Options for Ecosystem-Based Fisheries Management on Georges Bank: A Worked Example

Take-Away Messages

- Management of mixed species fisheries in which many species are caught together and some of these species prey on each other is particularly challenging. This situation is common in New England fisheries and elsewhere. Traditional single-species management is not specifically designed to meet these challenges.
- It is possible to construct computer models of fishery ecosystems that capture the main features of these systems. We built a multispecies-multifleet simulation model for 10 ecologically and economically important fish species on Georges Bank to test ideas on how we might effectively manage these mixed-species fisheries. We focus on management strategies for species that are caught together in different fishing gears, play similar roles in the ecosystem, and whose basic biology is similar. We examine the performance of different options based on this concept and test whether we can simplify management based on this concept.
- In these initial tests, we find that it is possible to effectively manage species complexes defined in this way and to identify and counter risks to the species in the complex. Management strategies that trigger action at early signs of decline in species are extremely valuable and result in outcomes with higher yield and revenue than alternative strategies that defer action until a threshold of low biomass is crossed.
- In comparing species complex management as developed here with single-species management, we find that it possible to achieve higher yields for many species while effectively controlling the proportion of species that are depleted below 20% of their unfished biomass. The strategy of ‘putting the brakes on early’ is particularly valuable in achieving this result. We also find that in our simulations, it is difficult or impossible to meet single-species management targets for all species simultaneously under these conditions.
- We note that should it prove useful to explore this form of species management in greater detail, a full management strategy evaluation with stakeholder involvement would be a logical next step. This process would entail not only an expansion of the scenarios and conditions used in this initial example, but consideration of additional ecosystem-based management approaches and objectives developed under the guidance of managers and other stakeholders.

Introduction

In this document, we describe a worked example of how we might manage fish species on Georges bank by focusing on groups of species (species complexes) rather than trying to manage each species separately. Our goal is to account for biological interactions such as predation and also fishery interactions such as by-catch in a way that could potentially simplify management. For this example, we concentrate on ten ecologically and economically important species on Georges Bank rather than all the species that occur on the bank. These ten species are: Atlantic cod, Atlantic haddock, silver hake, winter flounder, yellowtail flounder, monkfish, spiny dogfish, winter skate, Atlantic herring, and Atlantic mackerel. The first 9 species are under direct control of the New England Fishery Management Council (NEFMC) or are jointly managed with the Mid-Atlantic Fishery Management Council (MAFMC, spiny dogfish and monkfish). Mackerel are managed exclusively by MAFMC but are included because they are an important food for other fish species on Georges Bank. These species are known to interact, with some species eating others (Figure 1).

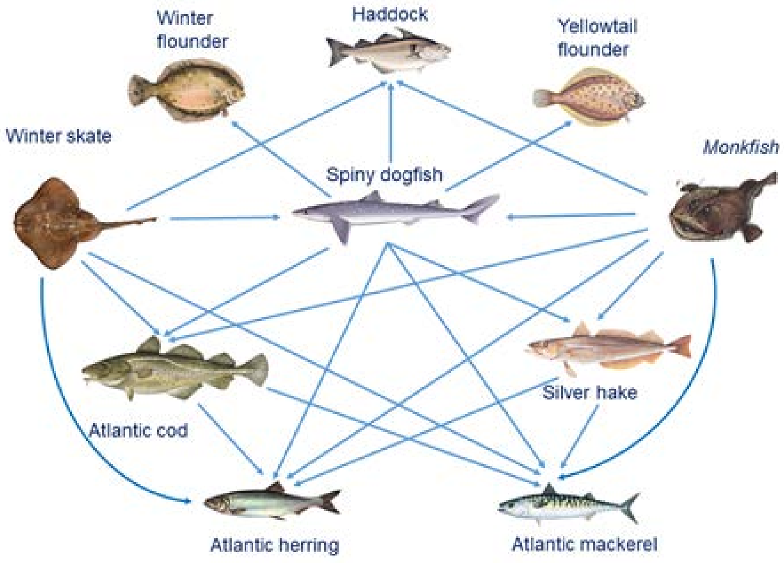

Figure 1. The species selected for our worked example and the predator-prey connections among them. The arrows point from predator to prey species.

Many of these species are also caught together in different fisheries, resulting in by-catch and other complications. It is important to take account of these interactions because when species are connected through predation, management actions that affect, say, a prey species can also affect their predators and *vice-versa*. Also, when species are caught together, we cannot closely control the fishing pressure on each species individually. If we do not take these interactions into account, we can have unintended consequences in management.

This worked example for the Georges Bank fish community involves the following steps:

- Identify the boundaries of the Georges Bank ecosystem
- Identify species that are caught together, play similar roles in the ecosystem, and whose basic biology is similar and use this information to define species complexes.
- Specify the rules for how we will manage these interacting species. In our worked example, this involves:
    - Setting target fishing rates and the corresponding catches for each species complex (we call this a catch ceiling).
    - Identifying baseline levels (floors) below which each species and each species complex as a whole is considered to be depleted.[1]
    - Establishing the rules that indicate how fishing will be adjusted in time based on updated indicators of change at the species complex and individual species levels (these are called harvest control rules)
- Create a computer model of the Georges Bank ecosystem to serve as a virtual world in which we can test the performance of different management options. We also specify how we will track changes in the fish community and the fishery over time and how we will determine the status of the fishery system. This simulation stage is called a Management Strategy Evaluation (MSE).
- Compare outcomes of single and multispecies management.

In the rest of this summary we will describe each of the steps involved in further detail. Additional details on the simulation model used can be found at https://github.com/NOAA-EDAB/hydra_sim/wiki.

