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Source: Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 2010(2010) : 146-158

Published By: American Fisheries Society

URL: https://doi.org/10.1577/C08-040.1

Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 2:146–158, 2010

DOI: 10.1577/C08-040.1

Local-Scale Ecosystem-Based Fisheries in a Gulf of Maine Estuary: Managing for Complexity, Adapting to Uncertainty

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Abstract.—A comprehensive resource management plan for the Taunton Bay estuary, Maine, was developed to support the estuary's capacity to accommodate human uses without degrading ecosystem integrity or resilience. The initial phases of this plan, which has little precedent in the Gulf of Maine, target issues of immediate concern regarding environmental alteration and stock depletion associated with fisheries for four benthic species. Having no dedicated funding, our overall approach to developing ecosystem-based fisheries for this estuary relies heavily on thrift and efficiency, two attributes not usually associated with managing for ecosystem complexity. Despite our gaining a better understanding of this estuary through site-specific research and management activities, the complexity of the ecosystem's components and the unpredictability of its responses to management actions leave much uncertainty. Advancing a nascent, ecosystem-based management effort under such conditions requires the adoption of coping strategies that allow positive shifts in management. Our overall approach emphasizes using alternative knowledge systems to their best advantage, encouraging the participation of and provision of guidance by local resource users, prioritizing key information needs, conducting local research and monitoring, creating opportunities for prompt management corrections, striving for fairness to and stewardship from resource users, and encouraging a long-term commitment to this process.

Coastal and nearshore management strategies that integrate a multisector, ecosystem-based approach are represented by relatively few examples. However, interest in managing resource use with an eye toward attaining systemwide sustainability has increased as the compromised condition of our oceans gains attention (Arkema et al. 1998; Pew Oceans Commission 2003; Rosenberg et al. 2005; Rosenberg 2006; Pauly and Chuenpagdee 2007). In the Gulf of Maine, serial depletions of commercial fish stocks (Cadrin et al. 1999; Rosenberg et al. 2005), dramatic shifts in ecosystem function (McNaught 1999; Jackson et al. 2001), loss of biodiversity (Collie et al. 2000a; Steneck et al. 2002), and pollution (Jones et al. 2001; Driscoll et al. 2003) represent a larger trend of compromised integrity and resilience in worldwide ocean systems. No less important are the challenges these pressures bring to regionwide social, cultural, and economic systems. Especially affected are the Gulf of Maine's commercial fishermen, who have persistently defined this region since the 1600s but today are faced with increasingly limited opportunities to derive a reasonable livelihood from fishing.

Ecosystem-based approaches to resource management take many forms because they must necessarily be shaped according to the unique conditions and challenges associated with distinct systems. McLeod et al. (2005) articulated several essential elements of ecosystem-based management that transcend differences between systems. Most notably, these include setting goals that maintain ecosystems in healthy, productive, and resilient condition so that they can provide the services that humans want and need. They also emphasized how ecosystem-based management strives to simultaneously integrate information relevant to multiple species, sectors, and concerns, ultimately considering the cumulative impacts of different sectors.

Human resource use, which is dependent on the delivery of ecosystem goods and services, is positioned squarely at the heart of ecosystem-based management. Explicit in the definition offered by McLeod et al. (2005) is the importance of maintaining the health and resilience of ecosystems, especially those expected to consistently provide wild products, goods, or services. There is growing evidence that some changes, such as declines in species richness and shifts in community structure that diverge from an historical or native condition, can reduce ecosystems' capacities to ac-

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Received November 12, 2008; accepted January 22, 2010
Published online April 19, 2010

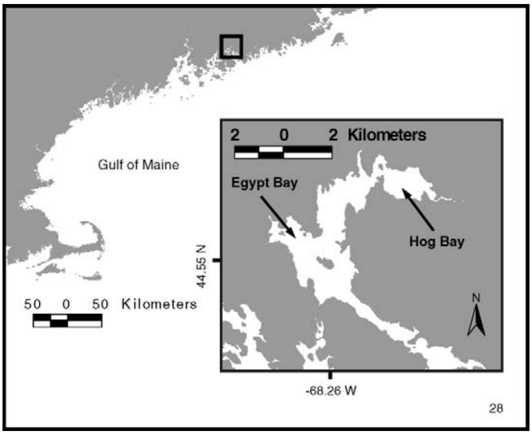

FIGURE 1.—Map of the Taunton Bay estuary and its subembayments.

commodate uses to which they are subject (Duarte 2000). Given the potentially high costs of declining ecosystem health and resilience, which include ecological, economic, and cultural impoverishment, well-informed resource use strategies must consider more than simply the magnitude of resources available for extraction.

In the absence of data describing the distributions, population structure, interactions, and trends of key species and communities, achieving the goal of long-term, sustainable resource use is left largely to chance. Specifically, knowledge of the spatial range and condition of key species, community types, and other ecological features is a basic prerequisite to considering the implications of extractive resource uses or other human activities that can influence the status of commercial resources, natural community structure, and ecosystem function and services. For natural resource agencies, acquiring data supportive of new ecosystem-based management is particularly challenging given the lack of institutional resources to adequately address current mandates.

