MARINE ECOSYSTEM-BASED MANAGEMENT:
THE INTERACTION OF PEOPLE, NATURE, AND SCIENCE

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MARINE ECOSYSTEM-BASED MANAGEMENT:
THE INTERACTION OF PEOPLE, NATURE, AND SCIENCE

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Interest in applying ecosystem-based management (EBM) to marine ecosystems has grown in recent years, but factors that affect its implementation have not been studied extensively. This dissertation focused on three implementation needs: (1) expanding scientific information about the ecosystem, (2) understanding diverse stakeholders' perceptions and priorities, and (3) incorporating scientific information into management.

One study investigated ecosystem change in the Gulf of Maine based on forty years of fish community data. Substantial compositional changes, shifts in biomass and abundance, and marked reductions in organism size were noted across multiple levels of organization, from individual species to the aggregate community. Many of these changes were concentrated in the mid-1980s and early 1990s, suggesting a rapid biological shift in the ecosystem.

Another study documented the perceptions of six stakeholder groups regarding EBM. Across the groups, stakeholders viewed EBM as building on a foundation of good resource management that is guided by both scientific information and stakeholder input. However, they also expected EBM to account for complexity in the ecosystem and address cross-jurisdictional issues. Despite some common perceptions and goals, key distinctions between groups were also noted, which may affect their ability to work together to implement EBM.

A final study evaluated the effectiveness of ecosystem indicators and state-of-the-environment (SOE) reports for providing stakeholders and decision-makers with scientific information needed to support EBM. Results show that current indicator and reporting programs do not convey fundamental ecosystem concepts, and improvements are necessary to ensure that they build scientific understandings that are relevant to EBM. Together these three studies highlight the utility of interdisciplinary perspectives and the need for strategic advancement of scientific knowledge to meet the goals of marine EBM.

BIOGRAPHICAL SKETCH

Katherine (Kathy) Esther Mills was born on August 26, 1974, to Katherine Harrington Mills and the late Fred McArthur Mills. She was raised in Polkton, North Carolina and graduated as valedictorian from Anson Senior High School in 1992. She attended Duke University in Durham, North Carolina, graduating in 1996 with a B. A. degree in environmental science and policy as well as political science. Kathy's love of the outdoors and of marine environments was evident from a young age, but her academic experiences and independent research endeavors shaped her desire to pursue further education and research in marine ecology and fisheries management.

She entered the graduate program in Natural Resources at Cornell University in 1998. Her M. S. thesis focused on fish communities in estuarine wetlands and ecological factors that influence their composition. In 2001, she was awarded a Knauss Fellowship through Sea Grant and spent a year working in the U. S. Senate Commerce Committee's Subcommittee on Oceans and Fisheries. Following that experience, she returned to Cornell to pursue a Ph. D. that would focus on the interface of fisheries ecology and management.

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I owe a debt of gratitude and incredible thanks to all of the members of my dissertation committee. Mark Bain, my committee chair, has been a valued advisor since I began my graduate studies at Cornell. The hands-on experience, new perspectives, and constant support I gained in working on various projects with him formed the foundation of my training as a research ecologist. Patrick Sullivan has been a key co-advisor on my dissertation. His patience and support enabled me to pursue new quantitative avenues of research and to build confidence in my own statistical and analytical skills. Barbara Knuth played an important role in advising the social science component of my dissertation, willingly taking me on as a student despite my limited previous experience in social science inquiry and analysis. Finally, Wendy Gabriel mentored me through the experience of working with data from the Northeast Fisheries Science Center and facilitated initial interactions with scientists who have extensive backgrounds in the Gulf of Maine and Georges Bank ecosystem.

I was fortunate to secure critical financial support for my dissertation research from a variety of sources. A Population Dynamics Fellowship from the National Marine Fisheries Service and Sea Grant provided three years of core funding for my research. In addition, support from a Heinz Scholarship for Environmental Research substantially covered field research costs. Additional research and travel funding was provided by the Edna Bailey Sussman Fund, SeaSpace Inc., Andrew W. Mellon student research grant, Cornell University Graduate School, Mario Einaudi Center for International Studies, Skinner Memorial Fund (American Fisheries Society), and Marine Fisheries Section (American Fisheries Society). I am thankful to the sponsors of each of these awards. I also received funding through two teaching assistantships from the Department of Natural Resources.

Assistance from several individuals was particularly valuable in the process of completing this research. The incredible time series of data used in the second chapter would not be available without the dedication and commitment of staff in the Ecosystems Surveys Branch of the Northeast Fisheries Science Center, who have maintained the trawl surveys and audited the data from them for over 40 years. Joan Palmer manages the survey databases, and she provided diligent, careful, and quick assistance in retrieving the data I needed for my analyses. Susan Wigley's guidance in orienting me to the databases when I began my research was also valuable. Brian Smith also provided food habits data needed to complete the trophic classifications used in chapter two. I learned so much from other scientists during my stays at the Northeast Fisheries Science Center, but Mike Fogarty and Jason Link were particularly helpful as I was formulating my research ideas. In addition, Anne Richards, Brian Smith, Robert Gamble, and Janet Nye welcomed me into their office space at the Center, and I appreciated their hospitality, friendship, and casual guidance.

Many friends provided essential support throughout the process of completing my dissertation. I enjoyed excellent lab colleagues in Marci Meixler, Kristi Arend, and Nong Singkran throughout my Ph.D. program. They all provided valuable advice that shaped me as a scientist and as a person. Although so many other friends encouraged me along the way, several were always available, understanding, and empathetic: Brian Barringer, Mia Park, Marissa Weiss, Louise McGarry, Noel Gurwick, and Gretchen Gettel.

Finally, I extend my deepest gratitude to my loving and supportive family, who showed incredible patience and provided constant encouragement throughout my degree programs. My mom, Katherine Mills, and sister, Elizabeth Lee, always had motivational words to share and supported me completely in my academic pursuits.

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CHAPTER 1

INTRODUCTION

Overview of ecosystem-based management and its foundations

Humans have long been aware of interactions within and between natural and social components of ecosystems. In contrast to our ability to recognize the importance of these ecosystem interactions, societies have structured environmental management regimes in ways that compartmentalize individual resources and dominant activities. This fragmentation is perhaps nowhere more apparent than in our oceans, where the inherent complexities of studying the ecosystem and the common property nature of resources have caused research and management efforts to focus on individual components rather than the ecosystem as a whole. However, recent attention has shifted towards managing marine ecosystems and the resources that they provide in a more holistic manner through an approach termed ecosystem-based management (EBM) (Pew Oceans Commission 2003, U. S. Commission on Ocean Policy 2004, McLeod and Leslie 2009).

The main tenets of EBM involve approaching environmental management in a manner that accounts for ecological interactions, accommodates multiple human uses, and sustains the ecosystem (Grumbine 1994, Christensen *et al*. 1996, McLeod *et al*. 2005). These three goals and the fact that EBM explicitly includes humans as part of the ecosystem (McLeod *et al*. 2005) require that EBM consider interactions within and between human and natural elements. Instead of scientific pursuits focused on either the ecological system or the social system, implementing EBM necessitates considering how these two systems overlap and how they can be integrated. Thus, interdisciplinary science is critical for supporting EBM.

EBM treats ecosystems as complex adaptive systems, rather than focusing piecemeal on individual parts. Complex adaptive systems are composed of diverse interacting components, and the interactions between the parts can cause abrupt changes in the broader system (Levin 1998). Recognizing the complex nature of ecosystems reinforces that they are not static or stable in time or space, nor do they necessarily change gradually. The propensity for ecosystems to change—sometimes suddenly—means that the resources and services that humans derive from the ecosystem may change rapidly as well. Understanding the dynamic nature of ecosystems should support EBM approaches that build capacities for managing within or adapting to change (Leslie and Kinzig 2009).

In addition to a need for a more nuanced understanding of ecosystems, effective governance systems are necessary for implementing EBM in ways that treat humans as key parts of the ecosystem. While there are many components to a strong governance foundation for EBM, one element involves participation by a broad array of stakeholders (U. S. Commission on Ocean Policy 2004). The involvement of stakeholders in establishing management goals, objectives, and strategies has been recognized as a critical factor determining the success of EBM (Yaffee *et al*. 1996, Cortner and Moote 1999). As the holistic and integrative nature of EBM reaches across multiple sectors and jurisdictions, a larger number and greater diversity of stakeholders will be affected by and engaged in EBM. The expansion of the types of stakeholders that will be affected by EBM means that they will also likely have different interests, concerns, and priorities. Reconciling these priorities within the context of technical understandings of the ecosystem presents a major challenge.

The importance of scientific and governance foundations of EBM have been recognized, but linking these two realms also requires attention. To support EBM, multi-faceted, interdisciplinary technical information about the ecosystem must be understood by stakeholders and integrated into management processes (Christensen et al. 1996, Leschine et al. 2003, Boesch 2006). Achieving this outcome requires condensing voluminous quantities of technical information, while preserving its scientific credibility and legitimacy (Boesch 2006). It also requires translating and presenting this information so that it is understandable and useful to diverse stakeholders (Ferriss and Leschine 2003, Turnhout et al. 2007). Ecosystem indicators offer one approach to accomplishing these goals and building a shared scientific understanding from which multiple stakeholders can engage in management deliberations. However, the extent to which ecosystem indicators convey and advance EBM principles has not been evaluated.

Focus areas and outline of dissertation

This dissertation investigates three themes relevant to the implementation of EBM in marine ecosystems. These focus areas parallel the foundations of EBM outlined above—interdisciplinary science that accounts for ecosystem complexity, expanded stakeholder involvement in the design of EBM, and mechanisms for bringing ecosystem science into management realms. These investigations have broad relevance to questions related to EBM implementation in coastal and marine ecosystems, but much of the work (i.e., Chapters 2 and 3) focuses on the Gulf of Maine ecosystem in the Northwest Atlantic.

The Gulf of Maine is a suitable focus for this research for a number of reasons. First, attention on EBM in the region has increased in recent years due to contentious dilemmas concerning social and ecological trade-offs in fisheries in the region. Further, the multiple political boundaries—five states and provinces as well as an international boundary—provide a realistic but manageable context for assessing governance considerations at large ecosystem scales. Finally, scientific information regarding the Gulf of Maine is among the best available in the world for marine ecosystems. Fish surveys, landings data, and oceanographic monitoring have been conducted frequently and in standardized manners since the early 1960s.

Chapter 2

A key feature of EBM is the ability to adapt to change in both natural and social realms of the ecosystem (McLeod and Leslie 2009). However, our ability to adapt to changing conditions is contingent upon our capacity to detect, understand, and (ideally) predict changes. Scientists recognize that ecosystems can exist in multiple states and abrupt switches between these states can occur (Levin 1998, deYoung *et al.* 2004, Steele 2004). Such regime shifts indicate the importance of developing EBM approaches that accommodate variability and dynamics within the natural system and that enhance resilience to these changes within the social system.

Chapter 2 investigates changes in the Gulf of Maine-Georges Bank ecosystem using data collected during semi-annual bottom trawl surveys conducted by the Northeast Fisheries Science Center. It assesses the nature and timing of changes in the composition and biological features of the fish community to discern whether substantial shifts have occurred. This analysis also compares findings at different scales of biological organization—from individual species to the aggregate community—to determine consistencies or distinctions that occur across scales and to identify appropriate scales for monitoring and assessment.

Chapter 3

Stakeholder involvement has been recognized as an important element of EBM (Yaffee *et al*. 1996, Cortner and Moote 1999). Stakeholder engagement has been shown to improve the quality of decisions, enhance relationships among groups, and strengthen the capacity for managing environmental problems (Yaffee *et al.* 1996, Duram and Brown 1999, Beierle and Konisky 2001). However, few studies have investigated how stakeholder perceptions may influence the implementation of EBM.

Chapter 3 reports findings of interviews with diverse stakeholder groups in the Gulf of Maine. It documents stakeholders' perspectives on EBM, evaluates how those perspectives relate to existing conceptual guidance, and identifies consistencies and differences among the groups in their ideas about what EBM means and what it may accomplish. The results provide a basis for assessing the challenges and prospects for implementing EBM in the Gulf of Maine and offer lessons that can apply to marine ecosystems more broadly.

Chapter 4

An important element of meaningful stakeholder engagement in environmental management is the development of a shared understanding of technical information about the ecosystem (Jacobs 2005, Hartley 2006). This outcome requires that stakeholders have access to technical information that they perceive as salient, credible, and legitimate (McNie 2007) that helps them better understand the ecosystem. Ecosystem indicators are one potential mechanism for making such technical information available to management arenas or stakeholders that participate in management processes (Turnhout *et al*. 2007).

Chapter 4 of the dissertation reviews ecosystem indicators as they are used and interpreted in ten state-of-the-environment reports developed by different types of agencies and programs. It assesses the way in which indicators are used to characterize ecosystems, the types of information they provide, and the process through which they are developed and interpreted against key principles and tenets of EBM (Arkema *et al*. 2006). As indicator and reporting programs continue to expand

and adapt, the findings of this chapter suggest ways in which they can more effectively support EBM by creating a common base of information for diverse stakeholders.

Chapter 5

The last chapter of the dissertation reviews key findings and lessons from the three core chapters to highlight implications of the results for efforts to advance EBM in coastal and marine ecosystems, particularly within the Gulf of Maine.

Recognizing the complexity and dynamism of marine ecosystems, considering stakeholder understandings and expectations, and bridging the gaps between science and management will all be critical elements for supporting EBM. This dissertation addresses these three specific elements, and it also broadly highlights the value and importance of multidisciplinary investigations for advancing marine EBM. The ecological and social insights gained from this research call attention to avenues that may facilitate the implementation of marine EBM as well as issues that will need attention as EBM moves forward.

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CHAPTER 2

COMPOSITIONAL AND BIOLOGICAL CHANGES OF THE FISH COMMUNITY IN THE GULF OF MAINE AND GEORGES BANK

Introduction

Traditionally, fisheries science and management have focused on population dynamics of and fishing impacts on targeted species. However, in recent years, a broader interest has emerged in ecosystem-based management (EBM) (e.g., NMFS 1999, Pew Oceans Commission 2003, U. S. Commission on Ocean Policy 2004). Instead of management goals centered on optimizing harvests of certain species, EBM strives to sustain the productivity of the underlying marine ecosystem (Pikitch *et al*. 2004, McLeod *et al*. 2005, Leslie and McLeod 2007). Successfully expanding the management purview from fish stocks to marine ecosystems requires broadening the scope of scientific information from population to community scales and considering complex ecosystem dynamics (Holling 1973, Folke *et al*. 2004, Mangel and Levin 2005, Levin and Lubchenco 2008).

Expanding the scientific scope is necessary to understand how species interactions, human impacts, and environmental dynamics shape the ecosystem. The interplay between these factors as well as variability within and feedbacks among different levels of organization create complexity in the ecosystem (Hartvigsen *et al*. 1998, Levin 1998), allowing multiple possible ecological outcomes, including the potential for alternate states and rapid regime shifts (Holling 1973, Scheffer *et al*. 2001). The occurrence of a regime shift has substantial ecological and societal implications; detecting and understanding these outcomes requires multi-species and community-scale analyses.

Understanding the nature and pace of change across multiple biological levels of organization can provide important insights into the state, stability, and resilience of an ecosystem. Fish and invertebrate community data, which are available for many marine areas because of the importance of these organisms to fisheries, can provide a useful basis for describing ecosystem changes. Characteristics of multiple populations and the aggregate community have been proposed as indicators of the impact of fishing on marine ecosystems (e.g., Rochet and Trenkel 2003, Mueter and Megrey 2005, Methratta and Link 2006). In addition, it has been recognized that fish and invertebrates integrate independent and interactive effects of numerous factors over a variety of habitats (Karr 1981). As such, changes in the distribution, abundance, and community composition of fish and invertebrates have been used to more broadly evaluate the state or integrity of ecosystems (e.g., Karr 1981, Fausch *et al*. 1984, Deegan *et al*. 1997).

In this chapter, fish and invertebrate community composition and biological attributes are used to assess the nature and timing of changes in the Gulf of Maine and Georges Bank (GOM-GB) ecosystem. These analyses identify the types of changes that have occurred in the GOM-GB fish and invertebrate communities since the late-1960s, evaluate the consistency of changes across different levels of biological organization, and assess whether they provide evidence of an ecosystem regime shift. Findings advance available knowledge about the history of changes as well as the current state of the GOM-GB ecosystem. In addition, they provide insights into the types of scientific information needed to support EBM and strategies that may help sustain fisheries within a complex ecosystem.

Overview of the Gulf of Maine-Georges Bank ecosystem

The GOM-GB region is one of the most productive continental shelf ecosystems in the world (O'Reilly *et al*. 1987), and its rich fishery resources have attracted fishermen for centuries (Serchuk and Wigley 1992, Kurlansky 1997, Mills 2006). Specific changes in fish community composition have been well-described, including a substantial decline in groundfish, a decimation and subsequent resurgence of pelagic fishes, and a marked increase in elasmobranches (Mayo *et al*. 1992, Fogarty and Murawski 1998, Overholtz *et al*. 2000). These changes have often been associated with the direct and indirect effects of fishery exploitation (Mayo *et al*. 1992, Fogarty and Murawski 1998), but the influence of predation (Overholtz *et al*. 2000, Overholtz and Link 2007), environmental conditions (Serchuk *et al*. 1994, Pershing *et al*. 2005) and species range shifts (Frisk *et al*. 2008) have also been investigated. While the research noted above has focused on key species in the GOM-GB ecosystem, a large number of additional species comprise the fish and invertebrate community of the region, and compositional and biological changes for the full community have been less studied.

Assessing ecosystem changes

Ecosystem changes can be evaluated through a variety of measures, but this chapter focuses on changes in community composition and biological features as indicators of ecosystem shifts in the Gulf of Maine and Georges Bank region. Changes in community composition reflect interactions between populations; in turn, the resulting community shapes the ecosystem's structure and function. As such, community composition can serve as a valuable measure of ecosystem stability or change. In addition, a number of biological features have been evaluated as indicators of the status of marine ecosystems generally (Rice 2003, Rochet and Trenkel 2003, Trenkel and Rochet 2003) and of the Northeast United States continental shelf region specifically (Link *et al*. 2002, Link 2005, Methratta and Link 2006). Trends in abundance, biomass, and organism size integrate the influences of multiple potential drivers, including fishing pressure, environmental conditions, and species interactions (e.g., Greenstreet and Hall 1996, Jennings *et al*. 1999, Trenkel and Rochet 2003, Frisk *et al*. 2008). These features will be evaluated to better understand the types and nature of changes in the GOM-GB ecosystem.

While composition is exclusively a community-level feature, other biological attributes can be assessed across multiple levels of organization, from individual species to species groups to the aggregate community. The value of comparisons across organizational levels extends from the fact that species populations are typically more sensitive to perturbations than aggregate ecosystem properties (Odum 1985, Schindler 1990). The reduced variability at higher levels of organization is attributed to fungibility among species, which may mask changes at an aggregate level even though substantial changes may occur at species or assemblage scales (Schindler 1990, Frost *et al*. 1995, Steele 1998). Further, lower-level changes may create distinct dynamics that shape higher-order patterns. Thus, there is value in assessing ecosystem change across multiple levels of organization (e.g., Rochet and Trenkel 2003, Trenkel *et al*. 2004). In this chapter, data from a long-term survey of fish and invertebrates in the GOM-GB region will be used to evaluate the consistency of biological changes across species, group, and community scales.

One particular type of change that may be experienced by marine ecosystems is a regime shift, or a transition from one relatively stable state to a distinctly different state (deYoung *et al.* 2004, Steele 2004). Regime shifts represent persistent changes in the structure of an ecosystem, and their reversibility is questionable (deYoung *et al*. 2004, Hsieh *et al*. 2005); as such, they have important implications for managing resources within an ecosystem (Rothschild and Shannon 2004). Regime shifts have been noted across multiple components of some marine ecosystems, often as biological responses to physical or anthropogenic influences (e.g., Conners *et al*. 2002, Beaugrand 2004, Alheit *et al*. 2005, Daskalov *et al*. 2007) but also as coherent biological changes in the absence of known external drivers (e.g., Hare and Mantua 2000). In the GOM-GB region, regime shifts have been investigated primarily as changes in climate conditions (Loder *et al*. 2001, Friedland and Hare 2007), but related changes in plankton community composition and fish recruitment have been noted (Drinkwater and Mountain 1997, Greene and Pershing 2001, Pershing *et al*. 2005). In this chapter, the question of regime shifts in the GOM-GB region is approached from an alternate perspective by focusing on the biological community and assessing changes therein for evidence of an ecosystem regime shift. This approach can be used to identify the nature and timing of substantial changes in the GOM-GB ecosystem, from which further investigations can explore a range of potential explanatory factors.

Methods

Study area

The GOM-GB region is bordered on the north and west by Nova Scotia, New Brunswick, Maine, New Hampshire, and Massachusetts. The region mixes at the surface with the North Atlantic Ocean, but the large (300 x 150 km) underwater plateau of Georges Bank semi-encloses the Gulf and forms its southeastern boundary. The Gulf of Maine is characterized by three deep basins (>200 m) separated by shallow ridges and banks. In contrast, depths on Georges Bank are around 50 m, with some areas as shallow as 20 m (Serchuk *et al*. 1994). Oceanographically, both the Gulf of Maine and Georges Bank are part of an extended coastal current system that flows southward from Labrador. Water masses circulate around the Gulf of Maine in a counter-clockwise motion, while a clockwise gyre moves water over Georges Bank (Wahle 2000). Water motions are dominated by strong tidal currents, which keep the water mixed and promote productivity in the region (Serchuk *et al*. 1994, Wahle 2000). Despite the distinct oceanographic patterns in the Gulf and on Georges Bank, species composition is similar in both areas. However, seasonal migrants and temperate species are more commonly observed on Georges Bank than in the Gulf of Maine.

Data source

The data used in this study were gathered during seasonal bottom trawl surveys conducted by the Northeast Fisheries Science Center (NEFSC) between 1967 and 2007 (Azarovitz 1981, NEFC 1988). The surveys employ a stratified random sampling design, with strata defined based on latitude and depth (Azarovitz 1981). The GOM-GB region is only a portion of the full spatial extent of the survey. As such, NEFSC offshore survey strata 13 to 40 were used to delineate the study region; data from strata 31, 32, and 35 were excluded due to changes in US-Canadian jurisdictions that affected the consistency of sampling in those areas (Figure 2.1). On average, approximately 270 stations were sampled each year in the study area (min=124; max=493). Data from spring and fall surveys were aggregated into annual values, and non-representative tows (i.e., those with short tow durations or substantial gear problems during the tow) were excluded from the data set. As the trawl net, trawl doors, and survey vessel have changed over time, species-specific correction factors (Sissenwine and Bowman 1978, Byrne and Forrester 1991) were applied to both the biomass and numbers reported in the catch data to standardize all records to the 2007

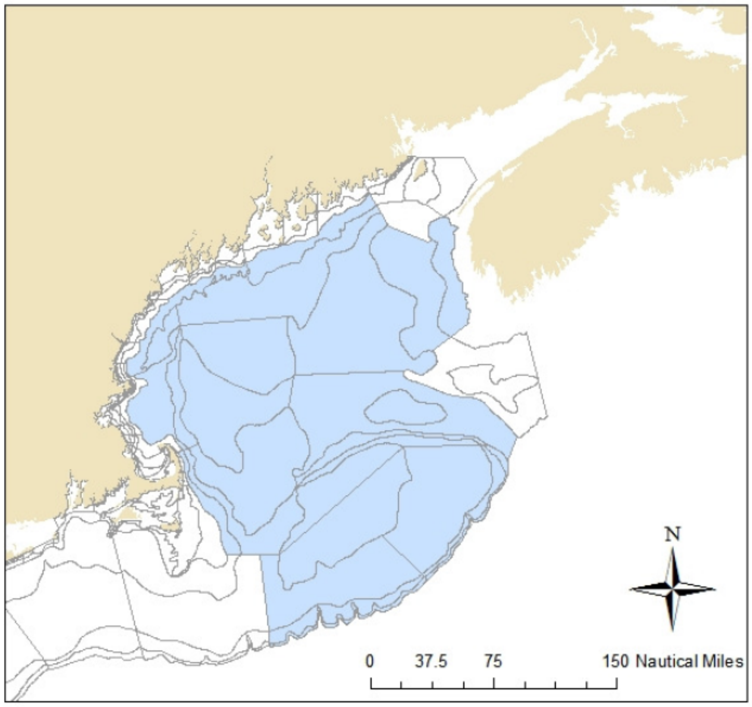

Figure 2.1. Map of the Gulf of Maine-Georges Bank study area. The trawl survey strata are outlined throughout the region, and strata used for this study are highlighted in blue.

survey configuration (i.e., Yankee No. 41 trawl with polyvalent doors fished by the *R/V Albatross IV*).

Data compilation

Compilation of community matrix

A composition matrix was compiled based on the stratified mean biomass per tow for all species[1] that were observed in more than four years between 1967 and 2007. Using species that were recorded in more than four years reduced the data set

[1] Shrimp species were all merged into one aggregate data series to be consistent with the early years of the survey when shrimp were not identified to species. Only the biomass of the total shrimp catch has been consistently recorded across the time series of the survey, so numbers per tow, mean length, and mean weight were not analyzed. In addition, inconsistencies in the database create the potential for double-counting shrimp biomass; to mitigate this situation, the maximum of either the 'shrimp unclassified' biomass or the total biomass associated with all shrimp species at each sampling station was used to compute the annual biomass of shrimp.

from 244 observed species to 138 analyzed species (Appendix A). Prior to computing the stratified means, the data set was adjusted by adding a small value (0.01 kg) to species biomasses in cases when a species was present in the sample but its biomass was recorded as zero. This situation occurred when the total biomass of the species could not be measured due to the resolution of the balance or other challenges of measuring small biomasses at sea. Making this adjustment distinguished very small biomass records from true zeros (i.e., the absence of a species) in the sampling record.

Compilation of biological features

Data on five biological attributes were compiled as key indicators: (1) frequency of occurrence (FO) in the survey, (2) mean biomass per tow, (3) mean number per tow, (4) mean individual length, and (5) mean individual weight. These features can be calculated and analyzed for all species combined, key groups of species, or individual species of interest.

The FO represents the proportion of tows in each year containing a given taxon. It eliminates the influence of exceptionally large catches and reflects the probability of capturing a taxon in an "average" tow. The biomass and number of organisms per tow were computed as annual stratified means based on the area within each survey strata. The mean length of a taxon was calculated as an annual arithmetic mean for surveyed organisms. The mean individual weight was calculated by dividing the total biomass of a taxon in each tow by the total number of organisms of that taxon in the tow and then computing the annual arithmetic mean over all tows.

Data on biological attributes of fish and invertebrates in the GOM-GB region were compiled at hierarchical levels of aggregation. At the highest level of aggregation, all species were combined into one community-level metric. An intermediate level of aggregation combined key groups of species based on taxonomic[2] (i.e., groundfish, demersals, elasmobranches, pelagics, and invertebrates), trophic (i.e., benthivores, piscivores), or economic[3] (i.e., commercial, non-commercial) classifications (Appendix A). In addition, species-level analyses were conducted for 49 species[1] that were observed in all years of the survey (Appendix A).

Trophic group categorizations were based on guilds developed in Garrison and Link (2000a). Species diets were assessed for each 10-cm size interval using results from Garrison and Link (2000a) or quantitative stomach contents data from the NEFSC food habits database (Bowman and Michaels 1984, NEFSC 2008) to discern ontogenetically-specific feeding habits and the size at which shifts occur (Appendix B). Species for which adequate diet data were available (i.e., more than 10 stomachs per 10-cm size category) to conduct trophic analyses represented over 97% of the total fish community biomass between 1967 and 2007. Species and size categories associated with benthivory and piscivory were identified (Appendix A, Appendix B) and used for further analyses. As biomass does not scale linearly with length, the biomass per tow represented by benthivores and piscivores was calculated using length-weight relationships in Wigley *et al*. (2003) to determine the proportional biomass of a species within size categories analogous to each trophic guild.

Data analysis

Community composition analysis

Temporal changes in overall species composition were analyzed using non-metric multidimensional scaling (NMS) with varimax rotation (Kruskal 1964a, 1964b)

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[2] The 'groundfish' category included all gadids (e.g., cod and haddock) and flatfish (e.g., flounders and halibut). The 'demersal' group encompassed all other bottom-dwelling finfish. The 'invertebrate' category included shellfish, cephalopods, and crustaceans.

[3] All species managed by the New England Fishery Management Council, Atlantic States Marine Fisheries Commission, or state fishery management agencies in Massachusetts, New Hampshire, and Maine were considered part of the 'commercial' group. All other species were classified as 'non-commercial.'

as implemented in PC-ORD version 4.34 (McCune and Mefford 1999). NMS is a multivariate ordination technique suitable for non-normal, zero inflated data sets and that has been demonstrated to accurately represent the original data structure (Minchin 1987, Clarke 1993, McCune and Grace 2002). It uses an iterative process to configure the points such that the ranked distance of their dissimilarity in the original space is preserved in the reduced dimensions of the ordination space (Legendre and Legendre 1998, McCune and Grace 2002). The final solution optimizes the goodness-of-fit between the rank order of the fitted distances and the ranks of the original distances within a specified number of dimensions; this solution is evaluated by minimizing an objective function representing stress. In PC-ORD, stress is computed using the following formula, where d is the distance between two observations:

$$S = \sqrt{\sum_{i,j} (d_{ij} - \hat{d}_{ij})^2 / \sum_{i,j} d^2_{ij}}$$

The composition data set was standardized by adjusting each species to a proportion of its maximum abundance. Compositional dissimilarity between years was quantified using the Relative Sorensen distance measure (McCune and Grace 2002). This distance measure quantifies the proportional abundance of species shared by two sample units, while standardizing by sample unit totals such that each contributes equally to the distance measure:

$$D_{ih} = 1 - \left[\sum_{j=1}^{p} MIN \left(\frac{a_{ij}}{\sum_{j=1}^{p} a_{ij}}, \frac{a_{hj}}{\sum_{j=1}^{p} a_{hj}} \right) \right]$$

The appropriate dimensionality for the ordination was determined by first running NMS with 50 runs for each of six dimensions, using a random starting configuration and a stability criterion of 0.00001. The lowest dimension was chosen that substantially reduced stress compared to the next lowest dimension (McCune and Grace 2002). To ensure that the final ordination avoided a local stress minimum, the analysis was then run 1000 times with random initial configurations, subject to the same parameters as above. The run resulting in the lowest final stress was used for subsequent analyses. A varimax rotation was applied to the solution, and the coefficient of determination (r^2 expressed as a percentage) between distances in the ordination space and distances in the original space was calculated to assess the variance explained by each axis.

Major transitions in community composition were determined by applying the change-point analytic procedure described below to annual scores on each NMS axis. Time periods identified before and after the change-points were used to further evaluate distinctions in community composition. A multi-response permutation procedure (MRPP; Biondini *et al*. 1985) was implemented in PC-ORD (version 4.34; McCune and Mefford 1999) to test the null hypothesis of no difference in the community composition between the time periods. The MRPP uses a randomization procedure to evaluate differences, thereby avoiding distributional requirements of alternative procedures such as multivariate analysis of variance (McCune and Grace 2002). The tightness of the groups was evaluated using the chance-corrected within-group agreement statistic, *A*, which describes the within-group homogeneity relative to random expectations (McCune and Grace 2002).

Following the MRPP, an indicator species analysis was used to identify species that contributed to community differences in the two time periods (Dufrêne and Legendre 1997, McCune and Grace 2002). The indicator species analysis integrates a species' proportional abundance and constancy in each time period into an indicator value that ranges from 0 (no indication) to 100 (perfect indication). The significance of the indicator value for each species was assessed using a Monte-Carlo test based on

1000 permutations (McCune and Grace 2002). Only species that were significant indicators ($p<0.05$) of a time period were interpreted further.

Change-point analysis

For each data series, non-parametric analyses were used to detect change-points and characterize the nature of those changes based on procedures described in Lanzante (1996). The change-point analysis first relies on a rank sum test to identify one primary change in each time series; secondary change-points are not identified in this study. The significance of this primary change-point is assessed with a Mann-Whitney test, and the nature of the transition at that change-point is evaluated using a signal-to-noise ratio. Although developed for analyzing climate data, these procedures have been applied to fish survey data by Conners *et al*. (2002).

First, a rank sum test identified the point at which the primary shift in the median level occurred in each time series. The test is based on the sum of the ranks of the data from the beginning to each point in the series, *i*:

$$SR_i = \sum_{j=1}^{i} R_j$$

Each raw sum was adjusted by an amount expected on average, which is linearly proportional to the point in the time series:

$$SA_i = |(2SR_i) - i(n+1)|$$

The maximum of the adjusted statistic was assessed for significance using a Mann-Whitney test to compare the two portions of the data series on each side of the change-point.

The nature of the change-point (e.g., step transition vs. gradual change) was assessed using a signal-to-noise ratio (Lanzante 1996). The measure is the ratio of the variance associated with the discontinuity of the mean (i.e., the "signal") to the variance that remains after the discontinuity is removed (i.e., the "noise"):

$$R_{DN} = \frac{s^2_D}{s^2_N}$$

Biweight estimates of the mean and variance were used to increase resistance and efficiency of the estimators. First, the biweight mean estimate of the two segments ($\overline{XL}$ and $\overline{XR}$) to the left and right of the change-point was computed and used to define an overall mean:

$$\overline{X} = \frac{(n_L\overline{XL}) + (n_R\overline{XR})}{n}$$

An estimate of the variance associated with the change-point was computed as:

$$s^2_D = \frac{n_L(\overline{XL} - \overline{X})^2 + n_R(\overline{XR} - \overline{X})^2}{n - 1}$$

The noise variance, s^2_N, is computed by normalizing the left and right segments and calculating the biweight variance over the two normalized segments combined, x:

$$s^2_N = \frac{\sum_{i=1}^{n} (x_i - \tilde{X})^2 (1-u_i^2)^4}{(\sum_{i=1}^{n} (1-u_i^2)(1-5u_i^2))^2}$$

where $\tilde{X}$ = median(X) and summation is restricted to $u_i^2 \leq 1$, with $u_i = \frac{x_i - \tilde{X}}{9(MAD)}$ where MAD=median absolute deviation.

Reeves *et al*. (2007) used simulation analyses to evaluate the performance of non-parametric change-point tests such as the one applied herein compared to other change-point detection techniques. They demonstrate that this family of tests displays >95% accuracy in selecting the correct model when no change-point exists (e.g., $Y_t=\mu$, where t is a point in the time series) in the data. When a change-point does exist in the data series (e.g., $Y_t=\mu+\Delta I(t>c)$, where c is the time of a change-point), the non-parametric procedures have the highest power in selecting the correct model and closely estimating the time of the change. However, trends in the time series are not accounted for by this type of change-point detection method. In models with a trend but no change-point, these types of tests increasingly (and incorrectly) identify a change-point as the magnitude of the trend increases. And in models with a trend element and a change-point, the correct identification of a change-point and its location increases with the magnitude of the change. Although no change-point detection methods perform well in all scenarios, the non-parametric Mann-Whitney test ranks among the best if the primary interest is in detection and location of a change-point.

Results

Composition analysis

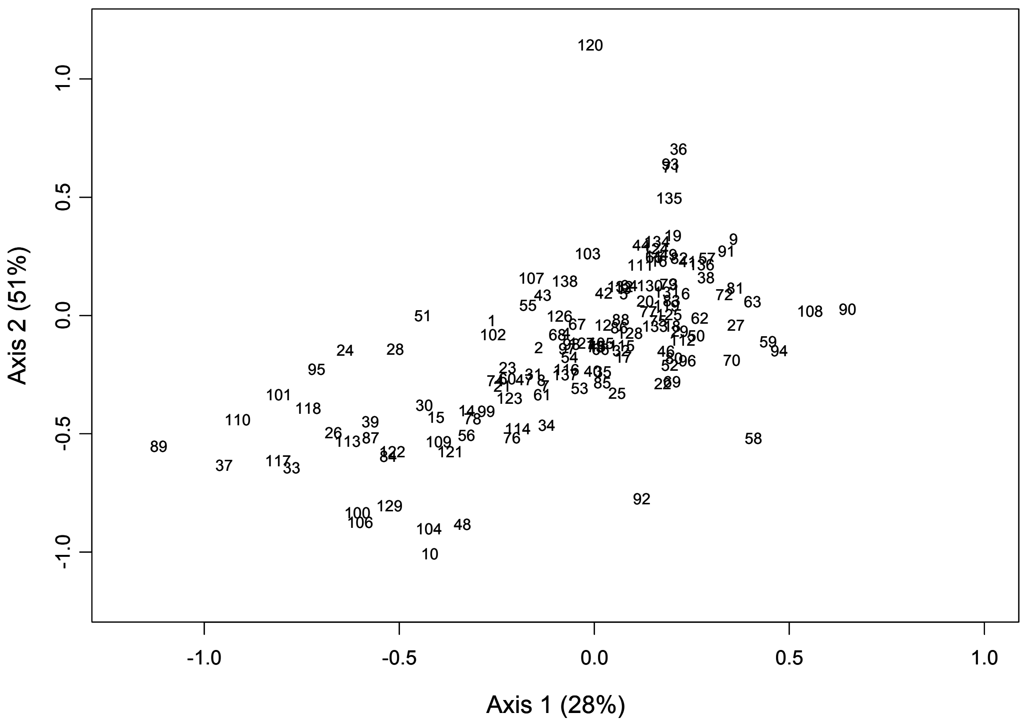
A three-dimensional ordination was chosen for examining patterns of change in fish and invertebrate community composition from 1967 to 2006 (Figures 2.2 and 2.3). A Monte Carlo test confirmed that the three-dimensional solution provided significantly more reduction in stress than expected by chance (p=0.02). The ordination had a final stress of 10.8, indicating a limited risk of drawing false inferences (Clarke 1993, McCune and Grace 2002); the three axes accounted for 90.4% of the variation in the dataset.

Scores on each axis showed shifts in species composition in the GOM-GB region between 1967 and 2007 (Figure 2.2). The first axis, which accounted for 28%

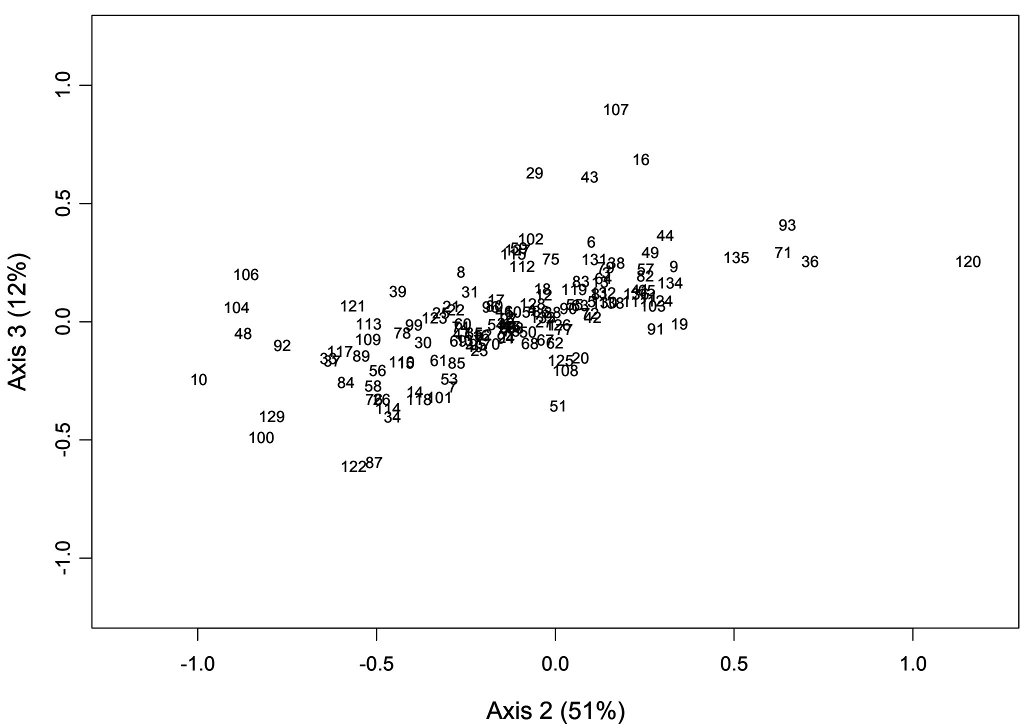
Figure 2.2. Orientation of species on the a) first and second NMS axes and b) second and third NMS axes. Species scores on each NMS axis reflect distances between species over all years of the survey. The key to species is as follows:

1 Acadian redfish
2 Alewife
3 Alligatorfish
4 American lobster
5 American plaice
6 American sand lance
7 American shad
8 Armored searobin
9 Atlantic argentine
10 Atlantic brief squid
11 Atlantic cod
12 Atlantic hagfish
13 Atlantic halibut
14 Atlantic herring
15 Atlantic mackerel
16 Atlantic menhaden
17 Atlantic rock crab
18 Atlantic saury
19 Atlantic sea snail
20 Atlantic silverside
21 Atlantic soft pout
22 Atlantic surfclam
23 Atlantic torpedo
24 Barndoor skate
25 Barracudina (uncl)
26 Bathyal swimming crab
27 Bay anchovy
28 Bigeye
29 Black sea bass
30 Blackbelly rosefish
31 Blueback herring
32 Bluefish
33 Bobtail (uncl)
34 Buckler dory
35 Butterfish
36 Cancer crab (uncl)
37 Common octopus
38 Conger eel
39 Conger eel (uncl)
40 Cunner
41 Cusk
42 Daubed shanny
43 Deepwater flounder
44 Eel (uncl)
45 Fawn cusk-eel
46 Fourbeard rockling
47 Fourspot flounder
48 Galatheid (uncl)
49 Goosefish
50 Greeneye (uncl)
51 Greenland halibut
52 Grenadier (uncl)
53 Grubby
54 Gulf stream flounder
55 Haddock
56 Hatchetfish (uncl)
57 Hookear sculpin (uncl)
58 Iceland scallop
59 Inquiline snailfish
60 Jonah crab
61 Lady crab
62 Lanternfish (uncl)
63 Ling (uncl)
64 Little skate
65 Longfin hake
66 Longfin squid
67 Longhorn sculpin
68 Lumpfish
69 Mackerel scad
70 Margined snake eel
71 Marlin-spike
72 Moustache sculpin
73 Northern pipefish
74 Northern searobin
75 Northern shortfin squid
76 Northern stone crab
77 Ocean pout
78 Octopus (uncl)
79 Offshore hake
80 Pipefish (uncl)
81 Planehead filefish
82 Pollock
83 Radiated shanny
84 Rainbow smelt
85 Red deepsea crab
86 Red hake
87 Righteye flounder (uncl)
88 Rock gunnel
89 Rosette skate
90 Rough scad
91 Round herring
92 Round scad
93 Scaly dragonfish (uncl)
94 Scorpionfish (uncl)
95 Sculpin (uncl)
96 Scup
97 Sea lamprey
98 Sea raven
99 Sea scallop
100 Shield bobtail
101 Shorthorn sculpin
102 Shortnose greeneye
103 Shrimp (uncl)
104 Silver anchovy
105 Silver hake
106 Silver rag
107 Slender snipe eel
108 Slope hatchetfish
109 Smallmouth flounder
110 Smooth dogfish
111 Smooth skate
112 Snake blenny
113 Snake eel (uncl)
114 Snow crab
115 Spider crab (uncl)
116 Spiny dogfish
117 Spoonarm octopus
118 Spotfin dragonet
119 Spotted hake
120 Squid (uncl)
121 Striped anchovy
122 Striped bass
123 Summer flounder
124 Thorny skate
125 Three-spine stickleback
126 Tonguefish (uncl)
127 Viperfish
128 Weitzman's pearlsides
129 White barracudina
130 White hake
131 Windowpane flounder
132 Winter flounder
133 Winter skate
134 Witch flounder
135 Wolf eelpout
136 Wolffish
137 Wrymouth
138 Yellowtail flounder

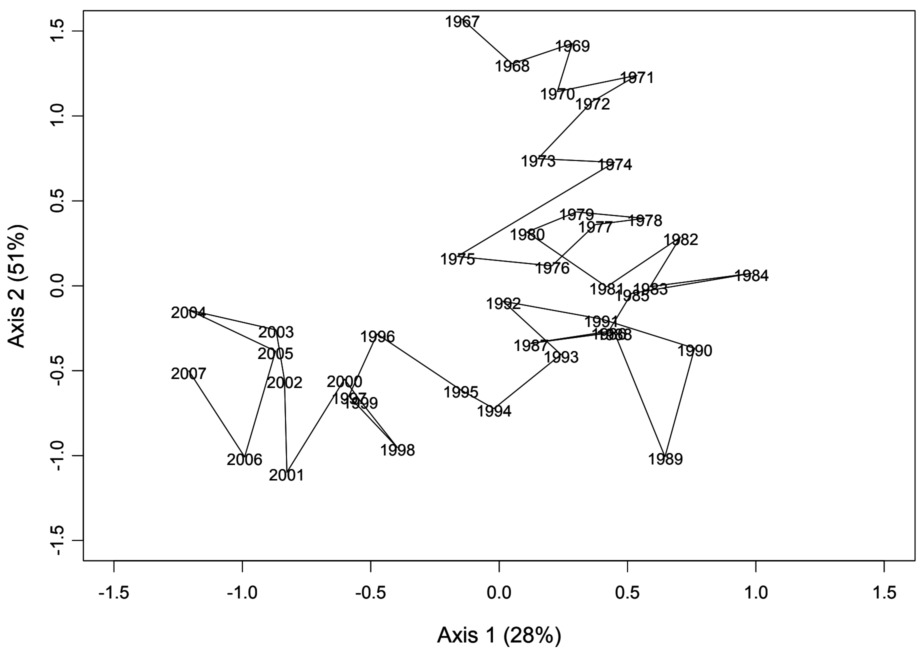
a.



b.



a.



