Subtidal Benthic Fisheries in the Taunton Bay Estuary:

Ecosystem Constraints and Management Options

June 2008

Subtidal Benthic Fisheries in the Taunton Bay Estuary: Ecosystem Constraints and Management Options

Prepared by:

Slade Moore

Biological Conservation LLC
979 River Road
Bowdoinham, Maine 04008

207.737.5700
smoore@bioconserve.net
www.bioconserve.net

On behalf of:

The Maine Department of Marine Resources

and

The Taunton Bay Advisory Group

TABLE OF CONTENTS

EXECUTIVE SUMMARY

There is little precedent in the northeastern U.S. for coastal and nearshore management strategies that address resource-use from a multi-sector, integrative, ecosystem perspective. However, as traditional management systems come under increasing scrutiny, approaches that support ecosystem health *and* long-term delivery of goods and services are gaining interest. Like other areas in the Gulf of Maine, several of the Taunton Bay Estuary's fishery stocks were subject to overexploitation and in some cases, eventual depletion. Aside from commercial resources, Taunton Bay also supports a unique assemblage of ecological elements warranting management interest, some of which are sensitive to resource uses that are common along the coast. Given its history, unique ecology, and desire on the part of harvesters to resume and/or initiate new fisheries, Taunton Bay's capacity to accommodate new and old uses will require development of an innovative management approach. This report reflects the most current phase of an effort to refine and implement a Comprehensive Resource Management Plan for Taunton Bay. The plan's principal goal is to guide the activities of resource users in such a way that the ecosystem's capacity to support those uses, and remain intact, is not compromised. Though concerned with the entire ecosystem, this approach will not attempt to manage the full complexity of all ecosystem interactions. Rather, it puts resource-use in the context of preserving and supporting relevant ecosystem functions and processes that influence, or can be influenced by those uses. To manage in this way requires not only the support of local citizens, but also a fairly comprehensive understanding of local ecology that integrates scientifically obtained data with the traditional knowledge of resource-users. Where knowledge is lacking, uncertainty is addressed by developing management guidelines that are most likely to uphold the goals of the Comprehensive Resource Management Plan. The adaptive nature of this process also speaks to uncertainty by affording ample opportunities to promptly adjust management direction when needed.

This report attempts to draw together what we know of Taunton Bay's sensitive ecological elements, interpret the data, and provide management recommendations as they relate to four fisheries in the bay: kelp, urchins, scallops, and mussels. The recommendations in this report address the potential for profound, unintended ecosystem-wide changes that can occur as a result of fishery activities, even in the absence of overharvesting. Dragging for mussels, urchins, and scallops, and other activities that have demonstrated the potential for causing intense, widespread disturbance to benthic communities are a major concern. Among other recommendations, this report offers alternatives that would manage the spatial and temporal scale of these disturbances in a way that is unlikely to grossly exceed natural levels of disturbance. If successful, benefits to the fisheries will include long-term sustainability and partnership in the management process. Ecosystem health and integrity, a prerequisite to furnishing the goods and services traditionally relied upon by shoreside communities, will also benefit.

ACKNOWLEDGEMENTS

The following individuals generously provided data, interpretations, and/or perceptions of various management alternatives that were instrumental to the preparation of this report: Seth Barker, Stew Fefer, Bob Houston, Don Katnik, Amy Meehan, Steve Perrin, Fred Short, John Sowles, Lindsay Tudor, Steve Walker, and the Taunton Bay Advisory Group.

1. INTRODUCTION

BACKGROUND AND INTENT

Coastal and nearshore management strategies that address resource-use from a multi-sector, ecosystem perspective are represented by relatively few examples. Yet, interest in managing resource-use with an eye toward system-wide sustainability has increased as the compromised condition of our oceans gains attention (Arkema et al. 1998, Pew Oceans Commission 2003, Rosenberg 2006, Pauly and Chuenpagdee 2007). In the Gulf of Maine, serial depletions and collapse of commercial fish stocks (Cadrin et al. 1999, Rosenberg et al. 2005), dramatic shifts in community structure (McNaught 1999, Jackson et all 2001), loss of biodiversity (Collie et al. 2000, Steneck et al. 2002), and pollution (Larson et al. 1986, Driscoll et al. 2003) are particularly concerning as they may represent a larger trend of compromised integrity and resilience in our coastal systems. No less important are the challenges these pressures bring to the commercial fishing culture that has persistently defined this region since the 1600s, but is today faced with increasingly limited opportunities to derive a reasonable livelihood, despite a growing list of marketable species.

This report represents the latest phase of a larger effort to refine and expand the initial Comprehensive Resource Management Plan (CRMP) (Sowles 2007) developed for the Taunton Bay Estuary. This plan emerged as a result of previous work documenting, among other areas of investigation, Taunton Bay's rich assemblage of ecological features, history of fisheries, and vulnerability to stock depletion and habitat alteration (Moore 2004, FTB 2006). A departure from longstanding management modalities, 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, and remain intact, is not compromised. To achieve this, a shift away from the more common "top-down", centralized resource management approach was necessary. In particular, critical attention was devoted to refining several key aspects of the existing resource management system, such as those that allowed few meaningful opportunities for the input of local resource users and other citizens during planning. Also addressed was the deeply rooted focus on fishery yields that in many cases excluded consideration of the ecosystem processes, functions, and services required to support a sustainable fishing industry. Convening the Taunton Bay Advisory Group (TBAG) was a demonstration of commitment by state government to evaluate multi-sector, ecosystem-based management approaches that would address and correct shortcomings of the previous system. The TBAG, which represents a variety of local and statewide perspectives, was established specifically to provide recommendations that will guide Taunton Bay's CRMP from revision to implementation. Some features of this process that distinguish it from the prevailing, statewide management system include:

- managing at scales (geographic and time) most relevant to the ecological characteristics and conditions of target species, natural communities, user groups and their interactions
- engaging resource users in developing aspects of the plan that are most relevant to their livelihoods, interests, and concerns

- recognizing the complimentary merits of scientific data and traditional knowledge (obtained by non-scientists) and using each to their best advantage
- developing research/monitoring priorities that incorporate the needs and concerns of local communities as well as regional considerations
- using an adaptive management approach that can promptly respond to emerging environmental/resource-use shifts and increased knowledge
- considering the local, system-wide, and regional ecological implications of resource-use within Taunton Bay

The current project phase is intended to provide a synthesis of ecological data for Taunton Bay that will inform the development of subtidal benthic fishery management guidelines. Commercial harvesters in Taunton Bay have an interest in targeting kelp (Laminarioles), blue mussels (*mytilus edulis*), green sea urchins (*Stronglyocentrotus droebachiensis*), possibly sea scallop (*Placopecten magellanicus*), and lobster (*Homarus americanus*). Lobster and kelp are examples of subtidal species that have a history of sustainable harvest in the estuary. Relatively small fisheries in Taunton Bay commercially depleted urchins and scallops in the late-1990s (Moore 2004). Mussels in the estuary have traditionally received little attention for the limited amount of marketable product available. More recently, fixed gear conflicts and water quality issues elsewhere have led to increasing interest in Taunton Bay's mussels (Moore 2004). Concentrating on these fisheries is an immediate priority for the TBAG for two primary reasons. First, the limited amount of resources and history of overexploitation in the estuary demonstrate that Taunton Bay's capacity to support even small fisheries was exceeded under the previous management system. Even in the absence of incidental fishery-associated habitat alteration, overharvests that lead to depletions can do far more than temporarily limit fishing/economic opportunities; they have been demonstrated to initiate wide-ranging, long-tem shifts in natural communities that hinder an ecosystem's ability to function in a predictable way and deliver services (Steneck et al. 2002). Second, among other methods of harvest, some of these fisheries anticipate using drags, which have been prohibited in the estuary since passage of a 2000 moratorium. Due to its habitat-altering potential and Taunton Bay's small size, only intensely managed, small scale dragging is likely to be compatible with the overall goals of the CRMP (Moore 2004). "Intense management" includes developing and implementing management guidelines that consider the incidental ecological effects of dragging and other similar activities. The current project phase identifies spatial and temporal management alternatives that consider, among other factors, where and when harvesting is least likely to represent a potentially destabilizing or unreasonable impact on local ecology. Management guidelines that identify harvest limits for the fisheries (i.e. the amount of biomass that can be sustainably removed) will be developed under a separate effort.

ECOSYSTEM-BASED MANAGEMENT

Ecosystem-based resource management takes many forms, as it must necessarily be shaped according to the unique issues and objectives associated with distinct systems. McLeod and colleagues (2005) defined the concept of marine ecosystem-based management as follows:

"*Ecosystem-based management is an integrated approach to management that considers the entire ecosystem, including humans. The goal of ecosystem-based management is to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the services that humans want and need. Ecosystem-based management differs from current approaches that usually focus on a single species, sector, activity or concern; it considers the cumulative impacts of different sectors.*"

Human resource-use, which is ultimately dependent on the delivery of ecosystem services, is positioned squarely at the heart of ecosystem-based management. Explicit in the definition above is the importance of maintaining the health and resilience of ecosystems, especially those expected to consistently provide "wild" products, goods, or services. Ecosystems are dynamic complexes of interacting biological and non-living components, which means they change, even in the absence of human activity or resource-use. Change can be intense, slight, fast, slow, widespread, localized, or anywhere between these extremes. There is growing evidence that some changes, such as declines in species richness and shifts in community structure away from a "native" condition result in systems less able to provide services that are valued by humanity (Duarte 2000). Given the potentially high costs of declining ecosystem health and resilience, which include ecological, economic, and cultural impoverishment, resource-use strategies must consider a variety of factors. Foremost among these is the capacity of ecosystems to accommodate, in a continued healthy state, those uses to which they are subject.

In the absence of data describing the distributions, population structure, interactions, and trends of at least key species and communities, evaluating ecosystem health and resilience and reaching the ultimate goal of long-term, sustainable resource-use is left largely up to chance. Specifically, knowledge of the spatial range and condition of key ecological features is a basic prerequisite to considering the implications of extractive resource-use or other human activities that can influence the status of commercial species, natural community structure, and ecosystem function. Having this knowledge allows a prioritization of ecological features or elements of management interest on which attention and effort should be expended. For the purposes of this project, "ecological features" of management interest or concern may include, but are not limited to:

1. habitats or community types supporting commercial species
2. species or community types so common that they are likely a dominant influence on estuary function
3. species or community types that are particularly sensitive to the effects of specific resource-uses
4. rare/uncommon species and community types that have little system-wide influence, but nevertheless contribute to local or regional biodiversity
5. community types and locations subject to brief, high intensity habitat-use for migratory species

2. METHODS

DATA ACQUISITION AND SOURCES

Locally relevant ecological data and information were obtained from a variety of sources. The Maine Department of Marine Resources (DMR) and Maine Department of Inland Fisheries and Wildlife shared statewide spatial data (e.g. shorebird area mapping) and supporting interpretations. Much of the site-specific data relevant to ecosystem function was extracted from findings of collaborative research conducted in the Taunton Bay Estuary from 2001-2005 in support of the Taunton Bay Assessment (Moore 2004).

Two field investigations made during the course of this project updated and refined previous data. These included fixed-wing overflights by Steve Perrin (7 June 2008) to provide trend information for eelgrass distribution and densities in the Bay, which had not been subject to quantitative analysis since 2005. Additionally, *Biological Conservation* and DMR conducted towed diver transects and scouting by skiff (10 June 2008) to detect the presence of recently germinated eelgrass shoots or other eelgrass distributional changes that might be missed by overflights.

DATA SYNTHESIS AND MANAGEMENT ALTERNATIVES

Spatial ecological data were used to develop geographic information systems (GIS). GIS allowed simultaneous layering of multiple types of ecological data to present a spatial understanding of select resources and features, including how they overlap with each other and areas subject to resource-use activities, such as harvesting. Where ecological features warranting management interest potentially overlapped with the activities of the four benthic fisheries (kelp, urchins, mussels, and scallops) management alternatives were developed to avoid negative impacts.

