A Framework for Providing Catch Advice for a Prototype Georges Bank Fishery Ecosystem Plan

Abstract

An ecosystem-based management procedure can be used to evaluate optimum yield from fisheries conducted in a specified location and provide catch advice, while taking into account important ecosystem considerations.

The Council's Ecosystem-Based Fishery Management (EBFM) Committee directed its EBFM Plan Development Team (PDT) to develop operating models for simulation testing of alternative Management Procedures, which could be implemented at the ecosystem and multispecies levels.   An ecosystem-based management procedure (EBMP) can be used to evaluate optimum yield from fisheries conducted in a specified location and provide catch advice, while taking into account important ecosystem considerations

The PDT started by developing an Ecosystem-Based Management Procedure (EBMP) and simulation model that focuses on evaluating exploitation rates on species/stock complexes, while also providing protection for individual species. Stock complexes in this context would be defined as groups of species that share similar diet and habitat niches and are often caught together in specific fisheries. The primary catch advice will therefore be provided at the stock complex level. For example, Acceptable Biological Catch limits would apply to piscivores in the trawl fishery, or benthivores in the gill net fishery, as opposed to specific species. To ensure that individual species within a stock complex do not become depleted, lower limits (floors) will be established for all (managed?) species considering potential ecosystem effects and other factors.

This strategy (*a*) provides an objective way of defining the spatial footprint of the ecosystem as a starting point for place-based management, (*b*) recognizes the critical role of ecosystem energetics and species interactions in defining constraints on fishery production and yield, and (c) specifies an Ecosystem-Based Management Procedure (EBMP) that addresses the challenge of managing species linked through biological and technical interactions.

The approach is proposed to be a more stable form of management and avoid some of the pitfalls that have been observed in single-species catch management, as has often been the outcome in the NE Multispecies Fishery Management Plan. Management of the groundfish complex has involved seemingly intractable problems since the inception of extended jurisdiction forty years ago. The PDT have specifically attempted to address the difficulties involved in managing species linked by technical (by-catch) and biological (predator-prey) interactions. Fishing mortality rates on individual species cannot be precisely controlled in mixed-species fisheries, leading to difficulties in meeting target exploitation rates of all species simultaneously.

The main steps in implementing a proposed Ecosystem-Based Management Procedure (EBMP) are:

1) Specify spatial management units
2) Define stock complexes
3) Establish specific management objectives and exploitation reference points directed at stock complexes rather than individual species.

4) Establish biomass thresholds (floors) below which the complex as a whole cannot fall (Option 1) or below which no individual species within the complex can fall (Option 2, species-specific floors).
5) Devise an ecosystem-based harvest control rule based on steps 2 and 3 that can be used to evaluate the risk of overfishing at the ecosystem level for a range of exploitation rates at the stock complex level and strategies for phased implementation of protective measures.
6) Simulate the performance of a set of scenarios constructed under the EBMP using a suite of metrics including biomass, catch, revenue, probability of breaching a threshold biomass level, maintaining robust size structure of the populations (large fish index), and the stability over time of the catch advice. Other metrics such as stock structure, spawning potential, fishery viability and profits, variability in catch, etc. could also be evaluated.
7) Identify and reconcile tradeoffs.

Once a target exploitation rate for a stock complex is chosen, the associated catch limit can be determined by applying the chosen exploitation rate (defined by the EBMP) to the estimated exploitable biomass of the stock complex. The sum of the catch limits would provide guidance for establishing an ecosystem-level cap on total yield. This procedure is shown as a diagram in Figure 1.

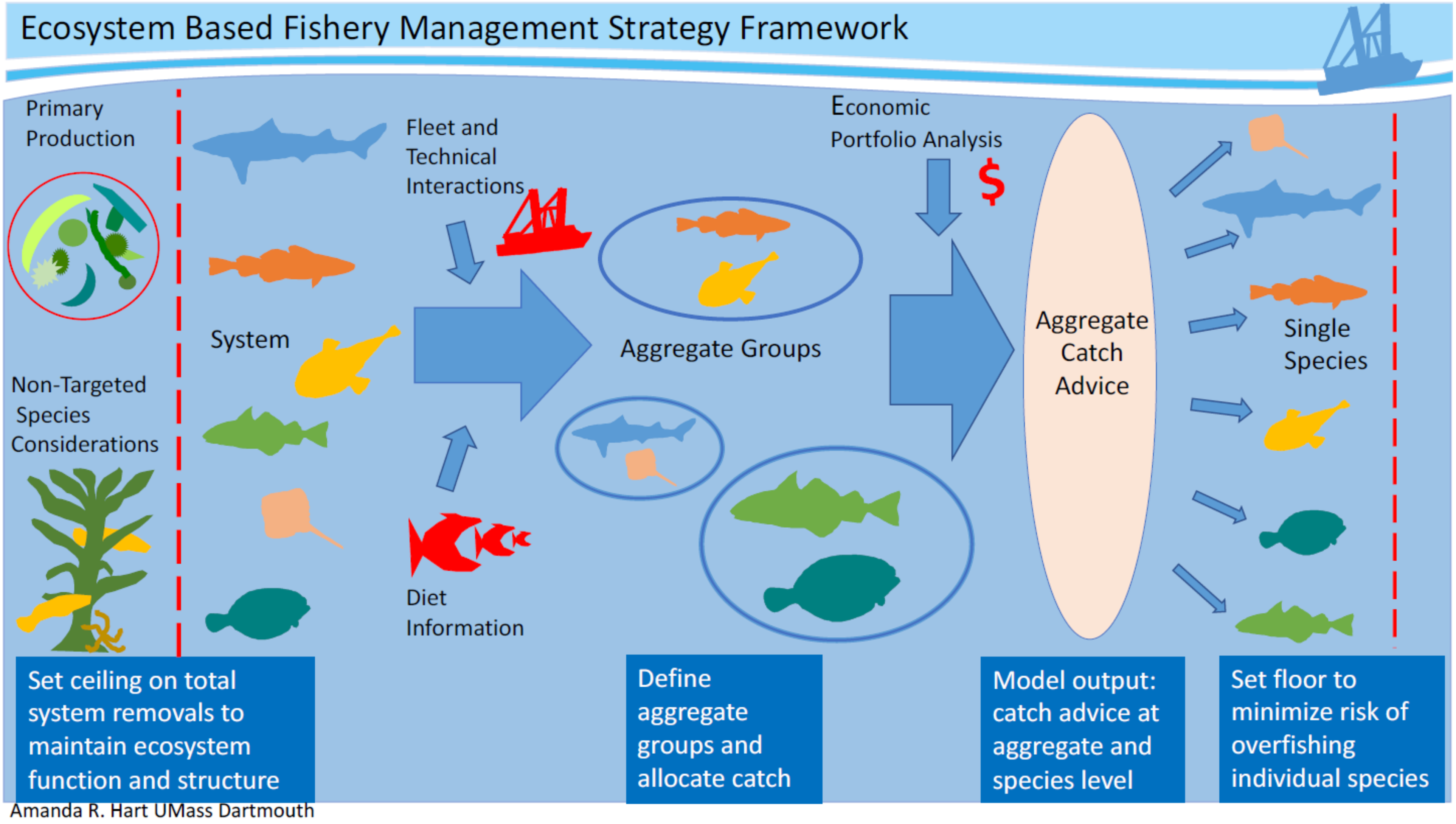
These biomass estimates for the stock complexes could be developed from multiple multispecies/multi-functional group assessment models or directly from survey data, adjusted for catchability to give total biomass estimates. The multispecies assessment models take the same data inputs as single species assessment models (trawl survey data, catch data, age-at-maturity data, etc.), but explicitly include trophic interactions Like single-species assessment models, these assessment models can also include the effects of environmental drivers and other species. Multiple assessment models will be run and the results compiled similar to hurricane modelling to estimate biomass levels. Model averaging will be applied to the ensemble of models.