Numerous studies have investigated the influences that various trawl and dredge fisheries exert on benthic environments (Watling and Norse 1998; Hall 1999, and Collie et al. 2000b). The catalyst for this project was the public concern that increased commercial dragging would threaten the Taunton Bay estuary's ecological health and nontarget biological populations. As a result of public pressure, dragging in the estuary was banned by a 5-year legislated moratorium in 2000. An ecological characterization of the estuary, which included an assessment of its vulnerability to dragging-induced ecological change, was initiated shortly thereafter to determine whether the moratorium should continue beyond its initial term (Moore 2004). Recommendations of the assessment led to development of a management plan intended to put resource uses in the larger context of ecosystem integrity (Sowles 2007). This approach would mark a dramatic departure from existing fisheries management in Maine waters, which did not previously tend to consider the influence of fishing on local-scale stock dynamics, habitat alteration, or natural community shifts resulting from fishery-induced habitat alteration or biomass removal. However, without support from several quarters, the plan would not have moved beyond the concept stage. At the agency level, the plan was supported with staff time and a modest budget. At the legislative level, there was interest in trying a new form of adaptive management, and a special law was passed enabling the flexibility to do so. Finally, at the community level, despite a mix of enthusiasm for the potential for success and the fear of failure and unintended consequences, key members of the surrounding community (including harvesters) committed the time and energy necessary to ensure a credible attempt.

This paper is intended to convey the approach and conditions under which we are attempting to develop and implement a management strategy that puts resource uses in the larger context of the ecosystem's ability to sustainably accommodate those human uses.

Study Area

The Taunton Bay estuary is a 1,400-ha embayment located in midcoastal Maine at the head of Frenchman Bay (Figure 1). The estuary is almost completely surrounded by land and is dominated by intertidal and shallow, subtidal mudflats. A main channel, which provides the deepest waters in the system (average = 8–9 m at low water), extends 13 km north from a tidal constriction that delineates southernmost extent of the estuary under the new management system. The bedrock constriction truncates tidal amplitude in the geographic center of the estuary to about 2 m, which is about 1 m less than the average amplitude experienced in adjacent waters downstream of the constriction. April–October midestuary salinities are polyhaline, often 20–30 g/L. Benthic temperatures on the subtidal flats average −1.8°C January–February and 20.6°C July–August (FTB 2006). Summer temperatures in the shallow intertidal can exceed 30°C (R. Goodwin, unpublished data). August dissolved oxygen measurements in the main channel range from 7.2 to 7.9 mg/L (J. Sowles, unpublished data).

The Taunton Bay estuary and adjacent uplands historically supported a variety of natural resource-based industries such as logging, agriculture, shipbuilding, quarrying, and mining (FTB 1991). Currently, aquaculture and commercial harvesting of marine algae, soft-shelled clams *Mya arenaria*, baitworms *Nereis* spp. and *Glycera dibranchiata*, American lobster *Homarus americanus*, Atlantic rock crab *Cancer irroratus*, juvenile American eels *Anguilla rostrata*, green sea urchins *Strongylocentrotus droebachiensis*, blue mussels *Mytilus edulis*, and alewives *Alosa pseudoharengus* comprise the predominant water-dependent uses. The estuary also supports a unique assemblage of exemplary ecological features, including historically extensive meadows of eelgrass *Zostera marina*, the northernmost documented breeding populations of horseshoe crabs *Limulus polyphemus*, nesting sites of bald eagles *Haliaeetus leucocephalus*, and shorebird and waterbird habitat of statewide management interest.

Developing an Ecosystem-Based Management Approach

The dragging moratorium was scheduled for repeal in July 2008. In anticipation of that repeal, a draft comprehensive resource management plan (CRMP; Sowles 2007) was proposed to not only address concerns over uncontrolled dragging, but to also describe a long-range, more inclusive program designed to integrate goals for supporting ecosystem integrity and the full spectrum of principal resource uses. An important component of the CRMP includes development of measurable ecological and resource use benchmarks. With the imminent expiration of the dragging moratorium, our immediate task was to mount an updated assessment of ecological condition and vulnerabilities to fishery-induced ecosystem change caused by dragging and inform further development of the CRMP.

Taunton Bay supports nine fisheries. We lacked the resources to immediately initiate a new management regime on all of these. Accordingly, our initial work focused on fisheries for several sympatrically occurring subtidal benthic species. Kelp (Laminarioles) and green sea urchin were historically associated with subtidal seabed classes of mixed coarseness, which were primarily found in the swift waters of the lower main channel. In past years, sea scallops *Placopecten magellanicus* were supported in harvestable densities on finer substrates in the northern main channel. Blue mussels are common on the extensive shallow subtidal and intertidal flats and intertidal bars formed by long-term settlement and accumulation. For these species, sustainability of harvest and fishery-induced environmental changes represented the immediate concern because proposals to reopen the estuary to dragging were imminent.

A shift away from the traditional focus on fishery yields toward one that also affords consideration of the ecosystem processes, functions, and services required to support a sustainable fishing industry required a depth of understanding that is uncommon for most areas of the coast. Initial tasking focused on describing local-scale populations and identifying the likelihood for incidental fishery-related impacts to habitats, communities, and ecosystem function. Although fisheries managers are frequently confronted with data scarcity, they must also contend with unpredictable population shifts that occur in the absence of human exploitation and habitat alteration and sometimes respond counterintuitively to management actions. Uncertainty associated with limited data and understanding of how natural systems respond to specific resource use or management activities threatened to bring any stage of this new management process to a standstill. Yet the nature of our mandate, which implied accountability for ecosystem integrity and the health of stocks that depend on it, demanded a novel set of coping skills to accommodate these somewhat unique levels of uncertainty. In the sections that follow we discuss key elements of our planning and management approach, which included methods for mediating the effects of uncertainty that otherwise could have provoked inaction.