3. ECOSYSTEM OVERVIEW

PHYSICAL

The Taunton Bay Estuary is a 3,500-acre embayment located in mid-coastal Maine at the head of Frenchman Bay (Fig. 1). The estuary is nearly completely surrounded by land. A main channel extends north for about 8 miles from Falls Point to the bridge at Card Mill Stream (Hog Bay) and provides the deepest waters in the system (average = 25-30 feet at low water). A list of broad benthic substrate classes for the main channel is provided in Table 1. A more finescale approach for distinguishing between bottom types resulted in the identification and mapping of at least nine distinct seabed

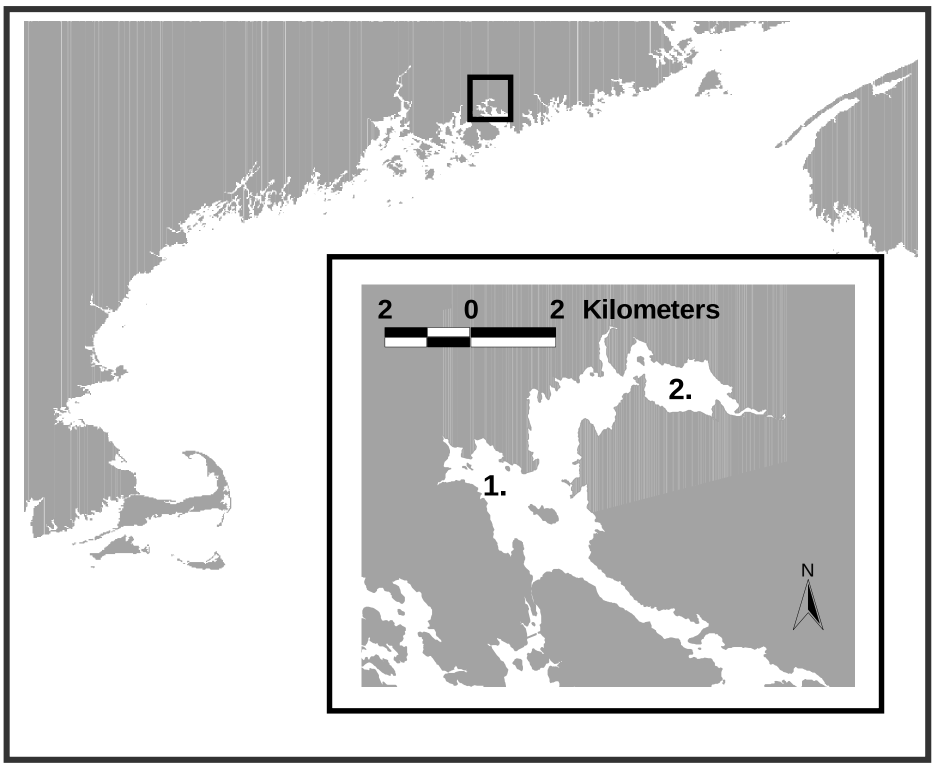


Figure 1. Inset of the Taunton Bay Estuary, Gulf of Maine. Egypt and Hog Bay subembayments are denoted by 1 and 2, respectively.

classes and community types in the estuary's main channel south of Hog Bay (Barker and Moore 2003). Extensive shallow subtidal (most areas $\leq$ 3 feet at low water) and intertidal mudflats flank much of the channel. Little data is available for circulation patterns or flushing rates within the estuary. A bedrock restriction at the southern extent of Taunton Bay truncates tidal amplitude to about 6 feet, which is about 6 feet less than the maximum amplitude experienced in adjacent, downstream waters. Two subembayments of the estuary exhibit very different basin geomorphologies. The southern extent of Egypt Bay merges with broad flats to the south, making a size estimate (about 600 acres) fairly subjective. Egypt bay's seabed is dominated by shallow subtidal mudflat, with intertidal mudflat and subtidal channels provide the balance of its area. In contrast, Hog Bay (600 acres) is almost completely surrounded by land and mostly composed of intertidal mudflat, with the upper reaches of Taunton Bay's main channel providing limited subtidal environment. April-October mid-estuary salinities are polyhaline, often 20-30 ppt (Author's observations). Benthic temperatures on the subtidal flats average 29 F January-February and 69 F July-August (Perrin 2005). Summer temperatures in the shallow intertidal can exceed 86 F (R. Goodwin, unpublished data). August dissolved oxygen measurements from the main channel ranged from 7.2-7.9 mg/L (J. Sowles, unpublished data).

Table 1. Occurrence of Taunton Bay Estuary benthic substrates according to tidal regime and geomorphological class (e.g. flats or channels). Adapted from Barker and Moore (2003).

	Intertidal		Subtidal	
Substrate Class	Flats/Low Gradient	Channels	Flats/Low Gradient	Channels
Peat (salt marsh)	X			
Fines (mud)	X	X	X	X
Mixed coarse and fines	X	X	X	X
Mixed coarse	X			X
Boulder fields	X		X	X
Ledge	X	X	X	X
Mussel bar	X		X	

BIOLOGICAL

Taunton Bay has historically supported a unique assemblage of exemplary ecological features including historically extensive eelgrass (*Zostera marina*) meadows, isolated horseshoe crab (*Limulus polyphemus*) breeding populations, bald eagle (*Haliaeetus leucocephalus*) nest sites, high value shorebird habitat, and high value waterbird habitat. Of the four harvestable benthic species the CRMP will initially consider, kelp and urchins are associated with subtidal, mixed coarse seabed classes primarily found in the swift waters of the lower main channel south of Burying Island. North of the Island, somewhat finer substrates historically supported scallops in harvestable densities. Mussels are most common on the extensive subtidal flats and also the bars that represent a pattern of long-term mussel settlement and accumulation.

4. ECOLOGICAL ELEMENTS OF INTEREST AND ASSOCIATED MANAGEMENT RECOMMENDATIONS

Some ecological elements are vulnerable to unwanted change as a result of anticipated resource-use in Taunton Bay. These elements warrant a heightened level of monitoring vigilance and consideration to achieve the CRMP's goal of keeping human activities in step with the estuary's capacity to accommodate those activities. The following ecological elements were selected based on findings and recommendations of the Taunton Bay Assessment (Moore 2004), the Taunton Bay Project (FTB 2006), the CRMP (Sowles 2007) and the author's fist-hand experience in the estuary and discussions with local and state experts. The elements discussed here are known to warrant attention based on the limits of our current collective knowledge. It is likely that the list is not complete and even more certain that it will require re-evaluation as our understating of the estuary grows. The discussions that follow are grouped according to major benthic geomorphic class.

INTERTIDAL/SUBTIDAL FLATS AND CHANNELS

Eelgrass - Background

Subtidal mud flats are a dominant feature of Taunton Bay's basin morphology and eelgrass has historically been a prominent component of those flats. Throughout its range, eelgrass supports highly diverse vertebrate and invertebrate communities when compared to substrates lacking the complex, three dimensional surface provided by eelgrass (Thayer et al. 1984). The rapid, widespread loss of eelgrass in Taunton Bay that began 1999-2000 (S. Perrin, personal communication; Figure 2) marked the onset of large-scale environmental shifts. Taunton Bay research (2002-2003) demonstrated the functional role of eelgrass as important fish and invertebrate habitat (Moore 2004, Moore, unpublished data). As that study progressed, sharp declines in fish community richness and abundance occurred in step with continuing eelgrass loss (Figure 3). The wide-reaching nature of those events were likely far more dramatic than can be easily perceived. Given the magnitude of lost biomass formerly represented by eelgrass and its associated invertebrate and fish communities, it is clear that an ecosystem-wide shift has occurred. Implications of the shift are less clear. Aside from the obvious loss of habitat, food web effects could impact

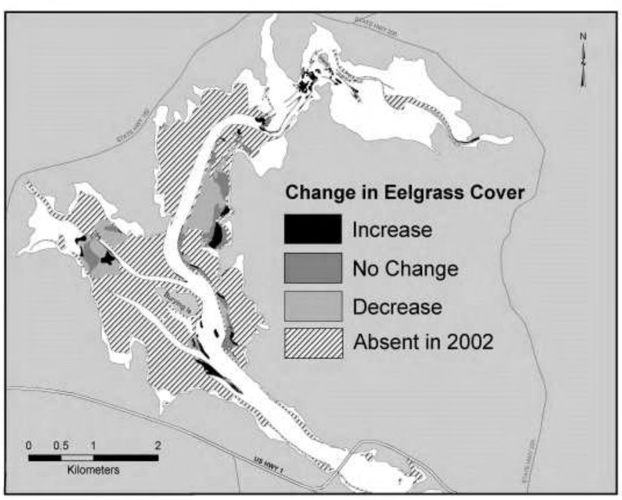


Figure 2. Taunton Bay Estuary changes in eelgrass density and distribution 1996-2002 (adapted from Barker and Moore 2003).

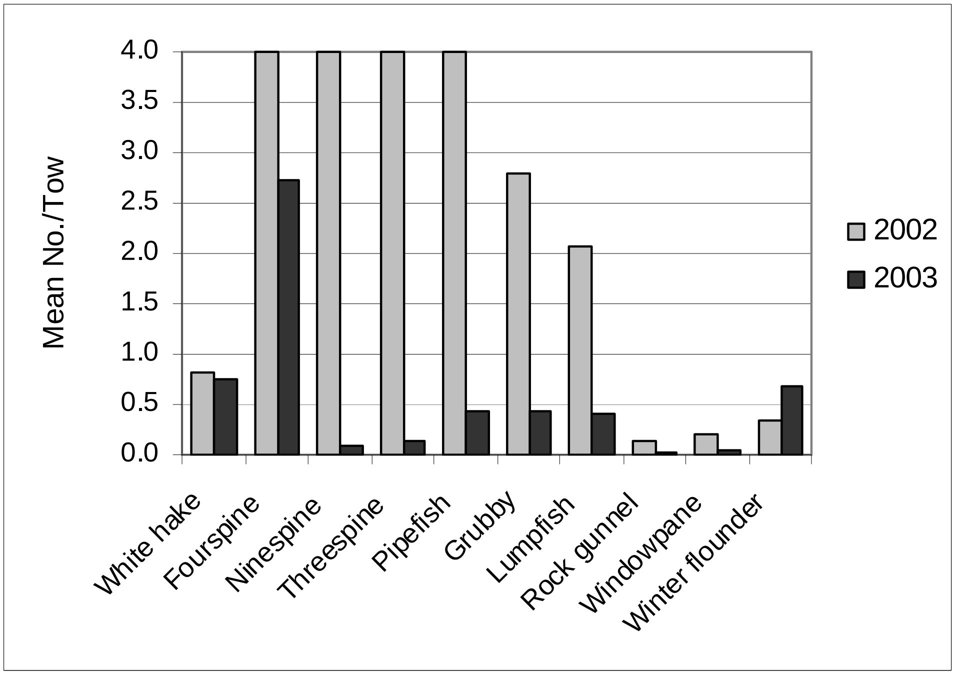


Figure 3. Catch-per-unit-effort declines of fish in the Taunton Bay Estuary's eelgrass community as a result of contemporaneous eelgrass loss, 2002-2003. Mean numbers of fourspine, ninespine, threespine and pipefish caught in 2002 tows were 75.5, 8.4, 4.7, and 6.3, respectively.

infaunal communities that were nourished by the detritus of extensive eelgrass meadows. These effects could also extend up into the water column where those same meadows supplied food for predatory fish and waterbirds.