Lower biomass limits or floors will be developed to ensure that individual species within a stock complex do not become depleted. Empirical indicators, such as current survey biomass compared to historical survey biomass, proportion of the stock in different age/length bins, risk to the ecosystem, or risk of not fulfilling FEP objectives, as well as other methods could be used to set these floors, which would be utilized to evaluate stock status. This is actually not very different from the existing procedures for many stocks, because the trawl survey index is currently being used for many of them.

This document focuses on the development and testing of an EBMP for NEFMC-managed fish species on Georges Bank. As a worked example, a length-based, multispecies, multi-fleet simulation model, Hydra, is demonstrated in this document which can be used to test the performance of candidate management procedures. Hydra incorporates nine NEFMC-managed species and additional forage species. The nine species (cod, haddock, silver hake, winter skate, spiny dogfish, monkfish, winter flounder, yellowtail founder and herring) account for approximately 90% of the landings of NEFMC-managed fish species on Georges Bank over the last decade.

This modelling approach (and potentially others) can be used to establish catch advice for stock complexes (ceilings) to achieve FEP goals, such as stabilizing the variation in catch, maximizing yield, minimizing depleted stocks, maximizing gross or net revenue, such that the total catch cap cannot be exceeded and that individual species are not driven below their floors.

Figure 1. Proposed catch advice framework diagram.



Introduction

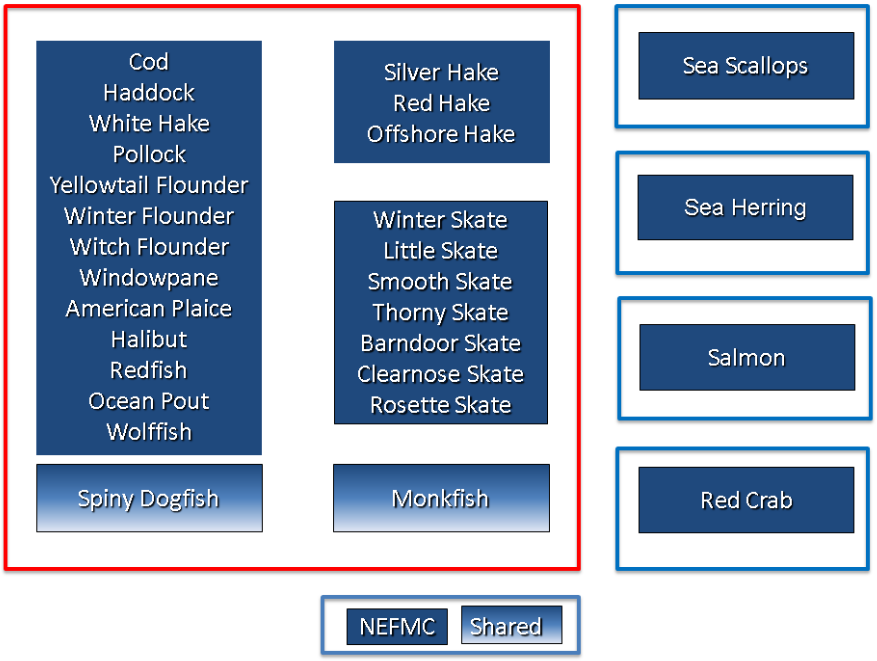
Georges Bank is widely recognized as a highly productive marine ecosystem. Its bounty has supported generations of fishing communities on the northeast seaboard since the early 18th century when offshore fisheries first developed in the United States. The Georges Bank ecosystem was changed by the arrival of distant water fleets in 1961, resulting in the decline of many groundfish and other stocks in a pattern of sequential depletion (Fogarty and Murawski 1998).

Shortly following the adoption of the Magnuson-Stevens Fishery Conservation and Management Act of 1976, the newly formed New England Fishery Management Council (NEFMC) established a Northeast Fishery Management Task to evaluate options for recovery and sustainable management of fisheries in the region. The Task Force clearly recognized that traditional single-species approaches were problematic for management of mixed-species fisheries in the region:

> *"To avoid the deficiencies of a single-species approach, management might address itself to the productivity and harvest potential of an entire ecosystem, since the ecosystem in the long run has greater stability than any of its components."*
>
> and
>
> *" … individual species, groups of species, or particular fisheries (defined by area or gear) would be regulated to control the relative balance of the species mix"* (Hennemuth et al. 1980) .

This suggestion was never implemented and a substantial fraction of Northeast groundfish species today remain classified as overfished. Management of the mixed-species groundfish fishery has involved seemingly intractable difficulties using traditional single-species approaches. EBFM offers the potential to return to this early recognition of the problem of managing fisheries that rely on interrelated stocks.

Figure 2. NEFMC-managed species. This update report focuses on the major fish species in the multispecies groundfish, spiny dogfish, small mesh (hake), skate, monkfish, and herring management plans



Core Elements of the Approach

Many definitions of Ecosystem-Based Management [EBFM] have been proposed. The definition suggested by NOAA Fisheries is broadly representative:

> "[EBFM is]…*a systematic approach to fisheries management in a geographically specified area that contributes to the resilience and sustainability of the ecosystem; recognizes the physical, biological, economic, and social interactions among the affected fishery-related components of the ecosystem, including humans; and seeks to optimize benefits among a diverse set of societal goals"*.