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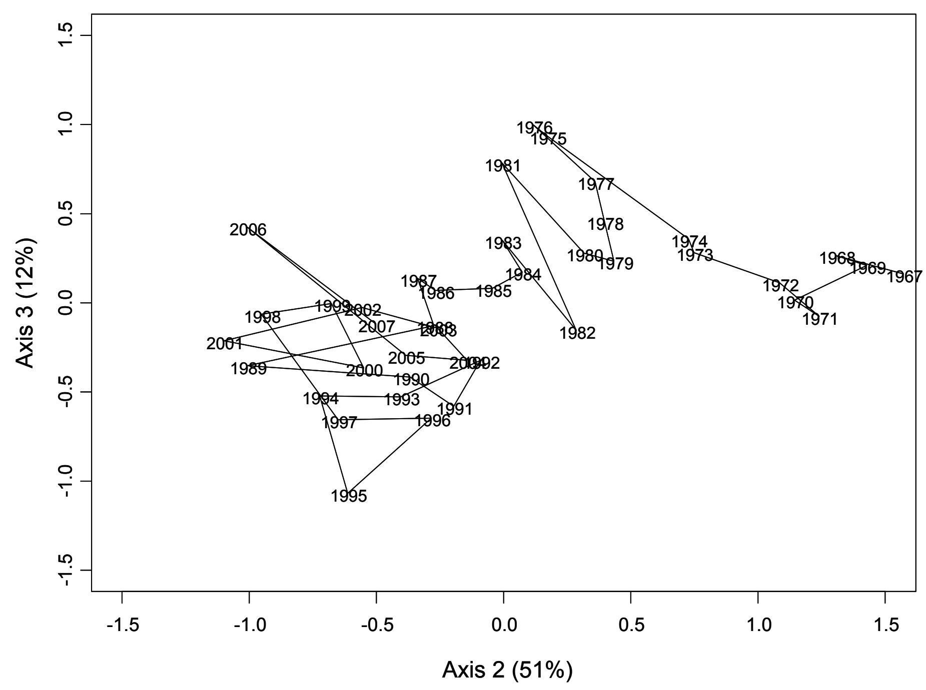


Figure 2.3. Orientation of years on the a) first and second NMS axes and b) second and third NMS axes. Annual scores on each NMS axis reflect distances between years based on their fish and invertebrate community composition.

of the variance, oriented species that peaked in biomass during later years of the time series (e.g., rosette skate, smooth dogfish; Figure 2.2a, Appendix C) at the lower extreme; the positive end of this axis was characterized by species that were prevalent during the middle portion of the time series (e.g., rough scad, hatchetfish). The second axis captured 51% of the variance in the data set; the low end of this axis represented species that were prevalent in late years of the time series (e.g., Atlantic brief squid, silver anchovy; Figure 2.2a, Appendix C), while the positive extreme represented those with higher biomasses in early years (e.g., squid (unclassified), *Cancer* crabs (unclassified), marlin-spike; Figure 2.2b, Appendix C). The third axis accounted for 12% of the variance. Its extremes were represented by species that were rarer in the survey, with the positive extreme representing those that showed spikes in early years (e.g., slender snipe eel, Atlantic menhaden) and the negative extreme capturing those that peaked in later years (e.g., striped bass, righteye flounder (unclassified)).

The ordination of years on the first and second axes shows early years of the time series (e.g., 1967-1980) oriented towards the positive extreme of axis two, with later years in its negative range (Figure 2.3a). Those years positioned in the negative range of axis two shift from an orientation on the positive portion of axis one during the 1980s to early 1990s towards the negative portion of axis one during the late 1990s and 2000s. Earlier years, which have high values on axis two, remain fairly stable near the center of axis one (Figure 2.3a). The ordination of axes two and three shows the mid-1970s to early 1980s clustered on the positive extreme of axis three, and the early to mid-1990s clustered at the negative extreme of axis three; the earliest and latest years of the time series lie near the center of axis three (Figure 2.3b).

Annual values on each NMS axis indicate change-points in 1991 for axis 1, 1985 for axis 2, and 1987 for axis 3 (Figure 2.4). The change-points for axes 1 and 2 conform to a step-change model, with R_{DN} above 1.0 for each of these transitions

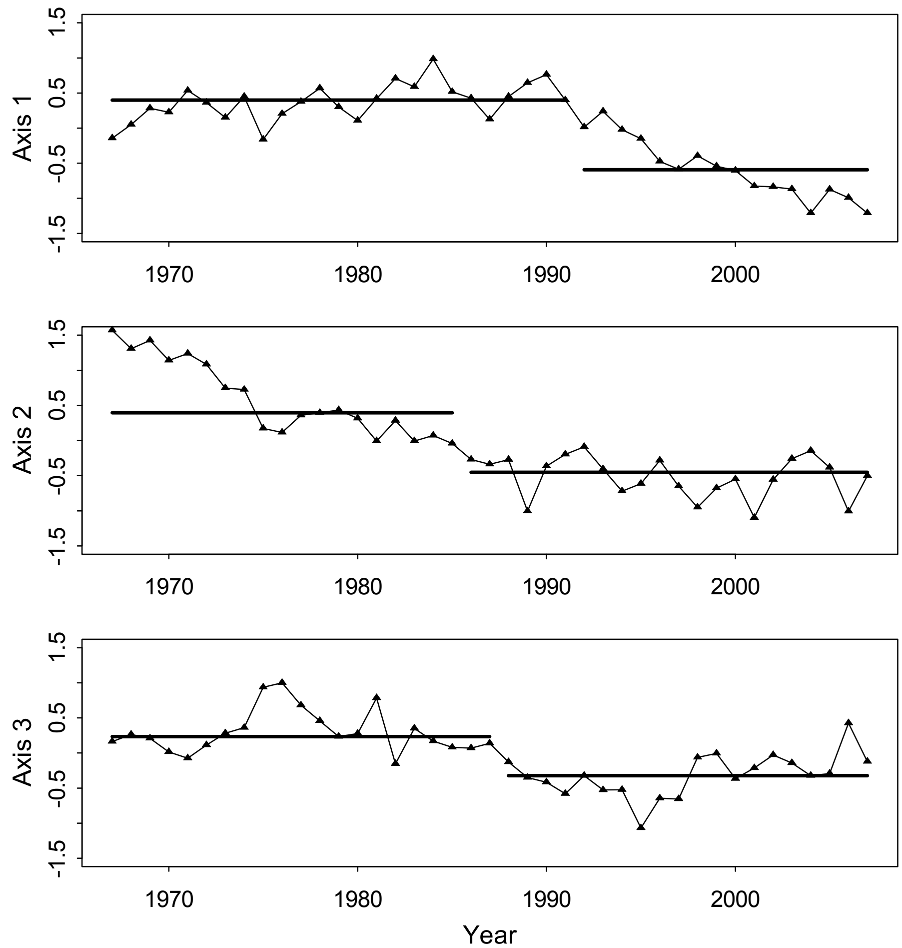


Figure 2.4. Time series of annual scores on each NMS axis. The year in which the primary change-point occurs is located at the break in the straight horizontal lines (i.e., 1991 for ordination scores on axis 1, 1985 for axis 2, and 1987 for axis 3). The horizontal lines represent the median of the ordination scores before and after the change-point in the data series.

(1.959 and 1.555, respectively); R_{DN} for axis 3 (0.863) indicated that a step function was not appropriate. The period from 1984 to 1992 appears to represent a major transition in the fish and invertebrate community. Based on this result, two distinct periods (i.e., 1967-1984 and 1992-2007) can be defined for further investigation of compositional differences.

A MRPP confirmed significant differences in species composition for the 1967-1984 and 1992-2007 time periods (A=0.431, p=0.0). The computed value of *A* indicates a fairly high level of homogeneity within the two time periods (McCune and Grace 2002). An indicator species analysis showed that 59 of the 138 species analyzed made significant contributions ($p \leq 0.05$) to this compositional difference (Table 2.1). The species most strongly indicative of the 1967-1984 time period included several species of groundfish (e.g., pollock, witch flounder, windowpane flounder, Atlantic cod), skates (i.e., thorny, little, and smooth), several other demersal fish species (e.g., goosefish, hookear sculpin, wolffish), and a few pelagic species (i.e., Atlantic argentine, dragonfish). The species most strongly associated with the 1992-2007 time period included several elasmobranches (i.e., spiny dogfish, barndoor skate, smooth dogfish), major pelagic species (e.g., Atlantic herring, Atlantic mackerel), several demersal species (e.g., blackbelly rosefish, grubby), and a variety of invertebrates, including both crustaceans (e.g., lady crab, Northern stone crab, queen crab) and cephalopods (e.g., spoonarm and common octopus).

Analyses of changes in biological attributes

Change-points were identified for survey time series data associated with five biological attributes (i.e., frequency of occurrence (FO), mean biomass per tow, mean number per tow, mean length, and mean weight) at three levels of organization (i.e.,

Table 2.1. Indicator values of species associated with the two time periods of interest. The left panel shows species that are strongly associated with the 1967-1984 time period, while the right panel shows those that are strongly associated with 1992-2007 period. The potential range of the values spans from 0 (no indication) to 100 (perfect indication). The table shows only species with indicator values that are significant at $p \leq 0.05$.

	Indicator Value				Indicator Value		
Species	**1967-1984**	**1992-2007**	**p-value**	**Species**	**1967-1984**	**1992-2007**	**p-value**
Atlantic argentine	89	11	0.001	Northern stone crab	2	93	0.001
Hookear sculpin, uncl.	85	15	0.001	Atlantic herring	11	89	0.001
Goosefish	83	17	0.001	Atlantic mackerel	15	85	0.001
Pollock	80	20	0.001	Blackbelly rosefish	17	83	0.001
Cusk	78	22	0.001	Bobtail, uncl.	0	81	0.001
Wolffish	78	22	0.001	Spoonarm octopus	0	81	0.001
Witch flounder	77	23	0.001	American shad	23	77	0.001
Windowpane flounder	76	24	0.001	Snow crab	2	77	0.001
Longfin hake	73	27	0.001	Fourspot flounder	31	69	0.001
Atlantic cod	72	28	0.001	Spiny dogfish	35	64	0.001
Thorny skate	72	28	0.001	Snake eel, uncl.	1	49	0.001
Little skate	68	32	0.001	Octopus, uncl.	9	75	0.002
Smooth skate	68	32	0.001	Jonah crab	27	66	0.002
White hake	66	34	0.001	Smooth dogfish	2	65	0.002
Winter flounder	64	36	0.001	Striped bass	0	49	0.002
American plaice	62	38	0.001	Barndoor skate	16	79	0.003
Offshore hake	88	8	0.003	Lady crab	13	71	0.003
Moustache sculpin	77	23	0.003	Red crab	20	70	0.003
Marlin-spike	64	4	0.004	Greenland halibut	1	56	0.003
Cancer crab, uncl.	55	0	0.012	Common octopus	0	44	0.003
Dragonfish, uncl.	39	0	0.012	Sea raven	42	58	0.004
Atlantic halibut	68	32	0.017	Hatchetfish, uncl.	1	49	0.004
Round herring	41	1	0.019	Buckler dory	3	61	0.005
Atlantic menhaden	37	0	0.025	Bathyal swimming crab	0	38	0.007
Northern sand lance	84	16	0.035	Shield bobtail	0	38	0.009
Northern shortfin squid	71	29	0.050	Grubby	11	75	0.012
				Righteye flounder, uncl.	0	42	0.012
				Cunner	34	66	0.017
				Acadian redfish	39	61	0.018
				Galatheid crab, uncl.	0	31	0.018
				Silver rag	0	35	0.020
				Summer flounder	23	61	0.021
				Northern searobin	26	69	0.031
				White barracudina	0	31	0.036
				Spotfin dragonet	0	25	0.038
				Alewife	41	59	0.041
				Smallmouth flounder	0	25	0.042

aggregate, group, and species). The biological conditions before and after each change-point as well as the timing and nature of each change-point are interpreted.

Changes in biological conditions associated with change-points

The FO of species in the survey showed no change at the aggregate community level, as organisms were present in nearly all survey tows (Table 2.2). The FO of the groundfish group, which comprises the dominant portion of the catch in the bottom-trawl survey, also showed no change. For all other groups, significant changes in the FO were noted before and after their detected change-point, but the direction of change varied. The FO increased for the demersal, pelagic, invertebrate, commercial, and non-commercial groups after their associated change-points; declines were noted for elasmobranches, benthivores, and piscivores (Figure 2.5). Similar patterns of change in FO were noted for the individual species analyzed in most groups (Appendix D). Increases and declines in the FO were fairly evenly balanced for the groundfish species. Most demersal (69%), pelagic (86%), invertebrate (100%), commercial (70%), and non-commercial (61%) species appeared in the survey with increasing frequency after the change-point. Consistent with the group pattern, the FO of most benthivorous species (64%) declined after their change-points. However, inconsistencies were noted between the group- and species-level results for elasmobranches and piscivores. For the three elasmobranch species with significant changes in FO, two increased and one declined after their change-points; for piscivores, 56% showed an increase and 44%, a decline.

The mean biomass per tow at the aggregate community level showed a slight, but non-significant, decline after the detected change-point (Table 2.2, Figure 2.5). Significant differences in the biomass per tow were found for all taxonomic and trophic groups examined in this analysis. The biomass per tow of groundfish and

Table 2.2. Year of primary change-points and the associated discontinuity signal-to-noise ratio (R_{DN}) for each variable. Years in bold indicate a statistically significant change-point ($p \leq 0.01$) based on a Mann-Whitney test of values before and after the change-point. Bold R_{DN} values (R_{DN}>1.0) indicate strong fits to a step-change model.

	Occurrence frequency		Mean biomass/tow		Mean number/tow		Mean length		Mean weight	
Aggregation level	Year	R_{DN}	Year	R_{DN}	Year	R_{DN}	Year	R_{DN}	Year	R_{DN}
All species combined	1985	NA	1982	0.164	**1991**	0.490	**1988**	**1.402**	**1988**	**3.448**
Groups										
Groundfish	1980	0.039	**1985**	**1.546**	**1972**	0.423	**1988**	**1.360**	**1988**	**2.421**
Demersals	**1997**	0.257	**1999**	0.696	**1995**	**1.020**	**1988**	**1.524**	**1988**	**1.980**
Elasmobranches	**1991**	0.274	**1972**	0.566	**1974**	0.667	**1996**	0.267	**1987**	**2.345**
Pelagics	**1988**	**3.248**	**1984**	**1.686**	**1987**	**1.989**	**1979**	0.259	1994	0.170
Invertebrates	**1994**	0.531	**1975**	0.392	**1972**	0.281	**1981**	**1.785**	**1981**	0.804
Commercial	**1986**	**8.072**	1982	0.194	**1991**	0.595	**1988**	**1.469**	**1988**	**3.391**
Non-commercial	**1988**	0.995	1976	0.158	**1974**	0.213	**1988**	**2.099**	**1988**	**2.436**
Benthivores	**1981**	0.349	**1981**	0.412	**1998**	0.580	**1987**	**1.773**	**1987**	**3.231**
Piscivores	**1991**	0.143	**1972**	0.251	**1989**	0.574	**1987**	**4.282**	**1986**	**8.367**
Species										
Groundfish										
American plaice	**1981**	0.503	**1983**	0.740	1983	0.147	**1987**	0.346	**1987**	0.848
Atlantic halibut	**2000**	0.334	**2000**	0.122	**1995**	0.431	**1984**	0.256	**1987**	0.328
Cod	**1990**	**2.123**	**1985**	**5.570**	**1985**	**1.394**	**1990**	**1.062**	**1988**	**2.728**
Cusk	**1988**	**2.239**	**1988**	**2.020**	**1988**	**2.525**	**1991**	**2.250**	**1995**	**1.641**
Fourbeard rockling	**1986**	0.353	**1973**	0.150	1987	0.216	**1991**	0.379	**1975**	0.336
Fourspot flounder	**1992**	**1.084**	**1992**	0.850	**1992**	0.862	**1972**	0.358	1975	0.107
Gulfstream flounder	1995	0.192	1988	0.169	**1996**	0.554	1970	0.036	1974	0.572
Haddock	**1983**	0.420	**1981**	0.232	**1988**	**1.188**	**1986**	0.931	**1986**	**2.190**
Longfin hake	**1976**	0.793	**1981**	0.686	**1981**	0.486	1986	0.111	1975	0.172
Pollock	**1981**	0.600	**1985**	**3.831**	**1985**	0.129	**1988**	**1.814**	**1987**	**3.802**
Red hake	**1993**	0.818	**1974**	0.477	**1972**	0.445	**1992**	**1.171**	**1992**	**1.455**
Silver hake	**1972**	**1.052**	**1974**	0.248	**1973**	0.384	**1988**	0.436	**1988**	**1.536**
White hake	**1994**	0.729	**1993**	0.584	**1993**	0.440	**1984**	0.873	**1984**	**1.250**
Windowpane flounder	**1975**	0.328	**1990**	0.435	1985	0.137	**1992**	0.433	**1992**	**1.637**
Winter flounder	**1992**	0.221	**1984**	0.550	1997	0.093	**1984**	**1.372**	**1984**	0.938
Witch flounder	**1981**	0.187	**1985**	**3.792**	1985	0.174	**1988**	**7.174**	**1988**	**10.05**
Yellowtail flounder	**1983**	0.261	**1981**	0.385	**1981**	0.469	**1975**	0.330	**1990**	0.532
Demersals										
Acadian redfish	**1978**	0.738	**1995**	0.740	**1995**	**1.993**	**1988**	**1.954**	**1988**	**1.990**
Alligatorfish	**1987**	0.375	1972	0.055	1987	0.193	1982	0.188	1999	NA
Atlantic hagfish	1981	0.153	**1971**	0.290	**1998**	0.381	**1987**	0.602	**1975**	0.739
Atlantic wolffish	**1993**	**1.980**	**1986**	**1.697**	**1994**	0.987	**1987**	0.274	**1987**	0.744
Blackbelly rosefish	**1985**	**1.095**	**1987**	0.965	**1988**	**1.001**	**1990**	**1.560**	**1990**	**1.022**
Cunner	**1974**	**1.199**	**1979**	0.347	**1979**	0.403	1998	0.036	1998	0.137
Fawn cusk-eel	1984	0.054	**1972**	0.158	1985	0.285	1974	0.107	1991	0.117

Table 2.2 (continued).

	Occurrence frequency		Mean biomass/tow		Mean number/tow		Mean length		Mean weight	
Aggregation level	Year	R_{DN}	Year	R_{DN}	Year	R_{DN}	Year	R_{DN}	Year	R_{DN}
Demersals (continued)										
Goosefish	**1992**	0.218	**1986**	0.679	**1972**	0.169	**1987**	**5.829**	**1988**	**4.514**
Hookear sculpin (uncl)	**1984**	0.840	1985	0.518	**1985**	**1.363**	1999	0.153	1975	0.142
Longhorn sculpin	**1987**	**1.195**	**1988**	0.461	1988	0.146	**1976**	0.523	**1981**	0.483
Lumpfish	**1991**	0.374	**2001**	0.359	**1991**	0.455	**1994**	0.186	**1994**	0.299
Moustache sculpin	**1991**	0.355	**1991**	0.409	**1990**	0.544	**1992**	0.232	**1975**	0.358
Northern sand lance	**1974**	0.416	**1974**	0.103	**1974**	0.079	**1977**	0.608	2000	0.091
Ocean pout	**1984**	0.287	**2002**	0.292	**1979**	0.524	**1997**	0.369	**1987**	0.707
Sea raven	**1980**	**1.166**	**1979**	**1.230**	**1984**	**2.013**	**1991**	0.368	1984	0.062
Elasmobranches										
Little skate	**1978**	0.524	**1985**	0.493	**1986**	0.340	**1973**	0.247	**1983**	0.809
Smooth skate	1981	0.078	**1981**	0.917	**1981**	0.374	1987	0.212	**1987**	0.839
Spiny dogfish	1993	0.140	**1984**	0.342	**1984**	0.655	**1982**	0.448	**1982**	0.935
Thorny skate	**1989**	**2.643**	**1986**	**2.659**	**1990**	**1.934**	**1984**	0.646	**1985**	**1.080**
Winter skate	**1979**	0.678	**1976**	0.196	**1982**	0.619	**1991**	0.422	**1990**	**1.225**
Pelagics										
Alewife	**1986**	**1.610**	**1994**	0.972	**1986**	0.761	**1983**	0.505	1988	0.146
American shad	**1986**	**2.326**	**1986**	**1.101**	**1986**	**1.101**	**2002**	0.355	1992	0.117
Atlantic argentine	**1987**	0.258	**1987**	**1.473**	**1987**	**1.404**	**1971**	0.219	1992	0.203
Atlantic herring	**1986**	**4.547**	**1986**	**3.700**	**1986**	**3.562**	1982	0.281	**1987**	0.350
Atlantic mackerel	**1990**	0.708	**1990**	**2.299**	**1990**	0.933	**1989**	0.317	**1996**	0.522
Blueback herring	**1987**	0.936	**1995**	0.711	**1990**	**1.208**	**1987**	0.429	**1974**	0.600
Butterfish	**1989**	0.547	1979	0.156	**1976**	0.220	**1987**	0.812	**1987**	**1.039**
Invertebrates										
American lobster	**1993**	**1.120**	**1994**	0.828	**1993**	**1.352**	**1981**	**1.737**	**1981**	**2.113**
Longfin squid	1975	0.072	1972	0.114	**1978**	0.201	**2001**	0.346	**1995**	0.376
Northern shortfin squid	**1974**	0.390	**1972**	0.145	**1974**	0.307	**1983**	**2.303**	**1991**	0.573
Sea scallop	**1975**	0.932	**1976**	0.506	**1972**	0.326	**1976**	0.379	**1995**	0.836
Shrimp (all species)	**1980**	0.982	1975	0.306	.	.	.	.	.	.
Benthivore size classes										
Cusk	1981	0.142	**1981**	0.180	**1976**	0.182	**2002**	0.235	2002	0.205
Atlantic halibut	**1986**	0.309	**1986**	0.325	**1986**	0.390	1976	0.137	1976	0.255
Yellowtail flounder	**1983**	0.257	**1981**	0.376	**1981**	0.370	1988	0.092	**1990**	0.825
Fawn cusk-eel	1984	0.100	**1972**	0.160	1985	0.291	1996	0.011	1975	0.336
Thorny skate	**1991**	**2.411**	**1991**	**1.864**	**1991**	**1.561**	1984	0.021	**1985**	0.146
Smooth skate	1987	0.002	1985	0.159	1974	0.084	1980	0.128	**1974**	0.150
Piscivore size classes										
Cusk	**1988**	**2.334**	**1988**	**2.007**	**1988**	**2.515**	**1995**	**3.154**	**1995**	**1.168**
Cod	**1990**	**2.692**	**1985**	**5.393**	**1985**	**1.904**	**1987**	**2.169**	**1987**	**2.982**
Goosefish	**1992**	0.194	**1986**	0.680	**1972**	0.149	**1987**	**5.368**	**1988**	**4.173**
Silver hake	**1987**	0.775	**1987**	0.912	**1987**	0.786	**1985**	0.593	**1984**	0.535
Fourspot flounder	**1992**	**1.155**	**1992**	0.811	**1992**	0.909	**1983**	0.106	1990	0.070
Winter skate	**1979**	0.272	**1992**	0.221	**1976**	0.238	**1975**	0.437	**1990**	**1.307**
Thorny skate	**1986**	**3.259**	**1986**	**4.416**	**1986**	**2.960**	**1977**	0.794	**1979**	0.563
Spiny dogfish	**1994**	0.355	**1989**	0.429	**1989**	0.980	**1991**	0.787	**1991**	**1.159**

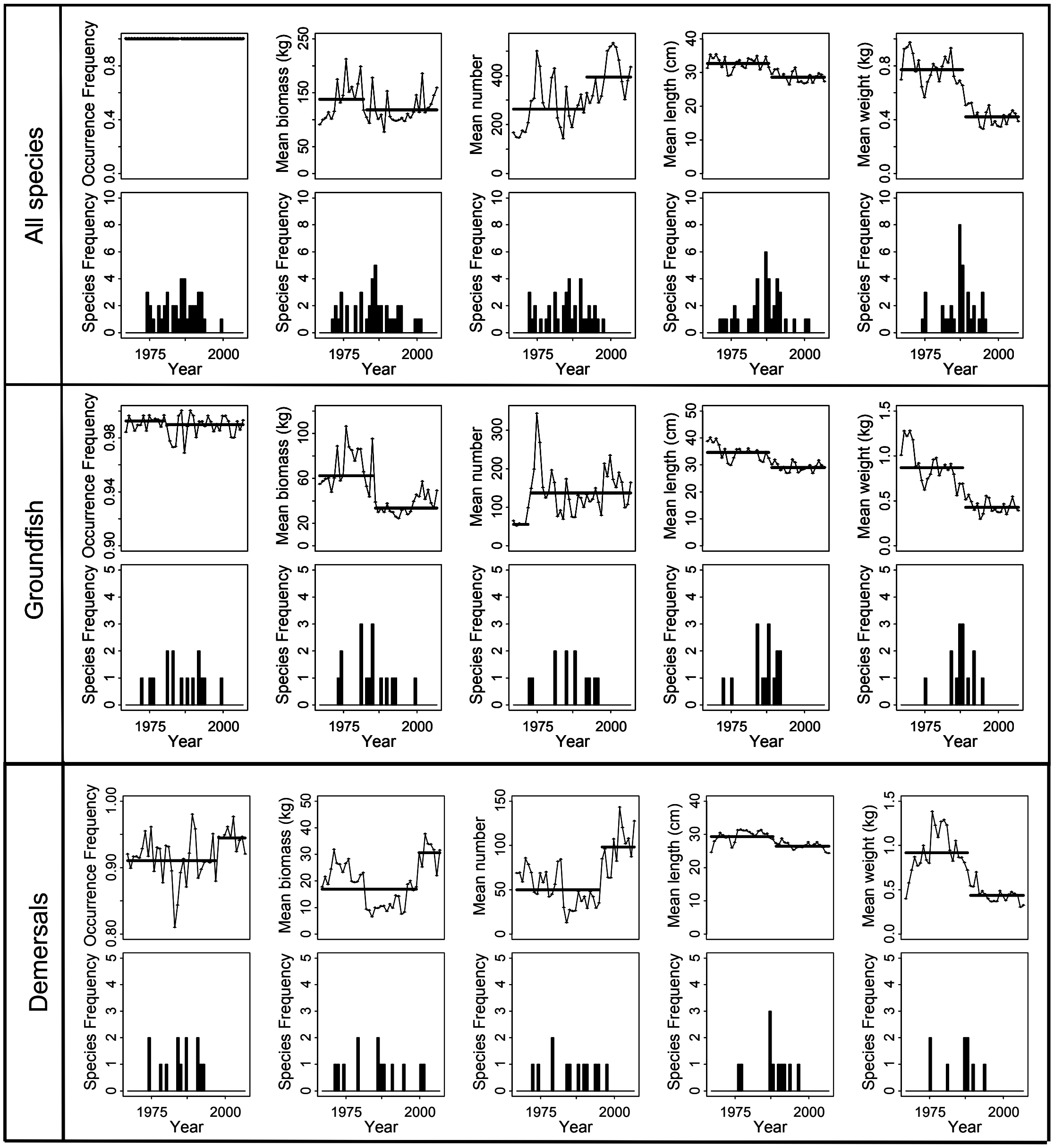


Figure 2.5. Time series and associated change points are shown for all species combined and for taxonomic, economic, and trophic groups. These time series are compared to the frequency distribution of years in which statistically significant ($p \leq 0.01$) change points occurred for species within each higher-level group.

Figure 2.5 (continued).

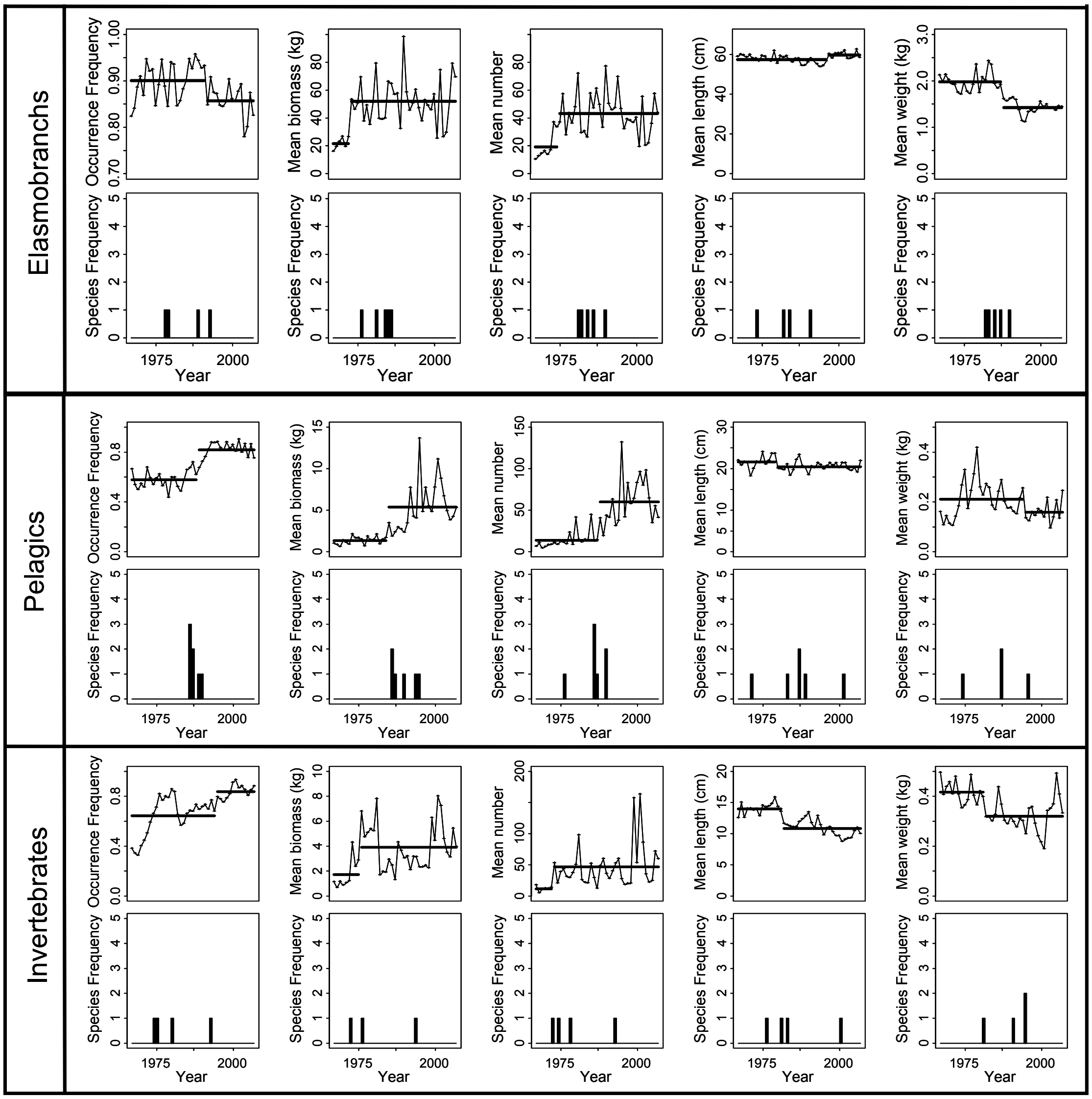
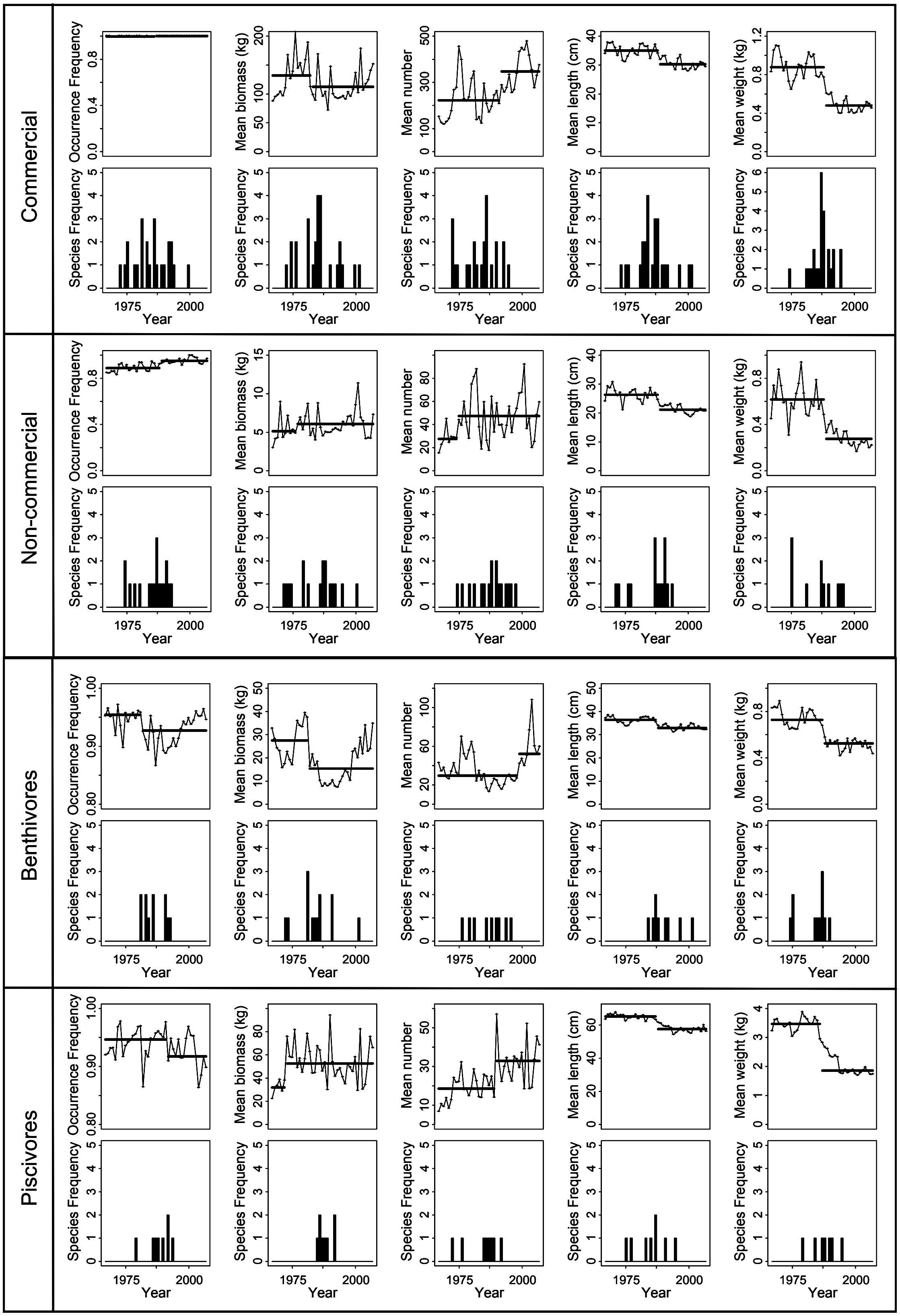


Figure 2.5 (continued).



benthivores declined significantly, but it increased for elasmobranches, pelagics, demersals, invertebrates, and piscivores. Changes were not detected for commercial and non-commercial groups. Most of the species-level changes in the mean biomass per tow generally supported those observed at the group level (Table 2.2, Appendix D), with declines noted for most groundfish (69%) and benthivorous species (77%) and increases observed for demersal (69%), pelagic (83%), and invertebrate (100%) species. However, elasmobranch, piscivorous, commercial, and non-commercial species showed changes contrasting those observed at the group level. Three of the five elasmobranch species analyzed (i.e., little skate, smooth skate, thorny skate) showed significant decreases in biomass per tow, but spiny dogfish and winter skates showed increases. While the biomass per tow of piscivores increased as a group, this pattern was consistent for only 33% of the piscivorous species analyzed. Finally, although biomass per tow did not change significantly for the commercial and non-commercial groups, it did for many of their constituent species. Twenty-six commercial species showed changes in biomass per tow, but increases (46% of species) and decreases (54% of species) were nearly balanced. The biomass per tow changed significantly for seventeen non-commercial species, with 71% increasing and 29% declining.

A significant increase in the number of organisms per tow was noted at the aggregate community level and for all taxonomic, economic, and trophic groups (Table 2.2, Figure 2.5). This pattern held across most of the individual species analyzed, but the number per tow declined for 25% of the species. Species showing declines in the mean number per tow after the detected change-point were concentrated among the groundfish (50%), elasmobranches (60%), and benthivores (56%). Most of the demersal (75%), pelagic (86%), invertebrate (100%), commercial (70%), non-commercial (64%), and piscivorous (56%) species showed increases.

The mean length of organisms in the survey declined significantly for the aggregate community and for all groups of species, except the elasmobranches, which increased slightly in length (Table 2.2, Figure 2.5). These patterns held true at the species-level, where most groundfish (93%), demersal (64%), pelagic (100%), invertebrate (100%), commercial (96%), non-commercial (73%), benthivorous (78%), and piscivorous (78%) species showed declines in length (Appendix D). However, while elasmobranches as a group did not indicate declines in length, all of the elasmobranch species analyzed did.

The mean weight of organisms in the survey declined significantly for the aggregate community and for all groups of species except pelagics, which did not change significantly (Table 2.2, Figure 2.5). This pattern was also observed at the species level, where high portions of the groundfish (93%), demersal (56%), elasmobranch (100%), pelagic (75%), invertebrate (75%), commercial (92%), non-commercial (55%), benthivorous (73%), and piscivorous (100%) species showed significant declines in mean weight (Table 2.2, Appendix D).

Timing and nature of biological changes

The timing and nature of biological changes in the GOM-GB region were assessed by (1) identifying the year in which a major shift occurred and determining the significance of the change and (2) evaluating the magnitude and consistency of a shift based on its fit to a step-function model as indicated by the signal-to-noise ratio, R_{DN}. At the aggregate community level, a significant change-point associated with the mean number of organisms per tow occurred in 1991, and primary change-points for mean length and mean weight were detected in 1988. The consistency of a step-function model was confirmed by R_{DN} values greater than 1.0 (Table 2.2).

At the group level, significant change-points in the biological attributes were noted across the time period, but many were clustered in the late 1980s and early 1990s (Table 2.2). Step changes in organism size were common across many of the groups, with the exception of the pelagics, and were clustered between 1986 and 1988. Marked changes were less common for other biological attributes examined and were inconsistently distributed among the groups. However, an exception was noted again for pelagics; abrupt and substantial increases in their FO, biomass per tow, and number per tow were detected between 1984 and 1988 (Table 2.2).

At the species level, significant change-points were identified for most of the biological features analyzed (Table 2.2). Few of these changes were abrupt and distinct enough to conform to a step-change model, but several exceptions were noted. First, the mean individual weight for more than half of the groundfish species examined showed a step discontinuity as weights substantially declined at change-points between 1988 and 1995 (Table 2.2, Appendix D). For most pelagic species, the biomass and number per tow abruptly increased between 1986 and 1990. Finally, a relatively high portion of step discontinuities were noted among piscivorous species across the suite of biological attributes. Piscivorous size classes of cusk and cod displayed step changes for each of the biological features examined (Table 2.2).

