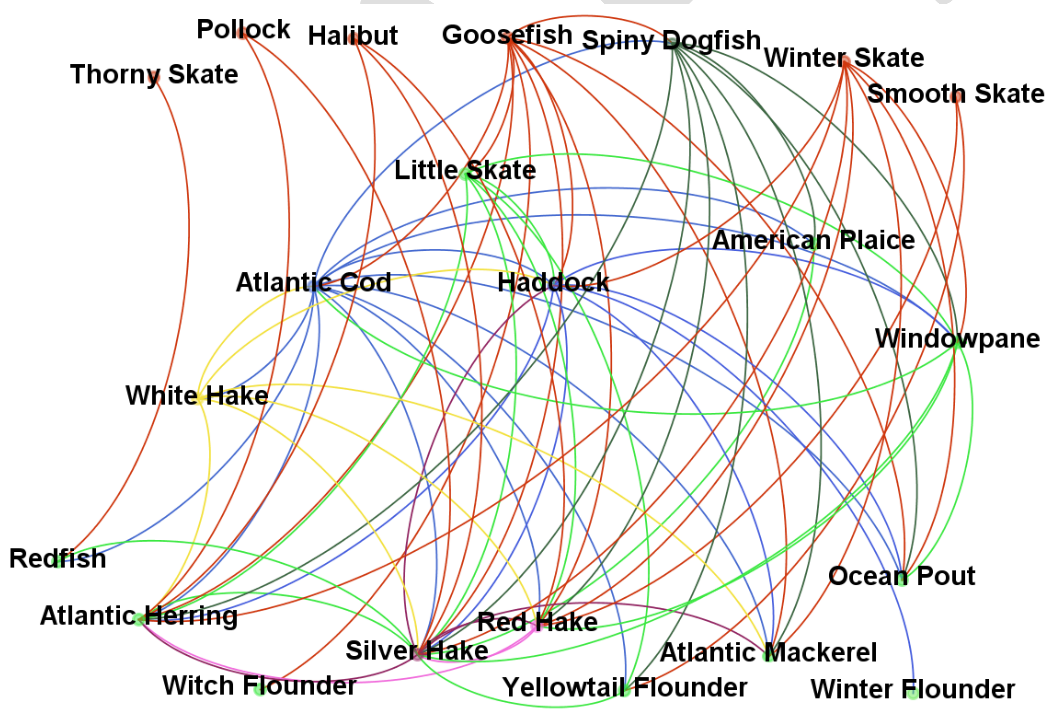
NEW ENGLAND FISHERY MANAGEMENT COUNCIL

Draft Example Fishery Ecosystem Plan for Georges Bank



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1.0 Executive Summary and Overview

This document describes a management approach, or operational framework, to conduct an evaluation of potential ecosystem management strategies using one or more operating models.

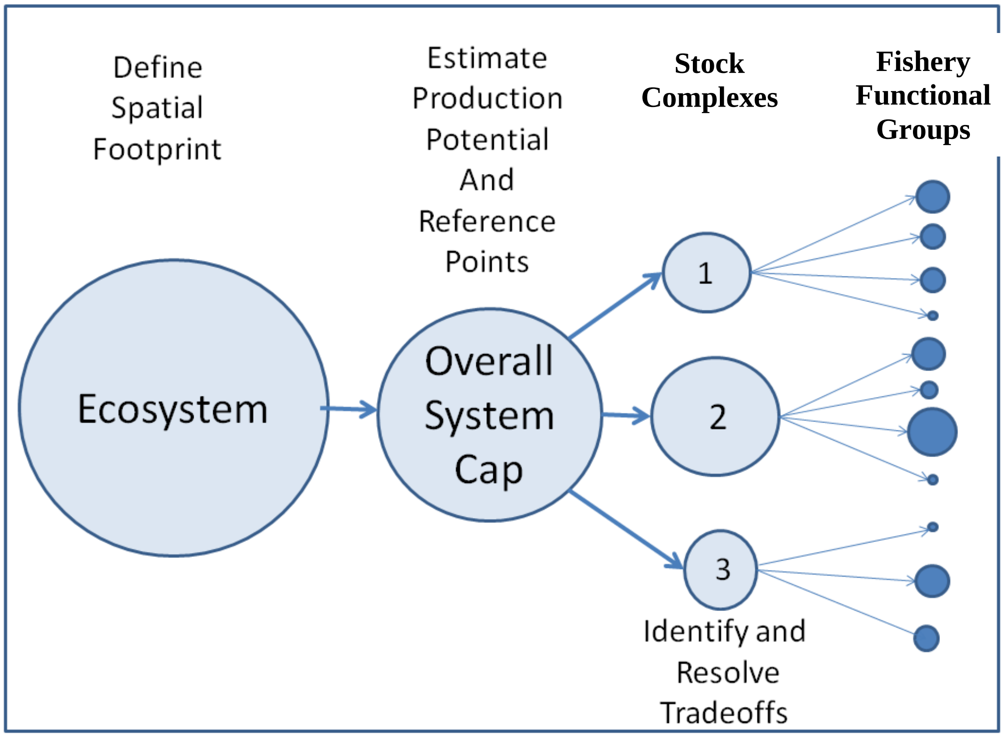
For purposes of further analysis and discussion, this document lays out a description of an analytical framework for a Fishery Ecosystem Plan for the Georges Bank Ecosystem Production Unit as a proof of concept. It provides core elements of a Fishery Ecosystem Plan to set the stage for full development of an FEP. Further guidance from the council with respect to its objectives for EBFM will be required to enter the next phase of FEP development. The approach is centered on developing management strategies for providing multispecies catch advice and explicitly testing those strategies on a simulated Georges Bank Ecosystem through a process of Management Strategy Evaluation (MSE). MSE comprises one or more operating models, candidate assessment methods, and potential management procedures for the system. Given a set of objectives defined by the NEFMC and interested parties and/or advisors, MSE can be used to compare the probable success of alternative management procedures. This document provides details about the systems, models, management process, and context/rationale for the development of an ecosystem plan. The document is intended to be a starting point for further discussion and performance analysis. It sets the stage for the process to be followed in the development of the FEP based on the principles noted above. To prepare for the start of this process, the PDT has assembled existing information on the Georges-Bank Fishery Ecosystem and has worked with one candidate operating model to conduct exploratory analyses. Changes and adjustments to the operating model and how catch advice under the FEP are generated is to be expected based on essential stakeholder engagement meetings that will start this process.

The overall approach is to assign species to Species Complexes using a combination of feeding guilds, technical interactions with fisheries and other ecosystem components, as well as biological characteristics. The strategy would employ an overall Ecosystem Production Unit (EPU) catch cap based on the estimated energetics of the system and observed primary productivity (Section 8.1). Catch limits by Species Complex would be allocated, but in aggregate should not exceed the EPU catch cap that would define overfishing (Section 8.2). Biomass 'floors' would be established to protect species from becoming unacceptably overfished or depleted (Section 8.2). These floors could be developed using survey information and could be based on a low percent of maximum stock size, considering the effect on risk and economic return.

The key elements of the approach described in this document include the objective specification of the spatial domain [Ecological Production Unit (EPU)] to be managed, the identification of Fishery Species Complexes defined by trophic interactions and co-occurrence in fishing gear within the EPU, and the critical role of management strategy evaluation in evaluating management options under consideration. It further requires the identification of Ecosystem Reference Points establishing limits and targets for management and methods for determining catch levels in an ecosystem context (See figure below)).

Consideration of energy flow and constraints on overall production in the system provide the foundation for the approach. Constraints related to patterns of energy flow and utilization and biological interactions within and between Fishery Species Complexes contributes to greater stability at higher levels of ecological organization.

Elements of the proposed hierarchical process for specifying Acceptable Biological Catch levels for species within defined Fishery Species Complexes.



Seventy-four species are commonly found in the Georges Bank EPU and have been assigned to Species Complexes (Section 4.3 and Table 5). In many cases, a catchability-adjusted swept-area biomass was estimated, but many species are also not well selected and sampled by trawl survey gear but are trophically related.

This document describes three operating models, or ecosystem simulations, that have been applied to Georges Bank species (Section 10.2.1). The Hydra model is well developed and has been parameterized to include 10 most common species. The Atlantis and Ecosym/Ecopath (EwE) models are also described. They are more comprehensive and complex but can potentially provide results for a broader range of objectives.

There are also several unfinished sections (Section 10.2.1, **Error! Reference source not found.**, and 10.0) toward the end of the document that focus on the process for using the operational models in this framework. They include a description of performance metrics and analysis including risk assessment, management strategy evaluation, and other related Fishery Ecosystem Plan (FEP) components.

Finally, Section 11.0includes a summary and description of the Georges Bank EPU. In total, this document describes an operating framework, but it is not the Fishery Ecosystem Plan itself. The latter would include additional features like strategic goals and objectives, as well as some broad management approaches that the PDT has begun developing. Much of this latter work raises questions when finished will help with the dialogue with and between fishermen, stakeholders, and managers.

1.1 Problem statement

Currently, the Councils manage mortality on individual stocks, with minimal regard to how they are caught together or have a primary predator/prey relationship. Stocks are managed to achieve an estimate of MSY for a stock, often with little regard of whether this is achievable for all stocks in a plan (much less between plans), what the expected benefits of achieving MSY are, or how the stock interacts with other related components of the ecosystem.

The sum of, and even on an individual basis, these MSY estimates may be considerably higher than that produced by the ecosystem and are thus unattainable. This eFEP to explore ways to seek to resolve these limitations, as well as address growing concerns about current single stock management approaches. It is expected that this document will provide a foundation for future regulatory mechanisms.

FMPs do not often address stakeholders that indirectly rely on the managed resources, fishery valued on the harvest side, but rarely considers benefits to other species and fisheries and businesses that rely on them.

To fish using a specific gear in an area, fishermen currently need to accrue a suite of permits or discard species for which they have no permits to land them. Many of these permits require qualification through a limited access program and are difficult or costly to obtain. Permitting, enforcement, and discarding can thus be economically expensive and inefficient. Also, low catch limits for depleted stocks can create a choke situation where either healthier stocks cannot be targeted without unacceptably high mortality on the choke species, yield is foregone for the healthy stocks, or the current management system imposes large economic costs on fishermen to lease or buy allocations and continue fishing. From the perspective of a fisherman, regulations are not streamlined and can be difficult to understand, much less stay in compliance with an array of regulations.

Furthermore, with rare exception, the stocks are managed individually by often separate FMPs with catch limits with little regard to anything but commercial and recreational fishing interests. With the exception of recent efforts to improve the Atlantic herring harvest control rule, providing adequate forage for fish, seabirds, and whales is generally not considered, except in the belief that independently derived MSY estimates for individual stocks will satisfy this ecological demand.