Effects of the eelgrass declines on sediment stabilization and other water quality functions formerly provided by the extensive meadows are uncertain. There are concerns that Taunton Bay's turbidity levels have increased since the 1980s (S. Perrin, personal communication). The estuary's currently turbid waters (and possibly other factors) may be limiting sunlight penetration and consequently, the depth at which eelgrass can become established and persist. Increased turbidity caused by unstable bottom sediments and activities that cause dense siltation plumes such as dragging (Author's unpublished data) can hinder the productivity of species common to eelgrass communities. Some research indicates that turbidity can negatively influence estuarine fish behavior and distributions (Blaber and Blaber 1980; Cyrus and Blaber 1987a; Cyrus and Blaber 1987b; Engstrom-Ost and Candolin 2007; Webster et al. 2007), although the scientific literature does not universally support these concerns.

Some proposed fisheries in the estuary intend to use drags and suction machines to harvest mussels on shallow subtidal flats. Eelgrass may occur sympatrically with mussels on these flats. The effects of suction on shallow flat communities and eelgrass have not been evaluated. If fine sediments are separated from mussels in the water, at least localized turbidity would likely result. The displacement and possible removal of non-target benthic organisms during suction harvesting is another concern, depending on the spatial scale of these activities. Dragging has the demonstrated potential to mechanically remove whole eelgrass plants, including root systems (Neckles et al. 2005, author's personal observation). This damage may require a minimum of about 5-6 years (max: >20 years) to fully recover (Neckles et al. 2005).

In light of eelgrass's historically dominant distribution and functional role in the bay, recolonization of the species is a high priority. The Comprehensive Resource Management Plan for Taunton Bay (Sowles 2007) recommended an eelgrass recolonization goal of approximately 90% of historic average acreages for several density classes, the idea being that not all classes provide the same functions equally. The implication of the 90% goal is that if eelgrass exceeds this threshold, the "surplus" 10% of eelgrass could be altered in some fashion. DMR has performed intermittent eelgrass coverage/density analyses starting with data from 1996, which is indicated as the year of greatest eelgrass coverage in that time series. However, earlier imagery indicates that spatial distributions of dense eelgrass meadows may have historically exceeded values indicated by the 1996 data (S. Perrin, personal communication). Consequently, developing a confident assessment of what constitutes a historically correct 90% figure may require going some decades back.

Recent overflights (Perrin, unpublished data) and towed diver observations by the author and S. Barker (Maine DMR) qualitatively suggest that increases in eelgrass density and some distributional expansions have occurred since the last imagery (2005) was analyzed. Yet, the current condition may still be some distance from achieving the 90% goal. Until scheduled 2008 imagery is collected and analyzed, measurable data describing the current status of eelgrass will be unavailable.

Eelgrass - Management Recommendations

1. Do not drag or allow other activities that have the potential for intense, large-scale disturbance of benthic sediments and communities (herein referred to as "large-scale benthic disturbance or "LBD") in eelgrass until the 90% goal is reached (see Appendices A-C). Harvesters will be provided with maps of areas to avoid.

   Rationale – Prohibiting LBD in areas currently supporting eelgrass is one of the few steps available towards promoting recovery of eelgrass and associated ecosystem functions (e.g. invertebrate, fish, and waterbird habitat, among others).

   Fishery implications – This recommendation disallows dragging and other LBD in eelgrass. If eelgrass coverage in the estuary continues to expand, commensurately less area of shallow flats will be available to harvest methods associated with LBD, potentially resulting in an incremental reduction of fishing opportunities for these harvesters, until perhaps when full recovery (90%) occurs. However, harvesters that acknowledge the value of eelgrass by excluding LBD from these areas would tend to demonstrate their standing among other resource-use sectors as responsible stewards of the estuary.

   Uncertainty – The extent of eelgrass recovery that will occur until the next onset of major decline is unknown, thus, the likelihood of a major loss of fishing grounds commensurate with eelgrass recolonization is unknowable. Also, the feasibility of long-term use of the shallow flats for mussel dragging has never been demonstrated in Taunton Bay. Consequently, a cessation of harvesting activities due to a lack of harvestable product may represent as much of an eventuality as the likelihood of limited fishing opportunities due to eelgrass expansion. Finally, the locations of prime mussel harvesting areas may not coincide, to great extent, with eelgrass, in which case, LBD prohibitions in eelgrass would not significantly limit fishing opportunities.

2. Designate a “no-LBD” buffer (example: 100 ft) surrounding areas of eelgrass growth.

   Rationale – In instances of harvester navigational errors, “no-LBD” buffers can help limit intrusion of LBD activities into eelgrass. Buffers may also limit potential effects on eelgrass community productivity of dense turbidity plumes associated with LBD.

   Fishery implications – Extending the “no LBD’’ area associated with eelgrass will, to varying degree, further limit the amount of shallow flats available to harvesters employing LBD-associated methods. On the other hand, it may also avoid potential management conflicts caused by harvesters crossing into eelgrass areas, which would tend to hinder their standing as responsible stewards.

   Uncertainty – The ability of harvesters to identify and stay out of eelgrass areas may be adequate enough to preclude the need for expanding the “no LBD” area associated with eelgrass. Also, although turbidity plumes associated with LBD (in this case, dragging, S. Moore unpublished data) are well documented, the effects of these plumes in Taunton Bay are unknown.

3. Promote sanctioned LBD to occur during the portion of the tide cycle when current flow is most likely to transport turbidity plumes away from nearby eelgrass.

   Rationale – Timing of LBD activities can advantageously use tidal currents to direct turbidity away from areas of eelgrass growth.

   Fishery implications – Taunton Bay’s shallow flats offer limited time on each tide for harvesting by fishing vessels of even moderate draft. Limiting time on the flats may, in and of itself, make harvesting economically unfeasible.

   Uncertainty – Although some levels and durations of turbidity can influence productivity of eelgrass communities, the influence of LBD-induced turbidity plumes on eelgrass and the communities they support is unknown.

4. Avoid conducting multiple, simultaneous LBD activities and provide some interval of time between activities.

   Rationale – Limiting LBD to one activity at a time addresses concerns that multiple activities might lead to more turbidity than the estuary can reasonably accommodate without compromising system integrity. Intervals between activities may allow time for fine sediments resuspended by LBD to settle or flush from the system.

   Fishery implications – This constraint may require enhanced coordination and planning on the part of harvesters that limits their scheduling flexibility.

Uncertainty – The magnitude and effects of LBD-associated turbidity are poorly understood, although aerial observations of other embayments demonstrated at least a temporary, dramatic shift in water clarity due to multiple, simultaneous dragging activities (Author's observations). Water circulation patterns in Taunton Bay and their ability to flush resuspended fine sediments are not well understood.

5. After eelgrass acreage increases beyond 90% attainment goals, continue to prohibit LBD in areas that, by nature of their persistence over time, may represent important sources of seed stock.

   Rationale – Protecting historical seed stock areas may prove key to the resilience and recolonization potential of eelgrass communities during episodes of decline.

   Fishery implications – After a 90% goal is attained, limiting harvester use of eelgrass areas to locations other than those supporting persistent eelgrass growth may constrain the size of their allowable fishing grounds.

   Uncertainty – Current perceptions of where eelgrass is persistent may be flawed because a long-term analysis of eelgrass distributional dynamics in Taunton Bay is lacking. Also, persistent eelgrass growth may not occur where mussels are sought.

Horseshoe Crabs - Background

The movements of adult horseshoe crabs in the Taunton Bay Estuary were tracked using sonic telemetry from June 2003-June 2005 (Moore and Perrin 2007). Individuals from the two major breeding aggregations in the estuary never exited the estuary nor did they leave the subembayments (Egypt Bay and Hog Bay) in which they were initially tagged, despite a <4 km separation between breeding areas (Figure 4). The average home range size for individual Egypt and Hog Bay crabs was about 150 acres. During the breeding and post-breeding season (late May-July), crabs frequently used the intertidal but made a mass movement to subtidal areas in August that lasted until May. For at least seven months (October-April), they were confined to wintering areas in the subtidal that represented only about 10% (15 acres) of their total home range size. During most of that time, they appeared to move very little, suggesting that they were in a physiologically distinct wintering state, which seemed to be triggered by water temperature. There was little evidence of year-year fidelity to specific wintering areas, except that channels and flats immediately adjacent to channels may have had some importance disproportionate to their availability. The

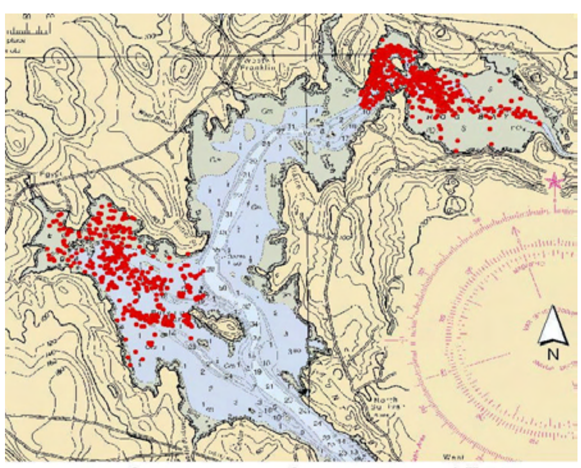


Figure 4. All horseshoe crab locations obtained from 2003-2005 sonic telemetry studies in the Taunton Bay Estuary.

apparent isolation observed in the Egypt Bay and Hog Bay populations has not been recorded elsewhere, but may occur in other Gulf of Maine locations that share unique physical properties and differ greatly from areas to the south.

Like many organisms, knowledge of the horseshoe crab's ecosystem role is incomplete, but it is understood that this species is a predator of opportunity (Botton 1984; Botton et al. 2003), a prey source (primarily early life stages) for fish, shorebirds, and waterbirds (Castro and Meyers 1993, S. Perrin, personal communication), and an environmental engineer, given its ability to incrementally modify large expanses of the benthos by creating shallow depressions in fine sediments (Kraeutner and Fegley 1994). The extent that Taunton Bay's ecosystem health or resilience would suffer from a loss of these functions is not known. That Taunton Bay's horseshoe crabs represent a unique element of biodiversity in region with few productive breeding grounds is generally accepted as sufficient justification to afford them heightened management attention. Horseshoe crabs in Taunton Bay also exist at the northern edge of their Atlantic distribution, far from the geographic core of their range where growth, reproductive potential, and population sizes are greatest. The lack of recruitment from sources outside the estuary and no documented exchange of individuals between Hog Bay and Egypt Bay populations suggest a heightened vulnerability to overexploitation, large-scale habitat alteration, and other pressures that could result in population declines. 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) has defined intertidal flats and spawning beaches as Habitat Areas of Particular Concern, although their primary interest is currently in large populations south of Maine.

Taunton Bay's flats have no history of widespread, intense habitat disturbance associated with resource-use, so the effects of LBD activities such as dragging on horseshoe crab populations are unknown. On the other hand, LBD is known to cause changes to benthic communities of which horseshoe crabs are a part. These communities, among other roles, support the feeding, resting, breeding, and nursery requirements of crabs. In 2003, about 1.5 acres of shallow subtidal flat in Taunton Bay was subject to three hours of experimental mussel dragging. Dramatic, short-term (<1 year) declines in benthic species richness and abundance were observed (Moore and Atherton 2005). One implication of benthic organism declines is that horseshoe crab prey abundance also declines. Disturbance at the scale of one small drag plot would be unlikely to have any effects at the horseshoe crab population level, but with a sufficiently large proportion of horseshoe crab habitat altered by LBD, commensurately large impacts to entire horseshoe crab populations might result. If these impacts came in the form population declines, the apparent isolation of Taunton Bay's crabs might make recovery difficult.

Another concern is that horseshoe crabs become mature at around 10 years of age, at which point they recruit into the adult population. Adults represent the only population segment regularly surveyed each year. If juvenile crab population levels declined as a result of LBD-induced habitat alteration or gear interactions, it might not be observed until 8-10 years later, possibly beyond the point at which remedial actions could be effectively implemented. Consequently, a conservative management approach is probably warranted unless it can be established that activities with the potential to rapidly and intensely alter large amounts of benthic habitat are compatible with maintaining healthy crab populations. The following recommendations focus on avoiding crab-fishing gear interactions and alteration of horseshoe crab habitat.