Integrating Local Knowledge and Involving Resource Users

Often overlooked by scientists and resource managers is the value and depth of first-hand experience and anecdotal information by resource users such as harvesters, recreationalists, and other community members. Predating development of the CRMP, a collaborative effort between resource users and science staff was conducted over several years to identify and explore management questions of the greatest local relevance. Dozens of public informational meetings related to the dragging moratorium and CRMP were also held to infuse those processes with equitability and local knowledge. This early work had profound strategic implications. It laid the foundation for continuous collaboration that proved necessary to address practical needs such as volunteer staffing over the next 6 years and also facilitated the unique form of comanagement that would follow. Early involvement of local resource users in research planning also facilitated a broader base of support for the project because key stakeholders were invited to participate in decisions on research direction.

Maintaining the continuity of relationships between key project staff and a small but influential group of local resource users was also a defining characteristic of early work in the estuary that has proven its value throughout the entire effort. Integrating the involvement of resource users not only strengthened support for the project, it made it more relevant to local concerns in a way that departs from top–down management. Local resource users also provided the project with traditional knowledge that has proven instrumental in mitigating uncertainty associated with insufficient data. By integrating the multigenerational knowledge of people who work and live in the estuary, we have sometimes been able to bridge data gaps and are afforded the opportunity to measure our short-term data against other lines of evidence.

To further this integrative approach, a long-range goal of promoting stewardship among resource users was identified and acted upon by establishing a volunteer Taunton Bay Advisory Group staffed by representatives of various sectors (e.g., fisheries, shoreside landowners, environmental advocacy, and conservation science). The primary role of the Taunton Bay Advisory Group is to provide guidance and advice to the Maine Department of Marine Resources pertaining to the development of the CRMP. A departure from longstanding management modalities in Maine, the CRMP's principal goal is to guide the activities of resource users in such a way that the ecosystem's capacity to support those uses remains functionally intact. Attention is also devoted to providing meaningful opportunities for input by local resource users and other citizens in the planning of each proposed management shift.

In Maine there is a strong cultural tradition of open access to all state fisheries; access to public resources is also guaranteed to all Maine citizens by statute. However, owing to the small size of the Taunton Bay estuary and historical fishing patterns, the potential for stocks to be overexploited was unequivocal, unless additional, locally relevant controls on harvesting could be implemented. The CRMP honored traditional open-access rights, but the potential for overharvesting was addressed by obligating harvesters to comply with the CRMP's requirements and coordinate among each other in ways that are uncommon along the rest of the Maine coast. For example, whereas monthly catch reporting is the norm in Maine, daily reporting is required by Taunton Bay harvesters to facilitate tracking of landed biomass. For draggers in the estuary, bycatch is also a required reporting item, particularly to identify occurrence of nontarget species in the catch (e.g., horseshoe crabs). Participation of harvesters in stock assessments and coordinated quota allocations are also required, and collaboration in research and monitoring is encouraged. By participating in this way, harvesters from any part of the state were provided commercial access to the estuary. It was hoped that exposure to the program's goals, requirements, and collaborative approach would foster stewardship among all resource users, but it also has had the effect of limiting the number of participating harvesters, which may help maintain manageable levels of fishing pressure. To meet the stewardship goals of the management plan, harvesters interested in any of the four species were required to attend meetings for stock assessment sampling and harvest allocation.

Site-Specific Ecological Data

Research arising from the dragging moratorium focused on documenting aspects of the estuary's rich assemblage of ecological features, fisheries and their vulnerability to stock depletion, and alteration of natural communities. Among the multitude of credible questions that could be raised, we prioritized research and information-gathering based on the impending management decision regarding the resumption of dragging. Specific categories of informational needs and relevant examples of research are described below.

Historical Harvesting Patterns

Harvester reporting of precisely where, when, and how often fishing occurs is nonexistent for most Maine waters. In the Taunton Bay estuary, we used data from interviews with local harvesters and Marine Patrol officers to reconstruct a coarse history of dragging in the estuary over the last 20–30 years, which informed development of the CRMP (Moore 2004). Other than the one documented incident of dragging after the moratorium, sea scallops were probably dragged by less than five vessels for over 20 years and green sea urchins for over 3 years, until stocks of each were sufficiently depleted to warrant displacement of effort elsewhere. Two vessels dragged for blue mussels in the mid-1980s, but product quality was considered relatively inferior and effort also shifted to areas outside of the estuary.

The limited size and short duration of the sea scallop and green sea urchin drag fisheries suggest that the ability of stocks in Taunton Bay to accommodate harvest pressure was relatively low. It should be noted that green sea urchins and sea scallops were also sought by diver–harvesters, and the affects of these activities on stocks would have been additive to that of draggers. Consequently, regardless of harvest method, any overexploitation leading to stock depletions not only limits immediate fishing and economic opportunities, but also has the potential to initiate wide-ranging, long-term shifts in natural communities that can hinder an ecosystem's ability to function and