The proposed catch advice framework addresses the principal elements of this definition including its geographical focus and emphasis on resilience and sustainability; consideration of interactions among the components of the system; and recognition of humans as an integral part of the ecosystem. Because EBFM addresses a broad spectrum of fishery-related issues, the development of tactical management advice is likely to require a suite of modeling and analytical approaches suitable for each. The overarching goal is to maintain ecosystem resilience at all levels to ensure the sustainable flow of ecosystem services.

This strategy (*a*) provides an objective way of defining the spatial footprint of the ecosystem as a starting point for place-based management, (*b*) recognizes the critical role of ecosystem energetics and species interactions in defining constraints on fishery production and yield, and (c) specifies an Ecosystem-Based Management Procedure (EBMP) that addresses the challenge of managing species linked through biological and technical interactions.

Identifying spatial management units

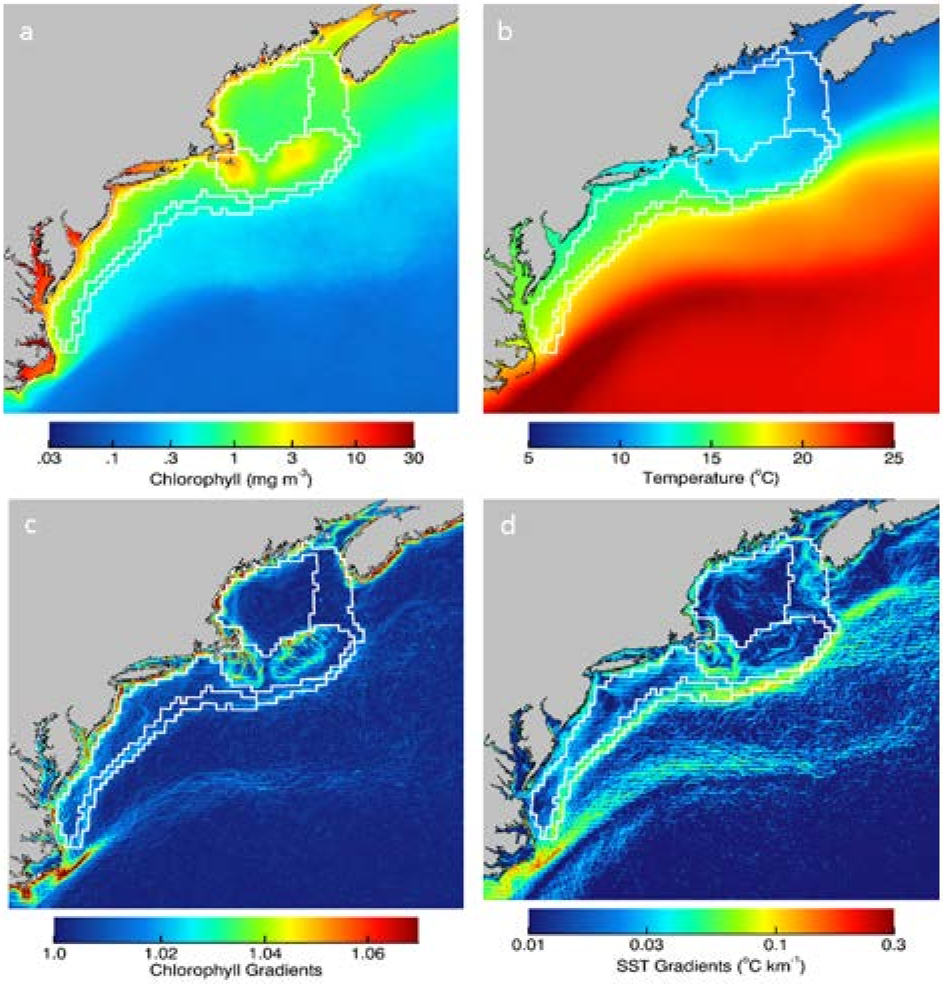
As reflected in the NOAA Fisheries definition above, EBFM is a place-based strategy. One of the fundamental ways in which EBFM will differ from current management approaches is in the development of an integrated management plan for a specified region rather than for individual species/stocks or groups of species. Of the 76 Georges Bank stocks, 29 species are managed by NEFMC: 20 as single-unit stocks, seven comprise 2-stock complexes, and two species are partitioned into three stocks. There are 28 distinct spatial footprints represented among these 36 stock units. Using a spatial footprint designed around ecological production units (EPUs, described below) substantially reduces the complexity of this stock-based system while also focusing on system-level properties, and takes into account interactions with neighboring EPUs.

Fogarty et al. (2012) identified a set of ecological production units on the basis of a set of physiographic, oceanographic and biotic (lower trophic level) variables. These EPUs can provide a basis for specification of ecological subareas on the Northeast Continental Shelf. Four major spatial production units were identified (1) Mid-Atlantic Bight, (2) Georges Bank (including Nantucket Shoals) (3) Scotian Shelf, (4) and Gulf of Maine. The analysis also identified distinct ecological domains in nearshore areas throughout the region and at the continental shelf break (Figure 2a-d; delineated in white). The nearshore and shelf-break systems were treated as nested subdivisions of the principal production units in the Gulf of Maine, Georges Bank, and the Mid-Atlantic Bight.

Examination of spatial patterns of a small subset of the variables included in the analysis reveal some of the principal drivers of the delineation of the EPUs. High chlorophyll *a* concentrations are found in nearshore waters throughout the Northeast Shelf, reflecting the influx of nutrients from land-based sources. The Georges Bank ecological production units is unique among the offshore regions in its high chlorophyll concentrations, reflecting its shallow depth, strong tidal mixing, and topographic features. Chlorophyll gradients not surprisingly mirror these patterns. Sea surface temperatures are highest in the Mid-Atlantic Bight and on the edge of the continental shelf; the influence of the Gulf Stream on temperature is evident in the shelf-break regions in the Mid-Atlantic and Georges Bank. Mean annual SST is lowest on the Scotian Shelf. Strong tidal mixing on the crest of Georges Bank and Nantucket Shoals results in isothermal conditions in the water column and contributes to the cooler mean annual surface temperatures in these regions. Temperature gradients are particularly strong at the shelf margins reflecting a persistent shelf-slope front that attracts a diverse array of fish, mammals, turtles and birds species.

It is evident that Georges Bank has ecological characteristics that warrant its identification a distinct ecological unit. It is also clear that the spatial delineation of stock units under current management that span multiple EPUs encompass a significant range of environmental conditions including temperature and primary production that differentially affect production of exploited species throughout the designated range of the stock under current management.

Figure 3. Satellite-derived maps of chlorophyll a concentration (upper left), chlorophyll gradient (lower left), Sea surface temperature (upper right) and SST gradient (lower right).