There are gaps in data and monitoring across the various FMPs that apply to Georges Bank species. Although the recently develop Ecosystem Monitoring Reports partially addresses the problem, there is not a routine ecosystem monitoring component that tracks the overall health of the ecosystem and the role that management of that species plays in it.

1.2 Vison statement

The NEFMC's vision is ecosystem-based fishery management that harmonizes ~~what is known, unknown, and unknowable about~~ fishery resources and ecosystems with realities of fishing operations and the law. Catches on Georges Bank would be managed by fishery and with consideration of a broader range of ecosystem objectives and considerations, "including trophic interactions between fished and un-fished species, and impacts on non-fishery elements including habitats and regional communities

As a result, the NEFMC expects that an FEP will:

- account for interactions between fishery resource species,
- promote sustainable, healthy ecosystems, including exploited and non- exploited species,

- achieve greater stability in fishery management and fishing opportunities,
- achieve more flexibility in fishing operations,
- strive to reduce the complexity of fishery management and regulations,
- strive to reduce discarding

1.3 Description of Key Features

Fishing within the Georges Bank EPU would be managed using a more dynamic and flexible approach. MSY for the EPU based on the sum of MSY for stock complexes and would limit overall EPU catch, subject to limits of primary productivity. Stock complexes would be defined as stocks that have similar trophic and life history characteristics, each having an MSY estimate that is more harmonious with the role of the species in the ecosystem. An example of a stock complex is flatfish that feed on the benthos (e.g. flounders and skates). Another example is piscivorous (fish eating) benthic roundfish (e.g. cod, pollock, monkfish, and silver hake).

Objectives would be identified that serve multiple needs, including production of economic value, sustenance of fishing communities, and support of fish, birds, sea turtles, and marine mammals at higher trophic levels. Some stock complexes could be limited at higher or lower mortality levels depending on the productivity of species in the complex and the needs of the ecosystem.

Reference points and harvest control rules would be developed for stock complexes, including accountability measures that apply at this level. The harvest control rule would define an Annual Catch Limit for the stock complex.

Protection against excessive depletion would apply as it is now as an overfished level for stocks, but the threshold would vary from existing values in consideration of the stock's vulnerability to fishing, resilience (i.e. speed of recovery), and the importance of its role in the ecosystem. If a stock is overfished, a rebuilding plan for the stock would be developed and include a carve-out for a sub-ACL applying to that stock alone and technical measures to limits its catch within the stock complex.

Catch limits would be allocated to functional groups, which are stock complexes caught together in a fishery (defined by gear and possibly area). These functional group catch limits would be equivalent to a sub-ACL with accountability measures that apply if and when the stock complex ACL is exceeded (and overfishing thus had occurred).

Vessels would be permitted on the basis of a fishery, instead of the species that it catches. For example, a vessel could be permitted in the large-mesh trawl fishery and would be allocated catches of functional groups that that fishery normally catches. With the single permit, it would be able to target and retain catches of large-mesh multispecies as well as monkfish, skates, and summer flounder. A vessel with a small-mesh trawl permit, for example, could target and retain catches of whiting, red hake, squid, butterfish, and herring.

Greater use of data sources and ecosystem monitoring would enable better management of the system as a whole and recognize changes in its characteristics due to environmental trends.

1.4 COMPONENTS

Scope – Draft Discussion Document 6

- Area description – Draft Discussion Document 2

- Fisheries

o E.G. Large-mesh trawl, small-mesh trawl, stand-up gillnet, tie-down gillnet, longline, hook and line, lobster trap, red crab trap, scallop dredge, clam dredge, other.

- Managed Stocks – all species managed by the NEFMC (MAFMC, ASMFC, NMFS?)

<u>Ecosystem MSY</u>

- MSY for the EPU is determined via the sum of the individual stock complexes. Total EPU catch cannot exceed this amount.

Biological Reference Points and Harvest Control Rules

- Stock complexes
  - o Maximum catch limits determined for groups of interrelated species (defined by similar diets and life histories)
  - o MSY for stock complexes is determined by assessment
  - o Special consideration for forage species and juvenile fish – Draft Discussion Document 10

- Assessment
  - o Multispecies assessment with interactions every three (?) years
  - o Single species benchmark assessments for overfished stocks

- Overfishing
  - o Level determined as the average mortality that would produce MSY for the stock complex, considering the appropriate catch composition to meet plan objectives

- Overfished stocks and Rebuilding – Draft Discussion Document 4
  - o Level for a stock determined from an evaluation of its
  - ☐ Vulnerability to fishing (i.e. how quickly biomass declines to excessive mortality),
  - ☐ Resilience (how quickly will a stock recover when biomass below the threshold), and
  - ☐ Role in the ecosystem (less risk allowed for species that play a key role, e.g. forage fish).
  - o Uses appropriate survey biomass indices and possibly standard commercial catch per unit effort data (lbs. per area swept) to make annual status determinations

<u>Fishing Access and Permitting – Draft Discussion Document 8</u>

- Instead of using a history of landing a specific species, limited access determined by a vessel having a permit to fish for a species that occurs on Georges Bank and has a history of fishing on Georges Bank with a specific gear type (trawl, gillnet, longline, hook and line, trap, clam dredge, scallop dredge, etc.).
- Inshore/offshore fisheries? Flatfish vs. roundfish trawls?
- Permits allow a vessel to use a specific gear type in a specific area (in this case the Georges Bank EPU)
- Vessels could have permits for one or more fisheries, but could not use a trawl permit to fish in a gillnet fishery, for example, but could possibly obtain such a permit from another vessel holding one (i.e. permit splitting is allowed).
- Community permit banking
- Catch sharing via sectors would be allowed, reducing the costs of exceeding a vessel's functional group catch allocation.
- Recreational fishing permits

  - o Limited access for charter/party boats?

<u>Catch Allotment/Allocation</u>

- Allocations made to permit holders in functional groups of species (i.e. a stock complex caught by gear type)
- A permitted vessel would receive an annual catch allocation of one or more functional groups that are caught by a Georges Bank fishery.
- Recreational catch allocations

<u>Spatial Management Measures for Habitat, Spawning, and Endangered/Threatened Species Protection – Draft Discussion Document 9</u>

- Improvements in productivity through better habitat quality and survival of juvenile fish

<u>Unmanaged and invasive species policies – Draft Discussion Document 12</u>

- Special policies, such as imported bait and closed area effects

<u>Technical measures</u>

- Size- and species-selective gear
- Mandatory retention of marketable species
- Area closures to reduce impacts on spawning, habitat, and/or endangered or threatened species
- Incentives to fish in low-impact, selective fisheries
- Measures to prevent excessive targeting of highest value and/or vulnerable species

<u>Jurisdiction, Cooperation, and Collaboration – Draft Discussion Document 7</u>

- Georges Bank EPU allocations consistent with FMP goals and objectives, not to exceed the EPU MSY limit or the constraints set by plans managed by other authorities
- Procedures for joint or cooperative management of fishing within the EPU.

<u>Advisory Teams</u>

- Individuals with interest in a Georges Bank EPU fishery

<u>Data collection, monitoring, and fishery research – Draft Discussion Document 5</u>

- Gaps in mandatory data collection
- New ecological data
- Electronic monitoring
- Research set-aside (RSA) program – a portion of allowable catch limit is reserved for supporting management-related research

<u>Decision support</u>

<u>Integrated Ecosystem Assessment</u>

- A broad summary of trends in various biological, oceanographic, economic, and social indicators.

<u>Ecosystem Risk Assessment</u>

- Expert opinion indicated the level and immediacy of risk factors that can affect the ecosystem and how well management will achieve its objectives.

<u>Management strategy evaluation (MSE) – Draft Discussion Document 11</u>

- Pre-plan development – objectives evaluation and models
- Simulation and evaluation of management via operating models – Draft Discussion Document 3

- Post plan – standard process for plan amendments

<u>Transition strategy to place-based FEP</u>

- How and when do new changes occur?
- Gradual phase ins?
- Functional group catch allocations for NEFMC managed species as well as unmanaged stocks initially and later applies to all managed stocks?

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3.0 Introduction

The need to adopt a more holistic view of human impacts on and benefits derived from the marine environment is now widely recognized. Global initiatives are now underway to implement integrated management strategies for ocean resource management recognizing the complexity of these systems, the role of humans as part of the ecosystem, and attempts to formulate strategies for sustainable use of natural resources in response to the cumulative effects of multiple stressors in the marine environment. Sectoral management issues, including fisheries management, fall under the broad remit of Ecosystem-Based Management. NOAA Fisheries has recently issued a policy statement defining Ecosystem-Based Fisheries Management (EBFM) as 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'*

and an ecosystem is defined as:

> *'a geographically specified system of fishery resources, the persons that participate in that system, the environment, and the environmental processes that control that ecosystem's dynamics. (c.f. Murawski and Matlock, 2006, NMFS-F/SPO-74). Fishermen and fishing communities are therefore understood to be included in the definition'.*

The above statement emphasizes that EBFM is inherently place-based, identifies the need to consider the interaction among system components in management and highlights the ways in which human communities both influence and are affected by changes in the ecosystem. Because the properties of an ecosystem are different from those of its parts, EBFM will necessarily differ from traditional single species approaches while maintaining some elements of more traditional management structures and tactical tools.

Consideration of ecosystem-level approaches to fishery management has a long history in the Northeast US. The fundamental difficulties inherent in managing multispecies fisheries in the region were identified by McHugh (1959) who called for management '*en masse*', effectively advocating management of species assemblages in the aggregate rather than of individual stocks. Edwards (1968) developed estimates of total fish biomass and productivity for the Northeast U.S. continental shelf and Brown and Brennan (1972) and Brown et al. (1976) subsequently developed estimates of maximum sustainable yield for the fish species complex of the northeast shelf as a whole. Implementation of the 'Two-Tier' quota management system in this area by the International Commission for Northwest Atlantic Fisheries in 1973, incorporating an upper constraint (second tier) on total removals (reflecting overall levels of system productivity) and individual species-level constraints (first tier) followed as a direct result (Edwards 1975; Hennemuth and Rockwell 1987). Current discussion of the adoption of holistic approaches to fisheries management on the Northeast continental shelf is therefore firmly grounded in historical precedent.

