1. Introduction

Why Do EMAX?

The Northeast U.S. (NEUS) Continental Shelf Ecosystem is a dynamic environment. The general observation is that it has shifted from a vertical to a horizontal system due to the resurgence of small pelagic fishes, namely herring and mackerel. With regard to this resurgence, the question is: How important have these small pelagics become to the success of other commercial fish stocks; protected, endangered and threatened species (PETS); National Environmental Policy Act (NEPA) species; and the overall functioning of the ecosystem? This issue has become increasingly important as multiple stakeholders have begun exploring potential tradeoffs in the NEUS Ecosystem.

More broadly, there have been numerous recent calls to adopt an ecosystem approach to fisheries (EAF, or Ecosystem-based Fisheries Management [EBFM]. Here EAF and EBFM are used synonymously). There are many rationales for why EAF is an emerging approach, such as competing stake-holders and legislation; debate over the importance of different processes (fishing, environment, predation, etc.); the need for explicit consideration of non-targeted species, protected species, habitats, etc.; and the need to directly assess tradeoffs among and within sectors and across biomass allocation. Central to these considerations is taking a more holistic look at an ecosystem and simultaneously evaluating tradeoffs among component biomass or user sectors.

To evaluate the response of this ecosystem to numerous human-induced perturbations and to explore possible future scenarios, the Northeast Fisheries Science Center (NEFSC) instituted the Energy Modeling and Analysis eXercise (EMAX). The primary goal of EMAX was to establish an ecological network model (i.e., a nuanced energy budget) of the entire NEUS Ecosystem food web.

The highly interdisciplinary EMAX work focused on four subregions of the ecosystem from contemporary times (1996-2000), had 36 network nodes (biomass state variables) across a broad range of the biological hierarchy, and incorporated a wide range of key rate processes. The emphasis of EMAX was to explore the particular role of small pelagic fishes in the ecosystem. Various model configurations were constructed and psuedo-dynamic scenarios were evaluated to explore how potential changes to the small pelagic fishes can affect the rest of the food web.

Why Do an Energy Budget and Network Analysis?

There are a wide range of approaches one could take to answer the question about the role of small pelagics. One way to explore holistic ecosystem perspectives and examine biomass tradeoffs is to use ecosystem models. Within the wide variety of possible ecosystem models, energy budgets and network analyses provide useful tools to evaluate relative biomass, system properties, and fluxes within an ecosystem. Many of these models allow one to explore the fate and flux of production within a system by explicitly tracking how the energy flows among various components of the system. Of the many network models available, we chose to use Ecopath and EcoNetwrk to evaluate various spatial, temporal, and hypothetical scenarios.

Key to our selection of a network analysis was the need to evaluate multiple processes and factors simultaneously and holistically. Further, the relative importance of any particular process or biological group is hard to capture without a broader context of energy flows and standing stock biomass in an ecosystem. Additionally, we wanted to compile information as a catalogue for future endeavors, and constructing an energy budget for the entire ecosystem was an excellent way to integrate such information. There are many other rationales for doing an energy budget and network analysis, but the major consideration we kept returning to was that evaluating scenarios and tradeoffs cannot correctly be done in a vacuum. A broader context of ecosystem structure and dynamics is truly required to evaluate the issue of tradeoffs among component biomass or user sectors.

Background of the Working Group

The core of our Working Group (hereafter, WG) started out in mid-1998 as a reading group for interested staff at the Northeast Fisheries Science Center who wanted to keep abreast of current issues in fisheries science and management. After reading and discussing material on the subject (including Steve Hall's 1999 book) the WG realized it could make a positive contribution toward the implementation of EBFM. Since the NEFSC has some of the world's premier time series of fisheries-independent data on subjects such as fish, mammal, and bivalve species abundance, zooplankton biomass, and food habits and temperature, the WG thought it would be useful to assemble these data and document the current status and recent history of the NEUS Ecosystem.

The WG became the Ecosystem Status Working Group (ESWG) from 2000-2002 and produced a report on the status of the NEUS Ecosystem (Link and Brodziak 2002). The WG had a vast array of personnel from a wide range of disciplines covering physics, biology, and social sciences. As 2002 ended, the core of the WG recognized a need to do more than simply compile a catalog of information. Several factors external to the NEFSC were influencing the prominence of ecosystem considerations and were expected to continue. Such factors included a global increase in calls for ecosystem-based approaches to fisheries management; potential changes to key U.S. legislation; two high-level Commission reports on the world's oceans; continuing conflicts across living marine resource (LMR) user sectors; important initiatives within NOAA and NMFS; and a regional recognition of LMR management complexity.