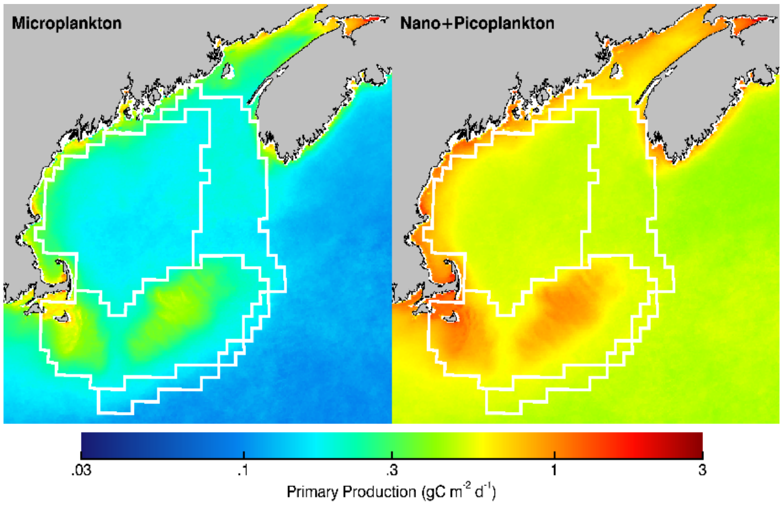


Primary Production and Energy Flow

Patterns of energy flow and utilization have been intensively studied on Georges Bank since the 1940s. It has been concluded that much of the fish production on Georges Bank is consumed by other fish and that energy is, in fact, a limiting factor (Cohen et al. 1982; Sissenwine 1984). The amount of primary production and its distribution throughout the food web sets constraints on system-wide productivity; this is referred to as ‘bottom-up’ ecosystem control. Changes in primary production at the base of the food web can accordingly change the production levels of exploited species. Further, the pattern of extraction of yield at different steps in the food web affects the production at higher levels. Because existing single-species approaches do not directly consider the amount of energy available for system-wide production as a constraint, it is possible that the sum of recommended catch levels under conventional management cannot be sustained. A number of studies around the world have concluded that this is, in fact, an issue.

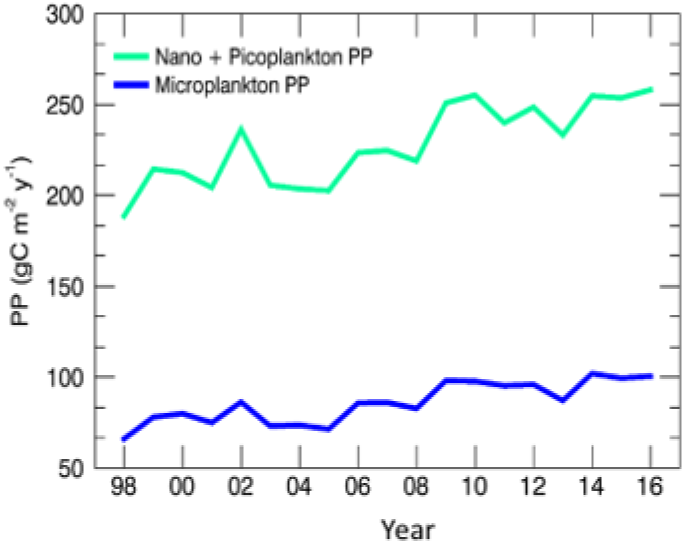
The spatial pattern of primary production on Georges Bank for microplankton (Figure 3, left) and nano-pico-plankton (Figure 3, right) reflects levels on the crest of the bank that are much higher than other regions on the outer Northeast U.S. Continental Shelf. On the crest of the bank, strong tidal mixing increases nutrient regeneration, fueling production. This is also true of the Nantucket Shoals region and it is one of the reasons that our definition of the Georges Bank EPU encompasses the shoals. For management purposes, Nantucket Shoals could be considered a distinct subregion of the Georges Bank EPU.

Figure 4. Spatial pattern of microplankton production and nano-pico-plankton production on Georges Bank and adjacent regions



Satellite-derived estimates of total net primary production averaged 321 gC/m^2/yr during 1998-2016. The earliest ^{14}C-derived estimate for Georges Bank production of 373gC/m^2/yr (Cohen et al. 1982) was subsequently lowered to 332 gC/m^2/yr with the accrual of additional information (Sissenwine 1984). Our recent estimates indicate a steady increase in nano-picoplankton production at a rate of 3.0 gC/m^2/ yr and an increase in microplankton production of 1.6 gC/ m^2/ yr over the period of instrumental record (Figure 4). The observed increase in primary production opens the possibility of an increase in overall fish and shellfish production and yield that can be incorporated into the management procedure by allowing higher exploitation rates under increased primary production.

Figure 5. Trends in primary production of nano- and pico-plankton and microplankton on Georges Bank based on satellite observations



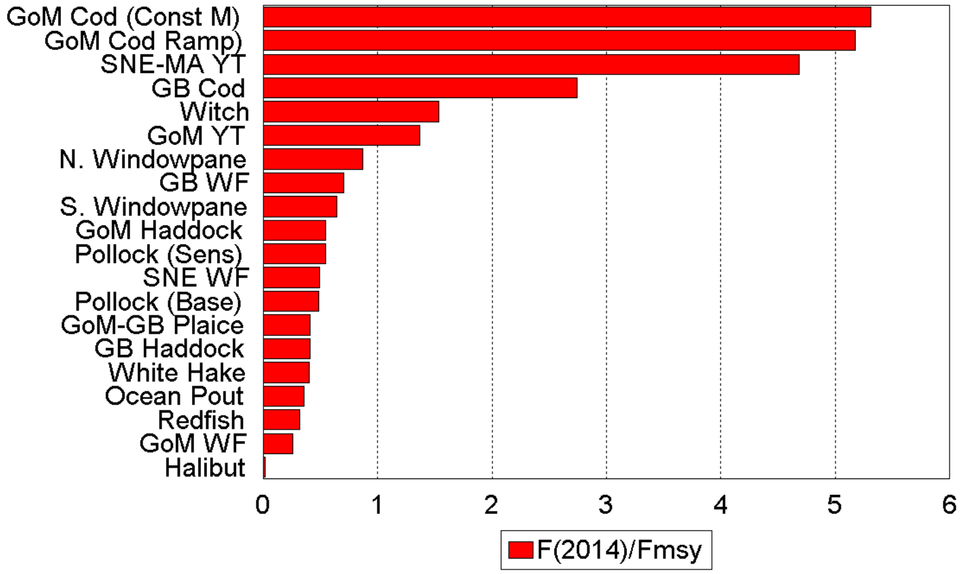
A Prototype Ecosystem-Based Management Procedure for Georges Bank