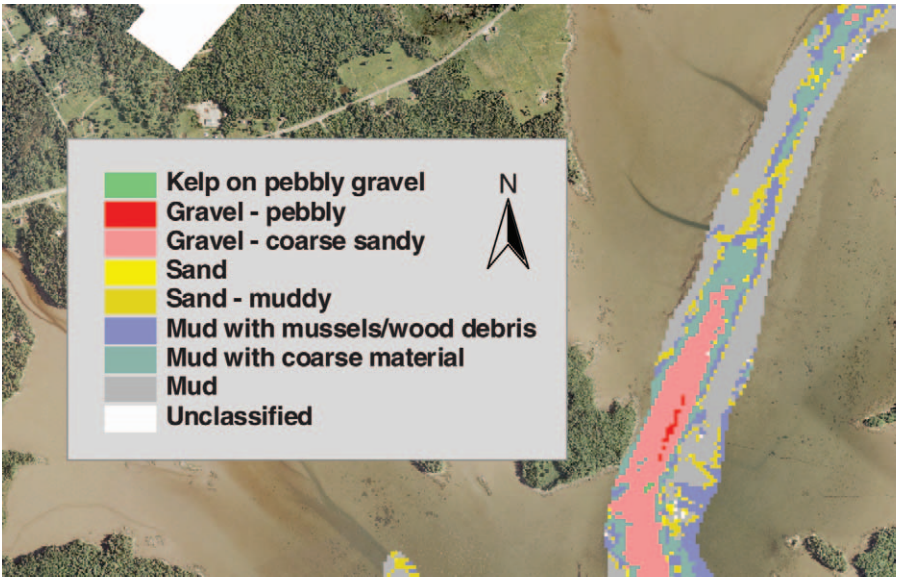

FIGURE 2.—Detail of a seabed map of the upper main channel of the Egypt Bay subembayment of Taunton Bay estuary. The gravel substrates mapped for this section of the main channel historically represented scallop grounds. Adapted from Moore and Barker (2003).

deliver valued services in predictable ways (Steneck et al. 2002).

Benthic Community Type Mapping

Informed management of coastal and marine resources requires knowledge of natural communities and habitats supporting species of interest. Spatial data characterizing benthic communities and substrate classes are often difficult to obtain due to financial, logistic, and technical challenges associated with the specialized equipment and training required. To inform the developing management plan and assess stocks, we used acoustic seabed discrimination data collected in 2001 and 2002 (Moore and Barker 2003) to provide information related to seabed condition. This work resulted in the identification and mapping (analogous to terrestrial cover type and natural community mapping) of eight distinct seabed classes in the Taunton Bay estuary's main channel and subtidal tributaries (Figure 2); the map provided the Taunton Bay Advisory Group with an uncommon coastal management tool. These seabed classes corresponded to benthic community types potentially supporting the four harvestable species under the emerging management plan. Despite adequate mixed–coarse habitat in the northern main channel, no sea scallops were observed during video ground-truthing that was done concurrent with collection of acoustic data. Coarse, gravelly substrates in the lower main channel indicated potentially suitable conditions for green sea urchin recolonization, but dense kelp suggested little evidence that these herbivores were active in substantial numbers.

Assessing Harvest-Induced Ecological Shifts

Renewed interest in a blue mussel drag fishery prompted an attempt to characterize the influence of dragging on shallow subtidal communities where mussels are abundant in the estuary. This research demonstrated dramatic, short-term declines (possibly lasting on the order of months) in benthic species richness and abundance in response to a one-time dragging event (Moore and Atherton 2005). Monitoring demonstrated that shallow benthic communities in the estuary can also exhibit swift turnover in species assemblages, even in the absence of dragging. During experimental dragging, benthic data loggers indicated what was clear to the eye: that resuspension of fine sediments during dragging caused dense turbidity plumes capable of limiting light transmission to the benthos. In the presence of tidal currents, plumes migrated offsite shortly after dragging, but the fate of transported sediments and their contribution to system-wide turbidity was not evaluated.

Vulnerabilities of Principal Communities and Species

Identifying ecologically influential natural communities and species that have disproportionately high influence on ecosystem function and services is crucial

TABLE 1.—Shifts in the eelgrass area of the Taunton Bay estuary between 1996 and 2002. Most losses in eelgrass coverage and density occurred in 1999–2000, the declines continuing throughout much of 2001–2010 (S. Barker and S. Moore, Maine Department of Marine Resources, unpublished data).

	1996		2002		
Areal cover class[a]	Area covered (ha)	Percent of estuary	Area covered (ha)	Percent of estuary	Percent change, 1996–2002
1	189	14	35	3	−81
2	235	17	54	4	−77
3	76	5	30	2	−60
4	18	1	21	2	17
1–4	518	37	141	10	−78

[a] Areal cover classes are as follows: 1(<10%); 2(10–40); 3 (41–70); 4 (71–100).

to implementing ecosystem-based management approaches such as those represented by the emerging CRMP. Among other functions, eelgrass supports highly diverse vertebrate and invertebrate communities compared with substrates lacking complex, three-dimensional structure (reviewed in Thayer et al. 1984). By comparing the metrics of fish communities within and outside of eelgrass beds, we found that eelgrass in Taunton Bay provides important fish habitat (Moore 2004). Widespread losses of eelgrass in the estuary occurred during 1999–2000 (S. Barker and S. Moore, Maine Department of Marine Resources, unpublished data) and continued at a reduced rate throughout much of the subsequent decade (Table 1). These losses signaled the onset of large-scale environmental change, as evidenced by sharp declines in fish species richness and abundance observed contemporaneously with deteriorating eelgrass densities in fish sampling plots (Figure 3). The species that were probably experiencing marked declines due to eelgrass reductions (density and area; Table 1) included fourspine stickleback *Apeltes quadracus*, ninespine stickleback *Pungitius pungitius*, threespine stickleback *Gasterosteus aculeatus*, northern pipefish *Syngnathus fuscus*, grubby *Myoxocephalus aenaeus*, and lumpfish *Cyclopterus lumpus*; decreases were not noted in fish species not closely associated with eelgrass (winter flounder *Pseudopleuronectes americanus* and white hake *Urophycis tenuis*). The ecosystemwide influences of lost eelgrass and associated invertebrate–vertebrate community biomass in the estuary are poorly understood, but the magnitude of these changes suggests that shifts in nutrient cycling and energy flow may have been considerable.