Horseshoe Crabs - Management Recommendations

1.A. *Egypt Bay and Hog Bay* – Prohibit LBD from the upper intertidal zone to the offshore extent of mapped horseshoe crab range (See Appendices D and E). For the purposes of this recommendation, traditional intertidal hand-harvest fisheries for worms and clams are not considered "LBD" as referred to above.

All other Intertidal flats north "upstream" of Cedar Point and Evergreen Point – prohibit all LBD.

Rationale – Horseshoe crabs are apparently well adapted to background benthic disturbance related to wind, waves, and ice. However, there is no precedent for intense, potentially widespread LBD, as might be associated with dragging, on Taunton Bay's shallow flats. Avoiding LBD in Egypt Bay and Hog Bay intends to promote crab conservation in the highest value areas by discouraging habitat changes to which horseshoe crabs might prove ill suited.

Avoiding LBD in all other intertidal flats "upstream" of Cedar Point and Evergreen Point intends to promote the conservation of smaller, isolated breeding and nursery areas throughout the estuary that may represent an important source of recruitment if at some point the Egypt Bay and Hog Bay populations radically decline.

Fishery implications – Designating core horseshoe crab habitat in Egypt Bay and Hog Bay as "no LBD'' areas will considerably limit the amount of shallow flats available to harvesters employing LBD-associated methods, although a sizeable portion of the core horseshoe crab habitat in Egypt Bay would already be protected for its eelgrass value. In the case of Hog Bay, mussels have never evoked commercial interest. Closing that portion of the bay's core horseshoe crab range to LBD would not apparently represent a loss of fishing opportunities to mussel harvesters.

Uncertainty – LBD induces at least short-term (on the order of months) benthic community change, including loss of species richness and abundance, but its influence on the value horseshoe crab habitat is not clear. It is also currently unknown whether the locations of prime mussel harvesting areas coincide, to any great extent, with prime horseshoe crab habitat in Egypt Bay. Likely results of crab-dragging gear interactions on any horseshoe crab life stage are unknown.

1.B. (Alternative to 1.A.)

Egypt Bay – Prohibit LBD in Egypt Bay mapped horseshoe crab range, except for designated LBD plots located in the subtidal (see an example in Appendix F). Harvesters will use the following preconditions to determine plot locations:

- Subtidal LBD plot locations will not conflict with other management efforts (e.g. eelgrass recovery).

- Total acreage of "active" plots will not exceed 5% (24 acres) of the mapped subtidal horseshoe crab range in Egypt Bay. A plot is considered "active" for 24 months after the last LBD activity in that plot.

- Total acreage of all plots (active or inactive) will not exceed 10% (48 acres) of the mapped subtidal horseshoe crab range in Egypt Bay. When total acreage of all plots reaches 10%, future LBD will be limited to previously used LBD plots.

- Until eelgrass recovery goals are met, no LBD will occur in plots that have been colonized by eelgrass.

- LBD in designated subtidal plots will be limited to June-September, when most crabs are fully emerged from their wintering state.

Hog Bay – Prohibit all LBD as in 1.A (see Appendix E).

All Intertidal flats "upstream" of Cedar Point and Evergreen Point – Prohibit all LBD as in 1.A.

Rationale – Compared to 1.A., this somewhat less conservative approach still avoids LBD in the estuary's intertidal flats, which are important to horseshoe crab early life stages. While providing an amount of subtidal horseshoe crab habitat for LBD-associated uses, it limits the amount of subtidal crab habitat in a state of post-LBD recovery at any one time. It is assumed here that plots will require some recovery time (24 months is offered) to re-attain most qualities of functional horseshoe crab habitat. Capping the total acreage of all plots (active and otherwise) to 10% (48 acres) of Egypt Bay's subtidal horseshoe crab habitat accounts for uncertainty as to the full magnitude of impacts on horseshoe crab habitat related to LBD and whether full-recovery can be attained. A hypothetical example in Table 2 illustrates how thresholds for the maximum total acreage of active plots and maximum total acreage of all plots would be used to govern LBD.

In this management recommendation, activities in plots are also timed to occur with consideration to horseshoe crab biology, i.e., during a period when most crabs are more likely resilient to interactions with dragging gear. The plot alternative is not offered for subtidal areas used by the Hog Bay breeding population because subtidal habitat is so limited in that area.

Fishery implications – Establishing plots where LBD can occur in the subtidal offers opportunities for dragging that have not existed since 2000. However, once the maximum amount of active plot acreage (24 acres) is met, no new plots can be established until some amount of active plot acreage rotates into inactive status. Having said that, 24 acres would represent a considerable area of harvested seabed, given Egypt Bay's limited mussel resources. The maximum acreage for all plots (48 acres) also represents a limit to fishing opportunities, but it is unlikely that the historically limited amount of mussels in

Table 2. Example of how establishment of new plots would be governed by maximum acreage limits and plot status (active or non-active). Maximum acreage limits for active status plots and all plots (active and non-active) are 24 acres and 48 acres, respectively. Plots rotate out of active status 24 months after the last LBD.

Month/Year	Acreage of new plots	Total acreage of active plots	Total acreage of all plots
August 2008	12	12	12
August 2009	4	16	16
August 2010	0	4	16
August 2011	24	24	40
August 2012	0	24	40
August 2013	0	0	40

Egypt Bay would facilitate such a large amount of harvested area. Preconditions such as those outlined in this recommendation represent constraints that most mussel harvesters do not have to accommodate. But in doing so, they are afforded the opportunity to employ methods that are under increasing scrutiny and also would tend to increase their standing as stewards among other resource-users.

Uncertainty – See 1. A. above

Other Ecological Elements of the Flats – Background

Several other ecological elements of Taunton Bay's intertidal and subtidal flats warrant management interest for their potential overlap with subtidal resource uses (see Appendices G and H).

Diadromous fish passage – Species such as rainbow smelt (*Osmerus mordax*), alewife (*Alosa pseudoharengus*), and various life-stages of the American eel (*Anguilla rostrata*) use Taunton Bay at least seasonally. Continued use of the estuary by these species depends, in part, on the success of the brief, high intensity spring migrations they make through tidal creeks (see Klein-MacPhee 2002; Munroe 2002; Smith and Tighe 2002 for a comprehensive discussion of habitat and life history traits). The target fisheries in this report are not expected to interact greatly with diadromous fish passage. However, because future resource-use proposals are difficult to predict, emphasizing the importance of these habitats now may have subsequent benefit as the CRMP expands to include other fisheries and uses.

Waterbird habitat – waterfowl, wading birds, and other waterbirds use Taunton Bay's emergent wetlands, expansive flats, and channels. The Maine Department of Inland Fisheries and Wildlife (MDIFW) has mapped most of the estuary's intertidal and subtidal flats as Coastal Waterfowl and Wading Bird Habitat. Limited only by ice cover, habitat use occurs throughout the year as different groups of species shift with the seasons. Use by waterfowl in the winter and early spring is notable (S. Perrin, unpublished data, Author's unpublished data). Many of these species can be considered part of the benthic community, as they seek prey in and on the estuary's seabed. At a sufficiently large scale, habitat alteration as a result of LBD might impact the value of these areas as waterbird habitat. However, protecting eelgrass, horseshoe crab habitat and other ecological elements from excessive LBD may have the added benefit of promoting waterbird conservation in the estuary.

Shorebird habitat – Several areas of shorebird use in the estuary are designated as Significant Wildlife Habitat by MDIFW for their high value to these species. Hog Bay, upper Taunton Bay (immediately west of Hog Bay), and Egypt Bay are areas of regional importance. One of the attributes that distinguishes Taunton Bay from other shorebird areas in the Frenchmans Bay region is that it provides habitat supporting both the feeding and roosting requirements of these long-distance migrants (L. Tudor, Maine Department of Inland Fisheries and Wildlife, personal communication). Burying Island Ledge and another area to the east of Burying Island were formerly among sites rated as Significant Wildlife Habitat by MDIFW, but shorebird use of these areas declined when eagles nested on Burying Island. The downgraded status of shorebird habitat around Burying Island may only be a temporary condition. Among horseshoe crab management recommendations in this report, prohibiting LBD from intertidal flats has the added benefit of preventing one form of shorebird habitat alteration. As the CRMP expands to other resource uses, the TBAG should consider the sources and effects of other intertidal shorebird habitat alteration and disturbance.

Bald Eagle Nest Essential Habitat – Protection of Bald Eagle nest sites is an important tool for achieving recovery of the species in Maine. One of the most important threats to nest productivity is disturbance, which can result in nest abandonment or lowered productivity. Active nest sites are most sensitive to disturbance between February 1 and August 31. MDIFW designates a ¼ mile buffer around nest sites as Essential Wildlife Habitat, which is intended to exclude activities associated with disturbance during the nesting season. Direct conflicts between Bald Eagle recovery goals and the subtidal fisheries described in this report are probably few. However, they could occur if excess turbidity associated with LBD were to hinder the visual prey acquisition capabilities of foraging eagles. Disturbance caused by fishing crews and recreational paddlers habitually using areas close to active nests might also represent a valid concern.

Seal haul-outs – Taunton Bay supports not less than 10 consistently used harbor seal (*Phoca vitulina*) haulouts (FTB 2006, S. Perrin, unpublished data). Supporting the habitat requirements of over 70 individuals (2005 count), these areas are selected preferentially based on the seasonal habitat requirements of seals. Burying Island Ledge is one of the first haulouts subject to high intensity use in April each year and also is the only major pupping site in the estuary (S. Perrin, unpublished data). The Marine Mammal Protection Act of 1972 ostensibly protects seals from disturbance, but enforcement of that portion of the law is rarely invoked (Lelli and Harris 2001). Power boats motoring too close to seal haulouts can cause disturbance, but a Maine study indicated that paddlers may represent a greater source of disturbance (Lelli and Harris 2001). Grella and colleagues (2001) and Pakenham and Fairly (2001) indicated that a 300-foot buffer around haulouts adequately limited disturbance to these areas and they particularly emphasized the need for these buffers during the pupping season. No such guidelines are in place for seals in Taunton Bay. Given the value of Burying Island Ledge to seals in the Bay, especially during the pupping season, resource-use guidelines in some form seem warranted.

Other Ecological Elements of the Flats – Management Recommendations

1. Avoid significant disturbance within Bald Eagle nest site Essential Habitat buffers during the February 1- August 31 nesting season. This is intended to be a guideline promoting avoidance, not a prohibition.

   Rationale – Limiting significant forms of disturbance near Bald Eagle nest sites to outside of the nesting season is intended to preserve the reproductive potential of those sites. Depending on their specific characteristics, some transient forms of disturbance would not represent a significant conflict with nesting success. MDIFW's ¼ mile Essential Habitat buffer was established due to the eagle's imperiled status. Consequently, it represents a necessarily conservative distance that experts in the field have determined will limit nest failures. The eagle is currently listed as Threatened in Maine and as such, still warrants this level of management vigilance.

   Fishery implications – This recommendation promotes cooperation to seasonally limit use of areas within nest site buffers, which if agreed-to, would limit fishing opportunities in the areas mentioned if harvestable resources are present.

   Uncertainty – In any wildlife species, there is variability in the amount of disturbance required to elicit a response from an individual. Some individuals and populations are more habituated to disturbance than others.

2. Establish a 300-foot "no disturbance" buffer around the Burying Island Ledge seal pupping area from April-August.

   Rationale – Limiting disturbance within this buffer is intended preserve the reproductive potential of the site.