The Scientific and Statistical Committee (SSC) of the New England Fisheries Management Council (NEFMC) developed a strategy document considering issues and potential pathways for implementing EBFM (NEFMC 2010) in the Northeast US. The SSC noted that a transition to EBFM offered opportunities for:

- The potential for simplification of management structures with associated cost savings in ultimately moving from a large number of species/stock-based management plans to a smaller number of integrated plans for ecological units defined by location.
- More realistic consideration of the effects of both fishery interactions (e.g. bycatch in different fleet sectors) and biological interactions (e.g. consideration of predator-prey interactions) within ecological units, including consideration of effects on biodiversity.
- Direct consideration of environmental/climate-related change, its effect on productivity and biological reference points.
- Consideration of the ecosystem constraints on simultaneous rebuilding of stocks to long-term target levels and evaluation of whether or not stock – specific recovery plans are compatible.
- More effective coordination among management actions taken for fishery management and protected resources (i.e., species protected under the Endangered Species Act or Marine Mammal Protection Act).

Currently the New England Fishery Management Council administers nine fishery management plans. Of these, six are single-species plans and the remaining three include consideration of multiple species bundled within overarching management plans (although interactions among the species are not currently directly considered in these plans). The Northeast Multispecies Groundfish plan covers 13 species (and a total of 20 stocks) while the Small Mesh Fishery Management Plan includes three hake species. The Skate Fishery Management Plan covers seven species. Adopting a spatial management strategy would substantially consolidate the number of individual fishery management plans administered by the council and would facilitate consideration of important interactions among species and fisheries now under separate management plans. To the extent that factors such as biological and technical interactions and climate effects are important but not directly taken into account in current management, such as whether simultaneous rebuilding of stocks and the choice of long term target levels, will remain in question. Adoption of EBFM would allow these issues to be addressed within an integrated framework.

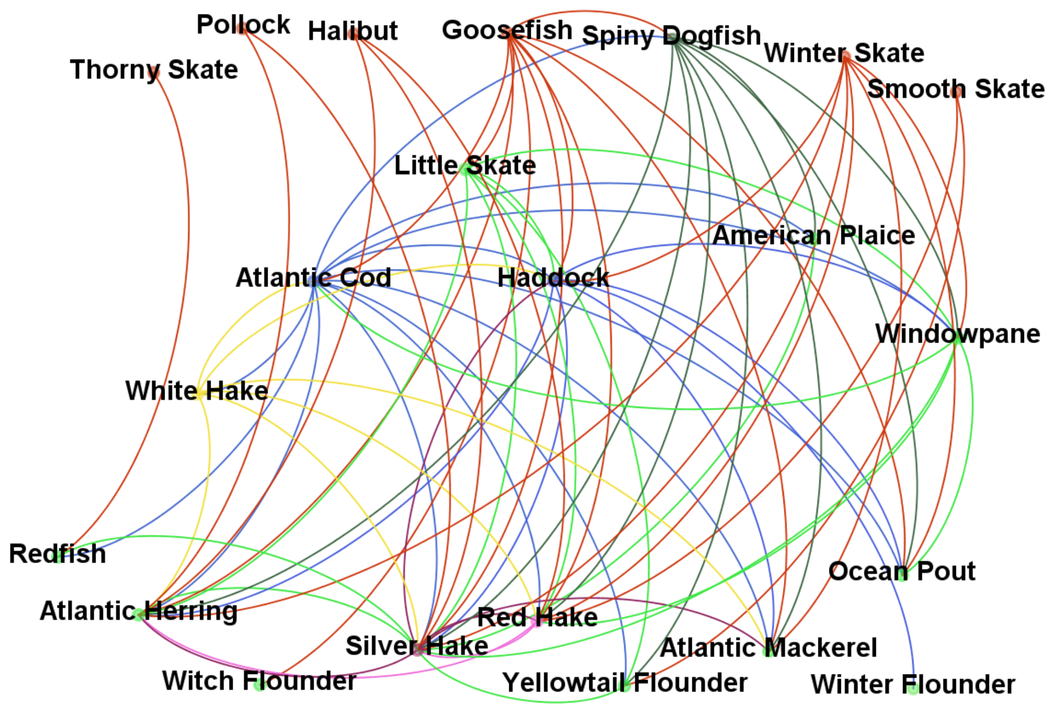
The unique challenges associated with managing mixed- species fisheries has been recognized by the NEFMC from its inception. To address these concerns and to formulate management strategies directed specifically at the mixed- species problem, the Northeast Fishery Management Task force was convened in 1979. The Task Force explicitly identified the limitations of attempting to apply single-species management strategies to stock complexes comprising interacting species:

- "*In view of the dynamic interactions in nature, a single-species approach to management is inadequate, particularly for multispecies fisheries, or fisheries where the by-catch is significant.*

- *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, However, to be practical, management must recognize the social fact that some species are more desirable than others, and in some measure direct the fisheries to certain species. This suggests a multispecies scheme of management: 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)*

These difficulties have played out in the course of groundfish management in the Northeast over the last several decades, leading to a seemingly intractable problem (Apollonio and Dykstra 2008). Of the stocks managed by NEFMC, fourteen are currently classified as being overfished. Of these, twelve fall under the Northeast Multispecies Groundfish Management Plan. The dominance of complex mixed-species fisheries involving stocks connected by both biological interactions (notably predation and competition) and technical interactions resulting in by-catch of targeted and untargeted species, plays a central role in the difficulties in establishing effective management strategies in this region (Apollonio and Dykstra 2008) . The nature of the problem is highlighted in Figure 1.1 in which NEFMC managed species connected by predator prey interactions are shown.

Figure 1. NEFMC managed species connected by predator-prey interactions based on Northeast Fisheries Science Center diet composition studies (see Smith and Link 2010 for a summary of methods and results). Connections between predators (red node) and their prey (green nodes) are shown for species pairs in which any predation interactions were recorded.



Potential competitive and by-catch interactions further contribute to the highly inter-connected nature of this fishery system and to the inherent difficulties in managing the fish assemblages found in New England mixed species fisheries using traditional single species approaches. A principal motivation for exploring alternative management strategies based on ecosystem principles, and multispecies approaches in particular is rooted in the complexity of these mixed-species fisheries.

The Council has tasked its EBFM Plan Development Team with developing

> *"An example of a fishery ecosystem plan that is based on fundamental properties of the ecosystem (e.g., energy flow and predator/prey interactions) as well as being realistic enough and with enough specification such that it could be implemented. The example should not be unduly constrained by current perceptions about legal restrictions or policies"*

In this document, we attempt to address this mandate. We explore options for an evolutionary development of the existing multispecies and single species management plans to encompass explicit consideration of interspecific interactions, by-catch, and environmental/climate change. We build on the existing structures and formalize the adoption of a systems approach to management of the resources under the jurisdiction of the council.

For purposes of further analysis and discussion, this document lays out a description of an operational framework for a Fishery Ecosystem Plan for the Georges Bank Ecosystem Production Unit as a proof of concept. It is intended to lay out the analytical underpinnings of a Fishery Ecosystem Plan. this region. The approach is centered on developing management strategies for providing multispecies catch advice and explicitly testing those strategies on a simulated Georges Bank Ecosystem through a process of Management Strategy Evaluation (MSE). MSE comprises one or more operating models, candidate assessment methods, and potential management procedures for the system. Given a set of objectives defined by the NEFMC and interested parties and/or advisors, MSE can be used to compare the probable success of alternative management procedures. This document provides details about the systems, models, management process, and context/rationale for the development of an ecosystem plan. The document is intended to be a starting point for further discussion and performance analysis. It is intended to set the stage for the process to be followed in the development of the FEP based on the principles noted above. To prepare for the start of this process, the PDT has assembled existing information on the Georges-Bank Fishery Ecosystem and has worked with one candidate operating model to conduct exploratory analyses. Changes and adjustments to the operating model and how catch advice under the FEP are generated is to be expected based on stakeholder engagement meetings that will start this process.

The core components for the operational framework are a set of strategic objectives defined by managers and interested parties, coupled with a set of ecosystem and multispecies assessment models that provide tactical advice under a hierarchical management approach. A linked management strategy includes the process for setting and adjusting catch limits based on the assessment model outputs that are intended to meet the ecosystem objectives. To test potential management procedures prior to implementing them in reality, MSE is proposed. The MSE contains a feedback loop from the management actions through to fishing a simulated Georges Bank ecosystem (such as occurs in reality). The simulated Georges Bank ecosystem is called the operating model. The MSE, thus, provides a test bed for adjusting the parameters of the management tools to quantify tradeoffs among the objectives with the goal of determining which management procedures and tools provide robust outcomes across uncertainty and objectives.

4.0 Vision Statement

The NEFMC's vision is ecosystem-based fishery management that harmonizes what is known, unknown, and unknowable about fishery resources and ecosystems with realities of fishing operations, and the law. Catches on Georges Bank would be managed by fishery and with consideration of a broader range of ecosystem objectives and considerations, "including trophic interactions between fished and un-fished species , and impacts on non-fishery elements including habitats and regional communities

As a result, the NEFMC expects:

- take account of interactions between fishery resource species,
- healthy ecosystems, including exploited and non- exploited species,
- greater stability in fishery management and fishing opportunities,
- more flexibility in fishing operations,
- less complex fishery management,
- reduced discarding

5.0 Goals and objectives

5.1 Goals – measurable or desirable outcomes

5.1.1 Overarching Goal

To protect the ecological integrity of US marine resources as a sustainable source of wealth and well-being for current and future generations (Goal A)

5.1.2 Strategic Goals (Derived from Magnuson definition of OY as in Risk Policy Document):

1. Optimize Food Provision through targeted fishing and fishing for species for bait
2. Optimize Employment
3. Optimize Recreational Opportunity
4. Maintain a healthy and balanced ecosystem
5. Optimize Profitability
6. Promote stability in both the biological and social systems

5.1.3 Objectives - General description of how the FEP is designed to achieve goals

5.1.3.1 Strategic Objectives

1. Manage fisheries and their catches together, rather than as individual stocks

2. Account for total benefits and balance tradeoffs, including economic returns, value to fishing communities, and the needs of a healthy ecosystem.

3. Reduce permitting and compliance costs.

4. Minimize discarding and economic waste (including the value of discarded fish, unnecessary steaming and gear costs, enforcement costs, sub-par catch allocations that don't meet overall objectives)

5. Promote and improve the sustainability of fishing communities as well as a diversity of fisheries and vessel classes.

5.1.3.2 Operational Objectives (SMART: Specific, Measurable, Achievable, Relevant, Time-bound)

- Establish overfishing levels based on MSY for the ecosystem, allocated to stock complexes of related species.
- Through Management Strategy Evaluation, develop valuation methods to analyze and balance tradeoffs in setting harvest control rules.
- Develop harvest control rules and associated assessment capabilities that account for trophic relationships.
- Develop flexible harvest control rules that account for changes in the environment and ecosystem.
- Protect stocks from depletion by promoting fishing for resilient and healthy species while discouraging targeting of vulnerable and depleted stocks.
- Develop a permitting system that is consistent with modes of fishing with a gear type in a specified area and stock complex catch limits with fishery functional group allocations to identified fisheries, instead of permits to fish for and retain specific species of fish.
- Allocate catch limits associated with stock complexes to fishery functional groups associated with identified fisheries

6.0 Overview of FEP framework

In the following sections, one potential strategy is described for defining and implementing a holistic approach to EBFM for the Northeast continental shelf. Guiding principles in approaching this problem include:

a. the desirability of striving for simplicity,
b. the importance of building on advances made in current management and analysis, particularly in establishing safeguards for exploited species,
c. the value of capitalizing on emergent ecosystem properties
d. the need to identify transparent adaptive management strategies, and
e. recognition of the need to confront the issue of tradeoffs among potentially competing objectives.