Discussion

Surveys conducted to support fisheries management provide a rich time series of data on the fish and invertebrate community of the GOM-GB region, which can be used to understand compositional and biological changes in the ecosystem. Analyses in this paper reveal substantial changes in both compositional and biological features across multiple levels of organization, from the aggregate community to single species. These changes provide evidence of a regime shift in the GOM-GB ecosystem, and the timing of changes suggests that multiple factors contributed to this shift. Altogether, the findings have substantial implications for structuring effective EBM programs in the GOM-GB region.

Patterns of compositional and biological change

Composition changes

The pattern of compositional change observed in these analyses indicates substantial shifts in the GOM-GB fish and invertebrate community over time, with the major shifts in ordination occurring in the mid-1980s and early-1990s. This analysis reinforces the importance of previously documented compositional shifts but utilizes comprehensive community information to indicate that less studied species also contributed to the community shift.

Results from the indicator species analysis call attention to species-specific changes that deviate from patterns observed at the taxonomic group level. For example, many of the species associated with the 1967-1984 time period are groundfish; the expectation that groundfish species made a greater contribution to fish communities during the early portion of the time series is consistent with declines that have been observed in more recent years (Mayo *et al*. 1992, Fogarty and Murawski 1998). However, a few groundfish species (e.g., fourspot flounder, Greenland halibut) were strongly affiliated with the 1992-2007 time period. The reverse holds true for some elasmobranch (e.g., thorny, little, and smooth skates), pelagic (e.g., round herring, Atlantic menhaden) and invertebrate (e.g., Northern shortfin squid) species; these species would be expected to contribute more to the community in later years (Fogarty and Murawski 1998, Overholtz *et al*. 2000, Frisk *et al*. 2008), but instead, they are associated with the earlier time period.

In addition, ordination results show the importance of non-dominant species in structuring the fish and invertebrate community. Species that characterized the extremes of each NMS axis included those that were observed infrequently in the survey (e.g., rosette skate) or that did not comprise a substantial portion of the biomass in the community (e.g., marlin-spike). While previous studies have focused on major shifts in commercially fished species in the GOM-GB region (e.g., Fogarty and Murawski 1998), this analysis reveals that less dominant non-target species have also contributed substantially to community changes over time. Similar patterns have been reported in the North Sea fish community, where small changes in the assemblage composition and relative abundance of non-dominant species created long-term community-level distinctions (Greenstreet and Hall 1996).

Biological changes

Changes in the five biological attributes examined for this study indicate shifts in the FO, biomass and numerical balance, and size structure of fish and invertebrates in the GOM-GB region. Increases in the FO, biomass per tow, and number per tow were observed for several groups—demersals, pelagics, and invertebrates. The consistency of this pattern across multiple biological attributes suggests that these groups have become more prevalent in the GOM-GB ecosystem over time. In contrast, while elasmobranches and piscivores increased in biomass and abundance, their FO in the survey declined.

The most consistent and striking biological changes occurred in individual body size, as assessed through measures of length and weight. Declines in body size paralleled an increase in the number of organisms per tow, indicating a shift towards larger numbers of smaller-sized fish in the GOM-GB ecosystem. At the aggregate community level, the mean length of organisms declined by 12.6% after the primary change-point, while the mean weight decreased by 45.5%. Further, it is also clear that these size changes were substantially more concentrated within the commercially fished species. Of species showing significant changes in length, 96% of commercial species versus 69% of non-commercial species declined in mean individual length. Similar patterns emerge when comparing changes in individual weight for these groups; 91% of commercial species declined in weight, compared to only 40% of non-commercial species.

Previous observations of declines in body size have been reported for Atlantic cod within the GOM-GB region; Serchuk *et al*. (1994) documented substantial reductions in the median size and age at maturity during the mid-1980s. Broad-scale declines in body size have also been reported for demersal fish on the Scotian Shelf (Zwanenberg 2000, Choi *et al*. 2004) and in the North Sea (Greenstreet and Hall 1996, Jennings *et al*. 1999). This study reveals the prevalence and coherence of declines in body size at the aggregate, group, and species levels within the GOM-GB region.

Cumulatively, changes in the biological attributes examined in this study suggest that a major restructuring has occurred within the GOM-GB ecosystem. Similar biological patterns have provided evidence of substantial restructuring of the Scotian Shelf ecosystem (Zwanenberg 2000, Choi *et al*. 2004), an area just north of the Gulf of Maine that has experienced similar fishing and climatic histories. Coupling these studies with the analyses reported herein suggests that the Northwest Atlantic as a whole may have experienced a large-scale biological shift.

Although the factors contributing to this biological shift are not investigated as part of this study, the timing and character of transitions set the context for future studies to examine potential drivers underlying the patterns observed. The differential responses noted in size changes of commercial and non-commercial species suggest that fishing in the region may have substantially affected biological characteristics.

While size-based metrics have been proposed as useful indicators of the effects of fishing at population and community levels (Jennings and Dulvy 2005, Shin *et al*. 2005), environmental conditions and prey availability can also affect the growth rates and size of organisms (Jennings *et* al. 1999, Bianchi *et al*. 2000, Zwanenberg 2000). The finding that 69% of the non-commercial species declined in length and 40% decreased in weight suggests that alternative factors merit consideration. In addition, composition changes could cause the size-related changes shown herein at the community and group scales if large-bodied species declined while small-bodied species became more prevalent. The observation that changes in FO and biomass per tow were negligible at the aggregate community level and mixed at the group level might support the compositional change hypothesis. However, the consistent increase in numbers per tow and declines in mean length and mean weight across most groups and species suggest that explaining the biological changes across all levels of organization requires evaluating a more complex set of hypotheses.

Consistency of changes across organization levels

Biological patterns were examined across three hierarchical organizational levels (i.e., community, group, and species) to assess the consistency of those changes at different levels of aggregation. It has been suggested that species populations are more likely to show changes than aggregate ecosystem properties (Odum 1985, Schindler 1990) due to fungibility among species (Schindler 1990, Frost *et al*. 1995). Thus, it is reasonable to question whether differential sensitivities exist between the species and community scales, as this information may influence the collection, analysis, and interpretation of ecosystem data.

Findings of this analysis indicate that for several of the biological features examined (i.e., FO, biomass per tow), the lack of change at the community level belies significant changes at the group and species scales. For the FO and biomass per tow, the direction of change was mixed at the group and species levels, indicating that a compensatory effect may have masked changes at the community scale. In contrast, substantial and consistent increases in the number per tow as well as declines in the mean length and mean weight of organisms at the community scale were mirrored across nearly all of the groups and high portions of the species analyzed.

Patterns of biological change were also generally consistent between groups and their constituent species, but several exceptions were noted. The majority of elasmobranch species did not conform to the group pattern for four of the five biological characteristics analyzed. While piscivores as a group decreased in FO and increased in biomass per tow, most individual species within this group showed opposite patterns for those two attributes. In addition, groundfish and benthivores increased in numbers per tow at the group level, but 50% and 55% of species in these groups, respectively, showed declines. In contrast, the majority of demersal, pelagic, invertebrate, commercial, and non-commercial species followed their groups-level patterns of change for all biological attributes.

While the patterns of change were typically consistent across the different organizational levels examined, the timing of changes exhibited greater variability. Change-points were detected across a wide range of years over the 41-year time period examined. At the community and group levels, many of the change-points occurred between the late-1980s and early-1990s. Species-specific change-points spanned a much wider range of the time series, and many changes took place beyond the narrow time window during which group- or community-scale changes occurred (Table 2.2, Figure 2.5). This discrepancy in timing of changes between individual species and higher-level aggregations suggests that the unique life histories of each species as well as their susceptibility to external perturbations may influence when biological shifts become apparent. Although the timing of changes did not align perfectly between the species and group levels, nearly 60% of the species change-points occurred between 1984 and 1992, the major period of change observed in the composition analysis.

On the whole, substantial consistency in the direction and general timing of biological changes across the three levels of organization was observed. However, exceptions were noted, particularly between the species and group levels of organization, and it does not seem realistic to fully understand species from group or community patterns alone or to anticipate higher-order patterns from those of just the dominant species. As unique dynamics can influence different scales of organization within the ecosystem, there is value to designing monitoring and management programs to track and protect the processes occurring at each scale. Routinely monitoring and reporting biological indicators at ecosystem, community, and functional group scales may advance this goal (Trenkel and Rochet 2003, Hughes *et al*. 2005, Methratta and Link 2006).

Evidence of a regime shift?

The aforementioned compositional and biological changes suggest that profound shifts in the GOM-GB marine ecosystem have occurred over the past 40 years. Similar changes have been characterized as a regime shift by several authors (e.g., deYoung *et al*. 2004, Pershing *et al*. 2005), and the results herein provide a strong basis for assessing the merits of this assertion. Several conditions that typically characterize regime shifts were identified by deYoung *et al*. (2004). First, during a regime shift, the ecosystem switches between discrete states rapidly relative to the temporal duration of each of the alternate states. Second, multiple biological components display coherent differences in states. Finally, regime shifts typically occur when external drivers force large-scale changes in biological features.

Compositional and biological changes presented in this paper will be assessed against these three criteria to evaluate the strength of evidence of a regime shift in the GOM-GB region.

The first consideration involves determining whether the ecosystem has exhibited discrete states and rapidly shifted between those states. The compositional and biological results presented above indicate that major changes have occurred in the GOM-GB region, and that these changes appear to characterize two distinct ecosystem states. Species composition differs between periods spanning 1967-1984 and 1992-2007, and biological changes, particularly a shift towards smaller-bodied organisms, are also concentrated in the mid-1980s and early 1990s. The magnitude of these changes can be assessed based on the signal-to-noise ratio, R_{DN}. Of the compositional and biological features examined in the GOM-GB region, several showed high magnitude changes (i.e., $R_{DN}>1.0$) during the time period analyzed.

While the high R_{DN} value indicates a substantial and consistent difference between the two time periods, it does not alone indicate that the transition occurred rapidly. In fact, many of the data series examined show consistent multi-year trends, rather than single-year threshold effects (Figure 2.5, Appendix D). It is important to note, however, that a multi-year trend may represent a biologically rapid shift in the context of life histories of the species and groups examined. Further, a change that occurs over multiple years may appear protracted within the context of the 40-year time series of data available for examination, but it could represent a rapid shift in a historical context. Similarly, changes that appear substantial in magnitude within the context of the 40-year time series may prove to be common or minor if a more extensive series of data could be examined.

The second characteristic of regime shifts is that multiple biological components of the ecosystem display coherent differences in states. In essence, the effect of the regime shift should extend across species and trophic levels. For the biological features analyzed from the GOM-GB ecosystem, high-magnitude changes are noted across all levels of organization, particularly in the size of organisms. Substantial declines in length and/or weight occur at the aggregate community level, within all the groups, and in 71% (length) to 59% (weight) of the species examined. In addition to the nature of the observed changes being coherent across multiple species and levels of organization, the timing of the high-magnitude changes exhibits some coherence as well. Most of the high-magnitude shifts occurred in the mid-1980s to early-1990s, with 85% of the shifts at the group level and 80% of the high-magnitude transitions among the species occurring within this time period. Further, the timing of these biological shifts coincides with the transition in community composition that occurred between 1984 and 1992.

Finally, regime shifts typically occur when changes in biological features are forced by external drivers, such as physical conditions or fishing pressure. However, Hare and Mantua (2000) describe a biological regime shift in the North Pacific in 1989 in which biological responses were more prevalent and coherent than changes in associated climate indices. Further, Steele (1996) suggested that synergistic effects of fishing pressure and environmental changes may cause ecological regime shifts. In addition, recent studies have focused on trophic cascades as forces that reinforce and extend the effects of regime shifts (Frank *et al*. 2007, Litzow and Ciannelli 2007, Casini *et al*. 2009).

Although the causative factors behind the shifts in community composition and biological attributes in the GOM-GB region are not examined directly in this paper, the cumulative effects of several external factors, such as environmental conditions and fishing pressure, as well as intrinsic life history characteristics, population dynamics, and trophic relationships may all be important. The concentration of many of the changes, including the high-magnitude shifts, in the mid-1980s to early-1990s suggests that this coherence may be influenced by a major ecosystem shift that transpired over a limited time period. The timing of this shift coincides with a change in North Atlantic oceanographic conditions that lowered salinities in the GOM-GB region in the late 1980s (Greene and Pershing 2007). Other changes documented in the GOM-GB area during the late-1980s to early-1990s included an increase in the abundance of phytoplankton and small copepods around 1989 (Greene and Pershing 2007) and a shift from top-down to bottom-up trophic control in the early- to mid-1980s (Frank *et al*. 2006).

While the aforementioned ecosystem events occurred over short periods of time, it is well known that fishing pressure has been applied to many of the populations in this region over many decades. The mid-1980s to early 1990s represented a period of overfishing on and collapse of groundfish stocks in the GOM-GB region (Fogarty and Murawski 1998). The broader ramifications of fishing, including those on the community composition and biological features of organisms in the ecosystem, may manifest themselves over protracted time periods. The timing of when fishing effects may be observed will depend on the intensity of pressure at different times, the life history attributes of different species, and intrinsic population dynamics. Given the time lags that would be expected before the biological effects of environmental changes are detected in the fish survey data, it is possible that the impacts of fishing initiated many of the compositional and biological shifts noted in the GOM-GB region. These may then have been exacerbated and perpetuated by changes in environmental conditions and trophic relationships.

A recent study by Hilborn and Litzinger (2009) relates declines in cod productivity in waters north of the GOM-GB to environmental factors, while linking cod productivity in the GOM-GB to fishing pressure. These findings and the lines of evidence in this study suggest the importance of considering multiple potential factors that affect fish populations and biological characteristics, recognizing that the relative importance of these factors can vary in space, time, and by species. Further research is necessary to understand the importance of multiple contributing factors and the mechanisms by which these factors may have driven the compositional and biological shifts in the GOM-GB ecosystem.

Implications for ecosystem-based management

The dominant approach to fisheries management at present focuses on managing individual species (or complexes of similar species) using scientific information about each population and its anticipated response to fishing pressure. This process assumes a high predictive capacity and produces guidance for setting fishing levels that should be sustainable under typical ecosystem conditions. However, it does not proactively accommodate unexpected dynamics that may be triggered by myriad forces external to population processes. Ecosystem-based management suggests the potential for moving beyond existing scientific and governance frameworks to develop new tools and approaches that are effective within the context of dynamic marine ecosystems.

As the concept of EBM has become more familiar in the fisheries management realm, it has often been suggested as an alternative to the current single-species approach. The findings presented herein indicate that an exclusive choice should not be made between continuing fisheries management from a single-species perspective or transitioning to managing fisheries from an ecosystem perspective. Analyses show that patterns of change across different levels of biological organization are not always congruent. The balance of variability in changes at the species scale may be magnified or diluted at group or community scales. While community or assemblage data may provide some indication of broad changes in the ecosystem, species-specific monitoring and analyses will continue to be necessary to detect, understand, and mitigate (if necessary) changes observed in the abundance or biological characteristics of individual species. Both single-species and ecosystem perspectives provide valuable and distinct information for (1) managing fisheries within the context of a dynamic ecosystem and (2) sustaining a functioning ecosystem in which fisheries constitute key human activities.

Some of the changes that have been noted in the GOM-GB region call attention to the need to focus on rebuilding ecological resilience to sustain both human activities and ecosystem functionality. Perhaps the most disconcerting biological change noted in this study is the broad-scale reduction in body size across many species. The convergence to smaller body sizes reduces resilience that might exist within species to help them withstand the effects of major natural or anthropogenic perturbations to the ecosystem. For example, larger and older individuals may be able to endure a wider range of environmental conditions and make greater contributions to the reproductive potential of a population than smaller, younger individuals. Whether fishing pressure contributed to this shift in body size has yet to be evaluated, but regardless of its causative factors, the outcome has substantial implications for sustaining fisheries, rebuilding populations, and supporting ecological interactions within the GOM-GB ecosystem.

The importance of resilience can be extended from the biological realm to the human realm, and new approaches to managing fisheries within the context of dynamic marine ecosystems should also seek to promote resilience within fishing communities. The ecosystem within which fisheries operate will constantly change, sometimes rapidly; these changes will likely have biological and compositional outcomes that will affect fisheries. However, the current structure of fisheries management does not ensure that individual fishermen can flexibly respond to these changes. In recent years, as the historically-valuable groundfish stocks in the GOM-GB region have collapsed, fishing communities have become more economically reliant on lobsters, scallops, and other species. In some communities and for fishermen with permits in multiple fisheries, this shift may be absorbed. But in communities in which fishermen are concentrated in one fishery, ecological shifts in the balance of species can have devastating social and economic consequences.

As fishery management rules are tightened to protect declining stocks, the social solution is not a loosening of regulations to allow unsustainable fishing pressure on any of the stocks, which will have negative ecological, social, and economic outcomes in the long run. Instead, the solution may lie in cooperative arrangements between fishermen that would be structured to minimize the socio-economic impacts associated with ecological changes. Community cooperatives that include fishermen from multiple and diverse fisheries might develop business management arrangements to provide insurance against the swings in individual fisheries. Such an approach would create social and economic resilience within fishing communities to buffer the impacts of ecosystem shifts that may substantially affect different fisheries at different times. Solutions that enhance resilience will be necessary to construct governance arrangements that enable human communities to flexibly adapt to marine ecosystem shifts.

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CHAPTER 3

STAKEHOLDER PERSPECTIVES AND EXPECTATIONS: IMPLICATIONS FOR ECOSYSTEM-BASED MANAGEMENT IN THE GULF OF MAINE

Introduction

Ecosystem-based management (EBM) has gained widespread appeal as a way to manage complex, multi-use marine ecosystems in a more holistic and integrated manner (e.g., McLeod and Leslie 2009). However, enthusiasm for marine EBM has outpaced its implementation. Part of this lag results from disconnects between conceptual guidance associated with EBM and actual implementation realities (Arkema *et al*. 2006). Although many EBM frameworks have emphasized the importance of engaging stakeholders, it is not clear how groups as diverse as fishermen, scientists, managers, and environmentalists conceive of EBM, and thus their roles in and expectations for EBM efforts. Social science inquiry can provide important insights regarding similarities and differences in stakeholders' perceptions of EBM, particularly in comparison to the extant conceptual guidance, to support future management efforts.

Through an in-depth investigation of multiple stakeholder groups with ties to fisheries management in the Gulf of Maine, this study: (1) documents stakeholders' perspectives on EBM, (2) evaluates how their perspectives relate to existing conceptual guidance, and (3) identifies consistencies and differences among stakeholder groups in their ideas about what EBM means and what they hope it will accomplish. The results provide a basis for assessing the challenges and prospects for implementing EBM in the Gulf of Maine, with implications for other marine ecosystems. They also offer insights into how stakeholder perspectives may influence the design of governance structures and management processes to support the transition from current sector-specific management approaches towards EBM.

Background

EBM offers natural resource managers a holistic approach for managing species, resources, and human actions within a larger ecosystem context. In recent years, national marine policy reviews have emphasized the merits of adopting EBM as an integrated approach to coastal and ocean management (Cicin-Sain and Knecht 2000, Pew Oceans Commission 2003, USCOP 2004) and as a complement to existing resource-based management approaches (e.g., NMFS 1999, NRC 1999). Numerous academic articles have suggested important goals, identified process features, and proposed conceptual frameworks for EBM (e.g., Grumbine 1994, Christensen *et al*. 1996, Stanford and Poole 1996, Brussard *et al*. 1998, Lackey 1998, Slocombe 1998) and have identified potential benefits, objectives, and approaches for applying EBM in marine ecosystems (Link 2002, Pikitch *et al*. 2004, de la Mare 2005, McLeod *et al*. 2005, Young *et al*. 2007). While many of these studies have proposed frameworks and offered tools for implementing EBM, evaluations of the suitability and feasibility of their ideas in the context of on-the-ground implementation realities have been limited.

Stakeholder participation has been recognized as an essential component of EBM (e.g., Yaffee *et al*. 1996, Cortner and Moote 1999, Arkema *et al*. 2006). Although the importance and value of stakeholder participation is widely touted in articles related to EBM—suggesting stakeholder involvement has the potential to improve the quality of decisions, enhance relationships among groups in the decision-making process, and strengthen the capacity for managing environmental problems (Yaffee *et al.* 1996, Duram and Brown 1999, Beierle and Konisky 2001)—few studies have addressed how stakeholder perceptions shape the implementation of EBM. Indeed, actual EBM efforts often fail to incorporate stakeholder engagement as a core element throughout all stages of the management process (Arkema *et al*. 2006). In marine areas, effective stakeholder engagement involves bringing together many groups with diverse interests. Understanding their perspectives from the outset will help ensure that EBM implementation strategies, priorities, and approaches are salient to and supported by local stakeholders.

Effective engagement of stakeholders may need to start with a basic step of building a shared understanding of what EBM means, what it could accomplish, and how it might be implemented. Many of the diverse coastal and marine stakeholders may not be familiar with EBM as it is conceptualized in the academic literature and policy reviews. Instead, their views and understanding of EBM may be determined by their own information sources, experiences, perceptions, and interests. Previous studies have demonstrated that stakeholders' knowledge, values, and experiences shape their conceptualizations of, and levels of support for, specific management goals (Scarnecchia 1988, Connelly and Knuth 2002), and they may influence stakeholders' acceptance of new or modified management arrangements (Kearney *et al*. 1999). Thus, the goals, structure, and process features of EBM that have been advanced in the conceptual literature may not correspond with the features that are of importance and concern to stakeholders, posing challenges for successful EBM implementation.

If personal knowledge, experiences, and interests shape individual stakeholders' expectations of EBM, it is likely that these expectations will vary across multiple stakeholder groups. Differences in attitudes towards EBM have been documented among diverse user groups (Jacobson and Marynowski 1997, Holsman and Peyton 2003). Further, management priorities may vary across stakeholder groups, such as between managers and citizens (Connelly and Knuth 2002) and among consumptive users, agency managers, scientists, and environmental advocates (Hilborn 2007). The success of EBM initiatives may depend on the extent to which their purpose and design accommodates stakeholders' expectations and interests. The diverse perspectives and priorities that exist among stakeholders may influence the potential for different groups to understand one another and work together towards common EBM goals.

Although finding common ground among varied stakeholder groups is a critical issue, empirical studies of marine stakeholders' perspectives on EBM have been limited and have largely focused on single stakeholder groups. For example, the New England Fishery Management Council (2006) has gathered data that primarily reflects fishermen's perspectives on EBM, and Barnes and McFadden (2008) surveyed employees of the National Oceanic and Atmospheric Administration to identify challenges that affect EBM implementation. Studies involving multiple stakeholder groups can advance an understanding of the consistencies between stakeholder groups that will facilitate implementation of EBM or the differences that may limit its success.

Further empirical studies of stakeholder perceptions and expectations of EBM are needed to assess the prospects for implementing EBM in ways that are meaningful to diverse stakeholders. In this study, we investigated the perspectives of different stakeholder groups and considered how they may shape implementation of EBM by documenting the ways in which six stakeholder groups characterize EBM, identifying their management priorities, and assessing differences in perspectives and priorities among the groups. Comparisons of responses across the stakeholder groups reveal areas of commonality that may help advance the implementation of EBM as well as areas of divergence that may require greater attention in the transition towards EBM. Key emergent themes provide insights into challenges and prospects for implementing

EBM within the Gulf of Maine, with implications for other coastal and marine ecosystems.

Study site and context

With its varied stakeholder groups and multi-layered governance structures, the Gulf of Maine was used as a case study of how stakeholder perspectives and expectations may affect EBM implementation in coastal and marine ecosystems. The waters of the Gulf of Maine extend across the international boundary between the U. S. and Canada as well as into coastal waters and watersheds of five states and provinces. Fisheries and aquaculture represent dominant human use sectors in the Gulf of Maine (with the term 'sectors' defined as interest groups or activities that impact or are affected by management decisions; Murawski 2007). Although many stakeholders hold interests in coastal and ocean management in the Gulf of Maine region, our research focused on a subset of stakeholder groups with ties to fisheries. Within the region, some important commercial fisheries (e.g., groundfish) have declined in recent years, while others (e.g., lobster) appear stable (Mayo *et al*. 2006). In addition, aquaculture development has increased, particularly in the waters of Nova Scotia, New Brunswick, and Maine (Mills 2004).

Changing patterns of human use of coastal and ocean waters of the Gulf of Maine, coupled with a desire to sustain a variety of uses while protecting the ecosystem, have increased interest in EBM within the Gulf of Maine. EBM has received attention in both the U. S. and Canadian portions of the Gulf of Maine, although the approach and progress towards implementation have taken different forms. In Canada, elements of EBM are supported through the 1996 Oceans Act (Government of Canada 1996). This legislation established a commitment to sustainable development, integrated management, and the precautionary approach; it also spurred development of a National Oceans Strategy, which provided new mechanisms for collaborating within government agencies and with other interested stakeholders (Government of Canada 2002). Similar enabling legislation to support EBM principles or facilitate multi-agency coordination on oceans management has not been passed at the federal level in the United States. Instead, efforts to address coastal and marine ecosystem concerns are currently advanced through provisions in disparate pieces of legislation, including the Magnuson-Stevens Act, Coastal Zone Management Act, Endangered Species Act, and National Environmental Policy Act (Searles Jones and Ganey 2009).

In contrast, efforts at state and local levels have applied integrated, multi-sector approaches to EBM. The state of Massachusetts adopted the Oceans Act of 2008, which requires the development of an integrated ocean management plan that incorporates many elements of EBM. In addition several pilot projects in the Gulf of Maine region have investigated how smaller geographic areas might be managed in a more integrated manner (e.g., Taunton Bay and Muscongus Bay studies; Maine Division of Marine Resources 2006) and how fisheries might be managed with greater consideration of ecosystem factors (e.g., NEFMC 2006 and Penobscot East Resource Center 2006). These varied initiatives have built a general awareness of the concept of EBM among stakeholders who actively participate in management arenas throughout the Gulf of Maine.

Methods

Data collection

We conducted 40 semi-structured interviews with members of six stakeholder groups that are engaged in or that interact closely with fisheries in the Gulf of Maine—aquaculturists, commercial fishermen, recreational fishermen, environmental group representatives, fishery scientists, and fishery managers. S*takeholders* were broadly defined to encompass individuals or groups who will either affect or be affected by EBM (sensu Decker *et al*. 2001). As such, managers and scientists were considered stakeholder groups for purposes of this study, as these groups directly and indirectly influence management processes and outcomes.

We identified individual interviewees through a stratified snowball sampling process (Patton 1990). To initiate the snowball sample, we contacted individuals in each of the stakeholder groups; these contacts were asked to recommend potential interviewees who: (1) lived or worked within the Gulf of Maine region, (2) were engaged in fisheries or environmental management sufficiently to have a general understanding of management concepts and decision-making processes, and (3) were viewed as "opinion leaders" within their respective stakeholder group. When selecting actual interviewees from those identified in the sample, we paid attention to diversifying participation across jurisdictions (i.e., between the United States and Canada, among the states and provinces bordering the Gulf of Maine, and between federal and state/provincial jurisdictions).

Interviewees in each stakeholder group encompassed a wide range of perspectives and backgrounds. In the aquaculturist group, respondents included owners and operators of shellfish and finfish aquaculture facilities, industry association leaders, and aquaculture researchers. The commercial fishermen interviewed were all groundfish or lobster fishermen who served as leaders of industry associations or members of management bodies. The recreational fishermen comprised anglers and charter boat operators who were also active participants on management boards or leaders of non-profit groups that protect and promote recreational fishing. Among the environmental group representatives were regional leaders of national organizations as well as directors of local and regional organizations involved in fisheries, water quality, and coastal management issues. The fishery scientists interviewed worked for regional offices of federal agencies (i.e., NMFS, DFO), state agencies, and academic institutions. Similarly, the fishery managers interviewed were employees of federal, state, and provincial management agencies.

Interviews were structured to gain insights into the respondents' perceptions of EBM and its potential application in the Gulf of Maine. Questions were piloted with one member of each stakeholder group to confirm their salience and clarity across respondents. All interviews were conducted in person or by phone during the fall of 2005 and spring of 2006. On average, interviews lasted about one hour (min=40 minutes, max=120 minutes). All in-person interviews were digitally recorded, and detailed notes were taken during phone interviews. Four of the major themes addressed in the interviews are described in this paper: (1) respondents' conceptualizations of EBM, (2) perceptions of key features of resource management processes, (3) desired goals for the ecosystem, and (4) major concerns related to the ecosystem.

Data analysis

The content of responses during each interview was reviewed to identify unique topics mentioned in discussions of the four interview themes. The types of comments associated with each coded topic are described in Appendix E. A binary coding structure was used to classify topics discussed by each interviewee. These binary data were summarized as percentages of respondents overall and within each stakeholder group who identified a specific topic as important in their comments associated with an interview theme. Non-respondents were excluded from proportion calculations, as some participants did not comment on specific themes of discussion.

To the extent appropriate, respondents' descriptions of EBM were coded using topical criteria identified in Table 1 of Arkema *et al*. (2006). These criteria were derived from a broad EBM literature review, and they were assumed to reflect key elements of EBM as it is characterized in current conceptual guidance. As such, they served as a basis for comparing Gulf of Maine stakeholders' conceptualizations of EBM to expert-derived definitions.

Nonparametric multivariate analyses based on the (dis)similarity in topics mentioned by respondents were used to understand relationships among the stakeholder groups. These methods are appropriate for the relatively small sample size and large number of groups of interest in this study, and they are suitable for data that do not fit normal distributions or linear models. First, information from individual respondents was used to test for multivariate differences among the stakeholder groups in a one-way analysis of similarities (ANOSIM) that was conducted in PRIMER Version 6 (Primer-E, Ltd.; Clarke and Warwick 2001). This analysis was based on a Bray-Curtis similarity matrix computed from the binary response matrix after excluding any topics that were identified by less than 10% of respondents to ensure that rare comments did not strongly influence the analysis results. The ANOSIM yields a test statistic (R), which ranges between 0 and 1 depending on the strength of dissimilarity between groups. A global ANOSIM tested the null hypothesis of no difference in the structure of responses among stakeholder groups. If the global ANOSIM rejected the null hypothesis, the ANOSIM was also applied to test for pairwise differences between specific stakeholder groups, and a similarity percentage analysis (SIMPER) was conducted to identify the response topics that contributed to the pairwise differences.

In addition to focusing on where differences exist among the stakeholder groups and factors that contribute to these differences, it is relevant to consider group relationships that may be indicated by the response data. Cluster analyses, conducted using PC-ORD 4 (McCune and Mefford 1999), were used to display these relationships based on the similarity among group responses to the four interview themes. These analyses used the proportion of members of each stakeholder group that mentioned specific topics related to each interview theme; topics that were identified by less than 10% of respondents were excluded. A Bray-Curtis distance matrix was computed from the proportional response matrix, and the group average linkage method was used to cluster the stakeholder groups. The dendograms that resulted from cluster analyses were scaled by Wishart's objective function and converted to the percentage of information remaining (McCune and Grace 2002).

Results

Stakeholder perspectives on EBM

Stakeholders' perspectives on EBM were revealed through four themes of discussion in the interviews: (1) their conceptualization of EBM, (2) features they considered important for good resource management, (3) their goals for the Gulf of Maine ecosystem, and (4) their concerns about the ecosystem. Key results identify the dominant topics that emerged from each theme of discussion across the respondents; some qualitative comparisons of responses by stakeholder groups are also highlighted.

EBM conceptualization

Features that respondents identified in their characterizations of EBM were classified into four major categories following a structure used by Arkema *et al*. (2006): (1) general criteria for EBM, (2) ecological considerations, (3) human dimensions factors, and (4) management process features (Table 3.1). Across all stakeholder groups, 63% of respondents discussed EBM as an approach that

Table 3.1. Categories and topics (after Arkema *et al*. 2006) of responses associated with stakeholders' characterizations of ecosystem-based management. Shading indicates percentage of respondents overall or in individual stakeholder groups mentioning a specific topic. Topics in italics represent those features not mentioned by more than 10% of respondents. 'ALL' indicates all interviewees combined; 'AQ'=aquaculturists, 'COM'=commercial fishermen, 'REC'=recreational fishermen, 'ENV'=environmental group representatives, 'SCI'=fishery scientists, 'MAN'=fishery managers.

Category	**Topic**	**ALL**	**AQ**	**COM**	**REC**	**ENV**	**SCI**	**MAN**
		n=40	n=7	n=8	n=6	n=6	n=6	n=7
General criteria	cross-jurisdiction/issue	30.1-45%	60.1-75%	60.1-75%	30.1-45%	15.1-30%	45.1-60%	45.1-60%
	sustainability	30.1-45%	30.1-45%	0.1-15%	15.1-30%	60.1-75%	30.1-45%	15.1-30%
	inclusion of humans	15.1-30%	0.1-15%	45.1-60%	15.1-30%	15.1-30%	60.1-75%	0%
	cumulative impacts	15.1-30%	45.1-60%	0.1-15%	0%	0%	30.1-45%	0%
	ecological health	0.1-15%	0%	0%	15.1-30%	60.1-75%	0%	0.1-15%
Ecological criteria	complexity	60.1-75%	45.1-60%	60.1-75%	>75%	>75%	>75%	45.1-60%
	spatial	15.1-30%	30.1-45%	0%	60.1-75%	30.1-45%	30.1-45%	15.1-30%
	temporal	0.1-15%	0.1-15%	0%	15.1-30%	0%	30.1-45%	0%
Human dimensions criteria	stakeholder	30.1-45%	15.1-30%	30.1-45%	>75%	45.1-60%	30.1-45%	60.1-75%
	economic	0.1-15%	0%	15.1-30%	0%	0%	0%	0.1-15%
	ecosystem services	0.1-15%	0%	0.1-15%	0%	0%	0%	0%
Management criteria	science-based	30.1-45%	60.1-75%	30.1-45%	45.1-60%	30.1-45%	15.1-30%	30.1-45%
	monitoring	15.1-30%	45.1-60%	15.1-30%	30.1-45%	15.1-30%	15.1-30%	45.1-60%
	interdisciplinary	15.1-30%	60.1-75%	0.1-15%	15.1-30%	15.1-30%	15.1-30%	0%
	boundaries	15.1-30%	45.1-60%	0.1-15%	0%	0%	15.1-30%	15.1-30%
	regional coordinating body	15.1-30%	15.1-30%	15.1-30%	0%	15.1-30%	15.1-30%	15.1-30%
	co-management	0.1-15%	0.1-15%	30.1-45%	15.1-30%	15.1-30%	15.1-30%	0%
	structure for trade-offs	0.1-15%	0%	15.1-30%	0%	0%	30.1-45%	0.1-15%
	adaptive	0.1-15%	0.1-15%	15.1-30%	0%	0%	0%	0.1-15%
	precautionary approach	0.1-15%	0.1-15%	0%	0%	15.1-30%	0%	0%
	technological	0.1-15%	0%	0%	0%	15.1-30%	0%	0%

Legend: 0%, 0.1-15%, 15.1-30%, 30.1-45%, 45.1-60%, 60.1-75%, >75%

accommodates the complexity of ecosystems. Integrating complexity into management ranked as the most commonly mentioned feature of EBM among commercial fishermen, environmental group representatives, fishery scientists, and recreational fishermen. Although widely identified as a core consideration for EBM, respondents spoke of complexity and its incorporation into management in a variety of ways. Some respondents, particularly commercial fishermen, focused on a need to consider species interactions; they aligned complexity with multi-species fisheries management. Other respondents emphasized the need to consider interactions between fish species and the broader marine ecosystem to reach fishery management goals, a view that is consistent with ecosystem-based fisheries management. A few respondents, primarily environmental group representatives, discussed complexity across the geography of the ecosystem; these respondents viewed EBM as an integrated and place-based approach to management that considers the effects of land-based activities on coastal and marine ecosystems.

Forty-five percent of respondents conceptualized EBM as a way of managing across political jurisdictions and sectoral interests. Associating cross-jurisdictional approaches with EBM ranked highest among aquaculturists but was also well-recognized by commercial fishermen, fishery managers, and fishery scientists. While some respondents focused on EBM as a way of working across political boundaries, most emphasized a need to coordinate across sectoral boundaries to unify management of many activities that are currently treated individually by multiple agencies. In considering the realities of working across jurisdictional and sectoral divides, respondents spoke of the need to develop objective methods for cumulative impact assessment and for evaluating trade-offs. Such objective decision-support information is critical for ensuring that EBM does not unnecessarily restrict certain activities without addressing other potential stressors.

Stakeholder participation in the management process ranked third among the features that respondents associated with EBM. Stakeholder participation was the most commonly mentioned feature of EBM among fishery managers and recreational fishermen, and it was also noted by a large portion of environmental group representatives. Many respondents who identified stakeholder participation as a central feature of EBM expected the number of user groups affected by decisions to increase and felt that these groups could contribute valuable information to advance EBM. They also noted that higher levels of support for management efforts could be obtained if stakeholders were involved in all phases of the process, from setting goals and objectives to selecting management options.

Finally, 38% of the respondents characterized EBM as a science-based process, although this was not a common response among fisheries scientists (17%), the lowest stakeholder group response for this topic. Many respondents viewed EBM as grounded in a solid understanding of the ecosystem—including its components, interactions, response, and resilience. The importance of scientific information ranked as one of the top features identified by aquaculturists, and it was mentioned by smaller portions of respondents from all other stakeholder groups. For aquaculturists, the importance of interdisciplinary perspectives in EBM ranked just as high as the science-based characterization. However, the need to integrate information from both natural and social science disciplines was not widely recognized by respondents in other stakeholder groups and was not mentioned at all by managers, who also did not recognize inclusion of humans or co-management as important components of EBM. The importance of including humans was a key difference between scientists (67%) and managers (0%).

Resource management features

Although interviewees identified some features that distinguish EBM from traditional management approaches, they viewed EBM as building from a foundation of good resource management practices. Interviewees mentioned a plethora of specific features (Table 3.2) when asked about characteristics they felt provided a basis for good management. Topics discussed by respondents addressed: (1) the information sources that should be used to guide management decisions, (2) the desired structure of the management process, (3) desired features of the management process, and (4) desired goals or outcomes.

The availability and use of scientific information was cited by 60% of respondents as an important element of resource management processes. The value of science ranked as the most frequently identified feature among fishery managers, commercial fishermen, and aquaculturists; it was also recognized by high portions of respondents in other stakeholder groups. Respondents viewed science as a vital source of information upon which management directions could be developed, decisions could be made, and a timeline for achieving goals could be determined.

Stakeholder input was also mentioned by half of the respondents as an important feature of good resource management processes. It ranked as the top feature identified by environmental group representatives and fishery scientists, and it was also rated highly by managers. Respondents spoke of stakeholders—specifically those from user groups and interest groups—as valuable sources of information that could strengthen the knowledge base upon which management decisions are formed. Further, interactions and information-sharing among managers, scientists, and diverse stakeholders were perceived as a way of reducing conflicts in management arenas.

Collaboration was also considered a key element of good resource management practices, particularly among recreational fishermen and fishery

Table 3.2. Categories and topics of responses associated with features of good resource management experiences. Shading indicates percentage of respondents overall or in individual stakeholder groups mentioning the specific topic. Topics in italics represent those features not mentioned by more than 10% of respondents.

Category	**Topic**	**ALL** n=40	**AQ** n=7	**COM** n=8	**REC** n=6	**ENV** n=6	**SCI** n=6	**MAN** n=7
Information	scientific information	45.1-60%	60.1-75%	60.1-75%	45.1-60%	30.1-45%	30.1-45%	>75%
	stakeholder input	45.1-60%	15.1-30%	15.1-30%	45.1-60%	45.1-60%	>75%	60.1-75%
	monitoring	15.1-30%	15.1-30%	0.1-15%	0%	15.1-30%	15.1-30%	15.1-30%
	local knowledge	0.1-15%	15.1-30%	0.1-15%	0%	15.1-30%	0%	0.1-15%
	broad information	0.1-15%	15.1-30%	0.1-15%	0%	0%	0%	15.1-30%
Structure	collaborative	15.1-30%	0.1-15%	15.1-30%	60.1-75%	0%	15.1-30%	45.1-60%
	bottom-up	0.1-15%	0%	45.1-60%	0%	15.1-30%	15.1-30%	0%
	local management	0.1-15%	0%	0.1-15%	15.1-30%	15.1-30%	15.1-30%	0%
	reasonable number of groups	0.1-15%	0%	0.1-15%	15.1-30%	0%	0%	0.1-15%
	top-down	0.1-15%	0%	0%	0%	15.1-30%	15.1-30%	0%
Process	objectives	30.1-45%	45.1-60%	0.1-15%	30.1-45%	15.1-30%	45.1-60%	60.1-75%
	accountability	15.1-30%	30.1-45%	15.1-30%	45.1-60%	30.1-45%	15.1-30%	0%
	consistency/equity/fairness	15.1-30%	45.1-60%	30.1-45%	30.1-45%	0%	0%	0.1-15%
	funding/resources	15.1-30%	15.1-30%	0.1-15%	30.1-45%	15.1-30%	0%	30.1-45%
	simple process	15.1-30%	0.1-15%	15.1-30%	15.1-30%	0%	15.1-30%	30.1-45%
	adaptability	15.1-30%	15.1-30%	0.1-15%	0%	30.1-45%	15.1-30%	0.1-15%
	enforcement	15.1-30%	0%	30.1-45%	30.1-45%	0%	0%	15.1-30%
	communication	0.1-15%	0.1-15%	0.1-15%	0%	0%	30.1-45%	15.1-30%
	flexibility	0.1-15%	0%	0.1-15%	15.1-30%	0%	45.1-60%	0%
	transparency	0.1-15%	0%	0.1-15%	15.1-30%	0%	15.1-30%	15.1-30%
	trust/respect	0.1-15%	0%	15.1-30%	0%	0%	15.1-30%	15.1-30%
	compromise	0.1-15%	0%	0%	0%	0%	30.1-45%	15.1-30%
	cooperation	0.1-15%	0%	15.1-30%	15.1-30%	0%	0%	0.1-15%
	leadership	0.1-15%	0%	0%	30.1-45%	15.1-30%	0%	0.1-15%
	precautionary	0.1-15%	0%	0%	0%	30.1-45%	0%	0%
Outcomes	integrated management	0.1-15%	15.1-30%	0%	15.1-30%	30.1-45%	0%	0%
	preserve environment	0.1-15%	0.1-15%	0%	0%	45.1-60%	0%	0.1-15%
	sustain communities	0.1-15%	0%	15.1-30%	0%	15.1-30%	0%	0%

Legend: 0%, 0.1-15%, 15.1-30%, 30.1-45%, 45.1-60%, 60.1-75%, >75%

managers. Although stakeholder participation and collaboration can be viewed as similar features, respondents characterized collaboration as entailing a higher level of engagement in management processes and commitment to working together to achieve outcomes that are amenable to many interests. Respondents suggested that collaborative partnerships involving key stakeholders are critical for developing solutions to achieve management goals.