The issue of cost and complexity in conventional fishery assessment and management has been a motivating factor in developing simpler Management Procedures as protocols (e.g Butterworth 2007). Management Procedures entail the specification of a potentially simple set of rules for translating information from empirical information or assessment models into a management action. Ideally there is binding agreement beforehand on factors such as the model choice, associated data, and the actions to be taken if a management threshold is crossed. MPs typically remain in place for multiyear (3-5 years, for example) time frames and can be explicitly structured to enhance prospects for stability in the fishery by constraining the amount of change in management action from one timestep to the next, providing a more manageable time horizon for business, scientific, and administrative planning. The performance of alternative MPs is rigorously evaluated by simulation with respect to factors such as yield and/or profitability, uncertainty, and risk before any consideration of actual implementation, with these factors reflecting societal, economic, ecological, and institutional objectives. While MPs are now widely applied in single species management throughout the world, very few examples exist for multispecies or ecosystem applications. Perhaps the most highly developed multispecies management procedure now in use is for the sardine anchovy complex in the Benguela Current (De Oliveria et al. 1997).

The specific approach adopted here is addresses a major problem for effective management of the mixed-species resources in the Northeast, i.e. managing the catches of individual species that form in interrelated stock complex. As proposed here, the complexes or Fishery Functional Groups (FFG) are defined as species that are typically caught together and that play similar functional roles in the ecosystem with respect to habitat usage and energy flow. For testing the performance of alternative management procedures, the operational model focus on three major fleet sectors with distinct catch characteristics (Lucey and Fogarty 2012): (1) demersal trawl, (2) fixed gear [gillnets and longlines], and (3) pelagic trawls. Species that are caught together *inter alia* typically share common habitats. Further three major trophic guilds that are considered which are critical to energy flow and utilization in this system (a) benthivores, (b) planktivores, and (c) piscivores. These three trophic guilds can be represented within one or more fleet sectors.

The prevalence of technical interactions in these mixed species fisheries places inherent limitations on control of fishing mortality possible, leading to unavoidable implementation error in management actions (Figure 5). Although many factors, including estimation error, market conditions, regulatory constraints related to choke stocks, can affect levels of implementation error, it is clear that by-catch issues are an important contributor. A focus on setting Annual Catch Limits applied independently to individual stocks further results in a disconnect with the underlying dynamics of the fishery based on the magnitude and spatial distribution of fishing effort by different fleet sectors. The recommended approach sets exploitation reference points at the FFG level (and by extension, the system level). Target exploitation rates that when applied to a biomass estimate for the FFG can be translated into a catch level for a specified period (fishing year). For status determination, the effects of exploitation at the FFG level and at the individual species level should be evaluated. If the total biomass of a guild drops below a specified threshold level, remedial action should be taken to reduce exploitation on the FFG. Consideration of guild-level status alone of course cannot eliminate the possibility of impact on the individual species comprising the FFG. Accordingly, the operational model can also evaluate alternative control rules, in which remedial action is taken if any one species drops below a threshold level.

Figure 6. Ratio of the estimated fishing mortality rate in 2014 to the target (F_{msy}) fishing mortality rate in recent operational assessments for groundfish species (NEFSC 2015).

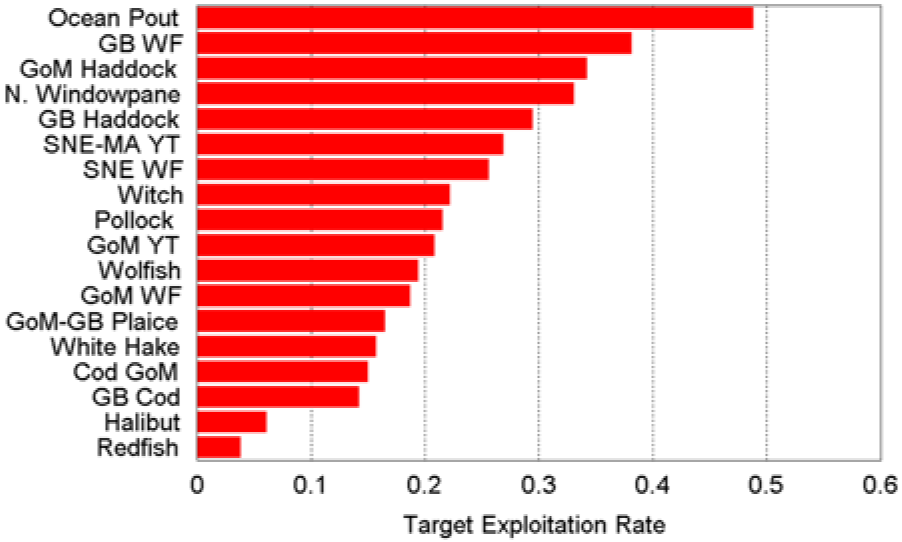


Ecosystem Reference Points

In contrast to population-level analyses, standard reference points have not yet been established to guide overall extraction policies for marine ecosystems. Iverson (1990) proposed that total exploitation rates (encompassing human and natural predators) should not exceed the *f*-ratio (the ratio of new primary production to total primary production) in marine systems. Ware (2001) noted that *f*-ratios of marine ecosystems that could be used to guide ecosystem extraction policies typically fall within a range of 0.25-0.40. Because the energetic needs of other predators must be considered, these *f-ratio* derived estimates must be considered limit reference points. Moiseev (1994) proposed that ecosystem exploitation rates should not exceed 20%. Alternative multidimensional criteria for ecosystem overfishing have been proposed by Murawski (2000) and Tudela et al. (2005).

In the following example, the observations of Moiseev (1994) and Ware (2001) are applied to establish a range of plausible exploitation rates to explore potential management procedures. As a demonstration, simulations of alternative exploitation strategies are applied at the FFG level ranging from 0.15 to 0.3, in increments of 0.05 for potential use as target exploitation rates. To place these rates in context, target exploitation rates employed in single species management for groundfish resources in the Northeast are provided in the figure below.

