II. Introduction

A. Why this topic?

Ecosystem-based fisheries management (EBFM) has generated a lot of scientific interest in recent years (see Link 2002b for an overview). Many factors have contributed to the recent focus on EBFM, including conflict among stakeholders, conflict between legislative requirements, ongoing debate over the most important processes in marine ecosystems, and recognition of the limitations of single species management. The relative effects of multi-species predator-prey interactions, intra- and interspecific competition, and changing oceanographic conditions are important scientific issues that could hinder the near-term application of EBFM. These ongoing issues are certainly not novel (e.g., Baird 1873; Lankester 1884; Lotka 1925; Volterra 1926). Further, while several approaches to address broader considerations in a fisheries context were proposed in the 1970s and 1980s (e.g., Steele 1974; Andersen and Ursin 1977; May et al. 1979; Mercer 1982; Kerr and Ryder 1989; Daan and Sissenwine 1991), many basic issues still remain unaddressed.

Recently, some progress has been made in defining terms for EBFM, providing rationale for using a more holistic management approach, and in particular, answering when, why, and how EBFM can be practically implemented in a fisheries context (e.g., Larkin 1996; Jennings and Kaiser 1998; Hall 1999; ICES 2000; Link 2000; NMFS 2000; Link 2002a, 2002b; Brodziak and Link 2002). To date, there are few empirical descriptions of fisheries ecosystems (see, for example, AFSC; Livingston 1999, 2000). Yet the direct implementation of broader ecosystem considerations has not become widespread in fisheries management even though they have been advocated (NMFS 1999; NRC 1999; ICES 2000) and even mandated in recent years (NOAA

1996). There are no clear protocols for actually implementing EBFM and some questions of feasibility and definition are still unaddressed. However, implementation will be via iteration and sequential improvement. To this end, the Group has focused on documenting the status of the northeast U.S. continental shelf ecosystem as an essential first step to facilitate the development of an operational approach to ecosystem-based fisheries management.

B. Background of the Group

The core of our Ecosystem Status Working Group (hereafter, the Group) started out approximately in mid-1998 as a reading group for interested staff from the NEFSC to keep abreast of current issues in fisheries science and management. After reading and discussing and numerous literature articles on the subject, including Steve Hall's (1999) book on the topic, the Group realized that we could make a positive contribution towards the implementation of ecosystem-based fisheries management. Since the NEFSC has some of the world's premier time series of fisheries independent data, on subjects ranging from species abundance to zooplankton biomass to food habits to temperature, the Group thought it would be very useful to assemble these data to document the current status and recent history of the northeastern U.S. continental shelf ecosystem.

Our first objective was to assemble the diverse, multi-disciplinary sets of time series that exist at the NEFSC in detail (Table 2.1). This document describes those abiotic, biotic and human metrics. For a list of these metrics, see Table 2.1. Our second objective was to compare these metrics. We compiled these diverse datasets in common formats amenable for easy comparison. From this compilation, we produced a set of simple, common, general observations.

Our third objective was to synthesize the information into a set of working hypotheses that can serve as a basis for future detailed examinations.