Building on these principles, we address the need to:

- Define clear objectives for the management program
- Identify spatial management units
- Determine constraints on system productivity conditioned on environmental states
- Select a ceiling for sustainable ecosystem exploitation rate
- Devise an allocation strategy for species-specific catches

- Decide on the mix of management tools to be employed to achieve objectives
- Apply formal strategies of decision theory to confront tradeoffs.

This Fishery Ecosystem Plan (FEP) framework will consider the management of living marine resources within ecological production units in an integrated, systemic fashion, providing a holistic perspective but at the same time providing flexibility for addressing societal objectives within biodiversity constraints provided by overfishing and overfished criteria central to legislation. A key element of the plan is to directly confront the difficulties that emerge in non-selective mixed species fisheries, making management of the multispecies groundfish fishery particularly problematic. The approach outlined below further seeks to simplify management by taking advantage of emergent properties of the fishery system resulting in greater stability and resilience of the whole relative to the parts. Central to the overall approach is the need to consider the fishery as an integrated social-ecological system and not a collection of parts. The ecological considerations underlying the approach focus on constraints related to patterns of energy flow and utilization. Emergent properties at higher levels of ecological organization (species complexes, communities) that provide a focal point in this strategy are suggested to be a direct result of energetic constraints in the system.

7.0 Scope

The objective identification of spatial management units is a critical pre-requisite for the development of Ecosystem-based Fishery Management. In this section, we describe previous designations of spatial boundaries of Ecological Production Units (EPUs) on the Northeast U.S. Continental Shelf based on physiography, hydrography, and production at the base of the food web. We then provide information on the spatial distribution of several ecosystem components including marine mammals, sea turtle, seabirds, fish, and benthic invertebrates in relation to the EPUs. To explore how fishers see the ecosystem as reflected in fishing patterns, we map fishing activities defined in relation to the species composition of the catch in relation to the EPU boundaries.

7.1 Ecological Production Units

Geographically-defined ecological units have previously been proposed for the Northeast Continental Shelf from Cape Hatteras to the Gulf of Maine. The region in its entirety has been designated as a Large Marine Ecosystem (LME) on the basis of bathymetry, productivity, population structure and fishery characteristics (Sherman and Alexander 1986). Longhurst (1998) identified three subdivisions of his Northwest Atlantic Shelves Province falling within the Northeast Shelf (NES) LME: *(1) Gulf of Maine and Bay of Fundy, (2) Shelf from Georges Bank to Long Island, and (3) Middle Atlantic Bight*. Subareas of the NES LME have also previously been defined for the Northeast Shelf for fishery assessment purposes. Clark and Brown (1977) considered a four-unit subdivision of the NES LME within U.S. waters including *(1) Gulf of Maine (2) Georges Bank (3) Southern New England and (4) Middle Atlantic* regions. Very few stock assessments include as many as four stock units and the vast majority (over 80%) comprise a single stock unit representing the observed area of occurrence of each stock species within the Northeast Shelf region. To meet a broader set of management mandates, the Northeast Regional Action Plan (Higgens et al. 1985) delineated six Water Management Units within the Northeastern United States: (1) *Coastal Gulf of Maine*, (2) *Gulf of Maine*, (3) *Georges Bank west to Block Channel*, (4) *Coastal Middle Atlantic, (5) Middle Atlantic Shelf* and (6) *Offshelf*.

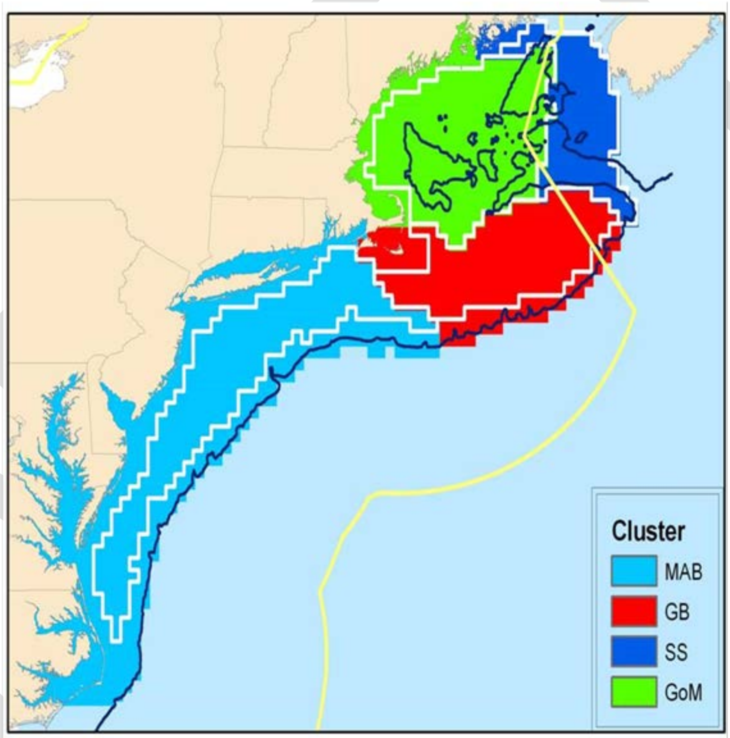
Fogarty et al. (2012; in prep.) defined Ecological Production Units on the Northeast U.S. continental shelf based on: (1) bathymetry, (2) bottom sediments, (3) satellite-derived estimates of sea surface temperature and annual temperature span , (4) ship-board estimates of surface and bottom temperature and salinity in spring and autumn based on Northeast Fisheries Science Center research vessel surveys, (5) satellite-derived estimates of chlorophyll concentration and primary production and (6) satellite-derived estimates of sea surface temperature and chlorophyll gradients to identify frontal zone positions.   Seven major production units were identified based on a cluster analysis of the physiographic, oceanographic and basal trophic level variables. The production units included: (1) Eastern Gulf of Maine- Scotian Shelf, (2) Western-Central Gulf of Maine (3) Inshore Gulf of Maine, (4) Georges Bank-Nantucket Shoals (5) Intermediate Mid-Atlantic Bight (6) Inshore Mid-Atlantic Bight and (7) Continental Slope (Cape Hatteras to Georges Bank). These spatial units are considered to be open and interconnected, reflecting oceanographic exchange and species movement and migratory pathways.   These boundaries are remarkably consistent with the sub-regions of the shelf proposed by Higgens et al. (1985) based on qualitative measures and expert opinion in the development of their ocean management areas.

Fogarty et al. (2012; in prep) proposed further consolidation of some ecological subareas to reflect movement patterns of exploited species from both the shelf-break region and the immediate nearshore regions to the adjacent shelf areas. The shelf-break regions are considered special zones associated with the adjacent shelf regions. The option for special management considerations to be implemented in both nearshore and shelfbreak areas to reflect the distribution of ecologically sensitive species, areas of high biomass and species richness, and/or the confluence of multiple human use patterns in nearshore regions is also considered. Following this approach, four major ecological zones (Figure 2) including:

1. the Western-Central Gulf of Maine,
2. the Eastern Gulf of Maine-Scotian Shelf,
3. Georges Bank-Nantucket Shoals, and
4. the Mid-Atlantic Bight

For the purposes of this representation, we have included estuaries and embayments with the nearshore regions but note that it may be desirable to identify these areas separately in the overall spatial structure.

Figure 2. Proposed ecological subunits of the Northeast Continental Shelf including (1) Western-Central Gulf of Maine (GoM) (2) Eastern Gulf of Maine-Scotian Shelf (SS), (3) Georges Bank-Nantucket Shoals (GB) and (4) Middle-Atlantic Bight (MAB). White lines indicate boundaries between areas, including the designation of special areas at the edge of the continental shelf and in the immediate nearshore areas of the Middle-Atlantic Bight and the Gulf of Maine.



7.2 Georges Bank Fisheries

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7.3 Fishing Patterns in Relation to the Georges Bank Ecological Production Unit

Lucey and Fogarty (2010) defined operational fisheries for fishers operating out of New England ports on the basis of species catch compositions in space and time in relation to Ecological Production Unit boundaries. Analyses were conducted separately for six gear types (otter trawl; dredges, pots; longlines, gillnets, and seines. Each gear category was further divided by vessel size. Small vessels were designated as those with a gross registered tonnage less than or equal to 150 tons, while large vessels were designated as those with a gross registered tonnage of greater than 150 tons. Murawski et al. (1983) had earlier delineated a total of 29 operational fisheries for the otter trawl fleet of New England which were then consolidated into 9 major operational trawl fisheries. Lucey and Fogarty (2010) defined a total of 36 operational fisheries for vessels originating in New England ports and operating on the Northeast US Continental Shelf. Of these, ten were found to have a substantial presence on Georges Bank (although none were limited to the confines of the Georges Bank EPU. Three otter trawl fisheries operating on Georges Bank from New England ports differed principally with respect to the relative mix of groundfish species targeted and their spatial location on the bank (Otter trawl operational fisheries 1,5, and 8; see Table 1 and Figure 3). One of these otter trawl fisheries also landed lobster (otter trawl fishery 1) and trawl fishery 8 also landed short fin squid (*Illex*). Of three identifiable longline operational fisheries, each targeted cod and haddock in different proportions while one (longline operational fishery 2) also landed pollock and spiny dogfish (Table 1). The spatial footprint of these three longline fisheries is shown in Figure 4. Pot fisheries on Georges Bank focused on lobster (pot fishery 1; Figure 5), lobster and Jonah Crab (pot fishery 2), and red crab (pot fishery 3). The latter operated exclusively on the shelf break (Figure 5). Finally, the sea scallop dredge fishery was broadly distributed throughout the Mid-Atlantic region and onto Georges Bank (Figure 6).

Table 1. Proportional species contribution to the identification of operational otter trawl, longline, pot and dredge fisheries encompassing Georges Bank. Black boxes represent a large contribution (>20%), grey boxes represent a medium contribution (~5-20%), light grey boxes represent a medium contribution (~1-5%).