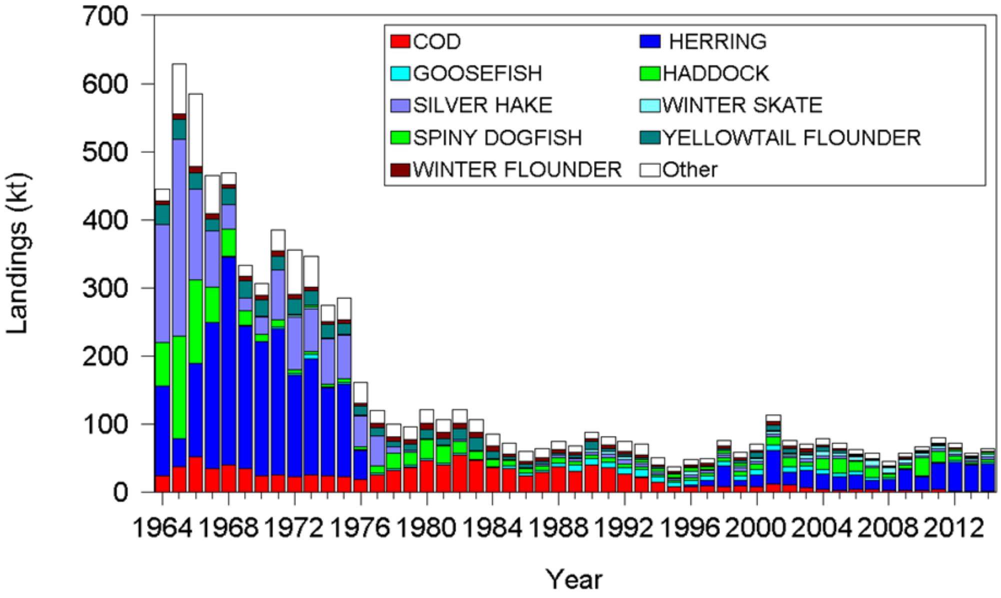
Figure 7. Target exploitation rate for groundfish species in recent operational assessments or groundfish species (NEFSC 2015). We have converted target Fmsy levels to annual exploitation rates based on natural mortality rates



Simulation Model

The Hydra model provides a simulation platform that focuses on a ten species subsystem of the whole, Atlantic cod (Gadus morhua), haddock (*Melanogrammus aeglefinus*), silver hake (*Merluccius bilinearis*), winter flounder (*Pseudopleuronectes americanus*), yellowtail flounder (*Limanda ferruginea*), monkfish (*Lophius americanus*), spiny dogfish (*Squalus acanthias*), winter skate (*Leucoraja ocellata*), Atlantic herring (*Clupea harengus*), and Atlantic mackerel (*Scomber scombrus*). The first nine species are under direct NEFMC management or control or are jointly managed with the Mid-Atlantic Fishery Management Council (spiny dogfish and monkfish). Mackerel are managed exclusively by MAFMC but are included here because of their historical importance as a forage fish on Georges Bank. The first nine species accounted for 86% of the landings of fish species for which NEFMC has complete or partial control during the period 1977-2014. This fraction increased to 90% during 2000-2014 Figure 7.

Figure 8. Landings of NEFMC-managed fish species included in the Hydra simulations and other fish species also managed by NEFMC

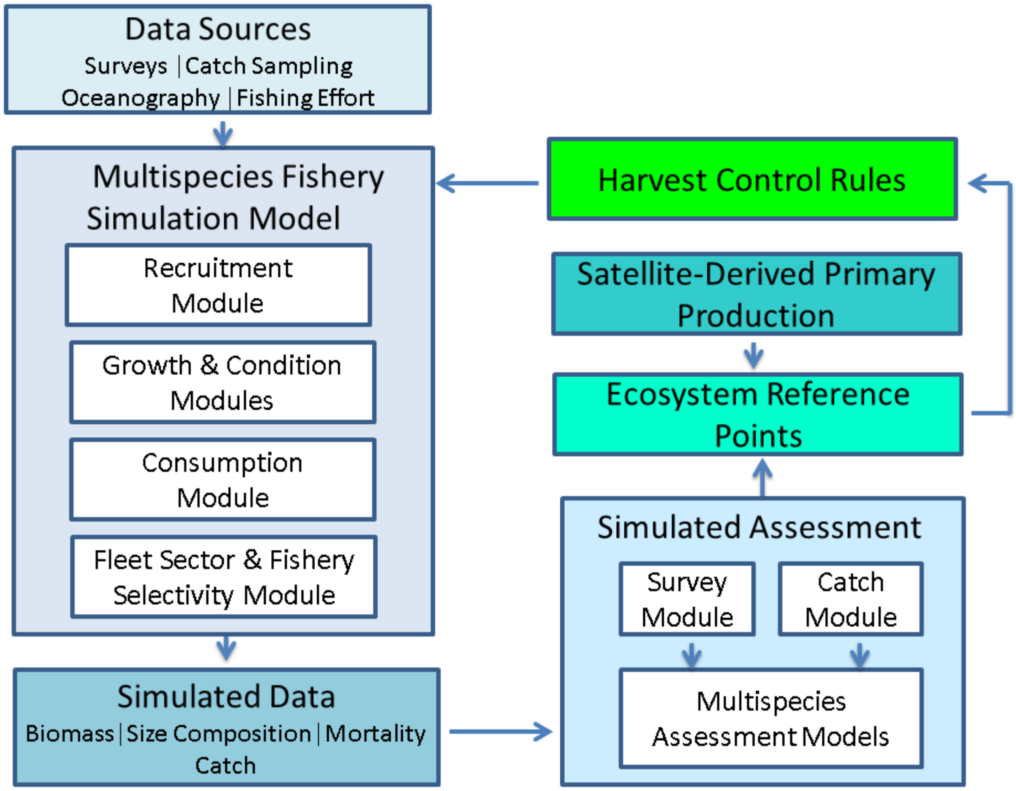


For context, the overall landed yield of fish and invertebrates on Georges Bank has averaged approximately 150,000 mt since 1977 when the US extended fishery jurisdiction to 200 miles.

Hydra simulates a ten species system with length structured population dynamics and predation (structured as in Hall et al., 2006; Rochet et al., 2011), and fishery selectivity with fishing mortality coming from three effort-driven multispecies fleets. A size-based model is preferable here, because fishing processes and predation are size-based rather than age-based and size composition information, in contrast to age composition, is available for most species on Georges Bank. Multiple forms for growth and recruitment are implemented in the operating model to represent different states of nature. In Hydra, the growth function is used to determine the time spent in each length category for each species. Environmental covariates for recruitment, growth, consumption, and for the length-weight relationship can also be included. The latter allows incorporation of change in the condition factor of fish. For simulations presented here, environmental factors including temperature were held constant. There is no mechanistic feedback between prey consumption and predator growth in Hydra, similar to most multispecies population dynamics models, including Multispecies Virtual Population Analysis.

In the simulations presented here, the implementation of Hydra dictates that sufficient food is always available from the pool of species directly modeled as an ‘other’ prey category. If evidence supports prey limitation or changes in food quality, it is possible to include prey abundance, availability, and quality in the growth module and the condition module to reflect the changes in predator growth and condition. Figure 8 provides a flow diagram of the process from the multispecies simulations described above to the elements of a simulated assessment process and ultimate specifications of harvest control rules.