   Fishery implications – This recommendation imposes a seasonal constraint on use of areas within 300 feet of the ledge, which would limit fishing opportunities if harvestable resources are present.

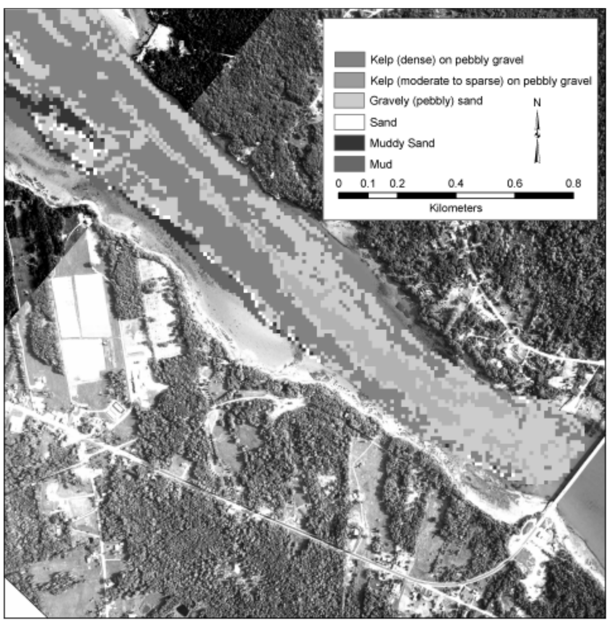
   Uncertainty – See 1. above.

MAIN CHANNEL

Maine Channel – Background

Taunton Bay's main channel is characterized by coarse and mixed coarse substrates (Figure 5) from the Rt. 1 Bridge north to the vicinity of Burying Island, after which finer materials predominate (Barker and Moore 2003). No seabed mapping is available for the area below the bridge, but it is assumed that much of the area is composed of mixed-coarse or coarse substrates. The lower channel traditionally supported two harvested species of relevance to this report: urchins and kelp. Urchins in this area were dragged and hand-harvested by divers. The channel north of Burying Island is thought to have represented the estuary's primary scalloping grounds. Scallops were also reportedly harvested by dragging and by diver. Much of the main channel has supported a small lobster fishery, with apparently no history of overexploitation or extensive habitat alteration. For these reasons, lobsters were not considered as a priority species currently warranting additional management consideration by the TBAG. However, coordination between lobster harvesters and other fisheries may be required to avoid resource-use conflicts, especially where dragging would overlap into areas traditionally used for lobster harvesting.

Figure 5. Seabed mapping of Taunton Bay's main channel (adapted from Barker and Moore 2003).



Given the demonstrated potential for urchin and scallop fishery depletion in Taunton Bay; dramatic habitat alteration associated with dragging (Watling and Norse 1998; Hall 1999; Collie et al. 2000), and conflicts between the drag fishery and other harvesters, heightened management guidance is warranted for the main channel fisheries. This guidance should address equitability of resource-use among kelp, scallop, urchin and lobster harvesters; promotion of the long-term sustainability of resource-use; and facilitate the health and resilience of main channel benthic communities. Harvesters will need to coordinate their efforts to avoid conflicts. This, and sound harvest limits for all species based on current stock assessments, may help to avoid overexploitation. However, as in any fishery, uncertainty over the adequacy of harvest limits will persist without extra measures, especially in the absence of dedicated funds to implement high-resolution monitoring of stocks. Where draggers fish the channel, concerns related to intense habitat alteration will also persist without additional management measures. One approach toward sufficiently addressing these concerns is to put aside some portion of the main channel as habitat in "reserve".

Maine Channel – Management Recommendations

1. Set aside areas of the main channel to be held in "reserve". Reserve areas would not be subject to any harvest or LBD, and should include:

    - representative scallop habitat and urchin/kelp habitat north and south of Burying Island, respectively.

    - an area near the outlet of Hog Bay that supports an uncommon example of hard bottom with high biological diversity. Mapping the extent of this area with certainty will require field data that are currently unavailable.

    Rationale – If Taunton Bay contributes significantly to supplying larvae for its own scallop, urchin, and lobster populations, establishing reserve areas for protected brood stock (especially scallops and urchins, which are less mobile than lobsters) might act as a safety net in the event that fishery-induced stock depletions reoccur. If most settling larvae originate from stocks outside of the estuary, holding areas in reserve may do little to promote the "safety net" of a larval source within the Bay. However, establishing these reserve areas promotes habitat conditions, which free from intense harvesting may represent optimal settlement areas for larvae of commercial species, regardless of their origin.

    Because these reserve areas would not be subject to any form of harvest or intense disturbance, community shifts related to overharvesting by hand or LBD-associated methods would be avoided. These reserves would also have value as scientific reference areas for tracking community change in other parts of the estuary's main channel.

    The high diversity bottom community near Hog Bay warrants protection because it represents an exemplary and uncommon example of this community type in the estuary.

    Fishery implications – Closing any section of the main channel potentially limits fishing opportunities for harvesters. However, if designating the locations of reserves integrates the knowledge and assistance of harvesters, establishment of these areas does not have to represent an unreasonable constraint on their activities.

    Uncertainty – patterns of larval transport, settlement, and recruitment of commercial benthic species in Taunton Bay are unknown.

5. CONCLUSIONS

This report attempts to assemble from disparate sources the collective knowledge describing Taunton Bay's ecology and in particular, ecological elements potentially sensitive to several subtidal fisheries in the bay. The hope is that the management recommendations, coupled with sound harvest limits, offer an approach that will facilitate the long-term sustainability of these fisheries. At the same time, the capacity of the entire ecosystem to accommodate the various fisheries is addressed by outlining distinct performance criteria for when and where specific activities should or should not occur. These alternatives represent one step of many that will be needed to support the long-term health and resilience of the Taunton Bay Estuary, which are prerequisites for long-term sustainable resource-use.

6. LITERATURE CITED

ASMFC. No Date. Horseshoecrab habitat fact sheet. Atlantic States Marine Fisheries Commission. http://www.asmfc.org/speciesDocuments/horseshoeCrab/hsc HabitatFactsheet.pdf. Accessed on 16 June 2008.

Arkema, K. K., S. C. Abramson, and B. M. Dewsbury. 1998. Marine ecosystem-based management: from characterization to implementation. *Landscape and Urban Planning* 40:31–39.

Barker, S. and S. Moore. 2003. Seabed mapping and eelgrass distributional change in Taunton Bay, Maine. Maine Sea Grant Program Interim Report. Maine Department of Marine Resources, West Boothbay Harbor, Maine.

Blaber, S. J. M. and T. G. Blaber. 1980. Factors affecting the distribution of juvenile estuarine and inshore fish. *Journal of Fish Biology* 17:143–162.

Botton, M. L. 1984. Diet and food preferences of the horseshoe crab *Limulus polyphemus* in Delaware Bay, New Jersey, USA. *Marine Biology* 81: 199–207

Botton, M. L., C. N. Shuster, and J. A. Keinath. 2003. Horseshoe crabs in a food web: who eats whom? Pp. 133–153, *In* C. N. Shuster, R. B. Barlow, and H. J. Brockmann (eds.). The American Horseshoe Crab. Harvard University Press, Cambridge, Massachusetts.

Cadrin S. X., S. H. Clark, D. F. Schick, M. P. Armstrong, D. McCarron, and B. Smith. 1999. Application of catch-survey models to the northern shrimp fishery in the gulf of Maine. *North American Journal of Fisheries Management* 19:551–568.

Cyrus, D. P. 1987. The influence of turbidity on the estuaries of Natal, South Africa. *Continental Shelf Research* 7:1411–1416.

Cyrus, D. P., and S. J. M. Blaber. 1987. Influence of turbidity on juvenile marine fishes in estuaries. Part 1. Field studies at Lake St. Lucia on the southeastern coast of Africa. *Journal of Experimental Marine Biology and Ecology* 109:53–70.

Castro, G. and J. P. Myers. 1993. Shorebird predation on eggs of horseshoe crabs during spring stopover on Delaware Bay. *The Auk* 110:927–930.

Collie, J. S., S. J. Hall, M. J. Kaiser, and J. R. Poiner. 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. *Journal of Animal Ecology* 69:785–798.

Collie, J. S., G. A. Escanero, and P. C. Valentine. 2000. Photographic evaluation of the impacts of bottom fishing on benthic epifauna. *ICES Journal of Marine Science* 57:987–1001.

Driscoll, C. T., D. Whitall, J. Aber, E. Boyer, M. Castro, C. Cronan, C. L. Goodale, P. Groffman, C. Hopkinson, K. Lambert, G. Lawrence, and S. Ollinger. 2003. Nitrogen pollution in the northeastern United States: sources, effects, and management options. *BioScience* 53:357–374.

Duarte, C. M. 2000. Marine biodiversity and ecosystem services: an elusive link. *Journal of Experimental Marine Biology and Ecology* 250:117–131

Engstrom-Ost, J. and U. Candolin. 2007. Human-induced water turbidity alters selection in sexual displays in sticklebacks. *Behavioral Ecology* 18:393–398.

FTB. 2006. The Taunton Bay study: a pilot project in collaborative bay management. Friends of Taunton Bay Hancock, Maine.

Grella, L., J. Mortenson, M. Brown, J. Roletto and L. Culp. 2001. SEALS: harbor seal protection and disturbance study, Pp. 47-50, *In* T. R. Spradlin, E. T. Nitta, J. K. Lewandowski, L. M. Barre, K. Brix, and B. Norwood (Eds.). Viewing Marine Mammals in the Wild: A Workshop to Discuss Responsible Guidelines and Regulations for Minimizing Disturbance. NOAA Fisheries, Washington, D.C.

Hall, S. J. 1999. The Effects Of Fishing On Marine Ecosystems And Communities. Blackwell Science Ltd Oxford UK.

Jackson, J. B., M. X. Kirby, W. H. Berger, K. A. Bjorndal, L. W. Botsford, B. J. Bourque, R. H. Bradbury, R. Cooke, J. Erlandson, J. A. Estes, T. P. Hughes, S. Kedwell, C. B. Lange, H. S. Lenihan, J. M. Pandolfi, C. H. Peterson, R. S. Steneck, M. Tegner, and R. R. Warner. 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science* 293:629–638.

Klein-MacPhee, G. 2002. Smelts. Family Osmeridae, Pp. 92–95 *In*: Collette, B. B. and G. Klein-MacPhee (eds.). Bigelow and Schroeder's Fishes of the Gulf of Maine. Smithsonian Institution Press, Washington, D.C.

Kraeutner, J. N., and S. R. Fegley. 1994. Vertical disturbance of sediments by horseshoe crabs (*Limulus polyphemus*) during their spawning season. *Estuaries* 17:288–294.

Larsen P. F, D. F. Gadbois, and A. C. Johnson. 1986. Polycyclic aromatic hydrocarbons in Gulf of Maine sediments: distributions and mode of transport. *Marine environmental research* 18:231–244.

Lelli, B. and D. E. Harris. 2001. Human disturbances affect harbor seal haul-out behavior: can the law protect these seals from boaters? Pp. 97 *In* T. R. Spradlin, E. T. Nitta, J. K. Lewandowski, L. M. Barre, K. Brix, and B. Norwood (Eds.). Viewing Marine Mammals in the Wild: A Workshop to Discuss Responsible Guidelines and Regulations for Minimizing Disturbance. NOAA Fisheries, Washington, D.C.

McNaught, D. C. 1999. The indirect effects of macroalgae and micropredation on post-settlement success of the green sea urchin in Maine. PhD dissertation. University of Maine, Orono, Maine.

McLeod, K. L. J. Lubchenko, S. R. Palumbi and A. A. Rosenberg. Scientific consensus statement on marine ecosystem-based management. Communication Partnership for

Science and the Sea. http://www.compassonline.org/pdf_files/EBM _Consensus_ Statement_v12.pdf. Accessed on 14 June 2008

Moore, S. 2004. The Taunton Bay assessment: a report to the Maine Legislature Marine Resources Committee for consideration of the 2000-2005 dragging prohibition. Maine Department of Marine Resources, West Boothbay Harbor, Maine.