Operational Fishery	**Otter Trawl**			**Longline**			**Pot**			**Dredge**
	1	5	8	1	2	3	1	2	4	1
Atlantic Cod	Grey	Light grey		Black	Black	Grey				
Haddock	Black	Light grey		Grey	Black	Black				
Pollock	Light grey				Grey					
Silver Hake			Light grey							
Monkfish	Light grey	Light grey								Light grey
Winter Flounder	Grey	Grey								
American Plaice	Light grey									
Witch Flounder	Light grey									
Summer Flounder		Light grey	Light grey							
Yellowtail Flounder	Light grey	Grey								
Skate	Light grey	Black								
Spiny Dogfish					Light grey					
American Lobster	Light grey						Black	Black		
Jonah Crab								Grey		
Red Crab									Black	

Loligo			■							
Sea Scallop										■

Figure 3. Operational Otter Trawl fisheries encompassing part or all of Georges Bank: (a) Operational Trawl Fishery 1; (b) Operational Trawl Fishery 5; (c) Operational Trawl Fishery 8. For further information on these designated operational fisheries, see Lucey and Fogarty (2010) and Table 4.1 for dominant species in the catch of each operational fishery.

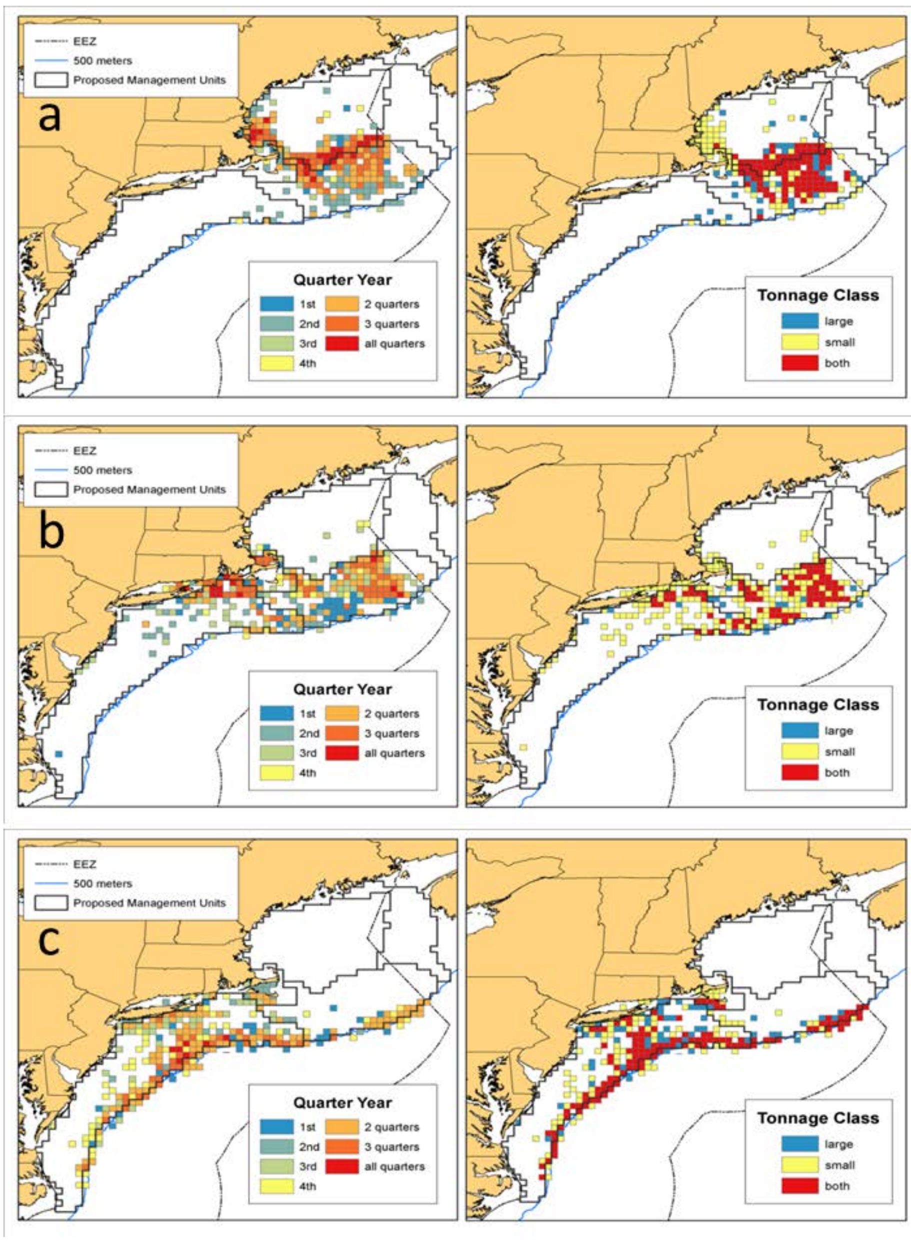


Figure 4. Operational Longline fisheries encompassing Georges Bank: (a) Operational Longline Fishery 1; (b) Operational Longline Fishery 2; (c) Operational Longline Fishery 3. For further information on these designated operational fisheries, see Lucey and Fogarty (2010) and Table 3.1 for dominant species in the catch of each operational fishery.

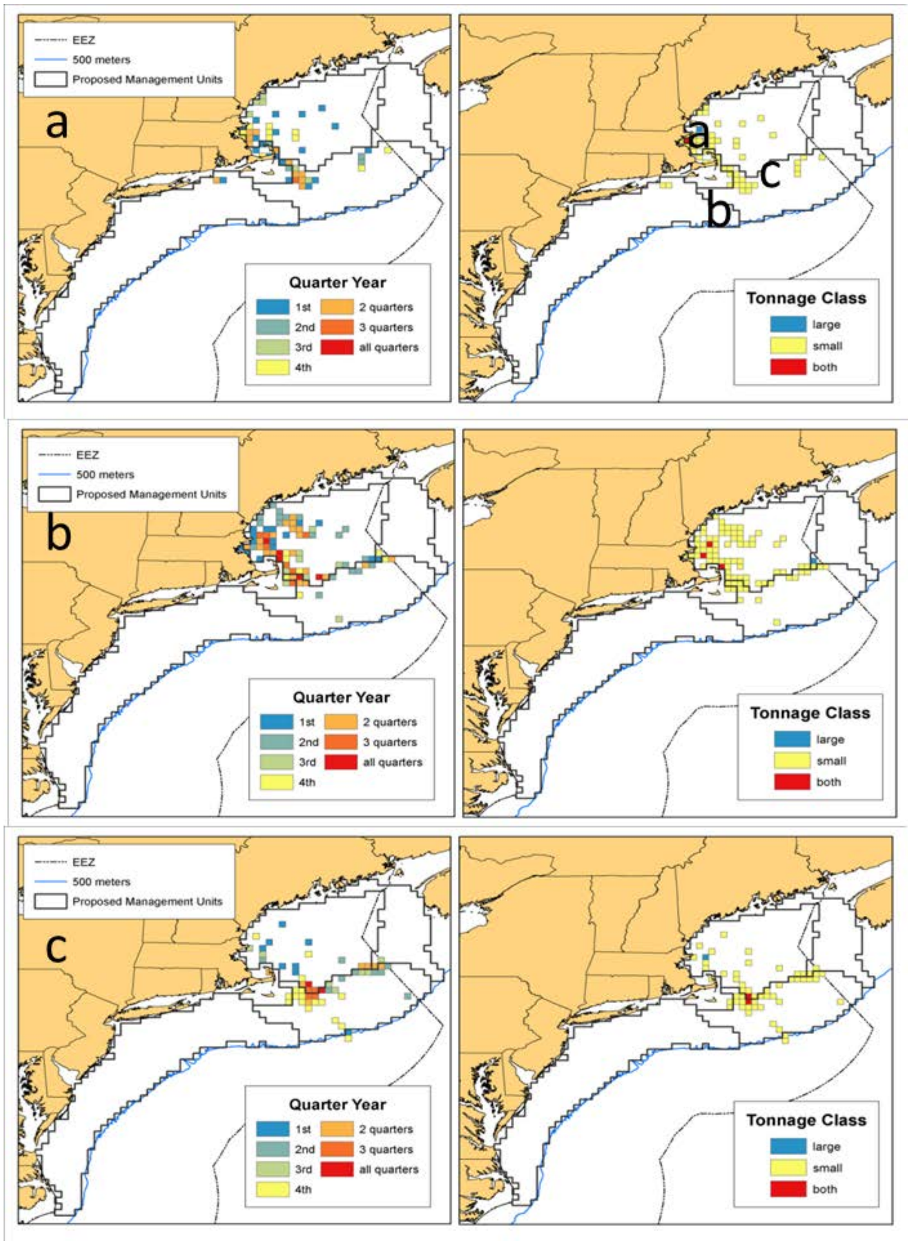


Figure 5. Operational Pot fisheries encompassing Georges Bank: (a) Operational Pot Fishery 1; (b) Operational Pot Fishery 2; (c) Operational Pot Fishery 4. For further information on these designated operational fisheries, see Lucey and Fogarty (2010) and Table 4.1 for dominant species in the catch of each operational fishery.