1. Identify the Boundaries of the Georges Bank Ecosystem

EBFM is a place-based approach with management plans for geographically-defined regions rather than for individual species. The first step therefore involves identifying the major fishery ecosystems off our coast. As we will see, Georges Bank and nearby Nantucket Shoals is one of the areas we identify as a distinct fishery ecosystem. We'll use Georges Bank as a shorthand for this region. Georges Bank provides a good test case – it is a very well-studied, highly productive, and important fishing ground. It is important to make clear that we are not saying that Georges Bank is a closed ecosystem. It is connected with other parts of the Northeast continental shelf by ocean circulation patterns, and the movement of animals and we do need to take these factors into account.

We used three major types of information to identify potential management areas:

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[1] Here we use the term 'depleted' rather than 'overfished' because the abundance of any species can be driven to low levels by species interactions, fishing, or both. In setting floors, we are trying to ensure that a species can retain a sufficient critical mass to continue to play a viable role in the ecosystem.

- physical features (depth and bottom type)
- oceanographic features (temperature, salinity, frontal zones)
- primary production and chlorophyll concentration (an index of microscopic plants responsible for primary production)

In all, we used 18 variables based on information from satellites and research vessels. Primary production reflects the amount of energy coming in at the base of the food web that fuels the rest of the ecosystem. Physical and oceanographic characteristics have important effects on this productivity.

We can identify four major spatial units on the Northeast Continental shelf using these variables: (1) Mid-Atlantic Bight, (2) Georges Bank (including Nantucket Shoals), (3) Gulf of Maine and (4) Scotian Shelf. We call these areas Ecological Production Units (EPUs). We further identify distinctive characteristics of nearshore areas and at the edge of the continental shelf that can be treated as subregions of some of the ecological production units (see Figure 2).

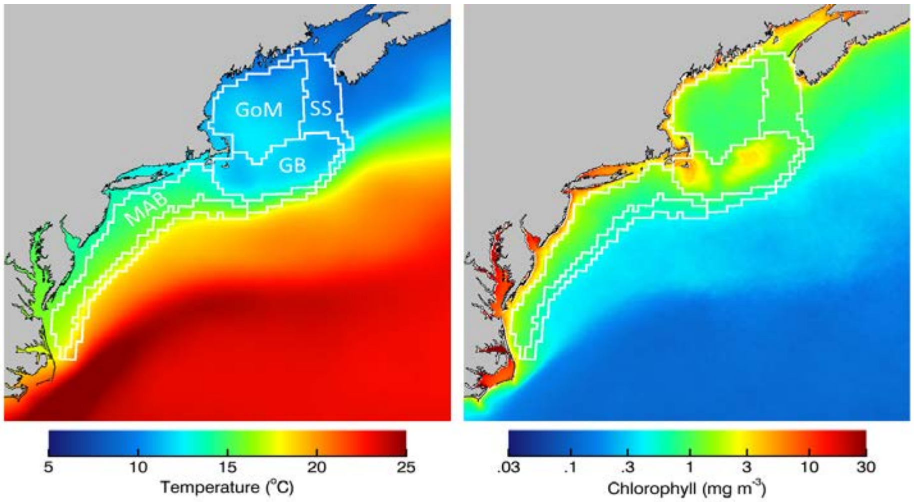

Figure 2.. Proposed Ecological Production Units for the Northeast U.S. Continental Shelf in relation to spatial patterns of sea surface temperature and chlorophyll concentration based on satellite imagery. The white lines indicate the major EPU boundaries and subdivisions (inshore and shelf-break) [Scotian Shelf (SS); Gulf of Maine (GoM); Georges Bank-Nantucket Shoals (GB); Mid-Atlantic Bight (MAB). Maps courtesy of Kim Hyde (NOAA Fisheries).

In this figure we can see the influence of factors such as surface water temperature and chlorophyll concentration in defining both the major boundaries between the ecological production units and subregions within each. For example, Georges Bank proper and Nantucket Shoals share certain features such as shallow depth and strong tidal mixing that result in centers of high chlorophyll concentration in each). This is also reflected in similarities in surface water temperature over the areas of high tidal mixing. For this reason, we treat them together. Nantucket Shoals can be considered a subregion of this EPU[2].

2. *Identify Stock Complexes*

We next explore ways to simplify management by identifying species that are routinely caught together, have similar biology, and play similar roles in the ecosystem as predators or prey. The majority of marine species in federal waters of the United States are in fact managed together as part of a species (or stock) complex (see Glossary). Currently the New England Fisheries Management Council manages seven skate species as a complex and silver hake and offshore hake are combined into another complex.

To identify groups of species that play similar roles in the Georges Bank ecosystem, we drew on long-term diet studies of fish conducted during research survey cruises. Food habits of over 100 species of fish on the Northeast Continental Shelf have been studied over the last half century, providing diet information on over three-quarters of a million individual fish. Also, by examining the very extensive catch information in monthly catch reports provided by fishermen over the last three decades, we can tell which species are routinely caught together in different types of fishing gear. Finally, studies of basic biology of fish conducted during research surveys and special studies provide a rich source of information on growth, reproduction and other information to identify species with similar biology.

In this worked example, we considered three major fishing fleets (demersal trawl; pelagic trawl; and fixed gear (longlines and gillnets)), and three broad categories of fish based on their diets: fish-eaters, bottom-feeders, and plankton feeders. Plankton are small animals that live in the water column and are very important parts of the food web.

Figure 3 shows how our 10 species break down in terms of the species that are caught together in different fishing fleets and their roles in the food web based on their diets. Biological studies indicated that dogfish and winter skate need extra protection because they produce small numbers of young each time they reproduce and they don’t become mature until fairly late in life. This makes them more vulnerable to fishing. So we treat them as a separate group in the analysis. Even here, there are important differences. Dogfish produce fewer young and mature at a much older age than winter skate. Both dogfish and winter skate are fish-eaters.