Moore, S. and T. Atherton. 2005. Mussel (*Mytilus Edulis*) dragging and short-term shallow subtidal community change. Maine Department of Marine Resources, West Boothbay Harbor, Maine.

Moore, S. and S. Perrin. 2007. Seasonal movements and resource-use patterns of resident horseshoe crab (*Limulus polyphemus*) populations in a Maine, USA estuary. *Estuaries and Coasts* 30: 1016–1026.

Munroe, T. A. Herrings. 2002. Family Clupeidae. Pp. 118–125 *In* B. B Collette and G. Klein-MacPhee (eds.). Bigelow and Schoeder's Fishes of the Gulf of Maine. Smithsonian Institution Press, Wahington, D.C.

Neckles, H. A., F. T. Short, S. Barker, and B.S. Kopp. 2005. Disturbance of eelgrass *Zostera marina* by commercial mussel *Mytilus edulis* harvesting in Maine: dragging impacts and habitat recovery. *Marine Ecology Progress Series* 285:57–73.

Pakenham, M. and L. Fairly. 2001. Marine mammal monitoring (m3) project: a stewardship and outreach partnership in the bc/washington transboundary waters. Pp. 65–68 *In*: T. R. Spradlin, E. T. Nitta, J. K. Lewandowski, L. M. Barre, K. Brix, and B. Norwood (Eds.). Viewing Marine Mammals in the Wild: A Workshop to Discuss Responsible Guidelines and Regulations for Minimizing Disturbance. NOAA Fisheries, Washington, D.C.

Pauly, D. and R. Chuenpagdee. 2007. Fisheries and coastal ecosystems: the need for integrated management. Pp. 171-185 *In* P. Nemetz (ed.). Sustainable Resource Management. Edward Elgar Publishing, Surrey, U.K.

Pew Oceans Commission. 2003. America's Living Oceans: Charting a Course for Sea Change. A report to the nation. Pew Oceans Commission, Arlington, Virginia.

Rosenberg, A. A., W. J. Bolster, K. E. Alexander, W. B. Leavenworth, A. B. Cooper, and M. G. McKenzie. 2005. The history of ocean resources: modeling cod biomass using historical records. *Frontiers in Ecology and the Environment* 3: 84–90.

Rosenberg, A. A. 2006. Regional governance and ecosystem-based management of ocean and coastal resources: can we get there from here? *Duke Environmental law and Policy Forum* 16:179–185.

Smith, D. G. and K. A. Tighe. 2002. Freshwater eels. Family Anguilidae. Pp. 93-95 *In* B. B. Collette and G. Klein-MacPhee (eds.). Bigelow and Schroeder's Fishes of the Gulf of Maine. Smithsonian Institution Press, Wahington, D.C.

Sowles, J. 2007. Report to the Joint Standing Committee on Marine Resources of the 123rd Maine Legislature on a comprehensive resource management plan for Taunton Bay, Maine. Maine Department of Marine Resources, Hallowell, Maine.

Steneck, R. S. M. H. Graham, B. J. Bourque, D. Corbett, J. M. Erlandson, J. A. Estes, and M. J. Tegner. 2002. Kelp forest ecosystems: biodiversity, stability, resilience and future. *Environmental Conservation* 29:436–459.

Thayer, G. W., W. J. Kenworthy, and M. S. Fonseca. 1984. The Ecology Of Eelgrass Meadows Of The Atlantic Coast: A Community Profile. U.S. Fish and Wildlife Service, FWS/OBS-84/02.

Watling, L. and E. A. Norse. 1998. Disturbance of the seabed by mobile fishing gear: a comparison to forest clearcutting. *Conservation Biology* 12:1180–1197.

Webster, M. M., N. Atton, A. J. W. Ward, and P. J. B. Hart. 2007. Turbidity and foraging rate in threespine sticklebacks: the importance of visual and chemical prey cues. *Behavior* 144:1347–1360.

Unpublished Data Sources

R. Goodwin, Maine Department of Marine Resources, Lamoine, Maine.

S. Perrin, Friends of Taunton Bay, Hancock, Maine.

J. Sowles, Maine Department of Marine Resources, West Boothbay Harbor, Maine.

7. APPENDICES - MAPS

A. Taunton Bay eelgrass “no LBD” areas (Route 1 Bridge to Burying Island).

B. Taunton Bay eelgrass “no LBD” areas. (Burying Island to Hatch Point).

C. Taunton Bay eelgrass “no LBD” areas (Hatch Point to eastern Hog Bay).

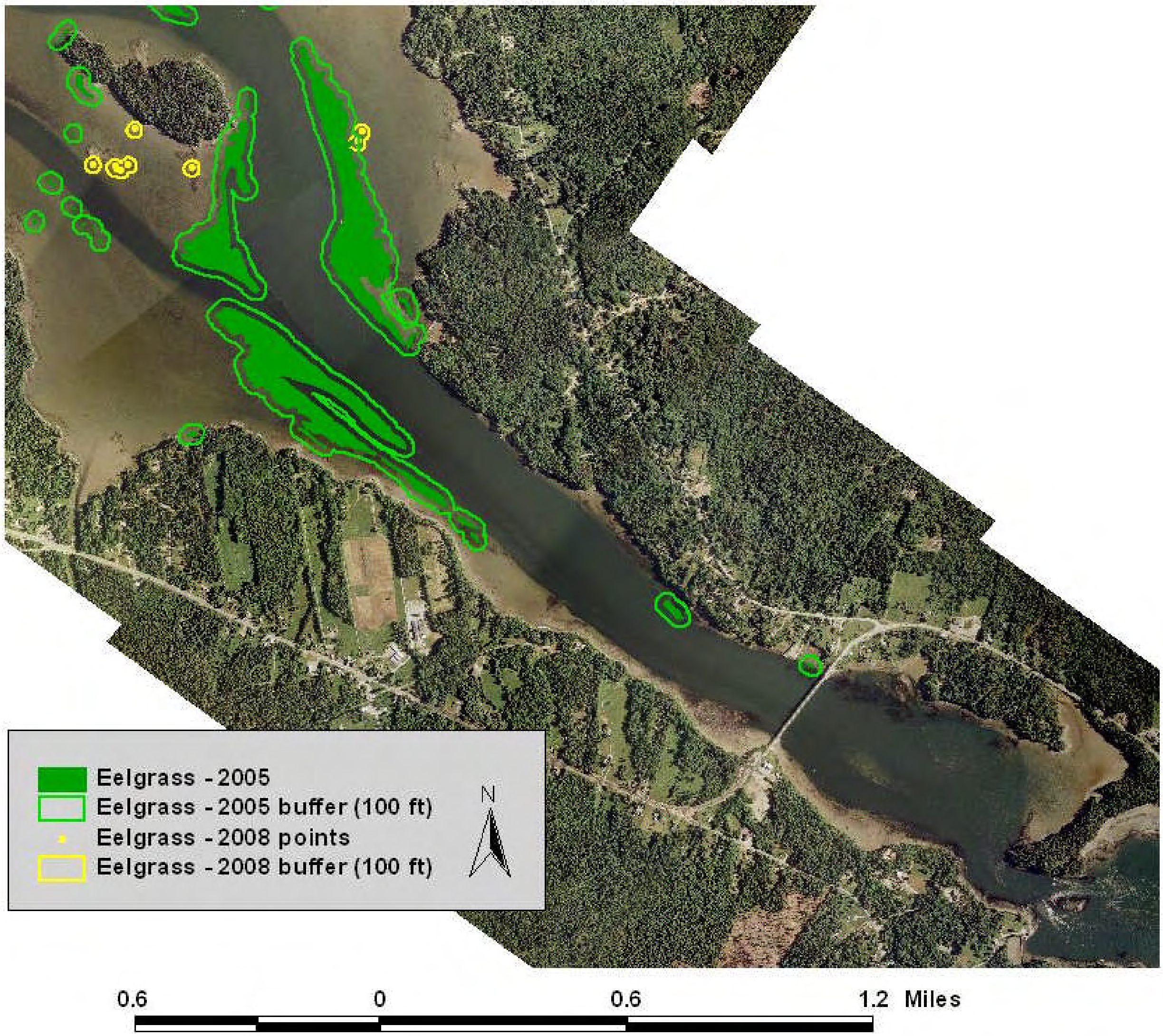
D. Egypt Bay Management Recommendation 1.A. Horseshoe crab “no LBD” area.

E. Hog Bay Management Recommendations 1.A. and 1.B. Horseshoe crab “no LBD” area.

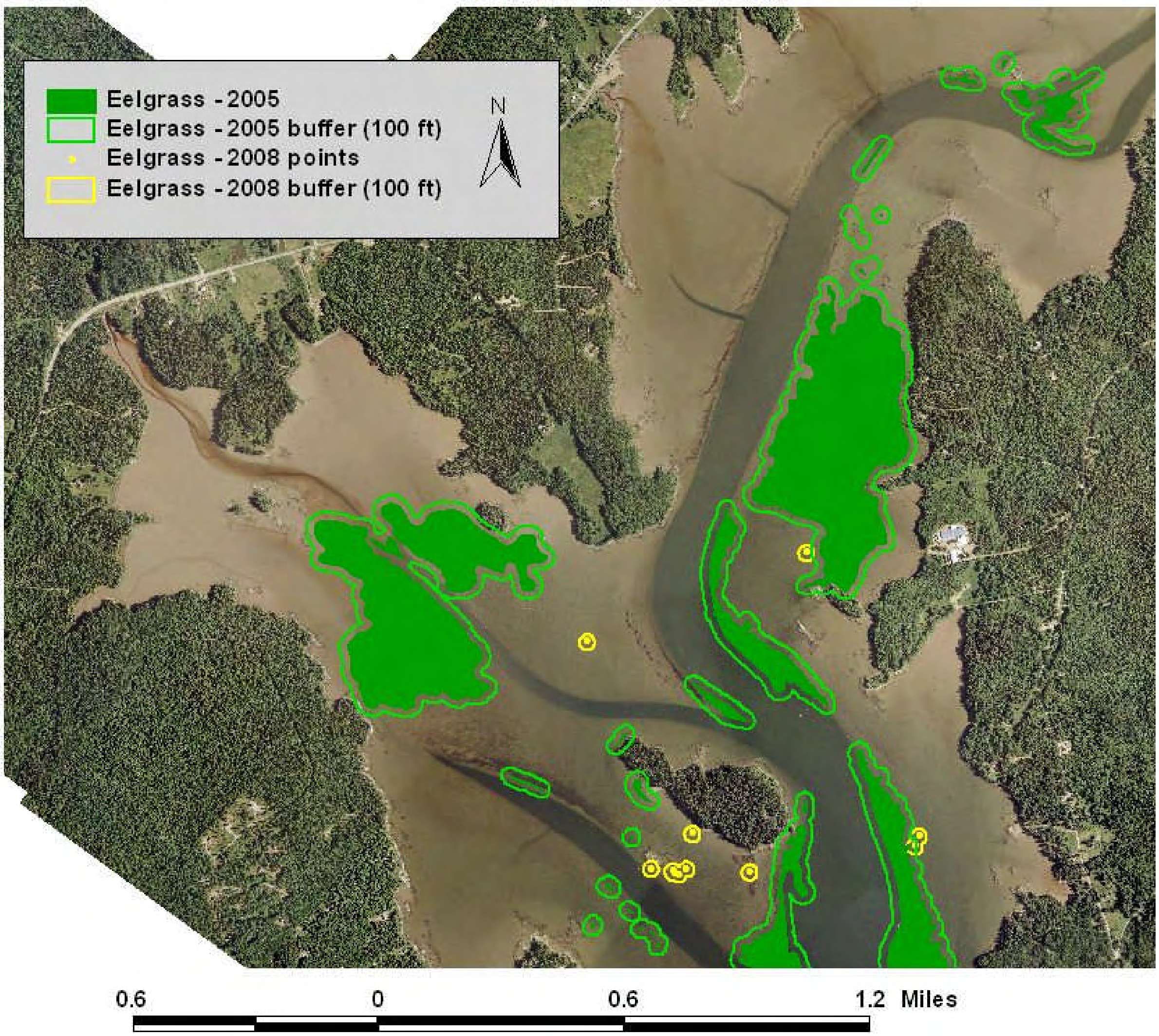
F. Egypt Bay Management Recommendation 1.B. Egypt Bay subtidal LBD plots.