C. New England fisheries: Case study for ecosystem-based fisheries management

The substantial changes in New England fisheries over the past several decades, and in particular groundfish fisheries, have been associated with excessive fishing pressure (Serchuk et al. 1994; Murawski et al. 1997; Boreman et al. 1997; NEFSC 1998a; Fogarty and Murawski 1998). The abundance of commercially desirable gadids (Atlantic cod, *Gadus morhua,* and haddock, *Melanogrammus aeglefinus*) as well as flatfish (yellowtail flounder, *Limanda ferruginea*, American plaice, *Hippoglossoides platessoides*, and winter flounder, *Pseudopleuronectes americanus*) has declined with a concurrent increase in the abundance of elasmobranchs (spiny dogfish, *Squalus acanthias*, and skates, *Raja* spp.) and small pelagic fishes. Changes in the fish community structure began occurring in the 1950s and 1960s with the arrival of distant water fleets and subsequent increase in fishing pressure exerted on the major gadid and flatfish stocks. As a result of the dramatic increase in landings (and presumably high discards), the estimated total biomass of these stocks declined by at least 50%. After the foreign fleets were displaced from the U.S. Exclusive Economic Zone (EEZ), moderate increases in stock sizes were observed in the late-1970s to early-1980s. Capacity and efficiency of the domestic fleet increased during the 1980s, however, and this led to subsequent declines in groundfish abundance. Groundfish abundance plummeted to historic lows in the 1990s, although abundances of some stocks have increased in recent years under restrictive fishery management measures. Yet some groundfish stocks, such as cod, have remained at low abundance. Many groundfish stocks on Georges Bank exhibited classic signs of overfishing in recent decades, including declines in abundance, faster growth, earlier age-at-maturity, and a truncated size structure (NEFSC 1998a, 1998b; reviewed in Jennings and Kaiser 1998). However, much less in known about the indirect and secondary effects of intense fishing pressure on the fish community in this and most marine ecosystems (Hall 1999; ICES 2000). Further, how fishing pressure affects other aspects of the northeast U.S. continental shelf ecosystem are generally not known. In this context, we hope to provide some insights on the issue of indirect effects, particularly in the context of the fishing and environmental changes that have occurred in this ecosystem.

D. Spatial delineation of northeastern U.S. continental shelf ecosystem

We use ecosystem to refer to the combination of physical processes and organisms existing within the spatial range of the system, taken together as a whole. The spatial range of the northeastern U.S. continental shelf ecosystem includes the estuarine and oceanic waters to depths of approximately 200 m from a southern boundary at Cape Hatteras, North Carolina to a northeastern boundary at the beginning of the Scotian Shelf (<100 m depth) in the northeastern Gulf of Maine through the Northeast Channel separating Georges Bank from Browns Bank and the Scotian Shelf (Figure 2.1). It is also commonly referred to as the Northeast Large Marine Ecosystem (LME; Sherman1991, Sherman et al. 1993). This ecosystem is an open oceanic system that is part of the northwestern Atlantic continental shelves province, which is a much larger oceanic region consisting of continental shelf and slope water from Florida to the Grand Banks of Newfoundland (Longhurst 1998). Within this ecosystem, we define four subdivisions with distinct hydrography and biota: the Mid-Atlantic Bight, Southern New England, Georges Bank, and the Gulf of Maine-Bay of Fundy. We will provide metrics to describe system attributes at several spatial scales, ranging from individual estuaries to subdivisions to the entire northeastern U.S. continental shelf ecosystem.

E. Temporal extent and resolution

Many of the metrics we examined are derived from the NEFSCs spring and fall bottom trawl survey (Grosslein 1969; Azarovitz 1981; NEFC 1988). These extend back to 1968 and 1963, respectively, and are maintained to the present time. Several other time series (e.g., MARMAP, SOOP, food habits, vessel landings) are available for the same time period. We present a suite of over 100 metrics, many of which span 25 - 40 years (Table 2.1). Metrics with short time series have been included even though they may represent only snapshots of particular system attributes, however, most of the metrics provide information on annual or interannual time scales. Although some data were available to examine seasonal contrasts, we did not require this level of resolution to document the status of the ecosystem.

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Table 2.1. Metrics we examined in this study and the extent of these time series. Source includes the principal researcher and the programmatic source of the data; BTS = bottom trawl survey, SS = scallop survey, SHS = Sandy Hook estuarine survey, FH = food habits, ZP = zooplankton, OBS = observer and port agent commercial landings database, OCE = oceanographic database, MAM = mammal survey, REG = regulations implemented, MAR = MARMAP Ships of Opportunity Program. The general process indexed by each metric is also listed.