The existence of clear objectives to guide management efforts was identified by 40% of respondents as essential for effective resource management. Most respondents felt that clear goals and objectives were necessary to focus attention and resources on the most pressing needs and to ensure that the scope of efforts remained manageable. A high portion of fishery managers, aquaculturists, and fishery scientists recognized the need for clear objectives, while smaller portions of recreational fishermen, commercial fishermen, and environmental group representatives noted their importance.

Several features received little attention in interviewees' descriptions of good resource management. Accountability was mentioned as an important feature by respondents in all stakeholder groups, with the notable exception of managers. Consistency and fairness were mentioned as key elements of good resource management by use-oriented stakeholders, but no scientists or environmentalists and few managers recognized the importance of these process features. Respondents rarely spoke of specific outcomes as being features of good management endeavors. However, substantial deviation from this pattern was noted among environmental group representatives, half of whom suggested that good resource management practices were characterized by the achievement of outcomes that preserve the environment.

Ecosystem goals

Interviewees expressed a variety of goals for the Gulf of Maine ecosystem and its management. Responses to this question were categorized into 20 different topics (Table 3.3) representing six major categories: (1) the state of the ecosystem, (2) components of the ecosystem, (3) functions of the ecosystem, (4) services provided by the ecosystem, (5) desired features of the management process, and (6) management strategies that would help achieve goals.

Table 3.3. Categories and topics of responses associated with stakeholders' goals for the Gulf of Maine ecosystem. Shading indicates percentage of respondents overall or in individual stakeholder groups mentioning the specific topic. Topics in italics represent those features not mentioned by more than 10% of respondents.

Category	**Topic**	**ALL**	**AQ**	**COM**	**REC**	**ENV**	**SCI**	**MAN**
		n=39	n=7	n=8	n=6	n=6	n=6	n=6
Ecosystem state	multiple uses	15.1-30%	30.1-45%	0.1-15%	15.1-30%	0%	15.1-30%	30.1-45%
	sustainability	0.1-15%	0.1-15%	15.1-30%	0%	15.1-30%	0%	15.1-30%
	ecosystem health/integrity	0.1-15%	0.1-15%	0%	15.1-30%	15.1-30%	15.1-30%	0%
Ecosystem components	populations	15.1-30%	0.1-15%	30.1-45%	30.1-45%	30.1-45%	0%	15.1-30%
	habitats	15.1-30%	0.1-15%	15.1-30%	15.1-30%	15.1-30%	0%	30.1-45%
	diversity	15.1-30%	0.1-15%	0%	30.1-45%	30.1-45%	15.1-30%	0%
	water quality	0.1-15%	0.1-15%	0.1-15%	15.1-30%	15.1-30%	0%	15.1-30%
Ecosystem function	productivity	15.1-30%	0.1-15%	30.1-45%	0%	0%	30.1-45%	0%
	balance	0.1-15%	0.1-15%	0.1-15%	30.1-45%	0%	0%	0%
	dynamism/resilience	0.1-15%	0%	0.1-15%	0%	15.1-30%	30.1-45%	0%
Ecosystem services	socio-economic quality	0.1-15%	0.1-15%	30.1-45%	0%	15.1-30%	0%	0%
	sustainable fisheries	0.1-15%	0.1-15%	15.1-30%	0%	15.1-30%	15.1-30%	0%
	cultural services	0.1-15%	15.1-30%	0.1-15%	15.1-30%	0%	0%	0%
Management process	scientific information	15.1-30%	0%	15.1-30%	30.1-45%	15.1-30%	30.1-45%	45.1-60%
	human-ecosystem linkages	15.1-30%	15.1-30%	15.1-30%	0%	15.1-30%	15.1-30%	15.1-30%
	multi-stakeholder processes	15.1-30%	15.1-30%	0.1-15%	30.1-45%	15.1-30%	0%	30.1-45%
	communication/education	15.1-30%	0.1-15%	15.1-30%	0%	15.1-30%	15.1-30%	30.1-45%
	holistic approach	0.1-15%	0%	0.1-15%	30.1-45%	15.1-30%	15.1-30%	0%
Management strategies	fishery management strategies	15.1-30%	0.1-15%	15.1-30%	15.1-30%	15.1-30%	45.1-60%	30.1-45%
	land management strategies	15.1-30%	15.1-30%	15.1-30%	0%	15.1-30%	0%	15.1-30%
	societal strategies	0.1-15%	0.1-15%	0%	0%	15.1-30%	0%	0%

Legend: 0%, 0.1-15%, 15.1-30%, 30.1-45%, 45.1-60%, 60.1-75%, >75%

The ecosystem goals identified by respondents were disparate, and less dominance emerged among the topics than was noted for responses to other questions. The most commonly mentioned goals across all stakeholder groups included: (1) expanding scientific information about the ecosystem and its components, (2) improving fisheries management, (3) restoring and sustaining healthy populations, (4) supporting multiple human uses of the ecosystem, and (5) engaging multiple stakeholders in management (Table 3.3).

Goals expressed by respondents varied widely across the six stakeholder groups. The highest ranked goals identified by commercial fishermen, recreational fishermen, and environmental group representatives emphasized the importance of protecting the ecosystem and its constituent parts. Top-ranking goals among these groups included sustaining species populations, protecting diversity within the ecosystem, maintaining the productivity of the ecosystem, and preserving a balance within species (e.g., age structure) and between species (e.g., trophic structure).

Other priority goals identified by aquaculturists and commercial fishermen related to the capacity of the ecosystem to support human uses and to sustain human livelihoods. Aquaculturists most commonly expressed a goal of sustaining multiple uses of the Gulf of Maine ecosystem, while commercial fishermen frequently noted the importance of maintaining socio-economic quality within coastal communities.

Improving features of the management process were included among the top goals identified by recreational fishermen, managers, and scientists. Key goals mentioned by these stakeholder groups included improving scientific information available about the ecosystem, adopting holistic management approaches, engaging multiple stakeholders in the management process, and improving the use of fishery management strategies (e.g., bycatch reduction) to achieve ecosystem benefits.

Ecosystem concerns

Interviewees identified 18 specific concerns about the Gulf of Maine ecosystem relating to: (1) the ecological functioning of the Gulf of Maine, (2) human relationships to and reliance on the ecosystem, (3) shortcomings of the management process and its structure, and (4) specific stressors that may impact the ecosystem (Table 3.4). The most commonly mentioned topic focused on the ecosystem's resilience; more than 30% of respondents were concerned about whether the

Table 3.4. Categories and topics of responses associated with stakeholders' concerns about the Gulf of Maine ecosystem. Shading indicates percentage of respondents overall or in individual stakeholder groups mentioning the specific topic. Topics in italics represent those features not mentioned by more than 10% of respondents.

Category	Topic	ALL	AQ	COM	REC	ENV	SCI	MAN
		n=33	n=6	n=8	n=6	n=5	n=4	n=4
Ecological	resilience/irreversibility	30.1-45%	15.1-30%	45.1-60%	30.1-45%	15.1-30%	15.1-30%	15.1-30%
	dynamism	0.1-15%	15.1-30%	0.1-15%	0%	0%	15.1-30%	15.1-30%
	balance	0.1-15%	0%	0%	30.1-45%	15.1-30%	0%	0%
	cross-boundary consequences	0.1-15%	15.1-30%	0%	0%	0%	0%	0%
Human	connections to ecosystem	15.1-30%	30.1-45%	0.1-15%	15.1-30%	15.1-30%	0%	0%
	social/economic impacts	0.1-15%	30.1-45%	0.1-15%	15.1-30%	0%	0%	0%
Process	cross-jurisdictional coordination	15.1-30%	15.1-30%	15.1-30%	15.1-30%	15.1-30%	0%	15.1-30%
	inadequate science	15.1-30%	45.1-60%	0.1-15%	0%	0%	45.1-60%	0%
	competing uses	0.1-15%	0%	0%	15.1-30%	0%	45.1-60%	0%
Stressors	cumulative impacts	15.1-30%	0%	30.1-45%	0%	45.1-60%	60.1-75%	0%
	coastal development	15.1-30%	30.1-45%	0.1-15%	45.1-60%	0%	0%	0%
	water quality	15.1-30%	30.1-45%	0.1-15%	0%	30.1-45%	0%	15.1-30%
	climate change	15.1-30%	15.1-30%	0.1-15%	15.1-30%	15.1-30%	15.1-30%	0%
	resource extraction	15.1-30%	15.1-30%	0%	15.1-30%	15.1-30%	15.1-30%	15.1-30%
	pollution	0.1-15%	0%	0.1-15%	15.1-30%	15.1-30%	0%	15.1-30%
	aquaculture	0.1-15%	0%	0.1-15%	15.1-30%	0%	0%	0%
	habitat alteration	0.1-15%	0%	0%	0%	30.1-45%	0%	0%
	invasive species	0.1-15%	0%	0%	0%	0%	0%	0.1-15%

Legend: 0%, 0.1-15%, 15.1-30%, 30.1-45%, 45.1-60%, 60.1-75%, >75%

ecosystem may reach a 'tipping point', beyond which its ability to function may be irreversibly impaired. This concern was particularly common among commercial and recreational fishermen.

Nearly 30% of respondents also cited concerns about cumulative impacts from multiple stressors being applied simultaneously to the ecosystem. The impact of multiple stressors was the most frequently noted concern of fishery scientists and environmental group representatives. One specific stressor—coastal development—was commonly mentioned by recreational fishermen. In addition, aquaculturists, environmental group representative, fishery managers, and commercial fishermen mentioned concerns about water quality, which can be impaired as a result of development in the coastal zone.

Across all stakeholder groups, other highly-ranked concerns encompassed features of the management process, specifically inadequate science and cross-jurisdictional coordination challenges. Concerns about the adequacy of current science to guide EBM ranked as the top issue noted by aquaculturists, and an equal portion of scientists shared this concern. Although it did not rank as the top concern for any single stakeholder group, the challenges associated with cross-jurisdictional coordination were mentioned by respondents from all stakeholder groups, except scientists.

Comparing stakeholder perspectives to existing EBM guidance

Comparing respondents' characterizations of EBM to those found in the academic literature (i.e., Arkema *et al*. 2006) reveals substantial overlap in the types of features that stakeholders and experts associate with EBM (Figure 3.1). Stakeholders in the Gulf of Maine mentioned all 17 of the criteria that are established for EBM in existing conceptual articles. Most of these 17 features were noted in a higher proportion of academic articles than in stakeholders' descriptions of EBM. The biggest difference existed in the portion of academic articles and stakeholders that identified ecosystem services as considerations in EBM; although ecosystem services are associated with EBM in more than half of the academic articles reviewed, this concept was mentioned by only one stakeholder interviewed for this study. Similar proportions of respondents and academic authors cited stakeholder participation and protecting ecological health as important elements of EBM. Further, the proportion of respondents that mentioned

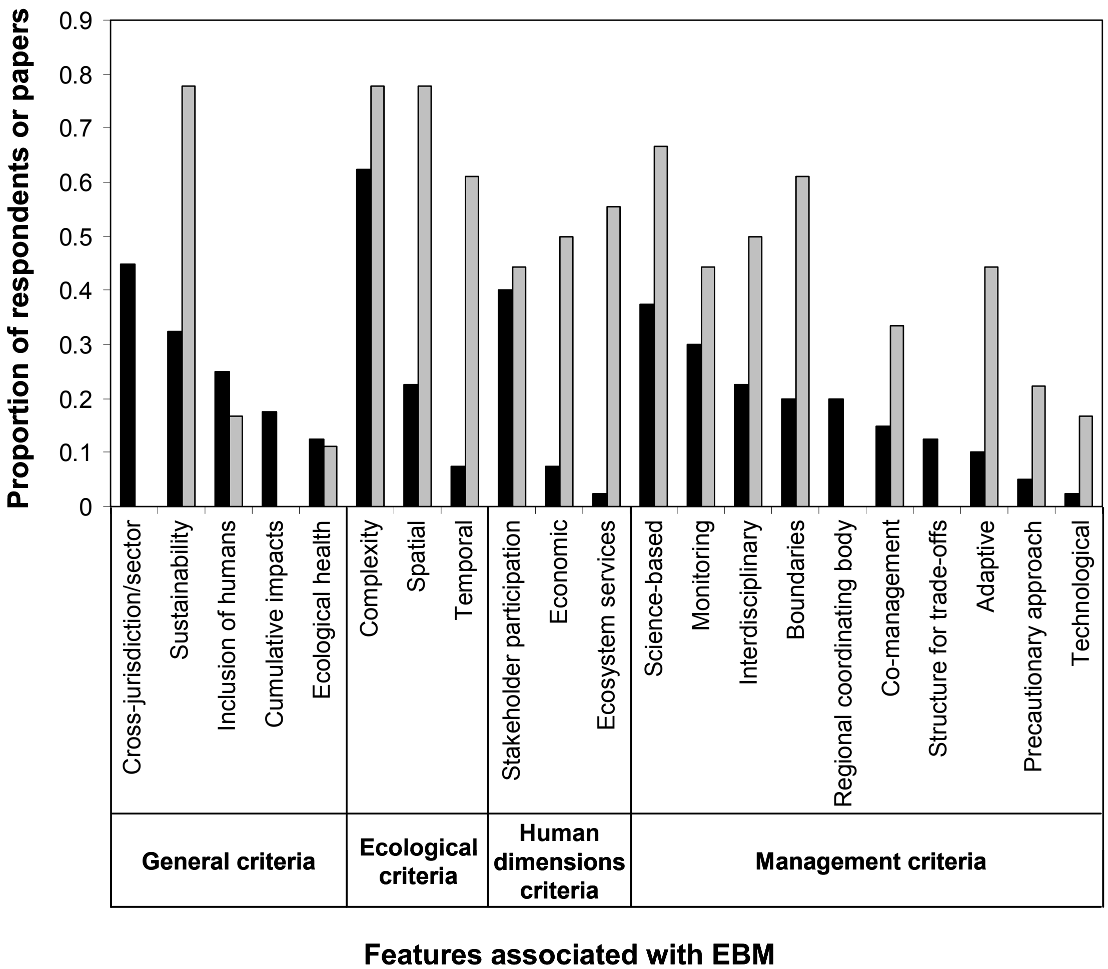

Figure 3.1. Proportion of interview respondents citing specific features in their characterization of EBM (black bars) compared to the proportion of academic journal articles reviewed by Arkema *et. al*. (2006) (grey bars) citing each feature.

the need to include humans in EBM exceeded that of academic authors. In addition, the stakeholders interviewed associated several features with EBM that were not identified as distinct attributes by Arkema *et al*. (2006), including: (1) cross-jurisdictional and cross-sector coordination, (2) regional coordination, (3) cumulative impact assessment, and (4) processes for making trade-offs.

Comparing stakeholder groups based on EBM perspectives

Respondents' comments related to each of the four interview themes were used to better understand differences between and relationships among the six stakeholder groups considered in this study.

Differences between stakeholder groups

Differences between stakeholder groups were investigated based on individual respondents' comments regarding each major interview theme. A global ANOSIM detected weak ($R=0.11$) but significant ($p<0.05$) differences among the stakeholder groups in their characterizations of EBM. Pairwise comparisons indicated significant distinctions in the features four pairs of groups used to characterize EBM: aquaculturists-commercial fishermen ($R=0.181$, $p<0.05$); aquaculturists-environmental group representatives ($R=0.433$, $p<0.01$); aquaculturists-scientists ($R=0.217$, $p<0.05$); and aquaculturists-recreational fishermen ($R=0.284$, $p<0.05$). Contributing to the overall pairwise dissimilarity between these groups, a higher portion of aquaculturists cited interdisciplinary perspectives, monitoring, cumulative impacts assessment, scientific basis for decision-making, and cross-jurisdictional integration as important features of EBM; other stakeholder groups placed a heavier emphasis on a goal of ecological health, inclusion of humans in the ecosystem, and stakeholder involvement in management (Table 3.5).

Table 3.5. Key factors contributing to multivariate differences between group characterizations of EBM, as identified in SIMPER analysis.

Aquaculturists vs. commercial fishermen

Feature	% AQ	% COM	% contribution to dissimilarity	Cumulative %
Interdisciplinary	71	13	9.93	9.93
Monitoring	57	25	8.76	18.68
Cumulative impacts	57	13	8.58	27.26
Science-based	71	38	8.51	35.77

Aquaculturists vs. environmental group representatives

Feature	% AQ	% ENV	% contribution to dissimilarity	Cumulative %
Cross-jurisdiction	71	17	9.30	9.30
Ecological health	0	67	9.08	18.38
Interdisciplinary	71	17	8.93	27.31
Monitoring	57	17	8.45	35.76

Aquaculturists vs. fishery scientists

Feature	% AQ	% SCI	% contribution to dissimilarity	Cumulative %
Science-based	71	17	9.47	9.47
Interdisciplinary	71	17	9.20	18.67
Inclusion of humans	14	67	9.15	27.81
Monitoring	57	17	8.88	36.69

Aquaculturists vs. recreational fishermen

Feature	% AQ	% REC	% contribution to dissimilarity	Cumulative %
Stakeholder involvement	29	83	9.95	9.95
Interdisciplinary	71	17	9.88	19.82
Cumulative impacts	57	0	9.19	29.02
Cross-jurisdiction	71	33	9.19	38.21

Similarly, a global ANOSIM showed weak ($R=0.098$) but significant ($p<0.05$) differences among the stakeholder groups in the features cited as important to good management. Pairwise comparisons indicated significant differences in the ways in which three pairs of stakeholder groups described good resource management: aquaculturists-scientists ($R=0.225$, $p<0.05$); commercial fishermen-environmental group representatives (R=0.203, p<0.05); and environmental group representatives-managers (R=0.257, p<0.05). Across the three significant pairwise comparisons, differences in how the groups valued stakeholder input and scientific information in resource management ranked among the top four factors contributing to the dissimilarity. Scientists, environmental group representatives, and fishery managers more frequently mentioned the importance of stakeholder input to management; aquaculturists, commercial fishermen, and fishery managers more commonly cited scientific information as necessary for good management than their pairwise

Table 3.6. Key factors contributing to multivariate differences between groups based on features associated with good resource management.

Aquaculturists vs. fishery scientists

Feature	% AQ	% SCI	% contribution to dissimilarity	Cumulative %
Stakeholder input	29	83	9.84	9.84
Consistency/fairness	57	0	9.78	19.62
Scientific information	71	33	8.95	28.58
Objective-based	57	50	8.41	36.98

Commercial fishermen vs. environmental group representatives

Feature	% COM	% ENV	% contribution to dissimilarity	Cumulative %
Stakeholder input	25	50	10.27	10.27
Scientific information	75	33	10.07	20.34
Preserve environment	0	50	9.12	29.46
Bottom-up structure	50	17	7.60	37.50

Environmental group representatives vs. fishery managers

Feature	% ENV	% MAN	% contribution to dissimilarity	Cumulative %
Scientific information	33	86	9.29	9.29
Objective-based	17	71	8.83	18.11
Stakeholder input	50	71	7.58	25.69
Preserve environment	50	14	7.58	33.27

counterparts (Table 3.6). The ANOSIM of the goals and concerns expressed by respondents did not show significant differences between the stakeholder groups.

Relationships among stakeholder groups

Relationships among stakeholder groups were investigated using cluster analyses of the proportion of respondents in each group that identified specific features in their responses to each of the four interview themes (Figure 3.2). Based on features that groups used to characterize EBM, cluster analysis results showed the strongest similarity between commercial fishermen and fishery scientists. Environmental group representatives and recreational fishermen showed the next highest level of similarity, while aquaculturists and fishery managers clustered at a

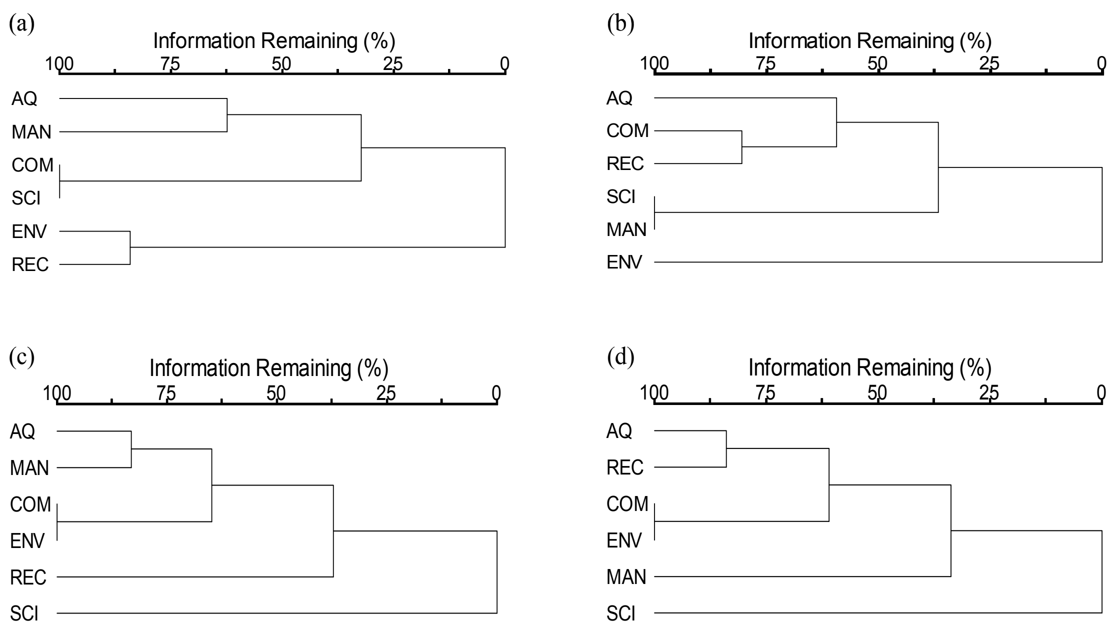

Figure 3.2. Cluster analyses of relationships between stakeholder groups based on responses regarding their (a) characterization of EBM, (b) characterization of good resource management practices, (c) goals for the Gulf of Maine ecosystem, and (d) concerns about the Gulf of Maine ecosystem.

lower level. Commercial fishermen, scientists, aquaculturists, and managers showed more similarity to one another in their characterization of EBM than they did to environmental group representatives and recreational fishermen (Figure 3.2a).

The cluster analysis based on features that stakeholder groups considered important for good resource management showed a strong similarity between fishery scientists and fishery managers. Commercial fishermen and recreational fishermen also formed a pair at the second highest level of similarity, and aquaculturists were combined with this group at the next node in the dendogram. All five of these stakeholder groups clustered with one another before they were joined with environmental group representatives (Figure 3.2b).

The clustering of groups based on their goals for the ecosystem showed that commercial fishermen and environmental group representatives shared the greatest similarity. Aquaculturists and fishery managers formed the next most similar cluster, and these first two clusters merged before other stakeholder groups were incorporated into the dendogram. Goals expressed by recreational fishermen and fishery scientists, respectively, showed increasing dissimiliarity from those identified by the other stakeholder groups (Figure 3.2c).

Results based on respondents' concerns about the Gulf of Maine ecosystem revealed the highest level of similarity between commercial fishermen and environmental group representatives. Aquaculturists and recreational fishermen formed the next most similar group, which then joined with the first cluster at the next node in the dendogram. Fishery managers and then scientists were subsequently attached at increasingly lower levels of similarity (Figure 3.2d).

Discussion

Using stakeholders' perspectives to advance EBM in the Gulf of Maine

Applying EBM within and across sectors of human activity

Interviewees' responses to the four themes of questions reveal important insights into their perspectives on what a shift towards EBM could accomplish and how this management approach might be structured. Respondents generally viewed EBM as a beneficial and necessary direction in the management of marine ecosystems for a number of reasons. Most frequently mentioned by interviewees was the fact that EBM would better accommodate the inherent complexity of the ecosystem, a focus that is also central in the EBM literature (Slocombe 1998, Szaro *et al*. 1998, Arkema 2006). Respondents primarily discussed this complexity at two levels—biological interactions between fish species and species-environment relationships that affect fisheries. A small portion of interviewees also discussed complexity from a watershed perspective, focusing on how land-based human activities affect marine ecosystems. These three levels of complexity and integration parallel the 'three faces' Yaffee (1999) identified to categorize EBM approaches.

In addition, respondents recognized the value of EBM as an approach that would engage participants across multiple sectors of human activities and independent political jurisdictions in coordinated ecosystem-scale management efforts. Considerations of ecological interactions and dynamics have typically been incorporated into management guidance within individual sectors of activity, such as fisheries (NMFS 1999, Link 2002, Francis *et al*. 2007, Overholtz *et al*. 2008), and it is not surprising that stakeholders interviewed for this study recognized ways of applying EBM within fisheries management. However, many respondents also articulated a vision of EBM as a means of coordinating management objectives and activities across multiple sectors, an application of EBM that has been supported by recent policy initiatives and reviews (e.g., Government of Canada 1996, Pew Oceans Commission 2004, USCOP 2004).

The emphasis on accommodating both ecological complexity and multi-sector interests calls attention to distinct but complementary applications of EBM. Developing EBM in a way that jointly expands ecological considerations within fishery management and also facilitates coordination across agencies and jurisdictions may enhance its relevance and salience to stakeholders in the Gulf of Maine. Such an approach would advance ecosystem considerations in fisheries management and stock assessments while also involving stakeholders from key activity sectors, including fisheries, in regional ecosystem planning initiatives (e.g., Eastern Scotian Shelf Integrated Management Initiative; Government of Canada 2007, O'Boyle and Worcester 2009). This approach to EBM implementation has the potential to strengthen existing management efforts while also enhancing the integration among management initiatives.

While many of the attributes of EBM that were identified by stakeholders are consistent with design criteria that have been developed in the literature (i.e., Arkema *et al*. 2006), interviewees identified four elements that have not commonly been mentioned in the academic literature on EBM but have appeared in more applied discussions of this topic (e.g., Rosenberg and Sandifer 2009). These features included: (1) cross-jurisdictional and cross-sector coordination mechanisms, (2) regional coordinating structures, (3) cumulative impact assessment approaches, and (4) objective processes for identifying and making trade-offs. That respondents recognized these features as necessary for EBM indicates their consideration of implementation realities and recognition of advances that will be necessary to ensure that scientific capacities and management structures are suitable for supporting EBM.

Building on a foundation of good management

Interviewees recognized core elements of good resource management processes and believed that these same features would provide a foundation for advancing EBM. Respondents consistently cited two sources of input and guidance—scientific information and stakeholder participation—as key features of EBM and as fundamental requirements for good resource management in general. Stakeholders' perspectives on scientific information acknowledged the importance of interpreting existing data to understand the ecosystem, conducting rigorous monitoring to maintain and expand available data, and broadening research efforts to address new questions that will arise when managing in an ecosystem context. The need for similar scientific advances to support EBM has also been emphasized in recent academic and political reviews (e.g., USCOP 2004, Magnuson-Stevens Act 2007, McLeod and Leslie 2009). However, respondents also felt that the process of moving towards EBM should not be slowed by waiting for more information to become available. Most respondents viewed the development of science to support EBM as an incremental process that could rely on syntheses of existing data and general ecological knowledge in the short term and on the development of more specific research and monitoring initiatives in the long term. Using existing scientific information in new ways and adaptively improving the science to support EBM is consistent with the perspectives articulated by both scientists and managers at the forefront of EBM development (Murawski 2007, Rosenberg and Sandifer 2009).

In addition to recognizing the value of scientific information, interviewees cited stakeholder input as another important source of information to guide EBM. Many commented that management decisions can never be entirely removed from the political realm and saw meaningful stakeholder engagement processes as a critical component of management within this political context. Others viewed stakeholders as important information providers whose observations and experiences could help fill gaps in scientific knowledge, particularly those related to the social and economic implications of trade-offs that may be confronted in EBM. This perception parallels findings of other studies that have recognized the value of stakeholders' knowledge to inform effective and durable ecosystem management plans and resource management decisions (e.g., Beierle and Koniskly 2001, Brody 2003). While respondents recognized that certain stakeholders are already involved in fisheries management, particularly in the United States, most respondents felt that the types of stakeholders involved in EBM would need to encompass a broader array of groups. At the same time though, respondents recognized that expanding the scope of stakeholders could bog down EBM efforts; separating the process of setting objectives from that of determining management actions could ameliorate this potential challenge.

Respondents recognized the importance of both science and stakeholder participation in EBM; bringing these two sources of information together has been considered an important feature of successful participatory processes (Tuler and Webler 1999, Chase *et al*. 2004, Dalton 2005). However, tensions between scientific guidance and stakeholder input are not uncommon, particularly within current fisheries management processes, as scientific stock assessment advice has serious social and economic implications for fishermen. Some of the challenges associated with combining these two sources of input may be overcome by ensuring that stakeholders can access and understand the scientific information on which decisions are based and that they have opportunities to guide the ways in which science will be used in decision-making processes (Tuler and Webler 1999, Hartley 2006, Karl *et al*. 2007).

Dialogue is an important mechanism for integrating scientific information and stakeholder input, but effective dialogues may be inhibited by language and conceptual differences. Stakeholders interviewed for this study did not use some terms that have become part of the EBM lexicon. For example, only one respondent spoke of the concept of ecosystem services, and although a number mentioned considerations related to the concept of cumulative impact assessment, very few used this phrase in their comments. Further, relatively few respondents mentioned specific tools that have been proposed for implementing EBM, such as spatial planning or ownership rights within fisheries. The lack of emphasis on these topics could indicate that stakeholders dissociated their conceptualizations of EBM from the tools that may be used to pursue certain goals, but it could also indicate that stakeholders are not familiar with specific tools that could accomplish EBM objectives. Ensuring a common language and conceptual understanding will be important for bringing together scientific information and stakeholder input to advance EBM.

Defining initial goals and issues for EBM

As interviewees spoke of their goals and concerns related to the Gulf of Maine ecosystem, comments pointed towards a central and overarching goal for EBM in the region: support multiple human uses while protecting the ecosystem. While this goal is broad, it embodies the tenets of sustainability and reflects the importance of accommodating both human and ecological considerations in EBM; similar goals have been discussed in the EBM literature (e.g., Christensen *et al*. 1996, Szaro *et al*. 1998). In addition, interviewees' responses highlighted specific issues that stakeholders expect to be addressed by EBM: species interactions that affect fisheries, fish population abundance, marine habitat conditions, water quality, and coastal development. These issues suggest focus areas that should be considered in an initial phase of shifting towards EBM. Many of these issues can be addressed within existing fishery management frameworks, but effectively addressing all of them requires working across multiple sectors and engaging diverse management entities. Initially focusing EBM efforts on a relatively small set of priority issues may support development of a model for integrated EBM that can incrementally be expanded to include more issues and sectors.

Consistencies and distinctions in stakeholder perspectives on EBM

The stakeholders interviewed for this study expressed many common themes in their conceptualizations of EBM, but some differences between the groups were apparent. Understanding patterns in these group distinctions and themes associated with them can provide important insights regarding the potential of different groups to work together towards EBM in the Gulf of Maine. The strongest distinctions emerged between aquaculturists and other stakeholder groups. The finding that aquaculturists appear to hold distinct perspectives on EBM and resource management may reflect the fact that their industry is not managed through the same laws and agencies as capture fisheries. Aquaculture primarily occurs in nearshore waters and is managed through state or provincial coastal management agencies, instead of fishery management agencies. Aquaculturists placed a stronger emphasis on interdisciplinary science and monitoring than other groups, and awareness of the importance of these features may derive from experiences that are unique to aquaculture operation. Because myriad factors—including social, oceanographic, and biological considerations—influence aquaculture siting and permitting decisions, aquaculturists may be more aware of the value of information from many disciplines than other stakeholder groups. In addition, aquaculture operators are responsible for tracking water quality and biological communities near their operations; because they are responsible for their own monitoring programs, they may have an increased awareness of monitoring as a key element of EBM. These distinctions between aquaculturists and other stakeholder groups suggest that: (1) personal experiences and knowledge may shape stakeholders' perceptions of EBM and (2) the consistency that was observed in stakeholders' conceptualizations may decline as a broader array of groups is integrated into EBM implementation processes.

Interesting relationships between stakeholder groups also emerged in their goals for and concerns about the Gulf of Maine ecosystem. The goals and concerns expressed by commercial fishermen and environmental group representatives clustered strongly with one another. These two stakeholder groups are generally viewed as having competing objectives, with fishermen focused more on economic gain and environmentalists focused on ecosystem protection (Valdimarsson and Metzner 2005, Hilborn 2007). Their similarity in this analysis indicates broad agreement on the goals and concerns that motivate each group. However, it is important to note that differences may arise in how these groups would achieve their expressed goals, but the acceptability of specific management actions was not addressed in this study.

In contrast to the similarity observed between commercial fishermen and environmental group representatives, the goals and concerns stated by scientists resulted in them clustering apart from all of the other stakeholder groups. The goals expressed by recreational fishermen and concerns identified by managers also showed low levels of similarity to other stakeholder groups. These observations reinforce the importance of carefully planning how stakeholder input will be integrated into management. Scientists and managers exert a strong influence on management directions by being involved in developing and assessing management options, but the options put forward may not reflect the interests or priorities of other stakeholder groups (e.g., Kearney *et al.* 1999). Capturing input from a broad array of stakeholders, particularly user groups and interest groups, before a suite of options is developed may be essential for fairly representing their goals and concerns in the management process (Dalton 2005, Karl *et al*. 2007).

In spite of some differences identified between certain stakeholder groups, strong general coherence exists across the groups in features they associated with EBM, characteristics they identified as important for effective management, and priorities and concerns they expressed for the Gulf of Maine ecosystem. Other authors have reported similar patterns of agreement among diverse stakeholders when discussing management concepts and high level goals, but they have found that more distinct interests arise when trying to reach agreement on specific objectives or implementation approaches (Barro and Bright 1998, Connelly *et al*. 2002). However, at least one study of stakeholders engaged in EBM in the Chesapeake Bay found similar management preferences shared across groups and noted fairly high levels of acceptance of policies needed to achieve those outcomes (Chuenpagdee *et al*. 2006). Assessing the acceptability of and preferences for specific management approaches and trade-offs among diverse stakeholder groups is important and should be the subject of future studies in the Gulf of Maine.

Implications for EBM in the Gulf of Maine

This study provides empirical insights into how stakeholders in the Gulf of Maine conceptualize EBM, including details of its structural scope, process elements, and priority issues. Such information can serve as a basis for designing EBM initiatives that are consistent with the expectations and priorities of key stakeholder groups in the Gulf of Maine. Analyzing stakeholders' characterizations of EBM in the context of literature on and frameworks for EBM provides a way of assessing the suitability of existing models to the Gulf of Maine.

A substantial amount of consistency was noted in the way that members of different stakeholder groups characterized EBM and the features they felt would be important for its implementation. It is important to note, however, that because this study targeted stakeholder groups with ties to fisheries and aquaculture, it does not represent all stakeholder groups that may be affected by a shift towards EBM. In addition, the use of a snowball sampling design means that subjects do not represent a random sample of individuals involved in fisheries and aquaculture. Instead, the results represent a highly engaged sub-group of stakeholders within those larger groups represented by this study, but this sub-group of "opinion leaders" will likely exert a disproportionate influence on EBM implementation. The key findings of this study should be viewed as a starting point for understanding stakeholders' perceptions and expectations of EBM in the Gulf of Maine as well as a basis for designing future inquiries to link stakeholder perspectives with EBM planning and implementation.

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CHAPTER 4

ECOSYSTEM INDICATORS: BRINGING SCIENCE TO SUPPORT ECOSYSTEM-BASED MANAGEMENT?

Introduction

Coastal and marine ecosystems and their associated management arenas are shaped by diverse physical, biological, ecological, social, and economic factors. The multiple environmental issues facing our estuaries, coasts, and oceans reinforce the need to improve resource management within a context of natural dynamics, human-induced pressures, and knowledge limitations. In recent years, the concept of ecosystem-based management (EBM) has gained increasing attention as a way of managing these ecosystems to accommodate their inherent complexity (McLeod and Leslie 2009).

EBM considers the inter-dependence of all ecosystem components—including physical, biological, and social features—within a geographically specific area (Grumbine 1994, Christensen *et al*. 1996). Goals associated with EBM include protecting the ecosystem's structure and function while also sustaining human communities and activities (Brussard *et al*. 1998, McLeod *et al*. 2005). Achieving these goals requires good scientific information and stakeholder input to shape priorities, establish objectives, and set target outcomes (Szaro *et al*. 1998, McLeod and Leslie 2009). While information from both scientific and stakeholder sources is important for EBM, challenges can arise in the process of bringing these two types of input together.

As interest in managing coastal and marine areas shifts towards a broader ecosystem-based perspective, ecosystem indicators and state-of-the-environment

(SOE) reports have become increasingly popular for conveying scientific information about the ecosystem to stakeholders and decision-makers (Ferriss and Leschine 2003). While complex multi-component ecosystem models are largely interpretable only by scientists, ecosystem indicators provide multidisciplinary information through metrics that can be understood and used by decision-makers and other stakeholders (Harwell *et al*. 1999, Turnhout *et al*. 2007). Indicators often track pressures on the ecosystem, the state of the ecosystem, and human responses to observed changes (Organization for Economic Cooperation and Development 1993, EPA 2008). They serve as foci for state-of-the-environment reports, which present and interpret indicators to inform management decisions by explaining each indicator's status, how it is changing, and what is causing those changes.

The relative simplicity of ecosystem indicators supports their use by a wide variety of stakeholders, and Turnhout *et al*. (2007) have characterized them as connecting the science and policy domains. One way in which indicators may function at this science-policy interface is by helping to build a shared base of knowledge regarding the status of and changes in key elements of the ecosystem. This shared understanding can be important for enabling diverse stakeholders to effectively engage in discussions and deliberations required to develop management priorities and directions for complex ecosystems (Jacobs 2005, Hartley 2006).

While a plethora of suggestions have been put forward on how to develop and communicate indicators so that they are of interest to multiple stakeholders (e.g., Harwell *et al*. 1999, Gibson *et al*. 2000, Dale and Beyeler 2001), much less attention has been devoted to how they contribute to management processes (but see Ferriss and Leschine 2003). With a proliferation of ecosystem indicators and associated SOE reports in coastal and marine settings occurring in conjunction with increasing interest in EBM, it is useful to consider how the information provided through indicators and

SOE reports may support EBM. Are the indicators and reports providing information that helps stakeholders understand the ecosystem in ways that are consistent with key tenets of EBM? In what ways do they advance EBM principles and processes, and in what ways could these connections be improved?

This paper addresses these types of questions by evaluating existing ecosystem indicator and reporting programs against features that have been suggested as important for EBM. Assessing the ways in which indicator and reporting programs characterize ecosystems, the types of information they convey, and the process they use to develop and interpret indicators against the features important to EBM offers important insights into ways in which these programs do—and do not—effectively support EBM. As indicator and reporting programs continue to grow and adapt, the findings of this review can help strengthen their connections to EBM.

Methods

Features of EBM were identified from a literature review of 18 peer-reviewed articles that helped define this concept (Arkema *et al*. 2006). Based on this review, we focused on 15 features that were consistently associated with EBM and that can be supported by ecosystem indicators and SOE reports. In the context of indicator and reporting programs, these features cluster into three categories related to: (1) how the ecosystem is characterized, (2) the types of information conveyed about the ecosystem, and (3) the process for developing the indicators and report. Specific EBM features that we looked for, along with the questions used to evaluate indicators and reporting programs against these features, are provided in Table 4.1.

Data were compiled from ten recent SOE reports produced for distinct coastal and marine ecosystems (Table 4.2). The ten programs reviewed were selected to provide widespread geographic coverage, to span a range of coastal and marine

Table 4.1. Indicator programs and associated state of environment reports were evaluated against a set of 15 features associated with EBM (subset of criteria identified by Arkema *et al*. (2006)). The focus of the evaluation (indicators, reports, or program) and the questions used to guide this evaluation are detailed in the right column.

	EBM feature	Focus of assessment	Assessment approach
Ecosystem characterization	Boundaries	Report	Are the ecosystem boundaries defined and presented clearly in report?
	Complexity	Indicators	Do indicators represent multiple components of the ecosystem? Do indicators represent ecosystem functions and processes?
		Report	Are interactions between each indicator and other ecosystem components presented using a conceptual model or discussed in the narrative?
	Humans as part of ecosystem	Indicators	Do the indicators represent humans within the ecosystem (e.g., human uses, management actions)?
		Report	Is the relevance of an indicator to human interests explained? Is the role of humans in maintaining the ecosystem explained?
	Temporal	Indicators	Are the indicators reported over time?
		Report	Are temporal trends discussed? Is the dynamic nature of ecosystems communicated in the narrative?
	Spatial	Indicators	Are spatial distinctions in the indicators displayed? Are indicators compiled at multiple spatial scales?
		Report	Are spatial distinctions discussed in report?
	Ecological health	Indicators	Are thresholds for indicators established to represent ecological health?
		Report	Is the concept of ecological health discussed? Is its discussion consistent with scientific understandings of this concept?
Information types	Science-based	Report	Does the state of environment report convey scientific understandings of the ecosystem?
	Monitoring	Indicators	Do the indicators transmit monitoring data?
		Report	Are monitoring programs that serve as sources for data identified?
	Interdisciplinary	Indicators	Are multiple disciplines represented by indicators?
		Report	Does narrative include insights from and connections to multiple disciplines?
	Stakeholder	Indicators or report	Do indicators or the report represent outreach efforts and stewardship initiatives that engage stakeholders?
Process	Science-based	Report	Are scientists involved in developing the indicators and report? Is the report reviewed by a panel that includes scientists?
	Stakeholder	Report	Did diverse stakeholders contribute to development of indicators and report?

Table 4.2. List of SOE reports reviewed for this study, along with the program developing the report and its geographic location.