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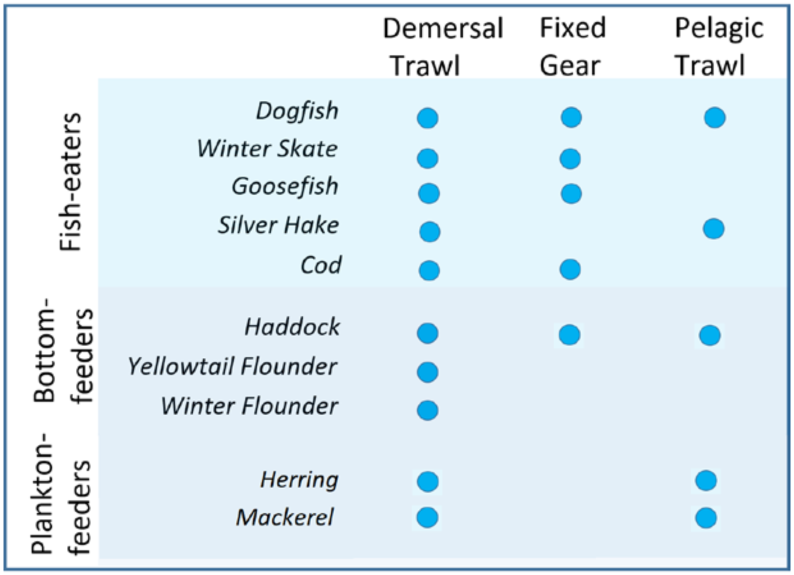
[2] Under current single-species management, most species have only one defined stock for the entire region. Four species (cod, haddock, yellowtail flounder, and winter flounder) currently have Georges Bank stocks but the areas covered on the bank differ for cod and haddock vs the flatfish. The cod and haddock area includes Nantucket Shoals.



		Demersal Trawl	Fixed Gear	Pelagic Trawl
Fish-eaters	Dogfish	●	●	●
	Winter Skate	●	●	
	Goosefish	●	●	
	Silver Hake	●		●
	Cod	●	●	
Bottom-feeders	Haddock	●	●	●
	Yellowtail Flounder	●		
	Winter Flounder	●		
Plankton-feeders	Herring	●		●
	Mackerel	●		●

Figure 3. Species caught together by gear type and their feeding types in our worked example.

3. Specify the Management Rules

Any fisheries management plan requires a clear set of rules to guide how we will achieve our objectives. The basic approach we describe below is similar in many ways to current single species management. But catch limits will be simpler to follow and enforce because they will be for the species complex as a whole. The set of rules to be applied is called a Management Procedure.

We need to specify how much fishing pressure will be used to achieve our objectives while still meeting guidelines to prevent depletion of the resource. Here we consider two possible objectives:

(1) Maximize total yield from the fish community subject to conservation constraints
(2) Maximize total revenues subject to these constraints.

These two objectives will of course give different answers in terms of the ‘right’ amount of fishing pressure to exert on different species complexes to give the desired outcome. This very simple measure of revenue does not account for the effects of changes in supply over time or differences in price for different sizes of fish. It does demonstrate however that ranking outcomes by landings versus revenue can lead to very different perceptions of what is ‘ best'. The conservation constraints are the safeguards we put in place to prevent depletion. Basically, we define baselines, or thresholds [usually measured as the total weight (or an index if total biomass is not known) of the population or a complex (biomass)] below which a species or a species complex is considered to be depleted. We can set these thresholds for each species individually or for the species complex as a whole. If we can define threshold values at the species complex level that can also prevent declines of the individual species in the complex below species-level thresholds, we will be able to use a simpler, more flexible, management strategy.

For this example, we adopted a simplified case of setting the same exploitation rate for each species complex. This allows us to present the results in a streamlined way in which we show the common exploitation levels. The overall approach, however, is designed to allow different target exploitation rates for each species complex, so as to identify the combination(s) of exploitation rates that meet the objectives. This is how it will be done in practice because it gives more flexibility in meeting objectives chosen for management. It also allows us to address different impacts on different species complexes to achieve more resilient outcomes. Exploring all possible potential exploitation rates for each stock complex entails evaluation of a very large number of possible combinations and is less easily shown in a small number of figures for this simple worked example.

We track changes in the fish populations and the fishery over time. The set of rules we use to determine appropriate catches given the state of the resource are called harvest control rules. The protective measures proposed here are slightly different for dogfish and winter skate (shown in parentheses) and include two major options:

(1) Landings of a species are prohibited once its biomass falls below a baseline level (or threshold) of 20% of the unfished level (30% for dogfish or winter skate as they require an additional safeguard). The species is still subject to being caught as by-catch. These thresholds are our floors.
(2) Fishing pressure is gradually reduced once any species within a species complex drops below a 'trigger' point of 40% of its unexploited state (50% for dogfish and skate). We assume that there will always be a minimum residual exploitation rate of at least 0.05 under any effort reduction.

The sliding (or 'ramp-down') strategy described in the second option reduces the fishing rate as the biomass declines to prevent the need for drastic management actions such as a fishery closure. So we basically apply the brakes early to avoid serious declines. When the species recovers, the harvesting can again be gradually increased. The basic idea is shown in Figure 4.

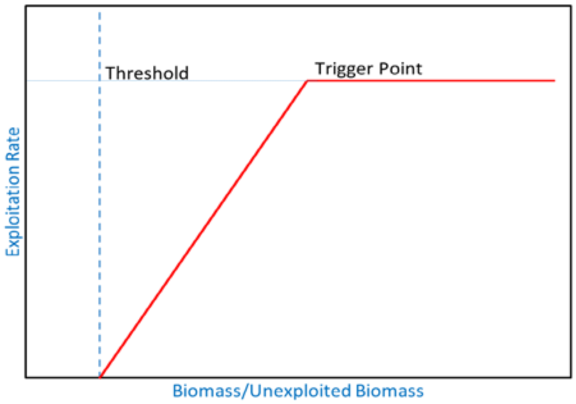


Figure 4. Illustration of harvest control rules employed in our management procedure.

This type of control rule can be particularly important for management at the species complex level in cases where fishing effort might be directed at one or more selected species in a complex. Identifying impacts on individual species early by detecting declines and taking action to prevent further reduction in biomass is essential. Other incentives to divert attention away from species at risk and toward healthy stocks might also be desirable.