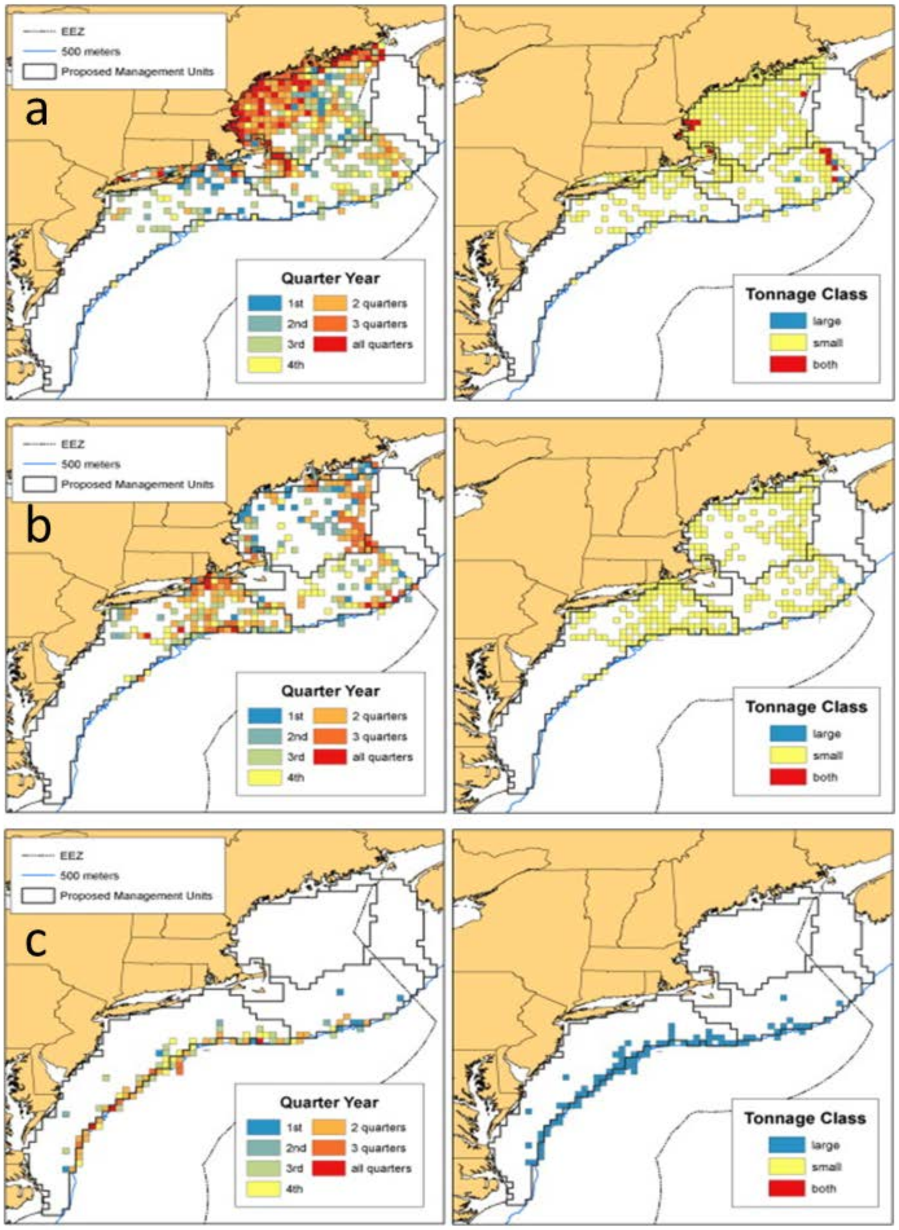
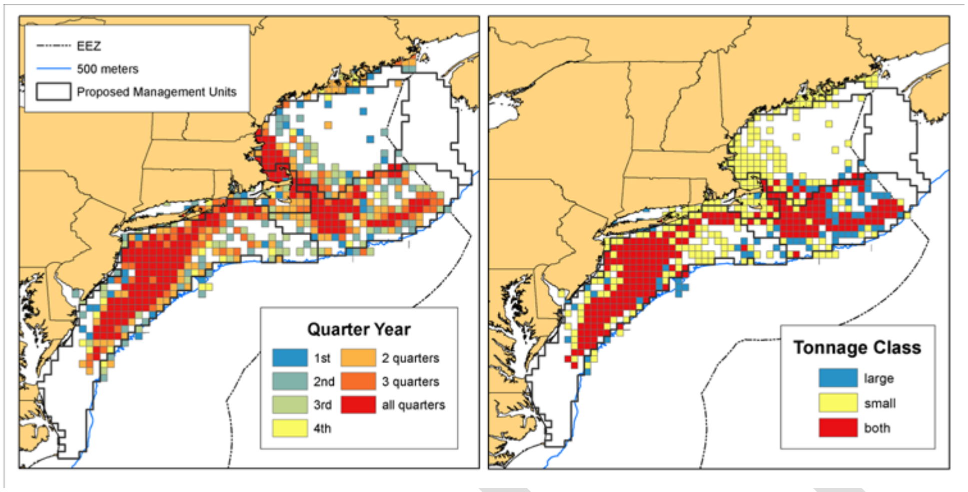


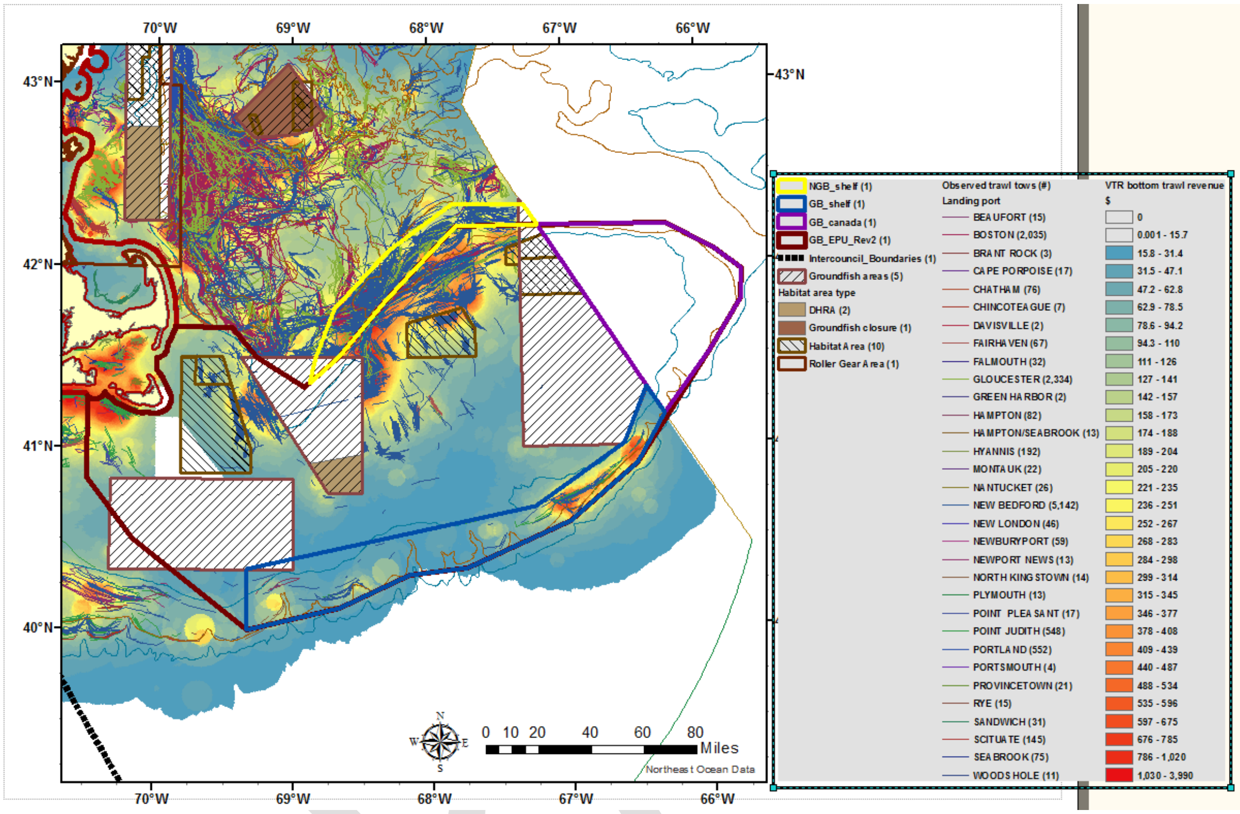
Figure 6. Operational Dredge Fishery 1 encompassing Georges Bank. For further information on these designated operational fisheries, see Lucey and Fogarty (2010) and Table 4.1 for dominant species in the catch of each operational fishery.



For the purposes of defining management units, the boundaries of a Georges Bank EPU can be defined on the basis of both biological (distribution of invertebrates, fish, marine mammals, sea turtles, and seabirds), physical (depth, bottom substrate, and temperature or water masses and circulation), and fishing activity. Ideally, the boundaries for the EPU should encompass the key components of the system and avoid cutting through areas of heavy biological and/or fishing activity.

The following analysis of observed and reported fishing distribution, fish distribution, and other species distributions suggests a Georges Bank EPU boundary shown in Figure 4.6. Areas in deep water along the shelf adjacent to the northern and southern edges of Georges Bank could be part of the Georges Bank EPU, but may require special management because the mix of fisheries and species overlap those on the shallower portions of the bank, but there are some important distinctions.

Figure 7. Potential Georges Bank EPU boundaries including special shelf, deeper water management areas north (yellow) and south (blue) of Georges Bank and Canada (purple). The data include observed bottom trawl commercial tows (2009, 2014) by port of landing and interpolated distribution of bottom trawl commercial landings revenue (2014).



7.4 Management Unit (or subunits) (MU)

A description of spatial boundaries and fisheries with allocated catch allocations and specific technical measures to regulate fisheries that occur there. Ideally, the boundaries chosen would be defined by a commonality among fisheries occurring within the MU, rather than on a species stock definition. A single management unit would not cross EPU boundaries.

7.5 Fishery Species Complexes

Coping with complexity is a central consideration in any attempt to implement operational EBFM. We began this document by noting that one of the underlying causes of the difficulties in effectively managing mixed-species fishery resources in the Northeast may reside in the complexity of the system related to biological and technical interactions among managed species and our inability to exert exact control of fishing mortality in mixed- species fisheries. The ubiquity of tradeoffs that often remain unresolved in conventional single species approaches contributes to the difficulty in developing effective management strategies. In many instances, management targets derived from a single species perspective in which species are treated in isolation work at cross purposes when applied to assemblages of interacting species. One possible avenue for addressing these intertwined issues is to ask whether management actions directed at higher levels of ecological organization may offer a viable alternative approach to management of mixed-species fisheries.

Here, we identify Fishery Species Complexes as possible focal points for management. Species Complexes are defined with respect to the role played by species within an ecosystem. Our interest centers on Fishery Ecosystems defined as coupled social-ecological systems. For our purposes, a Fishery Species Complex is defined as species that are caught together, share common life history characteristics, and play similar roles in the ecosystem with respect to energy transfer. Because the species are caught together, they typically share similar habitat use patterns and, often, size characteristics. Accordingly, the concept encapsulates information on the catch characteristics and targeting practices of different fleet sectors and trophic guild structure.[1]

There is in fact a rich history of applying various forms of species aggregation in the assessment and management of fishery resources to address these concerns. One of the earliest applications of this approach was in fact on the Northeast U.S. Continental Shelf. Under the International Council for Northwest Atlantic Fisheries, a so-called two-tiered management system was implemented in 1973. Building on the development of an aggregate production model for all finfish species in the region, an estimate of total maximum sustainable yield for the Northeast Shelf was made and used to determine a proposed limit to the total removals from the system. A subsequent 'second-tier' analysis was undertaken to determine catch levels for each species to be allocated to national fleets engaged in the fishery such that the total limit would not be exceeded. Further analyses examining the dynamics of Species Complexes on Georges Bank were undertaken by Fogarty and Brodziak (1992), Collie and DeLong (1999) and Bell et al. (2014).