Figure 9. Components of the simulation model used to test management procedures in Hydra



Simulated Stock assessment

For the simulation, a series of biomass, length composition, survival rates, and catch are generated by Hydra as 'observational' data incorporating environmental stochasticity and measurement error. The survey process is also simulated by taking the population outputs from Hydra and applied survey catchability coefficients and area swept corrections for each species and added variability to reflect factors such as measurement error and variation in availability to the trawls at the time of sampling. Hydra uses the generated survey data both as inputs to stock assessment models and as model-free estimators to be used to test the performance of model-free biomass estimates.

Harvest Control Rules

The harvest control rules examined here specify overfishing at the species complex level, but overfished status at the species complex or individual species levels (Figure 9; Table 1). As a demonstration of worked example harvest control rules, six principal scenarios were examined, with four levels of exploitation nested within each (Table 1) to define options for harvest control rules. The harvest control rules involve different options for floors and ceilings. Four ion rates of 0.15, 0.20, 0.25, and 0.3. In the present set of simulations, these exploitation rates are applied at the species complex level with each complex subject to this same sequence of exploitation levels. These are then translated into standardized fishing effort by dividing by the mean catchability coefficient for the species in the complex. These exploitation rates defined at the species complex level will be manifest as different rates on the individual species level because of different gear selectivity factors. The resulting catch for the complex as a whole and the individual species catch within each species complex is determined by the product of these species-level partial selectivity factors and the total biomass of the species complex. The exploitation rates specified above should be considered as fully recruited exploitation rates for the complex as a whole.

Figure 10.. Structure of the ecosystem-based harvest control rules tested. Overfishing is determined at the species complex level. Overfished status is determined at the species complex or individual species levels (see details in Table 1).

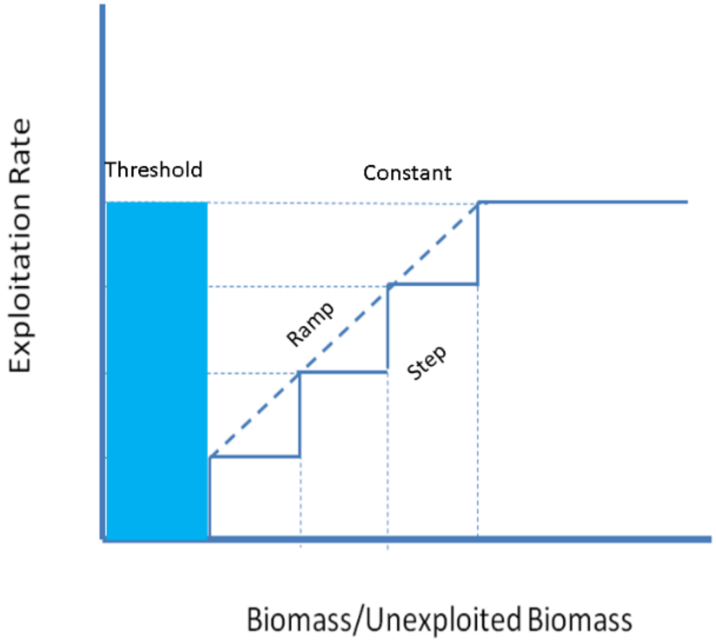


Table 1. Worked example management procedures tested in simulation studies

- **Scenario 1** Threshold exploitation (no ramp down) at Ex=0.15, 0.2, 0.25, 0.3 and Floor=0.2 of unfished biomass applied at the species complex level
- **Scenario 2** Threshold exploitation (no ramp down) at Ex= 0.15, 0.2, 0.25, 0.3 and Floor=0.2 of unfished biomass applied at the individual species level
- **Scenario 3** Threshold exploitation (no ramp down) at Ex= 0.15, 0.2, 0.25, 0.3 and Floor=0.2 of unfished biomass for each species except winter skate and dogfish (Floor=0.3 of unfished biomass) applied at the individual species level
- **Scenario 4** Ramp-down exploitation using 'steps' at Ex=0.15, 0.2, 0.25, 0.3 and Starting at B/Bo = 0.4 applied at the species complex level
- **Scenario 5** Ramp-down exploitation using 'steps' at Ex=0.15, 0.2, 0.25, 0.3 and Starting at B/Bo = 0.4 applied at the individual species level
- **Scenario 6** Ramp-down exploitation using 'steps' at Ex=0.15, 0.2, 0.25, 0.3 and Starting at B/Bo = 0.5 applied at the individual species level for winter skate and dogfish

Performance metrics

To evaluate fishery performance, the results presented here include catch, stock complex biomass, and the fraction of simulation runs in which the species and/or functional group constraint (floors) was exceeded. Each of the management procedures was simulated 500 times, and the median result of the 500 simulations was used to compare different control rules and their variants. The full range of results are also shown, characterizing uncertainty with a focus on the interquartile range. The simulation results also include associated revenues, the size composition of the catch and the population for each species. Additional metrics including indicators of biodiversity are also part of the output; similarly, metrics associated with other management objectives could be calculated.

Results

The following section describes a small subset of the results from the scenarios investigated to provide a flavor of the types of outcomes observed to date. We provide results for scenarios 1,4, and 5. Figure 10 shows comparisons of median catch and biomass among the functional groups for the threshold exploitation rate strategy; in this example, the overfished level was triggered when functional group biomass as a whole dropped below 20% of the reference level. As expected, the biomass drops with increasing exploitation rate in each functional group. In contrast, the median catch remains roughly comparable among functional groups at the lower exploitation rates of 0.15 and 0.2 but drops at an exploitation rate of 0.3 and exhibits increased variability in outcomes. When the threshold exceedance level is set for the functional groups as a whole rather than for individual species within the group, unacceptable frequency of overfished levels occur for the planktivore and benthivore functional groups, particularly when the maximum exploitation rate is set at the limiting level of 0.3.

Figure 11 and Figure 12, compare the performance of the constant exploitation rate strategy with the graduated response control rule when the protective floor is invoked when any individual species within a functional group falls below a threshold biomass level of 0.2 of the unexploited biomass. Again, the application of the graduated response considerably, and not unexpectedly, results in reduced occurrence of overfished status.

Collectively, these results show that under all of the scenarios chosen for illustration here, the limit exploitation rate of 0.3 is too high to allow acceptable performance with respect to the protective constraints tested here while also generally resulting in poorer catch performance. Application of the graduated exploitation response results in overall improved performance with respect to the threshold exceedance levels with little or no loss in yield at the functional group level.