SOURCE	WHAT IS IT?	START YEAR	END YEAR	YEARS IN SERIES	FIGURE NUMBER	PROCESS INDEXED
ABIOTIC METRICS						
BRODZIAK OCE	NAO Index	1823	2000	177	A.1	Long-term Forcing
BRODZIAK OCE	5-Year Average of NAO Index	1823	2000	177	A.2	Long-term Forcing
MOUNTAIN BTS	Shelf-Wide Surface and Bottom Water Temperature Anomalies, Autumn Survey	1963	2000	37	A.3	Forcing Physics
MOUNTAIN BTS, OCE	MAB Shelf Water Anomalies for Volume, Salinity, and Temperature	1977	2001	24	A.4	Forcing Physics
MOUNTAIN, BRODZIAK BTS, OCE	Surface and Bottom Temperature Anomalies	1963	2000	37	A.5	Forcing Physics
MOUNTAIN BTS	Average MAB Shelf Water Temperature Anomaly in 1990s for Five Regions	1990	1999	9	A.6	Forcing Physics
JOSSI OCE, ZP	Massachusetts Bay Anomalies from 1978-90 Averages of Surface Temperature, Salinity, and Bottom Temperature from a Fixed Transect	1978	2001	24	A.7	Forcing Physics
JOSSI OCE, ZP	MAB Anomalies from 1978-90 Averages of Surface Temperature, Salinity, and Bottom Temperature from a Fixed Transect	1978	2001	24	A.8	Forcing Physics
JOSSI BTS	Western Gulf of Maine Surface and Bottom Temperature and Salinity Anomalies	1978	2001	24	A.9	Forcing Physics
MOUNTAIN BTS, OCE	Georges Bank NAO, Salinity, Plankton and Cod	1970	1996	26	A.10	Long-term Forcing, Forcing Physics
BIOTIC METRICS						
HART BTS, SS	Georges Bank Scallop Biomass Density	1980	2000	20	B.1	Benthic Dynamics, "Canary" Populations

HART BTS, SS	Mid Atlantic Scallop Biomass Density	1980	2000	20	B.2	Benthic Dynamics, “Canary” Populations
HART BTS, OBS, SS	Georges Bank Scallop Survey Biomass and Landings	1962	1999	37	B.3	Benthic Dynamics, “Canary” Populations
HART BTS, OBS, SS	Mid Atlantic Scallop Survey Biomass and Landings	1962	1999	37	B.4	Benthic Dynamics, “Canary” Populations
LINK BTS	Sculpin mean number per tow on Georges Bank autumn NEFSC survey	1963	1998	35	B.5	Benthic Dynamics, “Canary” Populations
FABRIZIO SHS	Beam and Otter Trawl Catch of Blue Crab per Unit Area in an Estuary	1996	2000	4	B.6	Benthic Dynamics, “Canary” Populations
JOSSI ZP	GOM Percentile Anomalies of Calanus from 1961-90 Median	1961	2000	40	B.7	Secondary Production
JOSSI ZP	Anomalies of major zooplankton taxa	1977	1996	19	B.8	Secondary Production
JOSSI ZP	Spatio-seasonal density of Centropages across continental slope	1976	1990	14	B.9	Secondary Production
JOSSI ZP	Seasonal Calanus Abundance, Between Massachusetts and Cape Sable	1961	1998	37	B.10	Secondary Production
KANE ZP	Anomalies of Georges Bank Total ZooplanktonBiomass and Abundance for 2 major copepods	1977	2000	23	B.11	Secondary Production
KANE ZP	Anomalies of Gulf of MaineTotal ZooplanktonBiomass and Abundance for 2 major copepods	1977	2000	23	B.12	Secondary Production
KANE ZP	Mean Zooplankton Biomass, entire shelf	1977	2000	23	B.13	Secondary Production
NEFSC BTS	Groundfish, principal pelagics, dogfish & skates, and other fish	1963	1999	36	B.14	Aggregate Production, Biomass Allocation
BRODZIAK BTS	Georges Bank Principal Groundfish Abundance	1963	1999	36	B.15	Aggregate Production
BRODZIAK BTS	Georges Bank Elasmobranch Abundance	1968	1999	31	B.16	Aggregate Production
BRODZIAK BTS	Principal Pelagics Abundance	1967	1994	27	B.17	Aggregate Production
BRODZIAK BTS	Georges Bank Cephalopod Abundance	1963	1999	36	B.18	Aggregate Production