In our simulation studies, we first run the model without fishing until it stabilizes (reaches equilibrium). This gives us estimates of biomass (in the absence of fishing) at the end of this set-up period. We then introduce fishing according to the rules described in the previous section and run these for another 50 simulated years. It is important to note that in the real world we seldom, if ever, know what the unexploited biomass was in a place like Georges Bank which has been exploited for centuries. The way this is usually handled in real life is to use existing biomass (or biomass index) estimates from existing sources (surveys, assessments, etc.) for as long a time period as possible. A ‘reference’ period such as the period of highest biomass is then used as a proxy for unexploited biomass. Some assessment models also directly include unexploited biomass as part of the estimation method used.

Management Strategy Evaluation

To test the ideas outlined above, we need a way to determine whether some management options give better outcomes in terms of meeting our objectives than others. We cannot of course test all possible management options so we try to identify ones that have a good chance of meeting our objectives. We particularly want to identify (and eliminate) options that fail to give satisfactory results.

We could of course select options and try them out in the real world. But this has some obvious downsides, including the chance that the options tried will make things worse rather than better. An alternative is to first try out the ideas on a computer. To do this, we create a virtual world that tries to capture our understanding of the important parts of the ecosystem as realistically as possible[3] while still keeping things understandable. We also want to make sure that we account for the fact that we know some parts of the story better than others and that there is uncertainty that needs to be considered.

Georges Bank has been the focus of important scientific investigations for over half a century. And there is a very long history of developing mathematical and computer models of this ecosystem that we can build on. Some main findings from earlier work are:

- Energy coming in at the base of the food web sets limits on the overall production of the ecosystem, including that of exploited species
- Predation is an important feature of this system and most of the fish production is in fact consumed by other fish.
- Predation rates differ for different size classes of fish. Most predation is on smaller fish (which also account for the largest fraction of the total fish production).
- Fishing rates also depend on size and tend to be concentrated on larger size classes (especially when we have mesh size requirements and legal size limits).
- Larger individual female fish produce many more and often healthier eggs than smaller ones
- The rate of growth of individual fish is most rapid for the smaller size classes and then declines with larger sizes.
- Replenishment of the population(s) through reproduction (recruitment) is the most important (and variable) part of the overall production for most fish species

So we need to be sure to incorporate these features in the simulation model. Some of these main findings are illustrated in the very simple picture in Figure 5. Here we show three fish populations harvested by two fishing fleets, one focused on small pelagic fish and the second fleet catching two species, one of which preys on the small pelagic fish. We show the progression from smaller to larger fish for each species due to growth. The curved lines connecting the larger size categories with the smallest size class represent the recruitment process. The arrows connecting each successive size class represent the chances of surviving and growing into the next size class at each time step used in the model. Dotted

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[3] No computer model can capture the rich detail of the real world. In fact, it would be a mistake to try to make a model that is so complicated (realistic) that we cannot get good information on all its parts. Instead, we try to distill things down to the main essentials in our models.

lines and arrows connecting the predator to the prey represent size-specific predation. Different predator size classes prey on different (but overlapping) size classes of their prey. The model we developed to include these many factors is called Hydra (after the multi-headed creature in Greek mythology)

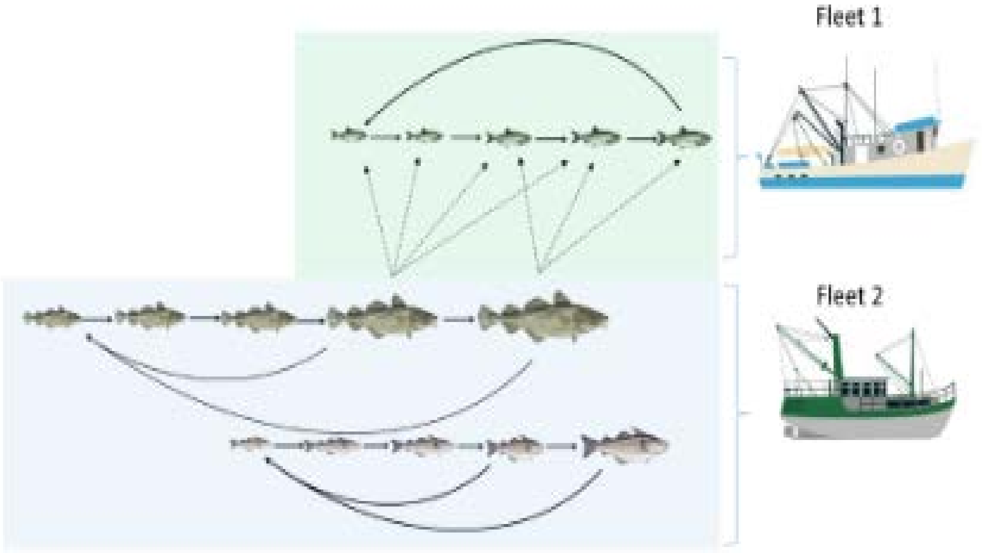

Figure 5. Some of the main features in a simplified picture of how Hydra works (shown here for three species harvested by two fishing fleets)

Of course, not all the details of the model can be easily shown in this simple picture. For example, Hydra can include environmental effects such as temperature on growth, recruitment, and predation. It can therefore be used to explore some possible implications of climate change. There is also a menu of different growth and recruitment sub-models to choose from. To mimic actual recruitment processes in the modeled fish populations (which in reality tend to be highly variable), we include random variability in the recruitment values in Hydra. Harvesting is driven by fishing effort in each of the fishing fleets. The exploitation rates on each species depend on the magnitude of fishing effort and the sizes of fish caught in the fishing gear.

Information provided by Hydra for each of the management procedures tested for each species and for each species complex include:

- Population biomass
- Catch (landings and discards)
- Gross revenues for the landings
- Stability in biomass
- Stability of the catch
- Probability of depletion
- Biomass of the largest size class in the population and in the catch.