Figure 11. Scenario 1 (fixed exploitation) box plots for biomass, catch, and exploitation status by species complex aggregated over all gear types. Values on the X-axis represent the exploitation rate applied to the stock complex.

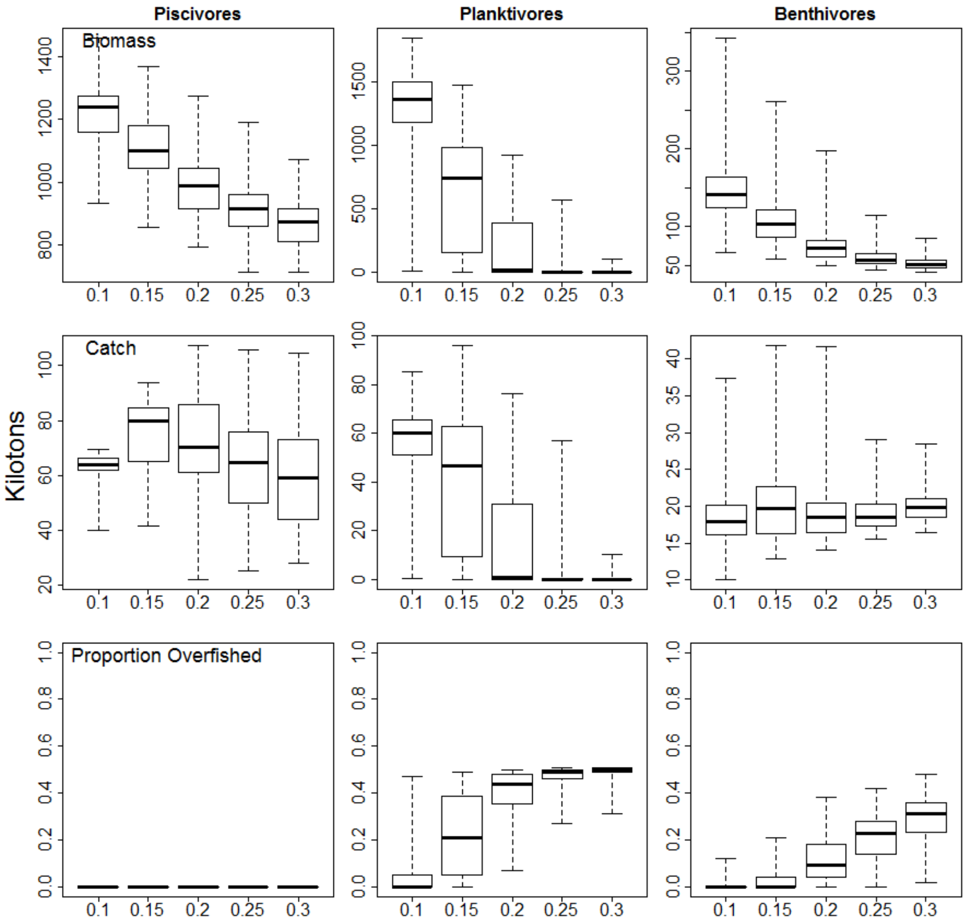


Figure 12. Scenario 4 (ramped exploitation below 0.4 B_0) box plots for biomass, catch, and exploitation status by species complex aggregated over all gear types Values on the X-axis represent the exploitation rate applied to the stock complex.

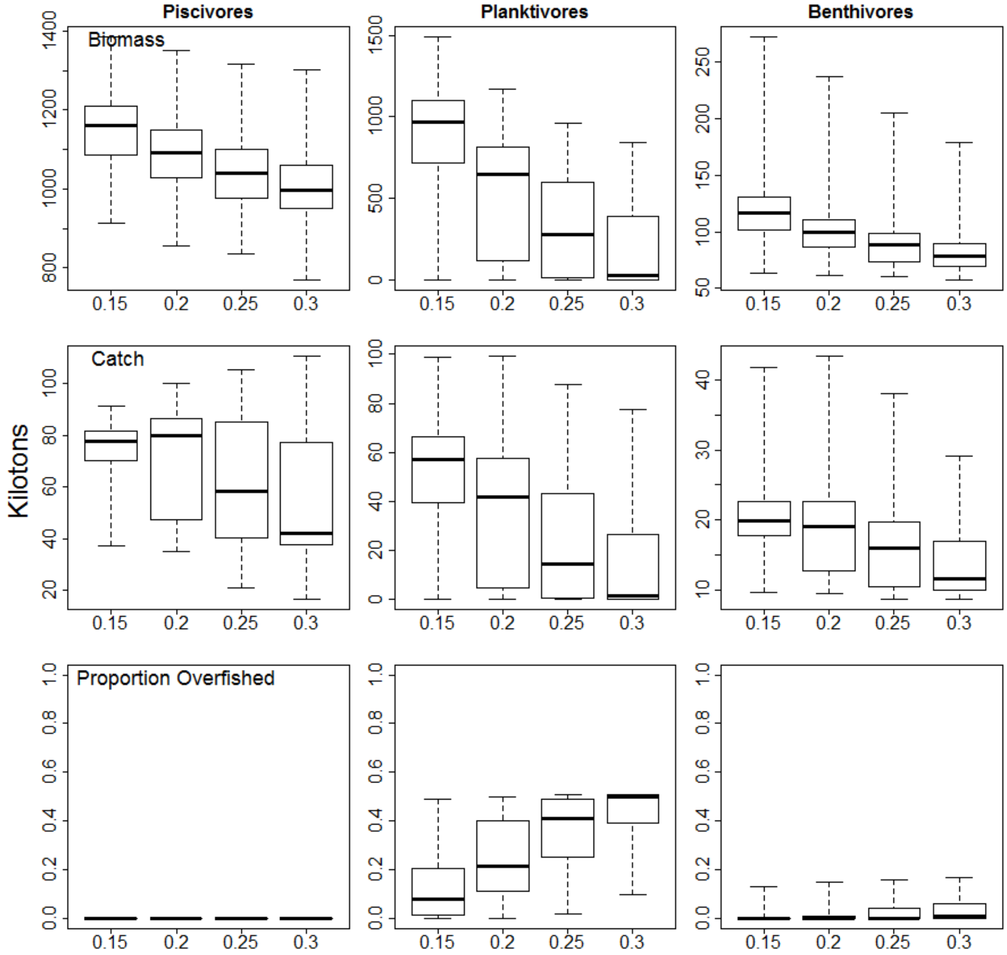


Figure 13. Scenario 5 (ramped exploitation for individual stocks below 0.4 B_0) box plots for biomass, catch, and exploitation status by species complex aggregated over all gear types. Values on the X-axis represent the exploitation rate applied to the stock complex.