State	Program	Report
LA	Barataria-Terrebonne National Estuary Program	Healthy Estuary, Healthy Economy, Healthy Communities 2002
AL	Mobile Bay National Estuary Program	State of Mobile Bay 2008
NH	New Hampshire Estuaries Project	State of the Estuaries 2006
WA	Puget Sound Action Team	State of the Sound 2007
NY/CT	Long Island Sound Study	Sound Health 2008
MD/VA	Chesapeake Bay Program	Bay Barometer 2008
VT/NY/Quebec	Lake Champlain Basin Program	State of the Lake 2008
GA	Gray's Reef National Marine Sanctuary (Office of NMS)	Gray's Reef National Marine Sanctuary: Condition Report 2008
WA	Olympic Coast National Marine Sanctuary (Office of NMS)	Olympic Coast National Marine Sanctuary: Condition Report 2008
ME to NC	Northeast Fisheries Science Center (Link and Brodziak, eds.)	Status of the Northeast U. S. Continental Shelf Ecosystem

ecosystems, and to represent different types of management initiatives. A key criterion in selecting programs was that they focus on geographically-specified coastal or marine areas that function as complete ecosystems, rather than smaller politically-bounded areas that represent only a unique portion of a larger ecosystem. We also required that programs had gone beyond environmental monitoring to develop indicators and communicate them to broader audiences through either a report or website. It should be recognized that the ten reports reviewed in this study are all produced by programs with ties to and funding from federal agencies; thus, indicator and reporting efforts of smaller, community-based organizations may take different forms and may not be represented by findings of this review.

For each ecosystem, we reviewed the most recent SOE report produced and evaluated it against the EBM features of interest. As indicated in Table 4.1, three scales of focus were used to identify EBM elements: (1) the indicators, (2) the report text, and (3) the process used to develop the indicators and report. Each report was reviewed and coded separately, addressing the questions in Table 4.1 on the basis of information presented for each indicator where possible and at the scale of the full report for more overarching questions. Indicator-specific data were synthesized on a percentage basis to facilitate comparisons across the reports, as the number of indicators used varied widely among the programs.

Our assessment of the extent to which the program encompassed key features of EBM was based entirely on material in the SOE reports. In some cases, information for answering all of the assessment questions was not available in each report. These results were recorded as missing data; external information was not sought to fill these data gaps, as its availability and accessibility varied greatly across the programs.

Results

Description of programs reviewed

The indicator and reporting programs reviewed in this study represented several different types of environmental management programs and ecosystem types. Of the ten reports reviewed, five were produced by sites within the EPA's National Estuary Program (Table 4.2). These reports focused on estuarine systems, including their surrounding watersheds. Despite their ties to the same federal program, the structure and style of these reports varied, as each was designed and developed with substantial local input into the topics that were covered. In addition, local data availability affected the choice of indicators by many of these programs.

Two of the reports were developed by regional ecosystem programs—Chesapeake Bay and Lake Champlain. These programs focused on distinct water bodies that intersect multiple jurisdictional boundaries. The reports produced by these programs were similar in nature to the NEP efforts in using extensive input from diverse stakeholders to guide the selection of indicators. However, these regional initiatives integrated data from a broader array of sources as necessitated by their jurisdictional complexity.

Two reports were produced by sites within NOAA's National Marine Sanctuaries (NMS) system that were located in nearshore coastal waters. The indicators used and reports produced by these programs were very similar in content and style to one another but very different from the NEP and regional ecosystem initiatives. These reports addressed 17 questions that were developed by the NMS system regarding the status of Sanctuary resources. As such, the reports were structured very similarly: they provided a short site description, highlighted pressures within the Sanctuary, described the state of resources, and explained management approaches and research initiatives to address pressures on and improve the state of the Sanctuary. Unlike the NEP and regional ecosystem programs which relied on data from many sources, the NMS reports mainly used and reported data that had been collected by their own programs.

The final program reviewed was an ecosystem status report compiled by the Northeast Fisheries Science Center (NEFSC) within the National Marine Fisheries Service. This report aggregated data that had been collected in offshore marine waters during oceanographic and fisheries surveys conducted by the NEFSC. It heavily focused on fisheries and factors that can affect commercial species and presented data on abiotic conditions, species populations, community interactions, and human activities within the ecosystem. This report was more data intense than other SOE reports, and it geographically spanned a larger region that extended from the Gulf of Maine to Cape Hatteras.

The ten reports varied widely in the number of indicators that they used and the types of issues the indicators addressed (Figure 4.1). The number of indicators developed by these ten programs totaled 278, ranging from eight indicators for the Long Island Sound ecosystem to 82 for the Northeast Fisheries Science Center. These indicators represented a variety of different topics. Key species of interest within the ecosystem were most commonly conveyed through indicators, but human uses within the ecosystem (e.g., recreation, fisheries) ranked a close second. Other common topics

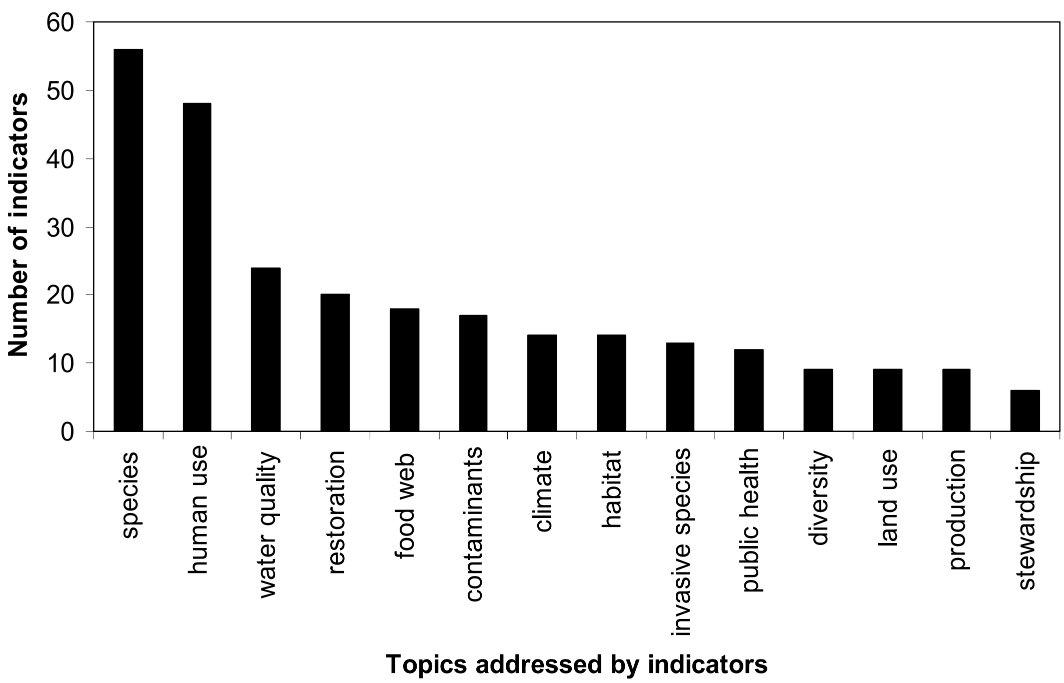

Figure 4.1. Common topics addressed by indicators used across all ten of the state of environment reports reviewed, and the number of individual indicators associated with each topic (N=278 across all programs).

encompassed concerns about the ecosystem, such as water quality, contaminants, climate change, and invasive species. Several indicators addressed topics related to the ecosystem's status and function, including features such as food web interactions, habitat conditions, species diversity, and primary and secondary production. Finally, indicators represented human impacts to (e.g., land use) and actions to protect (e.g., restoration, stewardship) the ecosystem. While this summary identifies issues of interest across all of the programs, topics represented by indicators varied widely among individual programs such that some topics were not addressed in certain programs. In fact, all of the diversity and production indicators were used by one program, the NEFSC.

Characterization of the ecosystem

The ten indicator and reporting programs reviewed shared some similarities as well as substantial differences in their approach to characterizing the ecosystem of interest. Our review focused on six features to compare the ecological information conveyed by each program.

Boundaries. All of the reports clearly defined and presented the boundaries of their respective ecosystems of interest. Each report included a map of the ecosystem, and nearly all of the reports briefly described the geographic extent and key features of the area. An exception is the New Hampshire Estuaries Project, which delineates the ecosystem but does not provide any description of its key features.

Complexity. The indicators used by the ten programs could be classified as pressure, state, and response indicators. A commonly-used approach to organizing indicators, the pressure-state-response framework incorporates indicators of pressures exerted by human activities on the environment (pressure), changes in the quality and quantity of natural resources or ecosystem conditions (state), and societal responses to these changes through actions or policies (response) (Organization for Economic Cooperation and Development 1993). Together these three categories of indicators capture diverse interacting elements of the ecosystem.

Across all of the programs, 21% of the indicators represented pressures on the ecosystem, 64% focused on the system's current state, and 14% emphasized management responses (Figure 4.2). At the level of individual programs, the New Hampshire Estuaries Project most heavily used pressure indicators, with 50% of its indicators falling into this category. Conversely, the NEFSC only used one pressure indicator in characterizing the Northeast Shelf ecosystem; instead, 95% of its

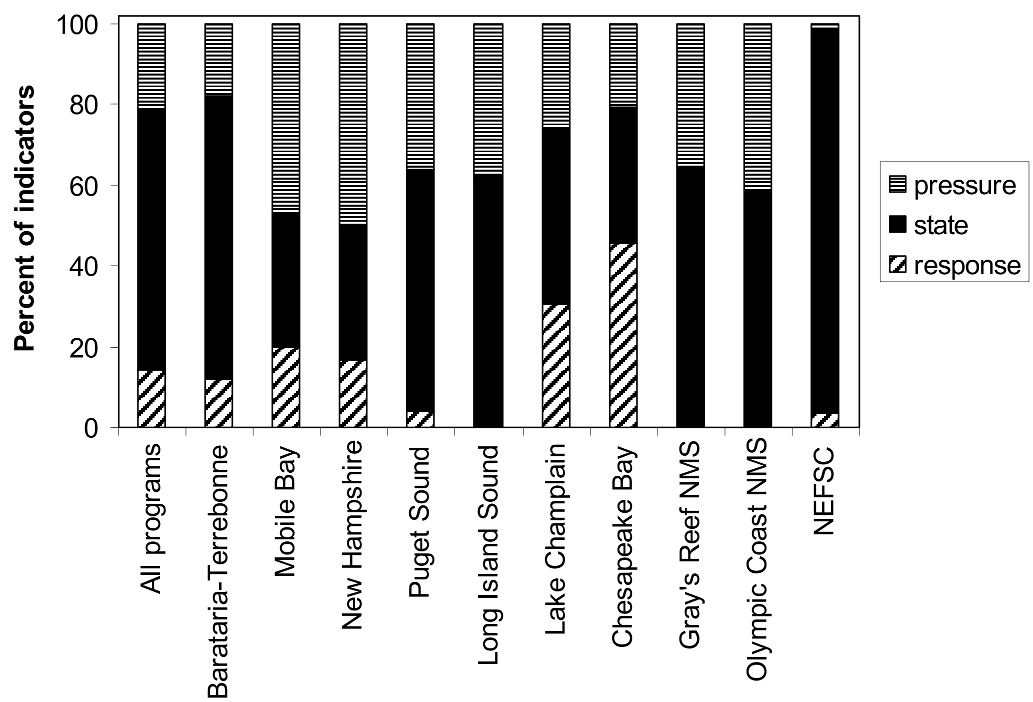

Figure 4.2. Portion of pressure, state, and response indicators used by all programs combined and by each of the ten indicator and reporting programs reviewed for this study.

indicators were of the ecosystem's state. At the lower extreme, only 33% of indicators used by the Mobile Bay NEP and New Hampshire Estuaries Project represented the state of the ecosystem. Three programs—Long Island Sound, Grey's Reef, and Olympic Coast—did not use any response indicators, while the Chesapeake Bay Program made the greatest use of these indicators (45%).

The SOE reports varied widely in the extent to which they established and explained connections between the indicators and other parts of the ecosystem. None of the reports presented a conceptual model that explained how the indicators were related to one another or how they should be used together to understand the ecosystem's status. Within the descriptions of each indicator, some reports mentioned connections between an indicator and other elements of the ecosystem (Figure 4.3).

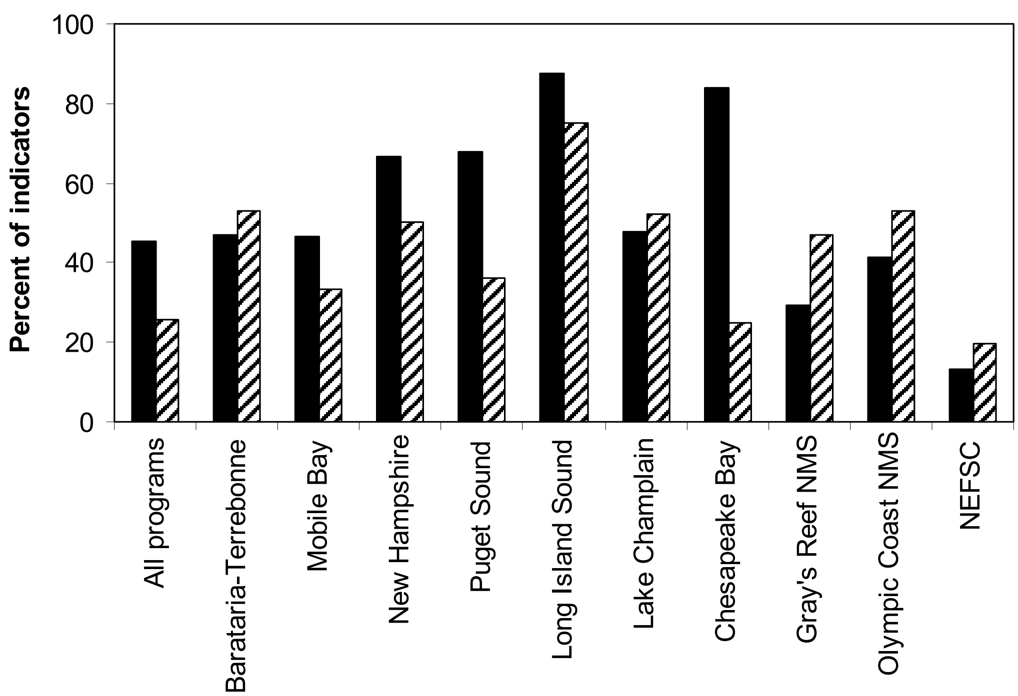

Figure 4.3. The percent of indicators for which the description of its status and changes included discussions of how the indicator affected other components of the natural ecosystem (solid bars) and how natural ecological factors drove changes in the indicator (dashed bars).

The Long Island Sound NEP presented these linkages for 88% of its indicators; in contrast, the NEFSC mentioned connections between only 13% of its indicators and other ecosystem features. Overall, the reports explained how changes in other conditions or features of the ecosystem could affect 25% of the indicators. The Long Island Sound NEP explained these natural drivers for 75% of its indicators, while the NEFSC discussed them for only 20% of its indicators.

Humans as part of the ecosystem. Twenty-nine percent of the indicators used by the reporting programs represented social features of the ecosystem, including human uses as well as stewardship efforts. These two social categories suggest two distinct roles for humans within an ecosystem: (1) as beneficiaries of ecosystem services and (2) as drivers of change, either positive or negative. Across all of the programs, the SOE reports explained how changes in 37% of the indicators affected human interests in the ecosystem, including extractive uses, recreational enjoyment, and aesthetic value (Figure 4.4). Among the individual programs, the Barataria-Terrebonne NEP included this explanation for 82% of its indicators; at the opposite extreme, the NEFSC related only 6% of its indicators to human interests and actions.

The programs reviewed more strongly emphasized humans as drivers of change in an ecosystem. Overall, the influence of human activities was discussed as part of the interpretation of 49% of the indicators (Figure 4.4). The Olympic Coast NMS mentioned human activities that affect all of its indicators; in contrast, the NEFSC explained the role of humans as drivers of change for only 26% of its indicators. In addition to explaining human activities that could drive changes in the ecosystem, many of the reports also included sections that explained actions readers could take to protect or improve the quality of the ecosystem.

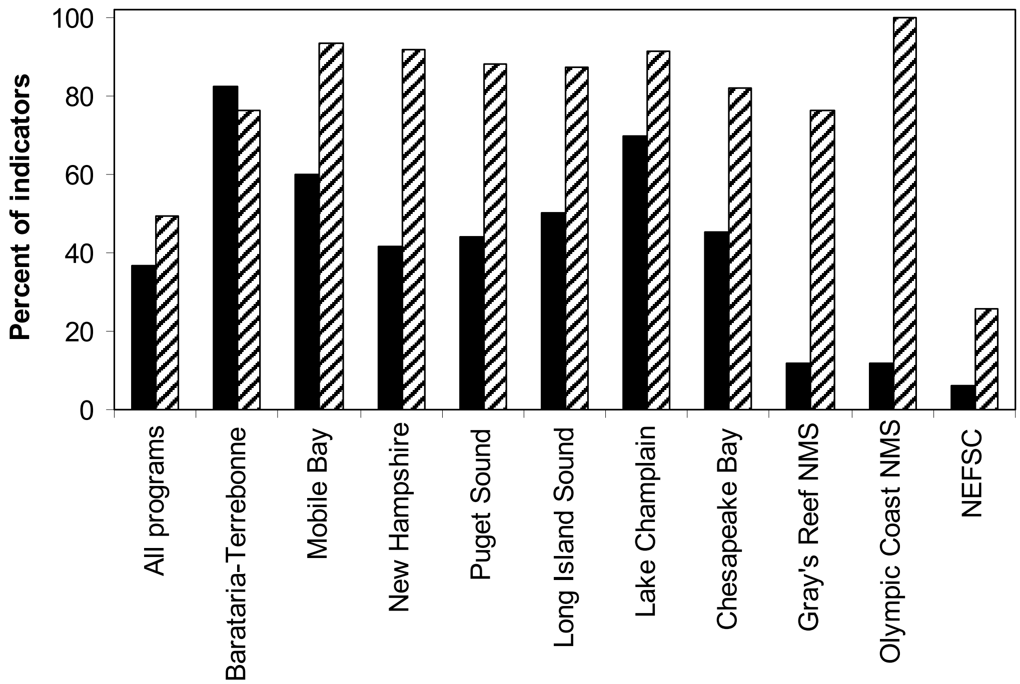

Figure 4.4. The percent of indicators for which the description of its status and changes included discussions of how the indicator affected human interests in the ecosystem (solid bars) and how human activities served as drivers of change in the indicator (dashed bars).

Temporal. The temporal nature of ecosystem change was conveyed by most of the reporting programs. Time series data were presented for 66% of the indicators, and temporal trends or changes were discussed for 75% of the indicators (Figure 4.5). The Long Island Sound NEP presented time series data and discussed temporal changes for all of the indicators reported by its program. In contrast, the Gray's Reef NMS did not show any temporal data and discussed temporal trends or changes for only 29% of its indicators.

Despite most programs presenting and discussing temporal data for their indicators, the interpretations of these temporal changes were not presented in the context of natural variability. Instead, direction trends in the time series were emphasized. Ways in which natural variability or cyclical patterns may affect the data series were not discussed.

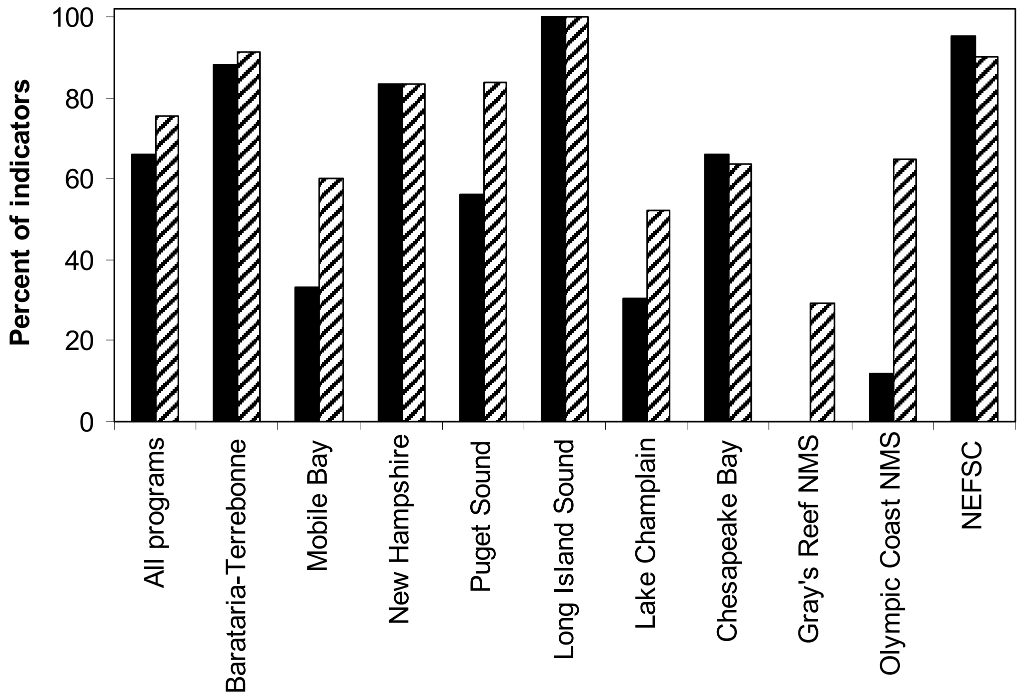

Figure 4.5. The percent of indicators for which temporal data were presented (solid bars) and temporal trends or changes were discussed (dashed bars) in state-of-the-environment reports produced by ten programs.

Spatial. Programs varied widely in whether they presented spatial distinctions associated with the ecosystem indicators. Overall, spatial distinctions in 29% of the indicators were conveyed through either figures, text, or both in the SOE reports (Figure 4.6). The New Hampshire Estuaries Project identified spatial differences for 75% of the indicators it used; in contrast, the Chesapeake Bay Program reported spatial distinctions for only 7% of its indicators. A smaller portion of the indicators were reported at multiple spatial scales to recognize nestedness within the ecosystem.

Only the Long Island Sound NEP reported all indicators at both sound-wide and sub-regional scales.

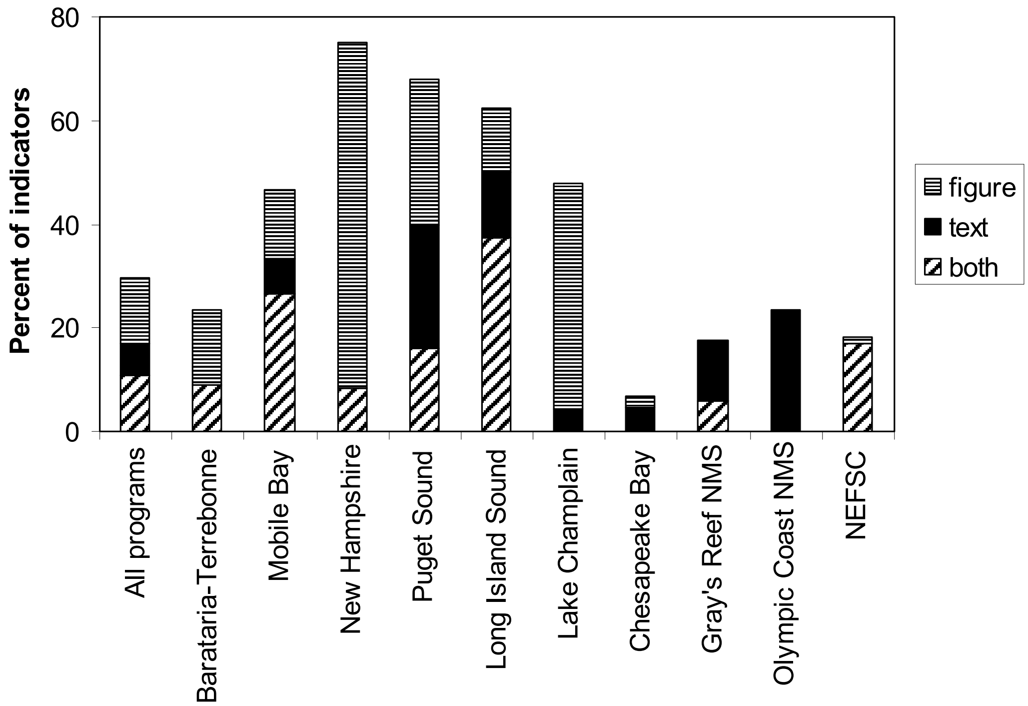

Figure 4.6. The percent of indicators for which spatial distinctions were conveyed in state-of-the-environment reports produced by ten programs. The three shading effects indicate whether the spatial information was conveyed through figures, in the report text, or in both forms.

Ecological health. Half of the programs reviewed suggested that the indicators they reported served to assess the "health" of the ecosystem. However, how the indicators translated to a health assessment was not explained, nor was a healthy ecosystem state characterized in most cases. An exception was found in the Chesapeake Bay report, which provided a vivid description of "healthy" and "unhealthy" estuaries to create an image in readers' minds of the characteristics of and distinctions between each state. However, the casual use and descriptions of "health" did not conform to scientific understandings of this term, such as the features of resilient and robust ecosystems identified by Levin and Lubchenco (2008) or more long-standing representations of ecosystem integrity (Karr 1991, Angermeier and Karr 1994).

Four programs identified target thresholds for some of their indicators as a way of distinguishing a "healthy" condition for the indicator. Most of these programs specified thresholds only for indicators that could be tied to existing regulatory standards (e.g., water quality standards, food safety guidelines). Other programs linked thresholds for some of their indicators to their program's goals, but little explanation was provided of how these targets were established or how they were related to ecosystem health. In setting a threshold for one indicator (i.e., beach closure days), the Lake Champlain Basin Program relied on a public survey to identify levels at which social impacts of closures become important.

Types of information

Science-based. In describing the status of and changes in the ecosystem indicators, many of the SOE reports characterized the current scientific understanding of the conditions in the ecosystem. Explanations of factors that influence the present conditions and the implications of the current status were less consistent. As noted above, for 49% of the indicators, human drivers that affected their status and trends were identified (Figure 4.4). In addition, natural ecological drivers influencing 26% of the indicators were discussed (Figure 4.3). While noting the underlying drivers of change associated with each indicator was common in some reports, others (e.g., NEFSC) offered few explanations of potential drivers. Across all reports, there was little explanation of the mechanism by which the identified drivers affected the indicator and little evidence presented on the magnitude of their effects.

Several of the reports also highlighted broader scientific initiatives that related to but extended beyond the indicators. Sidebars in reports produced by the New Hampshire Estuaries Project and Long Island Sound Study presented synopses of local research efforts and findings. These sidebar stories made readers aware of local research efforts pertinent to issues of interest. In the NEFSC report, the data that were presented raised questions for further investigation. These integrative questions were posed at the end of the report; while they were not answered in the context of the report, they suggest important future research directions.

Monitoring. Across all of the programs reviewed, monitoring data provided the basis for reporting on 86% of the indicators (Figure 4.7). All of the indicators presented by the New Hampshire Estuaries Project and NEFSC were backed by monitoring data. The National Marine Sanctuaries presented monitoring data for the smallest portion of indicators; 47% of the Olympic Coast and 59% of the Gray's Reef indicators relied on monitoring data. In the case of these latter programs, the SOE reports conveyed a baseline understanding of these marine ecosystems, and data gaps identified in the process of creating the report were being used to guide the development of future monitoring programs.

The SOE reports often aggregated data from sources beyond the organization publishing the report to support the indicators and characterize their status. An exception to this pattern was noted for the offshore marine ecosystems. The National Marine Sanctuaries used few data collected by other agencies or organizations, and the NEFSC presented exclusively data collected by its own research and monitoring programs.

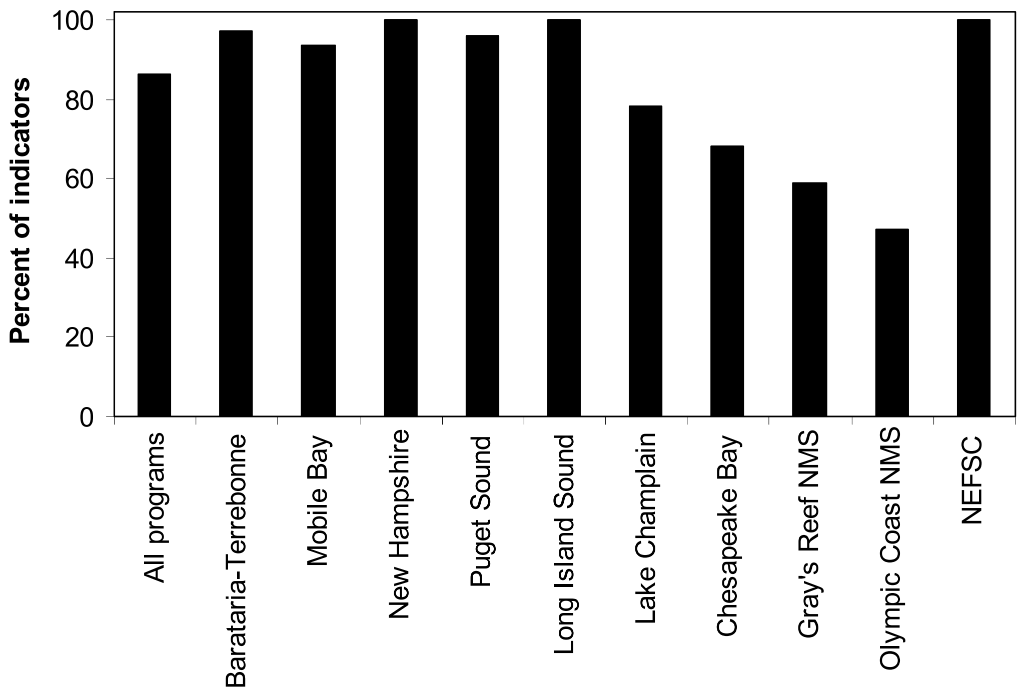

Figure 4.7. Percent of indicators used by ten state-of-the-environment reporting programs for which monitoring data were presented.

Interdisciplinary. The indicators used by the ten programs represented physical, biological, and social components of the ecosystem (Figure 4.8). Across all of the programs, 21% of the indicators represented physical elements of the ecosystem, 50% conveyed biological features, and 29% focused on social characteristics. Of the individual programs, the Mobile Bay NEP used the largest portion of indicators of the physical environment (40%) and smallest portion of biological indicators (33%), while the Northeast Fisheries Science Center used the smallest portion of physical (11%) and the largest portion of biological indicators (62%). Social indicators were least used by the Lake Champlain Basin Program (17%) and most heavily used by the Barataria-Terrebonne NEP (47%).

Despite the representation of multiple disciplines in the ecosystem indicators, unique contributions from different disciplinary perspectives were hard to discern in

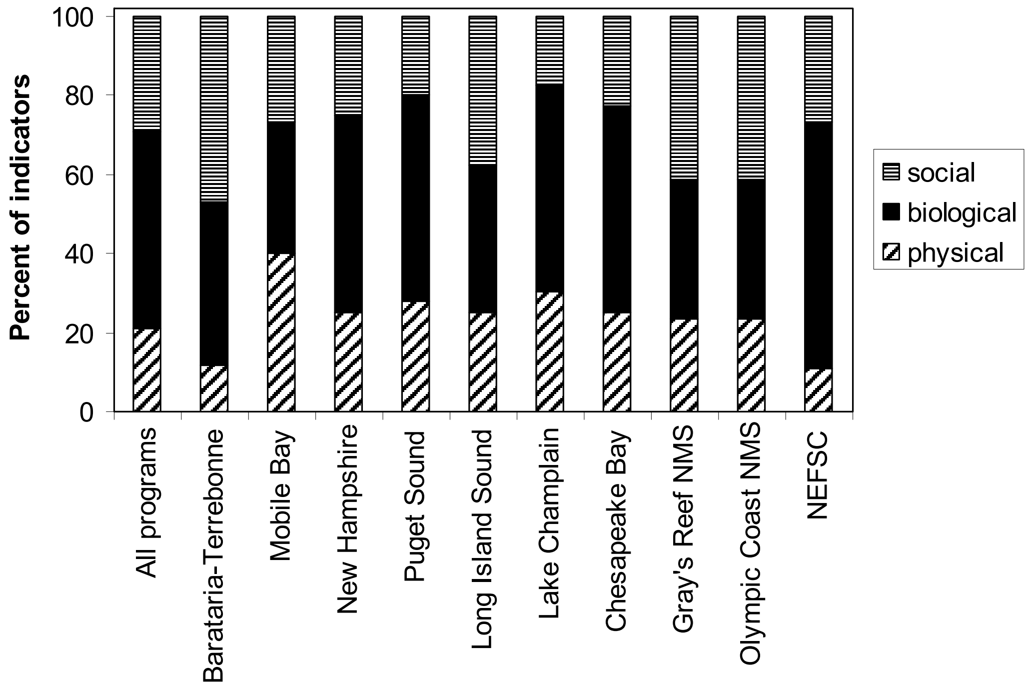

Figure 4.8. Portion of indicators of physical, biological, and social features of the ecosystem used by ten state-of-the-environment reporting programs.

the reports. For example, the reports did not highlight different questions that might be asked by natural and social scientists or suggest distinct explanations that might be offered for the changes observed in the indicators. Instead, the indicators tended to be reported in similar manners, typically with a short description of the topic, the data, and the patterns of change.

Stakeholder. Many of the "response" indicators represented actions that stakeholders were taking to protect certain parts of the ecosystem. As tracked by the indicators, stakeholder involvement took several forms, including efforts to protect habitats, reduce pollution, and improve management plans (e.g., watershed, stormwater, fisheries). A few programs used indicators that tracked citizen involvement through metrics such as participation opportunities and volunteer hours.

Finally, two programs—Barataria-Terrebonne and Chesapeake Bay—used indicators of educational and interpretation opportunities through which stakeholders could learn more about the ecosystem.

Process of developing and reporting indicators

Core tenets of EBM suggest that scientific and stakeholder input are both valuable sources of information that should be utilized to gain an understanding of and effectively manage the ecosystem (Arkema *et al*. 2006). The extent to which both were incorporated into the ten reporting efforts reviewed herein was evaluated based on information about how the indicators and reports were developed.

Science-based. Many of the reports acknowledged that scientists were involved in developing, vetting, and interpreting the indicators. Scientists were consulted to help identify both key environmental concerns that should be addressed and data available to support the indicators. In several of the programs, scientific advisory committees reviewed the indicators and SOE report to ensure that it reflected a consensus understanding of the ecosystem at the time.

Stakeholder. Stakeholders were consulted to a more limited extent than scientists in the process of developing indicators and SOE reports. Only the Mobile Bay NEP report mentioned that citizen input was used to shape the environmental concerns that would become the focus of the report. The New Hampshire Estuaries Project indirectly drew upon stakeholder input, as its indicators were structured to track progress against the program's management plan, which had been developed with extensive stakeholder input.

Discussion

Indicators and their associated SOE reports offer one mechanism for conveying scientific information to stakeholders who share an interest in the ecosystem. In doing so, the ways in which the ecosystem is characterized, types of information that are presented, and the process used to develop the indicators all have the potential to advance EBM principles and approaches. However, the extent to which these EBM-supportive outcomes are accomplished has not been evaluated. We offer an assessment of this matter by focusing on key themes that emerge from a review of ten indicator and reporting programs.

Ecosystem information conveyed through indicators and SOE reports

Ecosystem indicators and their interpretation through SOE reports convey information about key issues in and components of ecosystems of interest. Many of the issues addressed by indicators in the ten programs we reviewed aligned closely with ocean and coastal management priorities that have been identified in recent national policy reviews (Pew Oceans Commission 2003, Coastal States Organization 2004, U. S. Commission on Ocean Policy 2004). However, variation does exist in the issues addressed and emphasized across the programs. In some cases, these differences likely reflect distinct site-specific priorities and concerns (Leschine *et al*. 2003), as many of the programs were tailored to emphasize coverage of locally-relevant issues and interests. In other cases, the indicators used by certain programs, particularly the National Marine Sanctuaries and NEFSC, reflect their programmatic scope and mandates. These two indicator and reporting efforts were more narrowly focused to address specific questions or to distribute specific data, respectively.

Explanation of ecosystem complexity and "health"

While most of the indicator and reporting programs convey information about a wide range of issues of interest to local audiences, many of the issues and indicators were treated in relative isolation from one another. Few connections were drawn between the indicators to show how they relate to or interact with one another. The value of conceptual models as a simple way to link the indicators and show their interactions with other parts of the ecosystem has been emphasized in a number of reports and applications (e.g., Dennison *et al*. 2007, EPA 2008). Most of the reports we reviewed did not put forward conceptual models to show interactions between the indicators. The one exception to this statement was the Lake Champlain Basin Program, which described the pressure-state-response framework used to organize the report; this framework offered a very basic structure for relating the indicators used within specific topics.

The approach of treating each indicator separately limits the ability of the SOE reports to convey the complex, interactive nature of ecosystems to readers (Levin 1998). In addition, it parallels our traditional management approach of treating issues separately. As such, the current way in which indicators are presented and interpreted in SOE reports fails to advance the EBM ideal of viewing and managing ecosystems in an integrated manner (Arkema *et al*. 2006, McLeod and Leslie 2009).

The isolated treatment of the indicators also precluded an understanding of how the individual indicators might scale up to provide information on the status of the ecosystem as a whole. Half of the reports reviewed suggested that the indicators could be used to gain insights into the "health" of the ecosystem. However, the concept of health was presented generally and was not connected to ecological definitions of ecosystem health or integrity (Karr 1991, Angermeier and Karr 1994, Levin and Lubchenco 2008). Targets identified for certain indicators suggested that their achievement would move the ecosystem closer to a "healthy" status, but the scientific basis for most targets was not explained.

Treatment of temporal and spatial variability

The SOE reports attempted to convey temporal changes and spatial differences in the ecosystems. Time series graphs were presented for many indicators; in addition, changes across multiple years were described. Spatial distinctions were less commonly noted in the reports, likely due to a lack of spatially-explicit data for many of the indicators. However, all of the reports showed or discussed spatial distinctions for at least some of the indicators. The temporal and spatial presentations of indicators could help readers understand that the ecosystem is not the same from year to year, nor are conditions the same at all locations.

While temporal and spatial data were presented in the reports, interpretations of this information failed to emphasize the dynamic nature of ecosystems. Time series graphs enabled readers to see some of the inherent temporal variability in an indicator, but many of the data were highly aggregated (e.g., annual means) with no indication of variability. In addition, interpretations of these graphs generally focused on trends of change and emphasized the dominant pattern observed in the data, rather than interpreting the data in the context of natural variability. Spatial dynamics were not discussed in the reports. In only two reports (i.e., Lake Champlain, Long Island Sound) were spatial and temporal data presented together for certain indicators—a step that moves towards conveying the sense that ecosystems are dynamic in both space and time.

Portrayal of humans as part of the ecosystem

A key tenet of EBM is that humans are considered part of the ecosystem (McLeod *et al*. 2005). The indicator and reporting programs included humans as an element of the ecosystem in several ways. First, 29% of the individual indicators tracked across all of the programs captured social features, including pressures that human activities create on the ecosystem, the status of human uses supported by the ecosystem, and stewardship or management activities undertaken to protect and restore the ecosystem. In addition, the interpretations associated with 37% of the indicators explained how human interests will be affected by changes in the indicators. For 49% of the indicators, the effects of human actions and activities were explained as drivers of change.

Although the roles and interests of humans are conveyed through the indicators and SOE reports, distinctions appear in how human and natural elements of the ecosystem are treated in the reports. While interpretations of 37% of the indicators explained how the indicator's status affects human interests, an even larger portion of the indicators (45%) highlighted implications for natural elements of the ecosystem. Explanations of drivers of change in the ecosystem, however, tended to focus on human activities. Interpretations of 49% of the indicators emphasized human activities as drivers of change. Conversely, the role of non-human ecological drivers, such as environmental variability or shifts in trophic structure, was discussed for only 26% of the indicators.

The emphasis on human activities as drivers of change and the simultaneous focus on implications of change to natural elements of the ecosystem together suggest a privileging of concerns about the natural ecosystem and a greater culpability of humans as instigators of change. While these patterns do not create a balanced sense of the role or importance of human and non-human elements within the ecosystem, they may serve political purposes by promoting action to help minimize human impacts. Indeed, many of the reports highlight stories about what citizens are doing and include tips for actions that readers can take to protect and improve the ecosystem.

Insights from the indicator development and reporting process

Developing ecosystem indicators and SOE reports entails compiling and synthesizing scientific information, often from multiple sources, to convey the most current understanding of issues of interest. The production of SOE reports thus requires that scientists look beyond data that may be the focus of their own research endeavors to develop a more integrated understanding of the ecosystem, including the changes it has experienced as well as the drivers and implications of these changes. Creating a holistic understanding of the ecosystem in this manner could help reinforce the value of EBM as a way of working across issues and jurisdictions to address problems facing the ecosystem.

The ability to develop indicators and SOE reports is dependent on the presence of monitoring programs related to indicators of interest in the focus ecosystem. A large portion (86%) of the indicators used in the reports we reviewed were backed by quantitative monitoring data. The process of selecting meaningful indicators and seeking data to populate those indicators sometimes led to a recognition of monitoring gaps, as was evidenced in both of the NMS reports. As such, attempts to apply certain indicators can highlight needs for monitoring data and spur the development of new programs to gather those data. Although data gaps did not pose serious limitations for most programs in the reports reviewed herein, the lack of monitoring data may inhibit the development of indicators and SOE reports for other coastal and marine areas.

The different styles of reports reviewed in this study reinforce the importance of identifying and writing for a specific target audience (Gibson *et al*. 2000). It is unlikely that all of the reports reviewed would have been engaging to or understandable by the same types of readers. While the NEP and regional ecosystem reports seem understandable to a variety of interested stakeholders, the NMS reports seem to be written mainly for an internal audience. The NEFSC report will likely appeal most to a scientific audience, and its the usefulness to other stakeholders could be enhanced with greater interpretation of the data presented, including expanded explanations of factors that may contribute to changes in the indicators and the implications of those changes for key stakeholder groups.

The vagueness of audiences for the SOE reports reveals a greater need to incorporate stakeholders into the process of developing indicators and reports from the outset. For most programs, scientists played a much larger role in developing the indicators and reviewing the reports than did other stakeholder groups. The lack of broader stakeholder input into the content and design compromises the ability of the indicators and SOE reports to create a common base of understanding upon which diverse stakeholders can build discussions about management within the ecosystem (Turnhout *et al*. 2007, Vogel *et al*. 2007). The extent to which indicators and SOE reports actually function as a bridge between the science and policy realms requires further evaluation (Wells 2003), the results of which should help improve their relevance to EBM.