To get estimates for the various pieces of information needed to construct the Hydra model, we mined the rich data archives available for species inhabiting Georges Bank and adjacent areas using stock assessment reports, scientific papers and technical documents and NEFSC data bases [including regular catch reports from fishers that also allow us to determine fishing effort; seasonal NEFSC surveys during which information on abundance, biology (growth and reproduction); food habits; and physical measurement (temperature and salinity) is gathered]. These pieces of information then allow us to construct a simulation model of the fishery system that links back to the simple representation shown in Figure 5. This is called an Operating Model. It deals with (1) Recruitment, (2) Growth, (3) Predation and (4) the Fishery. These each in turn involve sub-models dealing with each part of the story.

The simulated data coming out of the operating model includes biomass for each species and species complex, a survey index, the size structure of the populations under different exploitation rates, mortality rates due to fishing, predation, and ‘other’ mortality (which is taken to be a constant), and the catch (including the part that is landed and sold, and the part that is discarded because it cannot be legally kept.

We then pass this simulated data to an assessment section that uses several types of models to develop measures of the status of the resource. In our worked example, these are fairly simple models including (1) single- and multi-species production models that do not account for the size structure of the species harvested (2) simple size-structured models that split the populations into two categories (recruits and adults).

We also construct a survey index based on the simulated biomass data. Many species on Georges Bank are currently assessed using survey and/or catch data in what are called Index-based assessments. Currently, in the real world, 6 out of the 10 species included in Hydra are evaluated using index-based assessments and depend strongly on research vessel survey data and/or other types of surveys and catch data. In this worked example, we therefore rely on population estimates using the simulated survey data to illustrate the process rather than the simple assessment models.

We also note that although this choice is currently driven by necessity in the real world for a number of the species involved, if we can reliably base our determination of resource status on simple direct measurements using survey information of various types and/or information from the fishery itself, we can streamline the process to produce timely evaluations. More detailed assessments using single and multispecies models would still be made to provide additional insights into resource status at pre-determined time intervals but we would also have interim assessments using index methods on a more frequent time schedule to track changes. In particular, annual evaluation of measures of biomass using research surveys of different types and information from the fishery (such as catch-per-unit-effort) would be made to detect problems. In practice, this would allow emergency intervention under all scenarios if warranted.

As in the real world, the results of the index method or assessments in the simulated data determine the catch decisions that are then applied to the simulated fishery-ecosystem structure of the operating model for that year. The overall sequence of operations described above is called a Management Strategy Evaluation (MSE). In real-world applications, consultation with stakeholders would play an important role in defining the issues to be addressed in the MSE, including the selection of objectives which then would set the stage for the harvest control rules to be tested.

5. Model Calibration

Prior to assessing the performance of alternative management strategies we need to calibrate the operating model, Hydra, such that simulated biomass and catch (in addition to other metrics) under historic fishing effort levels are somewhat captured adequately by the model. It is important to note that the simulation model is not directly ‘tuned’ to the actual data using a statistical procedure. Rather, we ensure that the results fall within the bounds of real-world observations of catch, biomass etc. by ‘filtering’ the many thousands of simulations conducted to remove ones that produce the results that fall outside these bounds. In Figure 6 we show simulated catch data from Hydra based on historical effort data to give an idea of the general level of predicted catch under our baseline simulations. As more information becomes available, we can refine these predictions by adjusting factors such as the efficiency of different fishing gears to catch each species in the analysis.