LINK FH	Frequency of parasite occurrence by predator	1973	1998	25	B.19	Trophic Dynamics, Density Dependence
FABRIZIO SHS	Beam and Otter Trawl Catch of Winter Flounder per Unit Area in an Estuary	1996	2000	4	B.20	Population Dynamics
NEFSC BTS	Percent mature at age-1 & age-2 for GB haddock and cod	1963	1997	34	B.21	Population Dynamics, Allometric Dynamics
BRODZIAK BTS	Georges Bank Cod Recruits per Spawner Anomalies	1978	1998	20	B.22	Recruitment Dynamics
BRODZIAK BTS	Georges Bank Haddock Recruits per Spawner Anomalies	1931	1998	67	B.23	Recruitment Dynamics
BRODZIAK BTS	Georges Bank Yellowtail Recruits per Spawner Anomalies	1973	1998	25	B.24	Recruitment Dynamics
LINK BTS	Swept-Area Total Biomass Index	1963	1999	36	B.25	System Production
LINK BTS	Mean animal length on Georges Bank from NEFSC bottom trawl surveys	1963	2000	37	B.26	Allometric dynamics
LINK BTS	Swept-Area Biomass Index by different Guilds	1963	1999	36	B.27	Aggregate Production
BRODZIAK BTS	Gulf of Maine Total Species Diversity	1963	2000	37	B.28	Diversity, Biomass Allocation
BRODZIAK BTS	Gulf of Maine Abundant Species Diversity	1963	2000	37	B.29	Diversity, Biomass Allocation
BRODZIAK BTS	Gulf of Maine Species Evenness	1963	2000	37	B.30	Diversity, Biomass Allocation
BRODZIAK BTS	Georges Bank Total Species Diversity	1963	2000	37	B.31	Diversity, Biomass Allocation
BRODZIAK BTS	Georges Bank Abundant Species Diversity	1963	2000	37	B.32	Diversity, Biomass Allocation
BRODZIAK BTS	Georges Bank Species Evenness	1963	2000	37	B.33	Diversity, Biomass Allocation
BRODZIAK BTS	Mid-Atlantic Bight Total Species Diversity	1963	2000	37	B.34	Diversity, Biomass Allocation
BRODZIAK BTS	Mid-Atlantic Bight Abundant Species Diversity	1963	2000	37	B.35	Diversity, Biomass Allocation
BRODZIAK BTS	Mid-Atlantic Bight Species Evenness	1963	2000	37	B.36	Diversity, Biomass Allocation
LINK FH	Silver Hake Linkage Density	1973	1999	26	B.37	Trophic Dynamics, Energy Flow