The ESWG morphed into the Ecosystem Status Steering Group (ESSG), which proposed multiple options for helping the NEFSC deal with these external considerations of mutual interest to the NEFSC's priorities, stakeholders, and the members of the WG itself. The ESSG set out to identify and develop a project that would form the basis for a fishery ecosystem plan. In developing EMAX, the ESSG decided it required:

- Broad Center involvement
- An interdisciplinary perspective
- A high degree of management relevancy
- The ability to serve as a pilot project, meaning that it would be short term in nature but designed with long term perspective in mind
- Be in the context of ultimately supporting a fisheries ecosystem plan (FEP)

After discussions with senior NEFSC staff during 2002-2003, an internal proposal was accepted and there began more formal analysis and examination of the region's ecosystems as a whole.

A network analysis-energy budget approach was determined a logical place to start for the construction and piecing together of relevant, interdisciplinary data across the NEFSC's programs. It was recognized that after the assembly of a network, multiple questions could be addressed, but it was difficult to address questions beforehand. Thus, in late 2003 the Energy Modeling and Analysis eXercise (EMAX) was formed from the core WG.

Emphasis of EMAX

The following outlines our original question and terms of reference. Some of the major products and deliverables proposed for this project are also listed.

Specific Question

What is the role of small pelagic fish in the NEUS Ecosystem as determined by a recent network analysis?

Why emphasize small pelagics as a pilot project? These organisms are keystone species, are found at mid trophic levels, interact with a large number of other species, are currently highly abundant, and have a minimal fisheries prosecuted on them (i.e., it was a relatively non-controversial issue).

Terms of Reference

1. For the NEUS Ecosystem, what are the annual, seasonally-resolved values for the following for each of the major sub-ecosystem regions over the past 5 years or so (1996 – 2000)?
    A. Primary production
    B. Secondary production (both zooplankton and benthos, as data permits)
    C. Fish production
    D. Marine mammal and bird production
    E. Fishery production (in terms of catch, landings, etc.)
2. What is the transfer efficiency between trophic levels or black boxes (i.e., develop an integrated and balanced energy budget)?
3. What is the role of small pelagics relative to other species in the ecosystem?

Proposed Key Deliverables

- Understanding the relative role of small pelagic species simultaneously with other organisms (target species [TS], non-target species [NTS], and protected species [PS])
- Examining how changes to small pelagics could potentially affect management of these and other interacting species
- A compiled set of integrated information and data
- Basis for further FEP efforts
- Basis for further modeling
- Identification of information gaps

Spatial and Temporal Extent

Our analyses cover 1996 to 2000. The choice was made to produce annualized estimates integrated across the appropriate seasonality for each taxa group. We separated the NEUS Ecosystem into four main subregions (ecoregions): Gulf of Maine (GOM), Georges Bank (GB), Southern New England (SNE), and Mid-Atlantic Bight (MAB) (Figure 1.1). These principally correspond to the major regions of the Center's bottom trawl survey (BTS; Table 1.1) according to a commonly-defined strata set, but also account for key oceanographic, sediment, and bathymetric considerations.

Network Nodes

In network parlance, a node is analogous to a box, group, etc., and this usage was adopted for EMAX. The current network configuration has 36 nodes, representing a wide amalgamation of species (Table 1.2). Each node can potentially interact with other nodes, and the network configuration is shown in Figure 1.2. Each node was not necessarily represented in each ecoregion (e.g., there are no pinnipeds on Georges Bank), but the vast majority were. A glossary of terms (see Section 26) provides further information about common network and energy budget concepts.

References

Hall, SJ. 1999. *The effects of fishing on marine ecosystems and communities*. Oxford, UK: Blackwell Publishing Ltd; 274 p.

Link, J; Brodziak, J, eds. 2002. Report on the Status of the NE US Continental Shelf Ecosystem. NEFSC Ecosystem Status Working Group. *Northeast Fish. Sci. Cent. Ref. Doc.* 02-11; 245 p.

Table 1.1. NEFSC Bottom Trawl Survey Strata used to define the four main EMAX regions.

	Strata		
Survey stratum definitions	Inshore	Offshore	Area (square kilometers)
Gulf of Maine (GOM)	57-90	24, 26-30, 36-40	79127.95
Georges Bank (GB)	NA	13-23, 25	43666.16
Southern New England (SNE)	1-14, 45-56	1-12	64060.37
Mid-Atlantic Bight (MAB)	15-44	61-76	59807.29

Table 1.2. EMAX network nodes and numbers.