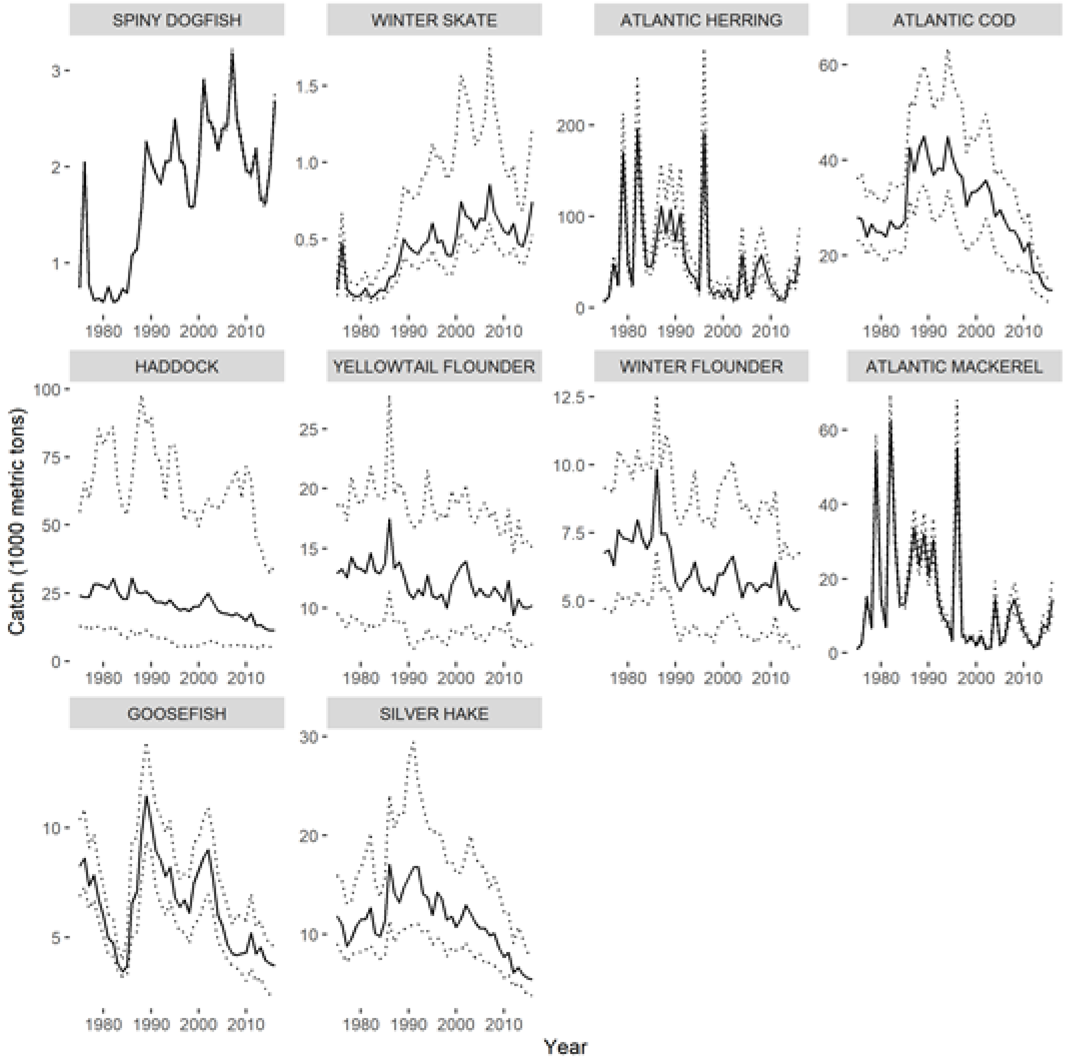

Figure 6. Simulated catch from the operating model, Hydra.

6. Management Outcomes

We explored 4 scenarios (Table 1) with 8 levels of exploitation nested within each. Each simulation produces a very large amount of output and in this short summary, we can only present a select number of results to demonstrate important differences in the outcomes of each scenario.

Table 1. Management scenarios

Scenario 1: Fixed exploitation rate. Exploitation rates = 0.05-0.4 in increments of 0.05. Floor assessed at the complex level. If the floor[*] of any complex is breached any further catch of this complex is considered a discard.

Scenario 2: The same as Scenario 1 with one addition. Floors assessed as the species level. If the floor[*] of any species is breached any further catch of this species is considered a discard.

Scenario 3: Variable exploitation rate. Starting exploitation rates = 0.05-0.4 in increments of 0.05. Each species complex is associated with a single fishing fleet. Species are still caught by multiple fleets, but when a species/complex becomes depleted, management actions only occur on the associated fleet. Each species complex is associated with the fleet that is considered the largest exploiter of the complex. The fishing fleets impact (exploitation) on the complex is adjusted through time[5] (as depicted in Figure 4) when the complex biomass falls below 40% unfished biomass.

Scenario 4: The same as Scenario 3 with one addition. The fishing fleets impact on the complex is adjusted through time (as depicted in Figure 4) as the biomass of an individual species within the complex falls below 40% unfished biomass (50% for Elasmobranchs). This can be thought of as additional species protection

[*] In all scenarios a floor of 20% unfished biomass is used to determine when a species population is depleted. At this level any fish caught are considered discards.

Figure 7 shows a comparison of all four scenarios illustrating the probability of the biomass of each species remaining above its floor (>20% unfished biomass) in the final 10 years of the simulation. The outer-most circle represents the most healthy state (the probability that unfished biomass > 20% = 1) while the inner circle represents an unhealthy state (the probability that unfished biomass > 20% = 0). The most noticeable difference is that scenarios 3 and 4 (adjustable exploitation rate) result in considerably less instances of species depletion (compared to fixed rate scenarios). As one would expect as exploitation increases the number of species entering a depleted state.. The frequency is considerably less in scenarios 3 and 4 than under scenario 1 and 2 due the adjustment of the exploitation level. If these complexes were assessed more frequently than every 3 years (the current time frame in the model), this may be mitigated further.