OVERHOLTZ BTS, FH	Total Biomass Consumption by 12 piscivores	1977	1997	20	B.38	Biomass Allocation, Energy Flow
LINK BTS, FH	Total fish consumption of 6 piscivores on Georges Bank	1977	1998	21	B.39	Biomass Allocation, Energy Flow
OVERHOLTZ FH, BTS	Consumption of 6 pelagic species by 12 predators	1977	1997	20	B.40	Biomass Allocation, Energy Flow
LINK FH	Food web 1977	1977	1977	1	B.41	Trophic Dynamics, Energy Flow
LINK FH	Food web 1987	1987	1987	1	B.42	Trophic Dynamics, Energy Flow
LINK FH	Food web 1997	1997	1997	1	B.43	Trophic Dynamics, Energy Flow
LINK FH	Cod fish consumption and percent fish in diet	1978	1997	19	B.44	Trophic Dynamics
LINK FH	Cod fish consumption by age class	1978	1997	19	B.45	Trophic Dynamics
LINK FH	Cod percentage diet composition of major fish prey	1973	1997	24	B.46	Trophic Dynamics
LINK FH	Spiny dogfish percentage diet composition of major fish prey	1977	1997	20	B.47	Trophic Dynamics
LINK FH	No. Predators of Major Species	1973	1999	26	B.48	Trophic Dynamics
LINK FH	Silver Hake Cannibalism	1973	1999	26	B.49	Trophic & Population Dynamics, Cycling
LINK FH	Silver and Red Hake Number of Prey	1973	1999	26	B.50	Trophic Dynamics, Energy Flow
OVERHOLTZ FH, BTS	Atlantic Herring Biomass Versus Consumption of Herring by 12 Predators	1977	1997	20	B.51	Biomass Allocation, Energy Flow
OVERHOLTZ FH, BTS	Atlantic Mackerel Biomass Versus Consumption of Mackerel by 12 Predators	1977	1997	20	B.52	Biomass Allocation, Energy Flow
OVERHOLTZ FH, BTS	Loligo Biomass Versus Consumption of Herring by 12 Predators	1977	1997	20	B.53	Biomass Allocation, Energy Flow
JOSSI & O'REILLY MAR	U.S. Northeast Continental Shelf Chlorophyll a	1977	1988	-	N/A	Primary Production
PALKA & SMITH MAM	Abundance of various marine mammals	various		-	Table 4.1	Apex Predators, Population Dynamics, “Canary” Populations
HUMAN METRICS						
EDWARDS OBS	Otter Trawl Landings by Species	1964	2000	36	H.1	Humans as Predators
EDWARDS OBS	Otter Trawl Revenue by Species	1964	2000	36	H.2	Humans as Predators
EDWARDS OBS	Number of Otter Trawl Vessels by Size Class	1964	2000	36	H.3	Humans as Predators

EDWARDS OBS	Otter Trawl Income in Year 2000 Value	1964	2000	36	H.4	Humans as Predators
EDWARDS OBS	Average Otter Trawl Income in Year 2000 Value	1964	2000	36	H.5	Humans as Predators
BRODZIAK OBS	Georges Bank Fishing Effort	1960	1987	27	H.6	Humans as Predators
BRODZIAK OBS	Georges Bank Catch per Unit Effort	1960	1987	27	H.7	Humans as Predators
BRODZIAK OBS, REG	Georges Bank Haddock Observed and Target Fishing Mortality	1931	1998	67	H.8	Human Management
BRODZIAK OBS	Georges Bank cod, haddock, and yellowtail yields	1935	2000	65	H.9	Humans as Predators
OLSON OBS	Total days absent by state of landing	1999	1999	1	H.10, H.11	Human Behavior, Spatial Dynamics
OLSON OBS	Summer flounder catch sites by state of landing and size of catch	1999	1999	1	H.12	Human Behavior, Spatial Dynamics
OLSON OBS	NE Landed Value by County	1994	2001	7	H.13	Human Behavior, Spatial Dynamics
OLSON OBS	NE Number of Federal Permits by County	1997	2001	4	H.14	Human Behavior, Spatial Dynamics
OLSON OBS	Average Days Absent by Location	1999	1999	1	H.15	Human Behavior, Spatial Dynamics
OLSON OBS	Groundfish Landings by Stat Area	1995	2000	5	H.16, H.17	Human Behavior, Spatial Dynamics
OLSON OBS	Pelagics Landings by Stat Area	1995	2000	5	H.18, H.19	Human Behavior, Spatial Dynamics
LINK/EDWARDS OBS	NE Bigeye tuna landings and revenue	1993	1997	4	H.20	Humans as Predators
LINK/EDWARDS OBS	NE Cod landings and revenue	1993	1997	4	H.21	Humans as Predators
LINK/EDWARDS OBS	NE Swordfish landings and revenue	1993	1997	4	H.22	Humans as Predators
BRODZIAK REG	Trawl Fishery Area Closures	1977	2000	23	H.23	Human Management
BRODZIAK REG	Trawl Fishery Mesh Restrictions	1977	2000	23	H.24	Human Management
BRODZIAK REG	Groundfish Vessel Days at Sea Restrictions	1977	2000	23	H.25	Human Management

Figure 2.1. Map of the northwest Atlantic, including the major subregions.