We re-examined the issue of defining Species Complexes for Georges Bank. Fogarty and Brodziak (1992) and Collie and DeLong (1999) employed a mix of taxonomic, trophic, habitat, life history, and fishery-related considerations in defining Species Complexes for this system. In many instances, the taxonomic considerations embed elements of the other four factors. Garrison and Link (2000) identified trophic guilds of fish and squid based on diet composition data obtained during NEFSC research vessel surveys. Ontogenetic shifts in diet composition were shown to be important for several species,; accordingly, some species were assigned to more than one trophic guilds depending on their size. Auster and Link (2009) employed these trophic guilds and examined the question of whether the guilds had remained stable over multi-decadal time scales. Bell et al. (2014) employed dietary guilds to define Species Complexes using a similar but somewhat consolidated set of species assemblage groups.

In the following, we adapt the trophic guild designations of Garrison and Link (2000) as the basis for defining the trophic-based element of Species Complexes for fish and squid included in their analysis. We consolidated some groups relative to the categories identified by Garrsion and Link. In particular, specialist feeding strategies on echinoderms and crabs noted by Garrsison and Link (2000) were combined with other benthivores. We added an additional trophic guild representing benthic organisms important in the fisheries (principally crustaceans and mollusks) and other species not routinely caught in NEFSC bottom trawl surveys (e.g Apex Predators).

These modified Species Complex categories include the following groups:

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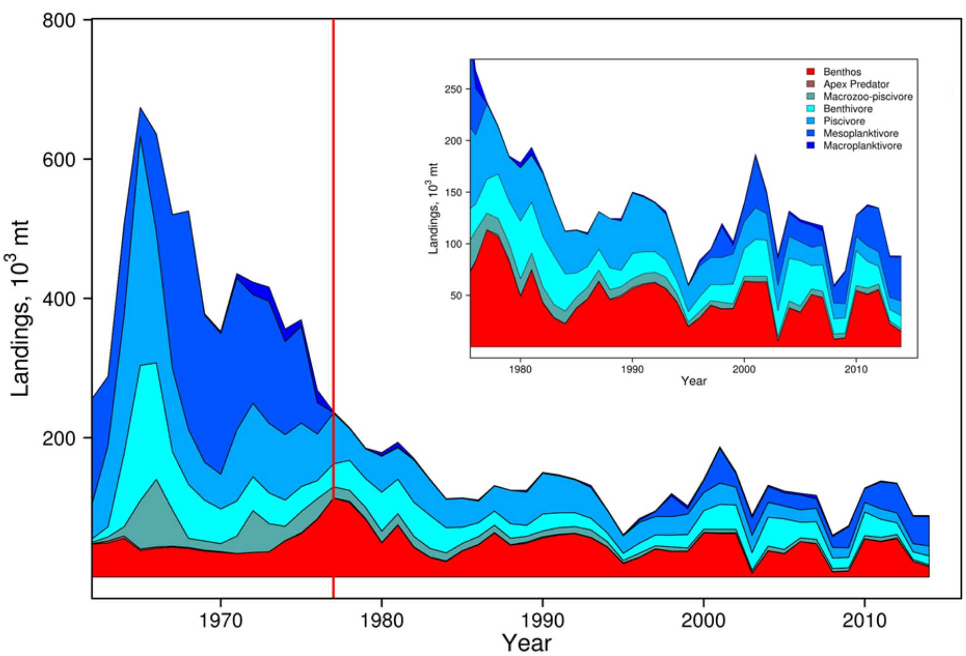
[1] Species Complexes and guilds can, under certain circumstances embody inter-related characteristics. For example, a planktivore Species Complex can be viewed as a conduit for energy flow from planktonic ecosystems to higher trophic levels within an aquatic ecosystem. Viewed as a trophic guild, planktivores are defined in terms of their similarity in diet preferences and requirements. In this context, species comprising a planktivore guild may be competitors and exhibit within-guild compensatory dynamics resulting in greater stability at the guild level than for the individual species within the guild.

1) Benthos (suspension and deposit feeders, principally crustaceans and mollusks)
2) Benthivores (predators of species in the benthos category)
3) Mesoplanktivores (predators of mesozooplankton, principally copepods)
4) Macroplanktivores (predators of macrozooplankton, principally amphopods but including decapod shrimp)
5) Macrozoo-Piscivores (predators of macrozooplankton and fish)
6) Piscivores (predators of fish species)
7) Apex Predators (typically large, fast moving predators that feed at the top of the food web)

A selected list of fish and invertebrate species on Georges Bank which are trophically-related to species caught by commercial or recreational fisheries, their designated trophic guilds and assigned Species Complexes is provided in Section 11.0. Information on the mean trophic level assigned to each species; its maximum size; whether it is considered to be ecologically but not currently economically important [i.e. an Ecosystem Component Species (ECS)]; and the dominant gear types in which the species is caught is provided in the table.

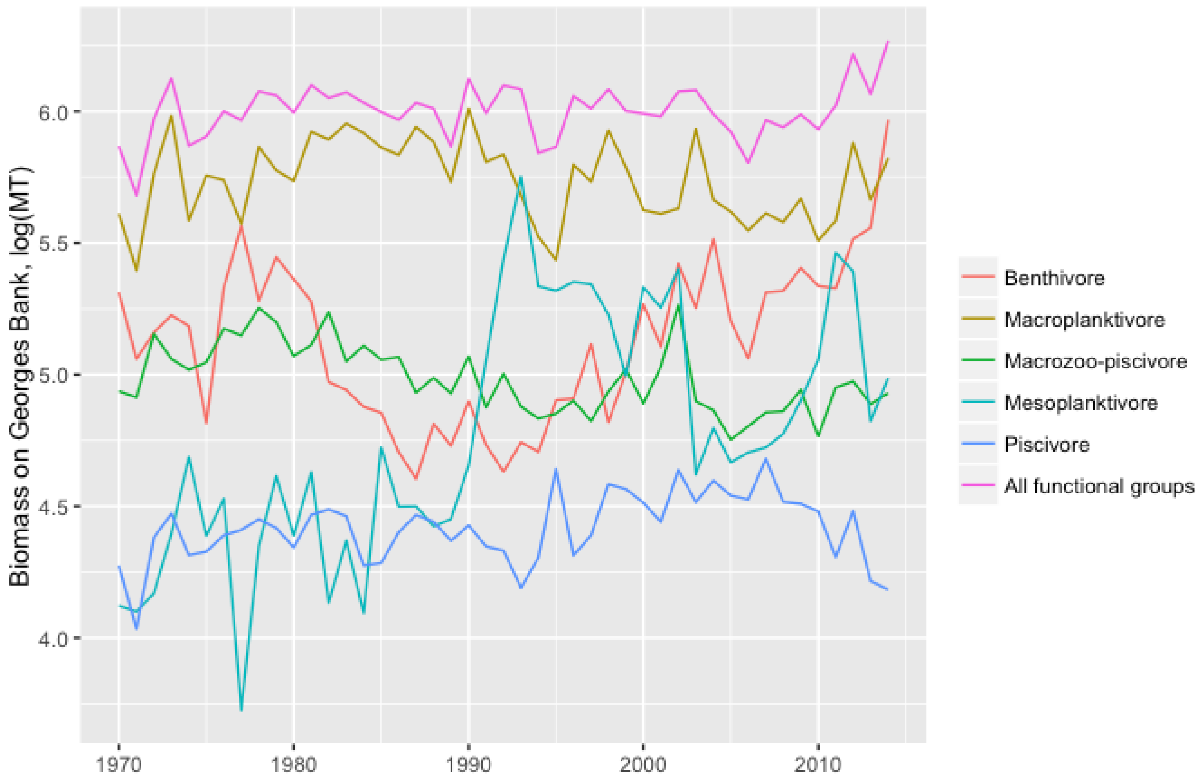
Reported landings on Georges Bank for the period 1964-2015 by the designated Species Complexes are shown in Figure 8. The initial impact of the distant water fleet, and the pattern of sequential depletion of species is clearly evident. By the mid-1980s, reported landings had stabilized (albeit at a slightly declining level).

Figure 8. Landings by Species Complex of species on Georges Bank 1964-2015. The vertical red line indicates the implementation of extended jurisdiction in 1977. The inset shows the landings from 1977-2015.



Estimates of the biomass of each Species Complex in NEFSC bottom trawl surveys adjusted for the area swept by the net and corrected for catchability are provided in **Error! Reference source not found.**. While declines in the biomass of most of the Species Complexes were observed during the period of operation of the distant water fleet on Georges Bank, subsequent increases in all components (albeit at different rates and overall levels) were evident in all. In many instances, species replacements within Species Complexes stabilized overall patterns of change within each. As overexploited species declined other, less intensively exploited, species increased (Fogarty and Murawski 1997)/

Figure 9. Estimated Species Complex biomass based on NEFSC fall bottom trawl surveys on Georges Bank, adjusted by the area swept by the trawl and corrected for survey catchability using estimates reported by Brodziak et al. (2008).

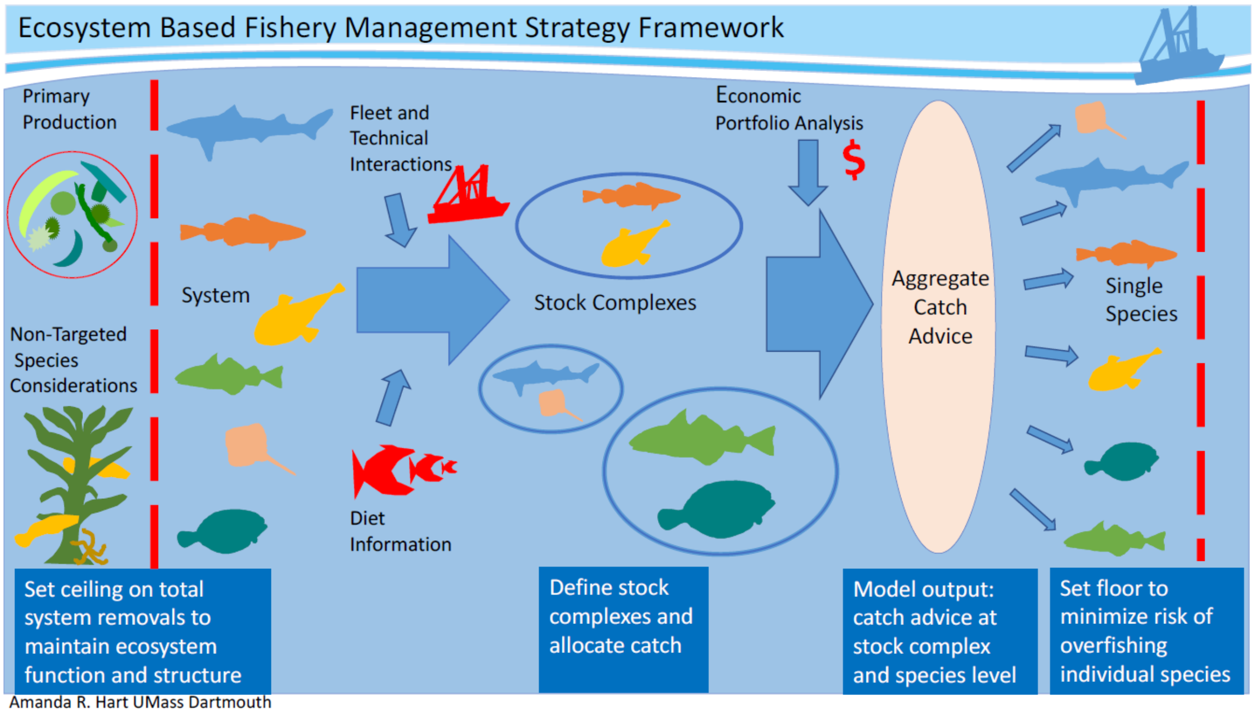


8.0 Operational Framework

In the preceding sections, we have described structural elements of one pathway toward the implementation of EBFM in the area of responsibility of the Council. The PDT focused on developing an eFEP for Georges Bank because most of the application of ecosystem models in the NE Region have focused on this area. Thus more models that are complete or well-developed are available here than for other areas with fisheries managed by the Council, in the Gulf of Maine or in Southern New England.