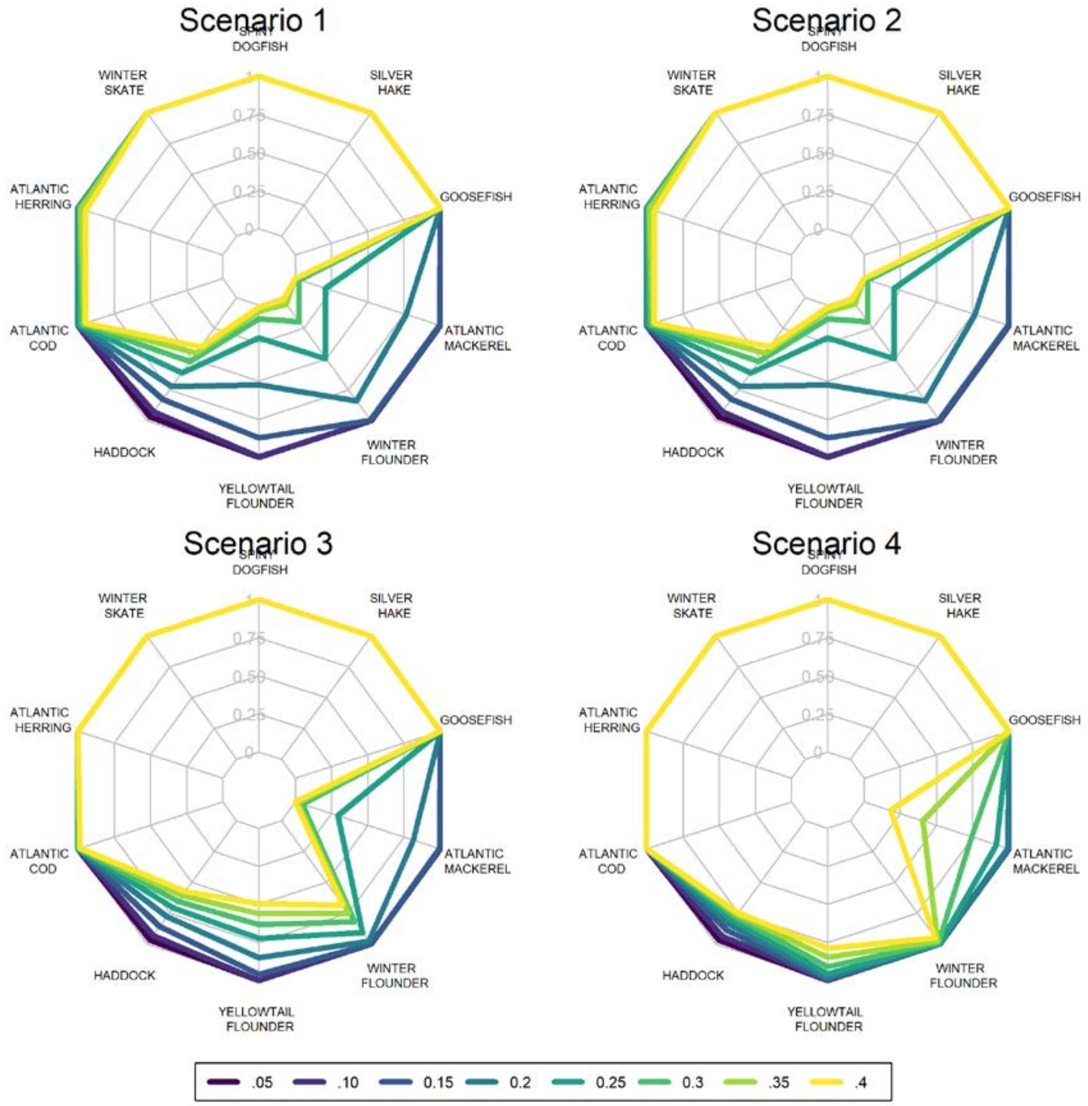

Figure 7. Radar plots illustrating the probability of species remaining above its floor (> 20% unfished biomass) for years 41-50 in the simulations. Probabilities are evaluated at eight levels of exploitation (represented by colored lines).

Many more metrics are calculated in the simulation model (as described in section 4) to assess the health of the system and the performance of the management scenarios. Figure 8 shows a comparison of all fours scenarios using 8 performance metrics. When the exploitation rate is sufficiently low (<= 0.15) all scenarios behave similarly since very few species enter a depleted state. However when exploitation rates are increased differences emerge. Under scenario 3 (variable exploitation rate) we see an improvement in the revenue, stability of the landings, and species status compared to that under scenario 1 (fixed exploitation rate). With the addition of species protection (scenario 4), the benefits are improved further. More large fish are landed, there are more large fish in the population, the species status is improved, and there is generally more biomass in the system, all while maintaining high levels of revenue.

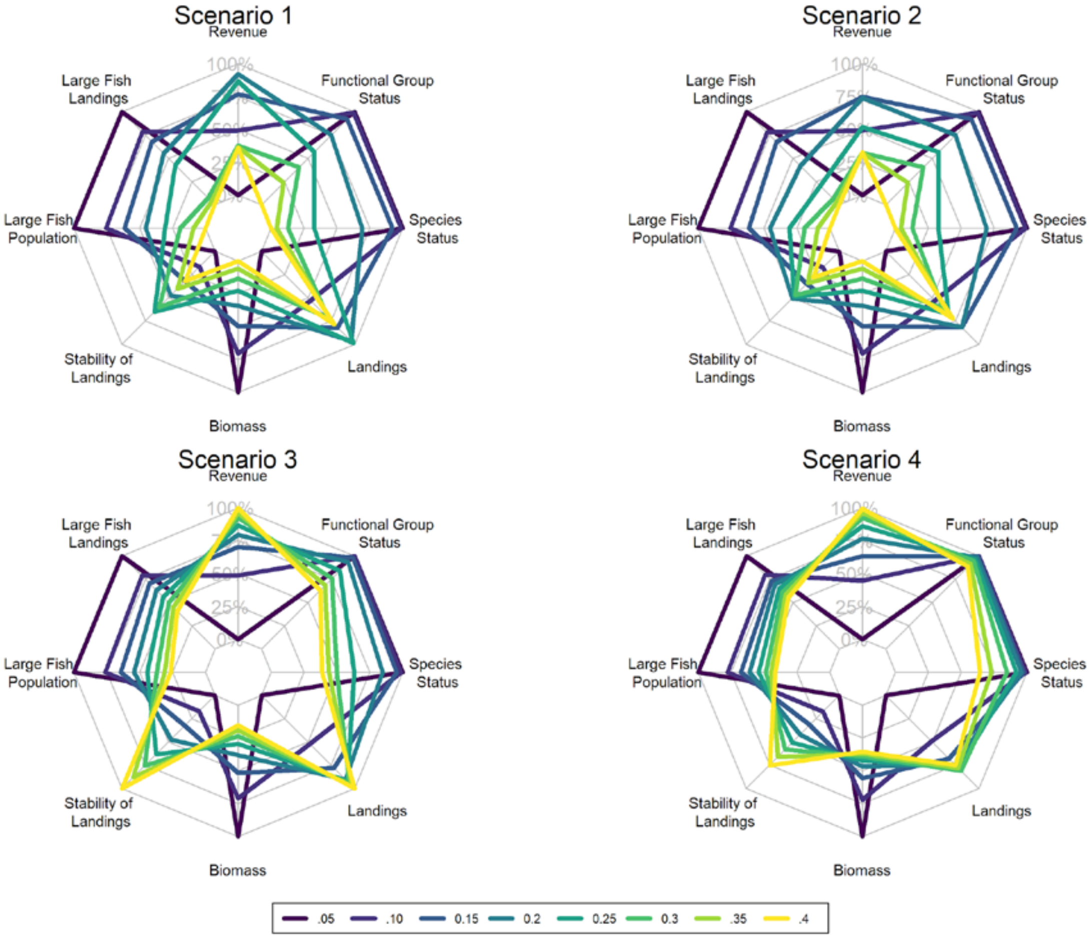

Figure 8. Radar plots depicting the performance of the 4 scenarios for 8 performance metrics for years 41-50 in the simulations. Performance metrics are each evaluated at eight levels of exploitation (represented by colored lines).

Comparison with Single-Species Management.