Effects of the eelgrass declines on sediment stabilization and other water quality functions formerly provided by the extensive meadows are also uncertain and represent a concern. Frequent turbid conditions (and possibly other factors) in the estuary may be limiting sunlight penetration and, consequently, the

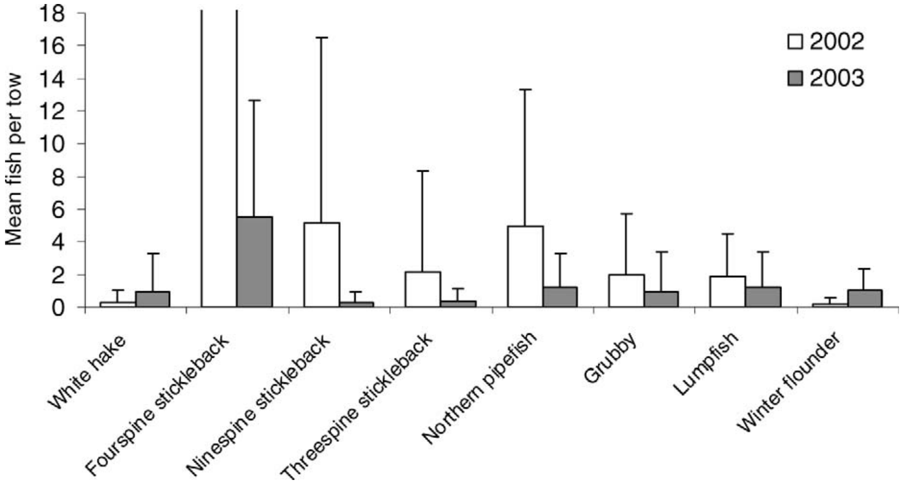

FIGURE 3.—Mean + SD catch rates of the fish species observed in eelgrass during trawl surveys in Taunton Bay estuary, June–November 2002–2003. The catch rate of fourspine sticklebacks in 2002 was 56 (SD = 100).

depth at which eelgrass beds can establish and persist. Increased turbidity caused by unstable bottom sediments and activities that cause dense siltation plumes can also hinder the productivity of species common to eelgrass communities (Blaber and Blaber 1980; Cyrus and Blaber 1987a, 1987b; Engstrom-Ost and Candolin 2007; Webster et al. 2007), although the scientific literature does not offer a consistent assessment of that risk. Aside from the unidentified causes of eelgrass loss in the estuary, activities with the potential for widespread, high-intensity bottom disturbance appear to represent the greatest threat to eelgrass communities and associated ecosystem functions. Neckles et al. (2005) estimated that dragging-induced damage to eelgrass beds could require at least 5–6 years to 20 years or more to fully recover.

Vulnerability of Horseshoe Crabs

Horseshoe crabs in Maine waters exist in relatively small populations and habitats of marginal quality compared with those found in more southern portions of their range. At their northernmost range extent and a genetic profile indicating potentially isolation (King et al. 2005), horseshoe crabs in the Taunton Bay estuary have for some time been thought to represent an ecological element warranting management attention. A panel of nine professional scientists in Maine listed the horseshoe crab as a high-priority species for monitoring in Taunton Bay (FTB 2006), and the Atlantic States Marine Fishery Commission (ASMFC dateless) has defined intertidal flats and spawning beaches as Habitat Areas of Particular Concern for horseshoe crabs, although their primary interest is apparently in large populations commonly occurring south of Maine.

We used site-specific data for horseshoe crab seasonal movements and resource use in the estuary to inform the CRMP. The movements of adult horseshoe crabs in the Taunton Bay estuary were tracked using sonic telemetry from June 2003 to June 2005 to determine potential sympatry with drag fisheries (Moore and Perrin 2007). This research demonstrated that horseshoe crabs occurred primarily in two populations confined to subembayments less than 4 km apart. The breeding season mean total home range size for individuals (60 ha) declined by 90% as horseshoe crabs entered a wintering phase of inactivity lasting 7 months or more each year (Moore and Perrin 2007). The apparent isolation of these horseshoe crabs, together with their lack of recruitment sources and occurrence at the species' northern limit may indicate a vulnerability to local extirpation by chance events or deterministic processes that exceeds the vulnerabilities of larger, more vagile populations (Botton and Ropes 1987; Pierce et al. 2000; Dulvy et al. 2003; Hutchings and Reynolds 2004; King et al. 2005). In particular, the 7-month or longer wintering period of inactivity suggested potential vulnerability to interactions with dragging gear during that time of the year.

Site-Specific Fishery Data

Like most other areas with fisheries, Maine lacks data describing fishery stocks at fine spatial scales. Rather, stocks are managed in larger management areas encompassing hundreds or thousands of square miles. For example, Maine's urchin and scallop fisheries are managed by dividing the state's coastline (5,600 km long) into two large zones. Lobsters, Maine's most valuable fishery, are managed as one statistical stock from Cape Cod, Massachusetts, to the Canadian border, and this area is subdivided into seven nearshore coastal fishing zones to control effort. In Taunton Bay, we used harvesters' knowledge of species' current distributions, historical harvesting patterns, substrate mapping, and aerial imagery to infer where each species was most likely to be harvested. One set of aerial photographs was provided for each of the four target resources, which harvesters used to delineate with marking pens the boundaries of their intended fishing grounds. The annotated photos defined the sampling blocks that we used to estimate a total allowable catch (TAC) for each resource. Knowing the potential to under-report productive fishing grounds, we reminded harvesters that to do so would risk underestimating stocks and potentially reduce the TAC.