Improving connections between indicator and reporting initiatives and EBM

The current use of ecosystem indicators and SOE reports could be enhanced in several ways to more effectively support EBM. Potential improvements can be grouped into two categories: 1) improving the communication of EBM principles and 2) strengthening the management relevance of the indicators and reports.

As currently used, indicators and SOE reports do not effectively convey certain core EBM principles. These principles and suggestions for enhancing their communication through SOE reports are outlined below.

- *Ecosystems as complex systems*. Increasing the emphasis on relationships between the indicators, including the use of conceptual models to organize this information, can help readers understand the presence and importance of interactions between different components of the ecosystem.
- *Temporal and spatial dynamics*. Discussing the temporal and spatial variability of indicators can help convey the dynamic nature of ecosystems. In addition, showing variance estimates on figures can visually place the data with a context of natural variability.
- *Humans as part of the ecosystem*. If humans are part of an ecosystem, they are not only drivers of change in that system but also are likely to be affected by changes. Identifying ways in which humans will be impacted by shifts in indicators can reinforce their interests in the ecosystem.

Results from this review also suggest some ways in which the management relevance of indicators and SOE reports can be increased. Effectively providing technical information for management is increasingly recognized as a two-way process, rather than just a transfer between science and practice (Vogel *et al*. 2007, Karl *et al*. 2007). Thus, the participation of stakeholders beyond scientists in the process of developing and interpreting indicators should be increased. The additional perspectives will help ensure that the selected indicators are salient to the intended users and that the information is viewed as legitimate and useful (McNie 2007). As such, the indicators and their interpretation are more likely to contribute to a shared base of knowledge among diverse stakeholders, which can then provide a foundation for their engagement in management deliberations.

The political context within which indicators and SOE reports exist also should be recognized (Turnhout *et al*. 2007, Turnhout 2009). The technical information conveyed through indicators is subject to negotiation in the management arena. This does not devalue indicators as a way of transferring information; in fact, it may enhance their value to EBM. EBM focuses on the array of benefits that can be derived from marine ecosystems, and indicators offer one basis for setting objectives and recognizing trade-offs within this complex management arena. This application could be supported by identifying scientifically acceptable ranges for each indicator, instead of setting single-value targets. This range then could be deliberated in the management arena as a basis for negotiating objectives and acceptable trade-offs. Such flexibility and ambiguity may be necessary for indicators to effectively connect the science and management arenas associated with EBM (Turnhout 2009).

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CHAPTER 5

CONCLUSION

This dissertation explored three critical themes related to marine ecosystem-based management (EBM) using distinct disciplinary perspectives. First, it provided a biological perspective, detecting and understanding ecosystem change through analysis of the multi-level dynamics of a large marine ecosystem. The subsequent section applied a social science perspective, investigating stakeholders' perceptions of EBM and how it might be implemented. These biological and social insights illustrate both the potential benefits from EBM as well as the constraints faced by those attempting to implement such an approach within the Gulf of Maine region. The final thematic section investigated connections between the two worlds in which science and stakeholders function, assessing the utility of ecosystem indicators and state of the environment reports as mechanisms for bridging the social and scientific realms. These three analytical approaches—and their joint application—provide integrated insights that may help shape the implementation of EBM in the Gulf of Maine as well as in other marine ecosystems.

Chapter Two of this dissertation demonstrated clearly that ecosystems experience substantial, and sometimes rapid, changes. Fish survey data for the Gulf of Maine and Georges Bank region indicated that widespread shifts have occurred in community composition and biological attributes within the past forty years. These shifts were detected across multiple levels of the ecosystem, from single species to the aggregate community. Some of the most pronounced and high-magnitude changes were noted in the size of organisms within the ecosystem, with major declines in length and weight detected across many groups of species. Many of the compositional and biological changes occurred during a narrow time period, largely concentrated in the mid-1980s and early 1990s, suggesting a rapid change in biological conditions in the ecosystem.

Chapter Three investigated different stakeholders' understandings of the concept of EBM as well as their expectations for its implementation. By focusing on six distinct stakeholder groups that will be affected by EBM in the Gulf of Maine, results from this analysis illustrate that considerable overlap exists between the features and goals of EBM that were identified by these respondents and those that have been put forward in the academic literature. Individuals interviewed for this study viewed EBM as building on a foundation of good resource management that was guided by both scientific information and stakeholder input. However, these stakeholders valued the enhanced capacity of EBM to accommodate complexity in the ecosystem and to work across jurisdictional and sectoral interests to achieve management goals. While many consistencies were apparent in how the stakeholder groups conceptualized EBM, some differences were also noted. These distinctions raise awareness of the potential for greater variability in understandings and priorities as more groups become involved in EBM.

Finally, Chapter Four assessed ecosystem indicators and state of the environment (SOE) reports as mechanisms for distributing scientific information about the ecosystem to broader audiences with interests in ecosystem management but without technical backgrounds. Indicators and SOE reports may serve to connect the scientific and social realms by providing interested individuals and groups with a common understanding of ecosystem issues and dynamics so that they can effectively participate in management discussions. While the potential for indicators and SOE reports to play this role is promising, findings demonstrate that their current use falls short of creating a foundational understanding of ecosystems that advances EBM principles. Indicators and SOE reports could better align with EBM by conveying the complexity and dynamics of ecosystems, considering the implications of ecosystem change to human interests, and engaging stakeholders in the design and interpretation of indicators.

Findings from these three thematic chapters collectively provide integrated insights that may help to guide EBM in marine ecosystems. They suggest that ecosystems are complex and dynamic and that they are influenced by multiple interacting factors. Stakeholders within the ecosystem are aware of its complexities, the potential negative effects from human activities on the ecosystem, and subsequent impacts of ecosystem change on human interests. Most importantly, scientific insights and stakeholder perspectives on the ecosystem align on a key point—people and nature are both important parts of the ecosystem, and neither exists apart from the other.

Effectively integrating considerations of people and nature is a critical challenge facing management professionals as they forward EBM. Science can help advance our understanding of natural and human elements of the ecosystem as well as their interactions, and this improved understanding will help support EBM. But one type of science alone will not accomplish this goal. Scientific inquiries necessary to support EBM will take many forms, and the unique perspectives gained from multidisciplinary approaches will be essential for building insights across the human and natural realms of the ecosystem. Integrated approaches such as these will be challenging to implement within the existing institutional frameworks in the academic and resource management communities; nonetheless, shared understanding of the social and environmental benefits from EBM may help overcome these barriers.

While science can provide important new insights into the social and natural components of ecosystems and how they function and change, another vital element of

EBM is ensuring that this information is relevant and available in a useful format for management applications. The value of scientific data and stakeholder input to EBM is widely recognized, but these two sources of information do not always point towards the same management directions. The challenges in EBM of setting objectives in the context of competing goals and making trade-offs between multiple interests may only exacerbate this potential disconnect. It will be increasingly important for stakeholders to understand the scientific data that informs management deliberations and for science-based processes to provide room for outcomes to be shaped by stakeholder input. Bringing science to management arenas, directly or through stakeholders, may take new forms and use novel tools.

Many challenges lie ahead as EBM is implemented in marine ecosystems. While these challenges may be viewed as daunting, they can also be viewed as opportunities—opportunities to investigate ecosystems in novel ways, develop new understandings of how social and natural elements of ecosystems interact, and devise innovative ways of linking scientific and management settings. New initiatives that focus both within and across disciplines and that approach problems from multiple perspectives can help us meet these challenges, capitalize on these opportunities, and forward marine EBM.

APPENDIX A

List of species and their classification into taxonomic (GF=groundfish, DEM=demersals, EL=elasmobranches, PEL=pelagics, INV=invertebrates), economic (COM=commercial, NC=non-commercial), and trophic groups (BEN=benthivores, PIS=piscivores). Numbers in the trophic categories represent lengths in centimeters at which a species was considered to be a benthivore or piscivore. Species in bold type were observed in more than four years of the survey and were used in the composition analysis. Species that are underlined were observed in all years of the survey and were used for species-level change-point analyses.

COMMON NAME	SCIENTIFIC NAME	GROUP CLASSIFICATIONS								
		GF	***DEM***	***EL***	***PEL***	***INV***	***COM***	***NC***	***BEN***	***PIS***
Blueback herring	***Alosa aestivalis***				X		X			
Hickory shad	*Alosa mediocris*				X		X			
Alewife	***Alosa pseudoharengus***				X		X			
American shad	***Alosa sapidissima***				X		X			
Orange filefish	*Aluterus schoepfi*				X			X		
Thorny skate	***Amblyraja radiata***			X			X		≤60	>60
American sand lance	*Ammodytes americanus*		X					X		
Northern sand lance	***Ammodytes dubius***		X					X		
Atlantic wolffish	***Anarhichas lupus***		X					X	X	
Striped anchovy	***Anchoa hepsetus***				X			X		
Bay anchovy	***Anchoa mitchilli***				X			X		
American eel	*Anguilla rostrata*		X				X			
Eel (unclassified)	**Anguilliformes**		X					X		
Deepbody boarfish	*Antigonia capros*		X					X		
Fourspine stickleback	*Apeltes quadricus*		X					X		
Twospot cardinalfish	*Apogon pseudomaculatus*		X					X		
Sheepshead	*Archosargus probatocephalus*				X			X		
White barracudina	***Arctozenus rissoi***				X			X		
Speckled swimming crab	*Arenaeus cribrarius*							X		
Atlantic argentine	***Argentina silus***				X			X		
Striated argentine	*Argentina striata*				X			X		
Silver rag	***Ariomma bondi***		X					X		
Spotted driftfish	*Ariomma regulus*		X					X		
Hookear sculpin (unclassified)	***Artediellus* sp.**		X					X		
Alligatorfish	***Aspidophoroides monopterygius***		X					X		
Gray triggerfish	*Balistes capriscus*		X					X		
Triggerfish, filefish (unclassified)	Balistidae				X			X		
Bathyal swimming crab	***Bathynectes longispina***					X		X		
Spoonarm octopus	***Bathypolypus arcticus***					X		X		
Simony's frostfish	*Benthodesmus simonyi*							X		
Combtooth blenny (unclassified)	*Blenniidae*		X					X		
Lefteye flounder (unclassified)	Bothidae	X						X		
Atlantic menhaden	***Brevoortia tyrannus***				X		X			
Cusk	***Brosme brosme***	X						X	≤40	>40
Jonah crab	***Cancer borealis***					X		X		
Atlantic rock crab	***Cancer irroratus***					X		X		
Cancer crab (unclassified)	**Cancridae**					X		X		
Jack pompano (unclassified)	Carangidae				X			X		
Blue runner	*Caranx crysos*				X			X		
Bank sea bass	*Centropristis ocyurus*							X		
Black sea bass	***Centropristis striata***		X				X			
Squid, cuttlefish, and octopod (uncl.)	**Cephalopoda**					X		X		
Horned lanternfish	*Ceratoscopelus maderensis*				X			X		
Viperfish	***Chauliodus sloani***				X			X		
Redeye gaper	*Chaunax stigmaeus*		X					X		

APPENDIX A (continued).

COMMON NAME	SCIENTIFIC NAME	GF	DEM	EL	PEL	INV	COM	NC	BEN	PIS
		GROUP CLASSIFICATIONS								
Snow crab	***Chionoecetes opilio***					X		X		
Iceland scallop	***Chlamys islandica***					X		X		
Greeneye (unclassified)	**Chlorophthalmidae**		X					X		
Shortnose greeneye	***Chloropthalmus agassizi***		X					X		
Gulf stream flounder	***Citharichthys arctifrons***	X						X	X	
Whiff (unclassified)	*Citharichthys* sp.	X						X		
Atlantic herring	***Clupea harengus***				X		X			
Herring (unclassified)	Clupeidae				X			X		
Sand dollar (unclassified)	Clypeasteroida					X		X		
Longnose grenadier	*Coelorhynchus carminatus*	X						X		
Conger eel	***Conger oceanicus***		X					X		
Conger eel (unclassified)	**Congridae**		X					X		
Bulleye	Cookeolus japonicus		X					X		
Sculpin (unclassified)	**Cottidae**		X					X		
Shrimp (unclassified)	**Crustacea shrimp**					X				
Wrymouth	***Cryptacanthodes maculatus***		X					X		
Bigeye cigarfish	*Cubiceps pauciradiatus*				X			X		
Lumpfish	***Cyclopterus lumpus***		X					X		
Flying gurnard	*Dactylopterus volitans*		X					X		
Mackerel scad	***Decapterus macarellus***				X			X		
Round scad	***Decapterus punctatus***		X					X		
Atlantic batfish	*Dibranchus atlanticus*		X					X		
Barndoor skate	***Dipturus laevis***			X			X		X	
Sea urchin and sand dollar (uncl.)	Echinoidea					X		X		
Fourbeard rockling	***Enchelyopus cimbrius***	X						X	X	
Anchovy (unclassified)	Engraulidae				X			X		
Silver anchovy	***Engraulis eurystole***				X			X		
Bigeye	*Epigonus pandionis*		X					X		
Smallmouth flounder	***Etropus microstomus***	X						X		
Round herring	***Etrumeus teres***				X			X		
Silver jenny	*Eucinostomus gula*		X					X		
Flying halfbeak	Euleptorhamphus velox				X			X		
Atlantic spiny lumpsucker	*Eumicrotremus spinosus*		X					X		
Red cornetfish	*Fistularia petimba*		X					X		
Bluespotted cornetfish	*Fistularia tabacaria*				X			X		
Spotfin dragonet	***Foetorepus agassizi***		X					X		
Hake (unclassified)	Gadidae	X						X		
Atlantic cod	***Gadus morhua***	X					X			>50
Galatheid (unclassified)	**Galatheidae**					X		X		
Threespine stickleback	***Gasterosteus aculeatus***				X			X		
Red deepsea crab	***Geryon quinquedens***					X	X			
Witch flounder	***Glyptocephalus cynoglossus***	X					X		X	
Lightfish (unclassified)	Gonostomatidae				X			X		
Blackbelly rosefish	***Helicolenus dactylopterus***		X					X		
Sea raven	***Hemitripterus americanus***		X					X		X
American plaice	***Hippoglossoides platessoides***	X					X		X	
Atlantic halibut	***Hippoglossus hippoglossus***	X					X		≤60	
American lobster	***Homerus americanus***					X	X			
Barrelfish	*Hyperoglyphe perciformis*				X			X		
Silverstripe halfbeak	*Hyporhamphus unifasciatus*				X			X		
Northern shortfin squid	***Illex illecebrosus***					X	X			
Shortbeard codling	*Laemonema barbatulum*		X					X		

APPENDIX A (continued).

COMMON NAME	SCIENTIFIC NAME	*GF*	*DEM*	*EL*	*PEL*	*INV*	*COM*	*NC*	*BEN*	*PIS*
		GROUP CLASSIFICATIONS								
Smooth puffer	*Lagocephalus laevigatus*		X					X		
Fawn cusk-eel	***Lepophidium profundorum***		X					X	≤30	
Little skate	***Leucoraja erinacea***			X			X			
Rosette skate	***Leucoraja garmani***			X			X			
Winter skate	***Leucoraja ocellata***			X			X			>60
Yellowtail flounder	***Limanda ferruginea***	X					X		>20	
Atlantic seasnail	***Liparis atlanticus***		X					X		
Inquiline snailfish	***Liparis inquilinus***		X					X		
Northern stone crab	***Lithodes maja***					X		X		
Longfin squid	***Loligo pealeii***					X	X			
Atlantic brief squid	***Lolliguncula brevis***					X		X		
Goosefish	***Lophius americanus***		X				X			>10
Tilefish	Lopholatilus chamaeleonticeps		X					X		
Snakeblenny	***Lumpenus lumpretaeformis***		X					X		
Daubed shanny	***Lumpenus maculatus***		X					X		
Snapper (unclassified)	Lutjanidae		X					X		
Wolf eelpout	***Lycenchelys verrilli***		X					X		
Longnose snipefish	*Macrorhamphosus scolopax*		X					X		
Grenadier (unclassified)	**Macrouridae**	X						X		
Roughhead grenadier	*Macrourus berglax*	X						X		
Ocean pout	***Macrozoarces americanus***		X				X		X	
Spider crab (unclassified)	**Majidae**					X		X		
Western softhead grenadier	*Malacocephalus occidentalis*		X					X		
Smooth skate	***Malacoraja senta***			X			X		<30	
Capelin	*Mallotus villosus*				X			X		
Weitzman's pearlsides	***Maurolicus weitzmani***		X					X		
Haddock	***Melanogrammus aeglefinus***	X					X		X	
Atlantic soft pout	***Melanostigma atlanticum***				X			X		
Atlantic silverside	***Menidia menidia***				X			X		
Offshore hake	***Merluccius albidus***	X					X			
Silver hake	***Merluccius bilinearis***	X					X			>40
Whiting (unclassified)	*Merluccius* sp.	X						X		
Atlantic croaker	*Micropogonias undulatus*		X				X		X	
Northern horsemussel	*Modiolus modiolus*					X		X		
Planehead filefish	***Monacanthus hispidus***		X					X		
Deepwater flounder	***Monolene sessilicauda***	X						X		
Mora (unclassified)	Moridae	X						X		
Striped bass	***Morone saxatilis***				X		X		≤50	>50
Smooth dogfish	***Mustelus canis***			X			X			
Lanternfish (unclassified)	**Myctophidae**				X			X		
Humboldt's lanternfish	*Myctophum humboldti*				X			X		
Grubby	***Myoxocephalus aenaeus***		X					X		
Longhorn sculpin	***Myoxocephalus octodecemspinosus***		X					X		
Shorthorn sculpin	***Myoxocephalus scorpius***		X					X		
Atlantic hagfish	***Myxine glutinosa***		X					X		
Moon snail, shark eye, and baby-ear	Naticidae					X		X		
Pilotfish	*Naucrates ductor*				X			X		
Slender snipe eel	***Nemichthys scolopaceus***				X			X		
Marlin-spike	***Nezumia bairdi***	X						X		
Octopus (unclassified)	**Octopoda**					X		X		
Common octopus	***Octopus vulgaris***					X		X		
Batfish (unclassified)	Ogcocephalidae		X					X		

APPENDIX A (continued).

COMMON NAME	SCIENTIFIC NAME	GF	DEM	EL	PEL	INV	COM	NC	BEN	PIS
						GROUP CLASSIFICATIONS				
Longnose batfish	*Ogcocephalus corniger*		X					X		
Shortnose batfish	*Ogcocephalus nasutus*		X					X		
Snake eel (unclassified)	**Ophichthidae**		X					X		
Margined snake eel	***Ophichthus cruentifer***		X					X		
Cusk-eel (unclassified)	Ophidiidae		X					X		
Striped cusk-eel	*Ophidion marginatum*		X					X		
Mooneye cusk-eel	*Ophidion selenops*		X					X		
Oyster toadfish	*Opsanus tau*		X					X		
Pigfish	*Orthopristis chrysoptera*		X					X		
Rainbow smelt	***Osmerus mordax***				X			X		
Lady crab	***Ovalipes ocellatus***					X		X		
Coarsehand lady crab	*Ovalipes stephensoni*					X		X		
Hermit crab (unclassified)	Paguroidea					X		X		
Barracudina (unclassified)	**Paralepidae**				X			X		
Sharpnose barracudina	*Paralepis coregonoides*				X			X		
Summer flounder	***Paralichthys dentatus***	X					X			>20
Fourspot flounder	***Paralichthys oblongus***	X						X		>20
Longnose greeneye	*Parasudis truculenta*		X					X		
Butterfish	***Peprilus triacanthus***				X			X		
Armored searobin	***Peristedion miniatum***		X					X		
Sea lamprey	***Petromyzon marinus***				X			X		
Rock gunnel	***Pholis gunnellus***		X					X		
Sea scallop	***Placopecten magellanicus***					X	X			
Righteye flounder (unclassified)	**Pleuronectidae**	X						X		
Flounder (unclassified)	Pleuronectiformes	X						X		
Pollock	***Pollachius virens***	X					X			
Slope hatchetfish	***Polyipnus clarus***				X			X		
	Polymetme thaeocoryla		X					X		
Beardfish	*Polymixia lowei*		X					X		
Stout beardfish	*Polymixia nobilis*		X					X		
Bluefish	***Pomatomus saltatrix***				X		X			X
Swimming crab (unclassified)	Portunidae					X		X		
Bigeye	***Priacanthus arenatus***		X					X		
Glasseye snapper	*Priacanthus cruentatus*		X					X		
Northern searobin	***Prionotus carolinus***		X					X	X	
Striped searobin	*Prionotus evolans*		X					X		
Short bigeye	*Pristigenys alta*		X					X		
Winter flounder	***Pseudopleuronectes americanus***	X					X		X	
Clearnose skate	*Raja eglanteria*			X			X			
Skate (unclassified)	*Raja* sp.			X				X		
Greenland halibut	***Reinhardtius hippoglossoides***	X						X		
Vermillion snapper	*Rhomboplites aurorubens*		X					X		
Atlantic salmon	*Salmo salar*				X			X		
Atlantic bonito	*Sarda sarda*				X			X		
Chub mackerel	*Scomber japonicus*				X			X		
Atlantic mackerel	***Scomber scombrus***				X			X		
Atlantic saury	***Scomberesox saurus***				X			X		
Windowpane flounder	***Scophthalmus aquosus***	X					X			
Scorpionfish (unclassified)	**Scorpaenidae**		X					X		
Chain dogfish	*Scyliorhinus retifer*			X				X		
Ridged slipper lobster	*Scyllarides nodifer*					X		X		
Acadian redfish	***Sebastes fasciatus***		X					X		

APPENDIX A (continued).

COMMON NAME	SCIENTIFIC NAME	*GF*	*DEM*	*EL*	*PEL*	*INV*	*COM*	*NC*	*BEN*	*PIS*
		GROUP CLASSIFICATIONS								
Bigeye scad	*Selar crumenophthalmus*				X			X		
Atlantic moonfish	*Selene setapinnis*				X			X		
Lookdown	*Selene vomer*				X			X		
Lesser shining bobtail	*Semirossia tenera*					X		X		
Bobtail (unclassified)	**Sepiolidae**					X		X		
Banded rudderfish	*Seriola zonata*				X			X		
Snubnose eel	*Simenchelys parasiticus*		X					X		
Bluntnose puffer	*Sphoeroides pachygaster*		X					X		
Northern sennet	*Sphyraena borealis*							X		
Barracuda (unclassified)	*Sphyraena* sp.				X			X		
Atlantic surfclam	***Spisula solidissima***					X		X		
Spiny dogfish	***Squalus acanthias***			X			X			>60
Sea star, brittle star, and baskets	Stelleroidea					X		X		
Scup	***Stenotomus chrysops***		X				X		X	
Hatchetfish (unclassified)	**Sternoptychidae**				X			X		
Shield bobtail	***Stoloteuthis leucoptera***					X		X		
Boa dragonfish	*Stomias boa*				X			X		
Scaly dragonfish (unclassified)	**Stomiidae**				X			X		
Butterfish (unclassified)	Stromateidae				X			X		
Offshore tonguefish	*Symphurus civitatus*		X					X		
Spottedfin tonguefish	*Symphurus diomedianus*		X					X		
Blackcheek tonguefish	*Symphurus plagiusa*		X					X		
Tonguefish (unclassified)	***Symphurus*** **sp.**		X					X		
Keelcheek bass	*Synagrops spinosus*		X					X		
Pipefish (unclassified)	**Syngnathidae**				X			X		
Northern pipefish	***Syngnathus fuscus***		X					X		
Lizardfish (unclassified)	Synodontidae		X					X		
Tautog	*Tautoga onitis*		X				X			
Cunner	***Tautogolabrus adspersus***		X					X		
Atlantic torpedo	***Torpedo nobiliana***			X				X		
Rough scad	***Trachurus lathami***				X			X		
Atlantic cutlassfish	*Trichiurus lepturus*		X					X		
Searobin (unclassified)	Triglidae		X					X		
Moustache sculpin	***Triglops murrayi***		X					X	X	
Radiated shanny	***Ulvaria subbifurcata***		X					X		
Longfin hake	***Urophycis chesteri***	X						X		
Red hake	***Urophycis chuss***	X					X			
Carolina hake	Urophycis earlli	X						X		
Spotted hake	***Urophycis regia***	X						X		>20
Ling (unclassified)	***Urophycis*** **sp.**	X						X		
White hake	***Urophycis tenuis***	X					X			
Buckler dory	***Zenopsis conchifera***				X			X		
Eelpout (unclassified)	Zoarchidae		X					X		

APPENDIX B

Species for which trophic categories were identified and size breaks at which ontogenetic changes in feeding habits occur. Data used for this classification are taken from Garrison and Link (2000) or derived from the NEFSC Food Habits Database. Size ranges shown indicate lengths for which a minimum of ten stomach samples were recorded in the food habits database; these ranges were used to establish sizes at which ontogonetic feeding shifts occur. Species and size categories classified as benthivores and piscivores are used for further analyses of group- and species-level change-points.

Scientific name	**Common name**	**Size category (cm)**	**Trophic group**
Alosa pseudoharengus	Alewife	1-40	Planktivore
Alosa sapidissima	American shad	1-50	Planktivore
Amblyraja radiata	Thorny skate	10-60 60-110	Benthivore Piscivore
Ammodytes dubius	Sand lance	1-10	Planktivore
Anarhichas lupus	Atlantic wolffish	1-90	Benthivore
Argentina silus	Atlantic argentine	21-40	Planktivore
Brosme brosme	Cusk	21-40 41-100	Benthivore Piscivore
Centropristis striata	Black sea bass	10-60	Crab eater
Citharichthys arctifrons	Gulfstream flounder	10-20	Benthivore
Clupea harengus	Atlantic herring	10-30	Planktivore
Dipturus laevis	Barndoor skate	11-130	Benthivore
Enchelyopus cimbrius	Fourbeard rockling	11-30	Benthivore
Gadus morhua	Atlantic cod	10-50 51-130	Amphipod/shrimp eater Piscivore
Glyptocephalus cynoglossus	Witch flounder	1-70	Benthivore
Helicolenus dactylopterus	Blackbelly rosefish	1-40	Shrimp/small fish eater
Hemitripterus americanus	Sea raven	10-50	Piscivore
Hippoglossoides platessoides	American plaice	10-70	Benthivore
Hippoglossus hippoglossus	Atlantic halibut	21-60 61-100	Benthivore Piscivore
Illex illecebrosus	Northern shortfin squid	1-40	Planktivore
Lepophidium profundorum	Fawn cusk-eel	11-30	Benthivore
Leucoraja erinacea	Little skate	10-60	Amphipod/shrimp eater

APPENDIX B (continued).

Scientific name	Common name	Size category (cm)	Trophic group
Leucoraja ocellata	Winter skate	10-60 61-110	Amphipod/shrimp eater Piscivore
Limanda ferruginea	Yellowtail flounder	10-20 21-70	Amphipod/shrimp eater Benthivore
Loligo pealeii	Longfin squid	1-40	Planktivore
Lophius americanus	Goosefish	1-10 11-110	Shrimp/small fish eater Piscivore
Macrozoarces americanus	Ocean pout	11-90	Benthivore
Malacoraja senta	Smooth skate	11-30 31-60	Benthivore Shrimp/small fish eater
Melanogrammus aeglefinus	Haddock	10-80	Benthivore
Merluccius albidus	Offshore hake	1-40	Shrimp/small fish eater
Merluccius bilinearis	Silver hake	10-40 41-70	Shrimp/small fish eater Piscivore
Micropogonias undulatus	Atlantic croaker	10-50	Benthivore
Morone saxatilis	Striped bass	21-50 51-100	Benthivore Piscivore
Mustelus canis	Smooth dogfish	11-80	Crab eater
Myoxocephalus octodecemspinosus	Longhorn sculpin	10-50	Amphipod/shrimp eater
Paralichthys dentatus	Summer flounder	11-20 21-70	Shrimp/small fish eater Piscivore
Paralichthys oblongus	Fourspot flounder	10-20 21-40	Amphipod/shrimp eater Piscivore
Peprilus triacanthus	Butterfish	21-30	Planktivore
Pollachius virens	Pollock	10-110	Shrimp/small fish eater
Pomatomus saltatrix	Bluefish	10-80	Piscivore
Prionotus carolinus	Northern searobin	1-40	Benthivore
Pseudopleuronectes americanus	Winter flounder	10-70	Benthivore
Scomber scombrus	Atlantic mackerel	10-50	Planktivore
Scopthalmus aquosus	Windowpane	10-40	Amphipod/shrimp eater
Sebastes fasciatus	Acadian redfish	1-26 26-50	Planktivore Shrimp/small fish eater
Squalus acanthias	Spiny dogfish	10-60 61-80	Planktivore Piscivore
Stenotomus chrysops	Scup	1-50	Benthivore

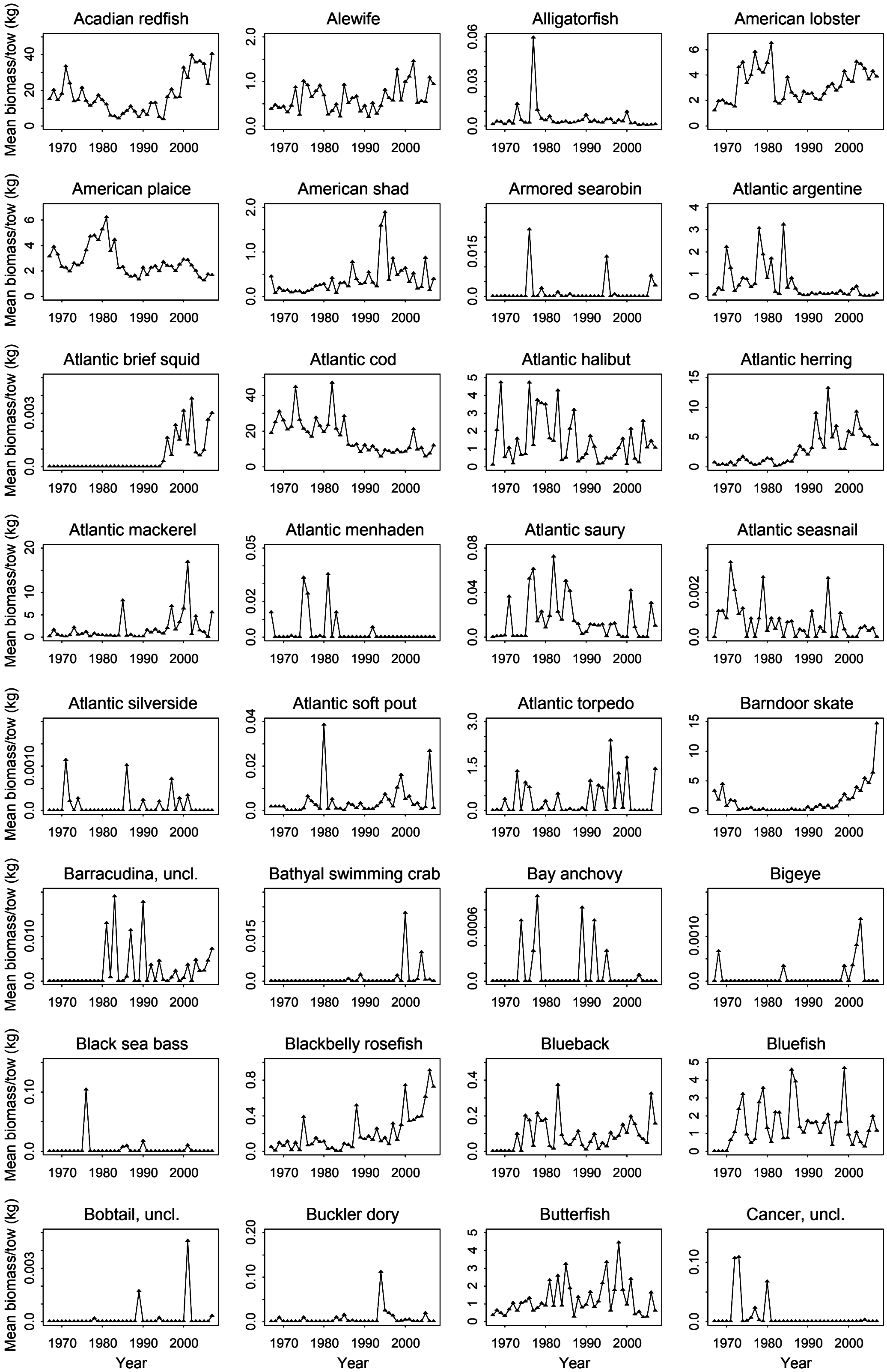
APPENDIX B (continued).

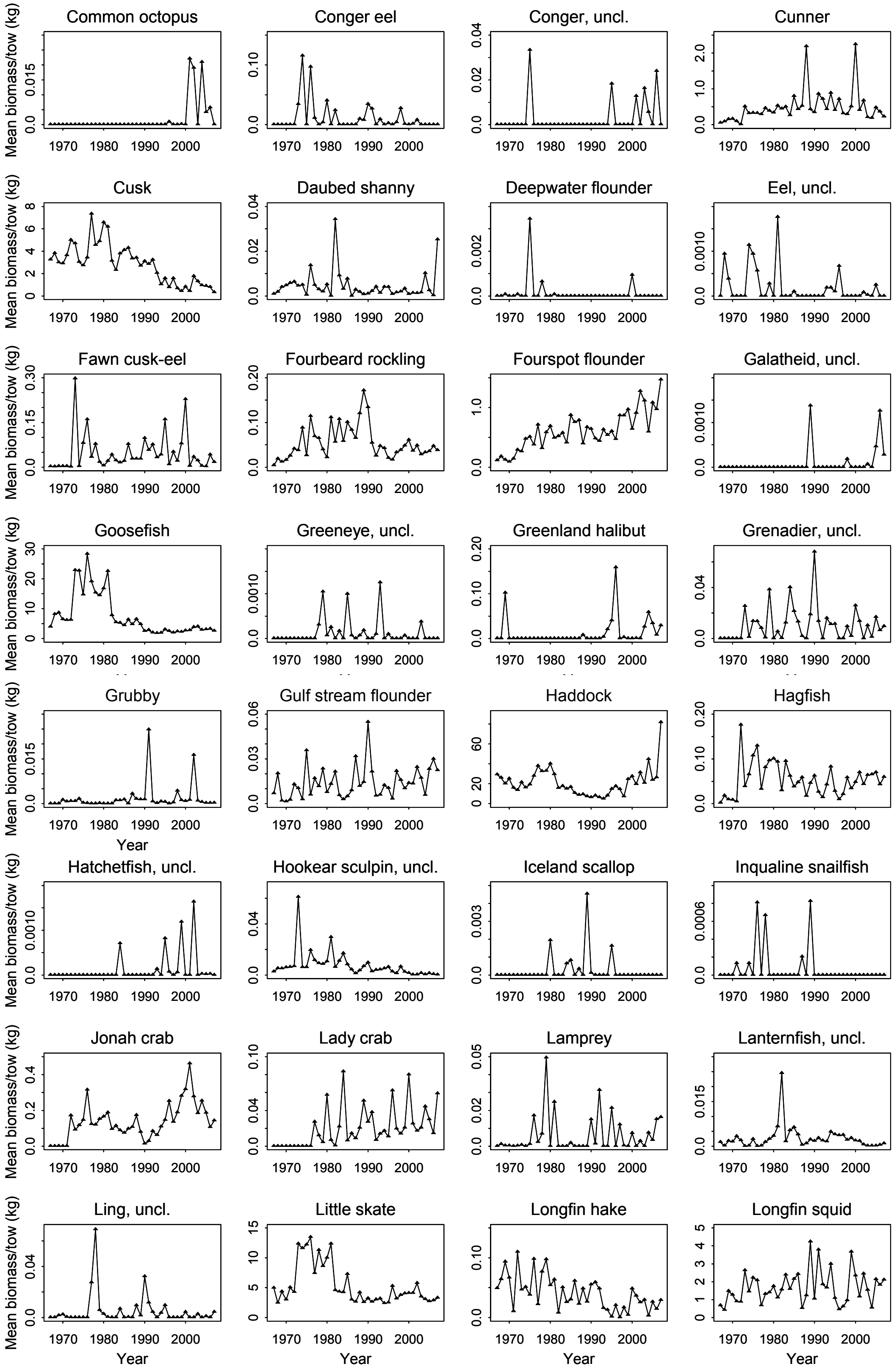
Scientific name	**Common name**	**Size category (cm)**	**Trophic group**
Triglops murrayi	Moustache sculpin	1-20	Benthivore
Urophycis chesteri	Longfin hake	11-20	Amphipod/shrimp eater
Urophycis chuss	Red hake	10-40 41-70	Amphipod/shrimp eater Shrimp/small fish eater
Urophycis regia	Spotted hake	10-20 21-40	Amphipod/shrimp eater Piscivore
Urophycis tenuis	White hake	10-20 21-40 41-120	Amphipod/shrimp eater Shrimp/small fish eater Piscivore

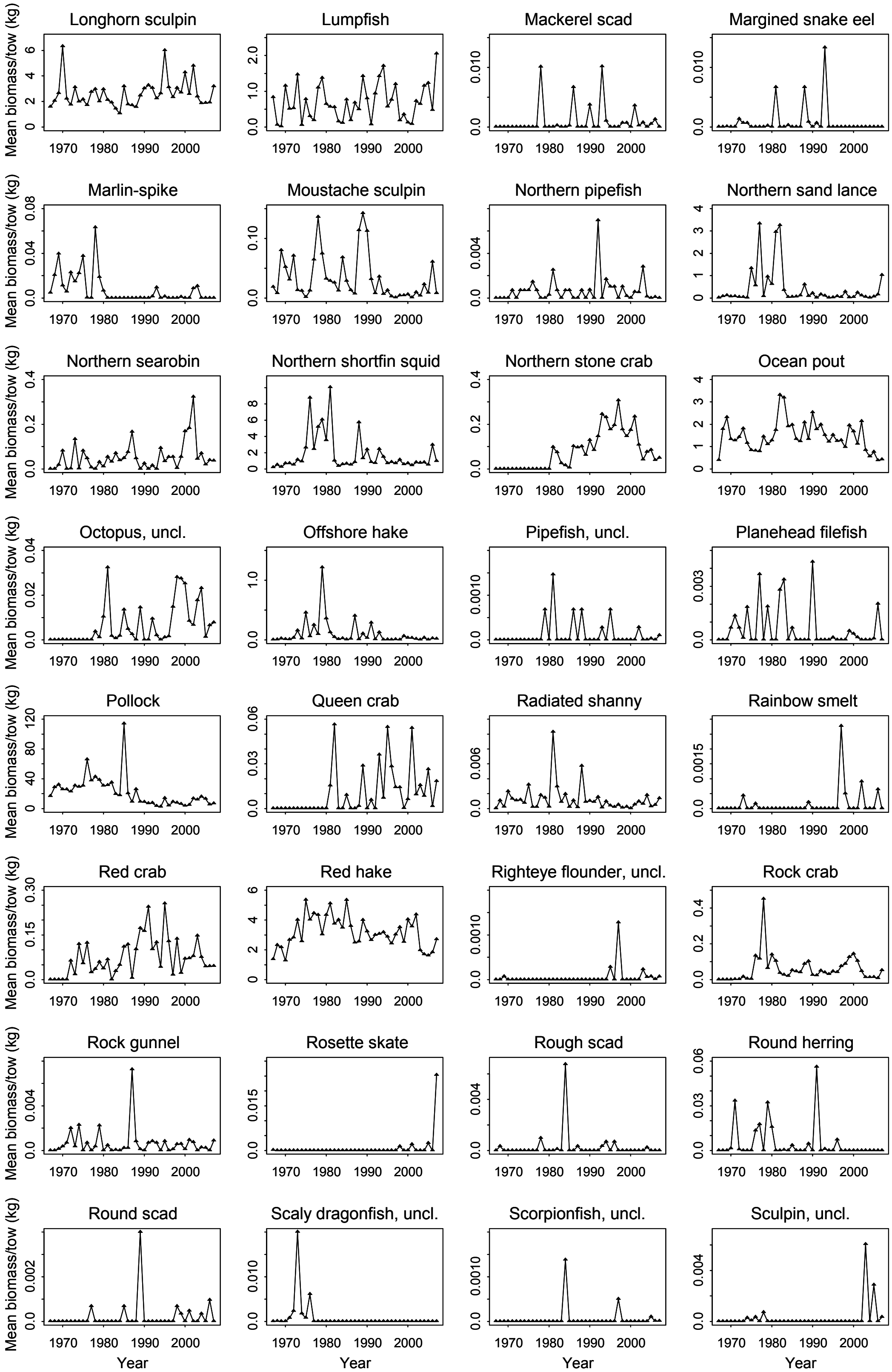
APPENDIX C

Time series plots of the annual mean biomass per tow for each species used in the composition analyses.