The key elements of the approach include the objective specification of the spatial domain [Ecological Production Unit (EPU)] to be managed, the identification of species complexes defined by trophic interactions and co-occurrence in fishing gear within the EPU, an overall system cap, and the critical role of management strategy evaluation in evaluating management options under consideration. In the following sections we build on these earlier elements and describe components of a potential operational approach to EBFM in the region including the identification of Ecosystem Reference Points establishing limits and targets for management and methods for determining catch levels in an ecosystem context (Figure 10).

Figure 10. Elements of the proposed hierarchical process for specifying Acceptable Biological Catch levels for species within defined Fishery Species Complexes



Consideration of energy flow and constraints on overall production in the system provide the foundation for the approach. In the identification of Species Complexes, the premise is that the whole is more stable than the parts (Figure 9). We attribute this greater stability to constraints related to patterns of energy flow and utilization and biological interactions within and between Species Complexes. Statistical averaging over a large number of species also contributes to this effect.

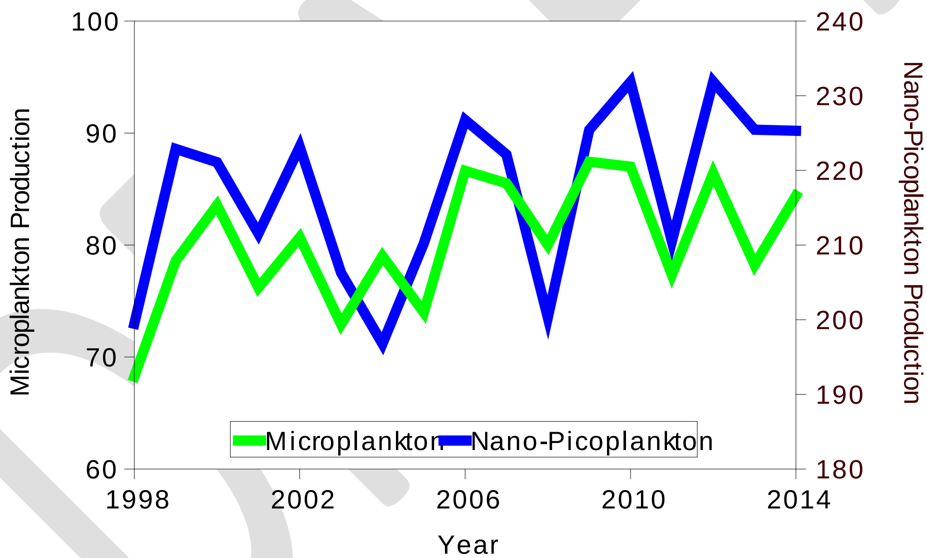
8.1 Ecosystem Reference Points

The production in an ecological system is ultimately constrained by the amount of energy available at the base of the food web. The production levels manifest throughout the food web reflect the joint effects of energy inputs and interactions among the components of the system, including humans. Iverson (1991) proposed an ecosystem reference point based on the fraction of 'new production' in the system. New production is the production generated by the renewal of nutrients in the water column and its uptake by phytoplankton. A modification of Iverson's approach focuses on the fraction of total production attributable to microplankton (species > 20 μ) principally composed of diatoms and large dinoflagellates. These species are dominant during the spring bloom period resulting from nutrient regeneration and increasing day length. We define a limit exploitation reference point for the system as the fraction of production by microplankton in the system (see Fogarty et al. 2016). Production by smaller-sized phytoplankton (nano- and picoplankton less than 20 microns in size) generally involves pathways through the microbial food web, depends substantially on recycled nutrients and do not contribute to higher trophic levels. A substantial fraction of the microplankton production goes directly into the grazing food web involving suspension feeding bivalves of economic importance (e.g. scallops, and clams and meso-zooplankton (e.g larger copepod species) which are grazed by planktivores such as herring, mackerel, and butterfish. In contrast, the transfer of energy from the microbial food web to species of economic importance involves at least one or two additional steps in which energy is dissipated before reaching the upper trophic levels. Accordingly, although the production of nano- and picoplankton accounts for the dominant share of total phytoplankton production in the sea, the role of microplankton production in the dynamics of upper trophic levels is comparatively very important.

Remote sensing satellite data allows for estimation of biomass and production for these phytoplankton size classes based on their spectral signatures. The estimated levels of production by the larger-sized phytoplankton Species Complexes and that of the smaller size classes are depicted in Figure 11. The estimated level of primary production on Georges Bank has increased since 1998 (Figure 11) based on satellite monitoring although the estimated ratio of microplankton to total production has remained more stable with a mean of 0.27 during the period 1998-2014.

An appropriate limit exploitation reference point for the system as a whole therefore is 27% of primary productivity. However, to ensure that the food requirements of other components of the ecosystem, including protected species such as marine mammals, sea turtles, and sea birds are met, a target level of exploitation should be established that is lower than this limiting exploitation rate. For example, a target exploitation rate of two thirds to three quarters of the limiting level would result in an exploitation rate of approximately 18-20%.

Figure 11. Estimates of primary production (gC m-2 yr-1) for microplankton and nano-picoplankton on Georges Bank (Kimberly Hyde, NEFSC, personal communication



In addition to direct examination of the primary production, ecosystem reference points have been developed from multispecies models for Georges Bank. Brown et al. (1976) applied an aggregate production modeling approach for the entire Northeast Continental Shelf System resulting in estimates of system-wide Maximum Sustainable Yield and an estimate of the level of fishing effort resulting in MSY for the system. A Georges Bank model with 21 species was examined to illustrate tradeoffs between yield and biodiversity in exploited marine ecosystems (Worm et al. 2008). It was shown that maximizing ecosystem yield resulted in numerous collapsed species (defined as species falling below 10% of their unexploited biomass levels), however, harvesting roughly 90% of eMSY greatly reduced the risk of species collapse. Similar results were shown by Gaichas et al. (2012) using a different multispecies model for Georges Bank.

The eFEP adopts a modification of the Iverson (1991) productivity method for establishing the ecosystem reference points from which an overall system catch cap can be developed, but recognizes that other methods could be employed.

8.2 Catch Limits

The EBFM PDT proposes a hierarchical approach to establishing catch limits that starts with the establishment of an overall cap or ceiling of removals from the system as a whole. A similar constraint was employed in the 1973 ICNAF Two-Tier Management System described earlier and is now employed in management of groundfish resources in the Gulf of Alaska and the Bering Sea (Wetherill et al. (19???). This ceiling could be adjusted according to changing patterns of production in the system. Catch limits would be set for each Species Complex and the sum of the Species Complex catch limits could not exceed the system-level ceiling (overall catch cap). This will require biomass estimates for each Species Complex and a target level of exploitation for each that will meet the ceiling constraint. The biomass estimates can be generated by multispecies assessment. It is also possible to use model-free estimation methods based on direct estimates of biomass from survey or other sources (for a list of feeding guilds and Species Complexes, see Figure 9). We recommend the use of multiple assessment models and estimation methods where feasible and to employ methods of multimodel inference.

To provide protection for individual species within Species Complexes, we define biomass levels below which species are deemed to be at risk. The most broadly applicable method available to inform these thresholds is based on survey estimates of biomass. Species falling below specified levels would be defined as at risk and requiring remedial management action for protection. Candidate threshold levels under consideration include a sustained drop below the 20th percentile in survey biomass over the time series for teleosts and below the 30th percentile for elasmobranchs (whose life history characteristics make them more vulnerable to exploitation). Threshold levels for defining individual species at risk would be made based upon the best scientific advice and Council policies.

The Council could make other choices for biomass floors that are related to risk assessment, considering the species vulnerability, productivity level, economic value, and/or ecosystem function. A final consideration in setting target catches involves maintaining stability. The NEFMC recently identified stability as a core component of its risk policy. In its Risk Policy Roadmap, stability is defined as "Evaluating the trade-offs of minimizing variability while achieving the greatest overall net benefits to the nation", and that "Metrics that monitor variability from year to year, e.g. in quotas, should be developed" (Risk Policy Working Group 2016). The overarching goal, then, is to assess the trade-offs between generating a high flow of benefits and the ability to ensure that flow of benefits can be generated in a stable and sustainable manner.

In economics, modern portfolio theory was developed to assess this exact trade-off (Markowitz 1952). Portfolio analysis measures the extent to which financial assets change relative to each other, with the idea that in a well-balanced portfolio a decrease in the value of one asset will be off-set by an increase in another. The framework has been extended to assess trade-offs in fishery management (Edwards et al. 2004, Sanchirico et al. 2008), in that species and Species Complexs can be viewed as generating a flow of benefits whose stability can be assessed in a similar manner to financial assets.

Jin et al. (2016) employed portfolio theory to assess historical performance in the Northeast Large Marine Ecosystem, and this model can be coupled to the multispecies models or direct estimation methods based on survey data in order to provide measures of stability and returns for the Georges Bank system. In particular, the ceiling or caps for the system as a whole and the floors as developed for each species can be used as constraints in the portfolio optimization, in order to ensure sustainability at the species level.

8.2.1 Catch Allotment/Allocation

- Allocations made to permit holders in functional groups of species (i.e. a stock complex caught by gear type)
- A permitted vessel would receive an annual catch allocation of one or more functional groups that are caught by a Georges Bank fishery.
- Recreational catch allocations