The preferred commercial harvest method for blue mussels in the Taunton Bay estuary is dragging on subtidal flats, an activity that we considered to be consistent with the management goals of protecting sensitive nontarget community types (e.g., eelgrass), habitats (e.g., for horseshoe crabs), and overall system integrity as long as it was sufficiently restricted by tailored management measures. We used two criteria to select areas for stock assessment from among the areas identified by fishermen: (1) the areas supported good-quality blue mussels and (2) to the greatest extent possible, they lacked eelgrass, horseshoe crab habitat, and other sympatrically occurring ecological elements of concern.

Sea scallops and green sea urchins are dragged and diver harvested. Assessment of these two species were confined to areas of the main channel, where harvesters reported adequate densities. Assessments provided volume or biomass estimates for legally harvestable product, depending on conventions unique to each fishery, such as bushels for blue mussels and trays for green sea urchins. Size-class data were also collected to afford some indication of population structure and recruitment.

Kelp, which is limited to the estuary's main channel, is primarily hand-harvested in Maine. Kelp harvesters used aerial photography to delineate kelp bed boundaries and quadrat sampling to quantify average wet biomass (kg/m^2) for assessments in the estuary. Because green sea urchins occur sympatrically with kelp and kelp holdfasts can be damaged during commercial dragging of sea urchins, kelp beds were classified as a vulnerable resource where dragging was prohibited.

Although conducted at a fine scale rarely matched anywhere else in the Gulf of Maine, the accuracy of our fishery-independent assessments were nevertheless limited by a lack of replication, among other factors. For instance, timing of the assessments was driven more by a need to meet a legislative deadline than by life history or biological characteristics of the target resources. As a result, our sampling may have missed much of the available green sea urchin population, which is thought to migrate seasonally between shallow and deep waters. Similarly, seed-stage (early juvenile) blue mussel sets had not yet established by the time we had sampled, making assessments for that portion of the resource also suspect. Despite a somewhat awkward start, we expect that over time, fishery dependent data, local knowledge of harvesters, and more rigorous fishery-independent assessments will improve our initial assessments.

Integrating Ecological Knowledge with Fisheries Data

Using the research findings described above, we integrated our emerging understanding of ecosystem vulnerability with fishery impacts into a management strategy for the first stage of the overall CRMP. Because of the habitat-altering potential of dragging, the potential for overharvesting, and Taunton Bay's relatively small size, only intensely managed small-scale fisheries were regarded as likely to be compatible with the overall goals of the CRMP (i.e., supporting ecosystem integrity). In this context, intense management included developing and implementing guidelines that recognize the potential for harvest-induced ecological shifts and overexploitation. With specific regard to dragging and other activities exerting potential large-scale benthic disturbance, these efforts led to the development of spatial and temporal management alternatives that considered, among other factors, where and when harvesting is least likely to represent a potentially destabilizing or otherwise unreasonable impact on local ecology. For all of the fisheries, harvest limitations were encouraged to promote sustainable harvests and avoid the destabilizing effect that depletions can have on ecosystems.

The final step in this stage of the CRMP was to present a range of management options to the Taunton Bay Advisory Group that would be consistent with the goals of the CRMP. The spatial distributions of sensitive ecological elements were provided via geographical information systems (GIS) to demonstrate how they overlap with potential resource use areas (Figure 4; Moore 2008). Included were horseshoe crab home ranges, eelgrass mapping from 2005, and eelgrass updates based on aircraft and diver scouting in 2008. A variety of other previously mapped elements having potential overlap with drag harvest areas were included, such as shorebird staging areas of statewide management importance, seal pupping areas, and traditional worm and clam hand-harvest areas. Along with this mapping, knowledge of local ecology and harvesting patterns were used to develop management alternatives related to the locations and timing of dragging or other activities having potential for similar levels of benthic disturbance. The alternatives were presented to the Taunton Bay Advisory Group at a public meeting along with analyses of fishery implications related to each alternative. After considering comments made during the public meetings, the Taunton Bay Advisory Group and Maine Department of Marine Resources evaluated the alternatives for adoption as part of the CRMP.

Harvest Options in Shallow-Water Communities

Two management alternatives for shallow subtidal and intertidal communities were developed to address conservation goals and the needs of blue mussel harvesters. Protracted eelgrass recovery and the vulnerability of eelgrass to damage caused by dragging were considered ample justification for developing management restrictions that prevented dragging in eelgrass until recovery goals for areal extent (ha) and density were identified and reached. As a result, each management alternative featured restrictions on dragging in eelgrass. To facilitate avoidance of mussel dragging in adjacent eelgrass, designated blue mussel harvest areas were marked with buoys. With eelgrass concerns adequately addressed, the two management alternatives were developed to address potential overlap between mussel dragging and horseshoe crab resource use.

