predation:

where is the preference for a prey of size n by predator size j, and is the vulnerability of prey m to predator i. The parameter 𝛌 is set to 0 if the predator does not prey on species m or 1 if it is known to prey on species m.

Size preference:

where is the weight at the midpoint of the length bin for a prey of size n, is the weight at the midpoint of the length bin for a predator of size j, is the 'preferred' predator/prey weight ratio on a logarithmic scale, and is the variance in predator size preference.

Daily food intake for predators:

where gives the temperature (T)-dependent hourly consumption rate with parameters and жi, and I,j,k,t is the mean stomach content weight (g) over a diel cycle.

Finally, the predation mortality rate:

where a and b represent all prey species and sizes for predator i, W is the mean weight of prey a in size class b, and Ω is ‘other’ food available in the ecosystem.

**Conditioning the Base Operating Model**

Annual fishing mortality deviations are fixed values to force the trends from the stock assessment reports, for demersal fleet we assumed high fishing rates for the first 20 years and constant deviations for pelagic fleet. Natural Mortality (M) is divided into two sources of natural mortality M1: due to all unmodeled factors and M2: due to predation. Different values of residual mortality M1 and other food OF were used until total natural mortality M was similar to those used in the stock assessments for each species.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Atlantic cod | Atlantic herring | Atlantic mackerel | Spiny dogfish |
| M1 | 0.28 | 0.32 | 0.2 | 0.102 |

Recruitment standard deviations were also fixed in 0.5 and to reduce the variability for Spiny dogfish in 0.1. Fishing mortality in the model is defined as fishing effort multiplied by catchability for each fleet and summed across the two fleets, also catchability q determines the proportion of secondary species on each fleet, for demersal fleet (Spiny dogfish) q was set in 0.25 and for pelagic fleet (Atlantic mackerel) in 0.1. Selectivity at length is assumed logistic for both fleets.  Initial parametrization of the operating model detailed in **Table 3**.

To understand the consequences of uncertainty in structural assumptions and how the strength of trophic interactions affects model performance to improve the operational management use of multispecies models; two different assumptions about the magnitude of the interactions were included:

* Increase magnitude of trophic interactions to approximate the dynamic of a single species approach.
* Decrease the magnitude of trophic interactions between predators and prey varying the amount of other food and residual mortality.

**Simulated data**

Multispecies and size-structured data was simulated using the operating model to simulate 100 datasets including a 42-years period with fixed values for the magnitude observation error variance e.g., CV and composition sample size (values in **Table 4**) of:

* catch (by species for each fleet).
* size composition of the catch (by species for each fleet.
* survey abundance index (by species.
* survey size composition (by species).
* survey diet proportions (stomach weight by predator size bin for each predator species).

Log based catches and indices for each species and survey/fleet will be simulated assumed normally distributed, size compositions in numbers for each fleet and survey will be modeled as multinomial given an input annual sample size for each year and species. Survey diet proportions by prey species will be assumed multinomial distributed with an input sample size for each year and species (**Table 4**).

**Estimation model**

The estimation model is a multispecies statistical size-structured integrated assessment model including the same 4 stocks and the same population dynamics described in the Operating Model section. To evaluate the impact of the strength of trophic interactions in model performance assume different structural assumptions varying the parameter governing the amount of other food available to the modeled predators, considering high values of other food available in the ecosystem to reduce the strength of the modeled species interactions and smaller values to increase the magnitude of predation mortality, assuming there is less availability of non-modeled species in the ecosystem.

The estimation model will share the same population dynamics with the operating model and fits to stomach contents data in addition to survey and catch size compositions, catch, and survey abundance indices (Objective functions in **Table 2**).

Estimated parameters

* + - initial year numbers at size for each stock
    - average annual recruits for each stock
    - annual F for each fleet
    - fishery catchability for each stock
    - fishery logistic selectivity at length for each fleet
    - survey catchability for each stock
    - survey logistic selectivity at length

**Model performance**

The performance of the model was evaluated first by verifying the calibration of the operational model. This involves adjusting the parameters to align the outputs with the trends observed in the stock assessments for each species. Next, the estimated parameters and derived quantities from each model (estimation and simulation) were compared to assess similarities, differences, and the coverage of estimated confidence intervals relative to the operating model quantities. Overall goodness-of-fit was calculated for each simulation, along with measures such as absolute error and mean squared error for each scenario, to determine if the model is sensitive to changes in the input data. Finally, a sensitivity analysis was conducted to quantify differences in the estimated parameters across models and scenarios, evaluating the sensitivity of the predictions.

Add equations for performance metrics (**Table 5**)

* + Description of how things summarized (over simulations, over years, by scenario, etc.)
    - Bias and precision in the estimates of derived quantities of interest from the estimations model (relative error in estimates).
    - Compare the values of estimated parameters from the estimation model to the true values from the operating model.
    - Overall goodness of fit of each simulation

## **Preliminary results**

Operative model (check power point for plots)

Comparing outputs from simulations and OM (check power point for plots)

**Table 1**



**Table 2**



**Table 3 incomplete**



**Table 4**