Node Name	Node #
Phytoplankton - Primary Producers	1
Bacteria	2
Microzooplankton	3
Small Copepods	4
Large Copepods	5
Gelatinous Zooplankton	6
Micronekton	7
Mesopelagics	8
Macrobenthos - Polychaetes	9
Macrobenthos - Crustaceans	10
Macrobenthos - Molluscs	11
Macrobenthos - Other	12
Megabenthos - Filterers	13
Megabenthos - Other	14
Shrimp and Similar Species	15
Larval Fish - All	16
Small Pelagics - Commercial	17
Small Pelagics - Other	18
Small Pelagics - Squid	19
Small Pelagics - Anadromous	20
Medium Pelagics - (piscivores and other)	21
Demersals - Benthivores	22
Demersals - Omnivores	23
Demersals - Piscivores	24
Sharks - Coastal	25
Sharks - Pelagics	26
Highly Migratory Species - (tuna, billfish and swordfish)	27
Pinnipeds	28
Baleen Whales	29
Odontocetes	30
Sea Birds	31
Fisheries - Demersal	32
Fisheries - Pelagic	33
Discards	34
Detritus - POC	35
DOC	36

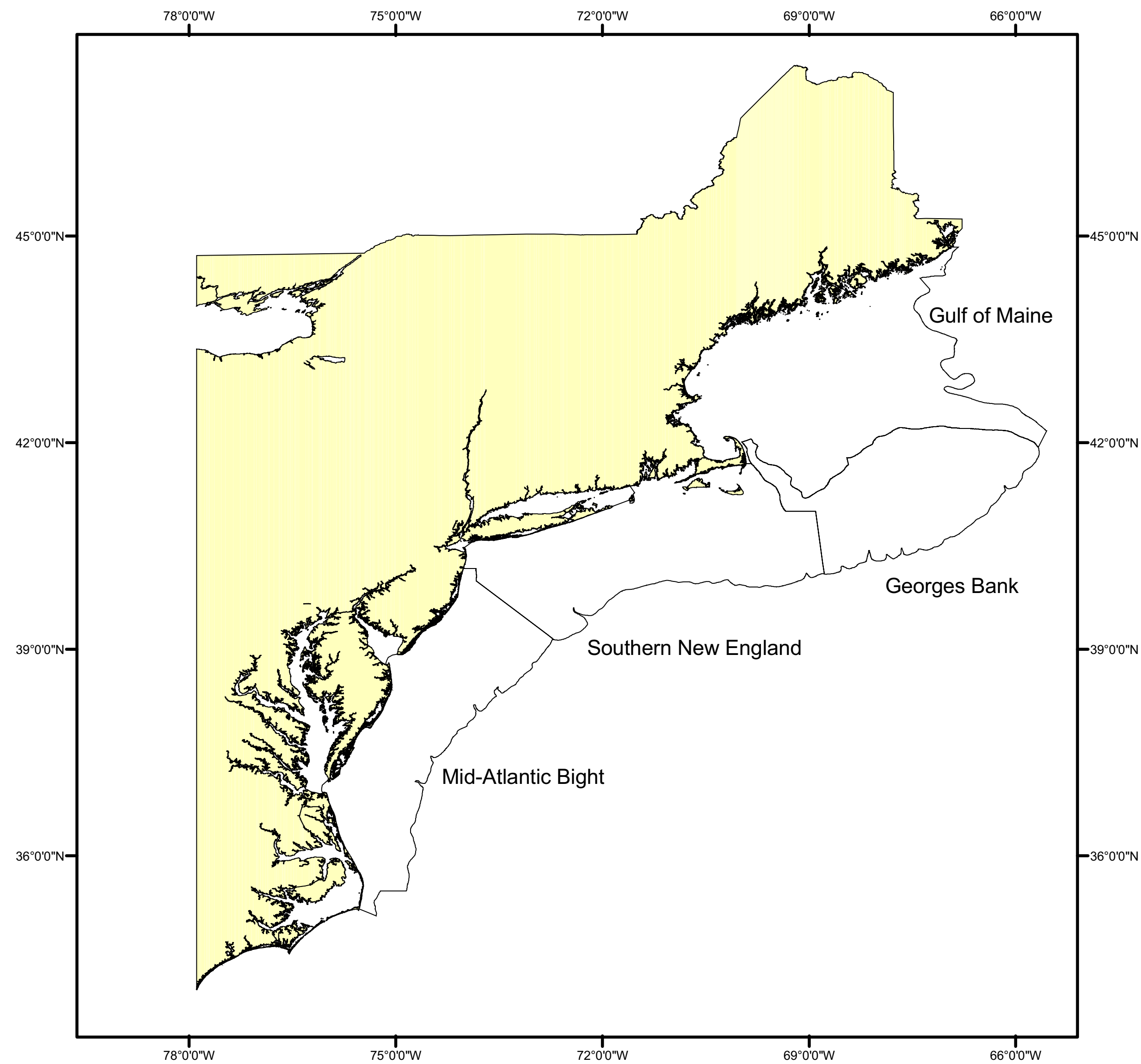

Figure 1.1. Map of the Northeast U.S. Continental Shelf Ecosystem and its four major subregions.