Alternative A designated areas for dragging that avoided the two horseshoe crab primary home ranges, a precautionary approach that sought to preserve benthic condition in intertidal and subtidal areas currently

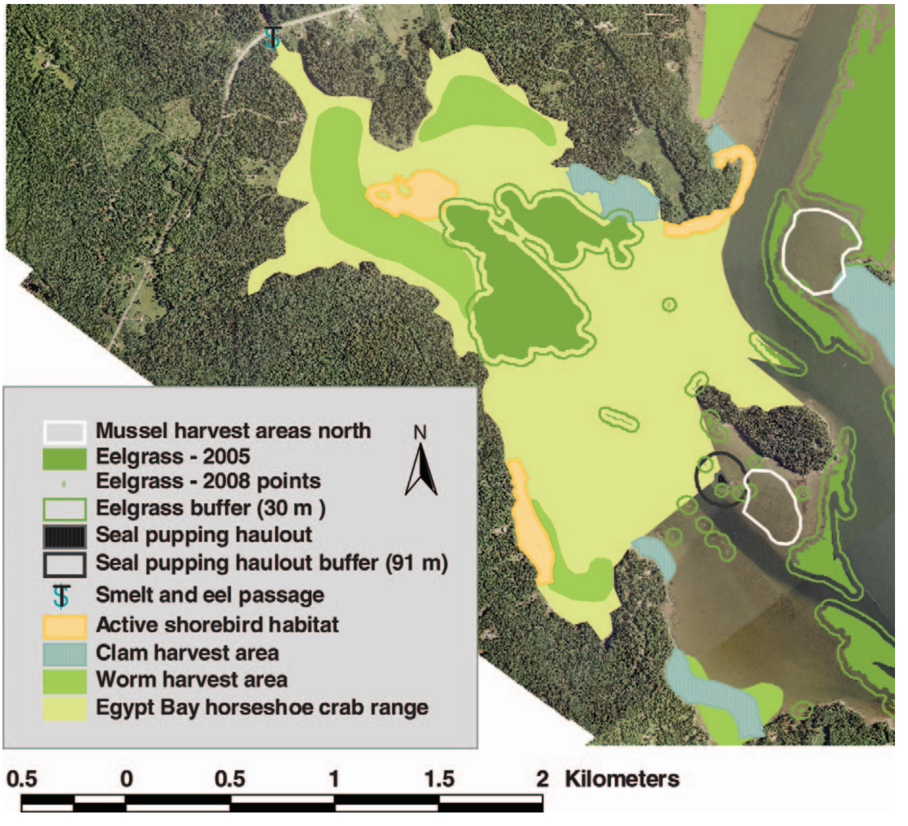

FIGURE 4.—Ecological elements of management interest in and near the Egypt Bay subembayment. Eelgrass points represent patches of recolonizing shoots observed during scouting. Harvestable blue mussels occur throughout the estuary, but drag-harvesting areas were selected to avoid obvious conflicts with other key elements. For management purposes, the Egypt Bay horseshoe crab home range partially overlaps the actual southern extent of observed horseshoe crab movements to provide an easily recognizable line of sight from points within the estuary. Adapted from data provided by the Maine Department of Marine Resources, the Maine Department of Inland Fisheries and Wildlife, Friends of Taunton Bay (2006), Moore and Perrin (2007), and Moore (2008).

supporting core populations of this species. Under this alternative, interactions between horseshoe crabs and drag gear, which we had little experience with, would also be limited. Intertidal areas throughout the entire estuary were designated as no-drag zones, which facilitated protection of early life stage and spawning horseshoe crabs that exist outside of the two primary home ranges. This provision also had the benefit of preventing intense and widespread benthic disturbance in intertidal areas that support migrant shorebirds and clam and worm hand-harvesting.

Alternative B provided more flexibility for harvesters by seeking less than a total ban on dragging in primary horseshoe crab home ranges. Dragging would be allowed in rotating subtidal plots that could occur anywhere in the estuary, including horseshoe crab primary home ranges. Key features of this alternative included mandated recovery periods for plots, a maximum cap on the total area (ha) disturbed by dragging, and seasonal constraints that would prohibit dragging in plots located in horseshoe crab home ranges during the horseshoe crab wintering phase (i.e., when they may be more vulnerable to drag-induced displacement, injury, or mortality).

Although alternative B would have provided fishermen more flexibility by allowing limited dragging within horseshoe crab primary home ranges, it brought with it much higher complexity and management costs. Consequently, Alternative A was chosen for its simplicity and because it would require less oversight, both of which were considered favorable attributes in this initial year of the plan's implementation. The final plan for blue mussel dragging in 2008 led to designation of three shallow subtidal areas that largely avoided eelgrass, horseshoe home ranges, intertidal flats, kelp beds, and other ecological elements of conservation interest (Figure 4, the Egypt Bay subembayment example).

Harvest Options in Main-Channel Communities

Fisheries for sea scallops and green sea urchins were deemed unlikely to degrade the condition of most elements of conservation interest. However, as a measure to hedge against uncertainty (Stefansson and Rosenberg 2005) associated with potentially excessive alteration of benthic communities, options for establishing reserve areas in the main channel were discussed. In particular, areas representative of prime sea scallop–kelp and green sea urchin–kelp grounds were thought to have conservation value. However, questions of reserve area size (ha), dynamics (fixed, rotating, or both), and intended objectives (to protect habitat, recruitment, seed source, or other functions) were not addressed sufficiently, and the concept was tabled for further consideration. Another main-channel area offered as potentially benefiting from reserve status is located in and near the upper estuary's Hog Bay subembayment, where epibenthic communities create areas of uncommonly diverse three-dimensional structure. However, that area is presently free of intense, widespread bottom disturbance owing to the present management guideline that requires avoidance of dragging and other large-scale benthic disturbance in core horseshoe crab habitats. The only spatial restrictions on dragging in the main channel were those that designate drag and diver harvesting areas for green sea urchin, which are located immediately south of traditional fishing grounds for the species, in an area that was not depleted by past fishing activities.