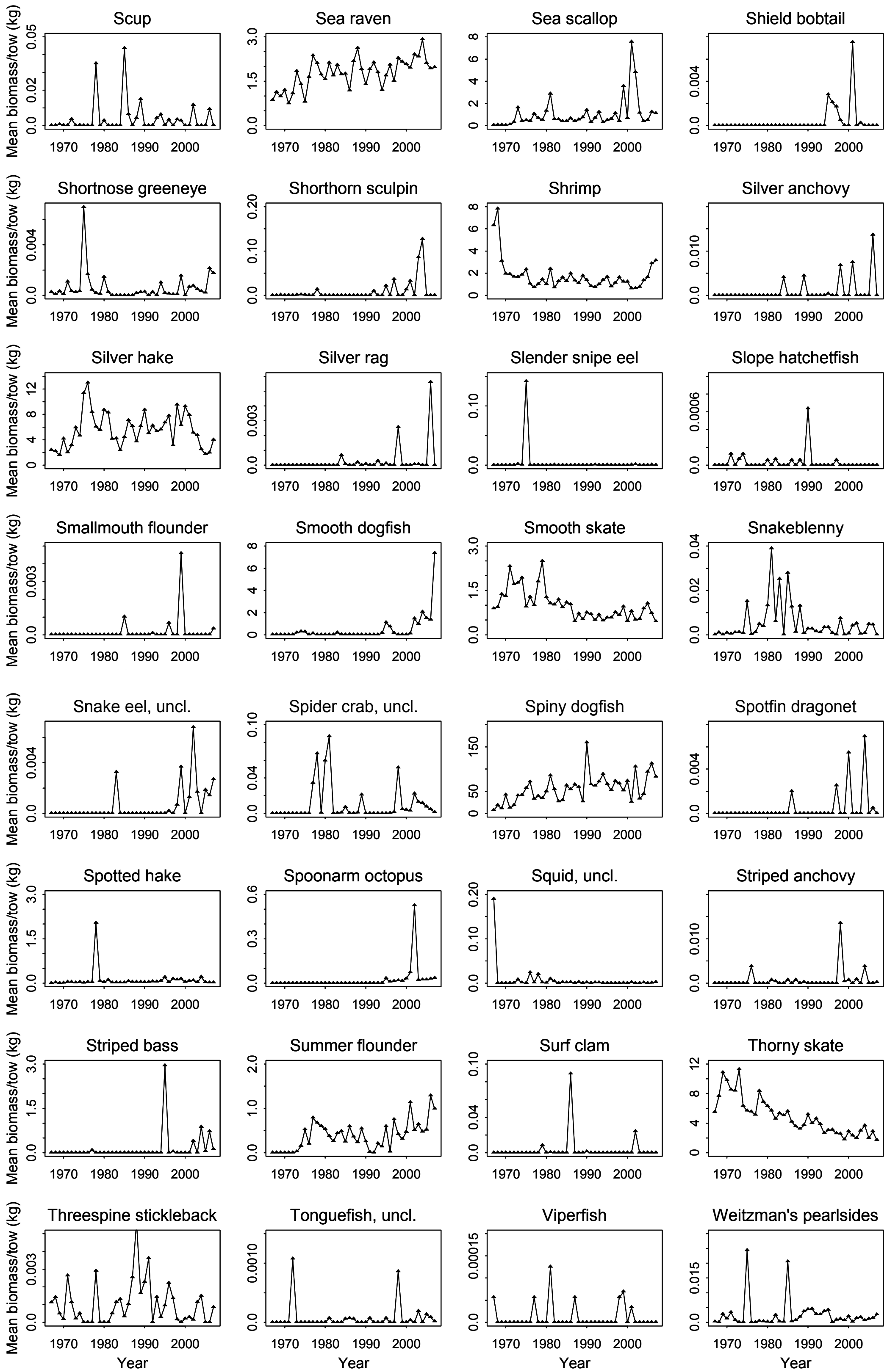
APPENDIX C (continued).



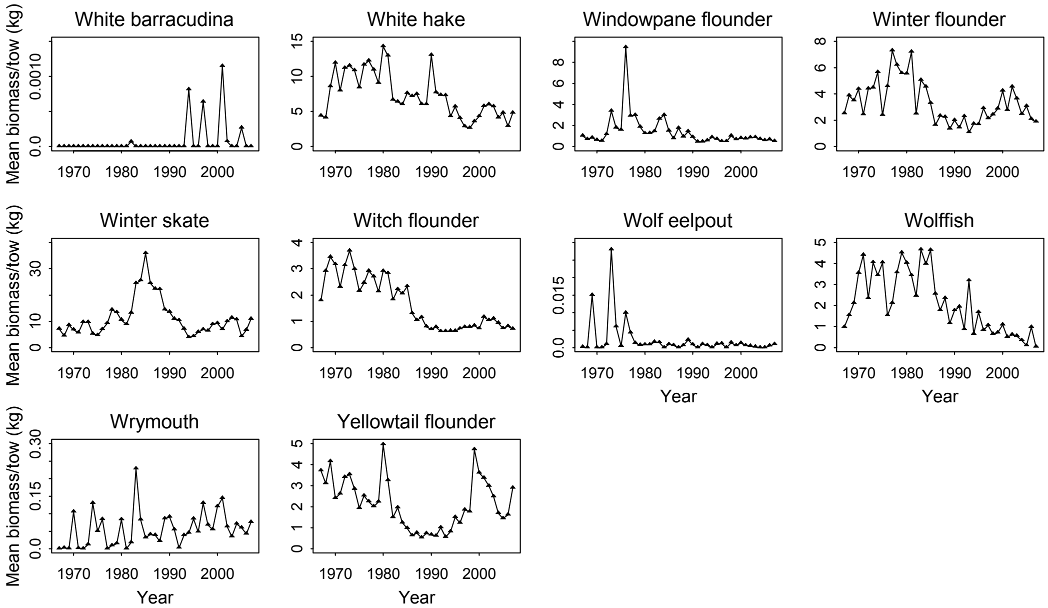

Common octopus
Conger eel
Conger, uncl.
Cunner
Cusk
Daubed shanny
Deepwater flounder
Eel, uncl.
Fawn cusk-eel
Fourbeard rockling
Fourspot flounder
Galatheid, uncl.
Goosefish
Greeneye, uncl.
Greenland halibut
Grenadier, uncl.
Grubby
Gulf stream flounder
Haddock
Hagfish
Hatchetfish, uncl.
Hookear sculpin, uncl.
Iceland scallop
Inqualine snailfish
Jonah crab
Lady crab
Lamprey
Lanternfish, uncl.
Ling, uncl.
Little skate
Longfin hake
Longfin squid
Mean biomass/tow (kg)
Year
1970 1980 1990 2000


Longhorn sculpin
Lumpfish
Mackerel scad
Margined snake eel
Marlin-spike
Moustache sculpin
Northern pipefish
Northern sand lance
Northern searobin
Northern shortfin squid
Northern stone crab
Ocean pout
Octopus, uncl.
Offshore hake
Pipefish, uncl.
Planehead filefish
Pollock
Queen crab
Radiated shanny
Rainbow smelt
Red crab
Red hake
Righteye flounder, uncl.
Rock crab
Rock gunnel
Rosette skate
Rough scad
Round herring
Round scad
Scaly dragonfish, uncl.
Scorpionfish, uncl.
Sculpin, uncl.
Mean biomass/tow (kg)
Year
1970 1980 1990 2000

APPENDIX C (continued).



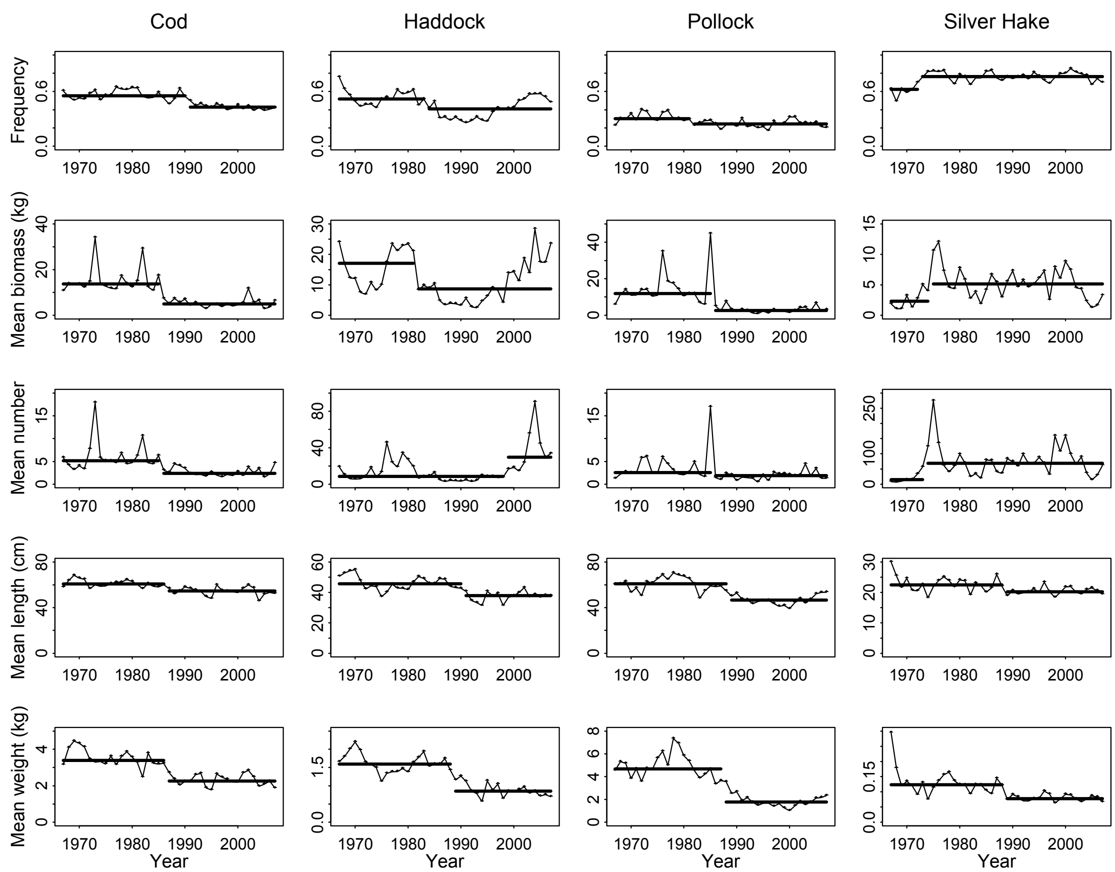
APPENDIX C (continued).



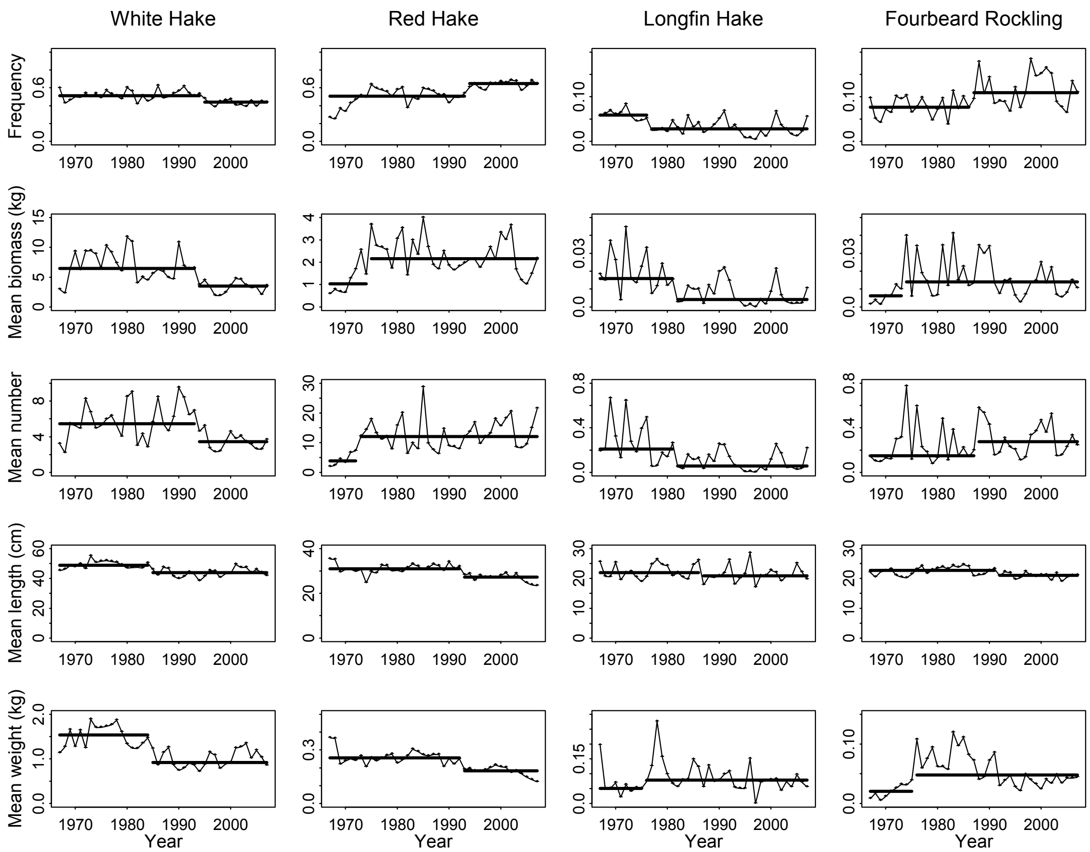
APPENDIX D

Time series data for five biological attributes and associated change-points for each individual species analyzed.

Groundfish



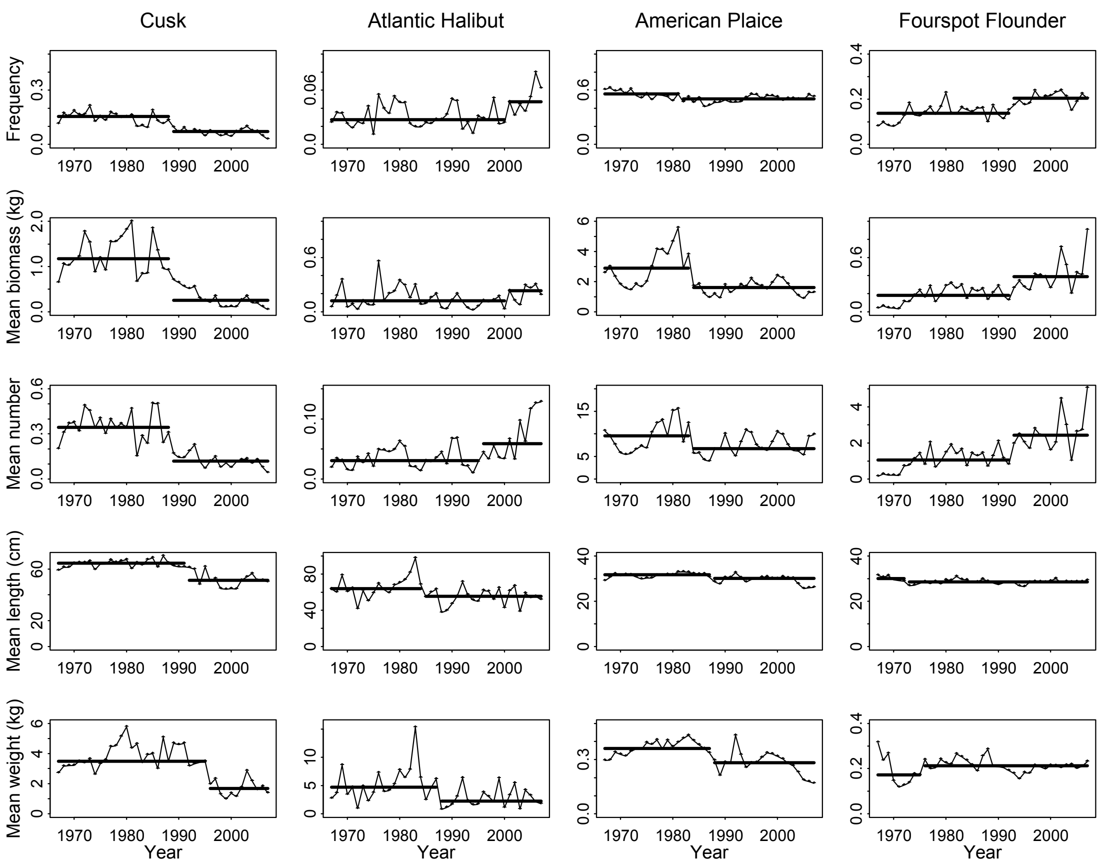
Groundfish



White Hake
Red Hake
Longfin Hake
Fourbeard Rockling
Frequency
Mean biomass (kg)
Mean number
Mean length (cm)
Mean weight (kg)
Year

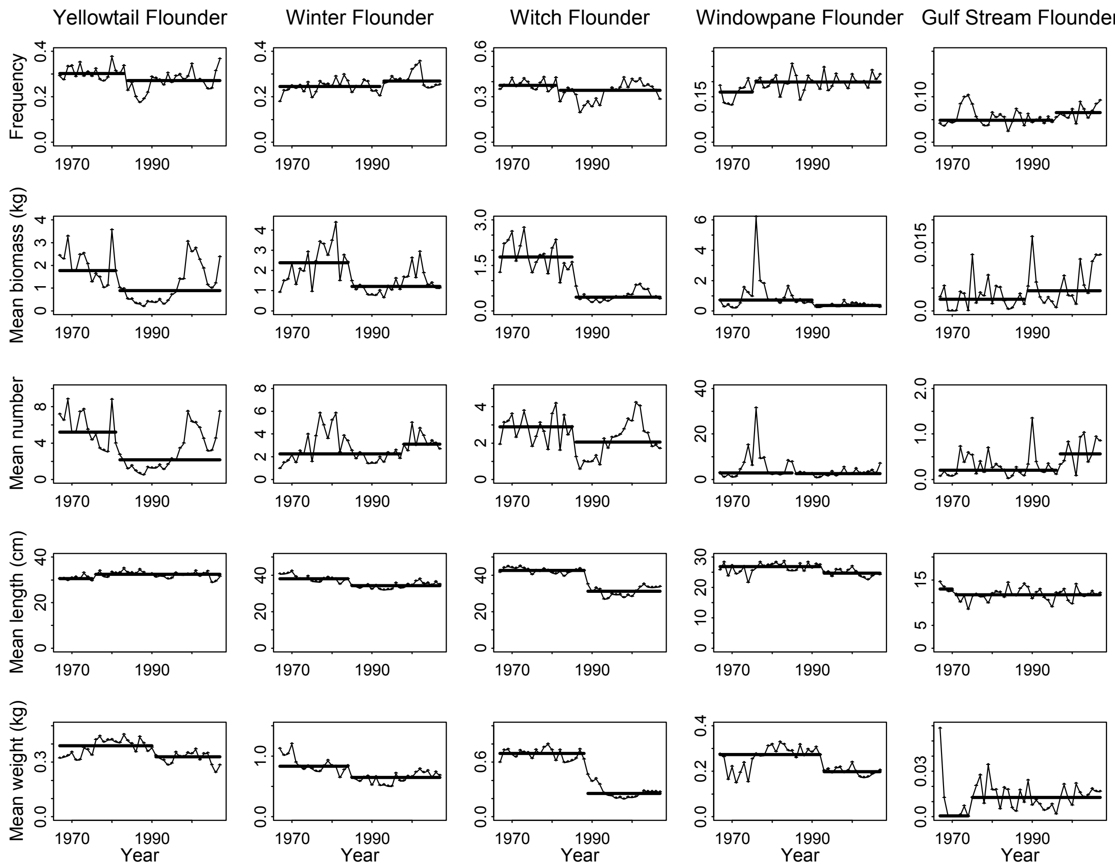
APPENDIX D (continued).

Groundfish



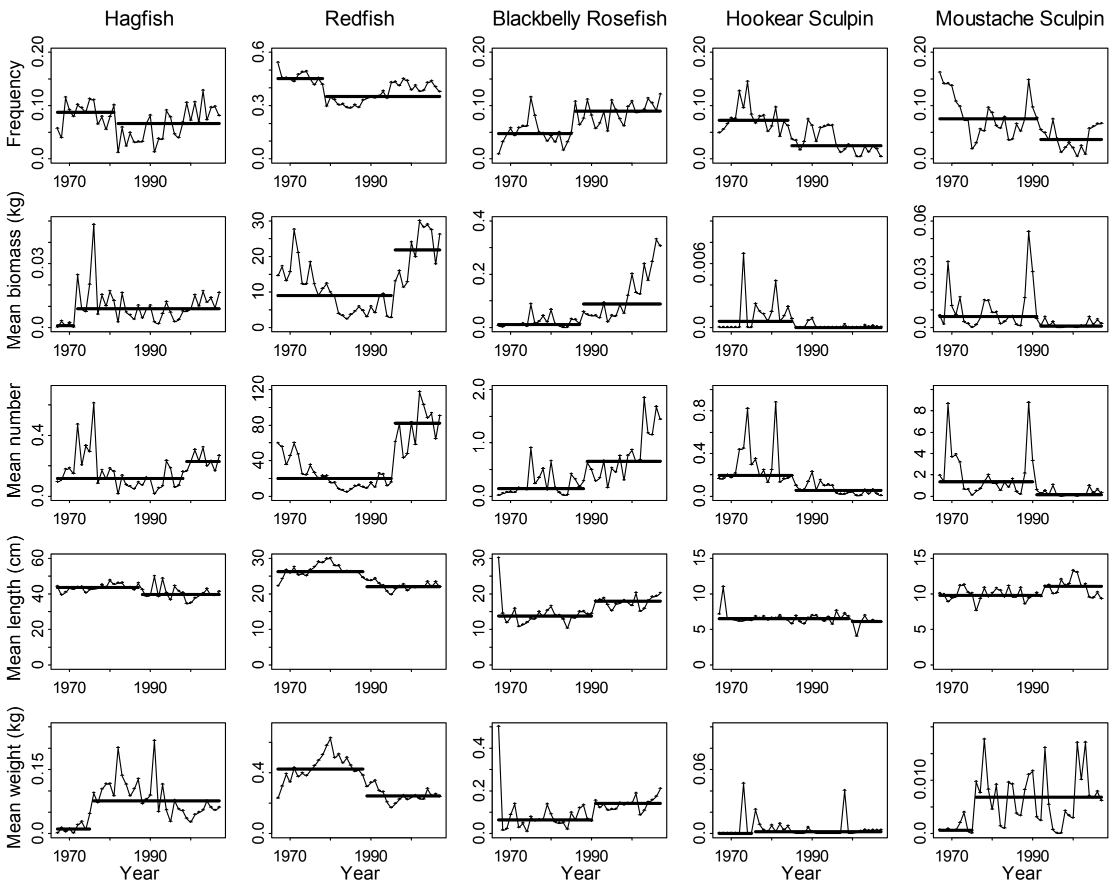
APPENDIX D (continued).

Groundfish

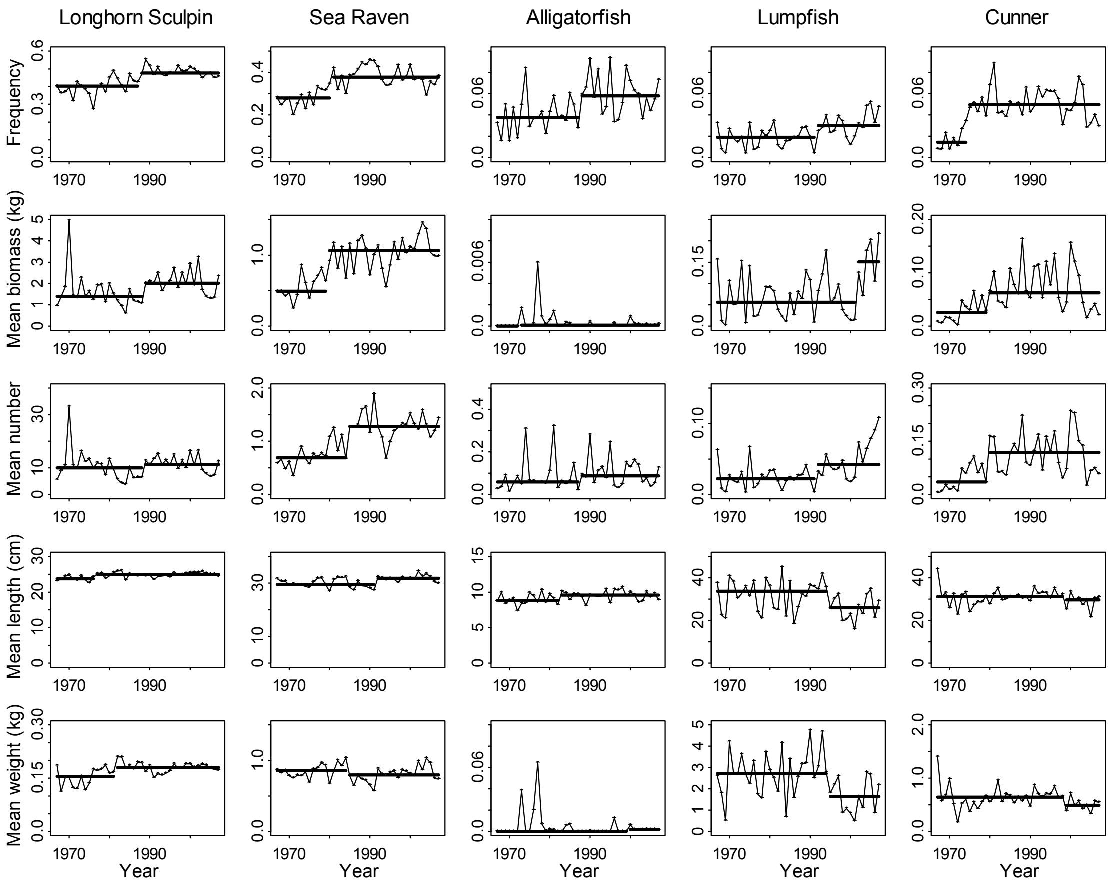


APPENDIX D (continued).

Demersals

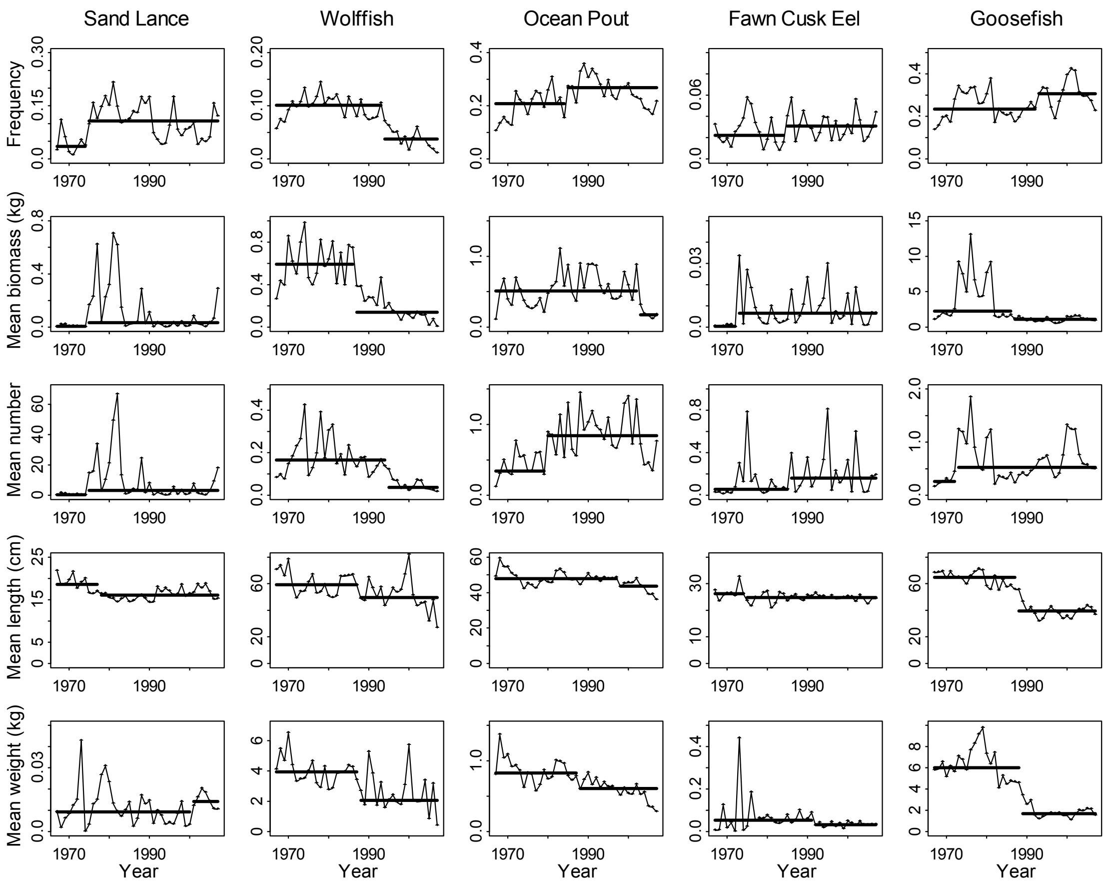


Demersals



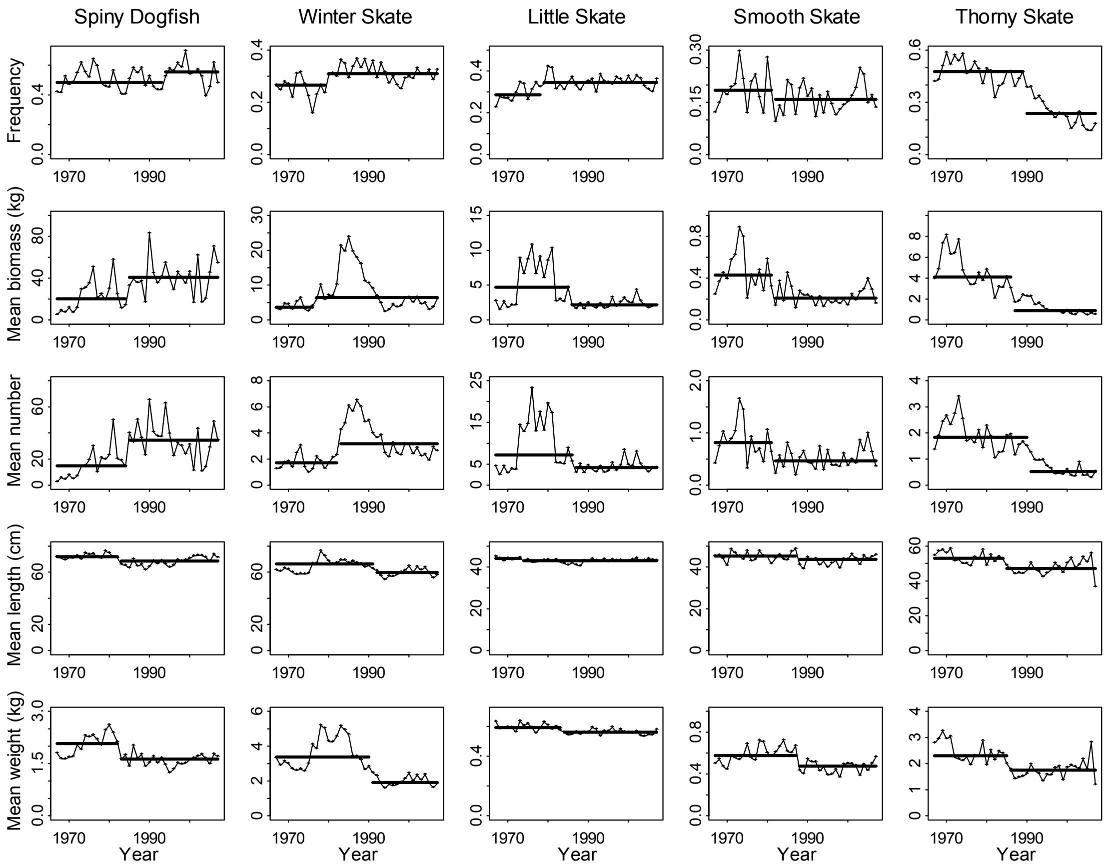
Longhorn Sculpin
Sea Raven
Alligatorfish
Lumpfish
Cunner
Frequency
Mean biomass (kg)
Mean number
Mean length (cm)
Mean weight (kg)
Year
1970
1990

Demersals


Sand Lance
Wolffish
Ocean Pout
Fawn Cusk Eel
Goosefish
Frequency
Mean biomass (kg)
Mean number
Mean length (cm)
Mean weight (kg)
Year
1970
1990

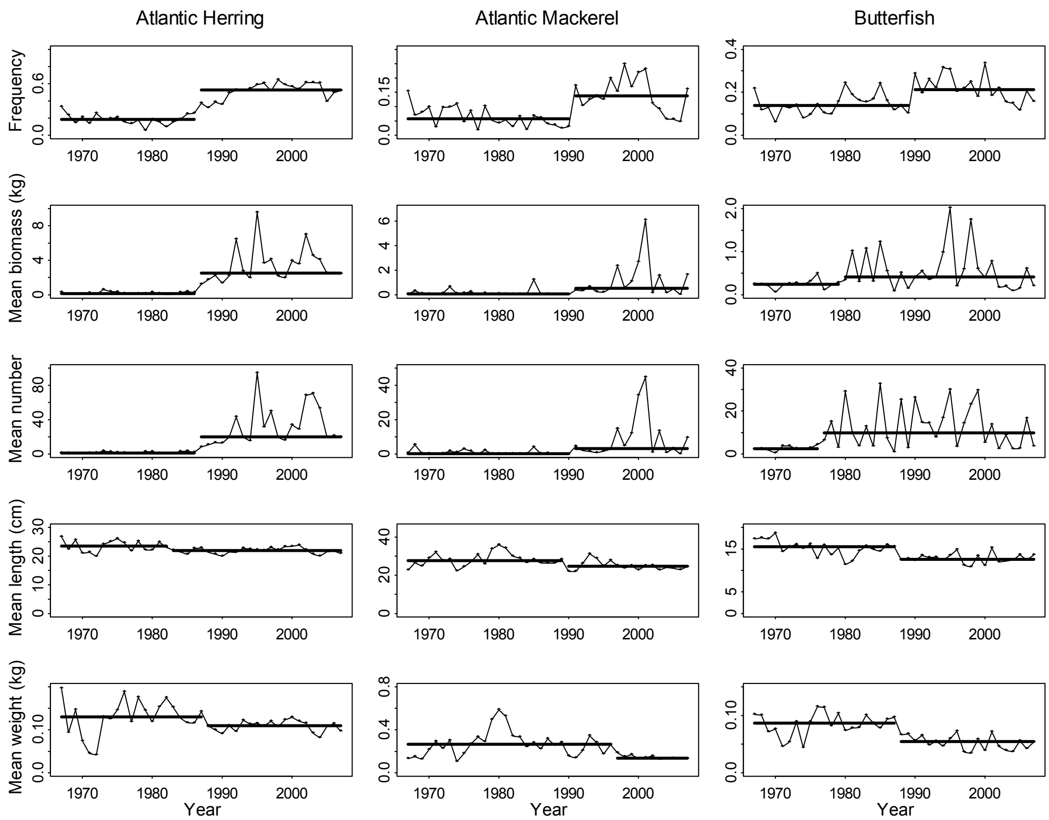
APPENDIX D (continued).

Elasmobranches



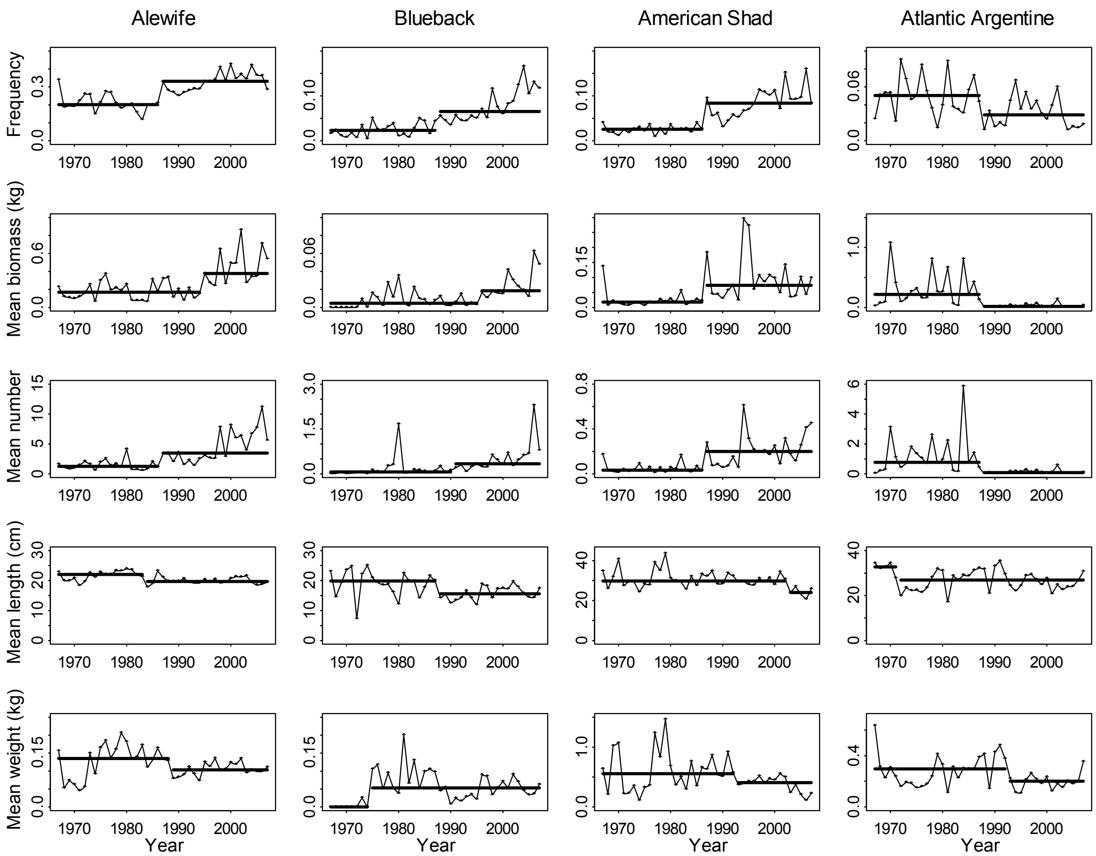
APPENDIX D (continued).

Pelagics



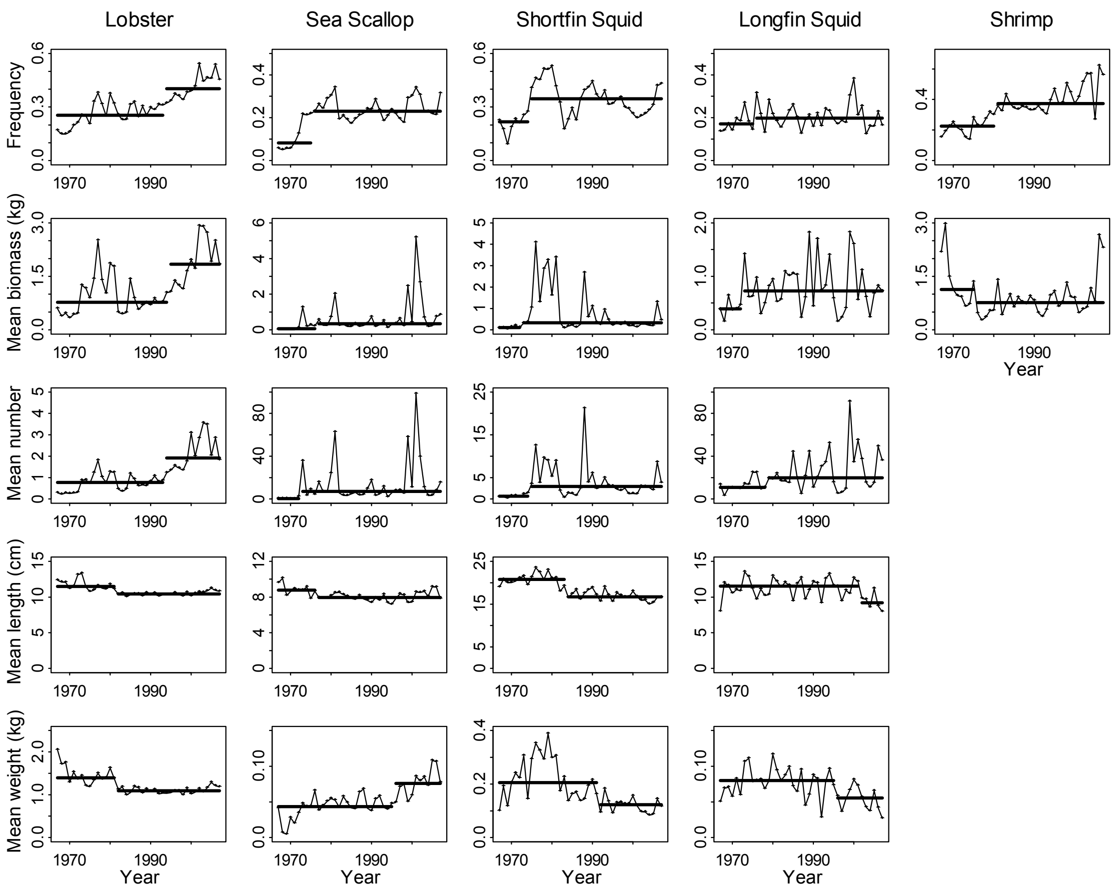
APPENDIX D (continued).

Pelagics

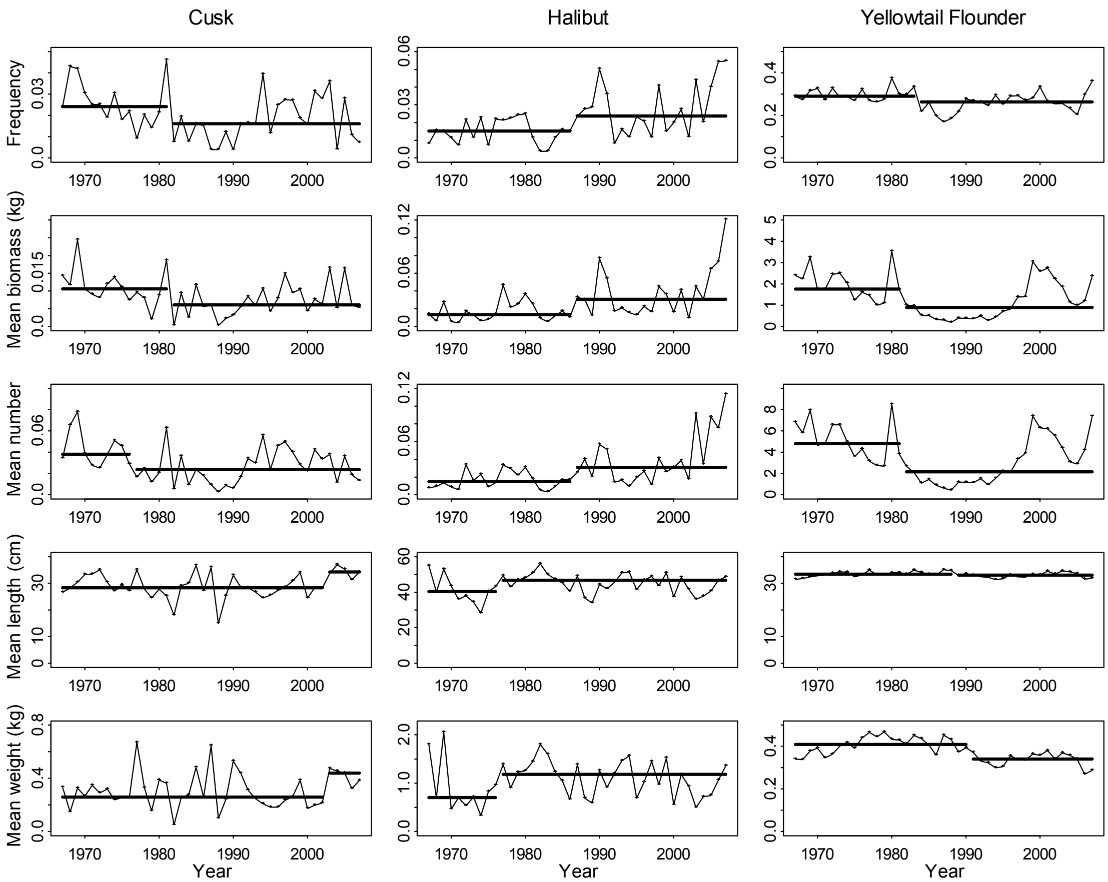


APPENDIX D (continued).