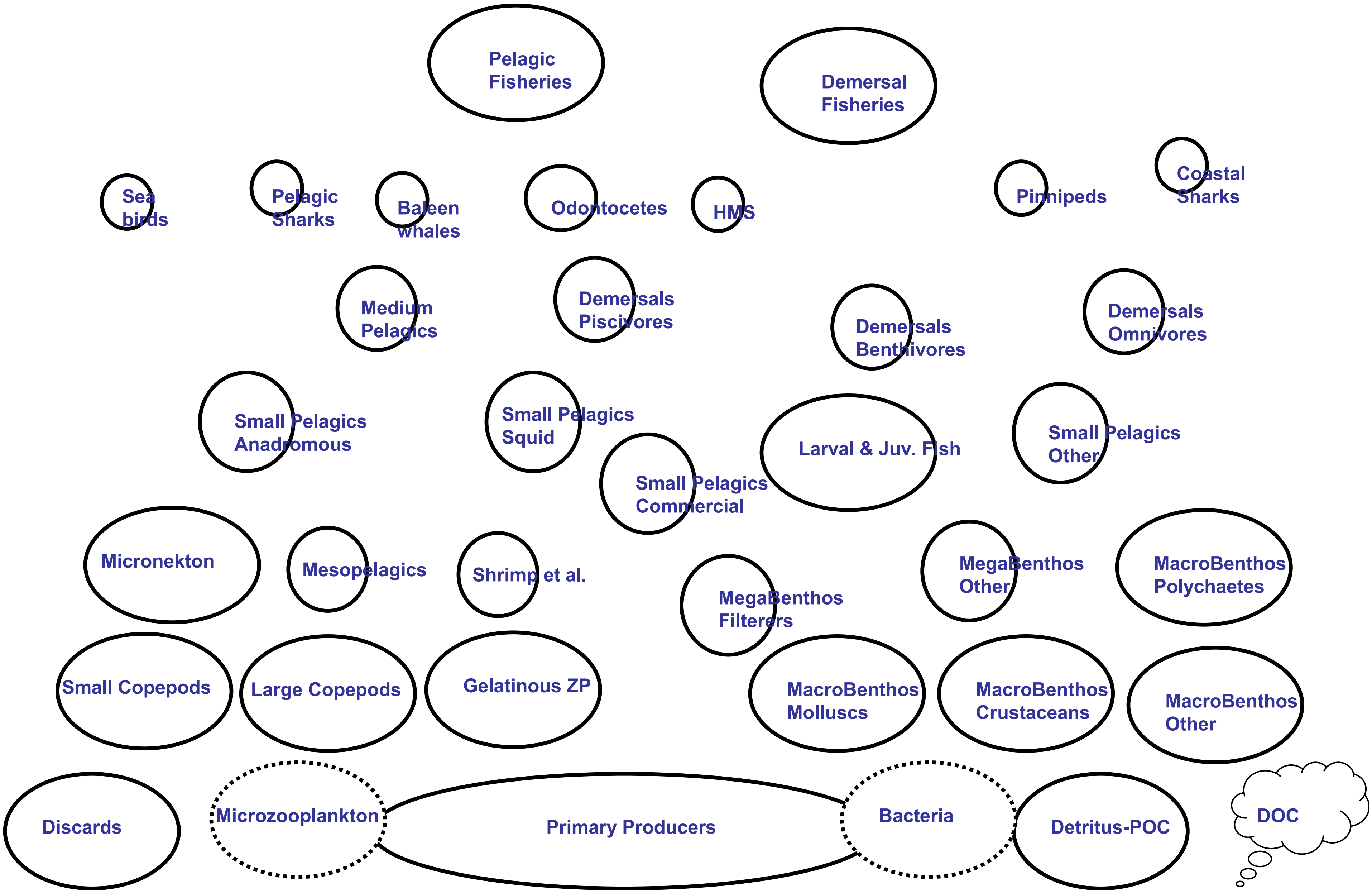

Figure 1.2. Major nodes of the EMAX network.