G. Other elements of ecological and management interest on subtidal and intertidal flats.

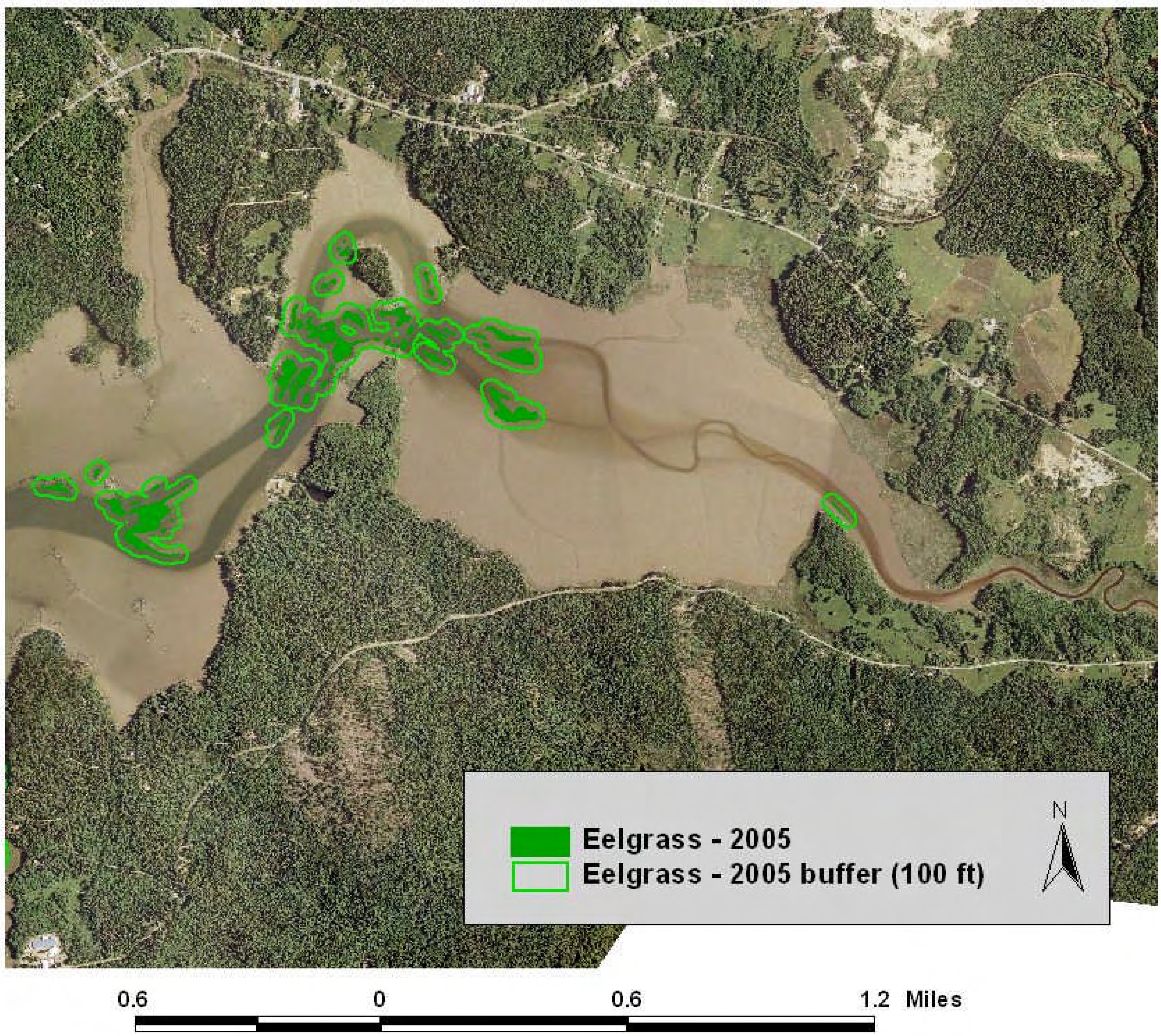
Appendix A. Taunton Bay eelgrass “no LBD” areas. This 2005 image extends from the southernmost extent of mapped eelgrass in the estuary (Route 1 Bridge) to Burying Island. 2008 eelgrass points were obtained during rapid site reconnaissance that was not intended to afford complete coverage. These points indicate that more eelgrass may be present than is shown in the image. 2005 eelgrass mapping courtesy of S. Barker, Maine Department of Marine Resources.



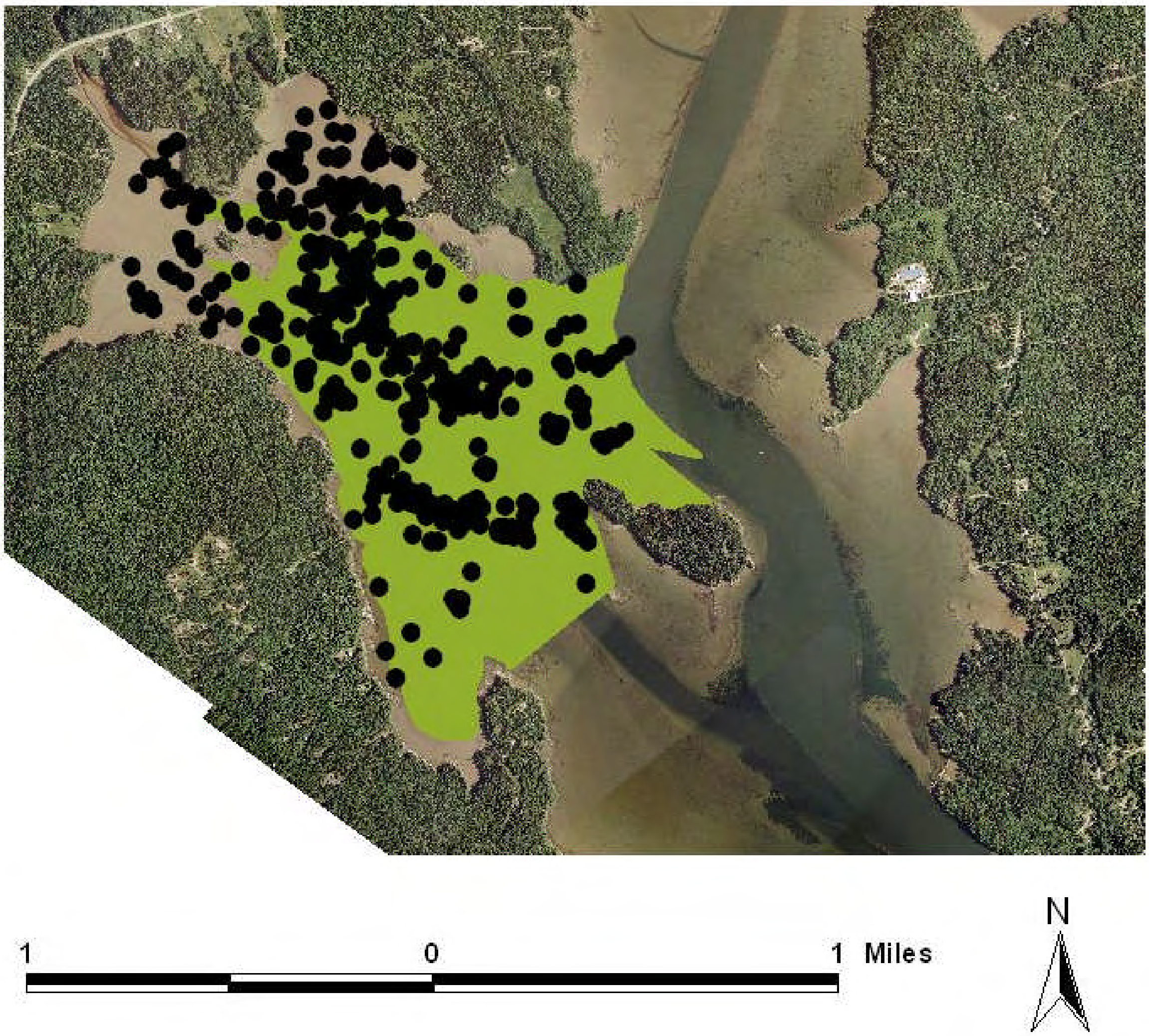
Appendix B. Taunton Bay eelgrass “no LBD” areas. This 2005 image extends from Burying Island north to Hatch Point. 2008 eelgrass points were obtained during rapid site reconnaissance that was not intended to afford complete coverage. These points indicate that more eelgrass may be present than is shown in the image. 2005 eelgrass mapping courtesy of S. Barker, Maine Department of Marine Resources.



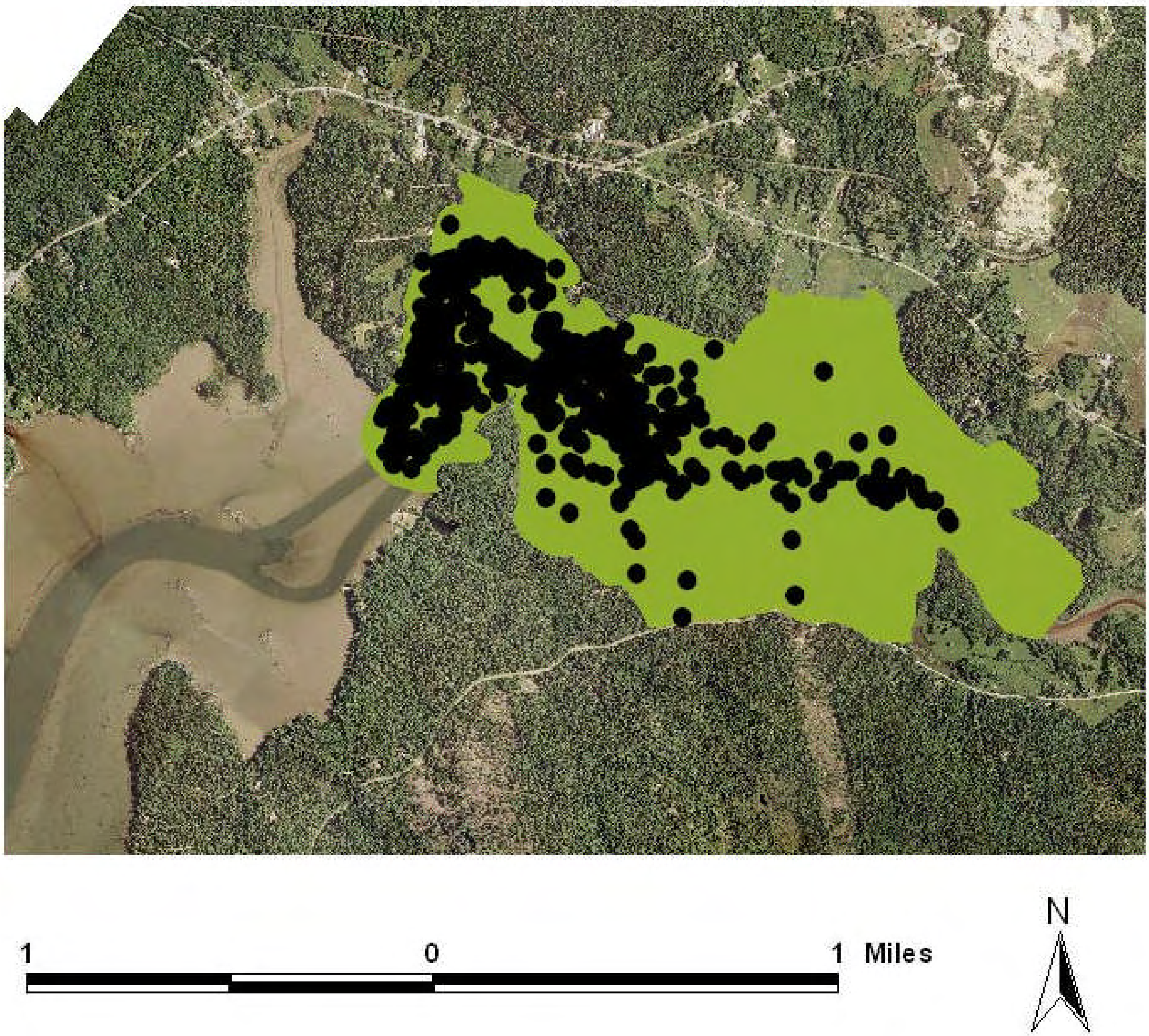
Appendix C. Taunton Bay eelgrass "no LBD" areas. This 2005 image extends from Hatch Point to the eastern extent of Hog Bay. 2008 eelgrass site reconnaissance was not conducted in this area. More eelgrass may be present than is shown in the image. 2005 eelgrass mapping courtesy of S. Barker, Maine Department of Marine Resources.