Under our current management system, different species are often assessed using different methods. In addition, different management strategies are applied to different species. Further, management strategies in the Northeast have changed over time. This makes it quite difficult to fully replicate what has happened in actual management practice in a simulation involving a comparison between current management and the species-complex approach. We have chosen to standardize the assessment methods and management strategies in our single-species simulations. We apply a standard fishery production model to simulated data for each species produced by our operating model. We then determine the fishing mortality rate that results in maximum sustainable yield (F_{msy}) for each species. For a target fishing mortality rate, we use 75% of F_{msy} as is currently used in groundfish management. We consider a species to be overfished if it is reduced below 20% of its unexploited level. At this point, landing that species is prohibited.

In these single-species simulations, fishing effort is exerted at a level intended to achieve 75% of F_{msy} for the focal species. This has consequences for all of the other species that are caught with this species. It affects whether their target fishing mortality rates can be met as required under current management strategies. For the purposes of our current example, we have examined the effects on the system when each of the species are considered to be the focal species. In practice of course, fishers may direct effort for different species during different fishing trips. For simplicity, we have not attempted to incorporate this consideration in our current simulations. It would require further information on how fishers decide which species to target under different circumstances.

Figure 9 shows the comparison of single species “management” with cod as the principal target species in relation to the four scenarios described in Table 1. We then compare the ratio of the landings under each of the four scenarios (the exploitation rate that produced the greatest return in yield under each scenario was selected) to the landings under the single species scenario. In all of the subpanel plots, a value of 1 indicates that the landings resulting from a fishing strategy targeting cod at its target fishing rate is equivalent to that of the species-complex approach. A value greater than 1 indicates that an increase in landings is achievable using one of the proposed species complex strategies. Figure 9 shows that for nearly all species an increase in landings is achievable (relative to the Atlantic cod target mortality rate) by adopting either scenario 3 or scenario 4.

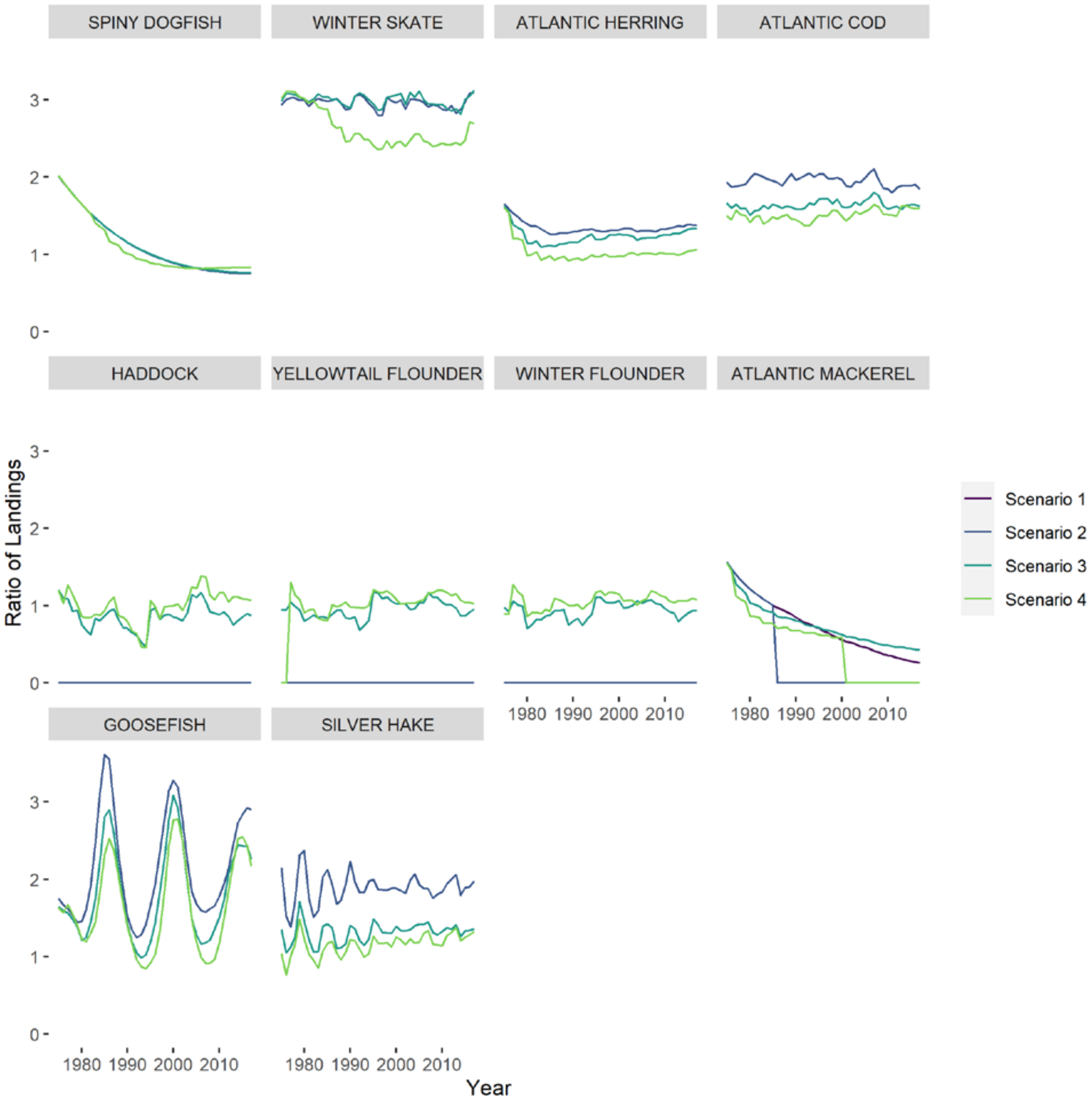

Figure 9. Ratio of landings (scenario:single species) when adopting a target mortality rate of 75% of F_{msy} for Atlantic cod

We find in examining these results in greater detail that, in general, the single species target fishing mortality rates are not met for all species simultaneously. It is of course these targets that we are accountable for under current management.