Harvest Limitations

Results of stock assessment data from the designated harvest areas led to the development of TACs for the four target resources, albeit TACs are not viewed favorably by Maine's fishing industry. To our knowledge, TACs have never been accepted as a fishery management tool in Maine waters. Instead, length limits and control on effort, gear, and season are locally preferred management tools. Some project participants expressed concern that TACs would become targets for harvesters, resulting in more biomass being removed than would otherwise be the case. However, it was generally agreed that given the small size of Taunton Bay and through adequate coordination and compliance among harvesters and use of reliable assessment data, TACs represented the most potentially effective option for equitably setting constraints on biomass removal.

Blue mussels were designated for harvesting in three distinct areas that represent only a small fraction of the total amount of mussel resources in the estuary. A blue mussel TAC was set at 80% (66,000 bushels) of the volume of legal (5-cm minimum shell length) individuals available within the three designated areas. Although 80% may appear to be a fairly liberal harvest rate, sublegal mussels represented approximately half the biomass per square meter and predominate numerically. Sublegal-size individuals are culled on site and returned to the harvest plots to continue growing. Harvest areas for green sea urchins and kelp encompassed nearly the entire area in which they are found within the estuary. Consequently, a smaller fraction of the assessed resource was recommended as the TAC for these species. For green sea urchins, the TAC of 240 trays represented 40% of harvestable individuals. For kelp, the TAC was set at 16% of the total biomass (11,800 kg), a rate that is consistent with sustainable harvest practices developed in Maine (Maine Seaweed Council 2009). Only about 90 kg of sea scallops were estimated for the entire area that represented potential scallop grounds. Low sea scallop abundance could have justified a closure of that fishery, but a decision was made to consult with the harvesters in an attempt to collaboratively arrive at a decision, especially at this early stage of the process when securing support and trust of harvesters is paramount to the long-range success of the CRMP. In the end, no scallops were harvested in 2009 due to a lack of harvester interest.

Monitoring and Adaptive Management

Where uncertainty regarding the predicted responses of the ecosystem to fishery activities was abundant, we often relied on a precautionary management approach. However, precaution was also a factor in other considerations. We were particularly sensitive to the complexity of management prescriptions selected. Whereas some management options might have allowed more flexibility for harvesters, in this first year we tended to select those that would be easiest to understand, implement and enforce and that might promote acceptance, if not gain support. Some components of the plan may rightly be perceived in hindsight as overly conservative. However, when viewed in the context of our unique responsibility to manage at this level of detail, our present understanding seems adequate only to allow deliberately measured, secure, and positive steps.

As knowledge of fisheries-ecosystem interactions in Taunton Bay estuary and our experience managing at this scale and intensity evolves, the management plan is expected to be refined in ways that reflect this progress. There are several elements to this effort that are required to facilitate adaptation to shifting environmental and fishery conditions and to an increased understanding of ecosystem processes. Fishery-related information will be enhanced as drag harvests proceed and we learn more about bycatch (through bycatch reporting) and turbidity duration and extent (through deployment of continuous water quality monitoring equipment). Areas subject to dragging will also shift in response to eelgrass recovery. Assessment methods, including season and areas, will be refined based on input from harvesters and actual harvest reports. Development and tracking of harvest-rate indices will also add to the data flow and aid our attempts to respond promptly to changing conditions.

Monitoring ecosystem elements will also be integral to comparing current conditions with established benchmarks for system health, which will thereby facilitate identifying needs for intervention. A steady flow of data describing water quality, eelgrass distributional dynamics, horseshoe crab spawning, shorebird use, and other variables and indicators of system health will be necessary to effectively track change in the estuary (FTB 2006).

A particularly unique feature of our efforts was the legislative designation of the estuary as a state resource management area. Where available evidence supports the need for prompt, substantive changes in management, this designation allows timely adjustments without legislative rulemaking, often a lengthy process without assurances of an intended outcome. Because the CRMP will be updated each year, this legislative mechanism is anticipated to feature prominently in efforts to implement adaptive management.

Conclusions

Ecosystem-based fishery management in the Taunton Bay estuary represents an initial step toward the development of a larger CRMP. Ultimately, the goal of this plan is to addresses the range of principal resource uses in the larger context of supporting ecosystem integrity and resilience. In doing so, we are challenged to manage at a level of detail and integration that has little precedent in the Gulf of Maine. Despite our ability to apply site-specific data addressing a variety of ecosystem attributes and processes, much uncertainty remains regarding system responses to management actions and resource use. Our overall approach tends to mitigate that uncertainty. It includes the following attributes:

1. Engaging resource users as early as possible in planning that is relevant to their livelihoods, interests, and concerns and affords them a voice in local management decisions;
2. Acknowledging the complementary merits of scientific data and traditional knowledge and using each to its best advantage;
3. Acquiring site-specific ecological data that address ecosystem function, services, and biodiversity in addition to fishery stocks and resource use patterns;
4. Managing at scales (geographic and temporal) that support local ecosystem processes, function, services, and biodiversity;
5. Developing and implementing research and monitoring priorities that will directly inform management and assessing the attainment of benchmarks;
6. Using an adaptive management approach that can promptly respond to emerging environmental and resource use shifts as well as increased knowledge; and
7. Supporting long-term, positive, incremental change that will at some point achieve our goals without irrevocable detrimental impacts.

Acknowledgments

Many people generously provided data, interpretations, and perceptions of various management alternatives that are described in this paper. They include Seth Barker, Rob Eaton, Sherm Hoyt, Maggie Hunter, Don Katnik, Amy Meehan, Steve Perrin, Andy Rosenberg, Fred Short, Lindsay Tudor, Steve Walker, and the Taunton Bay Advisory Group. Maine Sea Grant, the Maine Coastal Program, and the Maine Outdoor Heritage Fund funded various phases of this project.

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