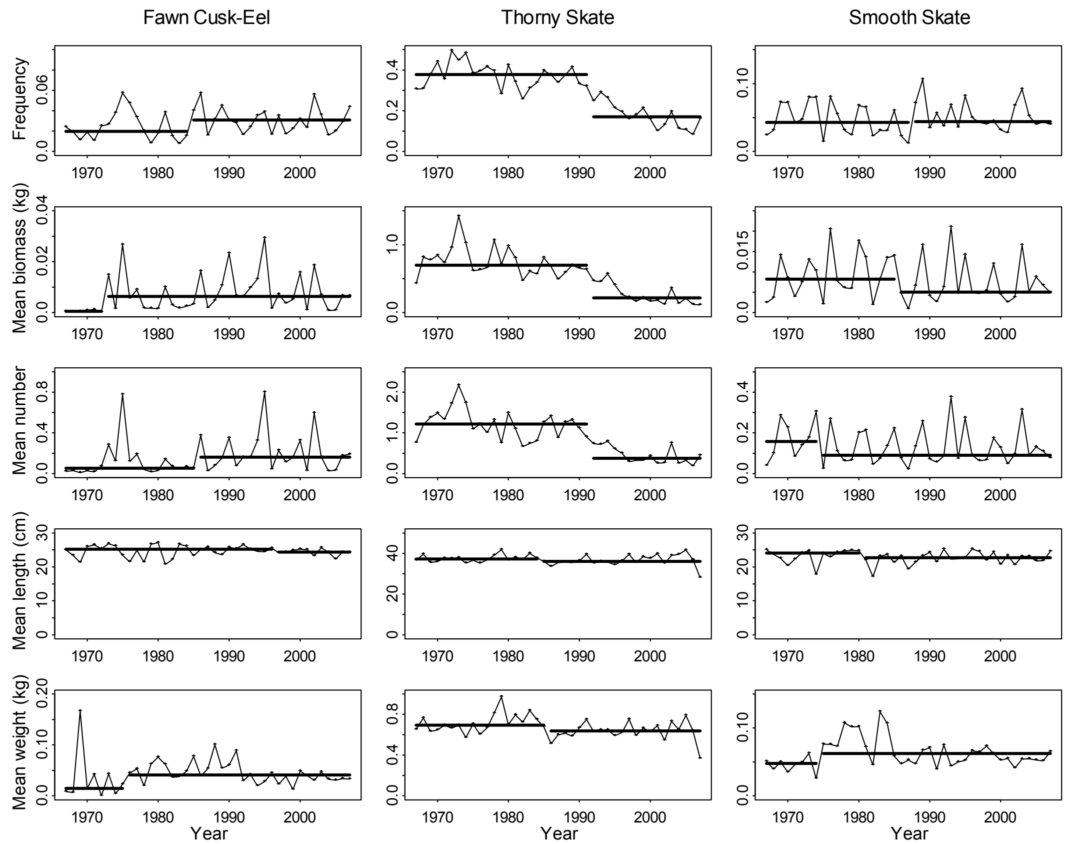
Invertebrates



Benthivorous stage (if ontogenetic feeding shift occurs within species)

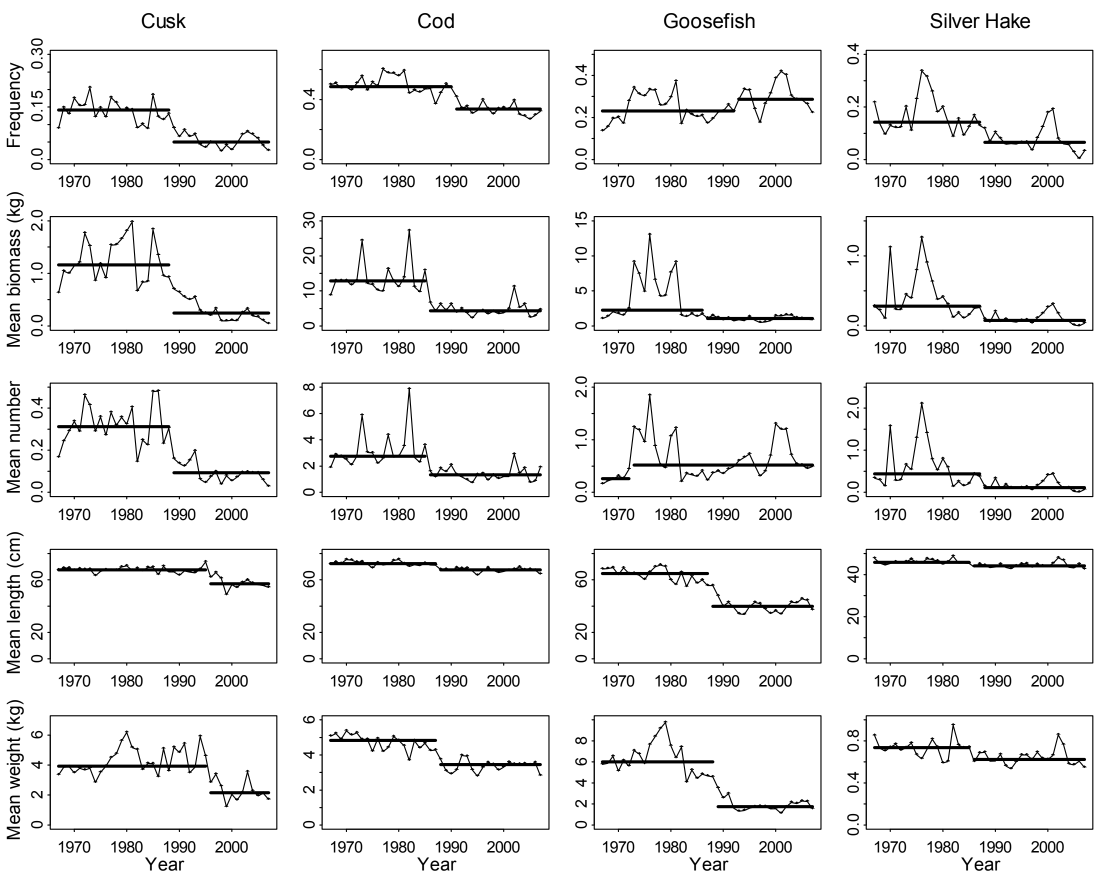


Benthivorous stage (if ontogenetic feeding shift occurs within species)

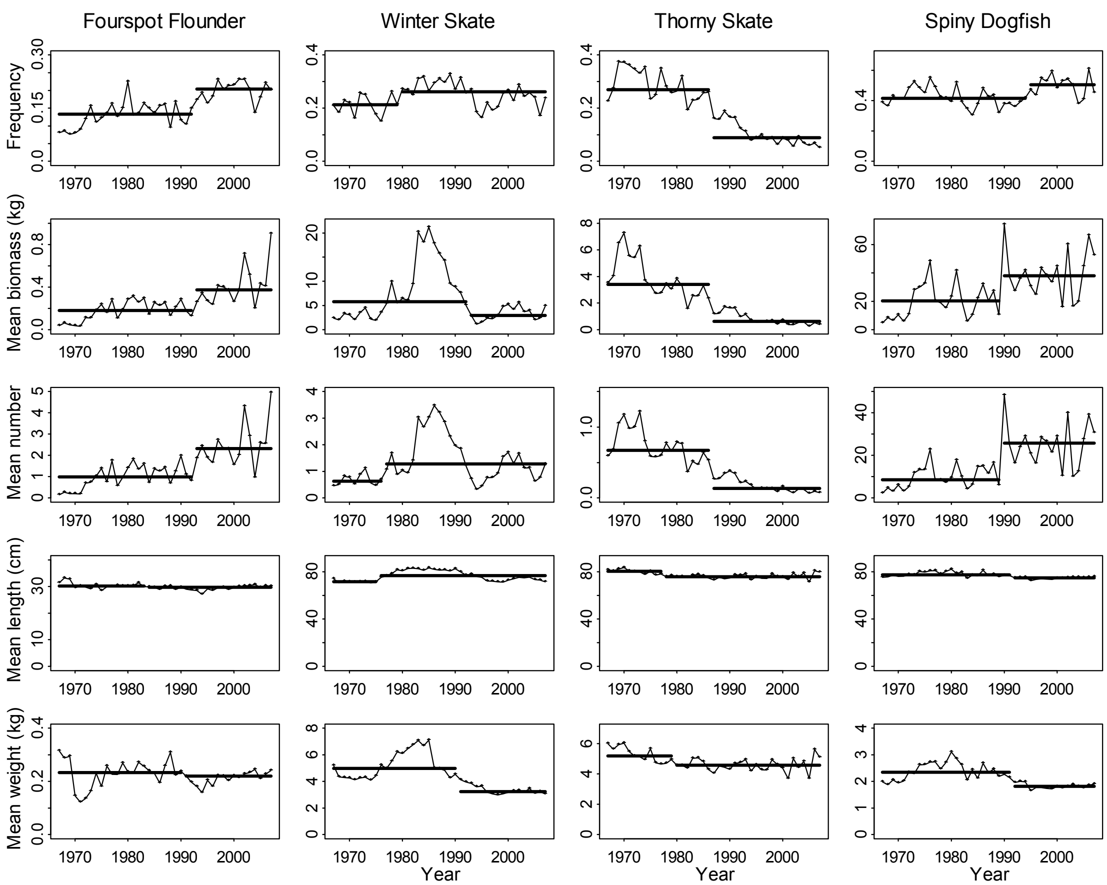


APPENDIX D (continued).

Piscivorous stage (if ontogenetic feeding shift occurs within species)



Piscivorous stage (if ontogenetic feeding shift occurs within species)



APPENDIX E

Description of the topics associated with each coded feature as they were discussed by respondents during interviews. The appendix consists of four sections: (1) features of ecosystem-based management, (2) characteristics of good resource management, (3) goals for the Gulf of Maine ecosystem, and (4) concerns about the Gulf of Maine ecosystem.

FEATURES OF ECOSYSTEM-BASED MANAGEMENT

General criteria

Cross-jurisdiction. Many respondents commented on the need for EBM to function across political and agency jurisdictions. Some interviewees mentioned that EBM should enable ecosystem-scale planning across political boundaries. Most respondents spoke of the need to engage participants in and managers of multiple marine activities. Respondents saw a need for EBM to jointly consider the effects of land use, water quality, nutrients, pollution, fishing, and other human uses on the ecosystem. This holistic evaluation of stressors in the marine ecosystem was necessary for advancing fair management that does not disproportionately restrict certain activities (e.g., fishing) when other stressors may be contributing to problems in the ecosystem. Respondents recognized governance challenges associated with coordinating across multiple uses that are managed by different entities, but they saw reaching across sectors and "silos" as a vital distinction of EBM. A few cautioned that other sectors have little incentive to become engaged in fishery management processes, even though activities in these sectors may affect fish stocks. Careful consideration of ways to bring groups to the table will be required for achieving cross-jurisdictional and cross-sector integration in EBM.

Sustainability. Approximately one-third of all respondents cited sustainability as a necessary outcome of EBM. EBM needs to focus on the ecosystem as a whole and on interconnections between multiple parts of the ecosystem. EBM should develop lasting solutions that meet multiple conservation, social, and economic objectives. Achieving sustainability means balancing use of the ecosystem with conservation in such a manner that human activities are not eliminated but are maintained within limits that can sustain both those uses and ecological processes over the long run. Achieving sustainability also means balancing community benefits with ecosystem considerations and recognizing that the amount of resources available for human use may change as the ecosystem changes.

Inclusion of humans. Many respondents spoke of the need to recognize humans as part of the ecosystem. Humans exert the single largest influence on the ecosystem; their activities can impact the ecosystem in both negative and positive ways. Due to human dependence on the ecosystem, several respondents felt that it was impossible to separate considerations of the natural environment from socio-economic aspects of human communities. Some interviewees found it difficult to distinguish current management approaches from EBM since both focus on managing human activities; a few respondents felt that EBM would be distinct in managing human activities in the context of ecosystem variability. One respondent expressed a need for improved scientific capacity to understand the extent to which human activities affect the ecosystem as part of implementing EBM.

Cumulative impact assessment. A number of respondents recognized the need for cumulative impact assessment in EBM. Instead of focusing on the effect of individual actions, they felt that EBM would be characterized by accounting for confounding or additive impacts of multiple activities. These cumulative effects should be considered in setting standards for activities in the ecosystem. Some recognized that broader science and new mechanisms may be needed to assess cumulative impacts.

Ecological health. A number of respondents cited a general need to preserve ecosystem integrity. Several respondents viewed EBM as a comprehensive approach to managing for integrity of the entire ecosystem and felt that protecting overall ecosystem health should be a central management goal. EBM should identify key indicators of ecosystem functioning that can guide management efforts in such ways that these fundamental indicators are not undermined. One respondent felt that EBM was only a first step towards ensuring that ecosystem concerns were considered, and another cautioned that it is necessary to be clear in EBM discussions about whether the goal is conservation, preservation, or responsible use of renewable resources.

Ecological criteria

Complexity. Many respondents recognized complexity in the ecosystem and spoke of a need to incorporate this complexity into EBM. Most respondents felt that EBM should take greater, more explicit account of species interactions, species-environment relationships, and ecosystem dynamics than is currently accommodated in single-species or single-sector management approaches. Specific examples cited by respondents included understanding and managing for predator-prey interactions, habitat needs, spawning cycles, recruitment success, and how human activities (e.g., harvest, water quality, coastal development, dams) may affect physical and biological attributes of the ecosystem. Many respondents commented on a need to maintain a balance among species in the ecosystem and to protect the forage base available to higher trophic levels. Several respondents also spoke of the need to preserve feedbacks, dynamics, and interactions within the ecosystem. A few interviewees expressed beliefs that it may be more important to protect the ecological processes and functions than individual species in the ecosystem; others felt that every species plays a role in the ecosystem, and each species should be protected to ensure the overall functioning of the ecosystem. Comments from respondents indicated that ecosystem complexity could be incorporated into EBM through multi-species, cross-sector management that considers direct and indirect effects of human activities and natural changes in the ecosystem. In addition, several respondents spoke of the importance of avoiding simple, deterministic rules in EBM, particularly those that violate ecosystem principles (e.g., striving to maintain all species at levels of maximum sustainable yield at the same time). Instead, ecosystem dynamics need to be recognized and accommodated, and the potential for threshold responses or "tipping points" need to be acknowledged.

Temporal. Several respondents recognized that ecosystem components and interactions are not stable across scales and may need to be understood at multiple scales. Many viewed EBM as taking a longer time scale into consideration in understanding ecosystem variability and setting management directions. One respondent mentioned that it should not be expected that EBM will bring resounding changes to the ecosystem in the short term; the ecosystem may not always respond to management actions in ways that are expected, and keeping a long-term perspective is important.

Spatial. Many respondents commented on spatial elements of EBM. They recognized that ecological processes taking place at different spatial scales interact with and affect one another. Thus, a nested delineation of the ecosystem and its subareas may make these cross-scale spatial influences more transparent. Further, accounting for these connections across spatial areas was commonly cited by respondents as an important element of EBM. Several mentioned the need to establish a strong connection between the sea and land (watersheds) and between nearshore and offshore areas in scientific information, governance structures, and management issues. Finally, several respondents mentioned the use of spatial management tools, such as marine protected areas, as valuable to EBM; others cautioned against heavy reliance on marine protected areas.

Human dimensions criteria

Stakeholder. Many respondents cited the importance of stakeholder involvement as an element of EBM. They mentioned that an expanded array of stakeholder groups would be relevant to EBM, and these groups must extend well beyond those currently engaged in fisheries management to those involved in other sectors of activity in the marine ecosystem (e.g., coastal landowners, coastal managers, oil and gas development, shipping and transportation, sand and gravel mining). A meaningful process for engaging stakeholders is needed to ensure stakeholder buy-in and support for EBM efforts. Elements that were viewed as important to this process included 1) giving stakeholders a voice from the start, 2) ensuring that all participants are working with the same information and some basic level of understanding of that information, and 3) finding a way to involve many stakeholders without having the process become bogged down and agonizingly slow. Respondents mentioned roles for stakeholders in setting objectives for EBM and in crafting management approaches for achieving objectives. A few respondents commented on the value of bringing specific stakeholder groups together, particularly 1) scientists and fishermen and 2) fishermen from different fisheries. The relationship between scientists and fishermen might be enhanced by increased cooperative research, whereas establishing a dialogue between fishermen may enable them to present a unified industry voice related to a wide array of marine issues.

Economic. A few respondents mentioned the need for EBM to include economic objectives and produce local community benefits. They felt that satisfying socio-economic needs should be core goals of EBM, while acknowledging that community benefits would need to be balanced with ecosystem considerations.

Ecosystem services. Only one respondent mentioned protecting an ecosystem service as a goal of EBM. This respondent was interested in EBM as a way to ensure that multiple fisheries were maintained in the ecosystem and that the food and financial benefits derived from these fisheries continued to accrue to local communities.

Management criteria

Science-based. A number of respondents mentioned the importance of science to EBM. A better understanding of the ecosystem—including its components, interactions, response, and resilience—was viewed as critical for EBM, and science was viewed as the avenue for obtaining this improved understanding. Several respondents felt that EBM should be grounded in an understanding of what the ecosystem response will be if human activities are changed. Generally, respondents perceived the present state of science as inadequate for anticipating such responses; several suggested that comprehensive ecosystem models that could be used for decision-making were needed but were not likely to be available soon. Others viewed the scientific base for supporting EBM as ever-evolving, and one respondent cited a need to strategically anticipate interdisciplinary, cross-issue scientific information that will be necessary to inform EBM. Some respondents cited specific research needs, such as determining explanations for year-to-year variations in fish stocks and setting appropriate levels of fishing effort based on ecosystem considerations. One respondent felt that more effort should be put into developing ecosystem indices and acquiring information to set reference points for indicators or indices. One respondent mentioned cooperative research as a way to learn more about the ecosystem.

Monitoring. Many respondents cited monitoring as a necessary source of information to guide EBM. They recognized monitoring as critical for 1) obtaining baseline data about the ecosystem, 2) providing data on human uses of the ecosystem, 3) improving understandings of ecosystem changes and interactions, and 4) tracking the outcomes of management actions. A couple of interviewees also commented on the need for ecosystem indicators tied to management objectives and the importance of monitoring to track these indicators over time. A few respondents mentioned the potentially high cost of improved monitoring, and they commented that new data collection should be structured around agreed-upon information needs and within existing observing or monitoring programs to avoid duplication.

Interdisciplinary. Several respondents mentioned a need for broader, interdisciplinary information to support EBM. Both natural and social science was viewed by participants as important, but integration of information across these disciplinary areas is critical. Social science was identified as important for cost:benefit and risk analyses and as a way for identifying potential local solutions to challenges faced in EBM. One respondent mentioned the need to reach out to other professions and adapt tools that may have been developed in other fields to fisheries and ecosystem management needs.

Boundaries. A number of respondents recognized the importance of focusing EBM on a specific geographic area that is delineated based on ecological, not political, conditions. Many respondents spoke of EBM as a regional endeavor, with the Gulf of Maine as the ecosystem and region of interest. However, several interviewees recognized that boundaries will never be perfect, as the ecosystem is influenced by processes that extend well beyond the Gulf of Maine itself; in other words, the ecosystem encapsulated within any regional boundaries will never be completely closed. One person mentioned the value of using nested ecosystem delineations.

Coordination. Respondents recognized a critical need for new coordination structures relevant to EBM. Several respondents felt that coordination for EBM could best be done through regional councils that work across multiple sectors and activities. Respondents did not envision existing management bodies disappearing in the shift towards EMB; rather, a broader coordinating body, perhaps without any management or decision-making authority, would work to bring existing entities together. One Canadian respondent credited the Oceans Act with giving agencies clearance to talk and cooperate with one another, an important step towards EBM. A few respondents were uncertain about whether regional EBM coordinating bodies would be effective, as they may just add another layer to current activities. One respondent cautioned against focusing coordination only on governmental entities and mentioned the critical importance of coordinating bottom-up involvement from less formalized groups. Finally, one respondent called for support for the substantial time, staff, and funding that can be required for coordination.

Co-management. Many respondents felt that EBM should be implemented through co-management arrangements. Some felt that co-management should focus on engaging managers, scientists, and industry in working together to identify priorities and achieve common goals. Others felt that local community control was important to EBM and that decisions should be made at the most local level possible.

Trade-offs. A mechanism for working through trade-offs that may arise was viewed by several interviewees as a fundamental need for implementing EBM. As EBM seeks to accomplish multiple objectives, it is important to have a transparent way of assessing multiple activities relative to one another in the context of those objectives. Trade-offs need to be made consistently across fisheries and other activities, and community benefits will need to be balanced with ecosystem considerations in evaluating trade-offs.

Adaptive. A few respondents mentioned adaptive management as a component of EBM. They recognized the need to make timely decisions, while remaining flexible and adaptable to conditions and learning lessons from past management efforts.

Precautionary approach. Only a few respondents mentioned the precautionary approach in characterizing EBM, and opinions of its purpose and relevance were mixed among respondents. One respondent felt that the precautionary approach should be generally prioritized in EBM. Another felt that EBM should allow for all uses but that some precaution should be exercised in considering their individual and joint effects on the ecosystem. One respondent commented that the precautionary approach could be too easily invoked and that acting in a precautionary manner makes it hard to move forward with any management action.

Technological. One respondent commented about technology related to EBM. This respondent pointed towards a need to place limits on the technological advancement of fishing gear efficiency to achieve ecosystem goals.

CHARACTERISTICS OF GOOD MANAGEMENT

Information

Scientific information. A large number of interviewees recognized scientific information as the base upon which management directions can be determined and decisions can be made. Science should be one source of reliable information on fish populations, species interactions, habitats, as well as on how the status of the resource changes in response to fishing pressure. Science should guide management goals and the time frame for achieving those goals, and the management structure should effectively pull in data and use it for goal-setting and decision-making. Several interviewees also commented that other information sources (such as stakeholder knowledge) could be used in addition to science and that stakeholders (particularly fishermen) should be involved in the scientific process. One interviewee noted that while scientific information is important for effective management, it does not and should not drive the management process.

Stakeholder input. Many interviewees recognized the importance of stakeholder input to management. They felt that management should be participatory and inclusive, with strong public-participation processes. Many interviewees cited increased knowledge as one major benefit of incorporating stakeholders into management processes. Stakeholders are sources of information that can improve the knowledge base upon which management decisions are formed. Also, by increasing interactions and promoting information-sharing between managers, scientists, and other stakeholders, conflicts caused by differences in scientific and stakeholder observations should ultimately be reduced. In addition, some interviewees discussed benefits of managers developing a good working relationship with the fishing industry and making decisions in consultation with industry. But some also recognized that stakeholder interaction needed to extend beyond just managers and industry, citing benefits of interaction within and between many diverse stakeholder groups. One interviewee cautioned that stakeholders participating in management processes should be interested in the issues and committed to participating in a constructive manner.

Monitoring. Interviewees recognized the importance of monitoring as a way of obtaining good information about a resource, pressures on resources, and human components of the ecosystem. This information is critical for tracking changes in fundamental features of the ecosystem. Some interviewees also cited monitoring as a means of assessing progress towards management objectives, evaluating the effectiveness of regulations, and ensuring compliance with those regulations. Respondents recognized the importance of rigorous, objective monitoring designs and the assurance of quality data.

Local knowledge. Respondents felt that good management should incorporate knowledge held by local citizens and marine resource users. Fishermen and the fishing industry were often cited as important sources of knowledge and potential contributors to ecosystem science.

Broad information. Drawing upon diverse types of information as inputs to management decisions characterized good management to many interviewees. This information could come from the general public, interested stakeholders, or scientists. Social scientists, in addition to natural scientists, should provide information for management. A general desire emerged for information being used as the basis for management decisions to focus on the human components of the ecosystem, not just the natural features of the ecosystem.

Structure

Collaborative. Several respondents felt that collaboration was critical for achieving good management. The management authority may be held by the state or by private actors, but management actions should be developed through collaborative partnerships where constituents are involved in developing solutions to achieve specific management goals. One respondent saw science, management, and industry as pillars of resource management and felt that collaborative relationships were needed across all of these groups. One respondent mentioned that fishermen needed to be collaborators in the scientific process as well as in management arenas, as scientific information typically influences management directions and options.

Bottom-up. Interviewees discussed the importance of bottom-up forces in management structures and processes. Respondents mentioned a need to move beyond top-down management perspectives and to delegate management decisions to the lowest level possible. However, some respondents felt there was a need for greater accountability and effectiveness of bottom-up initiatives. They called for participants to develop plans that meet specific objectives and actually solve problems and consider other stakeholders' needs, instead of advocating for certain outcomes or directions without plans for how these goals would be achieved. One respondent mentioned that the scale of social organization should be matched with ecological scales.

Local management. Several respondents cited local roles as important for good management. Respondents mentioned both community-based management and co-management as desirable management approaches for giving authority to local stakeholders. In fisheries in particular, local involvement can help divide quota allocations and manage those allocations according to local styles and needs. One respondent assumed that this approach would translate into altruistic outcomes such that all vessels would be allocated enough of the quota to survive.

Reasonable number of groups. While recognizing that stakeholder involvement was important for good management, some respondents felt that management can be paralyzed by having too many groups involved in the process. A balance must be achieved such that stakeholder groups have input but that the process is not endlessly open. The management process should ideally be designed to encourage groups to work together.

Top-down. A few respondents mentioned that top-down management was necessary and likely to be part of any management structure. Top-down influence was seen as necessary for ensuring adherence to existing laws and for balancing the interests of multiple stakeholders.

Process

Objectives. Many respondents felt that good management was predicated upon clear goals and objectives, with priorities established across the objectives. A few respondents mentioned that these goals needed to be understandable to the public and industry to achieve buy-in; one respondent suggested that the objectives be specified regionally so that stakeholders have meaningful input and understand the management direction.

Accountability. Accountability was seen as important at multiple levels in good management structures. Defining clear responsibilities for all parties was recognized as an important element of ensuring accountability. One respondent felt that performance measures should be used to hold managers accountable for achieving desired outcomes. Another interviewee suggested that stakeholders need to hold one another accountable for revealing their vested interests in management discussions and decisions.

Consistency/fairness. Respondents recognized the importance of consistency and fairness in a variety of ways. Some mentioned that consistent management approaches and use of tools over fairly extended periods of time were important so that industry could plan how it would satisfy management requirements. Others spoke of the importance of implementing regulations consistently across fisheries, and some suggested approaches that included the use of hard quotas, elimination of by-catch and discards, deducting overages from the following year's quota, and imposing sector-specific cuts to quota shares if certain sectors routinely violate regulations. A few respondents recognized the value of consistency in how data are analyzed and knowledge is developed. Some also mentioned the need to exercise fairness by acknowledging that other factors beyond fishing affect populations of target species.

Funding/resources. Several respondents commented on the importance of providing adequate funding as well as technical and other resources to support the management process. In addition, sufficient funding is needed to implement and monitor management decisions.

Simplicity. Effective management processes are easy to understand, practical, and logical. Common sense should guide the design and implementation of management strategies. Management processes should be as simple as possible, adhere to clear decision-making protocols, and specify well-defined roles for committees and advisors.

Adaptability. It was viewed as important for management processes to be structured so that there was some tolerance or allowance for mistakes but that lessons from those mistakes were learned and utilized.

Enforcement. Enforcement was cited as an essential element of management to ensure monitoring of and adherence to management decisions.

APPENDIX E (continued).

Communication. Communication was recognized as important in management to maintain transparency across activities and entities. Further, it was seen as a means of educating people about marine conditions and activities, with an ultimate goal of reducing enforcement needs.

Flexibility. Respondents cited the importance of flexibility in management; in particular, it is necessary for ensuring that managers can respond to changing conditions or try innovative new approaches. Interviewees felt that management approaches should be able to take on a variety of forms so long as they deal with the real underlying issues and problems. In addition, respondents commented that scientific advice needs to provide managers with some flexibility by exploring the outcomes associated with a variety of management scenarios.

Transparency. Several respondents placed a high priority on making the management process and criteria for allocation decisions clear to all stakeholders. Transparency and open communication across activities and entities was seen as vital to good management.

Trust/respect. Mutual understanding, trust, and respect between stakeholders were recognized as important for effective management; some saw cooperative research as a way to build this trust.

Compromise. Several respondents commented that good management processes create avenues by which participants can come to common ground on difficult choices. One example that was mentioned in several interviews involved the need to balance long-term conservation goals with short-term financial needs of fishermen and fishing communities.

Cooperation. Management should move beyond protecting individual interests and focus on cooperative approaches that benefit many stakeholder groups.

Leadership. A few respondents mentioned that effective management depends on the leadership skills of people in agencies, and strong leadership is often critical to stay the course needed to accomplish management objectives.

Precautionary. A few respondents spoke of the role of the precautionary approach in management and felt that management should avoid pushing the boundaries or working along the thresholds of the system. Others expressed concern that expanded use of the precautionary approach could result in unnecessary restrictions being implemented, with a resulting loss of future options and demise of certain industries.

Outcomes

Integrated management. Several respondents recognized the value of seeing the bigger context within which management is operating. Some mentioned a need to manage across multiple activities and to reverse the tendency to look at issue- and site-specific problems. Others recognized a need to integrate management across space, such that dynamics of and impacts in the ocean, coast, estuaries, rivers, and streams are all considered.

Preserve environment. A number of respondents felt that outcomes that preserve the environment were essential for good management. Such outcomes could seek to promote an environmental ethic, prevent or end overfishing, rebuild fish stocks, protect habitat, and preserve the physical environment so that marine organisms can thrive.

Sustain communities. Several respondents spoke of the importance of sustaining human communities in management outcomes. These respondents felt that ensuring the persistence of fishing communities and the process of handing down the privilege of fishing across generations important social outcomes of good management.

ECOSYSTEM GOALS

Ecosystem state

Multiple uses. Many respondents spoke of a desire to maintain multiple uses of the Gulf of Maine, including recreational and commercial fisheries. One person explained that uses should be compatible with the overall productivity of the ecosystem. Another respondent suggested expanding certain uses to solve existing environmental problems (e.g., using shellfish aquaculture to control eutrophication). One respondent recognized potential trade-offs between goals within a multiple use context.

Sustainability. Comments relating to sustainability included goals of sustainable resource use, sustainable fisheries, sustainable communities, and sustaining ecosystem processes. A few respondents specifically addressed inter-generational equity as a sustainability issue by citing a goal of ensuring that future generations have opportunities to participate in fisheries.

Ecosystem health/integrity. Some respondents directly mentioned a need to maintain ecosystem health or ecological integrity. Others commented on the importance of restoring the ecosystem to pristine or historical conditions. One person specifically mentioned a need to maintain the ecosystem's functional integrity, explaining that management efforts should protect the ecosystem's overall functions, rather than the particular species that create those functions.

Ecosystem components

Populations. Many comments focused on a desire for more abundant native fish and wildlife, forage species, and marine mammals in the Gulf of Maine ecosystem. Several respondents recognized that species beyond those typically considered valuable or charismatic needed attention. One respondent noted that populations in nearshore areas, where species richness and population abundance of some species have declined, may need specific attention.

***Habitat*.** Several interviewees cited ecosystem goals of maintaining and restoring a variety of habitat types, such as estuaries, salt marshes, shorelines, and benthic habitat. Others mentioned the importance of habitat functions, discussing the need to protect spawning areas and nurseries.

Diversity. Comments classified under the goal of diversity included those related to maintaining and/or restoring biodiversity or species richness. Several respondents cited diversity as critical to maintaining the health or stability of the ecosystem.

Water quality. A goal of protecting and improving water quality was stated directly by some respondents. Preventing water quality impacts from upland activities as well as controlling eutrophication through improved aquaculture practices or companion farming of bivalves were mentioned as specific strategies of achieving the water quality goal.

Ecosystem function

Productivity. Respondents expressed goals of maintaining and restoring productivity of the Gulf of Maine ecosystem and felt that this productivity would be reflected in the ecosystem's health and ability to provide services, such as food supplies, for humans.

Balance. Respondents expressed goals related to maintaining a balance between species, within species (e.g., age structure for a species), and within the trophic structure of an ecological community. Several respondents considered striving for "balance" to be more a more practical goal than trying to maintain all species at maximum levels.

Dynamism and resilience. Comments related to dynamism and resilience recognized that the ecosystem is dynamic and that change is a normal and important part of ecosystem functioning, independent of human-induced impacts. One respondent suggested that we should not work to restore populations or communities in the ecosystem based on *a priori* assumptions of what should be there, as the system is dynamic and may not support the same composition and abundance of species in all ecosystem states.

Ecosystem services

Socio-economic quality. Several interviewees expressed a desire to protect and enhance socio-economic quality by maintaining successful local businesses, local resource-based economies, and fishing communities. Some respondents expressed goals of sustaining certain uses of the ecosystem that are closely tied to socio-economic quality, such as being able to go out to catch one's own dinner or having a reasonable chance of catching enough fish to make a living.

Sustainable fisheries. Several interviewees expressed a goal of having sustainable fisheries in the Gulf of Maine. Some respondents recognized the value of protein derived from fisheries to human health, while others characterized sustainable fisheries more broadly to include ecological and socio-economic considerations.

Cultural services. Comments categorized under the goal of sustaining cultural services include those related to the aesthetic value, recreational benefits, and spiritual connections derived from the ecosystem.

Management process

Scientific information. Many respondents commented on goals associated with having improved scientific information to support EBM. Comments focused on needing more science to fundamentally understand the ecosystem, including trophic interactions, community structure, habitat use, and interactions between freshwater and marine portions of the ecosystem. Respondents also commented on 1) new ways of gathering data, such as using industry vessels as research platforms; 2) the need to better organize, manage, and synthesize existing data; and 3) the goals of developing integrated models from basic research. Two respondents expressed concerns about the tendency to pursue a "never-ending cycle of [scientific] studies," suggesting that scientific pursuits needed to be more closely coordinated with management needs.

Human-ecosystem links. In addition to the general recognition of a need for improved scientific information, some respondents cited a goal of developing specific information related to linkages between human actions and ecosystem conditions. One respondent recognized a need to understand what patterns observed in human activities may mean for environmental conditions; conversely, another interviewee identified the need to link ecosystem health to human well-being. Respondents specifically mentioned a need to understand 1) impacts of bycatch, incidental mortality, and discards; 2) impacts on shorelines and rivers; 3) factors other than fishing that may affect fish stocks; and 4) anticipated impacts to marine ecosystems from external factors such as climate change.

Multi-stakeholder. Many respondents recognized the value of multi-stakeholder participation in management and cited goals of ensuring that stakeholder participation is a part of the management process. Many different types of stakeholders need to be engaged in a broad discussion of objectives for the ecosystem. Some respondents felt that the interaction between fishermen, scientists, and regulators had improved in recent years, and that industry is playing a larger role in resource stewardship. Others recognized the need to foster cooperation, even if it means starting with issues that many stakeholders agree on and putting other issues on the back burner until working relationships between different stakeholder groups have improved.

Communication/education. Respondents felt that education and communication were needed for stakeholders to work together more effectively, understand the ecosystem better, and overcome reluctance to change a management paradigm. The fisheries observer program was identified as one way that communication and understanding has improved between different stakeholder groups. One respondent felt that work related to EBM in the Gulf of Maine region should be better profiled and more accessible; one interviewee suggested using big projects (e.g., establishment of liquid natural gas terminals) as opportunities to gain and communicate knowledge about the ecosystem to broad audiences.

Holistic approach. Respondents cited a general need for integrated, holistic approaches to managing natural resources that focus on big picture issues.

Management strategies

Fishery management strategies. Fishery management strategies put forward as ways to achieve ecosystem goals included reducing bycatch, reducing capacity, ending overfishing, managing fishing mortality, placing a moratorium on fishing, supporting fishing techniques that adapt to the behavior of fish, and offering incentives for fishermen to eliminate gears that damage bottom habitats.

Land-based management strategies. Respondents suggested the use of land-based management strategies, such as wise land use and restrictions on nearshore development, as approaches to advance ecosystem goals.

Societal strategies. A few comments focused on societal strategies, such as stopping population growth and reducing resource consumption, as ways of achieving ecosystem goals.

ECOSYSTEM CONCERNS

Ecological

Resilience/irreversibility. Many respondents recognized the enormous potential that ecosystems possess for resilience and recovery. Some felt that the ecosystem may take care of itself, but perhaps not in ways that satisfy human needs and interests. However, many respondents also expressed concern about pushing the ecosystem past its capacity for resilience and inducing irreversible consequences; they recognized that the ecosystem may have thresholds or tipping points, beyond which reversing the effects of certain actions may be impossible. Examples offered by interviewees included concerns that the pressures human place on the ecosystem could make shifts in species abundances difficult to repair, push populations below critical levels for recruitment success, or trigger ecosystem changes that manifest themselves in ways we have never contemplated. Some respondents specifically cited overfishing as a stressor that may destroy unique populations or push the ecosystem to a point that it may not be able to recover. Most respondents identified the cumulative effect of multiple activities as a disparate underlying driver that may lead to a loss of resilience in the ecosystem. One person referred to these cumulative impacts as our potential to "nickel and dime the system to death." Several respondents felt that it may be too late to reconsider our priorities for the ecosystem and avoid irreversible human-induced change.

Dynamism. Several respondents recognized that the ecosystem is dynamic and were concerned about tendencies to expect it to remain static in time or to strive for historical states of the ecosystem. Although most respondents felt that natural environmental dynamics combined with individual human actions set the ecosystem on a trajectory that cannot be expected to be stable or reversible.

Balance. Several respondents were concerned about a disrupted balance of species in the Gulf of Maine ecosystem and felt that there had been a loss of diversity among commercial species, non-commercial species, habitats, and other non-living components of the ecosystem.

Consequences beyond boundaries. One respondent expressed concern about the potential cross-boundary consequences of human activities and about society's general failure to examine these consequences while as part of decision-making processes.

Human

Connections to ecosystem. Some respondents were concerned that humans are becoming more and more disconnected from the environment in which they live. This disconnect may result in an unwillingness or inability of people to understand how their activities and decisions affect the environment. Some respondents felt that particular groups of people contributed to this declining connection, including new residents who do not have strong connections to anyone who depends on marine resources for his/her livelihood, recreational users who may have less direct interests in ecosystem quality, and citizens who move frequently and therefore may not care about long-term consequences of what happens in their back yard.

Economic/social impacts. Some respondents were concerned about the pain that some fishermen are experiencing and were worried about the future of fishermen and fishing communities in the Gulf of Maine. A number of respondents were concerned that the coast was becoming unaffordable to people of many economic circumstances. Respondents cited examples of resource-based industries losing access to working waterfronts and expressed concern that the demise of working waterfronts secondarily causes residents to lose touch with how the natural environment contributes to the local economy. One person expressed fear of a fisheries collapse, not because of stock failures but due to a major decline in processing capacity and infrastructure throughout the Gulf of Maine region.

Process

Cross-jurisdictional coordination. Several respondents cited a need for greater cross-jurisdictional coordination that would enable management of ecosystem problems across multiple sectors of activity. This need for cross-jurisdictional coordination applies across national boundaries, across state/provincial jurisdictions, and among different levels of government.

Inadequate science. A number of respondents were concerned about the ability to use currently available scientific information to guide EBM. Respondents expressed concern that there are many things happening in the ecosystem that are not understood; similarly, scientists do not understand how internal ecosystem dynamics will affect and by affected by human activities within the ecosystem. Some interviewees expressed a need for more management-relevant science, greater understanding of species interactions, improved understanding of physical-biological linkages, clear scientific linkages between single species assessments and ecosystem-based management, and an improved ability to discern healthy vs. unhealthy states of the ecosystem (particularly in the face of global climate change).

Competing uses/multiple uses. Many respondents recognized that there are multiple, sometimes competing, uses of the Gulf of Maine. Interviewees expressed concern about conflicts between different user groups and about the failure of management institutions and decision-making processes to holistically consider all activities occurring within an area.

Stressors

Cumulative impacts. Several respondents expressed concern that the cumulative effect of multiple activities may make the ecosystem break down ways that have not been contemplated. Many respondents felt that this cumulative effect of disparate underlying drivers may lead to a loss of ecosystem resilience and were generally concerned about serial degradation of the ecosystem. In addition to ecological concerns about cumulative impacts, many interviewees expressed concern that management processes tend to treat the ecosystem in a piecemeal manner. Some respondents worried that diverse impacts of specific activities—fishing, aquaculture, and land-based development—were not currently well-evaluated. Others felt that the attention focused on certain impacts—bycatch, incidental mortality, and habitat change—detracted from a need to take a balanced view of how all impacts affect ecosystem management objectives.

Coastal development. Several respondents expressed concern about the development and industrialization of coasts and shorelines, citing water quality implications and socio-economic impacts on traditional user groups. One person mentioned poor planning practices as an underlying cause of many negative impacts associated with coastal development.

Water quality. Many respondents were concerned about declines in water quality and the effects of these declines on the marine ecosystem. Most comments referred to nutrient enrichment caused by increased residential development, and one respondent expressed a need for nutrient standards. Other respondents expressed concern about degradation due to stormwater discharges, oil pollution from runoff, and offshore acidification.

Climate change. Several respondents expressed concern about the potential effects of climate change on the Gulf of Maine ecosystem and on our ability to understand and manage existing activities within the ecosystem.

Resource extraction. Several respondents singled out resource extraction as an important impact in the Gulf of Maine. One respondent was concerned that overfishing may cause stocks to decline to a certain point that populations may not be able to recover. Other respondents were more interested in community implications of resource extraction, citing concerns about how the depletion of one population may affect species interactions as well as the ability to accomplish management goals related to other species.

Pollution. Respondents were concerned about point source pollution as well as non-point nutrient pollution.

Aquaculture. A few respondents expressed concern about the growth of aquaculture, including potential unknown impacts, interactions between fish lost from cages and wild populations, physical disruption caused by cages placed in areas used for other purposes, and degradation of "viewsheds" due to aquaculture pens.

Habitat effects. A few respondents expressed concerns about coastal, wetland, and deepwater habitats. One respondent was particularly concerned about the impact of dragging on bottom habitats.

Invasive species. One respondent was concerned about invasive species and their impacts to the marine ecosystem.