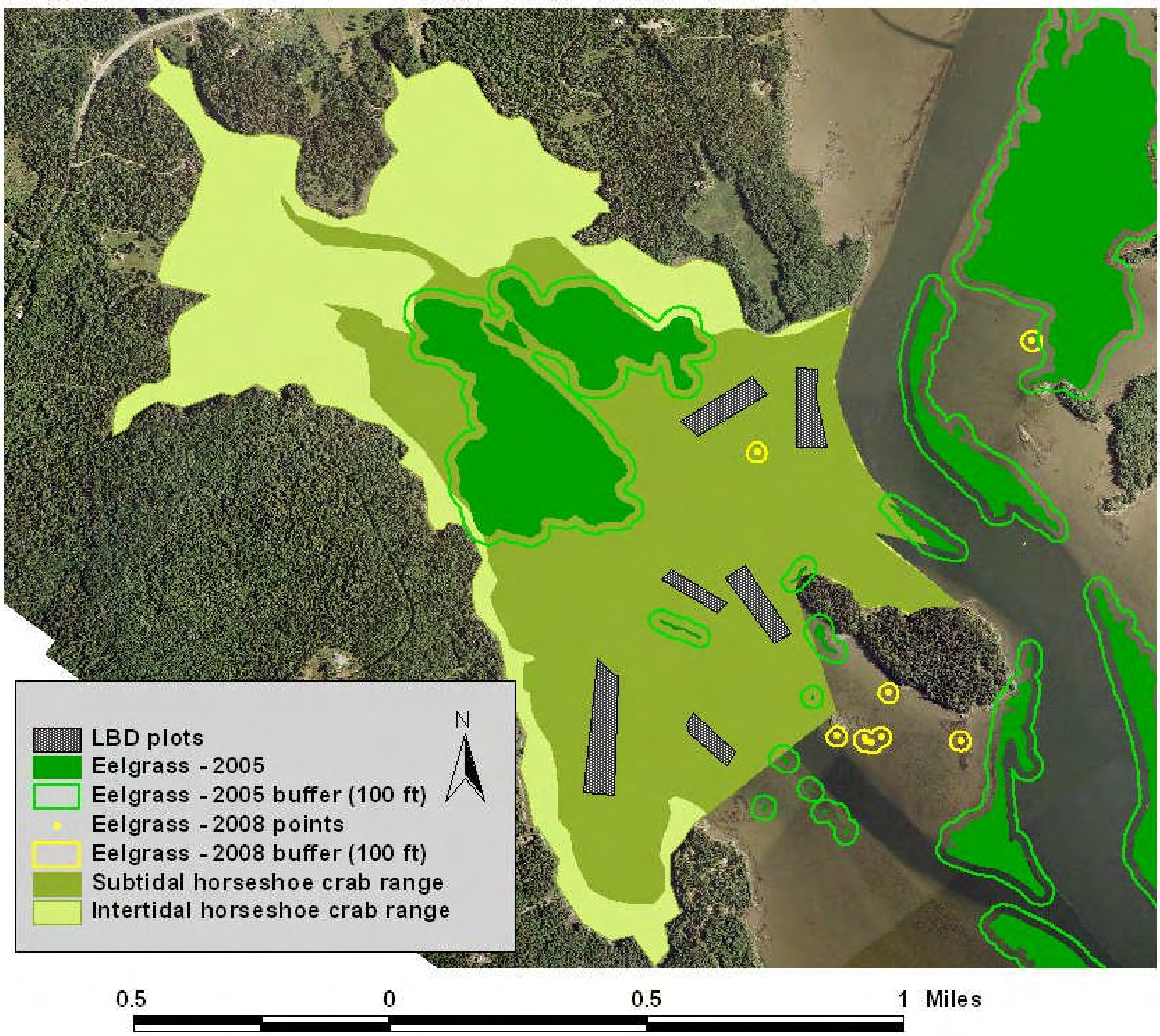
Appendix D. Egypt Bay horseshoe crab "no LBD" area (Management Recommendation 1.A.). Black points represent horseshoe crab GPS locations obtained during 2003-2005 with sonic telemetry. Under this recommendation, but not indicated on the map, is that all intertidal flats north of Cedar Point and Evergreen Point are also designated as "no LBD" areas. Horseshoe crab locations from Moore and Perrin (2007).



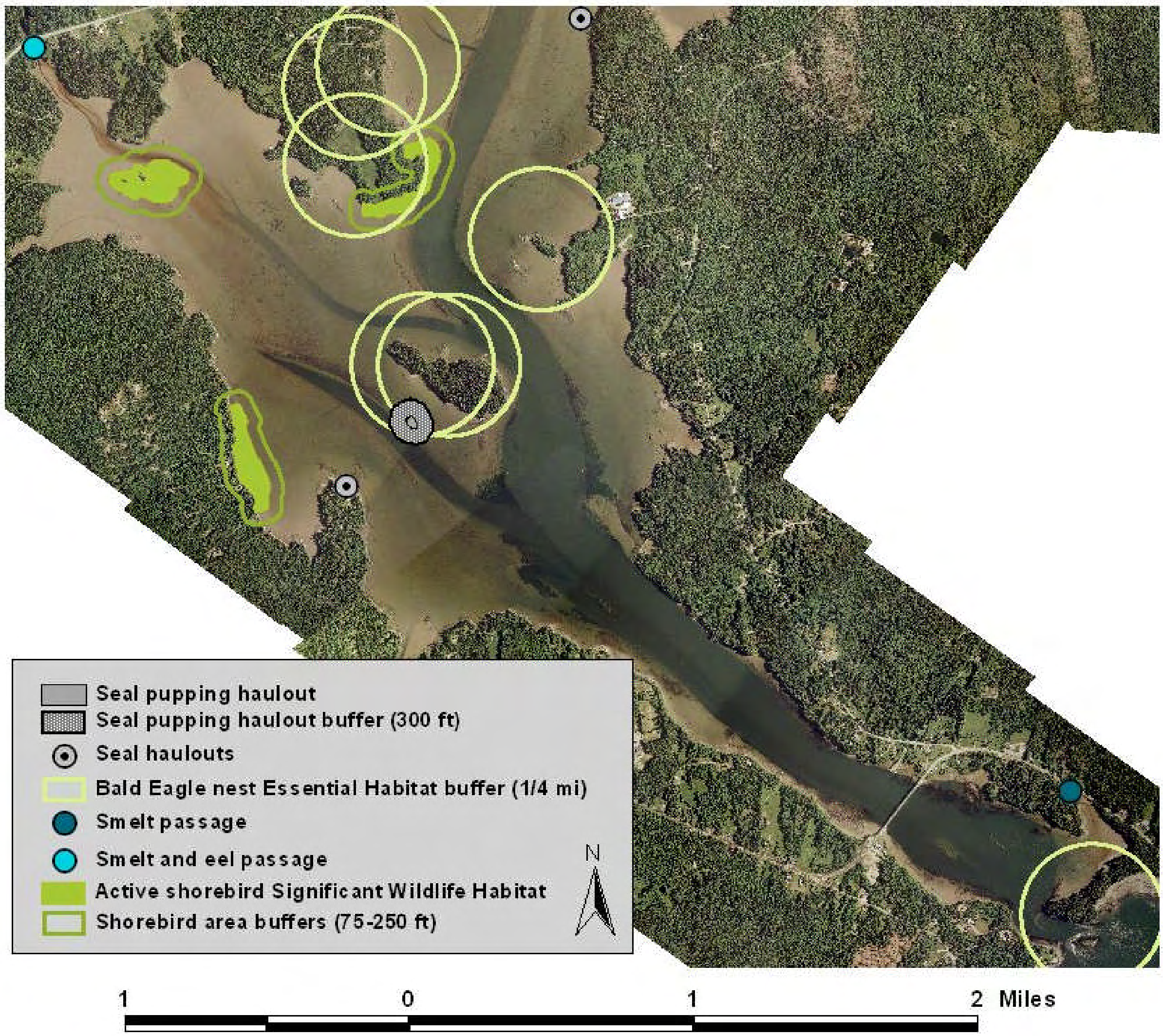
Appendix E. Hog Bay horseshoe crab “no LBD” area (Management Recommendations 1.A. and 1.B). Black points represent horseshoe crab GPS locations obtained during 2003-2005 with sonic telemetry. Under this recommendation, but not indicated on the map, is that all intertidal flats north of Cedar Point and Evergreen Point are also designated as “no LBD” areas. Horseshoe crab locations from Moore and Perrin (2007).



Appendix F. Egypt Bay Management Recommendation 1.B. Intertidal and subtidal portions of mapped horseshoe crab range are designated as “no LBD” areas, except for subtidal plots where LBD is allowed. Active plots are those that have been subject to LBD in the past 24 months. The total acreage of the active plots (gray polygons) in this example is the maximum amount allowable acreage (5% [24 acres]) of mapped subtidal horseshoe crab range in Egypt Bay). Total acreage of all plots (active or otherwise) will not exceed the maximum of 10% (48 acres) of the total subtidal horseshoe crab range in Egypt Bay. LBD in plots is limited to June through September, when crabs are fully emerged from their wintering phase. As indicated by this map, the location of plots is configured to avoid conflict with other management goals (e.g. eelgrass recovery). Also under this recommendation (but not indicated on the map) is that all intertidal flats north of Cedar Point and Evergreen Point are designated as “no LBD” areas. 2008 eelgrass mapping courtesy of S. Barker, Maine Department of Marine Resources.



Appendix G. Additional elements of ecological and management interest on subtidal and intertidal flats. Image frame extends south from Egypt Stream (far upper left) to Falls Point (lower right). Inactive shorebird areas associated with Burying Island are not shown. Mapping elements provided by the Maine Department of Marine Resources (fish passage), Maine Department of Inland Fisheries and Wildlife (shorebird habitat, Bald Eagle nests), and Steve Perrin (seal haulouts).



Appendix H. Additional elements of ecological and management interest on subtidal and intertidal flats. Image frame extends east from Butler Point (lower left) to Card Mill Stream (far right). Mapping elements provided by the Maine Department of Marine Resources (fish passage), Maine Department of Inland Fisheries and Wildlife (shorebird habitat, Bald Eagle nests), and Steve Perrin (seal haulouts).